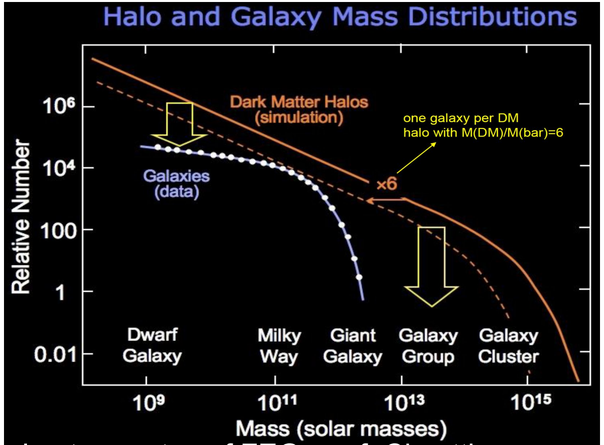
Multiphase AGN-driven outflows and X-ray winds

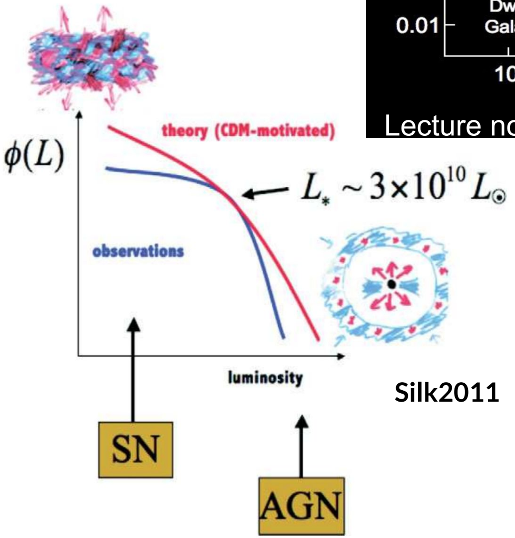
Elena Bertola
X-ray Lab AA 2021-2022

Credits: ESA/ATG medialab

Why do we care about AGN feedback?



Lecture notes of FEG, prof. Cimatti



Silk2011

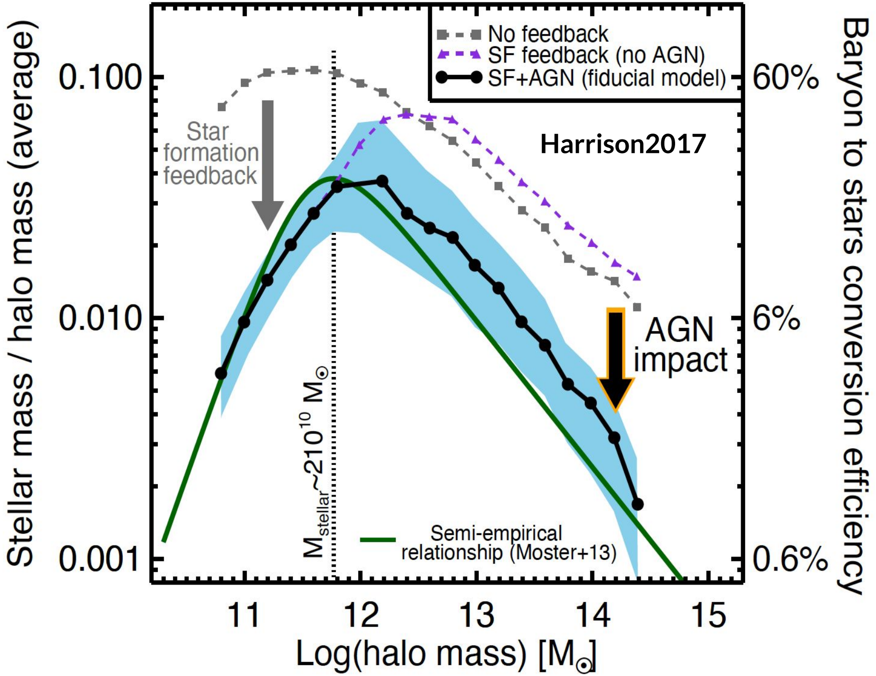
1. Galaxy evolution models

The mass functions of dark matter haloes and galaxies don’t agree at the *low and high mass ends*

Part of the gas available in the galaxy is not converted in stars

Why?

Why do we care about AGN feedback?



1. Galaxy evolution models

Models can explain the low-mass end if Supernova feedback is accounted for

Similarly, the high-mass end can be matched including AGN feedback

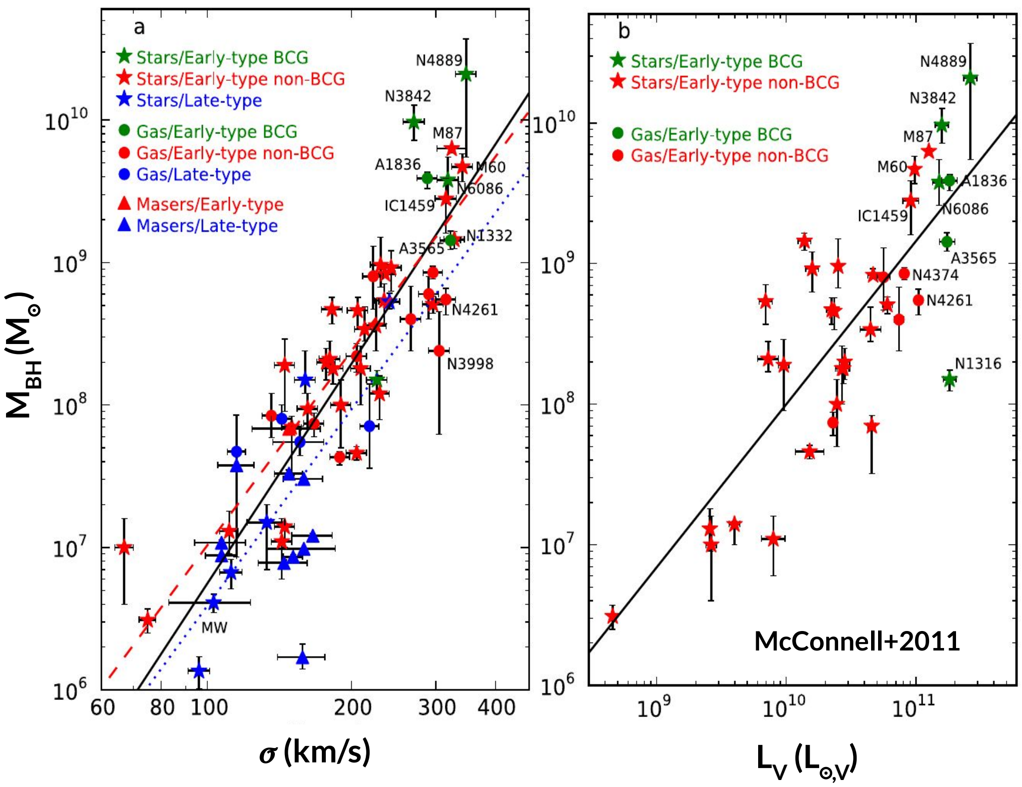
Why do we care about AGN feedback?

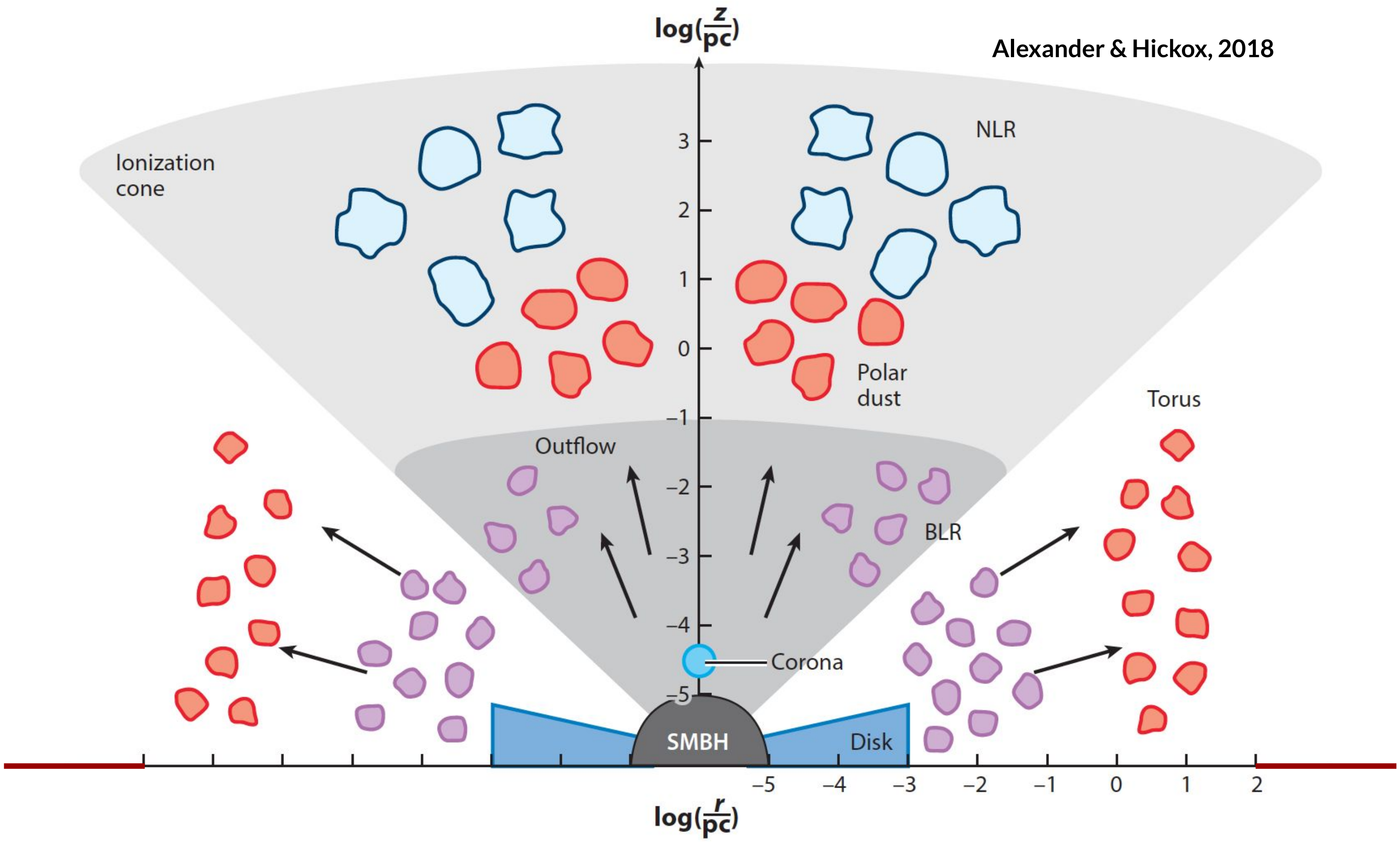
2. SMBH/host-galaxy scaling relations

Are AGN and host galaxies coevolving?

How is this coevolution set into place?

Magorrian+1989, Gebhardt+2000, Ferrarese+2000,2006, McConnell+2011, Kormendy & Ho 2013, etc.





log(z/pc)
Alexander & Hickox, 2018
NLR
Ionization
cone
3
2
1
0
−1
−2
−3
−4
−5
Polar
dust
Torus
Outflow
BLR
Corona
SMBH
Disk
−5
−4
−3
−2
−1
0
1
2
log(r/pc)

