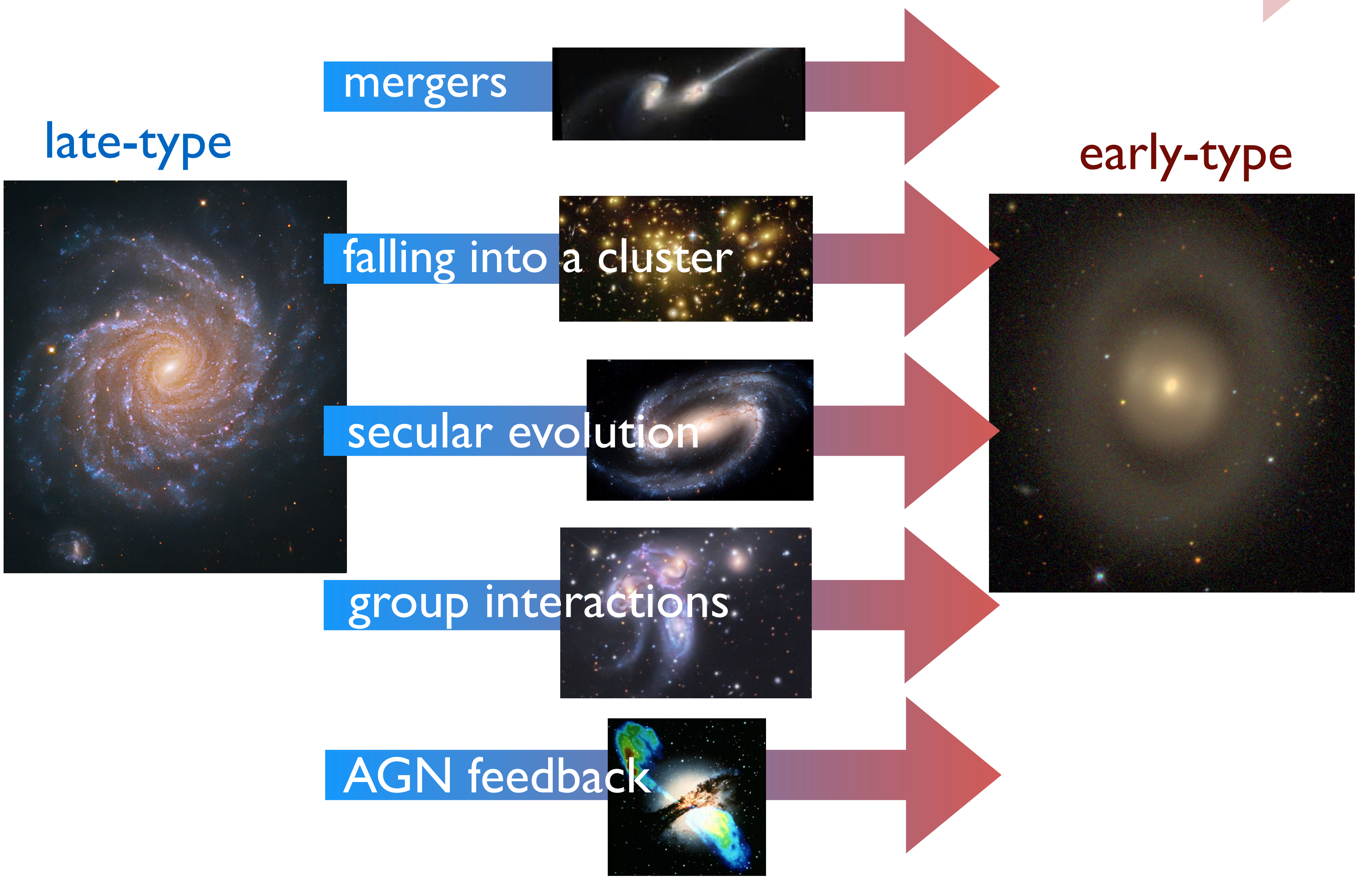
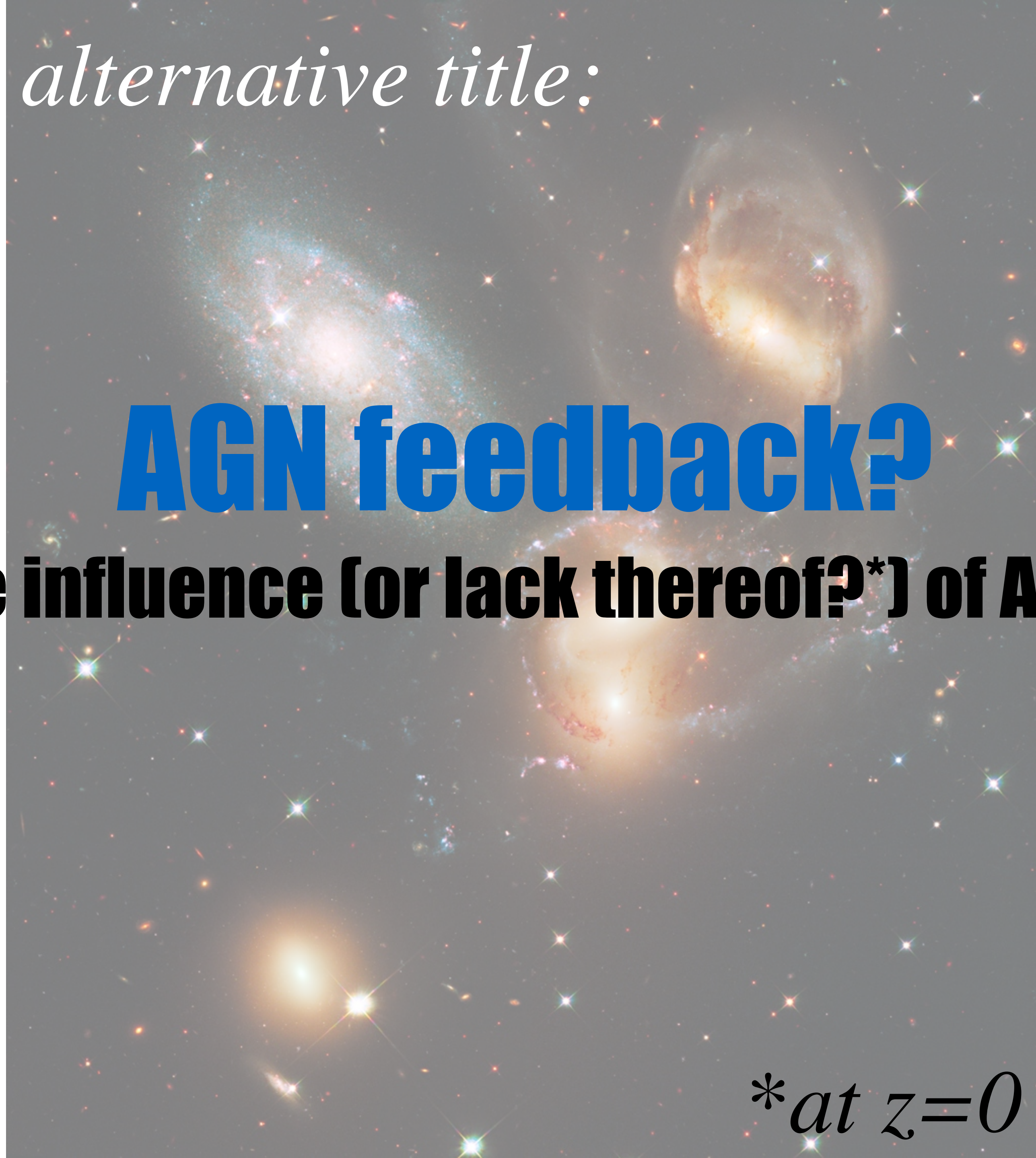
Molecular Outflows in AGN: The Role of ALMA

Katey Alatalo
Hubble Fellow
The Carnegie Observatories
kalatalo@carnegiescience.edu

with: Philip Appleton (IPAC), Theodoros Bitsakis (UNAM), Sabrina Cales (Yale), Philip Chang (UW - Milwaukee), Vassilis Charmandaris (U. Crete), Michelle Cluver (UCT), Tim Davis (Hertfordshire), P.T. de Zeeuw (ESO), Mike Dopita (ANU), Emily Freeland (Stockholm), Pierre Guillard (IAS), Tom Jarrett (UCT), Lisa J. Kewley (ANU), Mark Lacy (NRAO), Lauranne Lanz (IPAC), Ute Lisenfeld (U. Granada), Carol Lonsdale (NRAO), Sergio Martín (IRAM), David Meier (NMT, NRAO), Kristina Nyland (ASTRON), Patrick Ogle (IPAC), Jesper Rasmussen (Dark Cosmology Centre), Jeff Rich (IPAC/Carnegie), Lourdes Verdes-Montenegro (U. Andalucía), C. Kevin Xu (IPAC) and Min Yun (UMass - Amherst)

Paths to transition





alternative title:

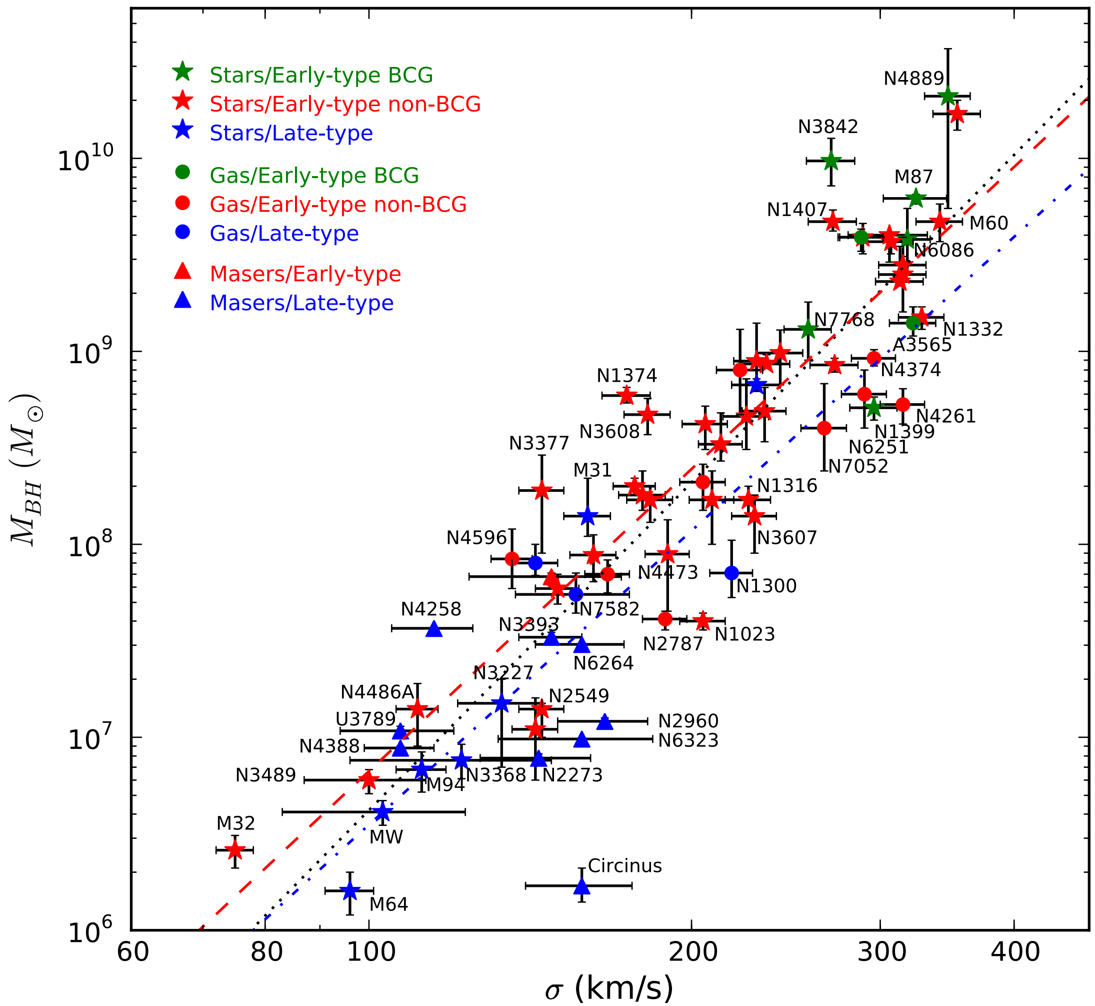
AGN feedback?

The influence (or lack thereof?*) of AGNs

**at z=0*

Why AGN feedback?

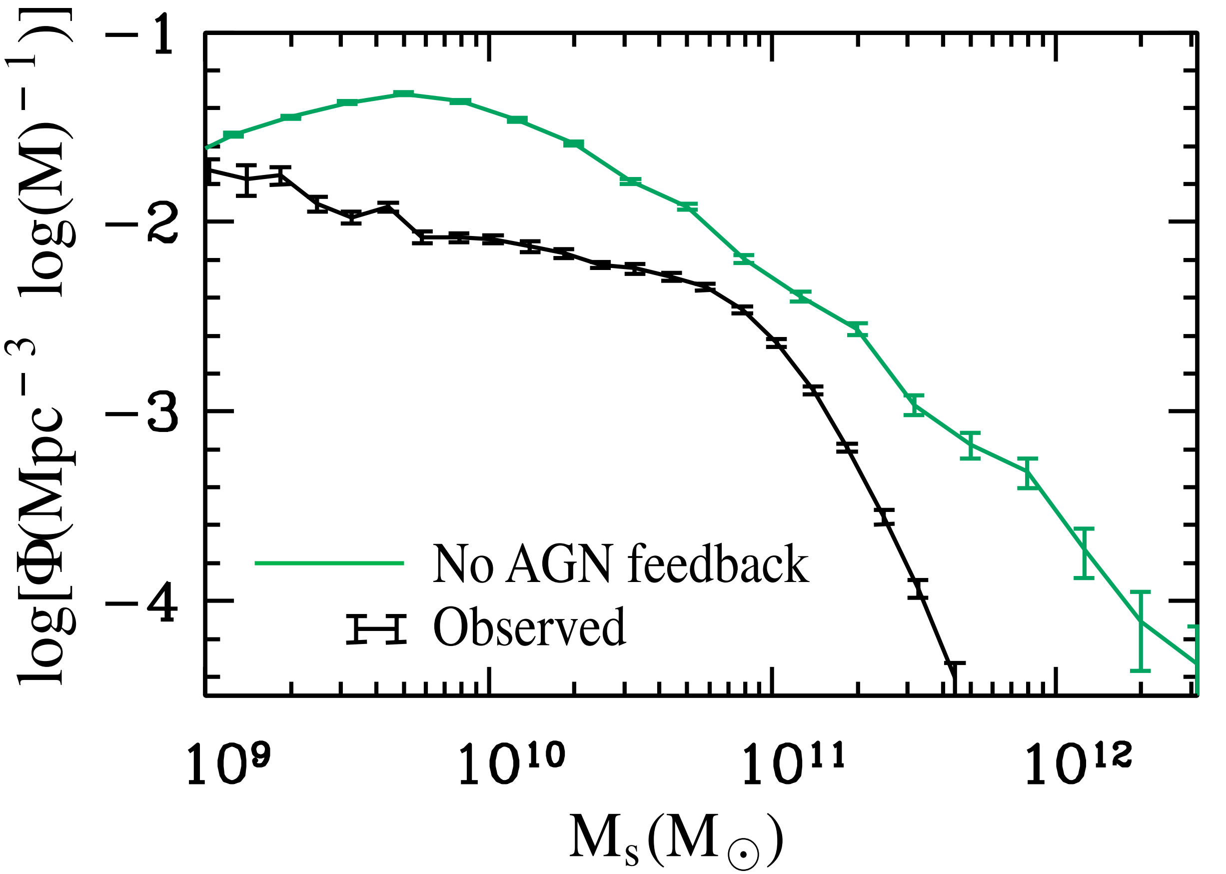
The masses of central black holes and bulges are correlated, suggesting co-evolution



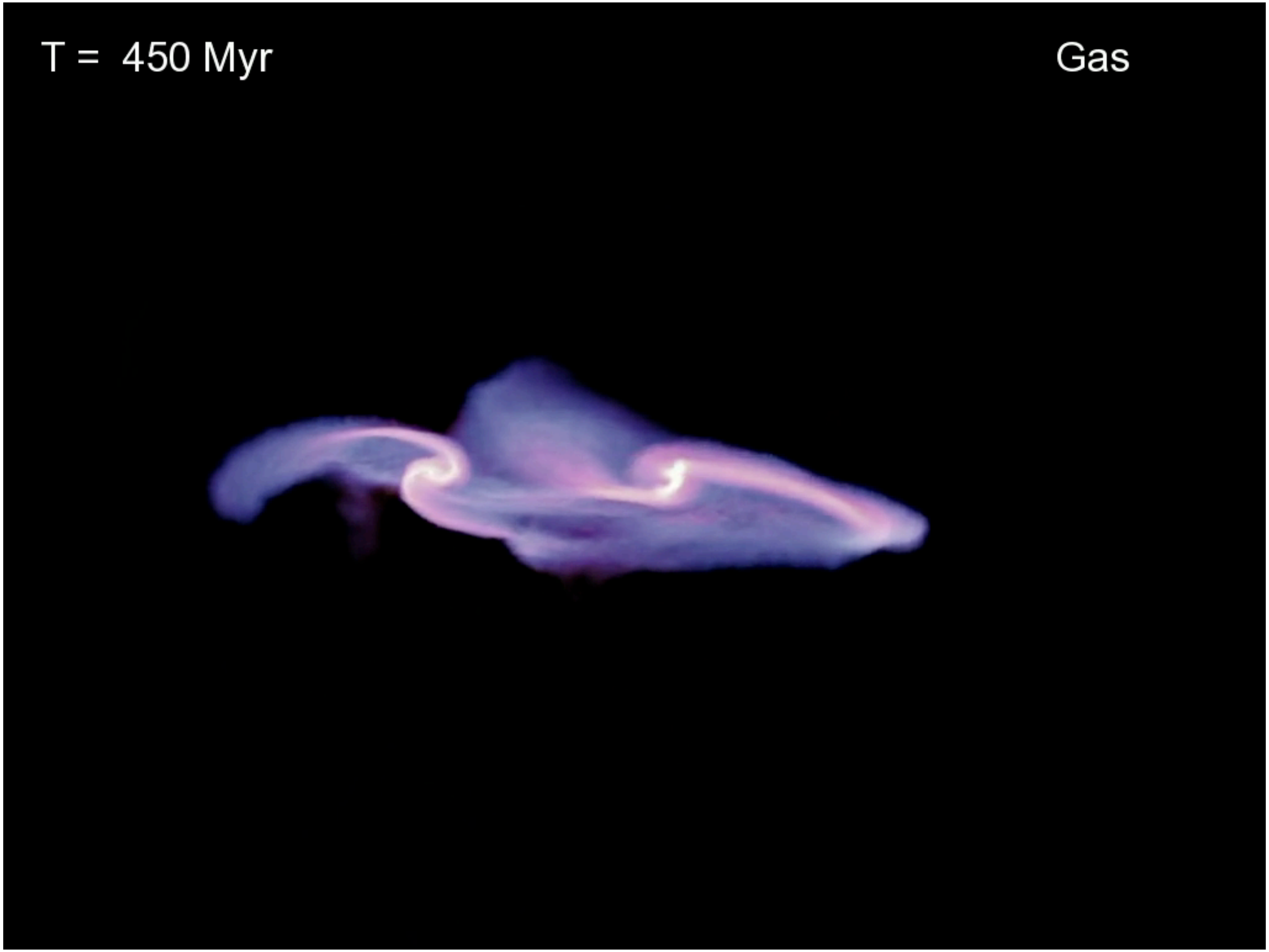
McConnell & Ma 2013

Why AGN feedback?

