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Near the monster: formation and dynamics of stars in galactic nuclei

COLLABORATORS: Alessandro Trani, Elisa Bortolas, Mario Spera, Alessandro Ballone, Nicola Giacobbo

631 Heraeus seminar: `Stellar aggregates', Bad Honnef, December 9th 2016

OUTLINE

1. Motivation: why do we care about star formation in Galactic nuclei?

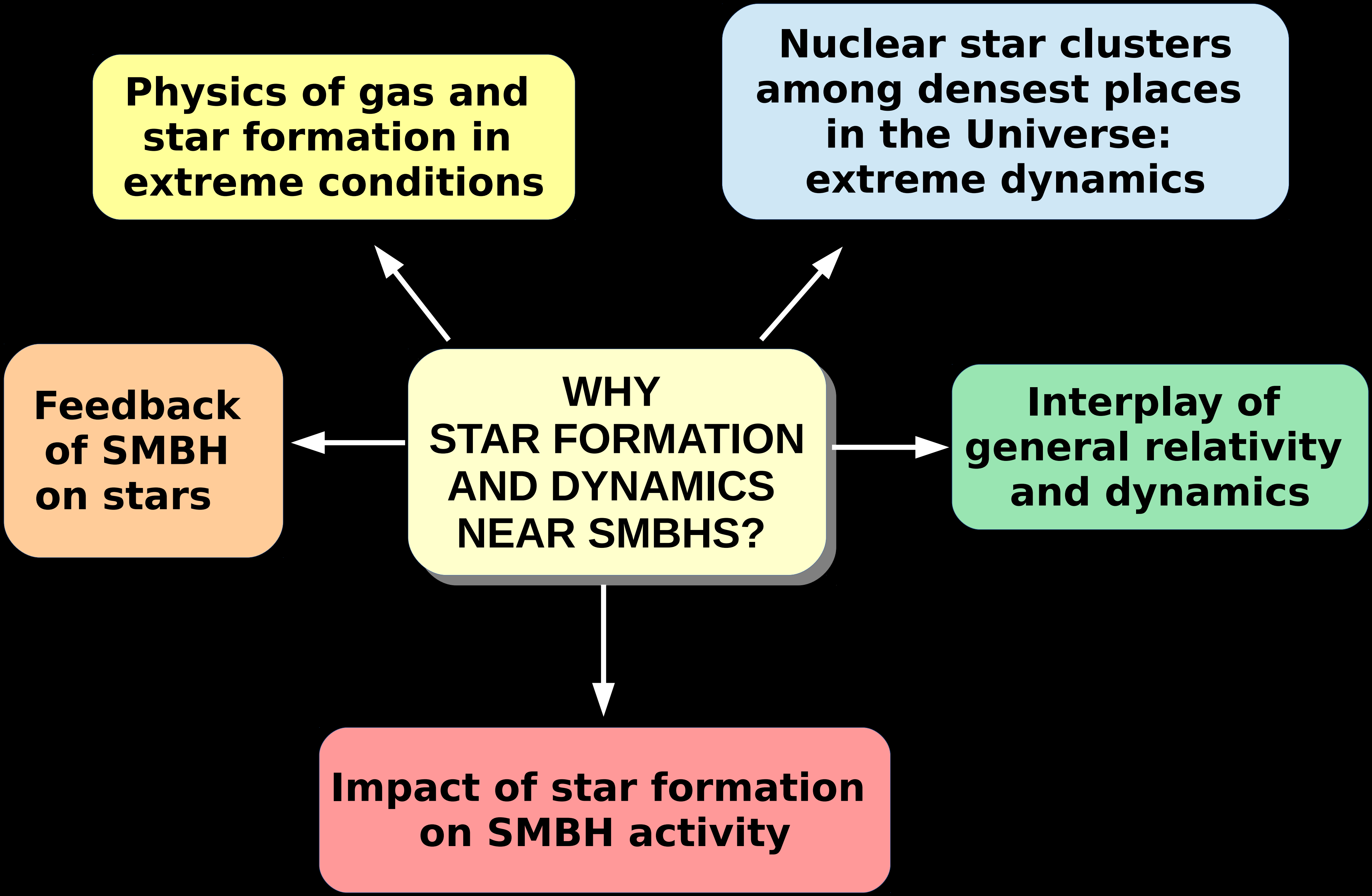
2. Theoretical models to explain star formation in Galactic nuclei

3. Circum-nuclear rings: formation and dynamics

4. Dynamics of binaries after supernova (SN) kick

5. Conclusions

1. Motivation



1. Motivation

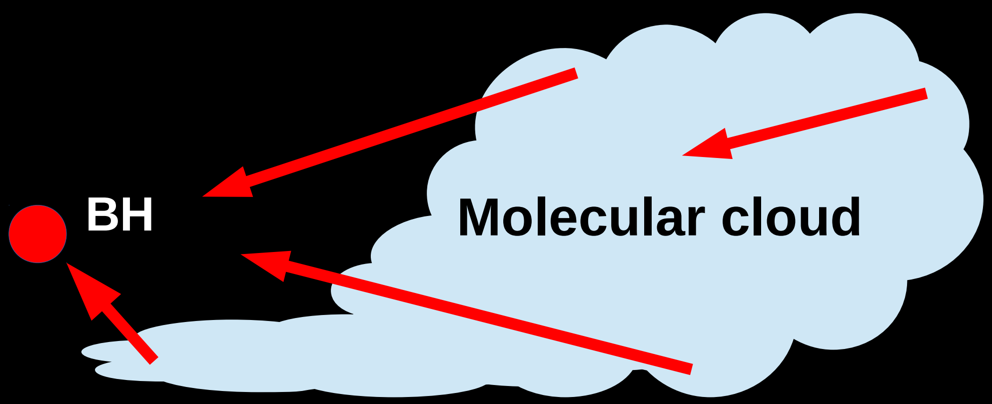
Stars should not form close to a SMBH even if quiescent

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



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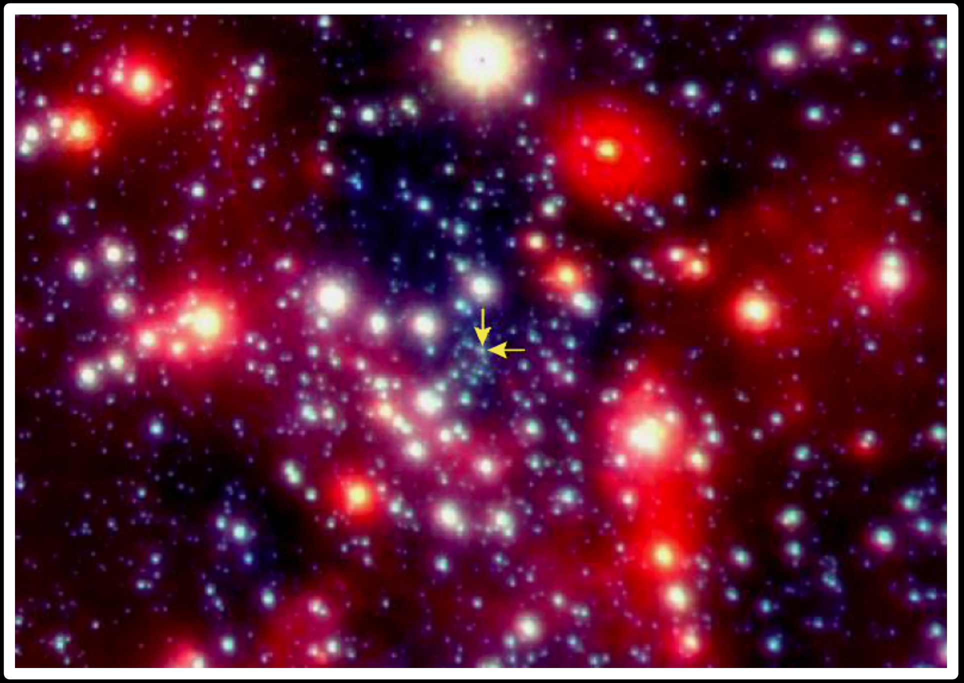
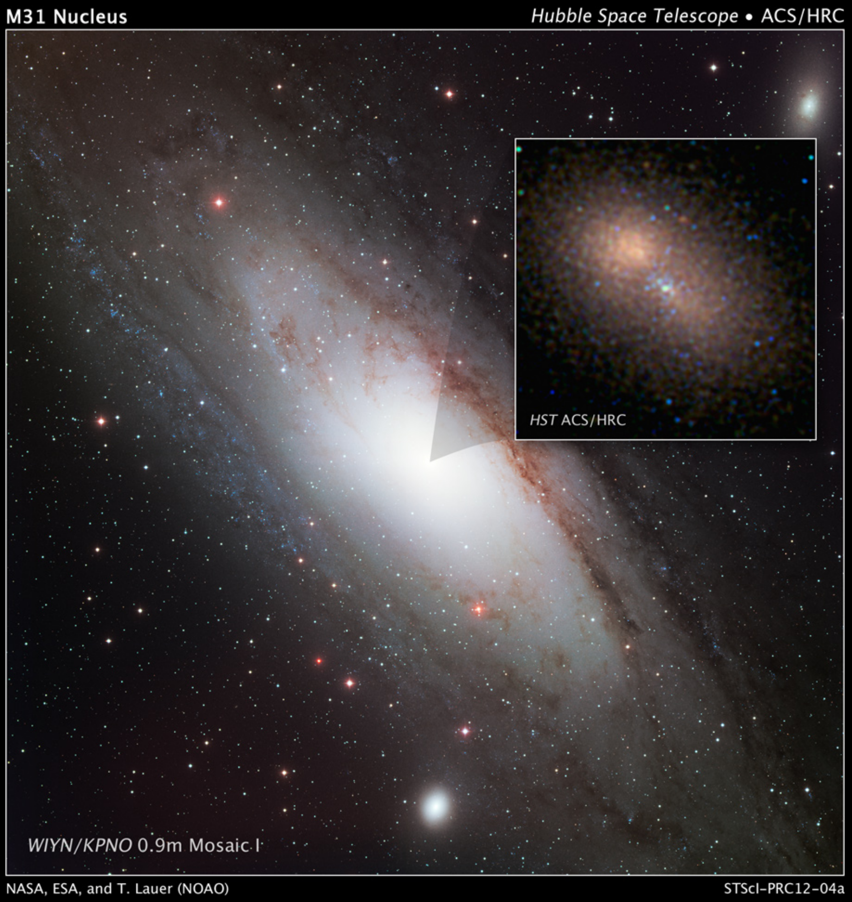


