FORMATION OF PRIMODIAL SUPERMASSIVE BLACK HOLES FROM A MONOLITIC (DIRECT) HALO GAS COLLAPSE

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FROM POP III STARS

Population III stars: $M_* \sim 10^{2\text{-}3} M_\odot$ can lead to

SMBH seeds: $M_* < 10^2 M_\odot$ (Haiman & Loeb 2001)

We know how to make BH seed

PITFALLS with POP III SEEDS

- Time Scale:
  - Growth by accretion/mergers from z>20 to z~7 to ~$10^9 M_\odot$
  - E-fold time (Salpeter 1964) → $t_e \sim \varepsilon \frac{c\sigma_T}{4\pi G m_p}\left(\frac{L_E}{L}\right) \sim 4.4\times10^8 \varepsilon \left(\frac{\dot{M}_E}{\dot{M}}\right) yrs$
  - Takes ~7×10^8 yrs to growth ~$10^9 M_\odot$ close to age of Universe fo high-z QSO!
- Additional difficulties:
  - Frequent mergers lead to BH slingshot and ejection from mini-haloes
  - BH feedback regulates gas accretion
  - Latest PopIII studies suggest rather reduced mass ~$50 M_\odot$ (e.g. Turk et al 2009; Stacy et al 2012)

DIRECT HALO GAS COLLAPSE

$M_{halo} \sim 10^8 M_\odot$ ($T\sim10^4$K) halo gas can collapse through atomic cooling

Yield very Massive SMBH seeds (>> $100 M_\odot$) (Bromm & Loeb 2003; Wise et al 2008)

