WHAT'S NEW IN PHANTOM ?

Daniel Price

4th Phantom & MCFOST users workshop

13th Feb 2023

1ST PHANTOM USERS WORKSHOP (2018)


EUROPEAN USERS WORKSHOP 2018…

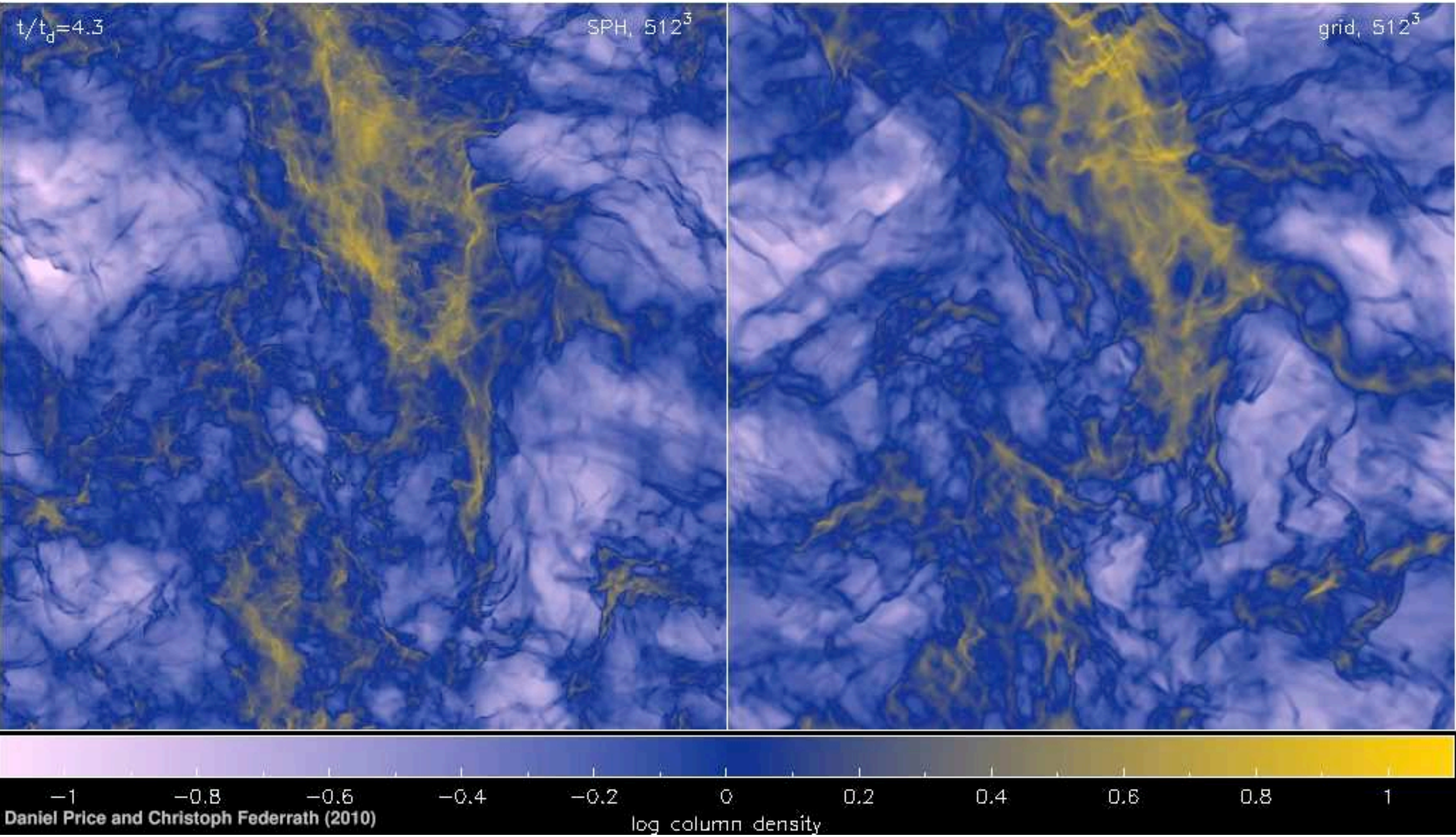

15
HIGH QUALITY
VHS CLUB 80'S
3RD PHANTOM USERS WORKSHOP 2020

ORIGINAL DESIGN MOTIVATIONS

- Get away from sphNG (in speed and pain)
- Cosmology codes are not ideal for star and planet formation (they don't care about the same things)
- Code should include physics relevant to stars and planets
- Take the best from my other codes and make it fast
- Needed a public code that stays up to date with our group's algorithm development (MHD, dust, etc)
- Low memory footprint

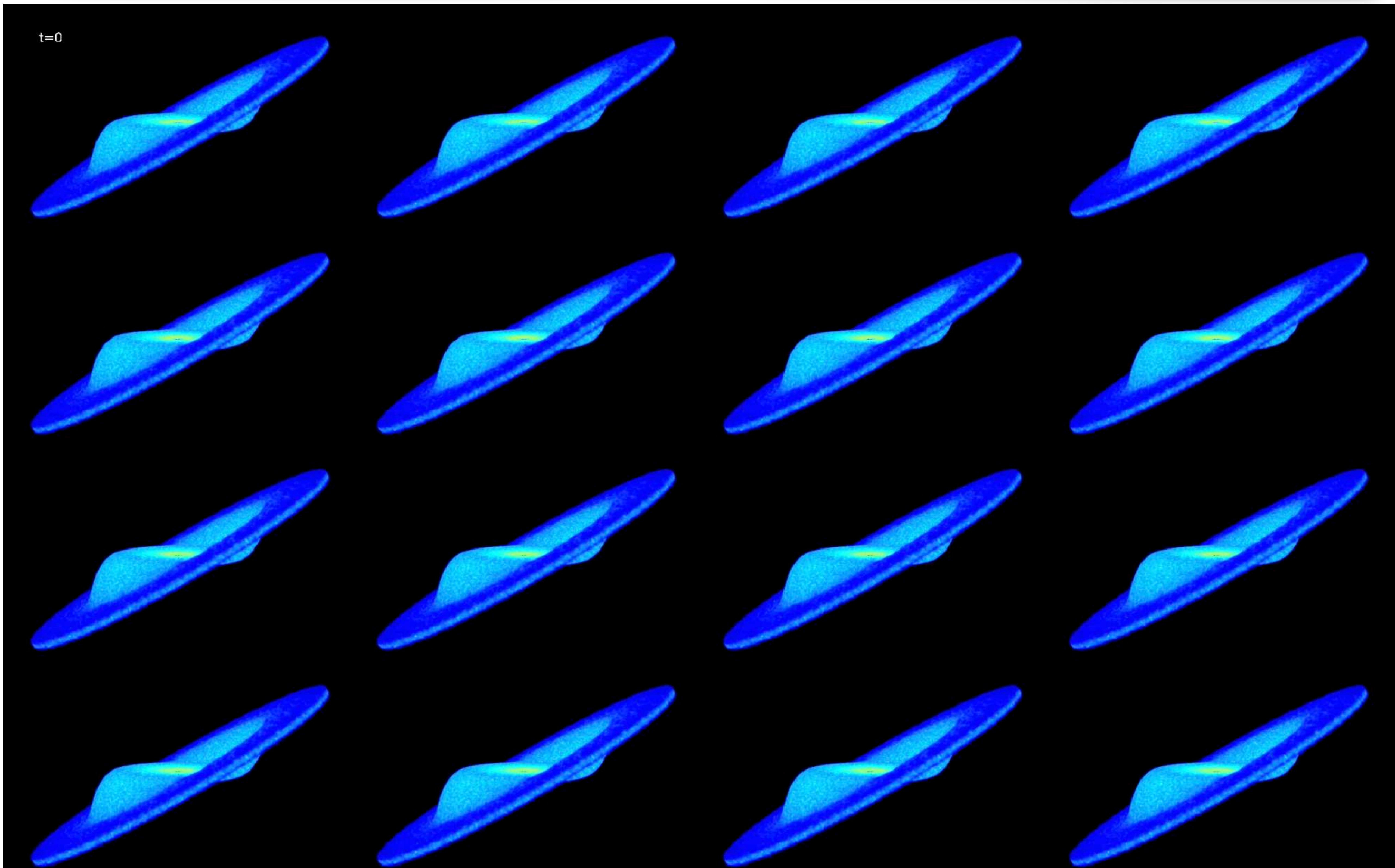
INITIAL APPLICATIONS AND PHYSICS DEVELOPMENT

Price & Federrath (2010): Comparison of driven turbulence

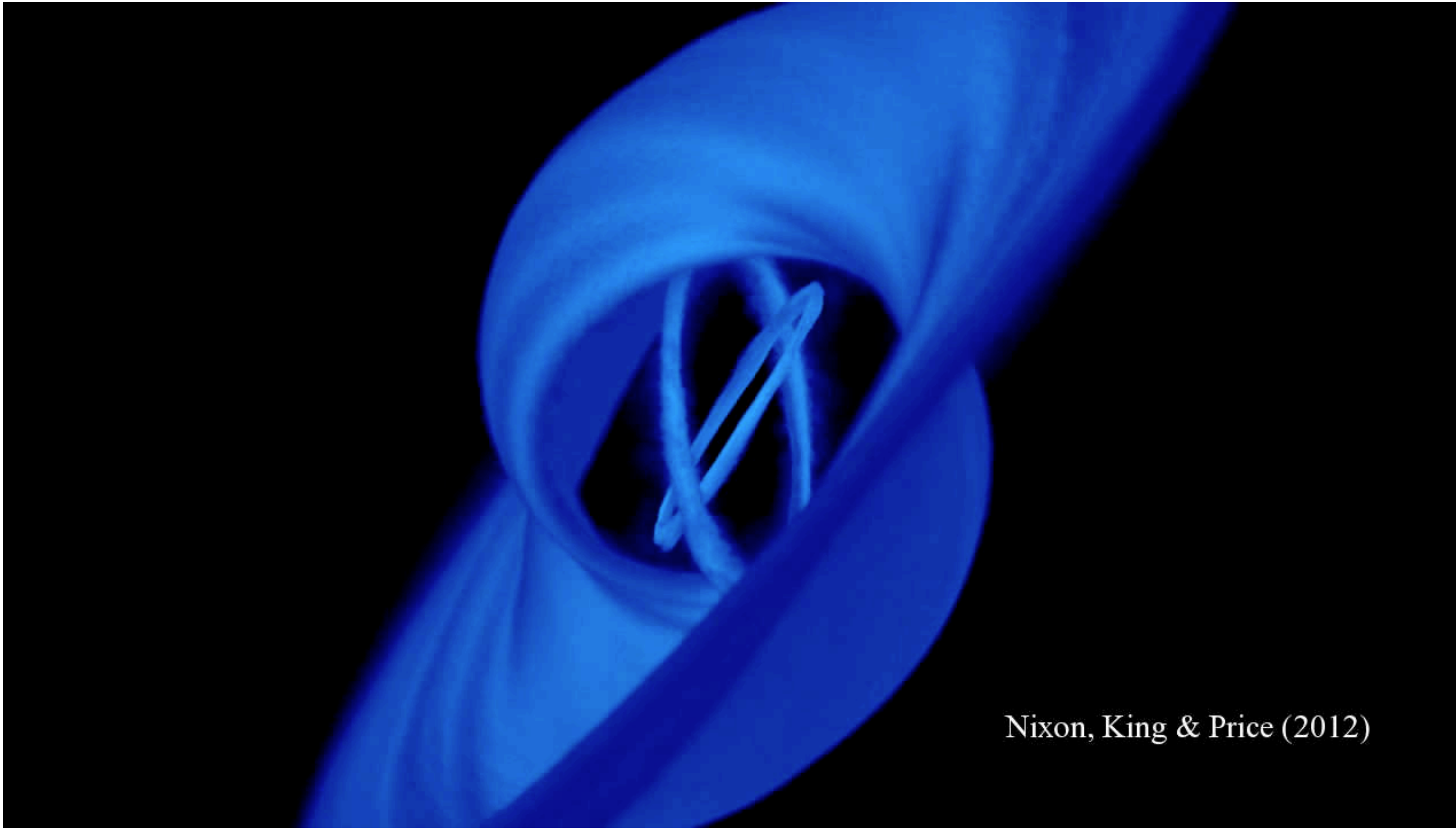


PHANTOM *FLASH*

Lodato & Price (2010) - warped discs

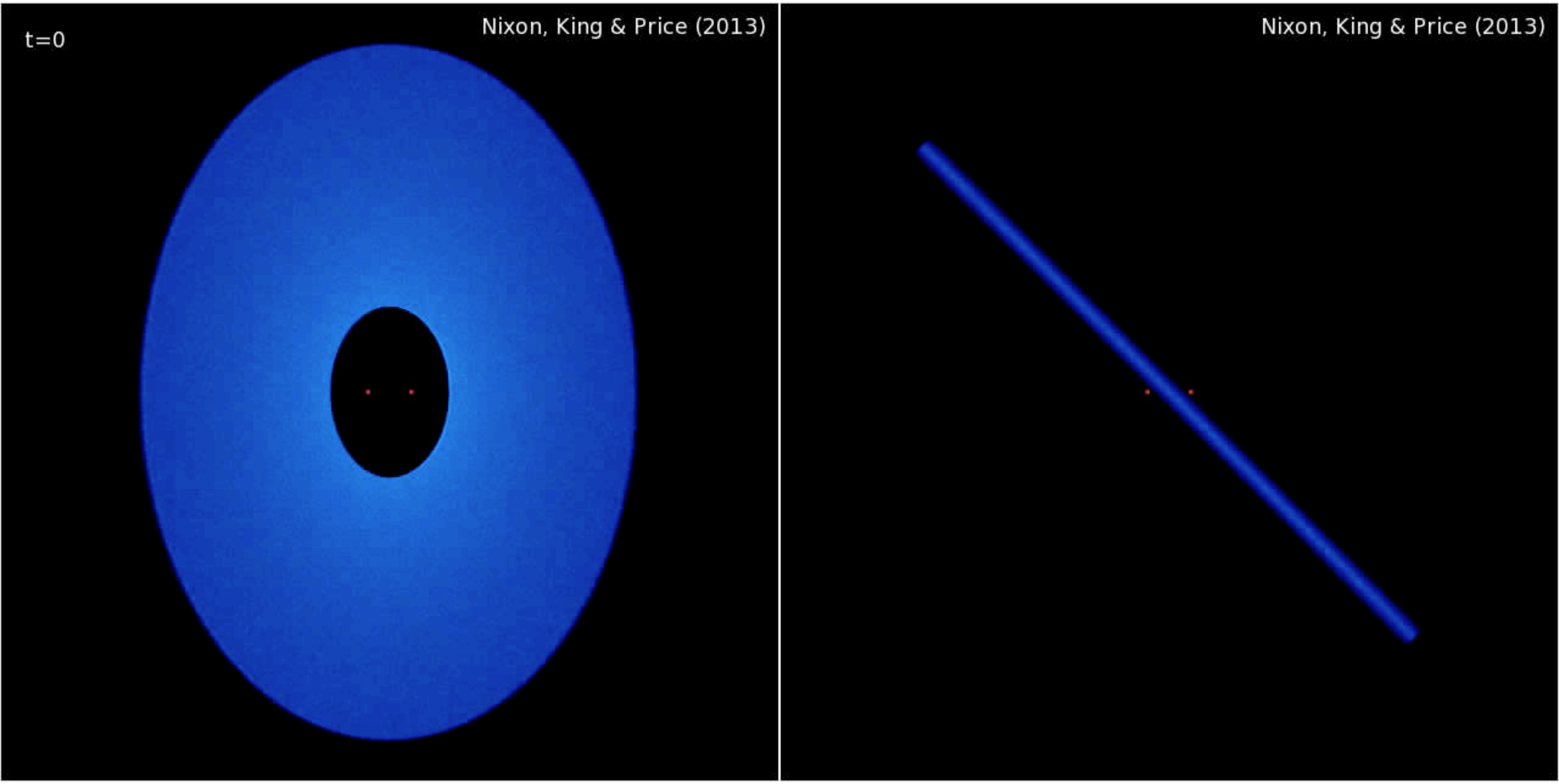


DISC TEARING



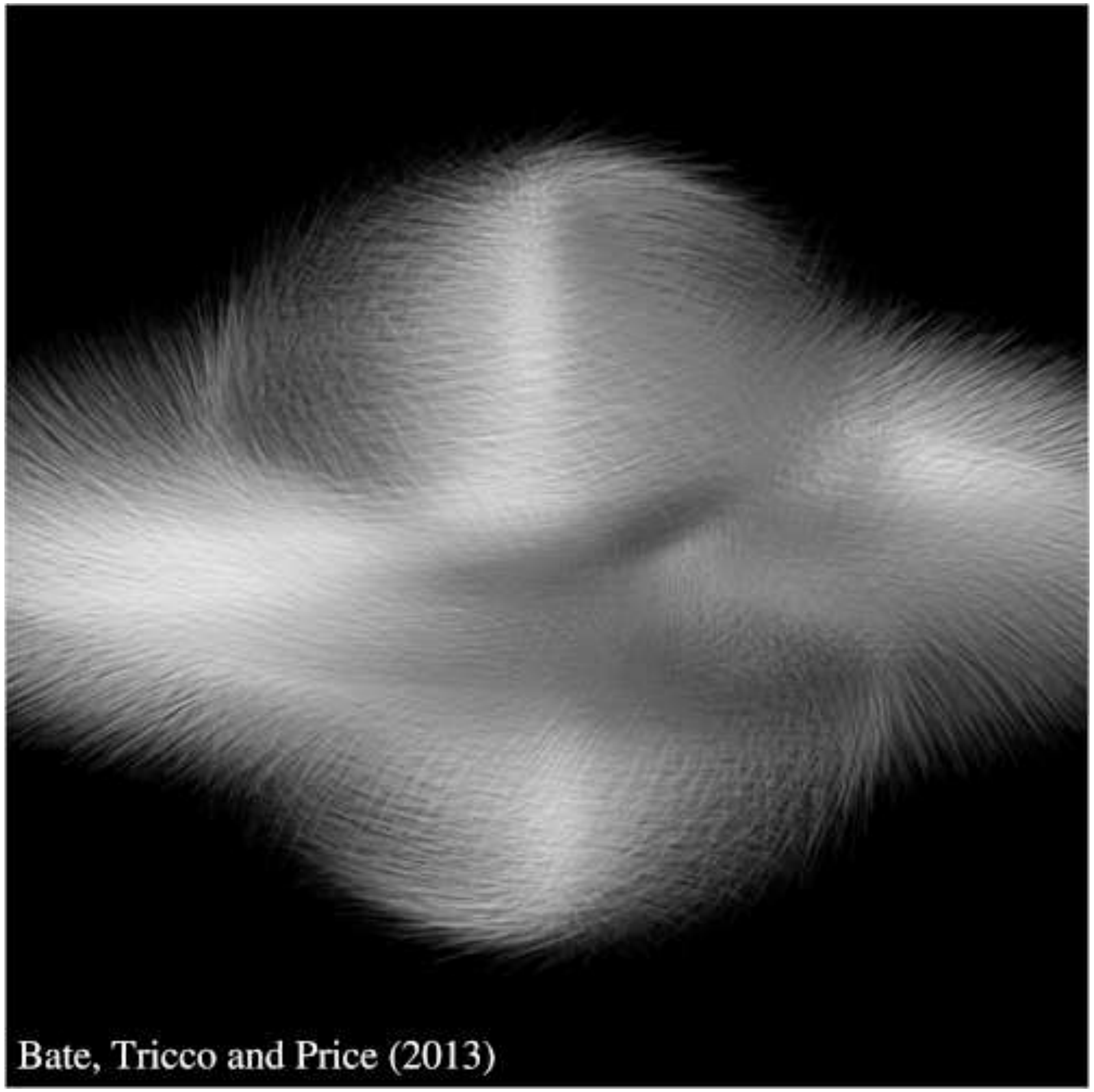
DISC TEARING BY BINARIES

Nixon et al. (2013)

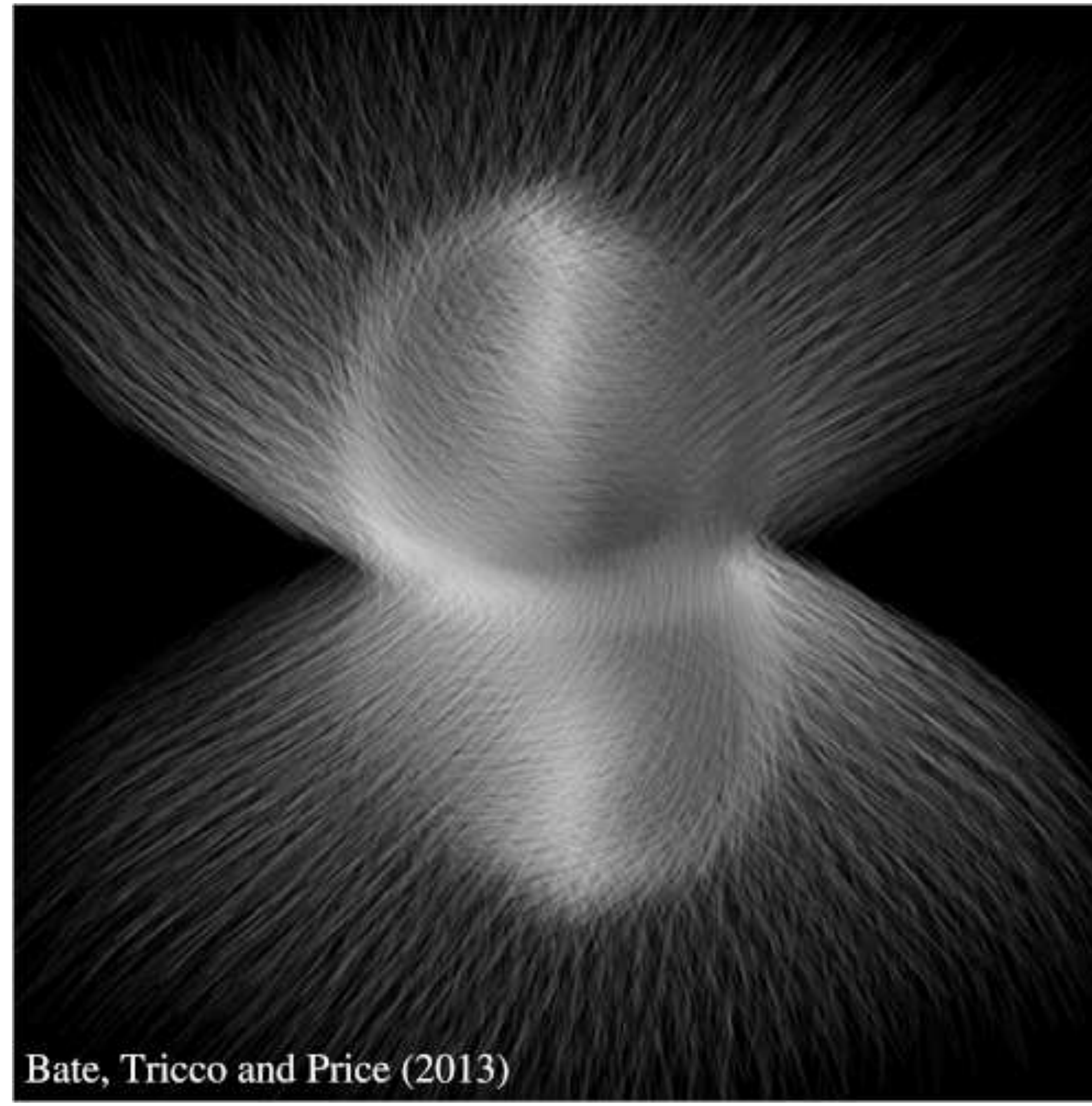


Sink particles used for first time

MAGNETOHYDRODYNAMICS (2012-)

