Europa Jupiter System Mission

Presentation to the Outer Planet Assessment Group

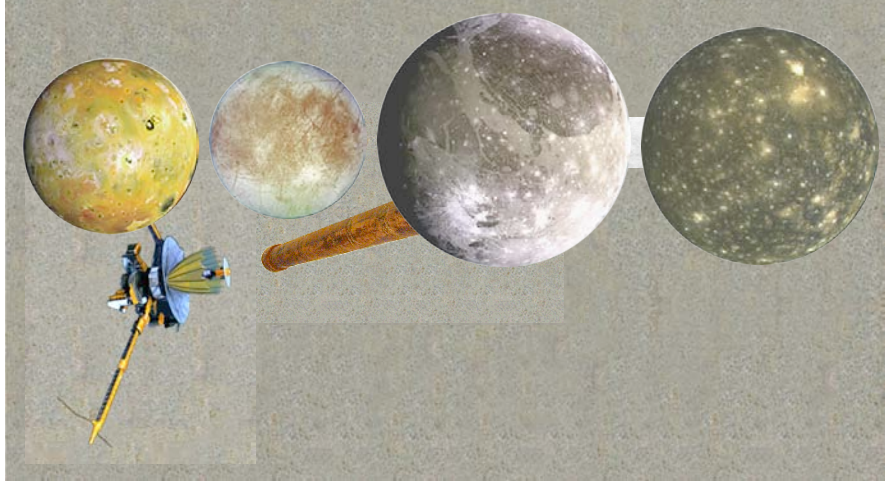
November 6, 2008

Europa Jupiter System Mission

• Introduction	Ron Greeley
• JEO Science	Bob Pappalardo
• JEO Mission	Karla Clark
• JGO Science	Michel Blanc
• JGO Mission	Anamarija Stankov
• Synergies and Wrap-up	Michele Dougherty

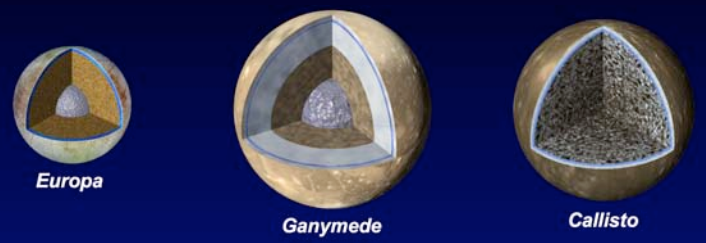
THE EUROPA JUPITER SYSTEM MISSION

Theme: The emergence of habitable worlds around gas giants

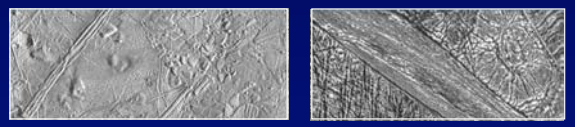


ASTROBIOLOGY FACTORS

1. Abundant liquid water

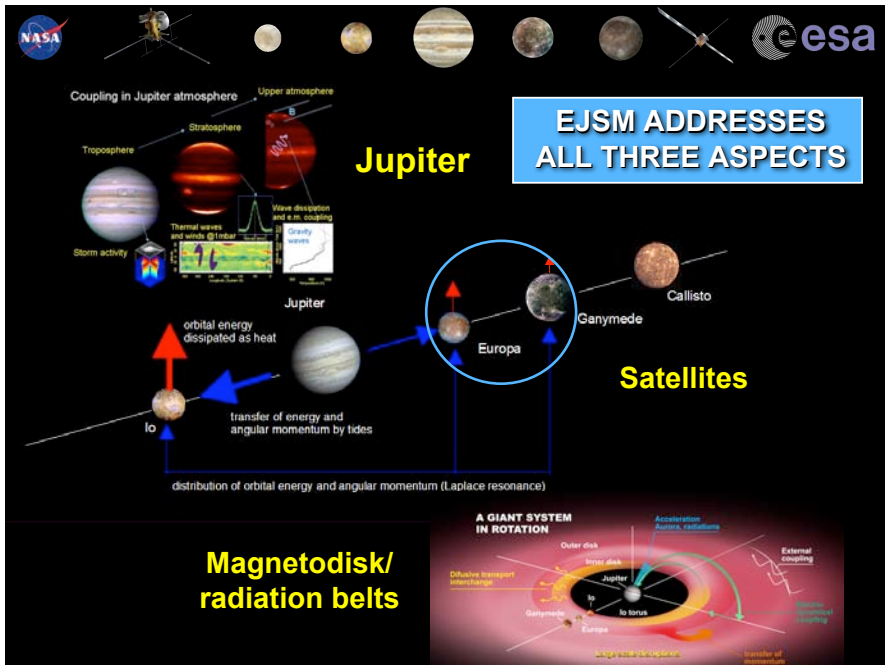


2. Organics, salts, oxidants, young surfaces



3. Energy Sources: Tidal and Radioactive Decay

The Jupiter System = "The Right Stuff"



Jupiter

EJSM ADDRESSES ALL THREE ASPECTS

Satellites

Magnetodisk/ radiation belts

EUROPA JUPITER SYSTEM MISSION

NASA Jupiter Europa Orbiter + ESA Jupiter Ganymede Orbiter

- EJSM Study
  - International Team
  - Built on previous studies
  - Community involvement
- Scientifically-rich
- Well-defined, mature science
- Exploration opportunities
- Technology/mission design mature

EJSM is ready to go!

