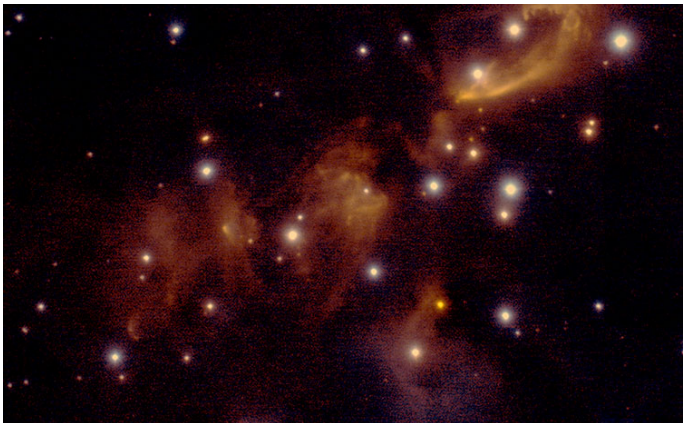
W. M. KECK OBSERVATORY
Maunakea, Island of Hawai'i

2020 Keck Science Collaborative Summary



This infrared image is the result of a long term Keck Science Collaborative project to study embedded star clusters. W. M. Keck Observatory Staff Astronomers who are part of this project include Carlos Alvarez, Randy Campbell and Jim Lyke. The image was acquired with Keck's Near InfraRed Camera, NIRC2, Instrument at high spatial resolution with the benefit of laser guide star adaptive optics, LGSAO. The LGSAO cancels out the turbulent blurring effects of the atmosphere and greatly improves the sharpness of the image. This is an area of star formation as evidenced by the dynamics of the gas and relatively young age of the stars. The infrared light transmits through the gas and dust to reveal the formation process that would otherwise be obscured at visible wavelengths.

CREDIT: WMKO

The Keck Science Collaborative (KSC) was created to provide W. M. Keck Observatory (WMKO) Staff Astronomers resources to facilitate research collaboration and publication with scientists from WMKO partner institutions. This program provides telescope time, travel support, and dedicated time for each WMKO Staff Astronomer to engage in observation, data analysis, writing, and institutional collaborations leading to the publication of results in key science journals. Through the KSC, WMKO Staff Astronomers not only engage with and enable the research of other astronomers using the Keck Instrumentation and Telescopes; they become an important new center for discovery and innovation in modern astronomy.

Promoting science research and collaboration is important to the mission of the observatory. Having scientific staff as active researchers greatly enhances the scientific instrumentation and data analysis capabilities. Direct collaboration with the general astronomy community is vital for both the Keck organization and the community of Keck users and although it's more of a challenge in the era of remote operations, the concerted effort in the form of the Science Collaboration Initiative has been successful in bridging the gap.

The following research and collaboration by WMKO Staff Astronomers was made possible by you, our Friends of W. M. Keck Observatory, who philanthropically support the KSC. Thank you.

CARLOS ALVAREZ

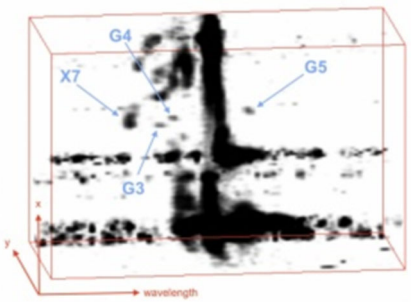
Embedded Clusters (ECs) are stellar clusters of young, forming stars, which are buried in interstellar gas and dust within molecular clouds. These stellar nurseries are fundamental to understanding the early stages of star formation. Dynamic interactions between forming stars in these dense environments can lead to the disruption of circumstellar disks and their planetary progeny. W. M. Keck Staff Astronomer Carlos Alvarez—in collaboration with Lowell Observatory Astronomer Lisa Prato and US Naval Observatory Astronomer Scott Dahm—unveil these often obscure processes. Thanks to funding from the KSC, Carlos recently visited the Lowell Observatory and presented the group's research in his talk, "Characterizing Embedded Star Clusters with MOSFIRE and NIRC2." He presented imaging data of three embedded clusters. Keck Observatory MOSFIRE Instrument imaging and spectroscopic data allowed the team to determine the cluster membership, cluster size, and the evolutionary stage of the cluster members. Their Keck Observatory NIRC2 Instrument

diffraction-limited images were critical in the assessment of the multiplicity fraction of the cluster members, which plays an important role on estimating the Initial Mass Function. Finally, Carlos used the results of the team's innovative observing technique to create arcminute-sized, diffraction-limited image mosaics using the Keck Observatory NIRC2 Instrument in combination with the Keck Laser Guide Star Adaptive Optics system. The team plans to publish an article on their research findings.

