PHANTOM

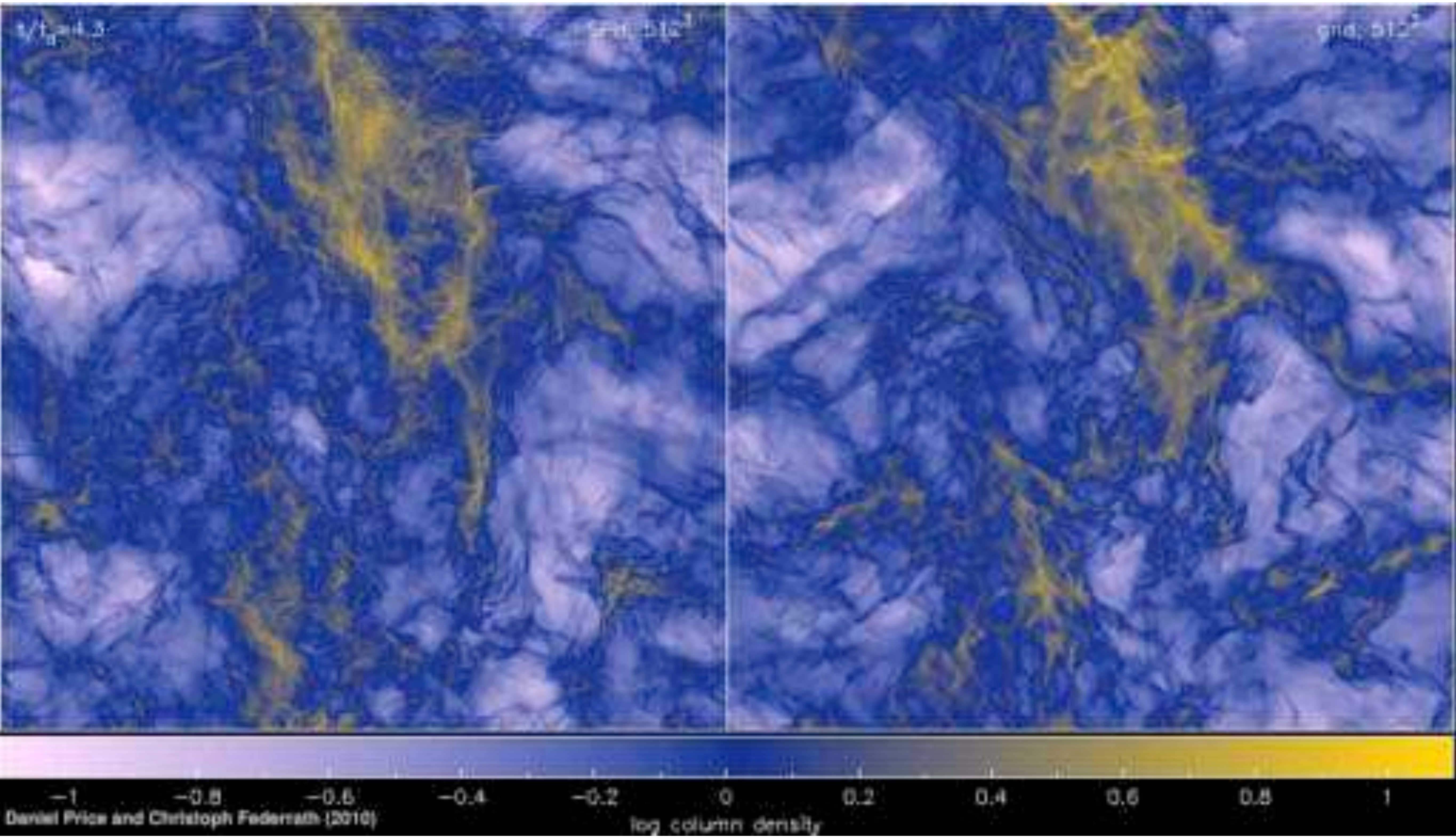
Daniel Price

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

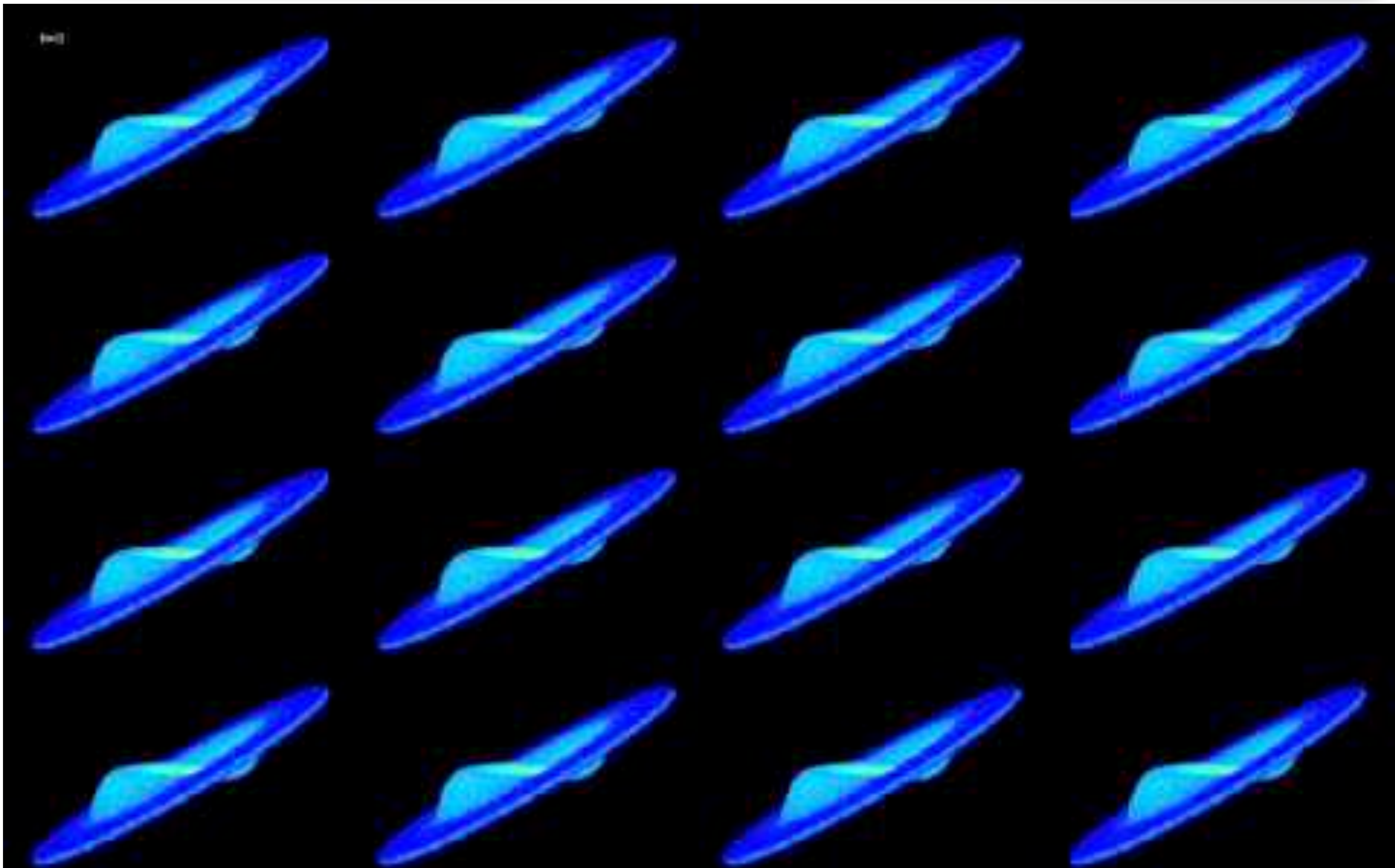
INITIAL APPLICATIONS

Price & Federrath (2010): Comparison of driven turbulence

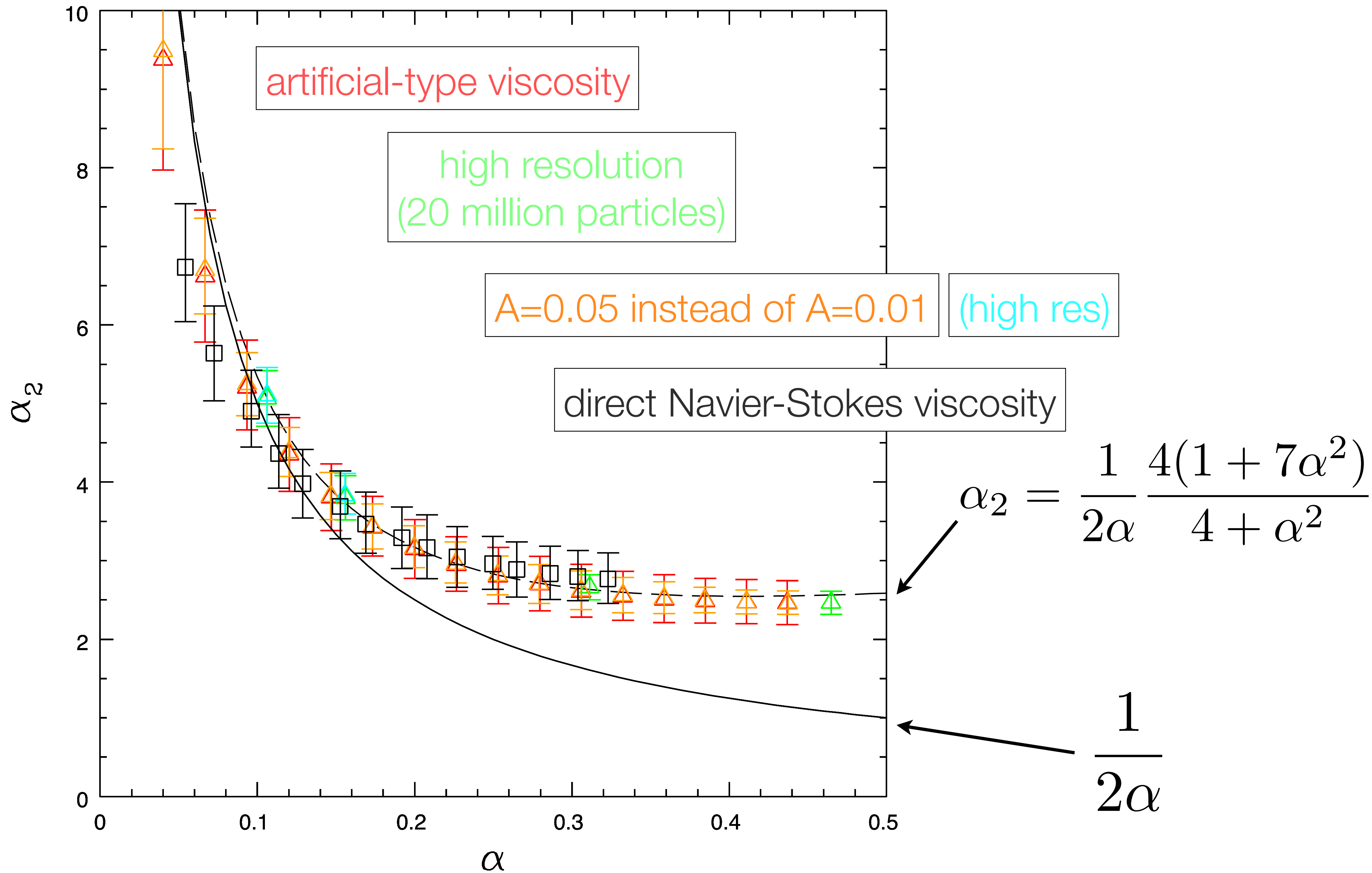


PHANTOM *FLASH*

Lodato & Price (2010) - warped discs

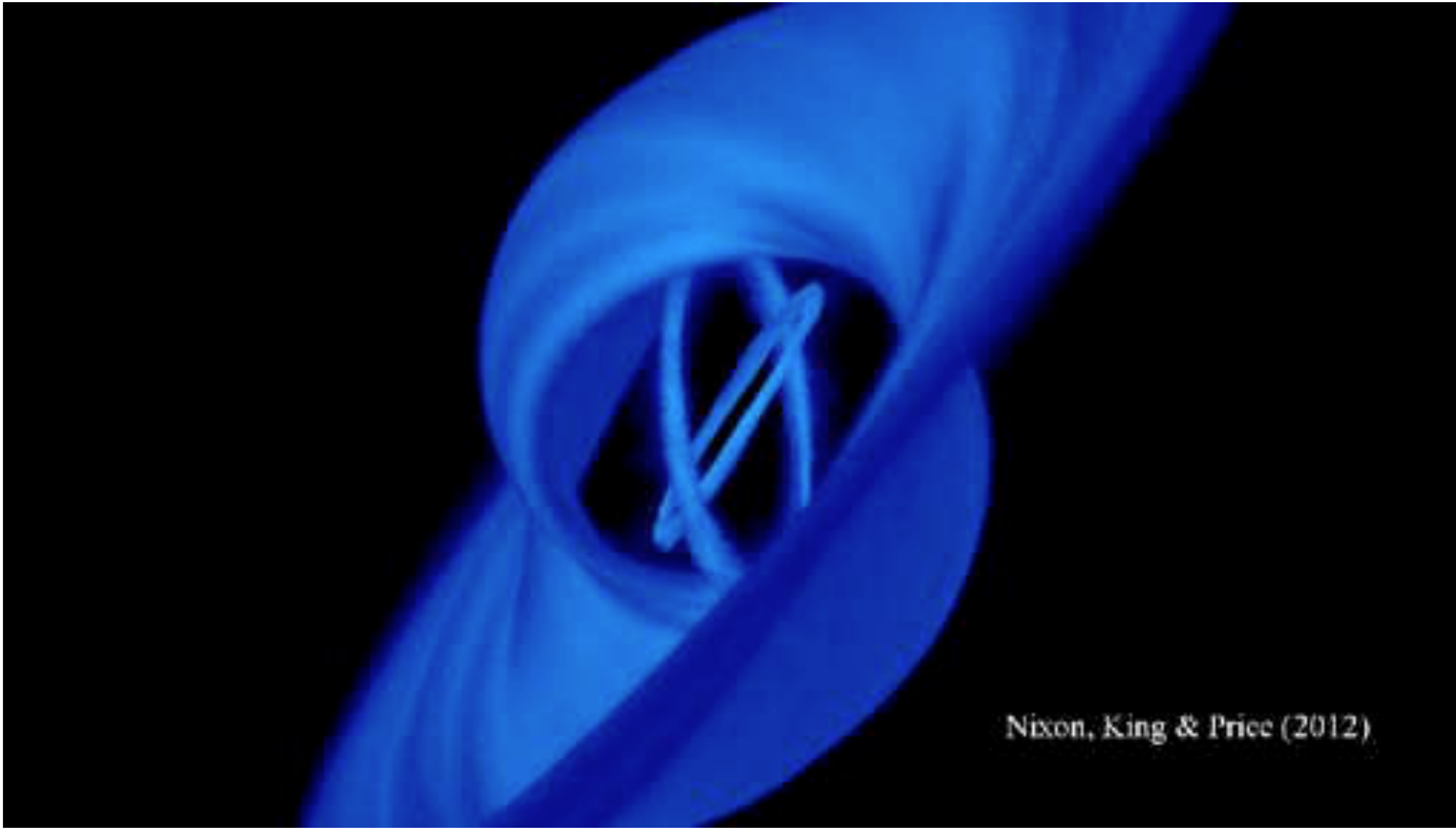


Results



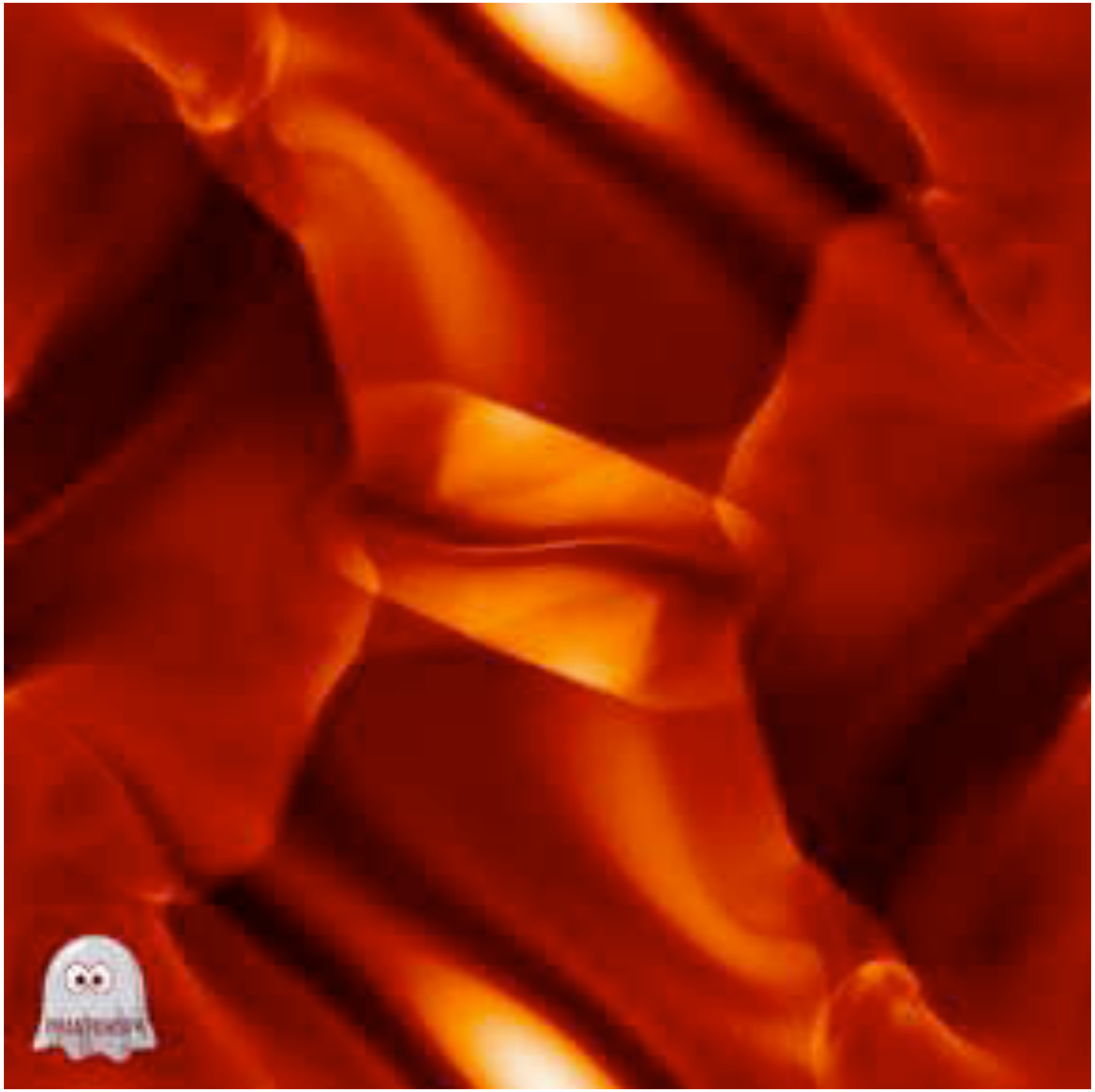
Lodato & Price (2010)

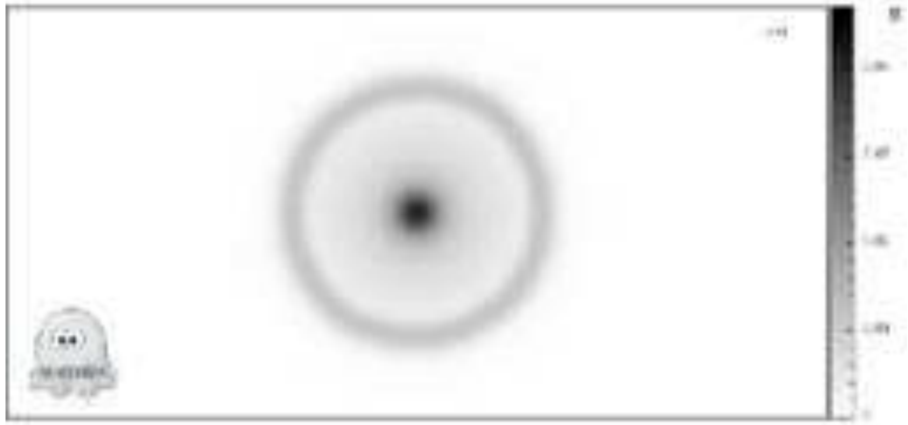
DISC TEARING



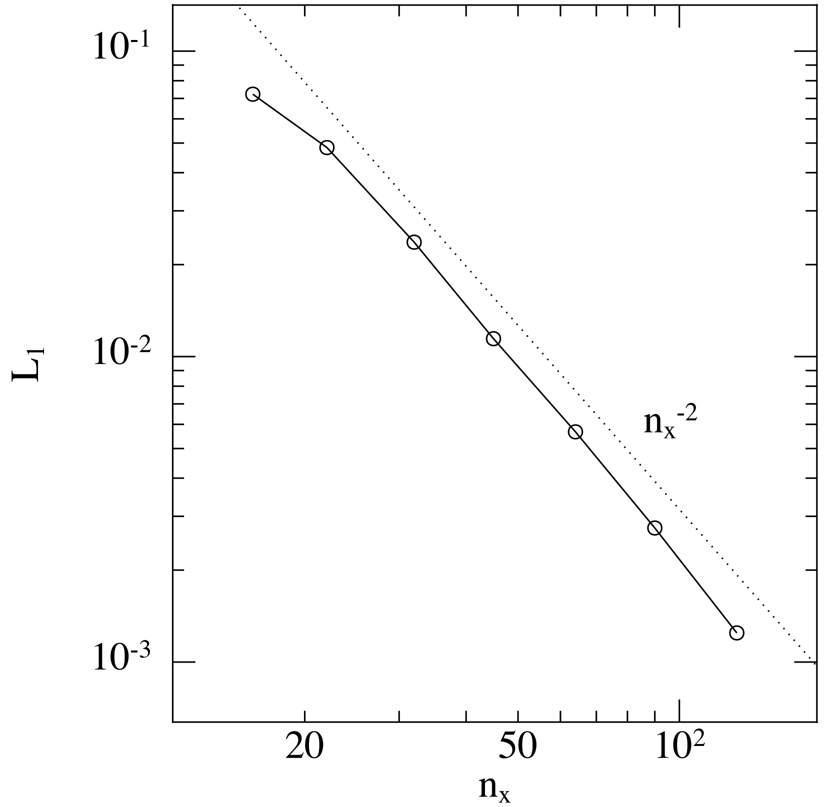
MHD (AROUND 2012)

Price et al. (2017)





