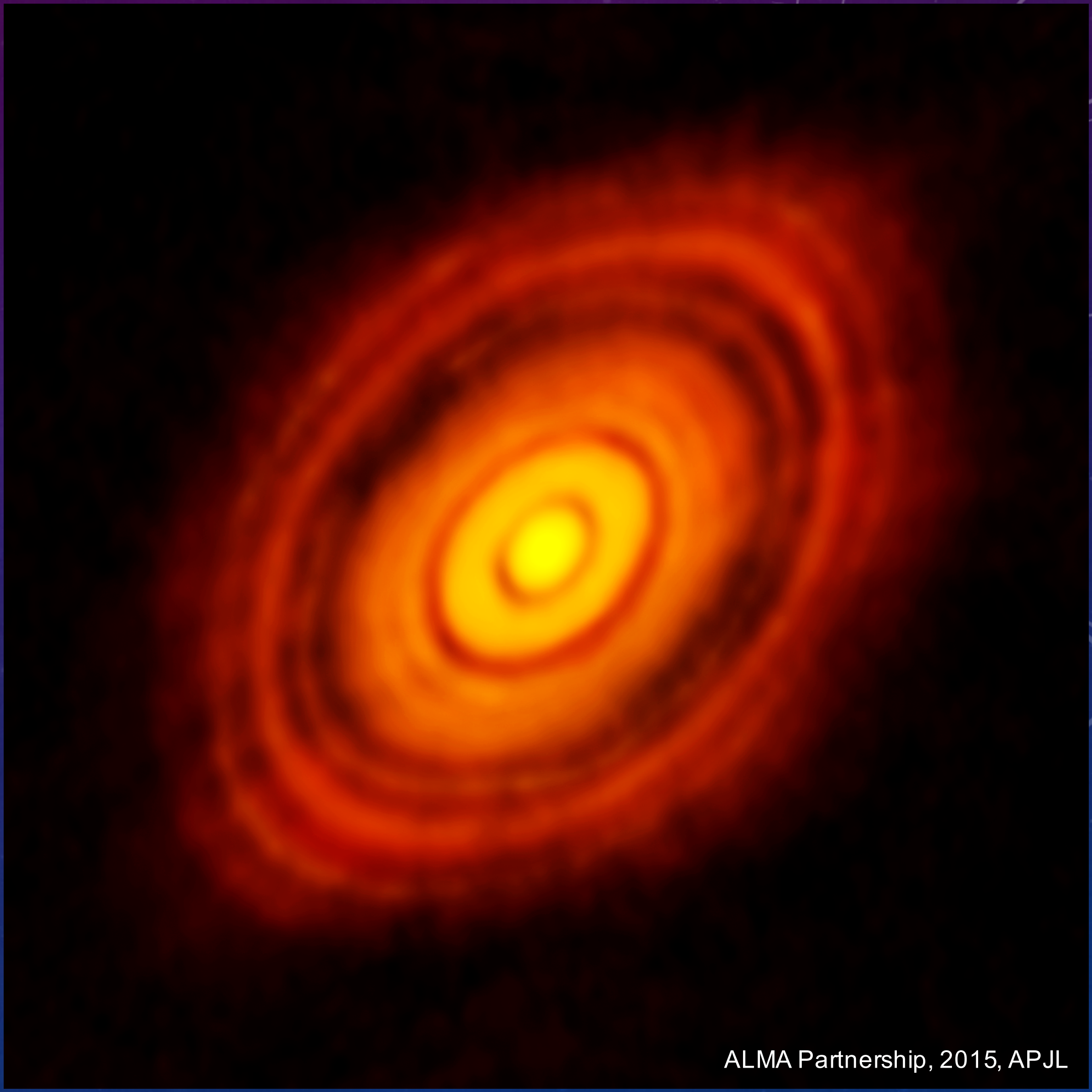
YOUNG PROTOSTELLAR DISCS AND THEIR ROLE IN PLANET FORMATION AND EVOLUTION

DIMITRIS STAMATELLOS

HOW EARLY DOES PLANET FORMATION START?

HL TAU

- Primary mass: ~1.3$M_\odot$
- Disc mass: ~0.1$M_\odot$
- Disc~100 AU
- **Age ~1 Myr**
- Dust gaps but also gas gaps (HCO^+ observations; Yen et al. , 2016, ApJL)
- Planets form in gaps? (e.g. Dipierro et al. 2015)
- Planets form in bright rings? (e.g. Carasco-Gonzalez et al. 2016)


ALMA Partnership, 2015, APJL

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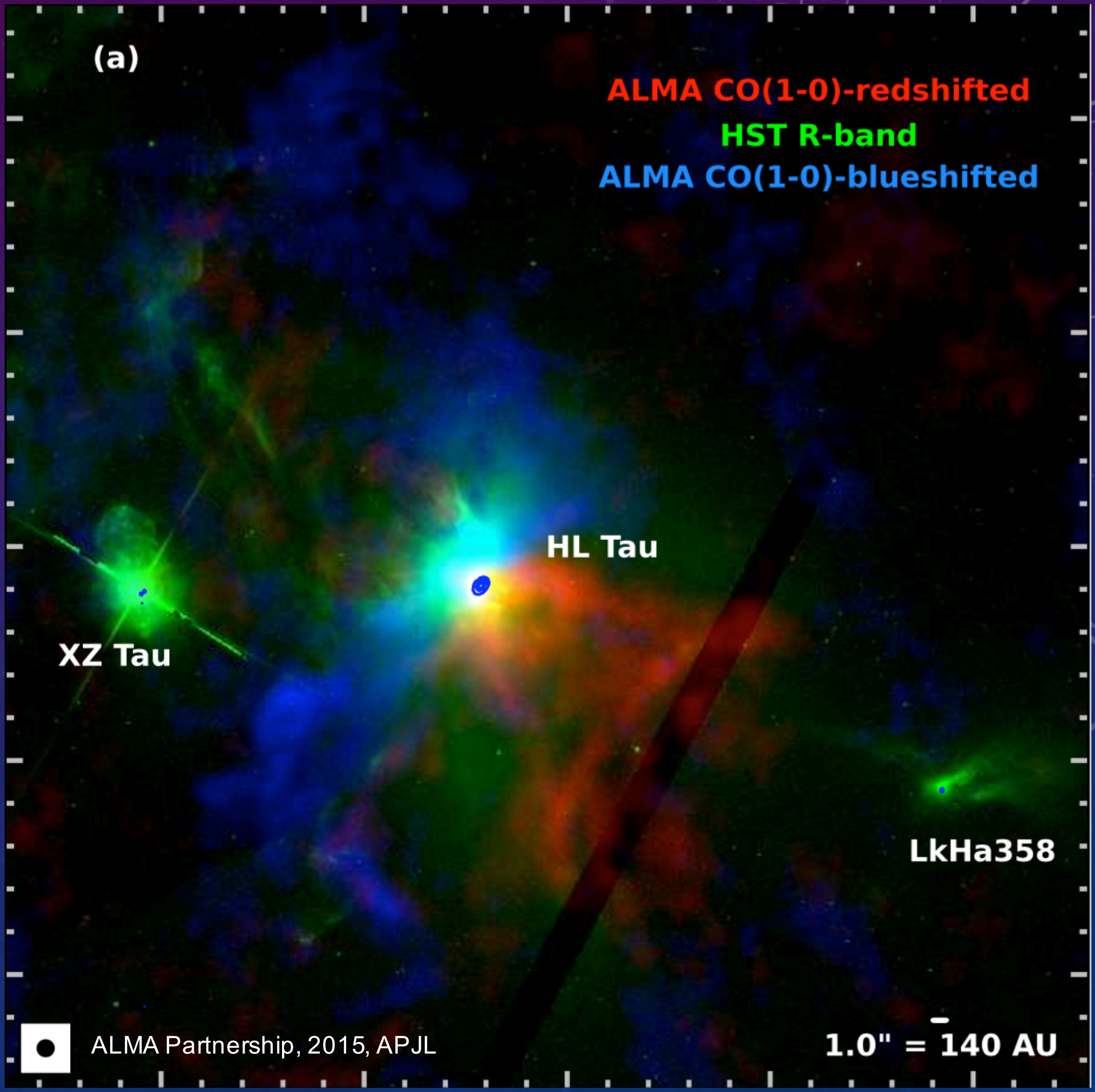
- Disc~100 AU

Age ~1 Myr

(CLASS I/II)

- Envelope radius ~3000 AU
- Envelope Mass ~ 0.2 $M_\odot$

Planet formation initial conditions?



EARLY PHASE DISCS

(I) WHAT ARE THE PROPERTIES OF EARLY-PHASE DISCS?
HOW ARE THEY AFFECTED BY INFALL AND STELLAR FEEDBACK?

(II) WHAT ARE THE CHARACTERISTICS OF PLANET FORMING IN AN EARLY-PHASE DISC?
CAN WE OBSERVE A FORMING PLANET?

WHAT ARE THE PROPERTIES OF EARLY-PHASE DISCS? HOW ARE THEY AFFECTED BY INFALL AND STELLAR FEEDBACK?

