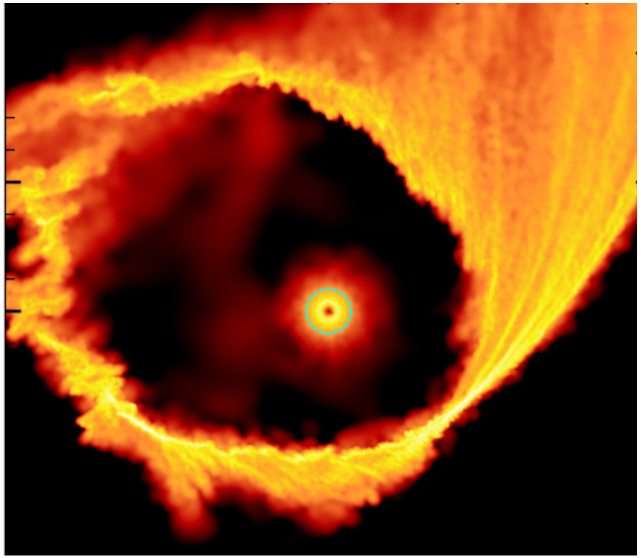
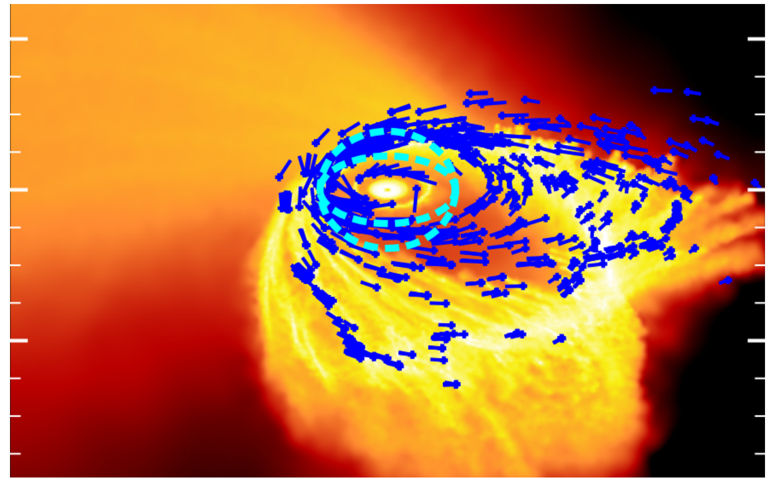
Formation of circumnuclear gas: the impact of nuclear star clusters and SMBHs





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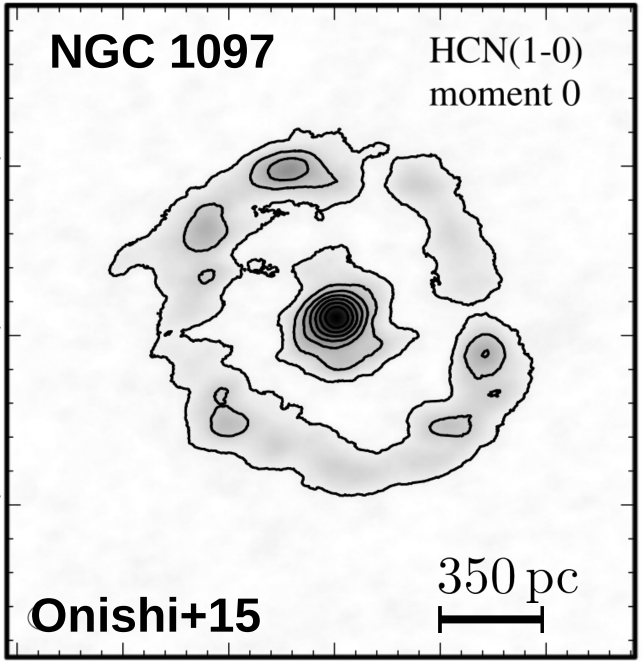
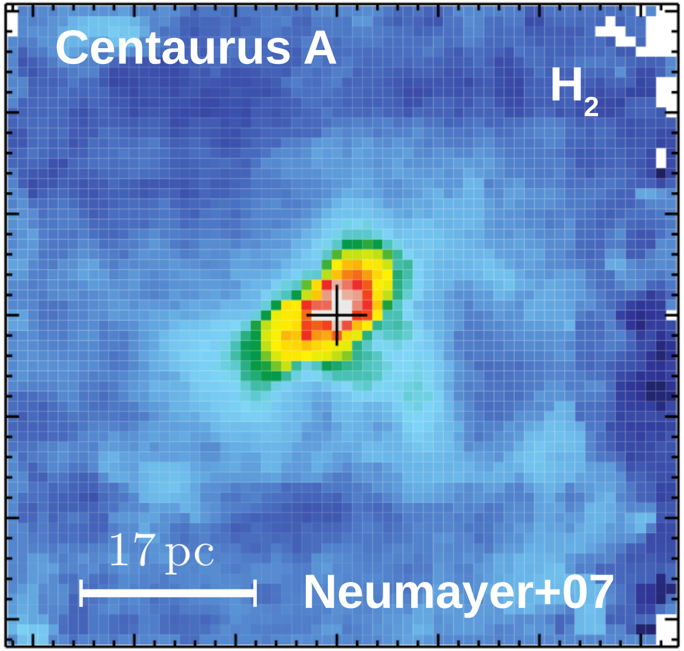
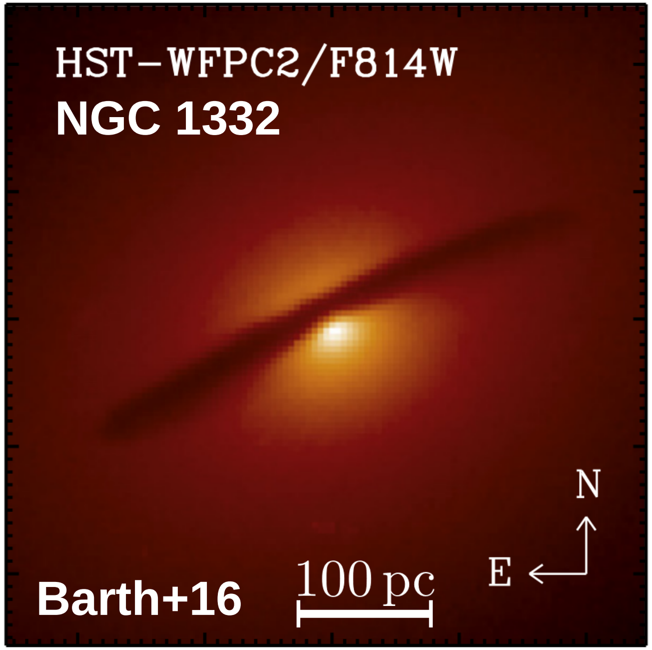
Friday 29 September 2017

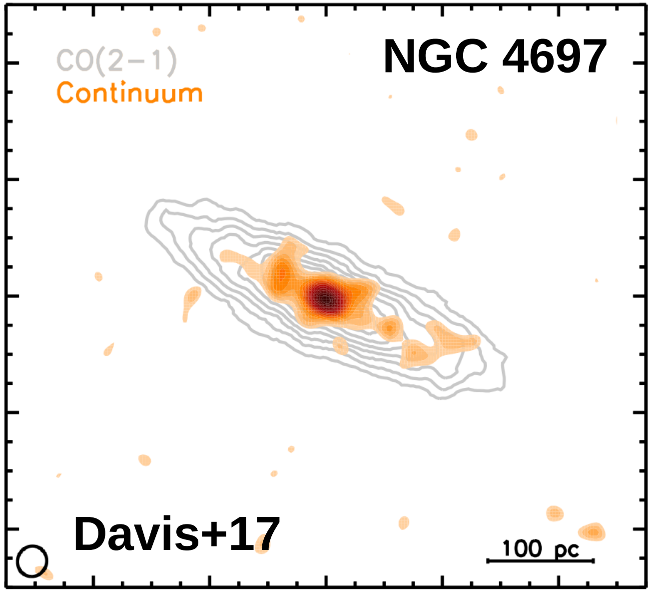
Molecular gas in galactic nuclei

- Widespread in the innermost ~100 parsecs of galactic nuclei
- Rotating about a gravitational centre
- Complex morphology and kinematics: clumpy streamers, warped rings and disks (Davis+13, Onishi+17)

