Star Formation Close to the Supermassive Black Hole Sgr A*

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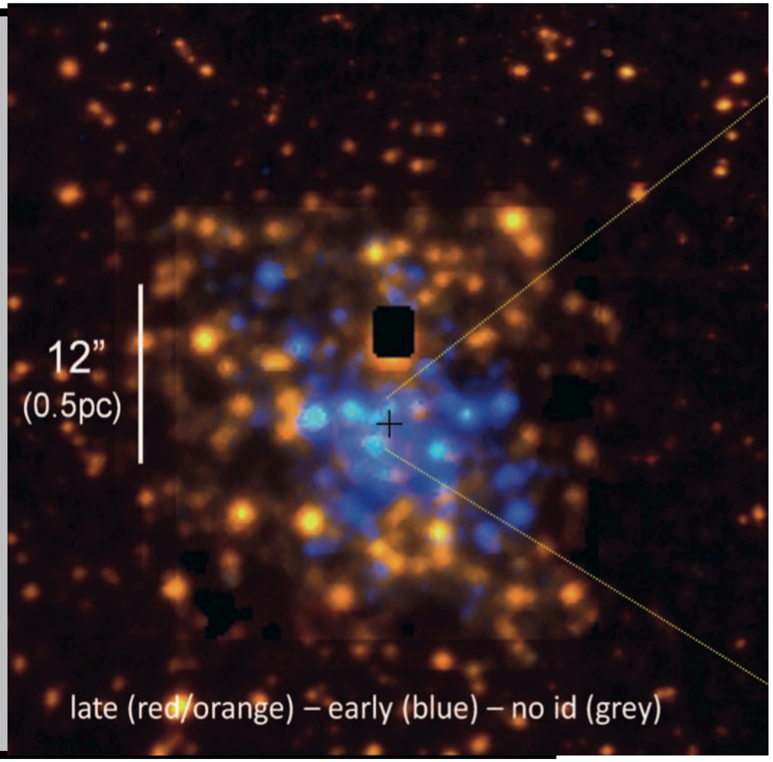
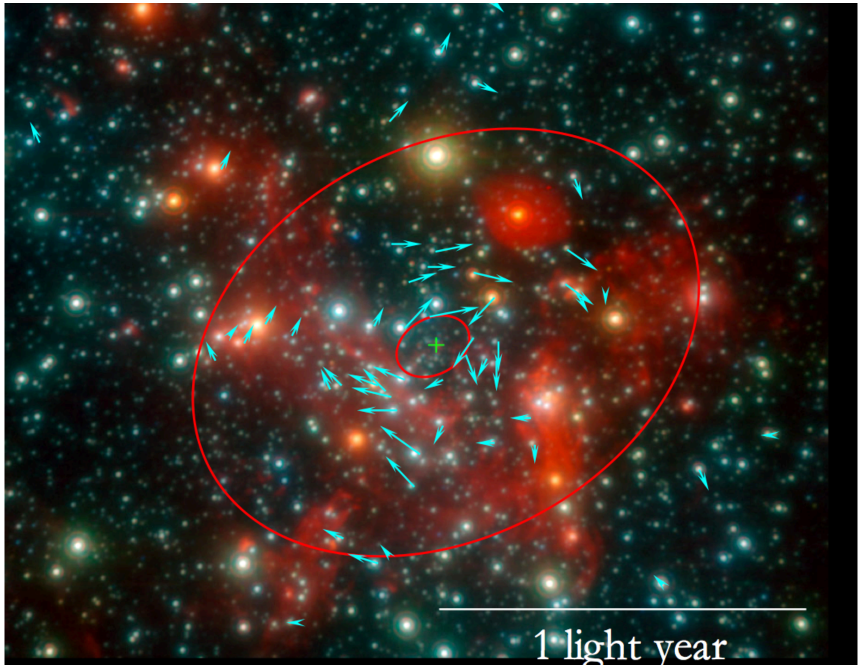
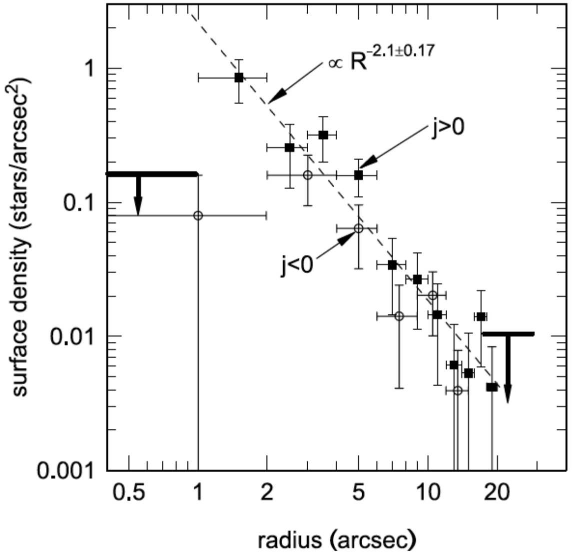
- **Outline**
  - Massive young stars
  - Disk-based mode of star formation
  - Five signatures of on-going star formation
  - SEDs of YSOs, SiO outflows, proplyds
  - Collapse mode of star formation
  - The conditions for cloud collapse
- **Conclusions**