- **Radiative hydrodynamic simulations of a collapsing 5.4 $M_\odot$ molecular cloud**

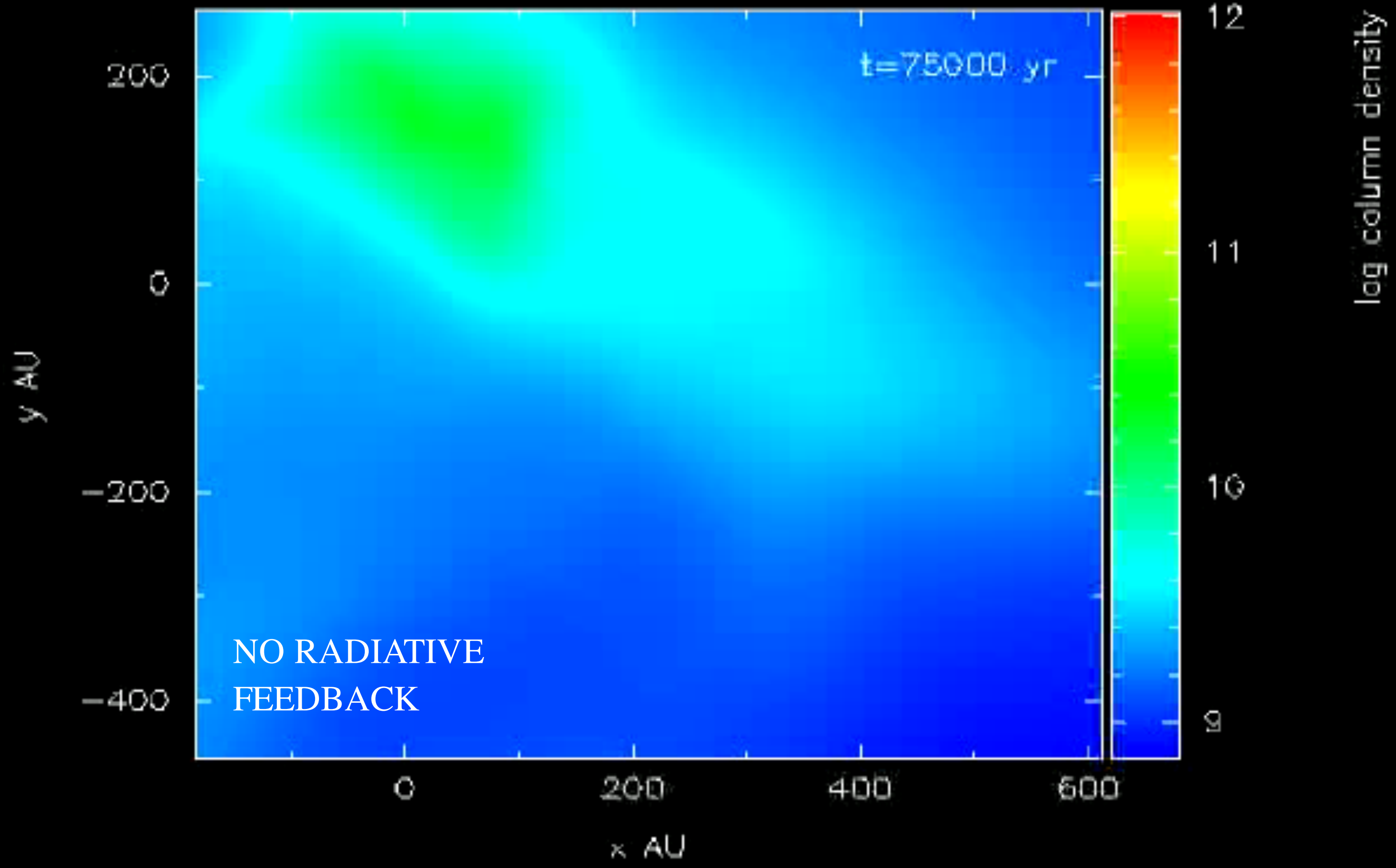
- Stars (once they form) they are represented by "sink" particles that do not interact via pressure forces with the gas

•**1st simulation:** no feedback from the forming stars

•**2nd simulation:** with continuous feedback

•**3rd simulation:** with episodic feedback (a combination of gravitational instability driving gas from the outer disc region to the inner disc region, and MRI driving accretion from the inner disc onto the star; e.g. Zhu et al. 2009+)

- The effect of magnetic fields is not included


t=75000 yr
200
0
−200
−400
y AU
0
200
400
600
x AU
12
11
10
9
log column density
NO RADIATIVE
FEEDBACK

WHAT ARE THE PROPERTIES OF EARLY-PHASE DISCS? HOW ARE THEY AFFECTED BY INFALL AND STELLAR FEEDBACK?

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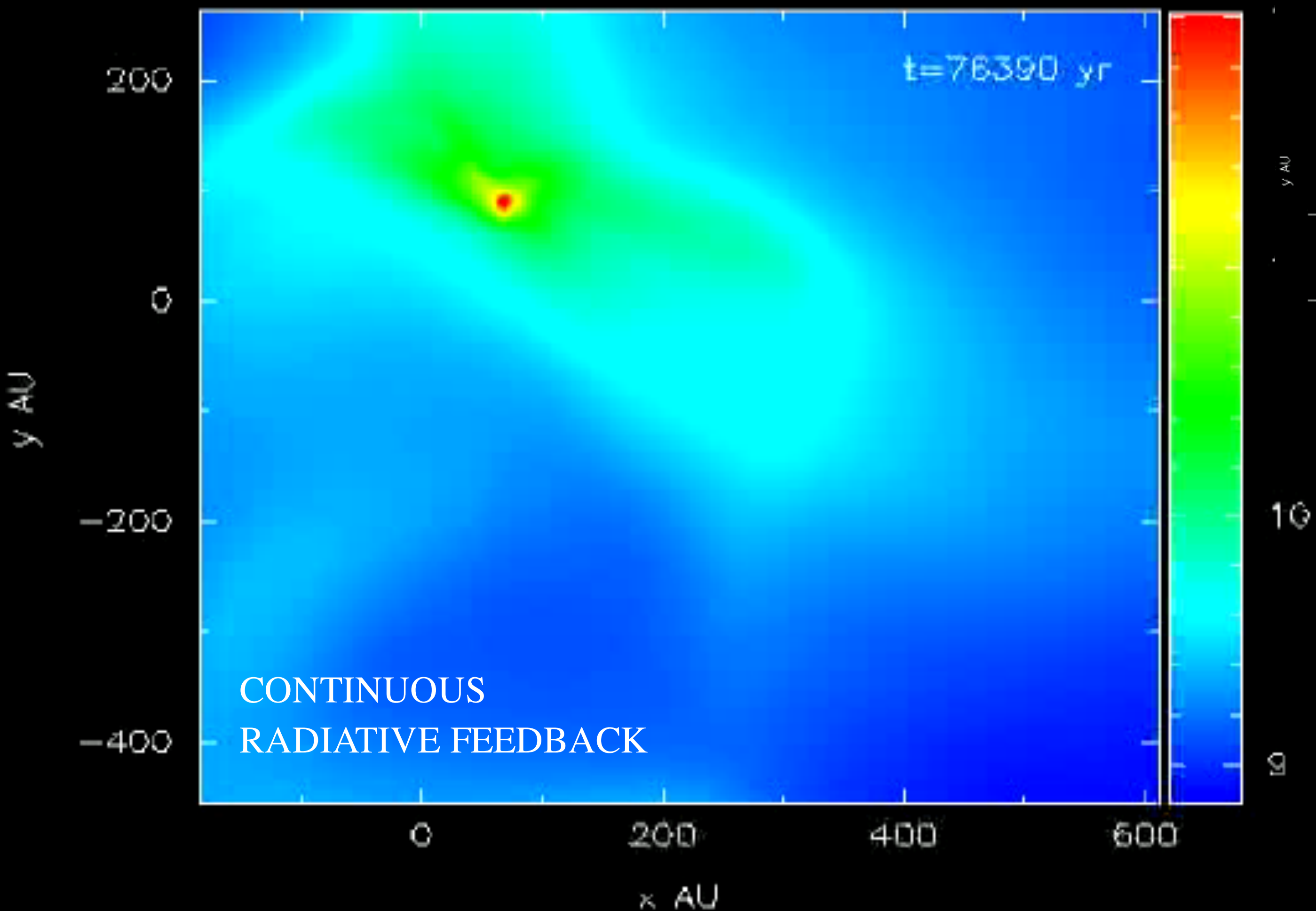
t=76390 yr
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y AU
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200
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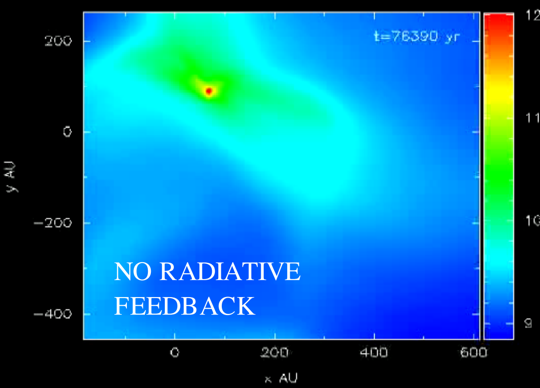
x AU
10
9
CONTINUOUS
RADIATIVE FEEDBACK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200
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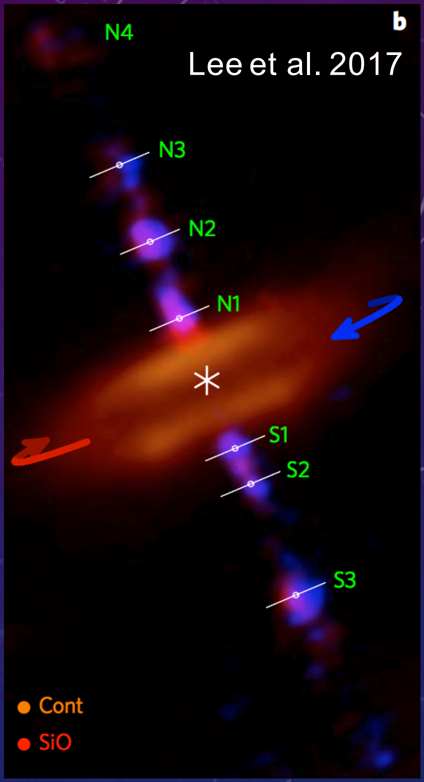
WHAT ARE THE PROPERTIES OF EARLY-PHASE DISCS?



