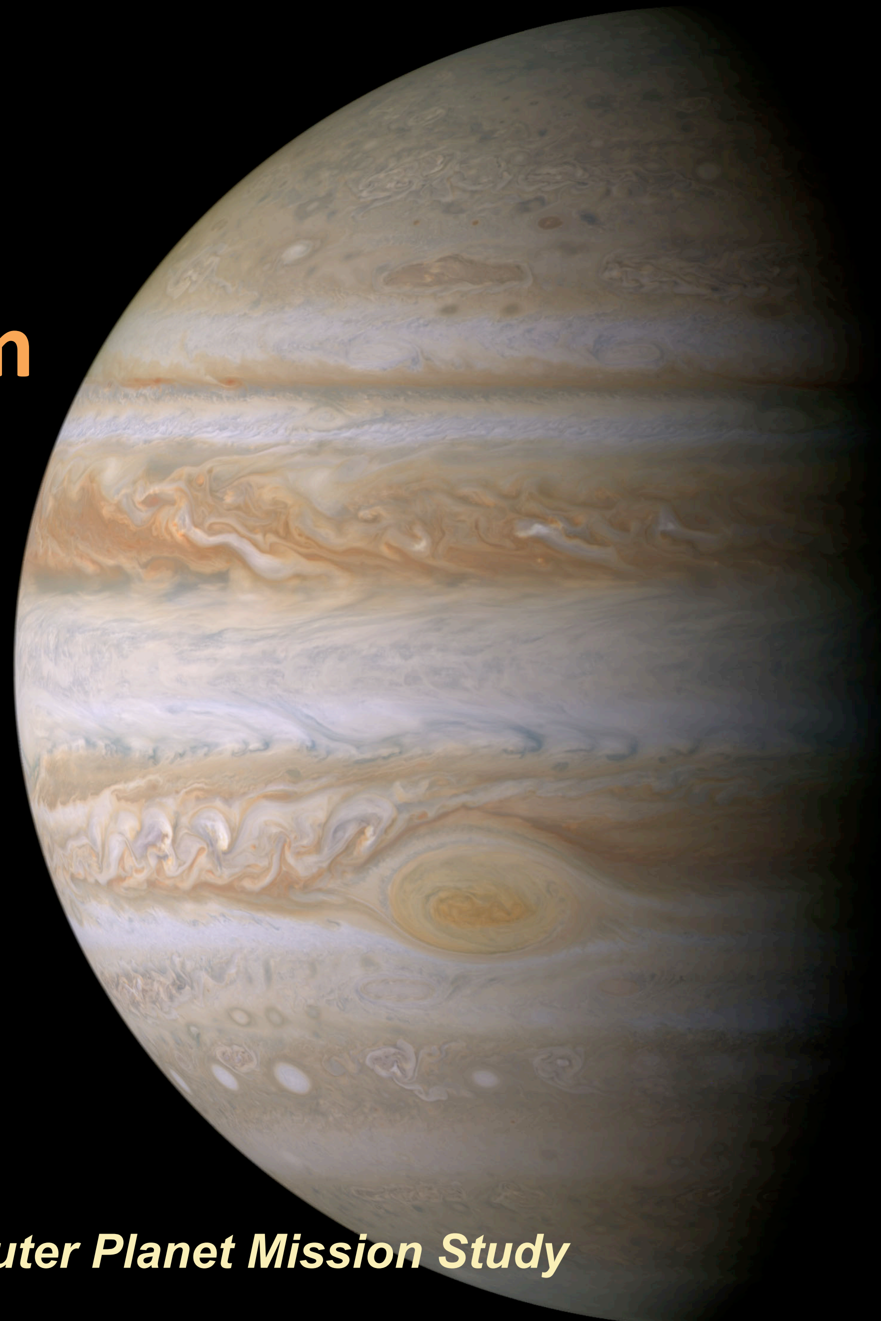
Jupiter Science and Capabilities on the Europa Jupiter System Mission

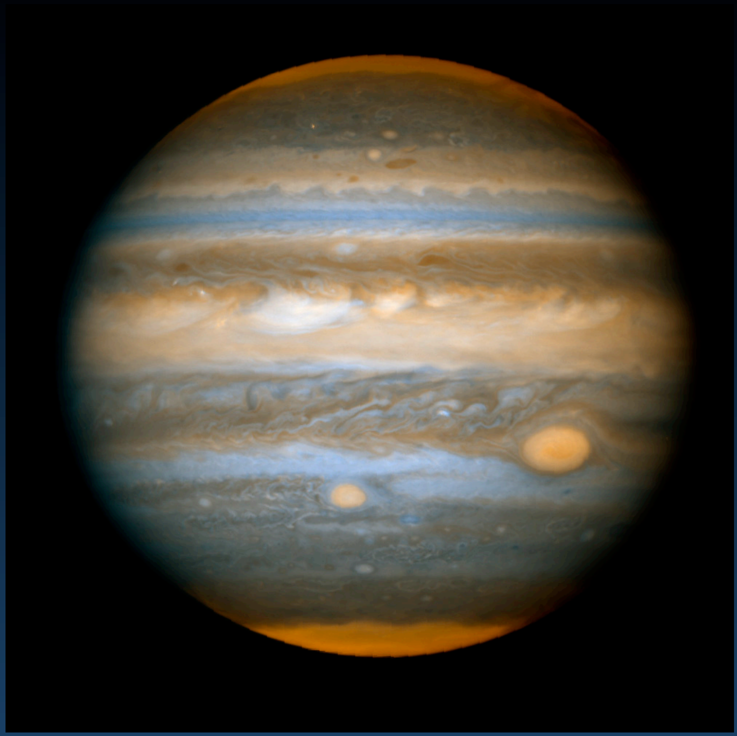
Amy Simon-Miller, P. Drossart, L. Fletcher, A. Showman, G. Orton, K. Baines and the EJSM Joint Science Definition Team



A Joint NASA-ESA Outer Planet Mission Study

Overview

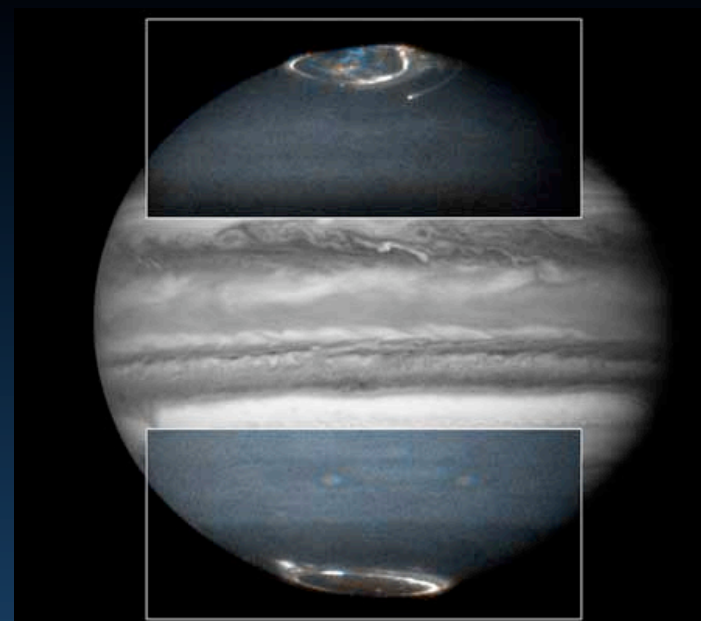
- EJSM as part of the Decadal Survey:
  - Themes in 2002 Decadal
  - Placement in 2011 Decadal
  - Role of Jupiter Science
- Mission Overview
  - Key Tour Opportunities
  - Model Payload
  - JEO/JGO Synergy
- Science Objectives
  - Big Picture Questions
  - Objectives and Investigations



Credit: NASA, ESA, A. Simon-Miller, I. de Pater, M. Wong

Jupiter Science as an Element of EJSM

- EJSM seeks to address two of the Science Themes of the 2002 Decadal Survey:
  - The Origin and Evolution of Habitable Worlds;
  - How Planetary Systems Work.
- For the next Decadal Survey:
  - All solar system is in one integrated plan
  - Must all fit in fixed budget
  - Critical to have community support for EJSM
- Jupiter science is a vital element of the study of interactions between the components of this complex planetary system (Jupiter, icy satellites, rings, magnetosphere and small bodies).
- The mission is responsive to ESA's Cosmic Vision: study of gas giants and exoplanets



NASA/ESA/J Clarke, Boston University

Jupiter system science is an importance component of EJSM.

Relation to 2002 Decadal Survey

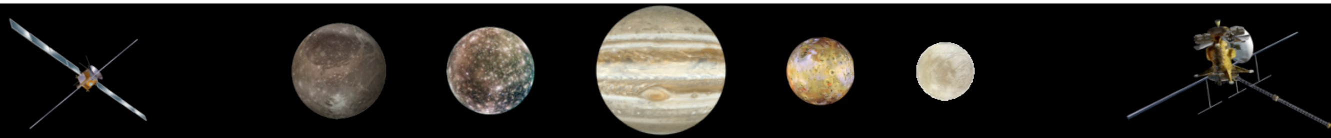
- Committee recommended 'Characterization of Jupiter' as the key goal for Outer Planets, with sub-goals of 'Origin and Evolution' and 'Interiors and Atmospheres'
- Juno will address bulk compositional questions, and an investigation of the interior and atmosphere below the cloud-tops.
- EJSM would extend the atmospheric characterization above the cloud-tops, to investigate dynamic and chemical coupling between:
  - (a) the deep interior convection and weather-layer dynamics;
  - (b) the troposphere and the middle atmosphere;
  - (c) the lower atmosphere and ionosphere/thermosphere; and
  - (d) the Jovian atmosphere and the immediate interplanetary environment (magnetosphere, satellite and ring system).
- Together, EJSM and Juno would provide the tools to significantly enhance our understanding of fundamental physical processes in gas giant atmospheres.