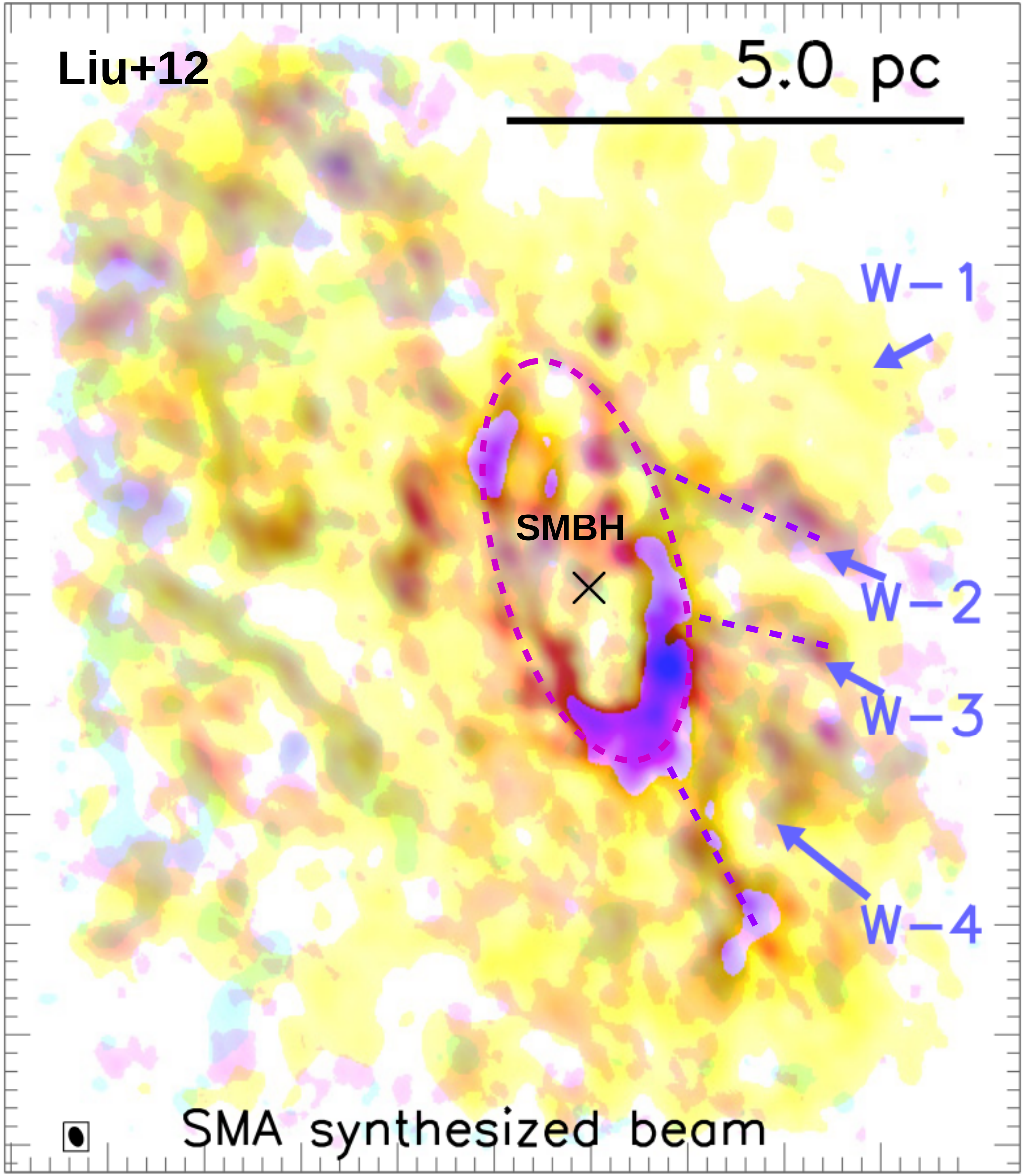








Molecular gas in the Galactic center



Circumnuclear ring (CNR)

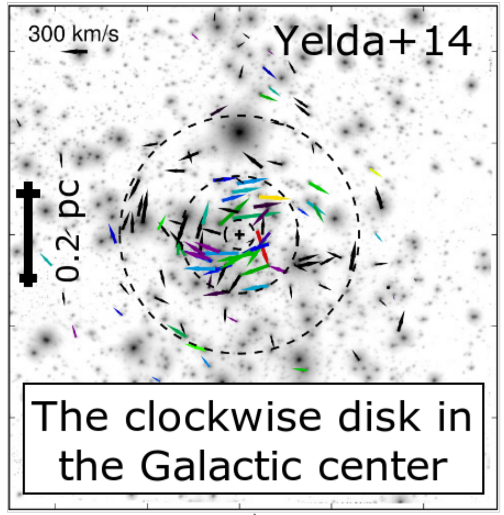
- Ring of molecular gas and dust
- Connected to/fed by streamers and nearby clouds
- Distance from SgrA*: $\sim 2\,\mathrm{pc}$

HOW CIRCUMNUCLEAR GAS FORMS?

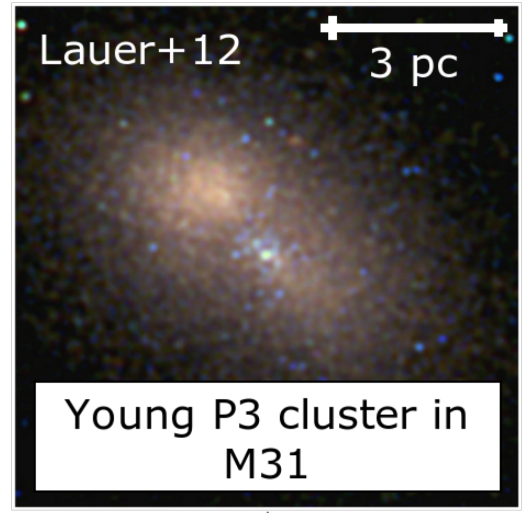
Why circumnuclear gas?

MOLECULAR GAS IN GALACTIC NUCLEI

- GAS PHYSICS IN EXTREME ENVIRONMENT
- SMBH FEEDBACK
- STAR FORMATION CLOSE TO SMBHs → stellar disks around SMBHs (*in situ*)
- IMPACT ON STELLAR DYNAMICS
- GOOD TRACER OF GRAVITATIONAL POTENTAL → ideal to infer SMBH mass in gas-rich, late type galaxies



