

## ガリレオ衛星の 内部構造と表層物質

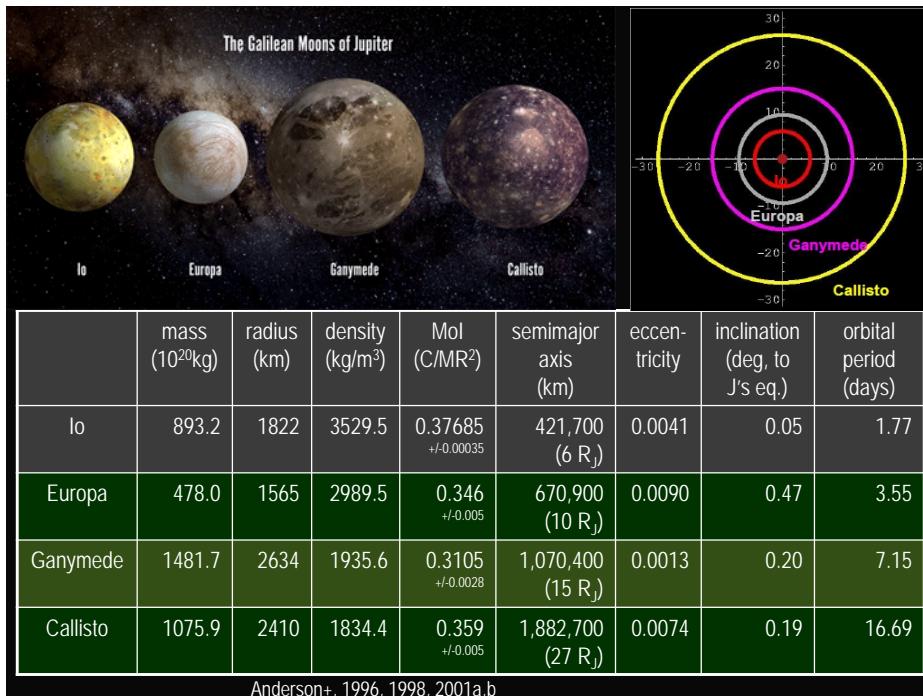
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ELSI/Titech



