Michela Mapelli
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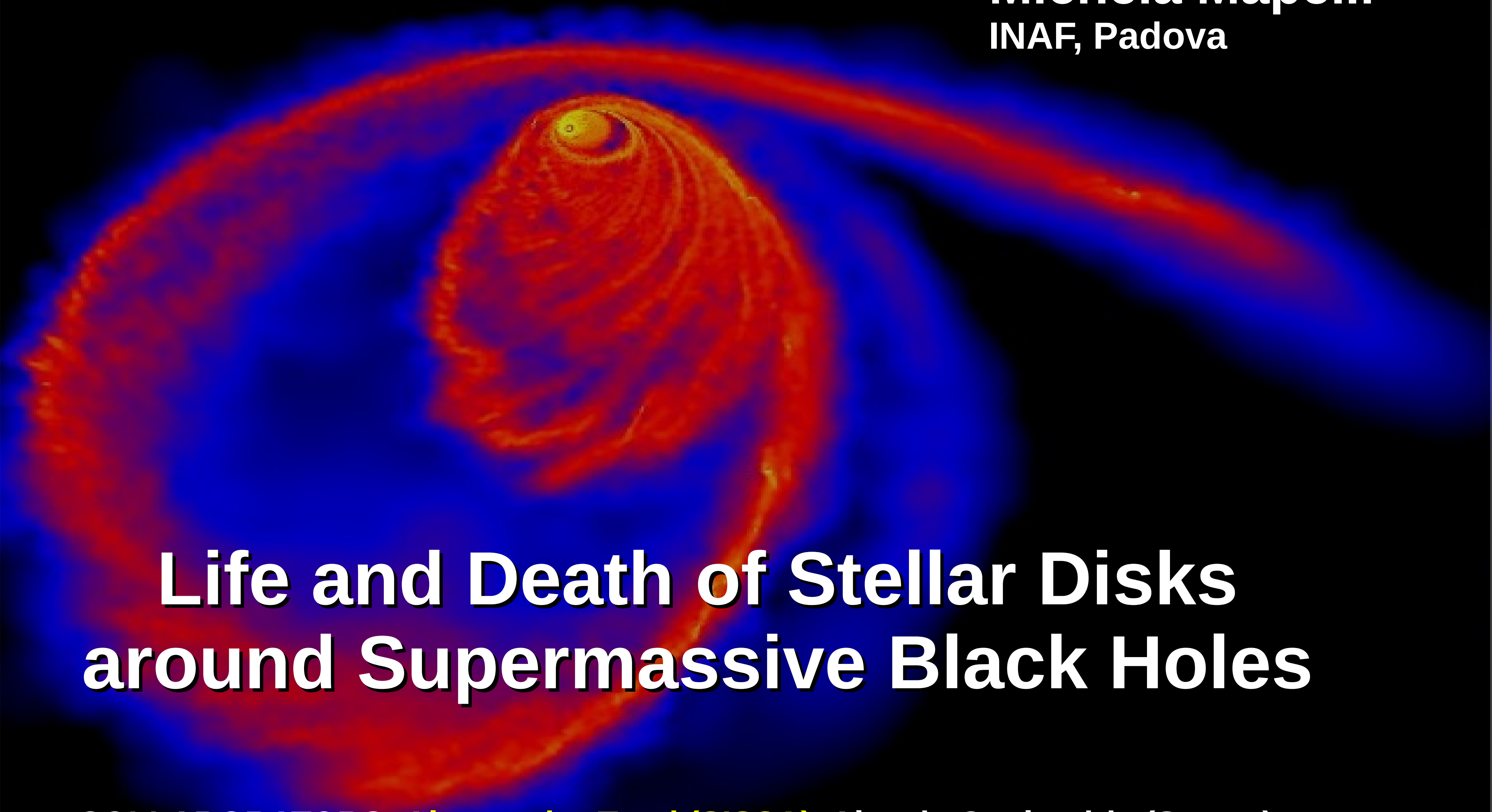

Life and Death of Stellar Disks around Supermassive Black Holes

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Black holes in dense star clusters, Aspen Center for Physics, January 17-22 2015

OUTLINE

1. Introduction: what do we observe in the Galactic center?

2. Tidal disruption of molecular clouds by SMBHs: the formation of a stellar disk

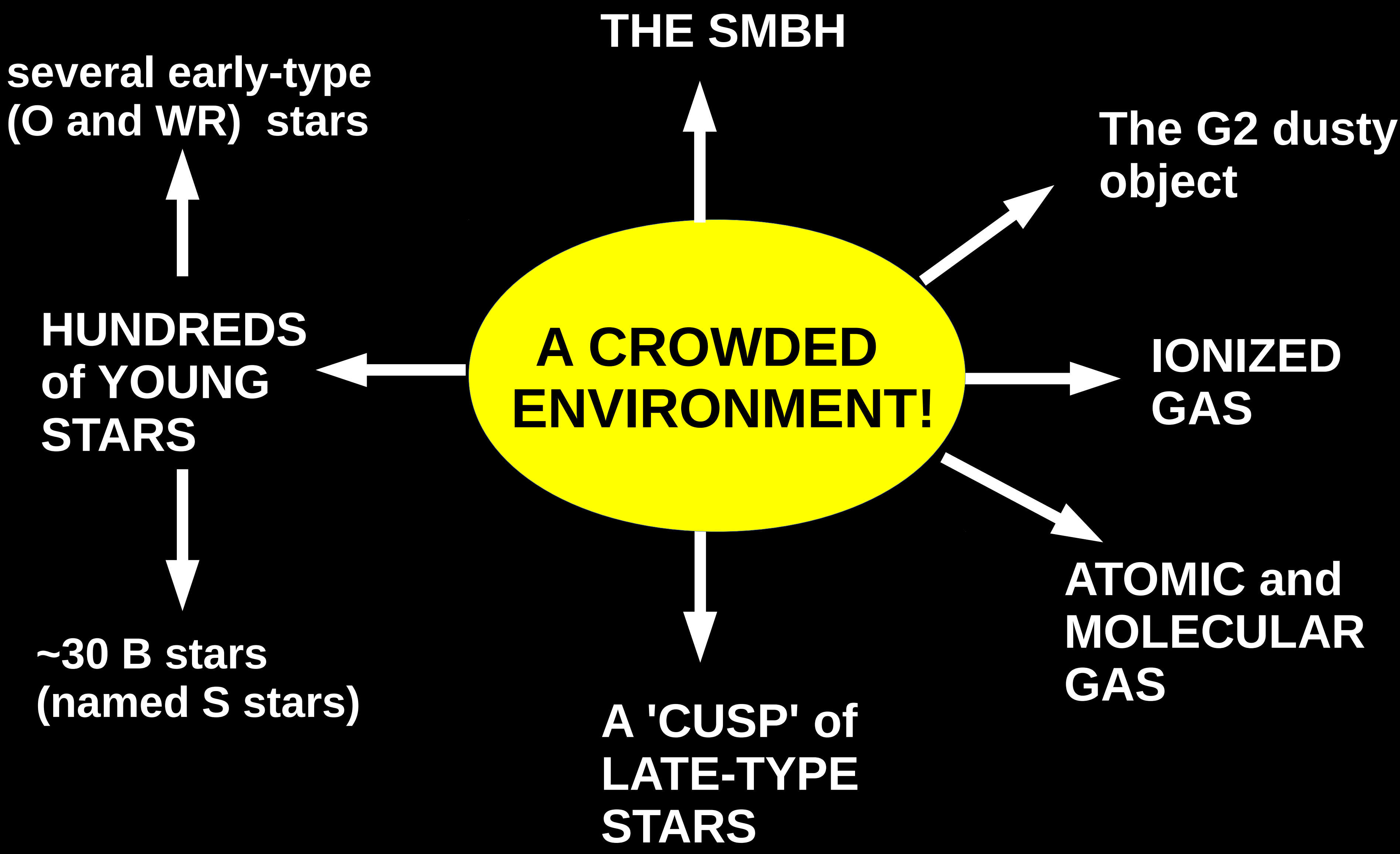
3. Dismembering the stellar disc through precession

4. The role of the circumnuclear ring

5. Planets in the Galactic center??

6. Conclusions

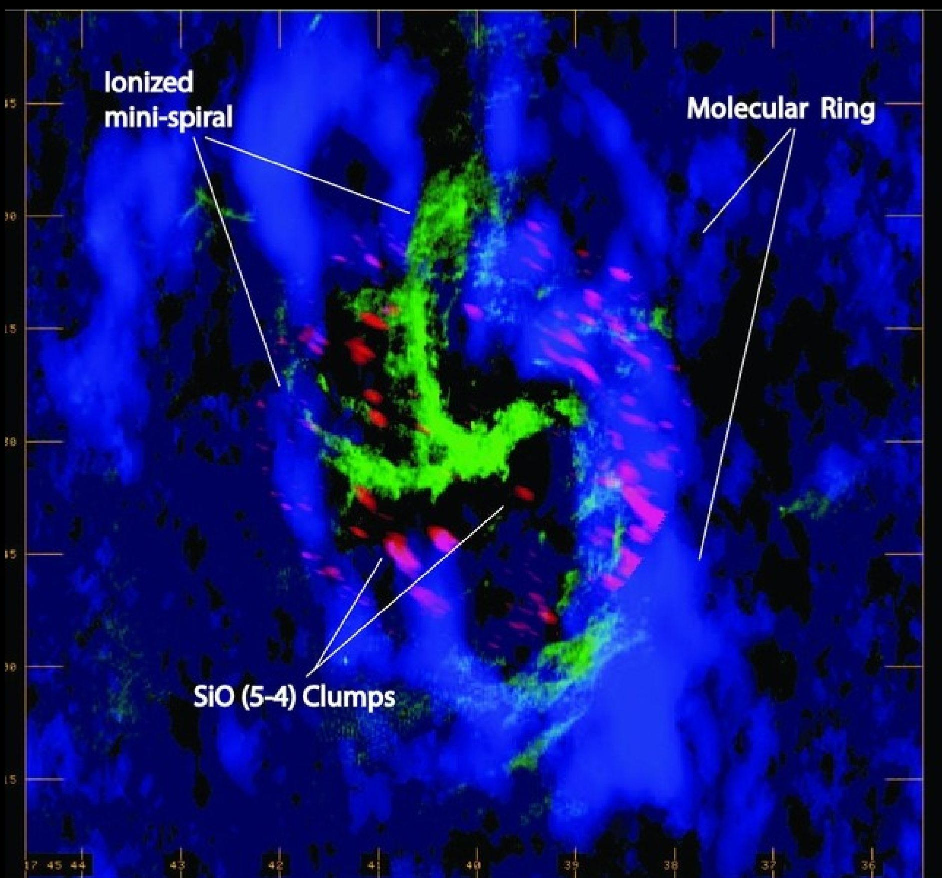
1. What do we observe in the Galactic centre?