A logarithmic view of the AGN-galaxy connection

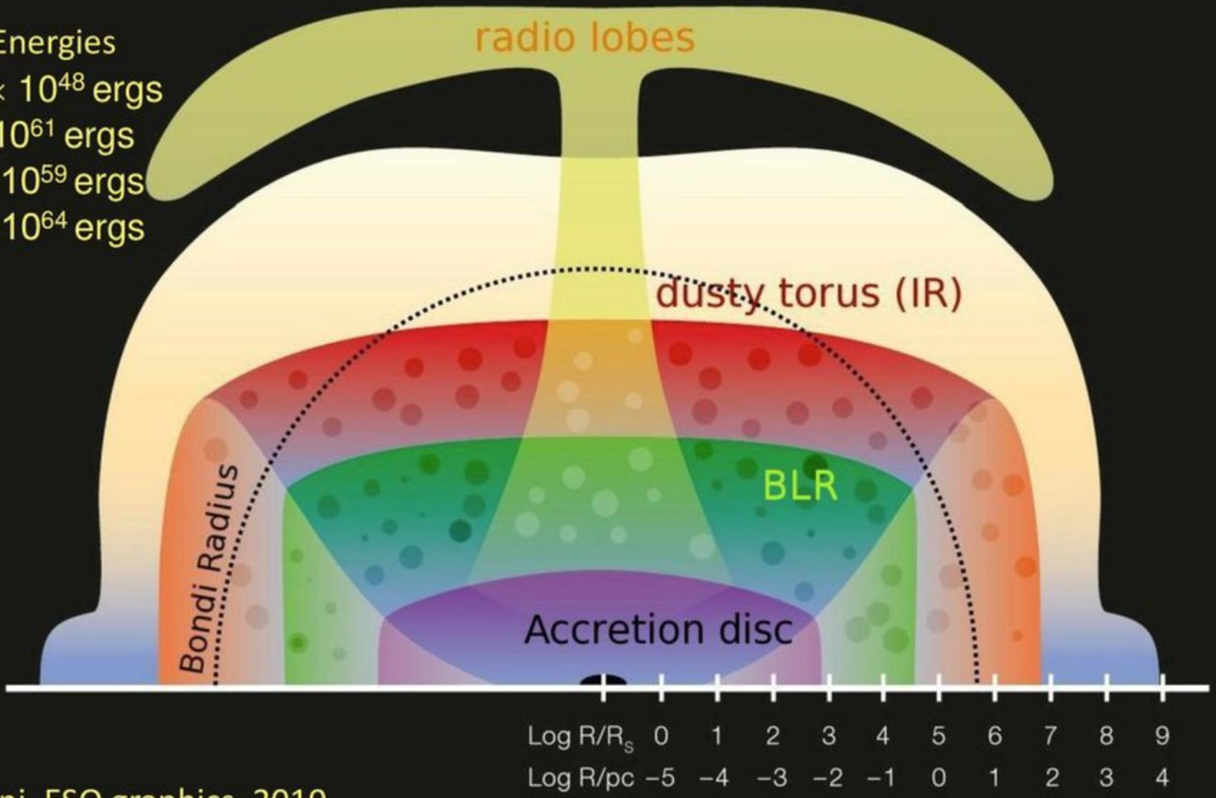
Binding Energies

$E_{b,\odot} \approx 4 \times 10^{48}$ ergs

$E_{b,BH,8} \approx 10^{61}$ ergs

$E_{b,gal,11} \approx 10^{59}$ ergs

$E_{b,Coma} \approx 10^{64}$ ergs



A. Merloni, ESO graphics, 2010

Types of AGN feedback

a) Direct radiation → Radiation usually escapes. This is how we see AGN

b) Mechanical → **Kinetic** vs. **Radiative**

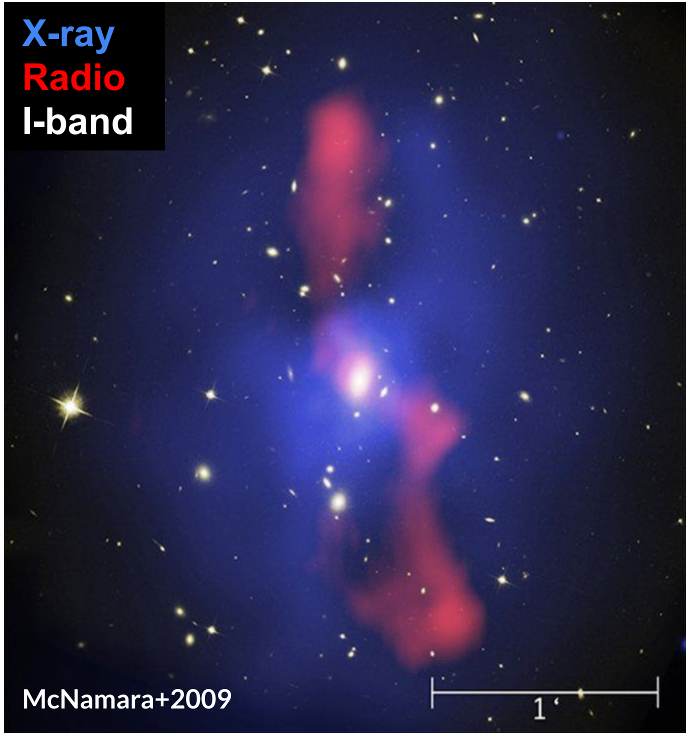
Kinetic → **Radio** mode

vs.

Radiative → **Quasar** mode

Radio mode: AGN relativistic jets

- Accretion onto the BH is generally inefficient
- Little energy goes in radiation
- Great part of the energy produced by the AGN is converted in kinetic energy
  $\longrightarrow$ *relativistic jets*
- Predominantly found in the most massive galaxies ($M_{star} > 10^{11} M_{\odot}$) with old stellar populations
- Jets heat up the gas they encounter, creating bubbles and cavities and *preventing radiative cooling*
- Radio mode can explain why we don't find cooling flows in galaxy clusters

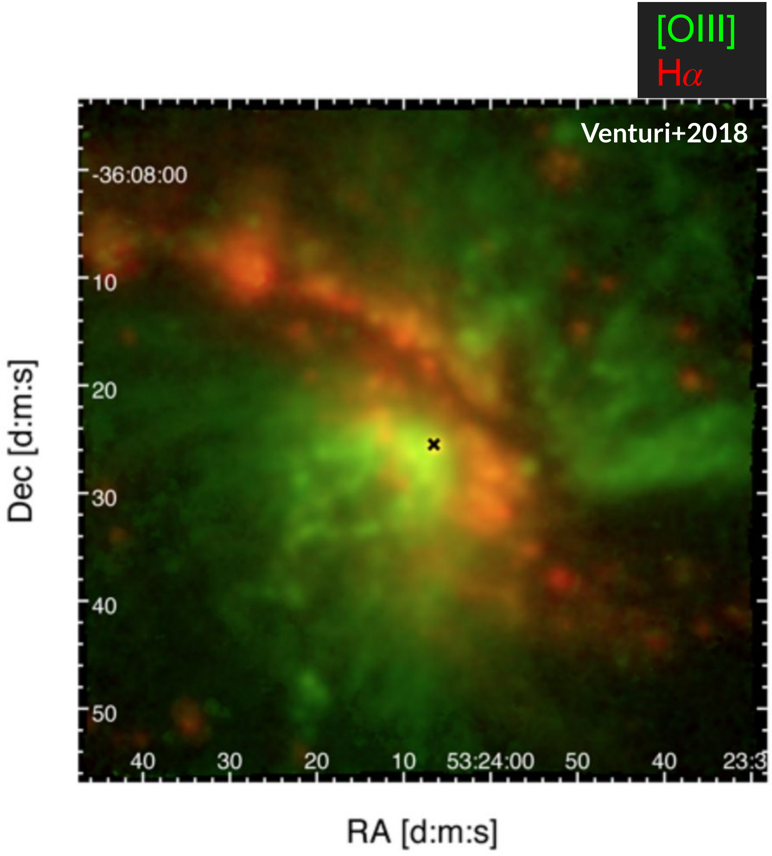


< ——— 700 kpc ——— >

Quasar mode: AGN-driven winds

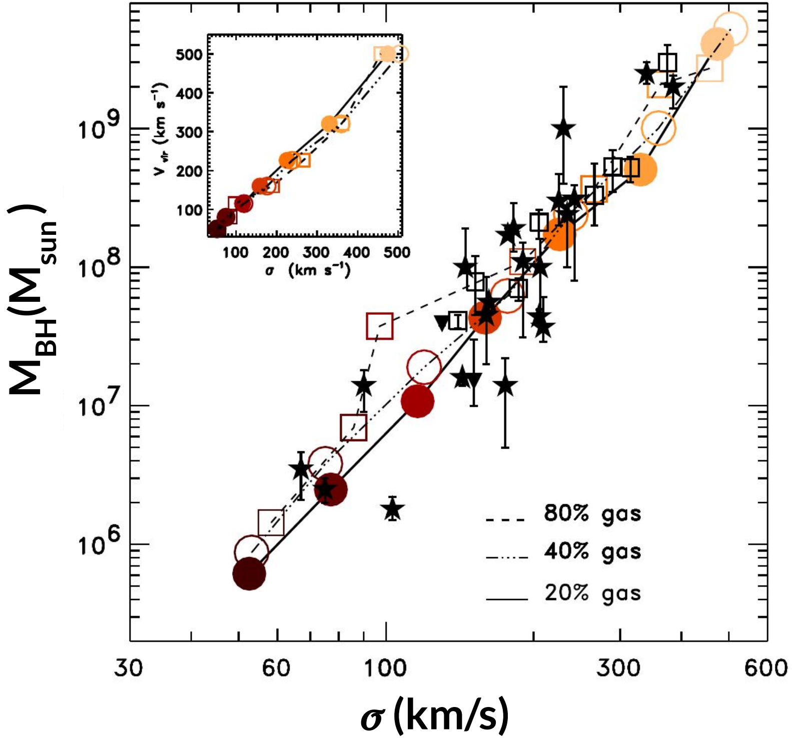
- Accretion onto the BH is efficient, Eddington ratios are high
- Great part of the AGN energy goes in radiation
- Radiative AGN are most common in galaxies with on-going star-formation and younger stellar populations at all cosmic epochs
- Production of AGN-driven *winds* via
  - ⟶ Radiation driving
  - ⟶ Line driving
  - ⟶ Magnetic acceleration
- Impact on the SF activity by
  - ⟶ heating
  - ⟶ dissociating
  - ⟶ removing

  the cold gas reservoir of the host galaxy



Modeling feedback through AGN-driven winds

Di Matteo+2005



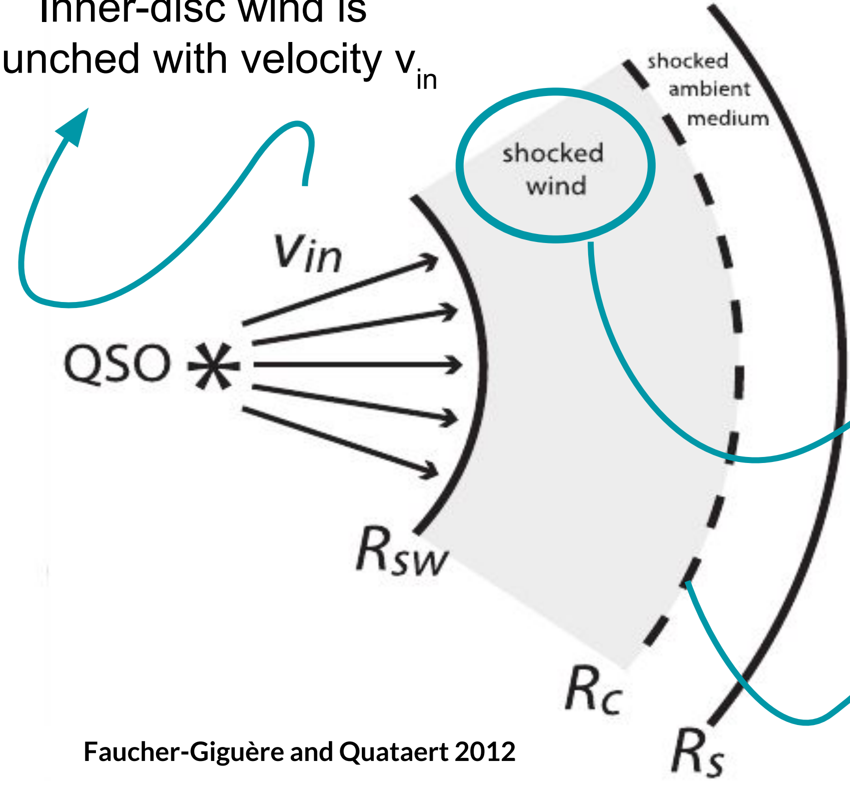
$$\dot{E}_{kin}^{wind}/L_{bol} = 0.05$$

Di Matteo+2005:
The observed scaling relations can be matched by simulations if the energy-loading factor of the AGN outflows is at least 5%

e.g., King 2003, Di Matteo+2005, Hopkins+2006, Hopkins&Elvis2010, Faucher-Giguère&Quataert 2012, Lapi+2014, Costa+2018,2020, …

How are AGN-driven winds linked to kpc-scale outflows?

