High-redshift massive black holes and AGN

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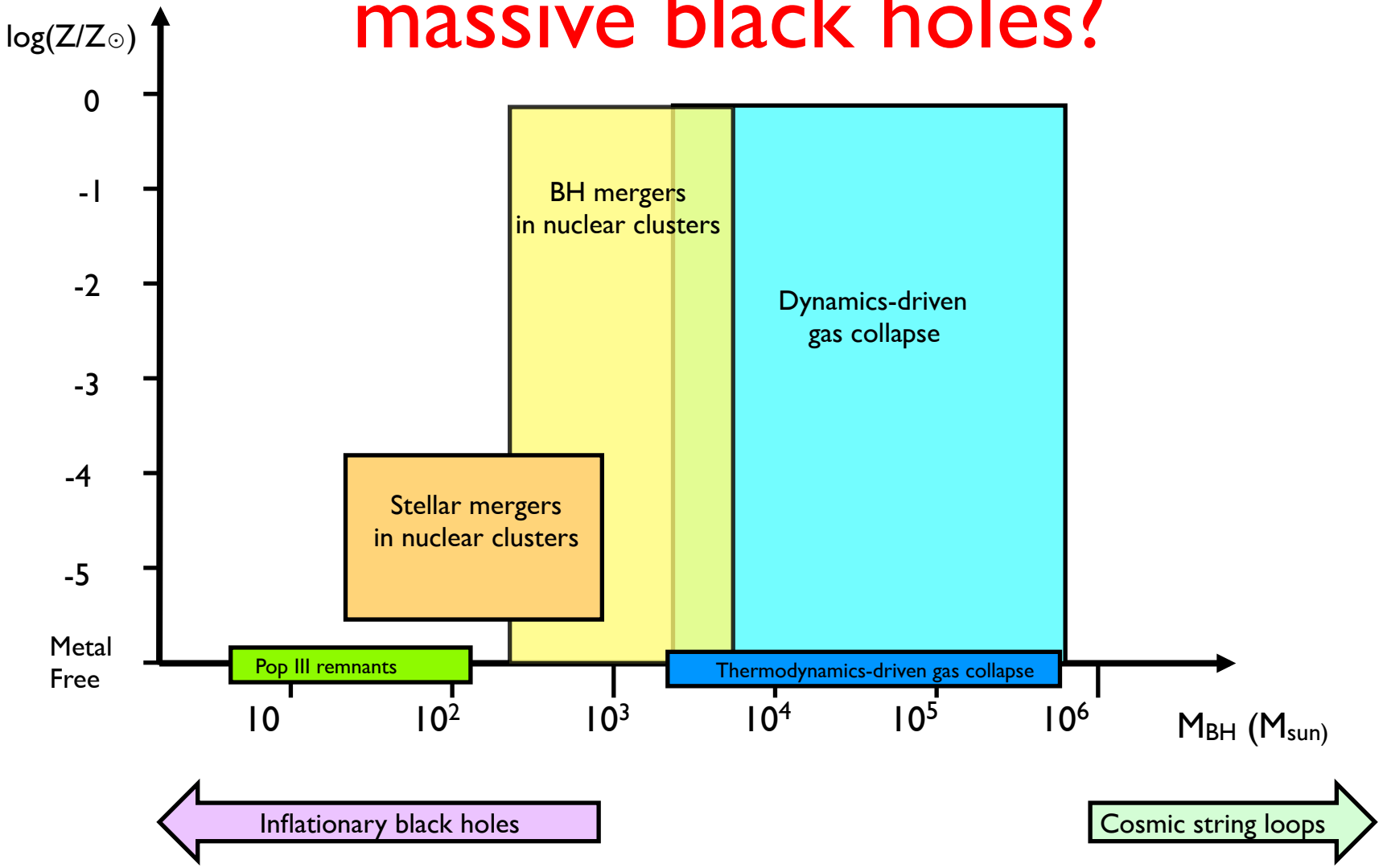
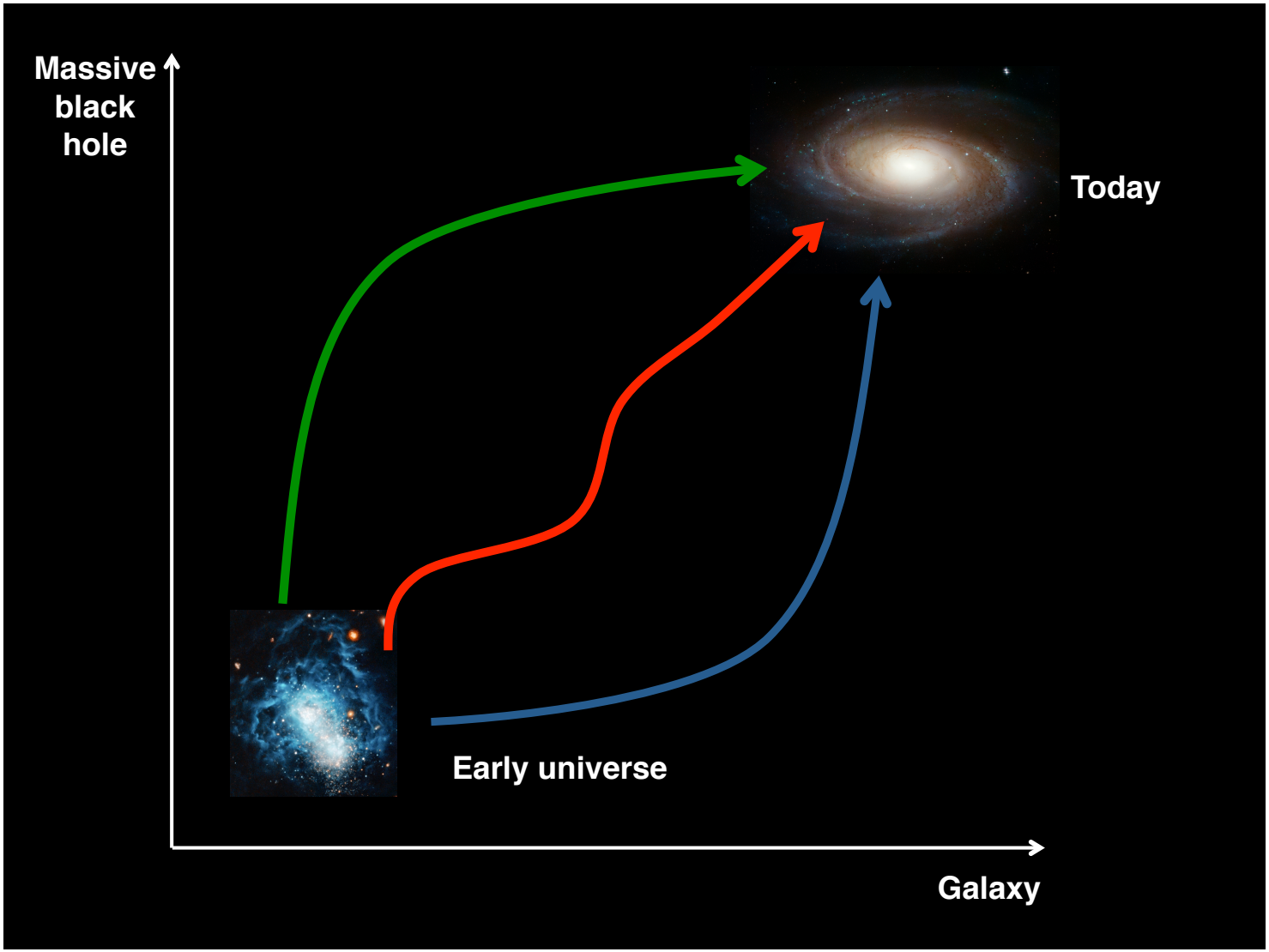
How do black holes grow to become super-massive?

Feeding BHs at high redshift

HOW can you make the first massive black holes?

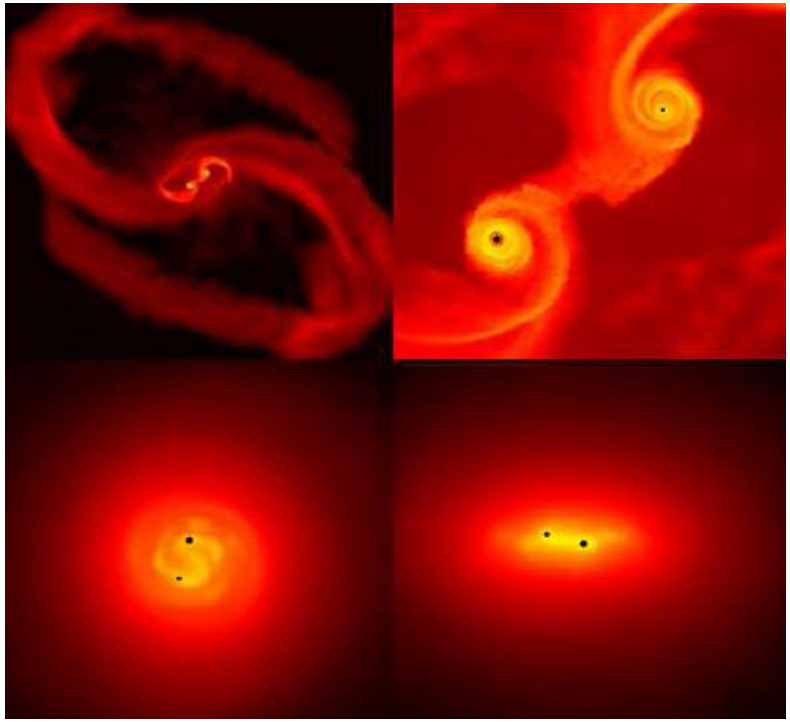


How do the seeds grow?