The clockwise disk in the Galactic center

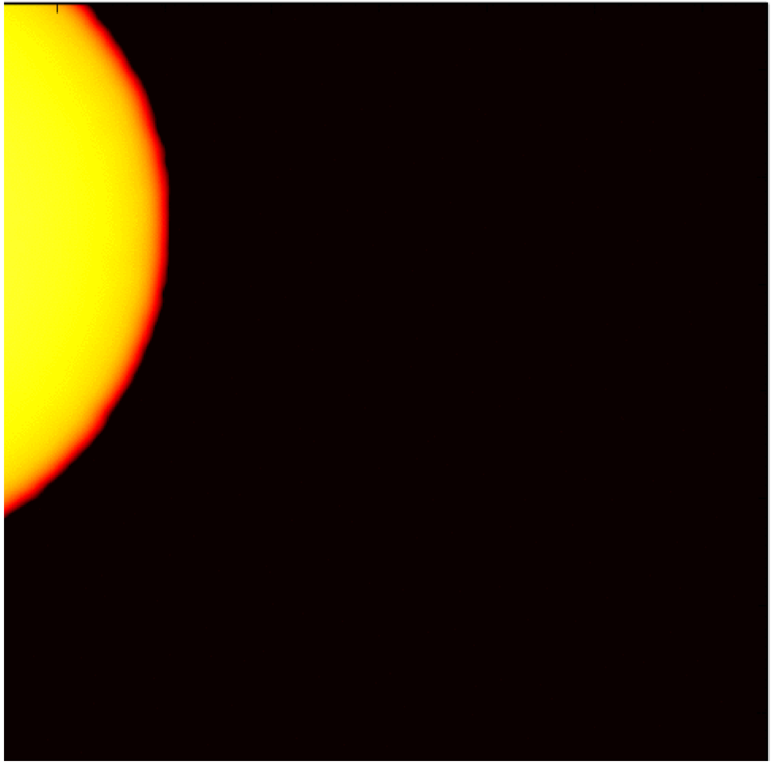


Young P3 cluster in M31

BUT HOW CIRCUMNUCLEAR GAS FORMS?

Formation of circumnuclear gas

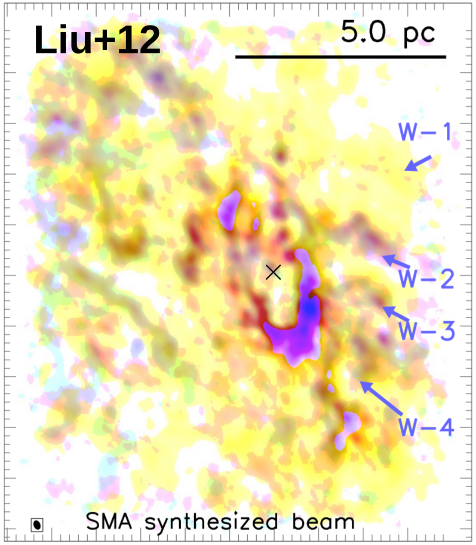
- Accumulation of ambient gas
- Funnelling of stellar winds
- Tidal disruption of infalling molecular cloud



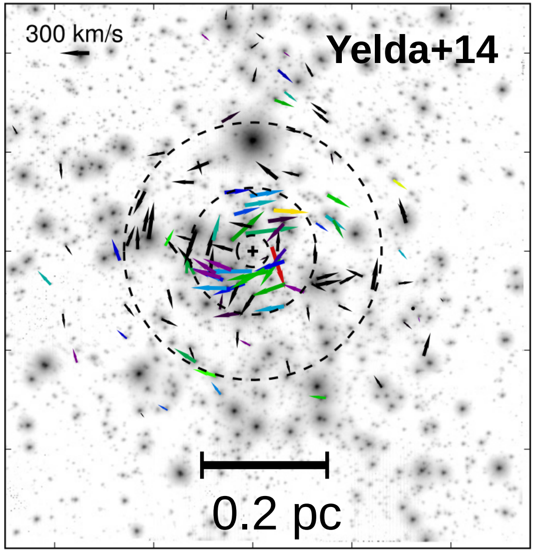
Sanders-98; Wardle+08; Hobbs&Nayakshin-09; Bonnell&Rice-08; Mapelli+08,12; Alig+11,13; Lucas+13; AAT+16a; Mapelli&AAT-16

Scenario proposed to explain:

The circumnuclear disk

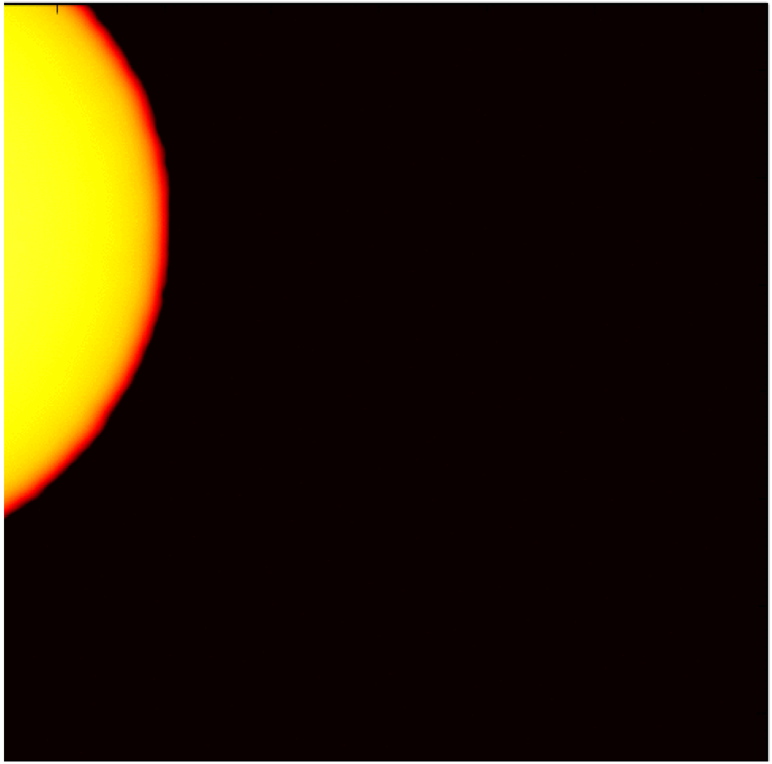


The disk of young stars



Formation of circumnuclear gas

- Accumulation of ambient gas
- Funnelling of stellar winds
- Tidal disruption of infalling molecular cloud



Sanders-98; Wardle+08; Hobbs&Nayakshin-09; Bonnell&Rice-08; Mapelli+08,12; Alig+11,13; Lucas+13; AAT+16a; Mapelli&AAT-16

Scenario proposed to explain:

The circumnuclear disk   The disk of young stars

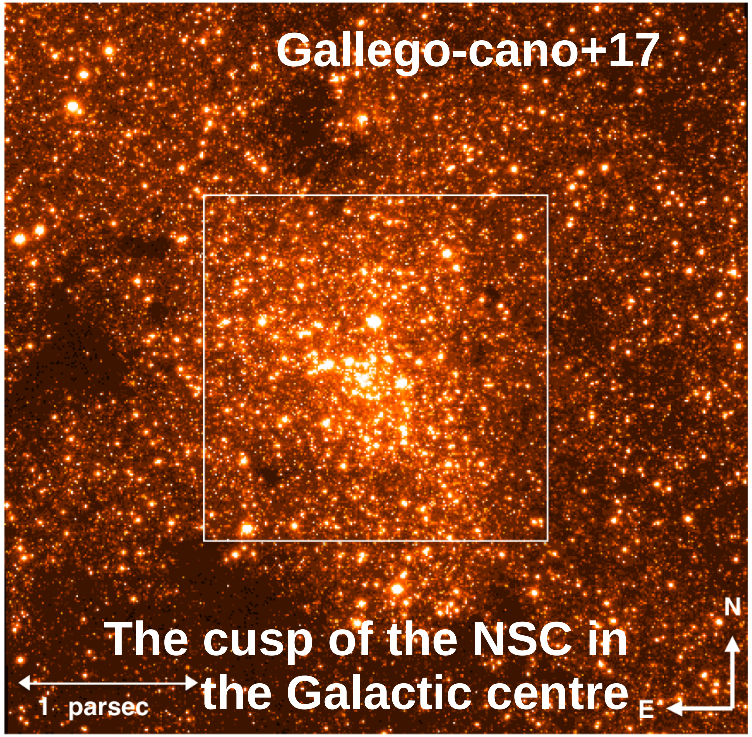
ONLY IN THE MILKY WAY!

What about other galactic nuclei??

