#757

Scientific discoveries of the Hayabusa2 mission, sample return from C-type asteroid Ryugu

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The Hayabusa2 spacecraft visited near-Earth C-type asteroid Ryugu, conducted intensive observations using optical and thermal cameras, NIR spectrometer, and LIDAR, landed a lander and rovers for *in-situ* measurements, performed a crater-forming experiment using a carry-on impactor SCI and deployable camera, and collected surface and subsurface particles from two separate locations. In December 2020, Hayabusa2 successfully delivered Ryugu samples to Earth, and initial analysis has been performed.

The major scientific finding to be presented are as follows: Analysis of returned particles shows that Ryugu consists of CI chondrite-like primitive material severely altered by aqueous processing in a fluid with a temperature of ~310 K generated by the decay heat of ^{26}Al in the interior of an ~100-km sized icy parent body at 5-6 million years after the formation of the Solar System. The presence of CO_2 in fluid inclusions in a large iron sulfide crystal, the NIR absorption of NH in ammonium salts or organic nitrogen compounds, and the very low content of chondrules and calcium aluminum-rich inclusions (CAIs) suggest that the parent body of Ryugu may have originated outside the snow lines of CO_2 and NH_3 (outside Jupiter's orbit). Based on the orbital analysis of Ryugu and comparison of the reflection spectra, its parent body is considered to be one of the collisional families in the inner asteroid belt. Therefore, it is necessary to verify whether the scattering of giant planets could bring planetesimals beyond Jupiter to such an inner region of the asteroid belt. In any case, it is a great discovery that the parent body of CI chondrites are collisional families in the inner asteroid belt.

Large surface boulders and the low bulk density indicate that Ryugu was formed by the catastrophic disruption of its parent body. The large artificial crater excavated by SCI indicates very low internal cohesion of Ryugu’s surface material and a very young resurfacing age (<10 Ma). The young surface age suggests that the spinning-top shape of Ryugu may have been formed through surface landslides in the past rapid rotation induced by the YORP thermal effect.

The scientific results of the Hayabusa2 mission will link asteroid observations, meteorite analysis, and laboratory experiments to future exploration of the Solar System.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust, planets (TOI-270 system), atmospheres, composition, JWST, Exploration, Carbonaceous chondrites, Planetesimals, Aqueous alteration, Impact crater, Sample analysis, Snow line

#3073

OSIRIS-REx – Status of NASA’s Near-Earth Asteroid Sample Return Mission

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The OSIRIS-REx mission was selected in 2011. The spacecraft launched in September 2016 and began its journey to Bennu, a carbon-rich, near-Earth asteroid. The spacecraft rendezvoused with Bennu in 2018 and successfully obtained a sample in October 2020. The spacecraft embarked on its return voyage to Earth on May 10, 2021. On Sept. 24, 2023, the spacecraft will jettison the sample capsule and send it onto a trajectory to touch down in the Utah desert. Sample analysis will continue until 2025. These samples will be the first for a U.S. mission and may hold clues to the origin of the solar system and the organic molecules that may have seeded life on Earth.

The University of Arizona leads the mission for NASA and will provide sample analysis laboratories for the returned samples. NASA’s Goddard Space Flight Center provides overall mission management. Lockheed Martin Space Systems built the spacecraft. United Launch Alliance built the mission’s Atlas V launch vehicle. The mission is in an exciting phase right now as the OSIRIS-REx spacecraft continues its return journey to Earth.

#2882

Overview of Space Weathering on Asteroid (101955) Bennu

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This presentation summarizes the evidence for the optical effects of space weathering, as well as the properties of the surface that control optical changes, on asteroid (101955) Bennu as was observed by NASA's OSIRIS-REx mission. First, we set the stage for the observations of Bennu by briefly reviewing what was known about space weathering of low-albedo materials from telescopic surveys and laboratory simulations prior to the OSIRIS-REx encounter. We then look at the evidence for the nature of space weathering on Bennu from spacecraft imaging and spectroscopy observations, including the visible to near-infrared and thermal infrared wavelengths, followed by other evidence such as normal albedo measurements from lidar scans. We synthesize these different lines of evidence in an effort to describe a general model of space weathering processes and resulting color effects on dark C-complex asteroids, with hypotheses that can be tested by analysing samples returned by the mission.

A working hypothesis that synthesizes findings thus far is that the optical effects due to increasing degrees of space weathering of C-complex asteroids are dependent on the level of hydration in the parent material (e.g., presence of hydroxl/water bearing phyllosilicates). On Bennu the oldest surfaces are redder and darker at visible to near-infrared wavelengths and have shallower absorption bands due to the presence of greater amounts of nanophase and/or microphase opaques.   Solar wind, dehydration, or migration of fines may cause intermediate-age surfaces to appear blue in visible wavelength images. Very young craters on Bennu are redder than their surroundings in both visible wavelength imaging and near-infrared spectra as a result of their smaller particle sizes and/or fresh exposures of organics by impacts.   However, Bennu is a rubble pile with a demonstrably active surface, making age relationships, which are critical for determining space weathering signals, difficult to locate and quantify.   Hence, the ultimate story awaits analyses of the returned samples.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy

#914

Determination of space weathering timescale and consideration of a possible event occurred on Itokawa

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Space weathering is a surface alteration process of airless bodies caused by solar wind implantation and micrometeorite bombardment. On the other hand, resurfacing counteracts the space weathering effect, exposing fresh subsurface materials. Several resurfacing processes are proposed, such as tidal encounters with planets [1].

A near-Earth asteroid (25143) Itokawa exposed fresh materials, but the resurfacing mechanism is less investigated. We noticed four orders of magnitudes discrepancies in the space weathering timescale derived by different techniques [2][3]. To eliminate the uncertainty, we first determined the space weathering timescale by focusing on the bright mottles on the boulders and estimated it to be 1000 years. This result is consistent with the He+ ion irradiation experiment [4]. Based on this result, we discuss a possible recent resurfacing process that might have rejuvenated the Itokawa's surface.

[1] Binzel et al. (2010), Nature, 463, 7279, p. 331-334.
[2] Noguchi et al. (2014), M&PS, 49, 2, p. 188-214.
[3] Koga et al. (2018), Icarus, 299, p. 386-395.
[4] Loeffler et al. (2009), JGR, 114, E03003.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering

#911

Thermal radiation pressure as a possible mechanism for losing small particles on asteroids

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Recent space explorations taught us µm-sized fine-grains are missing on smaller near-Earth asteroids (NEAs) (25143) Itokawa, (162173) Ryugu, and (101955) Bennu. Meanwhile, with sub-micron scale granular structures found in meteoritic samples, thermal fatigue or micrometeoroid impact would likely supply dust debris down to sub-micron scale on regolith. If so, there must be a mechanism that preferentially removes fine-grains on smaller asteroids. Among NEAs, (3200) Phaethon, the target of JAXA's DESTINY+ mission, repeatedly showed a detectable dust tail of 1 µm radius dust particles near its perihelion. This detection indicates that fine-grains are not only being generated but also being removed by ejection, and this generation and/or ejection process gets powerful near the perihelion, while the ejection mechanism is unknown.

This work suggests a novel idea that thermal radiation pressure exerted by the regolith can play a dominant role in ejecting those fine-grains. The model predicts the pressure is stronger (1) at smaller heliocentric distances, (2) for particles of radius ~ 1 µm, almost regardless of particle's physical properties, and (3) for smaller asteroids (weaker gravity). The first two findings from this theoretical work are consistent with observational studies on Phaethon that its dust cloud is formed only near the perihelion and consists of particles with a radius of ~1 µm. In this presentation, we discuss our findings and their implications on regolith science and the DESTINY+ mission.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic

molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium

#2596

Change of the Apophis' spin state during the 2029 Earth encounter

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On April 13, 2029, Potentially Hazardous Asteroid (99942) Apophis will closely encounter the Earth. The gravitational torque during the encounter will change the Apophis' orbit from an Aten-class orbit to an Apollo-class orbit while shifting the semimajor axis from 0.92 AU to 1.1 AU. It is also expected that the spin-state of Apophis will be significantly affected by the tidal torque as the current spin angular momentum of Apophis is relatively small. However, the change of spin angular momentum cannot be determined without the correct estimate of body axis orientation just before the 2029 encounter. This requires precise measurements of the spin state of Apophis which exhibits complex tumbling motion. Using photometric data from the apparitions in 2020-2021, we could measure the spin state of Apophis as well as its shape model with great precision. By propagating this to the time of encounter, we will present the expected spin state of Apophis after the Earth flyby.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter

#2926

Tangential YORP torque due to the asteroid surface roughness

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The tangential YORP effect, or TYORP, is a light pressure recoil force changing the asteroid's rotation rate via uneven thermal radiation by the small-scale structures on the asteroid surface. TYORP has been modeled numerically for individual boulders of different shapes, but not for a rough rocky or regolith surface. Still, many asteroids are known to have large portions of surface covered by regolith, and the contribution of this regolith to TYORP needs to be accounted for. Also, the rocks producing TYORP are much rougher on different scales than the idealized models typically used in simulations.