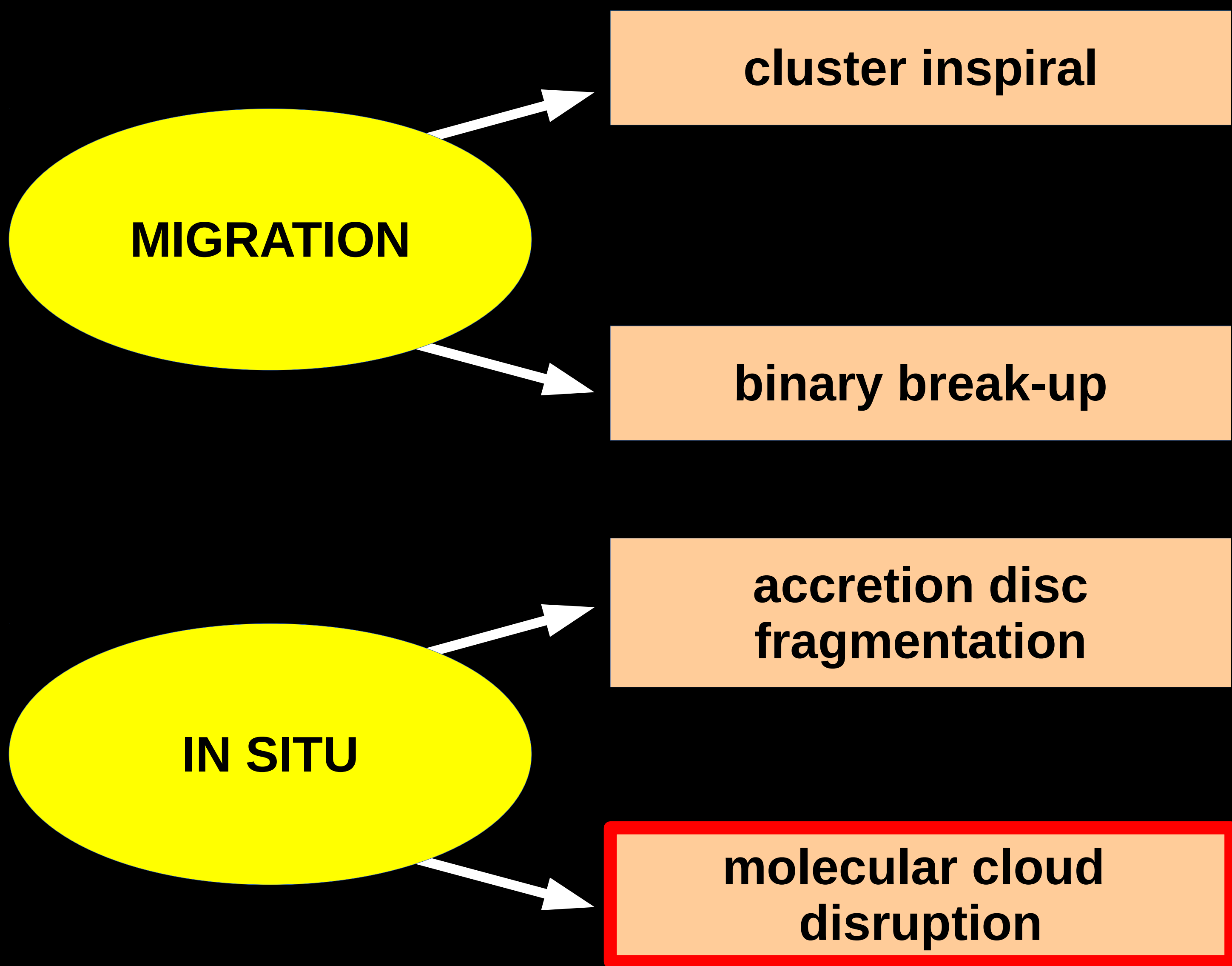


BUT WE OBSERVE YOUNG STARS IN THE CENTRE OF OUR GALAXY AND (MAYBE) OTHER GALAXIES

CAN WE EXPLAIN THIS?

2. Theoretical models to explain star formation in Galactic nuclei

Scenarios to explain the formation of the young stars



Molecular cloud disruption:

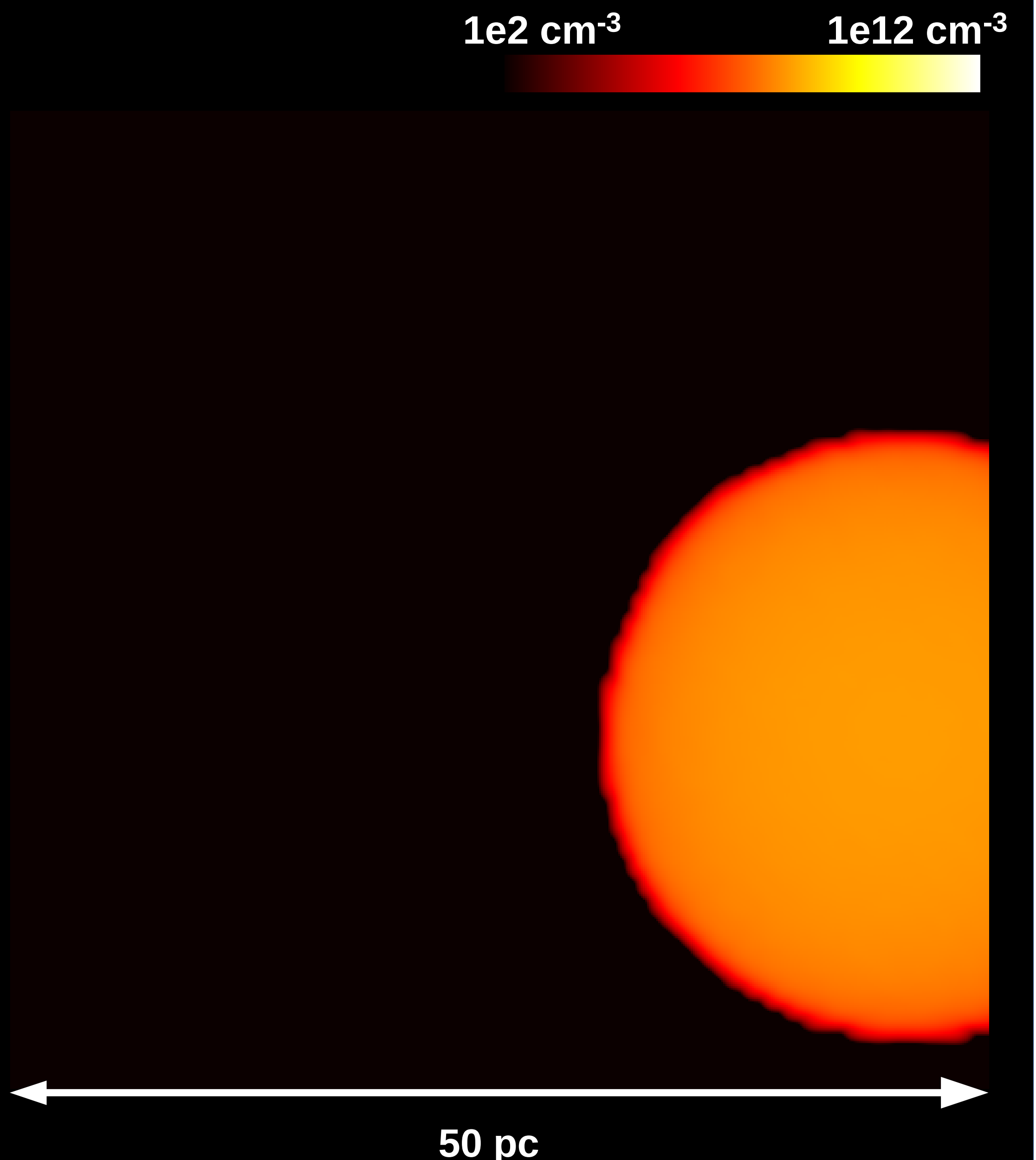
A molecular cloud is disrupted by the SMBH, but

(i) the residual angular momentum,
(ii) 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

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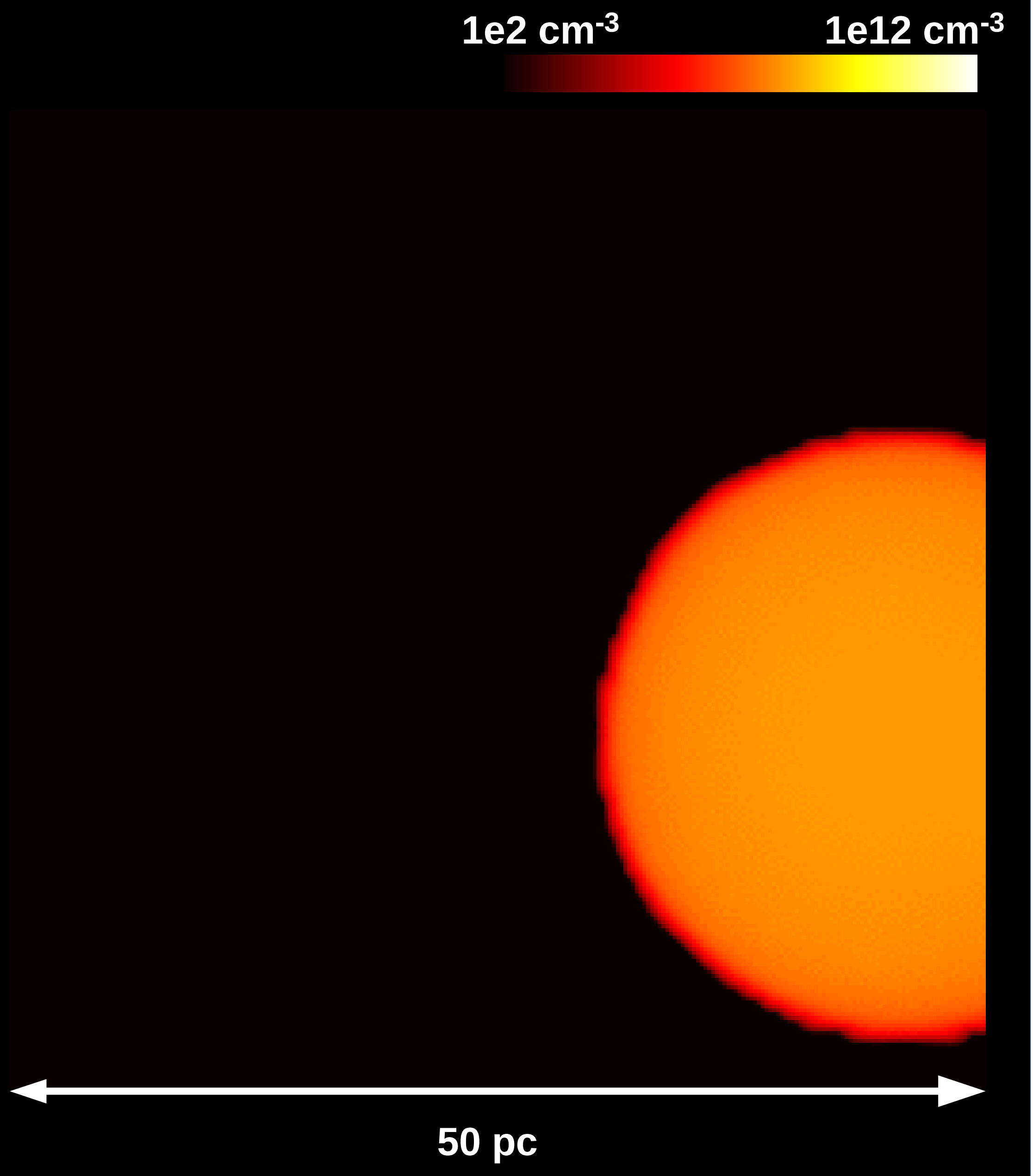