2013 08/07-09@定山渓

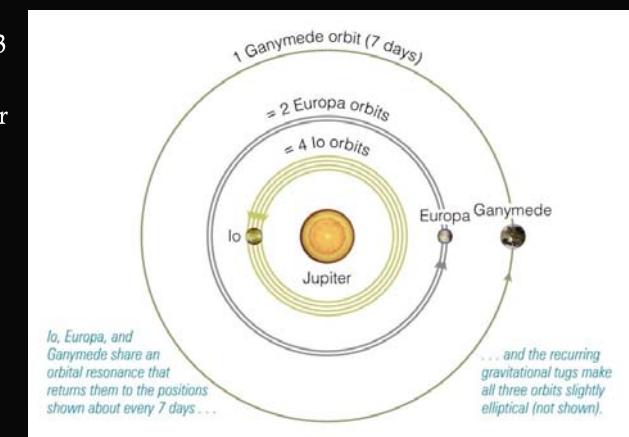
## Motivations

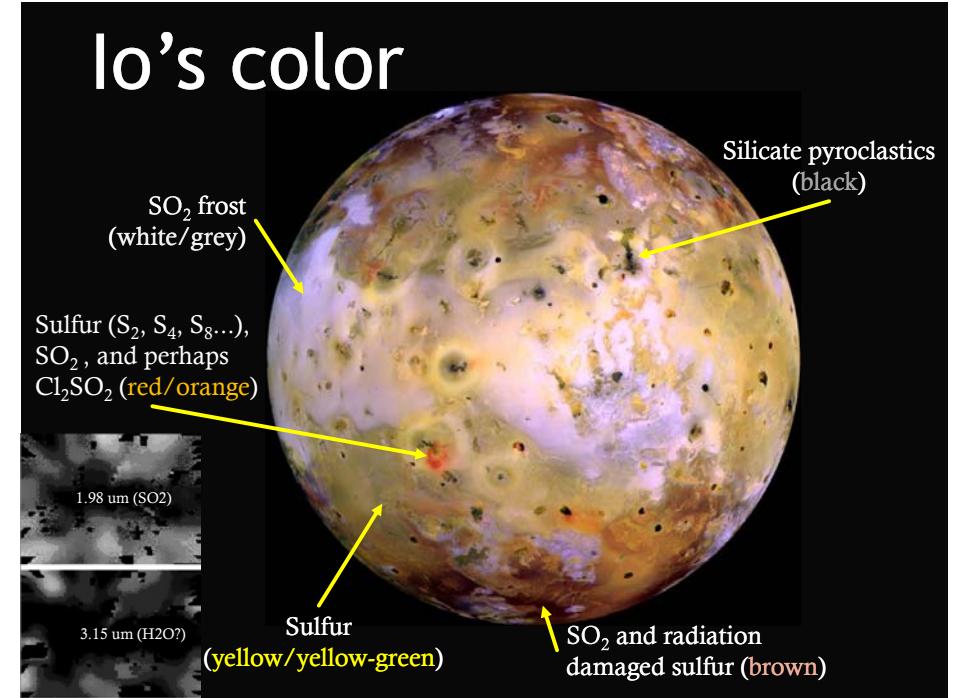
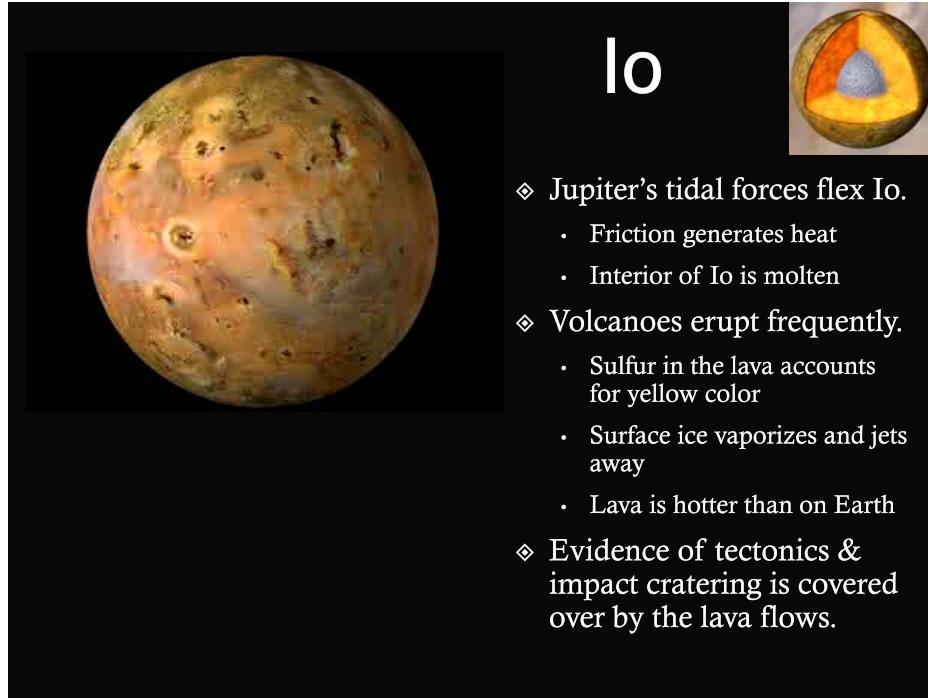
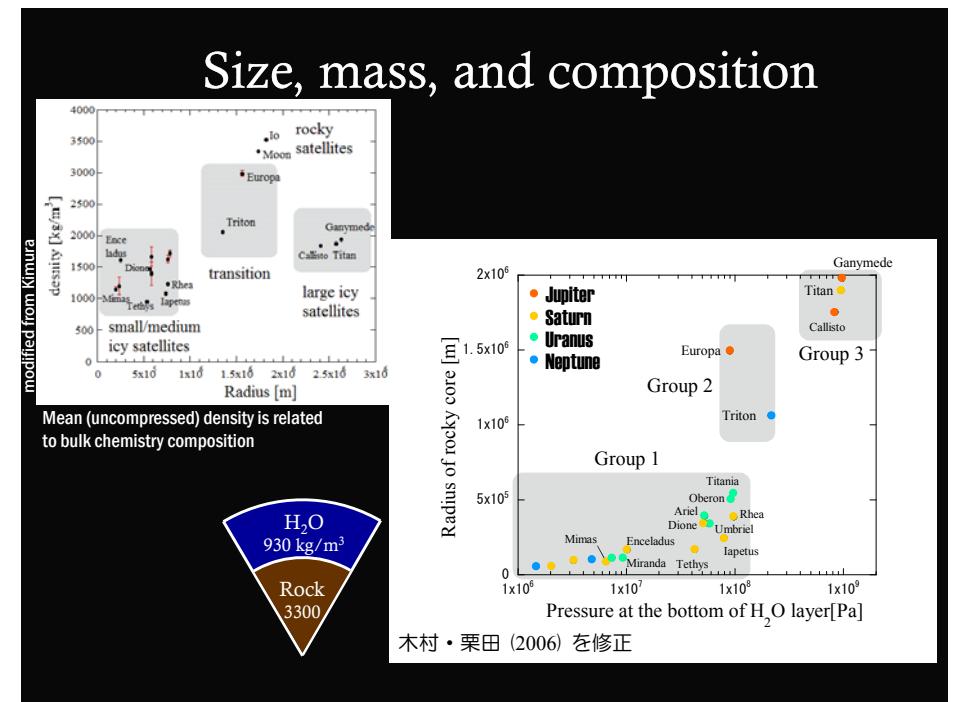
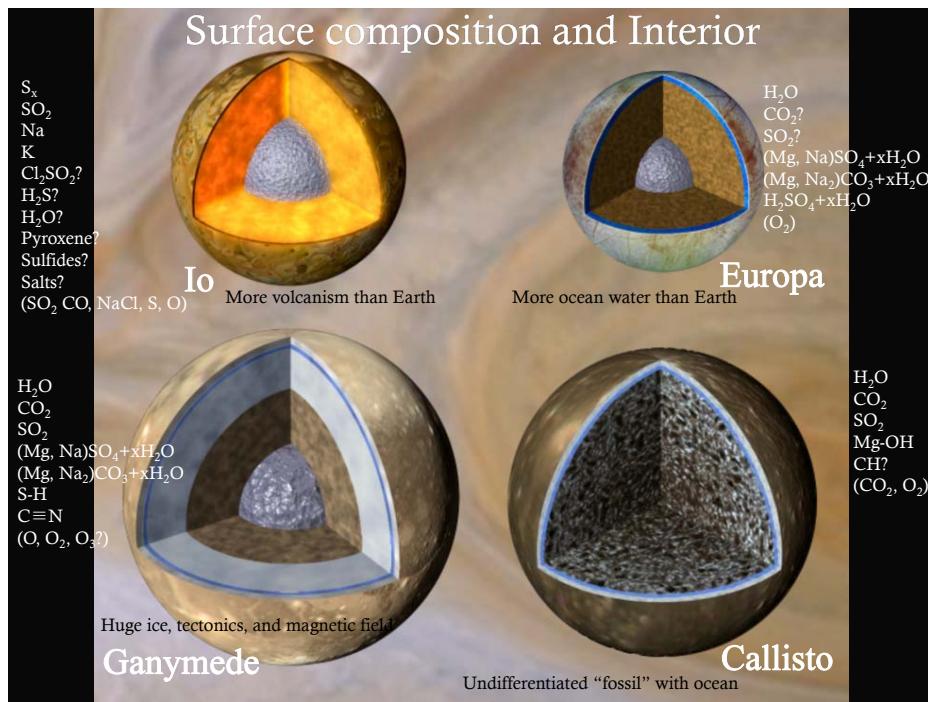
- 氷衛星を形作った物質はなにか？
- 氷衛星の水と地球の水の起源は同じか？違うか？



