Program of Earth-Based Support of the Juno Mission

What I'm going to cover

- Introduction to the Juno mission
  - Overview of the mission objectives and operations
- Earth-based support needs
  - Spatial context
  - Temporal context
  - Expanded spectral coverage
- Coordination and communication
  - Components of the program

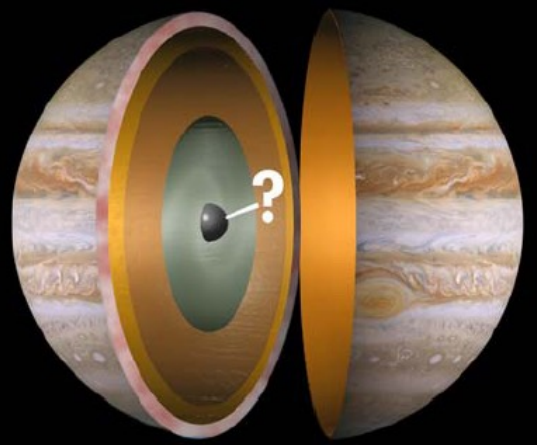
Juno's Science Objectives

Origin

Determine O/H ratio (water abundance) and constrain core mass to decide among alternative theories of origin.

Interior

Understand Jupiter's interior structure and dynamical properties by mapping its gravitational and magnetic fields

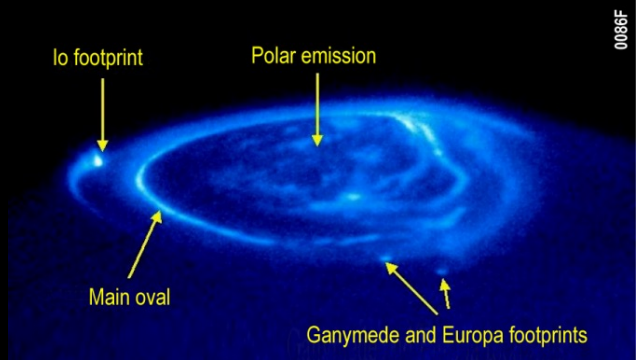


Atmosphere

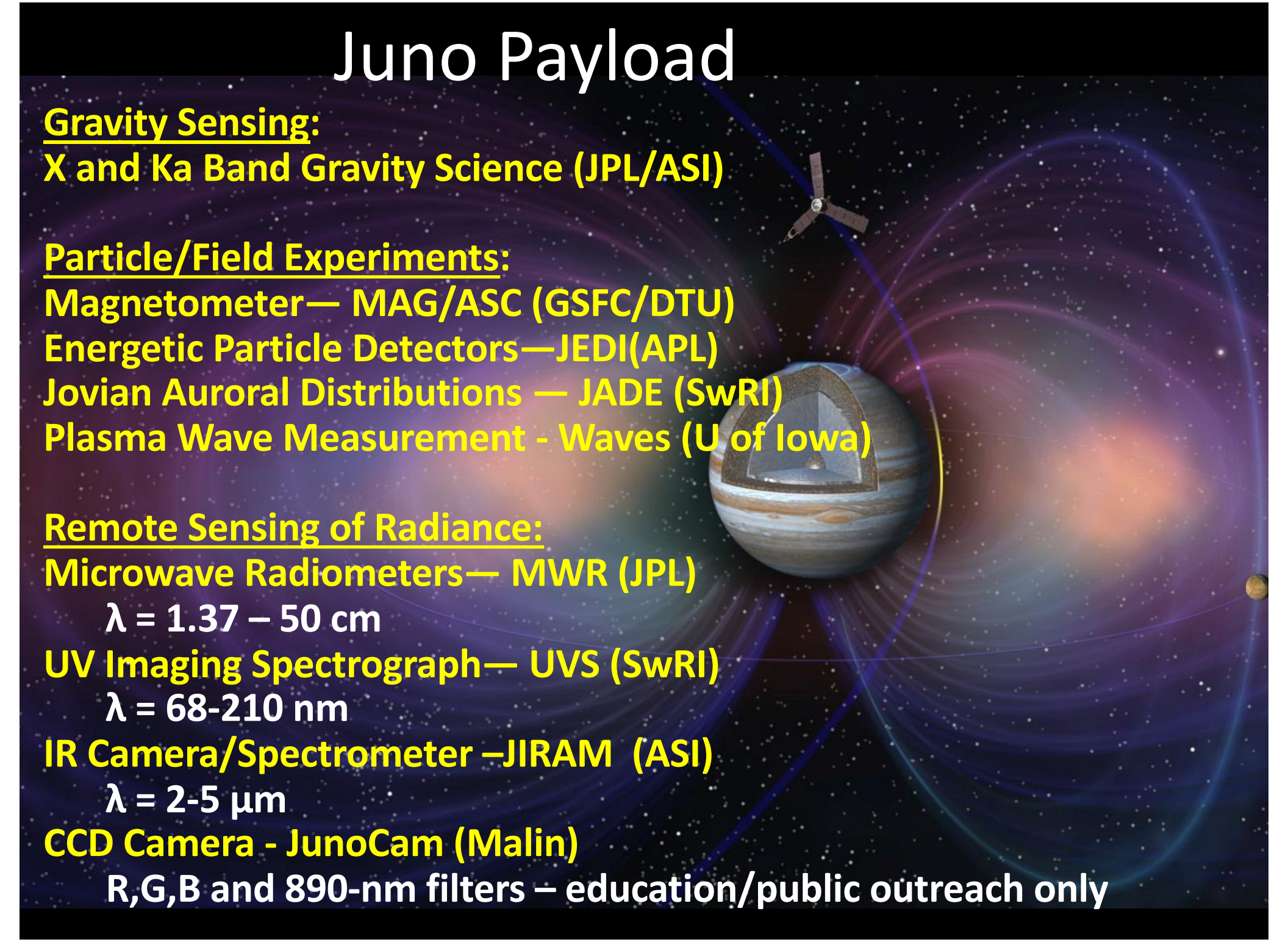
Map variations in atmospheric composition, cloud opacity and dynamics to depths greater than 100 bars at all latitudes.

Magnetosphere

Characterize the three-dimensional structure of Jupiter's polar magnetosphere and auroras.



Juno Payload



Gravity Sensing:

X and Ka Band Gravity Science (JPL/ASI)

Particle/Field Experiments:

Magnetometer— MAG/ASC (GSFC/DTU)

Energetic Particle Detectors—JEDI(APL)

Jovian Auroral Distributions — JADE (SwRI)

Plasma Wave Measurement - Waves (U of Iowa)

Remote Sensing of Radiance:

Microwave Radiometers— MWR (JPL)

λ = 1.37 – 50 cm

UV Imaging Spectrograph— UVS (SwRI)

λ = 68-210 nm

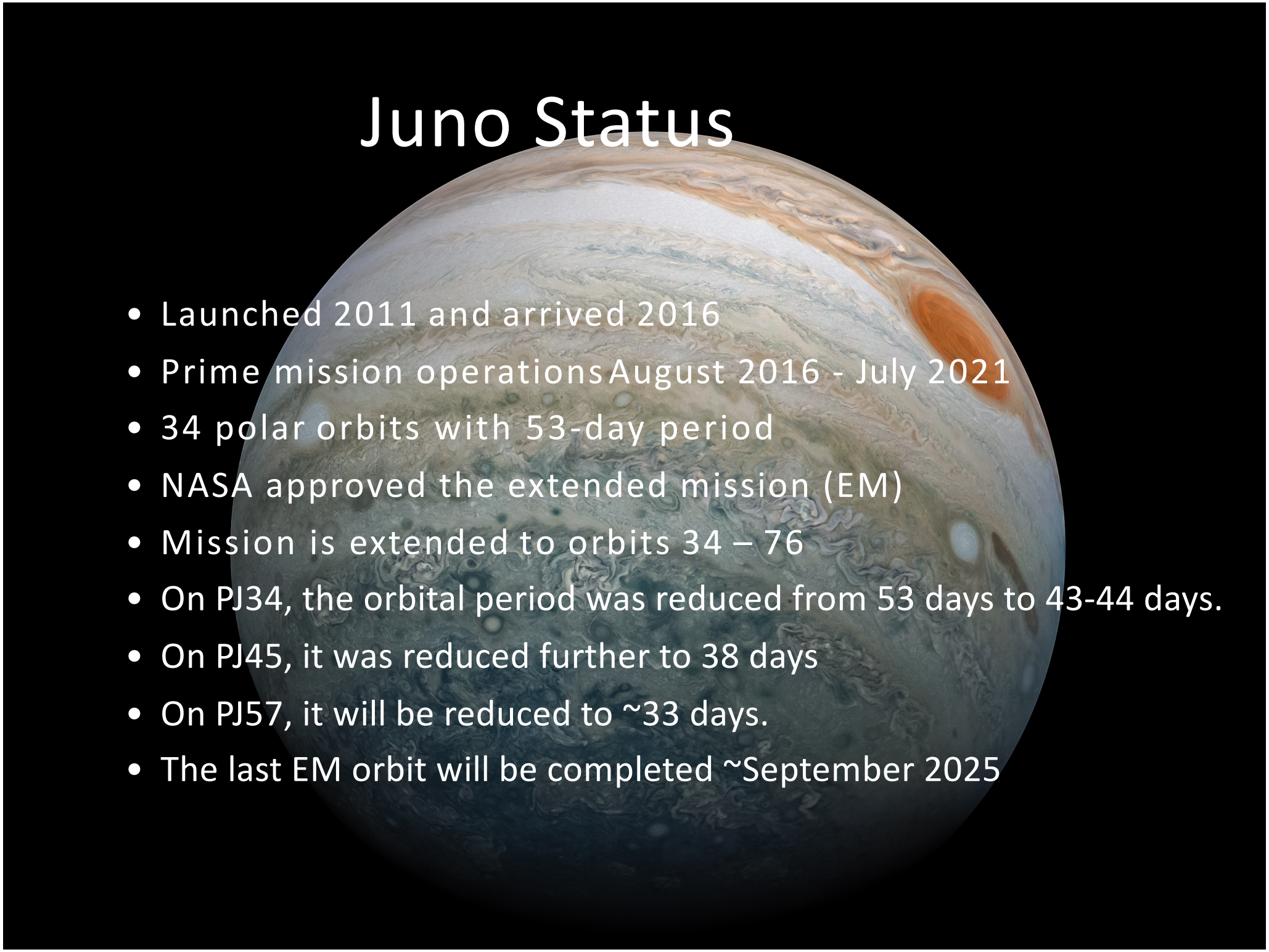
IR Camera/Spectrometer –JIRAM (ASI)