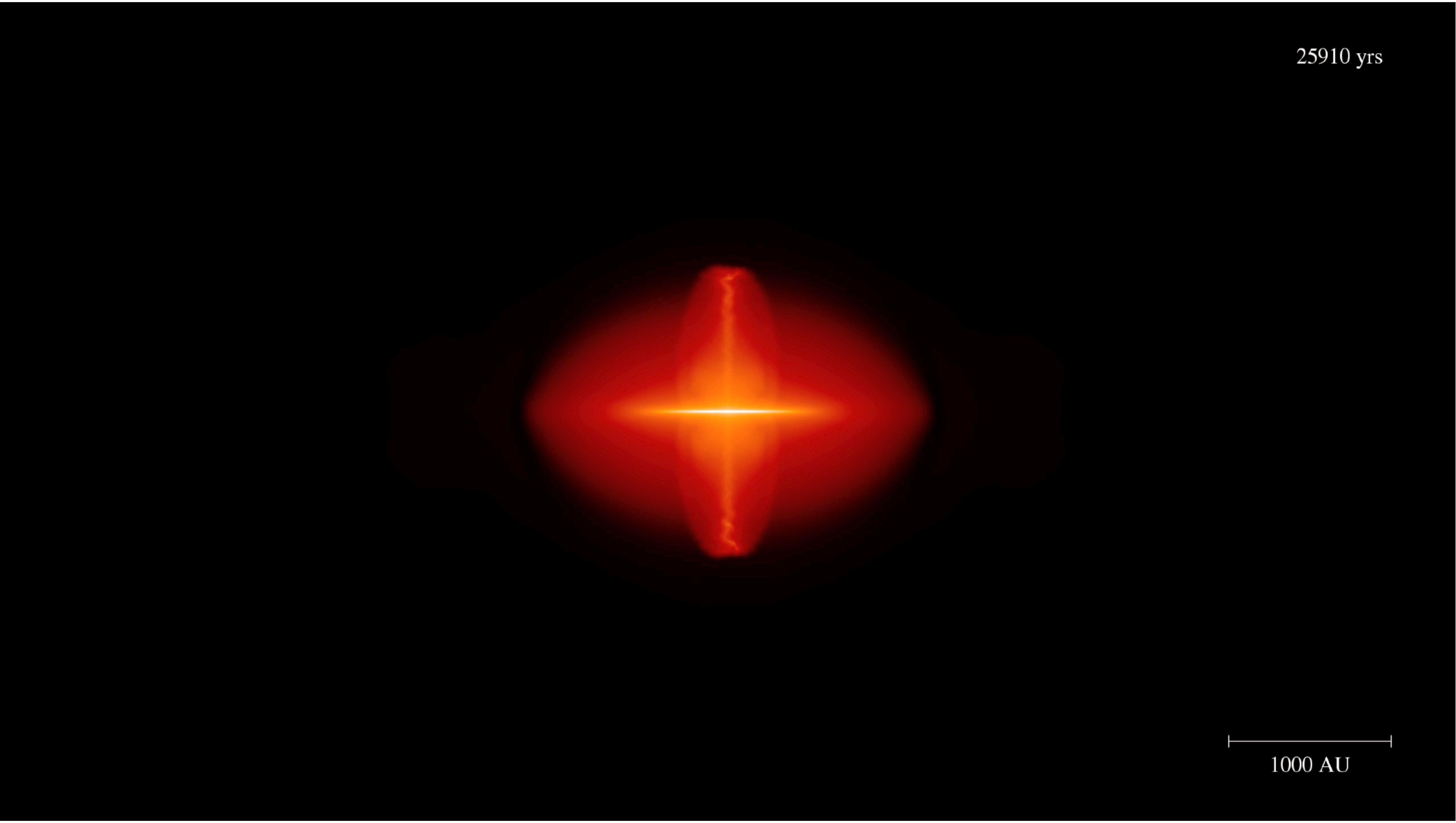


First core (100 x 100 au)



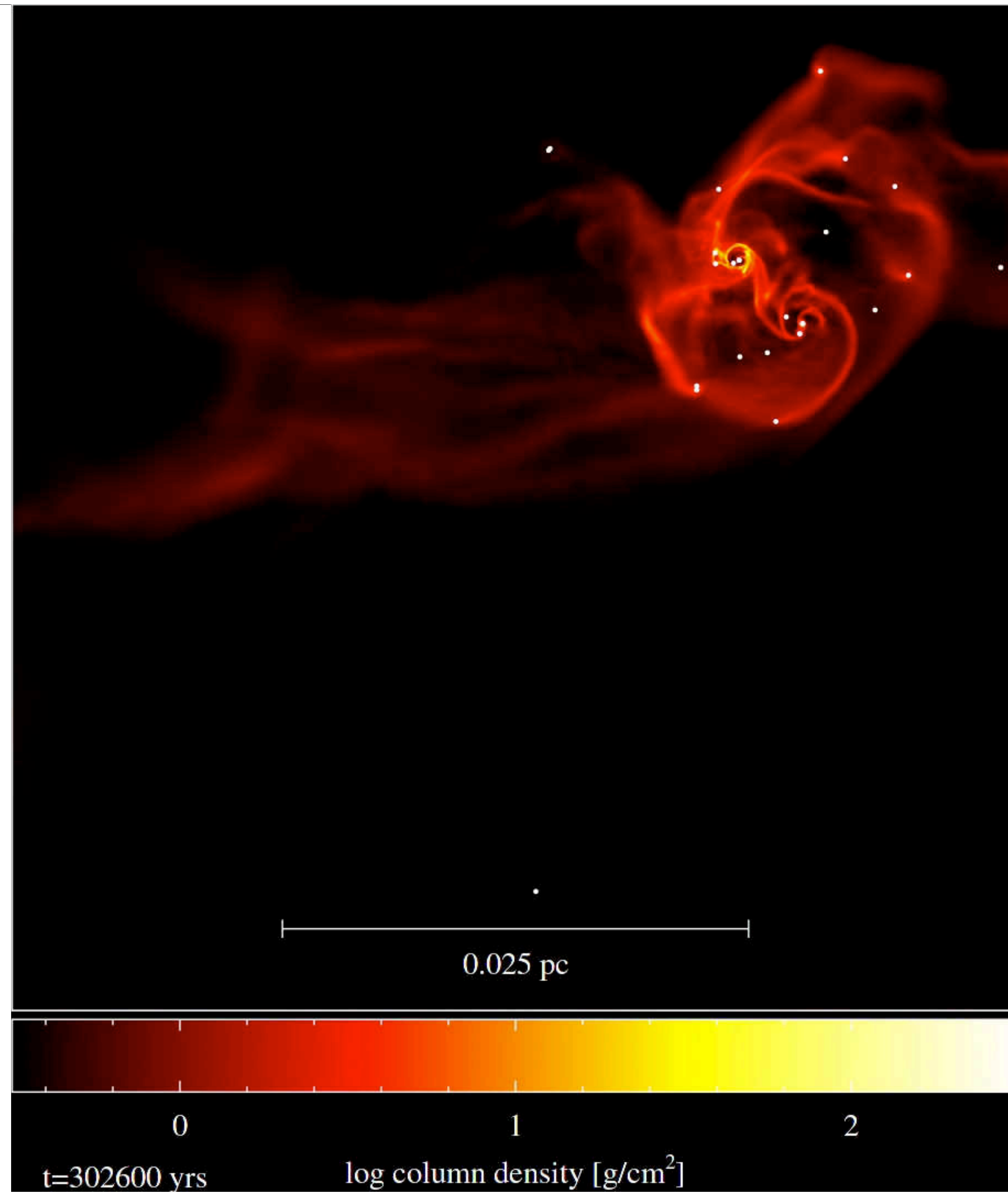
Second (protostellar) core (10 x 10 au)

SELF-GRAVITY



Price, Tricco & Bate (2012)

STAR CLUSTER FORMATION (INCL. SINK PARTICLE CREATION)



Liptai et al. (2017)

NON-IDEAL MHD

Wurster, Price & Ayliffe (2014), Wurster, Price & Bate (2016), MNRAS

Strong coupling approximation: $\rho \approx \rho_n; \;\; \rho_i \ll \rho$

$$\frac{\mathrm{d}\mathbf{B}}{\mathrm{d}t} = -\mathbf{B}(\nabla \cdot \mathbf{v}) + (\mathbf{B} \cdot \nabla)\mathbf{v} - \nabla \times \left[\eta_O \mathbf{J} + \eta_H \mathbf{J} \times \hat{\mathbf{B}} - \eta_A (\mathbf{J} \times \hat{\mathbf{B}}) \times \hat{\mathbf{B}} \right]$$

Ohmic **Hall** **Ambipolar**

See James Wurster talk for recent applications

Whistler/Ion-cyclotron modes

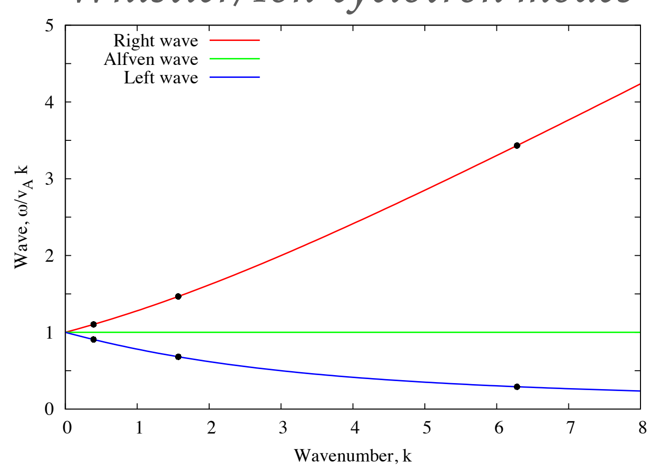
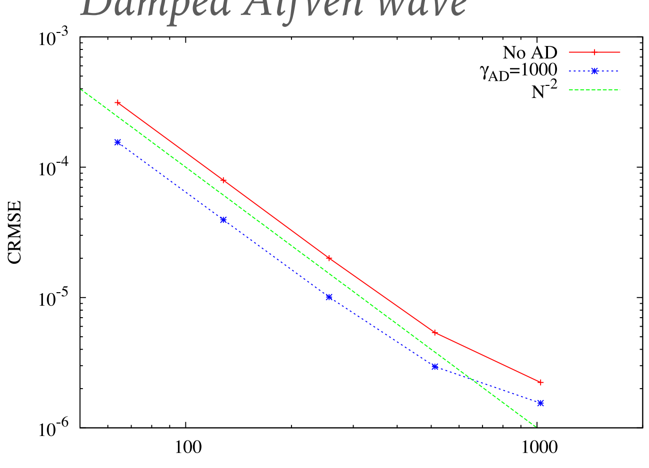


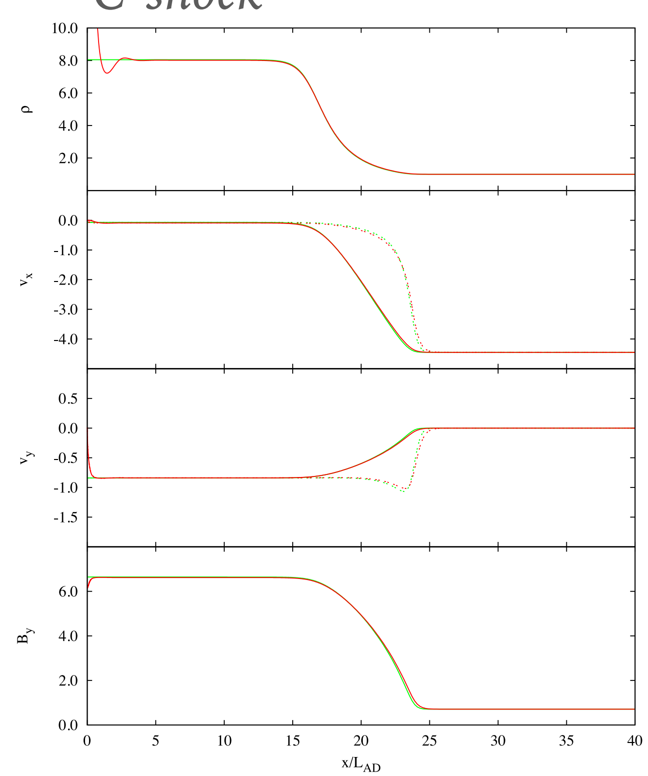
Figure C1. Dispersion relation for the left- and right-circularly polarised wave, corresponding to $\eta_{\rm HE} < 0$ and > 0, respectively. The solid circles are the numerically calculated phase velocities.

Damped Alfvén wave



Tests:
Mac-Low et al. (1995)
O'Sullivan & Downes (2006)
Choi et al. (2009)
Falle (2003)

C-shock



Standing C-shock

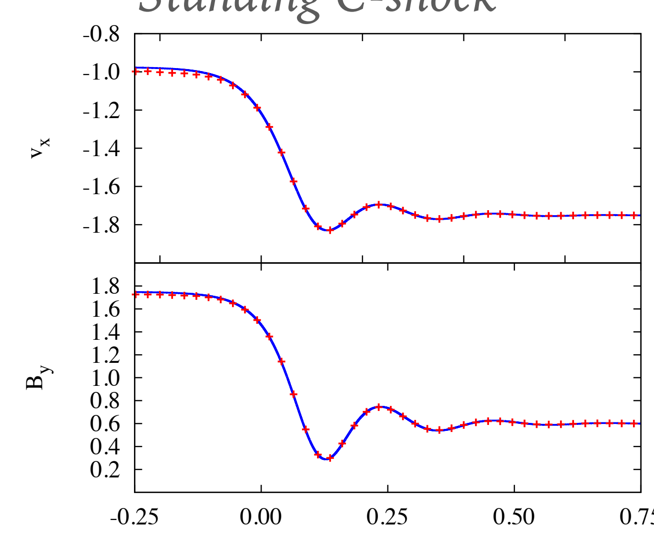
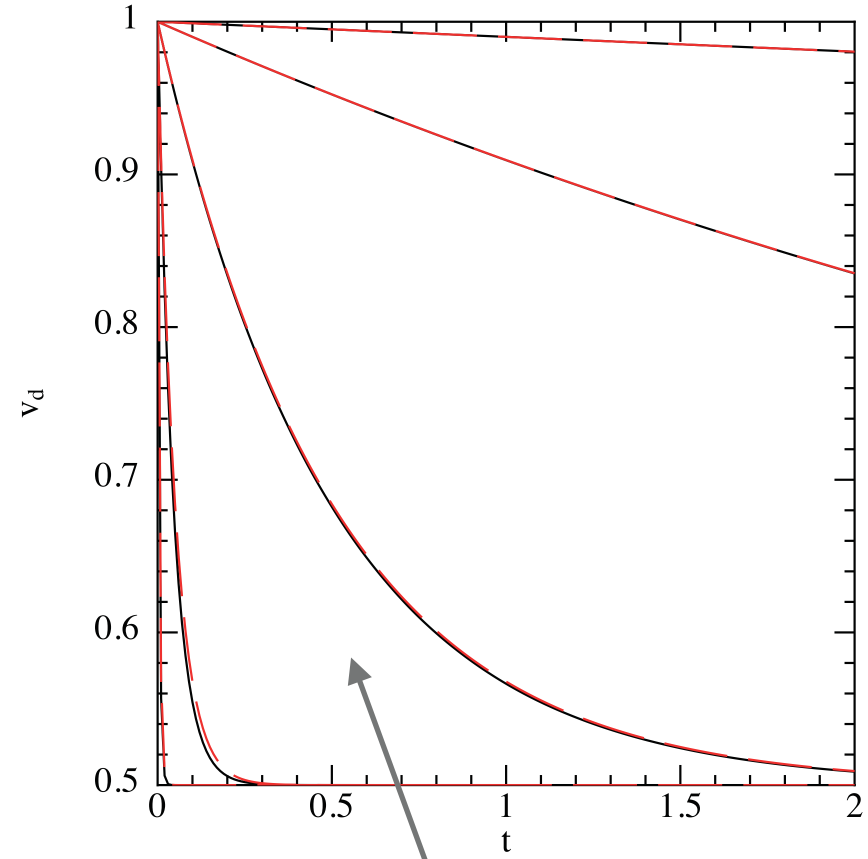


Figure C2. The analytical (solid line) and numerical (crosses) results for the isothermal standing shock. The initial conditions are given in the text. At any given position, the analytical and numerical solutions agree within 3 per cent.

"TWO FLUID" DUST-GAS MIXTURES



Characteristic timescale t_s

$$\frac{\partial \rho_{\rm g}}{\partial t} + \nabla . \left(\rho_{\rm g} \mathbf{v}_{\rm g}\right) = 0,$$

$$\frac{\partial \rho_{\rm d}}{\partial t} + \nabla . \left(\rho_{\rm d} \mathbf{v}_{\rm d}\right) = 0,$$

$$\frac{\partial \mathbf{v}_{\rm g}}{\partial t} + \left(\mathbf{v}_{\rm g} . \nabla\right) \mathbf{v}_{\rm g} = -\frac{\nabla P_{\rm g}}{\rho_{\rm g}} + K(\mathbf{v}_{\rm d} - \mathbf{v}_{\rm g}) + \mathbf{f},$$

$$\frac{\partial \mathbf{v}_{\rm d}}{\partial t} + \left(\mathbf{v}_{\rm d} . \nabla\right) \mathbf{v}_{\rm d} = -K(\mathbf{v}_{\rm d} - \mathbf{v}_{\rm g}) + \mathbf{f},$$

Timestep constraint: $\Delta t < t_{\rm s}$

DUST-GAS: ONE FLUID

One mixture with a differential velocity

$$\rho = \rho_{\rm d} + \rho_{\rm g}$$

$$\epsilon = \rho_{\rm d}/\rho$$

$$\mathbf{v} = \frac{\rho_{\rm d}\mathbf{v}_{\rm d} + \rho_{\rm g}\mathbf{v}_{\rm g}}{\rho}$$

$$\Delta\mathbf{v} = \mathbf{v}_{\rm d} - \mathbf{v}_{\rm g}$$

$$\frac{\partial \rho_{\rm g}}{\partial t} + \nabla\cdot(\rho_{\rm g}\mathbf{v}_{\rm g}) = 0,$$

$$\frac{\partial \rho_{\rm d}}{\partial t} + \nabla\cdot(\rho_{\rm d}\mathbf{v}_{\rm d}) = 0,$$

$$\frac{\partial \mathbf{v}_{\rm g}}{\partial t} + (\mathbf{v}_{\rm g}\cdot\nabla)\mathbf{v}_{\rm g} = -\frac{\nabla P_{\rm g}}{\rho_{\rm g}} + \frac{K}{\rho_{\rm g}}(\mathbf{v}_{\rm d} - \mathbf{v}_{\rm g}) + \mathbf{f},$$

$$\frac{\partial \mathbf{v}_{\rm d}}{\partial t} + (\mathbf{v}_{\rm d}\cdot\nabla)\mathbf{v}_{\rm d} = -\frac{K}{\rho_{\rm d}}(\mathbf{v}_{\rm d} - \mathbf{v}_{\rm g}) + \mathbf{f},$$

$$\frac{{\rm d}\rho}{{\rm d}t} = -\rho(\nabla\cdot\mathbf{v}),$$

$$\frac{{\rm d}\epsilon}{{\rm d}t} = -\frac{1}{\rho}\nabla\cdot\left[\epsilon(1-\epsilon)\rho\Delta\mathbf{v}\right],$$

$$\frac{{\rm d}\mathbf{v}}{{\rm d}t} = -\frac{\nabla P}{\rho} - \frac{1}{\rho}\nabla\cdot\left[\epsilon(1-\epsilon)\rho\Delta\mathbf{v}\Delta\mathbf{v}\right] + \mathbf{f},$$

$$\frac{{\rm d}\Delta\mathbf{v}}{{\rm d}t} = -\frac{\Delta\mathbf{v}}{t_{\rm s}} + \frac{\nabla P}{\rho_{\rm g}} - (\Delta\mathbf{v}\cdot\nabla)\mathbf{v} + \frac{1}{2}\nabla\left[(2\epsilon-1)\Delta\mathbf{v}^2\right].$$

Laibe & Price (2014) MNRAS 440, 2136

ONE FLUID FOR SMALL GRAINS

Laibe & Price (2014), Price & Laibe (2015)

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho(\nabla\cdot\boldsymbol{v})$$

$$\frac{\mathrm{d}\epsilon}{\mathrm{d}t} = -\frac{1}{\rho}\nabla\cdot\left[\epsilon(1-\epsilon)\rho\Delta\boldsymbol{v}\right]$$

