The Submillimetre Wave Instrument (SWI) on JUICE: NECP, PCWs & LEGA Preparations

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SWI Science Co-Is

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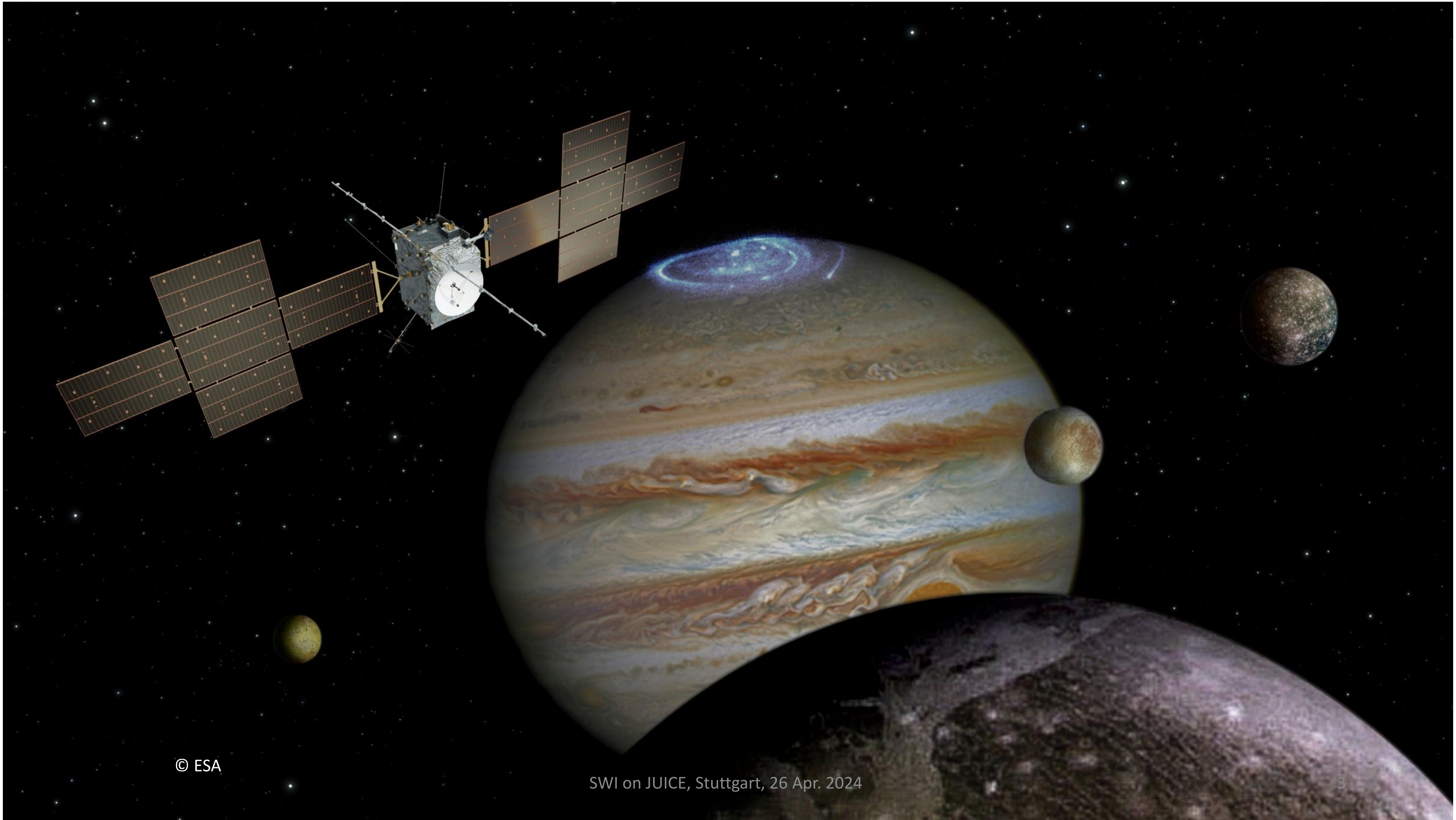
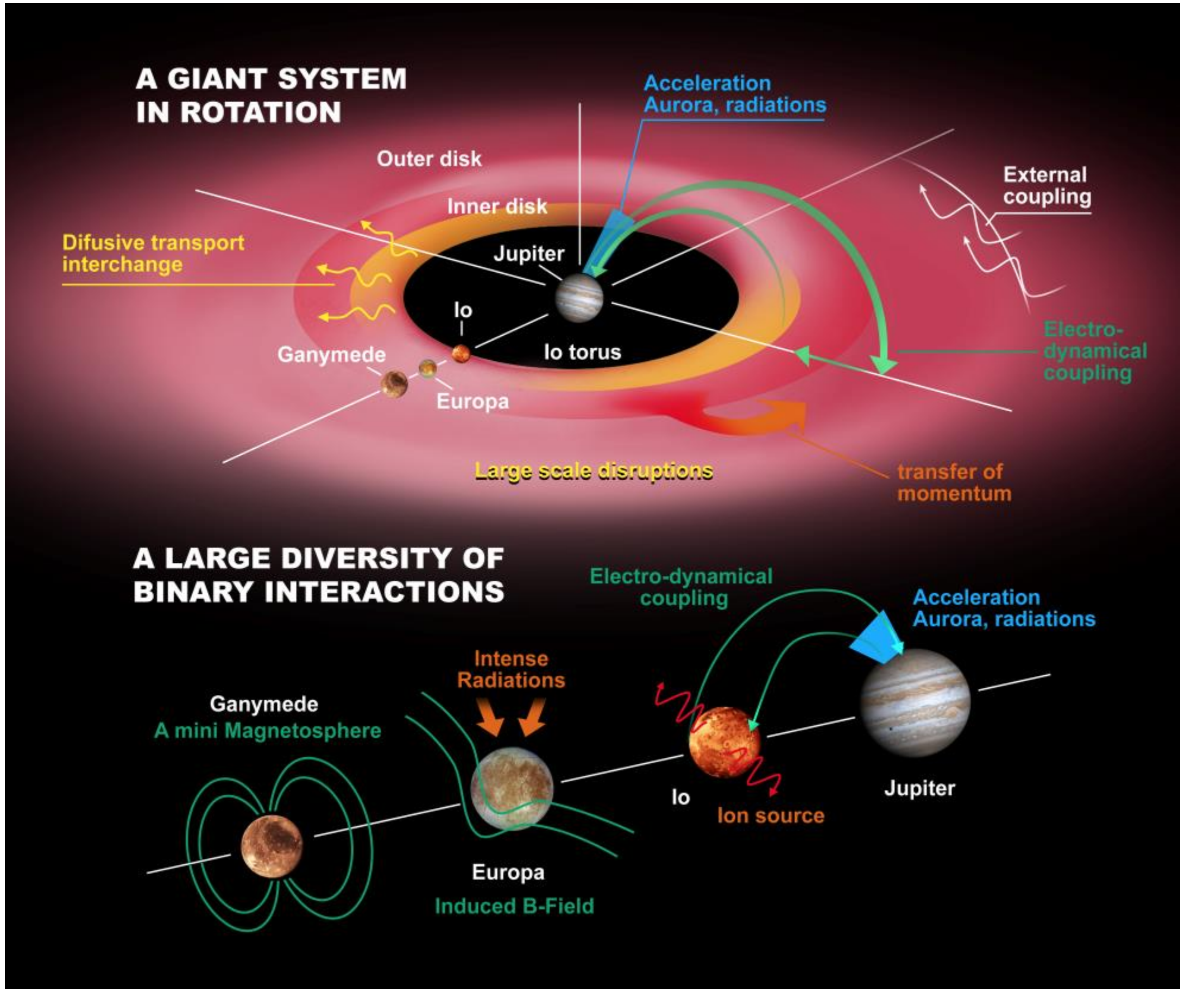


JUICE science themes

Emergence of habitable worlds around gas giants

- Ganymede as a planetary object and possible habitat
- Europas’s recently active zones
- Callisto as a remnant of the early jovian system

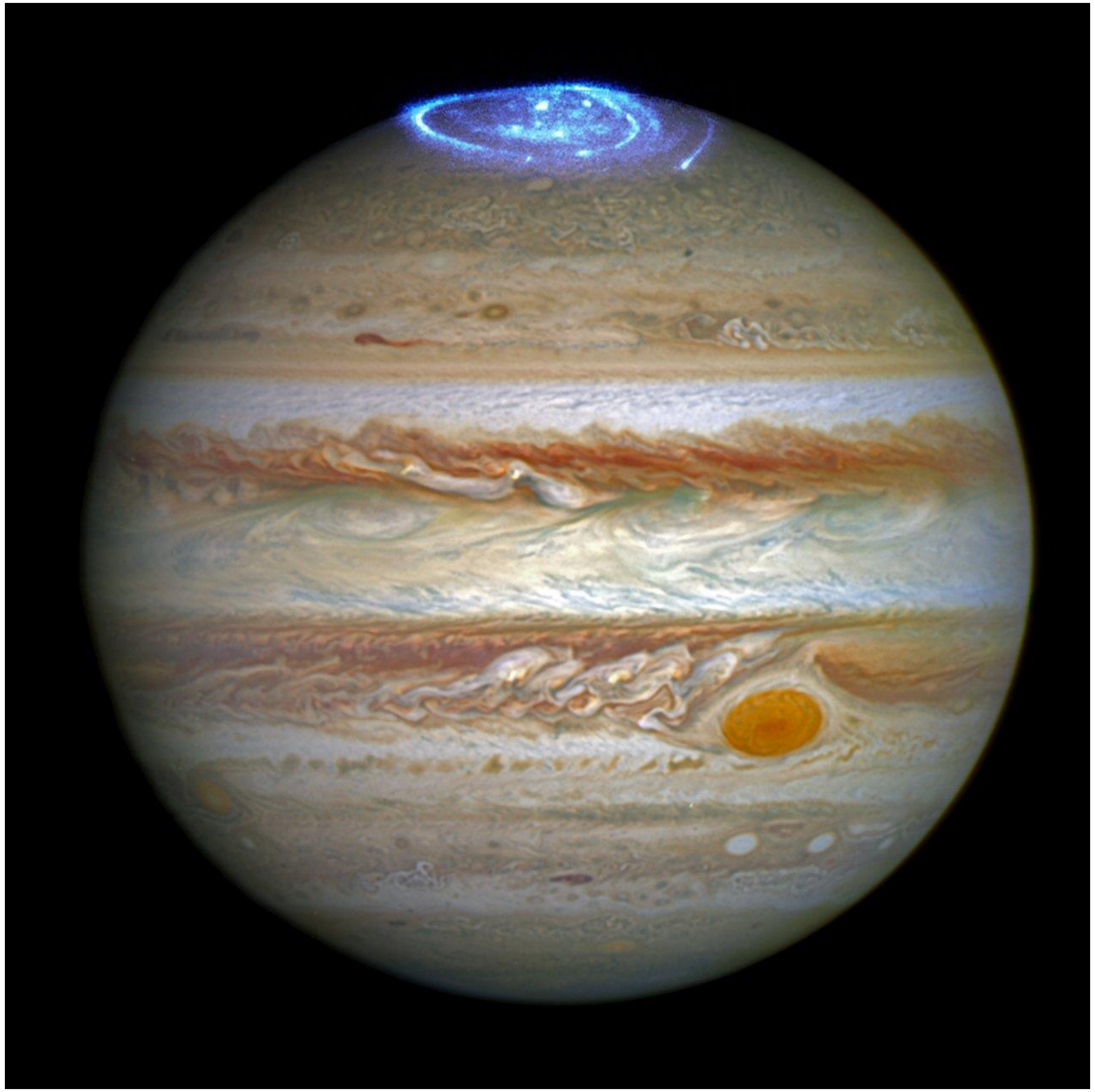


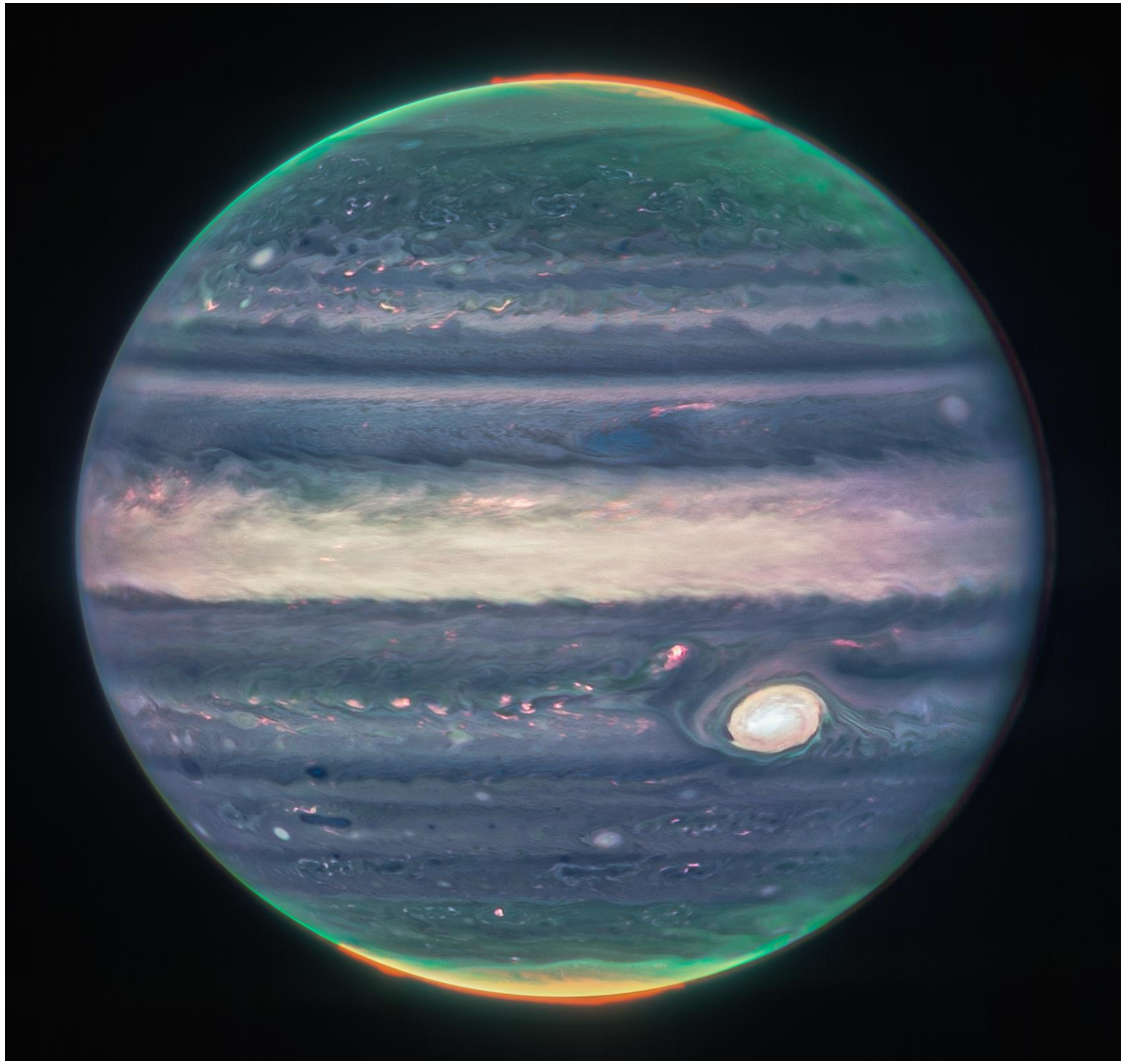
The Jupiter system as an archetype for gas giants