Infalling molecular cloud scenario in (extra)galactic nuclei

What can change?

- SMBH → Higher mass: faster tidal disruption, **larger** SMBH radius of influence $R_{\rm SOI}$
- Nuclear star cluster → Higher mass: faster tidal disruption, **shorter** SMBH radius of influence $R_{\rm SOI}$



NUCLEAR STAR CLUSTERS (NSCs)

Galactic nuclei can host both NSC and SMBH

Ferrarese+06, Seth+08b, Graham&Spitler-09, Kormendy+09, Neumayer&Walcher-12, Georgiev&Böker-14, Georgiev+16

Smoothed particle hydrodynamics (SPH) simulations

SPH simulations grid of infalling molecular cloud:

spherical, turbulent
R~15 pc, M~10^5 $M_\odot$

varying mass ratio

$$f_{\rm SMBH} = \frac{M_{\rm SMBH}}{M_{\rm tot}}$$

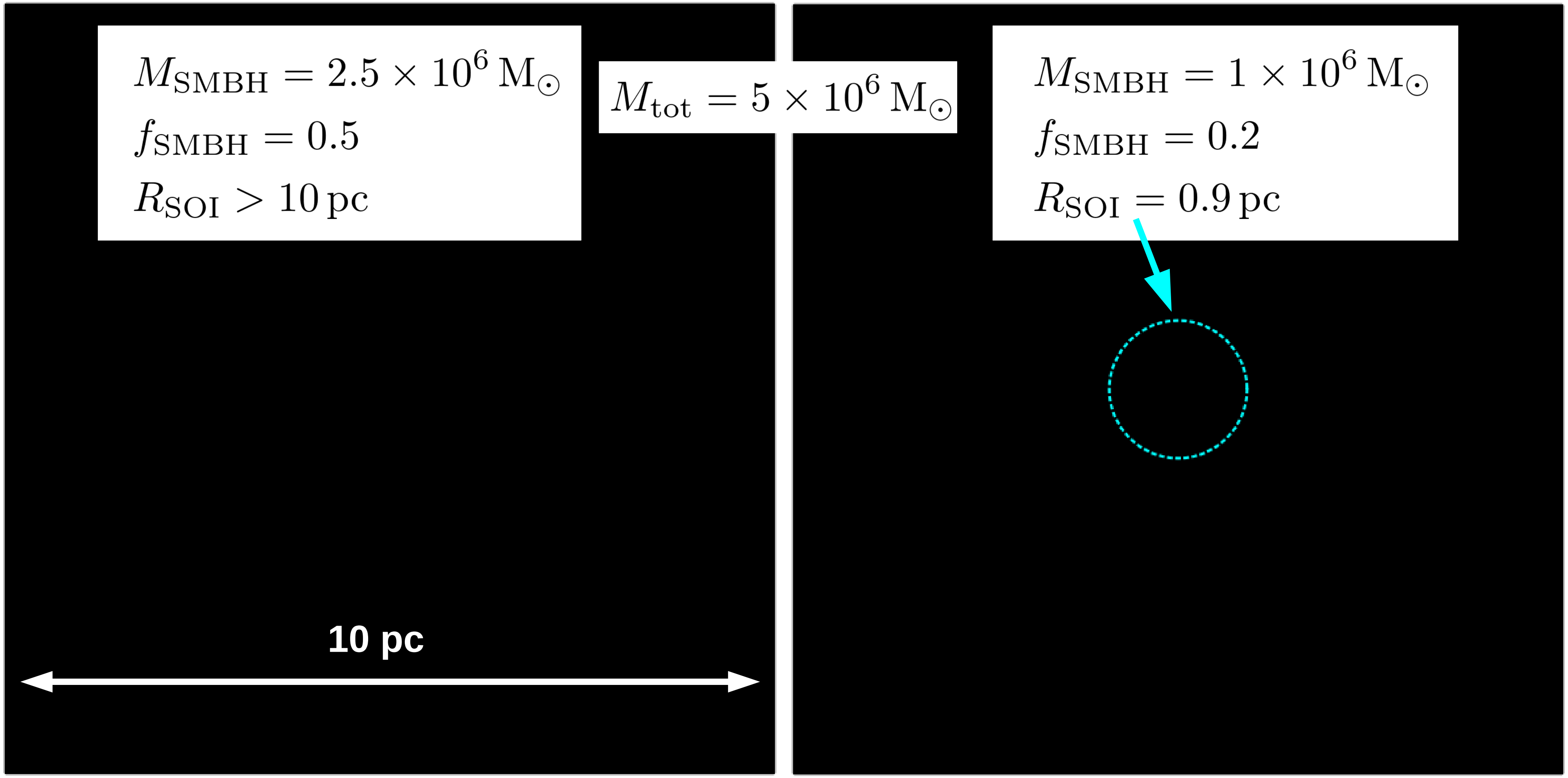
$$M_{\rm tot} = M_{\rm NSC}(< 10\,{\rm pc}) + M_{\rm SMBH}$$

SMBH AS SINK PARTICLE

NSC AS ANALYTIC POTENTIAL
(broken power-law spherical density profile – as in the GC)

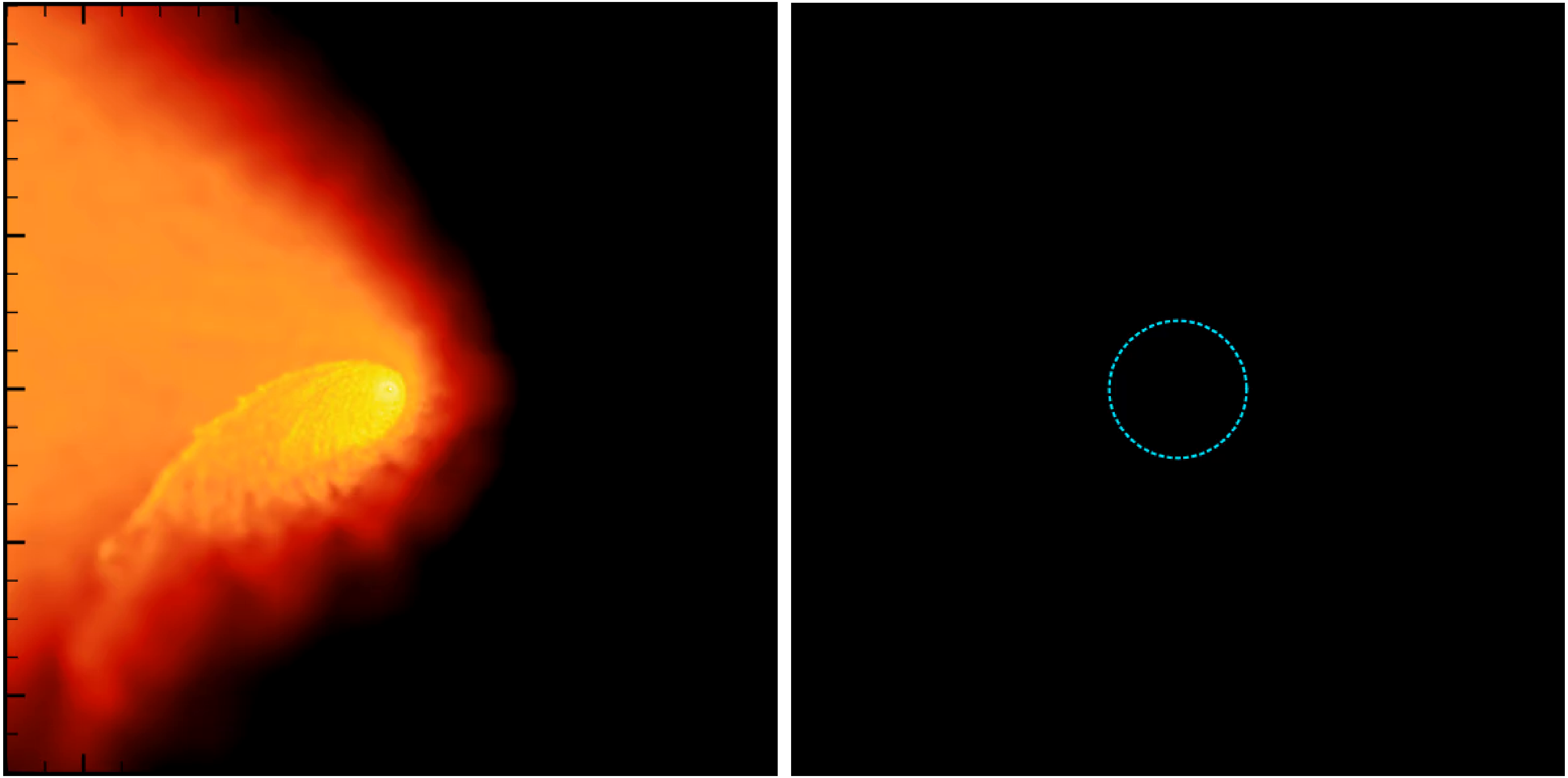
CODE GASOLINE2 (Wadsley+17): State-of-the-art Viscosity&Sinks + Cooling