Recently, Carlos collaborated with Keck Visiting Scholar Ph.D. student candidate Thomas Lai and Professor Adolf Witt, both from the University of Toledo, OH, and Associate Professor Jan Cami of the University of West Ontario, London, Canada to find a connection between the carrier molecules of two mysterious spectral features called Diffuse Interstellar Bands (DIBs) and Extended Red Emission (ERE), which have puzzled astronomers for decades. DIBs were discovered in the 1920's. They are ubiquitous absorption features observed in the spectra of distant stars that lay behind diffuse interstellar clouds. These interstellar clouds are part of the so called interstellar medium, which is composed of gas and dust that fills the space between stars. The interstellar medium is the stuff stars, planets and people (us) are made of, and it is replenished by stars themselves during their lifecycle. The ERE was discovered in the 1980's and consists of a red glow that it seen in the spectrum of dusty interstellar environments that are illuminated by ultraviolet radiation. The most plausible generation mechanism for the ERE is fluorescence from carbon nanoparticles that form part of the interstellar medium, when they are exposed to energetic ultraviolet light. There is a debate in the astronomical community on whether the carriers of DIBs and EREs are the same or not. The answer to this question is important to understand the distribution of carbon in the universe, which is one of the building blocks of life on Earth. Our work consisted on using the Keck Observatory DEep Imaging Multi-Object Spectrograph (DEIMOS) Instrument to look at the spectrum of a faraway star that happens to lay behind a reflection nebula known as the Ghost Nebula. In addition to DEIMOS, this study also made use of the DeVeny spectrograph at the Discovery Channel Telescope (DCT) in Arizona. This serendipitous alignment of the background star and foreground nebula provides the ideal geometry to determine if the carriers of the DIBs and ERE are the same. Our observations enabled a very detailed study of the DIBs contained in the spectrum of the background star. Even though the physical conditions on the foreground nebula are such that one would expect to see ERE, we did not detect it in our data. Therefore, our data strongly suggests that the carriers of the Diffuse Interstellar Bands are different than the carrier molecules of the Extended Red Emission. This work resulted in the following refereed publication: "Are the carriers of diffuse interstellar bands and extended red emission the same?", T. Y. Lai, A. N. Witt, C. Alvarez and J. Cami, 2020, MNRAS, 492, 5853.

RANDY CAMPBELL

In the central parsec of the Milky Way Galaxy, the environment of the Super-Massive Black Hole (SMBH) presents a complicated composition of stars, gas, and dust. These inner few tens of arcseconds of the Galactic Center have been observed at high resolution with Keck for 20 years with the primary goal of monitoring stars orbiting the SMBH. In addition, gas features in this region and their dynamics can also be closely examined in a unique baseline of data. In particular, the Keck OSIRIS integral field spectrometer instrument observations allowed examination of the dynamic properties of the gas and to identify new "G-type" objects, or dusty stellar objects. The team conducted a study of morphology and dynamics of sub-parsec scale gas features in the central region in order to disentangle the specific components and to place the gas structures in a 3D context.



This 3-D spectro-imaging data cube was produced using software called OsrsVol, short for OSIRIS-Volume Display. WMKO Science Operations Manager and Astronomer Randy Campbell developed this custom volume rendering tool to separate G3, G4, and G5 from the background emission. Once the 3-D analysis was performed, the team of researchers could clearly distinguish the G-objects, which allowed them to follow their movement and see how they behave around the SMBH.