Inner-disc wind is
launched with velocity v_{in}



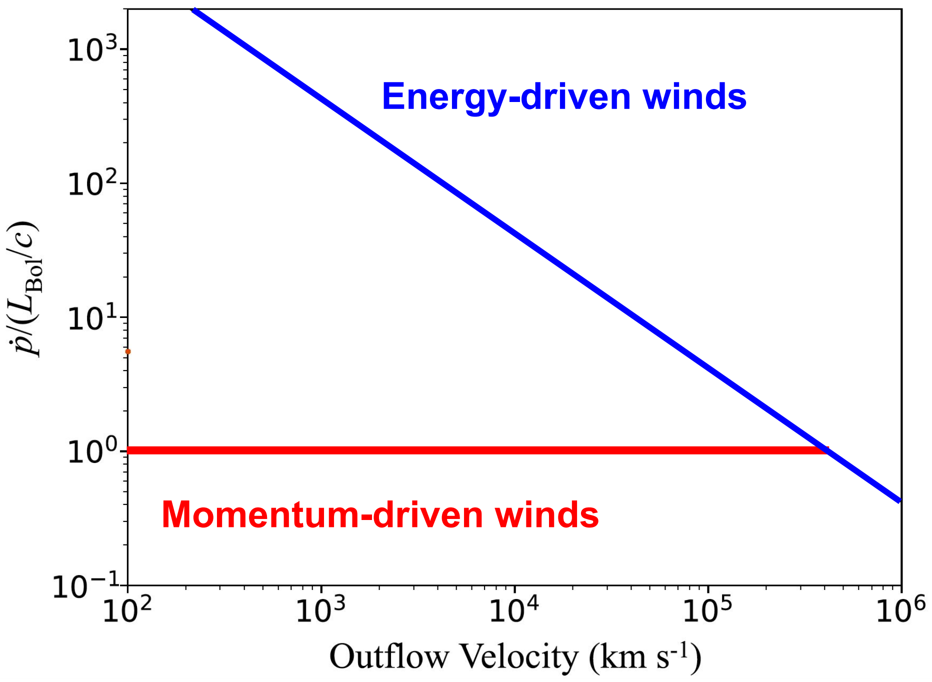
Faucher-Giguère and Quataert 2012

***Momentum*-driven**
vs.
***Energy*-driven**

Inner-disc wind
propagation

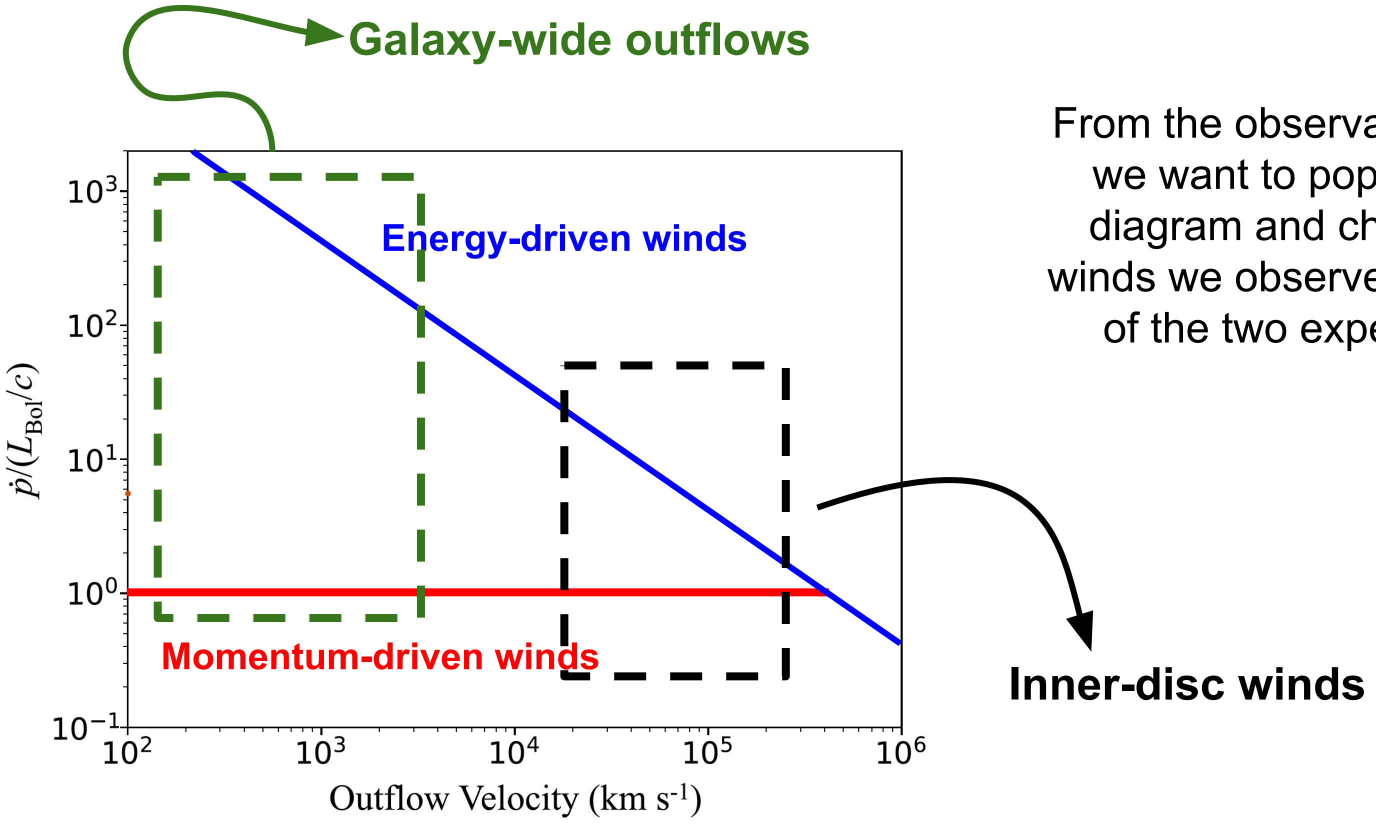
Inner-disc wind shocks the ISM *only if* the mechanical luminosity of the wind is thermalized at Rc, i.e., cooling at Rc is negligible

How are AGN-driven winds linked to kpc-scale outflows?



From the observational side, we want to populate this diagram and check if the winds we observe match any of the two expectations

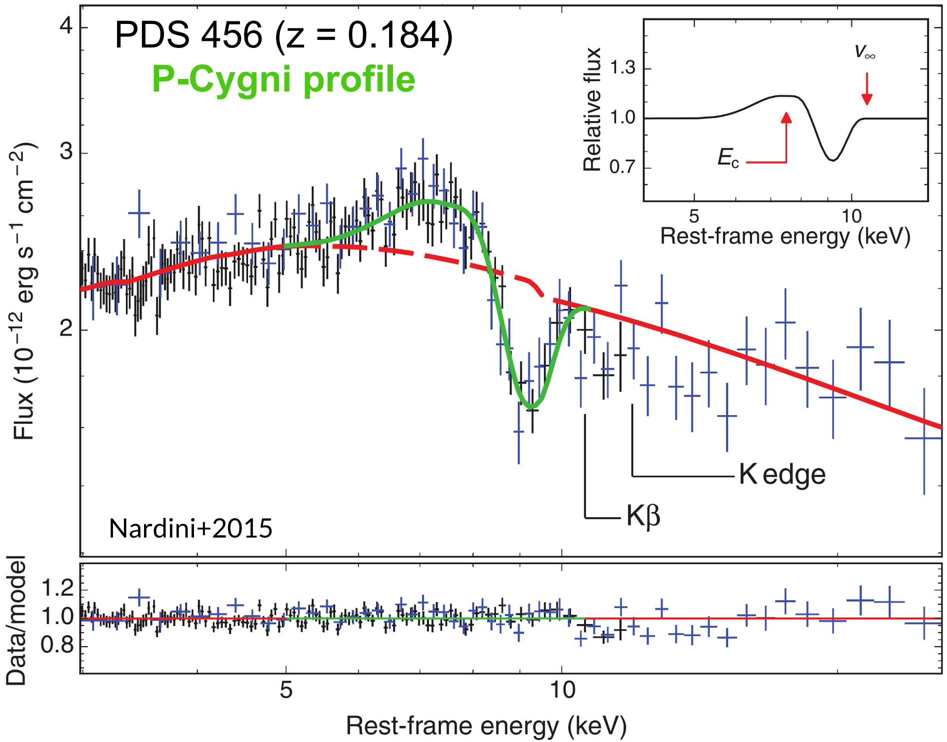
How are AGN-driven winds linked to kpc-scale outflows?



From the observational side, we want to populate this diagram and check if the winds we observe match any of the two expectations

Inner-disk winds: Ultra-fast Outflows (UFOs)

The *fastest* winds known to date



Present in 40% of RQ *and* RL AGN
(Tombesi+10,+14,Gofford+13,Igo+20)

$N_H \sim 10^{22}$–10^{24} cm^{-2} → thick
$\log(\xi/\mathrm{erg\ s^{-1} cm^{2}}) > 3$ → highly ionized
$v > 0.05c$ (up to $0.6c$) → ultra fast

Signature: P-cygni profile of FeXXV-XXVI

Commonly seen as resonant absorption lines of highly-ionized iron blueshifted at E > 7 keV

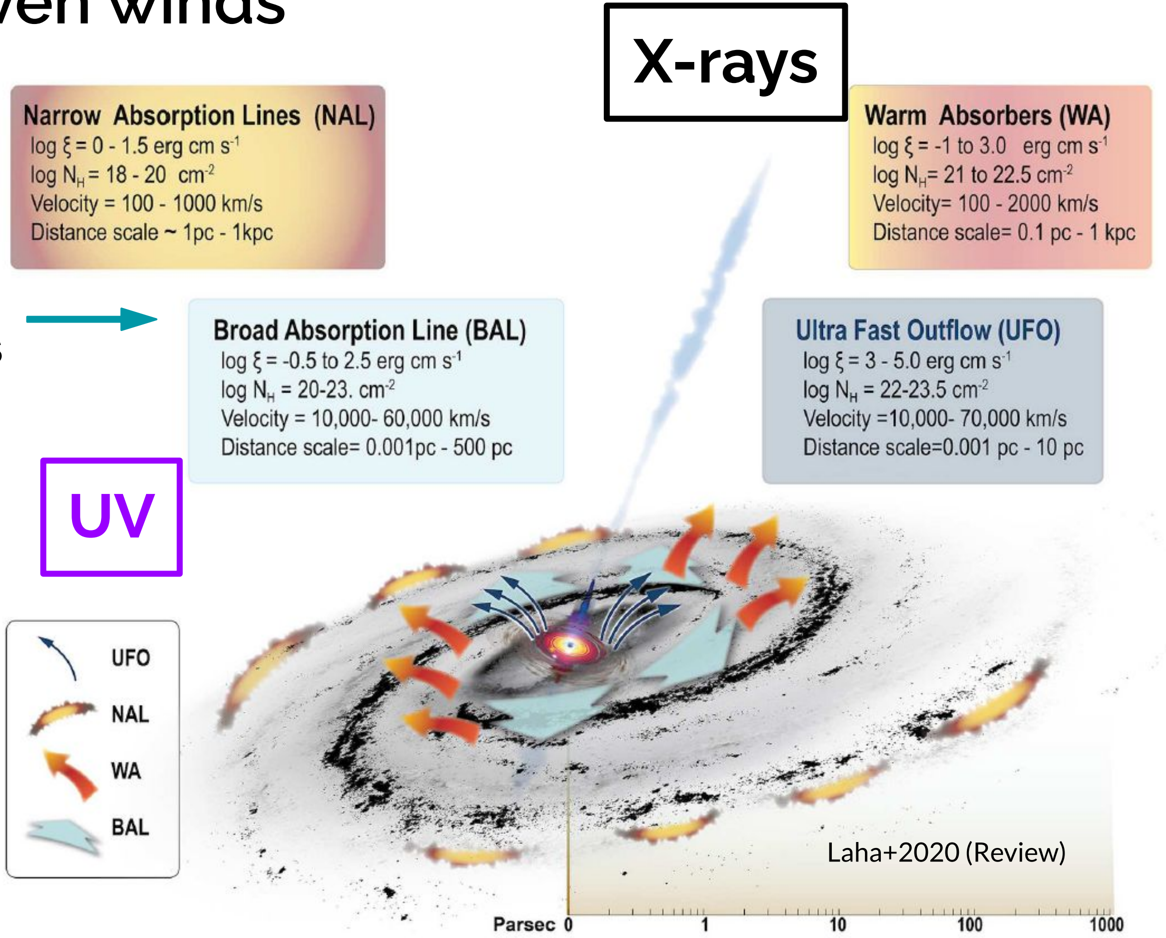
Need high S/N spectra to constrain them

Observing AGN-driven winds

Inner to outer:

1. UFOs, WA
2. UV BAL–NAL

} Disc winds →



Laha+2020 (Review)

Observing AGN-driven winds

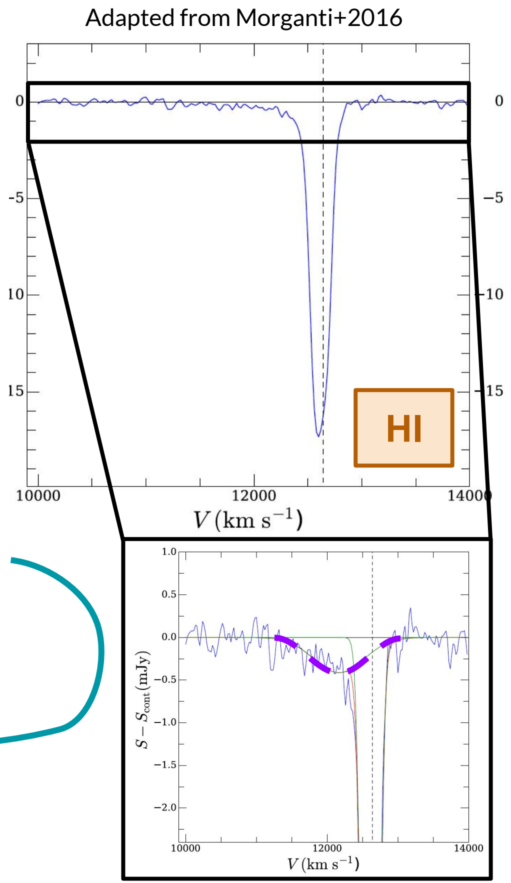
Inner to outer:

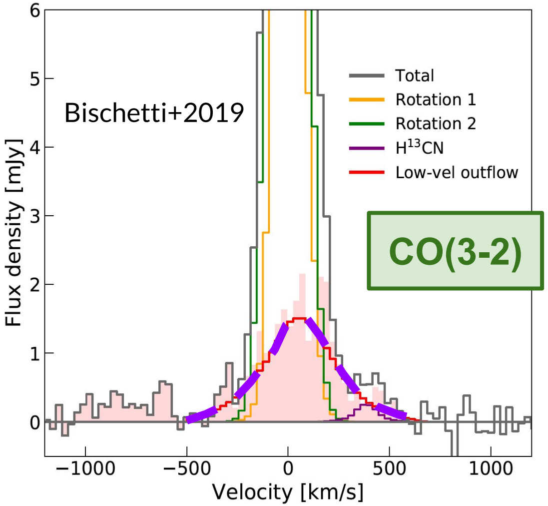
1. UFOs, WA
2. UV BAL–NAL

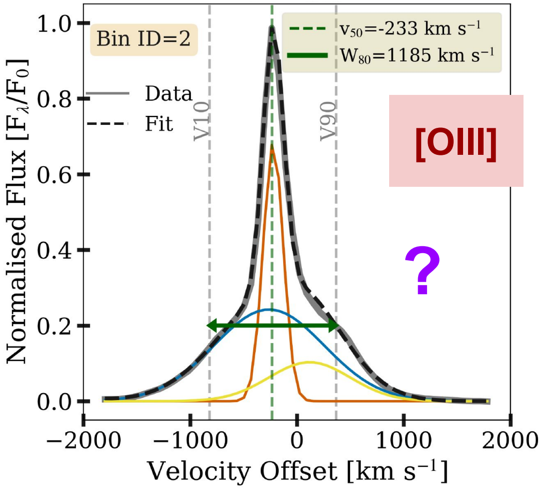
} Disc winds

3. Ionized outflows (e.g., [OIII])
4. Neutral gas outflows
5. Molecular outflows

Galaxy-wide outflows

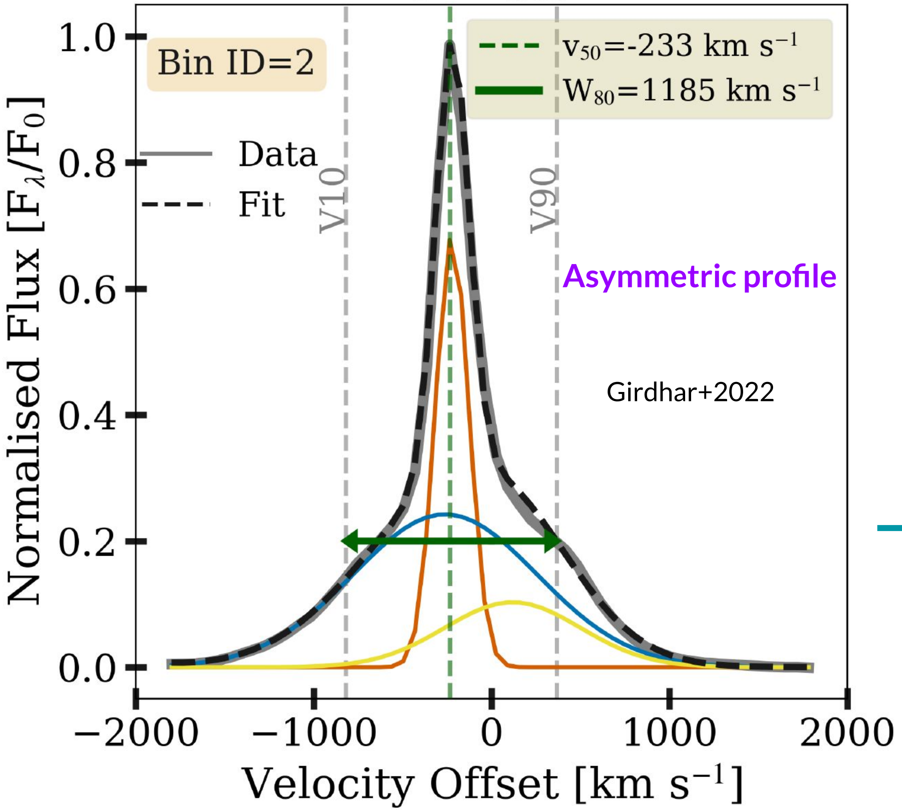


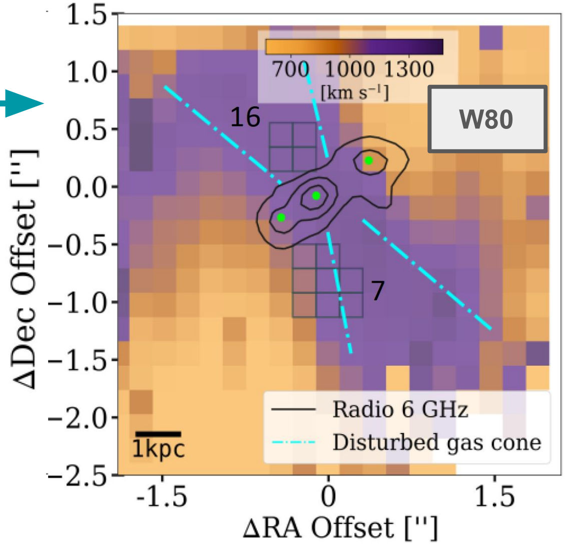




Non parametric approach

v_n:
n-th percentile of the emission-line profile
i.e., n% of the line area is enclosed at the left of v_n
$w_{80} = v_{90} - v_{10}$





W_{80}: a measure of the outflow strength

Observing AGN-driven winds

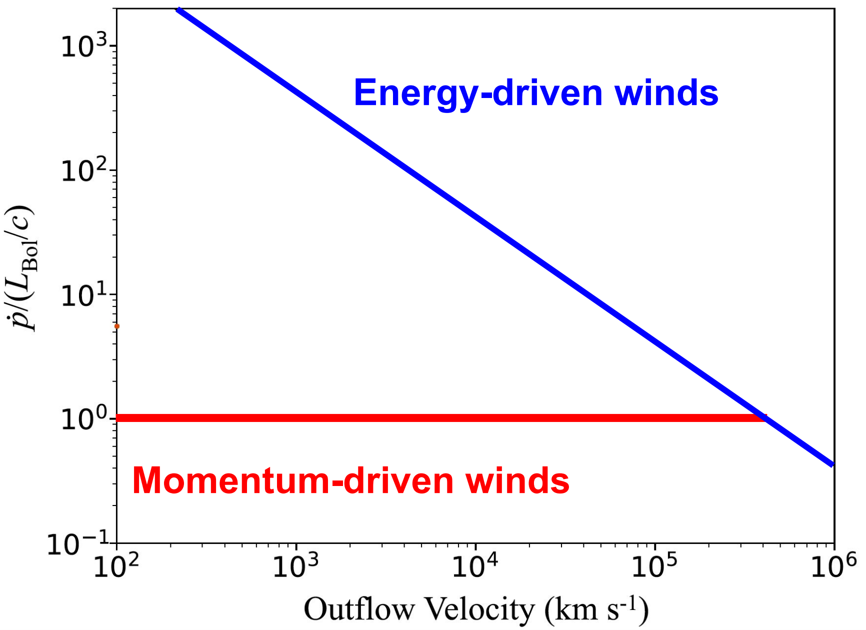
Inner to outer:

1. UFOs, WA
2. UV BAL–NAL

} Disc winds

3. Ionized outflows (e.g., [OIII])
4. Neutral gas outflows
5. Molecular outflows

Galaxy-wide outflows



Observing AGN-driven winds

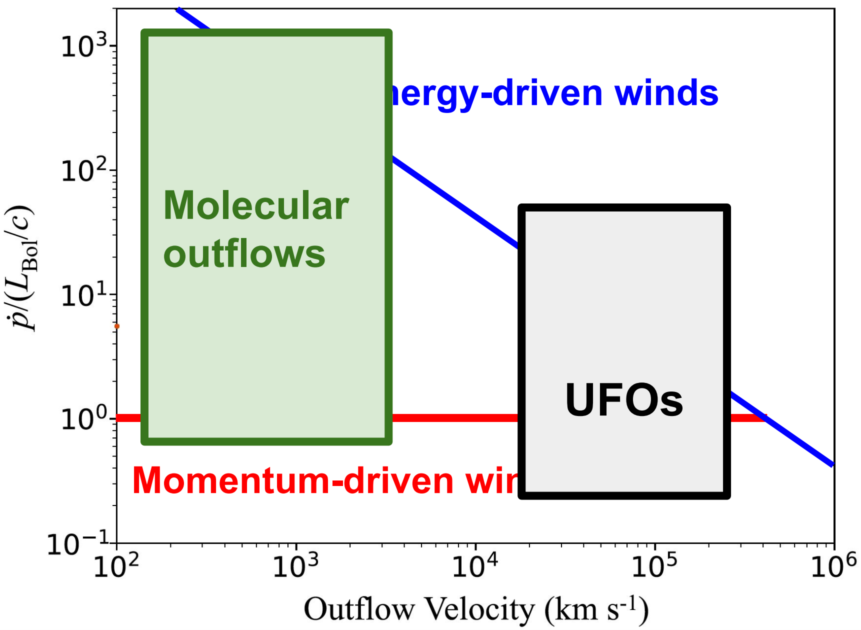
Inner to outer:

1. UFOs, WA
2. UV BAL–NAL

} Disc winds

3. Ionized outflows (e.g., [OIII])
4. Neutral gas outflows
5. Molecular outflows

→ Galaxy-wide outflows



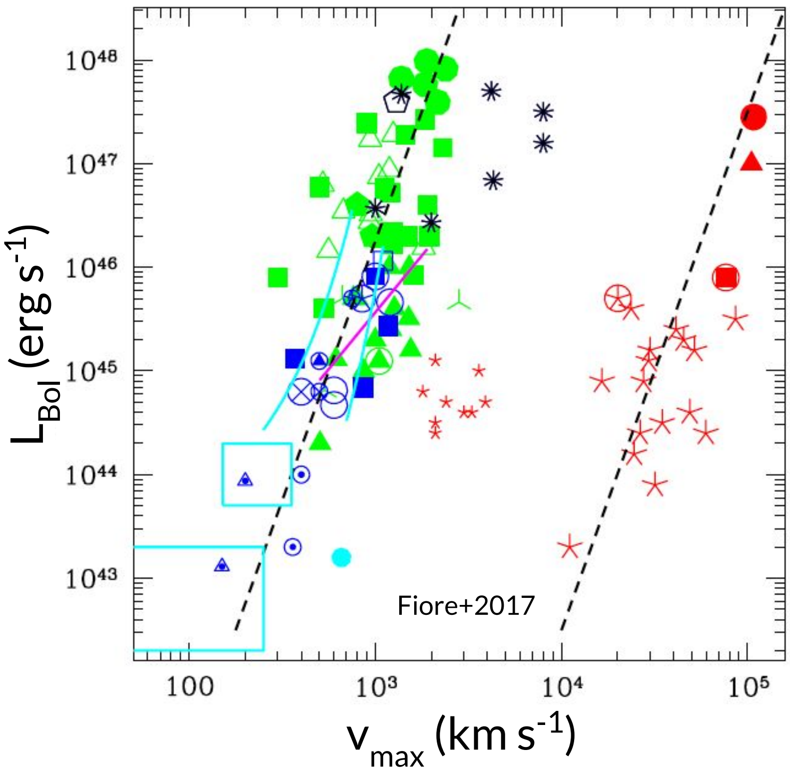
Local and low-z AGN

Testing the models with observations — I

<u>Issue</u>:
Need for **multi-wavelength coverage** and detection of multiphase outflows

Only a handful of AGN were found to show inner-disc- *and* galaxy-scale outflows

<u>Workaround</u>:
Build big samples of AGN outflows and search for correlations *within* the sample
e.g.: Fiore+2017 – the outflow velocity correlates with the AGN L_{bol} for **molecular**+**ionized** outflows and **UFOs**, and that the two scalings are statistically consistent with each other



Mout vs. Lbol is flatter for molecular outflows

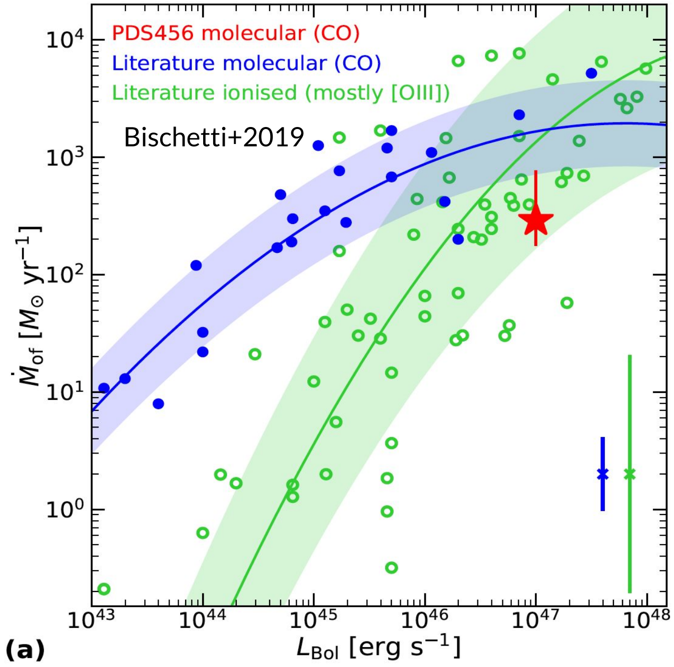
Most powerful AGN seem to have more massive outflows in the ionized phase