- Jovian atmosphere
- Jovian magnetosphere
- Jovian satellite and ring systems

Broad and interdisciplinary science

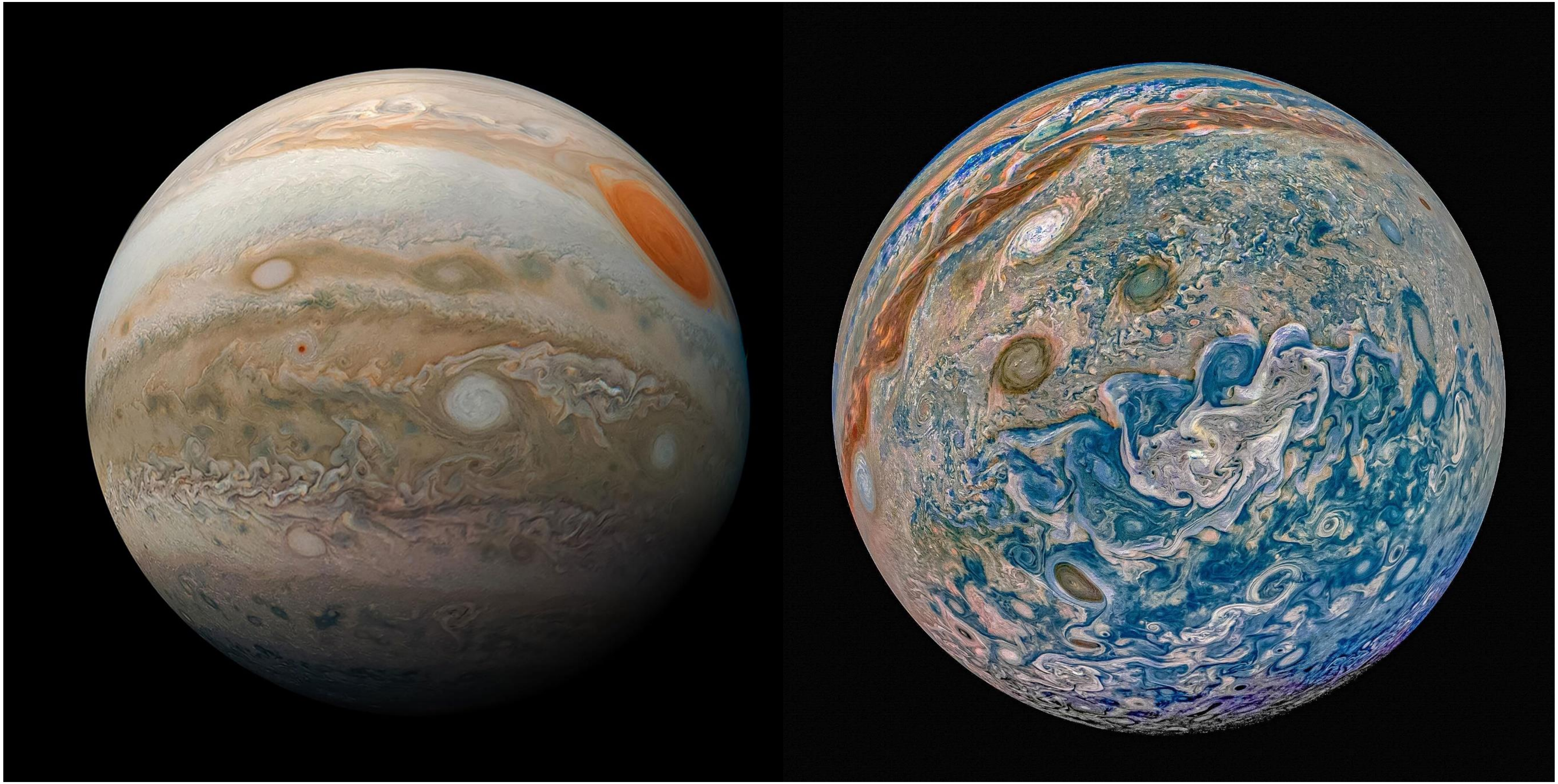
Hubble & JWST



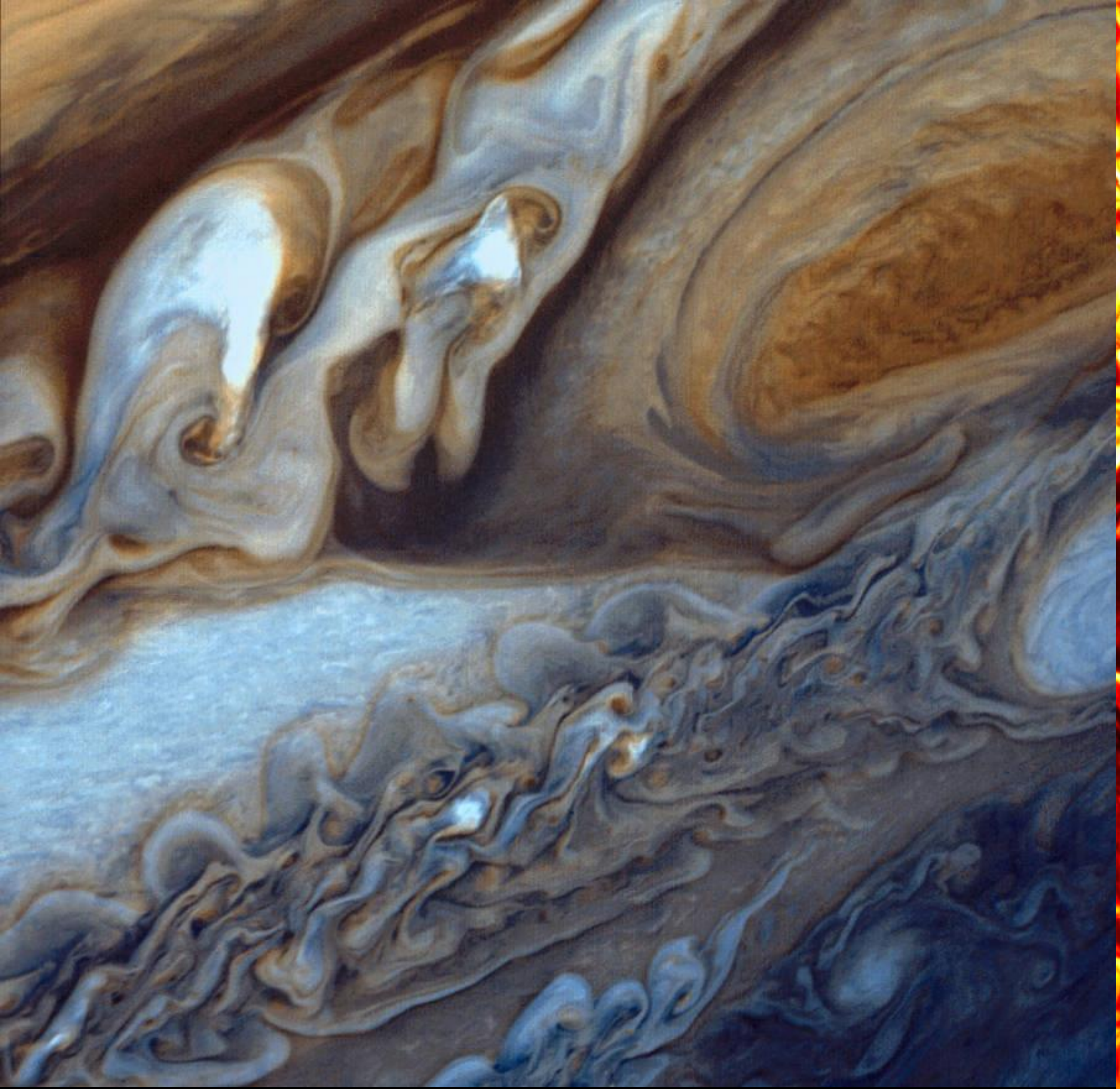


Credit: NASA/ESA

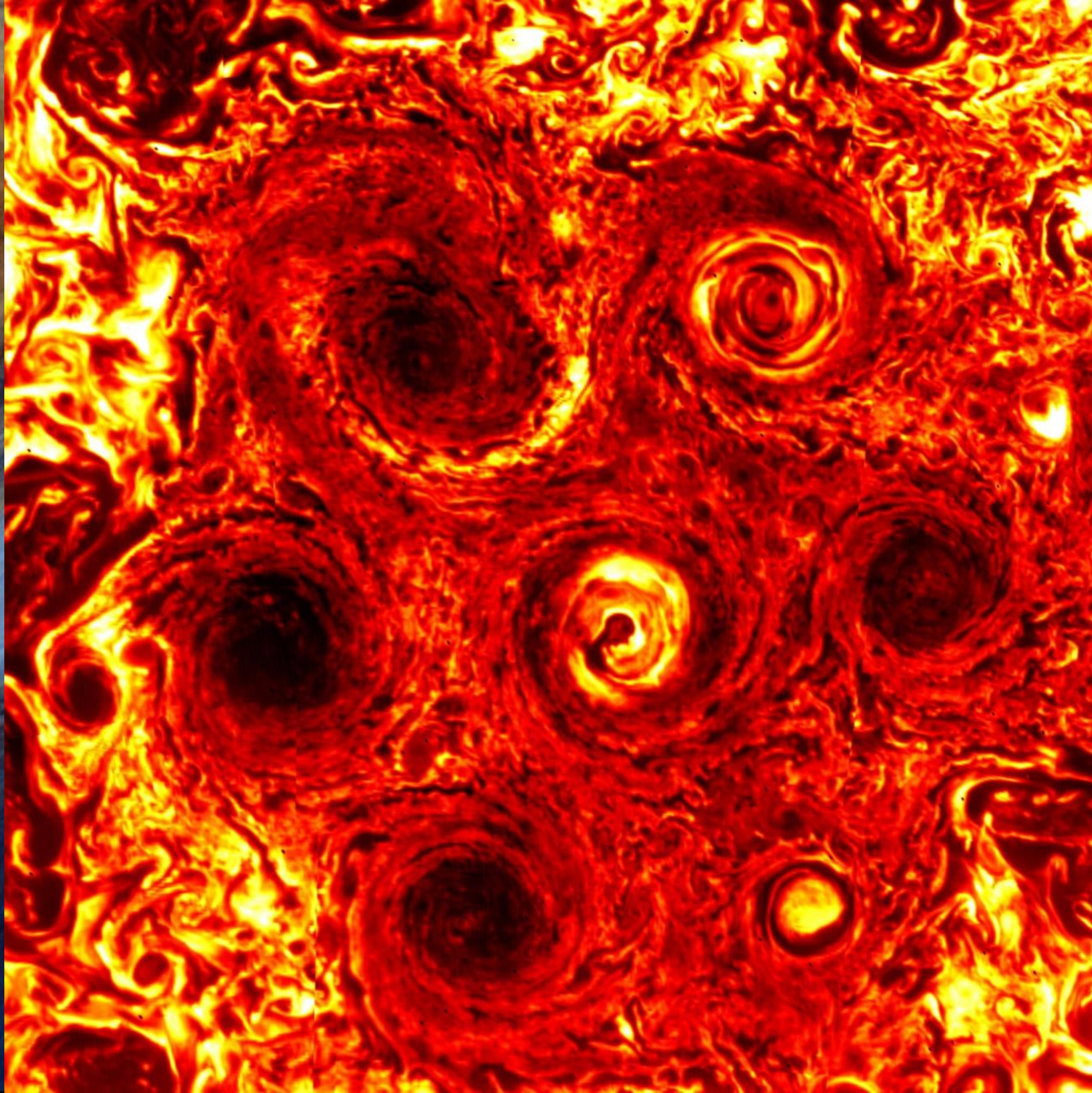
Juno



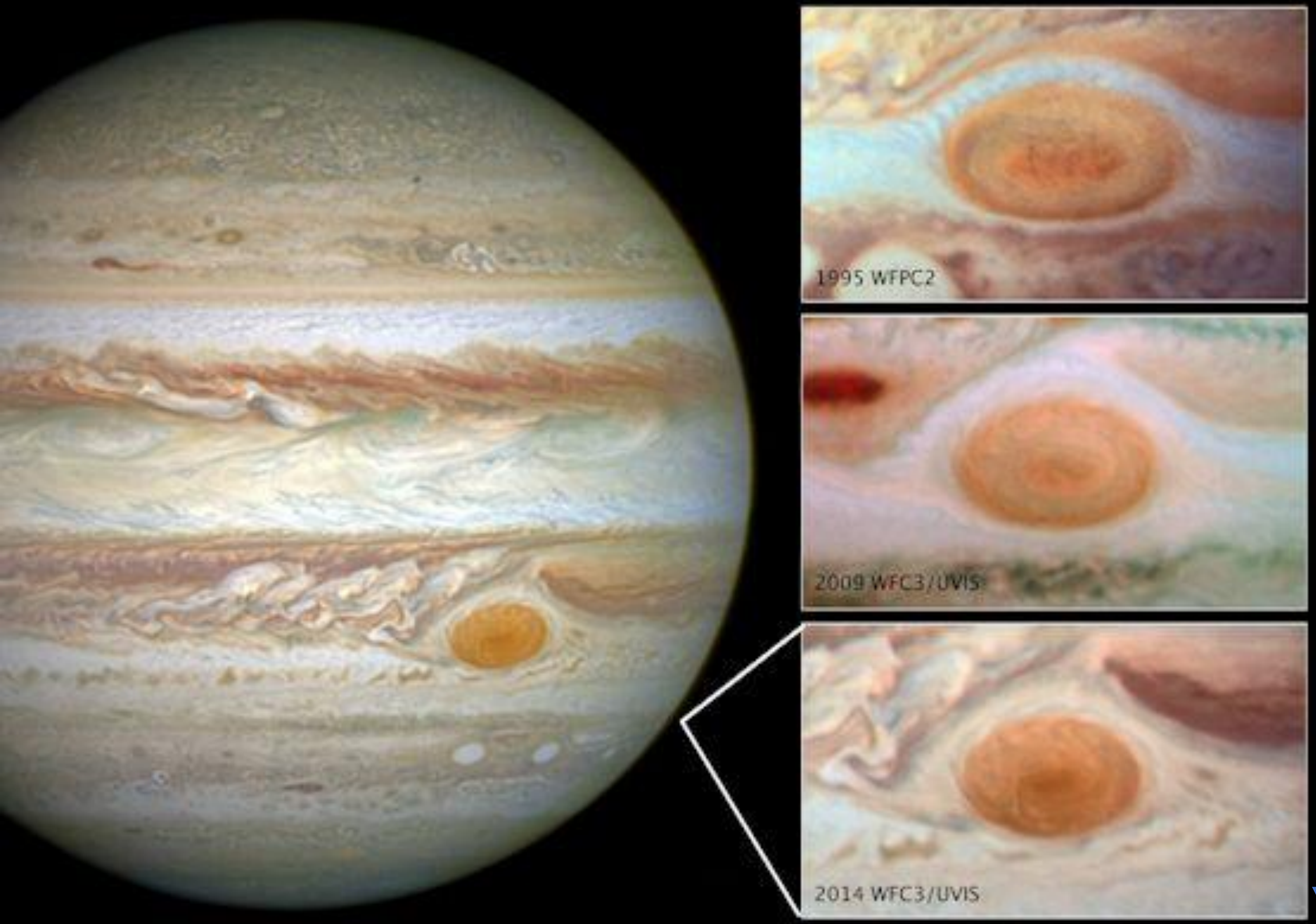
Credit: NASA/ESA



Voyager 1, 1979
©NASA

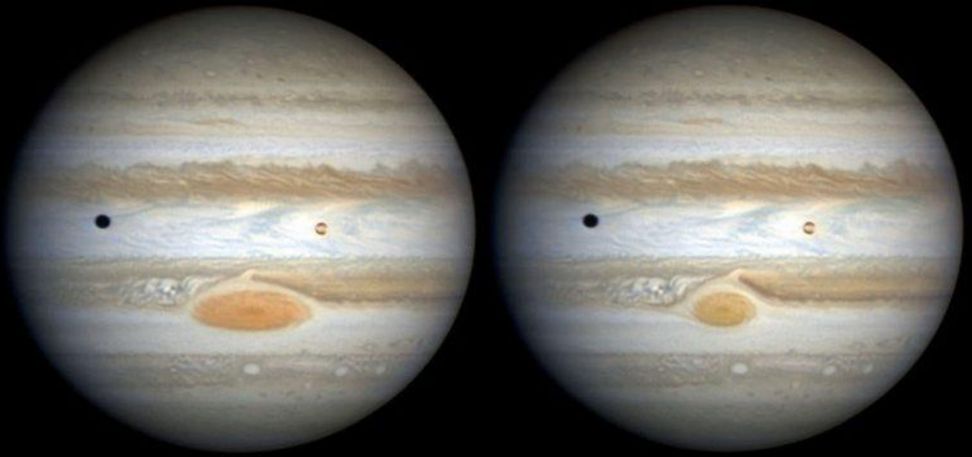


South pole of Jupiter in IR, Juno, 2019
©NASA



20 Years

125 years

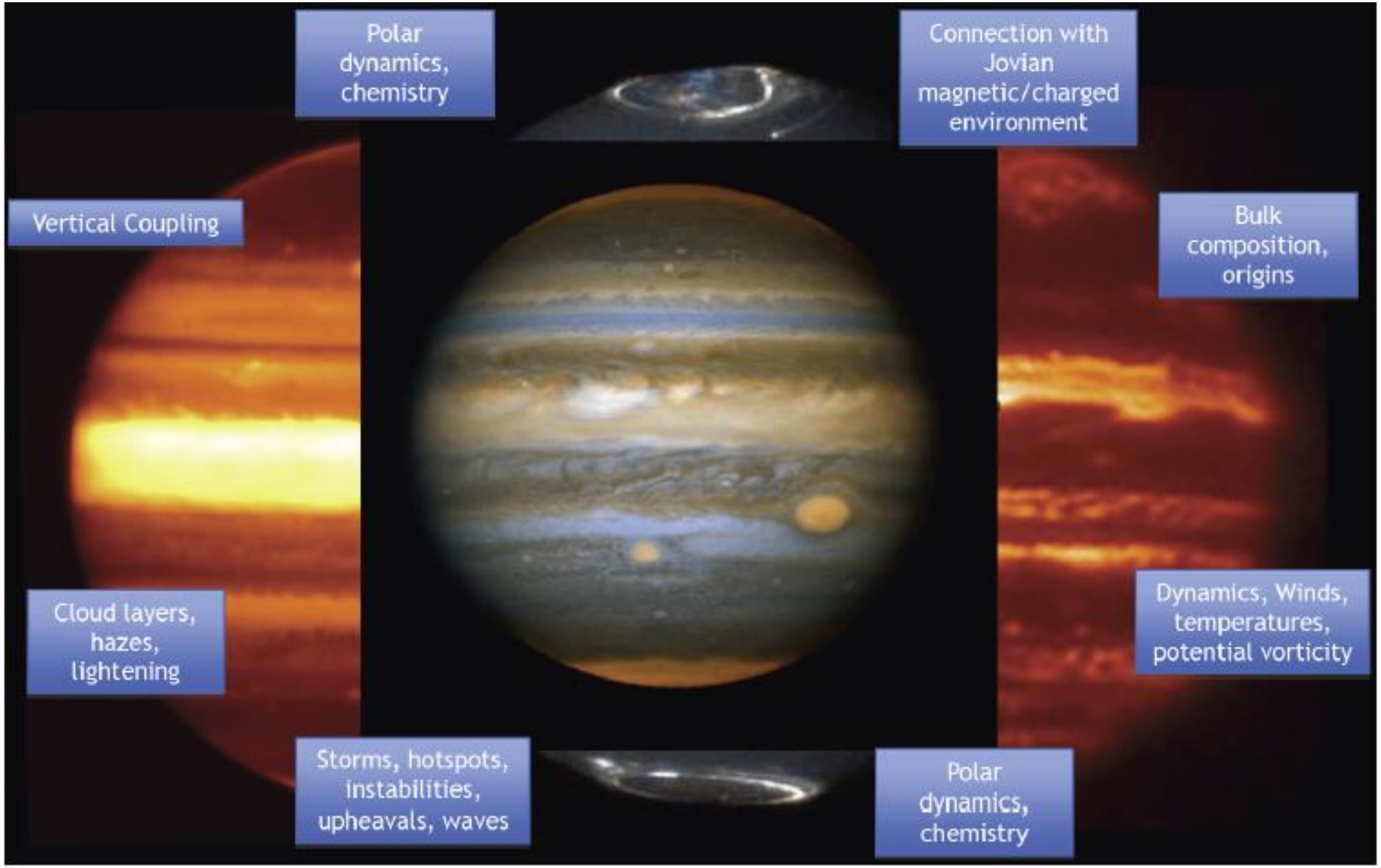


Great Red Spot in 1890
Length: 22,370 miles = 2.8 Earths

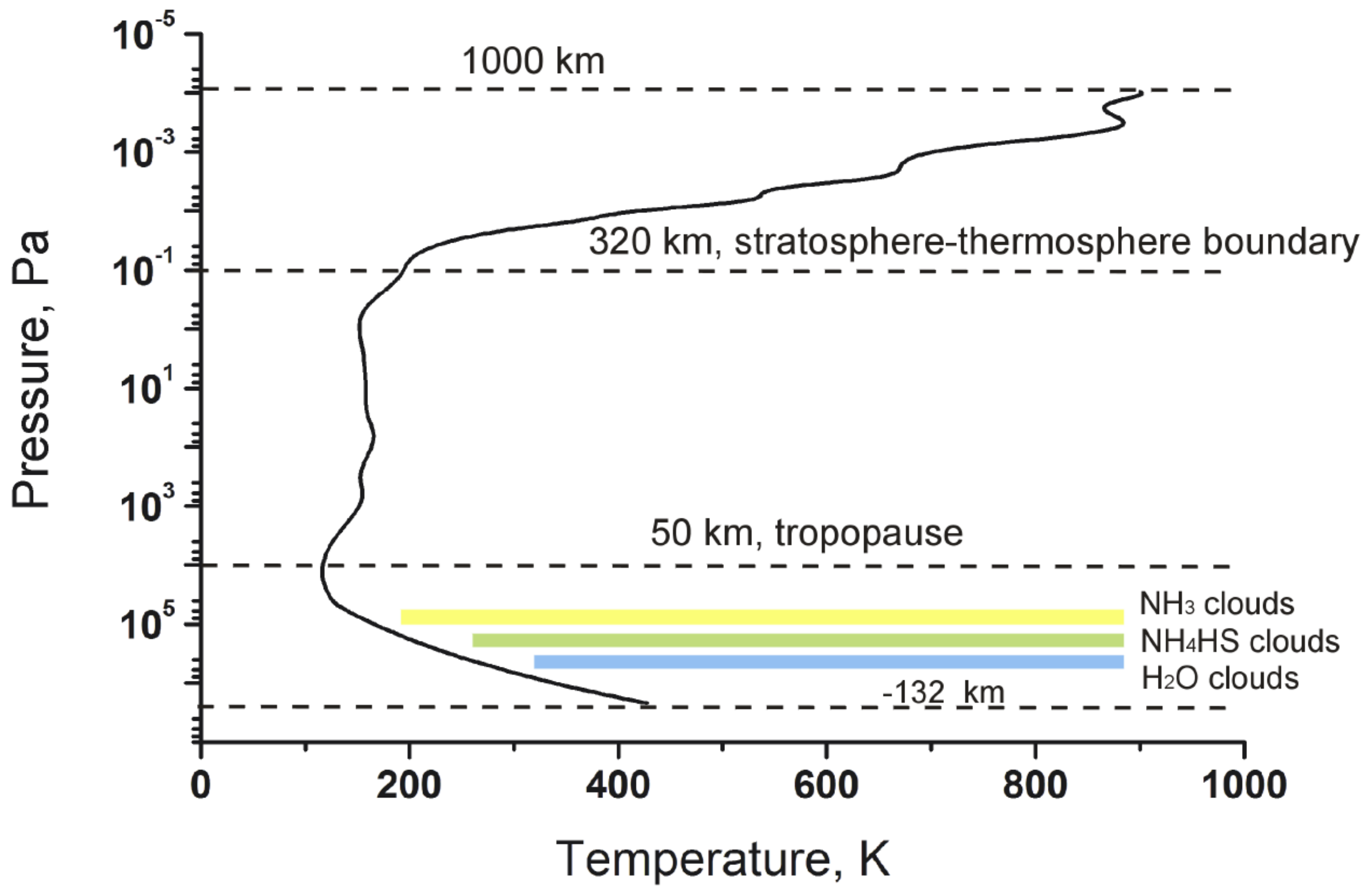
Great Red Spot in 2015
Length: 9,630 miles = 1.2 Earths

How will the great rot spot look like in 2032??

Investigations of the Jupiter atmosphere

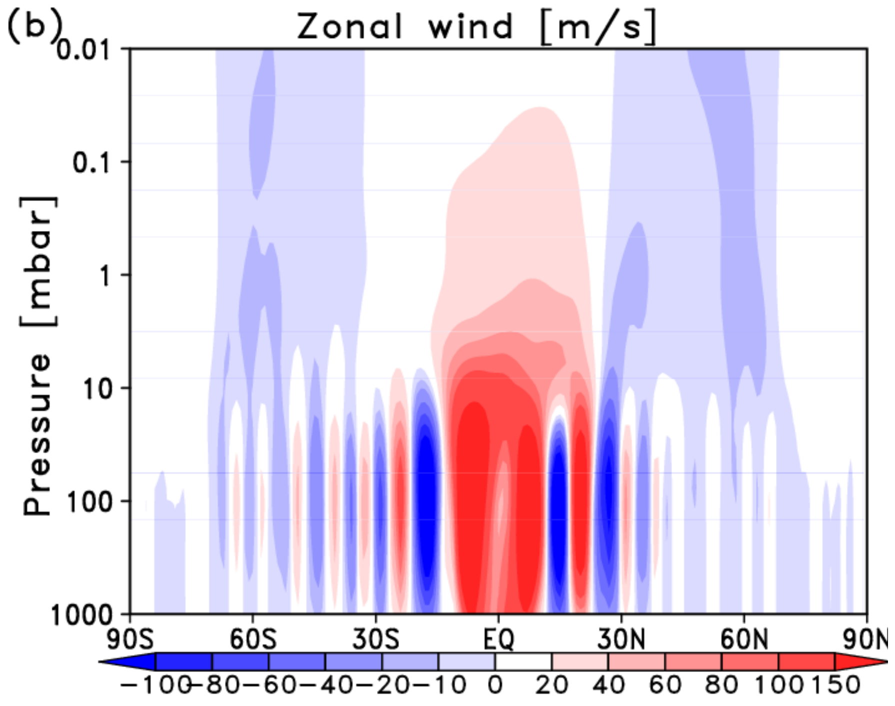


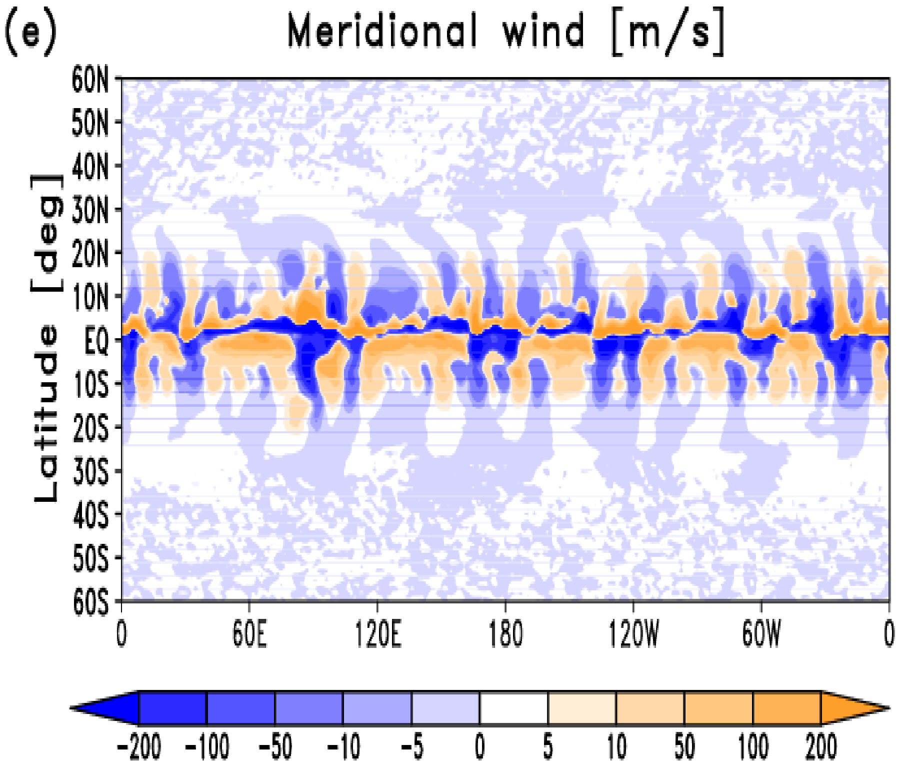
Structure of Jupiter's atmosphere



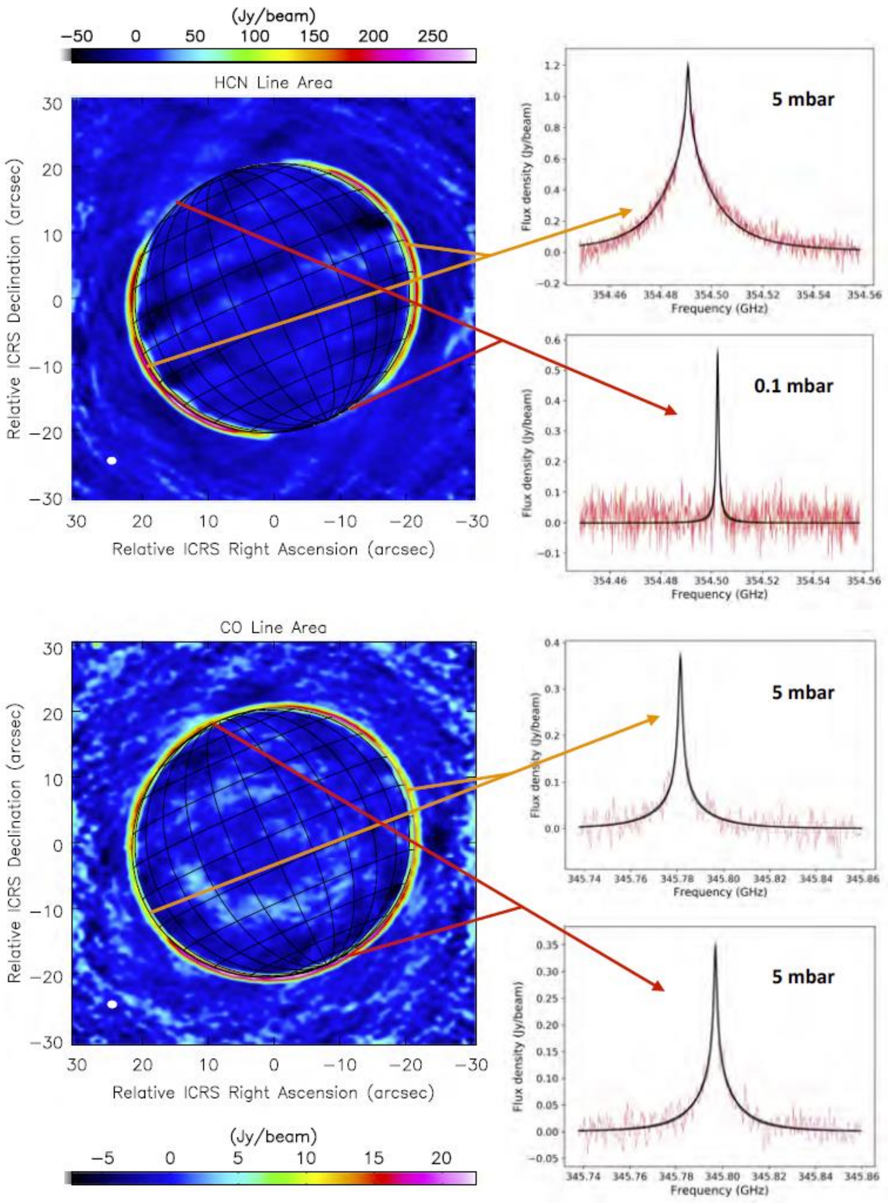
Zonal wind (u) & meridional wind deviations from u at 60 mb

MPI-JGCM: Sethunadh, 2014; Medvedev, 2013, Hartogh et al, 2005





Jupiter aurora



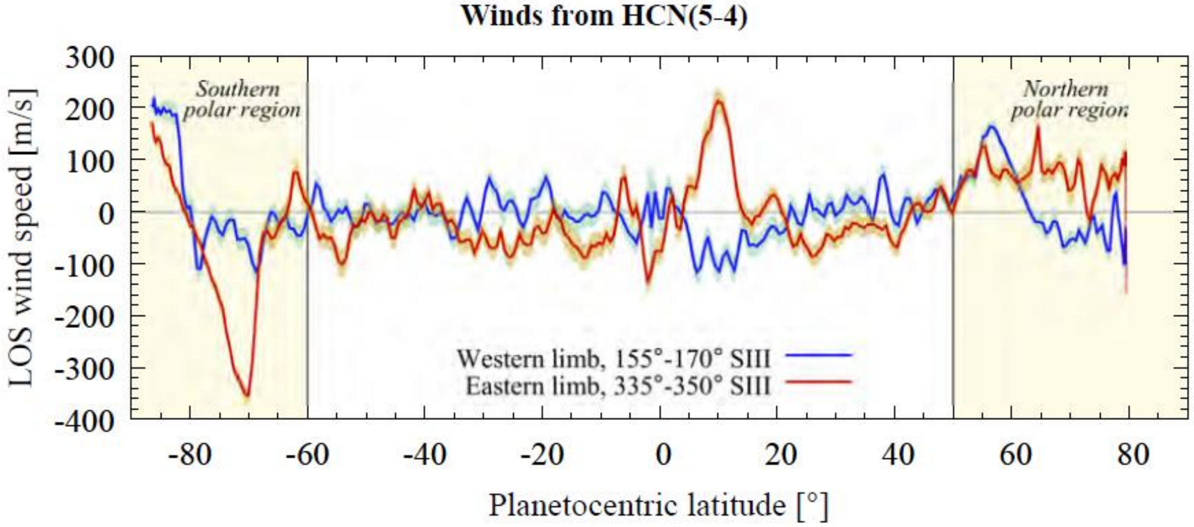
A&A 647, L8 (2021)
https://doi.org/10.1051/0004-6361/202140330