High Mass Star Formation near Sgr A*

- ~ 100 OB stars in two disks < 0.5pc
- L ~ $2x10^7$ L_{sun}
- Coeval disks t=(6+/-2)x10^6 yrs
- Stellar mass ~ 10^4 solar mass
- r^{-2} stellar density profile
- A central 1” hole





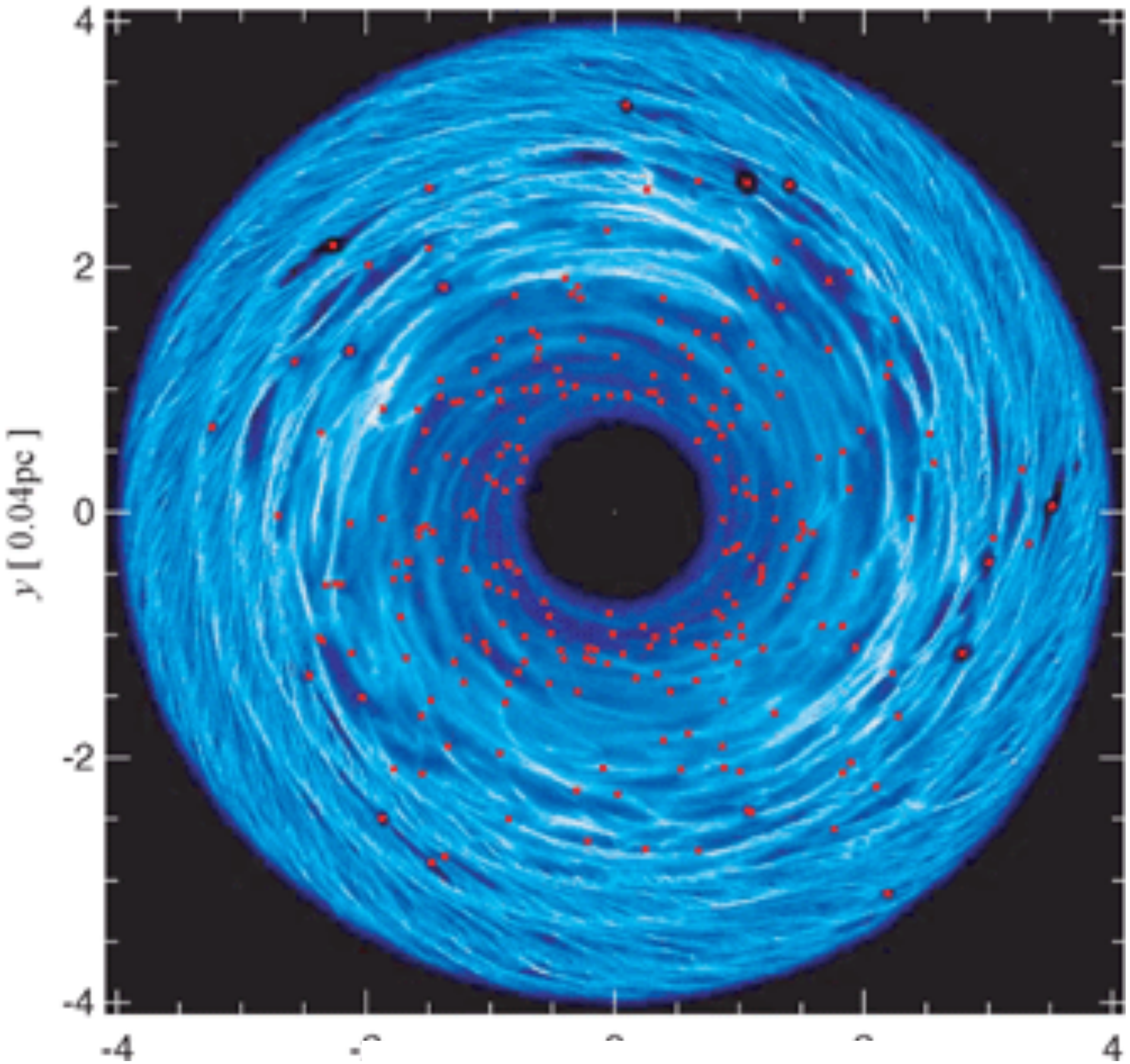
Stellar Disk Formation

- Toomre unstable
- Simulation of star formation in an accretion disk: efficient
- Snapshot of disk column density
