Japan Geoscience Union Meeting 2013
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PCG32-01 Room:101B Time:May 20 09:00-09:15

The standard scenario of solar system formation and its problems

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The solar system consists of planets, their satellites and rings, and a huge number of minor bodies. The planets can be classified into three groups: terrestrial planets (Mercury, Venus, Earth and Mars), gas giants (Jupiter and Saturn), and ice giants (Uranus and Neptune). These groups differ from one another by compositions, masses, and orbital radii. The terrestrial planets are light rocky ones with relatively small orbital radii, the gas giants are heavy planets with main components of hydrogen and helium gas in the middle of the solar system, and the ice giants are moderately massive with main components of water, methane, and ammonia ice in distant regions. These planetary orbits are nearly circular and coplanar, which suggests that the solar system was formed from a protoplanetary disk around the proto-sun.

The basic framework of the standard scenario for solar system formation was established in 1960's to 1980's. In the standard scenario, the solar system forms from a protoplanetary disk around the proto-sun that is a by-product of star formation and consists of gas and dust. The formation scenario can be divided into three stages: (1) formation of planetesimals from dust, (2) formation of protoplanets from planetesimals, and (3) formation of planets from protoplanets. In stage (1), planetesimals form from dust in the protoplanetary disk. Planetesimals are small building blocks of solid planets. Planetesimals grow by mutual collisions to protoplanets or planetary embryos in stage (2). The final stage (3) depends on a type of planets. The final stage of terrestrial planet formation is giant impacts among rocky protoplanets while sweeping residual planetesimals. Large protoplanets capture a massive gas envelope by self-gravity to become gas giant planets. Ice giants are leftover icy protoplanets that fail to become gas giants. Though the standard scenario can explain the formation of the basic structure of the solar system physically naturally, it has several serious unsolved problems such as planetesimal formation and timescale of giant planet formation. In the present talk, I review the basic elementary processes of solar system formation and discuss the problems now the standard scenario is facing.

Keywords: solar system, planet formation

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PCG32-02 Room:101B Time:May 20 09:15-09:30

Diverse formation mechanisms of exoplanetary systems revealed by observations

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Recent astronomical observations have revealed that there are diverse exoplanetary systems in the universe. In this talk, I will review the following two points, (1) what types of exoplanetary systems have been actually discovered, and (2) how can such diverse planetary systems form?

Keywords: Exoplanets

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PCG32-03 Room:101B Time:May 20 09:30-09:45

Warm Debris Disks Probed by Mid-Infrared Observations

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Some main-sequence stars are known to have dust disks around them, which should be composed of second-generation dust grains replenished during the main-sequence phase, rather than primordial dust from protoplanetary disks. These second-generation dust grains are thought to have originated in collisions of planetesimals or during the destruction of cometary objects, giving the reason circumstellar dust disks around main-sequence stars are named ”debris disks.” Debris disks are expected to be related to the stability of minor bodies and, potentially, to the presence of planets around stars. Debris disks are identified from the spectral energy distributions of stars that show an excess over their expected photospheric emission at infrared wavelengths, since circumstellar dust grains absorb the stellar light and re-emit mainly in the IR region. After the discovery of the first sample of debris disk, Vega, more than 100 others have been identified from the IRAS catalogue. Most of the known debris disks only show excess far-infrared emission. This excess comes from the thermal emission of dust grains with low temperatures, and is an analogue of Kuiper belt objects in the solar system. On the other hand, little is known to date about the warm debris disk material located close to the star, which should be an analogue of the asteroid belt in the solar system. Warm dust grains in the inner region of debris disks should have a more direct link to the formation of terrestrial planets than the low-temperature dust that has been previously studied.

To discover new warm debris disk candidates that show large 18 micron excess and estimate the fraction of stars with excess, we searched for point sources detected in the AKARI/IRC All-Sky Survey, which show a positional match with A-M dwarf stars in the Tycho-2 Spectral Type Catalogue and exhibit excess emission at 18 micron compared to expected photospheric level. In this presentation, we report initial results of the survey of warm debris disks around main-sequence stars based on the AKARI/IRC All-Sky Survey.