EJSM concept seeks to address the characterization of Jupiter's atmosphere required by the 2002 Decadal Survey

Community Involvement

- EJSM Jupiter Science Working Group (May 2009-Present):
  - A. Simon-Miller, P. Drossart, L.N. Fletcher, A. Showman, G. Orton, K. Baines (NASA and ESA input).
  - With input from: R. Achterberg, G. Bjoraker, J. Clarke, B. Conrath, P. Gierasch, P. Hartogh, W. Hubbard, P. Irwin, E. Marouf, K. Matcheva, J. Moses, C. Nixon, P. Steffes, R. Yelle, M. Galand, K. Altwegg, P. Irwin, A. Sanchez-Lavega, P. Gaulme, M. Paetzold, G. Davide, A. Fedorova, Y. Takahaki *R. West & K. Sayanagi*
- Jupiter Atmospheric Science White Paper (March-September 2009)
  - Required detailed community discussion of science goals for the coming decade, and provided updates to the EJSM Jupiter science goals. (Fletcher et al.)
- Continue to solicit input from the Outer Planet community (particularly OPAG, this meeting):
  - Suggestions for improvements/enhancements.
  - Details on vital targets, viewing geometries, timing, 2-spacecraft synergies etc.

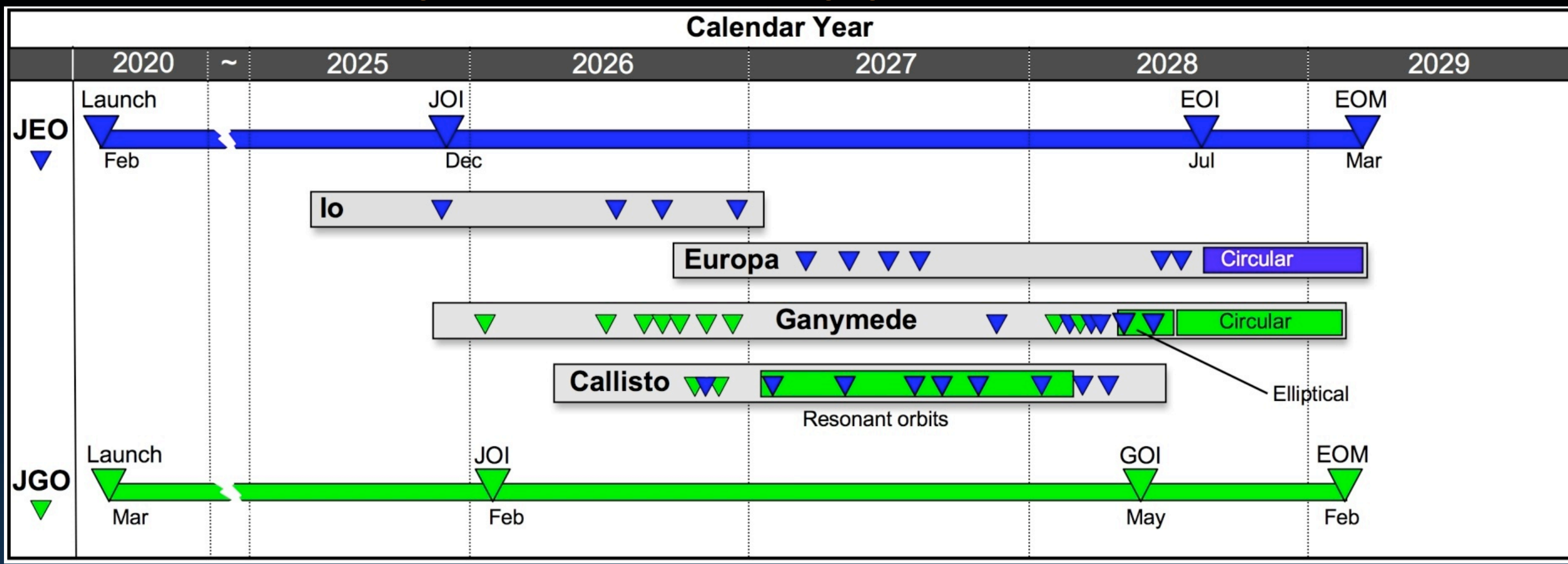
Jupiter working group continues to solicit input on EJSM science.



Community Results

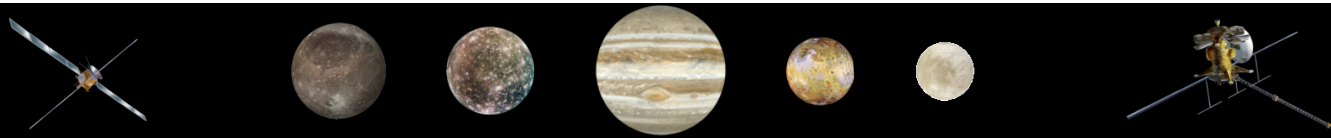
- Atmospheric Dynamics and Circulation
  - Investigate the dynamics of Jupiter's weather layer
  - Determine the thermodynamics of atmospheric phenomena
  - Quantify the roles of wave propagation and atmospheric coupling
  - Investigate auroral structure and energy transport
  - Understand the interrelationships of the ionosphere & thermosphere
- Atmospheric Composition and Chemistry
  - Determine the bulk elemental abundances
  - Measure the three-dimensional distribution of stratospheric hydrocarbons and their long-term variability
  - Study localized and non-equilibrium composition
  - Understand the importance of moist convection in meteorology, cloud formation, and chemistry
- Atmospheric Vertical Structure
  - Determine the 3-D structure of Jupiter's upper troposphere and stratosphere
  - Explore atmospheric structure deep below the clouds

Jupiter Tour Opportunities



- Pre-JOI:
  - Extensive opportunities for global mapping as JEO/JGO approach Jupiter
- Jupiter System Tour phase (with multiple perijove opportunities):
  - 30 months before Europa Orbital Insertion, 26 months before Ganymede OI
- End of Mission (from circular satellite orbits):
  - Potential to re-observe Jupiter 3 years after arrival if science drivers are strong enough

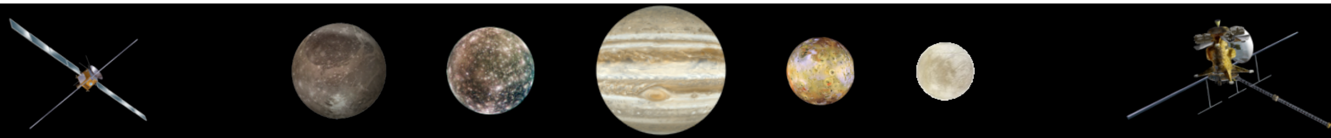
Jovian tour provides multiple opportunities for Jupiter science.



Jupiter Science: Temporal Coverage

- Jupiter has a dynamic atmosphere that evolves
  - Best cloud movie to date is Voyager 2 (143 rotations, single color, one gap – Cassini “best movie” was 20 rotations, with gaps)
  - Highest resolution is New Horizons/Galileo, in very limited regions
- Because the planet is always changing, monitoring is useful for understanding:
  - Wind generation and stability
  - Temperature, seasons, and atmospheric circulation
  - Vortex/eddy interactions and genesis
  - Convection and violent outbursts
  - Composition, photochemistry, and color
- These require a) a long time base, b) high spatial resolution c) high spectral resolution
  - During the Jupiter tour, EJSM provides this opportunity

EJSM provides longest, near-continuous, Jupiter coverage to date



EJSM Model Payloads

- Model payloads for two spacecraft emphasizes icy satellite science, but adaptations/modifications for Jupiter science were encouraged.
- Model instruments were defined by striking a balance among all EJSM science objectives.

= enhancements can be made for Jupiter science

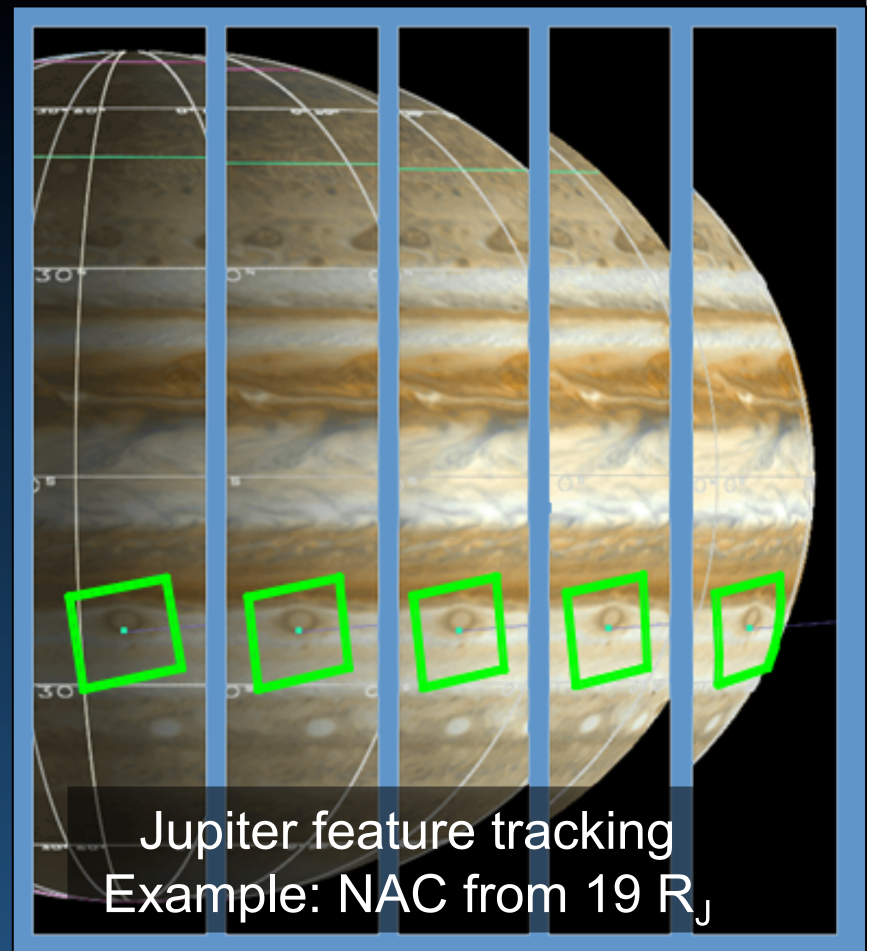
JEO model payload
Narrow Angle Camera
Wide Angle and Medium Angle Camera
Vis-IR Imaging Spectrometer
UV Spectrometer
Radio Science
Magnetometer
Ice Penetrating Radar
Laser Altimeter
Thermal Instrument
Ion and Neutral Mass Spectrometer
Particle and Plasma Instrument

JGO model payload
Narrow Angle Camera
Wide Angle and Medium Resolution Camera
Vis-IR Hyperspectral Imaging Spectrometer
UV Imaging Spectrometer
Radio Science
Magnetometer
Sub-Surface Radar
Laser Altimeter
Sub-Millimeter Wave Instrument
Plasma Package & Ion and Neutral Mass Spectrometer
Radio and Plasma Wave Instrument

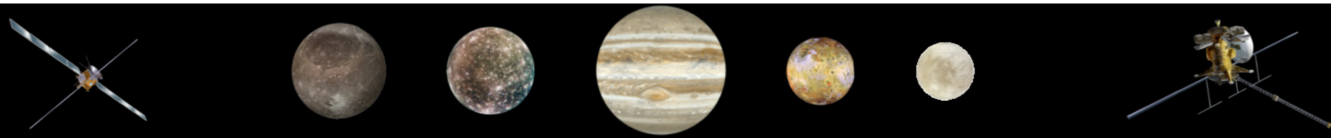
EJSM model payloads emphasize satellite science, but also provide significant potential for Jupiter science.

