# Detection of Water In The Jupiter System With a Submm Wave Instrument

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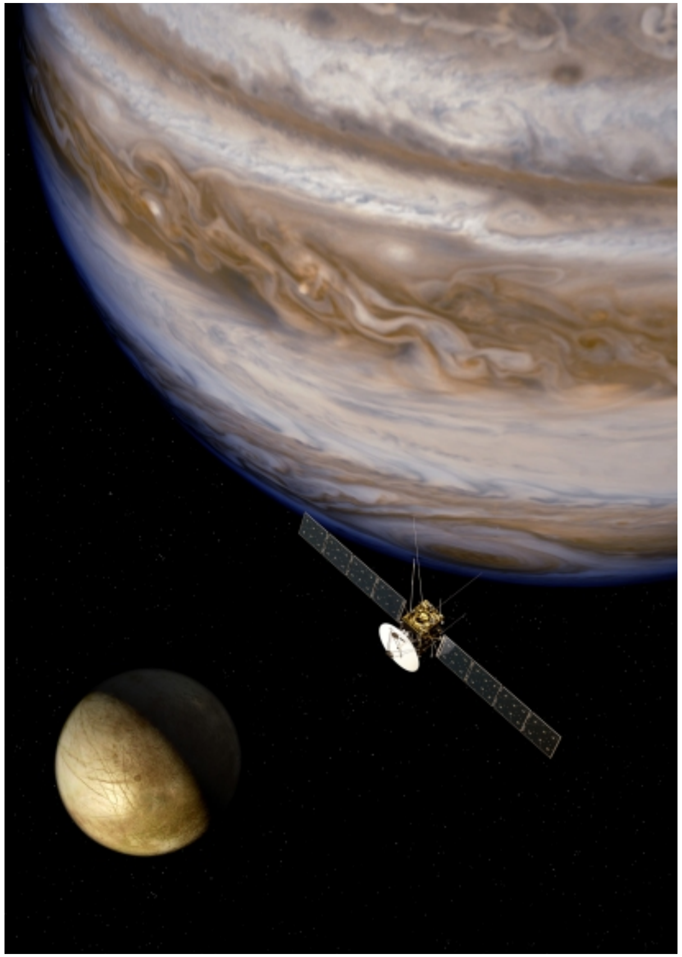
# Contributions from

- Germany (MPS/RPG)
- China (PMO)
- France (LERMA, LESIA)
- Japan (NICT)
- Poland (CBK)
- Russia (IKI, Phystech, Scontel)
- Sweden (Chalmers, Omnysis)
- Switzerland (IAP)

# **JU**piter **IC**y Moons **E**xplorer

**ESA's first Large Class mission (L1) of the Cosmic Vision 2015 – 2025 Program**

**Launch (baseline): 30 May 2022**
**Cruise Time: 7.5 years**
**Science Mission duration: 4 years (Nov. 2033)**



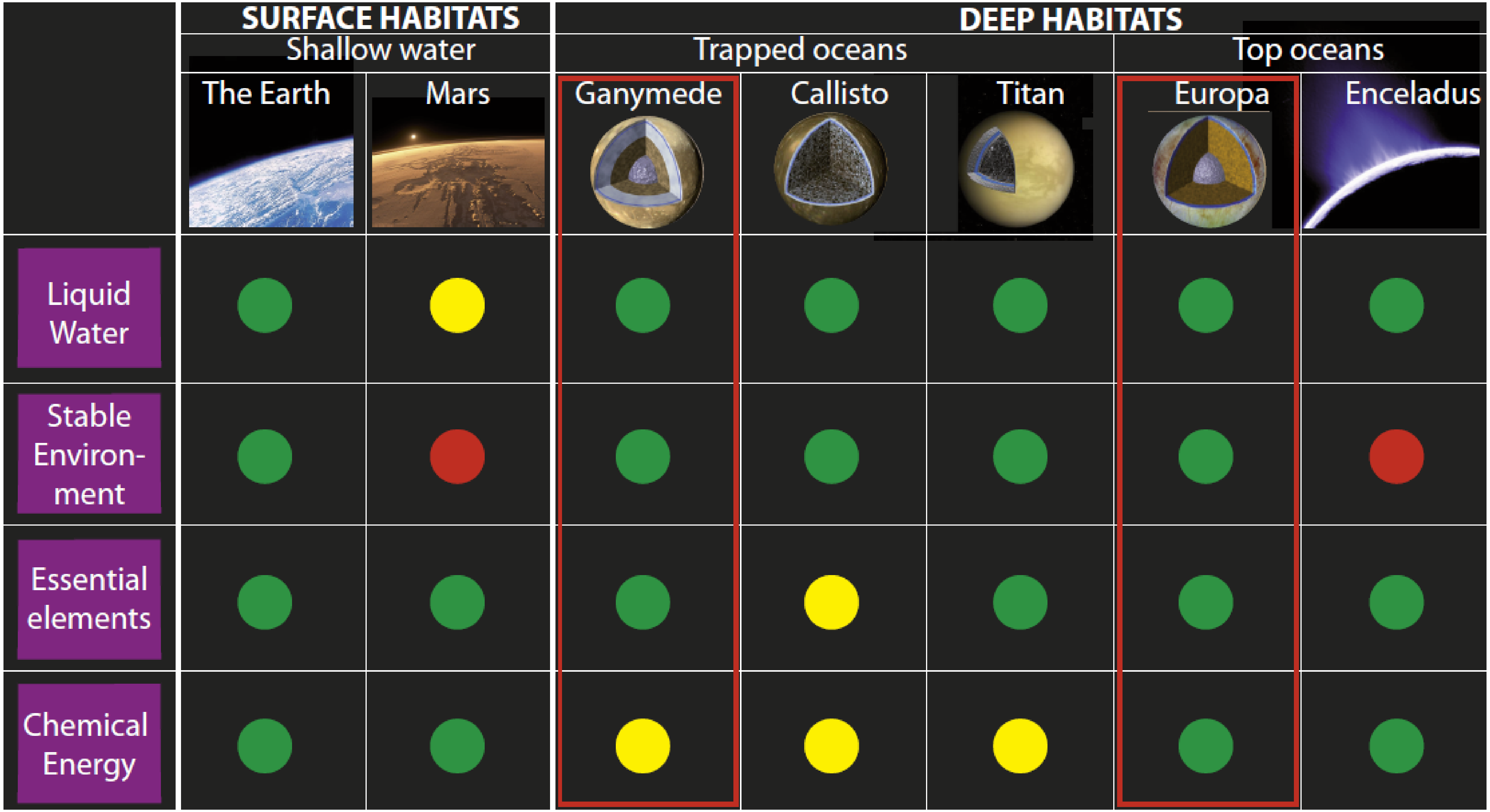
**Science Payload: 10 PI Instruments**

| | |
|---|---|
| **3GM:** | **Radio Science** |
| **GALA:** | **Ganymede Laser Altimeter** |
| **JANUS:** | **Camera System** |
| **J-MAG:** | **Magnetometer** |
| **MAJIS:** | **Infrared Imaging Spectrometer** |
| **PEP:** | **Particle Environment Package** |
| **RIME:** | **Subsurface Radar (9 MHz)** |
| **RPWI:** | **Radio & Plasma Wave Investigation** |
| ***SWI:*** | ***Submillimeter Wave Heterodyne Spectrometer*** |
| **UVS:** | **Ultraviolet Imaging Spectometer** |
| | |
| **PRIDE:** | **VLBI (no hardware)** |

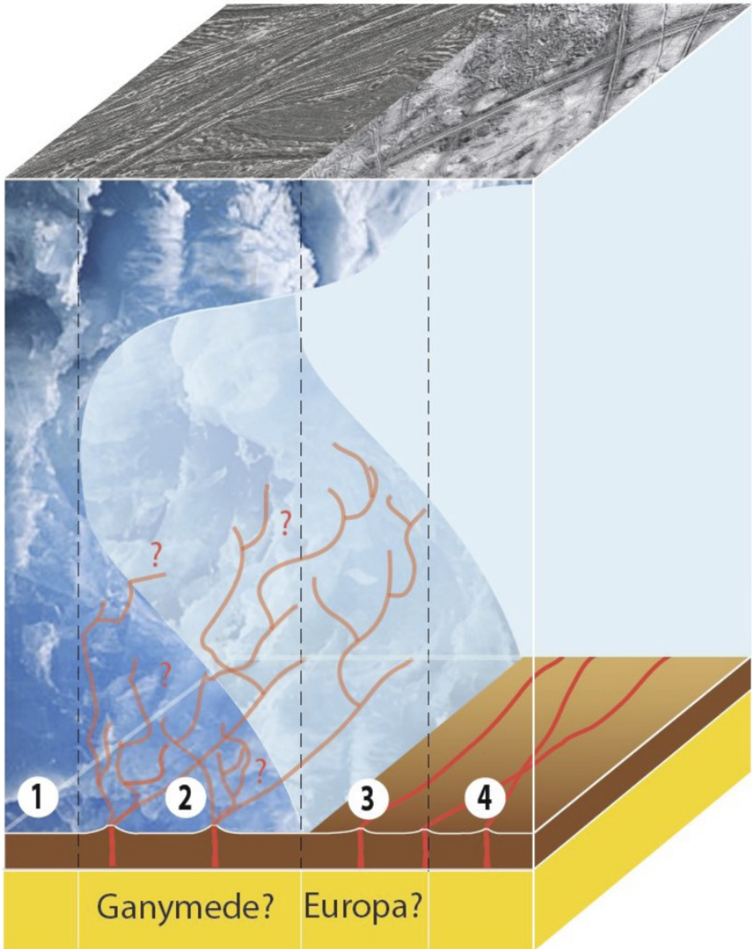
# JUICE Science Goals

| Goals | Science objectives | |
|---|---|---|
| **Exploration of the habitable zone: Ganymede, Europa, and Callisto** (*Section 3.1*) | **Characterise Ganymede as a planetary object and possible habitat** (*Sections 4.1 & 5.1.1*) | Characterise the extent of the ocean and its relation to the deeper interior |
| | | Characterise the ice shell |
| | | Determine global composition, distribution and evolution of surface materials |
| | | Understand the formation of surface features and search for past and present activity |
| | | Characterise the local environment and its interaction with the jovian magnetosphere |
| | **Explore Europa's recently active zones** (*Sections 4.1 & 5.1.2*) | Determine the composition of the non-ice material, especially as related to habitability |
| | | Look for liquid water under the most active sites |
| | | Study the recently active processes |
| | **Study Callisto as a remnant of the early jovian system** (*Sections 4.1 & 5.1.3*) | Characterise the outer shells, including the ocean |
| | | Determine the composition of the non-ice material |
| | | Study the past activity |

# Habitability in the solar system



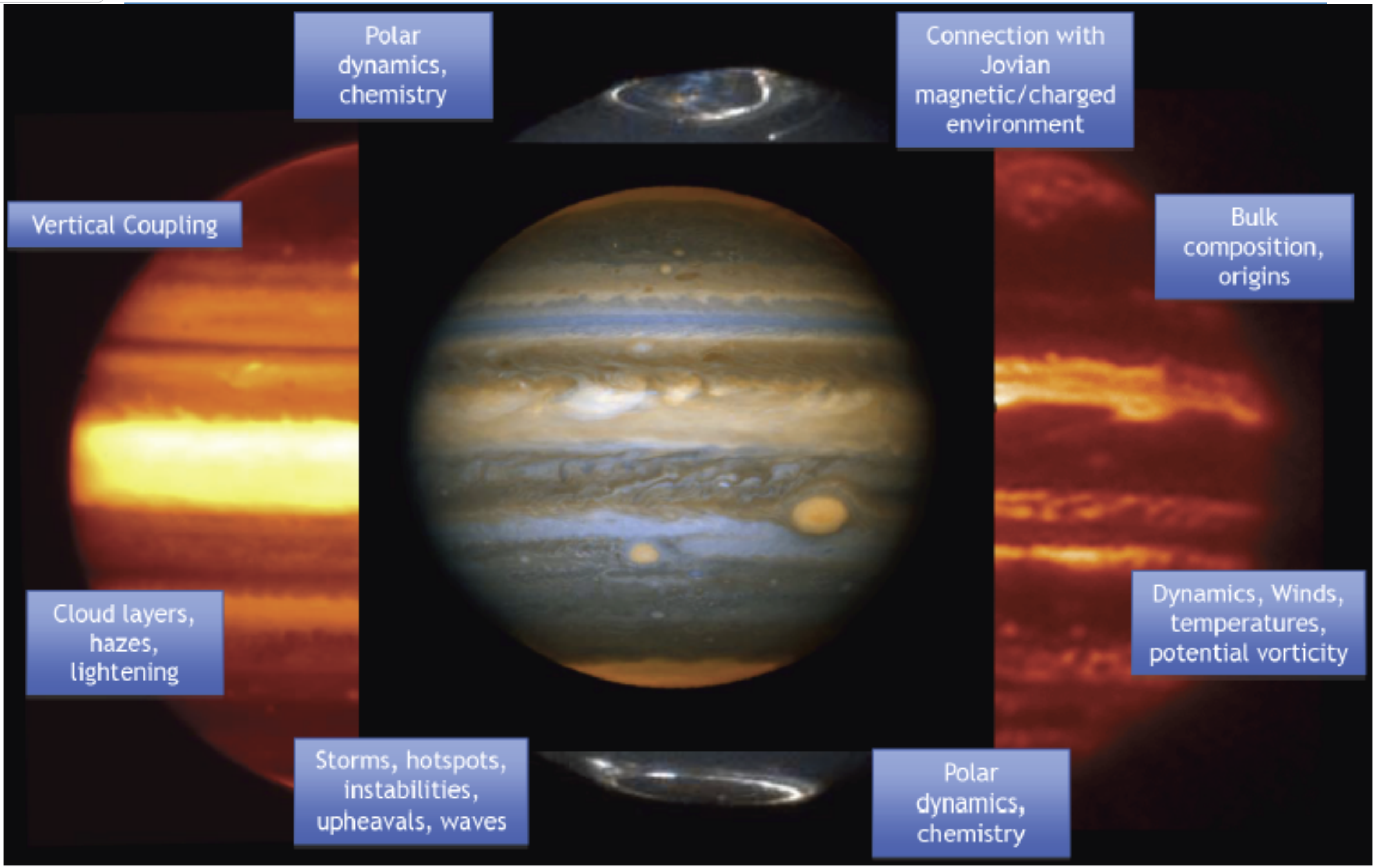
# Ices & Oceans



# JUICE Science Goals

| | | |
|---|---|---|
| **Explore the Jupiter system as an archetype for gas giants** (*Section 3.2*) | **Characterise the Jovian atmosphere** (*Sections 4.2 & 5.2.1*) | Characterise the atmospheric dynamics and circulation |
| | | Characterise the atmospheric composition and chemistry |
| | | Characterise the atmospheric vertical structure |
| | **Explore the Jovian magnetosphere** (*Sections 4.3 & 5.2.2*) | Characterise the magnetosphere as a fast magnetic rotator |
| | | Characterise the magnetosphere as a giant accelerator |
| | | Understand the moons as sources and sinks of magnetospheric plasma |
| | **Study the Jovian satellite and ring systems** (*Sections 4.4 & 5.2.3*) | Study Io's activity and surface composition |
| | | Study the main characteristics of rings and small satellites |

# Jupiter atmospheric science



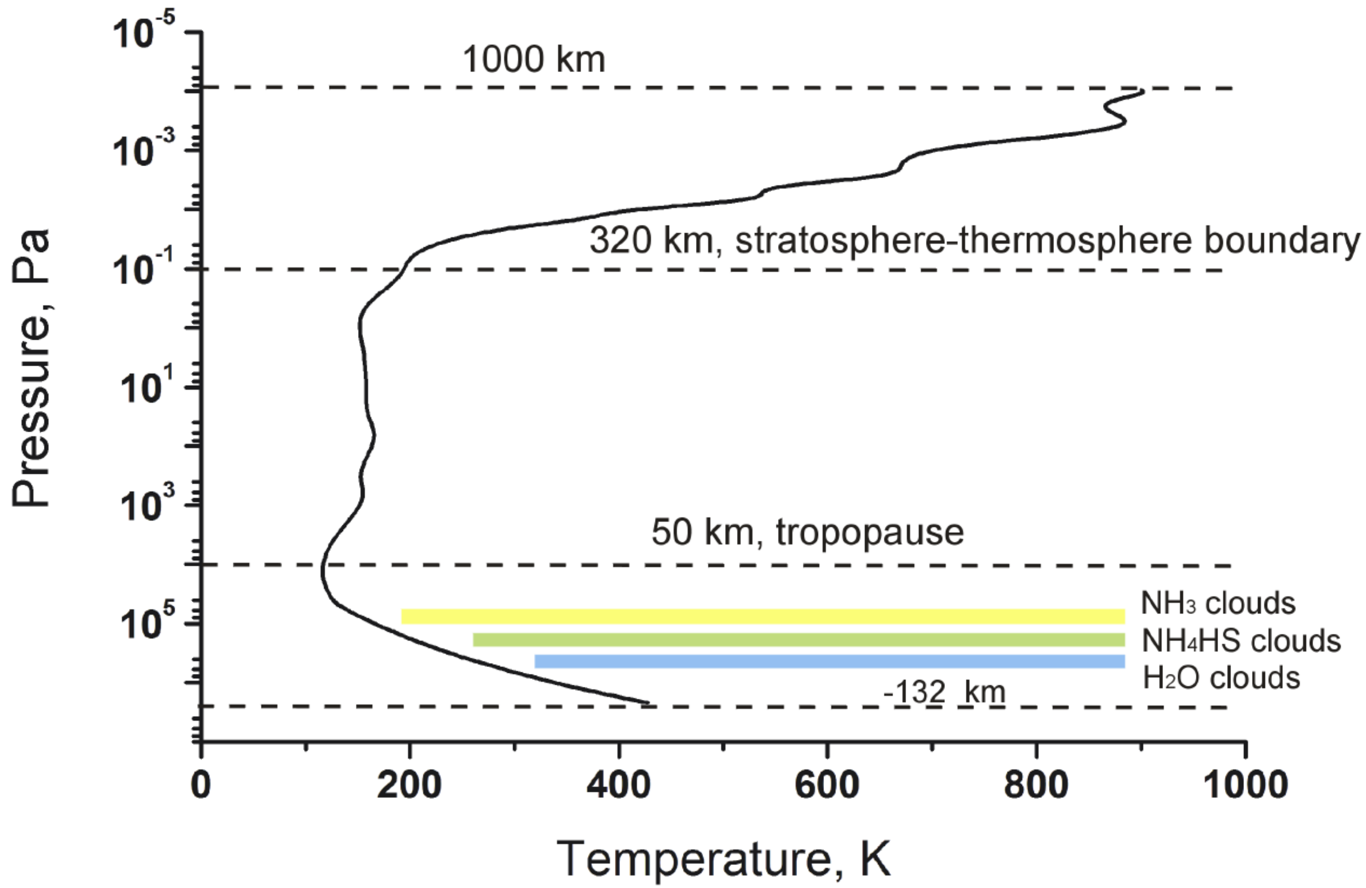
# SWI Science Goals

- Explore the structure, dynamics and composition of the Jovian stratosphere
- Structure, dynamics and composition of atmospheres/exospheres of Galilean satellites
- Search for plumes
- Origins: Important isotopes in the atmospheres of Jupiter, Europa, Ganymede and Callisto
- Origins: Ortho-to-para ratio of water
- Thermophysical properties of Ganymede's and Callisto's surfaces

# SWI Water Observations

- 3-d distribution in Jovian stratosphere: what is the source (comets, IDP, rings,…) of water and how is it transported?
- Multiple $H_2O$ line detection (+ $CH_4$ & HCN) for temperature/ wind retrievals in Jupiter
- HDO, $H_2O^{16}$, $H_2O^{17}$, $H_2O^{18}$ and OPR Jupiter&GS
- Water atmospheres and exospheres of GS: structure, distribution, hydrodynamics and kinetics.
- Source of the water in GS atmospheres (sputtering, sublimation, cryovolcanism, interaction with IDPs, ….?)
- Limb scanning from circular orbits & flybys.
- Monitoring of GS atmospheres from Jupiter orbit.