Funding from the KSC supported this work and its dissemination of the results of this work in a recent publication in the scientific journal Nature: "A population of dust-enshrouded objects orbiting the Galactic black hole" authors Ciurlo, Anna; Campbell, Randall D.; Morris, Mark R. et al. 2020 vol 577. Randy also recently attended the 2019 Galactic Center Workshop meeting at the University of Keio in Yokohama Japan, Randy—in collaboration with UCLA Astronomer Dr. Mark Morris and UCLA Postdoctoral Scholar Anna Ciurlo—presented their most recent research findings, which they obtained using 13 years of Keck Observatory data. Thanks to funding from KSC, Randy also attended the January 2020 American Astronomical Society meeting in Honolulu, HI and the American Geophysical Union (AGU) meeting in Washing D.C. to promote Keck Observatory Instruments as well as Education and Outreach. The collaborative work with the UCLA Galactic Center Group is ongoing with promising future of exciting phenomena to observe, analyze and publish.

GREG DOPPMANN

Residual gas in disks around young stars can spin down stars, circularize the orbits of terrestrial planets, and whisk away the dusty debris that is expected to serve as a signpost of terrestrial planet formation. WMKO Staff Astronomer Greg Doppmann and collaborators have carried out a sensitive search for residual gas and dust in the terrestrial planet region surrounding young stars ranging in age from a few to 10 Myr. They found that the CO emission from Transient Objects (TOs) is weaker and located farther from the star than CO emission from non-transition T Tauri stars with similar stellar accretion rates. The difference is possibly the result of chemical and/or dynamical effects (i.e., a low CO abundance or close-in low-mass planets). Doppmann and his collaborators illustrated how their results can be used to constrain the residual disk gas content in these systems and discussed their potential implications for star and planet formation. Greg presented these findings at the From Stars to Planets II Conference: Connecting our understanding of star and planet formation, Gothenburg, Sweden in his talk "Residual Gas and Dust around Transition Objects and Weak T Tauri Stars." His talk was based on research finding published in collaboration with National Optical Astronomy Observatory Chief Scientist Joan R. Najita and Naval Research Laboratory Astronomer John S. Carr.

In addition to presenting these findings, by attending the meeting Greg networked with the star and planet formation community in person to gauge the impact of his research findings. An additional benefit to Greg was the opportunity to network with researchers who are doing similar work in high resolution infrared spectroscopy of protoplanetary disks.

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Recently, Greg began work on a new project which involves characterizing a very interesting young multiple star system in Taurus, GV Tau. To make his observations, he uses the Keck Observatory Near Infrared Echelle Spectrograph (NIRSPEC) Instrument to analyze the stellar and disk properties of the enigmatic system, which have been changing on short timescales (i.e. months). Greg has applied for time on the Keck Telescopes using the upgraded NIRSPEC Instrument. He hope to discover more and ultimately submit a paper on his findings.

PERCY GOMEZ

WMKO Staff Astronomer Percy Gomez conducts research in galaxy cluster formation and evolution. Percy is part of the MAGNUM survey team whose goal is to study the physics of galaxy clusters at high redshift (z~3). The group aims to answer the following questions: when do galaxy clusters form, what type of galaxies form the first galaxy clusters, how does the environment affect the properties of these early galaxies, are there any evolutionary effects (i.e., are older systems different than younger ones), and the broader question of why these clusters form. Thanks to the KSC funding, Percy and collaborators had the opportunity to present a poster on their research, "NIRES observations of Z~3 quiescent Ultra-Massive Galaxies" at the 235th Meeting of the American Astronomical Society in Honolulu, Hawaii.

Other publications from this team:

- An Extremely Massive Quiescent Galaxy at z = 3.493: Evidence of Insufficiently Rapid Quenching Mechanisms in Theoretical Models by Forrest et al. in ApJ
- Spectroscopic Confirmation Of An Unusually Mature Protocluster Around A UVJ-Quiescent Ultra-massive Galaxy At Z = 3:36 by McConachie et al in preparation
- NIRES Observations of two z~3 Ultra-Massive Galaxies (UMGs) by Gomez et al -in preparation
- Most Massive Galaxies at 3 < z < 6 in the COSMOS-UltraVISTA Ultra-Deep Strips: Observed Diversity, Number Densities, and Rapid Formation Timescales by Marsan et al -in preparation.

