PHYS-GA-2000: Computational Physics Modeling the Dynamics of Pluto's Upper Atmosphere to Calculate Escape

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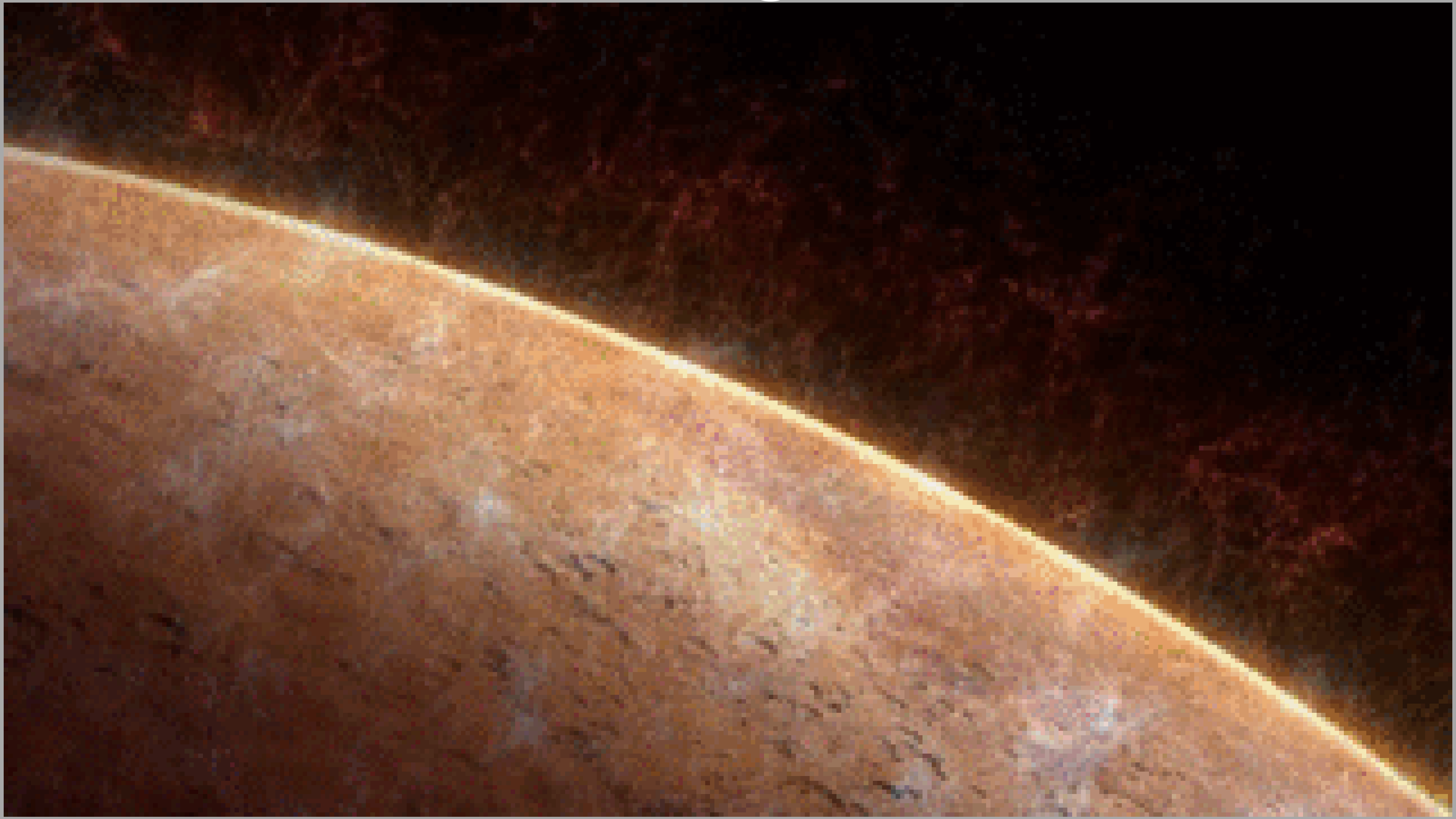
Motivation → Background → Results



http://las.colorado.edu/home/maven/2016/10/19/maven-observes-ups-and-downs-of-water-escape-from-mars/

