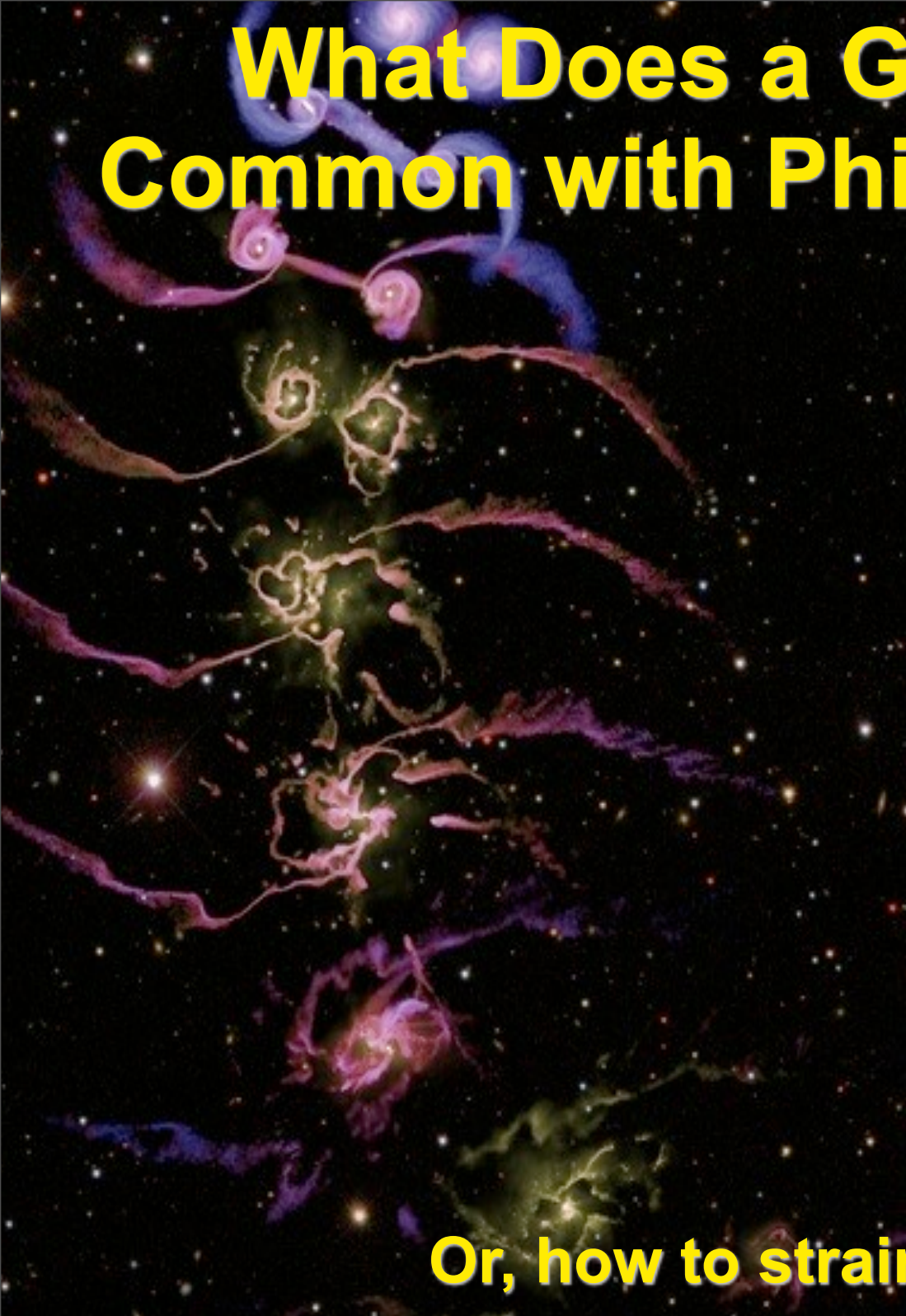


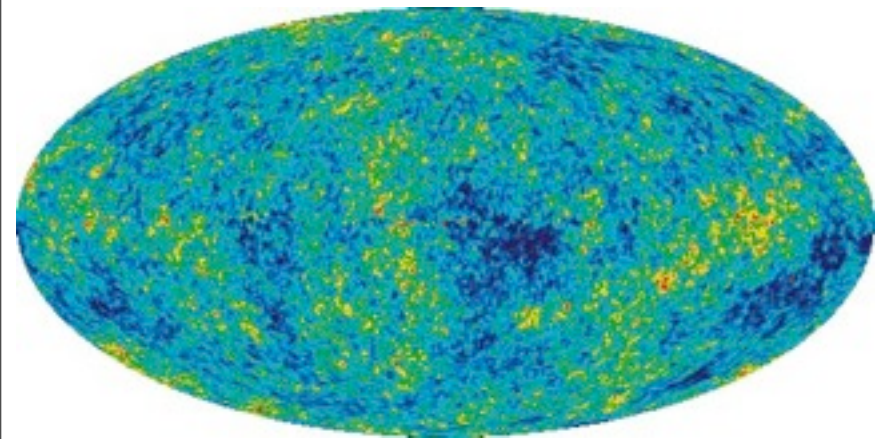
What Does a Galaxy Have in Common with Phil after N Drinks?



Or, how to strain an analogy...

Motivation

HOW DID WE GET TO GALAXIES TODAY?

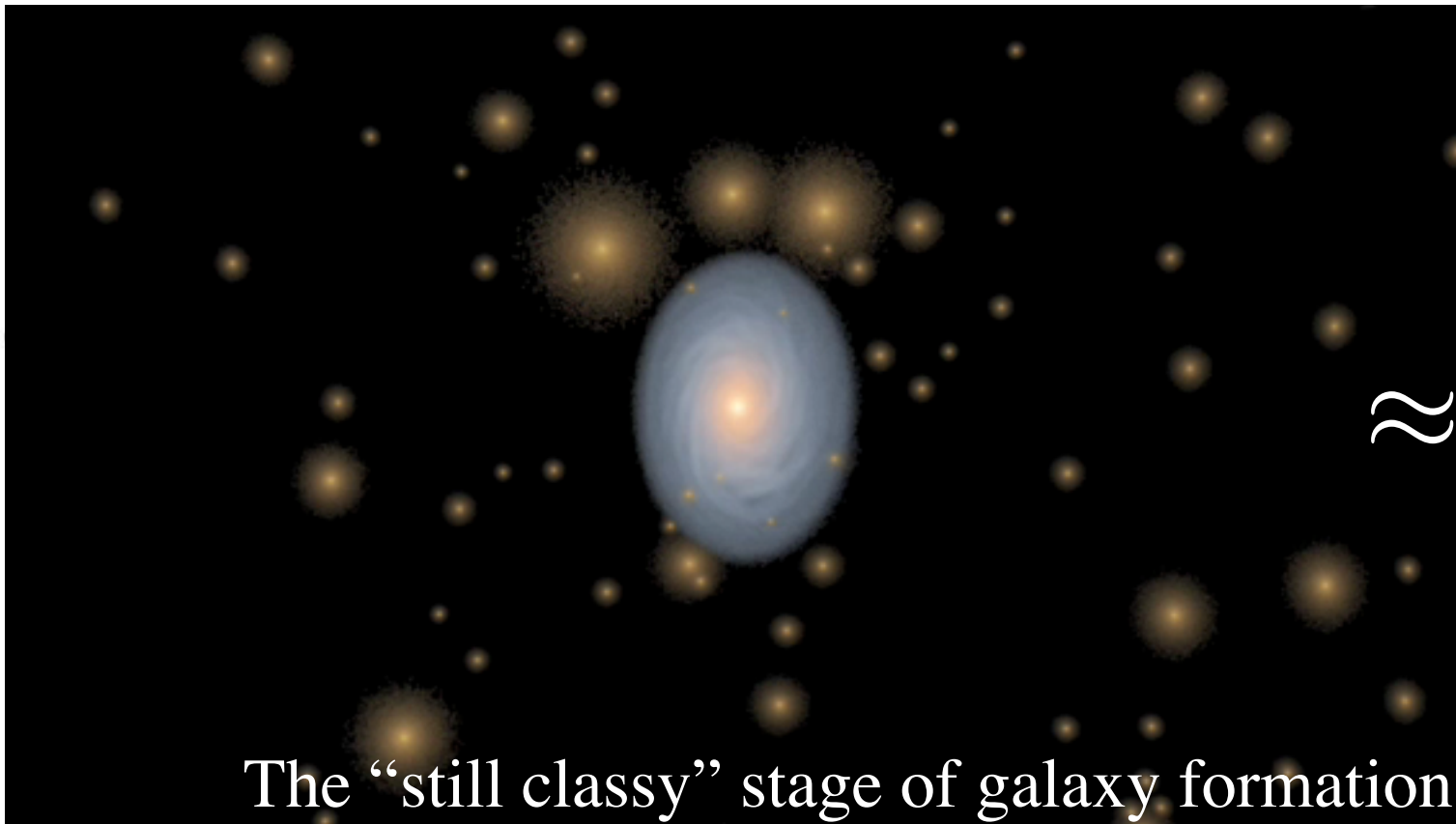
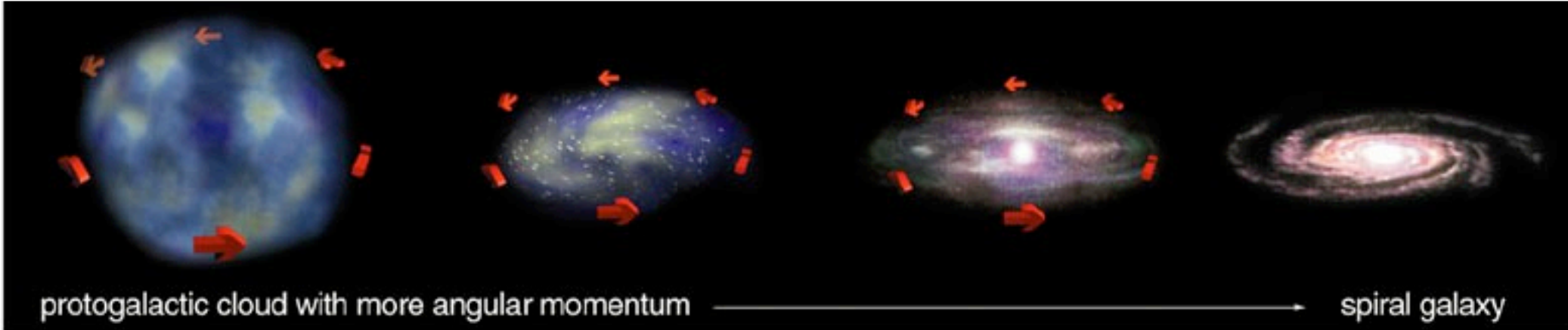


Also... how many embarrassing pictures
can we fit into a talk?

Sober: Disk Galaxies

ELEGANT, ORGANIZED, BRIGHT-EYED AND BUSHY-TAILED

- Dark matter halos collapse: gas cools into a disk



Cold Flows:
“Maybe just one...”



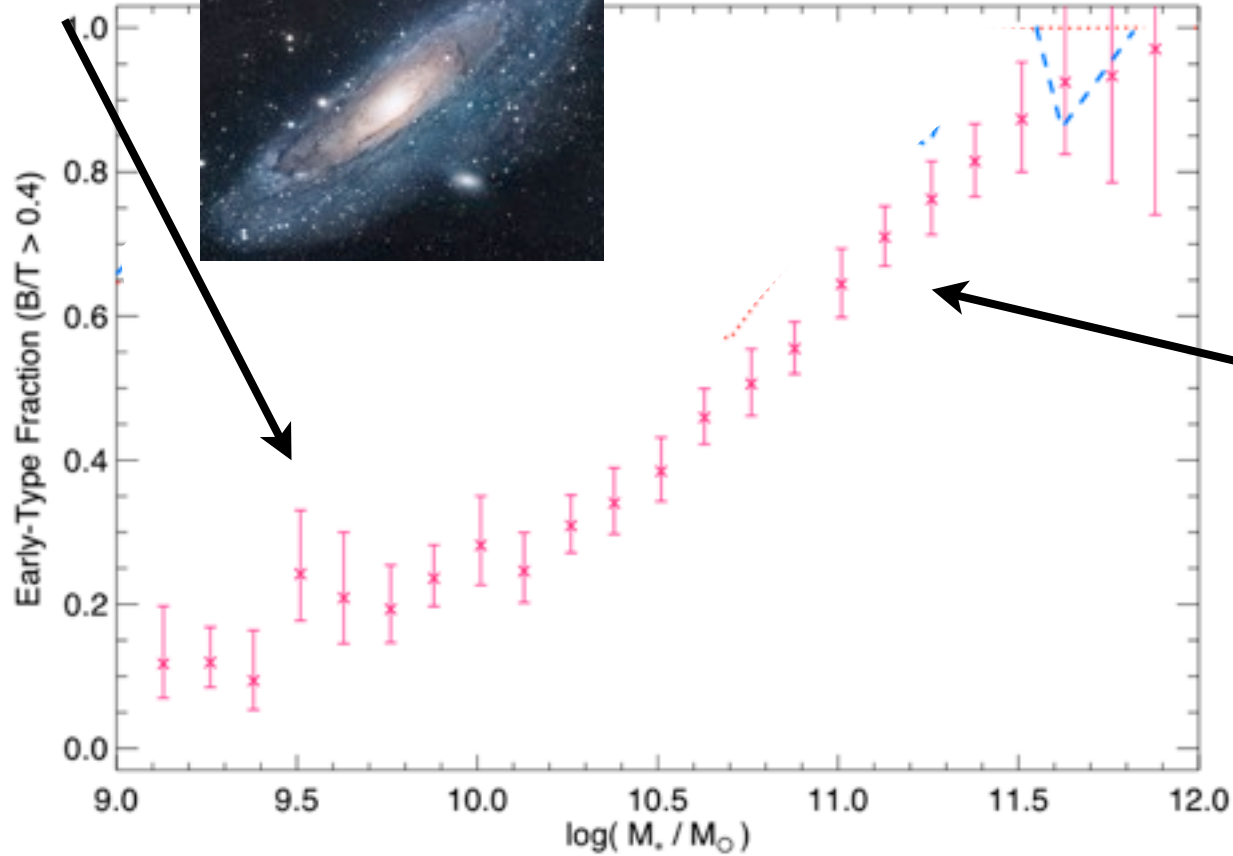
Cold Flows:
“Maybe just one...”



Crap, 5 Tequilas Down....

NOW THE NIGHT GETS INTERESTING

Low-Mass: Galaxies are nice, organized disks



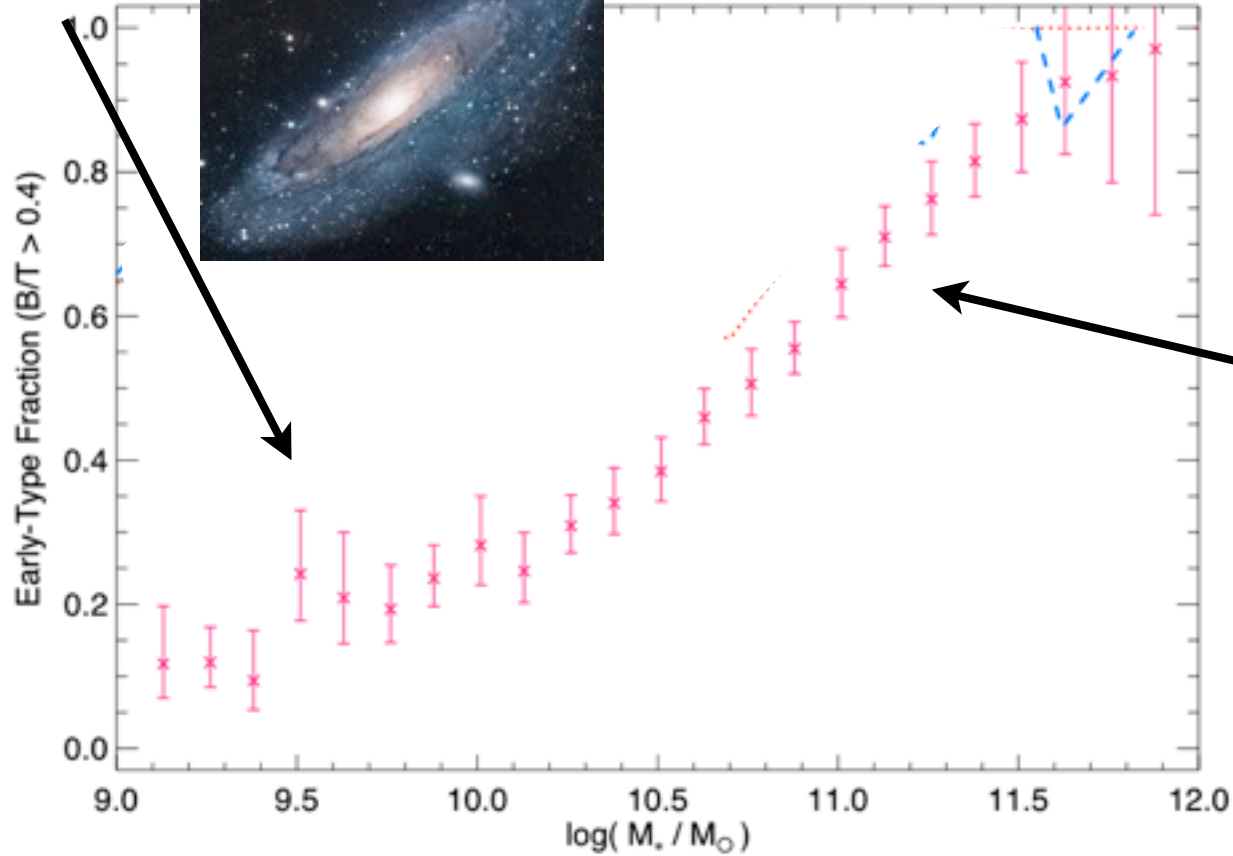
High-Mass: Galaxies are dead balls of stars



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Low-Mass: Galaxies are nice, organized disks



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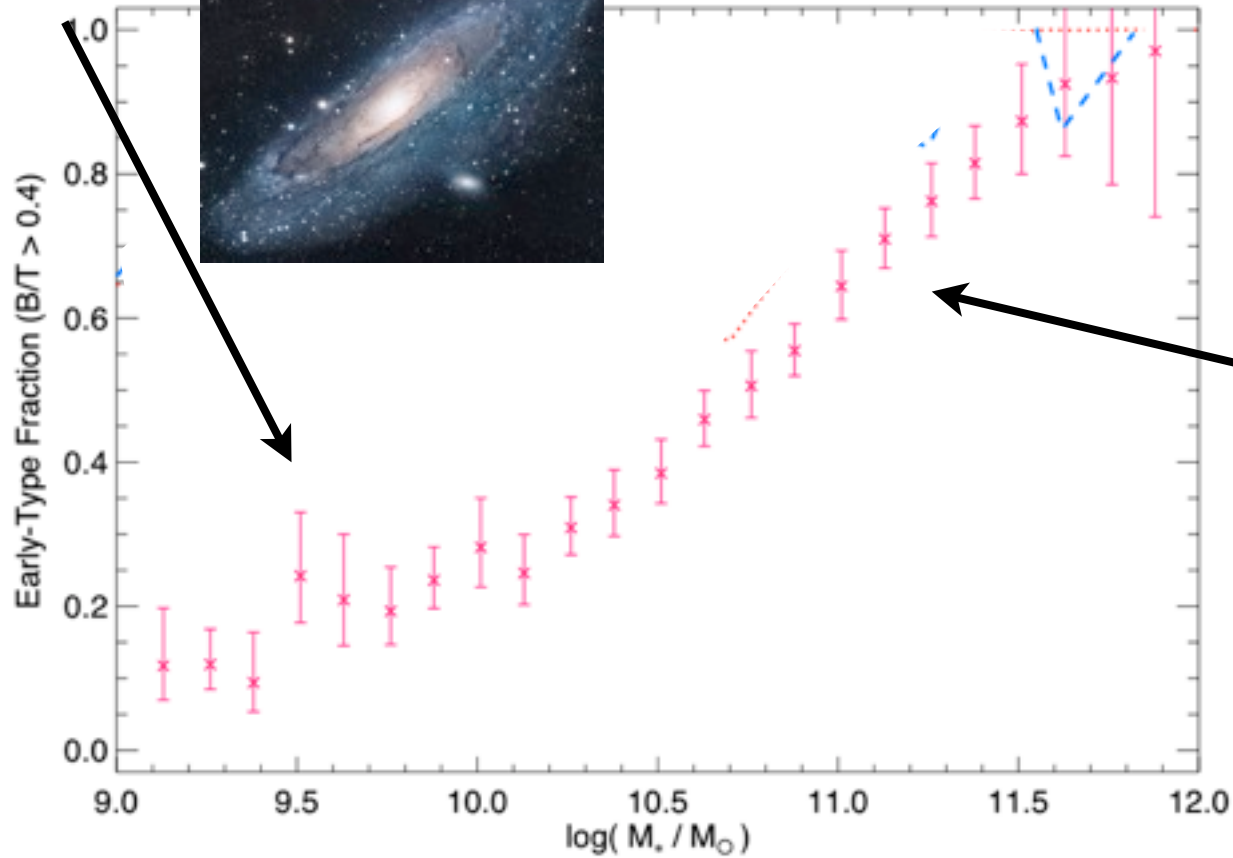


➤ What happens around $10^{10} - 10^{11} M_{\text{sun}}$?

Crap, 5 Tequilas Down....

NOW THE NIGHT GETS INTERESTING

Low-Mass: Galaxies are nice, organized disks



High-Mass: Galaxies are dead balls of stars

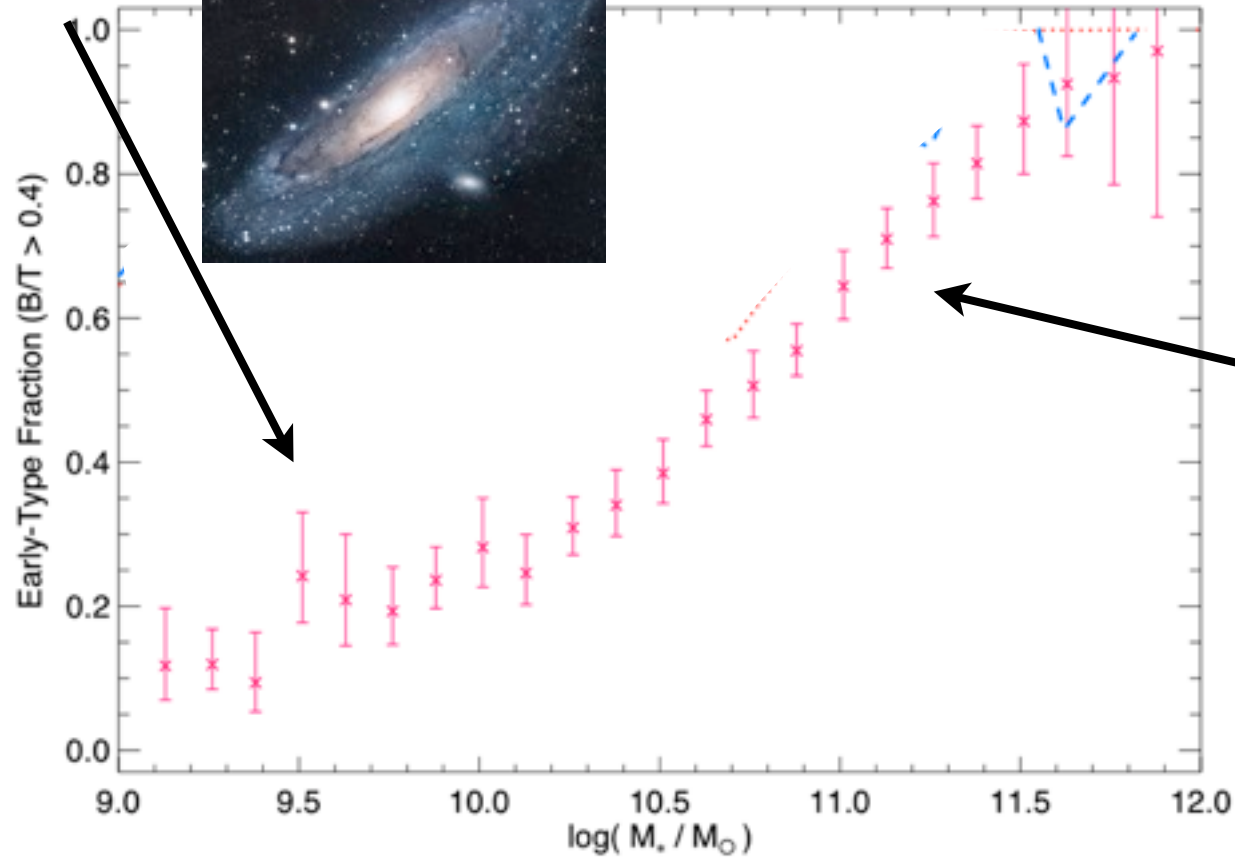


- What happens around $10^{10} - 10^{11} M_{\text{sun}}$?
- A1: Cold flows shut down

Crap, 5 Tequilas Down....

NOW THE NIGHT GETS INTERESTING

Low-Mass: Galaxies are nice, organized disks

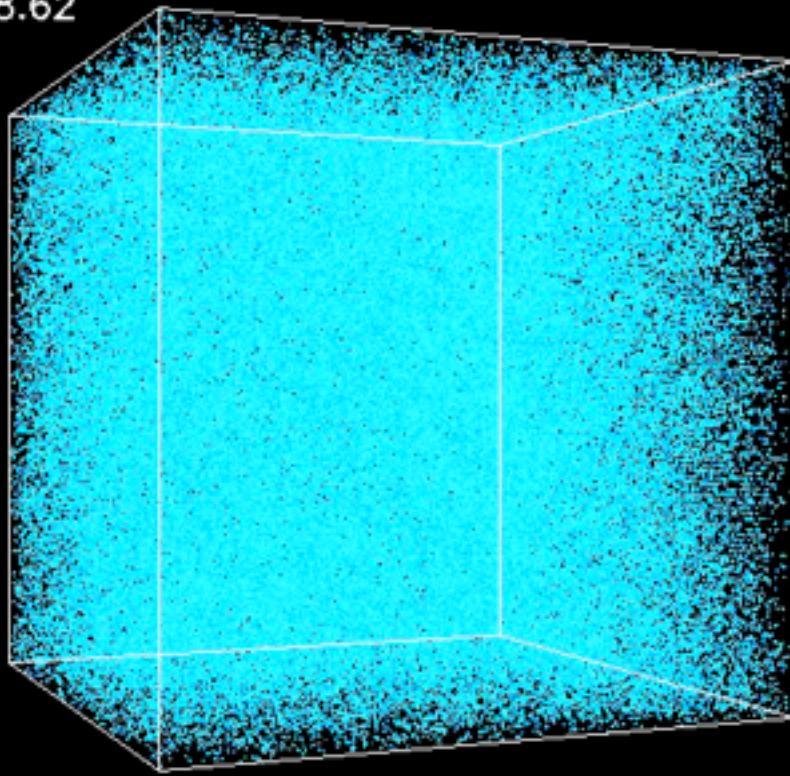


High-Mass: Galaxies are dead balls of stars



- What happens around $10^{10} - 10^{11} M_{\text{sun}}$
 - A1: Cold flows shut down
 - A2: Mergers rapidly pick up in efficiency

$Z=28.62$

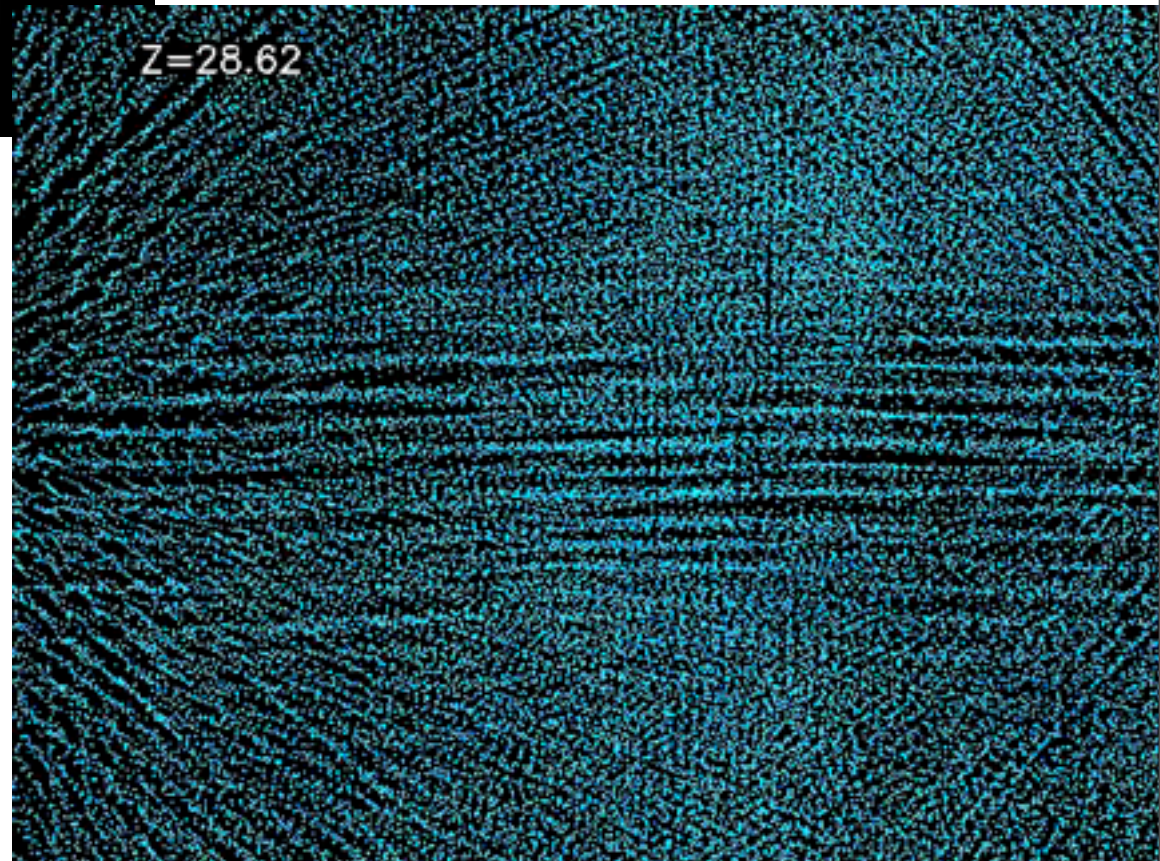


Crap, 5 Tequilas Down....

