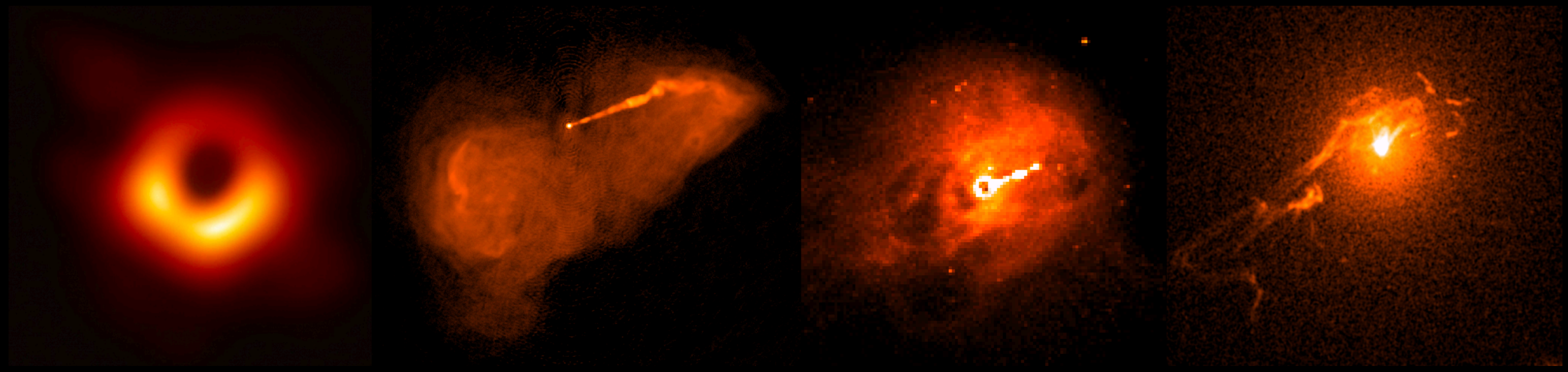
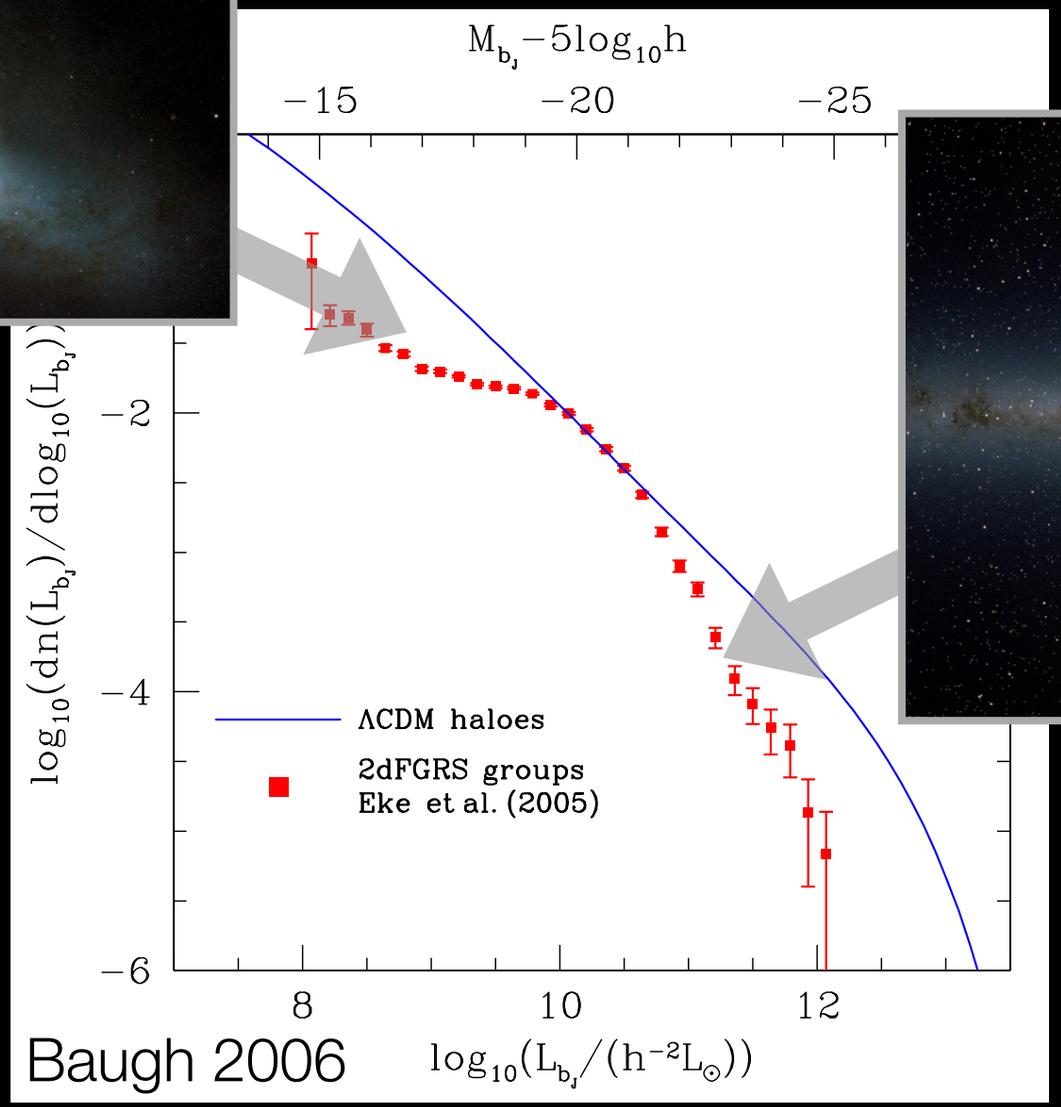
Fire on ice:

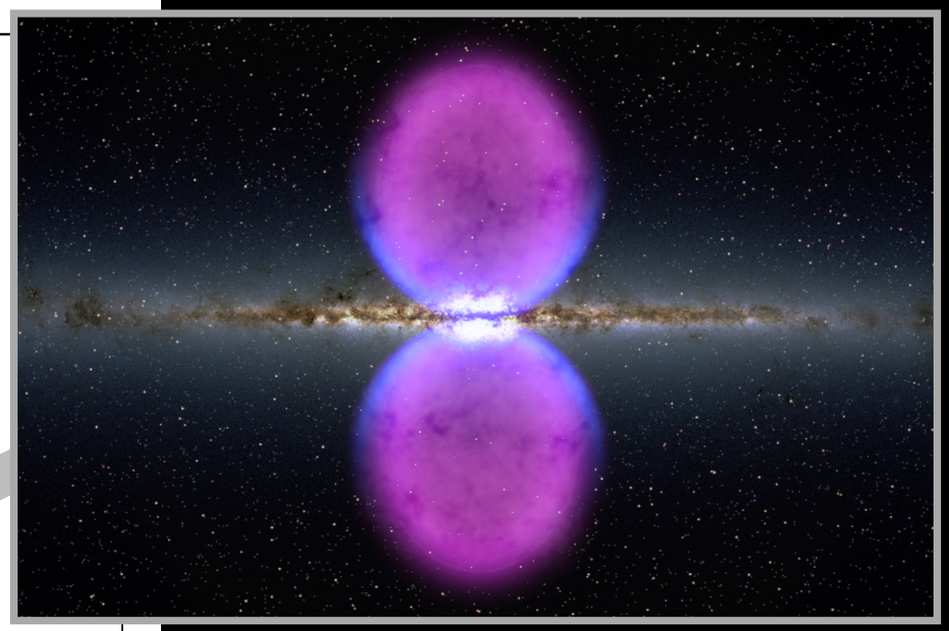
the complex relationship between
supermassive black hole feedback and
the cold and cooling gas in giant elliptical galaxies



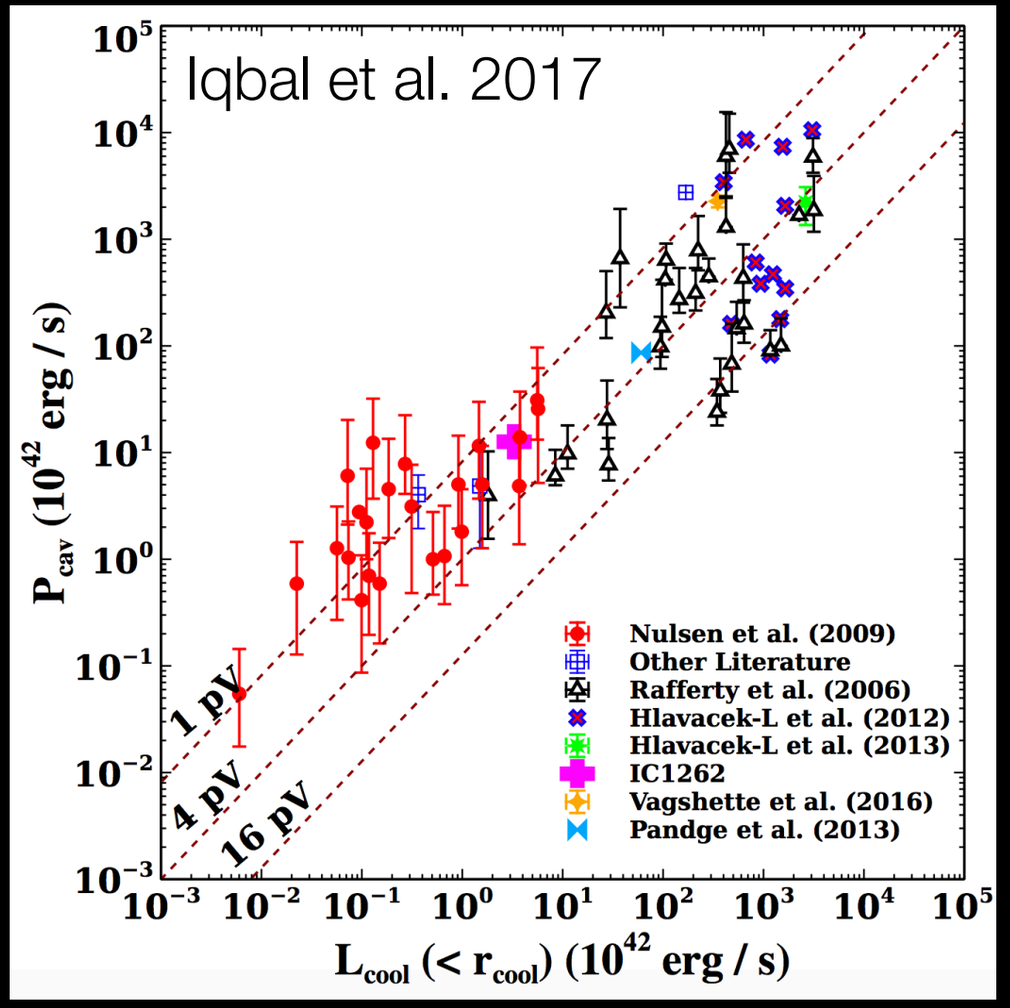
Aurora Simionescu
SRON/Utrecht

Why do Galaxies of different masses form stars at different rates?





Globally, supermassive black holes provide enough energy to prevent the formation of stars in the most massive galaxies



EHT

SMBH drives outburst

VLA

SMBH jets "pump" radio lobes which disturb and heat the hot halo.

Cold gas clouds "rain" onto SMBH driving next outburst

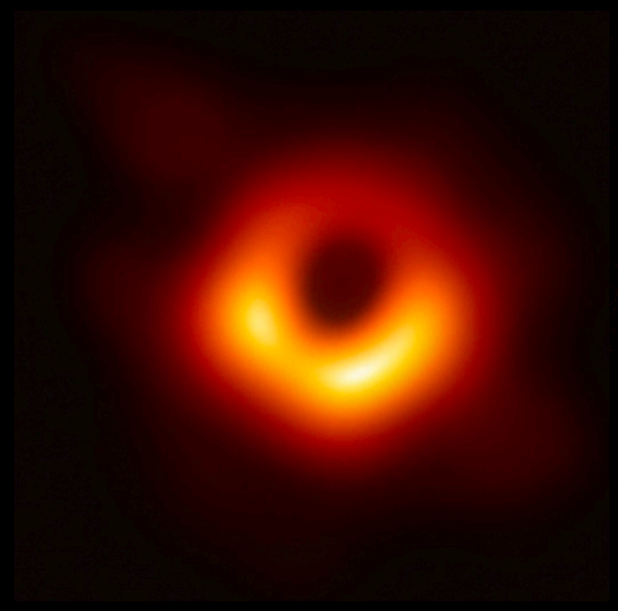
Once heat is radiated away, gas begins to cool again

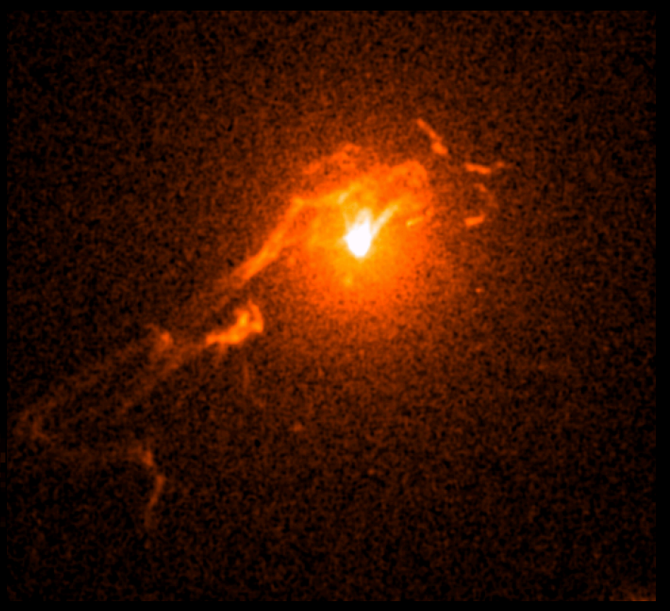
CFHT

Chandra

How much cold gas is there in elliptical galaxies, and how does the interaction with the SMBH affect its mass?

How does the SMBH feedback engine “run”, i.e. how do its various components move and evolve in time?