Motivation → Background → Results

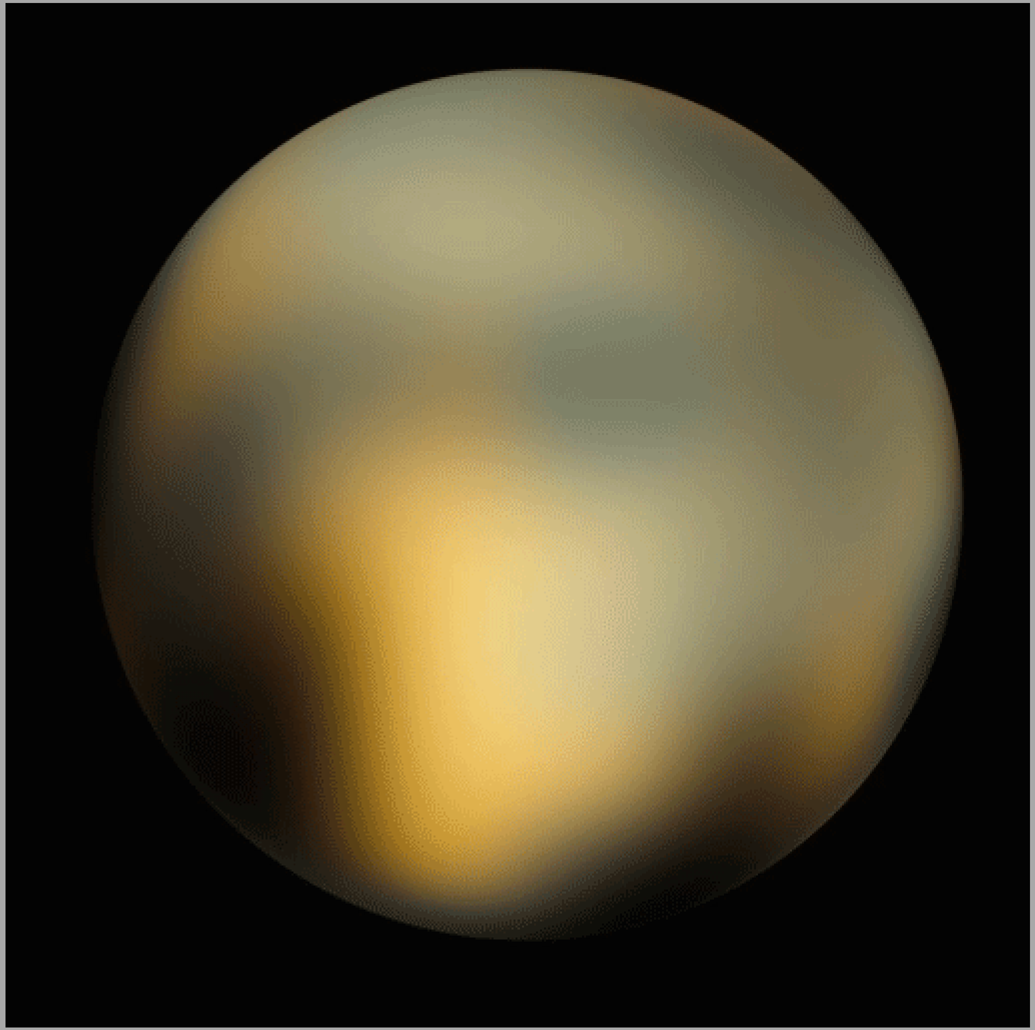
https://phys.org/news/2015-04-hubble-space-telescope-ground.html

https://www.spaceanswers.com/news/hottest-and-most-massive-double-star-found-by-ground-based-telescopes1/

https://nasa.tumblr.com/post/166016245839/chasing-the-shadow-of-neptunes-moon-triton

Motivation → Background → Results

http://for-all-mankind.tumblr.com/post/159273055401/cassini-prepares-for-final-orbital-grand-finale



http://www.slate.com/blogs/bad_astronomy/2015/07/15/pluto_from_hubble_to_new_horizons.html