NOW THE NIGHT GETS INTERESTING

Kravtsov et al.

$Z=28.62$

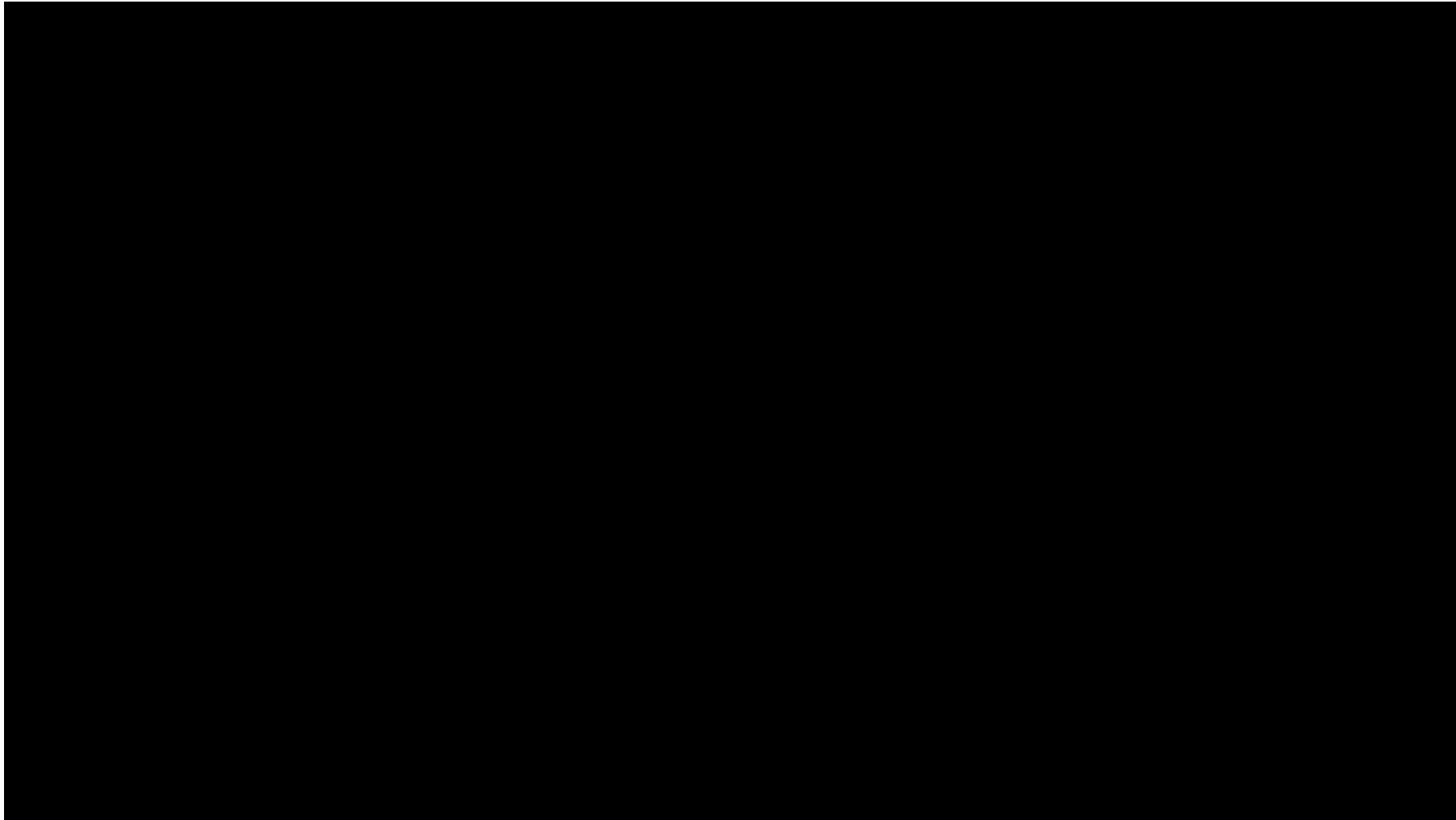


- L^* -- The “Slamming into Stuff” stage of galaxy evolution

Crap, 5 Tequilas Down....

NOW THE NIGHT GETS INTERESTING

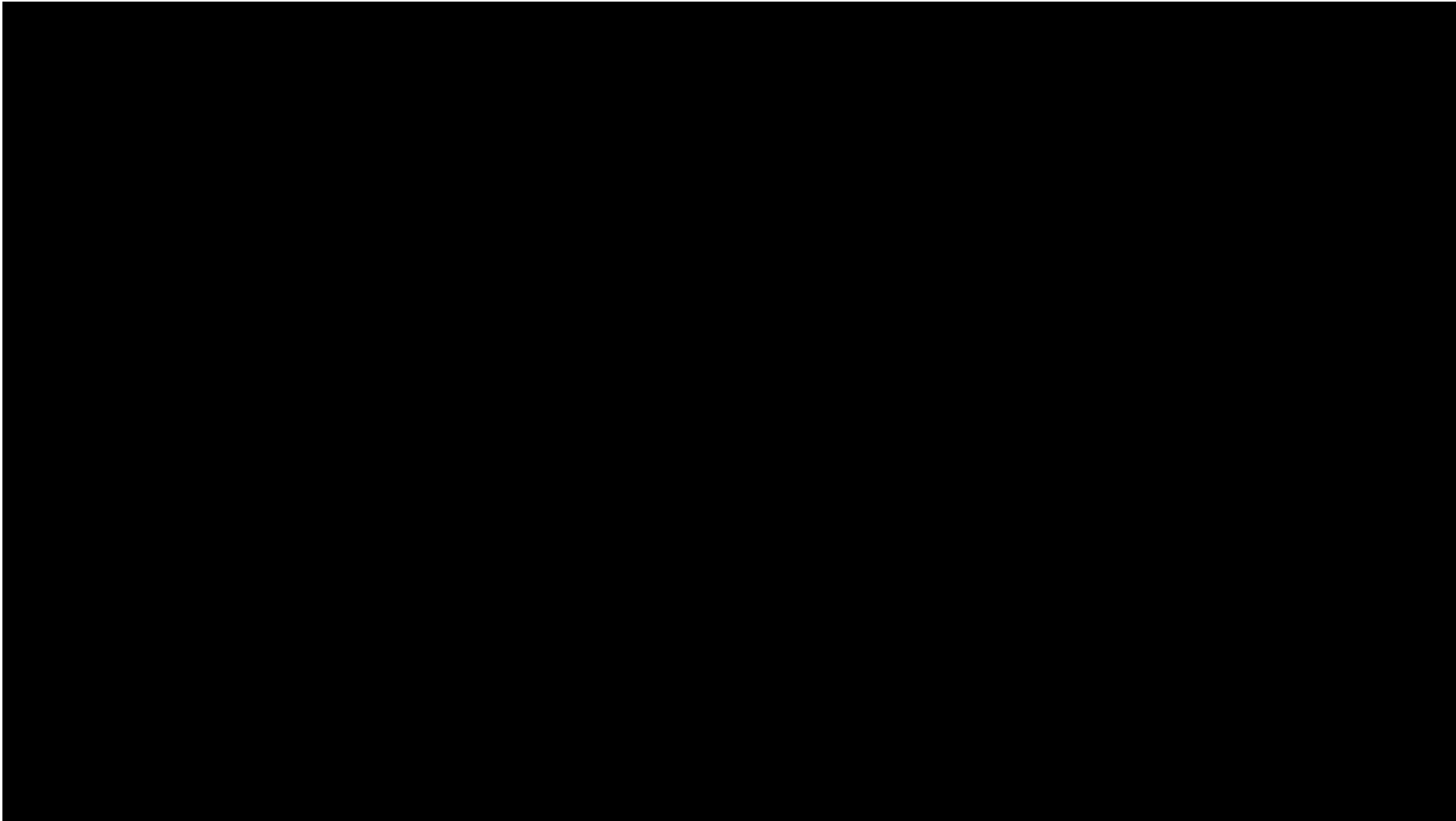
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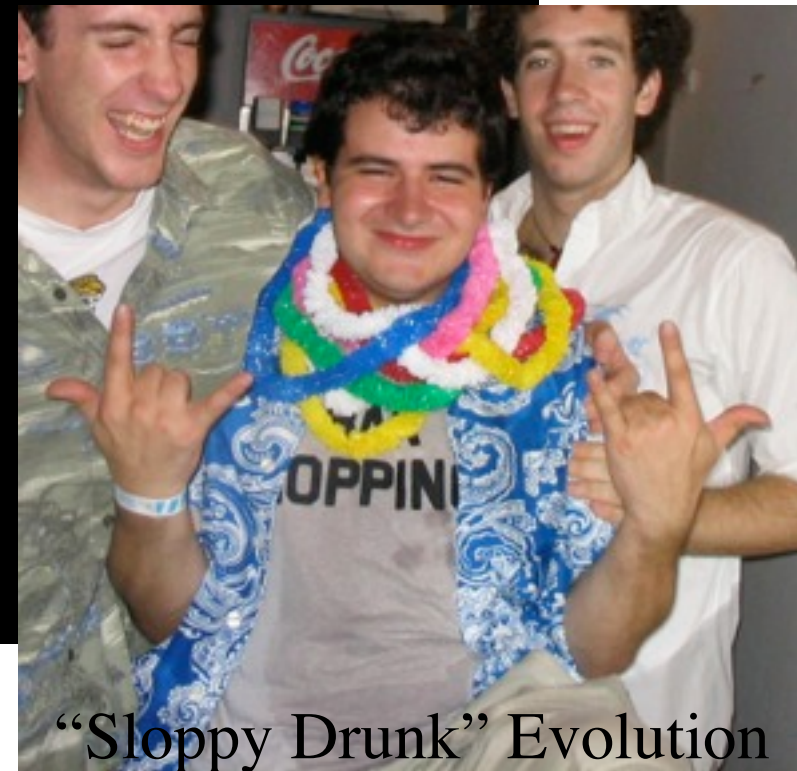
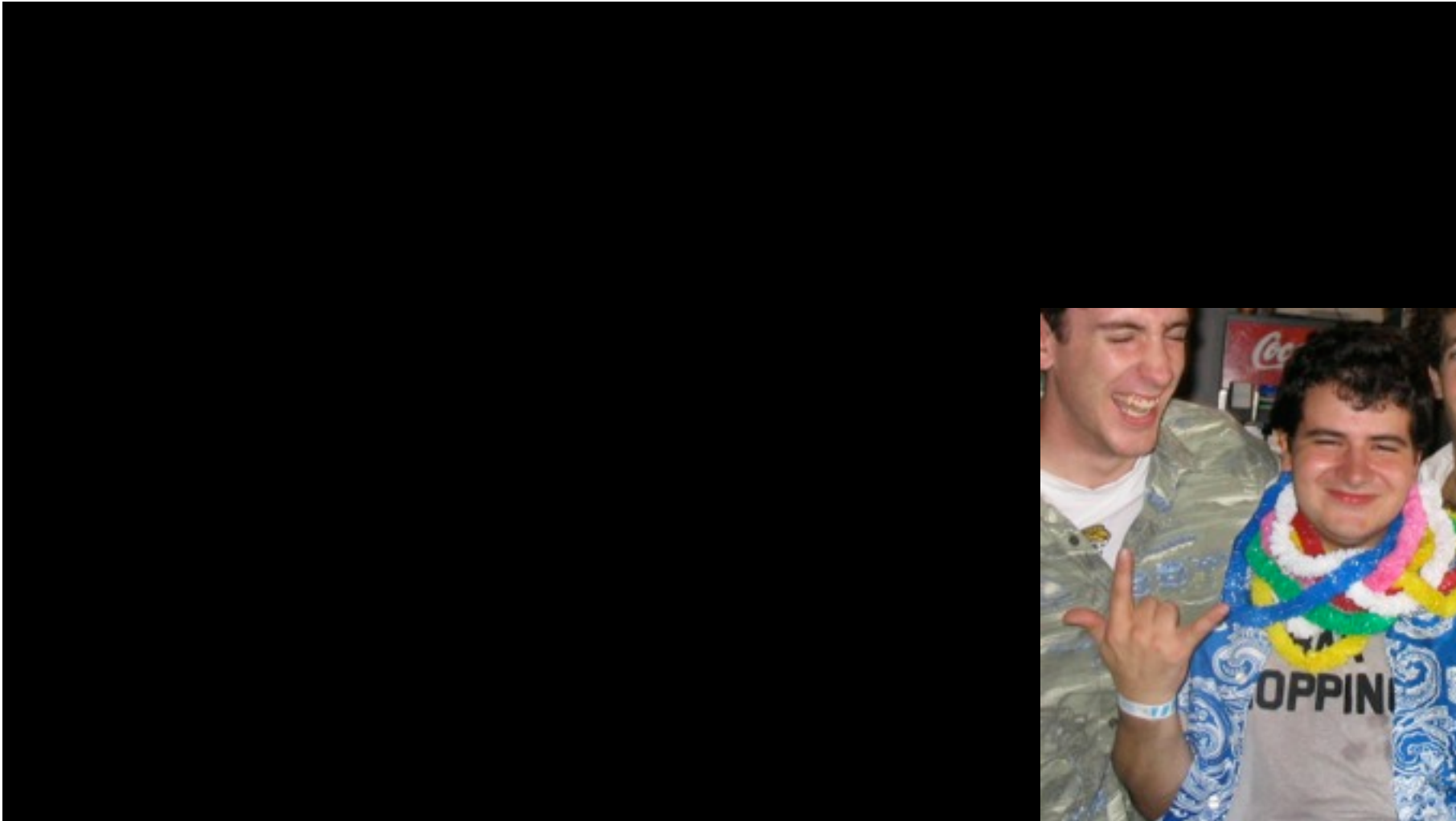


- Messy: Gas and stars thrown out in tails:
Non-axisymmetry allows gas to funnel to galaxy center

Crap, 5 Tequilas Down....

NOW THE NIGHT GETS INTERESTING

- L^* -- The “Slamming into Stuff” stage of galaxy evolution



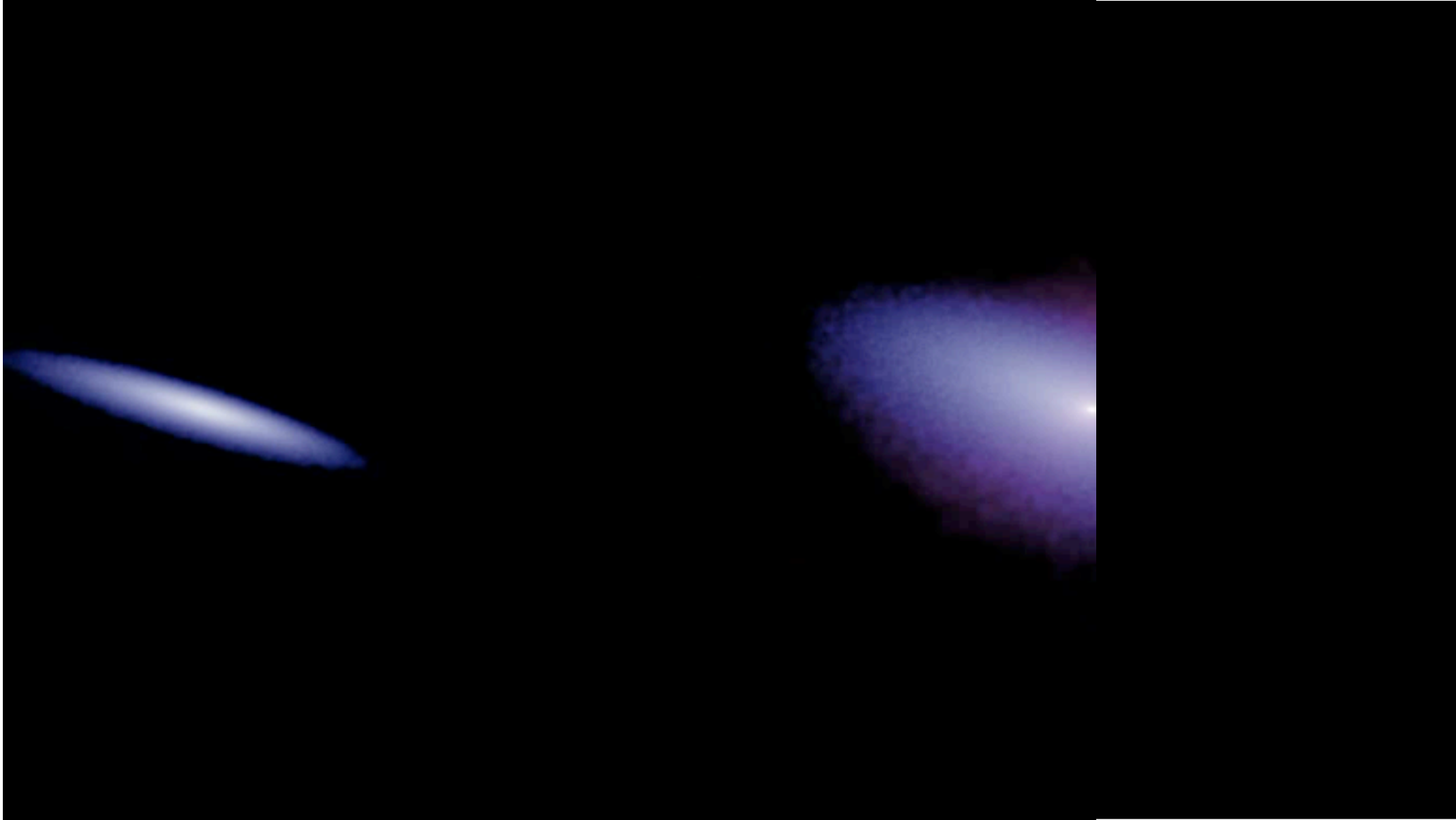
- Messy: Gas and stars thrown out in tails:
Non-axisymmetry allows gas to funnel to galaxy center

“Sloppy Drunk” Evolution

Crap, 5 Tequilas Down....

NOW THE NIGHT GETS INTERESTING

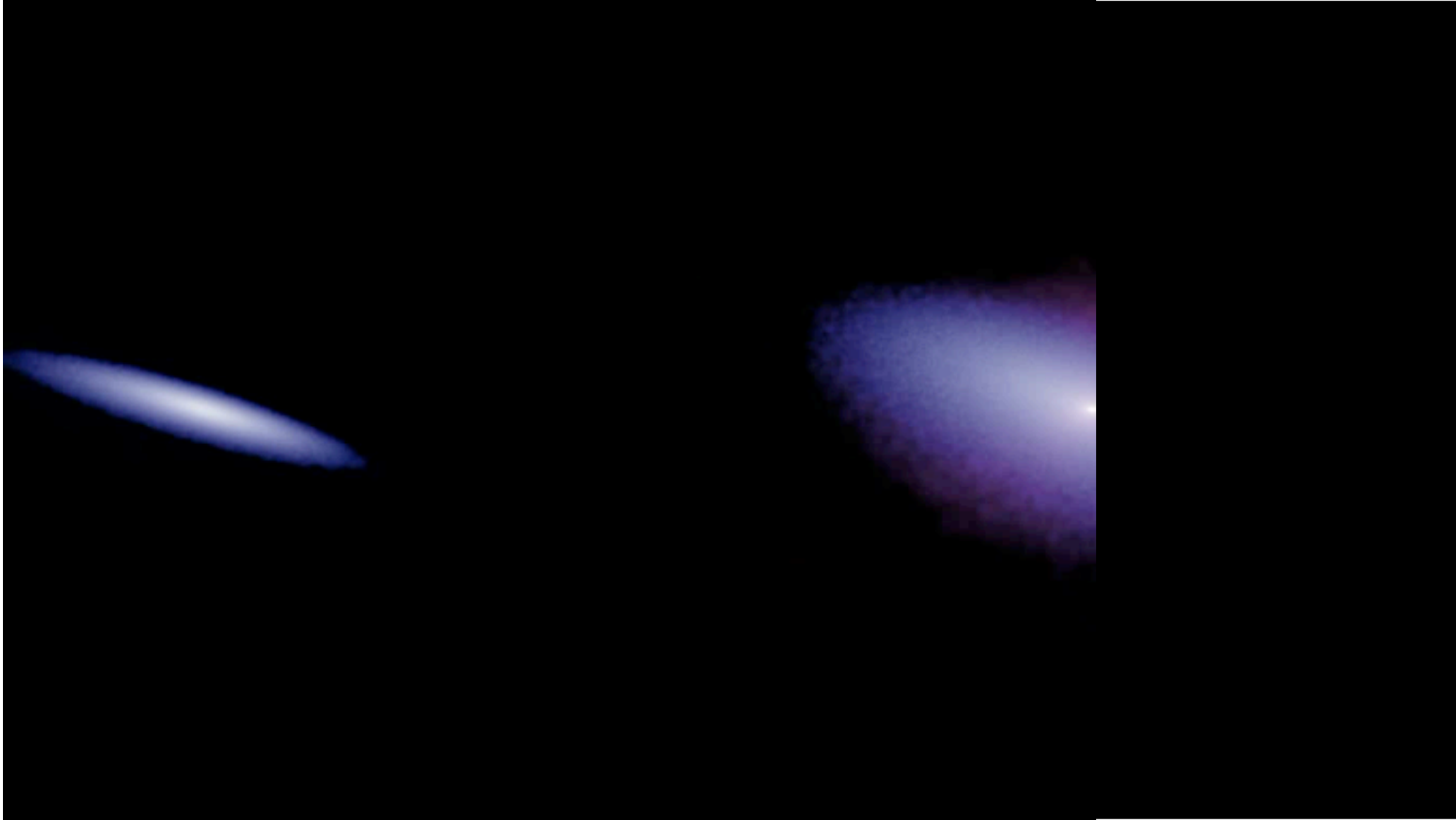
- L^* -- The “Slamming into Stuff” stage of galaxy evolution



Crap, 5 Tequilas Down....

NOW THE NIGHT GETS INTERESTING

- L^* -- The “Slamming into Stuff” stage of galaxy evolution

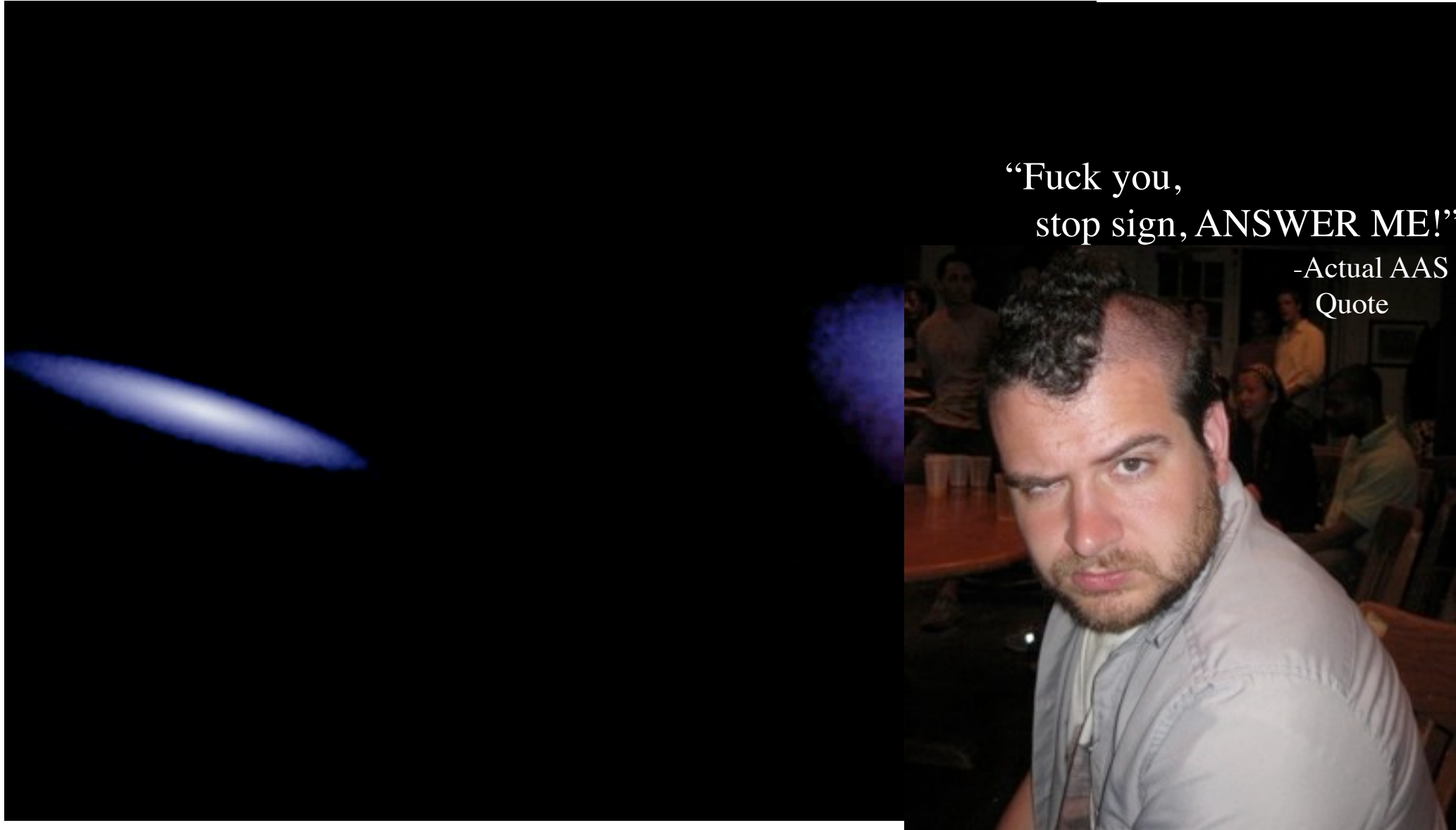


- Violent: Stars scatter off time-varying potential (“violent relaxation”)

Crap, 5 Tequilas Down....