- Red spots: stars > 3 solar mass

$$Q = \frac{c_s \Omega}{\pi G \Sigma}$$

- Toomre parameter:

$Q_{critical} \sim 1$



Nayakshin, Cuadra and Springel 2007

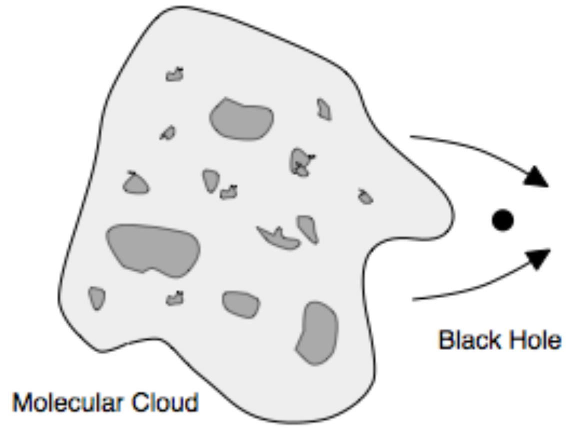
Molecular Cloud Engulfs Sgr A*

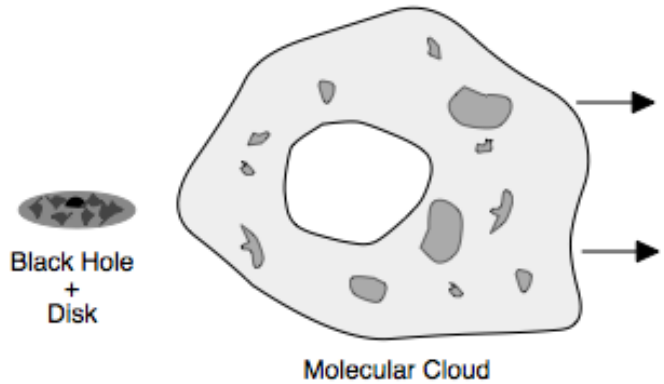
- Bondi-Hoyle: Inhomogeneous, extended cloud gravitationally focused

- Capture radius: 3pc
- 70% of angular momentum cancels out as r=3pc circularizes to 0.3pc