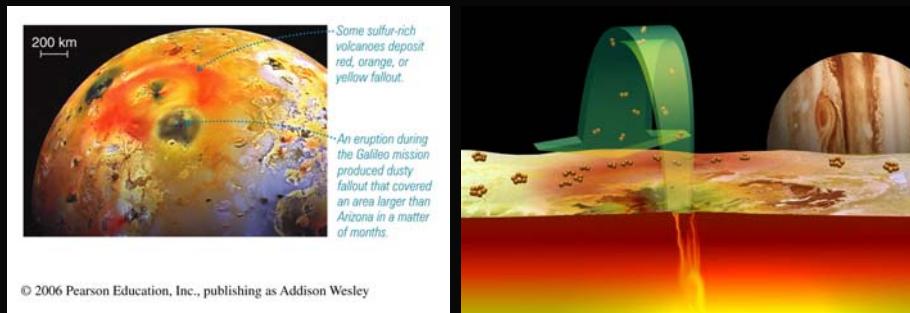
## Orbital Resonances play a role too

- ❖ Every 7 days, these 3 moons line up.
- ❖ The tugs add up over time, making all 3 orbits elliptical.





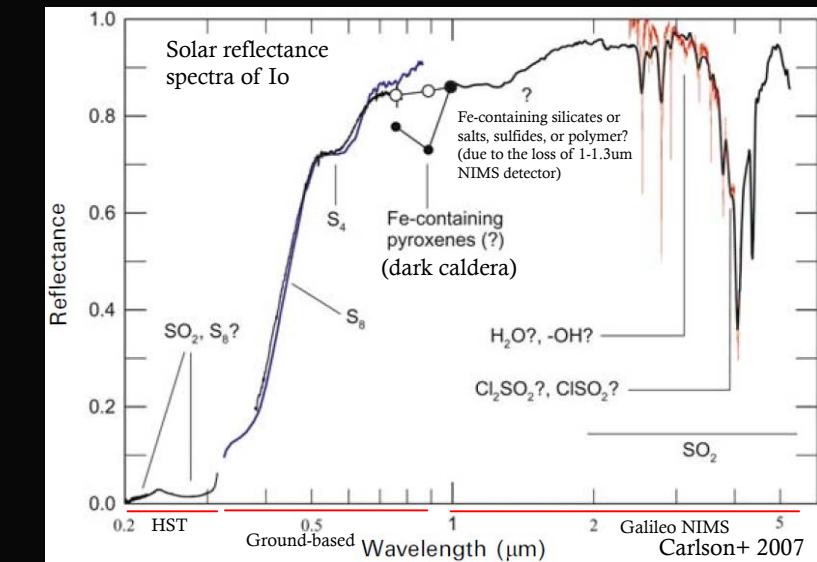
## What makes red rings around Io's volcanoes?



- ❖ Volcanic plumes containing S & SO<sub>2</sub> (& Na, K, Cl) are ejected at ~1 km/s.
- ❖ S<sub>2</sub> and S<sub>4</sub> make red rings around volcano and silicate pyroclastics make black spots.
- ❖ Sulfur (S<sub>2</sub>) ejected from vents → S<sub>4</sub>, S<sub>6</sub>, S<sub>8</sub>...
- ❖ Sulfuric red → (UV) → yellow.

## Io's composition

S, S<sub>2</sub>, S<sub>4</sub>, S<sub>8</sub>..., SO<sub>2</sub>, H<sub>2</sub>O, NaCl, KCl, ClSO<sub>2</sub>



## Interior of Io

Bulk density = 3.53 g/cc

Mol factor = 0.377

Reference model:

Assuming Core density=5150 kg/m<sup>3</sup>

Crust thickness=50 km

Crust density=2750 kg/m<sup>3</sup>

Core radius=870 km (0.48R)

Mantle density=3400 kg/m<sup>3</sup>

Mantle thickness=902 km

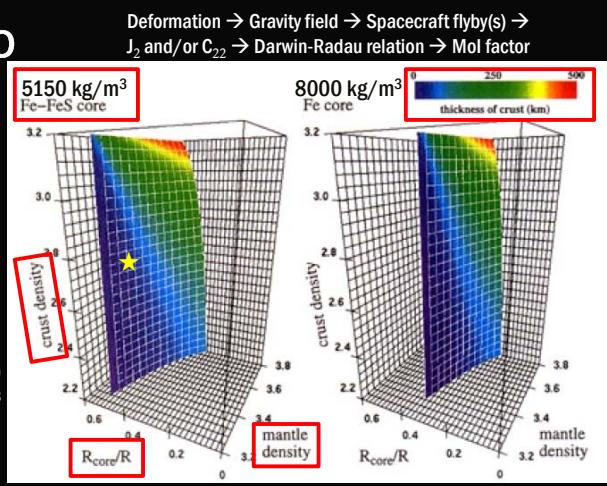
-Core radius is 550-900km (Fe-FeS core), 350-650km (Fe core)