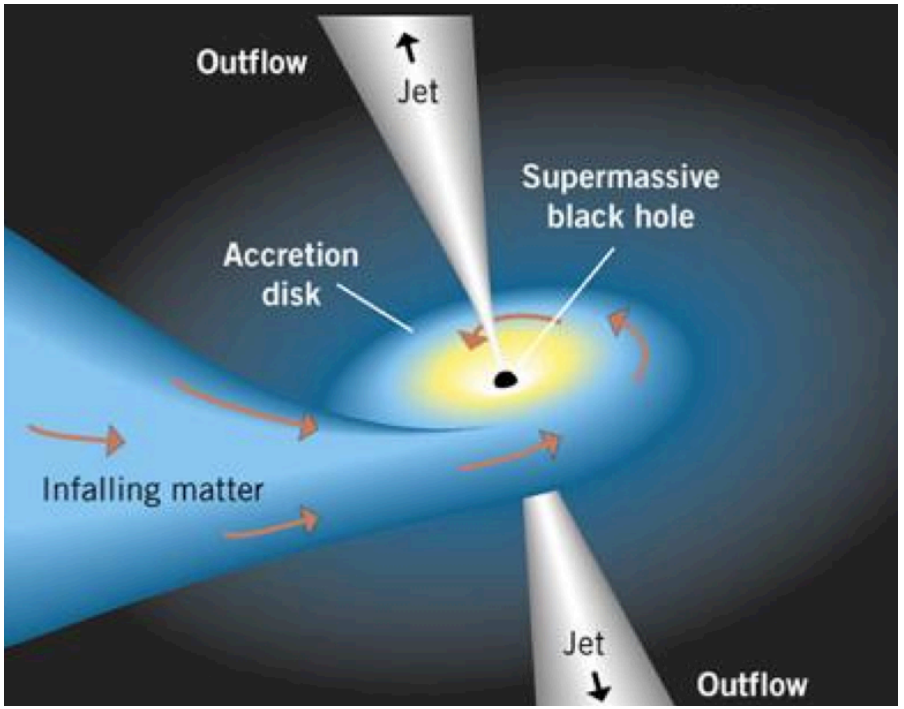


How do MBHs grow?

MBH-MBH mergers vs gas accretion



Total mass density in MBHs is constant in time: just reshuffle the mass function



Total mass density in MBHs grows with time

How do MBHs grow?

Soltan's argument: integral over the LF of quasars

$$L = \epsilon \dot{M}_{in} c^2$$

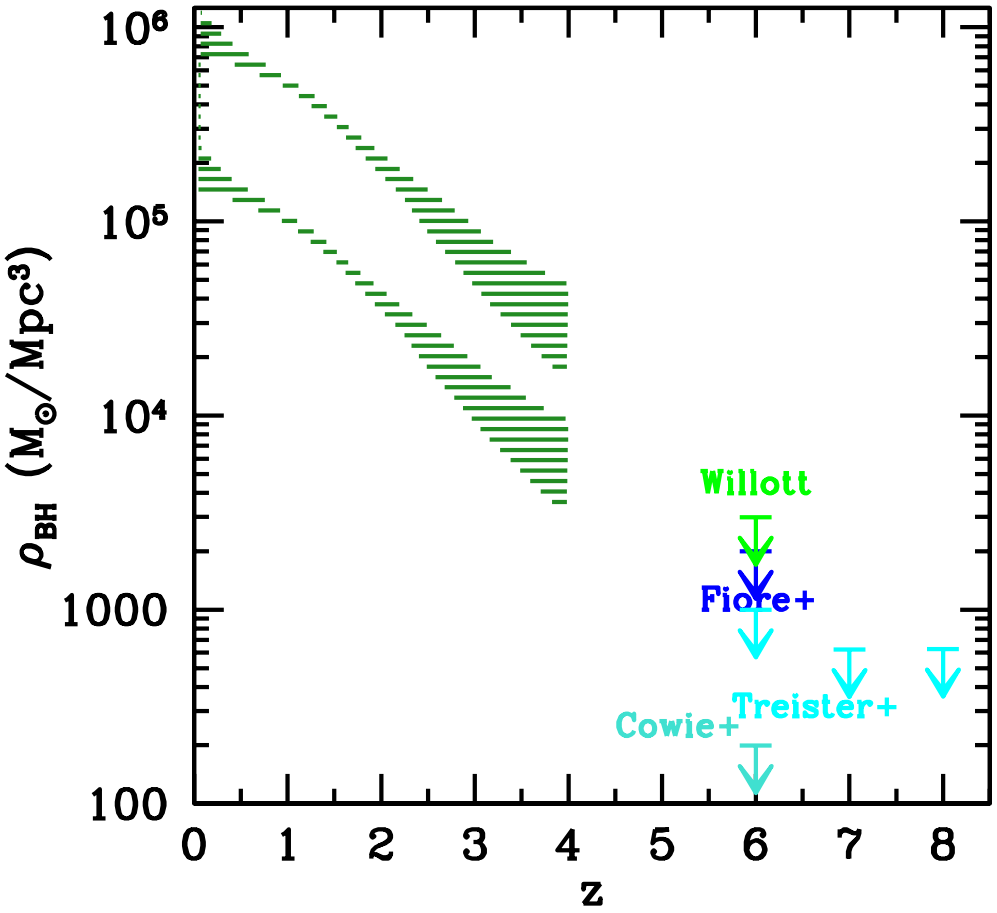
A fraction ε of mass goes into radiation

Soltan's argument

$$\Phi(L) = \frac{dN}{dLdV}$$

Luminosity function of quasars/ AGN

Soltan's argument

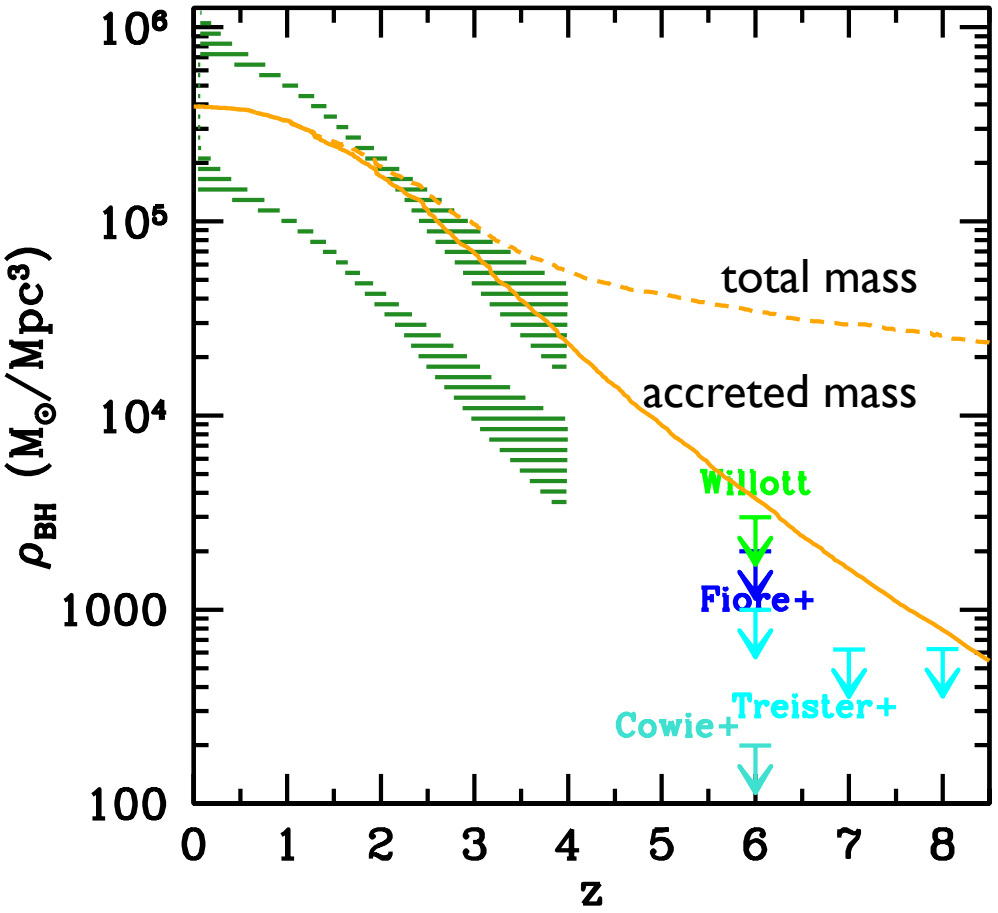


Mergers: total mass density in MBHs is constant in time

Accretion: total mass density in MBHs grows with time

mass density increases by > one order of magnitude in the last ~10 Gyr: **accretion** leads

Soltan's argument



Soltan's argument: measures mass accreted by AGN

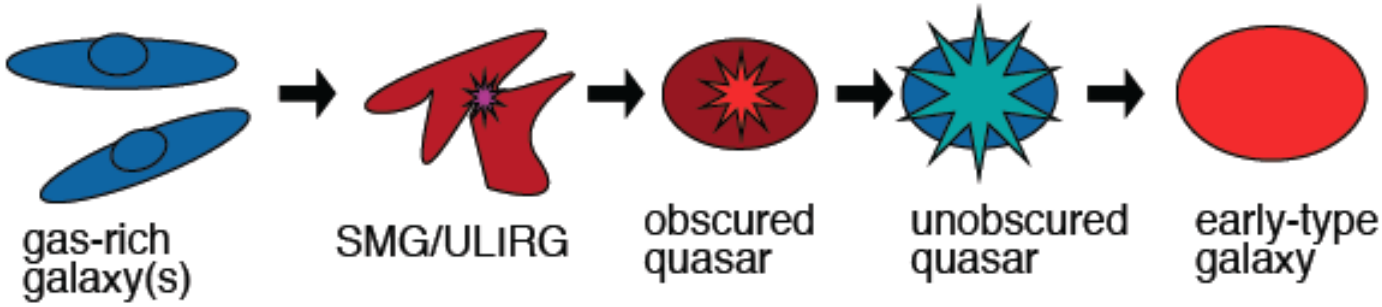
Not all MBHs are AGN: the total mass density may be higher, quiescent MBHs are not included (also obscured AGN are unaccounted for – ask A. Comastri!)