Jupiter Science: Spatial Resolution

- Best VIS/NIR resolution surpasses Voyager, Galileo, New Horizons
- Spatial resolutions (per pixel at 9.5 R_J):
  - Thermal Instrument: 1700 km
  - Wide-angle camera & UV spectrometer: 700 km
  - Near-IR Spectrometer: 170 km
  - Medium-angle camera: 70 km
  - Narrow-angle camera: 7 km
- Standard spatial resolution would be ~2 times these values.
- Jupiter science investigations call for higher UV/IR spatial resolutions than satellite science, a challenge to instrument providers.



EJSM concept would offer excellent visible/near-IR spatial resolutions.



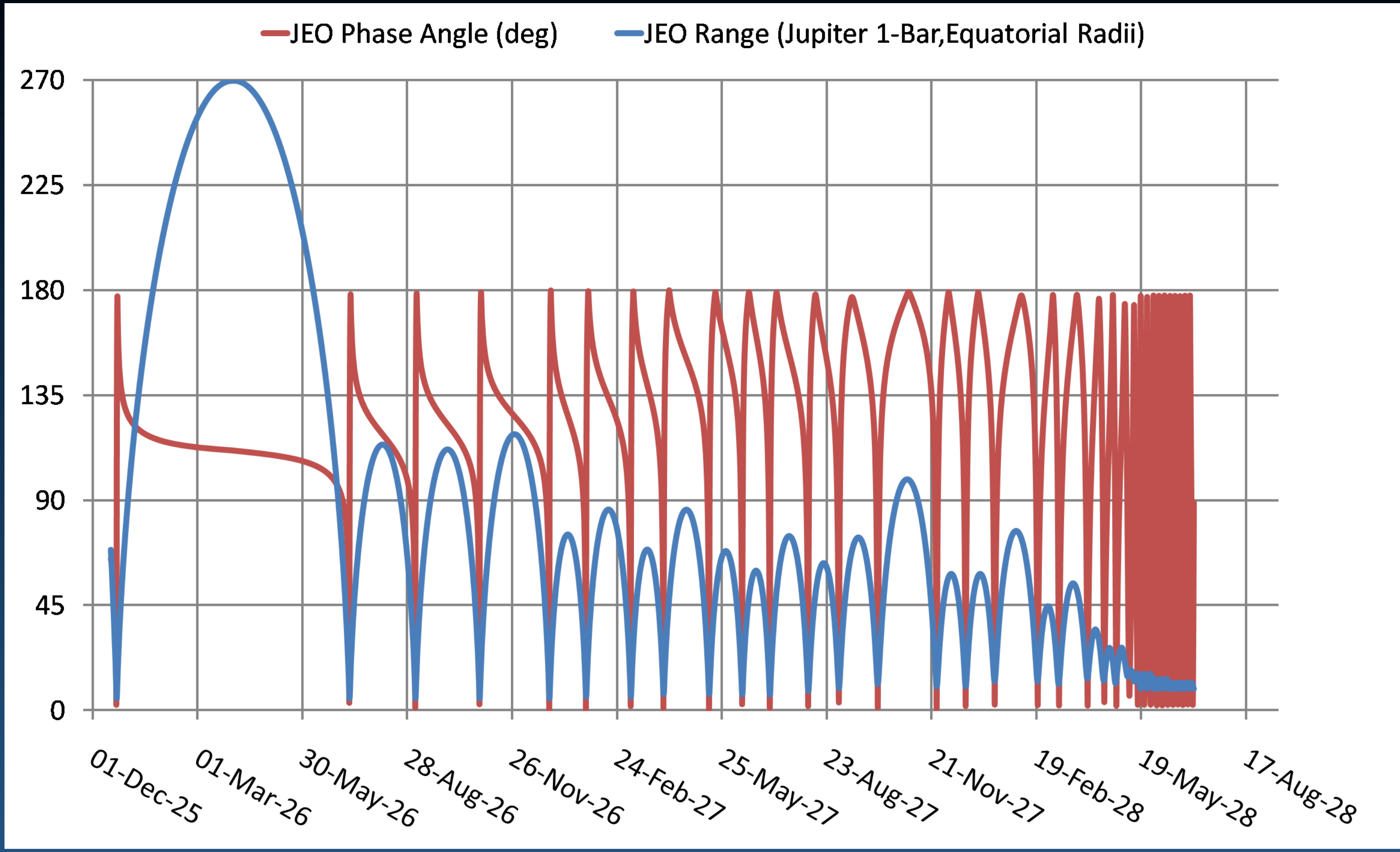
JEO/JGO Synergies

Only once before (Galileo & Cassini, 2000/2001) have two spacecraft visited Jupiter at once. The presence of JEO and JGO in orbit for ~2.5 years would provide a substantial opportunity for Jupiter science:

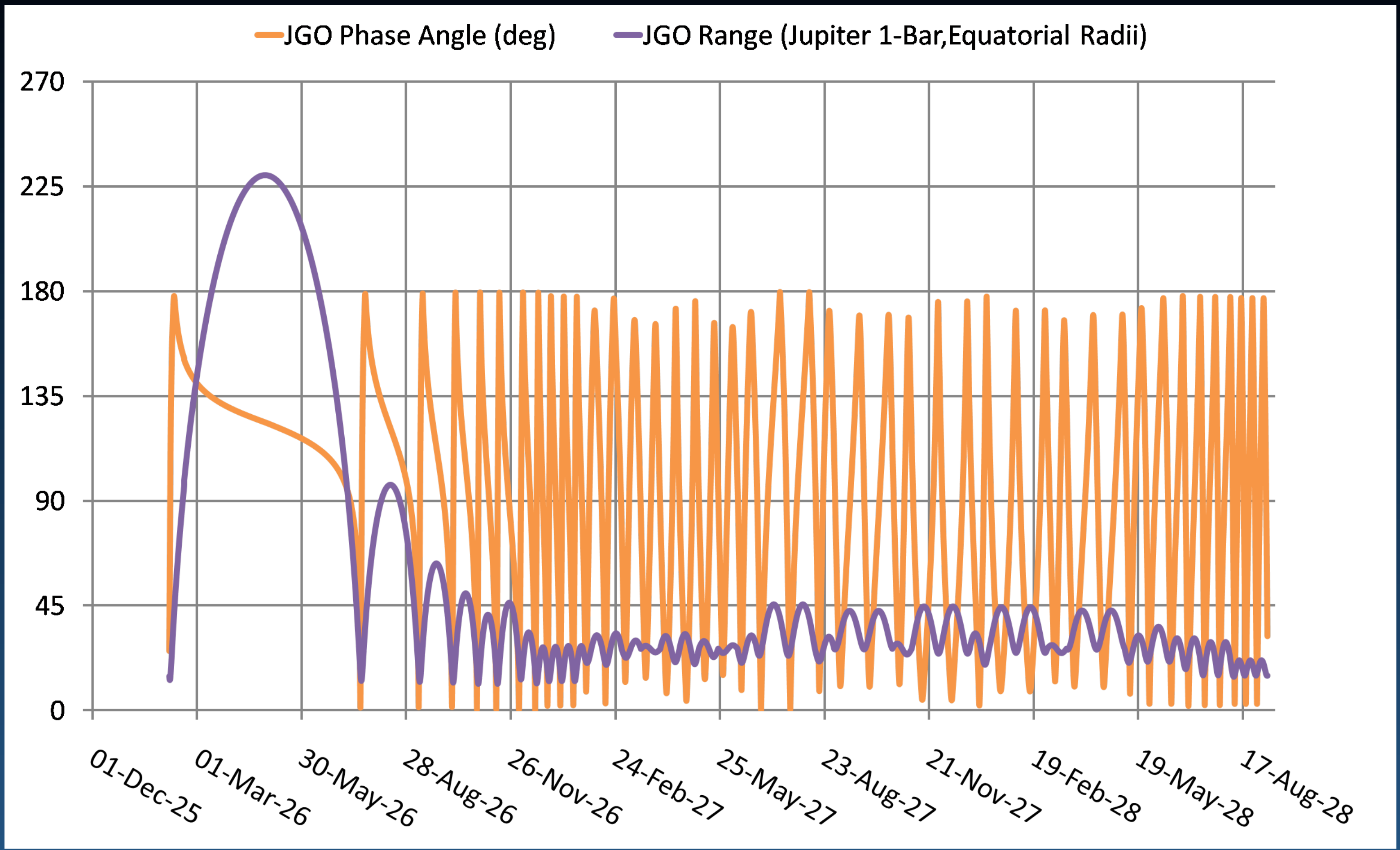
- Complementary instrumentation, some overlap, allows:
  - Dual views of Jupiter – narrow angle and contextual, ability to track same cloud features longer, simultaneous views from different emission angles (will improve cloud height retrievals)
  - Better sampling of the phase curves for aerosol scattering over the mission duration
  - Spacecraft-to-spacecraft occultations: probe deeper and with higher signal to noise
  - Observe discrete events (solar-magnetosphere interaction, lightning, etc) from two locations in the Jupiter system

JEO and JGO would provide a unique synergistic study of the Jovian atmosphere.

