# Fueling Black Hole Growth in Galactic Nuclei

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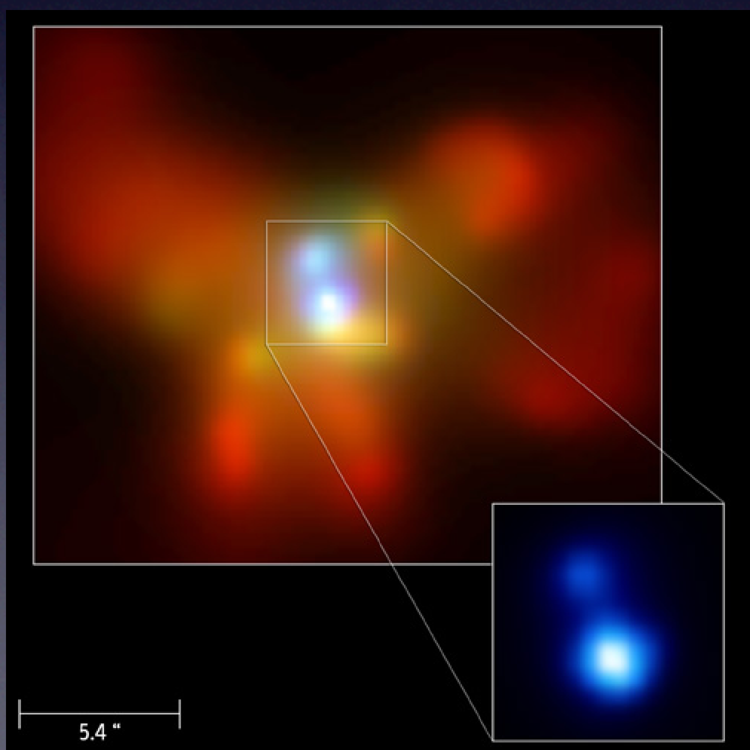
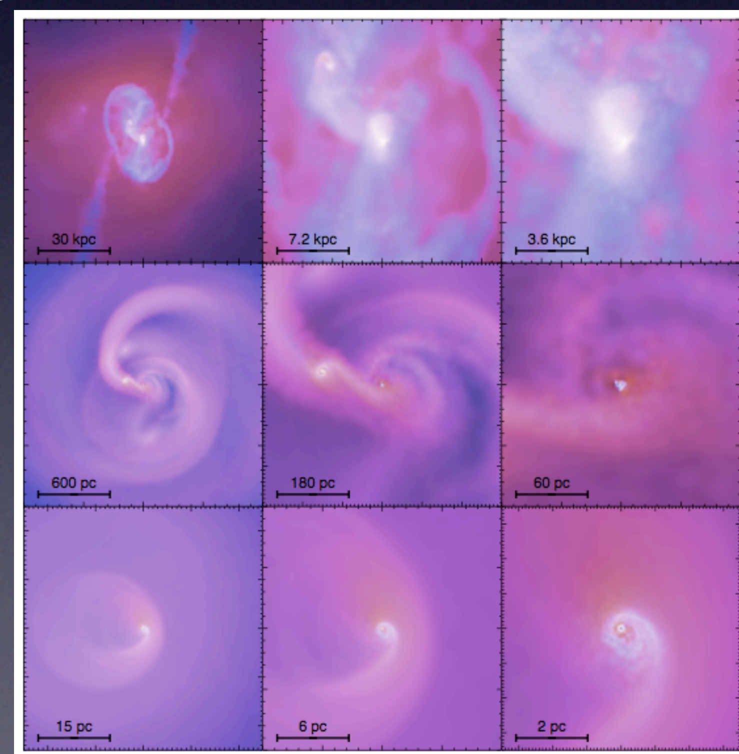
in collaboration w/ Phil Hopkins, Norm Murray,
Claude-Andre Faucher Giguere, Dusan Keres, ....



# Regimes of BH Fueling

- Mass return from stellar evolution: low-L AGN
  - $\dot{M} \sim 10^{-3.5} (M_* / 10^8 M_\odot) M_\odot yr^{-1}$ at $t \sim 10^{9-10}$ yr
- Individual GMCs over $\sim 10^{7-8}$ yrs
  - $\rightarrow \dot{M} \sim 0.01 M_\odot yr^{-1}$; $L \sim 10^{44}$ erg $s^{-1}$ $\rightarrow$ Seyferts
- Quasars: $\dot{M} \sim 1\text{-}10 M_\odot yr^{-1}$
  - $\gtrsim 10^8 M_\odot$ over quasar lifetime $\sim 10^7$ yr $\lesssim t_{dyn}$ of galaxy as a whole

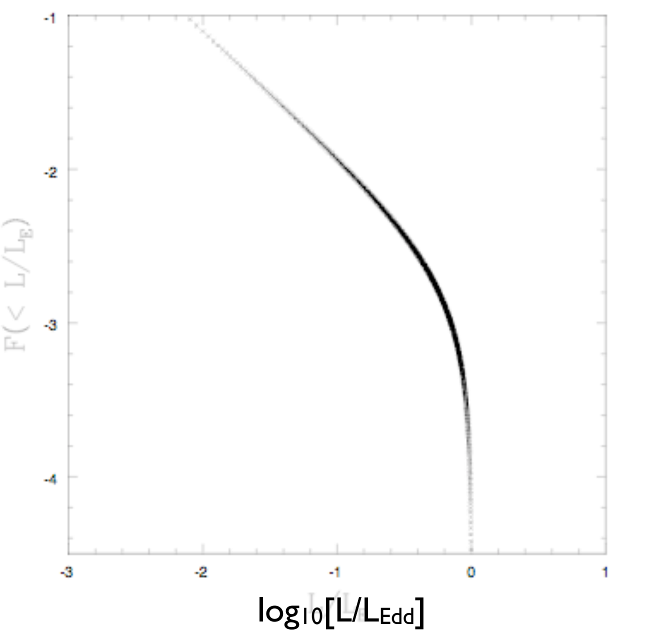
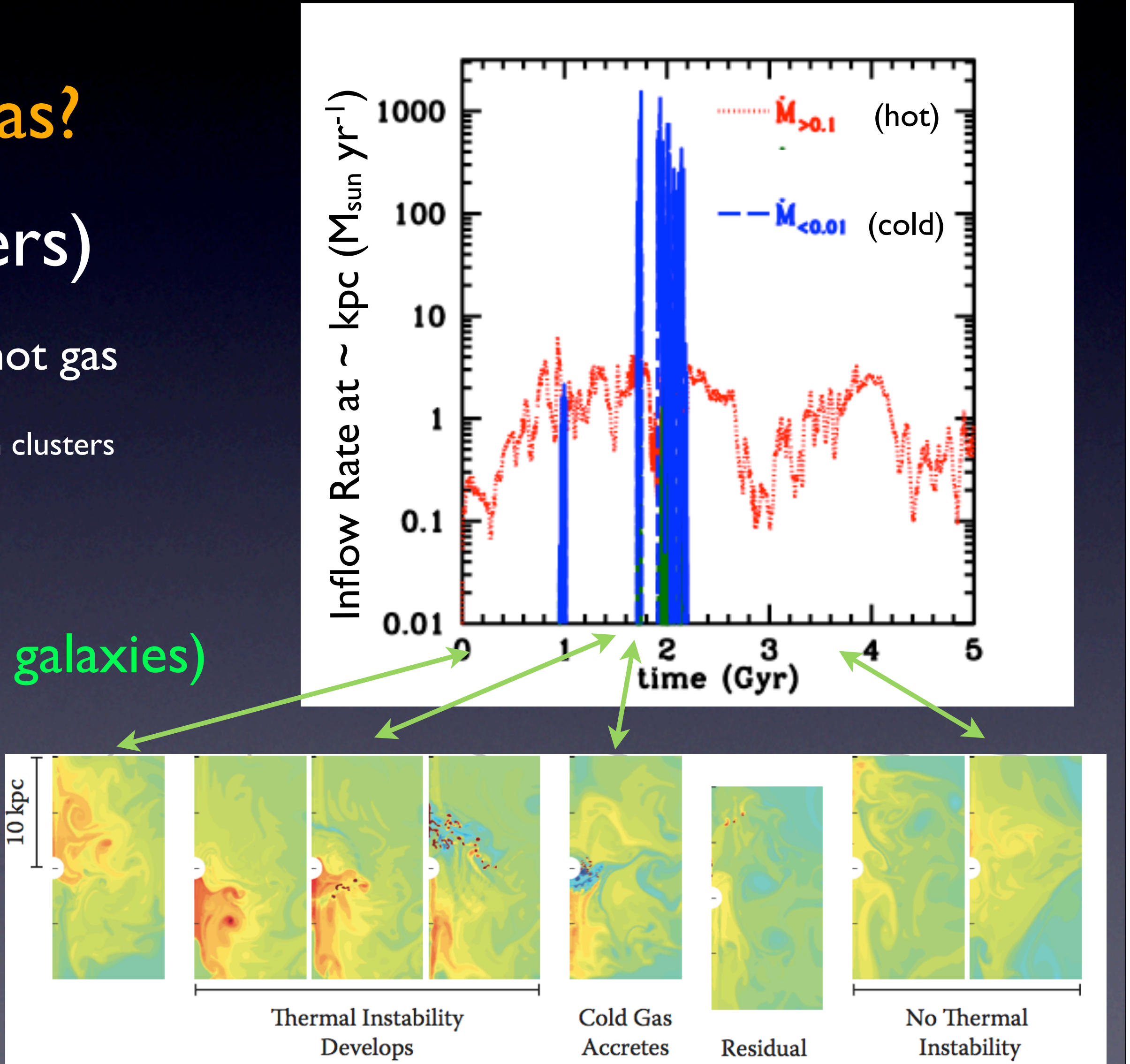