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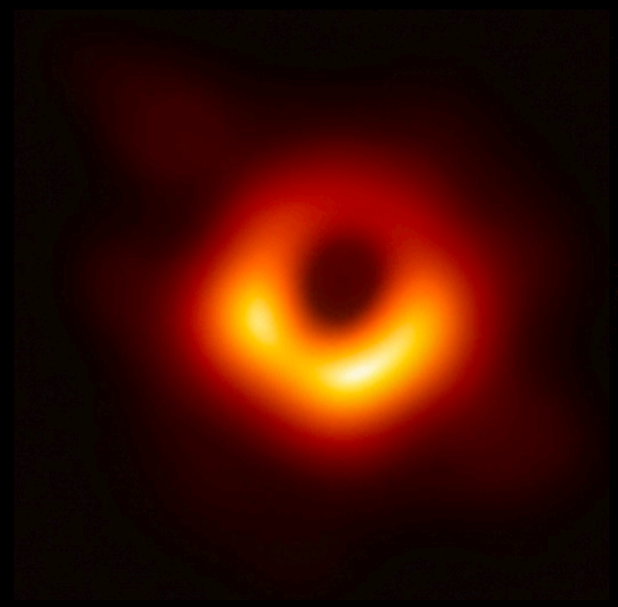
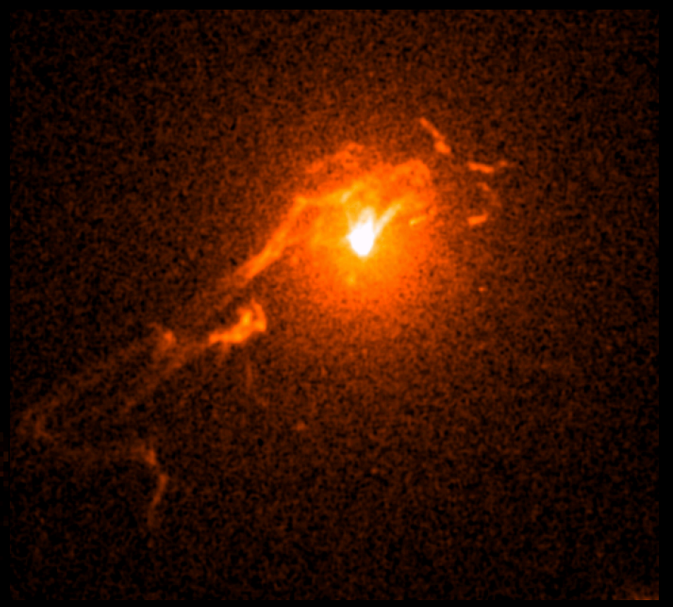
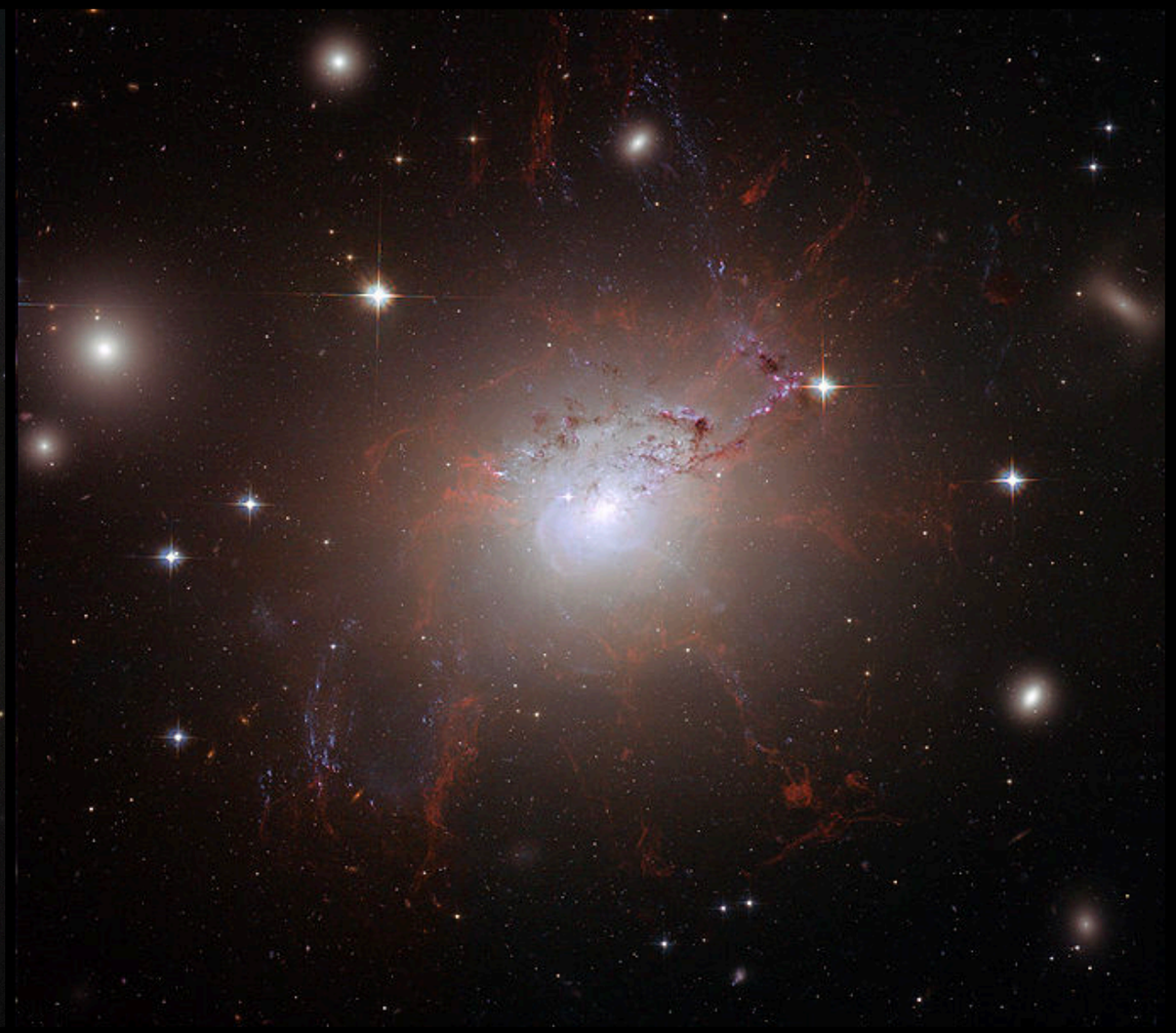
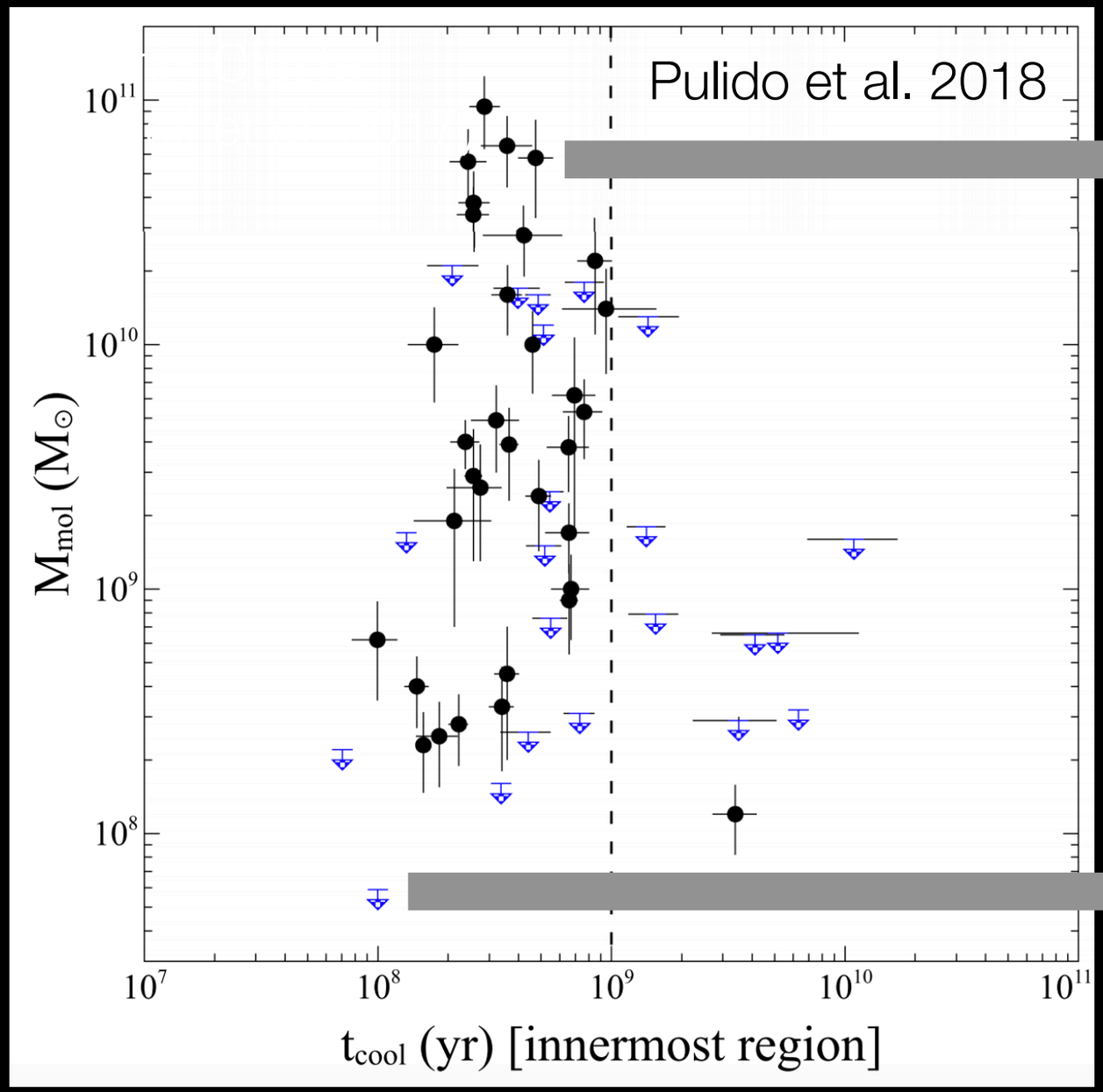


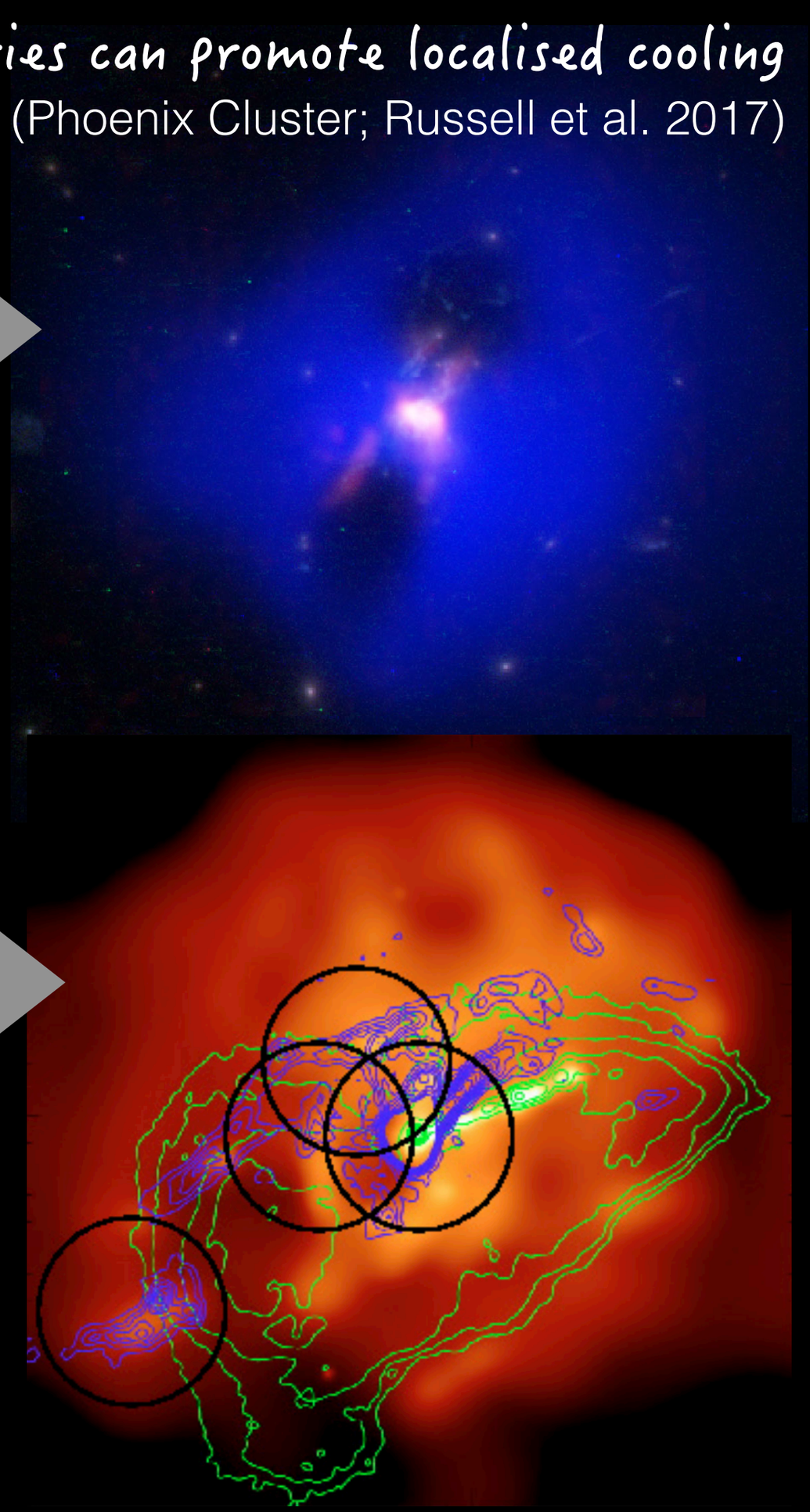





Thermal instabilities can promote localised cooling

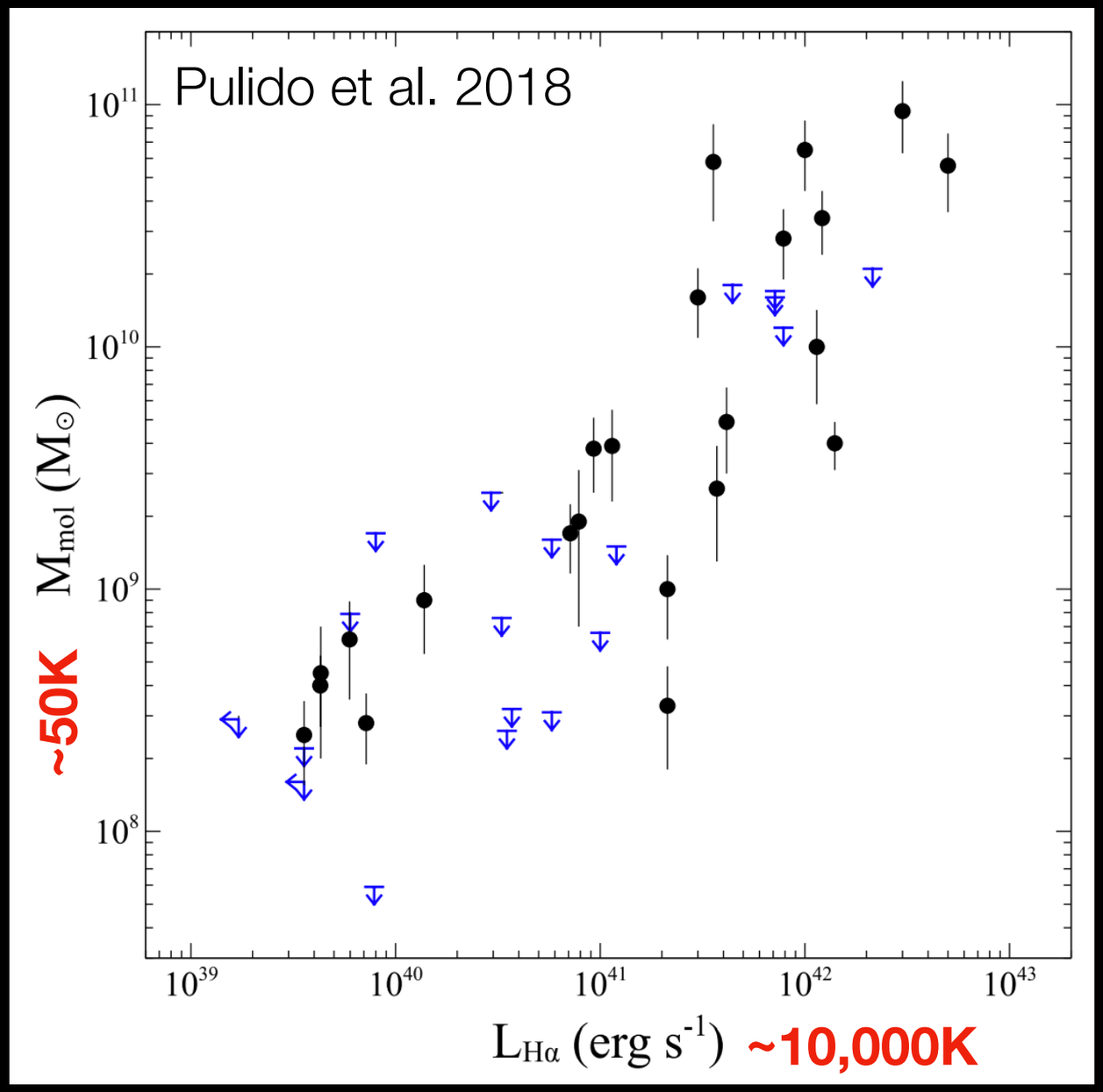
(Phoenix Cluster; Russell et al. 2017)