Simulations are not able to reproduce the observed galaxy mass distribution without feedback —they make too many very massive galaxies

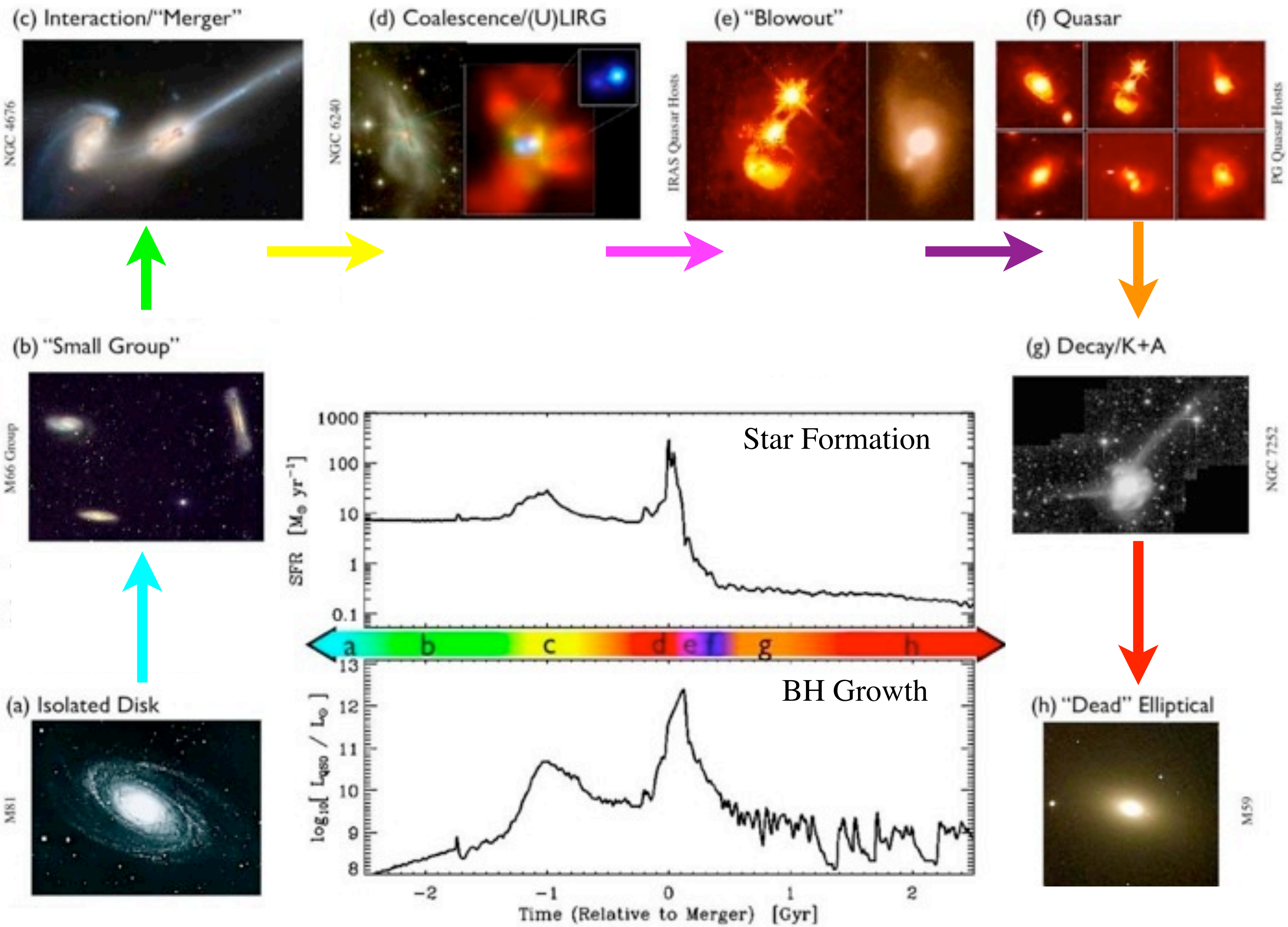


Bell et al. 2003, Oppenheimer & Davé 2010



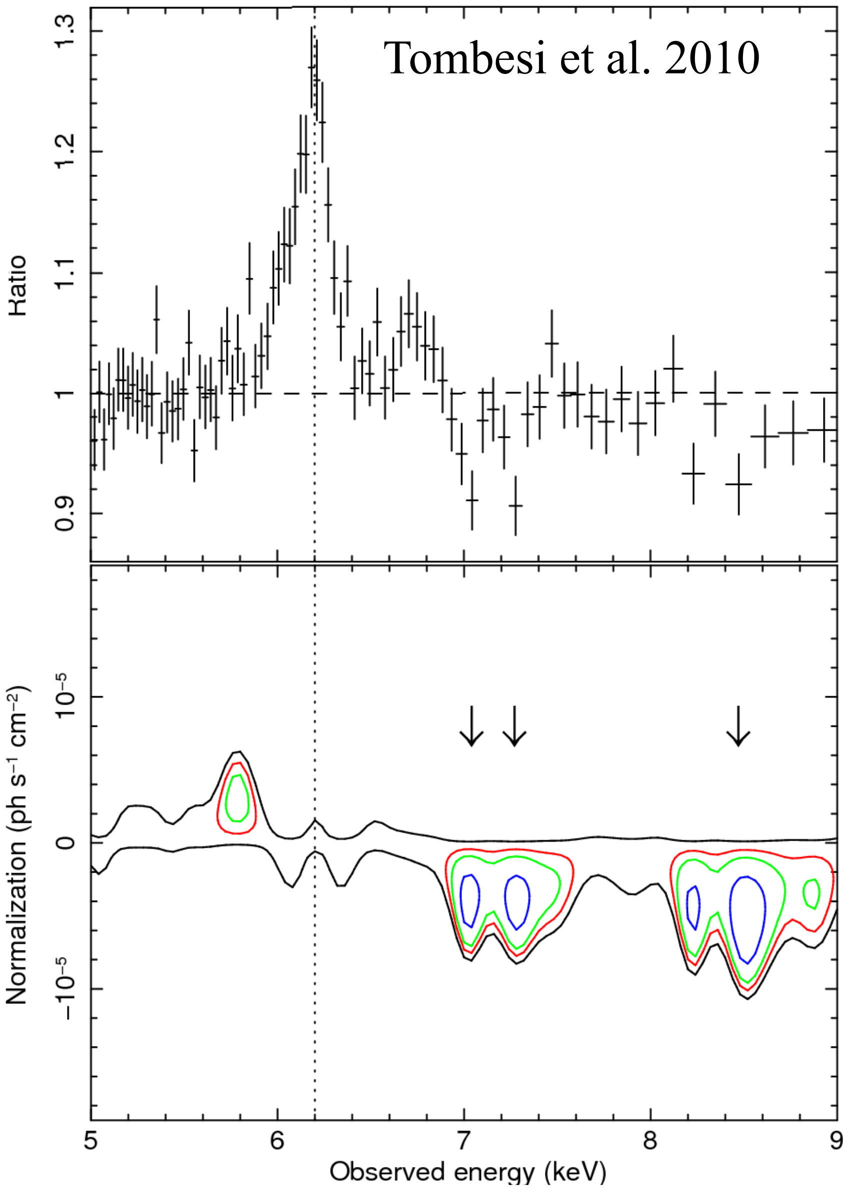
Credit: Volker Springel, Phil Hopkins

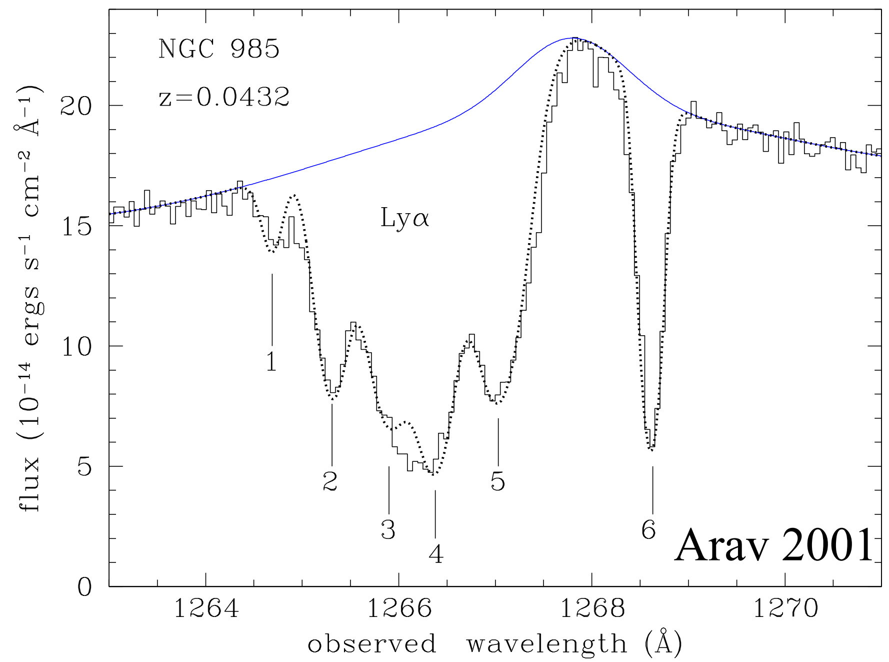
“Plugging in” AGN feedback



Hopkins et al. 2008

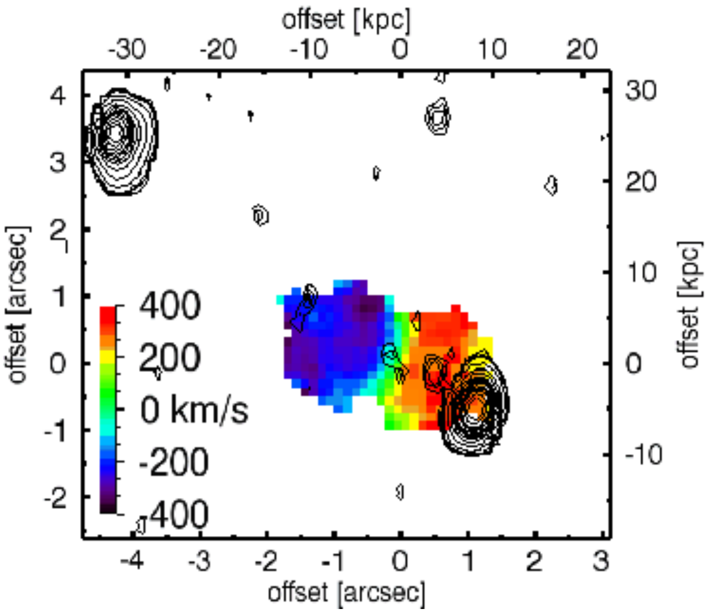
Finding AGN outflows



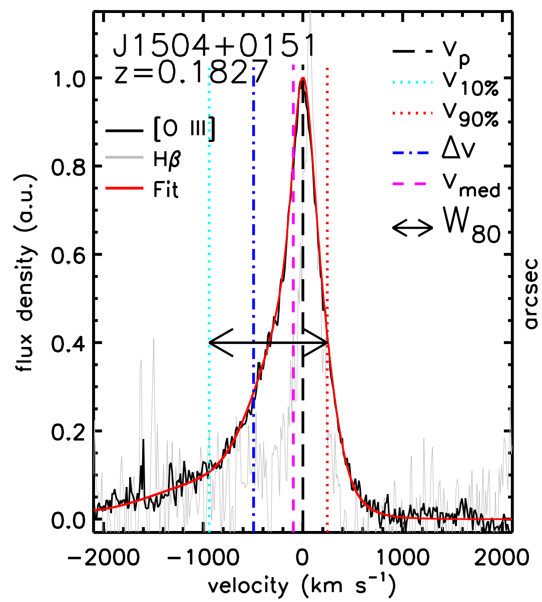


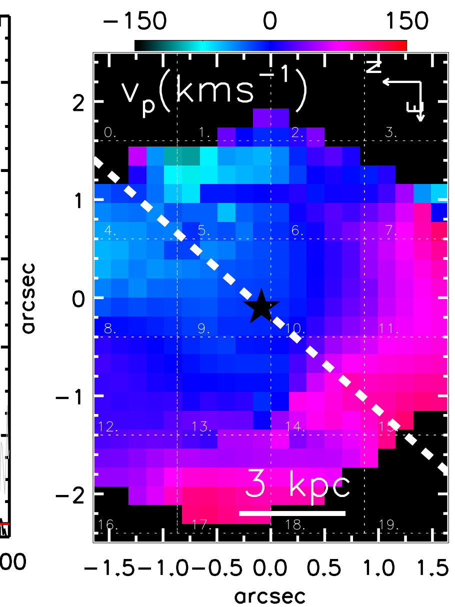
Near ubiquitous high-*v* outflows (*v*~0.1c) have been reported in UV and X-rays