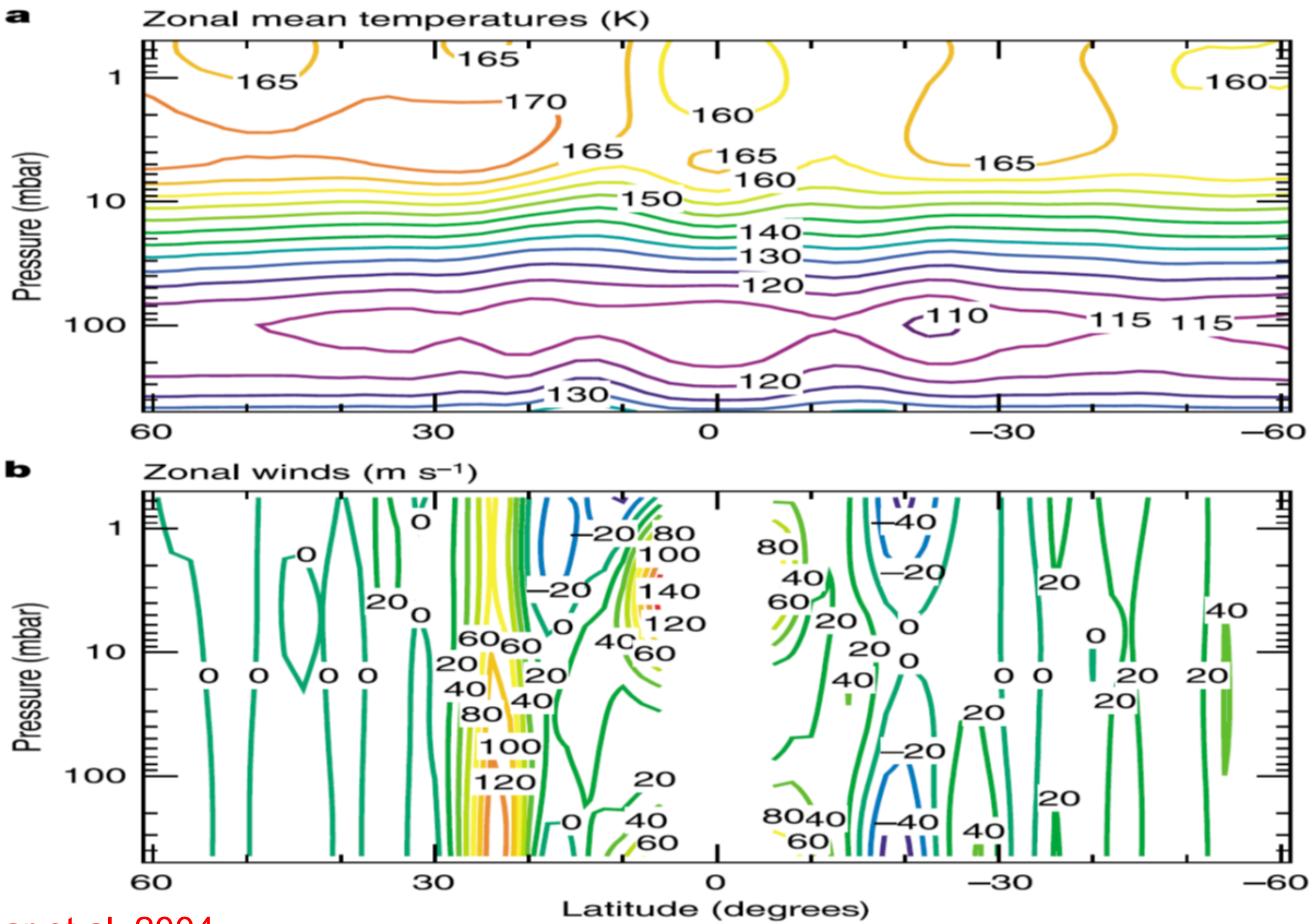
# Structure of the Jupiter's atmosphere



# Jupiter's middle atmosphere

- *Couples deeper tropospheric layers with the upper atmosphere*
- *Structure, circulation and composition poorly determined*
- *No cloud tracer, i.e. no direct wind measurements so far*
- *Ground-based observations and Voyager/Cassini provide:*
  - *temperature fields and thermal winds except around the equator*
  - *long term temperature variations (QQO)*

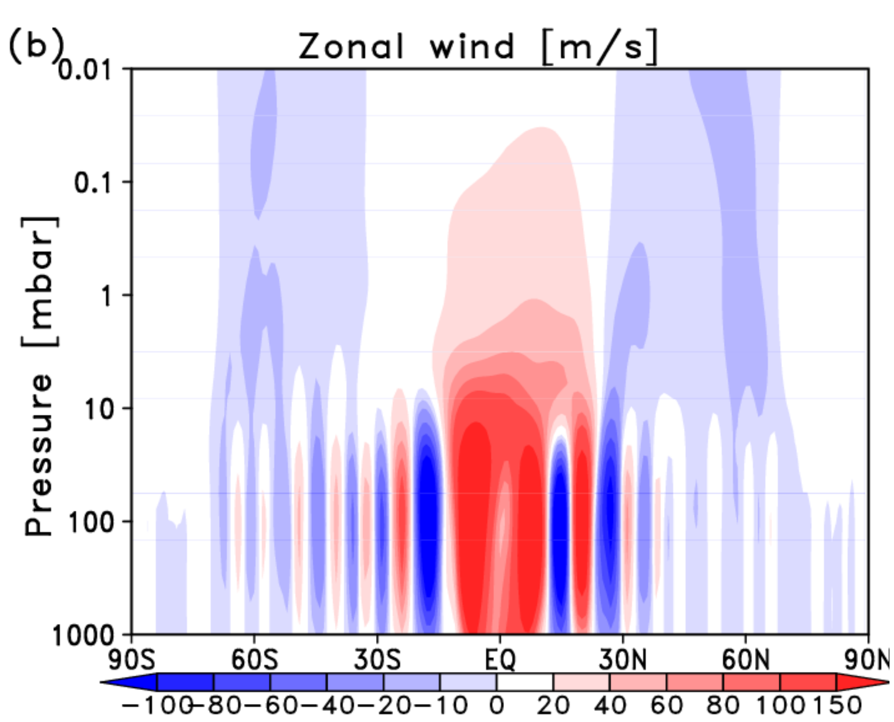
# CIRS temperatures and thermal winds

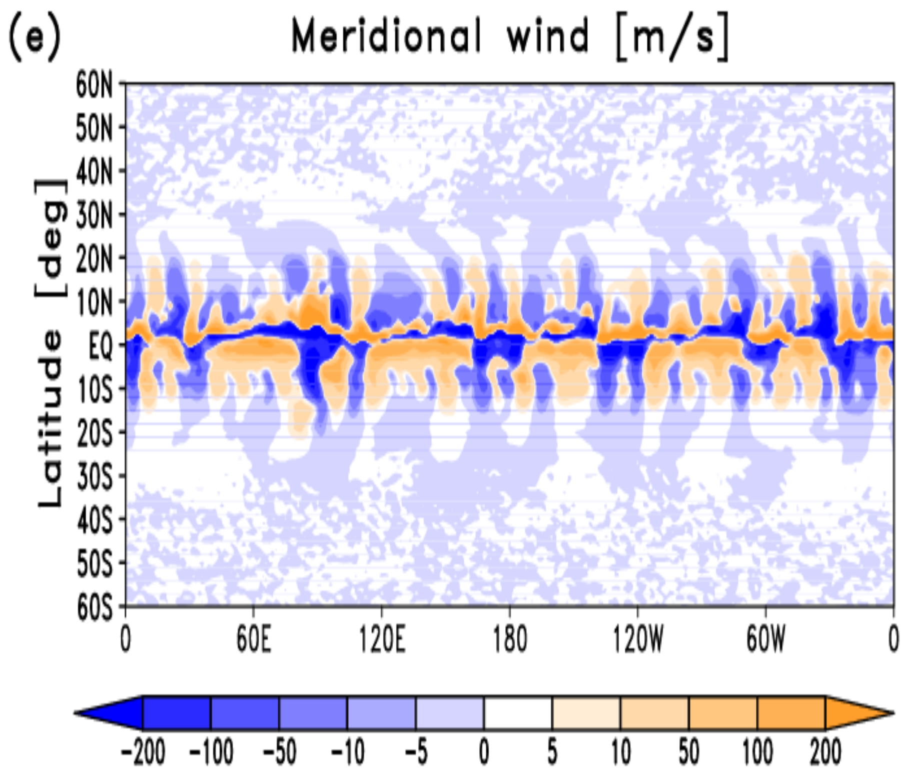



Flasar et al, 2004

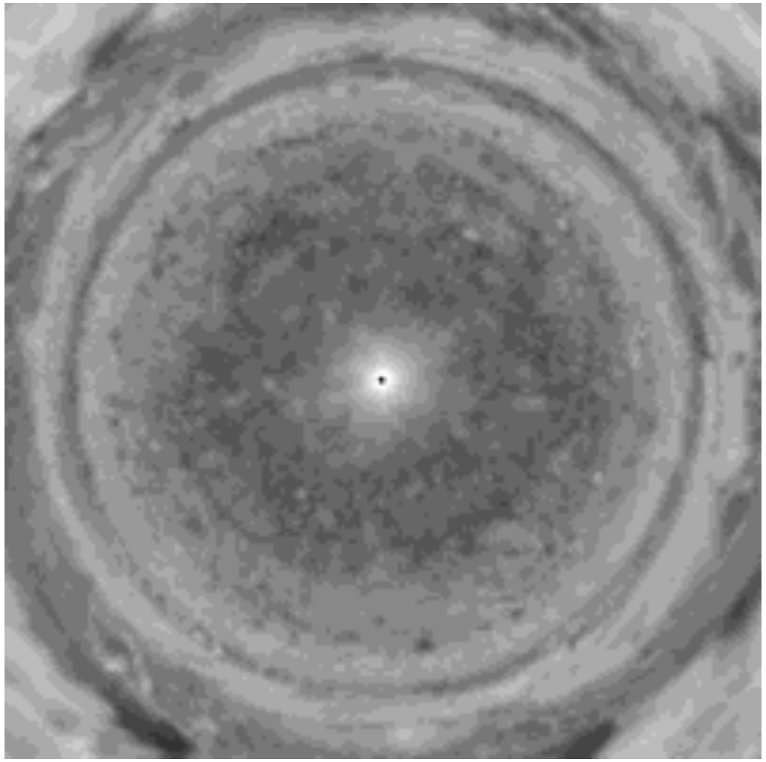
# Zonal wind (u) & Δv at 60 mb: role of mechanical forcing

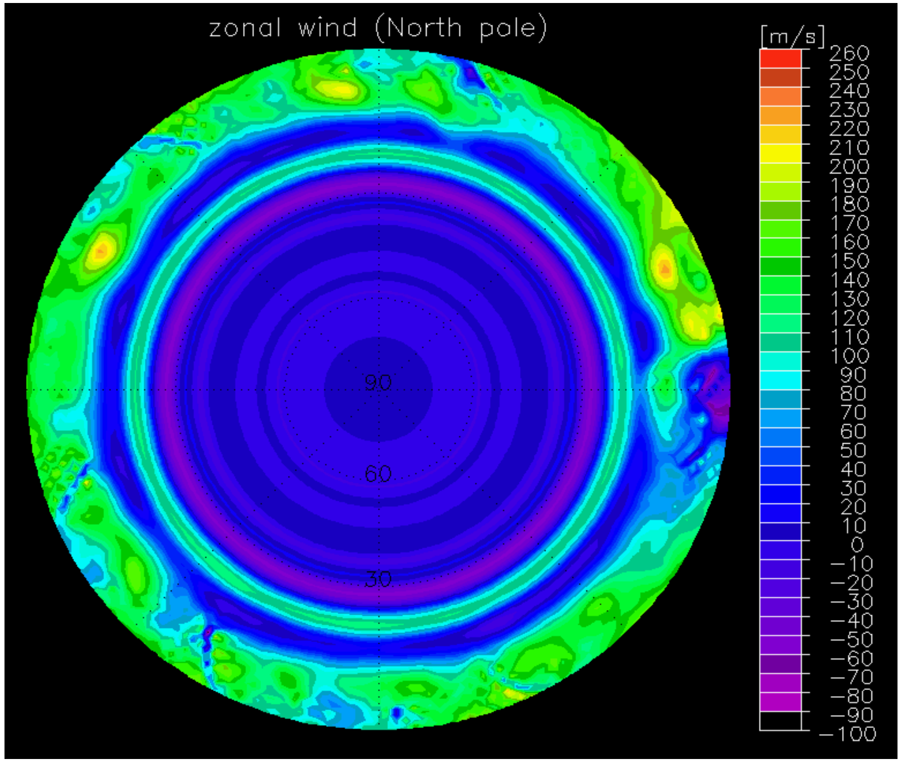
MPS-GCM: Sethunadh, 2014 (PhD thesis)



# Cassini (70 days movie, 756 nm) and 15 mb simulation



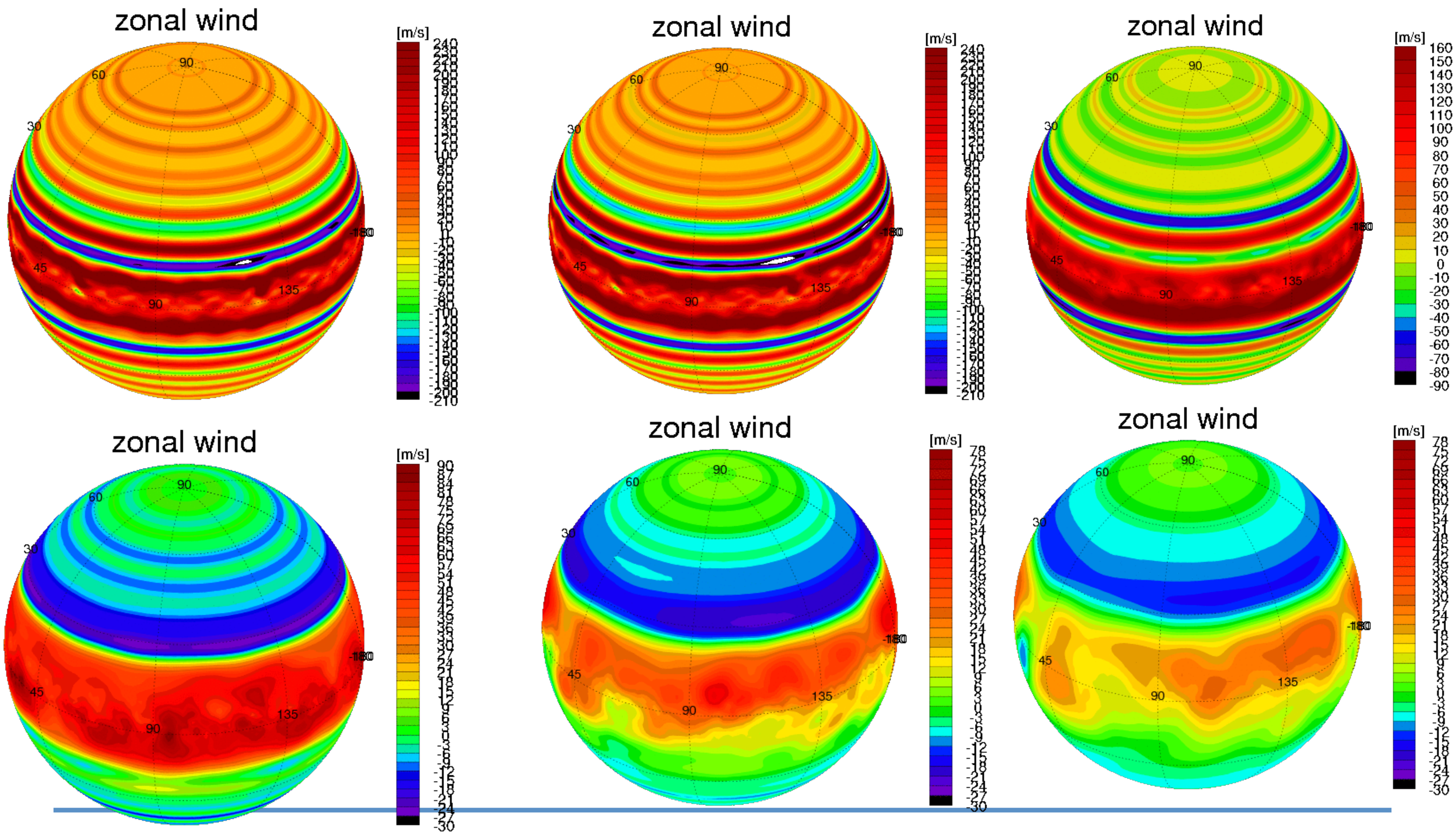


SWI Submillimetre Wave Instrument

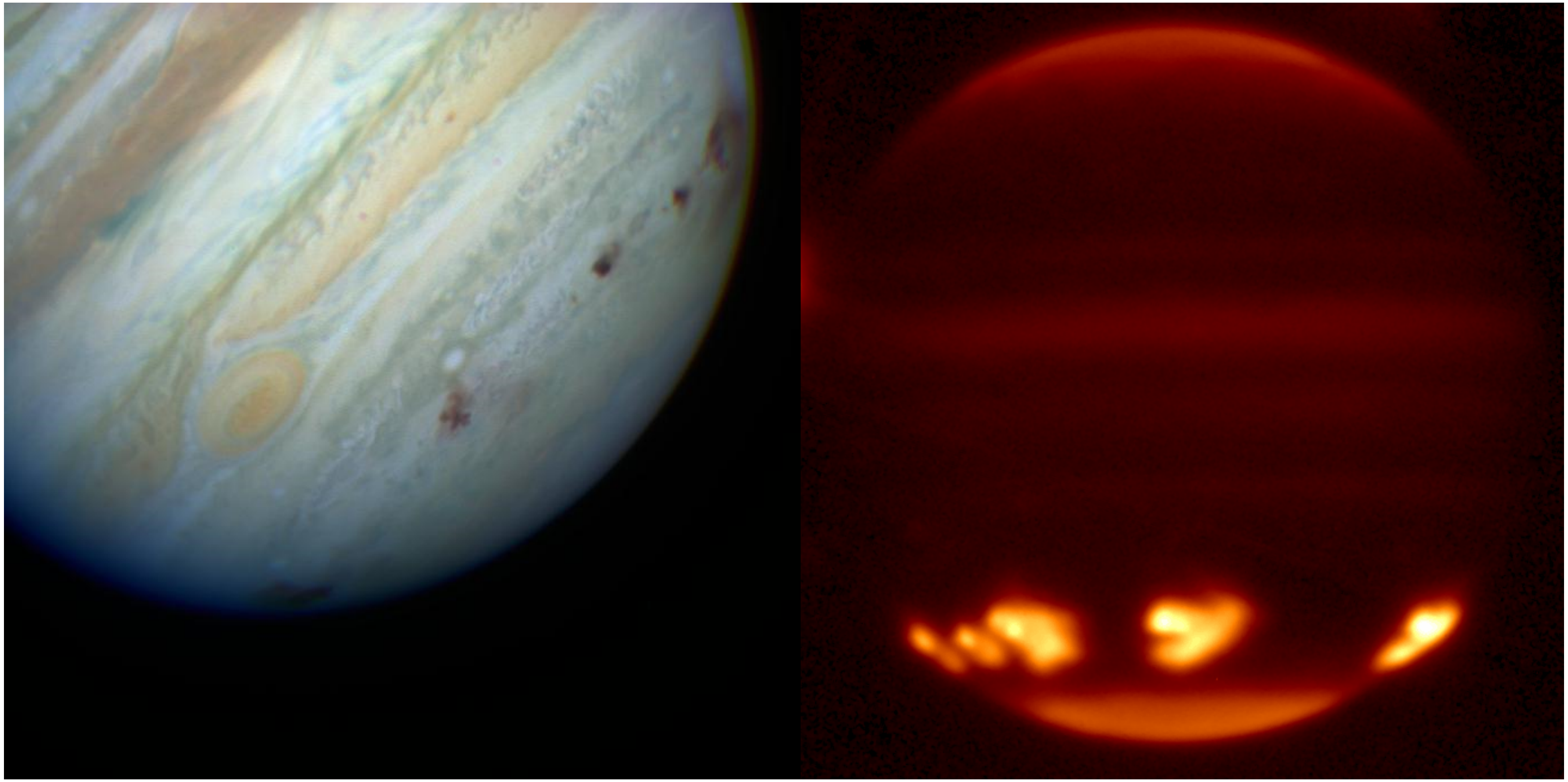
MPS Max-Planck-Institut für Sonnensystemforschung

