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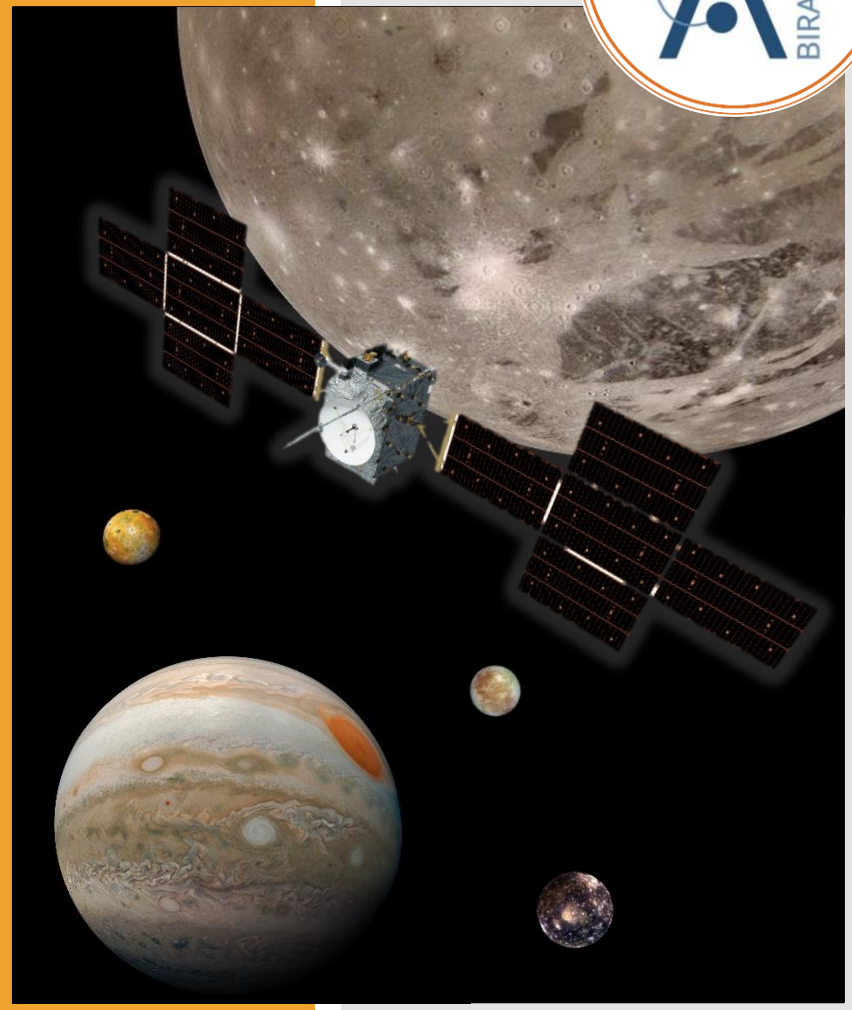
Radiative Transfer Model of Jupiter's Atmosphere

Miriam Estefanía Cisneros González

Supervisors:

Séverine Robert
Planetary Atmospheres Department, Royal Belgian Institute for Space Aeronomy

Clément Lauzin
Institute of Condensed Matter and Nanoscience Department, UCLouvain



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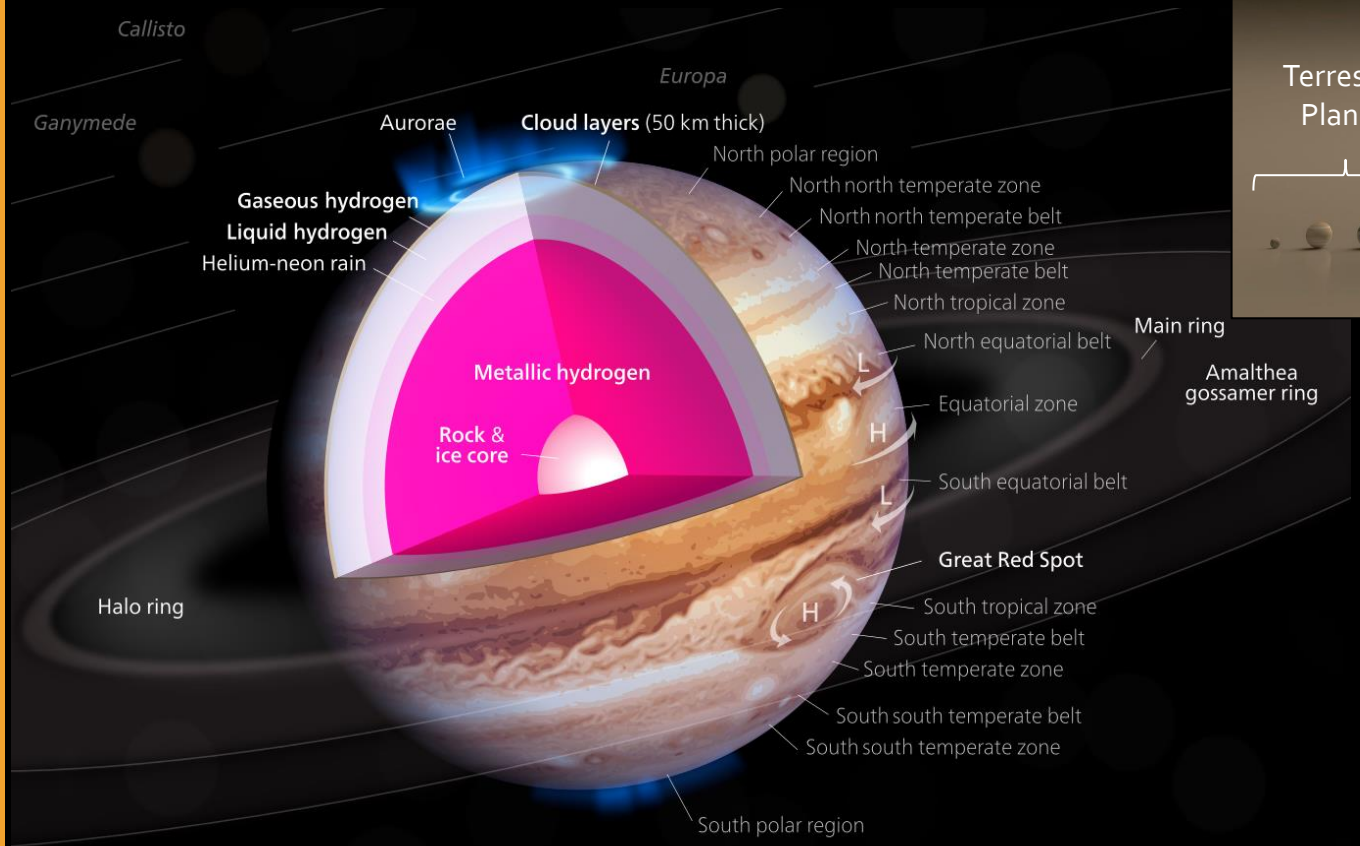
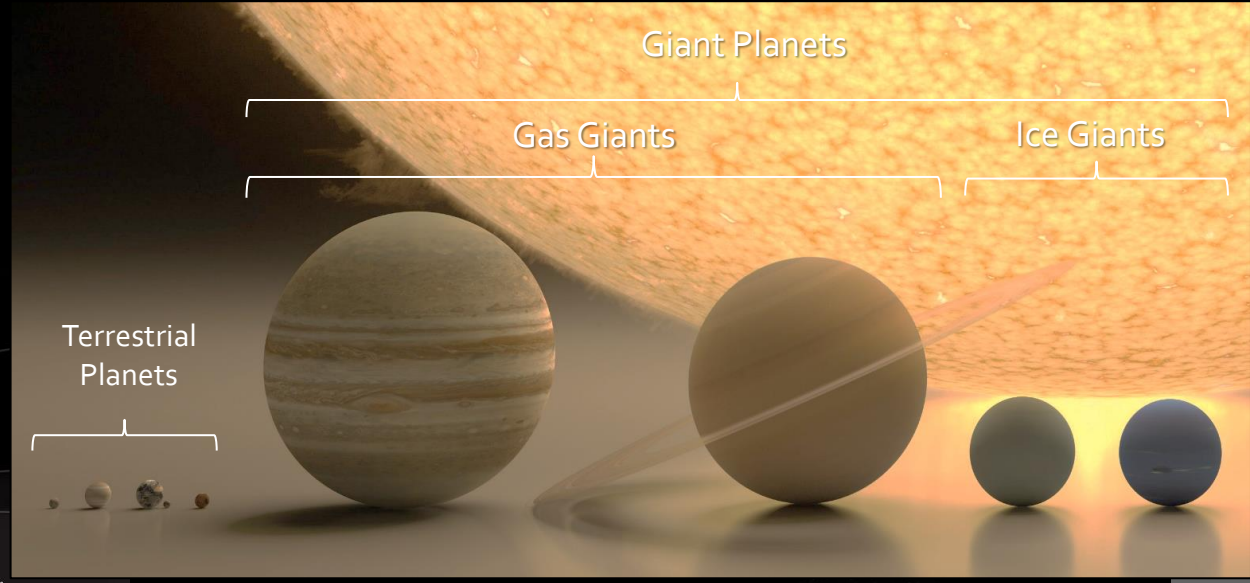
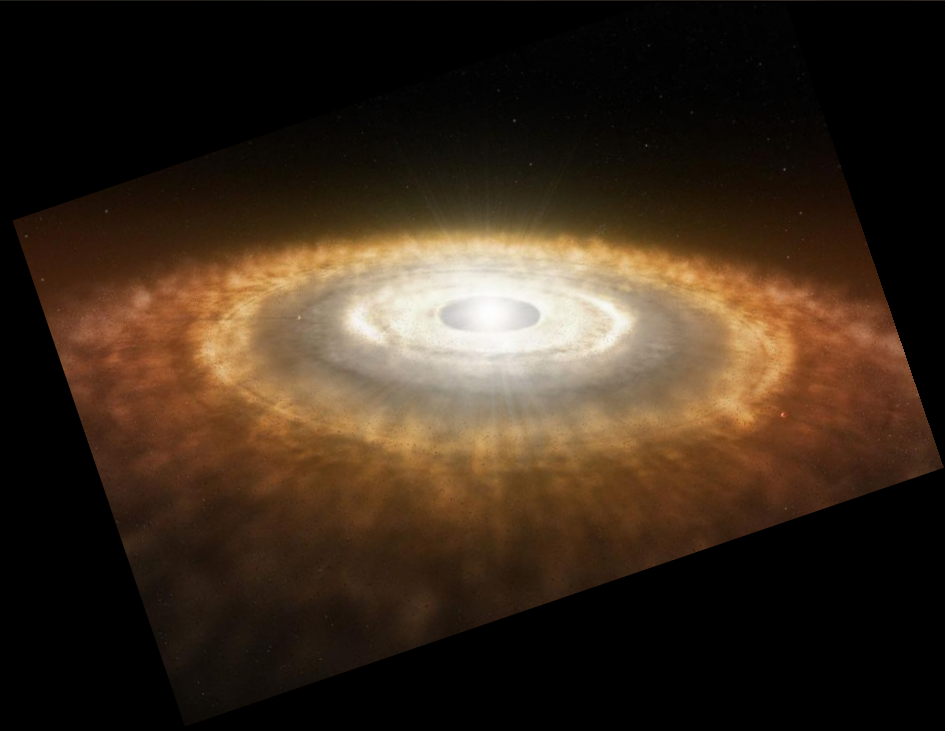
May 23rd 2024 – 22nd *Meeting of the Astronomie & Astrophysique contact group*