Percy has also lead and collaborated on other publications related to galaxy cluster evolution:

- Dissecting The Strong Lensing Galaxy Cluster MS 0440.5+0204I. The Mass Density Profile by Verdugo et al. in AJ
- The Dynamics Of The Wide-Angle Tailed (WAT) Galaxy Cluster Abell 562 by Gomez and Calderon in AJ

JIM LYKE

Observers have been pushing for knowledge of the point spread function (PSF) of Adaptive Optics (AO) systems for more than a decade. The PSF is how a perfect point source (like a star) will appear to the AO system as a function of time. If we know the PSF, we can squeeze out more information about the brightness and shapes of objects we study with AO-fed instruments. Because there is not always a star in our field of view, researchers seek ways to reconstruct the PSF from telemetry. This is called point spread function reconstruction (PSF-R). The telemetry is the collection of diagnostics from every sensor in the AO system as a function of time. The Keck Observatory AO system produces about 1.0 TB of telemetry each night. At the recent Center for Adaptive Optics Fall Science Retreat in Lake Arrowhead, California—a meeting that provides a forum for AO researchers to share results and plan future collaborations—WMKO Staff Astronomer Jim Lyke discussed ways to put telemetry in the hands of our researchers to aid their science data and simulations.

Keck staff and observers have always worked closely on Adaptive Optics. Recently a new AO Future Studies Group comprised of Keck AO operations and development and observers has come together to work on current and new issues to maximize science with AO. For example, Jim led discussions of Ground Layer Adoptive Optics (GLAO). The atmospheric conditions on Maunakea are ideal for GLAO. In this environment, AO is required because air can be turbulent and can result in blurred images. The primary contributors to the turbulence are the telescope dome, the free atmosphere, and the ground layer. On most observing nights this last factor is the dominant source of turbulence. Correcting the ground layer seeing can result in very sharp images over a large field of view. One often combines GLAO with an adaptive secondary mirror, which can extend the benefits of AO to fainter and fainter objects. Attendees discussed which of the current, seeing-limited, multi-object spectrometers at Keck Observatory would benefit the most from GLAO, which served to benefit the Observatory as a whole. Finally, in this forum Jim was able to discuss new AO algorithms with his colleagues, which again benefits Keck. A case in point: discussions that began at previous AO meetings are now being tested at Keck. One of these is predictive control, which is a way of using experience to predict future performance. Other algorithms are being programmed into our next real-time controller—the computer that actually does the work.

Close collaborations between Keck Staff Astronomers, such as Jim Lyke, and visiting astronomers are an essential component of the work. In the case with Jim's collaboration with astronomers of the Galactic Center Group, it lead to science success and the following refereed publication thanks to KSC supporters: "Relativistic redshift of the star S0-2 orbiting the Galactic center supermassive black hole", T. Do, A. Hees, A. Ghez, J Lyke, et. al., Aug 2019, Science, Vol. 365, Issue 6454, pp. 664-668.

ELENA MANJAVACAS

Support of the KSC made it possible for WMKO Staff Astronomer Elena Manjavacas to attend Exoclimes V: The Diversity of Planetary Atmospheres conference where she presented her research, "Hint of Sulfide Clouds in the Planetary-Mass, Brown Dwarf Companion Ross 458C." Ross 458c is a ~700K planetary-mass brown dwarf (5-20 masses of Jupiter) companion to a binary system formed by a M0+M7 stars. Using the Wide Field Camera 3 installed on the Hubble Space Telescope, Elena measured the variability of the brightness of Ross 458c across the 1.1 to 1.65 micron wavelength. She discovered that there is a variability of 2.6% in this wavelength range that would be explained by the existence of sulfide clouds of different thickness in the atmosphere of Ross 458c that rotate at the same rate as the brown dwarf.

Recently using the Keck Observatory Multi-Object Spectrometer for Infra-Red Exploration (MOSFIRE) Instrument, Elena collected spectra-photometric data of the giant planet analog 2M2208+2921, to study the evolution of its brightness due to the heterogeneous cloud coverage in the atmosphere of this planetary-mass object. The MOSFIRE light curve of 2M2208+2921 shows a brightness variability of ~3.5% across the 2.5 hours of monitoring. The variability of the object changes slightly with wavelength, decreasing toward longer wavelengths. The variability found for 2M2208 is very likely due to heterogeneous clouds in its atmosphere that vary across the time with the rotation of the object. The change on the variability with wavelength is most likely due to high hazes on the object's atmosphere. This suggests that the planetary-mass object (similar to a gas giant planet) has heterogeneous clouds, Neptune style, with a layer of high hazes covering it. Elena is currently working on refining the data analysis, and writing a manuscript to publish the results. This work is made possible through support received from the KSC program.

