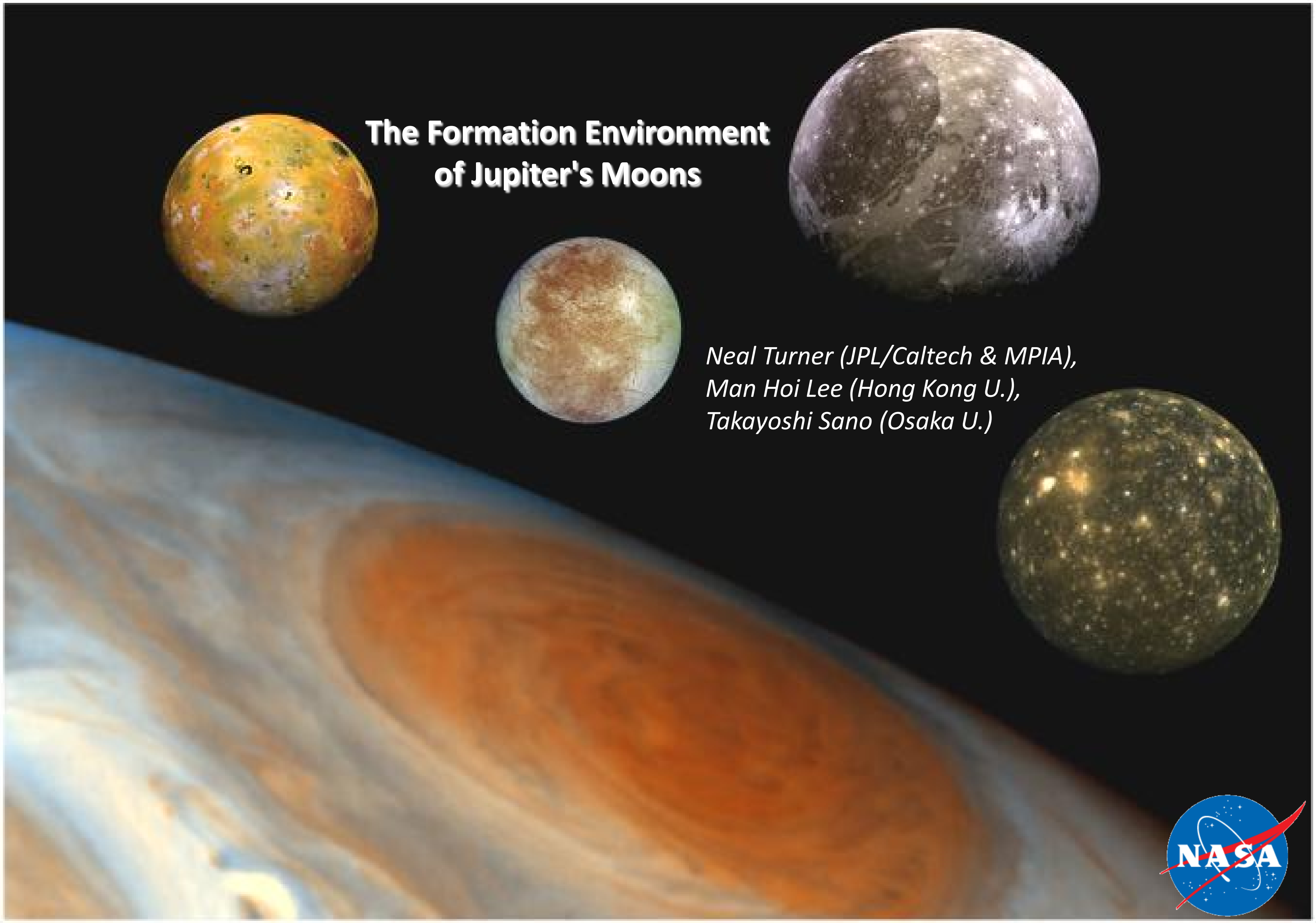
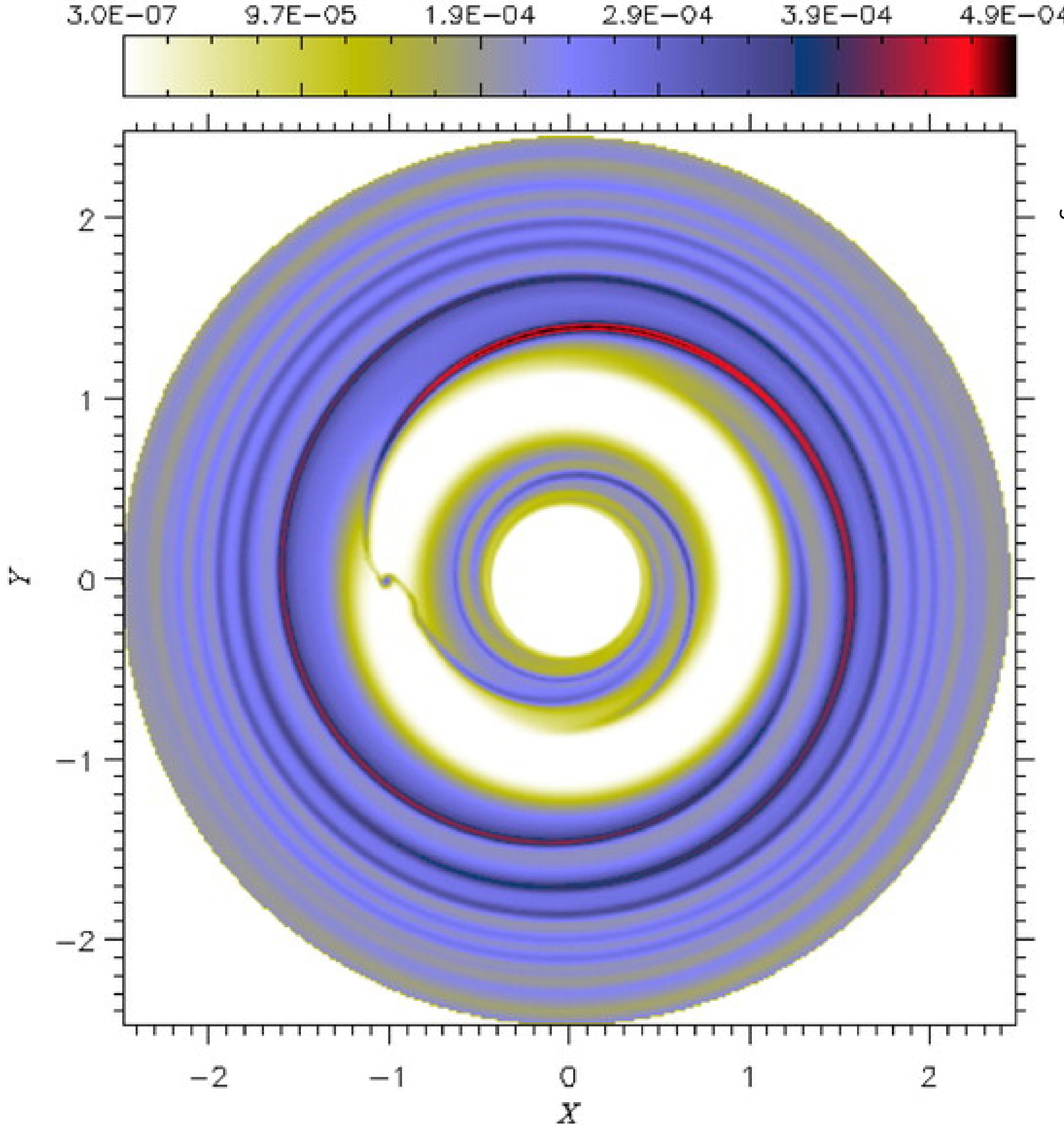