esa

# Zonal winds at 200, 100, 20, 5, 1 and 0.1 mb



# SL9 impacts 1994 (VIS/IR) at 44 S



Credits: NASA-HST/ U. Hawaii

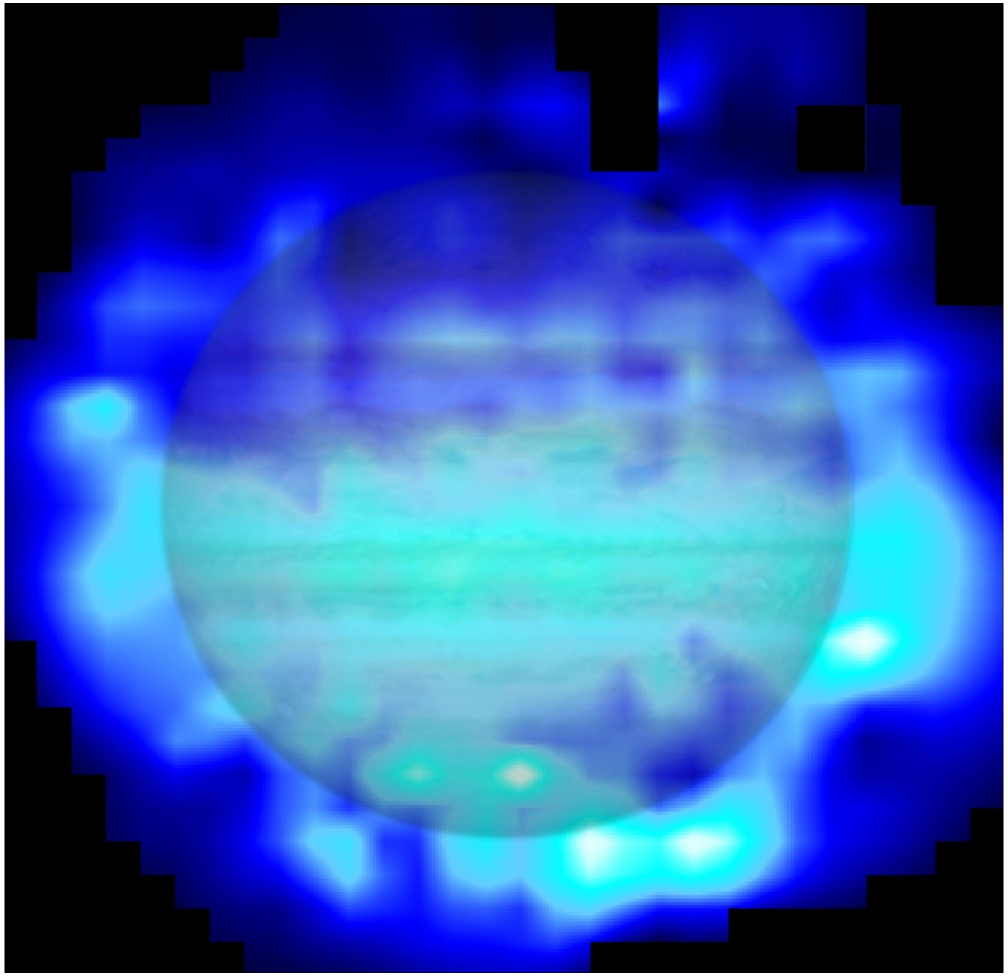
# Herschel-HssO results

- No feature found indicating a satellite/ring source
- Vertical distribution does not fit IDP source
- Horizontal distribution of water favors SL9 impact, hemispheric asymmetry: Globally averaged column density $3x10^{15}cm^{-2}$ with 2-3 times more water in the south.

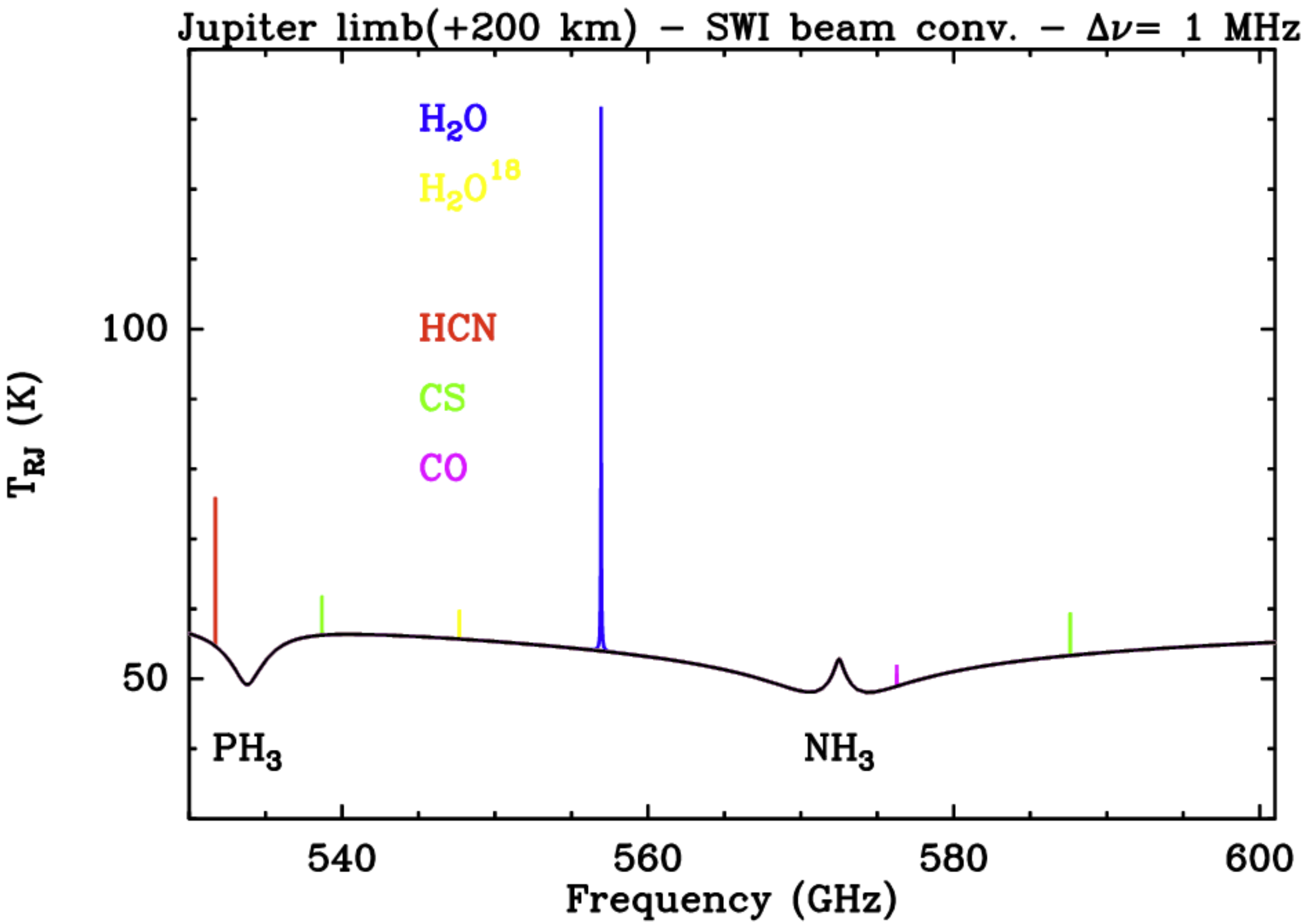
**SL9 impact main source of stratospheric water in Jupiter!**

*Cavalie et al., A&A 2013*

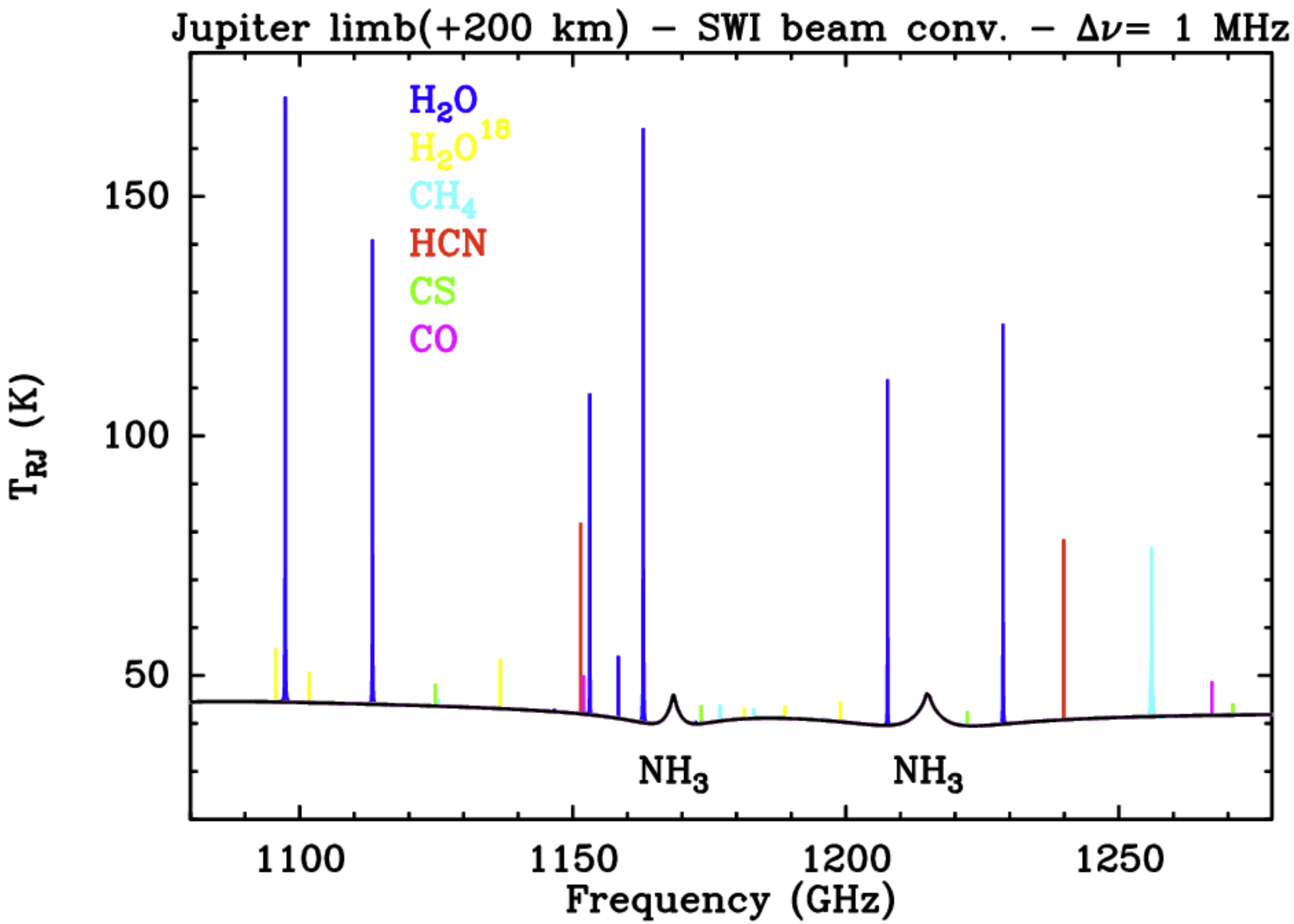
# Water distribution observed by PACS



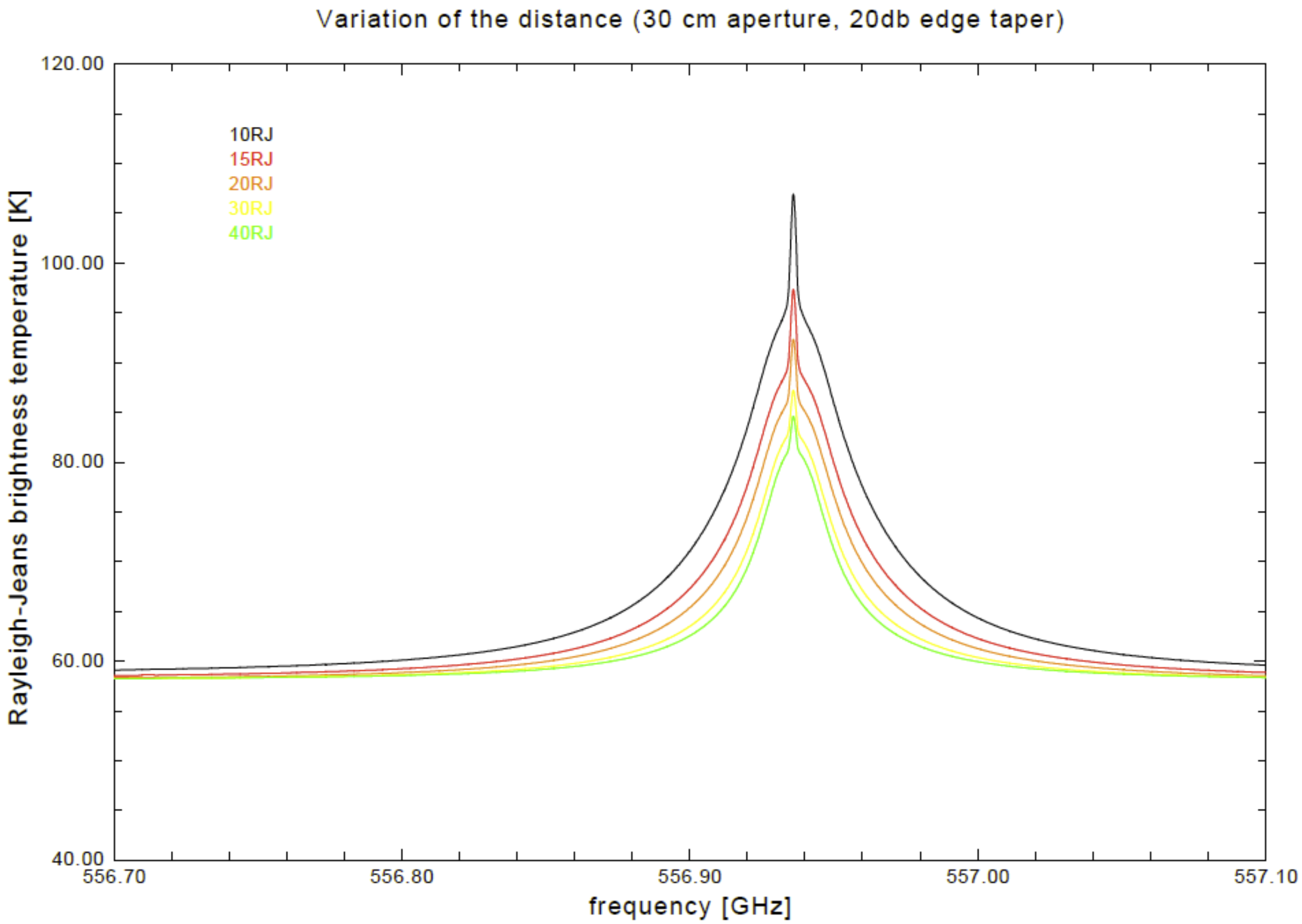
# SWI basic lines in Jupiter Stratosphere



# SWI basic lines in Jupiter Stratosphere

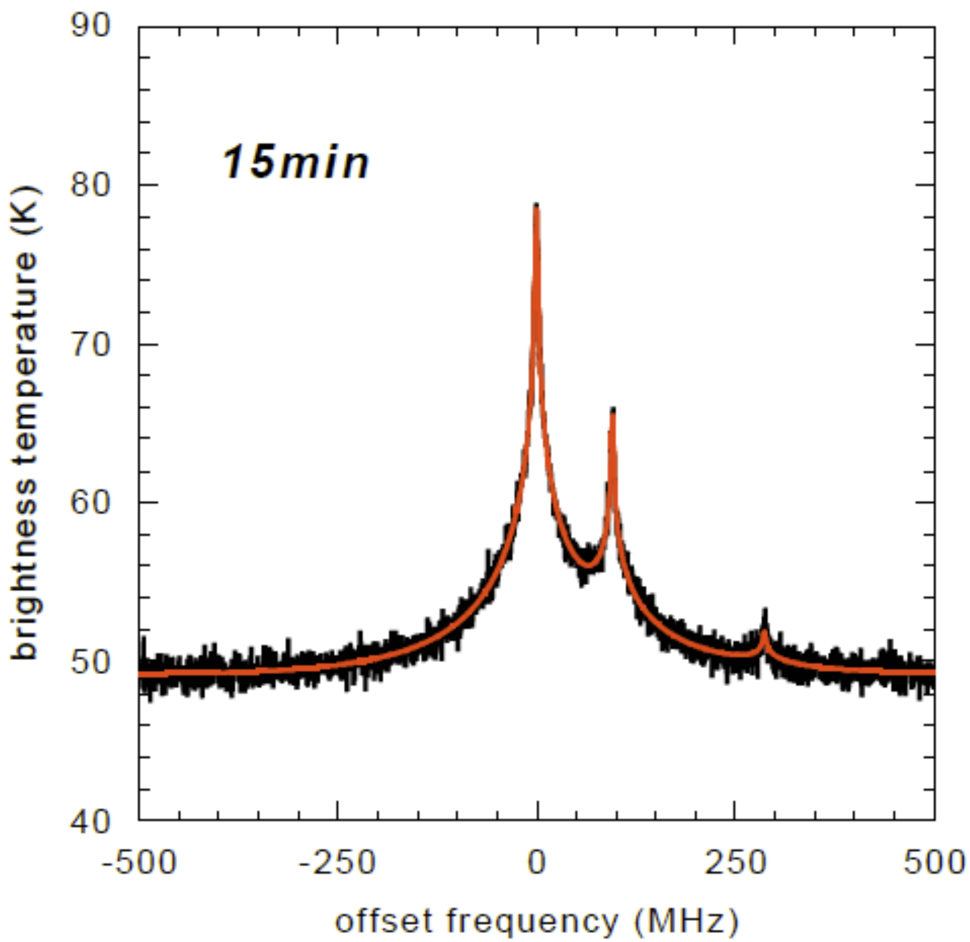


# Water vapour from 10 to 40 $R_j$



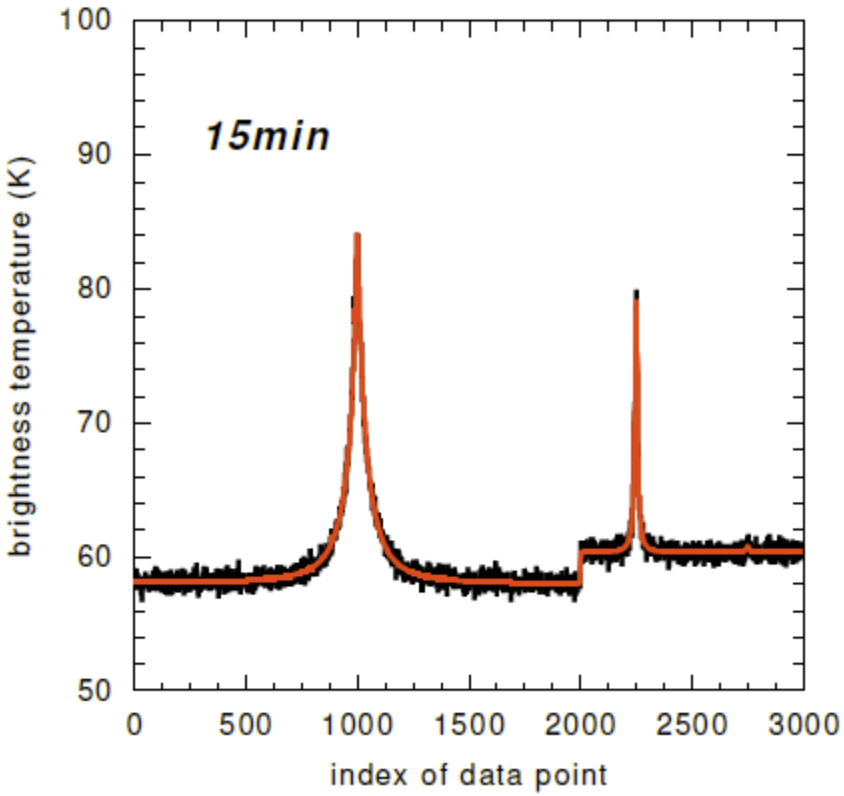
# Methane (20 $R_J$): 4000 K DSB / 15 min $T_{int}$

