The Missing Link Between Quasars and Galaxies

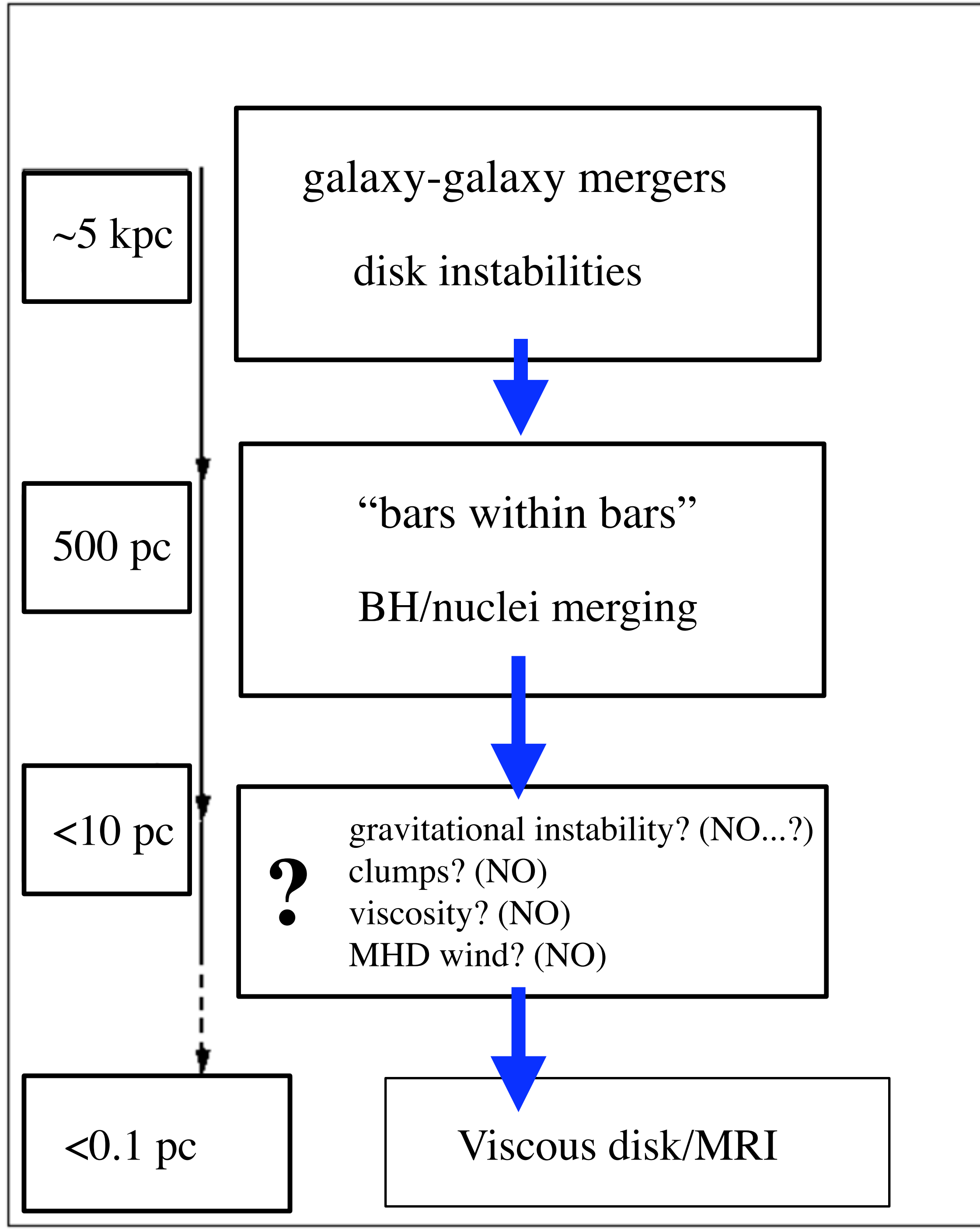
Philip Hopkins

07/28/10

Eliot Quataert, Lars Hernquist, T. J. Cox, Kevin Bundy, Jackson DeBuhr,
Volker Springel, Dusan Keres, Gordon Richards, Josh Younger,
Desika Narayanan, Paul Martini, Adam Lidz, Tiziana Di Matteo, Yuexing Li,
Alison Coil, Adam Myers, Patrik Jonsson, Chris Hayward

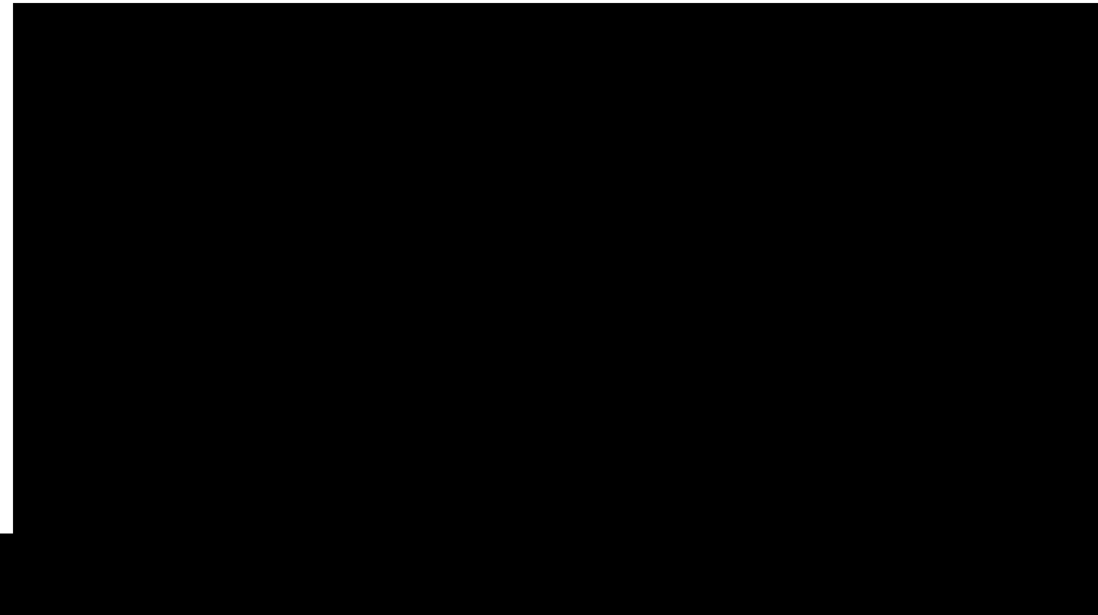
- Focus: Most luminous QSOs
  (~1-10 M_{sun}/yr)

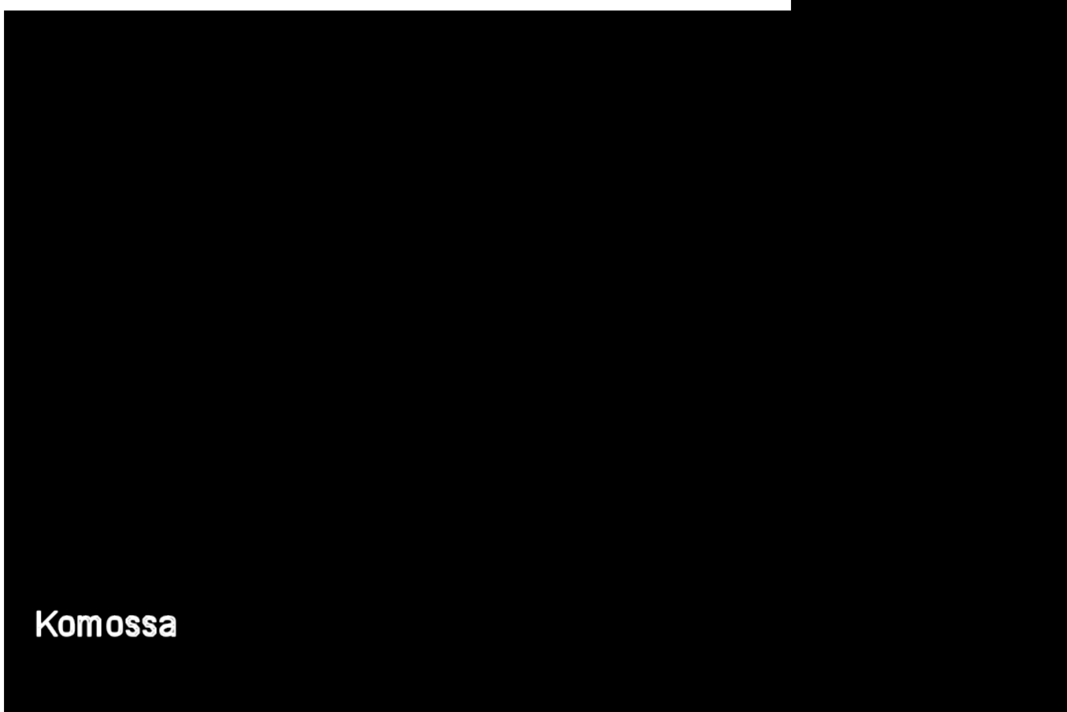
- 'Bottleneck' at
  <10-50pc: BH begins
  to dominate the potential
  (e.g. Goodman et al.,
  Jogee et al., Martini et al.)



- Galaxy merger: good way to get lots of gas to small scales!

- *If* BHs trace spheroids, then *most* mass added in violent events that also build bulges

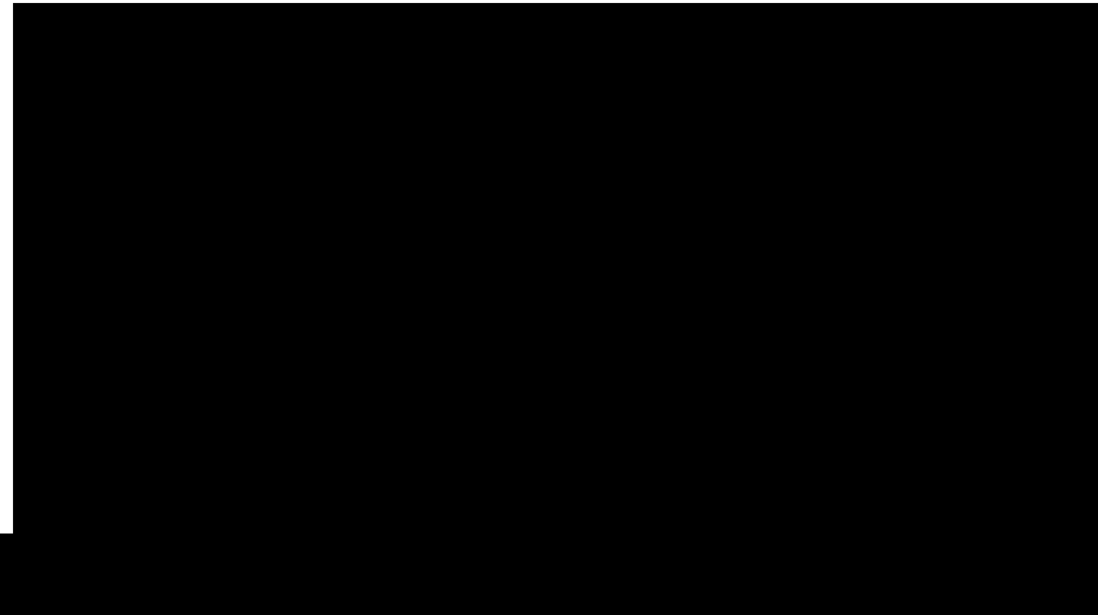


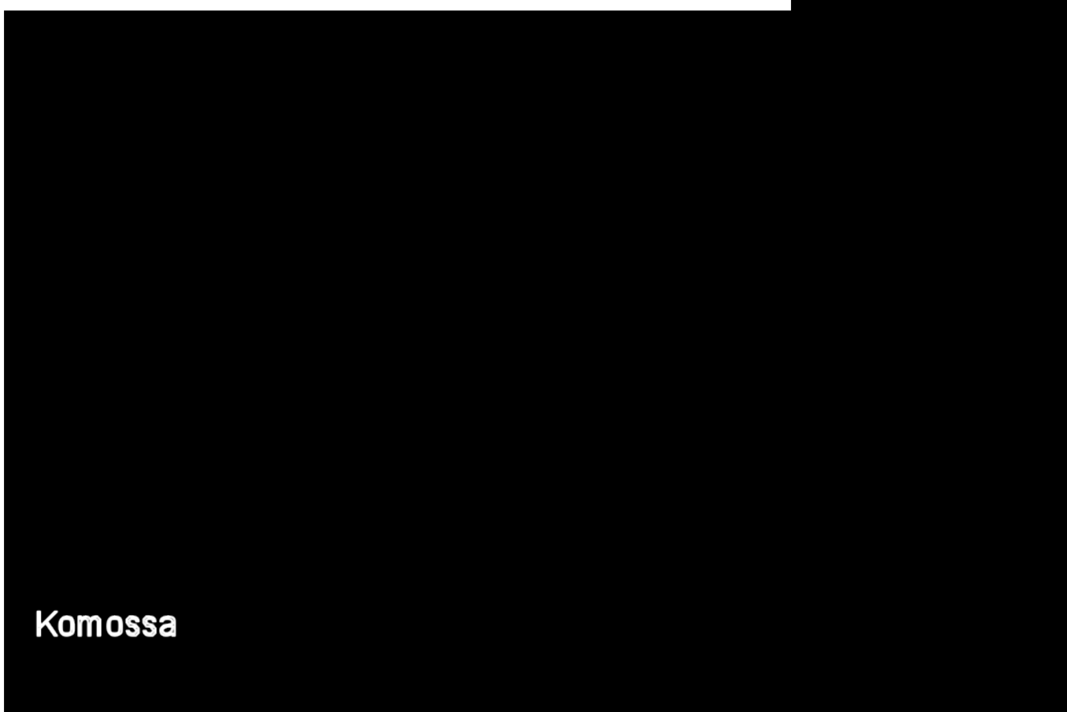


- Problem:
  Scale of merger: ~100 kpc
  Viscous disk: ~0.1 pc

- Solution 1: simple prescription

- Solution 2: re-simulate ("zoom in") and see what happens!





Simulations:

FOLLOWING THE GAS IN...

- Here: Focus on *robust* conclusions

Simulations:

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- Need to include:

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- Need to include:
    - Gas+Stars

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- Need to include:
    - Gas+Stars
    - Self-gravity!

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  - Cooling

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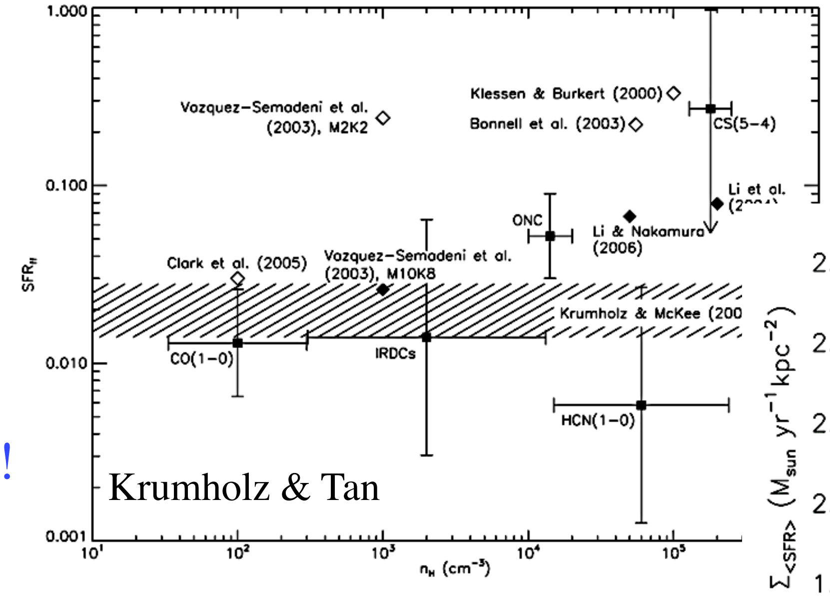

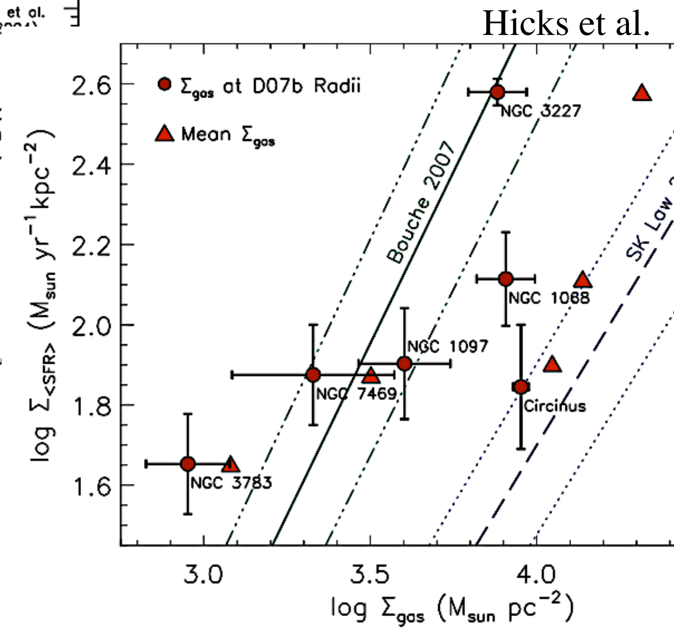

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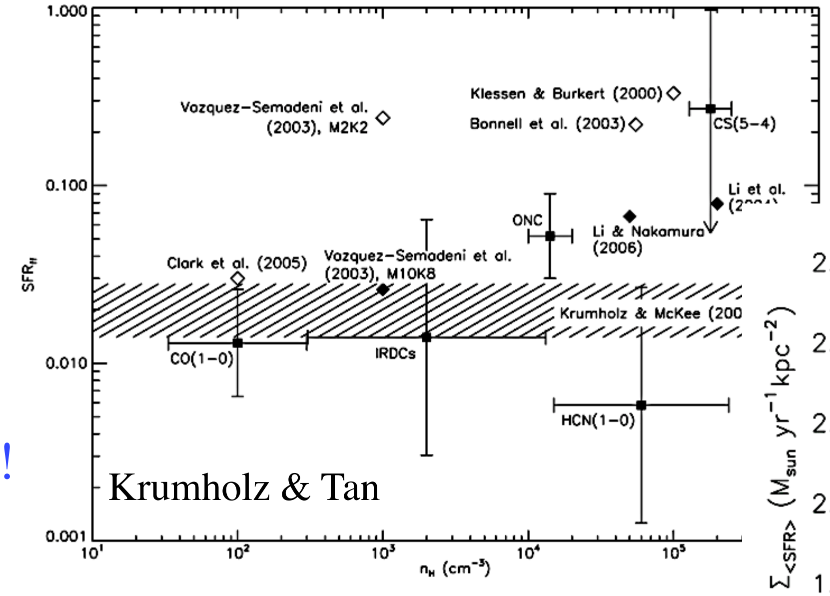
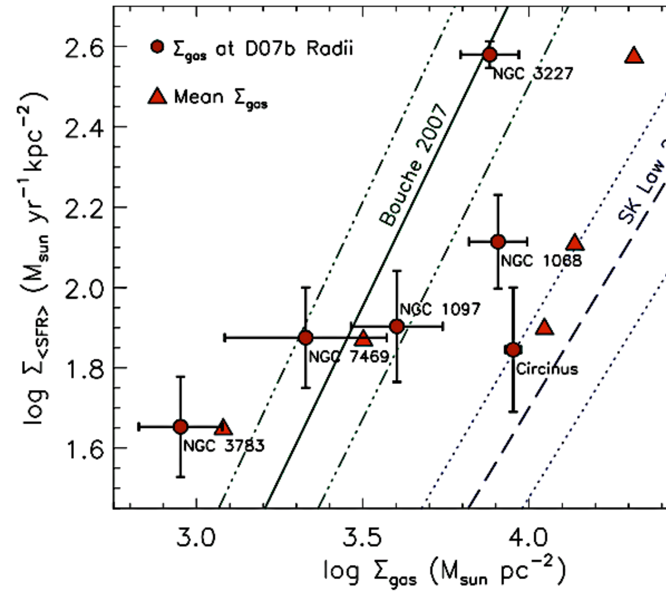
  - 'Feedback'
    - Admit we don't understand it!