What triggers AGN activity and MBH growth?

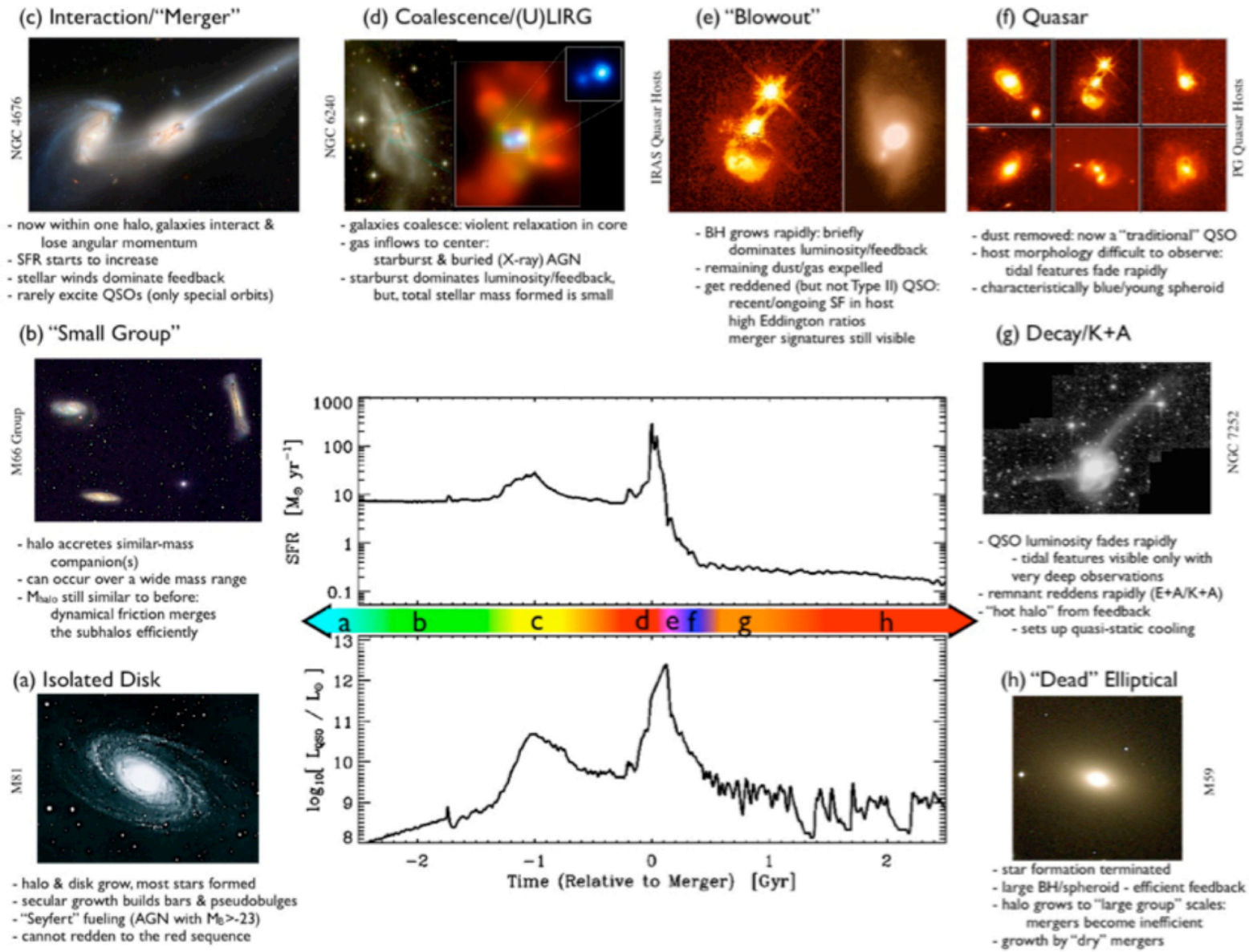
- Galaxy mergers
- Cold flows
- Secular instabilities
- Clumpy discs

Galaxy mergers

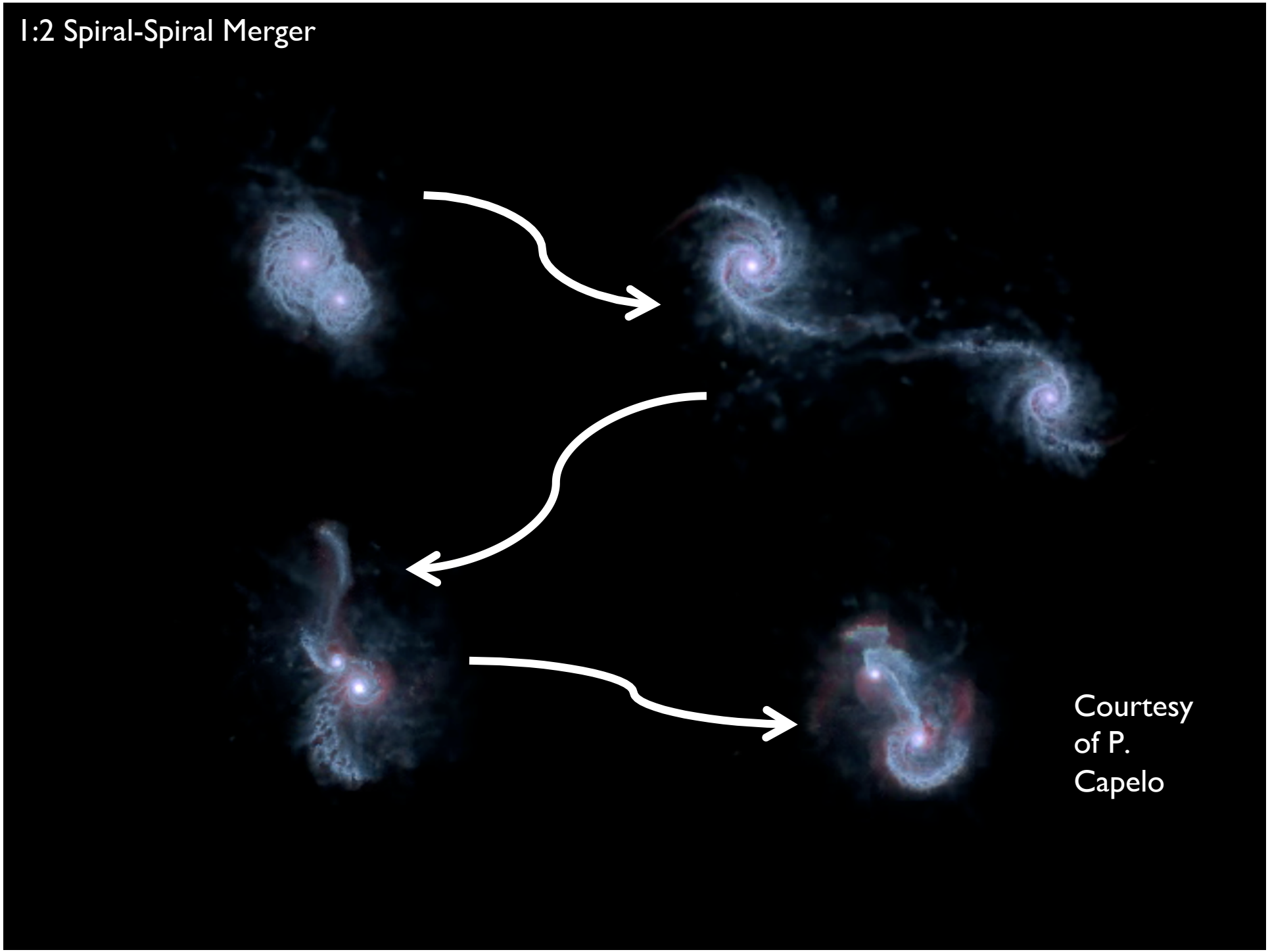
- Dynamical torques trigger strong inflows of low angular momentum gas that cause high levels of activity: “quasars”