Need to measure all the gas phases, especially at high luminosities, to properly study the impact of AGN winds

Energy-conserving scenario:

- · - Bulk of the outflow mass is molecular

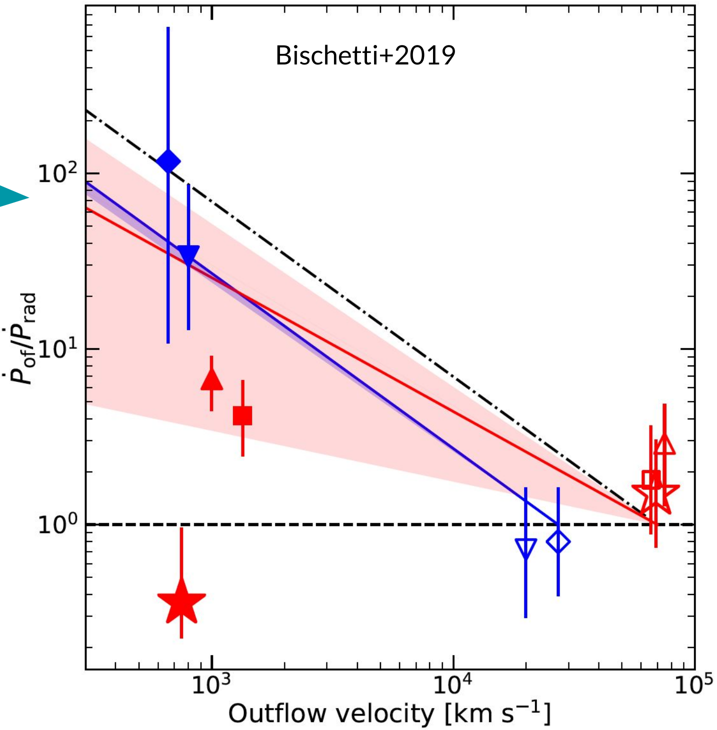
Luminosity corrected - a significant part of the outflow mass is in the ionized phase



Filled symbols = molecular
Empty symbols = UFOs

PDS 456
IRAS F11119+3257
APM 08279+5255
IRAS 17020+4544
Mrk 231

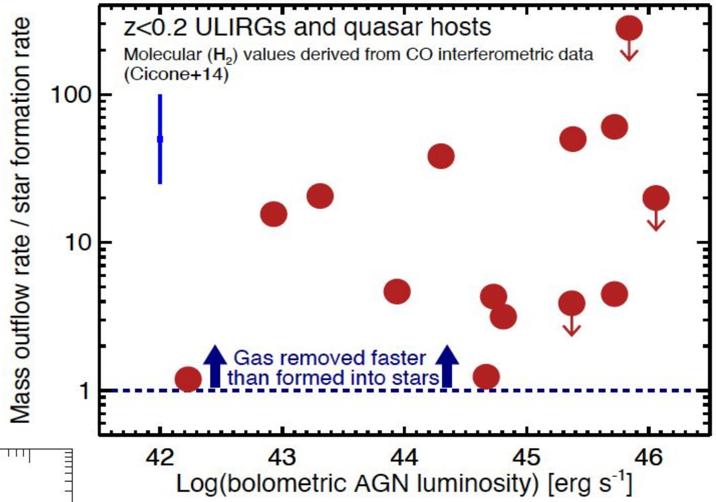
Momentum-conserving
Energy-conserving
$L_{Bol} \simeq 47$, μ corrected
$L_{Bol} \simeq 45$, μ corrected

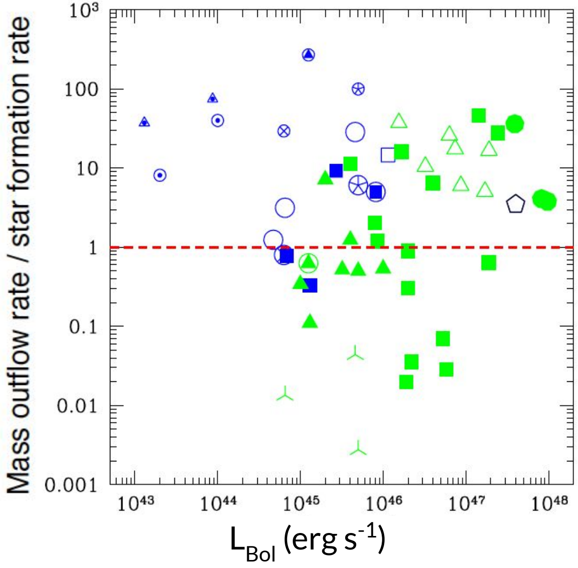


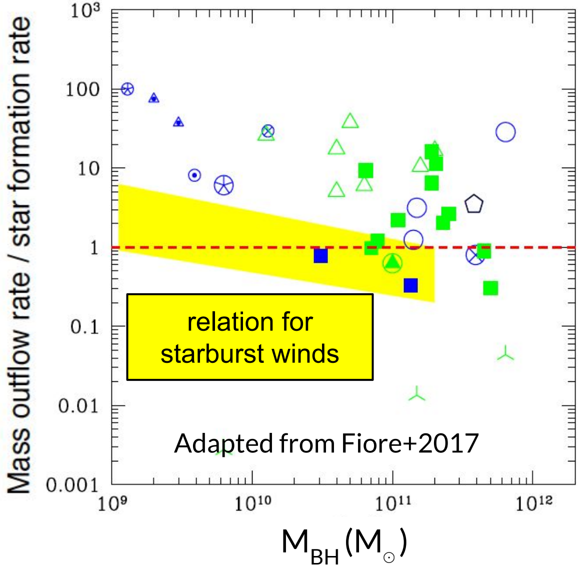
We can test the impact of AGN outflows by **comparing the mass-outflow rate to the SFR**, that is comparing how much gas is removed by the outflow to how much gas is converted into stars

mass-loading factor > 1: the outflow removes the gas faster than it takes to form stars – negative AGN feedback

Cicone+2014, adapted by Harrison+2017



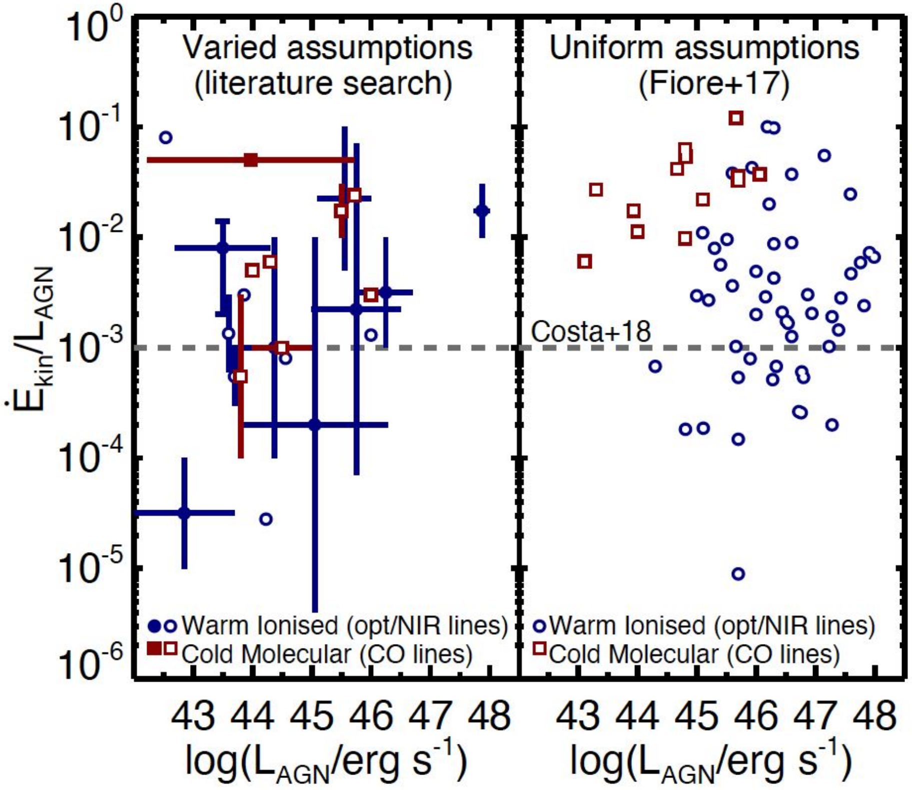




AGN winds are more effective in suppressing the SF than winds driven by starburst activity

Mass-loading factor shows mild correlation with AGN luminosity or SMBH mass

Testing the models with observations — II

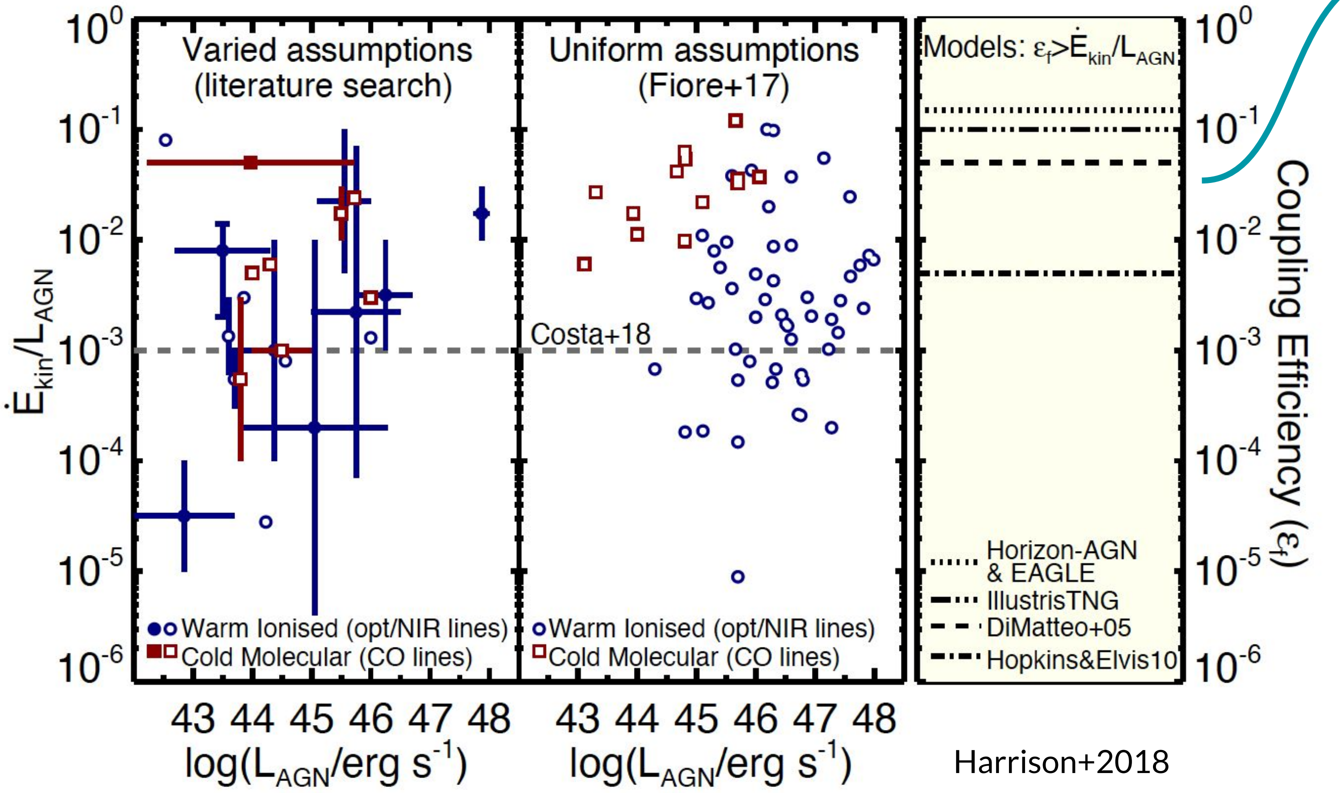


Another interesting parameter is the *energy loading factor*, because we can directly compare our results with the model predictions – *but can we??*

Issue 1 :
we need some assumptions to compute the kinetic power of the winds (e.g., geometry of the wind, gas density)