SAME M_{TOT}, DIFFERENT M_{SMBH}



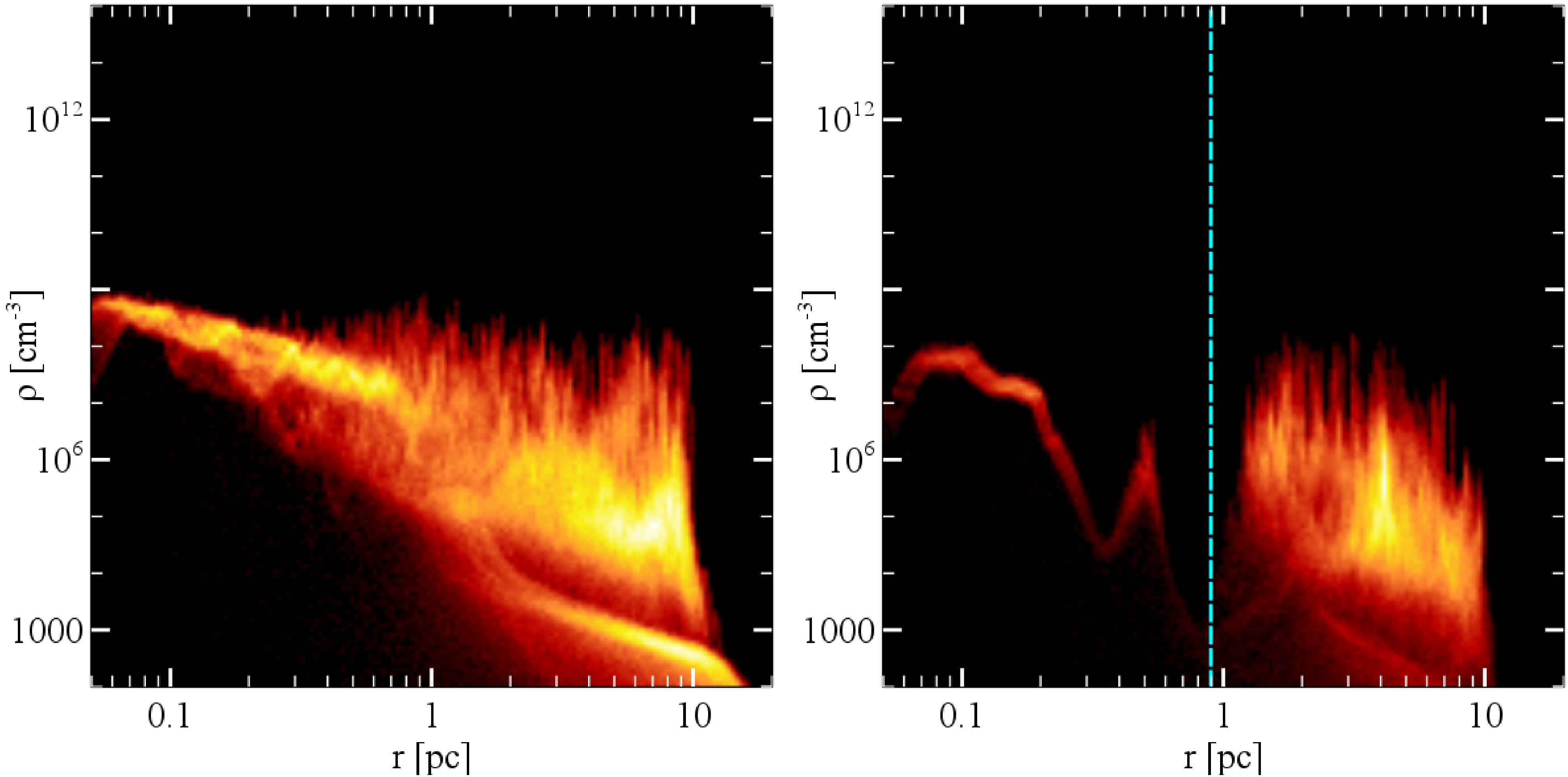
Fixed orbit: $v_{cloud} = 0.2\ v_{escape}$ falling from ~26 pc