Motivation → Background → Results

https://www.nasa.gov/mission_pages/newhorizons/images/index.html

Motivation → Background → Results

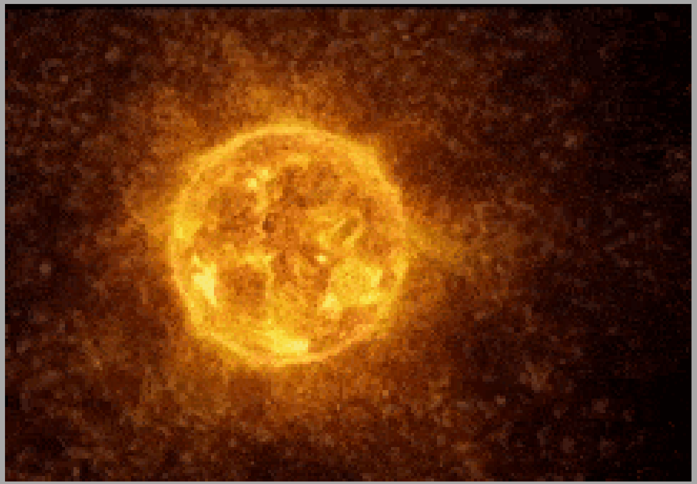
Factors that can drive escape:

- Solar/Magnetospheric Heating
- Impacts
- Gravity
- Surrounding Planets/Moons

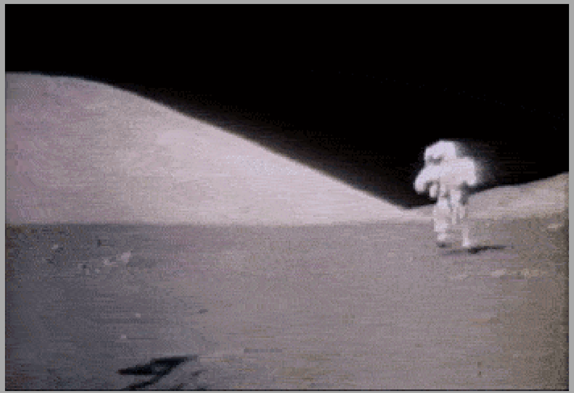
Motivation → Background → Results

Factors that can drive escape:

- **Solar**/Magnetospheric **Heating**
- Impacts
- **Gravity**
- Surrounding Planets/Moons*



https://thumbs.gfycat.com/FaithfulWealthyBantamrooster-max-1mb.gif



https://giphy.com/gifs/moon-nasa-3cJucqJLw37vq

Motivation → Background → Results

Factors that can drive escape:

- Solar/Magnetospheric Heating
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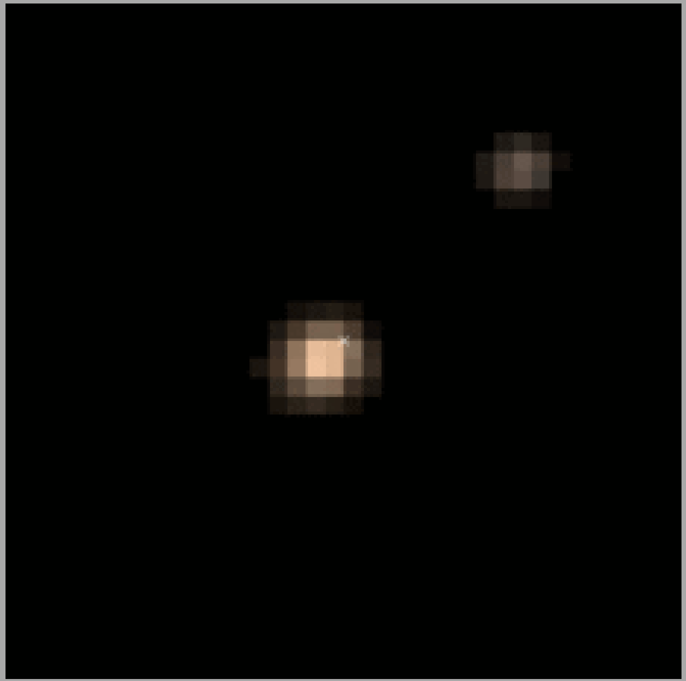
- **Surrounding Planets/Moons***



https://en.wikipedia.org/wiki/Barycenter

* Hoey, W.A., Yeoh, S.K., Trafton, L.M., Goldstein, D.B. and Varghese, P.L., 2017. Rarefied gas dynamic simulation of transfer and escape in the Pluto–Charon system. *Icarus*, *287*, pp.87-102.