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2. Theoretical models to explain star formation in Galactic nuclei

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

(MM et al. 2012, 2013; MM & Gualandris 2016)

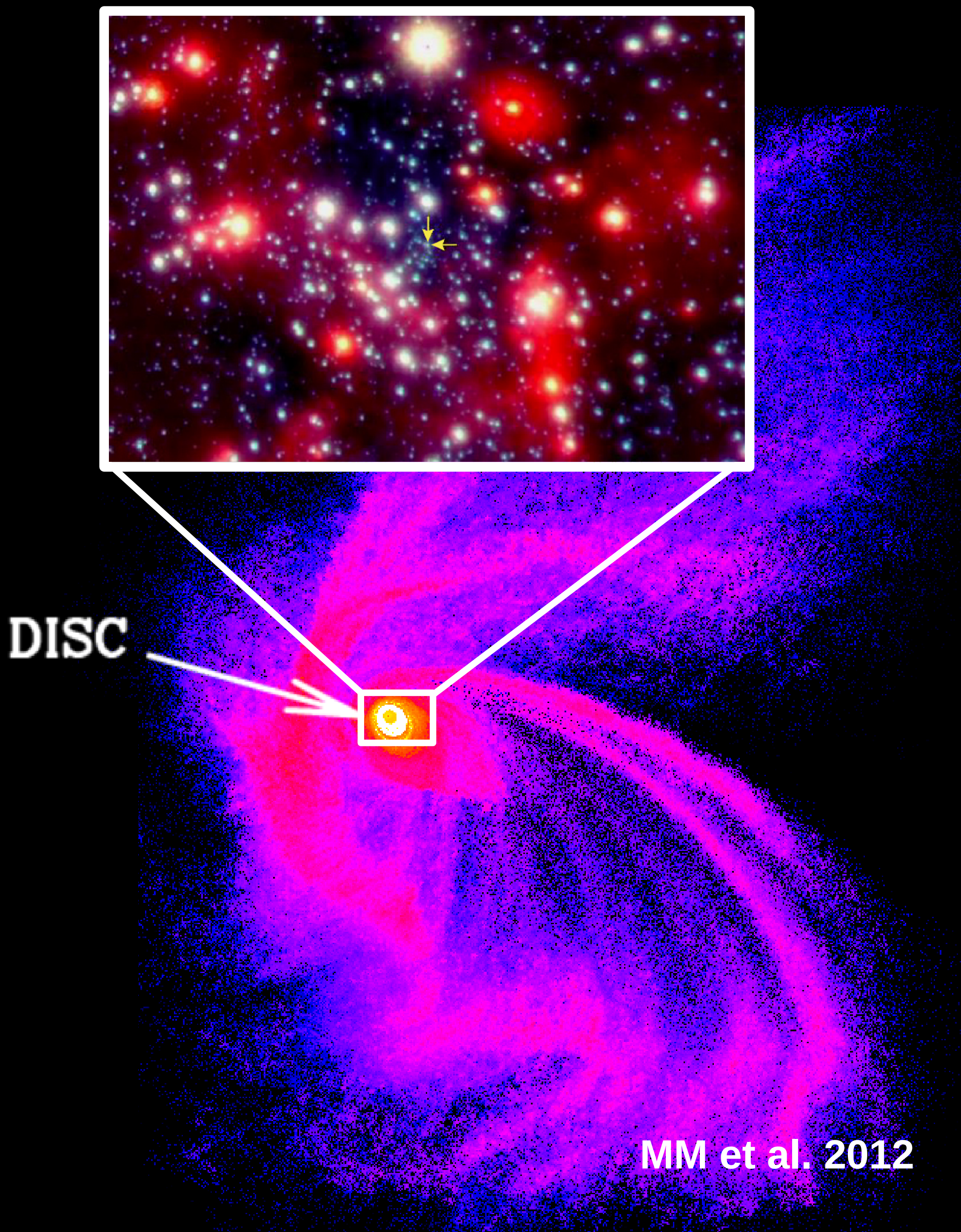
INGREDIENTS:

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

* a SMBH sink particle

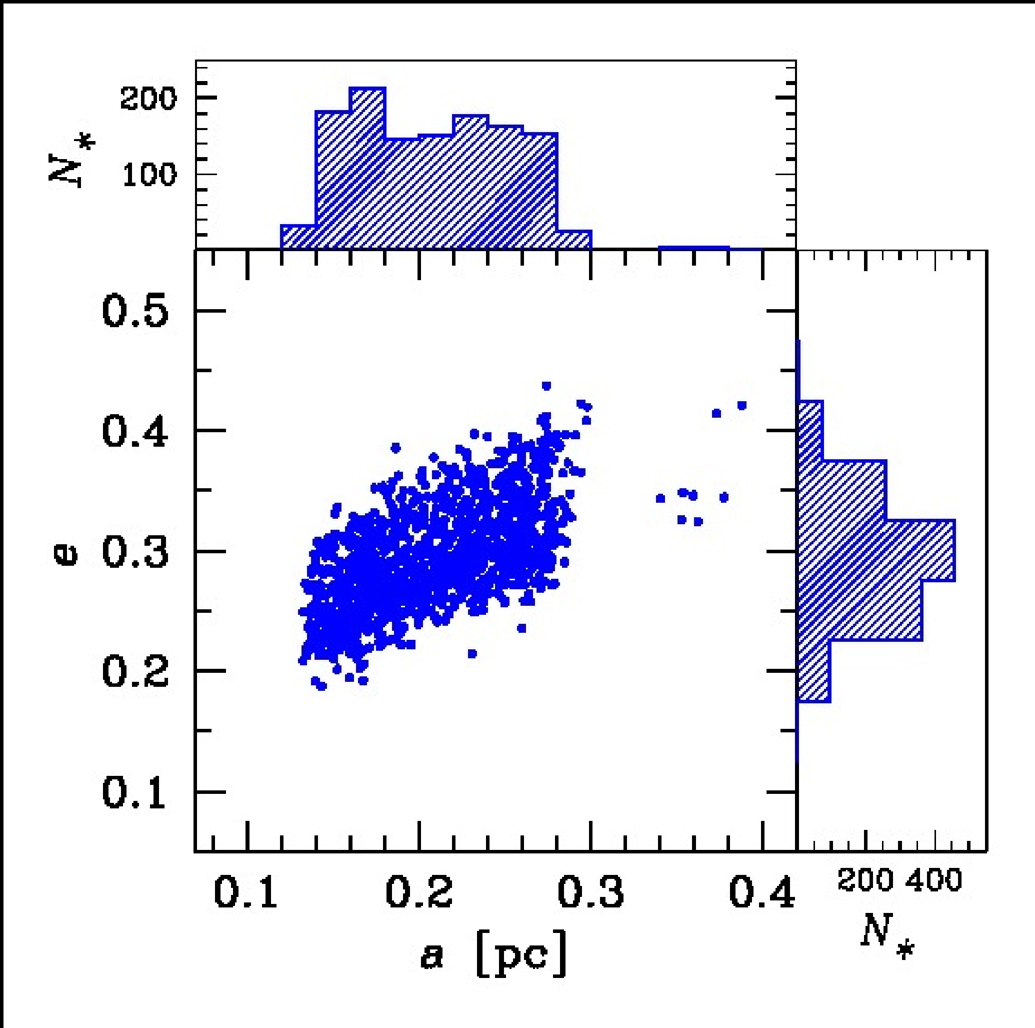
* integration with OSPH (Read et al. 2010)

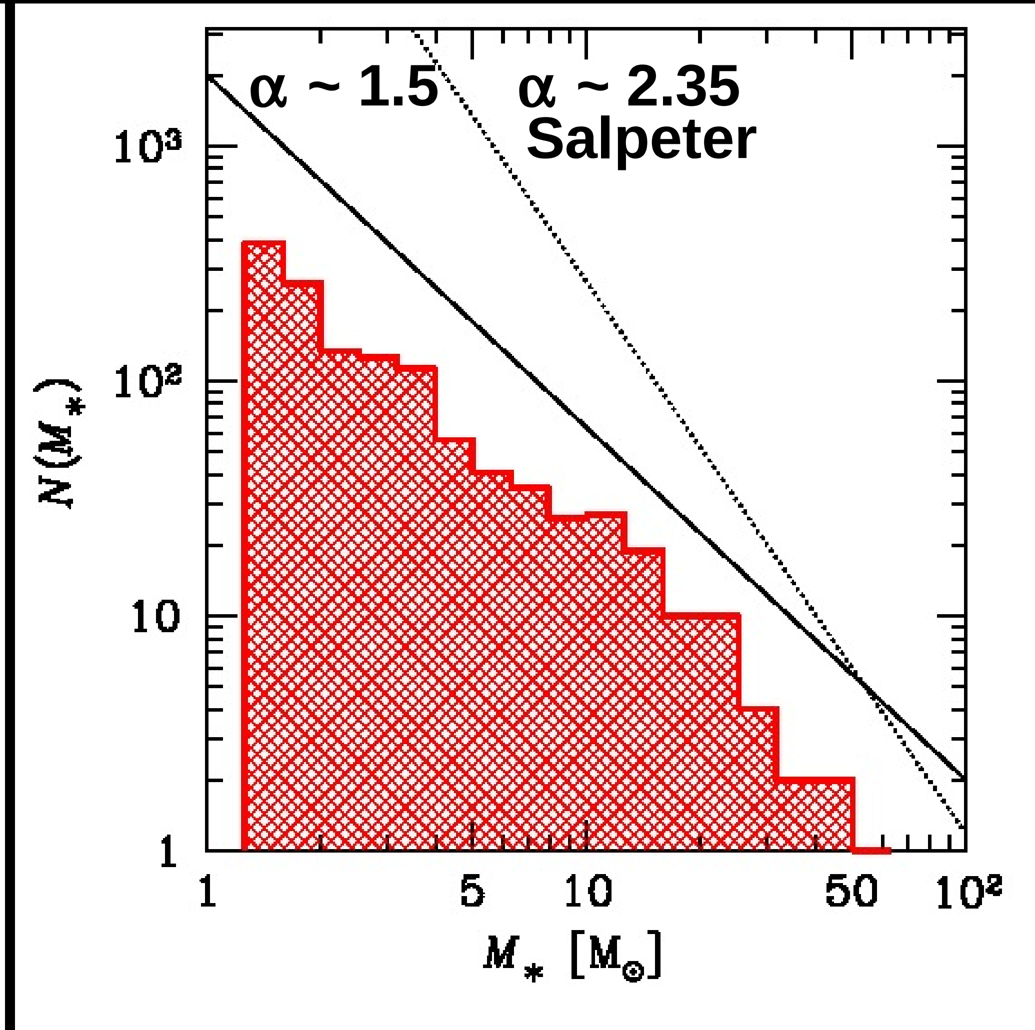
* cooling + Planck & Ross. opacities (Boley 2009, 2010)



