Seeking Young Planets' Signatures in Protostellar Disks with JWST

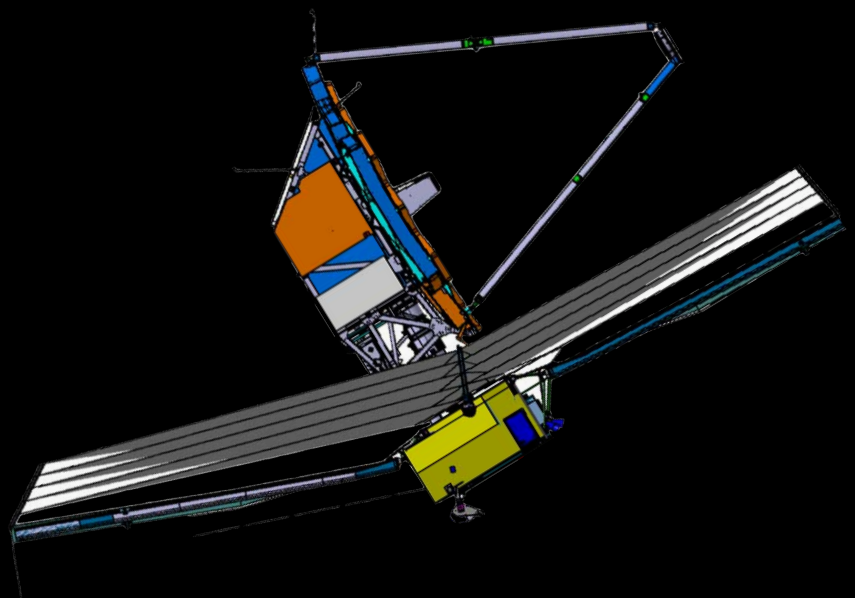
Neal Turner (JPL/Caltech), Andrea Isella (Rice Univ.), John Sepikas (PCC)

Copyright 2016 California Institute of Technology. Government sponsorship acknowledged

Artwork by W. K. Hartmann

Objectives

- Predict the infrared signatures of young planets embedded in protostellar disks, to build the case for observations with JWST.
- Advance understanding of the disks' thermal response to planets' perturbations.



Outline

1. A planet opening a gap lets scattered starlight and re-emitted infrared radiation reach the midplane.

1. Patches of disk respond to lighting changes on whichever timescale is slower: dynamics or heating/cooling.

1. We can use this response to choose between different radiative balance, hydrostatic solutions.

1. The resulting equilibrium models when synthetically observed look rather different from the usual radial power-law temperature models.

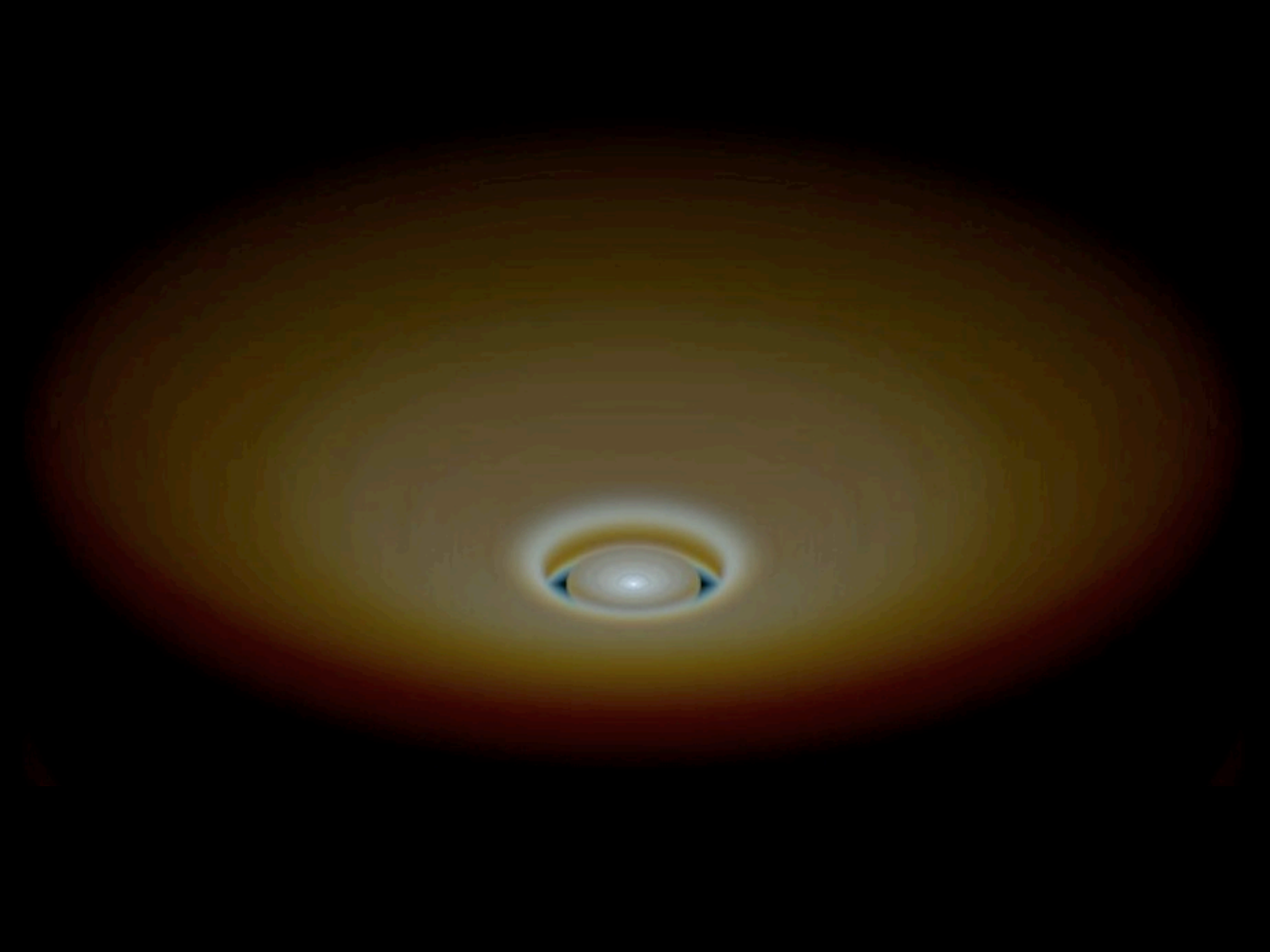
Outline

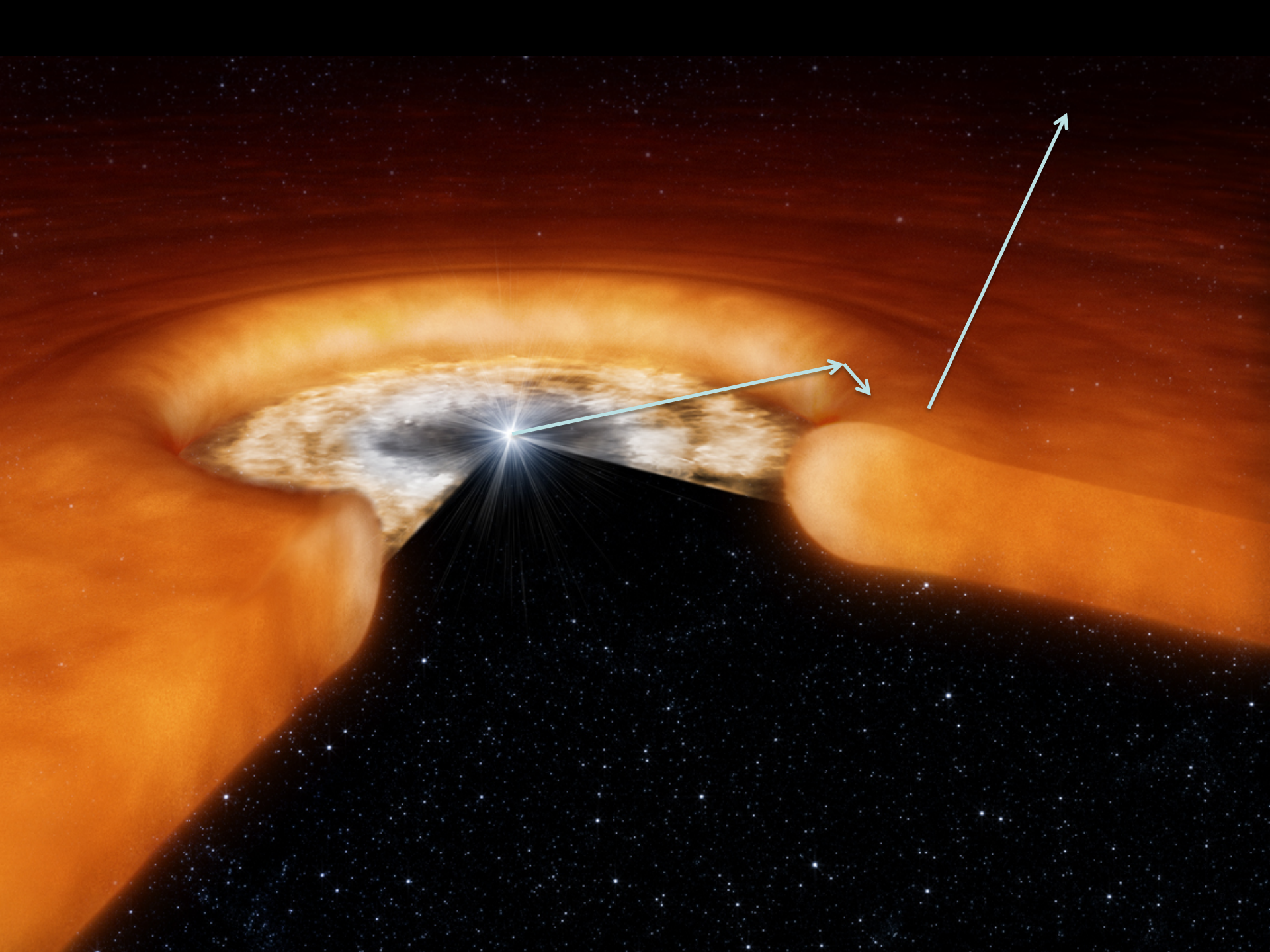
1. A planet opening a gap lets scattered starlight and re-emitted infrared radiation reach the midplane.

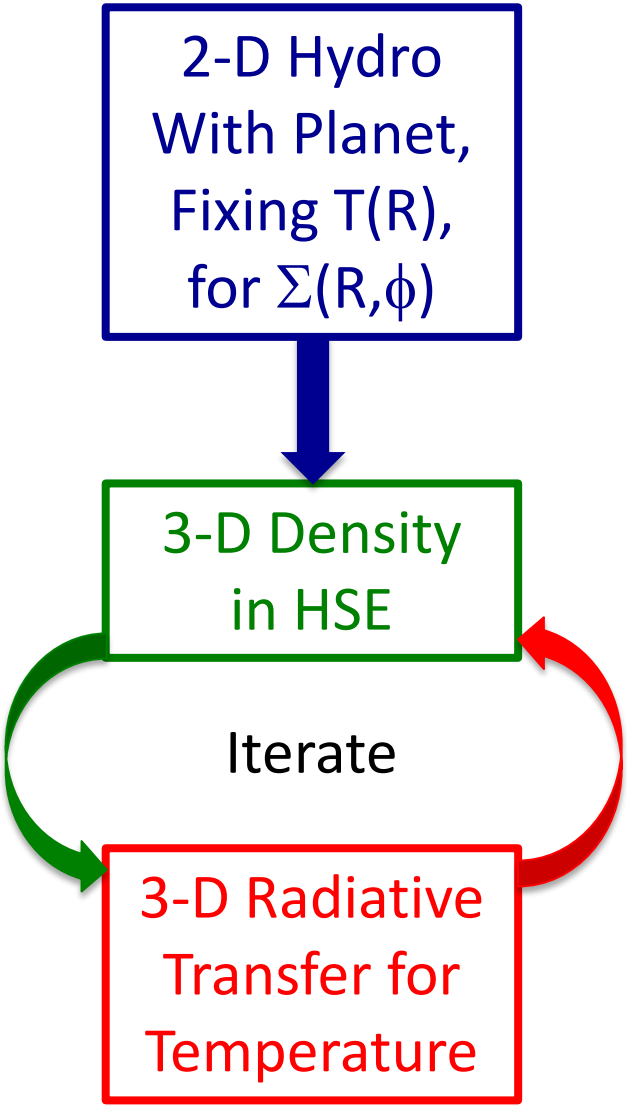
1. Patches of disk respond to lighting changes on whichever timescale is slower: dynamics or heating/cooling.

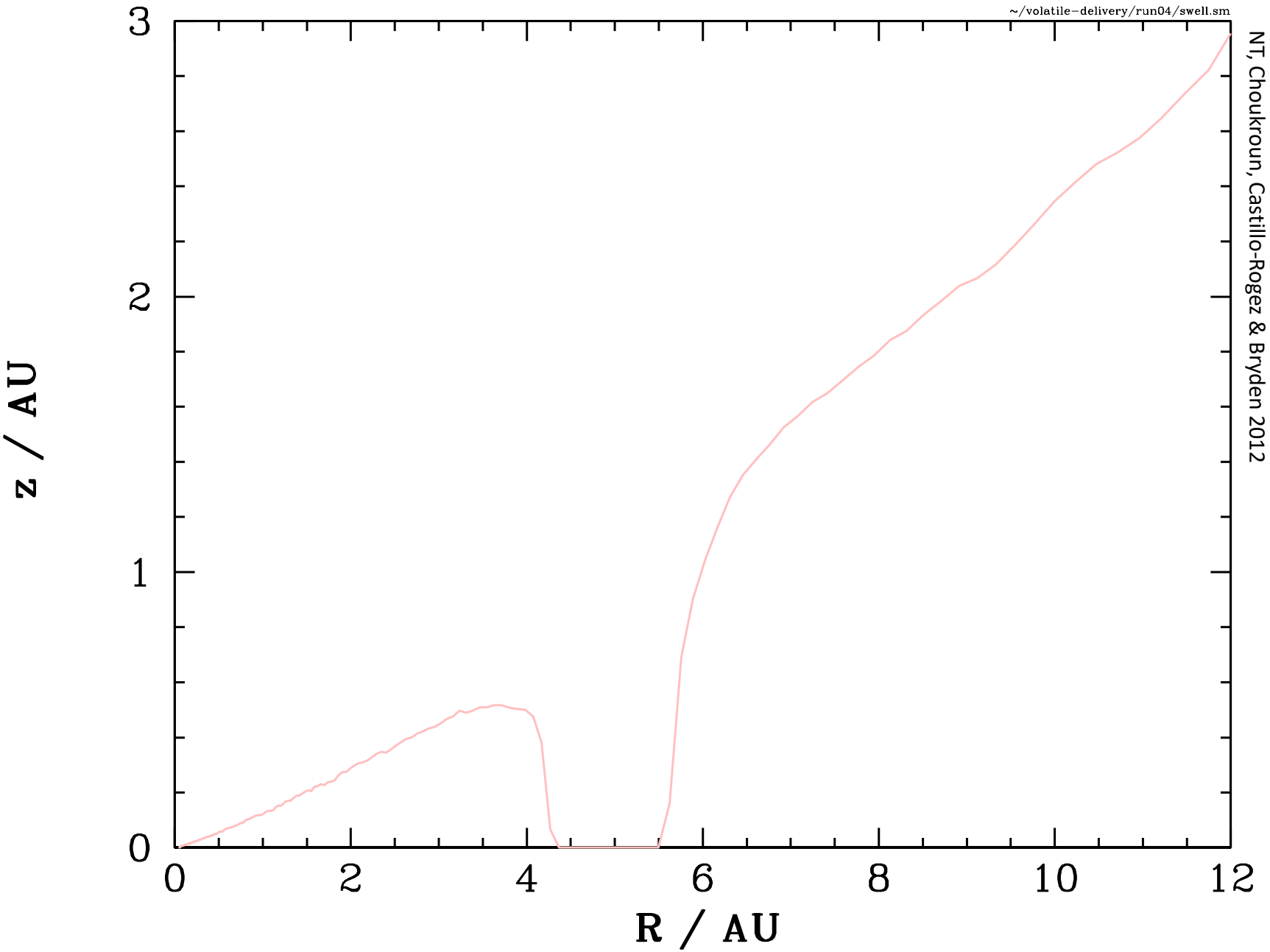
1. We can use this response to choose between different radiative balance, hydrostatic solutions.