Science of the Jupiter Europa Orbiter

Bob Pappalardo

Jet Propulsion Laboratory,
California Institute of Technology

November 6, 2008

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Goal: Explore Europa to Investigate Its Habitability

Objectives:

- Ocean & Interior
- Ice Shell
- Chemistry & Composition
- Geology
- Jupiter System
  - Satellite surfaces & interiors
  - Satellite atmospheres
  - Plasma & magnetospheres
  - Jupiter atmosphere
  - Rings

Europa is the archetype of icy worlds habitability

JEO Model Payload

Interdisciplinary Science, including Astrobiology		
	Ocean Team	
	Laser Altimeter	LA
	Radio Science	RS
	Ice Team	
	Ice Penetrating Radar	IPR
	Chemistry Team	
	Vis-IR Imaging Spectrometer	VIRIS
	UV Spectrometer	UVS
	Ion and Neutral Mass Spectrometer	INMS
	Geology Team	
	Thermal Instrument	TI
	Narrow Angle Camera	NAC
	Wide Angle Camera and Medium Angle Camera	WAC + MAC
	Fields and Particles Team	
	Magnetometer	MAG
	Particle and Plasma Instrument	PPI

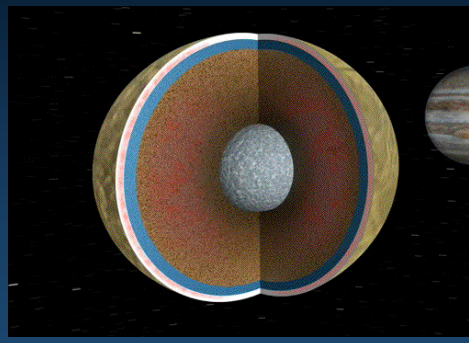
- 11 instruments (including radio sci.)
- Emphasizes Europa investigations
- Robust Jupiter system science
- Low cost, efficient teaming approach

Proven technology that does the job

Europa: Ocean • Ice • Chemistry • Geology

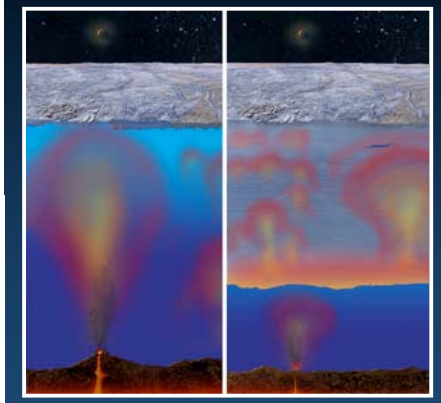
Ocean & deeper interior:

- Gravitational tides
- Magnetic environment (including plasma)
- Surface motion
- Dynamical rotation state
- Core, rocky mantle, & rock-ocean interface



Geophysical techniques give clear answers

Europa: Ocean • Ice • Chemistry • Geology

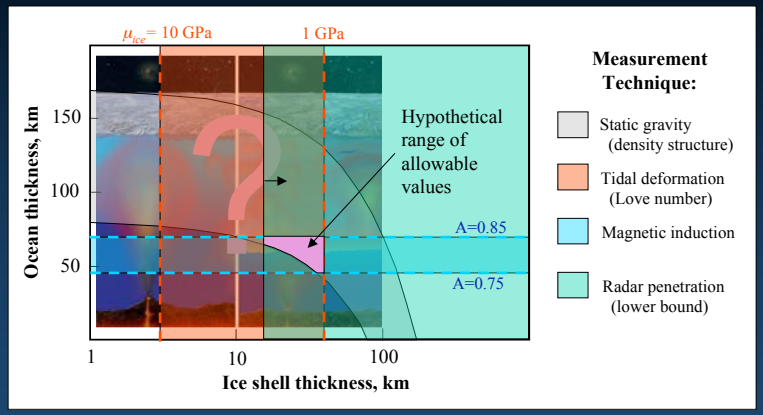


Ice shell & subsurface water:

- Shallow water
- Ice-ocean interface
- Material exchange
- Heat flow variations

Radar sounding will characterize the ice shell

Constraining Ice Shell Thickness:
Hypothetical Example



Multiple techniques constrain ice shell thickness

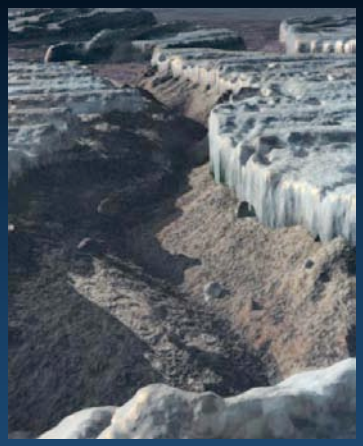
Europa: Ocean • Ice • Chemistry • Geology

Global surface composition & chemistry:

- Organic & inorganic chemistry
- Relation to geologic processes
- Radiation effects
- Exogenic materials

Composition is key to understanding Europa's habitability

Europa: Ocean • Ice • Chemistry • Geology

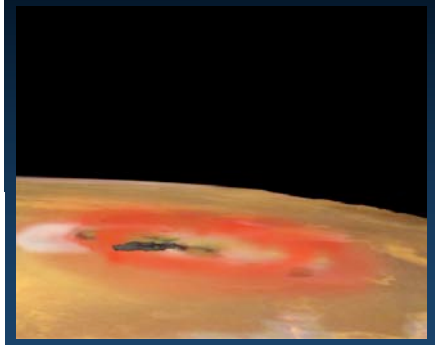


Surface features, activity, & landing sites:

- Formation history & 3-D characteristics
- Recent activity & future landing sites
- Erosion & deposition

Europa's varied and complex geology will be deciphered

♃ System: Geo • Atm • Mag • Jupiter • Rings



Satellite surfaces & interiors:

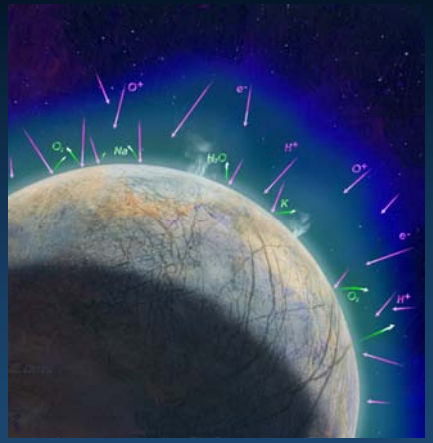
- Tidal heating & heat loss
- Io's active volcanism
- Water in Ganymede & Callisto
- Ganymede & Callisto surface materials
- Internal evolution &

The Galilean satellites provide context for Europa

♃ System: Geo • Atm • Mag • Jupiter • Rings

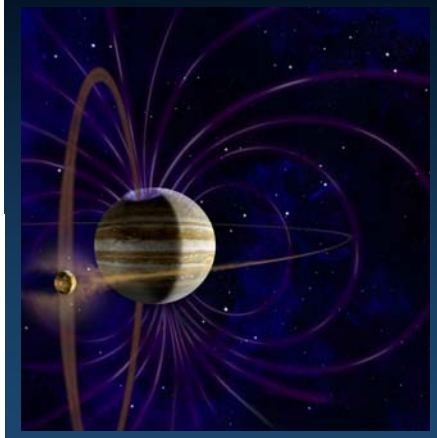
Satellite atmospheres:

- Europa: composition, variability, dynamics
- Io: sources & evolution
- Ganymede & Callisto: sources & sinks



Understanding atmospheric interactions and processes

♃ System: Geo • Atm • Mag • Jupiter • Rings



Plasma & magnetospheres:

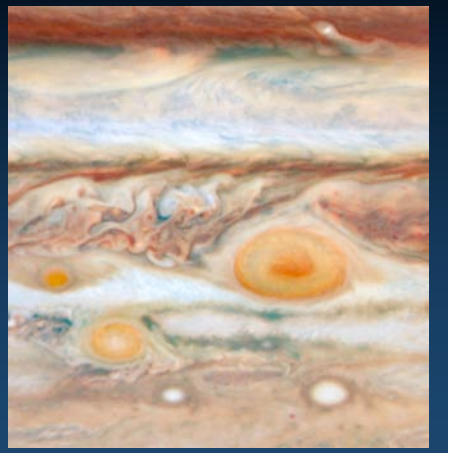
- Europa's escaping neutrals
- Io plasma torus
- Pickup & charge exchange
- Satellite interactions including Ganymede's field
- Magnetospheric structure
- Plasma transport

Understanding the Solar System's largest magnetosphere

♃ System: Geo • Atm • Mag • Jupiter • Rings

Jupiter atmosphere:

- Minor species abundances
- Dynamics & structure

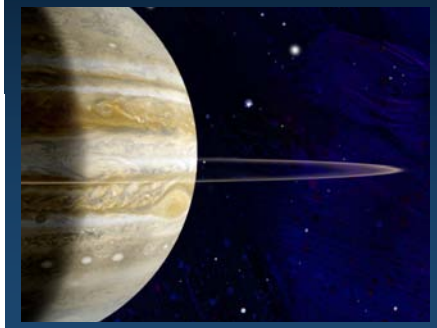


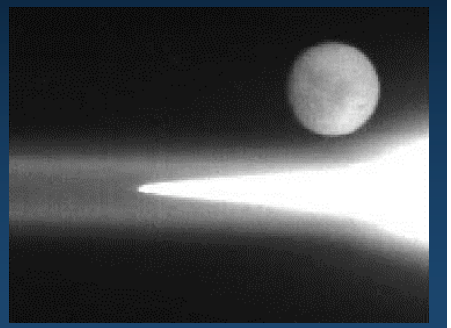
Addresses unanswered questions and complements Juno

♃ System: Geo • Atm • Mag • Jupiter • Rings

Rings:

- Ring source bodies
- Dynamical processes





Comparative studies of ring dynamics and evolution

Jupiter Europa Orbiter Science

Summary:

Habitability

- Ocean characterization
- Surface-ice-ocean exchange
- Compositional makeup
- Geological evolution
- Jupiter system science
  - Galilean satellite evolution
  - Sat. atmospheric interactions
  - Magnetospheric physics
  - Jupiter atmospheric dynamics
  - Ring system dynamics

Rich and robust science of Europa and the Jupiter system

Jupiter Europa Orbiter

Presented By:
Karla B. Clark
Jet Propulsion Laboratory,
California Institute of Technology

November 6, 2008

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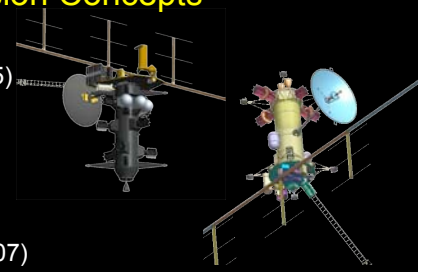
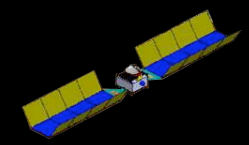
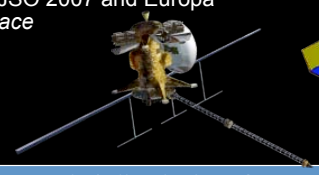
Heritage of Europa Mission Concepts

- Europa Orbiter (1997 – 2001)
- Jupiter Icy Moons Orbiter (2002-2005)
- Europa Geophysical Explorer (2005)
- Europa Explorer (2006)
- Europa Explorer (2007)
- Jupiter System Observer (2007)
- *Laplace* Cosmic Vision Proposal (2007)
- Jupiter Europa Orbiter
  - Combines EE 2007, JSO 2007 and Europa flight element of *Laplace*







JEO is the "Just Right" mission for Europa Science

JEO Baseline Mission Overview

- **NASA-led portion of EJSM extensively studied in 2007/2008**
- **Objectives: Jupiter System, Europa**
- **Launch Vehicle:** Atlas V 551
- **Power Source:** 5 MMRTG or 5 ASRG
- **Mission Timeline:**
  - Launch: 2018 to 2022, nominally 2020
    - Uses 6 year Venus, Earth, Earth gravity assist trajectory
  - Jovian system tour phase: 30 months
    - Multiple satellite flybys: 4 Io, 6 Ganymede, 6 Europa and 9 Callisto
  - Europa orbital phase: 9 months
  - End of Prime Mission in 2029
  - Spacecraft final disposition: Europa surface impact
- **11 Instruments including Radio Science**
- **Optimized for science, cost and risk**
- **Radiation Dose: 2.9 Mrad (behind 100 mils of Al)**
  - Handled using a combination of rad-hard parts and tailored component shielding
  - Key rad-hard parts are available, with the required heritage
  - Team is developing and providing design information and approved parts list for prospective suppliers of components, including instruments