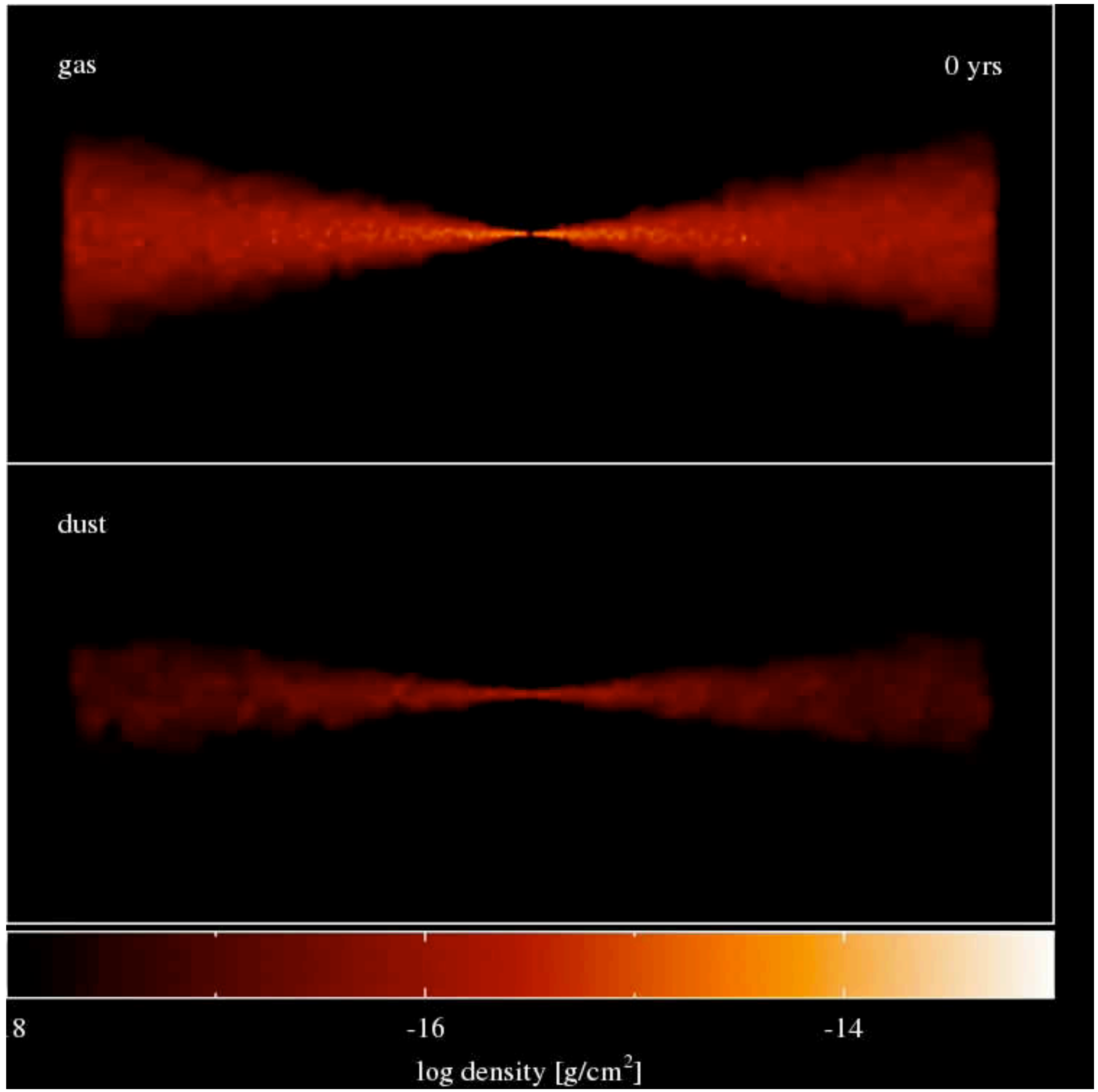
$$\frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} = -\frac{\nabla P}{\rho} - \frac{1}{\rho}\nabla\cdot\left[\epsilon(1-\epsilon)\Delta\boldsymbol{v}\Delta\boldsymbol{v}\right]$$

$$\frac{\mathrm{d}\Delta\boldsymbol{v}}{\mathrm{d}t} = -\frac{\Delta\boldsymbol{v}}{t_{\mathrm{s}}} + \frac{\nabla P}{\rho_{\mathrm{g}}} - (\Delta\boldsymbol{v}\cdot\nabla)\boldsymbol{v} + \frac{1}{2}\nabla\left[(2\epsilon-1)\Delta\boldsymbol{v}^2\right]$$

EXPLICIT when stopping time is short

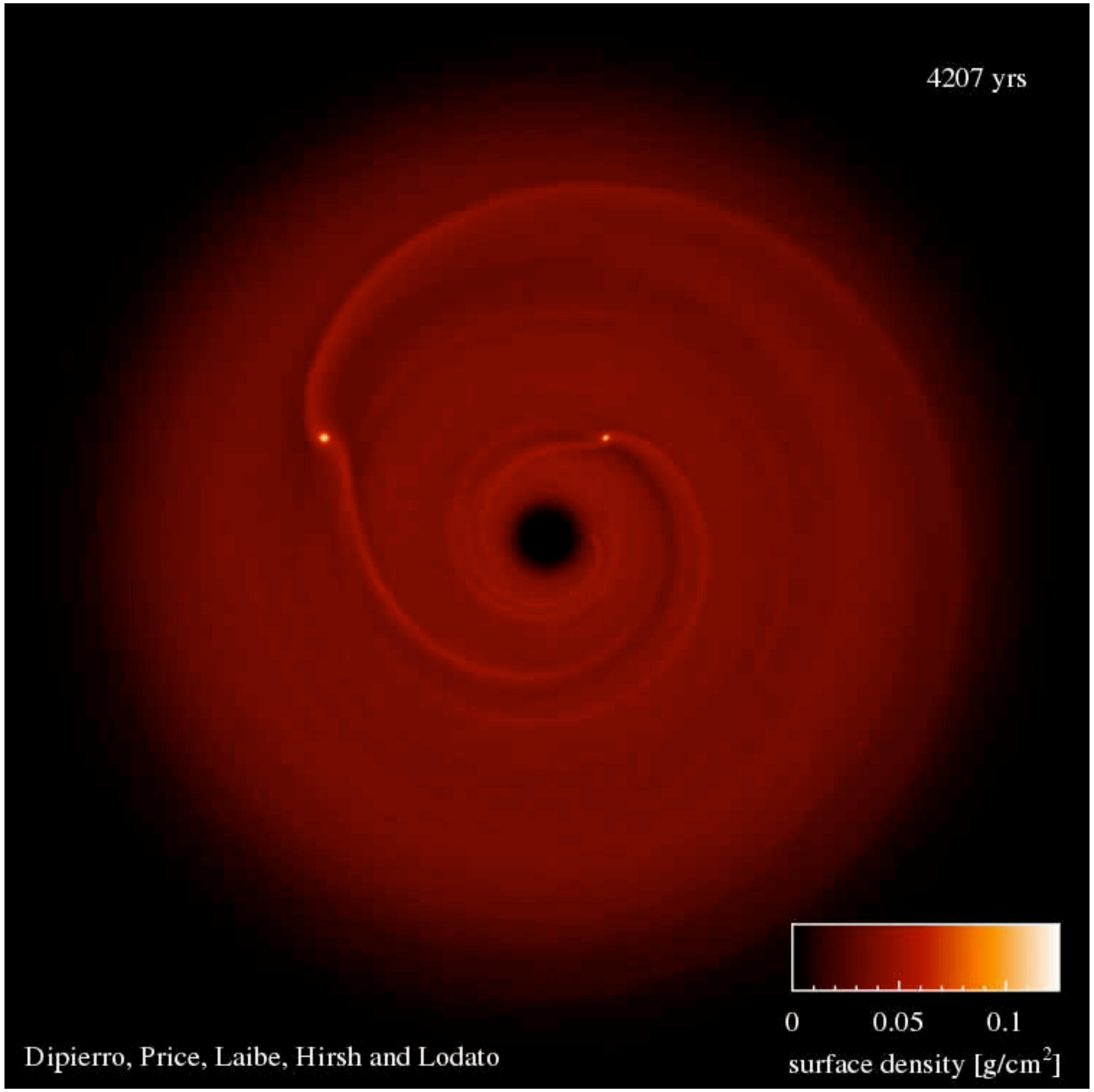
Terminal velocity approximation: See also Youdin & Goodman (2005); Chiang (2008); Barranco 2009, Jacquet et al. 2011

DUST SETTLING IN PROTOPLANETARY DISCS

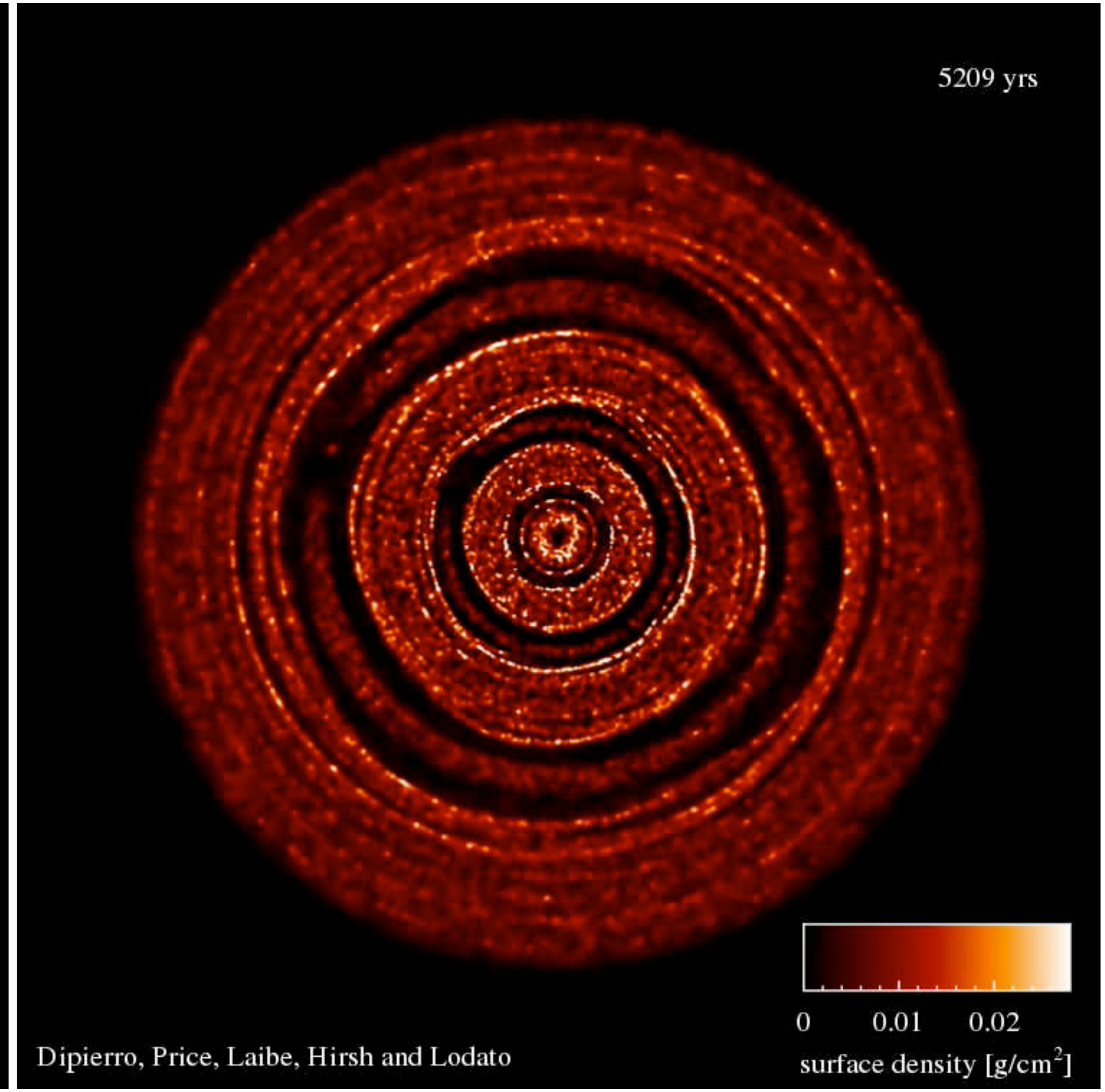


Dipierro, DP et al. (2015)

DUST, GAS AND PLANETS IN HL TAU



Gas



mm grains

DIFFERENT GRAIN SIZES

4 *Dipierro, Price, Laibe, Hirsh & Lodato*

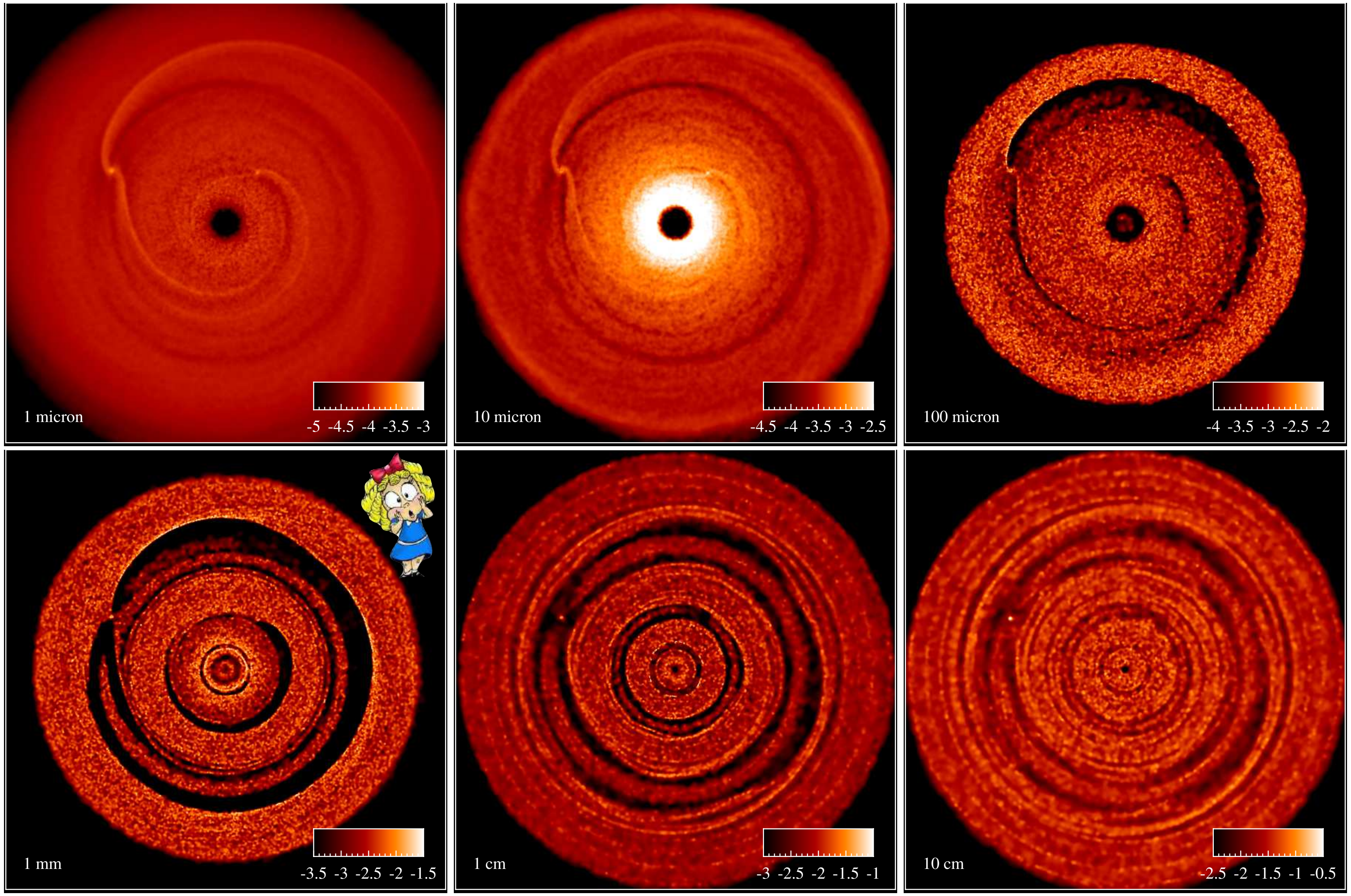


Figure 3. Rendered images of dust surface density for a disc containing three embedded protoplanets of mass 0.26, 0.30 and 0.35 $M_{\rm J}$ initially located at the same distance as the gaps detected in HL Tau. Each panel shows the simulation with gas+grains of a particular size (as indicated).

COMPARISON

Computed using RADMC3D radiative transfer code plus ALMA simulator

Observed

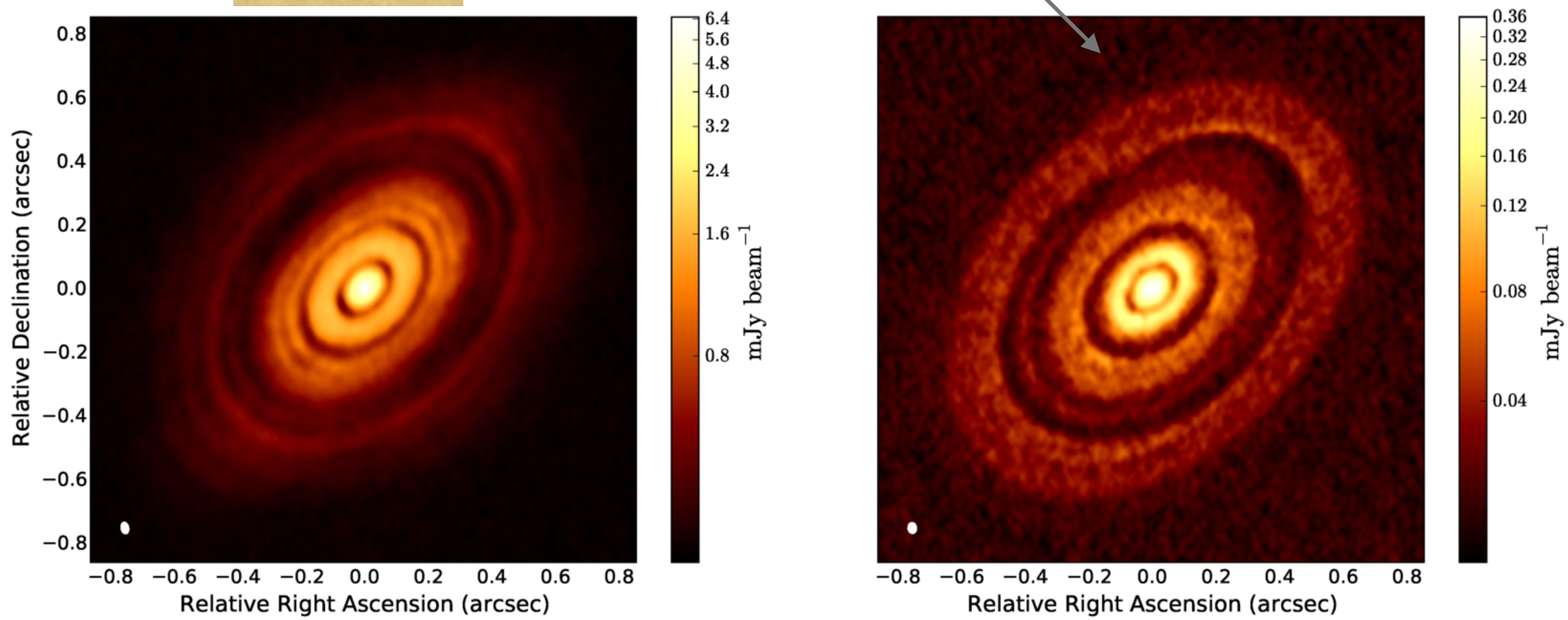
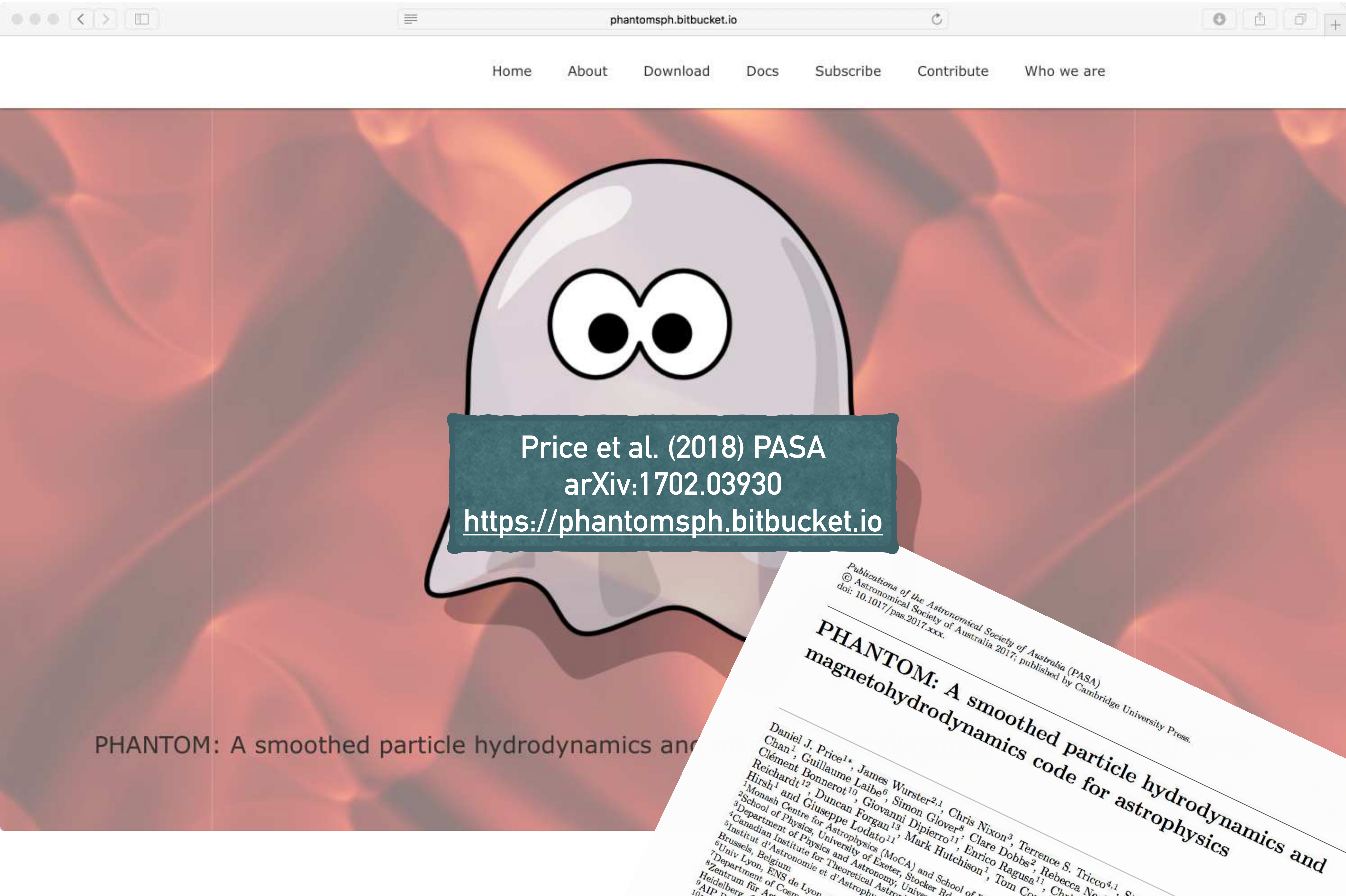


Figure 4. Comparison between the ALMA image of HL Tau (left) with simulated observations of our disc model (right) at band 6 (continuum emission at 233 GHz). The white colour in the filled ellipse in the lower left corner indicates the size of the half-power contour of the synthesized beam: (left) 0.035 arcsec × 0.022 arcsec, P.A. 11°; (right) 0.032 arcsec × 0.024 arcsec, P.A. 6°.

