CHARISMA: a space telescope for planetary science

[1]C. L. Young, [2]K .M. Sayanagi, [3]M.H. Wong, and team*

[1]NASA Langley Research Center (LaRC), Hampton, VA (Deputy PI), [2]Hampton University, Hampton, VA (PI), [3]UC Berkeley, Berkeley, CA

Summary

Caroline **H**erschel high-**A**ngular **R**esolution **I**n-**S**pace assembled **M**ulti-**A**perture (*CHARISMA*) telescope for solar system science addresses the Committee on Astrobiology and Planetary Science (CAPS)'s recommendation to study a large/medium-class dedicated space telescope for planetary science.

We are nearing the end of the Hubble Space Telescope (HST)'s lifetime, at which point the continuity of solar system UV measurements will be lost. **Scientific objectives critically dependent on UV capabilities include:** studies of exospheric and auroral emissions in planetary atmospheres and plumes.

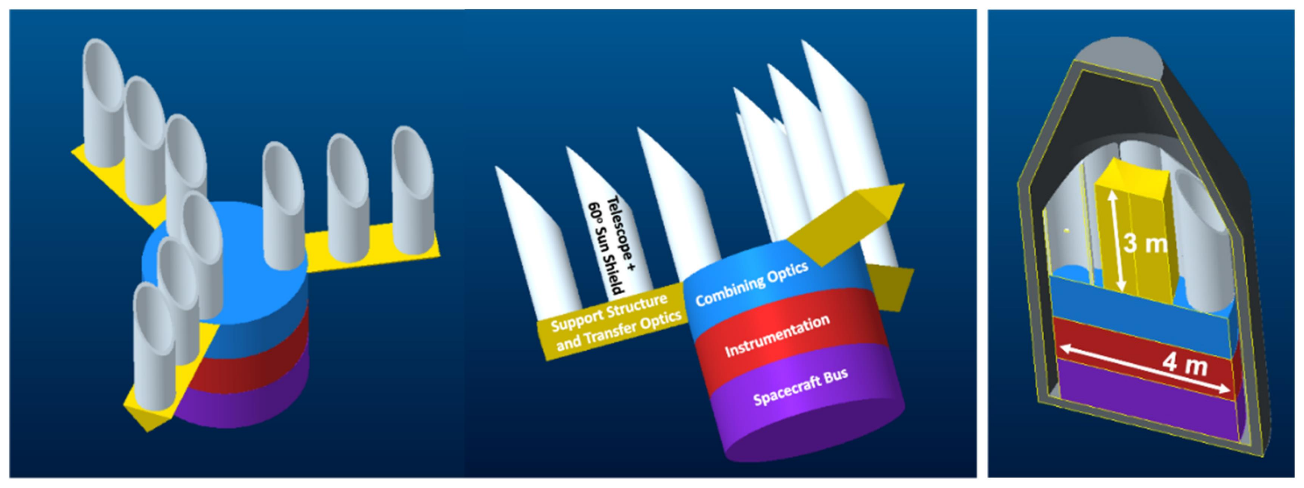
***CHARISMA* will also revolutionize our understanding of time-dependent phenomena in our solar system:**

- interaction of planetary magnetospheres with the solar wind,
- Venus and giant planet atmospheric dynamics,
- icy satellite geologic activity and surface evolution,
- cometary evolution, and evolving ring phenomena,
- comprehensive survey of the spectral characterization of minor bodies across the solar system, which requires a large time allocation not supported by existing facilities.

CHARISMA will examine the benefits of advanced in-Space Assembly (iSA) technologies that enable a 10-m class aperture at New-Frontiers cost. CHARISMA will have the greatest impacts on science objectives particularly sensitive to dynamically evolving phenomena with fine-scale structures in planetary rings, active plumes/volcanism, atmospheric energy/momentum transport, and aurora.

CHARISMA was proposed to Planetary Mission Concept Studies & received Excellent/Very Good rating.