The Formation Environment of Jupiter's Moons

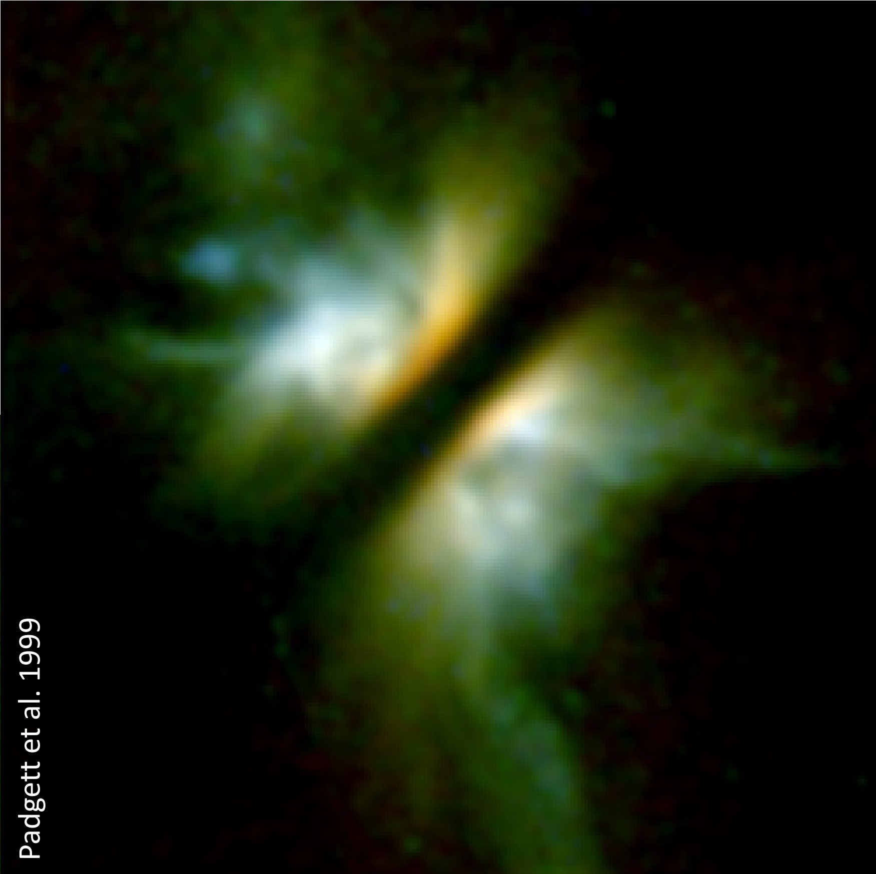
Neal Turner (JPL/Caltech & MPIA),
Man Hoi Lee (Hong Kong U.),
Takayoshi Sano (Osaka U.)