SAME M_{TOT}, DIFFERENT M_{SMBH}

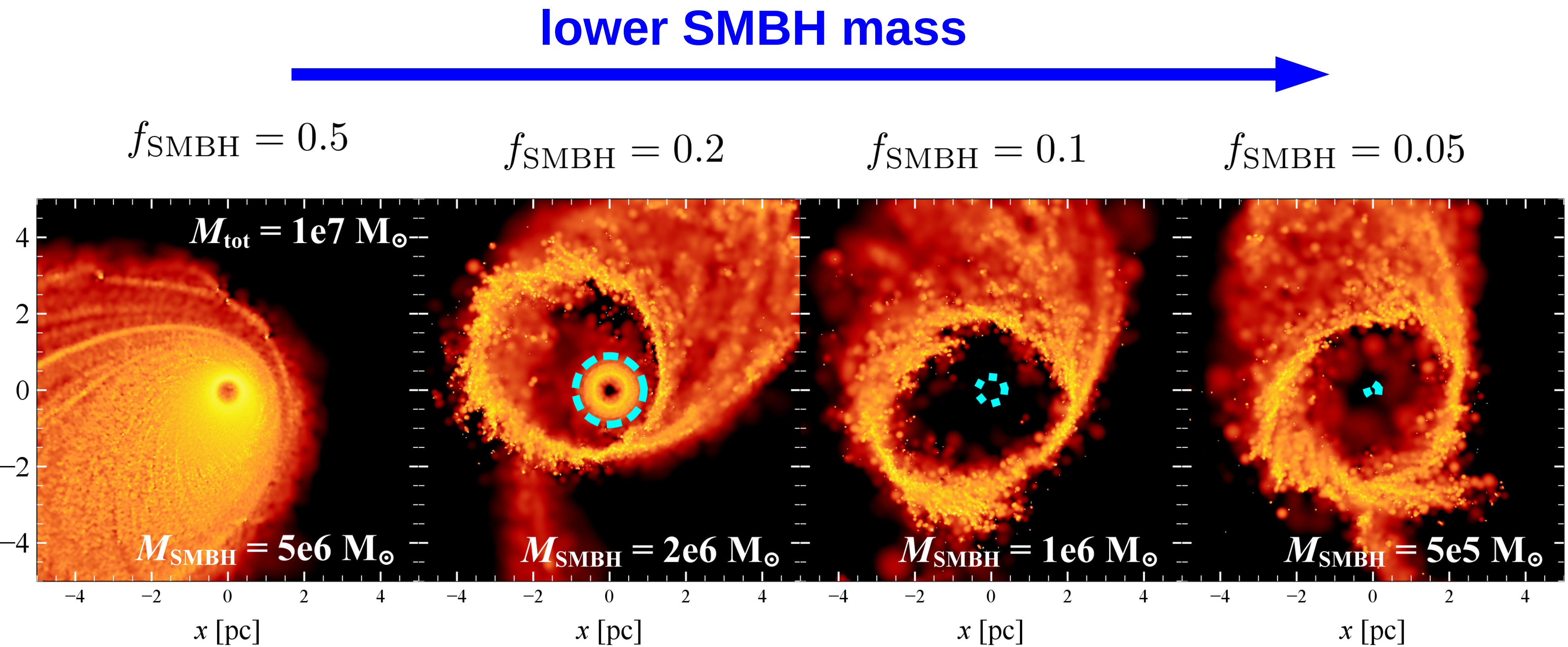


~1.5 Myr

SAME M_{TOT}, DIFFERENT M_{SMBH}

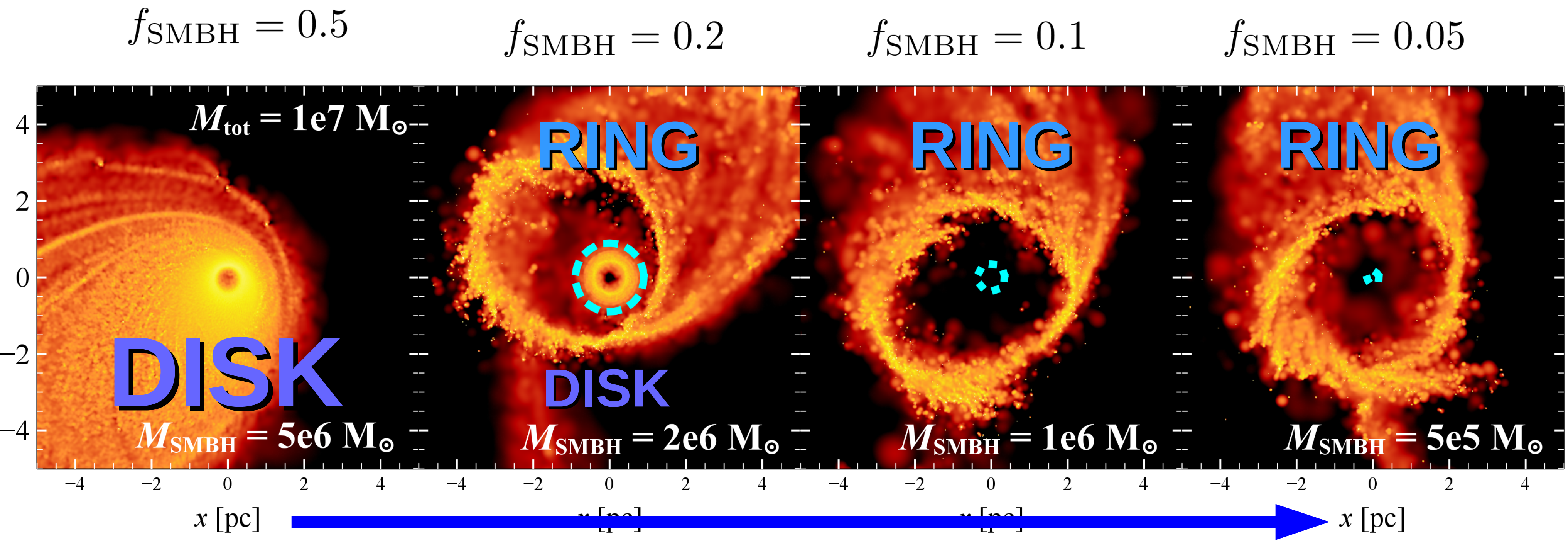


Simulation grid



Simulation grid

lower SMBH mass

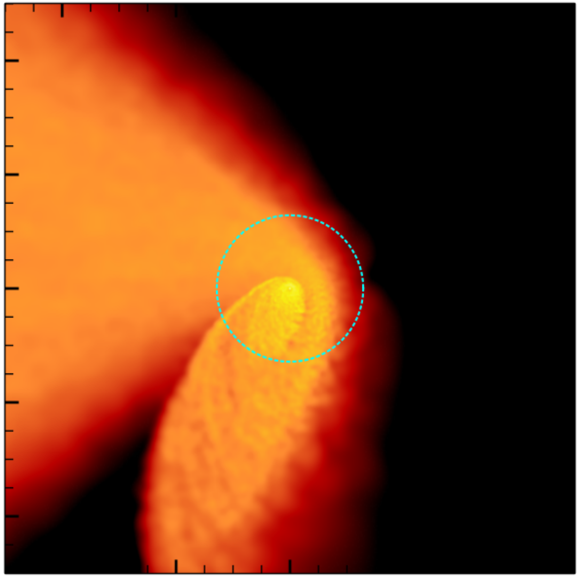


transition from disk to ring

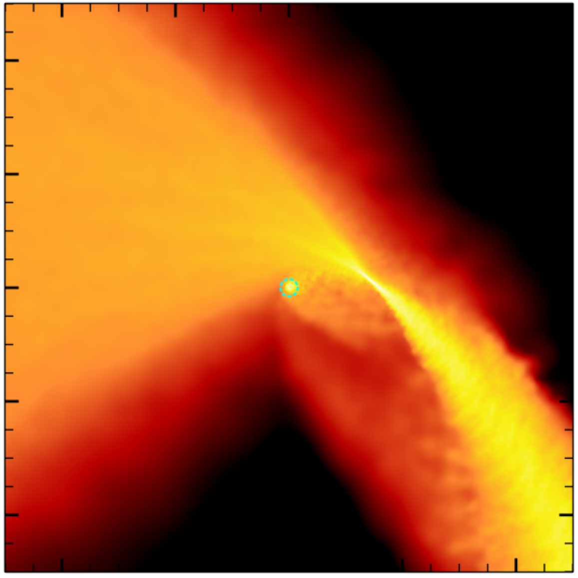
disk inside

ring outside

Disk vs ring



$a \propto r^{-2}$



$a \propto r^{1-\gamma}$

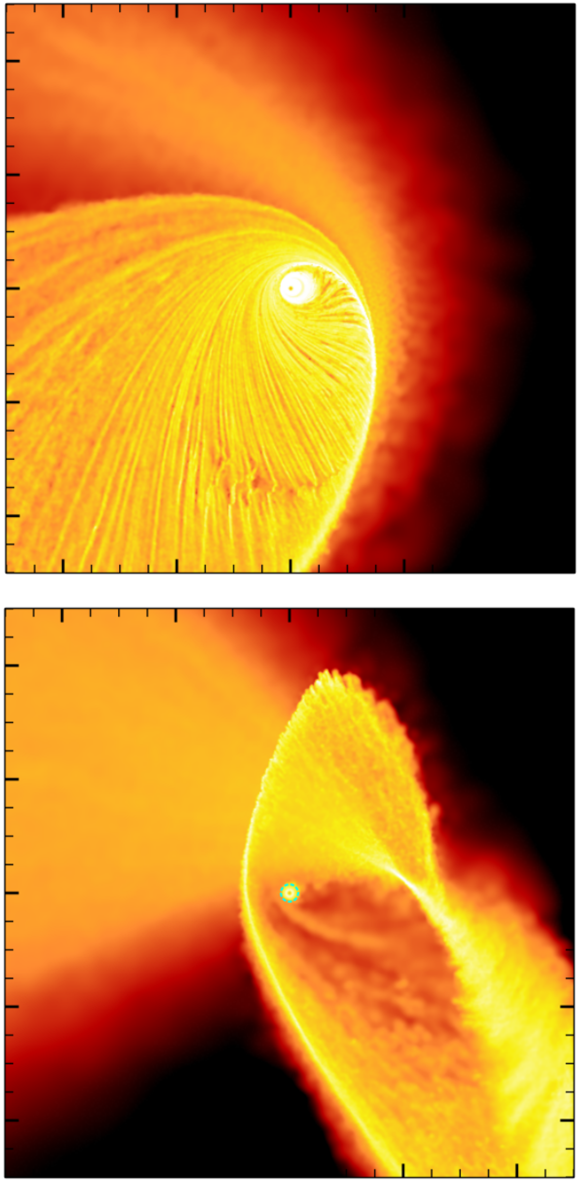
$\rho \propto r^{-\gamma}$

- Disk forms inside $R_{\rm SOI}$
- CNR-like ring outside $R_{\rm SOI}$
- Gas captured..