Technology



CHARISMA is enabled by iSA technologies. Study plan will:

- Leverage expertise across NASA Centers: iSA from LaRC and in-space servicing from GSFC.
- Adopt a sparse, distributed-aperture architecture (inherently modular in design and conducive to iSA)
- Examine the potential for future servicing and upgrades enabled by the iSA technologies.
- Provide an early demonstration of technologies needed for future astrophysics telescopes while serving as a fully functional telescope for planetary science.
- Take advantage of LaRC's leading role in the Orbital Servicing, Assembly and Manufacturing (OSAM) efforts to perform a series of trade studies.

CHARISMA design:

- Imaging and spectrographic capabilities in 110 nm - 1.7 µm
- Nine 1-m Cassegrain sub-apertures in a tri-arm configuration to form a 10-m effective aperture.
- Collimated beams emerging from the nine sub-apertures are brought in phase by the optical path adjustment mechanisms in the arm trusses. Combiner optics focus the beams on a single focal plane.
- Design has a light-collecting area equivalent of the 2.4-m HST and a diffraction limit of a 10-m telescope.
- A pick-off mirror directs the beam onto the detector (or the slit) of the desired instrument.
- Chamfered sunshields on the sub-apertures reduce the exclusion zone to about 30º around the sun, facilitating observations of Venus and comets near perihelion, and extending temporal coverage of the outer planets when they are near solar conjunction.
- Cost: nine sub-apertures and four instruments to be assembled by one robotic arm in low-Earth orbit, the LaRC Basis-of-Estimate tool predicts that CHARISMA will cost $815M including 30% reserve.

Scientific objectives enabled by different telescope architectures:

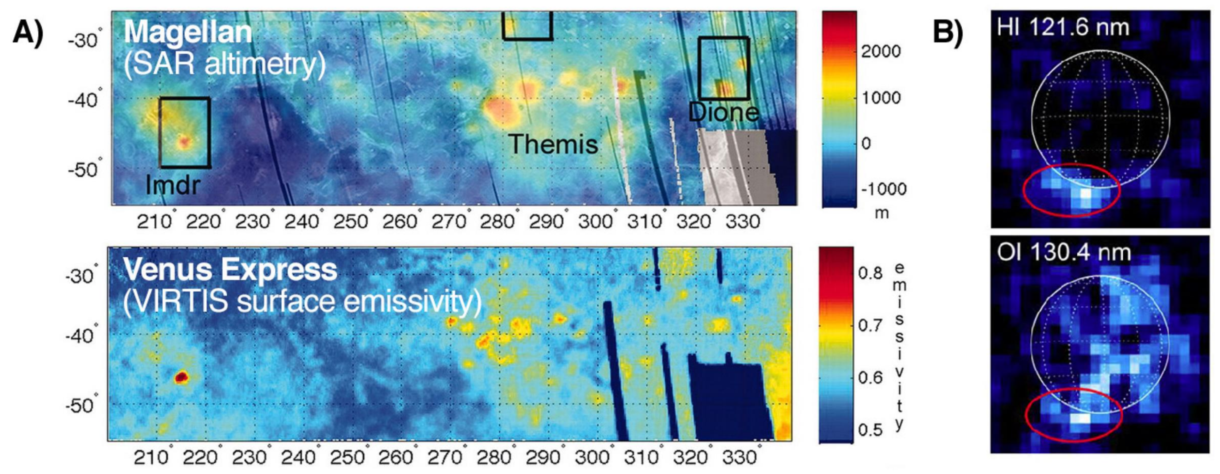
Science Questions	Science Objectives	Mission Size: Small 1.2 m	Mid./Large 2 m	Mid./Large 10 m
ACT-1: Are Venus and Titan volcanically active today?	Search for new evidence of ongoing activity on Venus and Titan	R	R	
ACT-2: What drives variability in volcanic and cryovolcanic activity?	Determine the statistics of plume activity	R	R	R
ACT-3: What is the composition of magma and cryomagma reservoirs?	Determine composition of lava and surface deposits	R	R	
MBS-1: What do the compositions/colors of minor bodies/irregular satellites reveal about planetary migration early in solar system history?	Determine the source population(s) of the Jupiter Trojans and irregular satellites of the giant planets.	D, S		S
MBS-2: What dynamical processes shape minor body populations today?	Determine the source population(s) of the Centaurs.	D, S		
MBS-3: What do the compositions of minor bodies reveal about the radial variations in the solar nebula?	Determine how formation distance influenced KBO surface composition.	D, S		
ATM-1: How does energy/momentum transport vary temporally and spatially in dense planetary atmospheres?	Determine statistics, properties, and evolution of convective events, wave systems, vortices, and jets	R	R	
ATM-2: How is vertical energy transport modulated by chemical and thermodynamic processes?	Determine the response of horizontal circulation, aerosol properties, and gas composition to internal and solar climate forcing	D		
ATM-3: What is the current outer solar system impactor flux?	Detect and characterize impact ejecta fields in giant planet atmospheres	R, D		
MAG-1: What controls auroral processes on different scales of time and planetary size?	Map auroral emission on terrestrial/gas giant/icy bodies, under varying solar wind and magnetospheric conditions	R	R	R
MAG-2: What is the balance between internal/external control of magnetospheric variability?	Measure the 3D structure and variability of the Io plasma torus at Jupiter and the E-ring at Saturn			
COM-1: How do the coma and nucleus evolve seasonally or with heliocentric distance (R_h)?	Determine coma activity and composition and nucleus reflectance over a range of heliocentric distances	D, S		
ICOM-2: What processes dominate in the coma?	Determine spatial associations of various coma species, as coma activity and morphology evolves	D, S		
RNG-1: What is the current and past environment of planetary rings across the solar system?	Determine the ring particle size distributions and compositions	R	R	
RNG-2: How do ring structures evolve and interact with moonlets?	Measure structural profiles and temporal variation	R	R	

