PHANTOM WORKSHOP 2024

RECENT SCIENCE HIGHLIGHTS AND NEW CAPABILITIES IN PHANTOM

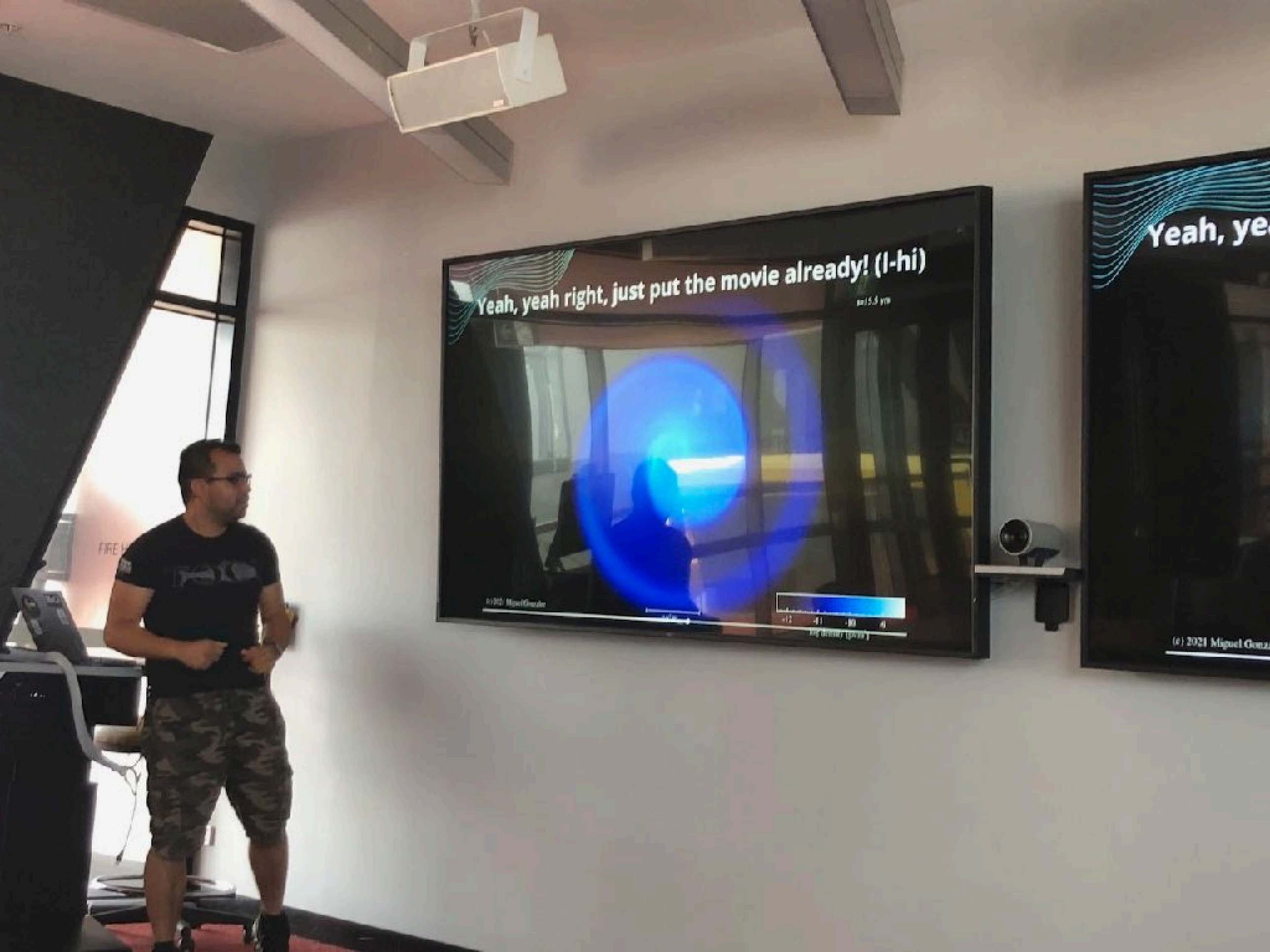
1ST PHANTOM USERS WORKSHOP (2018)

EUROPEAN USERS WORKSHOP 2018...

3RD PHANTOM USERS WORKSHOP 2020

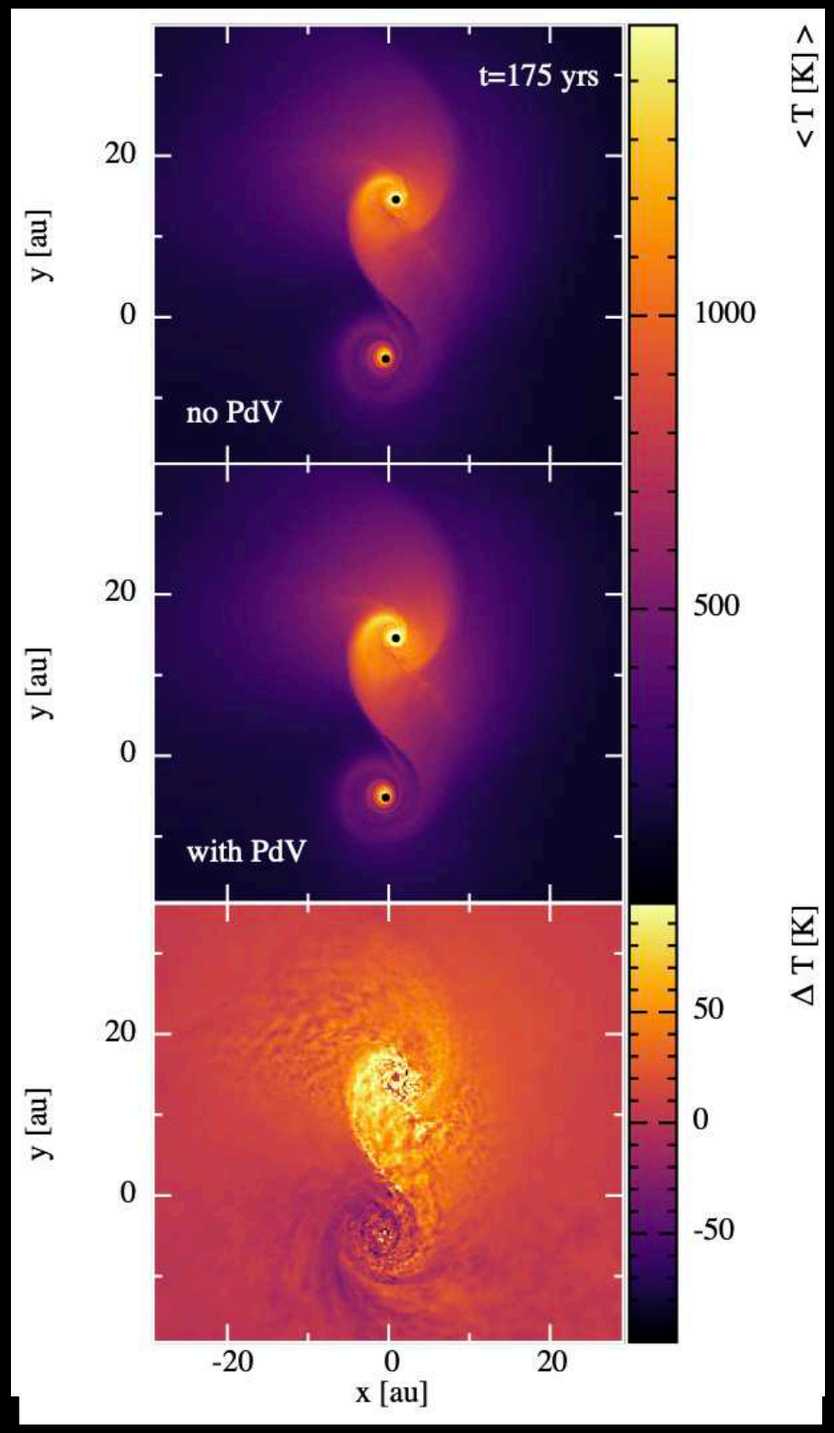
4TH PHANTOM USERS WORKSHOP 2023

WHAT IS NEW?


Yeah, yeah right, just put the movie already! (I-hi)
Yeah, ye
(c) 2021 Miguel Gonz

RADIATION: PHANTOM+MCFOST

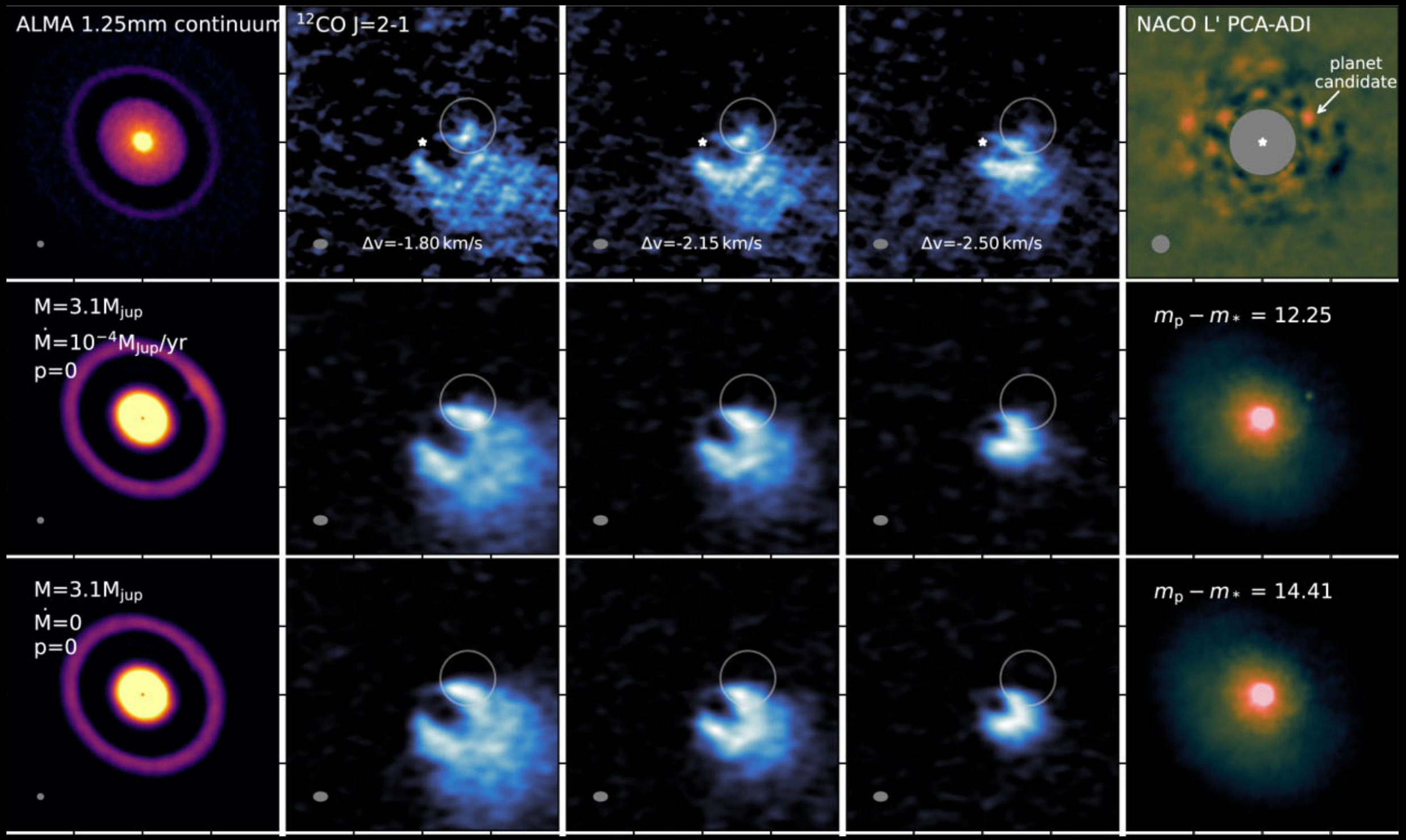
PHANTOM+MCFOST WITH PDV WORK AND SHOCK HEATING