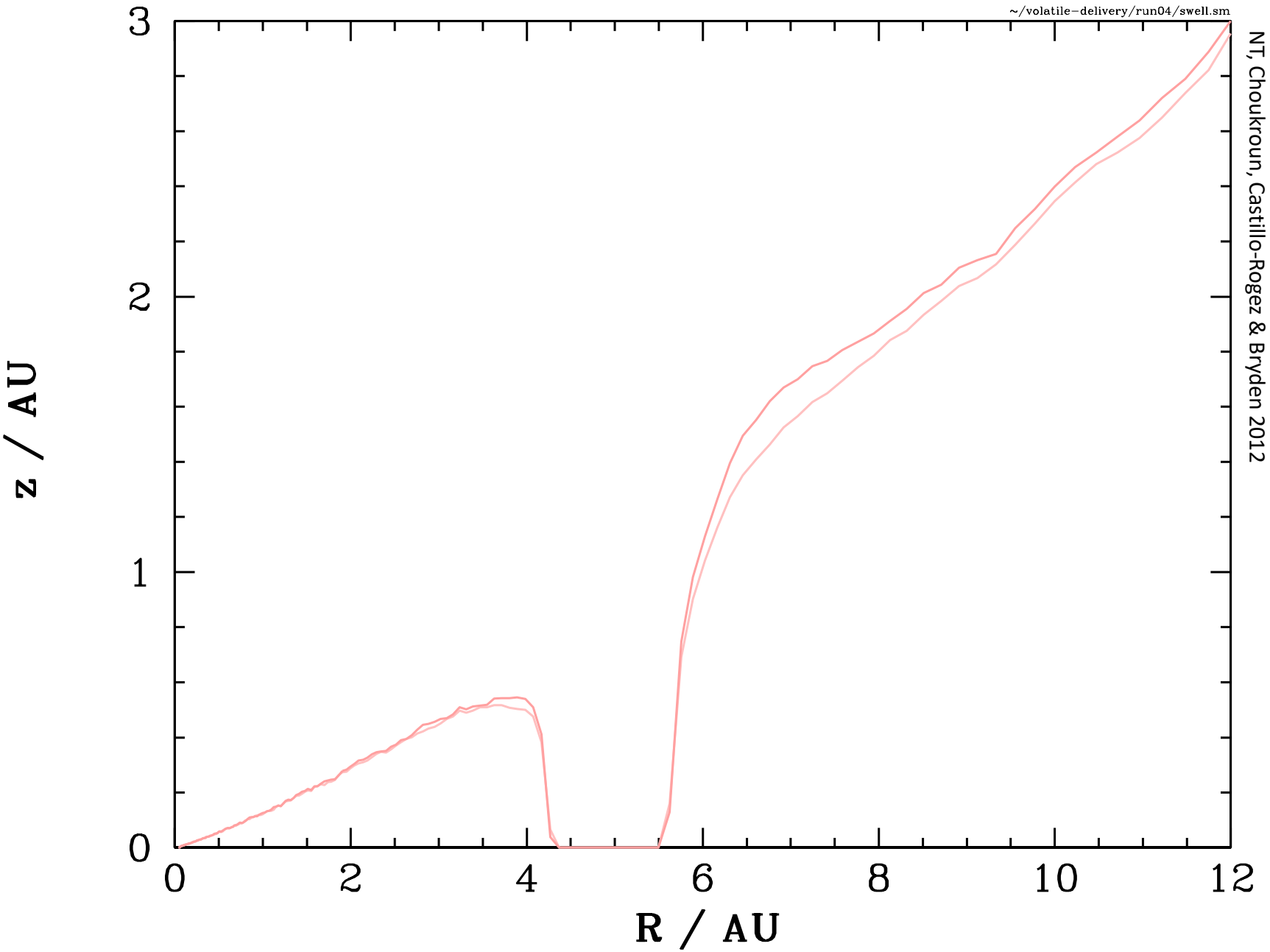
1. The resulting equilibrium models when synthetically observed look rather different from the usual radial power-law temperature models.

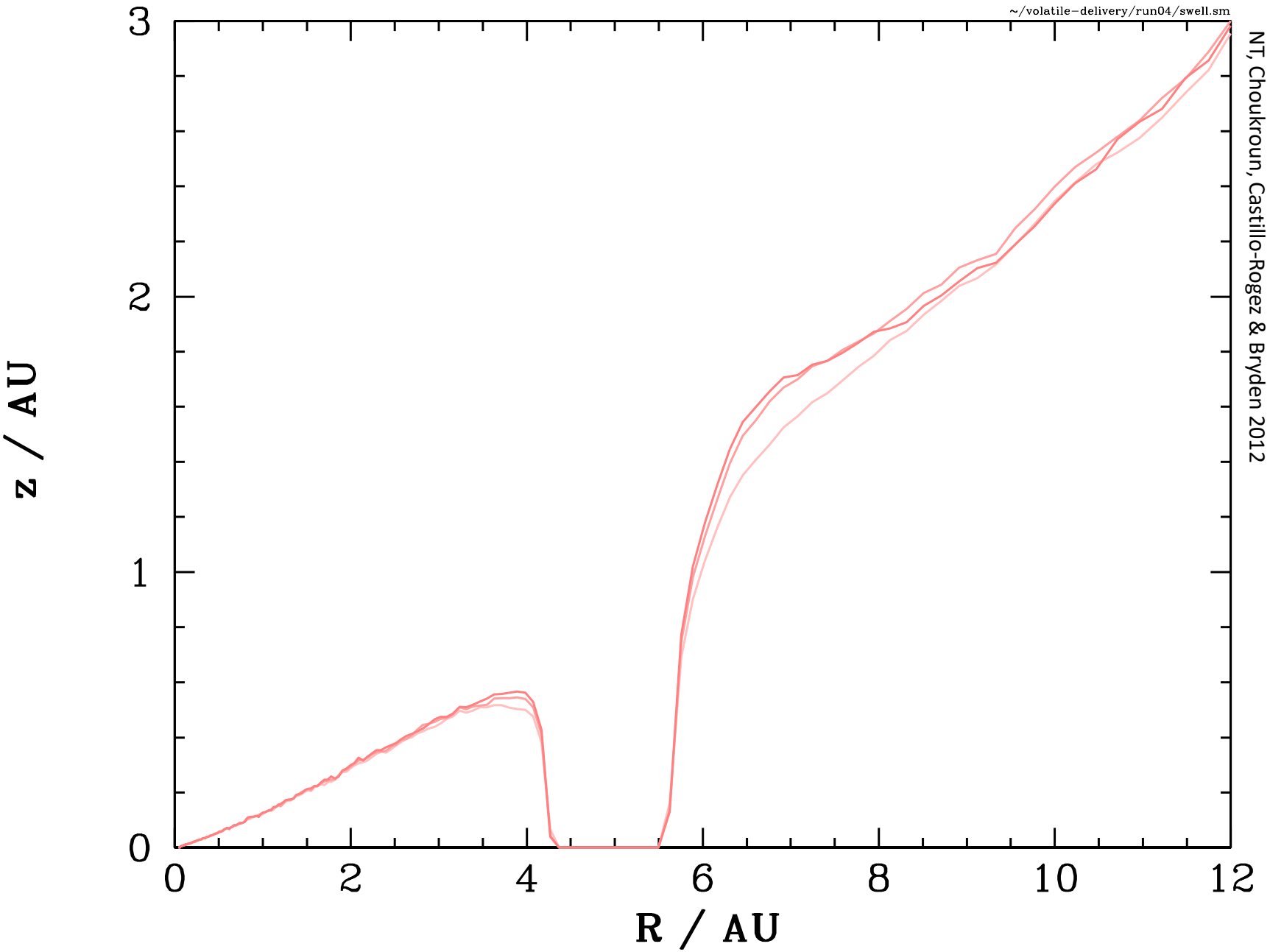


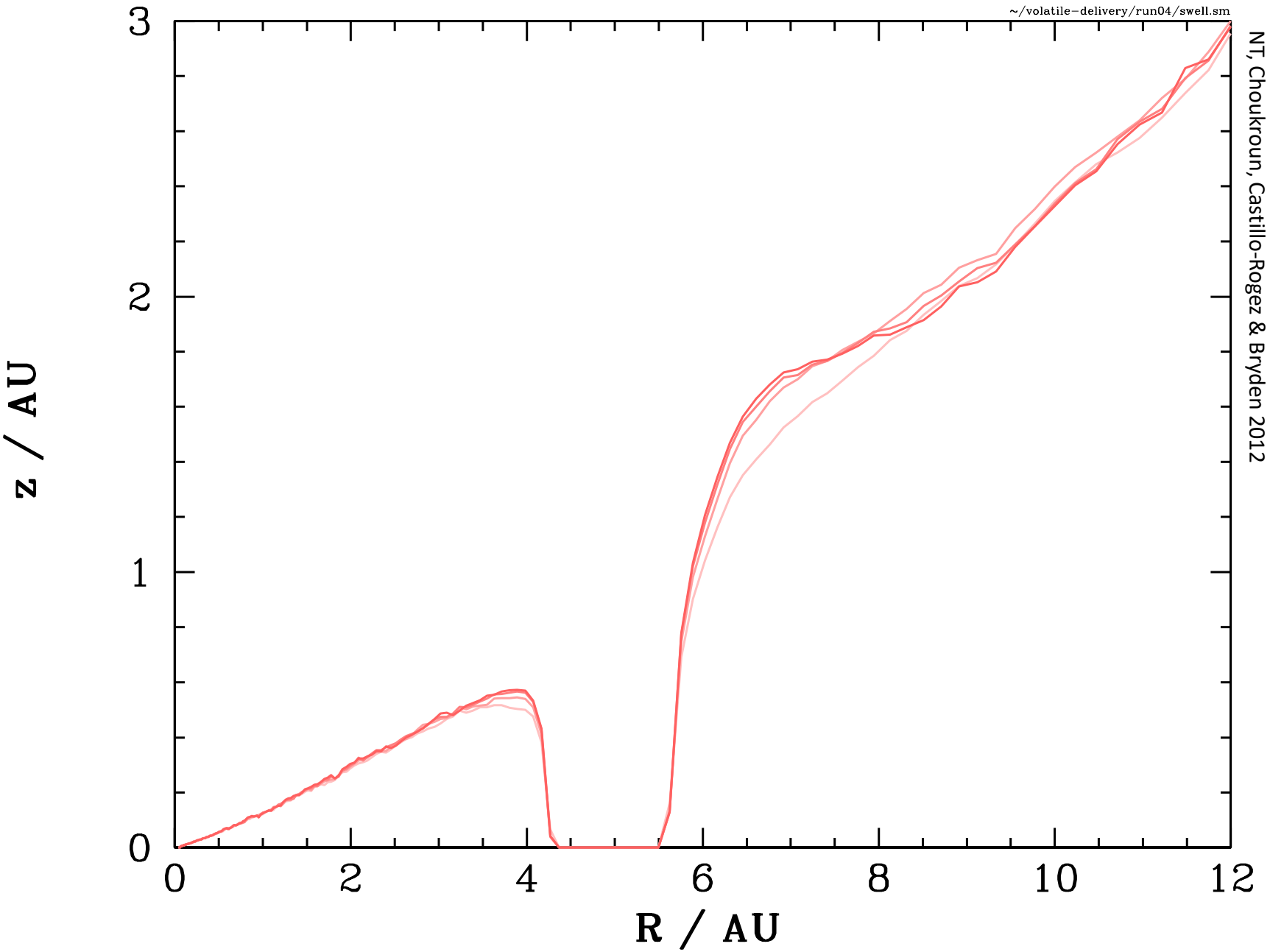


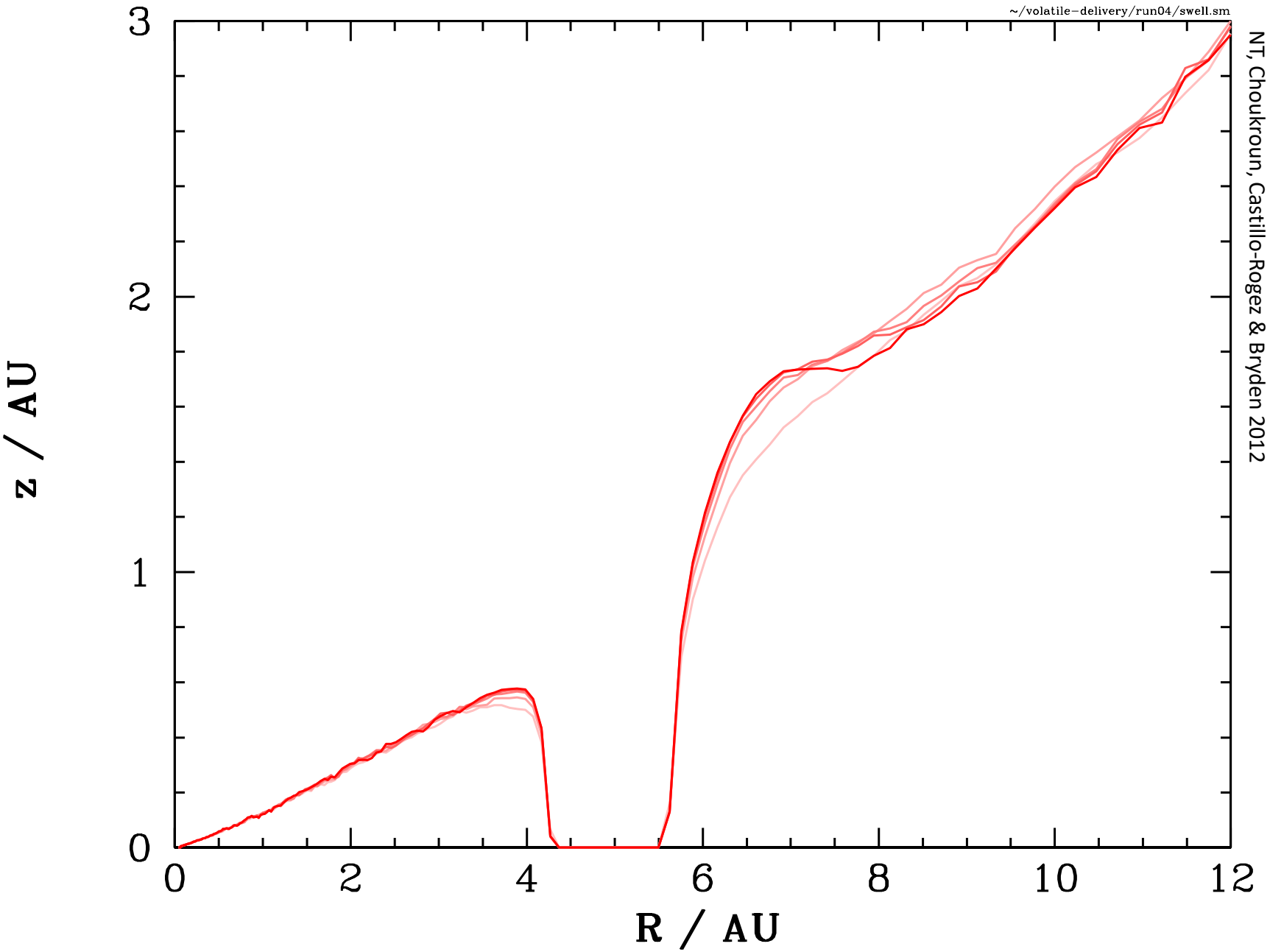

2-D Hydro
With Planet,
Fixing T(R),
for Σ(R,ϕ)
3-D Density
in HSE
Iterate
3-D Radiative
Transfer for
Temperature

