# AGN feedback in the form of powerful outflows:
## an observational perspective

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# OUTLINE

(1) Introduction:
short guide on AGN and AGN/galaxies co-evolution ("feedback")

(2) Outflows/winds probes and Multiphase Nature

(3) Incidence of AGN outflows

(4) Energetics and power

(5) Main open question
What's the impact of outflows on the host galaxy?

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Alessandro Marconi, Andrea Merloni talks

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Roberto Maiolino talk

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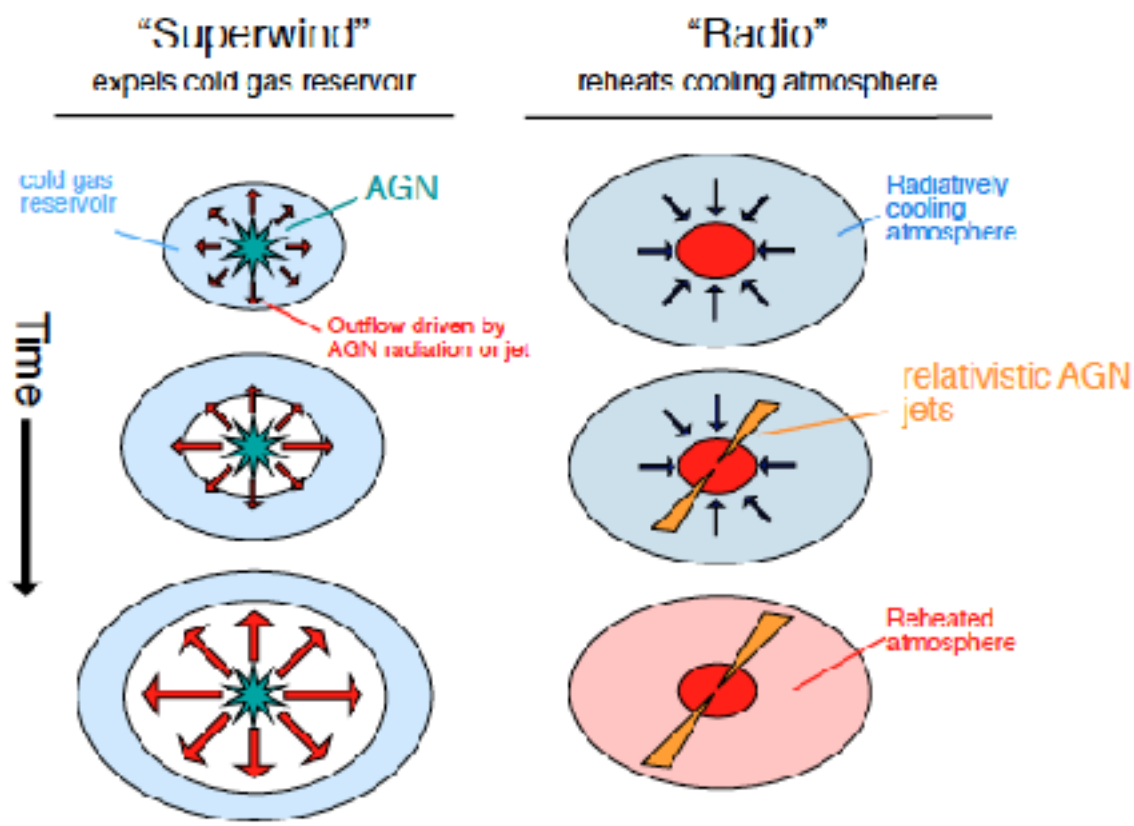
# AGN FEEDBACK MODES

Alexander & Hickox 2012




**Expectations:**

**The activity of the SMBH influences the life of the galaxy**

**MICRO vs. MACRO**

## Heating vs. Ejecting

**e.g. Croton+2006, Ciotti&Ostriker2007**

## Radiative vs. Kinetic

**e.g. King2012, Tadhunter+2014**

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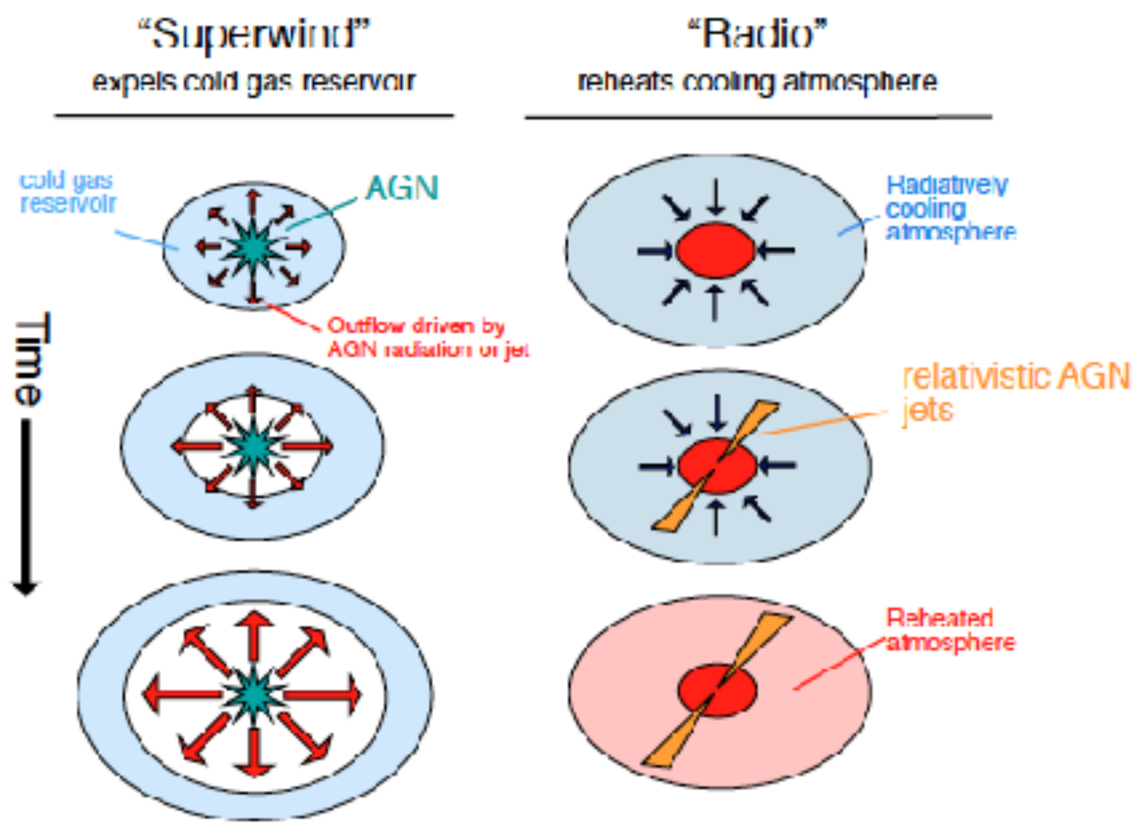


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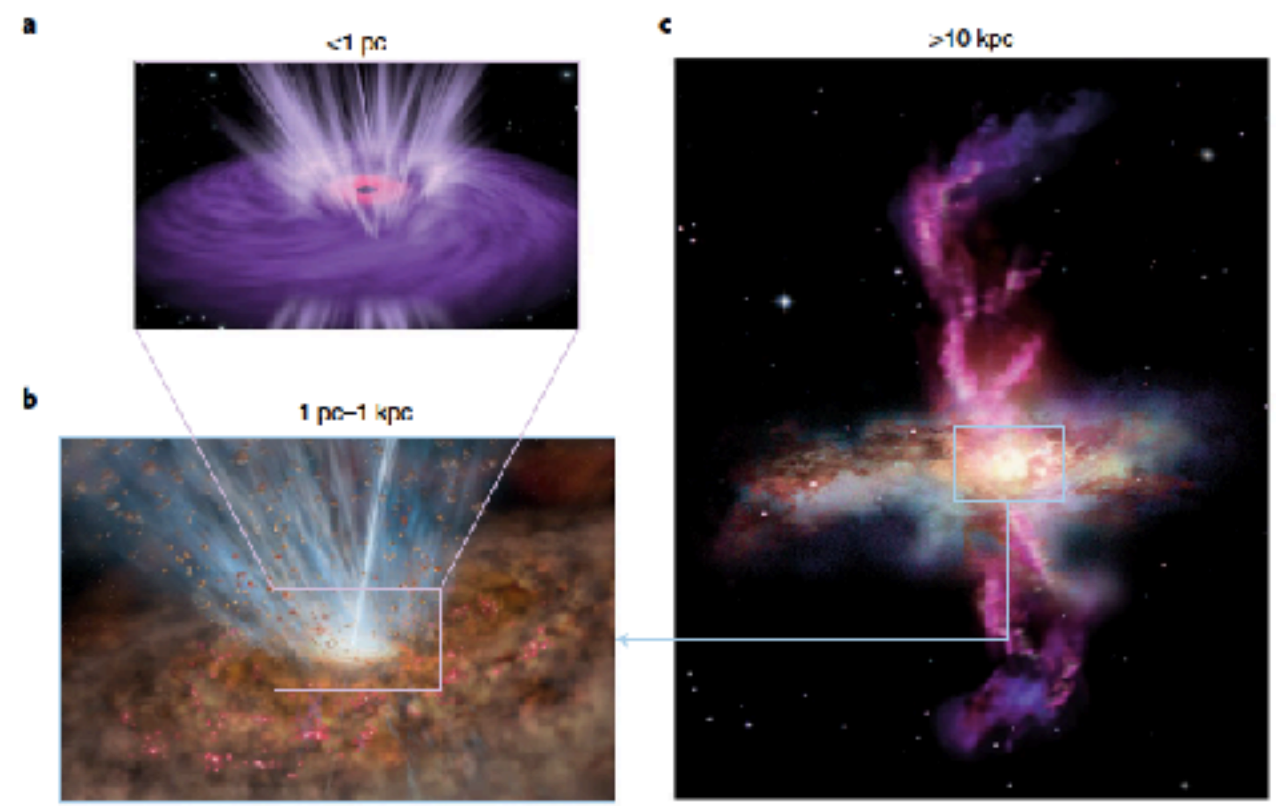
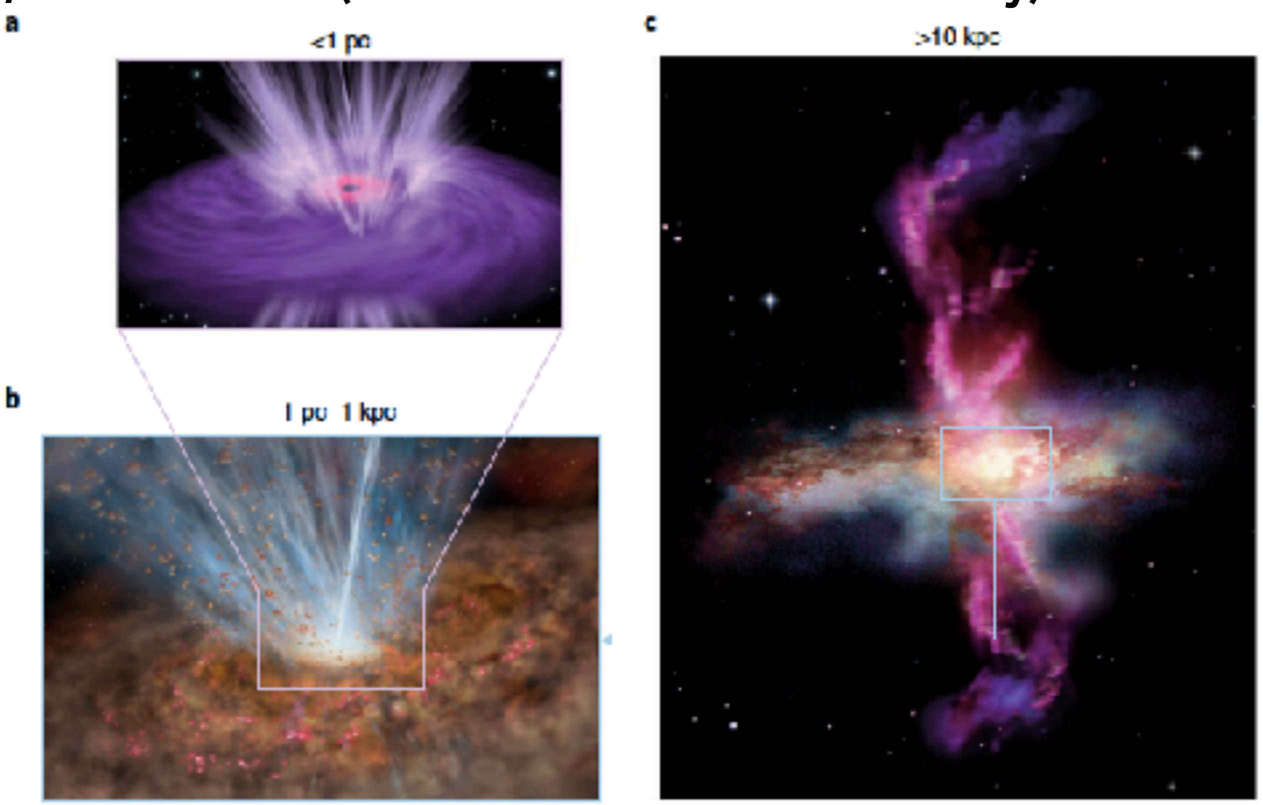



see Roberto Maiolino & other talks

# AGN FEEDBACK AS OUTFLOWS

Cicone, MB et al. 2018 ("Comment" in Nature Astronomy)




**Expectations:**

**Winds from the central AGN propagate into the host galaxy**

Wide-angle, wind-driven outflows, launched from the accretion disk and driven by **radiation pressure**

Faucher-Giguere+2012, King2012, Fabian2012
Zubovas&King 2012…2016, Costa+2014

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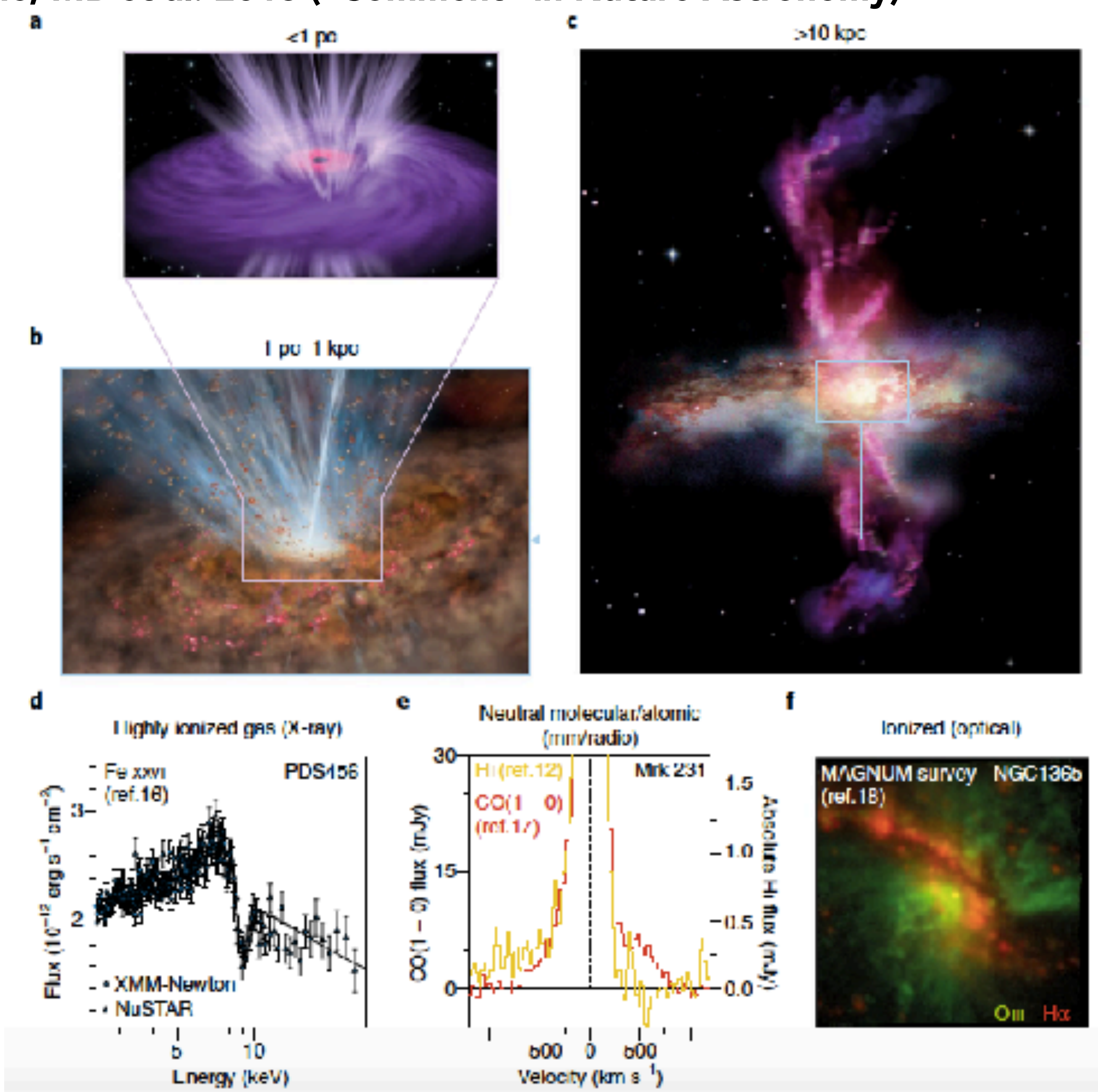


**highly-ionised gas (UFOs)**
Nardini+2015

**neutral gas molecular and atomic**
Morganti+2016, Cicone+2012

**ionised gas**
Venturi+2018

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Zubovas&King 2012…2016, Costa+2014

## Observations:

**Winds are seen across the electromagnetic spectrum**
(ionization state, redshift…)

**Different tracers probe different phases *and* different scales**

# OUTFLOW PROBES

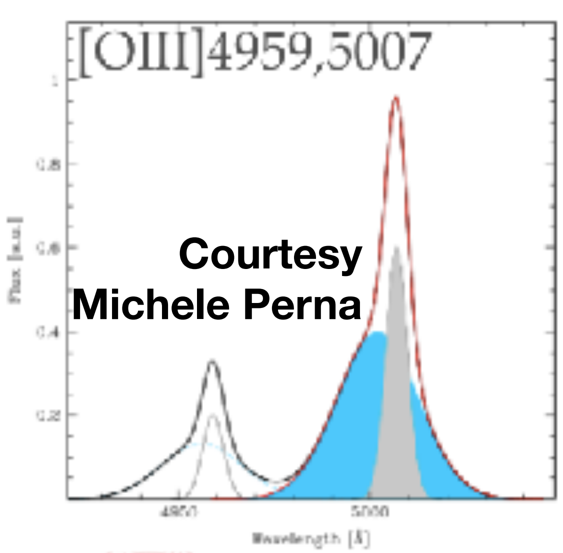
e.g. How can we identify the presence of gas flows in our observations?