**Figure 1.** Form of the AGN luminosity function predicted by the fuelling process, and subsequent disc evolution, discussed in this paper. The fraction $F$, of those sources with luminosities less than $L/L_E$ is shown as a function of $L/L_E$. This is similar in form to those presented in Figure 3 of Heckman et al., 2004

# Regimes of BH Fueling

- Cold Gas vs. Hot Gas?
- Hot Gas (e.g., clusters)
  - cooling limits $\dot{M} < \dot{M}_{EDD}$ in hot gas
    - Important for observed central ρ in clusters
  - $\dot{M}$(horizon) vs. $\dot{M}(R_{Bondi})$???
- Cold Gas (e.g., gas-rich galaxies)
  - ∡ Momentum Transport?
  - $\dot{M}$(horizon) vs. ???




Sharma, McCourt+ 2012

# Inward Bound: Cold Gas Inflow from ~ kpc to $\lesssim$ 0.01 pc

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- Inflow vs. Star Formation: BH Fueling Requires $t_{inflow} < t_{star} \sim 10\ t_{orb}$

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- Star Formation Plausibly Stirs up ISM, Maintaining Q ~ 1
  - Local $\measuredangle$-mom transport (e.g., MRI, turbulence)

$$t_{\rm inflow} \sim 3000 \frac{M_8}{\alpha^{1/3} \dot{M}_1^{2/3} R_{\rm pc}}\, t_{\rm orb}$$

$t_{inflow} \gtrsim 10^7$ yrs for R $\gtrsim$ few pc

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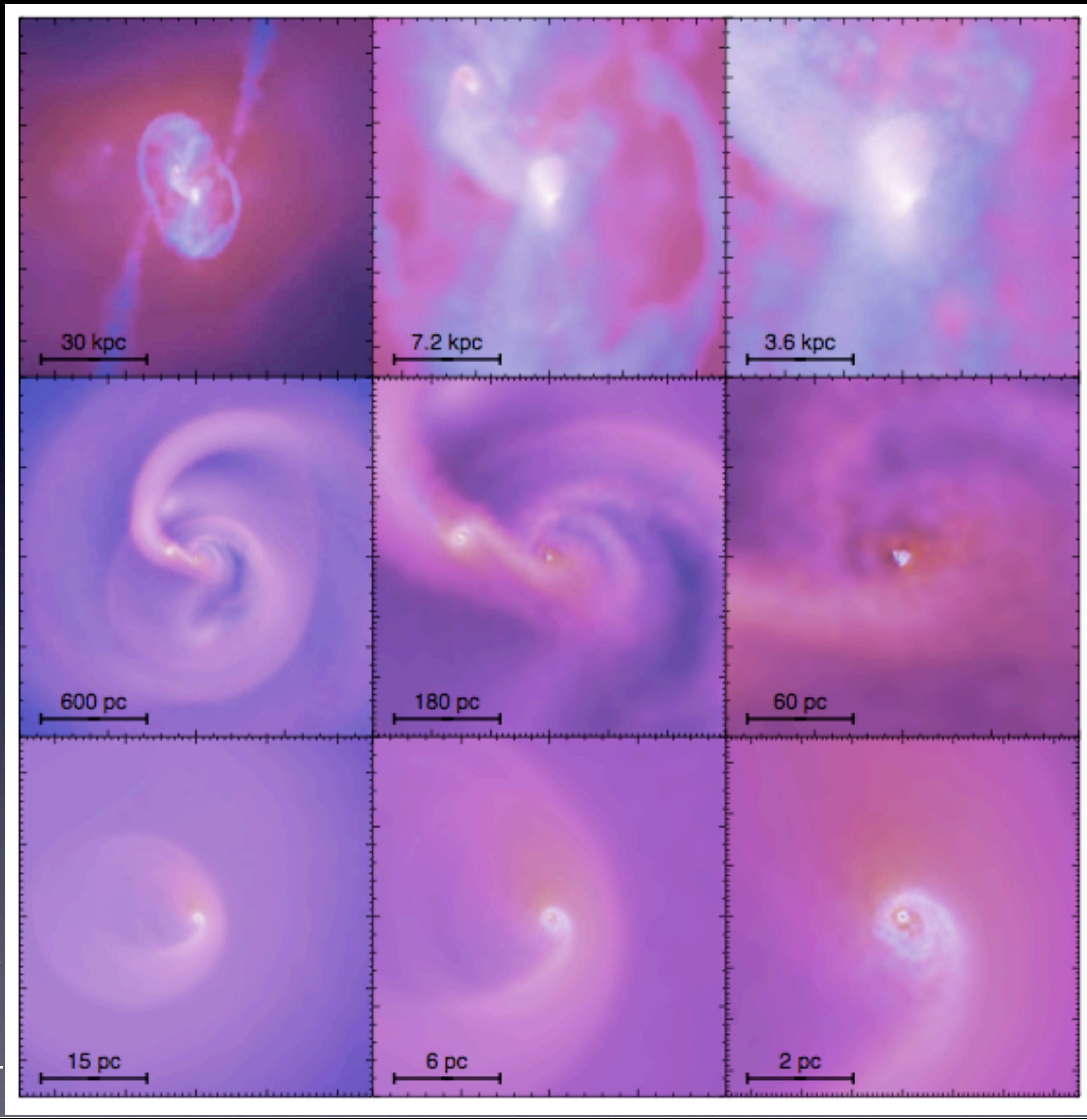
- ⇒ Transport Must be "Global" (bars, spiral waves, large-scale B-field, low ∢-mom gas, ...)