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Using the Keck Observatory MOSFIRE Instrument, Elena will follow up her research by monitoring the brightness of a specific exoplanet analog (2M2208136+2921213) which is a ~2000 K exoplanet analog with a mass of 12 Jupiter masses. She expects to find bright changes when monitoring this object due to the different thickness of the clouds that cover this planet analog.

LUCA RIZZI

The Keck Observatory Archive (KOA) is a database that stores raw data for all Keck Observatory instruments and reduced data for about half of them. It also provides high-level services such as calibration association and archival search for moving objects. It is open to the entire world and produces a significant fraction of all publications that site the WMKO. KOA also supports and distributes targeted science data related to individual projects. The Archive is funded by NASA in a cooperative agreement with the WMKO, and it is hosted at Caltech/IPAC/NExScI in Pasadena.

Thanks to generous funding from donors to the KSC, WMKO Staff Astronomer Luca Rizzi attended the 234th Meeting of the American Astronomical Society (AAS) in St. Louis, Missouri and the January 2020 American Astronomical Society meeting in Honolulu, Hawaii to promote scientific use of KOA. At the meeting, Luca focused his discussions on promoting the use of KOA and its scientific productivity with the final goal of increasing the scientific productivity of the observatory. KOA members routinely attend large astronomical meetings such as the AAS, where they have the opportunity to receive training sessions on the use of KOA.

Thanks to support by the KSC, Luca has been able to collaborate with colleagues at University of Hawaii at Manoa, to use the Keck Observatory Keck Cosmic Web Imager (KCWI) Instrument to study the kinematics of giant HII regions in M101. They discovered a complex set of substructures in the gas dynamics of the different chemical components. The work resulted in the following refereed publication: "Internal kinematics of giant H II regions in M101 with the Keck Cosmic Web Image", F. Bresolin, L Rizzi, I. Ho, et. al., 2020, MNRAS (https://arxiv.org/abs/2005.10369).

JOSH WALAWENDER

Protostellar outflows are the result of the magnetically driven launching of in-falling material during the accretion process of young stars. They trace the accretion (growth) history of the newborn star. In previous observations, the team found an unusual outflow in the Orion nebulae whose properties were unexpected. Using the unique capabilities of the Keck Cosmic Web Imagers (KCWI) Instrument, WMKO Staff Astronomer Josh Walawender and collaborators from the University of Colorado Boulder's Center for Astrophysics and Space Astronomy (CASA) are now able to probe the details of this strange object and formulate a theory to explain the observations. Currently the team is performing a detailed examination of the KCWI data and comparing it to their theory to see how well it holds up. The KCWI data have revealed the velocity structure of the object and the team is outlining a paper on this object. The team is also collaborating on a long running project to examine the motions of these outflows over time. They have imaging data from several telescopes with wide field imagers that go back over 20 years. By carefully cross matching those images, they can see subtle movements of the outflows and use that to measure their velocities and examine how young stars interact with the parent material from which they form. Josh is working on a data reduction process that will standardize the images from the various telescopes over the last 20 years so that they can be accurately cross-matched.

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SHERRY YEH

WMKO Staff Astronomer Sherry Yeh collaborates with Dr. Chao-Wei Tsai, of the National Astronomical Observatories and Chinese Academy of Sciences, and Dr. Thomas Geballe, of the Gemini Observatory. They study the interactions between high-ionization sources and their interstellar medium (ISM), which includes active galactic nuclei (AGN) in nearby galaxies and massive star clusters in giant HII regions. Sherry's most recent research looks at a once quiescent AGN in a nearby galaxy, which flared sometime around 2012. A suddenly brightened AGN can illuminate the ambient dust and gas, possibly destroying small dust grains and changing the physical conditions in the ISM. Because this AGN is heavily obscured by dust, it is best to observe it in the infrared and longer wavelengths. This AGN has been observed using WMKO, Stratospheric Observatory for Infrared Astronomy (SOFIA), and Subaru Telescope, all in the near- and mi-infrared wavelengths. The team is currently working on a series of peer-reviewed journal papers to report their findings. With funding from the KSC, Sherry was able to make the aforementioned collaborations and present a poster paper on the AGN research findings at the 2018 Annual Canadian Astronomical Society Meeting.

