Star formation within 0.5 pc of Sgr A*

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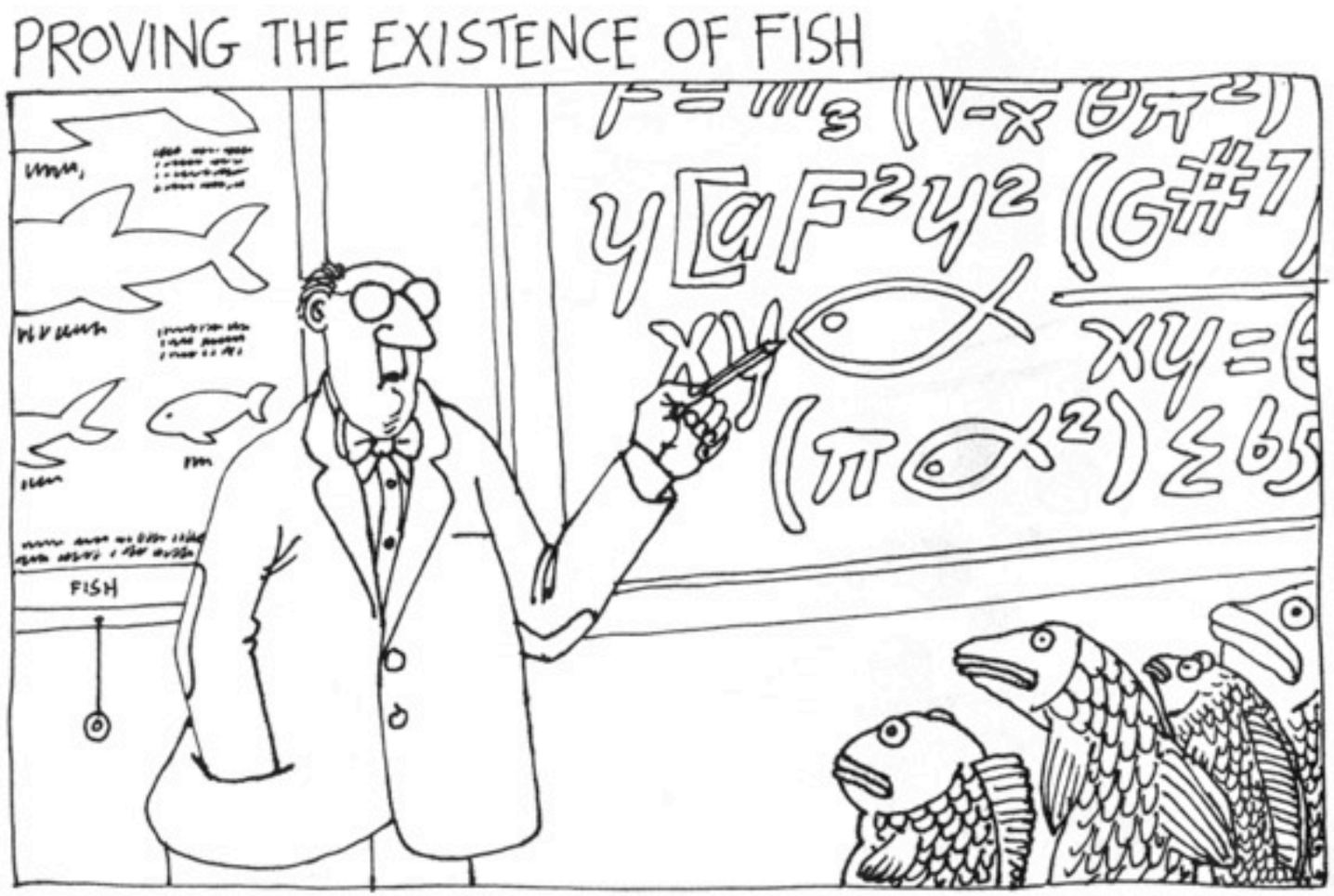
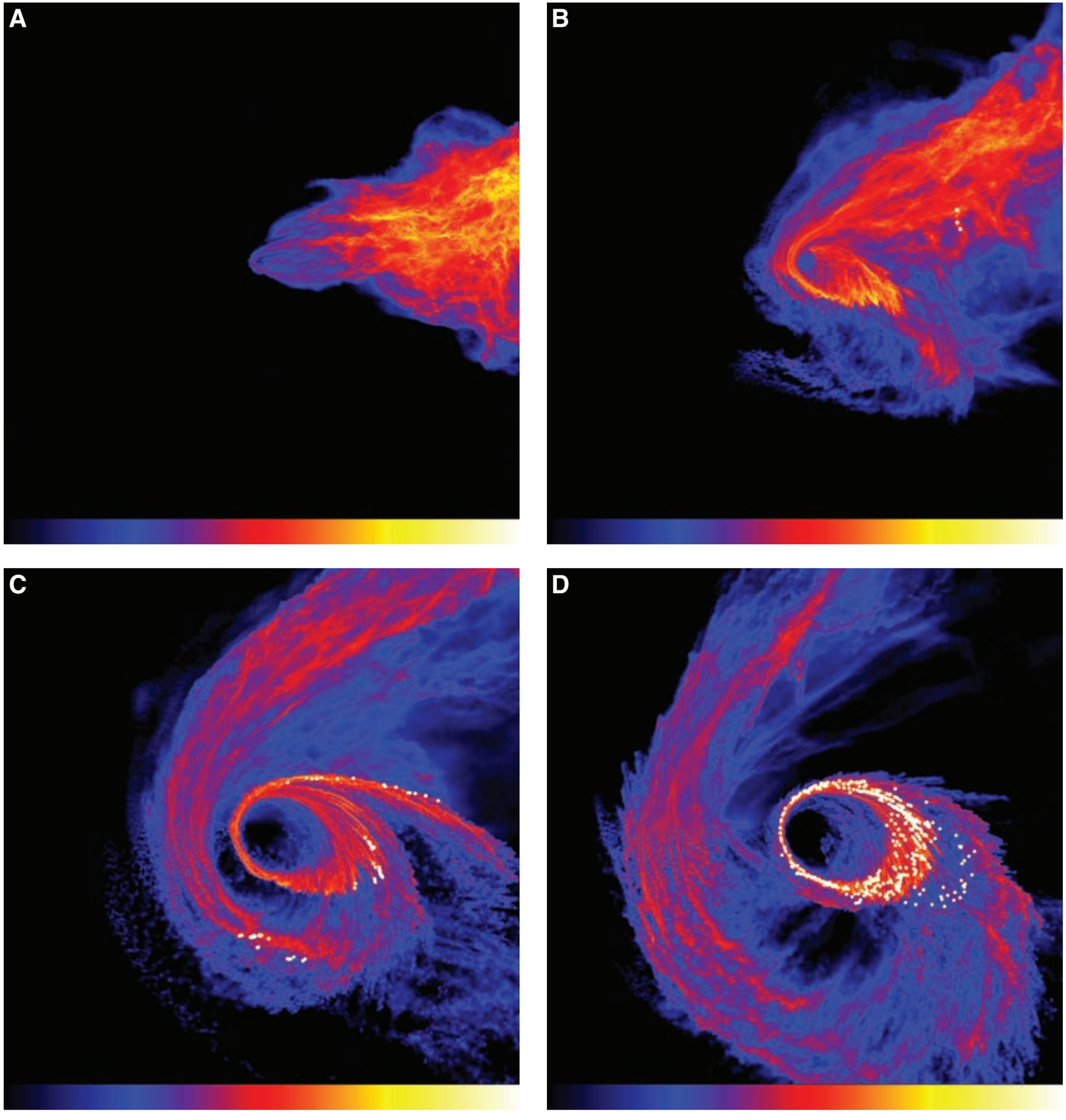