Flow From the Solar Nebula Into Jupiter’s Hill Sphere

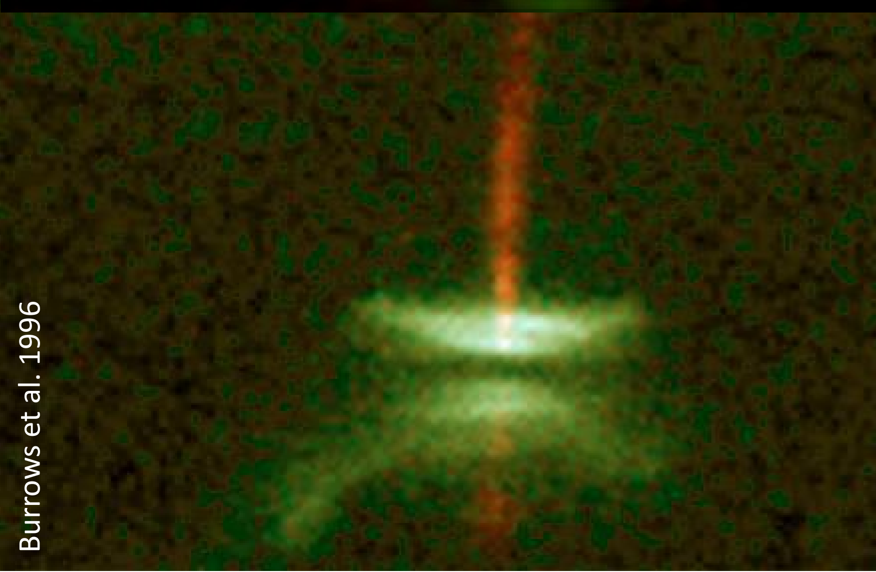


D’Angelo et al. 2003

Flock et al. 2012


Padgett et al. 1999

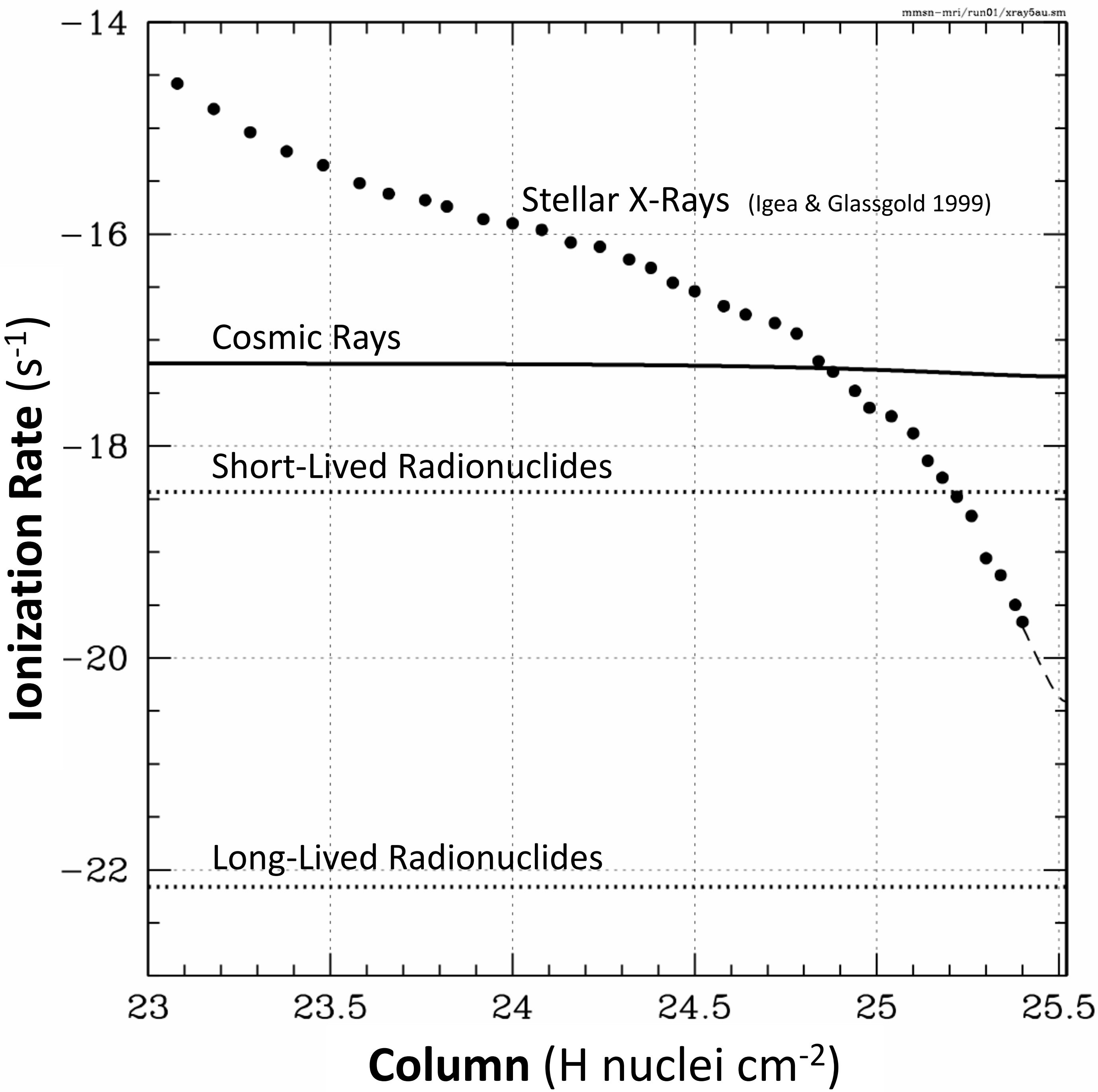

Cotera et al. 2001

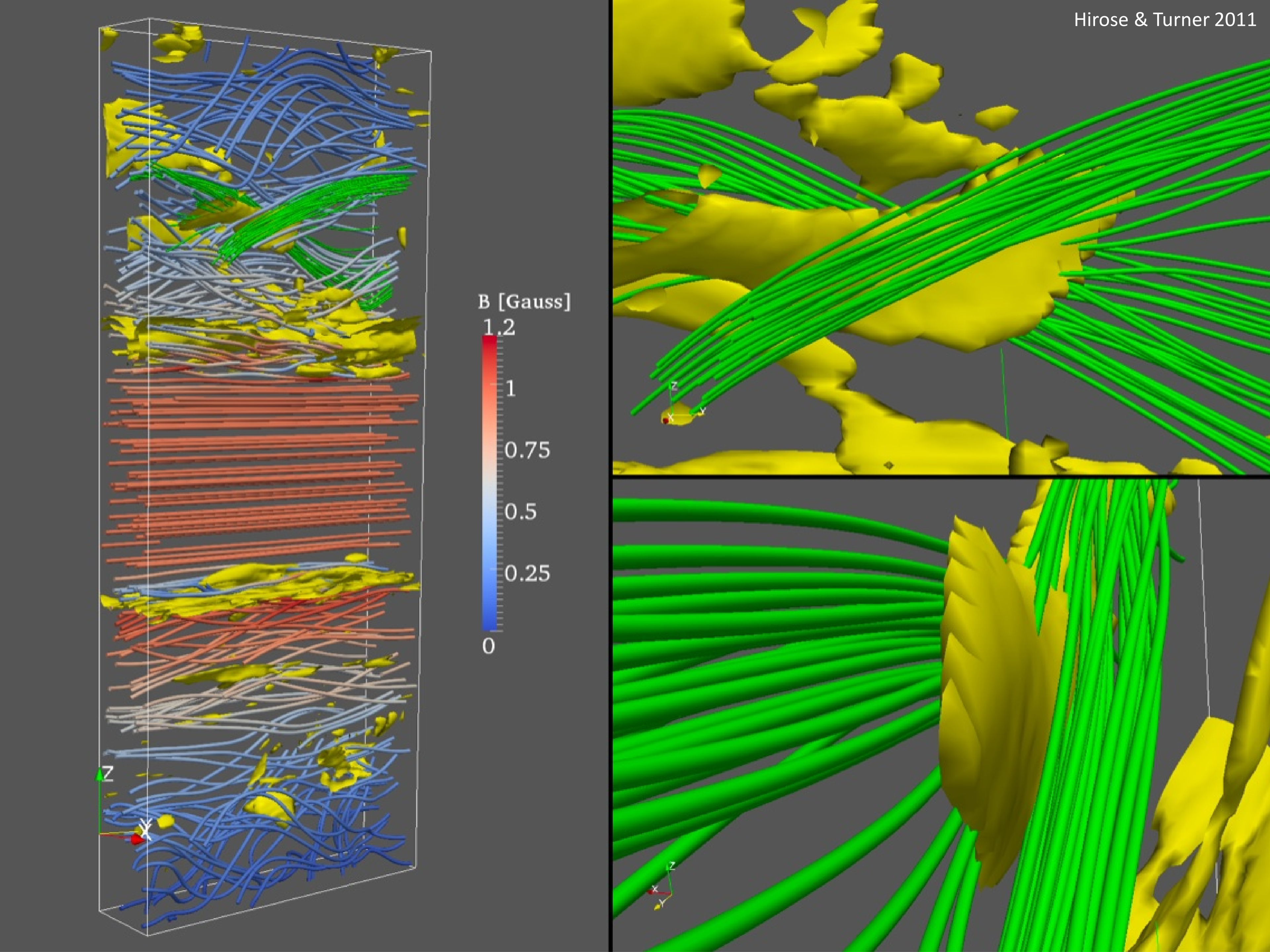

Burrows et al. 1996

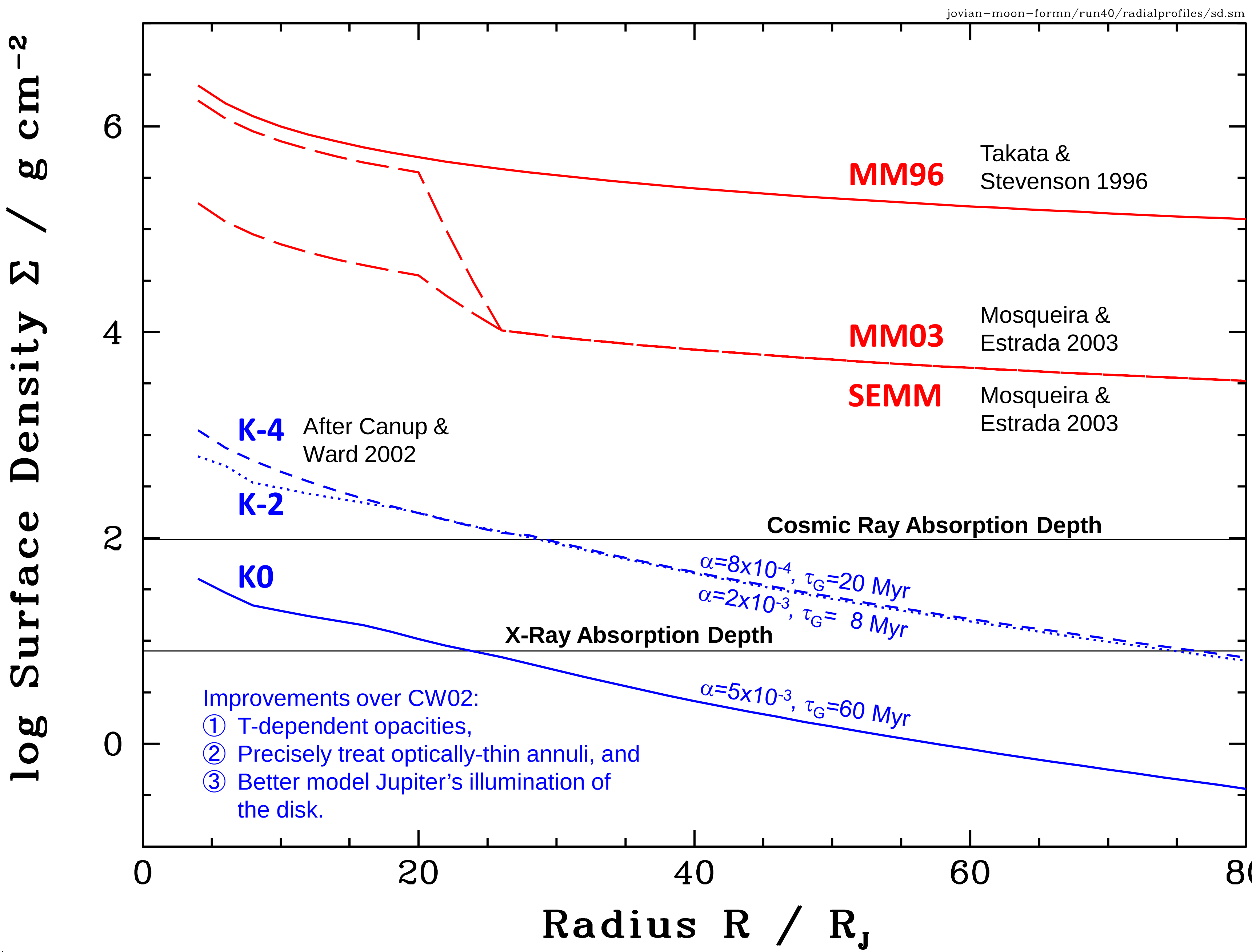

Hubble Heritage

Ionization Processes

at 5 AU in the minimum-mass Solar nebula




Hirose & Turner 2011
B [Gauss]
1.2
1
0.75
0.5
0.25
0
Z
X
Y



jovian−moon−formn/run40/radialprofiles/sd.sm
log Surface Density Σ / g cm⁻²
Radius R / R_J
MM96
Takata & Stevenson 1996
MM03
Mosqueira & Estrada 2003
SEMM
Mosqueira & Estrada 2003
K-4
After Canup & Ward 2002
K-2
K0
Cosmic Ray Absorption Depth
X-Ray Absorption Depth
α=8x10-4, τG=20 Myr
α=2x10-3, τG= 8 Myr
α=5x10-3, τG=60 Myr
Improvements over CW02:
① T-dependent opacities,
② Precisely treat optically-thin annuli, and
③ Better model Jupiter's illumination of the disk.

Ionization—Recombination Reaction Network

Involves 12 species: H_2, HCO^+, Mg, Mg^+, e^-, 0.1-μm grains charged up to +/-2, and grain-adsorbed H_2 and Mg

Also separately solve Saha eqn. for collisional ionization of potassium.

X-Ray Ionization	$H_2 \rightarrow HCO^+ + e^-$
Dissociative Recomb.	$HCO^+ + e^- \rightarrow H_2$
Charge Exchange	$HCO^+ + Mg \rightarrow H_2 + Mg^+$
Radiative Recomb.	$Mg^+ + e^- \rightarrow Mg + h\nu$
Grain Surface Recomb.	$Mg^+ + e^- + G \rightarrow Mg + G$

This simple model gives results similar to detailed networks of 2000+ reactions (Ilgner & Nelson 2006, Bai & Goodman 2009)

MRI turbulence requires

$$\frac{v_{Az}^2}{\eta\Omega} > 1$$

The instability grows if the magnetic fields cannot diffuse across its wavelength (v_{Az}/Ω) within its growth time ($\sim\Omega^{-1}$).

To find v_{Az} we assume B_z is indept. of height, with pressure 10^{-3}x midplane gas pressure, based on Solar nebula MHD calculations.