Jupiter, a Gas Giant Planet







Jupiter's Atmosphere

Species	VMR
H_2	0.86
He	0.136
CH_4	0.0018
NH_3	0.007
H_2O	>0.005
H_2S	77 ppm
Ne	20 ppm
Ar	16 ppm
HD	15 ppm
PH_3	0.5 ppm
CH_3D	0.3 ppm
Kr	7.6 ppb
CO	0.75 ppb
Xe	0.76 ppb
GeH_4	0.6 ppb
AsH_3	0.2 ppb

Main Building Blocks

H, He

The most abundant elements in the universe

Trace Elements

C, O, N, S, P

Volatiles

Photochemicals

C_2H_2, C_2H_6, C_3Hx, C_4Hx

Exogenic Contributions

Disequilibrium species

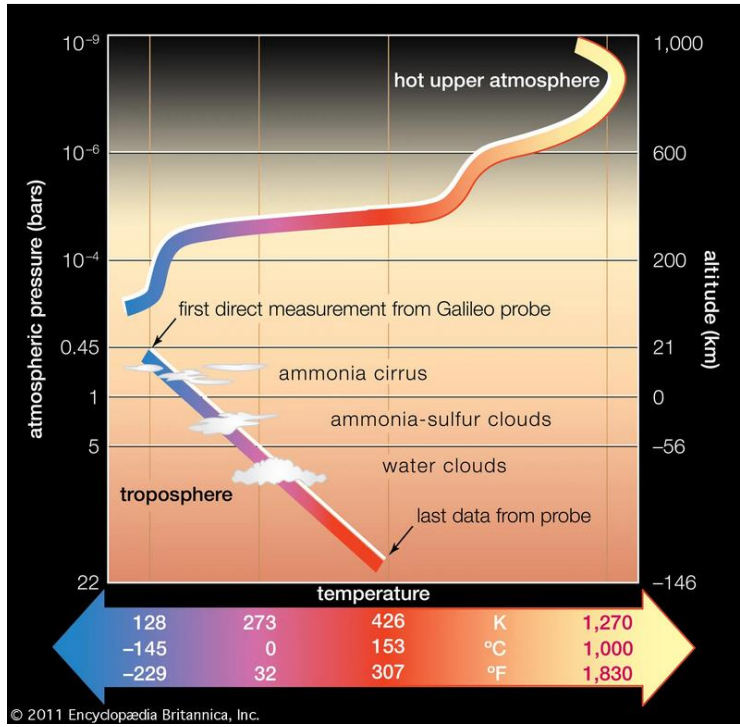
Mc Grath, et al., Cambridge University Press, Ed. 2004

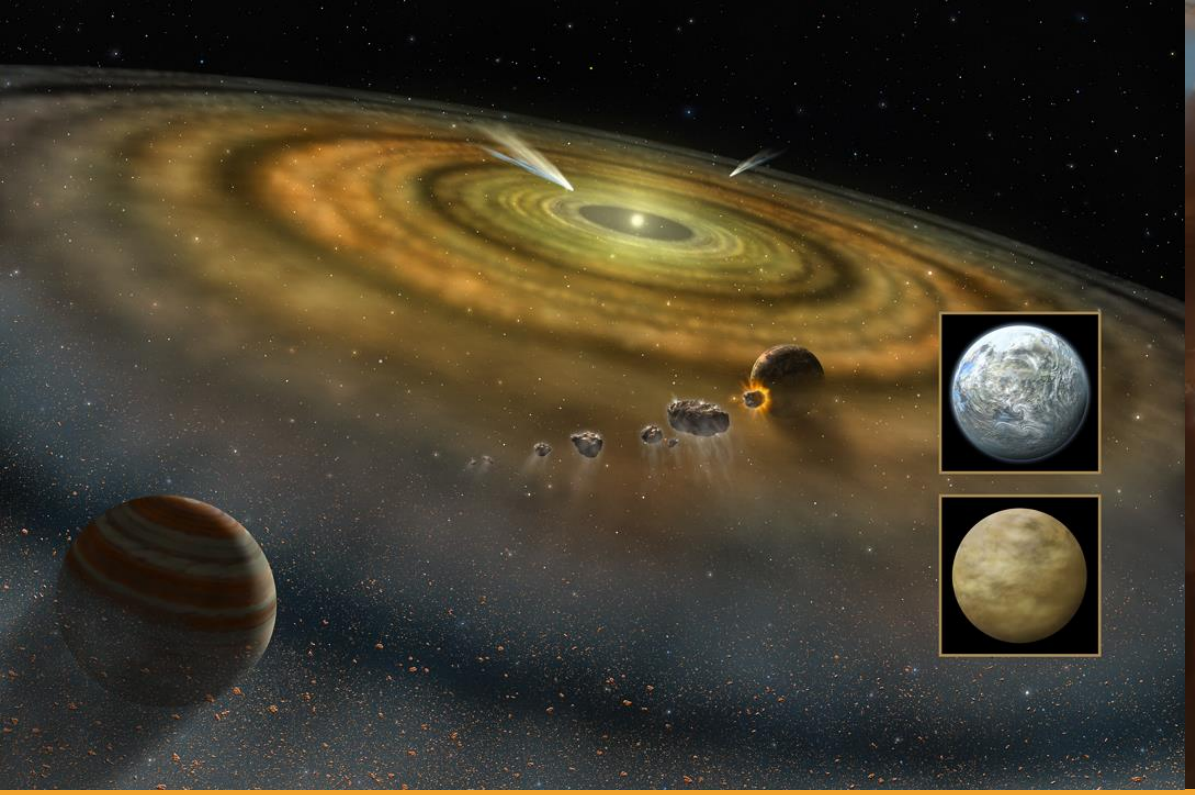
Main Consequences of the Circulation Mechanisms