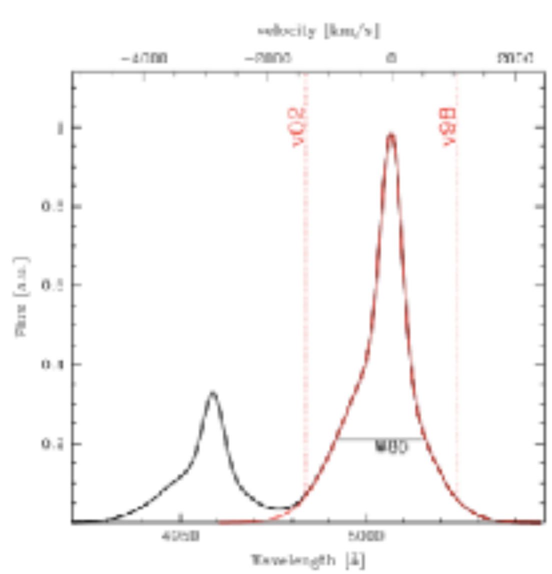
Gas flows, winds = **velocity**
**"disturbed" kinematics**

**$\Delta$v, FWHM, $v_{80}$, $v_{max}$, EW...**

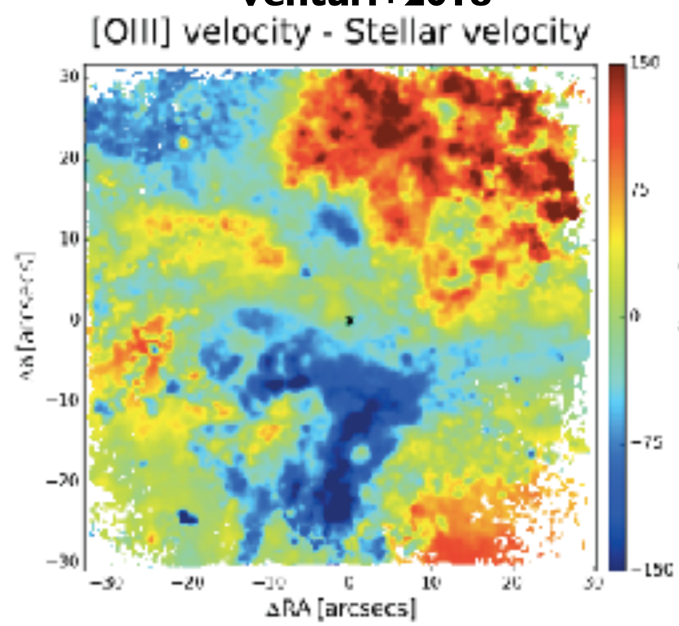
**ONE-D (slit spectroscopy):**
- asymmetries in absorption and emission lines (otherwise: symmetric)
- broad/deep spectral features (otherwise: narrow/less deep)

**3D (IFU spectroscopy)**
- velocities fields with significant blue/red components (otherwise symmetric/ consistent with rotation)

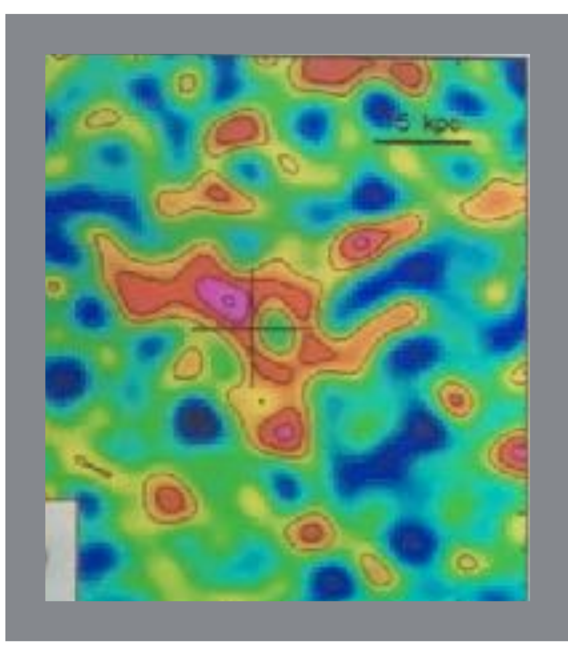


**NGC1365**
**Venturi+2018**

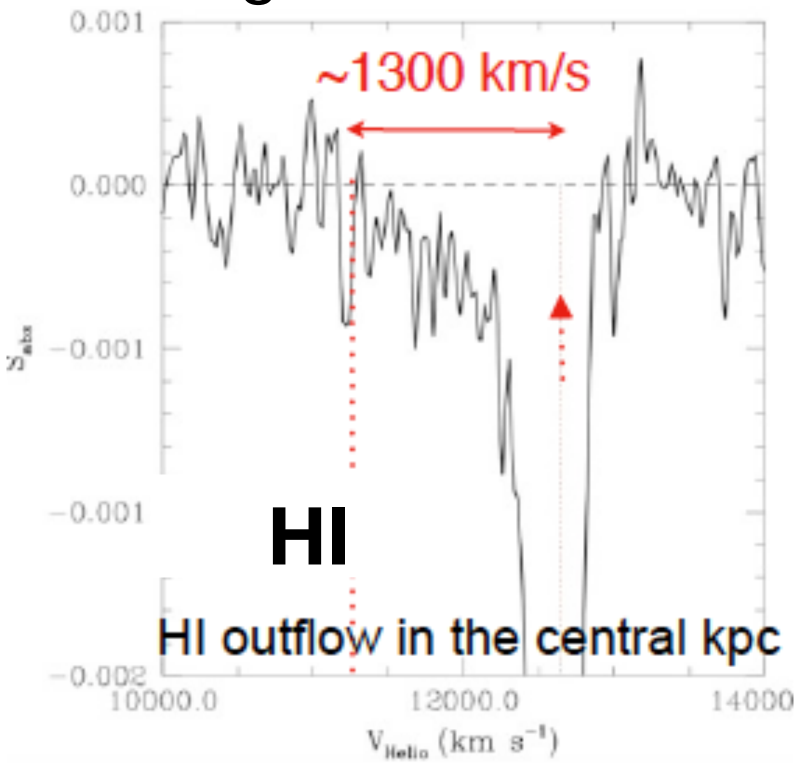



**z~6 QSO**
**Cicone+15**

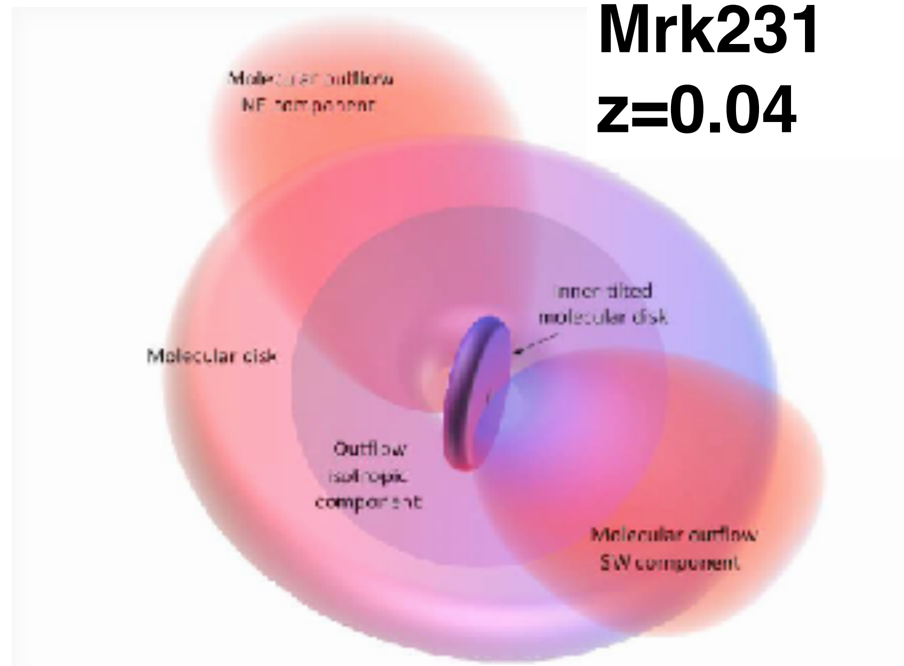


# WINDS ARE MULTI-PHASE & MULTI-SCALE

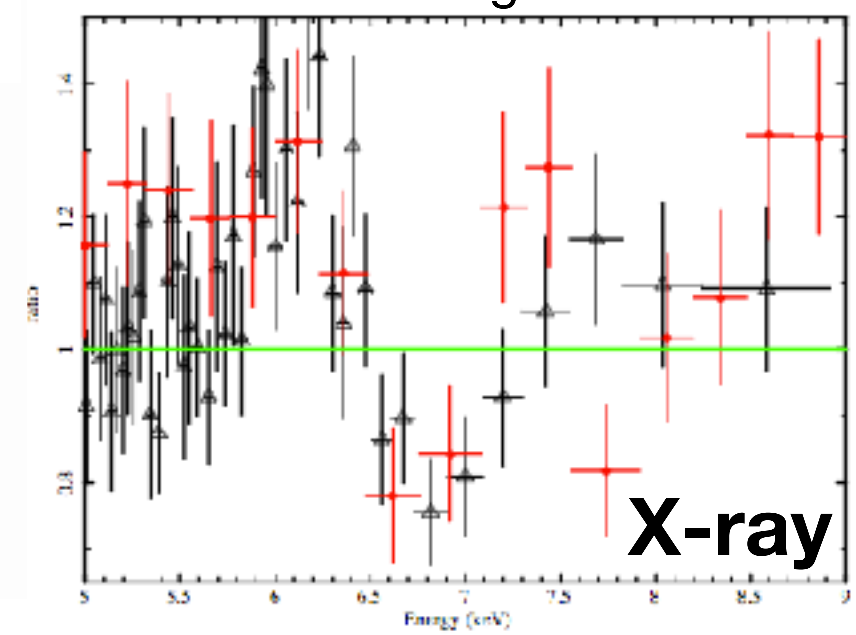
Morganti+2016




Mrk231
z=0.04

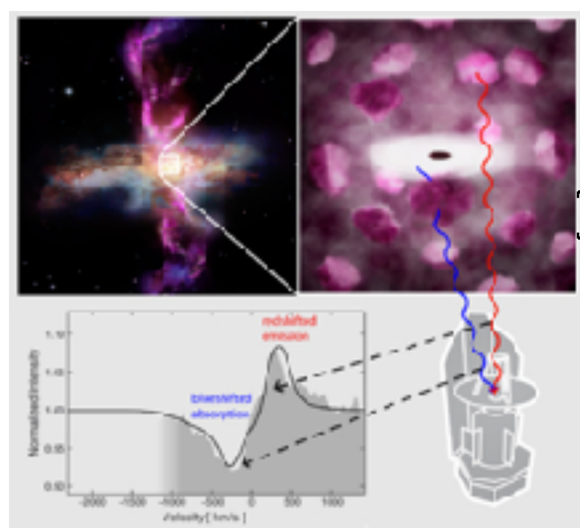



Feruglio+2015

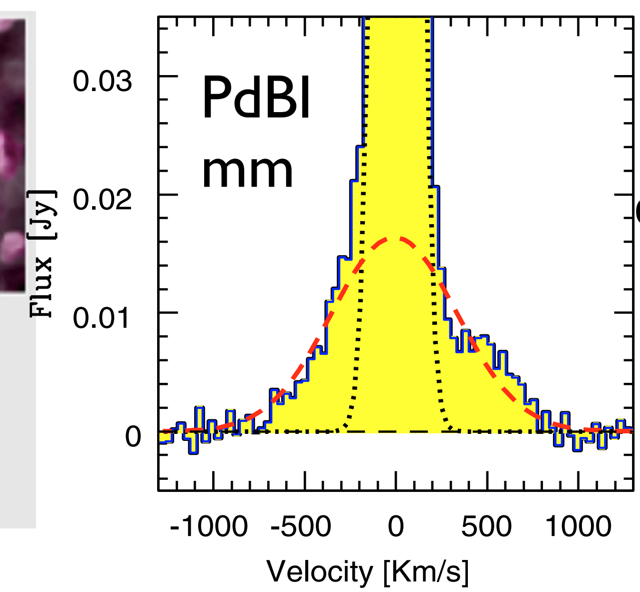



OH

Sturm+2011

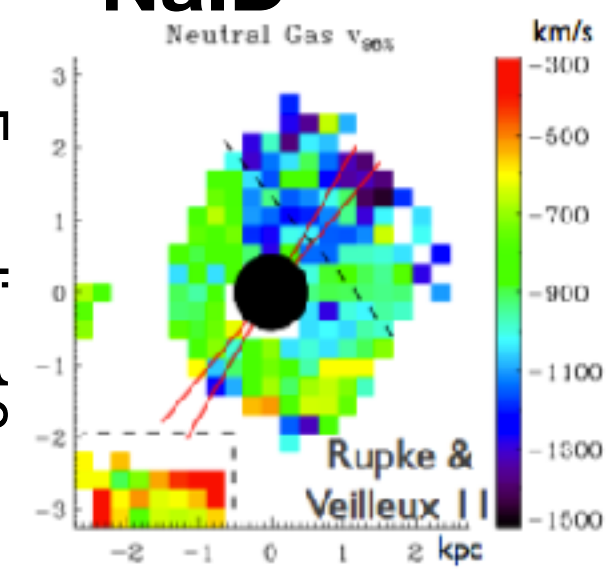


CO(2-1)




Feruglio+10

NaID




***On single objects see also:***

***low-z***
***Longinotti+2018 (IRAS17020)***
***Greene+2012/Sun+2014 (SDSS1356)***
***Tombesi+2015 (IRASF1119)***
***Feruglio+2013 (NGC6240)***
***Tadhunter+2015 (IC 5063)***
***Rupke+2013/Perna+2018 (Mrk848)***

***Circinus, NGC1266, NGC1068, PDS456…***

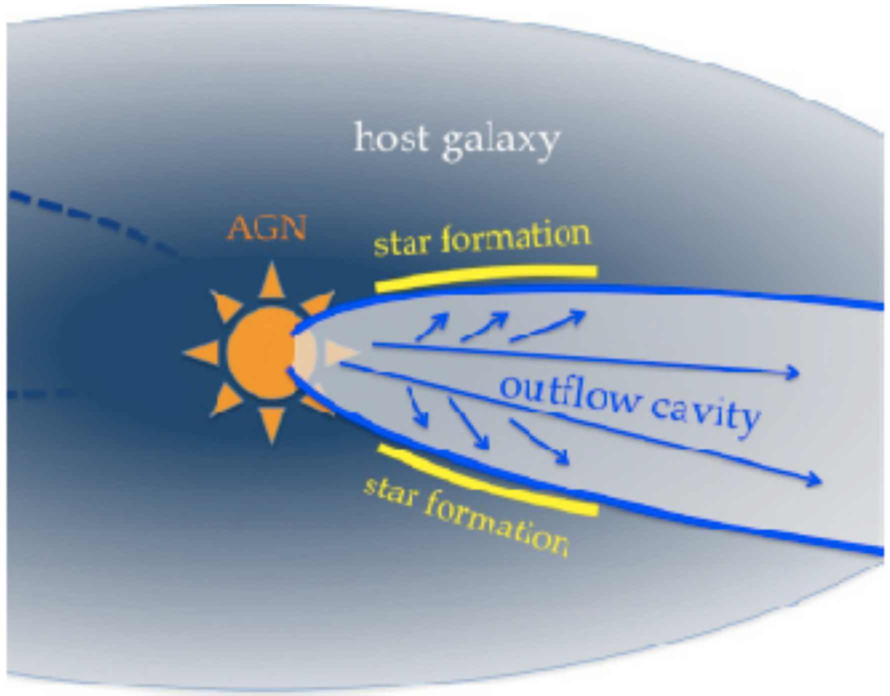
see Enrico Piconcelli talk

# WINDS ARE MULTI-PHASE & MULTI-SCALE

*On single objects see also:*

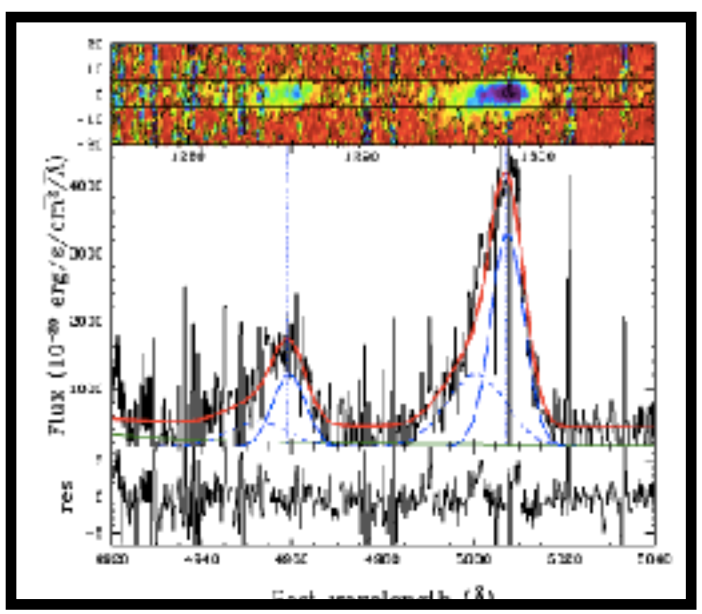
***high-z***
***Herrera-Camus+2018 (zC400528)***
***Vayner+2017 (3C298)***
***Cano-Diaz+2012/Carniani+2017 (2QZ J0028)***
***Chartas+2003/Feruglio+2017 (APM0279)***

see Stefano Carniani talk

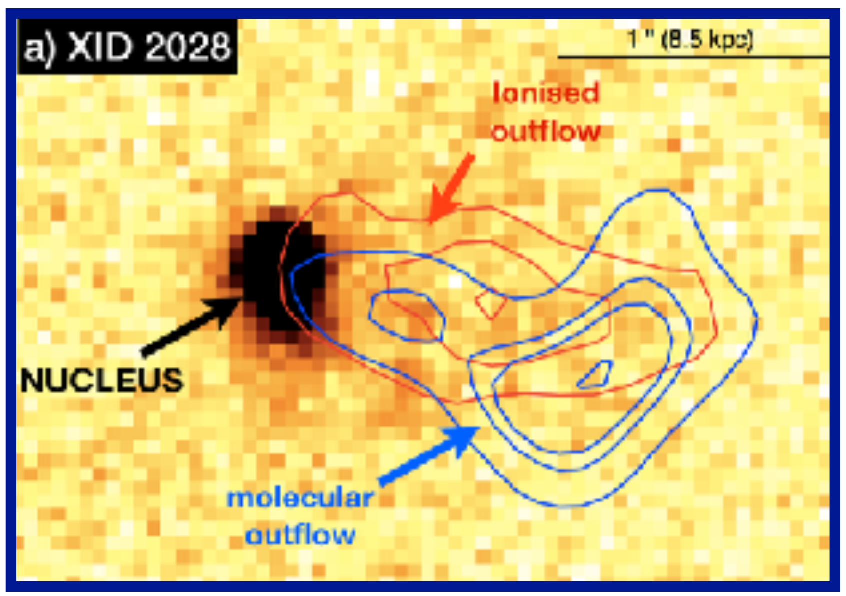



**XID2028**
**z=1.592**

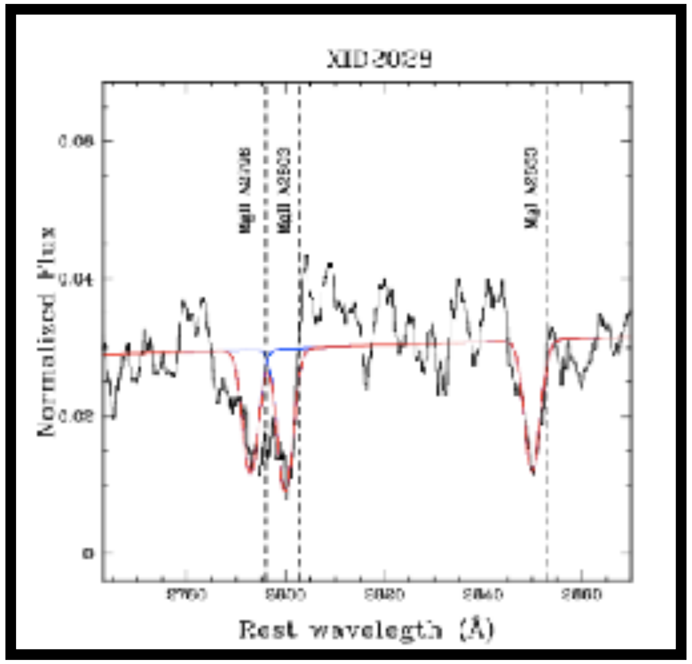
***Brusa+2015 X-shooter***
***Perna+2015 X-shooter+DEIMOS***
***Cresci+2015 SINFONI+HST***
***Brusa+2018 ALMA+LUCI***



**Ionised outflow ([OIII])**




**molecular and ionised winds**




**neutral outflow ([MgII])**

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AGN13 BEAUTY and the BEAST

**Marcella Brusa, Milano, 11 October 2018**

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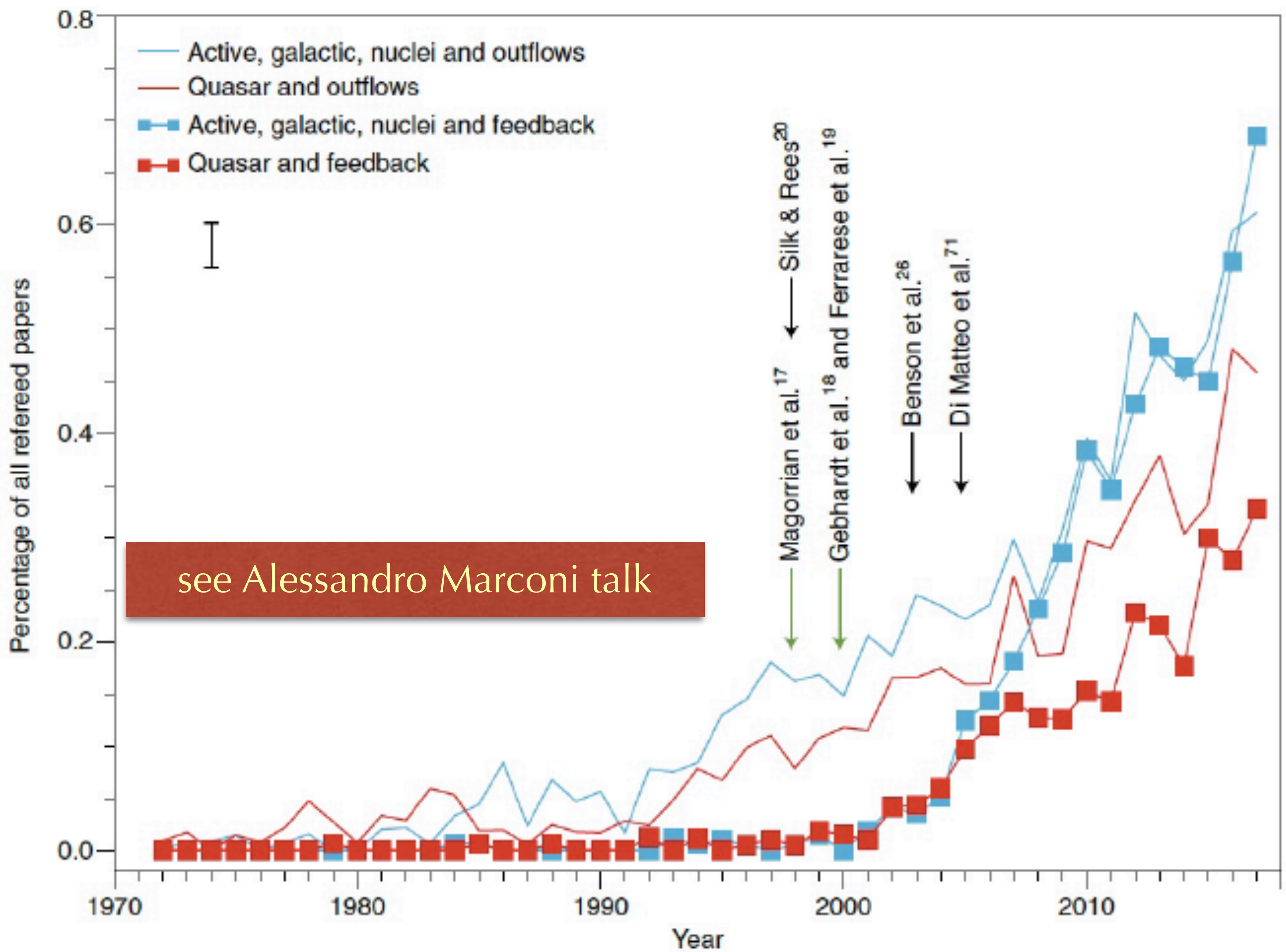
# AGN OUTFLOWS "INCIDENCE" IN REFEREED PAPERS