λ = 2-5 µm

CCD Camera - JunoCam (Malin)

R,G,B and 890-nm filters – education/public outreach only

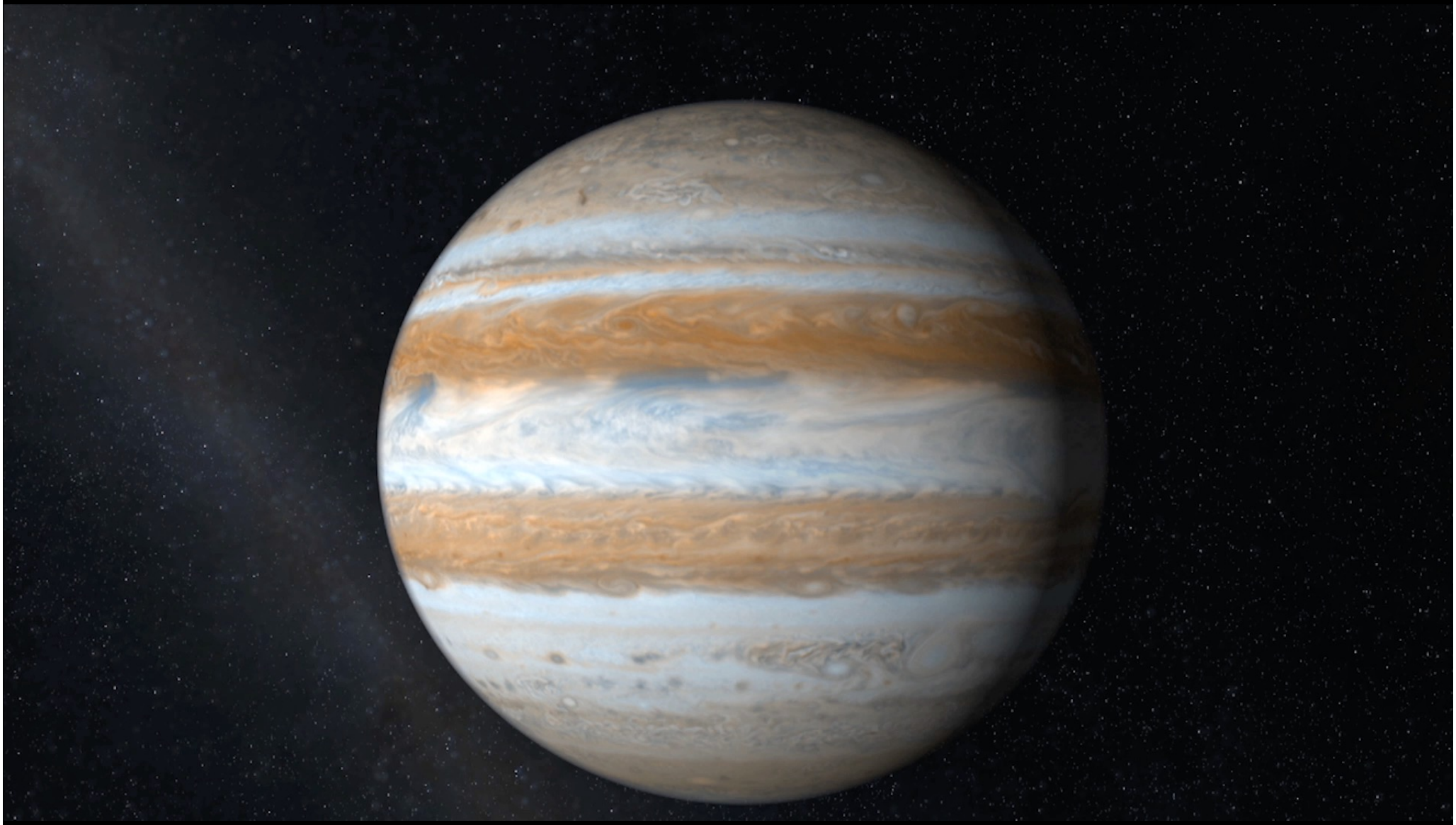
Juno Status



- Launched 2011 and arrived 2016
- Prime mission operations August 2016 - July 2021
- 34 polar orbits with 53-day period
- NASA approved the extended mission (EM)
- Mission is extended to orbits 34 – 76
- On PJ34, the orbital period was reduced from 53 days to 43-44 days.
- On PJ45, it was reduced further to 38 days
- On PJ57, it will be reduced to ~33 days.
- The last EM orbit will be completed ~September 2025

Initially in 53-day orbits

Spinning Orientation



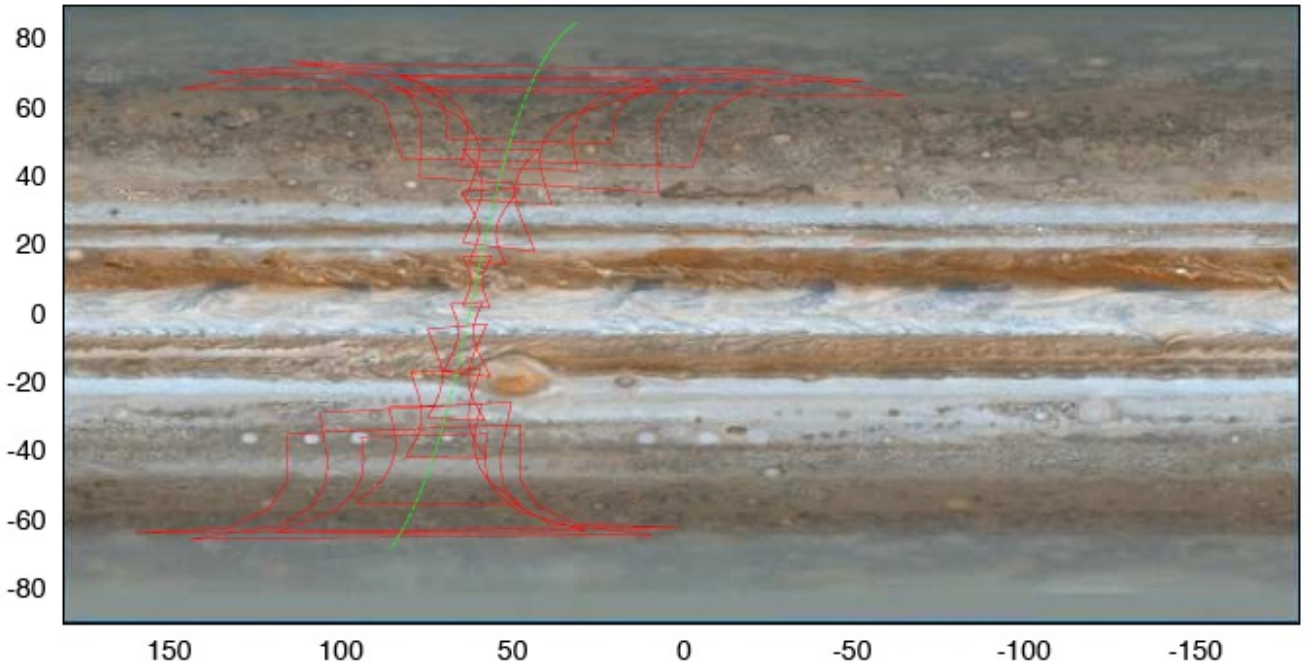
Motivation for the Earth-based supporting program:

- Extend and enhance Juno results by providing:
  - Spatial context over the globe where Juno is not observing
  - Context in time to track the evolution of features Juno is measuring
  - Coverage of spectral regions not included in Juno instrumentation
  - Simultaneous coverage of multiple components of Jovian system
    - Io

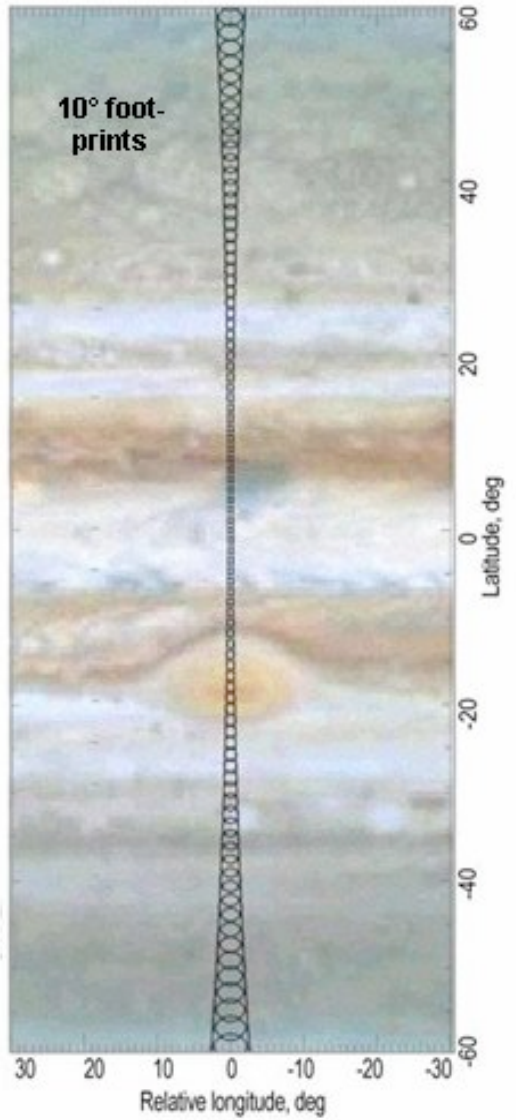
- Unprecedented opportunity to use state-of- the art instrumentation to make synoptic observations of Jupiter with close-up and *in-situ* measurements