- Clouds are not located at the altitude explained by the condensation theory
- Volatiles are not well mixed below the clouds
- The disequilibrium species do not always follow the expected patterns

From theory:

- CH_4 condensates @ 190K + 40atm



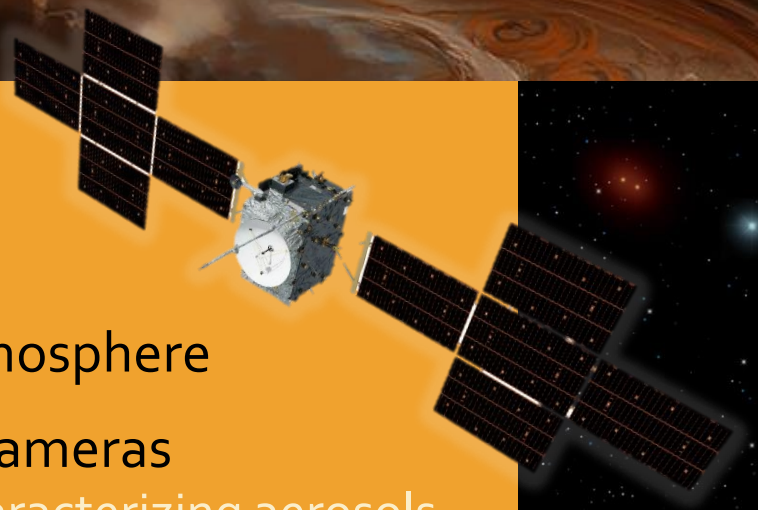


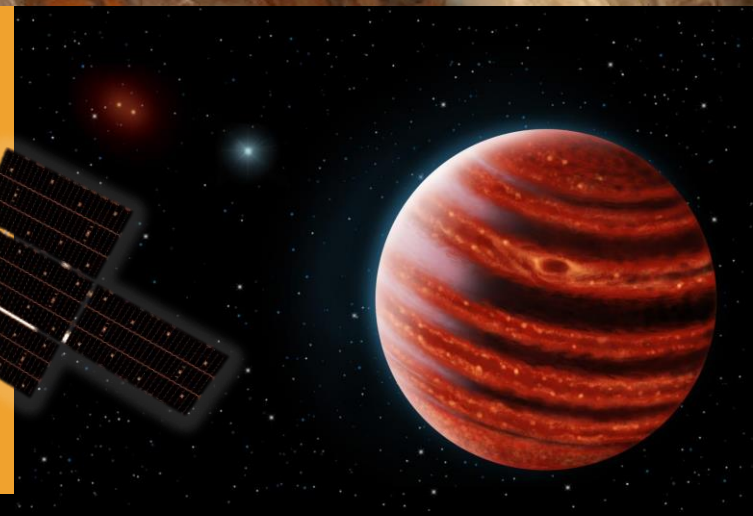
What do we need?

- Observational Data
- In-situ Measurements
- Radiative Transfer Models

In preparation to the JUICE mission

- Launch on April 2023 - Arrival in July 2031
- Detailed observations to characterize Jupiter's atmosphere
- 10 instruments on board including hyperspectral cameras
  - VIS-NIR range has the remarkable potential for characterizing aerosols



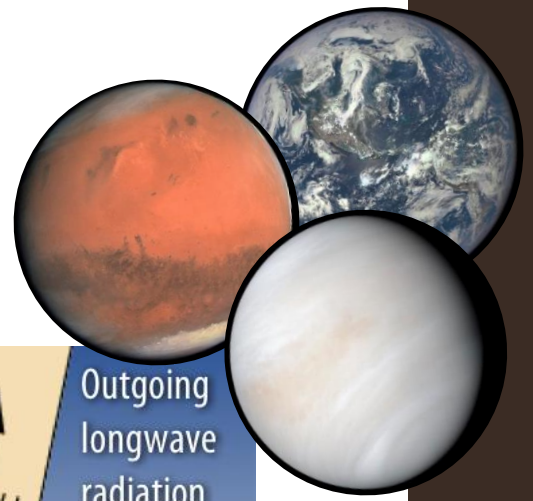


Radiative Transfer Model

ASIMUT-ALVL

A line-by-line Radiative Transfer (RT) code developed by BIRA-IASB that has been extensively used to characterize the atmospheres of Earth, Mars and Venus

A. C. Vandaele, et al., 2006



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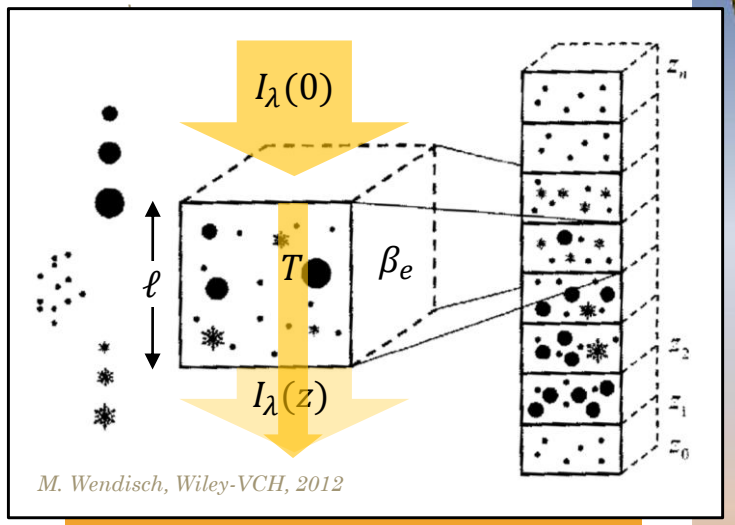
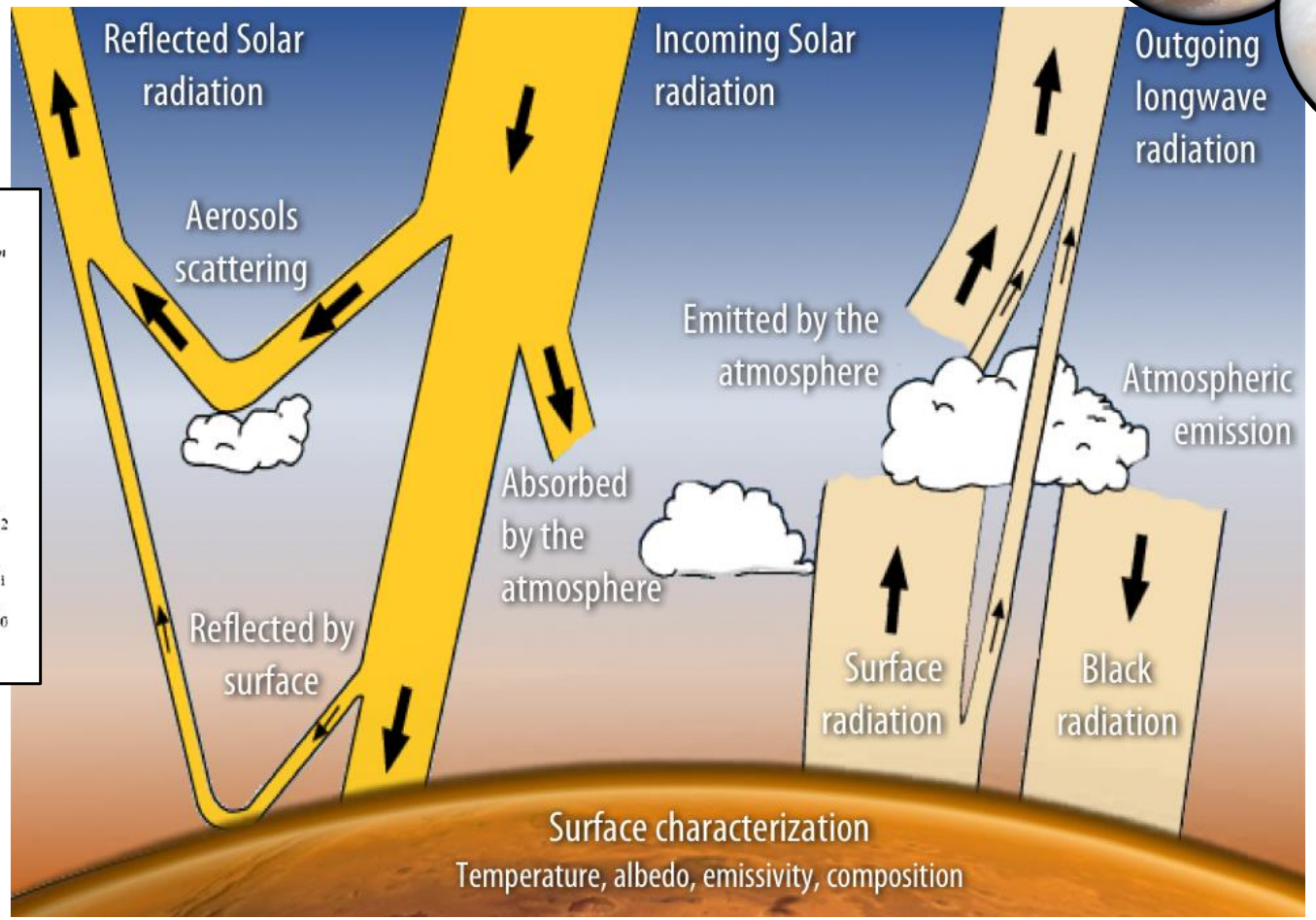