Here, we investigate TYORP produced by a rough surface, modeled by a sinusoidal wave or a Fourier series composed of sinusoidal waves. We present a theoretical model for heat conduction in a sinusoidal wave and an approximate analytic expression for TYORP created by it (Golubov & Lipatova, A&A, accepted). Also, for the first time, we present the results of numeric simulations of TYORP created by a sinusoidal wave and by a sum of sinusoidal waves.

We apply the theory to the asteroid (162173) Ryugu and find that the tangential YORP produced by its surface roughness is at least 5 times greater than its normal YORP.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric

#2037

Subsecond Photometry of Tiny Near-Earth Objects with Tomo-e Gozen

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Material transportation by asteroids is one of the leading hypotheses regarding the origin of life and water on Earth. To test this hypothesis, it is necessary to know how asteroids move in the solar system and what kind of physical properties (i.e., strength and composition) they have. Recently, explorations and sample returns of near-Earth asteroids (NEOs) have been conducted by Hayabusa, Hayabusa2, and OSIRIS-Rex mission. While in-situ observations of asteroids with diameters D > 100 m and analyses of mm-size particles have progressed, the intermediate-sized (1 < D < 100 m) objects remain to be studied. We attempt to characterize such tiny objects via ground-based observations of NEOs.

Most NEOs have their origins in the main belt and experience the rotation changes caused by Sun's radiation, the YORP effect. Since the YORP effect is stronger for smaller objects, tiny NEOs are good targets to investigate their dynamical histories and physical properties. For example, fast rotators suffer from strong centrifugal force and may experience deformation or rotational fission when their rotation periods reach critical values by YORP spin-up. Thus, it is thought that rotation periods of tiny NEOs are related to the strength of tiny bodies.

We conducted subsecond photometry of 60 tiny (D < 100 m) NEOs with Tomo-e Gozen on the Kiso 105 cm Schmidt telescope, and we successfully derived the rotation periods of 32 NEOs. We statistically confirmed that a certain number of tiny fast-rotating NEOs were missed in previous surveys. We have discovered that the distribution of the tiny NEOs in a diameter and rotation period (D-P) diagram is truncated around P = 10 s. The truncation is not explained well either by rotational fission of NEOs or the suppression of YORP by meteoroid impact. We propose that the dependence of the tangential YORP on the rotation period potentially explains the observed truncation in the D-P diagram.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP

#745

The impact process on small bodies: review of current knowledge and implications on the Solar System history

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Collisions play a crucial role in the Solar System history. Understanding this process is thus crucial to draw a robust scenario of this history. In particular, small body collisions can lead to their disruptions or to craters that are used to estimate surface strengths and ages. Impact hydrocodes have been developed, which rely on shock and fracture physics, and are confronted to laboratory experiments on centimeter-size targets. However, their use at larger scales is confronted to different issues.

The first is that the reliability of hydrocodes at large scales is not guaranteed by lack of comparisons. Fortunately, space missions including impact experiments exist, such as the JAXA Hayabusa2 and the coming NASA DART/ESA Hera missions. The second is that in the case of a disruption, hydrocodes cannot capture the entire process. Once fragmentation is over, the produced fragments can reaccumulate due to their mutual attractions, leading to a population of gravitational aggregates and not solid fragments. Small bodies of second generation at least should thus all be rubble piles, down to sizes of 100-200 meters, which is consistent with measured small body low bulk densities. The third issue is that for cratering events on low gravity bodies, shock physics codes have great difficulties to capture the final crater size. When the cohesion is small, crater formation can take several tens of minutes and the crater is still evolving after the shock phase. Therefore, another approach is needed to capture entirely the physics of the process. This has strong implication on the estimate of surface ages, as depending on the assumptions, this estimate can differ by orders of magnitude.

In recent years, huge progresses have been achieved concerning these issues, benefiting particularly from the data of space missions on small asteroids and comets. Numerical impact models could thus benefit from new knowledge in the correct environment. This led to advances that have enormous implications in the estimate of surface ages and the history of those bodies, which can be extended to other small bodies.

I will review the knowledge from the last years thanks particularly to space missions, and numerical simulations of collisions on small bodies with their implications on their formation and evolution, for the two regimes of cratering and disruption.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared,

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#868

Dust trails generated on the DART experiment

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NASA sent the DART (Double Asteroid Redirection Test) mission to the asteroid binary system Didymos-Dimorphos. The mission objective is to test the asteroid deflection technique called kinetic impactor.

DART will previously release the Italian “Cubesat” LICIACube (ASI); to obtain high-resolution images of the moments after the impact. The impact will produce a crater and a large amount of material ejected at high speed (hundreds of m/s), producing an ejecta cone that will quickly disperse.

We analyze an additional effect: the lofting of material at low speed because of the generation of seismic waves that propagate into the interior of Dimorphos and, even if highly damped, generate shaking at distant surface points. To analyze this effect, we divide the process into the following steps: i) generation of impact-induced seismic waves and propagation into the interior of the body; ii) arrival of these waves coming from the interior to the surface at points located far from the impact point; iii) shaking produced by the arrival of these waves on small particles located on the surface; iv) lifting of particles due to shaking and ejection at low speed (comparable to the escape velocity); v) evolution of particles under the influence of gravity and solar radiation pressure; vi) prediction of observation of this cloud of particles from the Earth.

We anticipate the following potentially observable effects: i) generation of a cloud of small particles that will produce a hazy or fuzzy appearance of Dimorphos' limb, detectable by LICIACube; ii) a brightness increases of the binary system due to enhancement on the cross section produced by the cloud of particles; iii) generation of a dust trail, similar to those observed in Activated Asteroids, which can last for several weeks after impact.

A numerical prediction of the detectability of these effects will be strongly dependent on the amount and size distribution of the ejected particles, which are largely unknown. On the other hand, in case these effects are observable, an inversion method can be applied to compute the amount of ejected material and discuss the relevance of the shaking process as well as some elastic and structural parameters of Dimorphos.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal

torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust

#1514

The potential of optical polarimetry for asteroid studies

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Historically, optical polarimetry of asteroids was one of the main techniques in study physical properties of asteroids but up to now its potential has not been sufficiently exploited. In recent years, the number of telescopes available and used for asteroid polarimetry has steadily increased. Measurements of the phase angle dependence of the linear polarization degree of asteroids of various dynamical and compositional groups in a wide range of phase angles revealed many interesting previously unknown features. Polarimetry has been proven to provide one of the best ways to determine the albedo of asteroids. This application is especially useful for near-Earth asteroids, for which even a single measurement of the degree of polarization at large phase angles can be sufficient to obtain an overall albedo estimate. Using polarimetric measurements it is possible to refine the taxonomy of asteroids and identify several types that are poorly distinguished based on spectral data. Although the interpretation of polarimetric observations of asteroids in terms of physical parameters is not straightforward, it is evident that polarimetry provides important complimentary information that cannot be obtained by any other remote sensing technique. An overview of recent advances in polarimetric observations of asteroids will be given.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy

#1126

Polarimetric Study on the Hydrates Asteroids

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Hydrated asteroids have undergone various processes, particularly aqueous and thermal alterations. Thus, observational evidence for these asteroids gives us a hint for a better understanding of the aqueous and thermal evolution. For example, (101955) Bennu was found to have evidence for widespread aqueously altered minerals via the OVIRS spectrometer onboard the OSIRIS-REx spacecraft [1]. Meanwhile, multi-band observations of the Hayabusa 2 mission found that (162173) Ryugu also contains hydrated minerals, but they might have experienced a moderate thermal alteration in its parent body [2]. Like these examples, hydrated asteroids have been studied extensively via spectroscopy or multiband photometry, focusing on absorptions near 0.7 µm and 3 µm. On the other hand, it is important to notice that Ch-type asteroids that are hydrated asteroids experienced weak thermal alteration with temperature < 400 degrees Celsius. They show different polarimetric properties (especially the minimum polarization degree, Pmin) from those of the asteroids with similar albedo [3]. However, despite their polarimetric particularity, polarimetric studies on hydrated asteroids have been scarcely conducted. To deepen our understanding, we made polarimetric observations of 18 dark main-belt asteroids including Ch-type asteroids by using the 1.6-m Pirka telescope of Hokkaido University. As a result, we confirm that 1) Ch-asteroids have very small Pmin (Most of them having Pmin< -1.5 %). Further, we found that 2) polarimetric parameters (e.g., the Pmin) show a strong correlation with spectral features (e.g., absorptions near 0.7 µm and 3 µm). In this presentation, we will share our results and interpret these results in connection with mineralogy and surface structure (e.g., grain size).
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Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid

#2565

Hydrated silicates on evolved cometary nuclei observed in the mid-infrared

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It is thought that comets are the remnants of planetesimals formed in the early solar nebula. Silicate features are often observed in cometary spectra as a 10-μm resonant feature which indicates the existence of small crystalline and amorphous silicate grains. Short-period comets that have orbited the Sun many times, however, are expected to evolve thermally and usually show weak silicate emission features. If a comet has a very weak or no silicate feature, we can observe a comet nucleus directly.

In these 20 years, we conducted mid-infrared spectroscopic observations of a dozen short-period comets with Subaru telescope. Among them, we will show mid-infrared spectra of comets P/2016 BA14 (PANSTARRS) and 2P/Encke, which are different from ordinary comets that show silicate emission features. Gas and dust production rates of comet PANSTARRS were notably low, even near the perihelion passage around 1 au from the Sun in March 2016, and it was expected that the observation obtained the thermal emission from the nucleus. The normalized emissivity spectrum of comet PANSTARRS in the mid-infrared is similar to those of phyllosilicates which are usually not observed in the comet spectra. Moreover, it is indicated that the prominent absorption-like feature peaked at 9.50 micron is associated with dehydroxylated phyllosilicates on the nucleus surface. Comet 2P/Encke is one of the evolved comets, which has one of the shortest orbital periods (3.3 years) of any known comet within our solar system. The mid-infrared spectrum of comet Encke looks blackbody-like, but weak negative features from the continuum can be seen. We will discuss the features and the dust properties of comets PANSTARRS and Encke in our presentation. It is suggested that the results indicate that one possible end state of comets may be an inactive small body covered with coarse grains of phyllosilicate minerals, not only anhydrous silicates, combined with organic materials.

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#1944

Asteroid physical characteristics from Gaia photometry

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Photometry is a key tool for estimating the physical characteristics of asteroids. An asteroid's photometric lightcurve and phase curve refer to the variation of the asteroid's disk-integrated brightness, respectively, in time and in phase angle (the Sun-asteroid-observer angle). They depend on the asteroid's shape, rotation, and surface light-scattering properties, and the geometry of illumination and observation. We present Bayesian lightcurve inversion methods for the retrieval of the asteroid's phase function, the unambiguous phase curve of a fictitious spherical asteroid with surface scattering properties equal to those of the original asteroid. A collection of such phase functions can give rise to a photometric taxonomy for asteroids. In the inverse problem, there are four classes of lightcurves that require individual error models. The photometric observations can be absolute or relative and they can be dense or sparse in comparison to the asteroid's rotation period. The observations extend over varying phase angle ranges, gradually requiring more and more sophistigated models for the phase function. For examples, first, the photometry from the ESA Gaia space telescope extends, typically, over a range of phase angles, where the photometric phase curve tends to be linear on the magnitude scale. Second, the ground-based photometry can reach small phase angles, where the asteroids show an opposition effect, a nonlinear increase of brightness on the magnitude scale towards zero phase angle. We provide error models for the four classes of lightcurves and make use of linear or linear-exponential phase functions for phase angles below 50 degrees. We then apply the inverse methods to sparse Gaia lightcurves (from Gaia Data Release 3 or GDR3 due in June 13, 2022) and dense ground-based lightcurves. This allows us to obtain absolute magnitudes and phase functions, with uncertainties, for a large number of asteroids: GDR3 comprises some 150,000 asteroids with high-precision G-band photometry.

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protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve,
YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation

#1456

Laboratory study for the light scattering on planetary regolith with 3D printed models

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Many airless bodies, such as the Moon and asteroids, are covered by loosely bounded particles, and it is called "regolith." For the lunar surface, it is known that the grains aggregate by weak gravity, and it consists of a structure like a fairy castle. The light scattered by such a surface shows different behavior concerning its porosity, particle size, and structure. In particular, the opposition effect, the nonlinear surge of its brightness at near-zero phase angle (i.e., the angle between the Sun, object, and detector), occurred by hiding shadows or coherently scattered light. It returns crucial information about the texture of the regolith; however, the detail relation has not been studied well. To understand how regolith's fine structure affects the light scattering on the surface, we measured the reflectance of samples in varying angular elements (e.g., phase angle, incidence angle, and emission angle). The examination samples are black resin regolith models similar to the fairy castle structure, printed by a 3D printer.

In this conference, we introduce a laboratory study for light scattering with 3D printed regolith models and show the initial results. We also suggest how this experiment contributes to future lunar exploration to observe the 3D micro-texture of the lunar regolith.

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#1313

Next Generation Ground-Based Planetary Radar Science at NRAO

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Advances in astronomical radar technology are paving the way for the next generation ground-based planetary radar capabilities at the National Radio Astronomy Observatory (NRAO). These advances are opening new avenues and renewed investment and interest from the industry and scientific community overarching planetary science and planetary defense.

This talk will provide an outlook of NRAO ground-based planetary radar science goals that have the potential to substantially expand our capabilities to advance knowledge in our Solar System. Next generation planetary radar capabilities using NRAO facilities are seeking to enhance detection and imaging of solid bodies in the Solar System, including small bodies (near-Earth asteroids, main-belt asteroids, comets, extrasolar interlopers), our Moon, the terrestrial planets (with exception of Venus), moons orbiting other planets, and potentially planetary debris. These science goals would be achieved through bi-static observations with the synergy of a planned high-power transmit system on the fully steerable, 100-meter Green Bank Telescope with NRAO's existing and future receive-array capabilities, such as the Very Long Baseline Array (VLBA) and the Next Generation Very Large Array (ngVLA), for increased science return.

This talk will also seek input from the community in expanding science goals in view of a new observation program to be developed at NRAO as the new radar capabilities become available over the next decade.

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polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array

#1274

The search for Planet Nine using the Subaru Telescope

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Planet Nine has been primarily proposed to explain the observed structure of the Kuiper belt objects with semi-major axes beyond 200 AU. Other lines of evidence, such as the detachment of the perihelia of outer solar system objects from Neptune, and the highly inclined orbits of some of the long period objects also point towards this hypothesis. In this talk, I will report on our multi-year observational program to search for Planet Nine with the Hyper Suprime-Cam instrument on the 8 meter Subaru telescope. We were allocated a total of 21 nights of observational time out of which we lost 40 percent due to bad weather. We were able to image over 200 sq degrees of data on multiple consecutive nights. The area covers the sky region near the apocenters of the proposed path of Planet Nine. The data was reduced with the state-of-the-art Rubin science pipelines and difference imaged in order to find moving objects. These objects were then linked to find candidates which match the orbits of Planet nine, and then finally visually inspected. We characterize the effectiveness of our detections by injecting simulated Planet nine candidates in raw imaging data, and run those through our end to end pipeline. Our pipeline is able to recover more than 90 percent of detectable simulated candidates out to a limiting magnitude of the survey (median limiting magnitude > 24). I will describe the challenges involved with the data reduction, management of a bleeding edge software pipeline over computing clusters separated over multiple continents and having to deal with a large number of false positive detections in difference images. I will report on the discovery of trans Neptunian objects from our data set and showcase some of the best candidates for Planet Nine we found in the data. Finally, I will summarize the current best constraints on the existence of Planet Nine.