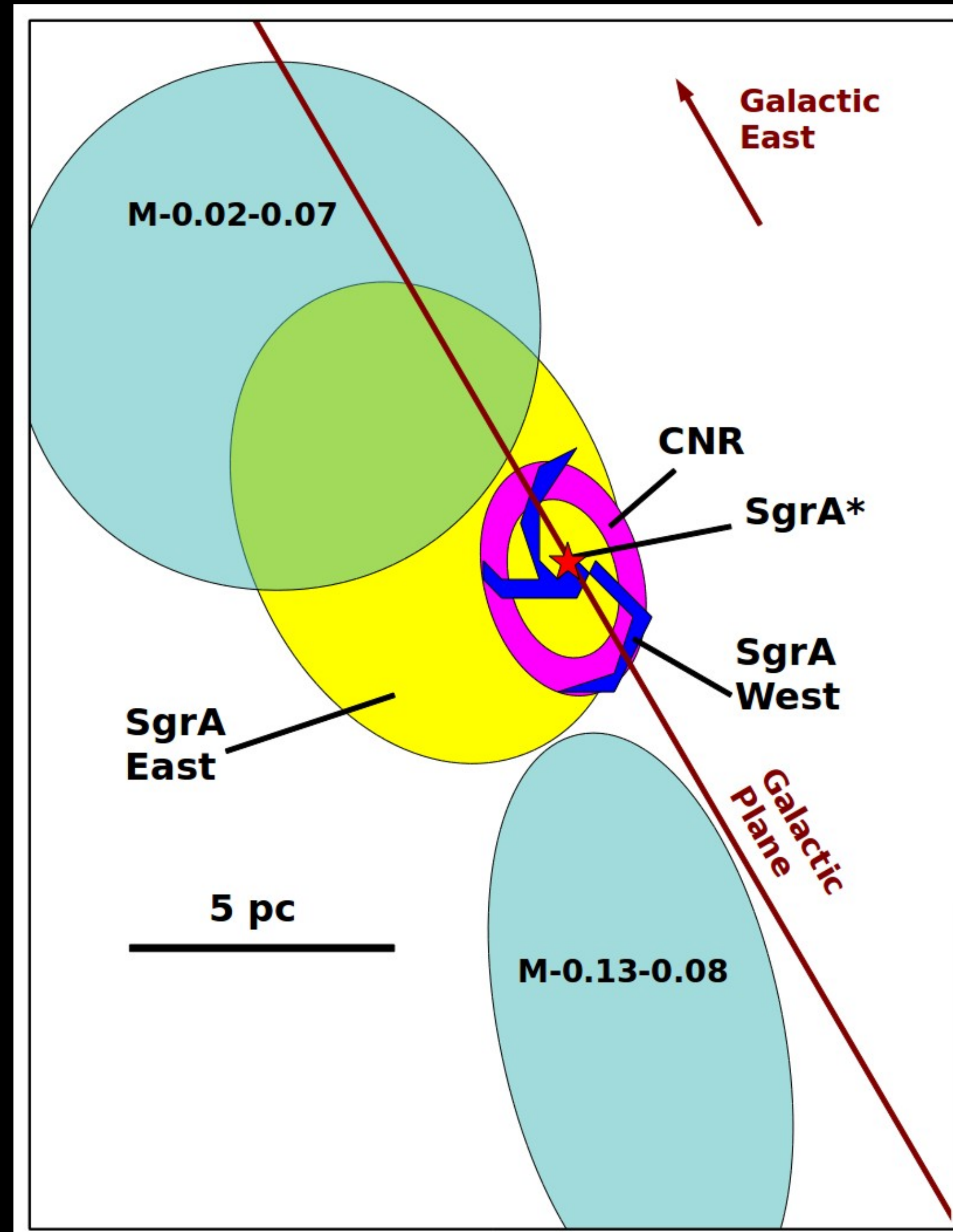
1. What do we observe in the Galactic centre?

IONIZED GAS
- SgrA East (non-thermal shell)
- SgrA West (thermal spiral)

MOLECULAR GAS
- circumnuclear ring
- young star outflows
- two giant molecular clouds



Yusef-Zadeh et al. 2013 ,ALMA Cycle0



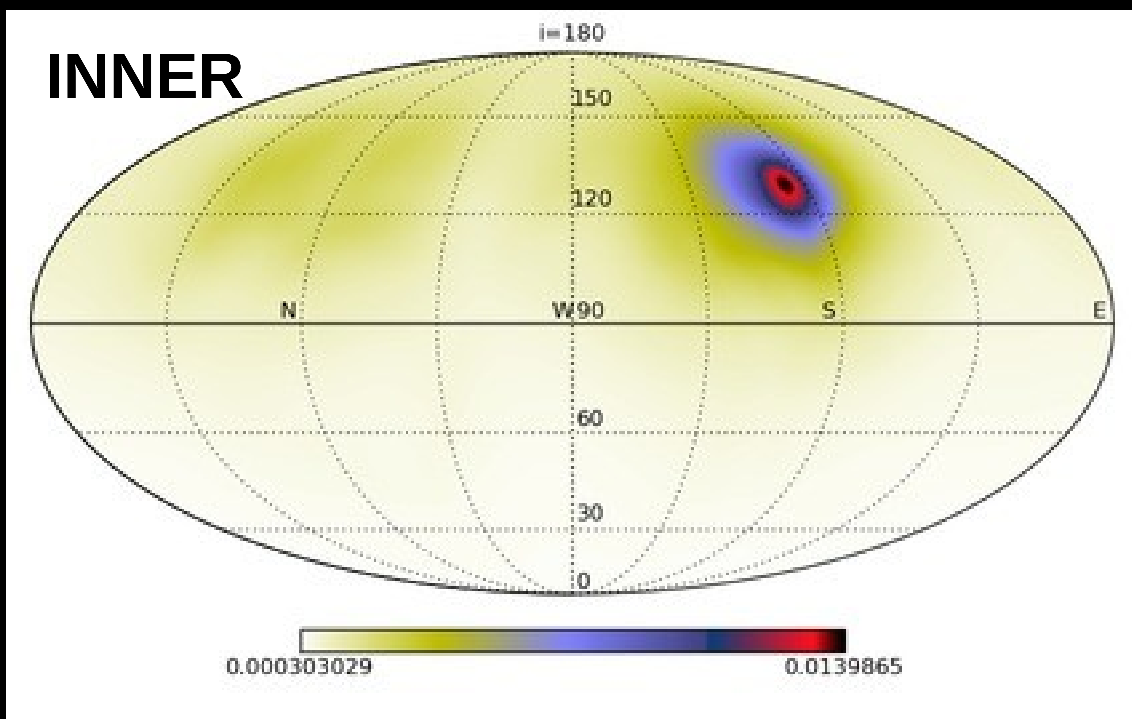
MM & Gualandris 2015, review on 'SF and dynamics in the Galactic center'

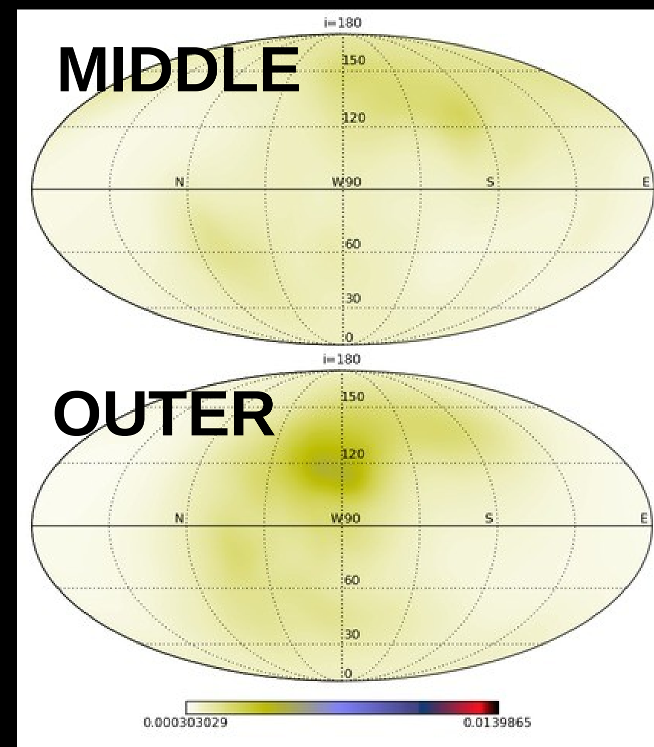
YOUNG STARS

The early-type stars in the central pc: O and WR stars, age~ 2-6 Myr

One or two discs?

- **20% stars in CW disc (a~0.04-0.13 pc, e~0.3, THIN, not warped)**
- **NO counter-CW disc**
- **80% ET STARS (r<1 pc) DO NOT LIE IN DISC**





Yelda et al. 2014

HOW DID THE EARLY-TYPE STARS FORMED?

A molecular cloud is disrupted by the tidal field exerted by the SMBH if its density is lower than the Roche density

$$n_{\rm RL} \sim 10^7\,{\rm cm}^{-3}\,\left(\frac{m_{\rm BH}}{3\times10^6\,M_\odot}\right)\,\left(\frac{\rm pc}{r}\right)^3$$

Typical cloud density < 10^6 cm^{-3}

The stars cannot form in 'normal conditions' if the cloud is disrupted (Phinney 1989).