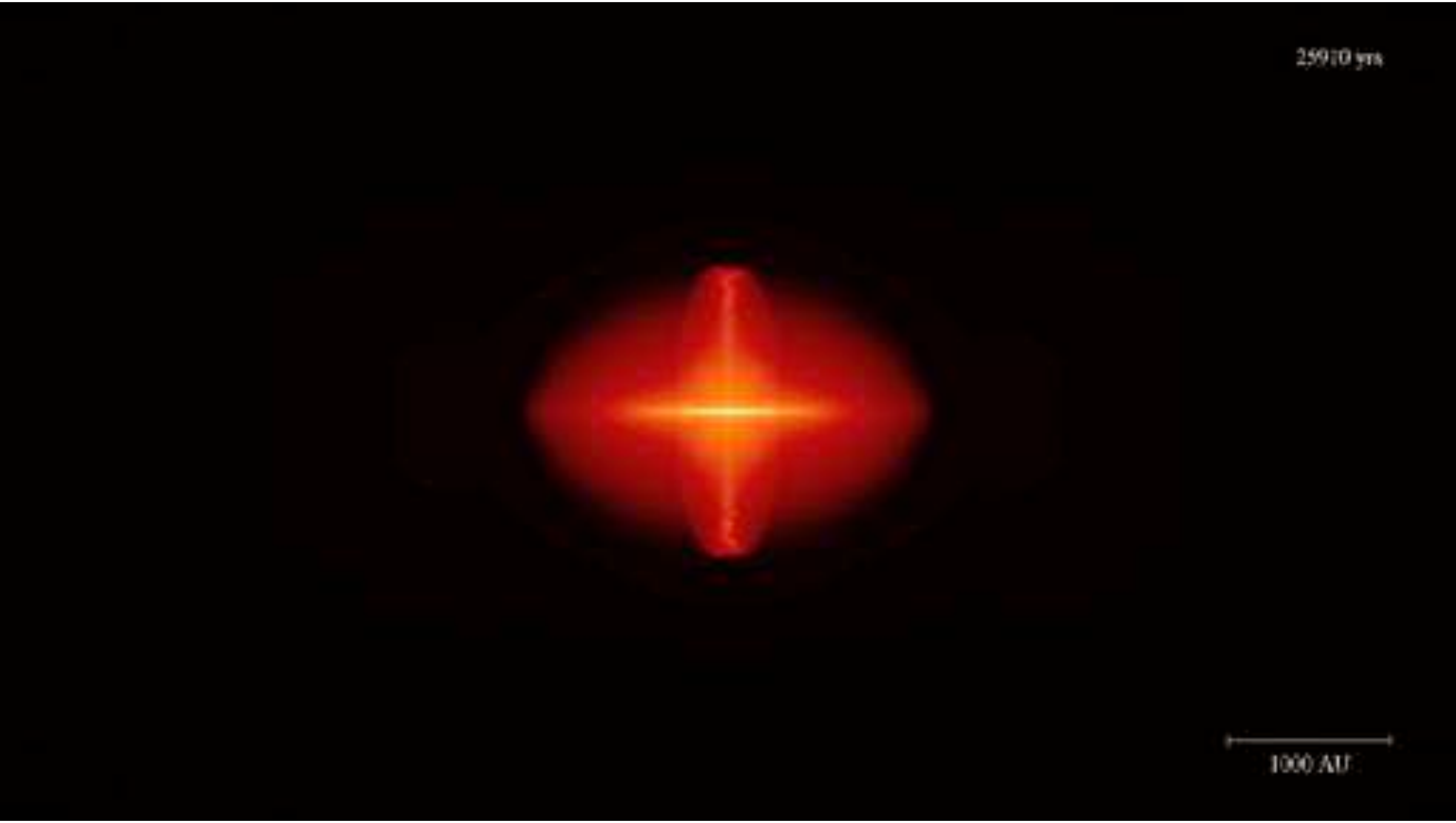
Advection of current loop (Gardiner & Stone 2005, 2008)



Convergence on circularly polarised Alfvén wave with ALL dissipation turned on

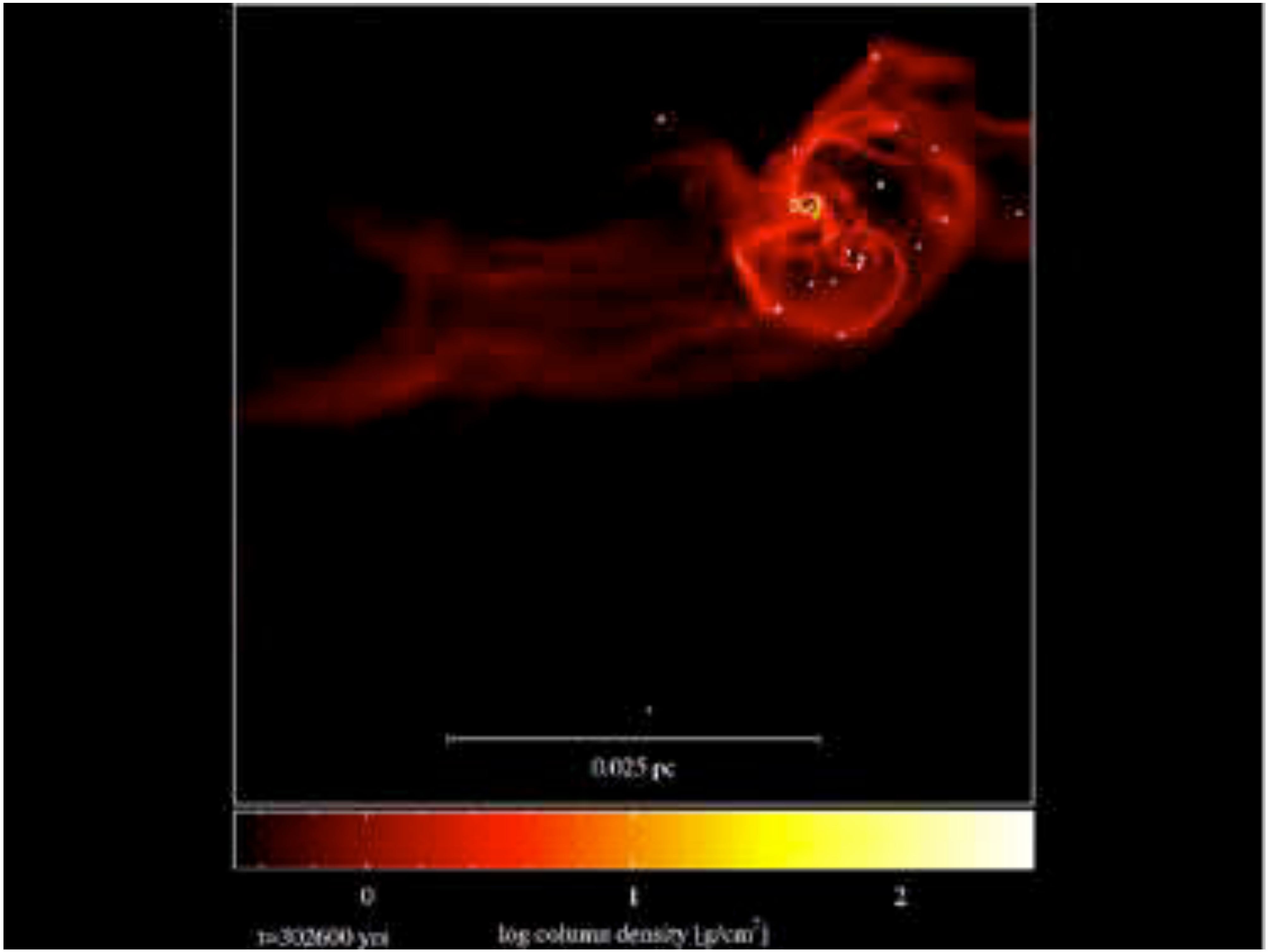
Performed with all dissipation, shock capturing and divergence cleaning turned on

SELF-GRAVITY



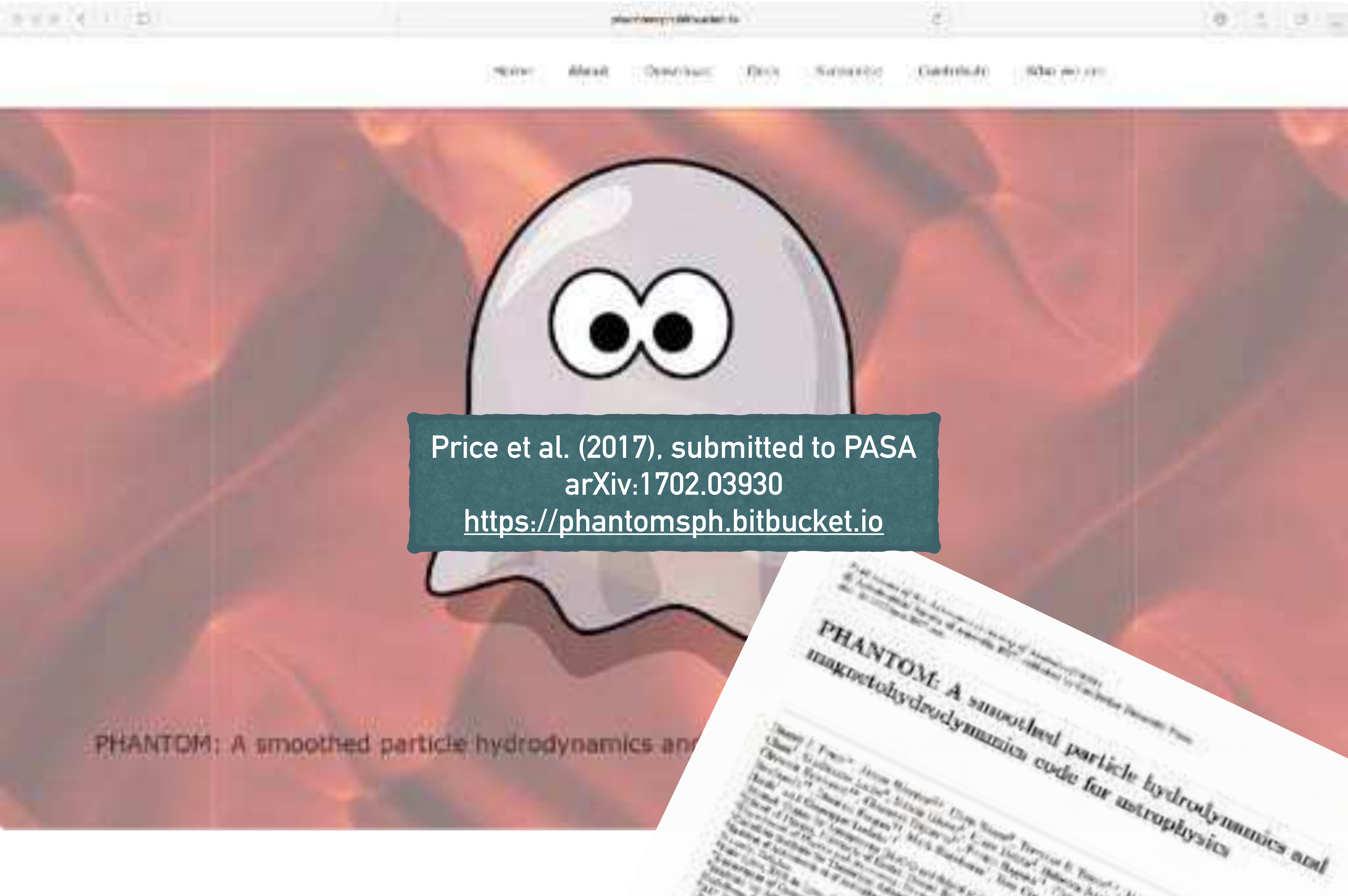
Price, Tricco & Bate (2012)

STAR CLUSTER FORMATION



Liptai et al. (2017)

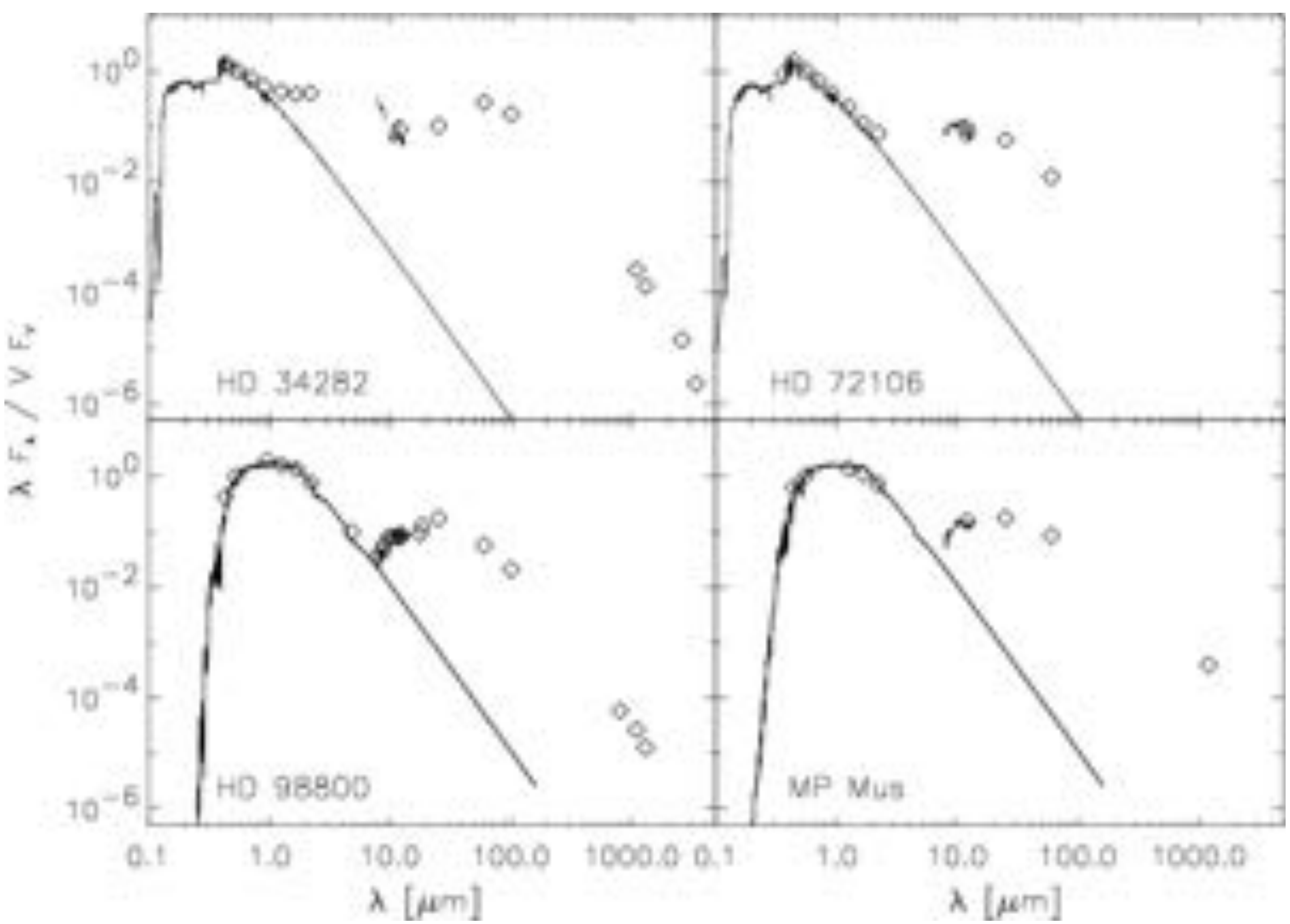
PHANTOM IS NOW PUBLIC



Price et al. (2017), submitted to PASA
arXiv:1702.03930
https://phantomsph.bitbucket.io

RECENT SCIENCE

YOUNG STARS BEFORE WE HAD GOOD TELESCOPES



T-Tauri stars

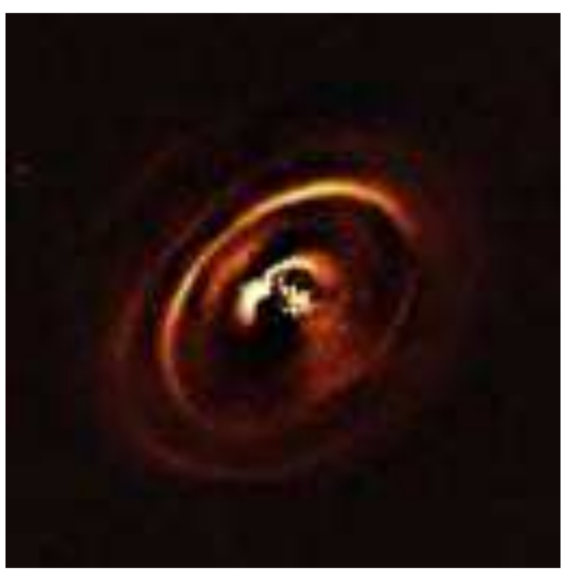
Herbig Ae/Be stars

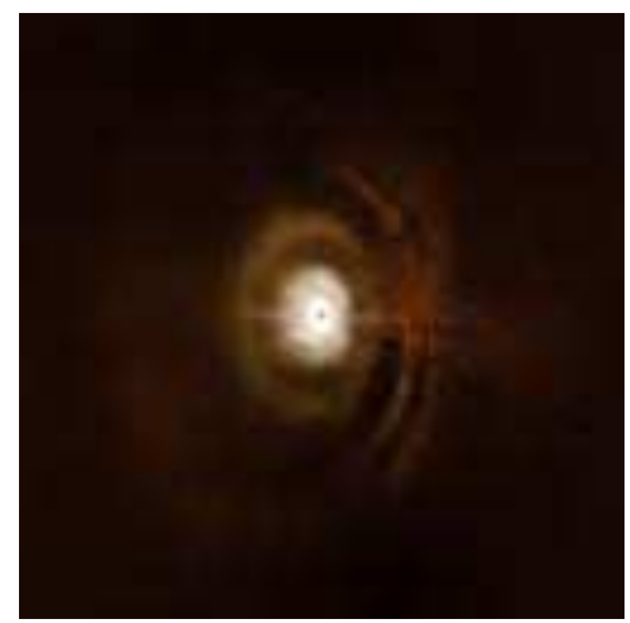
Credit: Schütz et al. (2005)


HL TAU

…BUT PLENTY OF THESE (ALL TAKEN WITH VLT-SPHERE)





Companions or other physics?

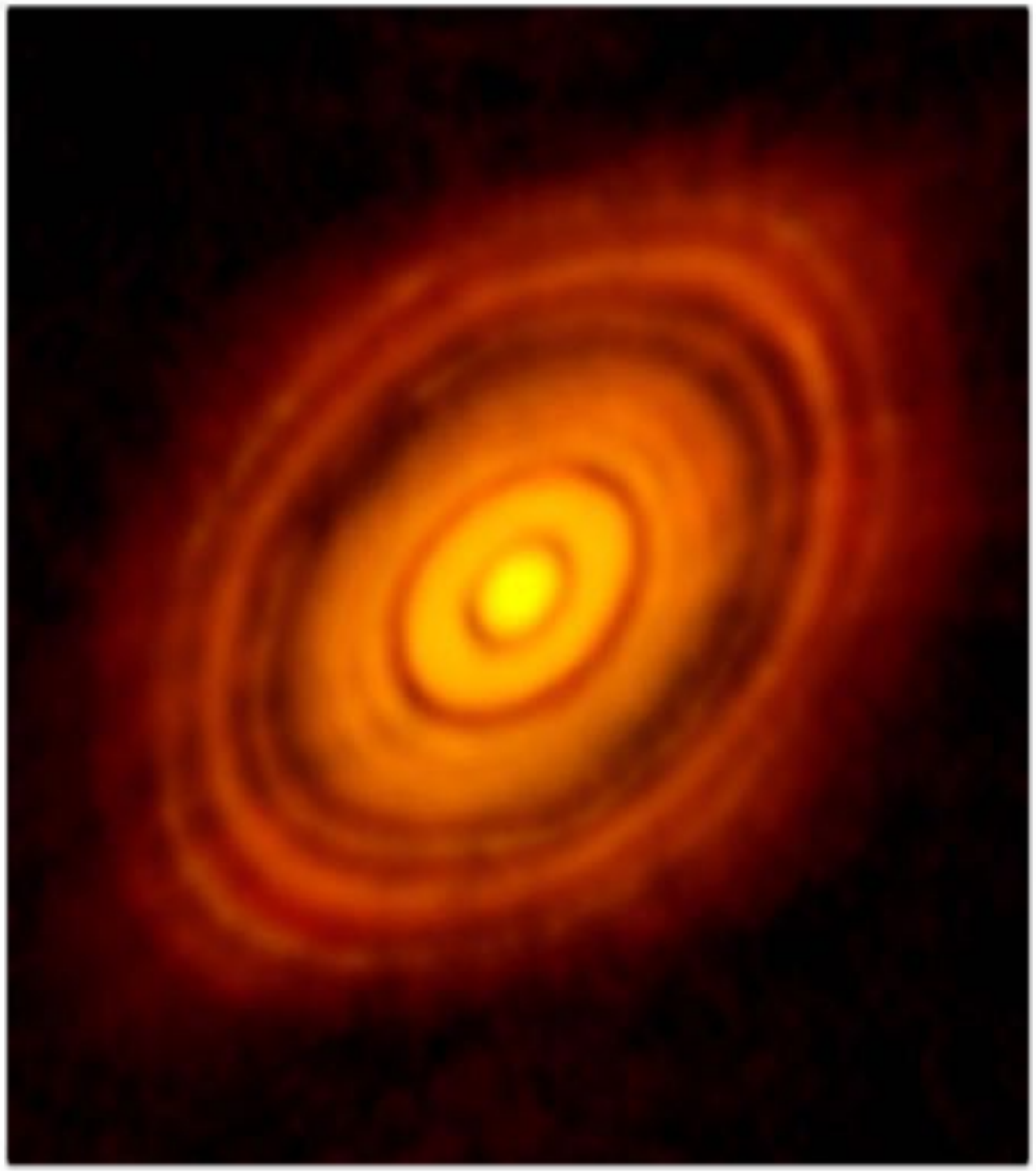
CRAZY EXPLANATIONS FOR HL TAU

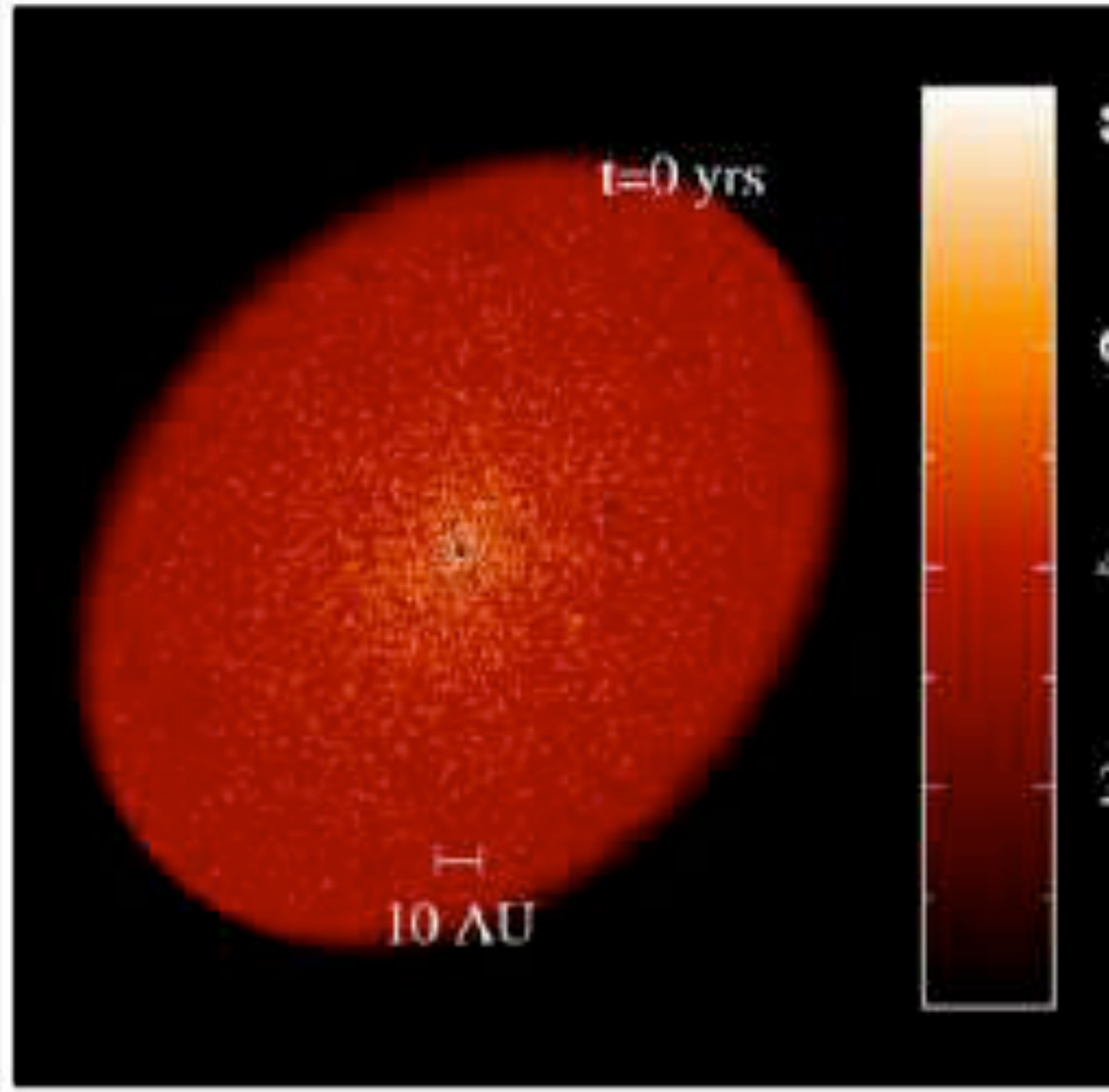
- Magnetic flux rings (Lesur, Bai, Lyra+)
- Rossby-wave instabilities (Pinilla et al. 2012, Meheut et al. 2012b, Zhu and Stone 2014)
- Clumping/photoelectric instability (Lyra & Kuchner 2013)
- Condensation fronts (Zhang, Blake & Bergin 2015)
- Counter-rotating infall (Vorobyov)
- Secular gravitational instability (Takahashi & Inutsuka 2012; Stoyanovskaya)
- Hall effect (Lesur)
- Magnetic field dead zones (Flock; Lyra et al. 2015, Dzyurkevich et al. 2010, 2013)
- Dust instability (Loren-Aguilar & Bate 2015)
- Dust growth/pressure traps at ice lines (Kretke et al. 2007, Dzyurkevich)

WHAT ABOUT PLANETS?

