Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

PPS01-01 Room:418 Time:April 30 14:15-14:35

The Solar Power Sail for Round Trip Exploration to Jupiter Trojans and Deep Space Cruising Observation

YANO, Hajime[1*] ; NAKAMURA, Ryosuke[2] ; MATSUURA, Shuji[1] ; SEKINE, Yasuhito[3] ; TOYODA, Michisato[4] ; AOKI, Jun[4] ; YOSHIDA, Fumi[5] ; TAKATO, Naruhisa[5] ; KINOSHITA, Daisuke[6] ; YONETOKU, Daisuke[7] ; YOSHIKAWA, Makoto[1] ; MORI, Osamu[1] ; SOLAR SYSTEM SMALL BODY EXPLORATION WGT, .[1] ; SOLAR POWER SAIL WG, .[1]

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Since 2002, the Solar Power Sail WG has been studying a mission design of Japan's first outer planet region exploration, by demonstrating the solar power sail technology, and it is bound to Jupiter Trojan asteroids, which may hold fundamental clues of the Solar System formation and revolution discussed by two competing hypotheses between the classic model and the planetary migration model. The former suggests that Trojan asteroids are mainly survivors of building blocks of the Jupiter system, while the latter claims that they must be intruders from outer regions after the planetary migration of gas planets settled.

After Jupiter flyby, the spacecraft will reach to a candidate Trojan asteroid, hopefully being larger than a few 10's of km in size. Both global remote observation and deployment of an autonomous lander will be conducted. On the surface of the Trojan asteroid, sampling will be attempted for in-situ TOF mass spectrometry and passing the sample container to the mothership for a possible sample return option.

Also during the cruising operation, "dust free" astronomical platform beyond the cocoon of the zodiacal light formed by the main asteroid belt for the benefit of infrared astronomy searching for the first generation light of the Universe, let alone continuous observation of the zodiacal light structure of the Solar System. Extremely long baseline with the observation from the Earth, gamma-ray burst observation can identify their sources.

This presentation discusses major scientific objectives of an exploration mission to Jupiter Trojans for the first time in the history, its mission design and spacecraft system using solar power sail, a hybrid propulsion system of electric propulsion and photon sail, which inherited from the IKAROS deep space solar sail spacecraft, together with major engineering challenges, in-situ observation instruments and operational options including landing and sample return from the surface of a Trojan asteroid.

Keywords: Solar Power Sail, Jupiter Trojans, Deep Space Exploration, Deep Space Astronomy, Zodiacal Light, Sample Return

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PPS01-02 Room:418 Time:April 30 14:35-14:55

EUROPA CLIPPER MISSION CONCEPT OVERVIEW

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A NASA-appointed Science Definition Team (SDT) recently considered options for a future strategic mission to Europa, with the stated science goal: Explore Europa to investigate its habitability. The team worked closely with a technical team from the Jet Propulsion Laboratory (JPL) and the Applied Physics Laboratory (APL). Together, the group considered several mission options, which were fully technically developed, then costed and reviewed by technical review boards and planetary science community groups. Study results strongly favored an architecture consisting of a spacecraft in Jupiter orbit, making many close flybys of Europa, and concentrating on remote sensing to explore the moon. The resulting nominal mission design is innovative for its use of gravitational perturbations of the spacecraft trajectory to permit flybys at a wide variety of latitudes and longitudes. The design enables globally distributed regional coverage of the moon's surface, nominally with 45 close flybys at altitudes from 25 to 100 km. We will present the science and reconnaissance goals and objectives, a mission design overview, and the notional spacecraft for this concept, which has become known as the Europa Clipper. The Europa Clipper concept provides a cost-efficient means to explore Europa and investigate its habitability, through understanding the satellite's ice and ocean, composition, and geology. The set of investigations derived from these science objectives traces to a notional payload for science, consisting of: Ice Penetrating Radar (for sounding of ice-water interfaces within and beneath the ice shell), Topographical Imager (for stereo imaging of the surface), ShortWave Infrared Spectrometer (for surface composition), Neutral Mass Spectrometer (for atmospheric composition), Magnetometer and Langmuir Probes (for inferring the satellite's induction field to characterize an ocean), and Gravity Science (to confirm an ocean). Among the many science investigations addressed, Europa Clipper could potentially characterize plumes linked to Europa's internal lakes or ocean. The mission would also include the capability to perform reconnaissance for a future lander, with the Reconnaissance goal: *Characterize safe and scientifically compelling sites for a future lander mission to Europa*. To accomplish these reconnaissance objectives and the investigations that flow from them, principally to address issues of landing site safety, two additional instruments would be included in the notional payload: a Reconnaissance Camera (for high-resolution imaging) and a Thermal Imager (to characterize the surface through its thermal properties). These instruments, in tandem with the notional payload for science, could assess the science value of potential landing sites. This notional payload serves as a proof-of-concept for the Europa Clipper during its formulation stage. The actual payload would be chosen through a NASA Announcement of Opportunity. If NASA were to proceed with the mission, it could be possible to launch early in the coming decade, on an Atlas V or the Space Launch System (SLS).