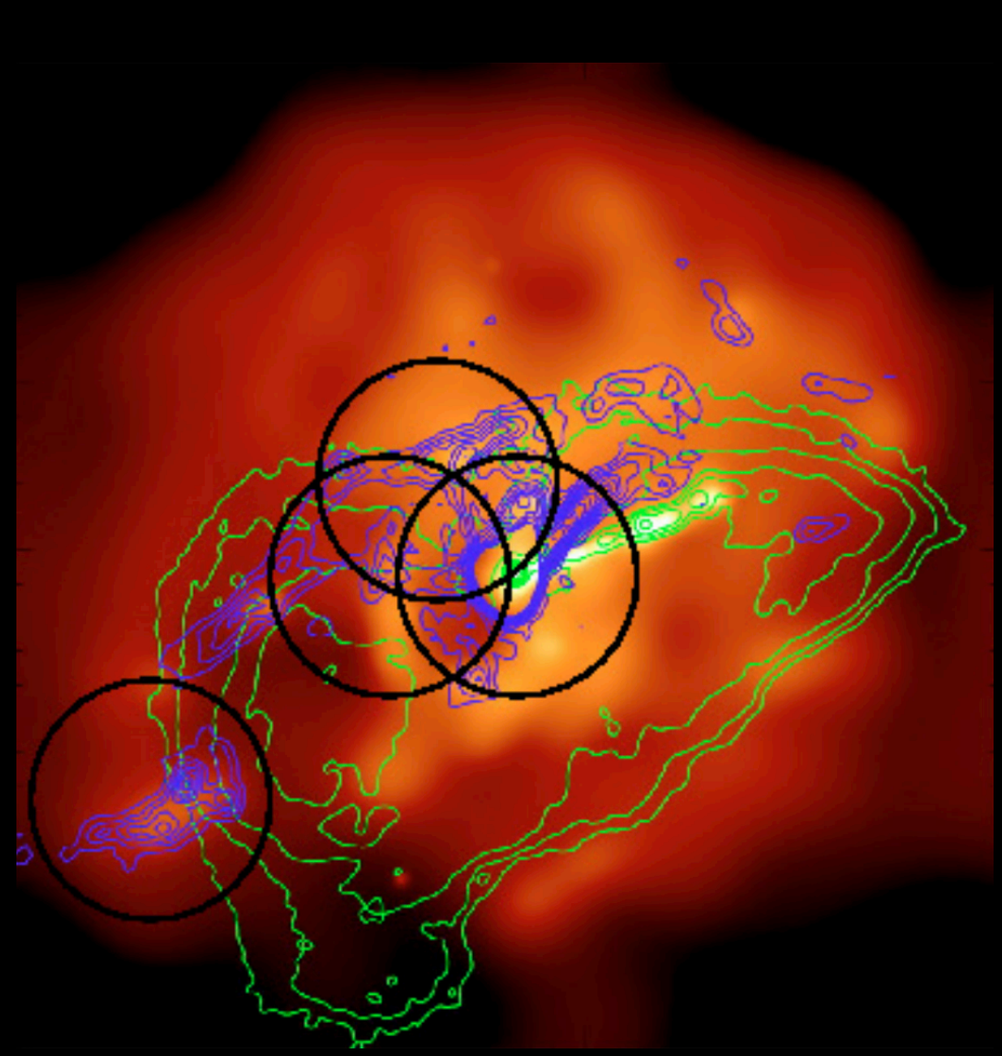


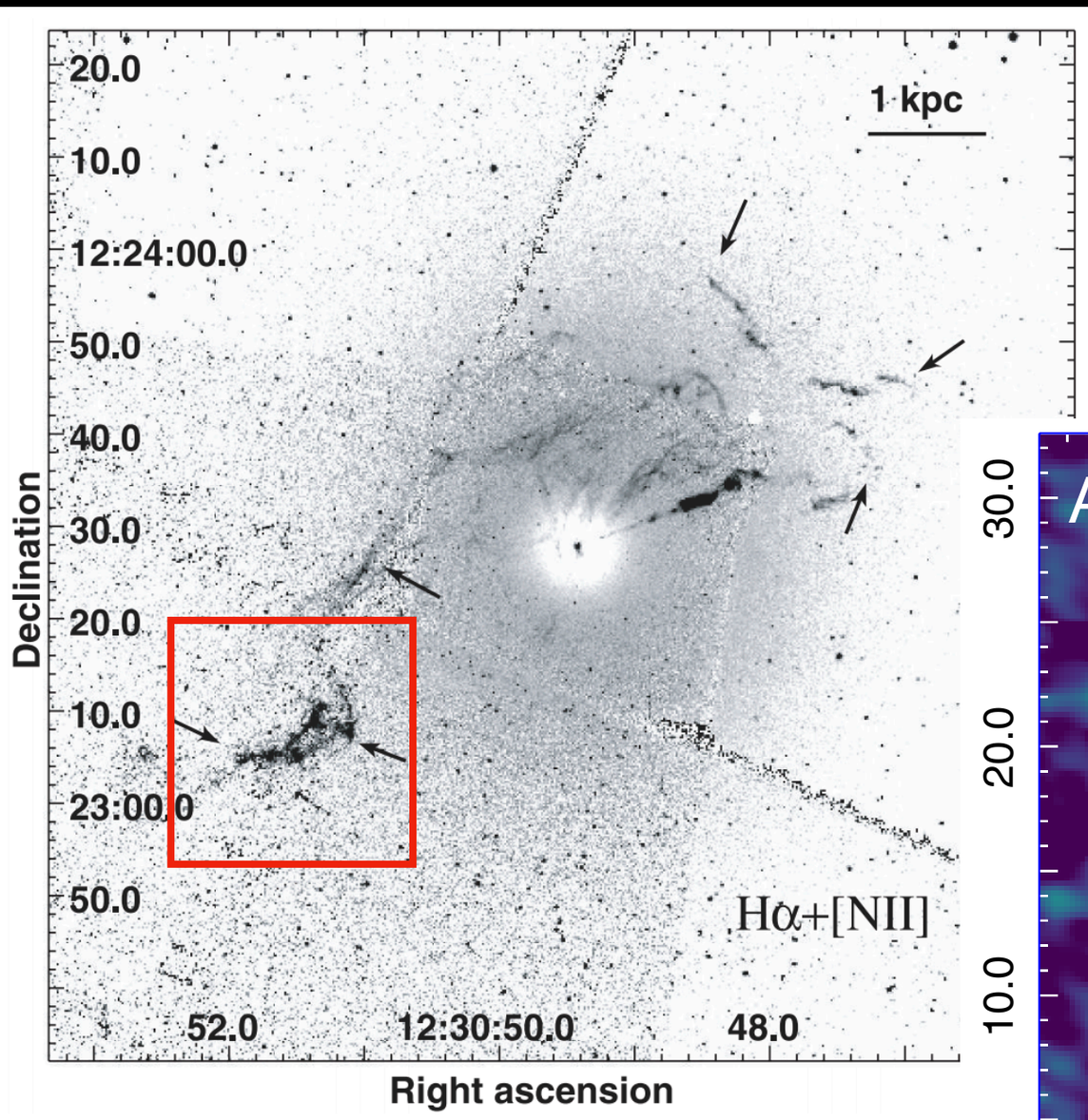
Along another part of the feedback loop, most of the cold gas is destroyed

(Salome & Combes 2008; no molecular gas in M87)



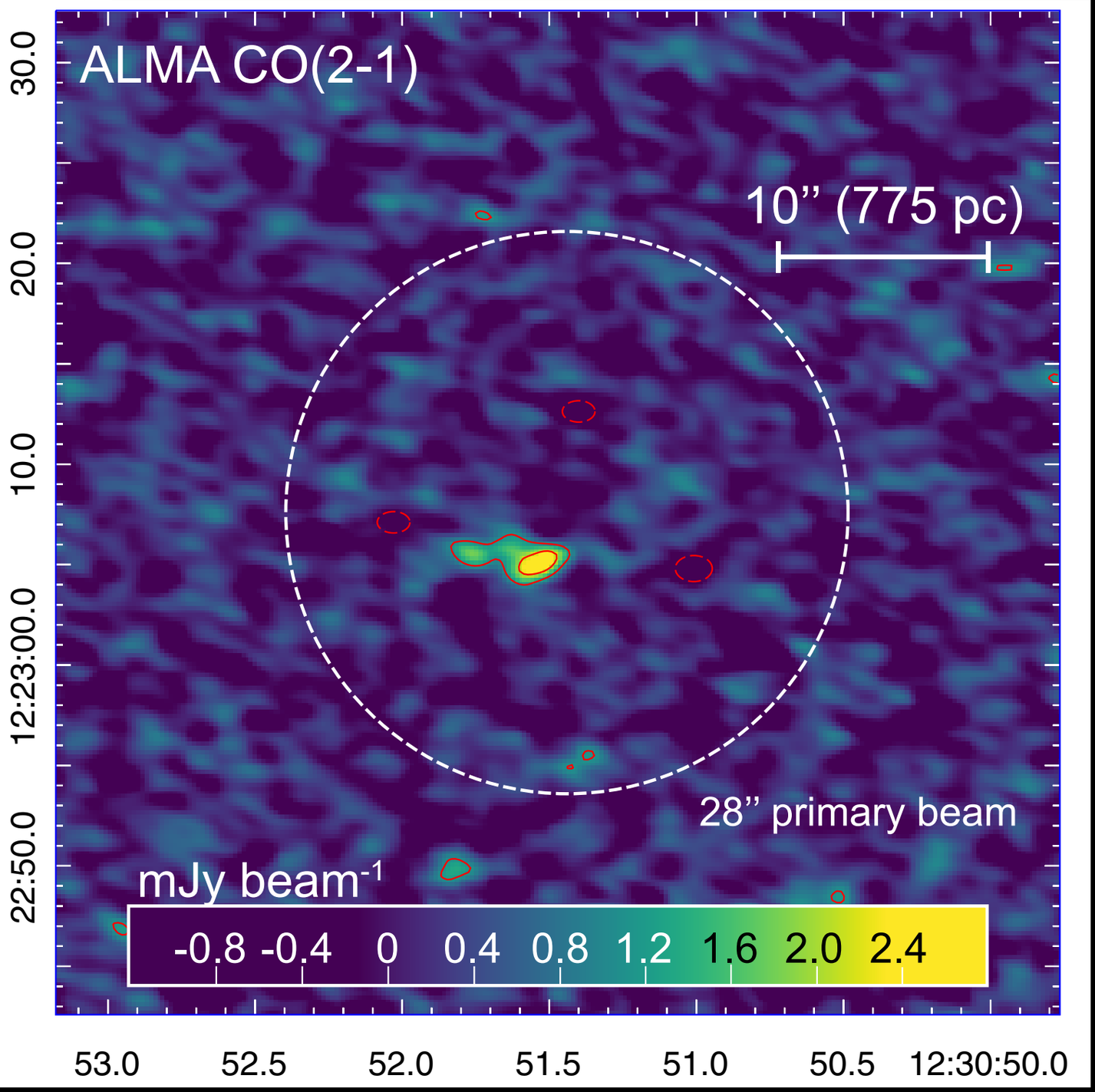
Once thermal instabilities take place, cooling usually cascades through all phases down to molecular gas





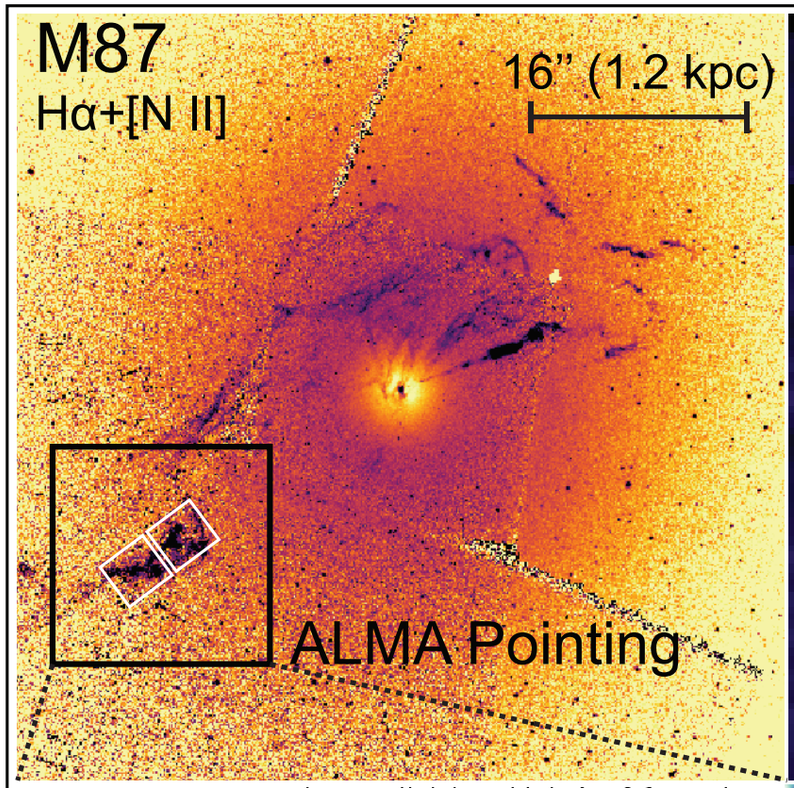
3h on source with ALMA
Simionescu et al. 2018

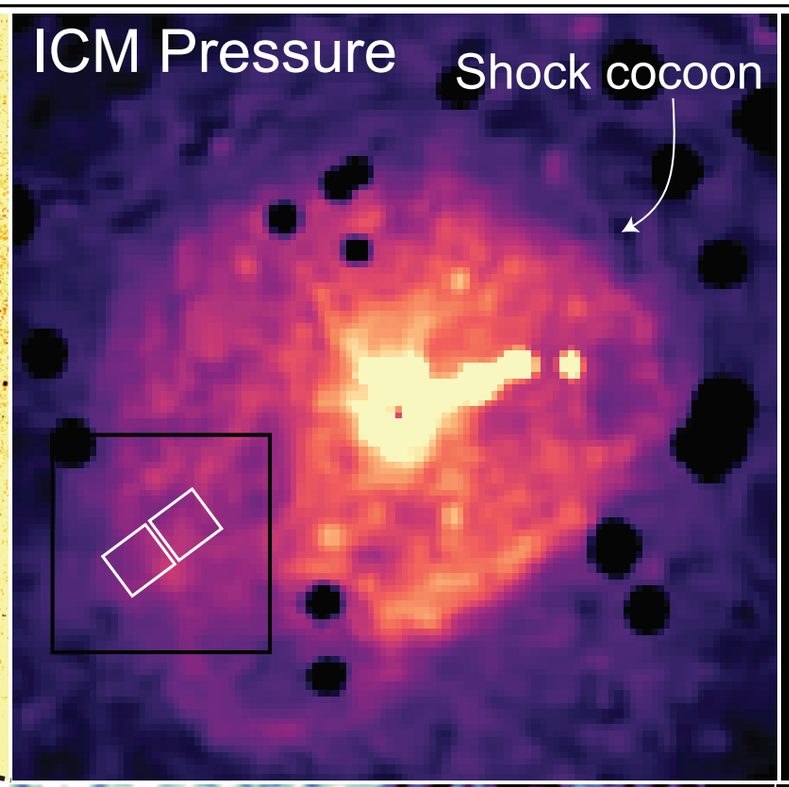
$$M_{H_2} = (4.7 \pm 0.4) \times 10^5 M_\odot$$