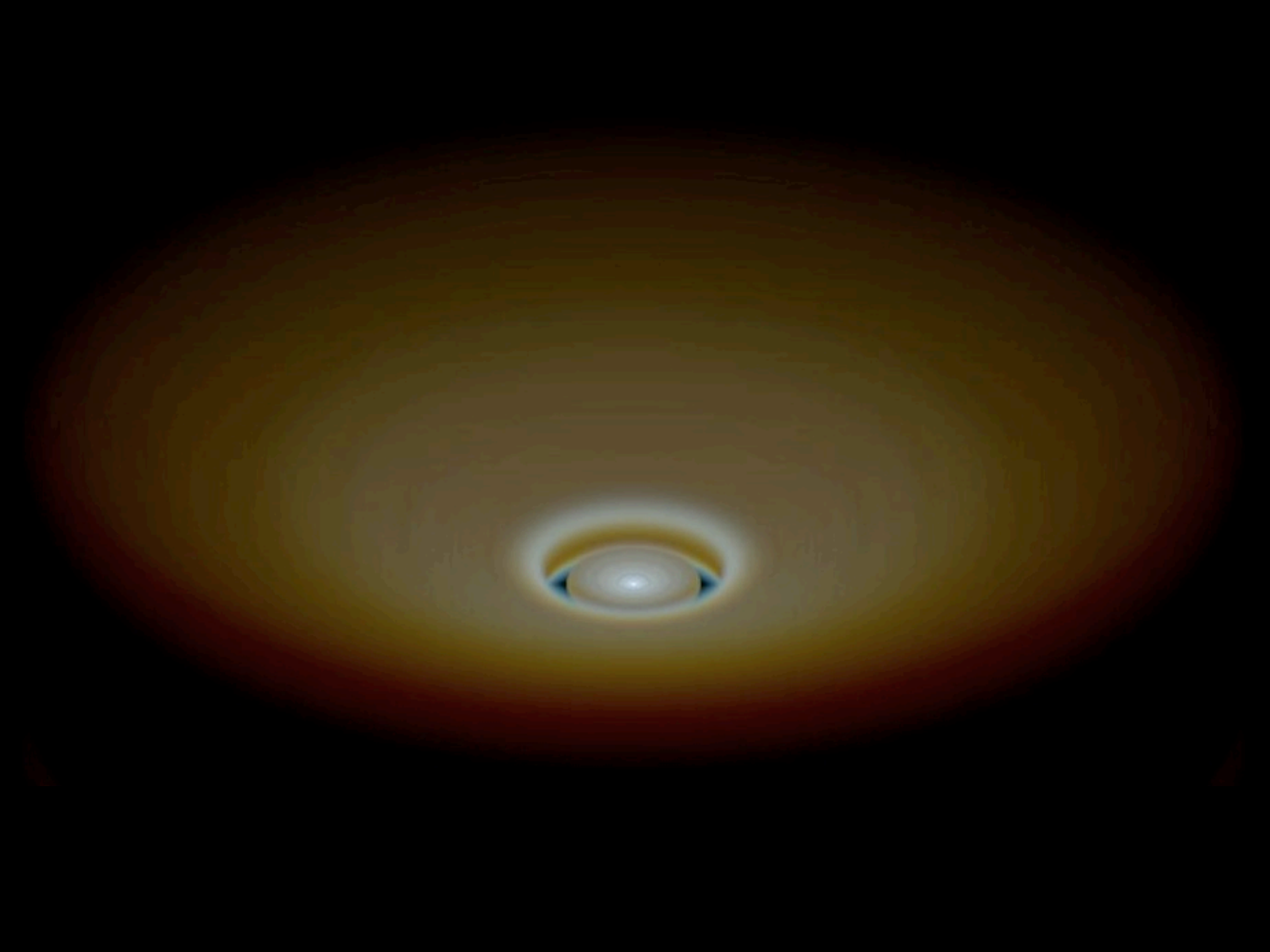

~/volatile-delivery/run04/swell.sm
NT, Choukroun, Castillo-Rogez & Bryden 2012
z / AU
R / AU
0
1
2
3
0
2
4
6
8
10
12


~/volatile-delivery/run04/swell.sm
NT, Choukroun, Castillo-Rogez & Bryden 2012
z / AU
R / AU
0
1
2
3
0
2
4
6
8
10
12


~/volatile-delivery/run04/swell.sm
NT, Choukroun, Castillo-Rogez & Bryden 2012
z / AU
R / AU
0
1
2
3
0
2
4
6
8
10
12


~/volatile-delivery/run04/swell.sm
NT, Choukroun, Castillo-Rogez & Bryden 2012
z / AU
R / AU
0
1
2
3
0
2
4
6
8
10
12


~/volatile-delivery/run04/swell.sm
NT, Choukroun, Castillo-Rogez & Bryden 2012
z / AU
R / AU
0
1
2
3
0
2
4
6
8
10
12



Artwork by W. K. Hartmann

Outline

1. A planet opening a gap lets scattered starlight and re-emitted infrared radiation reach the midplane.

1. Patches of disk respond to lighting changes on whichever timescale is slower: dynamics or heating/cooling.

1. We can use this response to choose between different radiative balance, hydrostatic solutions.

1. The resulting equilibrium models when synthetically observed look rather different from the usual radial power-law temperature models.

Two Timescales

$$t_{dy} = \frac{2\pi}{\Omega} \propto r^{3/2}$$

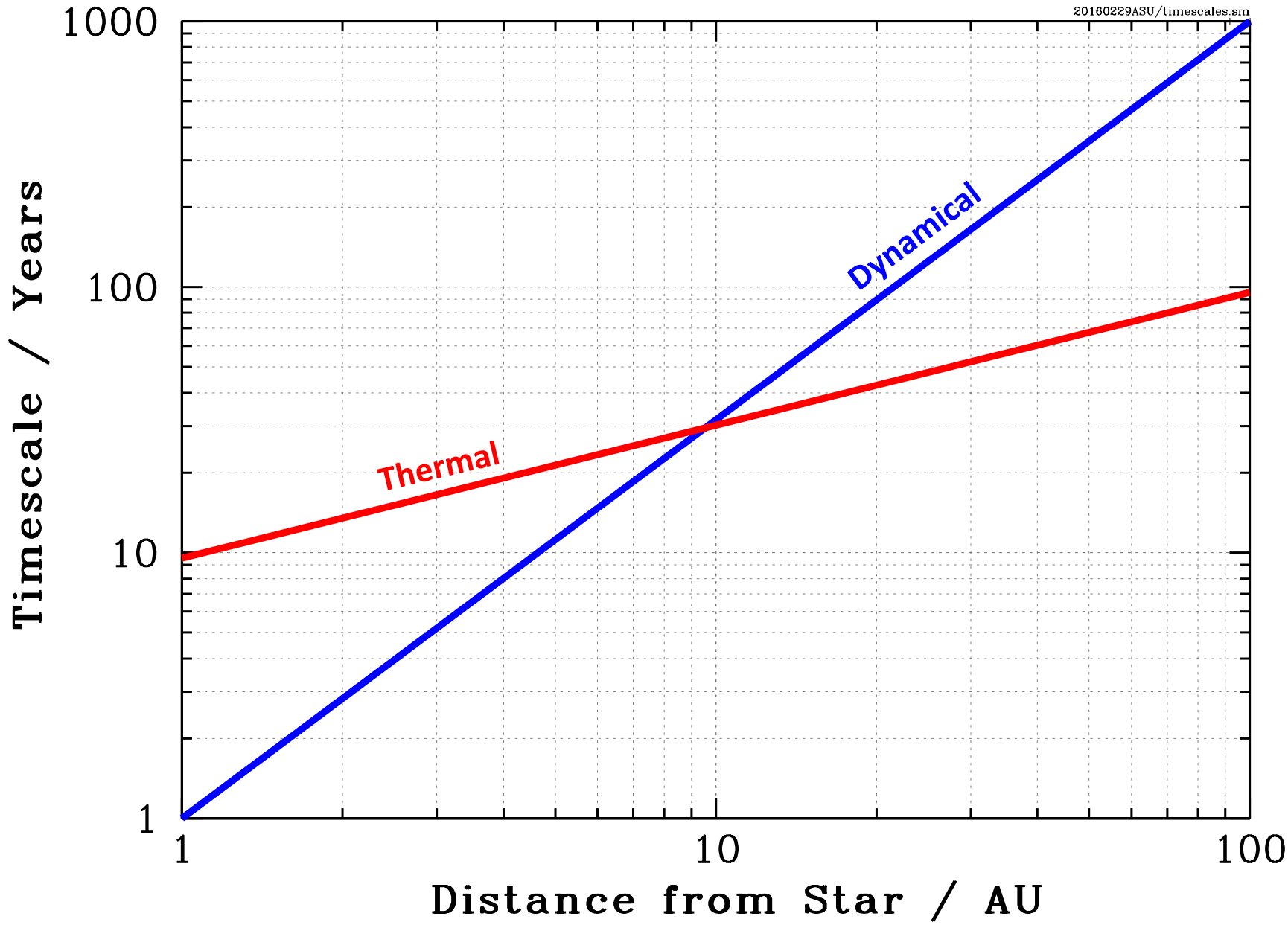
$$t_{th} = \frac{(\gamma+1)}{2(\gamma-1)} \frac{c_s^2 \Sigma}{\sigma T^4} \propto r^{1/2}$$

Two Timescales

$$t_{dy} = \frac{2\pi}{\Omega} \propto r^{3/2}$$

$$t_{th} = \frac{(\gamma+1)}{2(\gamma-1)} \frac{c_s^2 \Sigma}{\sigma T^4} \propto r^{1/2}$$

Watanabe & Lin 2008


20160229ASU/timescales.sm
1000
100
10
1
1
10
100
Timescale / Years
Distance from Star / AU
Dynamical
Thermal

Outline

1. A planet opening a gap lets scattered starlight and re-emitted infrared radiation reach the midplane.

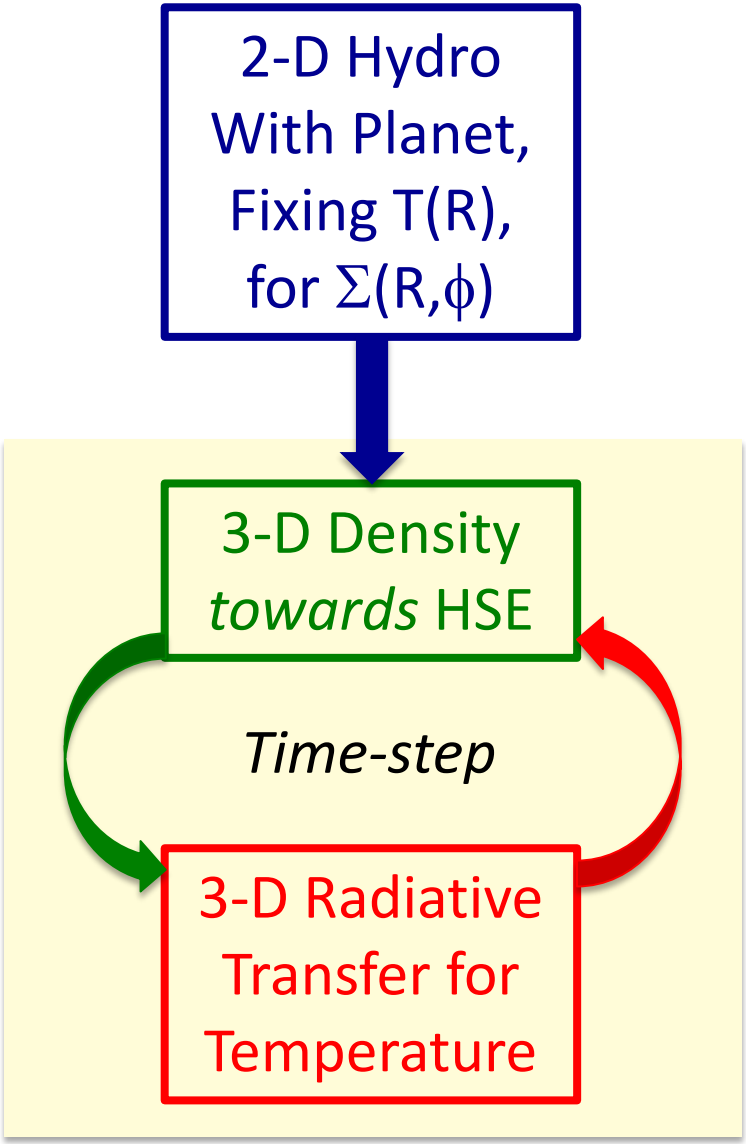
1. Patches of disk respond to lighting changes on whichever timescale is slower: dynamics or heating/cooling.

1. We can use this response to choose between different radiative balance, hydrostatic solutions.

1. The resulting equilibrium models when synthetically observed look rather different from the usual radial power-law temperature models.

Poor Man's Radiation Hydrodynamics

$$\Delta h \leq h \frac{\Delta t}{\max\left(t_{dy}, t_{th}\right)}$$


2-D Hydro
With Planet,
Fixing T(R),
for Σ(R,ϕ)
3-D Density
towards HSE
Time-step
3-D Radiative
Transfer for
Temperature

Outline

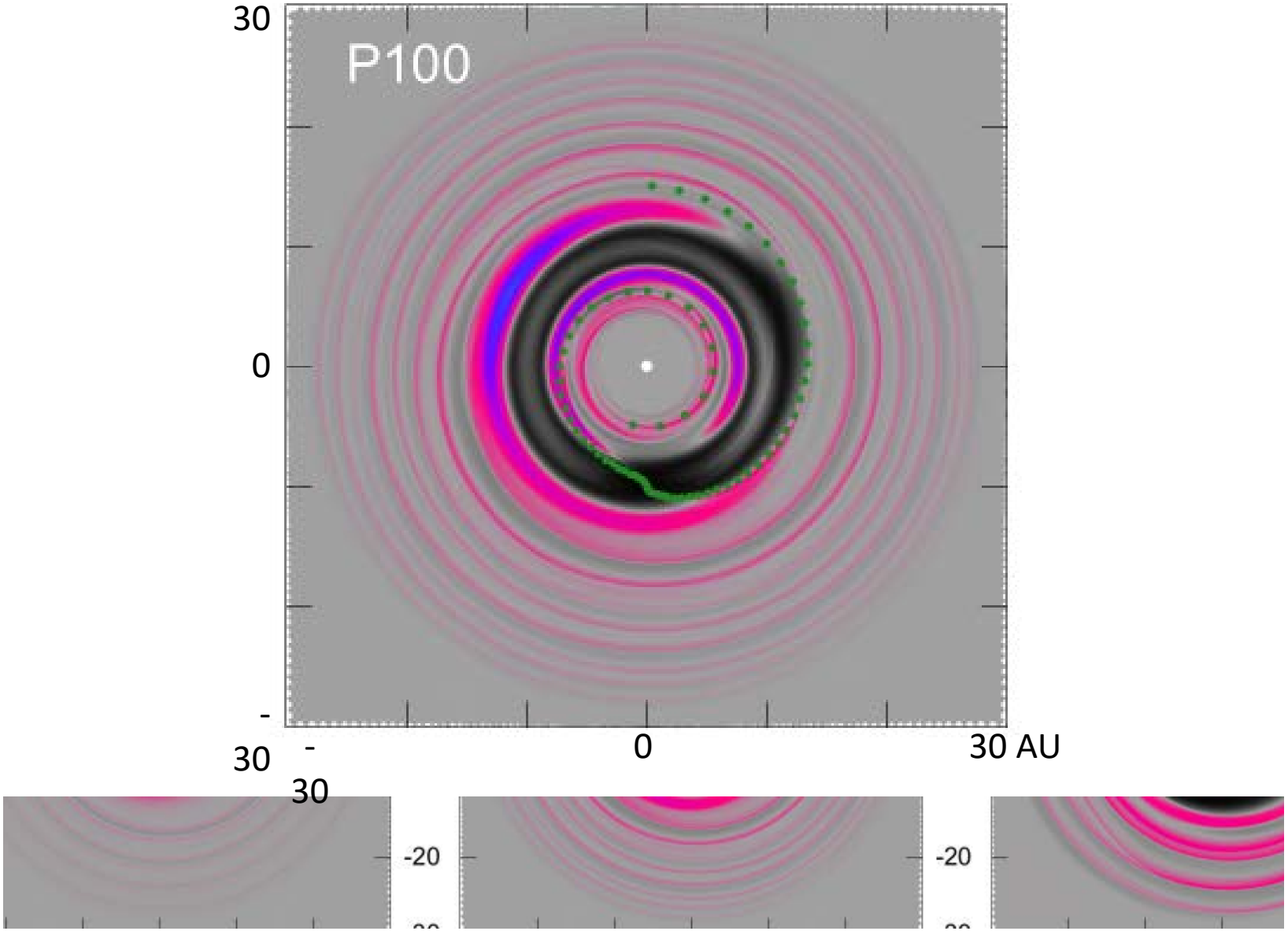
1. A planet opening a gap lets scattered starlight and re-emitted infrared radiation reach the midplane.