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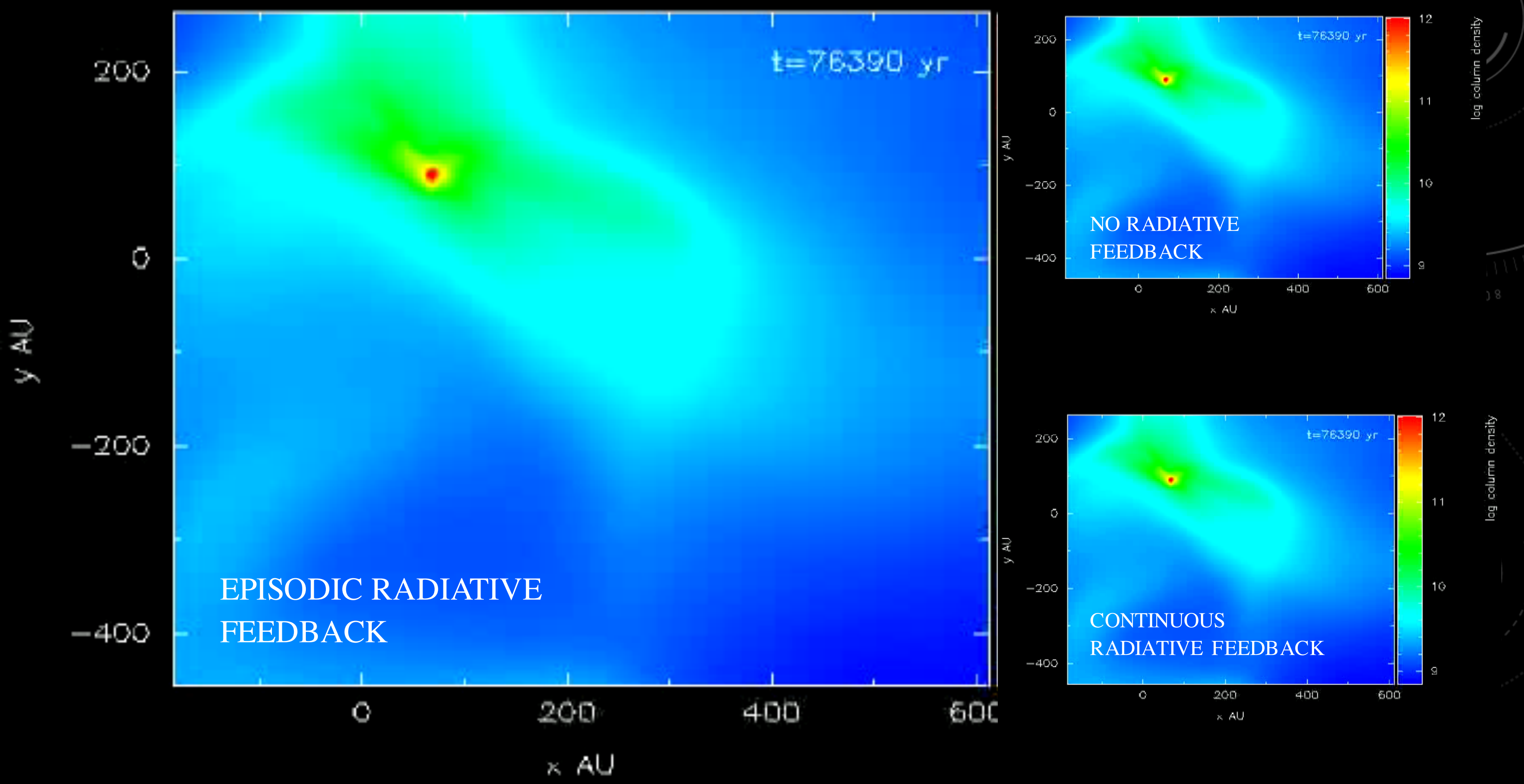
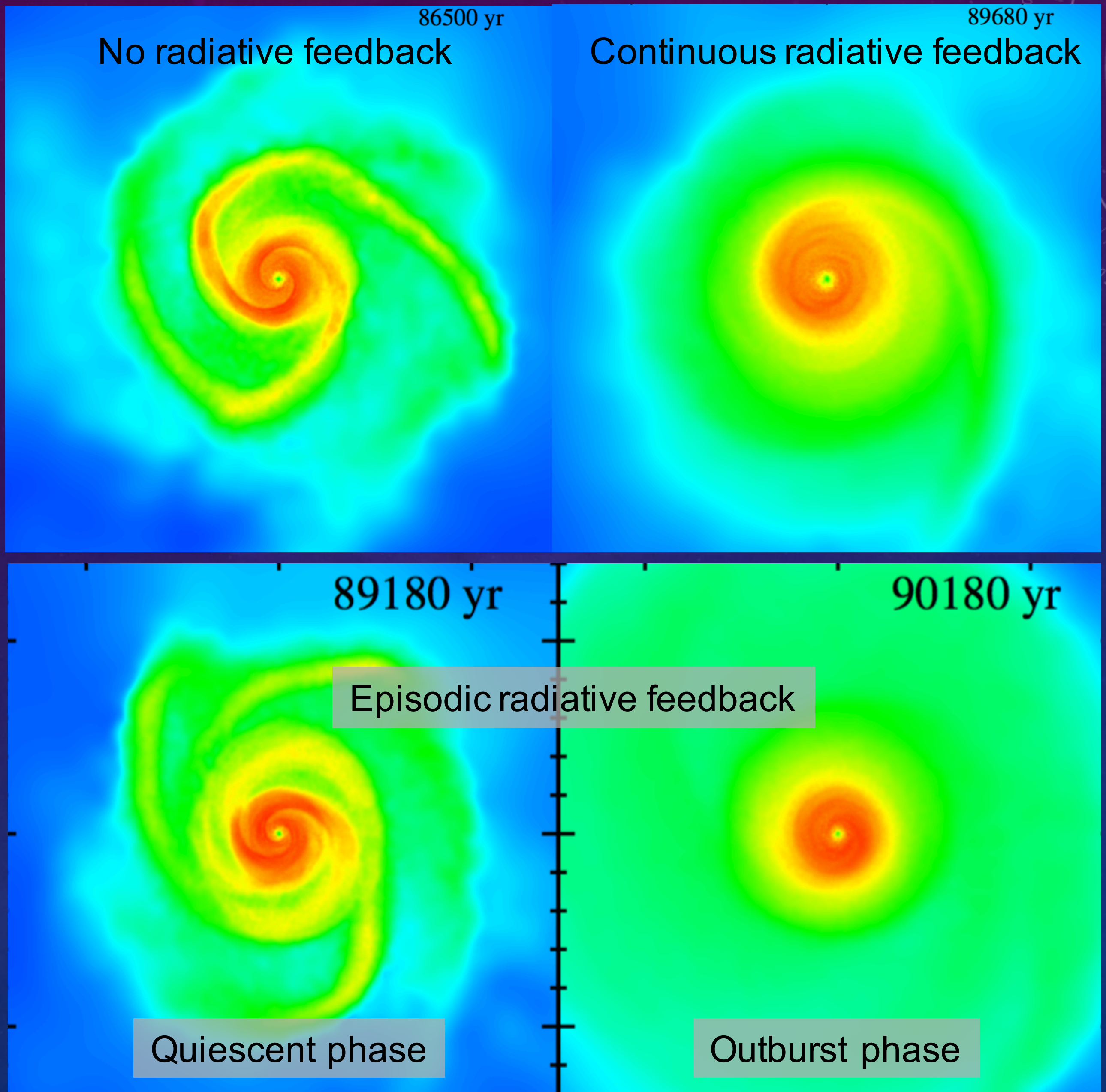


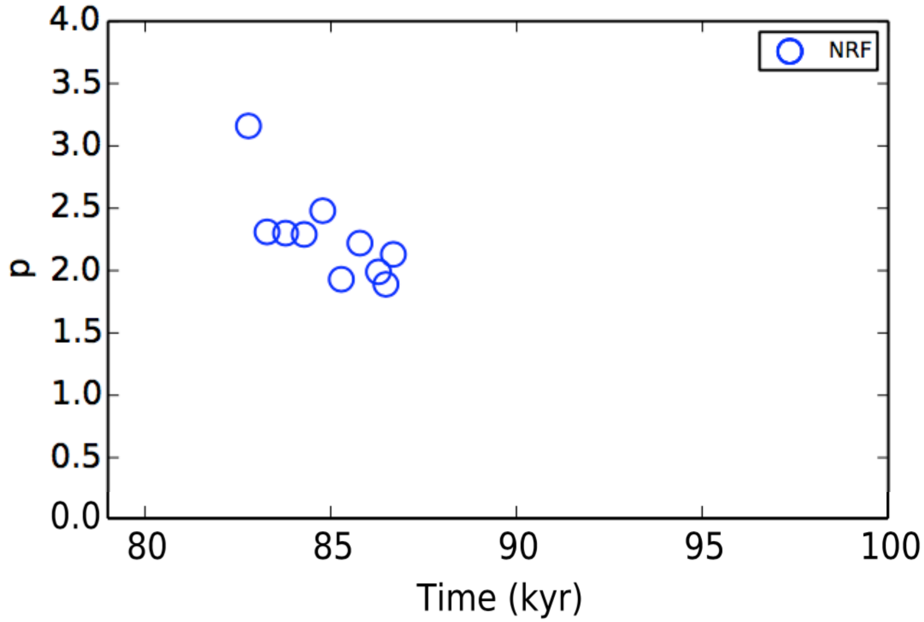
Stamatellos et al. 2011, 2012; MacFarlane & Stamatellos, 2017, MNRAS