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surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging

#1370

Previously Undiscovered Exoplanets Detected with Deep Learning in the Data Collected by the Kepler Space Telescope

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Using deep learning with the Adam optimization algorithm in this research, I detected 11 previously undiscovered exoplanets in the Kepler data. Although some of the exoplanet transit signals were evident, others were not as strong and need further evaluation. By using my own code, open source libraries, and deep learning packages such as TensorFlow and implementing the Adam algorithm as an optimizer, I developed a Python program for exoplanet detection. The program first normalizes the transit light curves, trains the deep learning model using the Adam optimizer, folds the transit light curves to intensify the transit signals, then uses the model to search for exoplanet transits in the Kepler light curves. Among the newly detected exoplanets, 9 of them are ultra-short period (USP) exoplanets with orbital periods shorter than a day, and the 2 others are short period exoplanets with periods between 1 to 10 days. Because the Kepler mission lasted for nine years and observed each star for a selected period of time, there are much more Kepler Objects of Interest (KOI) with shorter periods than those with long periods in the NASA database. This may be a reason why the orbital periods of the detected exoplanets in this study are shorter than 10 days. Meanwhile, the detection of these new exoplanets, especially the USP exoplanets, can shed light on their kind and expand our views on their planetary systems, which possess different features than our Solar System. Finally, these findings show that artificial intelligence such as deep learning can be an effective technological tool to detect objects of interest in astronomy big data.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow

#913

Numerical study of low-velocity dust ejection from Phaethon and its connection to the Geminid meteoroid stream

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Interplanetary dust particles (IDPs) give us valuable insight into the constitution and dynamics of the Solar System and also can be used as reference points for exoplanetary research. On Earth, IDPs are delivered to the planet via meteoroid streams (Love and Brownlee 1993), allowing us to get a closer look at the dust particles and their parent bodies. The Geminid stream is one such example. Asteroid (3200) Phaethon is considered as the parent body of the Geminids, and together they form the Phaethon-Geminid stream complex (Whipple 1983; Gustafson 1989). The DESTINY+* mission by JAXA/ISAS will perform in-situ observation of Phaethon in the late 2020s and further advance the science of near-Earth IDPs, and provide information on the dust ejection on Phaethon and even other active asteroids (see, Arai et al. the invited talk).

The dust ejection mechanism of Phaethon and the consequent formation of the Geminids is still not determined. Many dynamical studies were conducted to constrain our understanding of this process to recreate the Geminid stream by numerical simulation, but with varying degrees of success. However, none of them have successfully explained how mm- and cm-sized dust particles can be ejected from the asteroid and end up at the present day on Earth as Geminid meteoroids. In this work, we conducted a numerical simulation of large (> 1 mm) particles from Phaethon, assuming a low-velocity ejection. We will present our results and discuss its implications for the dust ejection mechanism on Phaethon.

* Demonstration and Experiment of Space Technology for Interplanetary voYage Phaethon fLyby and dUst Science

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growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation

#2576

DESTINY+ asteroid flyby of Geminid parent Phaethon

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Demonstration and Experiment of Space Technology for INterplanetary voYage with Phaethon fLyby and dUst Science (DESTINY$^+$) is the asteroid flyby mission in JAXA/ISAS small class program. It will be launched in 2024 by a Japanese Epsilon S solid-fuel rocket. It is a joint mission of technology demonstration and scientific observation. The major objective of DESTINY$^+$ is to demonstrate high performance electric propelled vehicle technology and high-speed flyby observation of asteroids. The primary target is (3200) Phaethon and the secondary one in the bonus mission is 2005 UD, which is a likely break-up body from Phaethon. Phaethon is the parent of the Geminid meteoroid stream and an Apollo-type near-Earth active asteroid, ejecting dust upon its perihelion passage, where the surface is heated up to 1000 K due to the small perihelion distance (0.14 au). Mechanism for the dust ejection from the sunburned asteroid has been little known and under hot debate. The scientific objectives of DESTINY$^+$ are (1) flyby imaging of Phaethon to study its geology and dust ejection mechanism, and (2) in-situ analyses of velocity, arrival direction, mass and chemical composition of interplanetary and interstellar dust particles around 1 au, the dust trails, and nearby Phaethon, to characterize cosmic dust deliver to the Earth. The DESTINY$^+$ science payloads include a panchromatic, telescopic camera with a tracking capability (TCAP), a visible-NIR multi-band camera with four bands of 425, 550, 700, 850 nm (MCAP), and a dust analyzer (DDA). DDA is developed by Univ. of Stuttgart, as an international collaboration with DLR. Ground calibration of DDA is performed with German/Japanese joint efforts. International observation campaign for Phaethon was conducted in December 2017, and that of asteroid 2005 UD in October 2018. International observation campaign for stellar occultation by Phaethon was performed in 2019. To further constrain its size and albedo, photometric, polarimetric, and stellar occultation observations of Phaethon were conducted mainly in Japan in October through December 2021.

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#2155

Chemical link between protostellar cores, protoplanetary disks, and primordial objects in the Solar system

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It has long been debated if and how much the Solar system material inherits the composition of interstellar medium. The high D_2O/HDO ratio compared with the HDO/H_2O ratio in both comet 67P and the central region of protostellar cores indicates the inheritance of water from interstellar ice. The variation of HDO/H2O ratio and molecular abundances among comets, on the other hand, suggests partial modification of ice composition in the disk. Theoretical studies predict active chemical reactions in protoplanetary disks. For example, ion-molecule reactions are triggered by X-ray ionization. Exothermic exchange reactions in cold outer regions and selective photodissociation trigger isotope fractionation. These predictions are now confirmed by high spatial resolution observations of protoplanetary disks, which show that the radial distributions of the column density and isotope ratio vary among molecules. While the line observations probe gaseous molecules, rather than solid material, from which the asteroids and comets are made, gas-phase chemistry and solid-phase chemistry are connected via adsorption and desorption. The coupling of gas-phase and solid-phase chemistry is affected by the dust growth, sedimentation, and turbulence in the disk. The inheritance would be more significant if the dust sedimentation is faster, and turbulence is weaker. Efficient grain growth, radial drift, and dust trap could result in spatial variation of elemental abundances, e.g. C/H and C/O ratio, which is observed in several disks.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation

#1459

Chemical Provenances of Cometary Volatiles

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Comets are thought to be the most pristine relics of the early stages of formation of our Solar System (A'Hearn 2011b, Weissman et al. 2020). More than two dozen molecules are regularly detected in comets (Mumma and Charnley 2011, Bockelée-Morvan and Biver 2017, McKay and Roth 2021). Complex organic molecules have also been detected in several comets, including methanol, formic acid, methyl formate, ethylene glycol, formamide, ethanol, and glycolaldehyde (Bockelée-Morvan et al. 2000, Biver et al. 2015b, Cordiner et al. 2017a). An unprecedented level of chemical complexity has been revealed in the Jupiter-family comet 67P/Churyumov-Gerasimenko by the ESA Rosetta mission (Taylor et al. 2017, Altwegg et al. 2019), including the detection of the simplest amino acid, glycine (Altwegg et al. 2016). The chemical inventory of comets and the isotopic ratios of cometary molecules provide clues to the processes and timing of comet formation. In my talk, I will describe the emerging picture of the origin of cometary volatiles and its implications for the chemical processes during star formation. I will highlight comparative studies of interstellar and cometary molecular inventories such as those of Drozdovskaya et al. 2019. I will focus in detail on the mounting evidence that supports a cold formative past of comets such as the D/H ratios of cometary volatiles (Drozdovskaya et al. 2021, 2022). I will advocate for continued efforts in investigating the chemical composition of comets as they are unique windows to our infant Solar System, including the development of future cryogenic sample return space missions such as AMBITION (Bockelée-Morvan et al. 2021).