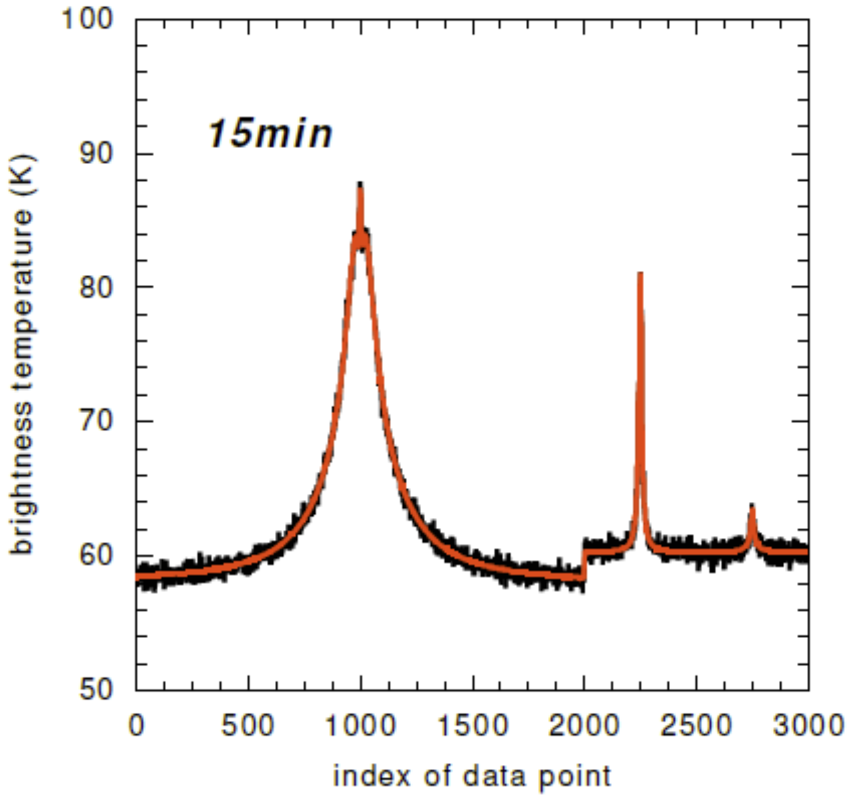
**1256 GHz**



# Polar and mid lat. water 557 and 621 GHz from 20 $R_j$

Tsys. 2000 K DSB. (incl. HCN line or temperature retrieval)

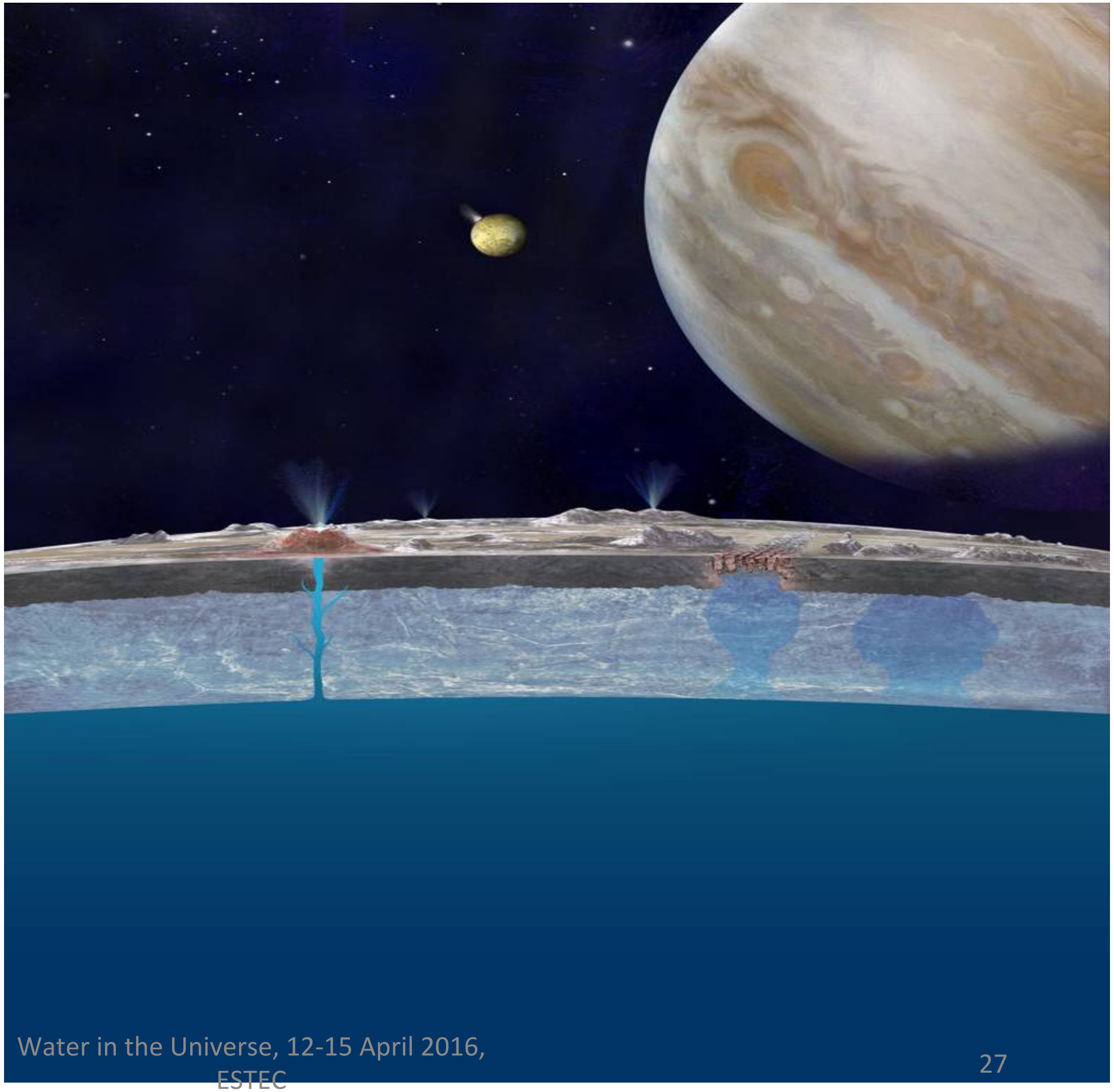


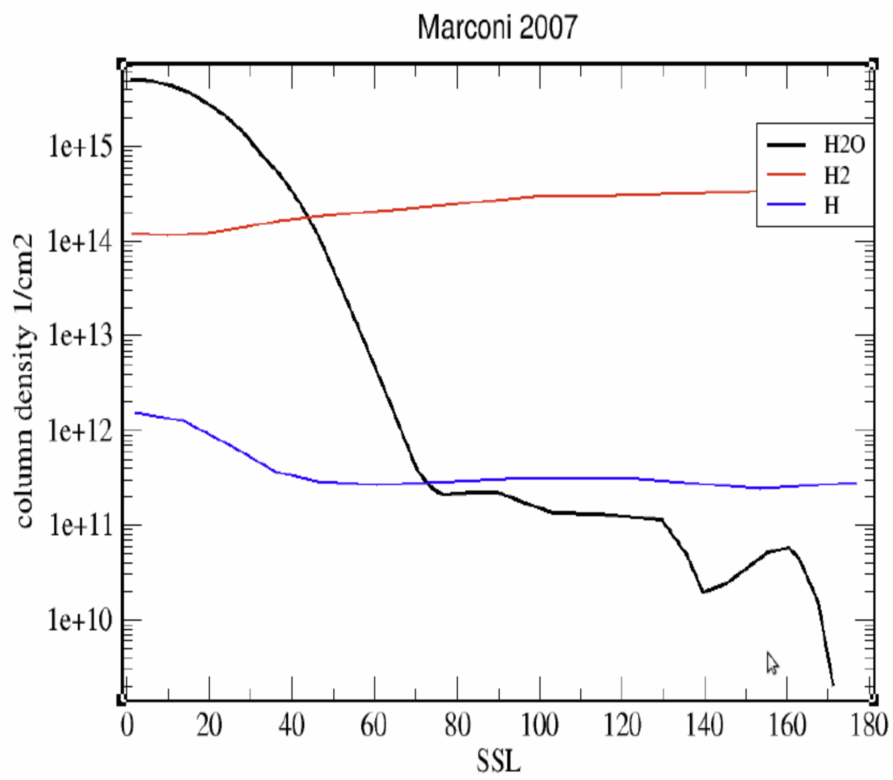
# Ganymede's water atmosphere

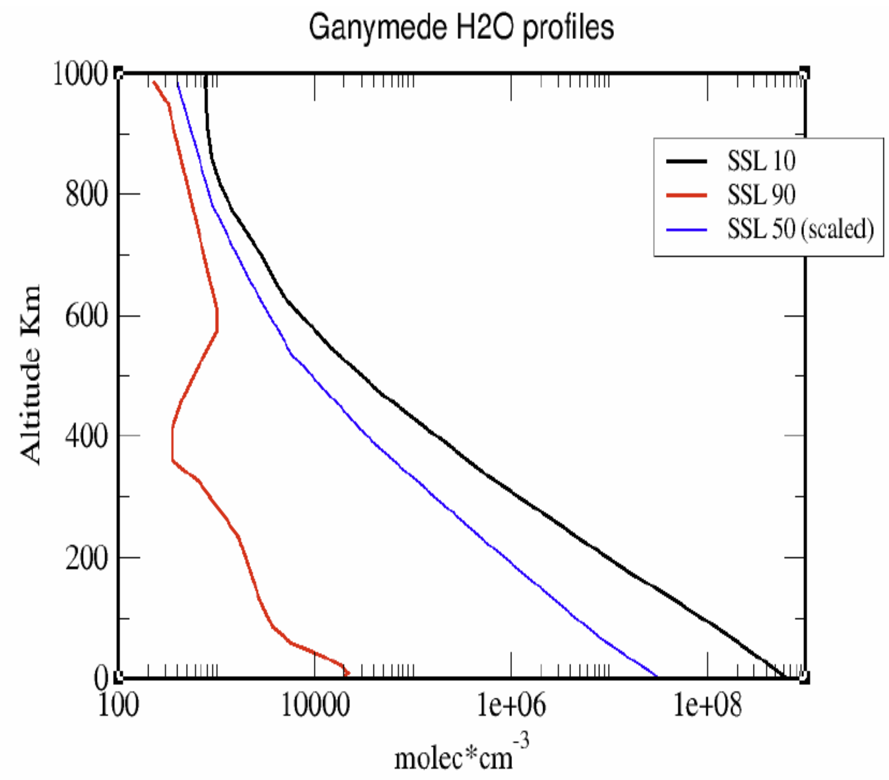
- Marconi 2007: main production mechanism is sublimation followed by sputtering.
- Highest atmospheric density expected around sub-solar point.
- Puzzling: leading side nearly a order of magnitude higher density
- Does cryovolcanism play a role?

# Cryovolcanism like on Enceladus?

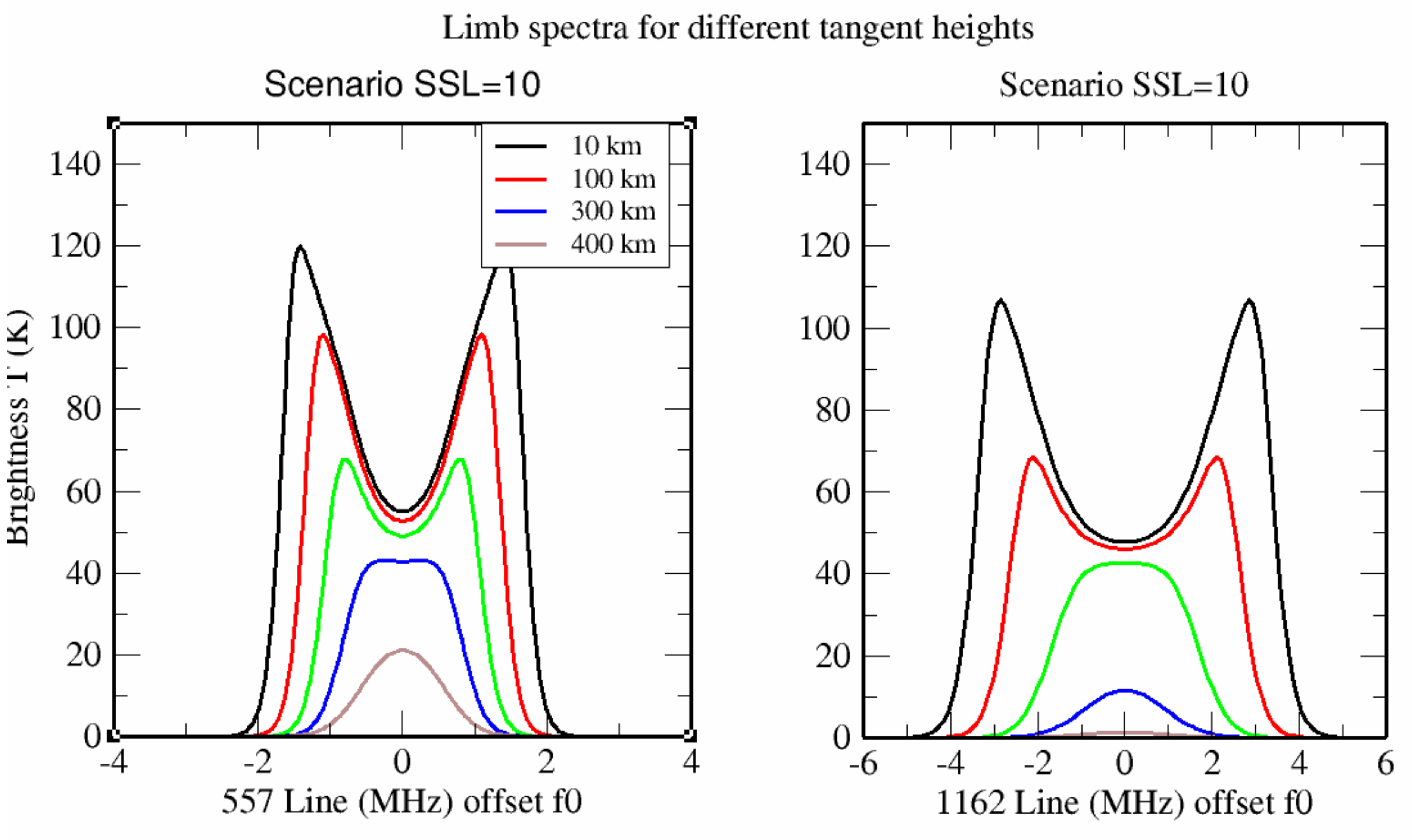


# Ganymede water profiles

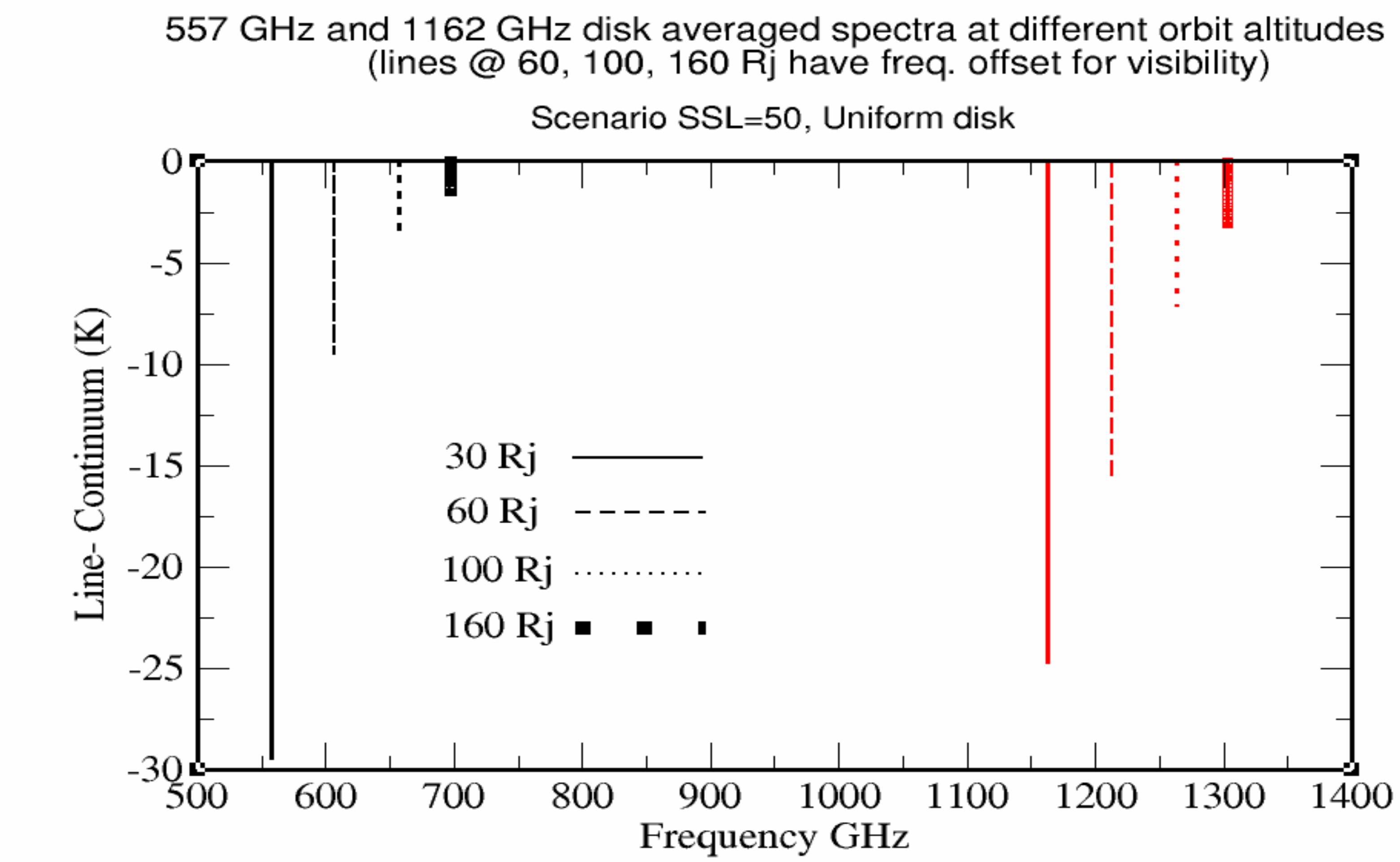


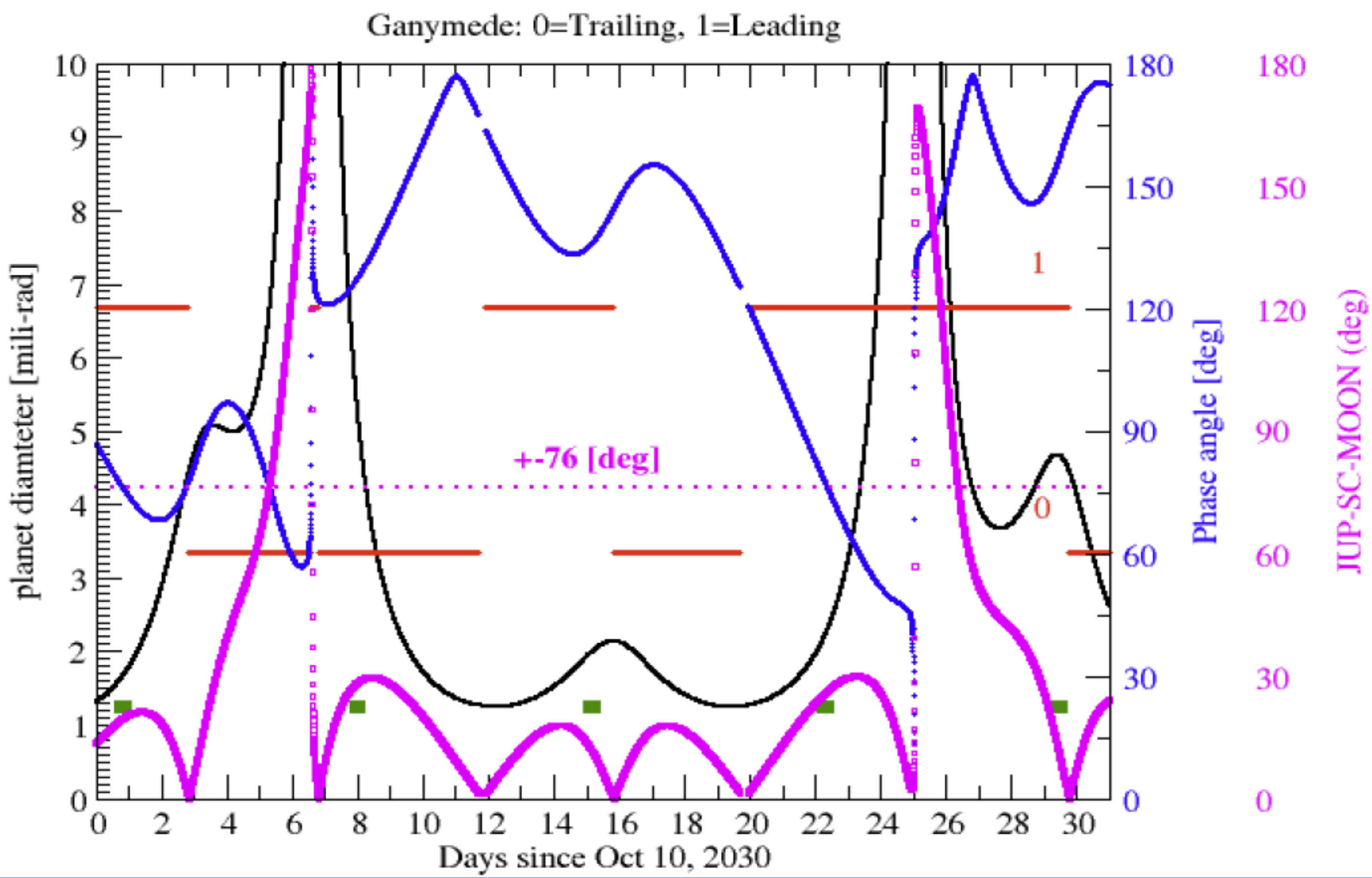
# NLTE limb spectra 557 and 1162 GHz – various TH