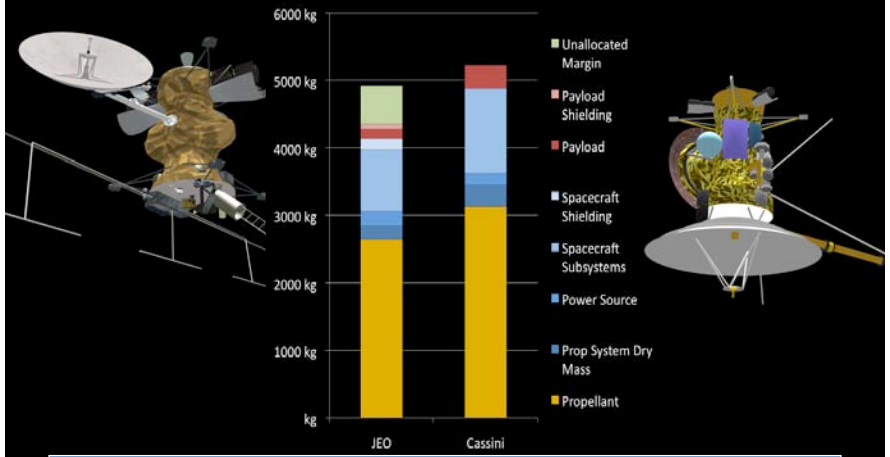
Highly Capable Model Payload

Laser Altimeter
Radio Science
Ice Penetrating Radar
Visible-IR Spectrometer
UltraViolet Spectrometer
Ion and Neutral Ion Spectrometer
Thermal Instrument
Narrow Angle Camera
Wide and Medium Angle Camera
Magnetometer
Plasma and Particle Instrument

- Instruments have operated in Jovian radiation belts before
- Detector Working Group formed to evaluate radiation aspects of model payload using:
  - Galileo (and current Juno) experience
  - Only publicly available technology
  - Shielding approaches
- Other proprietary options exist (instruments and detectors), but inlcuided in performance analysis
- AO process will select final capability, but Model Payload shows proof of concept for required techniques
- 106 kg current best estimate plus 57 kg shielding

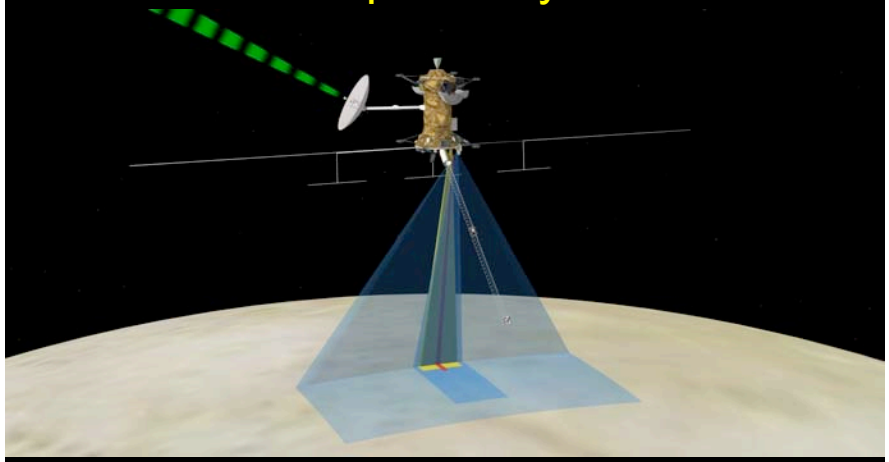
Model payload meets science requirements within the radiation environment

Spacecraft Mass



JEO functionality and mass is comparable to Cassini, with large mass margin

Operability



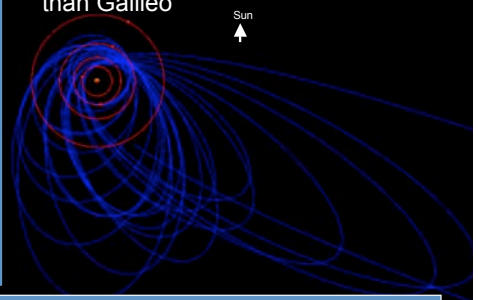
Articulated antenna allows simultaneous observations and downlink

Jupiter System Science

3 Gb per day average data return

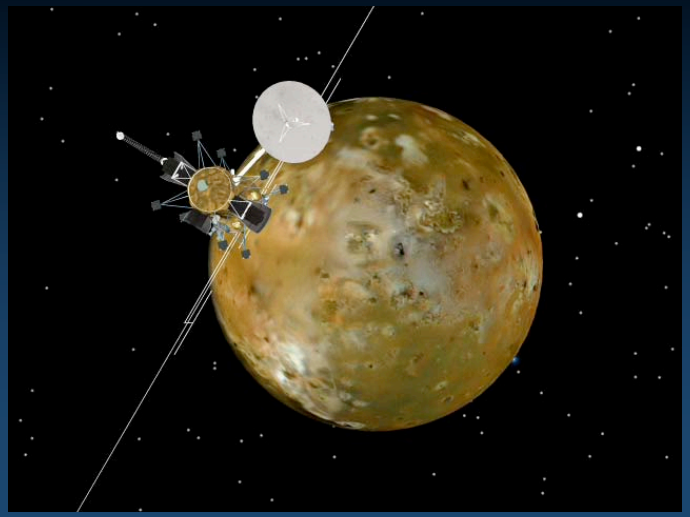
- Permits Hundreds of NAC images each day and context images with VIRIS, MAC, UVS, TI