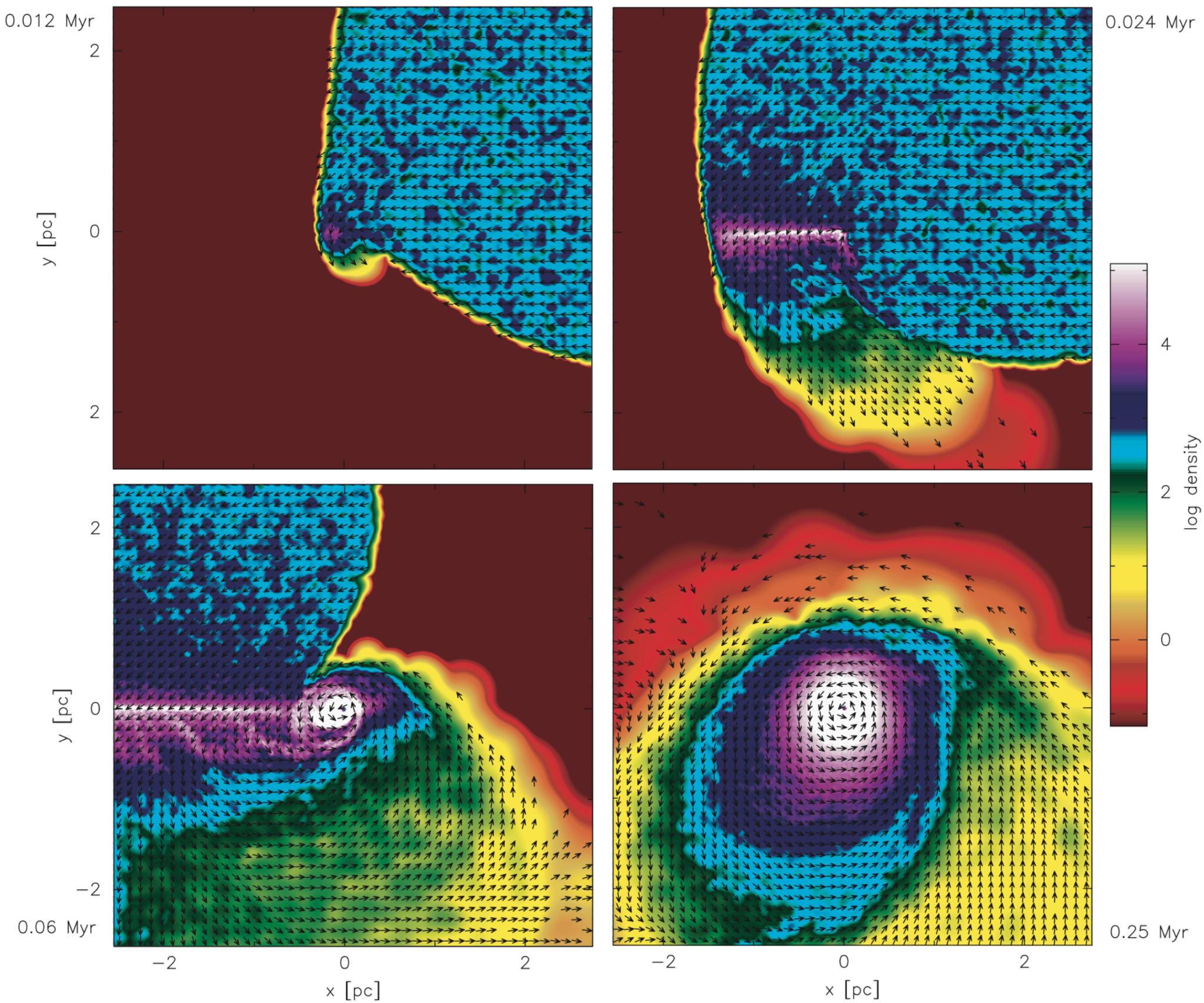
Farhad Yusef-Zadeh
Yoram Lithwick

Stellar disk formation

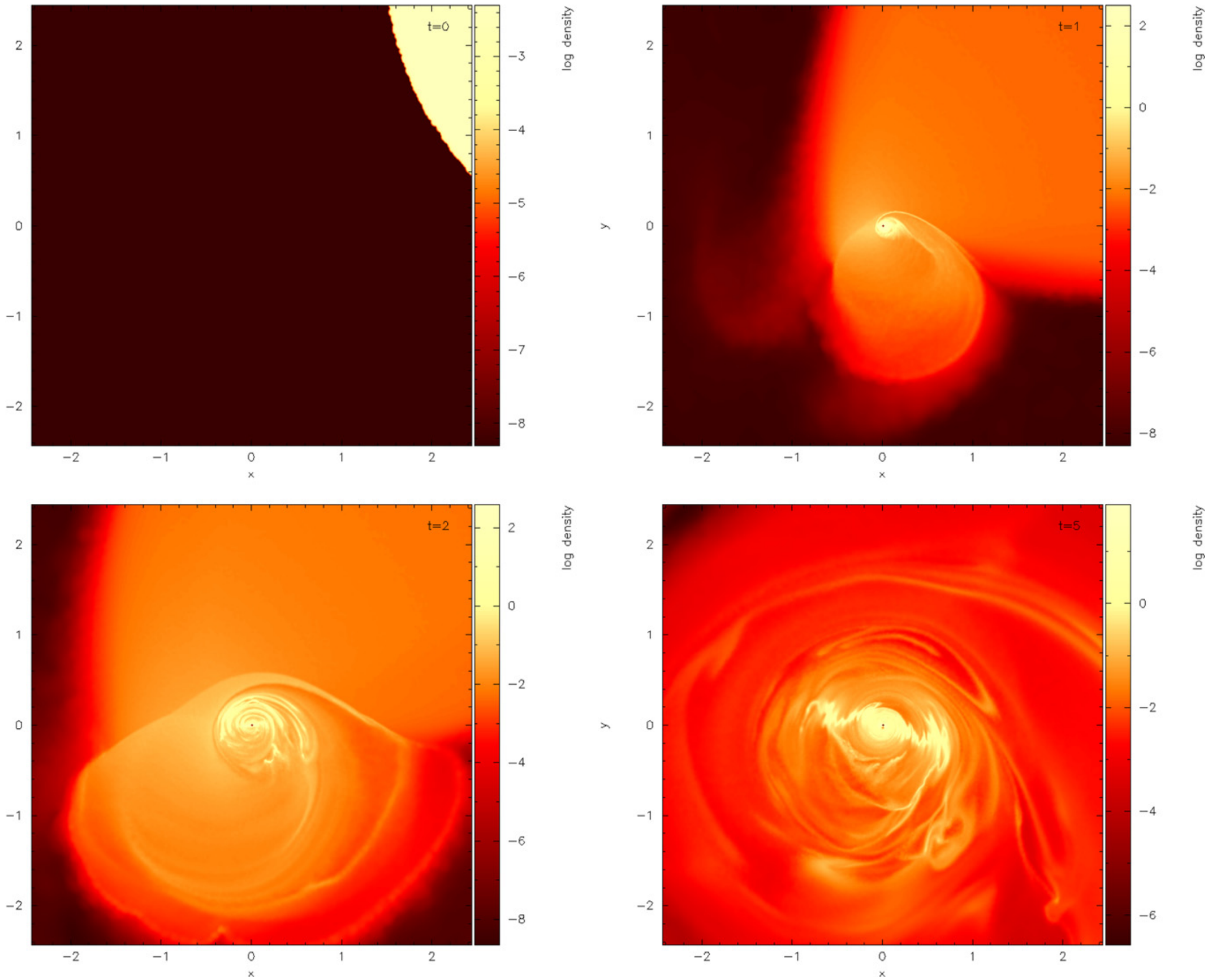
- Radii ~0.04 – 0.5+ pc from Sgr A*
- r^{-2} surface density profile with central hole
- Kinematically warm
- Age several Myr, top-heavy IMF, stellar mass ~ 5×10^4 M_{sun}
- Star formation via disk fragmentation
  - eccentric disk (Levin & Beloborodov 2003; Nayakshin, Cuadra & Springel 2007)
  - cf. inward migration and tidal disruption of stellar cluster
- Disk formation via cloud capture
  - circularisation of compact cloud (Bonnell & Rice 2008)
  - partial capture of extended cloud (Wardle & Yusef-Zadeh 2008; Alig+2011)
    cf. multiple disks (Alig et al 2013; Alig, Burkert & Dolag P34; Lucas et al 2013, P44)
  - central hole ==> accretion onto Sgr A*, but expected rate is too low
    (Alexander et al 2012)
  - magnetic fields suppress fragmentation and drive strong accretion
    (Gaburov, Johanssen & Levin 2012)