- Q<1 as the disk self-gravitates

- Cloud-cloud collisions: The circumnuclear ring (few pcs)





Wardle and FYZ (2008)

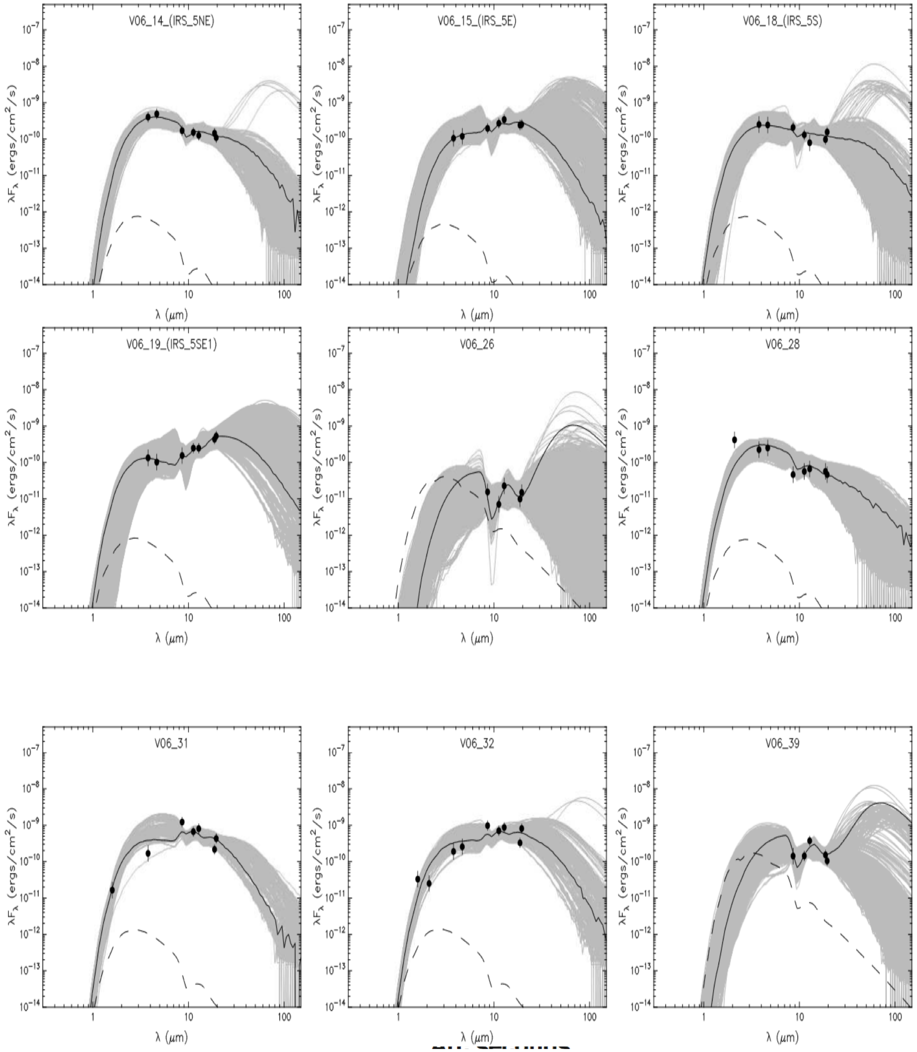
- ❑ Massive young stars
- ❑ Disk-based mode of star formation