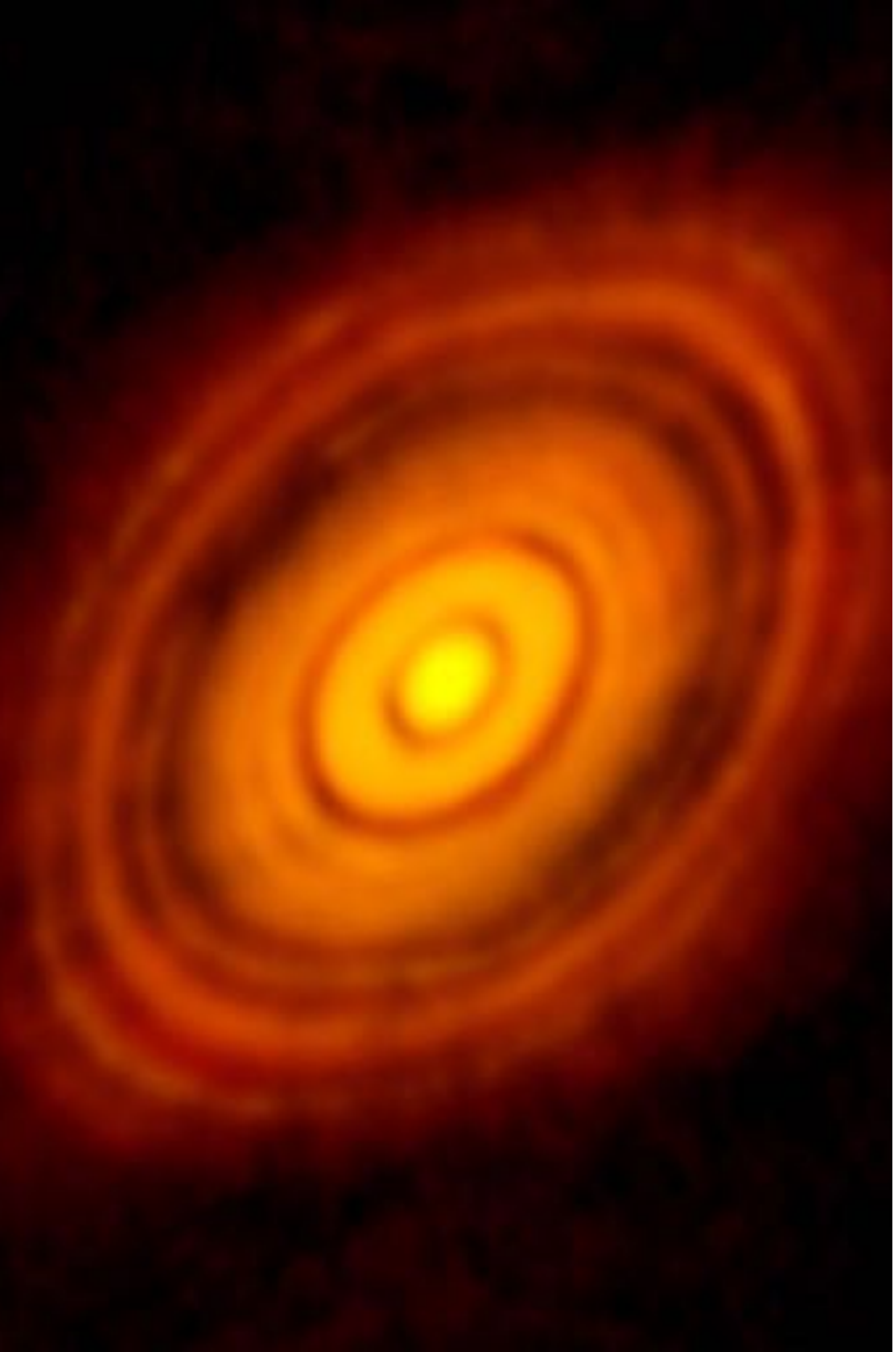
e.g. Wolf et al. (2002); Fouchet et al. (2007; 2012); Gonzalez et al. (2012); ALMA partnership et al. (2015)

ONE OF OUR BETTER ATTEMPTS





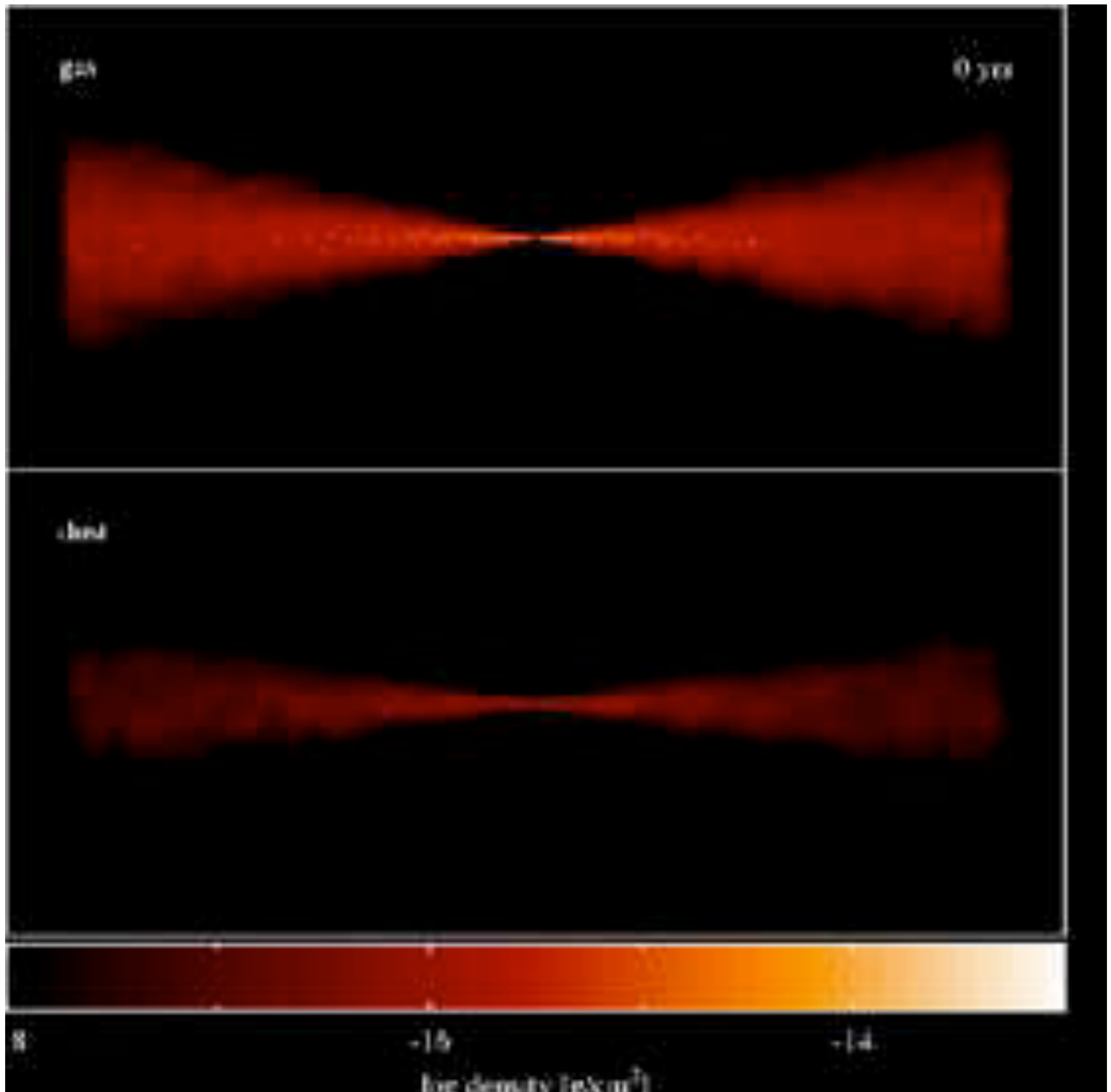
BUT: lots of spirals and require very thin disc (H/R ~ 0.01)



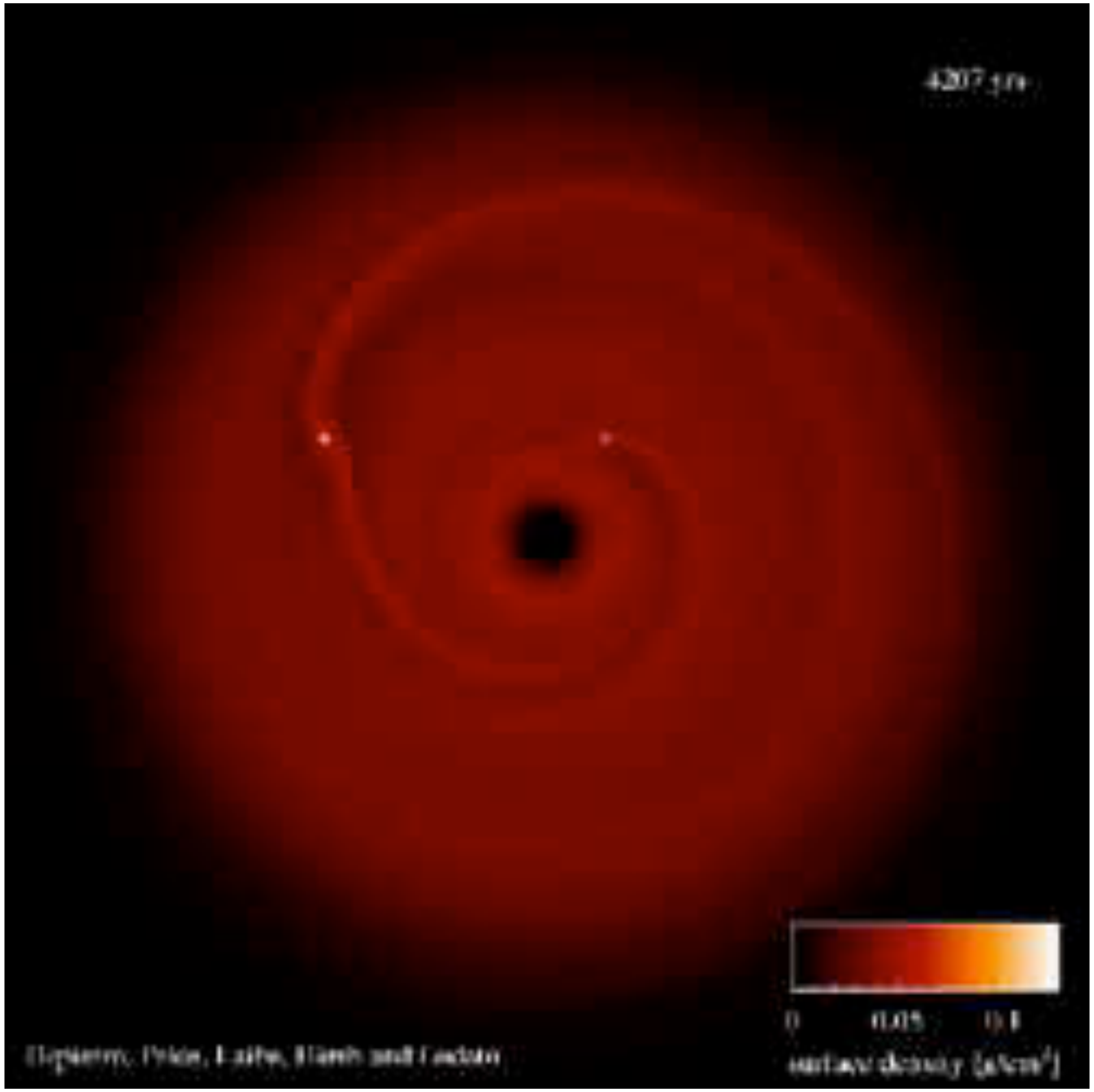
PLAUSIBLE EXPLANATIONS

- ALMA image is of mm dust, not gas
- Perhaps inferred gas disc mass too high because dust has migrated inwards?
- Easier to carve gaps in dust compared to gas
- Need dust-gas simulations

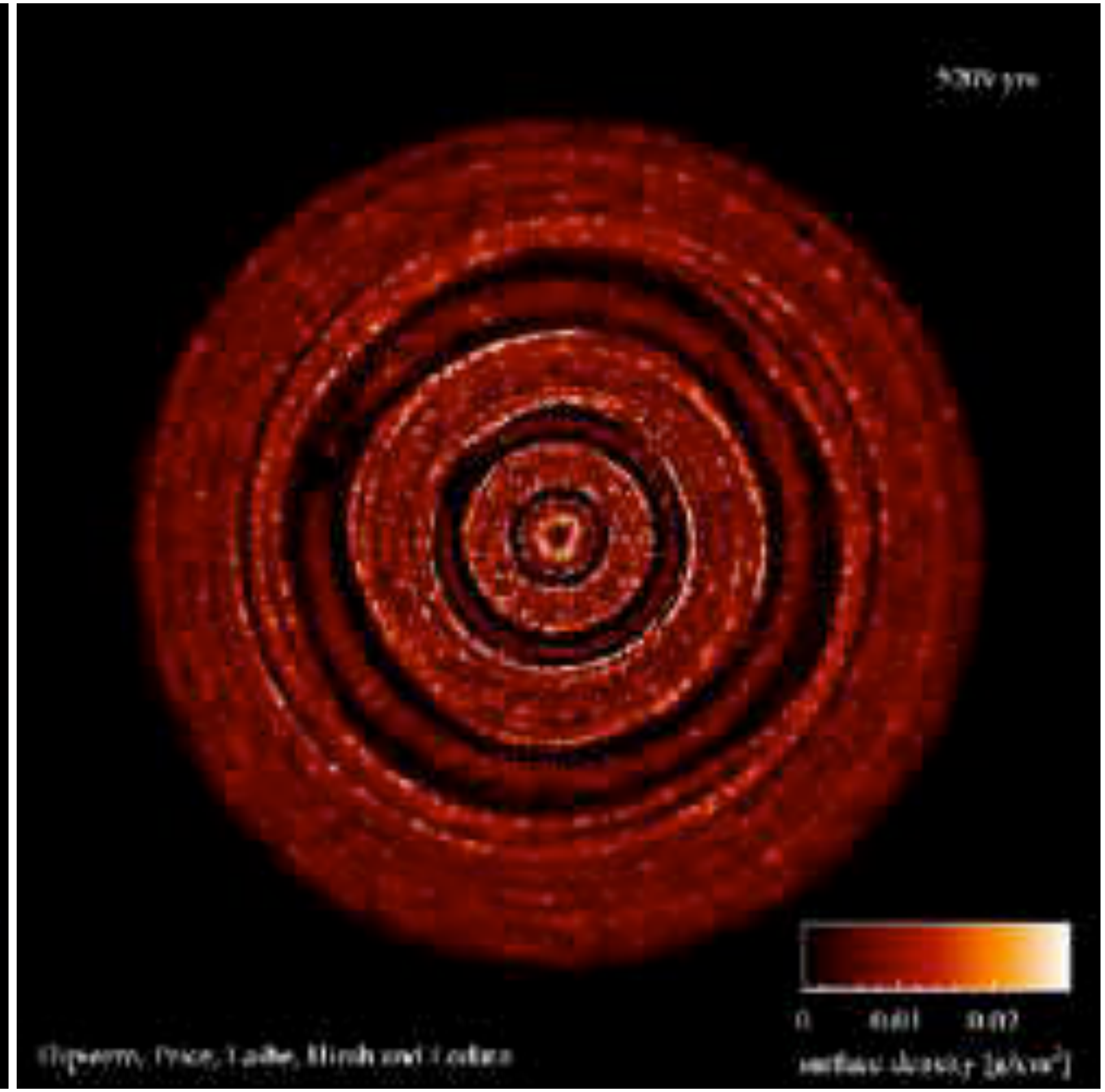
DUST SETTLING IN PROTOPLANETARY DISCS



DUST, GAS AND PLANETS IN HL TAU



Gas



mm grains

DIFFERENT GRAIN SIZES

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

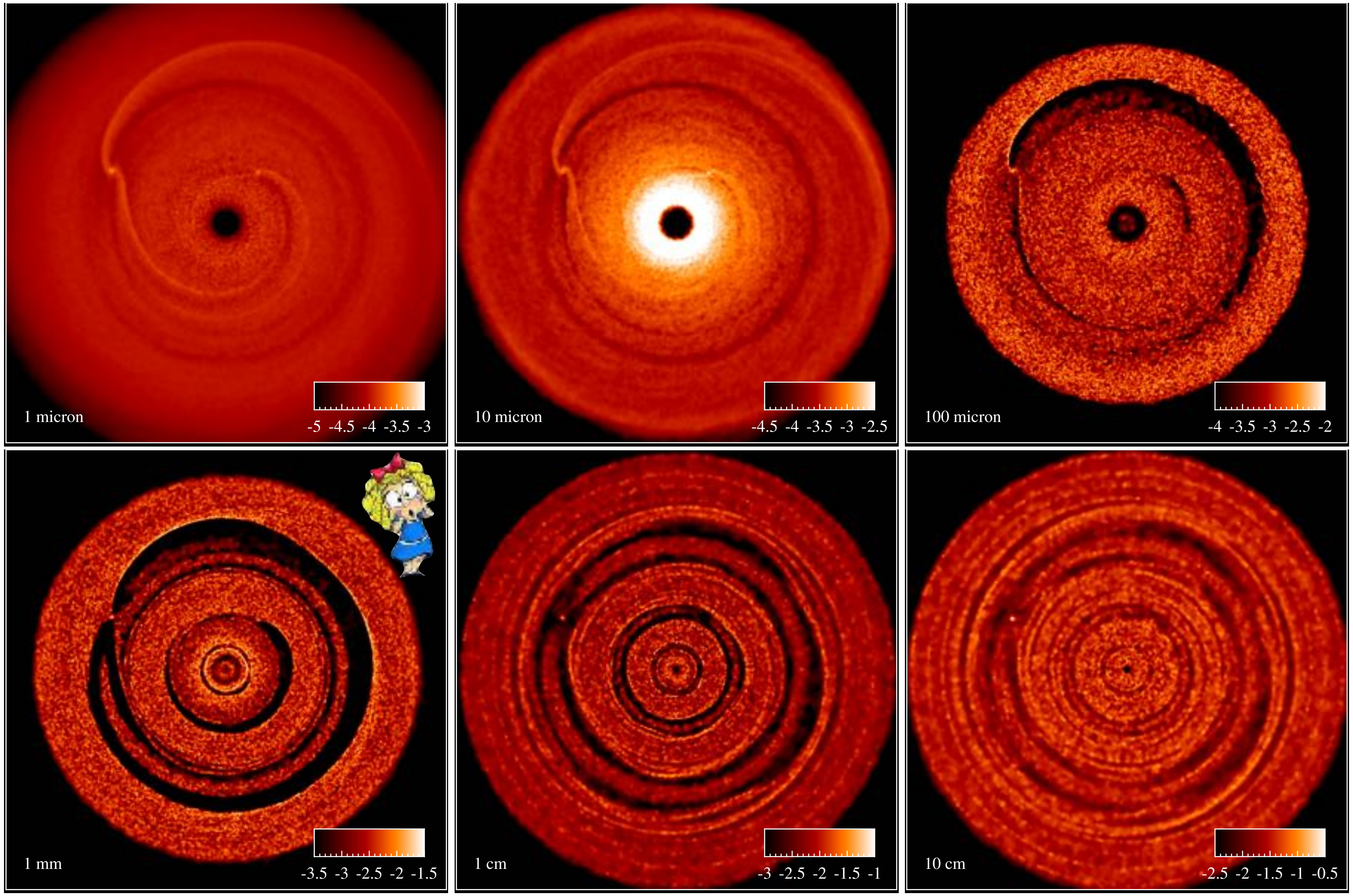


Figure 3. Rendered images of dust surface density for a disc containing three embedded protoplanets of mass 0.26, 0.30 and 0.35 M_J initially located at the same distance as the gaps detected in HL Tau. Each panel shows the simulation with gas+grains of a particular size (as indicated).

