Jupiter Science and Capabilities on the Europa Jupiter System Mission

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A Joint NASA-ESA Outer Planet Mission Study
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; and
• Jupiter science is a vital element of the study of interactions between the components of this complex planetary system (Jupiter atmosphere, icy satellites, rings, magnetosphere and small bodies).
• This presentation includes:
  – Eight updated scientific themes for Jupiter science on EJSM.
  – Capabilities for the current JEO/JGO Mission Scenario.

Jupiter system science is an importance component of EJSM.
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).

- **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.

- **Continue to solicit input from the Outer Planet community (particularly OPAG):**
  - Prioritization of Jupiter science themes.
  - 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._
EJSM Model Payloads

- Model payloads (proof of concept) 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.

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

- Jupiter Working group prioritization of Jupiter science themes:
  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.
- Each theme is subdivided into investigations and instrument requirements.

*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 NH₃ and H₂O 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 H₂O, NH₃, PH₃, CO, AsH₃, GeH₄ in 1-5 bar region; far-IR measurement of ortho/para-H₂ 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 (NH₃, H₂O, 1-100 bar level).
- Surpasses Galileo/NIMS spatiotemporal coverage, but requires enhanced spectral resolution over model payload.

VLT/VISIR NH₃ Distribution (Fletcher et al., 2009)
C: Clouds, Aerosols and Hazes

- 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.

Global properties of Jupiter’s cloud, haze and aerosol inventory (belt/zone contrasts, equatorial upwelling, vortices), and the relation between clouds and tropospheric circulation.

West et al. (2004)
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

Reuter et al., (2007)
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 H₂O 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.

- 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$_2$O 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.

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*EJSM would complement Juno in these final 2 themes.*
Summary: Eight Themes

- **EJSM’s key advantages:**
  - Long baseline for regular temporal monitoring observations across a wide spectral range (70 nm - 40 μm).
  - Huge data volume 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.

- Recently completed a 20-page report on the sub-investigations for each theme, but still looking for community input for individual ‘niche’ topics.

_EJSM would provide significant Jupiter science_
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 for JEO before Europa Orbital Insertion
  - 26 months for JGO before Ganymede Orbital Insertion

- **End of Mission (from circular satellite orbits):**
  - Potential to re-observe Jupiter 3 years after arrival if science drivers are strong enough.

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*Jovian tour would provide multiple opportunities for Jupiter science.*
Jupiter Science: Spatial Resolution

- Best VIS/NIR resolution surpasses Voyager, Galileo, New Horizons
- Spatial resolutions (per pixel) from 9.5 \( R_J \):
  - Thermal Instrument: 1700 km
  - Wide-angle camera & UV spectrometer: 700 km
  - IR Spectrometer: 170 km
  - Medium-angle camera: 70 km
  - Narrow-angle camera: 7 km
- Standard spatial resolution would be \( \sim 2 \) 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.*
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**
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.
- **Eight Jupiter science themes**
  - Subdivided into multiple individual investigations;
  - Prioritized with regard for Juno expectations;
  - Community involvement to improve Jupiter science prior to AO for instrument development.
  - Science investigations would complement the results of Juno.

  A. Dynamics and Circulation
  B. Tropospheric Composition
  C. Clouds, Aerosols and Hazes
  D. Wave Motion & Vertical Coupling
  E. Stratospheric Composition
  F. Upper Atmosphere/Aurora
  G. Bulk Composition
  H. Internal 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 - 40 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
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.
Jupiter Science from two Spacecraft

- Only once before (Galileo & Cassini) 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:
  1. Both **narrow-angle and contextual imaging** acquired simultaneously.
  2. Simultaneous **multi-angle, multi-wavelength** imaging of discrete features.
  3. **Better sampling of the phase curves** for aerosol scattering over the mission duration.
  4. **Complementary wavelength coverage** e.g. simultaneous near-IR and sub-mm characterization of a feature from JEO and JGO.
  5. Increased number of **occultation opportunities**, possibly S/C to S/C occultations.
  6. More **scope for unique instrumentation** (e.g. sub-mm) by having two platforms at Jupiter at once.

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