Harrison+2018

Testing the models with observations — II



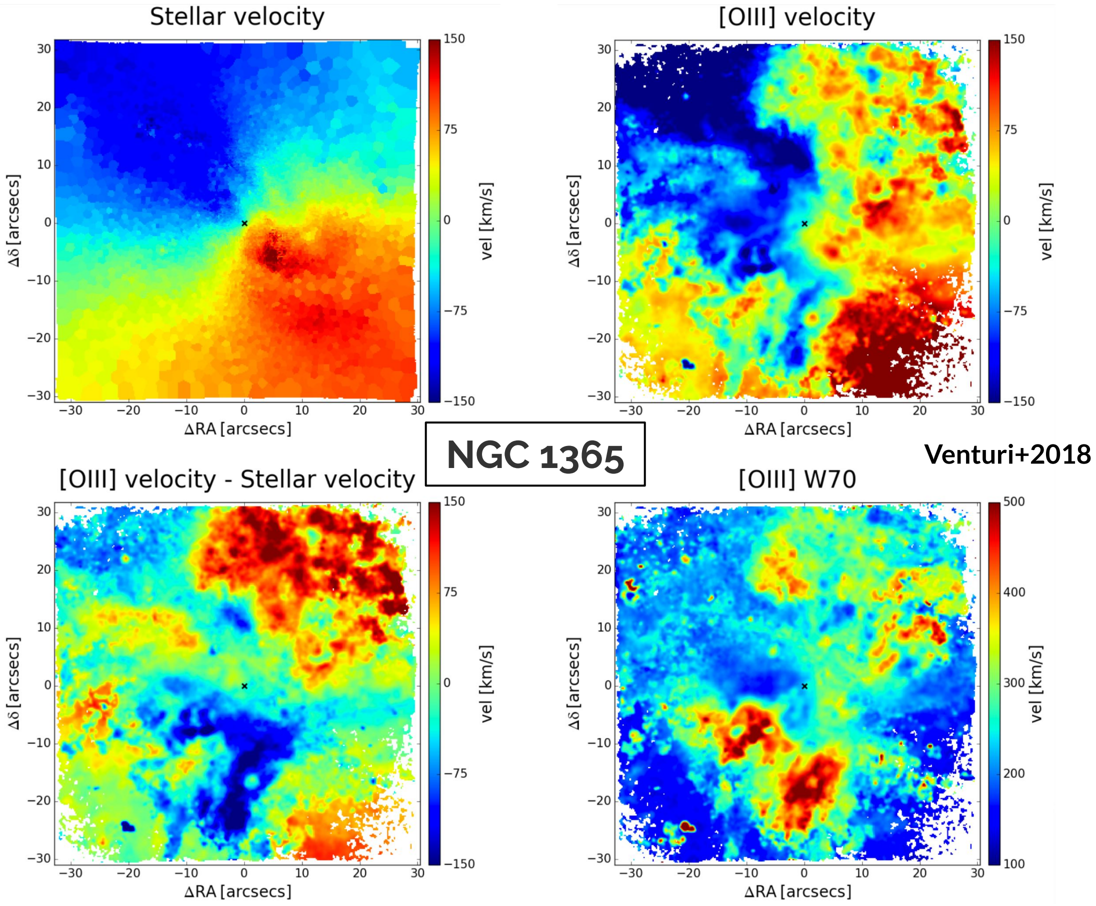
Harrison+2018

Issue 2 :
models do not agree on the predicted threshold for the coupling efficiency

Issue 3:
model predictions are usually based on all the outflowing material and not on the individual gas phases — back to the argument of Bischetti+19

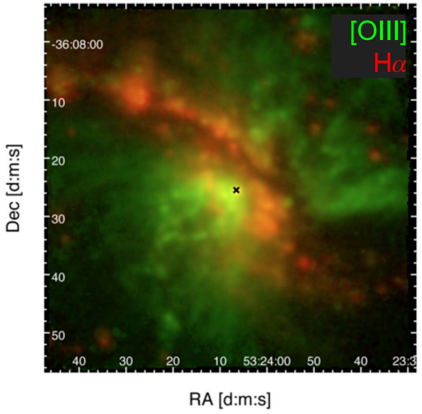
AGN feedback at high-z

High-redshift AGN and AGN outflows

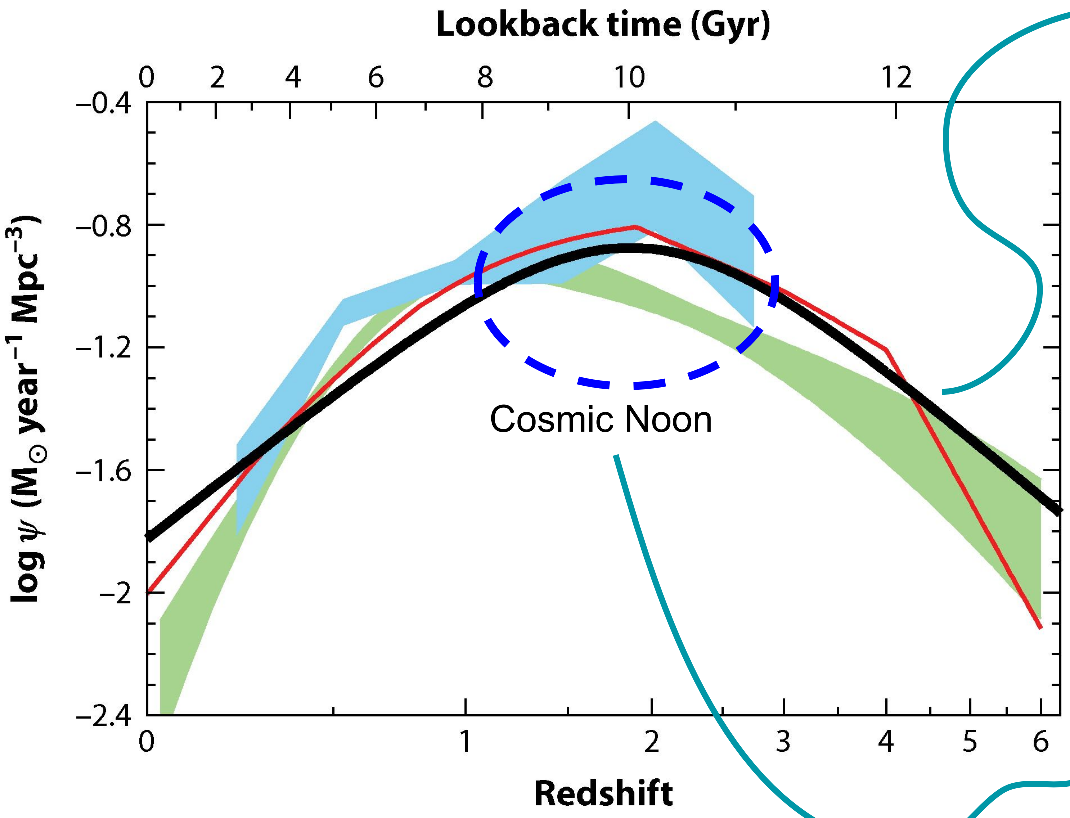


Local and low-z AGN allow for detailed studies of spatially resolved outflows and gas dynamics

But is the local Universe where we expect AGN feedback to be at its highest?



High-redshift AGN and AGN outflows



Star formation history

Black Hole Accretion history:

Shankar+2009

Aird+2010

Del Vecchio+2014

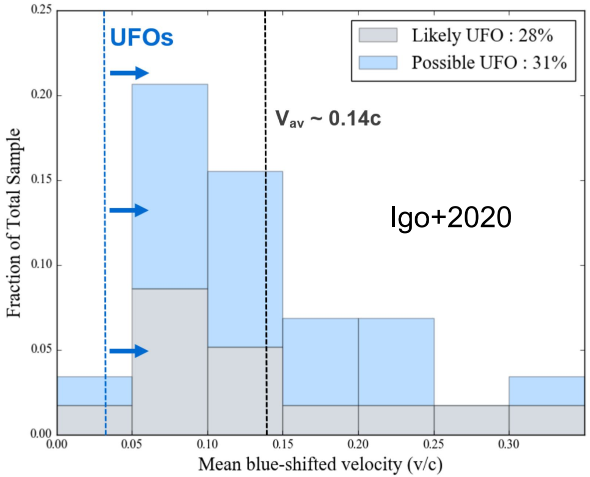
Here is where we expect AGN feedback to be at its maximum, but observations are more challenging than in the local Universe

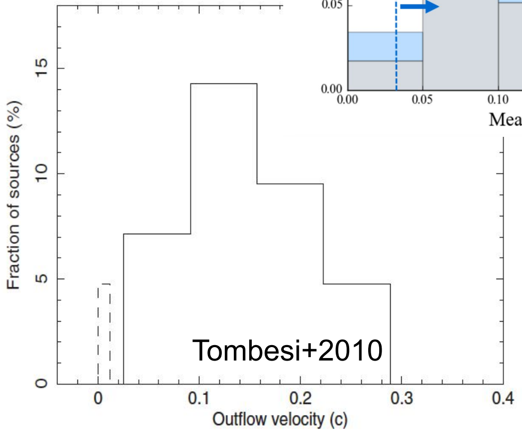
High-z UFOs

Local samples:
tens of AGN

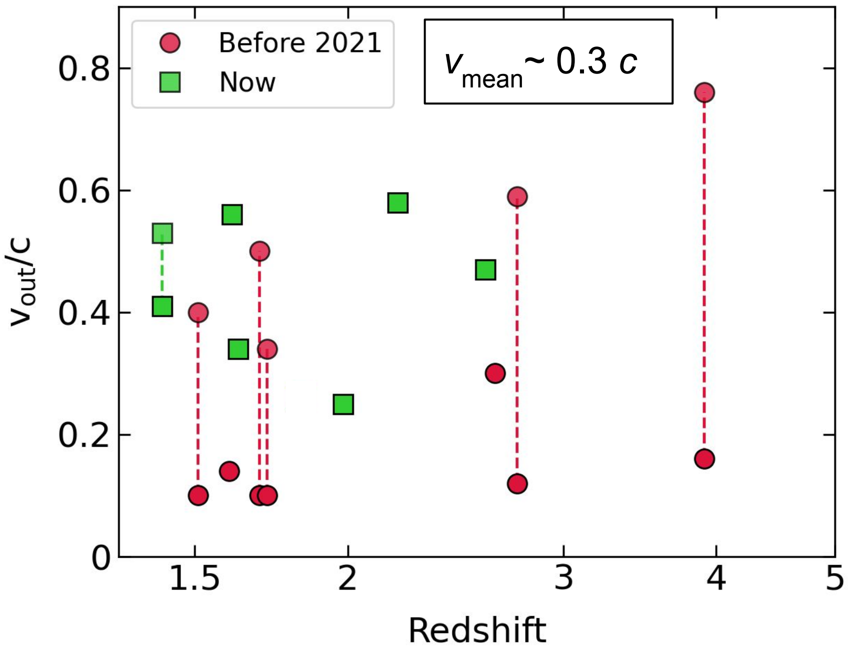
$v_{mean} \sim 0.15\ c$

DF ~ 0.3-0.4





$z > 1$: 14 AGN (only 7 before 2021)

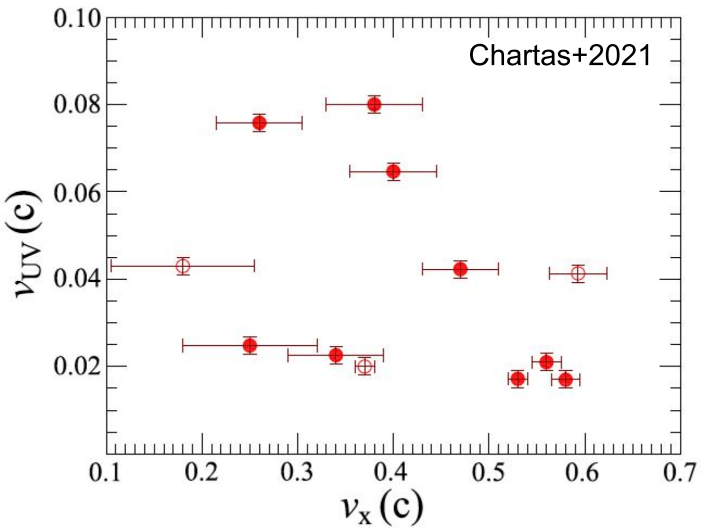


Chartas+2003,+2007,+2009b,+2016+2021, Vignali+2015,
Dadina+2018, Lanzuisi+2012, Bertola+2020

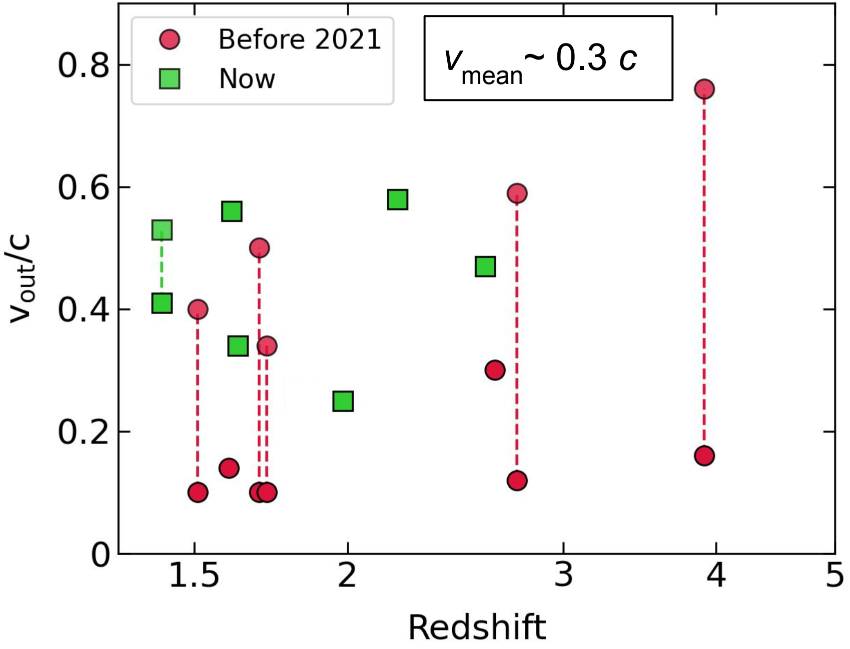
Chartas+21: XMM program on NAL AGN

NAL AGN show a UFO DF~80%
hints at link between multiphase winds on the meso- and micro-scale