COMPARISON

Computed using RADMC3D radiative transfer code plus ALMA simulator

Dust and gas in HL Tau 5

Observed

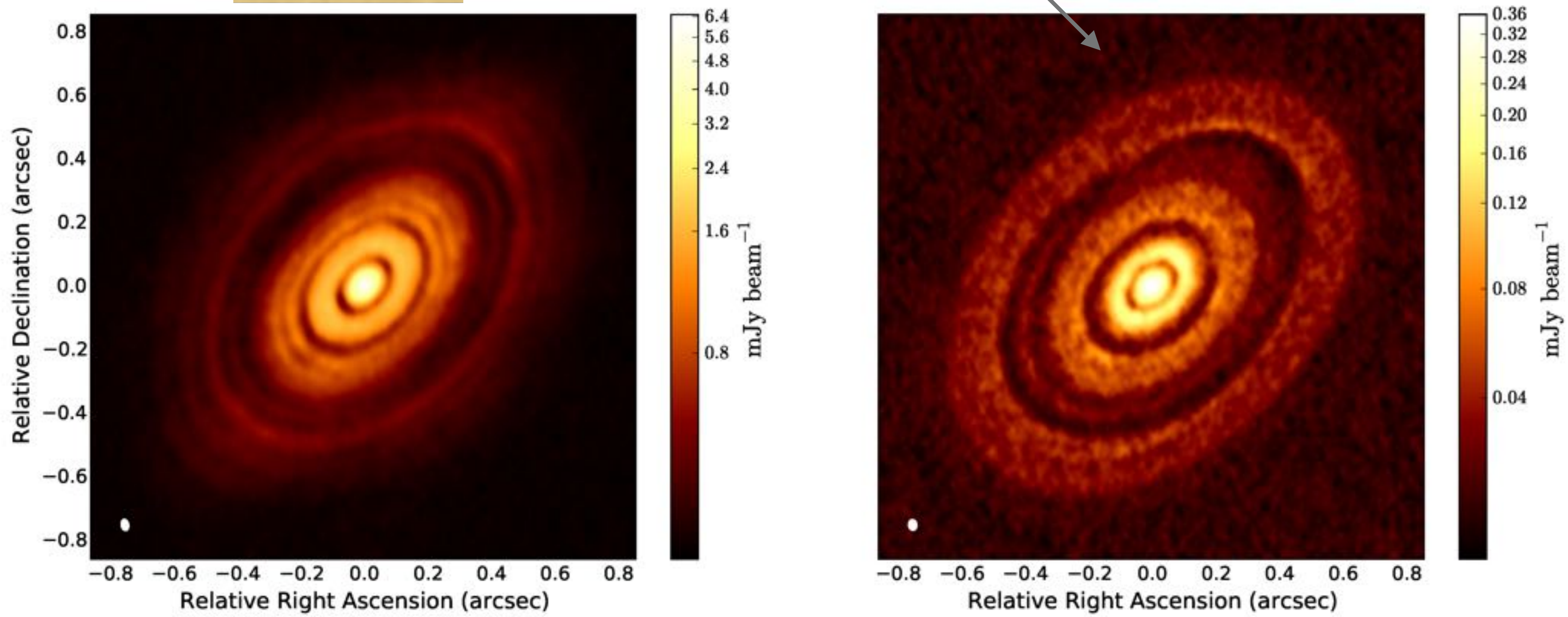


Figure 4. Comparison between the ALMA image of HL Tau (left) with simulated observations of our disc model (right) at band 6 (continuum emission at 233 GHz). The white colour in the filled ellipse in the lower left corner indicates the size of the half-power contour of the synthesized beam: (left) 0.035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

HL TAU: CONCLUSIONS

- Can reproduce major features in HL Tau with dust/gas simulations using 3 ~Saturn mass planets (0.2, 0.27 and 0.55 MJup)
- No spirals in the dust
- Suggests rapid planet formation

Hunting for planets in the HL Tau disk

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S. Esposito

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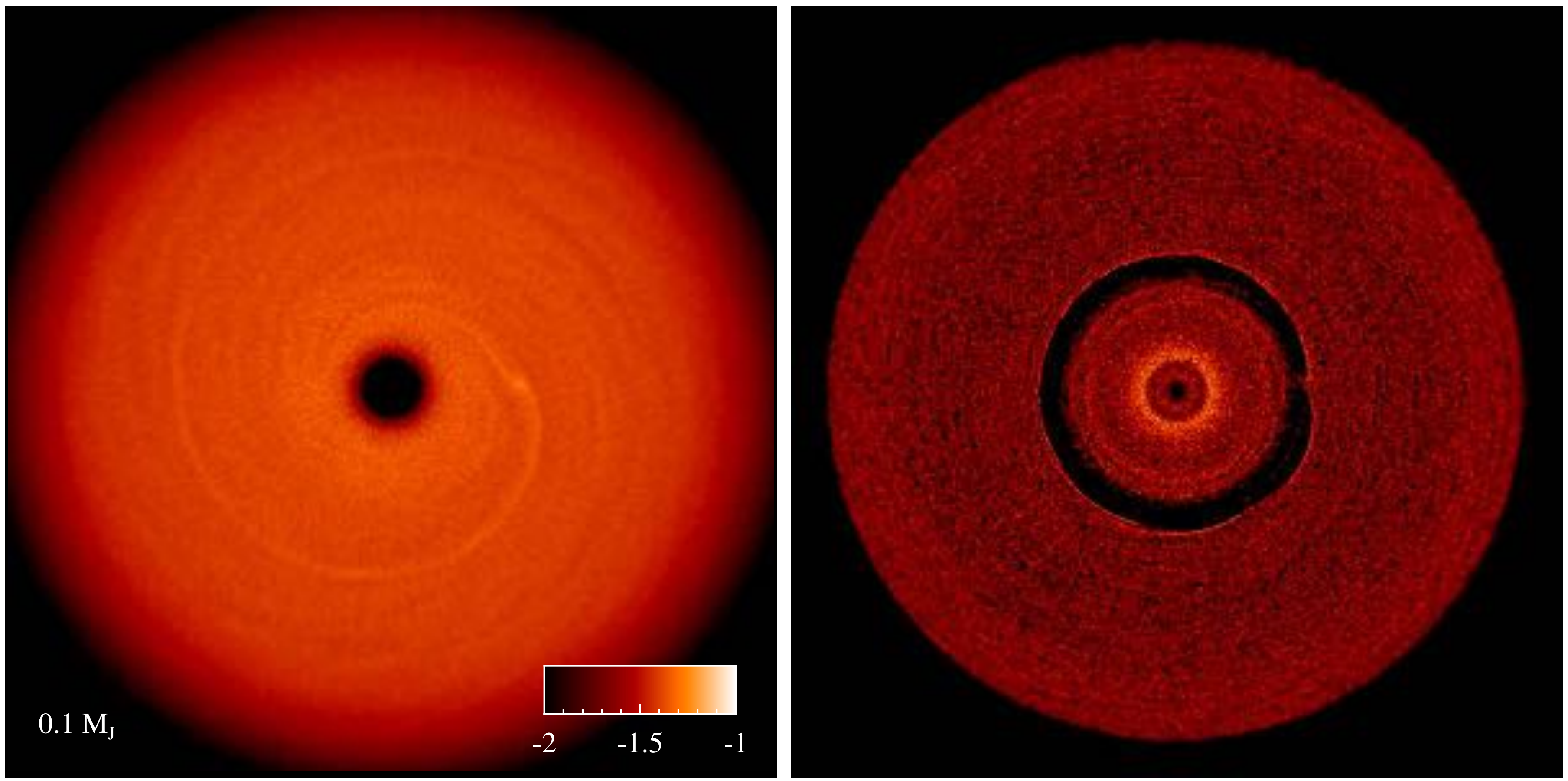
A. Marconi

Universitá degli Studi di Firenze, Dipartimento di Fisica e Astronomia, Firenze, Italy

$\sim$7.5 mag with respect to the central point source. Using evolutionary models we derive upper limits of $\sim$10-15 M_{Jup} at $\leq$ 0.5-1 Ma for the possible planets. Our limits suggest that there are no massive giant planets formed by gravitational instability in the outer disk and that the gaps seen in the dust distribution at $\sim$1 mm by ALMA are not be caused by giant planets opening gaps in the gaseous disk. The structures detected at mm-wavelengths could be gaps in the distributions of large grains on the disk midplane, caused by smaller planets or planetary cores. Future ALMA observations of the molecular gas density profile and kinematics as well as higher contrast infrared observations may be able to provide a definitive answer.

DUST GAPS WITH NO GAS GAPS?

Dipierro, Laibe, Price & Lodato (2016)



- ➤ Small planets only carve a gap in the dust

“TRANSITION” DISCS

“TRANSITION” DISCS

THE ASTROPHYSICAL JOURNAL, 630:L185–L188, 2005 September 10

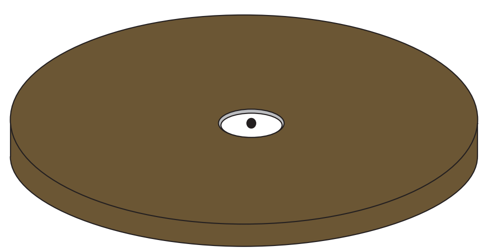
DISKS IN TRANSITION IN THE TAURUS POPULATION: *SPITZER* IRS SPECTRA OF GM AURIGAE AND DM TAURI

N. Calvet,[1] P. D’Alessio,[2] D. M. Watson,[3] R. Franco-Hernández,[1] E. Furlan,[4] J. Green,[3] P. M. Sutter,[3]
W. J. Forrest,[3] L. Hartmann,[1] K. I. Uchida,[4] L. D. Keller,[5] B. Sargent,[3] J. Najita,[6]
T. L. Herter,[4] D. J. Barry,[4] and P. Hall[4]

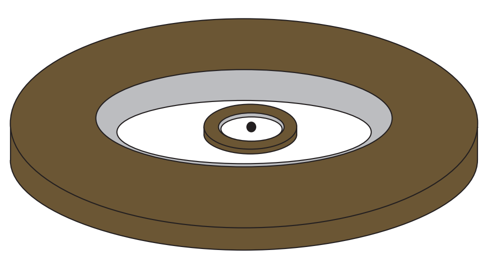
Received 2005 May 31; accepted 2005 July 27; published 2005 August 30

ABSTRACT

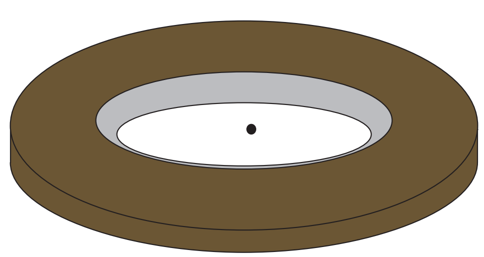
We present *Spitzer* Infrared Spectrograph (IRS) observations of two objects of the Taurus p
unambiguous signs of clearing in their inner disks. In one of the objects, DM Tau, the outer
3 AU; this object is akin to another recently reported in Taurus, CoKu Tau/4, in that the i
free of small dust. Unlike CoKu Tau/4, however, this star is still accreting, so optically t
remain in the inner disk region. The other object, GM Aur, also accreting, has ~0.02 lunar m
in the inner disk region within ~5 AU, consistent with previous reports. However, the IR
shows that the optically thick outer disk has an inner truncation at a much larger radius than pr
~24 AU. These observations provide strong evidence for the presence of gaps in protoplane



Full Disk



Pre-Transitional Disk



Transitional Disk

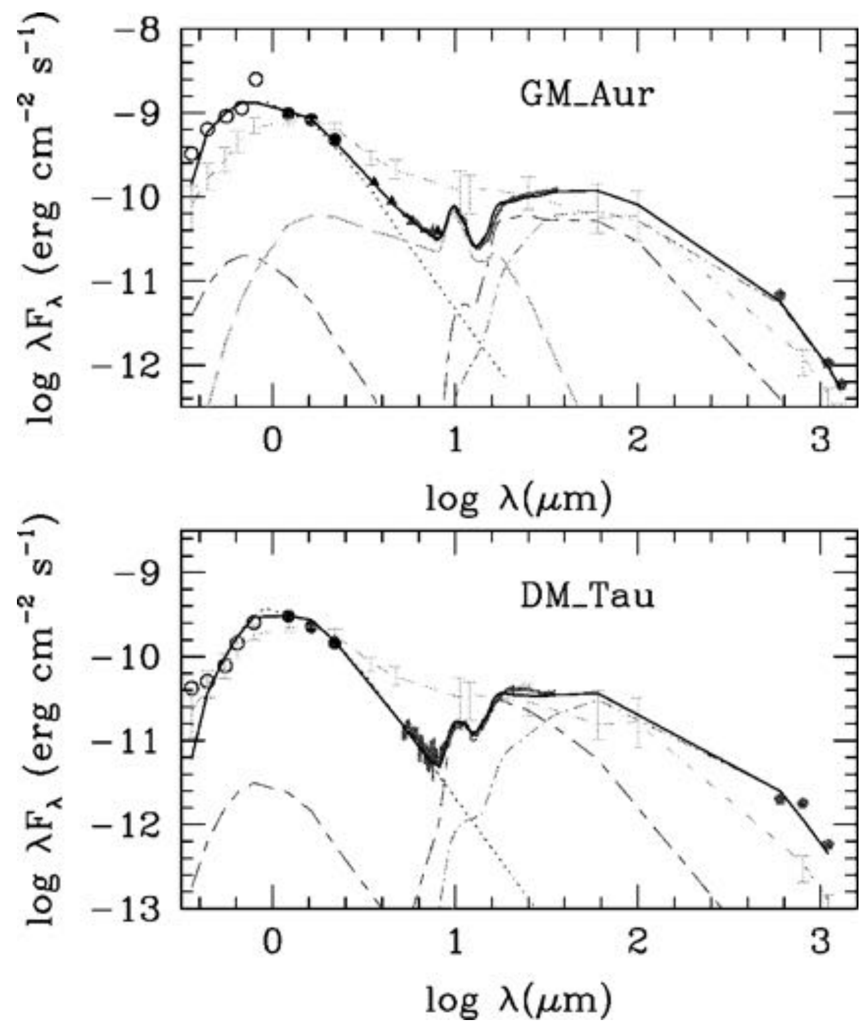
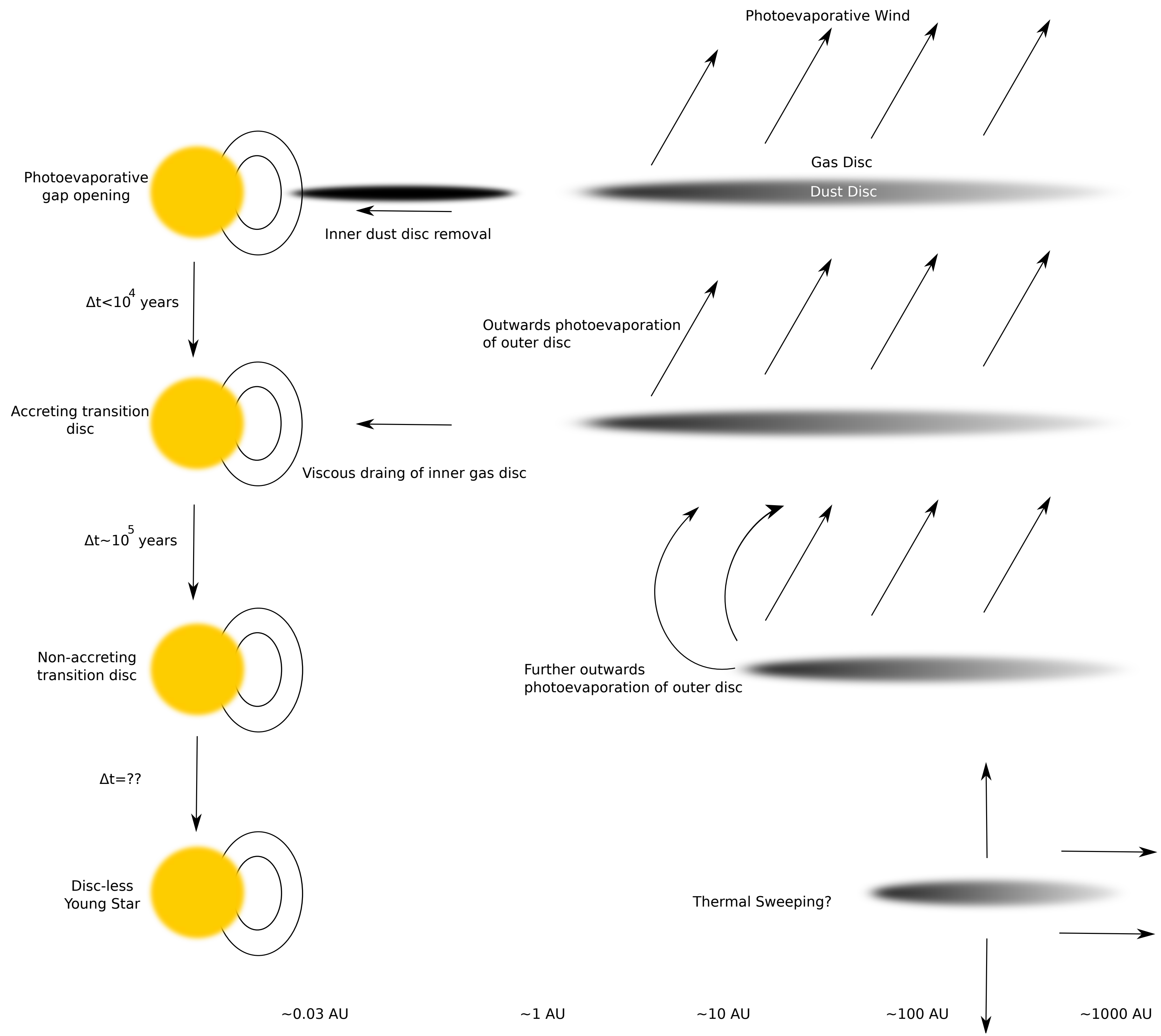


FIG. 2.—SEDs of GM Aur and DM Tau. IRS from Fig. 1. Optical (*open circles*) data from Kenyon & Hartmann (1995, hereafter KH95) and 2MASS (*solid circles*) corrected for reddening with extinctions A_V in Table 2 and the Mathis (1990) reddening law. Millimeter fluxes (*pentagons*) are from Dutrey et al. (1996). The short-dashed line is the median SED of Taurus with quartiles (error bars; D’Alessio et al. 1999). Photospheric fluxes (*dotted lines*) have being constructed from colors for standard stars in KH95, scaled at *J*. The model components are as in Fig. 1. [*See the electronic edition of the Journal for a color version of this figure.*]

PHOTOEVAPORATION OF DISCS



Owen (2016)

ARE TRANSITION DISCS TRANSITIONAL?

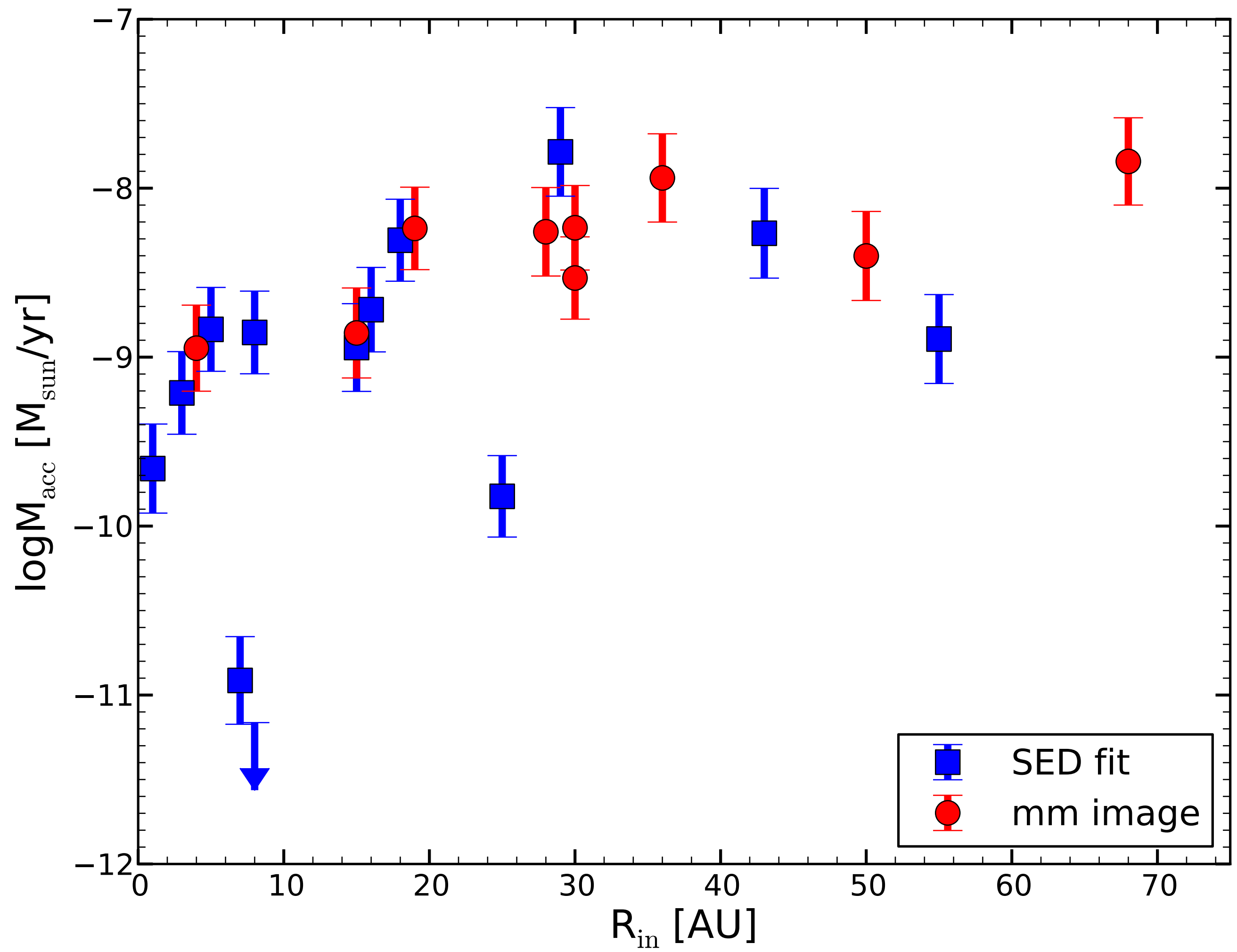


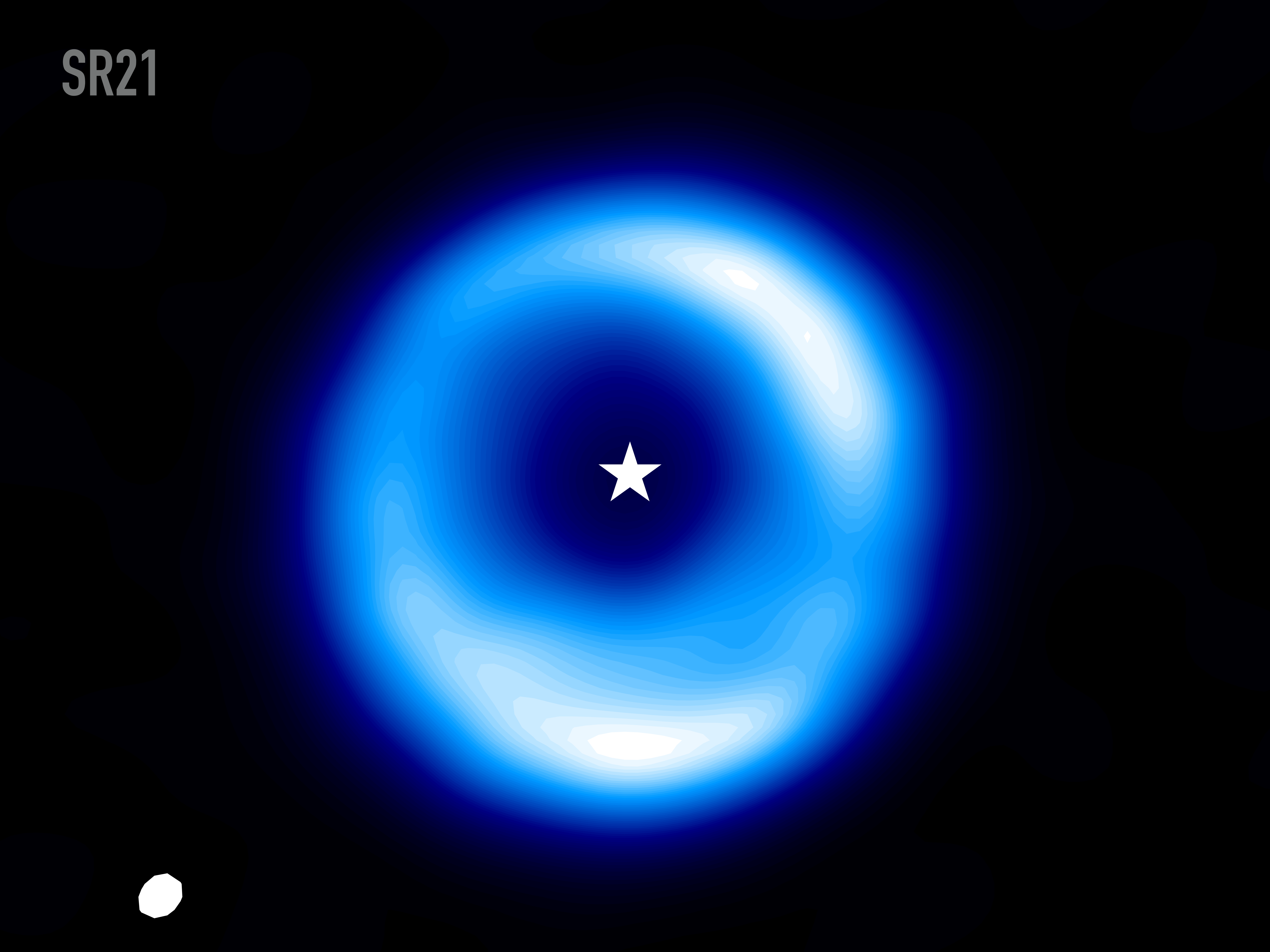
Fig. 8. Logarithm of the mass accretion rate vs inner hole size for our sample. Different symbols are used to distinguish the methods used in the literature to derive the size of the inner hole. *Blue squares* are adopted when this has been derived using

Manara et al. (2014)

IRS48: A DUST VORTEX?