Capabilities of 1.2-meter monolithic mirror design, 2-meter *HST-like* monolithic design, and 10-meter *CHARISMA* distributed aperture multiple telescope design. Objectives are partially (yellow) or highly (red) compromised in resolution (R), mission duration (D), or sensitivity (S). Durations are 3 years (Small) and 5+ years (Mid-Large). Our study will examine iSA's potential to achieve precision optical alignment to enable UV observation – the objectives that depend on precise alignment are boxed in yellow.

The Kuiper Space Telescope proposal to the 2014 Discovery call [1] demonstrated that the Vision and Voyages recommendation of a Discovery class implementation of this concept leads to significant limitations on science due to limitation on aperture size (1.2 m) and mission duration (see Table left).

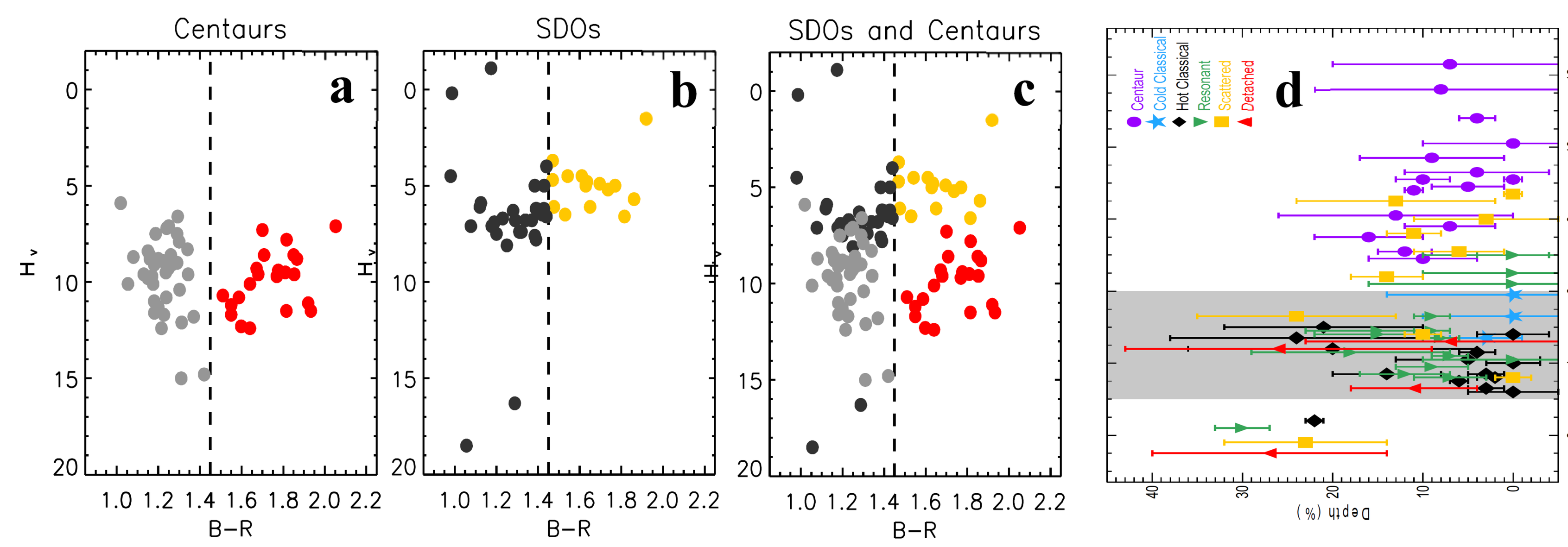
Science

Active Plumes and Volcanism (ACT):



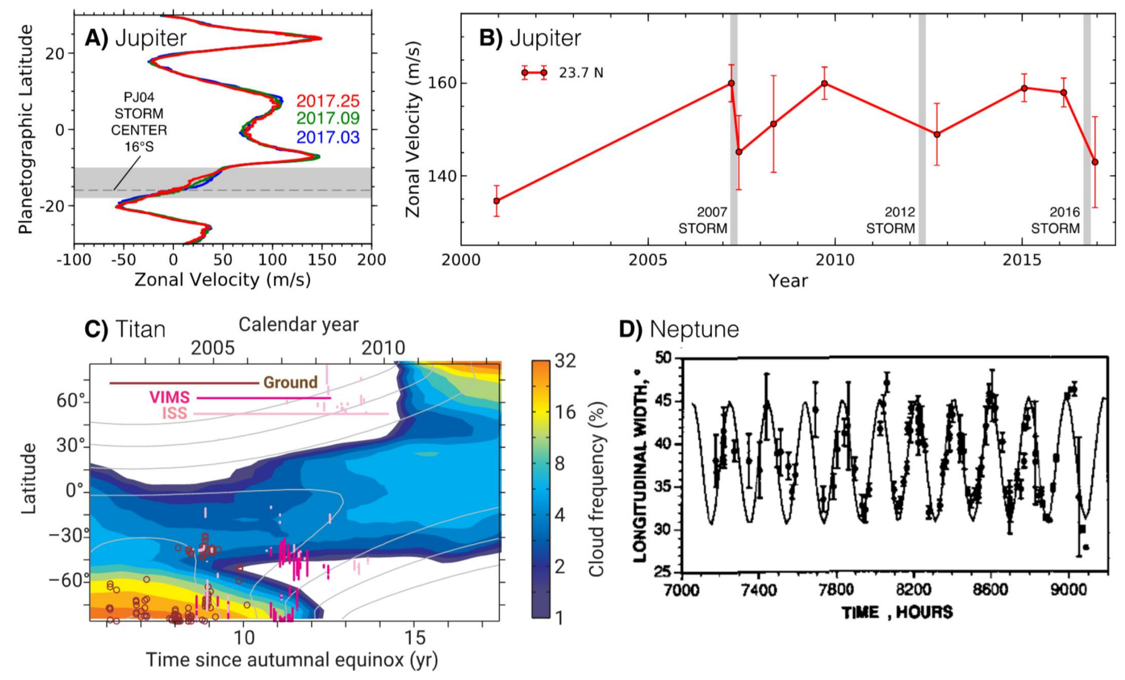
A) Surface emissivity (bottom) reveals areas of recent lava flow that are less weathered than their surroundings. Surface emissivity is derived from spectral data in the 1.02 µm region[2]. (B) Plume activity on Europa is suggested by HST UV observations of transient signals[3].