However, there is no clear link between the velocities of the two components

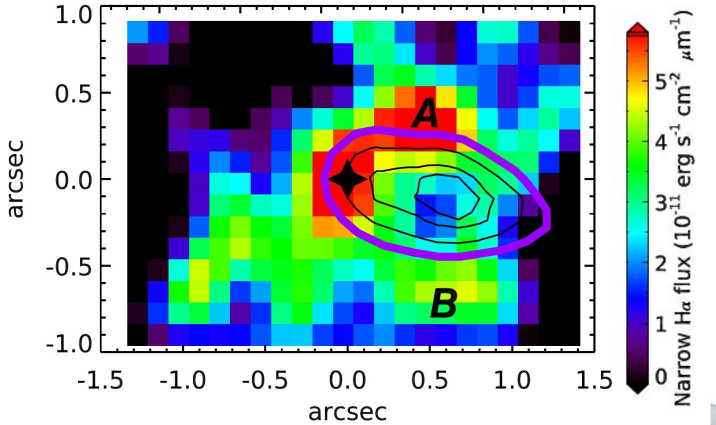


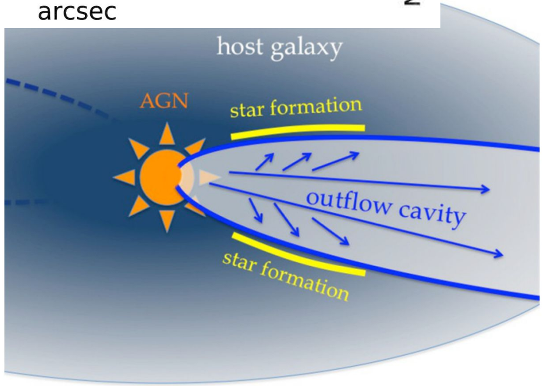
$z > 1$: 14 AGN (only 7 before 2021)



Chartas+2003,+2007,+2009b,+2016+2021, Vignali+2015, Dadina+2018, Lanzuisi+2012, Bertola+2020

The case of XID2028 (z=1.593): positive and negative feedback, and CO depletion

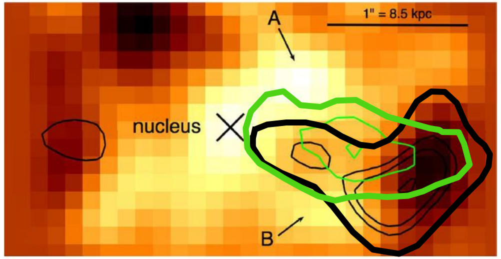




Narrow Hα map: tracer of SF

Black contours: **[OIII] outflow**

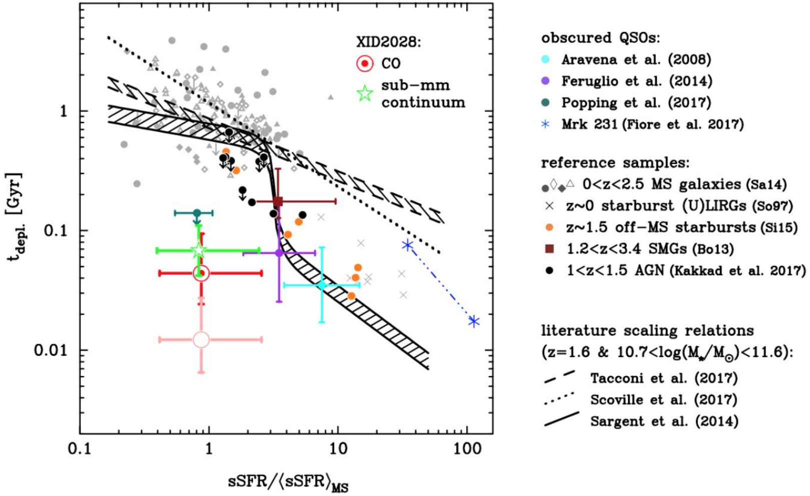
Cresci+2015



Brusa+2018

Black contours: **molecular outflow**

Green contours: **[OIII] outflow**



…but does AGN feedback actually have an impact on the star formation of galaxies?

The impact of AGN feedback on the SF of galaxies

If AGN winds establish the SMBH/host coevolution, then AGN must act on the SF of the host galaxy.

The most straightforward way to act on the SF is to impact the fuel of (future) SF, that is the molecular gas content

AGN are thus expected to reduce the molecular gas content of galaxies, but do we see this in our data? And what do the simulations predict?

The impact of AGN feedback on the SF of galaxies

How do we study this:

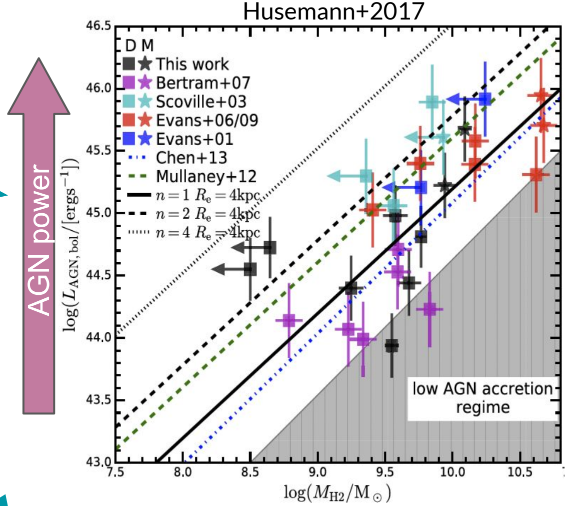
1. Build samples of AGN, measure the *total* molecular gas content of their host galaxies and obtain the other properties of the galaxy from SED fitting (for instance, the stellar mass, SFR).
2. Search for correlations between the *total* molecular gas mass of the host galaxy and molecular and/or ionized outflows (if any) and with AGN properties
3. Build a control sample of non-active galaxies matched in SFR and/or stellar mass to the AGN sample and search for differences - e.g., are AGN CO depleted?

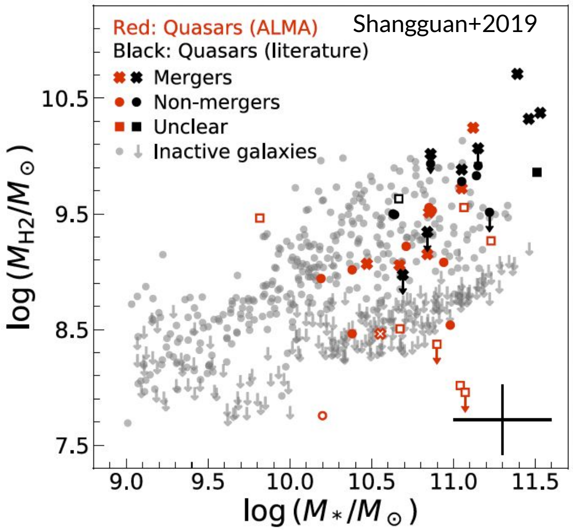
CO depletion: at fixed SFR/stellar mass, one galaxy sample shows *less* molecular gas than the selected control sample

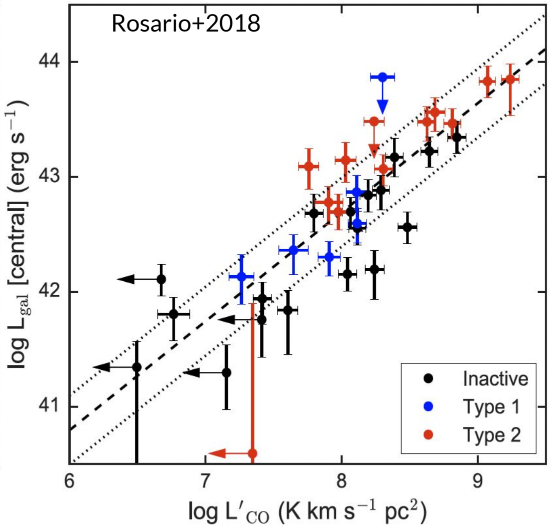
Low redshift and local Universe

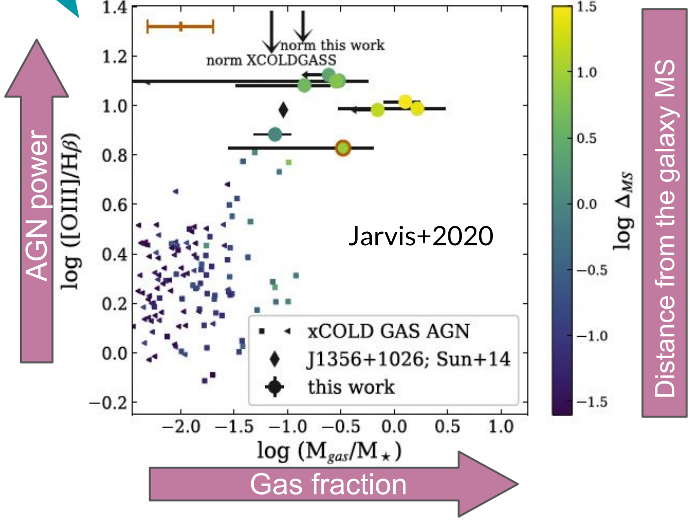
AGN host galaxies are consistent with non-active galaxies

The more powerful the AGN, the *more gas rich* the host:
AGN need gas to power the central activity,
the same gas that powers star formation





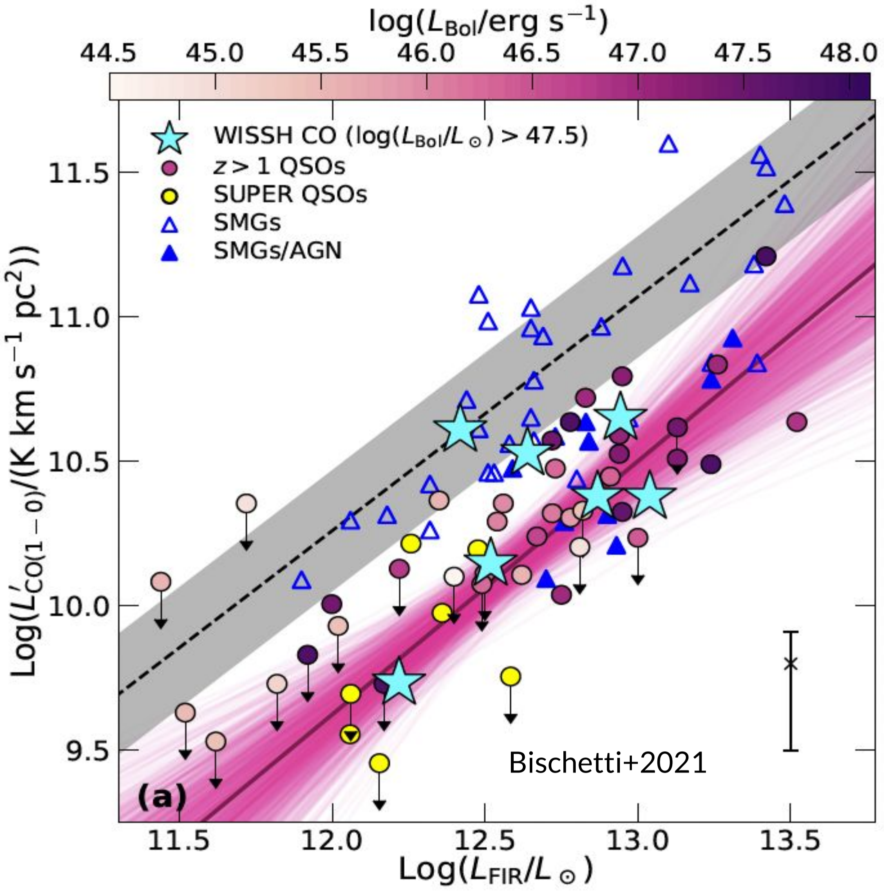




High redshift

High-z AGN seem to reside in CO depleted host galaxies

Issue: studies based on few, powerful AGN, pre-selected as good candidates for hosting outflows