**Harrison et al. 2018, (*Perspective article, in Nature Astronomy March 1 2018 special issue on AGN feedback*)**

**It has become "popular" to attempt to derive outflow properties observationally in order to test feedback models**

# AGN OUTFLOWS "INCIDENCE" IN REFEREED PAPERS

*ADS SEARCH for "Quasar & feedback" or "AGN & outflows", years 2015-2018*

******************** *TOP 20 most cited references* ********************************************

Sijacki+2015 *The Illustris simulation: the evolving population of black holes across cosmic time*
King&Pounds 2015 *Powerful Outflows and Feedback from Active Galactic Nuclei*
**Tombesi+2015** *Wind from the black-hole accretion disk driving a molecular outflow in an active galaxy*
Khandai+2015 *The MassiveBlack-II simulation: the evolution of haloes and galaxies to z ~ 0*
Rosas-Guevara+2015 *The impact of angular momentum on black hole accretion rates in simulations of galaxy formation*
Schawinski+2015 *Active galactic nuclei flicker: an observational estimate of the duration of black hole growth phases of ~$10^5$ yr*
**Feruglio+2015** *The multi-phase winds of Markarian 231: from the nuclear, ultra-fast wind to the galaxy-scale, molecular outflow*
Faucher-Giguere+2015 *Neutral hydrogen in galaxy haloes at the peak of the cosmic star formation history*
**Brusa+2015** *X-shooter reveals powerful outflows in z ~ 1.5 X-ray selected obscured quasi-stellar objects*
Rahmati+2015 *The distribution of neutral hydrogen around high-redshift galaxies and quasars in the EAGLE simulation*
**Volonteri+2015** *The Case for Supercritical Accretion onto Massive Black Holes at High Redshift*
**Nardini+2015** *Black hole feedback in the luminous quasar PDS 456*
Weinberger+2017 *Simulating galaxy formation with black hole driven thermal and kinetic feedback*
**Cresci+2015** *Blowin' in the Wind: Both "Negative" and "Positive" Feedback in an Obscured High-z Quasar*
Yuan+2015 *Numerical Simulation of Hot Accretion Flows. III. Revisiting Wind Properties Using the Trajectory Approach*
**Carniani+2015** Ionised outflows in z ~ 2.4 quasar host galaxies
Croton+2016 *Semi-Analytic Galaxy Evolution (SAGE): Model Calibration and Basic Results*
Alatalo+2015 *Suppression of Star Formation in NGC 1266*
**Fiore+2017** *AGN wind scaling relations and the co-evolution of black holes and galaxies*
Thompson+2015 *Dynamics of dusty radiation-pressure-driven shells and clouds: fast outflows from galaxies,…. and AGN*

**It has become "popular" to attempt to derive outflow properties observationally in order to test feedback models**

# HIGH INCIDENCE OF IONISED OUTFLOWS

**Outflows are common**

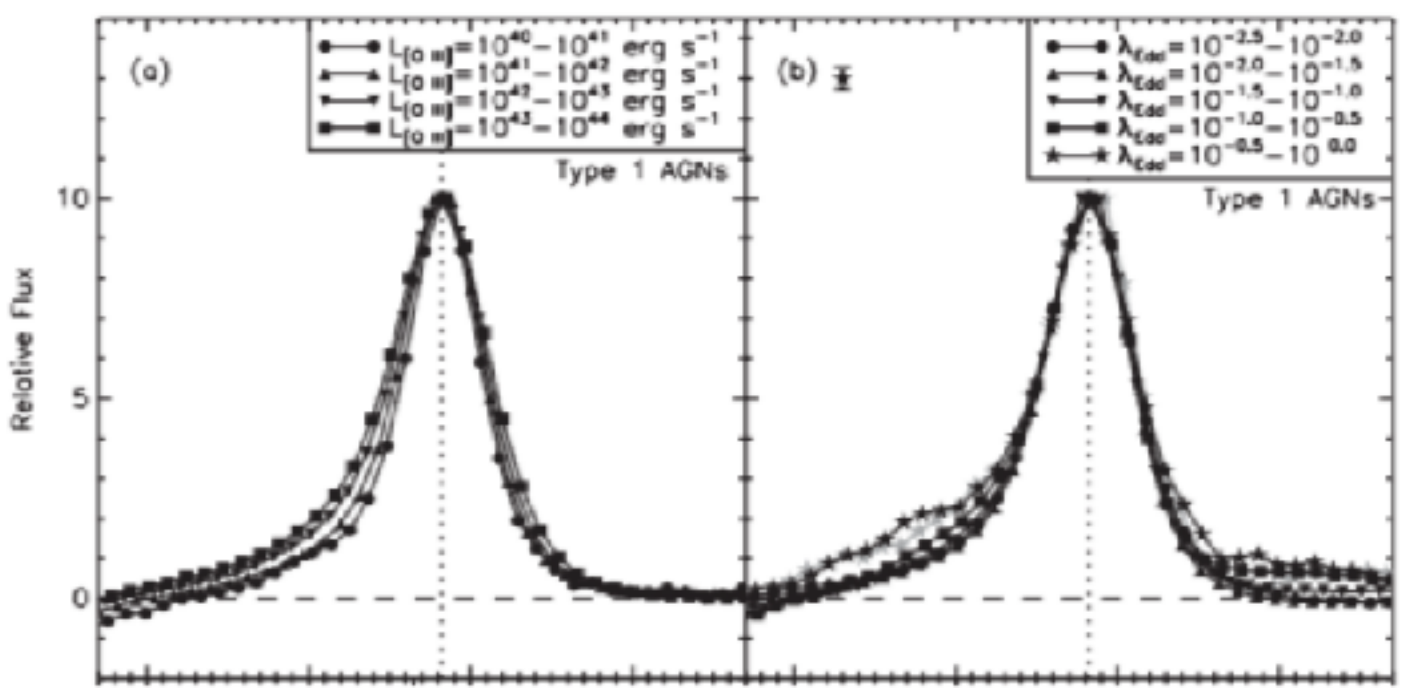
SDSS + stacked results: "ubiquituous" in the ***ionised*** components

**Outflows "incidence*" increases with Luminosity and/or Eddington ratio**

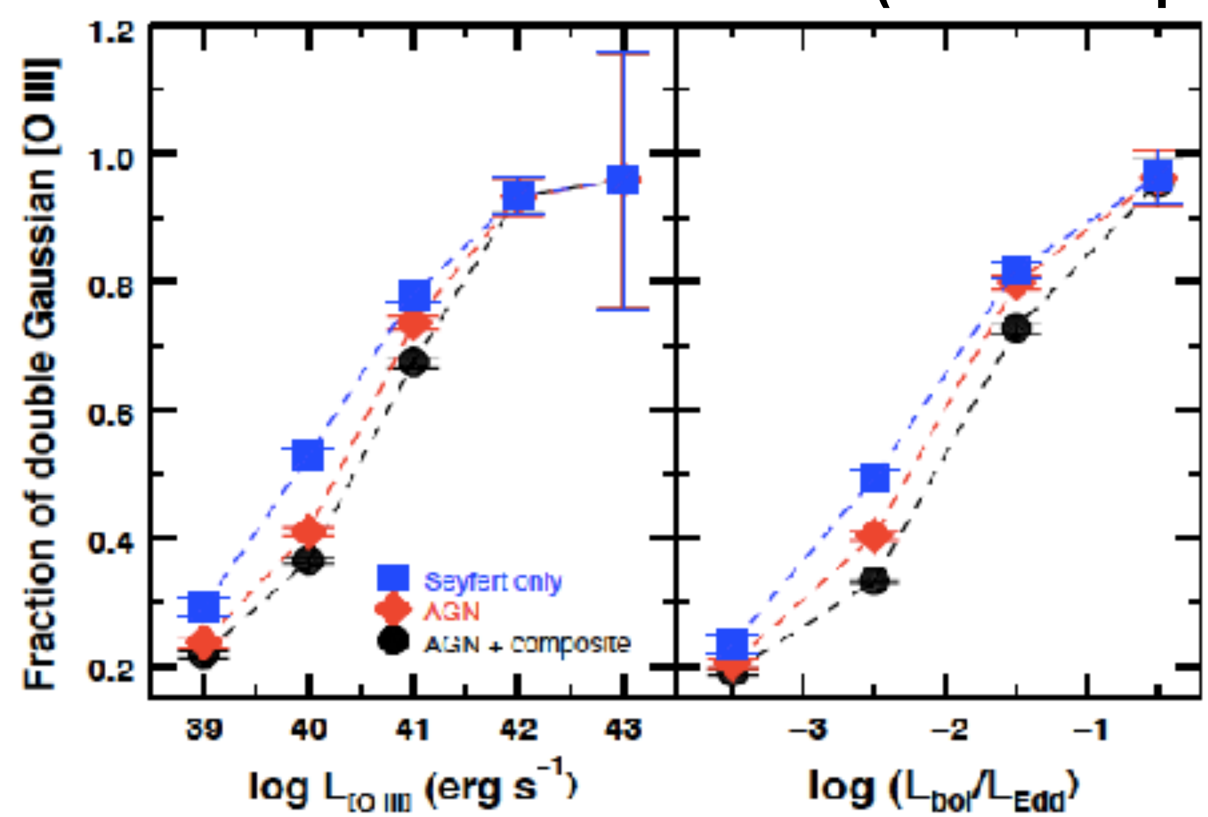
*based on fraction of sources with v>threshold or # of gaussians needed to fit the profile

from 20% to 100% !

**Mullaney +2013 (SDSS, lowz, [OIII])**




**Woo+2016 (SDSS sample)**

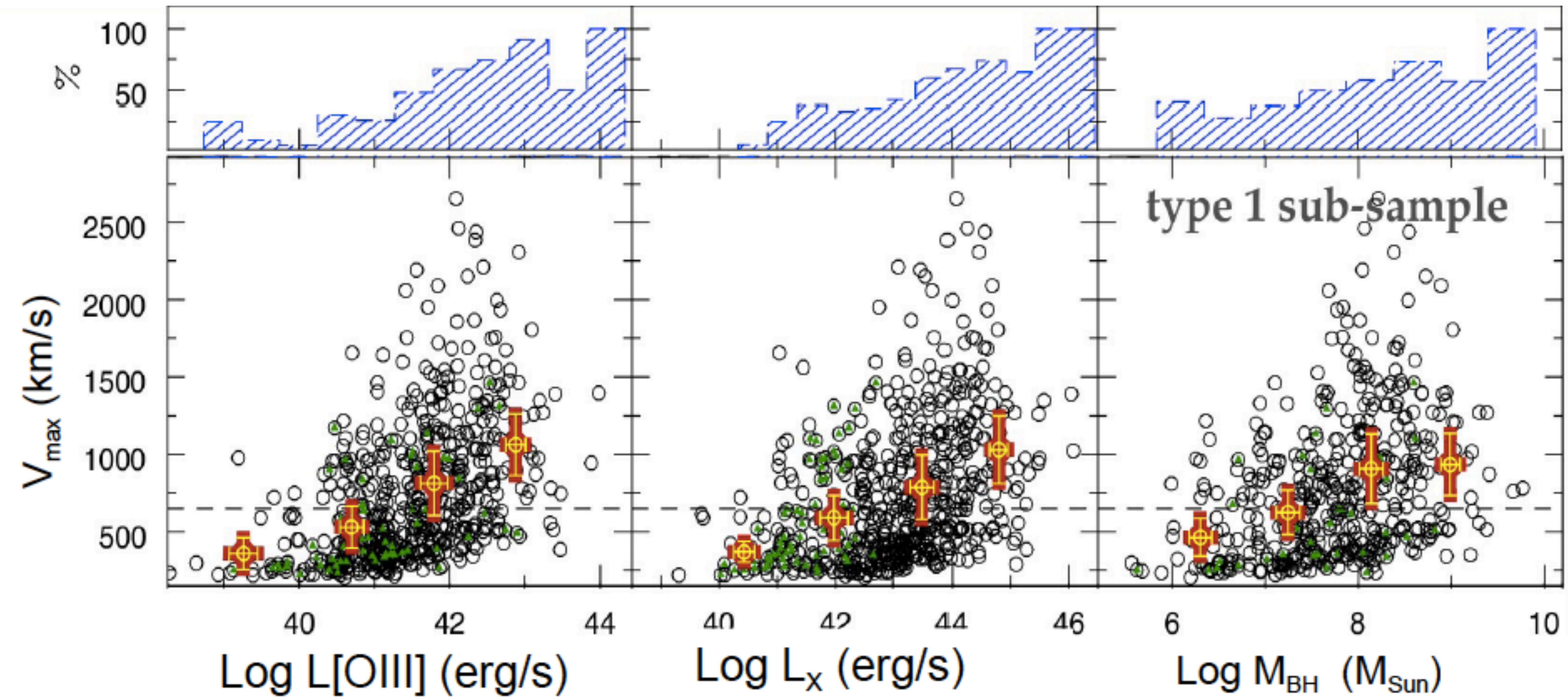


# IONISED OUTFLOWS INCIDENCE VS. LUMINOSITY

**Similar results in different samples - SDSS + Optical/radio/X-ray selected**

Mullaney+2013, Bae&Woo2014, Zakamska&Greene2014, Balmaverde+2016 + Harrison+2016 (KMOS+SINFONI,z>1)

**Perna+2017a**
**(Xray/SDSS sample, z<0.8)**



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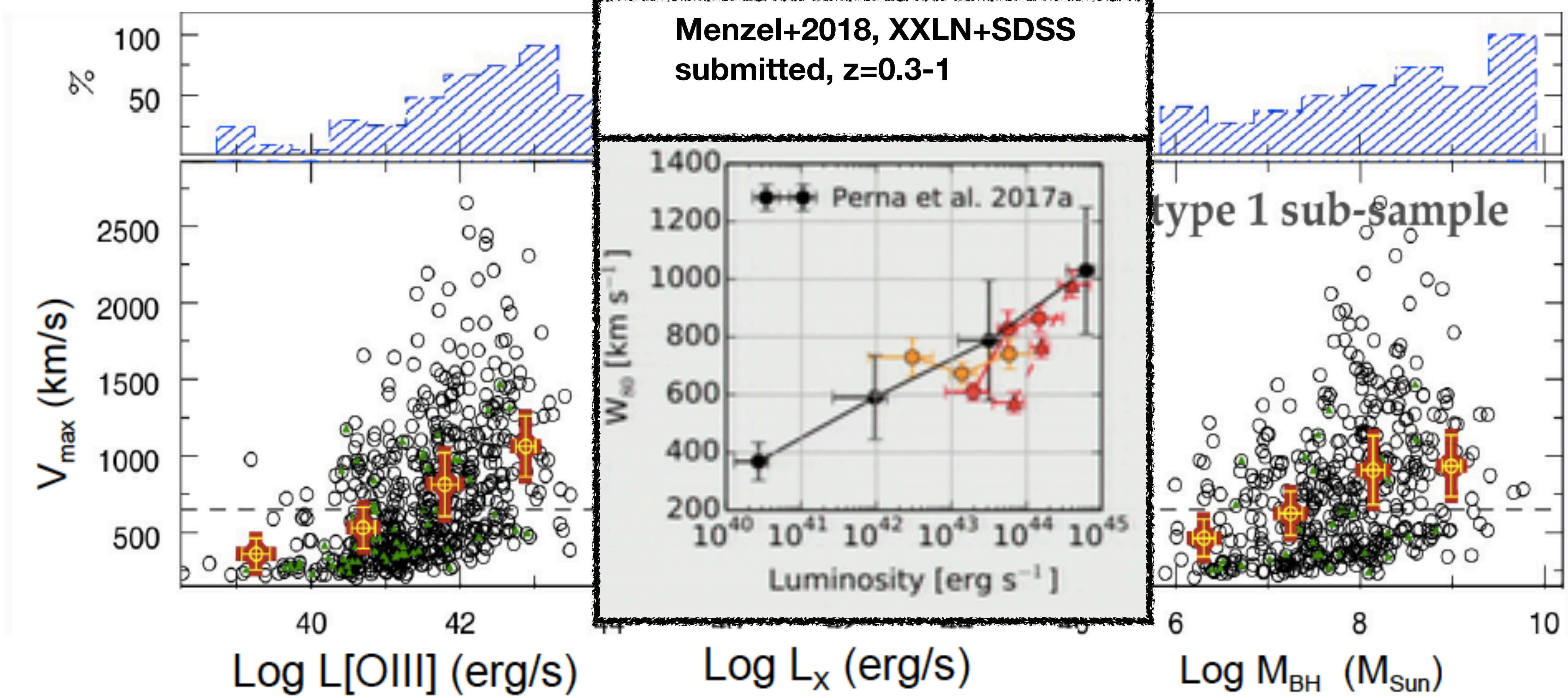
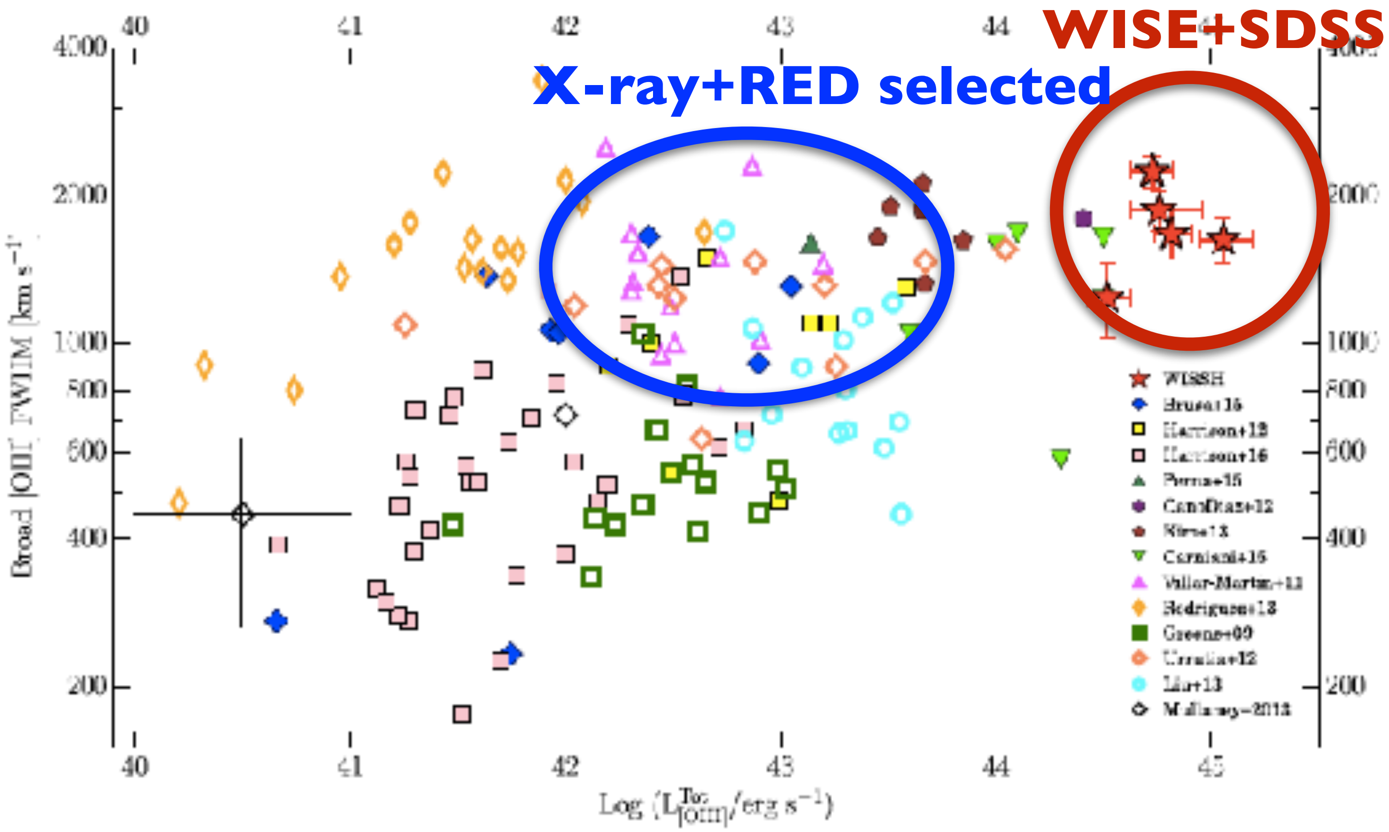
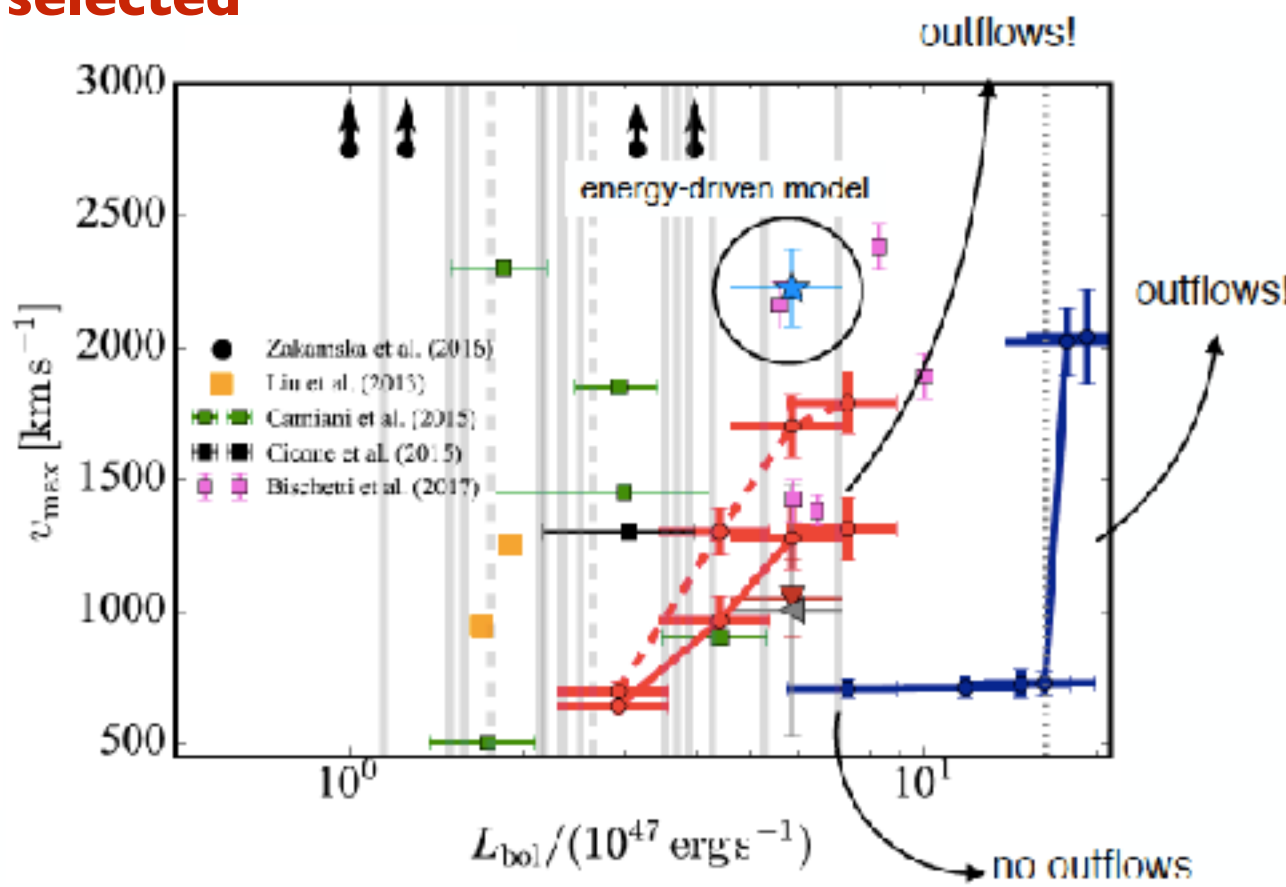
**Menzel+2018, XXLN+SDSS submitted, z=0.3-1**