Dipierro, Price, et al. (2015), MNRAS 453, L73-L77

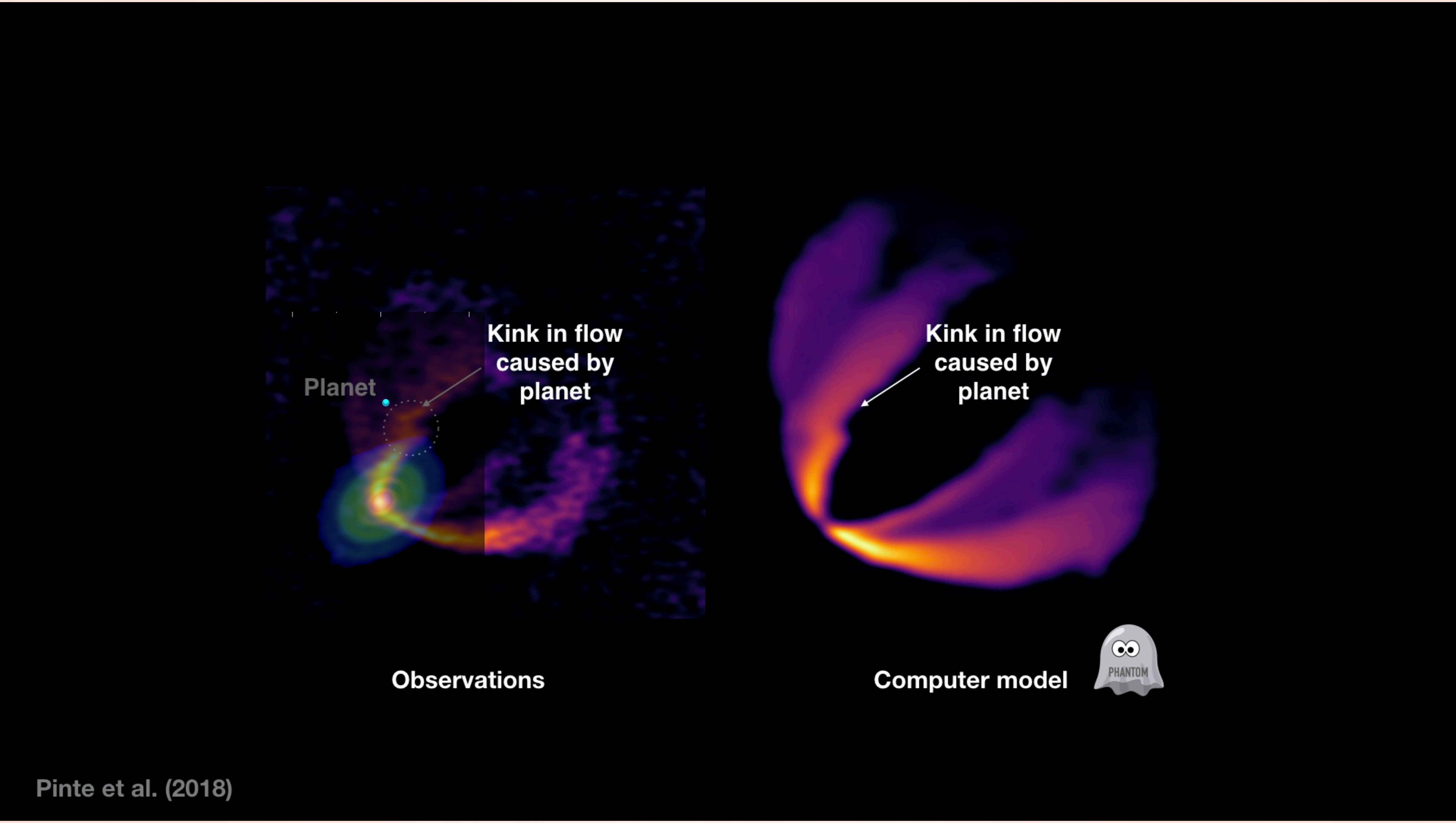
PHANTOM WENT PUBLIC IN 2018



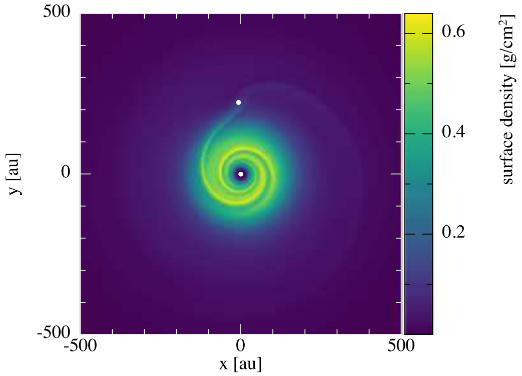
Price et al. (2018) PASA
arXiv:1702.03930
https://phantomsph.bitbucket.io

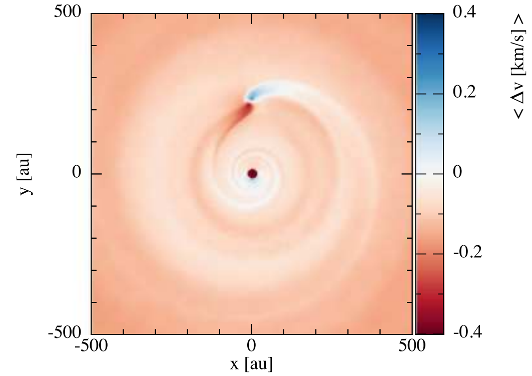
NEW CAPABILITIES (SINCE 2018)

PLANET HUNTING WITH DISC KINEMATICS

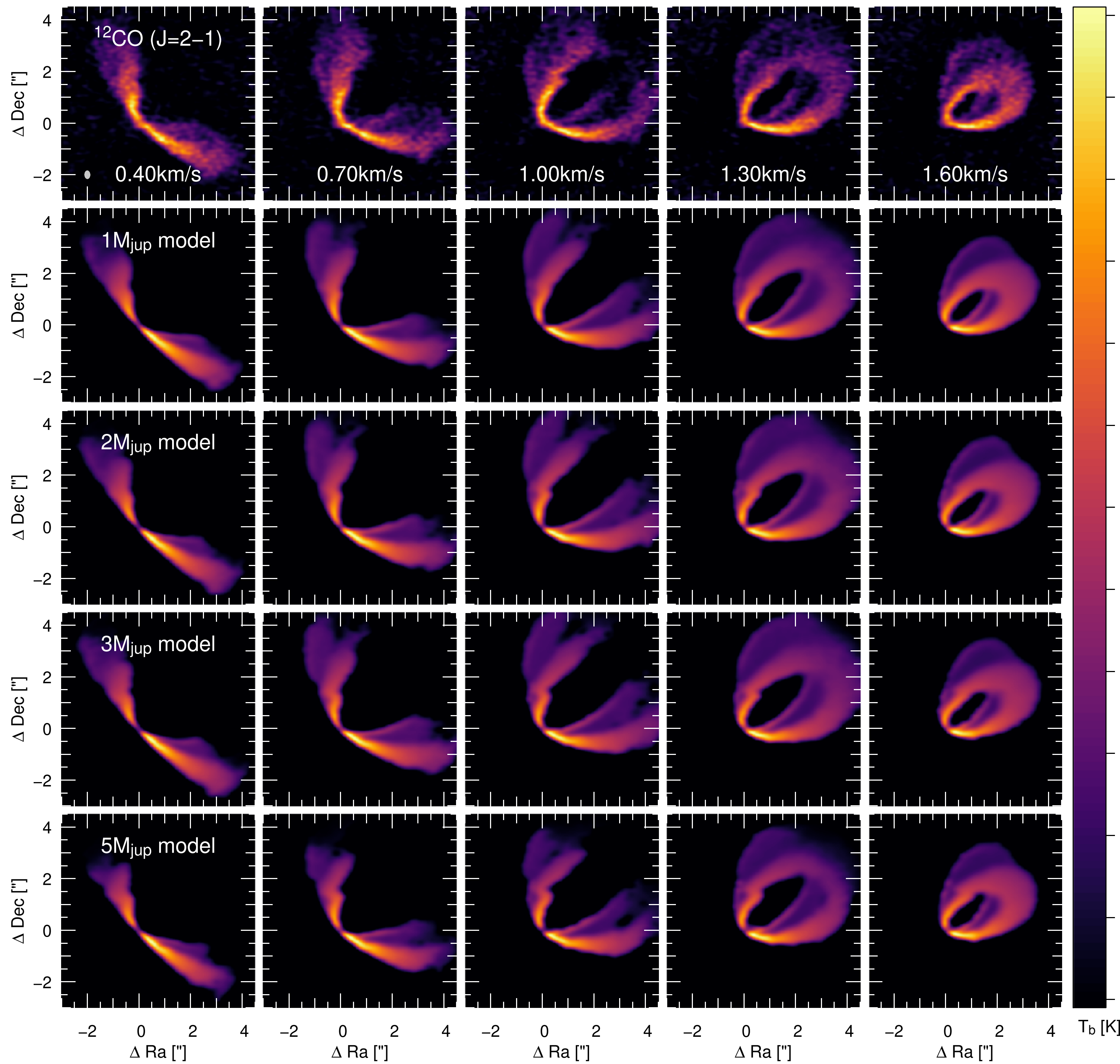


Enabled by direct post-processing of phantom snapshots with MCFOST, first implemented for Price+(2018) study of HD142527



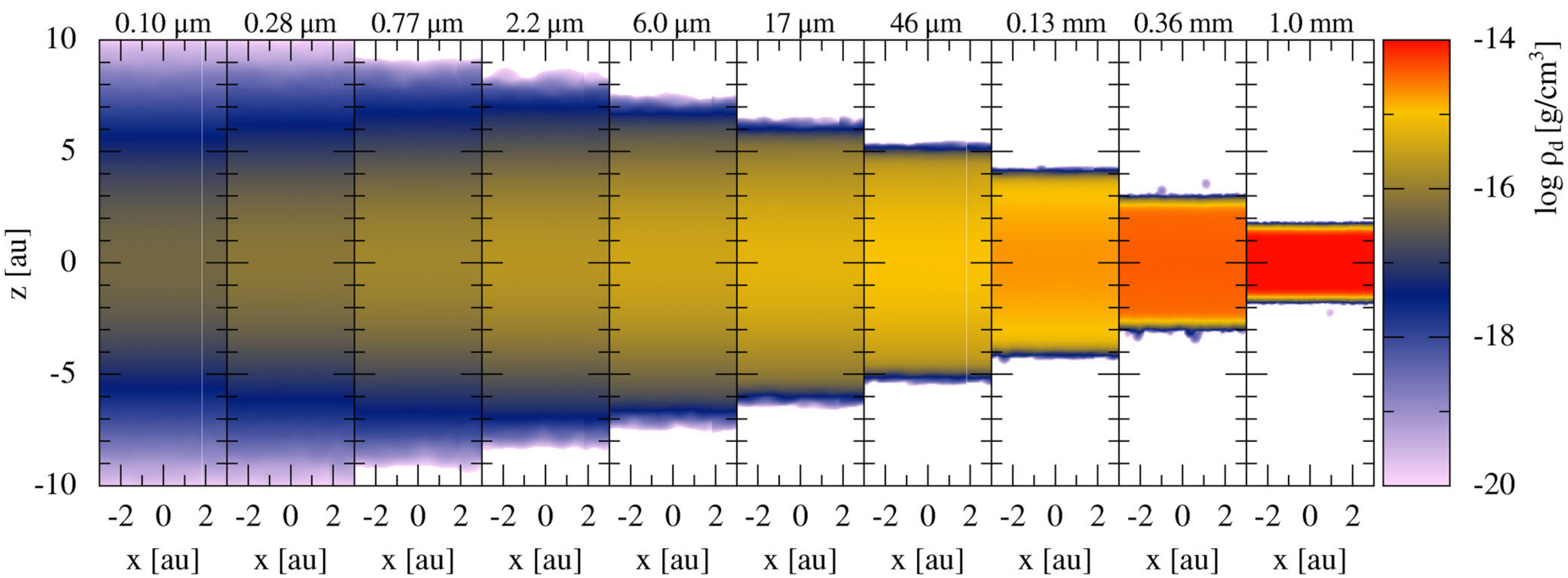


MCFOST

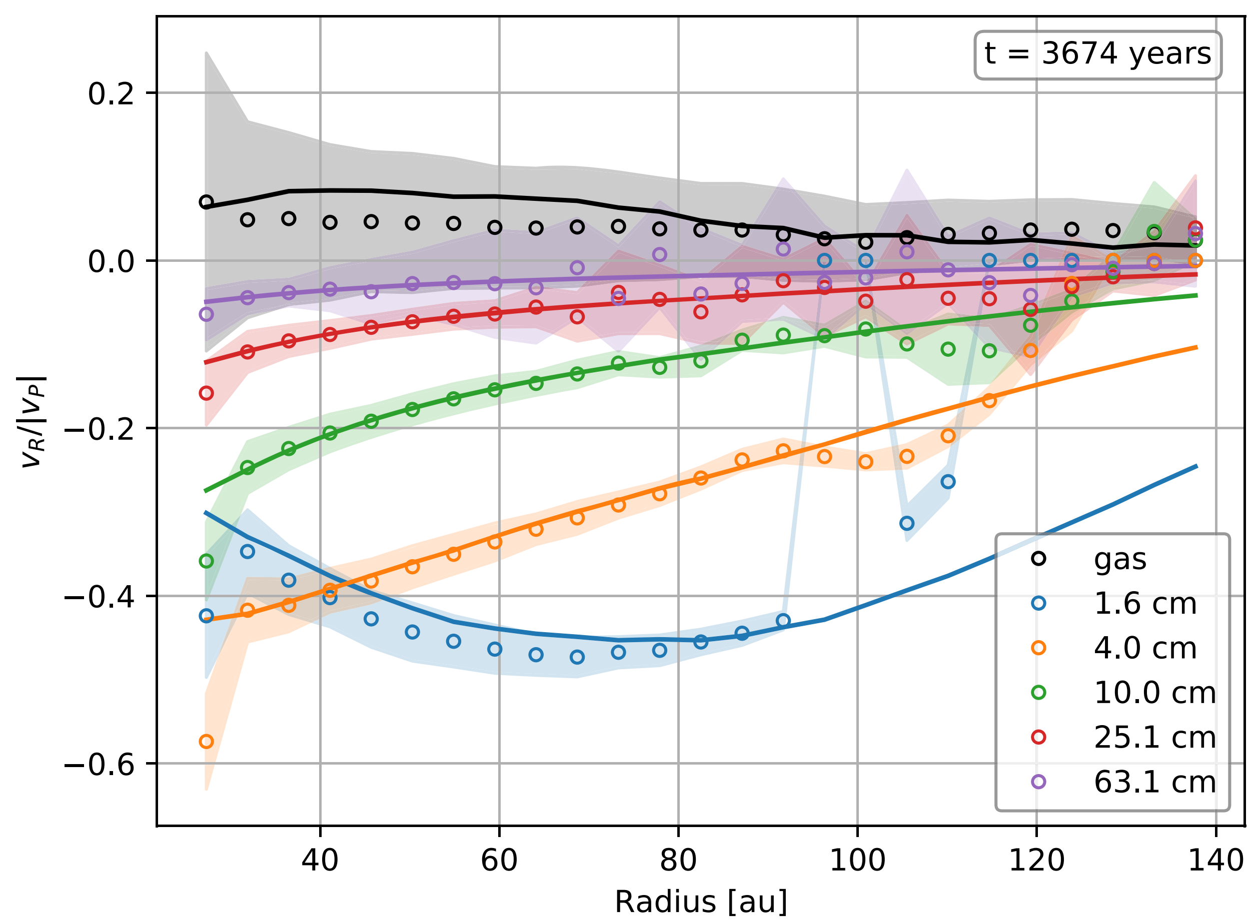


Pinte, Price et al. (2018)

MULTIGRAIN DUST (HUTCHISON+2018, MENTIPLAY+2020)

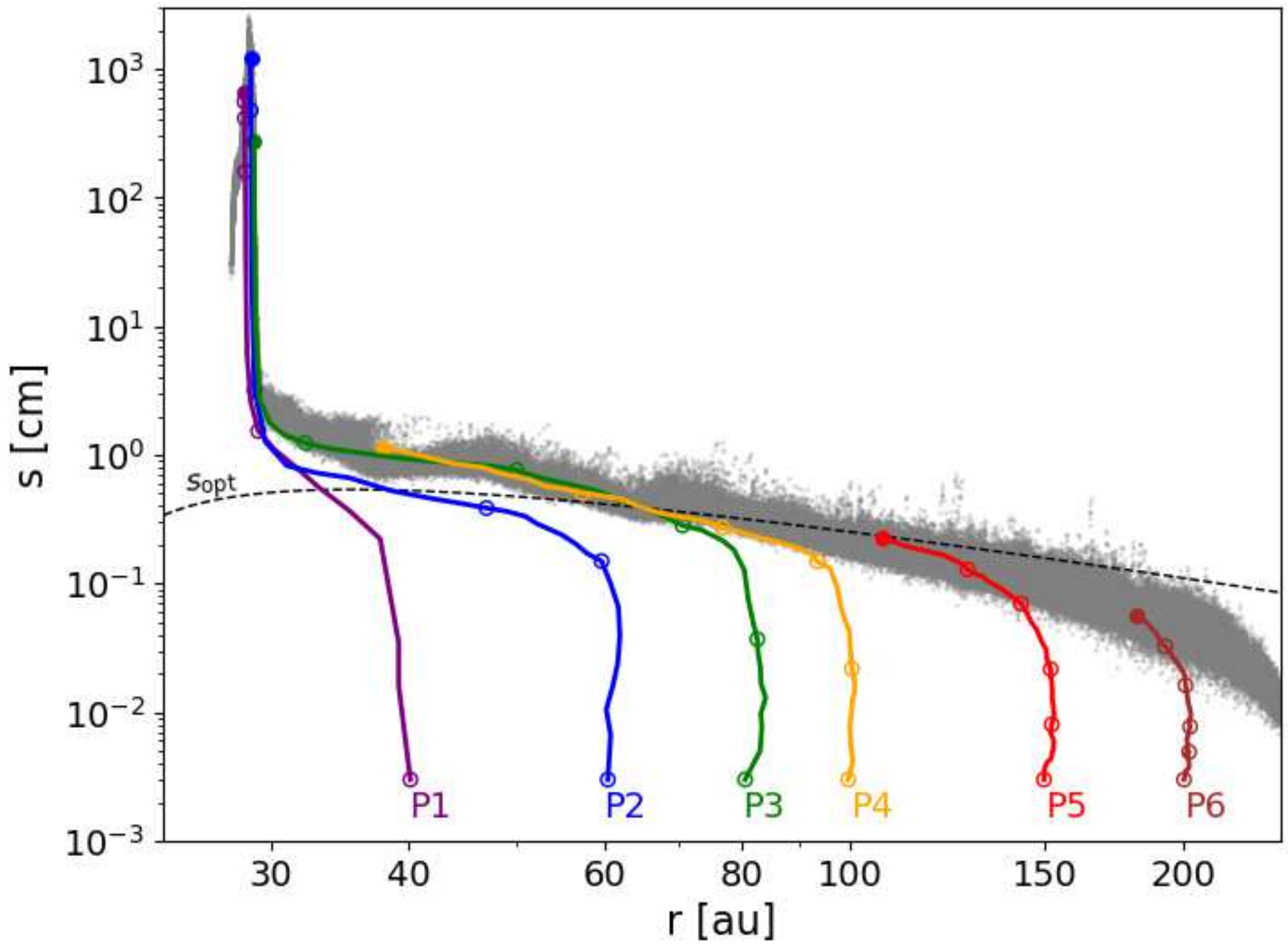


- Multiple grain species in one calculation using either one fluid (Hutchison+2018) or two fluid (Mentiplay+2020)