Spatial Context Needed

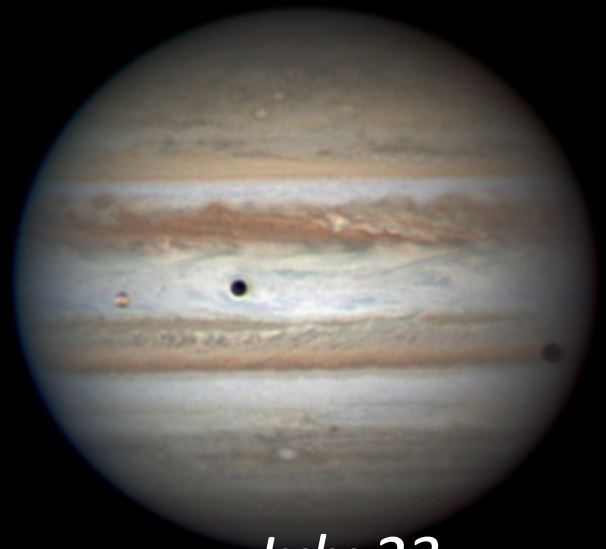
- For JunoCam

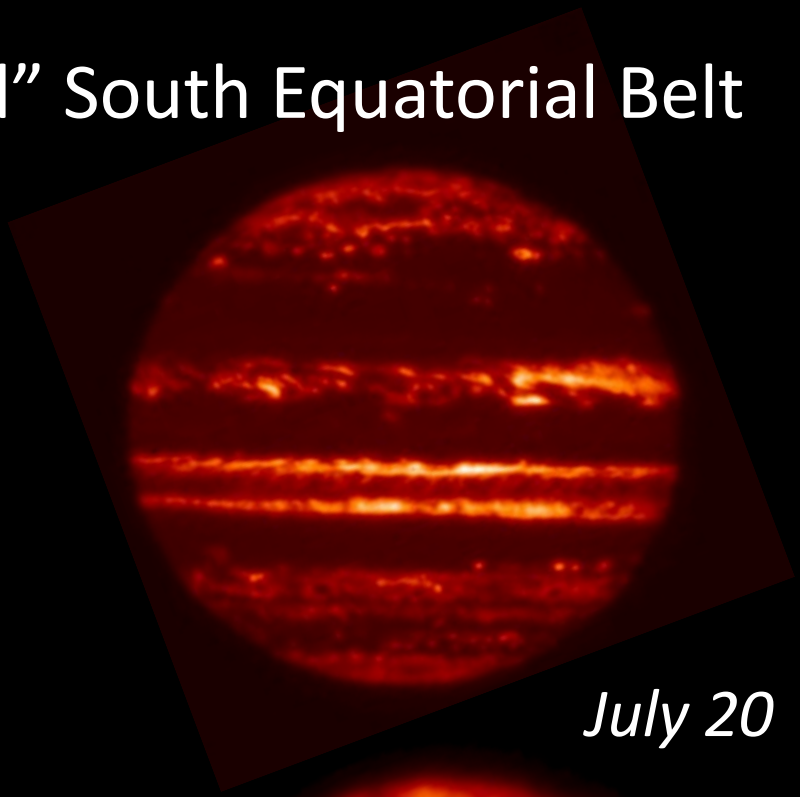


- And for the MWR

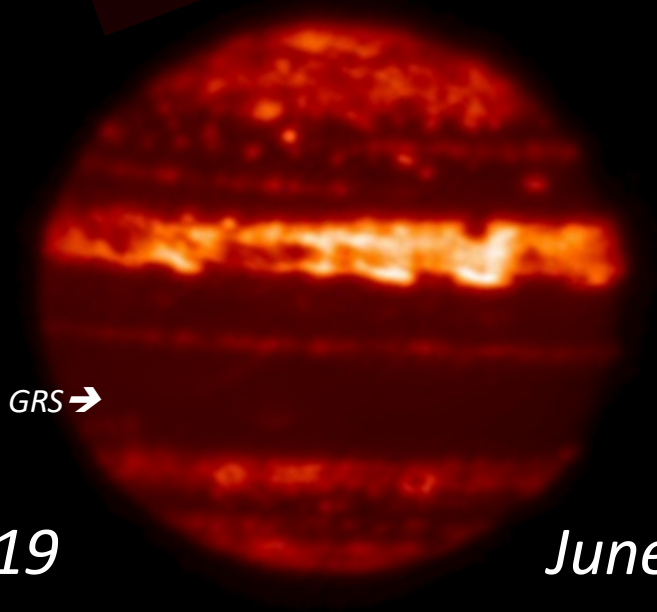


Temporal context needed
Example: Jupiter's "Faded" South Equatorial Belt





2009: *July 23* *July 20*

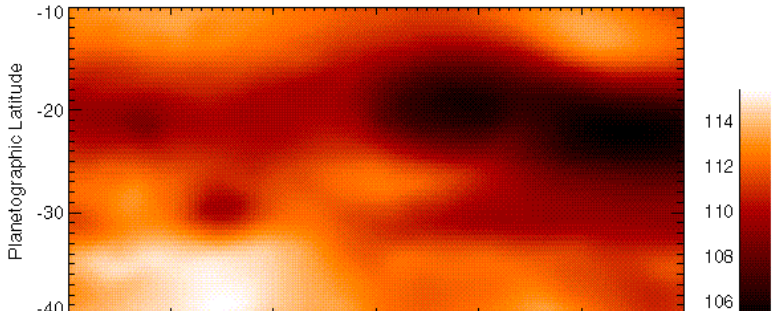


2010: *April 19* *June 25*

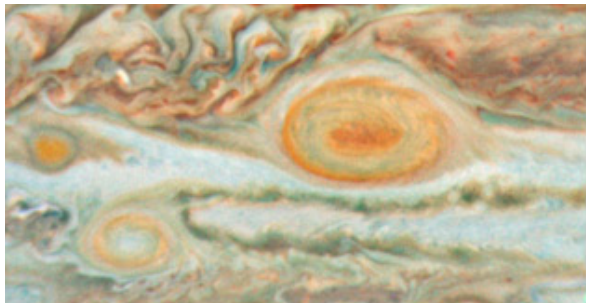
A. Wesley images *4.8 μm images*

Atmospheric properties derived from 18 May 2008 VLT/VISIR multi-spectral images (resolution <1700 km)