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation

#2157

A brief story of grain growth in young stellar objects

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Terrestrial planets including our own Earth show that sub-micrometer grains of the interstellar medium have grown by more than ten orders of magnitude in size. Then, when and how have such grains grown? These are ones of the fundamental questions to tackle in astronomy. My story starts with the results that dust grains have significantly grown already at the earliest stage of young stellar objects (YSOs).   As YSOs evolve, they grow further in circumstellar disks and can move around. A brief story about evolution of YSOs focusing on grain growth is presented with selected results. In addition, how we can study grain sizes of YSOs is addressed.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects

#2213

Multi-Scale Understanding of C-type Near-Earth Asteroid (162173) Ryugu from Proximity Exploration by Hayabusa2 Spacecraft to Microanalysis of Returned Material

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The JAXA's Hayabusa2 spacecraft explored C-type Near-Earth Asteroid (162173) Ryugu to return the first sample from carbonaceous asteroids, which have long been hypothesized as parent bodies of carbonaceous chondrites. The mission aims to understand the long history of the asteroid and the Solar System from 4.567 billion years ago to the present through multi-scale investigation [1].

The Hayabusa2 spacecraft explored a 1-km-size spinning-top-shaped Ryugu for 17 months. Its low bulk density of 1.19 ± 0.03 g cm^{-3} and the presence of many boulders suggest that Ryugu is a rubble-pile body [2, 3]. The surface has a low geometric albedo (~0.02) [3], and shows a weak but ubiquitous 2.72-μm O-H vibration absorption feature indicating the presence of hydrous minerals [4]. The MASCOT lander and two MINERVA-II rovers investigate morphology and physical properties of surface boulders and pebbles at multiple surface locations [5-7].

The spacecraft made two landing operations for sample collection, the latter of which was made near the spacecraft-made artificial crater to collect the impact ejecta [8]. The sample was successfully delivered to the Earth in December 2020. Because spectroscopic and morphological features of returned sample are consistent with the spacecraft observation, the returned sample well represents the Ryugu's surface material [7, 9, 10]. A fraction of Ryugu sample (0.3 g in total) was allocated to the Hayabusa2 initial analysis team for science-oriented detailed investigation from chemical (both inorganic and organic), mineralogical, and petrological perspectives. This presentation will focus on multi-scale understanding of Ryugu through the proximity observation of the asteroid and the analysis results of Ryugu sample.

[1] Tachibana et al. (2014) Geochem. J. 48, 571. [2] Watanabe et al. (2019) Science 364, 268. [3] Sugita et al. (2019) Science 364, eaaw0422. [4] Kitazato et al. (2019) Science 364, 272. [5] Jaumann et al. (2019) Science 365, 817. [6] Grott et al. (2019) Nat. Astron. 3, 971. [7] Tachibana et al. (2022) Science 375, 1011. [8] Arakawa et al. (2020) Science 368, 67. [9] Yada et al. (2021) Nat. Astron. 6, 214. [10] Pilorget et al. (2021) Nat. Astron. 6, 221.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active

asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System

#493

Observing small bodies from light points to micro-particles

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The knowledge of the physical and compositional properties of asteroids, comets, transneptunian objects, is fundamental to understand the processes that occurred in our solar nebula as well as in the other planetary systems.

In the last century, small bodies began to no longer appear as starlike points of light in our telescopes, but to be resolved worlds with measurable sizes, shapes, and surface morphologies. Many of these objects, particularly transneptunians, continue to be on the limit of observability by the today ground-based telescopes.

By the end of the XXth century, space exploration and advances in remote observations have triggered major progress in our understanding of the small bodies, which appear more complex and fascinating than ever. More than 20 small bodies, all different from one another, have been the targets of past space missions. Starting in 1986, when the Giotto ESA mission was the first to take a close look at a comet nucleus, passing through the inner coma of 1P/Halley, many others followed.

On the last decade the ESA mission Rosetta had a successful rendezvous with the comet 67P/Churyumov-Gerasimenko and delivered a surface science package, the NASA mission New Horizons arrived in an extraordinary short time to Pluto system, visiting also with a fly-by the small TNO (486958) Arrokoth. The JAXA Hayabusa, Hayabusa2, and NASA OSIRIS-REx missions allowed to analyze the respective target asteroids at different scales up to analyze at micro-nano scales the returned sample.

All together these missions have revolutionized our understanding of the small bodies. The obtained results allowed us to test many ground based techniques and the lessons learned will help to better characterize our continuing investigations of the small body population. A short non exhaustive overview of the principal results will be presented.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry,

protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust, planets (TOI-270 system), atmospheres, composition, JWST, Exploration, Carbonaceous chondrites, Planetesimals, Aqueous alteration, Impact crater, Sample analysis, Snow line, Collisions, Asteroids, Comets, Craters, Disruptions, Rubble piles, Aggregates, asteroids, polarimetry, near-infrared, Solar System, Atmosphere, Hydrogen, Helium, Gravity, Energy, Planet, Solar System, Wobble, Earth, The Moon, Sun, Chondrite, Magnetism, Solar System, Kamacite, Tetrataenite, small bodies, space missions

#2243 [e-Poster]

Early activity in Jupiter Trojans after being captured and their influence on the surface colors

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Jupiter Trojans came from an outer primordial planetesimal disk to the present location during a dynamical instability. The changed thermal environments might have altered the thermal and mechanical structures of the Trojans. Using a numerical simulation, we examined the evolutionary processes of the Trojans in the early stage after their migration. When the initial phase of water ice is amorphous, comet-like activities occur at the present location of the Trojans regardless of other parameters like dust to ice ratio and dust thermal conductivity. It implies that a crystallization mechanism after the migration caused the activity that possibly changed the surface colors as suggested for the active Centaurs. It is expected that we can understand the evolutionary processes of Jupiter Trojan and their influence on the surface colors.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface

#347 [e-Poster]

Results of Photometric Observations of Comet P/2019 LD2 at the Sanglokh Observatory

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Optical observations of short-period comet P/2019 LD2 (Atlas) were carried out over five nights in August 2020 at the Sanglokh International Astronomical Observatory of the Institute of Astrophysics of the NAST with the Zeiss-1000 telescope using a broadband filter *R*. Based on data from observations, the following physical characteristics of the comet were obtained:

(1) Apparent magnitudes m_R by measurements of each night of observations; (2) Absolute magnitude $m_R(1,1,0) = 11.42 \pm 0.03^m$; (3) Parameter of dust production *Af*ρ about 250±6.5 cm (at ρ=4.05″); (4) Estimate of the upper limit of the radius of the comet's nucleus r_{max}=6.1± 0.1 km at albedo *A*=0.12; (5) Isophotes of the comet were constructed, demonstrating the distribution of brightness along the tail; (6) Finson–Probstein diagrams of the inner and all visible part of the comet's dust tail were constructed and its structure, namely the distribution of dust particles by size and by the time of ejection from the surface of the nucleus, was found. It was shown that large particles over 100 μm in size are dominant in the inner regions of the dust tail; (7) Photometric data indicate that during the monitoring period the comet was in a stage of slightly increased cometary activity, associated mainly with the recent passage of the perihelion. During the observations, the comet's heliocentric distance was 4.591–4.593 AU. At such distances, less than the so-called "snow line", to some extent, the typical processes responsible for normal cometary activity can still acting, namely, solar heating of the surface, sublimation of surface frozen volatile components, dust emission and the formation of a coma and tail; (8) The comet's current orbit indicates that the comet is in the transition from Centaurs to Jupiter family comets. A slightly increased value of *Af*ρ compared with other comets of the Jupiter family may indicate a previous long stay of the comet in the outer regions of the Solar system.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve,

YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust, planets (TOI-270 system), atmospheres, composition, JWST, Exploration, Carbonaceous chondrites, Planetesimals, Aqueous alteration, Impact crater, Sample analysis, Snow line, Collisions, Asteroids, Comets, Craters, Disruptions, Rubble piles, Aggregates, asteroids, polarimetry, near-infrared, Solar System, Atmosphere, Hydrogen, Helium, Gravity, Energy, Planet, Solar System, Wobble, Earth, The Moon, Sun, Chondrite, Magnetism, Solar System, Kamacite, Tetrataenite, small bodies, space missions, comet, photometry, brightness, diameter, dust production, distribution of dust particles, transition stage

#1419 [e-Poster]

2-micron Mapping of the Jovian Polar Haze using Juno/JIRAM data

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We have analyzed 2-micron spectro-images of the polar haze of Jupiter, which have been obtained by the Jovian Infrared Auroral Mapper (JIRAM/Juno), in order to study polar haze distributions. The polar haze may be actively formed by auroral particle precipitations on the polar regions of Jupiter. For the investigation of this formation scenario, the first step is to determine the morphology of the polar haze distribution. We have constructed detailed contour maps of the polar haze by selecting specific 2-micron spectral ranges, where the polar haze most prominently shows; and we will present our preliminary results.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora

#862 [e-Poster]

Atmospheric properties of sub-Neptune atmospheres: TOI-270 system

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We investigate the potential for the James Webb Space Telescope (JWST) to detect and characterize the atmospheres of sub-Neptunian exoplanets in the TOI-270 system. Sub-Neptunes are considered more likely to be water worlds than gas dwarfs. We model their atmospheres using three atmospheric compositions – two examples of hydrogen-dominated atmospheres and a water-dominated atmosphere. We then simulate the infrared transmission spectra of these atmospheres for JWST instrument modes optimized for transit observation of exoplanet atmospheres: NIRISS, NIRSpec, and MIRI. We then predict the observability of each exoplanet's atmosphere. TOI-270c and d are excellent targets for detecting atmospheres with JWST transmission spectroscopy, requiring only 1 transit observation with NIRISS, NIRSpec, and MIRI; a higher signal-to-noise ratio can be obtained for a clear H-rich atmosphere. Fewer than three transits with NIRISS and NIRSpec may be enough to reveal molecular features. Water-dominated atmospheres require more transits. Water spectral features in water-dominated atmospheres may be detectable with NIRISS in two or three transits. We find that the detectability of Ammonia, which is a unique biosignature in atmospheres rich in Hydrogen (Seager et al. 2013), would only require one transit with NIRISS/SOSS to be detected at higher SNR. TOI-270c and d are promising sites for follow-up atmospheric characterization with JWST.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids,

observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust, planets (TOI-270 system), atmospheres, composition, JWST

#730 [e-Poster]

Asteroid Polarimetric-Phase Behavior in the Near-Infrared

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Polarimetry offers us a unique way of characterizing asteroid surfaces and probing their mineralogical makeup. We present our first results from a survey of asteroid polarization-phase curves using the WIRC+Pol instrument on the Palomar 200" telescope. We find that C-complex objects show nearly identical behaviors at J and H bands as they do at visible wavelengths. However, S-complex asteroids show a significant shift in their polarization-phase curves, indicative of a change in refractive index of the surface material from visible to J and H bands. Future work will investigate the behaviors of specific objects and taxonomic classes.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust, planets (TOI-270 system), atmospheres, composition, JWST, Exploration, Carbonaceous chondrites, Planetesimals, Aqueous alteration, Impact crater, Sample analysis, Snow line, Collisions, Asteroids, Comets, Craters, Disruptions, Rubble piles, Aggregates, asteroids, polarimetry, near-infrared

#2928 [e-Poster]

Harnessing the Yarkovsky effect to measure densities of probable M-type near-Earth asteroids

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The Asteroid belt must contain some part of metallic asteroids, whose material formed in the cores of differentiated planetesimals, liberated in disruptive collisions, and now routinely falls on the Earth in the form of iron meteorites. Still, we can point out at very few asteroids whose metallic composition is more or less certain.

Most remote sensing techniques only probe the surface properties of an asteroid. The consensus is that asteroids of the taxonomic type M are the most probable candidates for metallic asteroids. But do asteroids with seemingly metallic surfaces also have metallic interiors? The most effective way to answer this question is by measuring asteroid densities.

Densities of small near-Earth asteroids can be measured via their Yarkovsky effect, which is a secular change of an asteroid orbit due to the asymmetric emission of thermal radiation. The Yarkovsky effect has been observationally detected for about 250 near-Earth asteroids. Comparing these results to theoretical predictions from the thermophysical modeling results in density estimates for the asteroids. On the observational side, the number of detected Yarkovsky drift is expected to increase dramatically due to the Gaia data. Still, on the theoretical side, a simple and robust theory for the Yarkovsky effect is needed to analyze these data.

Here, we present such a mathematical model of the Yarkovsky effect. It accounts for the asteroid's oblateness and thermal properties but does not require such unaccessible information as the detailed asteroid shape. We test this model and create a Monte Carlo program that simulates the density of an asteroid given the uncertainties in the asteroid's Yarkovsky drift rate, thermal inertia, shape, pole, and radius.

We use the proposed method to measure densities of a dozen NEAs, whose optical, thermal and radar properties are close to those of the M-type asteroids Resulting densities for all the studied asteroids cluster around 1-2 g/cm^3, indicating no presence of large quantities of metal in their interiors.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect

#3419 [e-Poster]

Thermal design of a suite of two optical cameras mounted on a rover for lunar mid-latitude exploration

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We provide thermal modeling and design of GrainCams which consists of optical systems mounted on a lunar rover. GrainCams is a suite of two light field cameras, SurfCam and LevCam, designed to study the characteristics of the upper lunar regolith and levitated dust grains on the Moon. The Commercial Lunar Payload Services (CLPS) manifest selection of GrainCams is under consideration, and if successful, the payload will perform lunar surface exploration in the mid-2020s. Achieving a viable thermal design is essential for the success of the mission despite the extreme lunar thermal environment. Our thermal design, thus, employs both passive and active thermal control techniques: thermal insulation blankets, surface control of thermal radiation, radiators with a specially designed inclination angle, and heaters. We first completed the radiator design that satisfies the temperature requirements in the worst hot case through thermal analysis and then calculated the required heater power with the radiator design in the worst cold case. The design of SurfCam also satisfies the temperature requirements for the observation (deployed) mode when the instrument approaches the lunar surface to make close-up observations as well as the stand-by (stowed) mode.

Keywords: Lunar surface payload, Thermal analysis, Thermal design, Lunar rover

#3406 [e-Poster]

High-Resolution Mid-Infrared Observations of Planetary Rings from the Ground

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We present mid-infrared (MIR) high spatial resolution images of Saturn's rings obtained with the Subaru Telescope as an example of observations of solid particles around a planet. The temperature profiles of the rings were estimated from the MIR spectral energy distributions (SEDs) of the C, B, and A rings and the Cassini Division in 2008 composed from the images. The achieved spatial resolution of the profile is 4000 km, almost comparable to the one by Cassini/CIRS, and, to our best knowledge, seems the highest ever reported from ground-based observations. We found that the C ring and the Cassini Division were warmer than the B and A rings in 2008, which could be accounted for by their lower albedos, lower optical depths, and smaller self-shadowing effect. We also found that the radial profile of the MIR emission contrast of Saturn's rings in 2008 was the inverse of that in 2005. This temporal variation is probably caused by seasonal changes in the elevations of the Sun and observer above the ring plane as varying angles will lead to differing filling factors and temperatures of the particles in the rings.

Keywords: Planetary Rings, Infrared Observations

#3402 [e-Poster]

Introduction to GrainCams for Lunar Surface Exploration Mission

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GrainCams aim to understand characteristics of the uppermost regolith and levitating dust on lunar surface. GrainCams will operate on lunar surface with a rover. It has two light field cameras that are surface camera (SurfCam) and levitating dust camera (LevCam). The main objective of SurfCam and LevCam is to obtain three dimensional images of microscopic structure of the uppermost regolith and levitating dust grains, respectively. Lunar regolith microstructure, usually called ‘fairy castle structure’, is significant to understand regolith properties such as light scattering, thermal emissivity, albedo and so on. However, it is not well-known yet. SurfCam will take light field images of the upper few millimeters of the regolith with various region near the landing site. The data obtained by SurfCam will provide the enigmatic shape of the fairy castle structure and will improve the photometric and thermal emissivity characteristics of airless bodies. SurfCam is a x3 microscope with a 30 mm aperture and its spatial resolution is smaller than 12 μm. The micro lens array employed by SurfCam contain 409 × 341 lenses.