AGN outflows: ionized gas



Nesvadba et al. 2008



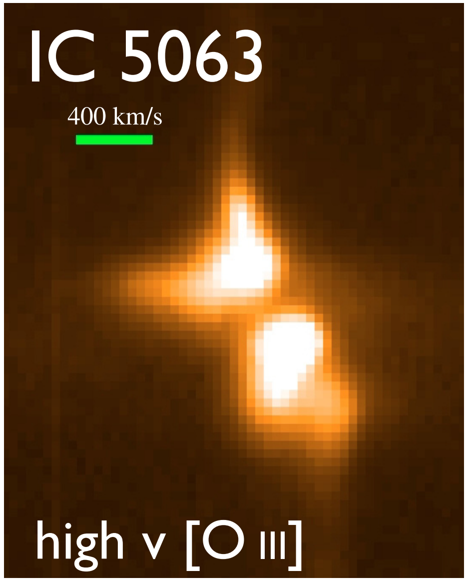


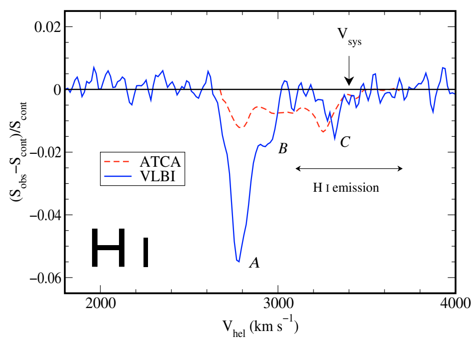
Harrison et al. 2014

AGN outflows were then discovered in [O III] in bright radio galaxies

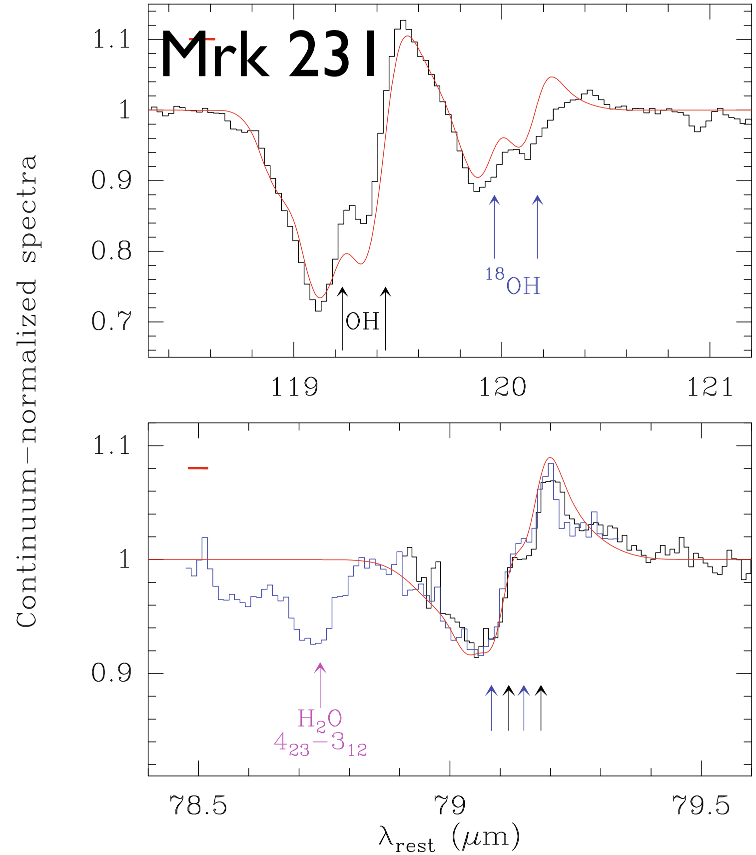
Then a systematic [O III] IFU study of normal star forming AGN hosts confirmed that ionized gas outflows were nearly ubiquitous as well

AGN outflows: neutral ISM





Morganti et al. 2007



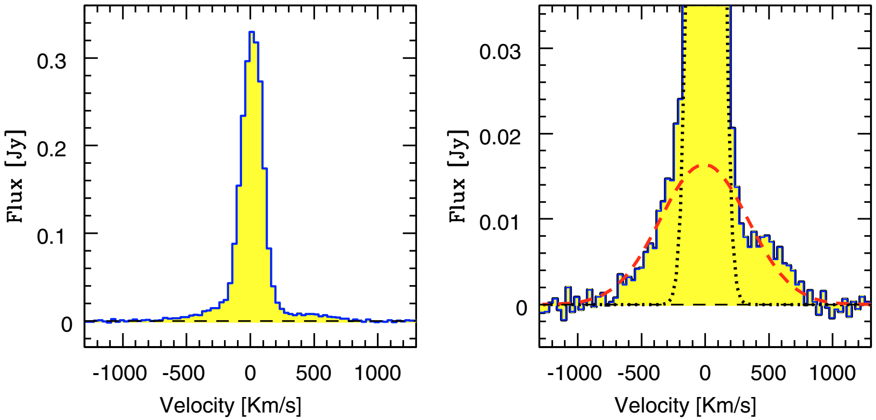
Fischer et al. 2010; Sturm et al. 2011

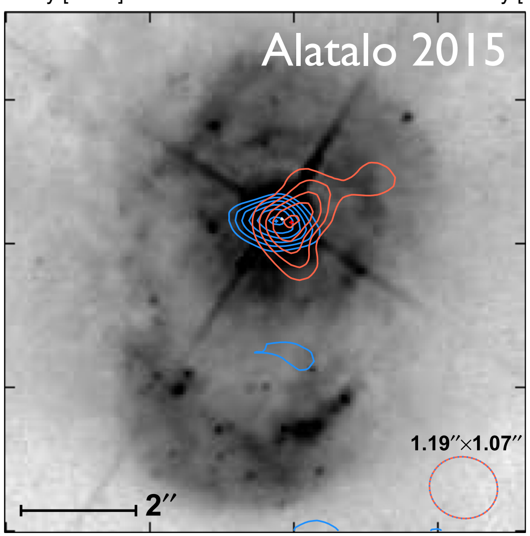
Blue-shifted H I absorption was reported in many radio galaxies