If crust density = mantle density (2-layer model),

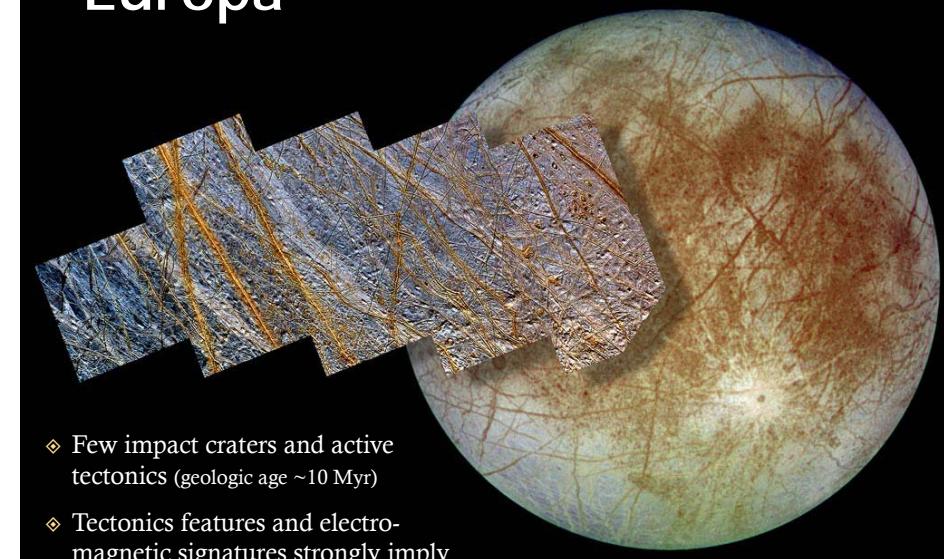
core radius = 950 km (0.52R) for Fe-FeS (5150 kg/m<sup>3</sup>)

core radius = 650 km (0.36R) for Fe core (8000 kg/m<sup>3</sup>)

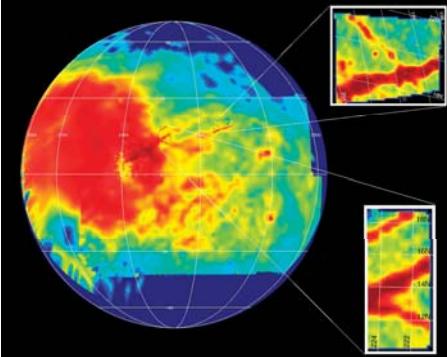
-Galileo's magnetometer failed to detect an intrinsic magnetic field.



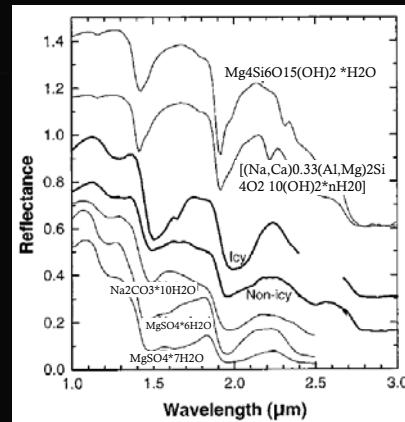
## Europa



## Surface composition on Europa: sulfate



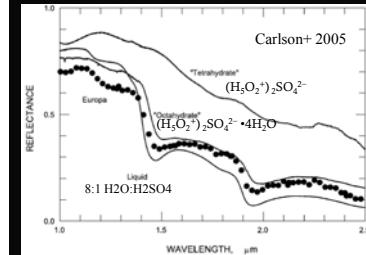
Distribution of the non-ice component, with red being high non-ice concentration. The non-ice material is associated with the surface cracks and chaos. (McColl+ 1998)



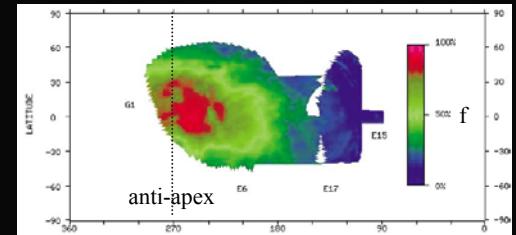
Near IR reflectance spectra of Europa's non-icy and icy areas, and possible surface minerals. (McColl+ 1998)

- $\text{MgSO}_4$ ,  $\text{Na}_2\text{SO}_4$ ,  $\text{MgCO}_3$ ,  $\text{Na}_2\text{CO}_3 + \text{xH}_2\text{O}$
- > exposed the subsurface ocean's brine??
- > implying hydrothermal activity as occurs on Earth?

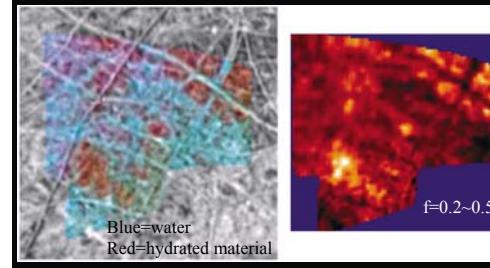
## Surface composition on Europa: sulfuric acid



$\text{H}_2\text{SO}_4$  is another possible contaminant.



$f = [\text{H}_2\text{SO}_4 \cdot n\text{H}_2\text{O}] / ([\text{H}_2\text{SO}_4 \cdot n\text{H}_2\text{O}] + [\text{H}_2\text{O}])$   
Hydrate abundance & distribution is consistent withogenic sulfur ion implantation.