# SSL=50, NLTE nadir disk averaged spectra (uniform disk)



# Water observations of Ganymede from Jupiter Orbit

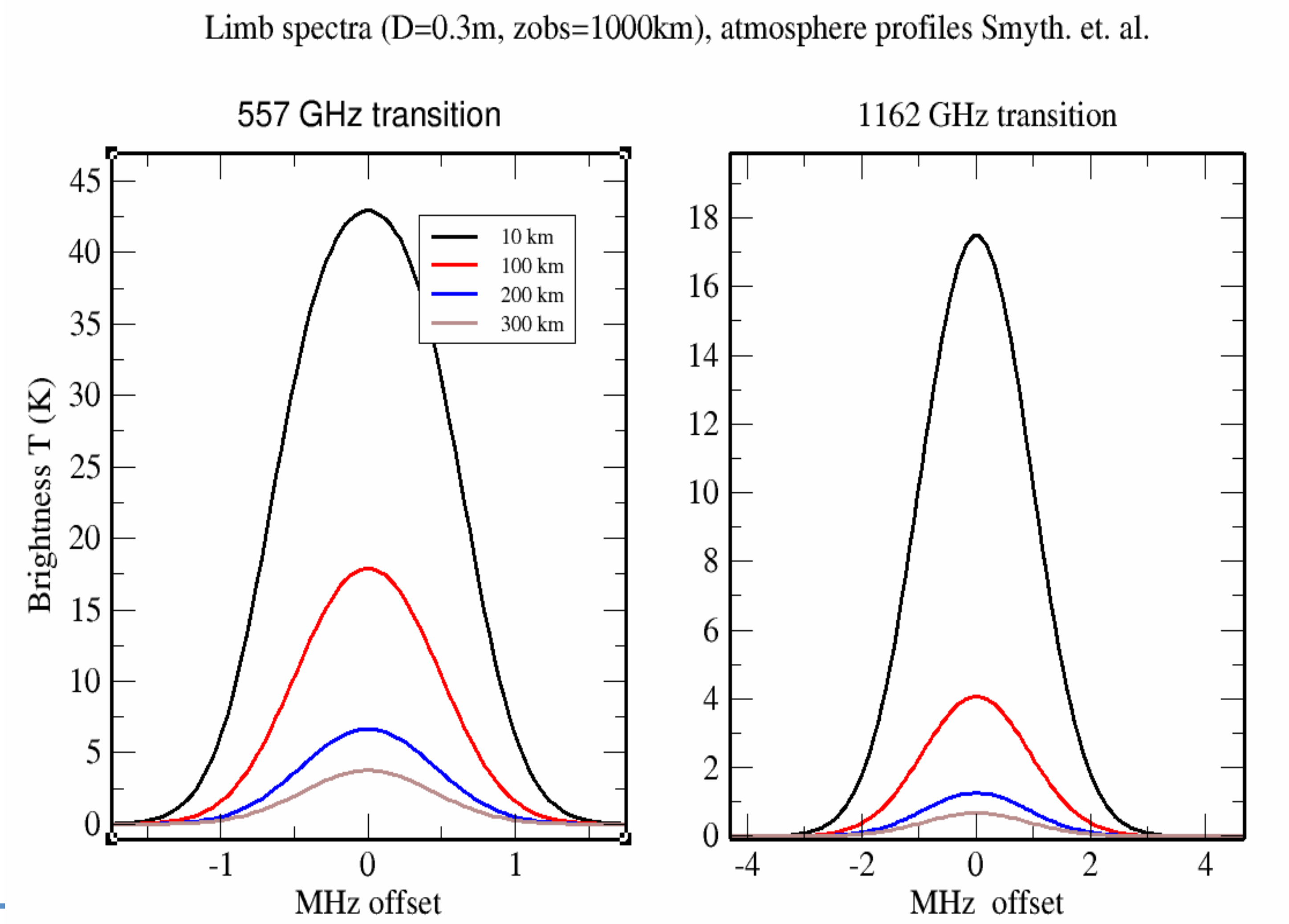


# Europa

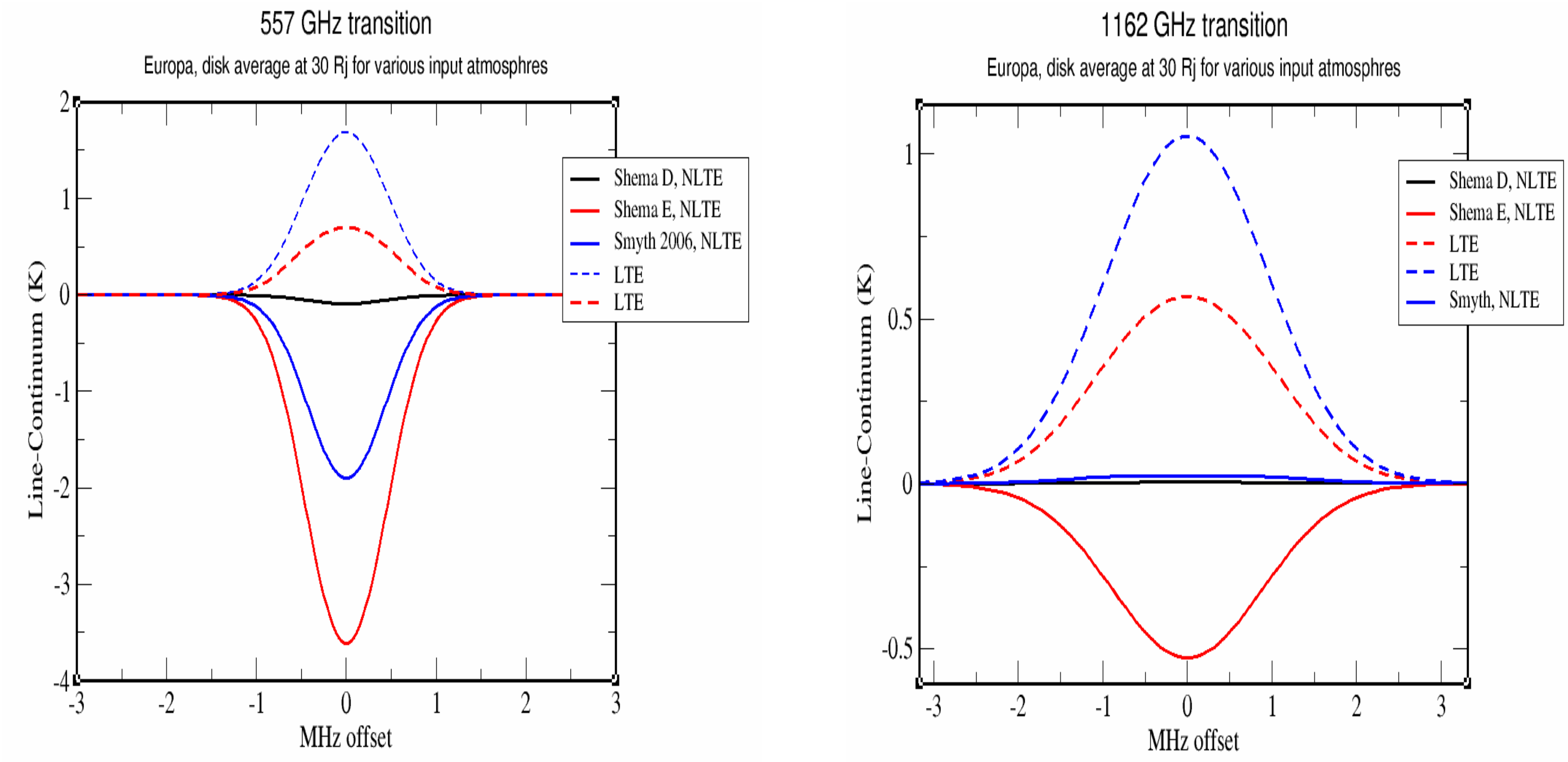
# Europa's water atmosphere

- sputtering seems to dominate (models)
- sublimation only near equator (130 K)
- Detection of plumes reported

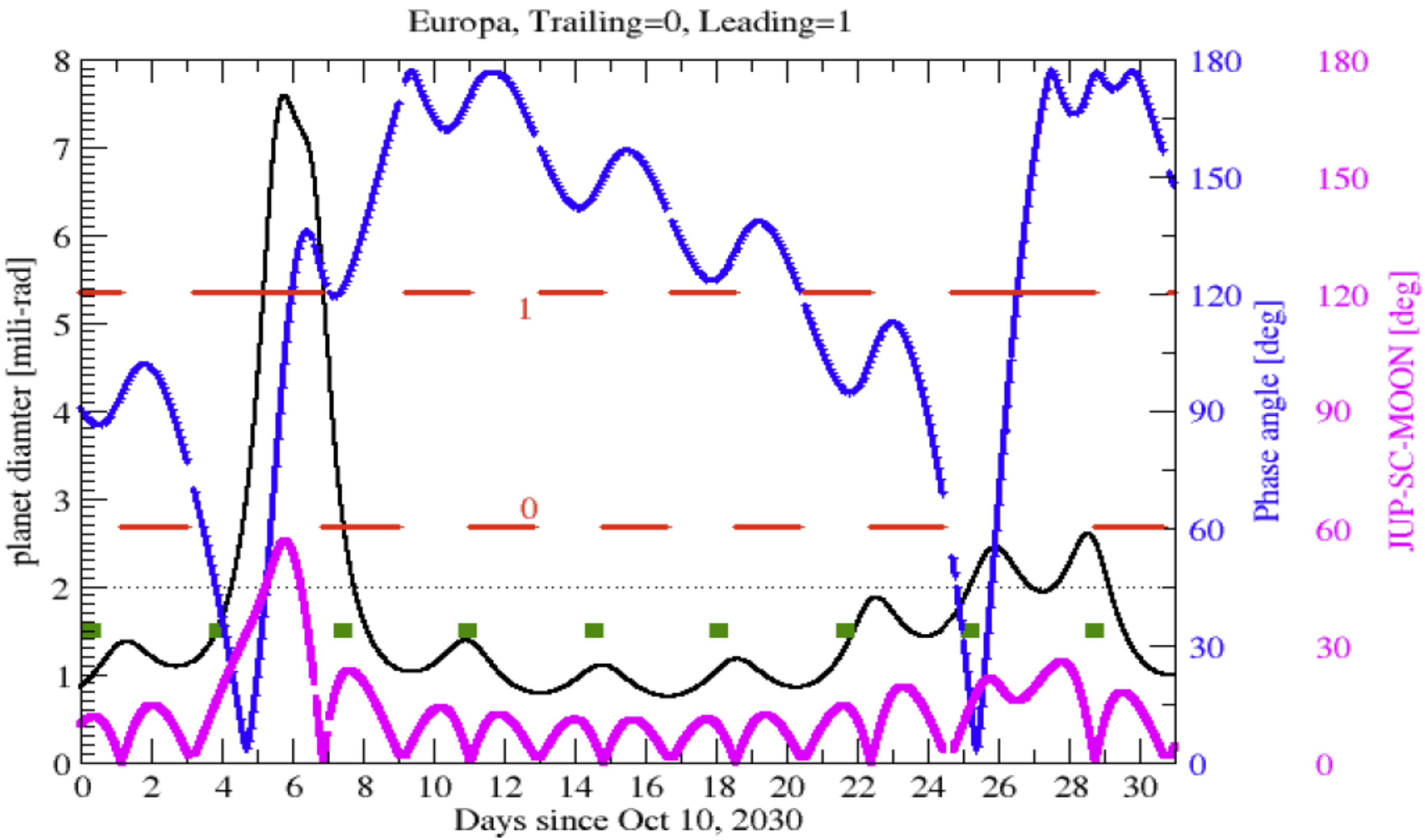
# NLTE - limb spectra for various TH



# LTE & NLTE nadir spectra, 557, 1162 GHz, 30Rj distance



# Water observation in Europa from Jupiter Orbit

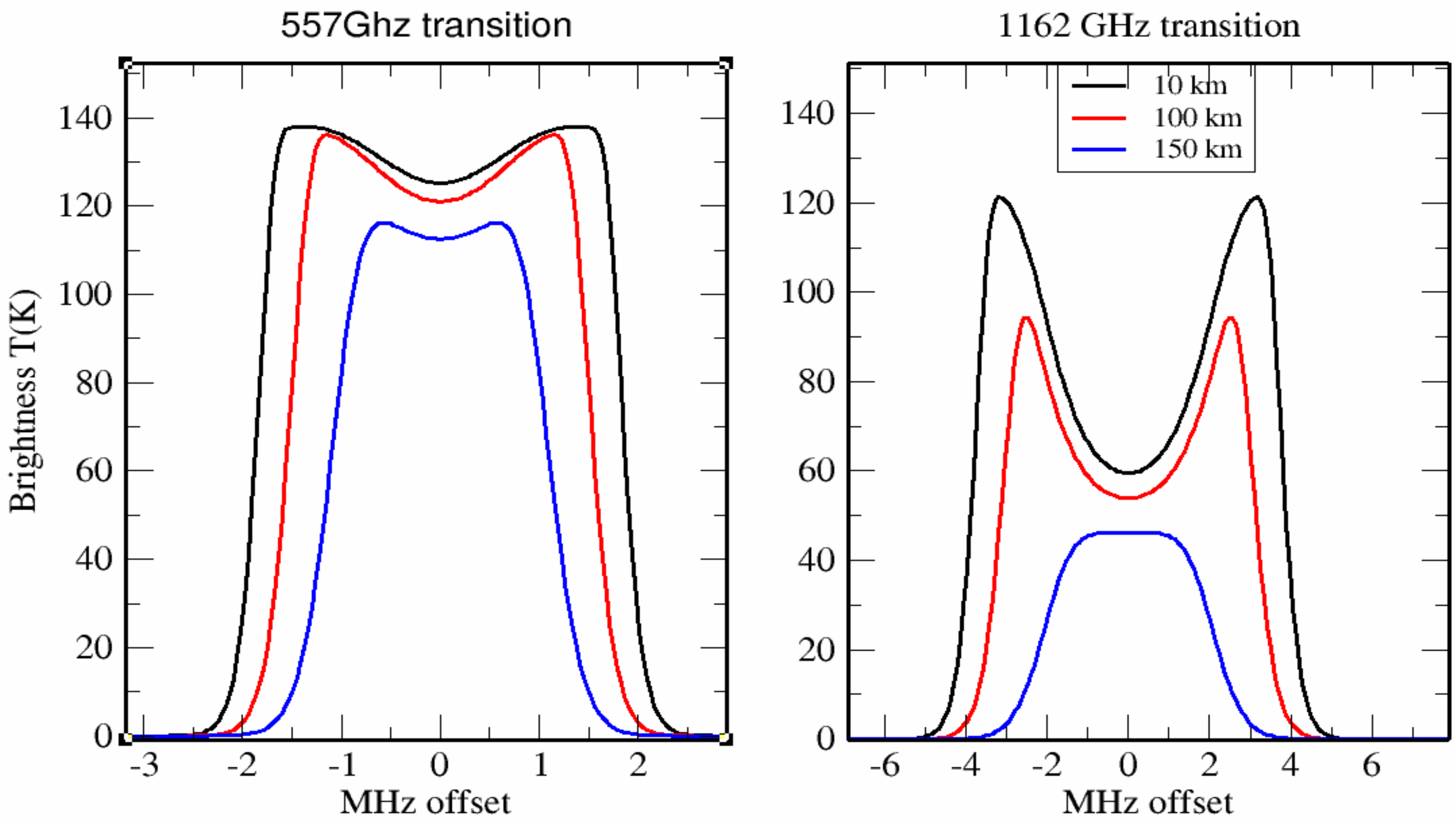


# Callisto

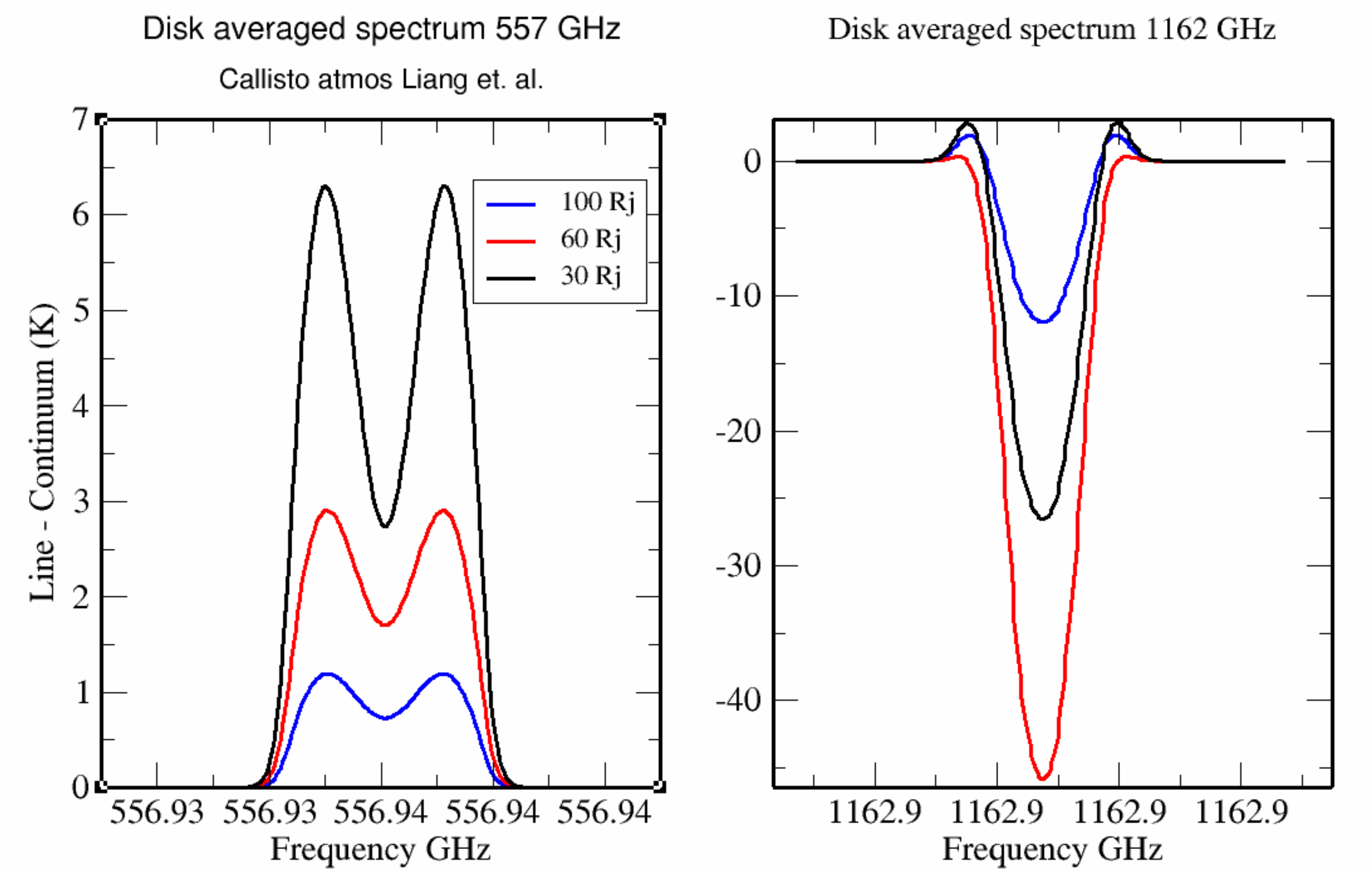
# Callisto

- Sputtering has small contribution
- Rather low albedo -> higher surface temperatures: sublimation should dominate
- Other sources?

