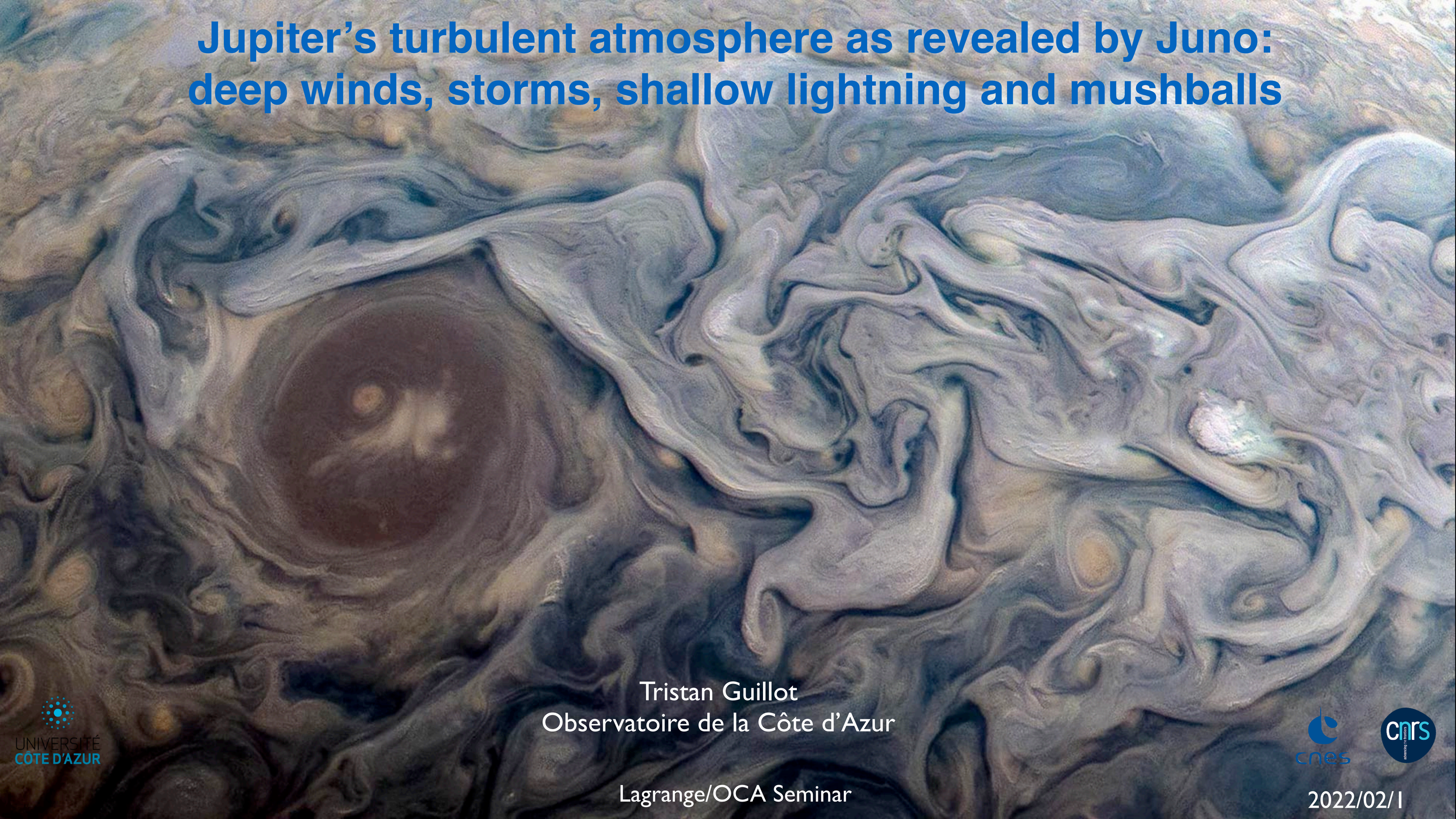
Jupiter's turbulent atmosphere as revealed by Juno: deep winds, storms, shallow lightning and mushballs



Tristan Guillot
Observatoire de la Côte d'Azur

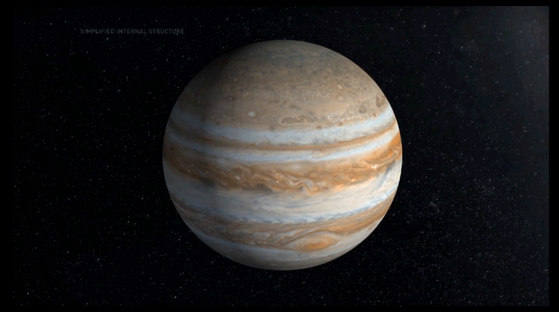
Lagrange/OCA Seminar

2022/02/1

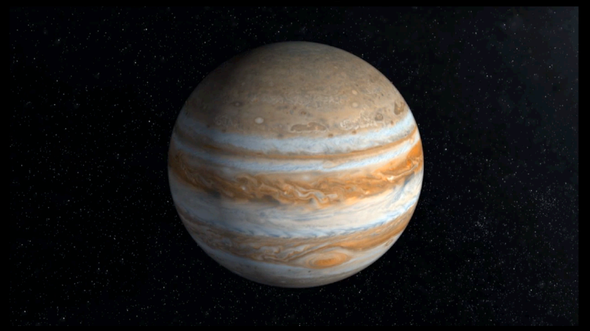
from D. Peach

Does Jupiter rotate

as a rigid body…

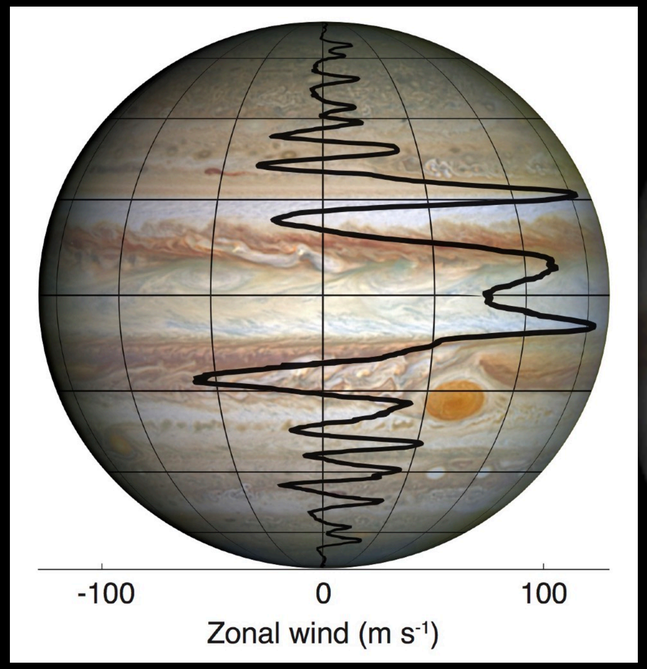


…or on cylinders?

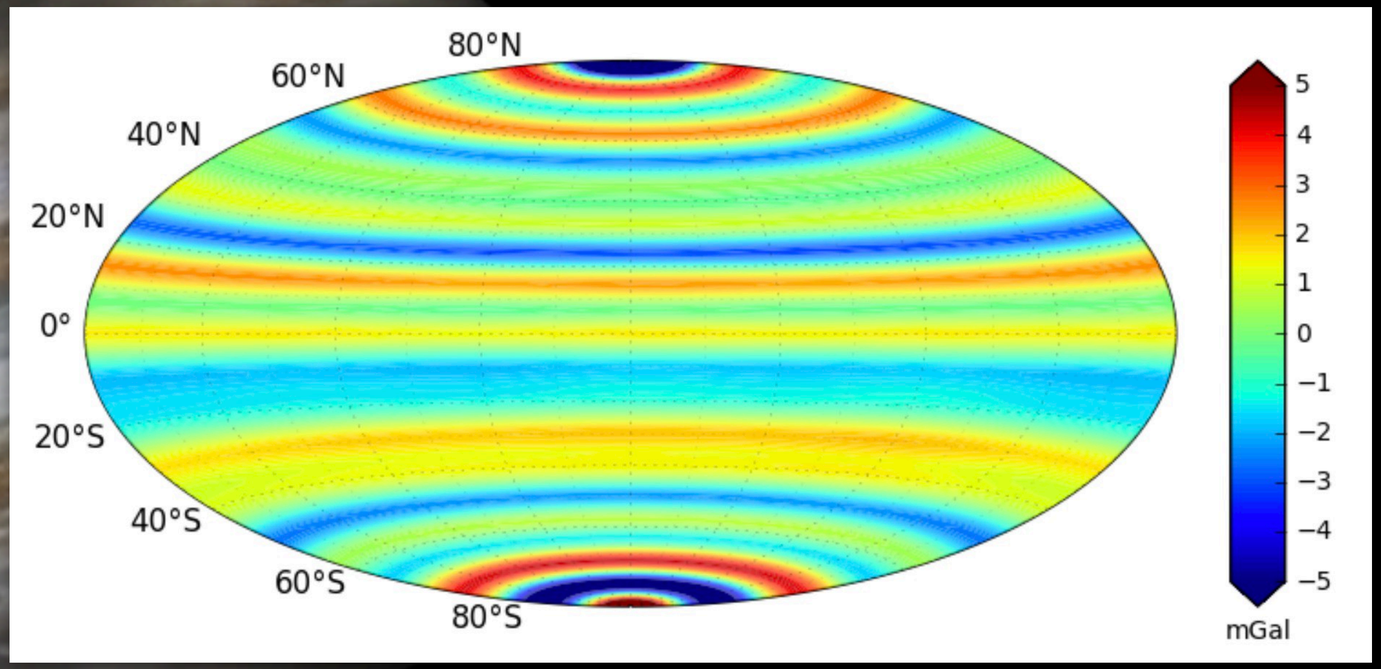


© Peter Rosen - a contribution to the Mission Juno Pro-Amateur project

Zonal winds

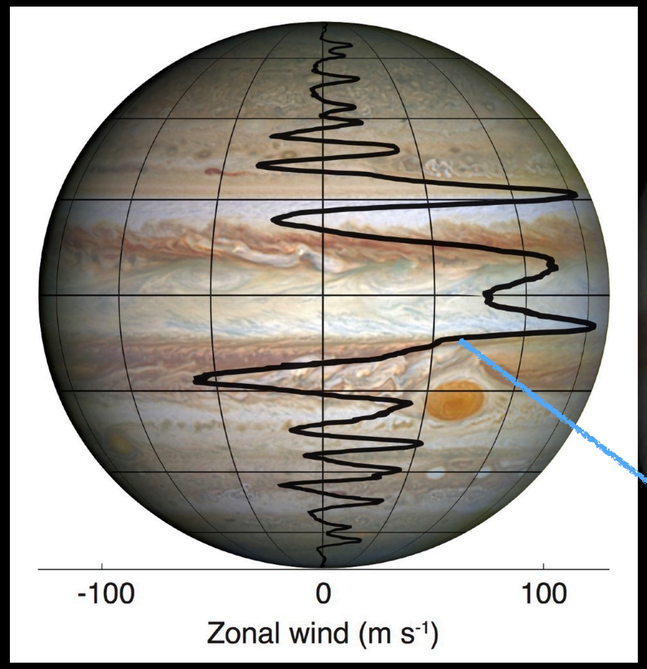


Map of gravity anomalies

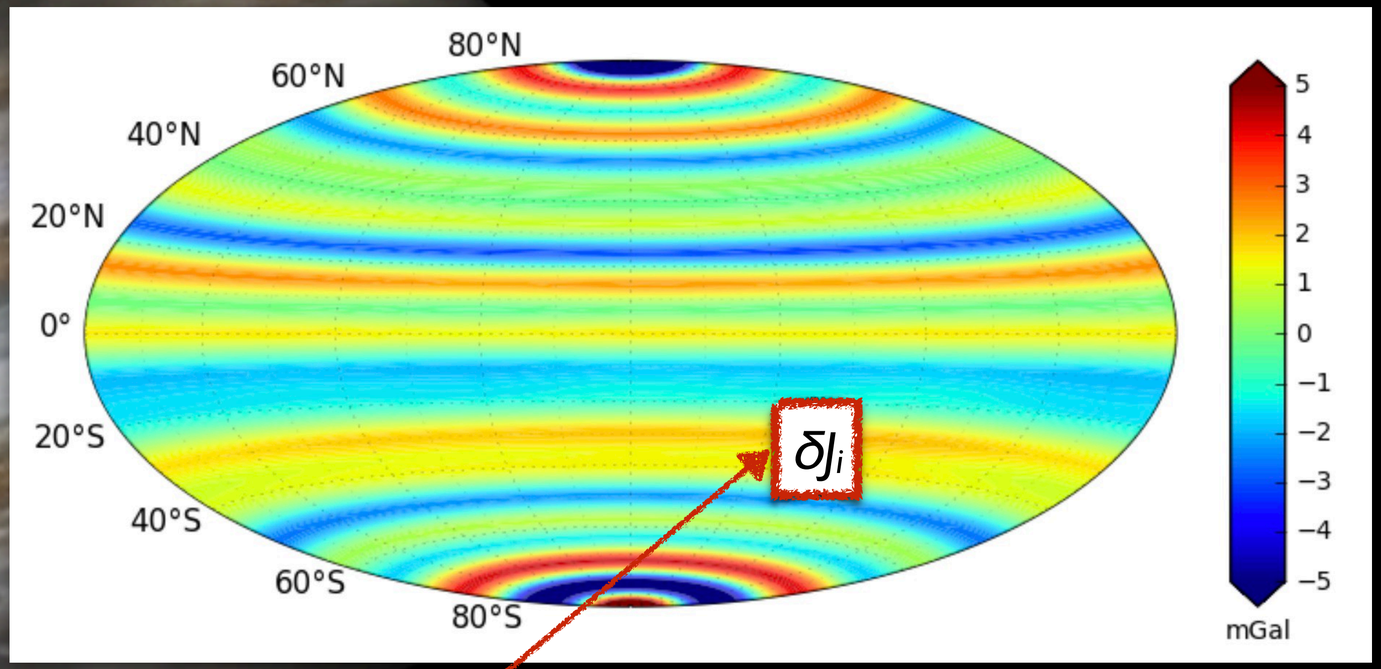


Iess et al. (2018)