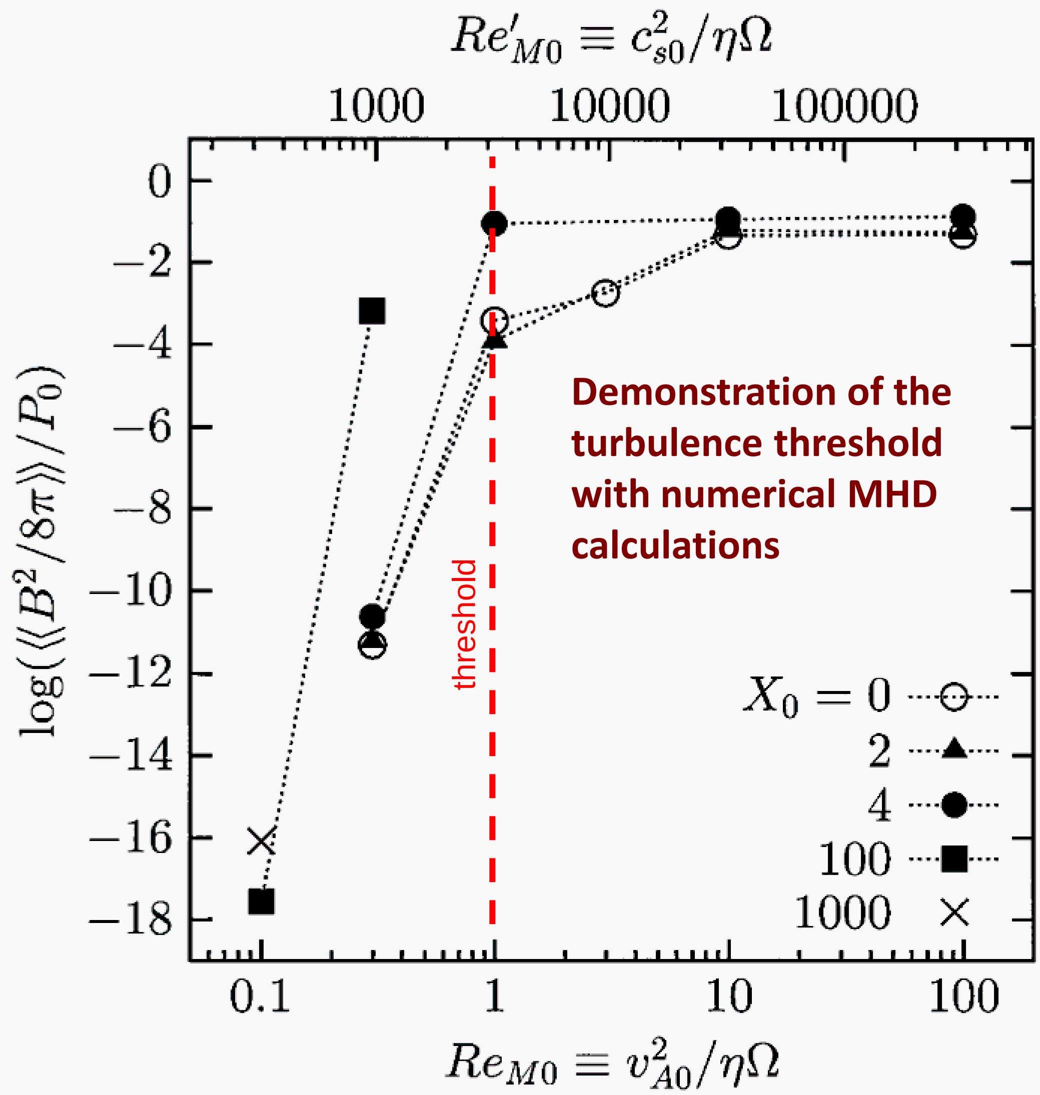
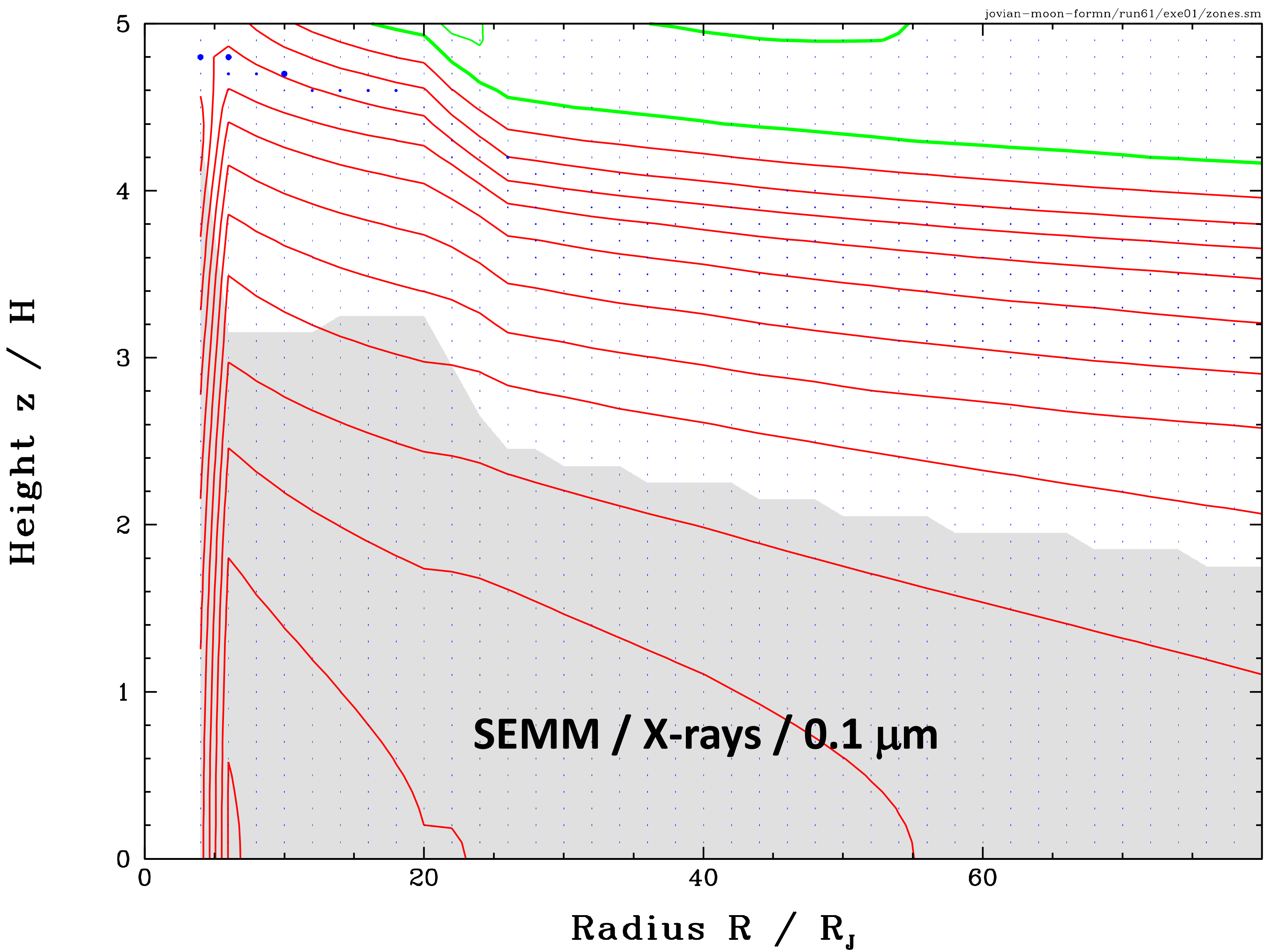
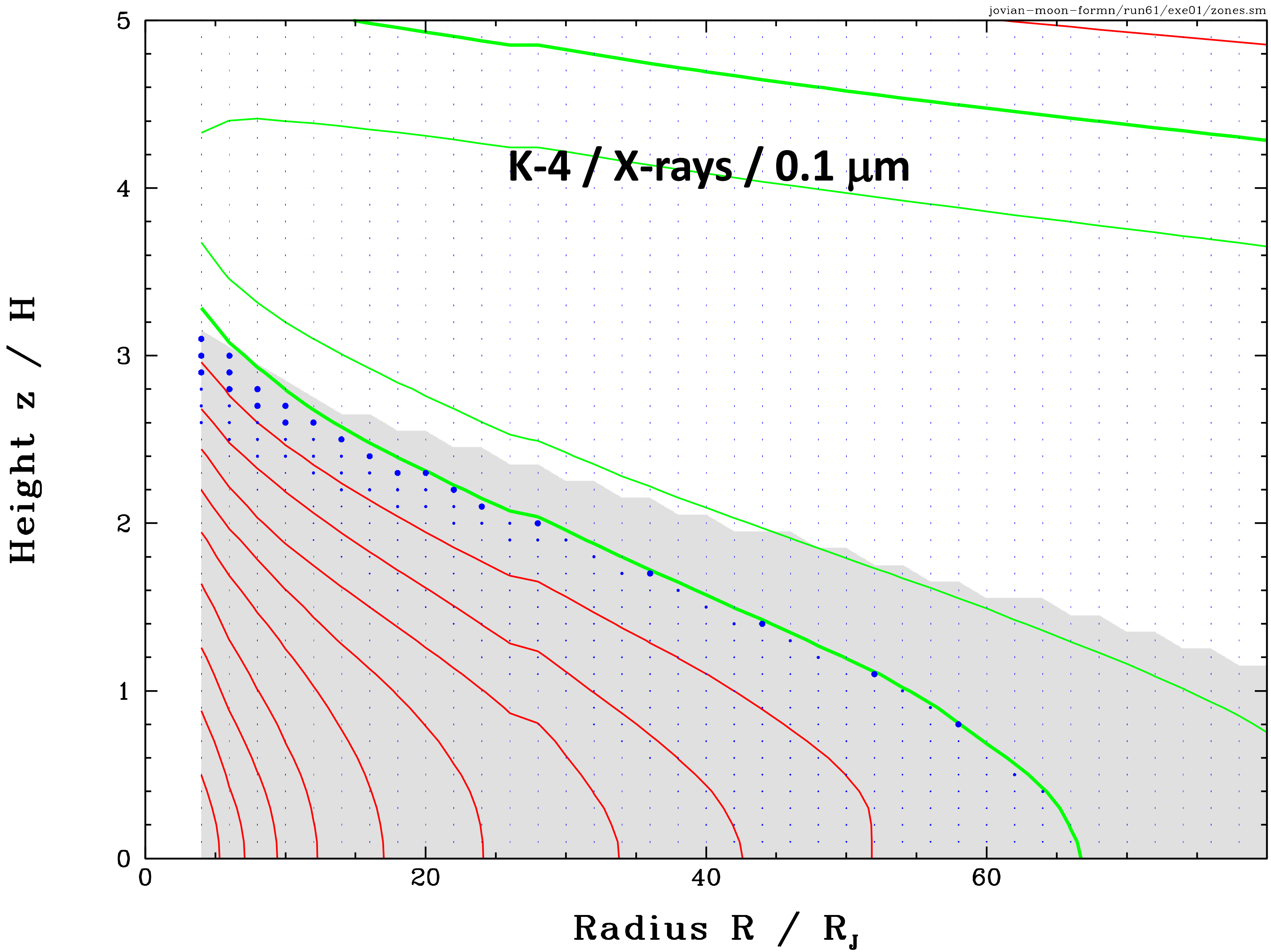