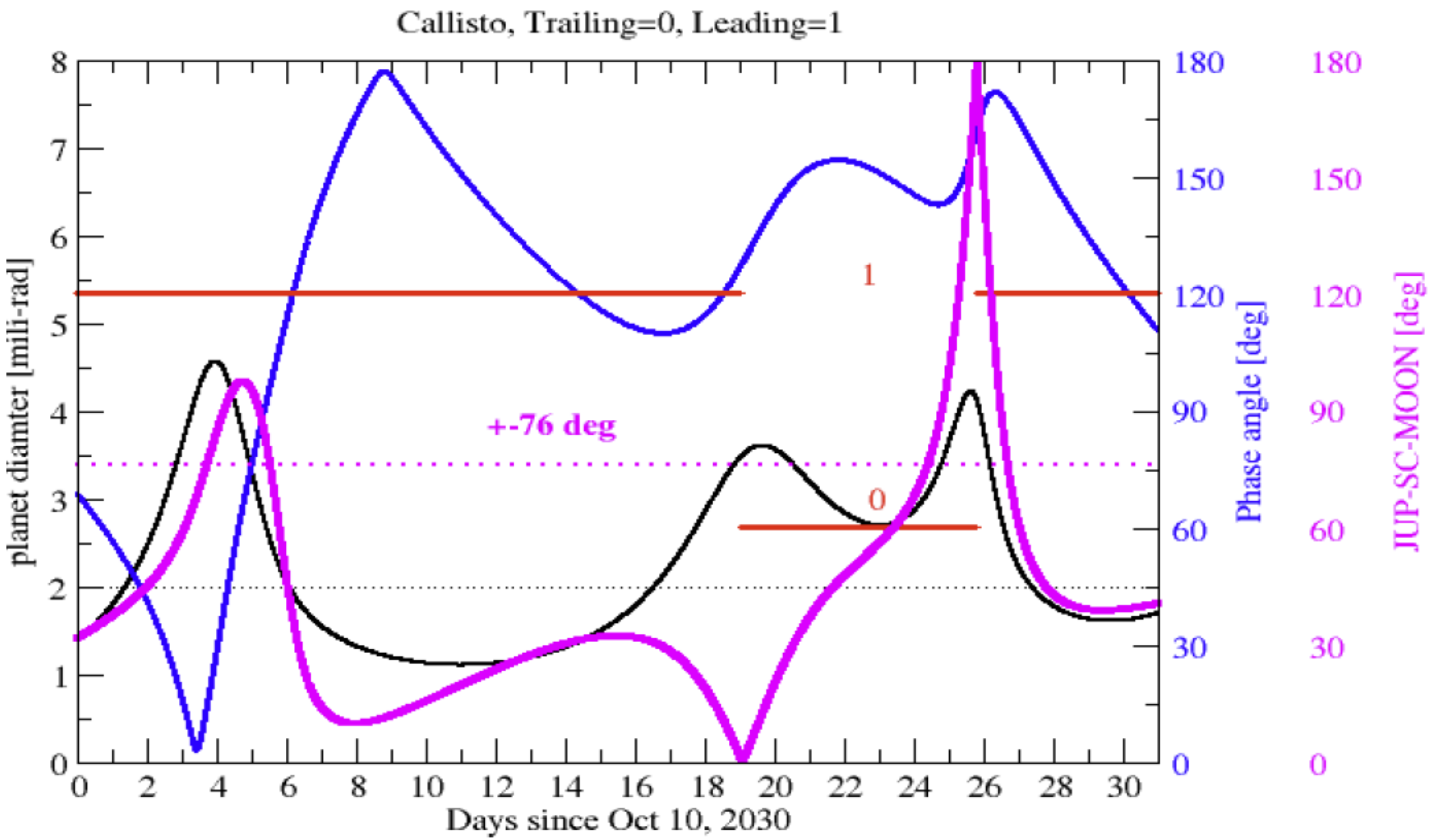
# NLTE limb spectra 557 and 1162 lines at various TH



# NLTE nadir disk averaged spectra

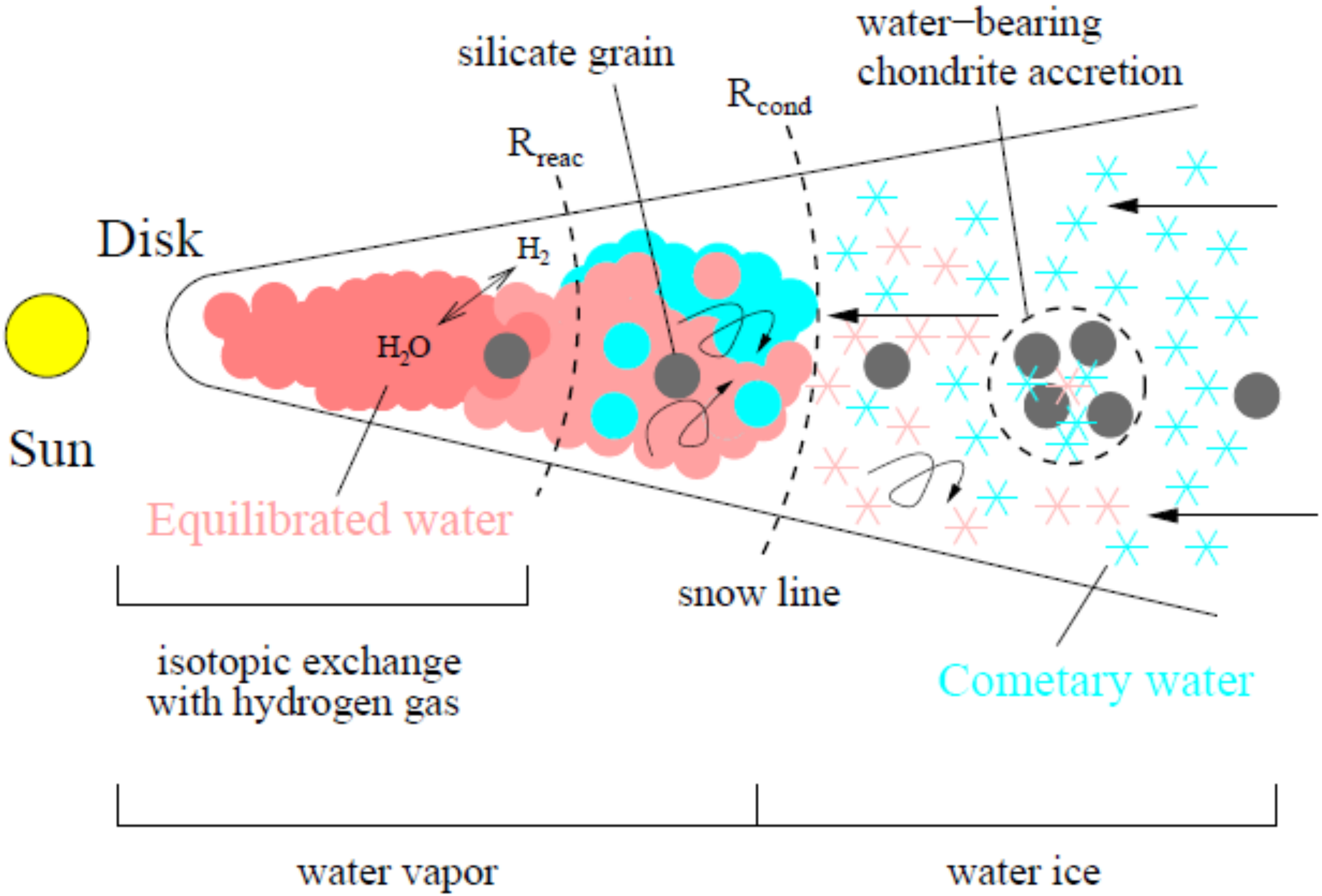


# Water observations of Callisto from Jupiter Orbit



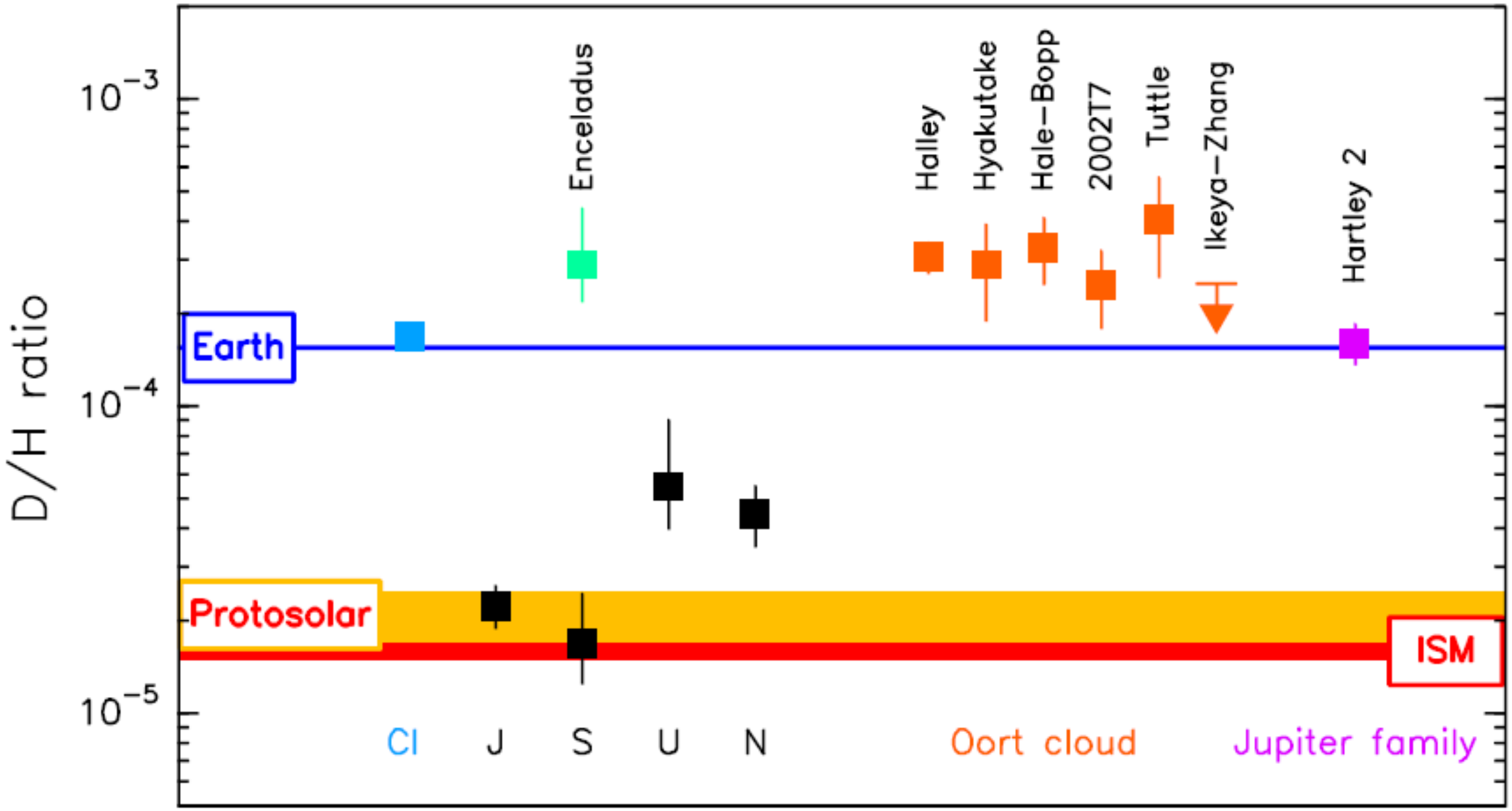
# Isotopes

- Origin of ices from which the Galilean Satellites formed: D/H



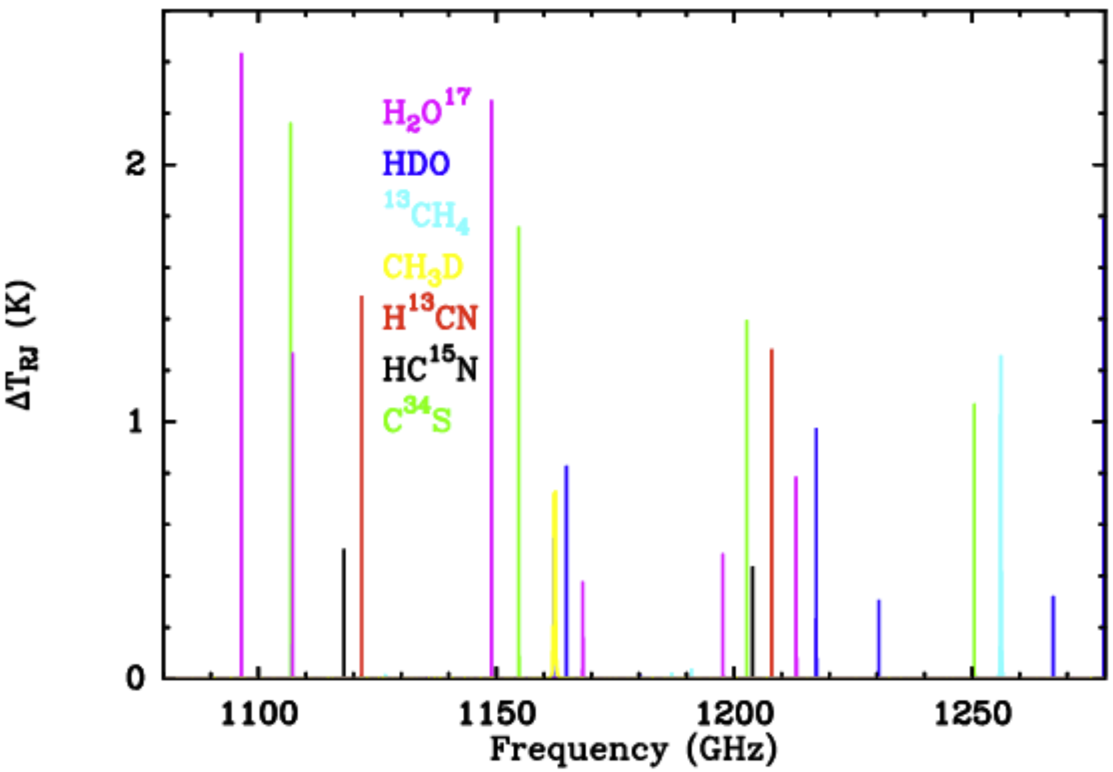

Jacquet et al. Icarus 2013

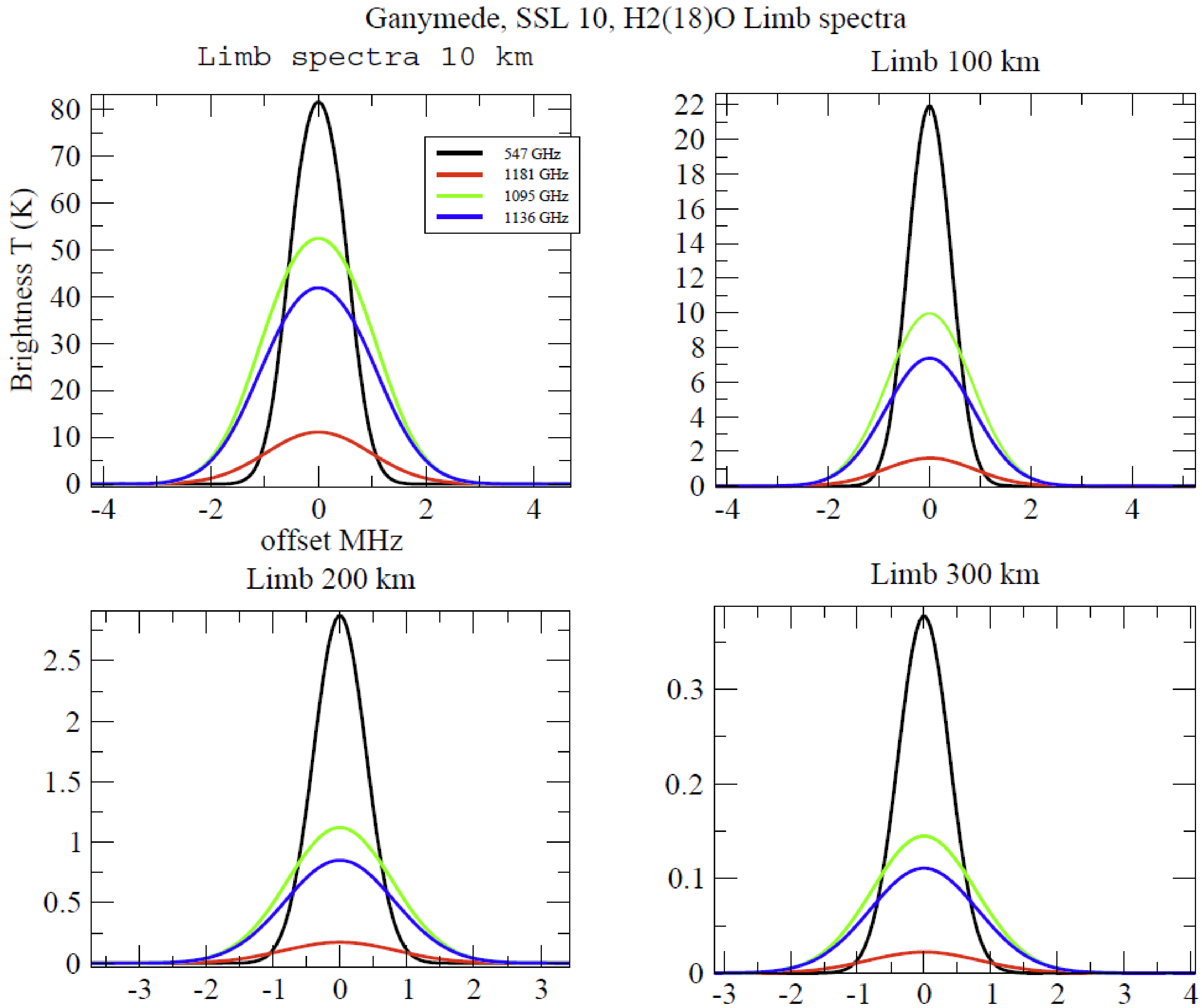
# D/H in the solar system



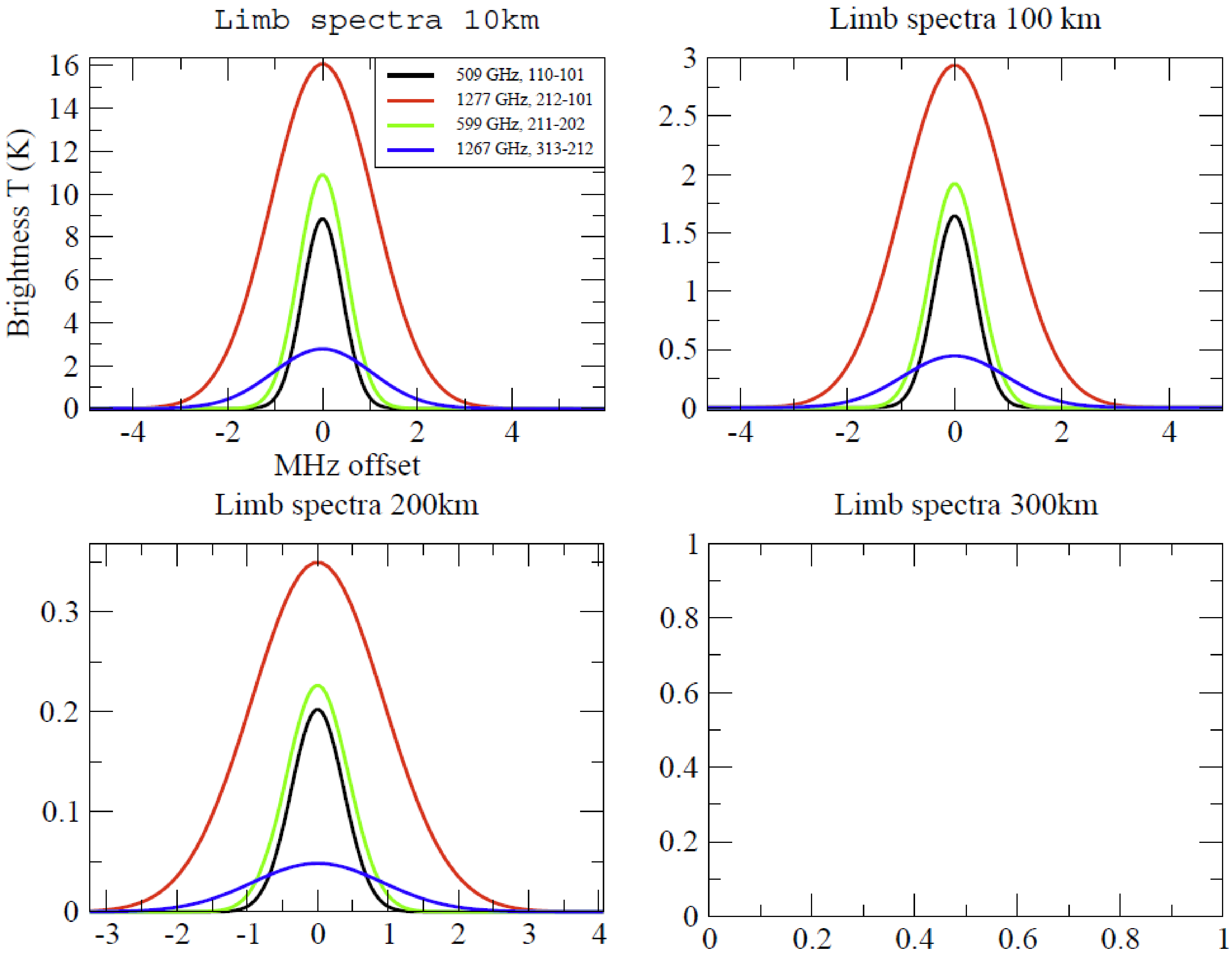

*Hartogh et al, Nature 2011*

# Isotopes lines




Ganymede, SSL 10, H2(18)O Limb spectra
Limb spectra 10 km
Limb 100 km
Limb 200 km
Limb 300 km
Brightness T (K)
offset MHz
547 GHz
1181 GHz
1095 GHz
1136 GHz