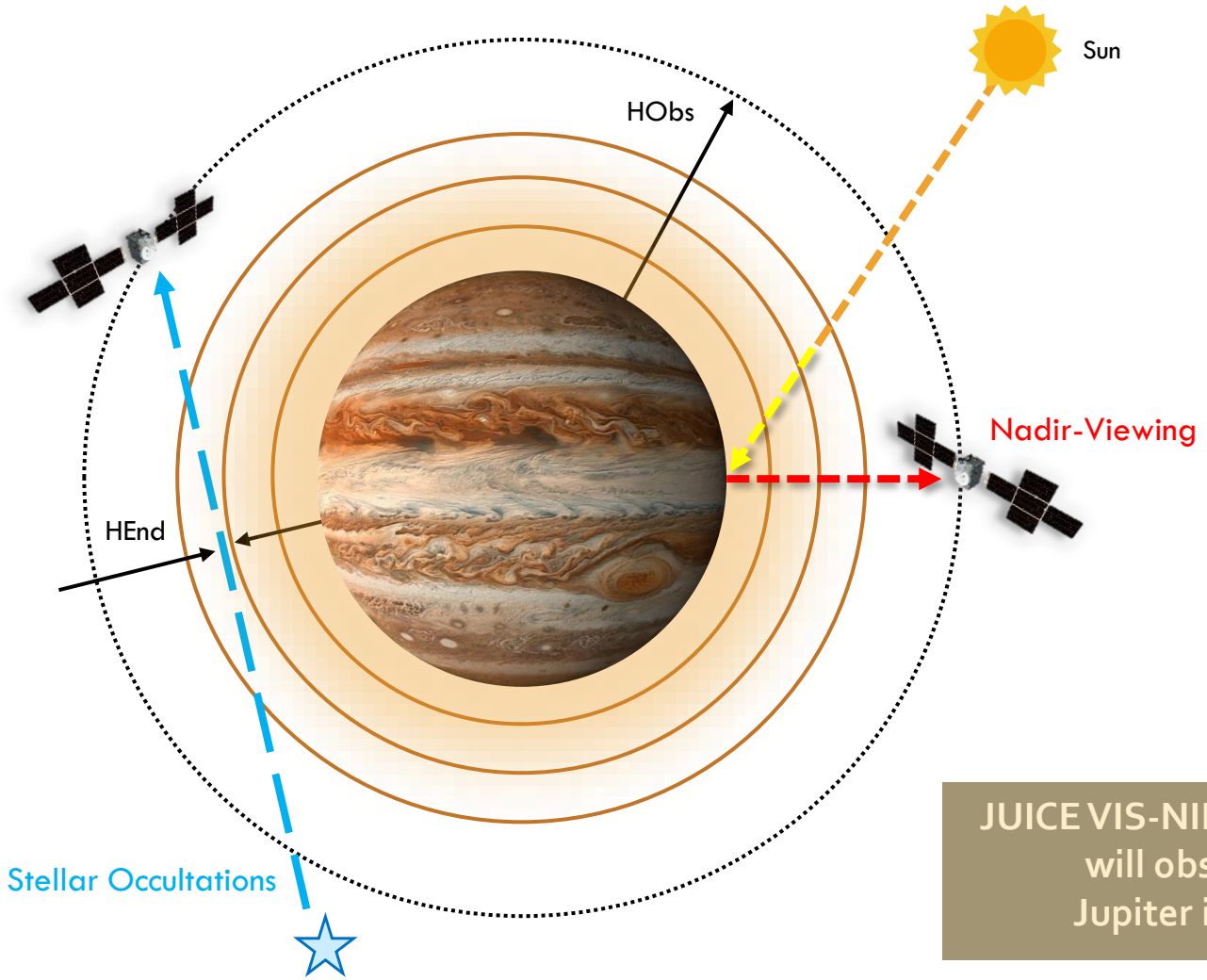
M. Wendisch, Wiley-VCH, 2012

How the energy is transferred during the propagation of light through a medium



Geometry of Observation

From where the light is coming and from where we measure it



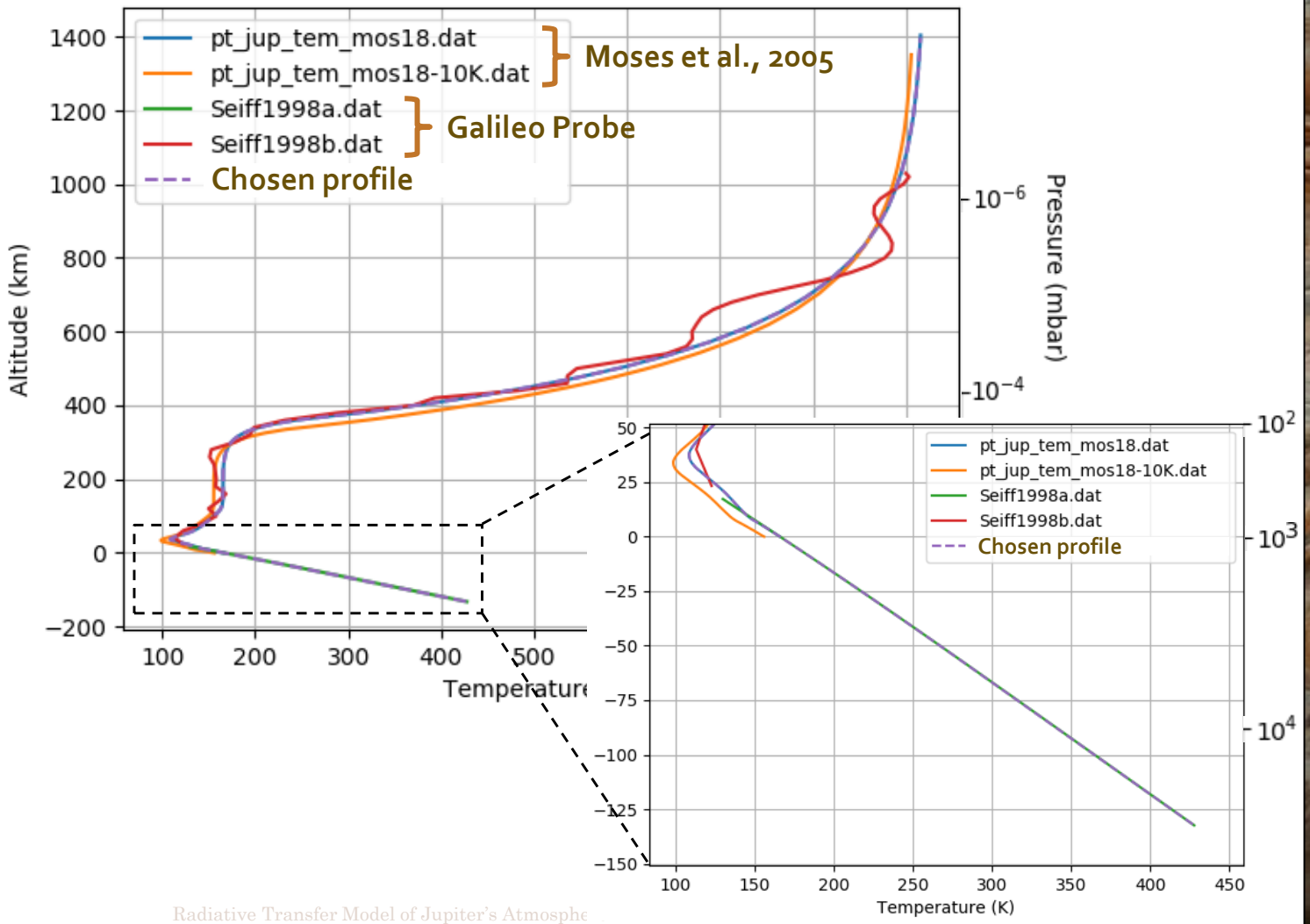
JUICE VIS-NIR spectrometer (MAJIS) will observe the atmosphere of Jupiter in these two geometries