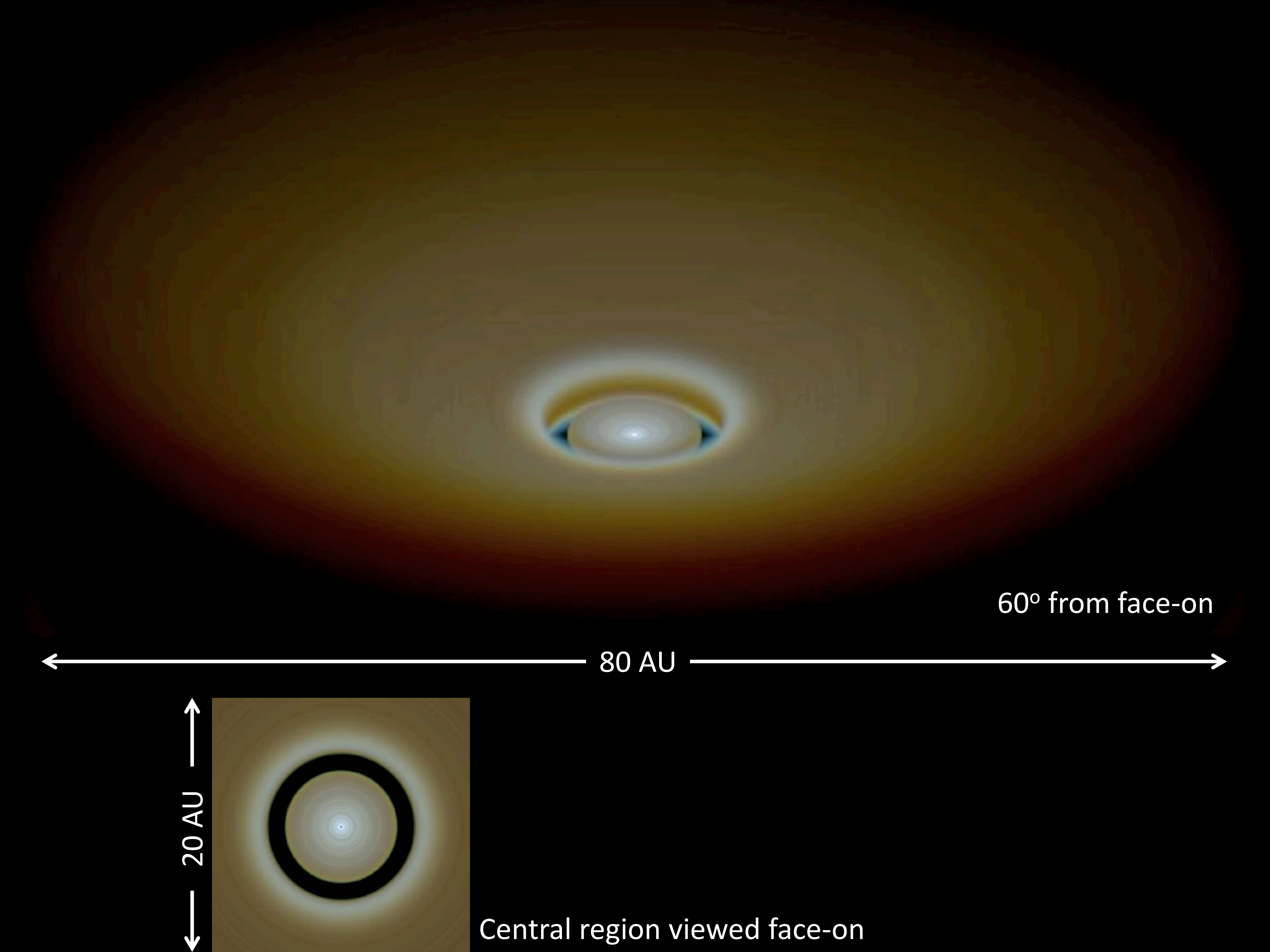
FIG. 14.—Saturation level of the magnetic energy as a function of the magnetic Reynolds number Re_{M0} for zero net flux B_z models ($\beta_0 = 3200$). Open circles denote the models with only the ohmic dissipation ($X_0 = 0$), and the other symbols are including also the Hall effect ($X_0 = 2, 4, 100$, and 1000).

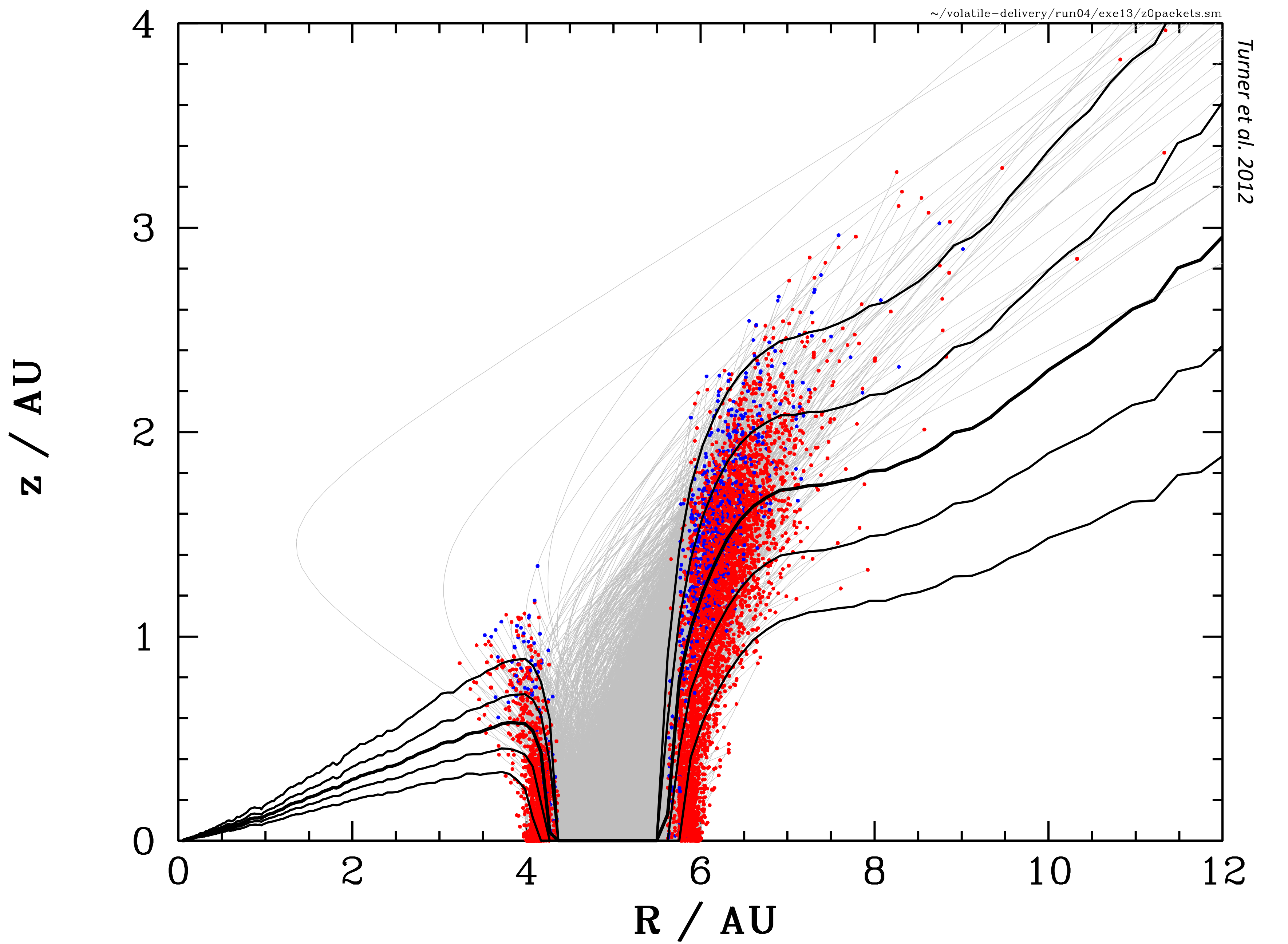
Sano & Stone 2002b


jovian−moon−formn/run61/exe01/zones.sm
SEMM / X-rays / 0.1 μm
Height z / H
Radius R / R_J
0
1
2
3
4
5
0
20
40
60