Molecular cloud disruption:

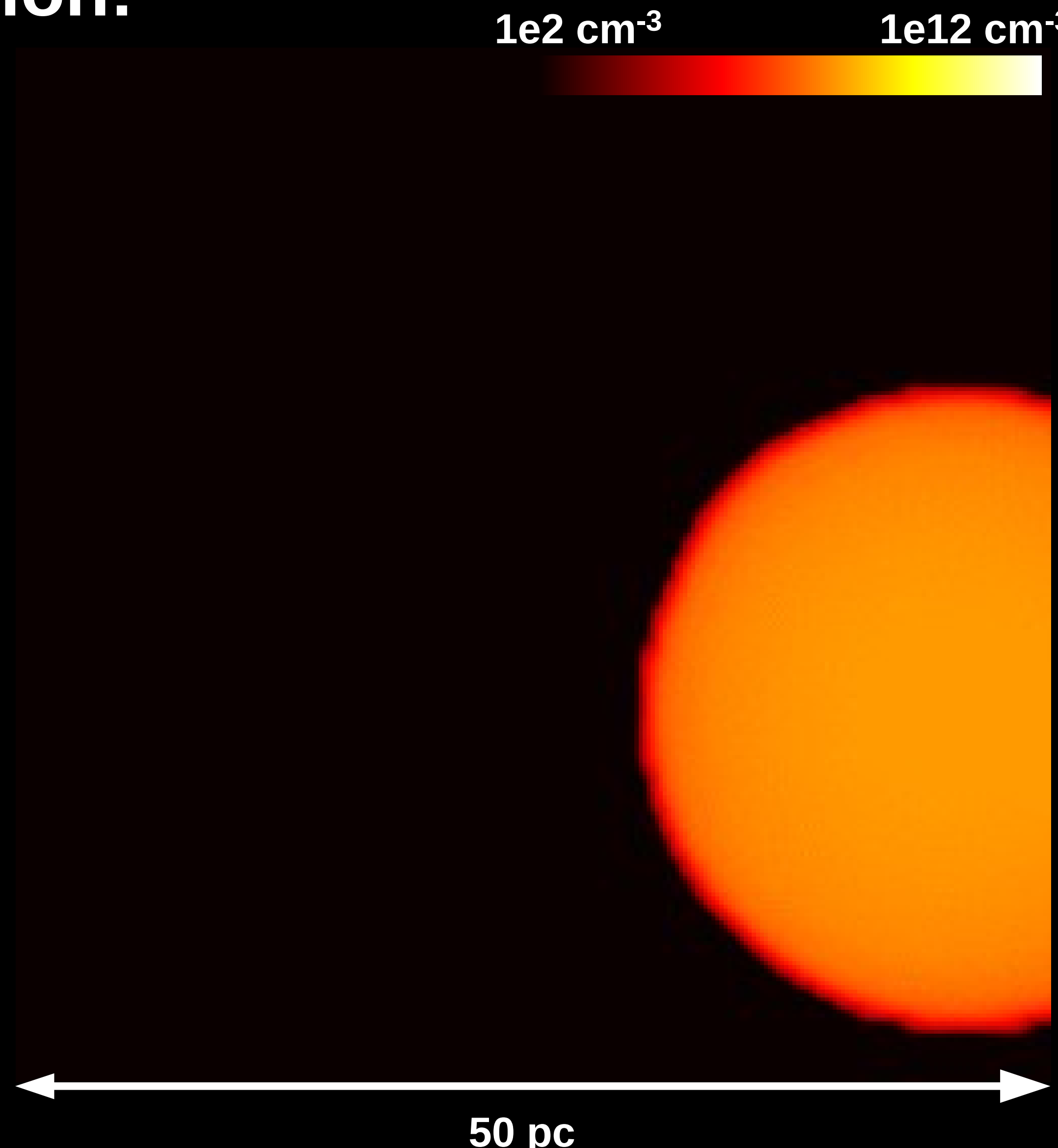
A molecular cloud is disrupted by the SMBH, but

- the residual angular momentum,
- the shocks that take place in gas streams

might lead to the formation of

a DENSE DISC,

denser than Roche density



Bonnell & Rice 2008; MM et al. 2008; Hobbs & Nayakshin 2009; Alig et al. 2011; MM et al. 2012; Alig et al. 2013; Lucas et al. 2013

2. Tidal disruption of molecular clouds by SMBHs: the formation of a stellar disk

Stars can form in a gas disc, born from the disruption of a molecular cloud

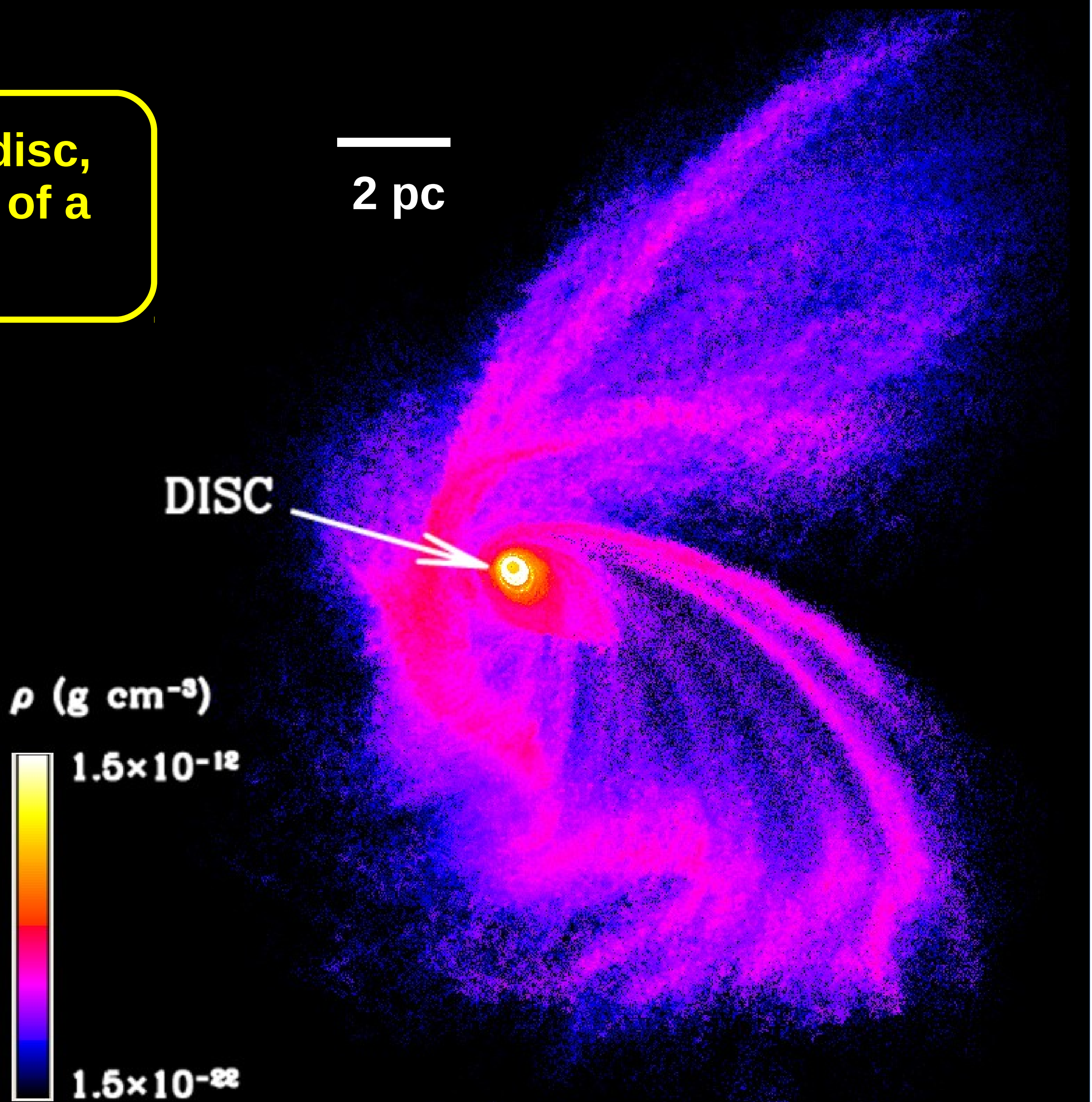
INGREDIENTS:

* A turbulent molecular cloud r~15 pc, M~10^5 M⊙

* a SMBH sink particle

* integration with OSPH
(Read et al. 2010)

* cooling + Planck & Ross. opacities
(Boley 2009, 2010)



MM et al. 2012; Gualandris, MM & Perets 2012

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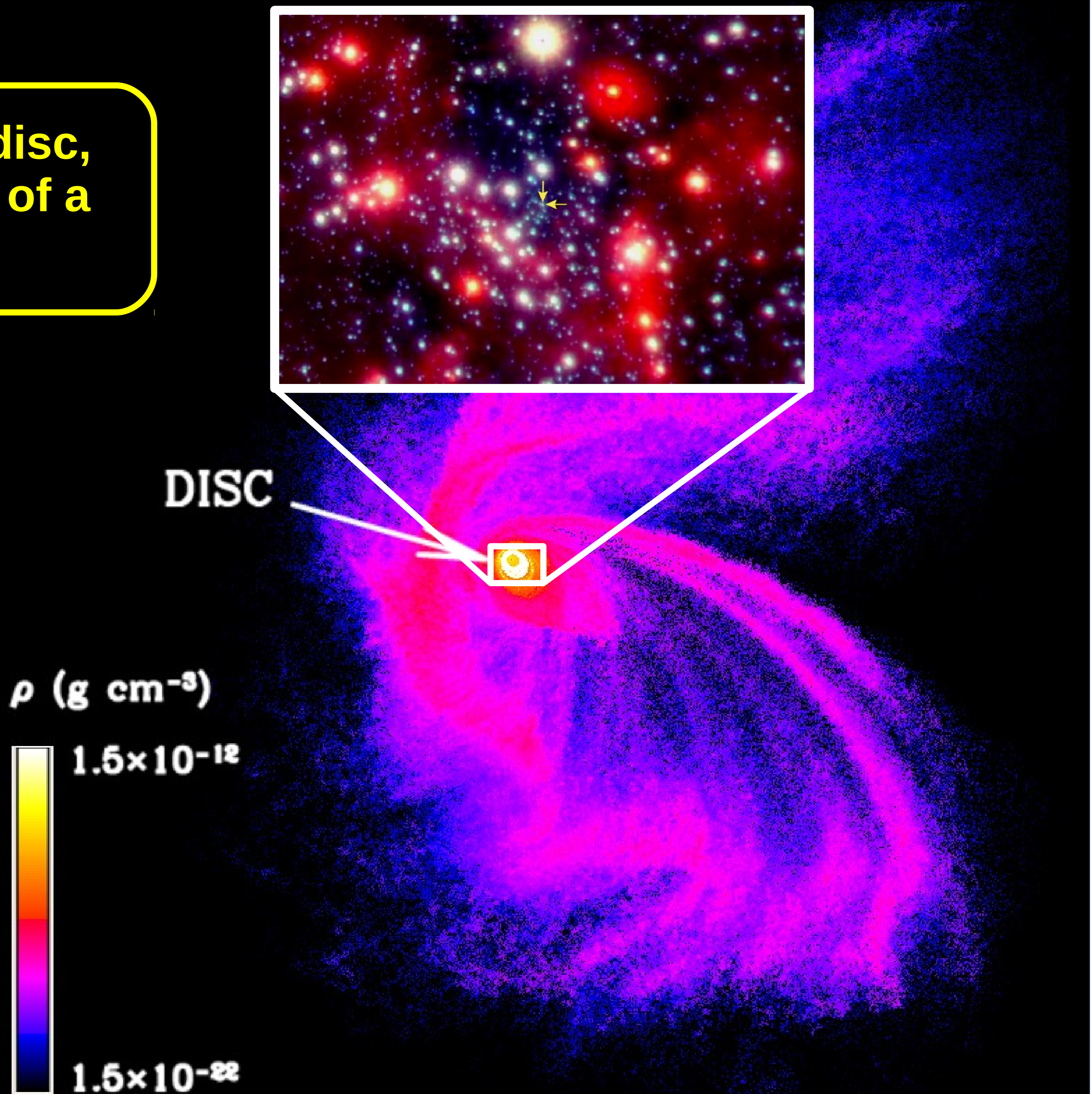