NOW THE NIGHT GETS INTERESTING

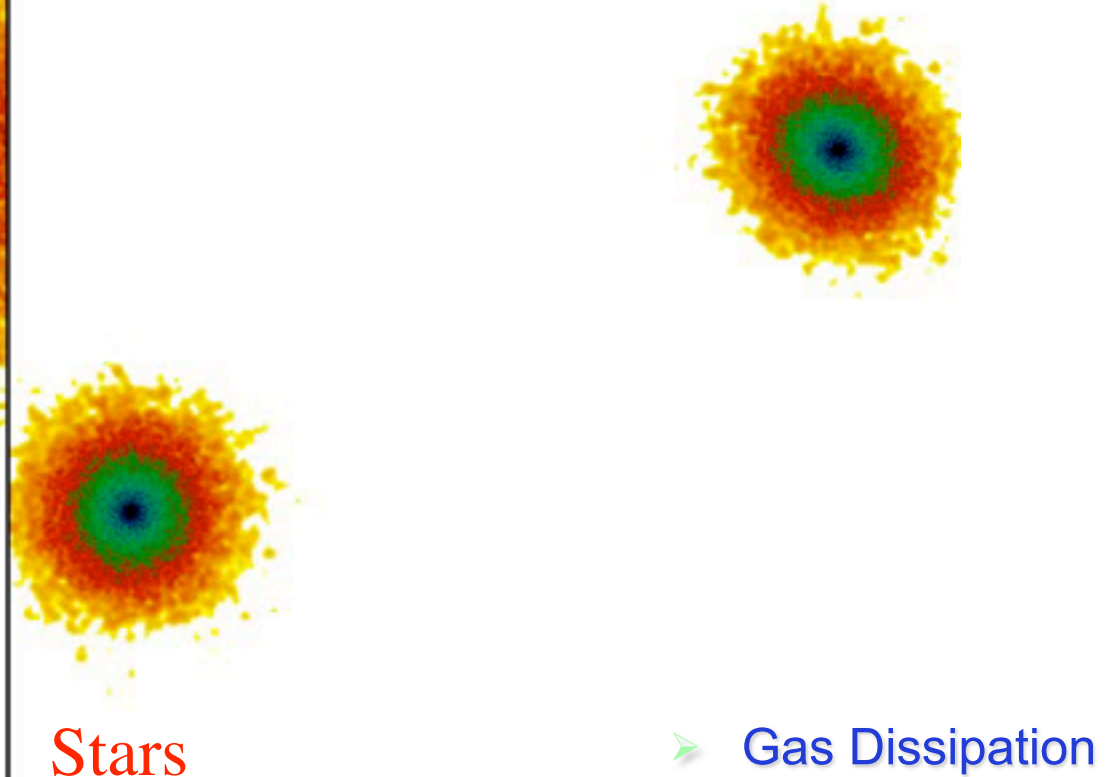
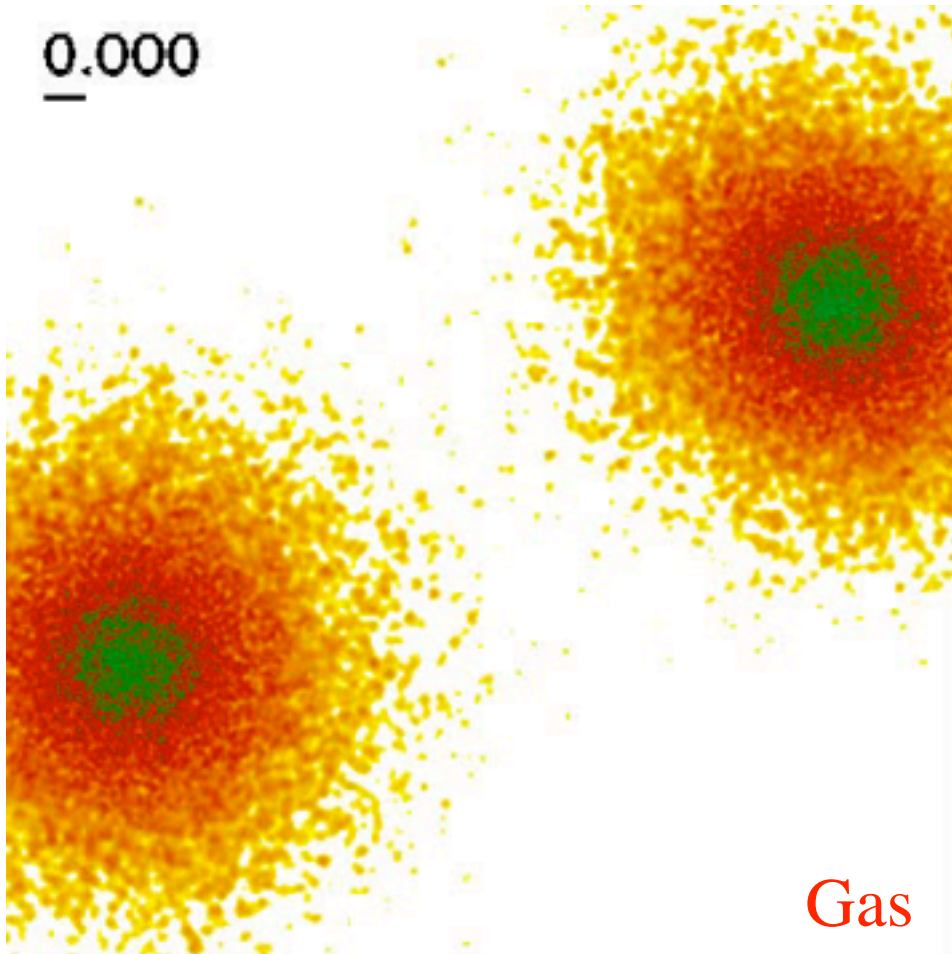
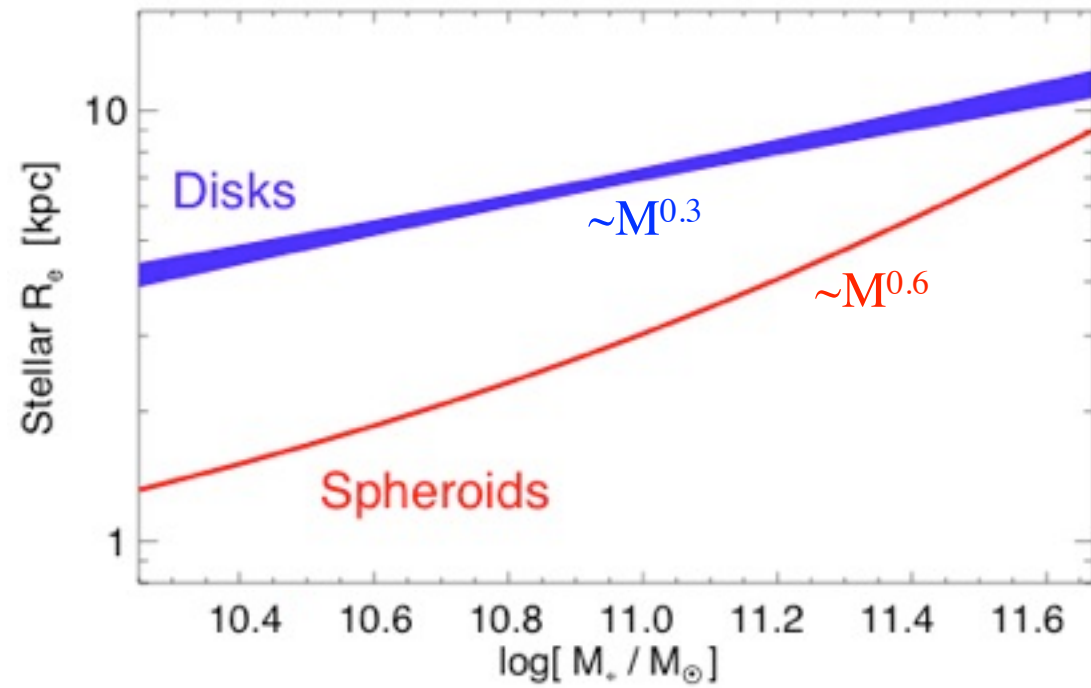
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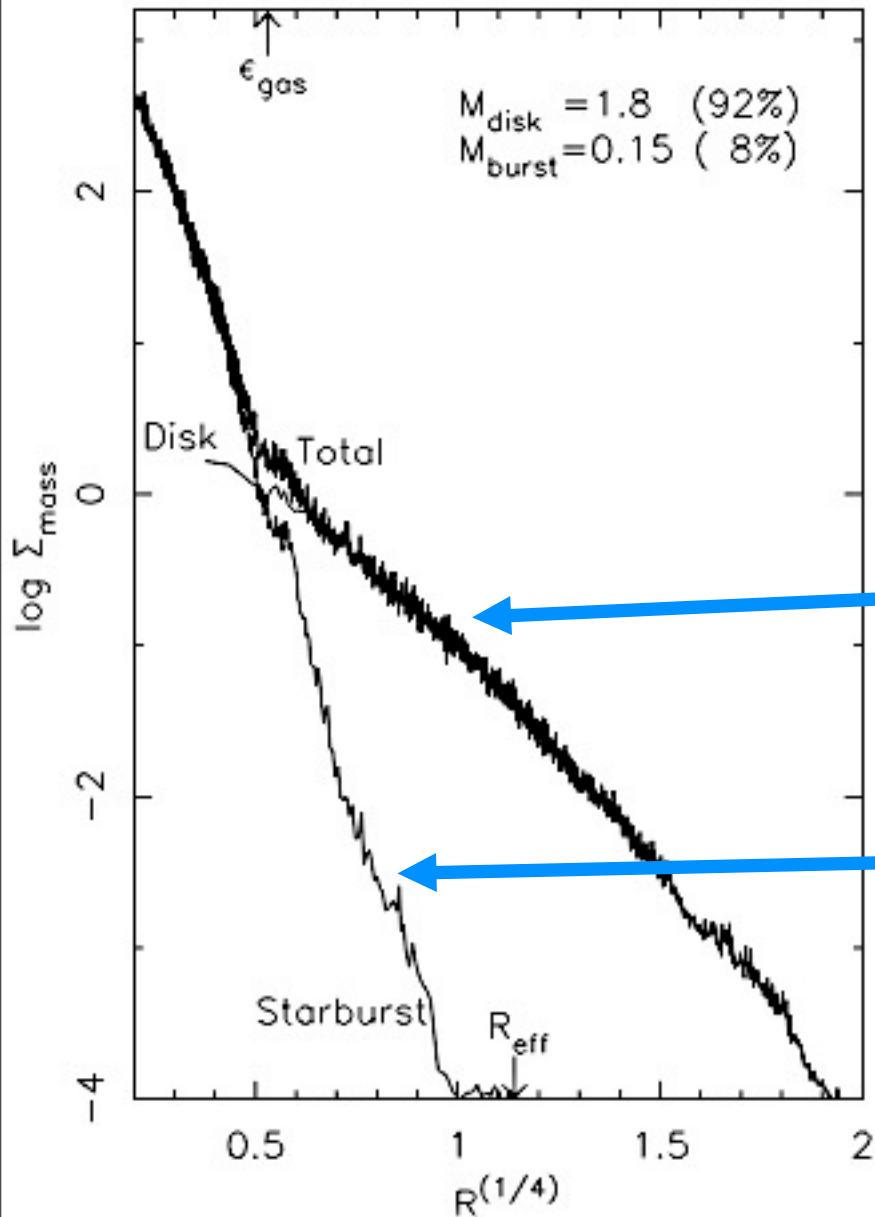
Science Detour: The Fundamental Plane & Bulge Densities

➤ Why are ellipticals smaller than disks?



Starburst Stars in Simulations Leave an “Imprint” on the Profile

RECOVERING THE GASEOUS HISTORY OF ELLIPTICALS



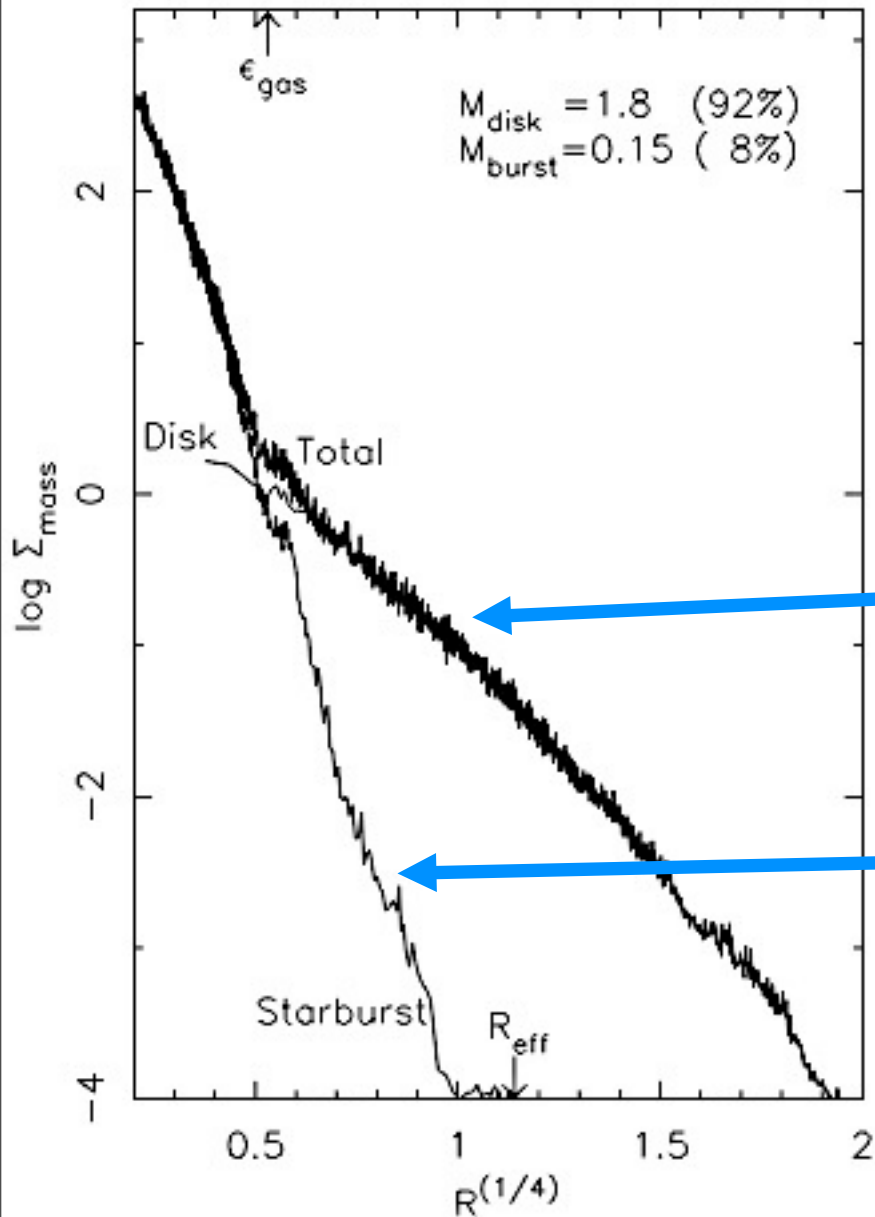
Merger remnant elliptical profiles
are fundamentally
two-component:

Pre-starburst/Disk
(dissipationless, violently
relaxed)

Starburst
(dissipational, no strong
violent relaxation)

Starburst Stars in Simulations Leave an “Imprint” on the Profile

RECOVERING THE GASEOUS HISTORY OF ELLIPTICALS



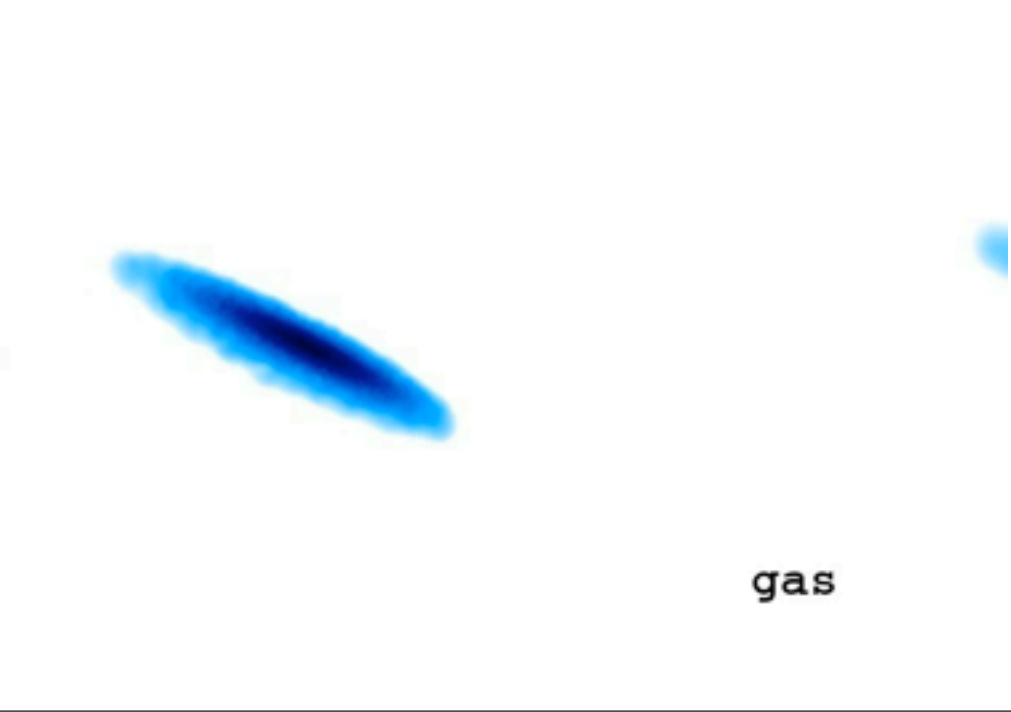
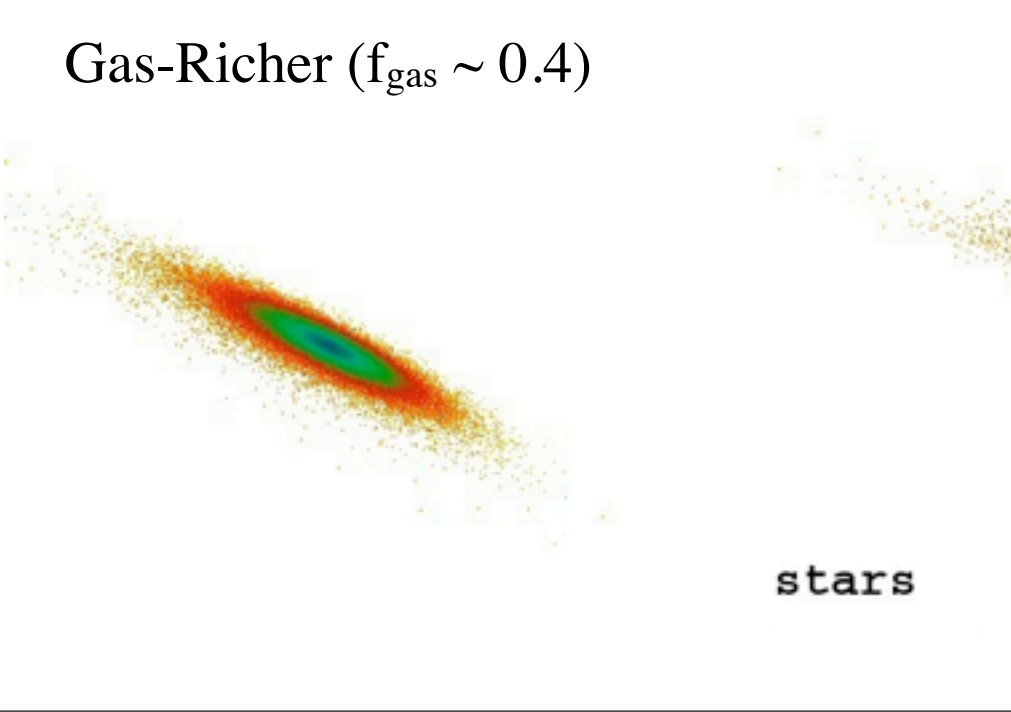
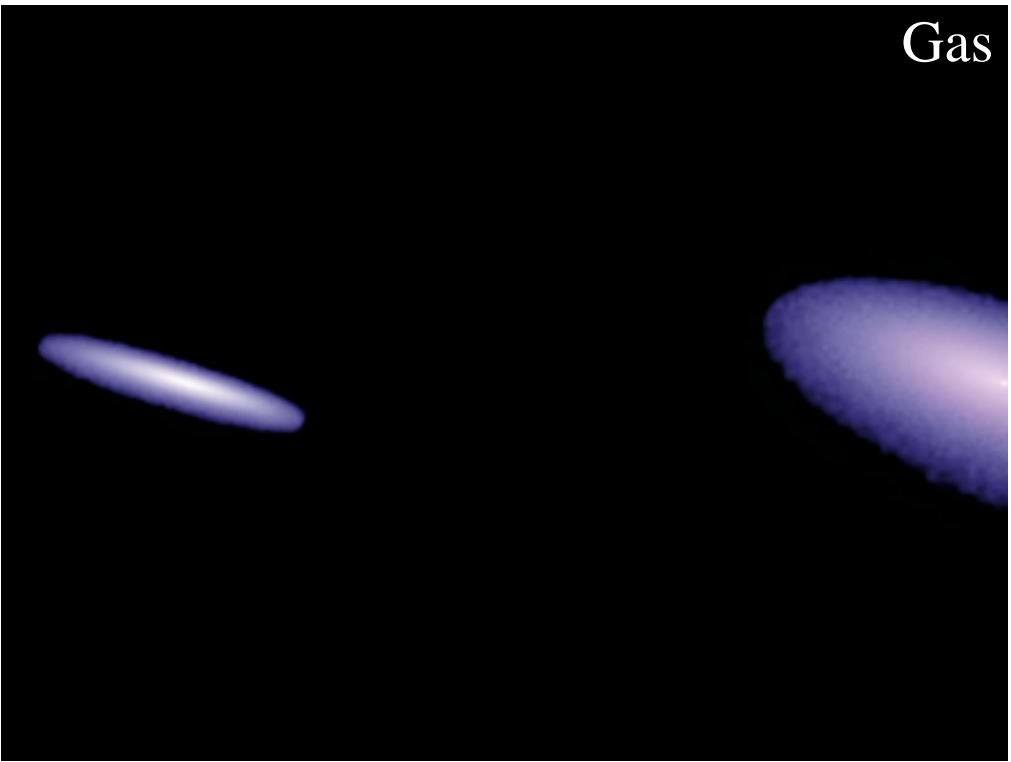
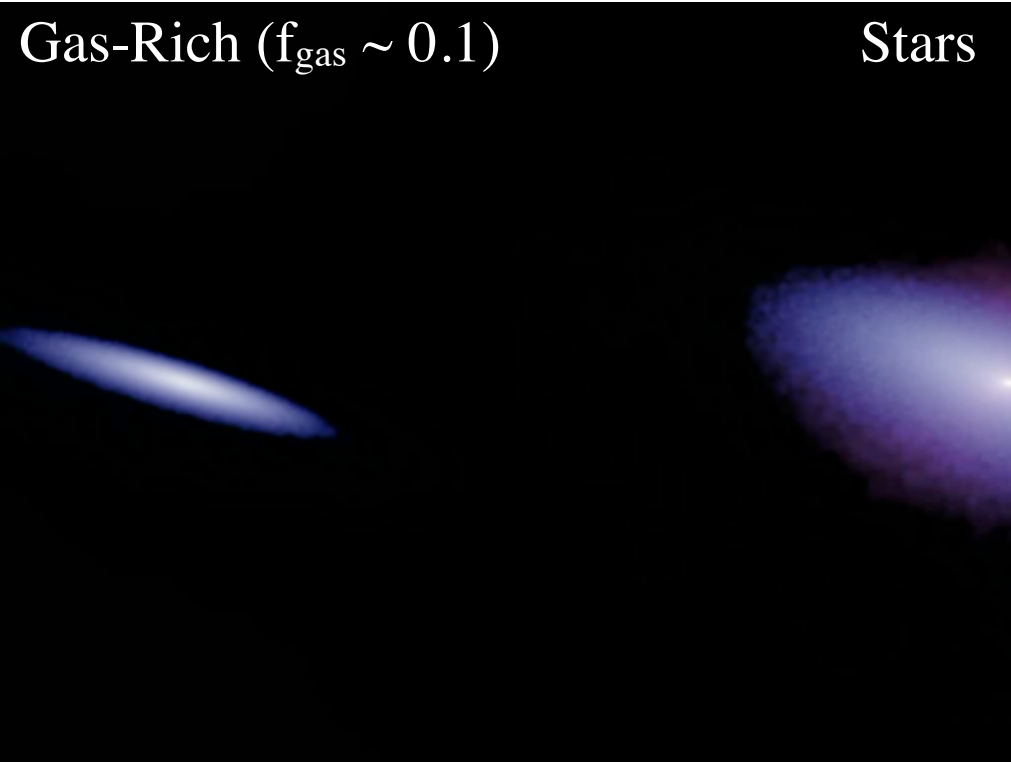
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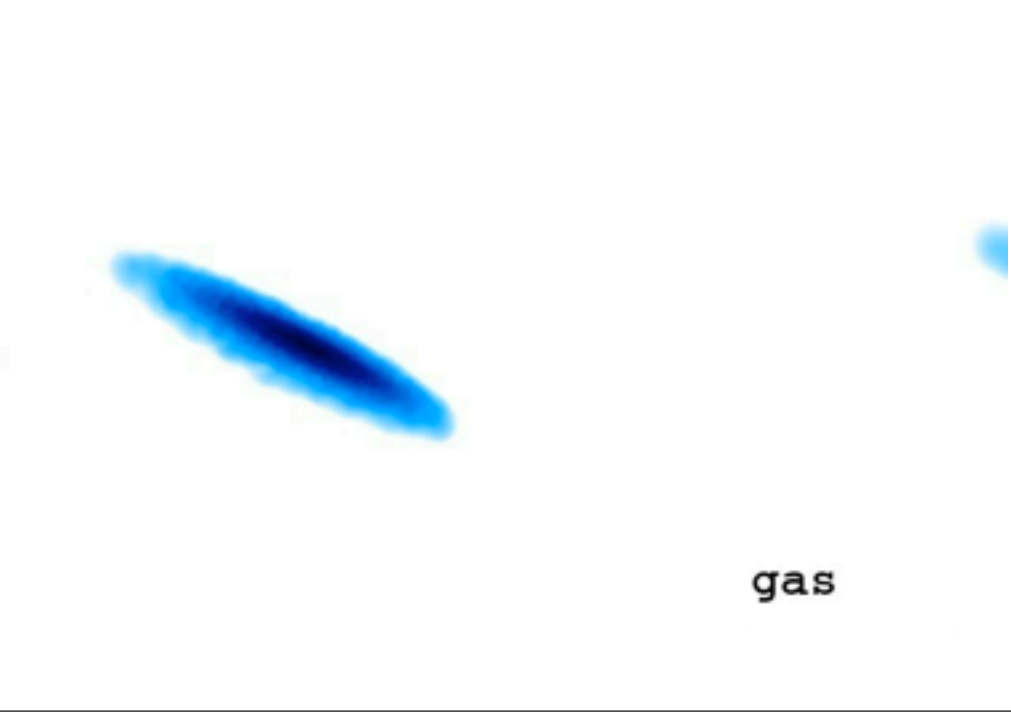
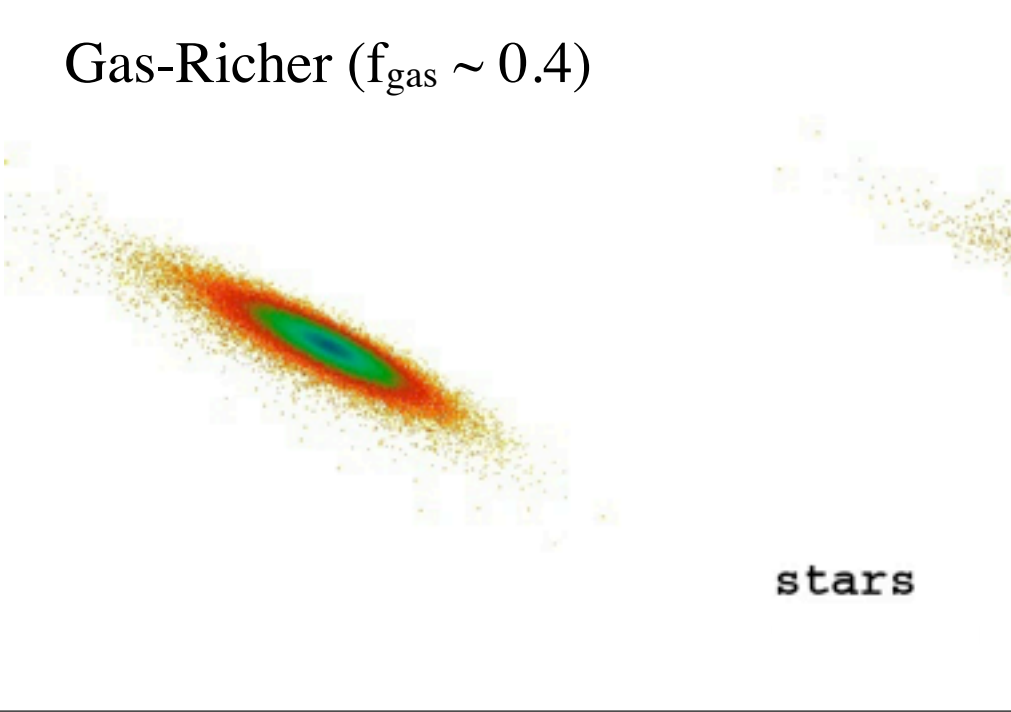
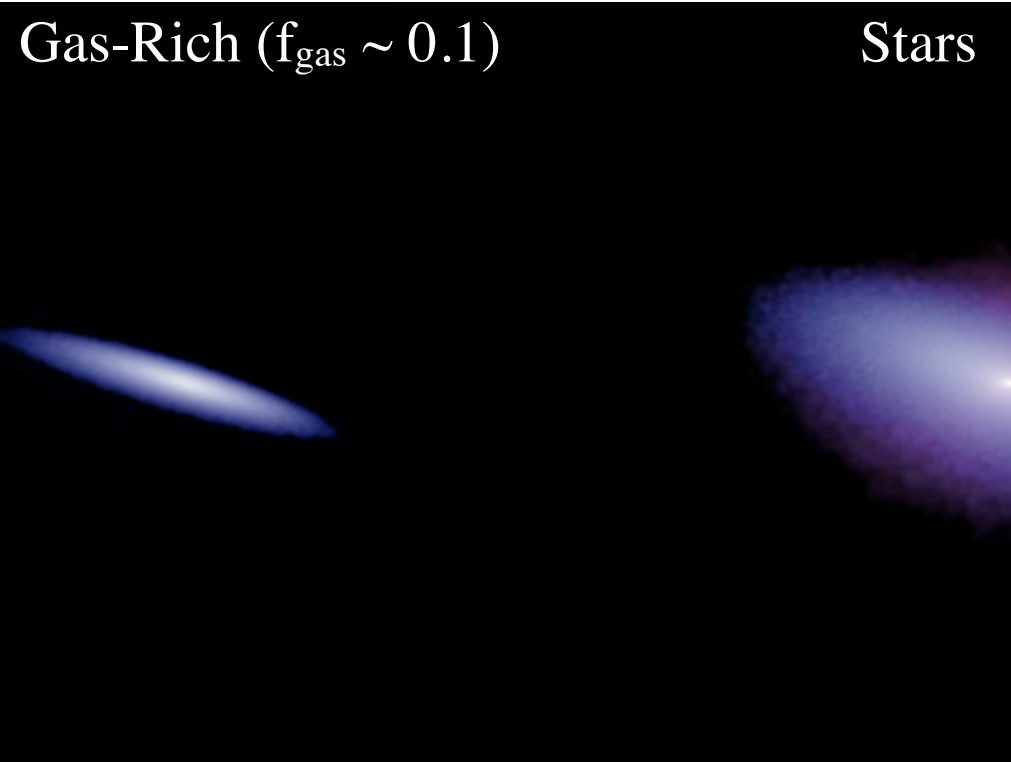
Starburst
(dissipational, no strong violent relaxation)

➤ Explains classic de Vaucouleurs $R^{1/4}$ law profiles, shapes, etc.