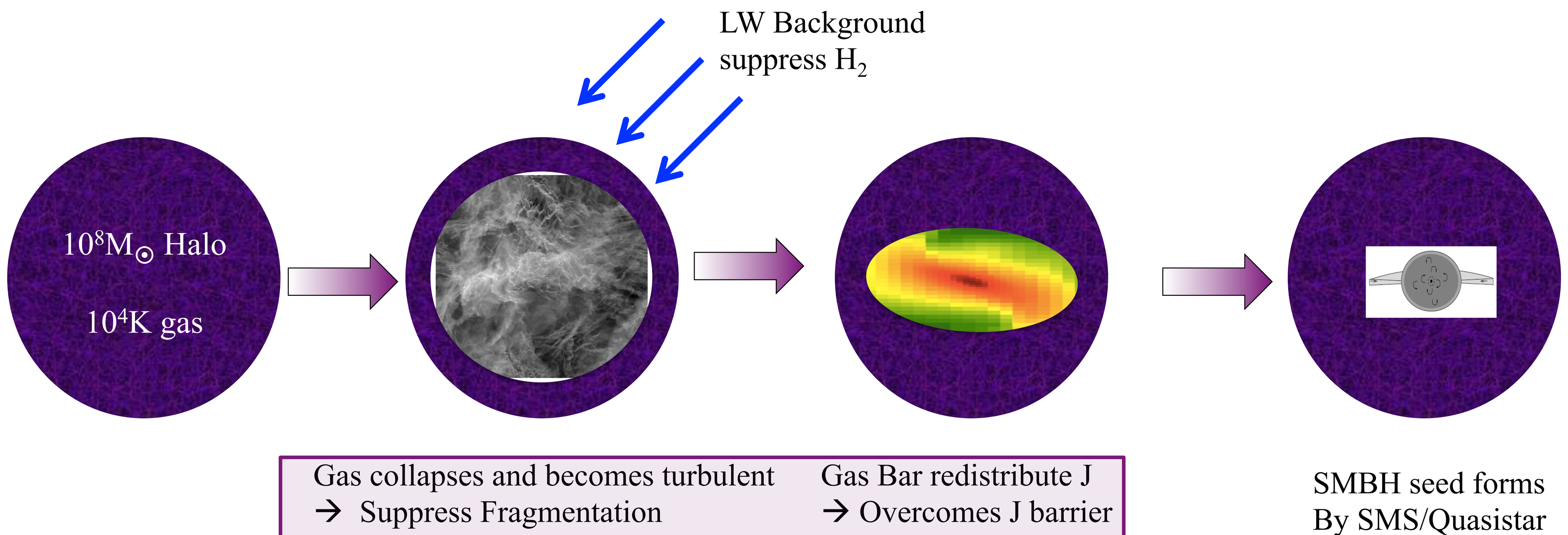
Easy to make high-z QSOs

PITFALLS with a direct collapse to SMBHs

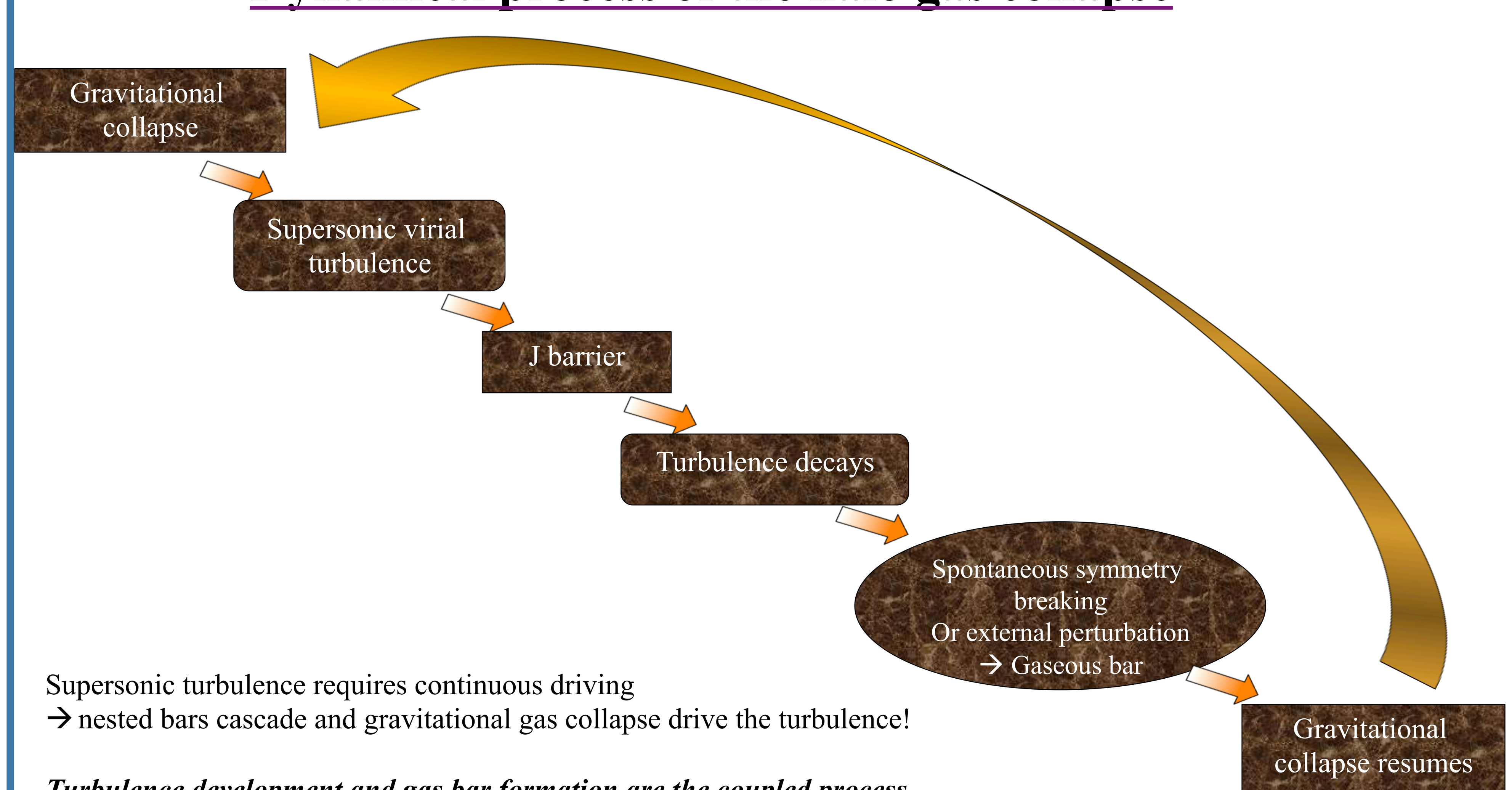
- SMBH Formation at very small scale
  - Need exotic processes to make seed BHs
    - SMS/Quasistar model (Begelman et. al. 2006, 2008; Begelman 2010)
    - This mechanism requires very rapid gas accretion around a central object. → 0.1-1 $M_\odot$/yr
- Dynamical Problems
  - J-barrier prohibit gas collapse
  - Fragmentation depletes accreting gas
  - Low or zero metallicity halo gas and need more aids