Hopkins & Quataert 2010

## Simulation of Major Merger of Galaxies (SPH)

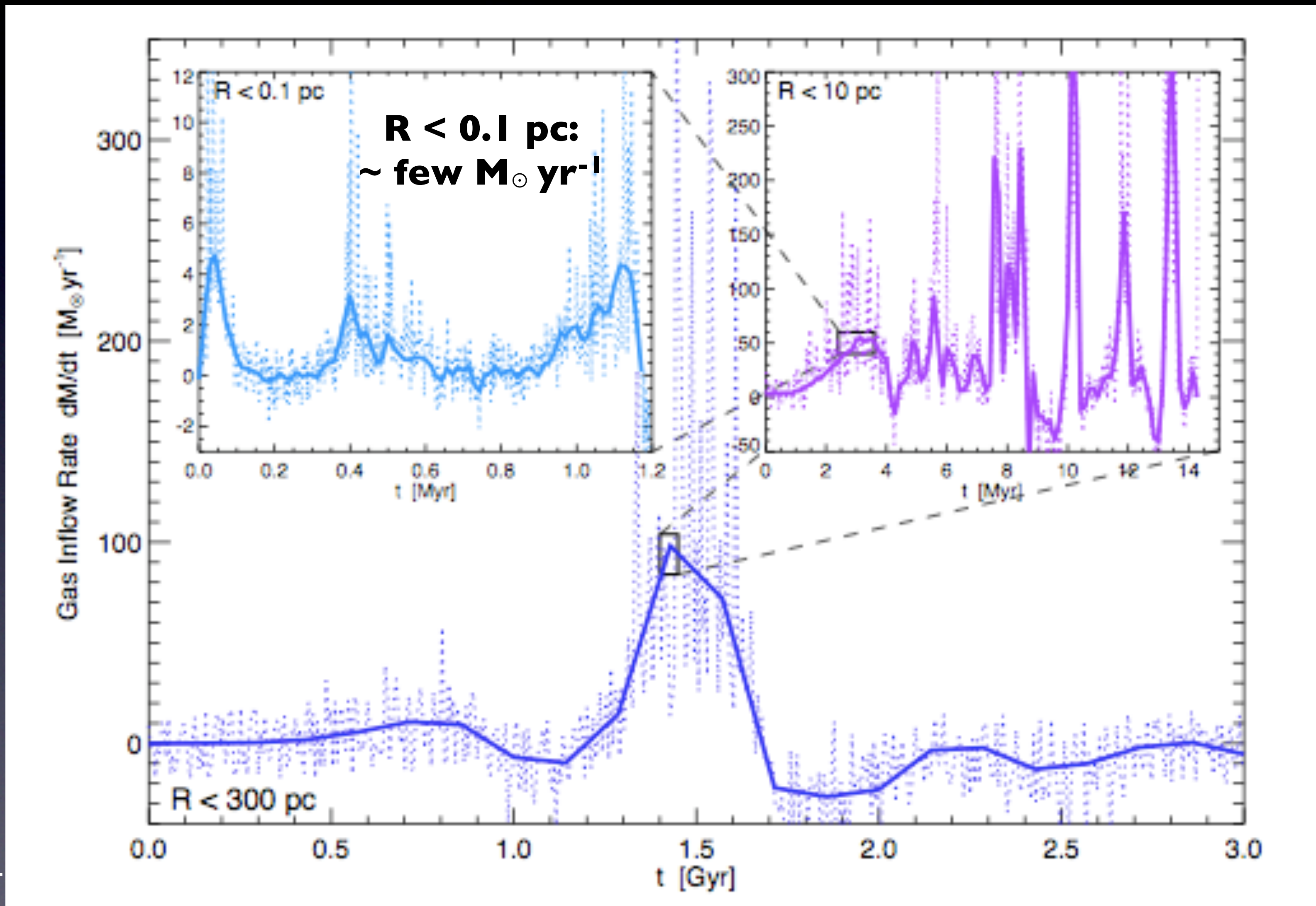
(gas, stars, star formation, simplistic ISM model; BH gravity, but no BH feedback)

## Separate sim of central ~ kpc near final merger of 2 galaxies

## Separate sim to central ~10s pc down to ~ 0.1 pc

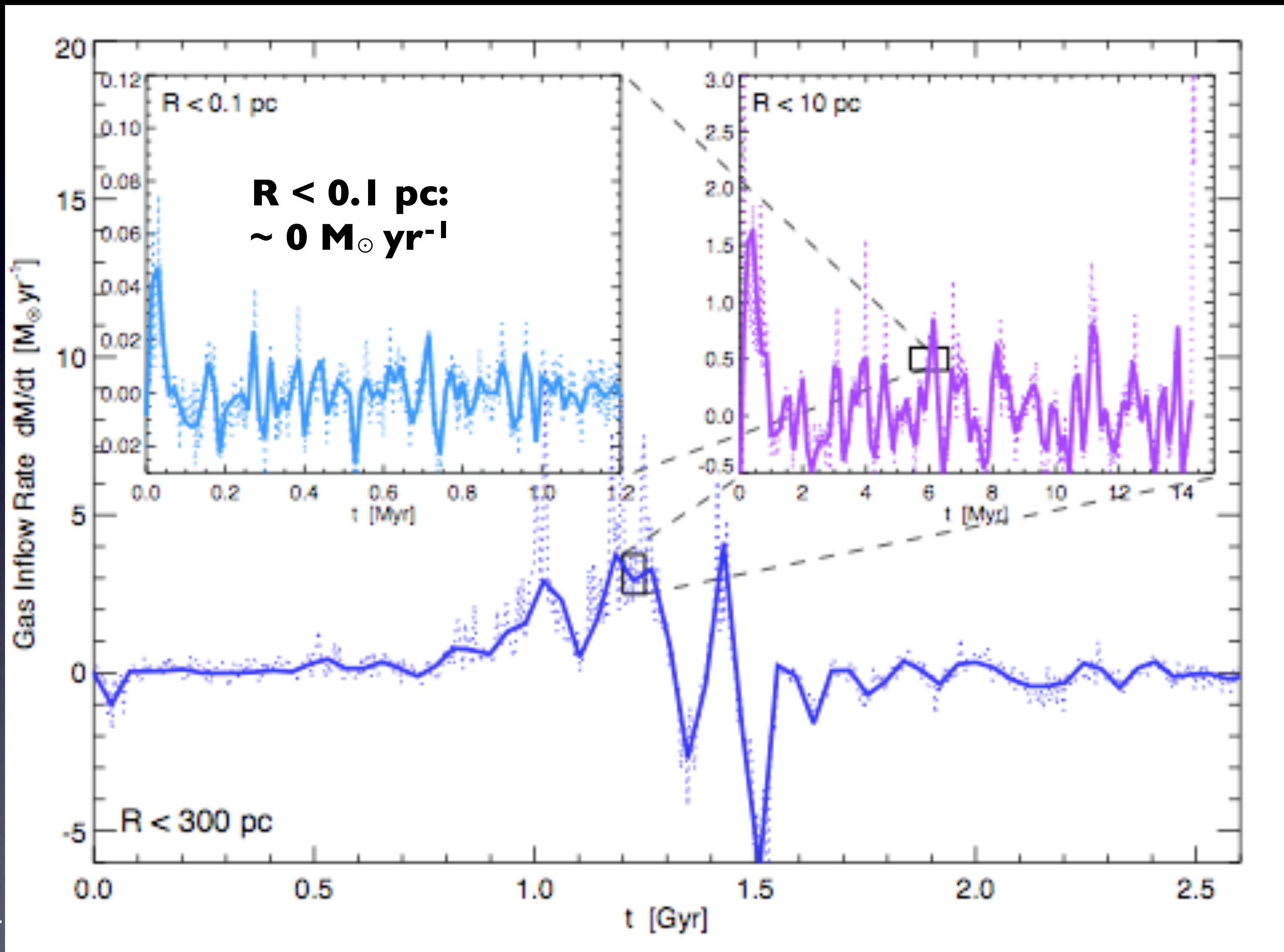
merger sufficient, but not nec: similar physics in very gas-rich isolated galaxies

# Major Merger (high gas fraction): Inflow Rates




Hopkins & Quataert 2010

# Isolated Galaxy (low gas fraction): Inflow Rates




Hopkins & Quataert 2010

# Physics of Gas Inflow

## Bars w/in Bars

(Shlosman et al. 1989)