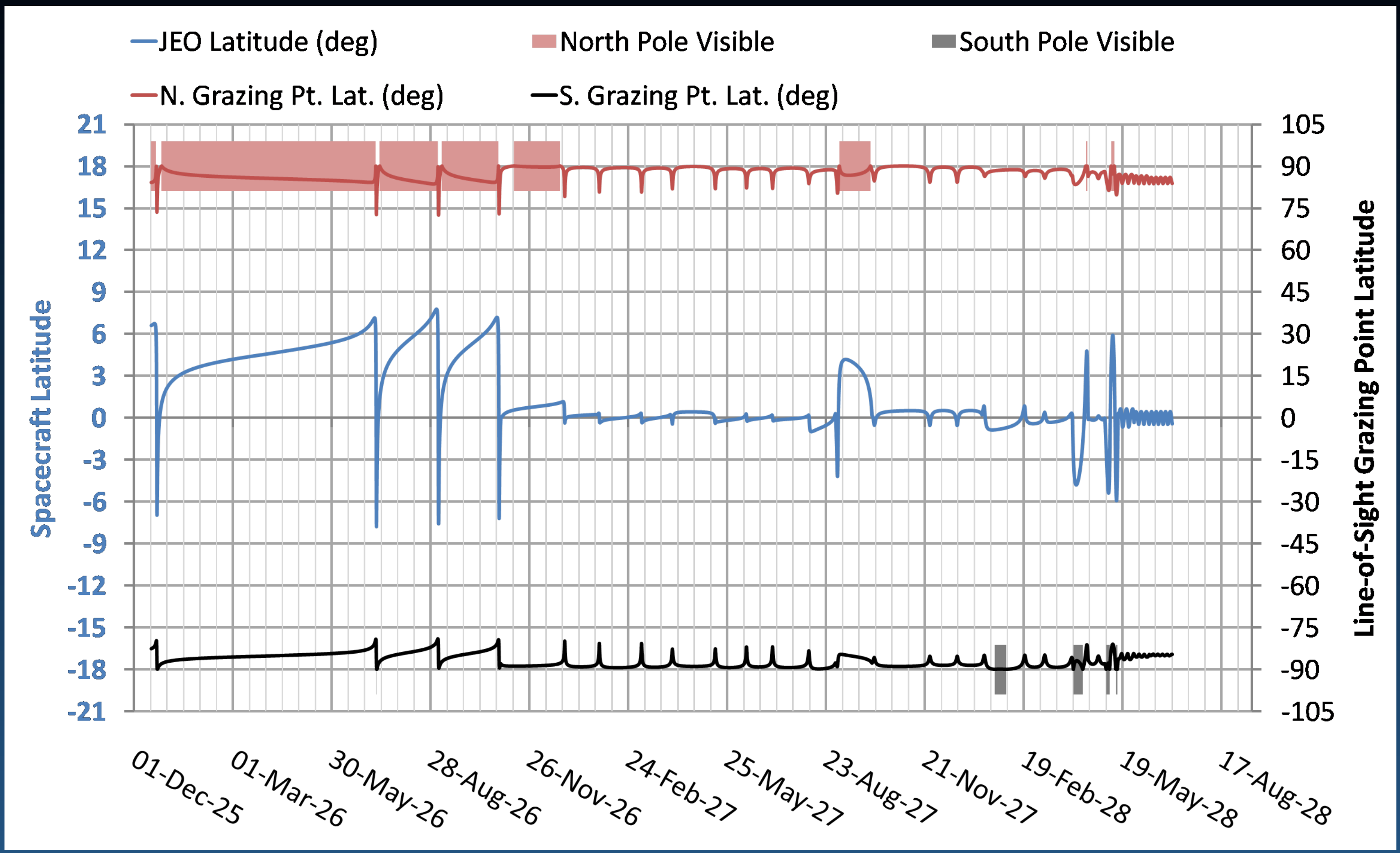
JEO Jupiter Range and Phase Angle



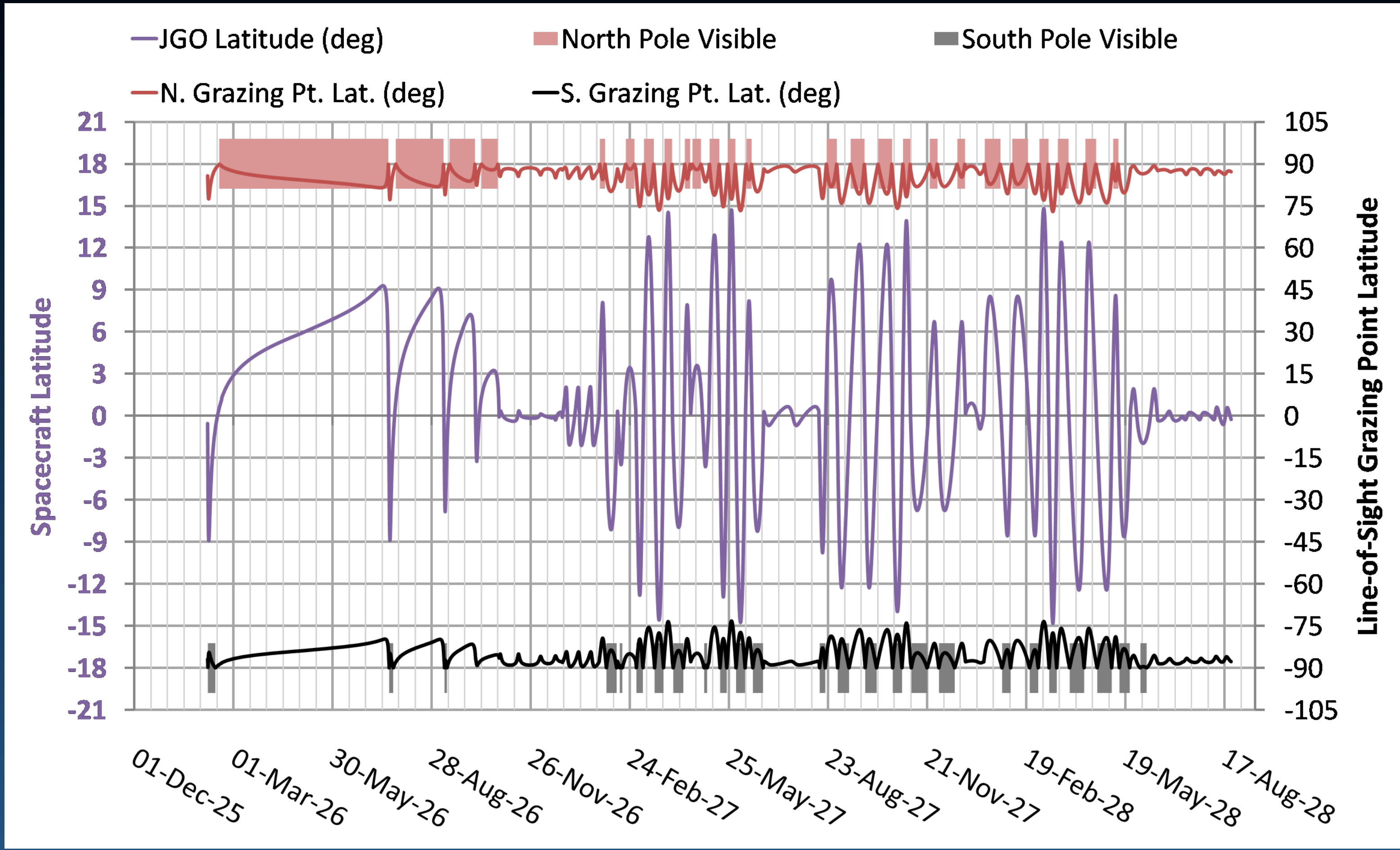
JGO Jupiter Range and Phase Angle



JEO Latitude & Pole Visibility



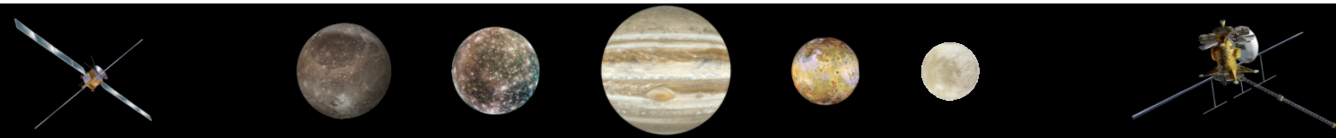
JGO Latitude & Pole Visibility



Mission Summary

- EJSM's key advantages:
  - Long baseline for regular temporal monitoring observations across a wide spectral range (70 nm - 200 μm).
  - Dual spacecraft views, for complementary and synergistic science
  - Data volume capability for global 3D mapping, at quasi-regular intervals, of dynamics, structure and composition, from the upper troposphere to the ionosphere and thermosphere.
  - Addresses unanswered questions, and complements Juno.
- EJSM would not probe below the cloud tops to:
  - Repeat Juno-style investigations of the deep atmosphere; or
  - Repeat bulk compositional measurements of Galileo.