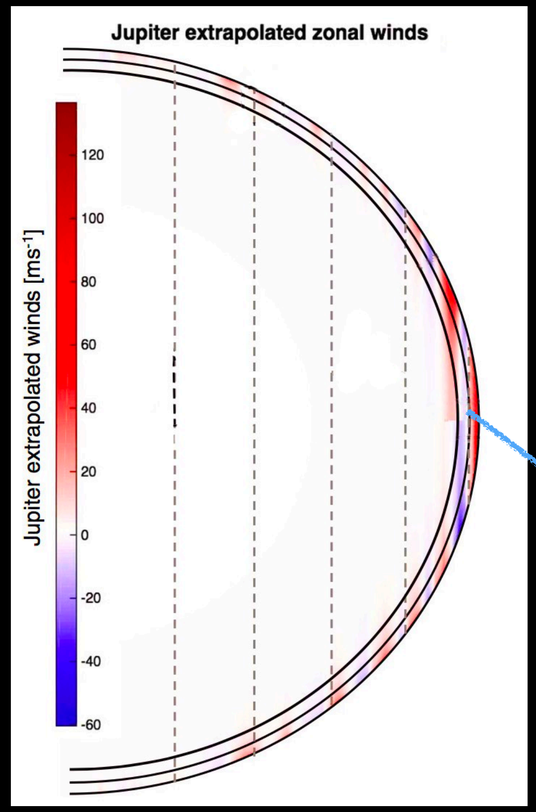
Zonal winds



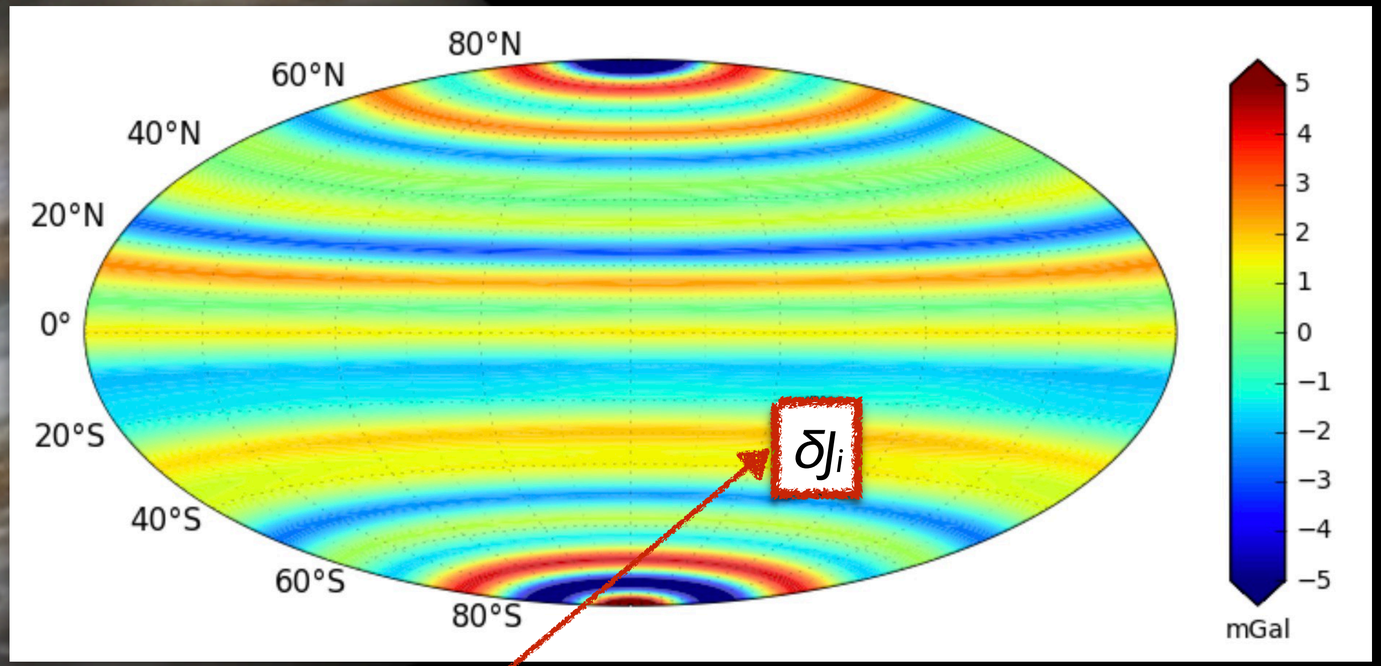
Map of gravity anomalies



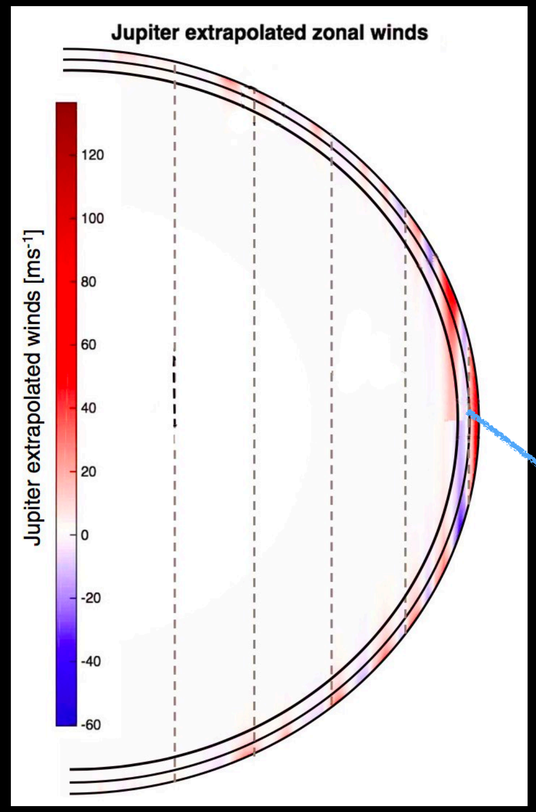
$$2\Omega \cdot \nabla \left(\rho_s \mathbf{u}\right) = \nabla \rho' \times \mathbf{g},$$

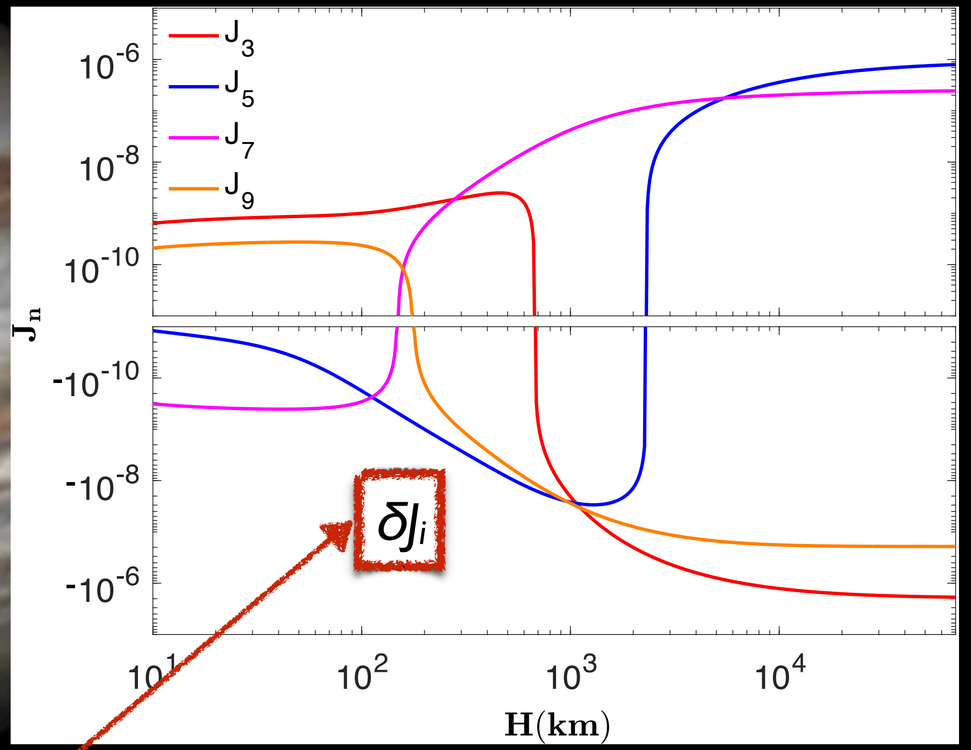


Map of gravity anomalies



$$2\Omega \cdot \nabla \left(\rho_s \mathbf{u}\right) = \nabla \rho' \times \mathbf{g},$$





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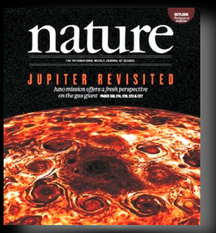