We also report the discovery of an intriguing debris disk toward the F3V star HD 15407A in which an extremely large amount of warm fine dust is detected. The dust temperature is derived as ˜500-600 K and the location of the debris dust is estimated as 0.6-1.0 AU from the central star, a terrestrial planet region. The luminosity of the debris disk is ˜0.5% of the stellar luminosity, which is much larger than those predicted by steady-state models of the debris disk produced by planetesimal collisions. The mid-infrared spectrum obtained by Spitzer indicates the presence of abundant micron-sized silica dust, suggesting that the dust comes from the surface layer of differentiated large rocky bodies.

Keywords: Debris Disks, Dust, Infrared Observations

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PCG32-04 Room:101B Time:May 20 09:45-10:00

Evolution of disk structure around the young intermediate-mass star based on the mid-infrared

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We have made 20 micron imaging observation studies of disks around young intermediate-mass star (Herbig Ae/Be stars) using Subaru/COMICS & GeminiS/T-ReCS, and showed that the spatially resolved disks have interesting structures such as gaps and inner holes (e.g. Fujiwara et al. 2006, Honda et al. 2010, Honda et al. 2012, Maaskant et al. submitted). These gaps and holes are also observed in other wavelengths, indicating that some disks show rapid dissipation of their inner region. On the other hand, there are disks without specific structures in them, which implies the diversity of the evolution of disk structure. We would like to discuss the possible scenario of the disk structure evolution based on the current observational studies.

Keywords: protoplanetary disk

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PCG32-05 Room:101B Time:May 20 10:00-10:15

Probing the morphological evolution of circumstellar disks around solar-type stars with near-infrared direct imaging

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Circumstellar disks are considered to be the
birthplace of planets. In theory, planets
can open gaps when they form in a disk
(e.g., Zhu et al. 2011). Recently, a deficit of near- and mid-infrared excess in a spectral energy distribution of a object has been observed
so far (e.g., Strom et al. 1989), and disks with an inner hole have been also detected with a radio interferometry (e.g., Andrews et al. 2011).
These objects, so-called transitional disk, might be a signature of recent planet formation in these system.

As mentioned above, the inner resion ($r < 100$ AU) of the circumstellar disks are considered to be deeply related to planet formation. Thus, there have been many observational investigations of protoplanetary disks.
However, for optical and near-infrared observations, it is quite difficult to observaed such inner regions due to bright central star (e.g., Grady et al. 1999).
Also, for radio interferometry observations, its spatial resolution is limited to 40 AU, and thus, it is difficult to conduct detailed direct observations (Andrews et al. 2011).

In order to observe planet-forming region (r<100AU) in protoplanetary disks with higher spatial resolution (<10AU), we developed a new high contrast instrument HiCIAO (Tamura et al. 2006).
HiCIAO employs dual-beam polarimetry, which suppress speckle noise of the central star. In addition, combining with adaptive optics, HiCIAO acheives higher resolution of less than 10 AU.

Using HiCIAO, we have observed protoplanetary disks as a strategic project in Subary Telescope (SEEDS; Tamura 2009). As a result of high-resolution near-infrared polarimetric observations, we achieved a spatial resolution of less than 10 AU, and accessed planet-forming regions (r<100AU) of protoplanetary disks. We divided observed ~20 disks into three categories;
(1) disks with double-ring structures,
(2) disks with cavities,
(3) disks without cavities in the near-infrared.
In the talk, I would like to review the SEEDS disk observations, and discuss a disk evolution to a planetary system.

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PCG32-06 Room:101B Time:May 20 10:15-10:30

New frontier of chronology of the Solar System based on in-situ U-Pb dating

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Collisions between planetesimals and/or asteroids in the Solar System are frequent, casing fragmentation of clast and disturbing the ”clock” of radiometric age. However, careful assessment of two decay series of U (both 238U and 235U) could potentially reveal not only cyratallization age but also alteration age. Here, we report the U-Pb systematics of multiple-processed ordinary chondrites that suffered metamorphism, collision, fragmentation, mixing, and reaccretion, using ion microprobes.