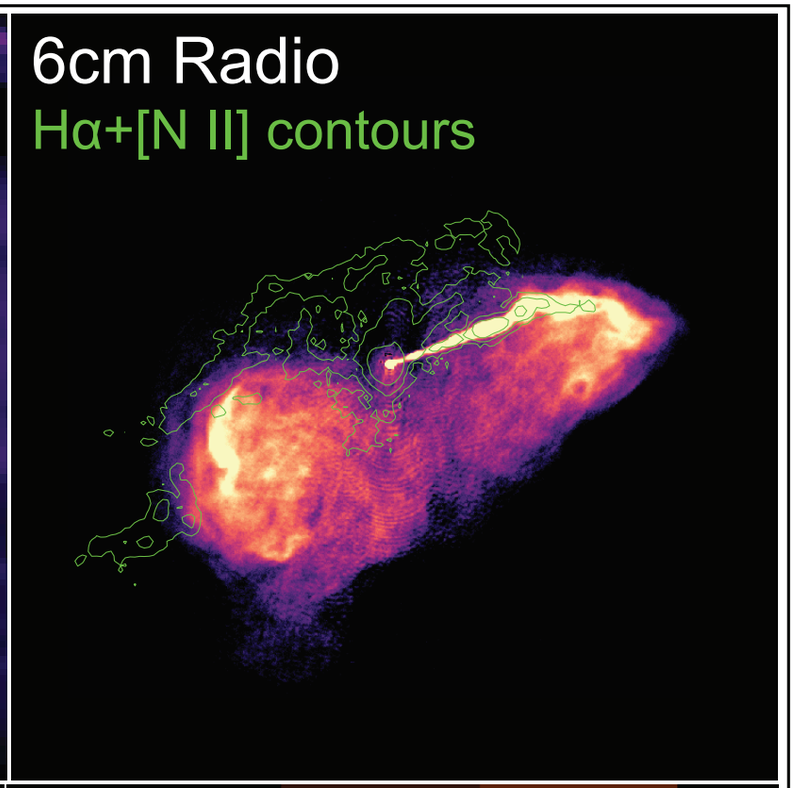


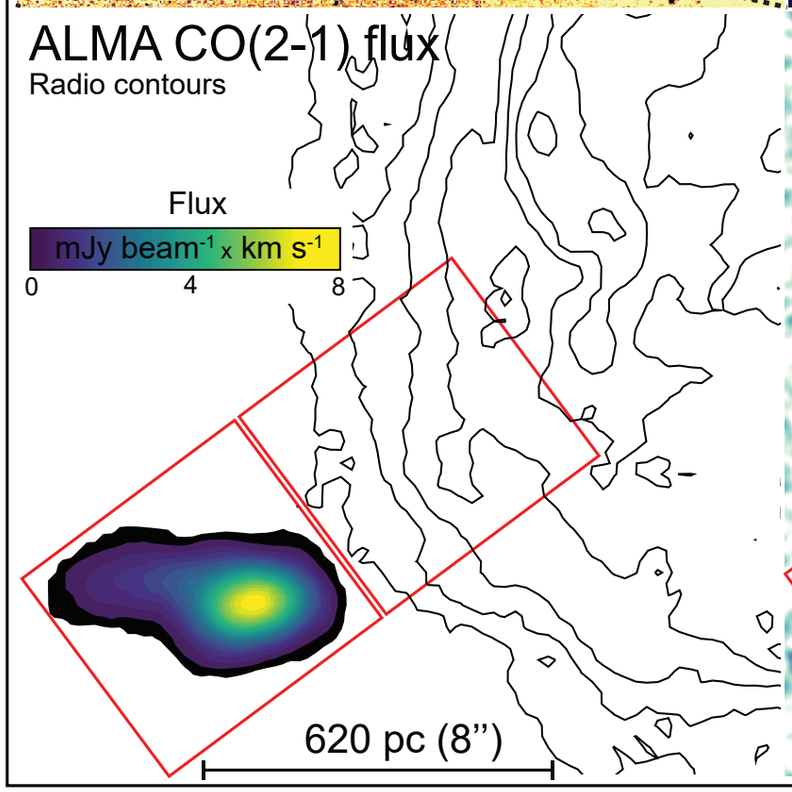
★ CO(2-1) detected outside but not inside AGN radio lobe

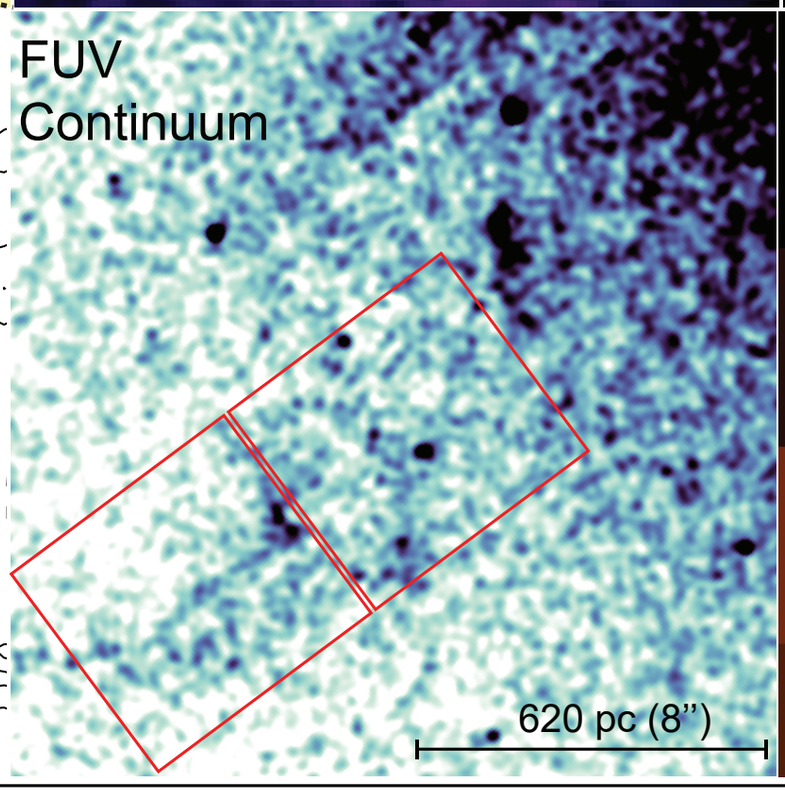
★ Hα to CO ratio changes by a factor >5 across radio lobe edge

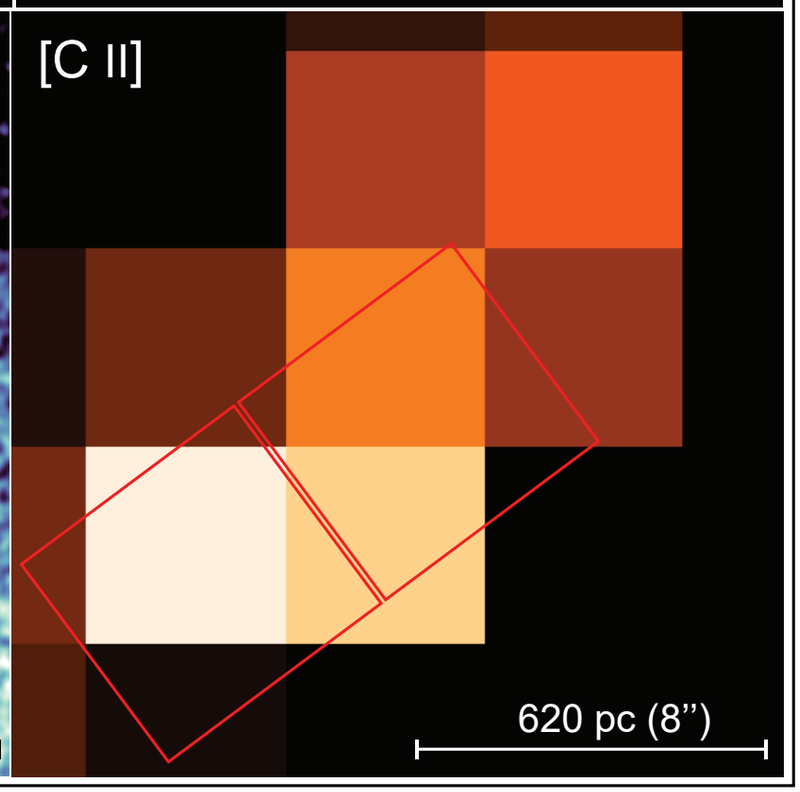












What destroys (disrupts?) the molecular gas in M87?

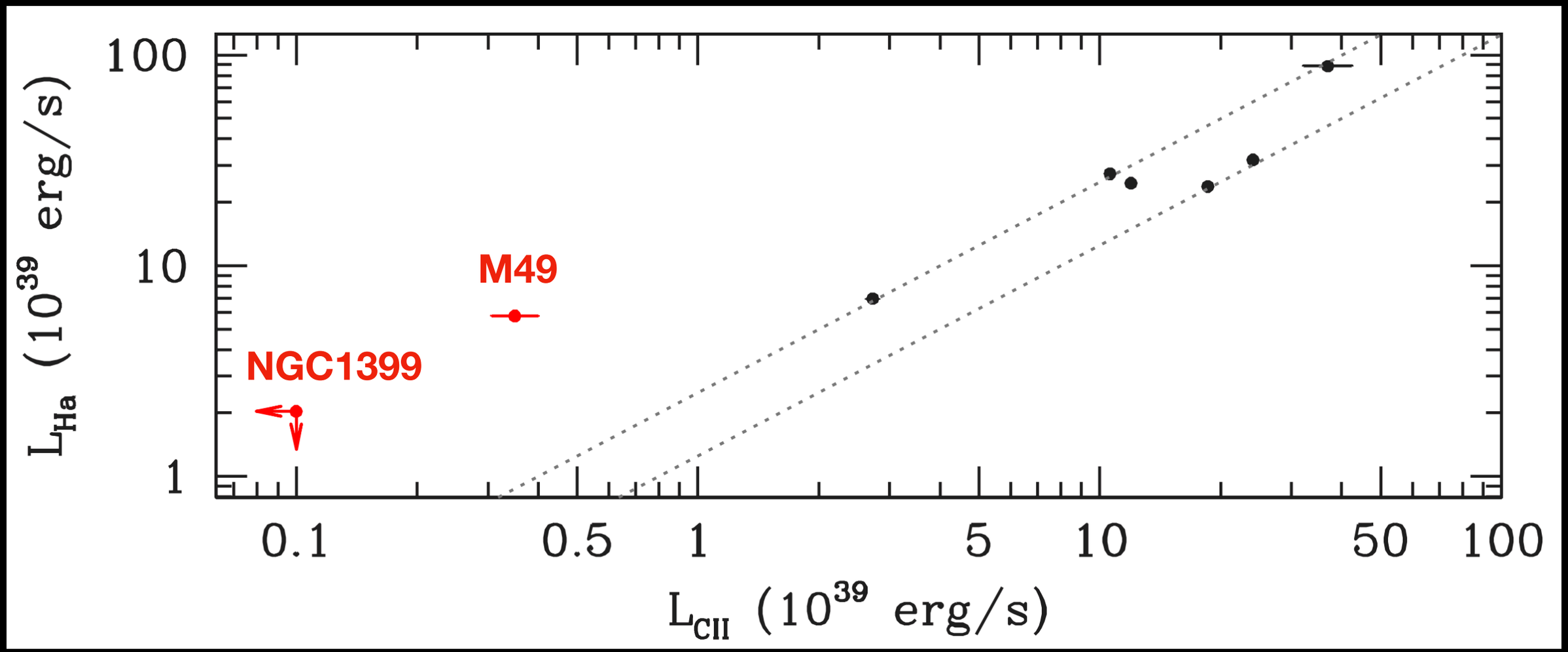
★ ~~Has the 'missing' molecular gas been converted into stars?~~

★ Does the relativistic plasma in the AGN radio lobe actively destroy the molecular gas (e.g. magnetic reconnection)?

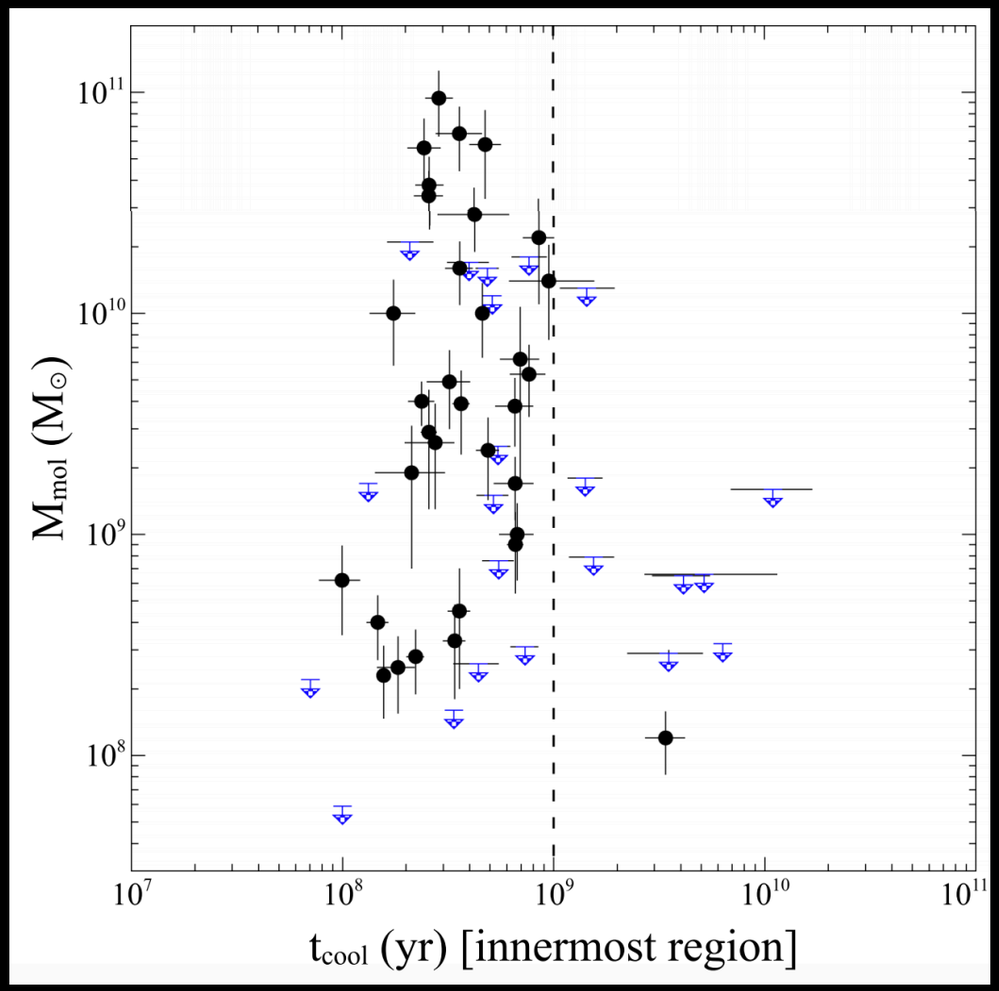
★ Does the X-ray shock destroy the gas, but with a "time delay"?
(estimated time elapsed since shock passage: 1.1 Myr)

★ Perhaps the molecular gas is not destroyed at all but heated/excited?