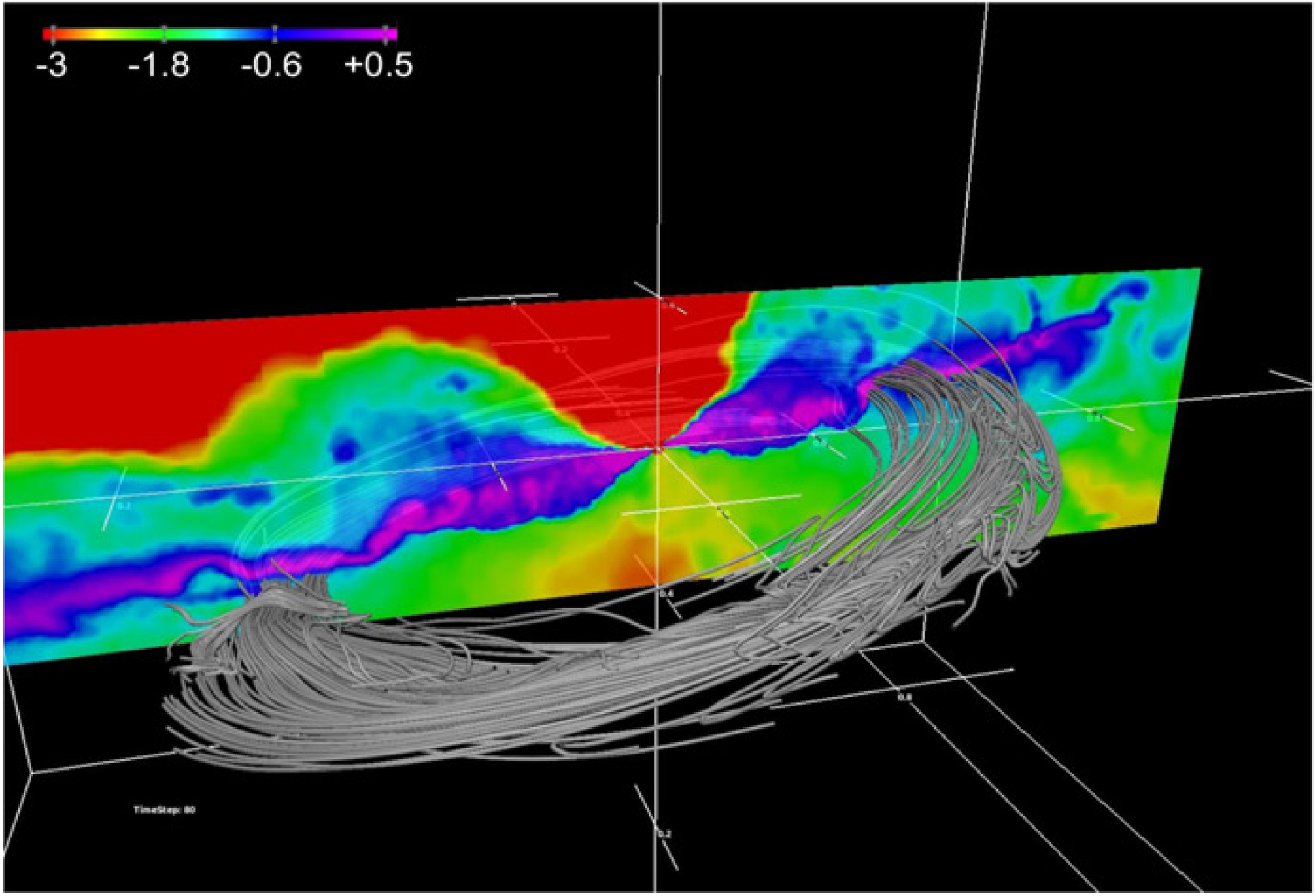
Bonnell & Rice 2008



Alig et al 2011



Gaburov, Johanssen & Levin 2012



Gaburov, Johanssen & Levin 2012

Magnetic fields vs fragmentation....

- Fragmentation requires high density and rapid cooling
  - disk is self gravitating when density exceeds roche density (i.e. $Q < 1$)

    $\Omega\, t_{cool} < 3$ ==> fragmentation

    $\Omega\, t_{cool} > 3$ ==> “gravitoturbulent” state

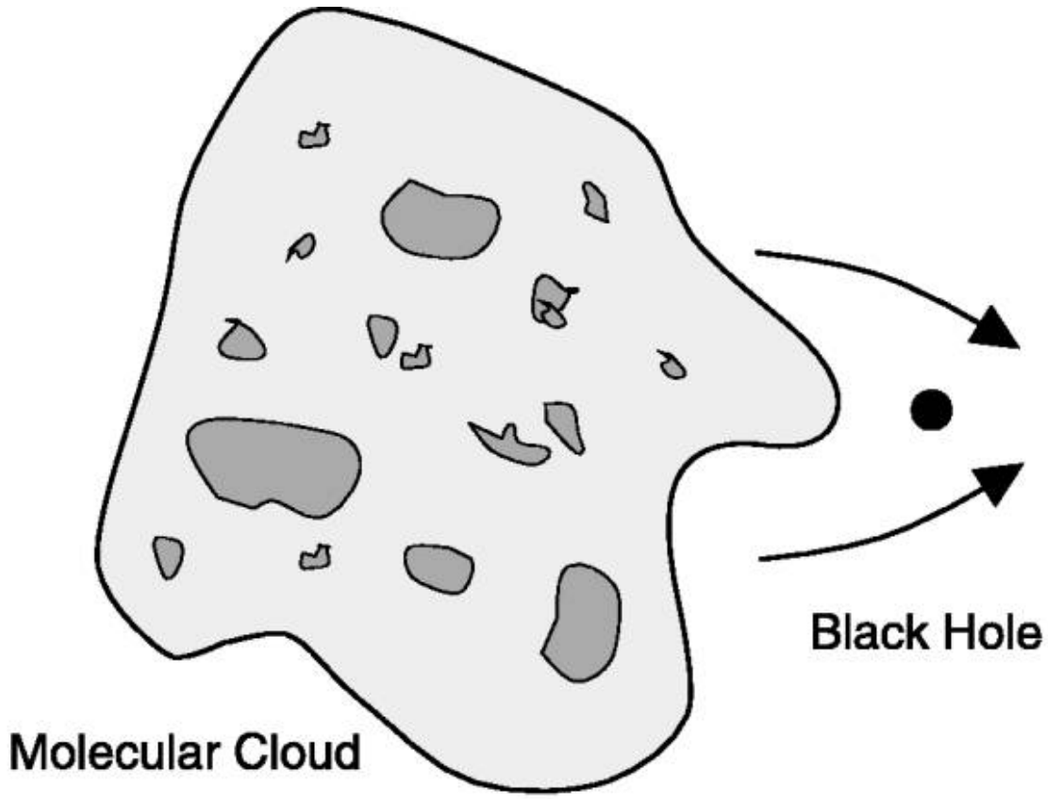
- Fragmentation is suppressed by magnetic fields
  - magnetic pressure = 10 x gas pressure
  - scale height 3 x thermal