Keywords: Europa, Icy Worlds, Astrobiology, Europa Clipper, Missions, Planetary Science

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PPS01-03 Room:418 Time:April 30 14:55-15:10

Investigation of the Galilean Moons with the Ganymede Laser Altimeter (GALA)

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The icy moons of Jupiter ? Europa, Ganymede, and Callisto ? are believed to contain global subsurface water oceans underneath their icy crusts. The possibility is intriguing that these large liquid water oceans represent "habitable" environments. Investigation of the latter is a major objective of ESA's Jupiter Icy Moons Explorer (JUICE) mission. The Ganymede Laser Altimeter (GALA) is one of the instruments focusing on aspects related to the presence and characterization of subsurface water oceans by measuring Ganymede's tidal deformation. GALA will further contribute (a) to the exploration of the surface morphology and physical properties of Ganymede, Europa and Callisto, (b) to determination of their interior structures from a combination of shape, topography and gravitational field data, and (c) to understanding the satellites formation and evolution especially with respect to subsurface water oceans. GALA will investigate the surface and topography of Ganymede in particular. Topography data is needed to account for the effects of topographic heights on the gravity field and to account for near surface mass distribution anomalies above the reference figure; to support geological studies, e.g. to identify and characterize tectonic and cryo-volcanic regions on the icy moons and to identify periodic variations of Ganymede's shape due to tides.

Investigations by GALA will furthermore contribute to determine the orientation and rotational state of Ganymede and to study surface characteristics (roughness, slopes, and albedo) on Ganymede, Europa, and Callisto.

The instrument can be operated from ranges smaller than about 1000 to 1300 km (depending on the different albedo values and surface slopes of Europa, Ganymede and Callisto) during flybys and orbital pericenter passages. The main phases for acquiring data at Ganymede are the final circular orbit phases, where continuous operations are possible from altitudes around 500 km and 200 km, respectively.

Here, we will give an overview on the GALA experiment focusing on its scientific goals and performance.

Keywords: Laser altimetry, Satellites of Jupiter, Ganymede, Tides

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Longevity of an internal ocean in Ganymede

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The outer solar system may provide a potential habitat of extra-terrestrial life. Most moons orbiting planets in the outer Solar System, at orbits beyond the snow line, such as Jupiter or Saturn, are covered with water ice and are referred to as "icy moons". Galileo's detection of induced magnetic fields combined with imaged surface characteristics and thermal equilibrium modeling of the moons, support that the Jovian icy moons Europa and Ganymede, and possibly Callisto, may harbor liquid water oceans underneath the icy crusts. The presence of internal oceans in the icy moons means that a deep habitat different from Earth's biosphere may exist, located beyond the "habitable zone" of the Sun. Evidence for oceans is not definitive, however, and awaits confirmation measurements. Also, the depth and composition of the oceans remain unclear, as do their variability through time.

Here we focus on Ganymede, the largest moon in the Solar System and the primary target of a new mission to the Jupiter system, the Jupiter Icy Moons Explorer (JUICE), which is planned by the European Space Agency (ESA). The bulk density of Ganymede, 1.936 g/cc, indicates a composition of approximately equal amounts of rocky material and water. Previous measurements of Ganymede's gravitational field and intrinsic magnetic field by the Galileo orbiter suggest that its interior is completely differentiated into three layers, a convecting metallic core at the center, a rocky mantle surrounding the core, and an outermost water-ice shell. The water-ice layer in total has a thickness of 800-1000 km. A layer of melted, salty water that lies beneath the icy crust would be the best way to explain the signal of magnetic induction.