MM et al. 2012; Gualandris, MM & Perets 2012

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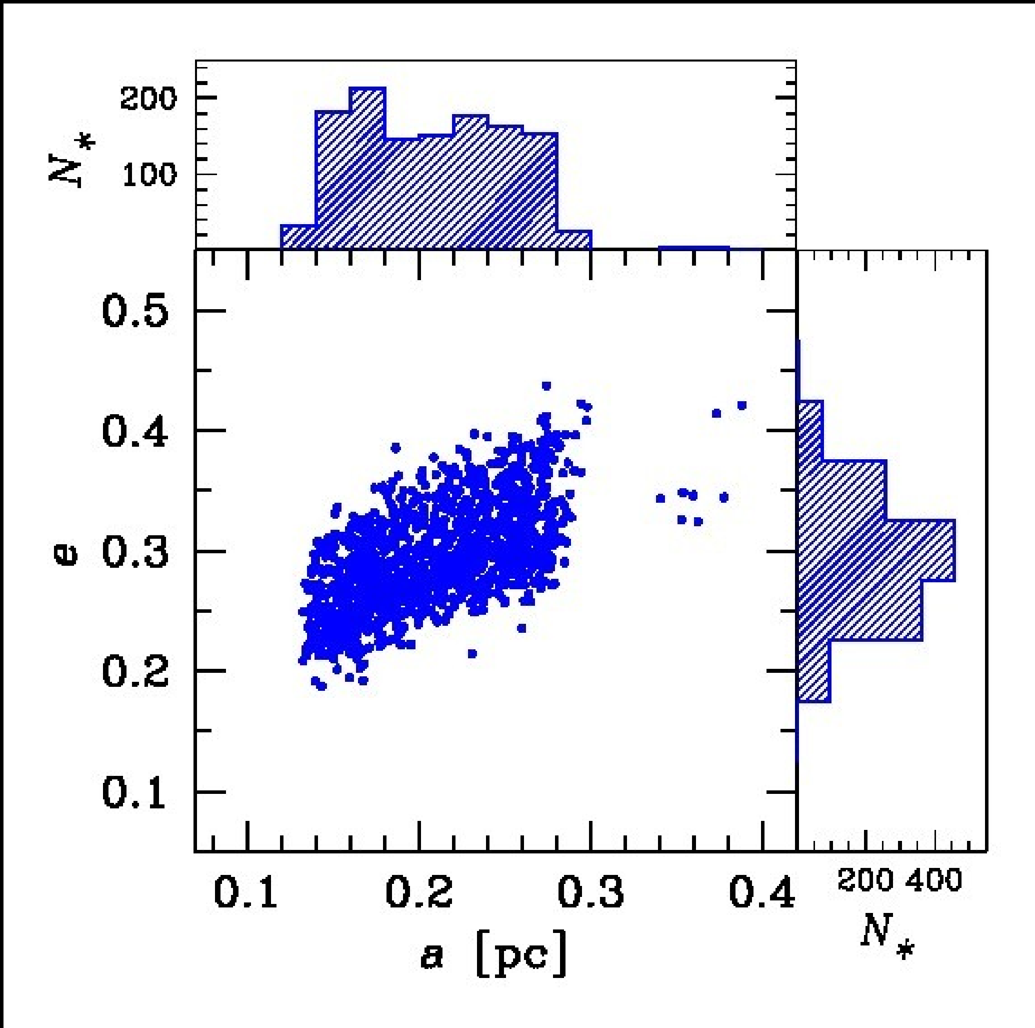
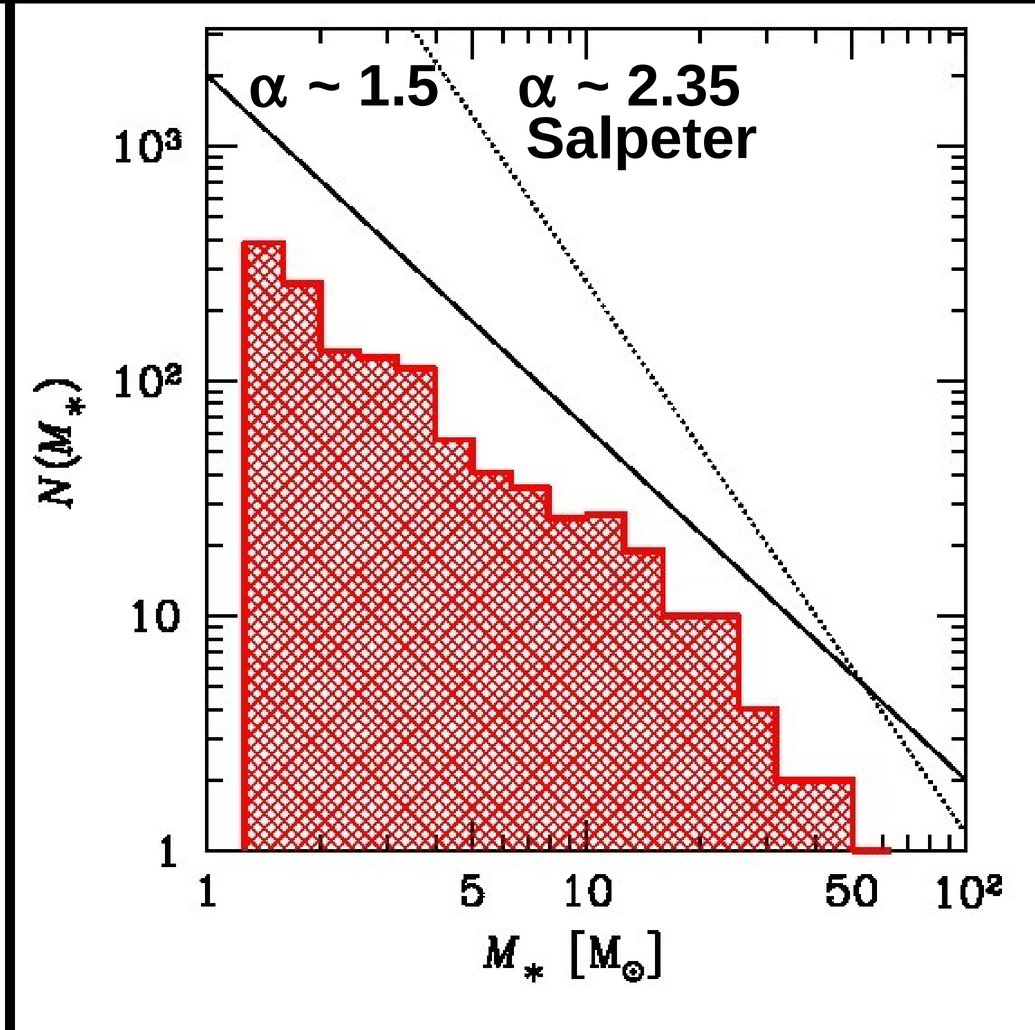




Av. ecc.~ 0.3 in agreement with observations (Yelda et al. 2014)