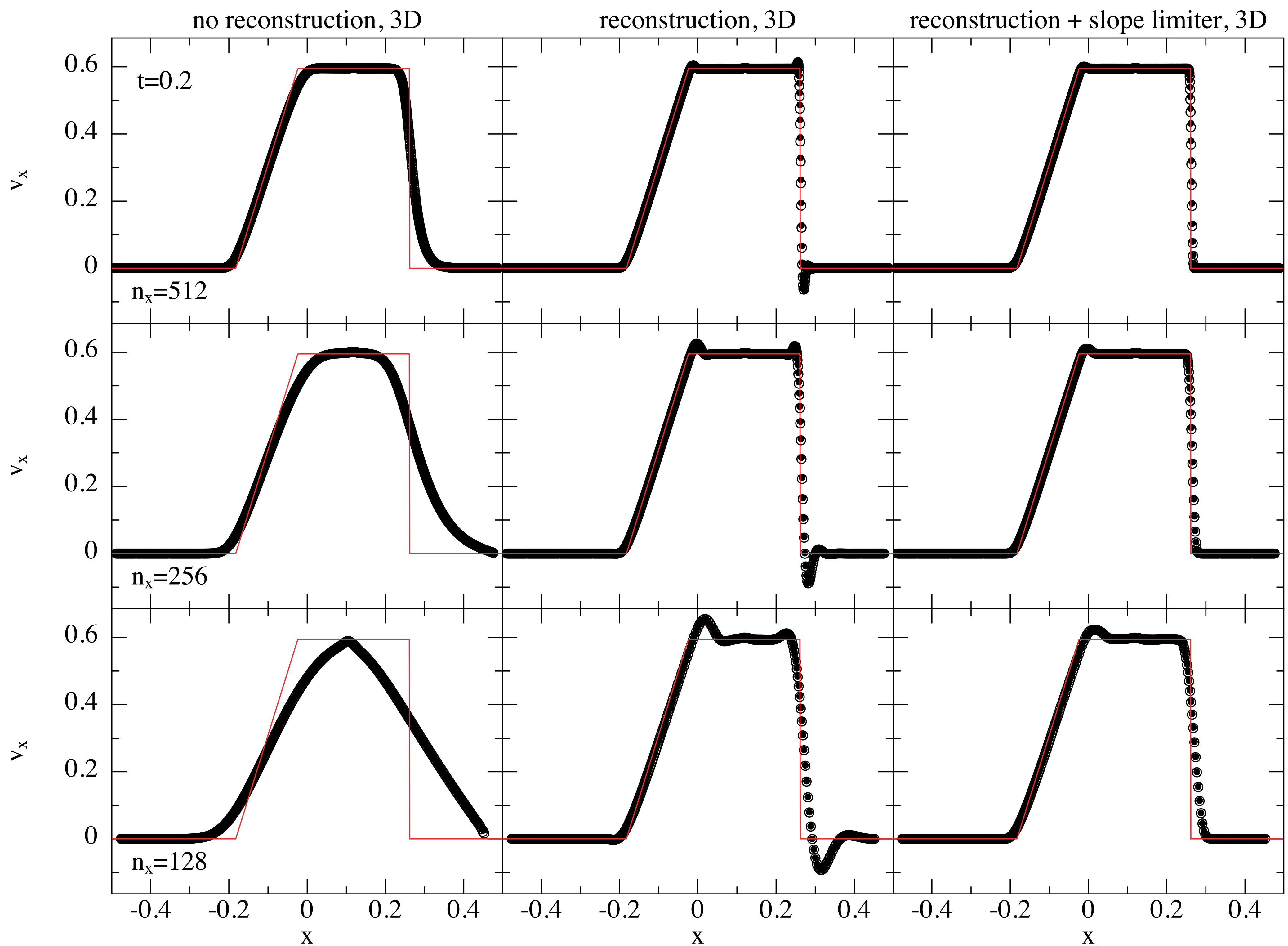
DUST GROWTH (VERICEL ET AL. 2021)

- Using moment method
- Evolve mean grain mass (size) on each SPH particle based on relative collision velocity between grains
- Works with both one fluid mixture and dust-as-particles methods

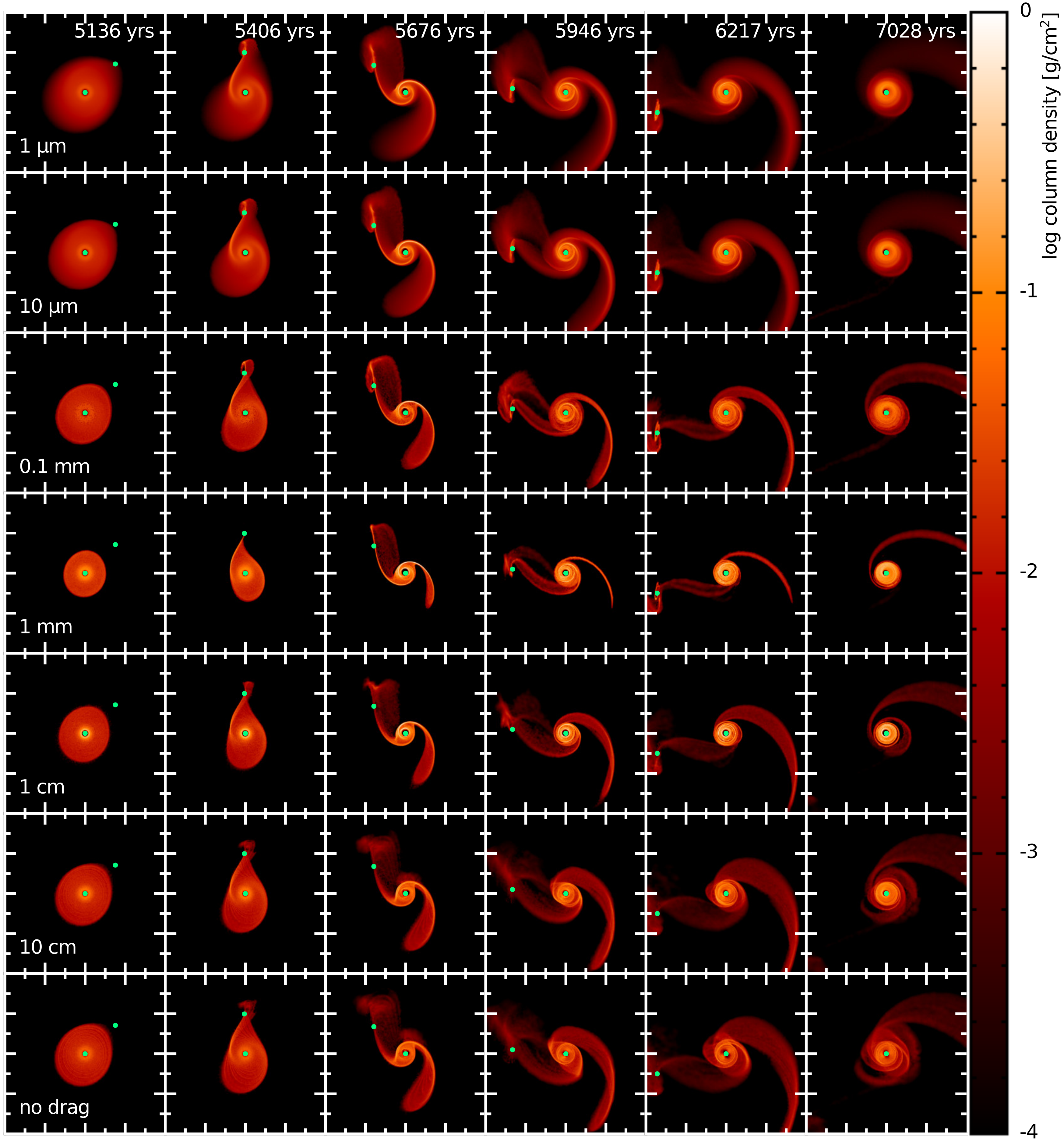


See Michoulier talk

FIX TO OVERDAMPING PROBLEM IN DUST-GAS MIXTURES



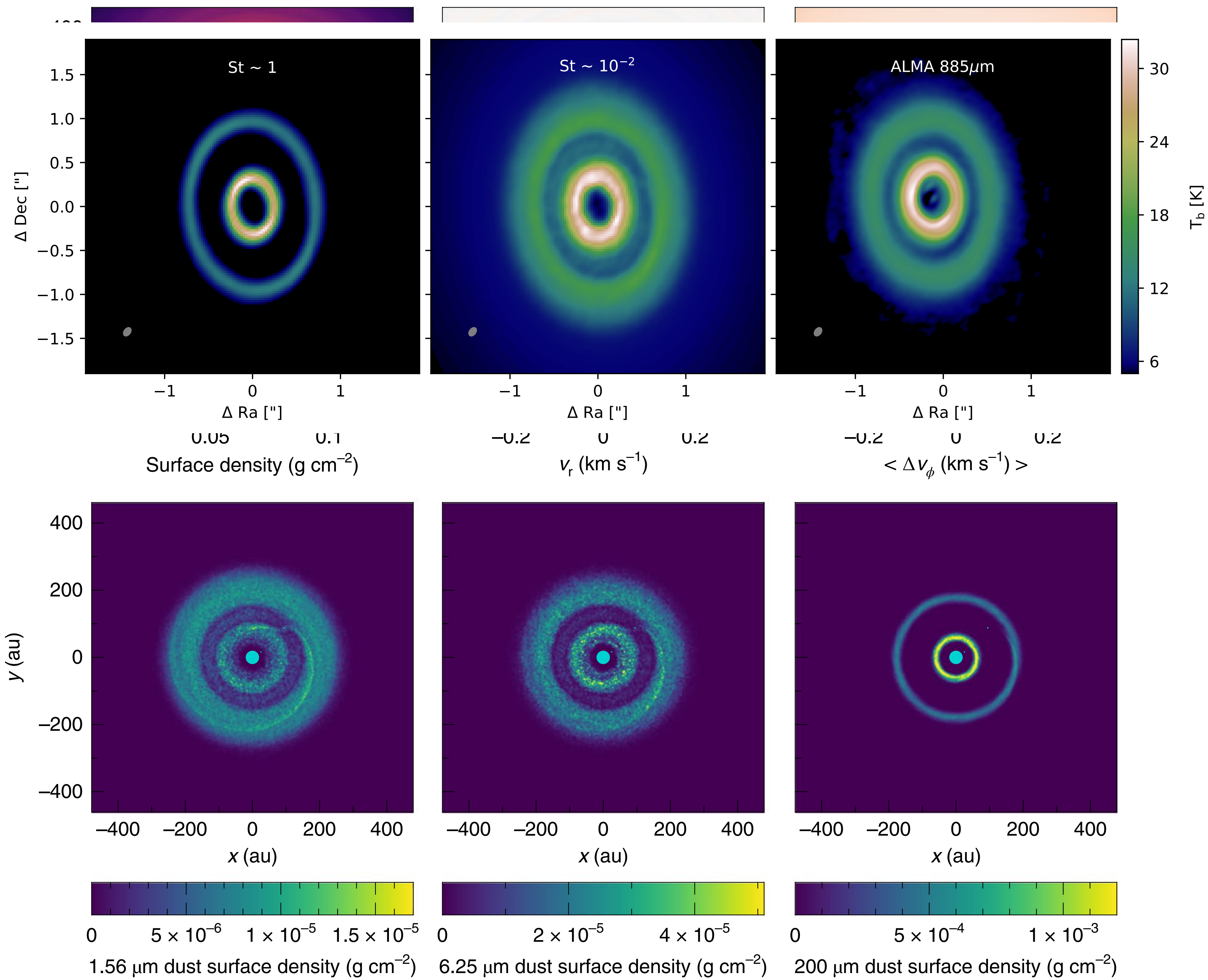
Price & Laibe (2020)



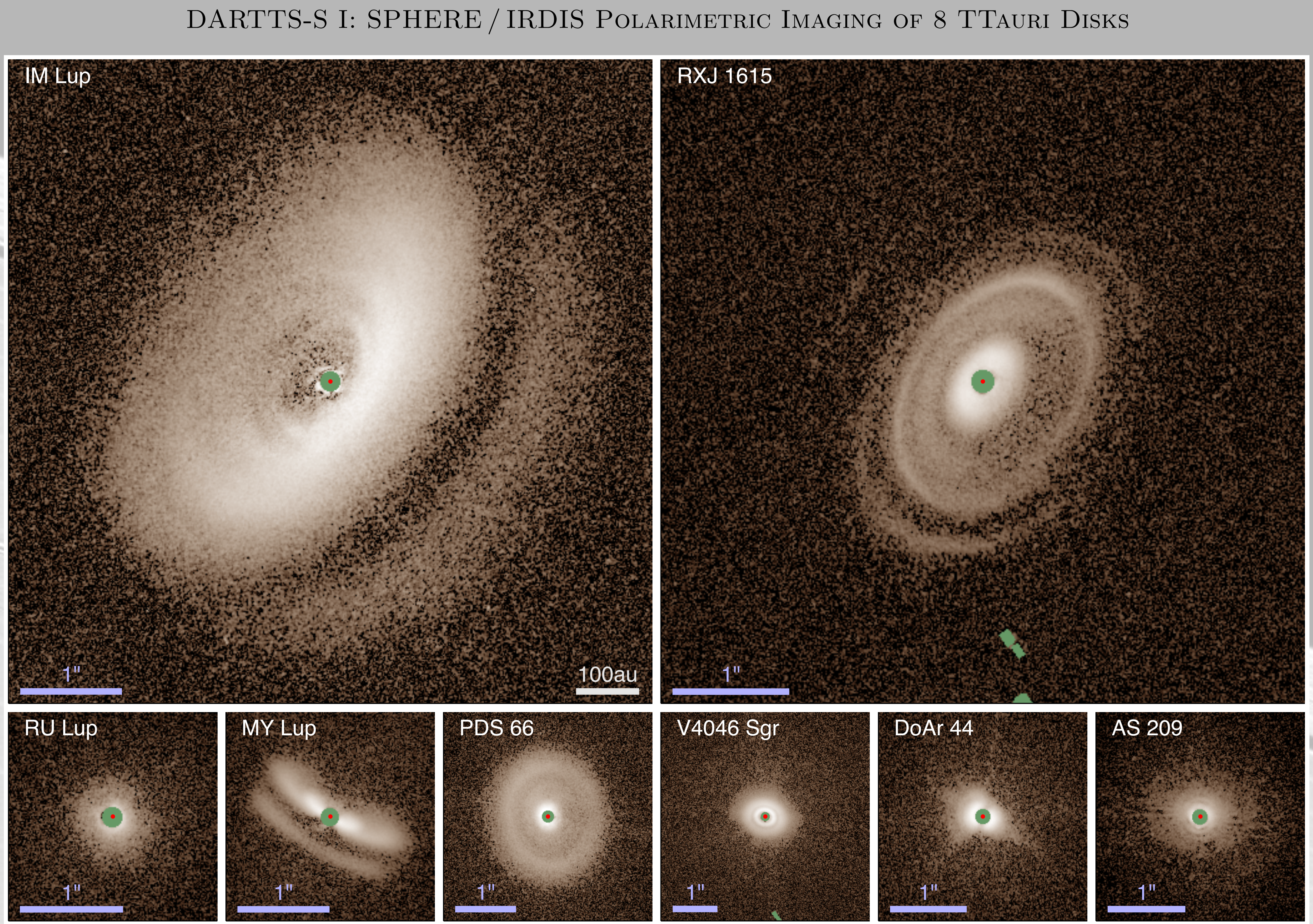
Stellar flybys with dust: Cuello et al. (2019)

MULTIGRAIN + PLANETS

Pinte et al. (2019)

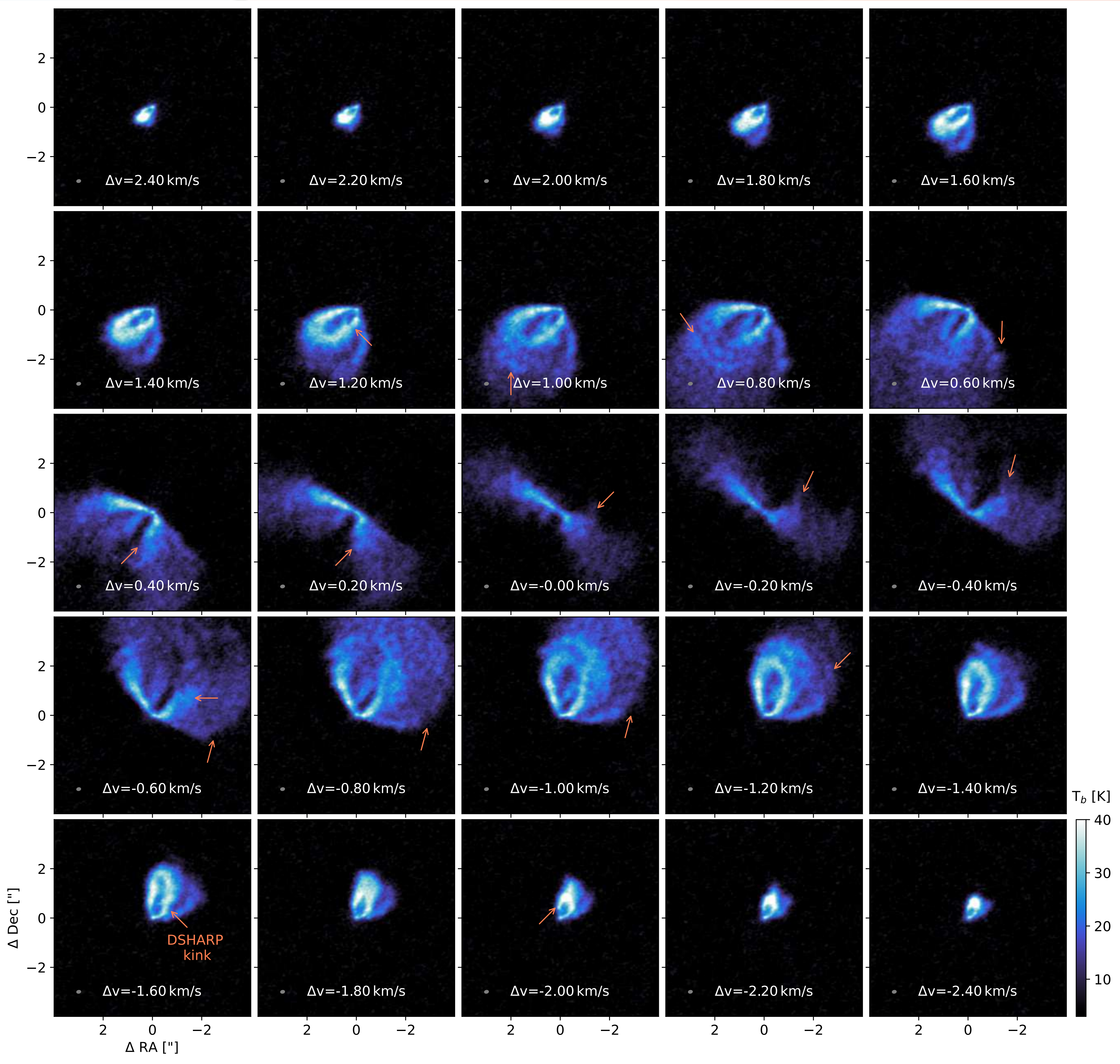


IS THERE A PLANET IN IM LUPI?



Avenhaus+(2018), aka “The Miracle Run”

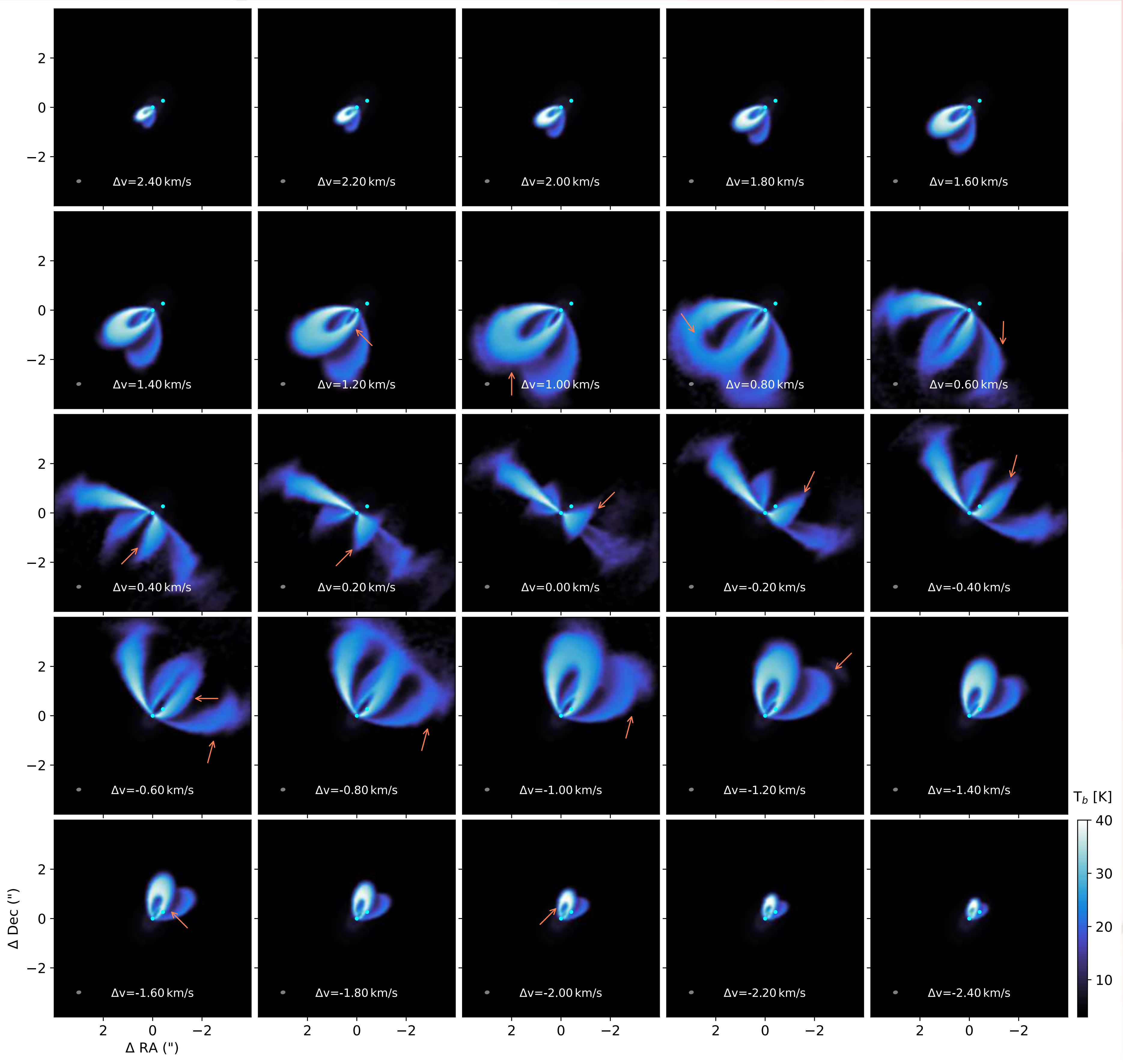
IM LUPI KINEMATICS - OBSERVATIONS



Verrios, Price+ 2022 ApJL.