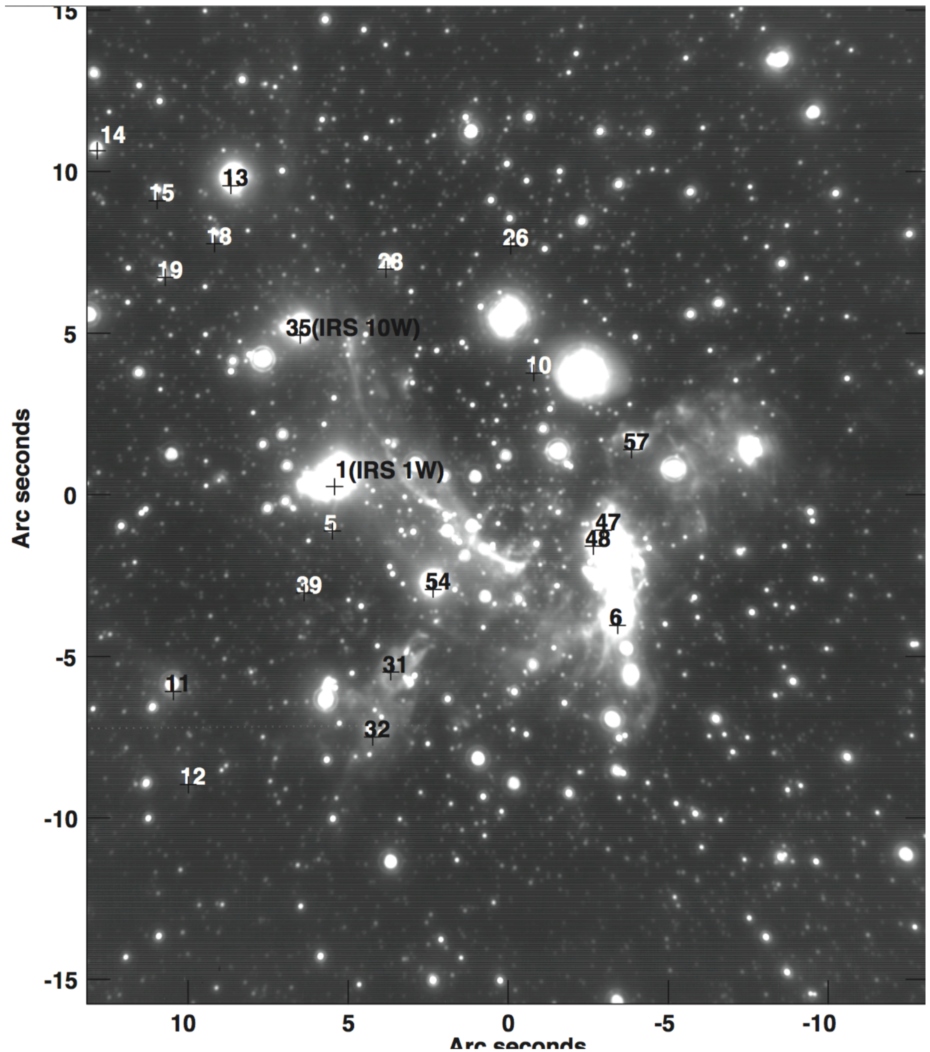
- ❑ Severl signatures of on-going star formation
- ❑ SEDs of YSOs, SiO outflows, proplyds and water masers