  by SMBH winds up around it

  by NSC get squeezed in a self-intersecting streamer

Disk vs ring



- Disk forms inside R_{SOI}
- CNR-like ring outside R_{SOI}
- Gas captured..

    by SMBH winds up around it

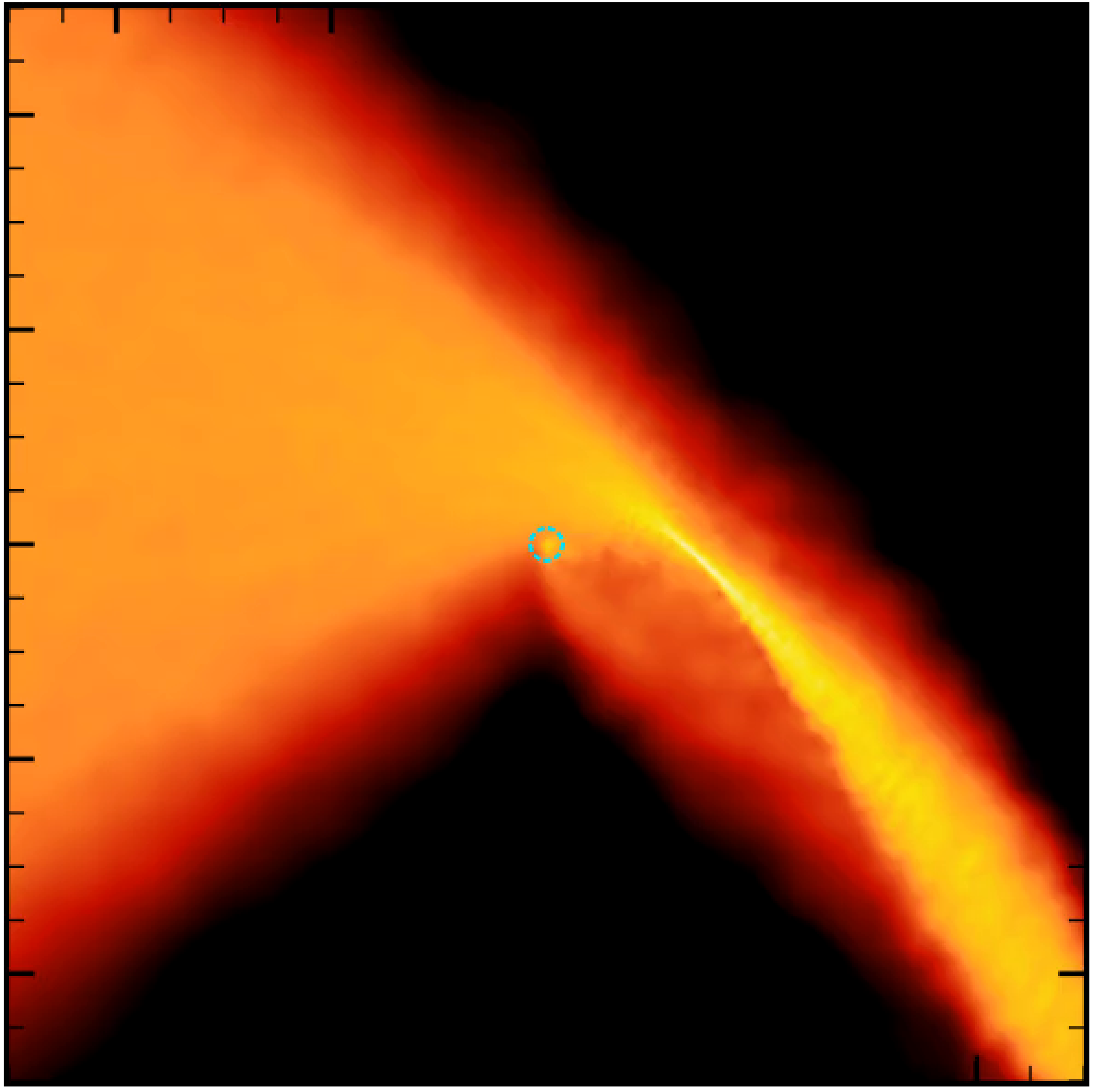
    by NSC get squeezed in a self-intersecting streamer

- Circularization..

    in eccentric disk, through shocks of intersecting streamlines

    in streamer, by self-intersection shocks

Star formation

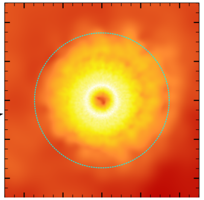


- Stars form before gas settles
- Gaseous and stellar streamers decouple
- Very different gas and star final distribution

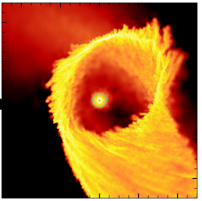
Summary

AAT et al. 2017, to be submitted

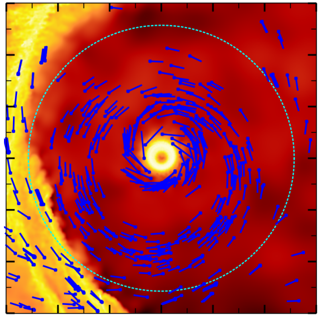
- Gaseous disk forms inside $R_{\rm SOI}$



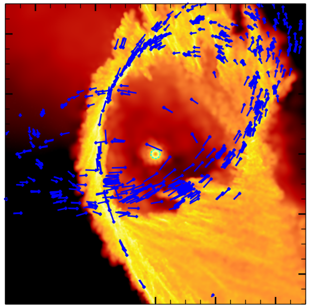
- Clumpy ring forms outside $R_{\rm SOI}$