What about other galaxies?

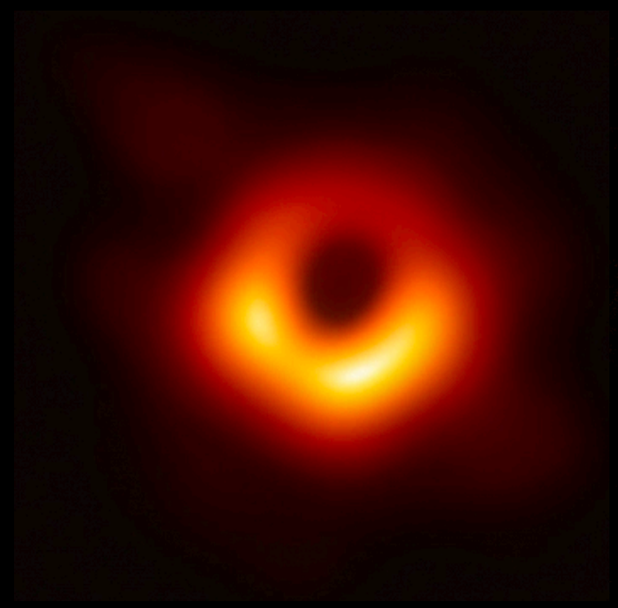
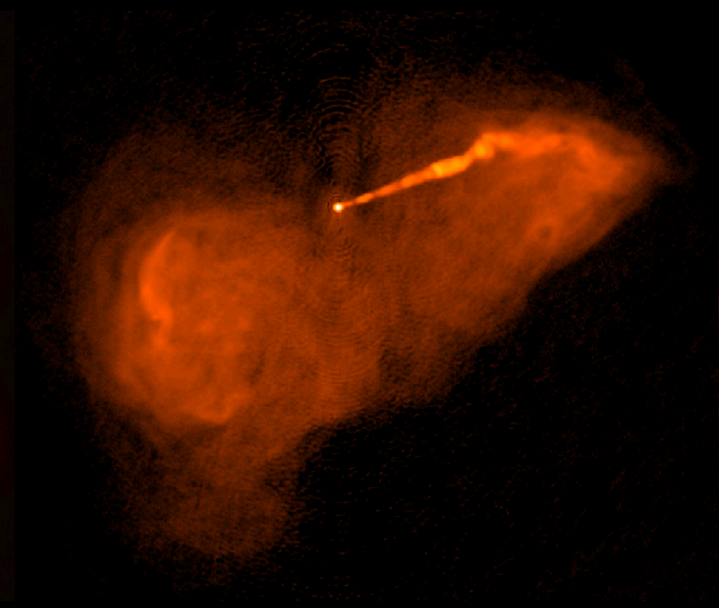


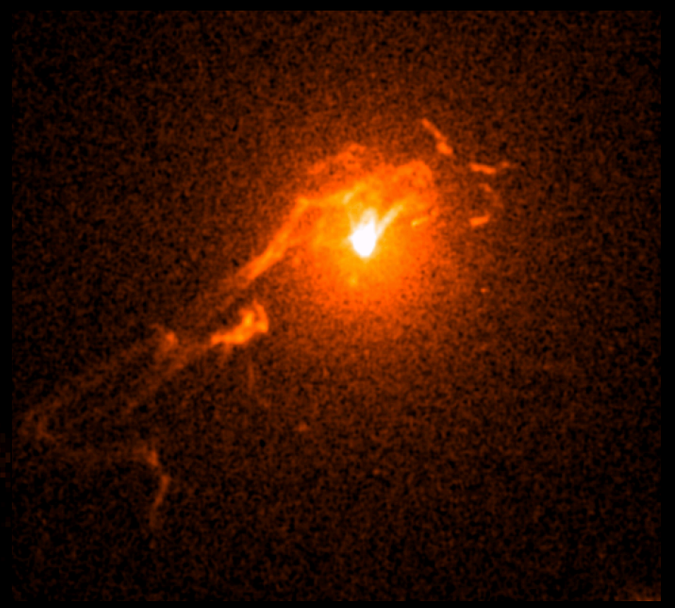
Herschel/PACS sample of optically and X-ray brightest giant elliptical/SO galaxies within a distance < 35 Mpc



How much cold gas is there, and how does the interaction with the SMBH affect its mass?

When the remaining amount of cold gas is low (the "engine" is about to switch itself off), various phases of the atomic vs molecular gas may decouple from each other.



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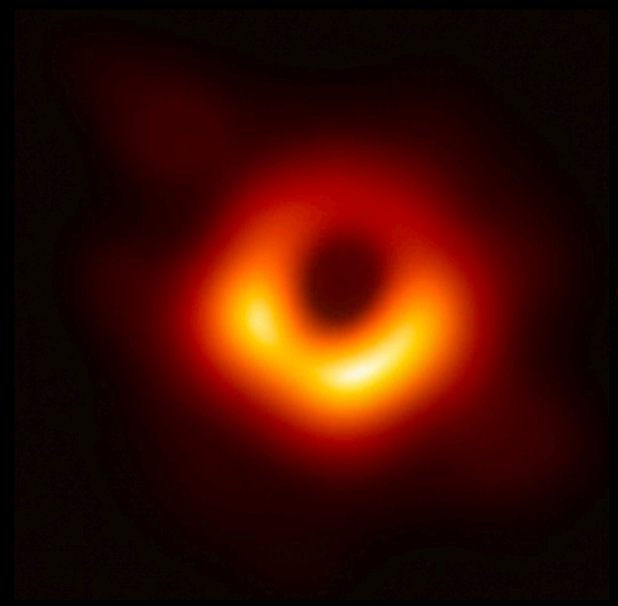
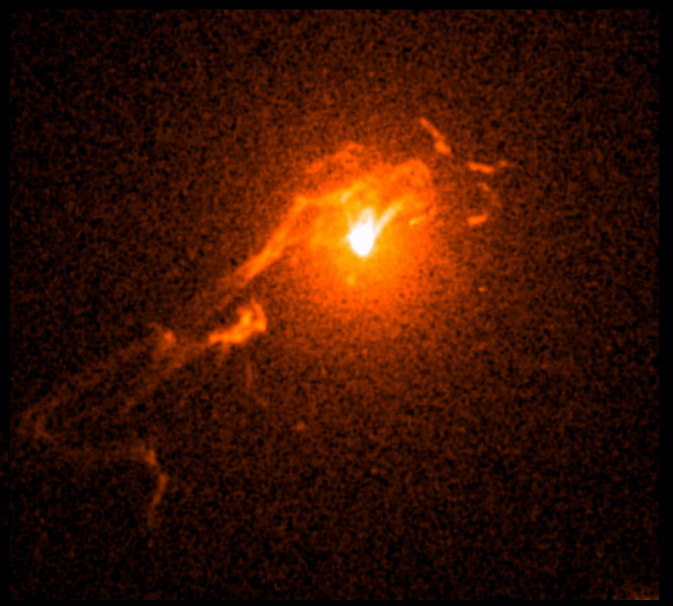
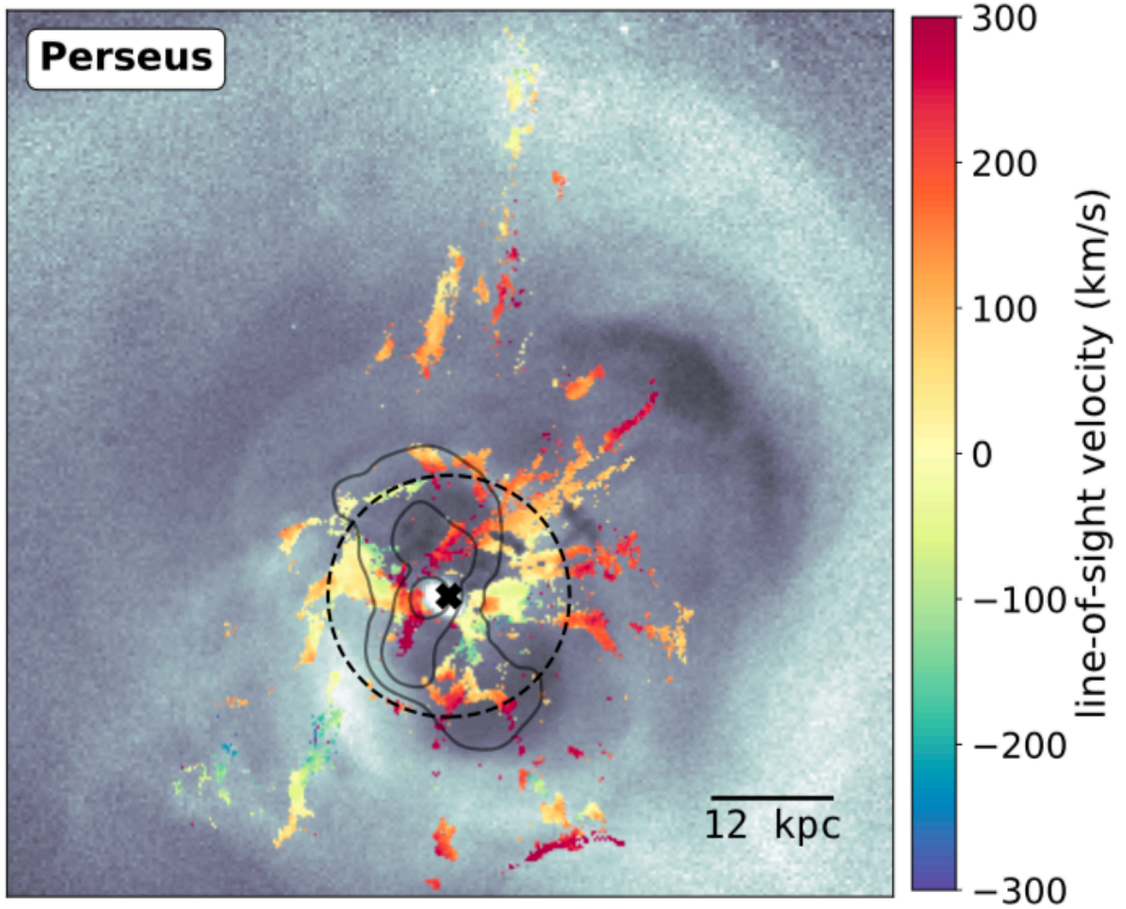
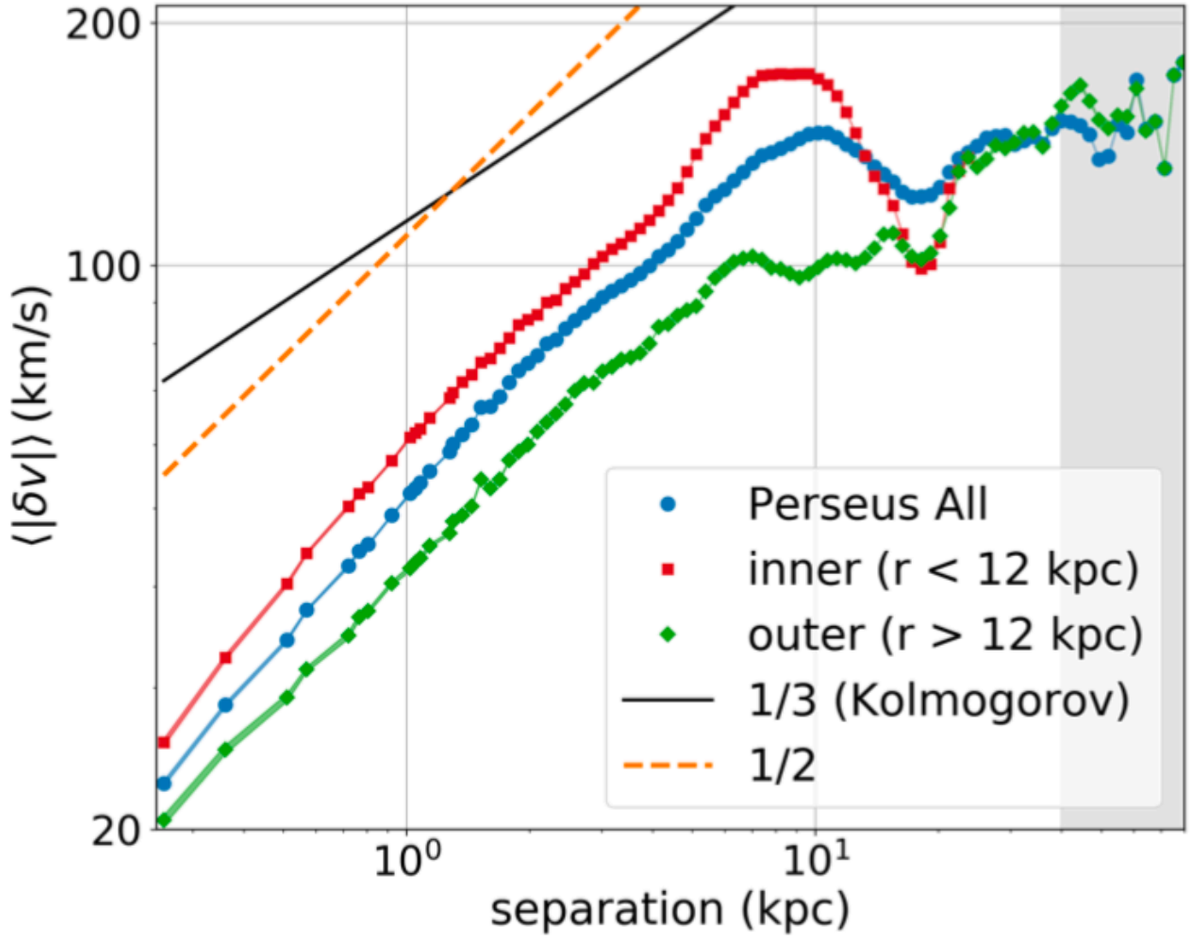