Mergers are very different, depending on what you slam into:



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Gas-Rich ($f_{\text{gas}} \sim 0.1$)

Stars

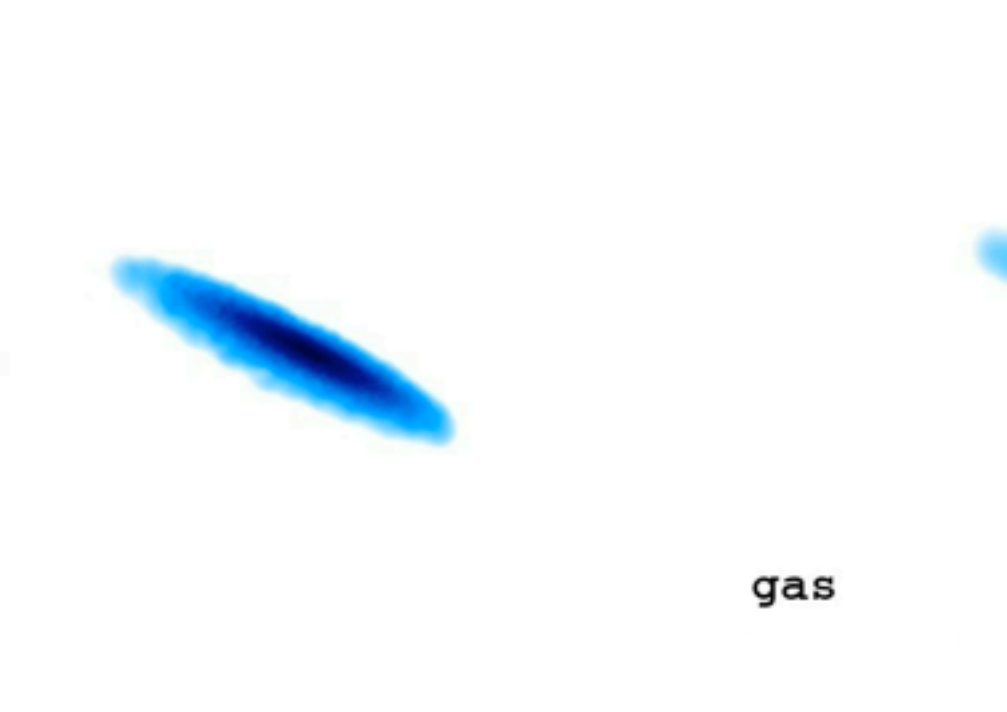


...that tree hurt...

Gas-Richer ($f_{\text{gas}} \sim 0.4$)



“I’m cool!
Good for
round 2!”



gas

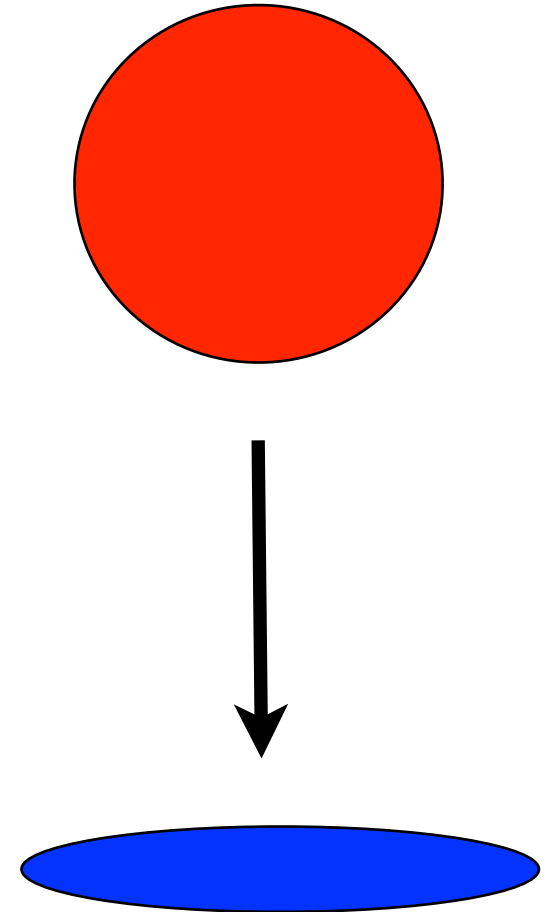
The Unsolved Questions

HOW CAN A DISK SURVIVE?

- Gas, however, is collisional (will cool into new disk): only goes to center and bursts if angular momentum is removed

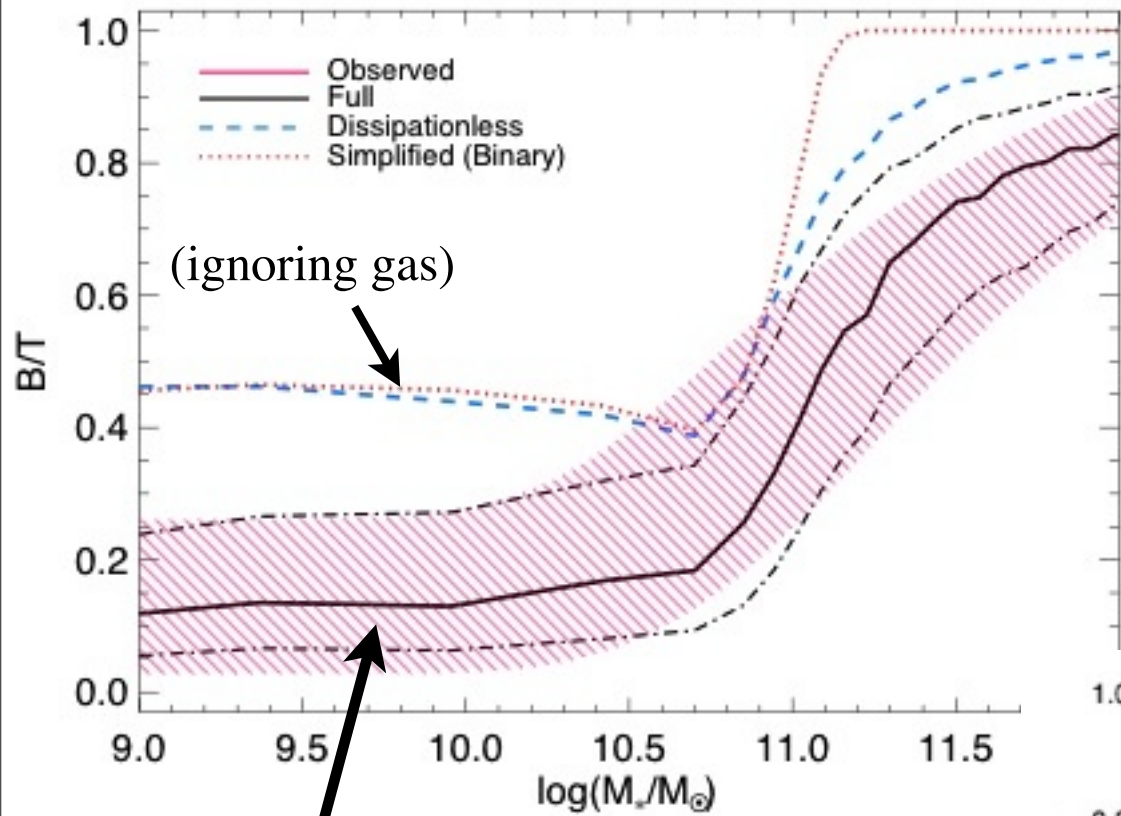


Governato et al.



Why Do We Care?

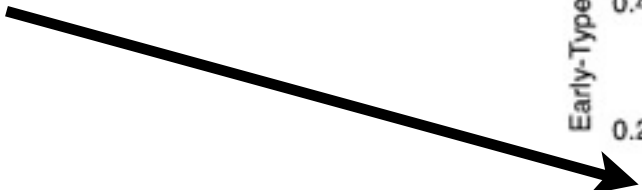
HOW DISK SURVIVAL IN MERGERS IS IMPORTANT



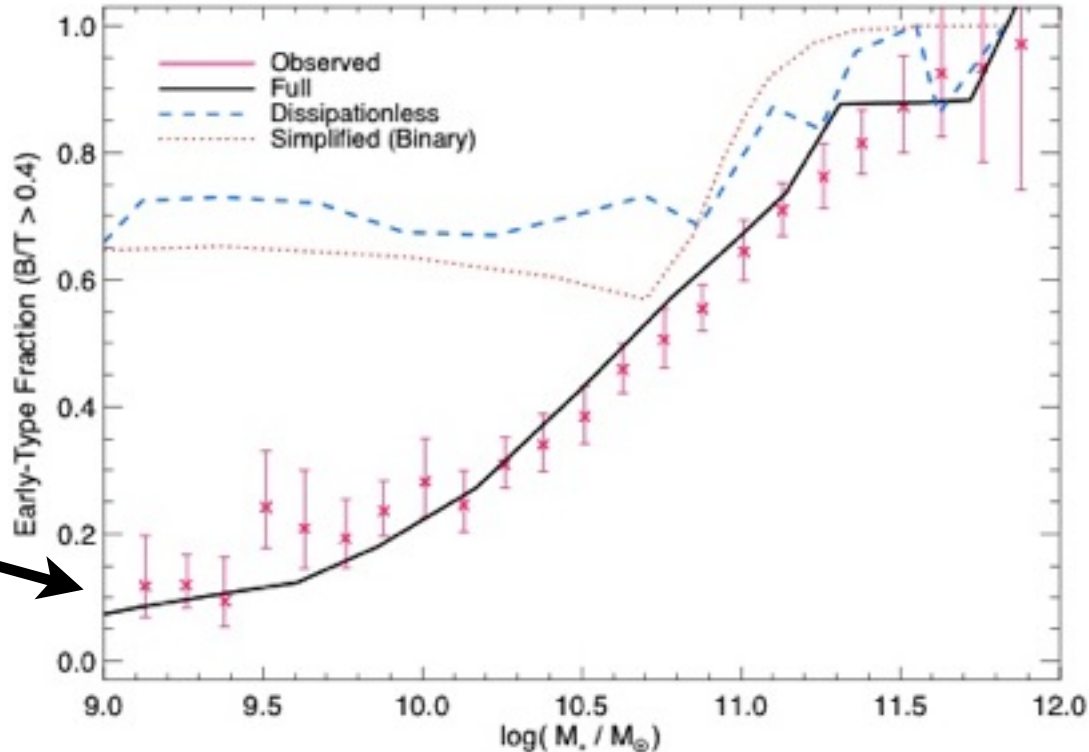
(ignoring gas)



(including effects of gas)

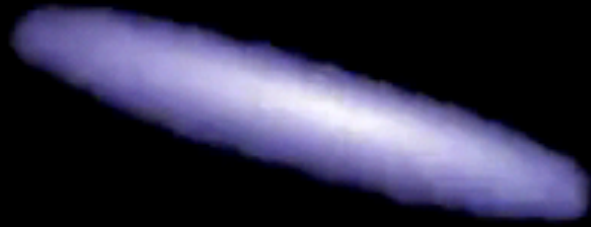


- Morphology-mass relation:
- Natural consequence of f_{gas} -mass



T = 0 Myr

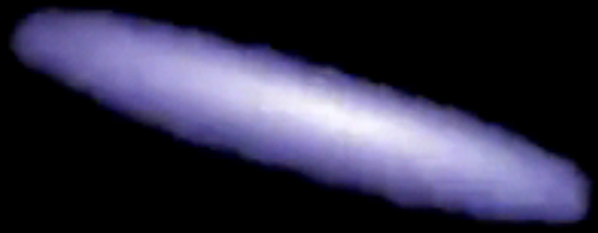
Gas



What about the gas that gets channeled to small radii?

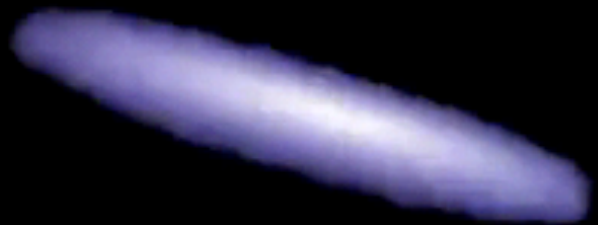
T = 0 Myr

Gas



T = 0 Myr

Gas

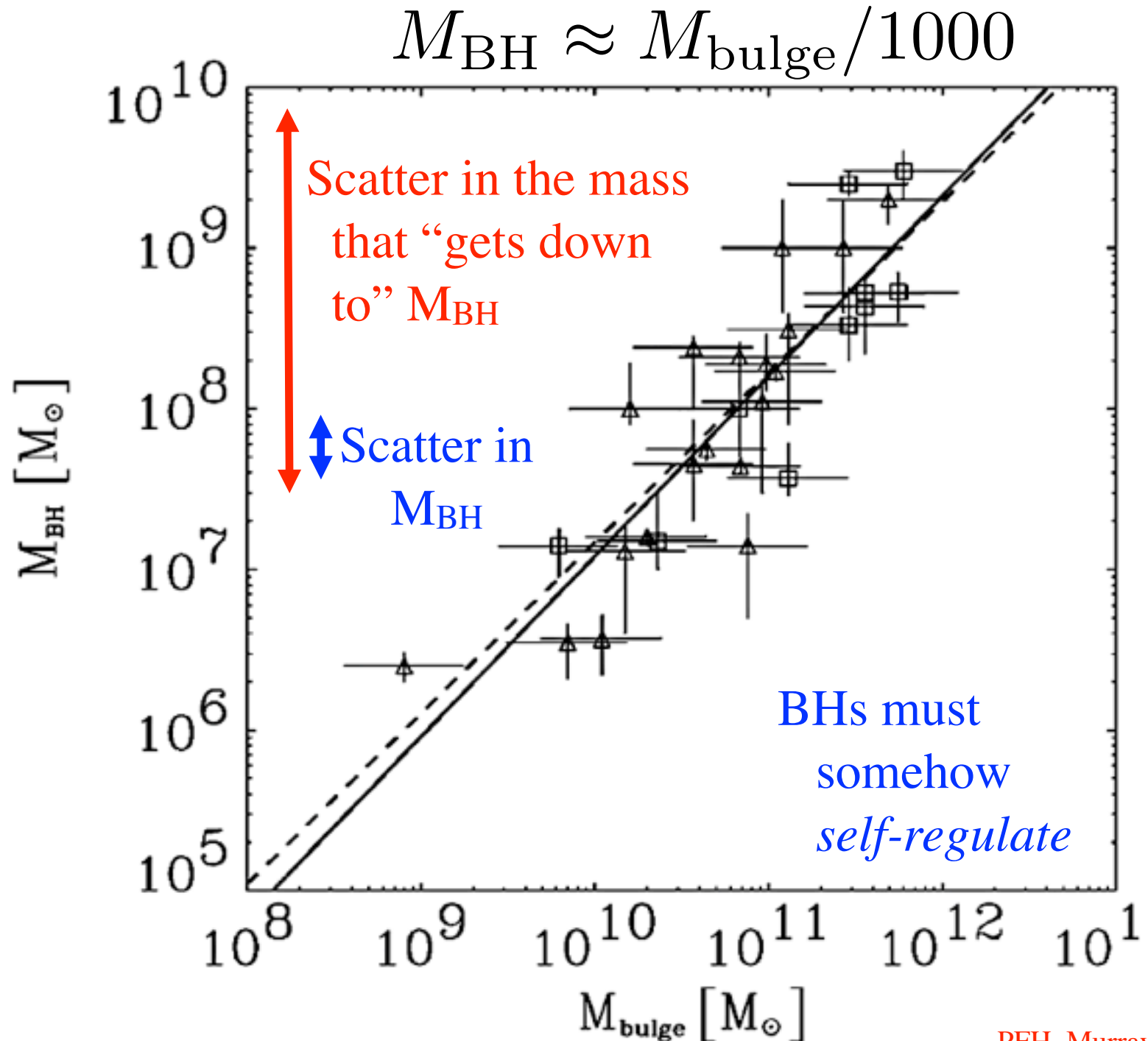


Tequila

5...6...7...

Uh oh... 7 Tequila: Feedback

WHY FEEDBACK?



Simplest Idea:

FEEDBACK ENERGY BALANCE (SILK & REES '98)

- Accretion disk radiates:

$$L = \epsilon_r (dM_{\text{BH}}/dt) c^2 \quad (\epsilon_r \sim 0.1)$$

- Total energy radiated (typical $\sim 10^8 M_{\text{sun}}$ system)

$$\sim 0.1 M_{\text{BH}} c^2 \sim 10^{61} \text{ ergs}$$

- Compare to gravitational binding energy of galaxy:

$$\sim M_{\text{gal}} \sigma^2 \sim (10^{11} M_{\text{sun}}) (200 \text{ km/s})^2 \sim 10^{59} \text{ erg}$$

- If only a few percent of the luminous energy coupled, it would unbind the baryons!

- Turn this around: *if* some fraction $f \sim 1\text{-}5\%$ of the luminosity can couple, then accretion must stop when

$$M_{\text{BH}} \sim (1/f\epsilon_r) M_{\text{gal}} (\sigma/c)^2 \sim 0.002 M_{\text{gal}}$$

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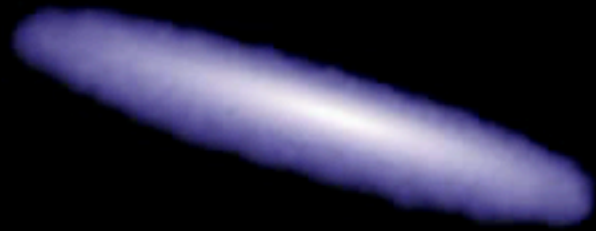
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Past this threshold, some of what goes down must come back up..... (picture omitted for your sake)

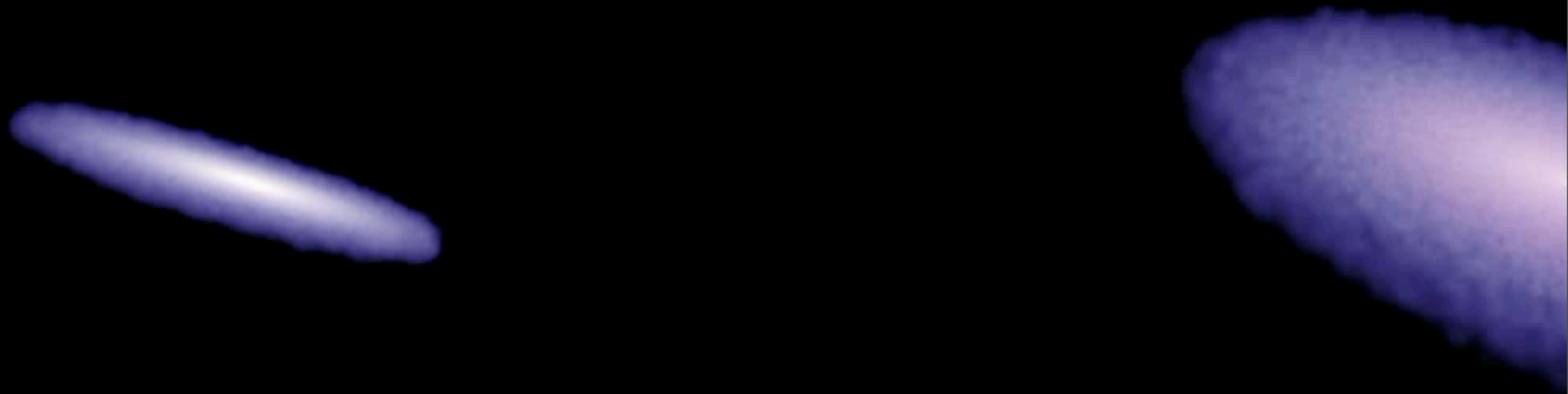
T = 0 Myr

Gas



T = 0 Myr

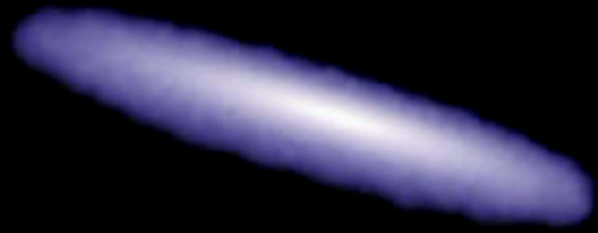
Gas



Tidal torques \Rightarrow large, rapid gas inflows (e.g. Barnes & Hernquist 1991)

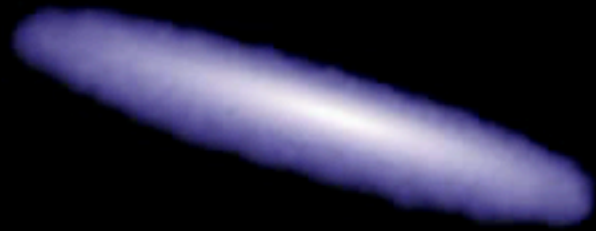
T = 0 Myr

Gas



T = 0 Myr

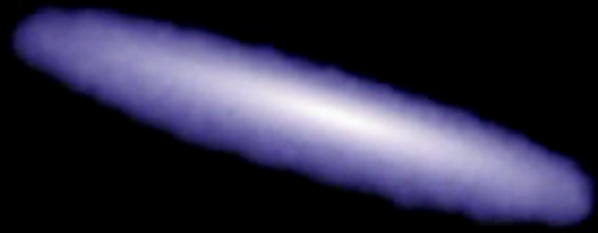
Gas



Triggers Starbursts (e.g. Mihos & Hernquist 1996)

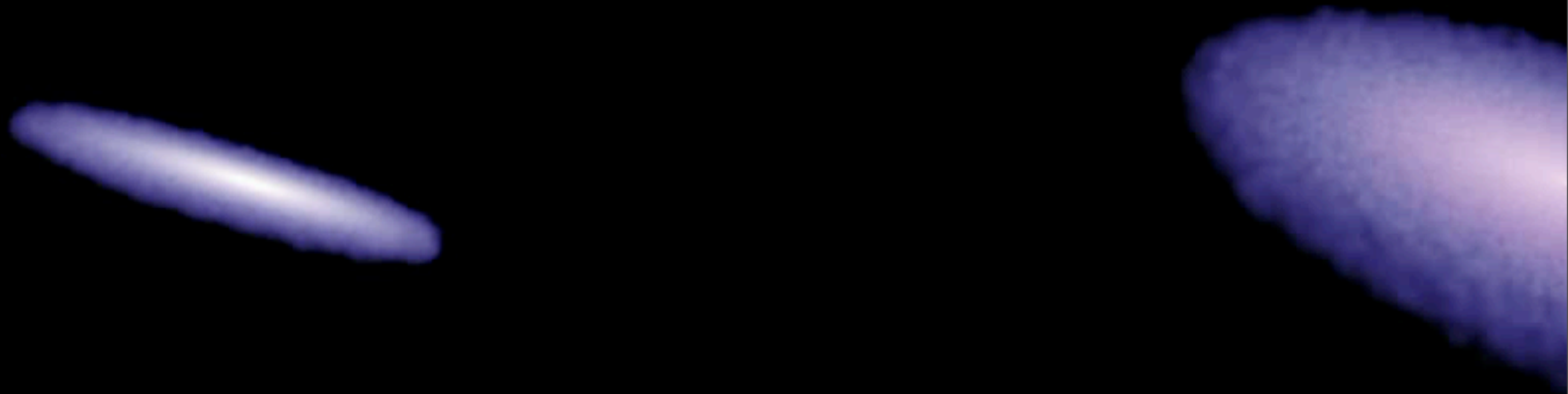
T = 0 Myr

Gas



T = 0 Myr

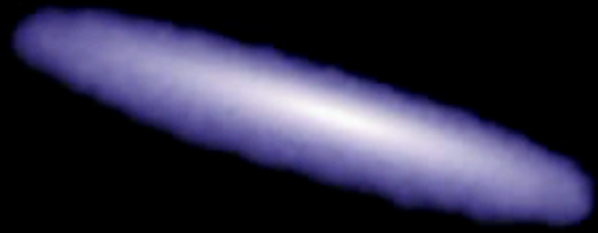
Gas



Fuels Rapid BH Growth (e.g. Di Matteo et al., PFH et al. 2005)

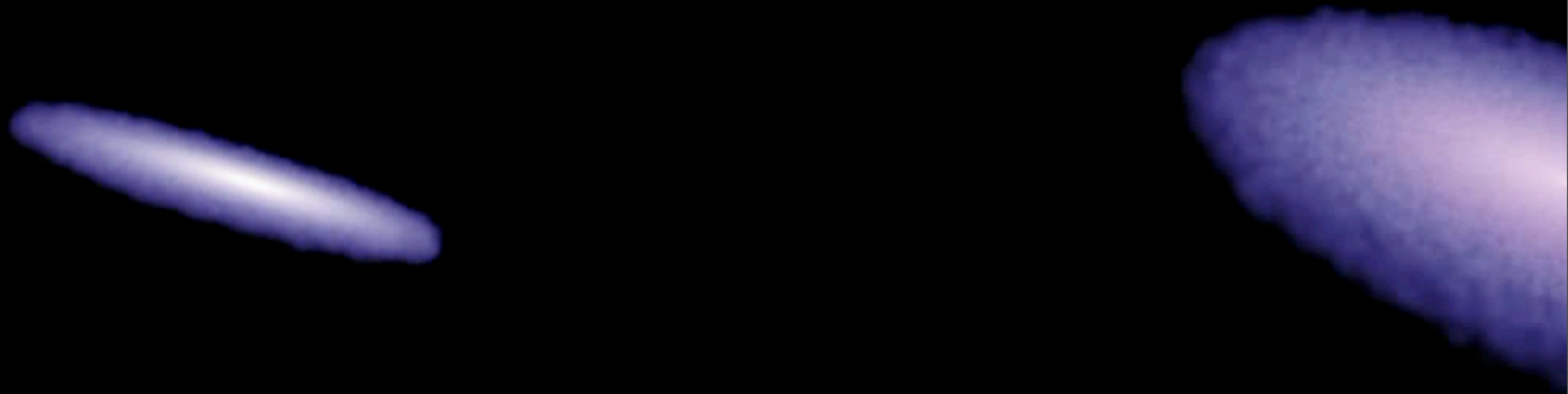
T = 0 Myr

Gas



T = 0 Myr

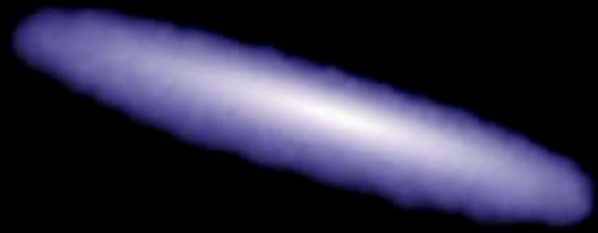
Gas



Feedback expels remaining gas, shutting down growth (more later...)