$\text{H}_2\text{SO}_4$  concentration is lower in the lineae.  
- argues against an endogenic source of sulfurous or hydrated material?

## Interior of Europa

Bulk density = 2.99 g/cc

Mol factor = 0.346

Reference model:

Assuming

Core density = 5150 kg/m<sup>3</sup>

Water layer thickness = 100 km

Water layer density = 1000 kg/m<sup>3</sup>

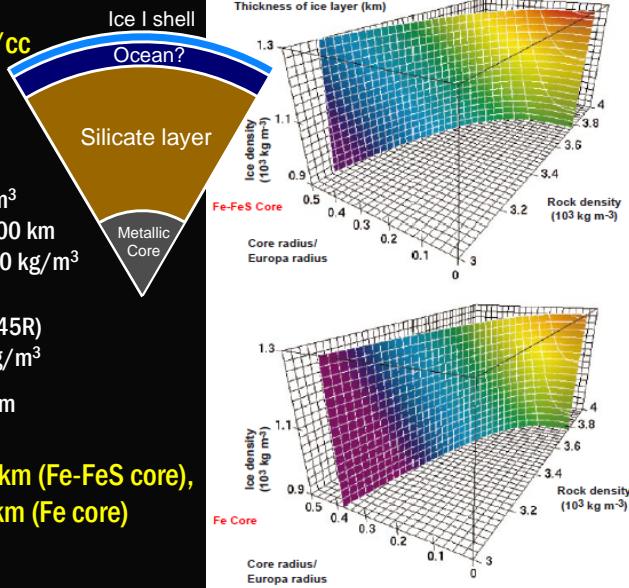
↓

Core radius = 704 km (0.45R)

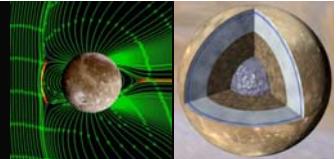
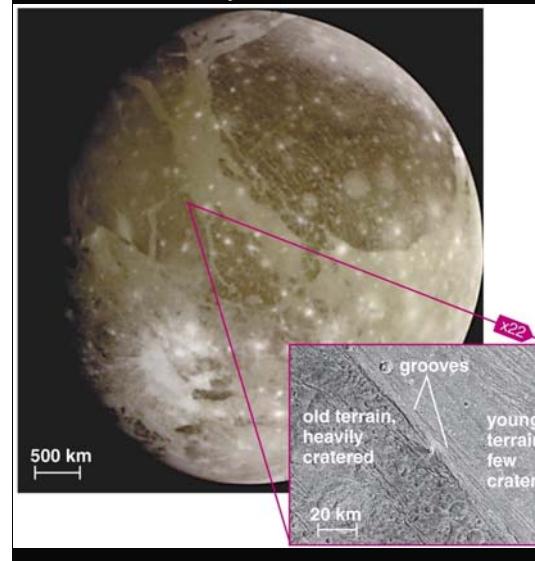
Mantle density = 3300 kg/m<sup>3</sup>

Mantle thickness = 761 km

- Core radius is 0-780 km (Fe-FeS core),  
0-600km (Fe core)