Data from MAPS project (Oberg+2021)

IM LUPI KINEMATICS - MODELS

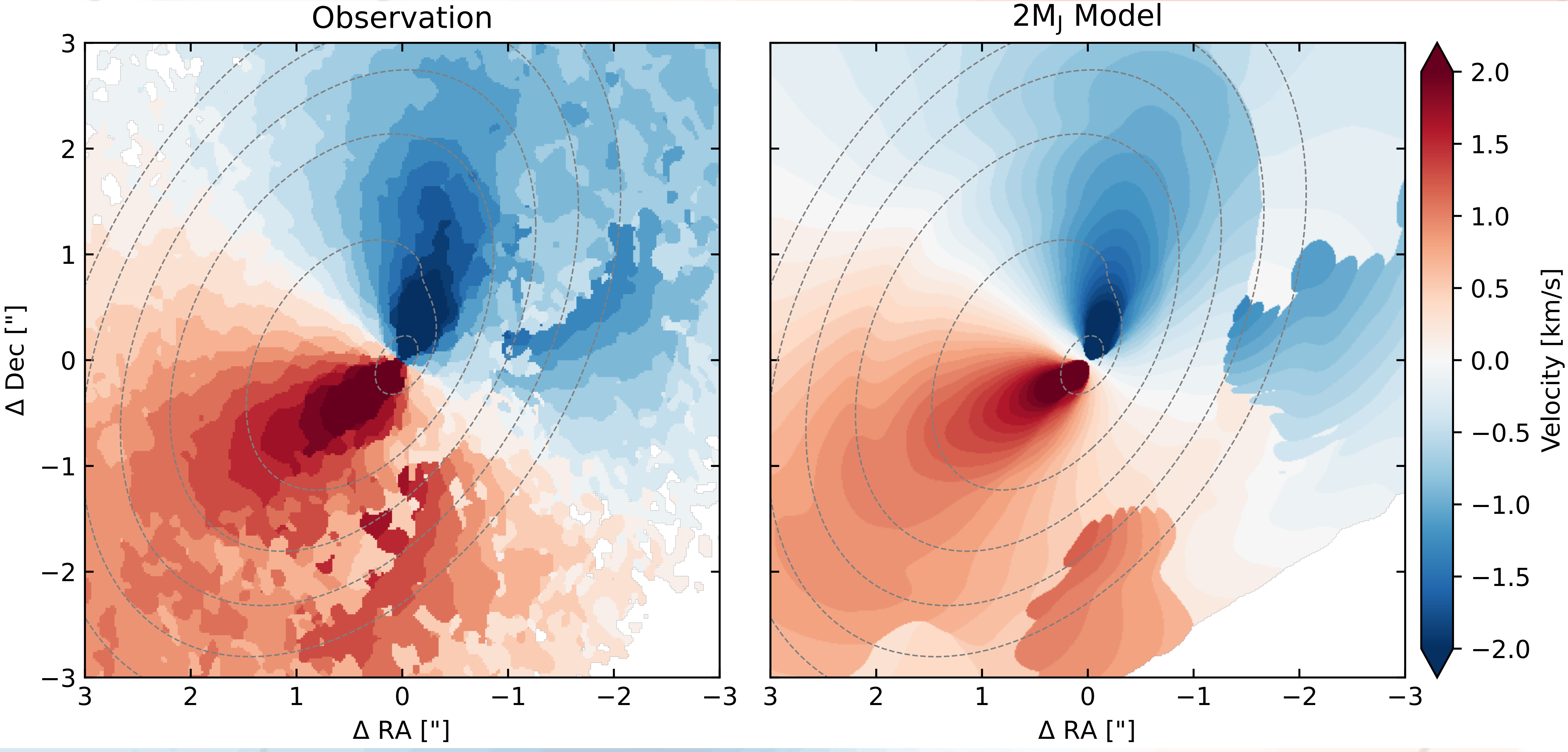


Verrios, Price+ 2022 ApJL

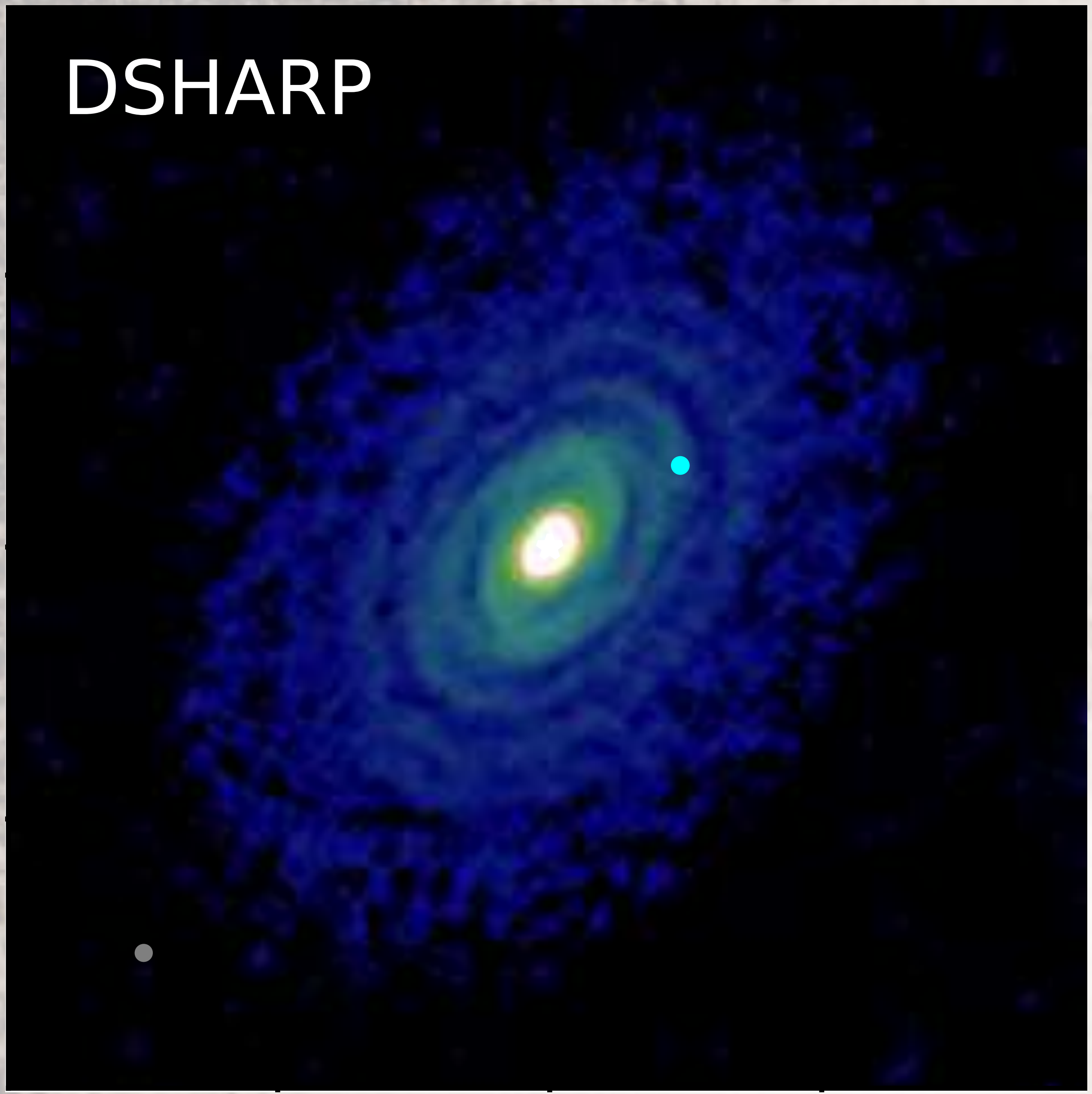
Simulations using Phantom SPH hydro + MCFOST radiative transfer

THE PLANET WAKE IN IM LUPI

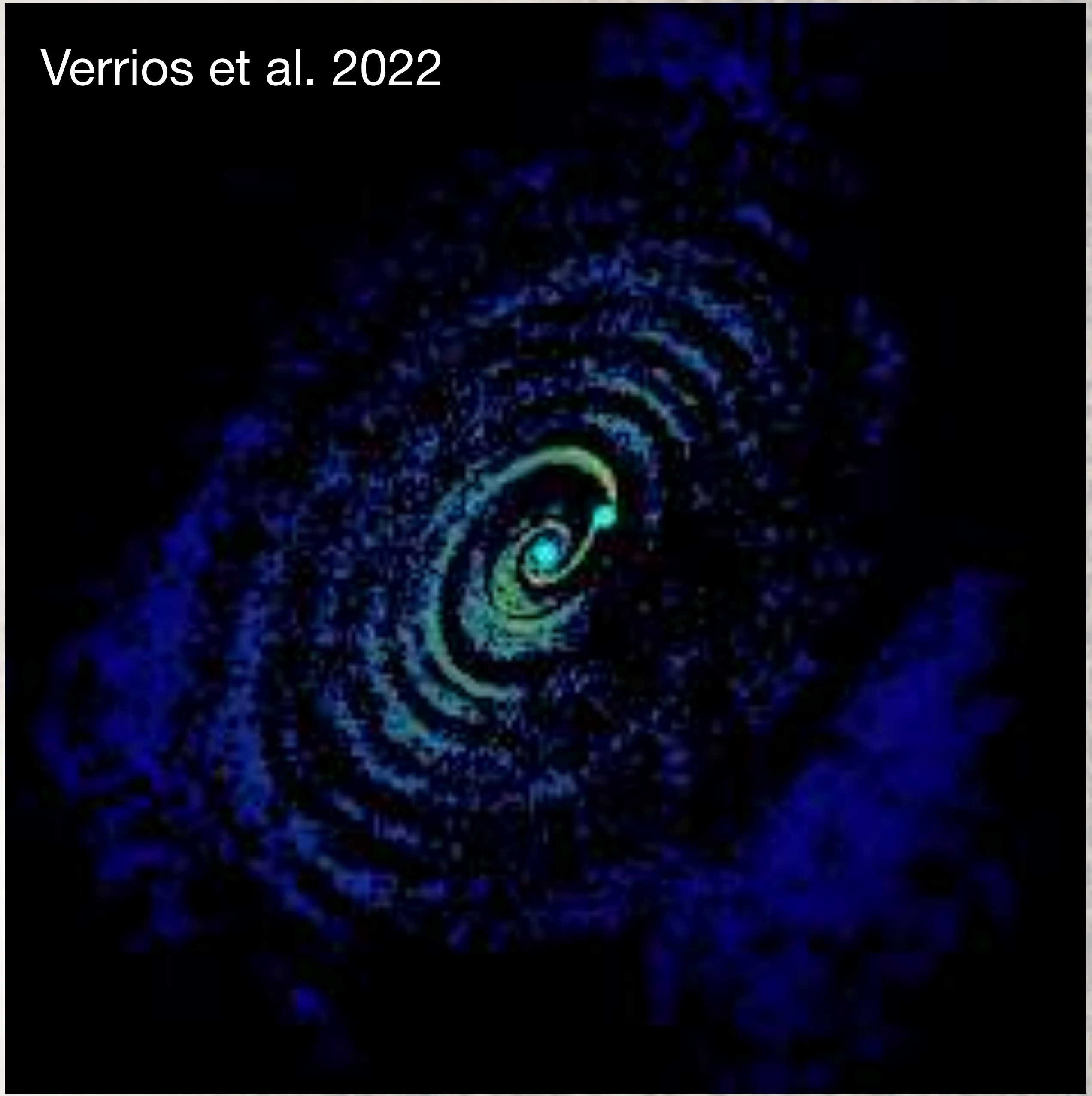
Verrios, Price, Pinte, Hilder & Calcino (2022), ApJL 934, L11



CAN'T WE JUST SEE THE SPIRAL WAKE?



Observations

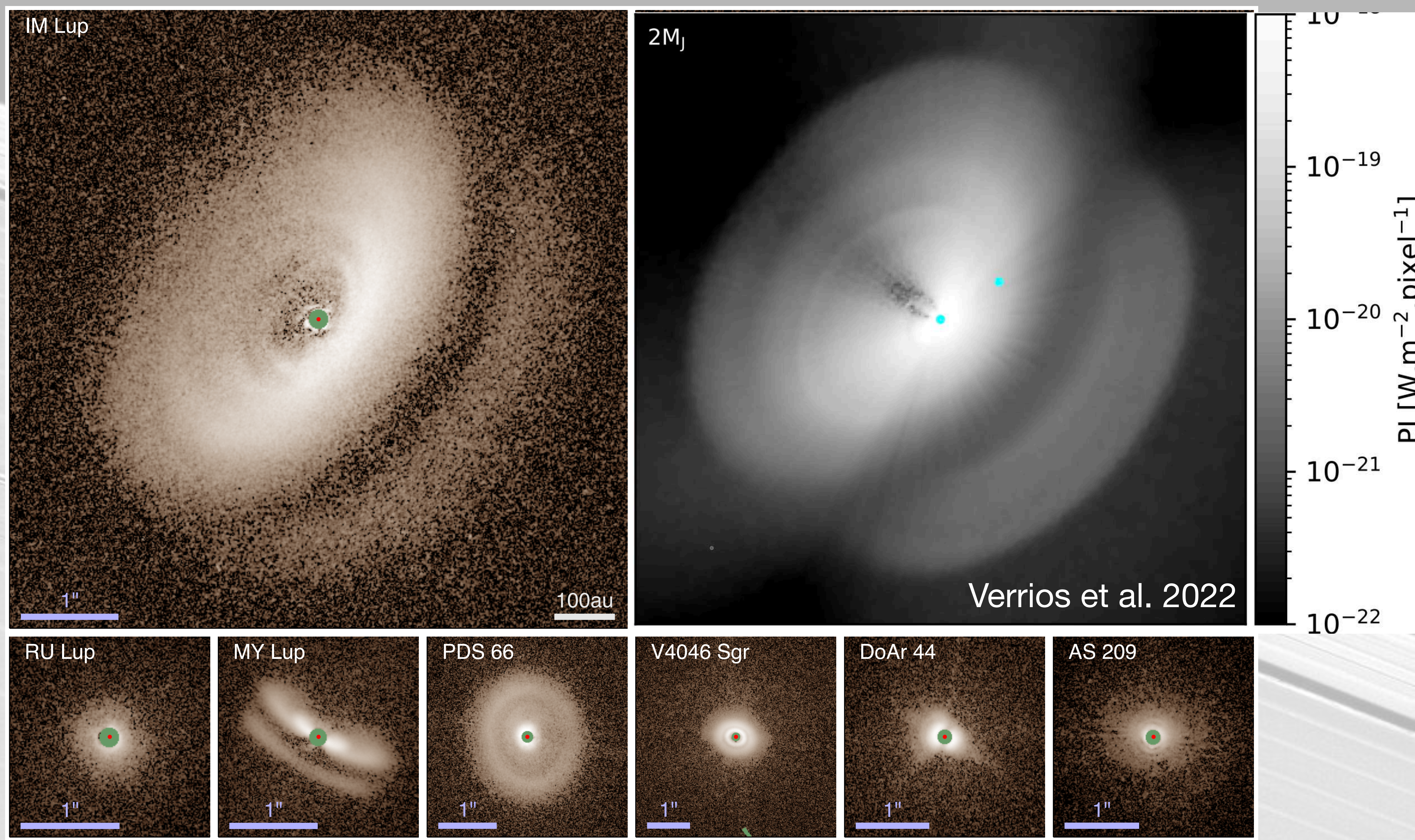


Model with azimuthally averaged background subtracted

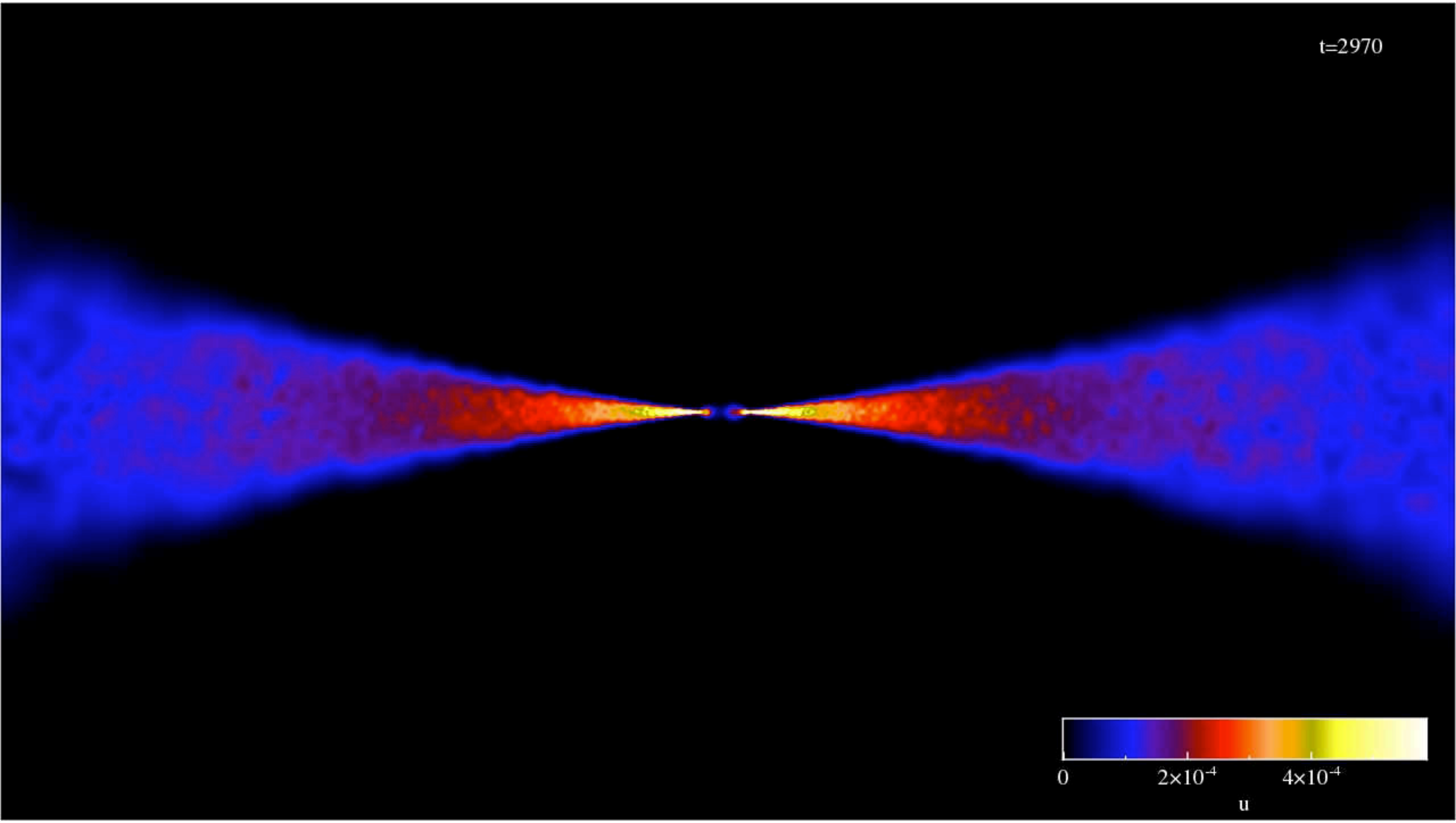
Need high disc mass (~0.1 Msun) to give low Stokes number for mm-emitting grains: self-gravity also important? But ask me later why IM Lupi is not a self-regulated disc…

A PLANET WAKE IN SCATTERED LIGHT

DARTTS-S I: SPHERE / IRDIS Polarimetric Imaging of 8 TTauri Disks 7



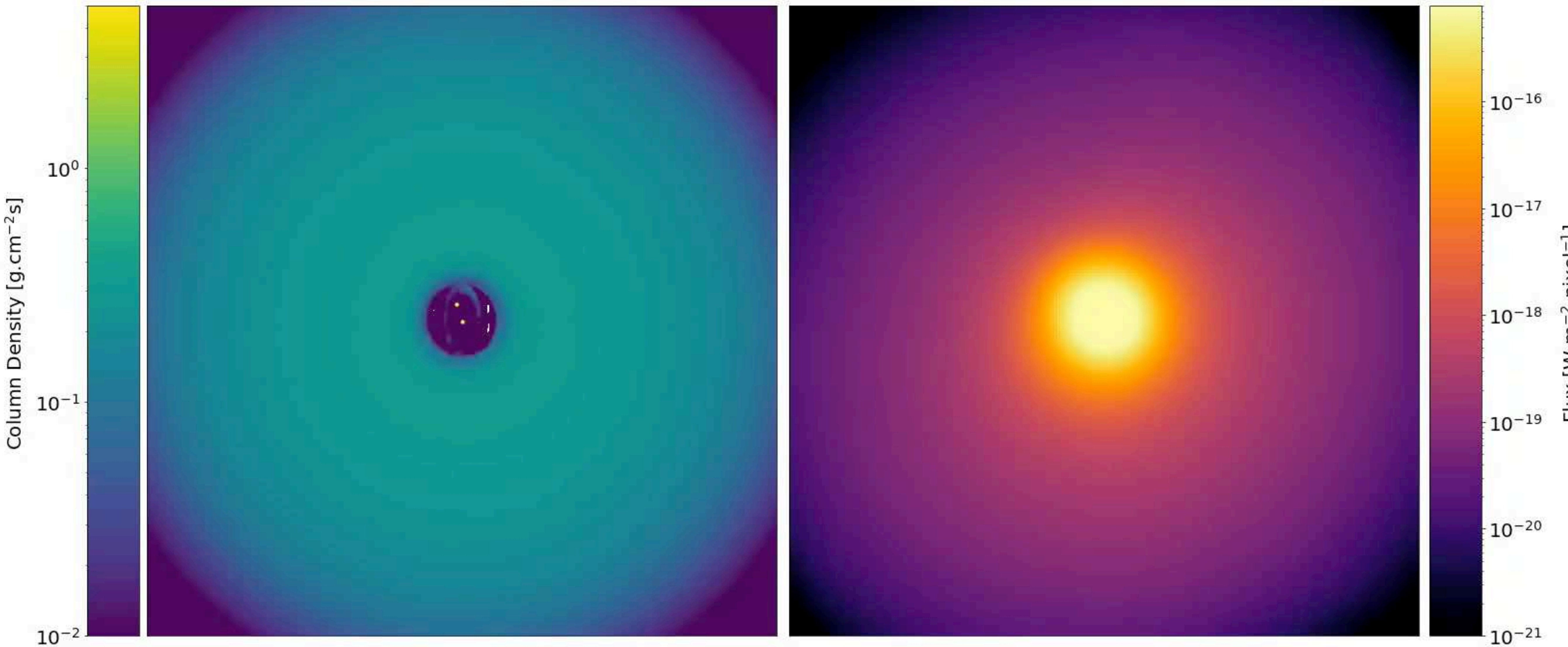
PHANTOM + MCFOST MONTE-CARLO RADIATION: LIVE COUPLING