Hicks et al.



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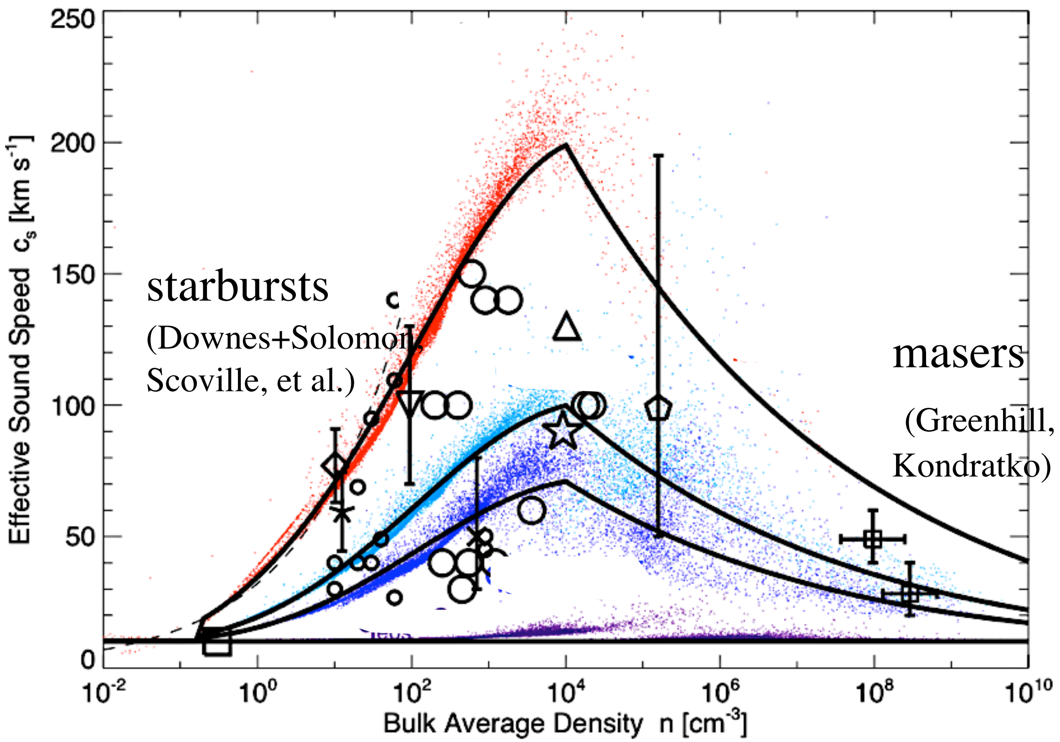
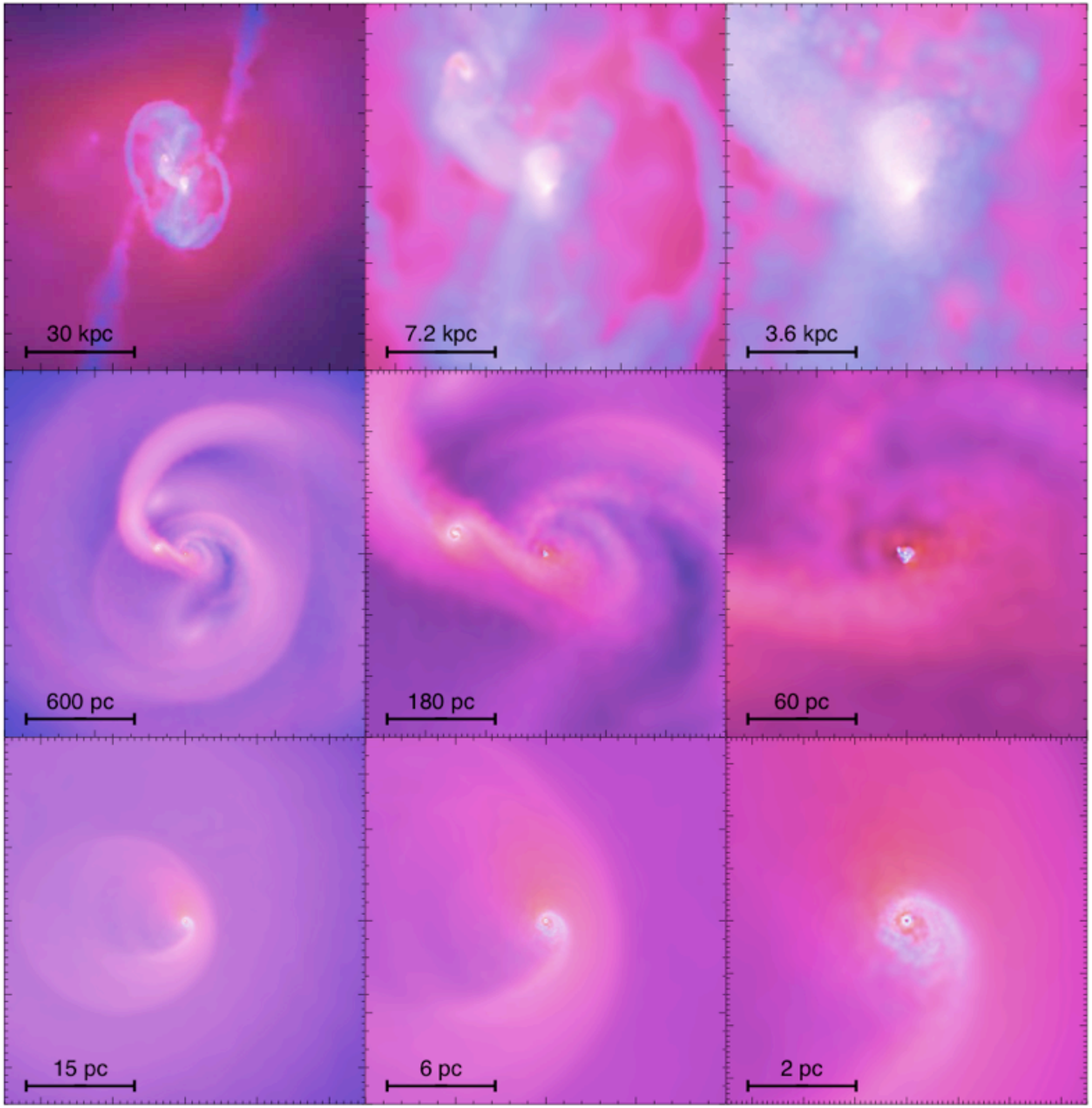


- Here: Focus on *robust* conclusions


T = 0 Myr
Gas

How do massive BHs get their gas?

CAN WE FUEL THE MONSTER?

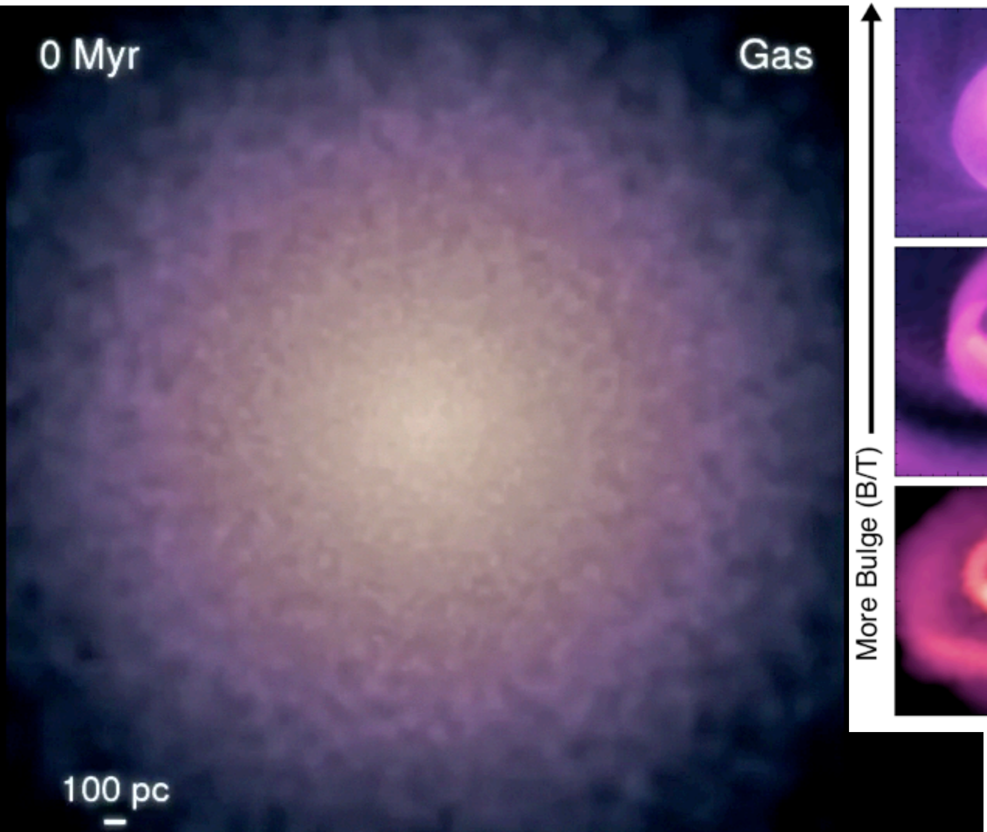


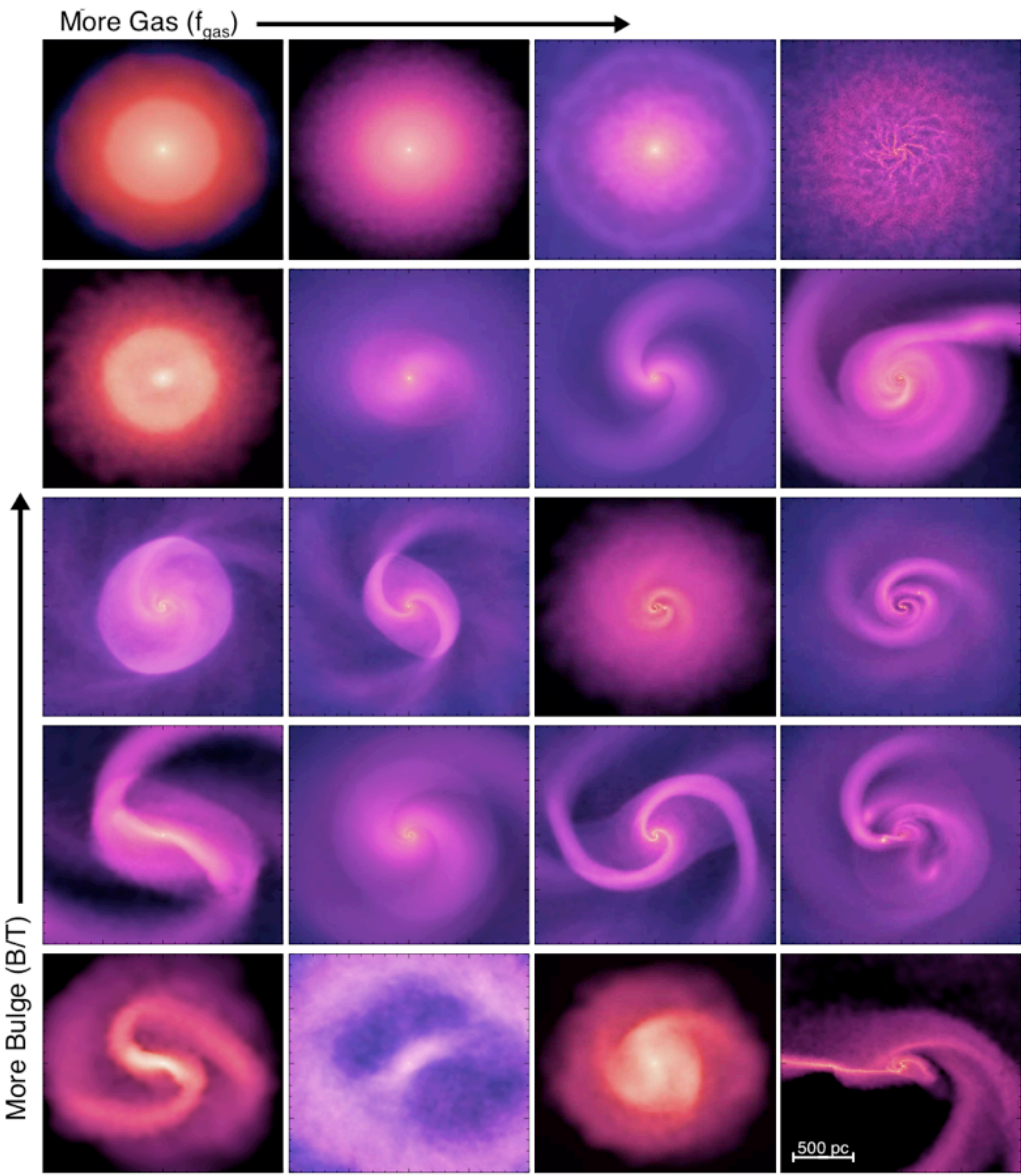
- Cascade of instabilities: merger not efficient inside ~kpc
- *Any* mechanism that gets to similar densities at these scales will do the same
- Instabilities change form at BH radius of influence

Sub-kpc scales: “Stuff within Stuff”

- Diverse morphologies on sub-kpc scales: not just bars!