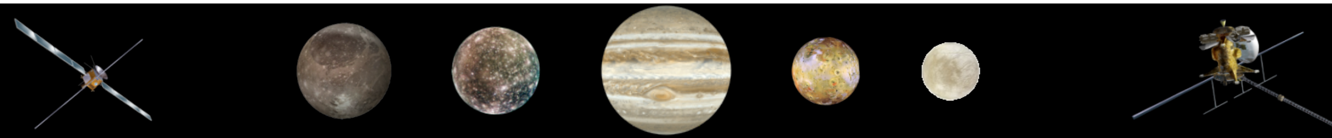
EJSM would provide significant Jupiter science



Science Advances and Big Picture

- What can be done that is not just "incremental" science?
  - New questions have emerged, advances in instrumentation, long time-base of observations, dual spacecraft

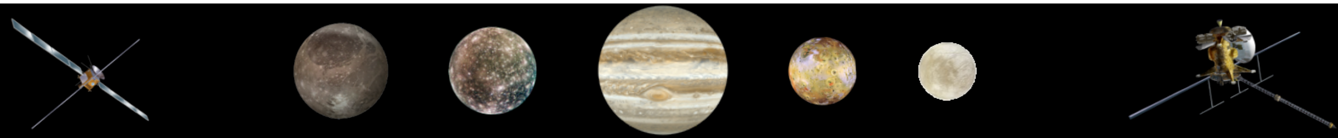
  - Polar processes
    - Vortices and polar jets, auroral connection with chemistry and aerosol production, UV "great dark spot"
  - QQO and wave-induced dynamics
    - Study of Kelvin, Rossby and gravity-inertia waves at multiple altitudes, including phase speed, direction, etc.
  - Potential vorticity mapping
    - 3 and 4D wind velocity fields from multi-color, long, movies
  - Cloud vertical structure and evolution
    - Dual spacecraft simultaneous "stereo" views, tracking water convection and ammonia ice, coupling to deep atmosphere
  - Paradigm for exoplanets



Three Science Objectives

- Condensed from eight more specific areas into:
  - Atmospheric Dynamics and Circulation
  - Atmospheric Composition and Chemistry
  - Atmospheric Vertical Structure
- Each contains a number of investigations and example measurements
  - Meant to encompass a large array of science
- Cross-disciplinary in nature, meant to be combined to address the big picture science questions

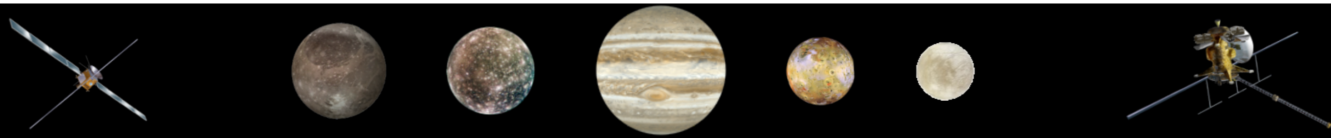
EJSM would provide significant Jupiter science



Atmospheric Dynamics and Circulation

- Investigate the dynamics of Jupiter's weather layer; zonal and meridional wind speeds, eddy momentum fluxes, redistribution of energy and momentum
- Determine the thermodynamics of atmospheric phenomena; global three-dimensional temperature structure and horizontal gradients, temperatures within discrete atmospheric features
- Quantify the roles of wave propagation and atmospheric coupling; depth of the zonal wind field, coupling of the jet stream pattern with convection within the deep interior; coupling between the troposphere and the middle-atmosphere by vertical wave propagation and eddies, horizontal distribution and temporal evolution of wave phenomena, particularly the QQO
- Investigate auroral structure and energy transport; three-dimensional morphology including internal structure and satellite footprints, mechanisms for energy transport within the Jovian aurora
- Understand the interrelationships of the ionosphere and thermosphere; vertically propagating waves and heating mechanisms (the “energy crisis”), wave characteristics and persistence, temporal variability of ionospheric total electron densities and ionization processes, upper atmospheric circulation.

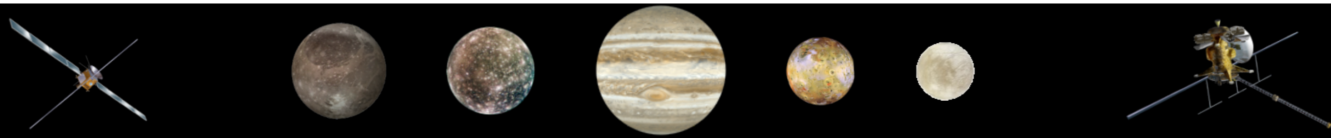
Understand dynamical processes and effects



Atmospheric Composition and Chemistry

- Determine the bulk elemental abundances; elemental enrichments in He, C, N, S, P, As and Ge; isotopic ratios (D/H, C, N, O)
- Measure the three-dimensional distribution of stratospheric hydrocarbons and their long-term variability; relation to photochemistry and haze production, distribution of water and other minor species of exogenic origin, response to seasonal insolation over short-term and decadal timescales (by comparison to Voyager, Galileo and Cassini results), non-thermal loss mechanisms at high altitudes.
- Study localized and non-equilibrium composition; composition and evolution within discrete atmospheric features (plumes, vortices, storms), three-dimensional distribution of disequilibrium species in the upper troposphere
- Understand the importance of moist convection in meteorology, cloud formation, and chemistry; global distribution of water vapor humidity and gaseous ammonia, vertical distribution of radio/microwave opacity sources (NH3, H2S and H2O), spatial distribution and power of lightning in the troposphere.

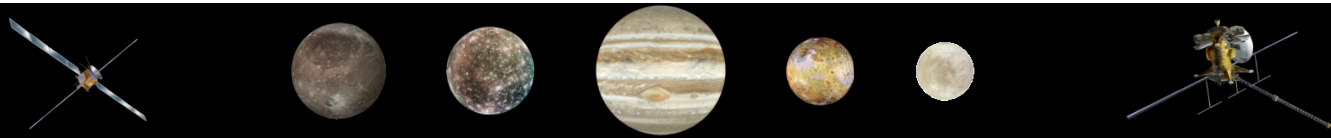
Measure composition and properties



Atmospheric Vertical Structure

- Determine the three-dimensional structure of Jupiter's upper troposphere and stratosphere; global properties of Jupiter's clouds, hazes and aerosols, vertical structure within discrete atmospheric features, temporal evolution and response to global and local events
- Explore atmospheric structure deep below the clouds; oscillation modes as diagnostic of wave propagation within the bulk of the atmosphere, phase transitions of molecular and metallic hydrogen within the deep interior
- Study coupling across atmospheric layers. Overlaps Dynamics Objective

Investigate how interior interacts with weather layer



Conclusions I

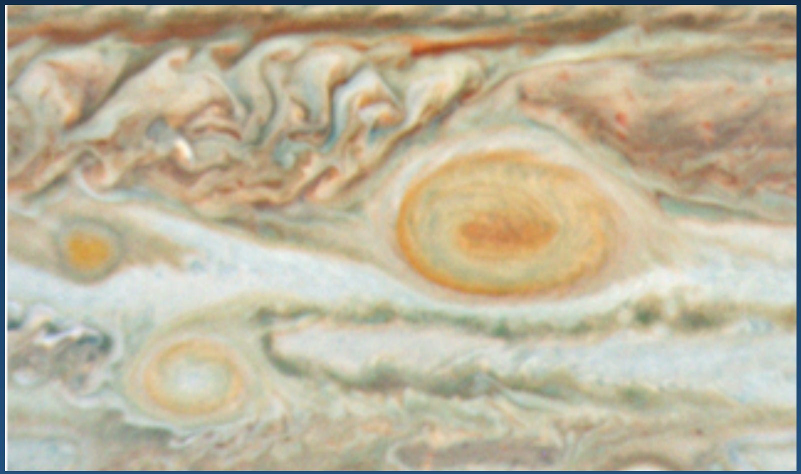
- EJSM would offer considerable potential for Jupiter science even with a satellite-focused payload.
- A long baseline of high resolution observations would allow us to construct a Jupiter 'climate database' to inform detailed physiochemical models of the atmosphere and the coupling processes between different layers.
- Three overarching Jupiter science objectives
  - Subdivided into multiple individual investigations;
  - Science investigations would complement the results of Juno and meet the objectives of the last Decadal

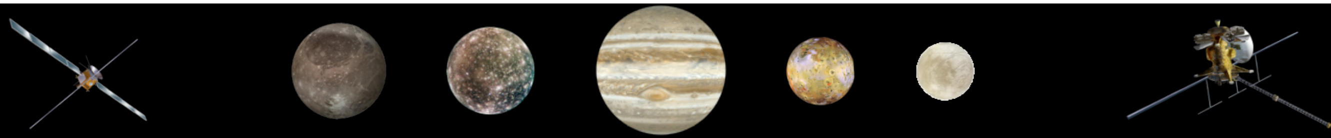
Atmospheres Objectives:

A. Dynamics and Circulation

B. Composition and Chemistry

C. Vertical Structure



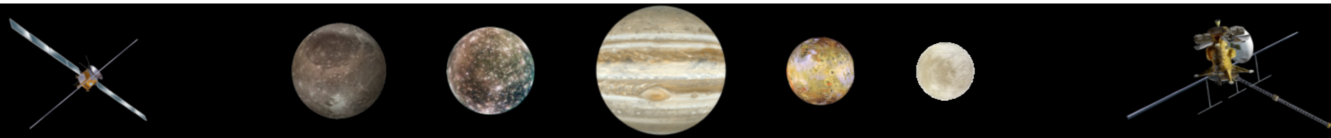


Conclusions II

- Key EJSM advantage: 2.5-3.0 years of regular Jupiter monitoring with high spatial resolution to study a plethora of atmospheric processes across a broad range of wavelengths (70 nm - 200 μm).
- Jupiter science would significantly benefit from a comprehensive program of ground-based support from enhanced 8-m class observatories.
- Working group has identified Jupiter-specific measurements:
  - Spectral/spatial resolutions; viewing geometries and lighting conditions; temporal ranges, in addition to instrumentation not presently in the model payload.
- Aim: *Give potential proposers the scope to address key Jupiter science questions, in addition to satellite-focused science, to truly advance our knowledge of the Jovian atmosphere.*

Jupiter science is a vital element of EJSM, and has the potential to significantly advance our understanding of the archetypical gas giant.

Supplemental Material



Relation to Galileo 1995-2003

The science goals of the Galileo Probe were to:

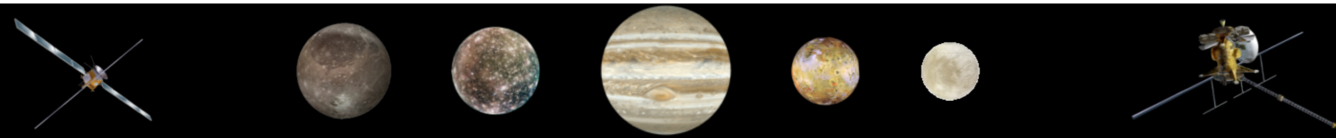
- determine the chemical composition of the Jovian atmosphere;
- characterize the structure of the atmosphere to a depth of at least 10 bars;
- investigate the nature of cloud particles and the location and structure of cloud layers;
- examine the Jovian radiative heat balance;
- study the nature of Jovian lightning activity; and,
- measure the flux of energetic charged particles down to the top of the atmosphere.

The objectives of the Galileo Orbiter were to:

- investigate the circulation and dynamics of the Jovian atmosphere;
- investigate the upper Jovian atmosphere and ionosphere;
- study the interaction of the Jovian magnetosphere with the Galilean satellites; and,
- characterize the vector magnetic field and the energy spectra, composition, and angular distribution of energetic particles and plasma to a distance of 150 Rj.