Keywords: dating, Solar System, U-Pb age, in-situ analysis, meteorite, isotope

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PCG32-07 Room:101B Time:May 20 11:00-11:15

Cratering chronology and evolution of the solar system

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In this talk, I would like to review the cratering chronology and its findings.

Keywords: cratering chronology

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PCG32-08 Room:101B Time:May 20 11:15-11:30

U-Pb chronology of Northwest Africa 6704

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Northwest Africa (NWA) 6704 is a very unusual ungrouped fresh achondrite. It consists of abundant coarse-grained (up to 1.5 mm) low-Ca pyroxene, less abundant olivine, chromite, merrillite and interstitial sodic plagioclase. Minor minerals are awaruite, heazlewoodite, and pentlandite. Raman spectroscopy shows that a majority of the low-Ca pyroxene is orthopyroxene. Bulk major element abundances are nearly chondritic and distinct from those of howardite-eucrite-diogenites. Oxygen isotopic study demonstrated that 18O/16O and 17O/16O of this meteorite plot within the acapulcoite-lodranite field, but these meteorites differ in mineralogy and geochemistry. These observations suggest that NWA 6704 originated on a distinct parent body from all other known meteorites. Here we report U-Pb chronology of the unique achondrite NWA 6704.

U-Pb dating was performed on nine 10?20 mg fractions of pyroxene. All fractions were washed 4-5 times in ca. 0.5 ml of 0.5 M HNO3. Subsequently, the fractions were washed twice with hot 6 M HCl, followed by twice washing with hot 7 M HNO3. All residues were spiked with mixed 202Pb-205Pb-229Th-233U-236U tracer. Spiked residues were digested in a HF+HNO3 mixture, converted to a soluble form by repeated evaporation with 7 M HNO3, 6 M HCl, 9 M HBr, and dissolved in 0.3 M HBr. The Pb separation was performed using 0.05 ml of anion exchange resin AG1x8 200?400 mesh. After the Pb separation, U and Th were separated using 0.05 ml of UTEVA resin. Pb isotopes were measured on a TRITON Plus TIMS at the ANU. U and Th isotopic analyses were carried out on a Neptune MC-ICPMS at the Australian National University.

Two residues yielded higher 206Pb/204Pb values (148 and 213) relative to the others (from 344 to 5494). Model 207Pb*/206Pb* dates (assuming primordial Pb as initial Pb, and 238U/235U=137.88) for seven most radiogenic residue analyses with 206Pb/204Pb more than 500 yielded a weighted average of 4563.34 +/- 0.32 Ma. The U-Pb discordance of residue analyses range from -3% to -6% for more radiogenic data, and up to -10% for the two residues that contain less radiogenic Pb. A Pb-Pb isochron for the seven radiogenic residues yielded a radiogenic 207Pb/206Pb value (y-intercept of the regression line) of 0.62351+/-0.00017. This corresponds to a 207Pb/206Pb date of 4563.75 +/- 0.41 Ma, assuming a 238U/235U=137.88. Yet this assumption may be invalid likewise for Ca-Al-rich inclusions (CAIs) and basaltic achondrites. Hence, to establish an assumption-free reliable 207Pb/206Pb date, precise 238U/235U needs to be determined for this meteorite. Using, instead, the 238U/235U value of 137.79+/-0.02 (an approximate estimate for most Solar System materials except CAIs), yields the isochron age of 4562.80+/-0.46 Ma. This age estimate is valid unless 238U/235U in NWA 6704 is significantly lower than in the angrites and chondrites. Determination of the 238U/235U is in progress.

The estimated U-Pb age of NWA 6704 is substantially older than those of plutonic angrites, and only marginally younger than those of quenched angrites. NWA 6704 is about 4-5 Ma younger than the CAIs. Considering the old crystallization age, the expected simple geologic history (suggested by nearly concordant U-Pb systems), the mineral assemblage including pyroxene, plagioclase, olivine, chromite and metal, and the considerable sample size (8.4 kg in total), NWA 6704 has the potential to serve as a reliable reference point of various short-lived isotopic chronometers such as 26Al-26Mg, 53Mn-53Cr and 182Hf-182W chronometers. A new reliable reference point is essential for checking uniform distribution of the short-lived radionuclides and for building a consistent time scale of the early Solar System.