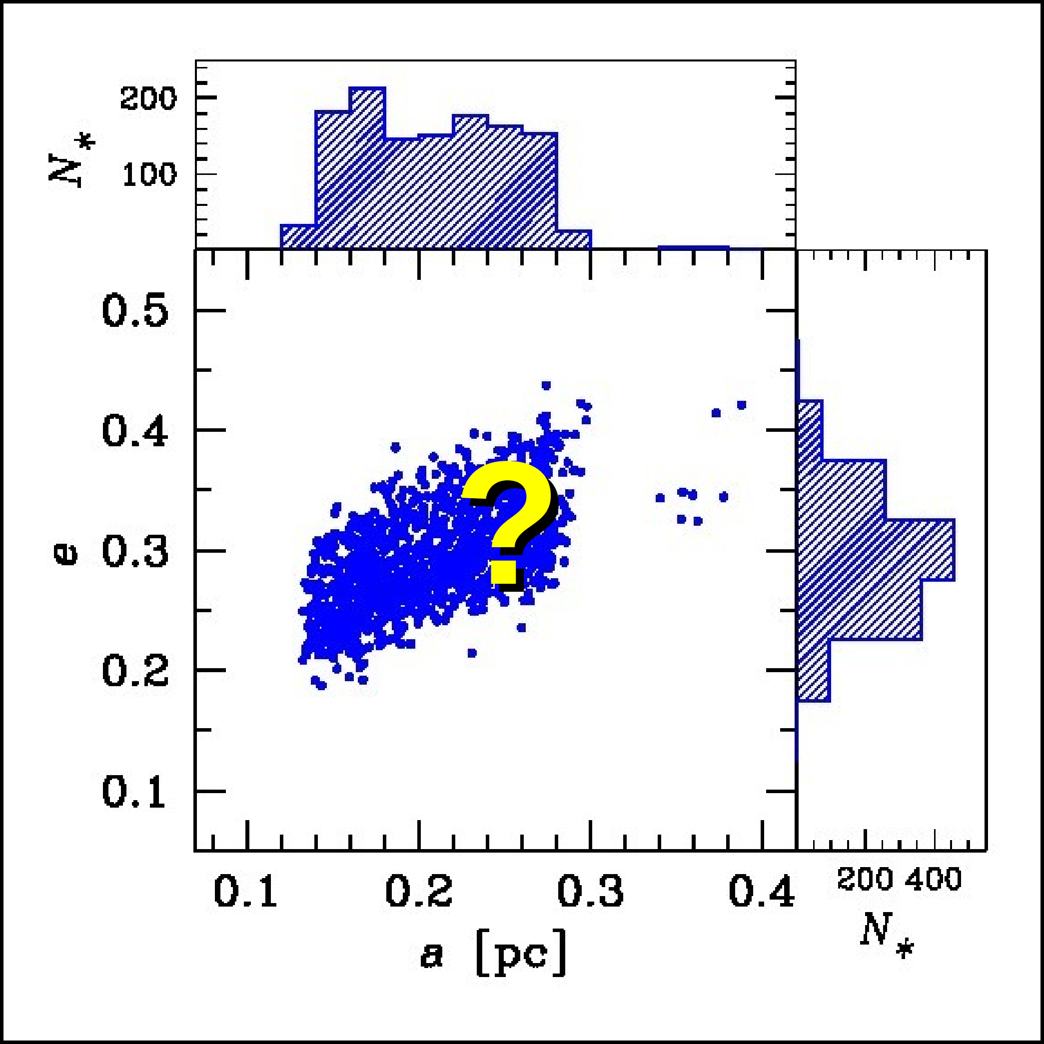
Semi-major axis<~ 0.4 pc in agreement with old obs. (Bartko et al. 2009; Lu et al. 2009), not with new obs. (Yelda et al. 2014)

Best fitting slope: α ~ 1.5 +/- 0.1

Best fitting obs. Slope: α ~ 1.7 +/- 0.2 (Lu et al. 2013)

MM et al. 2012

2. Tidal disruption of molecular clouds by SMBHs: the formation of a stellar disk



PROBLEM!!!

MATCHES ONLY CW DISC (20% stars)

NOT THE OTHER STARS!!!

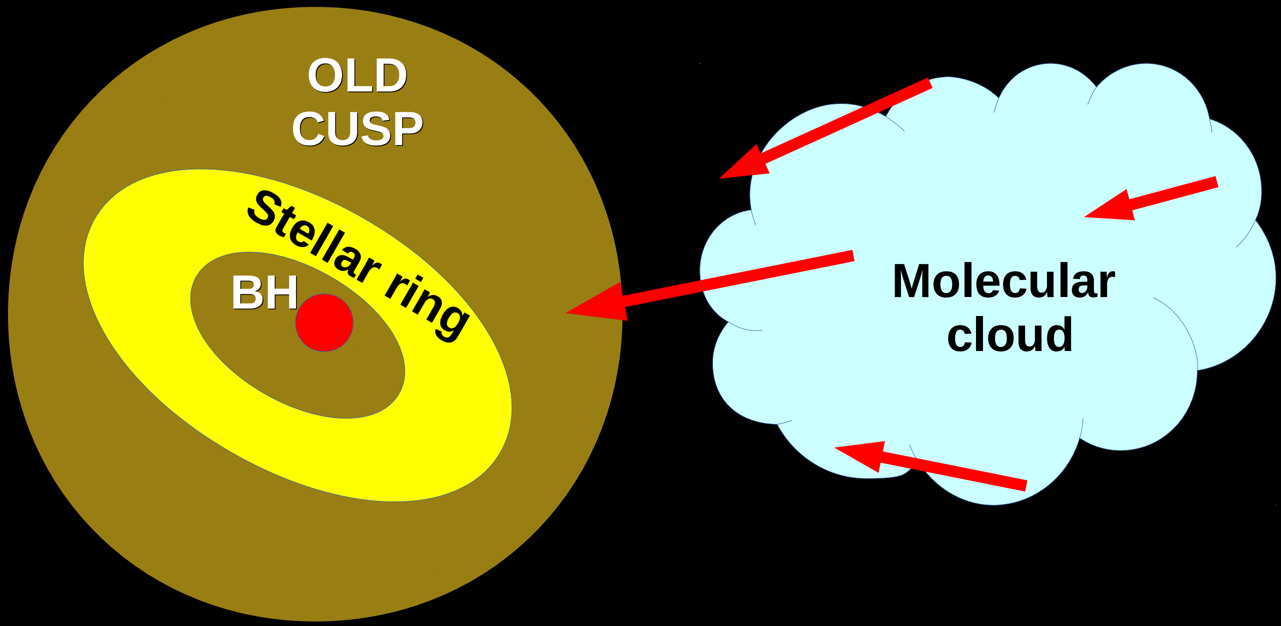
BUT THE STARS EVOLVE VIA DYNAMICAL PROCESSES

ARE DYNAMICAL PROCESSES SUFFICIENT TO EXPLAIN CURRENT PROPERTIES OF STARS IN THE GALACTIC CENTRE?

→ **WE FOCUS ON NEWTONIAN PRECESSION**

WHICH ARE THE MAIN EFFECTS OF NEWTONIAN PRECESSION IN OUR GALACTIC CENTRE?

We simulate the infall of a second molecular cloud and study the precession exerted onto the stellar disc



STELLAR DISC: formed from previous simulation of molecular cloud disruption (MM+ 2012)

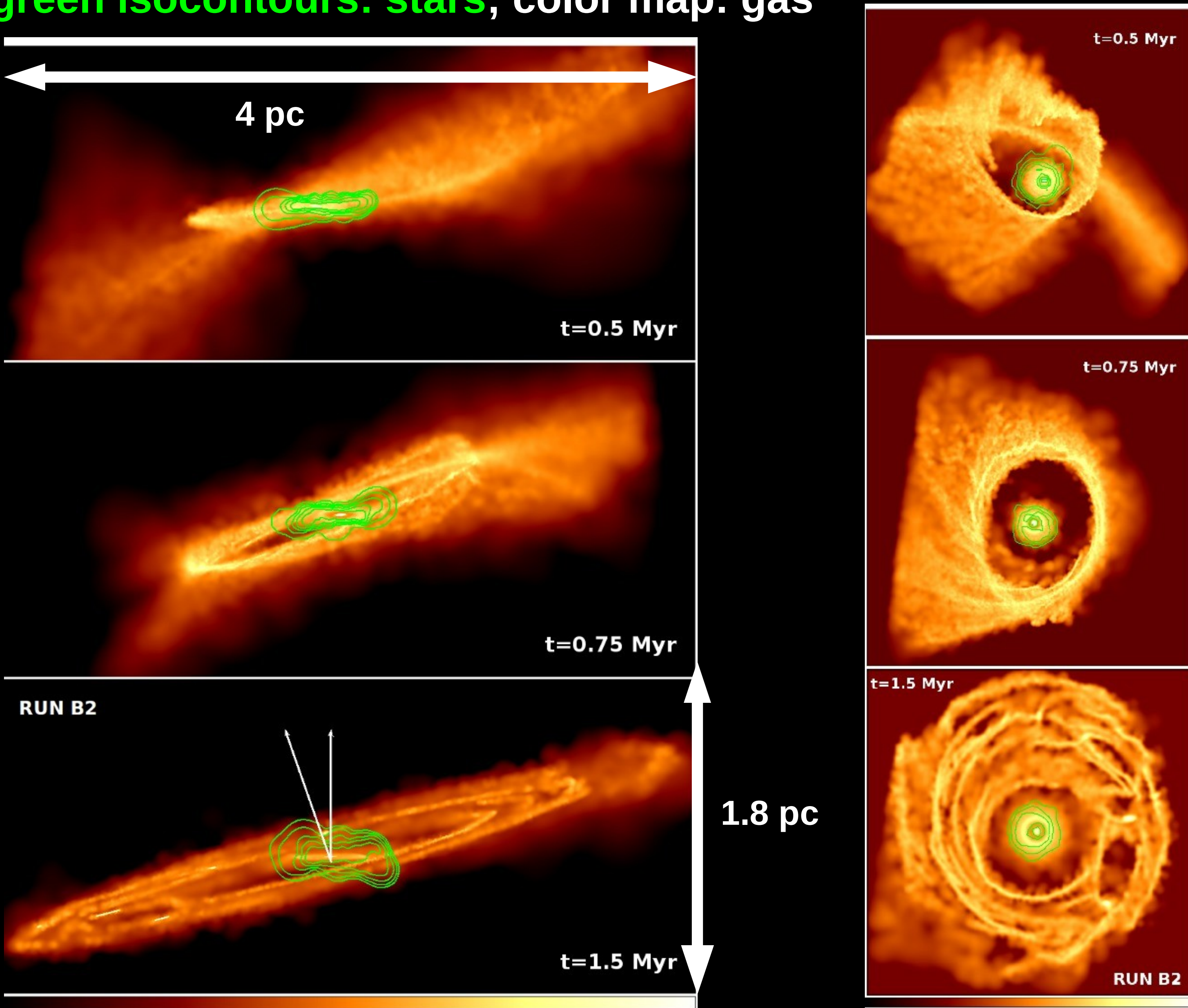
SECOND MOLECULAR CLOUD: turbulence supported