Astronomy & Astrophysics

Letter to the Editor

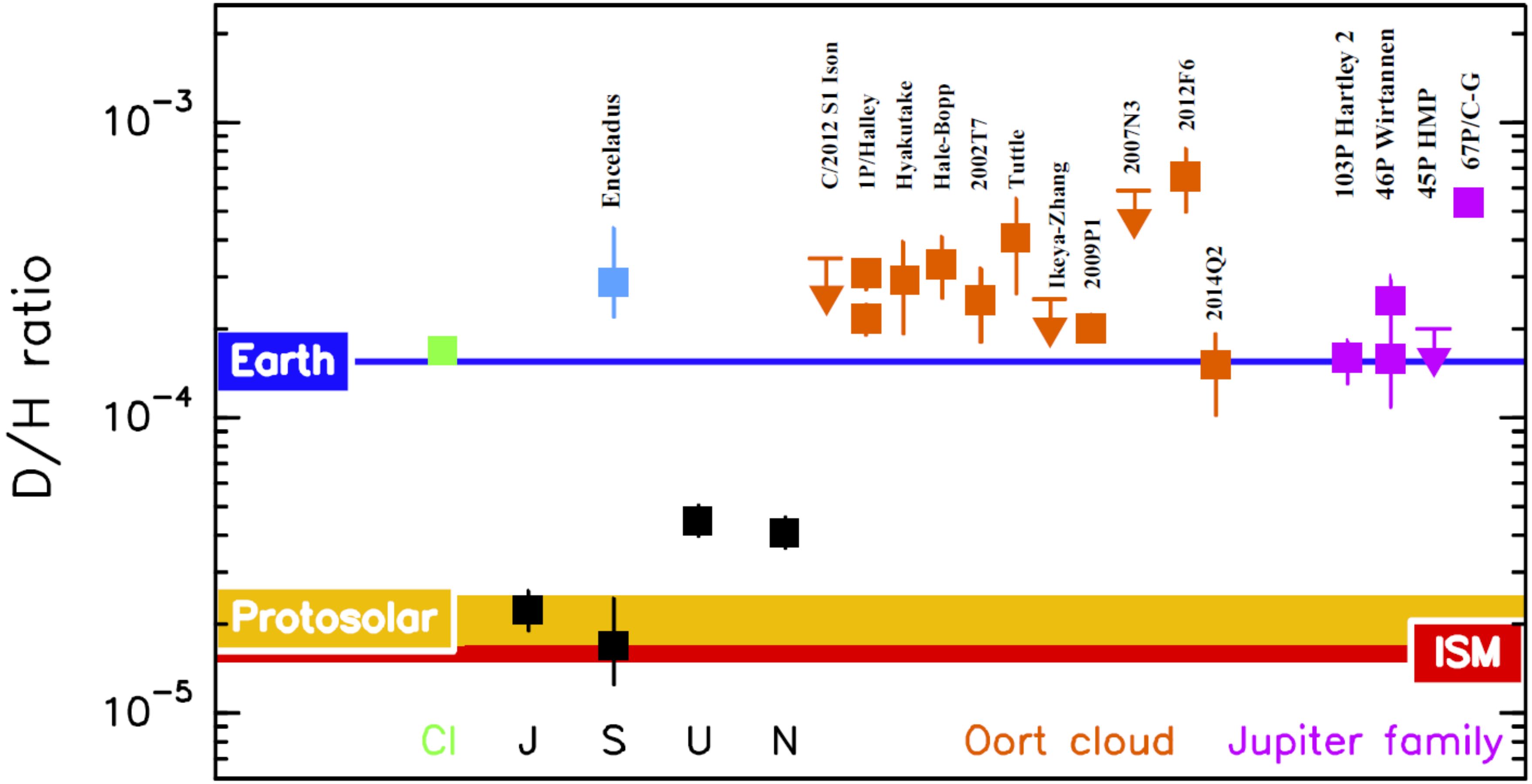
First direct measurement of auroral and equatorial jets in the stratosphere of Jupiter

T. Cavalié[1,2], B. Benmahi[1], V. Hue[3], R. Moreno[2], E. Lellouch[2], T. Fouchet[2], P. Hartogh[4], L. Rezac[4], T. K. Greathouse[3], G. R. Gladstone[3], J. A. Sinclair[5], M. Dobrijevic[1], F. Billebaud[1], and C. Jarchow[4]

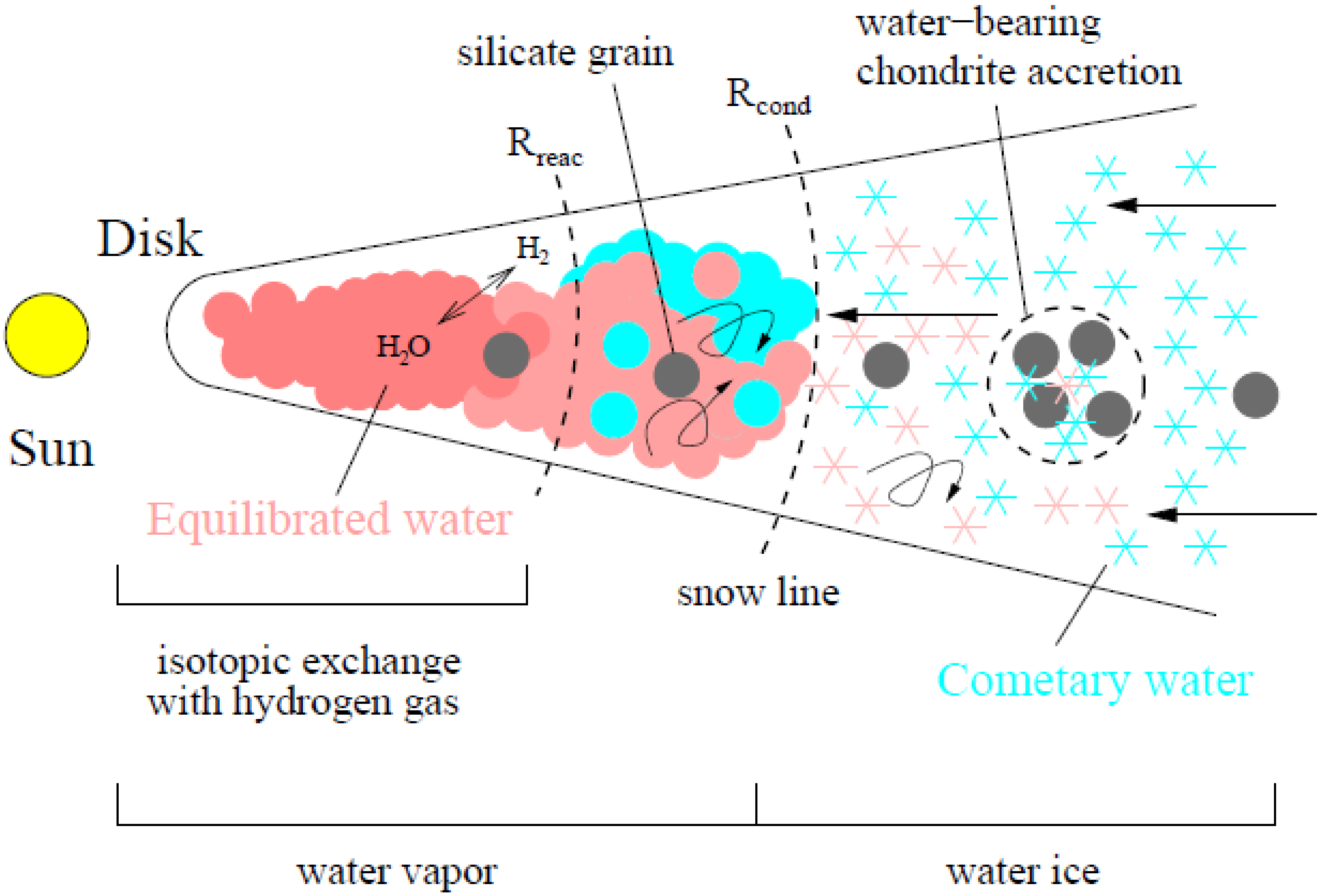


Wind speeds up to 1300 km/h detected at 0.1 hPa. Coupling mechanism between aurora and thermosphere/stratosphere not understood yet

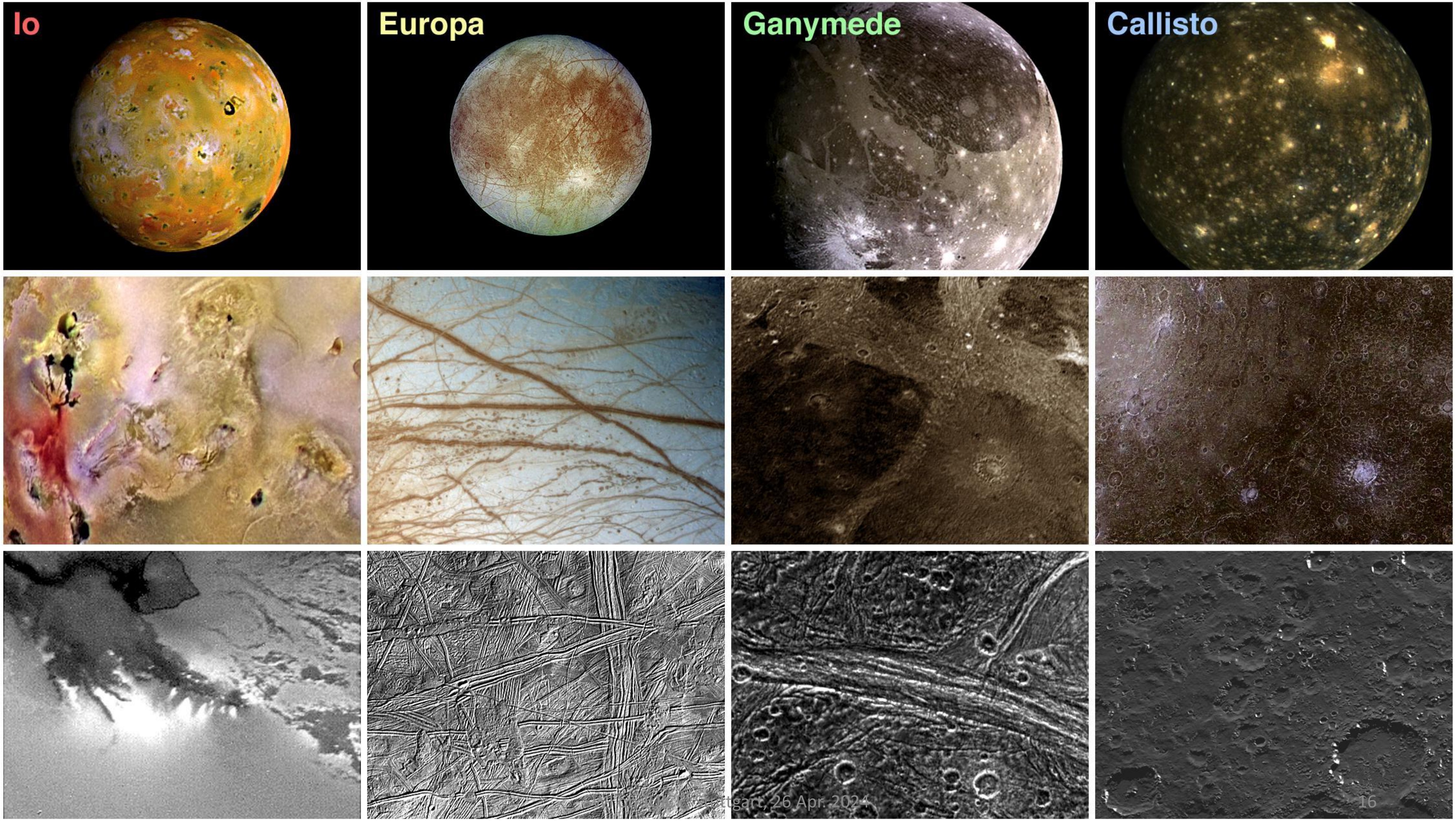
D/H in the solar system

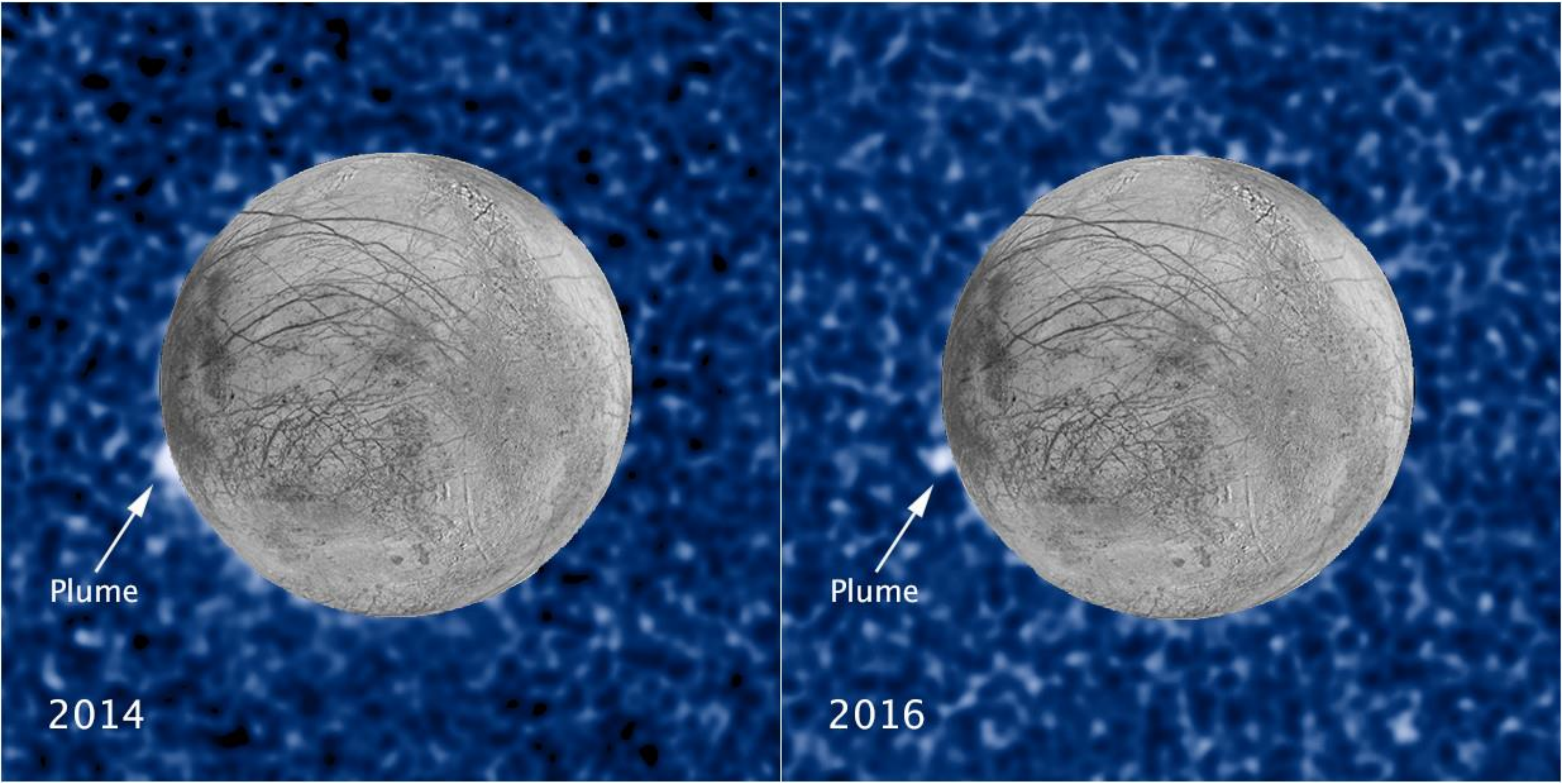


Hartogh et al., Nature 2011, updated: status 2020

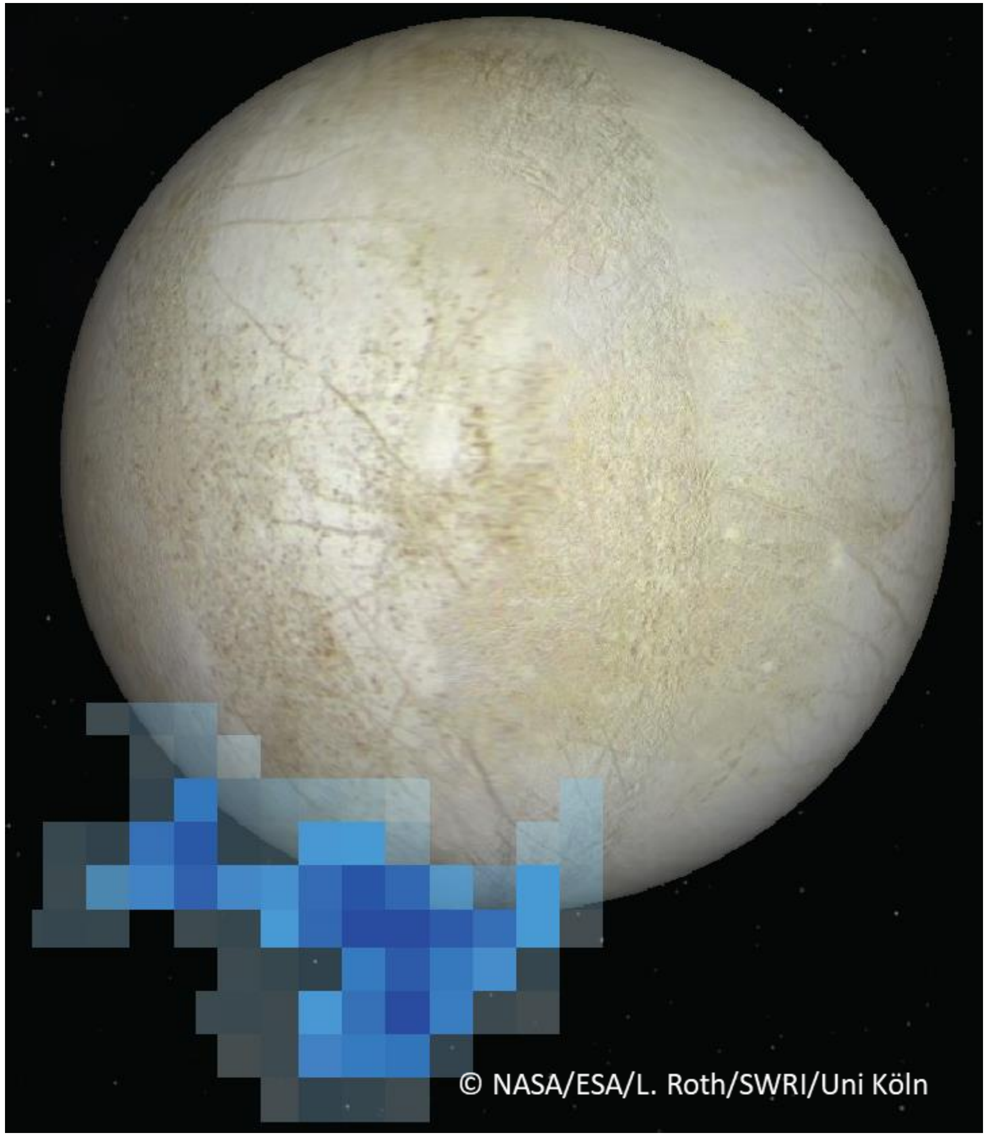


Jacquet et al. Icarus 2013


Io
Europa
Ganymede
Callisto


Plume
2014
Plume
2016

Geysers on Europa?



ARTICLES
https://doi.org/10.1038/s41550-019-0933-6

nature astronomy

A measurement of water vapour amid a largely quiescent environment on Europa

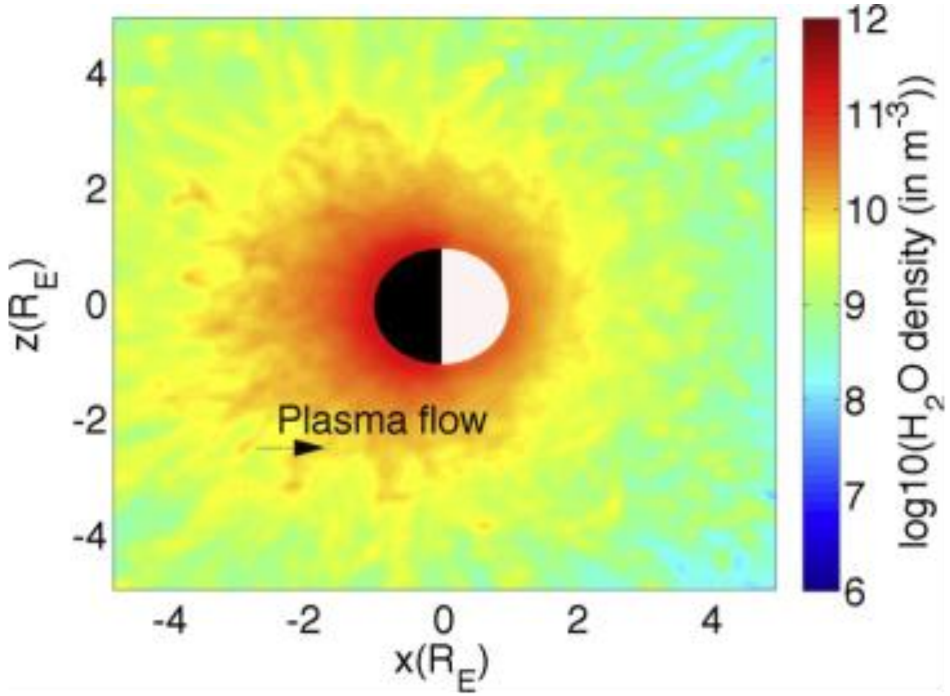
L. Paganini[1,2]*, G. L. Villanueva[1], L. Roth[3], A. M. Mandell[1], T. A. Hurford[1], K. D. Retherford[4] and M. J. Mumma[1]

Previous investigations proved the existence of local density enhancements in Europa's atmosphere, advancing the idea of a possible origination from water plumes. These measurement strategies, however, were sensitive either to total absorption or atomic emissions, which limited the ability to assess the water content. Here we present direct searches for water vapour on Europa spanning dates from February 2016 to May 2017 with the Keck Observatory. Our global survey at infrared wavelengths resulted in non-detections on 16 out of 17 dates, with upper limits below the water abundances inferred from previous estimates. On one date (26 April 2016) we measured 2,095 ± 658 tonnes of water vapour at Europa's leading hemisphere. We suggest that the outgassing of water vapour on Europa occurs at lower levels than previously estimated, with only rare localized events of stronger activity.