Jupiter Properties

* Not at scale

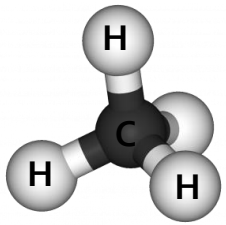
Main Physical Parameters of Jupiter	
Mean Radius	69911 km
Mean Distance from the Sun	5.2 AU
Mass	1.8982×10^{27} kg
Equatorial gravity	24.79 m/s^2
Bond Albedo	0.343
Molar Mass of Dry Air	2.3047 g/mol

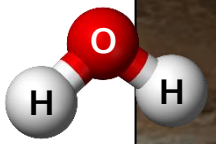
Bagenal et al., Cambridge University Press, 2004

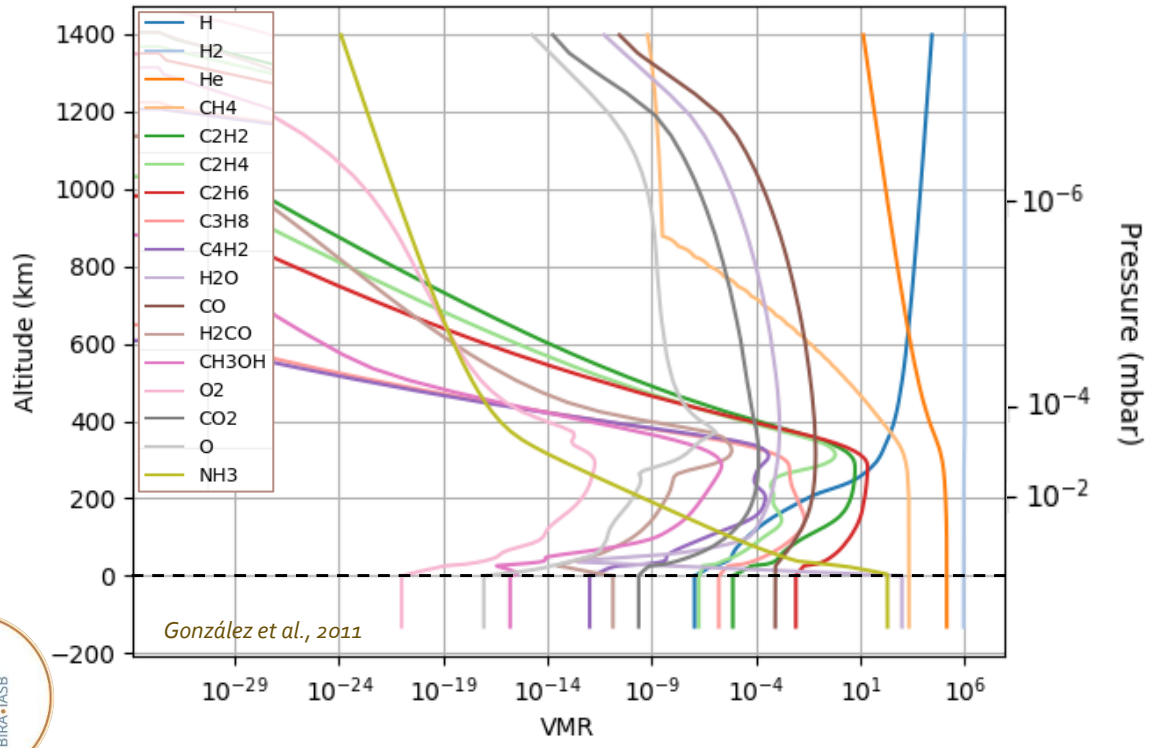


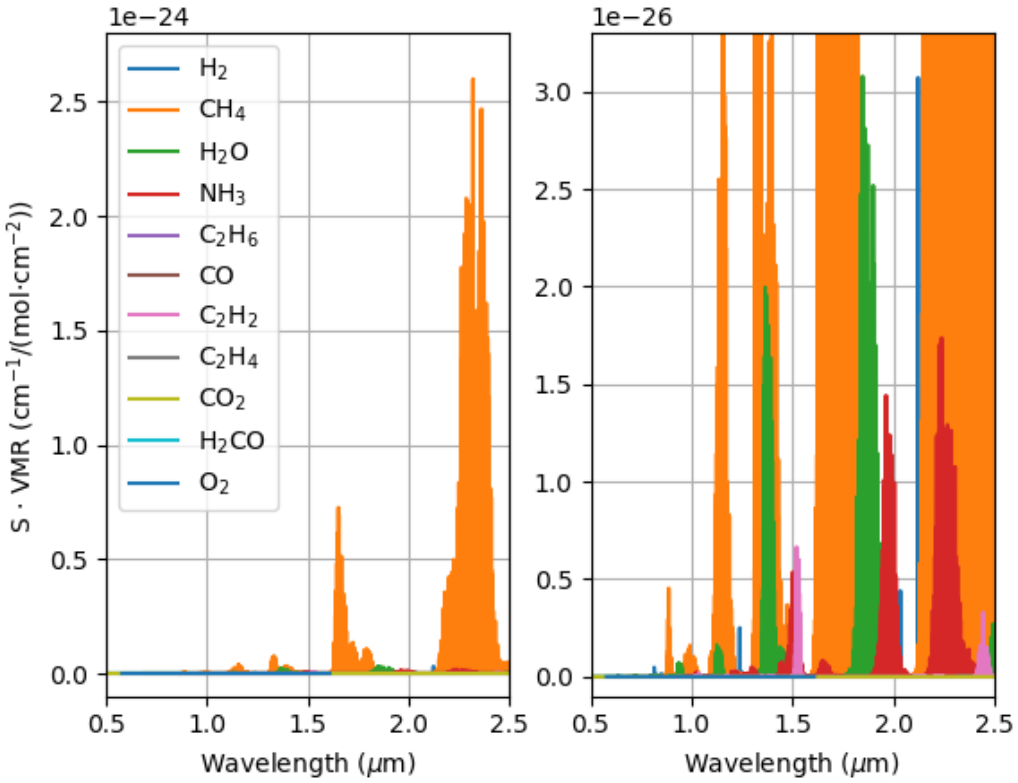
Jupiter's Atmospheric Composition

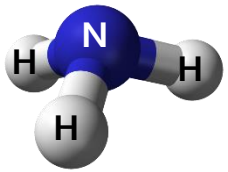
* Not at scale











Molecular Line Lists

HITRAN2020

Radiative Transfer Model

Jupiter's VIS-NIR spectrum

* Not at scale

Main Spectral Contributions

- **Molecular Bands**
  - CH_4 → Karkoschka et al. 2010
  - NH_3 → Coles et al. 2018 (ExoMol)
  - H_2O → Conway et al. 2020 (HITRAN2020)
- **Rayleigh Scattering**
  - H_2
  - He

$$\sigma = \frac{24\pi^3}{\lambda^4 N^2}\left(\frac{n^2-1}{n^2+2}\right)^2 F_k$$

Sneep et al., 2005

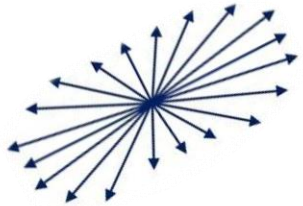
- **Mie Scattering**
  - Clouds
  - Hazes