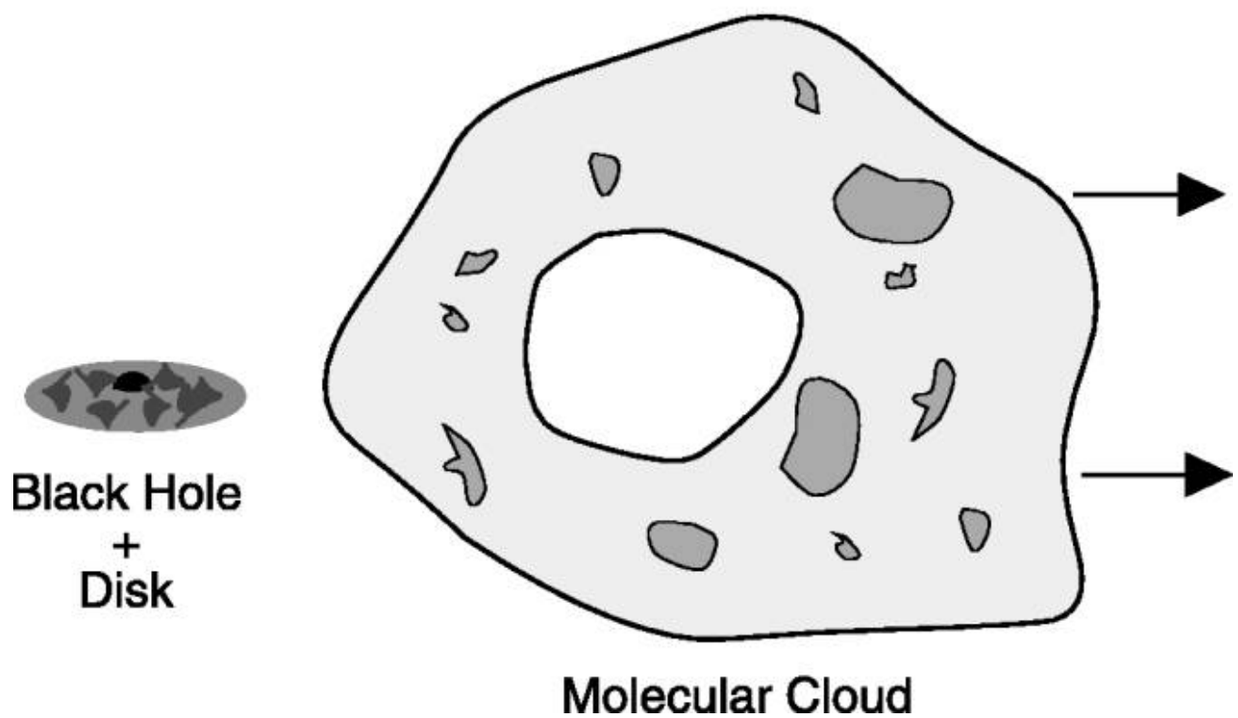
    $Q < 0.3$ for fragmentation

    $Q > 0.3$ ==> alpha ~ 1 !!

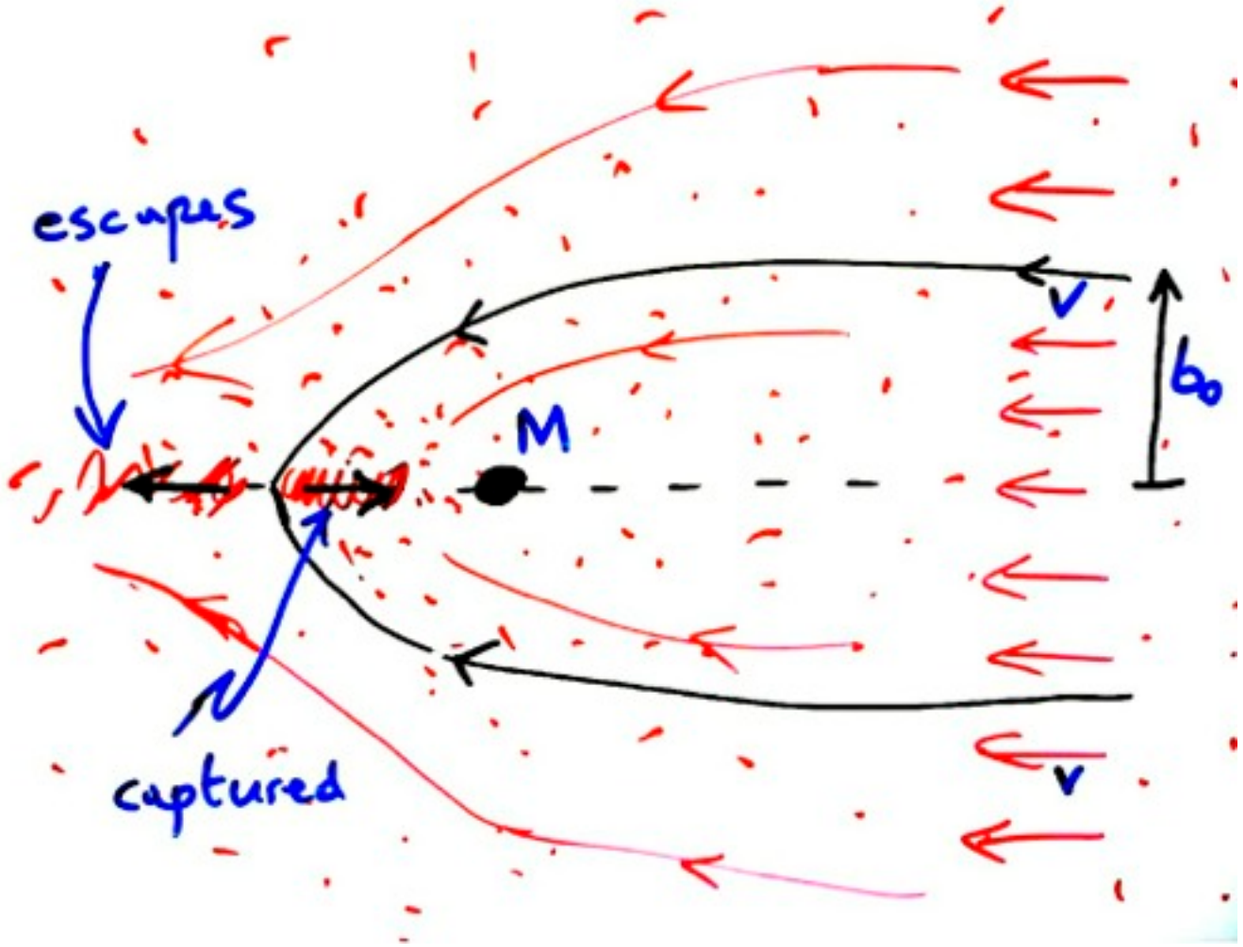
- Magnetisation is suppressed by ambipolar diffusion
  - need $T > 900K$ so that thermal ionisation ==> neutral–ion collision frequency $> \Omega$

- Build a vertically-averaged disk model including these effects
  - surface density profile implied by cloud capture
  - heating by starlight, gravitoturbulence, magnetic activity
  - radiative cooling