# CRUCIAL ROLE OF DUST/OBSCURATION

**Ionised AGN outflows more common in highL/highEddratio *and in* red/obs/dusty sources**
(in agreement with models; e.g. Hopkins+2008)




Fraction of ionised outflows
**75% in X-ray selected, Obscured, Red sources**
(e.g. Brusa et al. 2015, Perna et al, 2015a,b
(see also Brusa et al. 2016, Kakkad et al. 2016,
Zakamska+2016, LaMassa+2017, Toba+2017 etc.)

Fraction of ionised outflows in
**30% in luminous IR selected samples:**
(e.g. Bischetti et al. 2017)

Consistent with model predictions which take into account **radiation pressure on dust**
(e.g. Costa+2018)

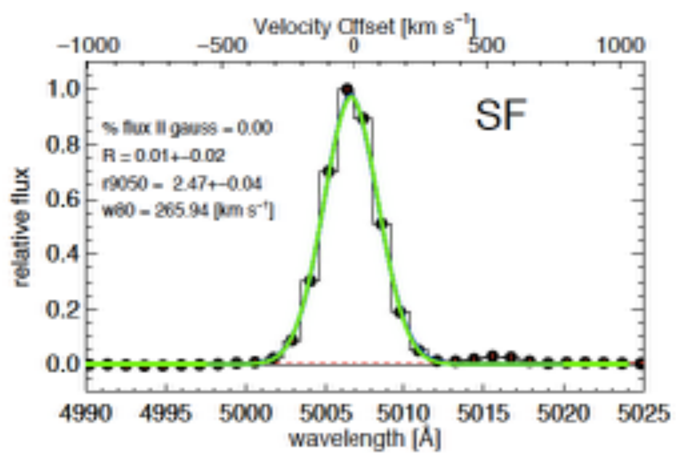
Importance of **highly obscured environment to launch outflows**

**Much LARGER SAMPLES needed — eROSITA!**

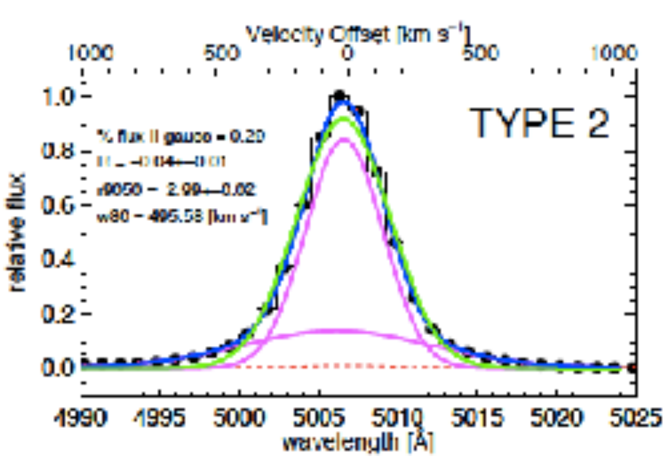
# IONISED OUTFLOWS VS. HOST GALAXY (SFR,M*)

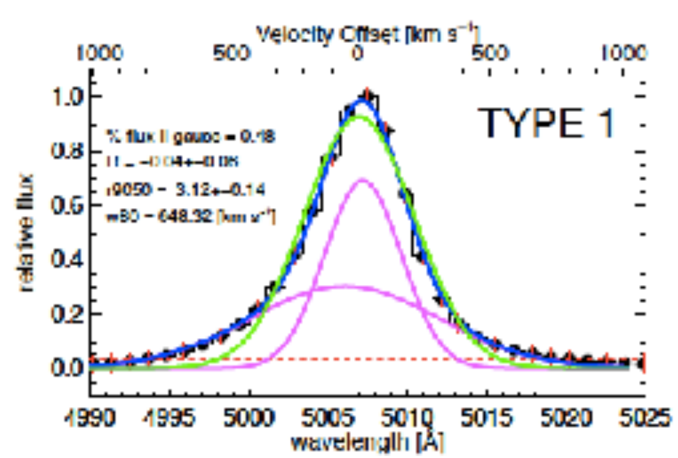
**Low-z (SDSS)**
**ionised outflows present at high stellar mass and high SFR (only in AGN samples..)**

**High-z (KMOS)**
**ionised outflows present at high stellar mass and all SFR (dominated by AGN)**




Cicone+16
Concas+17

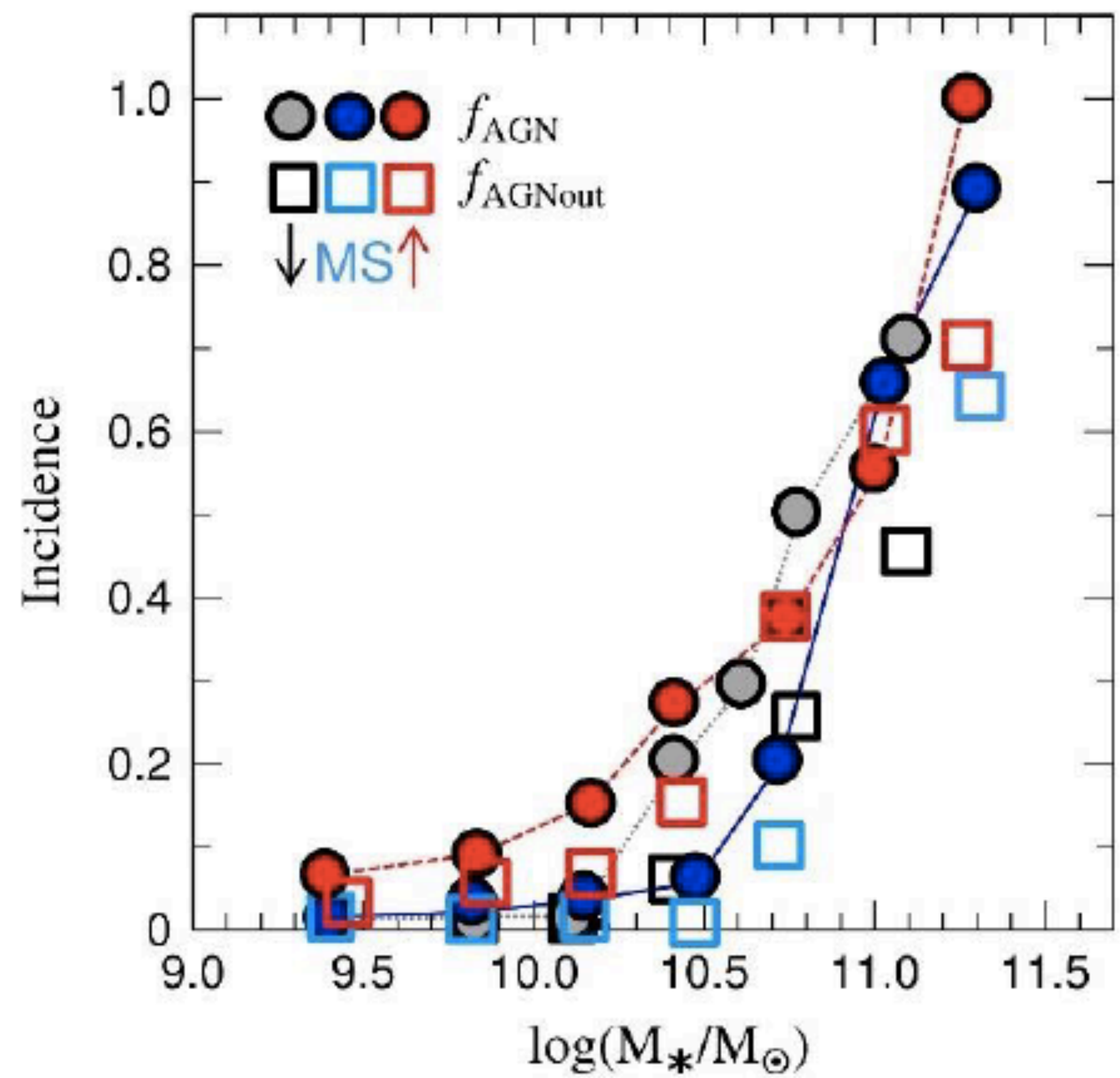



**Broad/shifted components in stacked spectra only needed for the AGN sample (see also Rodriguez-Zaurin+2013)**

see Roberto Maiolino talk for molecular outflows

Foerster-Schreiber+18




Cimatti, MB+2013, Foerster-Schreiber+2014, Genzel+2014,Brusa+2016

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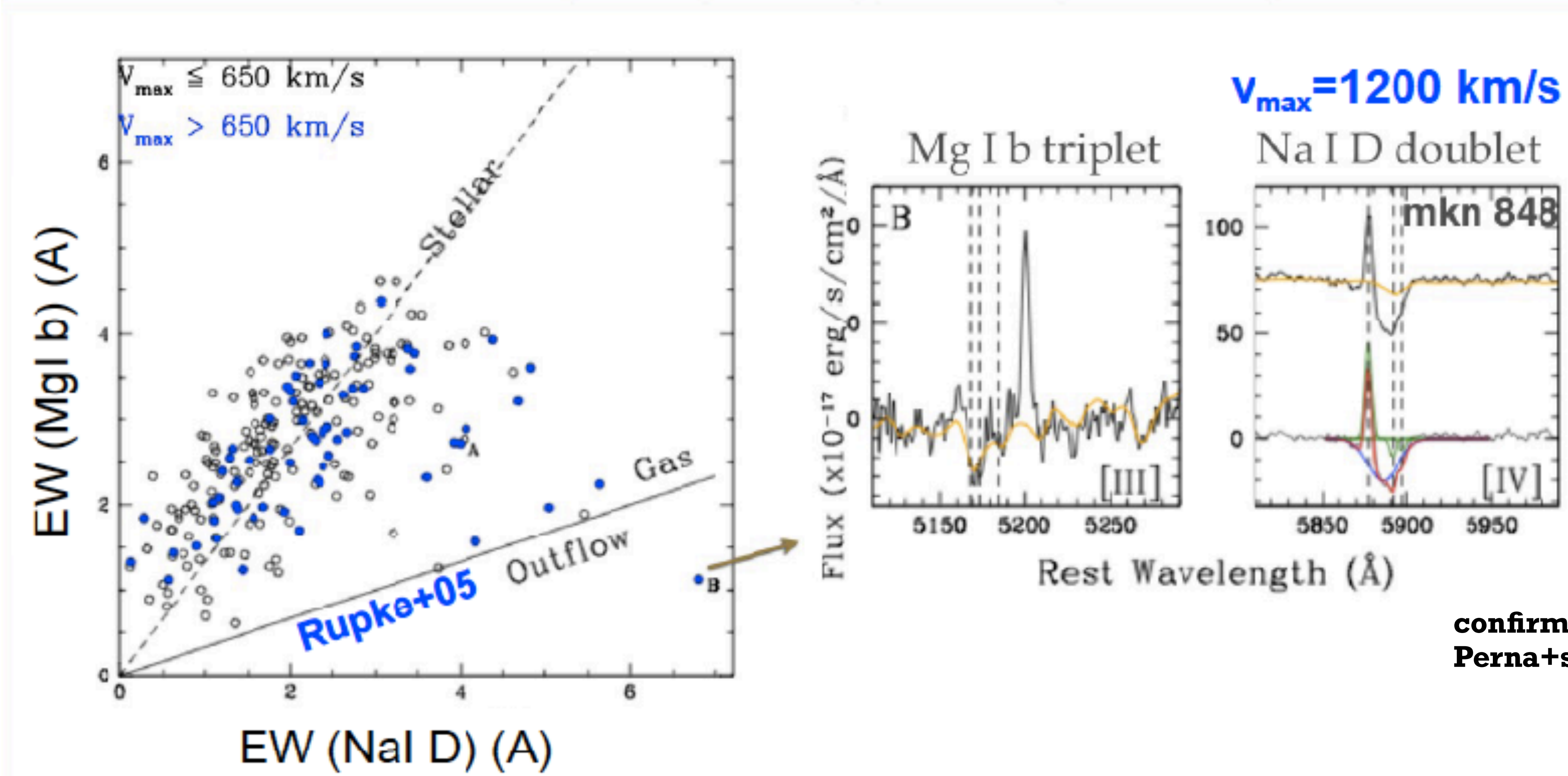
# LOW INCIDENCE OF NEUTRAL OUTFLOWS (?)

Outflows are not common in the ***neutral*** component at low-z
<1-few% NaD detections in AGN samples / **Perna+2017a**, Sarzi+2016, Nedelchev+2017




**confirmed on ManGA data**
**Perna+submitted**

**Diagnostic to select neutral outflows (NaD)**

**Concomitant ionised and neutral outflows only in sources with SB+AGN nature / mergers ?**

see Alice Concas talk

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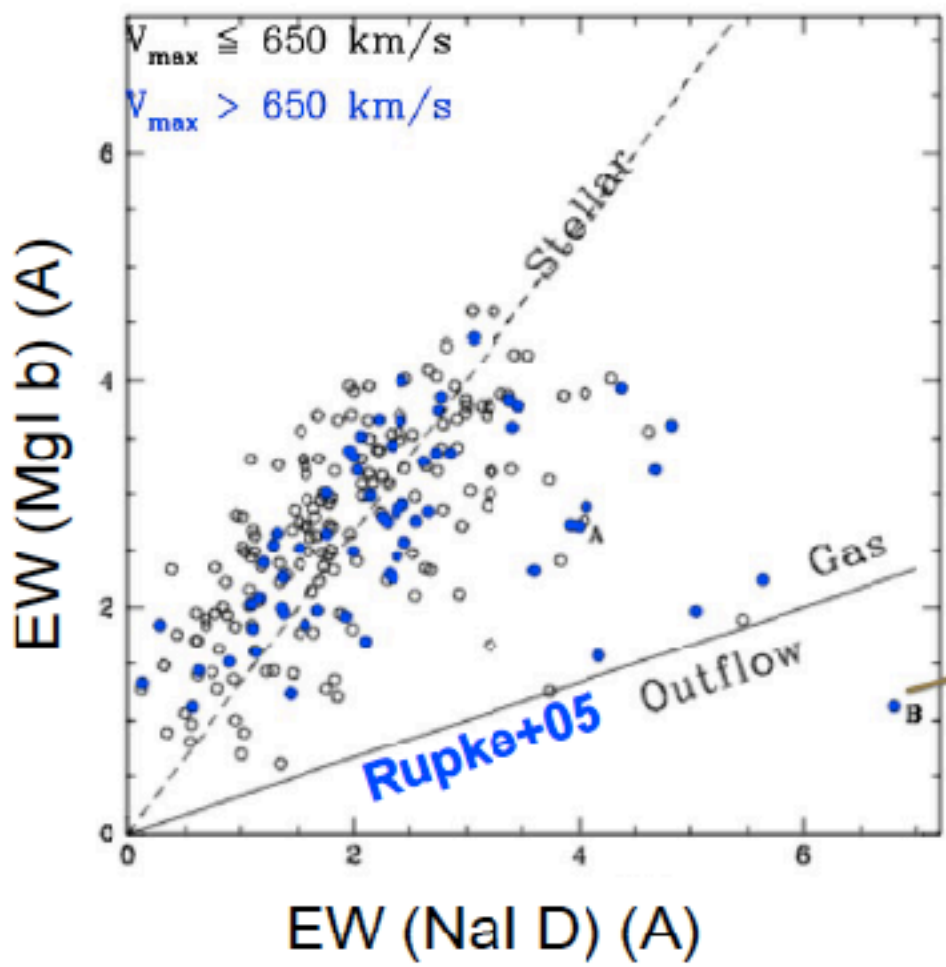