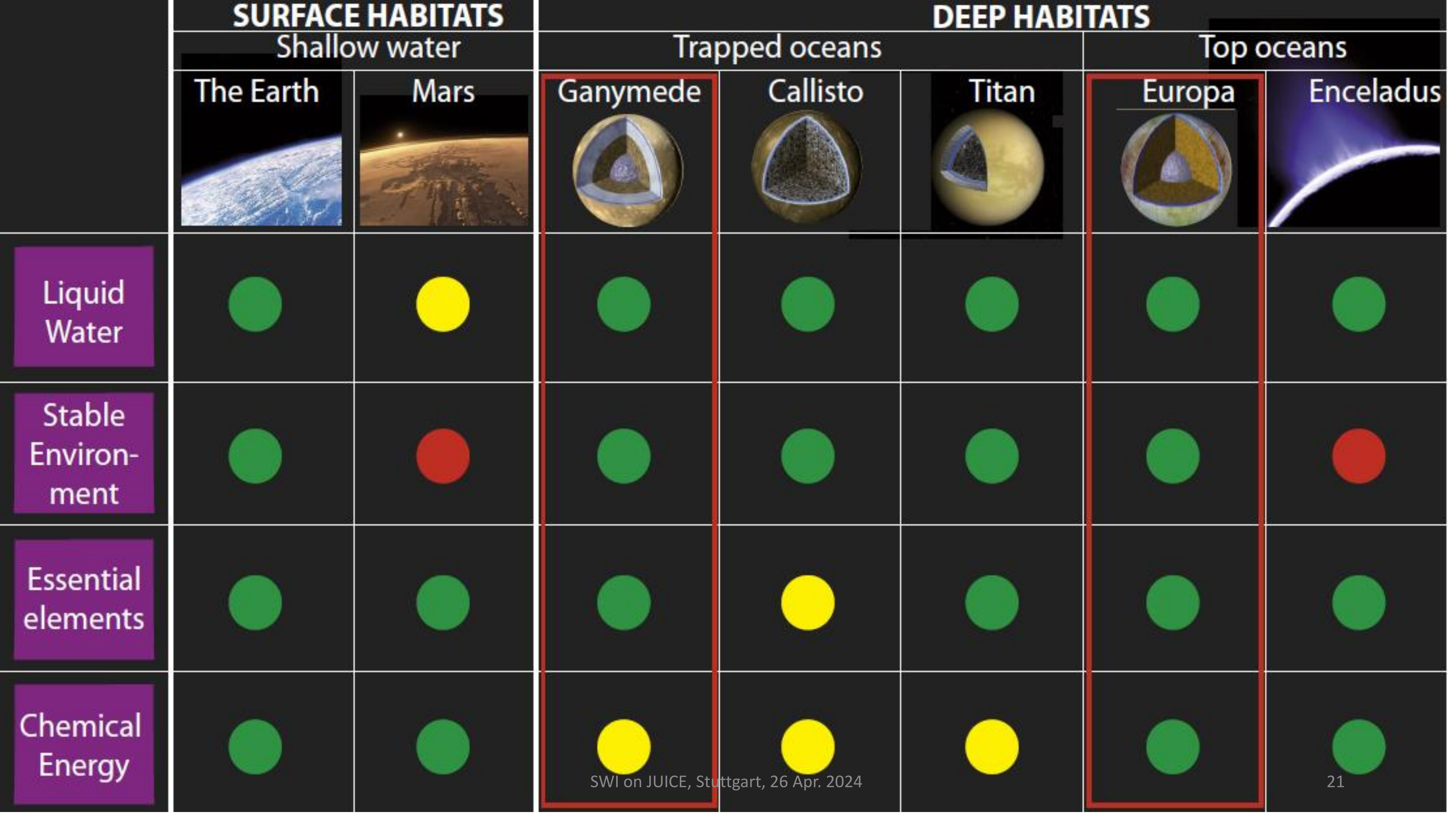
Nature astronomy, March 2020

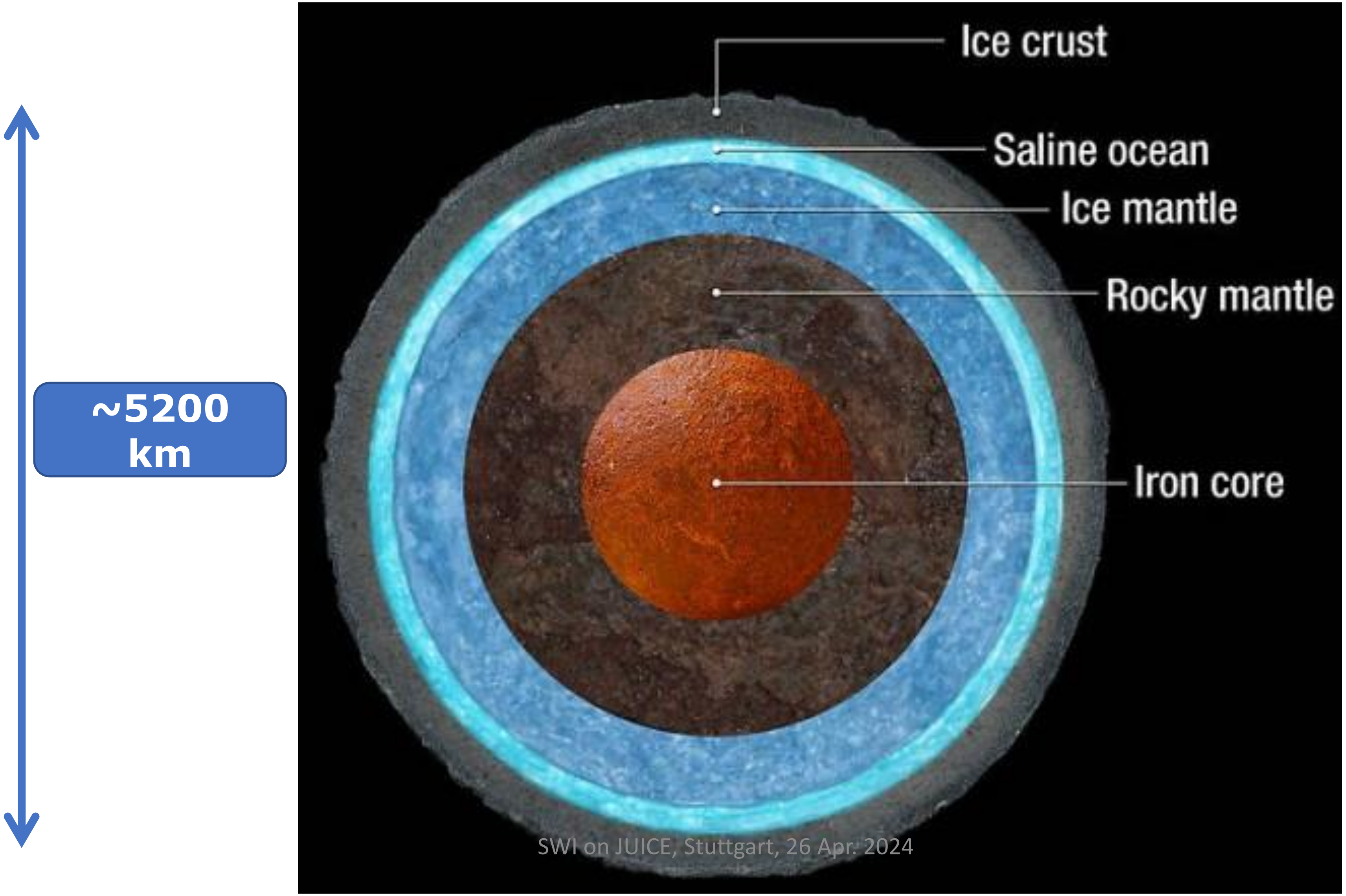
Persistent water atmosphere of Europa

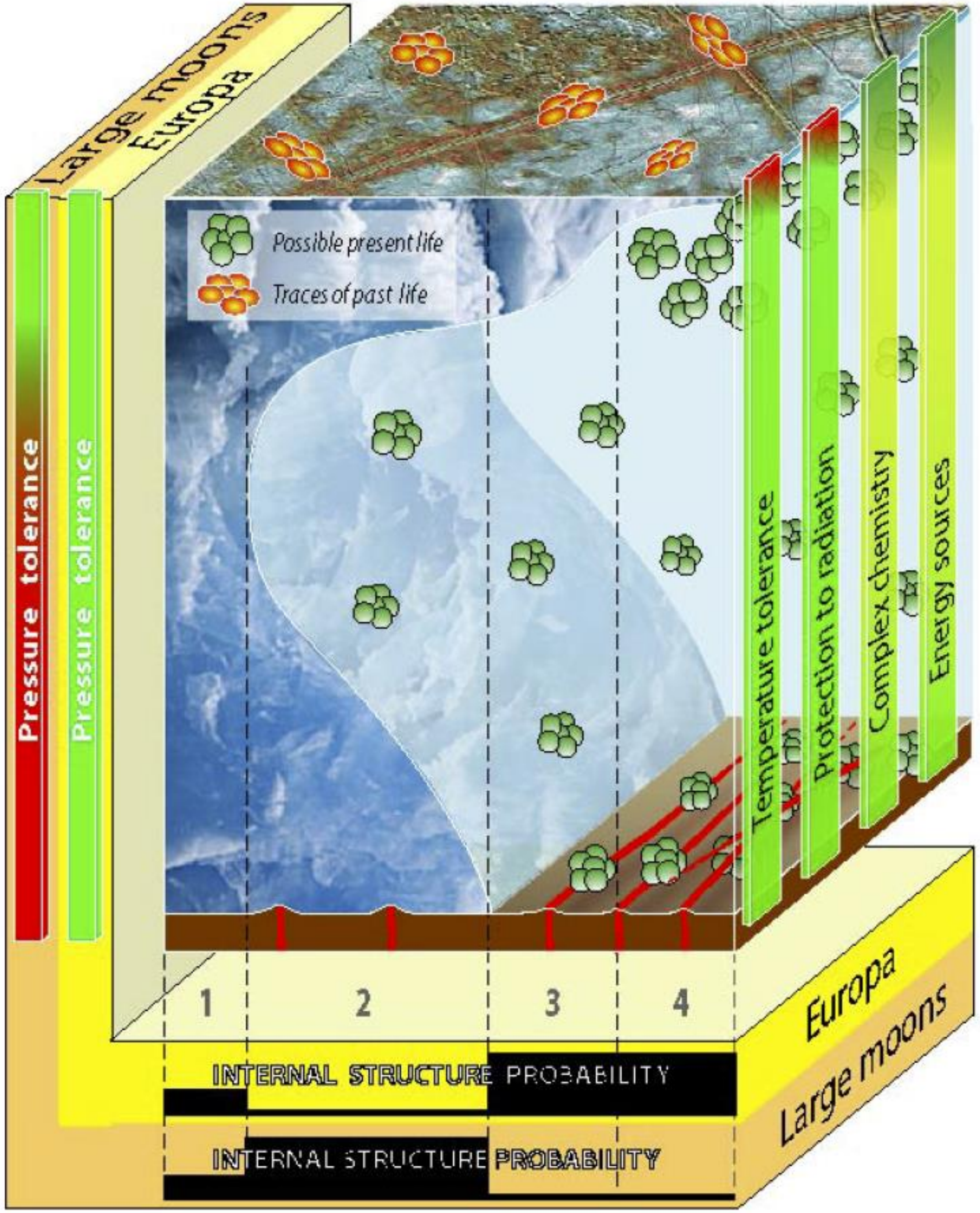
- Models predict a water atmosphere created by sputtering, radiolysis and to a small amount by sublimation. Total mass: 20-100 tons. HST/Keck 3 sigma sensitivity 1800 tons (Roth 2014, Paganini 2020). SWI sensitivity << 1 ton.



Plainaki et al, 2018


SURFACE HABITATS
DEEP HABITATS
Shallow water
Trapped oceans
Top oceans
The Earth
Mars
Ganymede
Callisto
Titan
Europa
Enceladus
Liquid Water
Stable Environ-ment
Essential elements
Chemical Energy


~5200
km
Ice crust
Saline ocean
Ice mantle
Rocky mantle
Iron core


Large moons
Europa
Possible present life
Traces of past life
Pressure tolerance
Pressure tolerance
Temperature tolerance
Protection to radiation
Complex chemistry
Energy sources
1
2
3
4
Europa
Large moons
INTERNAL STRUCTURE PROBABILITY
INTERNAL STRUCTURE PROBABILITY

JUpiter ICy Moons Explorer

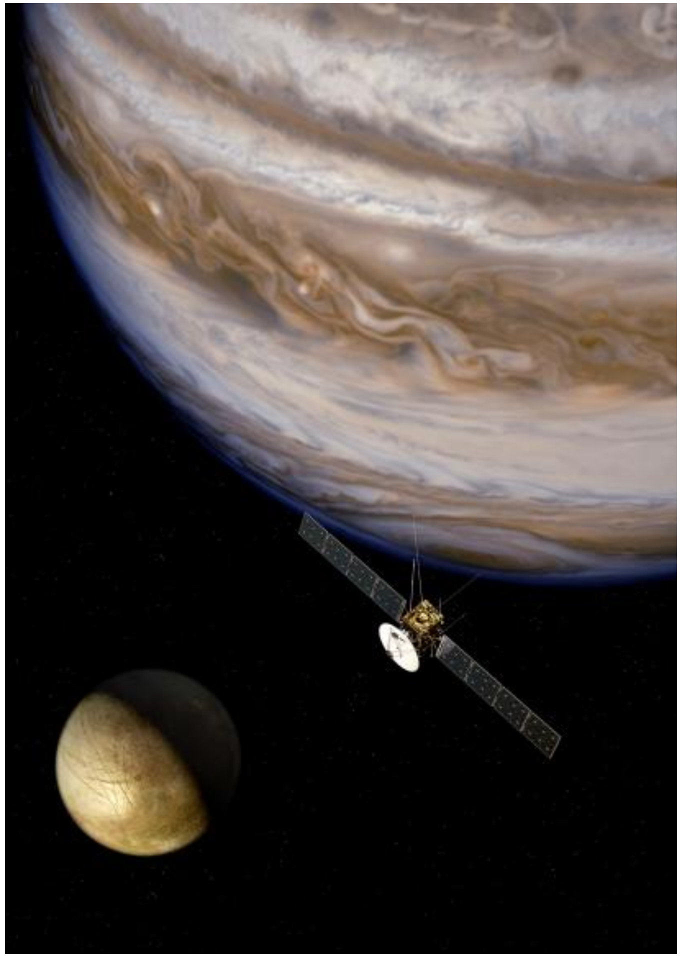
ESA's first Large Class mission (L1) of the Cosmic Vision 2015 – 2025 Program

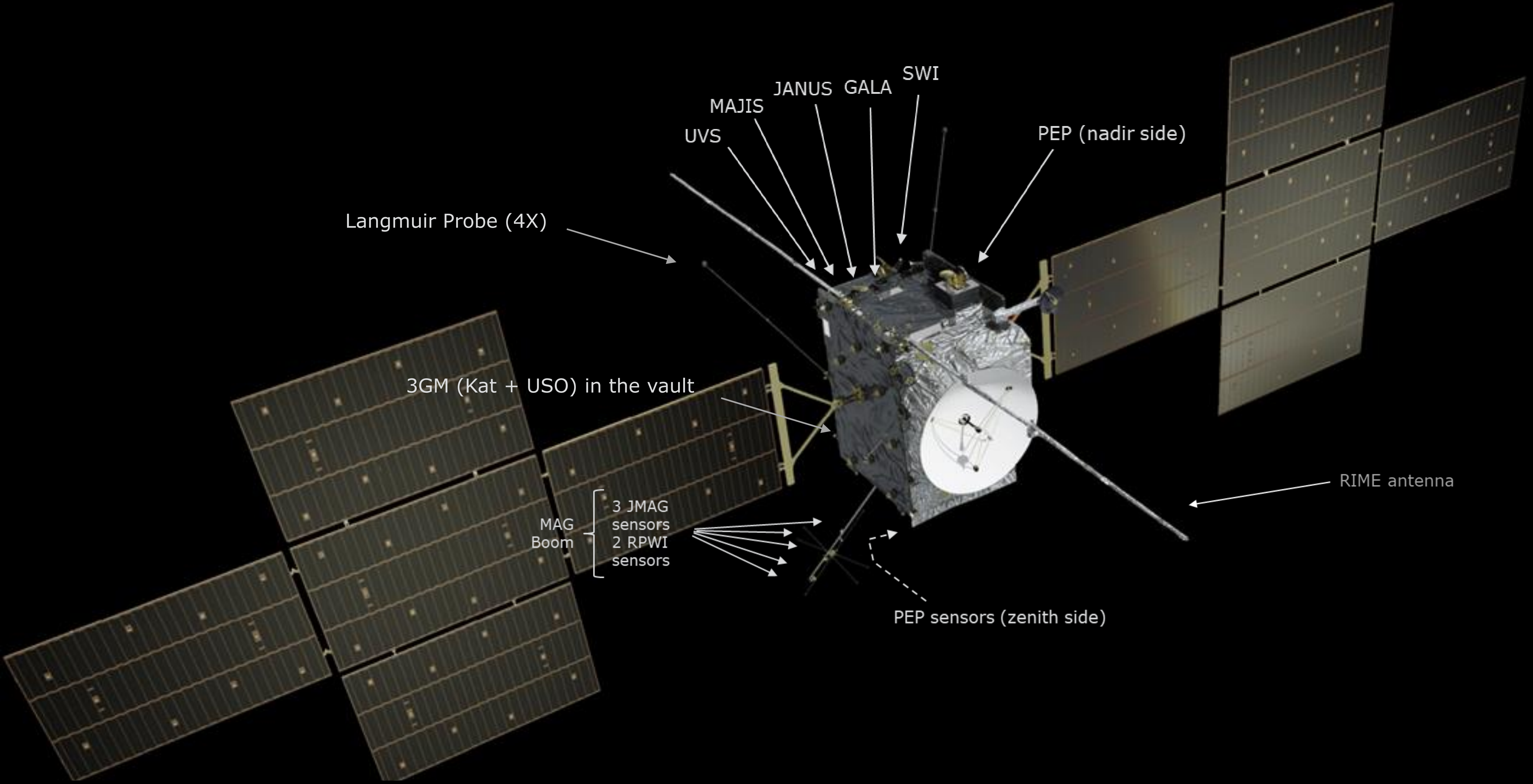
Launch (baseline): 14 April 2023
Cruise Time: 8.2 years
Science Mission duration: 3.5 years (December 2035)

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)**



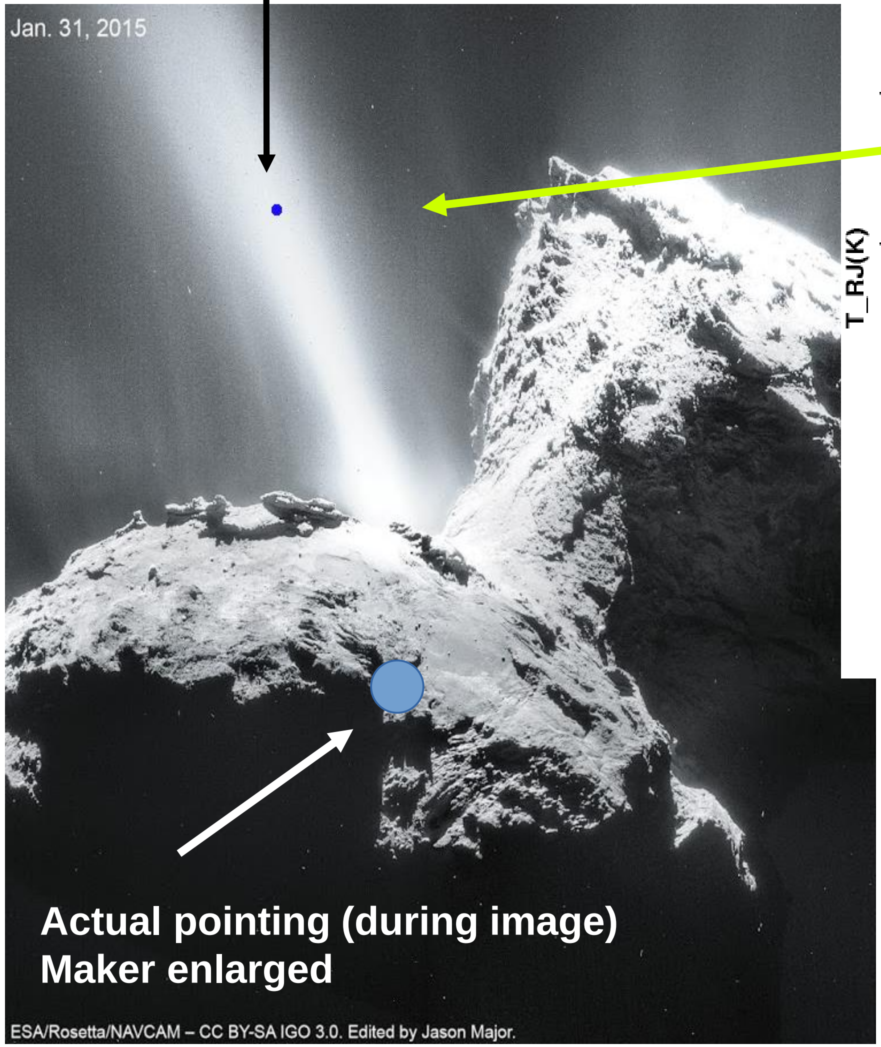

SWI
GALA
JANUS
MAJIS
UVS
PEP (nadir side)
Langmuir Probe (4X)
3GM (Kat + USO) in the vault
RIME antenna
MAG
Boom
3 JMAG
sensors
2 RPWI
sensors
PEP sensors (zenith side)

Why heterodyne spectrometer?

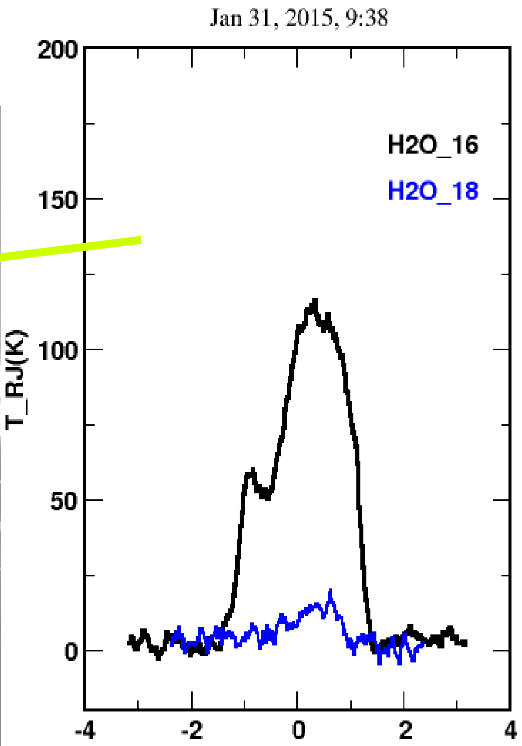
- SWI has a spectral resolution of 100 kHz at 1280 GHz ~ 1E7
- Other mostly non-coherent spectroscopy techniques are limited to a resolution of ~ 1E5 (e.g. CRIRES+)
- Line shapes contain important information about the observed gas (density, speed of molecules, temperature).
- Measurement of exact line shape fundamental requirement

MIRO H2O(16,18) spectra + geometry

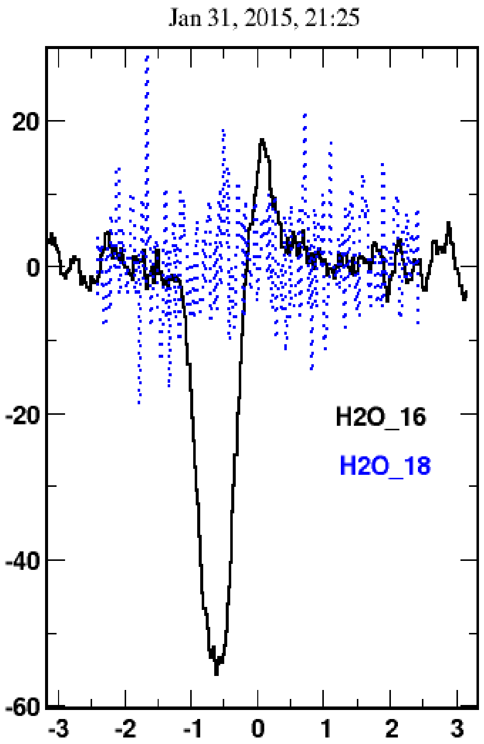
Estimated real beam size



30km SC distance



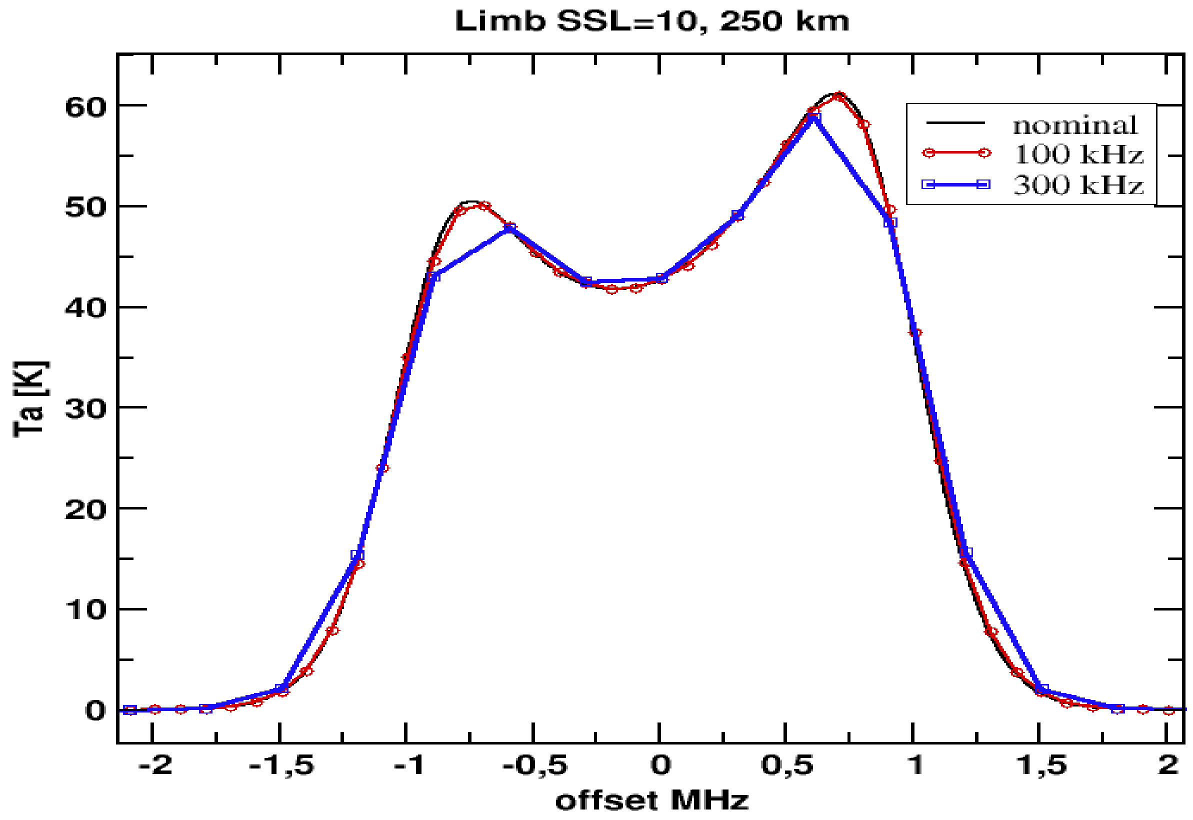
Resolution 100000



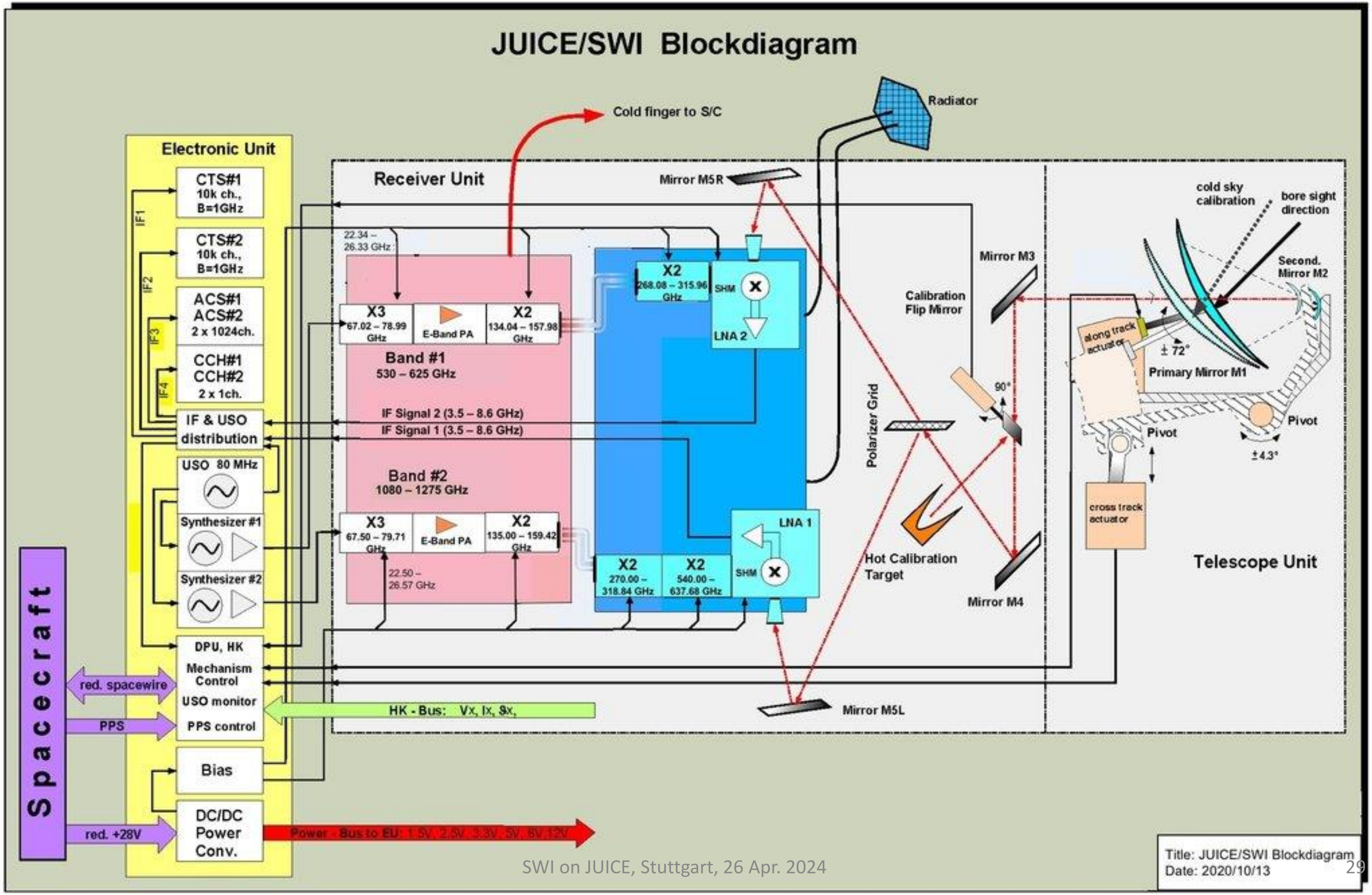
Resolution 100000

Simulation non-lte water vapour spectrum Ganymede (rotational ground state ortho-water)