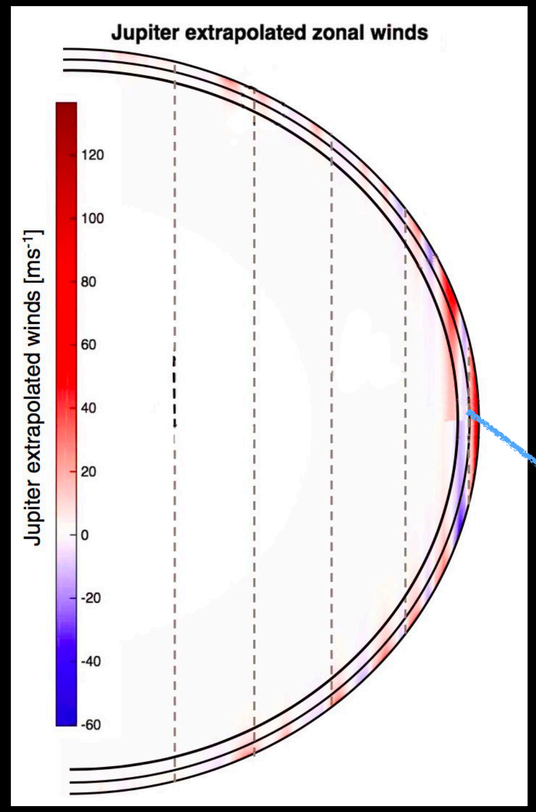

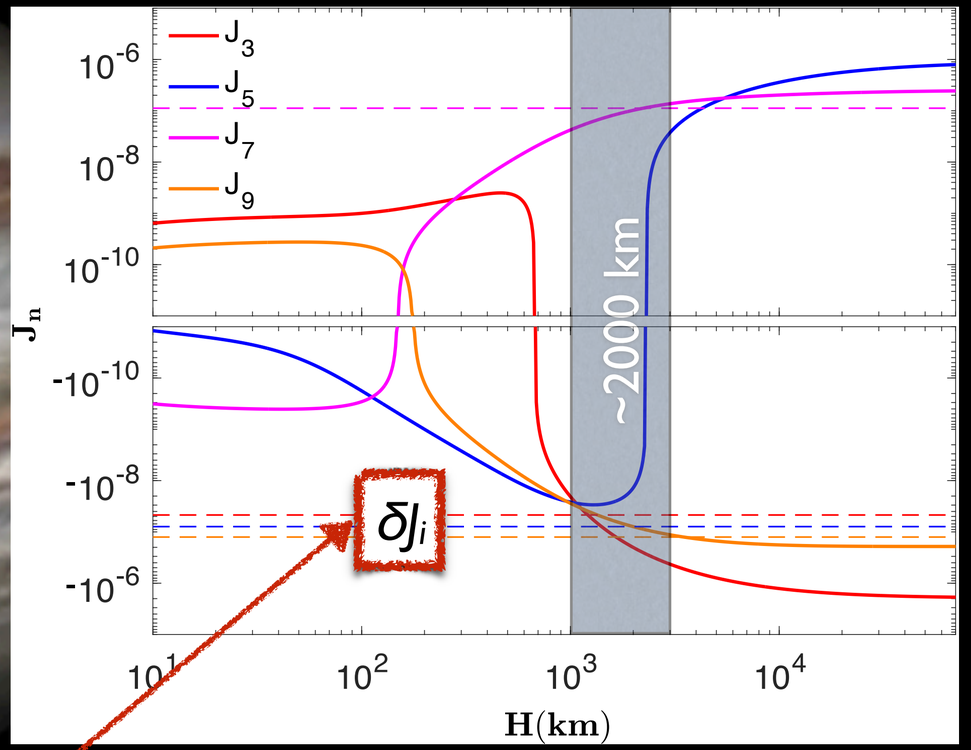

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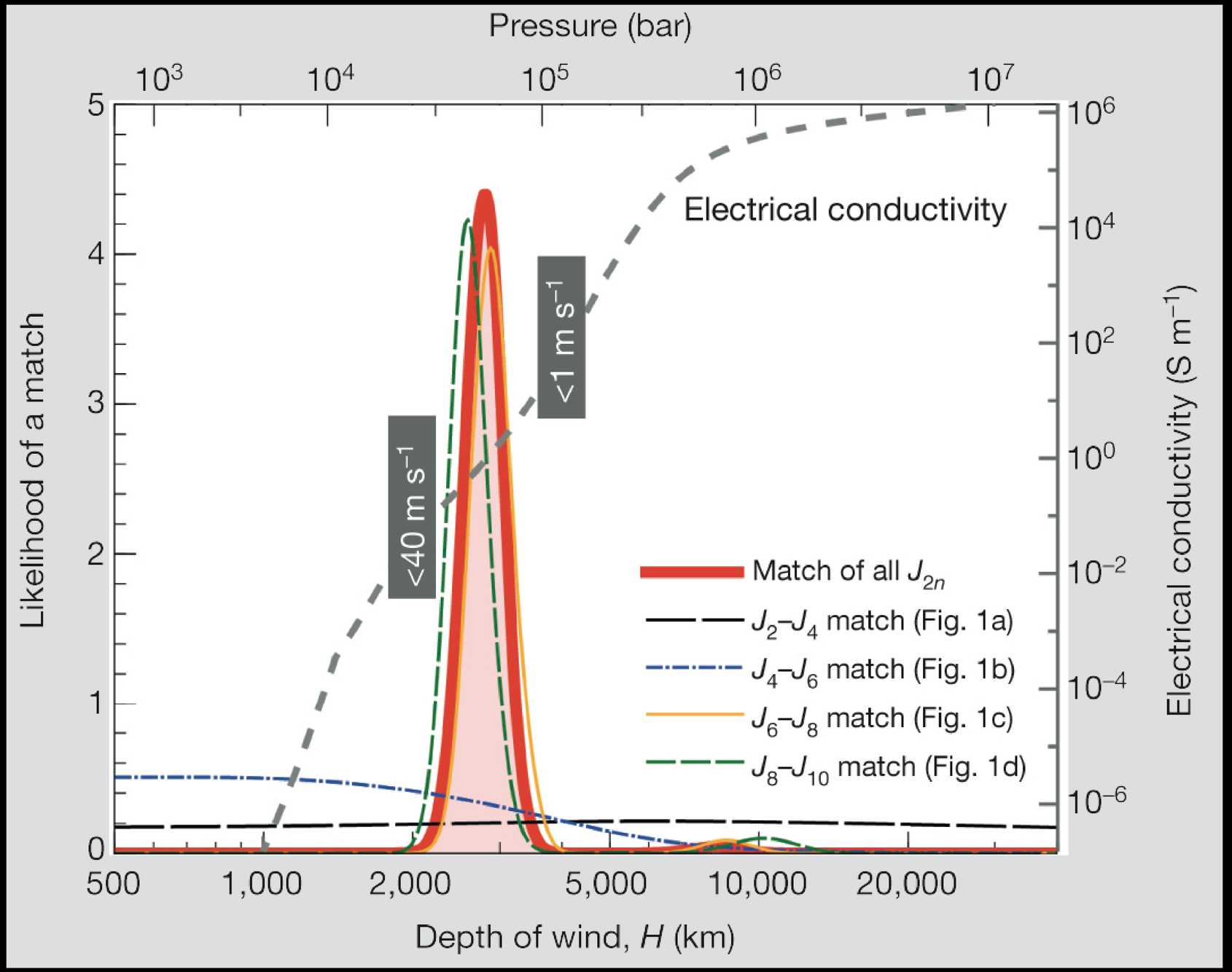
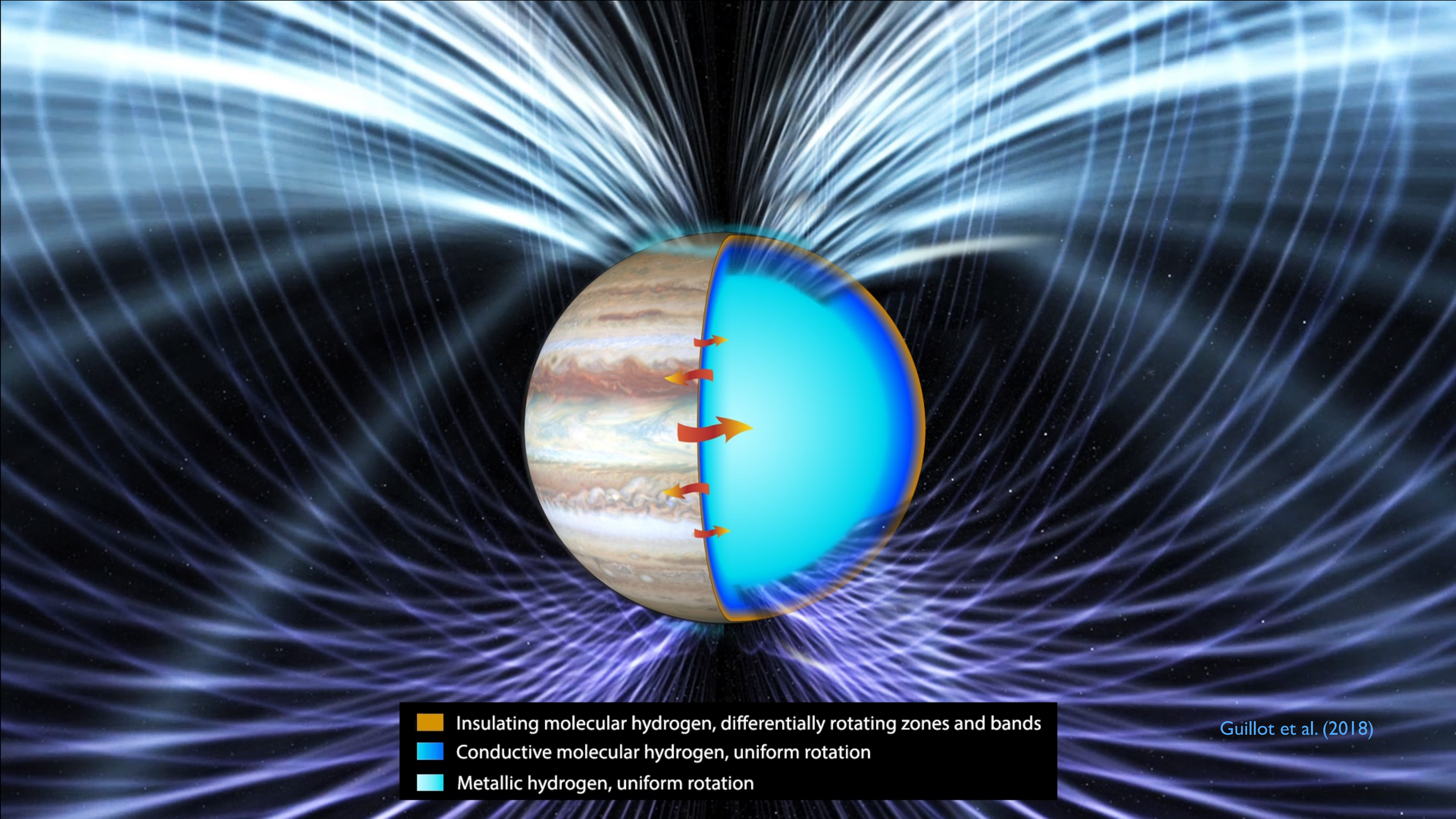
Kaspi et al. (2018)