Through the Keck Visiting Scholar Program, Sherry mentored Amy Steele, was a Ph.D. candidate at the University of Maryland, on a project about investigation of the chemical abundances in the circumstellar medium around one polluted white dwarf system. Amy developed a series of one dimensional numerical models to find the best fit of the observed HIRES spectral feature of the white dwarf. By finding the best numerical fit, Amy was able to constraint the chemical abundances in the circumstellar medium. Amy's project is one of the pioneer works in the field. She presented a poster paper on this project at the 235th American Astronomical Society Meeting in Honolulu in January 2020, and she is finishing a journal paper to report the findings. With this work and support through the KSC, Sherry begins to collaborate with Dr. Siyi Xu at the Gemini Observatory, who is a leading expert in the field of polluted white dwarf systems. Sherry currently is developing three-dimensional numerical models, which include spatial and spectral information, to study chemical abundances in polluted white dwarfs newly discovered by the Gaia Space Telescope.

ABOUT W. M. KECK OBSERVATORY

The W. M. Keck Observatory telescopes are among the most scientifically productive on Earth. The two, 10-meter optical/infrared telescopes on the summit of Maunakea on the Island of Hawaii feature a suite of advanced instruments including imagers, multi-object spectrographs, high-resolution spectrographs, integral-field spectrometers, and world-leading laser guide star adaptive optics systems.

Some of the data presented herein were obtained at Keck Observatory, which is a private 501(c) 3 non-profit organization operated as a scientific partnership among the California Institute of Technology, the University of California, and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation..

We recognize and acknowledge the very significant cultural role and reverence that the summit of Maunakea has always had within the Native Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain.

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2019 KECK SCIENCE COLLABORATIVE SUMMARY TABLE

Scientist	Name: Meeting / Collaborator	Location: Meeting / Collaboration	Science Goal	Papers: Published & Pending
Carlos Alvarez	Astronomers Lisa Prato, Lowell Observatory and Scott Dahm US Naval Observatory	Flagstaff, Arizona	Characterizing Embedded Star Clusters with Keck Instruments MOSFIRE and NIRC2	1 published and 1 pending
Randy Campbell	2019 Galactic Center Workshop	Yokohama, Japan	Present findings on G-type objects in SBMBH region	1 published
Greg Doppmann	Stars to Planets II Conference: Connecting our understanding of star and planet formation	Gothenburg, Sweden	Present research results, network and gauge impact of research result in larger context of existing research.	1 published
Percy Gomez	235th Meeting of the American Astronomical Society	Honolulu, Hawaii	Study the physics of galaxy clusters from formation (z~3.5) to the present	3 published and 3 pending
Jim Lyke	Center for Adaptive Optics (CfAO) Fall Science Retreat	Lake Arrowhead, California	Relationships with WMKO research partners. Share PSF-R, ground layer AO for Keck, and new AO algorithms.	1 published
Elena Manjavacas	Exoclimes V: The Diversity of Planetary Atmospheres	University of Oxford, United Kingdom	Hint of Sulfide Clouds in the Planetary-Mass, Brown Dwarf Companion Ross 458C	1 published
Luca Rizzi	234th Meeting of the American Astronomical Society (AAS)	St. Louis, Missouri	Promote scientific use of the Keck Observatory Archive (KOA)	1 published
Josh Walawender	University of Colorado at Boulder, Center for Astrophysics and Space Astronomy(CASA)	Boulder, Colorado	Use Keck Cosmic Web Imager (KCWI) Instrument data to study Protostellar Outflows	2 pending
Sherry Yeh	DChao-Wei Tsai, National Astronomical Observatories and Thomas Geballe, Gemini Observatory	Christchurch, New Zealand	Interactions Between High-Ionization Sources and Their Interstellar Medium	2 pending

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