Wardle & Yusef-Zadeh 2008



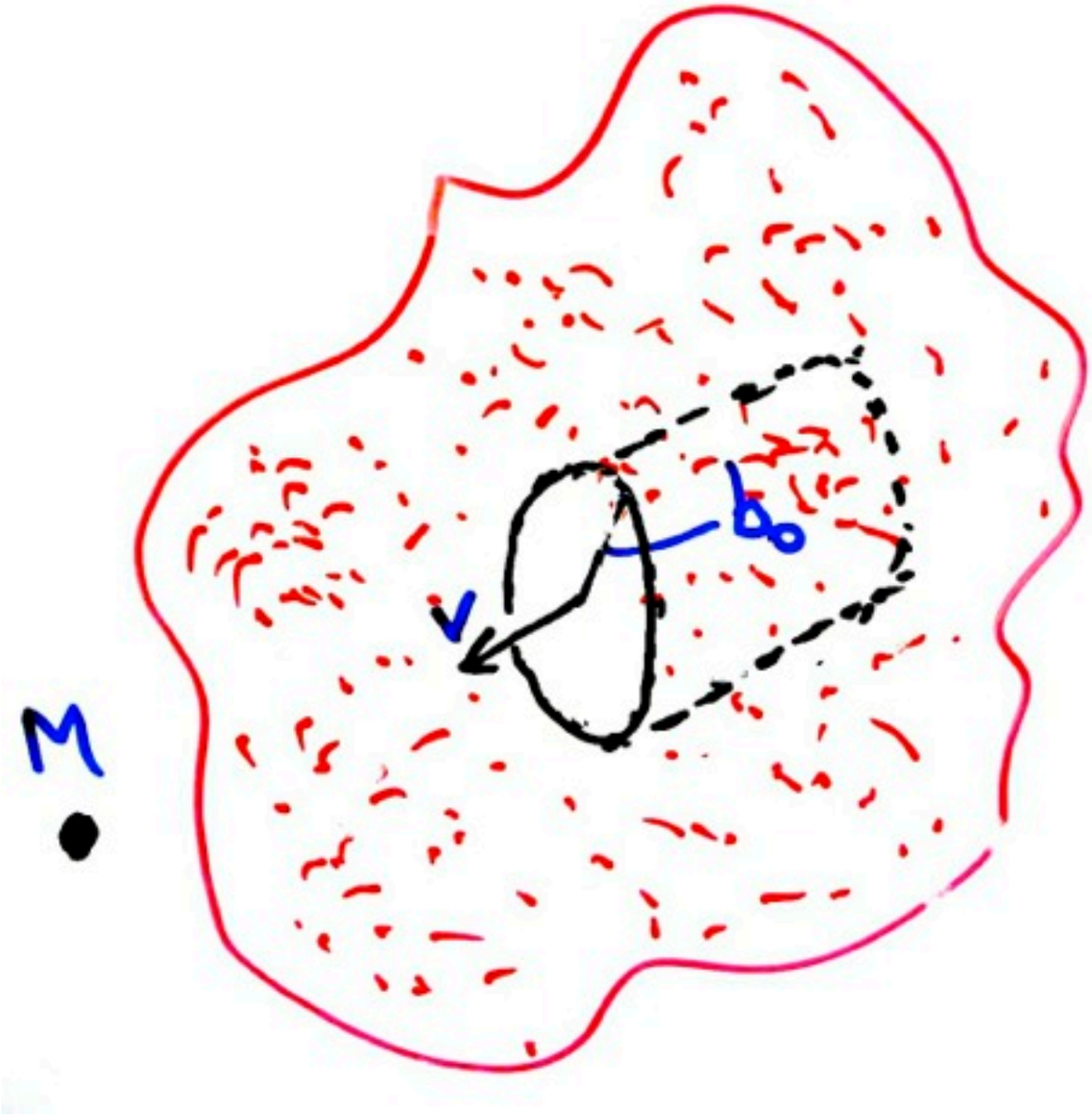
$b < b_0$ **escapes**

$b > b_0$ **captured**

$$\frac{1}{2}v^2 = \frac{GM}{b_0} \implies b_0 = \frac{2GM}{v^2} = 2.4\,\mathrm{pc}$$

$$\text{for} \quad v = 120\,\mathrm{km\,s^{-1}}$$

Disk mass



$$M_{\rm disk} = \pi b_0^2 \, \Sigma_{\rm cloud} = 2.0 \times 10^5 {\rm M}_\odot$$

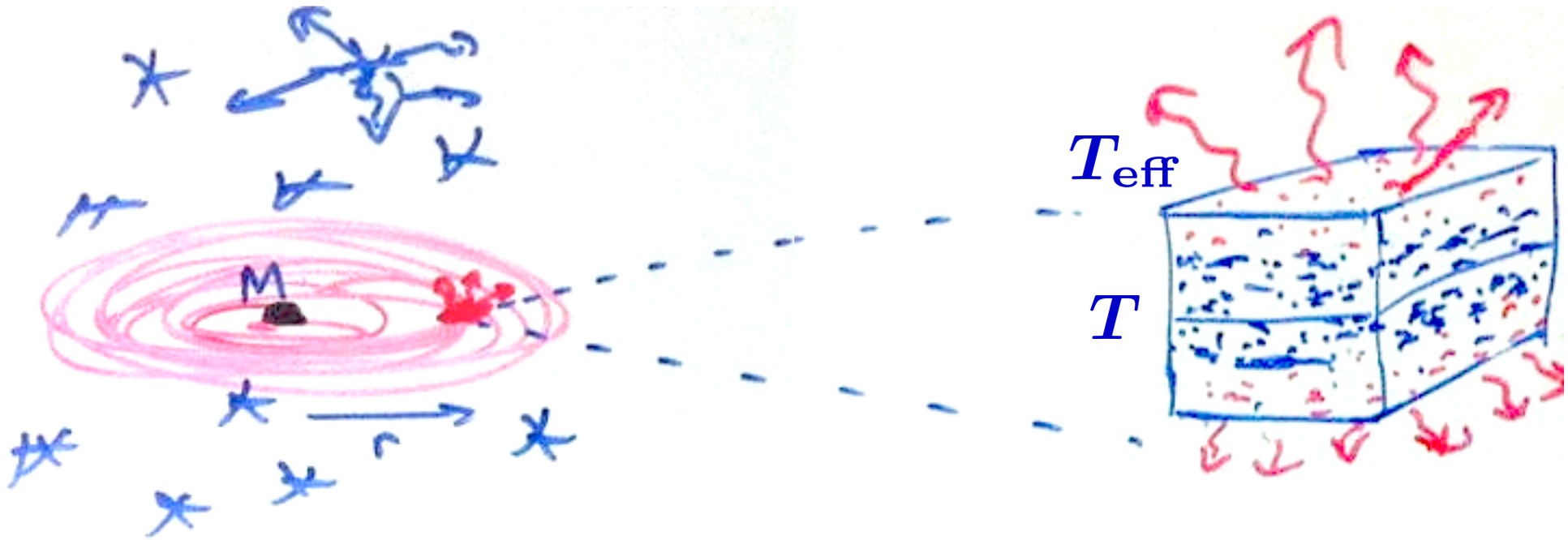
$$\text{for} \quad N_{\rm H} = 10^{24} {\rm cm}^{-2}$$

Disc profile: angular momentum

$$r_d \sqrt{\frac{GM}{r_d}} = \lambda\, b_0 v \quad \Longrightarrow \quad r_d = 0.43\,\mathrm{pc} \quad \text{for} \quad \lambda = 0.3$$

$$\Sigma(r) = \frac{M_{\mathrm{disk}}}{2\pi^2 r_d^2} \left(\frac{r}{r_d}\right)^{-7/4} \sqrt{1 - \left(\frac{r}{r_d}\right)^{1/2}}$$