## “It’s Bars all the Way Down ...”

Physics of Gas Inflow

Bars w/in Bars

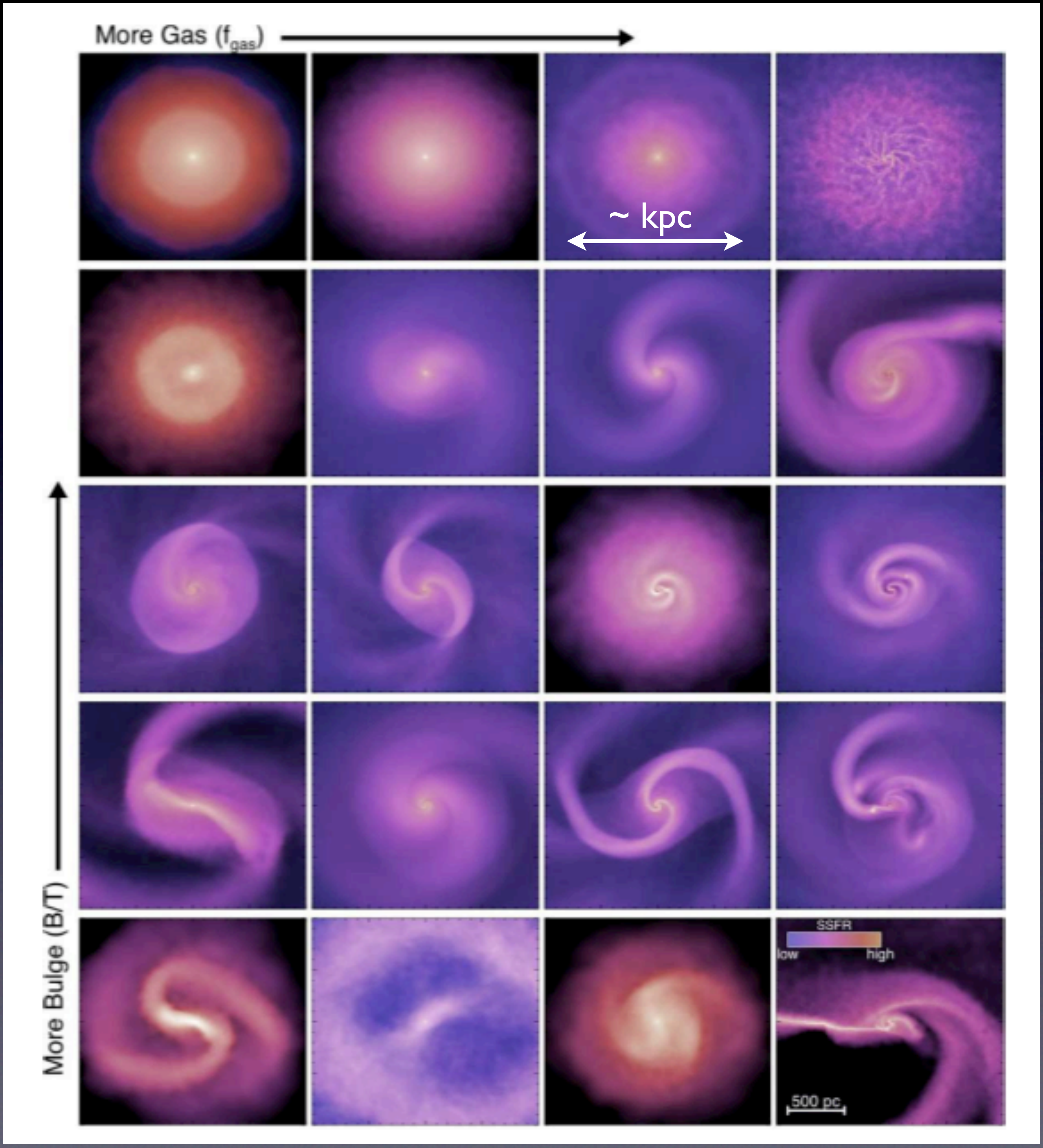
(Shlosman et al. 1989)

“It’s Bars all the Way Down ...”

More accurately ...

“It’s Non-axisymmetric Features all the Way Down ...”