Sanders 1988 via Alexander & Hickox 2012

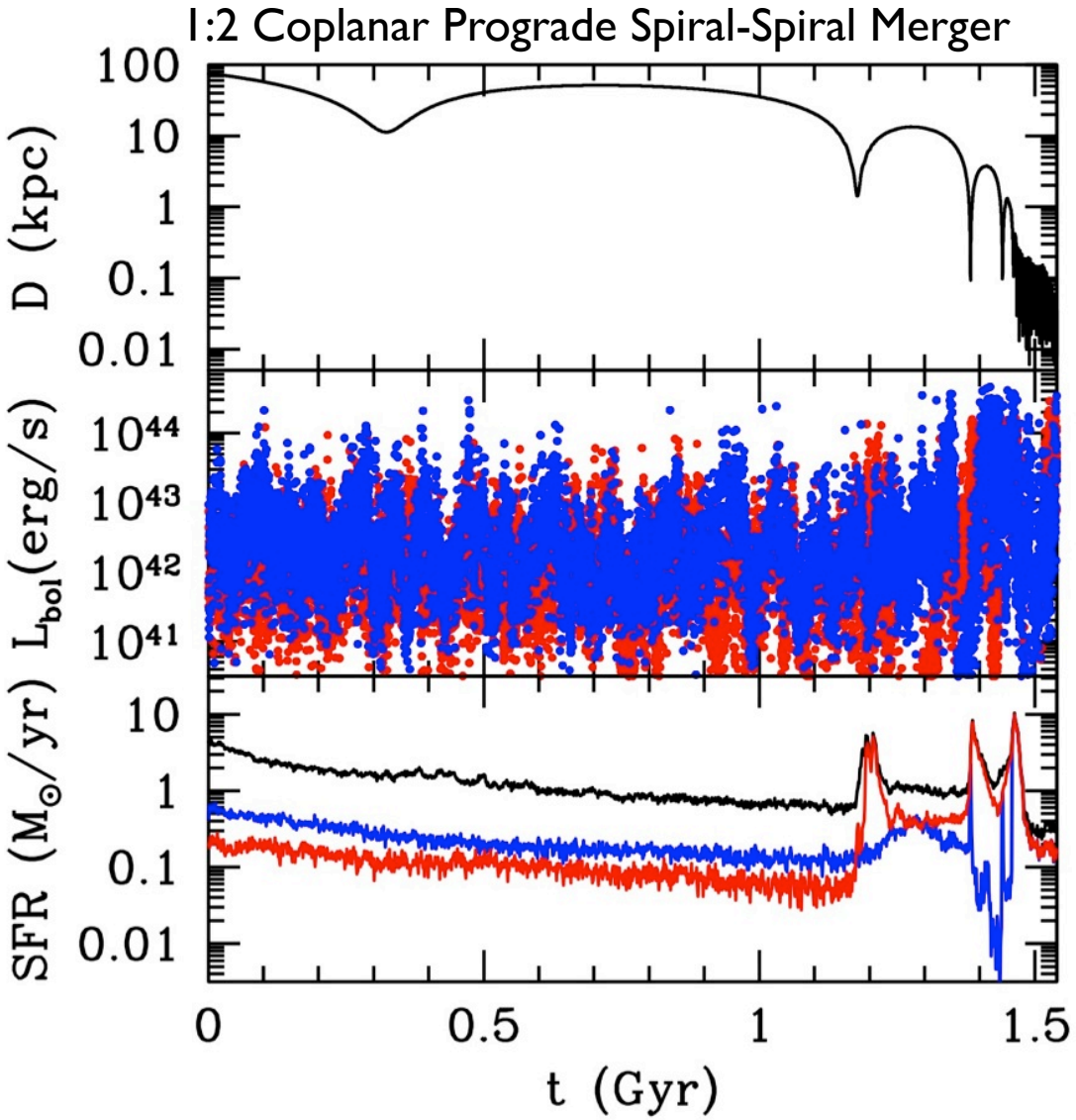


Hopkins et al. (2006+)


1:2 Spiral-Spiral Merger
Courtesy of P. Capelo

Major mergers

- Tidal forces trigger gas inflows and angular momentum loss in both galaxies
- Star formation rates and AGN activity peak following pericenter passages



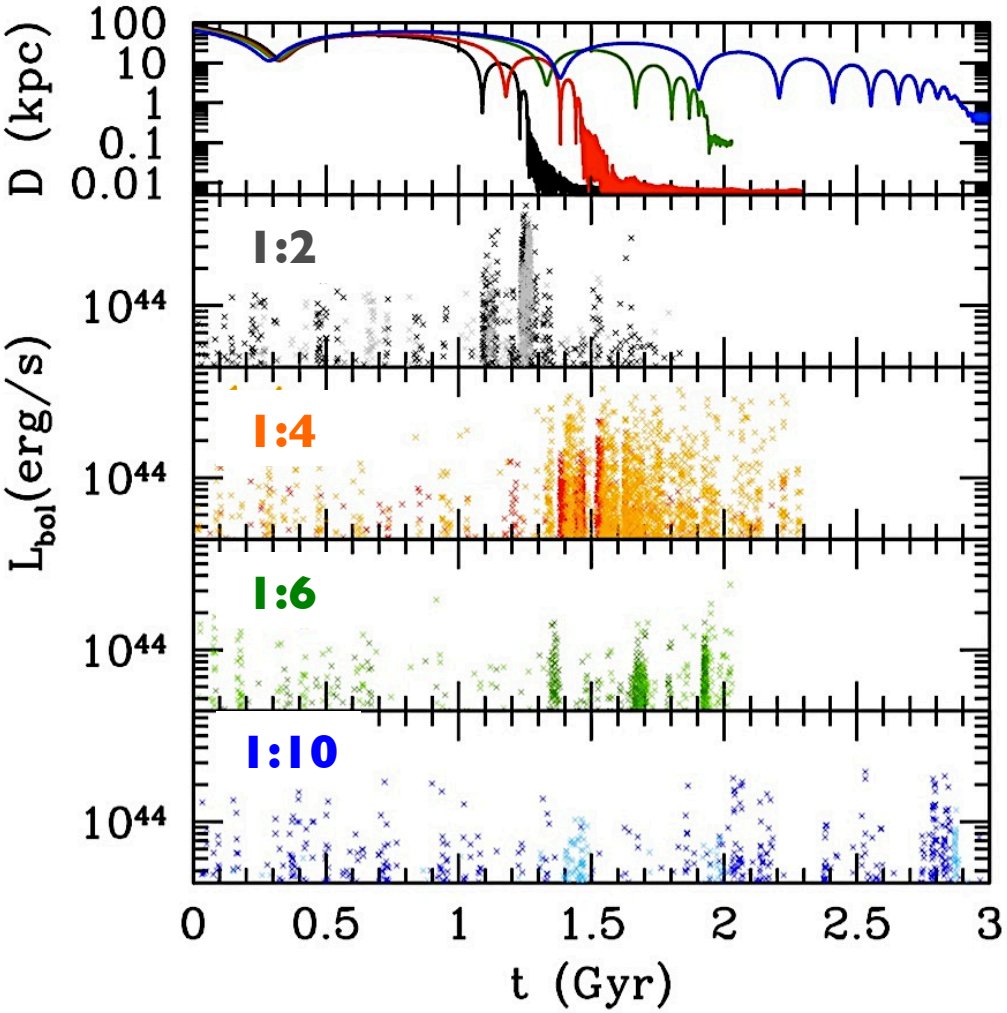
Minor mergers

- Ram pressure depletes the small galaxy of gas, and it is eventually disrupted in 1:6 and 1:10 mergers

- The large galaxy does not even notice it's in a merger

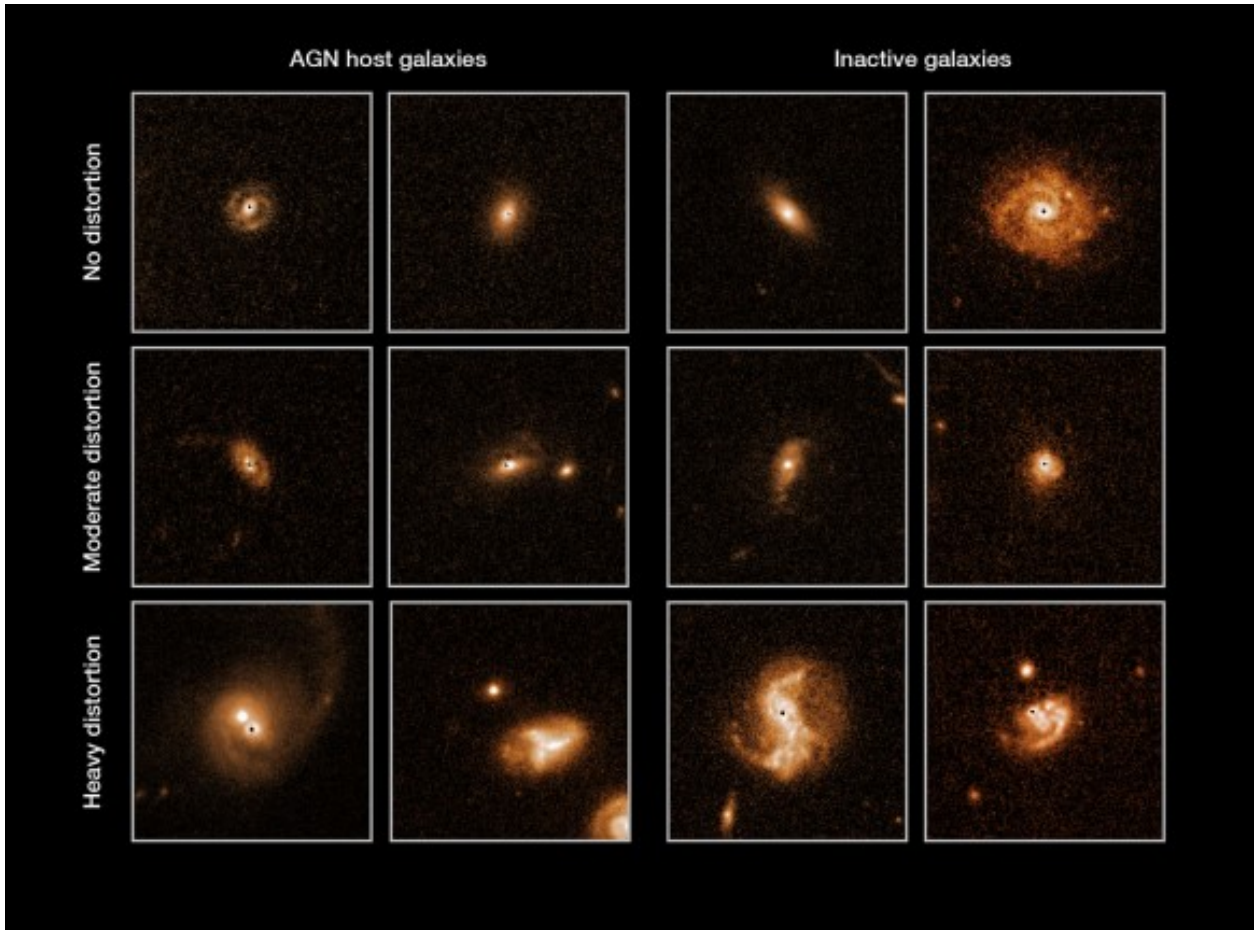
- Very low AGN activity

Galaxy Mergers: AGN activity



Is AGN activity triggered by galaxy mergers?

Probably not much (at z<1)



The observed HST morphologies of "intermediate-luminosity" type-1 AGN hosts are indistinguishable from those of a "inactive" galaxies sample

Is AGN activity triggered by galaxy mergers?