MM et al. 2012

2. Theoretical models to explain star formation in Galactic nuclei





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

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

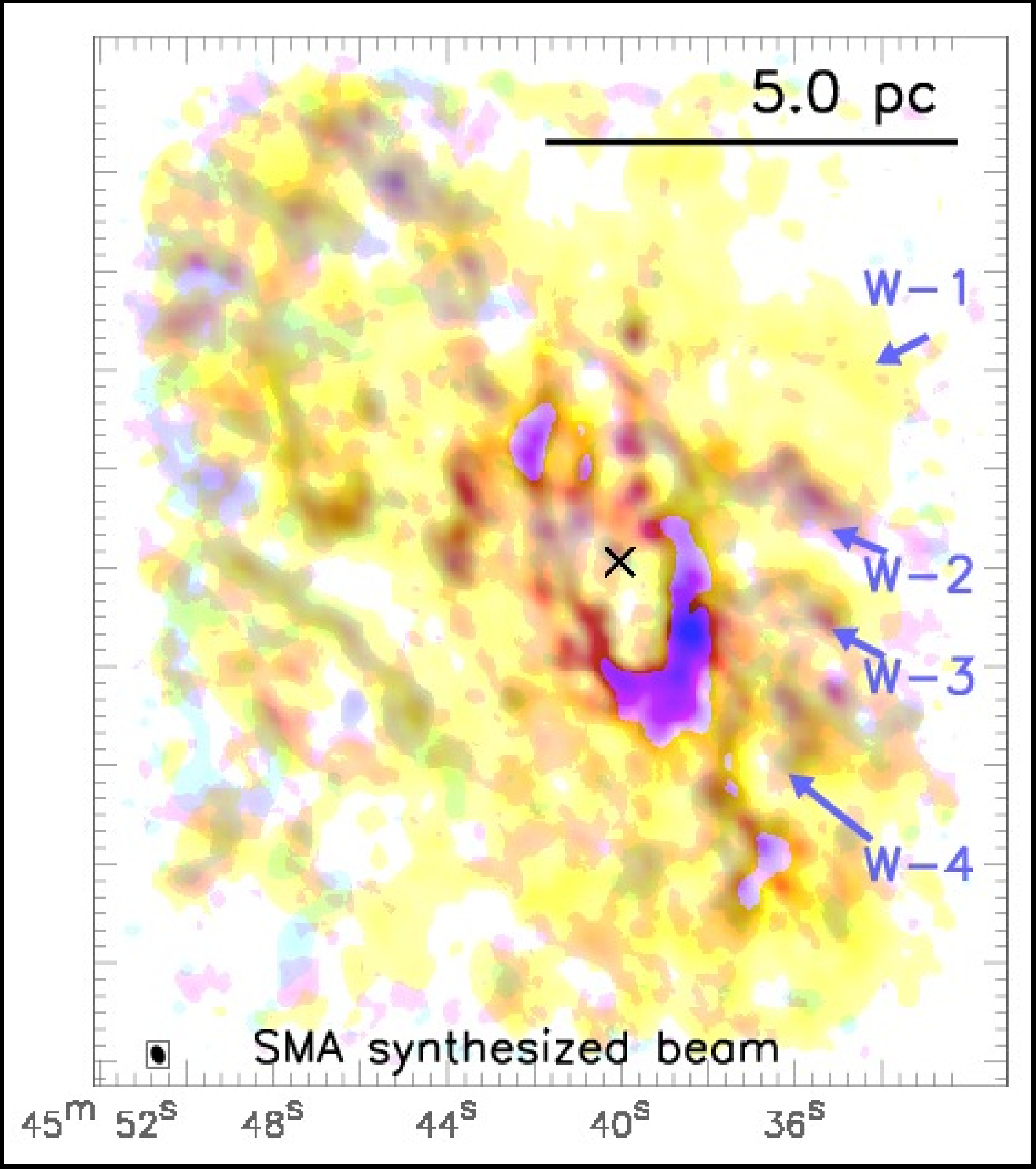
Best fitting slope: α ~ 1.5 +/- 0.1

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

MM et al. 2012

3. Circum-nuclear rings: formation and dynamics

IS THERE ANY OTHER POSSIBLE INDICATION OF MOLECULAR CLOUD DISRUPTION IN THE GALACTIC CENTRE?



THE CIRCUMNUCLEAR RING (CNR):

Mass ~ 10^{4-5} Msun

Radius ~ 2 pc

Vcirc ~ 100 km/s

High density (>10^2 cm^{-3})

Temperature ~ 10 – 100 K

W-1,4: Western streamers

HOW DID THE CNR FORM?

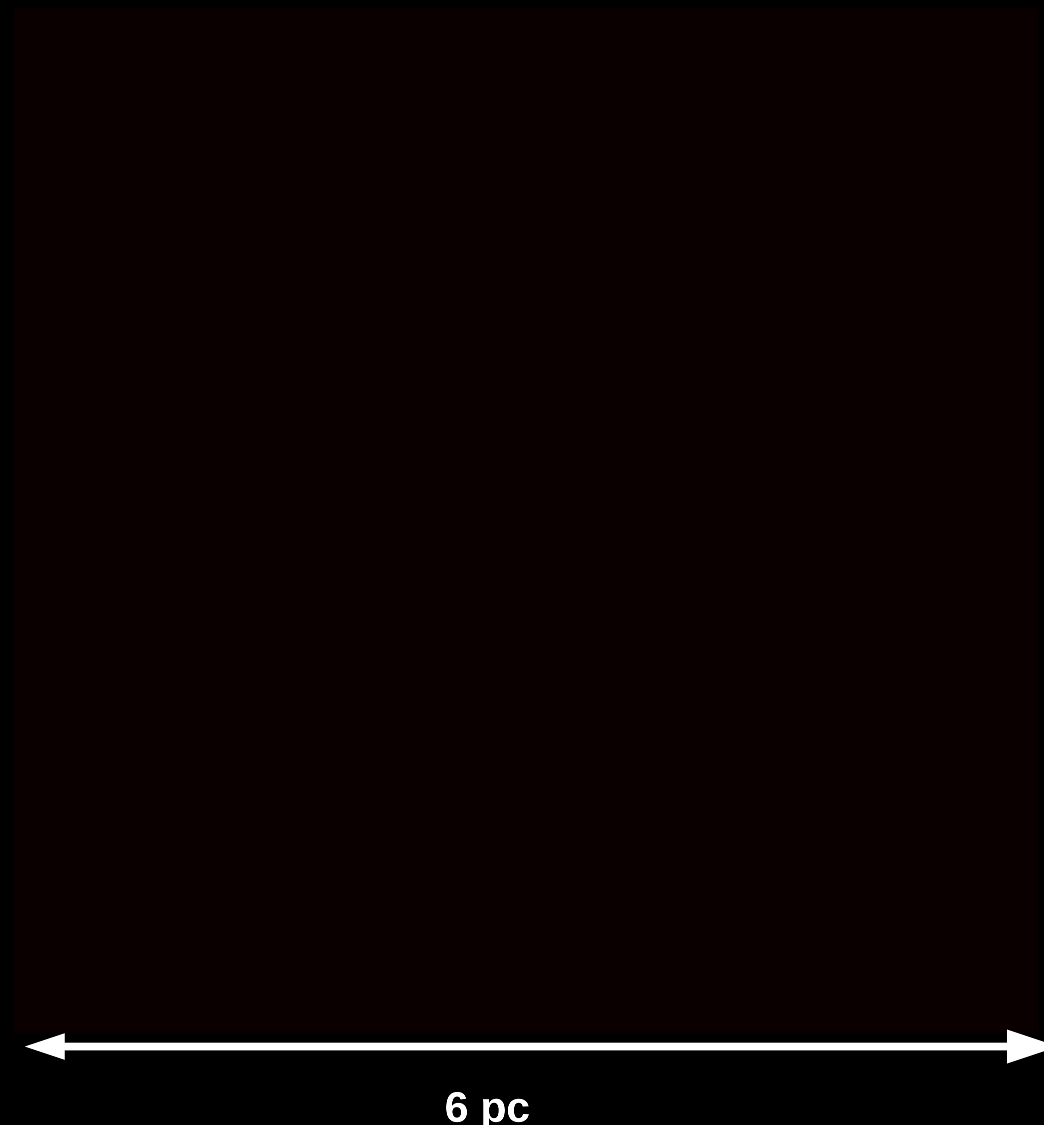
Baobab Liu et al. 2012

How did the circumnuclear ring form?

Simulation of MC disruption with

- Velocity ~ 0.2 escape velocity from SMBH

- impact parameter *b*~ 25 pc



→ formation of an inner disc with ~0.4 pc radius

→ formation of an outer ring with ~ 2 pc radius

SIMILAR TO THE CNR!