Motivation → Background → Results

Solar Heating:

- Radiation (UV, EUV), Cycle
- Composition (N2, CH4)
- Atmospheric Thickness
- Distance (~30-50 AU)

Gravity:

- Planet Mass (Pluto)
- Molecular Mass (N2, CH4)
- Radial Temperature

Motivation → Background → Results

Important Fluid Properties:

Altitude, r [km]

Number Density, $n(r, T)$ [#/m3]

Temperature, $T(r, n)$ [K]

Bulk Flow Velocity, $u(r, n)$ [m/s]

Conservation of Mass

Conservation of Momentum

Conservation of Energy

Equation of State

Motivation → Background → Results

Conservation of Mass

$$4\,\pi\, r^2 n(r) u(r) = \phi$$

Conservation of Momentum

$$nm\frac{d}{dr}\left(\frac{1}{2}u(r)^2\right) + \frac{dp(r)}{dr} = nm\frac{d}{dr}\left(\Phi_G(r)\right)$$

Conservation of Energy

$$\frac{d}{dr}\left(\phi\left(C_P T + \frac{1}{2}mu(r)^2 - \Phi_G(r)\right) - 4\,\pi r^2 \kappa\left(T(r)\right)\frac{dT(r)}{dr}\right) = 4\,\pi r^2 q(r)$$

Equation of State

$$p = n\, k_B T$$

Motivation → Background → Results

Number Density

$$n(r) = n_0\left(\frac{T_0}{T(r)}\right)\exp\left[-\int\left(\frac{\lambda(r)}{r} + \frac{m\frac{d}{dr}\left(u(r)^2\right)}{2k_B T(r)}\right)dr\right]$$

Temperature

$$\frac{dT(r)}{dr} = \left(\frac{1}{4\,\pi r^2 \kappa\left(T(r)\right)}\right)\left[-\left(\phi_E + Q(r)\right) + \phi\left(C_P T(r) + \frac{1}{2}mu(r)^2 - \Phi_G(r)\right)\right]$$