Probably some of it (at z<1)

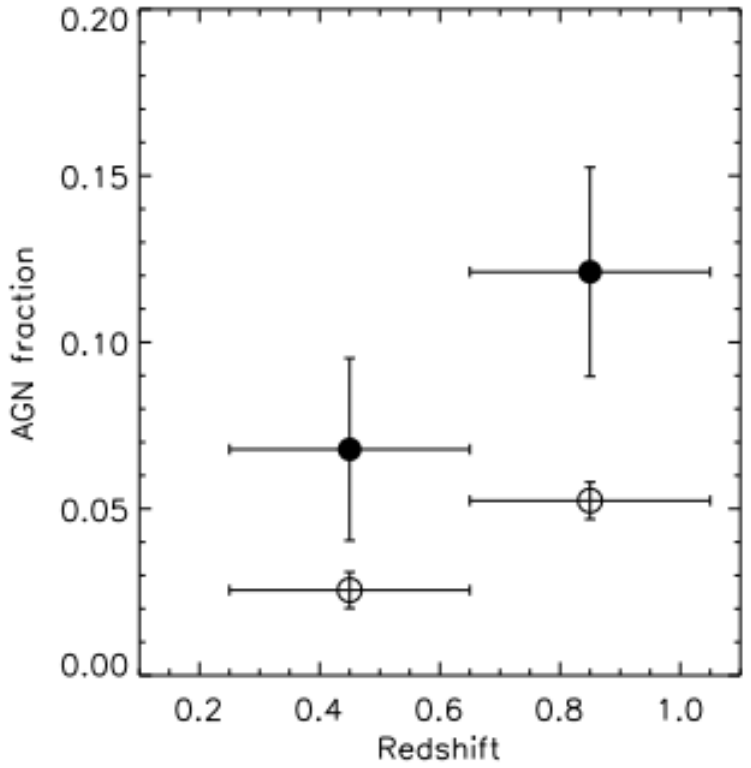


FIG. 4.— Observed AGN fraction of galaxies in close kinematic pairs ($dr < 75$ kpc and $dv < 500$ km s^{-1}; filled black circles) as compared to galaxies with no neighbor within a projected separation of 143 kpc and a velocity offset less than 500 km s^{-1} (open circles) for two redshift intervals. The horizontal bars indicate the redshift range for each value while the vertical bars are the 1σ error.

Higher fraction of AGN (Lx>2e42 erg/s) in galaxies in pairs of projected separation less than 75 kpc relative to isolated galaxies of similar stellar mass.

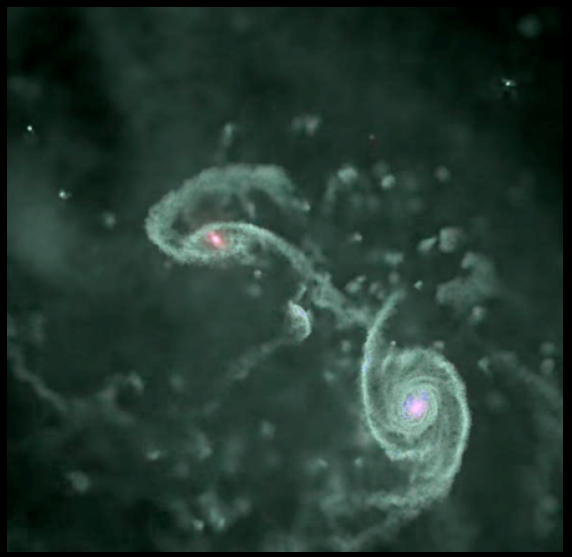
Silverman et al. (2011)

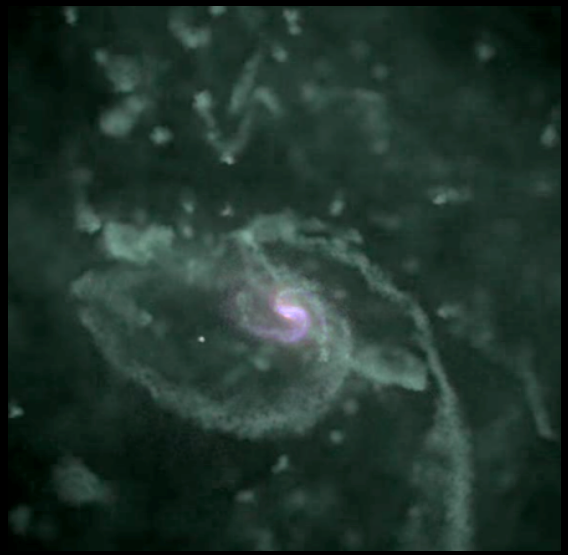
Is AGN activity triggered by galaxy mergers?

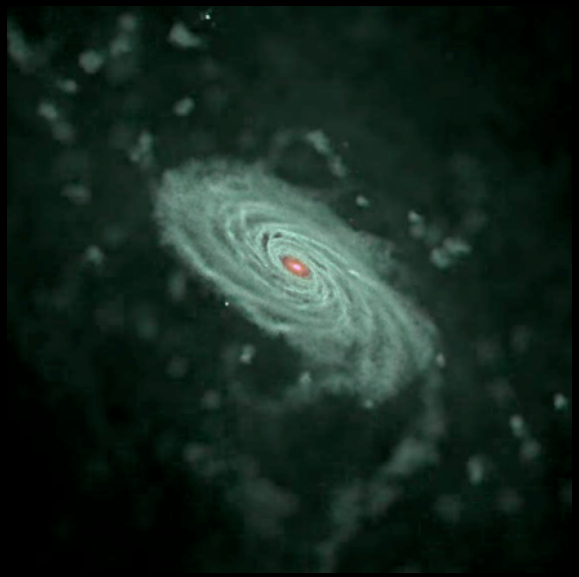
- Not all (or most of) AGN activity is merger driven = AGN activity is not merger driven (in general)

- A merger or interaction enhances AGN activity = Mergers drive some AGN activity

Cold Flows

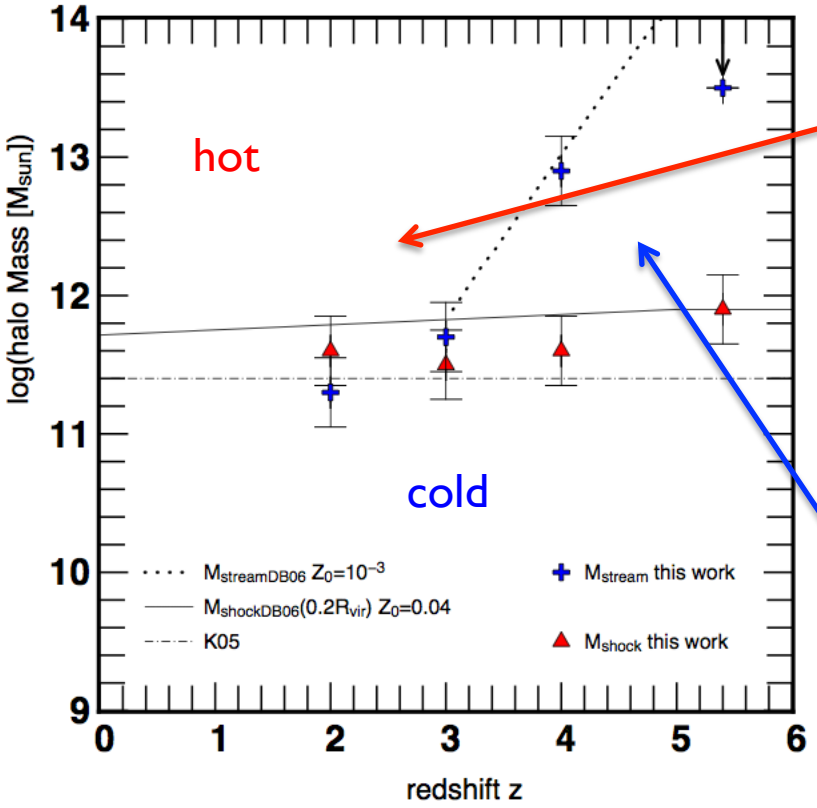




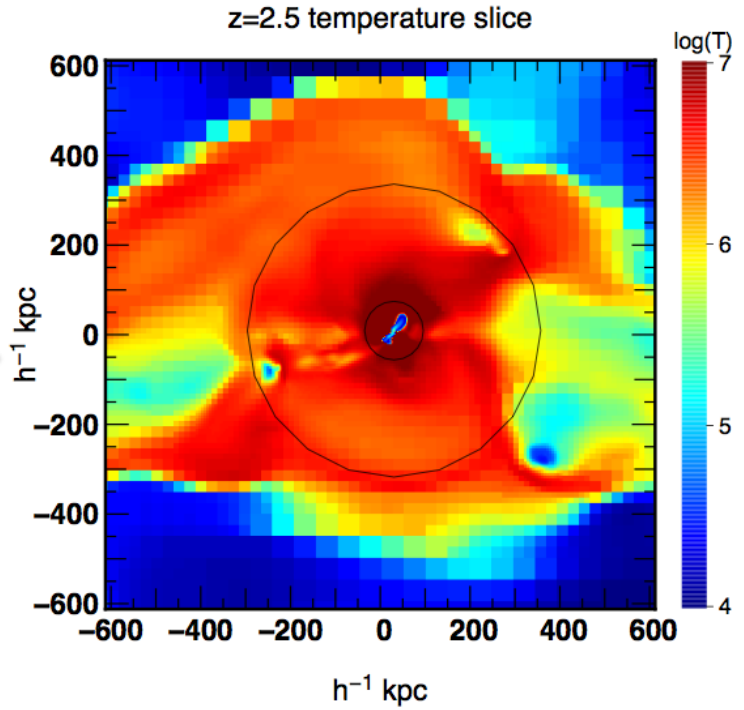


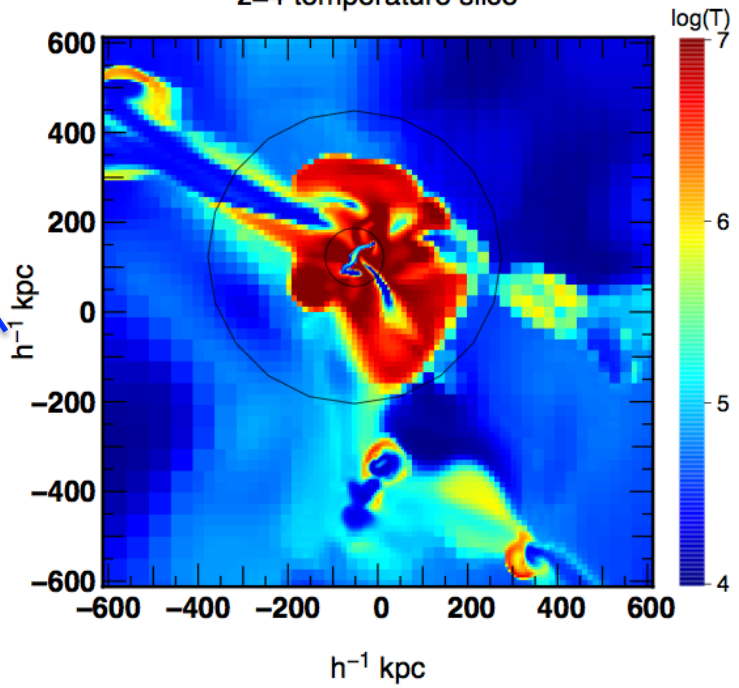
Bellovary, MV et al.
2011

Cold flows or Hot flows?