1. Patches of disk respond to lighting changes on whichever timescale is slower: dynamics or heating/cooling.

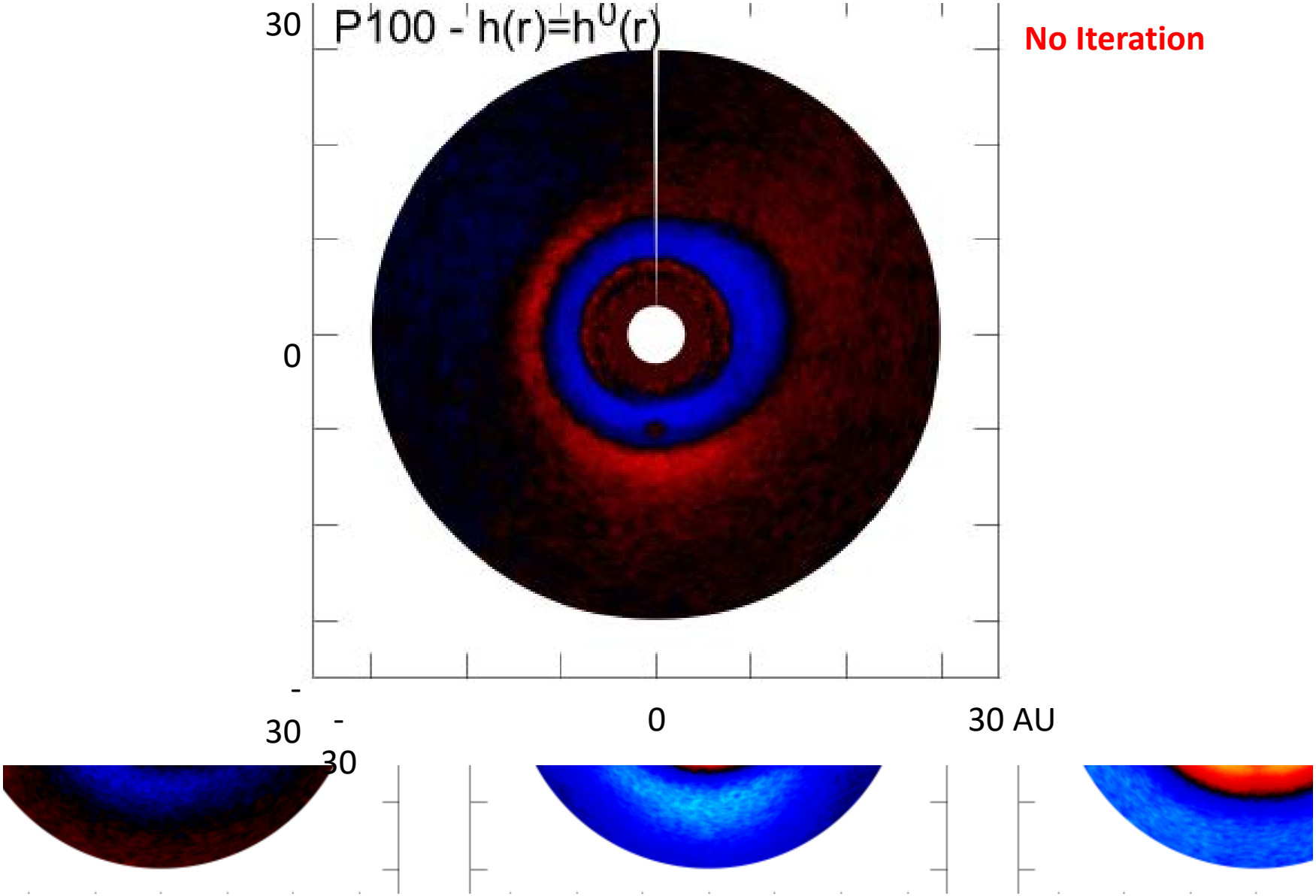
1. We can use this response to choose between different radiative balance, hydrostatic solutions.

1. The resulting equilibrium models when synthetically observed look rather different from the usual radial power-law temperature models.

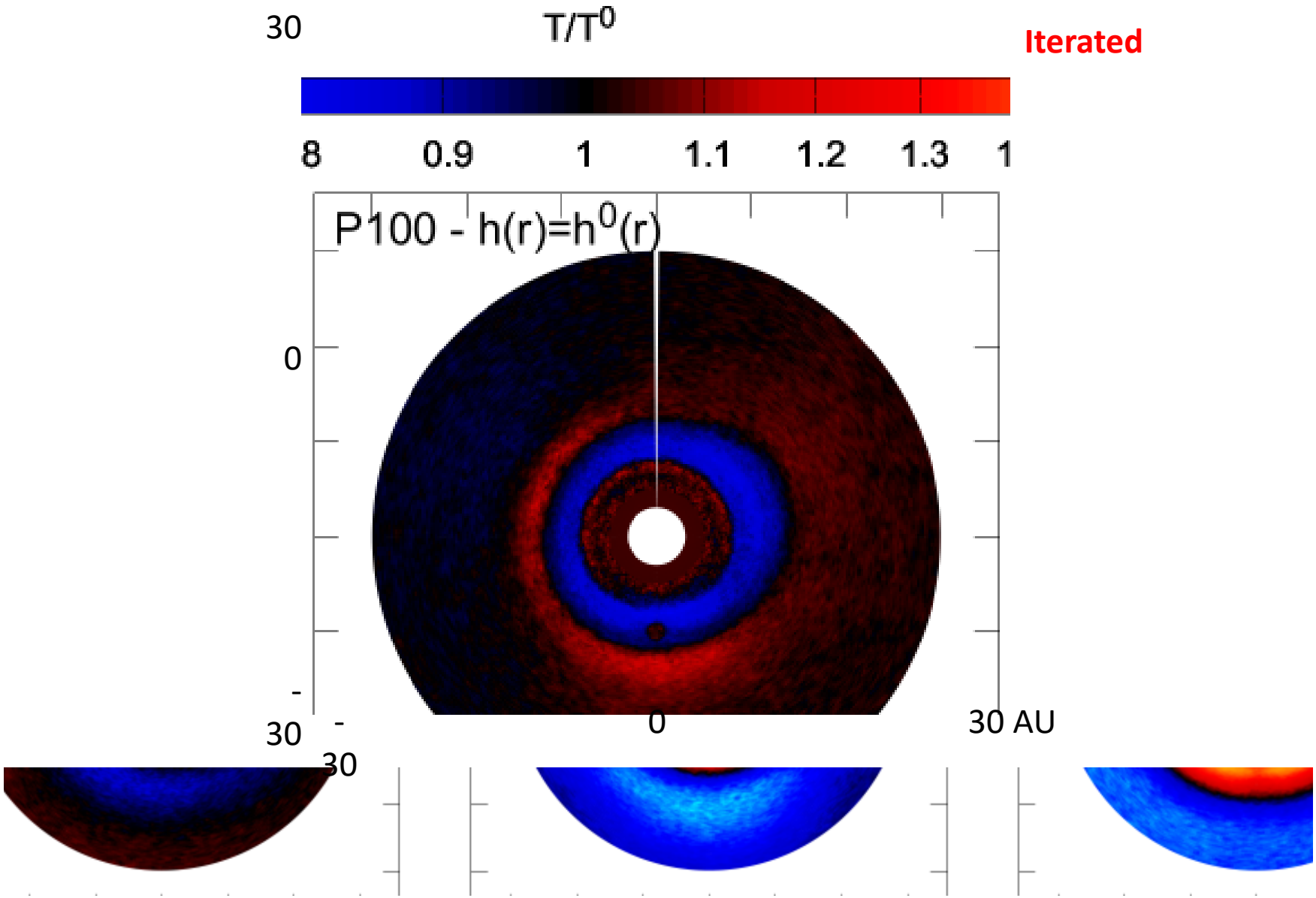
Surface Density Ratio With 100-Earth-Mass Planet



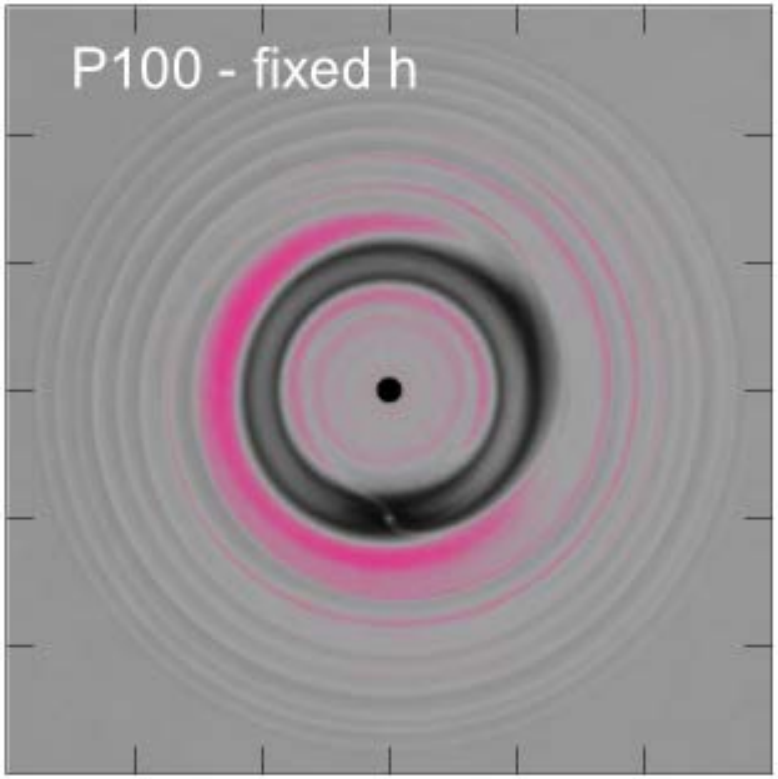
Midplane Temperature Ratio With 100-Earth-Mass Planet

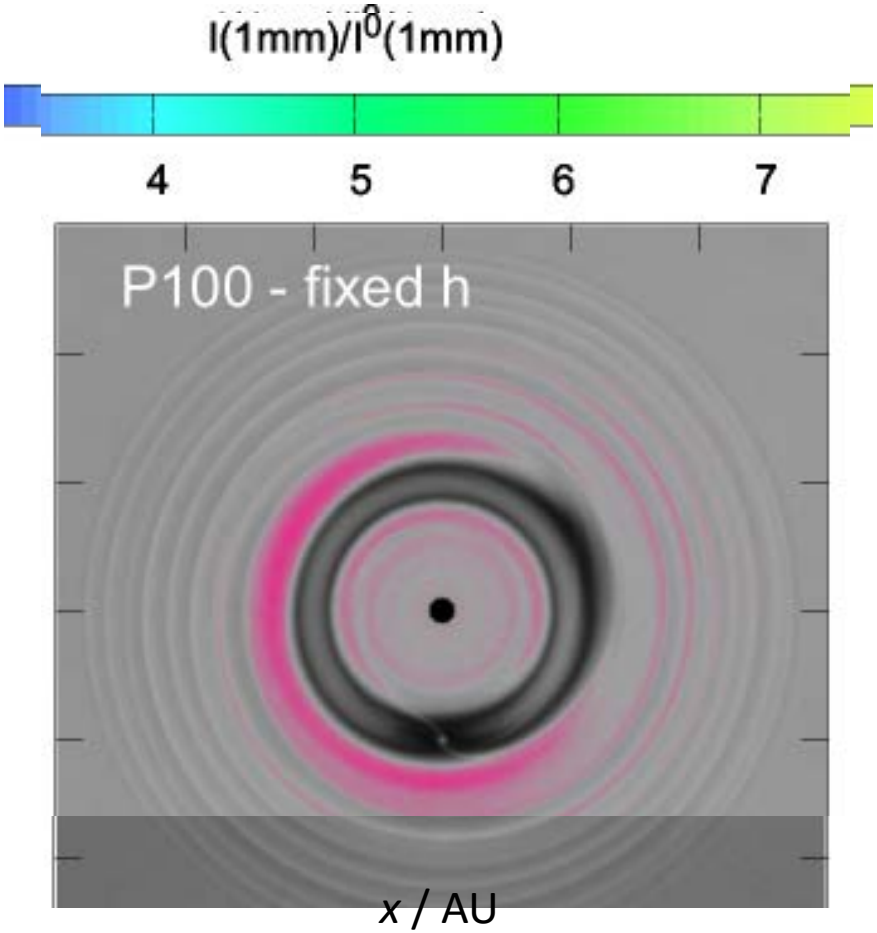


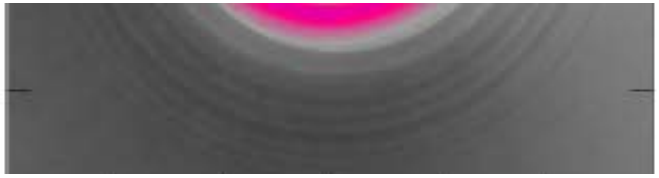
Midplane Temperature Ratio With 100-Earth-Mass Planet

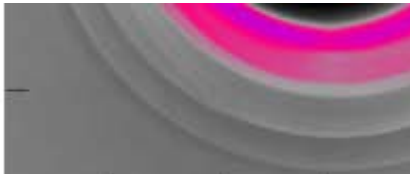


The disk's response to starlight heating changes the shape of the brightest area in the millimeter continuum.