Van der Marel et al. (2013, 2016)

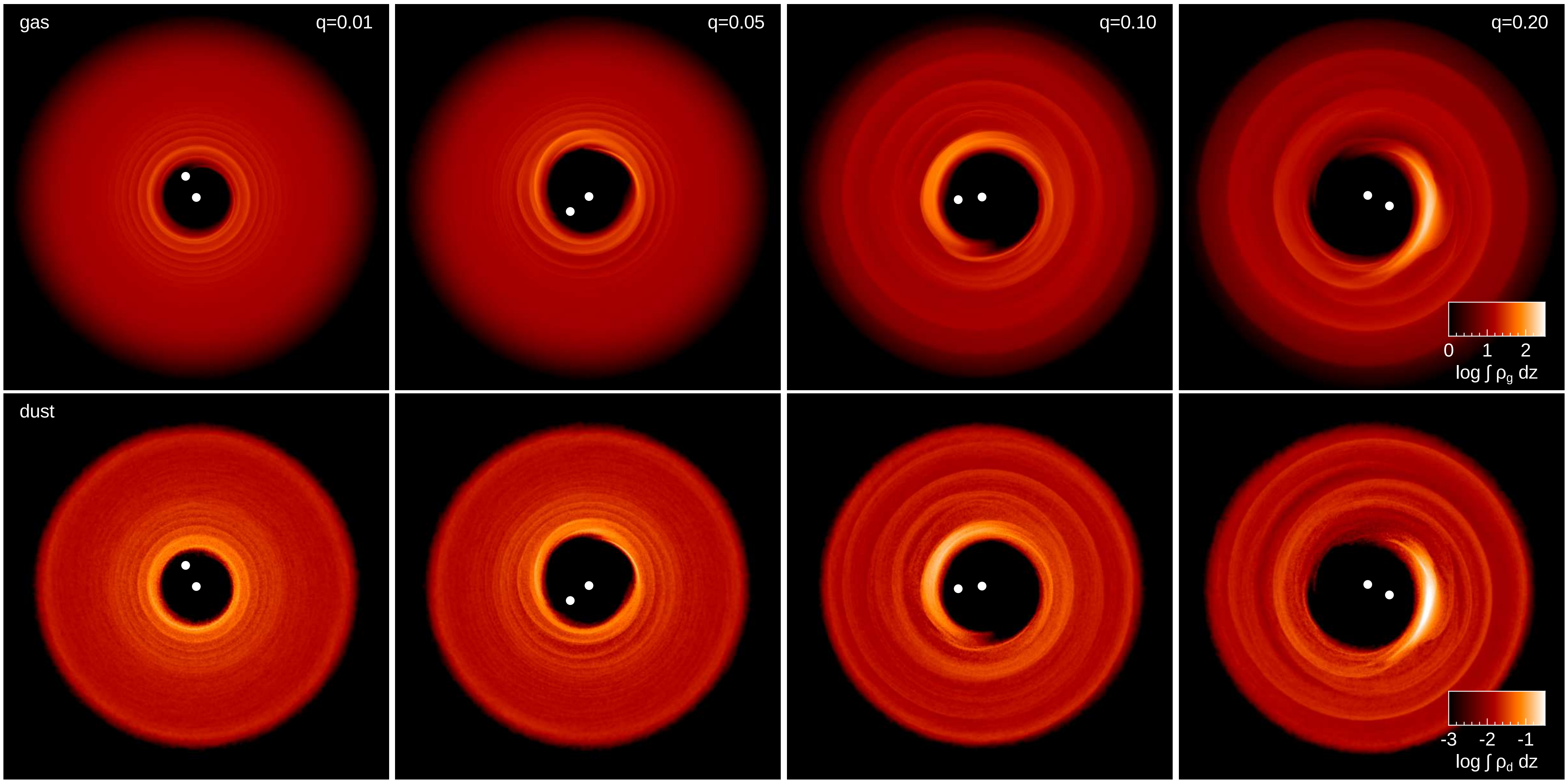

HD135344B
Van der Marel et al. (2016)


SR21

DOAR44

HORSESHOES IN TRANSITIONAL DISCS

Ragusa+ (2017)



See also Lyra & Lin (2013), Zhu & Stone (2014), Mittal & Chiang (2015), Zhu & Baruteau (2016), Baruteau & Zhu (2016)

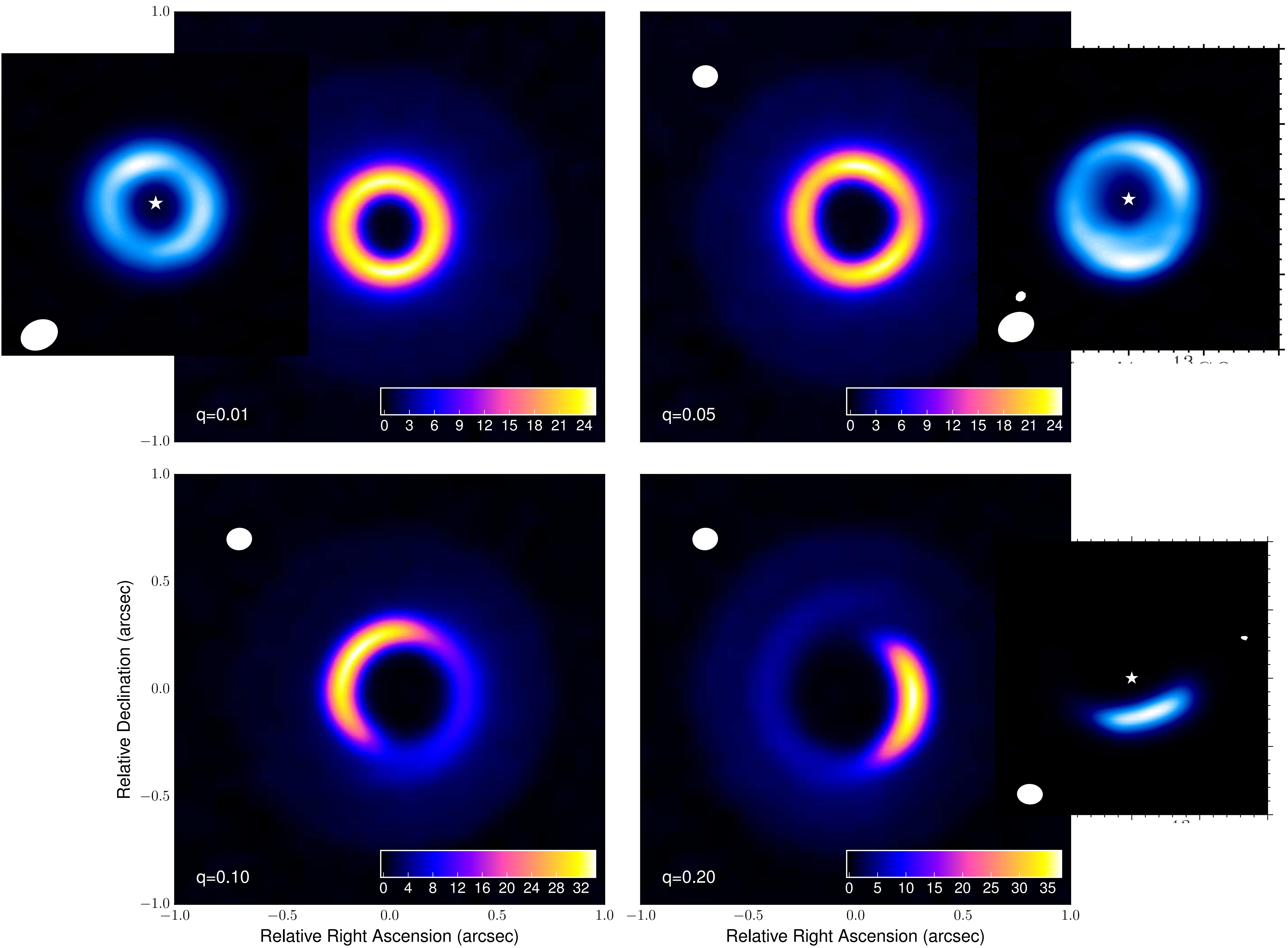


Figure 2. Comparison of ALMA simulated observations at 345 GHz of disc models with a mass ratio $q = 0.01$ (upper left), $q = 0.05$ (upper right), $q = 0.1$ (bottom left) and $q = 0.2$ (bottom right). Intensities are in mJy beam^{-1}. The white colour in the filled ellipse in the upper left corner indicates the size of the half-power contour of the synthesized beam: 0.12×0.1 arcsec ($\sim 16 \times 13$ au at 130 pc.).

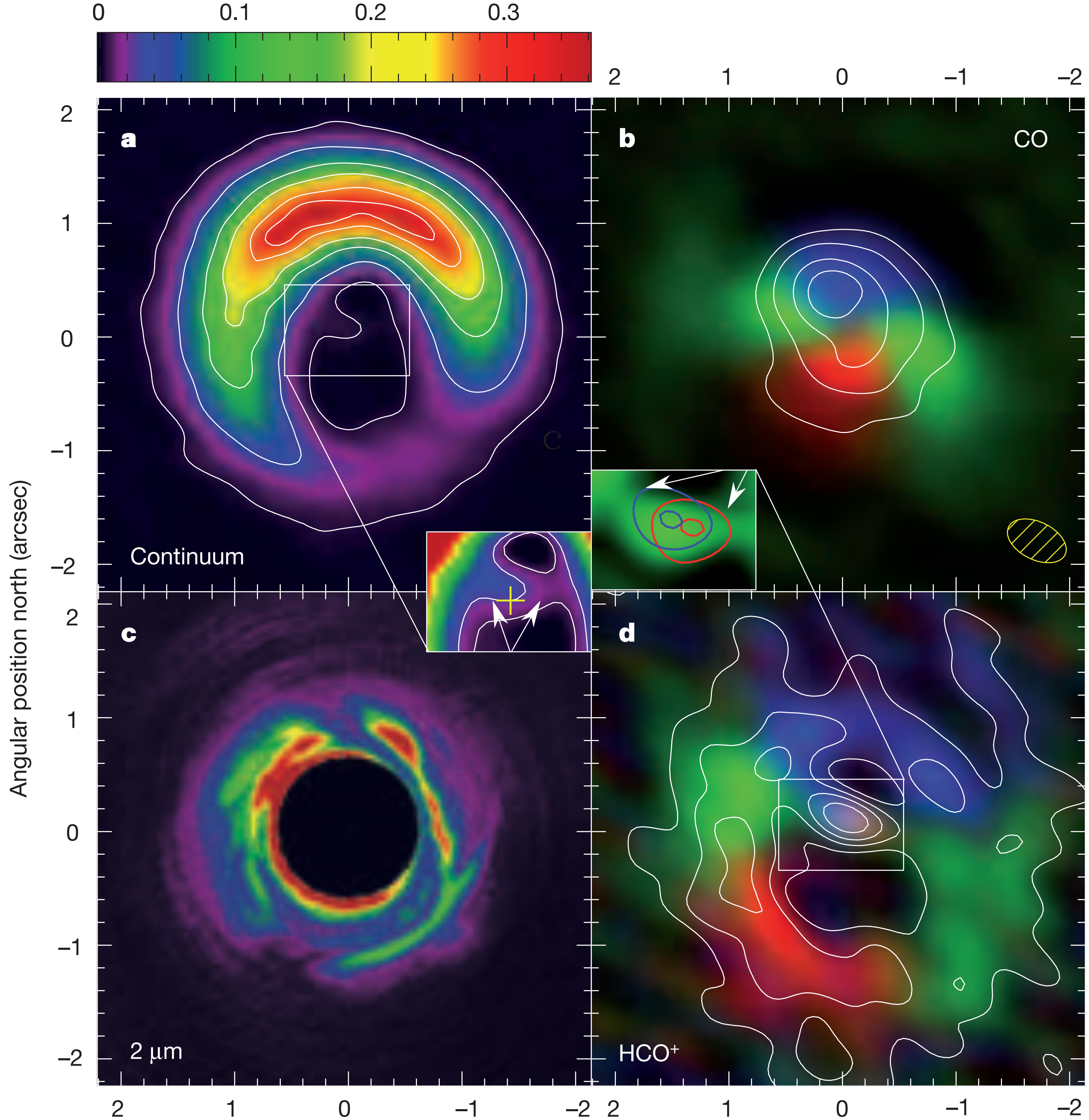
HD142527

LETTER

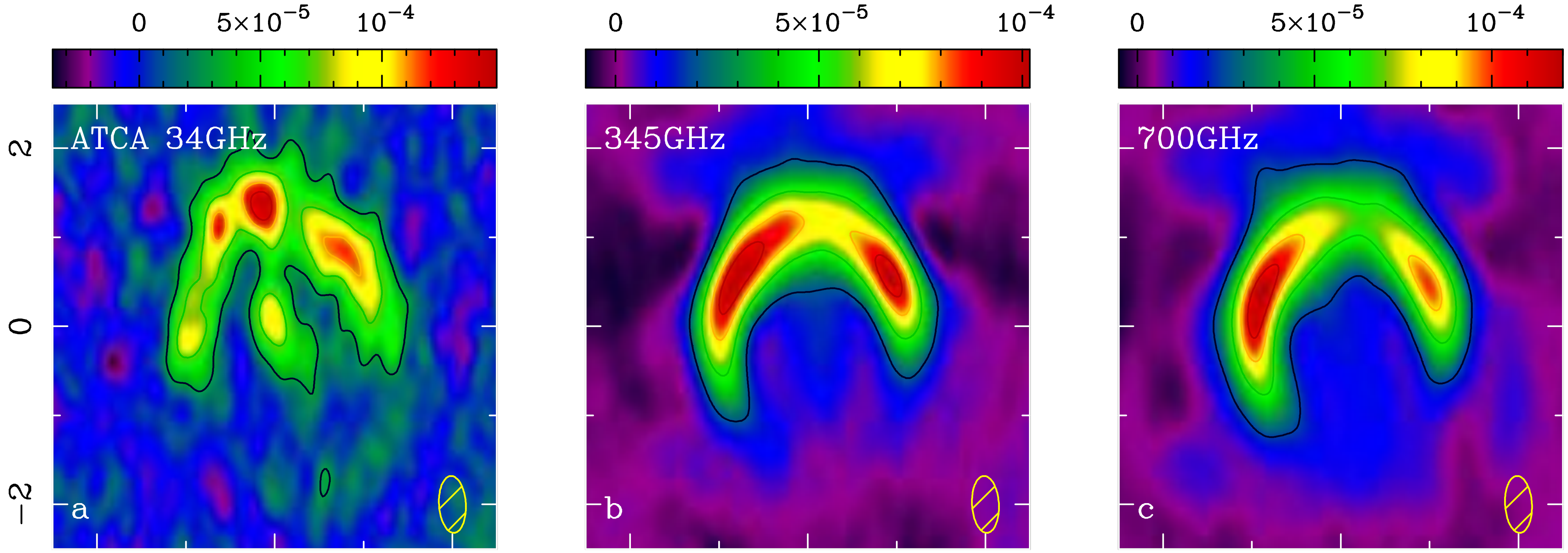
doi:10.1038/nature11769

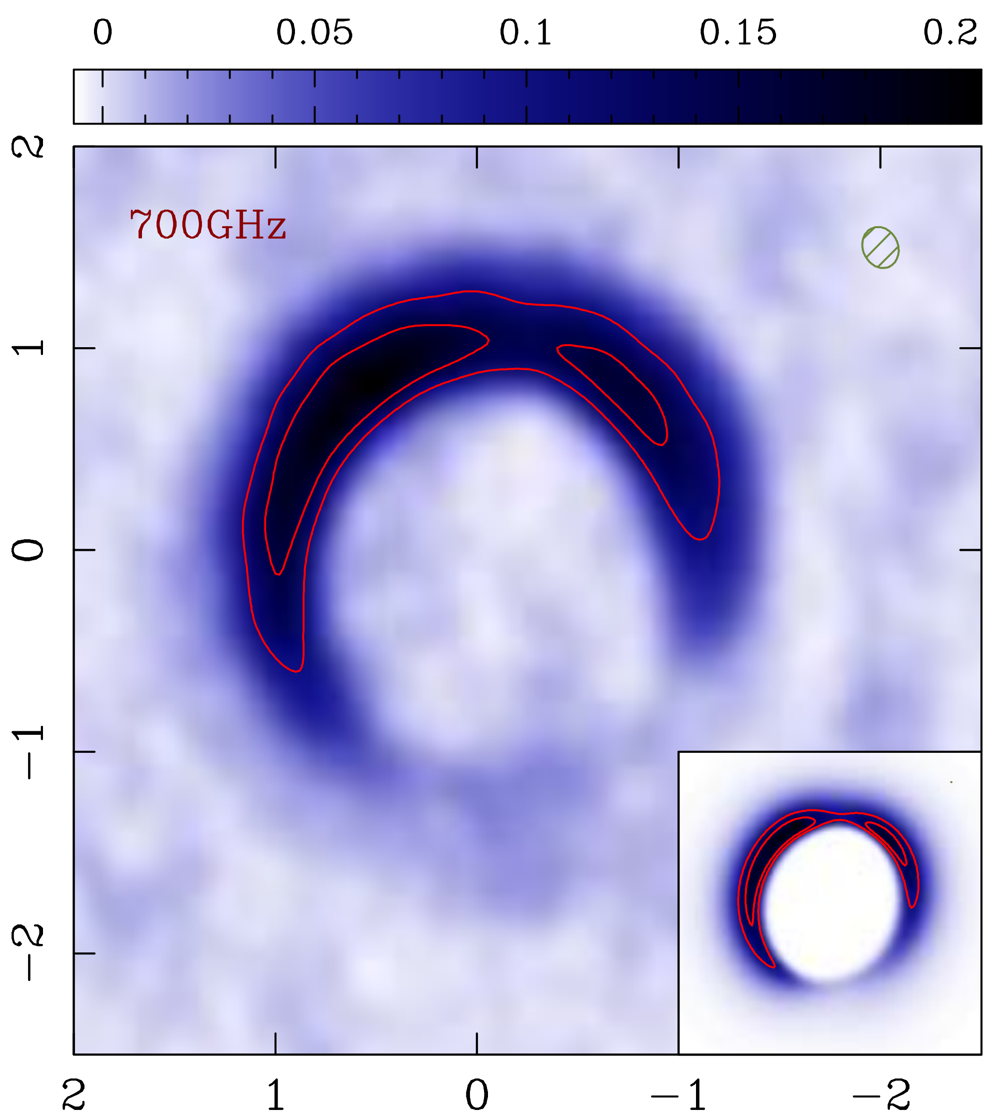
Flows of gas through a protoplanetary gap

Simon Casassus[1], Gerrit van der Plas[1], Sebastian Perez M[1], William R. F. Dent[2,3], Ed Fomalont[4], Janis Hagelberg[5], Antonio Hales[2,4], Andrés Jordán[6], Dimitri Mawet[3], Francois Ménard[7,8], Al Wootten[4], David Wilner[9], A. Meredith Hughes[10], Matthias R. Schreiber[11], Julien H. Girard[3], Barbara Ercolano[12], Hector Canovas[11], Pablo E. Román[13] & Vachail Salinas[1]



Dust trapping in HD 142527 9





"the large sub-mm crescent mostly reflects the gas background, with relatively inefficient trapping, so that the observed contrast ratio of ~ 30 is accounted for with a contrast of 20 in the gas"