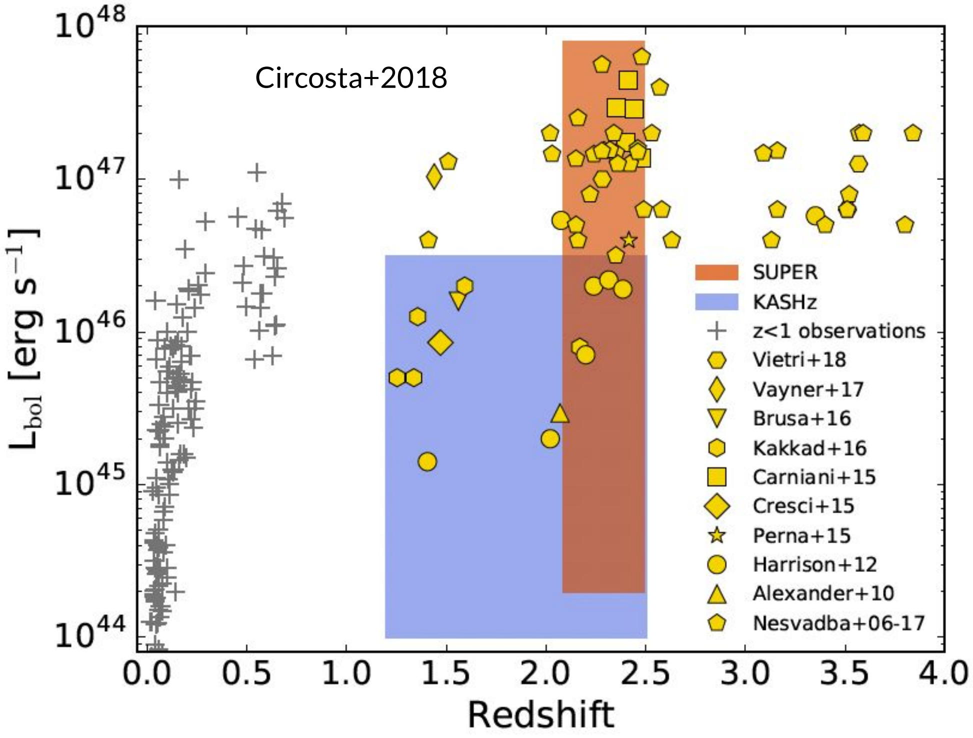
KASHz and SUPER

SUPER: *SINFONI* Survey for Unveiling the Physics and Effect of Radiative feedback

KASHz: *KMOS* AGN Survey at High redshift

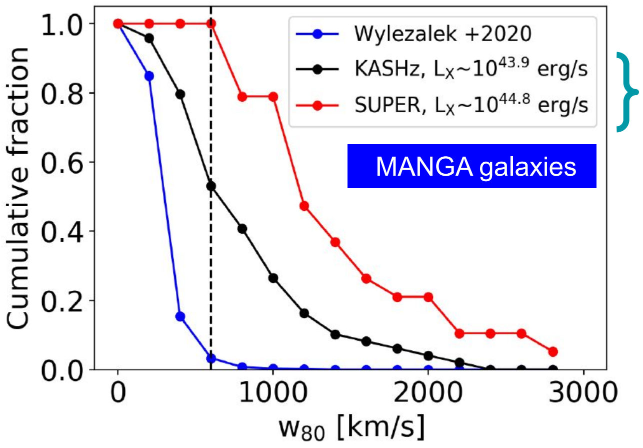
Unbiased samples of high-z, X-ray selected AGN spanning a wide range of AGN power

Aim: study relation between AGN-driven ionized outflows and host galaxy properties (star formation and molecular gas content)

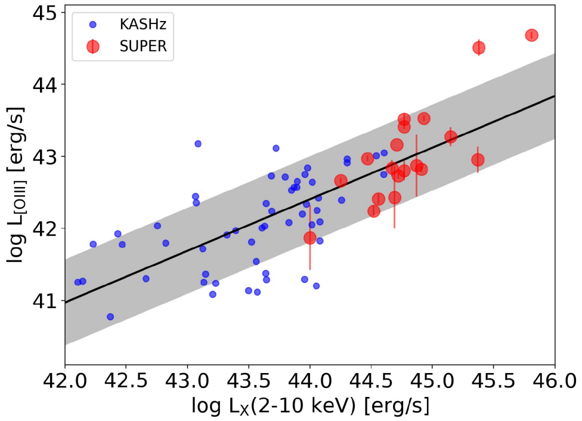


KASHz and SUPER outflows

Adapted from Kakkad+2020



Kakkad+2020



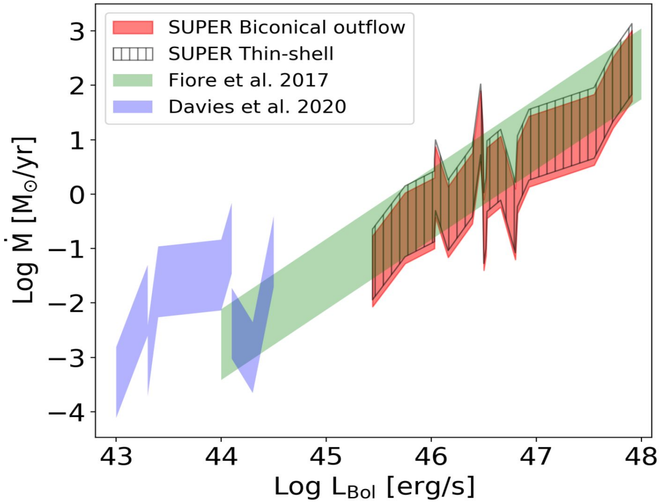
KASHz AGN:
strong [OIII] outflows + targets consistent to non-active galaxies

SUPER AGN Type 1:
all have w_{80} > 600 km/s

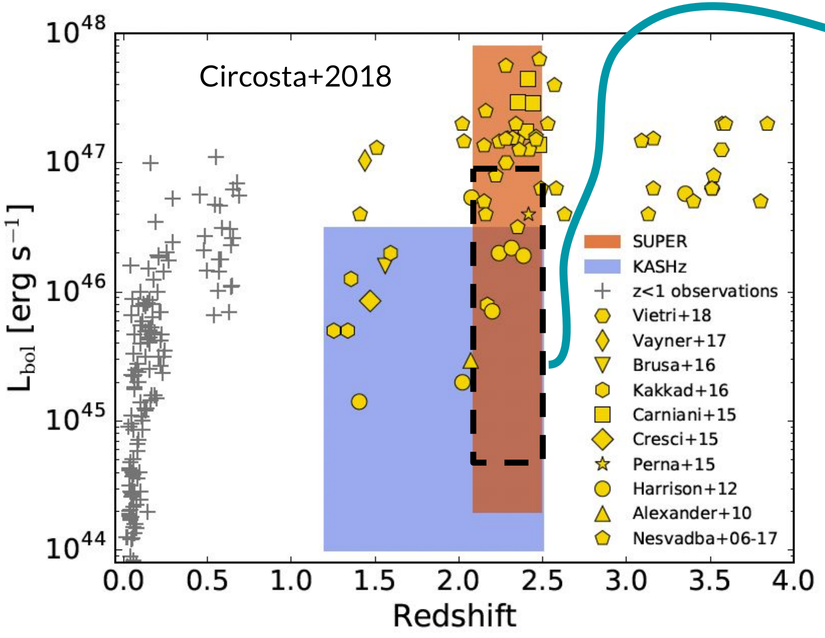
Samples are matched in redshift and stellar mass

Difference between KASHz and SUPER: X-ray luminosity

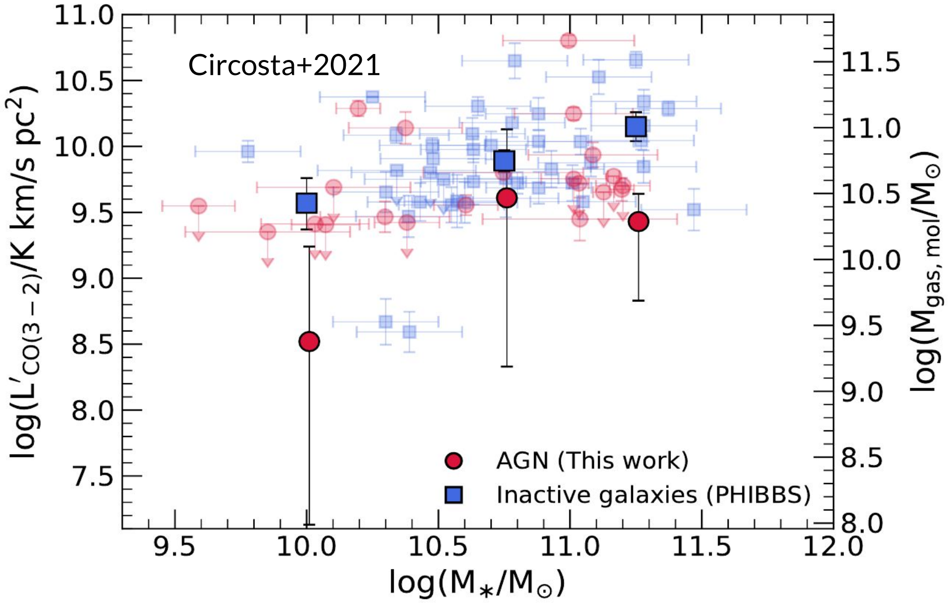
SUPER OFs match $\dot{M}_{out}$-L_{bol} relations of local and low-z AGN



SUPER AGN - CO depletion?

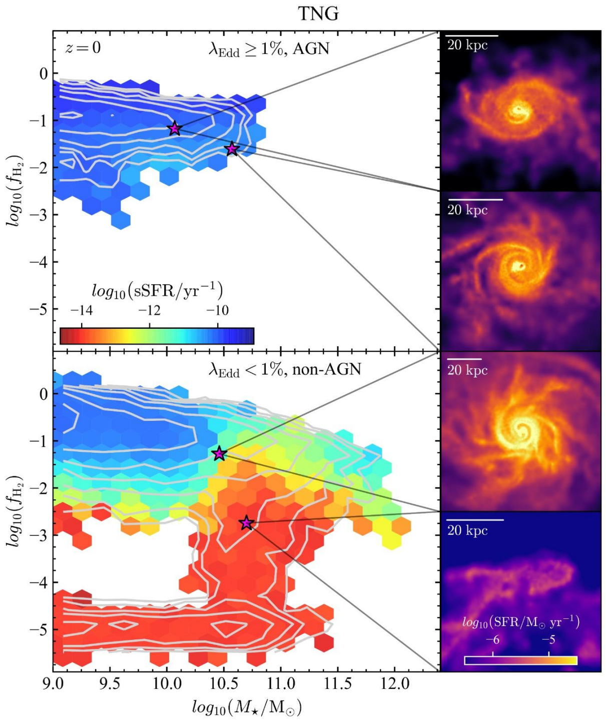


SUPER AGN show significant CO depletion only in the most massive host galaxies (Mstar>10^{11}Msun)



Demonstrates the importance of including 'regular' AGN in our high-z samples

And what do simulations predict?



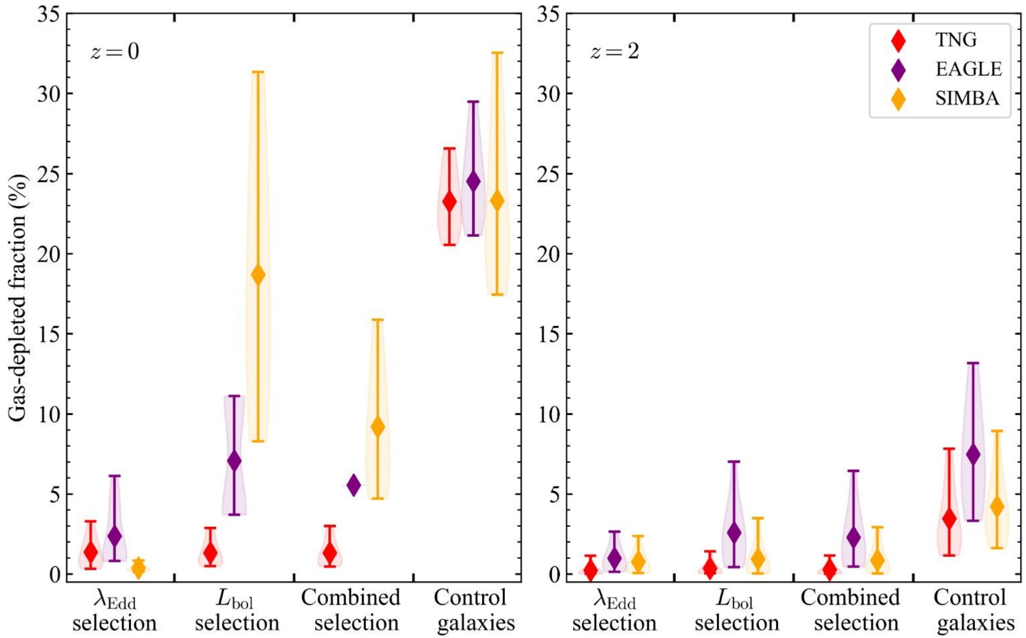
Ward+2022, subm.

AGN live in high gas fraction and high SFR galaxies

Qualitative agreement with results in low-z AGN

Potentially in tension with those at high-z, which also have a less coherent picture

And what do simulations predict?



Ward+2022, subm.

Predictions on gas-depletion are simulation-dependent, but in general there is no evidence for AGN hosts being more depleted than non-active galaxies

Issues:

1. It is hard for cosmological simulations to implement small-scale AGN feedback
   → need for smaller grids and better physical implementation of feedback

2. Include results on high-L_{bol} AGN (rare and short lived)
   → need for bigger volumes

Piace a **alessandropeca** e **altre persone**

astromemes_unibo E dal festival di Quasan Remo è tutto 🎵