BH: sink

OLD CUSP: rigid potential

3. Dismembering the stellar disc through precession

green isocontours: stars; color map: gas

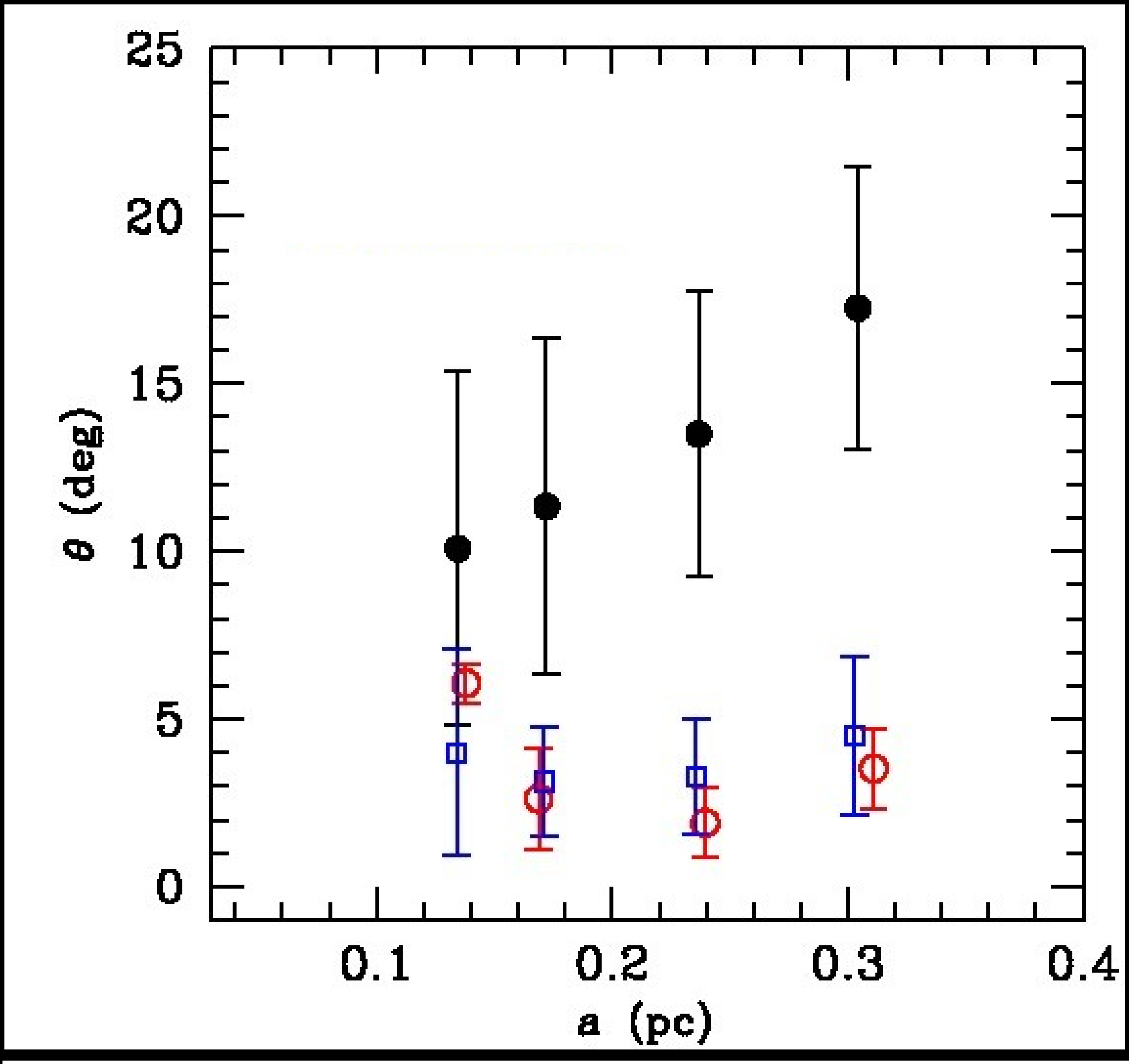


MM et al. 2013

3. Dismembering the stellar disc through precession

DISTRIBUTION OF INCLINATION of stellar orbits

(with respect to initial angular momentum vector)



Change of inclination depends on semi-major axis

Red: initial conditions

Blue: run with no gas t=1.5 Myr

Black: run with gas perturber, t=1.5 Myr

MM, Gualandris & Hayfield 2013

3. Dismembering the stellar disc through precession

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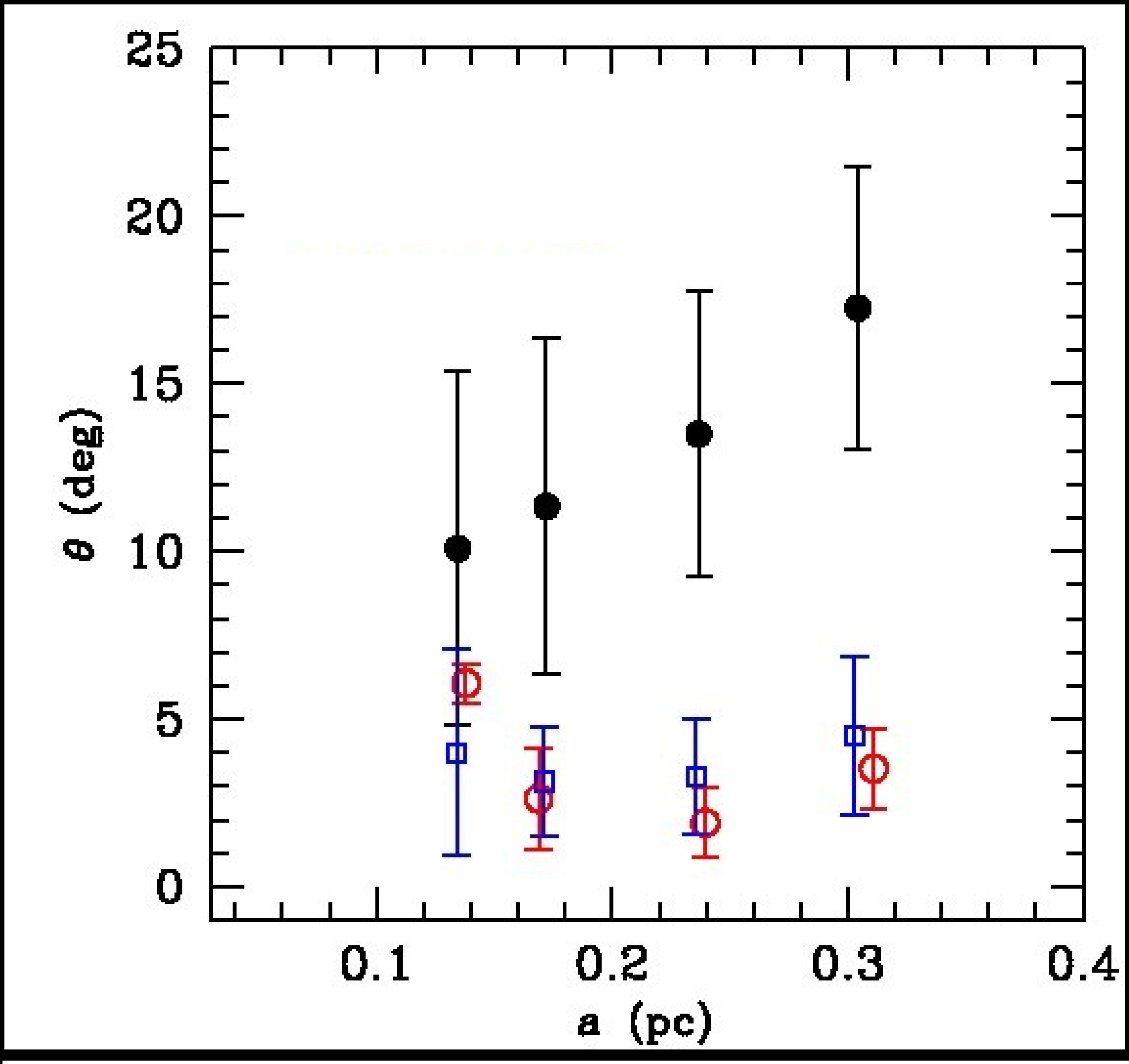


Red: initial conditions
Blue: run with no gas t=1.5 Myr
Black: run with gas perturber, t=1.5 Myr

Change of inclination depends on semi-major axis **because of precession**

→precession time scale

$$T \propto a^{-3/2}$$

→ star on outer orbits precess FASTER

THE DISK IS ABOUT TO BE DISMEMBERED

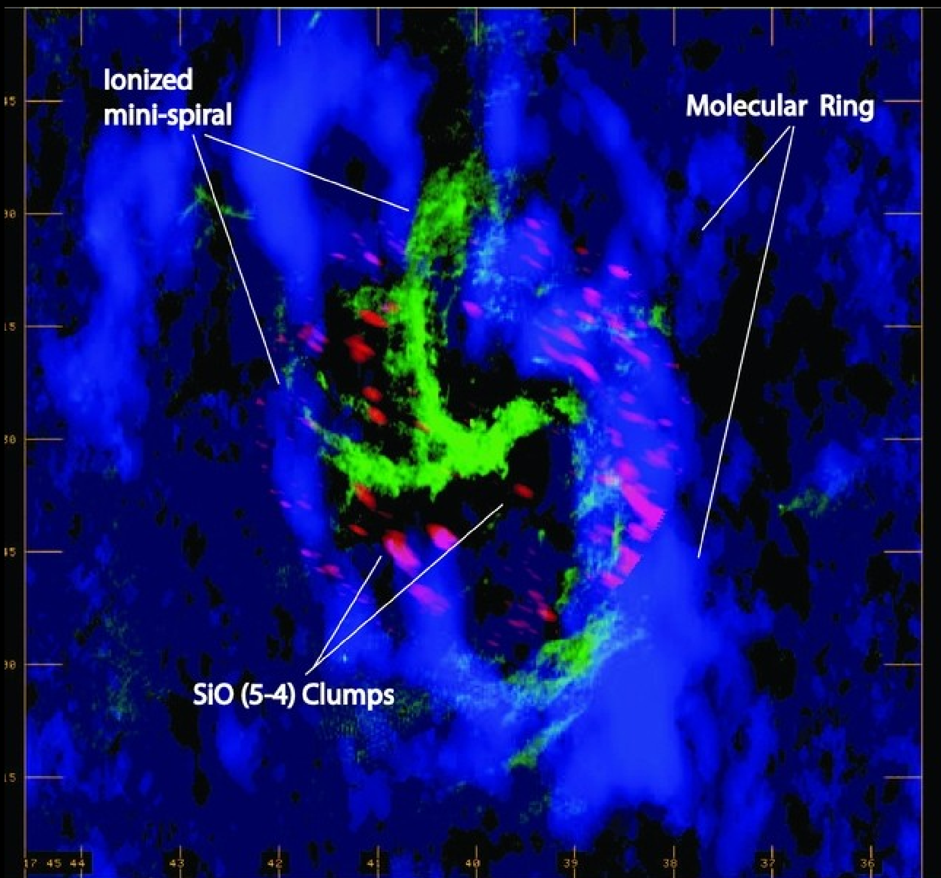
Can this explain the stars that do not lie in the CW disk?

It is very promising!