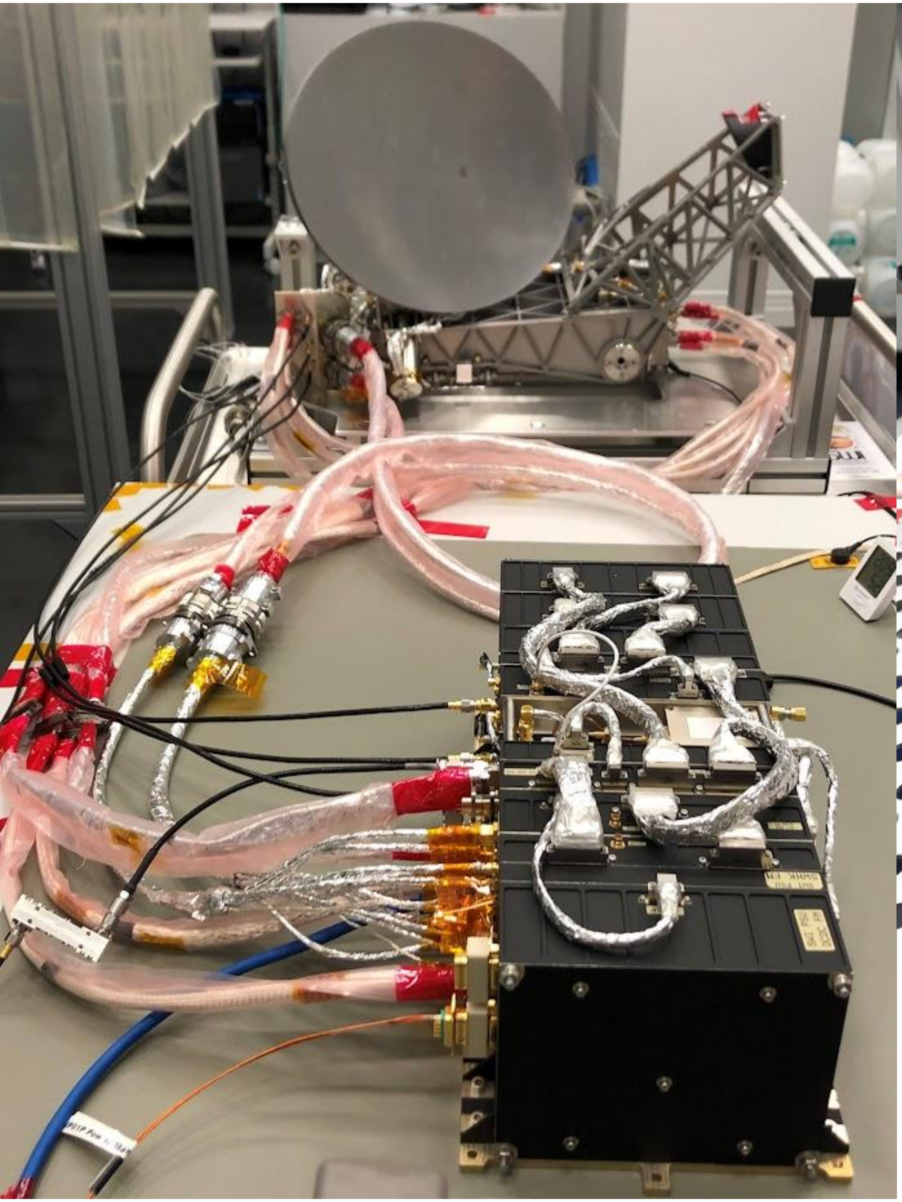
Compare spectral resolution of ~ 1.9x10^6 (does not resolve the line) and 5.6x10^7 (resolves the line)

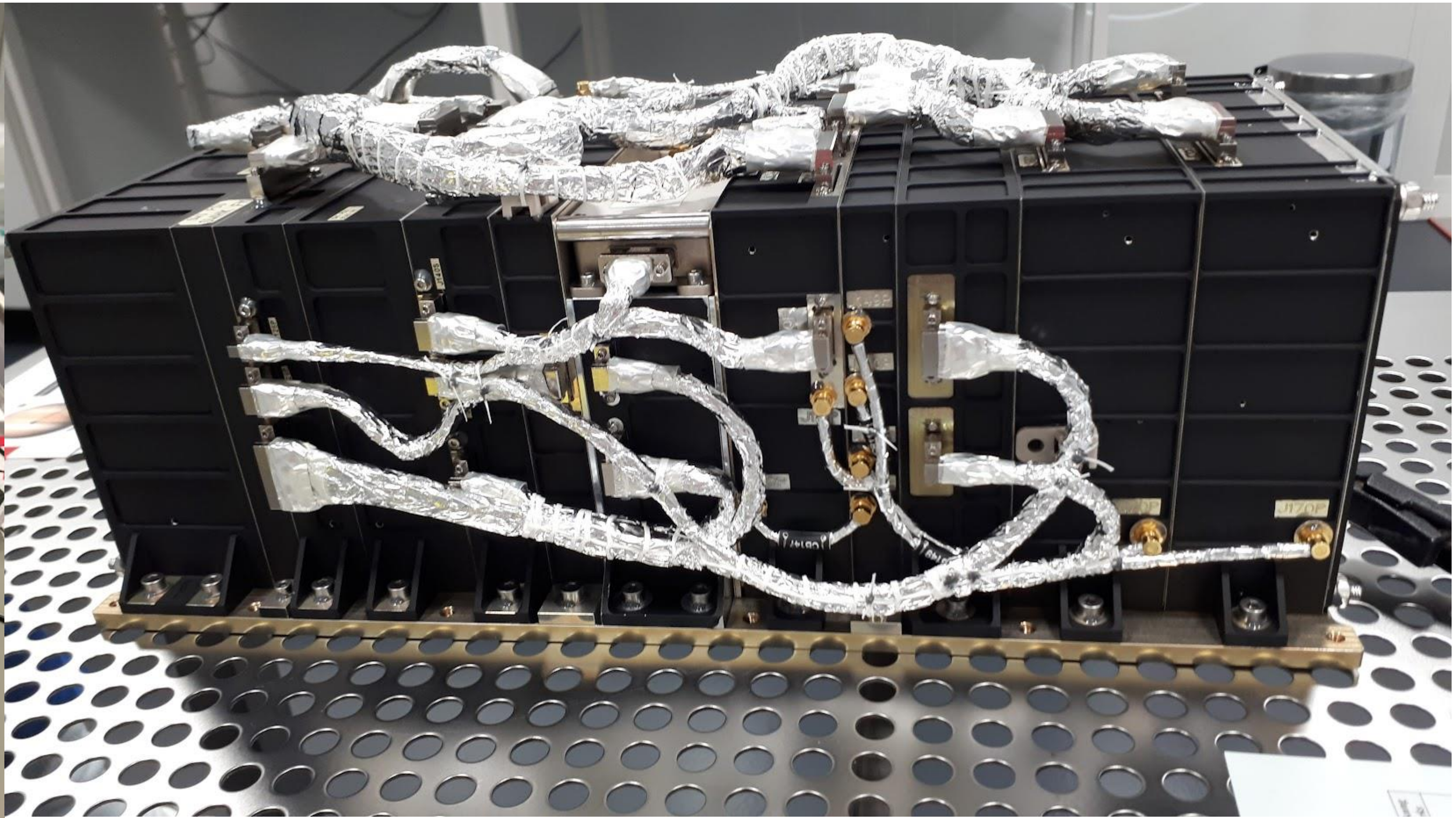


Resolution 100000


JUICE/SWI Blockdiagram
Cold finger to S/C
Radiator
Electronic Unit
CTS#1
10k ch.,
B=1GHz
CTS#2
10k ch.,
B=1GHz
ACS#1
ACS#2
2 x 1024ch.
CCH#1
CCH#2
2 x 1ch.
IF & USO
distribution
USO 80 MHz
Synthesizer #1
Synthesizer #2
DPU, HK
Mechanism
Control
USO monitor
PPS control
Bias
DC/DC
Power
Conv.
IF1
IF2
IF3
IF4
Spacecraft
red. spacewire
PPS
red. +28V
HK - Bus: Vx, Ix, Sx,
Power - Bus to EU: 1.5V, 2.5V, 3.3V, 5V, 6V,12V
Receiver Unit
22.34 –
26.33 GHz
X3
67.02 – 78.99
GHz
E-Band PA
X2
134.04 – 157.98
GHz
Band #1
530 – 625 GHz
X2
268.08 – 315.96
GHz
SHM
LNA 2
IF Signal 2 (3.5 – 8.6 GHz)
IF Signal 1 (3.5 – 8.6 GHz)
Band #2
1080 – 1275 GHz
X3
67.50 – 79.71
GHz
E-Band PA
X2
135.00 – 159.42
GHz
22.50 –
26.57 GHz
X2
270.00 –
318.84 GHz
X2
540.00 –
637.68 GHz
SHM
LNA 1
Mirror M5R
Mirror M5L
Mirror M3
Mirror M4
Calibration
Flip Mirror
Polarizer Grid
90°
Hot Calibration
Target
cold sky
calibration
bore sight
direction
Second.
Mirror M2
along track
actuator
± 72°
Primary Mirror M1
Pivot
Pivot
±4.3°
cross track
actuator
Telescope Unit
Title: JUICE/SWI Blockdiagram
Date: 2020/10/13

PFM: TRU and EU & connected (MPS clean room)



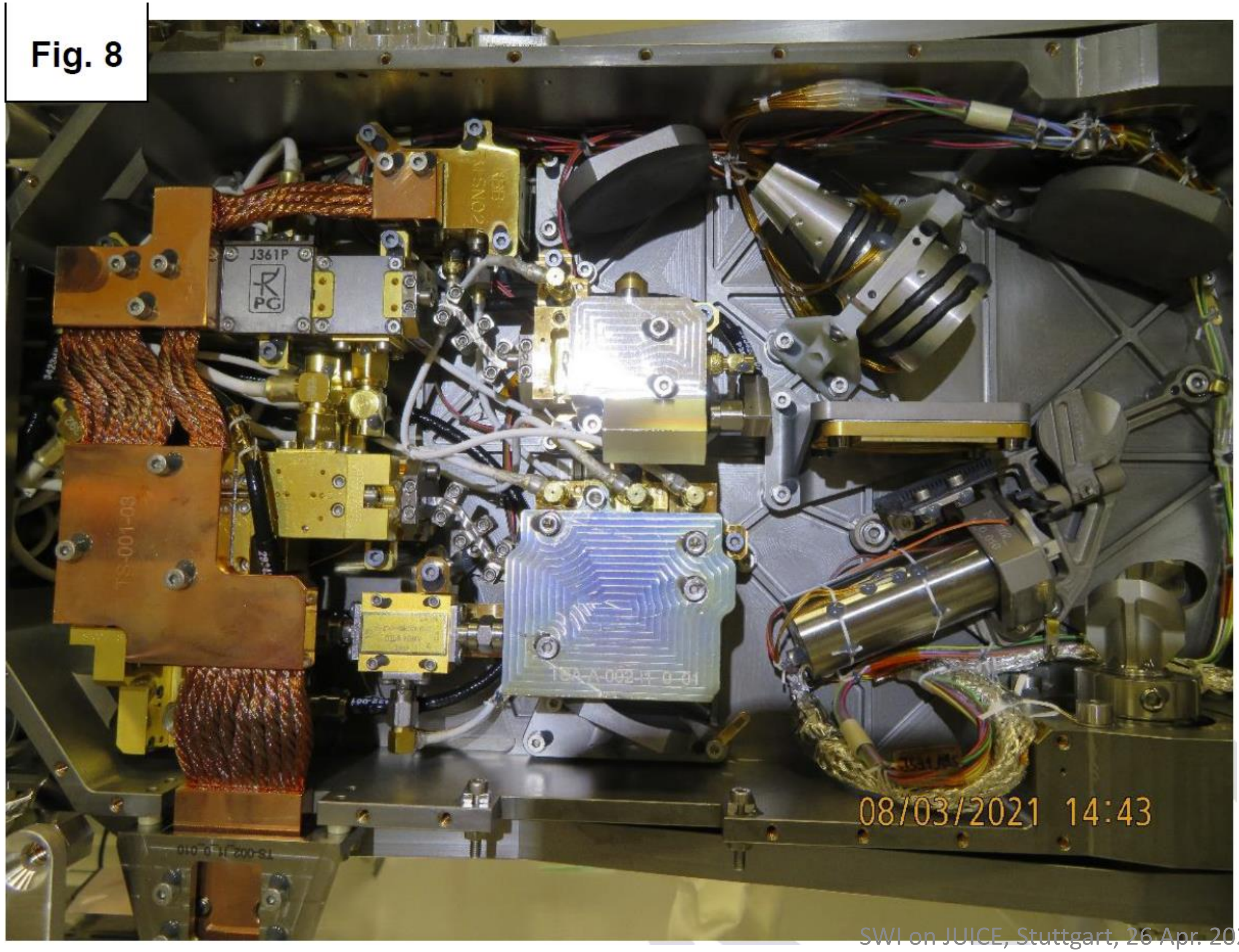


530 – 630 GHz / 1165 – 1280 GHz
M1 has a diameter of 29 cm
Az/El: ± 72 deg / ± 4.3 deg

WBS: 4 GHz / 4 MHz
HRS: 1 GHz / 0.1 MHz

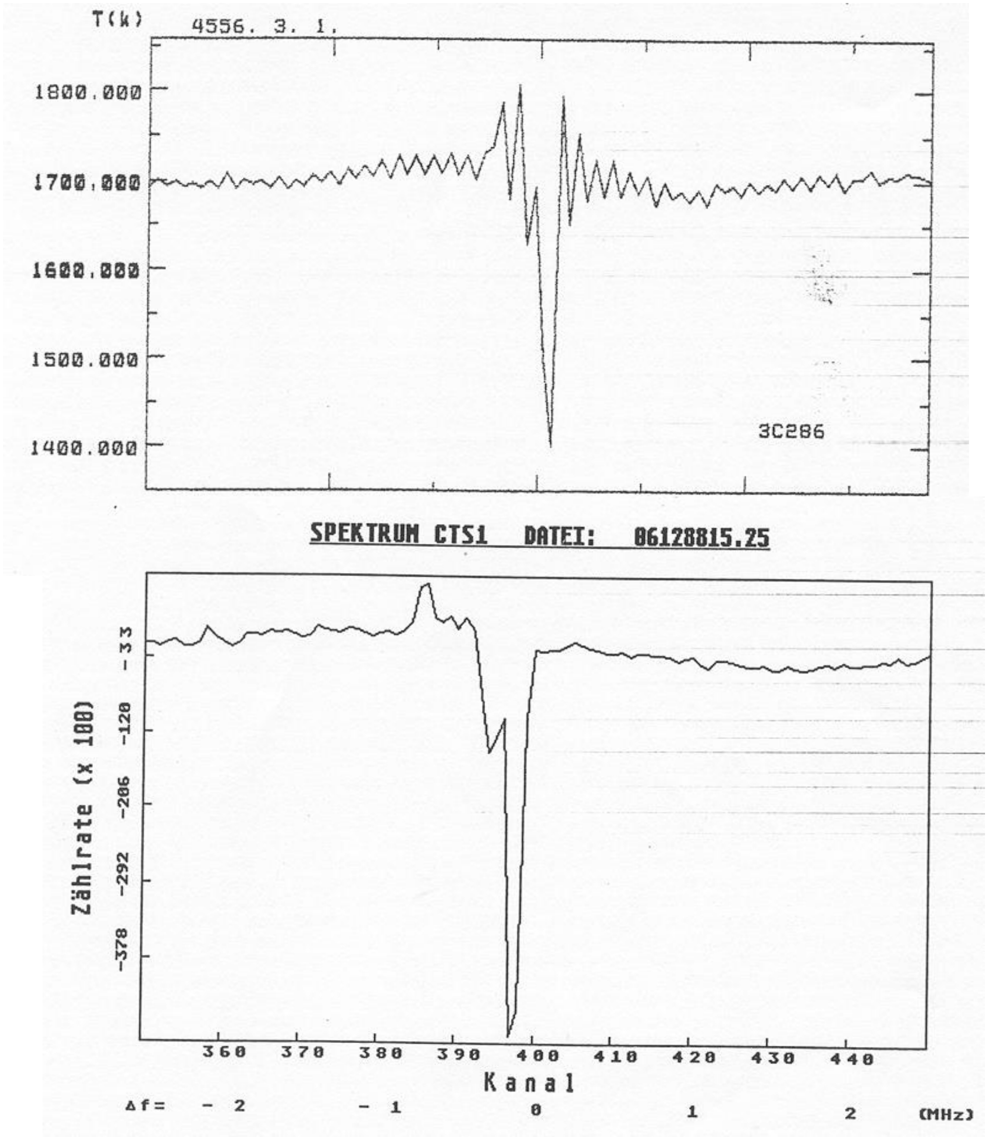
Receiver Unit 600 GHz and 1200 GHz

Fig. 8



530 – 630 GHz, Trec ~ 1000 K DSB
1066 – 1280 GHz Trec ~ 2500 K DSB

15 years Effelsberg: first astronomical obs. with CTS (1986)



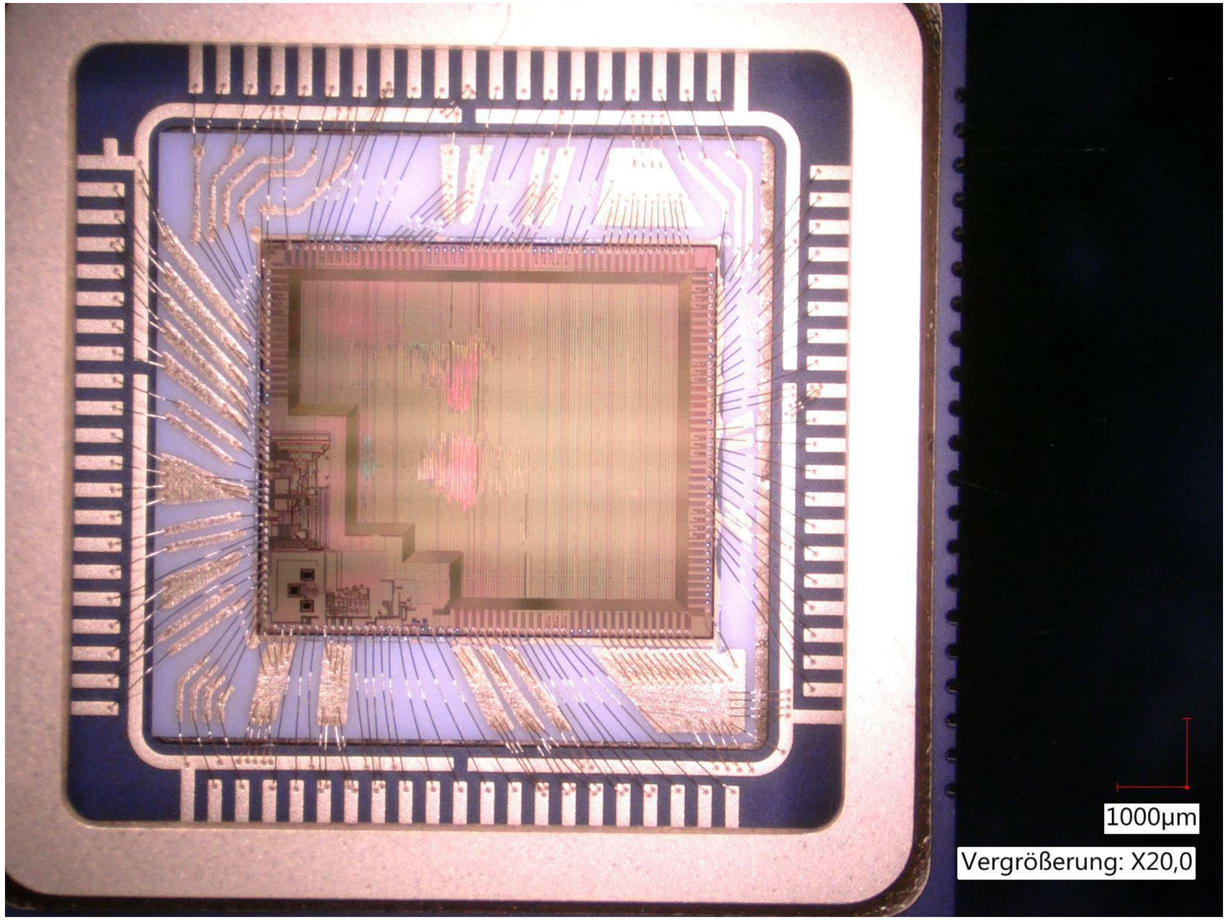
Dimensions: 19“, 12 HU
Power consumption: ~ 1 kW
Mass: ~ 30 kg
Bandwidth: 40 MHz
No of spectral channels: 1024

1990-2001: Rosetta MIRO

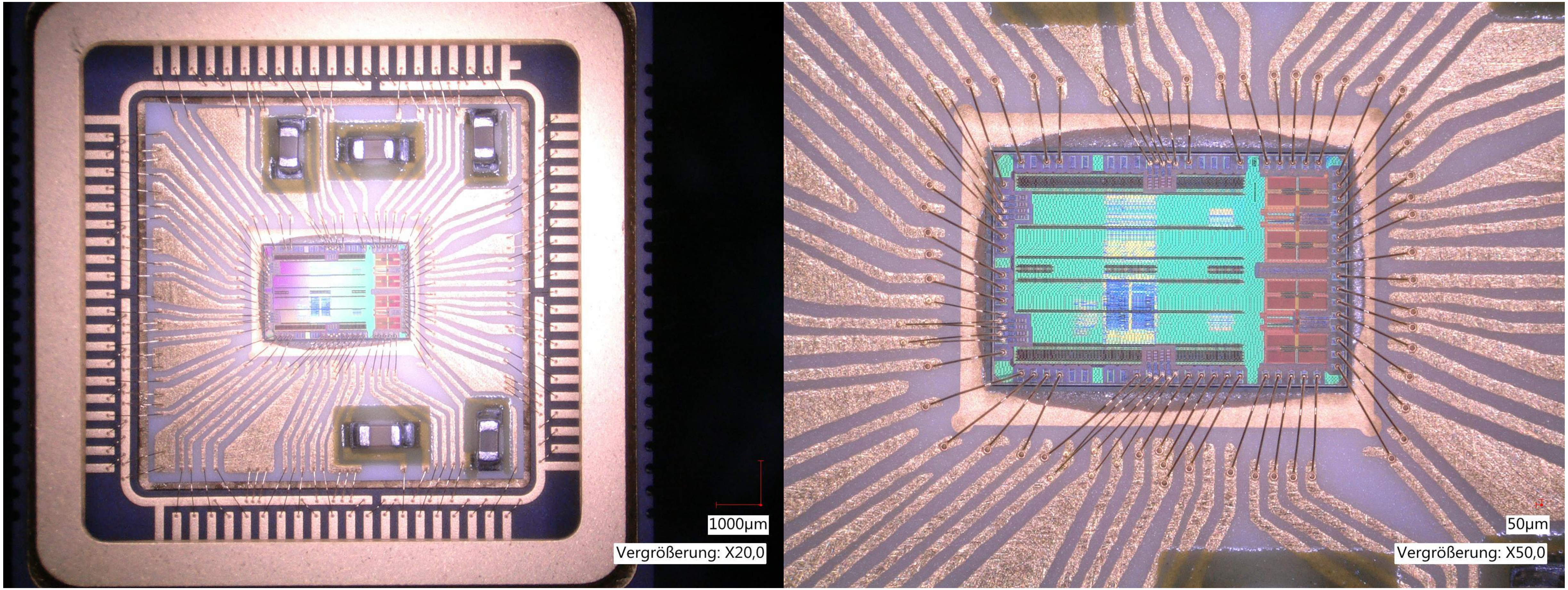
Dimensions: 30x20x10 cm^3
Power consumption: 15 W
Mass: 2,3 kg
Bandwidth: 180 MHz
Resolution: 44 kHz
No. of channels: 4096