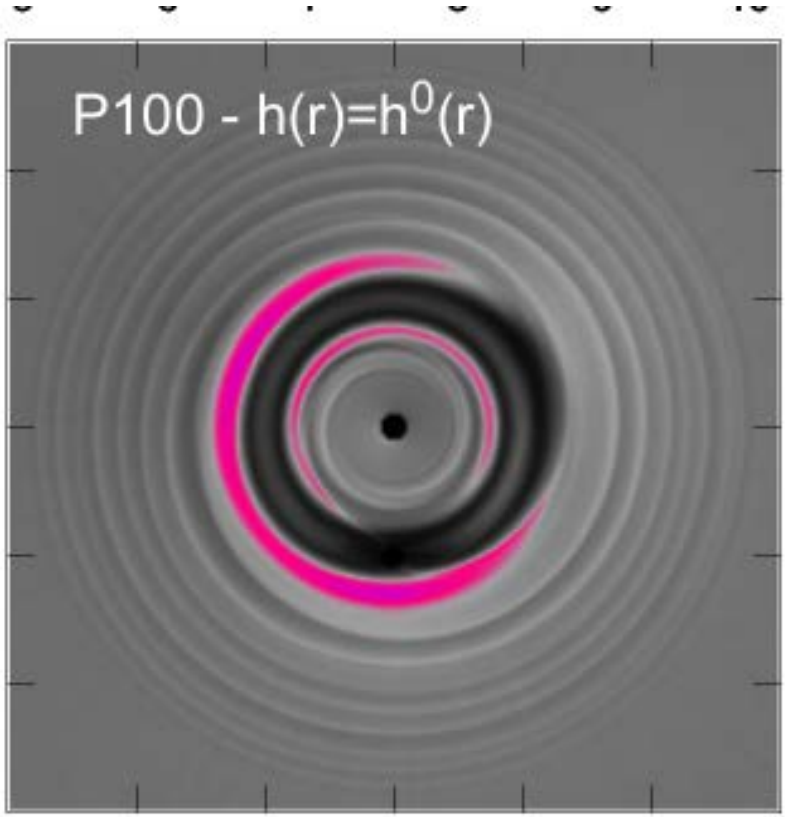


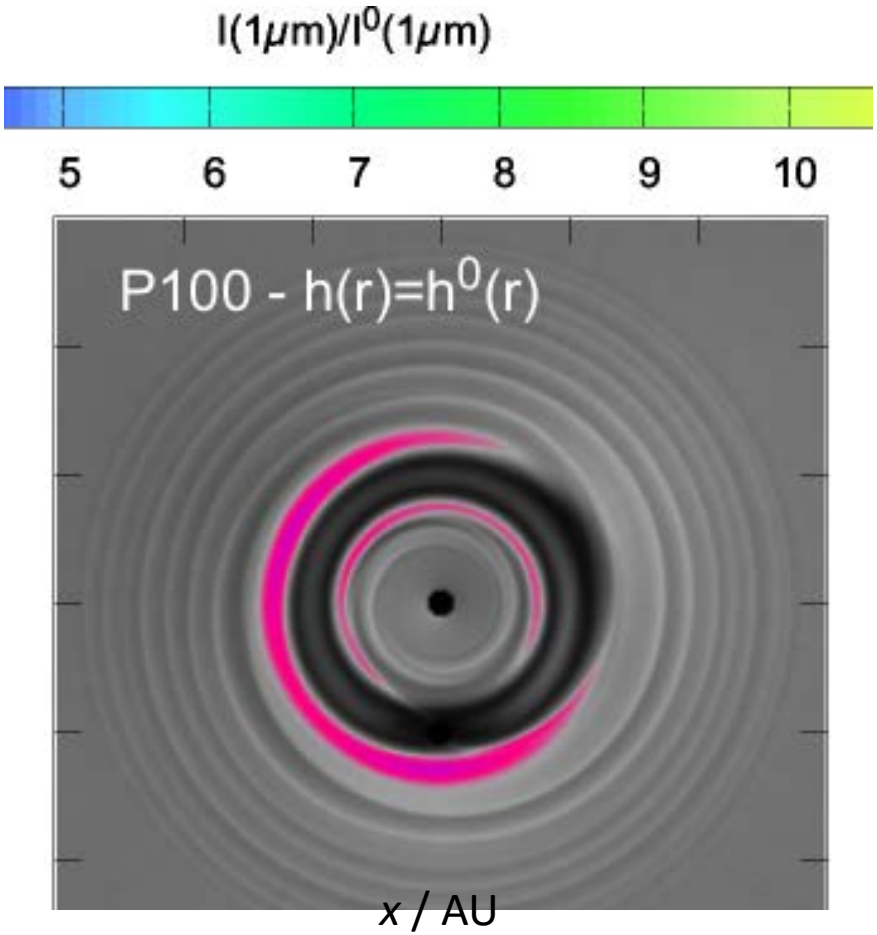


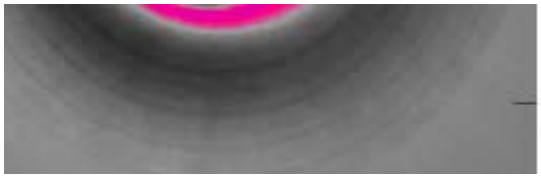


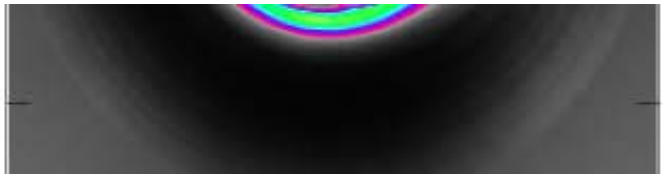


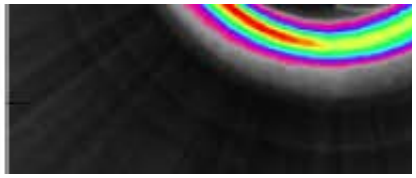
The disk's response to starlight heating drastically changes the appearance in scattered light!



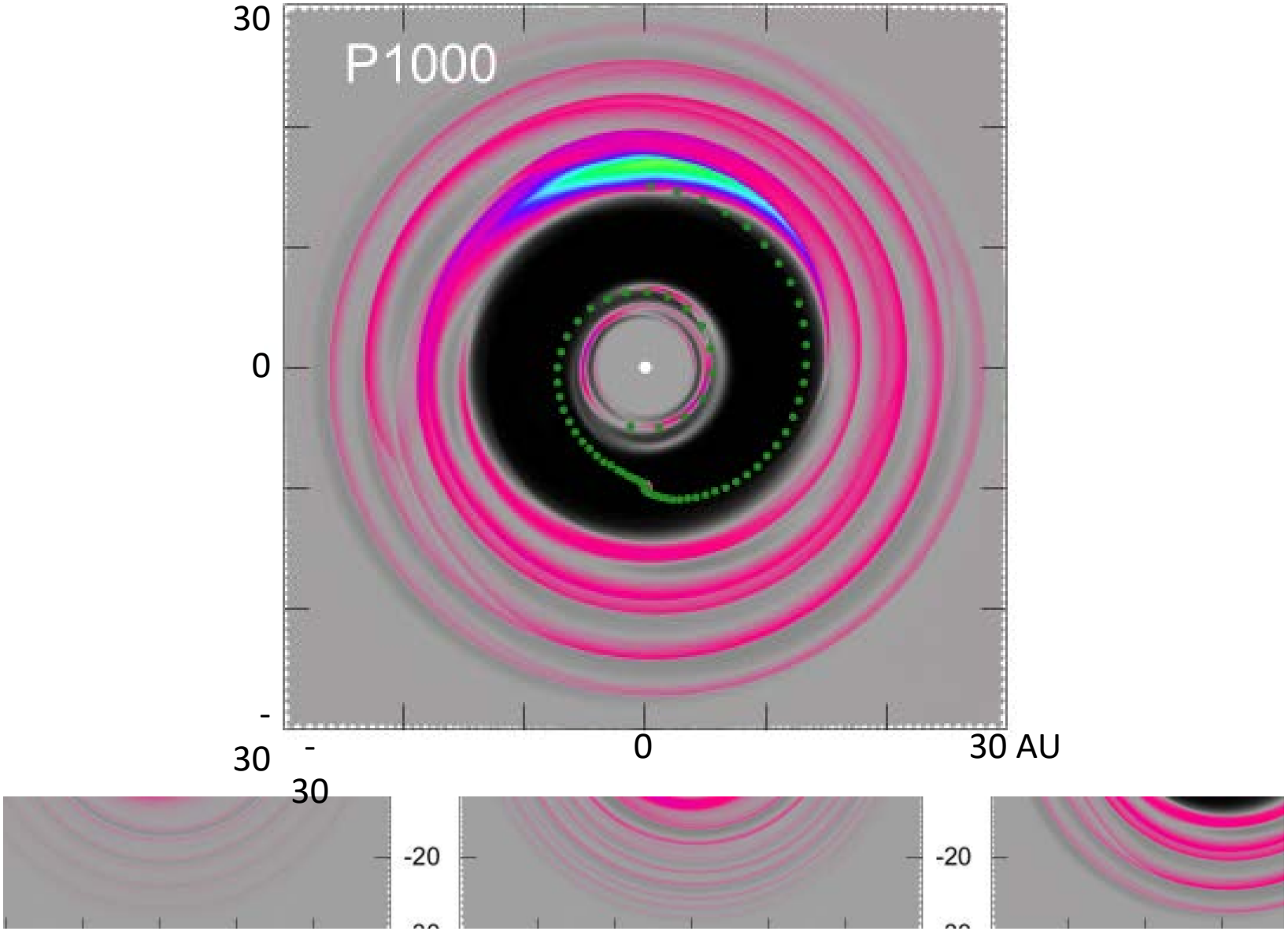




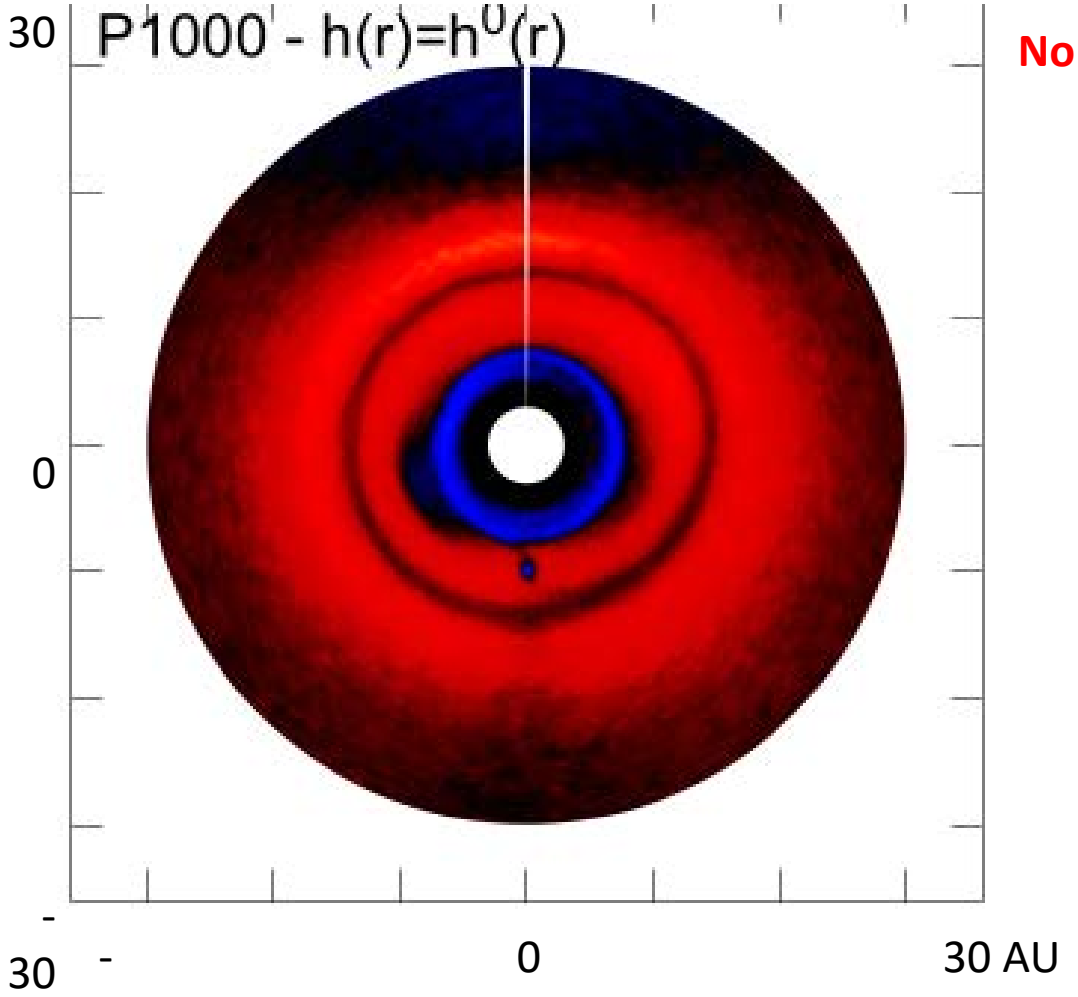




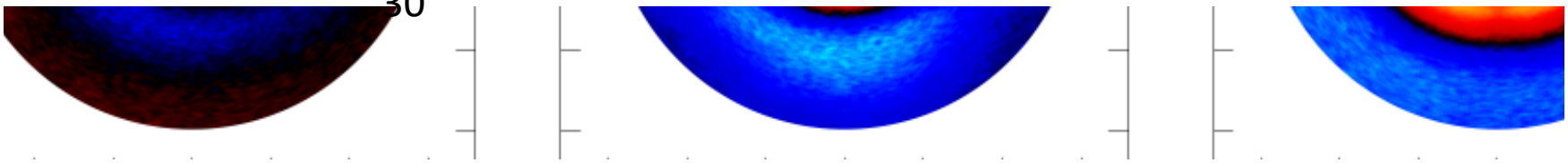
Surface Density Ratio With 1000-Earth-Mass Planet



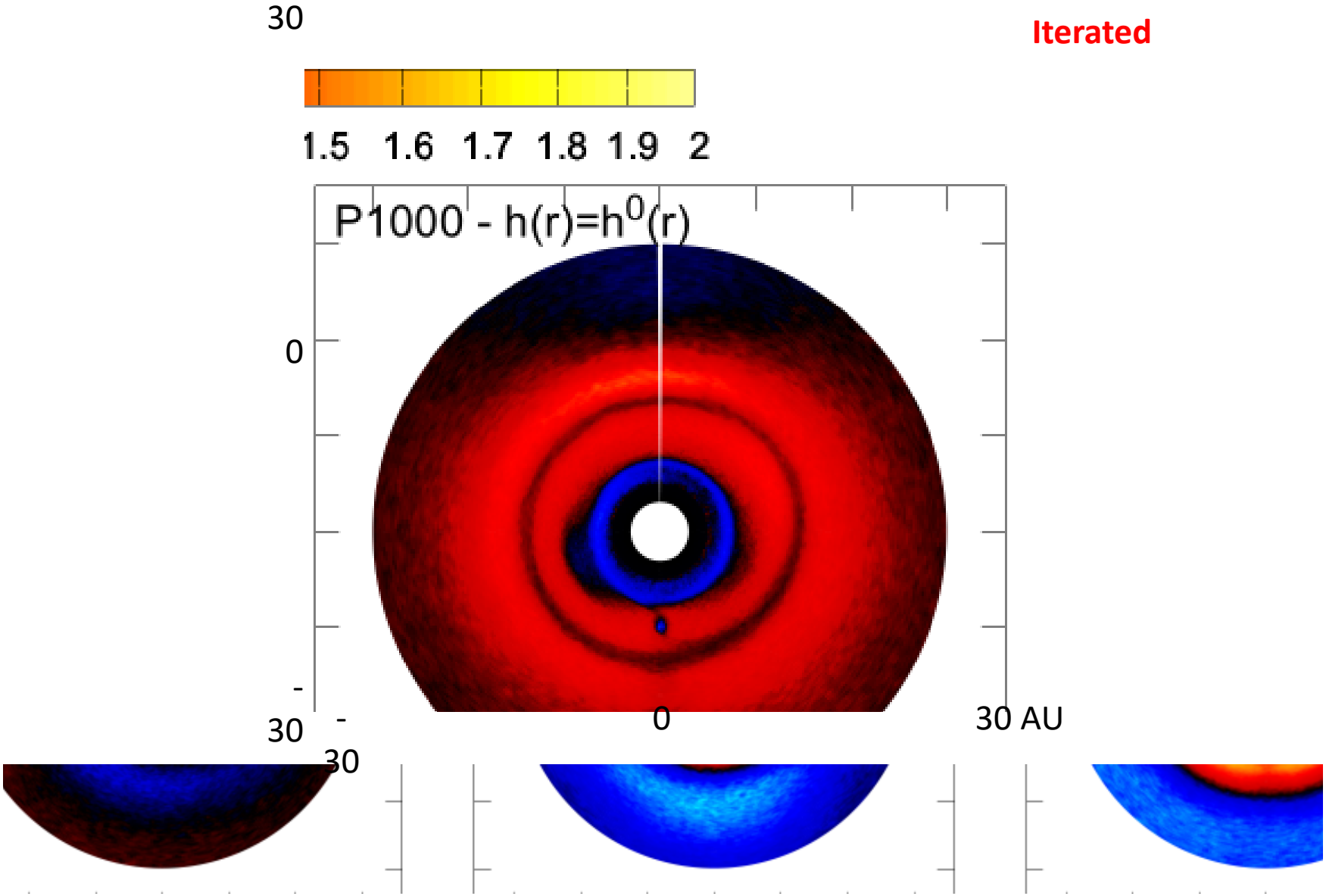
Midplane Temperature Ratio With 1000-Earth-Mass Planet