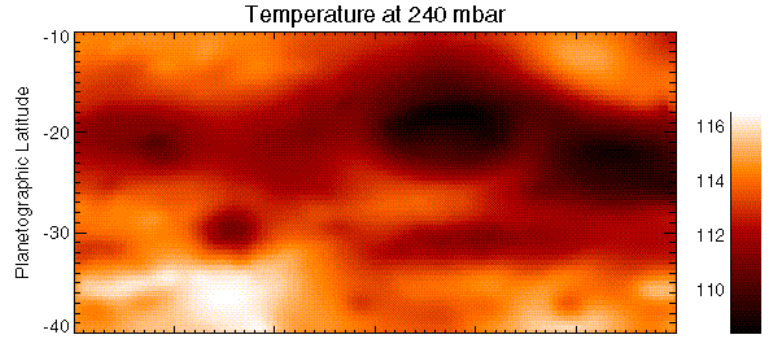
Temperature



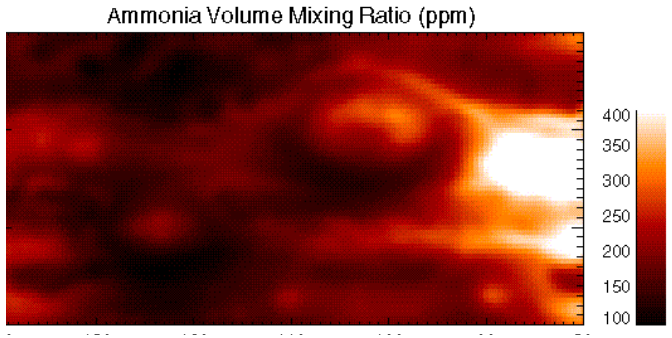
140 mbar



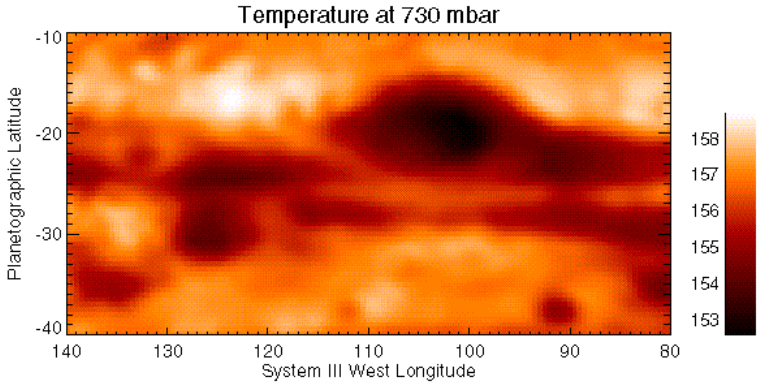
HST WF/PC color composite 15 May 2008



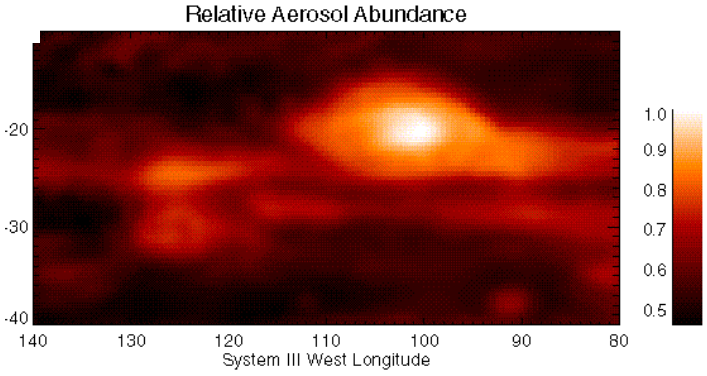
240 mbar



NH_3 VMR 300 mbar



730 mbar



600-mbar relative cloud thicknes

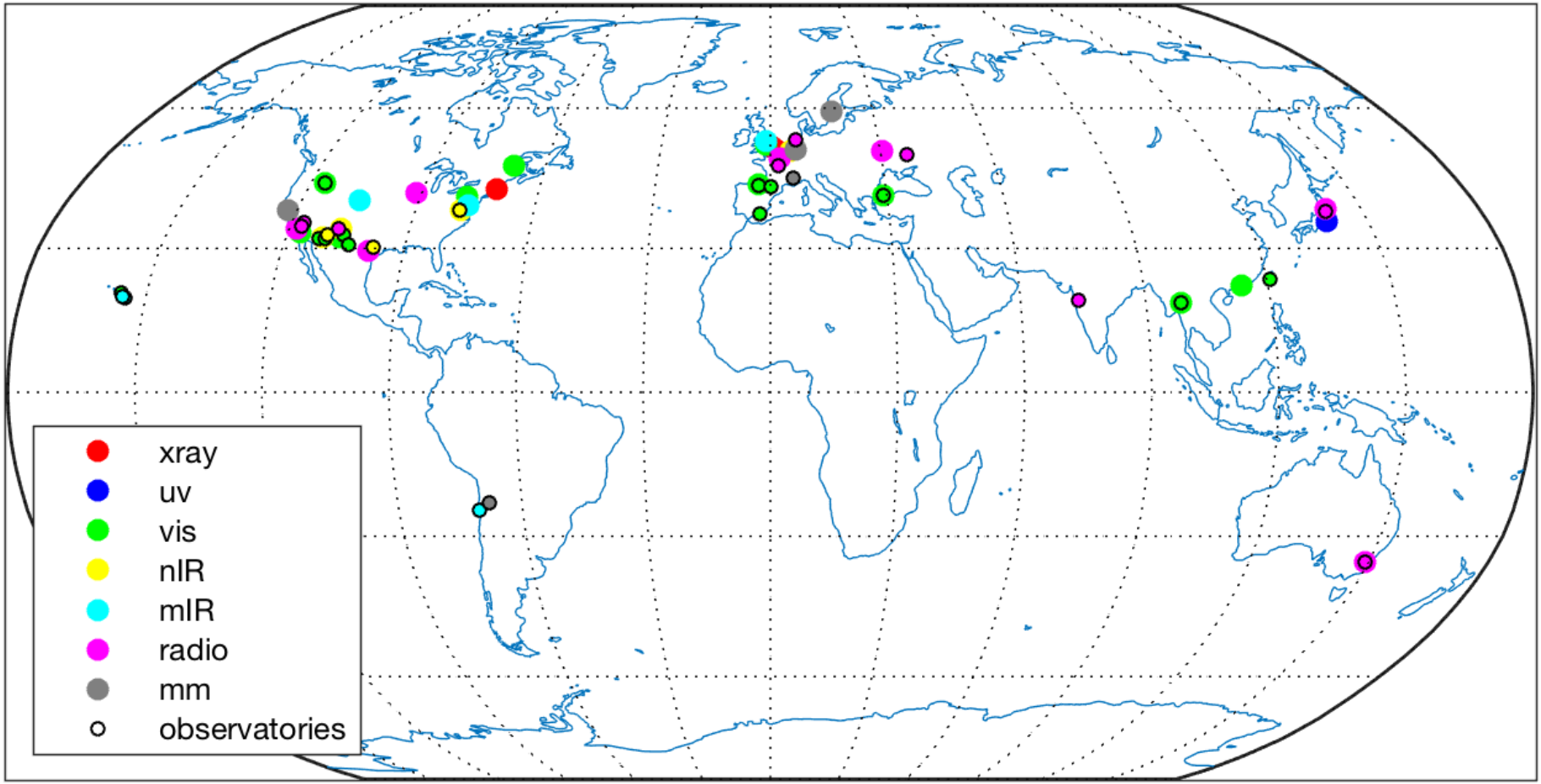
Over 60 Groups Contributing to the Program

Observatory/Instrument	Investigation Contact
X-ray	
Chandra/HRS	Kraft, Jackman, Gladstone
XMM	Dunn
EUV/FUV	
Hisaki/EXCEED	Kimura, Yoshikawa
HST/STIS	Nichols, Grodent
CCD/ "Visible"	
VLT/MUSE – IFU	Irwin
Bilbao 11" Celestron	Sanchez-Lavega
Calar Alto 2.2m/PlanetCam	Sanchez-Lavega
Calar Alto 2.2m/Astralux	Sanchez-Lavega
Lulin Obs. 1m/35cm w/ CCD	Ip
ISTEK Belde Obs. 16" w/ CCD	Acar, Ates
Boise State 16" w/ CCD	Jackson
Apache Point/AOTF imager	Chanover
Apache Point/DIS (Io)	Schneider
McDonald Obs./IFU	Schmidt
Tohoku U. / Haleakala 60cm	Kagitani, Yoneda
Pic du Midi/T1M CCD	Colas, Dauvergne
Robo-AO/CCD	Riddle
Io Input/Output Robot. Tel.	Morgenthaler
Thailand Nat. Tel. 2.4m/0.7m	Poshyachinda, Go
HST/WFC3 (OPAL program)	Simon
HST/WFC3	Wong

Observatory/Instrument	Investigation Contact
Near-IR	
IRTF/SpeX imaging	Orton
(NOTE: All images are downloadable from: http://junoirtf.space.swri.edu)	
IRTF/CSHELL,iSHELL	Kita
IRTF/iSHELL	Johnson
IRTF/iSHELL	Bjoraker
Keck/NIRSpec	O'Donoghue
VLT/NACO	Bonfond
LBT/LMIRCAN+NOMIC	Defrere
Gemini N/NIRI+AO (Io)	de Kleer
Gemini N/NIRI+AO (Jup)	Orton
Gemini N/NIRI 5-µm (Jup)	Wong
Fan Mountain 31"/Fan Cam	Skrutskie
Keck/NIRC2 (Io)	Davies
Subaru/IRCS	Kasaba, Kita
DCT/IGRINS (Io)	Schmidt
Keck/NIRSPEC	Bjoraker, de Pater
Mid-IR	
IRTF/TEXES	Greathouse
IRTF/TEXES	Fletcher
IRTF/TEXES	Sinclair
ITYG/MIRSI	Orton
IRTF/TEXES (Io)	Retherford
Gemini N/TEXES	Greathouse
Gemini N/TEXES	Fletcher

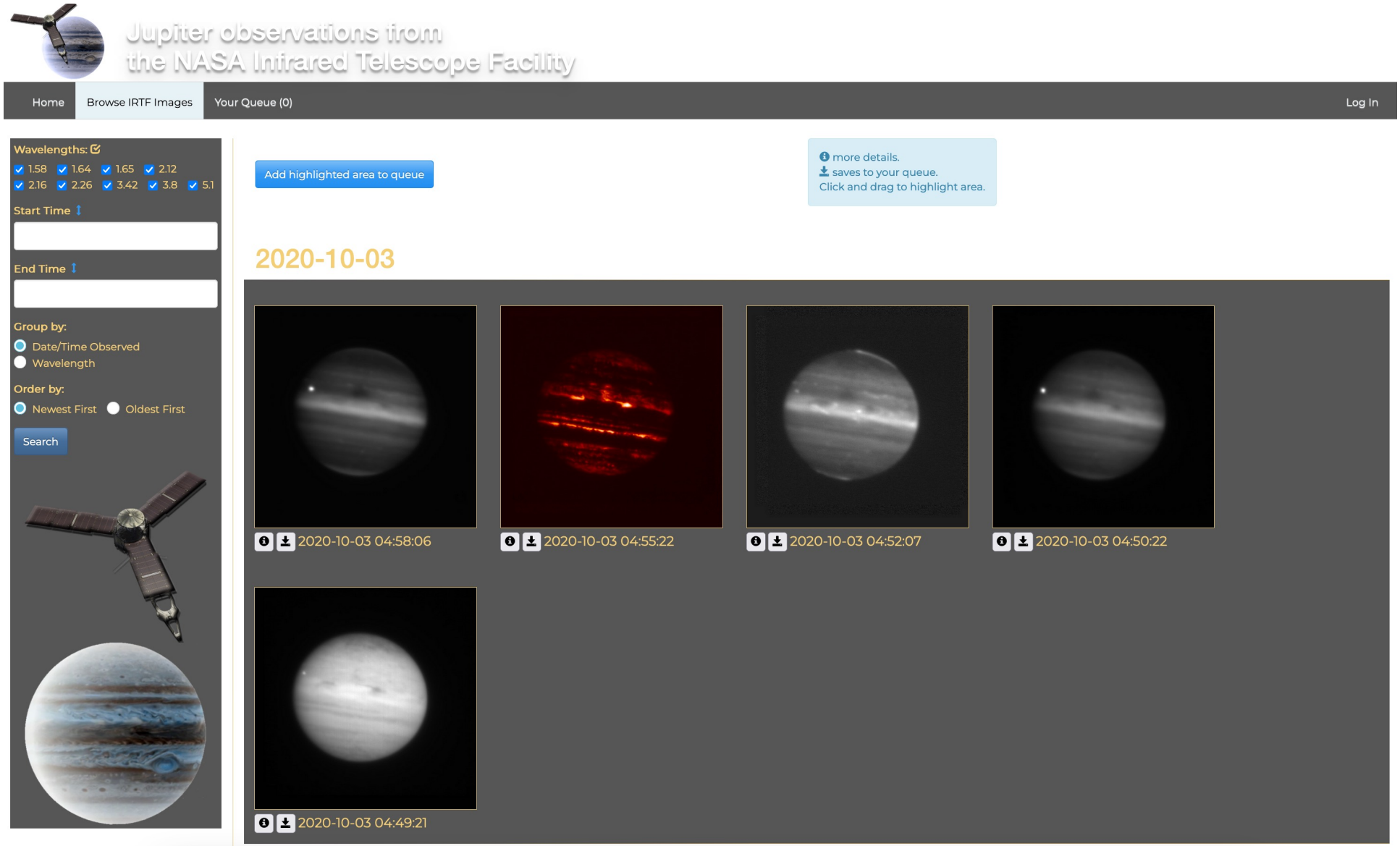
Observatory/Instrument	Investigation Contact
Mid-IR (continued)	
Gemini N/TEXES	Sinclair
IRTF/TEXES (Io)	Tsang
Subaru/COMICS	Kasaba
Subaru/COMICS (Keck x-ch)	Orton
VLT/VISIR	Fletcher
IRTF/HIPWAC	Kostiuk
SOFIA/EXES	Orton
SOFIA/FORCAST	de Pater
Submm	
IRAM/NOEMA	Roth, Sanchez-Monge
MM	
ALMA	de Pater
Radio	
VLA	de Pater
Nancay Decameter Array	Lamy, Zarka, Cecconi
Iitate Planet. Radio Telesc.	Misawa, Tsuchiya
LWA1 (USA), UDA (France), UTR-2, GURT, URAN-2, URAN-3 (Ukraine),	Imai
GMRT	Kita
LOFAR	Santos-Costa
DSN Goldstone	Levin
DSN Canberra	Horiuchi
GAVRT	Levin