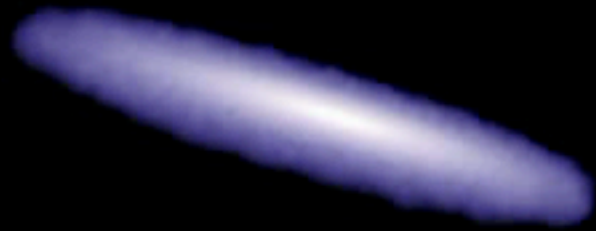
T = 0 Myr

Gas



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Gas

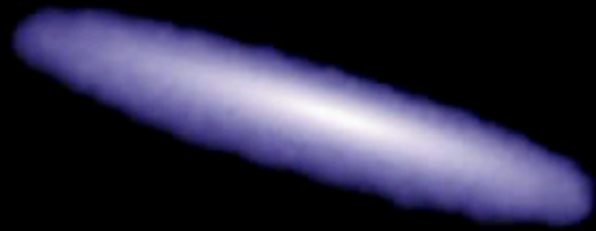


Merging stellar disks grow spheroid

Tuesday, December 25, 12

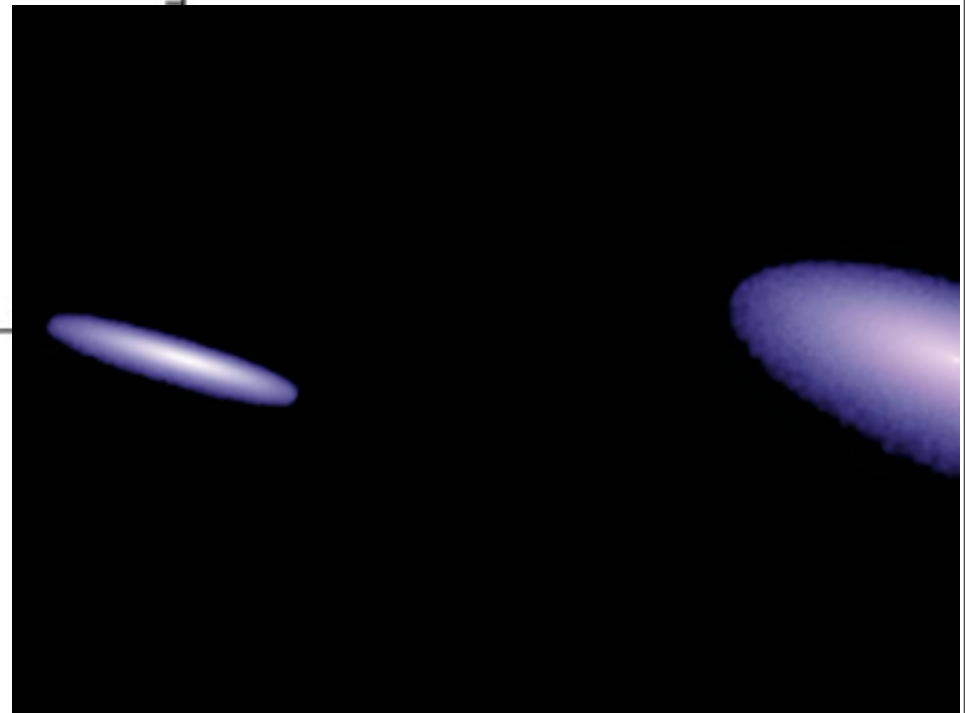
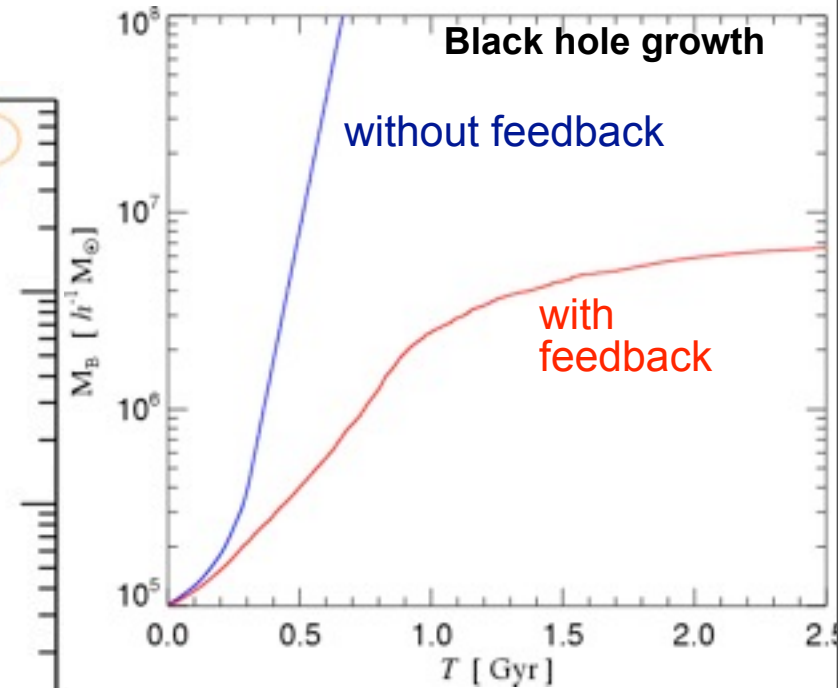
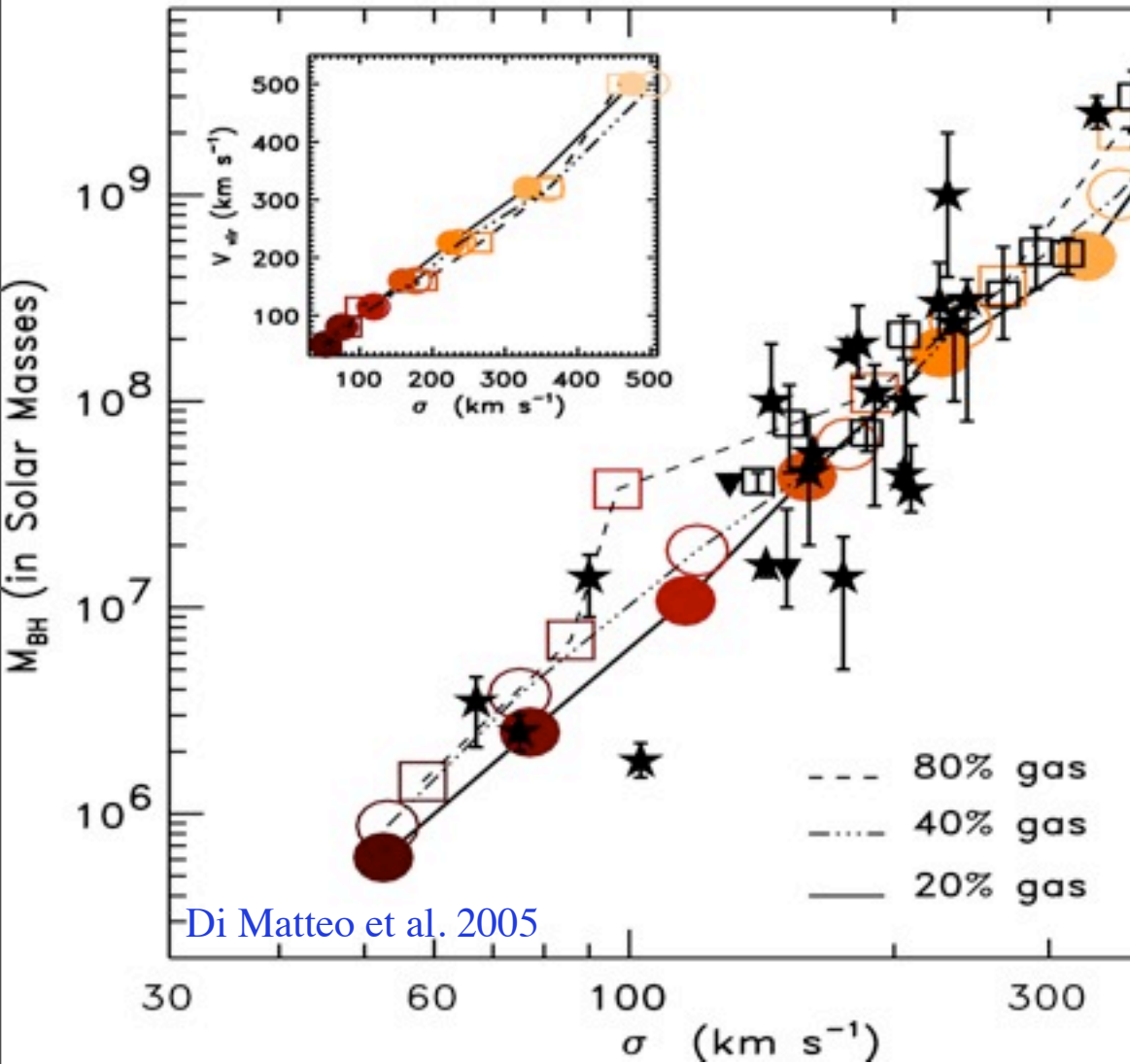
T = 0 Myr

Gas



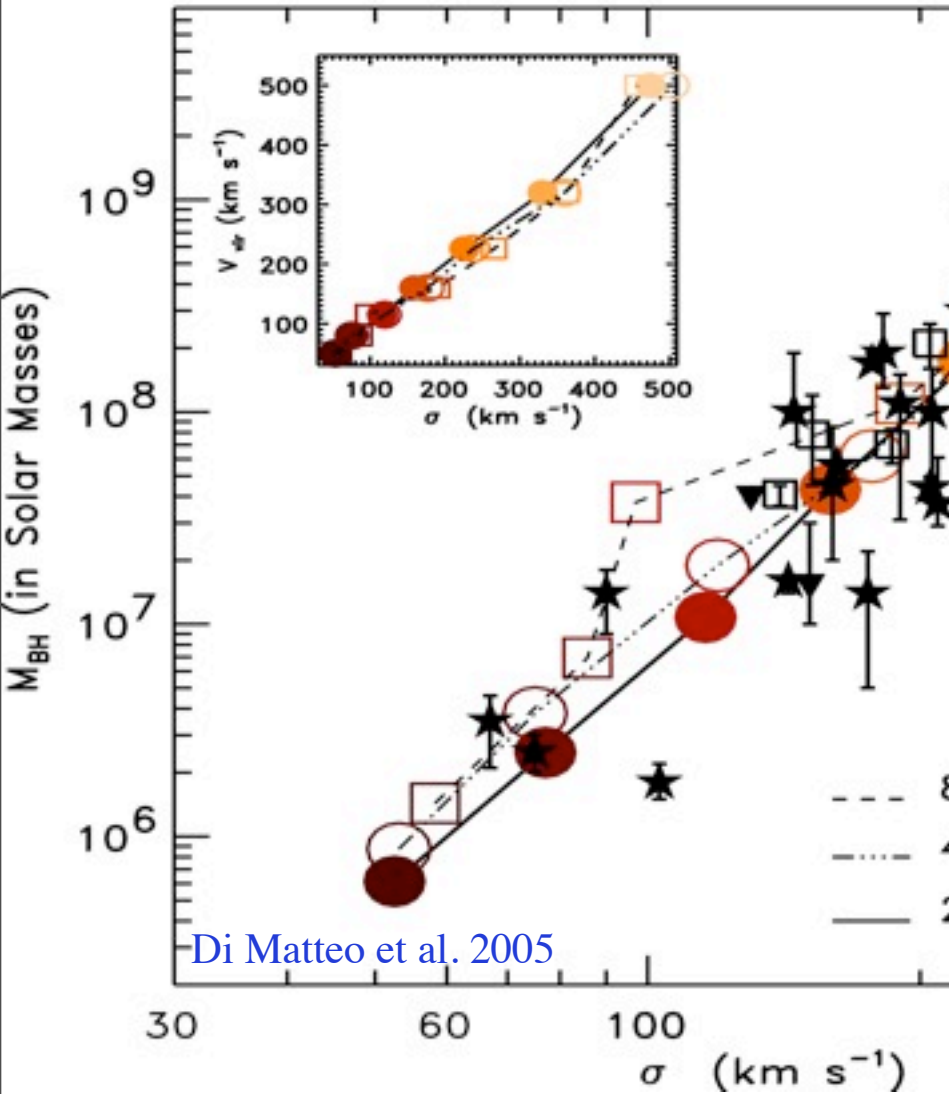
M-sigma Relation Suggests *Self-Regulated* BH Growth

PREVENTS RUNAWAY BLACK HOLE GROWTH

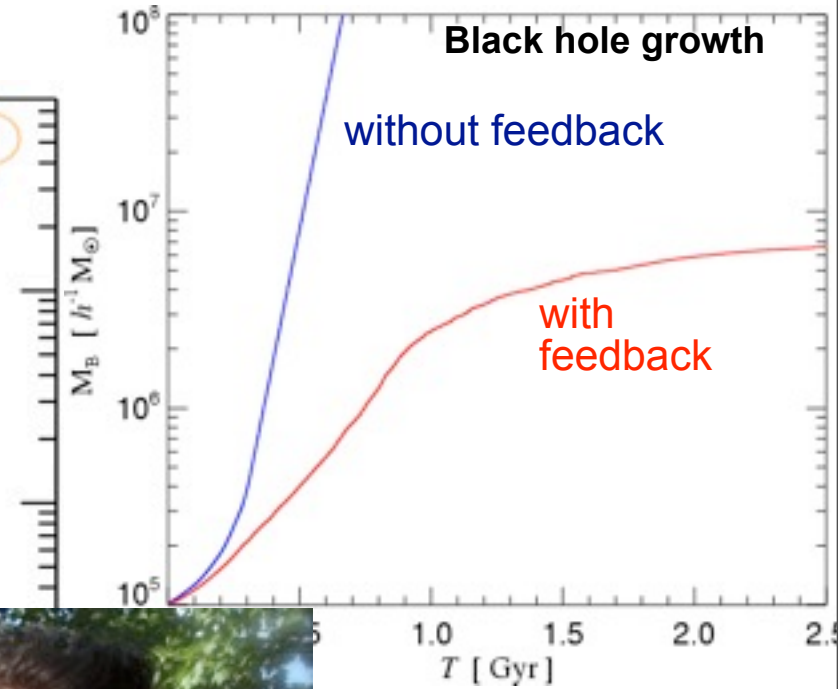


M-sigma Relation Suggests *Self-Regulated* BH Growth

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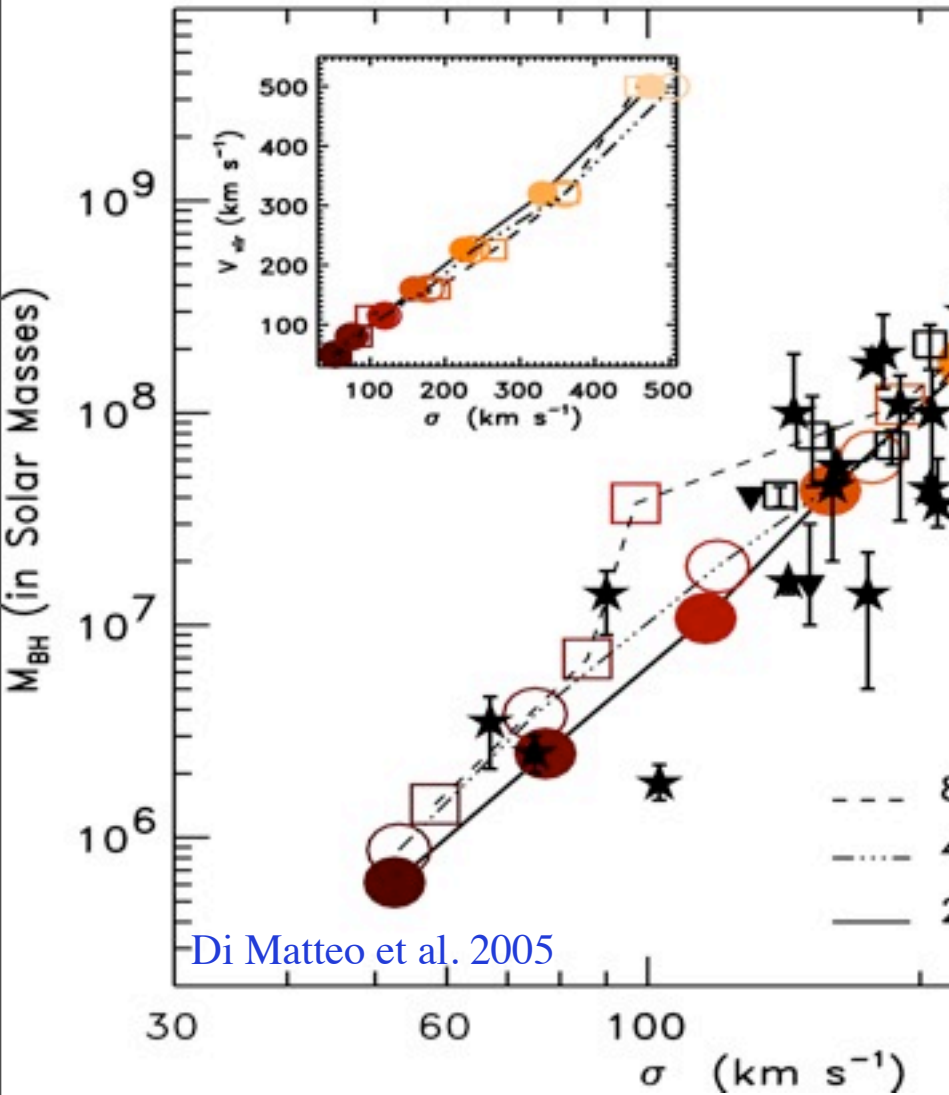


Di Matteo et al. 2005

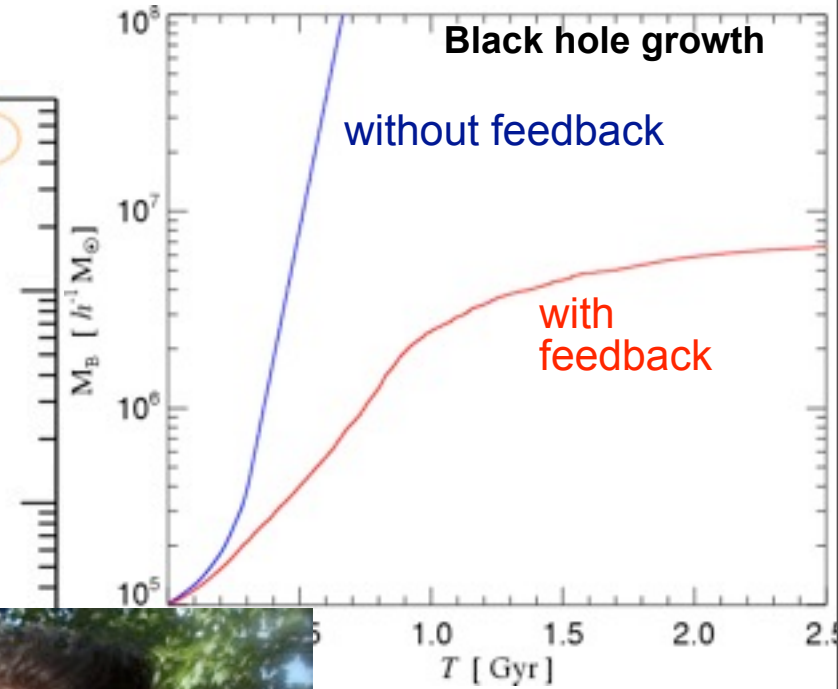


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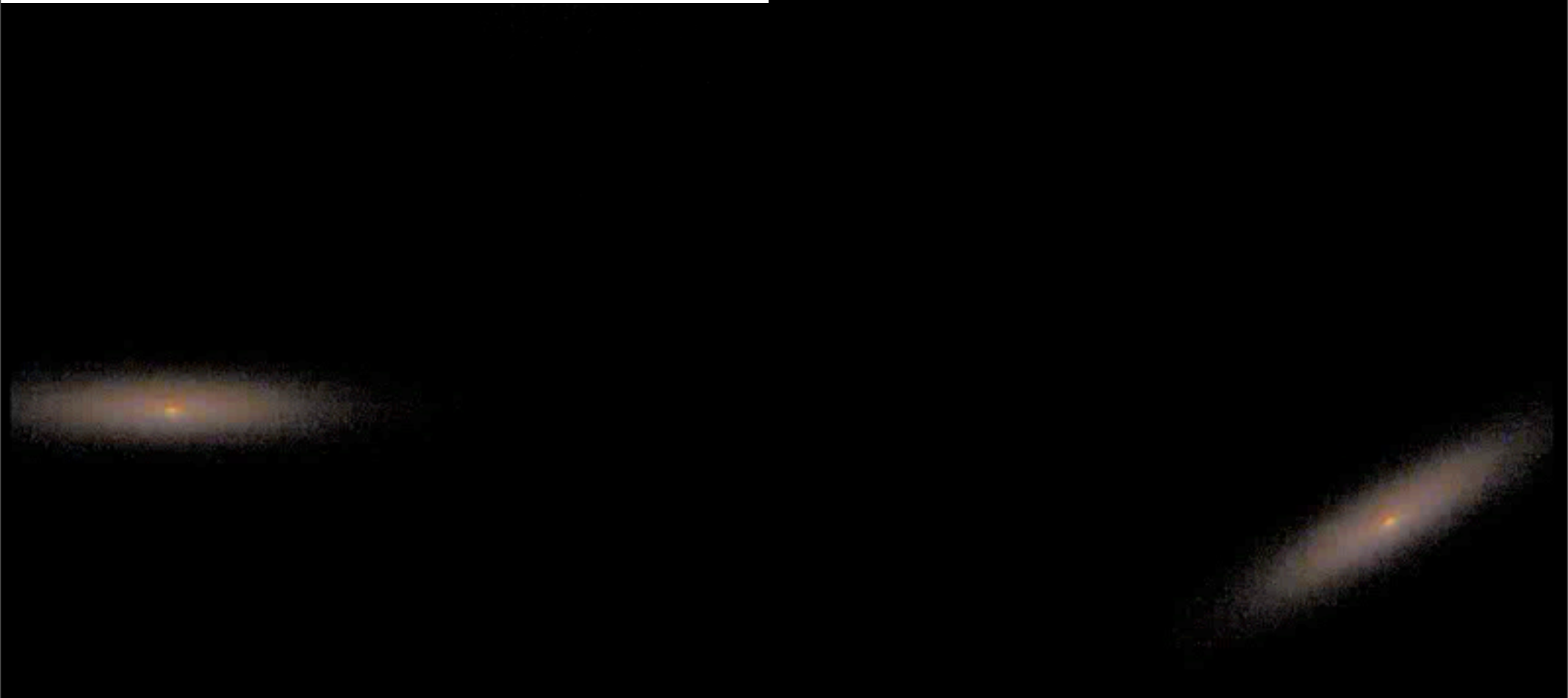
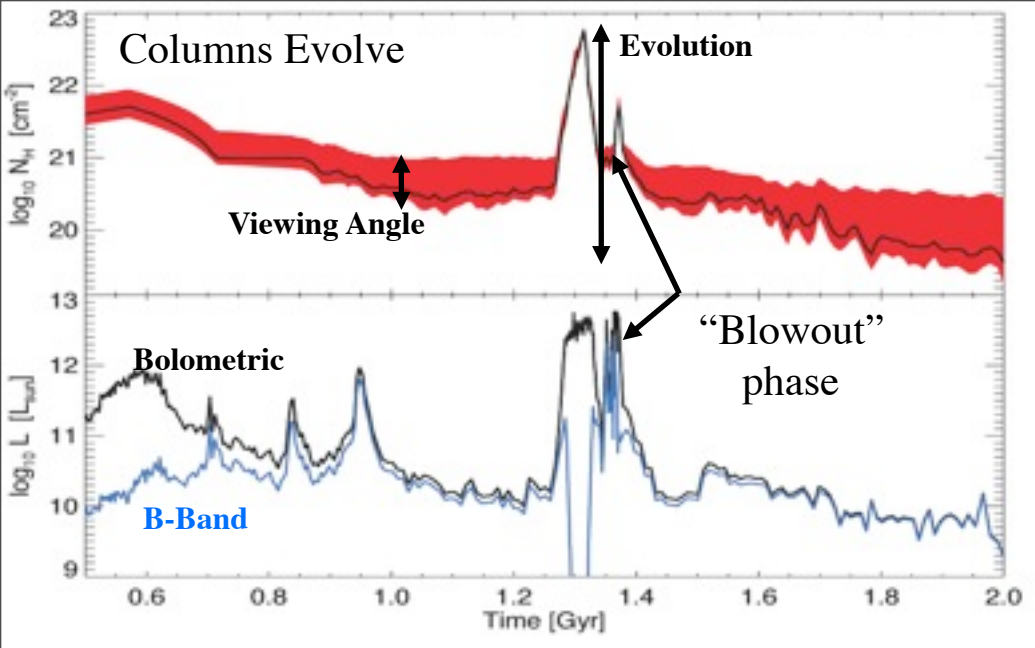


Di Matteo et al. 2005



Feedback!