- Disk can fragment and form stellar disk inside $R_{\rm SOI}$



- Gas and stars can dynamically decouple

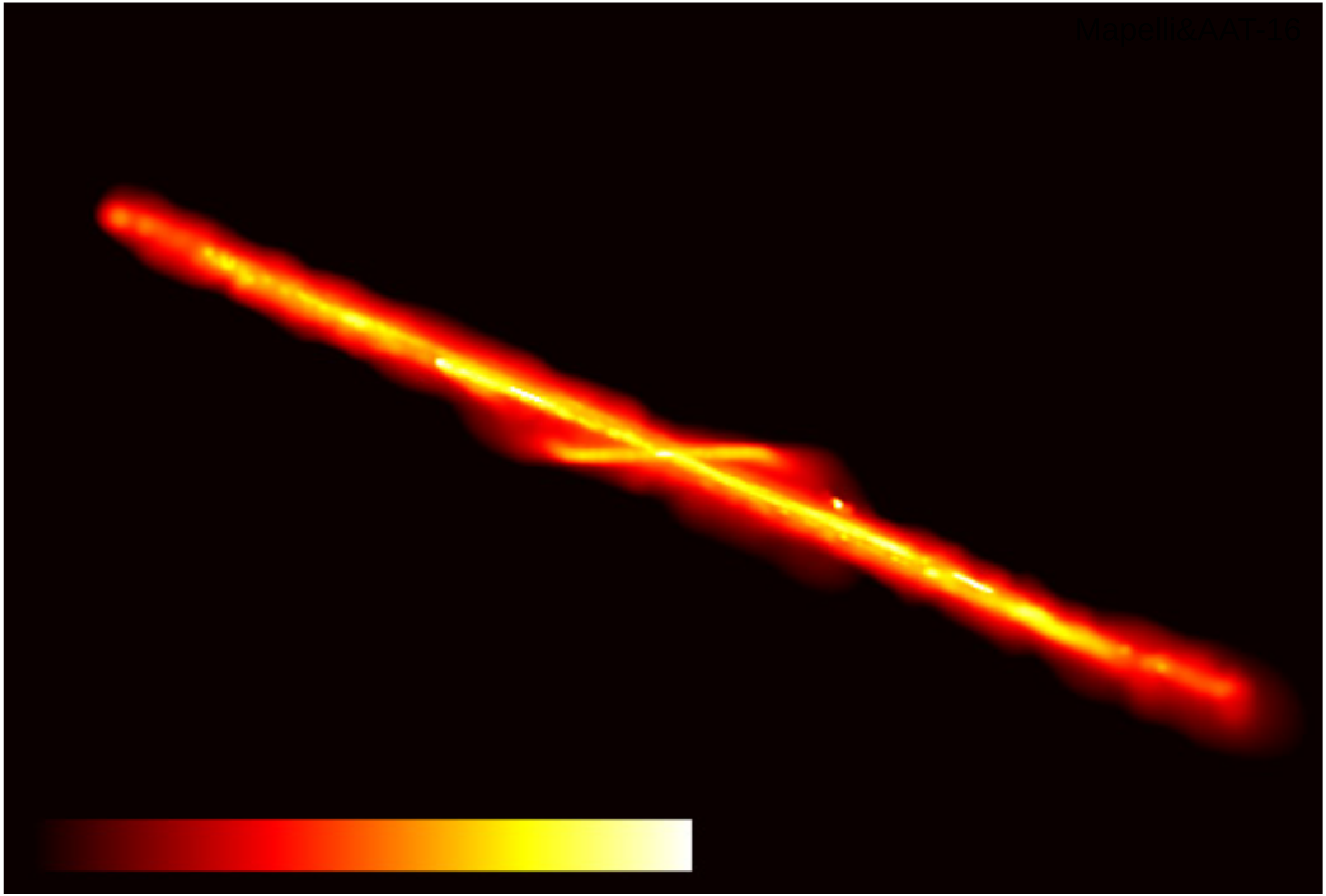


remarks

1. radius of gaseous ring is upper limit to $R_{\rm SOI}$
2. CNR formed by tidal disruption in NSC
3. to form only disk, entire cloud has to fit within $R_{\rm SOI}$

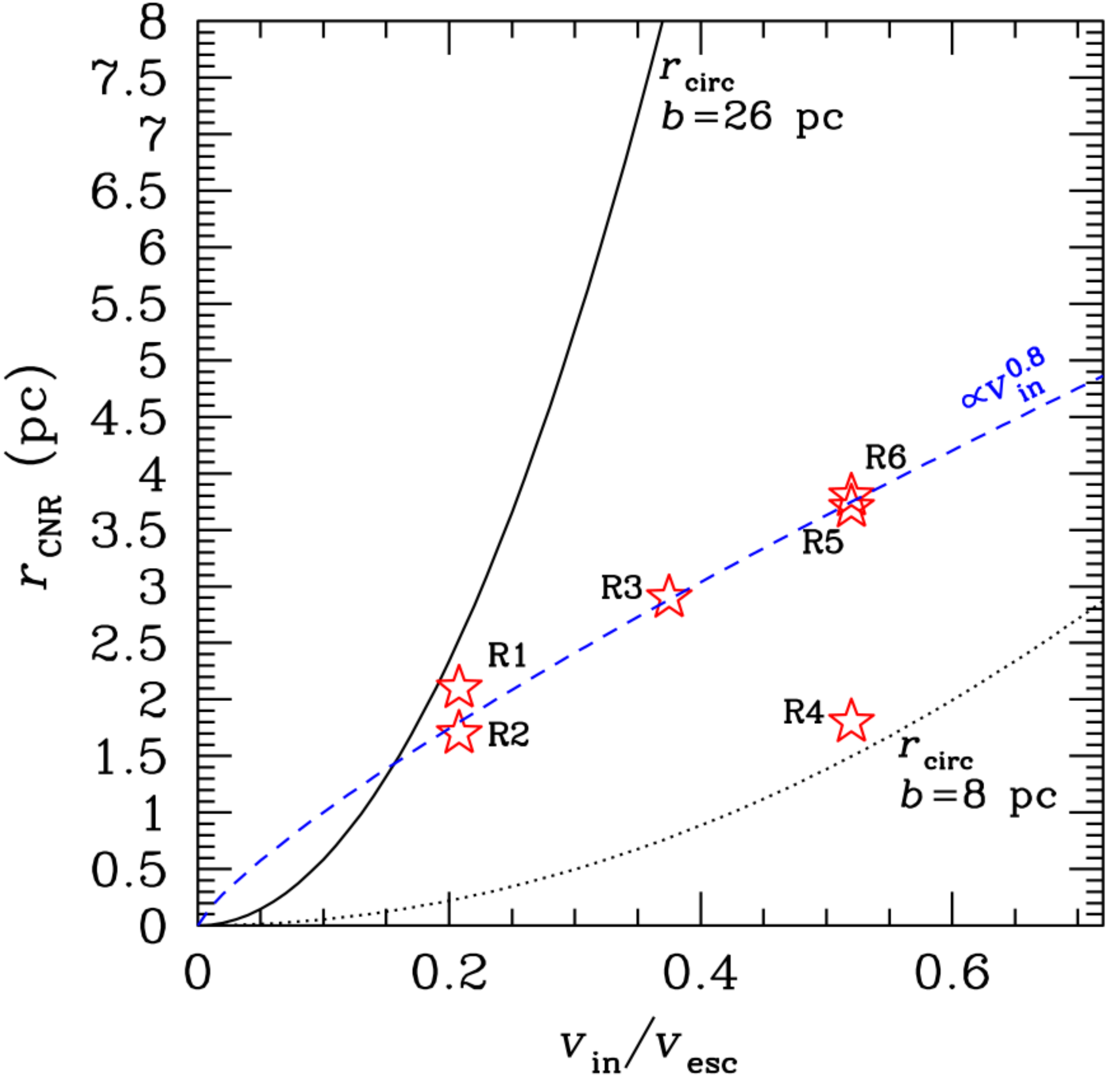
- CNR & young stellar disk in the GC formed by same episode?

Next steps: non-equilibrium chemistry, mock PV diagrams


Mapelli&AAT-16

Initial conditions

Mapelli&AAT-16



Smoothed particle hydrodynamics simulations

CODE: GASOLINE2 (Wadsley+04, Read+10 Wadsley+17)

- State-of-the-art viscosity treatment (Monhagan-97, Cullen&Dehnen-10)
- Cooling (Plank+Rosseland opacities, Boley+10)
- State-of-the-art sink particles algorithm (Bate+95, Federrath+10)

INFALLING MOLECULAR CLOUD

- Spherical
- R~15 pc, M~10^5 $M_{\odot}$
- Turbulent velocities
- V_{COM}~0.2 V_{escape}

SMBH AS SINK PARTICLE

NSC AS ANALYTIC POTENTIAL

$$\rho(r) = \rho_0 \left(\frac{r}{r_0}\right)^{-\gamma}$$

$$\gamma = 1.75 \text{ for } r > r_0$$
$$\gamma = 1.2 \text{ for } r < r_0$$

Nuclear star clusters

Georgiev+16