Locations of contributors and observatories



Some observations are available publicly

- HST images are on MAST
- IRTF near-IR images are on http://junoirtf.space.swri.edu



Observing Coordination

- Google Table that lists all observations

Mission Juno : Planned Observations

File Edit View Insert Format Data Tools Extensions Help Last edit was yesterday at 8:26 PM

A1 Note: On this orbit the spacecraft orientation optimizes gravity sensing with the antenna pointed toward the Earth. This orbit is for an extended m

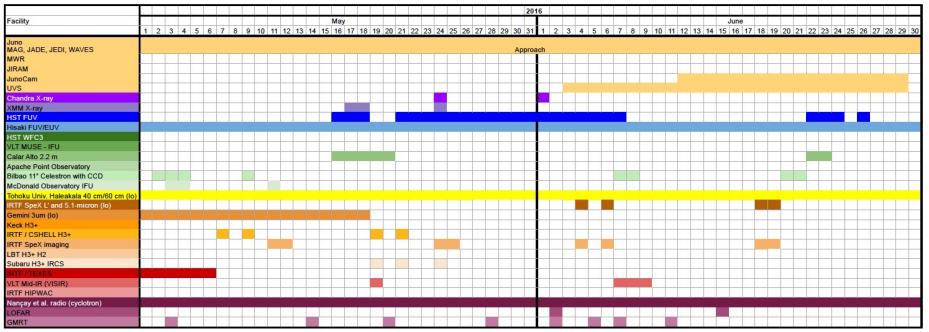
Near this perijove, on September 29, the spacecraft will make a close approach of the Galilean satellite Europa.

The period has been defined as a week before perijove to a week before the subsequent perijove, unlike the mission-planning definition, which extends from a c

Period: Orbit 45-EXT [GRAV] (2022 Sep 20 - 2022 Oct 31)

Spectral Region	PI	Facility/ Instrument	Description	Date Scheduled/ Requested	Data Availability
FUV	Roth	HST / STIS	Ganymede's aurora in eclipse, FUV imaging	23 Oct, 30 Oct	after 6 months proprietary period or contact PI
FUV	Bonfond	HST/STIS	Timetag imaging of northern aurora		
visible/NUV	Wong	HST/WFC3 UVIS	hi-resolution map of perijove track, single orbit snapshot		
UV, VIS, near-IR	Sanchez-Lavega	Planetcam, 2.2m Calar Alto Observatory	Observing Jupiter with new detectors (0.35-1 micron) & (1-1.6 micron)	26, 27, 28, 29 September	
Visible	**Morgenthaler**	**Io Input/Output robotic telescope (IoIO)**	**35-cm telescope and coronograph to study the Jovian sodium nebula and Io plasma torus in [SII] 6731A**	**Nightly, weather permitting**	
visible/nearIR	Alexander, Irwin	VLT/MUSE - IFU	spectroscopic imaging, 475-930 nm to determine cloud structure and albedo spectrum of particles.	Dates near PJ45 requested.	Raw data publicly available to download from ESO portal this time next year. Standard calibration pipeline takes of the order of 1-3 days to complete.
Visible & Near IR	Schmidt	Keck I Hires & Keck II NIRSPEC	Europa sputtered Na and K atmosphere. Jupiter at opposition, Europa flyby near transit. Plasma structure and composition of IPT H2/H3+ mapping of Jovian Aurora: northern oval velocity + global temperature (PJ45 @ 7:11)	28 Sept	immediately available on KOA public archive: https://koa.ipac.caltech.edu/cgi-bin/KOA/nph-KOAlogin
near IR	**Bjoraker**	**IRTF/iSHELL**	**5 micron spectra**	**30 Sept UT**	**later**
near IR	**Orton**	**IRTF/SpeX**	**filtered imaging and scanning spectroscopy between 1.58 and 5.1µm**	**filtered imaging obtained on September 28, 30 at high resolution (0.6" or better) and photometric nights. Also on October 14 with 1" seeing and thin cirrus.**	**raw images available immediately from IRTF web site; fully reduced images available within a month or sooner, as desired. Reduced "quick-look" observations (geometrically but not**

-Requested observing time
-Granted observing time
-Successful observing
-Unsuccessful observing

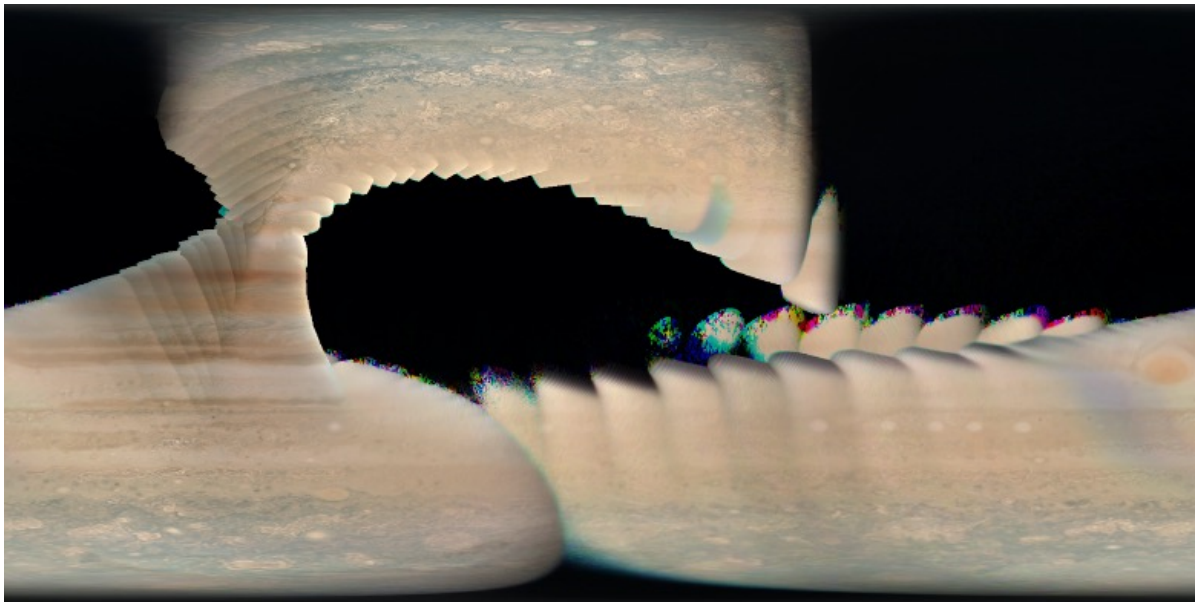


- Tabular – Google Table, interactive
  - https://docs.google.com/spreadsheets/d/1mKGmvxJNlba3PPls6vikhbThsyIAiiKj1ZabkmPPKTI/edit#gid=973703919
- Mirrored in a public non-interactive table
  - https://www.missionjuno.swri.edu/planned-observations

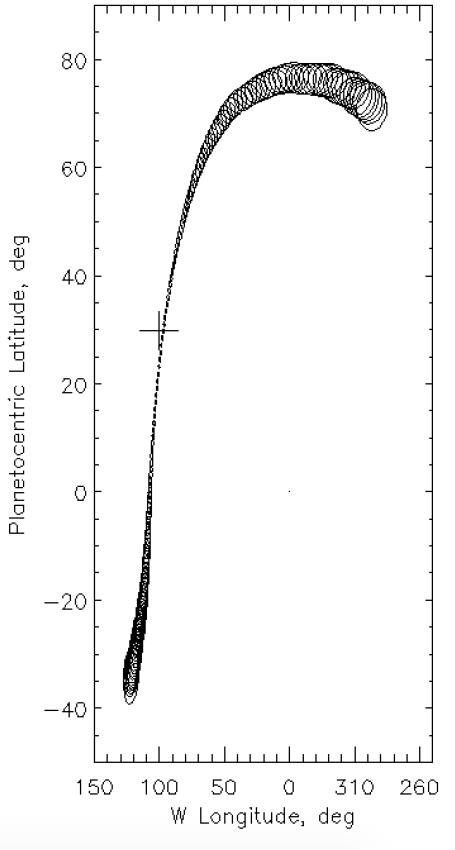
- Reports at all Juno Science Team Meetings, this program is treated in the same category as an instrument
- Group emails