Casassus et al. 2015b

SHADOWS

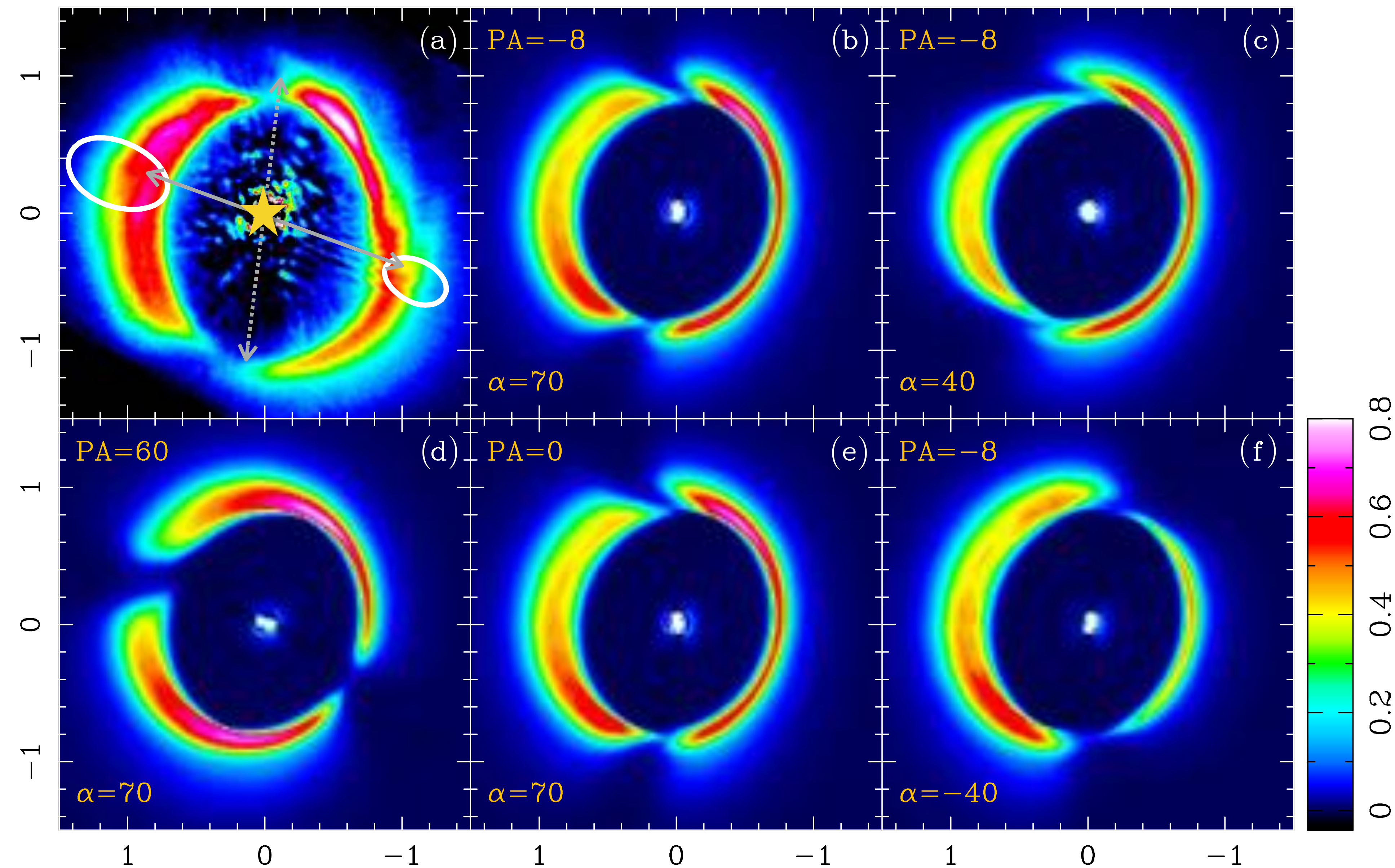
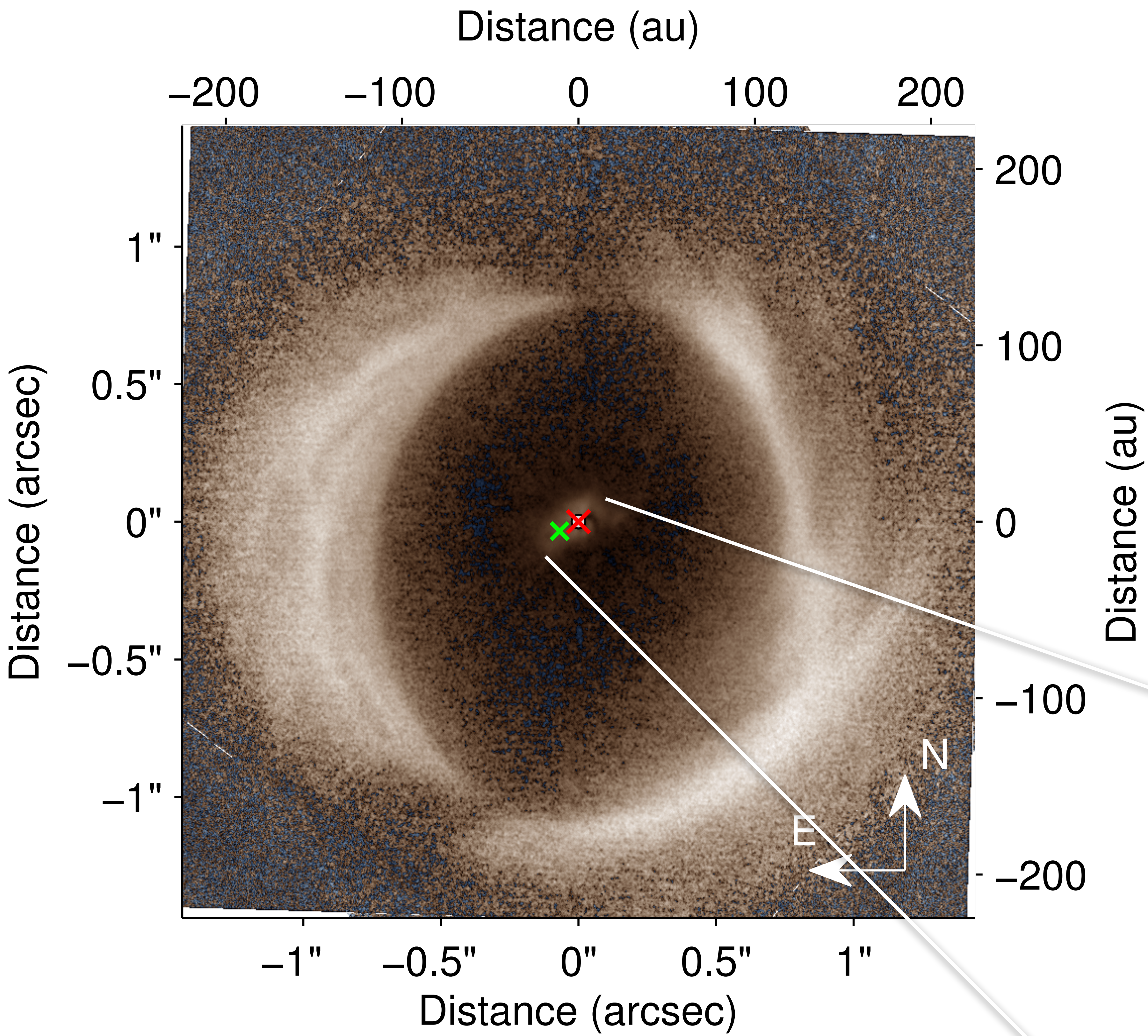
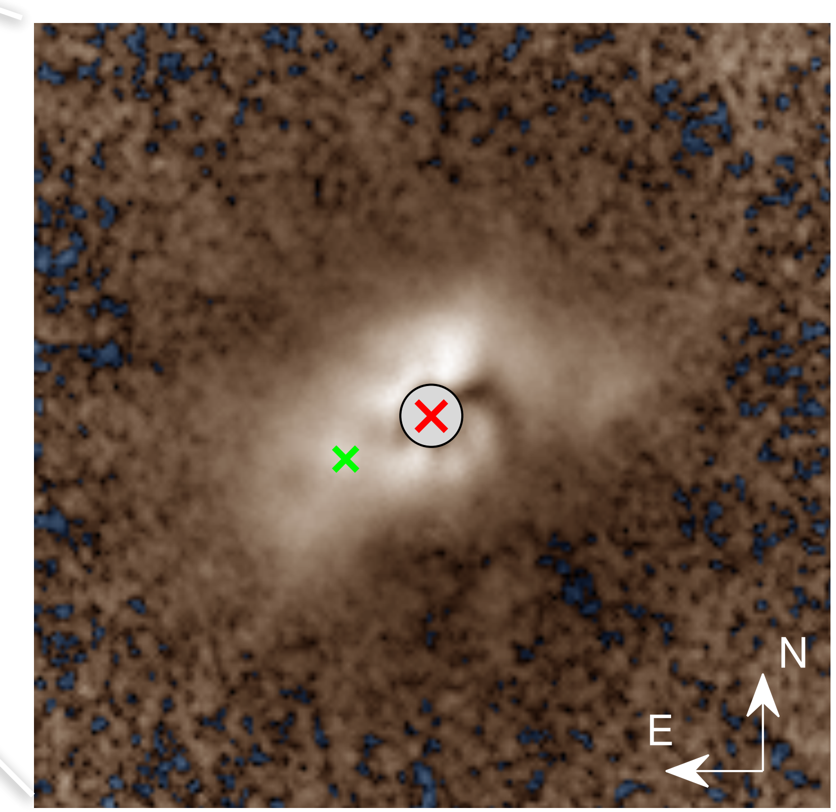


Figure 2. Impact of the inner disk orientation on the *H*-band light scattered off the outer disk. (a) NACO-PDI *H*-band image from Avenhaus et al. (2014) compared with the $C^{18}O(2–1)$ emission at systemic velocity from Perez et al. (2014). The $C^{18}O(2–1)$ emission, represented here as one white contour at 0.75 maximum, shows that the position angle (P.A.) of the outer disk is at −20° east of north, and perpendicular to the solid gray double arrow, while the position angle of the intensity nulls is indicated by the dashed double arrow (−8°). (b)–(f) Radiative transfer prediction for polarized intensity in the *H* band for different inner disk P.A.s (indicated in degrees on the plots) and for different relative inclinations α between the inner and the outer disks. The $x-$ and $y-$axes indicate offset along R.A. and decl., in arcsec.

VLT-SPHERE Image of HD142527

(Avenhaus+ 2017)





THE ASTROPHYSICAL JOURNAL LETTERS, 798:L44 (4pp), 2015 January 10 doi:10.1088/2041-8205/798/2/L44

SHADOWS CAST BY A WARP IN THE HD 142527 PROTOPLANETARY DISK

S. MARINO[1,2], S. PEREZ[1,2], AND S. CASASSUS[1,2]
[1] Departamento de Astronomía, Universidad de Chile, Casilla 36-D Santiago, Chile; smarino@das.uchile.cl
[2] Millenium Nucleus "Protoplanetary Disks in ALMA Early Science," Universidad de Chile, Casilla 36-D Santiago, Chile
Received 2014 December 14; accepted 2014 December 15; published 2015 January 7

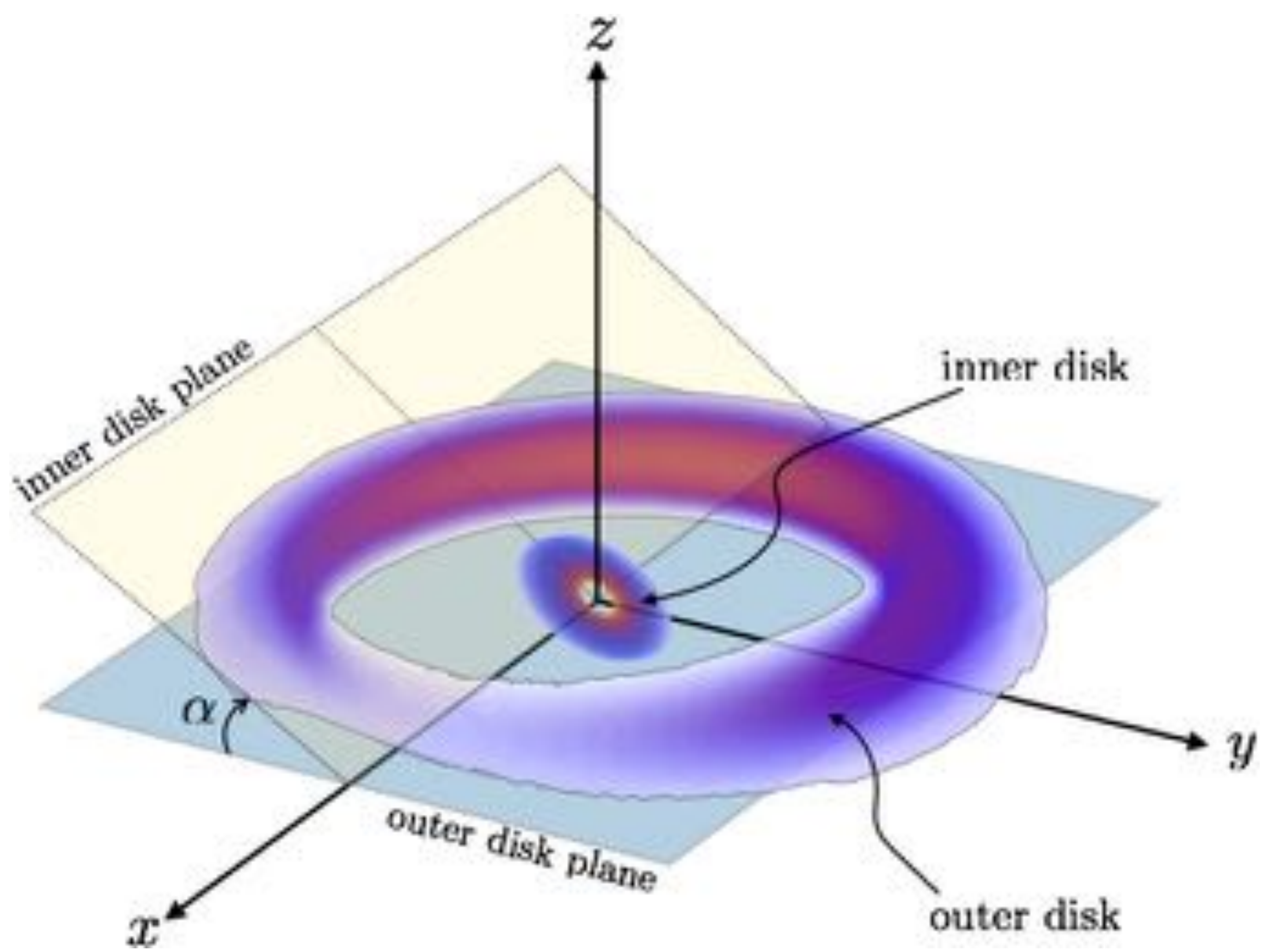


Figure 1. Schematic view with arbitrary orientation of the parametric model presented in Section 2. The central star is placed at the origin. The outer disk lies in the x–y plane. The angle α is the relative inclination between the midplane of the outer disk and the plane of the inner disk. The dust mass density distribution of the inner disk and outer disk sections are rendered in false color. The gap is shown devoid of material for simplicity. The inner disk is scaled up in size and density for better visualization.

“FAST RADIAL FLOWS” = DISC TEARING?

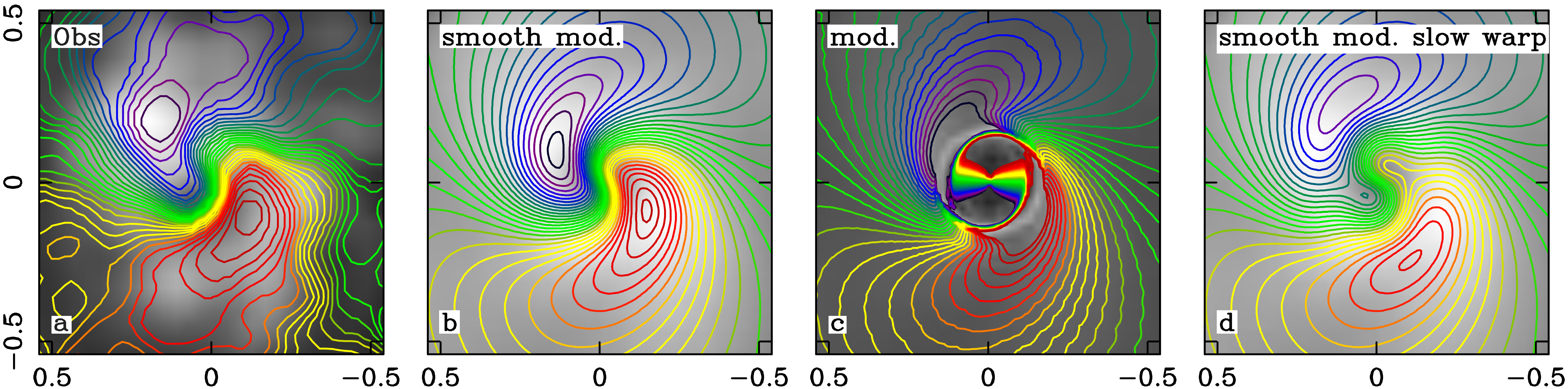
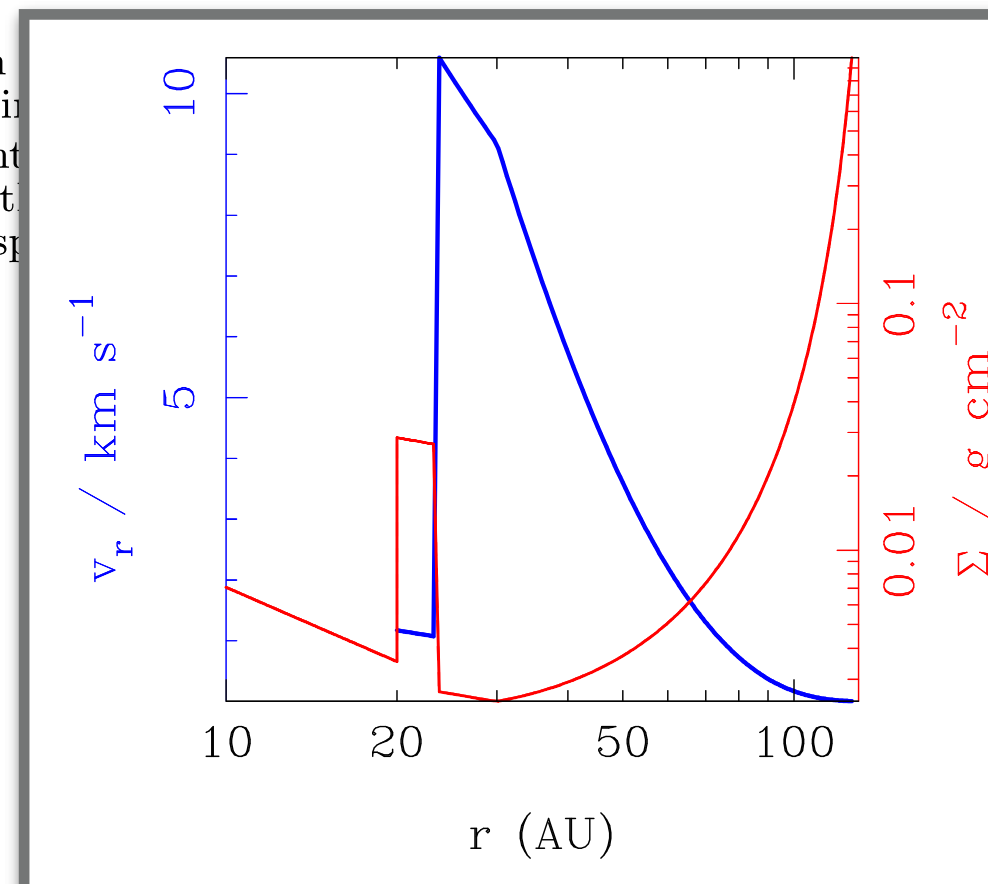


Figure 7. Comparison of observed and model CO(6-5) kinematics in … rdinates is set to the stellar position. Velocity-integrated intensity in CO(6-5) is shown i… tant interval and are spread over $[0.21, 7.87]$ km s^{-1} (as in Fig. 1). **a)**: Observed moment… nts extracted on the radiative transfer prediction, after smoothing to the resolution of t… odel resolutions, without smoothing. Regions without contours near the origin corresp… a slow velocity component perpendicular to the disk plane ($v_{\rm warp}$ in the text).

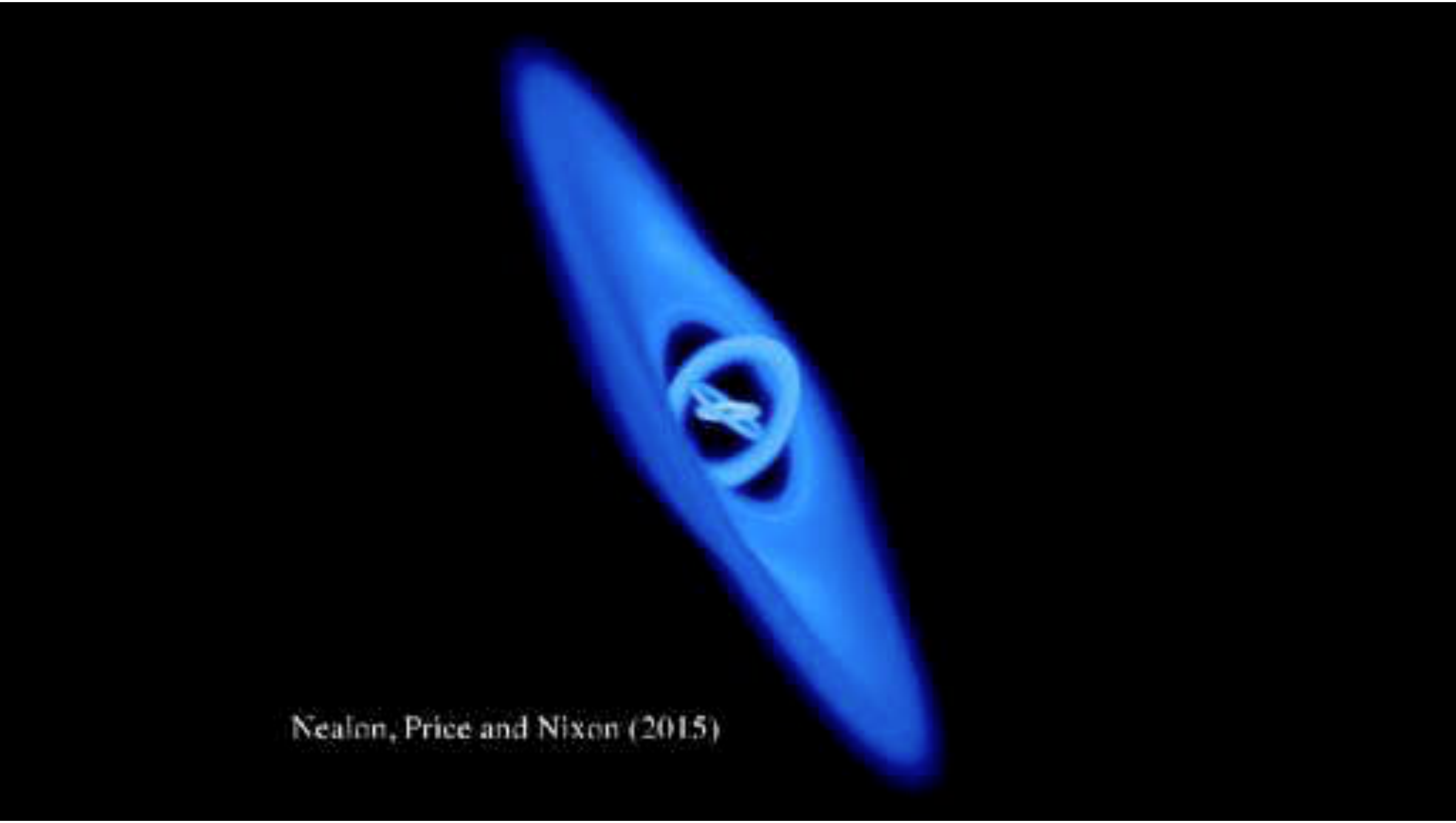
dubbed disk tearing (Nixon et al. 2013; Nealon et al. 2015; Doğan et al. 2015), where nodal precession torques induced by the binary produce a warp at the inner edge … companion on … 100 AU scale … cavity. It is



Require infall motions from cavity edge at the free-fall velocity!