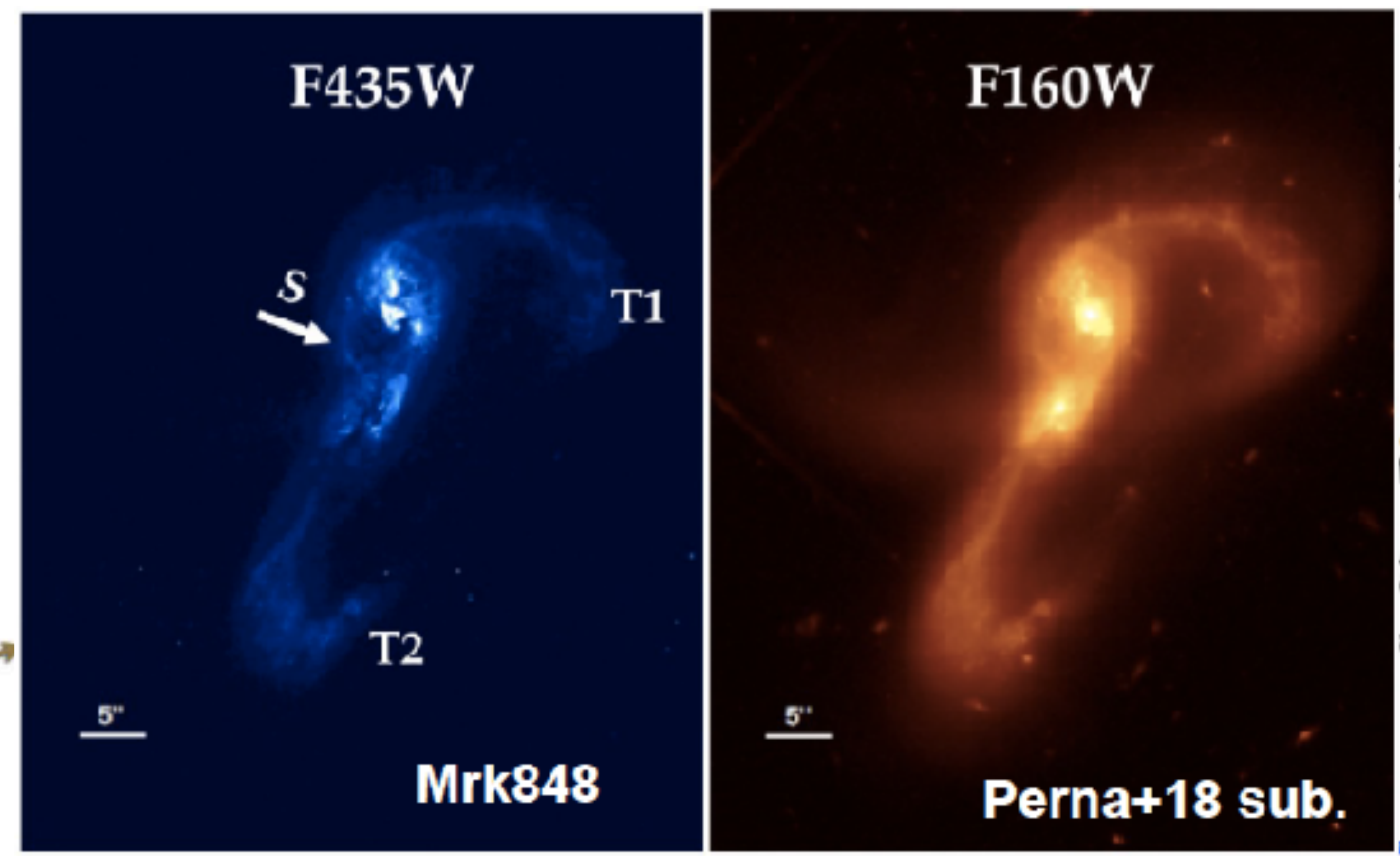


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# NO "ENERGY PROBLEM"

The energy released by a typical SMBH over its lifetime ~100 times the binding energy of the host galaxy

$$\frac{E_{\rm AGN}}{E_{\rm bind}} \approx 300 \left(\frac{\sigma}{250 {\rm km\,s^{-1}}}\right)^{-2}$$

*(Silk & Rees, 1998; Fabian, 1999; King, 2003, Fabian, 2012)*

- ***Quasar***: $E_{AGN} \sim 10^{61}$ **($\varepsilon$/0.10) ($M_{BH}/10^8$ $M_{sun}$) ergs >> $M_{gal}$ $\sigma^2$**

**few % of Lbol coupled to ISM enough to unbound gas in the galaxy**

**SN feedback models require 100% efficiency or more…**

# ESTIMATING OUTFLOW PROPERTIES

outflow mass rate:

$$\dot{M}_{out} \propto M_{out} V_{out} / R$$

kinetic power:

$$\dot{E}_{out} \propto \dot{M}_{out} V^2_{out}$$

momentum flux:

$$\dot{P}_{out} \propto \dot{M}_{out} V_{out}$$

**Ionised gas mass**

[OIII],Hβ, **Hα** flux/luminosity

(+ionization correction)
+metallicity
+density, temperature
+extinction
+ ……

**Molecular gas mass**

(mainly) CO(1-0) outflow flux/luminosity

+excitation ratio (factor of 2-10!)
+alpha_CO (range 0.13-4, a factor of 30!)
+….

**+ Geometry**

radius, (uniform) density, filling factor, clumpy etc.

**+ Time**

Radius/velocity

# ESTIMATING MASS OUTFLOW RATES

## Ionised gas mass

*for details*
*see Appendix B in Cano-Diaz+2012*

$$\dot{M}^{out}_{ion} = 164 \frac{L_{44}([OIII])\, v_3}{n_{e3}\, 10^{[O/H]}\, R_{kpc}}\, M_{\odot}\, yr^{-1}$$

<u>assumptions</u>:
all Oxygen is in $O^{2+}$
T=10000 K (**factor ~2**)
(bi)conical geometry
uniform density (**factor 3**)

<u>observational uncertainties:</u>
**Radius**
**velocity,**
**density,**
**extinction,**
**metallicity**

# ESTIMATING MASS OUTFLOW RATES

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*for details*
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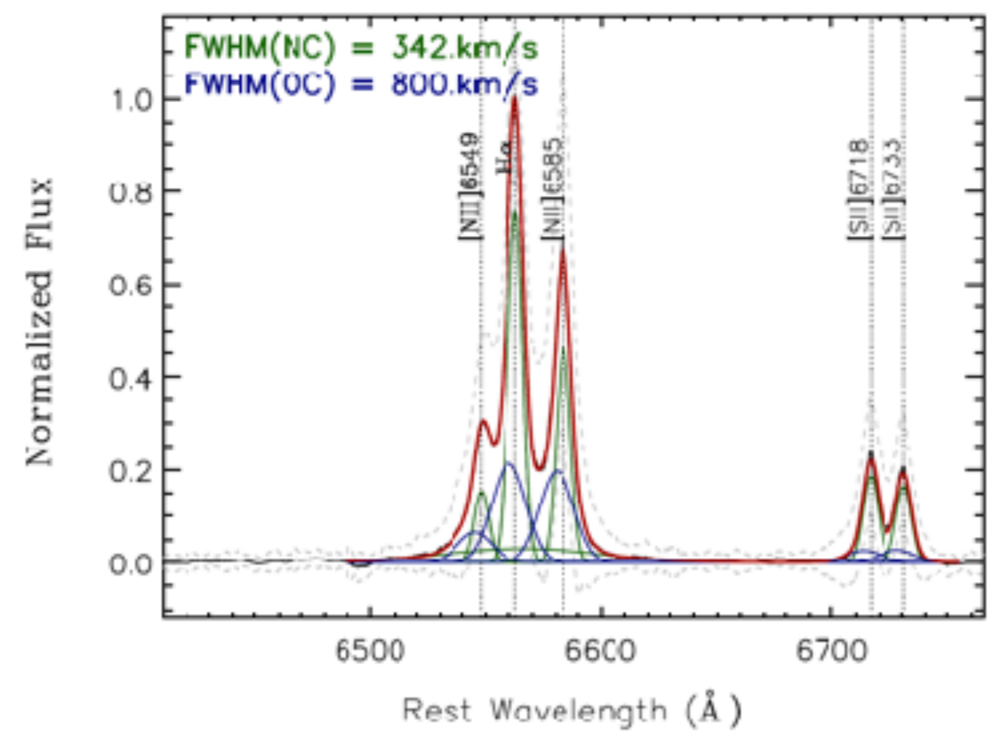



assumptions:
all Oxygen is in $O^{2+}$
T=10000 K (**factor ~2**)
(bi)conical geometry
uniform density (**factor 3**)

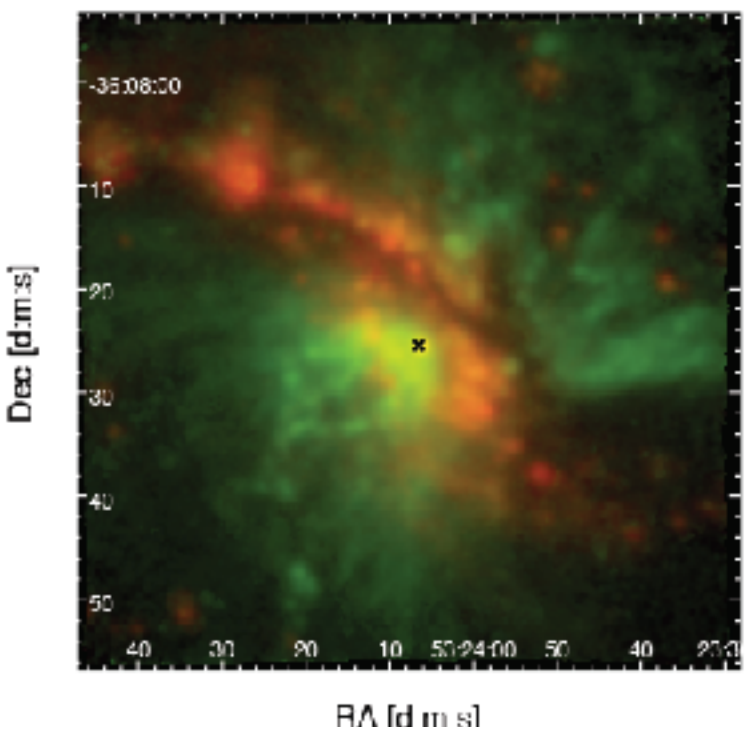
observational uncertainties:
**Radius** —> need spatially resolved data (otherwise lower limits on energetics)
**velocity** —> need spatially resolved data, disk subtraction, definition dependent
**density** (T dep) —> **converging around 1000 $cm^{-3}$** (**Perna+2017b**, Förster-Schreiber+18)
**extinction** —> need good spectral coverage
**metallicity** —> need good metallicity tracers

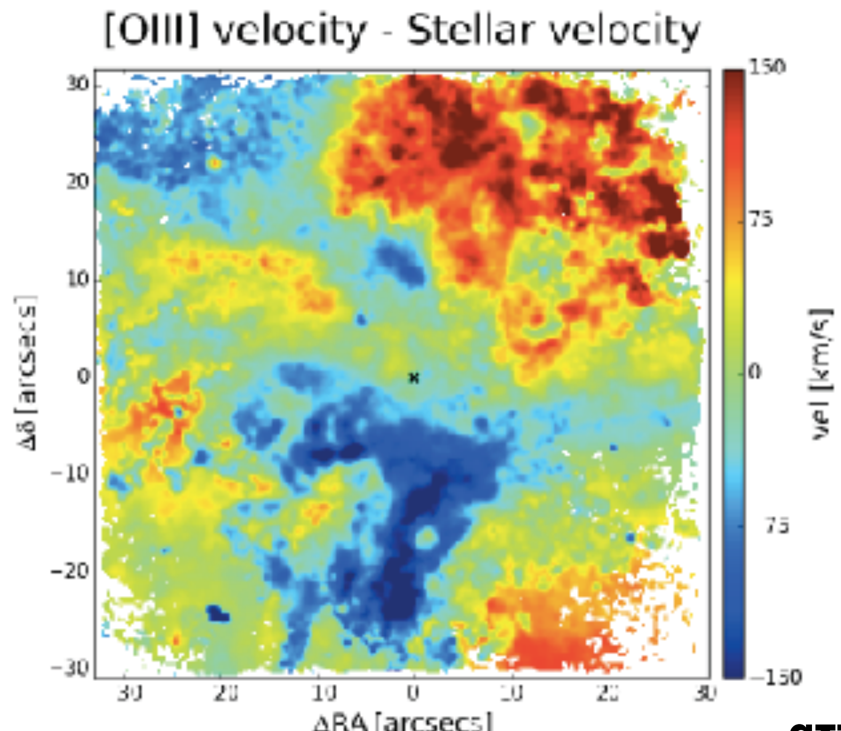
# THE ERA OF SPATIALLY RESOLVED SPECTROSCOPY

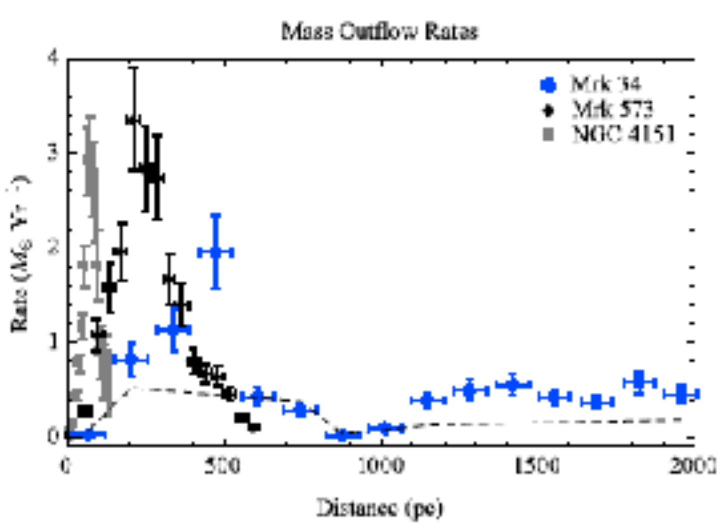
**MUSE + ALMA + SINFONI/AO + ....**
**MaNGA, CALIFA +**
**waiting for JWST**

**MUSE observations of NGC1365**
**(MAGNUM sample; Venturi+2018)**

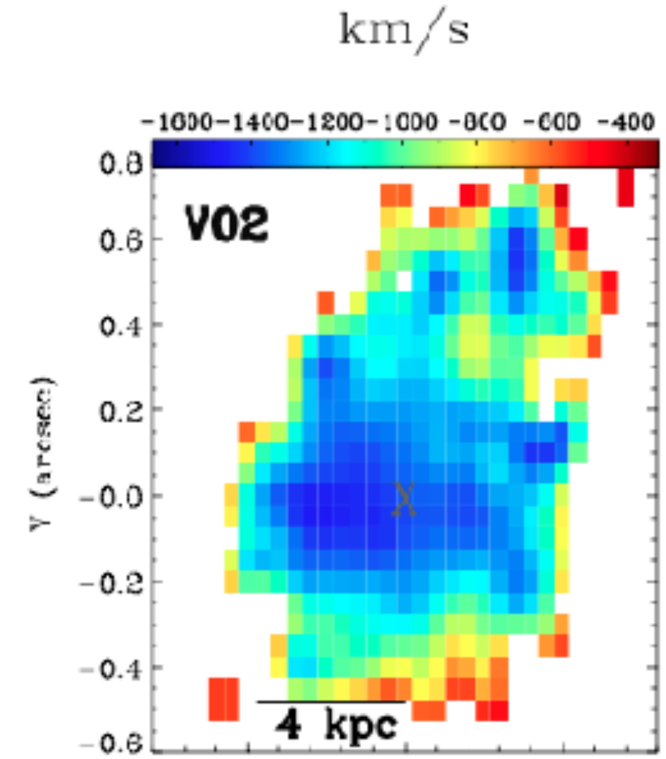
see Giacomo Venturi talk

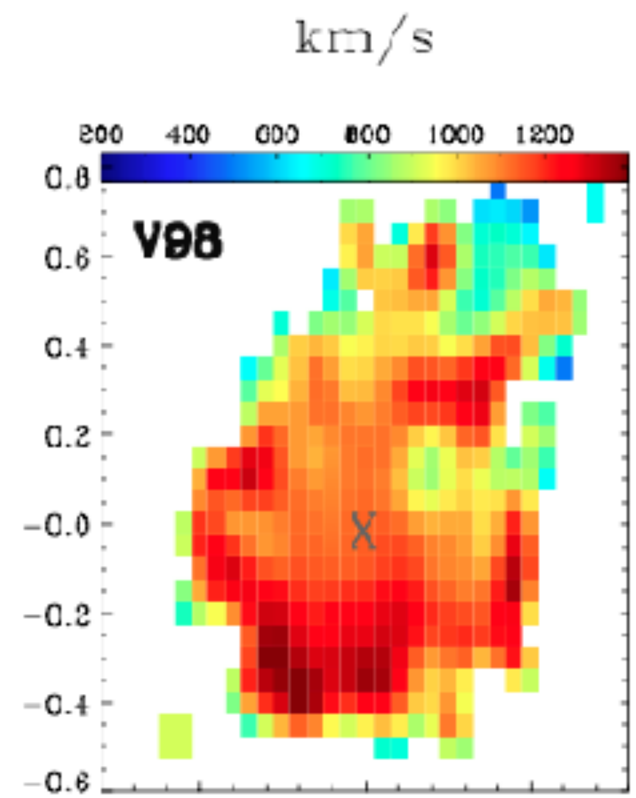



**Spatially resolved mass outflow rates Revalski+2018**



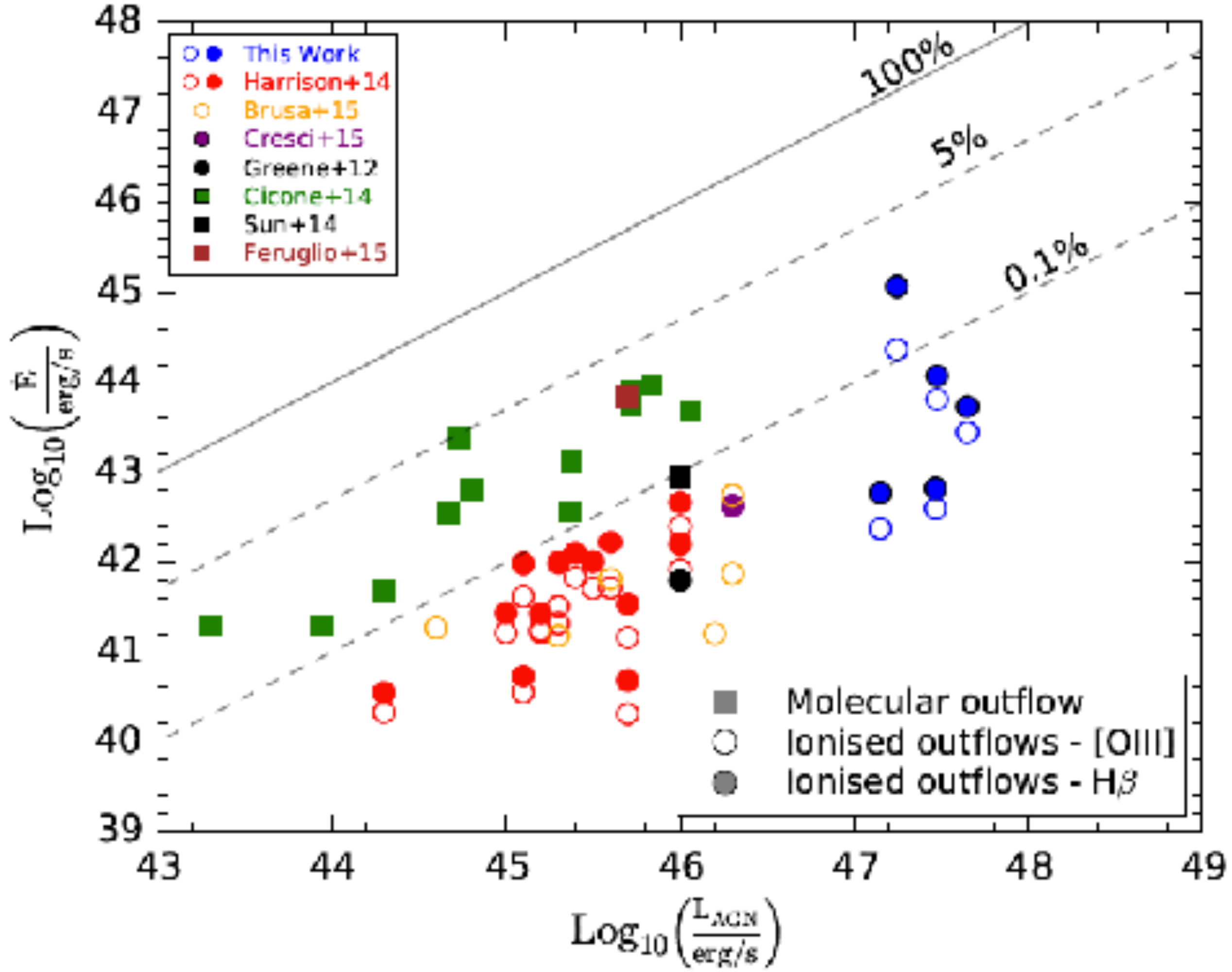

**SINFONI/AO observations z~1.5 QSO (Brusa+2016)**

**SUPER project (PI: Mainieri) Circosta+2018**

# MEASURED OUTFLOW PROPERTIES VS. LUMINOSITY

**Kinetic power**

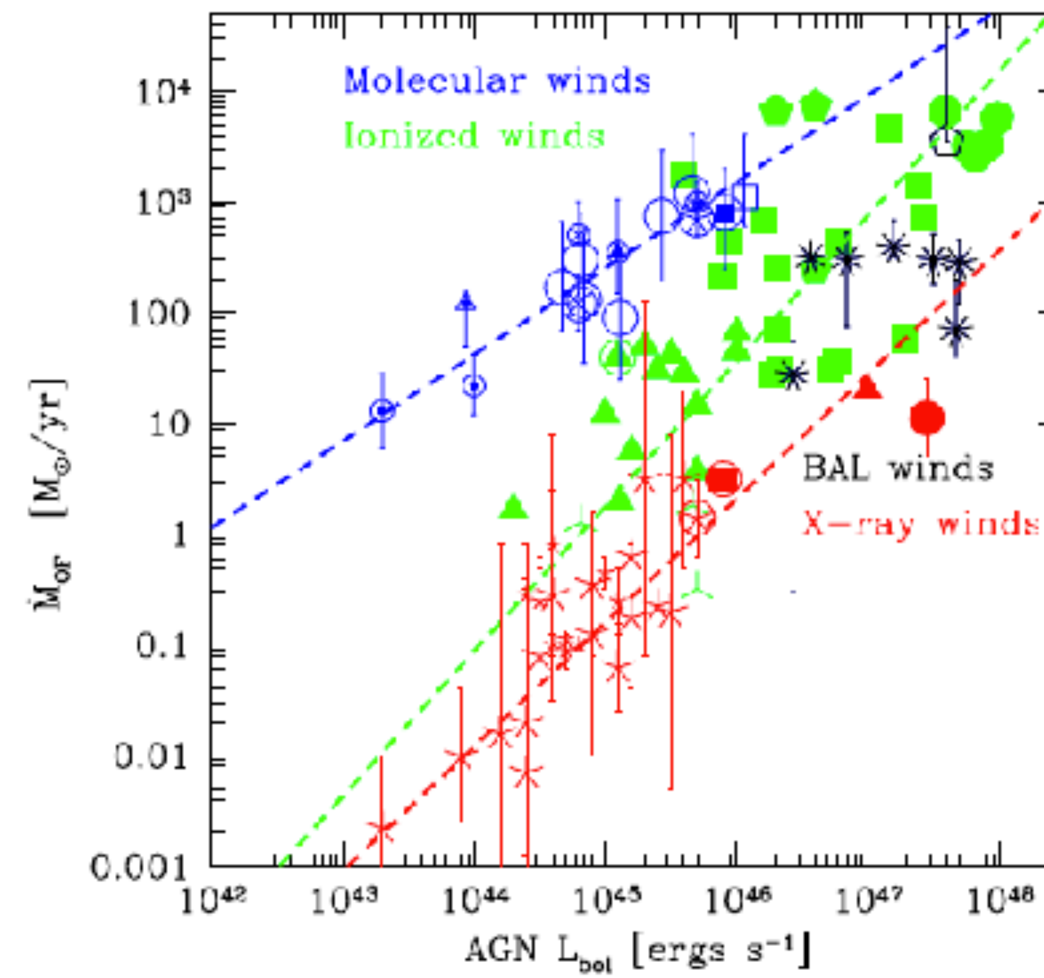
Carniani et al. 2015




---> "fiducial" outflow kinetic power consistent with predictions in feedback models **(few% of $L_{bol,AGN}$)**