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PCG32-09 Room:101B Time:May 20 11:30-11:45

The oldest rocks in the world

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The solar system was formed at 4.567 Ga; thus we can obtain the age from chondrules in a chondrite. On the other hand, it is well known that the earth was formed soon after the formation of the chondrites, but we cannot directly obtain the age of the formation of the earth from materials on the earth. So far, the oldest rock in the world goes back to 4.03 Ga, and occurs in the Acasta Gneiss Complex, Canada. The first five hundred million years of the history of the earth are still in dark. The Hadean from the formation of the earth to the oldest age of rocks or geologic bodies is the most mysterious period because no rocks and geologic bodies are preserved at present except for the Hadean zircons only in several terranes, Western Australia, Canada, China and Greenland [1]. But, the Hadean period is the most important because the early evolution in the Hadean possibly clinched the evolution of the earth. In order to investigate the Hadean tectonics, we try to find the earliest Archean geologic terranes in the world. So far, the oldest geologic terranes comprise Acasta Gneiss complex, Akilia association in the West Greenland, Nuvvuagittuq in Quebec, Canada, and Nain Complex in Labrador, Canada [2].

We made geological survey in the Nain Complex, and reinvestigated the occurrence of the supracrustal rocks and the relationship with the ambient orthogneisses. Because previous works focused on distribution of the supracrustal belts within the orthogneisses, the detailed field occurrence of the supracrustal rocks within the belts is still ambiguous. Therefore, we focus on their internal structures.

Although the supracrustal belts are repeatedly intruded by granitic intrusions with some ages and their original structures are obscured, their lithostratigraphies are relatively well preserved in Nulliak, Big and Shuldham islands and St Jones Harbor. The supracrustal belts in Nulliak Island and Big Island comprise ultramafic rocks, mafic rocks and mafic sediments intercalated with banded iron formations in ascending order. In the St. Jones Harbor, it is composed of ultramafic rocks, mafic rocks, banded iron formation, and clastic sediments, intercalated with chert in the middle and with bedded carbonate rocks in the upper part, in ascending order. In the Shuldham Island, it consists of ultramafic rocks, layered gabbro with precursors of plagioclase and pyroxene accumulation layers, mafic rocks and psammitic sediments in ascending order.

Recently, we found 3.956 Ma zircons from the Nanok Gneiss, intruding the supracrustal rocks in the St. Jones Harbor area [3]. So far, the host rock including the zircons is the second oldest rock in the world. Because no supracrustal rocks are found in the Acasta Gneiss Complex, the Nulliak supracrustal rocks are the oldest supracrustal rocks in the world. The discovery of the oldest supracrustal rocks opens the door to investigate the early evolution of the earth in the Hadean.

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PCG32-10 Room:101B Time:May 20 11:45-12:00

Ion microprobe U-Pb dating of individual phosphate minerals in Martian meteorite: ALH 84001.

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Introduction:

Mars is the only planet we can take its surface material directly as meteorites. To date, a number of meteorites have been identified as Martian origin. ALH 84001 shows extremely old age among them and is believed to have valuable information concerning the ancient environment and the evolution history of the planet. Phosphates, volumetrically minor phases, are important careers of trace elements. In the previous study, in-situ U-Pb age of the phosphates in ALH 84001 was determined as ~4 Ga [1], which interpreted as impact-reset age.

Meanwhile, smaller-scale investigation such as interior of individual grain will provide further information on the physical and/or chemical history of the meteorite. Due to the limitation of grain size and spatial resolution, several grains were required for one isochron previously. In this study, we measured U-Pb ages of individual phosphate grains in ALH 84001 using a NanoSIMS.