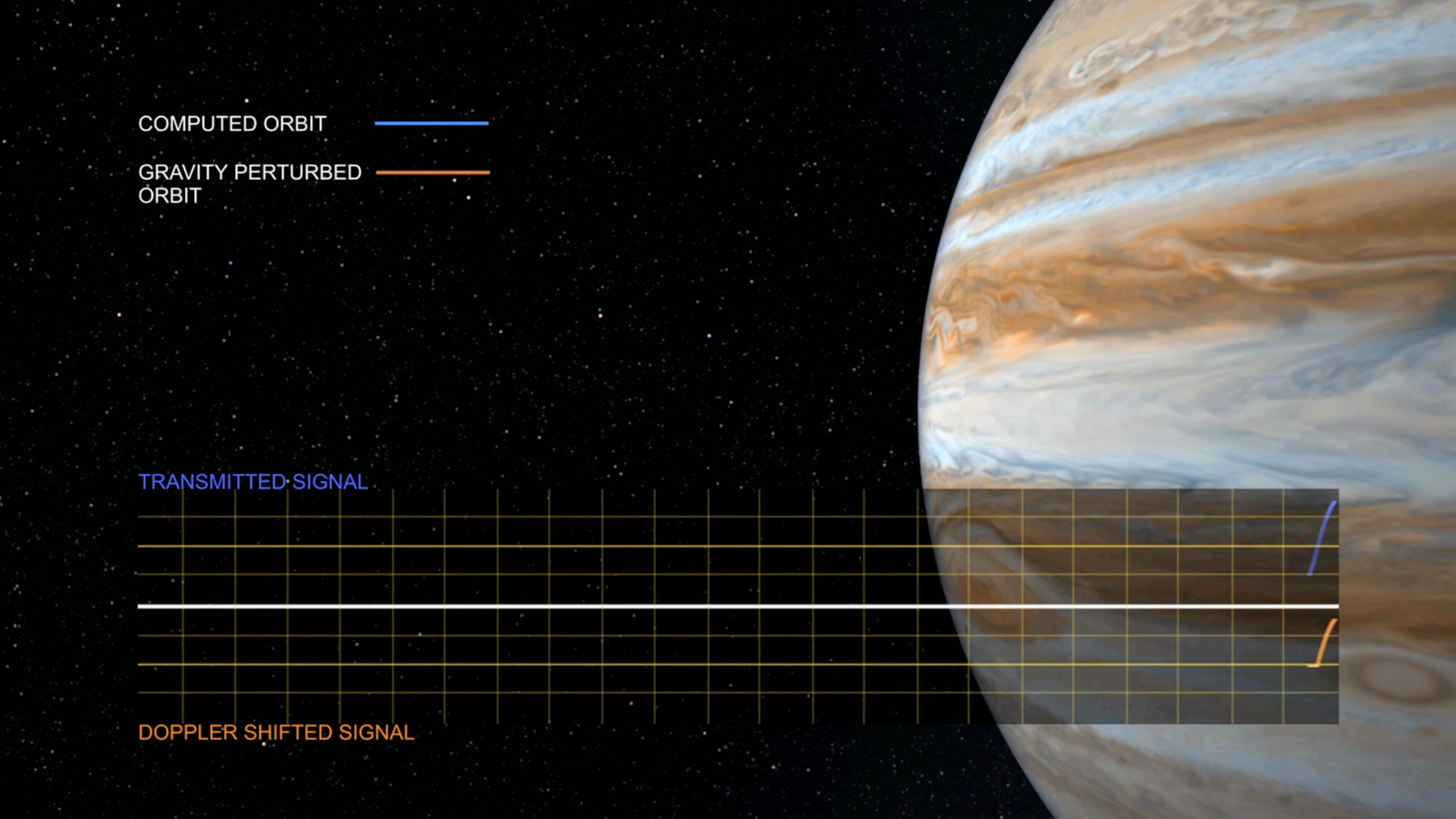


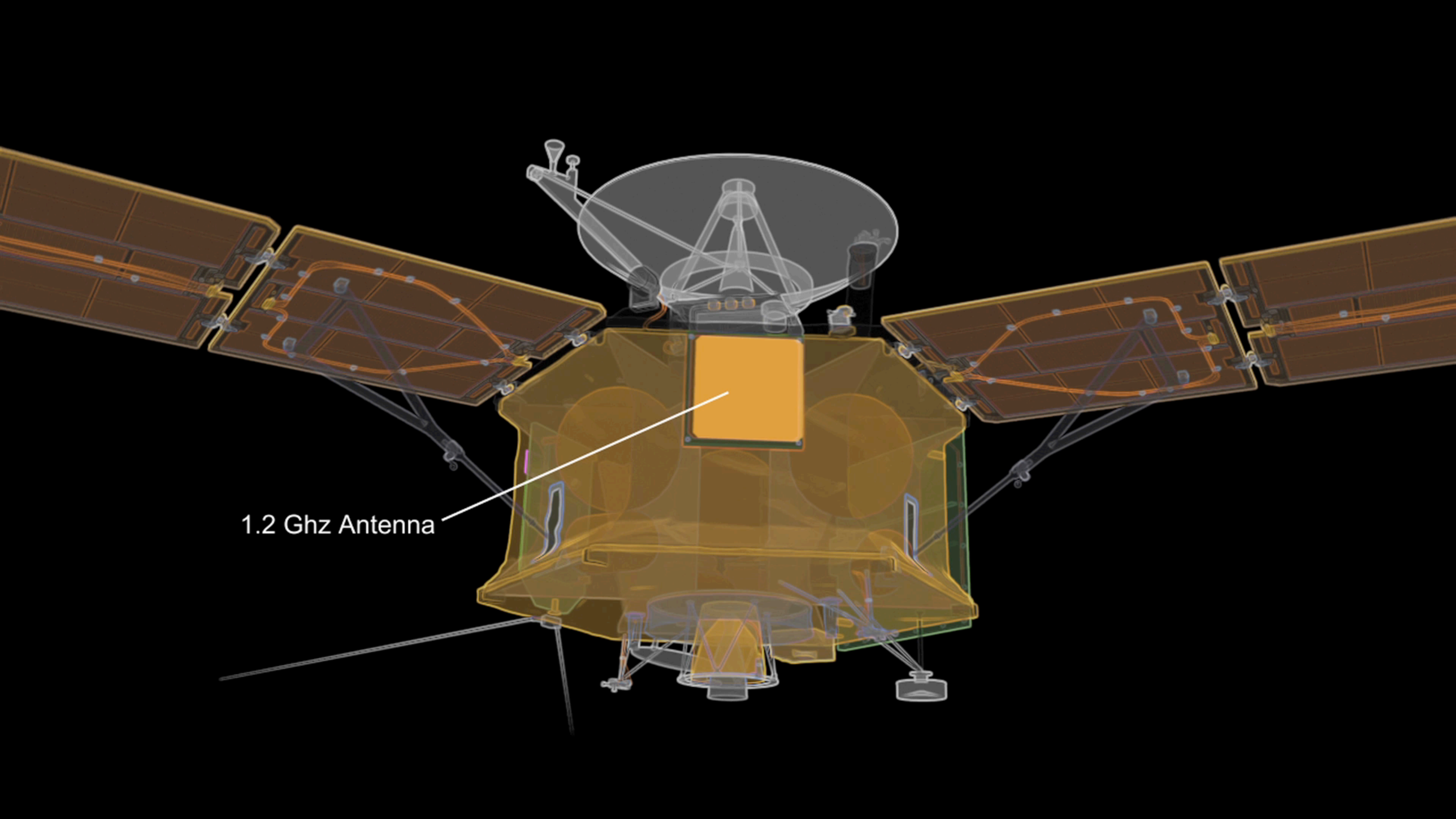
Guillot et al. (2018)



Guillot et al. (2018)


SPACECRAFT DIMENSIONS
Diameter: 66 feet (20 m)
Height: 15 feet (4.5 m)
JunoCam
camera
UVS
UV spectrometer
Waves
Radio & plasma
JIRAM
IR spectrometer
JEDI
High-energy particles
JADE
Low-energy particles
Gravity Science
Magnetometer
MWR
Microwaves


COMPUTED ORBIT
GRAVITY PERTURBED ORBIT
TRANSMITTED SIGNAL
DOPPLER SHIFTED SIGNAL


1.2 Ghz Antenna

The promise of satellite monitoring for preserving biodiversity p. 926

Antiaging diets dissected p. 953

How a viral RNA hijacks host machinery p. 955

Science

$15
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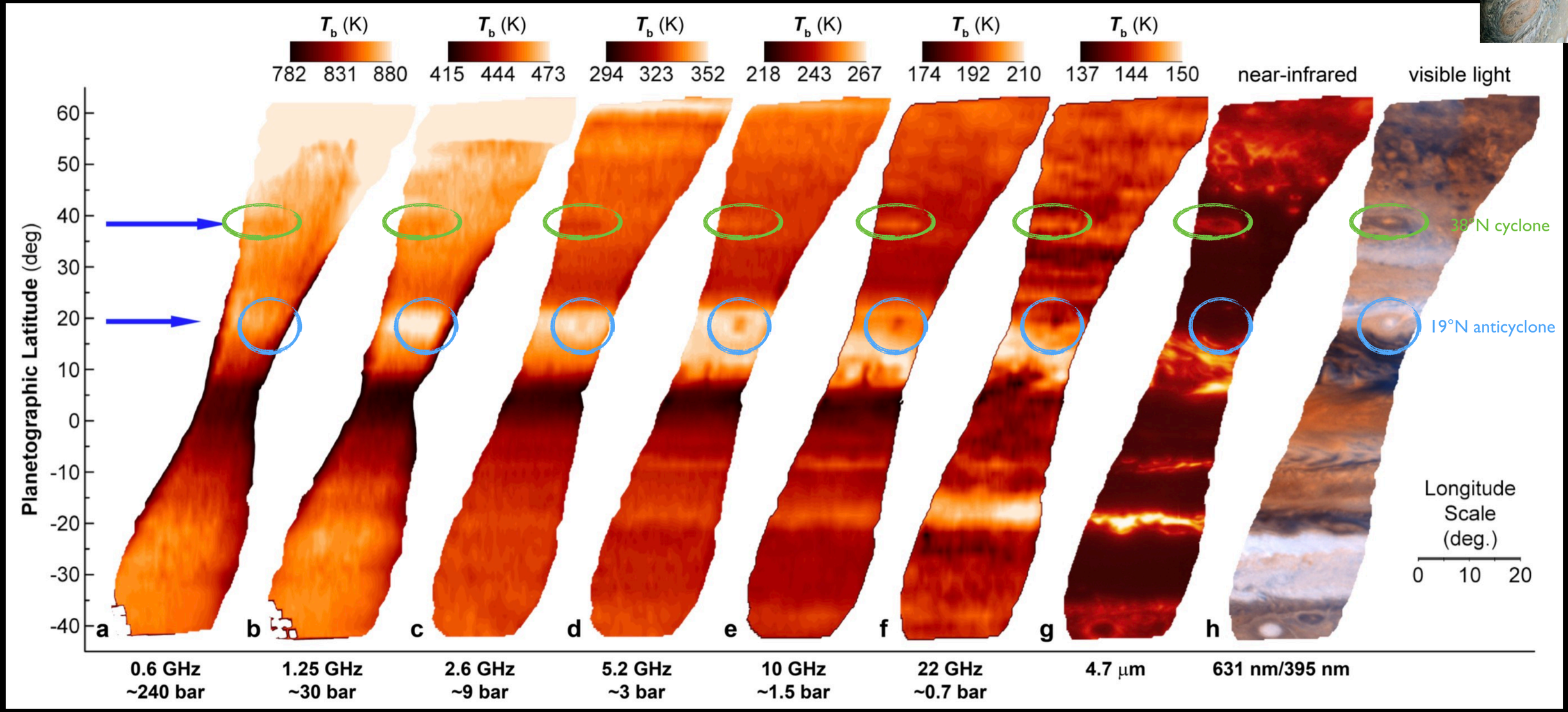
AAAS

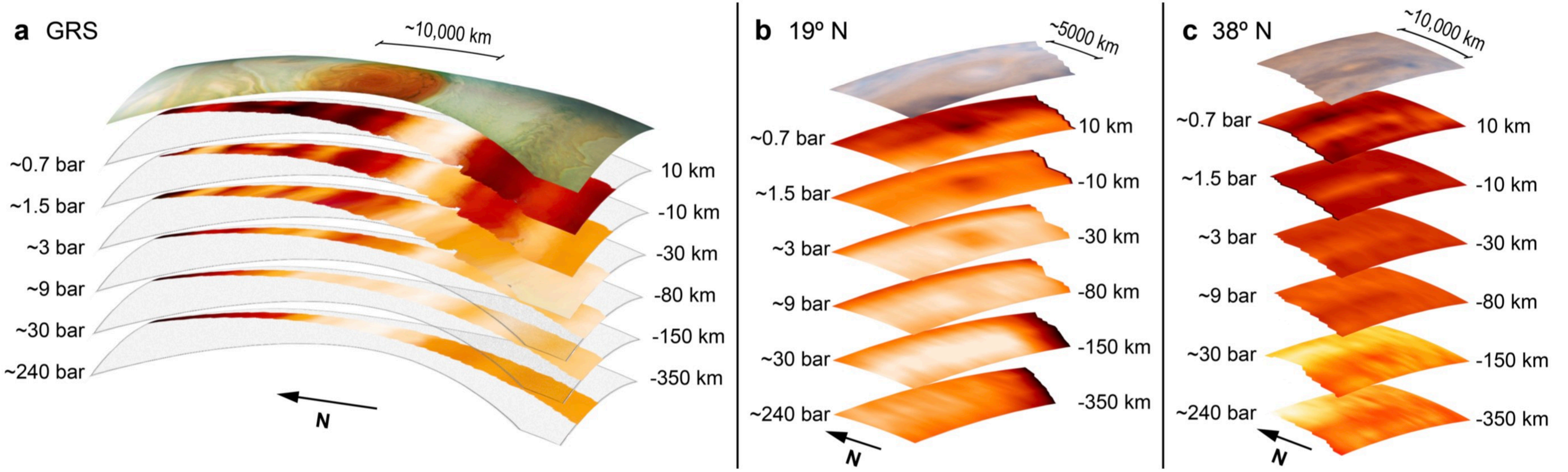
JUPITER'S STORMS

Juno peers into the atmosphere

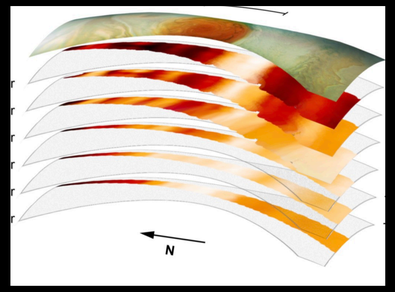
pp. 964 & 968

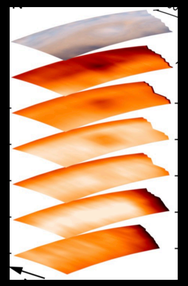


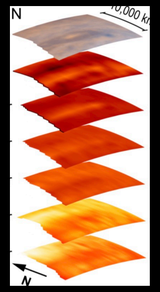
Bolton et al. (2021)



Bolton et al. (2021)







GRS 18°S

19°N anticyclone

38°N cyclone

A

B

C

D

E

F

G

H

I

NH3

NH4SH

H2O

Pressure [bar]