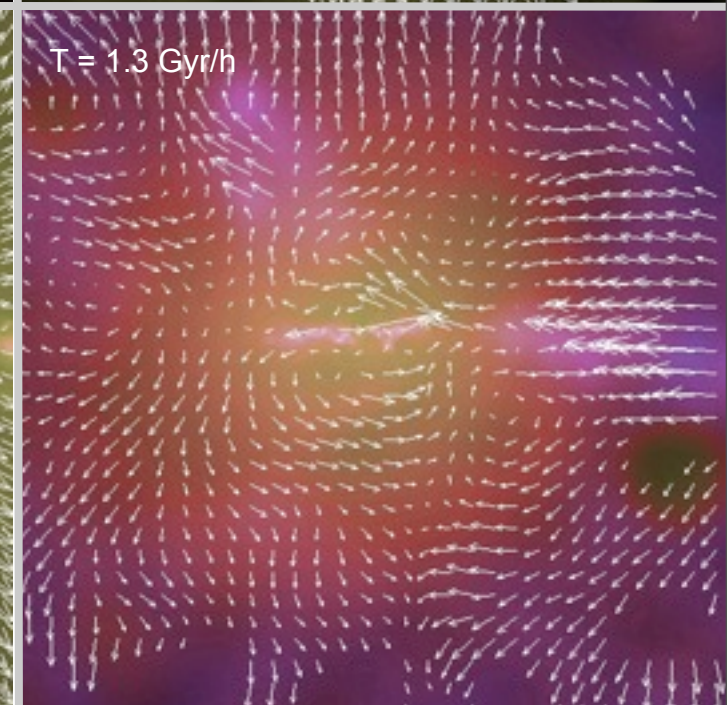
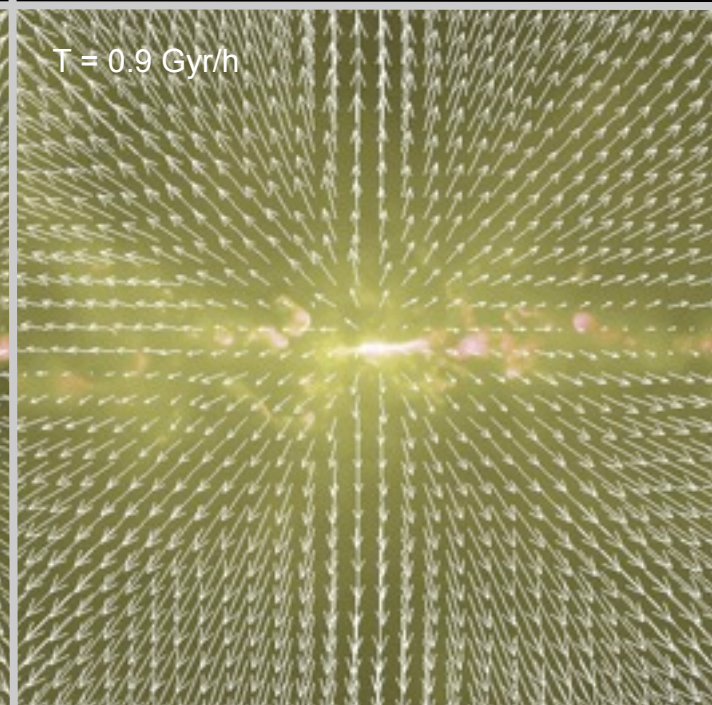
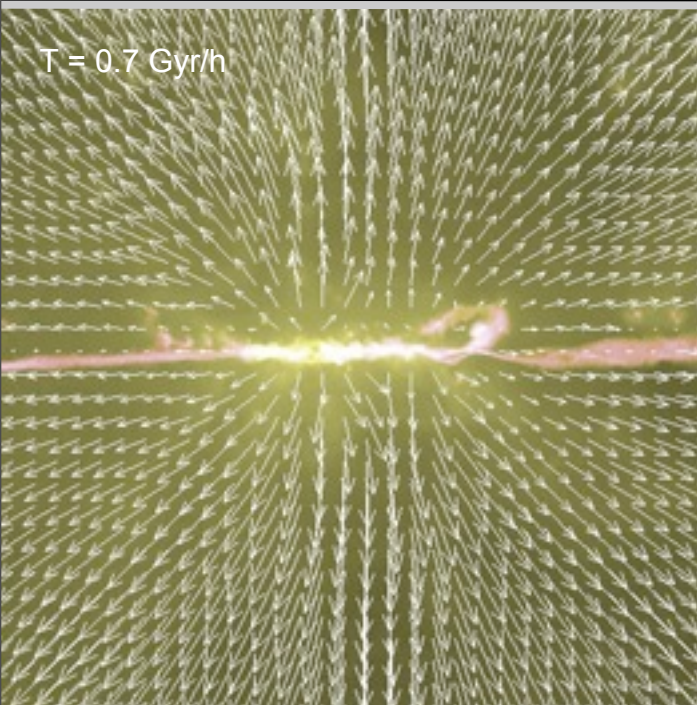
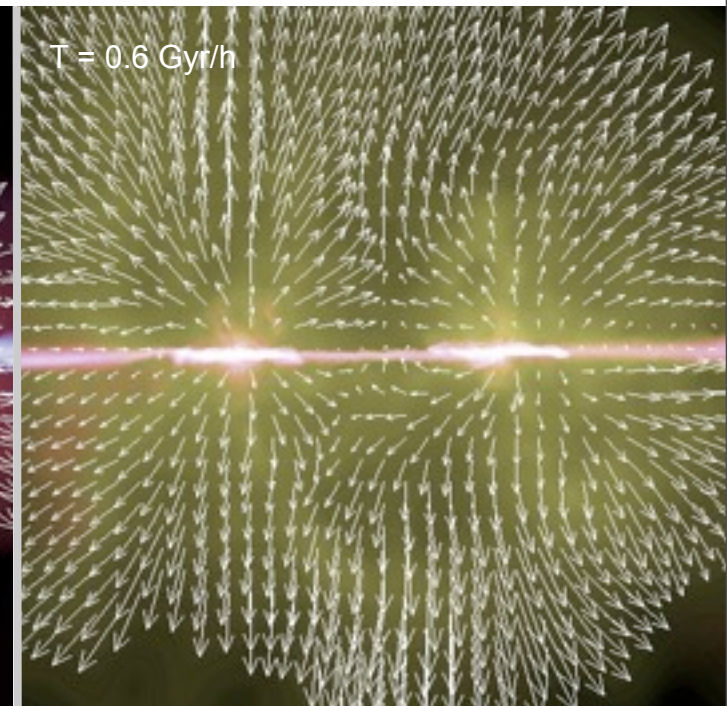
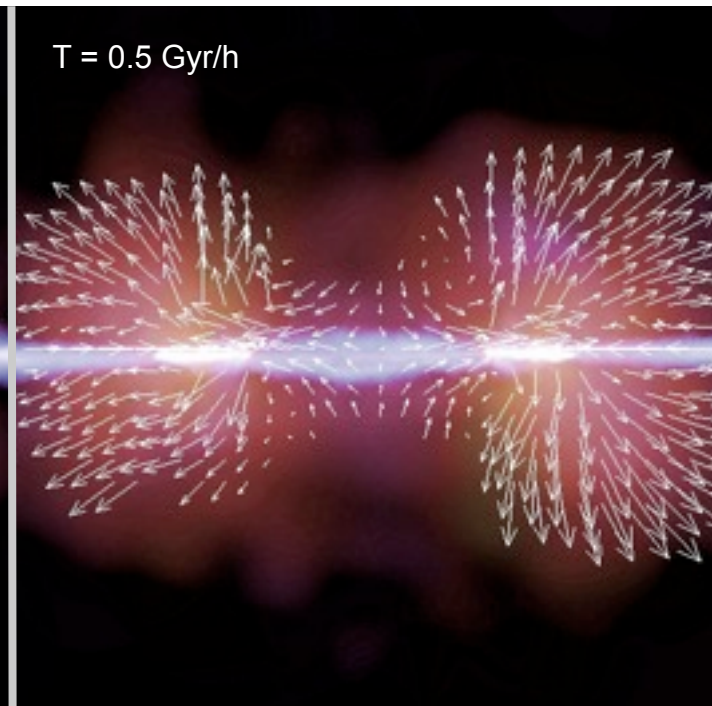
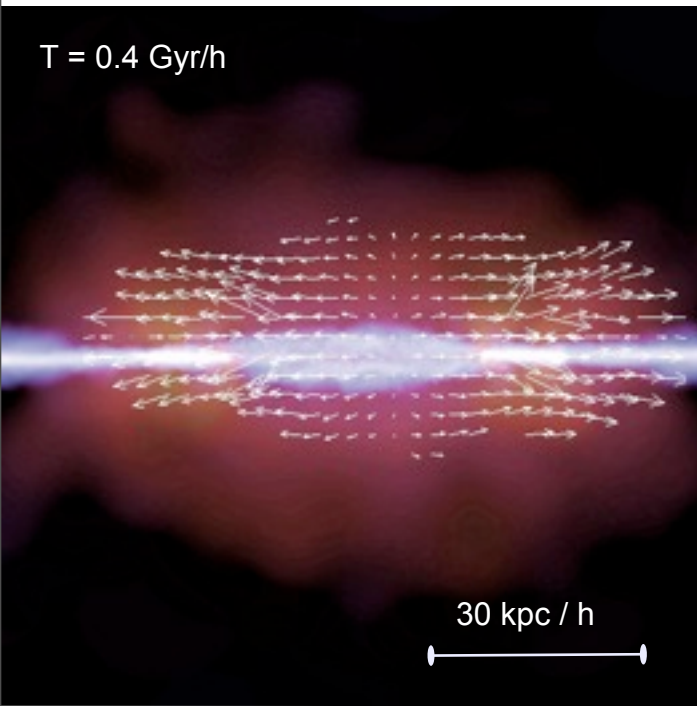
“Dude, better not let Phil have any more...”



Where Does the Energy/Momentum Go?

QUASAR-DRIVEN OUTFLOWS?

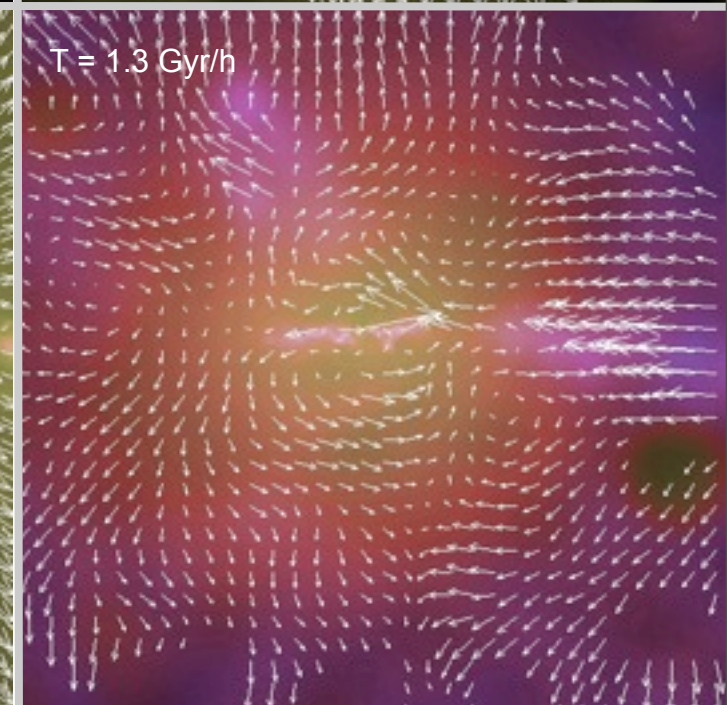
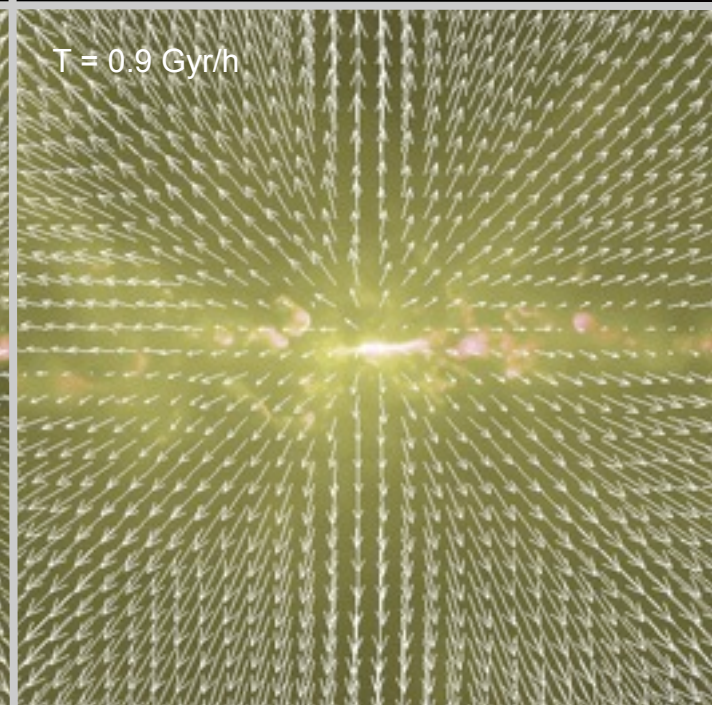
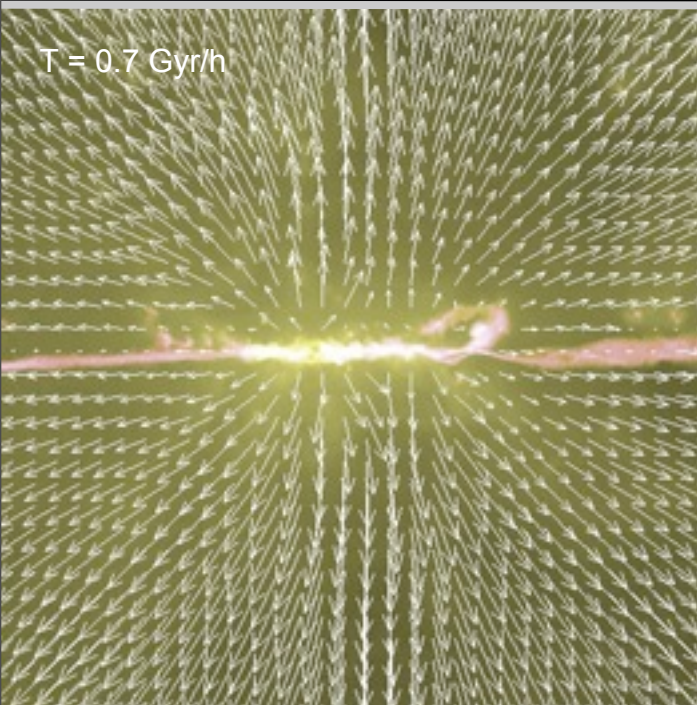
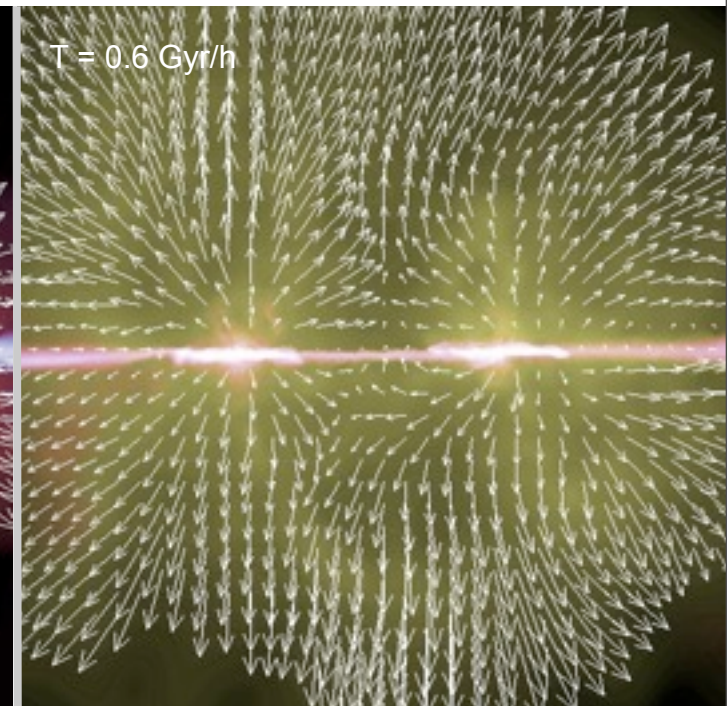
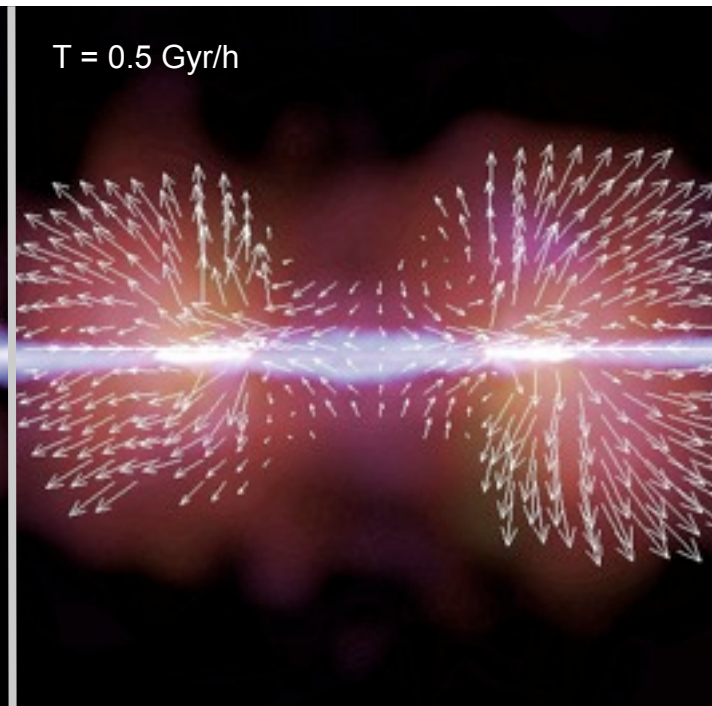
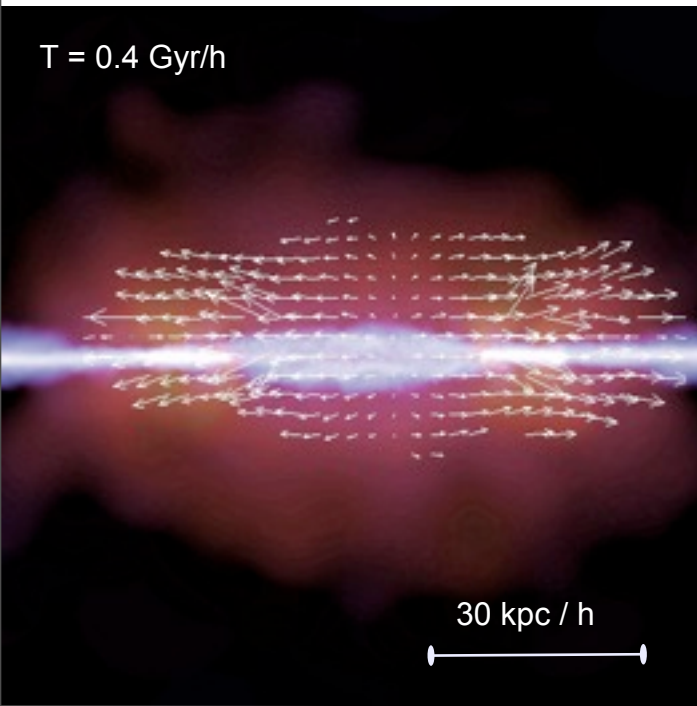
(outflow reaches speeds of up to ~ 1800 km/sec)



Where Does the Energy/Momentum Go?

QUASAR-DRIVEN OUTFLOWS?

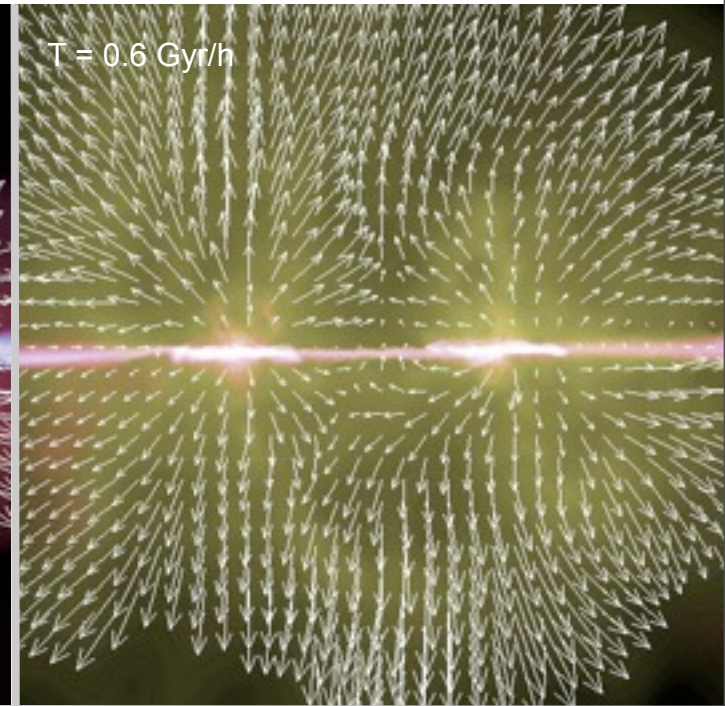
(outflow reaches speeds of up to ~ 1800 km/sec)



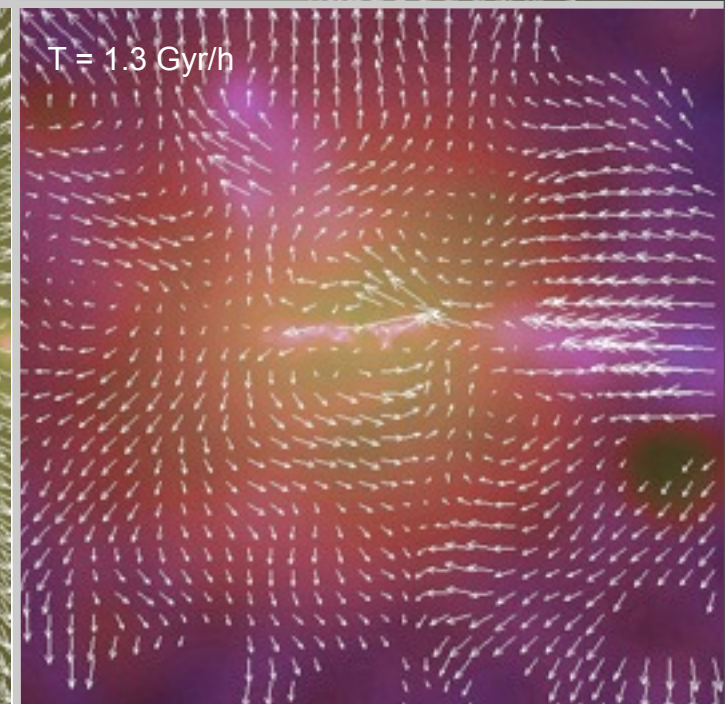
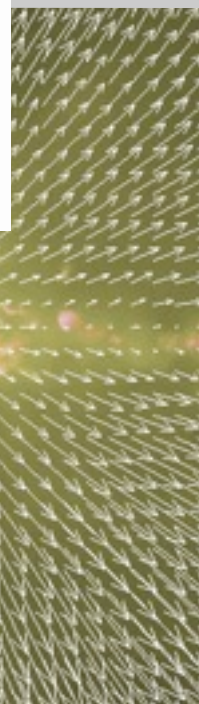
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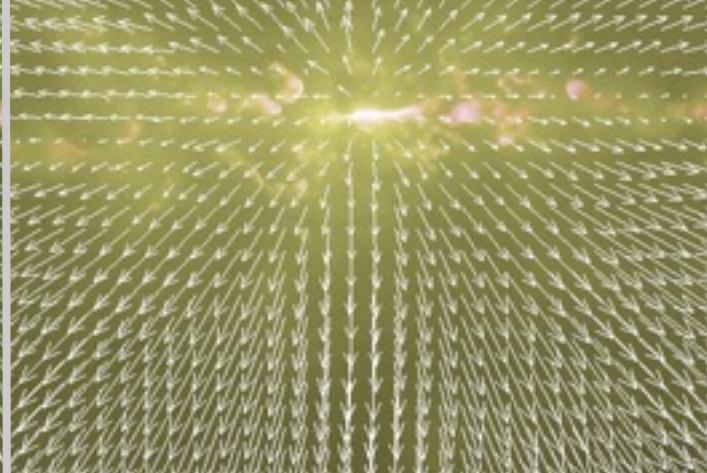
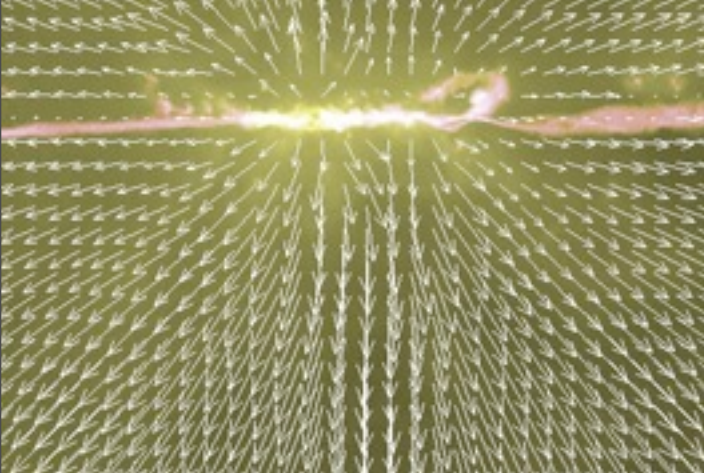
(outflow reaches speeds of up to ~1800 km/sec)



$T = 0.6 \text{ Gyr/h}$



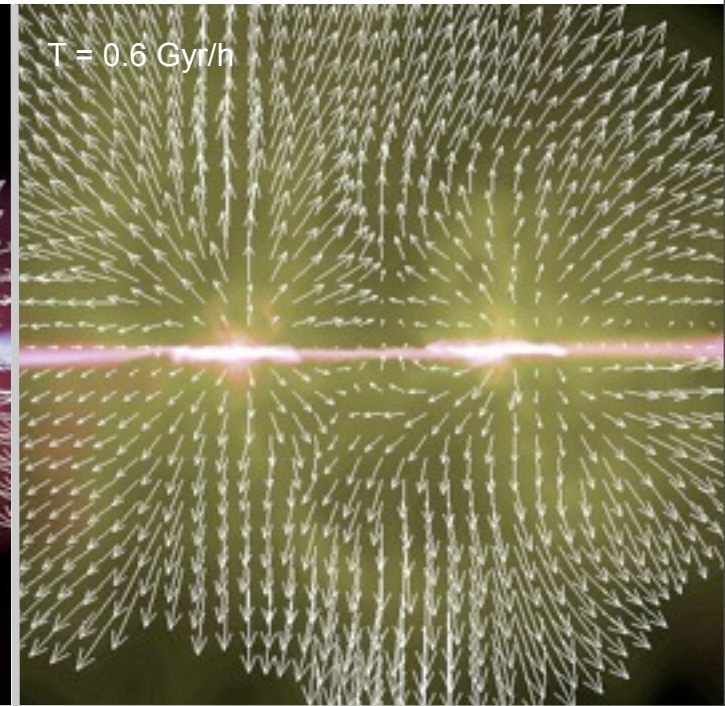
$T = 1.3 \text{ Gyr/h}$



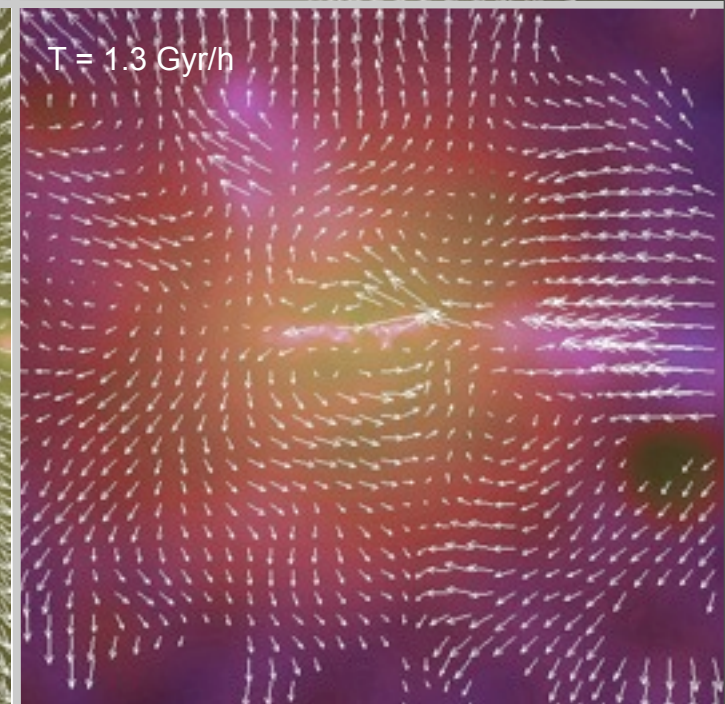
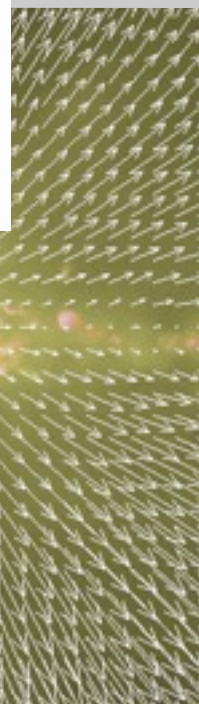
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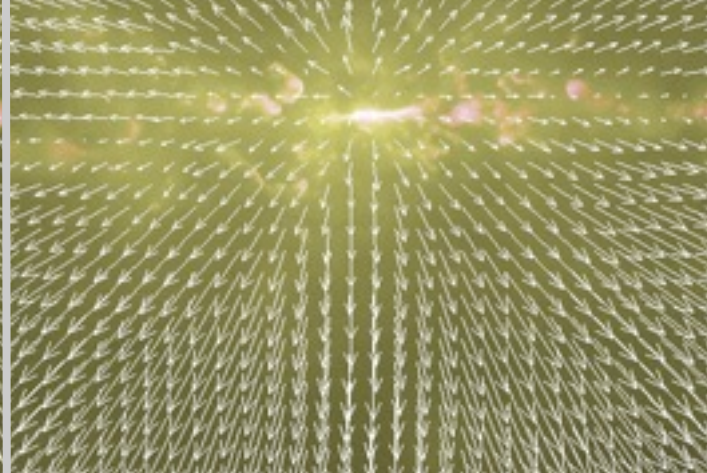
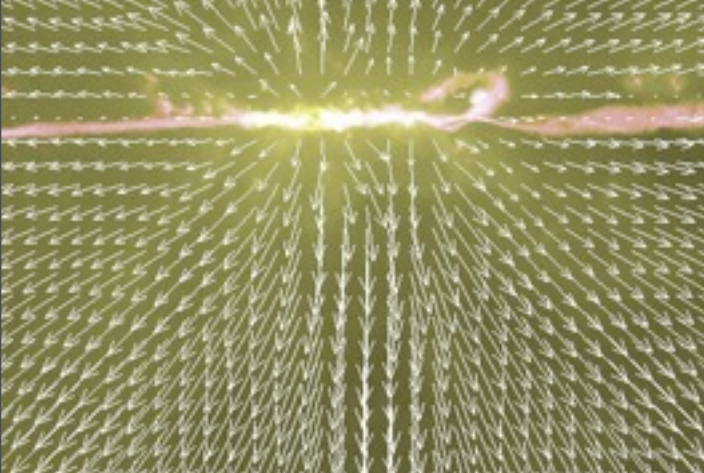
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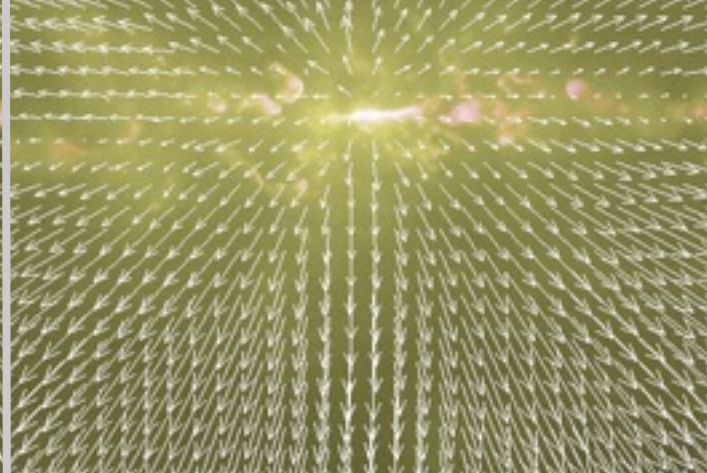
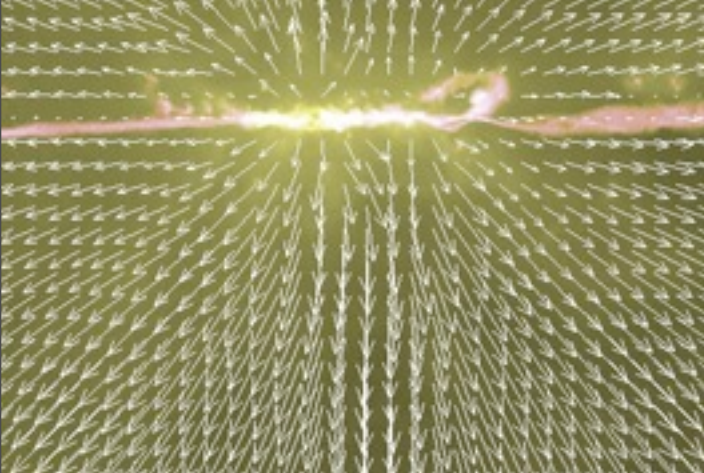
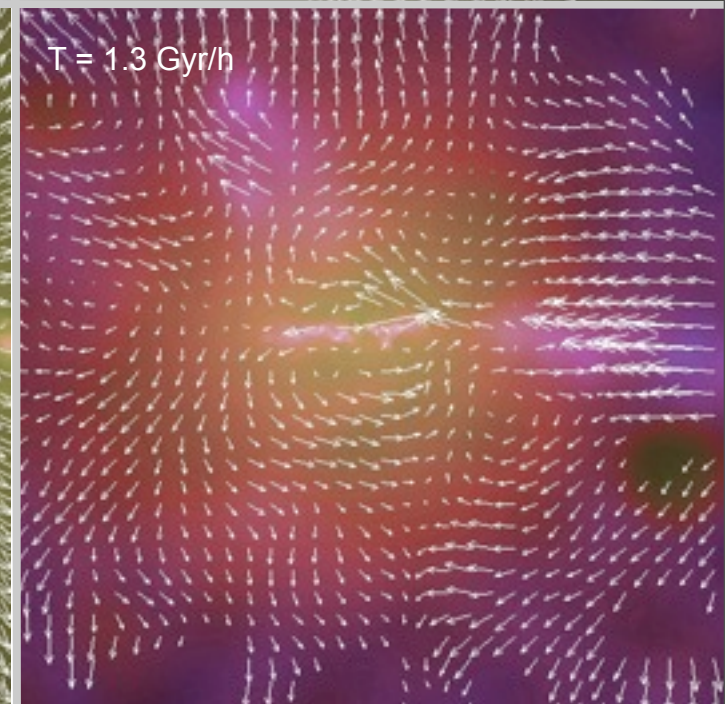
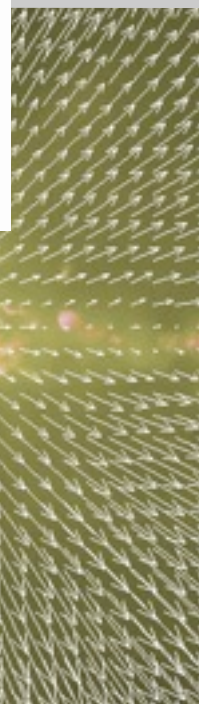
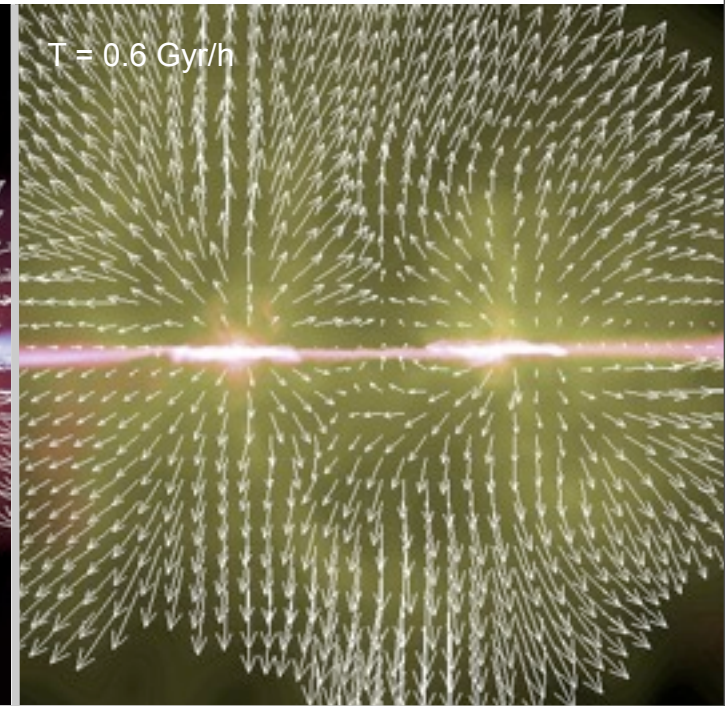
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Where Does the Energy/Momentum Go?