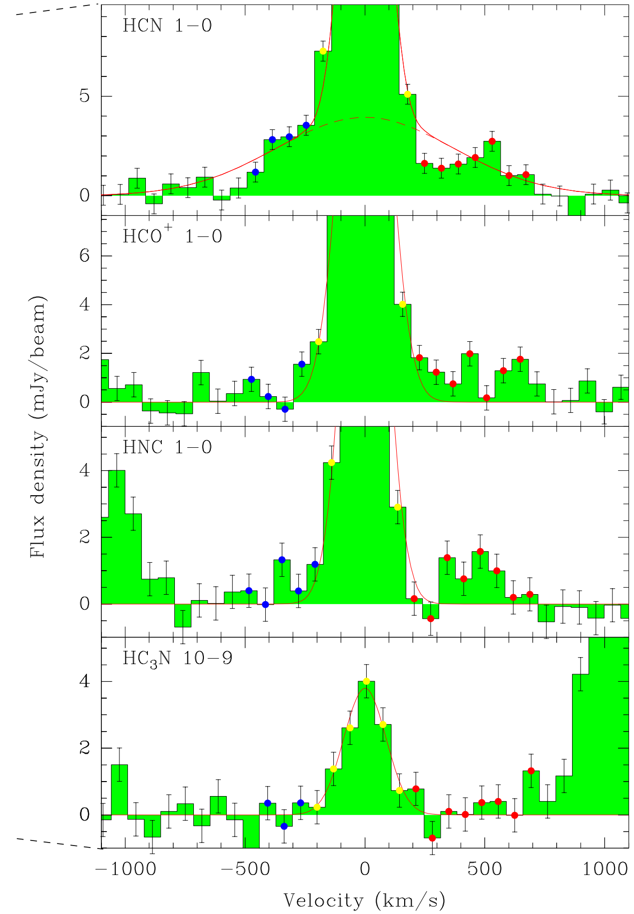
Herschel observations of nearby ULIRGs show P-Cygni profiles in OH, a sign of outflow

AGN outflows: molecular gas

Feruglio et al. 2010



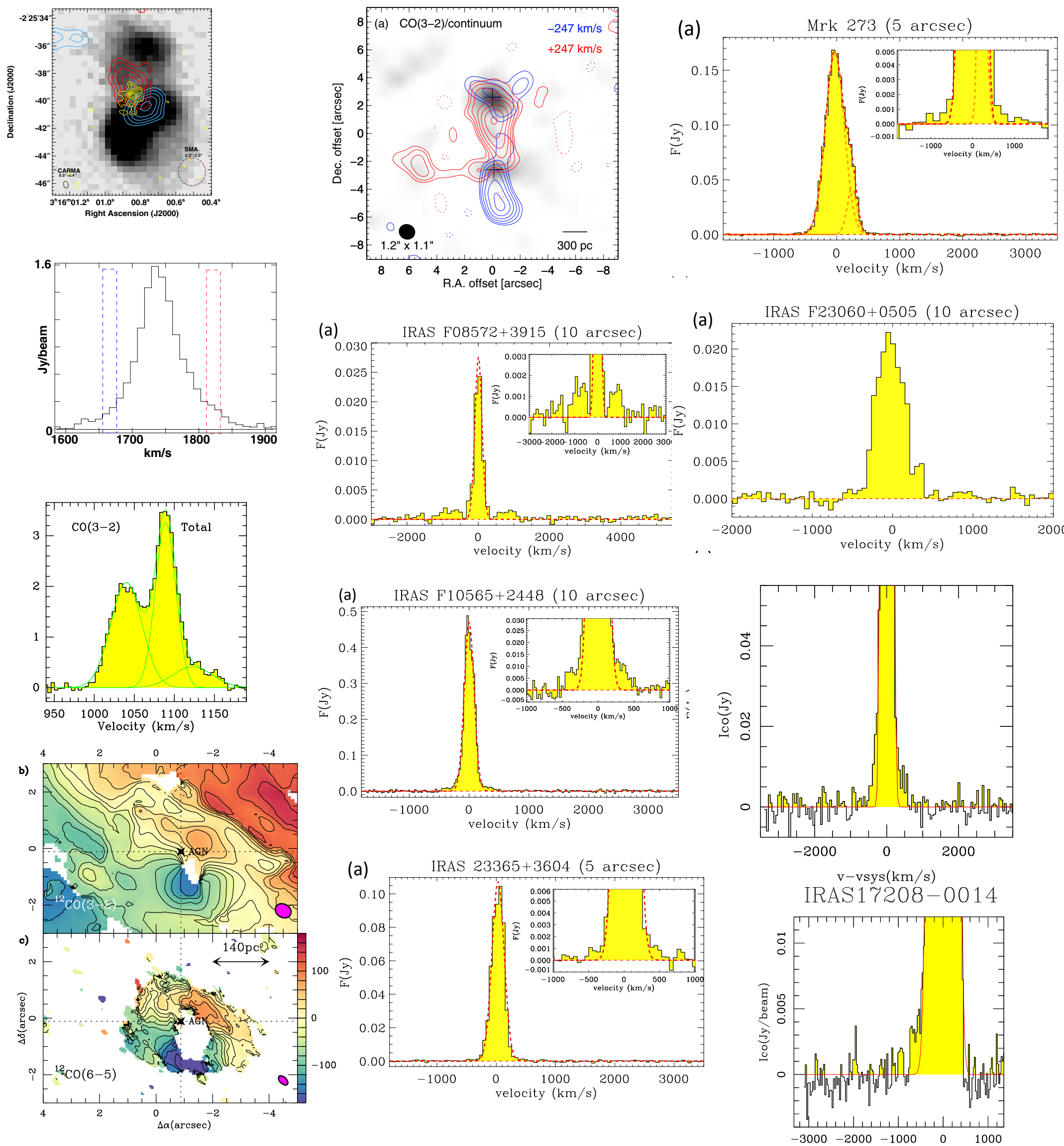




Aalto et al. 2012a

Mrk 231 was the first AGN-driven molecular outflow discovered in CO(1-0), and later in dense gas

More outflows discovered since Mrk 231…



Mrk 231

NGC1266

Alatalo et al. 2011

NGC1377

Aalto et al. 2012b

NGC1433

Combes et al. 2013

NGC1068

Garcia-Burillo et al. 2014

NGC3256

Sakamoto et al. 2014

IRAS F08572+3915

IRAS F10565+2448

IRAS 23365+3604

Mrk 273

IRAS F23060+0505

Cicone et al. 2014

NGC1614

IRAS 17208-0014

Garcia-Burillo et al. 2015

NGC 1266

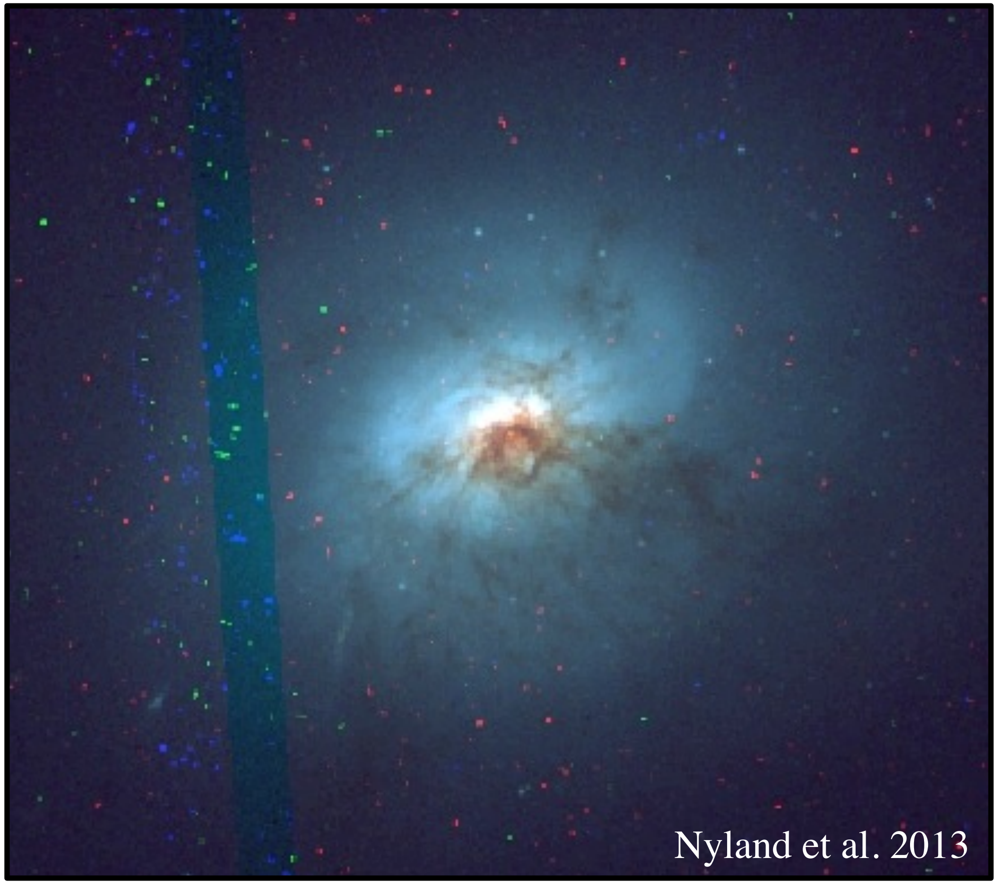
NGC 1266 appears to be a “quiescent” S0

NGC 1266 hosts a massive molecular disk (>10^9 $M_\odot$)
and a massive (>10^8 $M_\odot$) molecular outflow that is multiphase