Cooling

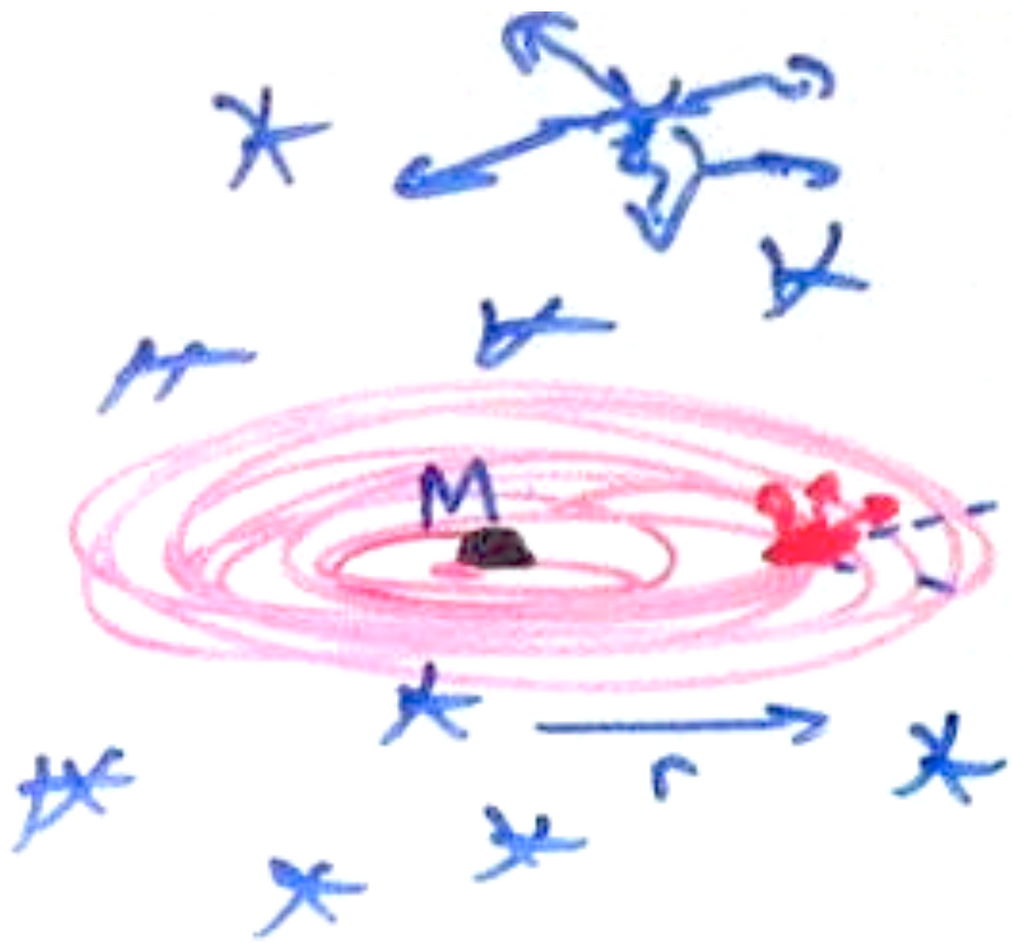


Thermal energy / unit area = $\frac{5}{2}\,\Sigma\,c_s^2$

Power radiated / unit area = $2\sigma T_{\rm eff}^4 = \frac{2\sigma T^4}{\tau} = \frac{4\sigma T^4}{\kappa\Sigma}$

Cooling time scale $\quad t_{\rm cool} = \frac{7}{8}\,\frac{\kappa\Sigma^2 c_s^2}{\sigma T^4}$

Heating



Heating by starlight / unit area = $\dfrac{10^7\,L_\odot}{4\pi(1\,\mathrm{pc})^2}$

Heating by accretion / unit area = $\dfrac{3}{4\pi}\dot{M}\,\Omega^2$

Accretion rate

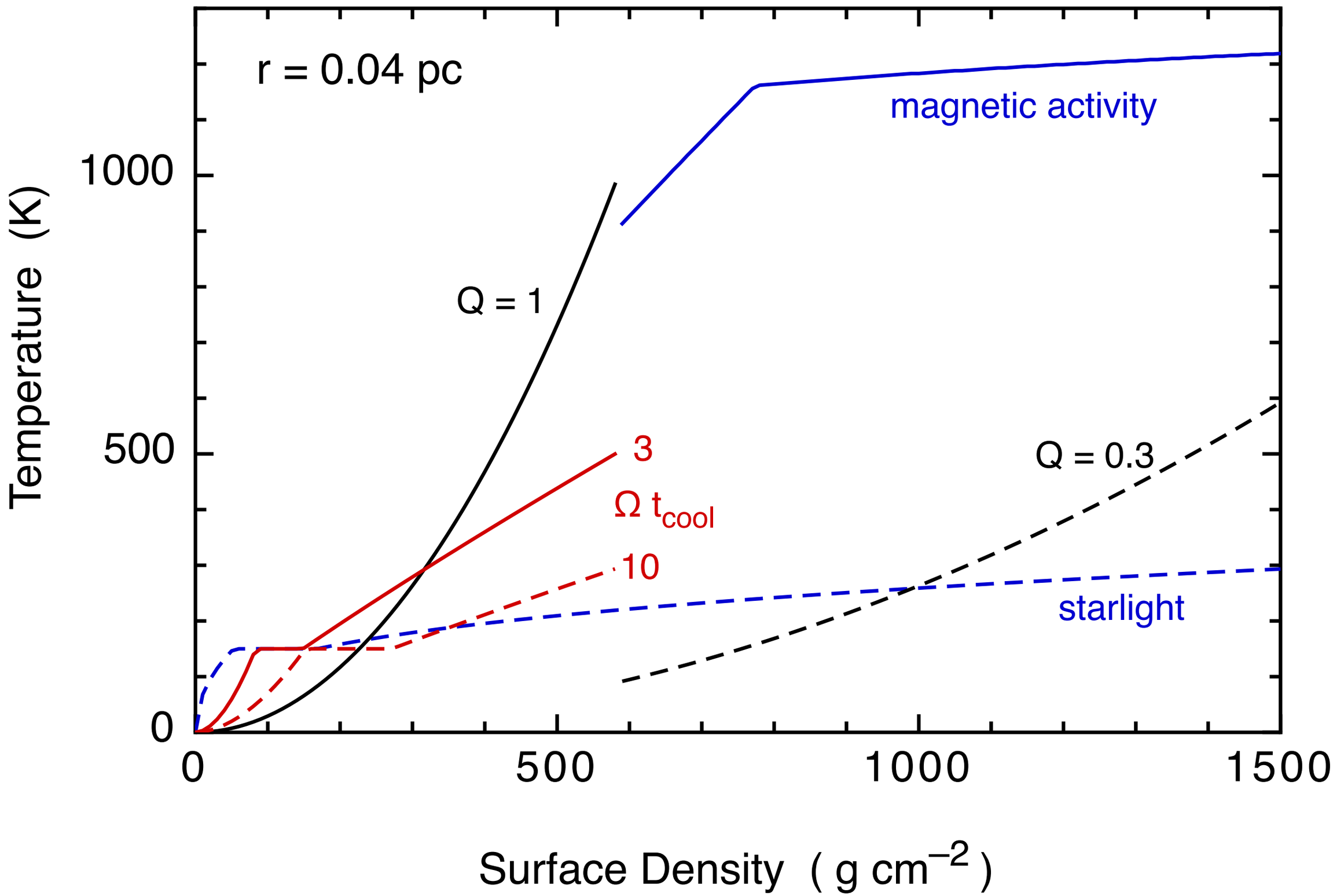
$$\dot{\mathrm{M}} = 3\pi\,\alpha\,\frac{c_s^2}{\Omega}\,\Sigma$$

Gravitoturbulence: $Q \equiv \dfrac{c_s \Omega}{\pi G \Sigma} = 1$ $\quad \Omega\, t_{\mathrm{cool}} > 3$