Launched in 2004, now stored on 67P

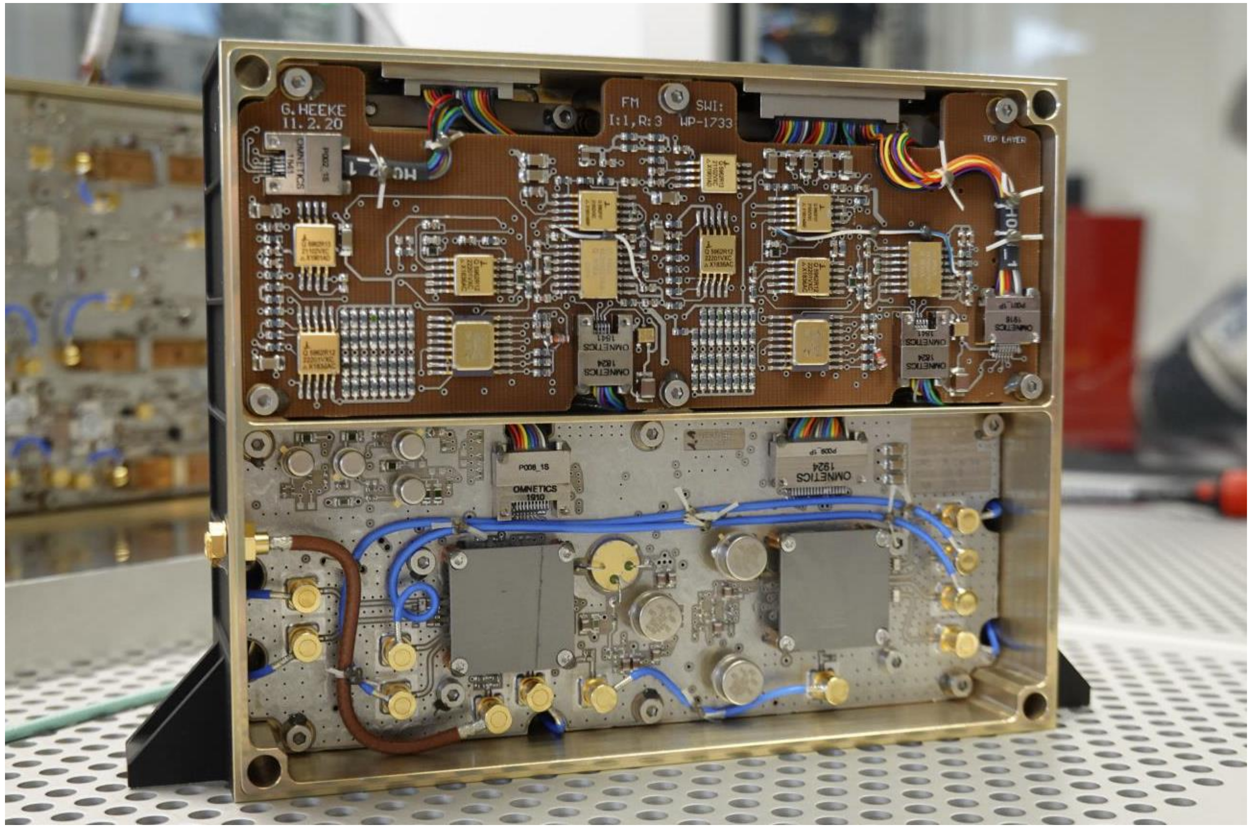
Chirp Generator ASIC (130 nm SiGe, 16 GHz clock)

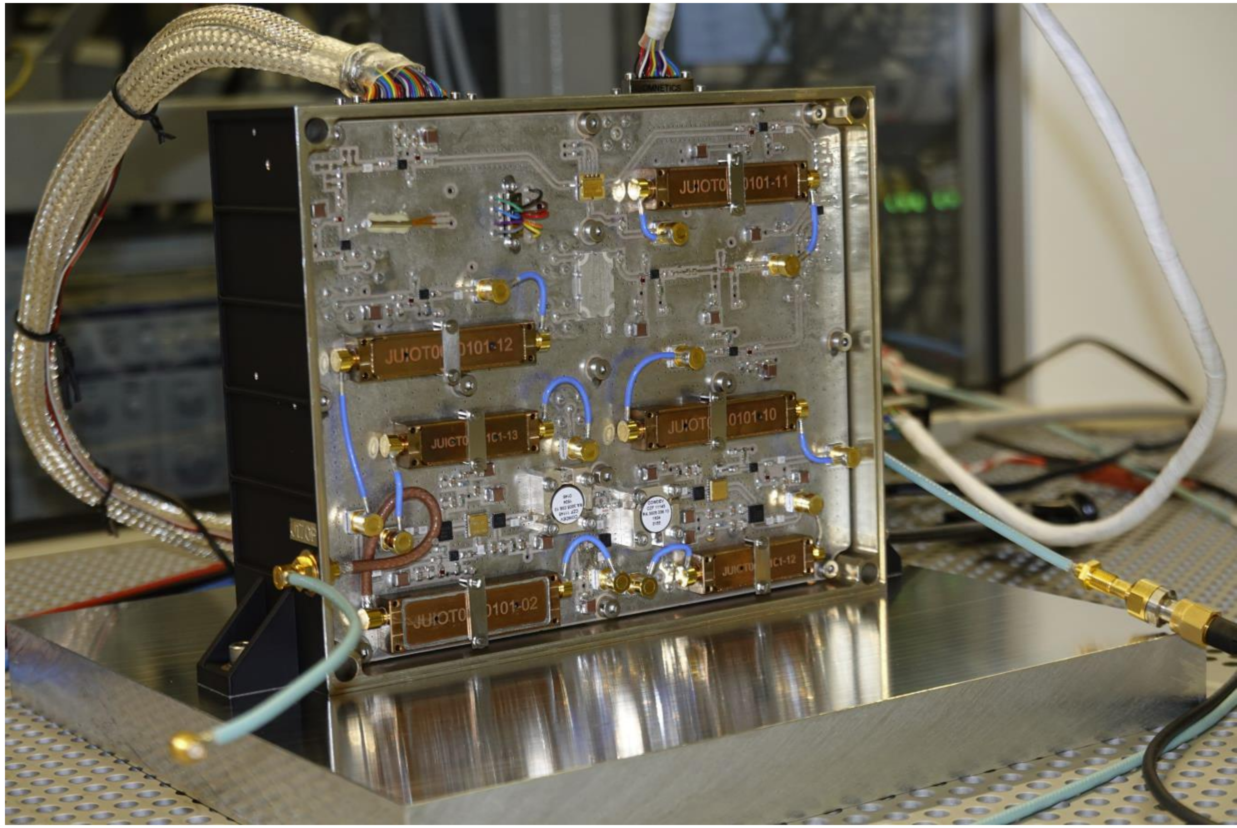


Preprocessor ASIC (65 nm ST rad hard)



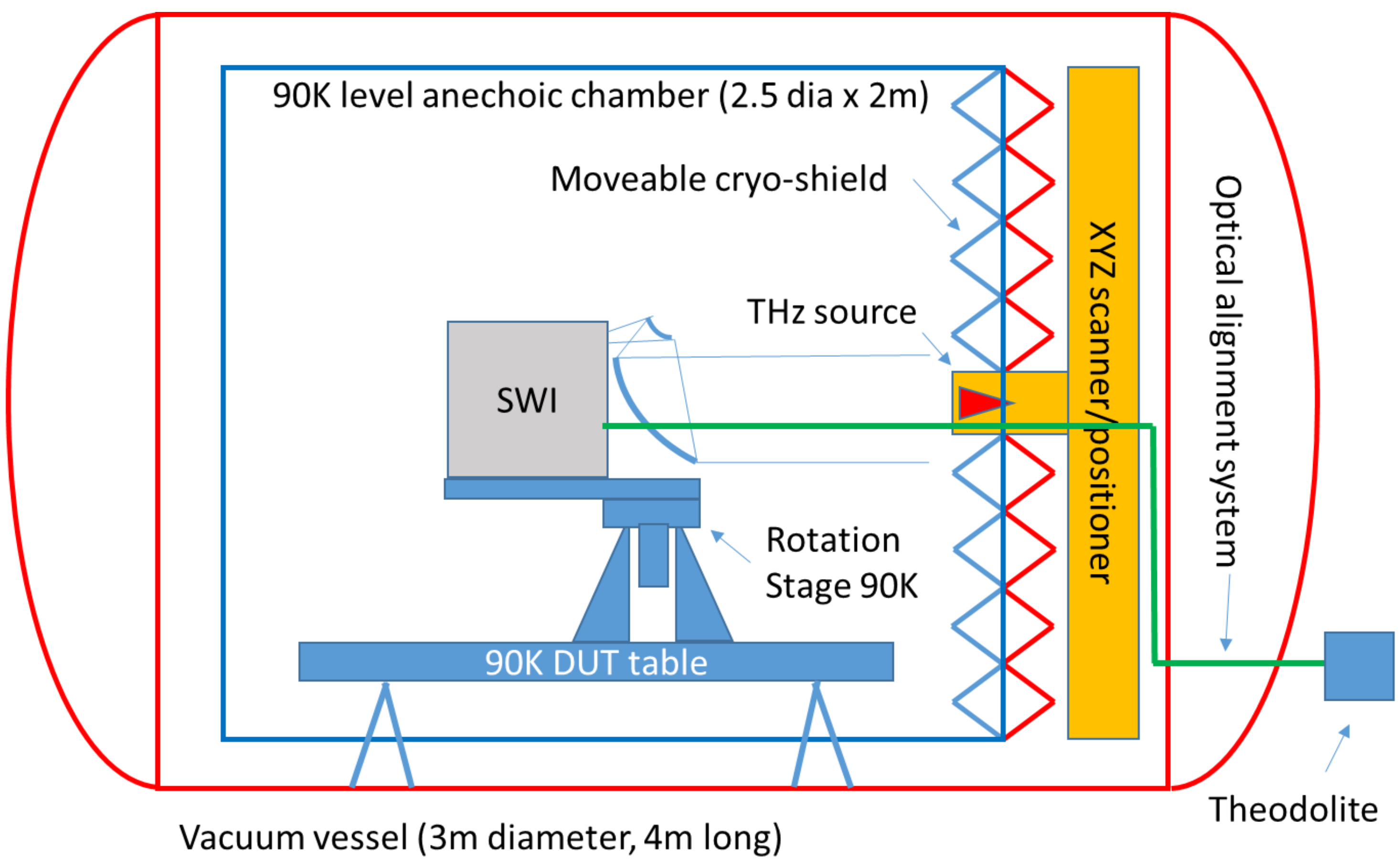
JUICE-SWI Chirp Transform Spektrometer





Dimensions: 15x12x4,3 cm^3 .   Power consumption: 5 W
Mass: 680 g,
Bandwidth: 1000 MHz
Spectral resolution: 100 kHz / 10000 channels

ESA Lorentz Facility and JUICE SWI near field measurements set up (SWI pilot exp)



Lorentz Antenna Test Facility

Parameter	Value
Scanner Measurement range	1 x 1 x 0.1 m
Position accuracy (after calibration)	~3 μm
Cold volume diameter	2.5 m
Cold volume length	2 m
Temperature	90 K (4K)

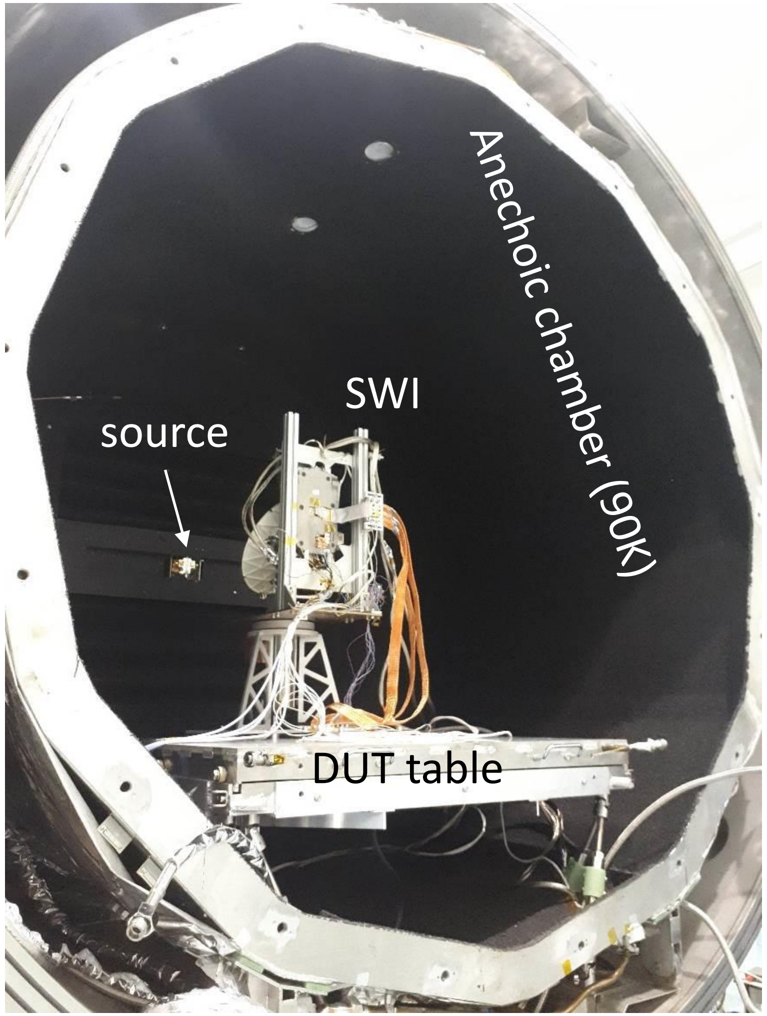
JUICE SWI Antenna

Parameter	Value
Diameter	0.29 m
Rotation	+-75 deg
Low F band	560 GHz
High F Band	1.1 THz
Temperature	90 K (4K)

Photos of the set-up

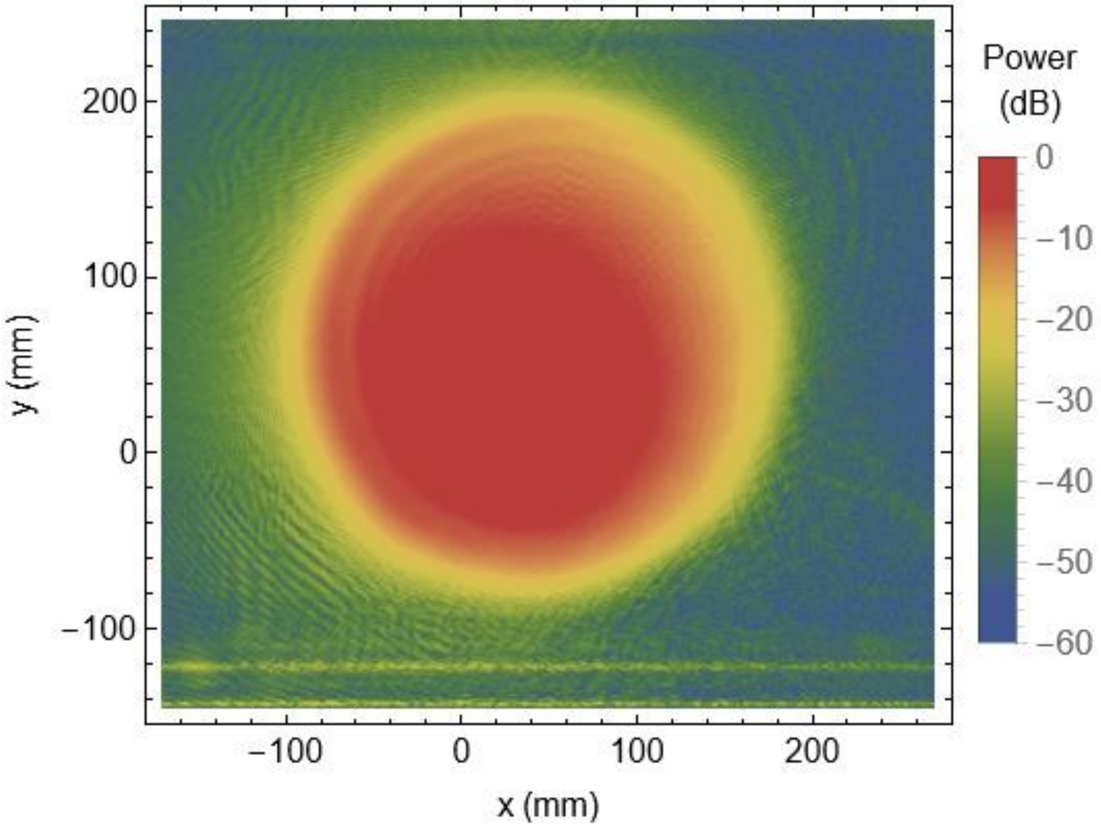
Overview of the chamber at ESA test centre

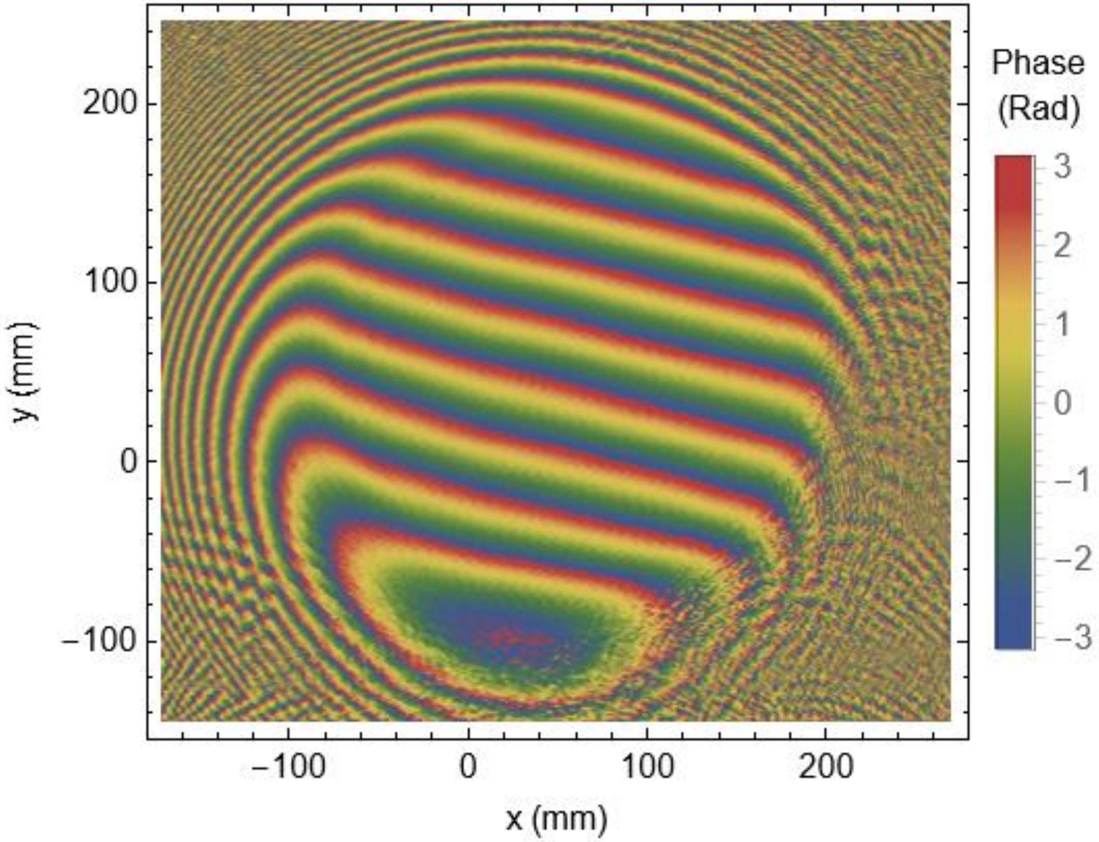
JUICE SWI mounted in Lorentz facility



Near field scan of antenna aperture, raw phase and amplitude

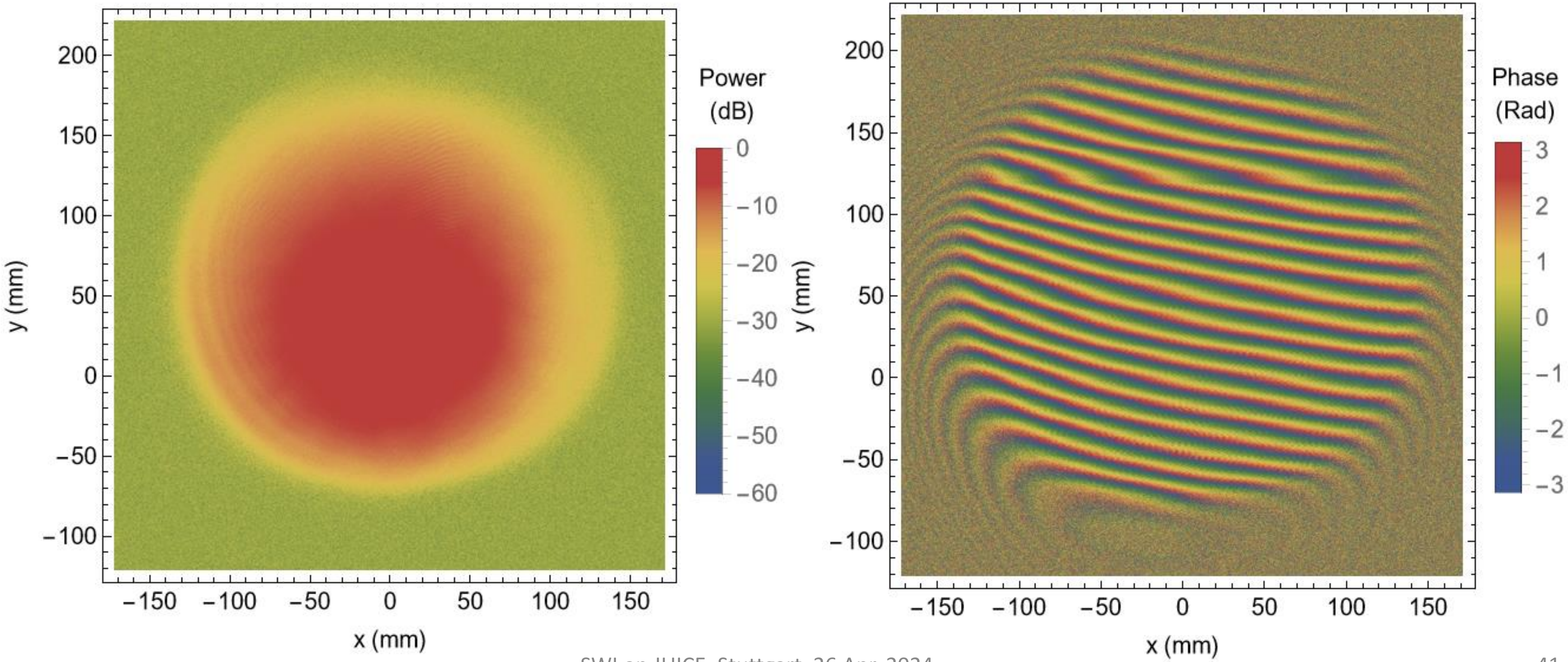
555.42 GHz, M1 angle 0 Degrees, **R36a** dataset





High frequency band – measurement is more challenging

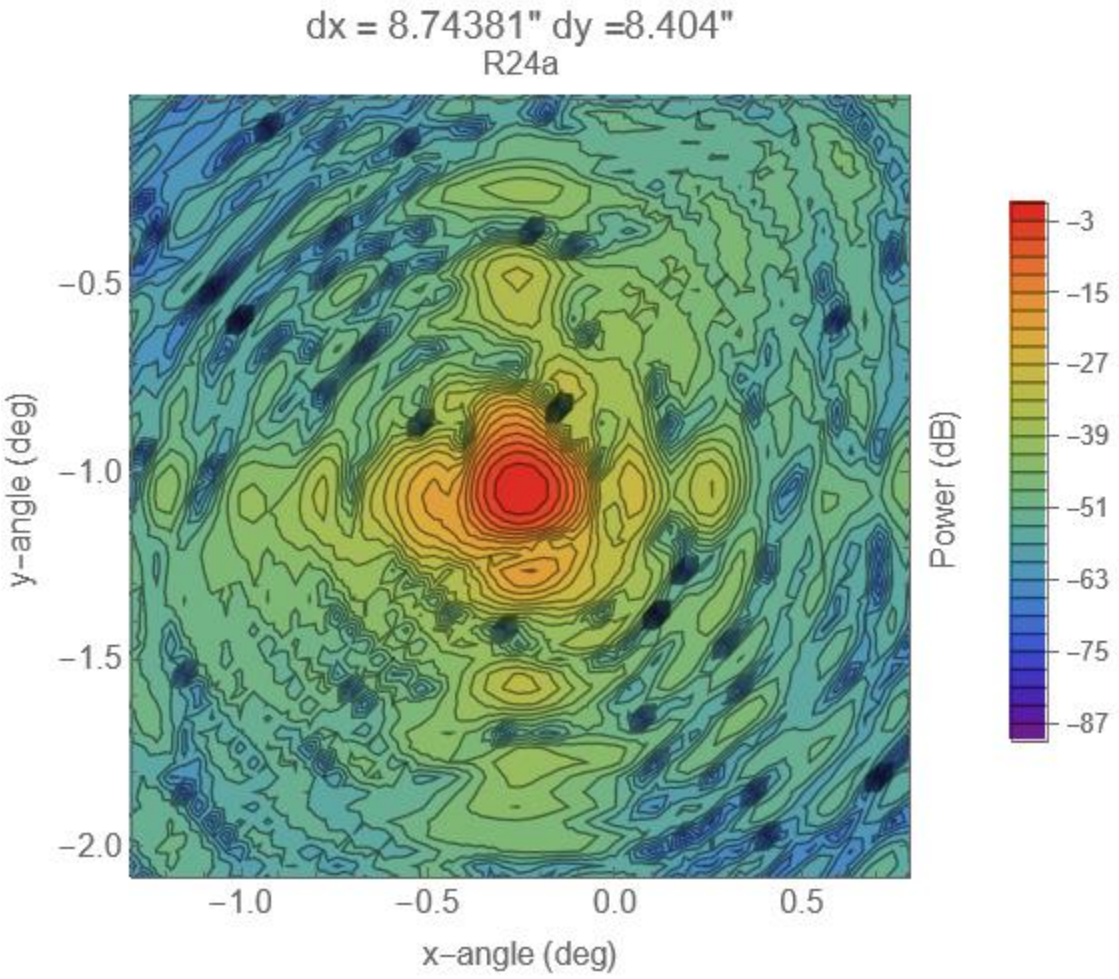
Measure complex beam map for **R034a** set, F=1145.04 GHz, M1 angle = -45deg