Table includes some graphical summaries of Juno results

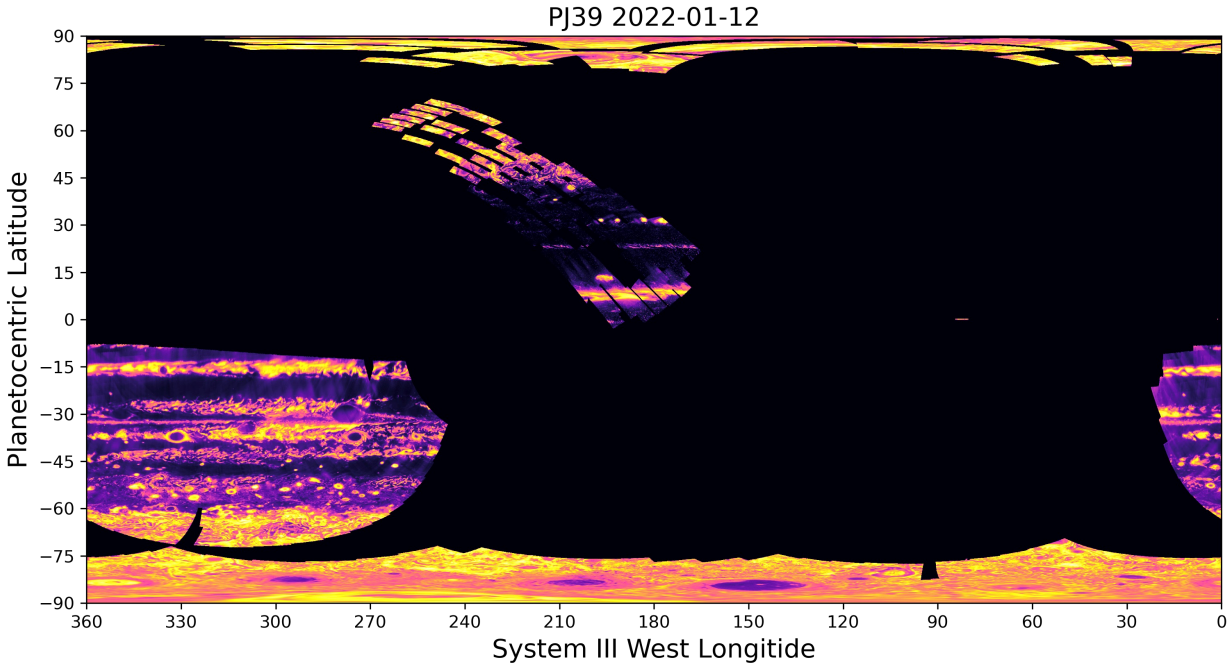
JunoCam composite map: PJ36



MWR Footprints PJ36



JIRAM 5-μm band map: PJ39



Workshops

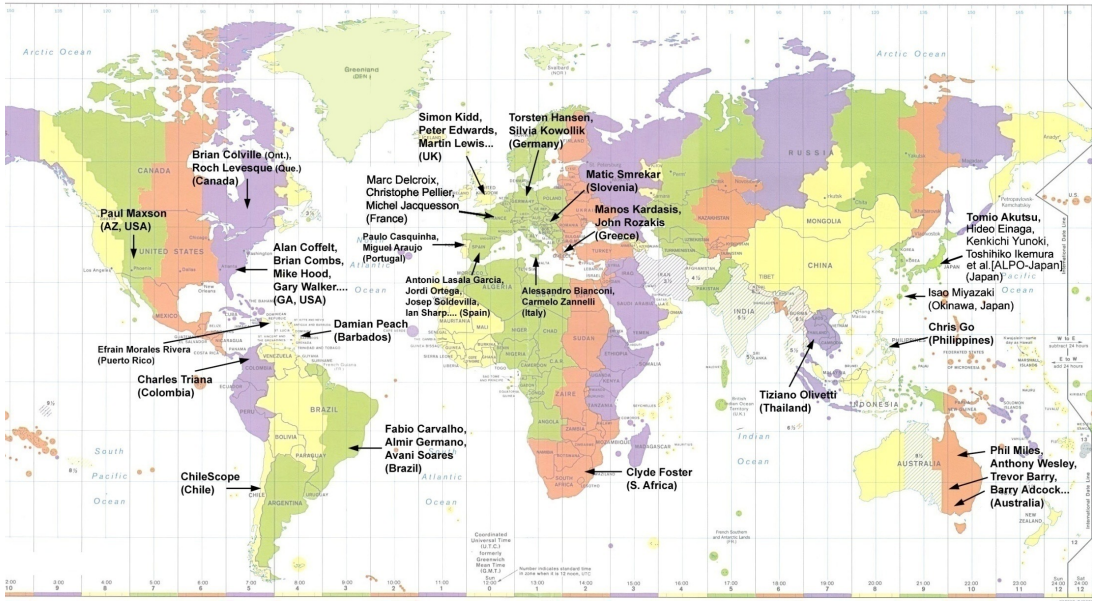
- Magnetospheres: Results given at Magnetosphere of Outer Planet (MOP) meetings
- Atmospheres: Centered on 2018 October 21 American Astronomical Society / Division for Planetary Science meeting
  - maybe another one at the combined EPSC/DPS meeting in 2023 October)

Involvement by Citizen-Science ”Amateur” Astronomers

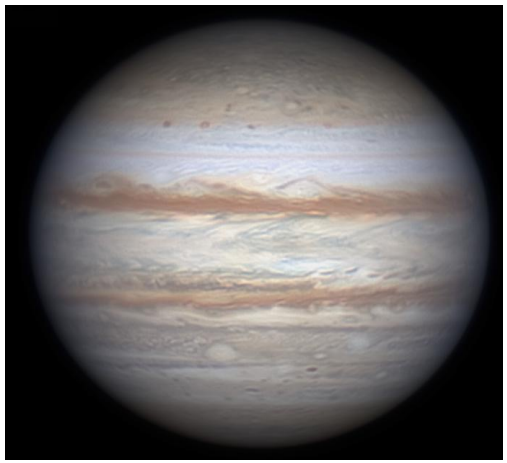
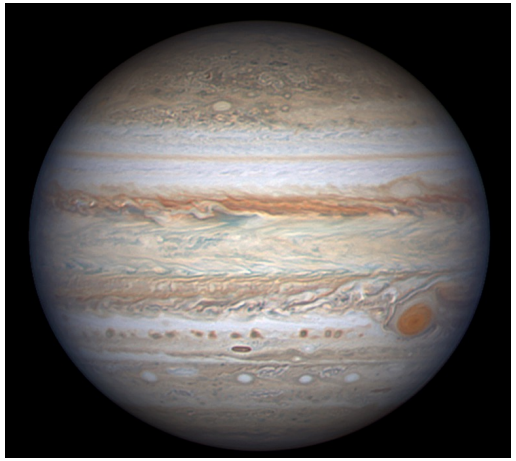
- **Potentially large cadre of data, immense interest by some quite accomplished amateurs in a chance to get involved with a NASA mission – lots of motivation**

Contributions of Amateur Astronomers

- World-wide 24/7 coverage
  - Almost continuous atmospheric scrutiny
  - Sensitive to both sudden and long-term atmospheric changes
- Benefit to professional Earth-based Juno support, as well as directly to Juno
- Upload images to the "Mission Juno" site:



https://www.missionjuno.swri.edu/junocam/planning


Workshops with the Amateur Community

- Juno Pro-Am workshop 2016 May 12-13, Nice
- Europlanet RAS-Juno Europlanet Meeting 2018, London

Juno Pro-Am Workshop 12-13 May 2016

Observatoire de la Côte d'Azur, Nice, visit to the 77 cm refractor

1. Jean-Pierre Prost
2. Isshi Tabe
3. Paulo Casquinha
4. Kuniaki Horikawa
5. Dominique Albanese
6. Gerald.Eichstädt
7. Constantin Sprianu
8. Matej Mihelčič
9. Leigh N. Fletcher
10. Marc Delcroix
11. John Sussenbach
12. François Xabier Schmider
13. Matic Smrekar
14. Manuel Scherf
15. Emil Kraaikamp
16. Alessandro Bianconi
17. John McKeon
18. Michel Jacqueson
19. Paolo Tanga
20. Glenn S. Orton
21. John H. Rogers
22. Padma Yanamandra-Fisher
23. Marco Vedovato
24. Johan Warell
25. Damian Peach
26. François Colas
27. Christopher Go
28. Jean-Pierre Rivet
29. Agustin Sánchez Lavega
30. Ricardo Hueso
31. Jean-Luc Dauvergne
32. Christophe Pellier

1.Jean-Luc Dauvergne 2.Glenn Orton 3.Peter Rosen 4.Manos Kardasis 5.Clyde Foster 6.Silvia Kowollik 7.Leigh Fletcher 8.Ricardo Hueso 9.Simon Kidd 10.Tirs Abril 11.Christopher Go 12.Joaquin Camarena 13. Agustin Sanchez-Lavega 14.Josep Soldevilla 15.Paulo Casquinha 16.John Rogers 17.Peter Edwards 18.John Sussenbach 19.Martin Lewis 20.Patrick Irwin 21.Candy Hansen 22.Ashwin Braude 23.Constantin Sprianu 24.Kuniaki Horikawa 25.Michel Jacquesson 26.Anthony Wesley 27.Sean Doran 28.Padma Yanamandra-Fisher 29.Peter Lawrence 30.Emil Kraaikamp 31.Matt Brealey 32.Gerald Eichstaedt 33.Marc Delcroix 34.Arrate Antuñano 35.Padraig Donnelly 36.Alexei Pace 37.Johan Warell 38.Christophe Pellier 39.Mike Foulkes 40.Manuel Scherf 41.Marco Vedovato 42.Miguel Araújo 43.Scott Bolton

Current estimated parameters for the rest of the Juno extended mission:

- PJ45 Europa encounter
- PJ45-PJ57, period: 38d
- PJ57 Io encounter
- ~PJ50-75, nightside perijove
- PJ57-75, period ~33d

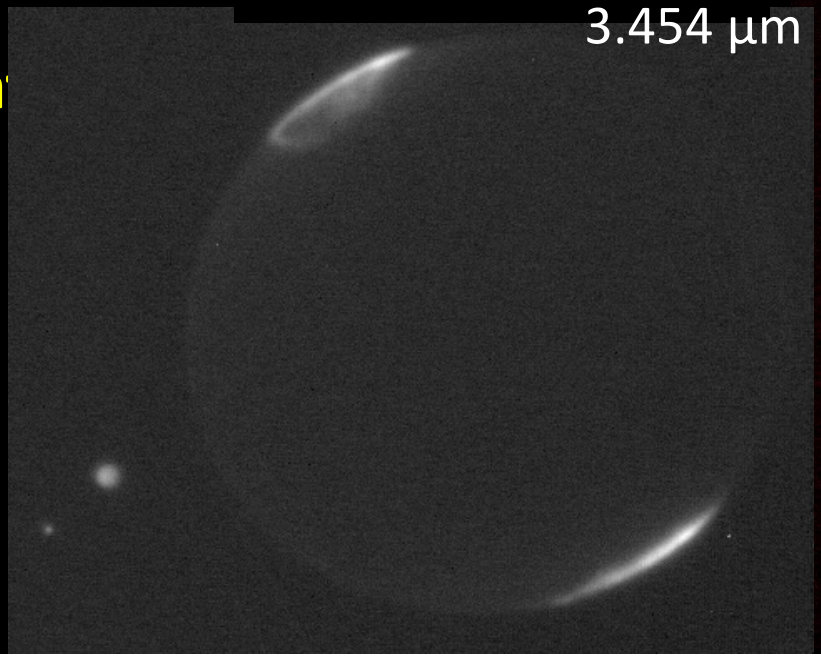
(orbit timings become less certain)