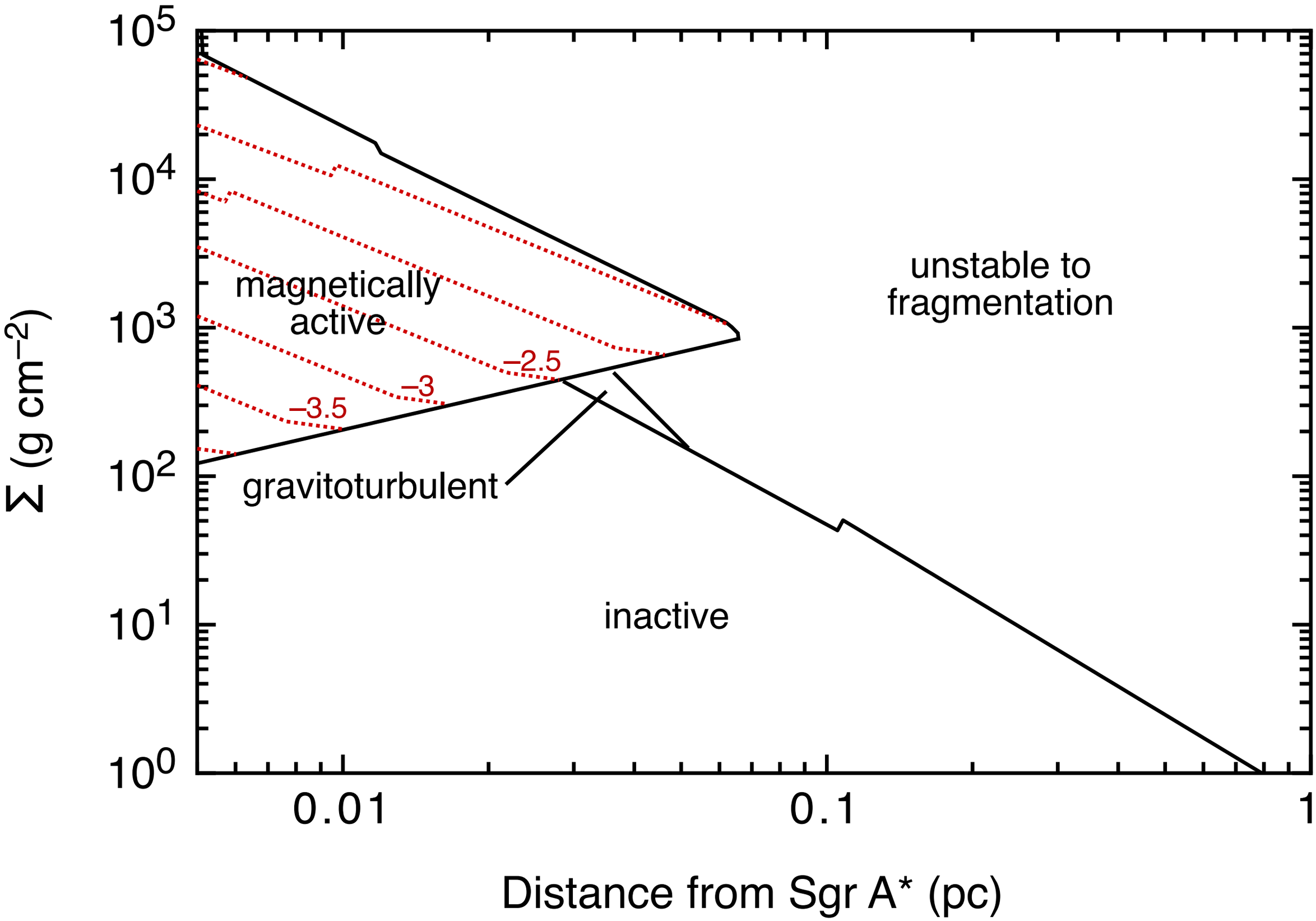
$$\alpha = \frac{14}{9}\,\frac{1}{\Omega\, t_{\mathrm{cool}}}$$