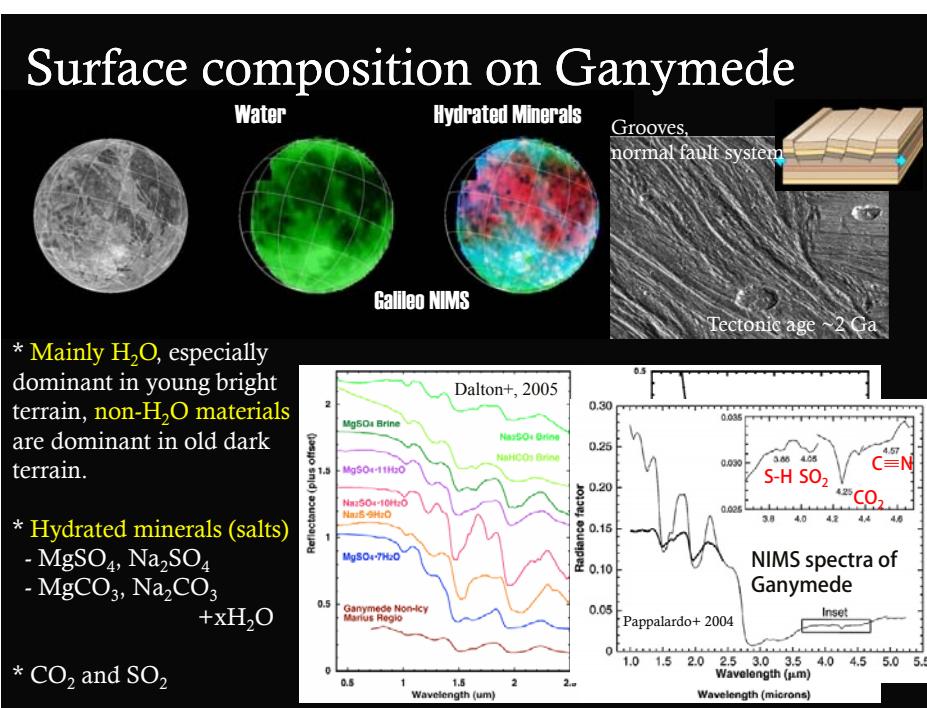


## Ganymede

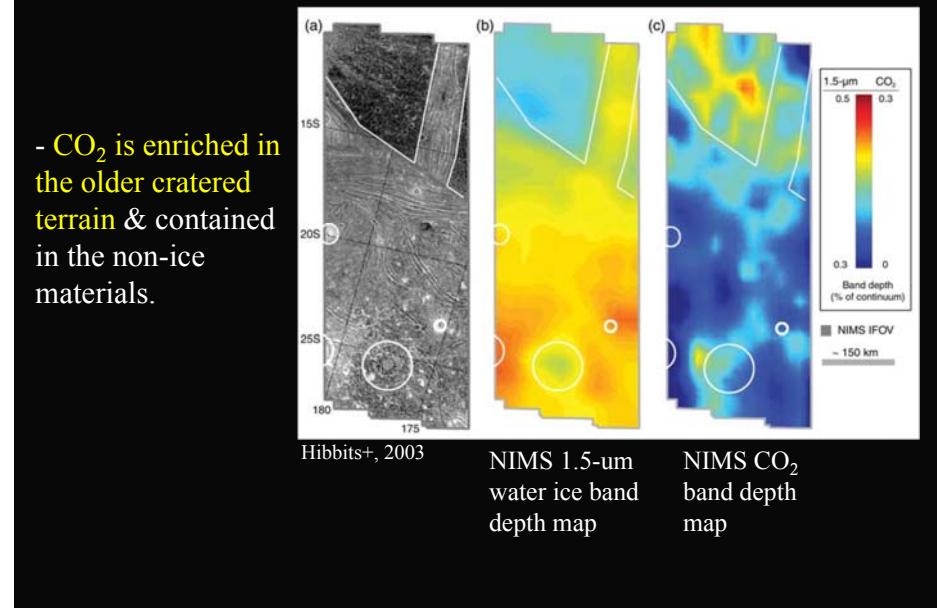


- ◆ Largest moon in the solar system ( $r=2634\text{ km}$ , larger than Mercury).
- ◆ Smallest MoI in the solar system (0.31), implying that outer water layer (~1000km thick), rocky mantle, and metallic core (600~1100km radius).
- ◆ Clear evidence of geological activity (surface dichotomy).
  - > Older cratered terrain
  - > Young tectonic terrain
- ◆ Inductive response implying an existence subsurface water ocean has been observed (but ambiguous).
- ◆ Unique moon having an intrinsic magnetic field.
  - > Originated by a dynamo motion in the metallic core.

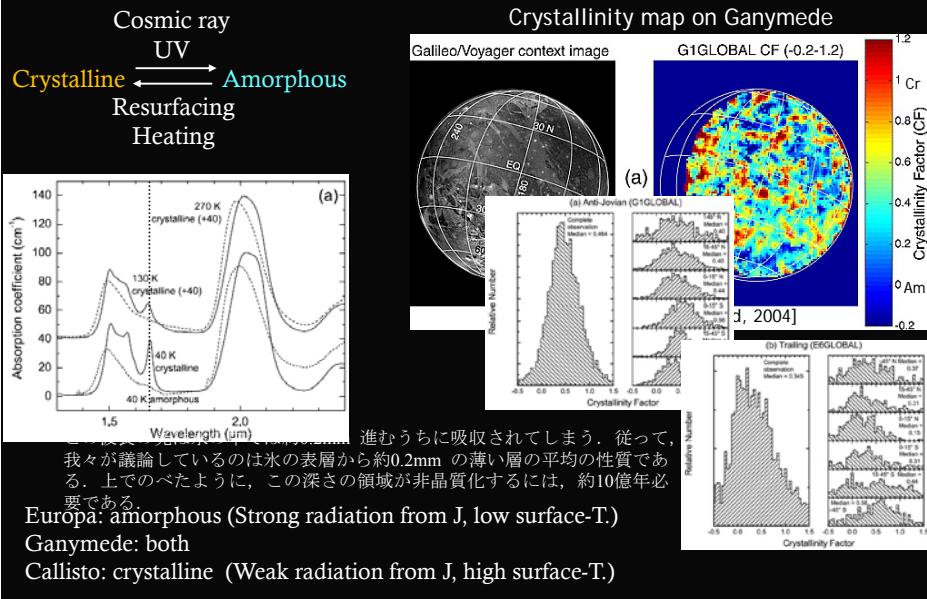
## Surface composition on Ganymede



## $\text{CO}_2$ on Ganymede



## Ice is crystalline or amorphous?



## Interior of Ganymede

$$\text{Bulk density} = 1.94 \text{ g/cc}$$

$$\text{Mol factor} = 0.311$$

Reference model:

Assuming

$$\text{Core density} = 5150 \text{ kg/m}^3$$

$$\text{Water layer thickness} = 1000 \text{ km}$$

$$\text{Water layer density} = 1200 \text{ kg/m}^3$$

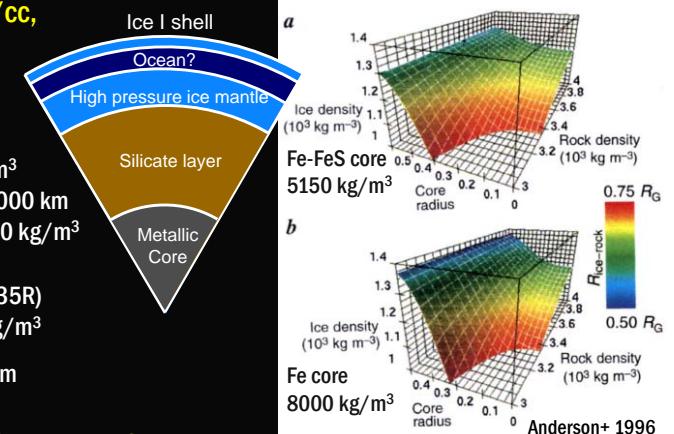
$$\downarrow \text{Core radius} = 920 \text{ km (} 0.35R \text{)}$$