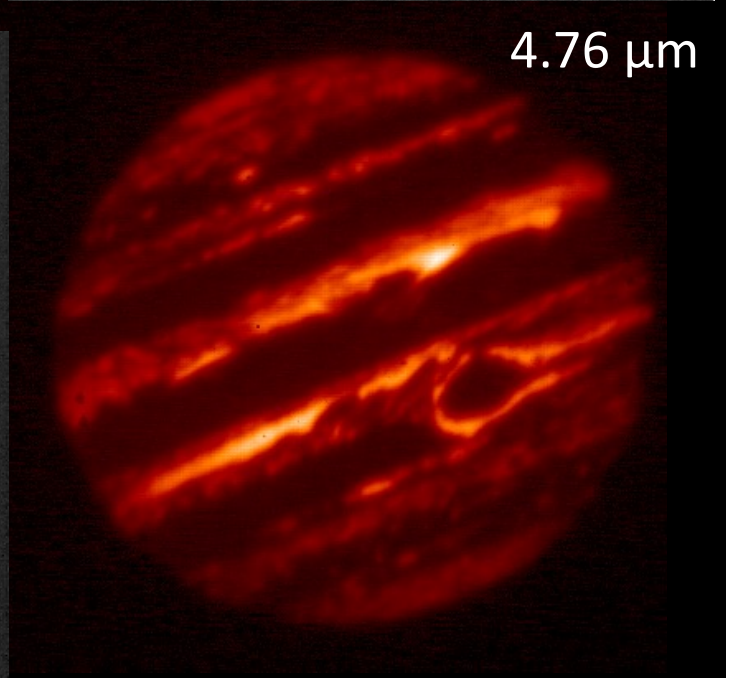
PJ	Date	Approx. Spacecraft Event Time	PJ lat. (centric)	Approx. Eq. Crossing PJ long. (Sys. III)	Solar Elongation
45	2022 Sep 29	17:00	37°	240°	177°
46	2022 Nov 6	21:00	38°	1°	136°
47	2022 Dec 15	03:00	39°	170°	97°
48	2023 Jan 22	06:00	40°	215°	63°
52	2023 Jun 23	07:00	44°	100°	53°
53	2023 Jul 31	09:00	44°	139°	84°
54	2023 Sep 7	12:00	45°	204°	119°
55	2023 Oct 15	11:00	46°	125°	158°
56	2023 Nov 22	12:30	47°	136°	158°
57	2023 Dec 30	12:30	47°	108°	118°
58	2024 Feb 3	22:00	48°	311°	84°
59	2024 Mar 7	16:00	49°	24°	55°
63	2024 Jul 17	0:30	53°	260°	43°
64	2024 Aug 18	21:00	54°	66°	68°
65	2024 Sep 20	19:00	60°	271°	97°
66	2024 Oct 23	14:30	56°	46°	129°
67	2024 Nov 25	9:30	57°	148°	165°
68	2024 Dec 28	7:00	57°	350°	157°
69	2025 Jan 30	3:30	58°	100°	121°
70	2025 Mar 4	2:00	59°	13°	89°
71	2025 Apr 5	0:00	60°	226°	61°
72	2025 May 8	2:30	61°	72°	35°
75	2025 Aug 15	18:00	63°	94°	38°
76	2025 Sep 17	17:00	64°	300°	64°


Thank You
601
GSOLRB
Backup slides

Use a similar program as we did during the Galileo mission that tracks changes in the atmosphere as a program each night the IRTF SpeX instrument scientific-grade guide camera would be used a these same wavelengths.

Jupiter: 2014 December 21
NASA Infrared Telescope Facility





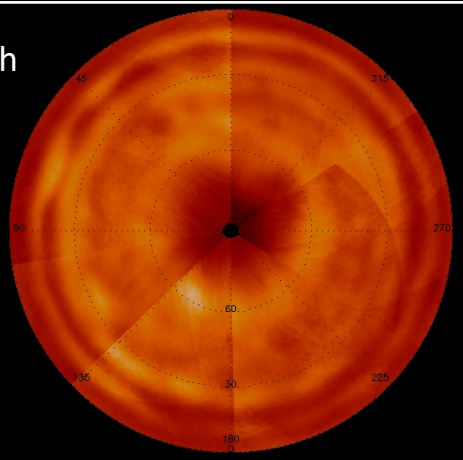
Cold polar vortices: 360^{o} longitude mapping: 2017 May 19-20 (PJ6)

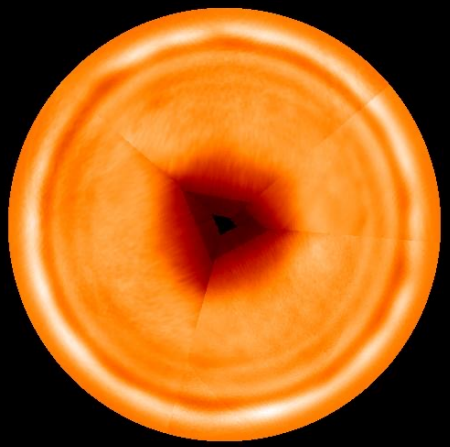
Subaru COMICS 7.8 µm

Subaru COMICS 17.65 µm

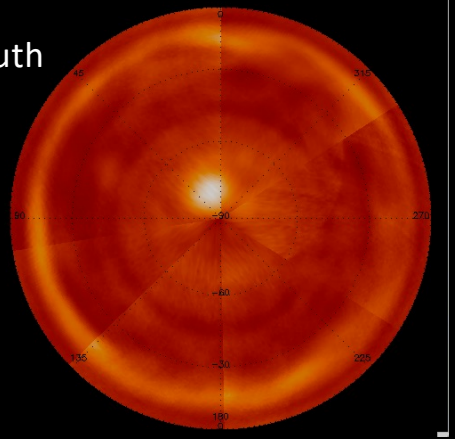
JunoCam 890nm

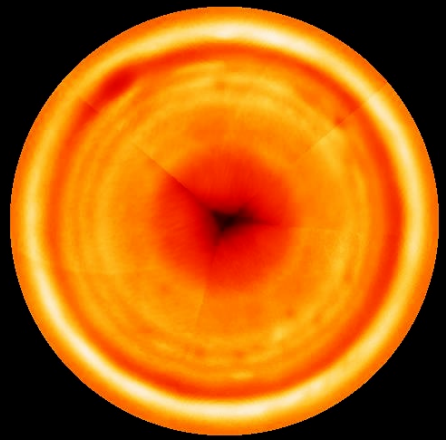
North

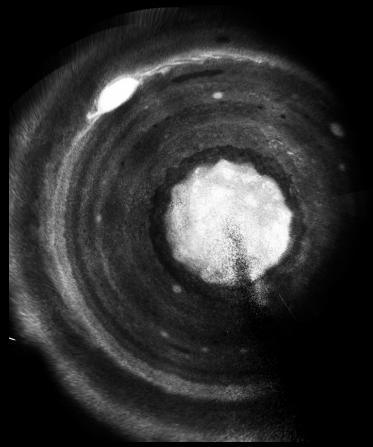




South

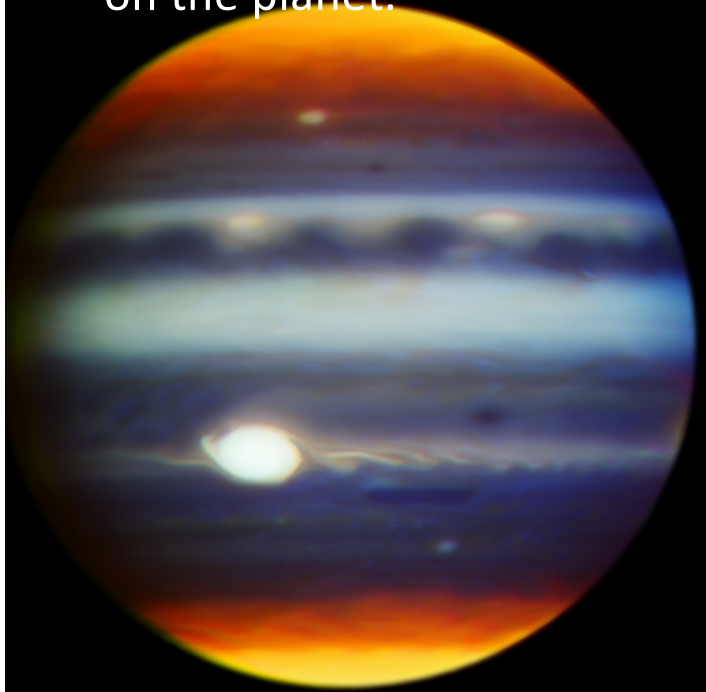




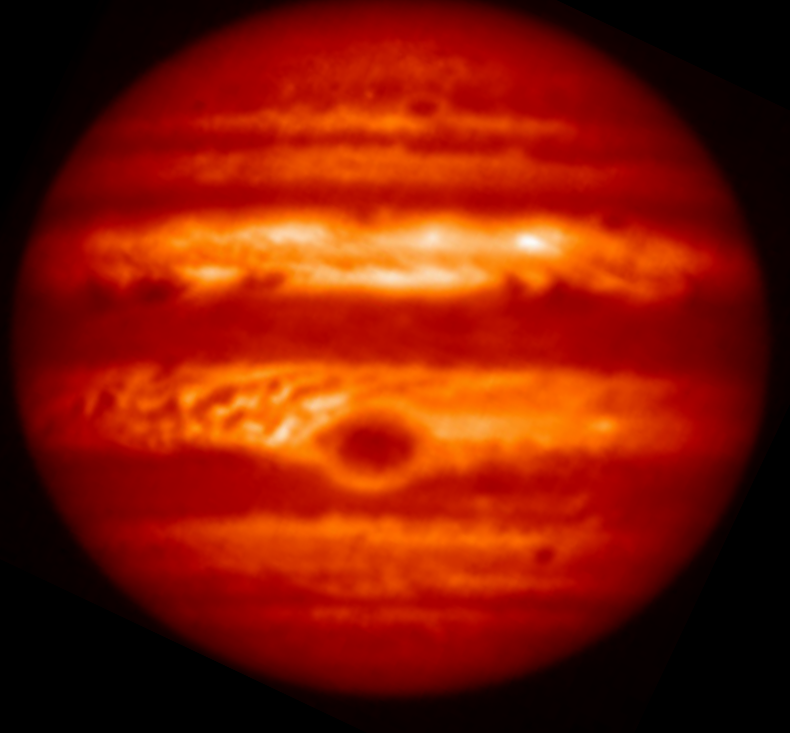


GRS Observations at PJ 6, preparation for PJ7

Gemini N NIRI, 2017 May 18
near-infrared composite:
GRS has highest-altitude cloud /haze
on the planet.