- Inflow is *not* smooth/continuous





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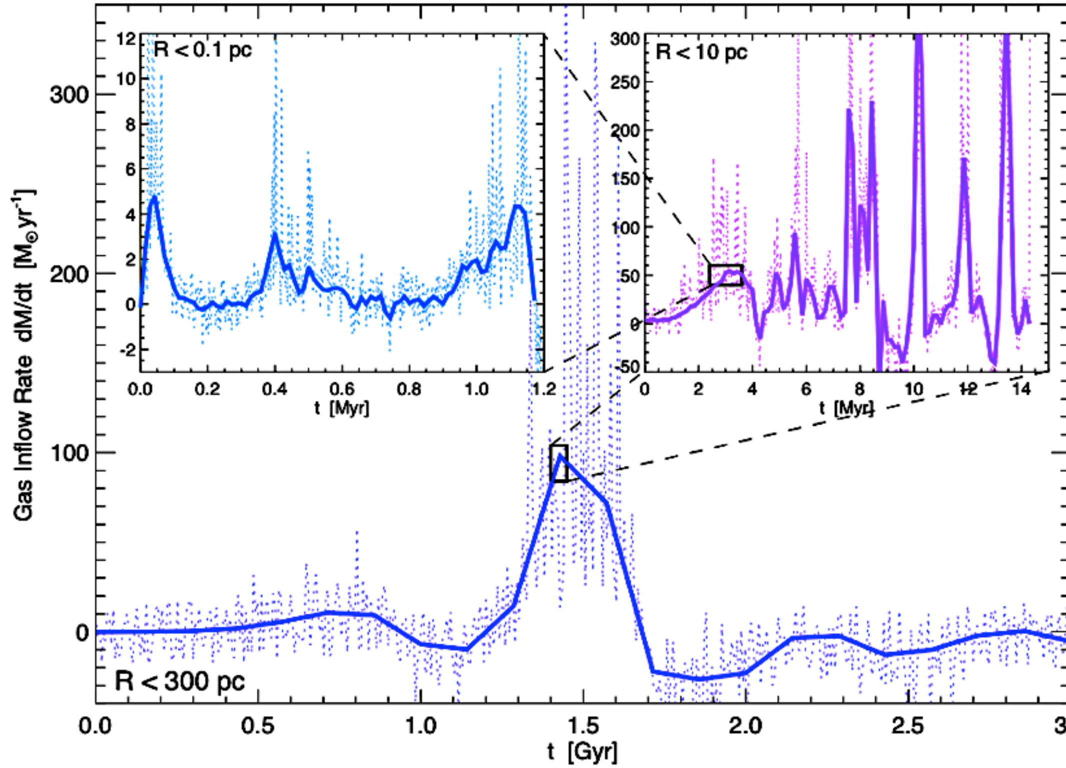
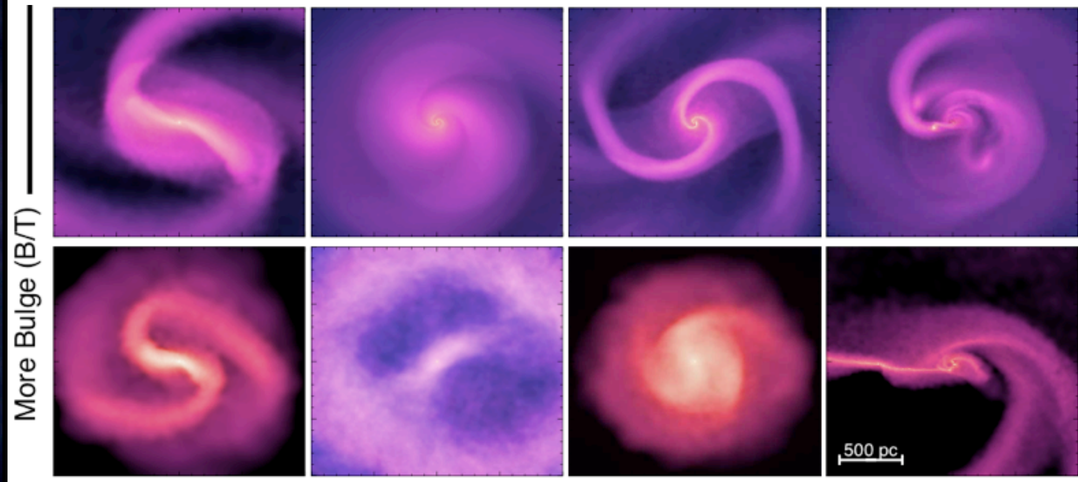
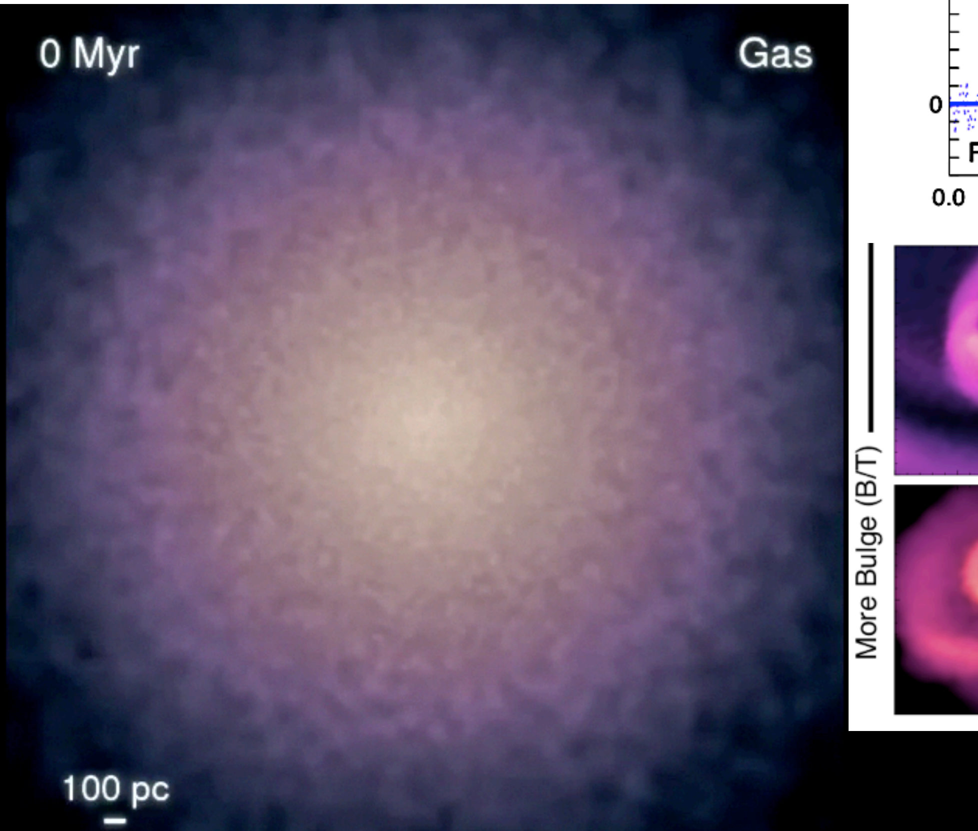
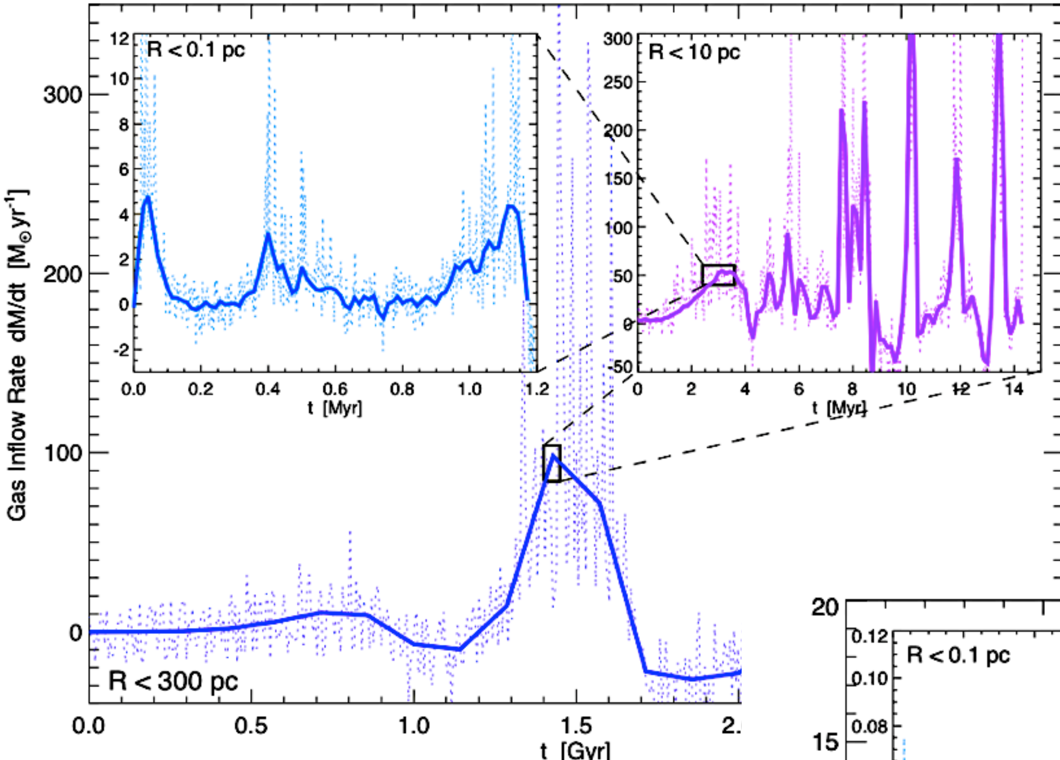


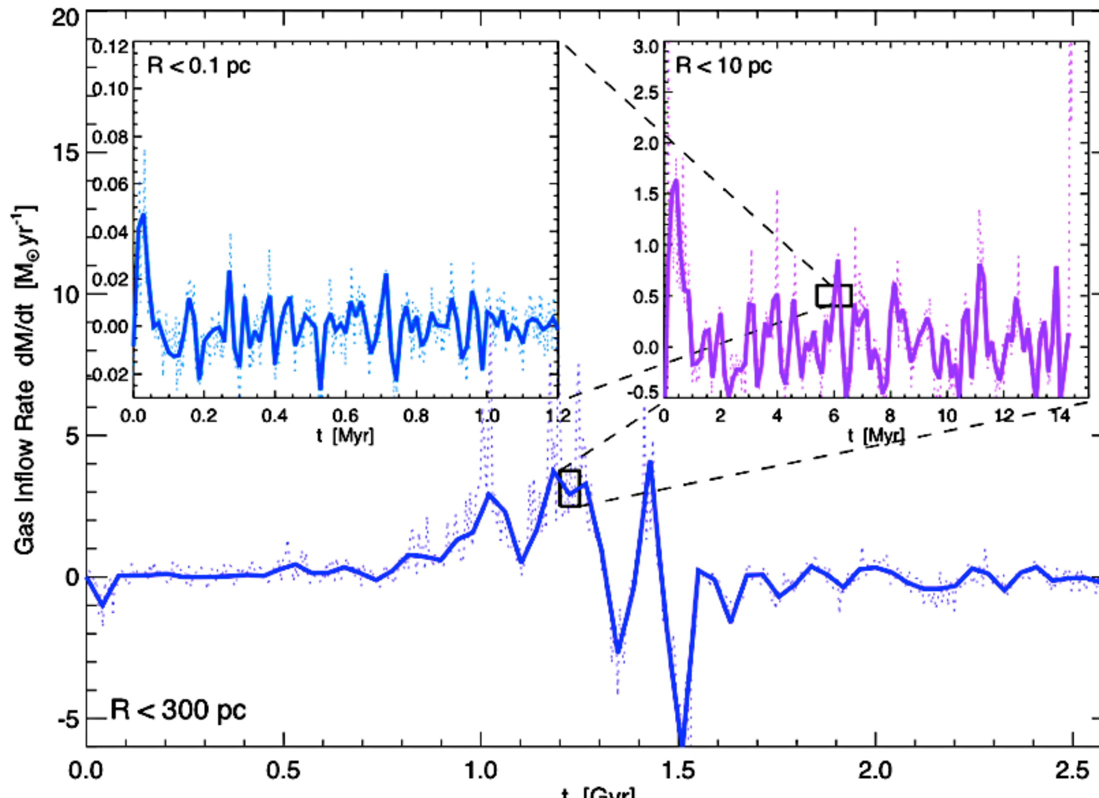




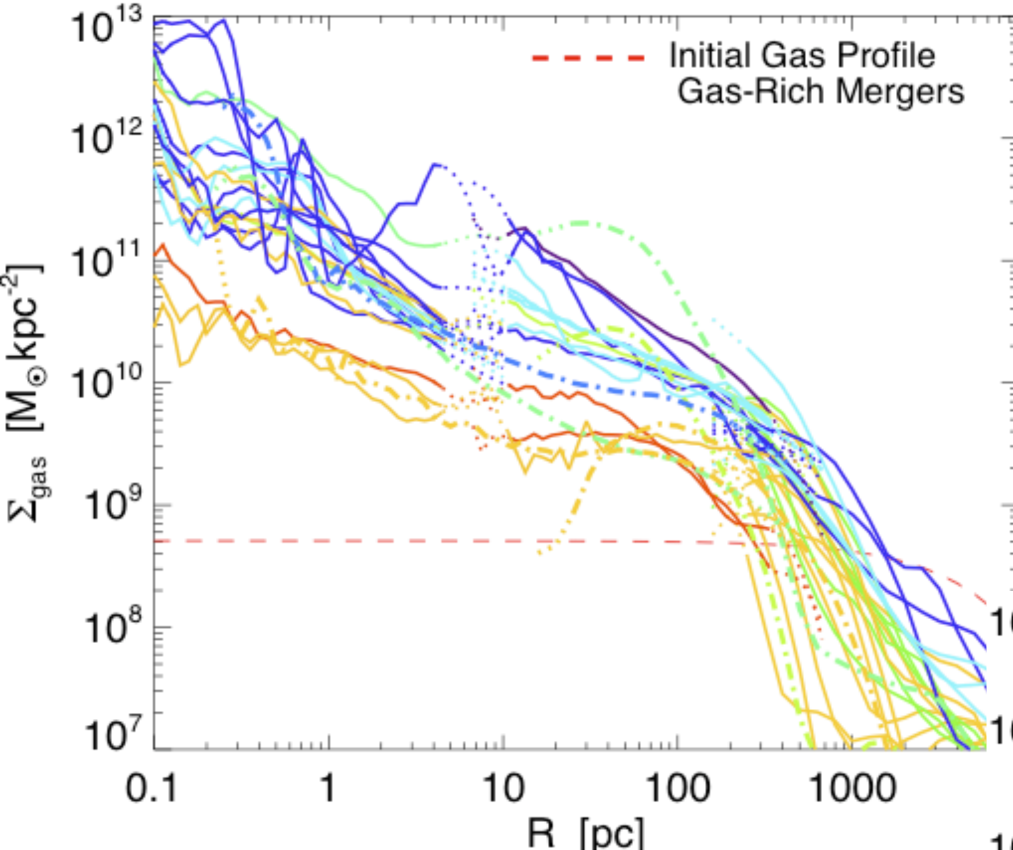


Gas-rich merger
(lots of inflow)

Weakly bar-unstable disk
(less inflow)



- Key parameter:
  Gas driven in, vs.
  pre-existing bulge/BH mass



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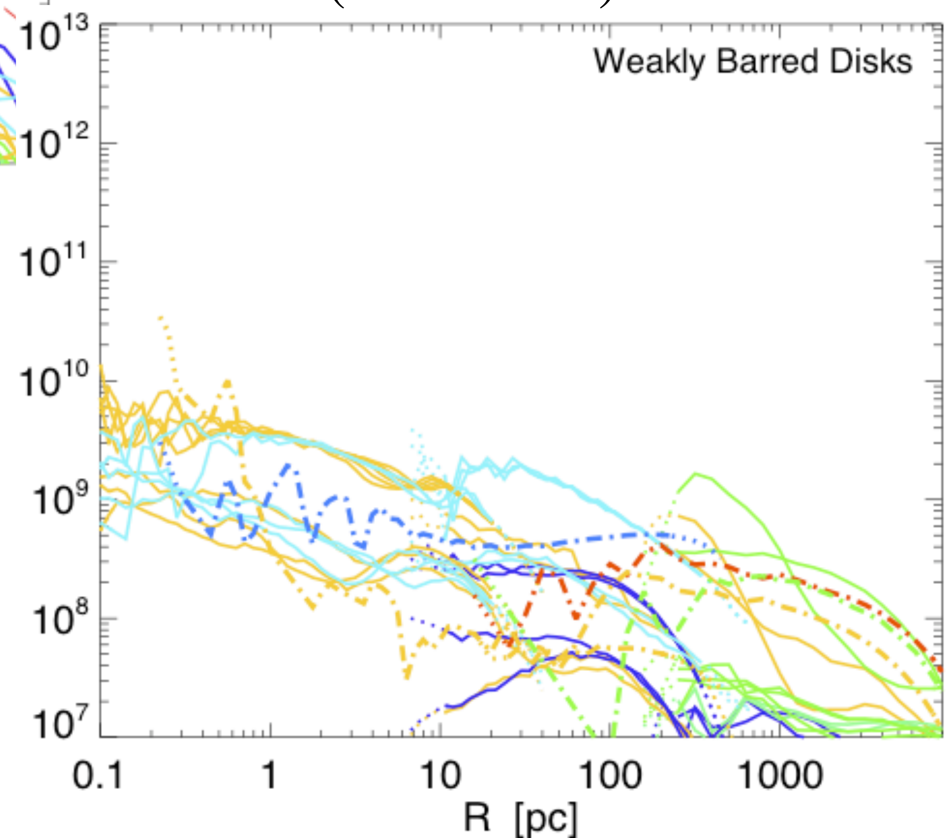
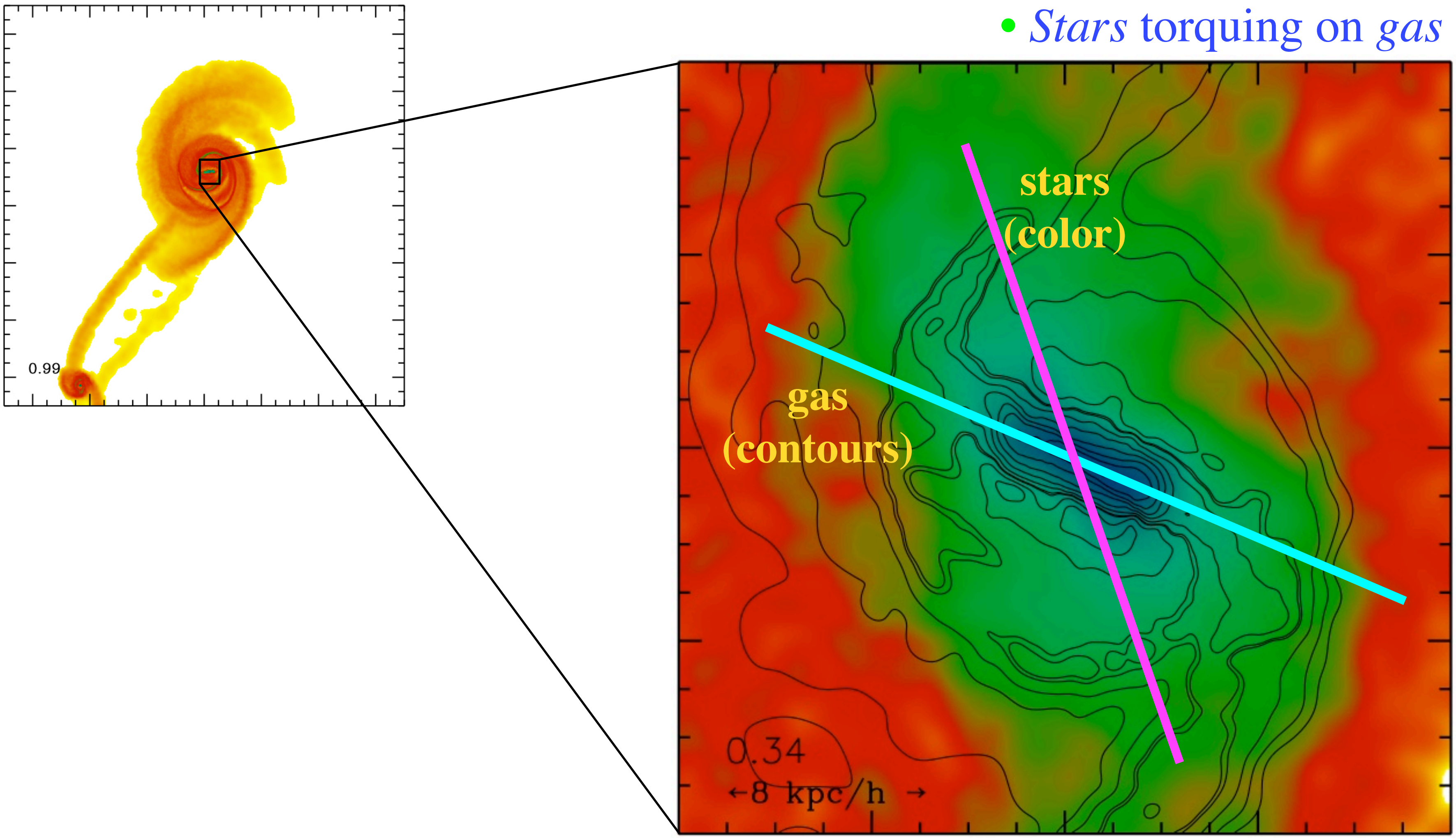


- Key parameter:
  Gas driven in, vs.
  pre-existing bulge/BH mass

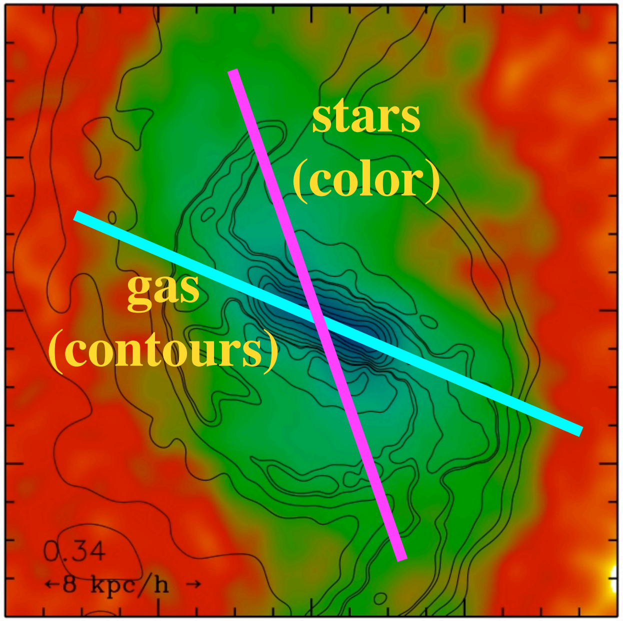
- Gravity dominates torques from 0.1 - 10,000 pc:

- *Stars* torquing on *gas*



How does this work?