- ❑ Collapse mode of star formation
- ❑ The conditions for cloud collapse

- **Conclusions**

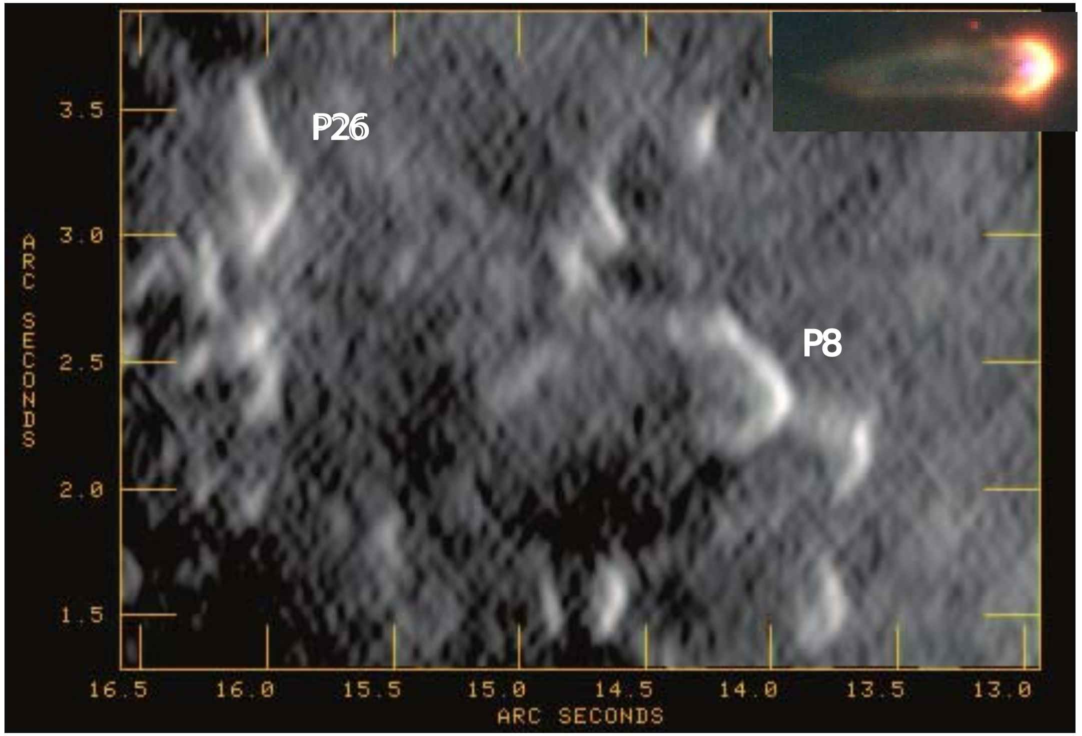
1. Infrared Excess Sources





- The distribution of YSO candidates is superimposed on a 7mm and 3.6 micron continuum image based on VLA and VLT observations. (FYZ et al. 2015).

2. Star Formation near Sgr A*: Proplyd Candidates



- Cometary morphology
- Size scale ~500AU
- $[NLy/d^2]_{(GC)} \sim [NLy/d^2]_{(Orion)}$
- Protoplanetary disk candidates
- Multiple sources of illumination

1) Gas needs to be replenished ~ 240 yr
2) Must be bound by self-gravity to be stable against tidal disruption

$n(H) \sim 10^6$ cm^{-3} $\ll$ Roche density $< 2 \times 10^8 (r/1pc)^{-3}$ cm^{-3}

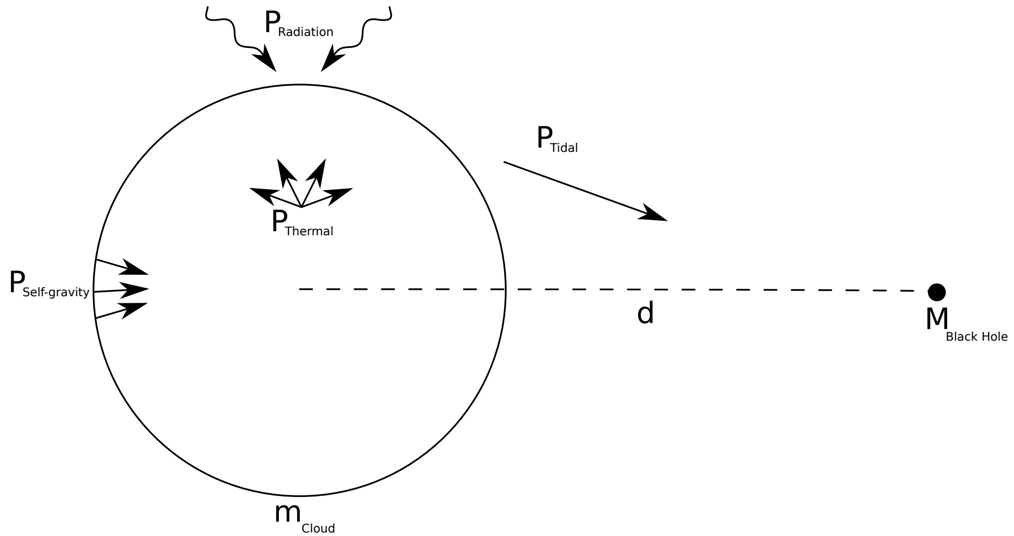
- ❑ Massive young stars
- ❑ Disk-based mode of star formation