To investigate the lifetime of an ocean (thickness change through time) assumed to be initially in an entirely liquid state, we performed numerical simulations for the internal thermal evolution using a spherically symmetric model for the convective and conductive heat transfer with radial dependence of viscosity, heat source distribution, and other material properties. Here we take into account the energy due to decay of long-lived radioactive elements and also evaluate the effect of tidal heating. If the ocean were composed of pure water, a primordial ocean would have disappeared (completely solidified) within 1 Gyr even if tidal heating for the current orbital state were included. Consistent with previous predictions , this result indicates that significant tidal heating in the past, or strong antifreeze components (e.g., salts or ammonia),

are needed if the presence of the internal ocean in Ganymede would be confirmed from future JUICE observations. We numerically investigate their effect on the lifetime of the ocean.

Keywords: satellite, evolution, ocean, habitability, ice, Ganymede

PPS01-05 Room:418 Time:April 30 15:25-15:40

Impact basin relaxation on Pluto: Implications for the presence of a subsurface ocean

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Large-scale topographies, such as impact basins, on solid planetary bodies deform in geologically long timescales. The degree of deformation depends mainly on the viscosity, and the viscosity is strongly controlled by temperature. Consequently, viscous relaxation of large impact basins has been studied to investigate the thermal evolution of terrestrial planets as well as that of icy satellites of giant planets [e.g., 1-4].

Pluto, an icy dwarf planet, is likely to possess large impact basins. In this study, we investigate long-term viscoelastic deformation of impact basins on Pluto which can be compared with forthcoming observational data from New Horizons, the first Pluto explorer.

Although little is known for Pluto, its interior is likely differentiated into a rocky core and an outer H_2O layer [e.g., 5]. The presence of a subsurface ocean, however, is highly uncertain. If the outer (solid) H_2O layer is convective, the radiogenic heat from the rocky core is efficiently transferred to the surface, and temperature of the H_2O layer can be lower than its melting temperature. On the other hand, if the outer H_2O layer is conductive, the heat from the core can melt the H_2O layer. The main controlling factor whether the H_2O layer is convective or conductive is the reference viscosity: the ice viscosity at its melting temperature [6]. In this study, we calculate viscoelastic deformation of impact basins assuming different viscosity profiles and examine the effect of the presence of a subsurface ocean on basin relaxation.

For the initial study, we use two time-independent viscosity profiles; one profile assumes a stiff top shell overlying a thick subsurface ocean, and the other assumes a completely solidified interior. The same viscosity profile in the shell is assumed.

Our results indicate that the instantaneous elastic response largely differ between the viscosity models. However, long-term relaxation does not differ much because it is controlled by the viscosity profile in the shell, which is identical in our calculations. Nevertheless, long-term relaxation strongly depends on the reference viscosity, the main controlling factor whether the shell is convective. Consequently, relaxation state of impact basins can be used to infer the reference viscosity as well as the presence of a subsurface ocean. This result would be applicable to icy satellites of Jupiter and Saturn.

Our next step is to use time-dependent viscosity profiles. To do so, we have modified our relaxation code to take into account the temporal change in the shell thickness. The results will be discussed.

[1] Kamata et al. JGR 118, 398-415, 2013. [2] Mohit and Phillips, GRL, 34, L21204, 2007. [3] Robuchon et al. Icarus 207, 959-971, 2010. [4] Solomon et al. JGR 87, 7763-7771, 1982. [5] McKinnon et al. in Pluto and Charon, pp. 295-343, 1997. [6] Robuchon and Nimmo, Icarus 214, 426-439, 2011.

Keywords: Impact basin, Relaxation, Pluto, Viscoelasticity

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PPS01-06 Room:418 Time:April 30 15:40-15:55

Sub-millimeter observations of icy bodies toward understanding of planetary formation and cosmochemistry

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The present-day composition of regular icy satellites consists of combinations of initial conditions and subsequent evolution. These icy satellites are considered to have been formed in a circumplanetary disk associated with giant planet formation. Thus, icy satellites that are not geologically active, such as Callisto, would serve as solar system fossils, which may preserve the information of the protoplanetary disk and planetary formation. On the other hand, geologically active satellites, such as Europa and Enceladus, would provide particular geological processes and consequent products of geochemical reaction. Sub-millimeter observations are capable of providing unique isotopic and chemical compositions of gas molecules in atmospheres and plumes of the icy satellites. In this paper, we discuss key observational targets and their importance for planetary formation theory and geo/cosmochemistry, especially focusing on sub-millimeter observations of Galilean satellites by the Jupiter Icy moons Explorer mission, JUICE.