NGC 1266 contains an AGN

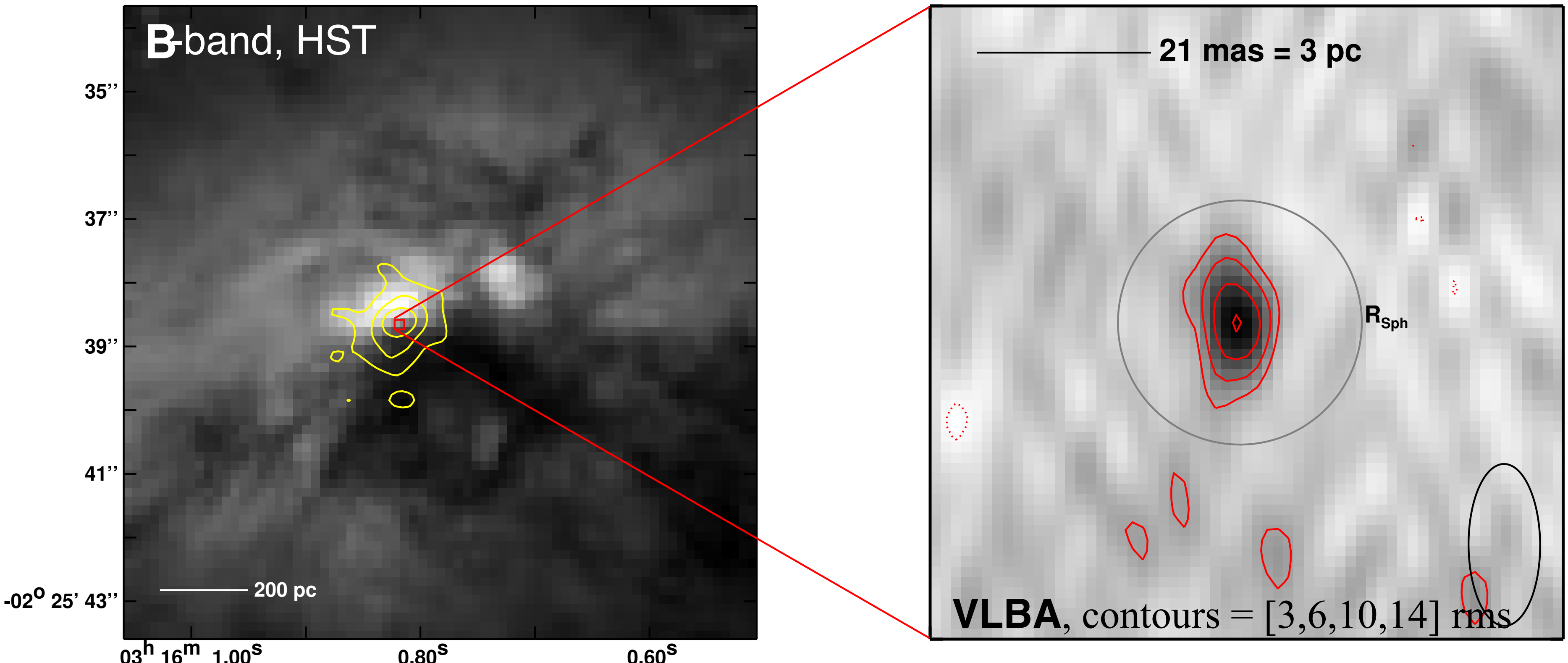
A young (1/2 Gyr) stellar population outside the nucleus points to a gravitational interaction causing the molecular gas to move to the center

Star formation is suppressed by a factor of 50-150 seen in the nucleus



Alatalo et al. 2011, 2014a, 2015a

NGC 1266 contains an AGN



(contours at [-3,3,6,10,14] times the rms)

VLBA $T_b \sim 1.5\times10^7$ K, but only recovered 2% of VLA A-array flux

VLBA data were able to resolve the AGN sphere of influence and pinpoint the position of the AGN

Currently, the AGN is still unresolved.

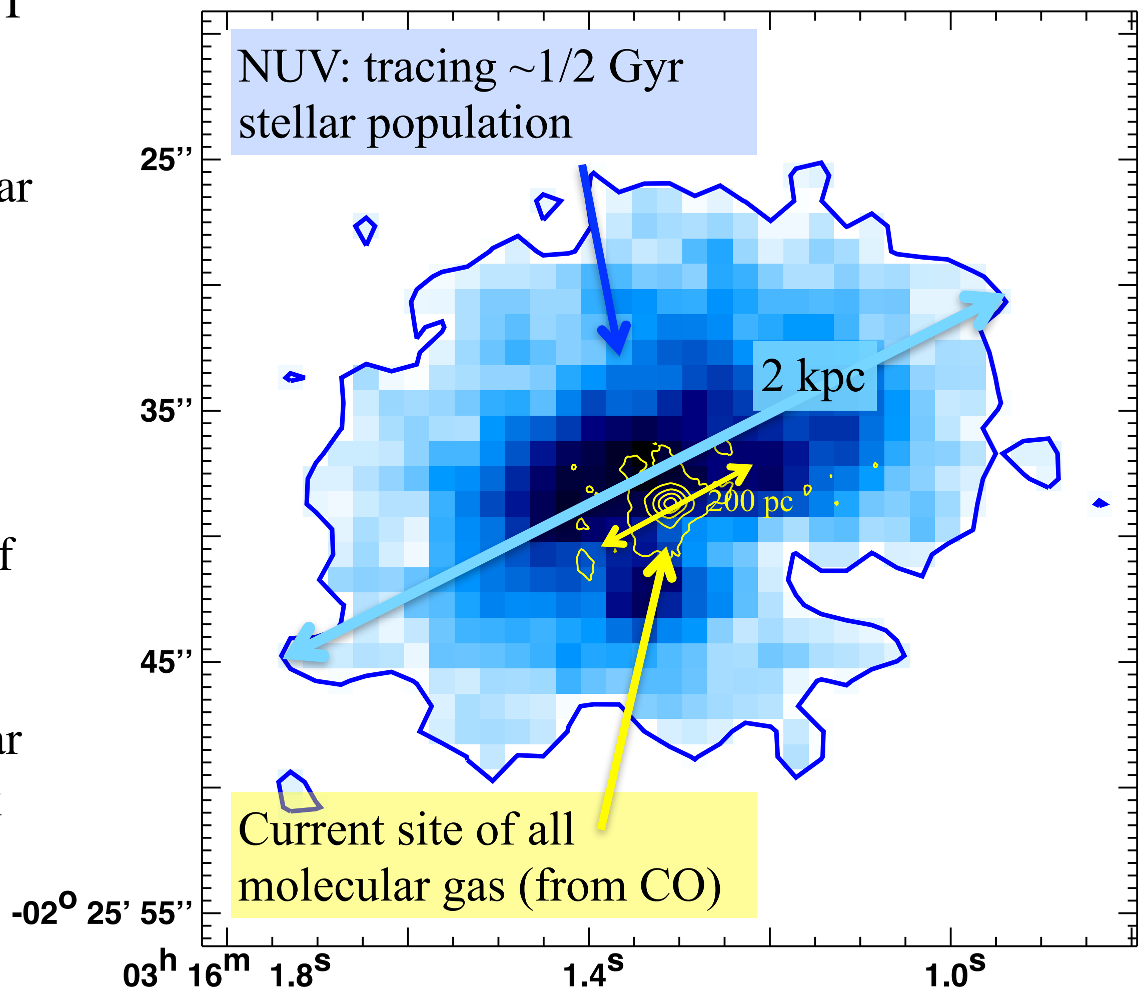
Nyland et al. 2013

NGC 1266 is a poststarburst galaxy

NUV imaging from the *Swift* UVOT as well as GALEX show a much larger distribution of young stars than the current site of the molecular gas

A stellar population analysis of the spectrum from Moustakas & Kennicutt (2006) shows that the stellar population is poststarburst of age (~500 Myr)

SAURON Hβ absorption and stellar population synthesis mapping back up the UV data, showing a young population



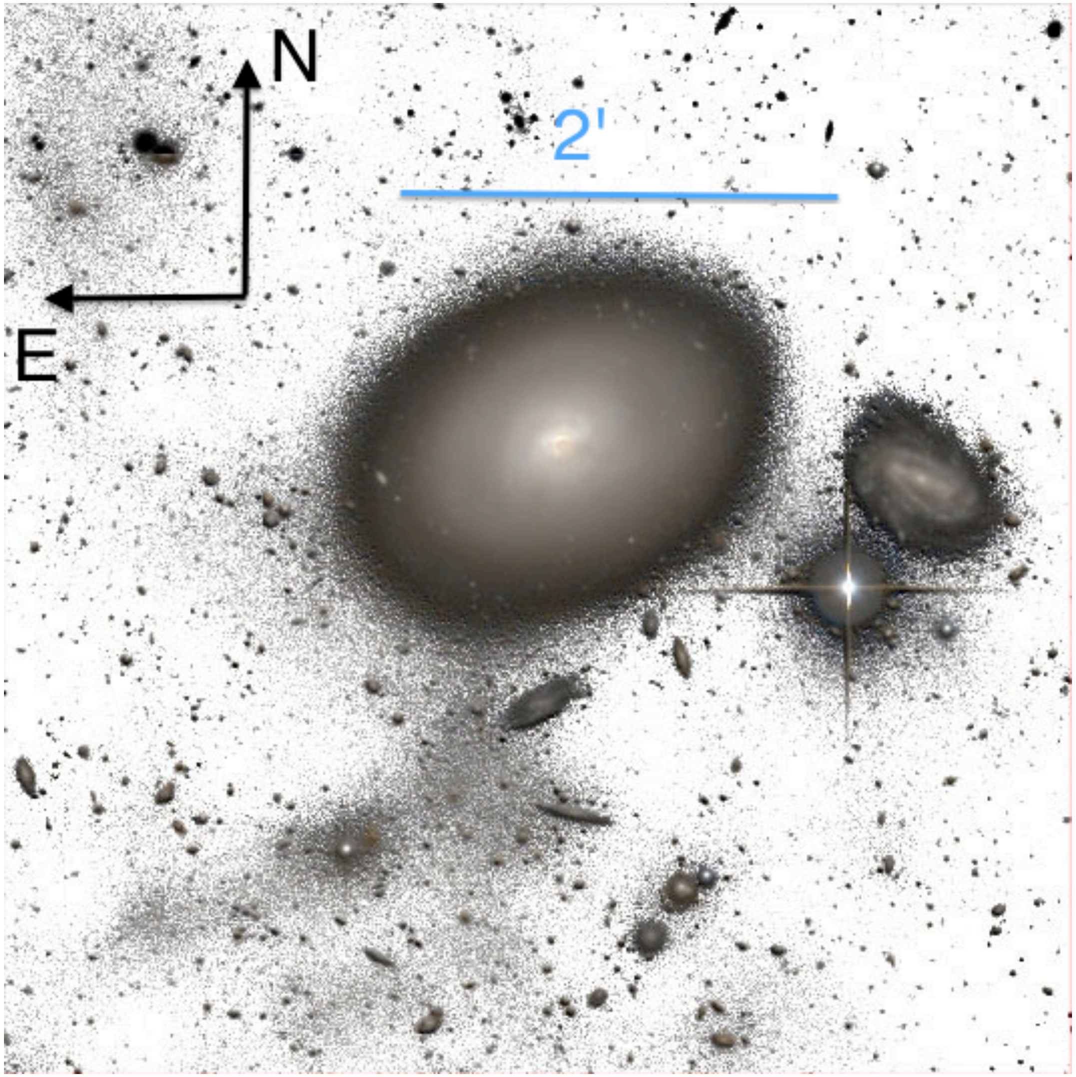
Alatalo et al. 2014a

NGC 1266 has not interacted *recently

MEGACAM deep imaging at the CFHT (sensitivity: 29 mag arcsec^{-2})