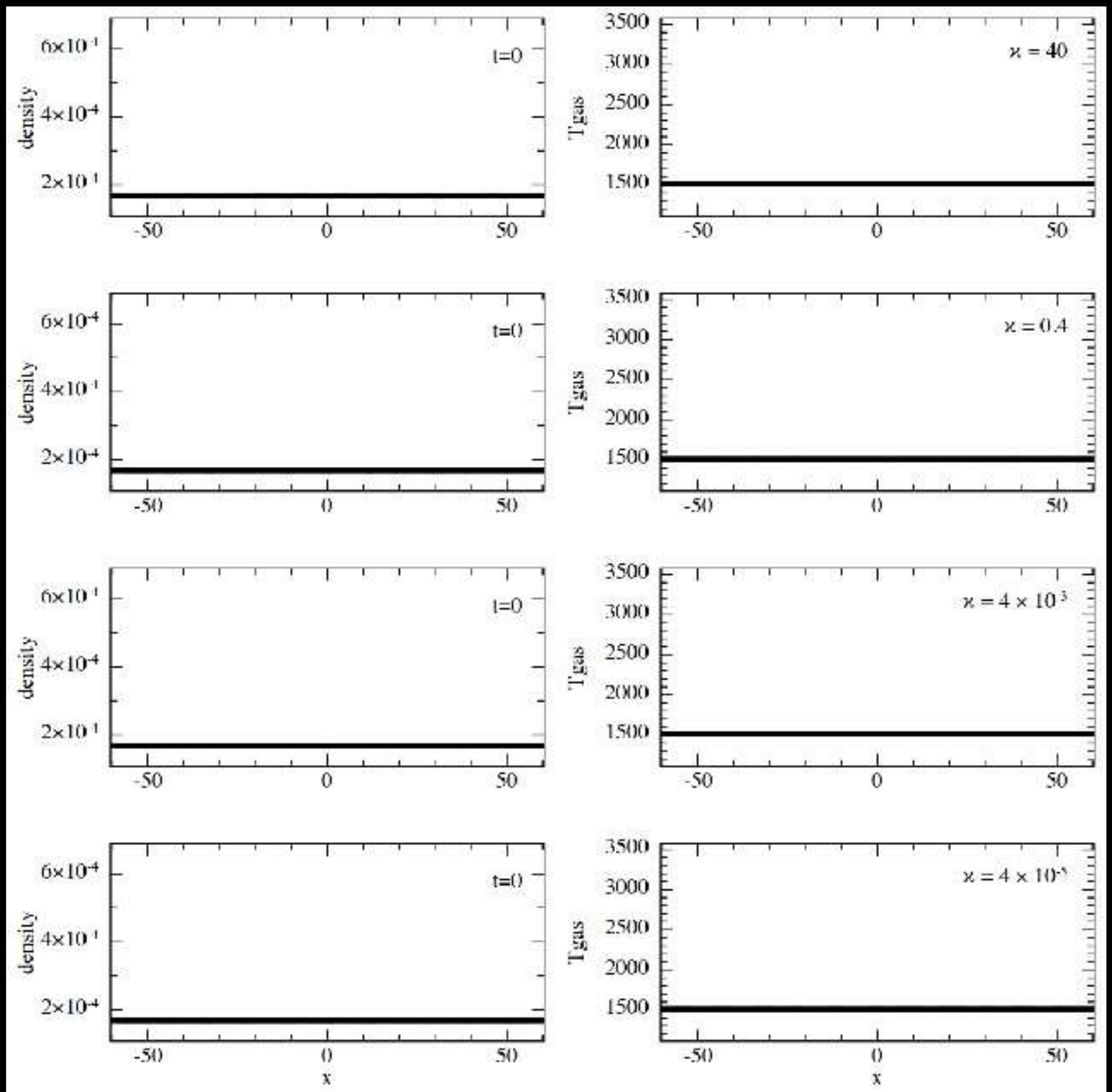
Borchert+2022b

CAN WE DO SELF-GRAVITATING DISCS THIS WAY?

PLANET FEEDBACK FROM MASS ACCRETION: COMPARISON WITH OBSERVATIONS



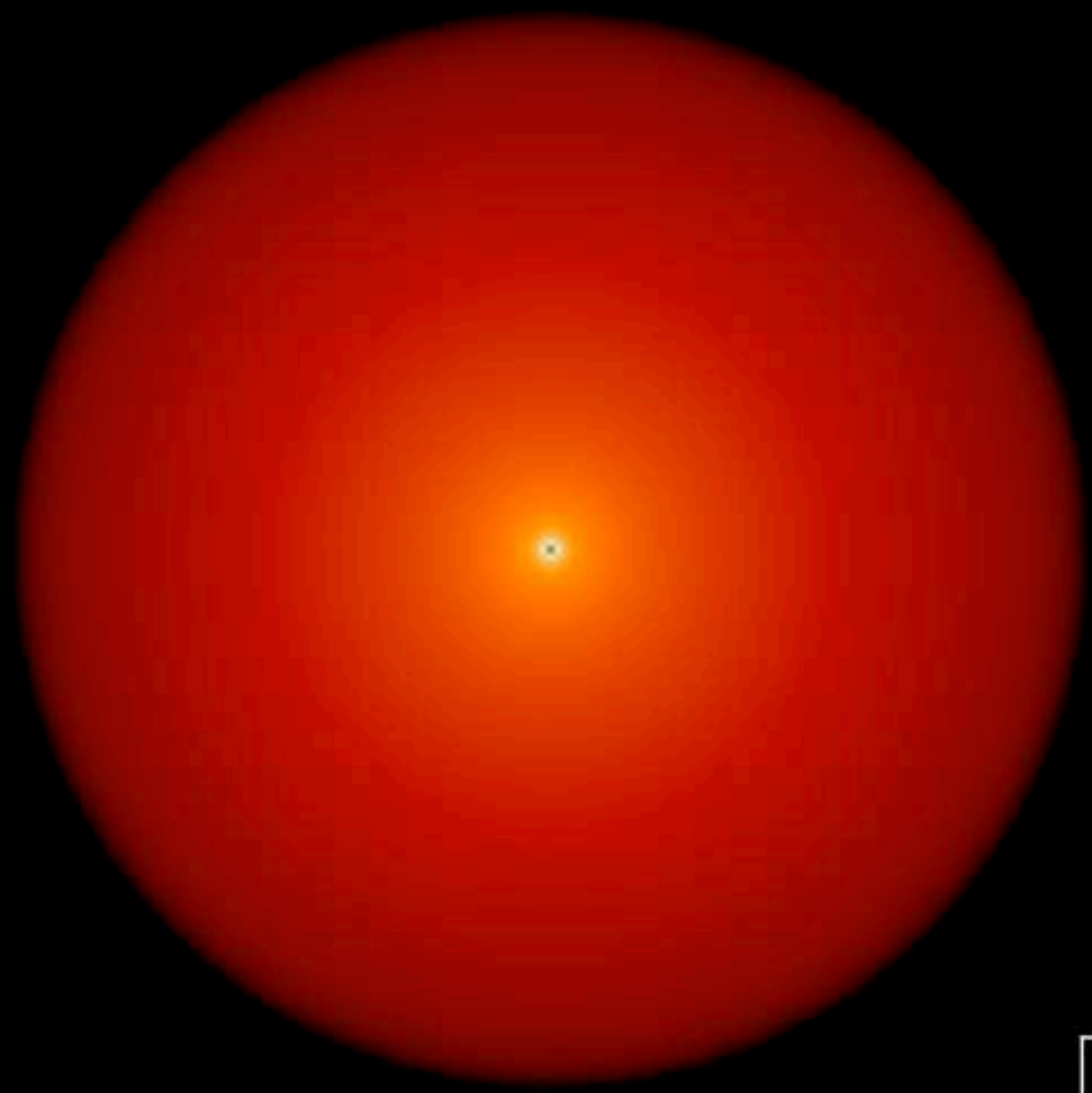
RADIATION: IMPLICIT FLUX-LIMITED DIFFUSION