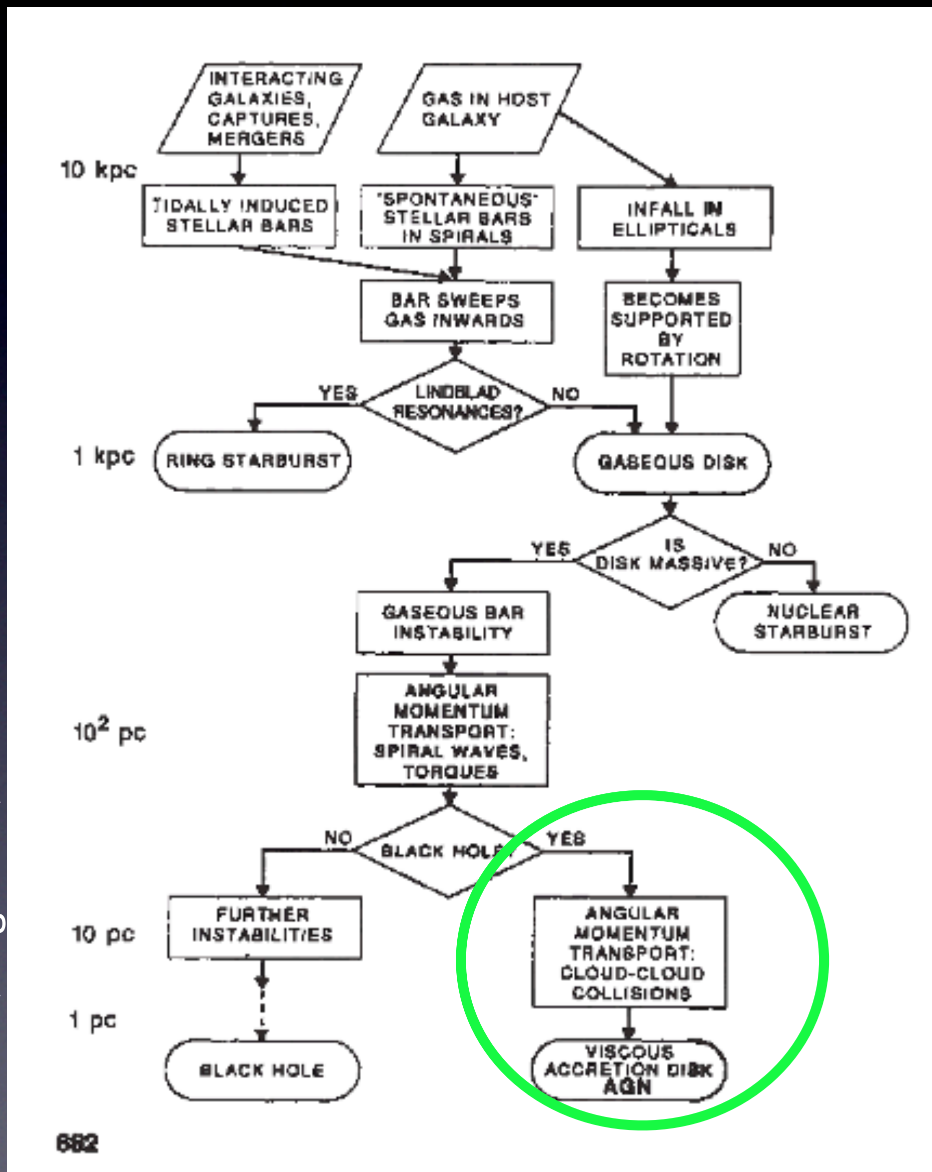
# Surface Density




Large Diversity in Observational Appearance at ~ 0.1-1 kpc Depending on

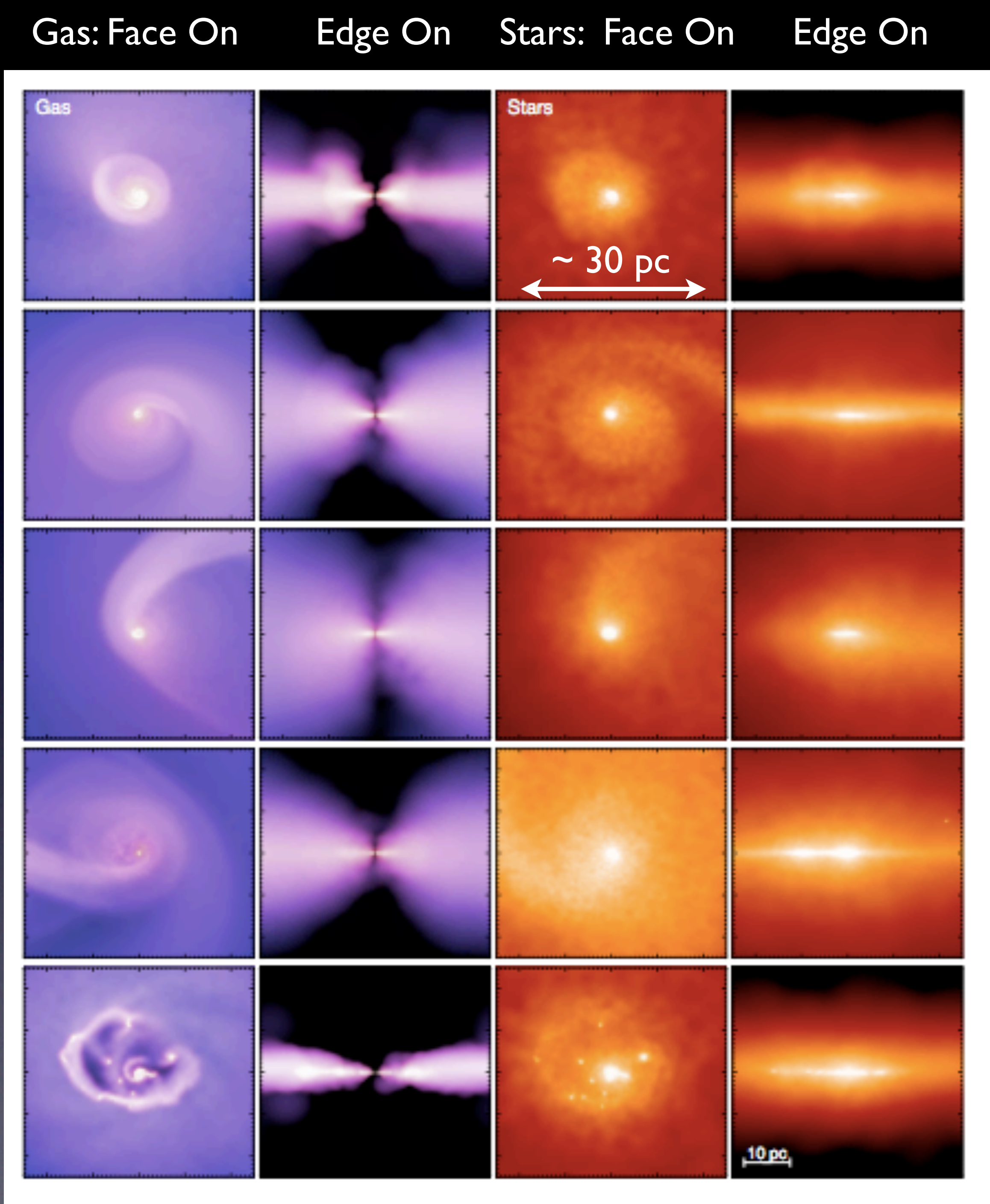
- Time
- Gas Fraction
- Bulge Fraction

# Inward Bound




Shlosman, Begelman, Frank 1990

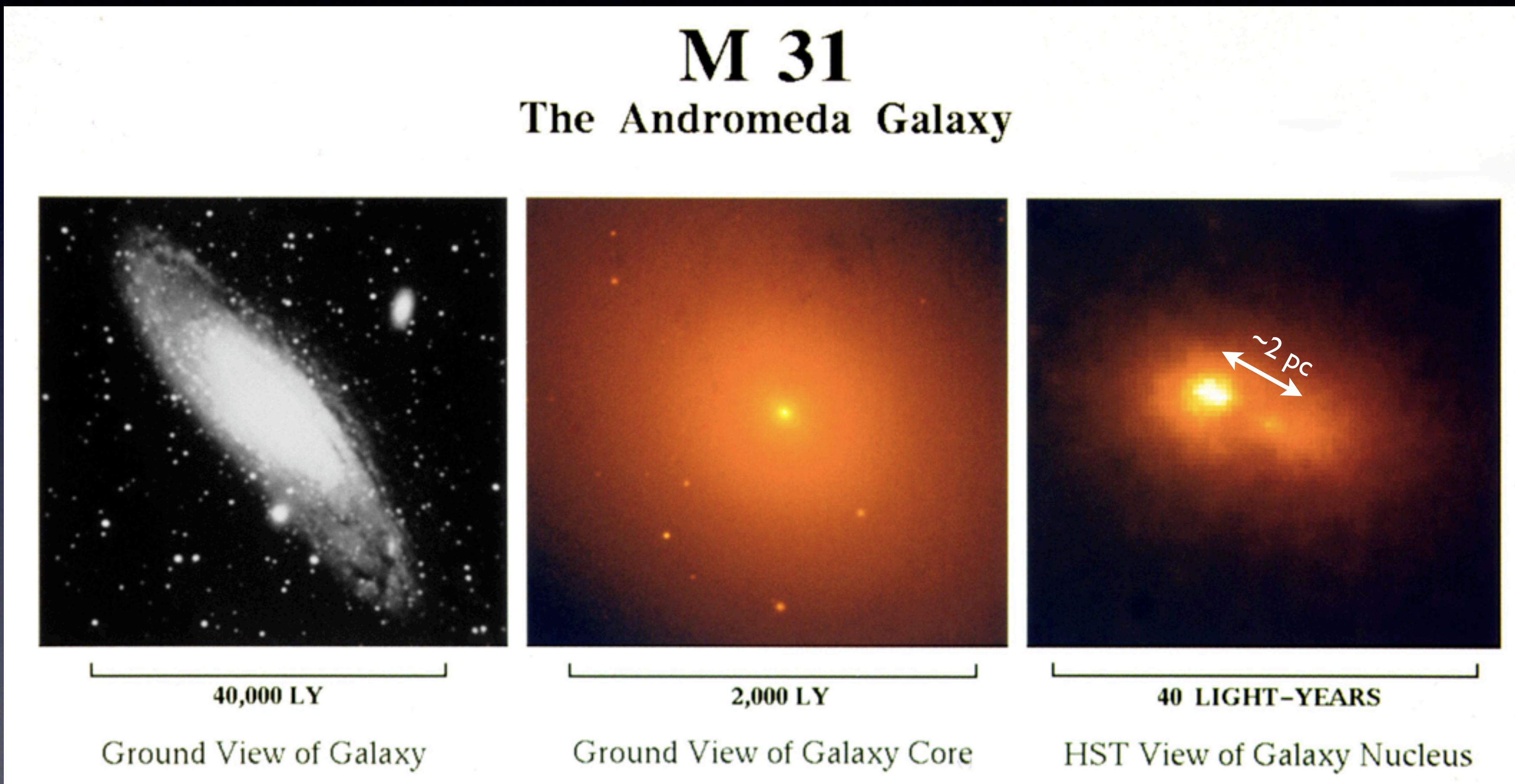
Once BH Forms: Large Gap btw Bar Transport at $\gtrsim$10s pc & viscous disk at $\lesssim$ 0.1 pc




Inside BH potential dominant asymmetry that drives gas inflow is not bar-like (m=2)

Instead: eccentric/ lopsided disk (m=1), in both stars & gas

# The 'Double' Nucleus of M31: a Fossil from the Era of BH Growth?




Lauer et al.