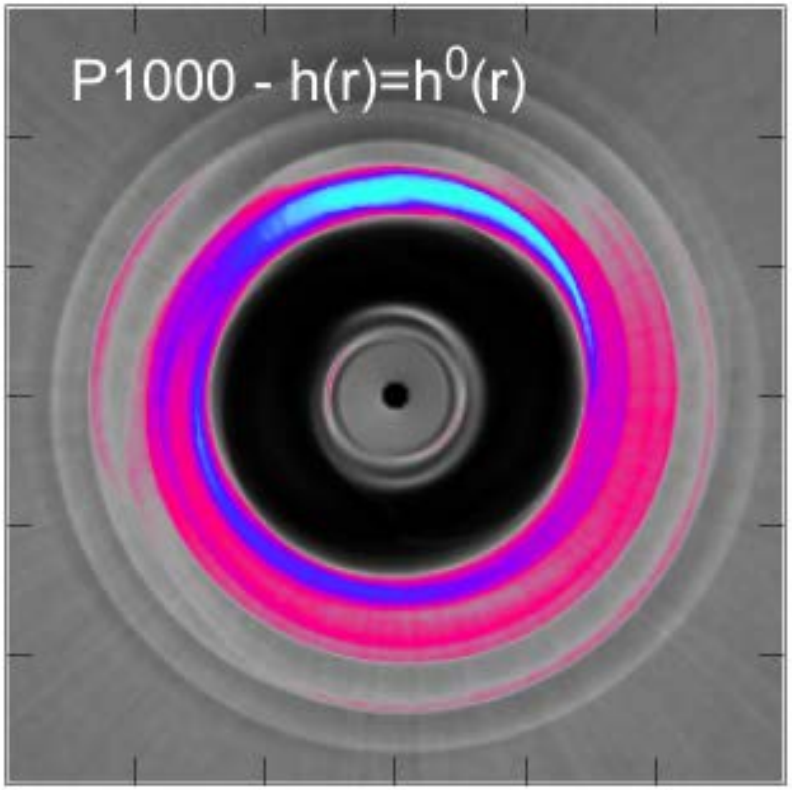
No Iteration

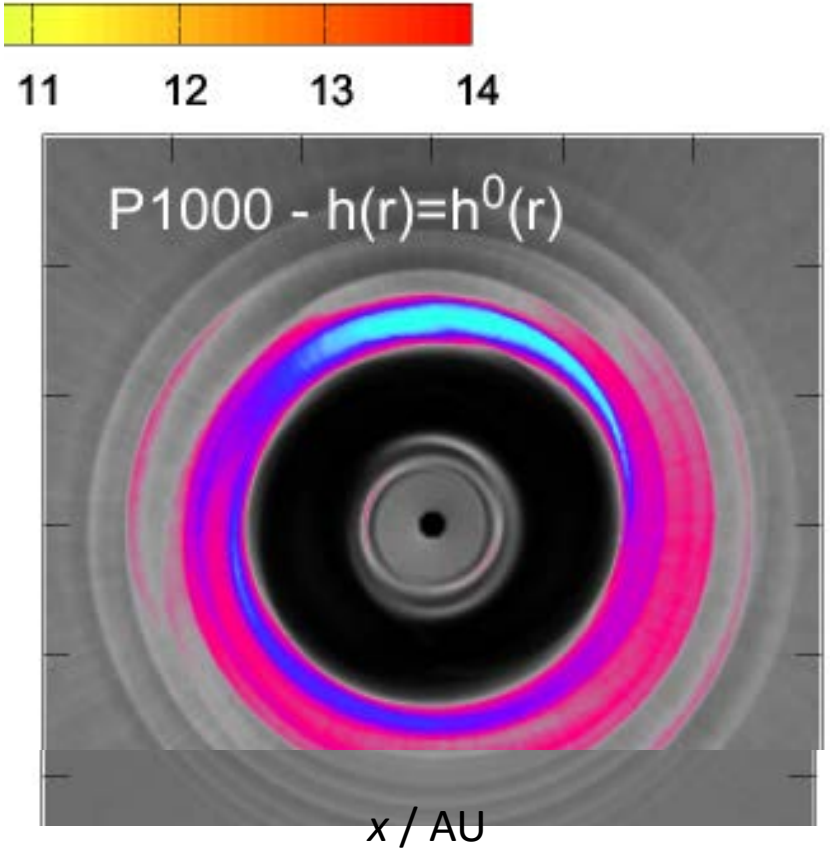


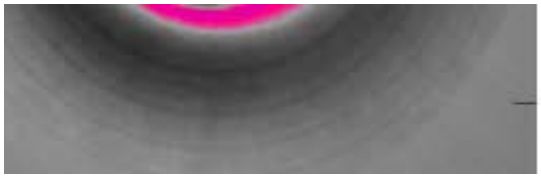
Midplane Temperature Ratio With 1000-Earth-Mass Planet

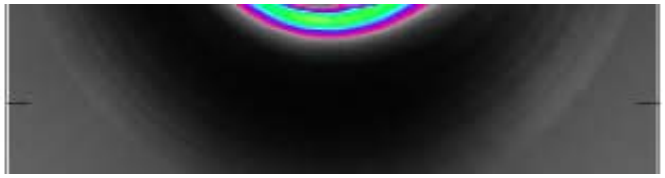


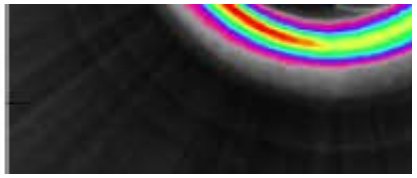
The disk's response to starlight heating drastically changes the appearance in scattered light!









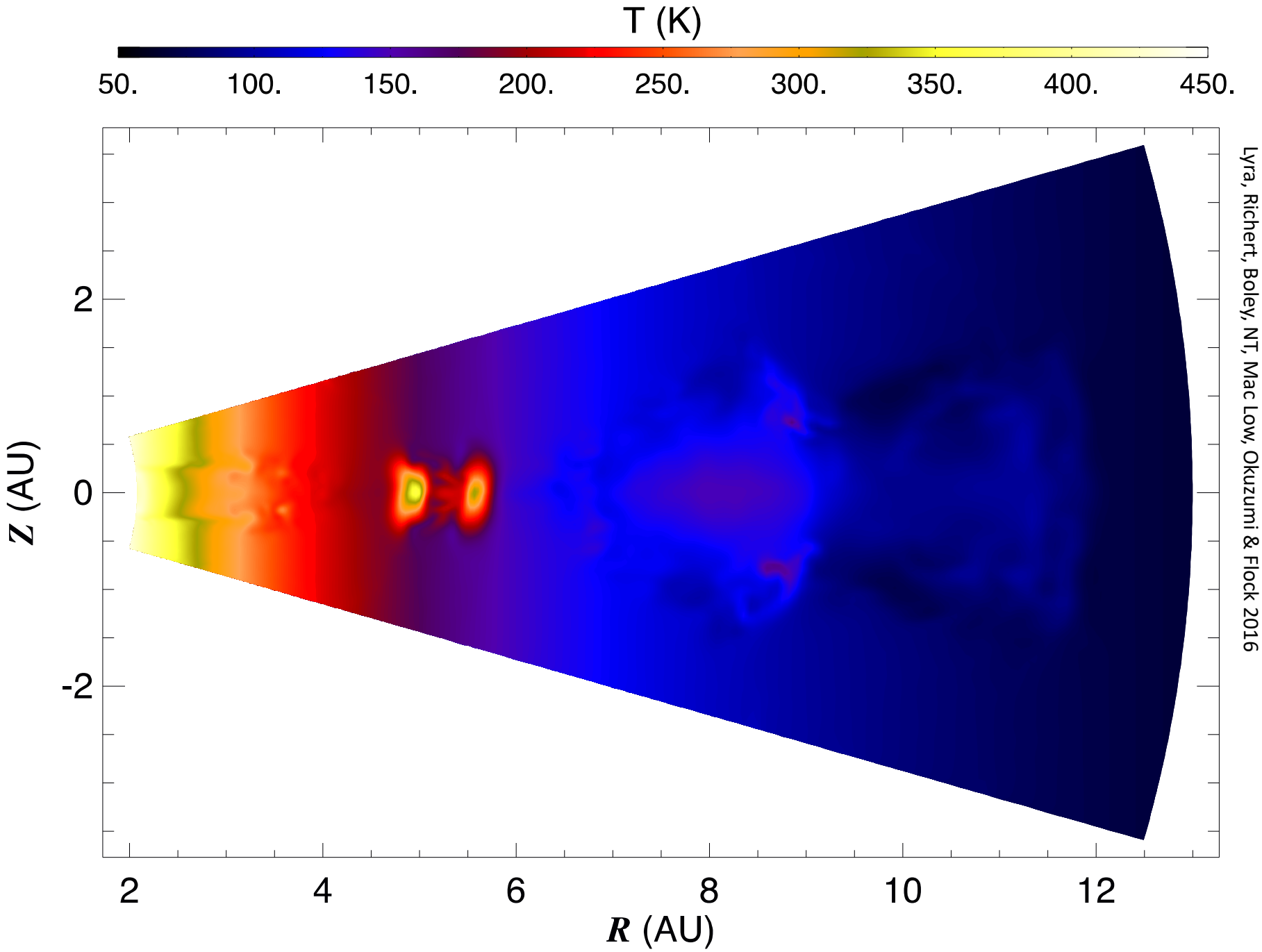


Summary

Reliably predicting young planets' signatures requires treating disks' response to starlight falling across the planet-raised features.

The equilibrium response:

- **Drastically increases the scattered-light contrast at the gap's outer edge.**
- **Reduces the outer spiral arm's brightness in scattered light.**
- **Reshapes the millimeter continuum emission.**


T (K)
50.
100.
150.
200.
250.
300.
350.
400.
450.
Z (AU)
2
0
-2
2
4
6
8
10
12
R (AU)
Lyra, Richert, Boley, NT, Mac Low, Okuzumi & Flock 2016

Outlook

- Writing up the results for publication.
- Watching others publish related results!
- Examining ALMA gas and dust data for signs the two are distributed differently.
- Preparing an Exoplanet Research Program proposal. Step-1 is due Mar 29.
- Discussing topics for an NSF Astronomy & Astrophysics proposal due Nov 15.

The minimum mass of detectable planets in protoplanetary discs and the derivation of planetary masses from high resolution observations

Giovanni P. Rosotti*[1], Attila Juhasz[1], Richard A. Booth[1], Cathie J. Clarke[1]
[1] *Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK*

arXiv:1603.02141v1 [astro-ph.EP] 7 Mar 2016

Accepted . Received ; in original form

ABSTRACT

We investigate the minimum planet mass that produces observable signatures in infrared scattered light and submm continuum images and demonstrate how these images can be used to *measure* planet masses to within a factor of about two. To this end we perform multi-fluid gas and dust simulations of discs containing low mass planets, generating simulated observations at 1.65μm, 10μm and 850μm. We show that the minimum planet mass that produces a detectable signature is $\sim 15M_\oplus$: this value is strongly dependent on disc temperature and changes slightly with wavelength (favouring the submm). We also confirm previous results that there is a minimum planet mass of $\sim 20M_\oplus$ that produces a pressure maximum in the disc: only planets above this threshold mass generate a dust trap that can eventually create a hole in the submm dust. Below this mass, planets produce annular enhancements in dust outward of the planet and a reduction in the vicinity of the planet. These features are in steady state and can be understood in terms of variations in the dust radial velocity, imposed by the perturbed gas pressure radial profile, analogous to a traffic jam. We also show how planet masses can be derived from structure in scattered light and sub-mm images. We emphasise that simulations with dust need to be run over thousands of planetary orbits so as to allow the gas profile to achieve a steady state and caution against the estimation of planet masses using gas only simulations.

Key words: hydrodynamics, protoplanetary discs, planet-disc interactions, submillimetre: planetary systems

1 INTRODUCTION

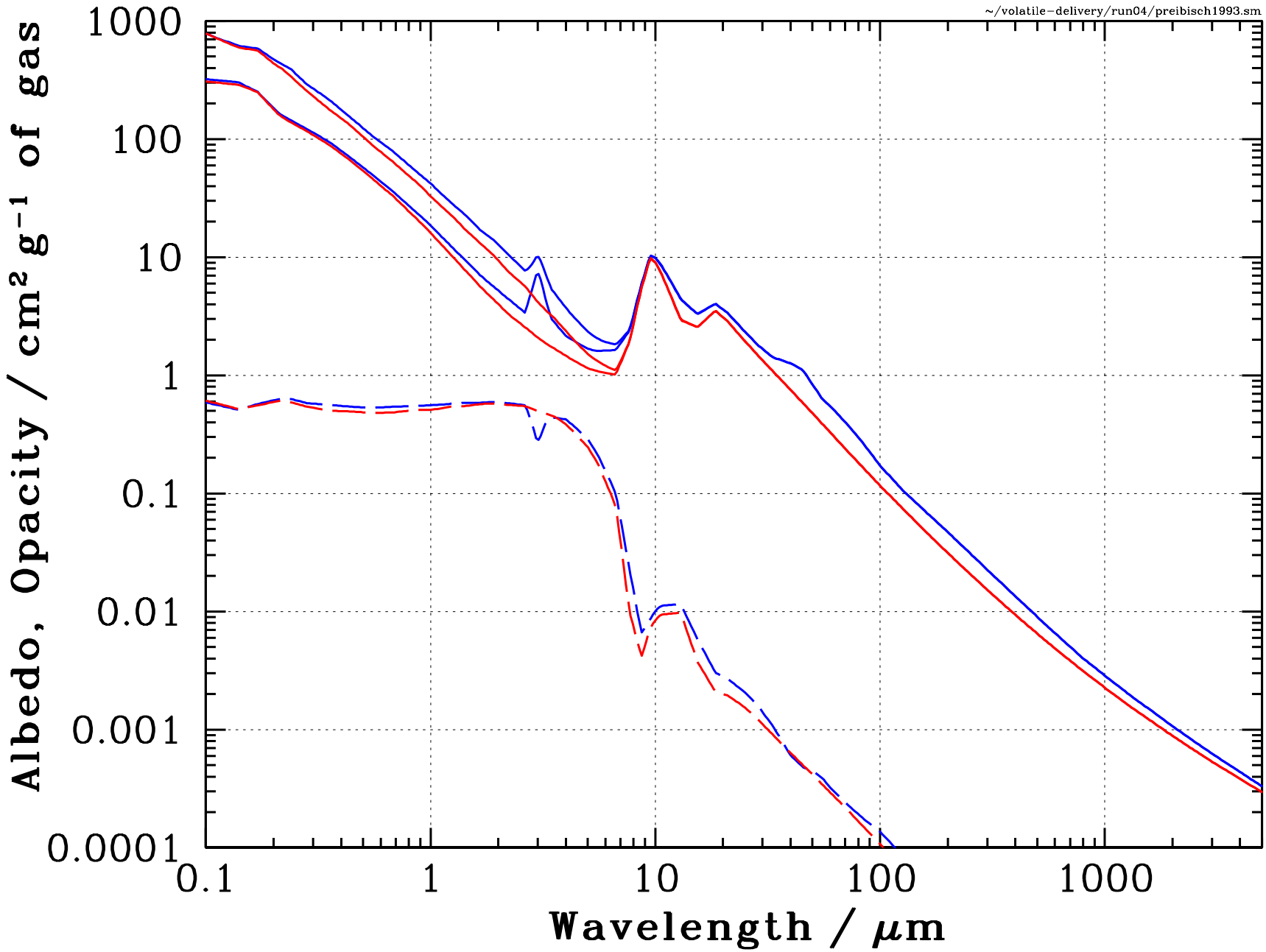
Planets form in the dense, rotationally flattened structures of dust and gas called "proto-planetary disc" (see Williams & Cieza 2011 for a review). Despite the rapid expansion of our knowledge of exo-

imaging at similar resolution as ALMA in the sub-millimetre. In the near future similar resolution will be available in the thermal mid-infrared (MIR) when the 30–40m class telescopes (e.g. the European Extremely Large Telescope, E-ELT) will come online.