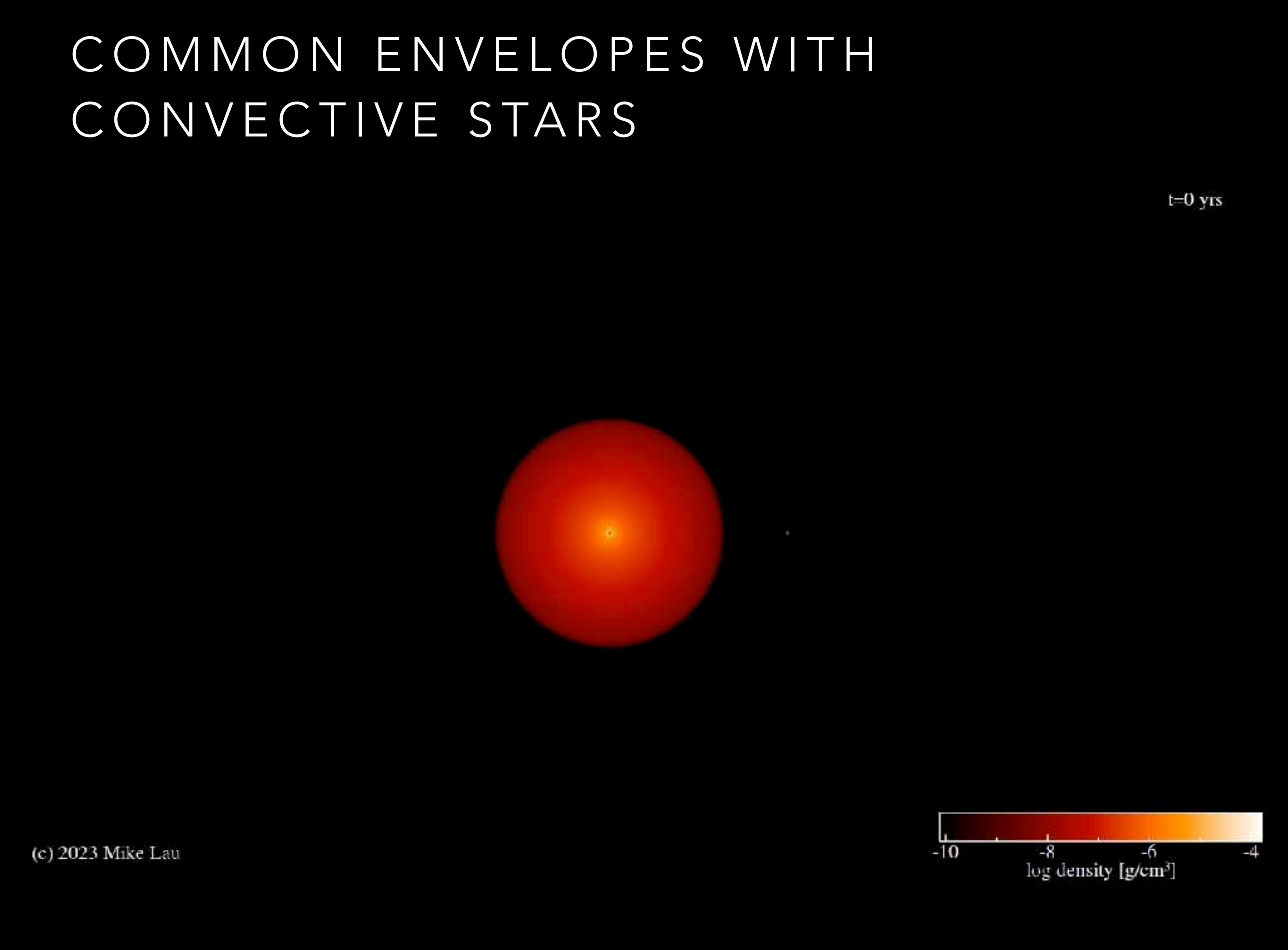
Whitehouse & Bate (2004), Whitehouse, Bate & Monaghan (2005)

Ported to Phantom by Mike Lau, Ryo Hirai and Daniel Price, with thanks to Matthew Bate

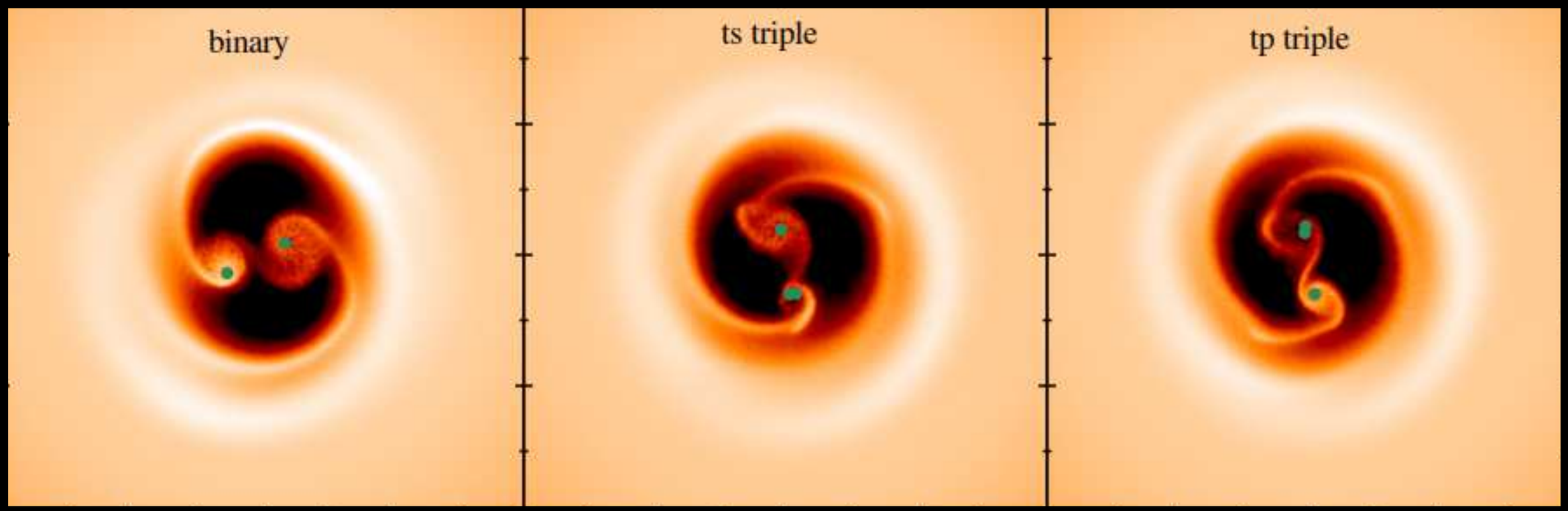
CONVECTING STARS WITH FLD



COMMON ENVELOPES WITH CONVECTIVE STARS



TRIPLES!



Complete Hierarchical Endless System Setup™
thanks to Simone Ceppi

Inhomogeneous Cosmology using General Relativistic Smoothed Particle Hydrodynamics coupled to Numerical Relativity

Spencer J. Magnall,* Daniel J. Price, and Paul D. Lasky
School of Physics and Astronomy, Monash University, VIC 3800, Australia and
OzGrav: The ARC Centre of Excellence for Gravitational-wave Discovery, Clayton, VIC 3800, Australia

Hayley J. Macpherson
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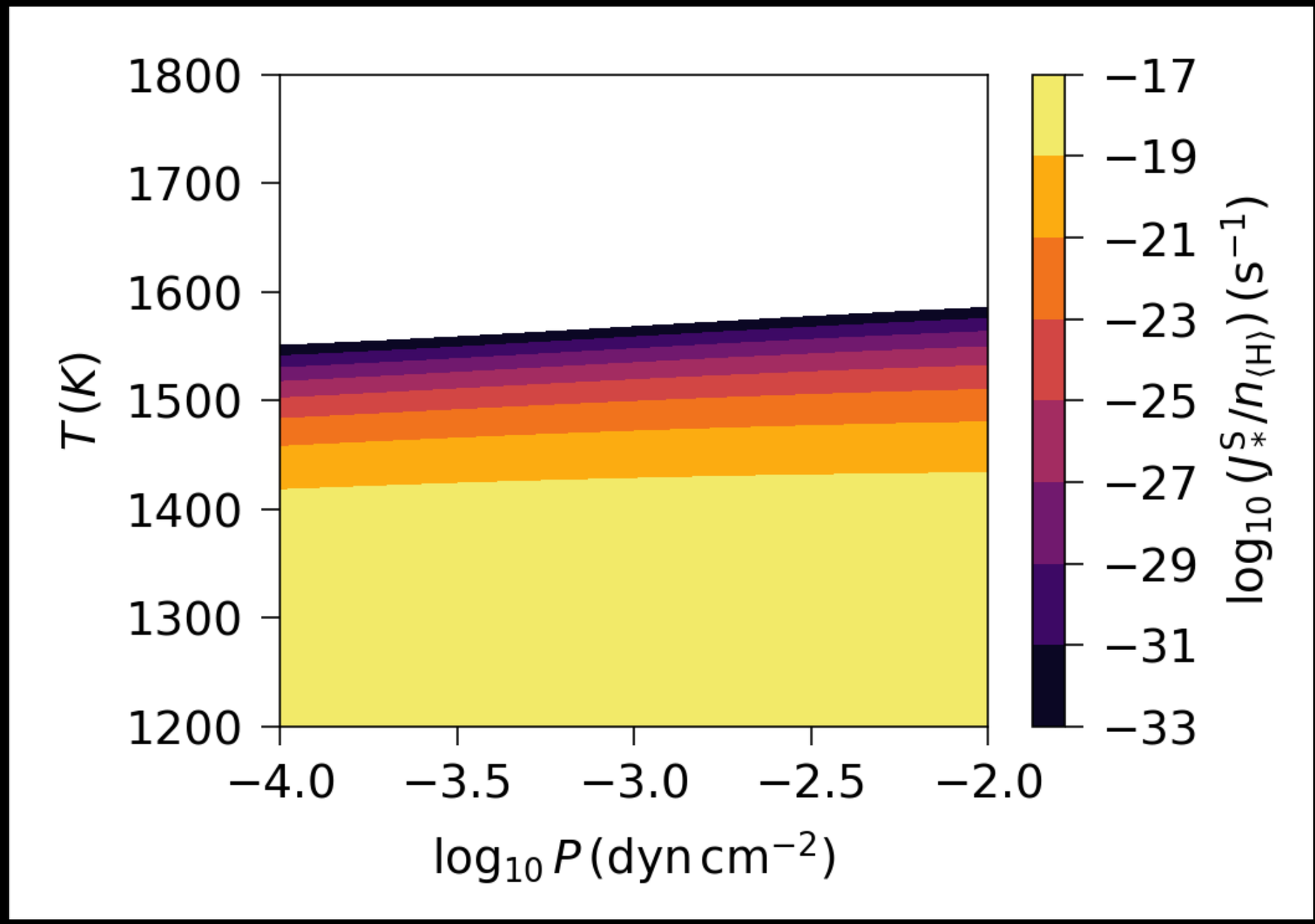
NASA Einstein Fellow

(Dated: July 31, 2023)

We perform three-dimensional simulations of homogeneous and inhomogeneous cosmologies via the coupling of the EINSTEIN TOOLKIT numerical relativity code for spacetime evolution to the PHANTOM smoothed particle hydrodynamics (SPH) code. Evolution of a flat dust and radiation dominated Friedmann-Lemaître-Roberston-Walker (FLRW) spacetime shows an agreement of exact solutions with residuals on the order 10^{-6} and 10^{-3} respectively, even at low grid resolutions. We demonstrate evolution of linear perturbations of density, velocity and metric quantities to the FLRW with residuals of $\approx 10^{-2}$ compared to exact solutions. Finally, we demonstrate the evolution of non-linear density perturbations past shell-crossing, such that dark matter halo formation is possible. We show that numerical relativistic smoothed particle hydrodynamics is a viable method for understanding non-linear effects in cosmology.