Ocvirk et al., 2008





Courtesy of Y. Dubois

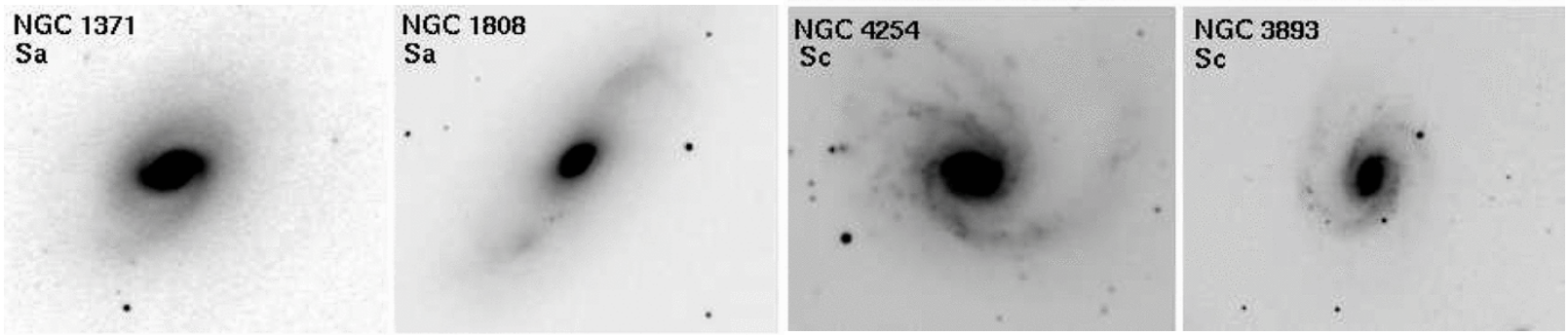
Secular Instabilities

- Seems to be common in Seyfert galaxies: nearby AGN hosted in quiescent spiral galaxies where kinematics can be studied well

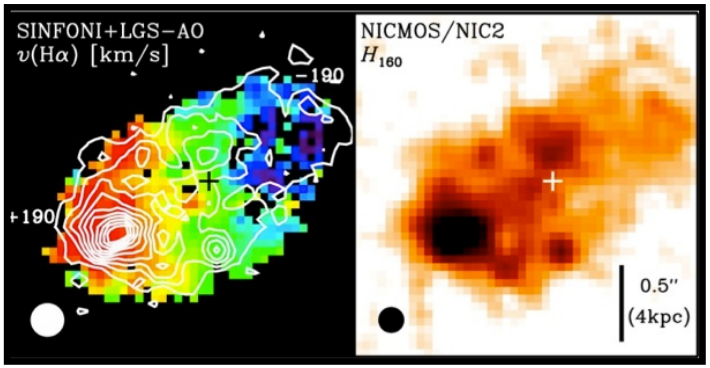
- There is at best only a marginal relation between Seyferts and bars (eg. Shlosman+ 00, Hao+ 09)

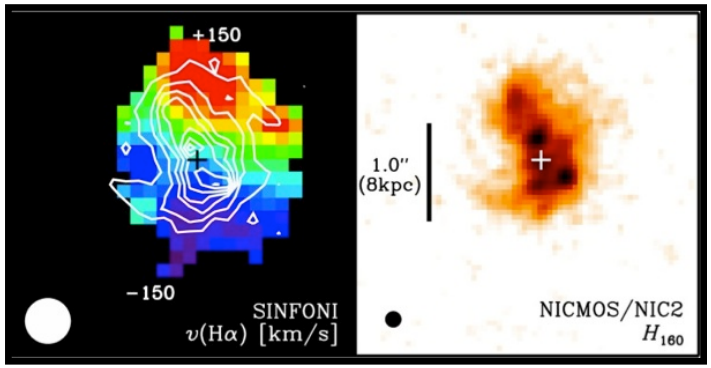
- Bars seem however to be linked to Narrow Line Seyfert 1s: strong bars, circumnuclear spirals

Smooth discs vs clumpy discs



Weinzirl+ 09





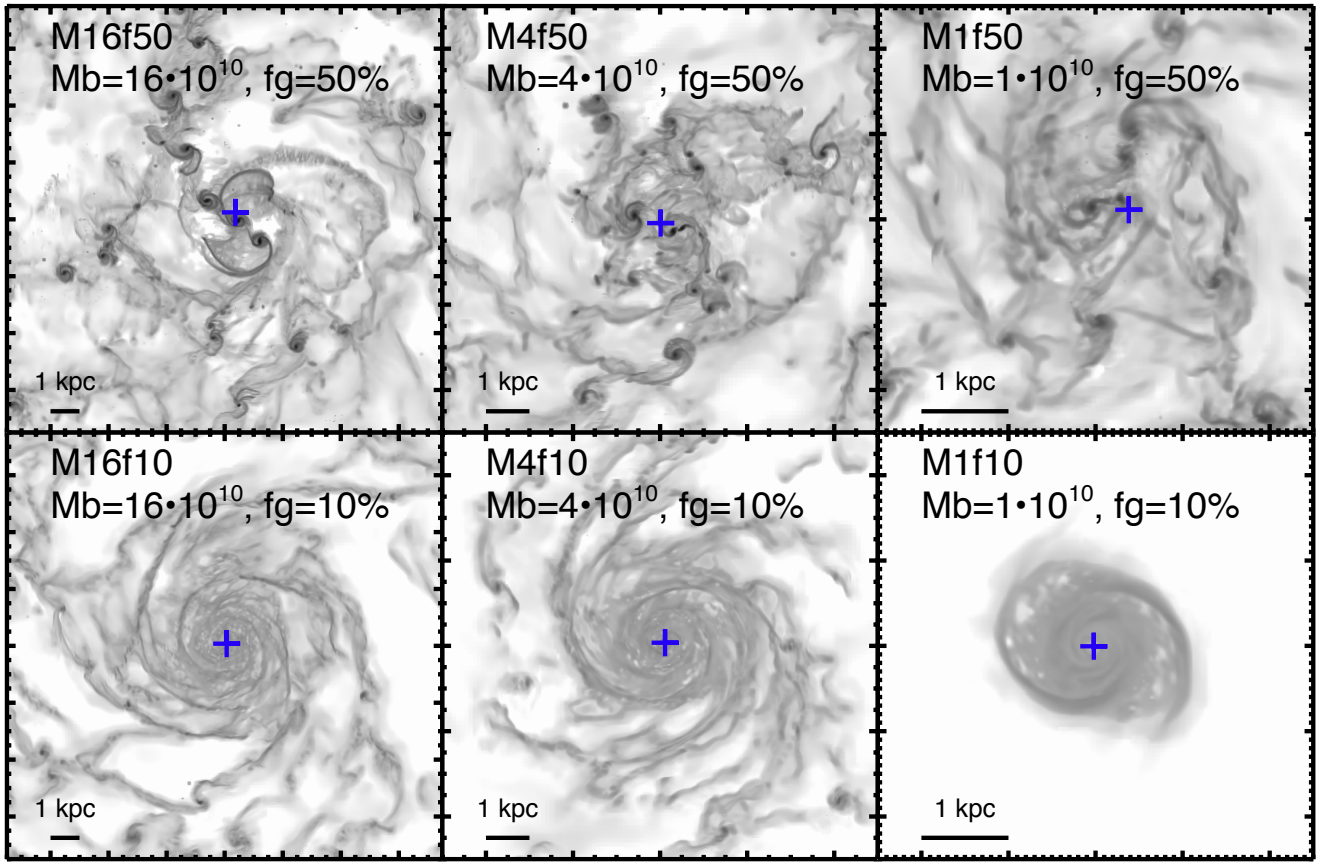
Förster Schreiber+ 06, 09, 10

Courtesy of R. Davies

Clumpy high-z discs

fgas = 50%
(z=2)