- ❑ Four signatures of on-going star formation
- ❑ Water masers, SEDs of YSOs, SiO outflows & proplyds

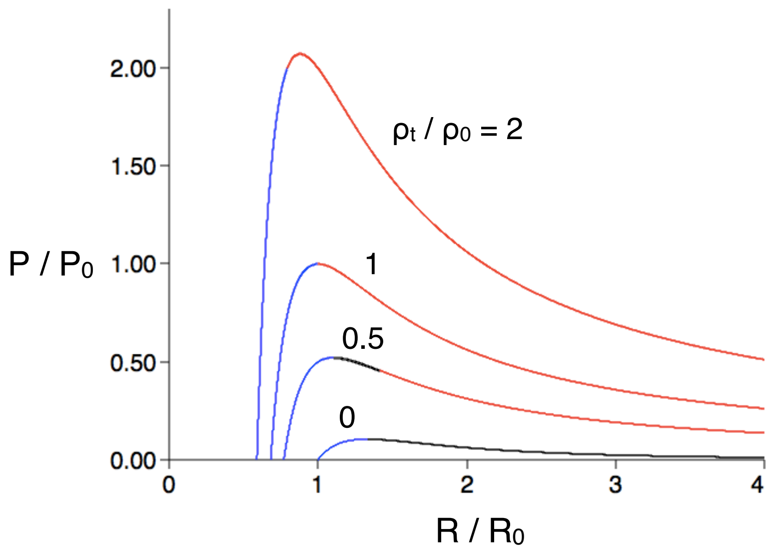
- ❑ Collapse mode of star formation
- ❑ The conditions for cloud collapse

- **Conclusions**

Cloud Collapse near Sgr A*: Pressure vs Cloud size



- Stability analysis
- Confinement by self-gravity and $P_{external}$
- Tearing by internal $P_{internal}$ and tides