- Build analytic models:
  - Structure
  - Growth rates
  - Stability
  - Inflow rates



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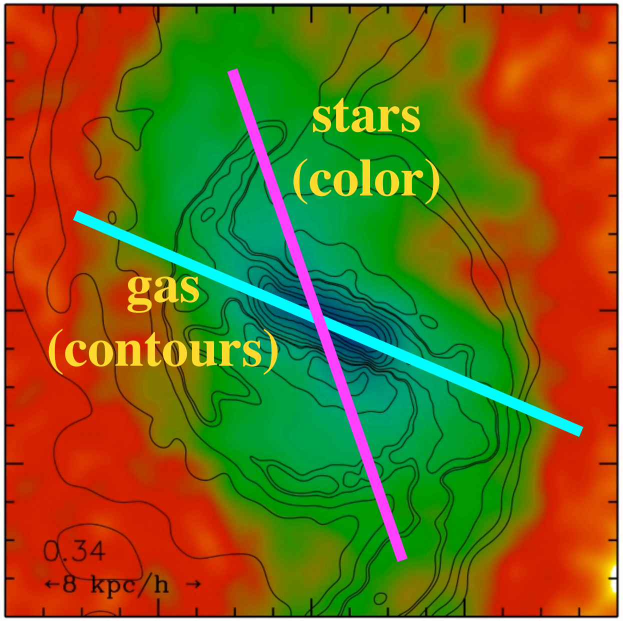

standard (dissipationless) formulation: spiral waves carry the angular momentum: (Lynden-Bell & Kalnajs '72)

$$\dot{M}_{\rm inflow} = \Gamma[k, |a|]/\Omega\, R^2 \sim \frac{|a|^2}{|kR|^2}\, \frac{M_{\rm disk}}{M_{\rm tot}}\, \frac{M_{\rm gas}}{t_{\rm dyn}} \qquad (|kR| \gg 1)$$

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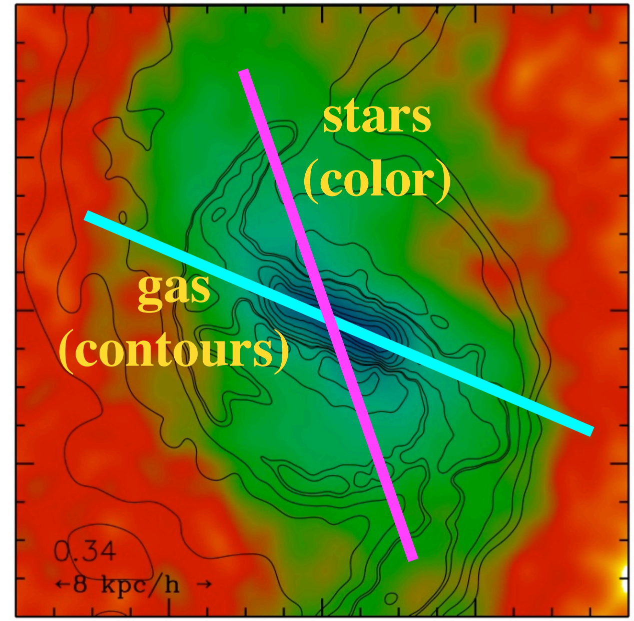

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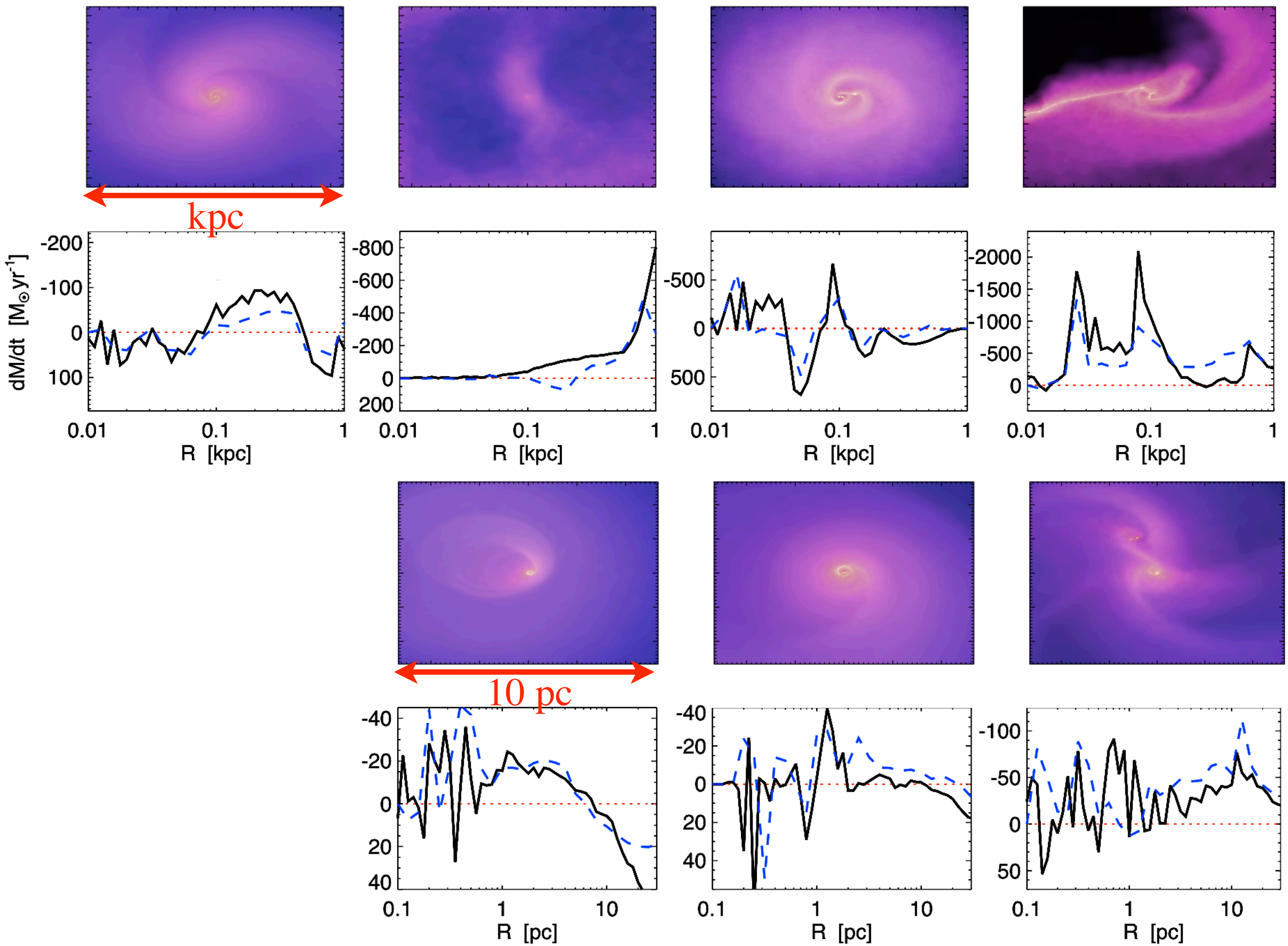
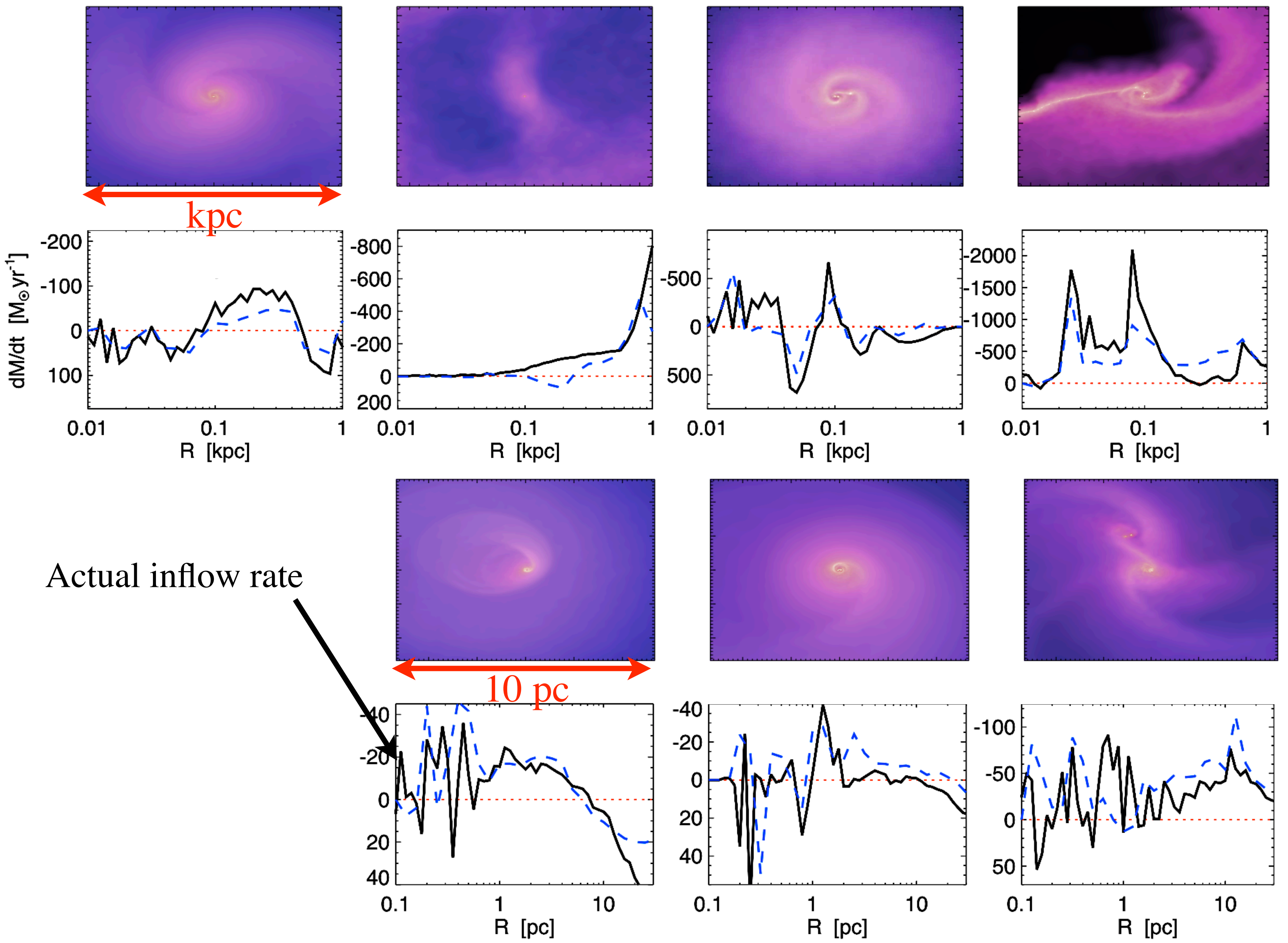
with shocks & dissipation:

$$\dot{M}_{\rm inflow} = \Sigma_{\rm gas}\, R^2\, \Omega \left|\frac{\Phi_1}{V_c^2}\right| \frac{m\,{\rm sign}(\Omega-\Omega_p)}{1+\partial \ln V_c/\partial \ln R}\, F(\zeta) \sim |a|\, \frac{M_{\rm gas}}{t_{\rm dyn}}$$

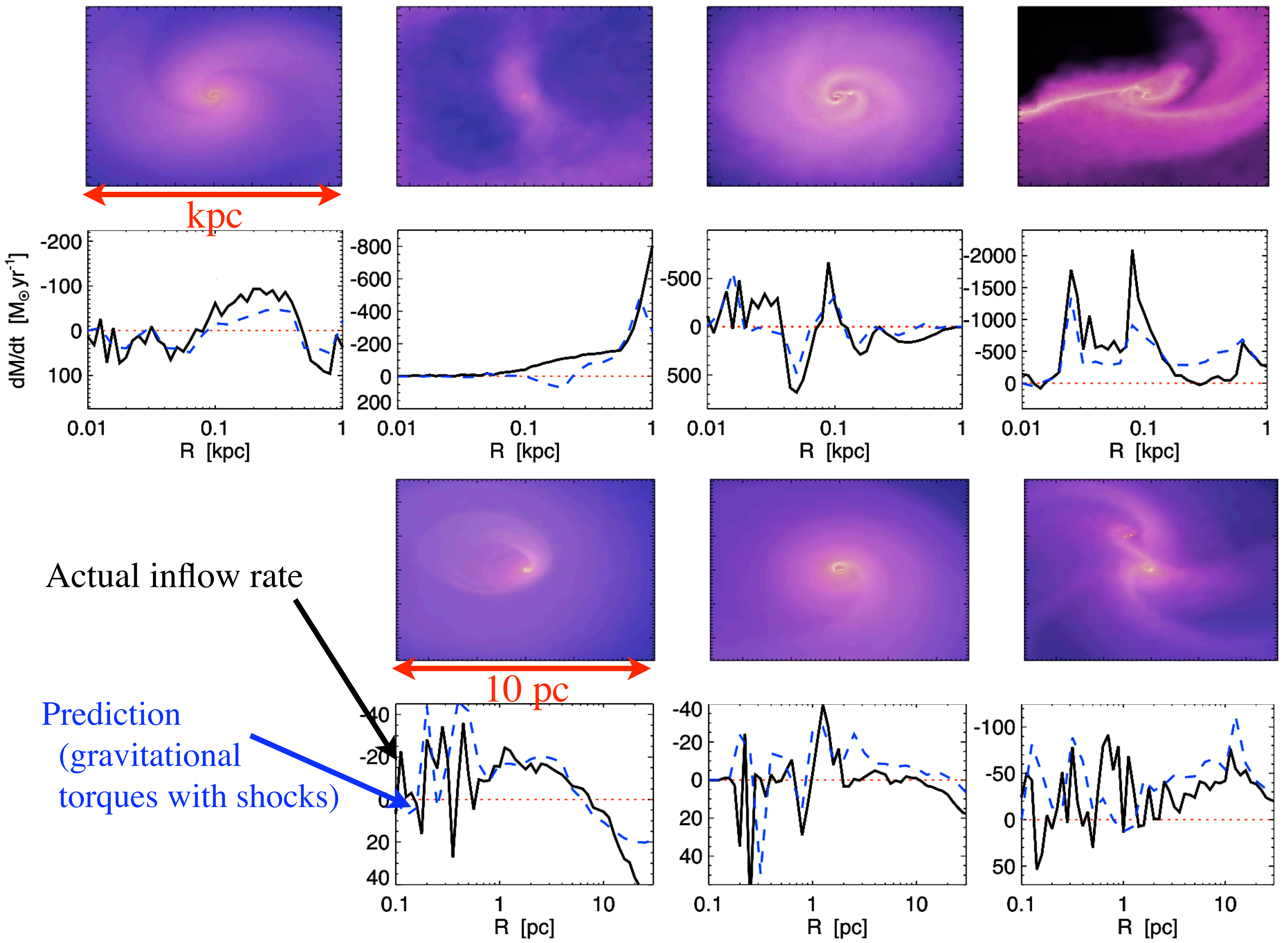
>100x larger!!!



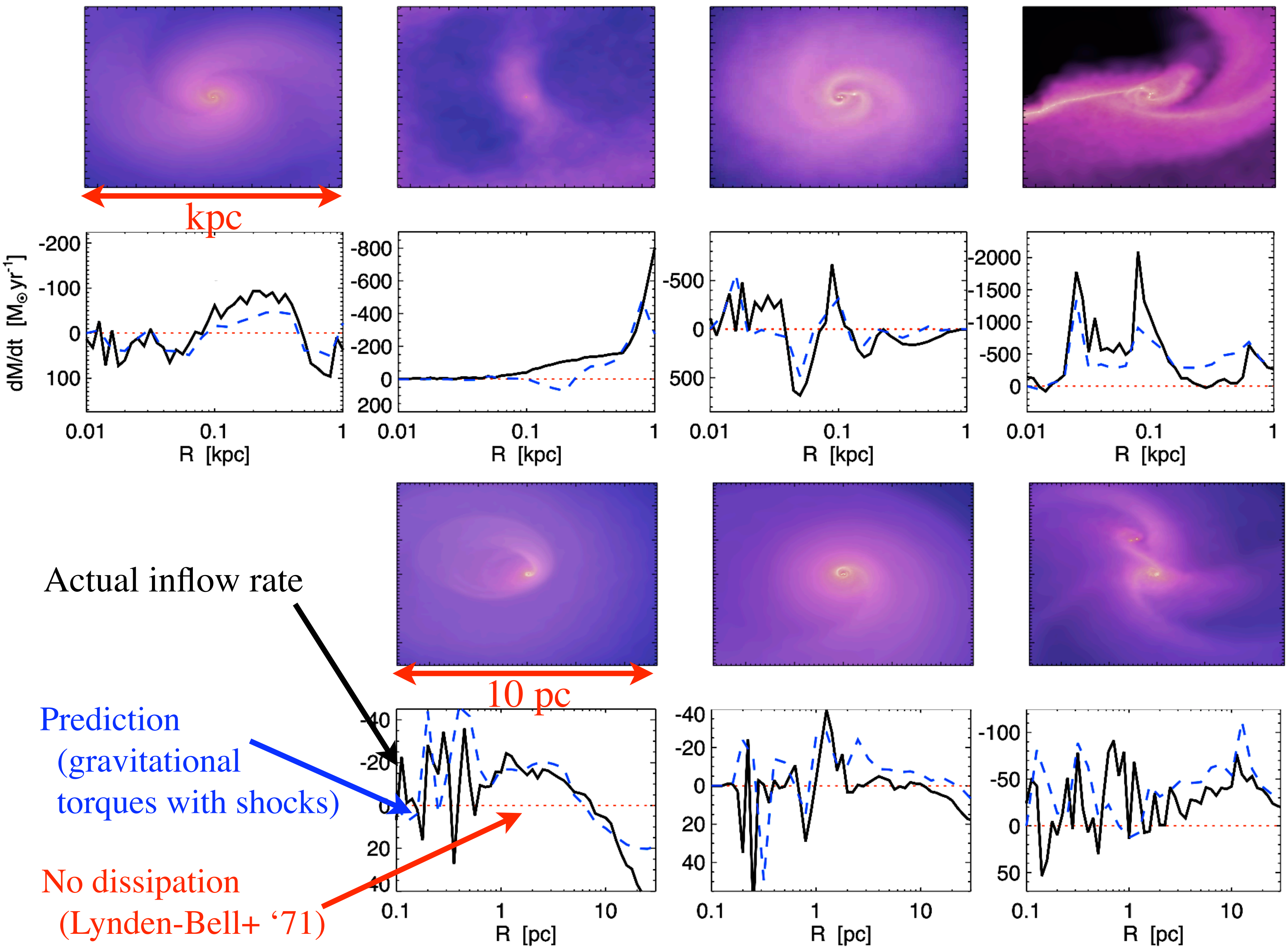
kpc
dM/dt [M⊙yr⁻¹]
R [kpc]
10 pc
R [pc]



kpc
dM/dt [M⊙yr-1]
R [kpc]
Actual inflow rate
10 pc
R [pc]



kpc
10 pc
Actual inflow rate
Prediction
(gravitational
torques with shocks)
dM/dt [M$_\odot$yr^{-1}]
R [kpc]
R [pc]



kpc
dM/dt [M$_\odot$yr^{-1}]
R [kpc]
R [kpc]
R [kpc]
R [kpc]
Actual inflow rate
10 pc
Prediction
(gravitational
torques with shocks)
No dissipation
(Lynden-Bell+ ‘71)
R [pc]
R [pc]
R [pc]

Can we build a better accretion rate estimator?