1

10

100

1000

maximum extent compatible with Juno gravity

denser

lighter

-0.03 0 0.03

ΔTb/Tb

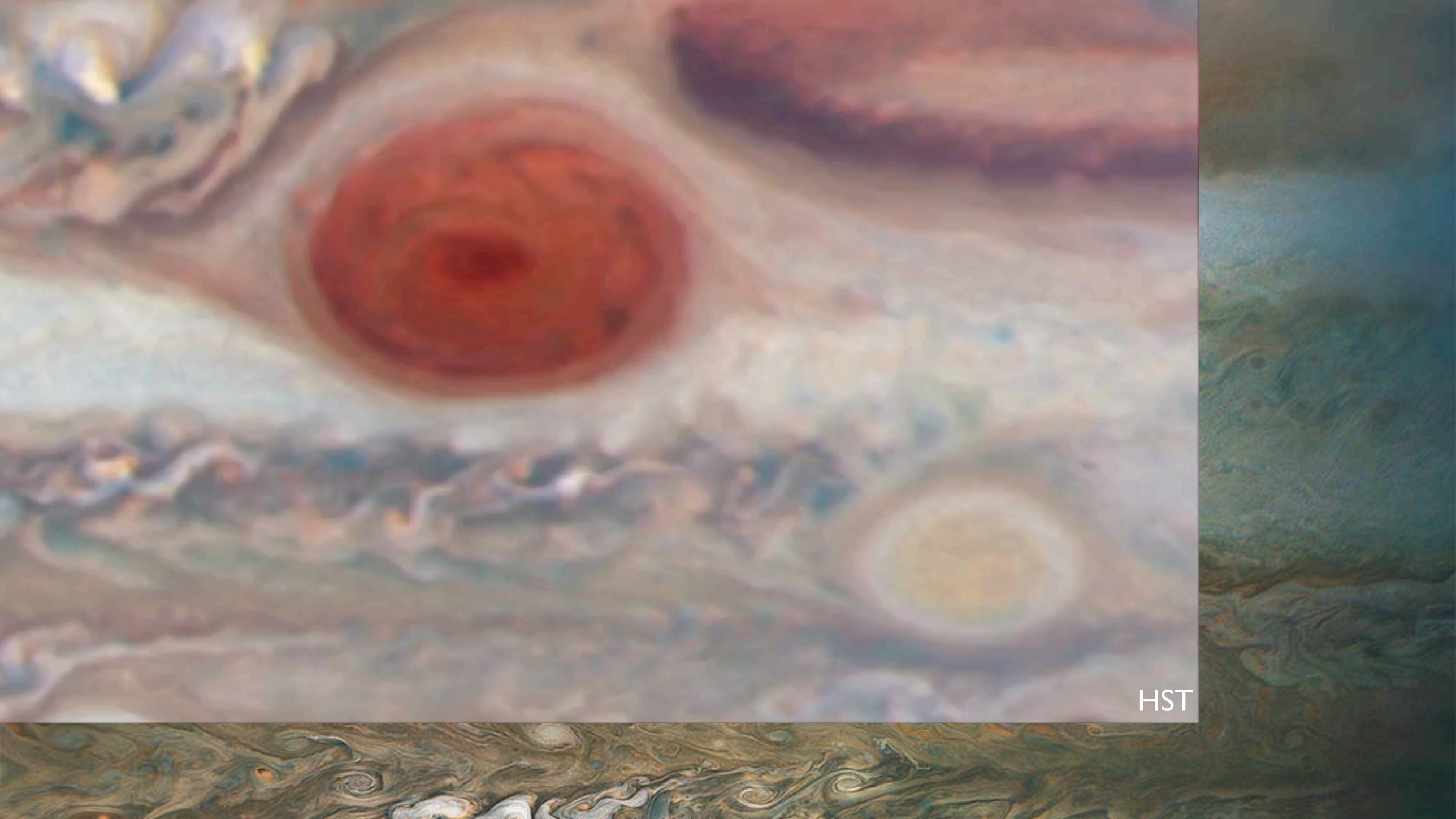
-0.05 0 0.05 0.1 0.15

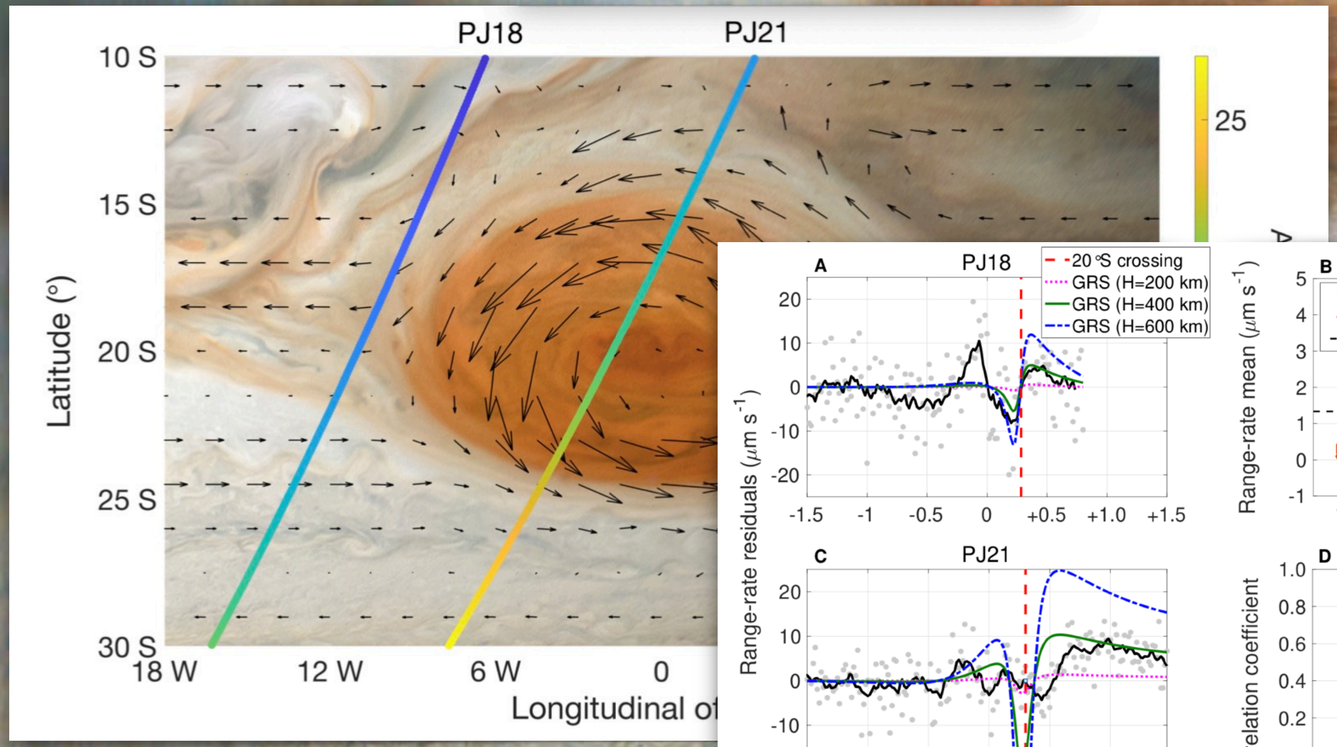
δx

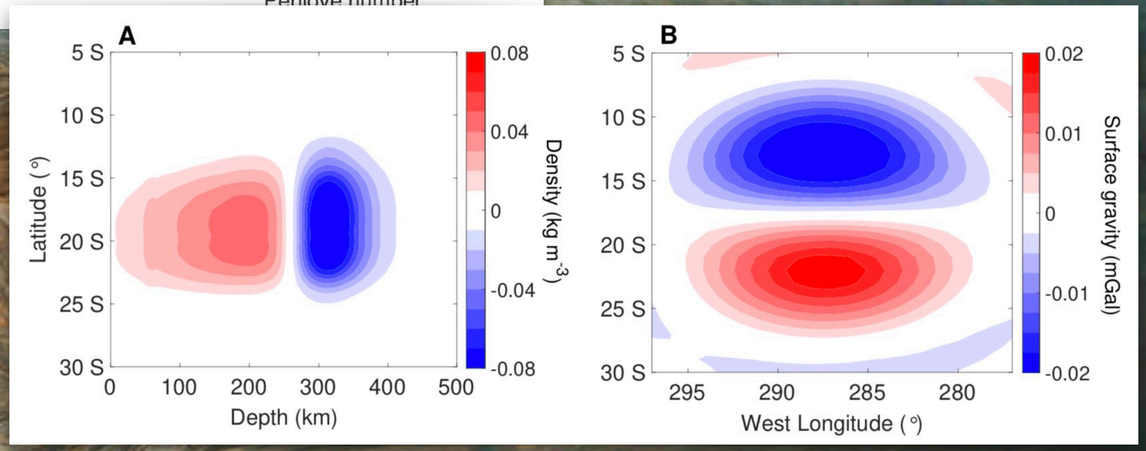
-0.05 0 0.05

Bolton et al. (2021)