Tremaine: Double nucleus due to eccentric stellar disk

# Physics of Gas Inflow

## Bars w/in Bars

(Shlosman et al. 1989)

## More accurately ...

## "It's Non-axisymmetric Features all the Way Down ..."

**dominant torque:**

**asymmetry in stars → shocks in gas**

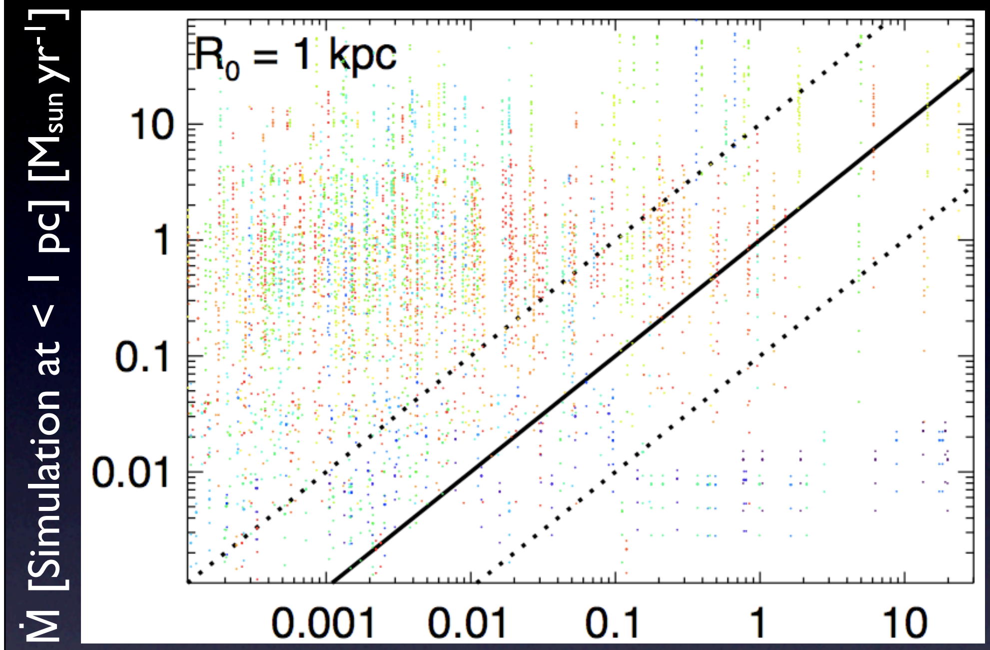
$$\dot{M} \sim \frac{\delta\Phi_*}{\Phi_0} \frac{M_{\rm gas}}{t_{\rm orb}}$$

$$t_{\rm inflow} \sim \frac{\Phi_0}{\delta\Phi_*} t_{\rm orb}$$

cf. local α model: $t_{\rm inflow} \sim t_{\rm orb}\, \alpha^{-1} (r/h)^2$

spiral waves in gas alone: $t_{\rm inflow} \sim t_{\rm orb}\, \alpha^{-1} (r/h)$

# Analytically Bridging the Gap: From ~ kpc to <~ 0.1 pc




Bondi Prediction at ~ kpc
($M_{sun}$ $yr^{-1}$)

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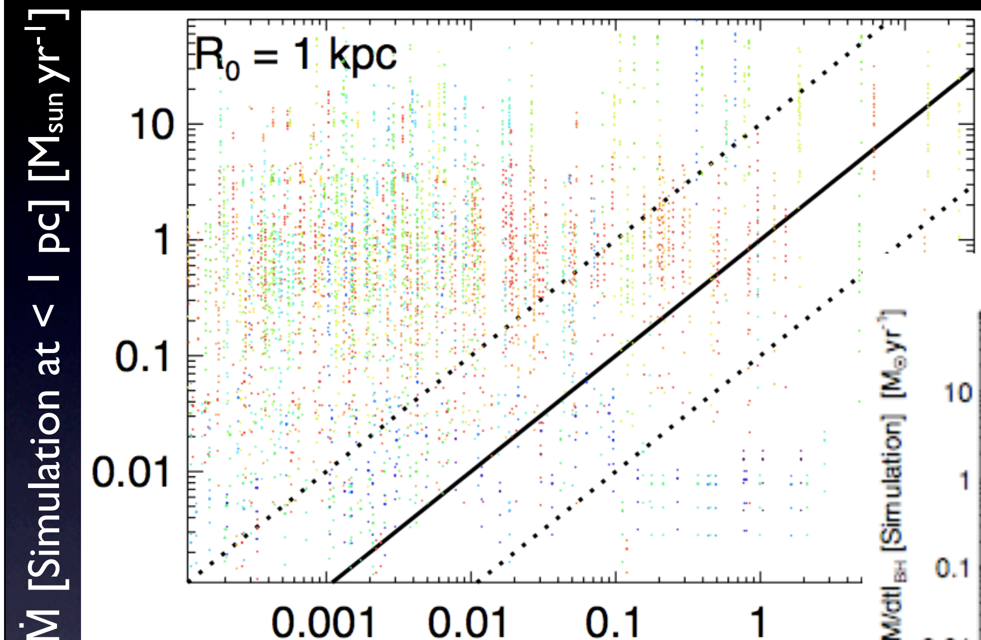
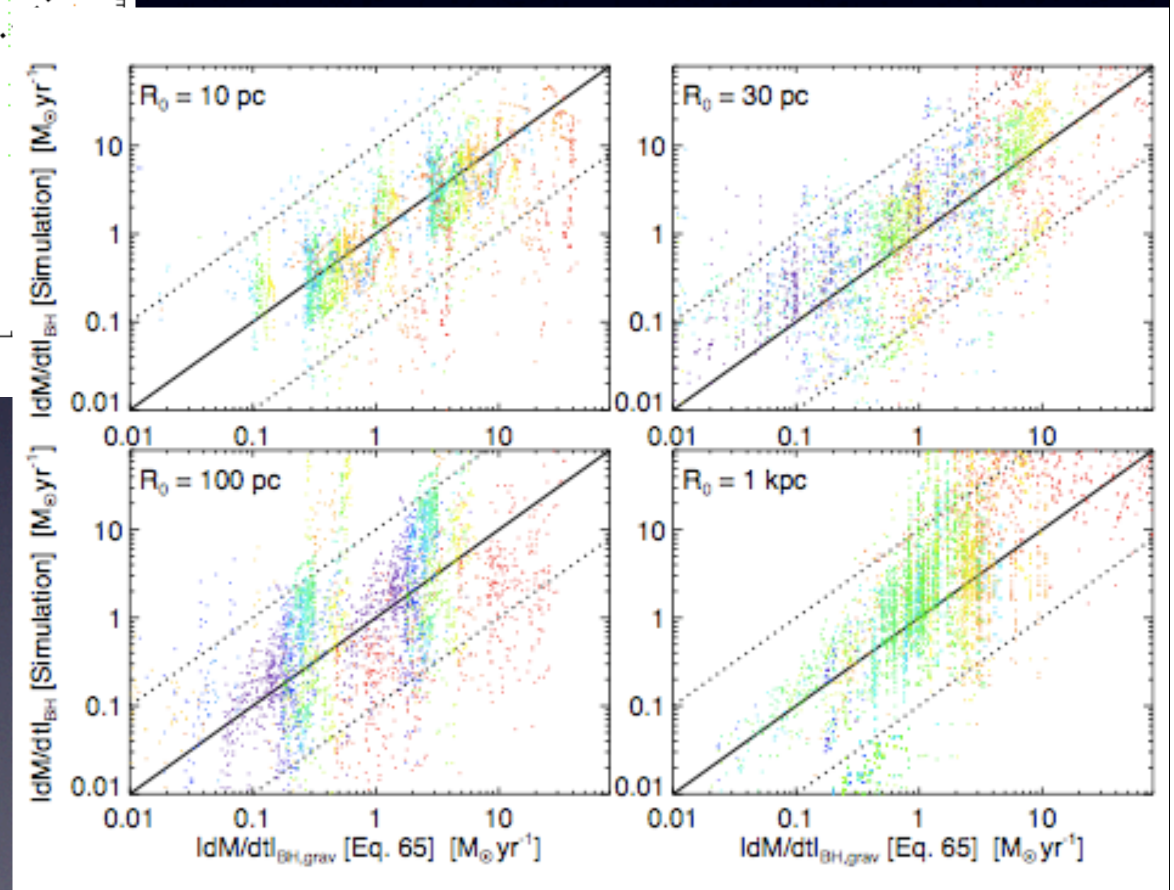