DUST FORMATION



Siess+2022, Bermúdez-Bustamante+2024

DUST NUCLEATION: METHOD

Siess+2022, Gail & Sedlmeyer (1997)

$$\frac{\mathrm{d}J_*}{\mathrm{d}t} = \frac{J_*^S - J_*}{\tau_*}$$

$$\frac{\mathrm{d}K_0}{\mathrm{d}t} = J_*$$

$$\frac{\mathrm{d}K_i}{\mathrm{d}t} = \frac{i\,K_{i-1}}{3\tau} + N_l^{i/3} J_*$$

K_0 ~ mean grain size

K_1 ~ mean grain area

etc

Start forming dust once reach supersaturation ratio

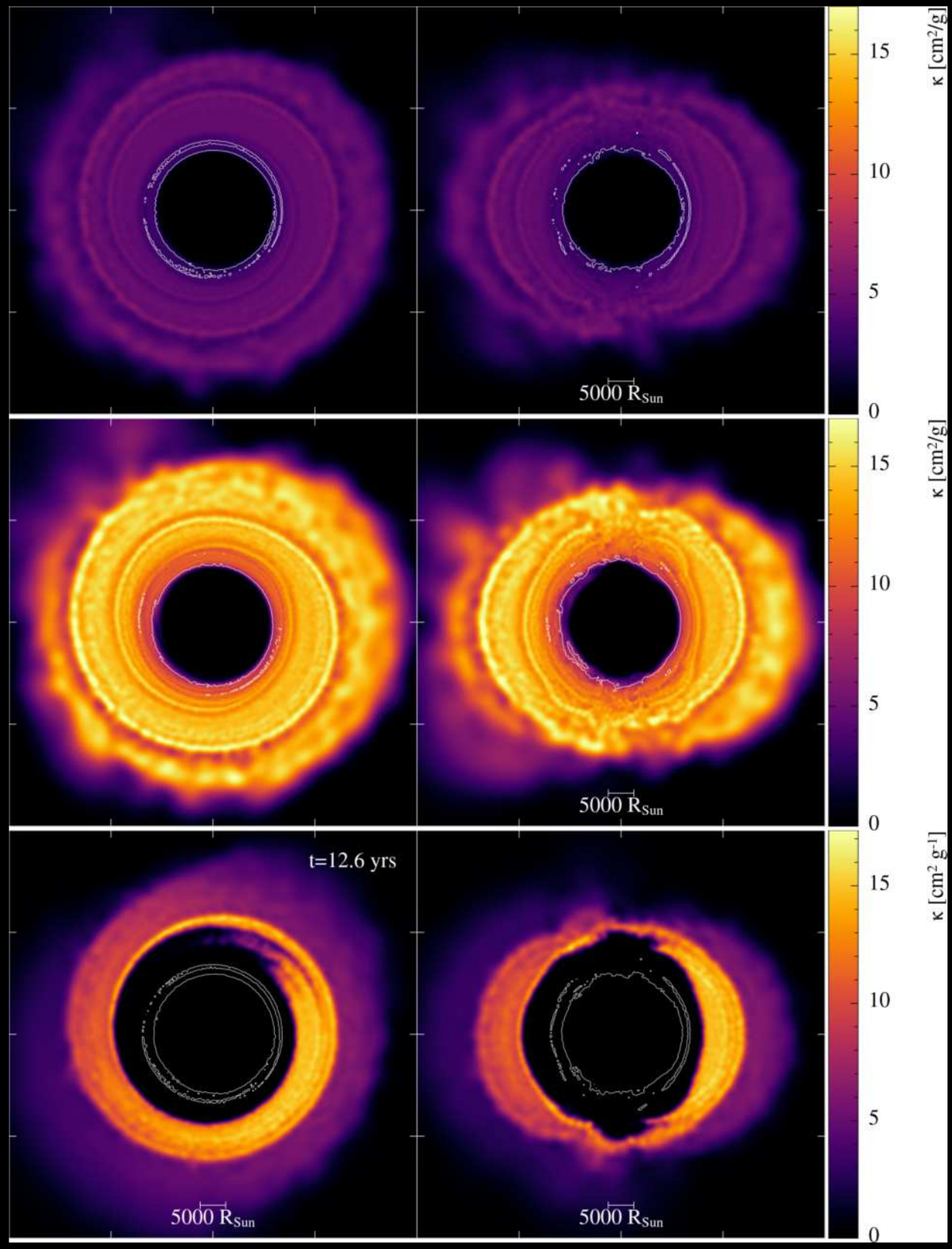
Evolve moments

$$K_i \equiv \int N^{i/3} f(N) dN$$

PROBLEM: NEED F(N) FOR MCFOST POST-PROCESSING

OPACITY CHANGE DUE TO DUST FORMATION

$$\kappa \propto K_3$$



Bermúdez-Bustamante+2024

RECONSTRUCTING MOMENTS?

$$K_i \equiv \int N^{i/3} f(N) dN \quad \Rightarrow \quad f(N)?$$

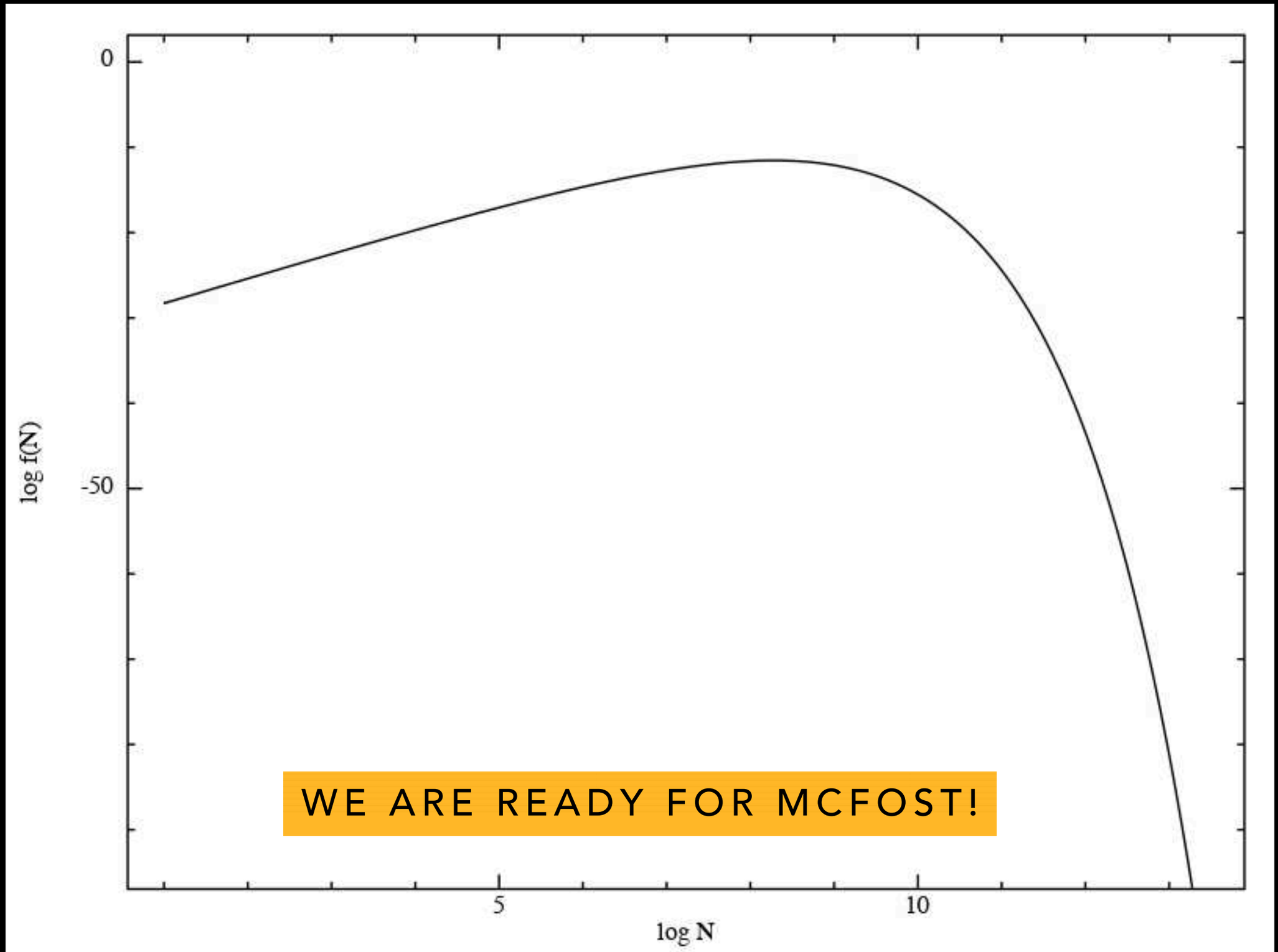
Attempt 1: $f(N) = \exp[\lambda_0 + \lambda_1 N + \lambda_2 N^2 + \lambda_3 N^3 + \ldots]$

COMPUTE MOMENT INTEGRAL NUMERICALLY

Attempt 2: $f(N) = f_0 \left(\frac{N}{\theta}\right)^{(d-1)} \exp[-(N/\theta)^p]$