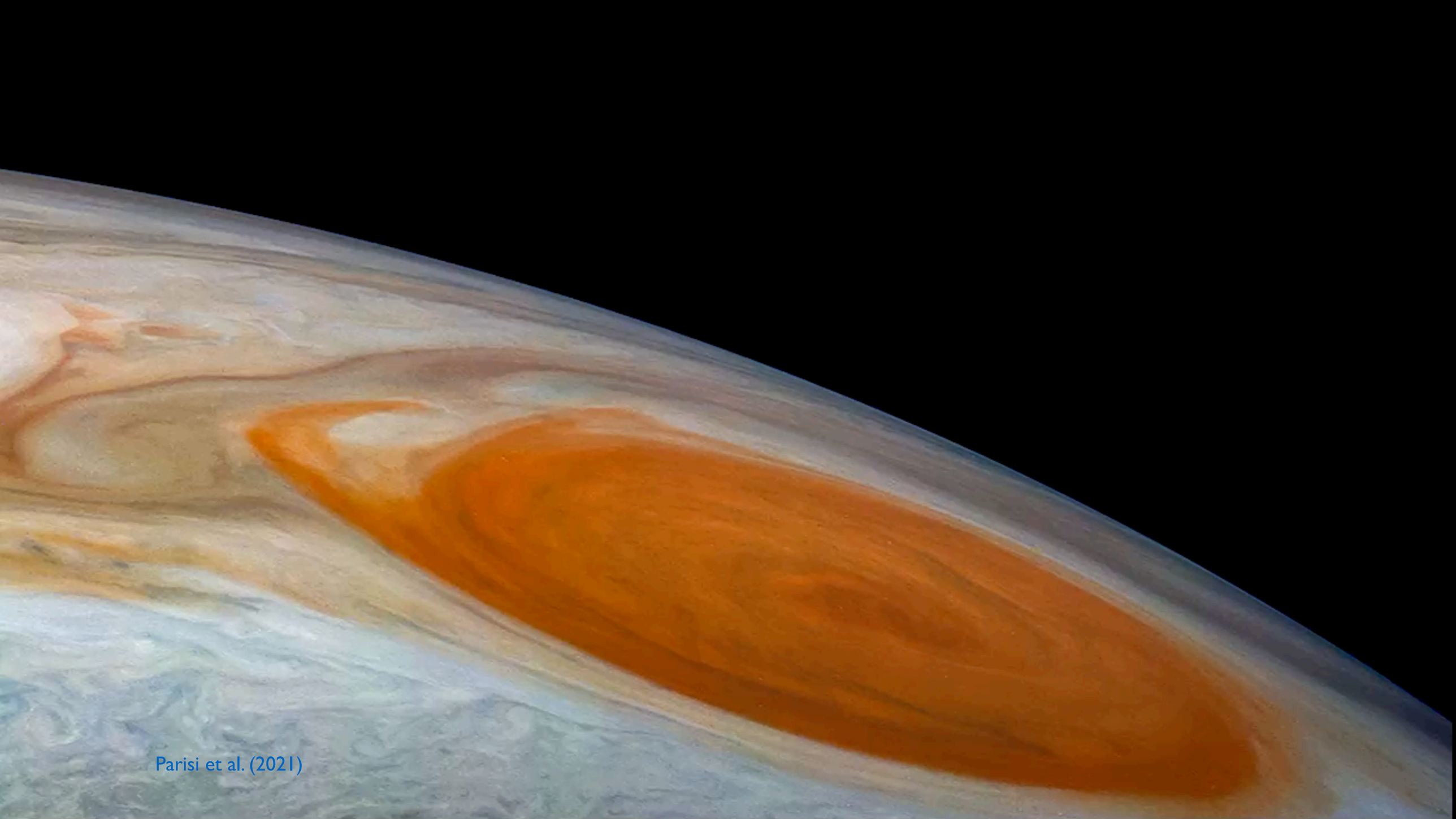

JunoCam

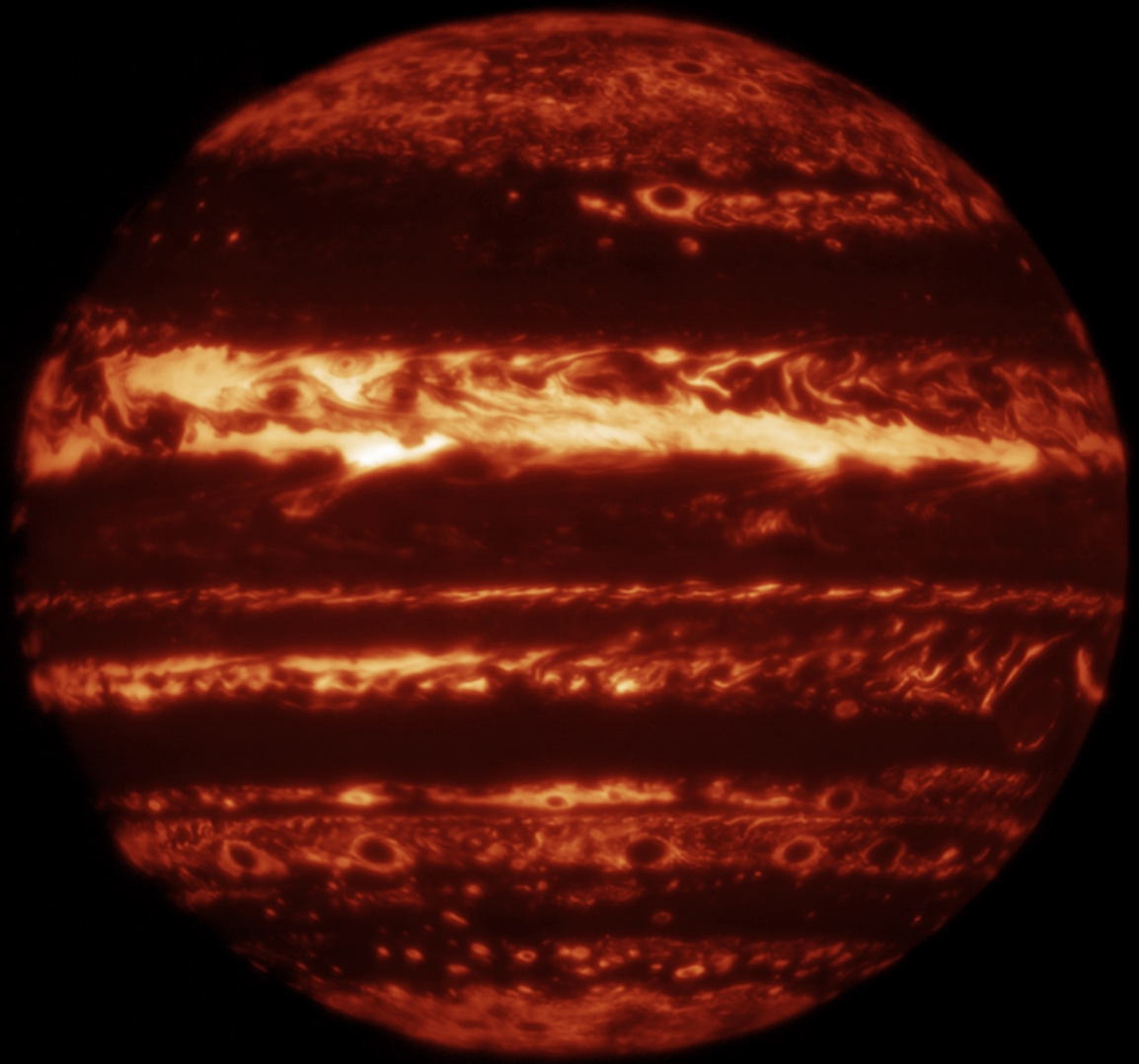

HST



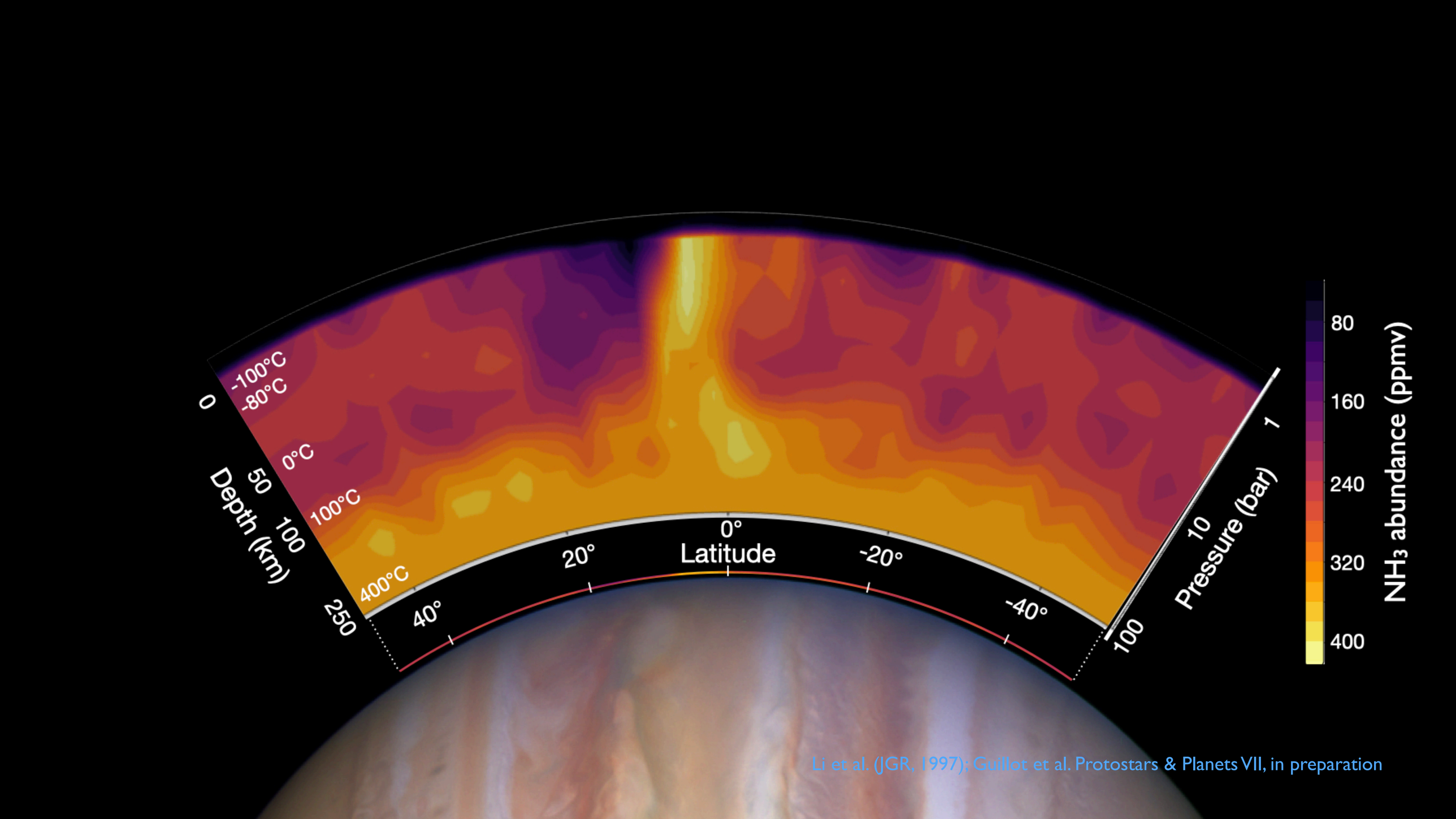


Parisi et al. (2021)

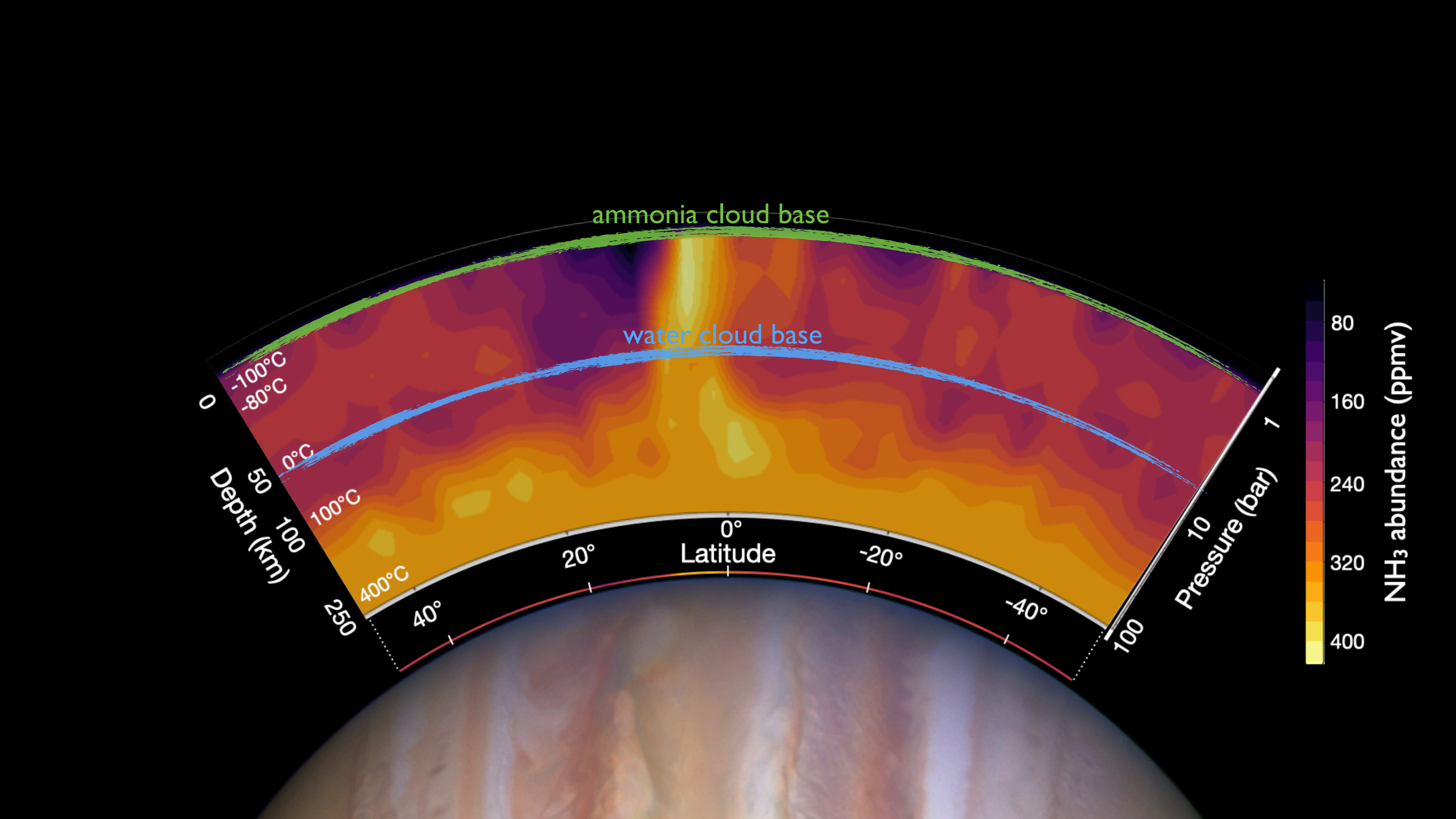

Parisi et al. (2021)

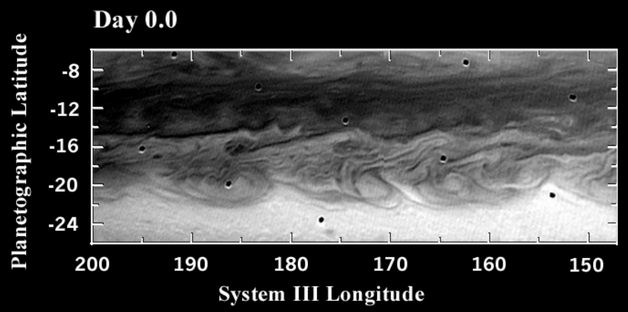


5μm Gemini/M. Wong



Li et al. (JGR, 1997); Guillot et al. Protostars & Planets VII, in preparation


ammonia cloud base
water cloud base
-100°C
-80°C
0°C
100°C
400°C
0
50
100
250
Depth (km)
0°
20°
40°
-20°
-40°
Latitude
1
10
100
Pressure (bar)
80
160
240
320
400
NH3 abundance (ppmv)



Hueso, Sanchez-Lavega & Guillot (2002)

ammonia cloud base

water cloud base

-100°C
-80°C
0°C
100°C
400°C

0
50
100
250
Depth (km)