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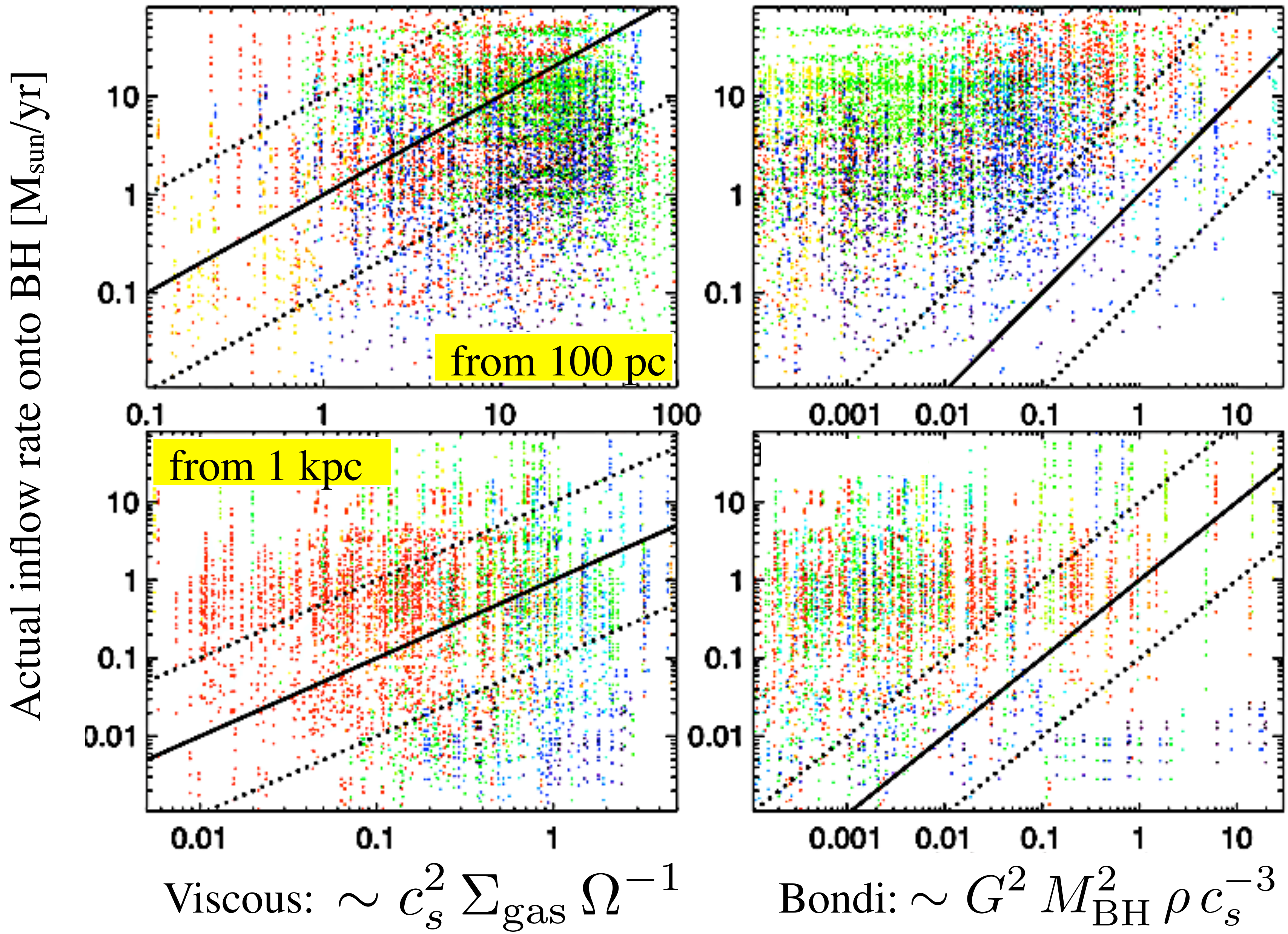
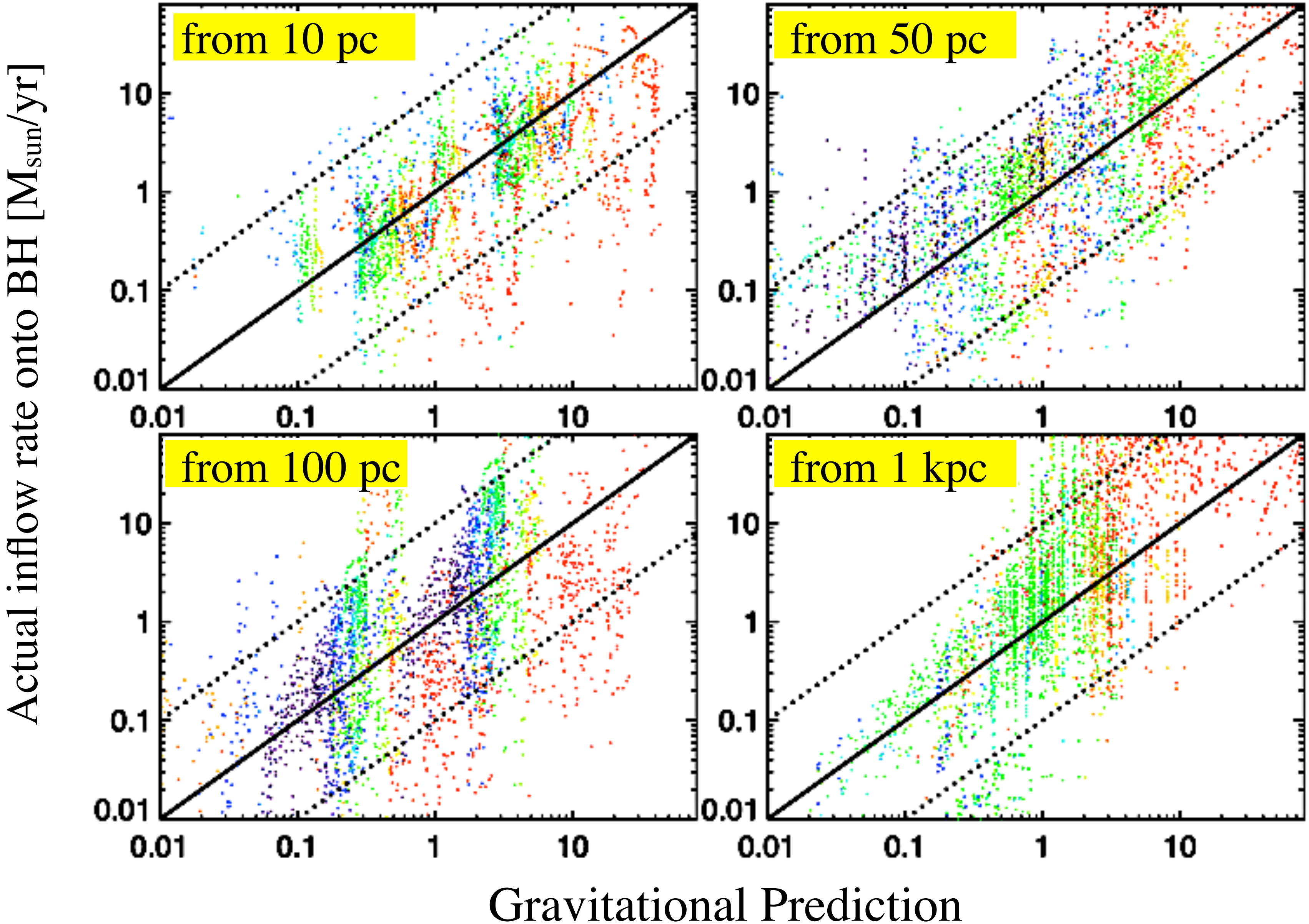
Derive 'Gravitational Torque' Rate:

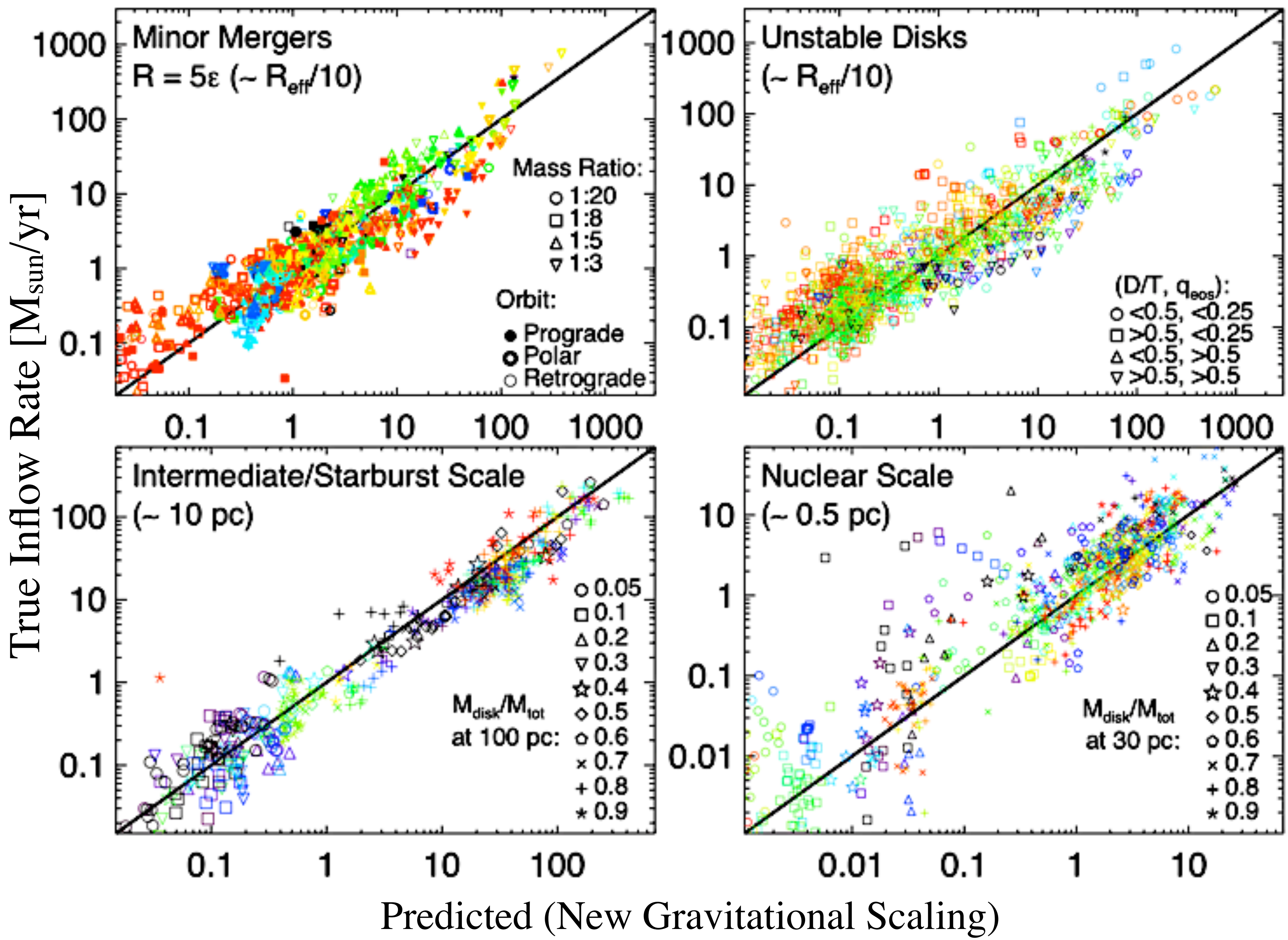
$$\dot{M} \approx 10\, M_{\odot}\, \mathrm{yr}^{-1} \left(\frac{\mathrm{Disk}}{\mathrm{Total}} \right)^{5/2} M_{\mathrm{BH},\,8}^{-1/6}\, M_{\mathrm{gas},\,9}\, R_{0,100}^{-3/2}$$

Inflow from ~kpc to ~0.1 pc is NOT viscous or Bondi-Hoyle:





from 10 pc
from 50 pc
from 100 pc
from 1 kpc
Actual inflow rate onto BH [M_sun/yr]
Gravitational Prediction
0.01
0.1
1
10



Minor Mergers
R = 5ε (~ Reff/10)
Mass Ratio:
1:20
1:8
1:5
1:3
Orbit:
Prograde
Polar
Retrograde
Unstable Disks
(~ Reff/10)
(D/T, qeos):
<0.5, <0.25
>0.5, <0.25
<0.5, >0.5
>0.5, >0.5
Intermediate/Starburst Scale
(~ 10 pc)
Mdisk/Mtot
at 100 pc:
0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Nuclear Scale
(~ 0.5 pc)
Mdisk/Mtot
at 30 pc:
True Inflow Rate [Msun/yr]
Predicted (New Gravitational Scaling)

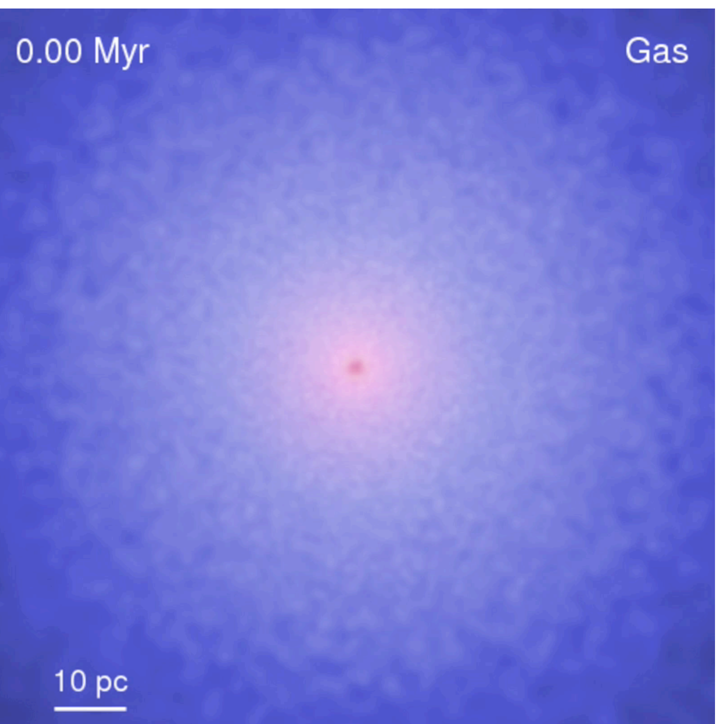
So, what about the “small” scales

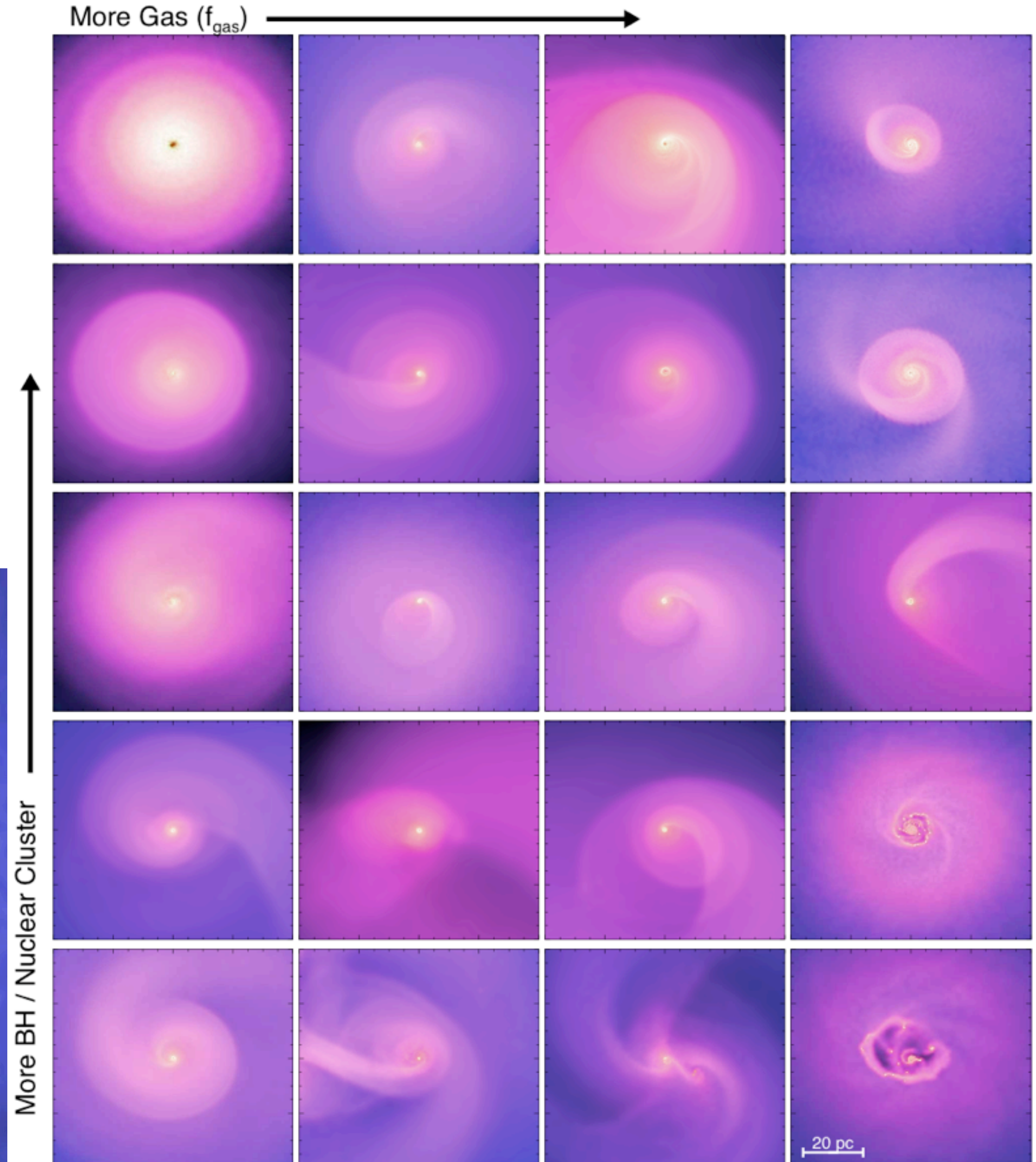
near the BH?