DIFFERENCES IN DISC MORPHOLOGIES/SPIRAL ARMS

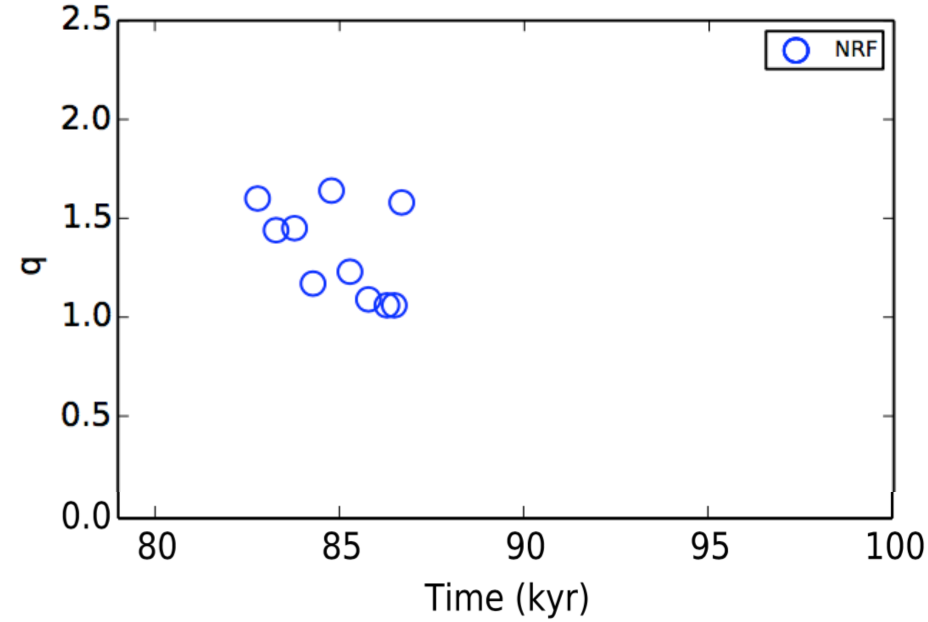


DENSITY AND TEMPERATURE PROFILES

p index (density) **Σ~r^-p**



q index (temperature) **T~r^-q**



No radiative feedback

Continuous radiative feedback

Episodic radiative feedback

MacFarlane & Stamatellos, 2017, MNRAS

DENSITY AND TEMPERATURE PROFILES

p index (density) **$\Sigma \sim r^{-p}$**

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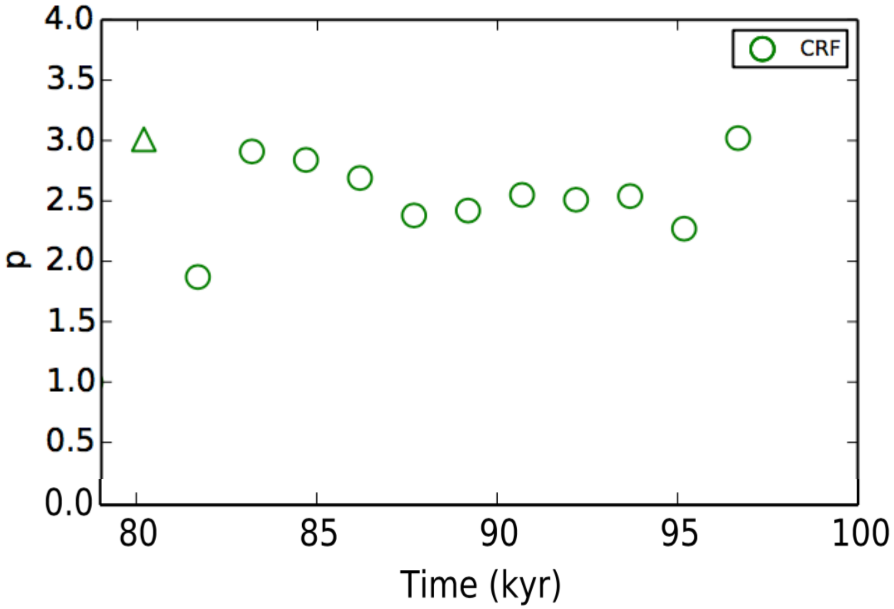

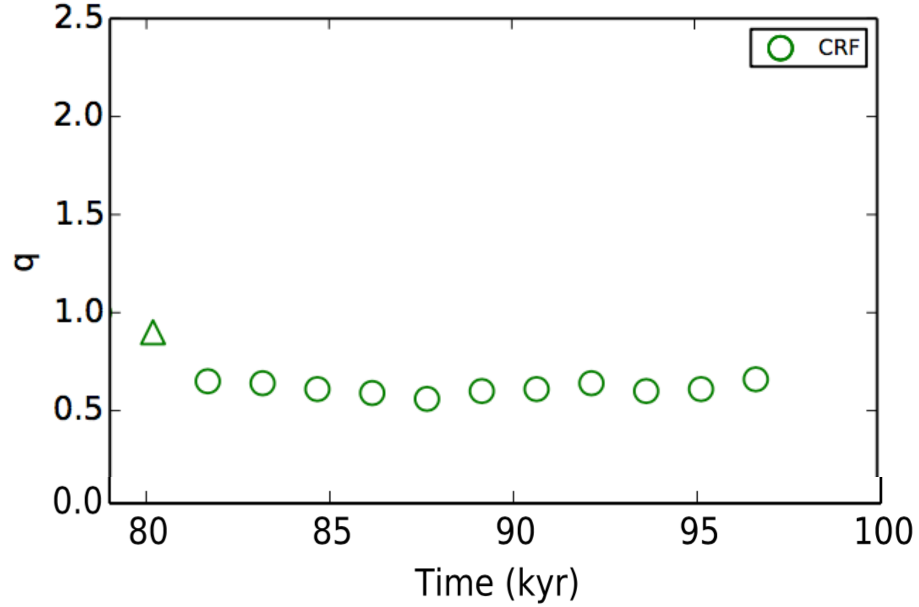

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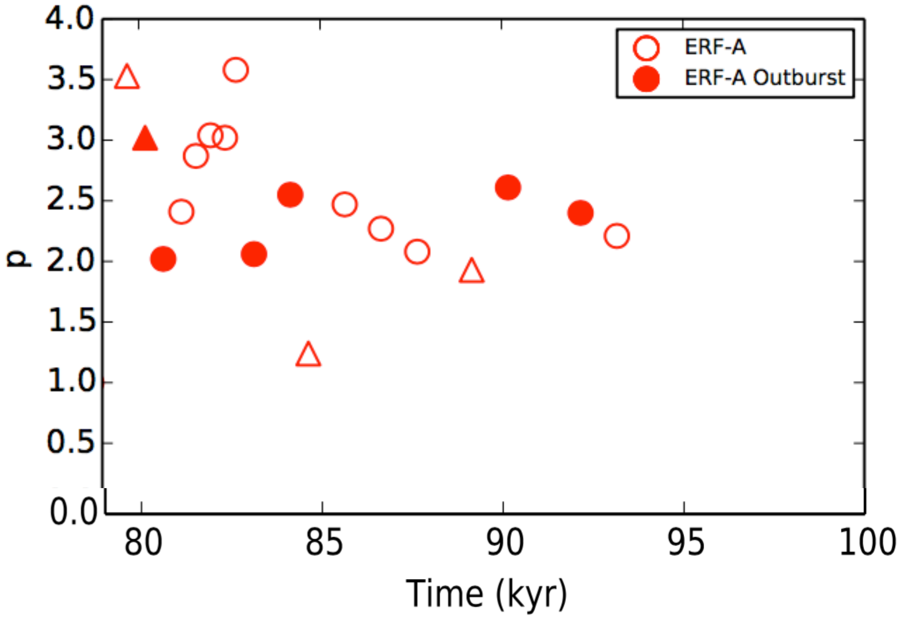
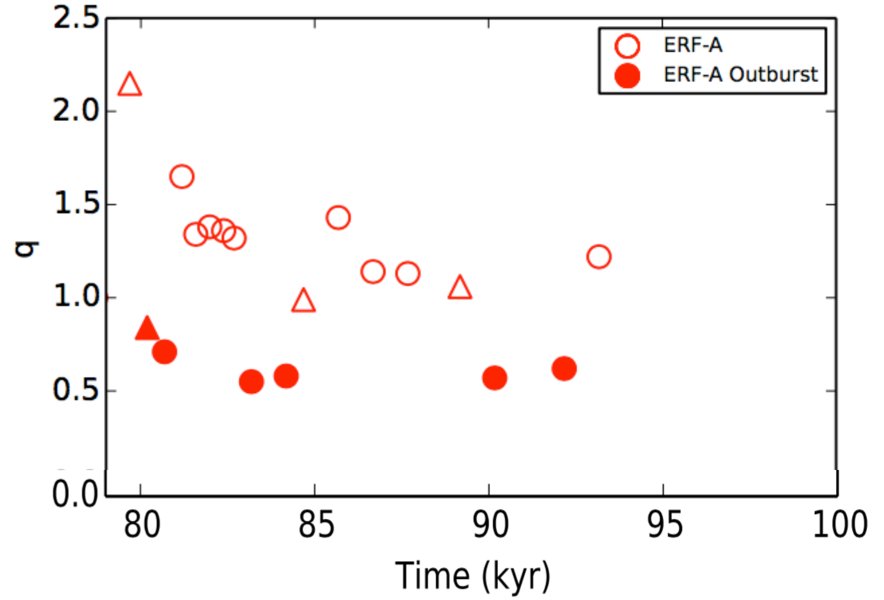