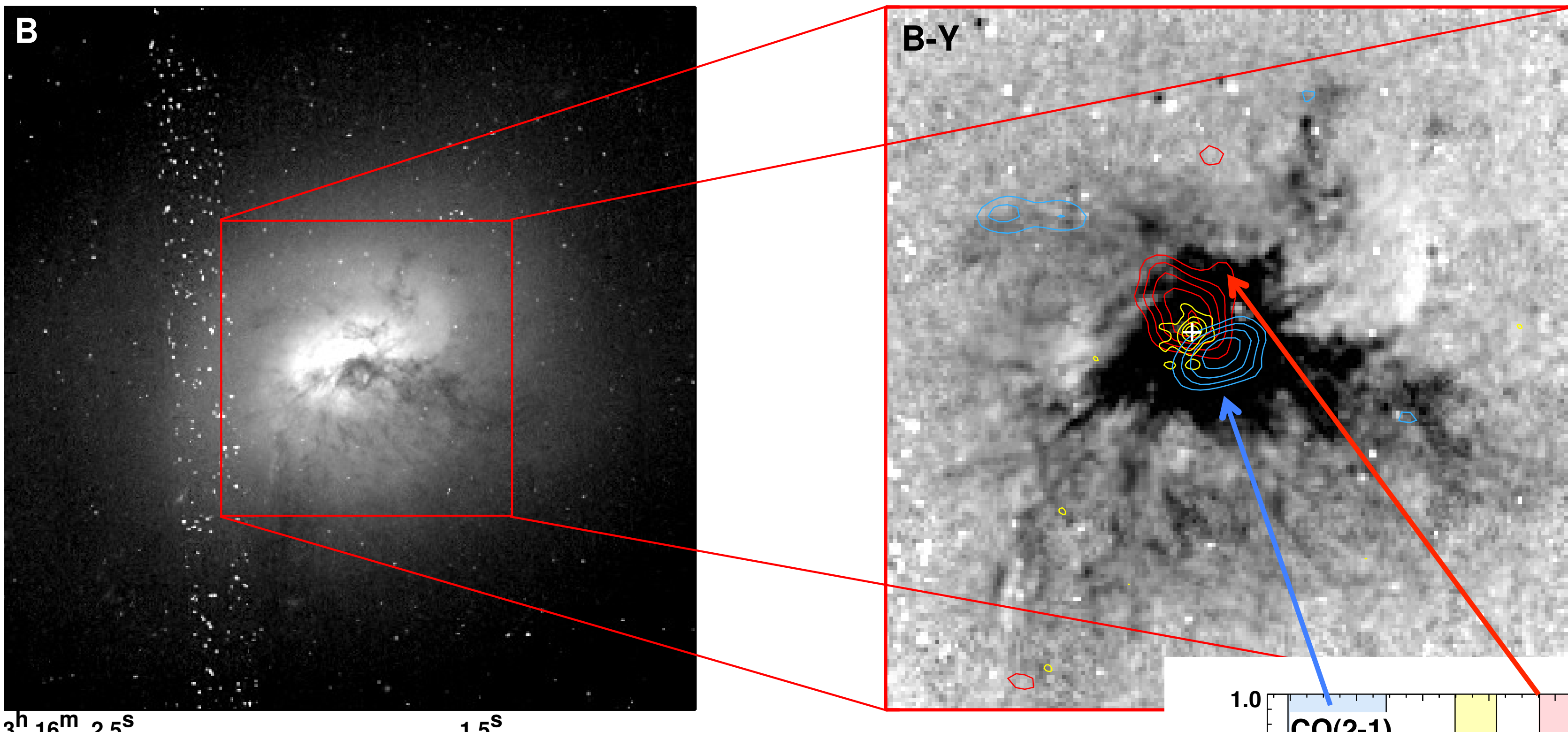
low surface brightness stellar filament to the South-East may be a sign of a **minor** merger, but also possibly galactic cirrus

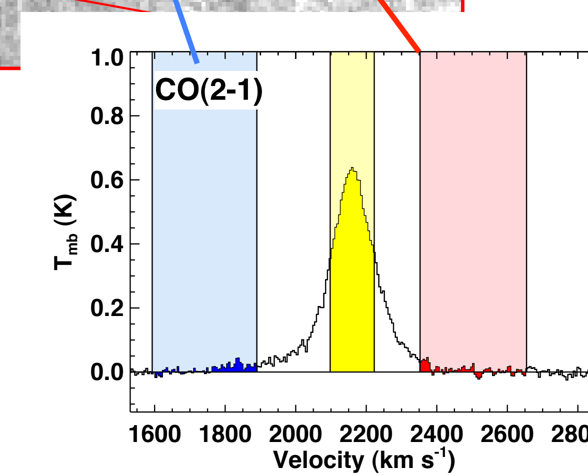
no signs of a major interaction in the past 2 Gyr, even of the scale of M51, so a major merger does not explain the quenched star formation



Alatalo et al. 2014a

NGC 1266 is depleting its gas





$M_{gas} \sim 4\times10^9\ M_\odot$ (Young et al. 2011; Alatalo et al. 2011, 2015a)

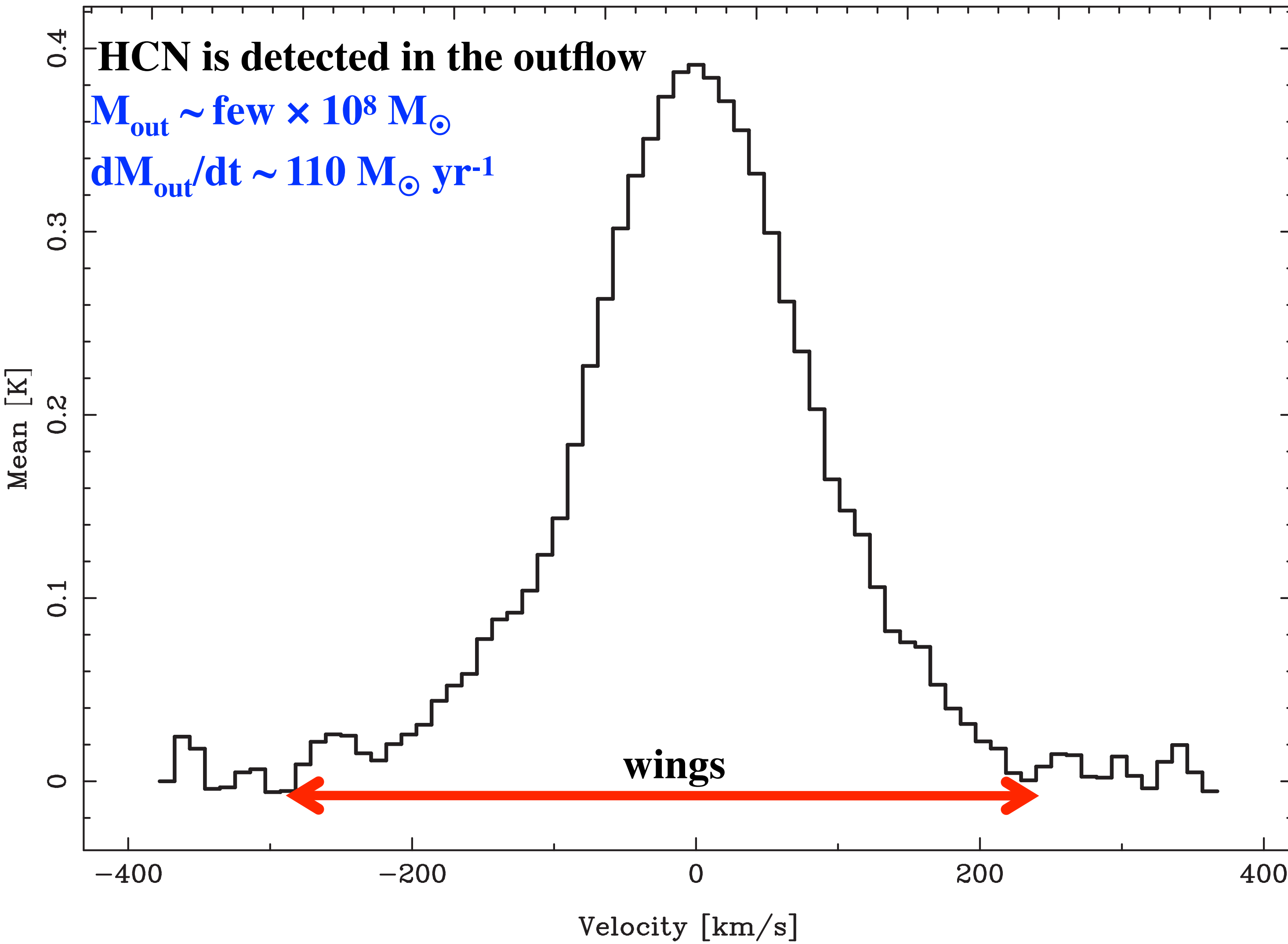
$M_{outflow} \sim$ few$\times10^8\ M_\odot$