~1000 times more system data return than Galileo

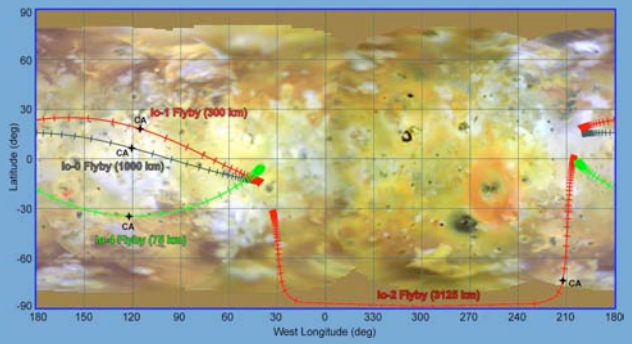


Enables observations of dynamic events over long periods of time

Io Flyby Example

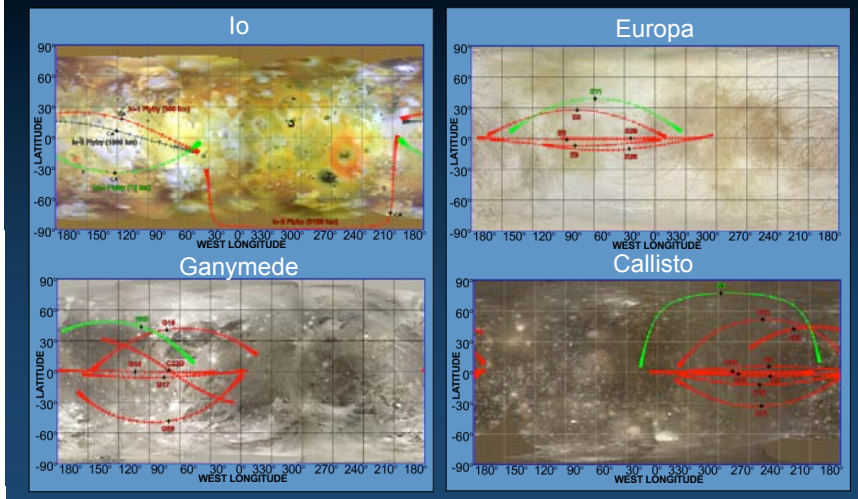


Io Example



- 3 Io Science Flybys
- 25% Surface imaged at better than 200m per pixel
- Opportunities for sub-surface radar sounding and altimetry
- 75 Km Flyby at I4 enables In-situ sample of plume with INMS

Jovian Tour Phase



Europa Science Campaigns

Eng Assessment (6d)

1A 1B 2A 2B 3

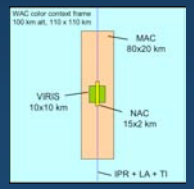
Focused Science: Follow up on discoveries

4

By end of Europa Campaign 3:

4 global maps
- 2 @ 200m Color + Stereo
- 2 @ 100m Stereo

730 imaging and radar targets
18 km profile spacing for LA and TI
35 km spacing for IPR and VIRIS
400 UVS stellar occultations



- Finer global and regional grid of profiling observations (IPR, VIRIS, TI)
- Continue gravity, laser altimetry, and fields and particles measurements
- Additional coordinated target sets
  - Investigate new discoveries and priorities
  - Characterize candidate future landing sites
- Off-nadir NAC stereo images
- Lower altitude operations
- Monitor Io and Jupiter, 1 to 2 times per week

Extended time in Europa orbit

Risk Reduction Effort

Risk Mitigation Plan: Radiation and Planetary Protection	System Reliability Model Environment and Shielding Model Radiation Design Methods Sensors and Detectors Parts Evaluation and Testing Approved Parts and Materials List (APML FY08)

- **Systematic approach to understanding inherent margins**
- **Practical testing and approval of characterized parts and materials**
- **Dissemination of learned approaches**

Early and consistent Radiation Tolerance Design methodology protects JEO to the end of prime mission

Support to Instrument Designers

A wealth of resources are available now to assist in lower radiation risk

JEO Baseline Mission Overview

- **NASA-led portion of EJSM extensively studied in 2007/2008**
- **Mission Timeline:**
  - Nominal Launch: 2020
    - 6 Year Interplanetary trajectory
  - Jovian system tour phase: 2.5 years
  - Europa orbital phase: 9 months
  - End of Prime Mission in 2029
- **11 Instruments including Radio Science**
- **Radiation Design Approach:**
  - System Approach
  - Disseminate design data
  - Reduce risk early

The Jupiter Ganymede Orbiter

Science objectives and planning payload

Michel Blanc

CESR & Ecole Polytechnique

November 6, 2008

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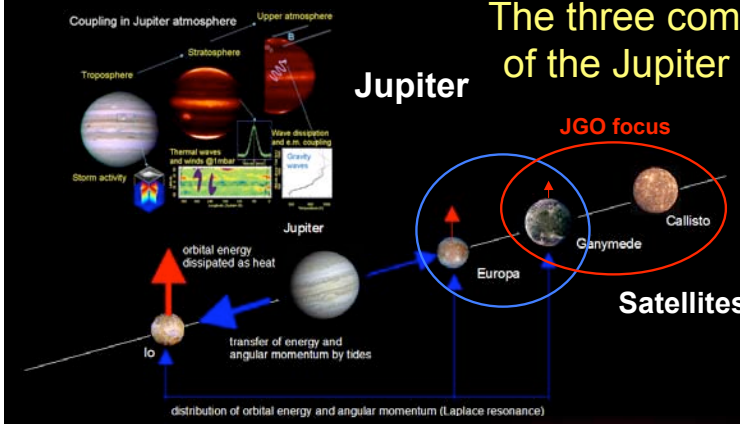
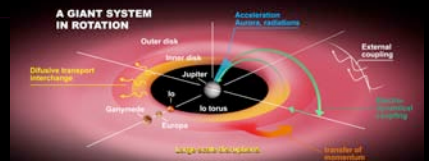
The three components of the Jupiter system

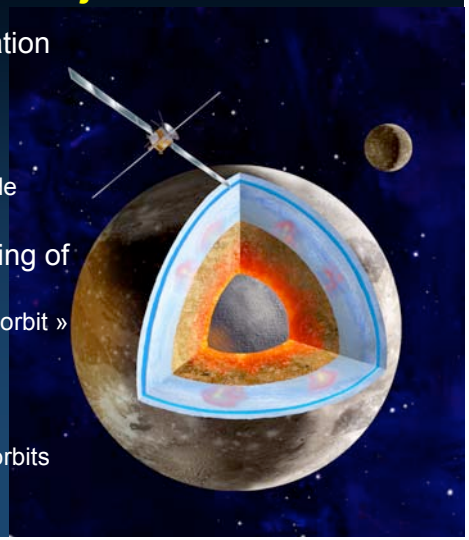


Magnetodisk/ radiation belts



JGO Key Objectives

- In-depth post-Galileo exploration of the **Jupiter system**, synergistically with JEO
  En route to Callisto and Ganymede
- In-depth study and full mapping of **Callisto**
  Multiple fly-bys using a « pseudo-orbit »
- Detailed orbital study of **Ganymede**
  two successive dedicated moon orbits (elleptical first, then circular)



Reference Model Payload (1)

73 kg core payload:

Imaging	➢ Wide Angle and Medium Resolution Camera ➢ V/NIR Imaging Spectrometer ➢ EUV/FUV Imaging Spectrometer
Planetary fields and internal structure	➢ Ka-band transponder ➢ Ultra Stable Oscillator ➢ Magnetometer ➢ Radar Sounder ➢ Micro Laser Altimeter
Atmosphere	➢ Thermal IR Mapper ➢ Sub-millimeter wave sounder
Magnetosphere	➢ Plasma Package