- Orbiter obtained discrete snapshots (thermal/VNIR/UV) of small regions, but lacked the spatiotemporal coverage of EJSM.

EJSM provides an opportunity to solve the mysteries left over from Galileo.



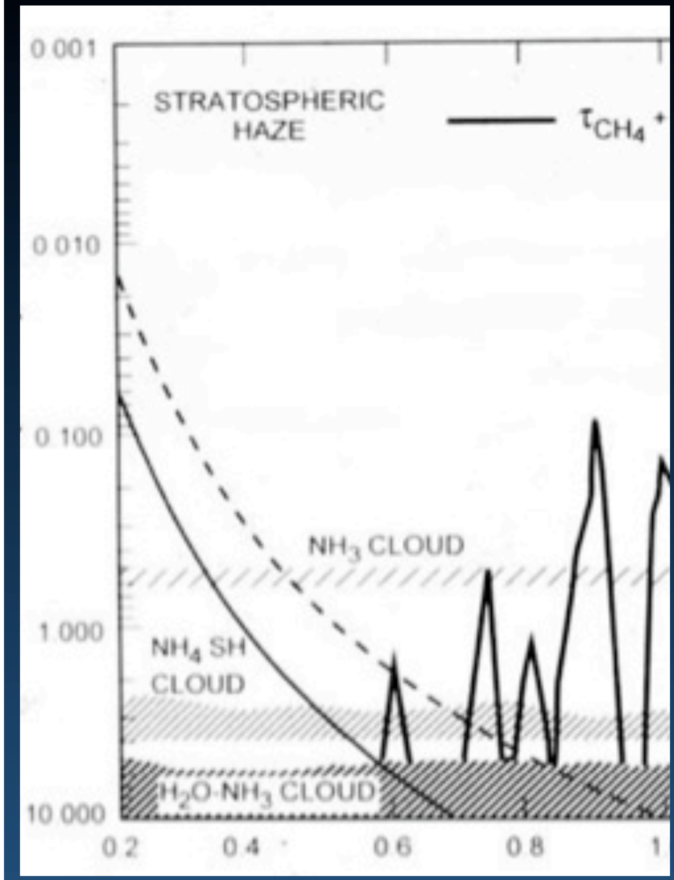
Relation to Juno Objectives

The Juno spacecraft's suite of seven science instruments will:

- **Origins:** Determine the ratio of oxygen to hydrogen, giving an idea of the abundance of water on Jupiter; Obtain a better estimate of Jupiter's core mass, which will help distinguish among prevailing theories linking the gas giant's formation to the solar system.
- **Interior:** Precisely map Jupiter's gravitational and magnetic fields to assess the distribution of mass in Jupiter's interior, including properties of the planet's structure and dynamics.
- **Atmosphere:** Map the variation in atmospheric composition, temperature structure, cloud opacity and dynamics to depths far greater than 100 bars at all latitudes (In 1995, the Galileo probe reached only ~ 22 bars at a single location).
- **Magnetosphere:** Characterize and explore the three dimensional structure of Jupiter's polar magnetosphere and its auroras.

EJSM would complement Juno's goals by investigating the atmosphere above the clouds tops.

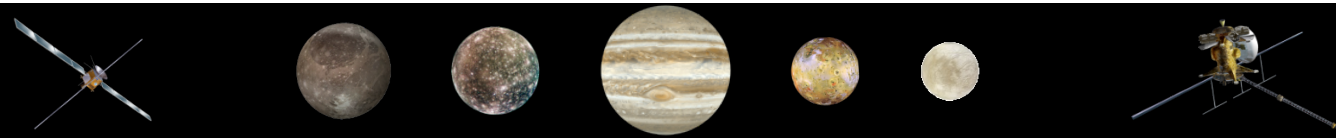
EJSM Instrument Priorities



Augmentations (or maintain capability):

- Camera filters (NAC):
  - Require: filters that sample along the 892-nm strong methane band, color, etc. Minimum set: Cassini ISS, changes to sample along 892-nm band.
- Vis/Near IR spectral coverage (0.4 to 5.2 μm)
  - Ensure full spectral range is maintained
  - Minimum spectral resolution to resolve ammonia ice features near 1.99 and 3 microns (5 to 10-nm OK). Higher spatial res
- UV
  - Hi Spatial Res, extended spectral coverage
- Thermal Imager
  - Augment or replace with spectrometer

EJSM strawman payload can achieve much science with simple augmentation.



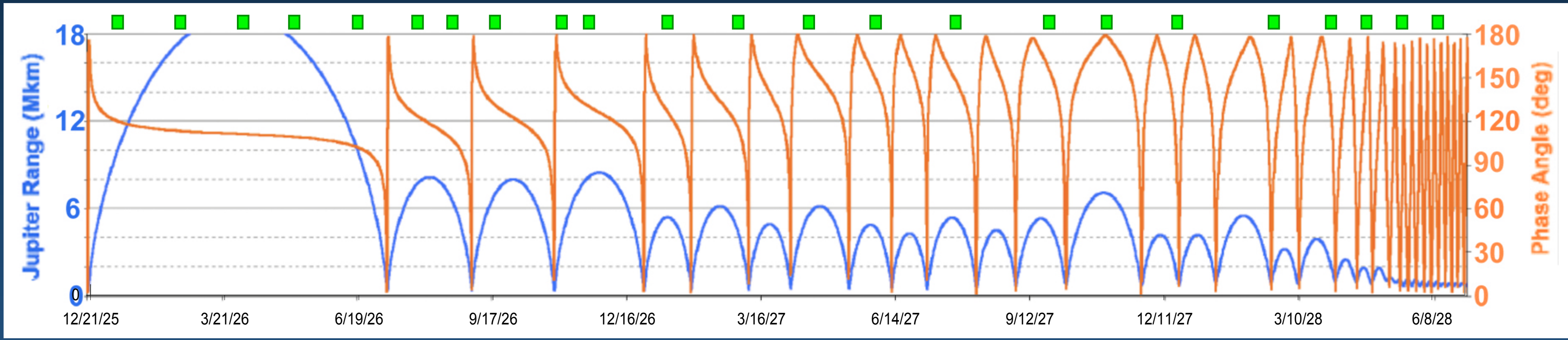
EJSM Instrument Priorities

NEW INSTRUMENTS (Dependent on Resource availability)

- Mid to far-IR Spectrometer (could replace thermal imager?)
  - Spectral coverage from 5-500 micron at 0.5 cm^{-1} or better (Troposphere and stratosphere temperatures and composition).
  - Adjustable resolution, if high-res is not desired for satellites
  - Examples: Cassini CIRS, LRO Diviner, etc.
- Sub-mm spectrometer (on JEO)
  - 500-1000 micron range (vertical winds, NH_3, PH_3, CH_4, isotopologues, and a multitude of trace species), resolution depends on species
  - Also depends on what JGO includes
  - Examples: Rosetta MIRO, Herschel HIFI, etc.
- Re-instate Thermal Imager on JGO (STRONGLY SUPPORT THIS)
  - Included channels specific to atmospheric temperature sounding
    - 4D thermal and dynamical structure of the atmosphere
    - Lack of TI puts extra constraints on needed joint observations
  - At least allow by keeping science objectives in AO

Perijove Observations

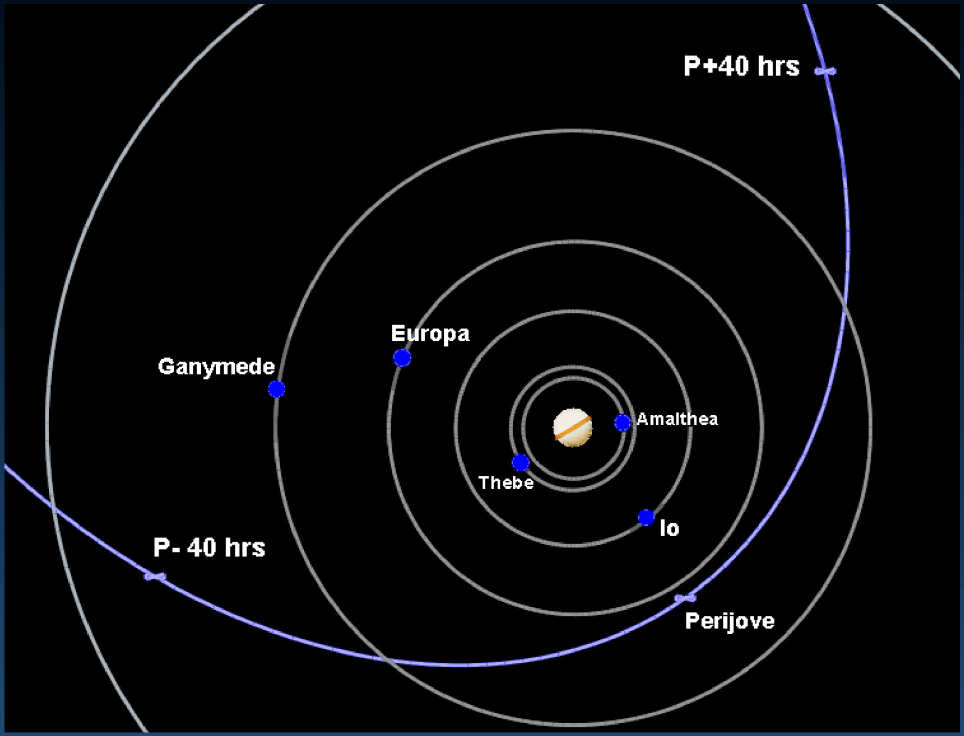
- JEO would feature multiple perijove opportunities in this example JEO Jovian tour:
  - 33 perijoves during Jovian tour, 10 with no satellite flybys, 22 permit X/Ka band occultations JEO-Earth
  - Good lighting and JEO-Jupiter range during perijove enables:
    - Comprehensive remote sensing observations
    - Dynamical studies over hourly/weekly/monthly timescales



Several opportunities devoted exclusively to Jupiter science.

Jupiter Science: Data Volume

- JEO features 16 Gb "hybrid" SSR
- ~3 days within 1.5 Mkm per perijove, with ~25 Gb collected
- 100s of NAC images plus contextual remote sensing every day
- ~3.2 Tb available throughout 2.5 yr Jovian tour
- ~1000x Galileo data return from JEO alone.