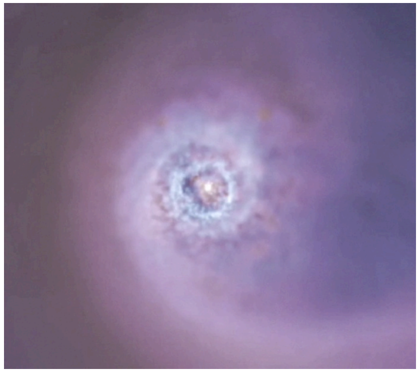
~10 pc scales: Nuclear eccentric disks

- Inside BH radius of influence: develop thick, precessing disks

- Need *both* star formation and self-gravity





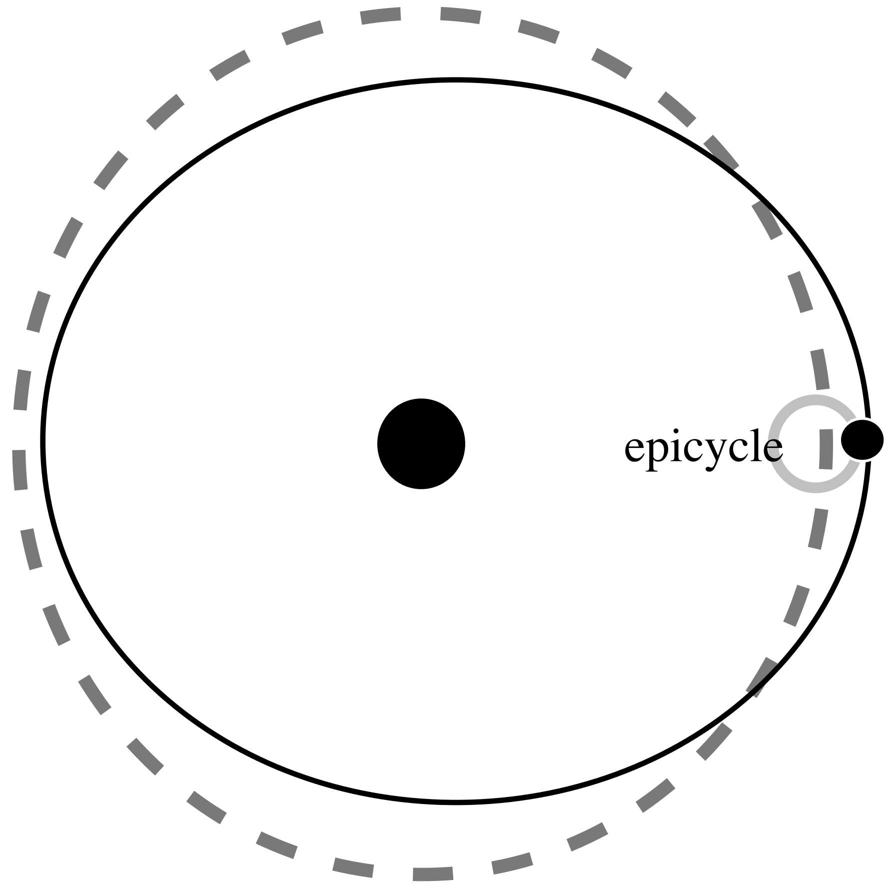


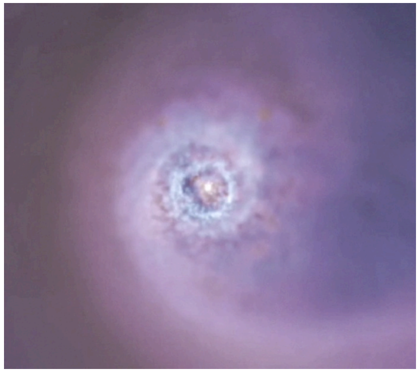
Eccentric/lopsided disks (m=1 modes) are special in a near-Keplerian potential

Keplerian potentials are special:

$$\kappa = \Omega$$

Hence, closed elliptical orbits!

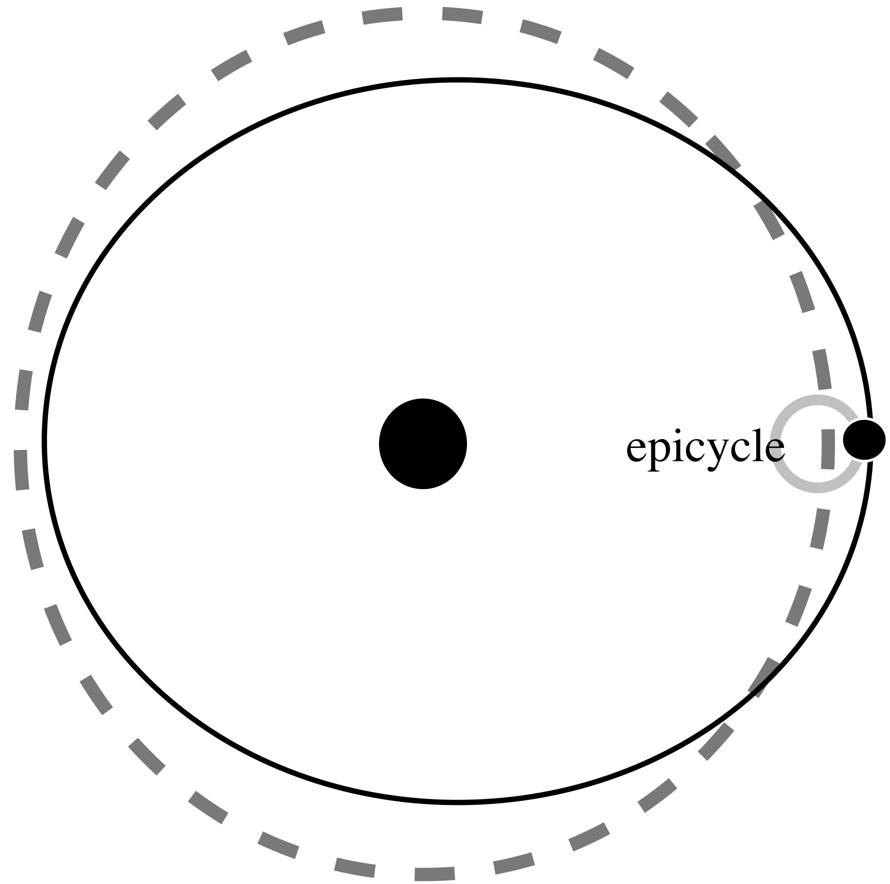


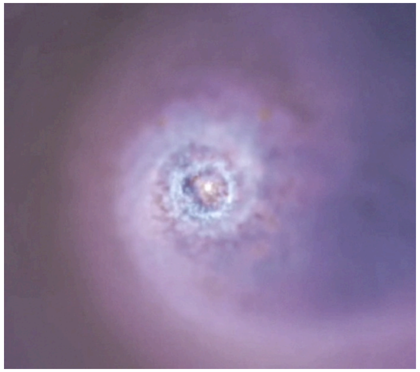


Eccentric/lopsided disks (m=1 modes) are special in a near-Keplerian potential

Disturb the stars with some perturbation in the disk:

$$\delta\Sigma \propto \cos m\phi$$





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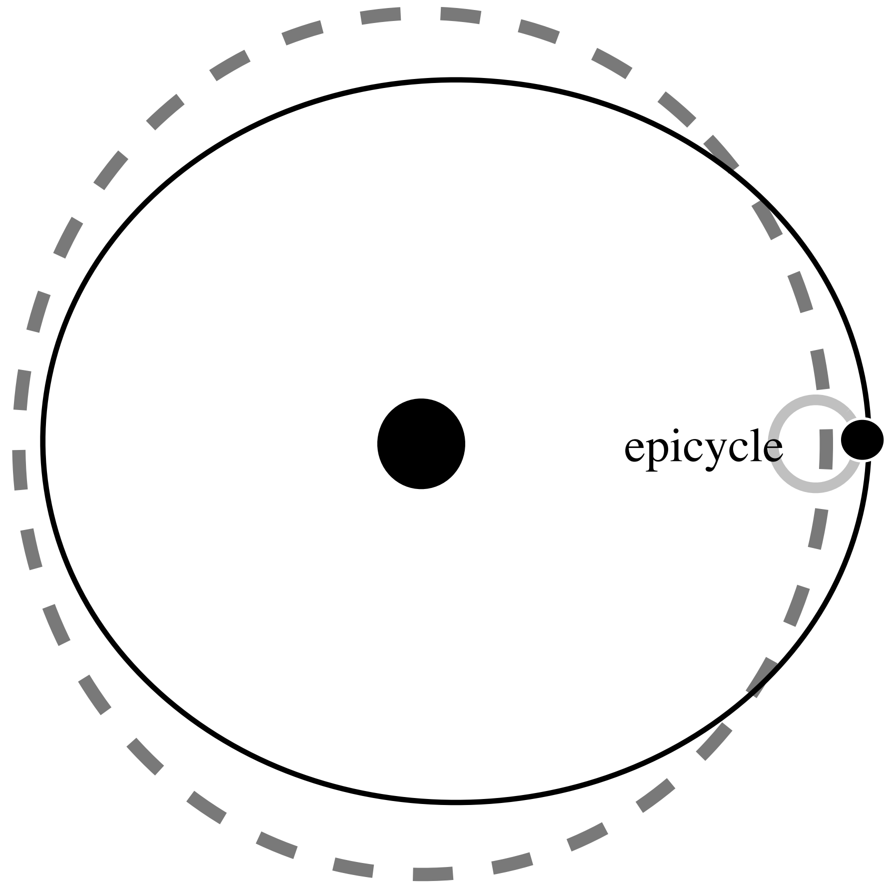
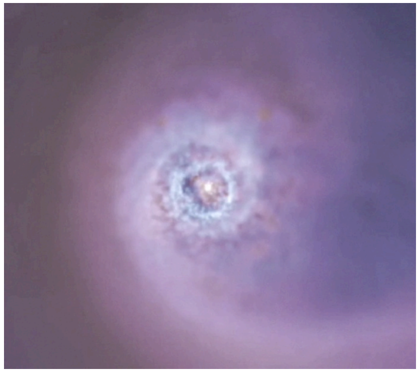
$$\left|\frac{\delta v}{V_c}\right| \sim \left(\frac{\delta\Sigma}{\Sigma}\right) \frac{M_{\rm disk}(<r)}{M_{\rm BH}}$$





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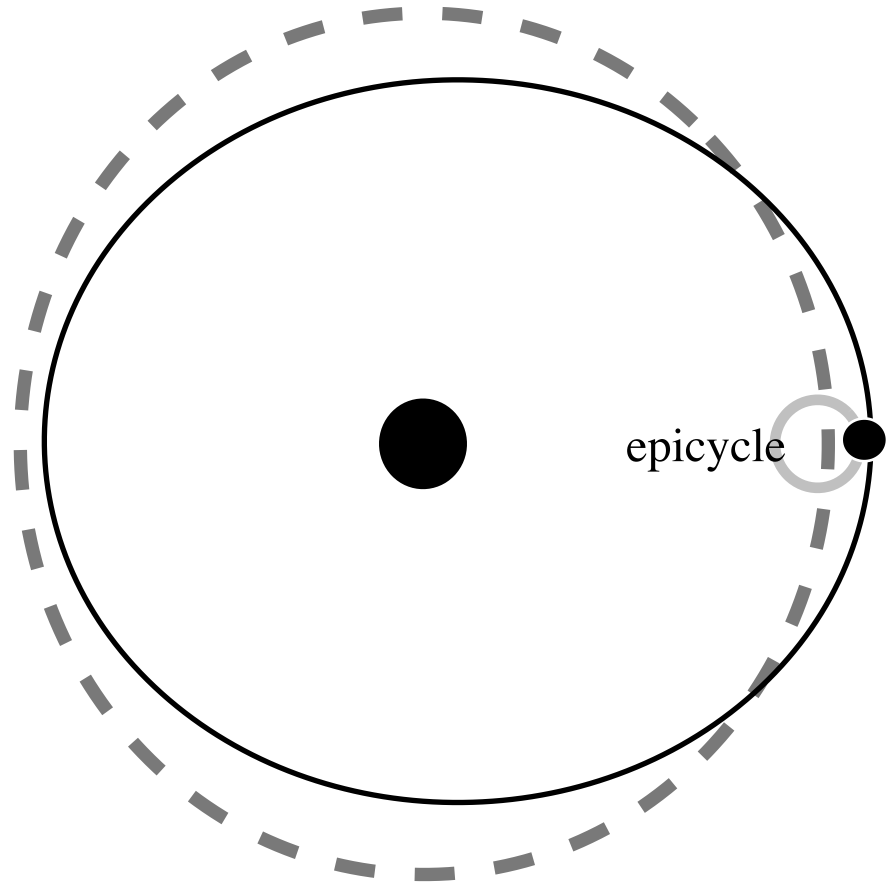
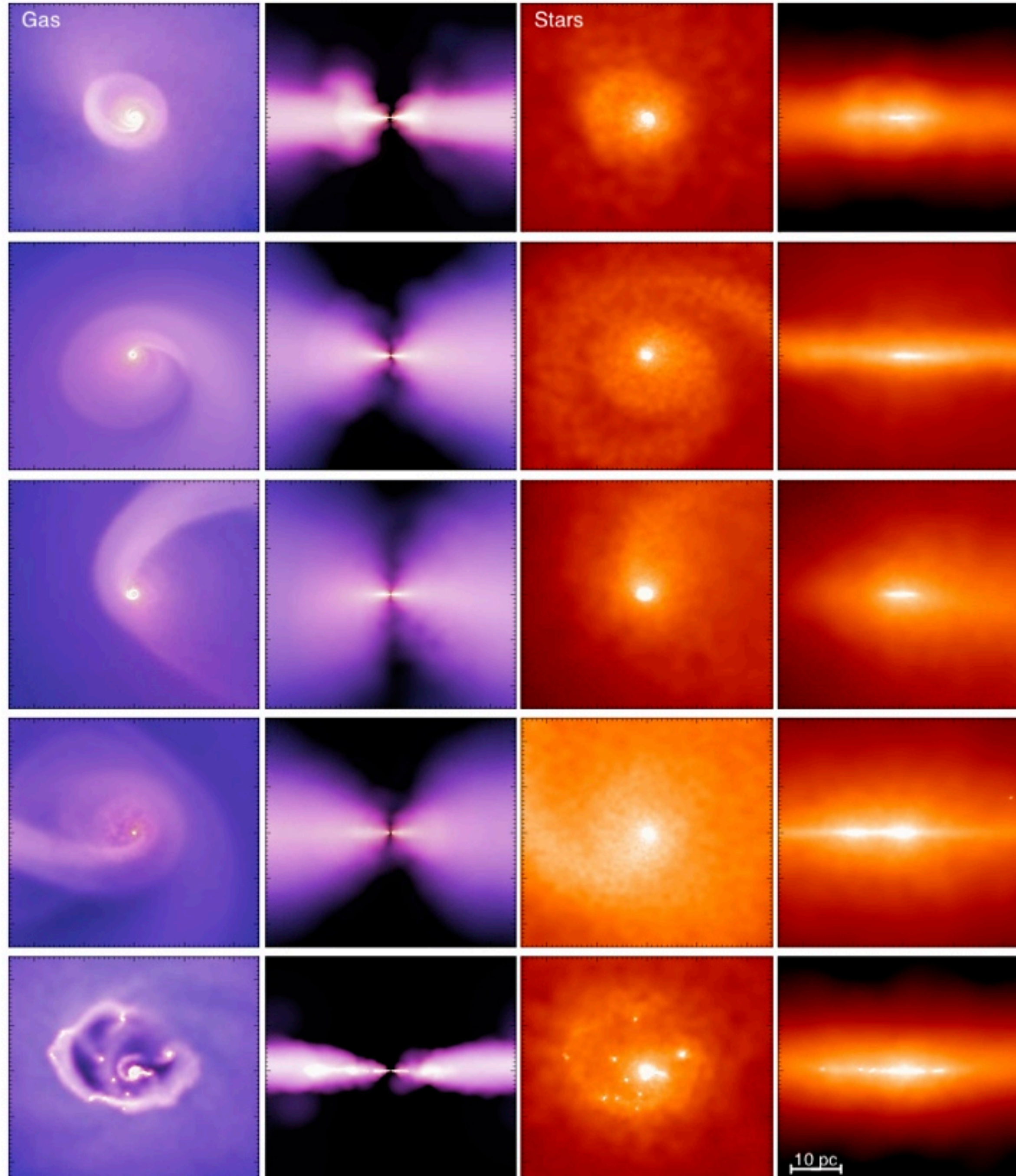
But, if (and *only* if) m=1:

$$\left|\frac{\delta v}{V_c}\right| \sim \left(\frac{\delta\Sigma}{\Sigma}\right)$$