Experimental:

Two polished thick sections of ALH 84001 were firstly observed by SEM-EDS to locate phosphate minerals. A ~50-100 micrometer sized phosphate grain were found on each section (named Grain 1 and Grain 2). The sections were polished again, gold-coated and baked overnight, and then analyzed by a NanoSIMS. For primary beam, ~2-10 nA O- ions were used with spot diameter of ~10-20 micrometer. An apatite from Prairie Lake circular complex, PRAP, with a known age of 1155 +/- 20 Ma [2] was used as a standard of ^{238}U-^{206}Pb dating.

Results & Discussion:

For both Grain 1 and Grain 2, the obtained ^{238}U-^{206}Pb age and ^{207}Pb-^{206}Pb age show well agreement with ~4 Ga, suggesting the U-Pb system is concordant. These are also consistent with the previous total U/Pb age [1], indicating this method provides accurate age information with smaller quantity of sample consumption.

To understand what these U-Pb ages mean, closure temperature of U-Pb system in the phosphate grains is calculated. The approximated relationship between closure temperature (T_c) and cooling rate (T') for thermally activated diffusion process can be expressed as the following equation [3]:

T_c=(E/R)/(ln[ART_c^2(D_0/a^2)/ET'])

where R is the gas constant, E is the activation energy of 55.3 kcal/mol, D_0 is the diffusion constant of 0.0002 cm^2/s [4], A is the geometry constant of 55, and a is 50 micrometer. ALH 84001 experienced an impact heating ~4 Ga and subsequent carbonates deposition [5]. While the deposition process is still controversial, the ~1 micron scale variations of Ca-Mg in carbonates provide some constraints in thermal process; (i) low temperature (<200 ^{o}C) with slow cooling (10^{-1} to 10^3 ^{o}C/Ma), or (ii) high temperature (>600 ^{o}C) with rapid cooling (10^7 ^{o}C/Ma) [6]. T_c is ~400 to 550 ^{o}C for the first case, and > 800 ^{o}C for the second case. The deposition temperature did not exceed the T_c for the both cases, suggesting the U-Pb system in the phosphates closed during and after this event. The U-Pb system still may have been reset at a precedent heating, if any. While further investigation is required for appropriate interpretation, our results leave the possibility that these phosphates preserve the igneous information.

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Keywords: in-situ U-Pb dating, Martian meteorite, phosphates, thermal history

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PCG32-11 Room:101B Time:May 20 12:00-12:15

Solar wind and cosmic-ray irradiation history of surface materials on small asteroid Itokawa

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Surface materials of small asteroids are exposed to various energetic particles such as solar wind (SW), solar cosmic rays (SCRs), and galactic cosmic rays (GCRs). SW particles (with energy of ca. keV per nucleon) are implanted into thin layer, smaller than micro-m from the grain surface. SCRs are composed of more energetic solar particles (1-100 MeV per nucleon), whereas GCRs have even higher energies of larger than 0.1 GeV. The high energy protons from SCRs penetrate several centimeters, and GCRs penetrate up to 1 meter or more beneath the surface of asteroid. Nuclear reactions caused by these energetic cosmic rays can produce noble gases with characteristic isotopic compositions (cosmogenic noble gases) on their passages in solid materials. SW and cosmogenic noble gases can be easily identified because of their characteristic isotopic and elemental compositions [1-4].

The Hayabusa samples are pristine undamaged grains collected from the unconsolidated surface of small asteroid Itokawa with micro-gravity. The samples are essentially different from other extraterrestrial materials such as micrometeorites (MMs) and stratospheric interplanetary dust particles (IDPs) recovered on Earth. They have experienced frictional heating and ablation of the surface layer during passage through the atmosphere and have then suffered from contamination of terrestrial atmospheric noble gases [5, 6].

We have measured noble gases for three Hayabusa grains [7] as an initial investigation, and are continuing for additional Hayabusa samples as an international AO investigation (JAXA). They were olivine grains, and their sizes and weights were as small as 40-60 micro-meter (SEM observation) and 0.05-0.1 micro-gram (estimation from their shapes and density of olivine), respectively.

Variable amounts of light noble gases of SW origin were measured for the samples, which are clear evidences that the grains had been exposed directly to SW particles on the uppermost surface of Itokawa. The detection of SW noble gases is relatively easy because of the high fluxes of SW-light noble gases (He, Ne and Ar). Observed abundances of SW gases in the samples could be accumulated if they were exposed to SW particles for 100-1000 years [7].