Pinte, Price, Mentiplay, Biriukov, Borchert+ (methods paper not yet published)

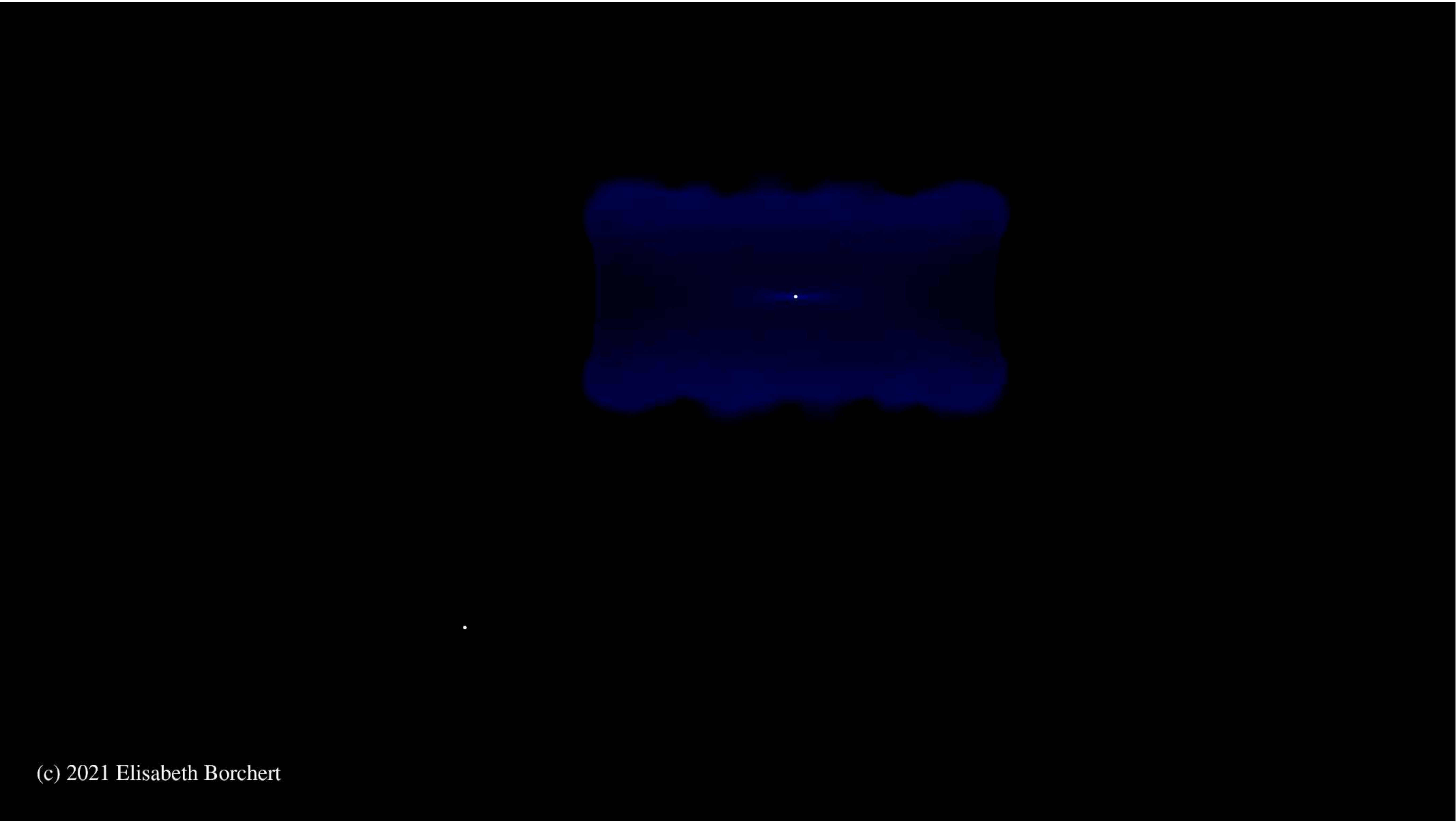
ROCKING SHADOWS

Nealon et al. (2020)



First publication using live coupling between PHANTOM and MCFOST

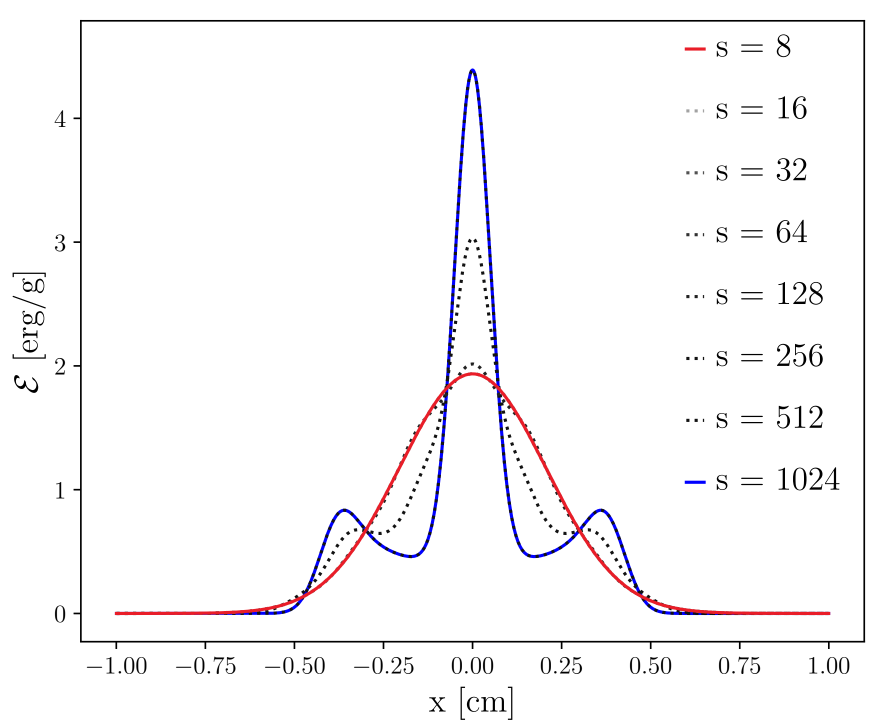
STELLAR FLYBYS WITH LIVE RADIATION (INCL. ACCRETION LUMINOSITY)



Borchert et al. (2022a,b), see Elli's talk

ATTEMPTS AT HYBRID SCHEME (BIRIUKOV 2020)

- Using "super-timestepping" to try to avoid small timesteps at low optical depths



Diffusion of a Gaussian with super-time stepping, showing development of (wrong) oscillatory solutions

Radiation Diffusion in Smoothed Particle Hydrodynamics

Sergei Biriukov

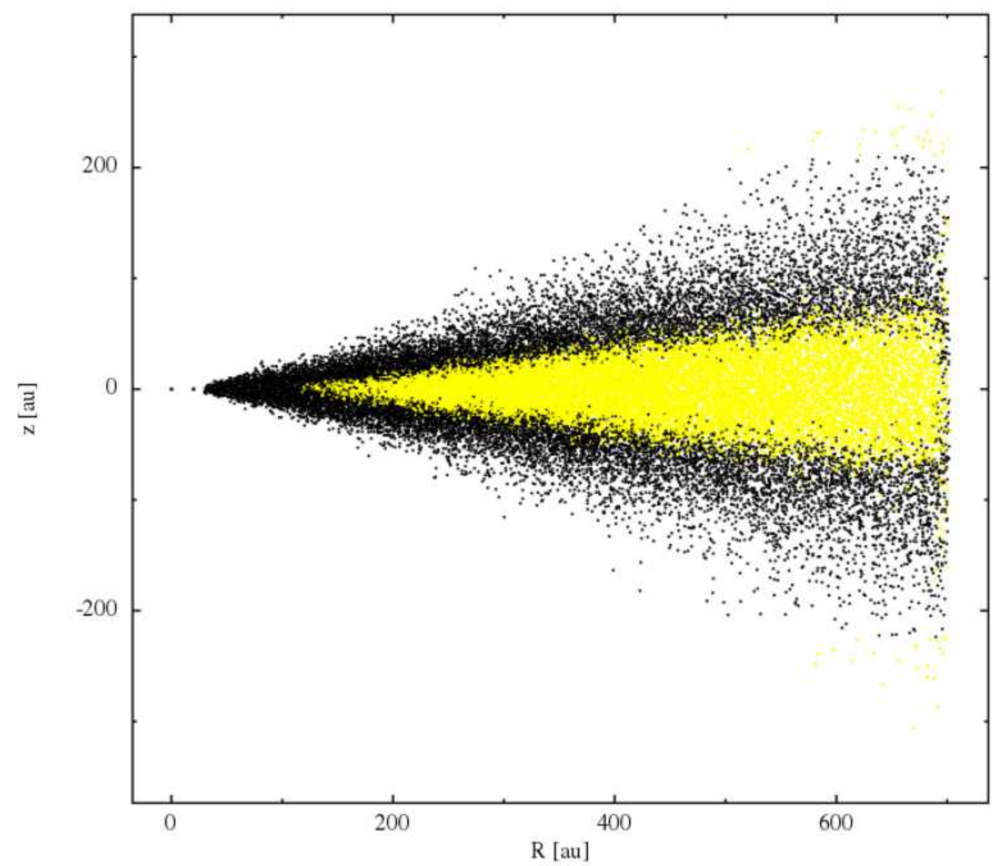
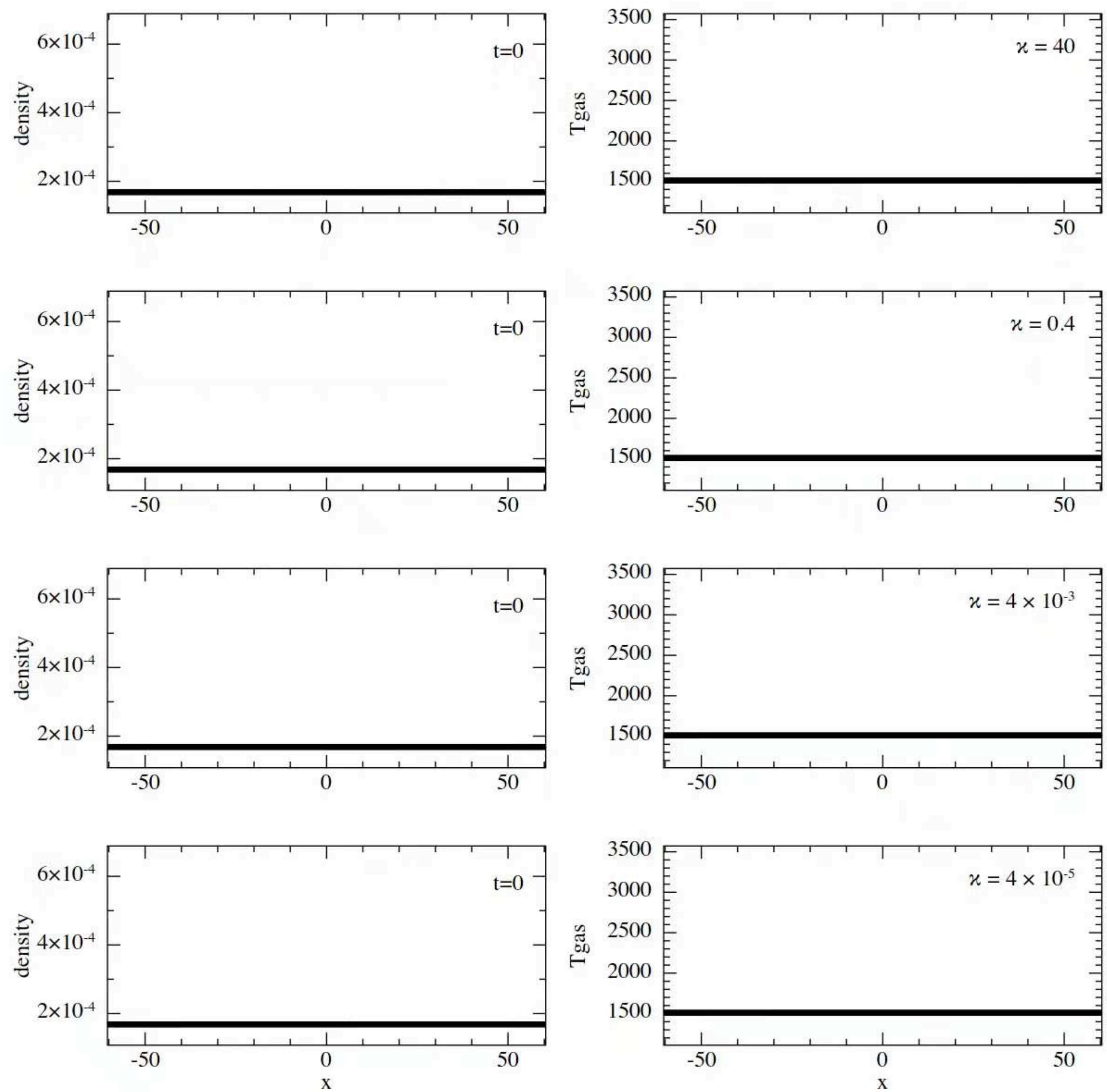


Figure 5.9: Protoplanetary disc of SPH particles on meridional cut through the disc. Radiation diffusion for yellow particles is handled by Phantom and for black particles by MCFOST

IMPLICIT RADIATION (2023)

- Direct port of sphNG algorithm (Whitehouse & Bate 2004)
- Fast (Whitehouse, Bate & Monaghan 2005)
- Just merged and now available in public code!

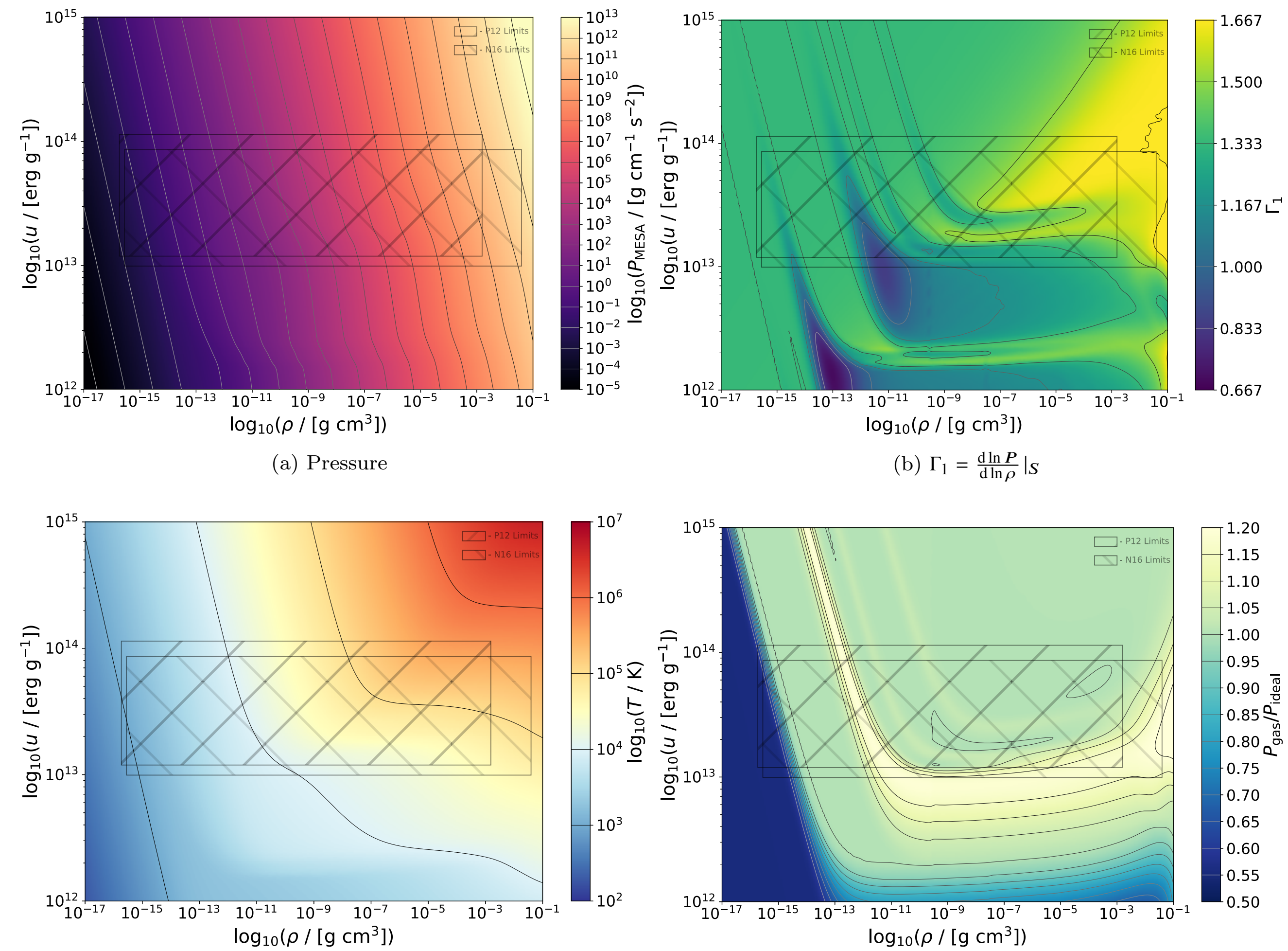


Radiation shock tube test, showing heat "leaking" through the shock front as opacity is lowered

STARS AND COMMON ENVELOPE INTERACTION

Iaconi+2017, Reichardt et al. (2019, 2020)

See Mike Lau, Miguel González-Bolivar, Luis Bustamante-Bermudez talks



(a) Pressure

(b) $\Gamma_1 = \frac{d \ln P}{d \ln \rho}|_S$

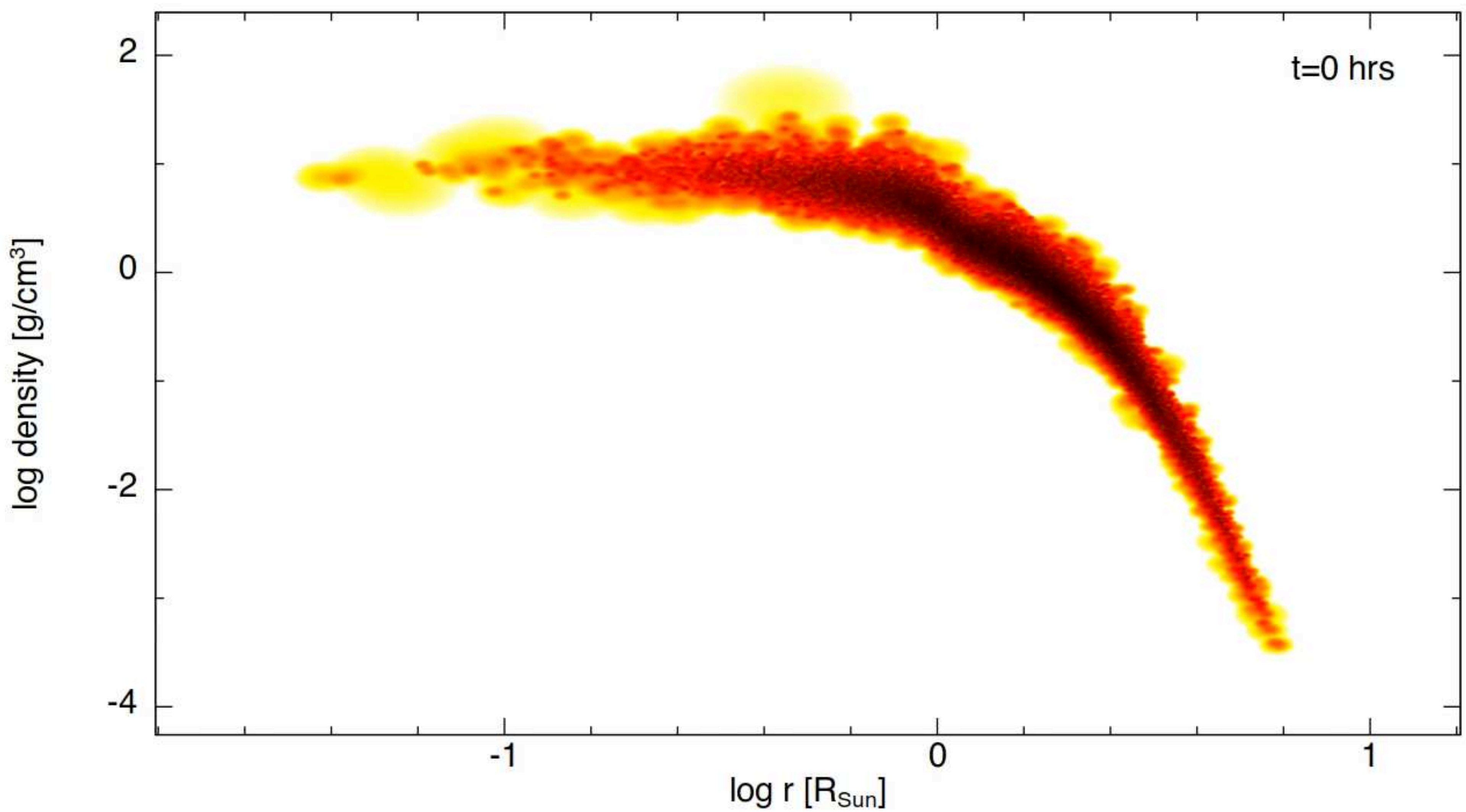
(c) Temperature

(d) Ratio of MESA gas pressure to ideal equation of state pressure

Reichardt et al. (2020): First use of tabulated equation of state including gas, radiation pressure, ionisation, etc