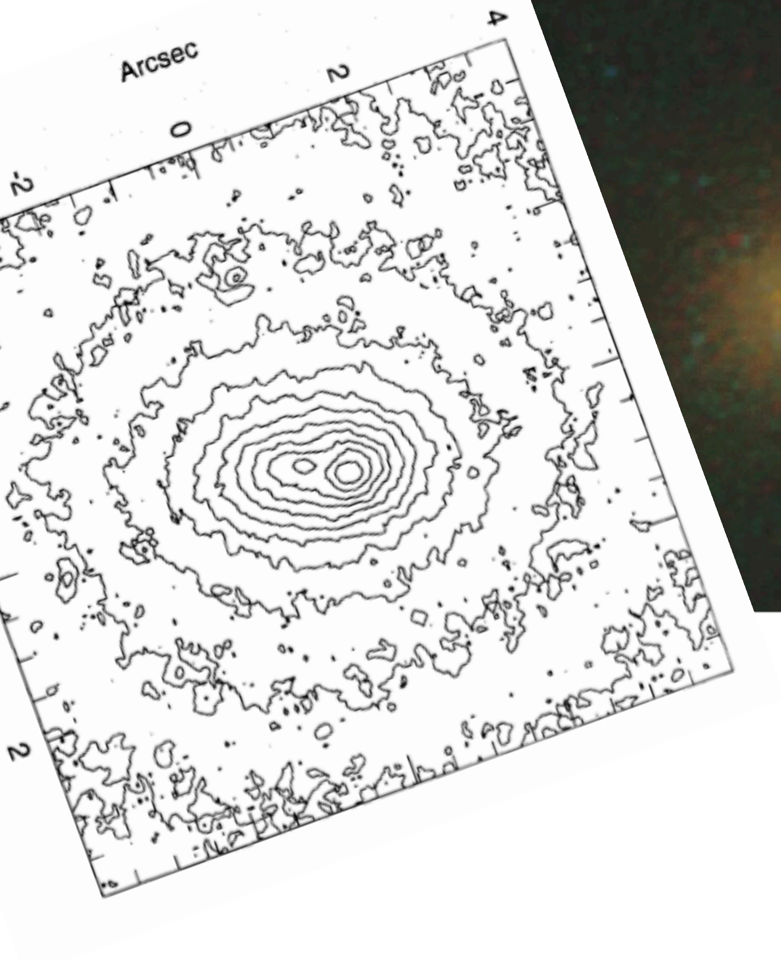


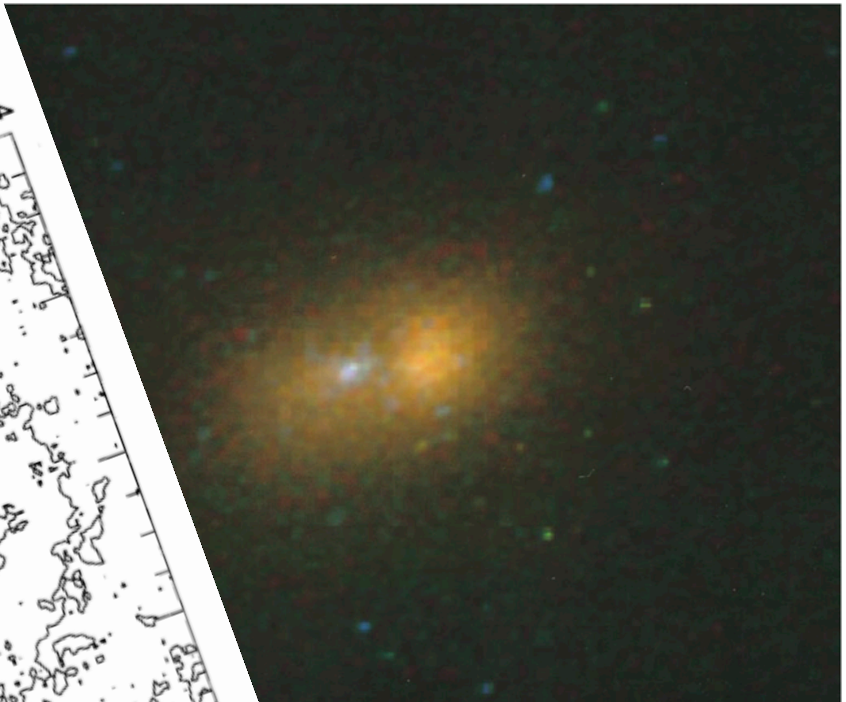


- Gas-stellar exchange dramatically enhances torques
- Drives ~10 M_{sun}/yr inflow
- Leave relic stellar disks?

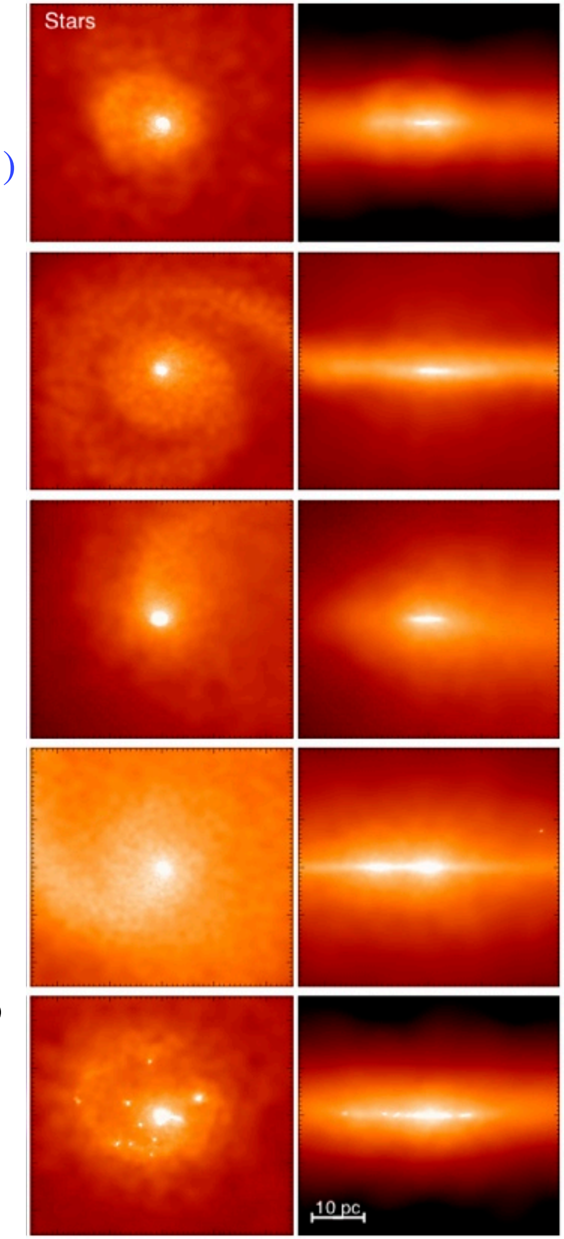
- These are observed!
  M31, NGC4486B, many candidates
  (NGC 404,507,1374,3706,4073,4291,4382,5055,5576,7619, VCC128, M32,83)

M31:





Lauer et al. 1993
Kormendy & Bender 1999



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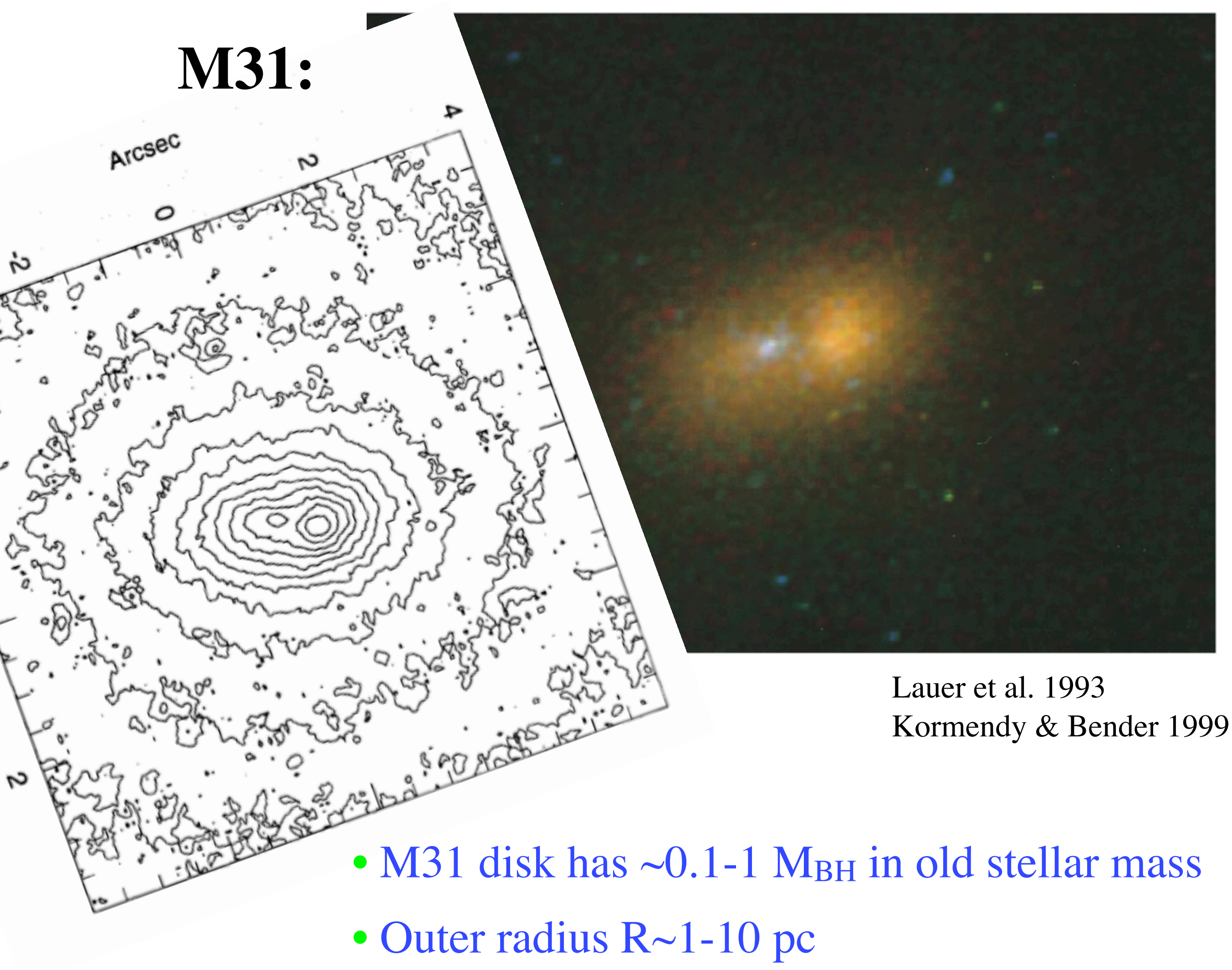

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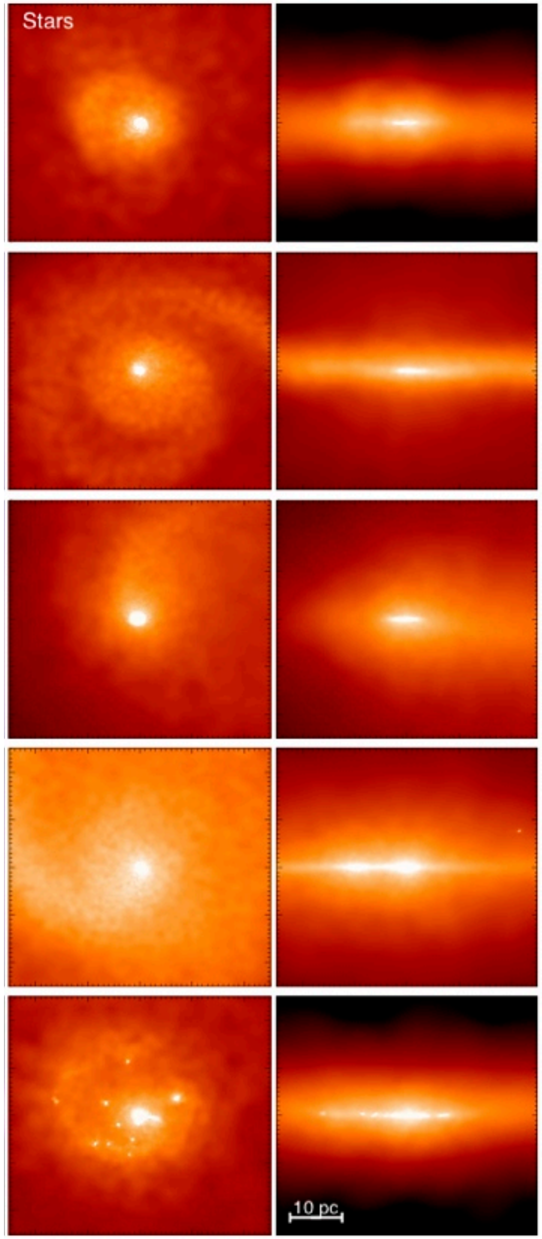

- M31 disk has ~0.1-1 M_{BH} in old stellar mass
- Outer radius R~1-10 pc
- Moderate thickness, high eccentricity

- These are observed!
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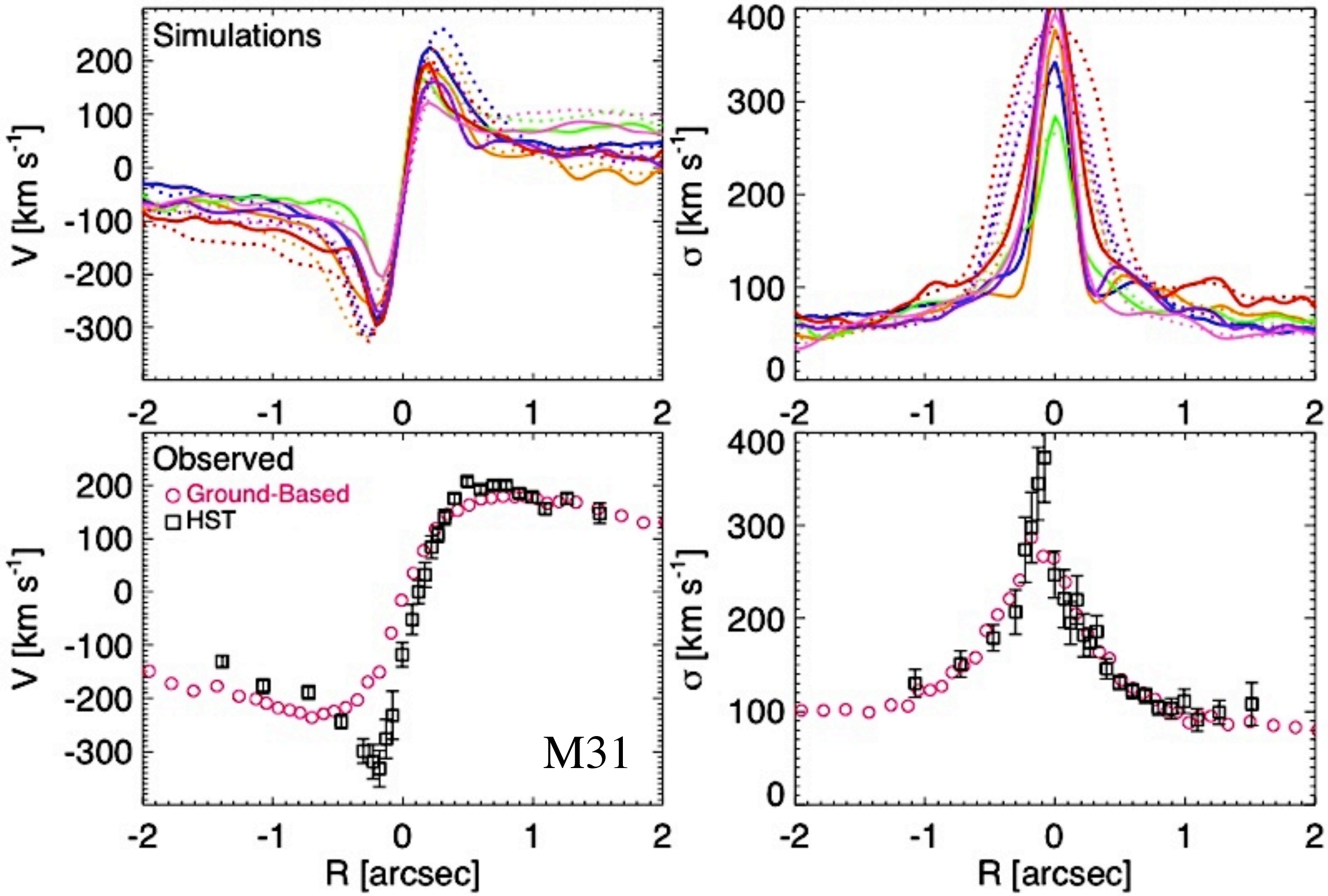
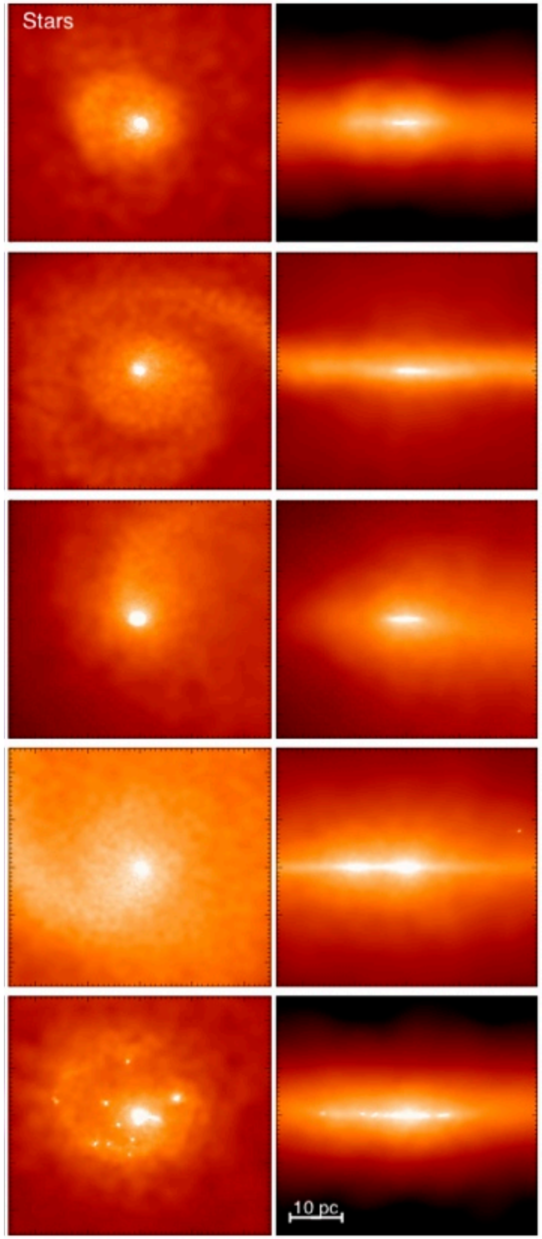
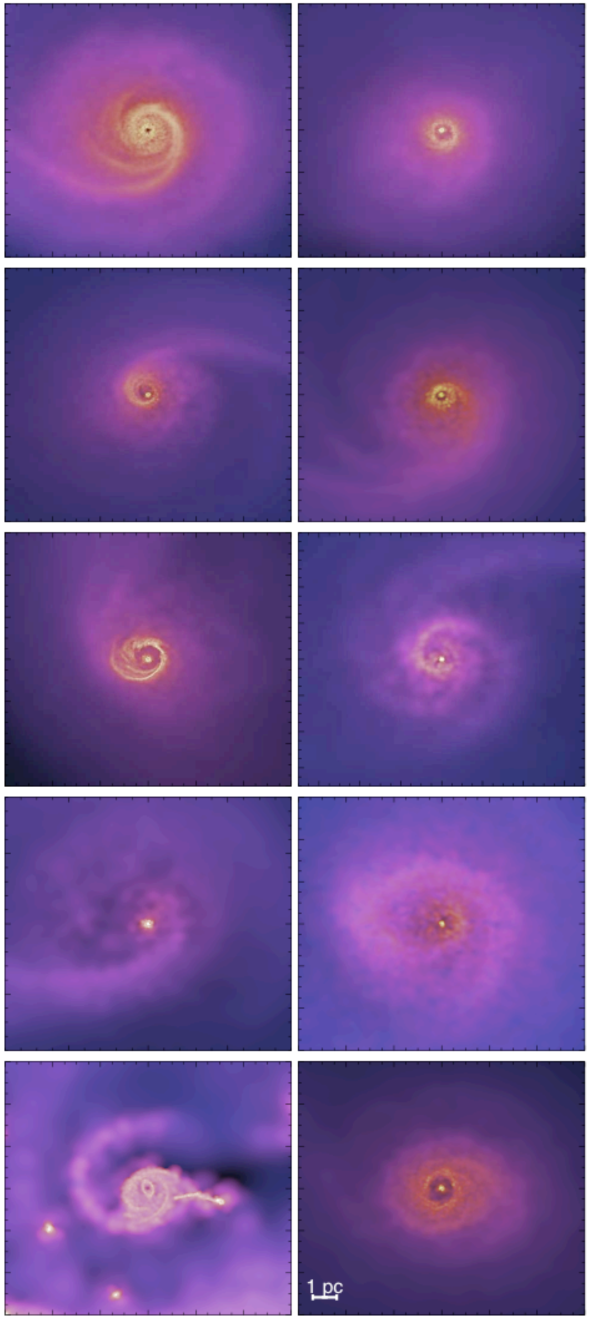
  (NGC 404,507,1374,3706,4073,4291,4382,5055,5576,7619, VCC128, M32,83)