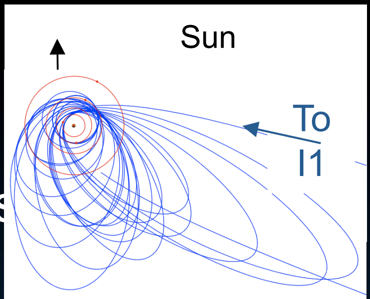


EJSM would provide higher data rates/volume for Jupiter science than any previous mission.

Longer Observations of Jupiter's Day Side

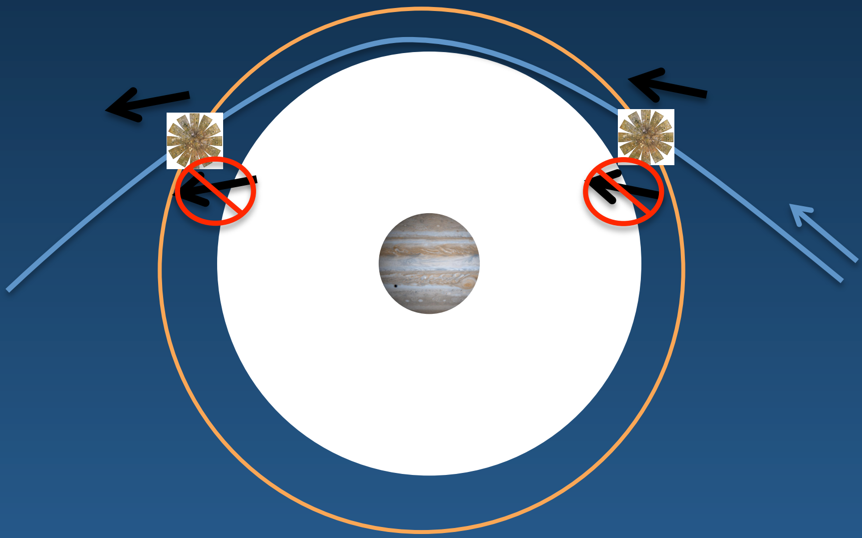
Tour T08-008:

- Cumulative time spent on day-side: ~10% (3
- Longest continuous view of day-side: ~6.5 days



How can we rotate the tour petals to put apoapses on or near the Jupiter day-side?

Constrain the flybys and Expend some ΔV



- target flybys specifically for turning the line of apsides

Possible Ramifications on Tour Design

- Tour would likely grow in duration (~months) and radiation exposure:
  - Satellite phasing becomes more complicated
    - Half of the flyby types are excluded for apsidal rotation purposes
    - Phasing orbits will likely be needed
  - Excluded flyby types reduce the variety of encounter geometry options (longitude and lighting)
  - Additional flybys might be added to achieve the desired the apsidal rotation, than would otherwise be needed

Eight Objectives for EJSM Jupiter Science

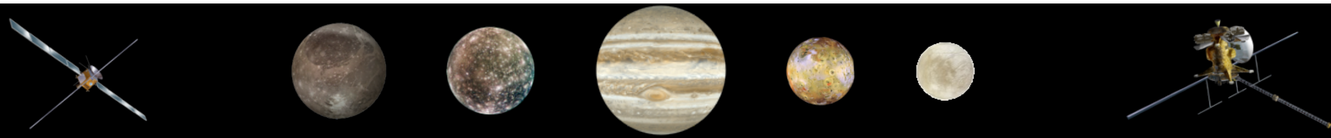
- Jupiter Working Group defined and prioritized Objectives:

A. Dynamics and Circulation of the Troposphere and Stratosphere
B. Tropospheric Chemistry and Composition
C. Clouds, Aerosols and Hazes in the Troposphere and Stratosphere
D. Wave Motion, Eddies and Vertical Coupling
E. Stratospheric Composition and Photochemistry
F. Circulation and Composition of the Upper Atmosphere/Aurora

G. Bulk Composition of Jupiter and Formation Mechanisms
H. Internal Structure of Jupiter

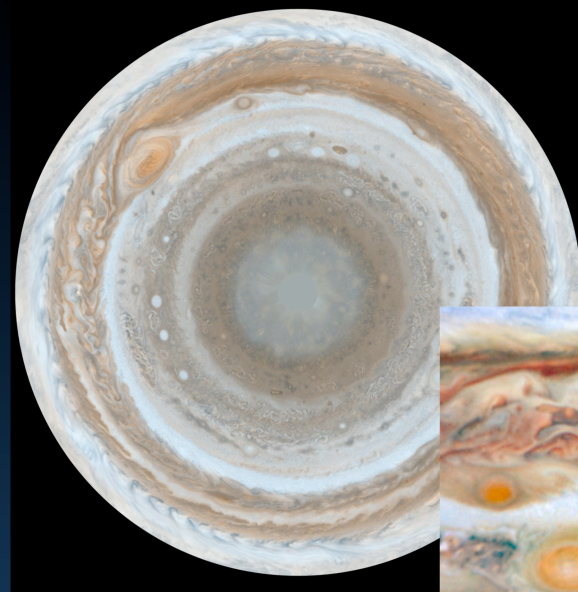
- Top six have similar priorities.
- Last two will be addressed by Juno, so are given lower priority.

Updated Jupiter science investigations fall into eight themes.



A: Dynamics and Circulation

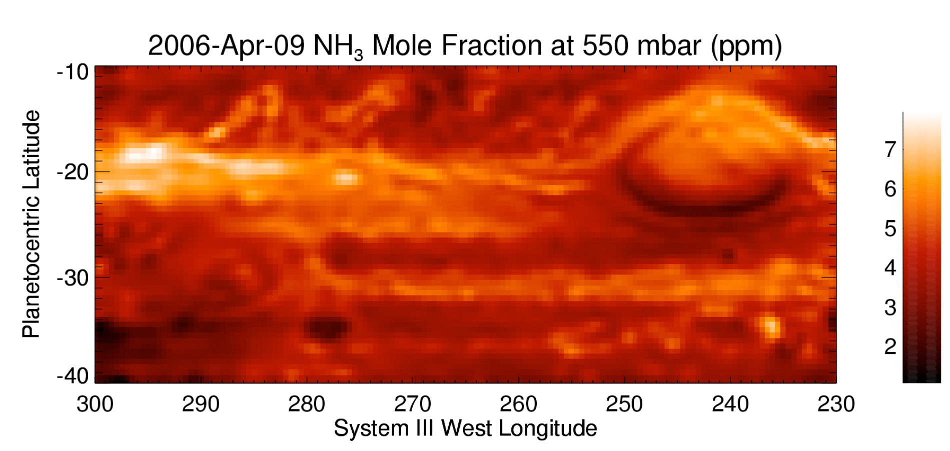
- 3D structure of Jupiter's upper troposphere and stratosphere.
- Relation between the weather layer and convective overturning in the planet's interior.
- Temporally-evolving atmospheric phenomena (upheavals, plumes, storms and vortices) over a variety of timescales (hours to years).
- Strength of vertical coupling in the atmosphere down to the troposphere.
- Example Measurements:
  - Atmospheric winds, redistribution of energy and momentum (NAC, NIR, sub-mm).
  - Thermal structure, wind shear, potential vorticity (thermal mapping, radio science).
  - Distribution of lightning activity.
  - Compositional variations/asymmetries associated with dynamic activity (Vis, NIR, sub-mm).



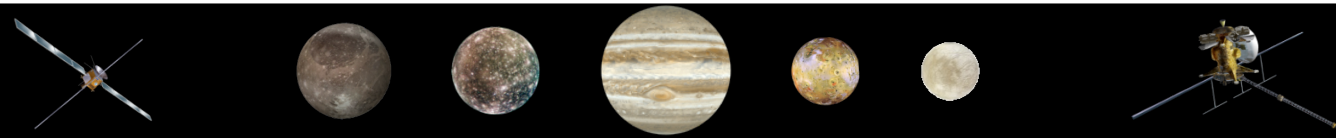
- Excellent temporal coverage (frequent, 2-yr baseline) prior to arrival in satellite orbits.
- NAC filters chosen to provide altitude-sounding in visible range.
- Infrared spatial resolutions presently insufficient.

B: Tropospheric Chemistry and Composition

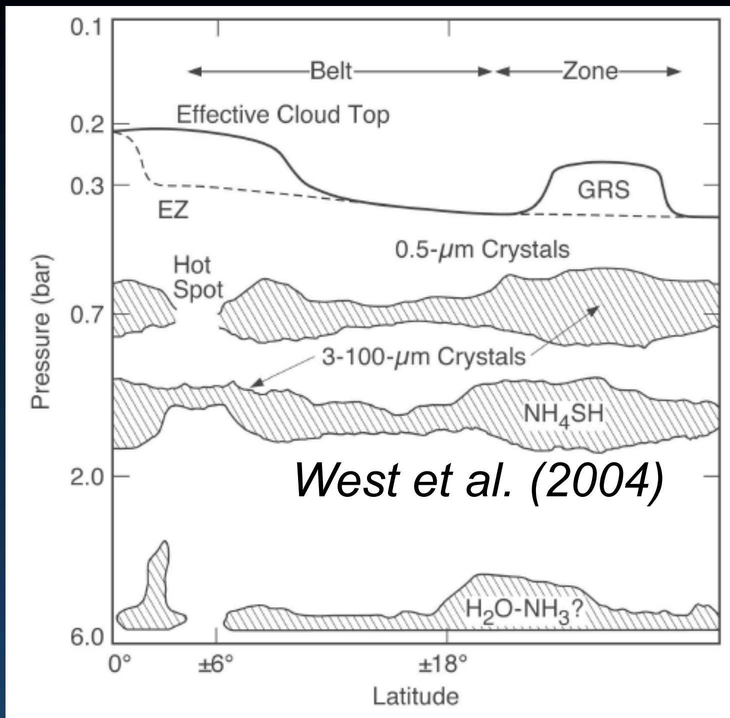
- Global spatial distribution of volatiles (particularly NH_3 and H_2O humidity) and relation to circulation and cloud condensation.
- Determine the importance of moist convection in determining the vertical atmospheric structure.
- Distribution of disequilibrium species as quasi-conservative tracers of motion and to study thermochemical and photochemical processes in the troposphere.
- Example Measurements:
  – IR/UV determination of H_2O, NH_3, PH_3, CO, AsH_3, GeH_4 in 1-5 bar region; far-IR measurement of ortho/para-H_2 distribution; distribution of radio-wave opacity sources (1 bar); lightning activity (related to moist convection).
- Complements Juno/MWR investigation of spatial distribution of microwave opacity sources (NH_3, H_2O, 1-100 bar level).
- Surpasses Galileo/NIMS spatiotemporal coverage, but requires enhanced spectral resolution over model payload.