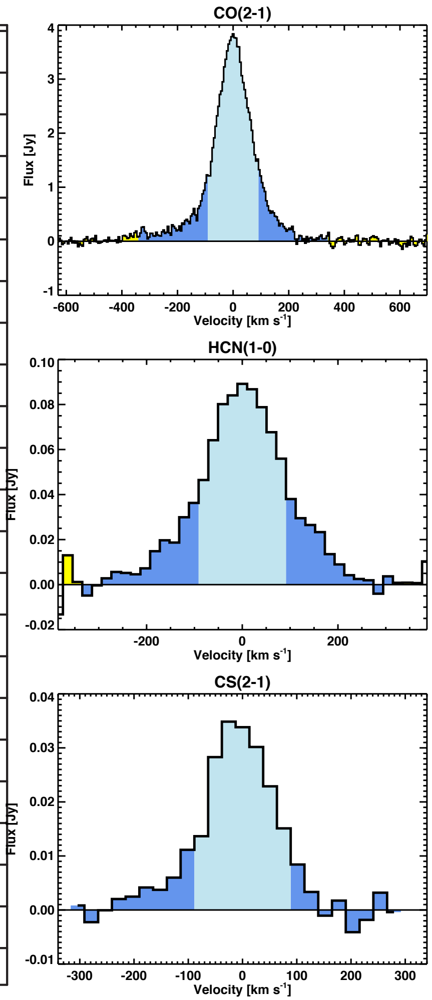
(Alatalo et al. 2011, Alatalo et al. 2014b)

Outflow mass flux $\approx 110\ M_\odot\ yr^{-1}$ (Alatalo et al. 2015a)

Outflow dynamical time < 3 Myr (Alatalo et al. 2011)

but most molecules are not escaping



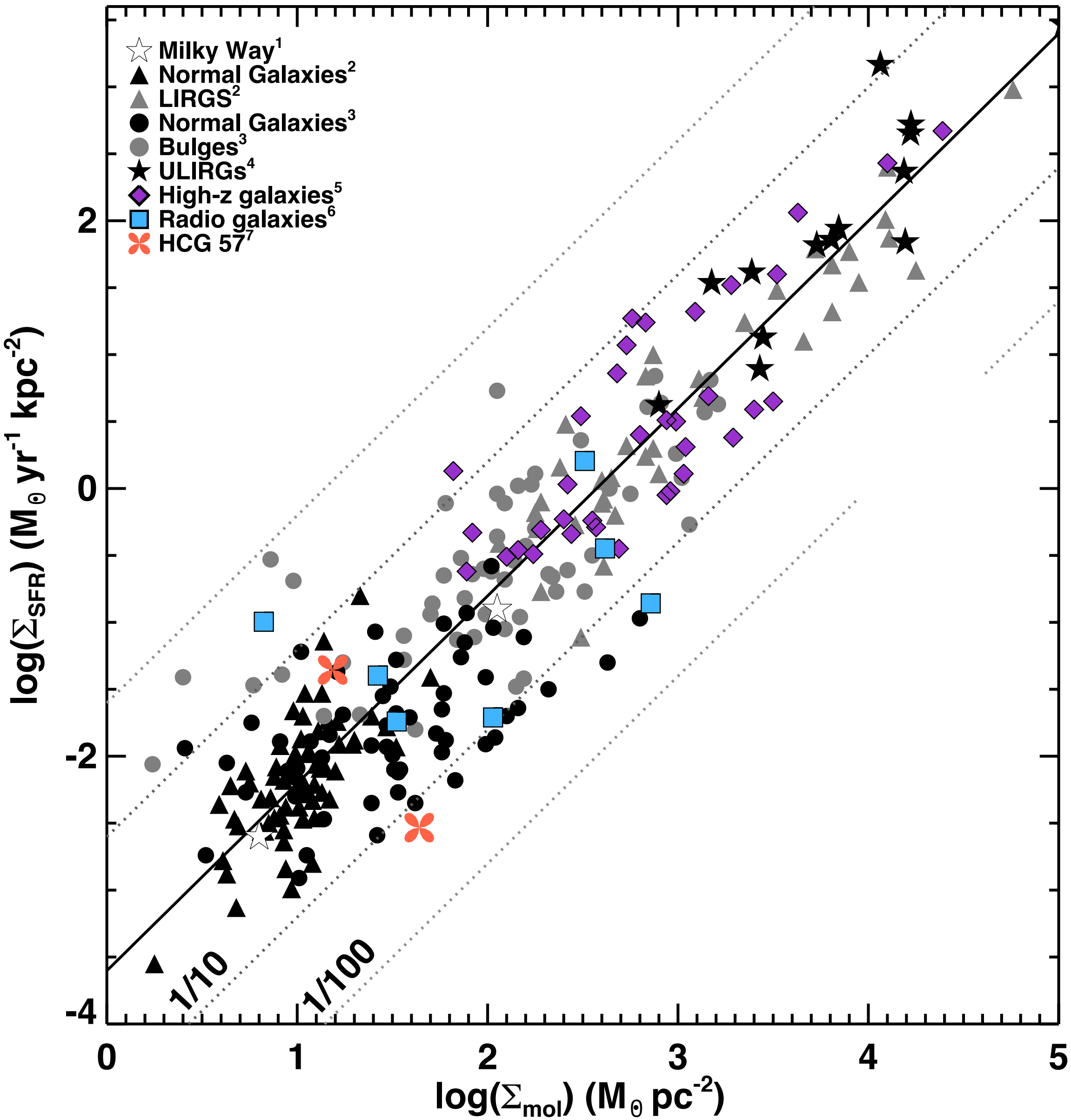


but outflow rate does not reflect how much mass is **escaping.**

The **mass escape rate** is closer to **$2 M_\odot yr^{-1}$**

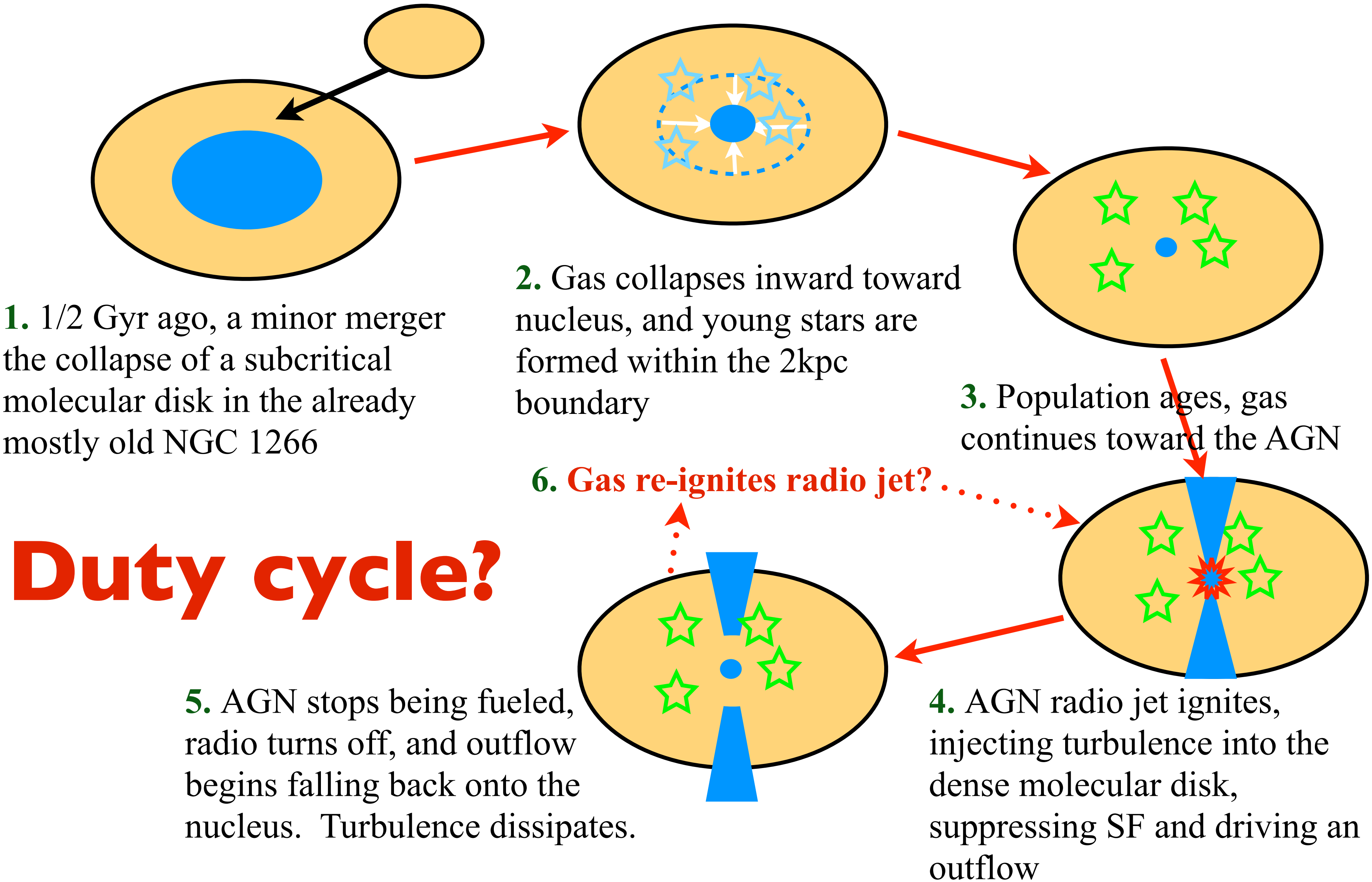
Alatalo et al. 2015a

NGC 1266 is not forming stars efficiently



Alatalo et al. 2015a

NGC 1266: not your standard feedback



other

conclusions

AGN feedback solves a well-known problem with creating too many massive galaxies

AGN outflows have been observed in all wavelengths, including mounting evidence that they are ubiquitous even in H_2

An AGN removes its interstellar medium by expelling it, and turbulence can prevent that ISM from forming stars - *but not as fast as we think*

A duty-cycle might be able to explain the slow evolution from the cessation of SF to complete expulsion of molecular gas (for NGC 1266)

Using the *escape* rate rather than the *outflow* rate can explain the mismatch between depletion time and ubiquity of mass-loaded outflows