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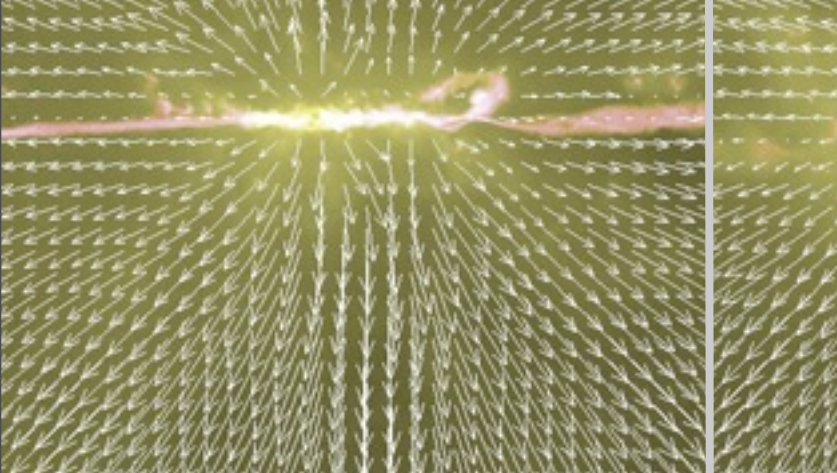
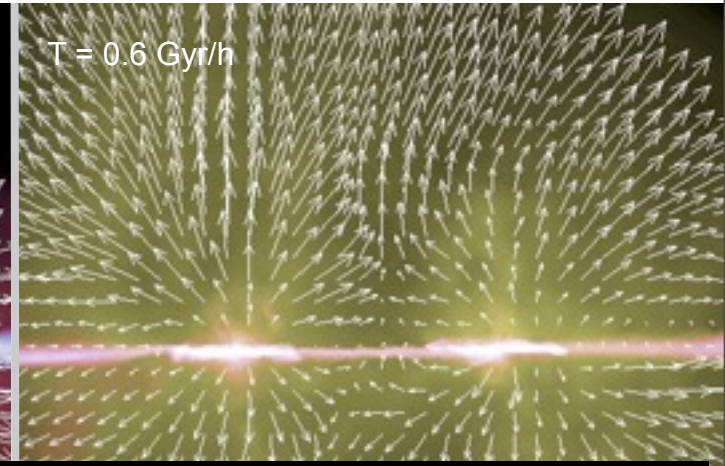
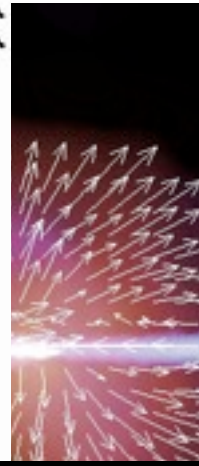
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QUASAR-DRIVEN OUTFLOWS?

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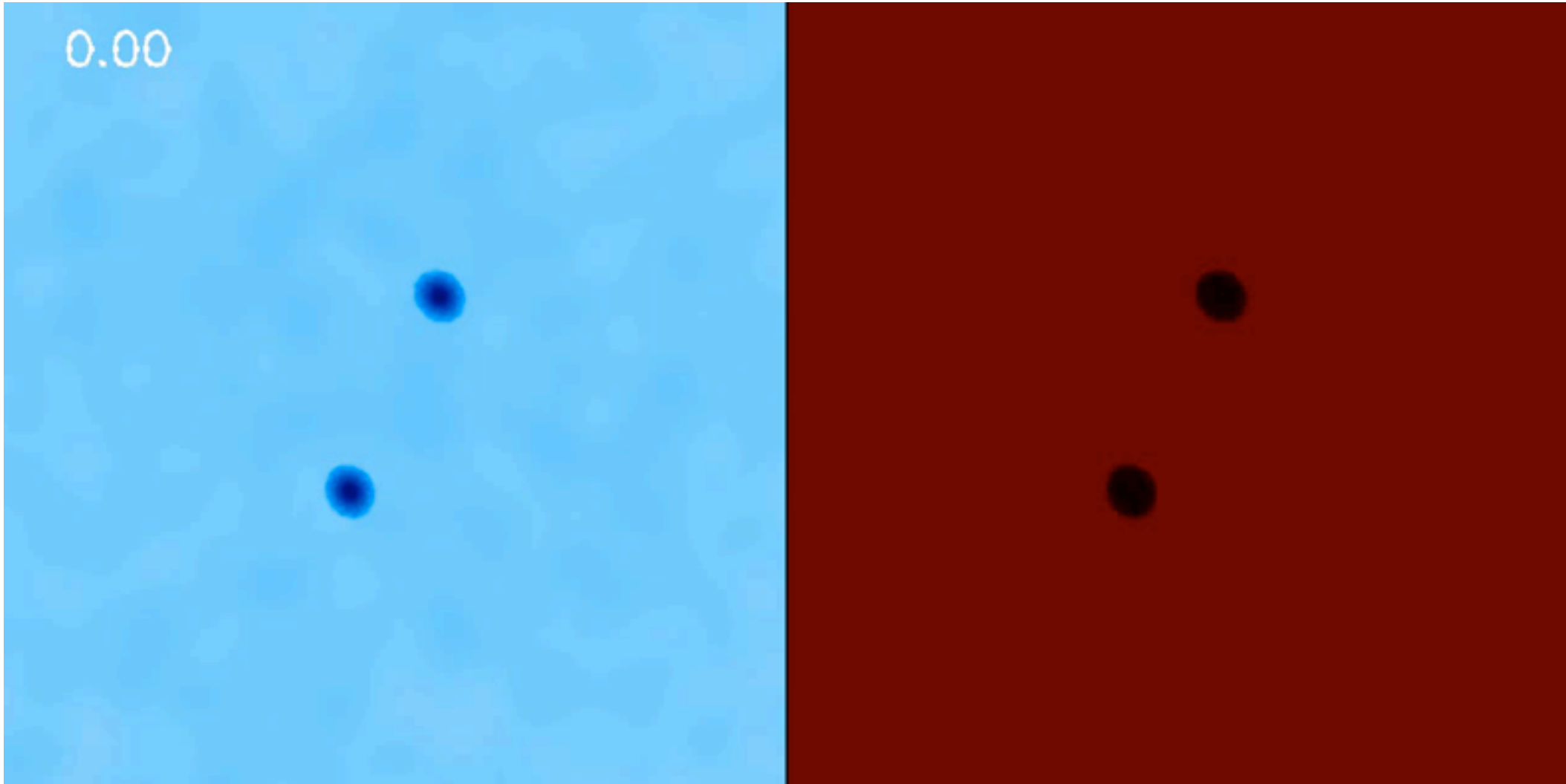
=

Quasar Outflows May Be Significant for the ICM & IGM

THAT FEEDBACK REALLY CLEARS OUT THE PARTY.....

Gas Density

Gas Temperature

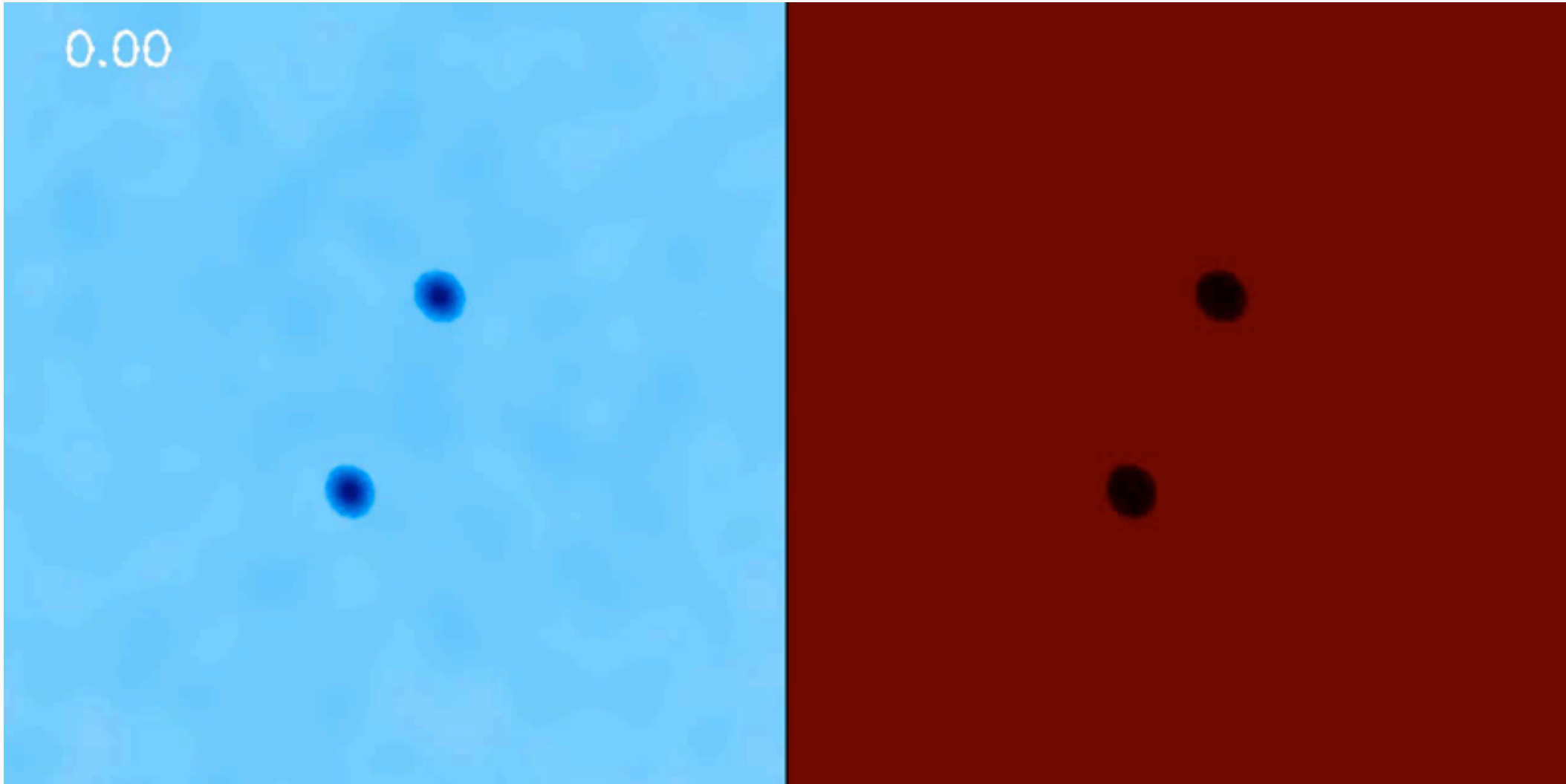


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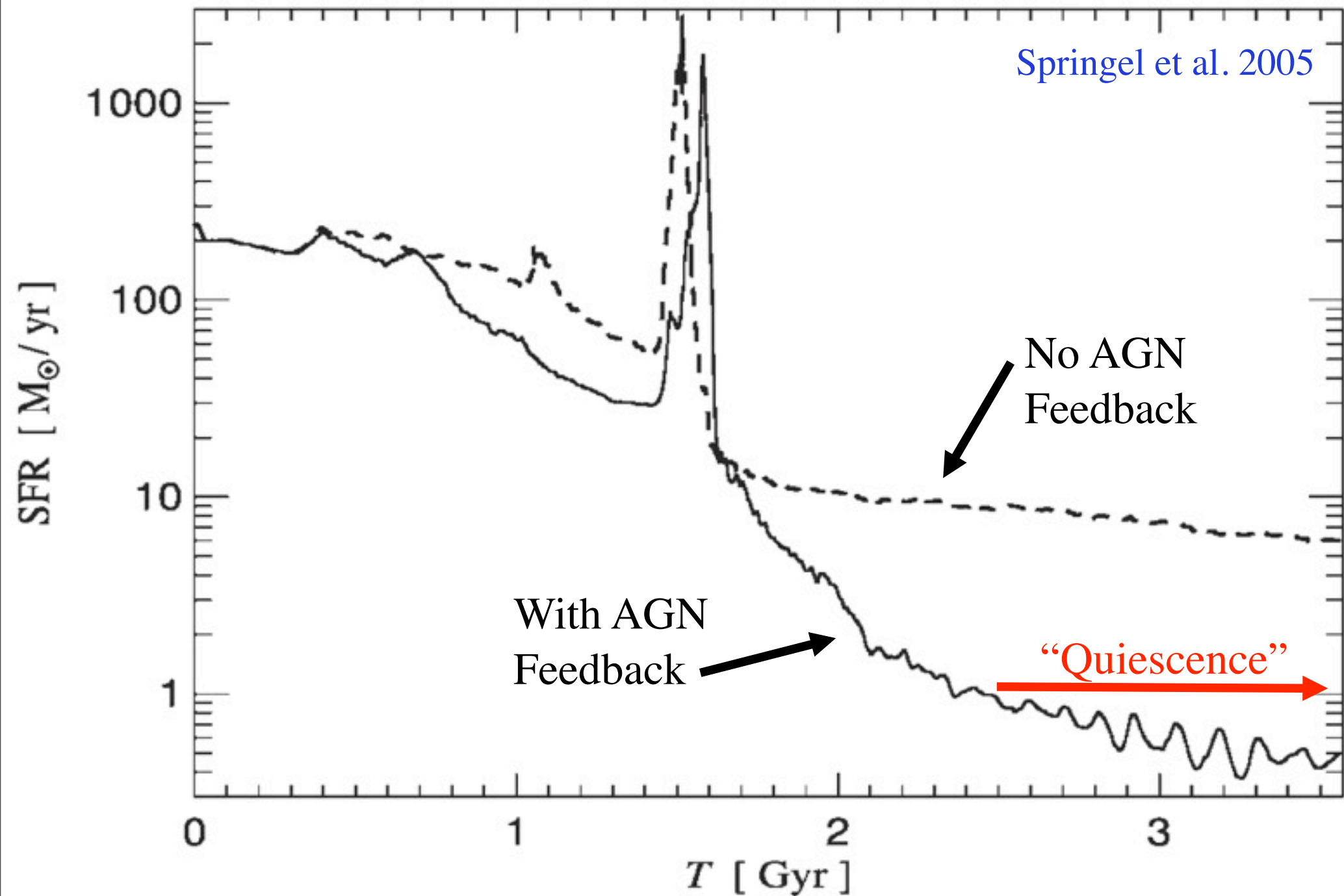
Gas Temperature

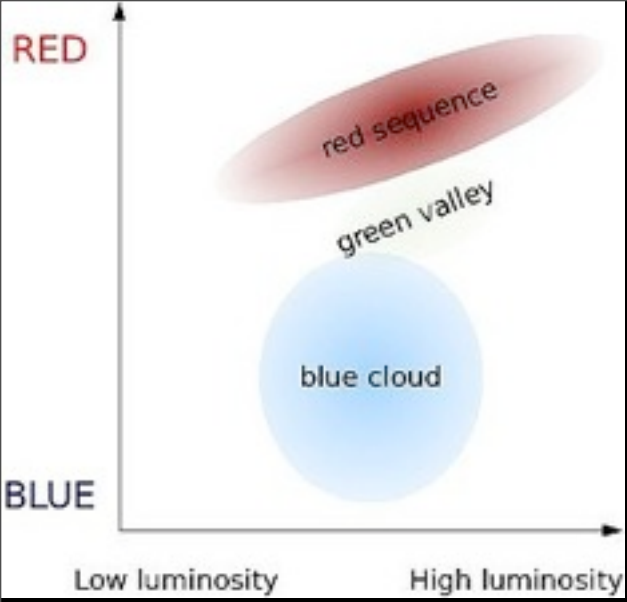


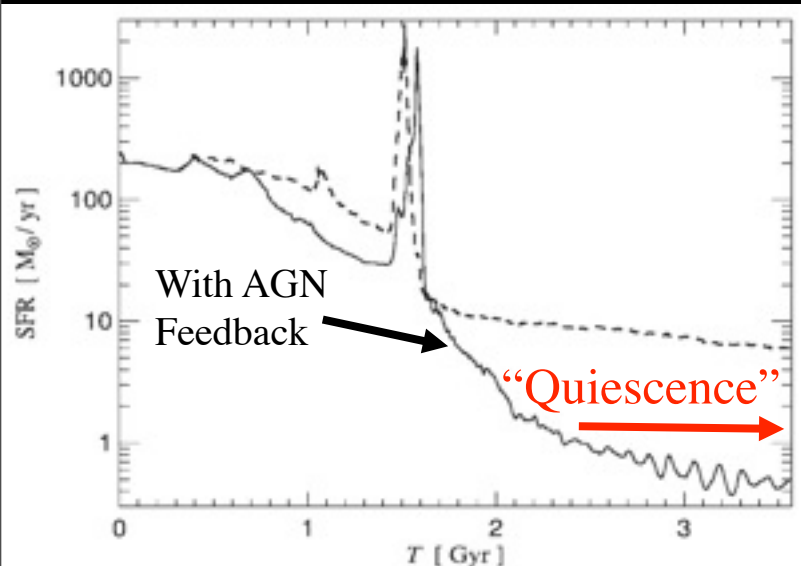
Explosive... yikes

The Post-Tequila Aftermath.....

ENSURES ELLIPTICALS ARE SUFFICIENTLY "RED & DEAD"?



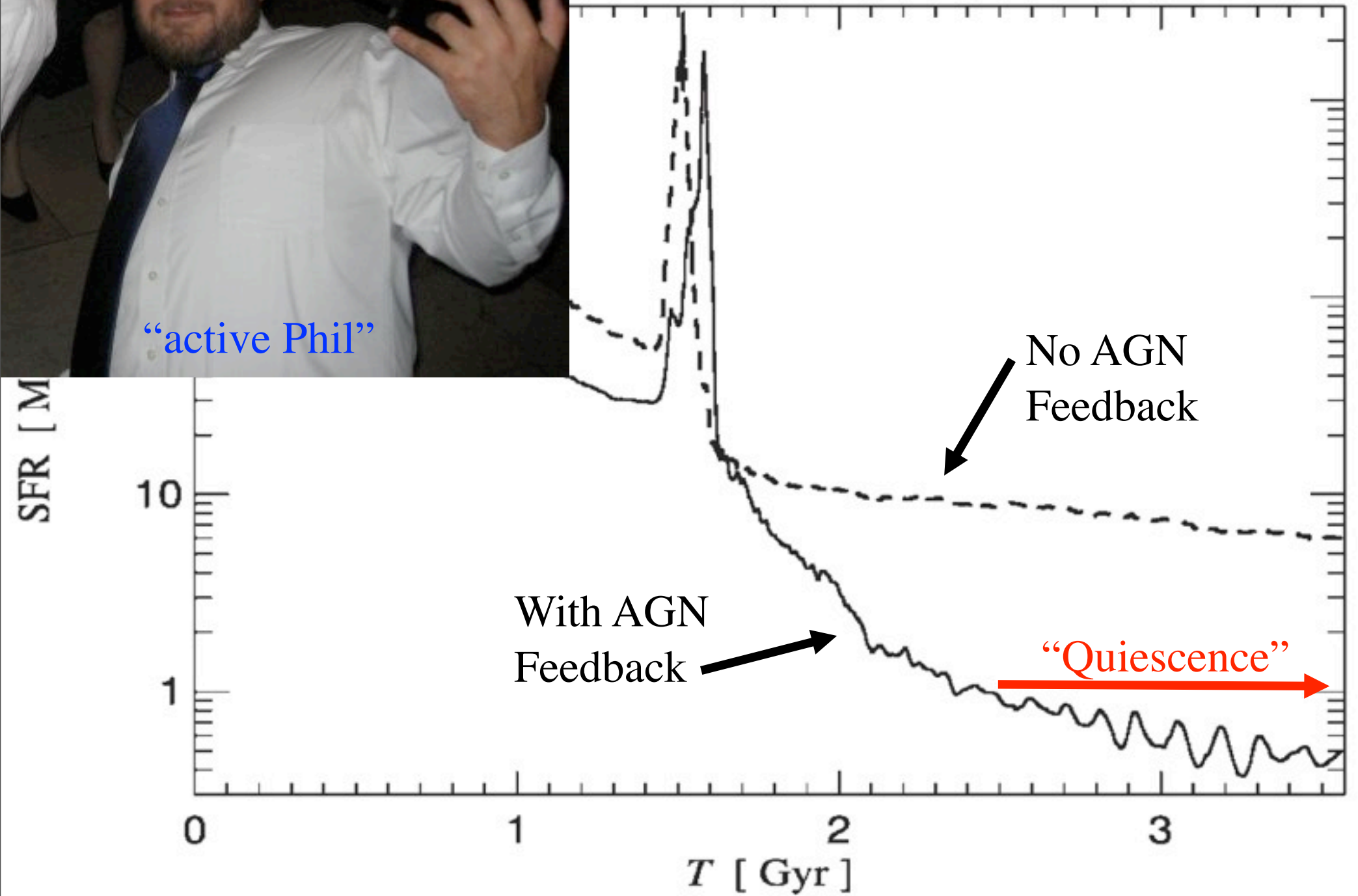






“active Phil”

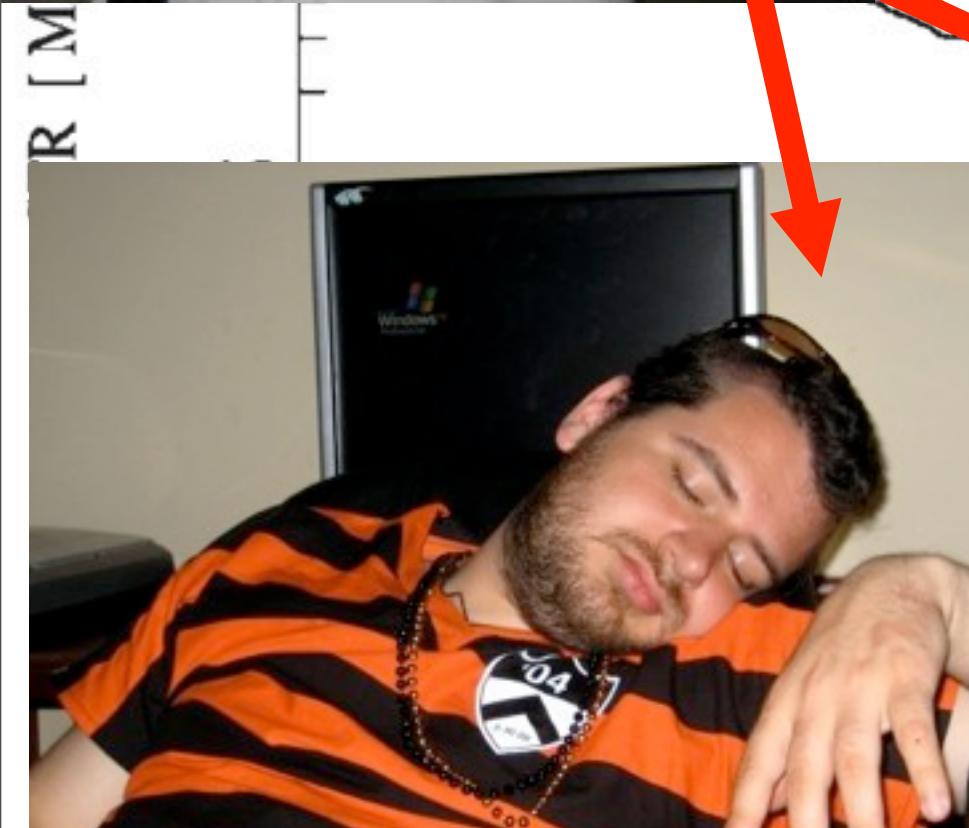
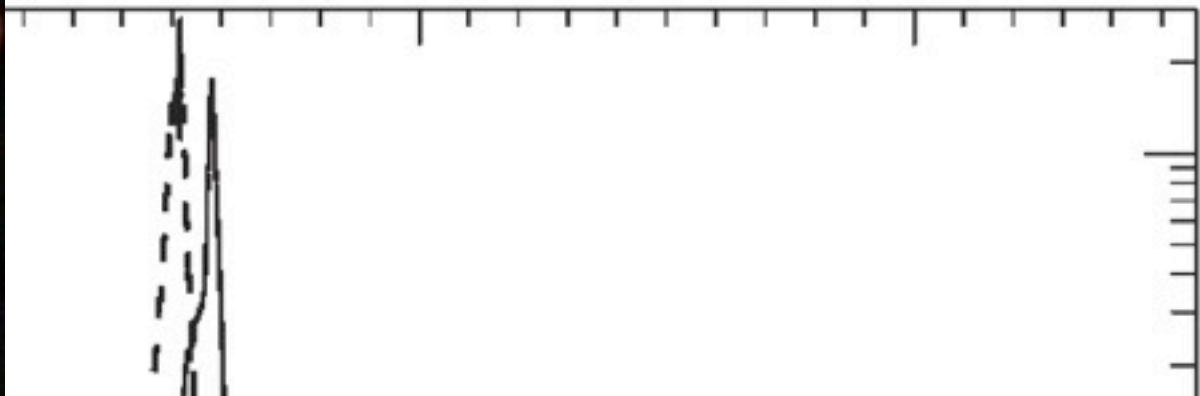
NTLY “RED & DEAD”?