Motivation → Background → Results

Total Heating Rate

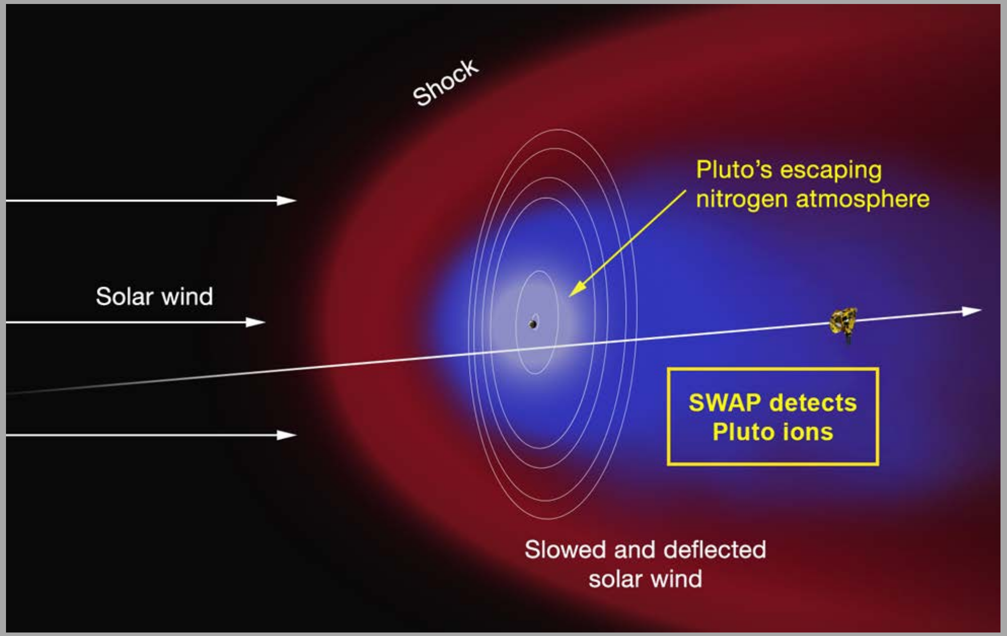
$$Q(r) = 4\pi \int_{r_0} r^2 q(r) dr$$

Local Heating Rate

$$q(r) = \frac{dF(r)}{dr} = \chi\, \varepsilon\, \sigma\, n(r)\, F(r)\, \exp\left(-\frac{\tau(r)}{\mu}\right)$$

Vertical Optical Depth

$$\tau(r) = \int_{r_{\max}} \chi\, \sigma\, n(r)\, dr$$



https://www.nasa.gov/nh/pluto-wags-its-tail

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Knudsen Number, Kn

$$\text{Kn} = \frac{l}{H}$$

l = **Mean Free Path,**
H = **Density Scale Height**

Exobase, r(Kn~1)

Above Kn~1, Fluid Equations FAIL;

Can still receive valuable information at Exobase

Motivation → Background → Results

Jeans Parameter

$$\lambda(r) = \frac{GMm}{r k_B T(r)}$$

$\lambda_x \leq 2$**: Hydrodynamic Escape,**
$\lambda_x > 10$**: Jeans Escape**

Jeans Escape Rates

Molecular Escape Rate*

$$\phi \rightarrow \phi_J = \pi r_x^2 n_x v_{th,x} (1 + \lambda_x) \exp(-\lambda_x)$$

Energy Outflow*

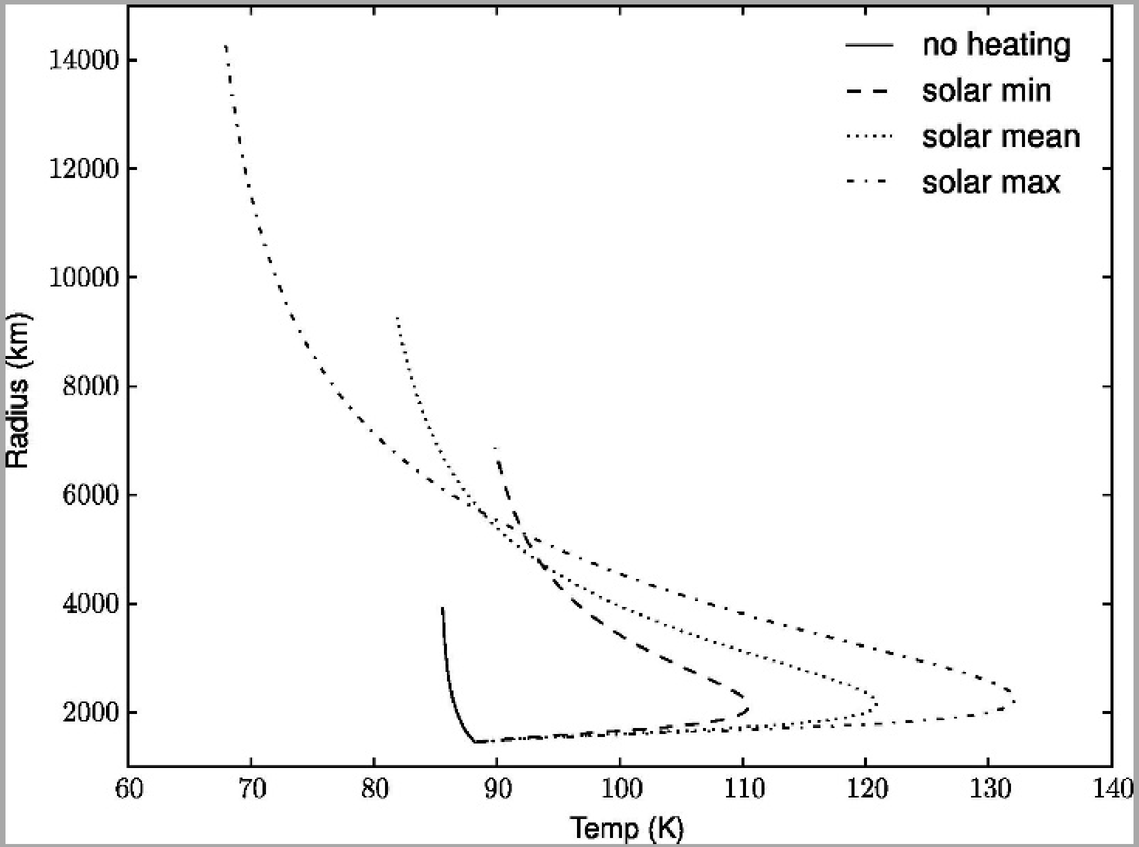
$$\phi_E \rightarrow \phi_{E,J} = (k_B T_x)\left(2 + \frac{1}{1 + \lambda_x}\right)\phi_J$$