Bondi Prediction at ~ kpc
($M_{sun}$ $yr^{-1}$)

$$\frac{\dot{M}_{\rm BH,\,grav}}{M_\odot\,{\rm yr}^{-1}} \approx \alpha(\eta_K)\, f_d^{5/2}\, M_{\rm BH,\,8}^{1/6}\, M_{d,\,9}\, R_{0,\,100}^{-3/2}\, (1 + f_0/f_{\rm gas})^{-1}$$

HQ 2011

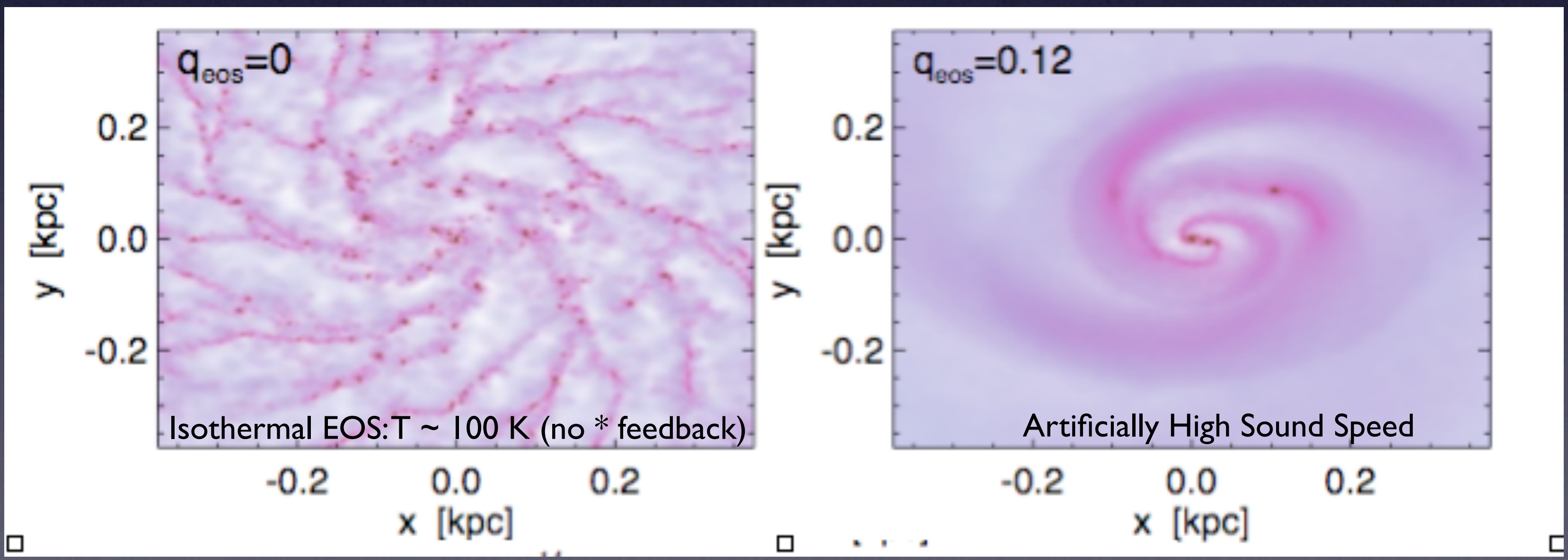



$\dot{M}$ Prediction Grav Torques [$M_{sun}$ $yr^{-1}$]

# Critical Physics: More Realistic ISM

- *To get the BH physics 'right' we need to get the ISM 'right'*
  - Bulge & BH Growth: gas inflow vs. star formation
  - BH Feedback: coupling of AGN winds & radiation to inhomogeneous vs. smooth ISM

Eg: Gas Inflow in Galaxies: Bulge Formation & BH Growth




Both of these Sims (ours) are wrong; Need to both form and disrupt GMCs

# Feedback associated with Star Formation

- Direct Momentum & Energy Input
  - $\dot{P}_{photons} \sim \dot{P}_{SNe} \sim \dot{P}_{*\ winds} \sim L/c$ ; $\dot{E}_{SNe} \sim 10^{-2}\,L \sim 10\,\dot{E}_{*\ winds}$ ; $\dot{E}_{ionization}$
- Interaction with Ambient ISM
  - $\dot{P}$ can ↑ (work done) while $\dot{E}$ ↓ (energy radiated away)

$$\text{Photons}: \quad \dot{P} \simeq \frac{L}{c}\left(1 - \exp[-\tau_{UV}]\right) + \frac{L_{FIR}}{c}\tau_{FIR} \sim \frac{L}{c}\left(1 + \tau_{FIR}\right)$$

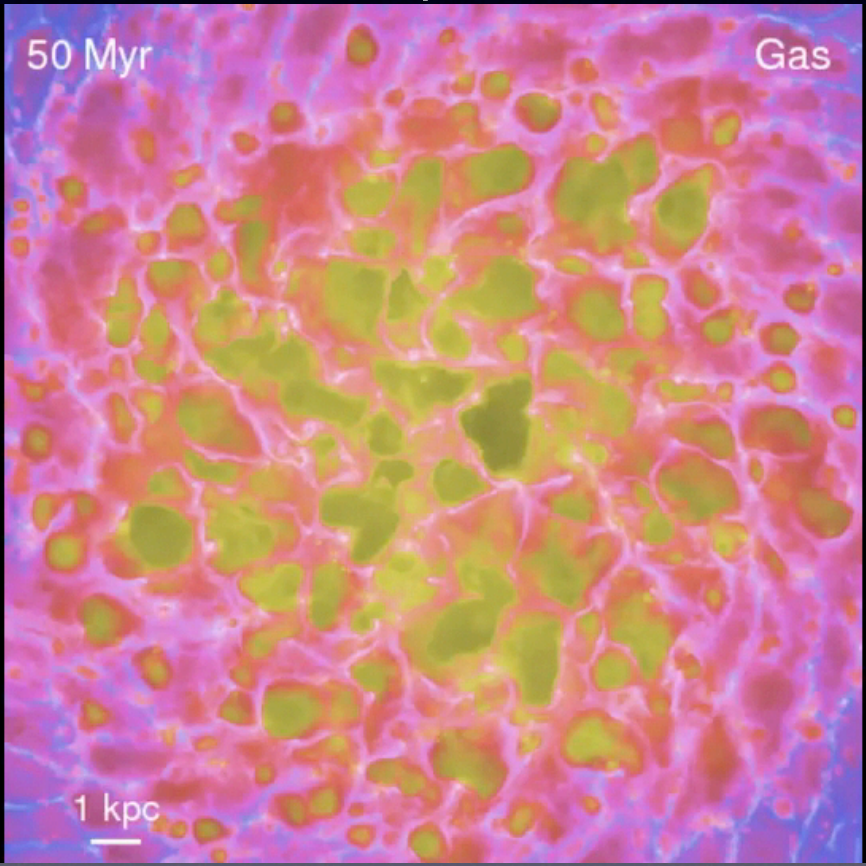
UV degraded into FIR — FIR scattering/absorption