On the contrary, cosmogenic noble gas isotopes were difficult to be detected for these tiny samples. Fluxes of SCR and GCR are much smaller than those of SW, and production rates of cosmogenic isotopes are very small, i.e., estimated production rate by GCR in a single grain weighing 0.1 micro-g is as small as 3500 atoms /My. Even in the case, we can give an upper limit to the time span of cosmic-ray irradiation (cosmic-ray exposure age) for each grain. Combining the production of ^{21}Ne by SCR and GCR [8] we obtained 8 My as an upper limit for the RA-QD02-0065 sample [7]. These data can provide unique chronological information about the grains in surface layer of small asteroids.

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Keywords: Solar wind, Cosmic ray, irradiation history, Itokawa, Hayabusa

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PCG32-12 Room:101B Time:May 20 12:15-12:30

A K-Ar dating instrument for future in-situ dating on planetary surfaces

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Surface retention age is one of the most fundamental observables in planetary science. Crater chronology is often used to estimate the timing of geologic events. For example, crater counting on lunar maria revealed most of the mare basalts were emplaced 3.5 Gyr ago, while the latest eruptions occurred 1-2 Gyr ago mainly in the Procellarum KREEP Terrane [Hiesinger et al., 2004; Morota et al., 2011]. The absolute age determination relies on correlation between crater number density and age (chronology function), which is calibrated with the radiometric ages of the samples due to the Apollo and Luna missions [e.g., Neukum, 1983]. Since there are no returned samples showing $>$3.9 Ga and 3.0-1.0 Ga, however, the chronology curve has 0.5-1 Gyr of uncertainty in this range. To determine the shape of the chronology function is important not only for accurate age determination but also for understanding the temporal variation of the impact flux to the Earth-Moon system. For example, whether or not the impact flux has a spike around 3.9 Gyr ago, namely the lunar cataclysm hypothesis, is one of the main issues regarding the uncertainties of the impact flux [e.g., Gomes et al., 2005].

In-situ age measurements and/or sample-return mission(s) are needed to resolve this problem. We have been developing an in-situ dating method using K-Ar system for future planetary landing missions on the Moon or Mars [Cho et al., 2011, 2012]. The K-Ar dating method employs radiometric decay of 40K into 40Ar with half-life of 1.25 Gyr [Steiger & Jager, 1977]. This method requires much less technological developments than other dating methods, such as Ar-Ar, U-Pb, and Sm-Nd dating, because K is relatively abundant (~100 ppm-1 wt%) in the igneous rocks and Ar can be easily extracted (i.e., simply heat the sample). This leads to a simpler instrumental configuration. Our system measures the abundance of both K and Ar at the same laser irradiation spot on a sample using with two techniques (i.e., laser-induced breakdown spectroscopy (LIBS) and quadrupole mass spectrometer (QMS)). Potassium and argon are extracted from a sample simultaneously by the laser ablation, in which the sample is vaporized by a series of intense ($>$ 1GW/cm2) laser pulses.

Using our instrument, we measured three samples whose K concentrations and ages have been measured previously with flame photometry and a sector mass spectrometer: a hornblende (K2O=1.12 wt%, 1.75 Ga), a biotite (K2O=8.44 wt%, 1.79 Ga), and a plagioclase (K2O=1.42 wt%, 1.77 Ga) [Nagao, unpublished data]. We obtained the model ages of 2.1+/-0.3, 1.8+/-0.2, and 2.0+/-0.3 Ga, respectively. We measured K2O with a calibration curve constructed by measuring 24 geologic samples with known K2O concentration. The absolute amount of the extracted Ar is measured with the QMS. The sensitivity to Ar isotopes was calibrated by introducing the known amount of atmospheric Ar into the experimental system.