Reference Model Payload (2)

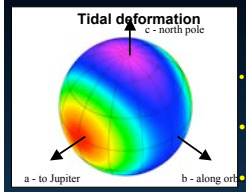
Additional instruments under consideration (should be up to 30 kg)
In order of priority:

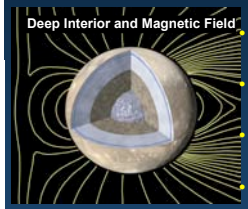
- ➢ Narrow Angle Camera
- ➢ Doppler Spectro-Imager
- ➢ INMS
- ➢ Dust Telescope
- ➢ Plasma Wave Instrument / supplementary Plasma Package
- ➢ Optical Lightning Detector
- ➢ X-ray spectrometer

Gravity Advanced Package
for Fundamental Physics objectives

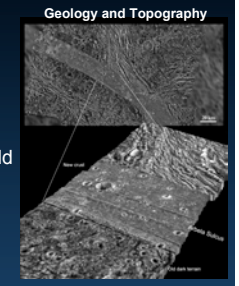
Ganymede:

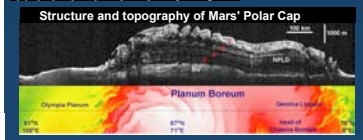
Europa's "false twin"

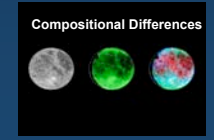




- Presence and extent of a subsurface ocean
- Ice shell and subsurface water
- Deep internal structure, dynamo, magnetic field
- Surface/exosphere/magnetosphere coupling
- Surface composition and chemistry
- Surface features, tectonic processes
- Thermal evolution, geology, Laplace resonance





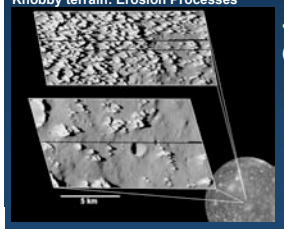


Callisto

A witness of the Early Ages ?

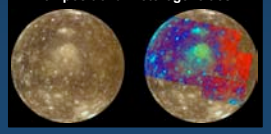
Crater Distribution and Morphology

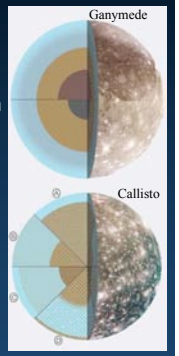
Knobby terrain: Erosion Processes



- Presence and extent of a subsurface ocean
- Ice shell and subsurface water
- Deep internal structure, degree of differentiation
- Cratering record and early geological history
- Surface composition: hydrocarbons and CO2
- Surface degradation processes (erosion and sublimation)

Compositional Heterogeneities





Internal differentiation: Where is Callisto ?

Image: Bagenal et al., 2004

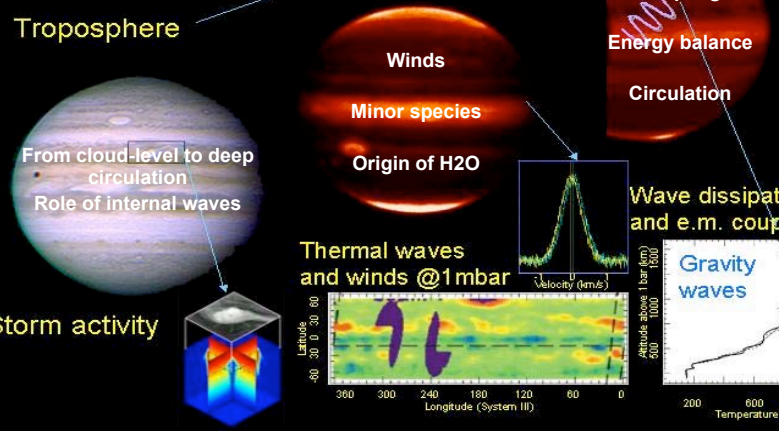
Coupling in Jupiter atmosphere

In-depth study of three key layers by JGO

Upper atmosphere

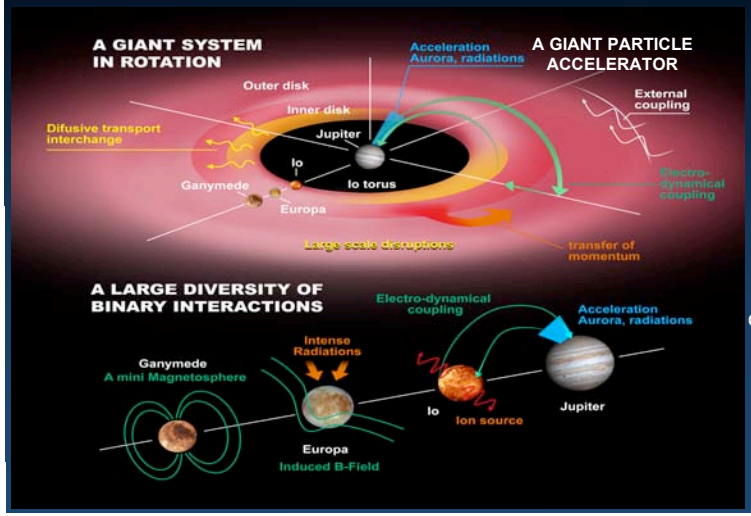
Stratosphere

Troposphere



The Magnetosphere of Jupiter:

Studying an astrophysical magnetodisk in situ

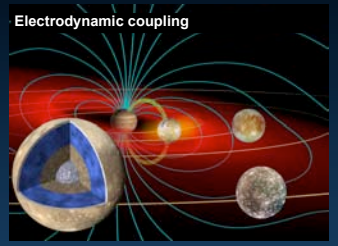


- Angular momentum transfer
- Energy dissipation
- Formation of Radiation Belts
- Effects on moons and habitability

Studying the Jovian World as a Coupled System:

where JGO, JEO (and JMO?) unite

Electrodynamic coupling



Comparative geology of the Galilean Satellites

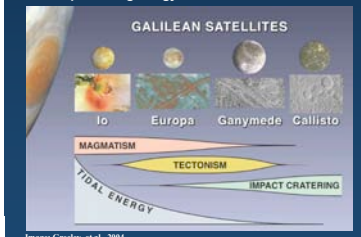
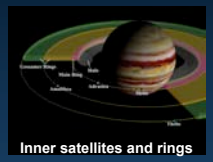


Image: Greeley et al., 2004

- **ELECTRODYNAMIC COUPLING**
  Studying "astrophysical" binary systems in situ

Irregular Satellites?