Outer Solar System Minor Body and Irregular Satellite Survey (MBS):



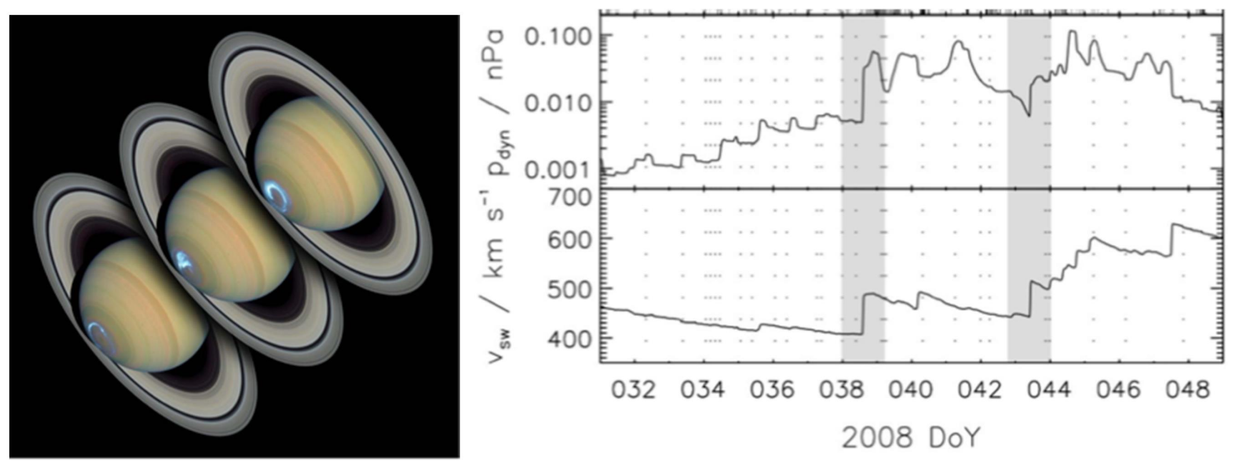
Broadband color data[4] (for (a) Centaurs, (b) SDOs, and (c) both overplotted) cannot conclusively validate the dynamically-based hypothesis that Centaurs originate from the SDOs, requiring a spectroscopic sample from each population. (d) The transition region from water-rich to water-poor surfaces is shown in grey, in a plot of water ice feature strength vs. absolute magnitude[5]. We propose to increase the sample size of KBOs and Centaurs by an order of magnitude and enable comparisons of water ice abundance, color, and diameter, shedding light on the formation and evolution of the various dynamical populations.

Dynamic Atmospheres (ATM):