Keywords: sub-millimeter observation, icy satellite, planetary formation, cosmochemistry

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PPS01-07 Room:418 Time:April 30 16:15-16:30

Proto-atmospheres on giant icy satellites forming within gaseous circum-planetary disks

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In spite of the great similarity in size and mean density, the giant icy satellites Ganymede, Callisto, and Titan have very different surface environments. In particular, only Titan holds a thick atmosphere dominated by N_2. Recent data of the Cassini spacecraft indicated that atmospheric N_2 is probably originated from other nitrogen-bearing species like NH_3. However, it still remains an open question when and how N_2 was generated. This is partly because the physical states of giant icy satellites have been poorly understood.

According to a widely-accepted theory of regular satellites formation, the giant icy satellites were formed in subnebulae with low temperature and low pressure taking a long accretion time. Some models assert that their surfaces were kept too cold to induce significant differentiation during accretion. However, these satellites may capture a significant amount of subnebula gas, which possibly forms proto-atmospheres along with gases volatilized from icy components. Such a hybrid-type proto-atmosphere may have significant blanketing effect.

Here, we numerically analyze the structure and effect of a hybrid-type proto-atmosphere. Our model atmosphere is hydrostatically connected with subnebula at the satellite Hill radius. It contains H_2 and He as nebula gas components, H_2O and NH3 as volatilized ice components. The radiative-convective equilibrium structure is solved as a function of surface temperature. The subnebula conditions are given by Canup and Ward (2002), the temperatures are 150 K at Ganymede, 120 K at Callisto, and 50 K at Titan, and the corresponding subnebula pressures are varied over 0.1-10 Pa.

For all the boundary conditions, the proto-atmosphere is opaque due to water vapor, so that the outgoing thermal radiation (OTR) flux at top of the atmosphere is smaller than that of black body radiation without atmosphere when the surface temperature is higher than 273 K. When the surface temperature is lower, the OTR fluxes from the proto-atmospheres of Ganymede and Callisto are close to black-body radiation because these atmospheres have low surface pressure and are optically thin due to large scale height under high background temperature. On the other hand, the proto-atmosphere of Titan has another type of solution with the OTR fluxes significant lower than blackbody radiation under low surface temperature. This is due to the formation of optically thick atmosphere tightly bounded by gravity because of low background temperature.

These results imply that a warm proto-atmosphere near 200 K could be kept on Titan for a long time after the end of accretion. Our stability analysis suggests that the proto-atmospheres of Ganymede and Callisto were lost associated with the dissipation of the Jovian subnebula, but that of Titan survived after the dissipation of the Saturnian subnebula.

In the case, NH_3 vapor pressure would be kept high under the irradiation of the solar UV for a long time. The present atmospheric N_2 of Titan may be generated by photochemical reaction of NH_3 vapor in such a warm proto-atmosphere.

Keywords: Giant icy satellites, Atmosphere, Circum-planetary disks

PPS01-08 Room:418 Time:April 30 16:30-16:45

The difference of cloud formation process between Jupiter and Saturn.

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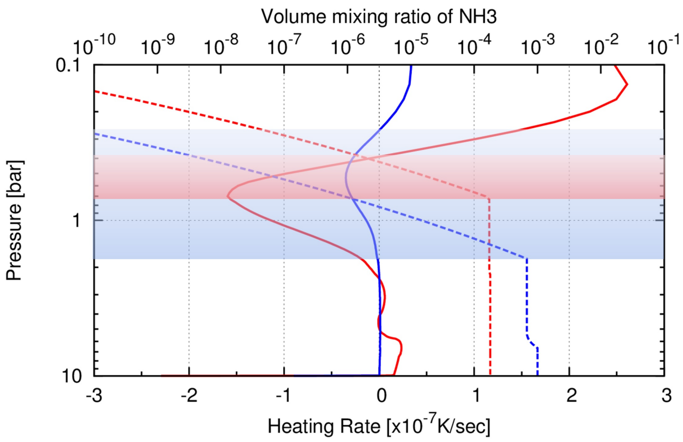
Gas giant planets have hydrogen-rich, thick atmospheres, and their styles of cloud activities are thought to be closely related to the profile of radiative cooling rate in troposphere. For example, Recent studies indicate that it basically controls the intermittency of cumulonimbus clouds. In spite of its significance, however, no systematic estimate has been made for the radiative cooling profiles of gas giant planets.