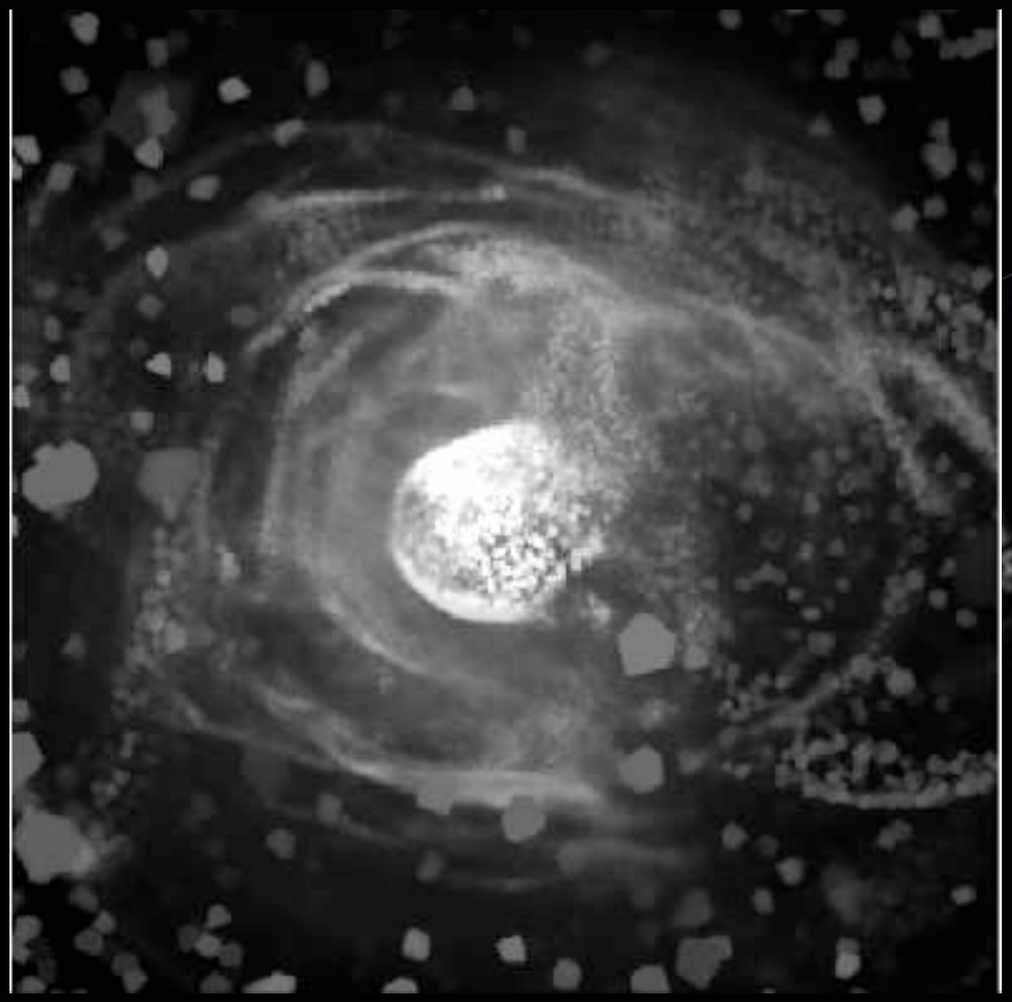
MOMENT INTEGRALS ARE ANALYTIC, JUST HAVE TO ROOT FIND FOR D AND P

RECONSTRUCTING MOMENTS

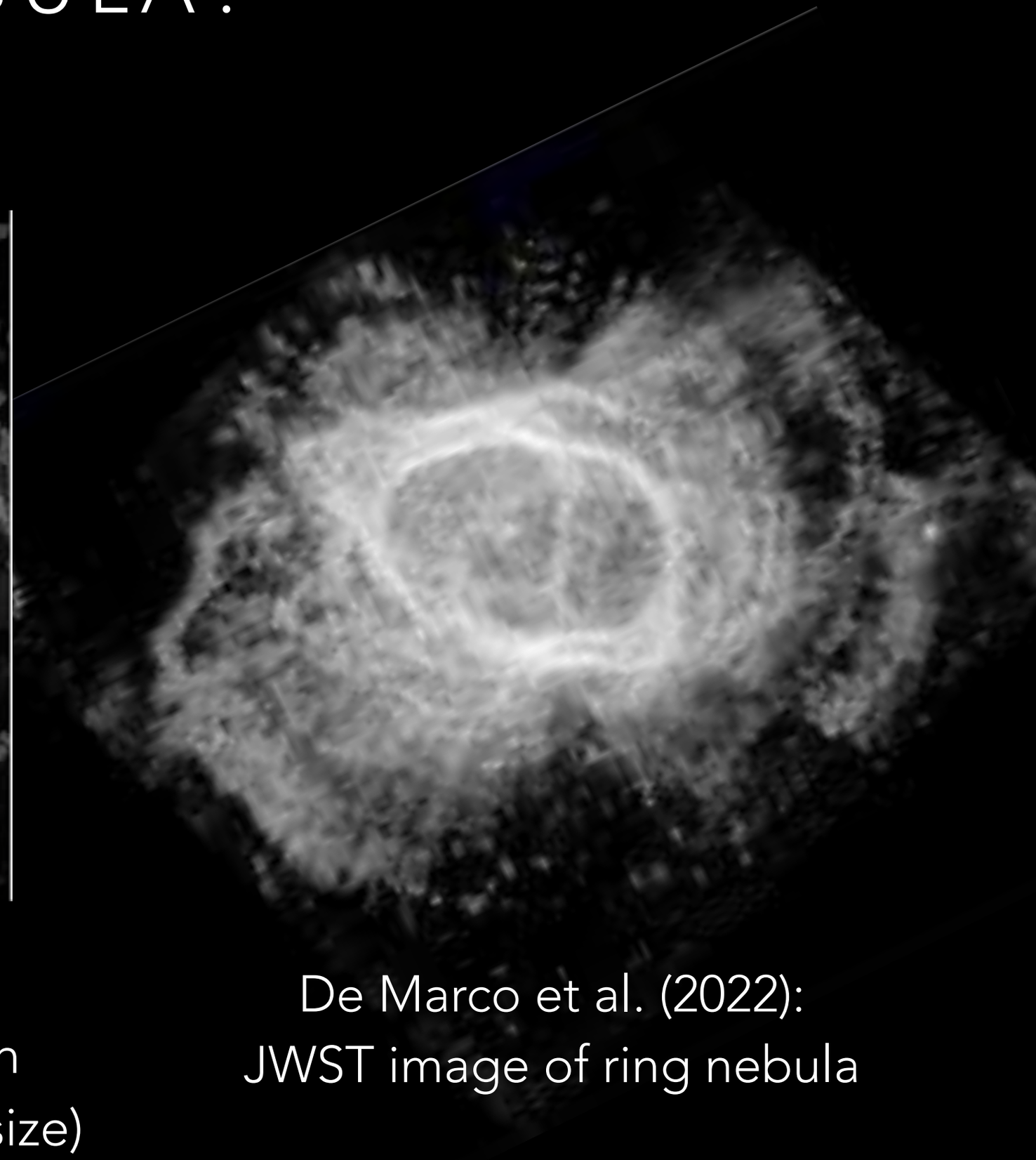


WE ARE READY FOR MCFOST!

THE RING NEBULA?



Made by Christophe Pinte
(MCFOST image of common envelope with assumed grain size)



De Marco et al. (2022):
JWST image of ring nebula

TIDAL DISRUPTION EVENTS

t=0 days

THE EDDINGTON ENVELOPE (BLACK HOLE SUN)

t=0 days

300 au

300 au

-16 -15 -14 -13 0

log density [g/cm³]

5000 1×10⁴ 1.5×10⁴

temperature [K]

See also Hu et al. (2024)