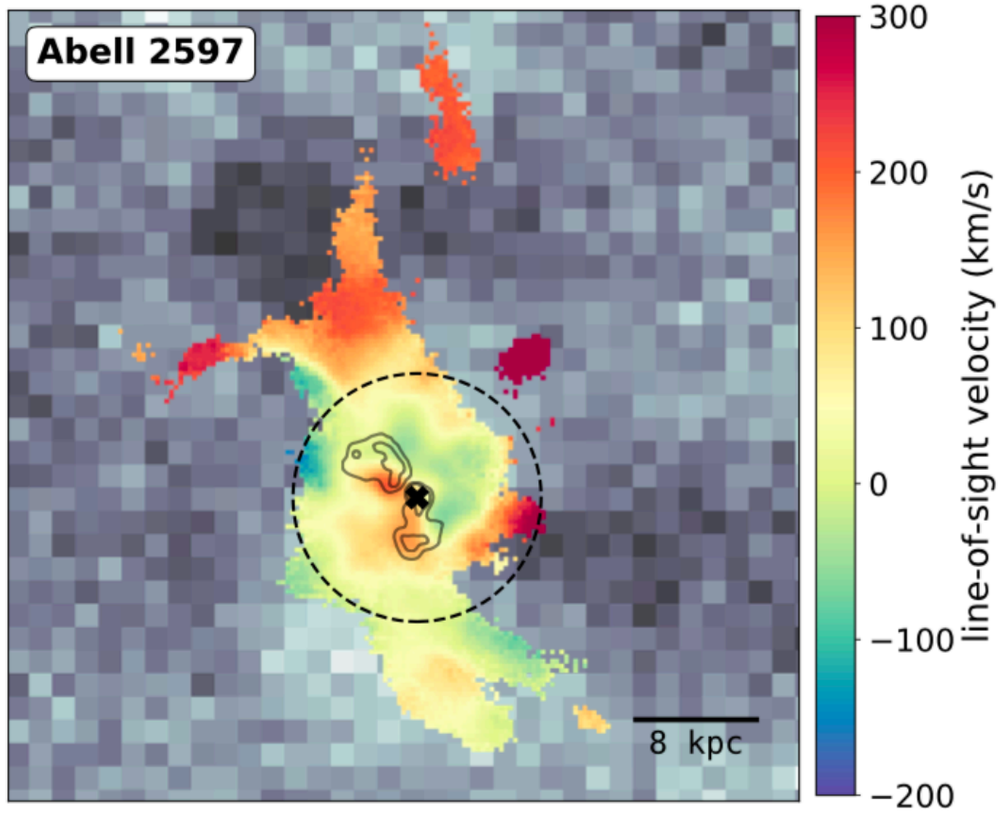


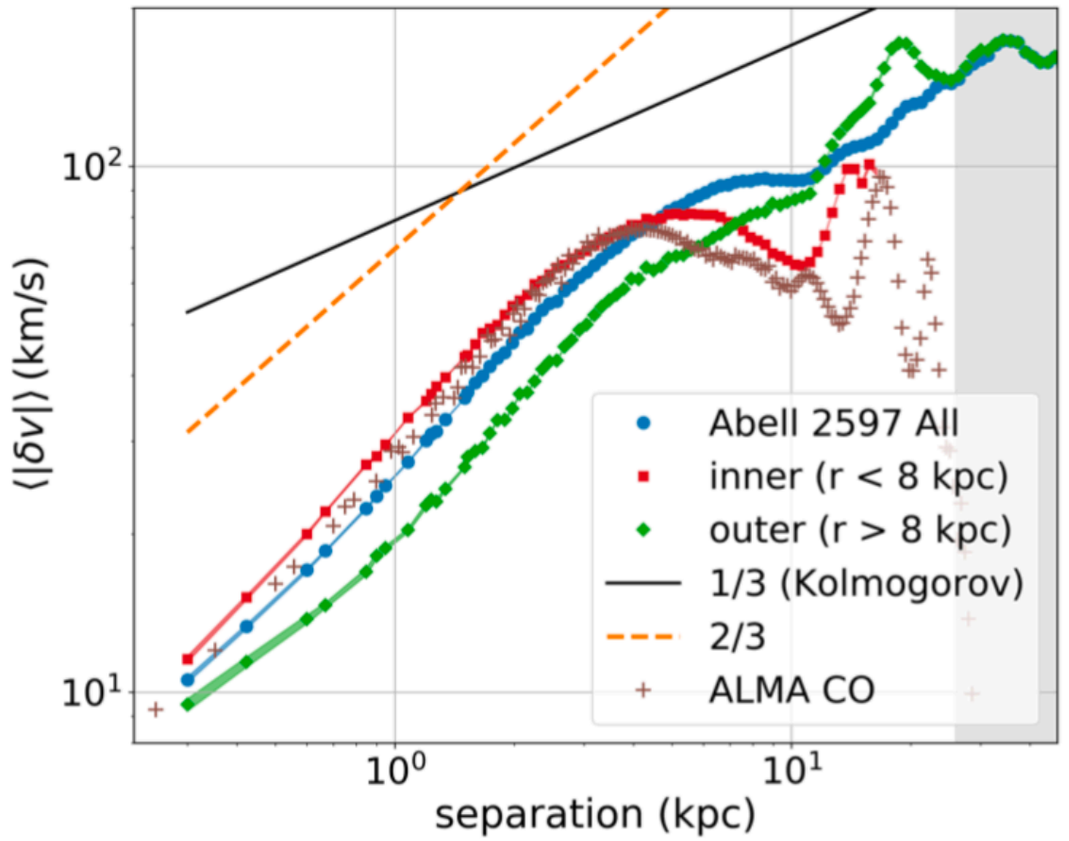


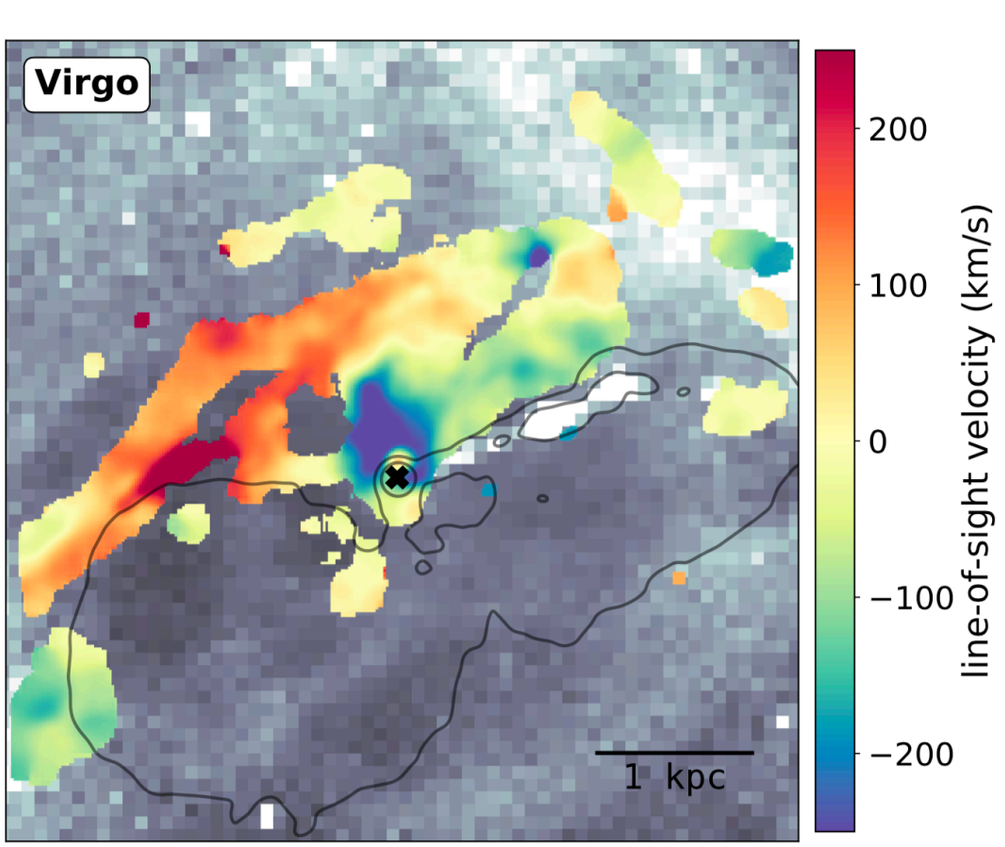
Li et al. 2020

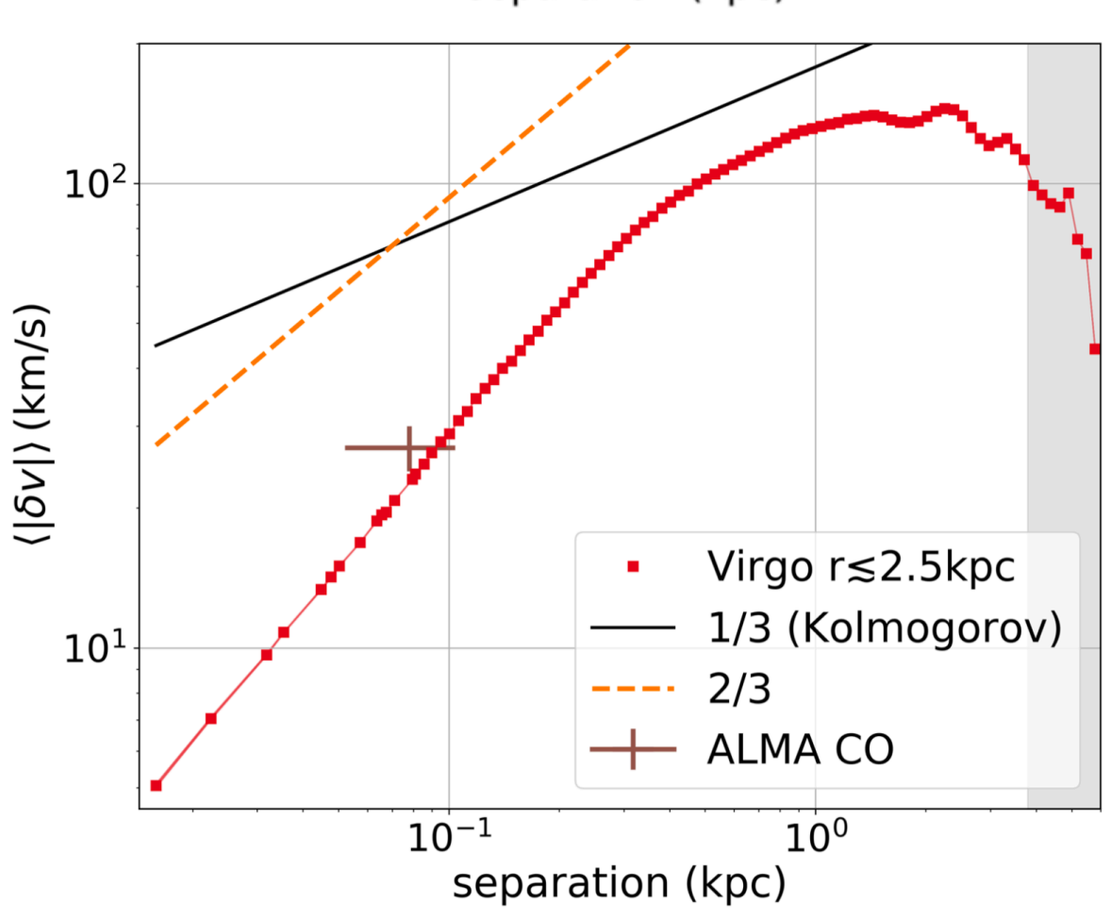
Motions of warm gas are turbulent (not ballistic!)

There is a clear correlation between injection scale of turbulence and size of AGN bubbles.


Abell 2597
8 kpc
300
200
100
0
−100
−200
line-of-sight velocity (km/s)

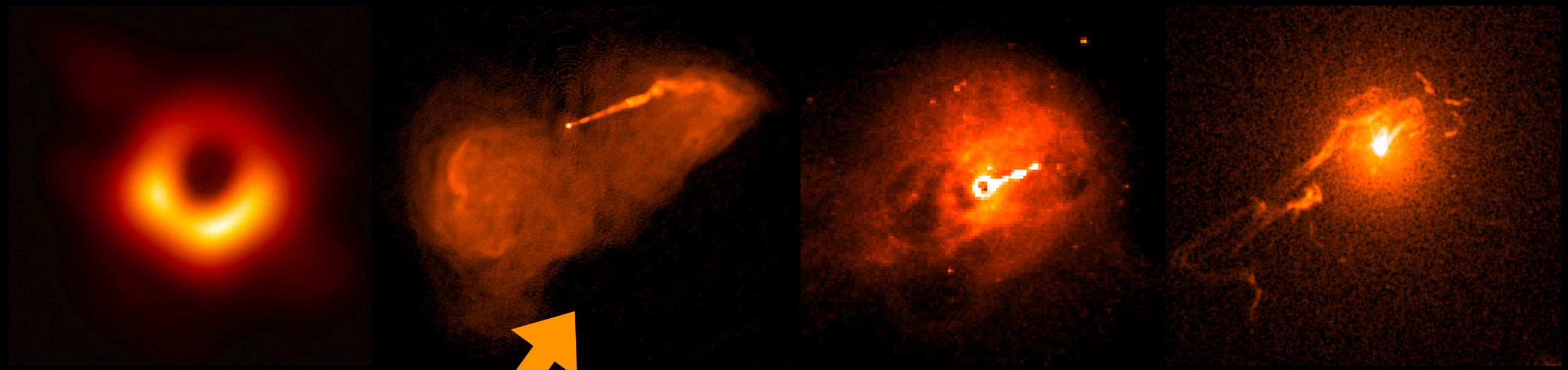

10^2
10^1
10^0
10^1
⟨|δv|⟩ (km/s)
separation (kpc)
Abell 2597 All
inner (r < 8 kpc)
outer (r > 8 kpc)
1/3 (Kolmogorov)
2/3
ALMA CO


Virgo
1 kpc
200
100
0
−100
−200
line-of-sight velocity (km/s)


10^2
10^1
10^{-1}
10^0
⟨|δv|⟩ (km/s)
separation (kpc)
Virgo r≲2.5kpc
1/3 (Kolmogorov)
2/3
ALMA CO

How does the SMBH feedback engine "run", i.e. how do its various components move and evolve in time?