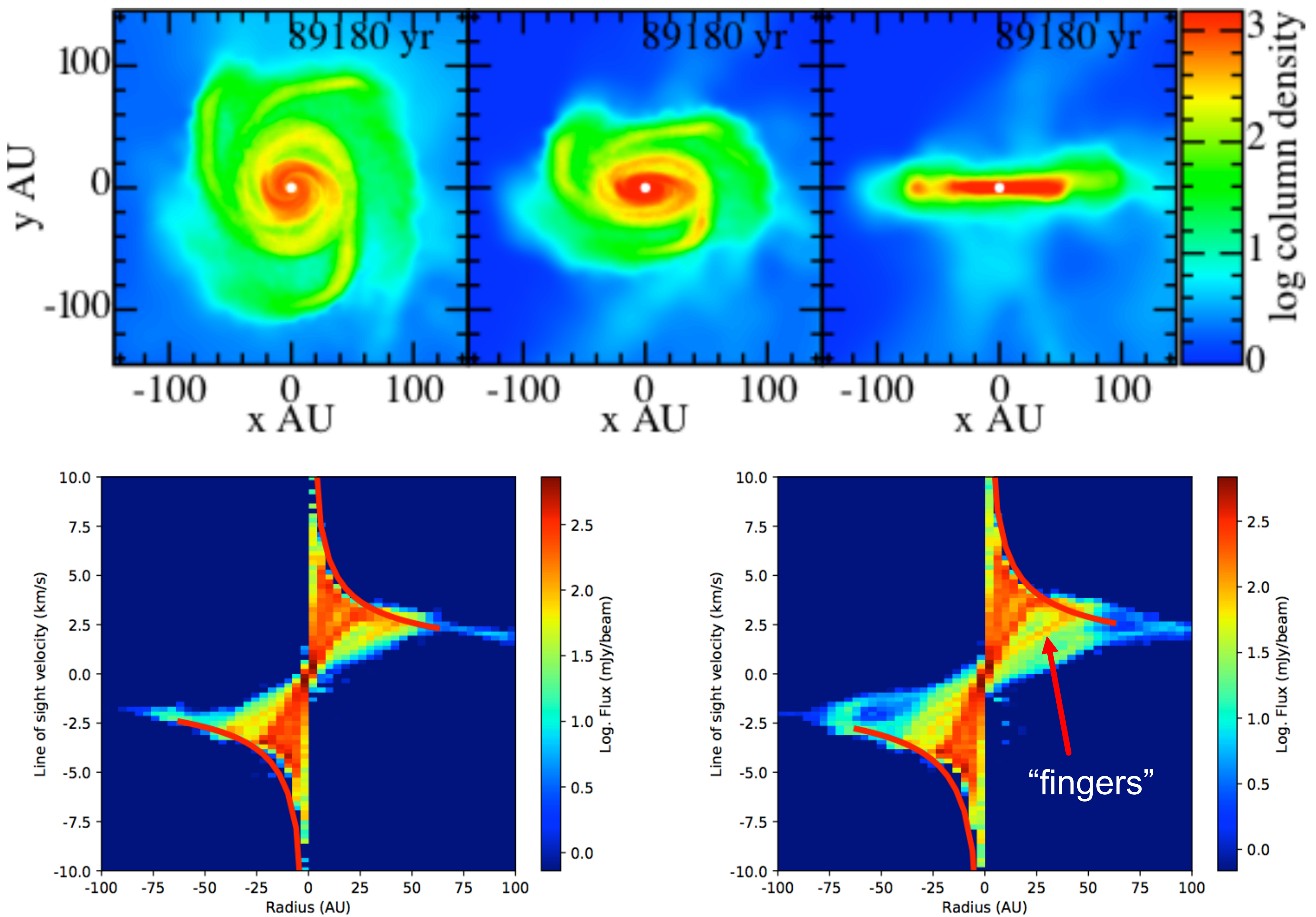
No radiative feedback

Continuous radiative feedback

Episodic radiative feedback

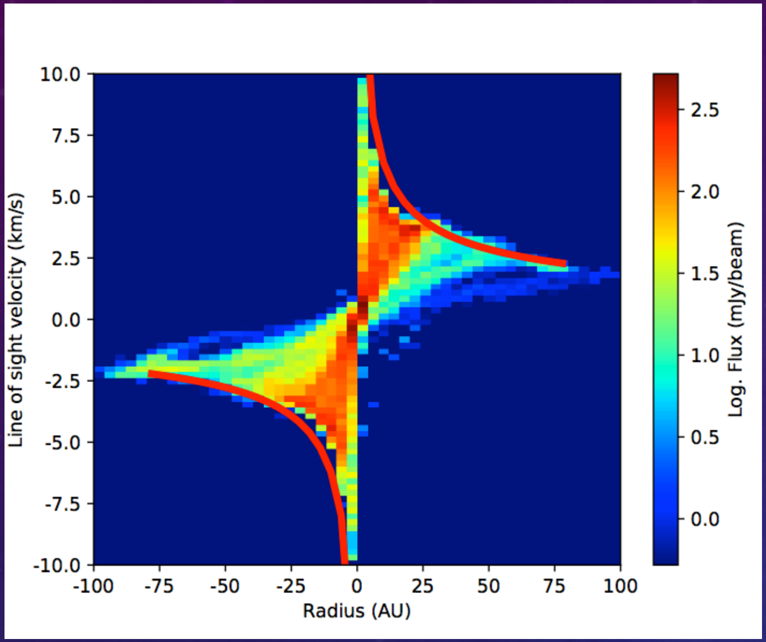
- Variable infall from the envelope modify the disc temperature and density profile
- The type of radiative feedback affects the disc morphology