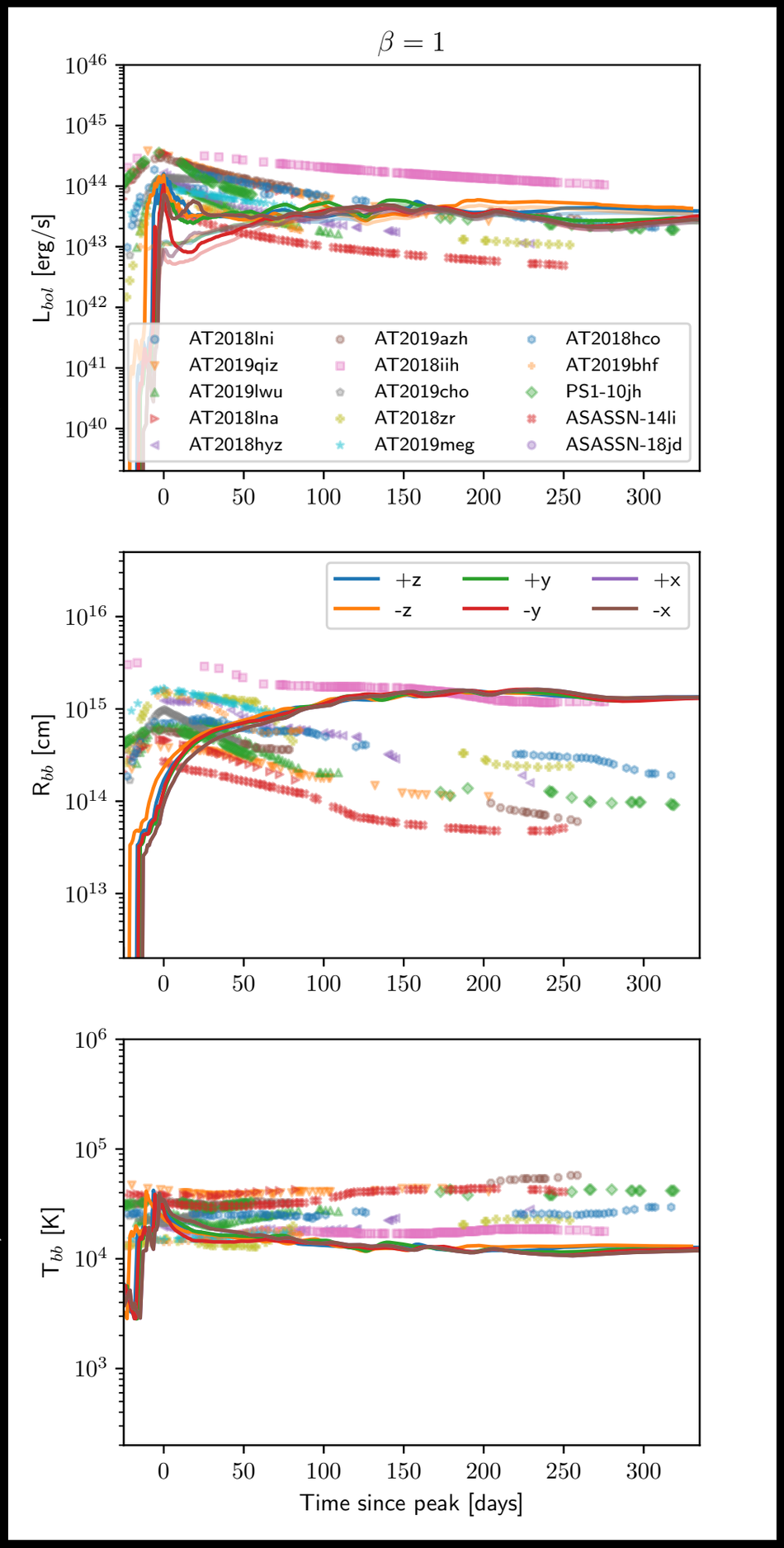
COMPARISON WITH OBSERVATIONS

MOSTLY UV/ OPTICAL EMISSION

LOW LUMINOSITIES 10^{43}-10^{44} ERG

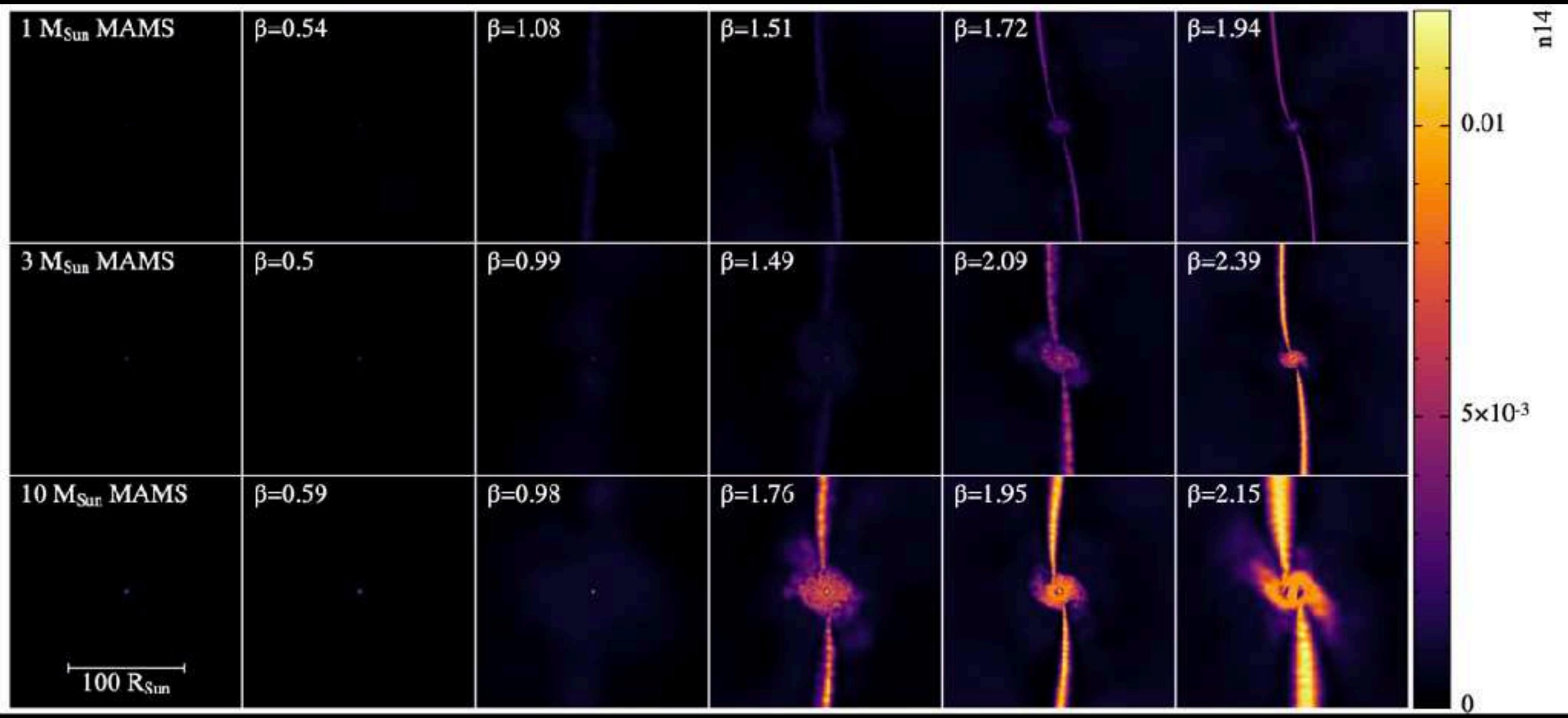
LARGE EMISSION REGION 10-100 AU

10^{4} - 10^{5} K, NOT 10^{8} K



Price et al. (2024), see also Hu et al. (2024)

COMPOSITION TRACKING IN PARTIAL TDES



Sharma et al. (2024), in prep.

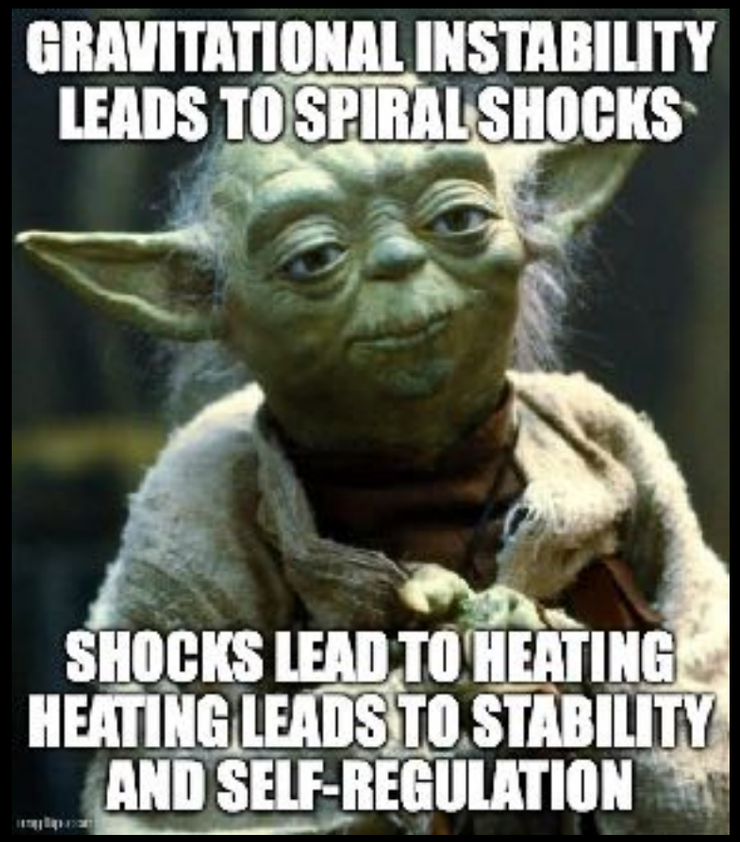
A QUICK WORD ON SELF-GRAVITATING DISCS...

TOOMRE (1964): DISCS ARE UNSTABLE IF Q < 1

$$\frac{M_{\rm disc}}{M_*} \gtrsim \frac{H}{R}$$ Global criterion

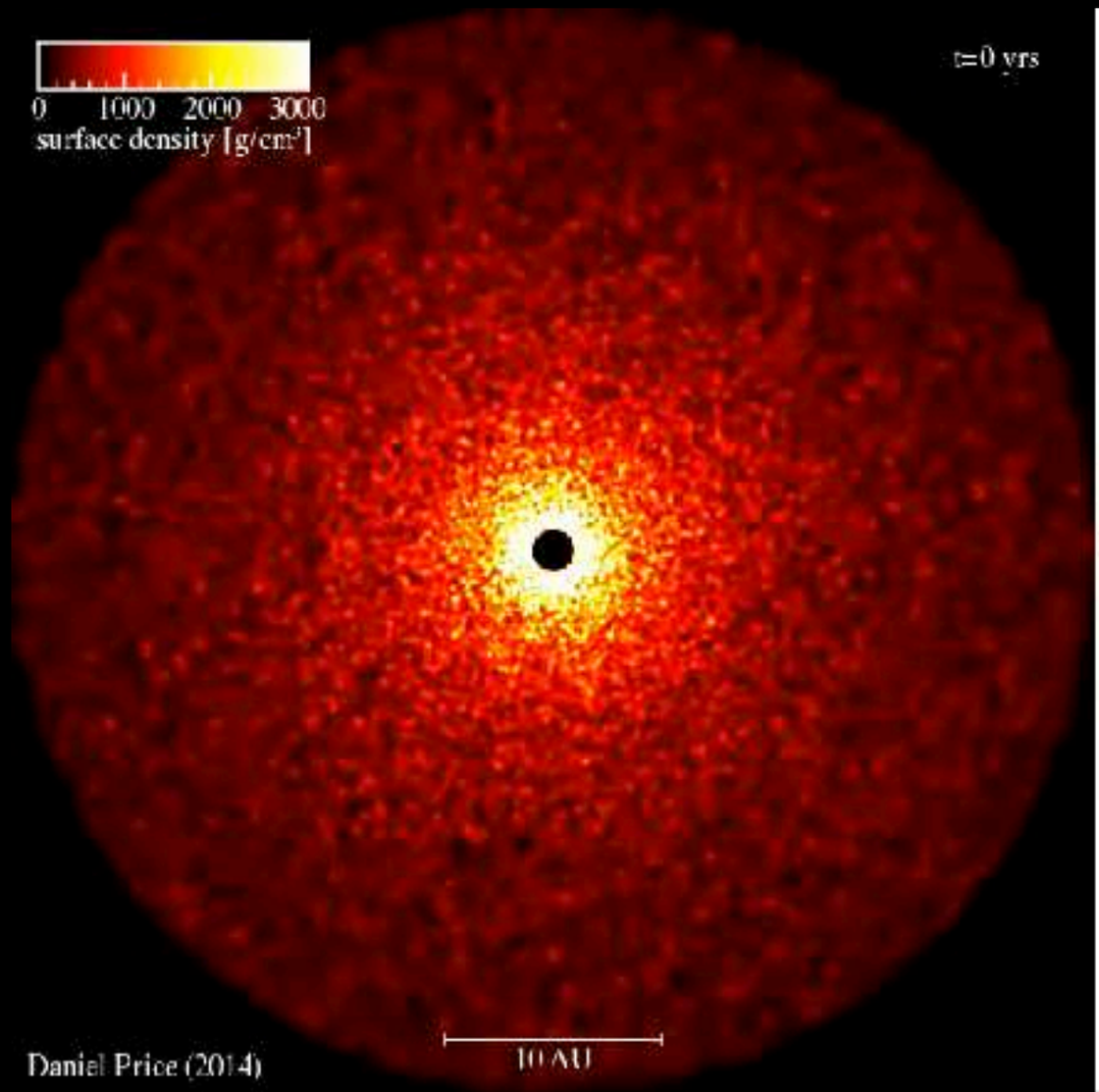
$$Q \equiv \frac{c_{\rm s}\Omega}{\pi G\Sigma} < 1$$ Local criterion