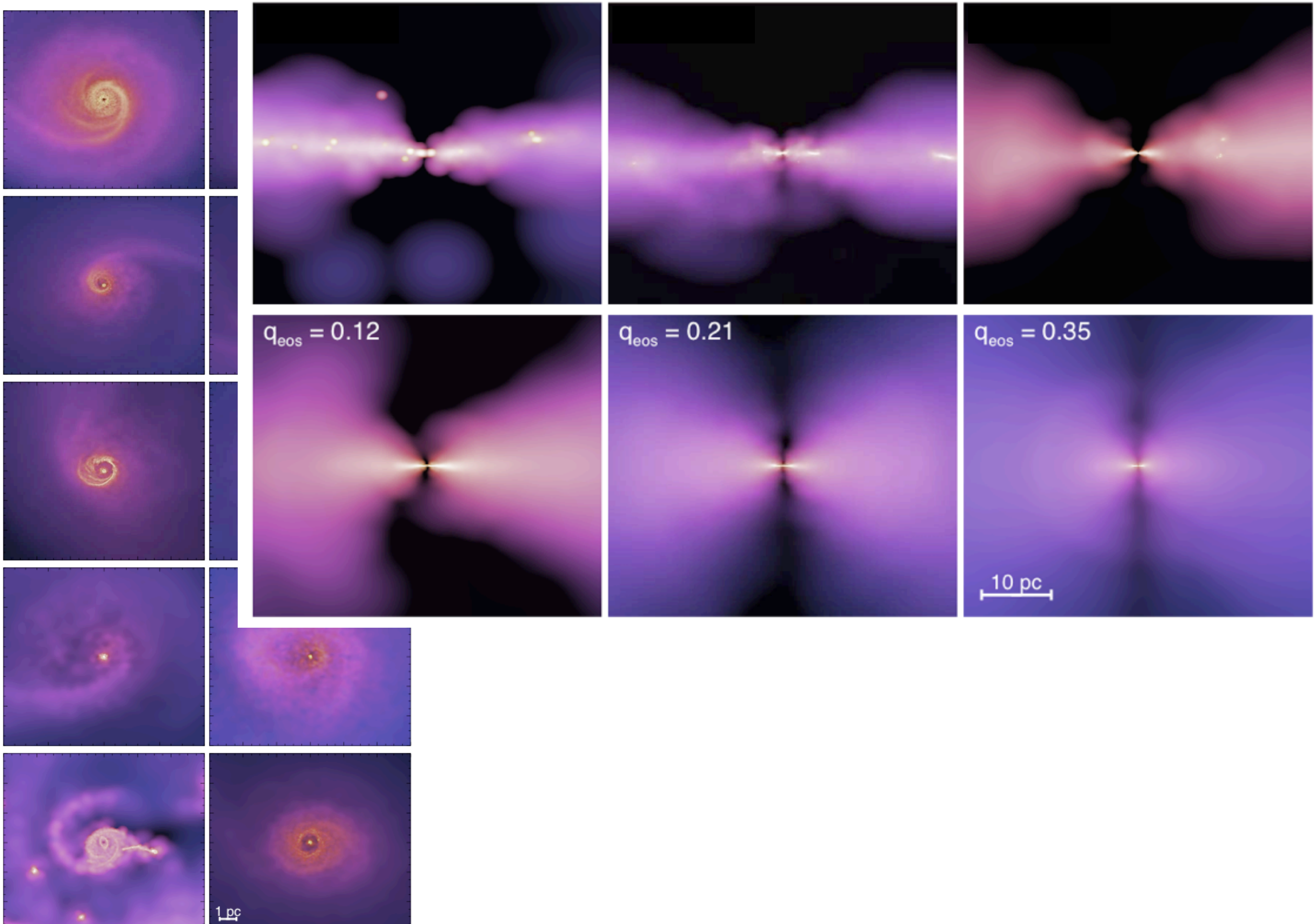
- "run backwards": the M31 disk implies accretion at ~0.5-3 M_{sun}/yr (~L_{Edd}) for ~100 Myr (~ M_{BH}) !

What about the obscuration from these disks?

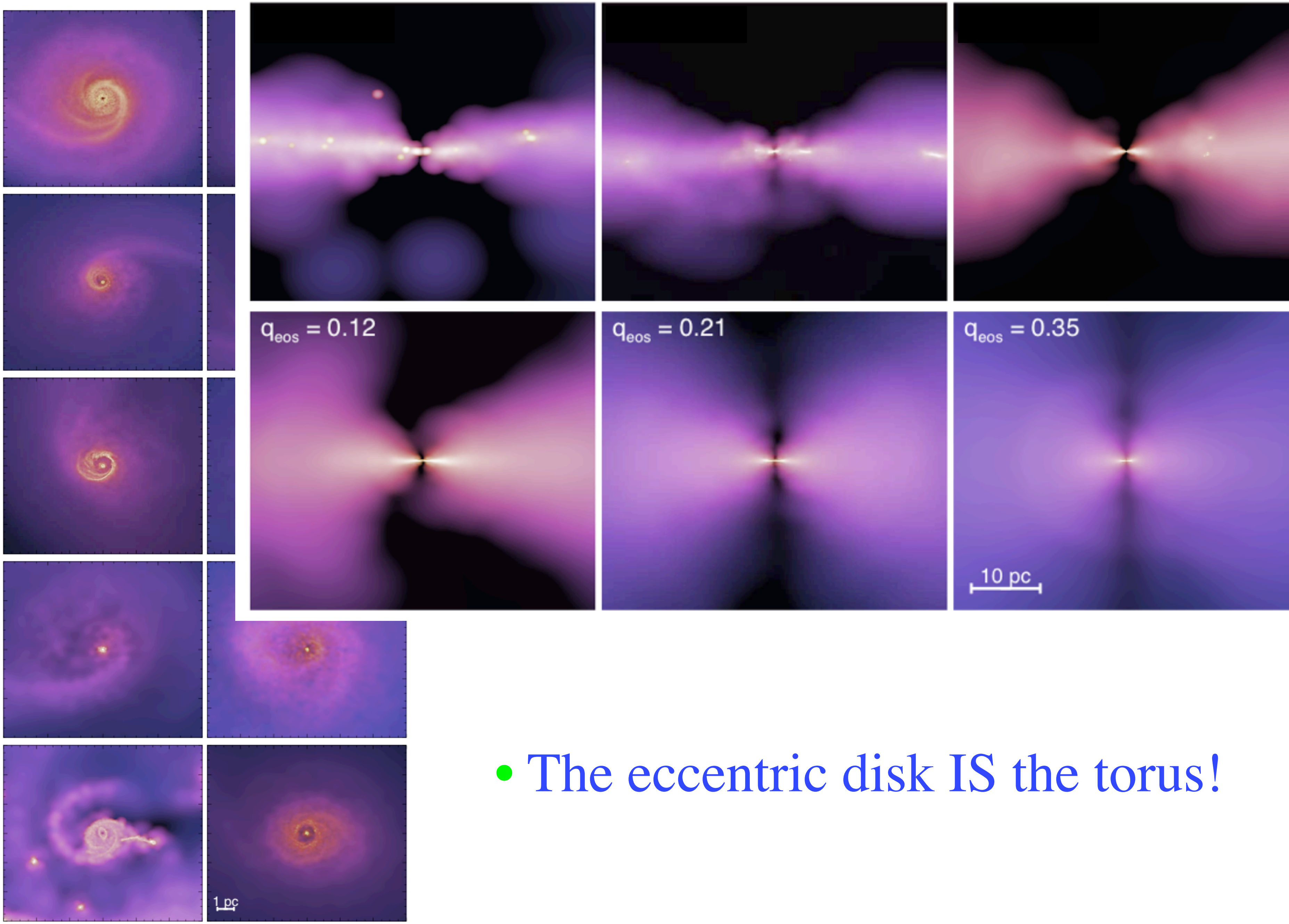


- Lots of gas in this disk during the inflow stages...

What about the obscuration from these disks?

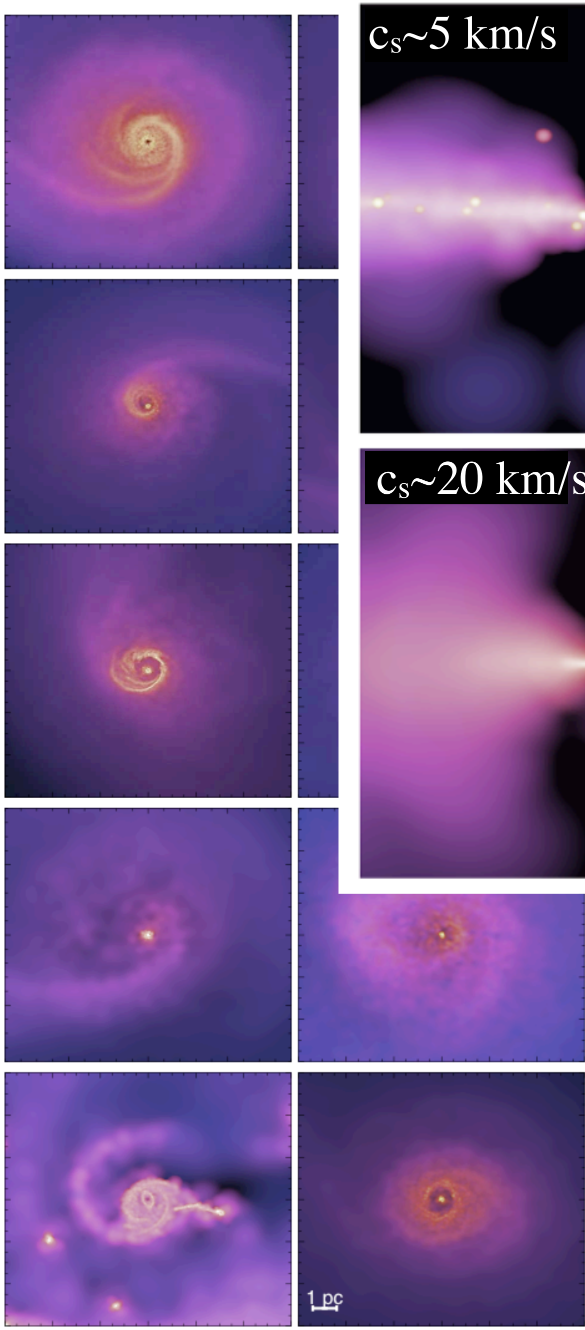


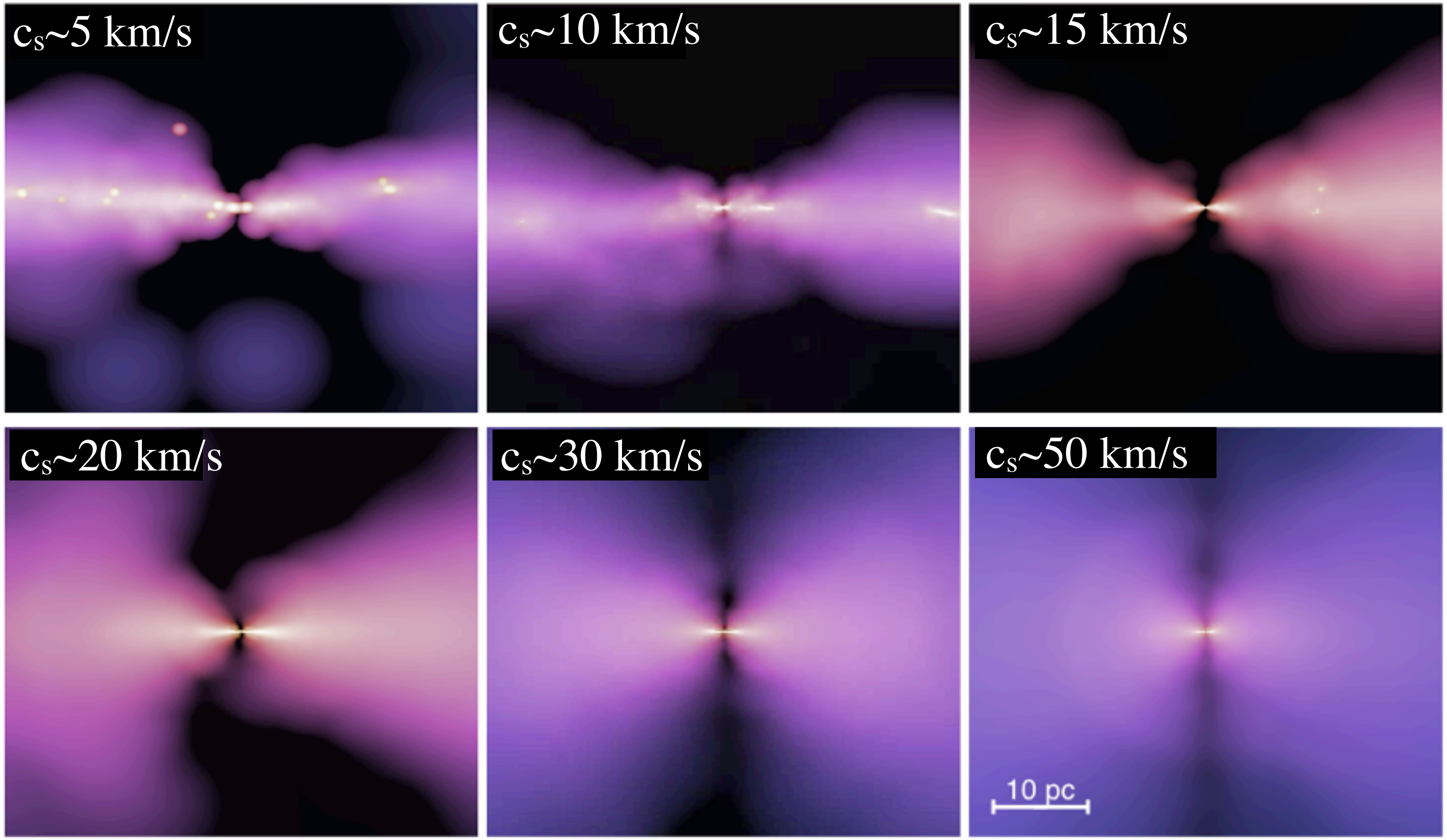
What about the obscuration from these disks?



- The eccentric disk IS the torus!

What about the obscuration from these disks?





- The eccentric disk IS the torus
- Occurs even if allow cooling and no stellar feedback!
    - Heating by bending/warping modes, themselves excited *by the eccentric pattern*

Summary

Fueling Most Luminous BHs:

Global gravitational instabilities CAN power ~10 M_{sun}/yr! Really!

- New Mdot estimator: neither viscous nor Bondi

“Stuff within Stuff”: Cascade of instabilities with diverse morphology

- Doesn’t matter how *first* ‘get down’ from large scales

Accretion rates & orientations are stochastic

- Vary on *all* timescales
- Angular momentum changes rapidly - no correlation with host disk

The torus is the disk: a dynamical accretion driver

- Bending/warping instabilities: thick even without stellar feedback

Stellar nuclear disk ‘relics’: M31 & 4486b:

Can we directly observe the ‘fossil’ of the accretion driver & torus ?