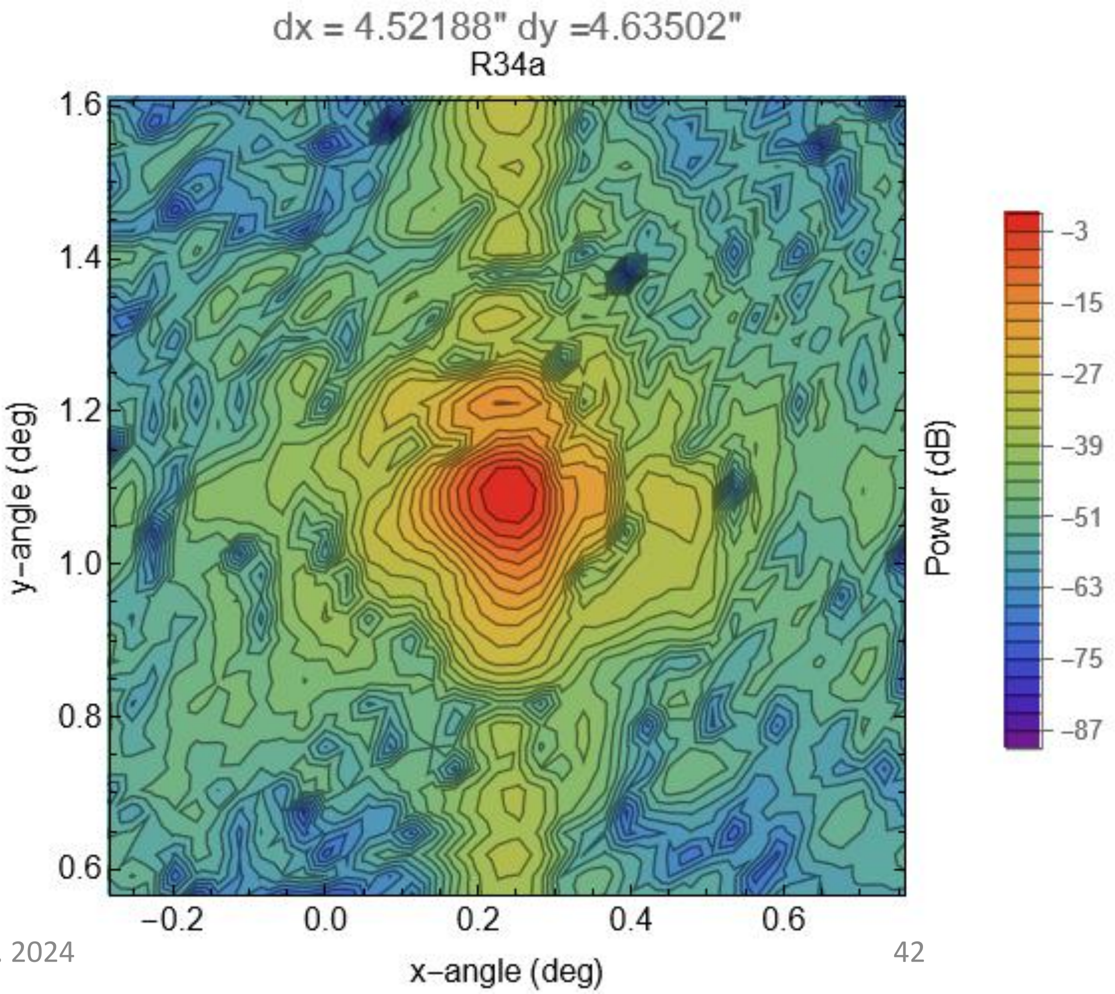
Far field at 555 and 1145 GHz

F=1145.04 GHz, M1 angle = -45deg

Measurement



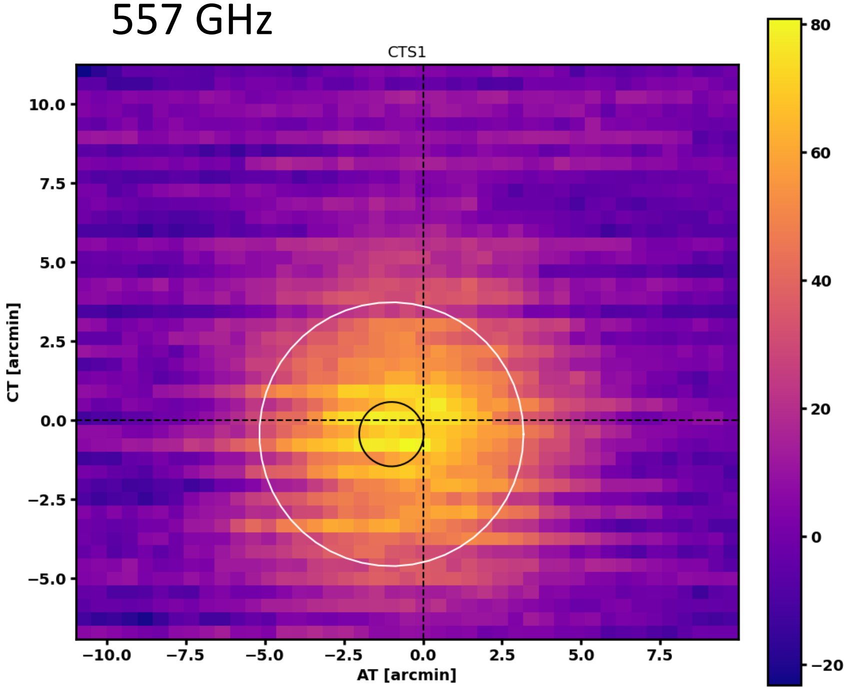
Model



NECP results on pointing and co-alignment

Far field beam characterization 600/1200 GHz receivers

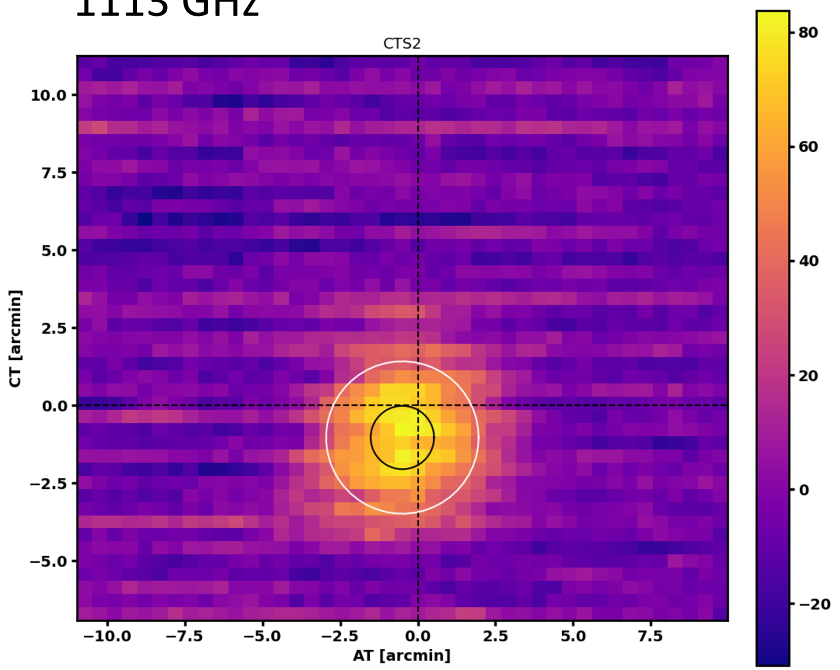
557 GHz



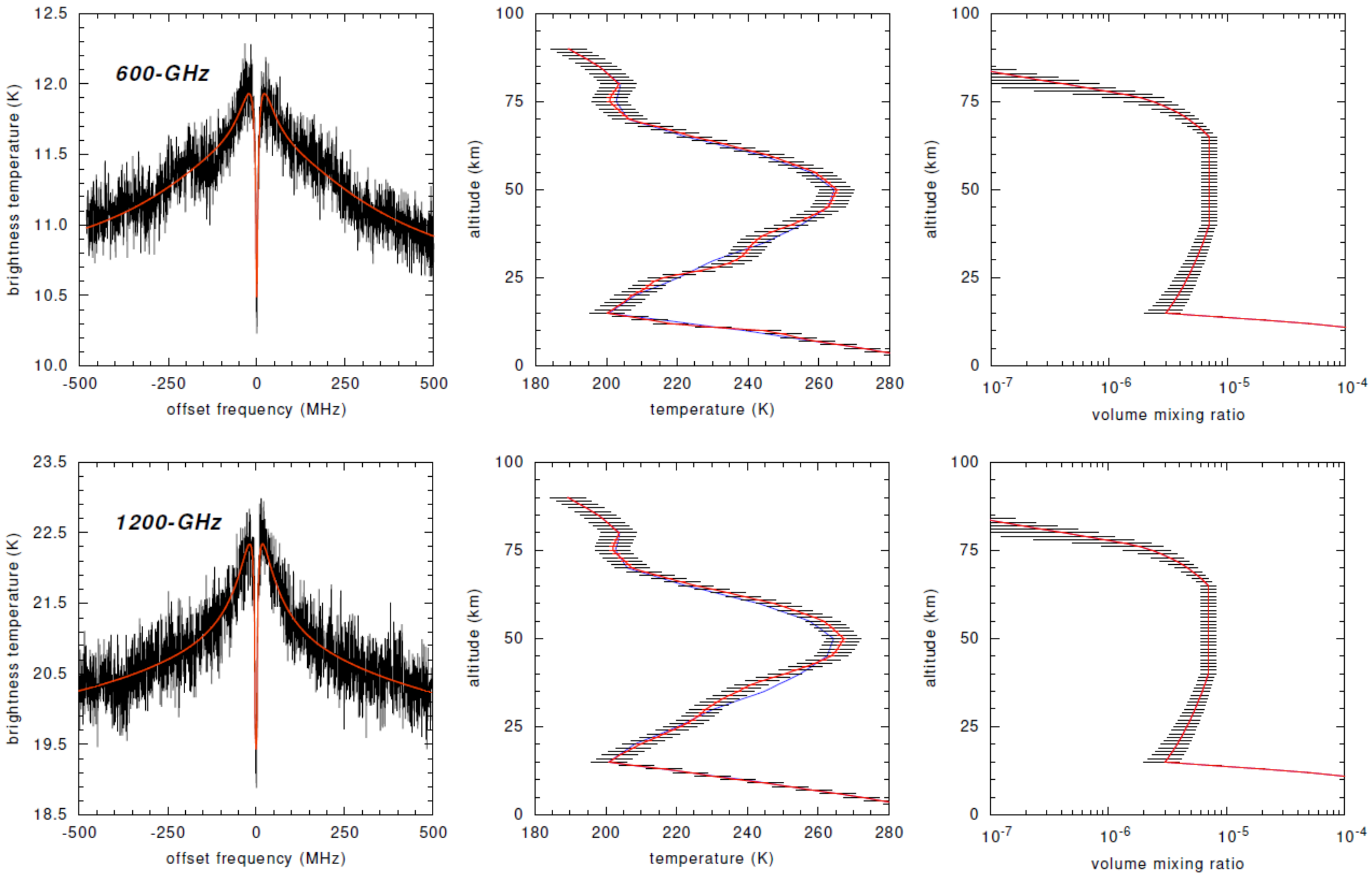
43x43 map, 0.5&1 arcmin step resolution
4 s integration time per step
~22 million km distance from Earth

Upper panel: 557 GHz map on Earth
Lower Panel: 1113 GHz map on Earth
Beams are diffraction limited
Beamwidths 557 GHz: 8.3 (8.4 NF) arcmin
Beamwidths 1113 GHz: 4.5 (4.5 NF) arcmin
Misalignment 600/1200 : ~ 0.5 (~ 2 NF) arcmin
NF measurement (AT): 0 degrees (nadir)
NECP measurement (AT): ~ 20 degrees

1113 GHz



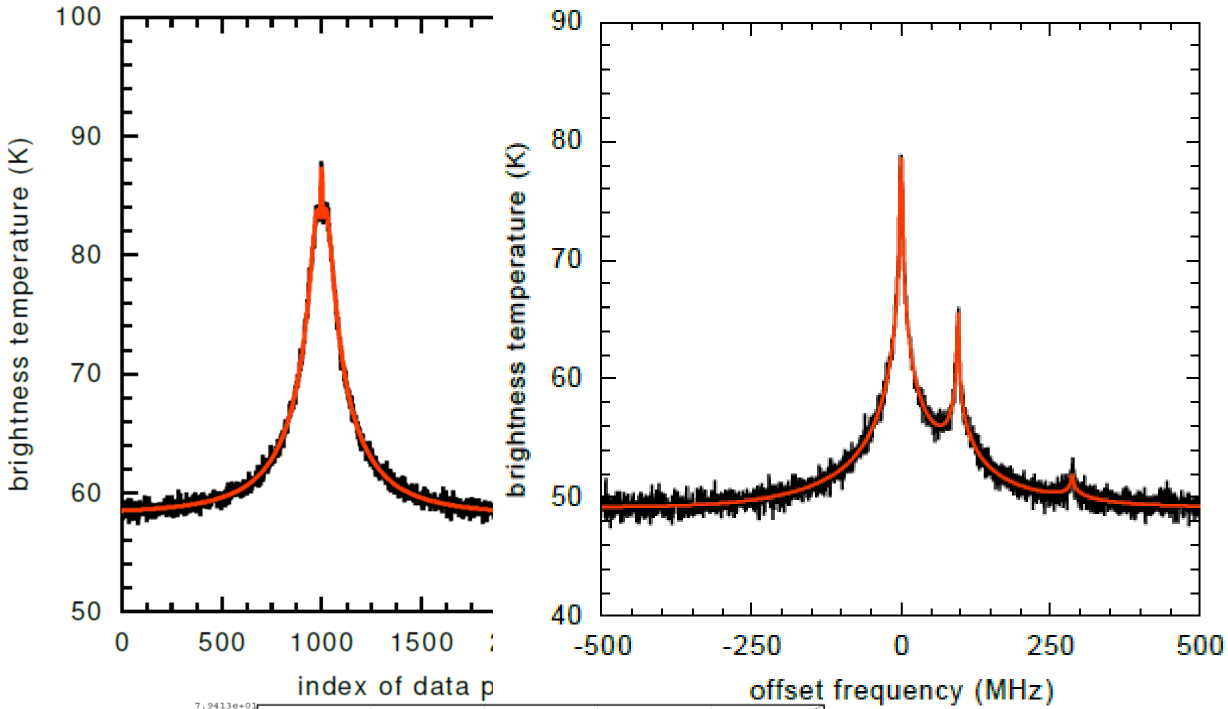
Constraining water vapour and temperature profiles (Earth)

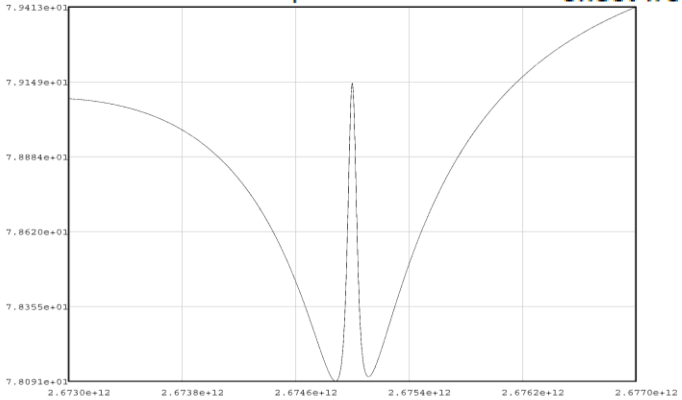


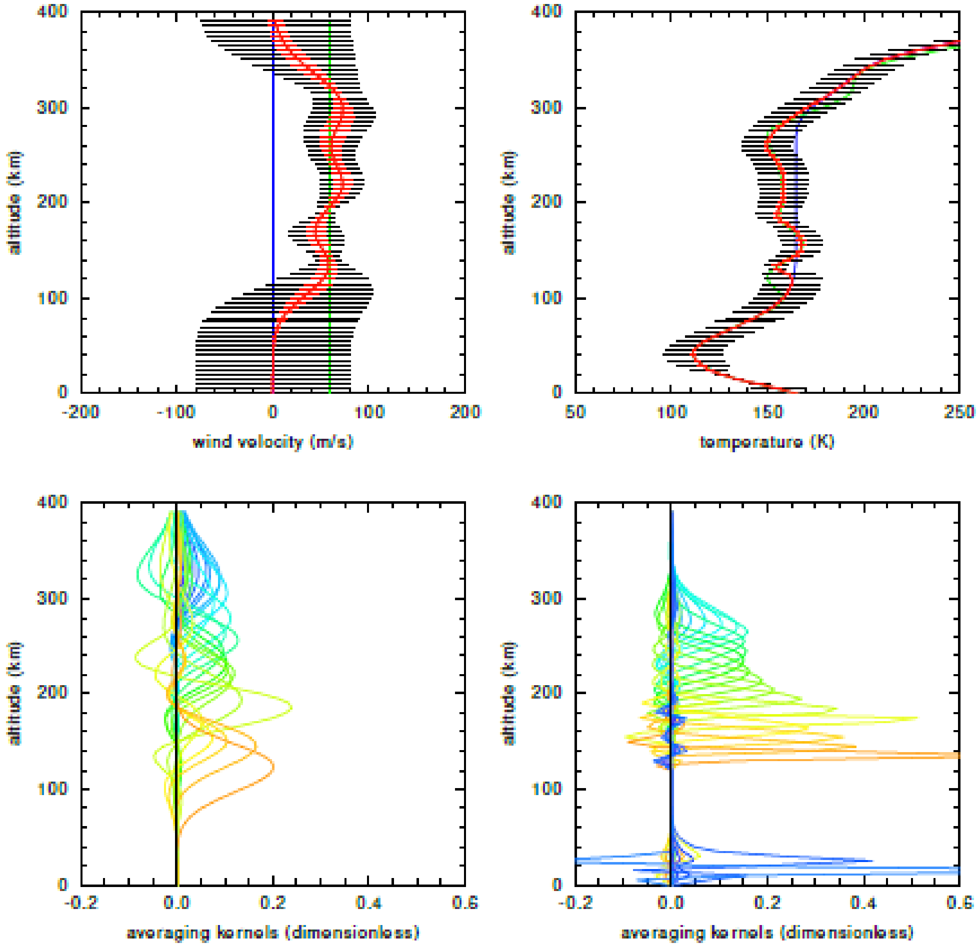
Jupiter & satellites science

- Strukture, dynamics and composition of the stratosphere of Jupiter
- Coupling mechanism between Jupiter’s troposphere and thermosphere
- Strukture, dynamics and composition of the atmospheres/exospheres of the Galilean moons, search for cryovolcanic activity
- OPR of water
- Origins: determination of important isotopic ratios in the atmospheres of Ganymede, Europa and Jupiter
- Thermophysical and electrical properties of the surfaces and sub-surfaces of Ganymede, Callisto and Europa, search for recent activity.
- “Flyby Science”

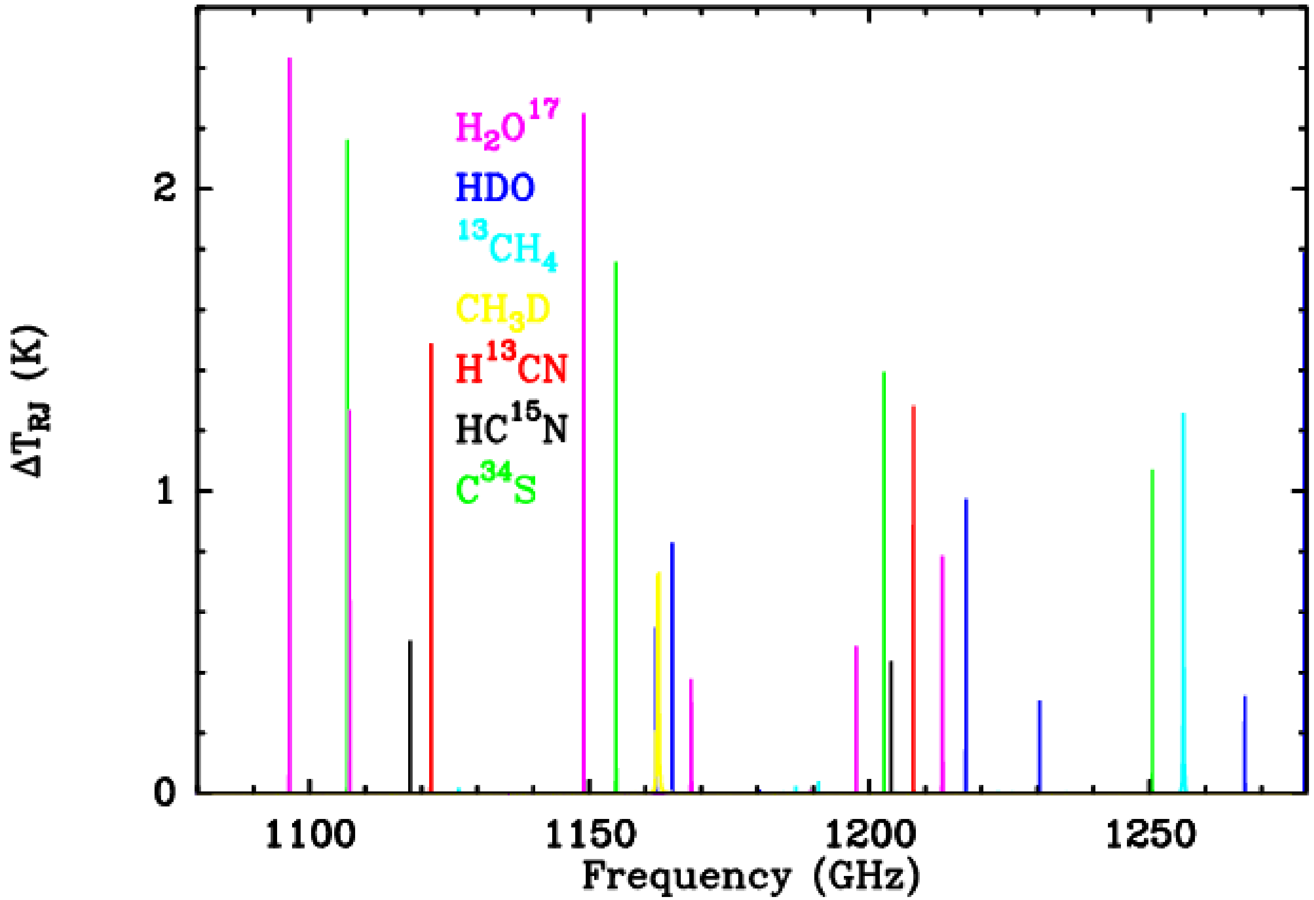
Detection of wind and temperature: 557/1256 GHz from 20 RJ