MM & Trani 2016, A&A

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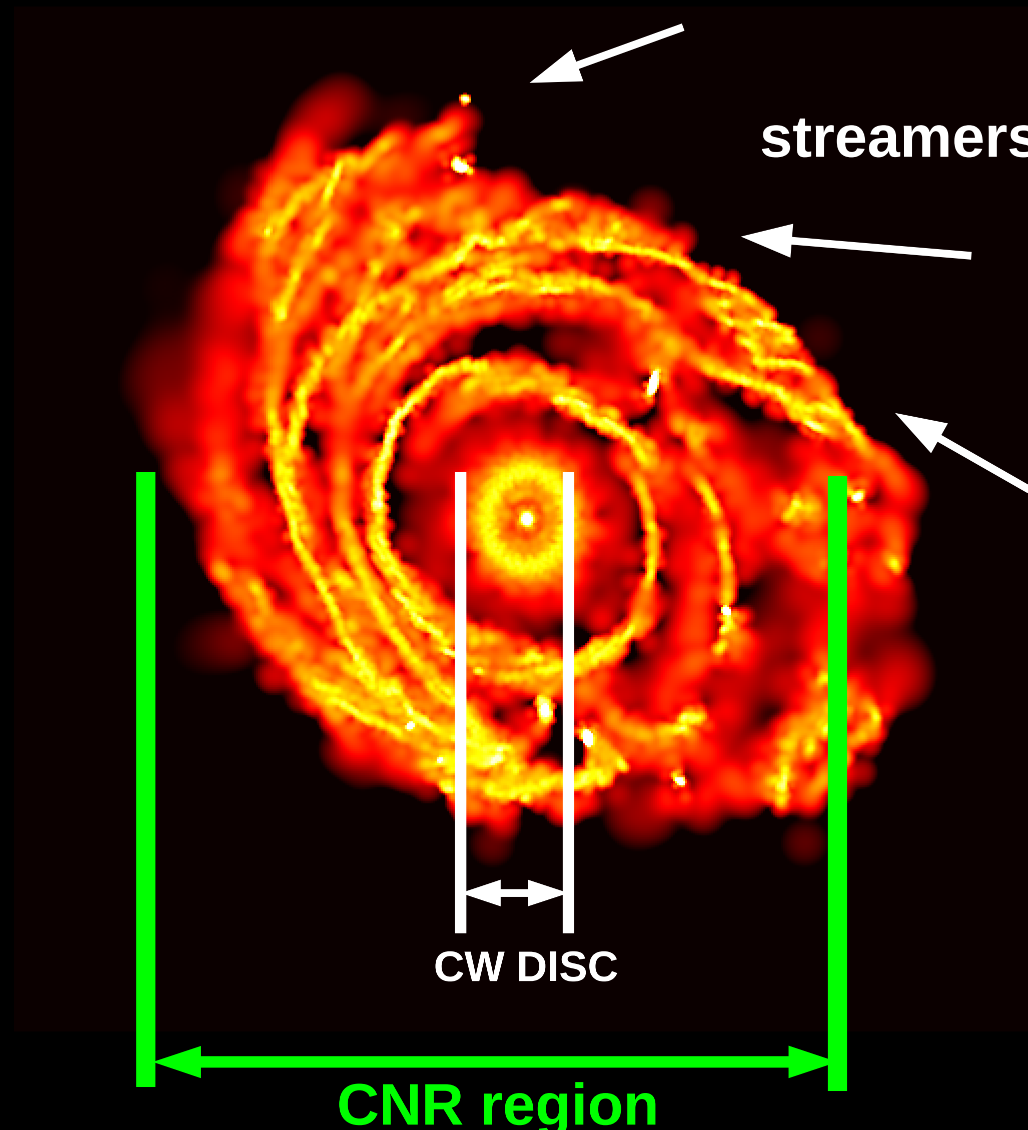
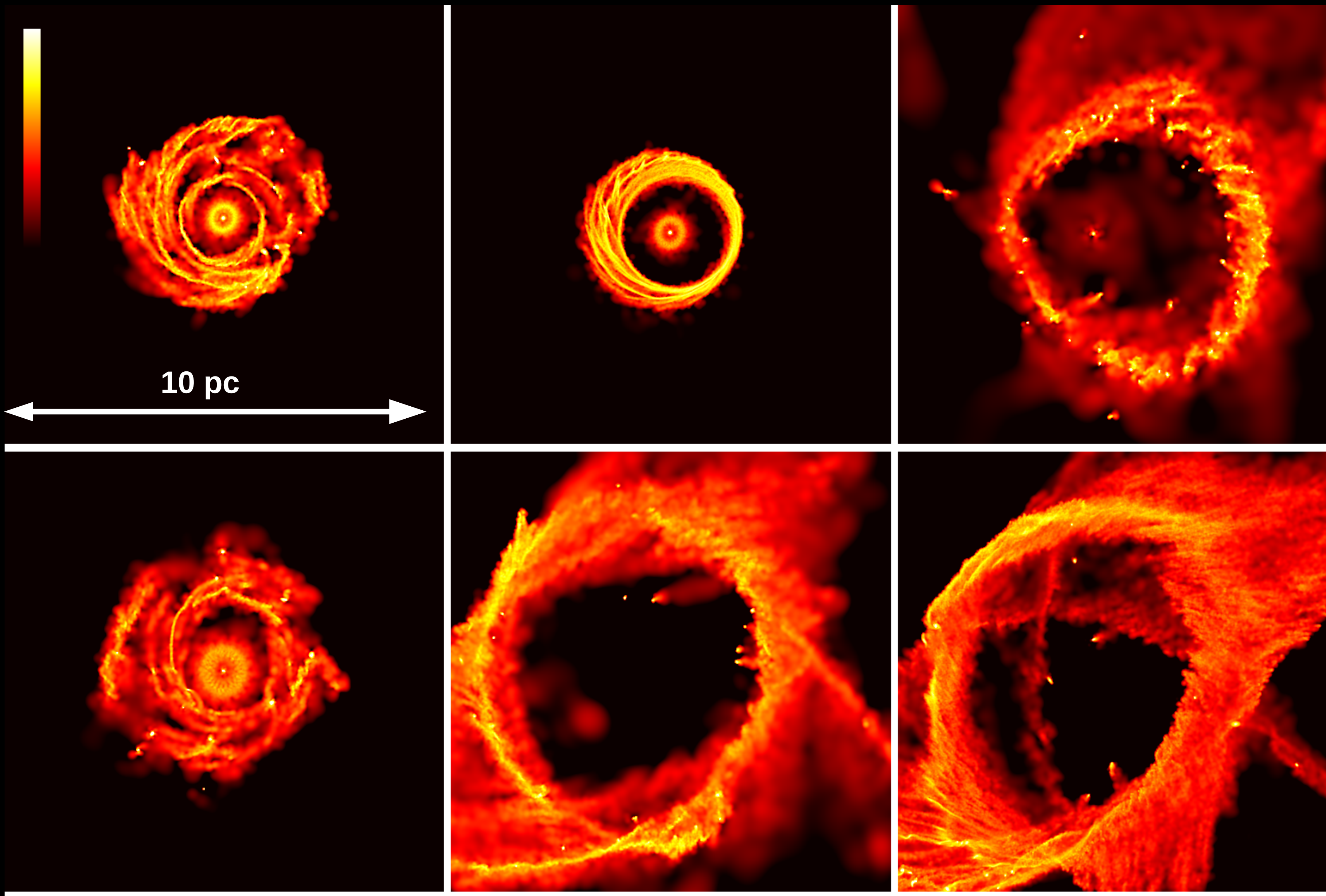


MM & Trani 2016, A&A

Which kind of MC disruption events can form a CNR-like ring?

We compare MASS, OUTER RADIUS, ROTATION VELOCITY of the simulated ring with observations (MM & Trani 2016)



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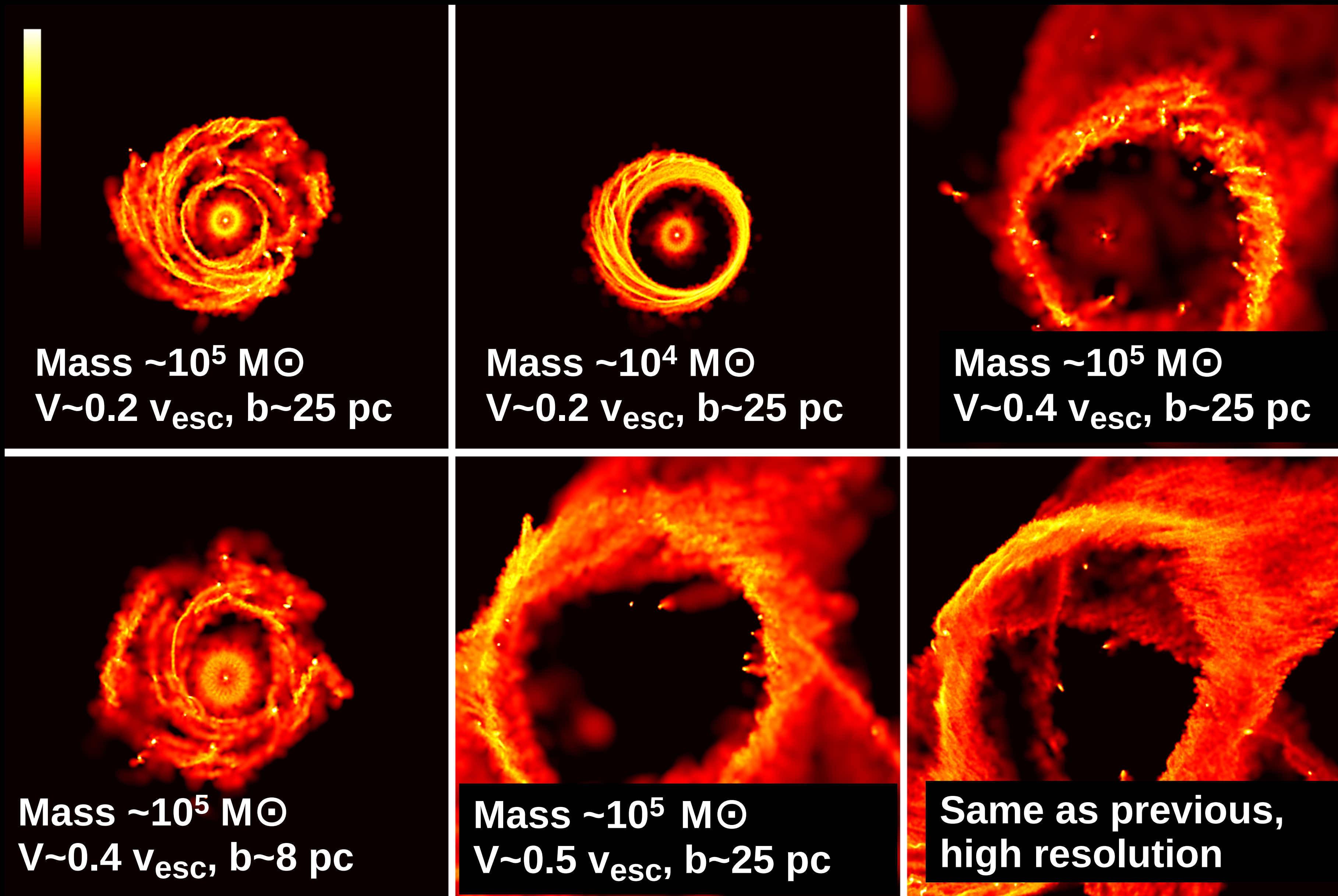