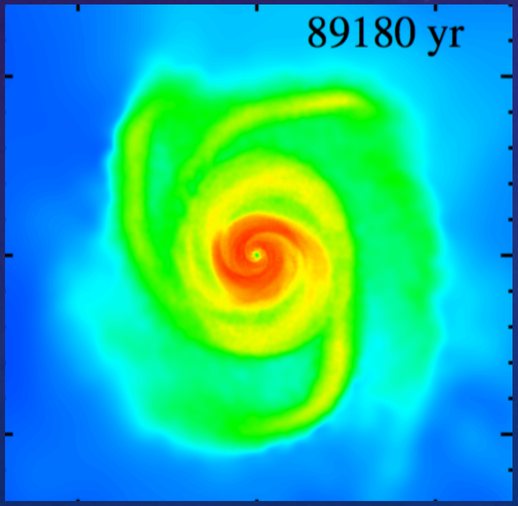
SPIRAL ARMS: COLUMN DENSITY VS POSITION-VELOCITY DIAGRAMS



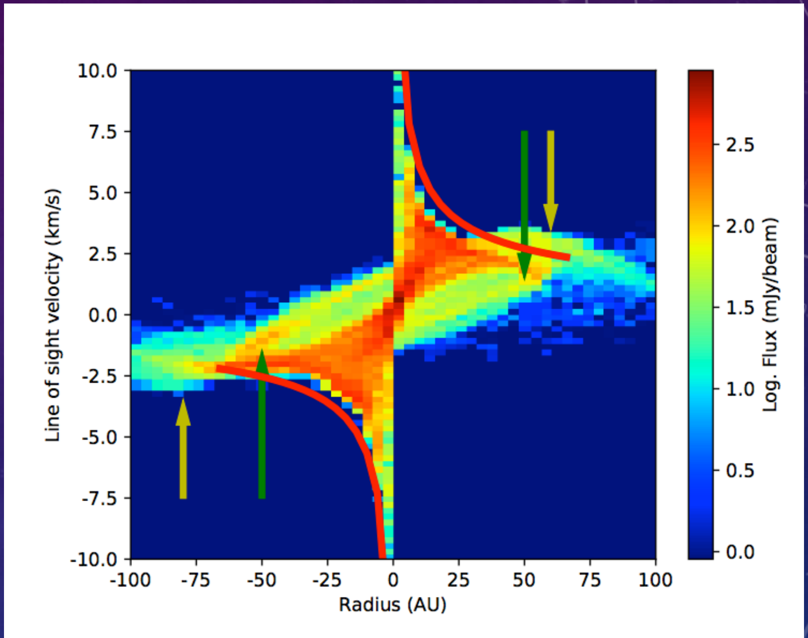
SIGNS OF EPISODIC FEEDBACK IN POSITION-VELOCITY DIAGRAMS

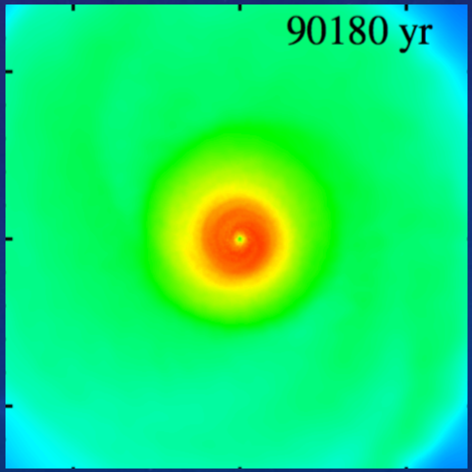
Quiescent phase



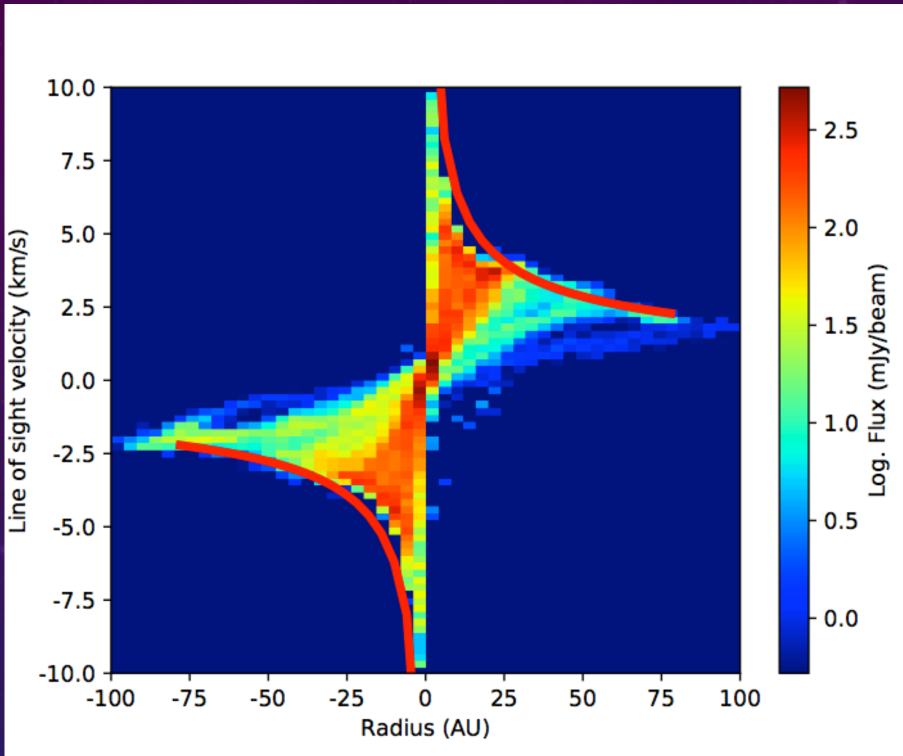


Outburst phase





CAUTION ON MASS ESTIMATES FROM POSITION-VELOCITY DIAGRAMS



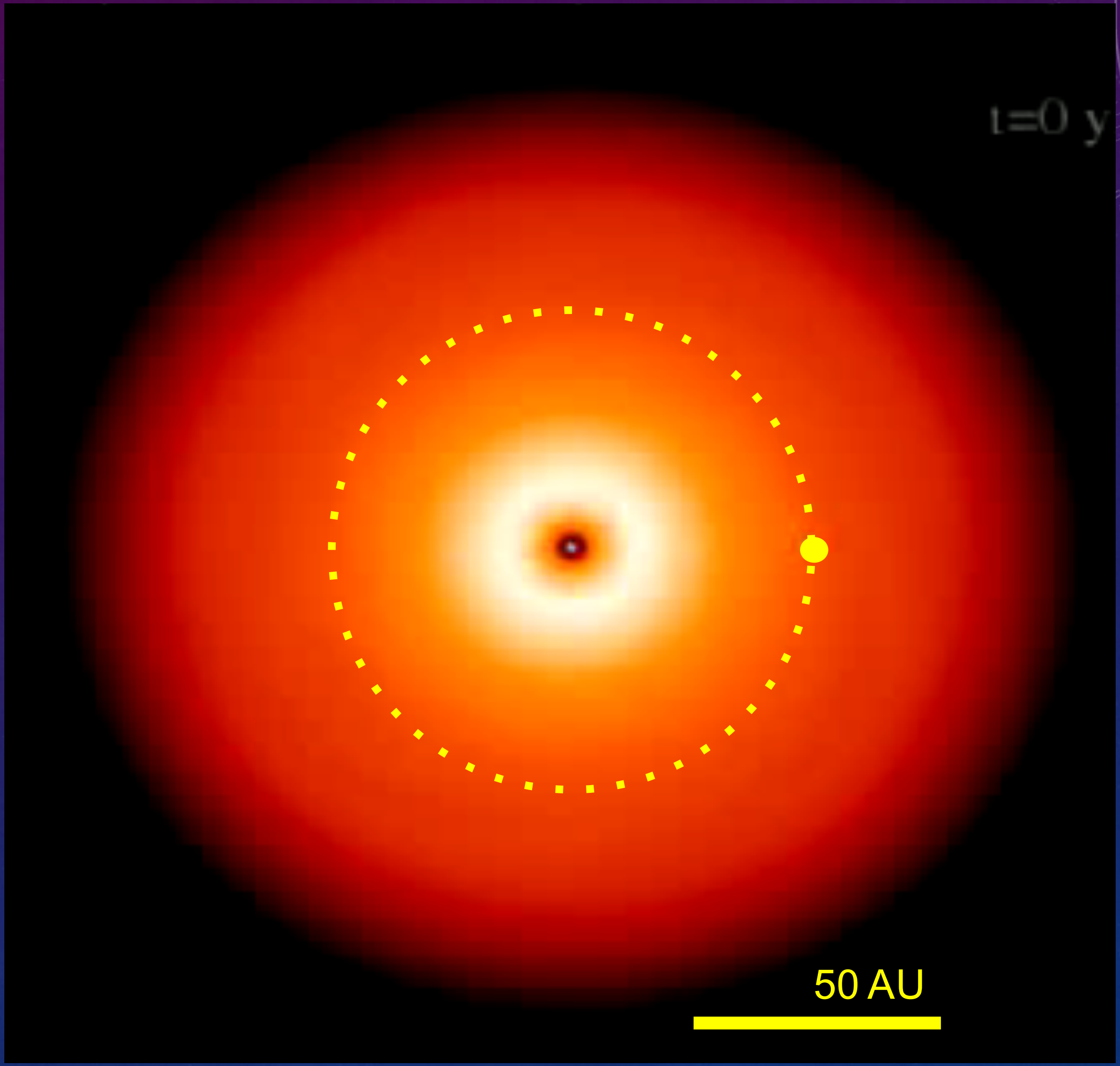
$$\frac{v_{\phi,\mathrm{gas}}^2}{r} = \frac{GM_*}{r^2} + \frac{1}{\rho}\frac{\mathrm{d}P}{\mathrm{d}r}$$

- For T Tauri star discs: $\upsilon_{gas} \sim 0.996 \upsilon_{Keplerian}$
- For early-phase discs: $\upsilon_{gas} \sim 0.9 \upsilon_{Keplerian}$
- Estimated disc mass $M_{disc} \sim \upsilon_{gas}^2$ → Disc mass is underestimated by 20% if the Keplerian velocity is used

SIGNATURES OF PLANETS FORMING IN EARLY-PHASE DISCS

$M_{disc}=0.1M_{\odot}$

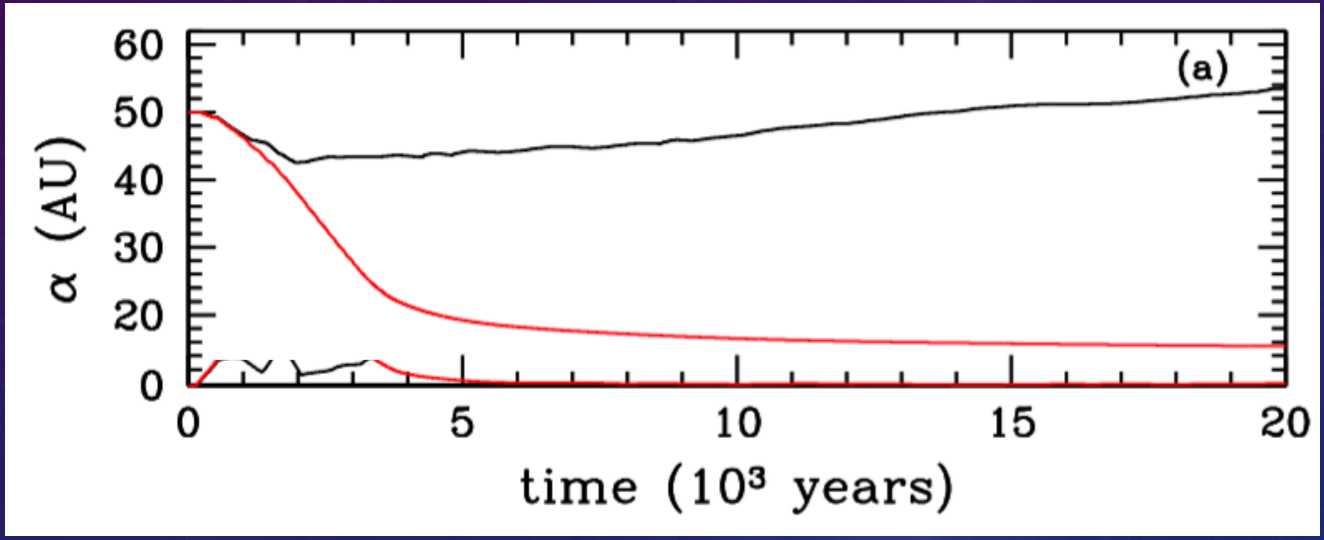
$M_{planet}=1M_J$

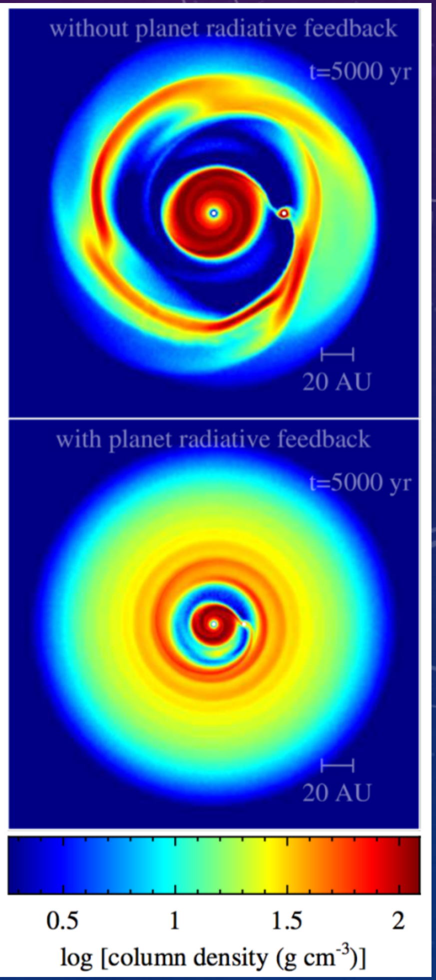


Stamatellos, 2015, ApJL; Stamatellos & Inutsuka, 2017, submitted

SIGNATURES OF PLANETS FORMING IN EARLY-PHASE DISCS

- Could the planet avoid rapid inward migration (e.g. Baruteau et al. 2011, Michael et al. 2011)?
- Could the planet avoid rapid mass growth (e.g. Stamatellos & Whitworth, 2009, Kratter et al. 2010)?