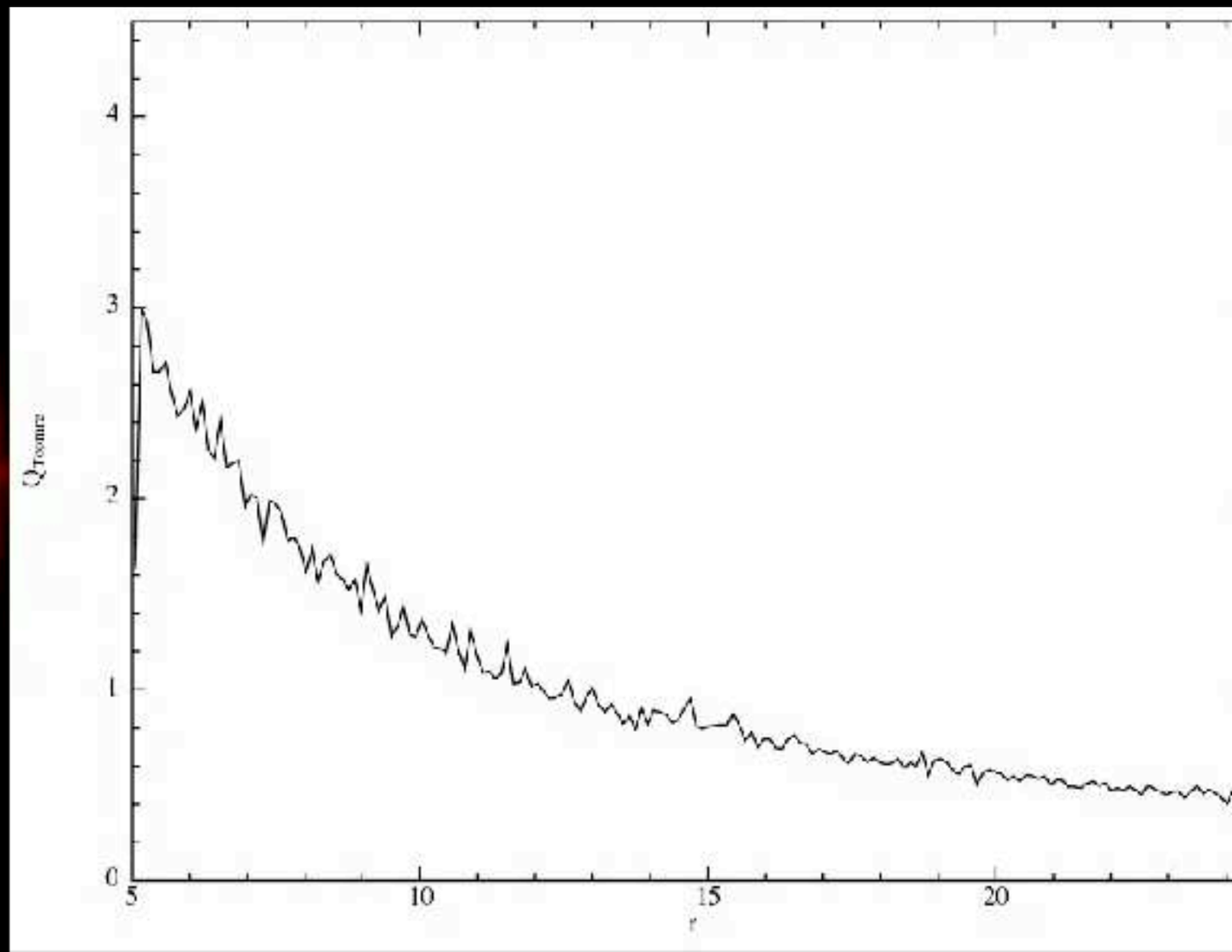
GAMMIE (2001): NOT SO SIMPLE...



SELF-REGULATION IN SELF-GRAVITATING DISCS

$$\frac{\mathrm{d}u}{\mathrm{d}t} = -\frac{P}{\rho}(\nabla \cdot \mathbf{v}) + \Pi_{\rm shock} - \frac{u}{t_{\rm cool}} \qquad t_{\rm cool} = \frac{1}{\beta\Omega(R)}$$ Gammie (2001)

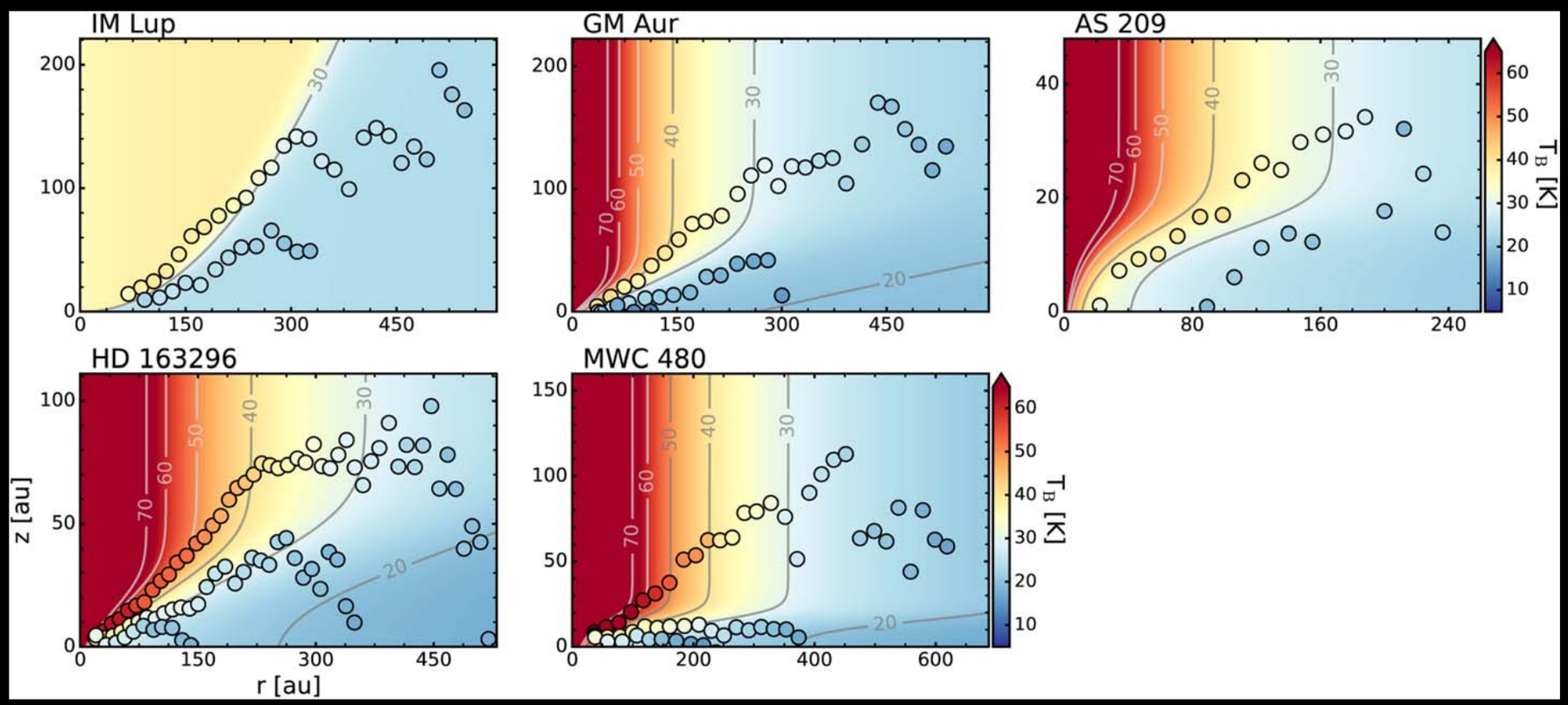




Long history of global simulations with β-cooling e.g. Rice et al. (2003a,b), Lodato & Rice (2004) and many others

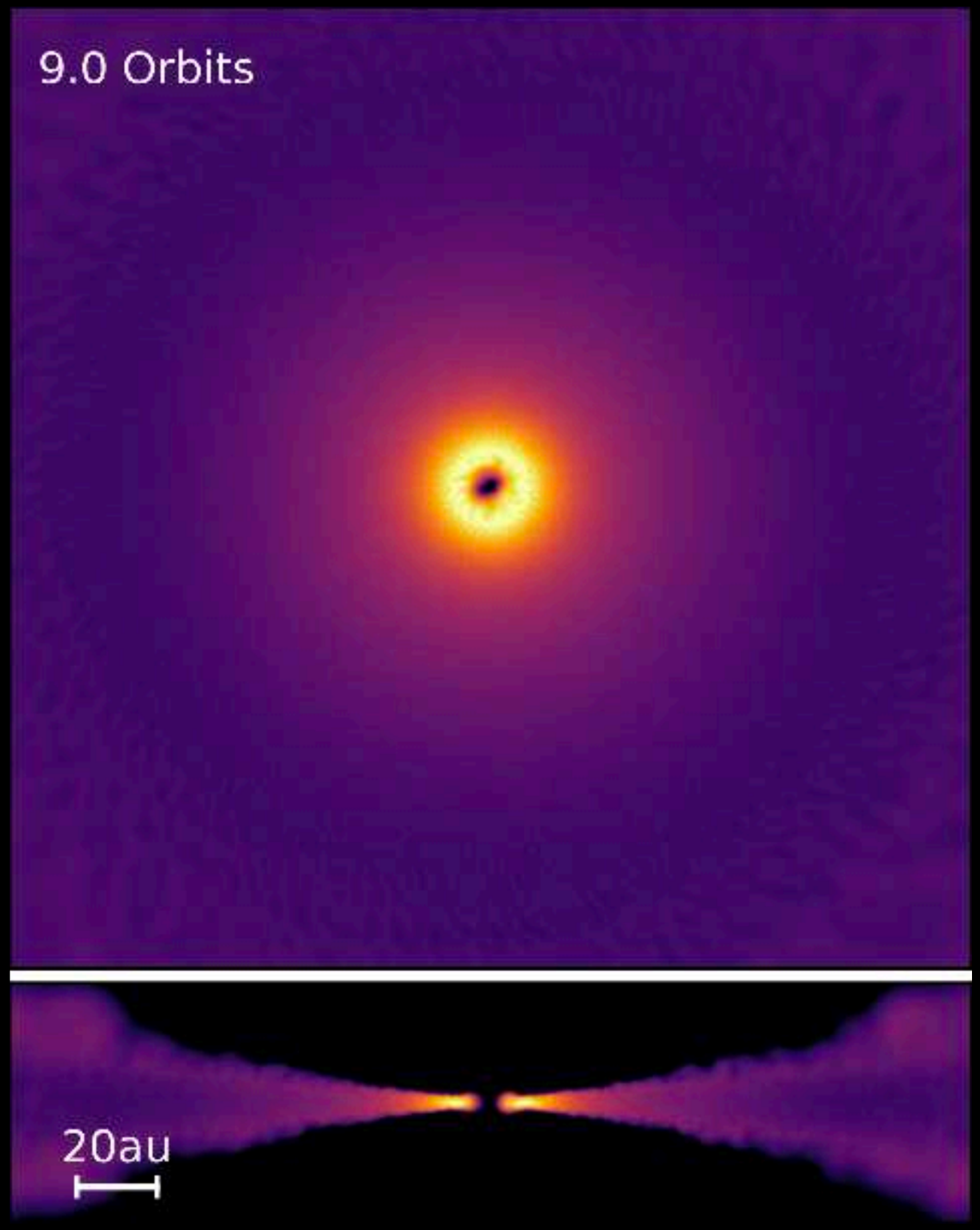
BETTER BETA-COOLING?