Inner satellites and rings

- **CHEMICAL EVOLUTION OF THE SATELLITE SYSTEM**
  From formation to habitability ?
- **GRAVITATIONAL COUPLING**
  The coupled history of the Laplace resonance, thermal evolution, differentiation and geological activity

JGO SCIENCE HIGHLIGHTS

A major step forward in our understanding of the two "icy" Galilean satellites, Ganymede and Callisto:

- Ocean detection/characterisation
- State of internal differentiation
- Global surface mapping: morphology and chemistry
- Comprehensive study of Ganymede's magnetism
- Relations between thermal history, geology, oceans and the Laplace resonance

The first global description of the Jovian World as an "integrated system", together with JEO:

- Jupiter's atmosphere 3-D meteorology and coupling processes,
- Jupiter's magnetosphere as an "astrophysical object",
- A major step towards untangling the history of the chemical evolution of the Jupiter system, from formation to potential habitability

Jupiter Ganymede Orbiter

Presented By:

Anamarija Stankov
European Space Agency

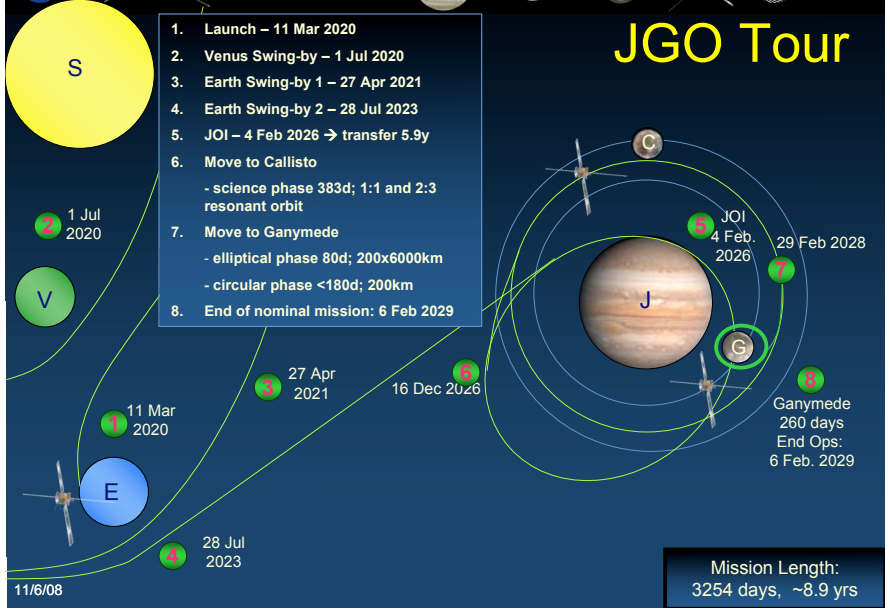
November 6, 2008

Europa Jupiter System Mission

Presentation to the Outer Planet Assessment Group

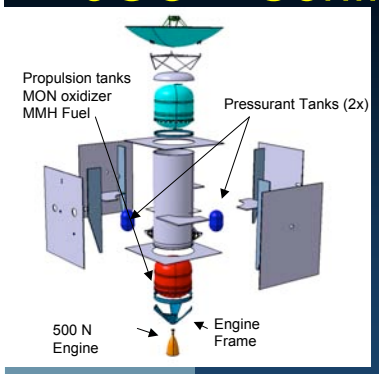
JGO Tour

1. Launch – 11 Mar 2020
2. Venus Swing-by – 1 Jul 2020
3. Earth Swing-by 1 – 27 Apr 2021
4. Earth Swing-by 2 – 28 Jul 2023
5. JOI – 4 Feb 2026 → transfer 5.9y
6. Move to Callisto
   - science phase 383d; 1:1 and 2:3 resonant orbit
7. Move to Ganymede
   - elliptical phase 80d; 200x6000km
   - circular phase <180d; 200km
8. End of nominal mission: 6 Feb 2029



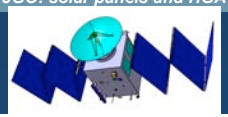
Mission Length: 3254 days, ~8.9 yrs

JGO – Configuration/Structure



JGO: exploded view

JGO: solar panels and HGA



Key figures

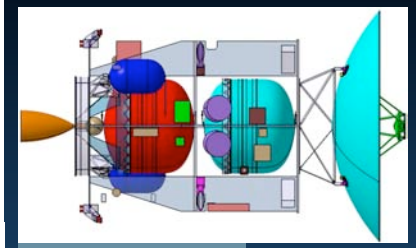
- S/C total dry mass: 1275 kg (payload: 87 kg*, shielding: 80 kg)
- Launch mass: 3493 kg (capacity 4362 kg)
- Delta-V: 2990 m/s
- Propellant: 2027 kg

Power

- EOL: **539W** (410 W max. power in Jupiter orbit mode + PCDU inefficiencies + margins)
- Solar cell array: GaAs LILT; 28% efficiency BOL; ~20% degradation in 9 years; Solar arrays: **51m²**, ~253 kg, 4 panels per wing
- Batteries: Sizing case: eclipse mode (270 min); EOL requirement **1534 Wh** → Li-Ion battery of 26 kg

Note: Masses including margins
** Instruments 73kg w/o margin*

JGO – Subsystems (1)



JGO: Main engine, tanks, HGA

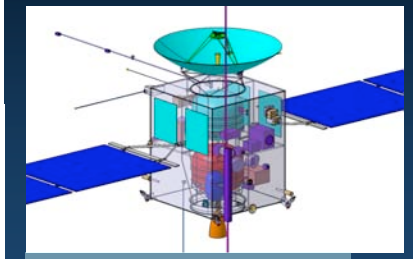
General
- 3-axis stabilized S/C (4 reaction wheels)
- Engine must perform 2990m/s (**including** margins)
- EAM 500 N main engine (I_{sp} = 325 s)
- Bi-propellant MON/MMH system
- 2 1108L OST-22/X tanks, 2 He pressurant tanks, 2x8 AOCS 10 N thrusters
- ~80 kg shielding mass (for 87kg* P/L & avionics)