DISC TEARING?

Nixon et al. (2012, 2013), Nealon et al. (2015), Dogan et al. (2015)

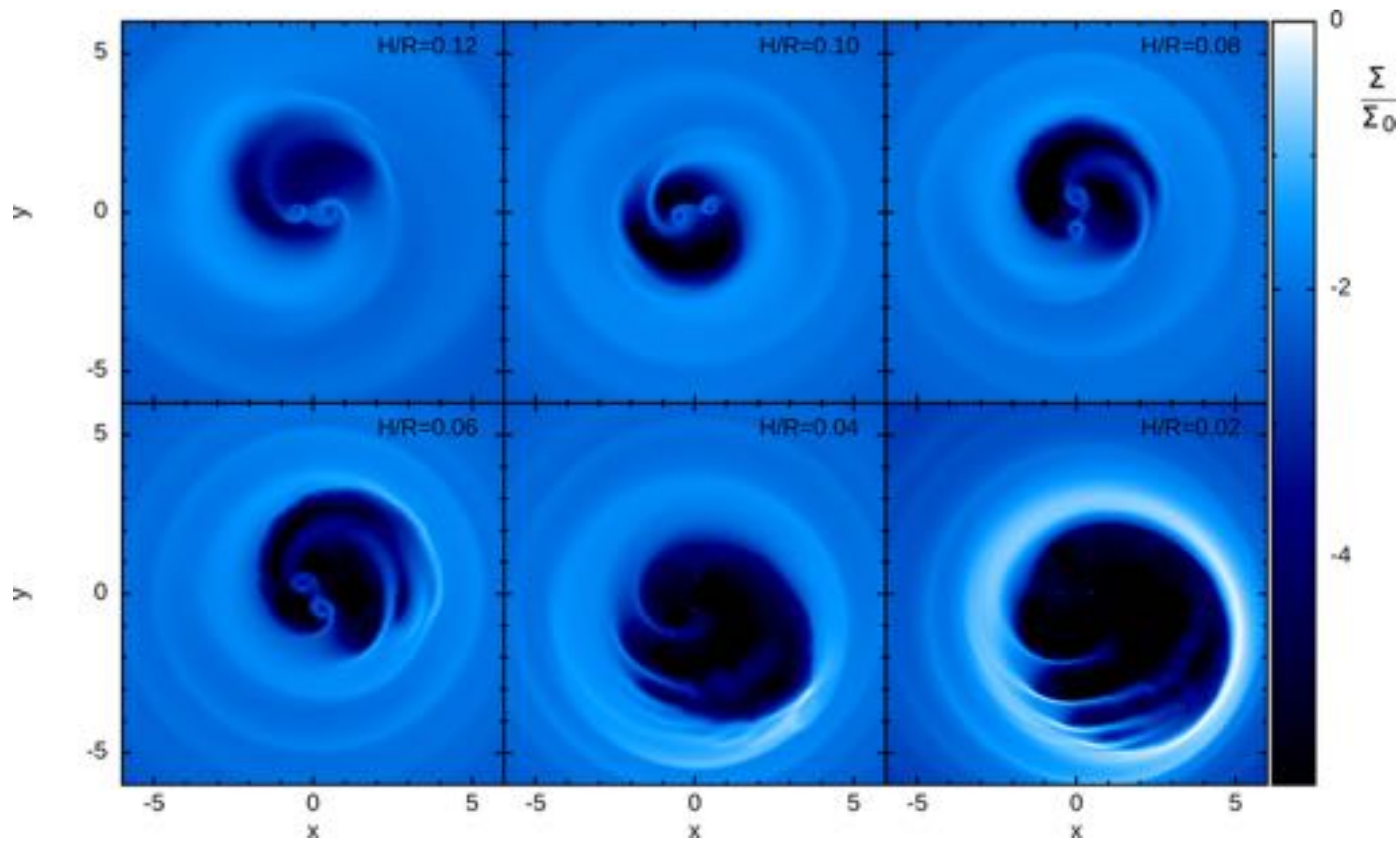


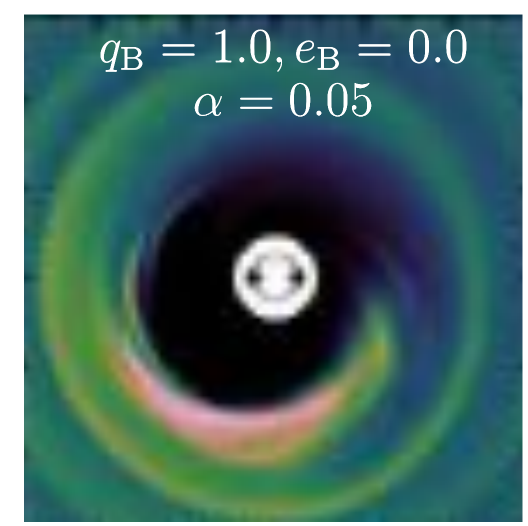
BUT WHAT ABOUT IN PROTOSTELLAR DISCS?

CIRCUMBINARY DISCS = ECCENTRIC CAVITIES *Ragusa et al. (2016)*

See also: MacFadyen & Milosavljevic (2008), D'Orazio+ (2013), Farris+ (2014), Miranda+ (2016)

1248 *E. Ragusa, G. Lodato and D. J. Price*

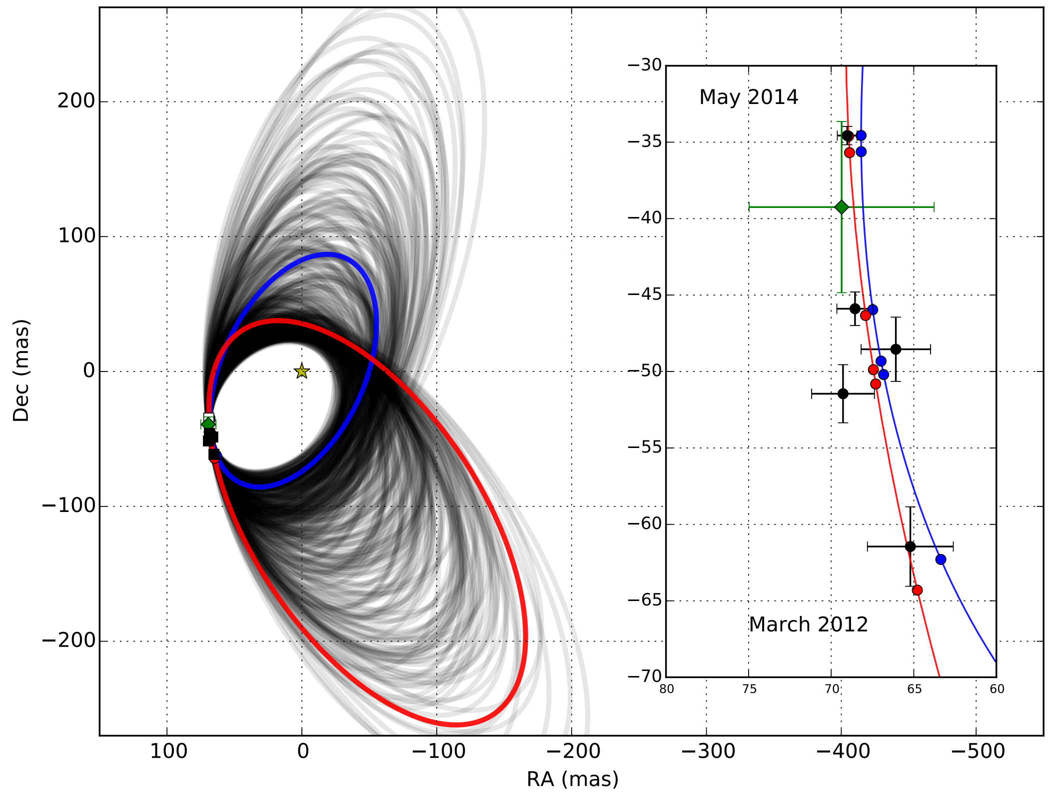




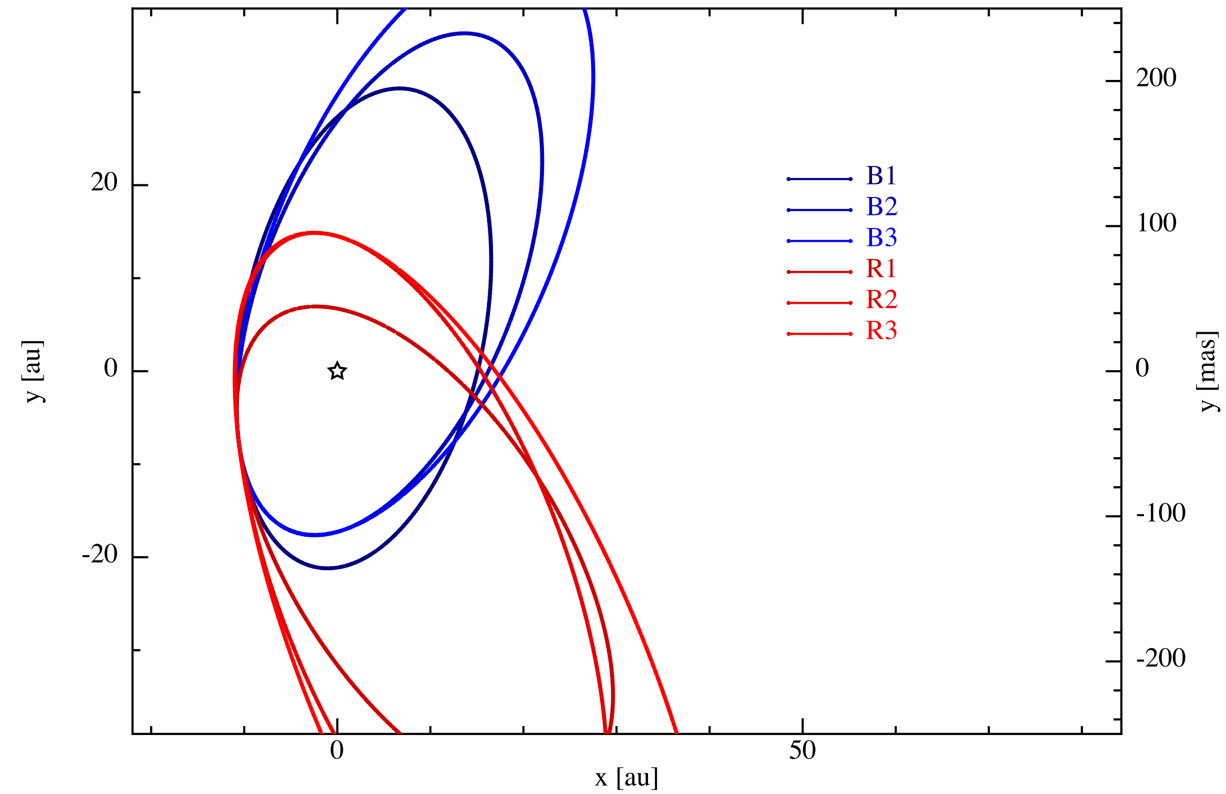
Miranda+2016

MODELLING HD142527

Price et al. (2018)



Lacour et al. (2016)

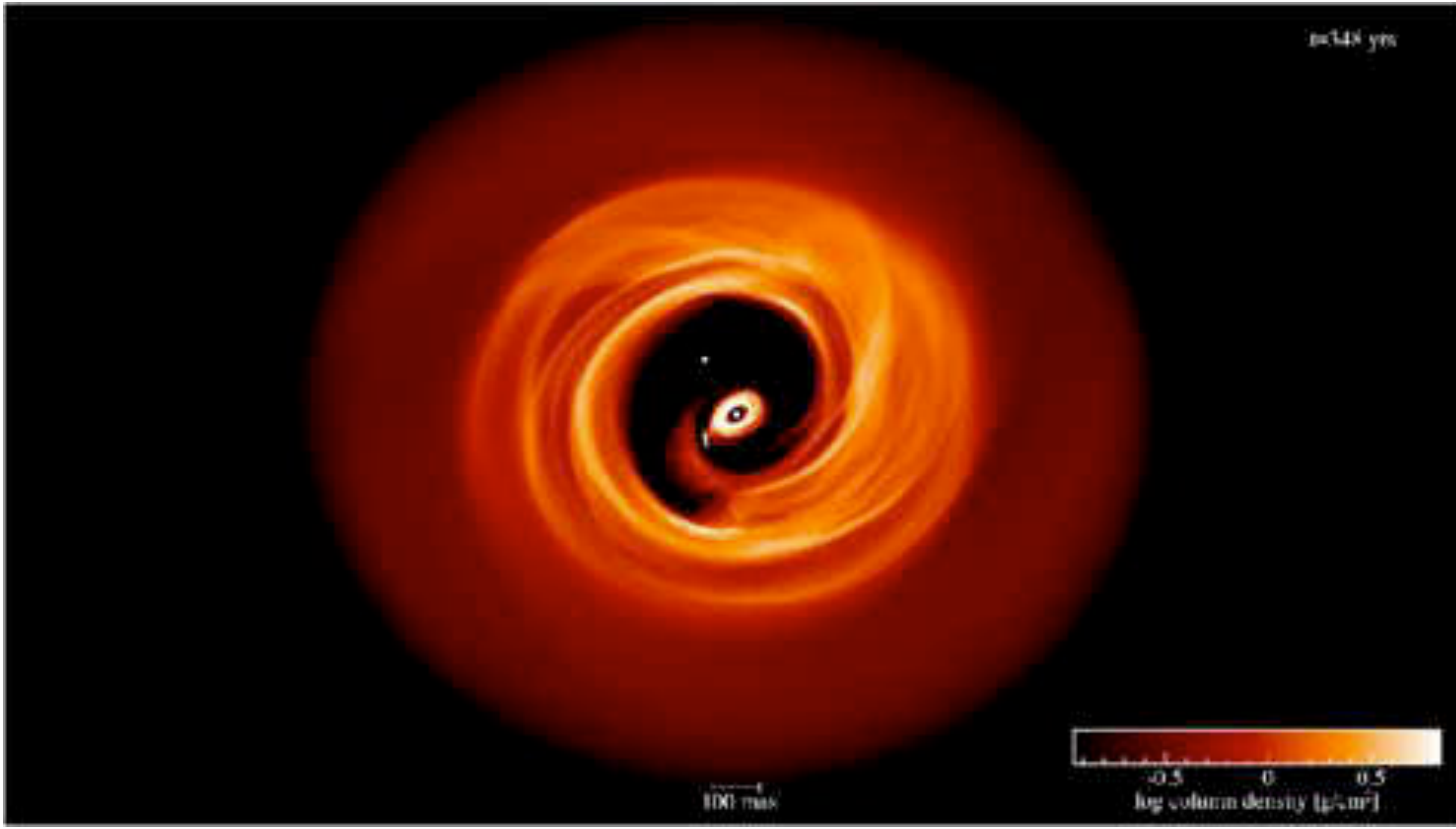


Orbital arc fits using IMORBEL (Pearce, Kennedy & Wyatt 2015)

	a	e	i	Ω	ω	f
Orbit B1	26.5	0.24	119.9	349.7	218.0	25.93
Orbit B2	28.8	0.40	120.4	340.3	201.5	33.78
Orbit B3	34.3	0.50	119.3	159.2	19.98	35.04
Orbit R1	31.4	0.74	131.3	44.95	27.88	249.3
Orbit R2	38.9	0.61	120.3	19.25	354.0	268.3
Orbit R3	51.3	0.70	119.3	201.4	173.3	270.4

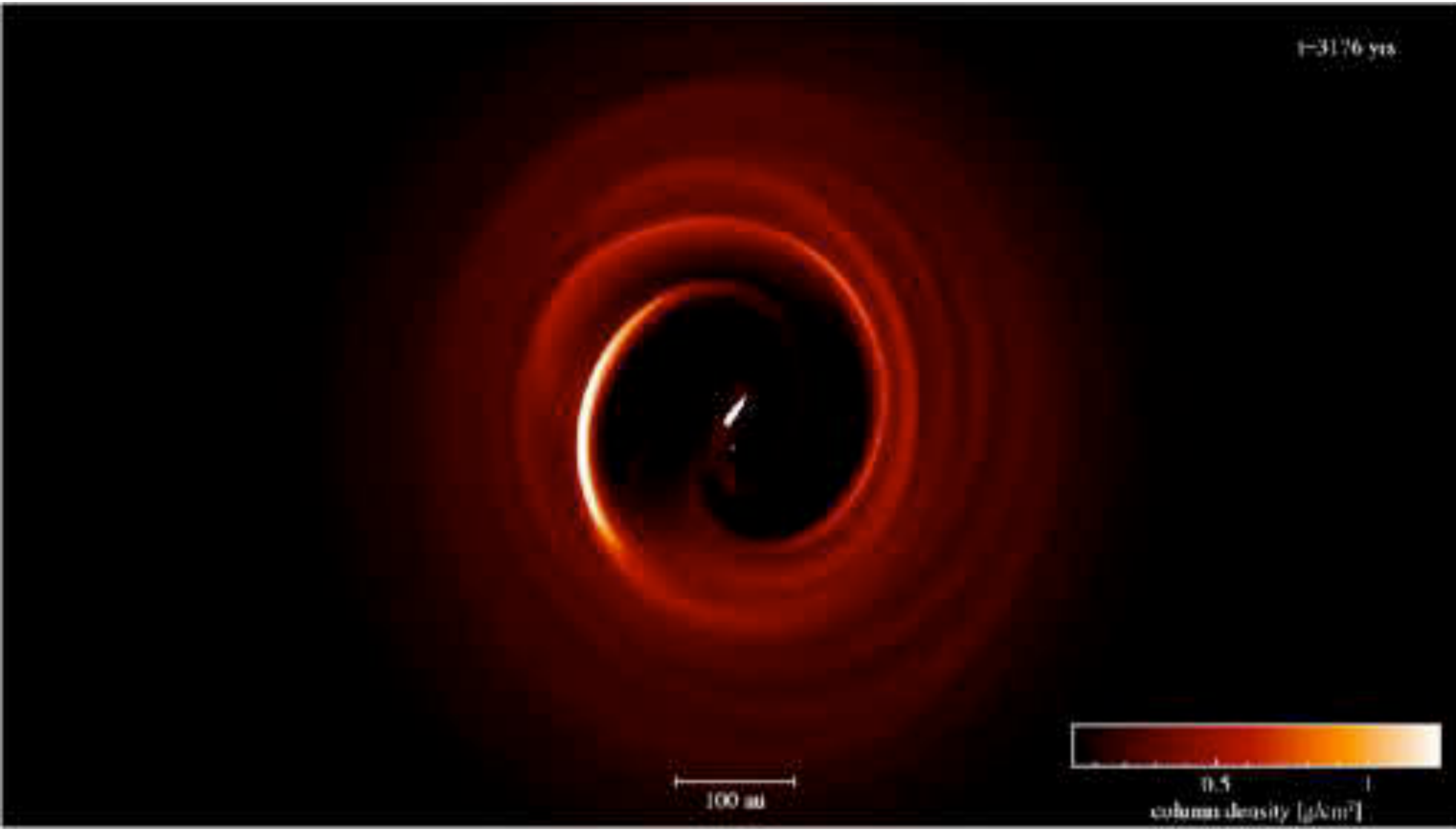
BLUE ORBIT

Price et al. (2018), submitted to MNRAS



RED ORBIT

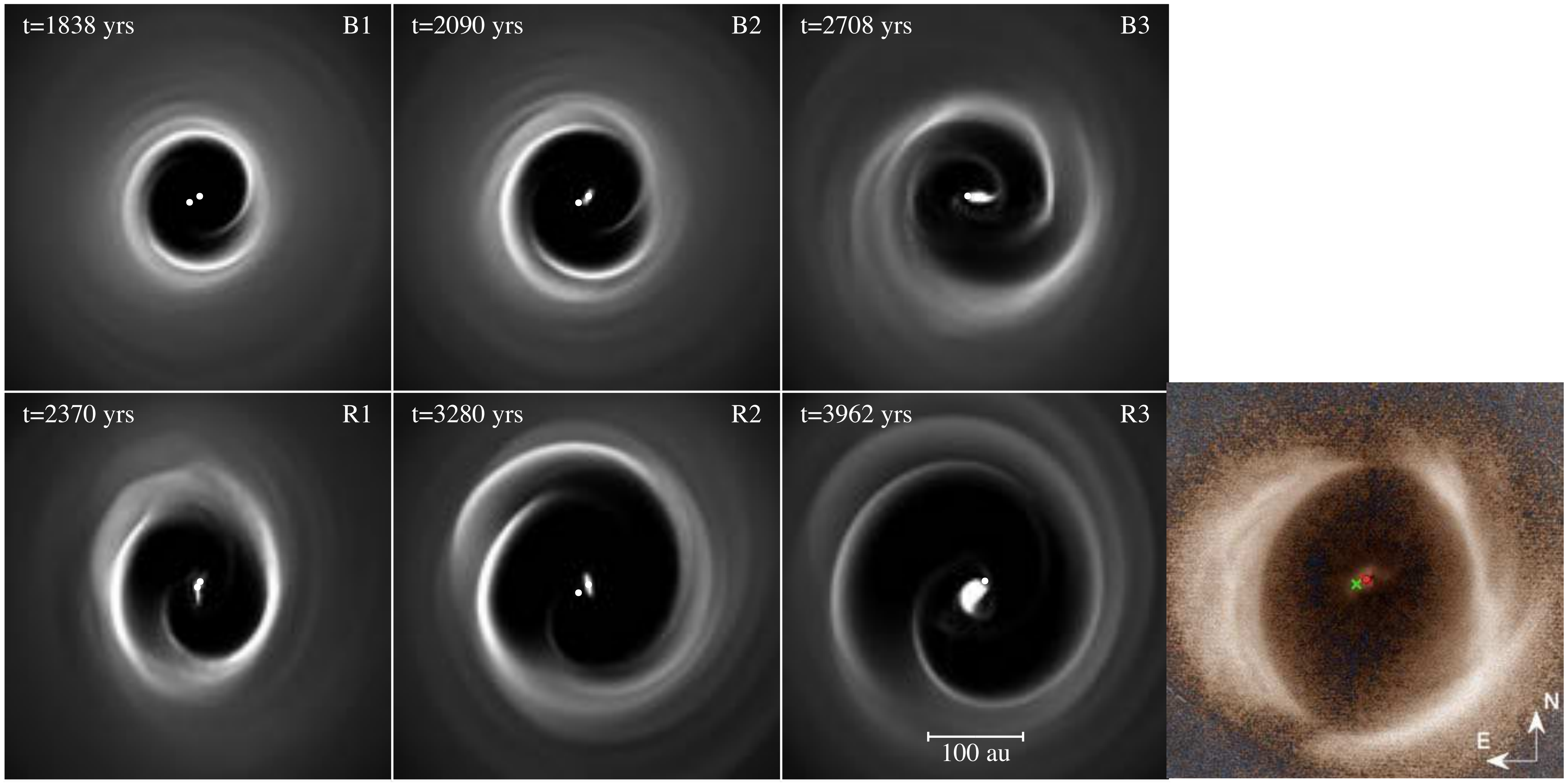
Price et al. (2018), submitted to MNRAS



See almost polar alignment of binary to disc, c.f. Aly et al. (2015), Martin & Lubow (2017)