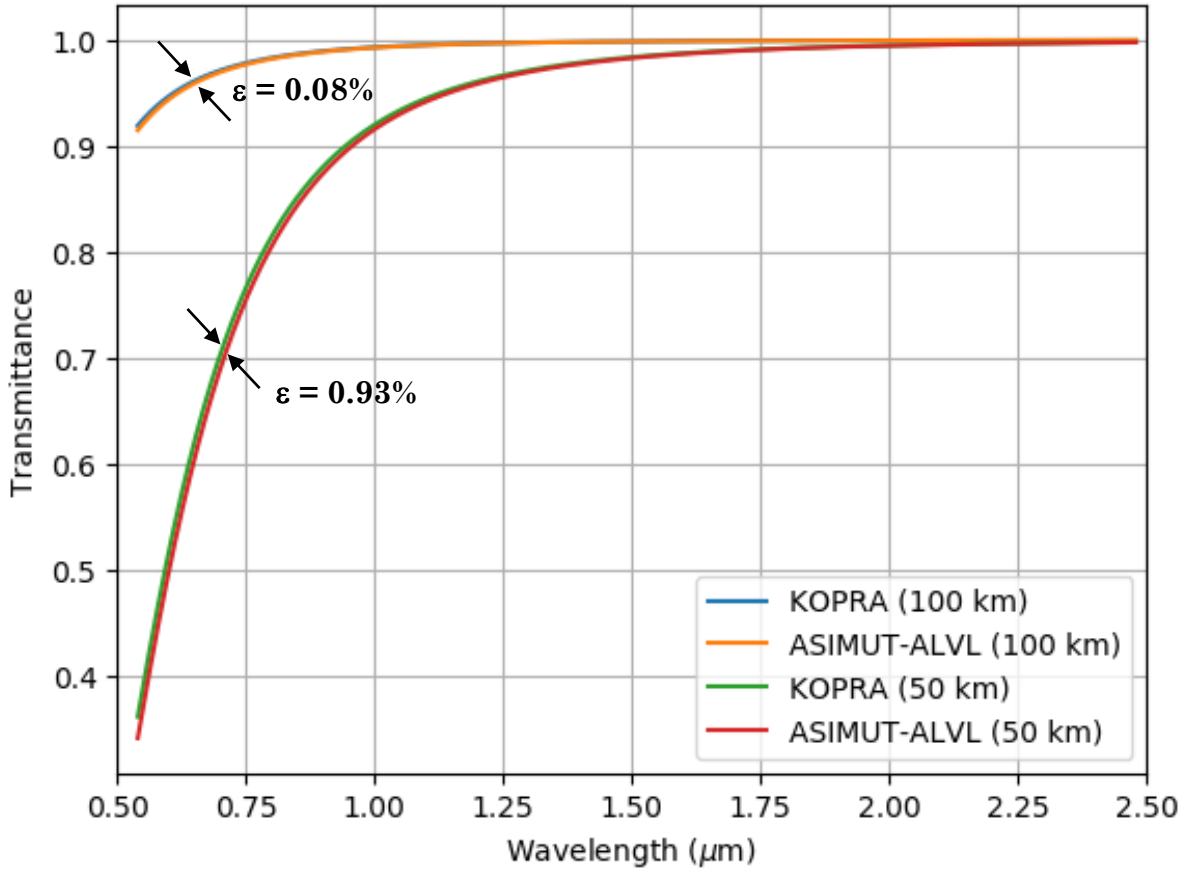
→ Baines et al., 2019 (Crème Brulée model)

- **Collision-Induced Absorption**
  - H_2-H_2 → Abel et al. 2011 (150 K)
  - H_2-He → Abel et al. 2012 (200 K)

Rayleigh Scattering

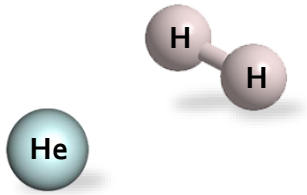
Scattering by particles much smaller than the wavelength of radiation