Jeans, J.H., 1925.
The Dynamical
Theory of Gases, 444.

***** $()_x$ **= Exobase**

Motivation → Background → Results

Erwin et al., 2013



Erwin, J., Tucker, O.J. and Johnson, R.E., 2013. Hybrid fluid/kinetic modeling of Pluto's escaping atmosphere. *Icarus*, *226*(1), pp.375-384.

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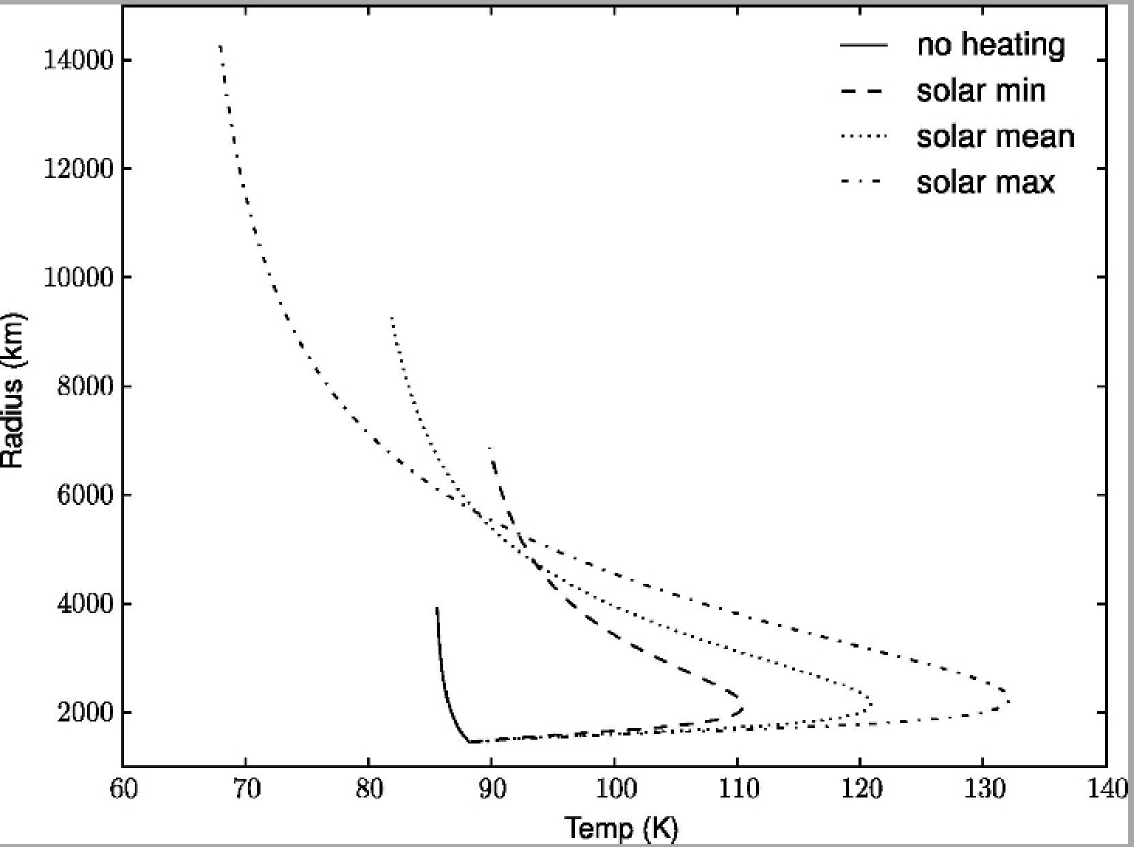
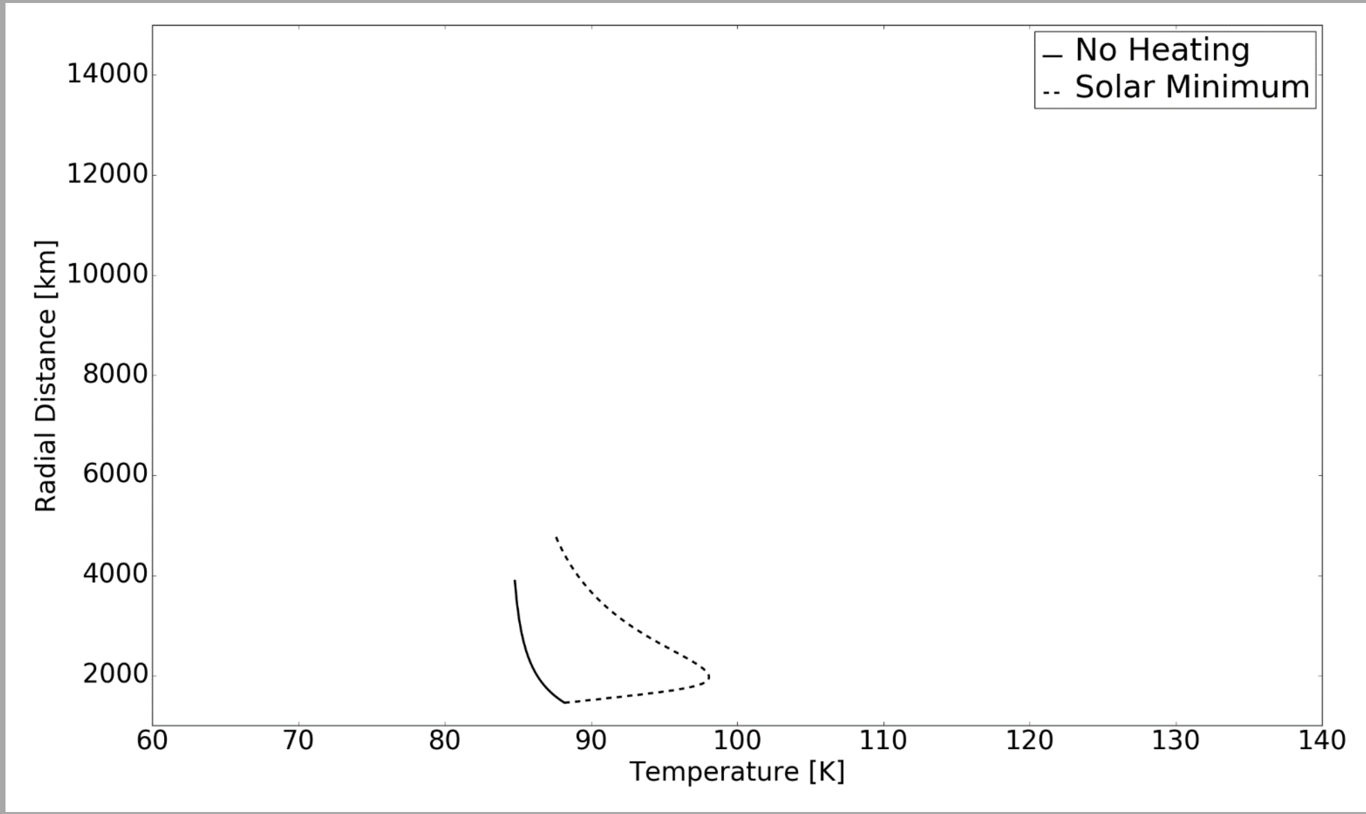


My Results



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