Ganymede, SSL 10, HDO limb spectra

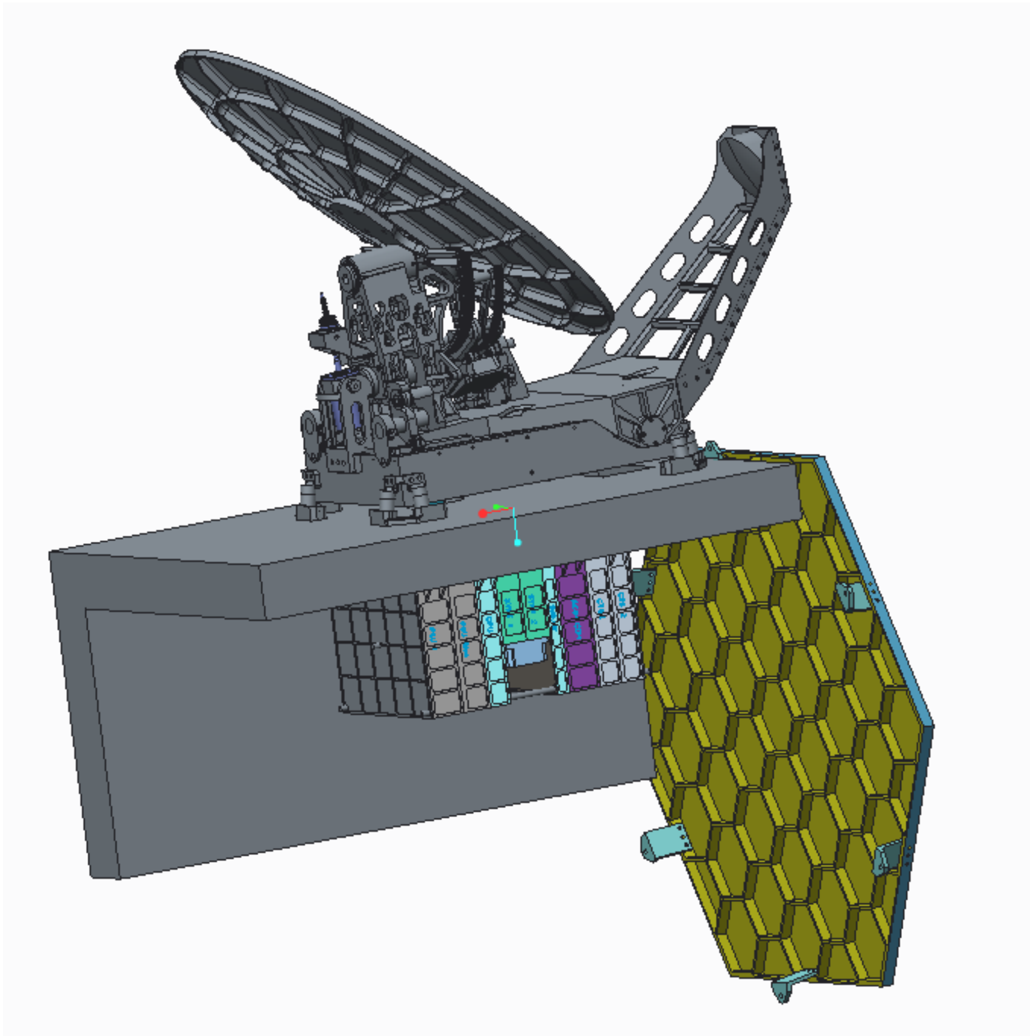


# Isotopes

Measurements of isotopes help to constrain solar system formation processes

- Jupiter: 17-O, 18-O, D, 13-C, 15-N, 34-S
- Ganymede/Callisto/Europa: 17-O, 18-O, D, 13-C

# JUICE-SWI



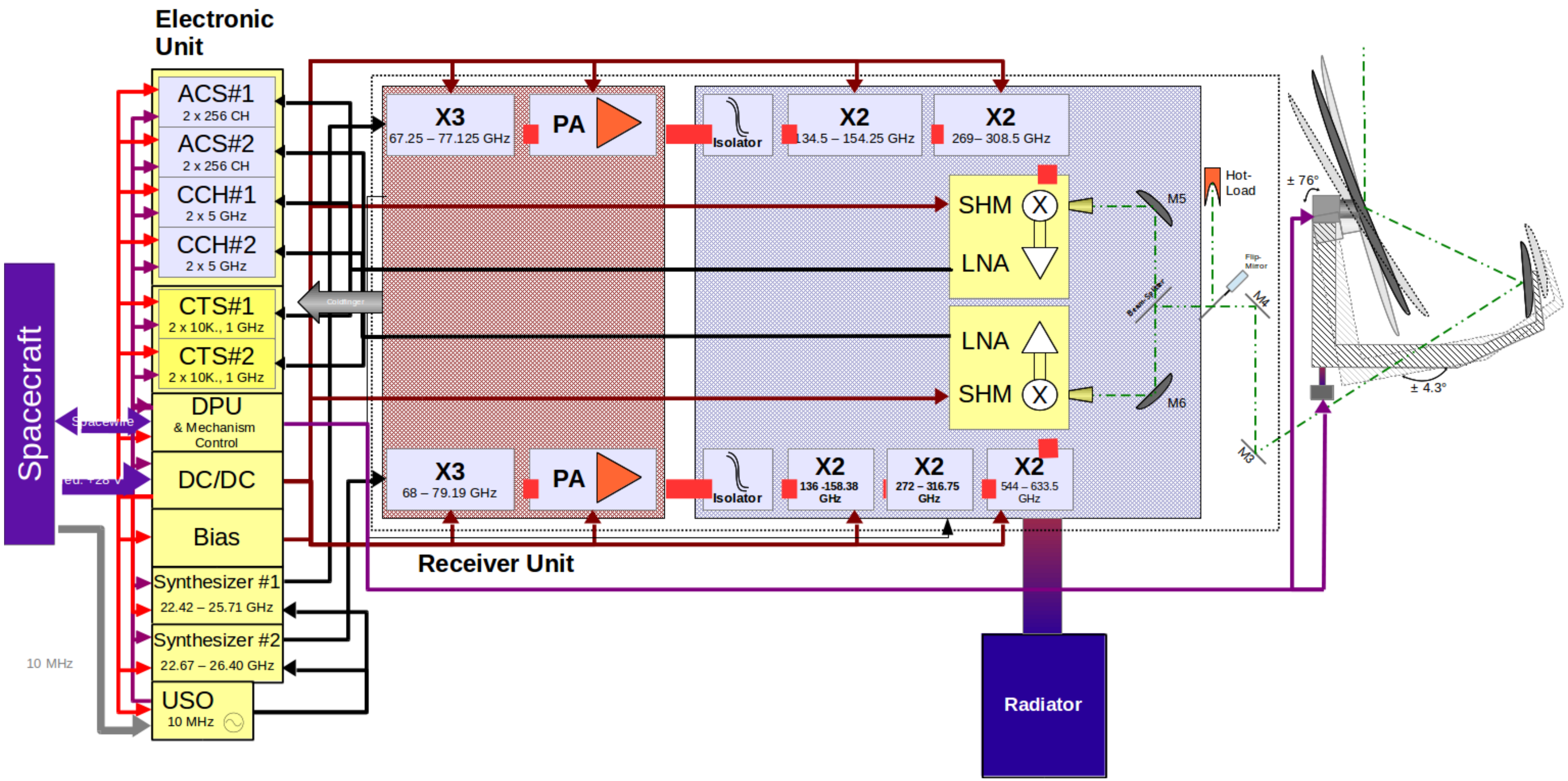
# Main Instrument Specifications

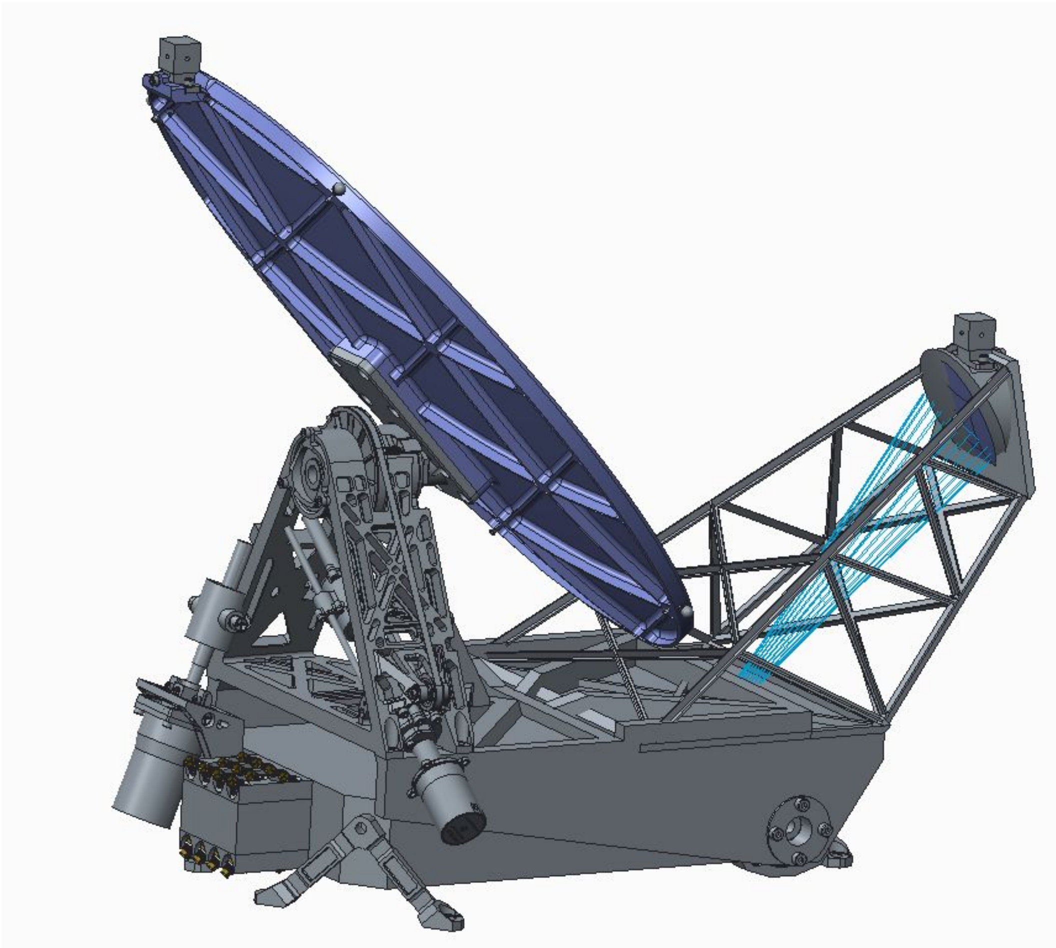
- Two passively cooled (140 K) Schottky receivers
- Option 1: 2 x 530 – 625 GHz (600-900 K DSB)
- Option 2: Second rec: 1 x 1080 – 1275 GHz (3000-4000 K DSB)
- IF-range: 3.5 – 8.5 GHz
- 30 cm aperture elliptic antenna, movable ± 76 and ± 4.3 deg
- Pointing accuracy/knowledge 30/5 arcsec
- 2 Autocorrelator backends 4 GHz, 256 channels
- 2 Chirp Transform Spectrometers 1 GHz, 10000 channels
- Basic power consumption: ~ 50 W (long peak)
- Mass: 12 kg

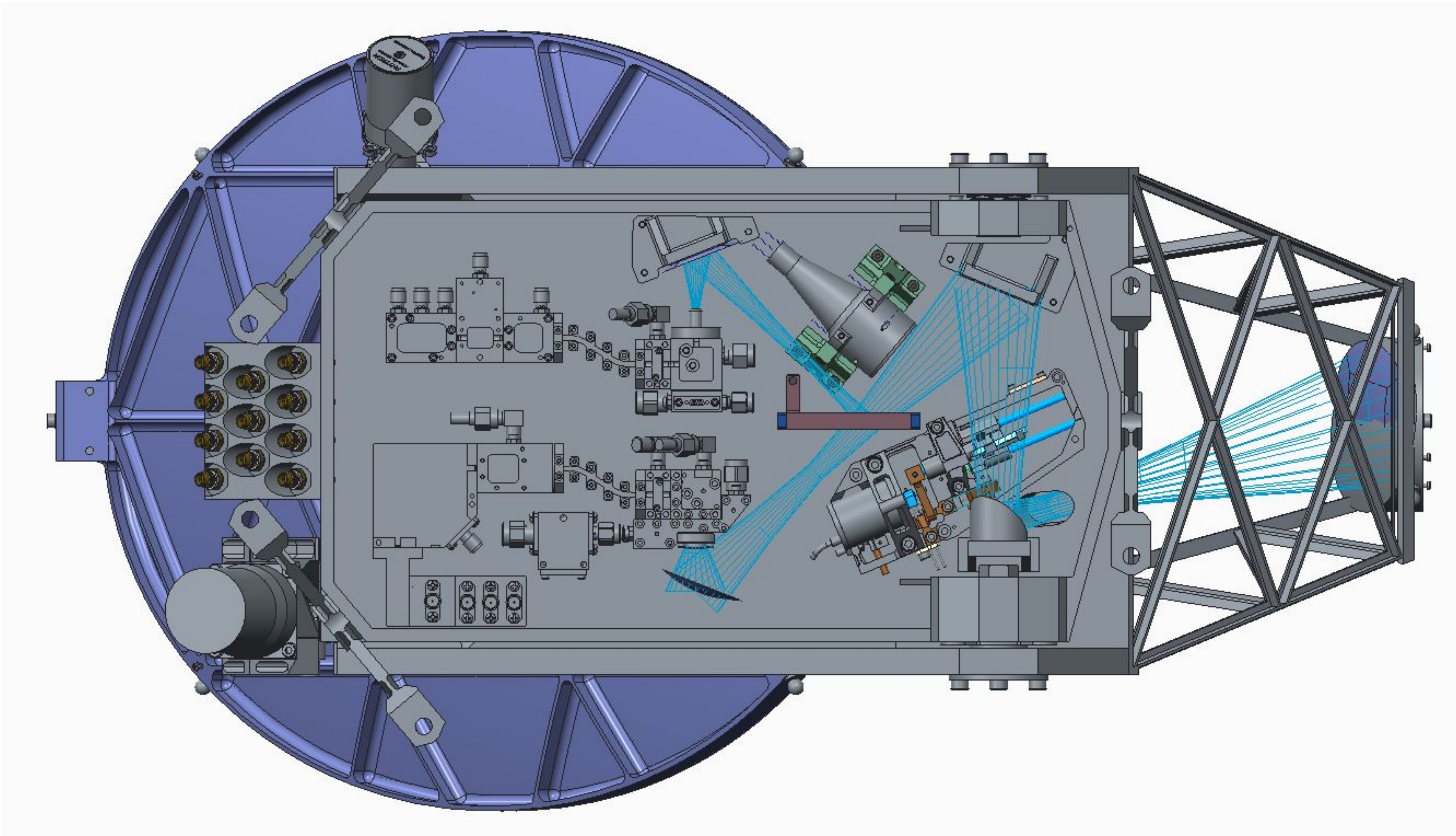
Submillimetre Wave Instrument

Max-Planck-Institut für Sonnensystemforschung

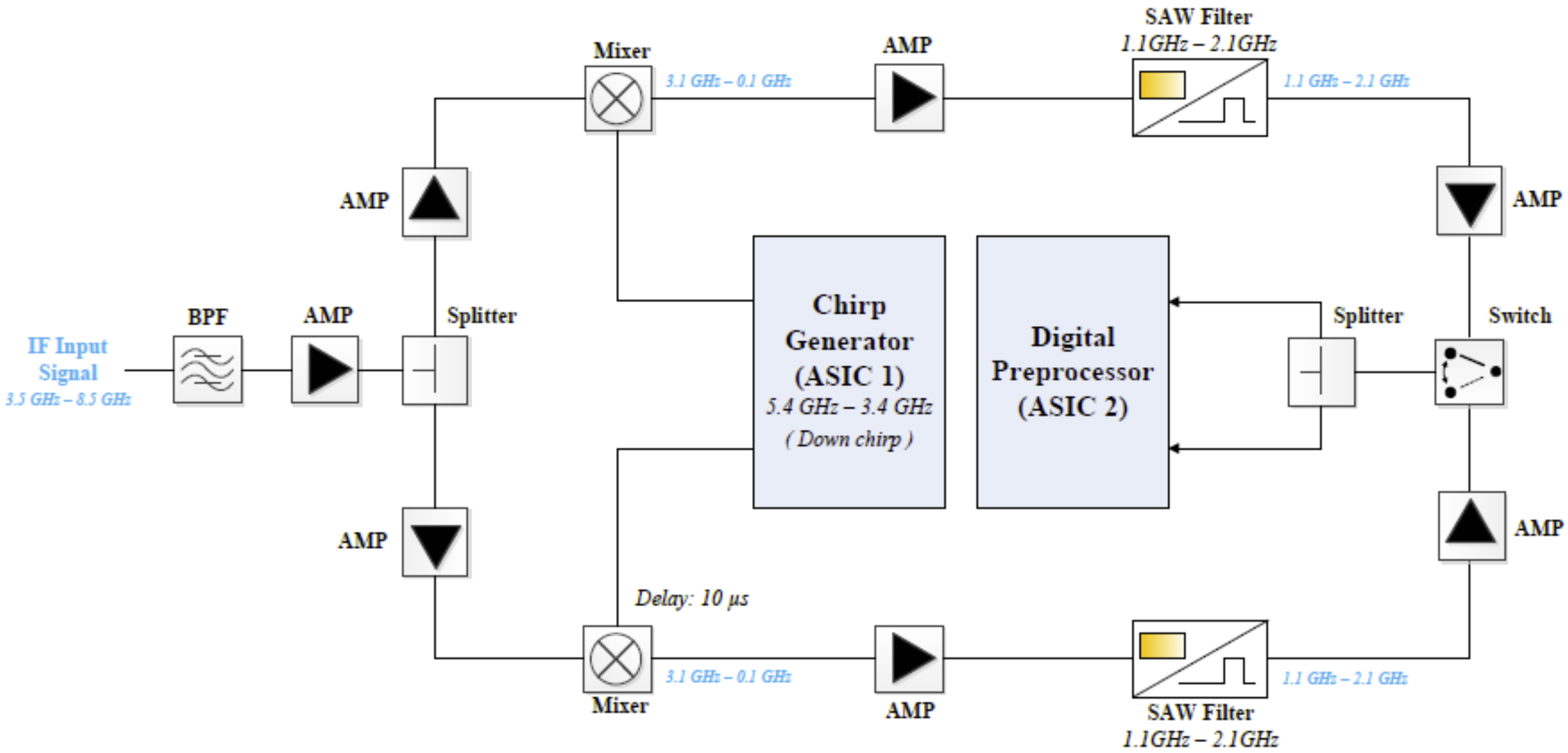
# Block diagram with 600/1200 GHz option