**Mass outflow rate**

Fiore et al. 2017




---> all winds components correlate with Lbol AGN, **with different slopes and normalisations**

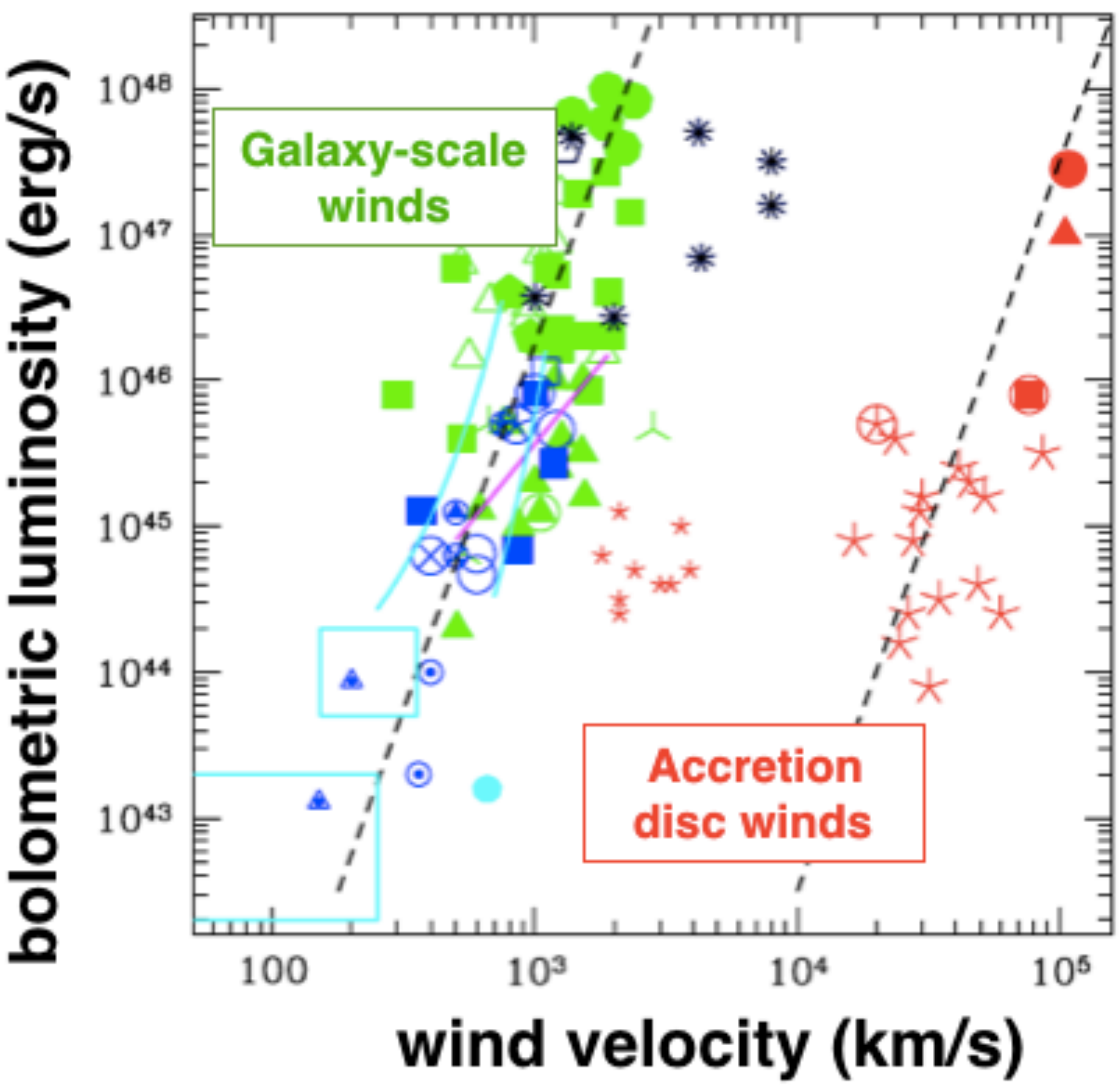
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA DIPARTIMENTO DI FISICA E ASTRONOMIA

INAF ISTITUTO NAZIONALE DI ASTROFISICA

AGN13 BEAUTY and the BEAST

# OUTFLOW PROPAGATION MECHANISMS

Fiore+2017



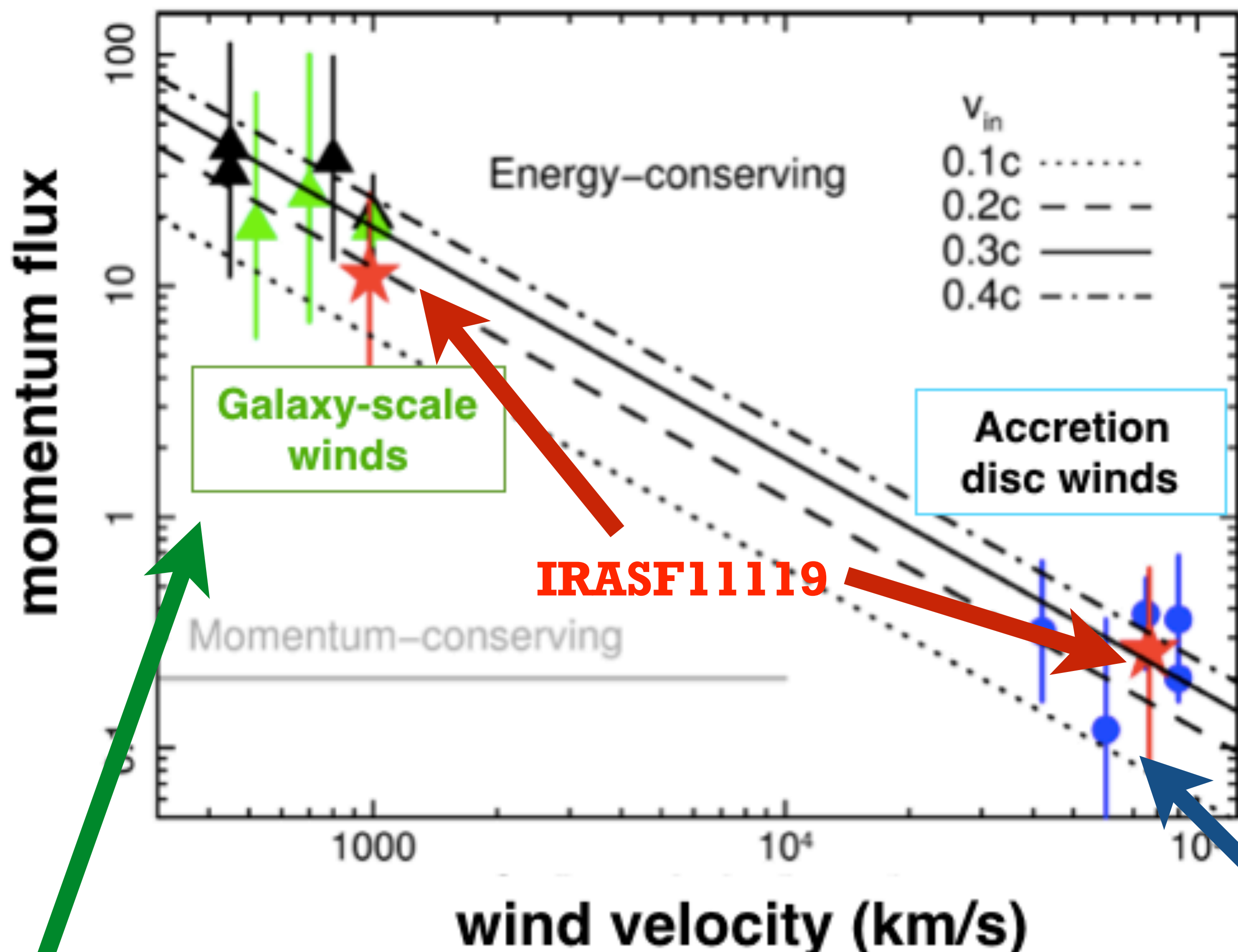

same trend of Lbol vs. $v_{out}^5$
for both UFOs and galaxy scale winds

data (statistically) consistent with predictions for energy conserving mechanisms for wind propagation (Costa+2015)

The wind bubble retains its the thermal energy

# OUTFLOW PROPAGATION MECHANISMS

Tombesi+2015




**radiation pressure that accelerates accretion disc winds at Pdot~$L_{AGN}$/c and energy-conserving wind bubble boosts the momentum by a factor of ~15-20**

**see also Rupke+2017 (including all kpc scale components)**

**Time scale issues?**

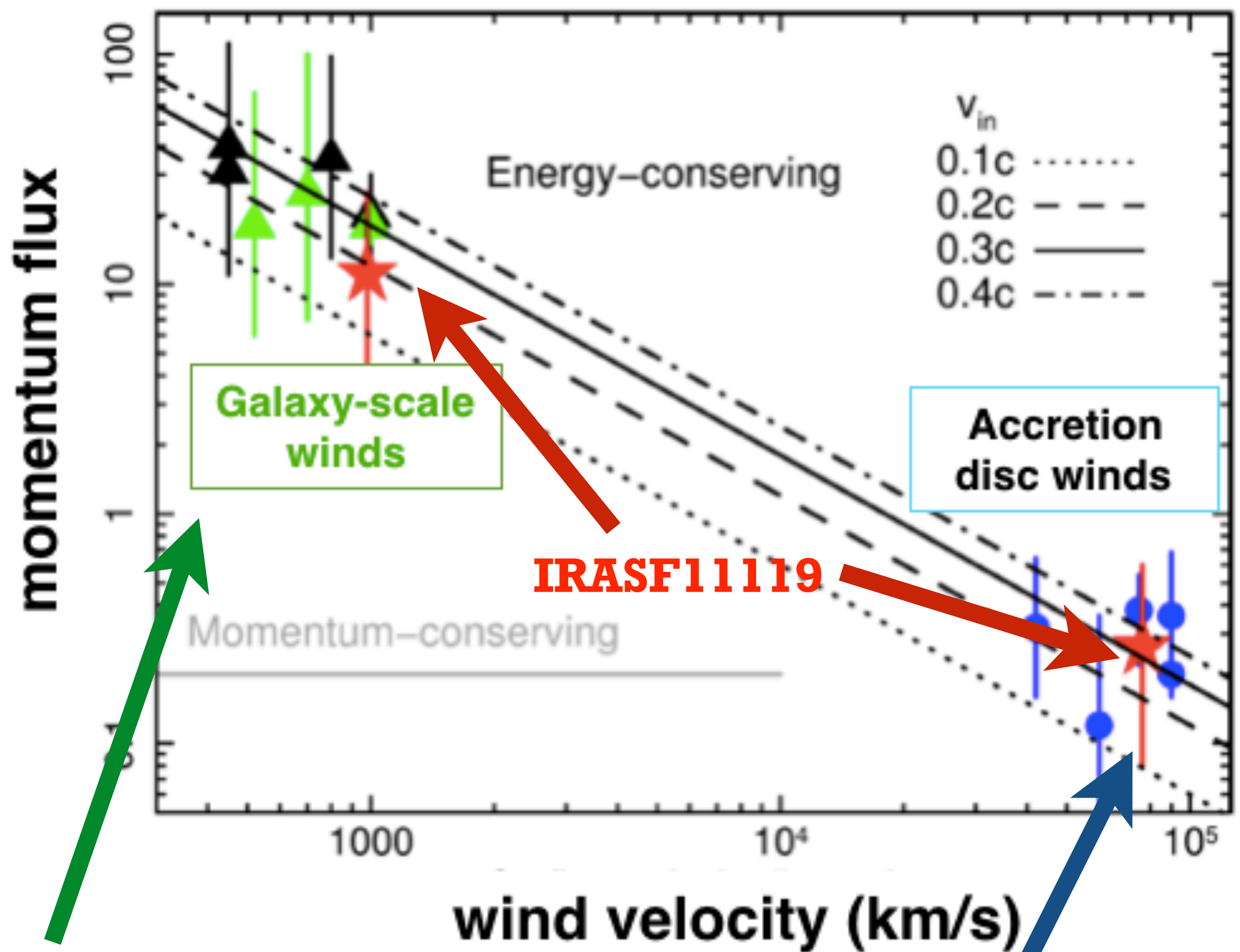
**Molecular outflows (OH and CO)**
**in <u>local</u> Seyferts (all at z<0.2)**
**v~500-1000 km/s**

**Ultra Fast Outflows(X-rays)**
**in <u>high-z</u> Quasars (mostly at z>1)**
**v~0.1-0.4c**

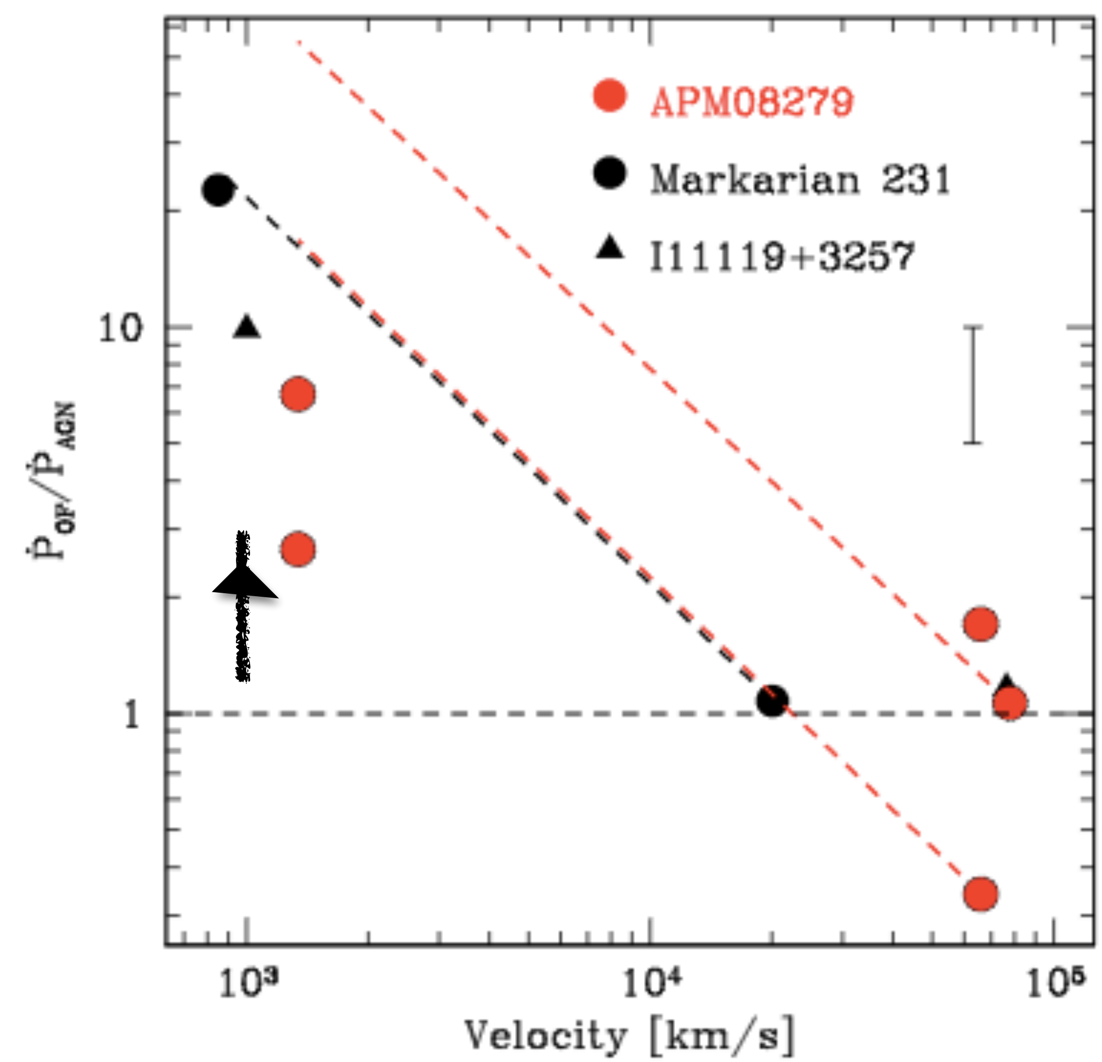
see Francesco Tombesi talk

# OUTFLOW PROPAGATION MECHANISMS

Tombesi+2015




Feruglio+2017

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**After 3 years…**
**Molecular outflows and UFOs in 4 QSOs**
**(see also Longinotti+2018)**

**synergies ALMA/NOEMA+XMM/Nustar**

**Energy conserving mechanism is favoured, but difficult to get a definitive measurement**

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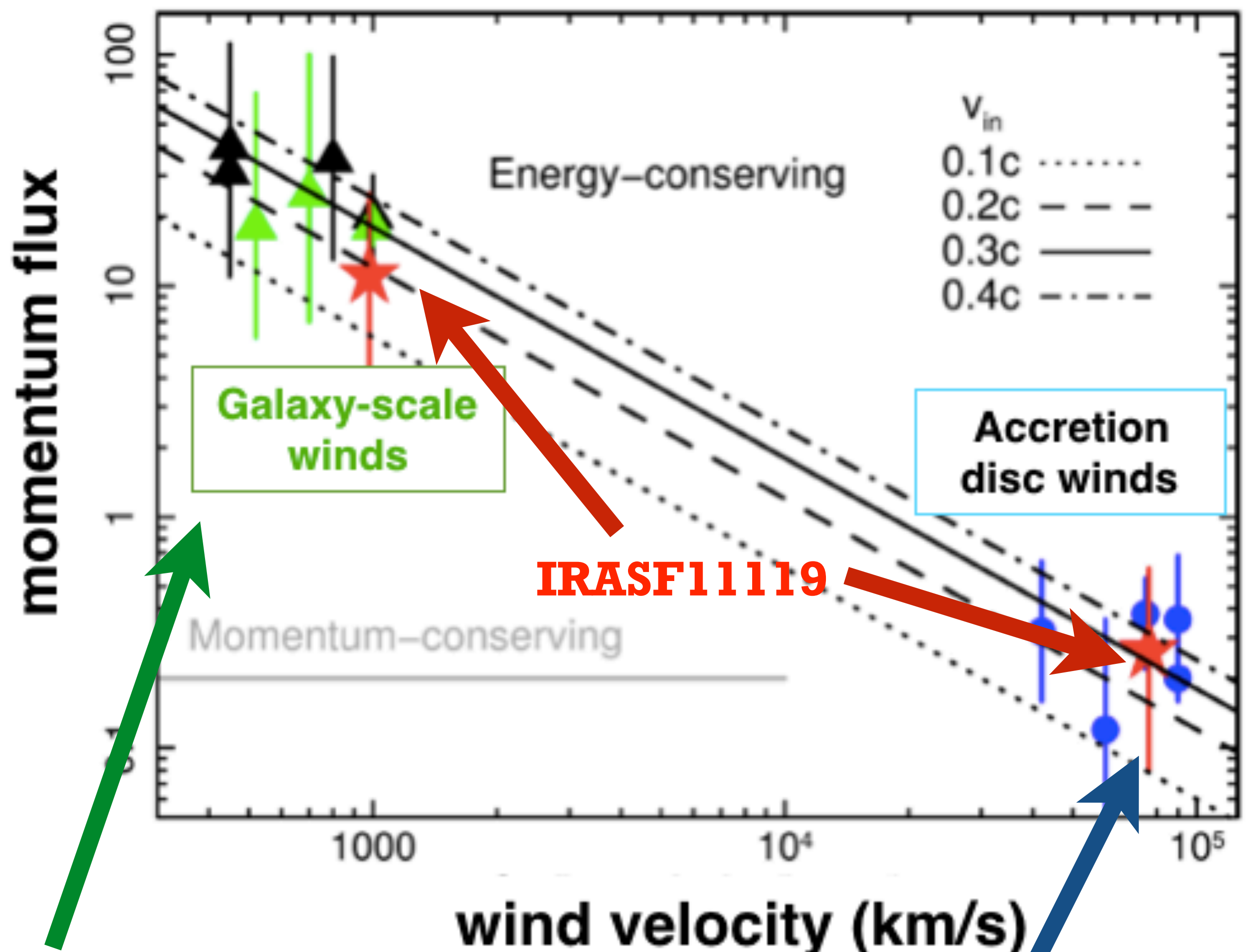
Tombesi+2015