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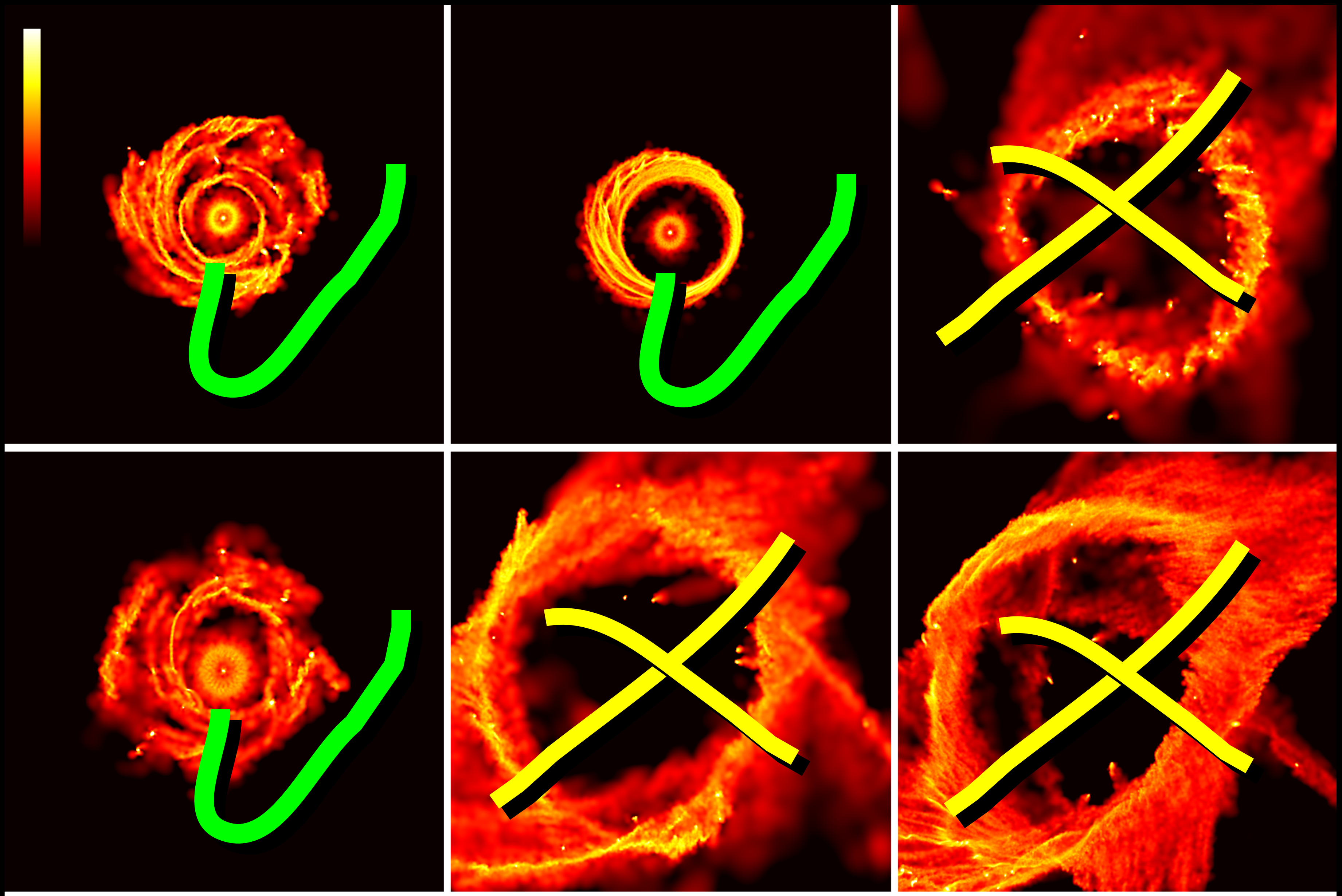
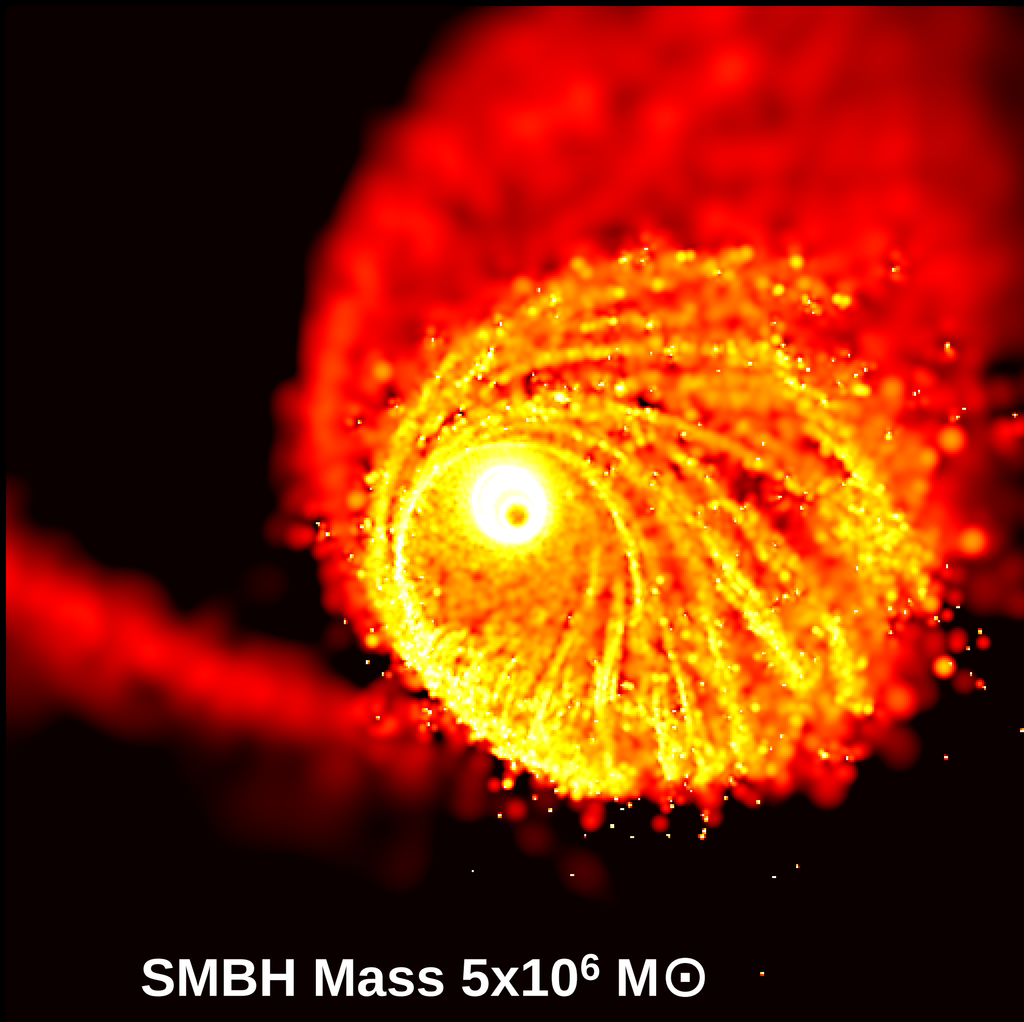
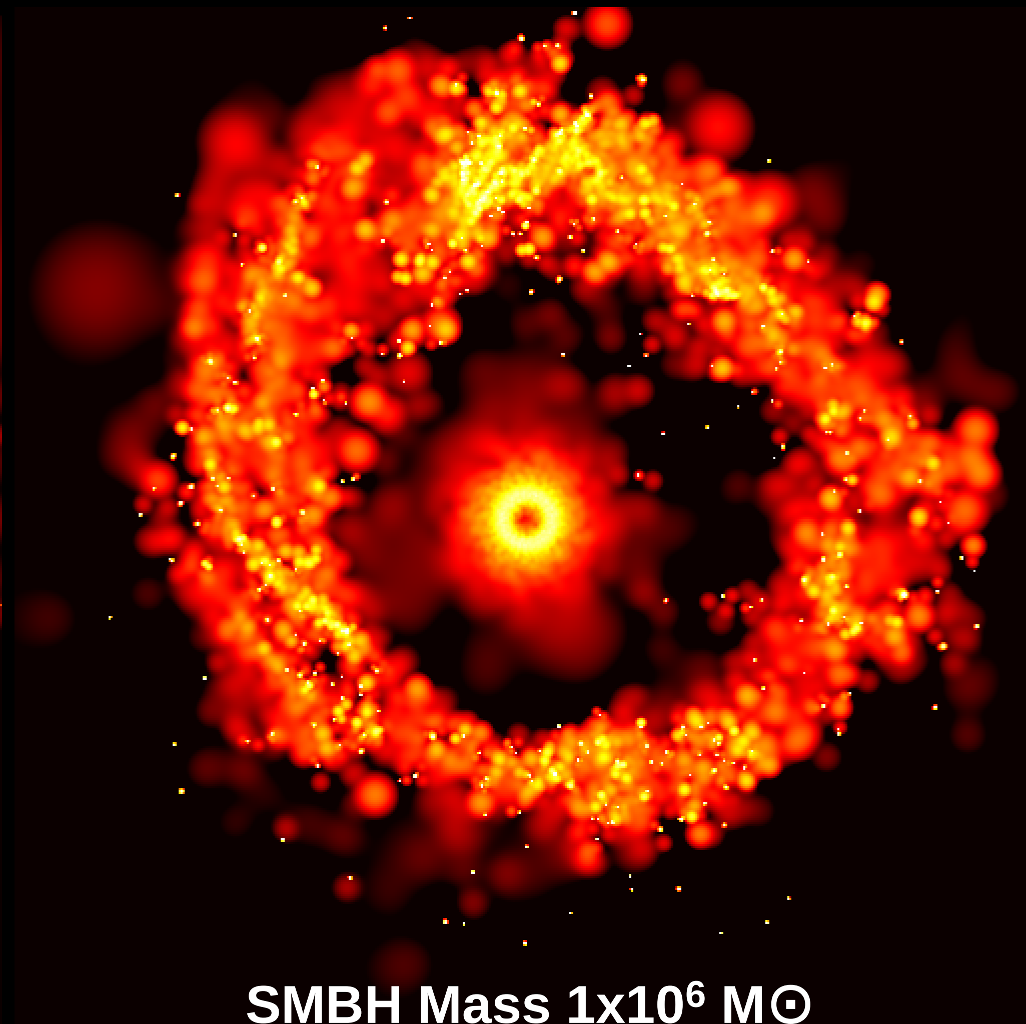


WHAT ABOUT OTHER GALAXIES?