Recently, we have developed a 1D radiative-convective equilibrium model for such hydrogen-rich atmospheres. The model atmosphere continues to a lower boundary where the optical depth from the top of atmosphere is sufficiently large and the thermal structure follows convective equilibrium. The atmospheric composition and potential temperature of each planet are given from observational constraints. The mixing ratios of H2O, CH4, NH3, H2S, PH3 and NH4SH follow their saturation vapor pressure in the altitudes where their condensation occurs. Collision induced absorption of H2-H2 and H2-He, and line absorption of H2O, CH4, NH3, H2S, PH3 are included while the extinction by condensates is neglected. Under these settings, our model can calculate a reasonable atmospheric vertical structure by the iteration of radiative transfer calculation and convective adjustment.

For the case of Jupiter, the peak of radiative cooling rate is 1.6e-7 K/sec at 0.7 bar level. Also, our model predicts the radiative-convective boundary i.e., tropopause to be located around 0.3-0.4 bar level, where is slightly higher than the uppermost NH3 condensation layer ˜0.5 bar. For the case of Saturn, the peak of radiative cooling rate is 3.5e-8 K/sec at 0.53 bar, and the separation of tropopause and NH3 cloud layer is larger than that of Jupiter. This implies that the Saturnian NH3 cloud formation is essentially confined in the troposphere, whereas the Jovian one is also affected by the stratospheric processes.

Figure description : Radiative heating rate profile (solid lines, bottom x axis, K/sec) and Volume mixing ratio of NH3 profile (dashed lines, top x axis, mole fraction). Y axis is pressure (bar). Shaded area represents between NH3 condensation level and tropopause level. Red means Jovian model, and blue means Saturnian model. Note that these results are calculated with the polytropic temperature profiles for preliminary calculation, not thermal equilibrium profiles.

Keywords: Jupiter, Saturn, Cloud, Radiative transfer, Convection



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Near-infrared detections of surprisingly bright Ganymede and Callisto in the Jovian shadow

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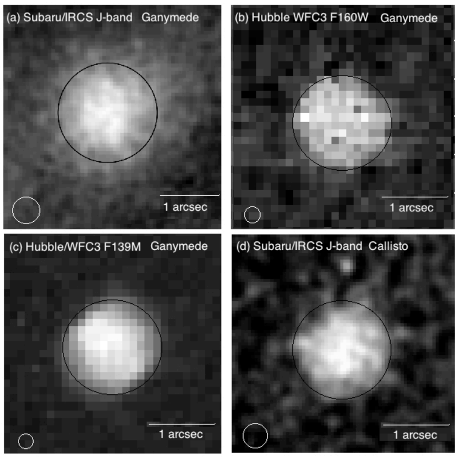
The Galilean satellites (Io, Europa, Ganymede, and Callisto) are expected to be dark when eclipsed by the Jovian shadow. However, we have discovered that Ganymede and Callisto are still surprisingly bright at 1.5 μm even when not directly lit by sunlight, based on observations from the Hubble Space Telescope and the Subaru Telescope. Their eclipsed luminosity was one-millionth of their uneclipsed brightness (i.e. $\sim$50 μJy for Ganymede and $\sim$30 μJy for Callisto in eclipse), which is low enough that this phenomenon has been undiscovered until now. In contrast, Europa in eclipse was not detected ($<$5.5 μJy), a potential clue to the origin of the source of luminosity. Likewise, Ganymede was observed at 3.6 μm by the Spitzer Space Telescope but it was not detected either ($<$3.6 μJy), suggesting a significant wavelength dependence. Why are they luminous even when in the Jovian shadow? These facts may be consistent with sunlight scattered by dust in the Jovian upper atmosphere, and if this is the case, observations of Ganymede and Callisto while eclipsed by the Jovian shadow provide us with a new method to investigate Jupiter's atmospheric composition.