The scientific objective of the LevCam is to observe the motions of levitating dust grains with sizes of ~ 1 μm. LevCam is also a light field camera system. Thus, LevCam will measure three dimensional positions and speeds of levitating dust grains, which can provide the density of dust grains ~ 10 cm above the lunar surface and the strength of the electric fields near the lunar surface. LevCam has a 70 mm aperture main lens and its working distance is around 1 m from the optics. The micro lens array contains 48 × 45 micro lenses.

The GrainCams is expected toimprove the our knowledge of the electrostatic environments of the lunar surface.

Keywords: Moon, exploration, regolith, instrument

#3315 [e-Poster]

Korea's Scientific Payloads on the Lunar Surface through the NASA/CLPS initiative

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Korea Astronomy and Space Science Institute (KASI) is developing four payloads, GrainCams, LVRAD, LSMAG, and LUSEM, to make scientific measurements on the lunar surface to be onboard Commercial Lunar Payload Services (CLPS) landers based on the KASI-NASA Exploration Working Group. Korea's Ministry of Science and ICT (MSIT) supports the development, mission operation, and data analysis processes.

GrainCams has two light-field cameras, SurfCam and LevCam. SurfCam will take light-field images of the microscopic structure of the uppermost regolith at several different places on the Moon. LevCam will detect the regolith grains levitating and lofted above the surface and take measurements of their motions. These phenomena are not reproducible on Earth nor preserved via a sample return mission.

LVRAD is a suite of instruments to measure the radiation environment on the lunar surface using a Particle Dosimeter and Spectrometer (PDS), Tissue-Equivalent Dosimeter (TED), and Epithermal and Fast Neutron Spectrometers (NS-E and NS-F, respectively).

LSMAG will measure the magnetic field on the lunar surface using two fluxgate magnetometers on a 1-m boom to model the strength and direction of dipole sources lie buried nearby the lander, possibly in collaboration with other magnetometers onboard orbiters of different altitudes such as ones onboard ARTEMIS, Korean Pathfinder Lunar Orbiter (KPLO), and so one.

LUSEM consists of two pairs of the two solid-state telescopes (SST) to detect high-energy particles of tens keV to tens MeV on the lunar surface. Each pair consists of a nadir- and zenith-viewing SST to take measurements of the incoming high-energy particles and the reflected ones simultaneously.

LUSEM will be onboard a Nova-C lander in Intuitive Machines to visit the Reiner Gamma swirl as a part of IM-3 in 2024. The embarkment of the other payloads is under discussion. All the science, technology, and experiences built up from this project will also help Korea's lunar landing mission.

Keywords: Moon, exploration, lander, CLPS

#3302 [e-Poster]

Asymmetric space weathering in northern and southern hemispheres on the Moon

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Space weathering on the Moon is generally known to be dominated by solar wind irradiation and micrometeorite impacts. They change the lunar regolith to optically mature by altering its compositions and spectral properties. The wall quadrants of lunar craters have the advantage of studying the optical maturity (OMAT) difference caused by the solar flux difference between opposing quadrants. The wall quadrants had been exposed on the surface for the same duration but the quadrants facing each other have different incident angles of the space weathering particles depending on the location.

Previous studies have found latitudinal and longitudinal dependencies of optical properties on the lunar surface. Following Sim et al., who studied the space weathering asymmetry inside lunar craters, here we apply the extended lunar crater database (Robbins et al.) to consider more and smaller craters. A total of 26,802 craters ranging from 2 to 150 km in diameter are used, more than 10 times the 1,872 in the previous study. We reproduce the dependencies with the improved processes—finding the rim, defining the inner structure, and dividing wall quadrants of the craters.

Furthermore, we find that the OMAT difference between the equator-facing (EF) and pole-facing (PF) walls has opposite trends in the northern and southern hemispheres at lower latitudes. Below 25 degrees, the EF wall is more mature than the PF wall in the northern hemisphere, but it is the opposite in the southern hemisphere. Unlike previously known, the hemispheres seem not to be symmetrically affected along the ecliptic plane. In particular, the degree of weathering on the EF and PF walls is significantly asymmetric near the equator. We speculate that this unexpected result is caused by asymmetric impacts of meteoroids in the northern and southern hemispheres on the Moon.

Keywords: The Moon, Lunar science, Lunar surface, Lunar craters, Planetary science, Surface processes

#1838

The role of continents on the global surface temperature of an Earth-like planet

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One of the requirements for habitability is liquid water. Its presence depends strongly on temperature and this, in turn, is determined by the distance between the planet and its host star. However, there are also other factors that are less studied such as the geodynamic and geophysical environments. These environments include many factors that could modify the temperature of a planet, such as the composition of its atmosphere, or the continental distribution, the latter being the focus of this work. We use Planet Simulator (PlaSim), a climate model of intermediate complexity for the Earth and other planets, to study the effect in temperature of stepwise change of continental area with respect to that of Earth. Preliminary results show that the global surface temperature varies depending on the position of each continent removed, although it has a clear tendency to decrease with decreasing in the amount of total continental land.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation

#3145 [e-Poster]

Grain Growth and Dust Segregation Revealed by Multi-wavelength Analysis of the Class I Protostellar Disk WL 17

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Disks around protostars are the natal place of planets. The first step toward planet formation is grain growth from (sub-)micrometer to millimeter/centimeter sizes. Grain growth has been reported not only in Class II protoplanetary disks but also in Class 0/I protostellar envelopes. However, such rapid grain growth is little known on the protostellar disk scale. Here we present the result from the ALMA Band 3 (3.1 mm; 97.5 GHz) and 7 (0.87 mm; 350 GHz) archival data of the Class I protostellar disk WL 17 in the ρ Ophiuchus molecular cloud. Disk substructures are found in both bands as reported in previous studies but they are different: while a central hole and a symmetric ring appear in Band 3, an off-center hole and an asymmetric ring are shown in Band 7. Furthermore, we obtain an asymmetric spectral index (α) map with a low mean value of 2.28 ± 0.02, indicative of rapid grain growth and dust segregation on the protostellar disk scale. Radiative transfer modeling demonstrates that 10 cm-sized large grains are symmetrically distributed, whereas 10 μm-sized small grains are asymmetrically distributed, and that the disk is massive and gravitationally unstable. We suggest a single Jupiter-mass protoplanet formed by gravitational instability as the origin of the rapid grain growth and dust segregation revealed in WL 17.

Keywords: radio astronomy, star formation, planet formation, protostellar disk, grain growth

#673 [e-Poster]

The light field camera simulation based on ray-tracing for CLPS/GrainCams

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In general, Light Field Camera (LFC) can obtain spatial and directional light information. It can be designed by adding an appropriate microlens array (MLA) to a general camera system. In order to design a custom light field camera for scientific purpose, one need to find appropriate trade-off calculations between spatial and directional resolutions through image test with various diameter sizes of microlens. Custom MLAs can be rather expensive, thus an accurate light field camera simulation could allow to reduce production costs. In this study, we simulated virtual observation images based on ray-tracing for CLPS/GrainCams composed of two light field camera instrument package, SurfCam and LevCam, designed to understand the environment of the lunar surface.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust, planets (TOI-270 system), atmospheres, composition, JWST, Exploration, Carbonaceous chondrites, Planetesimals, Aqueous alteration, Impact crater, Sample analysis, Snow line, Collisions, Asteroids, Comets, Craters, Disruptions, Rubble piles, Aggregates, asteroids, polarimetry, near-infrared

#1974 [e-Poster]

Color indexes survey of NEOROCKS Near Earth Objects targets

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Asteroids are composed by remnant material, mostly unmelted, from the formation of our Solar System. Near-Earth Objects (NEOs) physical characterization is important into understanding of chemistry of planetary system nebula.