Comms
- Data rate: 40 - 66 Kbps
- X/X for TC/TM and science down link; Ka band for Radio Science Experiment
- 2 omni-directional LGAs
- 2 MGAs
- 2.8 m HGA
- ground station: Cebreros

Data Handling System
- HICDS - LEON2 Based Dual Redundant Computer (design based on BepiColombo)
- Integrated processor, TMTC modules (plus redundancies)
- Integrated mass memory board and controller
- Single flash-based SSMM board of 256Gbits

** 73kg w/o margin*

JGO – Subsystems (2)



JGO: HGA, solar panels, instruments, booms

Radiation
- Total Ionizing Dose 82krad (behind 8mm Aluminum)
- Shielding mass ~80kg (w/o) margin for payload and avionics (73kg payload w/o margin); mainly box shielding
- Radiation model will be improved (Ganymede shielding)

Thermal
- Challenge: high T at Venus; very low T at Jupiter
- High temperature Multi Layer Insulation (MLI) on S/C external surface for Venus fly-by. Black paint inside to minimize thermal gradient.
- Optical solar reflectors (OSR) mounted on solar arrays (mirrors)

JGO – summary

- **Mass:** 1275kg dry mass (incl. margins, excl. adapter)→ launch mass incl. adapter: 3493kg (max. launch mass is 4362kg).
- **Planning payload**: 87kg (73kg excl. margin; excl. shielding and several mechanisms)
- A **higher launch margin** (more than 20% system margin) is beneficial in such an early study phase.
- **Power:** SA size: ~51m², mass: ~280kg (incl. margins, PCDU, battery)
- **Comms:** min. 40-66kbps, 2.8m HGA, X&Ka band up and down link (data), Cebreros ground station, assumed comm. windows 8 h; total data volume for Ganymede science phase ~300Gbit.
- **Radiation:** TID for whole mission and after 260 days in Ganymede orbit 82krad (=upper limit; improved Ganymede radiation model (moon shielding,..), composite shielding material,… should reduce TID)
- **Cost:** preliminary calculations → within Cosmic Vision 2015-2025 L-class cost cap of 650M€

JGO – schedule

Date \ Time frame	Action
January 2009	**Joint ESA/NASA down-selection;** confirmation of down-selection by the ESA Science Programme Committee (SPC) on 4 Feb. 2009
1st quarter 2009	- Preparation for Invitation to Tender (ITT) for 2 parallel industrial studies. - Call for instrument studies (Declaration of Interest for national funded studies) for the down-selected mission
March 2009	Issue of ITT
June 2009 – June 2010	2 Competitive industrial studies; nationally funded instrument studies in parallel
September 2010	**Due date for L-Class assessment report**
Late 2010	**Selection of 2 of the remaining 3 L-class missions for launch in 2020**: Candidates: Outer Planet Mission, IXO (Xeus), LISA
1st quarter 2011 to mid 2012	**Industrial studies** (start of phase B1) – Definition Phase
End 2012	**Selection of 1 L-class mission for launch in 2020** → mission moves into phase B2 (12 months)
May 2015 – Nov. 2016	Phase C (30 months)
Nov. 2016 – Nov. 2019	Phase D (36 months)
11 March 2020	Launch

Wrap-Up

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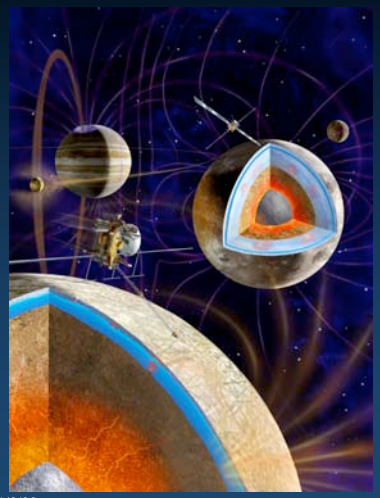
November 6, 2008

Europa Jupiter System Mission

Presentation to the Outer Planet Assessment Group

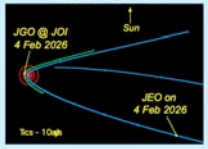
EJSM Science Highlights



- Europa
  - Exploration & habitability
- Ganymede
  - Magnetosphere & interior
- Diversity in satellite evolution
  - Io to Callisto
  - Small bodies, rings
- Magnetospheric science
  - Jupiter
  - Ganymede
- Jupiter Atmosphere
- Io & Io torus

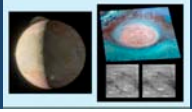
EJSM Synergistic Science

Jupiter Magnetosphere Studies



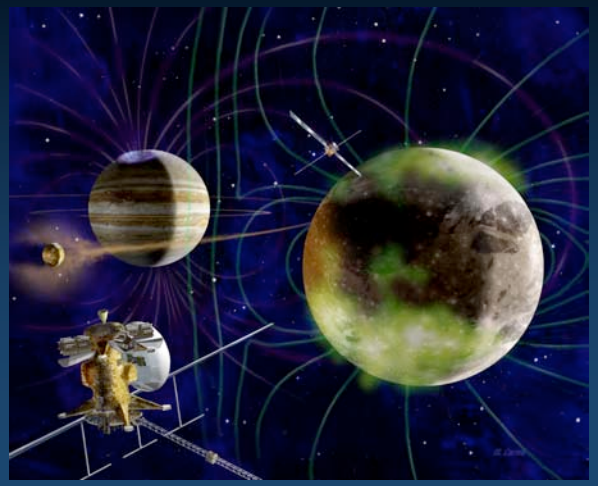
Io Volcanism & Io Torus Dynamics

Satellite/Jupiter Monitoring



Ganymede Magnetosphere Studies

Ganymede Magnetosphere Studies



EJSM: Powerful Science, Technologically Ready

- Broad and thorough science:
  - Satellites, Jupiter, magnetosphere
  - EJSM will do for the Jupiter system what Cassini is doing for the Saturn system - *and much more!*
- Jupiter-Europa missions have been honed for 10+ years
  - Mission concepts are stable
  - Technology is ready
  - Testable hypotheses and exploration

EJSM will study the Jupiter mini-solar system intensely & thoroughly

Europa & Ganymede

potentially habitable worlds in the Jupiter system