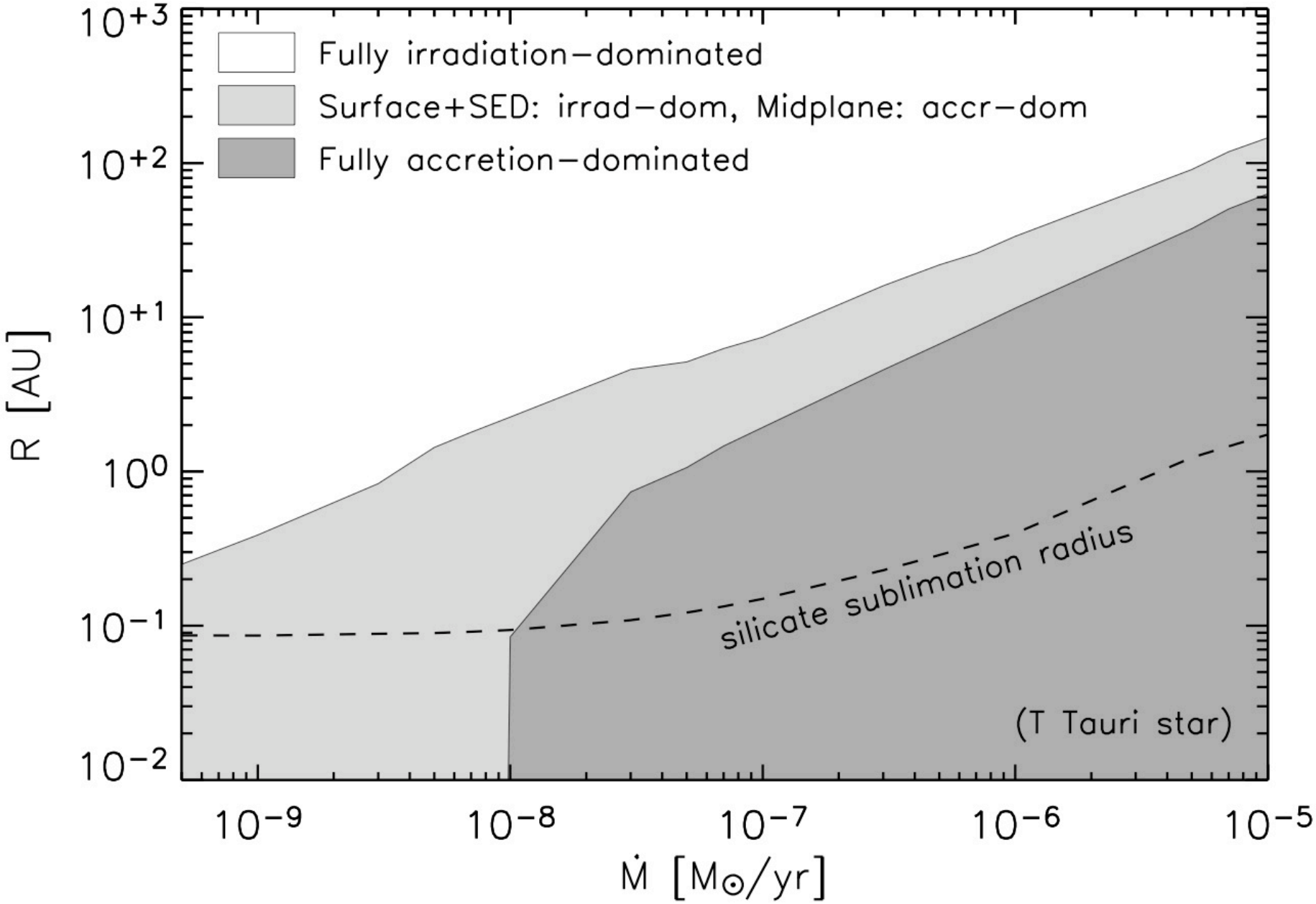
Outlook

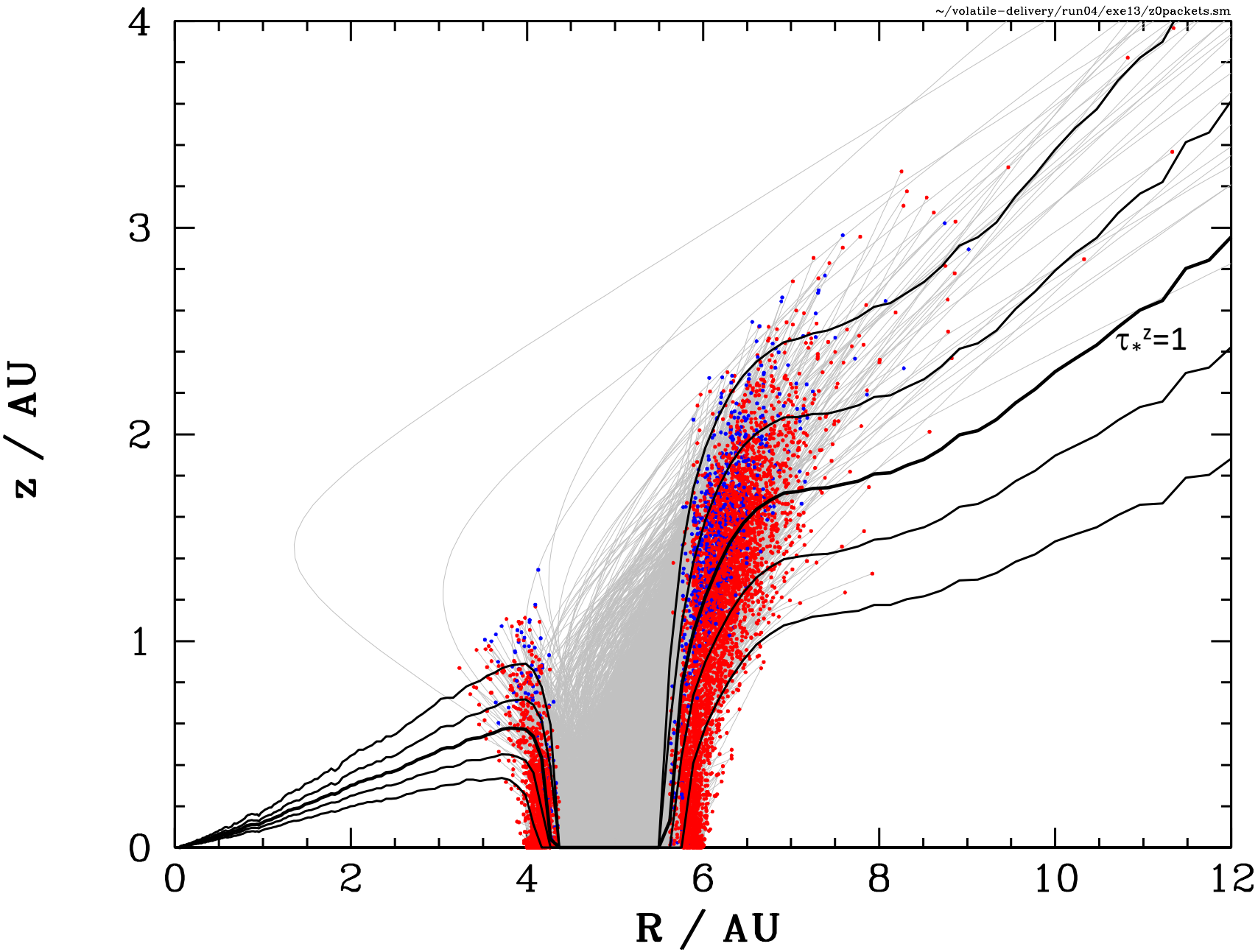
- Writing up the results for publication.
- Watching others publish related results!
- Examining ALMA gas and dust data for signs the two are distributed differently.
- Preparing an Exoplanet Research Program proposal. Step-1 is due Mar 29.
- Discussing topics for an NSF Astronomy & Astrophysics proposal due Nov 15.

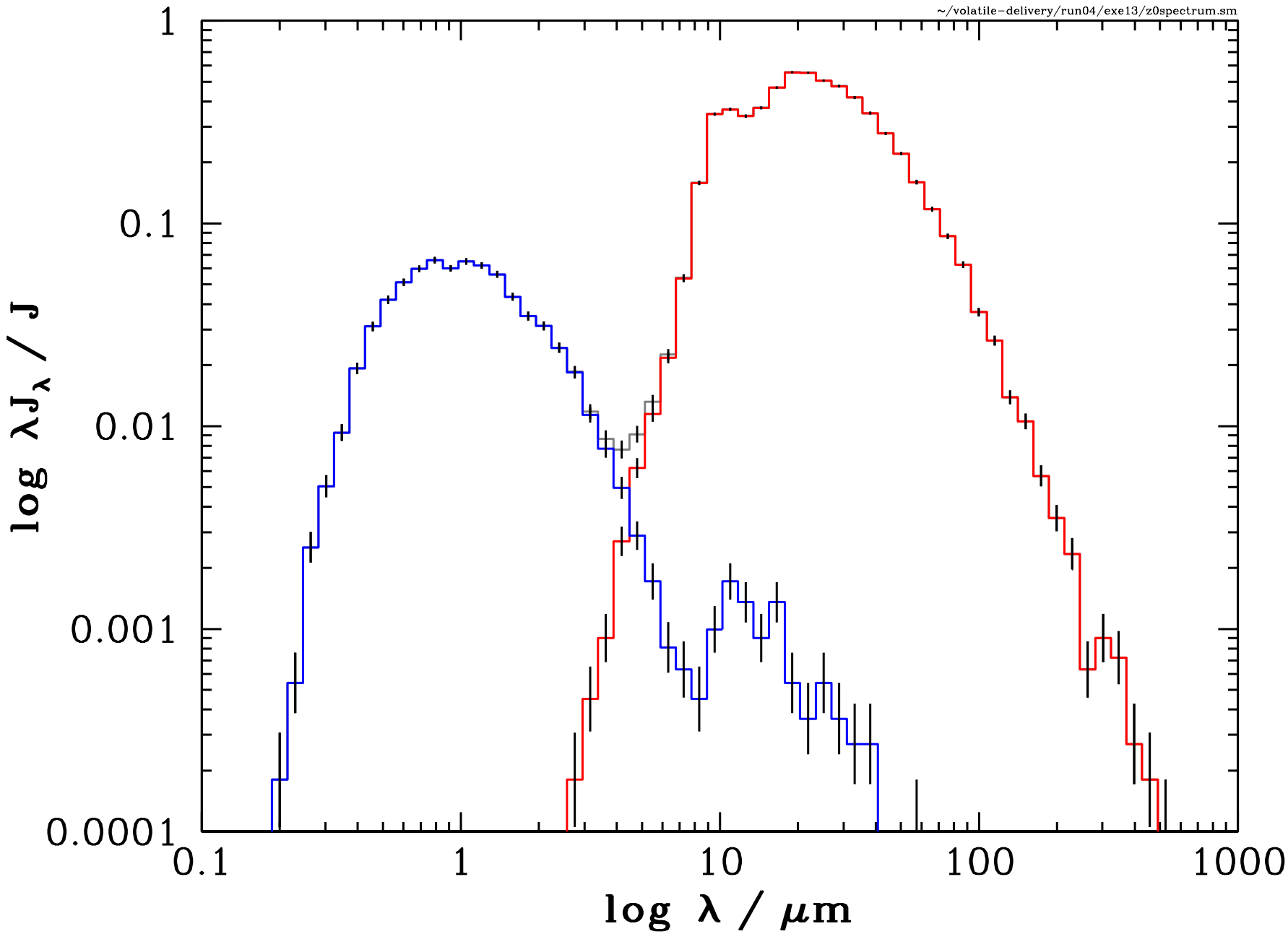
Backup Slides

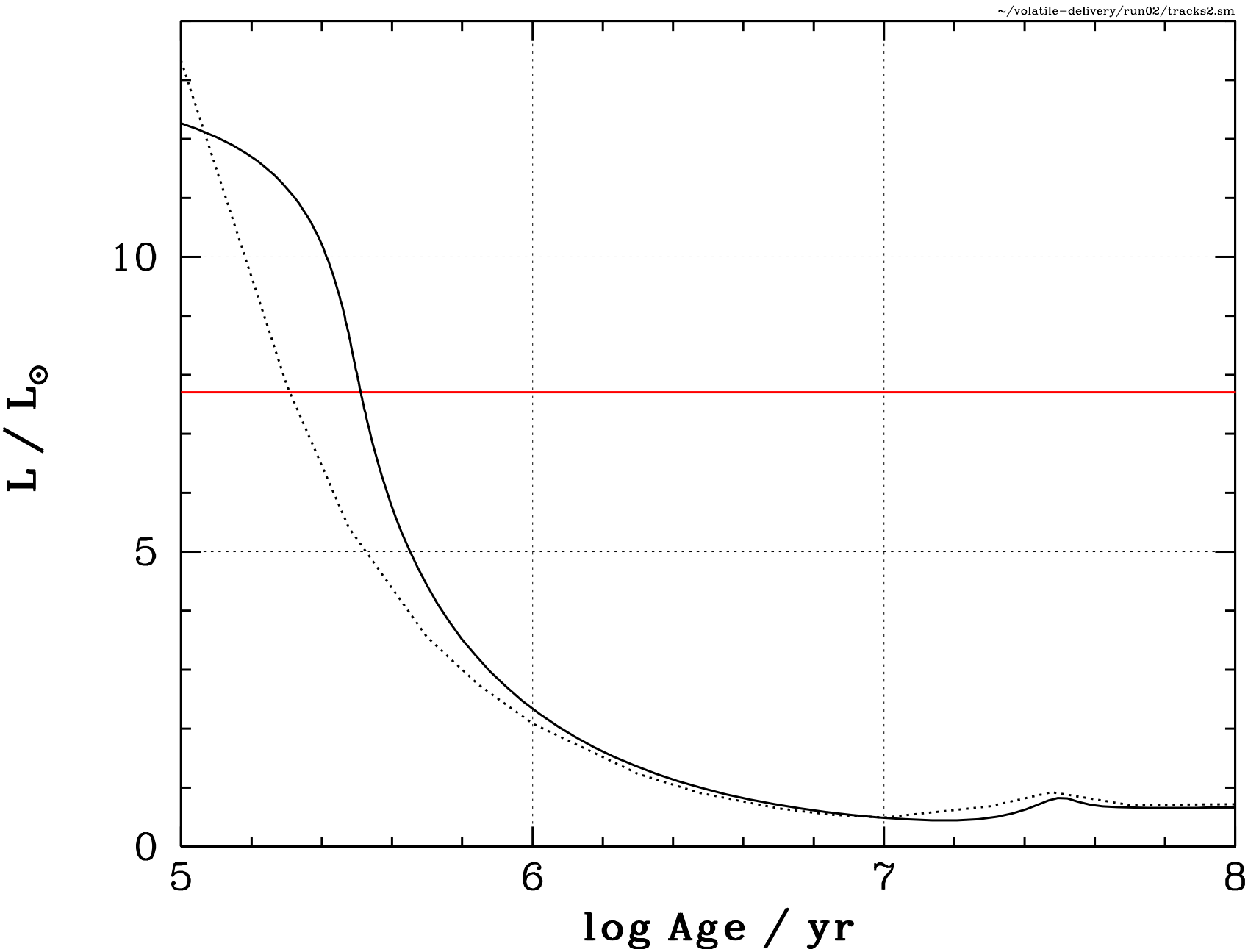

~/volatile-delivery/run04/preibisch1993.sm
Albedo, Opacity / cm² g⁻¹ of gas
1000
100
10
1
0.1
0.01
0.001
0.0001
0.1
1
10
100
1000
Wavelength / μm