SPIRALS

See also Ogilvie & Lubow (2002), Rafikov (2002), Fung & Dong (2015)

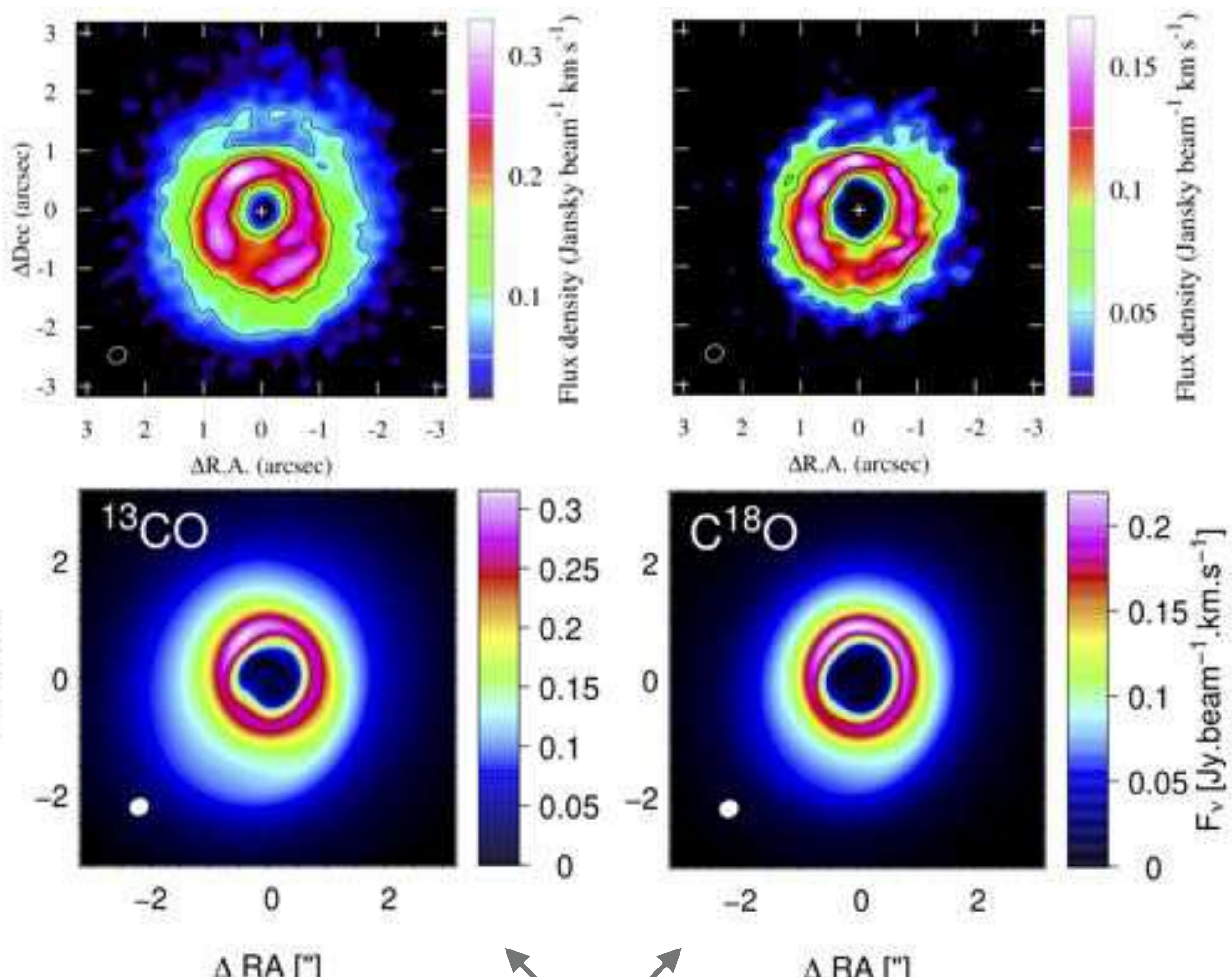


Price et al. (2018)

Binary must be on RED orbit!

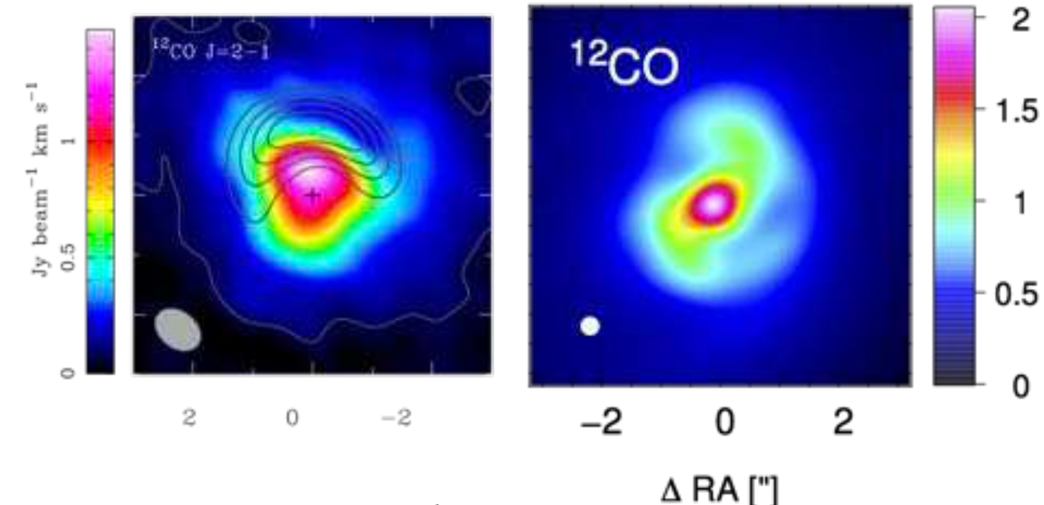
CO EMISSION (USING MCFOST RT CODE, PINTE ET AL. 2006)

Observations

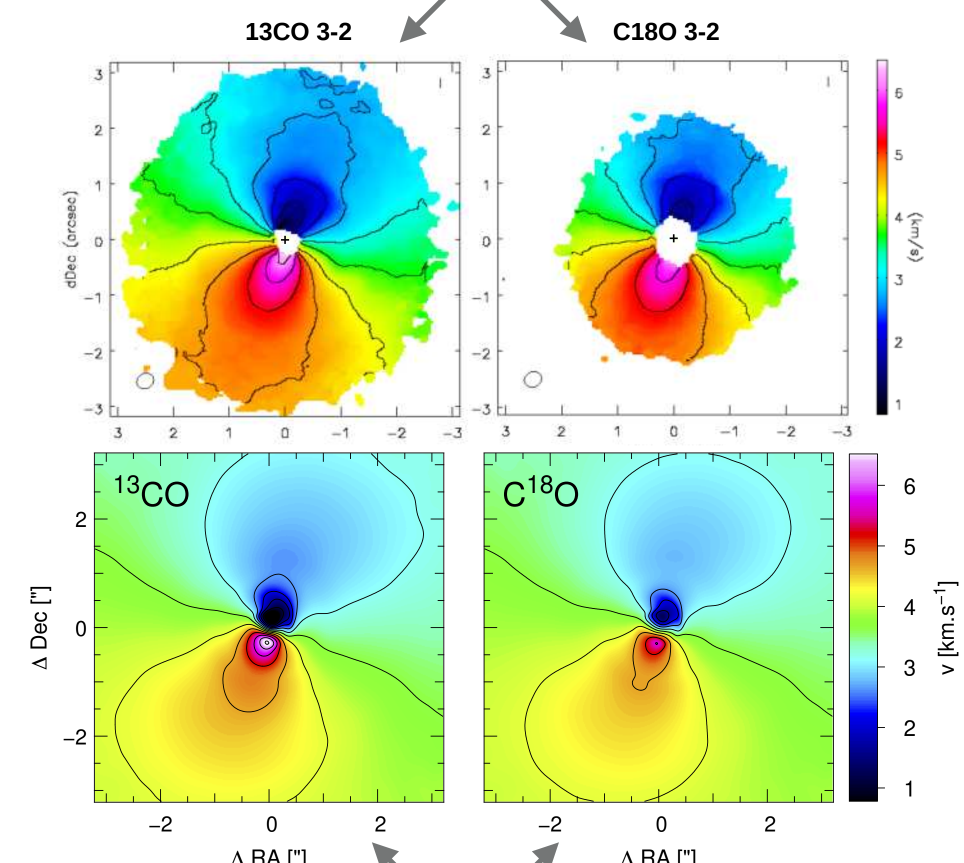


Simulations

Obs Simulation

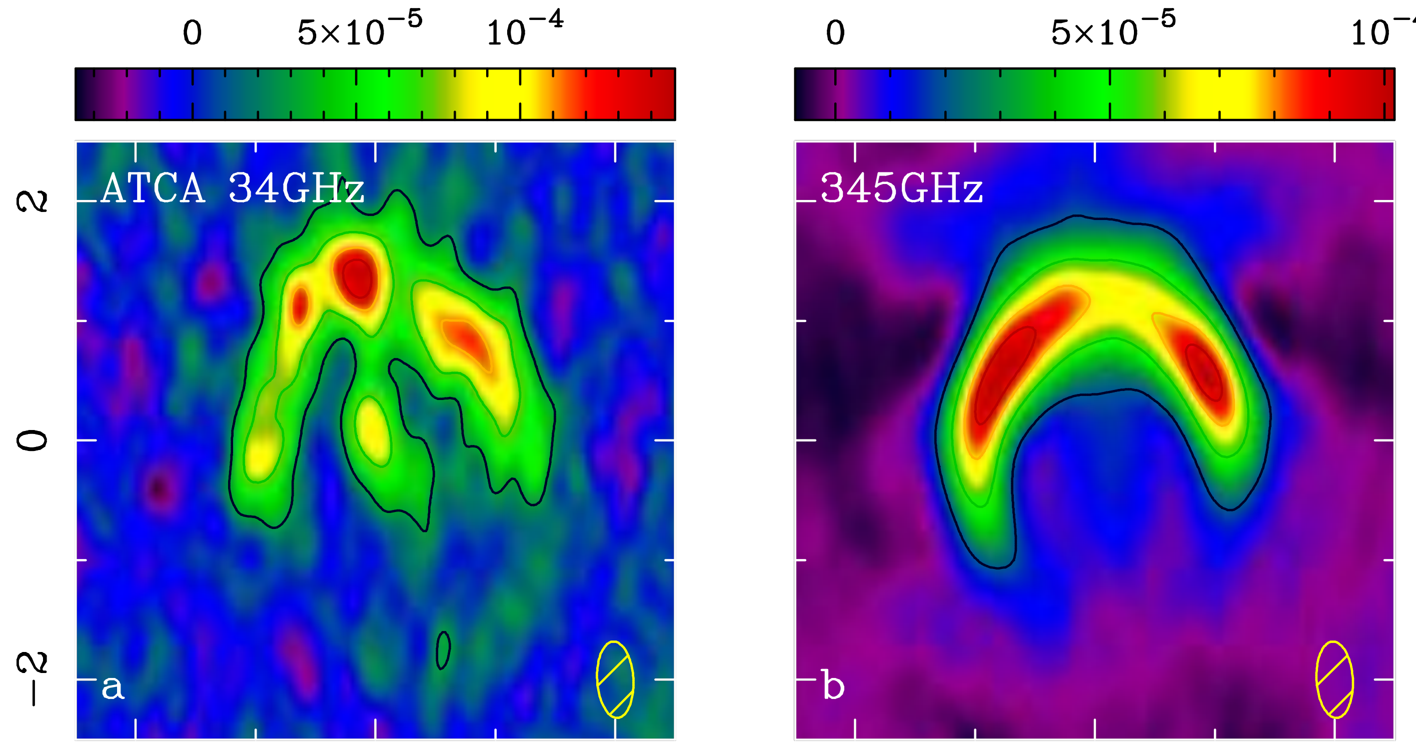


Observations

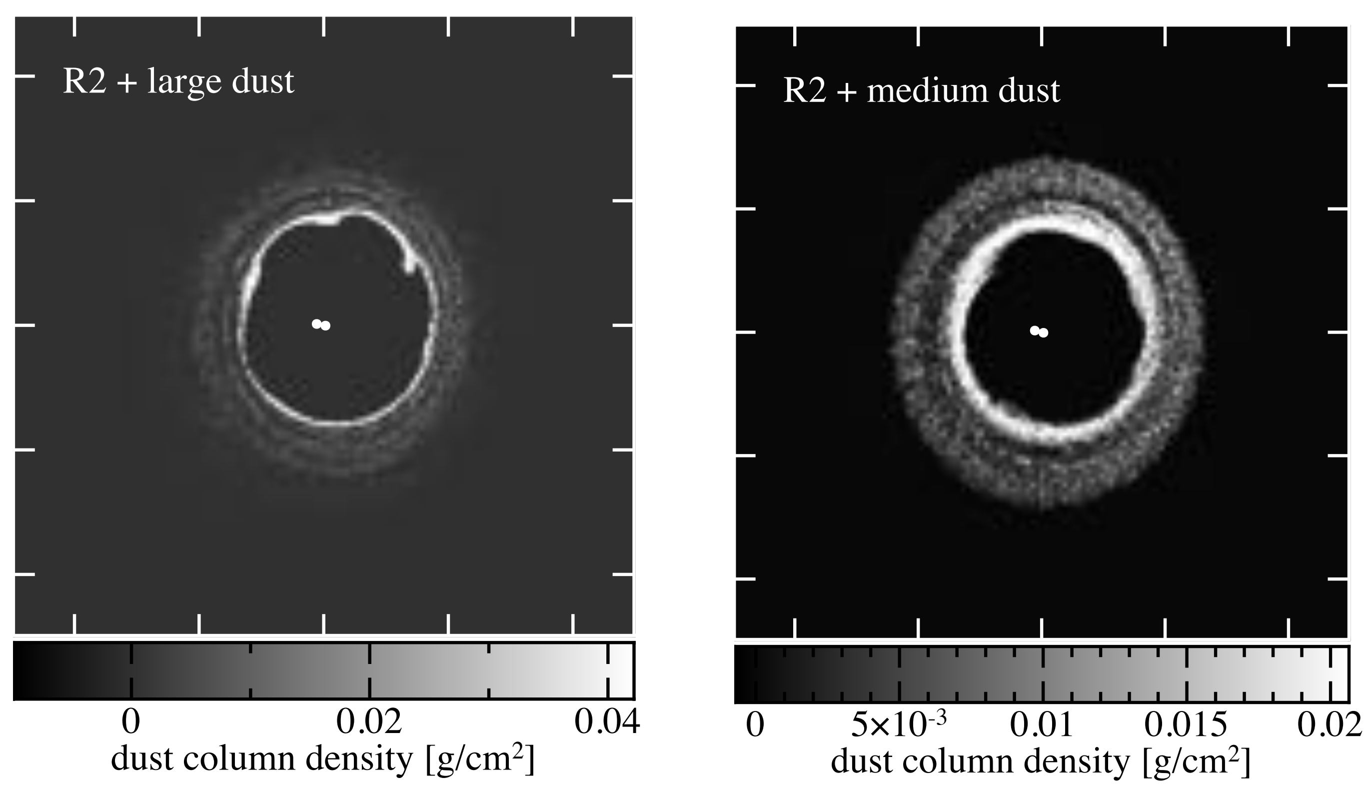


Simulations

HORSESHOE



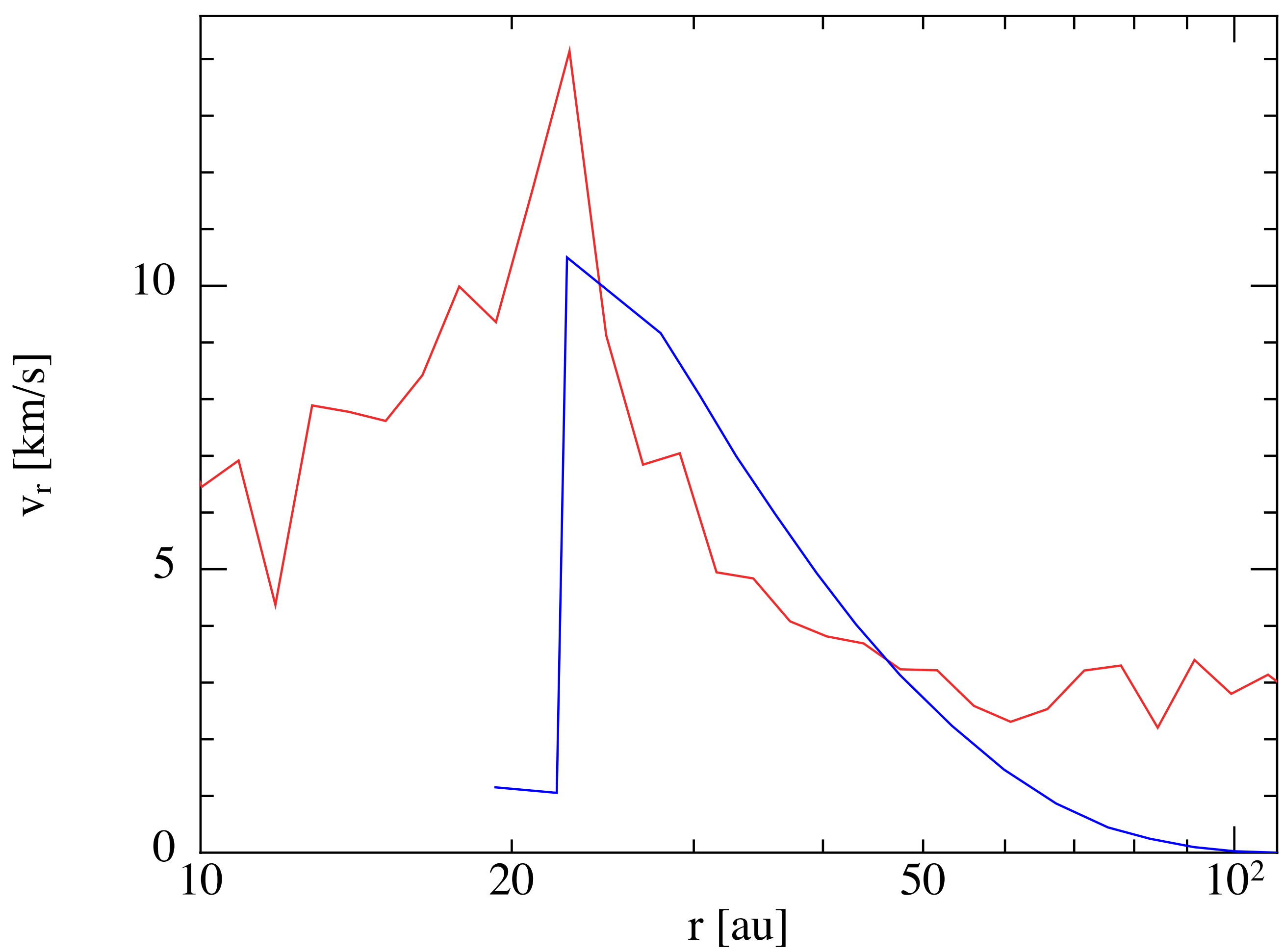
Observations



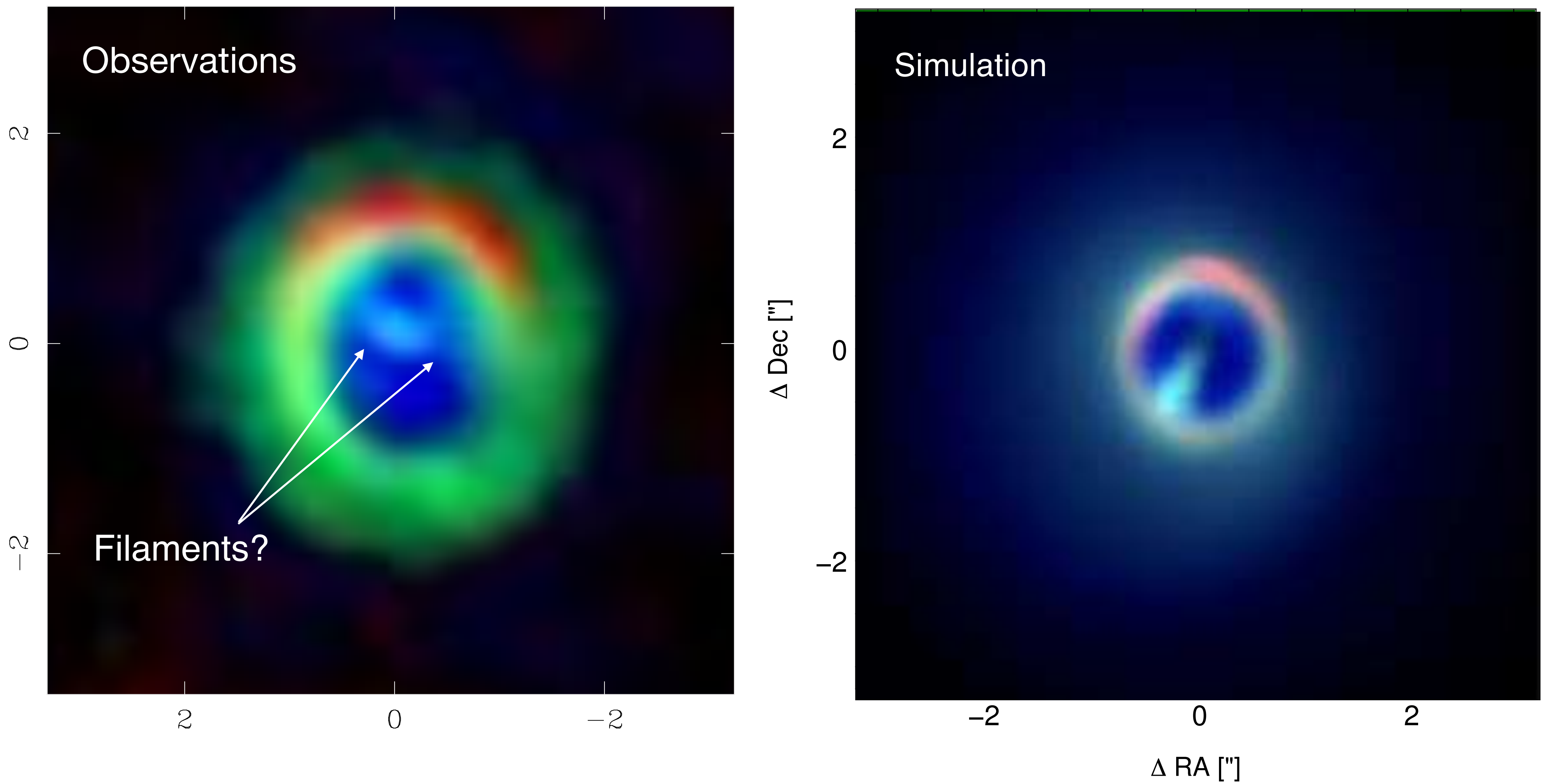
Simulations

FAST RADIAL FLOWS

Price et al. (2018)



GAP-CROSSING FILAMENTS



SUMMARY

- Modelling discs with dust and gas can shed light on observations
- Suggests circumbinarity may be the origin of many features seen in transitional discs (c.f. LkCa15; Sallum et al. 2015)
- Are all transitional discs circumbinary?