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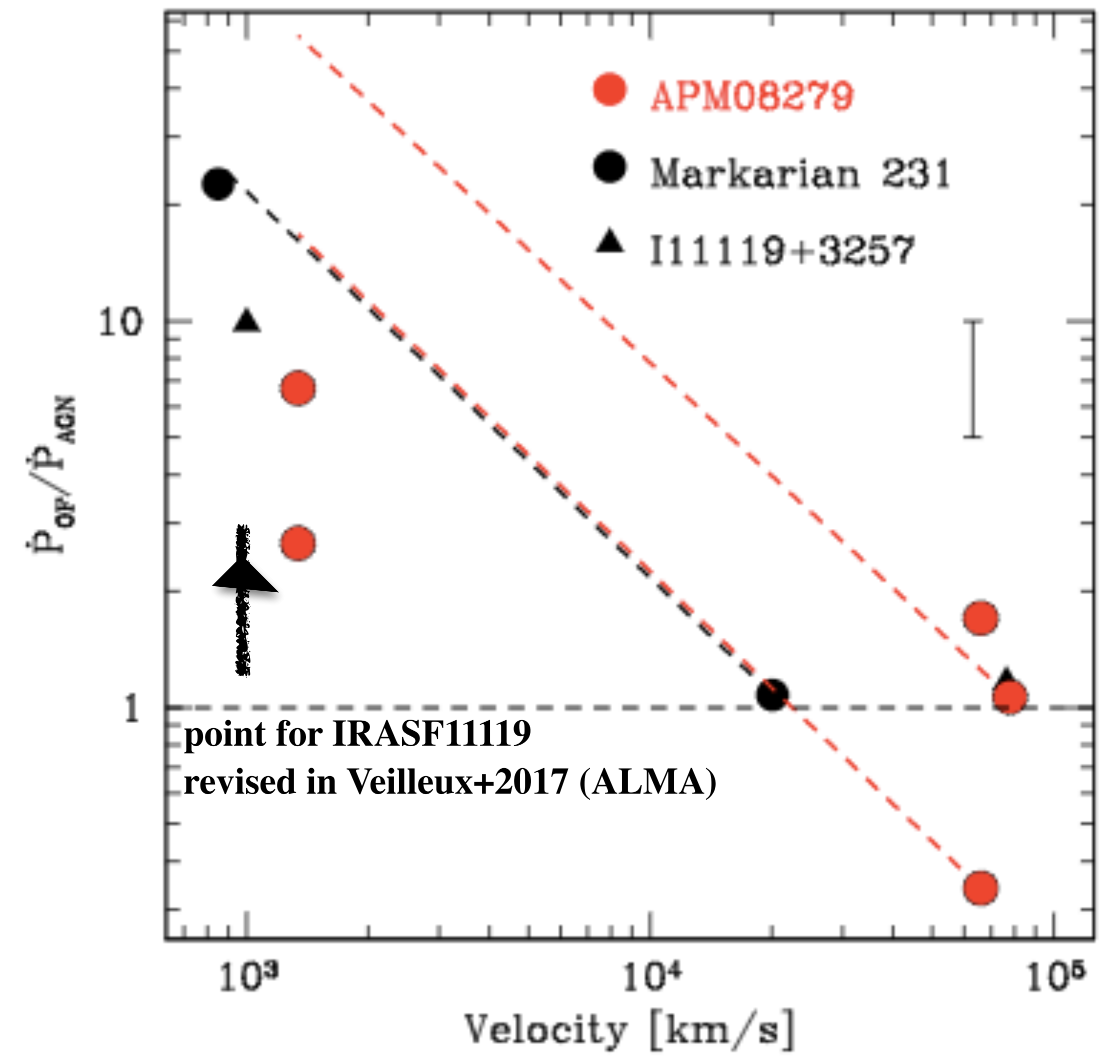


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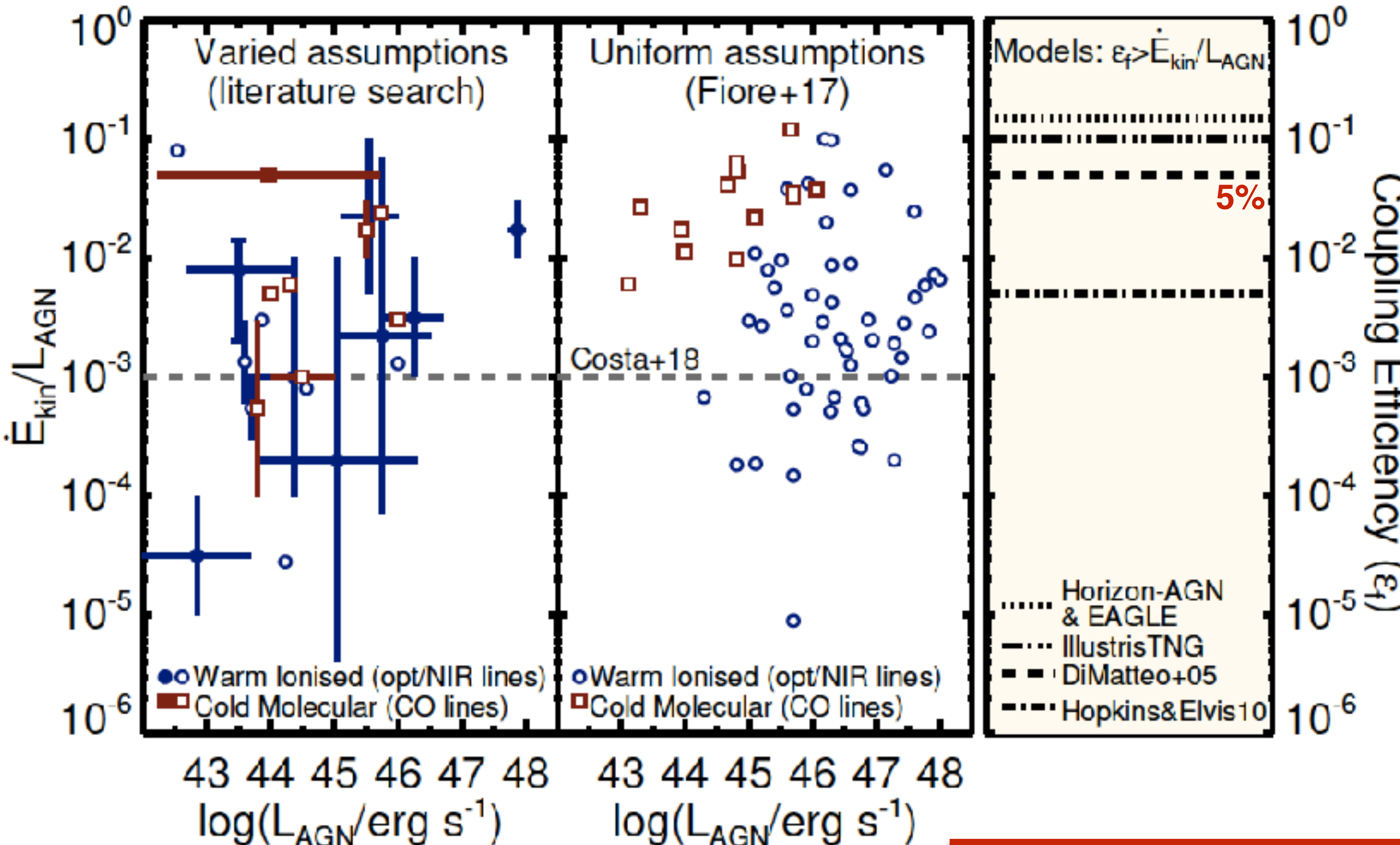
# COUPLING EFFICIENCIES

*Harrison et al., 2018, Nat. Astr.*




$$\dot{E}_{kin} < \epsilon_f L_{AGN}$$

**Much LARGER SAMPLES needed — eROSITA + dedicated follow-up**

# TAKE HOME MESSAGES

**(1) Outflows are present, both at low and high-z, in AGN**
**---> winds are multi-phase and multi-scale**
**—> spatially resolved outflows studies now possible out to high-z!**

**(2) Three lessons learned from observations:**

**(Ionised) outflows particularly common in luminous and red AGN**
**—> importance of radiation pressure on dust**

**Neutral outflow phase less common than ionised phase**
**—> Short-lived phase?**

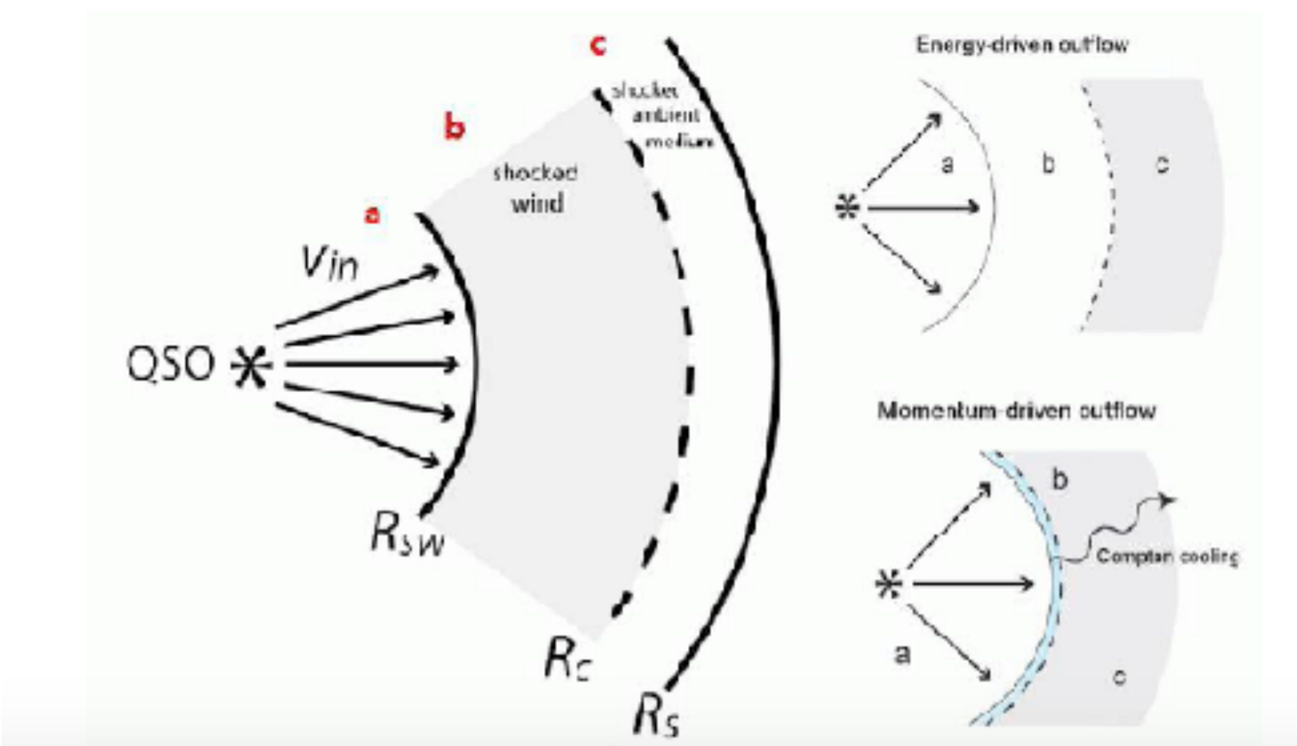
**Energy conserving mechanisms seem favoured**
**—> Feedback models seem to work (but difficult to have a definitive measurement)**

**But…**
**Statistics and/or spatial/spectral resolution still limited**
**Huge leaps expected in the next years**

# BACK-UP SLIDES

# RADIATIVE FEEDBACK

Wide-angle, wind-driven outflows, launched from the accretion disk and driven by **radiation pressure**




Faucher-Giguere+2012, King2012, Fabian2012
Zubovas&King 2012…2016, Costa+2014

radiation pressure from the QSO accelerates accretion disc wind at **Pdot(AGN)~$L_{AGN}$/c** (King2012)

**momentum-conserving wind bubble** predicts large scale outflows with **Pdot(out)~Pdot(AGN)~$L_{AGN}$/c**

**energy-conserving wind bubble** boosts the momentum by a factor **Pdot(out)~20xPdot(AGN)~20x$L_{AGN}$/c**

**Are we able to observe radiatively driven outflows and disentangle between different kinds of energy transfer on the ISM?**

**Role of dust?**

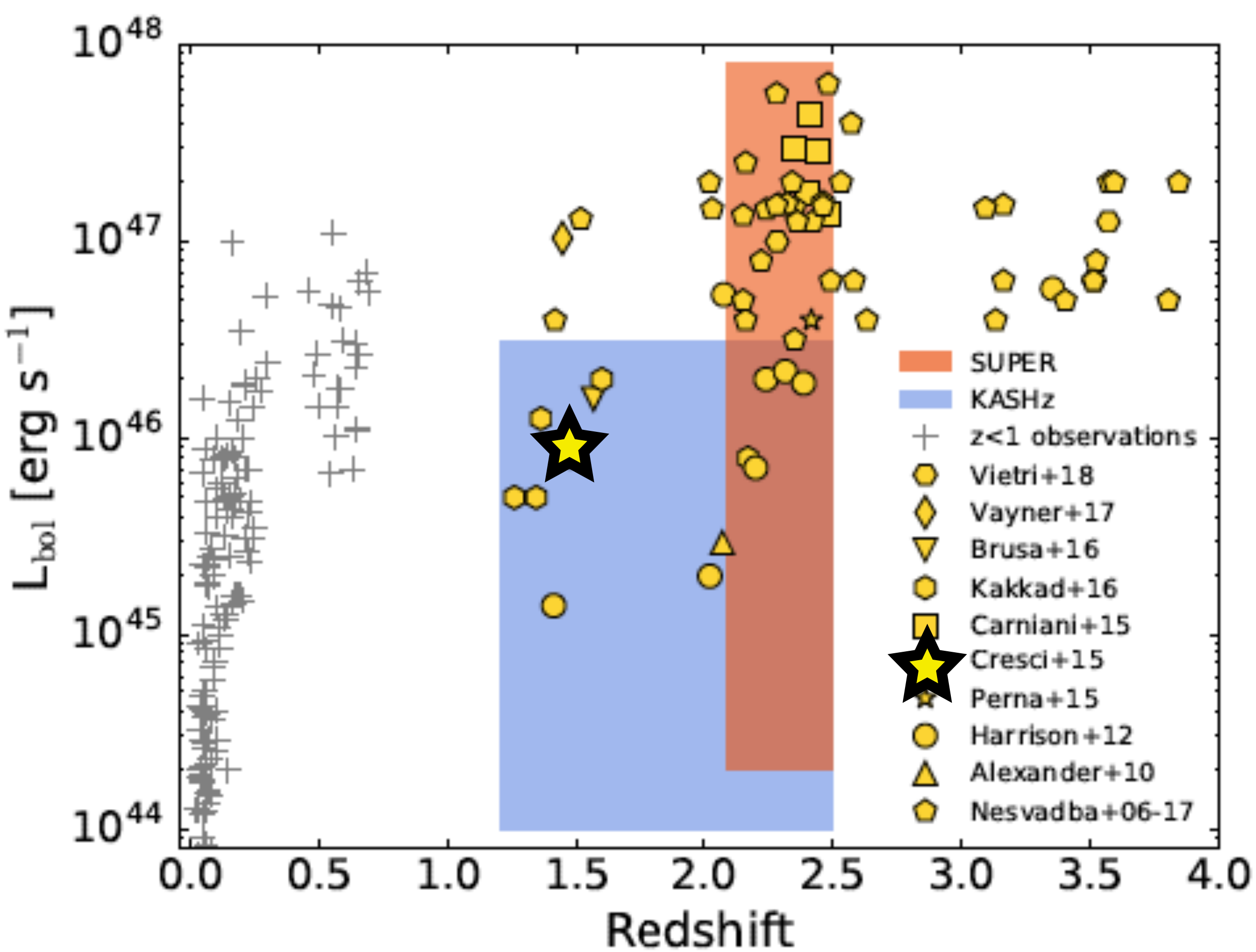
# SUPER

## a SINFONI Survey for Unveiling the Physics and Effects of Radiative feedback

## ESO Large Programme

## PI: V. Mainieri

*F. Fiore, A. Marconi, B. Balmaverde, A. Bongiorno, M. Brusa, S. Carniani, C. Circosta, F. Civano, A. Comastri, G. Cresci, C. Feruglio, A. Georgakakis, B. Husemann, D. Kakkad, A. Lamastra, G. Lanzuisi, Z. Liu, F. Mannucci, N. Menci, M.-L. Menzel, A. Merloni, H. Netzer, P. Padovani, M. Perna, E. Piconcelli, P. Popesso, M. Salvato, M. Schramm, A. Schulze, J. Silverman, G. Vietri, C. Vignali, G. Zamorani, L. Zappacosta*




***Circosta et al. 2018, submitted***

280 hrs, 2years
~40 X-ray selected AGN from COSMOS, CDFS, XXL, Stripe82X

SINFONI-AO LGS
mapping of [OIII] and Hα
Same strategy of XID2028

Explore outflows power and incidence as a function of AGN & host properties

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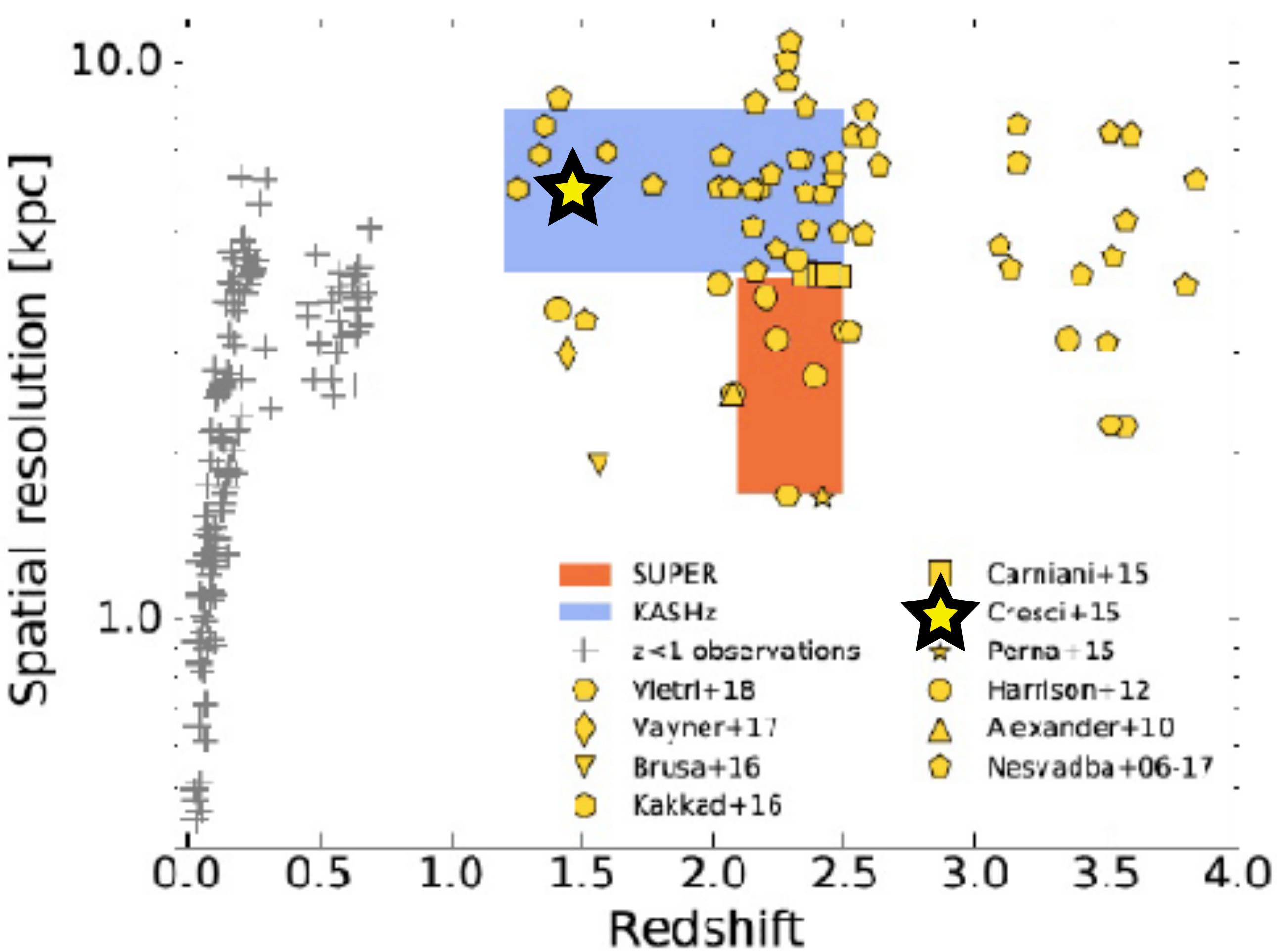