- Problem with β-cooling is that mid plane and atmosphere cool at same rate, but radiation should diffuse from midplane upwards…
- Also β-cooling assumes only shock heating, no heating from central star (important for protostellar discs)
- Protostellar discs are hotter at the top: should have β-heating, not β-cooling!



Law et al. (2021)

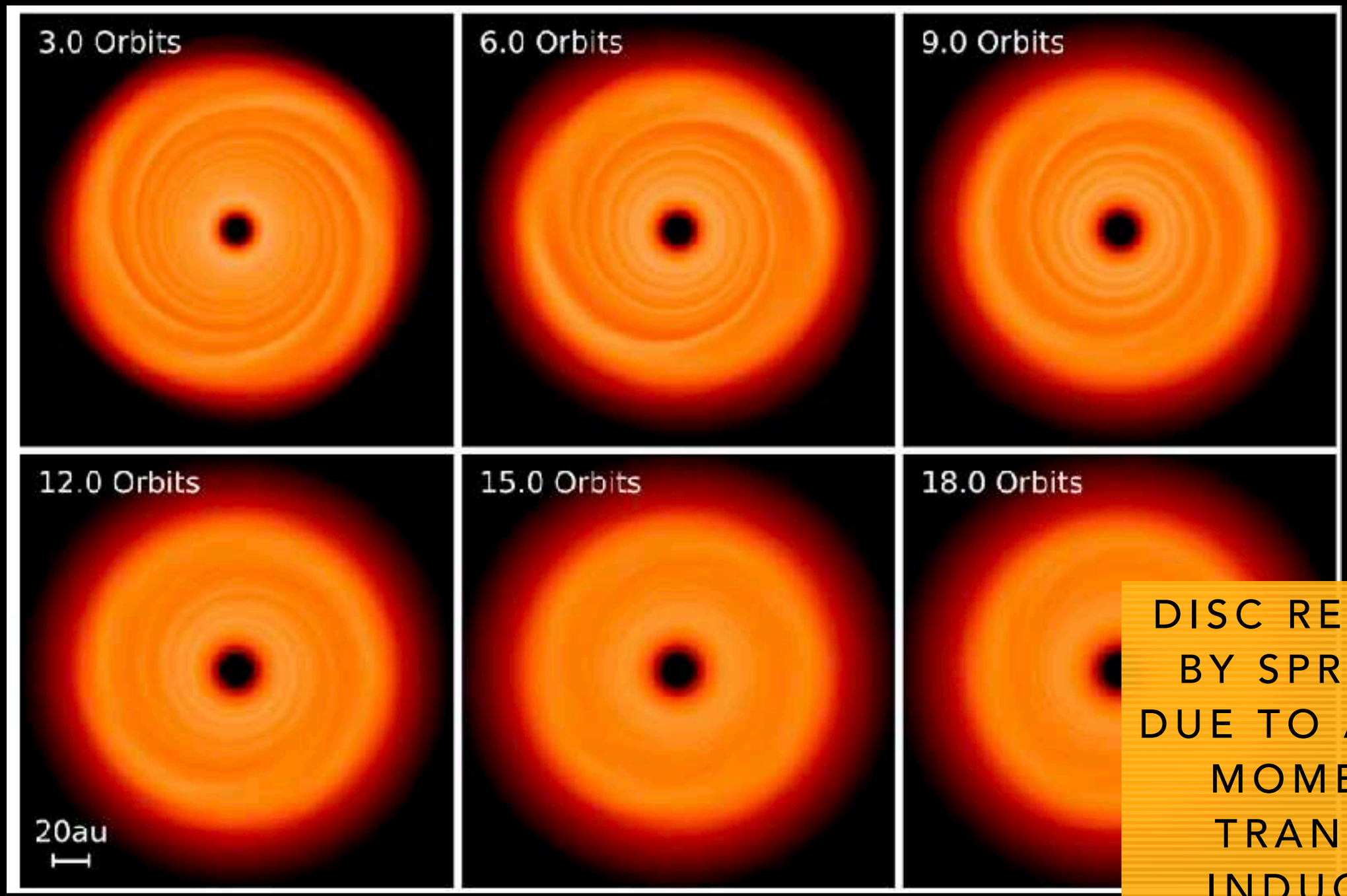
SELF-GRAVITATING DISCS USING PHANTOM+MCFOST WITH SHOCK HEATING



- MCFOST computes the balance between heating and cooling
- Call MCFOST several times per inner orbit
- Start with marginally unstable disc
- Initially no shock heating, but as disc becomes unstable, shock heating will increase…

Rowther et al. (in prep)

SELF-REGULATION USING PHANTOM+MCFOST WITH SHOCK HEATING



Rowther et al. (in prep)

$$\mathcal{Q} \equiv \frac{c_s \Omega}{\pi G \Sigma}$$

DISC REGULATES BY SPREADING DUE TO ANGULAR MOMENTUM TRANSPORT INDUCED BY SHOCKS, NOT BY HEATING UP

SUMMARY

- Lots of recent work on radiation hydro, GR and dust formation in particular
- Goal in all areas is to enable direct comparison with relevant observations
- We have a proof-of-concept on a new way to tackle self-gravitating discs
- Still some way to go to be where we want to be

WISH LIST

- Faster MCFOST in optically thick regions
- Time dependent radiative transfer in MCFOST
- Electron scattering in MCFOST atomic line transfer
- MCFOST that works with gas + dust radiative transfer
- Feedback from planets / sink particles with surfaces
- GRMHD for tidal disruption events
- A faster GR code
- Adaptive particle refinement (see R. Nealon talk)
- As many stars as you want, any way you want them

SOME IDEAS FOR THE WEEK (2020)

- Multi-resolution SPH / particle splitting (moddump). Be able to re-start a simulation at higher/lower resolution. EXTENSION: run fixed spatial portion of simulation at higher res.

- Improve modularity + compile time. Build MESA-style sequence of libraries that do not require recompilation and can be used by other software, e.g. libsetup, libcore, libutils. DM: Should aim to split phantomsetup, phantommoddump into separate repos (core, others)

- Benchmarks. Create 5 new benchmarks to be performed nightly.

- phantom-examples repository, e.g. all tests from code paper / published methods papers. To be re-run at every formal release?

IDEAS II - PHYSICS

- Test thermodynamic consistency of MESA EOS, discuss approaches to handling stellar / degenerate equations of state

- Improve MCFOST coupling for live radiation (can we simulate a star? YES)

- DM: Code issues with live-MCFOST. Can we decouple the MCFOST frequency from dtmax? Could we make output frequency LONGER than dtmax. Integer multiple of dtmax for output (ndtmax).

NON-CODING ISSUES

- Policy: Are current policies re: commits and merges working? Move towards no ifdefs?
- Sustainability: How to encourage meaningful contributions? (DM: Breaking into different repositories?)
- DP: Can we make a phantom store for third party contributions? DM: Maybe we could use conda ?
- Governance: How to resolve potential conflicts?
- ~~Encourage use of the issue tracker on bitbucket? Should we shut down the slack channel? Delete the bugs channel? ** make a pinned post on the slack channel regarding where bugs should be posted?~~
- ~~Benedetta: added option to remove particles outside given radius~~

WEDNESDAY PROJECTS

- Spencer + Daniel P.: Measure openMP scaling for benchmarks, in particular on GADI. Can we get a factor of 2?
- Benedetta: test deleting particles that go outside a spherical outer radius
- Benedetta+Spencer: delete analysis_dustydisc
- Maxime, Arnaud & Daniel: hybrid multigrain, try to get something going…
- Can we delete ifdefs? Make a list of ifdefs that are NOT used in density/force/kdtree
- Daniel M: phantomconfig. phantombatch can depend on phantomconfig?
- Josh C: can we keep a fixed resolution in an accreting simulation by creating new particles?
- Daniel P and Christophe: randomised particle splitting/merging
- Sink particle boundary conditions: can we fix the stellar profile to not be flat in the central regions? (Mike, Ryusuke, Orsola)

THURSDAY PROJECTS

- Spencer + Joanna: Measure openMP scaling for growth benchmarks
- Benedetta: further work on deleting particles that go outside a spherical outer radius (kill not accrete, do it every timestep)
- Benedetta+Spencer: delete analysis_dustydisc
- Daniel P: debug seg fault in analysis_dustydisc
- Maxime, Arnaud & Daniel: hybrid multigrain, try to get something going…
- Can we delete ifdefs? Make a list of ifdefs that are NOT used in density/force/kdtree
- Daniel M: phantomconfig. phantombatch can depend on phantomconfig?
- Josh C: can we keep a fixed resolution in an accreting simulation by creating new particles?
- Daniel P and Christophe: randomised particle splitting/merging
- Sink particle boundary conditions: can we fix the stellar profile to not be flat in the central regions? (Mike, Ryusuke, Orsola)