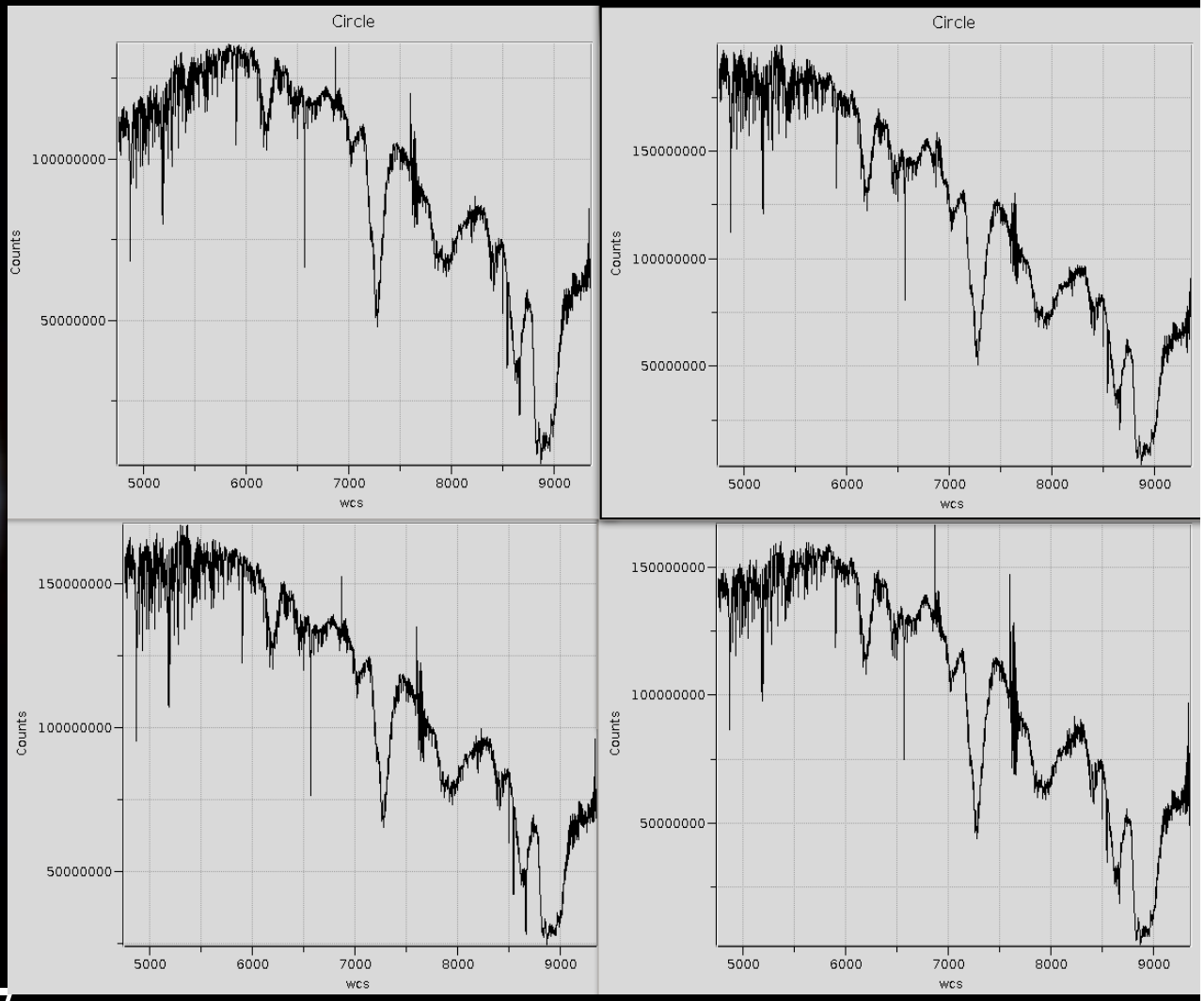


Subaru COMICS, 2017 May 18
8.7-µm image
GRS and environs have complicated
cloud structure for particles ~600 mbar



Spatially resolved spectra of atmospheric features

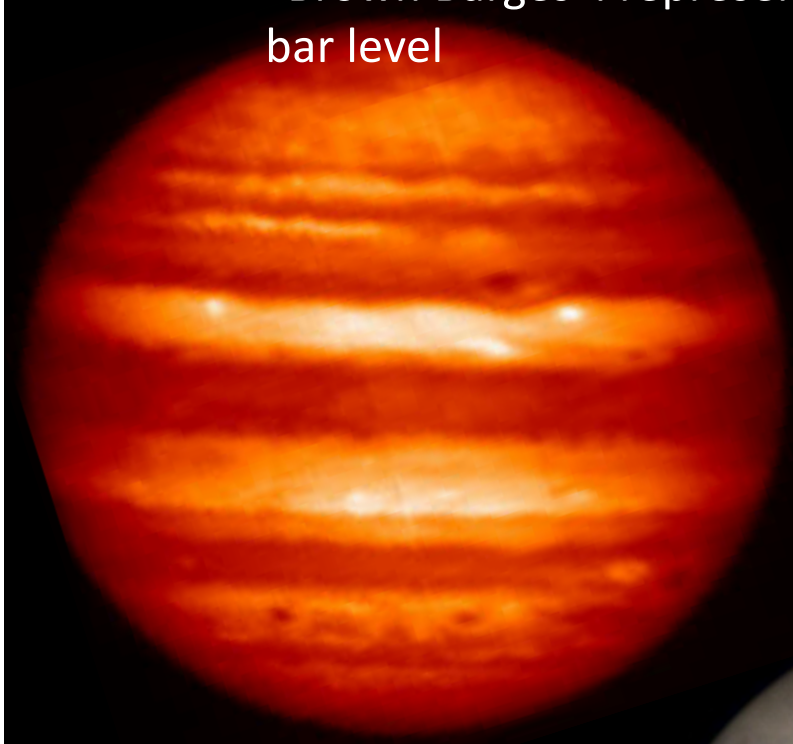
ESO Very Large Telescope: MUSE



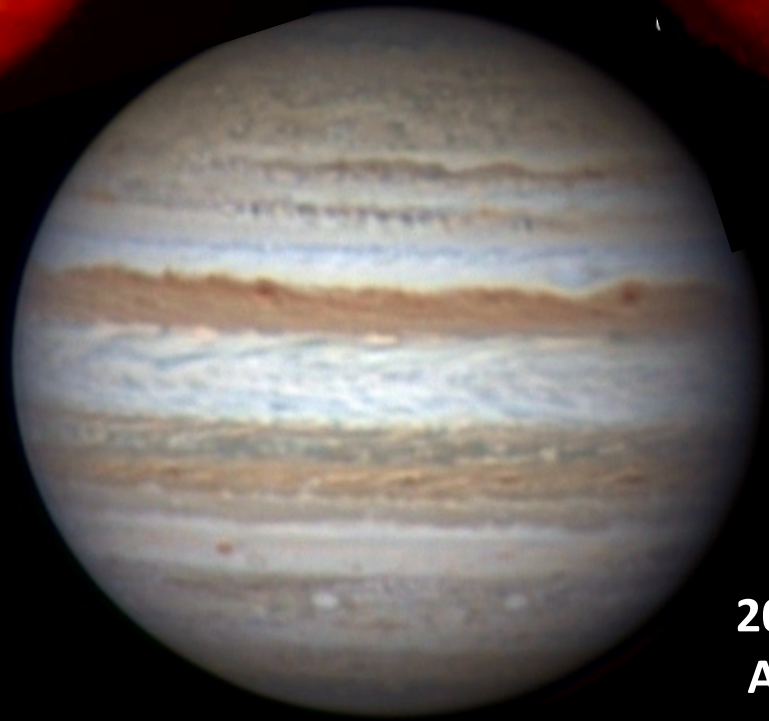
early test results, 2014 Feb 17

Example of contemporaneous multi-spectral observations

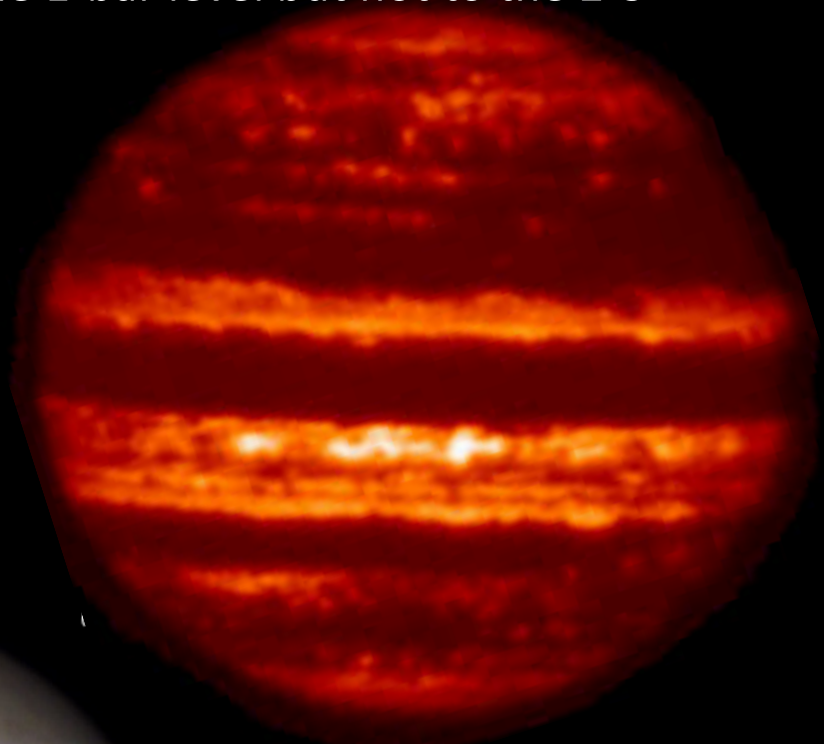
“Brown Barges”: represent clear regions at the 1-bar level but not to the 2-3 bar level



2011 Aug 27, 8.6 µm
Subaru, COMICS



2011 Aug 28, visible
A. Kazemoto, Kyoto



2011 Aug 29, 4.8 µm
IRTF, NSFCam2