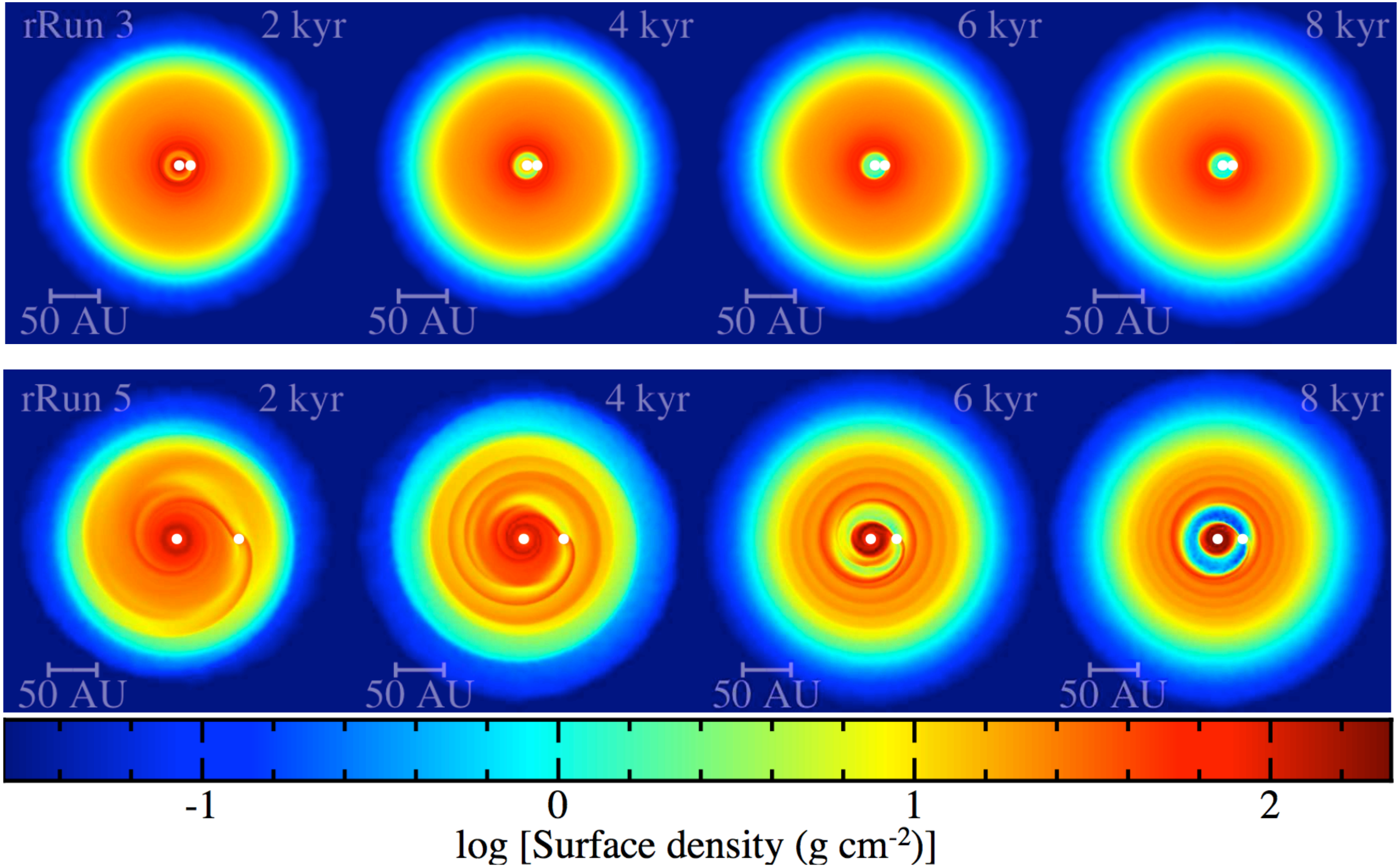




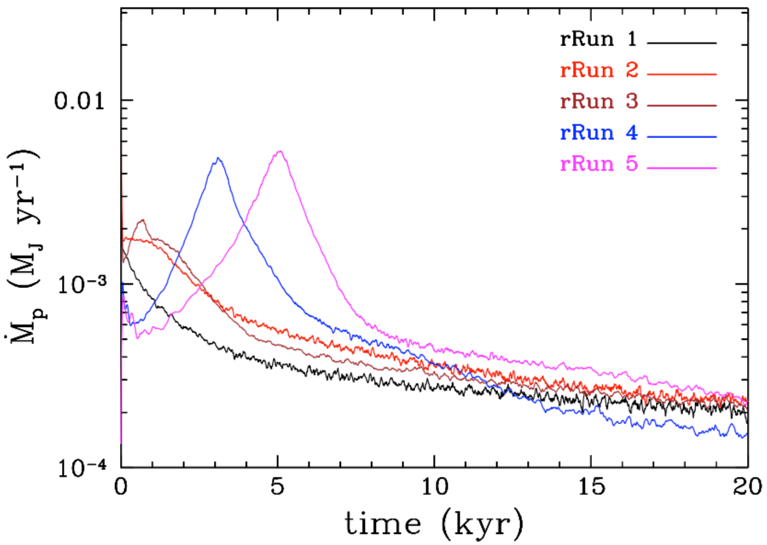
- The planet can open up a gap to avoid migration.
- Radiative feedback from the planet (due to gas accretion) may limit mass growth.

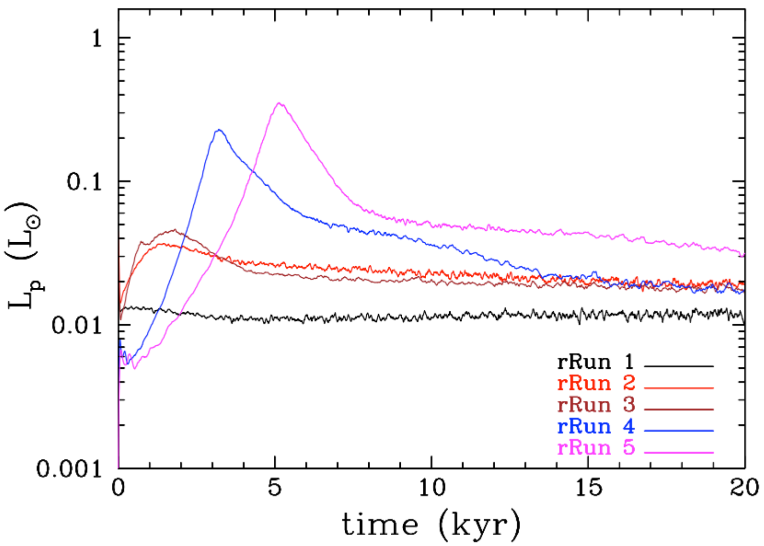
Stamatellos, 2015, ApJL; Stamatellos & Inutsuka, 2017, submitted

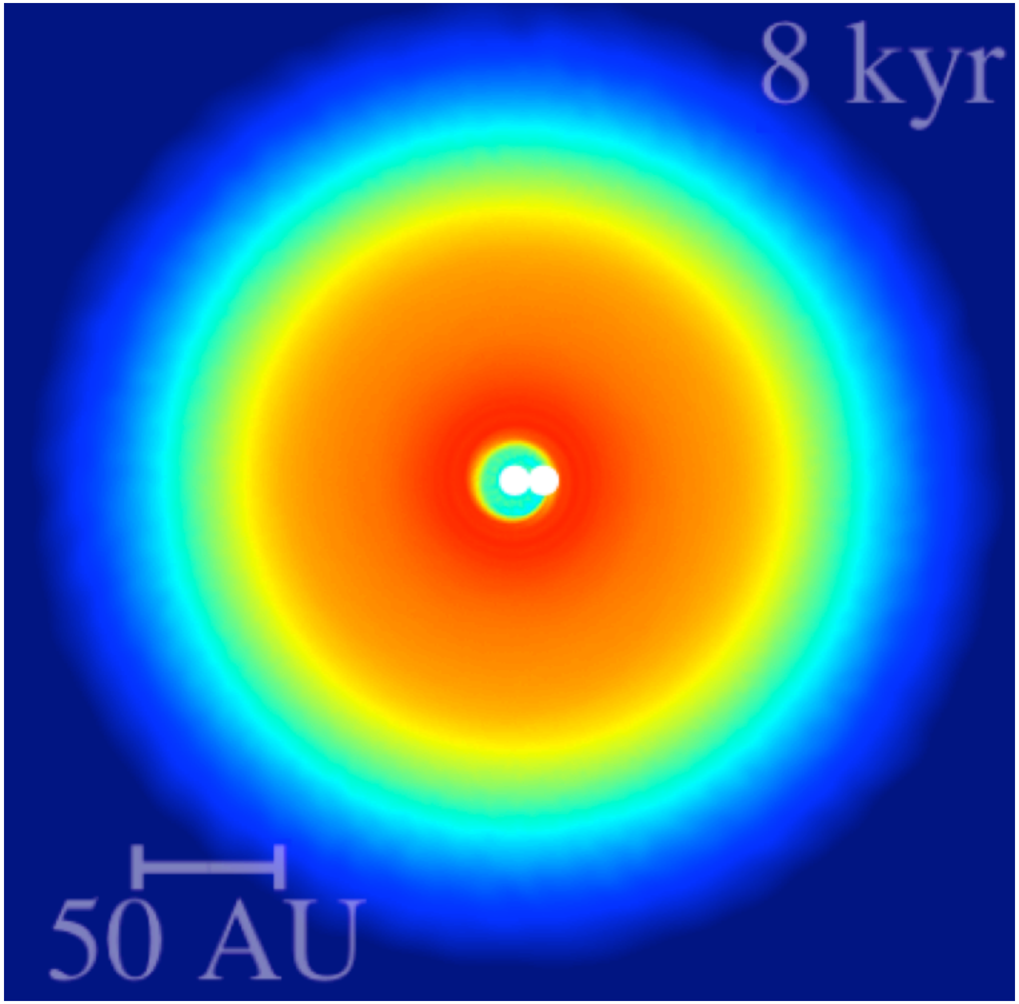
SIGNATURES OF PLANETS FORMING IN EARLY-PHASE DISCS