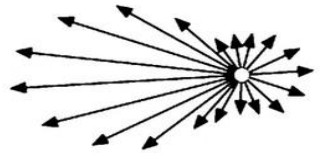


KOPRA IAA

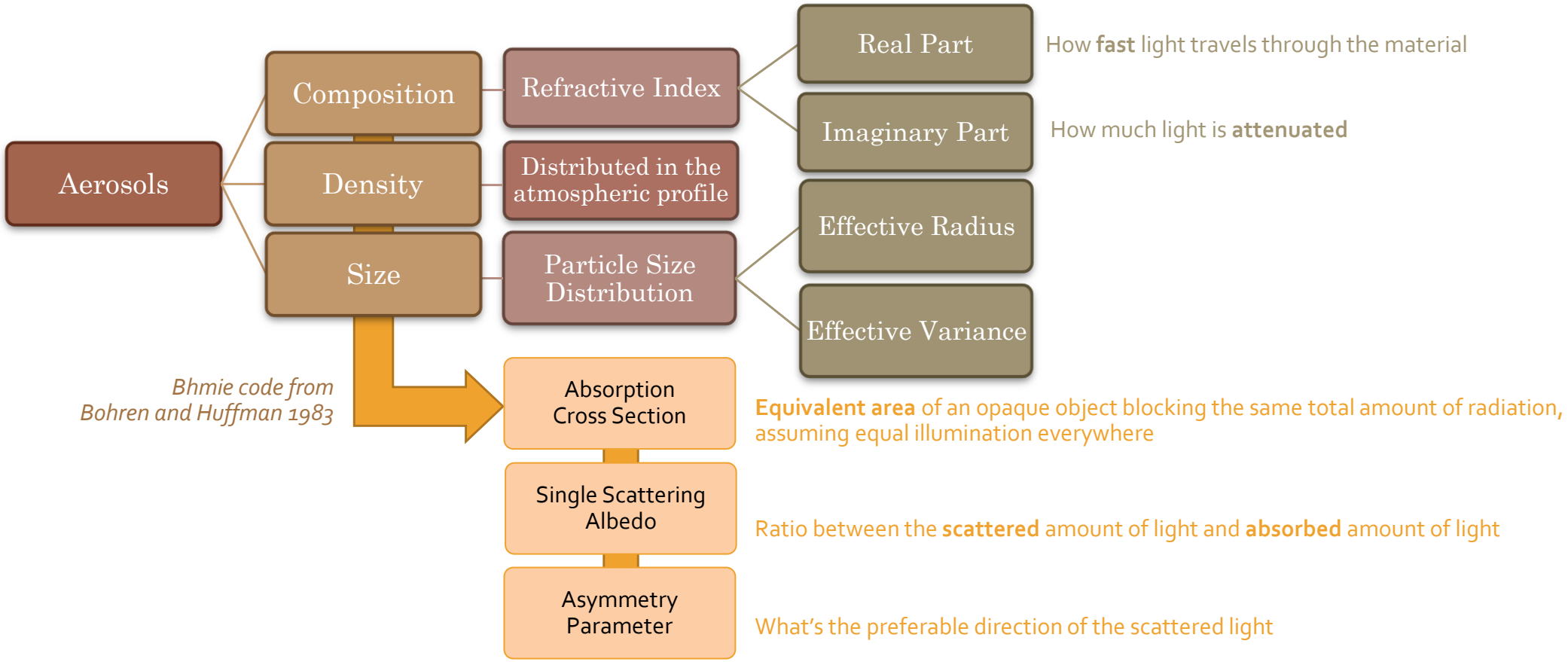
ASIMUT-ALVL



Mie Scattering



Scattering by particles <u>much smaller</u> than the wavelength of radiation

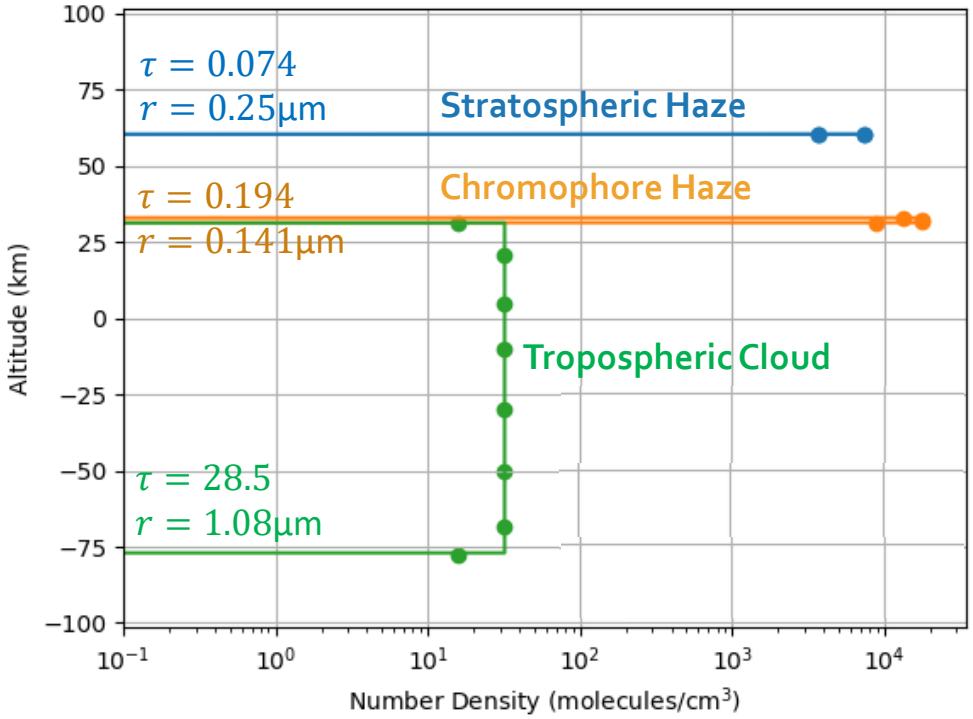


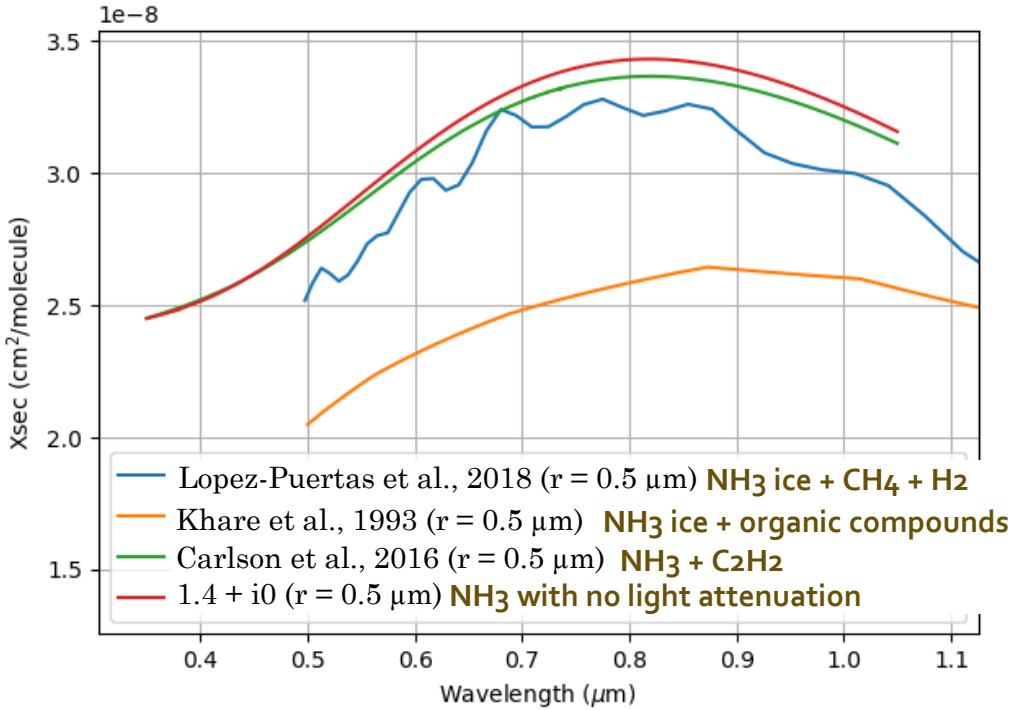
The *Crème Brulee* model

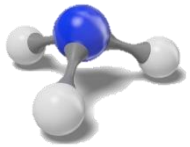
From Baines et al., 2019

Chromophores

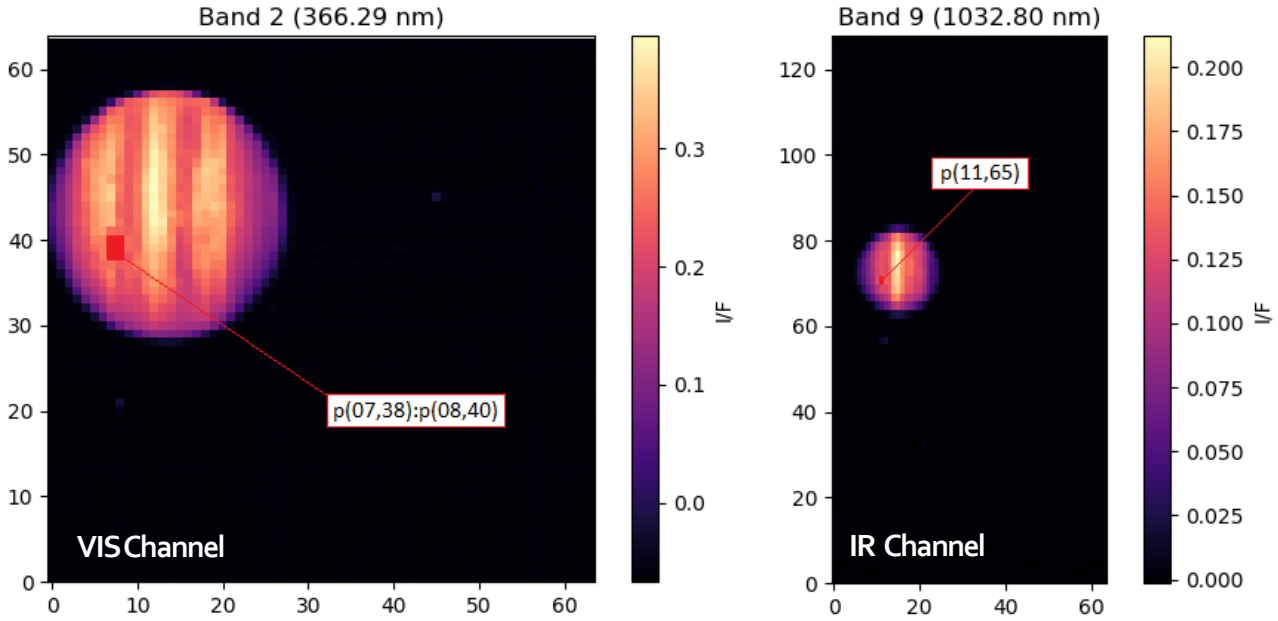
The responsible for coloration of clouds as result of vertical motions that lift material to the troposphere where photochemical reactions can occur