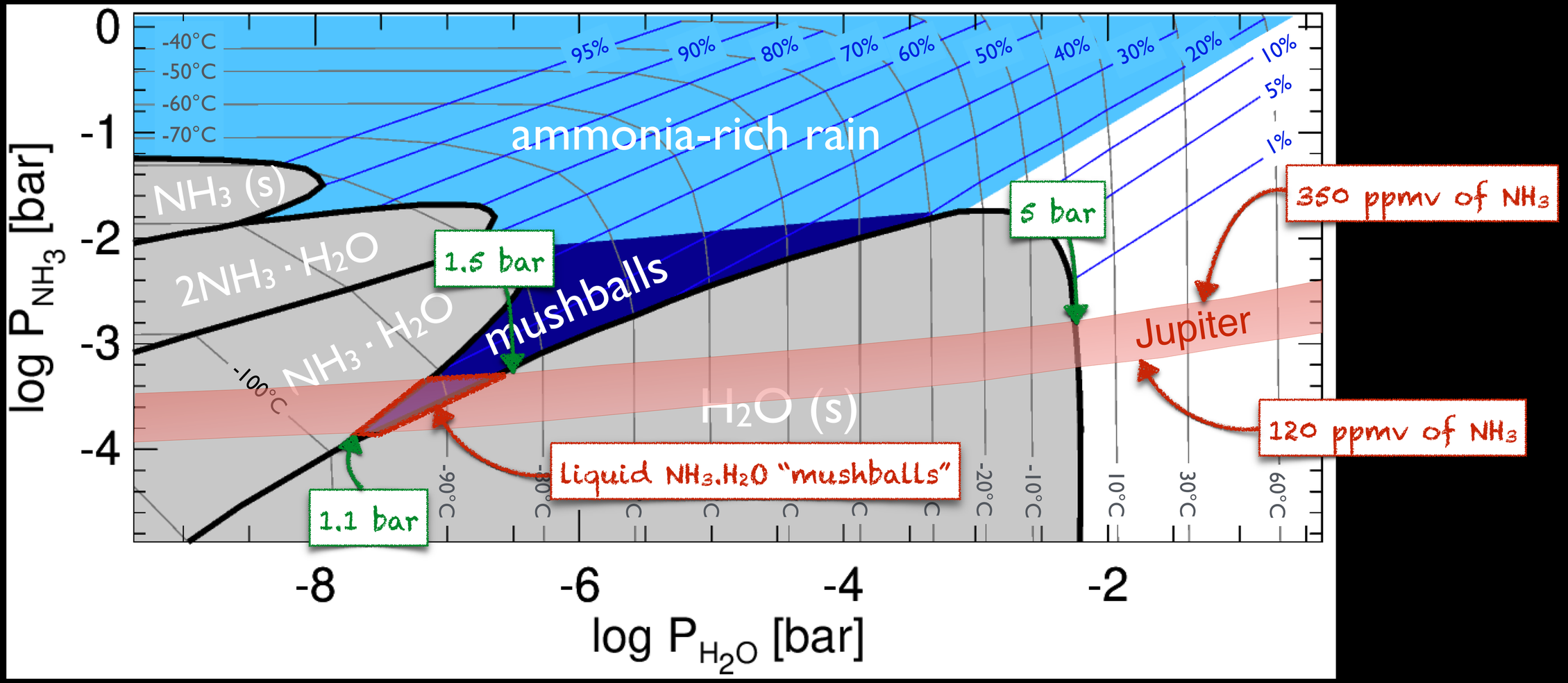
0°
20°
40°
Latitude
-20°
-40°

1
10
100
Pressure (bar)

80
160
240
320
400
NH_3 abundance (ppmv)

Guillot et al. (JGR, 2020a,b)

The water-ammonia phase diagram



from Weidenschilling & Lewis (Icarus, 1973)

Guillot et al. (JGR, 2020a,b)

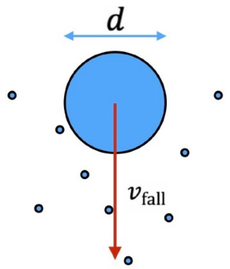
Hailstones / mushballs

Growth

$$dm/dt = E\,(\pi/4)\,d^2\,X_{\mathrm{cond}}\,\rho v_{\mathrm{fall}}$$

v_{fall} terminal velocity of mushball

E: collection efficiency



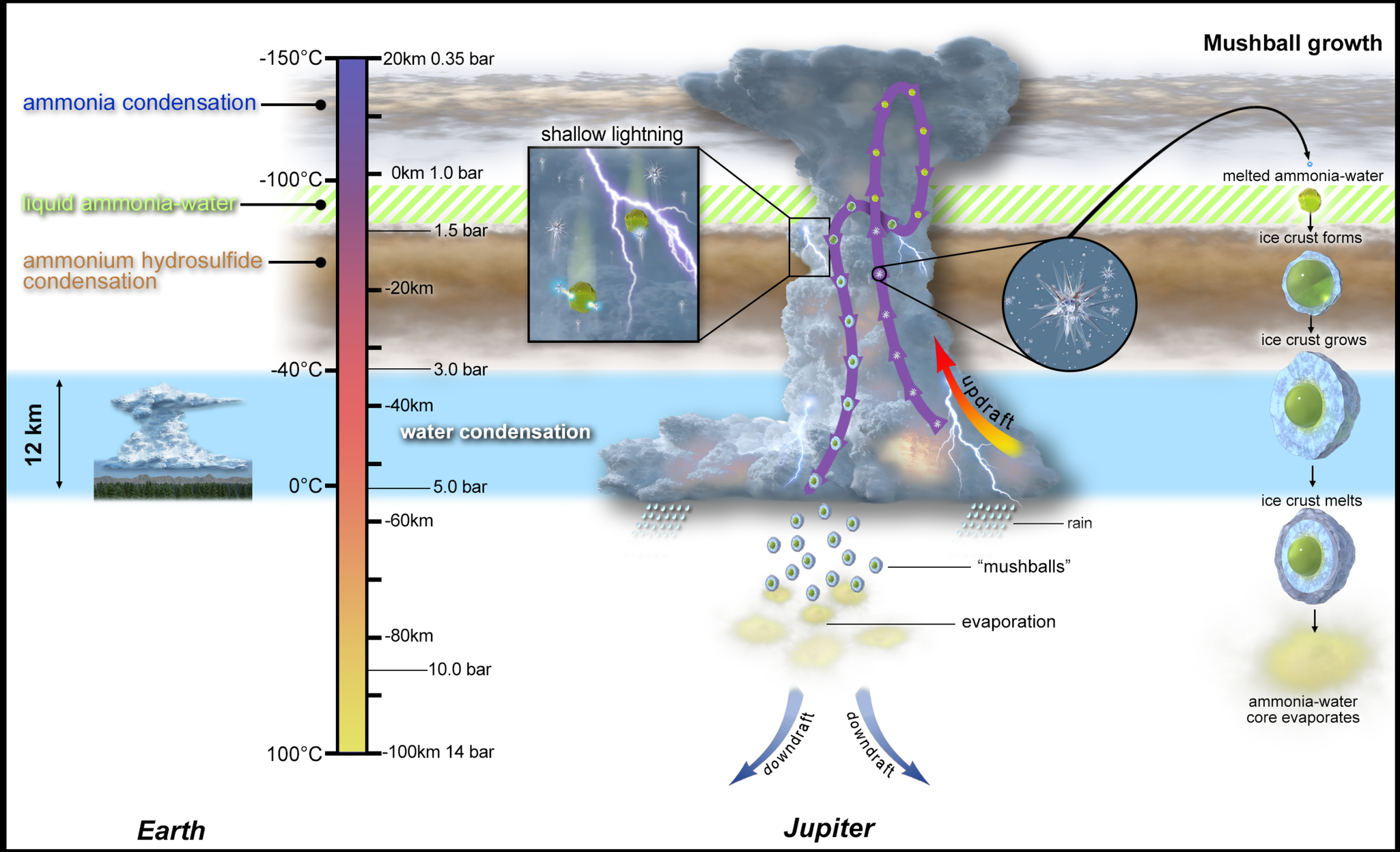
Melting/evaporation

$$\frac{da}{dt} = \frac{1}{(L_{\mathrm{m}} + c_P \Delta T)\tilde{\rho}_{\mathrm{i}} a}\left[-k_{\mathrm{a}}(T_{\mathrm{ext}} - T_0) f_{\mathrm{h}} + D_{\mathrm{v}} \frac{\mu_{\mathrm{v}} L_{\mathrm{v}}}{\mathcal{R}}\left(\frac{P_{\mathrm{sat}}(T_0)}{T_0} - \mathcal{H}_{\mathrm{a}} \frac{P_{\mathrm{sat}}(T_{\mathrm{ext}})}{T_{\mathrm{ext}}}\right) f_{\mathrm{v}}\right]$$

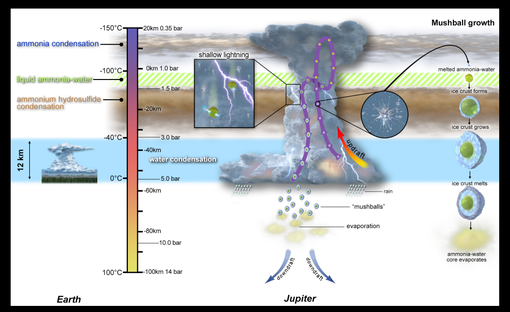
$$f_{\mathrm{h}} = \frac{\chi}{2} N_{Re}^{1/2} \left(\frac{\nu_{\mathrm{a}}}{K_{\mathrm{a}}}\right)^{1/3}$$

$$f_{\mathrm{v}} = \frac{\chi}{2} N_{Re}^{1/2} \left(\frac{\nu_{\mathrm{a}}}{D_{\mathrm{v}}}\right)^{1/3}$$

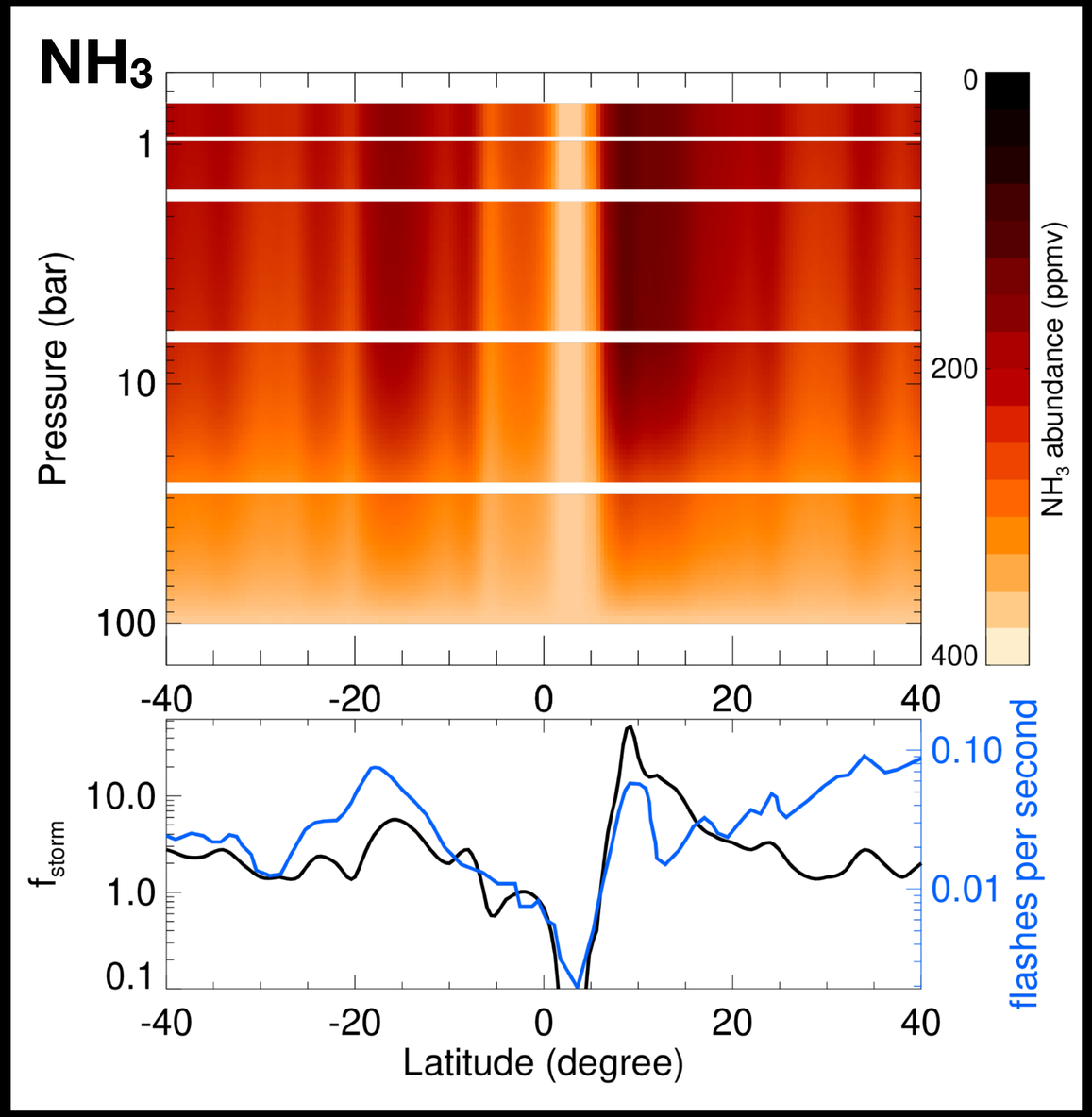
Rassmussen et al. (1984), Pruppacher & Klett (1997)