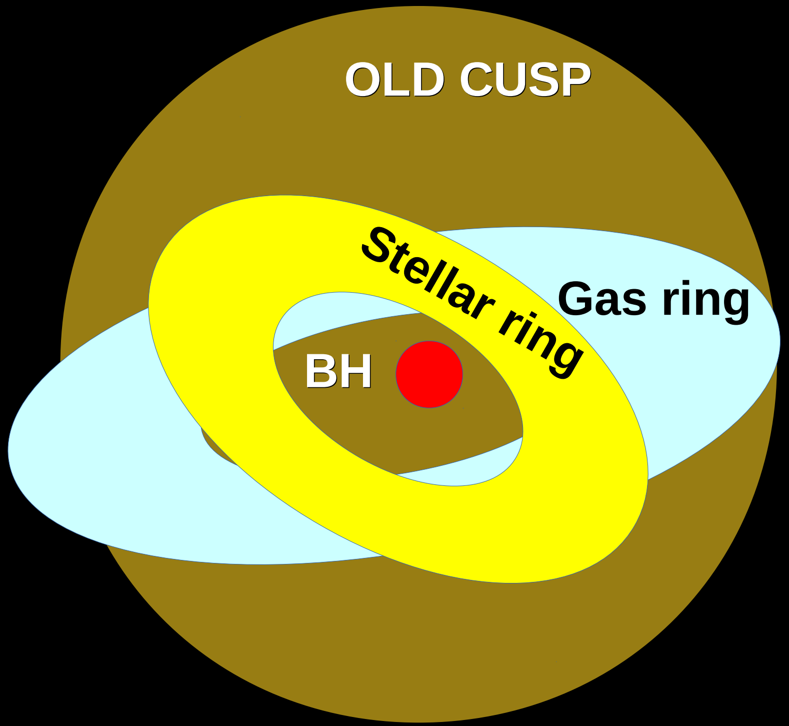
Impact of SMBH mass and stellar cusp mass on CNRs





Trani, MM, + in prep.

WHAT IS THE IMPACT OF GAS ON THE DYNAMICS OF STARS?



We simulate effect of old cusp (rigid potential) + gas ring (SPH)

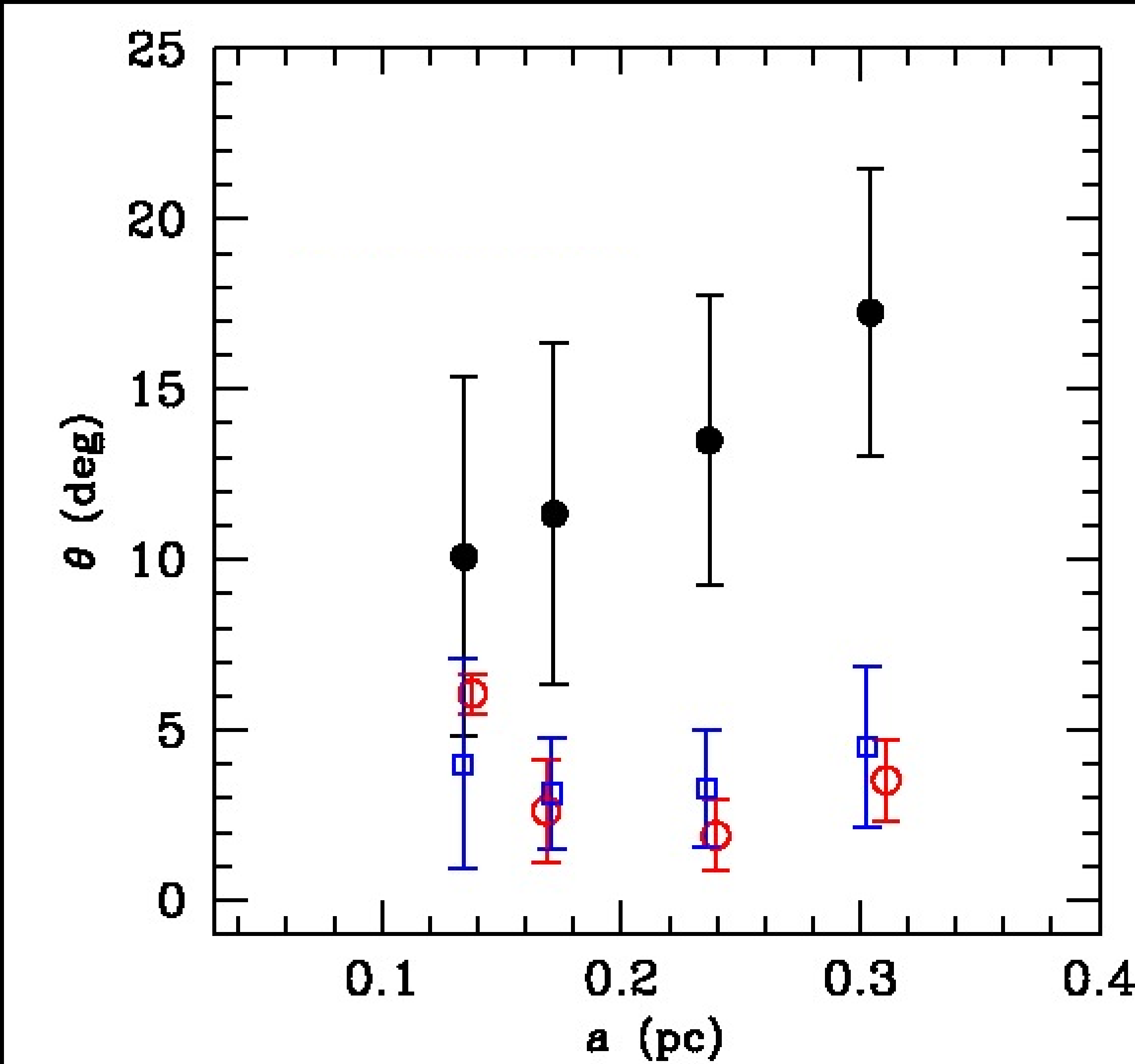
OLD CUSP: spherical potential

→ only precession of argument of periapsis

GAS RING: axisymmetric potential

→ precession of argument of periapsis, long. of asc. node, inclination and orbital eccentricity

MM+ 2013; Trani, MM+ 2016



Red: initial conditions
Blue: run without 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

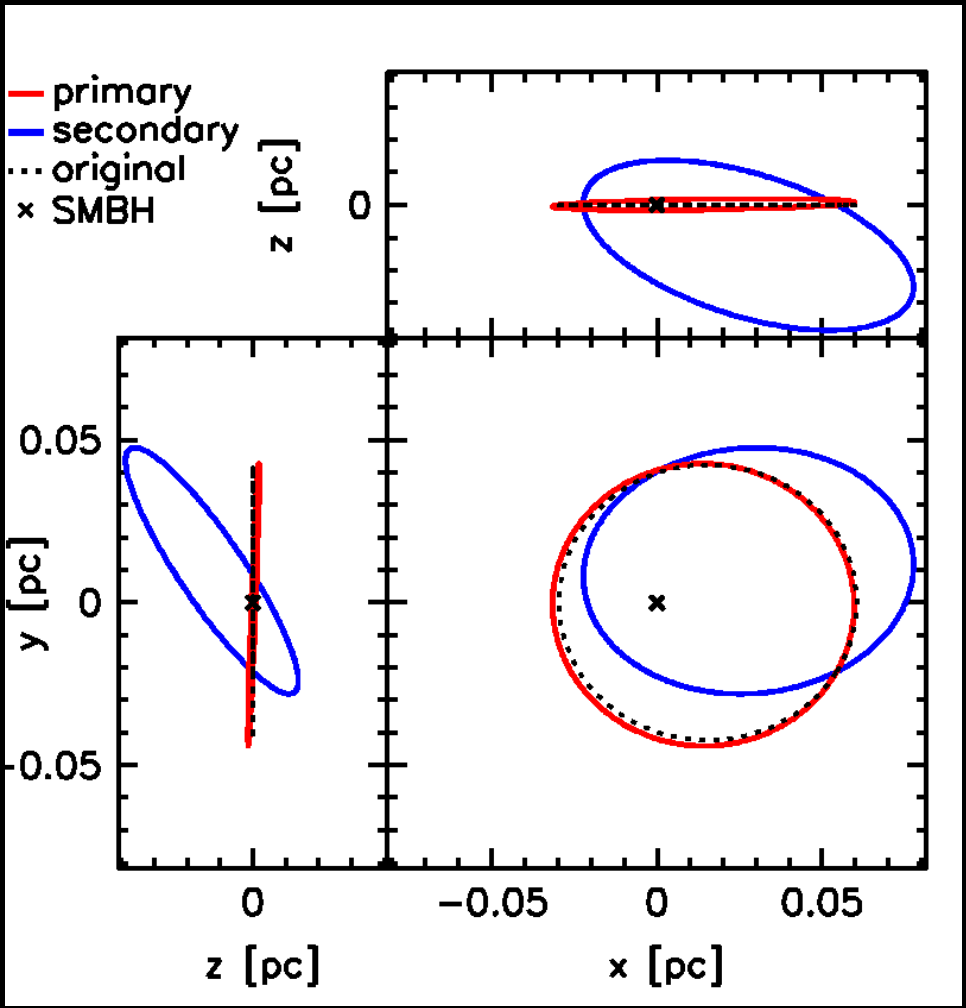
THE DISK IS DISMEMBERED
starting from outer parts
because of precession + two-body relaxation

Precession might explain the stars that do not lie in the CW disk (Yelda et al. 2014)

MM, Gualandris & Hayfield 2013; Trani, MM + 2016

4. Dynamics of binaries and SN kicks

- Many massive stars in the CW disc
- Massive stars generally in BINARY SYSTEMS
- WHAT HAPPENS WHEN SUPERNOVA EXPLODS IN BINARY?

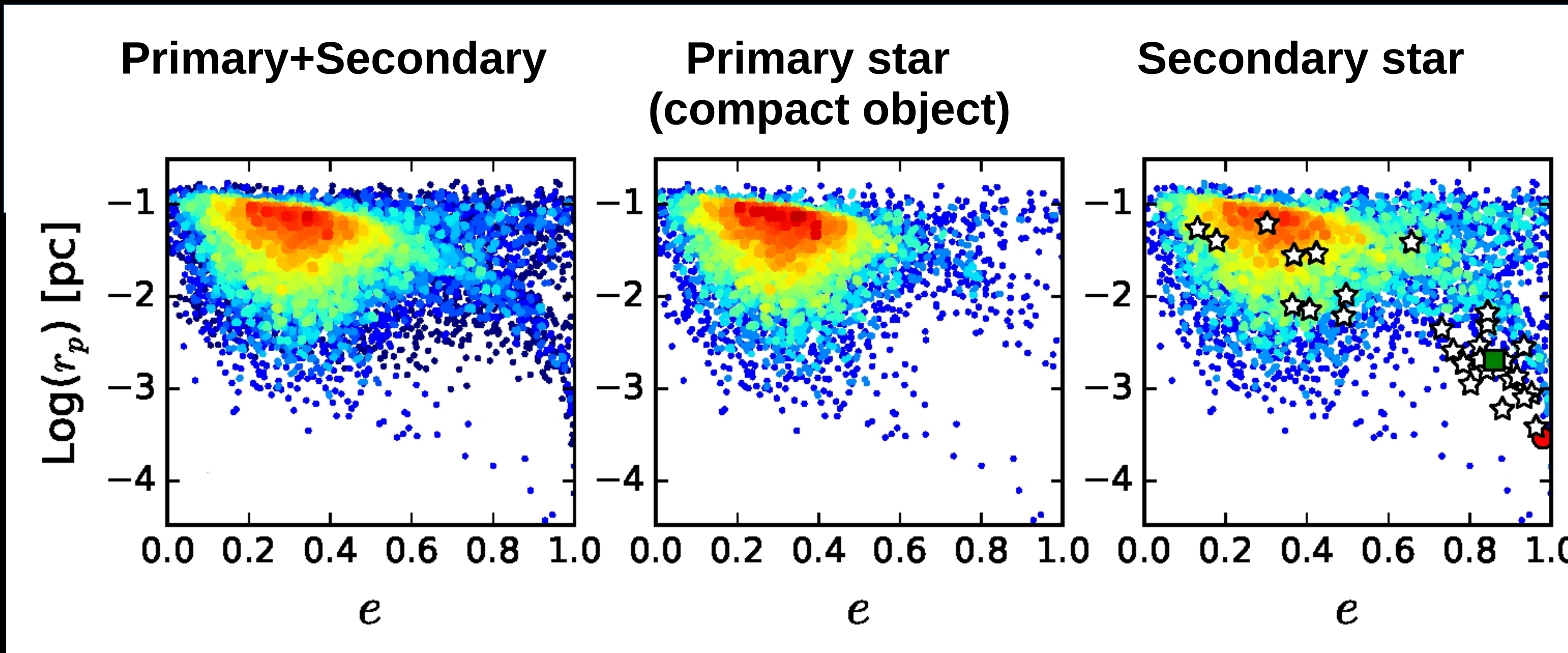


Bortolas, MM, + in prep.