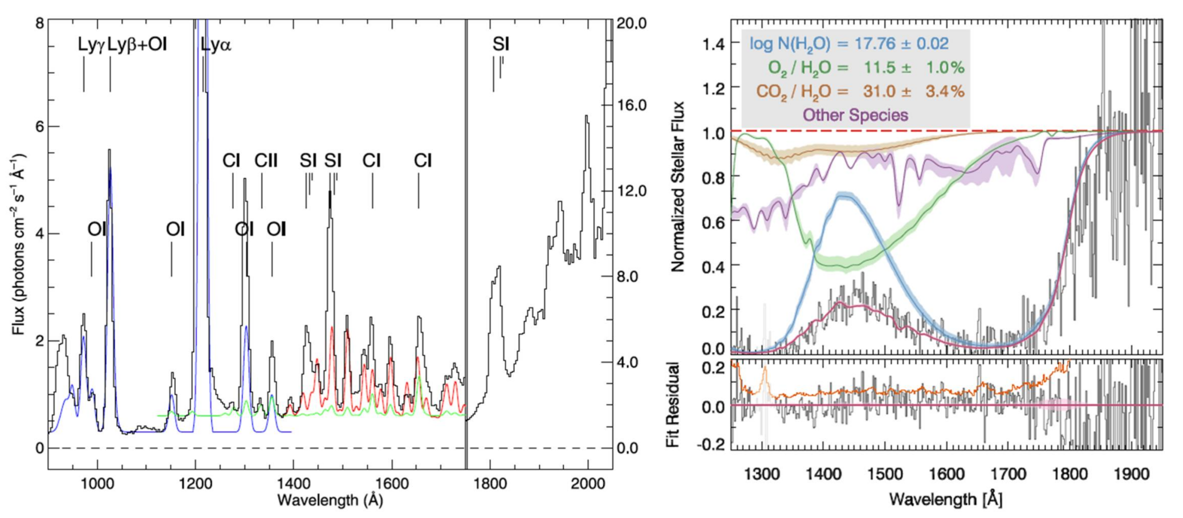
There are gaps in our understanding of storm/cloud activity, jets, and vortices of all planets with atmospheres due to the limited temporal coverage currently available. Major storm eruptions in Jupiter's southern (A) and northern (B) hemisphere alter zonal winds[6]. Models[7] duplicate storm activity at Titan's pole but not at mid-latitudes (C). Oscillations in the shape of Neptune's Great Dark Spot (D) from Voyager's Neptune approach give insights into deep stratification, wind shear, and chemistry[8].

Magnetospheric Interactions (MAG):



(left) HST far-UV images of Saturn's aurora and changes during an auroral storm, and (right) total auroral power at Saturn vs arriving solar wind speed. The shaded regions indicate the arrival of solar wind shocks at Saturn[9].

Cometary Evolution, Morphology, and Processes (COM):



In multiple comets, CHARISMA would measure (left) atomic and molecular UV emission to distinguish coma processes such as electron impact (blue, green) and fluorescence (red), and (right) transmission during stellar occultation to determine associations between species such as O_2 and H_2O, as shown in these examples from Rosetta/Alice data[10, 11].

Planetary Ring Systems (RNG): The study of planetary ring systems is not only critical for understanding the dynamic history of our own solar system, but also sheds light on physical processes that lead to planet formation in protoplanetary disks. CHARISMA would address outstanding questions related to ring systems of Jupiter, Saturn, Uranus, Neptune, Chariklo, Haumea, and other potentially ringed minor bodies.

*Team: S. Curry, K.L. Jessup, T. Becker, A. Hendrix, N. Chanover, S. Milam, B. Holler, G. Holsclaw, J. Peralta, J. Clarke, J. Spencer, M. Kelley, J. Luhmann, D. MacDonnell, R. Vervack, K. Rutherford, L. Fletcher, I. de Pater, F. Vilas, L. Feaga, A. Simon, O. Siegmund, J. Bell, G. Delory, J. Pitman, T. Greathouse, E. Wishnow, N. Schnieder, R. Lillis, J. Colwell, L. Bowman

[1] Bell et al., 2014 Tucson DPS, #214.18.
[2] Smrekar et al., 2010 Science.
[3] Roth et al., 2014 Science.
[4] Hainaut et al., 2012 Astronomy and Astrophysics.
[5] Barucci et al., 2011 Icarus.
[6] Tollefson et al., 2017 Icarus.
[7] Schneider et al., 2012 Nature.
[8] Sromovsky et al., 1993 Icarus.
[9] Clarke et al., 2009 JGR (Space Physics).
[10] Feldman et al., 2018 Astronomical Journal.
[11] Keeney et al., 2019 Astronomical Journal.