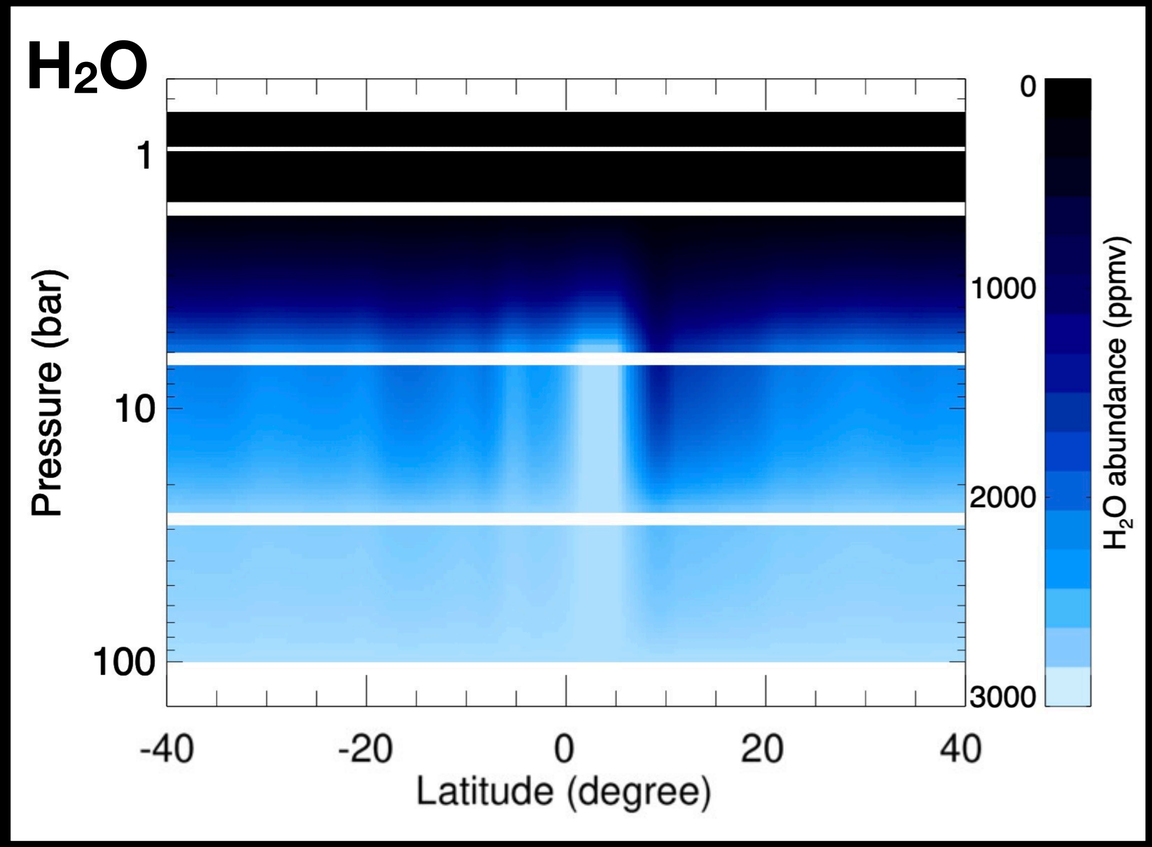


Guillot et al. (JGR, 2020a,b)


-150°C
20km 0.35 bar
ammonia condensation
shallow lightning
Mushball growth
0km 1.0 bar
-100°C
liquid ammonia-water
1.5 bar
melted ammonia-water
ice crust forms
ammonium hydrosulfide condensation
20km
ice crust grows
-40°C
3.0 bar
40km
water condensation
12 km
Earth thunderstorm
0°C
5.0 bar
ice crust melts
60km
rain
"mushballs"
evaporation
80km
10.0 bar
ammonia-water core evaporates
100°C
100km 14 bar
downdraft
updraft
Earth
Jupiter

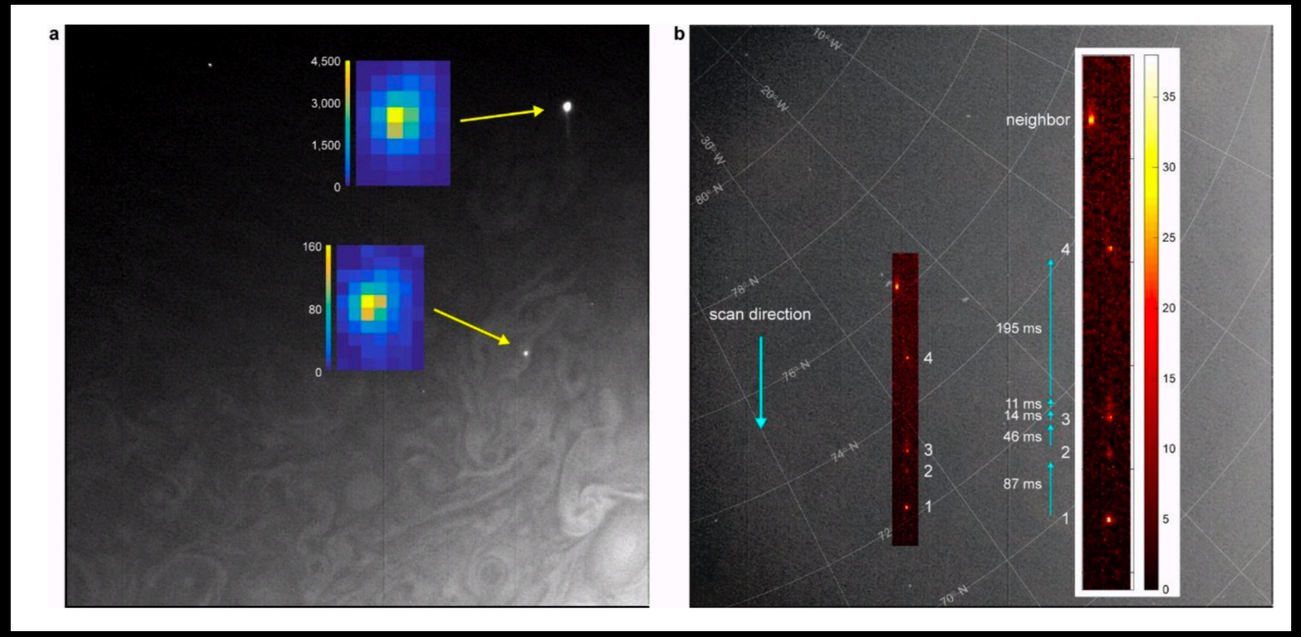
Consequences of storms & mushballs



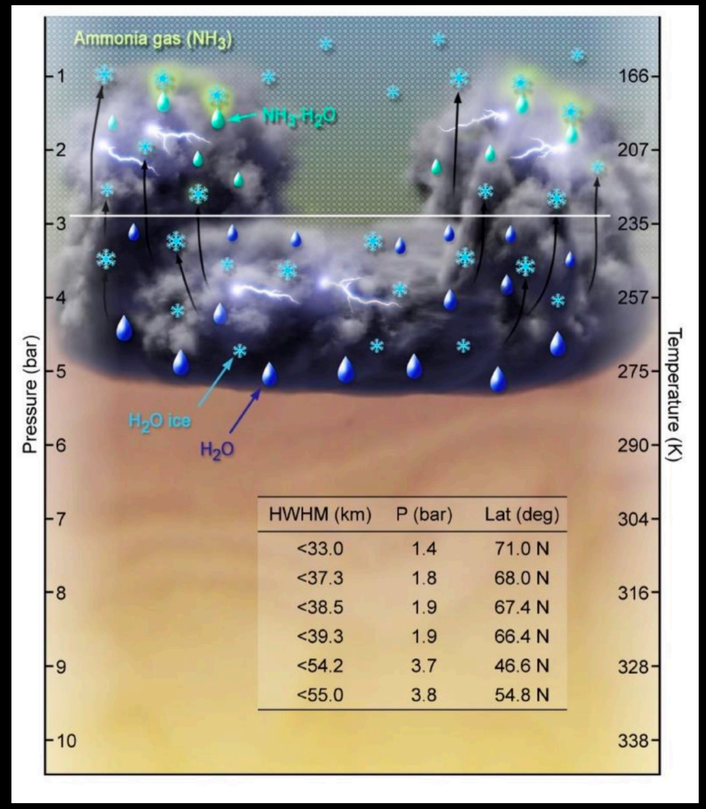


Guillot et al. (JGR, 2020a,b)

Shallow lightning



Becker et al. (Nature, 2020)



HWHM (km)	P (bar)	Lat (deg)
<33.0	1.4	71.0 N
<37.3	1.8	68.0 N
<38.5	1.9	67.4 N
<39.3	1.9	66.4 N
<54.2	3.7	46.6 N
<55.0	3.8	54.8 N

Perspectives

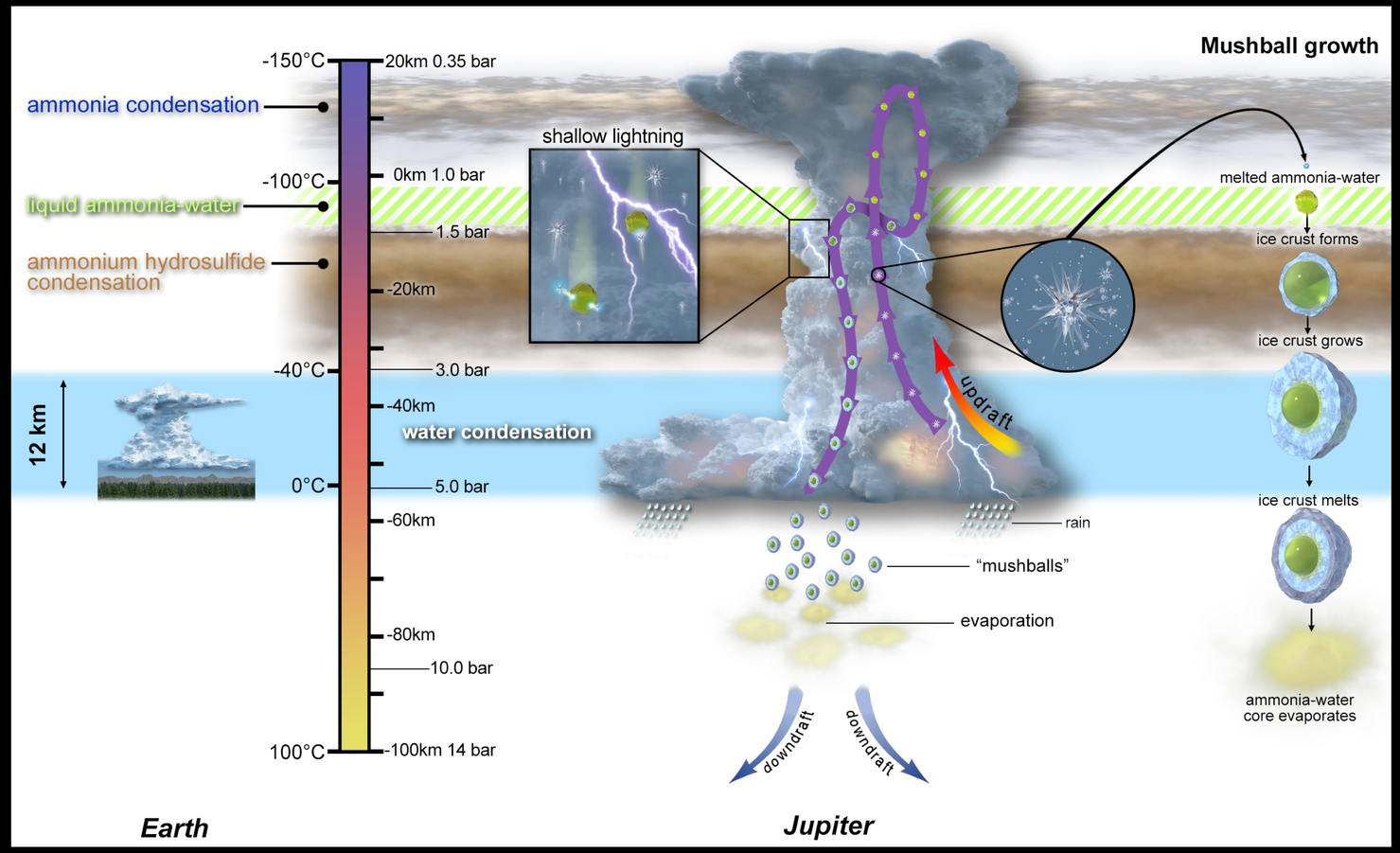
Consequences on interior models?

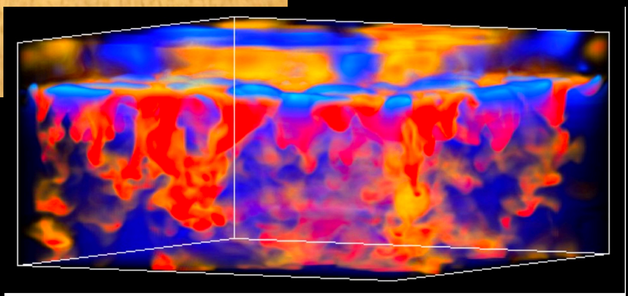
Saburo
HOWARD

Moist convection in giant planets?

Steve
MARKHAM

How Deep?





Solar downdrafts (Nordlund et al. 2009)

Merci!