SCHEMATIC MODEL OF DIRECT COLLAPSE PROCESS

(Shlosman et al. 1989,1990; Begelman & Shlosman 2009)



Dynamical process of the halo gas collapse



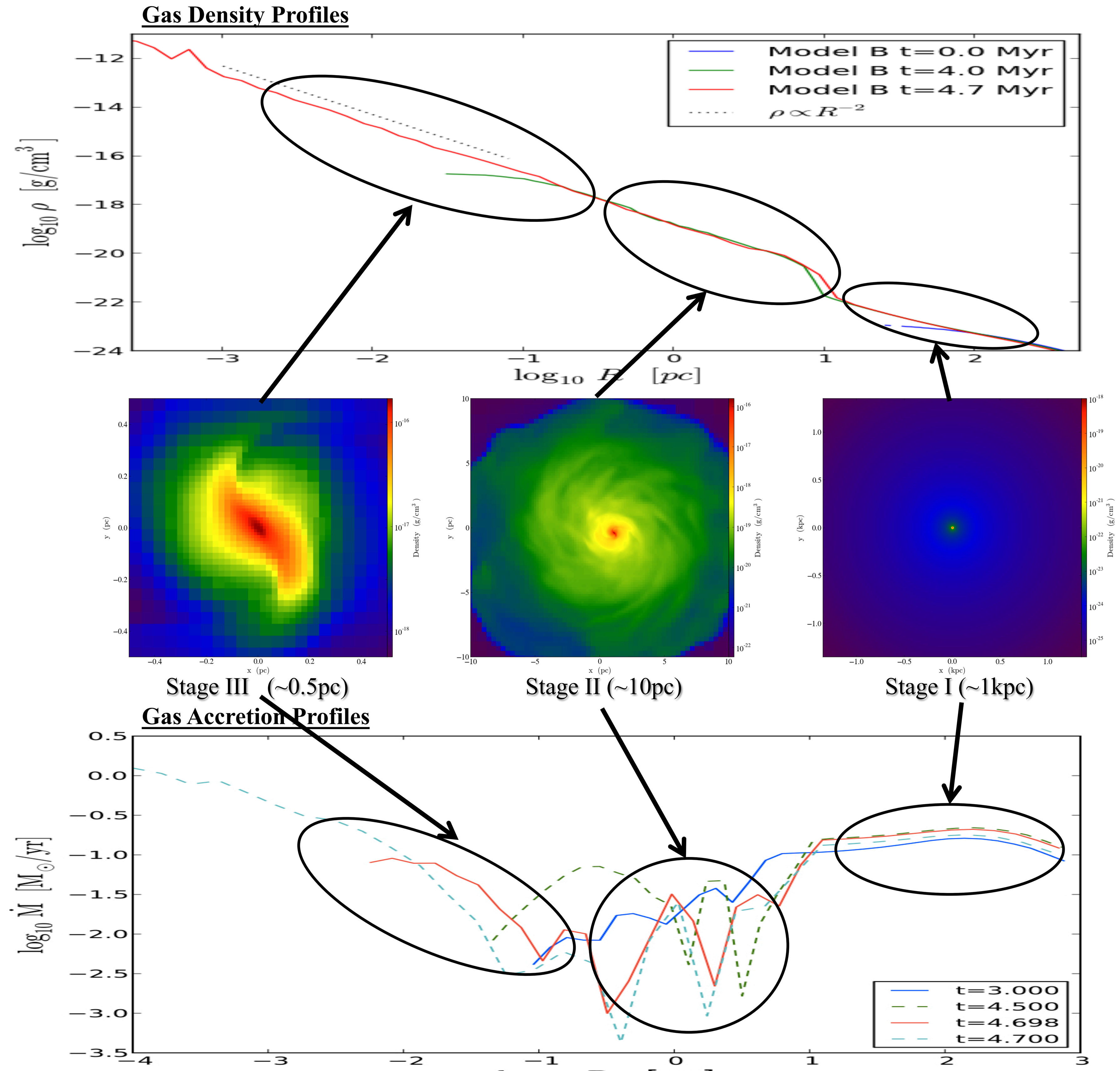
Supersonic turbulence requires continuous driving
→ nested bars cascade and gravitational gas collapse drive the turbulence!