European efforts formalized into the NEOROCKS program imply the improvement knowledge on the physical properties of the NEOs population, the implications for their origin and evolution, and the topics related to planetary defense.

Color indexes survey of NEOs was started in 2020 as a regular program of observations implying a minimum of 20 nights each year. Observations are performed in France at the Observatoire de Haute Provence and Observatoire de Pic du Midi. Two assets are used, namely 1.20m telescope and 1.05m telescope respectively.

The NEOs targets covered preferentially the Potential Hazardous Asteroids (PHAs) population. Johnson B and V, Cousins R and Gunn I filters are used for their characterization. Between 2020 and January 2021, color indexes were computed for 81 objects. Among these, 38 asteroids belong to the PHAs category. Data analysis, statistics, and taxonomic classification are presented.

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Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics

#582 [e-Poster]

Thermal Escape of Hydrogen and Helium in the Solar System

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The effective temperature of the Sun is about 5780 K, far less than the temperature (= 1.552 × 10^7 K) needed for most Hydrogen to escape from the Sun's gravity by thermal activation. It is therefore easy to anticipate that all the Hydrogens are gravitationally bound to the Sun. In fact, only a minute leakage of Solar Hydrogen occurs from the Solar Corona in a form of Solar wind. For Jupiter, the average speed of thermally activated molecular Hydrogen (1.889 km s^{-1}) or Helium (0.944 km s^{-1}) is much smaller than the escape velocity (= 60.2 km s^{-1}). That is why Hydrogen and Helium are hardly lost from the Jupiter's surface. On the other hand, temperatures in the Earth's upper thermosphere ranges from 800 to 2300 K, which is comparable to that (= 5086 K) calculated from molecular activation energy of Hydrogen. Then, it is natural to expect thermal escape of Hydrogen and Helium from Earth's atmosphere. According to thermodynamic statistics, a significant proportion of molecules can escape from the uppermost layer of the planetary body when the ratio of escape velocity to thermal activation velocity is confined within six. As a result, Jovian planets retained nearly all the atmospheric constituents while very little leakage of Hydrogen and Helium into space occurred.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust,

planets (TOI-270 system), atmospheres, composition, JWST, Exploration, Carbonaceous chondrites, Planetesimals, Aqueous alteration, Impact crater, Sample analysis, Snow line, Collisions, Asteroids, Comets, Craters, Disruptions, Rubble piles, Aggregates, asteroids, polarimetry, near-infrared, Solar System, Atmosphere, Hydrogen, Helium, Gravity, Energy

#581 [e-Poster]

Resolution of Wobble Method for Detecting Planets

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The center of mass (CM) is a unique point where the mean of the masses factored by their distances from the known reference position. The CM is analogous to the mass–balance with respect to a pivot point of the seesaw. Using the CM relation, magnitude of wobble of the Sun exerted by the Jupiter was estimated as 7.5×10^{8} m. Such wobble generates a Solar motion of 2 m s^{-1}. Similarly, the wobble of the Earth produced by the Moon was determined as 4.7×10^{6} m, induces radial velocity of Earth with 6.0×10^{-6} m s^{-1}. The wobble of the Neptune produced by the Triton was 7.4×10^{4} m, responsible for the small radial velocity of Neptune (7.5×10^{-6} m s^{-1}). The maximum angular diameter of the wobble would be about 500 micro arc sec at 10 pc for the Jupiter–Sun system. Magnitude of Solar wobble produced by terrestrial planets are less than 1% to that produced by Jupiter. For instance, magnitude of Solar wobble produced by Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune are 1.0×10^{-3} m s^{-1}, 1.4×10^{-2} m s^{-1}, 1.4×10^{-2} m s^{-1}, 1.0×10^{-3} m s^{-1}, 2.0×10^{0} m s^{-1}, 4.4×10^{-1} m s^{-1}, 4.7×10^{-1} m s^{-1}, and 4.5×10^{-1} m s^{-1}, respectively.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust, planets (TOI-270 system), atmospheres, composition, JWST, Exploration, Carbonaceous chondrites, Planetesimals, Aqueous alteration, Impact crater, Sample analysis, Snow line,

Collisions, Asteroids, Comets, Craters, Disruptions, Rubble piles, Aggregates, asteroids, polarimetry, near-infrared, Solar System, Atmosphere, Hydrogen, Helium, Gravity, Energy, Planet, Solar System, Wobble, Earth, The Moon, Sun

#579 [e-Poster]

Brecciation and Magnetic Lock-in of Chondrites

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To decipher erratic magnetic behavior of chondrites, a suite of rock magnetic experiments including alternating–field demagnetization, thermal demagnetization, and temperature dependence of anhysteretic remanent magnetization and saturation isothermal remanent magnetization were carried out. While Kamacite ($Fe_{0.9}Ni_{0.1}$) displayed virtually no remanent magnetization, stable ancient planetary magnetic field was retrieved from tetrataemite ($Fe_{0.6}Ni_{0.4}$). Directional scatters in higher unblocking fractions for tetrataenite (500–550ºC) were probably originated from the first episode of brecciation occurred in a presence of a planetary magnetic field. The second shock–related episode of metamorphic event occurred under the influence of a planetary magnetic field with a peak temperature ~500°C. It is possible that the second shock–related event induced a partial thermal overprint. A subsequent third shock–induced disturbance modified existing magnetic signals. Of course, the second and third events can be simplified as a single pervasive shock–induced magnetic lock–in process.

Keywords: Asteroids, Near-Earth objects, Thermophysical modelling, Yarkovsky effect, Asteroids, Thermophysical modeling, YORP effect, Methods: analytical, Methods: numeric, Bennu, Space weathering, optical maturation, color imaging, spectroscopy, Apophis, tidal torque, tumbling asteroid, close encounter, flyby, Phaethon, Geminid meteor stream, active asteroid, dust ejection, near Sun asteroid, Apollo-type asteroid, comets, dust, mid-infrared, hydrated silicates, scattering, regoliths, porosity, surfaces, photometry, 3D printer, Particle Physics, Electron Structure, Proton Structure, Primary Particle, Photon, Up-photon, grain growth, young stellar objects, Near-Earth Objects, observations, color index, statistics, Trojan asteroids, Kuiper belt objects, Comets, Planetary surface, C-type asteroid, chondrite, Hayabusa2, Solar System, C-type asteroid, Hayabusa2, Solar System, astrochemistry, protoplanetary disks, star formation, asteroid, near-Earth object, photometry, lightcurve, YORP, asteroid, photometry, Gaia, phase curve, light scattering, shape, rotation, Global surface temperature, Continental land, Earth-like planet, Planetary simulation, asteroid, polarimetry, albedo, taxonomy, astrochemistry, comets, ALMA, Rosetta, complex organic molecules, D/H ratio, star formation, Jupiter, Haze, Juno, JIRAM, Infrared, Spectroscopy, Aurora, Kepler space telescope, exoplanet discovery, ultra-short period exoplanet, short period exoplanet, big data, deep learning, TensorFlow, radar, planetary, asteroids, observations, receive-array, Outer Solar system, Planet Nine, Trans-Neptunian objects, Subaru telescope, Hyper Suprime-cam, Difference imaging, Polarimetry, Hydrated asteroid, Solar system, Asteroid, Space weathering, active asteroid, Geminids, Phaethon, numerical simulation, minor planets, asteroids, asteroids: individual: 3200 Phaethon, active asteroids, interplanetary medium, asteroid, Didymos, Dimorphos, DART, impact, kinetic impactor, dust, planets (TOI-270 system), atmospheres, composition, JWST, Exploration, Carbonaceous

chondrites, Planetesimals, Aqueous alteration, Impact crater, Sample analysis, Snow line, Collisions, Asteroids, Comets, Craters, Disruptions, Rubble piles, Aggregates, asteroids, polarimetry, near-infrared, Solar System, Atmosphere, Hydrogen, Helium, Gravity, Energy, Planet, Solar System, Wobble, Earth, The Moon, Sun, Chondrite, Magnetism, Solar System, Kamacite, Tetrataenite