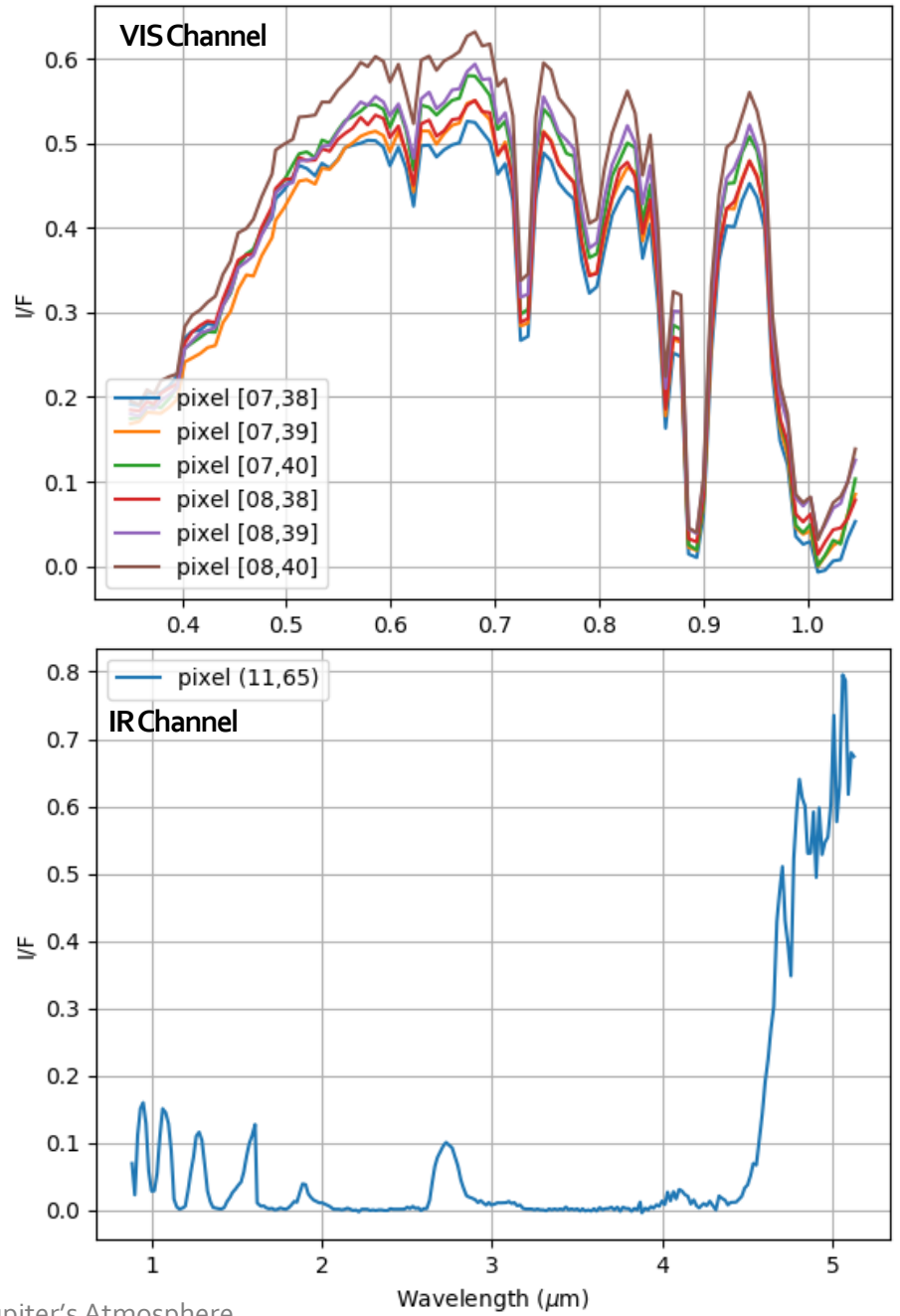






Observational data from Cassini/VIMS





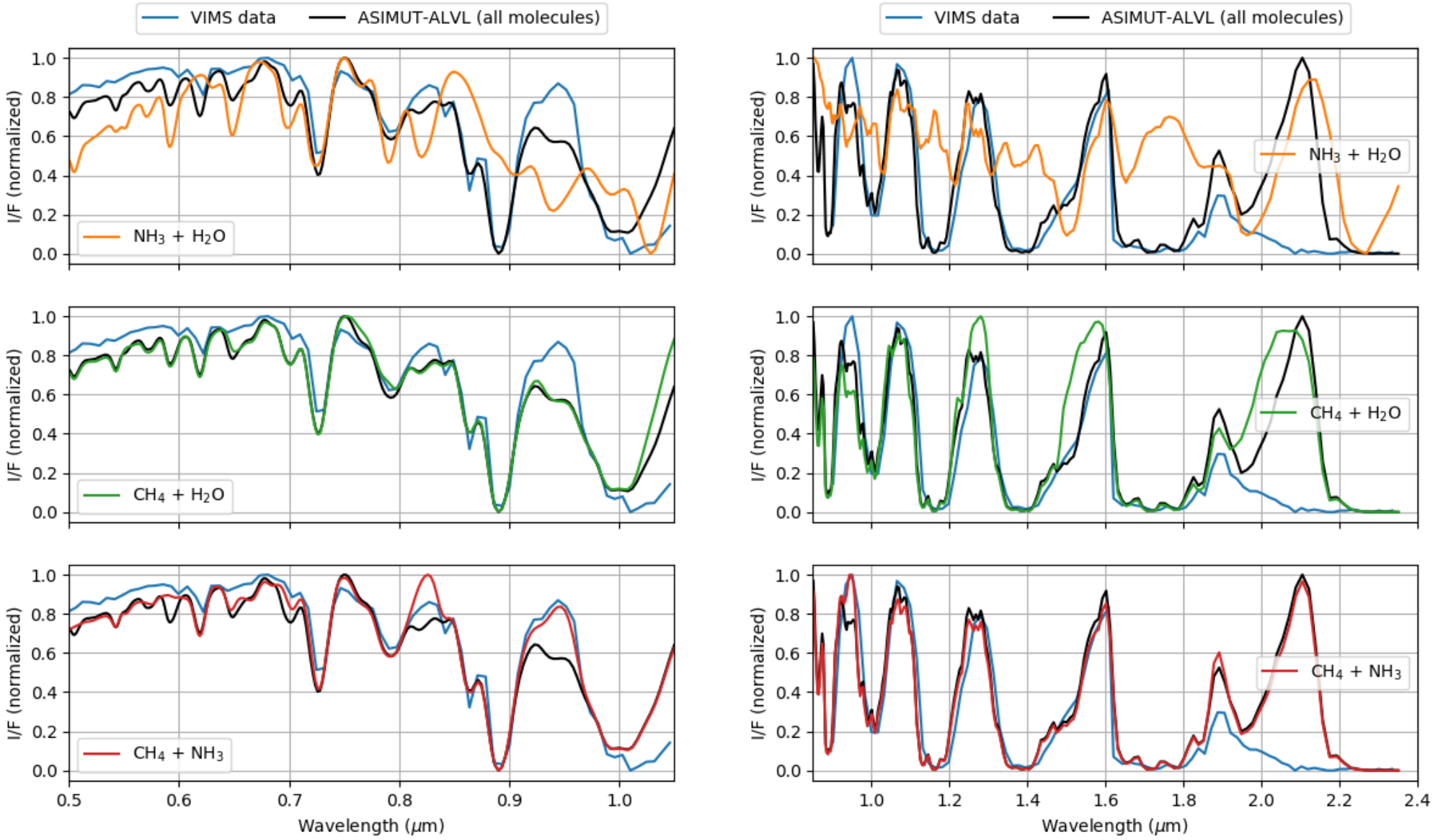
Performances	VIS channel	IR channel
Spectral range	0.35-1.05μm	0.85-5.1μm
Spectral resolution	1.46nm	16.6nm
Signal to Noise Ratio	100	100

Observation Geometry	
Distance from Jupiter	28×10^6km
Phase angle (nadir)	11.4°

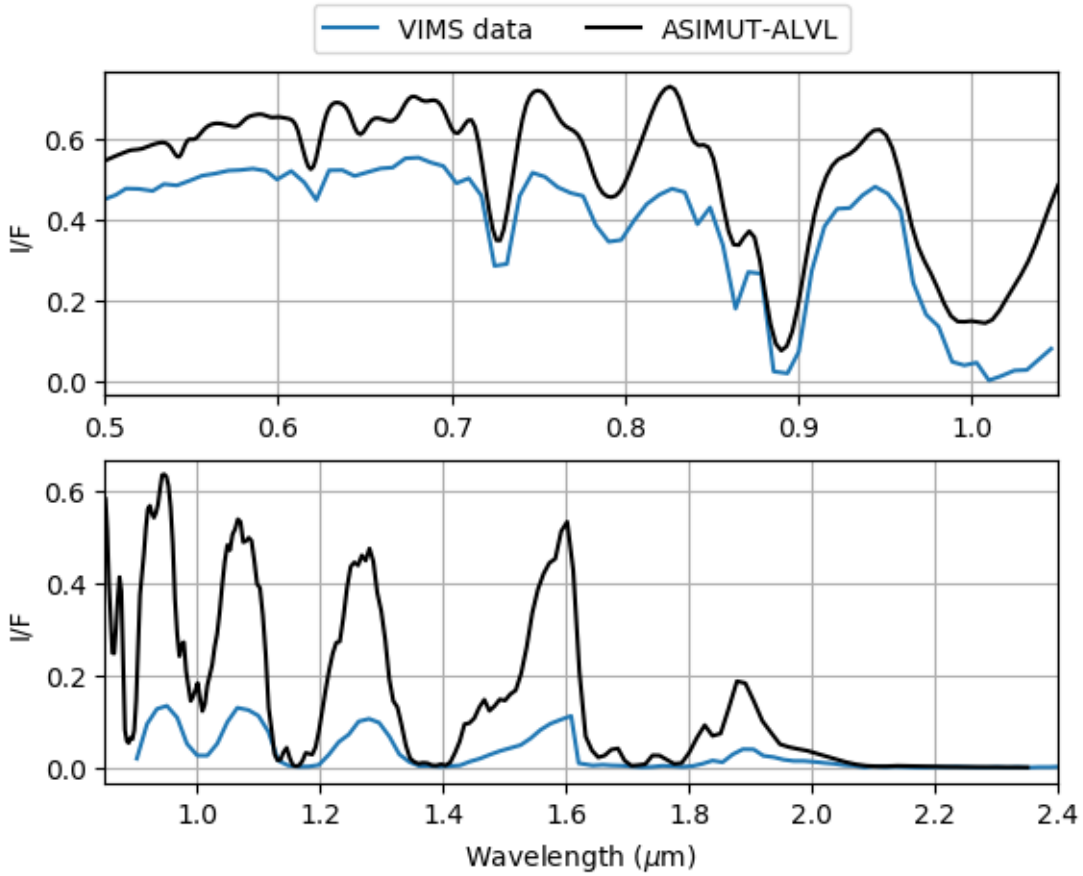
Reflectance relative to a diffuse surface

$$I/F = \frac{\text{Observed Radiance}}{\text{Solar Radiance}}$$

Comparison against observational data



Final Results and Conclusions



- The radiative transfer model of Jupiter's atmosphere in ASIMUT-ALVL was completed with the different spectral contributions at the VIS-NIR wavelength:
  - CH_4 and NH_3
  - Rayleigh and Mie scattering
  - CIA due to H_2-H_2
- The model was successfully validated:
  - Against KOPRA
  - Against Cassini/VIMS data
- The developed Radiative Transfer model of Jupiter's atmosphere can be used to perform simulations of the Jovian atmosphere, as observed by different instruments
  - Especially MAJIS on board JUICE
- Our RT code will be used to assess the capabilities of the VIS-NIR spectrograph on board of the next mission to the Jovian system JUICE, supporting the scientific activities of the MAJIS Team

Thank you for your attention

Miriam Estefanía Cisneros González

miriam.cisneros@aeronomie.be