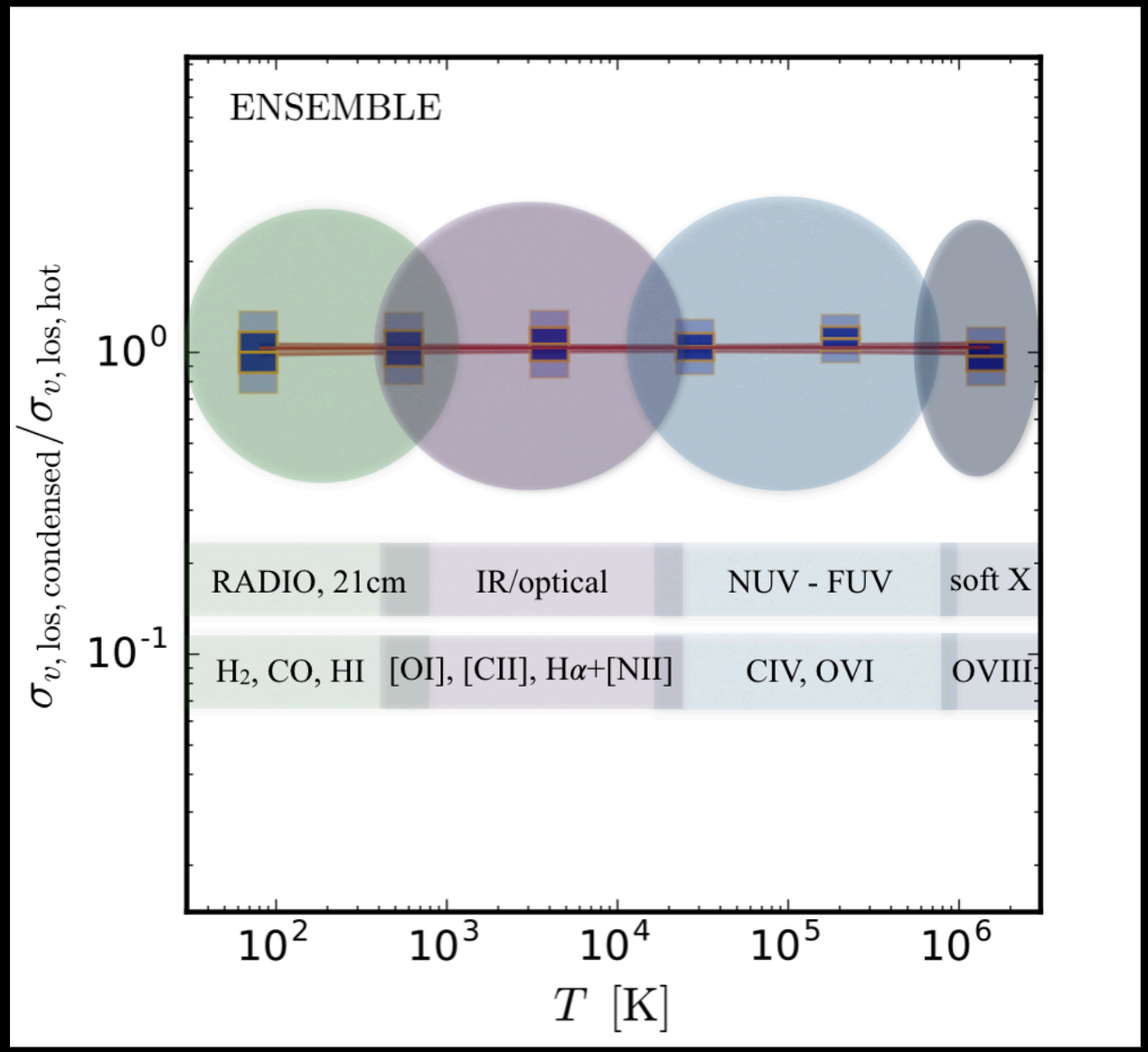
This part of the engine…

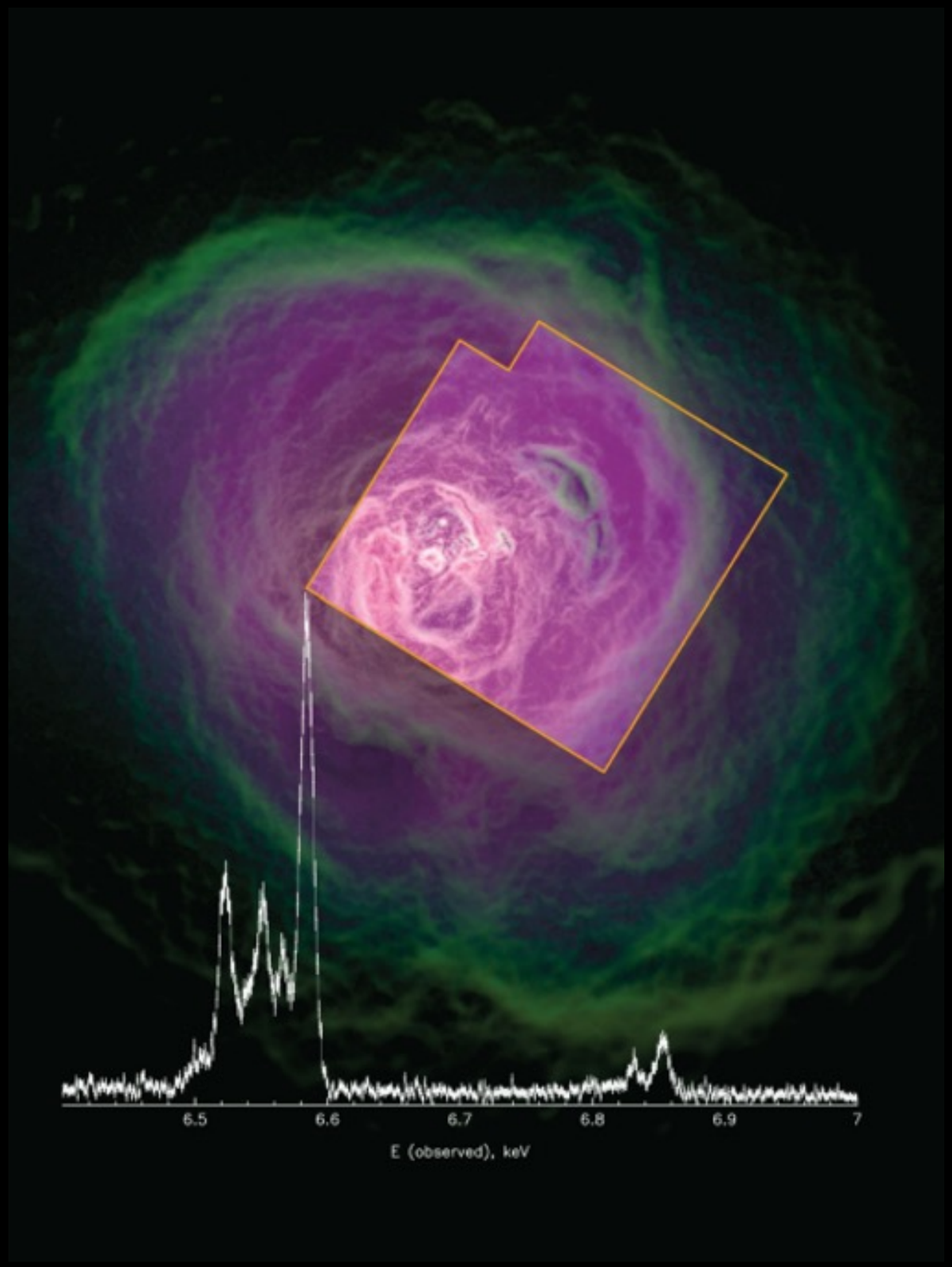


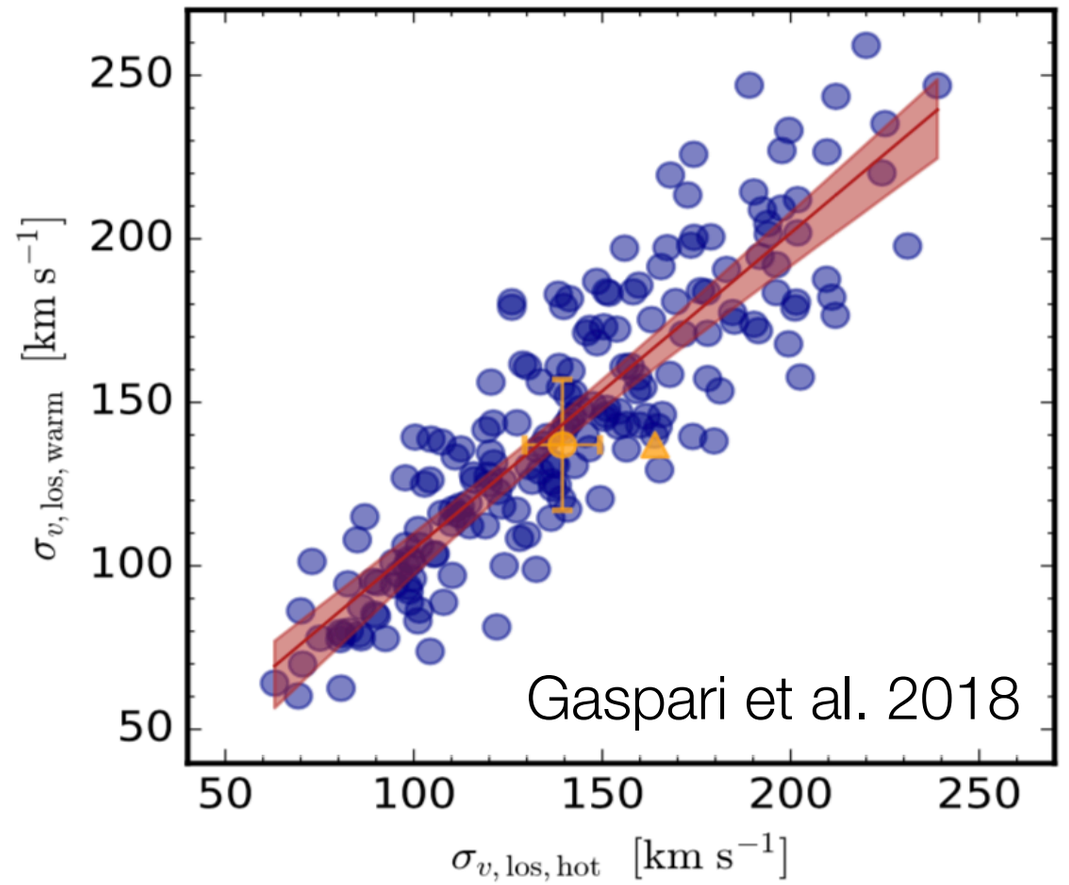
…is being driven by that moving part!

The ensemble velocity dispersion is expected to be tightly linked between all thermal phases