$$\text{Mantle density} = 3400 \text{ kg/m}^3$$

$$\text{Mantle thickness} = 724 \text{ km}$$

- Core radius is 0-1300 km (Fe-FeS core),

$$0-1050 \text{ km (Fe core)}$$



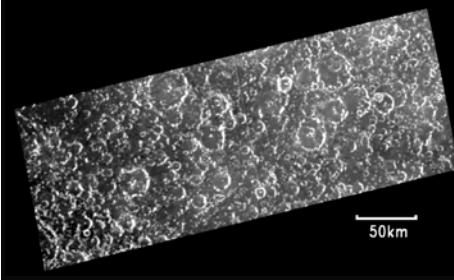
Reference model:

$$R_c = 0.4-0.5R \quad (\rho_c = 5150 \text{ kg/m}^3)$$

$$R_c = 0.15-0.2R \quad (\rho_c = 8000 \text{ kg/m}^3)$$



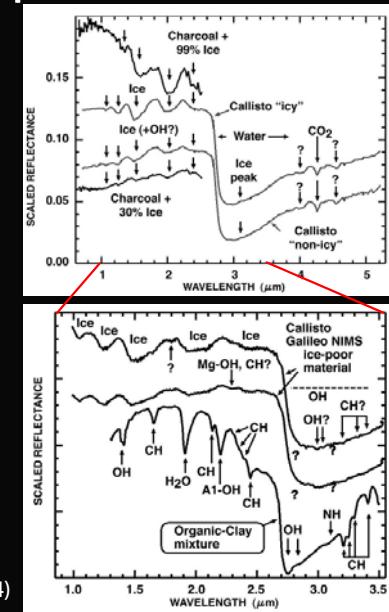
## Callisto



- ❖ **Globally old surface.**
  - heavily cratered, dirty ice
  - cratering reveals clean, white ice underneath
  - no evidence of tectonics
- ❖ No tidal heating, no orbital resonances (in current orbital state).
- ❖ But it has (**inductive**) magnetic field !!
  - Could it have a subsurface ocean anyway?

## Callisto's surface composition

- Similar to Ganymede's dark terrain
- Water ice
  - Crystalline (Callisto/Ganymede)
  - Amorphous (Ganymede)
- Dark materials
  - Organics? (CN, CH)
  - Hydrate salts (sulfates and carbonates)
- Other Volatiles
  - CO<sub>2</sub>
  - SO<sub>2</sub>

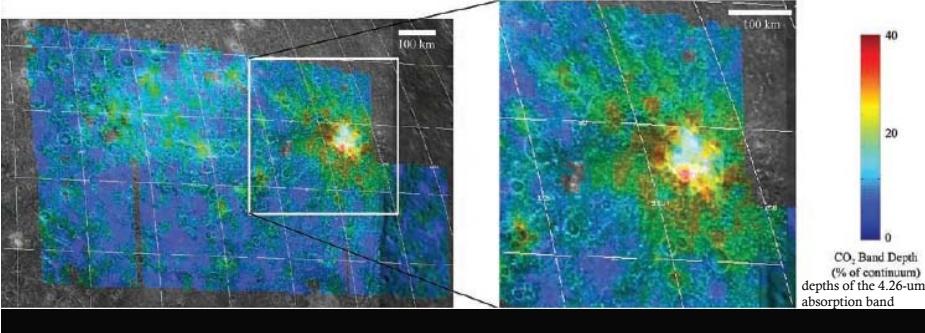


Moore+ (2004)

## CO<sub>2</sub> on Callisto

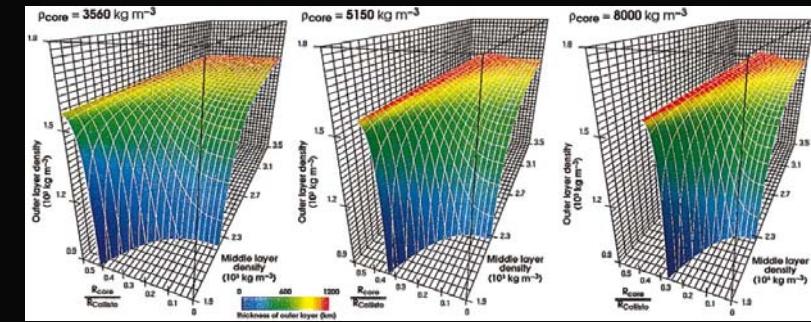
- CO<sub>2</sub> is often concentrated in and around morphologically fresh and bright impact craters, but not in degraded craters.
  - CO<sub>2</sub>-bearing material is being excavated by impacts?
  - CO<sub>2</sub> Source is possibly not exogenic because known comet crater chains are not CO<sub>2</sub>-rich.
  - If CO<sub>2</sub> is being exhumed, water-ice clathrates would act as a stable subsurface reservoir of CO<sub>2</sub>.