MM, Gualandris & Hayfield 2013

4. The role of the circumnuclear ring

But how realistic is that a 2nd cloud is disrupted by SMBH in <6 Myr?

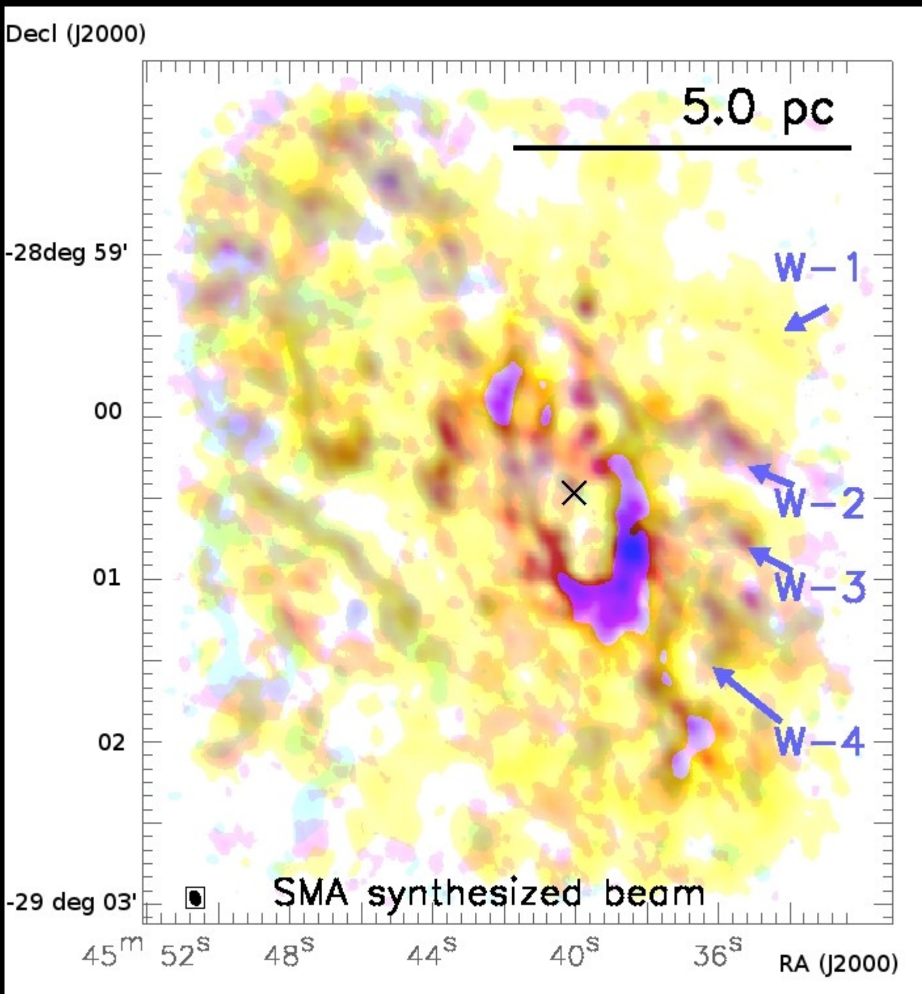


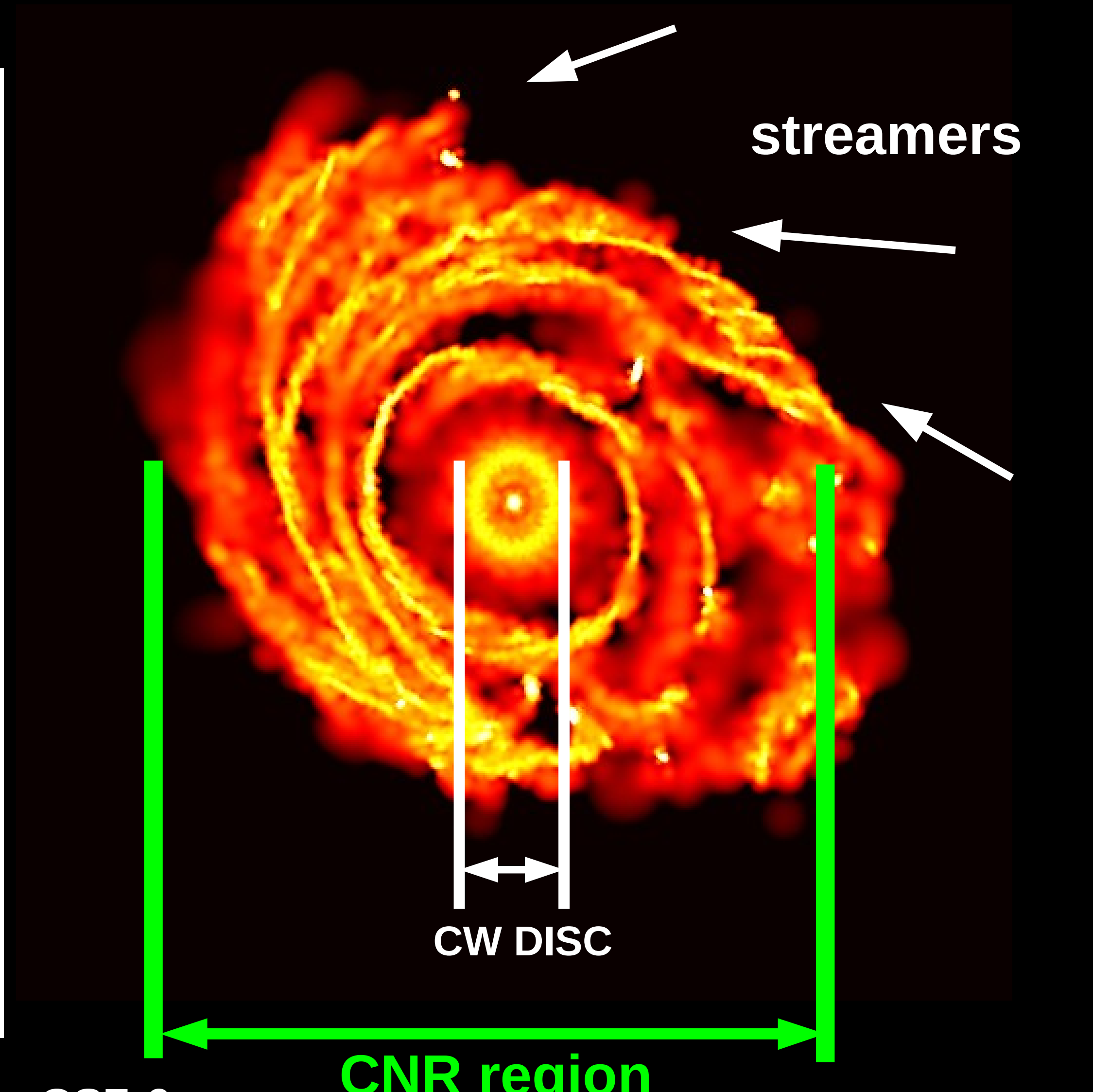
Yusef-Zadeh et al. 2013 ,ALMA Cycle0

WE DO OBSERVE THE CIRCUM-NUCLEAR RING!!

4. The role of the circumnuclear ring

Disruption of the same molecular cloud can produce both the CW disc and the circumnuclear ring!



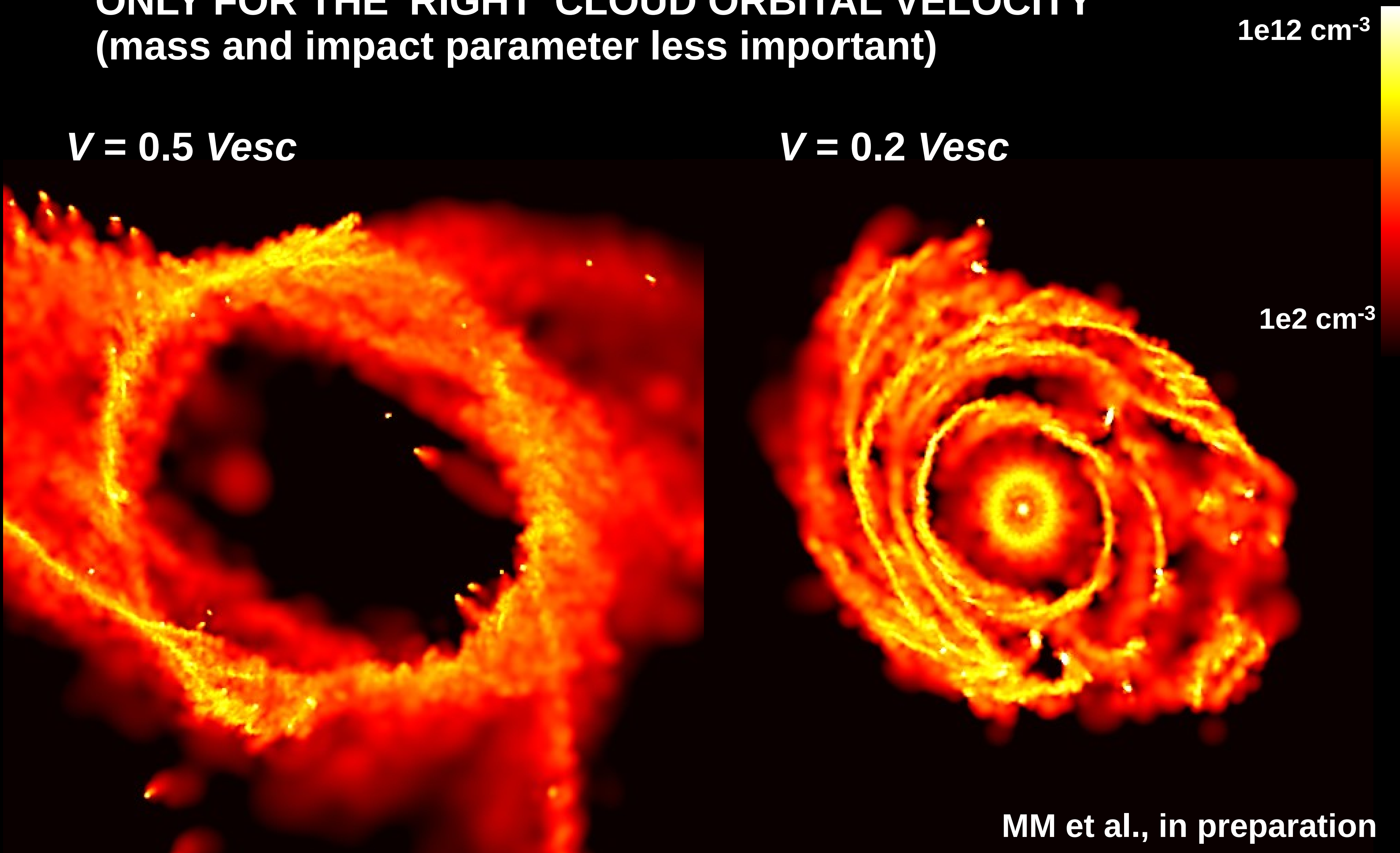


yellow: ^{12}CO3-2; magenta HCN 4-3; blue: CS7-6
Liu et al. 2012

MM et al., in preparation

Disruption of the same molecular cloud can produce both the CW disc and the circumnuclear ring!