Since the three samples have similar ages and different K concentrations, we should be able to construct a "virtual" isochron by plotting the concentrations of K and $40Ar_{rad}$. The slope of the isochron simulated with our experimental data yields 1.34 Ga of age. The data with known values yields 1.79 Ga. Such underestimation probably results from both overestimation for K and underestimation for 40Ar in the biotite data, which have large weight for the regression. Nevertheless, a clear correlation between [K] and [$40Ar_{rad}$] is observed. Although further improvement in the accuracy of our measurements is necessary, the data obtained in this study demonstrate that our LIBS-QMS method can reproduce the trend essential for quantitative isochron-based age measurements.

Keywords: In-situ age measurement, K-Ar dating, Planetary explorations

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PCG32-13 Room:101B Time:May 20 12:30-12:45

In-situ K-Ar dating using Vacuum Ultraviolet LIBS

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Laser-induced breakdown spectroscopy (LIBS) is widely used for chemical composition analysis. A high-intensity pulse laser is focused to ablate the surface of the target material in order to form light-emitting plasma. The composition of this ablated material can then be analyzed using atomic emission spectroscopy. This technique has already been successfully used in ChemCam onboard Mars Curiosity (Wiens et al., 2012, Maurice et al., 2012). We can see the first spectrum on the mission website. It clearly shows the emission lines of major elements-Mg, Si, Ca, Fe, Ca, Na, K, and Al-and light elements-H, C, and O. This new technique will be the standard for future planetary exploration. We can also expect an innovative performance of LIBS on the surface of Ganymede since in principle, it can be used for ice as well.

Since the concentration of K on the surface of the planet or satellite can be estimated using LIBS, measuring the amount of Ar enables us to date the age of the surface. However, it is difficult to estimate the amount of degassed Ar. In the method adopted in Curiosity, the amount of K and Ar are measured by different instruments. Although a large sample is necessary for measuring Ar, it is difficult to measure bulk density using LIBS. Moreover, this method requires much resource, e.g., LIBS composed of a laser unit and a spectrometer, as well as a mass spectrometer, and a vacuum chamber with a window capable of being opened and closed.

To solve this problem, we are studying an in-situ K-Ar dating method that uses LIBS with vacuum ultraviolet (VUV) spectroscopy. Ar has no strong emission line in the near UV?near IR range. However, the result of a past LIBS experiment in Ar gas shows the detectability of Ar emission lines in the VUV range. If the amount of Ar in a target rock or ice can be determined using LIBS with VUV spectroscopy, in situ K-Ar dating could be feasible at a smaller mass budget. Additionally, this method enables K and Ar to be quantified at the same area ablated by a high-energy laser pulse, which reduces the uncertainty caused by target nonuniformity.

We have already started to simultaneously design the LIBS instrument as well as the VUV spectrometer. The conceptual design of the LIBS instrument is similar to that of ChemCam. However, a refractive optical design was adopted instead of the reflective optical design of ChemCam in order to increase the focusing effectiveness of the high-intensity pulse laser and to minimize the size of the instrument and therefore its mass. Additionally, we are developing a small piezoelectric linear stage to move the secondary lens. The stroke is 8 mm; the step, 0.1 um; and the mass, 87 g. The prototype model has been developed, and we plan to conduct the vibration test in ISAS/JAXA. In the preliminary design, the mass is estimated to be 3.55 kg, which is approximately one third the mass of ChemCam (~11 kg). The objective distance is limited to 1.5 m, which is shorter than that of ChemCam (1?7 m). The objective distance of this instrument may not be long enough for a huge rover such as Mars Curiosity; however, its size and mass are suitable for a small- or middle-size rover or lander.

We have also finished the preliminary design of the VUV spectrometer for Ar emission. The VUV spectrometer is composed of a concave grating and a micro channel plate with a multi-anode detector. The dimensions of the instrument are 25x25x62.5 mm, and its mass is ~50 g without the electronics. The objective distance is 10 cm. If the Ganymede lander has a high-energy pulse laser for ablation, this instrument could potentially measure the amount of Ar.. We are preparing the VUV spectroscopic experiment for detecting Ar in a rock or ice, including Ar that is artificially mixed in the sample. In this presentation, we will introduce the design of the LIBS and the VUV spectrometer and report the preliminary results of the experiment.

Keywords: LIBS, Chronology, Planetary Exploration