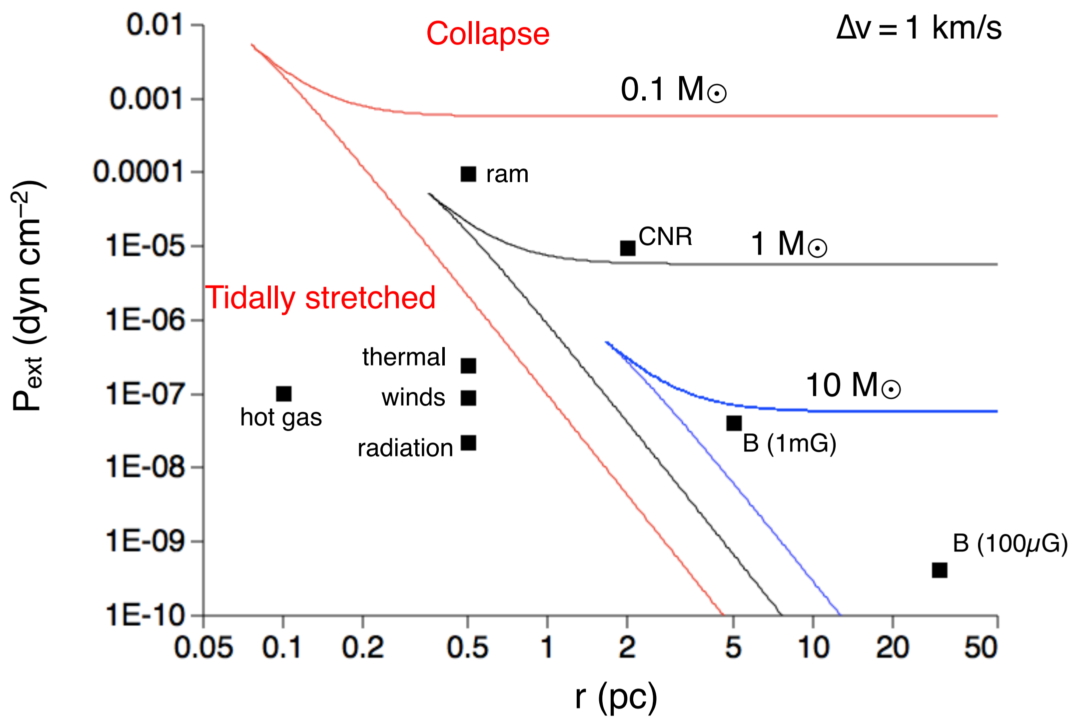


- Peak: Stable equilibrium (black)
- Left of the peak, gravitationally unstable
- Right of the peak, tidally unstable

- How much $P_{external}$ is needed to keep a cloud with certain size
  - Big size: not much $P_{external}$
  - Small size: you need high density

Cloud Collapse near Sgr A*

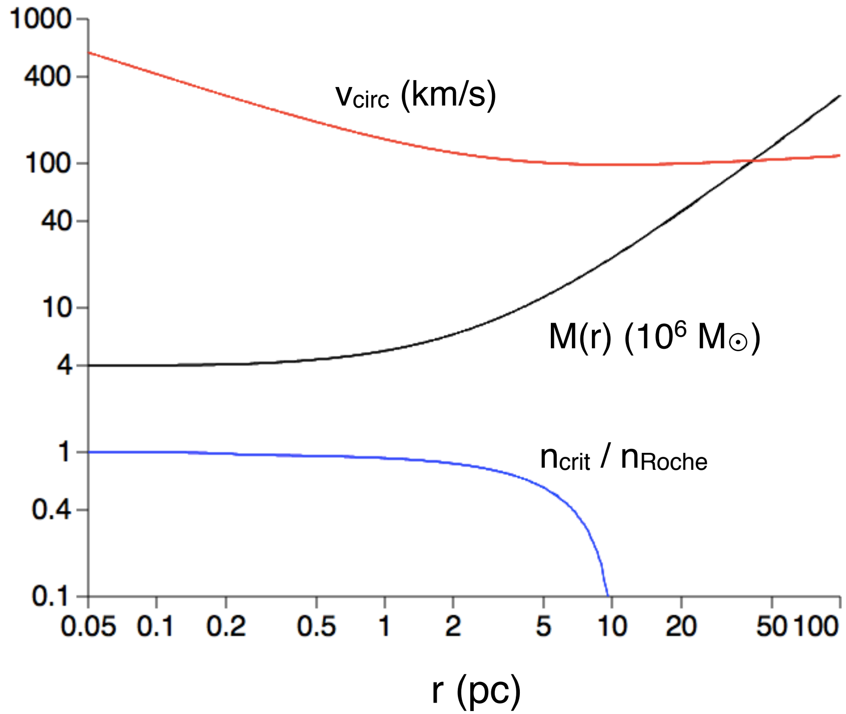
- Range of $P_{external}$ vs distance from Sgr A*
- Cloud mass is 0.1, 1, 10 & 100 solar mass
- Fixed velocity dispersion 1 km/s



Wardle & Yusef-Zadeh (in prep.)

Cloud Collapse in the Nuclear Cluster and Beyond

- Rotation Curve and Tides
- Tides become compressive at large distances from Sgr A*
- The Arches and Quintuplet clusters



Wardle & Yusef-Zadeh (in prep.)

- **Conclusions**

  - There is strong evidence for in-situ star formation
  - Disk-based mode of star formation
  - Collapse-based mode of star formation

  - High external pressure contribution to star formation near Sgr A*
  - Tidal pressure help formation of stars at large distances