“active Phil”

NTLY “RED & DEAD”?



“quiescent Phil”



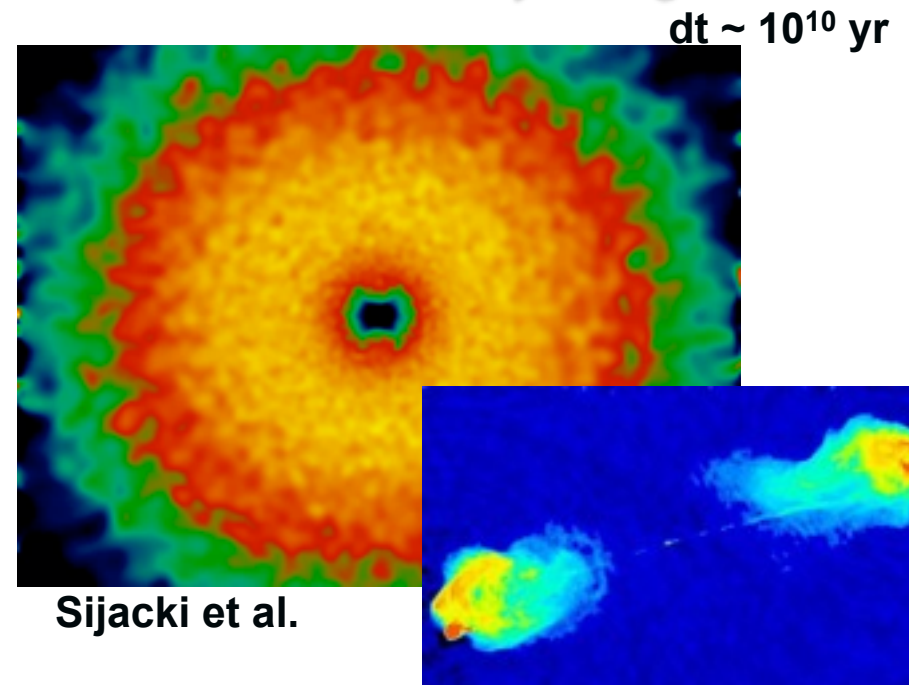
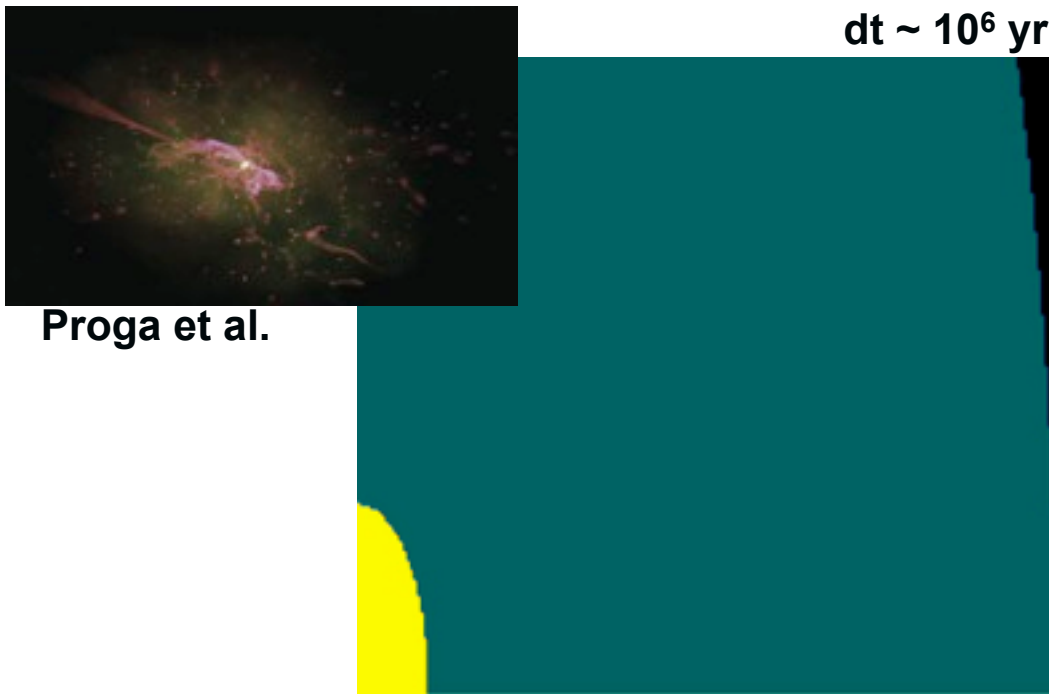
“Transition”

vs.

“Maintenance”

- Move mass from Blue to Red
- Rapid
- Small scales
- “Quasar” mode (high \dot{m})
- Morphological Transformation
- Gas-rich/Dissipational Mergers

- Keep it Red
- Long-lived (~Hubble time)
- Large (~halo) scales
- “Radio” mode (low \dot{m})
- Subtle morphological change
- Hot Halos & Dry Mergers



- Regulates *Black Hole* Mass

- Regulates *Galaxy* Mass

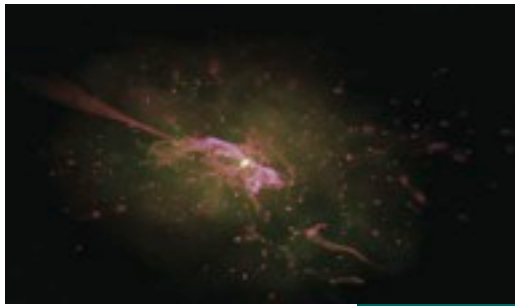
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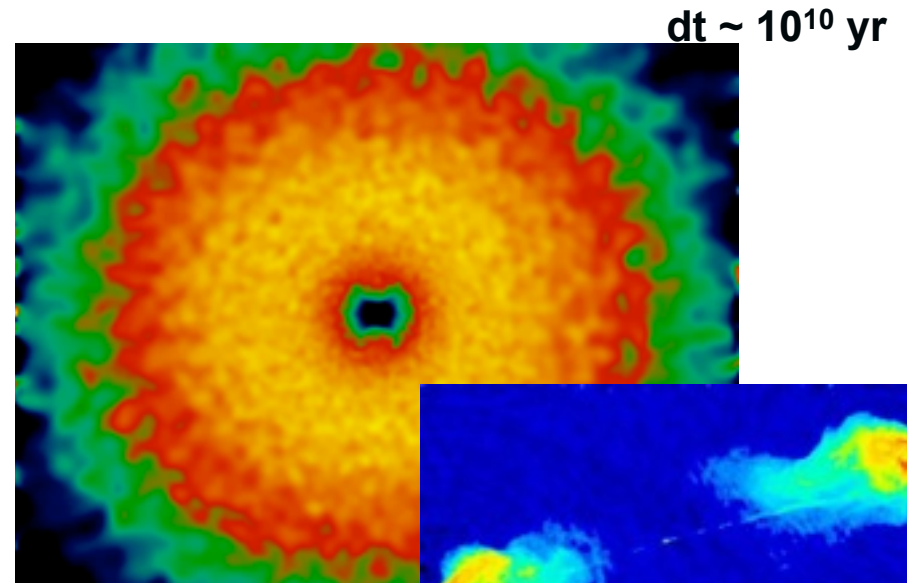
The “violent expulsion of tequila” mode...

The “meh” or “dude, seriously, I can’t have more tequila” mode....



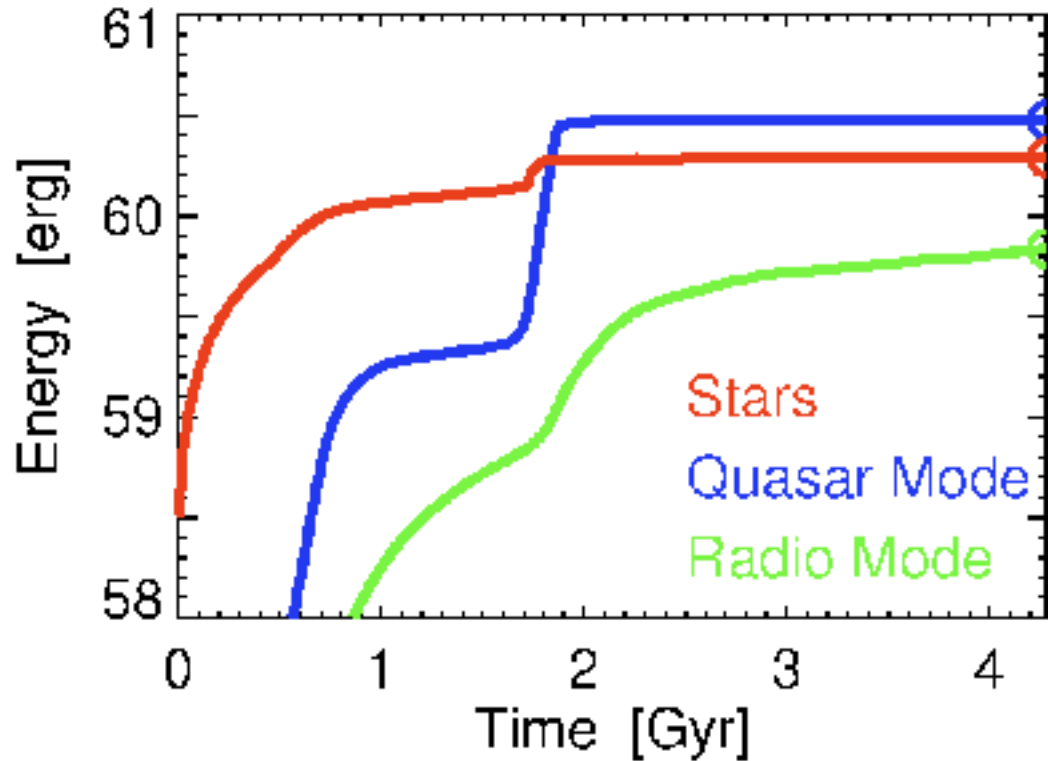
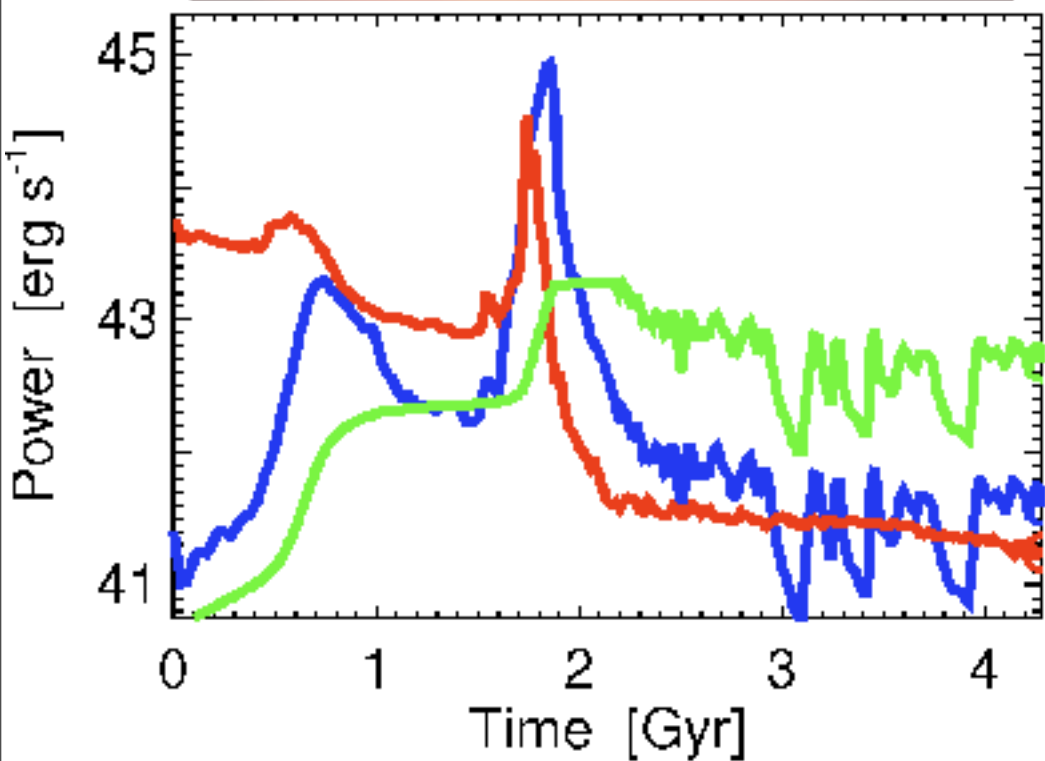
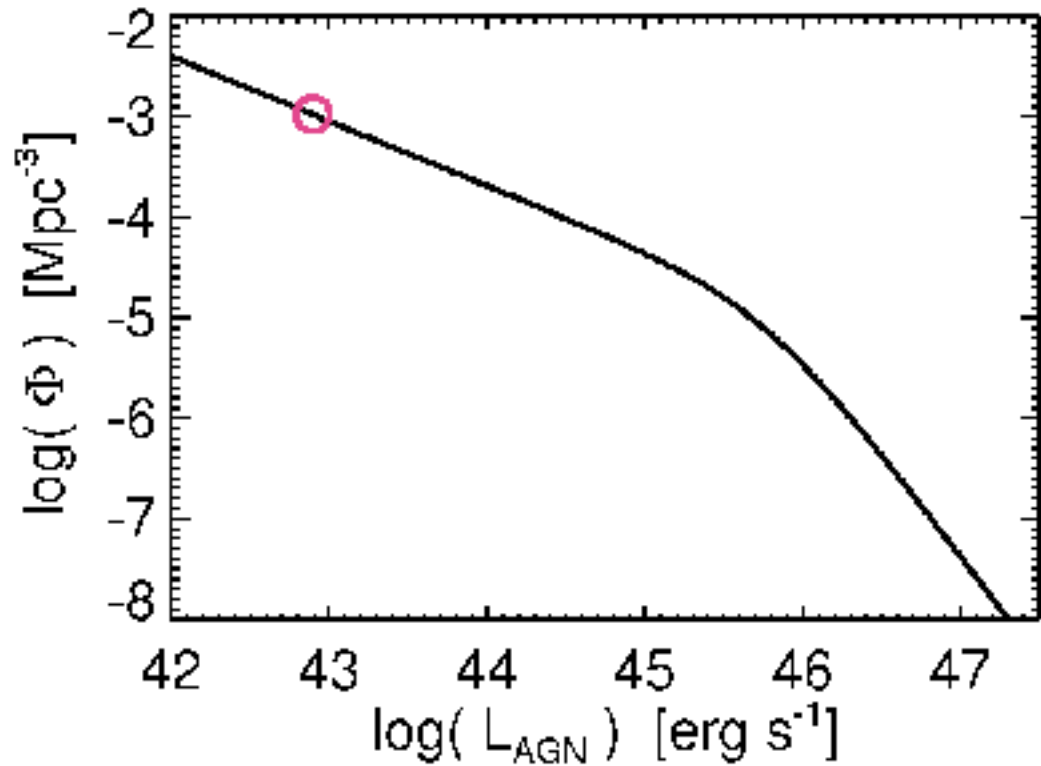
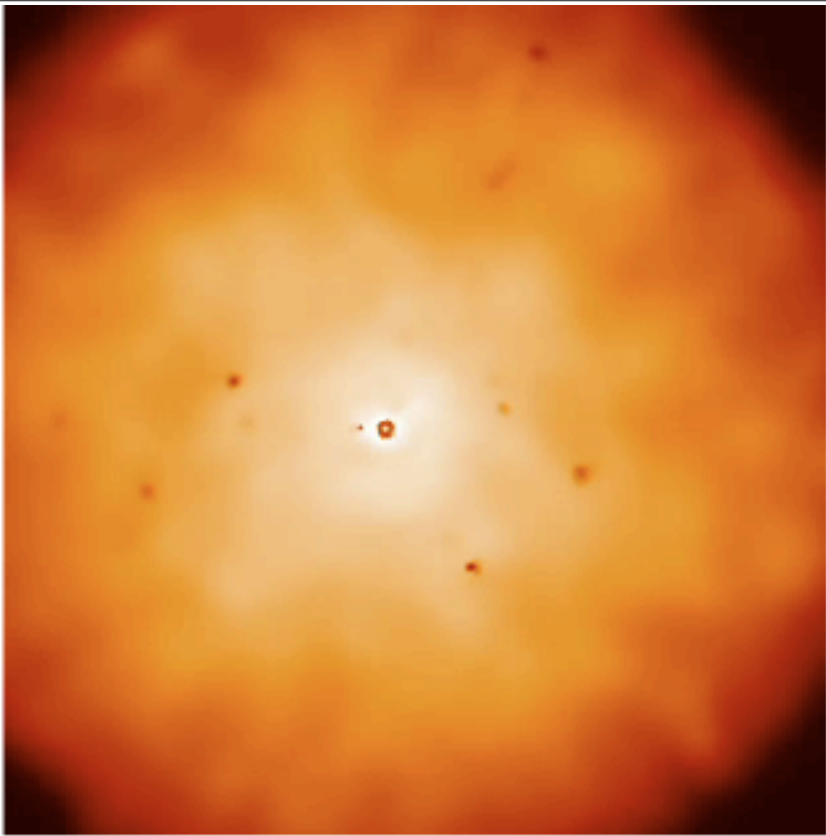
Proga et al.

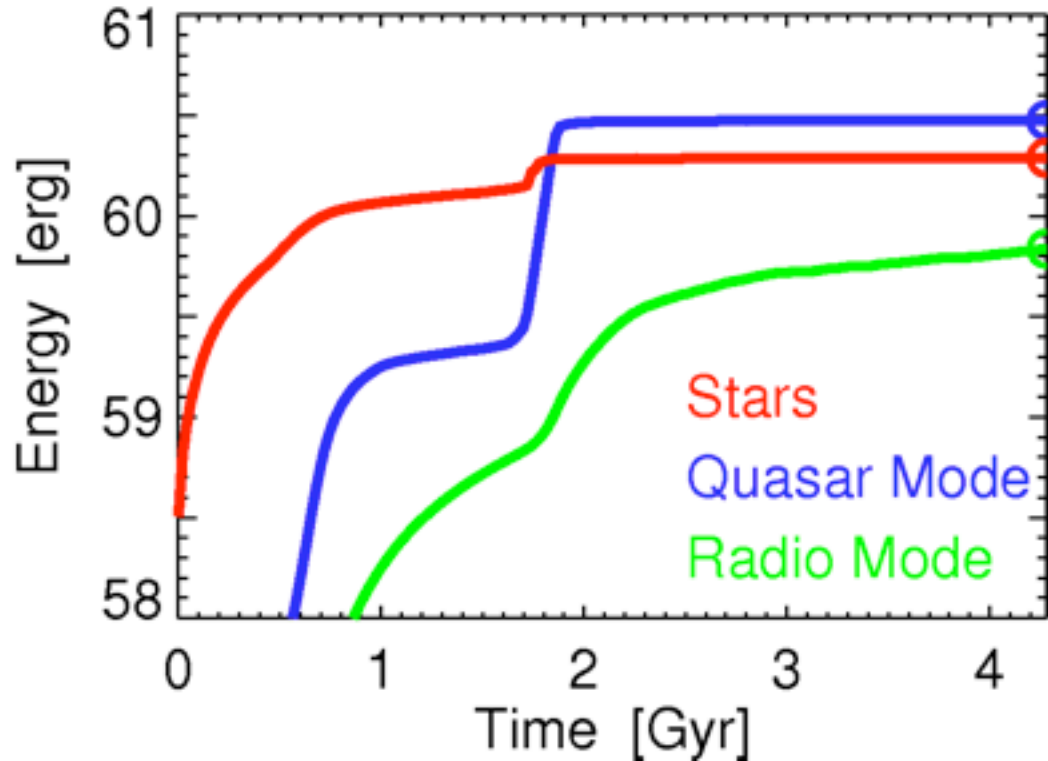
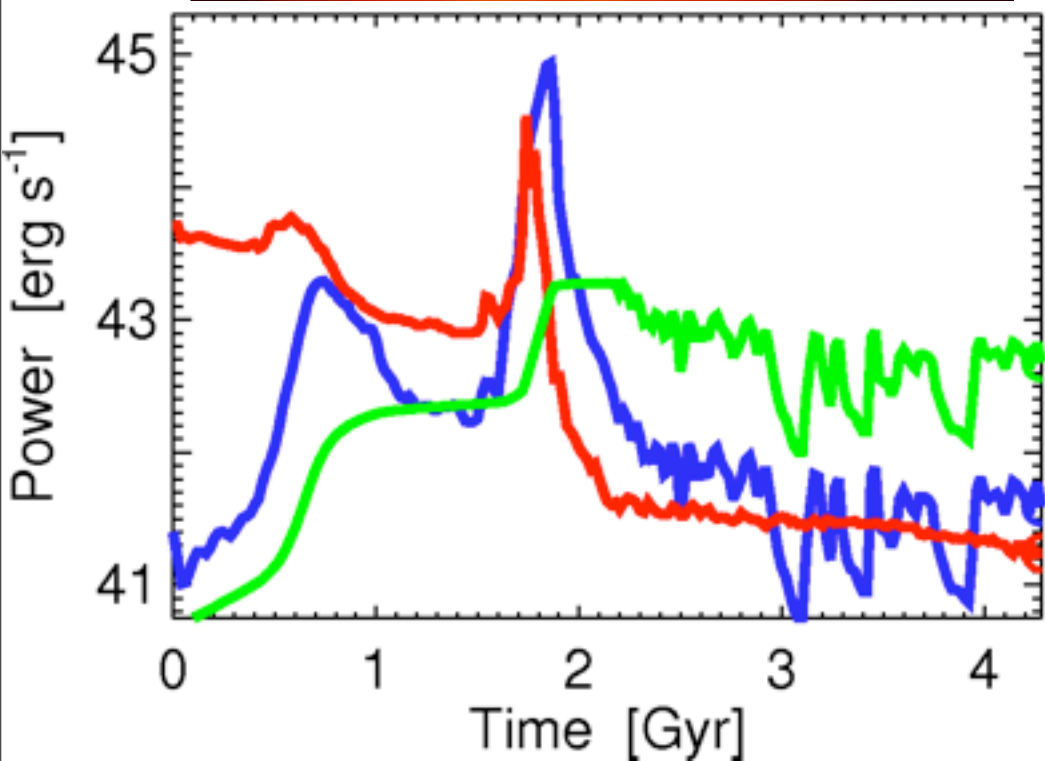
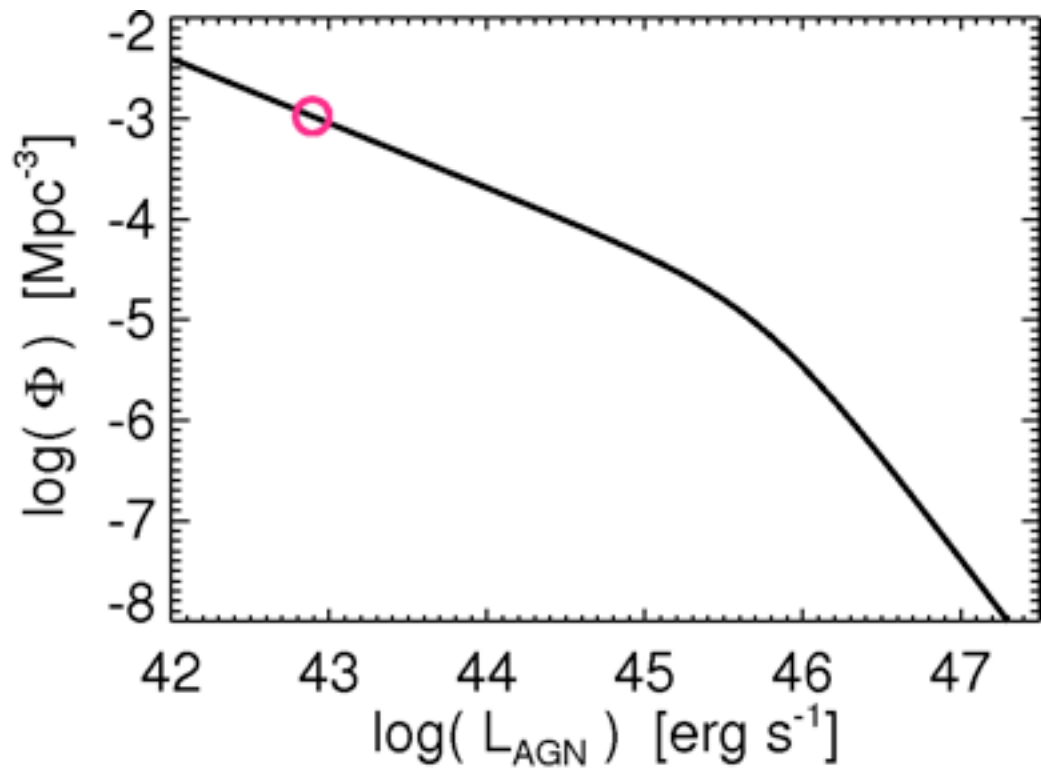
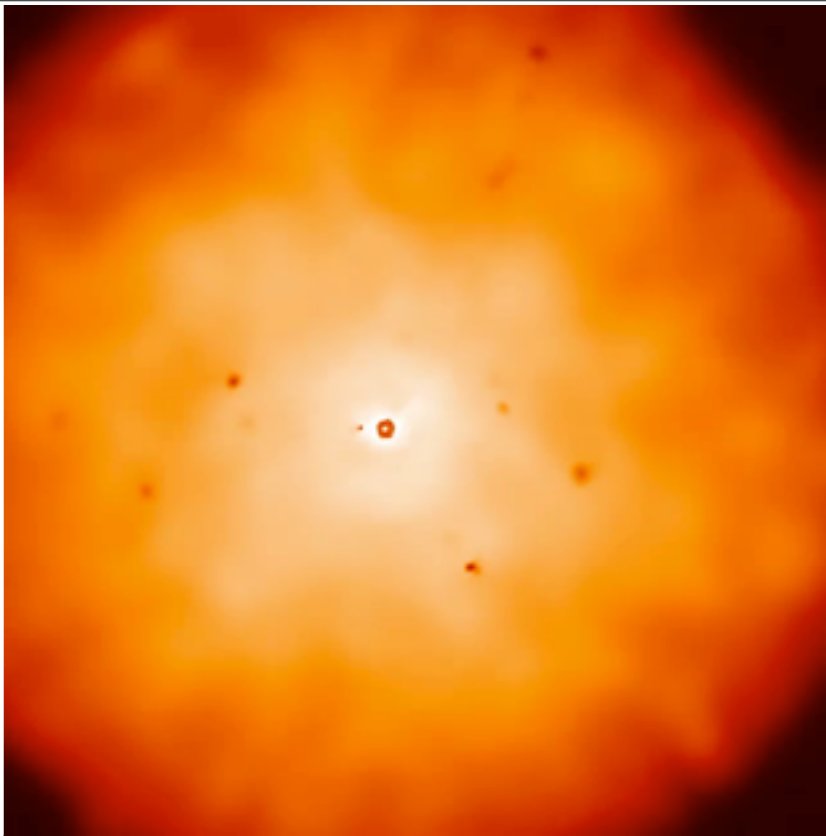
dt ~ 10⁶ yr



dt ~ 10¹⁰ yr

Sijacki et al.





Summary

- Galaxies have interesting lives:
 - Grow rapidly as disks via cold flows (early in the night)
 - Encounter major mergers (belligerent stage)
 - Gas-rich ones preserve the disks (not so bad, just sloppy)
 - Gas-poor ones destroy them (ouch)
 - Gas funnels down, fuels BHs (uh oh, why?)
 - BH feedback has its vengeance (ummm... sorry)
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Summary

Also, I probably drink too much



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