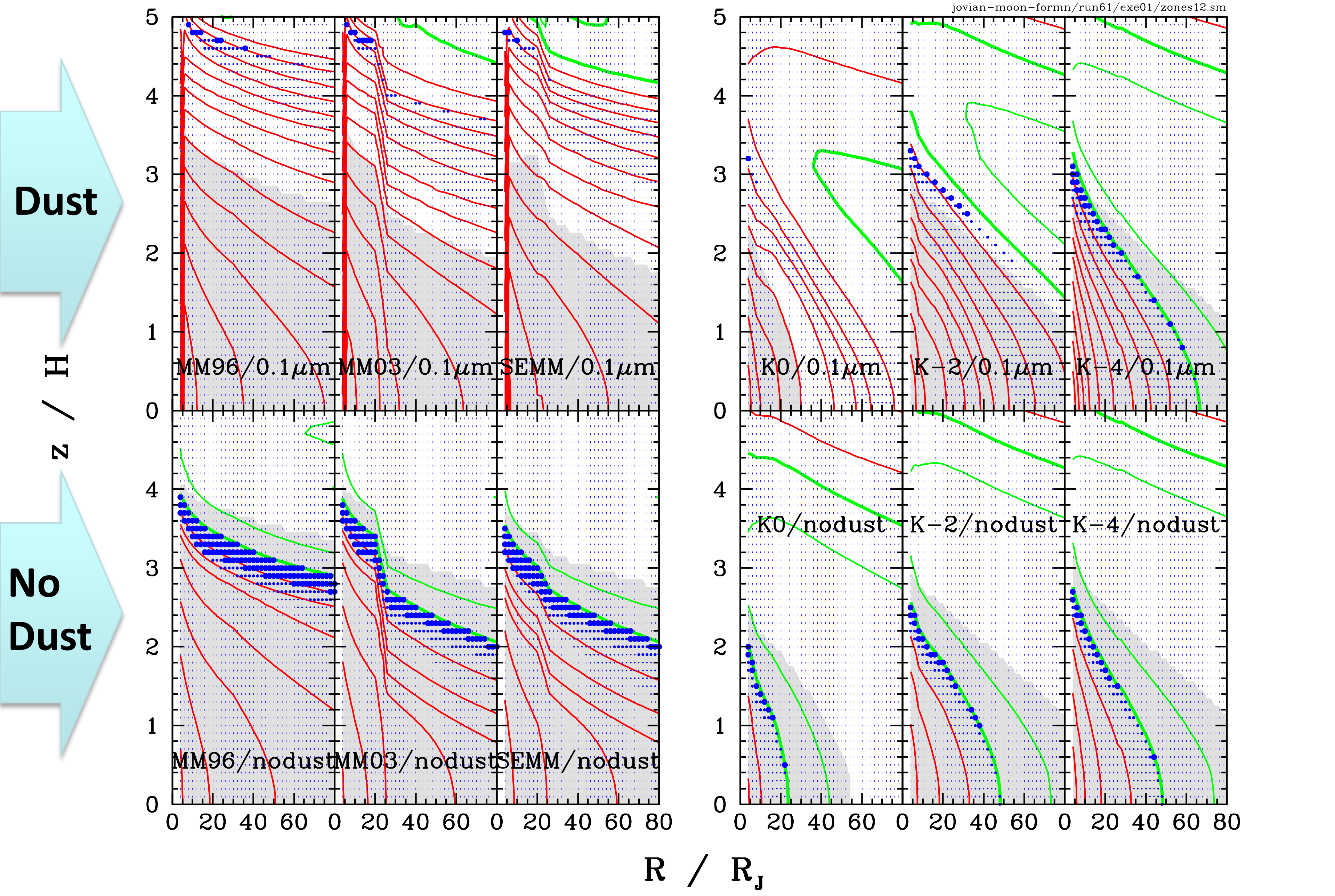


jovian−moon−formn/run61/exe01/zones.sm
K-4 / X-rays / 0.1 μm
Height z / H
Radius R / R_J
0
1
2
3
4
5
0
20
40
60

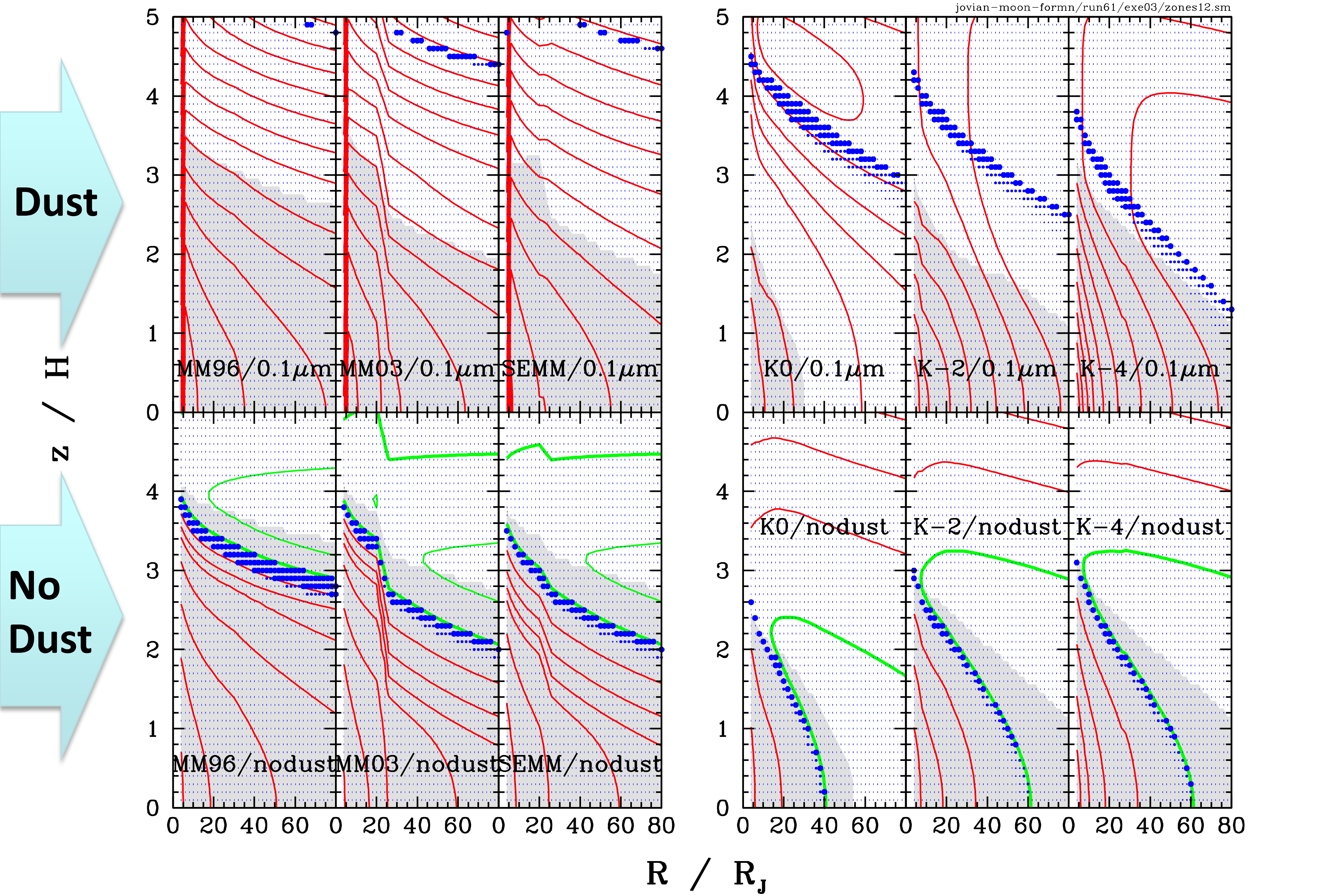

60° from face-on
80 AU
20 AU
Central region viewed face-on


~/volatile-delivery/run04/exe13/z0packets.sm
Turner et al. 2012
z / AU
R / AU
0
1
2
3
4
0
2
4
6
8
10
12