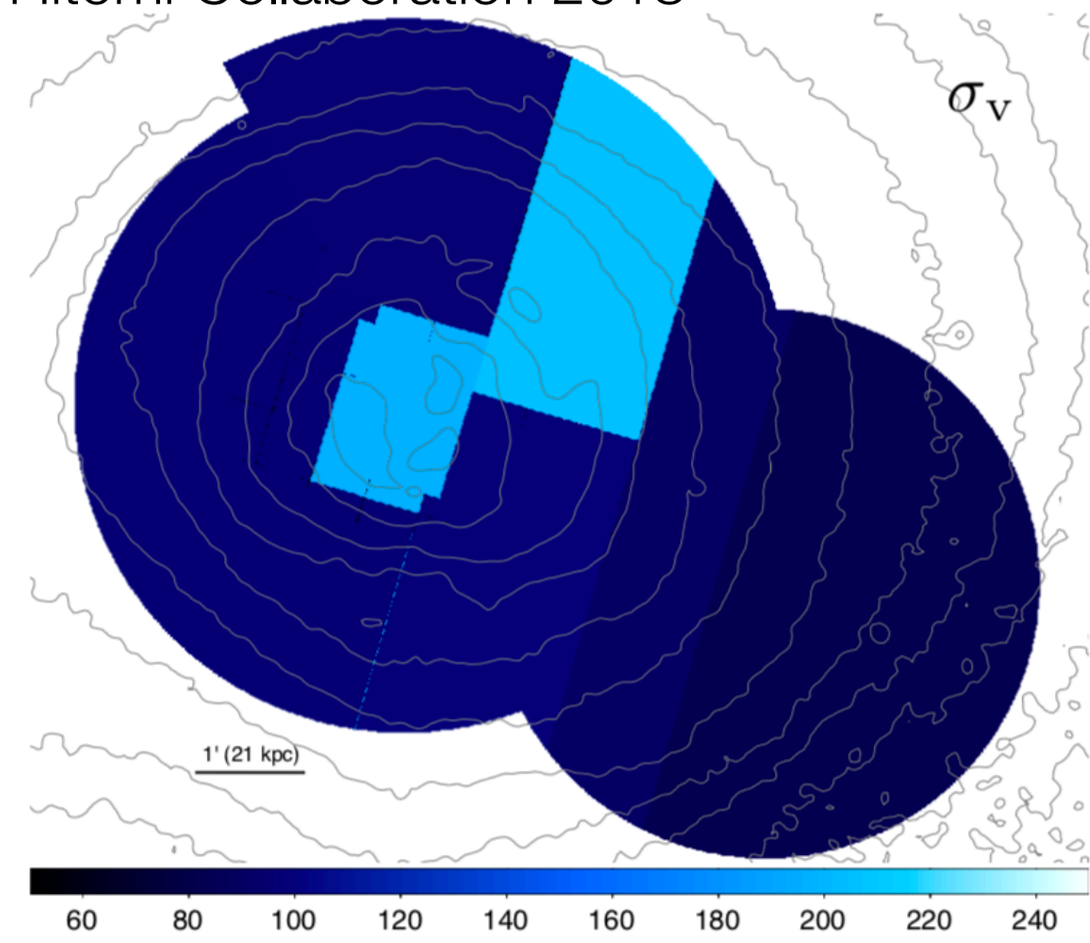
Gaspari et al. 2018

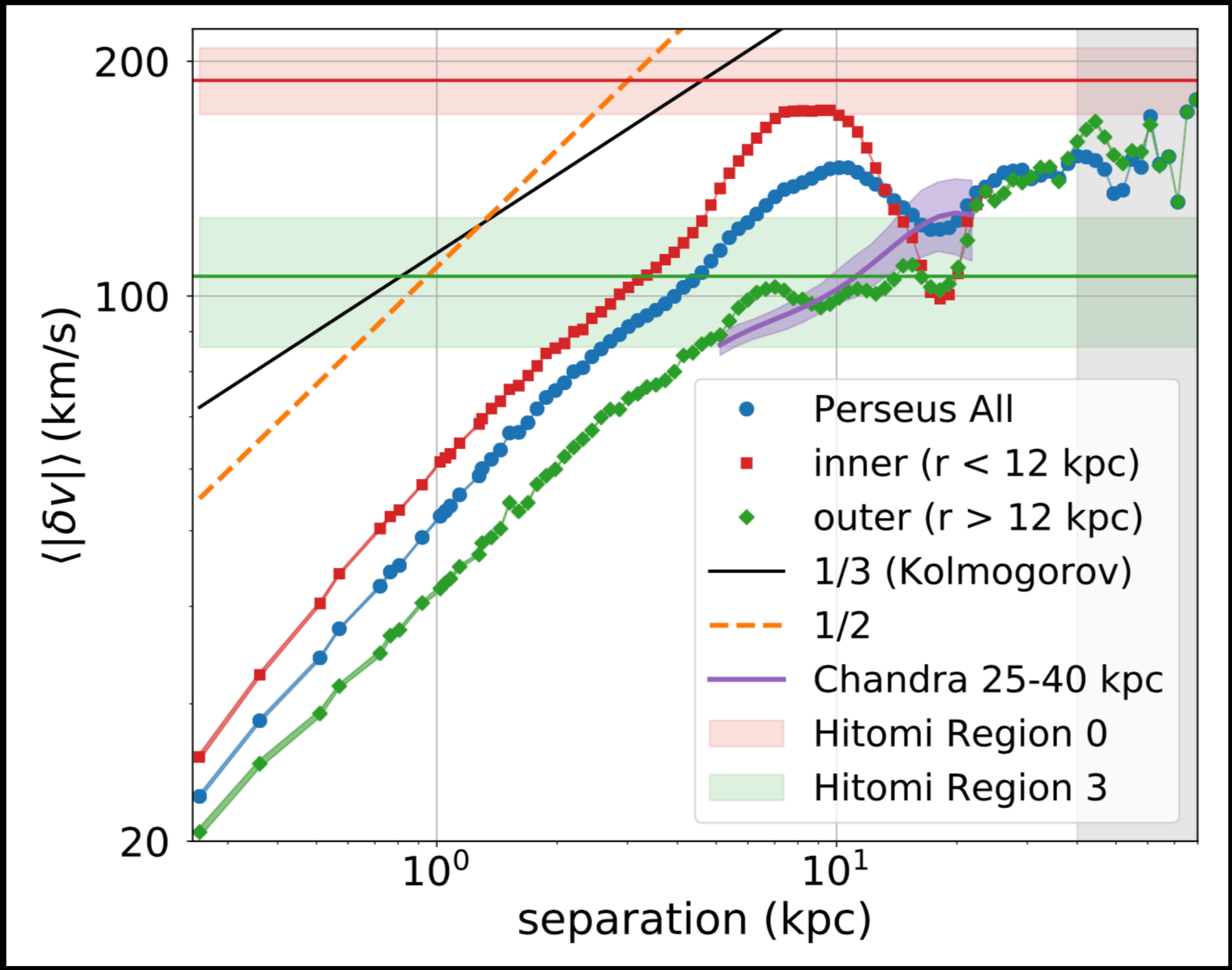






Hitomi Collaboration 2018



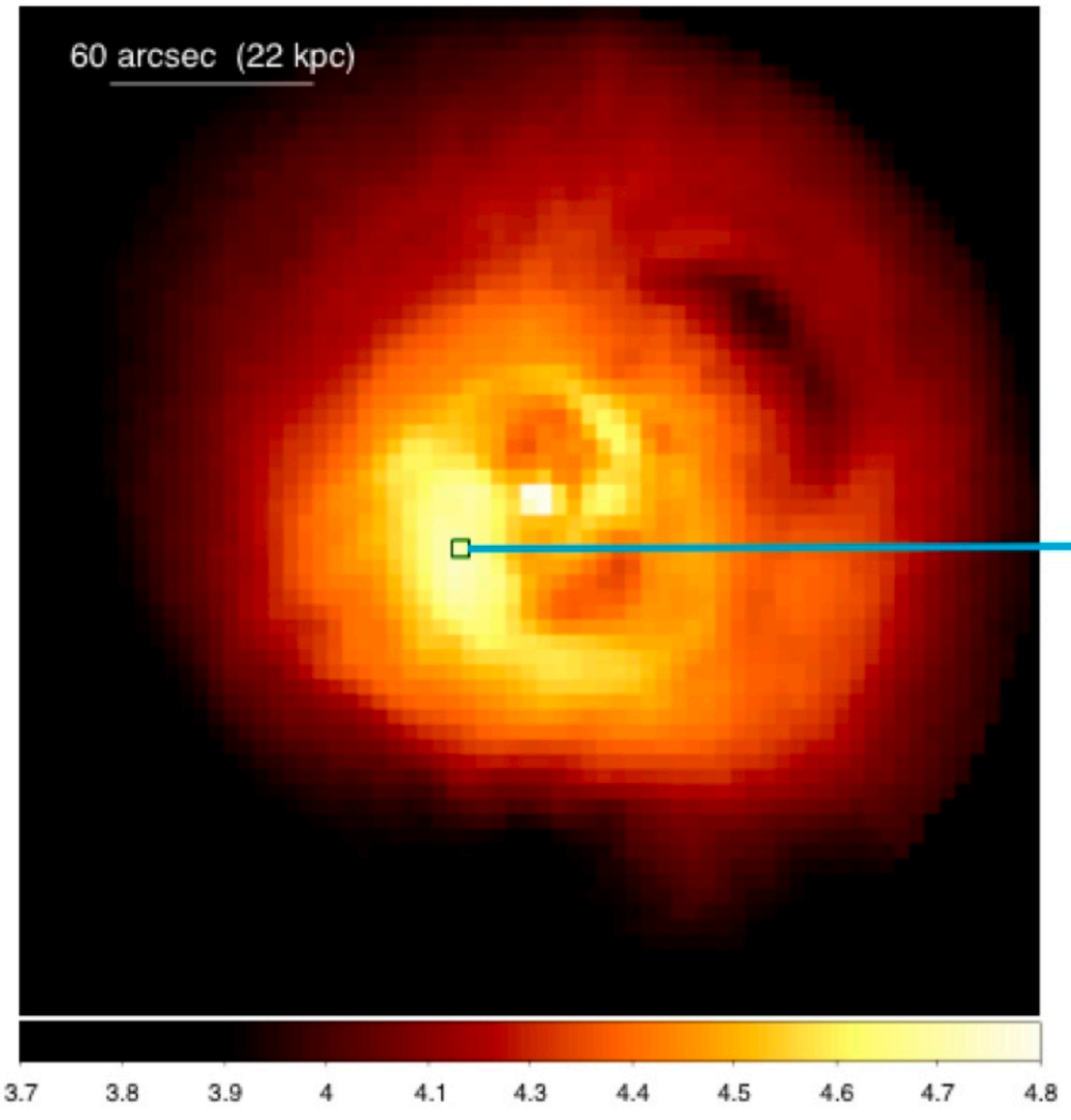


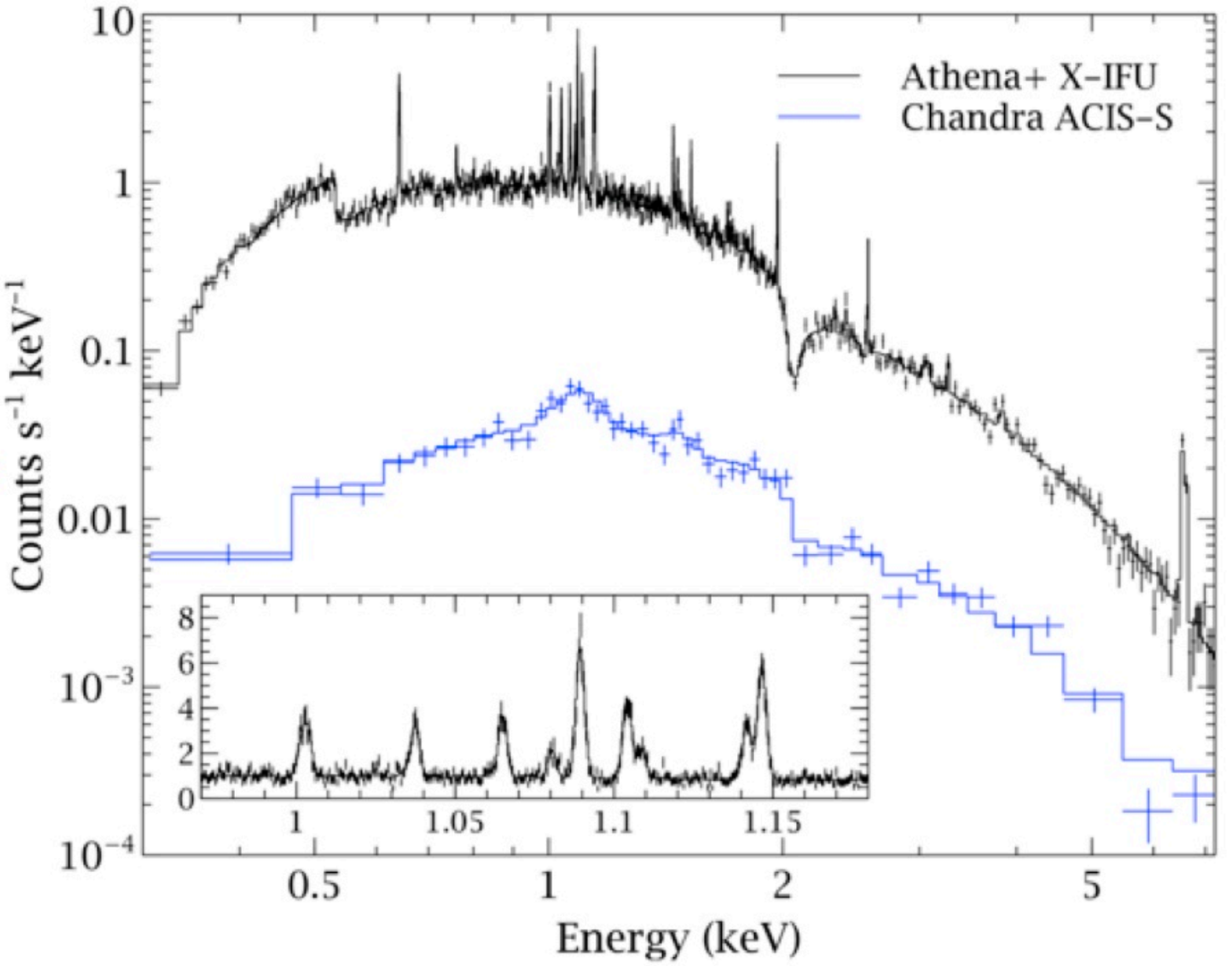
Li et al. 2020

Look forward to

XRISM X-Ray Imaging and Spectroscopy Mission

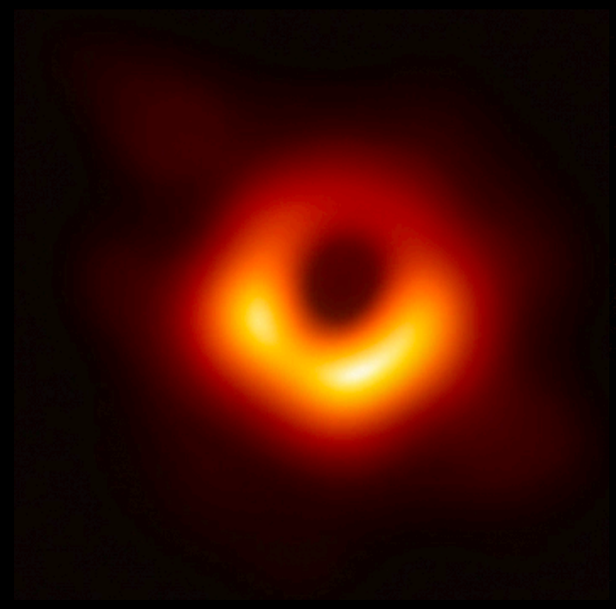
ATHENA X-ray Integral Field Unit

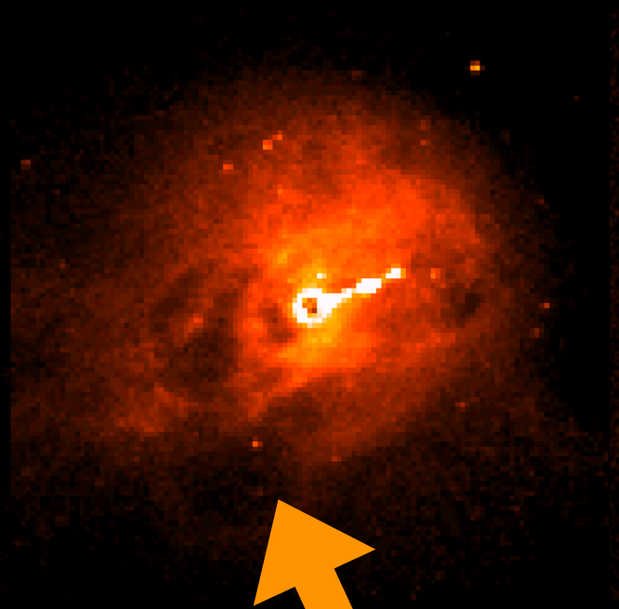


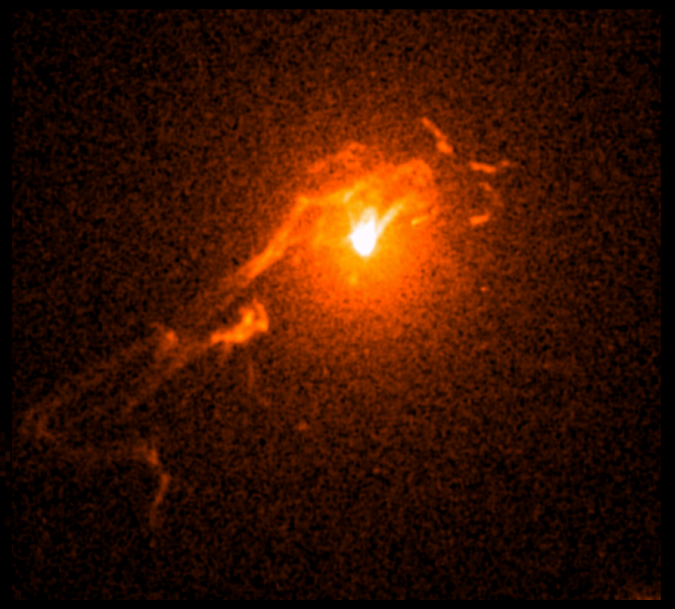


Croston et al. 2013

This part of the engine…



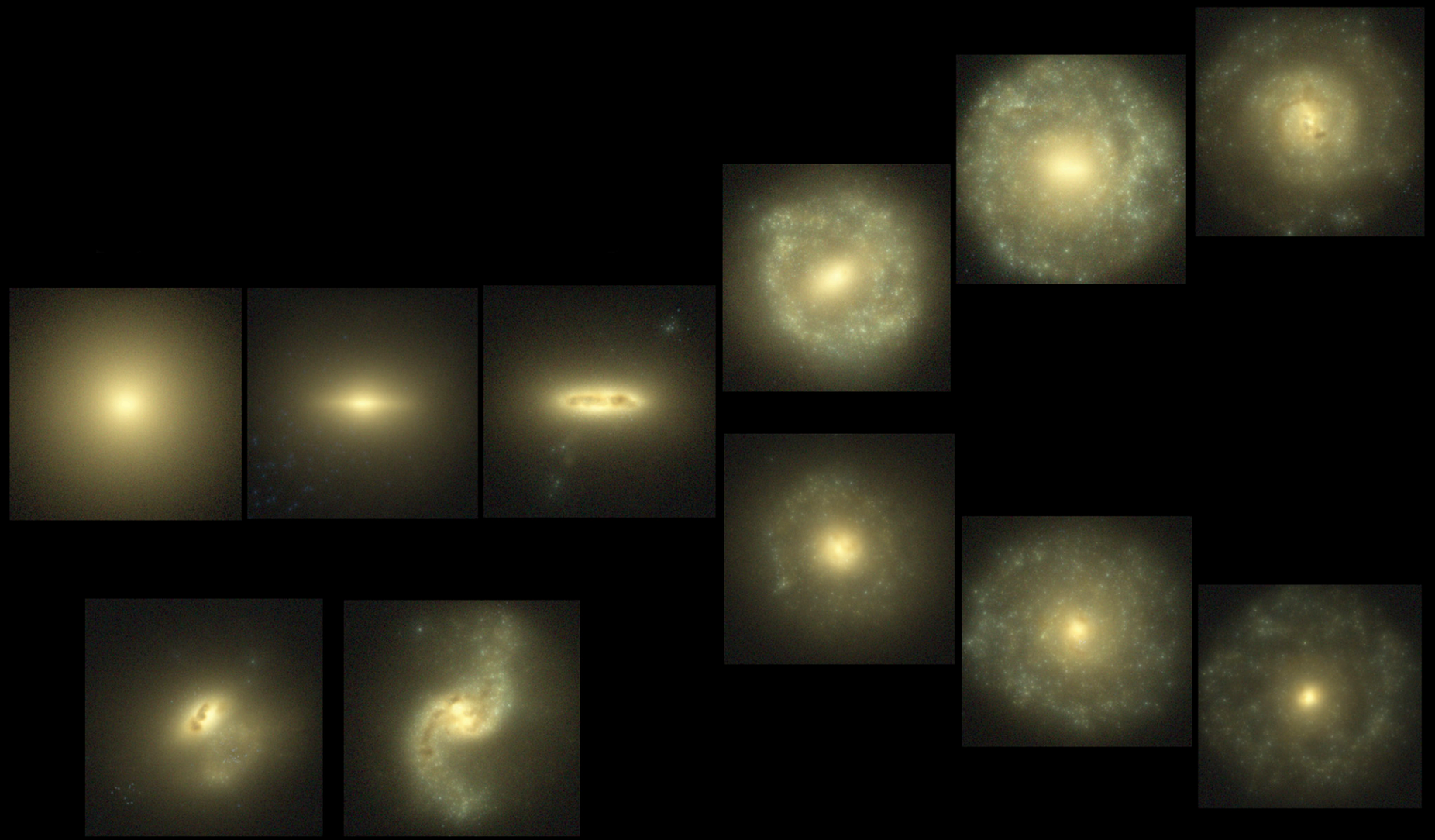




…is being driven by that part!

…and is probably moving in sync with that part

…but when the remaining amount of cold gas is low (the "engine" is about to switch itself off), various phases of the atomic vs molecular gas may actually decouple from each other.



"EAGLE" simulation,
Schaye et al. 2014

Even though modern numerical simulations can now produce "realistic" galaxies, their predictions for the X-ray phase vary by orders of magnitude for L* galaxies. Understanding the AGN feedback engine is the key for resolving this!