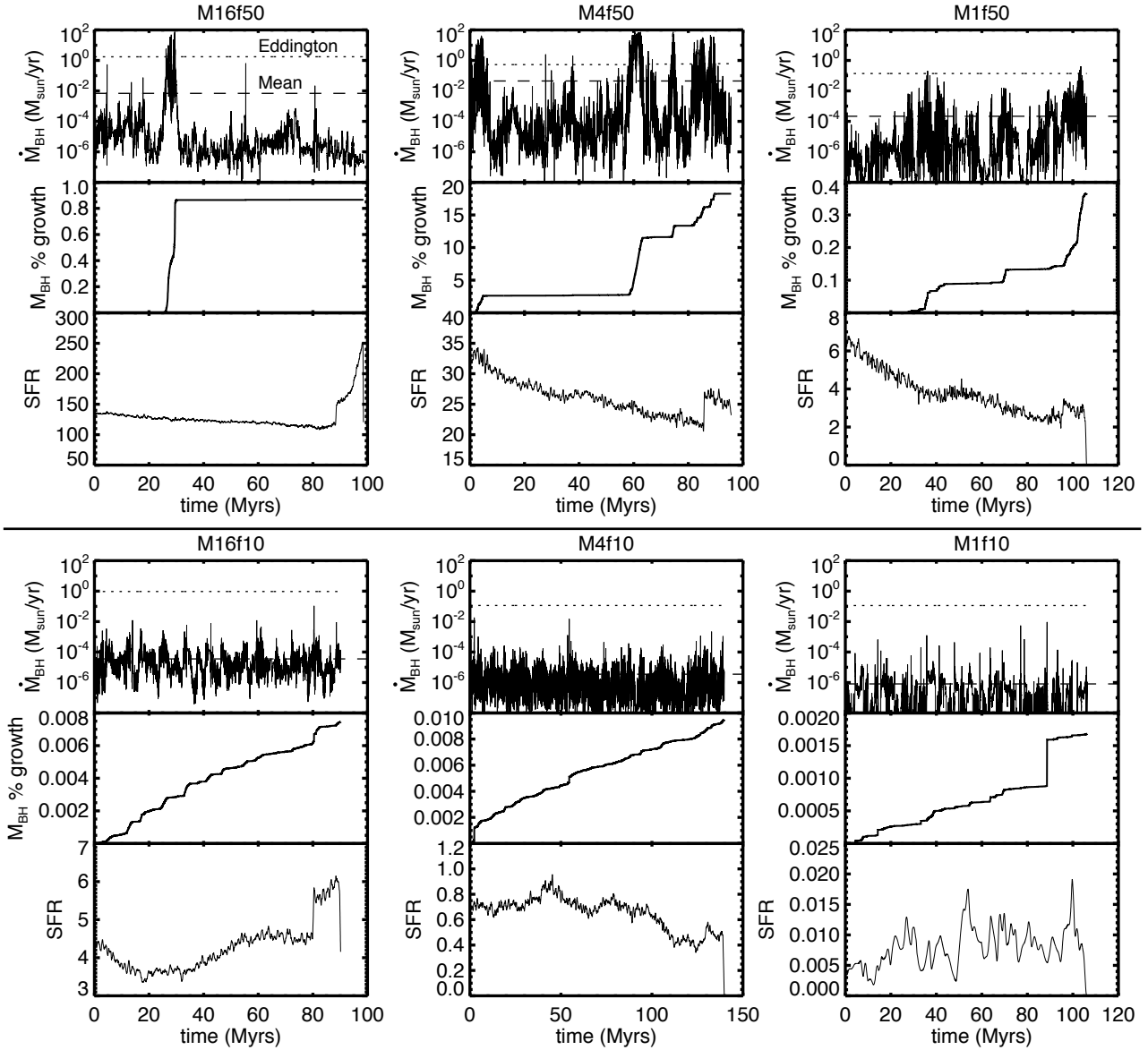
fgas = 10%
(z=0)



6 Simulations

- Gas+stars+dark matter with Ramses AMR code
- 6 pc max. resolution
- Thermal supernova feedback
- Black hole: Bondi accretion + thermal AGN feedback

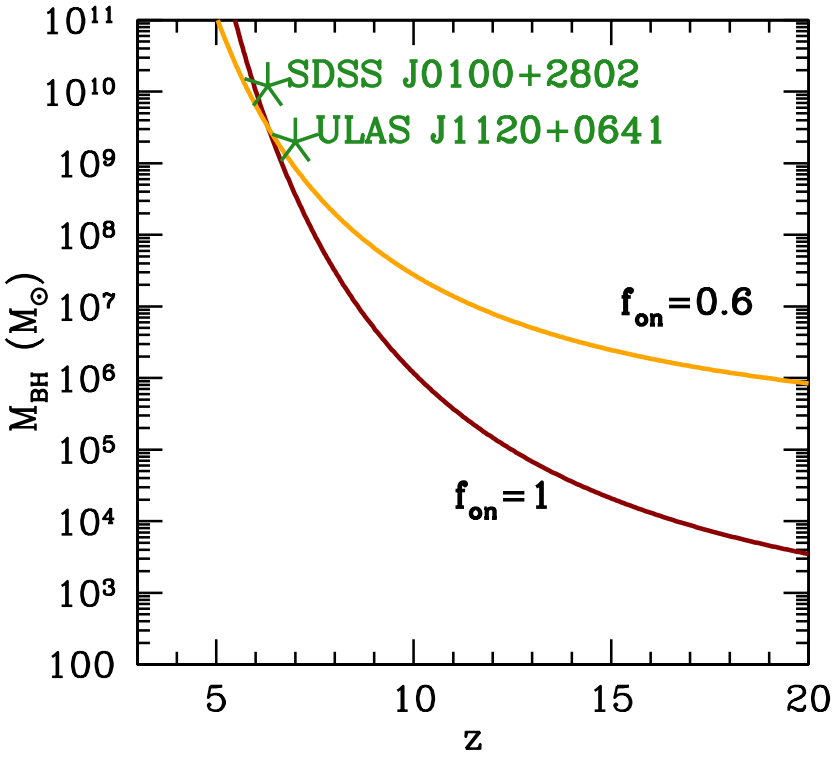
Black hole accretion rates



High-redshift quasars

Very bright quasars in the SDSS with z>6 (Willott et al., 2003; Fan et al., 2006; Jiang et al., 2009)

Detection of a 2×10^9 M_{sun} BH at z=7 and a 10^{10} M_{sun} BH at z=6.3 (Mortlock et al., 2011, Wu et al. 2015)



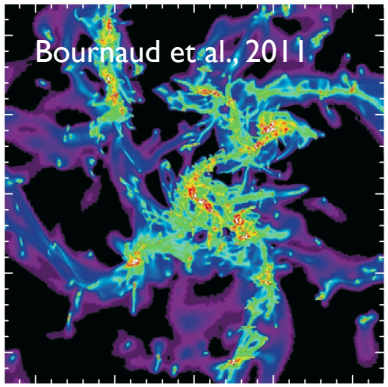
<u>Requirement</u>:

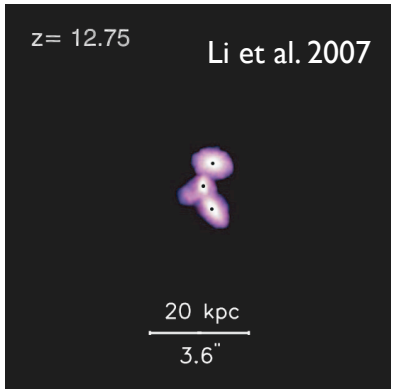
- Need to grow at the Eddington limit for the whole time (M_0~300 M_{sun}) or 60% of the time (M_0~10^5M_{sun})

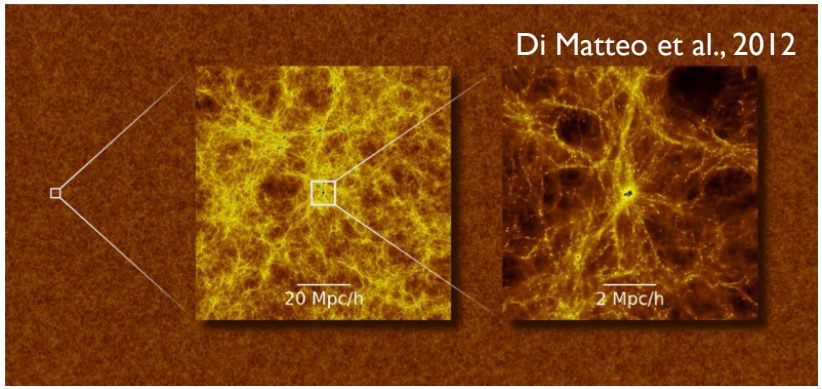
Merger-driven accretion (Li et al. 2007)
series of successive mergers using tree extracted from cosmological run

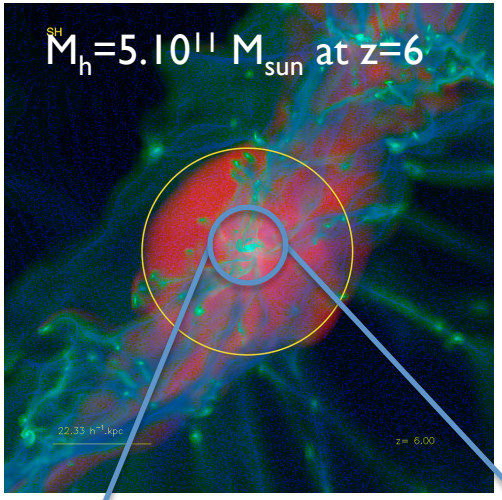
Direct accretion from the cosmic cold flows
(Di Matteo et al., 2012)
Cosmological context with large statistics but low resolution (~1kpc)

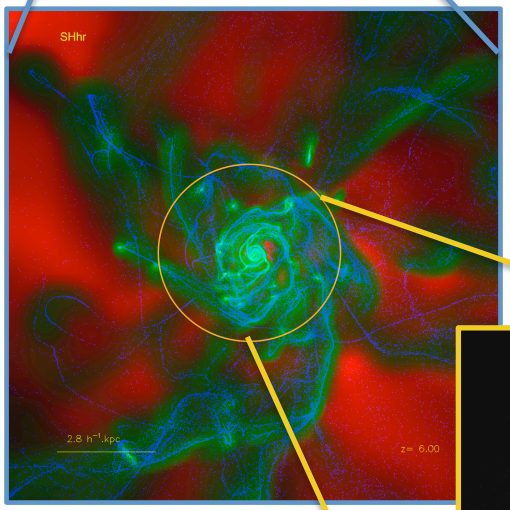
Violent disc instabilities (Bournaud et al., 2011)
High resolution (1pc) but isolated disc