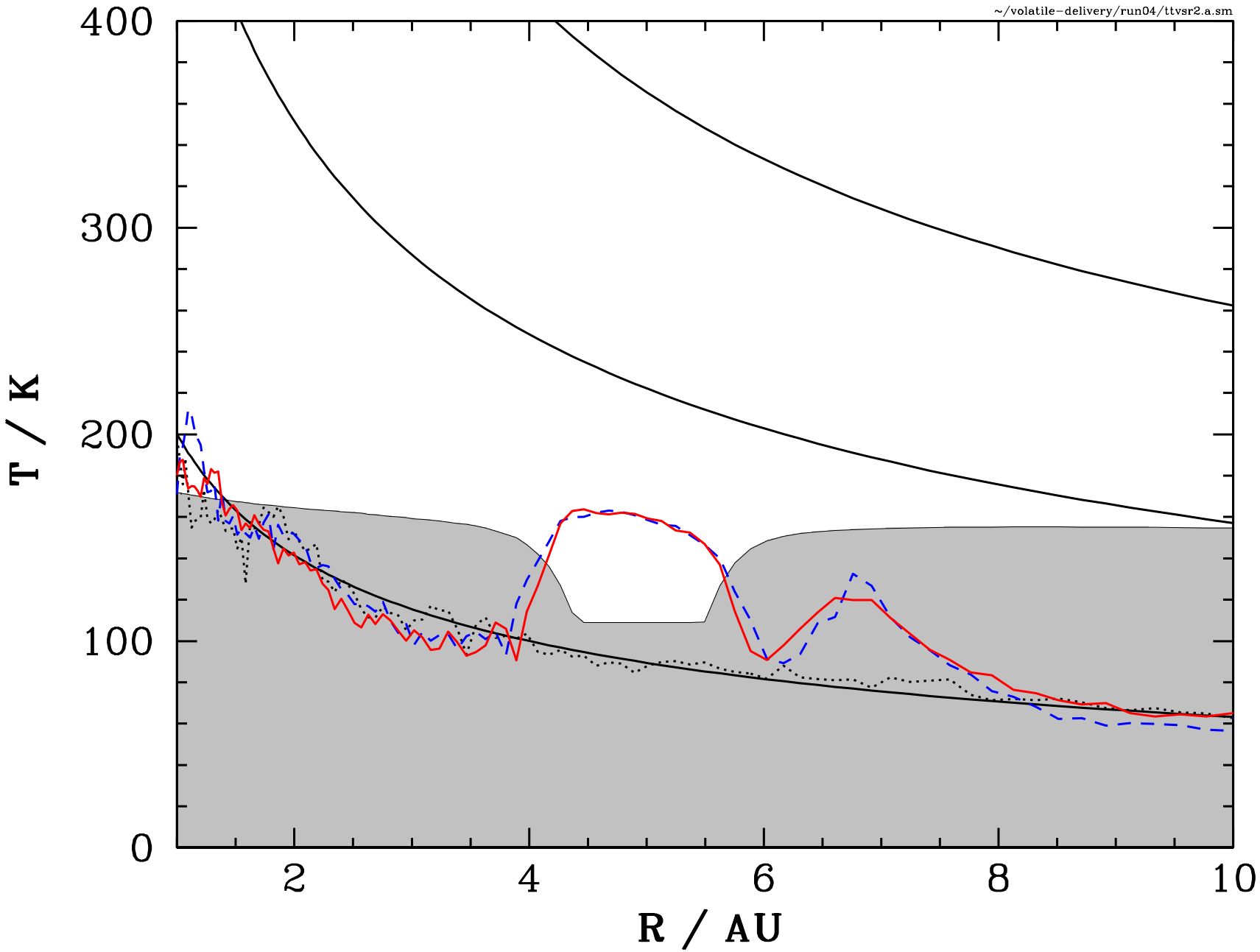
Dullemond et al. 2007 in PPV



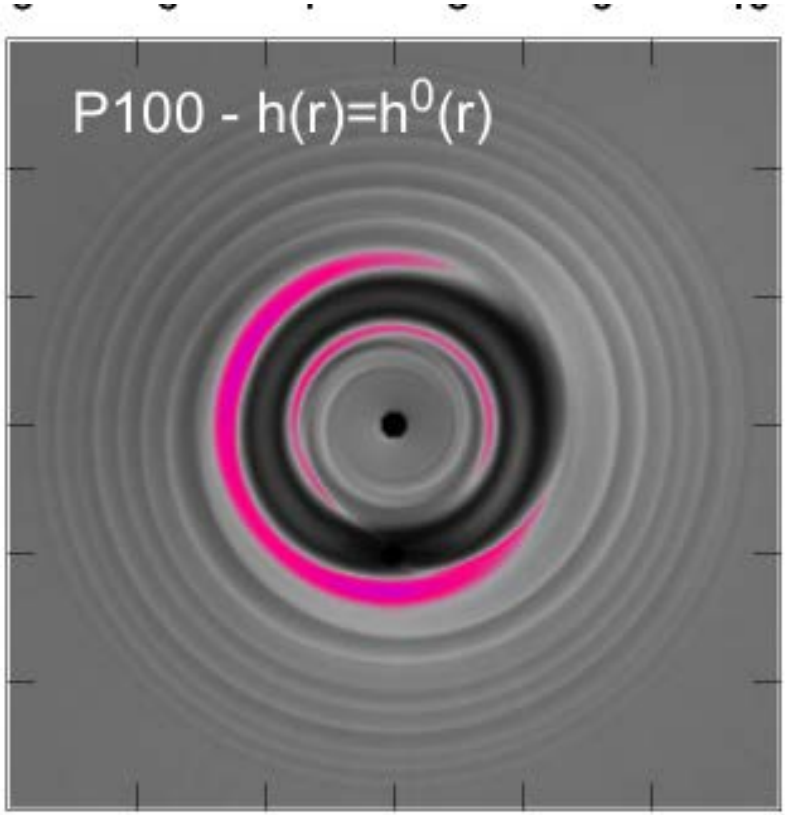

~/volatile-delivery/run04/exe13/z0packets.sm
z / AU
R / AU
0
1
2
3
4
0
2
4
6
8
10
12
τ_*^z=1

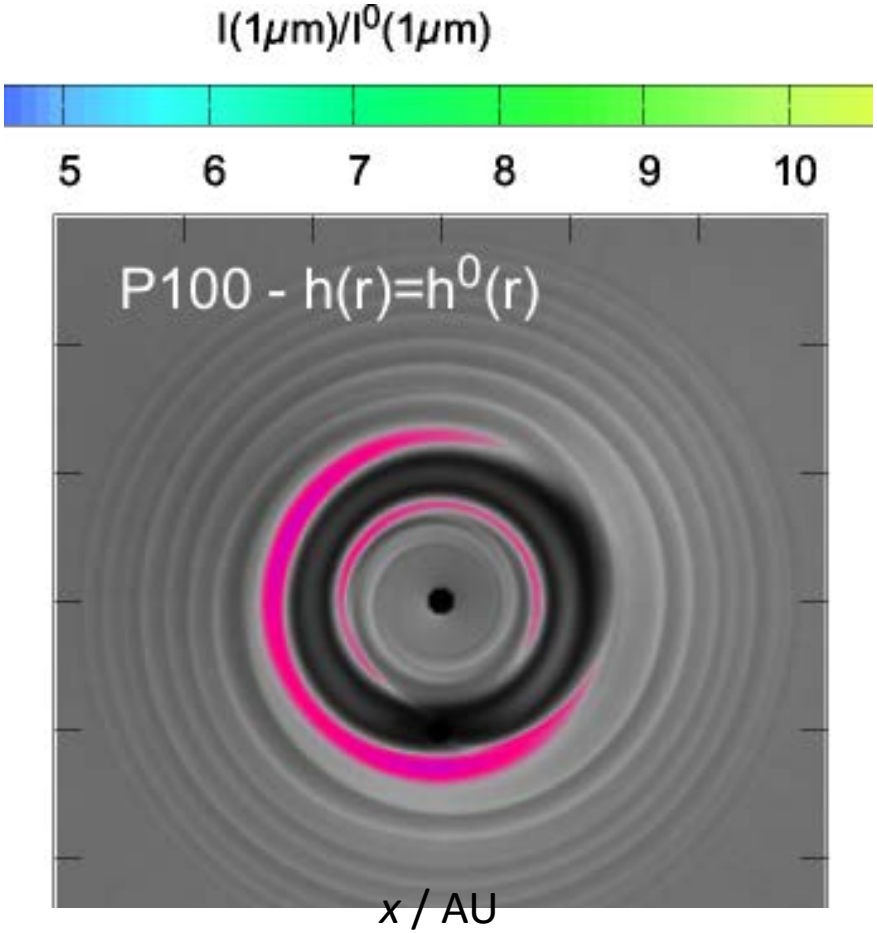

~/volatile-delivery/run04/exe13/z0spectrum.sm
1
0.1
0.01
0.001
0.0001
0.1
1
10
100
1000
log λJ_λ / J
log λ / μm

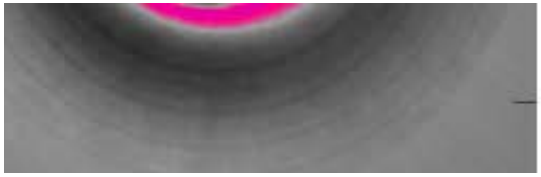

~/volatile-delivery/run02/tracks2.sm
10
5
0
5
6
7
8
L / L⊙
log Age / yr

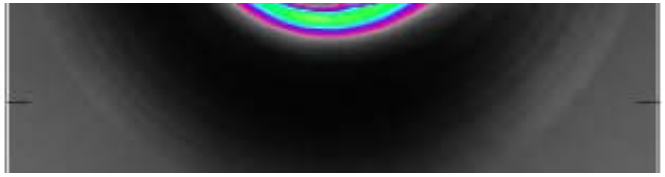

~/volatile-delivery/run04/ttvsr2.a.sm
400
300
200
100
0
T / K
2
4
6
8
10
R / AU

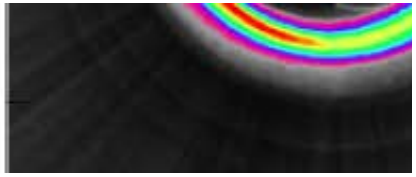
Synthetic 1-μm Images With 100-Earth-Mass Planet

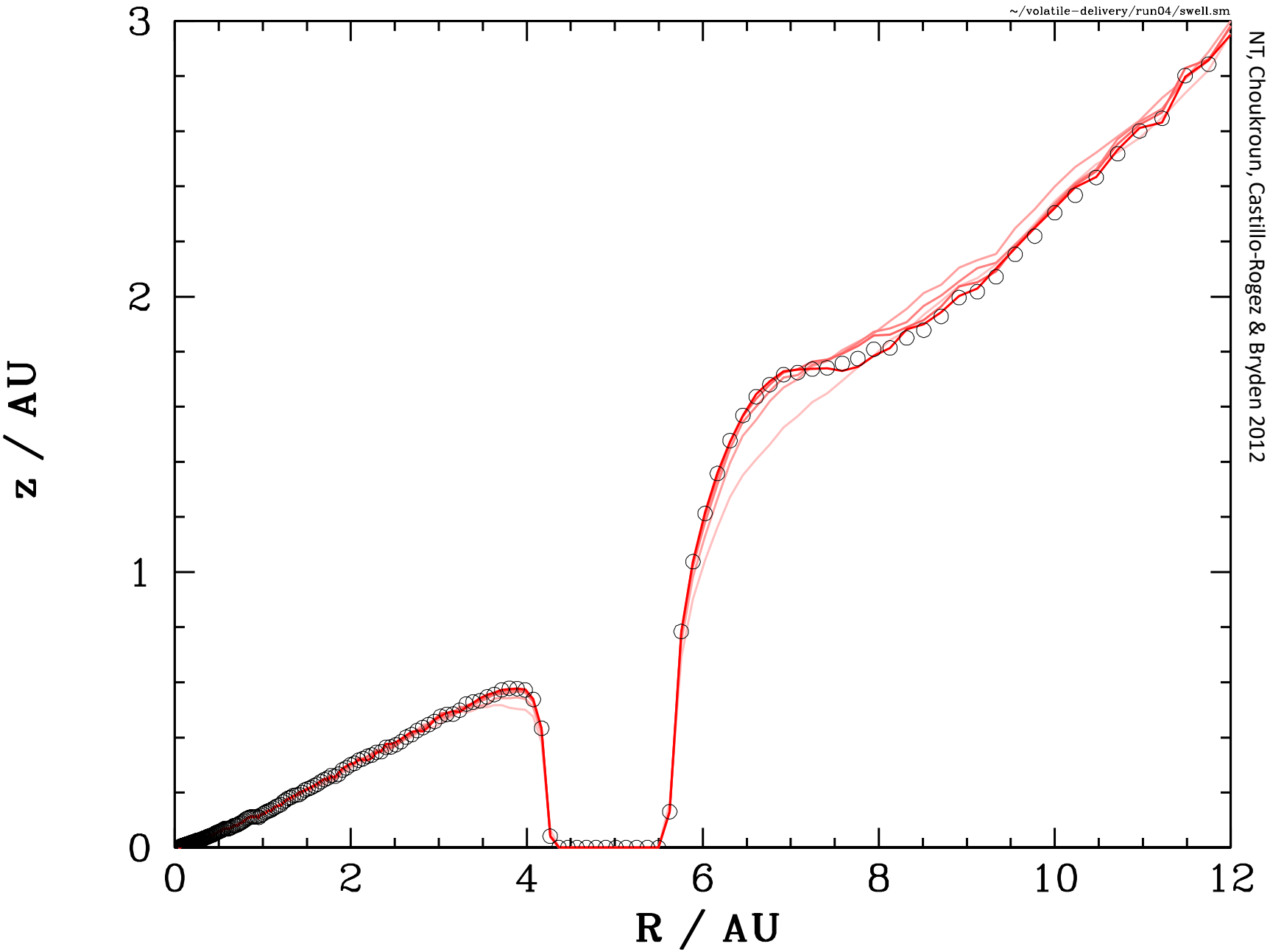


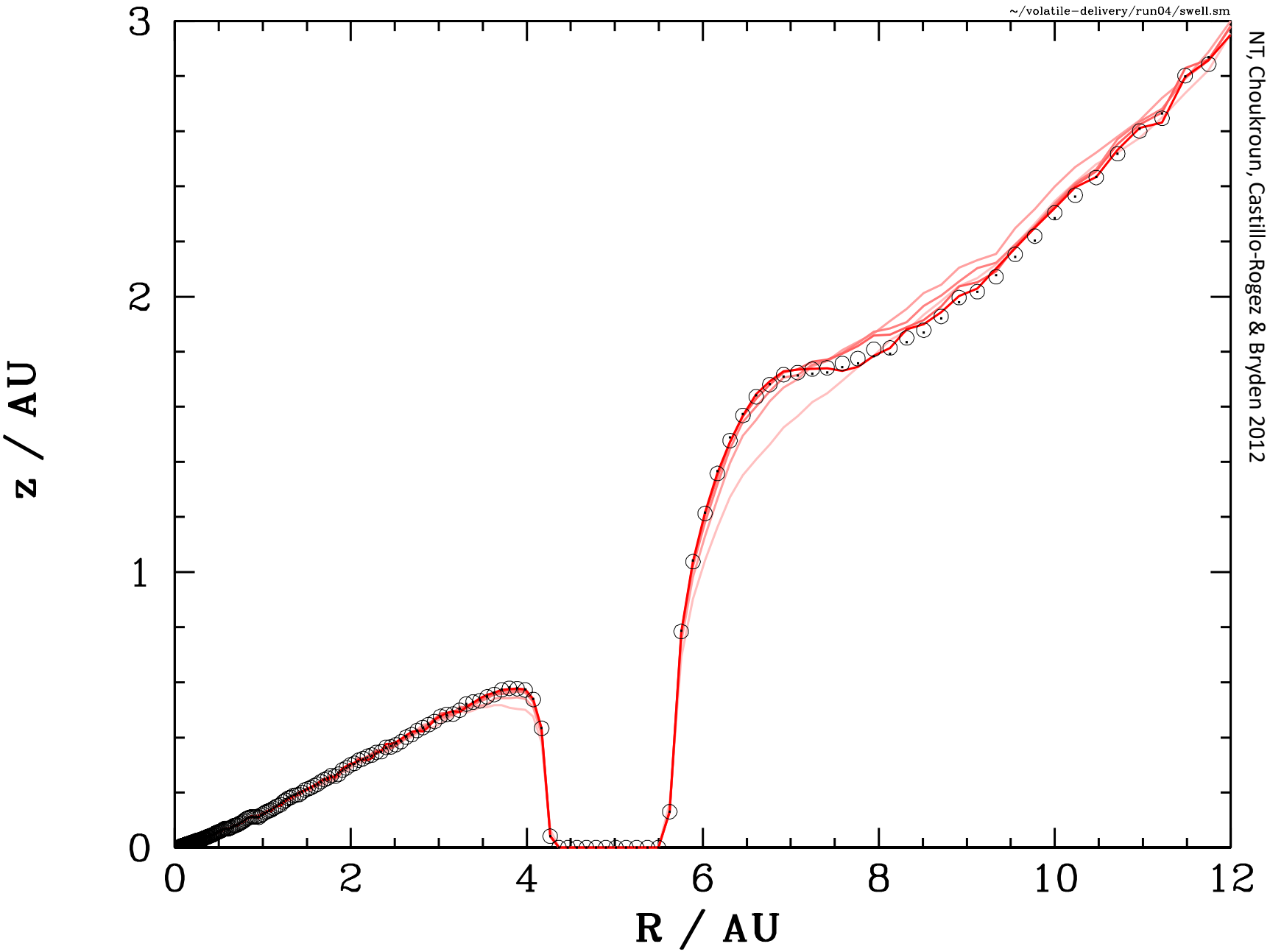









~/volatile-delivery/run04/swell.sm
NT, Choukroun, Castillo-Rogez & Bryden 2012
z / AU
R / AU
0
1
2
3
0
2
4
6
8
10
12


~/volatile-delivery/run04/swell.sm
NT, Choukroun, Castillo-Rogez & Bryden 2012
z / AU
R / AU
0
1
2
3
0
2
4
6
8
10
12