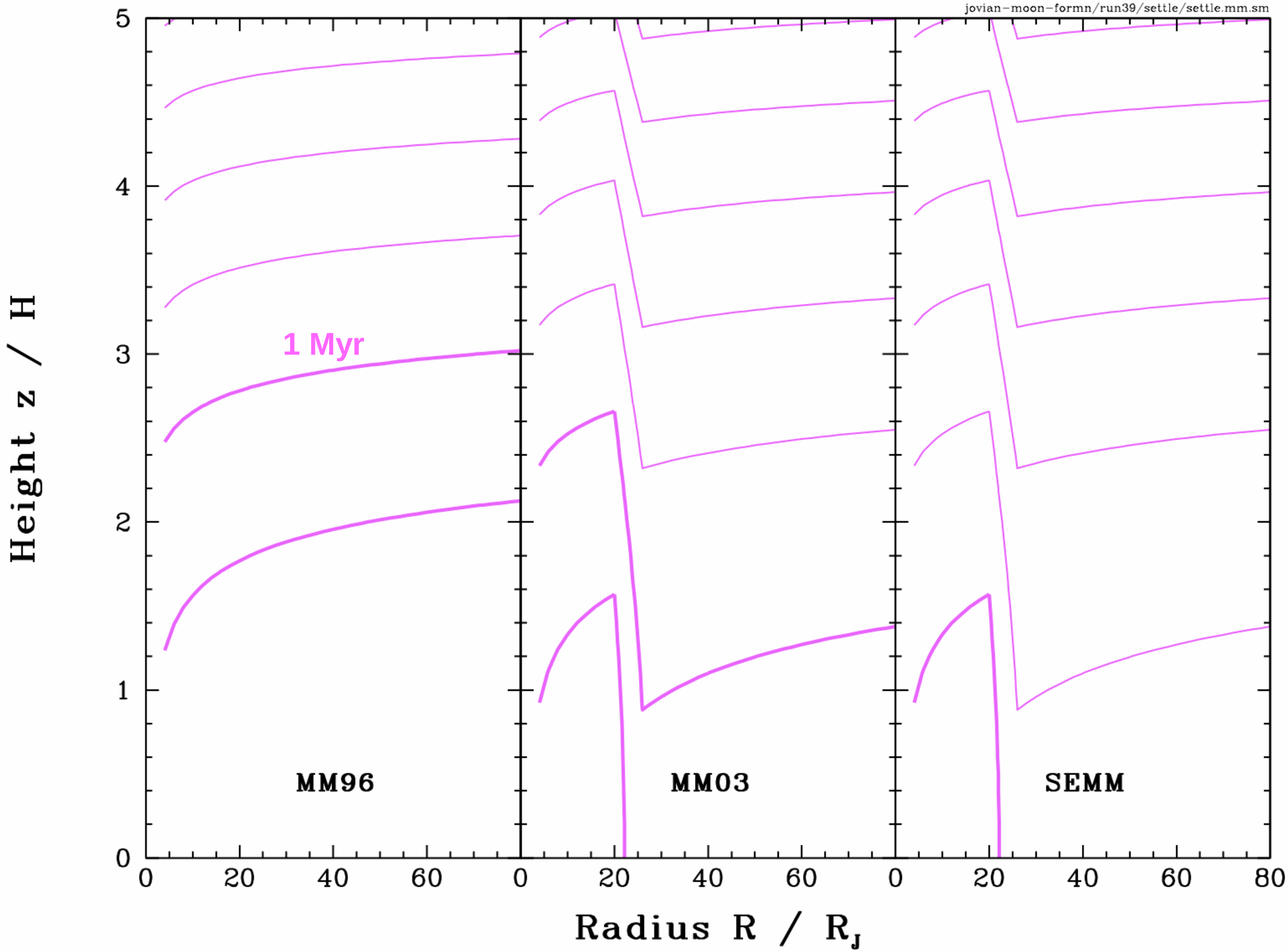
With Stellar X-rays



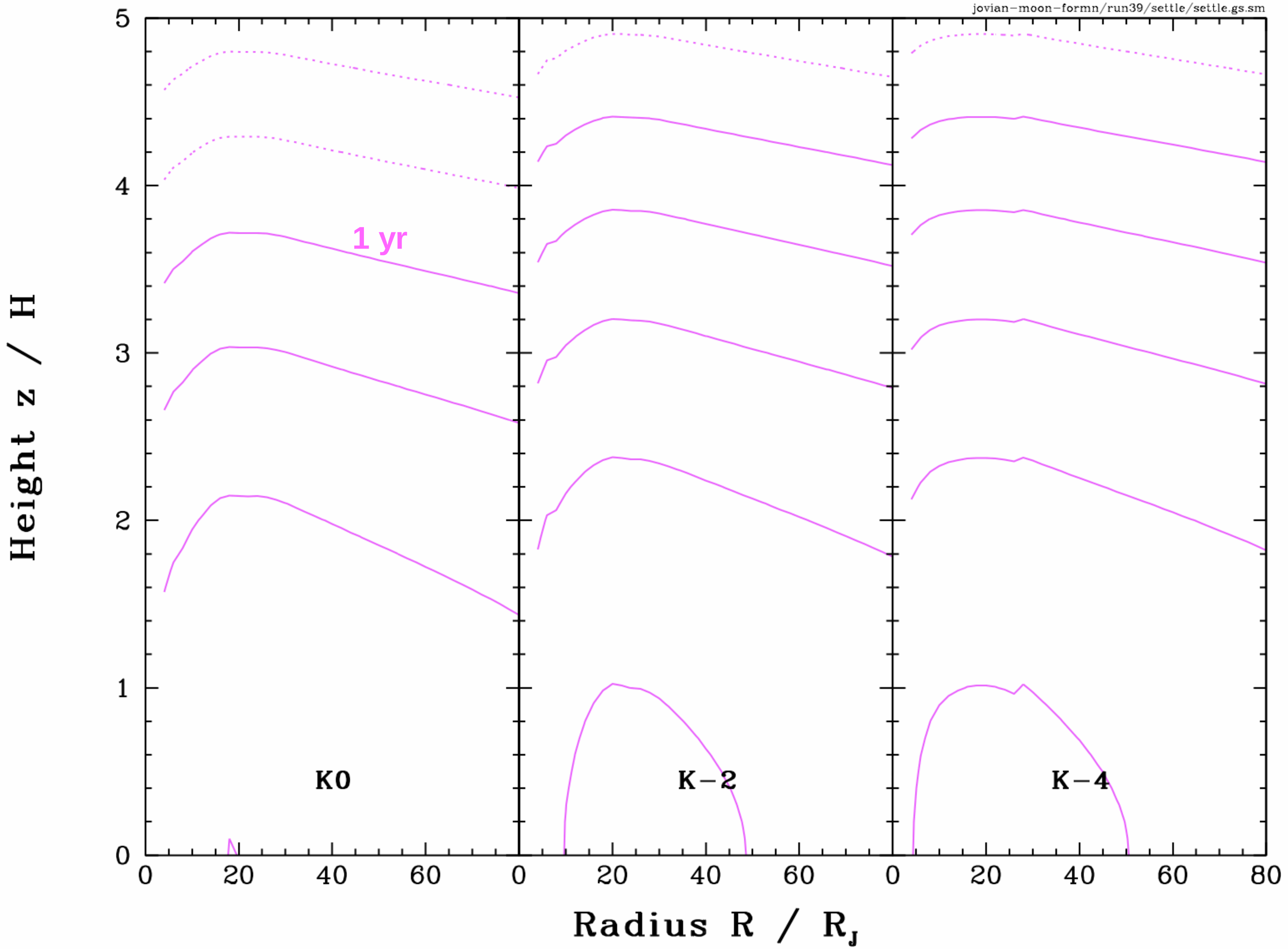
Without Stellar X-rays



Grain Settling Times



Grain Settling Times



Summary

Do circumjovian disk models have conductivities consistent with the assumed accretion stresses?

Broadly, YES, for both minimum-mass and gas-starved models: magnetic stresses are weak in the MM models, as needed to keep the material in place. Stresses are stronger in the gas-starved models, as assumed in deriving the flow to the planet.

However,

- Future minimum-mass modeling may need to consider the loss of dust-depleted gas from the surface layers to the planet.
- The gas-starved models should have stress varying in radius.
- Dust evolution is a key process for further study, since the recombination occurs on the grains.