(very approx implementation; see HQM 2011)

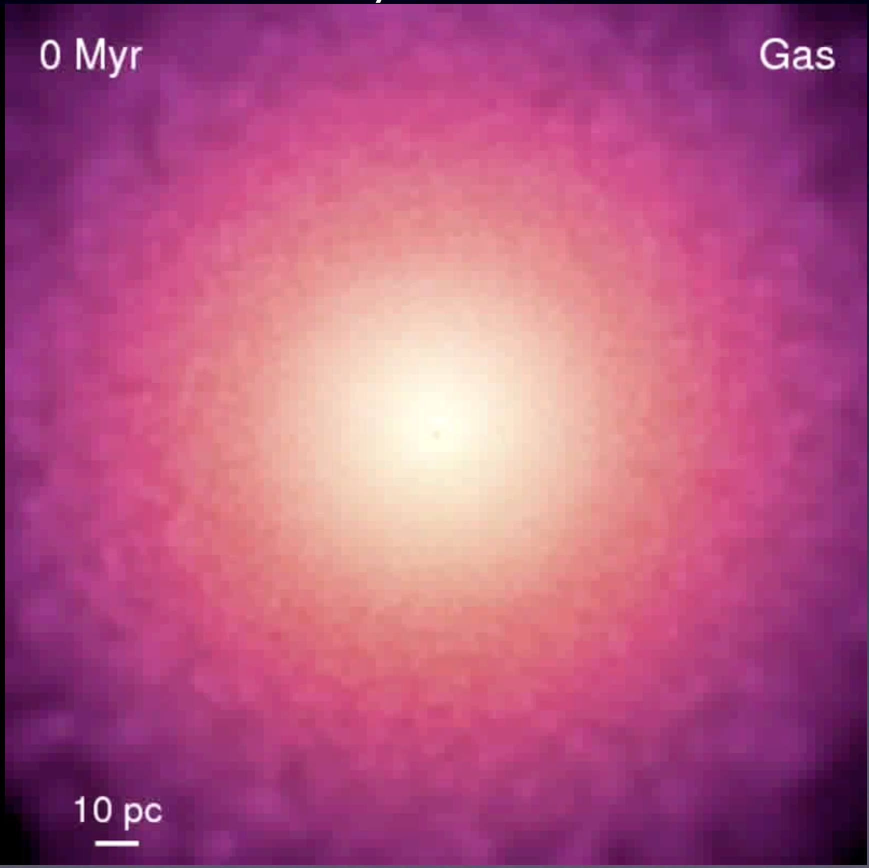
$$\text{SNe}: \quad \dot{P} \sim 10s\,\frac{L}{c}$$

# Towards a More Realistic Model of the ISM

Galaxy-Scale




Galaxy Nucleus



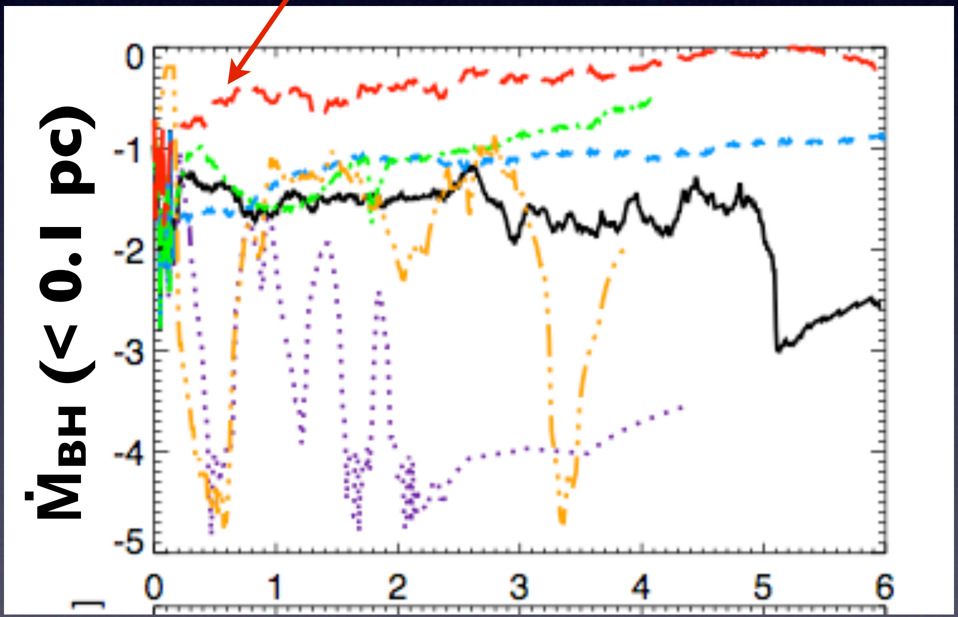

w/ Phil Hopkins & Norm Murray

Inhomogeneous ‘turbulent’ ISM & galactic winds self-consistently created

Subgrid ISM Model w/ OOM Plausible Treatment of Stellar Feedback

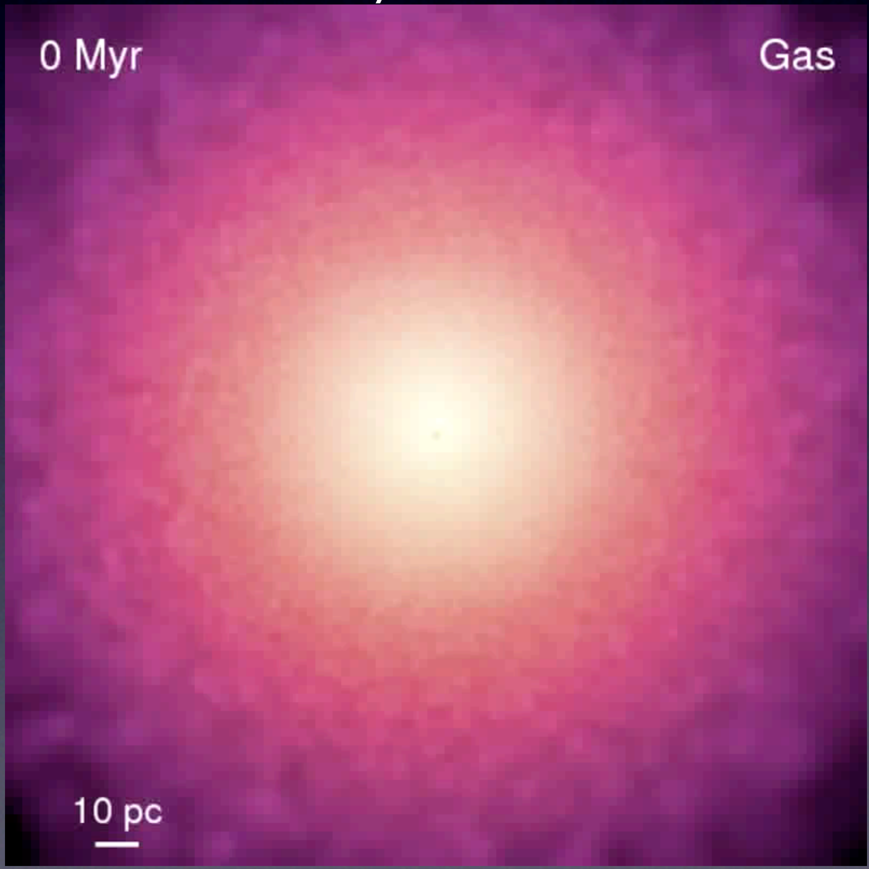
# Towards a More Realistic Model of the ISM

Sim w/ no
AGN Feedback




Time (Myr)

Galaxy Nucleus




w/ Phil Hopkins & Norm Murray

Subgrid ISM Model w/ OOM Plausible
Treatment of Stellar Feedback

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