ONLY FOR THE 'RIGHT' CLOUD ORBITAL VELOCITY (mass and impact parameter less important)

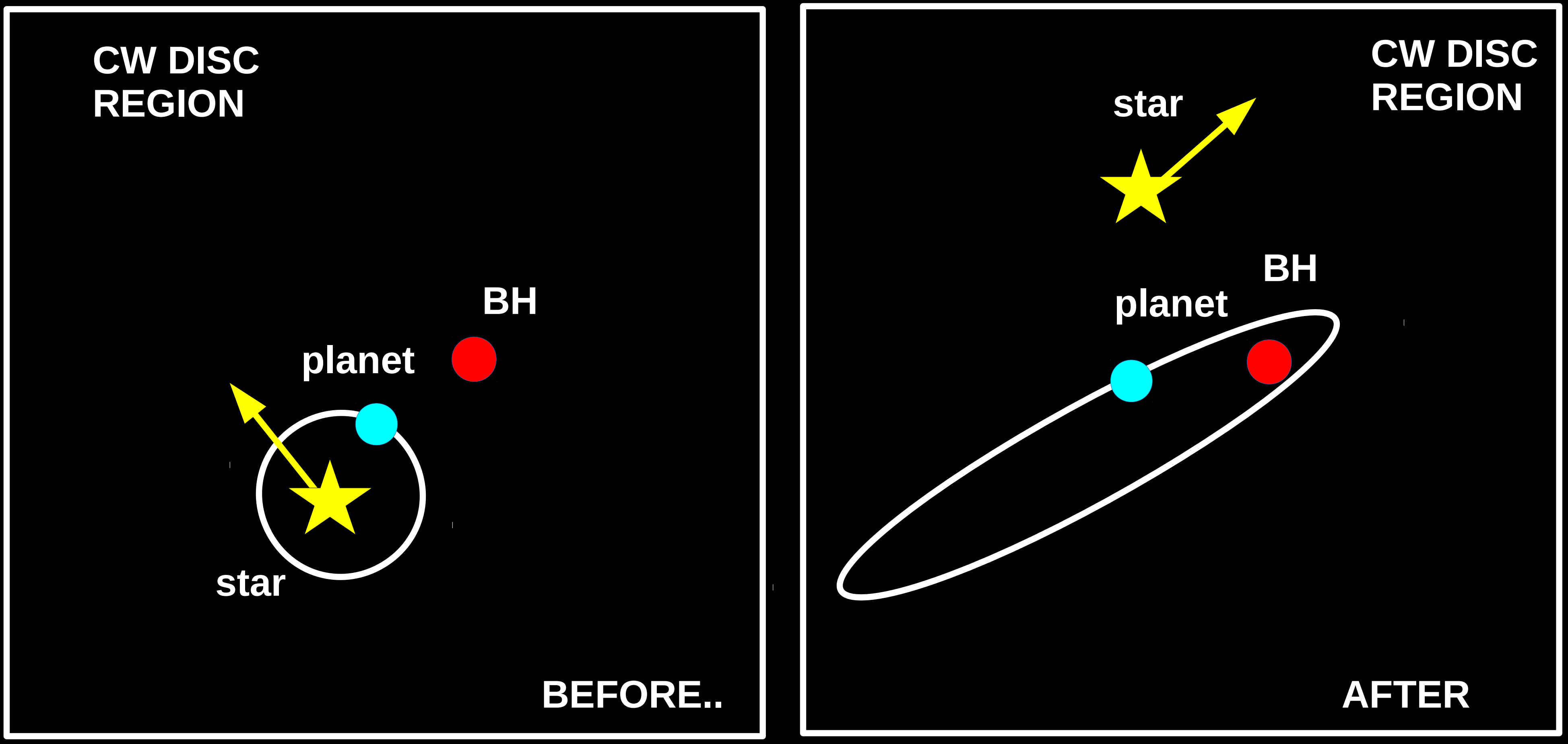


5. Planets in the Galactic center??

STARS in CW disc might host planets and planetary discs
(Cadez et al. 2008; Nayakshin et al. 2012; Ginsburg et al. 2012; Zubovas et al. 2012)

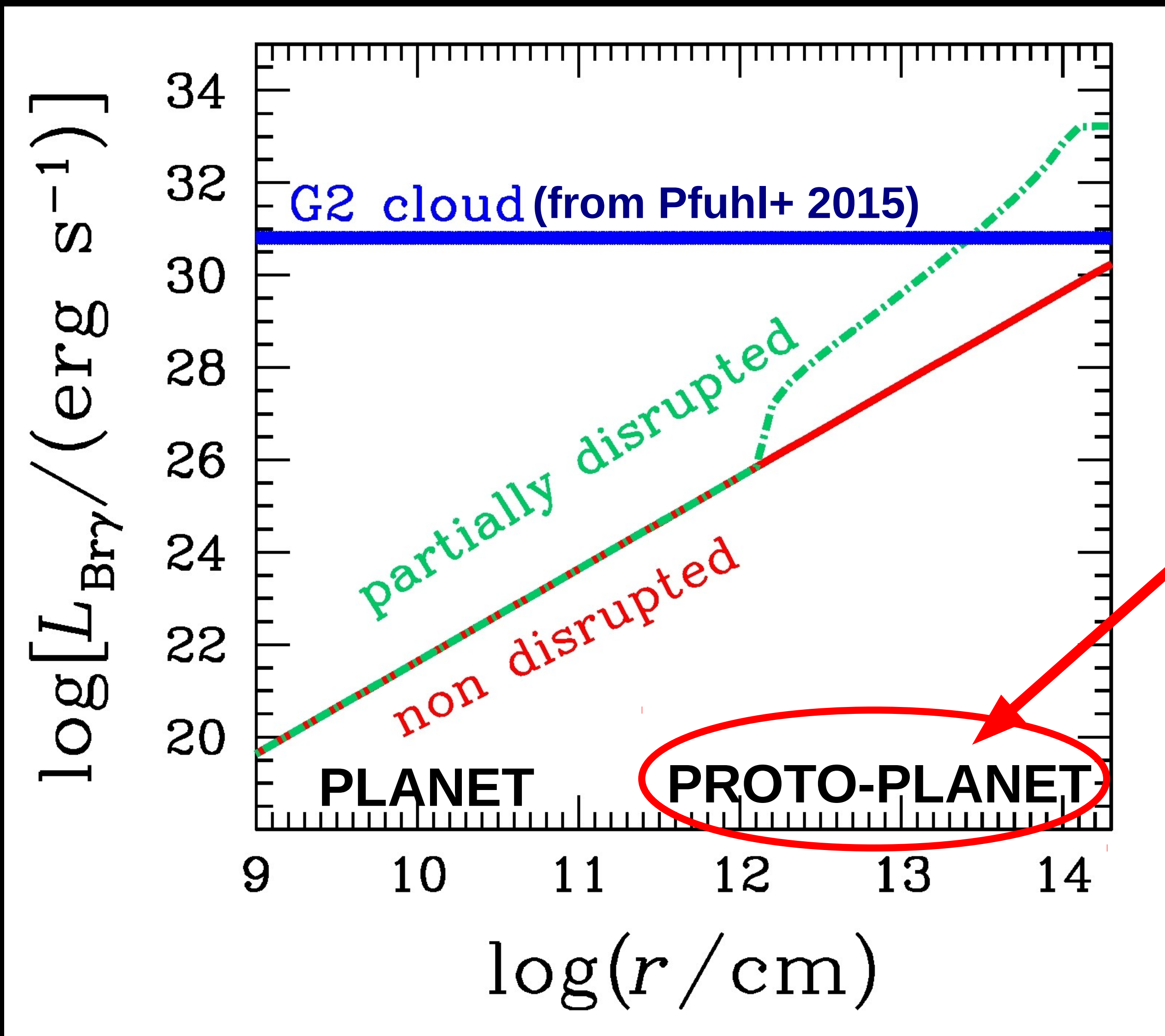
SMBH's TIDAL SHEAR splits planets/ protoplanets from stars
→ produces ROGUE planets and protoplanets

and tidal capture preserves the initial orbital plane! (see yesterday discussion about G2, G1)



5. Planets in the Galactic center??

- ROGUE planets /protoplanets and proto-brown dwarfs are PHOTOEVAPORATED by UV BACKGROUND of the CW DISC
- PHOTOEVAPORATION is ENHANCED if planet/protoplanet is PARTIALLY TIDALLY DISRUPTED (similar to Murray-Clay & Loeb 2012 calculation for protoplanetary disc)



Red: non disrupted (proto-)planet

Green: partially tidally disrupted (proto-)planet

Blue: G2 cloud

PROTO-PLANET:= bound GAS CLUMP formed from GRAVITATIONAL INSTABILITY in protoplanetary disk, which is going to contract to a planet or brown dwarf size (Kuiper 1951, Boss 1997)

MM & Ripamonti, submitted

5. Conclusions

- Molecular cloud disruption scenario matches several orbital properties of CW disc in the Galactic center

- First HYDRO simulations (MM+ 2013) of a stellar disc interacting with a clumpy gas disc indicate that Newtonian precession dismembers the stellar disc in ~few Myr (starting from outer stars)

- The circumnuclear ring might have formed in the same molecular cloud disruption event that produced the CW disc and the other early type stars (MM+ in prep.)

- The G2 dusty object **might** be a giant proto-planet formed in the CW disc and then tidally captured by the SMBH (MM & Ripamonti, submitted)

THANKS