Keywords: Galilean satellite eclipse, Ganymede, Callisto, Europa, Jovian upper atmosphere



PPS01-10 Room:418 Time:April 30 17:00-17:15

Simulated radiative forcing by molecules in Jupiter's stratosphere

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We present the radiative heating and cooling rates by molecules for Jupiter's upper troposphere and stratosphere (10^3 to 10^{-3} hPa) with a newly developed parameterization which is suitable for general circulation models. The scheme is a band model based on the correlated k-distribution approach, which accounts for the heating due to absorption of solar radiation by CH_4, and cooling in the infrared by C_2H_6, C_2H_2, CH_4 and collision-induced transitions of H_2-H_2 and H_2-He.

The band model achieved the accuracy of within 10% in comparison with the line-by-line calculations. We show the sensitivity of the heating/cooling rates due to variations of the mixing ratios of hydrocarbon molecules calculated with this scheme, in addition to the calculated radiative-convective equilibrium temperature which is in agreement with observations in the equatorial region. Our results suggest that the radiative forcing in the upper stratosphere is much stronger than it was thought before [Conrath et al., 1990]. In particular, the characteristic radiative relaxation time decreases exponentially with height from 10^8 s near the tropopause to 10^5 s in the upper stratosphere.

Keywords: Jupiter, atmospheric radiation, gas giants, JUICE

PPS01-11 Room:418 Time:April 30 17:15-17:35

EXCEED EUV spectral images of Jupiter and Venus

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An earth-orbiting Extreme Ultraviolet (EUV) spectroscopy is the first mission of the Small scientific satellite Platform for Rapid Investigation and Test -A (Sprint-A) conducted by ISAS/JAXA. A single science instrument (EXCEED) is boarded on Sprint-A. We have started to observe the solar planets in the EUV spectral range, and will extend to the identification of extrasolar planet atmosphere.

I will show the first light of the EXCEED and the next.

Keywords: Planetary Airglows, Sprint-A, EUV, plasma, visualization

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Occurrence characteristics of Saturn's short-term radio burst

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Saturn kilometric radiation (SKR) is emitted from auroral electrons and suggested to be correlated with Saturn's auroral processes. We extracted northern SKR (N-SKR) and southern SKR (S-SKR) burst events, by newly defined selection criteria, with radio data observed by the Cassini Radio and Plasma Wave Science (RPWS) instrument in the period from day 250 of 2005 to day 200 of 2006. The data was separated into northern and southern components according to its circular polarization degree. As a result, 16 N-SKR burst events and 36 S-SKR burst events were identified in this period. Based on statistical studies of these events, we obtained the following results: (1) We derived typical frequency profiles of N- and S-SKR during SKR bursts to compare the intensity of N- and S-SKR bursts. The profiles show that the S-SKR burst was more intense than the N-SKR by 7 dB in the main frequency range. From the recent studies, the north-south asymmetry could be explained by the difference in solar illumination due to the tilted the magnetic and rotational axis. (2) By comparing onset timings of N- and S-SKR bursts, we found that 67 % of S-SKR burst events were accompanied by N-SKR bursts or burst-like enhancements. (3) To elucidate what determines the timing of SKR burst onsets, we compared the onset timing of N- and S-SKR bursts with each SKR phase of the periodic modulations. The result showed that the timing of SKR burst onsets generally depends on both the N- and S-SKR modulation phases. This suggests the existence of the internal control of SKR burst onsets. It is, however, noted that some SKR bursts occurred out of phases with SKR modulation phases. That indicates the timing of SKR bursts can also be determined by the external process, i.e., solar wind compressions. (4) We investigated the time evolutions of SKR intensities in the main frequency range and the low frequency range before and after SKR bursts. By comparing them with AKR intensity evolutions at AKR breakup, we found that they had two similarities: the enhancement of lower-altitude source regions prior to onsets and the formation of the distinct higher source regions. On the other hand, their timescales are quite different. In addition, this study pointed out that the two-step evolution scenario could not be directly applied to Saturn's case.

In conclusion, our study demonstrated the north-south asymmetry, the conjugacy and the dependence on the SKR periodic modulations of SKR bursts. These results would be helpful for understanding the auroral process at Saturn's magnetotail reconnections by elucidating the relationship between SKR bursts and reconnections. We consider the third result is particularly important because this suggests that both northern and southern periodicities would affect magnetotail reconnections.

Keywords: Saturn, SKR, aurora, Cassini