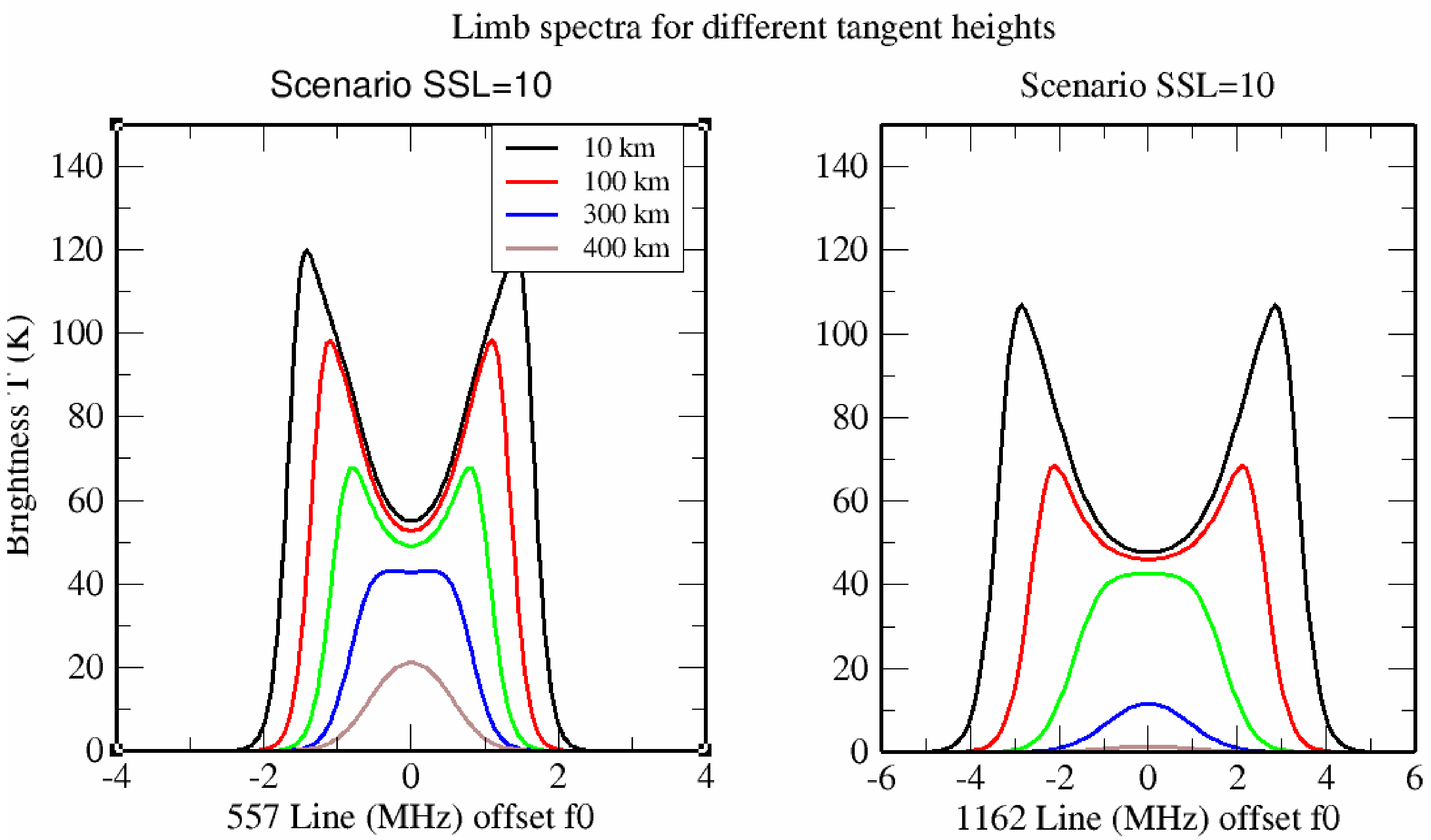


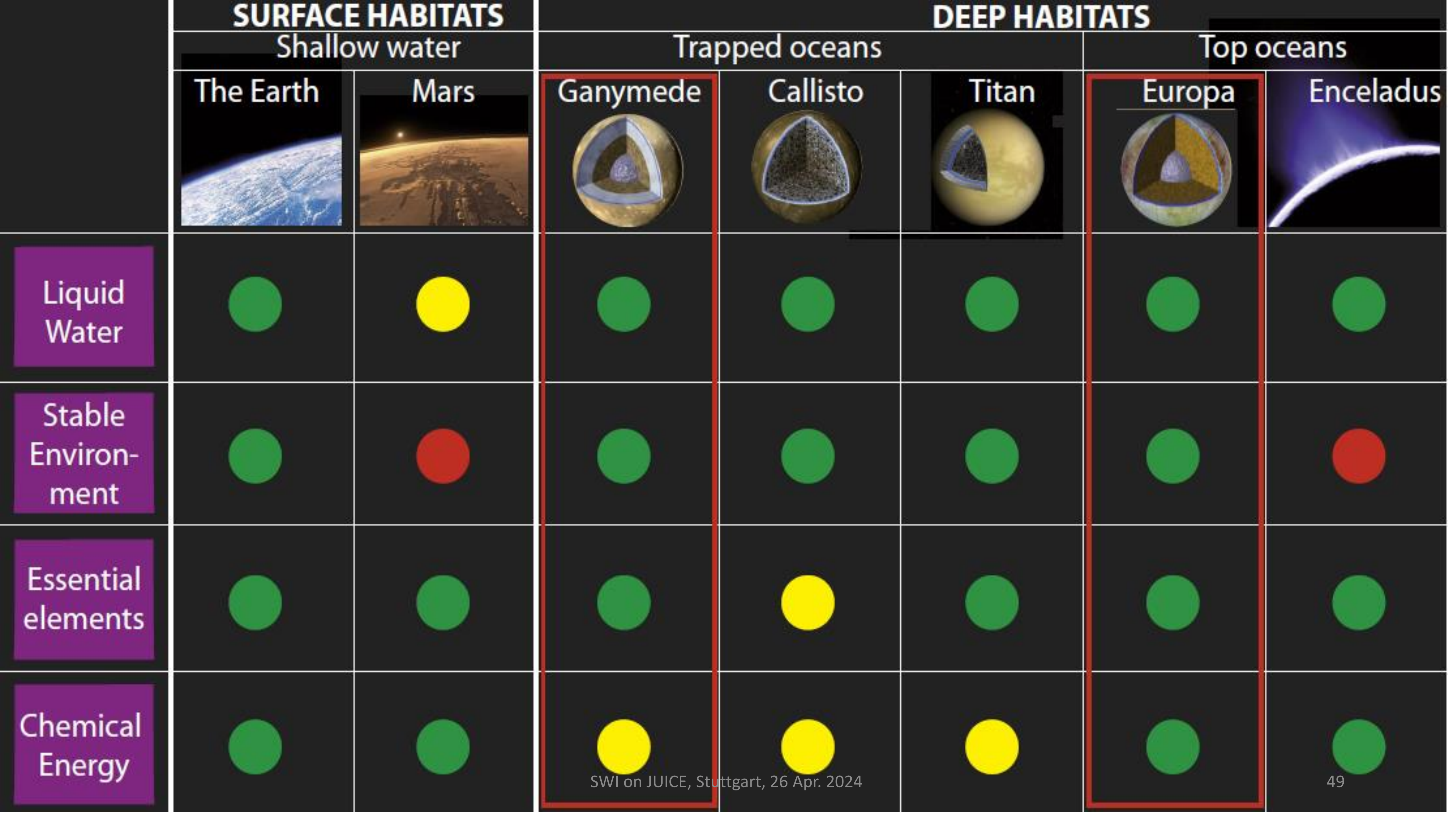


Isotopologues in Jupiter‘s stratosphere (1200 GHz receiver)

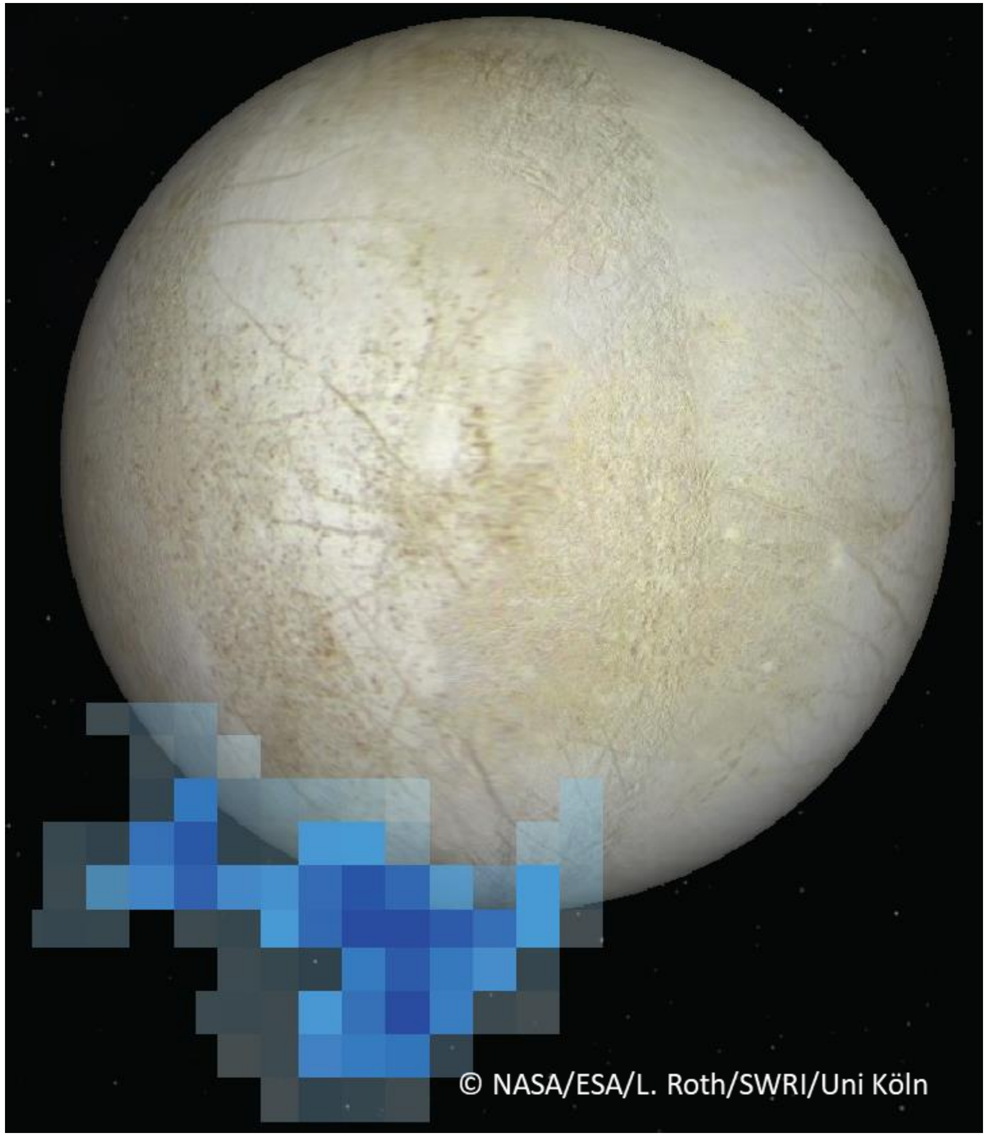


NLTE limb spectra 557 und 1162 GHz – different tangential heights




SURFACE HABITATS
DEEP HABITATS
Shallow water
Trapped oceans
Top oceans
The Earth
Mars
Ganymede
Callisto
Titan
Europa
Enceladus
Liquid Water
Stable Environ-ment
Essential elements
Chemical Energy

Geysers on Europa?



SWI sensitivities (potential plumes compositions)

(similar for isotopologues of C, S und N)

SWI can be tuned on more than 70 different molecules

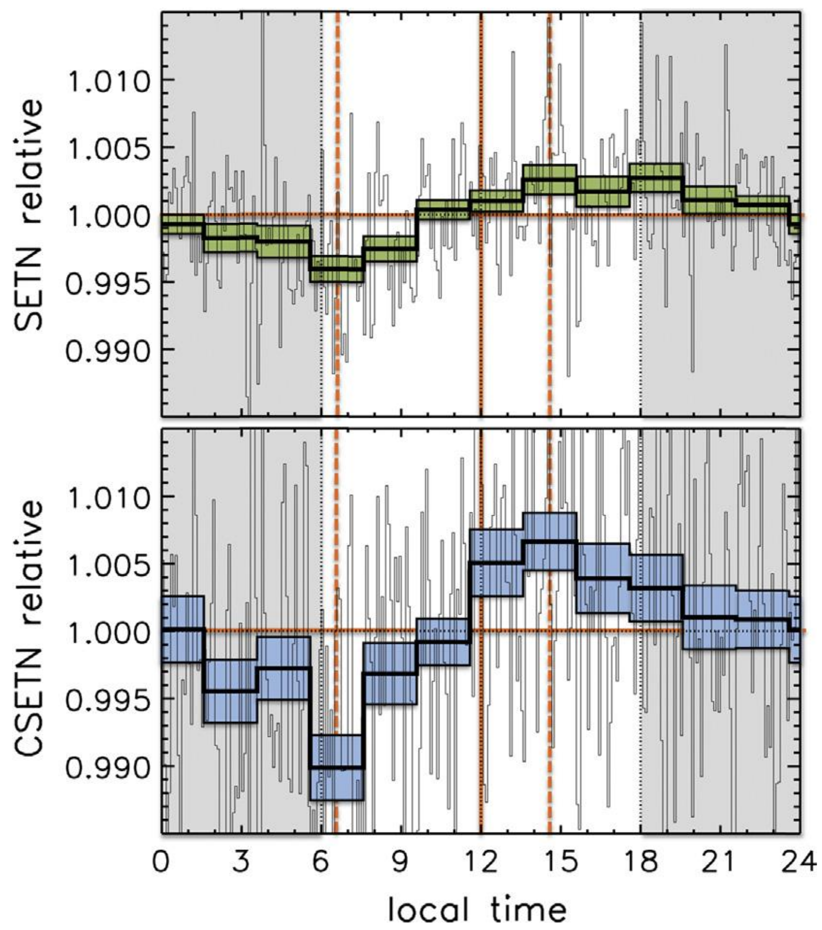
Molecule	Column (m^{-2})		Molecule	Column (m^{-2})
H_2O	5×10^{14}		H_2O+	3×10^{14}
$H_2{}^{18}O$	5×10^{14}		SO	8×10^{15}
$H_2{}^{17}O$	5×10^{14}		SO_2	2×10^{16}
HDO	5×10^{14}		NaCl	1×10^{14}
H_2O_2	5×10^{15}		KCl	2×10^{14}
O_2	1×10^{19}		MgCl	3×10^{15}
CH_3OH	4×10^{15}		H_2CO	2×10^{16}
CO	2×10^{17}		NaOH	1×10^{14}
H_2CO	4×10^{16}		MgO	1×10^{14}
HCN	2×10^{15}		CH_3CN	2×10^{15}
NH_3	1×10^{15}		PO	4×10^{14}

Molecules in the SWI tuning ranges

Red: Chemical energy; Blue: CHNOPS

- C3H, CH3CC, CH3CCH, CH3CN, CH3D, CH3OH, 13-CH4, ClO, CN, CN-CO,
- CO+, 13-CO, CO-17, CO-18, CS, CS-36, CS-33, CS-34, DCN, FeO, H-13CN
- H2O, H2O+, H3O+, H2-17O, H2-18O, H2O2, H2CO, H2CS, H2S, HCl,
- HCl-37, HCN, HC-13-N, HC-15-N, HCNH+, HCP, HC3N, HCO+, HDO, HF
- HNC, HO2, HCO+, HOC+, KCl, KCl-37, MgCl, MgO, N-15-H3, N2-H+, NaCl
- NaCl-37, NaOH, N2H+, NH2D, NH2S, NS, O-18-CO, OO-16, OO-17,
- OO-18, O3, OCS, PH3, PO, SiO, SO+, SO-18, SO2, SOO-18, SO, SO-18,
- S-34-O, S-34-O2, SiC

Lunar gravity assist: diurnal variations of H absorption at equator detected by LEND. Goal: detection of water vapor by SWI

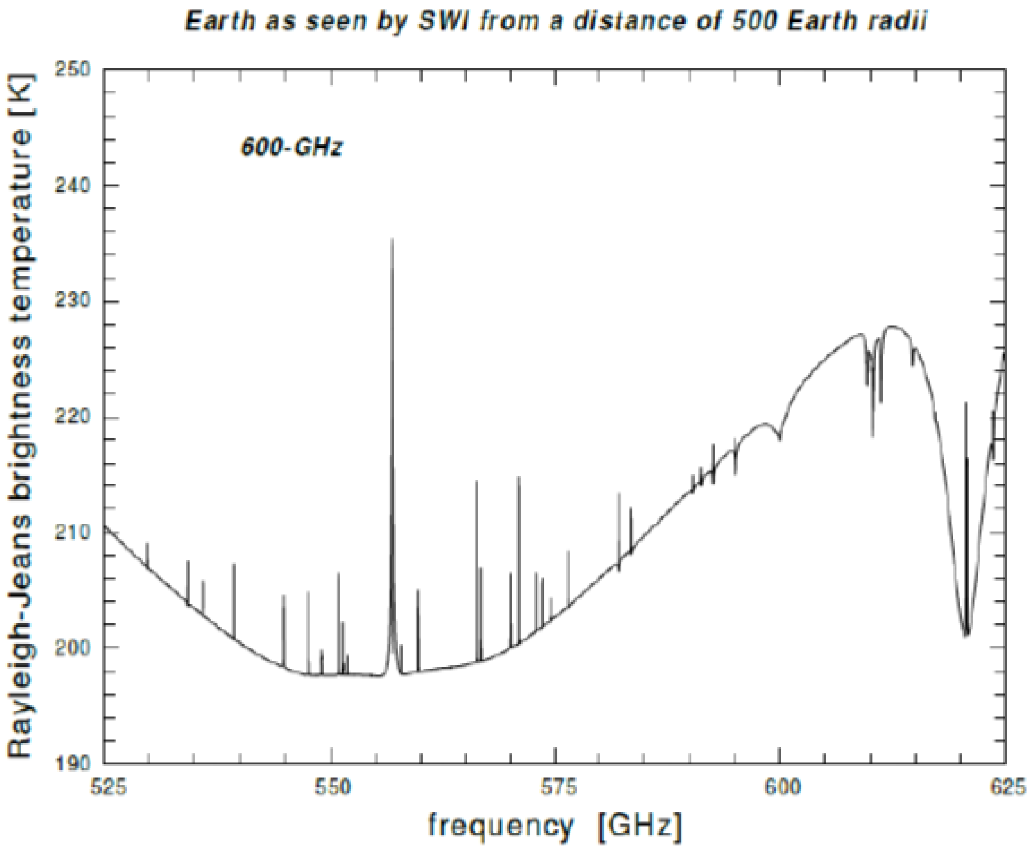


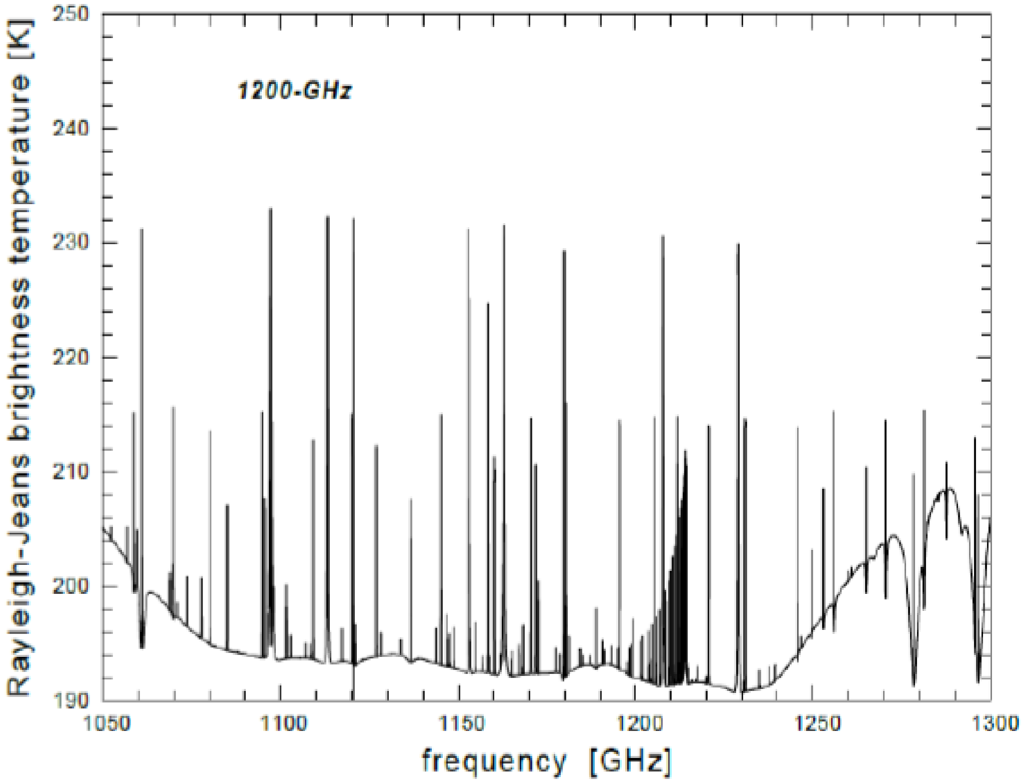
LEND results and discussion

- H and H_2 escape to a large extend
- Heavier molecules fall back to the surface (H_2O, CH_4, NH_3)
- Zonally averaged water-equivalent hydrogen suppression is 0,0046 wt%, or 0,0069 g/cm^2 => $2.3 \times 10^{20}/cm^2$ for regolith density of 1,5 g/cm^3
- From the speed of desorbed volatiles diffusing across the terminator: about 1 % of the volatiles will be above the surface at the terminator.
- Conclusion: the amount of water vapour above the dawn terminator is $1.6 \times 10^{18}/cm^2$ based on LEND detection. (The lower limit given by NIR spectroscopy is $5 \times 10^{13}/cm^2$). **SWI sensitivity: $5 \times 10^{10}/cm^2$**

(Livengood et al, 2015)

Earth submm spectrum in SWI bands





Earth swingby planned line detections (limb stare at 40 km)

Molecule	Freq /GHz	dTb (K) max
H_2O	557 & 1113	> 100
O_2	1121	> 100
O_3	566 & 1180	> 100
HCl	626 & 1256	~ 60
CO	576 & 1152	> 10
N_2O	552	> 10
NO	552 & 1153	> 10
HNO_3	544	> 10
HO_2	569 & 1265	<10
HOCl	599 & 1075	< 10
BrO	602	< 10
HDO	600 & 1278	< 10
$H_2{}^{17}O$	552 & 1107	< 10
$H_2{}^{18}O$	548 & 1102	< 10

nature astronomy

ARTICLES

https://doi.org/10.1038/s41550-020-1174-4

Check for updates

Phosphine gas in the cloud decks of Venus

Jane S. Greaves[1,2], Anita M. S. Richards[3], William Bains[4], Paul B. Rimmer[5,6,7], Hideo Sagawa[8], David L. Clements[9], Sara Seager[4,13,14], Janusz J. Petkowski[4], Clara Sousa-Silva[4], Sukrit Ranjan[4], Emily Drabek-Maunder[1,10], Helen J. Fraser[11], Annabel Cartwright[1], Ingo Mueller-Wodarg[9], Zhuchang Zhan[4], Per Friberg[12], Iain Coulson[12], E'lisa Lee[12] and Jim Hoge[12]

Measurements of trace gases in planetary atmospheres help us explore chemical conditions different to those on Earth. Our nearest neighbour, Venus, has cloud decks that are temperate but hyperacidic. Here we report the apparent presence of phosphine (PH_3) gas in Venus's atmosphere, where any phosphorus should be in oxidized forms. Single-line millimetre-waveband spectral detections (quality up to ~15σ) from the JCMT and ALMA telescopes have no other plausible identification. Atmospheric PH_3 at ~20 ppb abundance is inferred. The presence of PH_3 is unexplained after exhaustive study of steady-state chemistry and photochemical pathways, with no currently known abiotic production routes in Venus's atmosphere, clouds, surface and subsurface, or from lightning, volcanic or meteoritic delivery. PH_3 could originate from unknown photochemistry or geochemistry, or, by analogy with biological production of PH_3 on Earth, from the presence of life. Other PH_3 spectral features should be sought, while in situ cloud and surface sampling could examine sources of this gas.

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nature astronomy

MATTERS ARISING

https://doi.org/10.1038/s41550-021-01422-z

Check for updates

No evidence of phosphine in the atmosphere of Venus from independent analyses

G. L. Villanueva[1]✉, M. Cordiner[1,2], P. G. J. Irwin[3], I. de Pater[4], B. Butler[5], M. Gurwell[6], S. N. Milam[1], C. A. Nixon[1], S. H. Luszcz-Cook[7,8], C. F. Wilson[3], V. Kofman[1,9], G. Liuzzi[1,9], S. Faggi[1,9], T. J. Fauchez[1,10], M. Lippi[1,9], R. Cosentino[1,11], A. E. Thelen[1,10], A. Moullet[12], P. Hartogh[13], E. M. Molter[4], S. Charnley[1], G. N. Arney[1], A. M. Mandell[1], N. Biver[14], A. C. Vandaele[15], K. R. de Kleer[16] and R. Kopparapu[1]

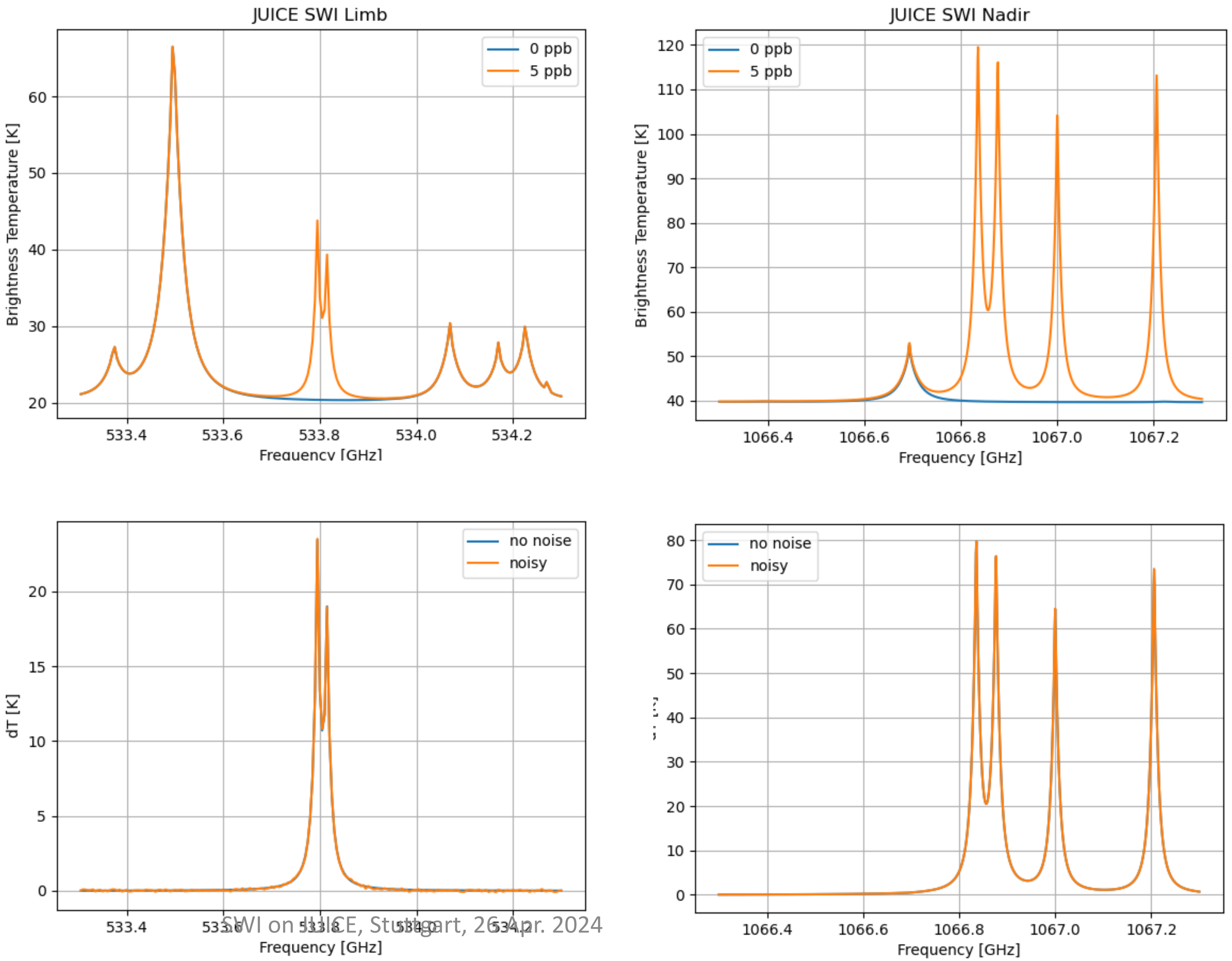
Venus swingby: SWI limb view PH3 (70-90 km) spectra

Limb sounding works only above 70 km.

5 ppb (Encrenaz et al. 2020 upper limit).

Pointing altitude 80 km, 1 hour integration time

3-sigma upper limits:
35 ppt (600 GHz)
15 ppt (1200 GHz)



- **Thanks for your attention!**