Turbulence development and gas bar formation are the coupled process

NUMERICAL EXPERIMENT OF DIRECT COLLAPSE DYNAMICS

(Choi et al. 2013)

- Enzo AMR simulation – Refined by gas density w/ non-equilibrium atomic cooling (Abel et al. 1997; Bryan et al 2013)
- Dark Matter Halo
  - Isolated isothermal sphere
  - $M_{vir} = 10^8 M_\odot$ with $R_{vir} \sim 1.3$ kpc
- Isothermal gas sphere with 100 pc core:
  - f_{gas}~0.16 and initial gas temperature is ~30,000K
  - Solid body rotation in the gas core; flat rotation curve outside the gas core, assuming halo λ~0.05.



Stage I Free fall halo gas collapse (10pc < R < 1kpc)

- Atomic cooling facilitates the isothermal gas collapse in a $10^8 M_\odot$ halo.
- Rotation support is not yet significant (J/J_c << 1).

Stage II Gas disk (1pc < R < 10pc)

- J-barrier slows down and prohibits the continuous gas collapse.
  - Gas accretion rate decreases
  - Shock is formed at the surface of disk and develops the turbulence.
- Gas disk forms turbulence decays inside of the gas disk.
- Gas disk growth → bar unstable.

Stage III Gas bar forms and experience run-away gas collapse (R < 1pc)

- J-transfer and gas resumes collapse.
- Gas bar shows the bar-within-bar configuration
- Very strong gas accretion to the central object is established (0.1-1 $M_\odot$/yr)
- Estimated gas mass inside of the collapsing region is $2\times10^4 M_\odot - 2\times10^6 M_\odot$.

TAKE AWAY

- ✓ Gas in ~$10^8 M_\odot$ halo experiences direct collapses and forms the gas disk in the fraction of t_{ff}.
- ✓ The gaseous bar is formed, redistributes J, and allows gas inflow from ~ 1 pc to ~ 100 AU scale.
- ✓ Gas accretion rate :~ 0.05 $M_\odot$/yr outside of the disk and ~ 1 $M_\odot$/yr around central region.
- ✓ Turbulence is developed (supersonic at inner disk).
- ✓ Estimated initial SMBH seed : $2\times10^4 M_\odot - 2\times10^6 M_\odot$.

Massive SMBH seeds can be form through the direct halo gas collapse at high-z.

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