VLT/VISIR NH_3 Distribution (Fletcher et al., 2009)



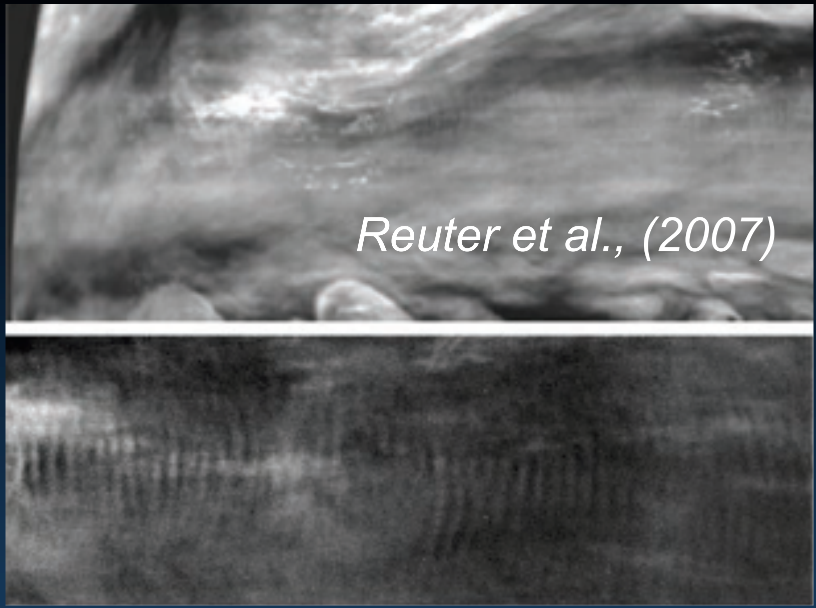
C: Clouds, Aerosols and Hazes



- Global properties of Jupiter's cloud, haze and aerosol inventory (belt/zone contrasts, equatorial upwelling, vortices), and the relation between clouds and tropospheric circulation.
- Haze production mechanisms (auroral chemistry, photochemistry).
- Color-changes coincident with thermophysical atmospheric changes (temperature, composition) during discrete events (e.g. upheavals).
- Example Measurements:
  - Spectroscopic characterization (UV, VIS, NIR) of composition, vertical structure, column abundance, albedo, particle sizes, topography of upper cloud layers. Occultation studies for haze-absorption on the limb.
  - Quasi-regular observations of localized storms, polar vortices, giant anticyclones, upheavals.
- Planned diverse orbital tour would permit multiple viewing geometries, phase angles, inclinations,etc.

D: Wave Motion, Eddies and Vertical Coupling

- Nature of wave propagation (horizontal and vertical) in neutral and charged atmosphere, and the extent of energy, momentum and material transport by wave motion (small-scale gravity waves, larger-scale Rossby waves, QQO).
- Coupling between different vertical regions of the atmosphere (troposphere, middle atmosphere, upper atmosphere) by waves and eddies.
- Example Measurements:
  – Quasi-regular imaging with a long baseline, multiple wavelengths, to determine temporal evolution of zonal waves. Vertical wave structure from sub-mm sounding, RSS profiles and thermal imaging.

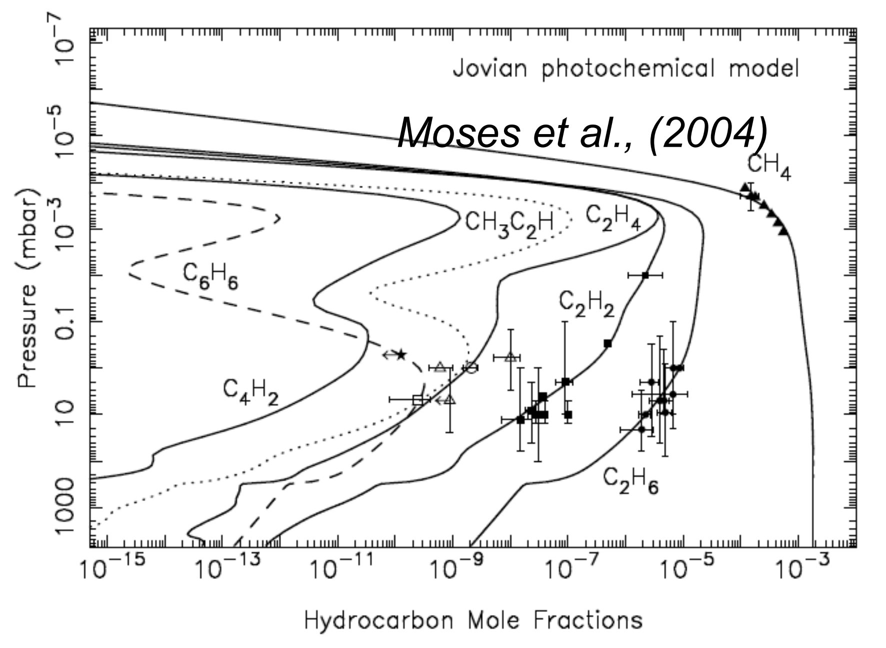


  – Wavelengths, direction, location and persistence of upper atmospheric waves and their influence on upper atmosphere heating.
- Limited thermal-IR resolution prevents limb sounding of vertical structure

E: Stratospheric Composition and Photochemistry

- Study unique chemistry of the stratosphere (hydrocarbon pathways, haze production, global circulation),
- Connections to the immediate interplanetary environment (magnetosphere, infalling exogenic materials, etc.)
- 3D structure and circulation of the stratosphere (temperatures, hydrocarbon distributions).
- Atmospheric response to seasonal variations; and the unique chemistry of the polar regions.
- Distribution of stratospheric H_2O and other O-compounds of external origin.
- Example Measurements:
  - Sub-mm sounding of trace species and vertical winds in the stratosphere; radio occultations to determine density profiles; thermal mapping to study wave activity, seasonal variability; UV spectroscopy for hydrocarbons.

- Absence of thermal spectroscopy in the model payload limits capabilities for hydrocarbon mapping,
- Higher UV and NIR spatial resolutions are required for occultation measurements.

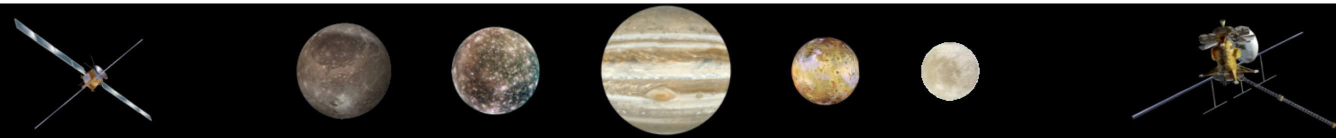


F: Circulation of Upper Atmosphere/Aurora

- Morphology and temporal variability of the Jovian aurora; mechanisms for energy, mass and momentum transport within the aurora.
- Understand the coupling to the dynamics of the magnetosphere and external influences (solar winds, breakdown of corotation, structure of Io plasma torus).
- Coupling between the neutral atmosphere and the charged particle environment; evidence for non-thermal loss mechanisms, particularly at polar latitudes.
- Variability of ionospheric electron density and ionization processes.
- Ionospheric and thermospheric circulation and winds, and the connection between upper atmospheric heating and vertical wave propagation.

NASA/ESA/J Clarke, Boston University

- Example measurements:
  - Electron density profiles and neutral temperatures from radio occultations; UV imaging of H_2 emission, IR imaging of H_3^+ emission, regular observations hourly-daily timescales.
- Low spatial resolutions in model UV/IR instruments may prevent limb studies/ occultations.

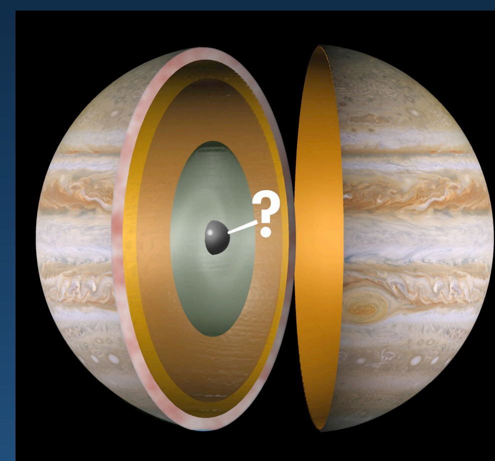


G: Bulk Composition

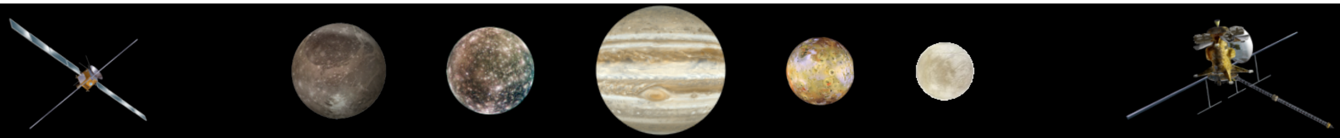
- Lower priority: spectroscopy to support (a) Galileo Probe results on bulk composition; and (b) Juno investigation of deep O/H, N/H. Determination of bulk elemental enrichments and isotope ratios serve as constraints on formation/evolution theories.
- Example Measurements:
  - Vertical NH_3 and H_2O distributions (near-IR); sub-mm determination of oxygen isotope ratios, HCN, CO abundances; near-IR measurement of D/H ratio in CH_4.
  - EJSM would provide better constraints on disequilibrium species (PH_3, AsH_3, GeH_4, etc.), provided a sufficient near-IR spectral resolution.

H: Internal Structure

- Lower priority: radial internal structure (density profile, composition, equation of state, existence of a core) of Jupiter requires gravity mapping (Juno) or determination of acoustic modes (Jovian 'seismology', potentially from JGO).
- This is a key investigation for Juno, so was not given high priority for EJSM, which would probe no deeper than the 1-5 bar region.



EJSM would complement Juno in these final 2 themes.



End