Hibbits+ (2002)



## Interior of Callisto

Anderson+ (2001)



Bulk density = 1.83 g/cc, Mol factor = 0.359

**Reference model:** Assuming

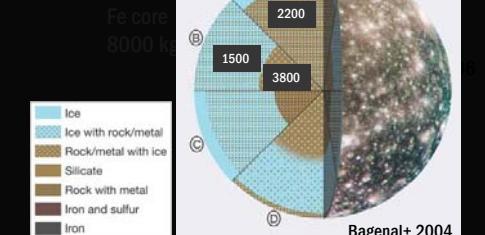
Core density = 5150 kg/m<sup>3</sup>

Outer layer thickness = 500 km

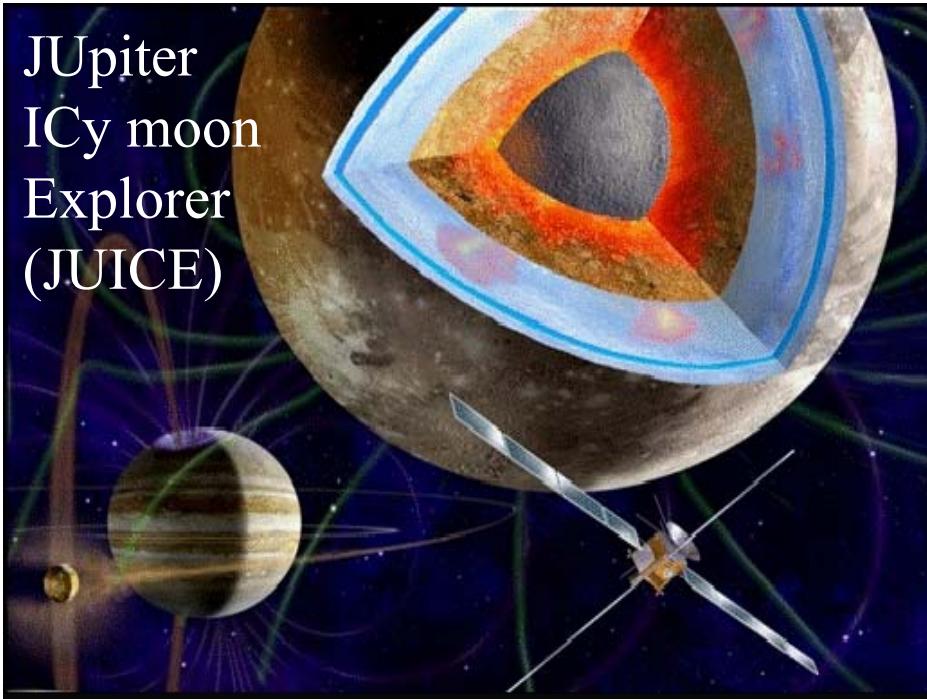
Outer layer density = 1300 kg/m<sup>3</sup>

Core radius = 480 km (0.2R)

Mid-layer density = 2400 kg/m<sup>3</sup>



# JUpiter ICy moon Explorer (JUICE)



# JUICE



## JUICE (JUpiter ICy moons Explorer)



### JUICE Science Themes

- *Emergence of habitable worlds around gas giants*
- *Jupiter system as an archetype for gas giants*

### Cosmic Vision Themes

- *What are the conditions for planet formation and emergence of life?*
- *How does the Solar System work?*

### JUICE concept

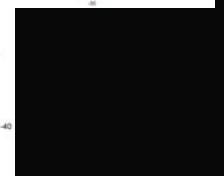
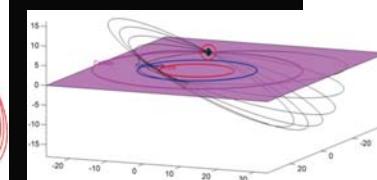
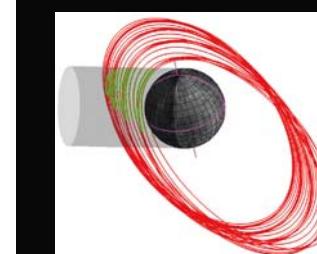
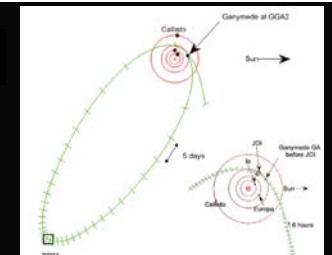
- *European-led mission to the Jovian system*
- *JGO/Laplace scenario upgraded with two Europa flybys and high-inclination phase at Jupiter*
- *Model payload is the same as it was on JGO/Laplace*

## JUICE Mission

JUpiter ICy moons Explorer

Exploring the emergence of habitable worlds around gas giants

2022年6月	打ち上げ	地球一金星一地球重力アシスト
2030年1月	木星周回軌道投入 木星ツアー	- エウロバフライバイ2回 - カリストフライバイ3回 高軌道傾斜角フェイズ - カリストフライバイ9回
2032年9月	ガニメデ周回軌道投入 ガニメデツアー	高高度橭円軌道周回フェイズ（1か月） 高高度（5000km）円軌道周回フェイズ（3か月） 高高度橭円軌道周回フェイズ（1か月） 中高度（500km）円軌道周回フェイズ（3か月） 低高度（200km）円軌道周回フェイズ（1か月）
2033年6月	ノミナルミッション終了	



# SELECTED INSTRUMENTS

観測装置	
JANUS (Jovis, Amorum ac Natorum Undique Scrutator)	可視分光撮像カメラ
MAJIS (Moons And Jupiter Imaging Spectrometer)	可視・近赤外撮像分光計
UVS (UV Imaging Spectrograph)	紫外撮像分光計
SWI (Submillimetre Wave Instrument)	サブミリ波観測器
GALA (GAnymede Laser Altimeter)	レーザ高度計
RIME (Radar for Icy Moons Exploration)	レーダーサウンド
J-MAG (Magnetometer for JUICE)	磁力計
PEP (Particle Environment Package)	非熱的中性粒子観測器
RPWI (Radio and Plasma Wave Investigations)	電波・プラズマ波動観測器
3GM (Gravity and Geophysics of Jupiter and Galilean Moons)	重力観測器
PRIDE (Planetary Radio Interferometer and Doppler Experiment)	惑星間電波干渉・ドップラー実験