30k simulations of 3-body systems BH+stellar binary

Integration with Mikkola regularized dynamical code (Spera 2017)

4. Dynamics of binaries and SN kicks



r_p = periapsis wrt SMBH
e = eccentricity wrt SMBH

Bortolas, MM, + in prep.

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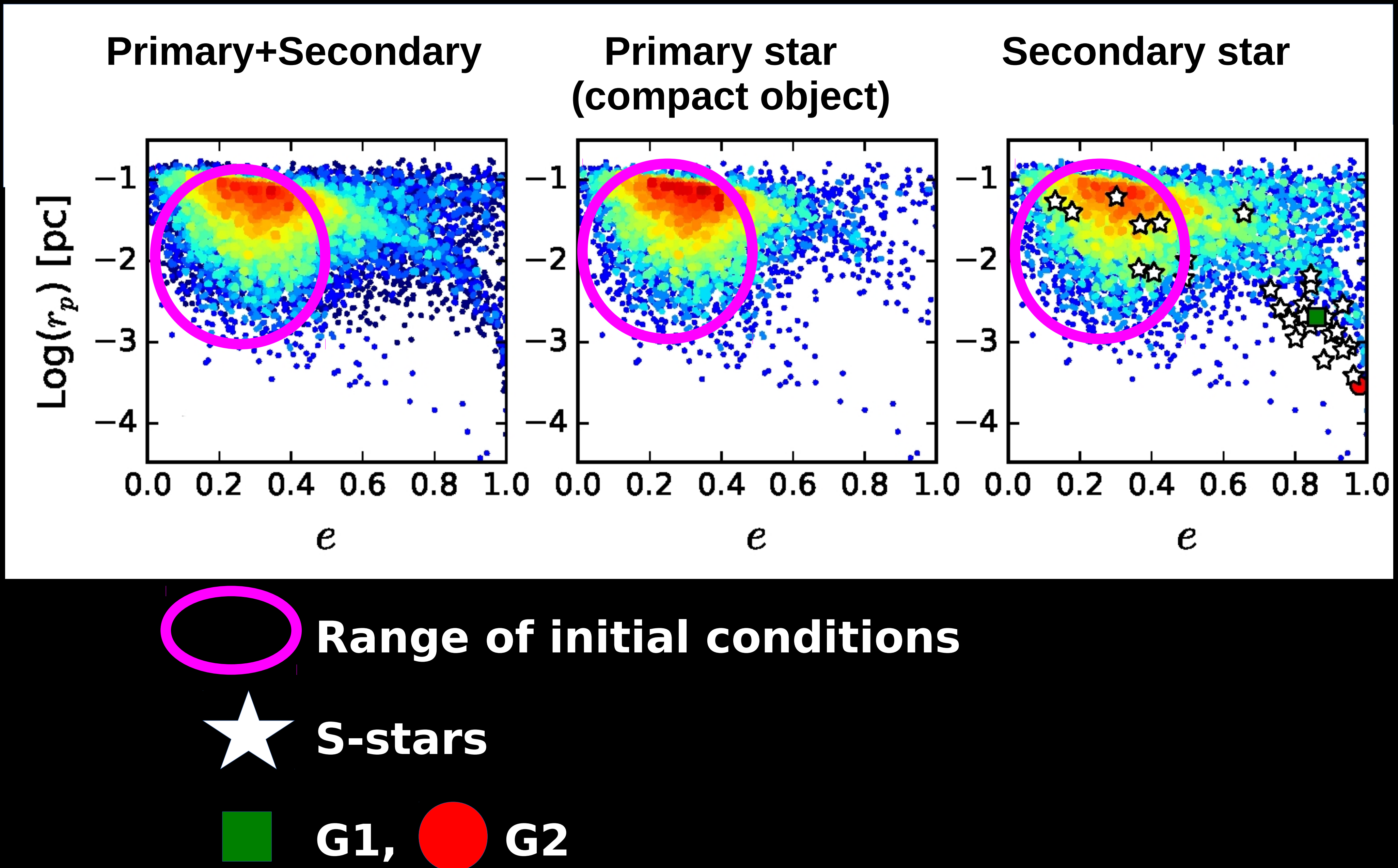

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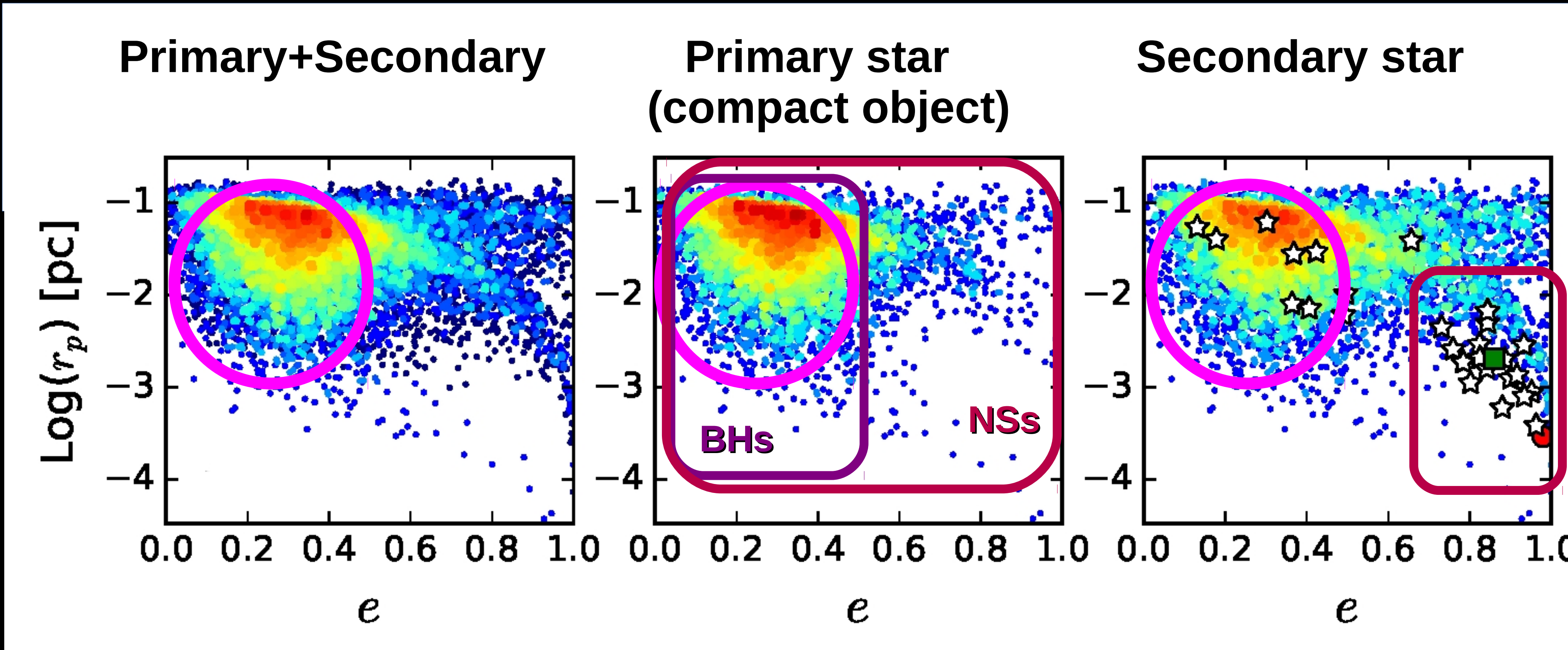

NSs: receive stronger kicks & end on eccentric orbits

BHs: ~ do not move

<10% LIGHT STARS ON VERY ECCENTRIC ORBITS AND SMALL PERIAPSIS (S-cluster, G1, G2)

Bortolas, MM, + in prep.

5. CONCLUSIONS:

- *Star formation close to SMBHs is observed in the Milky Way and in other galaxies, but is against our expectations*

- *Many scenarios have been proposed to explain star formation close to SMBHs: both migration and in situ*

- *MM+ 2012 simulations of molecular cloud disruption are the ones that BEST MATCH properties of observed CW disc*

- *In general, CIRCUMNUCLEAR RINGS might form from molecular cloud disruptions (MM+ 2013; MM & Trani 2016; Trani+ in prep.)*

- *DYNAMICAL PROCESSES induced by circumnuclear rings (and other gas structures) change stellar orbits (Trani, MM+ 2016)*

- *Supernova KICKS in massive binaries affect ORBITS OF LOW-MASS COMPANION STARS and NEUTRON STARS (Bortolas, MM+ in prep.)*

- *Interested in dynamics of planets close to SMBHs?*
  Listen to Alessandro Trani's talk this afternoon!

THANK YOU!

5. MAIN REFS TO OUR WORK:

MM+ 2012,ApJ, 749, 168
http://adsabs.harvard.edu/abs/2012ApJ...749..168M

MM+ 2013, MNRAS, 436, 3809
http://adsabs.harvard.edu/abs/2013MNRAS.436.3809M

MM & Trani 2016, A&A, 585, 161
http://adsabs.harvard.edu/abs/2016A%26A...585A.161M

Trani, MM+ 2016, ApJ, 818, 29
http://adsabs.harvard.edu/abs/2016ApJ...818...29T

MM & Gualandris 2016, chapter of Astrophysical Black Holes, Springer Lecture Notes in Physics
http://adsabs.harvard.edu/abs/2016LNP...905..205M

Bortolas+ 2016, http://adsabs.harvard.edu/abs/2016arXiv160606851B (proceeding version, the full manuscript being submitted to a peer-reviewed journal)