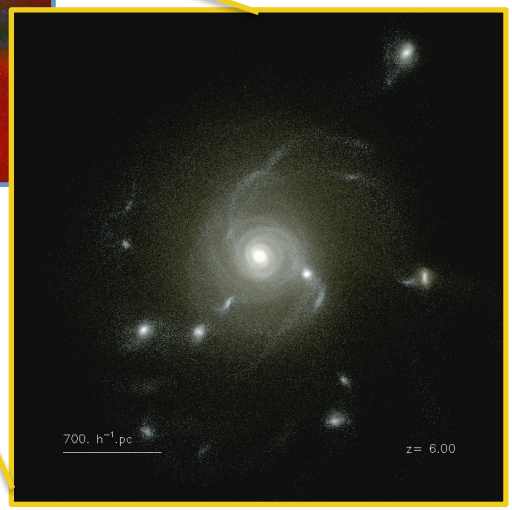










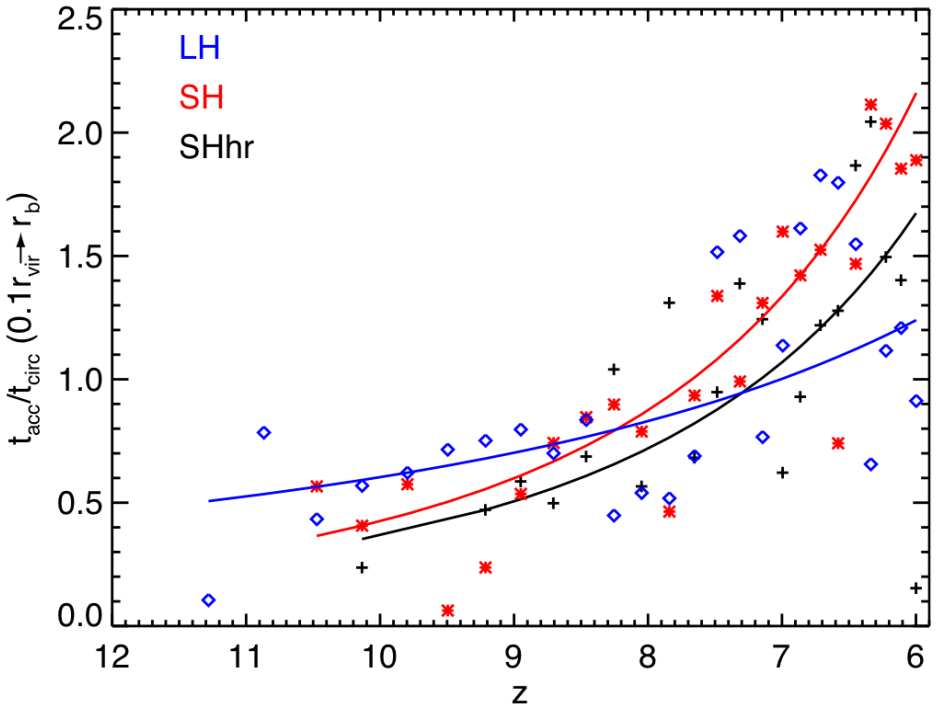


Cosmological zooms
10 pc resolution

Dubois+2012

Courtesy of Y. Dubois

Trace back the gas particles that belong to the galactic bulge: what's their history?

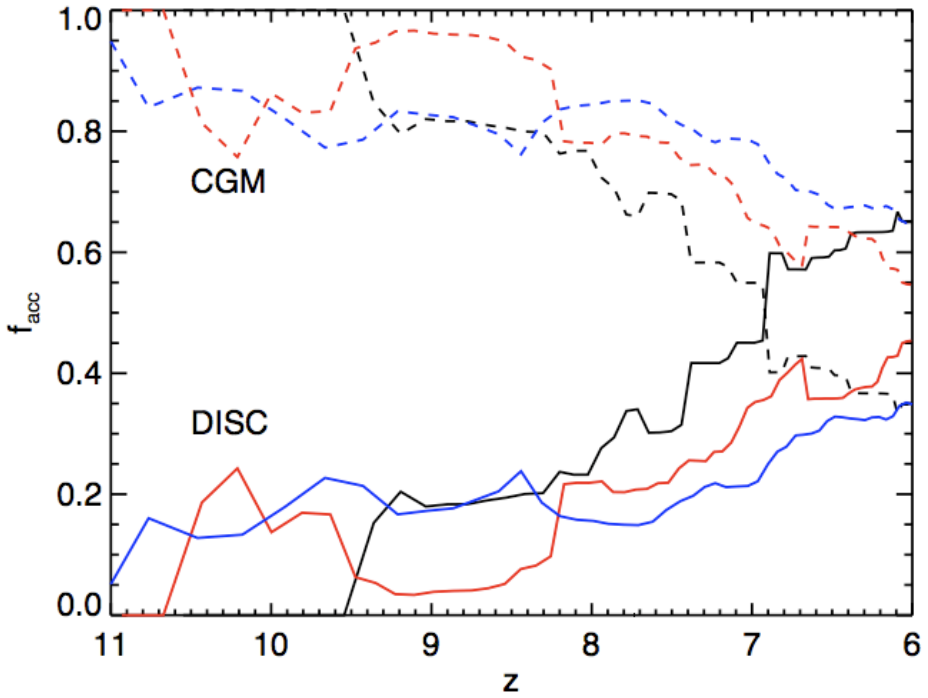


Gas infalling at late times does more rotations before being accreted – it belongs to the disc

Courtesy of Y. Dubois

Dubois+2012, see also Bellovary+2013, Feng+2014

Trace back the gas particles that belong to the galactic bulge: what's their history?



Gas infalling at late times does more rotations before being accreted – it belongs to the disc

Direct accretion of cosmic gas dominates early, disc feeding takes over at later times

Mergers become important even later on

Courtesy of Y. Dubois

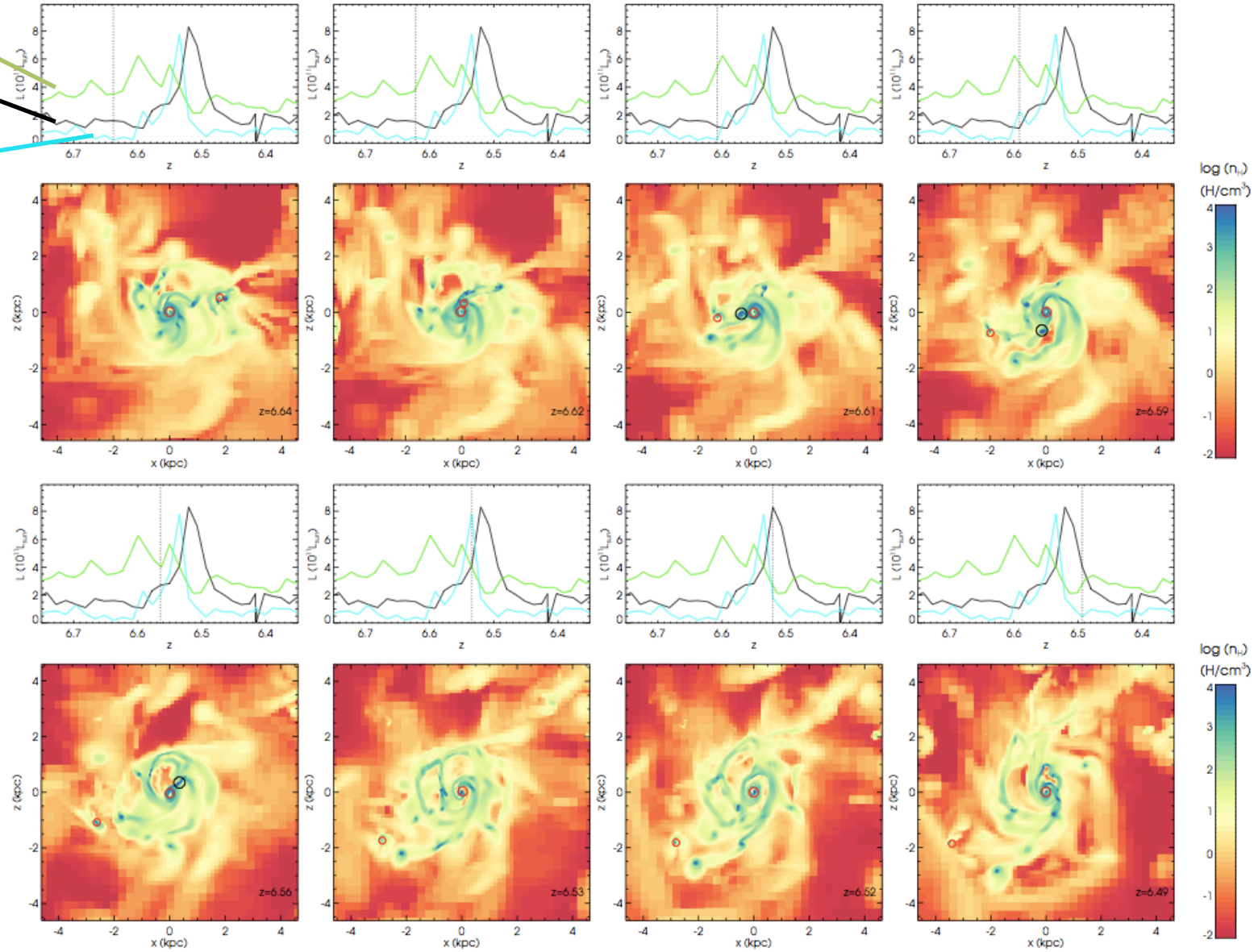
Dubois+2012, see also Bellovary+2013, Feng+2014

A rapid clump migration to trigger an AGN bursts

SFR

AGN luminosity

Gas accretion rate @ 100 pc



Courtesy of Y. Dubois

Dubois, Pichon et al., 2013

First phase: direct accretion from cosmic flows

Second phase: migration of clumps in the disc

Third phase: merger-driven accretion