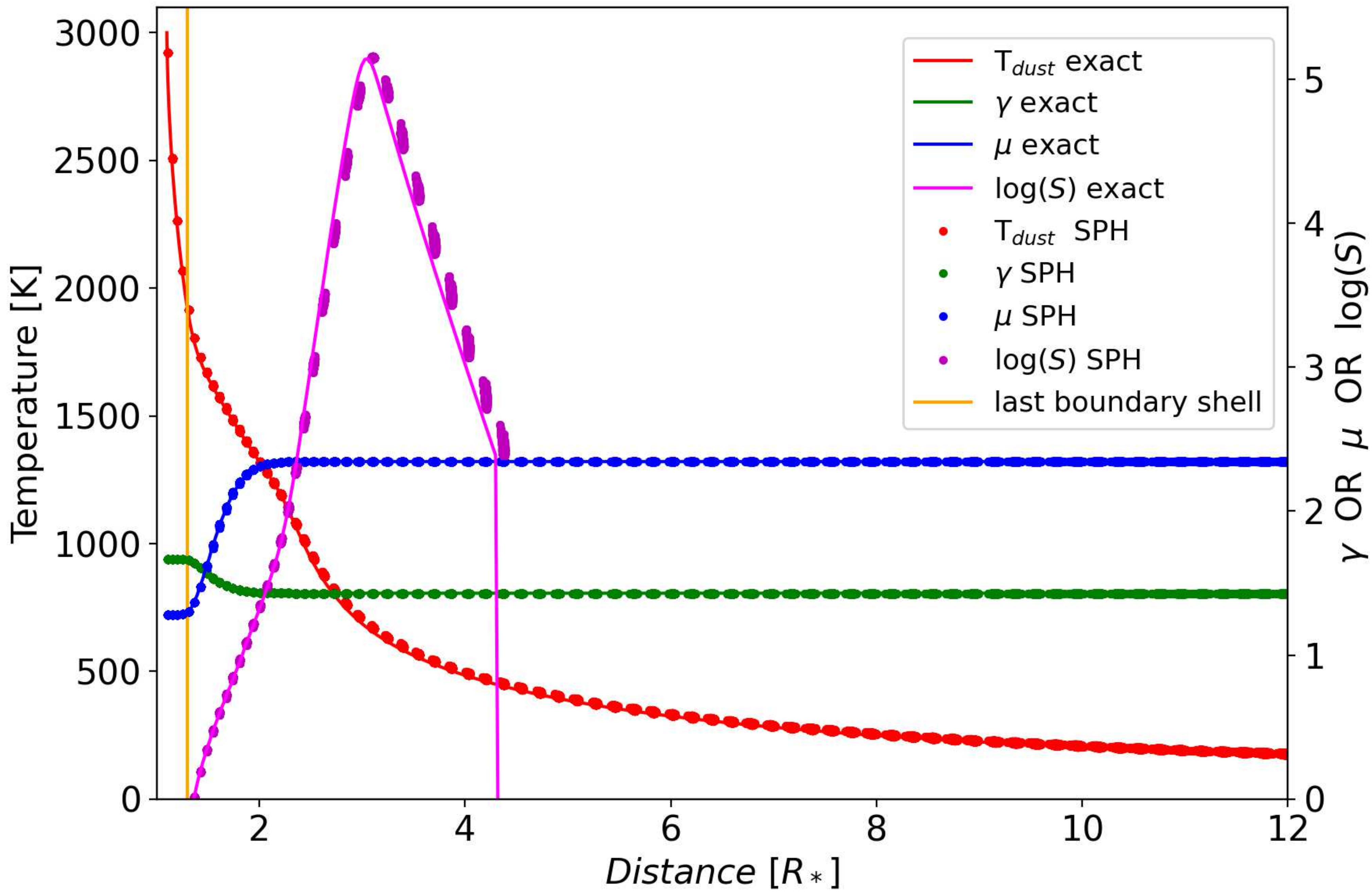
STELLAR RELAX-O-MATIC™ (BY DP, ML AND RH FOR LAU+2022)

1. Random-but-symmetric particle placement based on 1D stellar profile (e.g. MESA, Kepler)
2. Fix temperature profile during relaxation (tabulated as a function of mass)
3. Relax by shifting particles until hydrostatic equilibrium achieved, shifts are asynchronous and individual to each particle



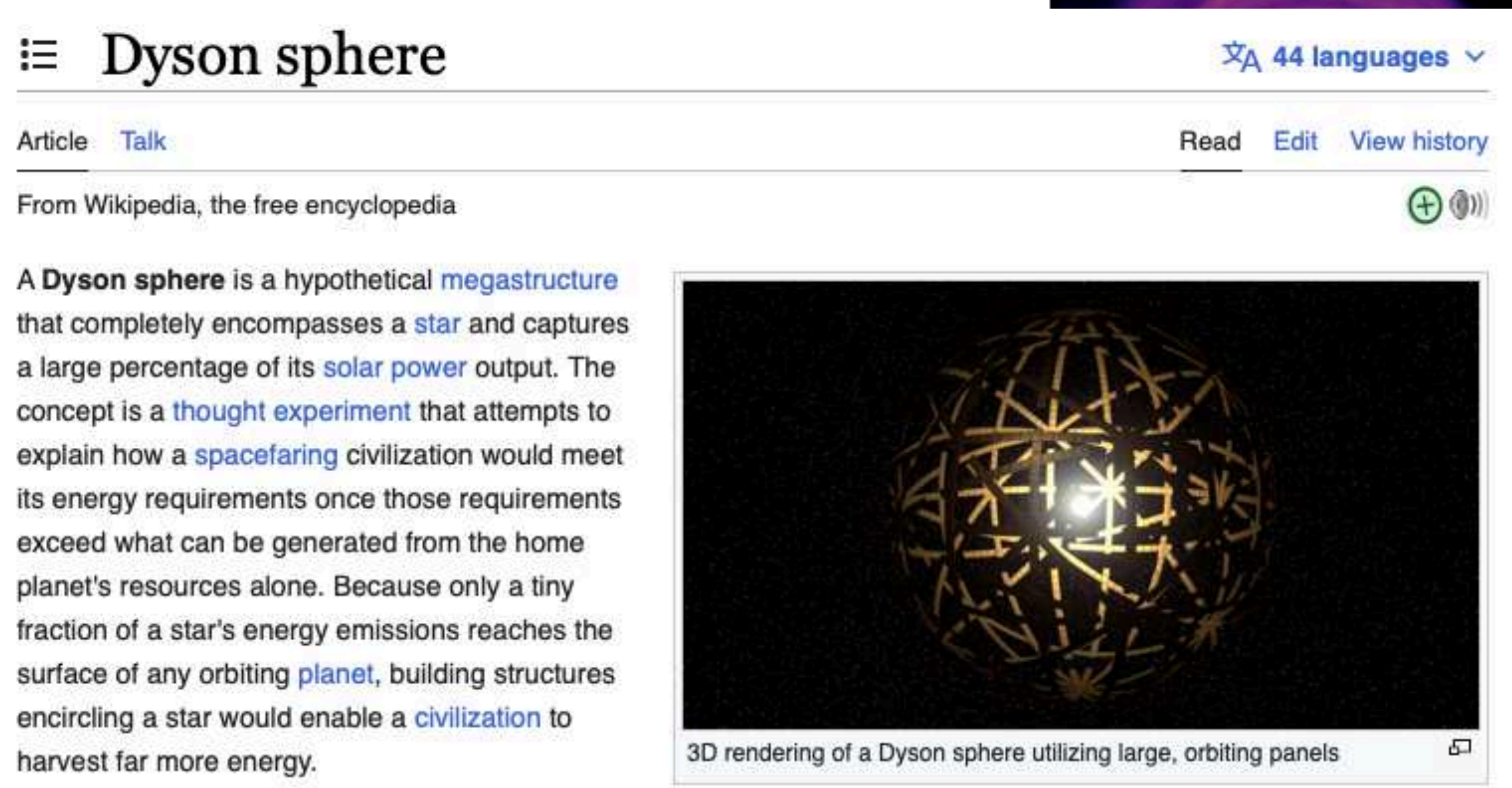
STELLAR WINDS AND DUST NUCLEATION

➤ Implemented in Siess, Homan, Toupin & Price (2022)



See Malfait and Danilovich talks for applications

DUST FORMATION IN COMMON ENVELOPES



Dyson sphere

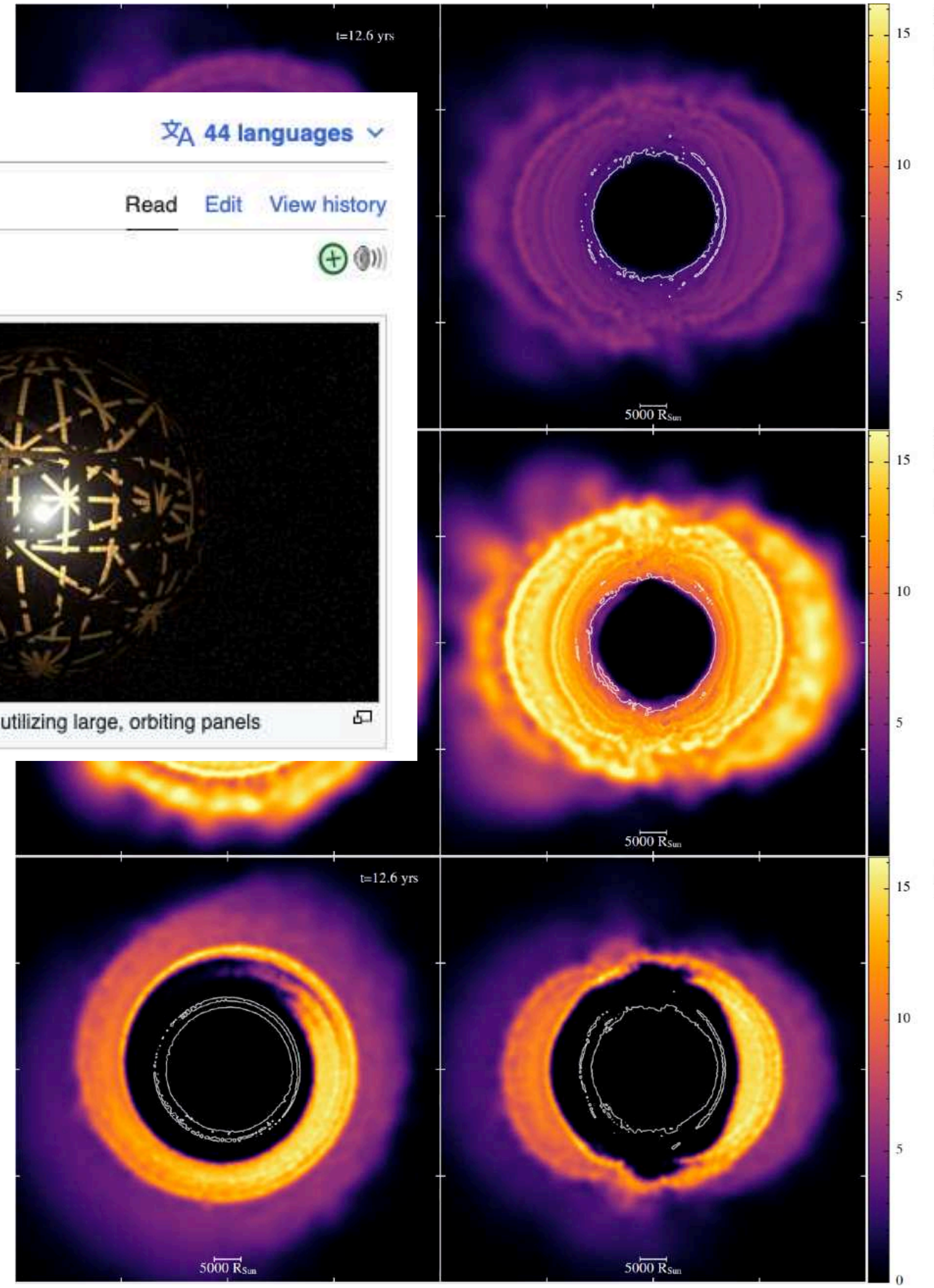
44 languages

Article Talk Read Edit View history

From Wikipedia, the free encyclopedia

A **Dyson sphere** is a hypothetical megastructure that completely encompasses a star and captures a large percentage of its solar power output. The concept is a thought experiment that attempts to explain how a spacefaring civilization would meet its energy requirements once those requirements exceed what can be generated from the home planet's resources alone. Because only a tiny fraction of a star's energy emissions reaches the surface of any orbiting planet, building structures encircling a star would enable a civilization to harvest far more energy.

3D rendering of a Dyson sphere utilizing large, orbiting panels

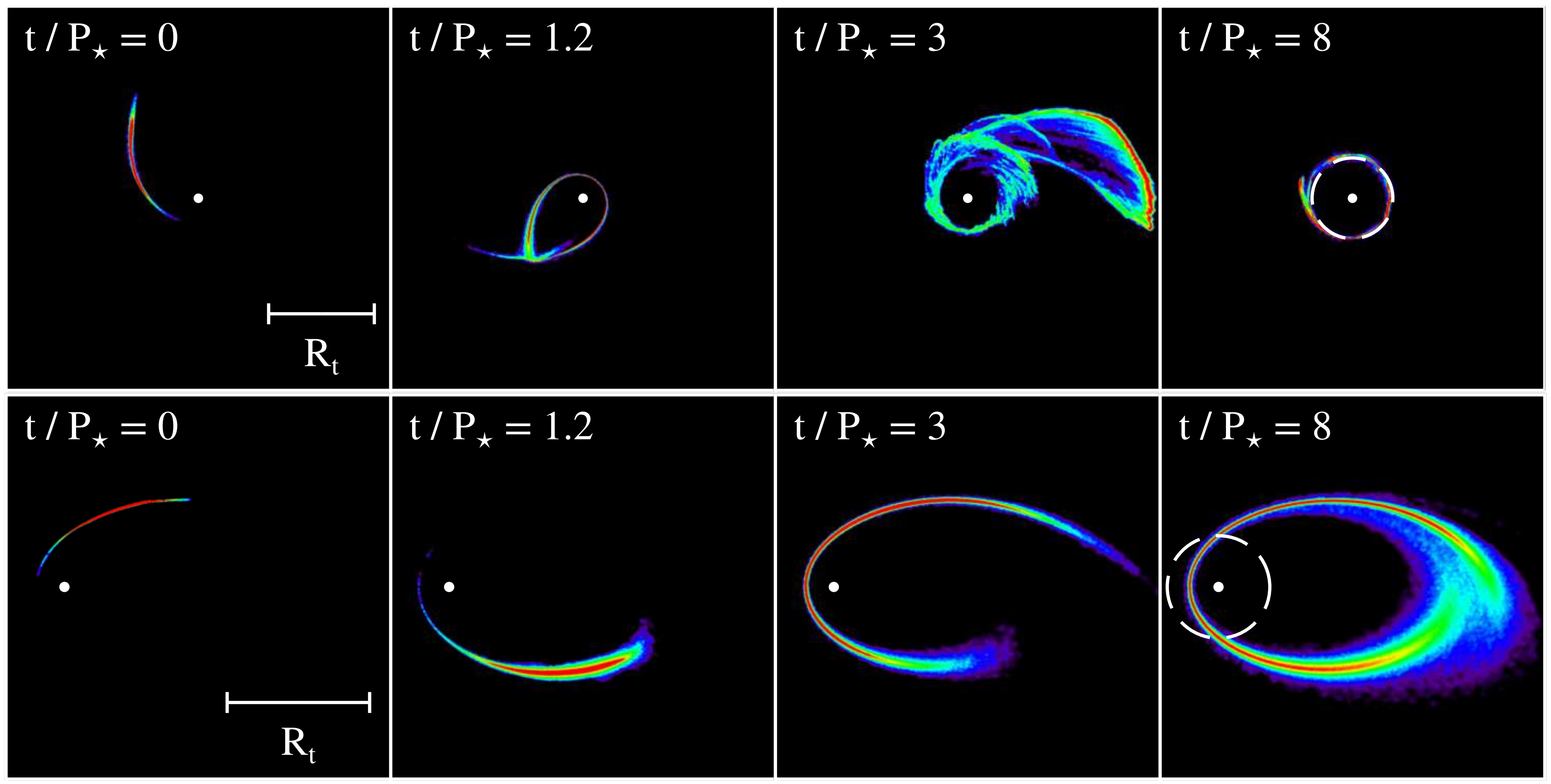


See Miguel and Luis's talks

Aim is to couple this to radiation driving

TIDAL DISRUPTION EVENTS

- Lense-Thirring precession implemented in 2012
- Tejeda-Rosswog potential implemented (Bonnerot+2016)



- GRSPH: Liptai & Price (2019)

TIDAL DISRUPTION EVENTS IN GR (LIPTAI, PRICE, TOSCANI, HU, SHARMA)

See Martina Toscani, Megha Sharma and Fitz Hu's talks; also Spencer Magnall

SUMMARY

Recent significant capabilities:

1. phantom+MCFOST for post-processing = lots of science!
2. Multigrain dust
3. Dust growth
4. Live Monte-Carlo radiation
5. Implicit radiation diffusion
6. Stars can be modelled "out of the box"
7. GR in fixed metrics
8. Dust nucleation and wind driving
9. Add your contributions here…

THIS WEEK

(1) Unit test for drag bug

(2) moddump - stackdust

~~(3) merge dynamic allocation~~ 80%

~~(4) St-based choice of dust method~~ TDD

↳ WIKI PAGE on dust+gas discs

(5) MULTIGRAIN vis

~~(6) PDEs => wiki, moddump, setup } analysis => dm/dt~~

~~(6) (5) AM budget in discs~~

~~(7) Binary disc analysis~~ => modularise these

(8) Default = quintic COMING SOON

(9) Test problem repo DIAL

(10) Regression test suite

~~(11) Fortree wiki page~~

(12) moj...

(13) Roc...

(14) One...

~~(15) Fix...~~

sta...

gi...

gi...

80%

TDD

ES

~~dM~~
~~dE~~

se

(12) ~~moji collection ⇒ website~~
~~image license~~

(13) Roche lobe injection

(14) One fluid + two first derivatives

(15) ~~FIX MARK SEG FAULTS~~

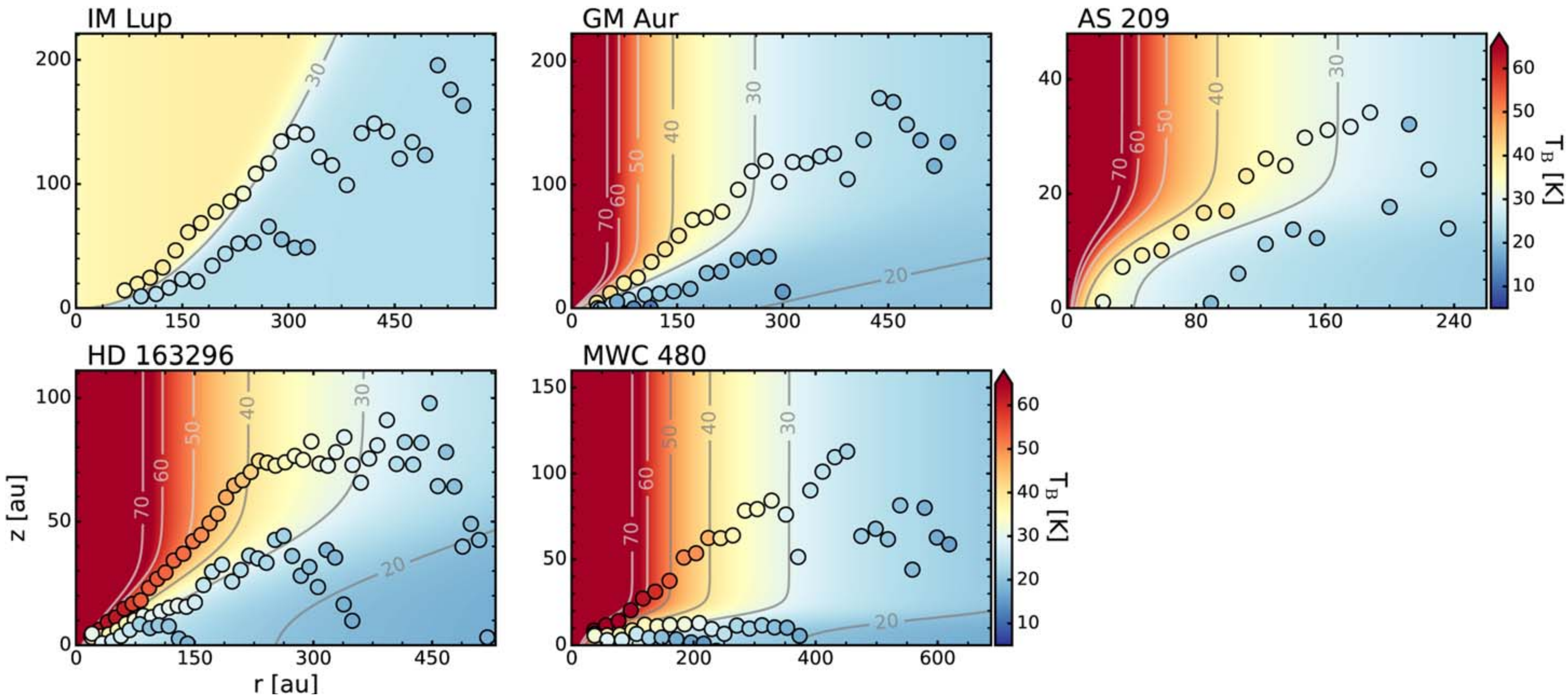
stable

git checkout stable

git pull

WHY IM LUPI IS NOT A SELF-REGULATED DISC

➤ It is hotter at the top



Law et al. (2021)