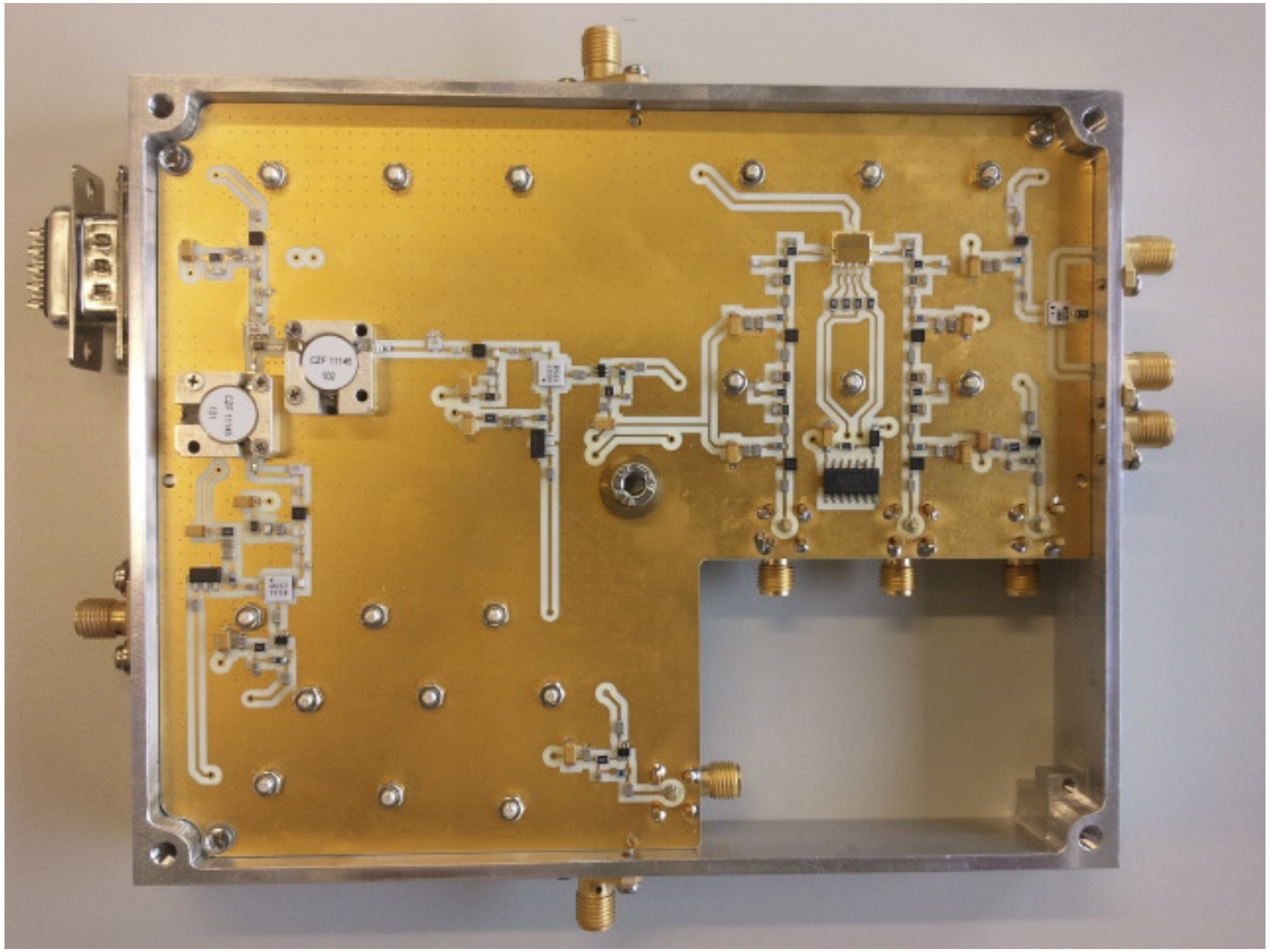




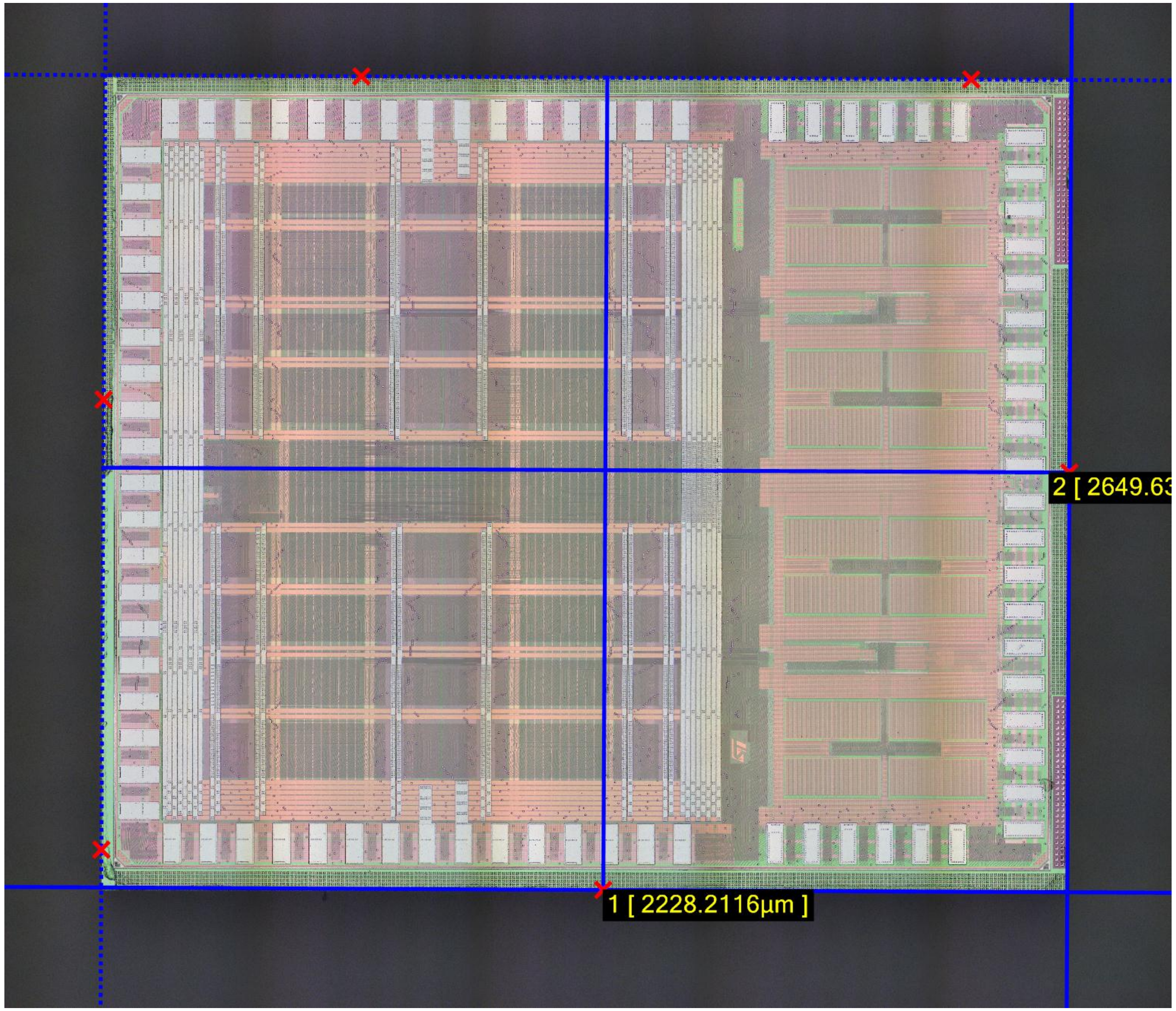
# Chirp Transform Spectrometer Block Diagram



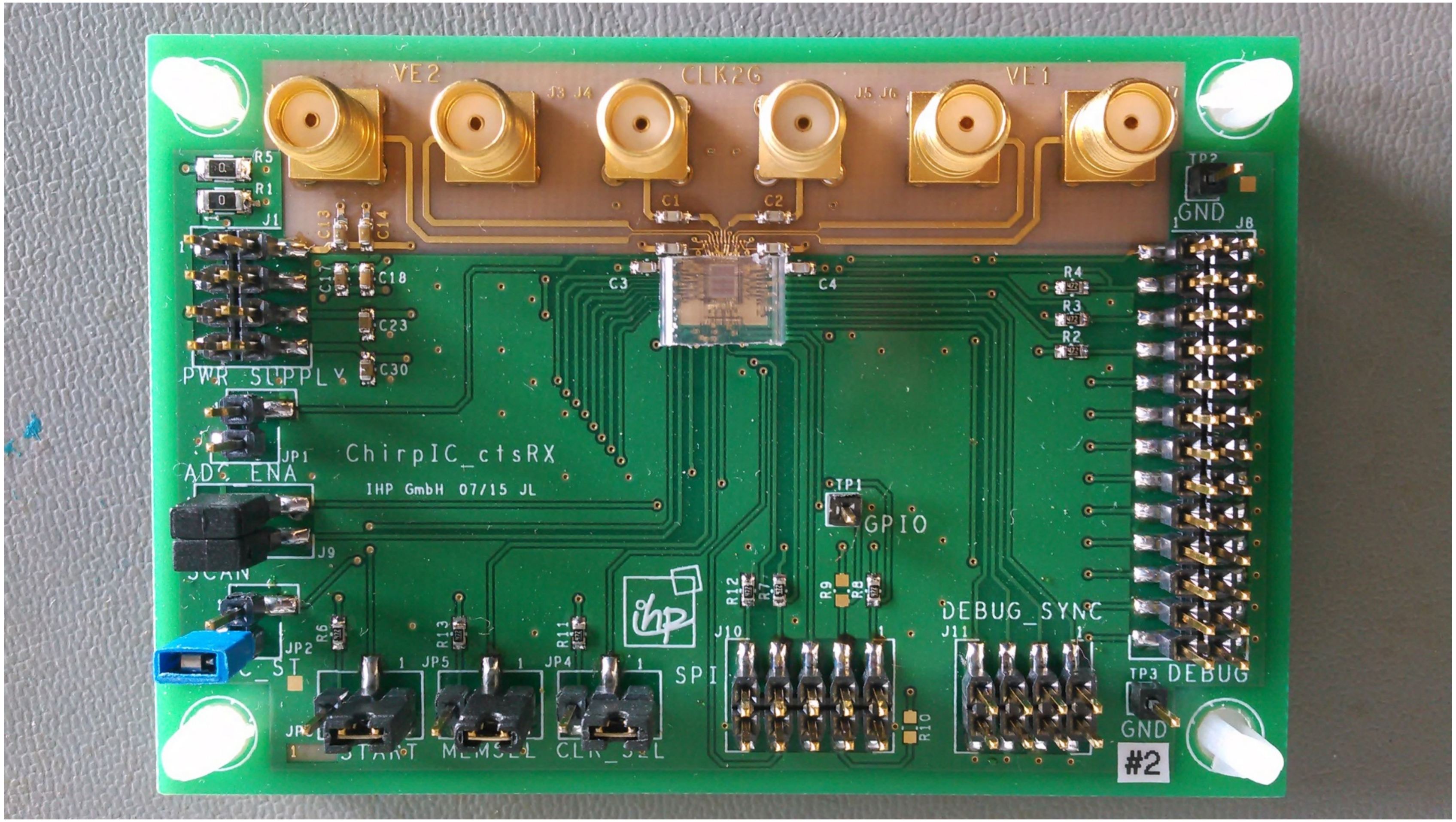
# CTS Tray Breadboard

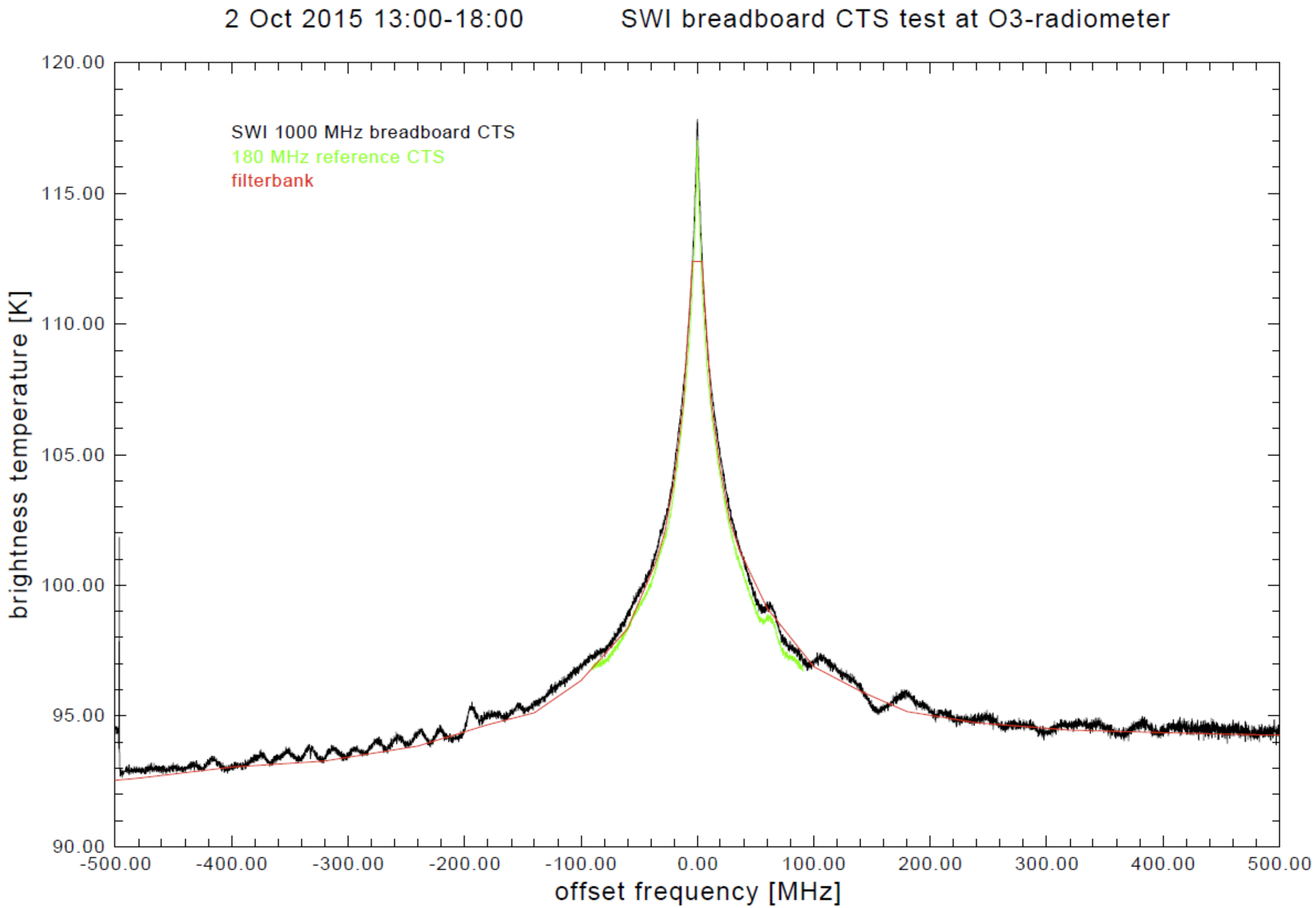


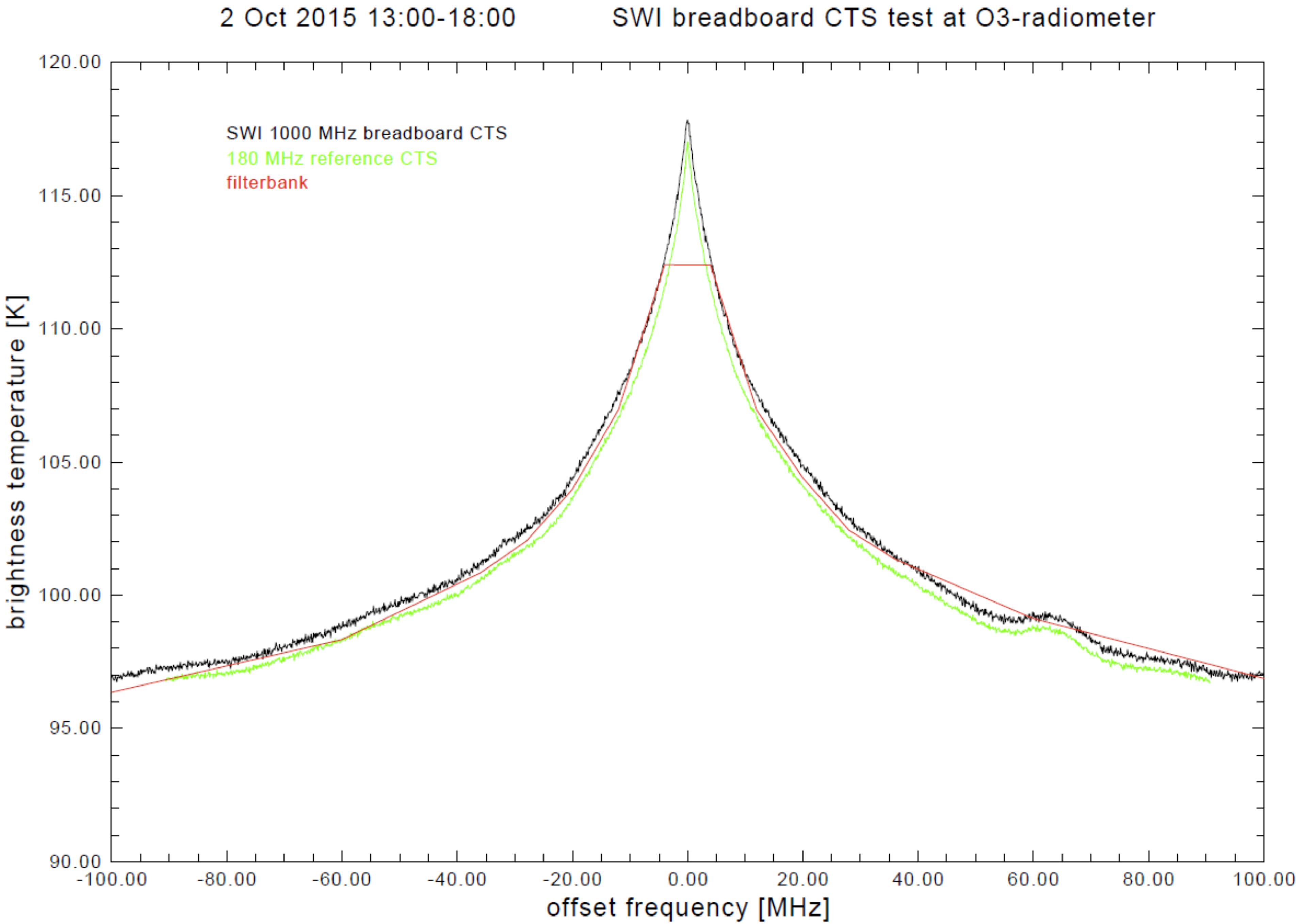
# Preprocessor ASIC chip



# Preprocessor ASIC test board




2 Oct 2015 13:00-18:00
SWI breadboard CTS test at O3-radiometer
SWI 1000 MHz breadboard CTS
180 MHz reference CTS
filterbank
brightness temperature [K]
offset frequency [MHz]
120.00
115.00
110.00
105.00
100.00
95.00
90.00
-500.00
-400.00
-300.00
-200.00
-100.00
0.00
100.00
200.00
300.00
400.00
500.00


2 Oct 2015 13:00-18:00
SWI breadboard CTS test at O3-radiometer
SWI 1000 MHz breadboard CTS
180 MHz reference CTS
filterbank
brightness temperature [K]
120.00
115.00
110.00
105.00
100.00
95.00
90.00
-100.00
-80.00
-60.00
-40.00
-20.00
0.00
20.00
40.00
60.00
80.00
100.00
offset frequency [MHz]

# Status and Schedule

- Implementation Phase: April 2015 – May 2022
- Next event: PDR in October 2016
- EM: spring 2018, QM fall 2018, FM spring 2019
- Launch: June 2022
- Cruise Phase: June 2022 – November 2029
- Science Phase: December 2029 – 2033
- Crash on Ganymede