Magnetic turbulence: $T > 900\,\mathrm{K}$

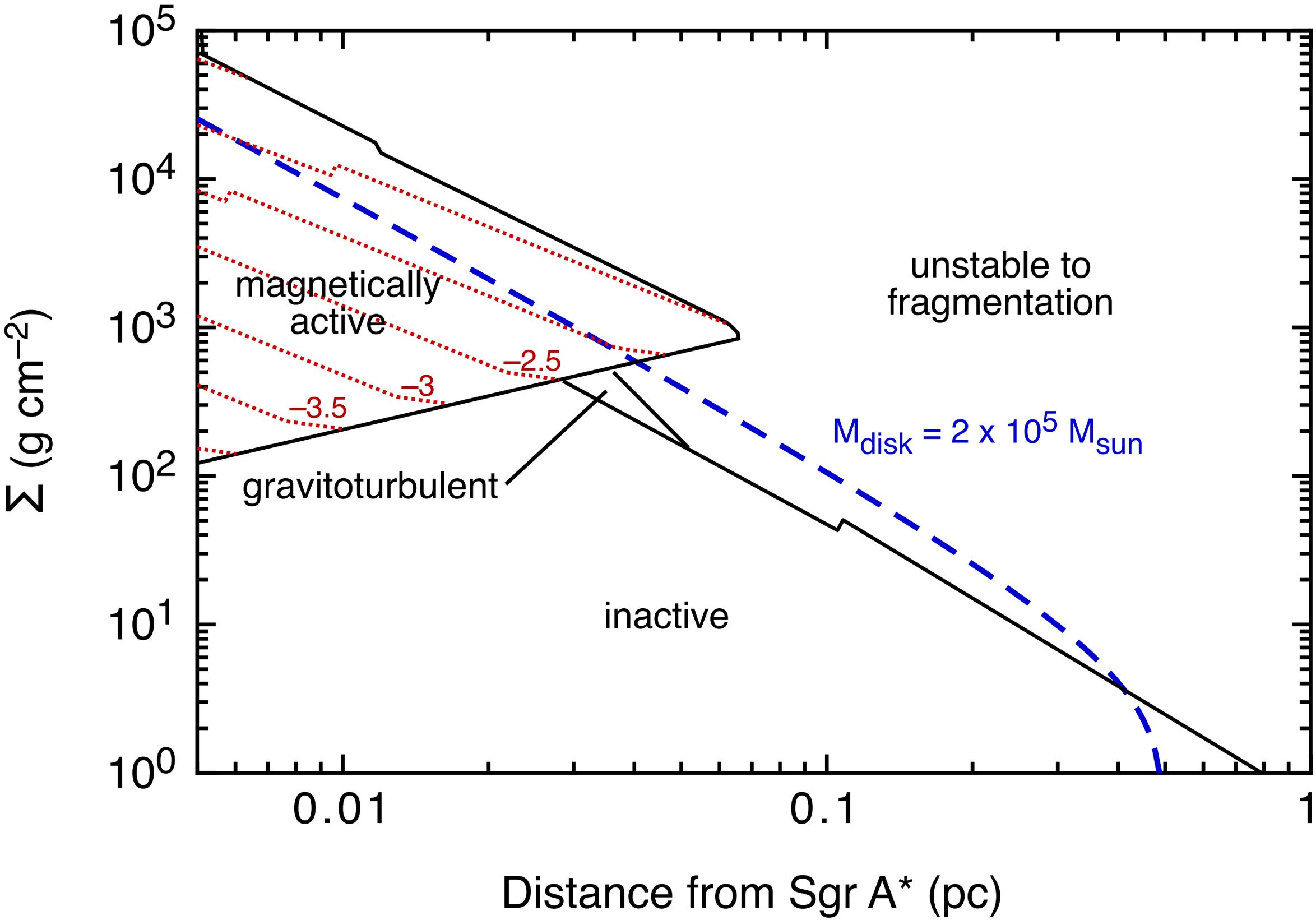
$$\alpha = 1$$



Wardle & Yusef-Zadeh in prep



Wardle & Yusef-Zadeh in prep



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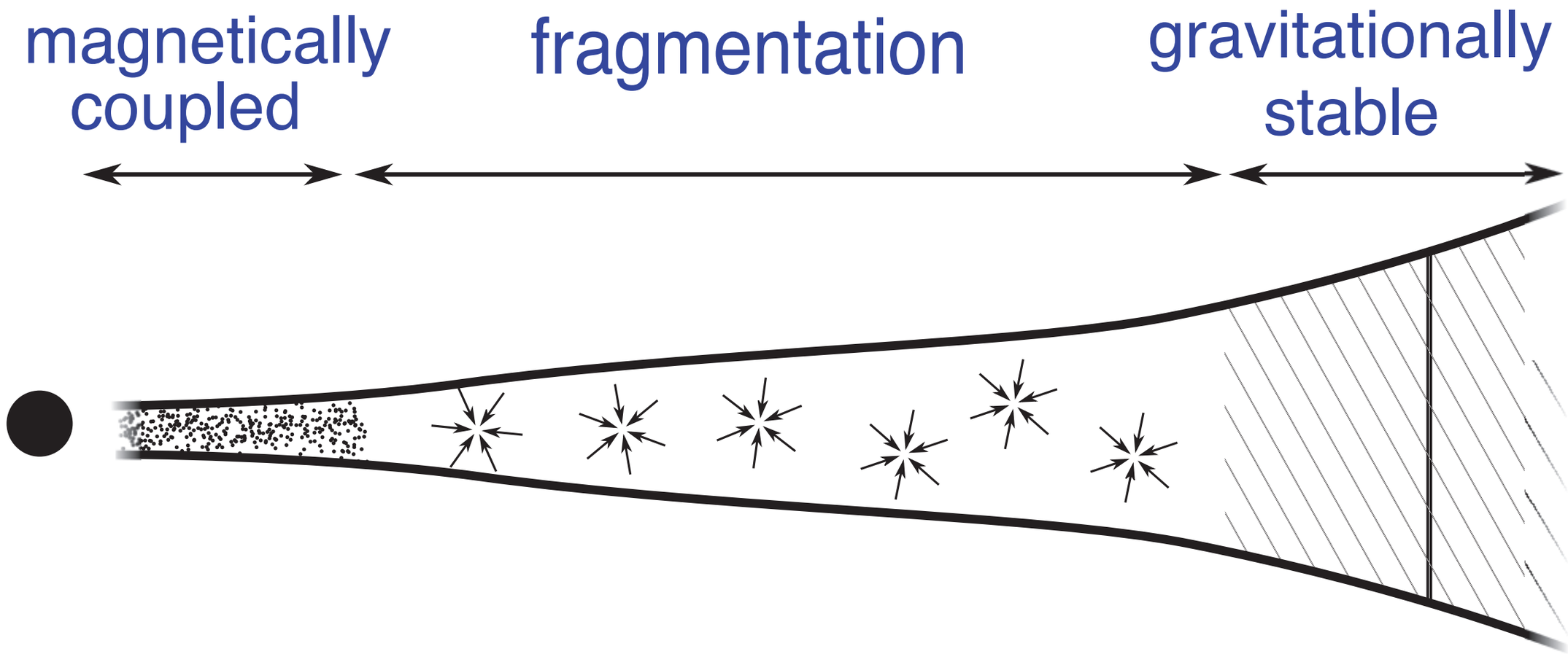
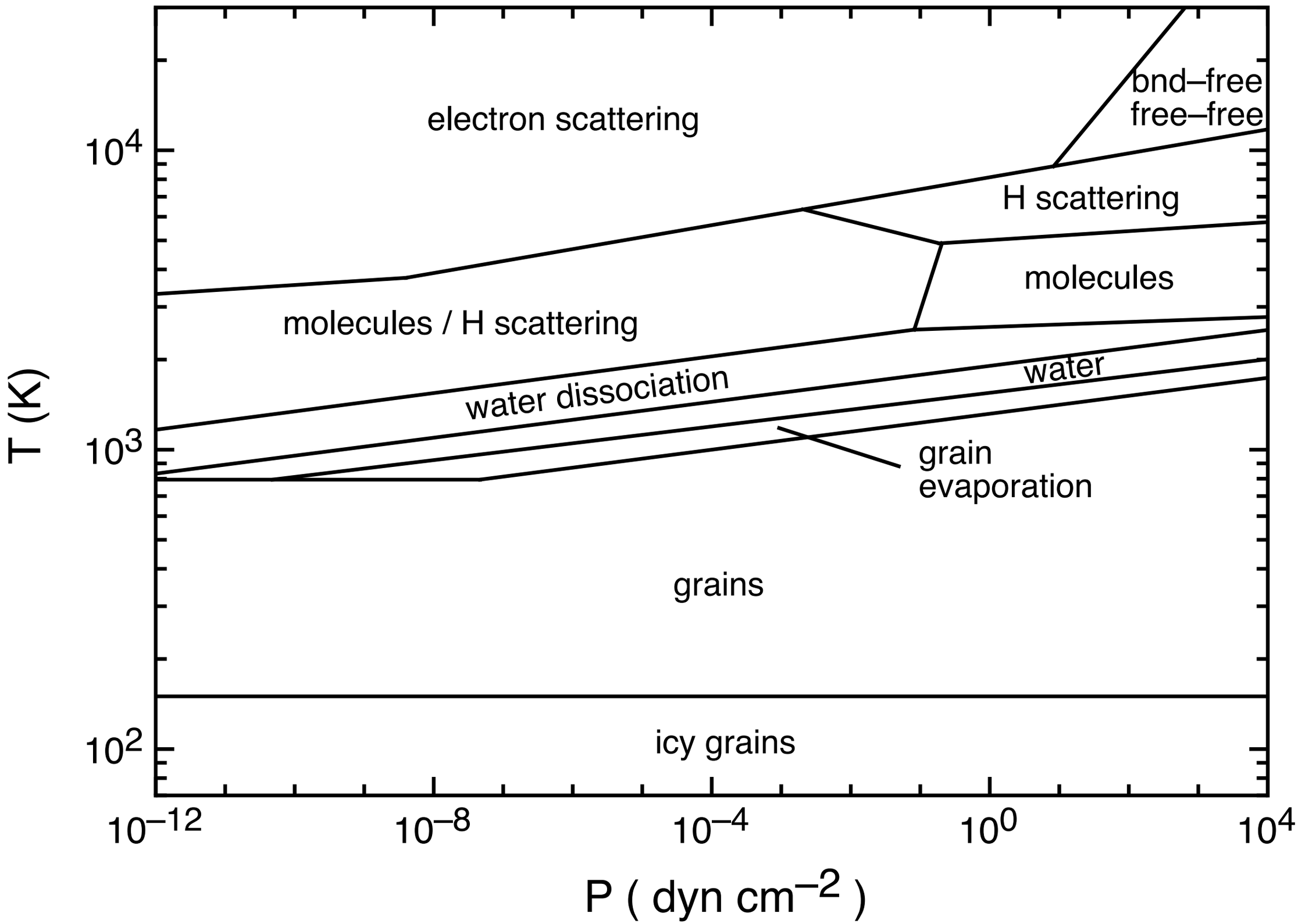


$$\Sigma(r) = \frac{M_{\rm disk}}{2\pi^2 r_d^2}\left(\frac{r}{r_d}\right)^{-7/4}\sqrt{1-\left(\frac{r}{r_d}\right)^{1/2}}$$

Summary

- Disk formation and evolution model
  - disk mass and size, steep surface density profile
  - fragmentation outside of 0.04 pc (kinematics?)
  - rapid accretion of bulk of material inside 0.04 pc (0.01-0.03 M_{sun} yr^{-1} for 1–3 Myr)
- Formation of S stars?
  - dynamical evolution
- History of accretion events onto Sgr A*?
  - high accretion rate ==> Fermi bubble?
  - 10^4 M_{sun} every 10 Myr => 10^6 M_{sun} per Gyr
- Simulations needed!
  - magnetic fields: either direct or via prescription for magnetic activity
  - sensible prescriptions for heating/cooling/magnetic decoupling/fragmentation

Opacity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bnd–free
free–free
H scattering
molecules
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water dissociation
water
grain
evaporation
grains
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10^4
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T (K)
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10^{-8}
10^{-4}
10^0
10^4
P (dyn cm^{-2})