PLANETS CAN BE QUITE LUMINOUS IF THEY FORM EARLY

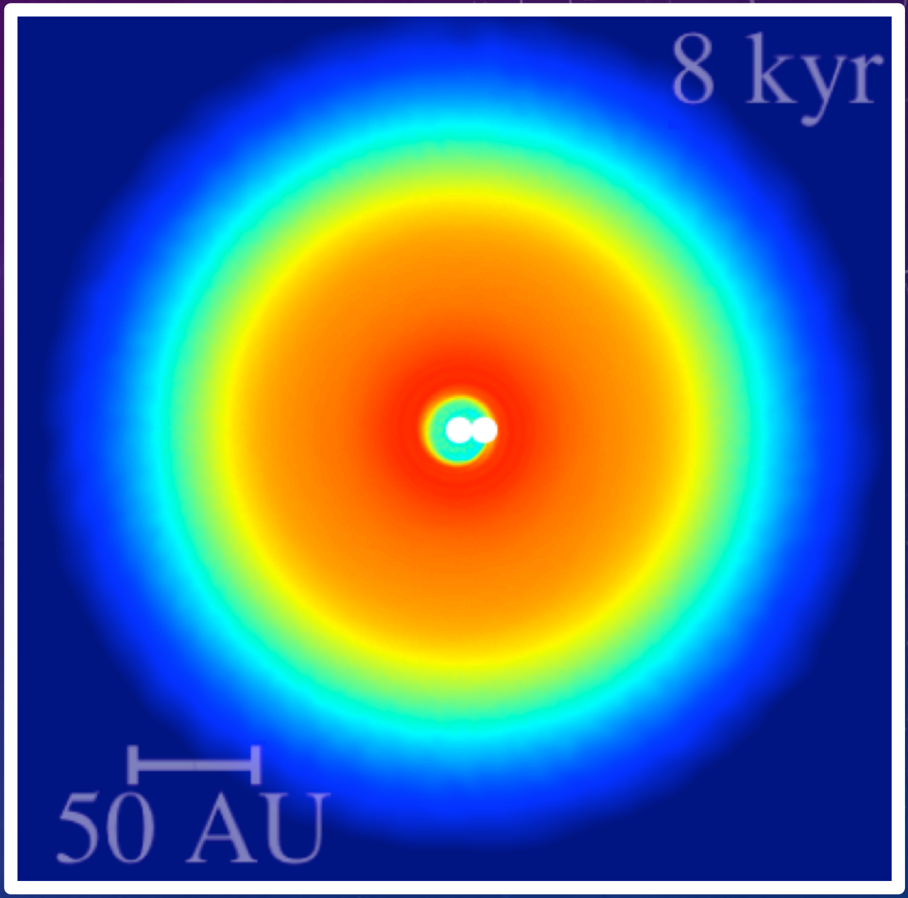






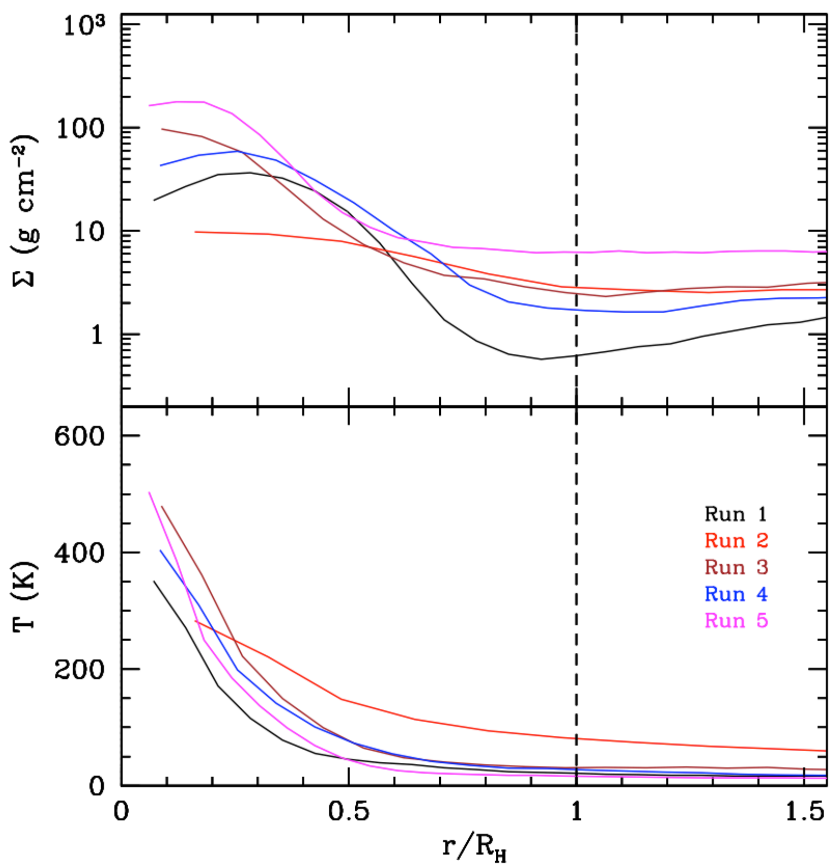
TRANSITION DISCS?

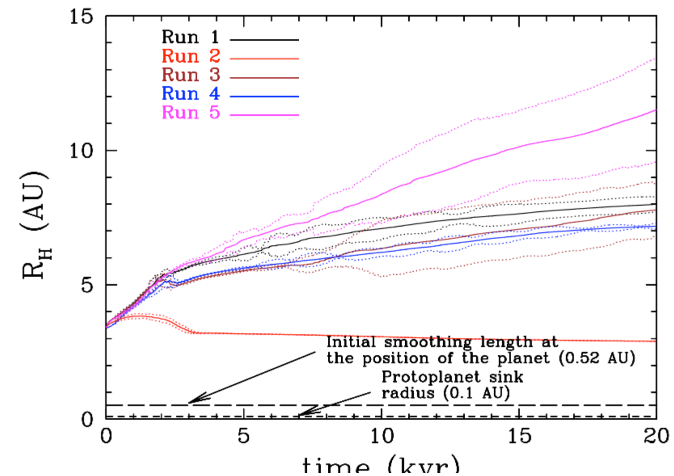
- Duration of high-luminosity phase for a young planet $\sim 10^4$ yr
- Lifetime of transition discs $\sim 10^6$yr
- Only up to 1/100 transitions discs may host a luminous young planet

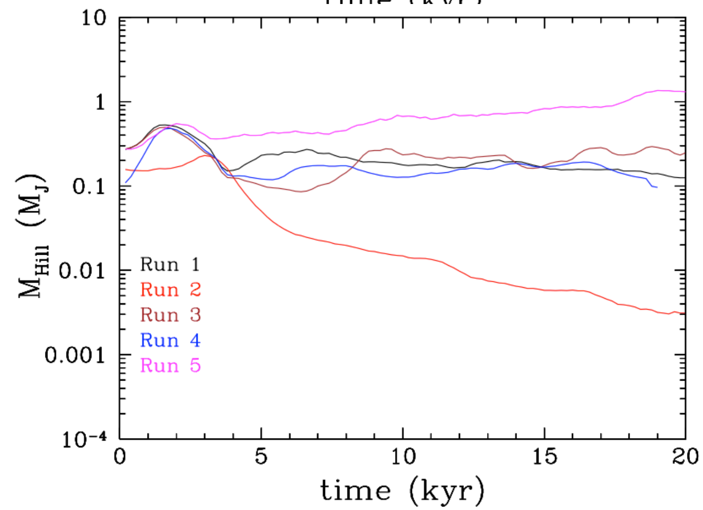


OBSERVABITY OF CIRCUMPLANETARY DISCS

PLANET RADIATIVE FEEDBACK AND DISTANCE FROM CENTRAL STAR MAKE THIS EASIER







CONCLUSIONS

- **Early-phase discs set the initial conditions for planet formation**
- Disc density and temperature profiles depend on the type of stellar feedback
- Position-velocity diagrams may provide significant information about the disc properties when disc is not obersved phase-on
- Planets that form in early-phase discs could be quite luminous and their circumplanetary discs are large if the are on wide orbits around their host star
- **How can these be observed with ALMA (radiative transfer simulations in progress…)**