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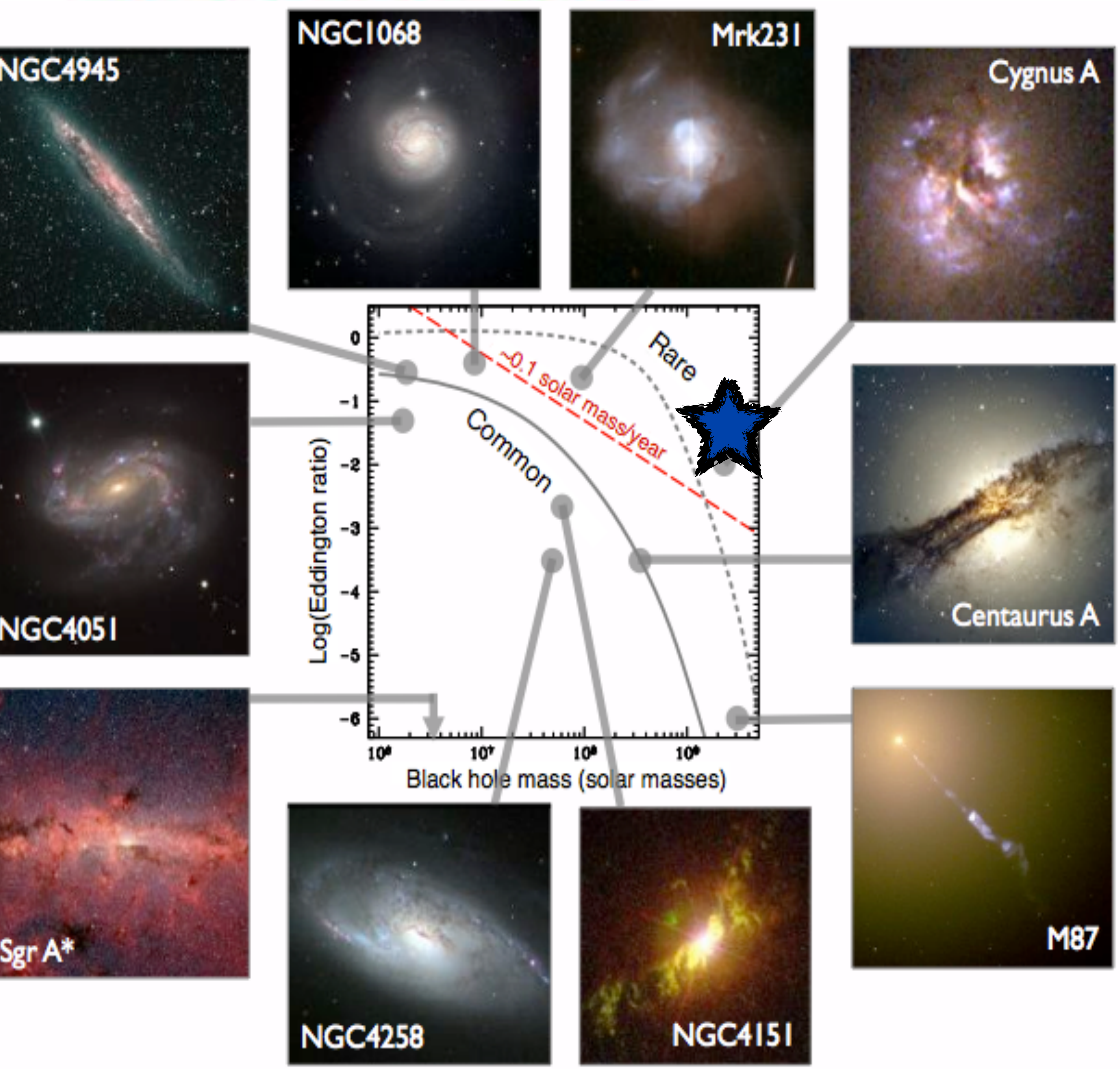
# Rare sources

Alexander & Hickox 2012




<u>**These sources are rare!**</u>

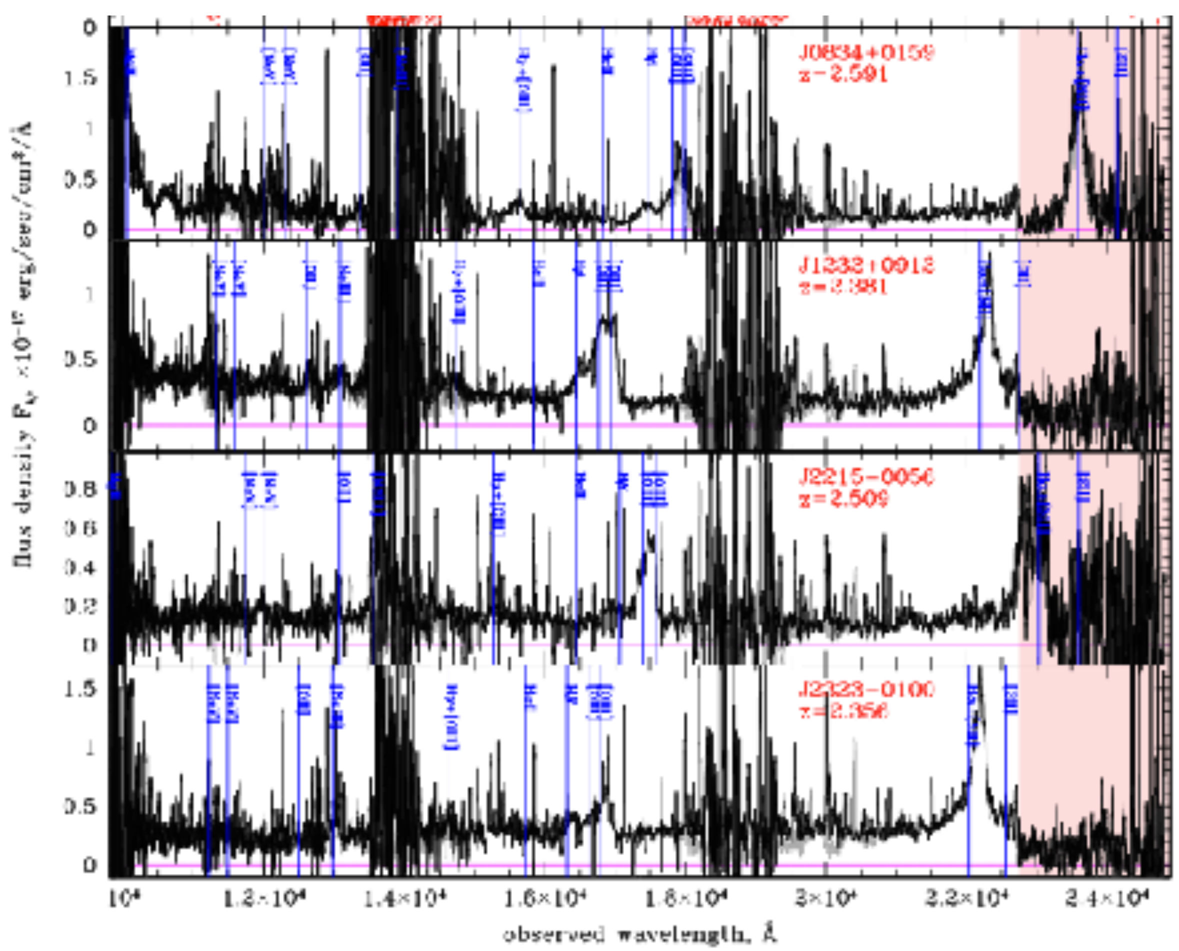
Need **large areas** to be explored

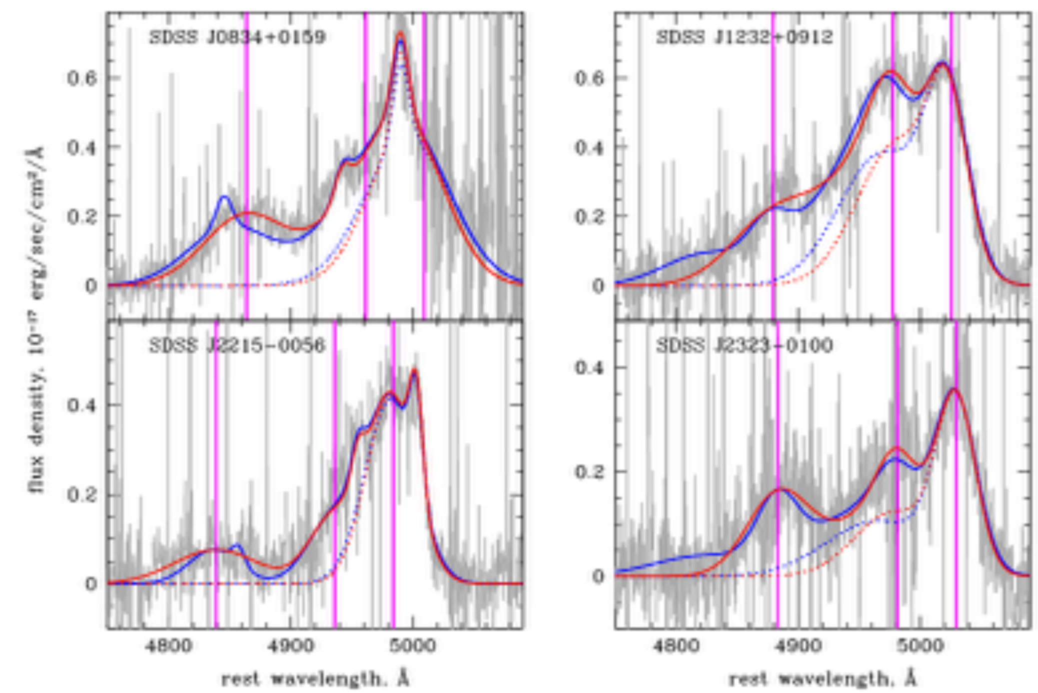
COSMOS is **a very powerful resource!**

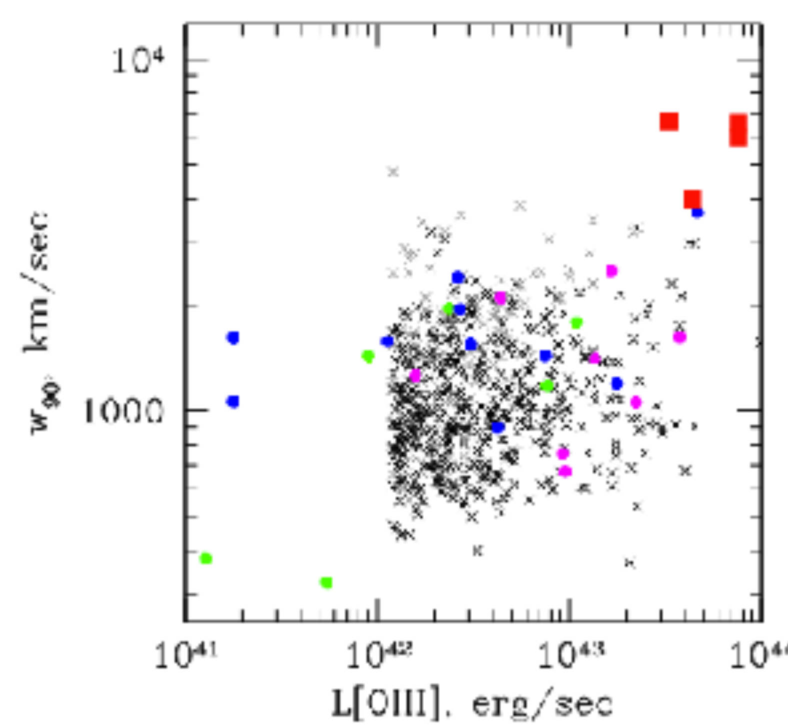
**XMM-COSMOS** was crucial

still, out of mainstream COSMOS area(s) **(no HST/ CANDELS, no Aztec/ SCUBA2/MAMBO/GMRT etc.)**

huge prospects for large area surveys **(XXL, Stripe82 & eROSITA)**

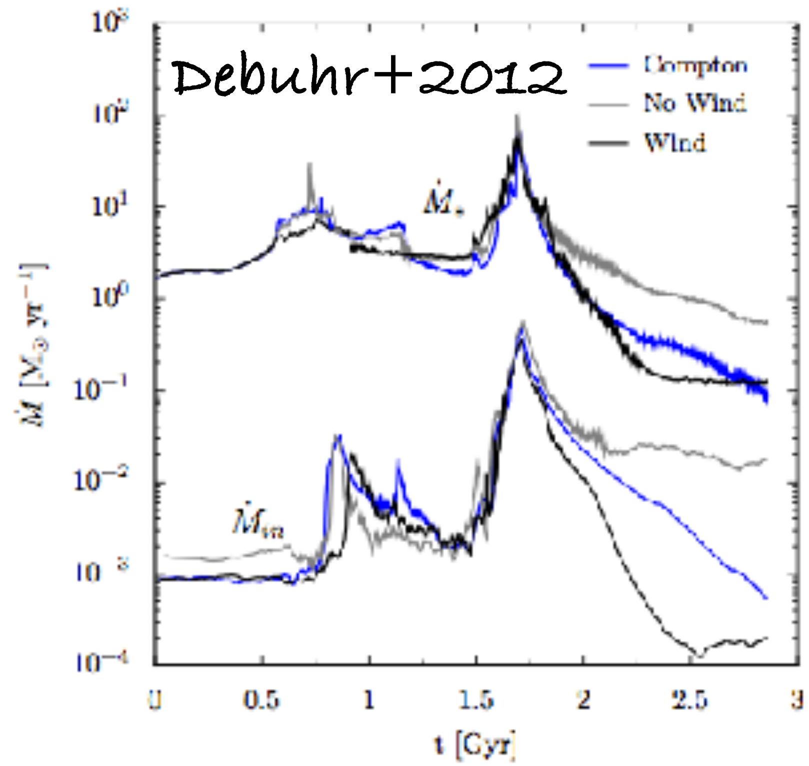


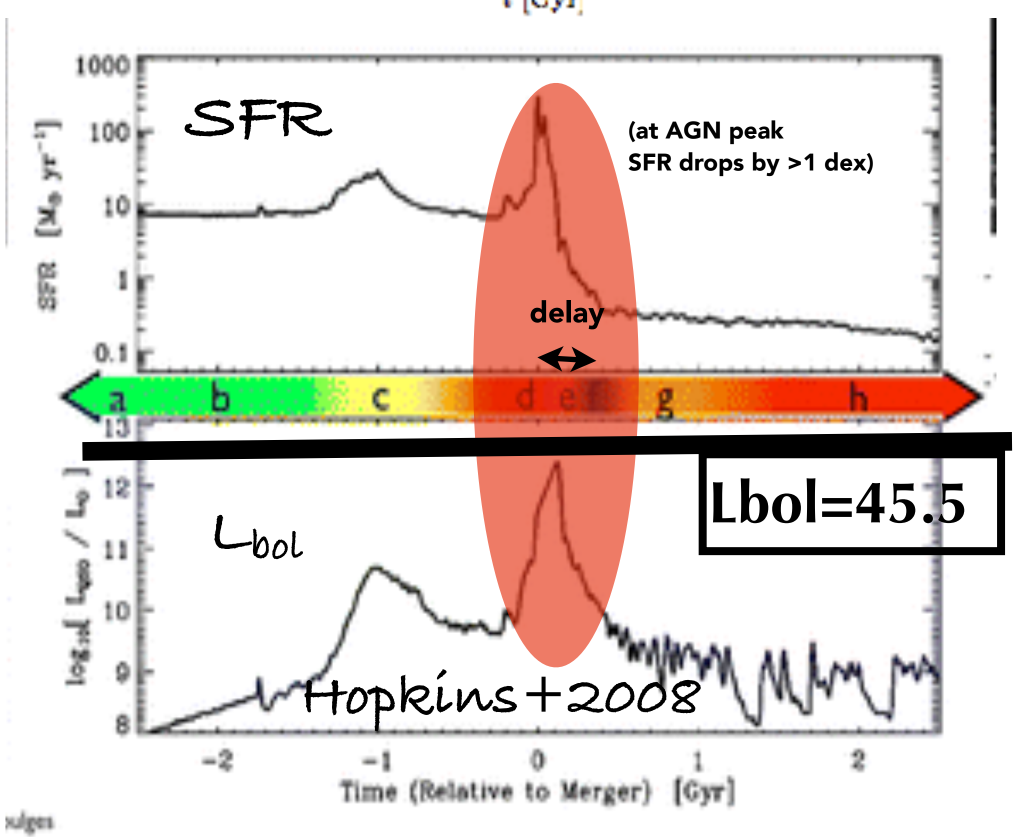



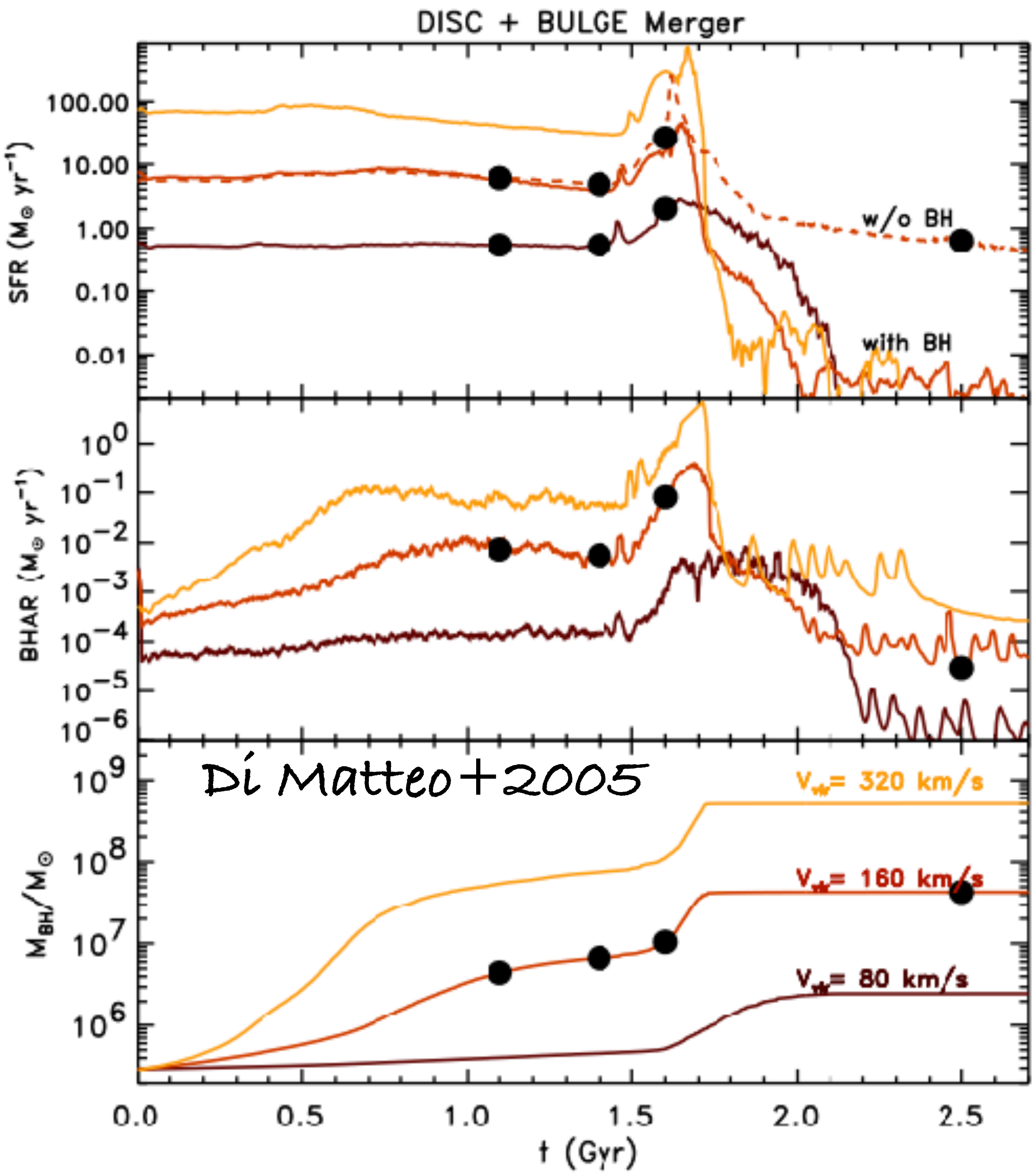




**Zakamska+2016**

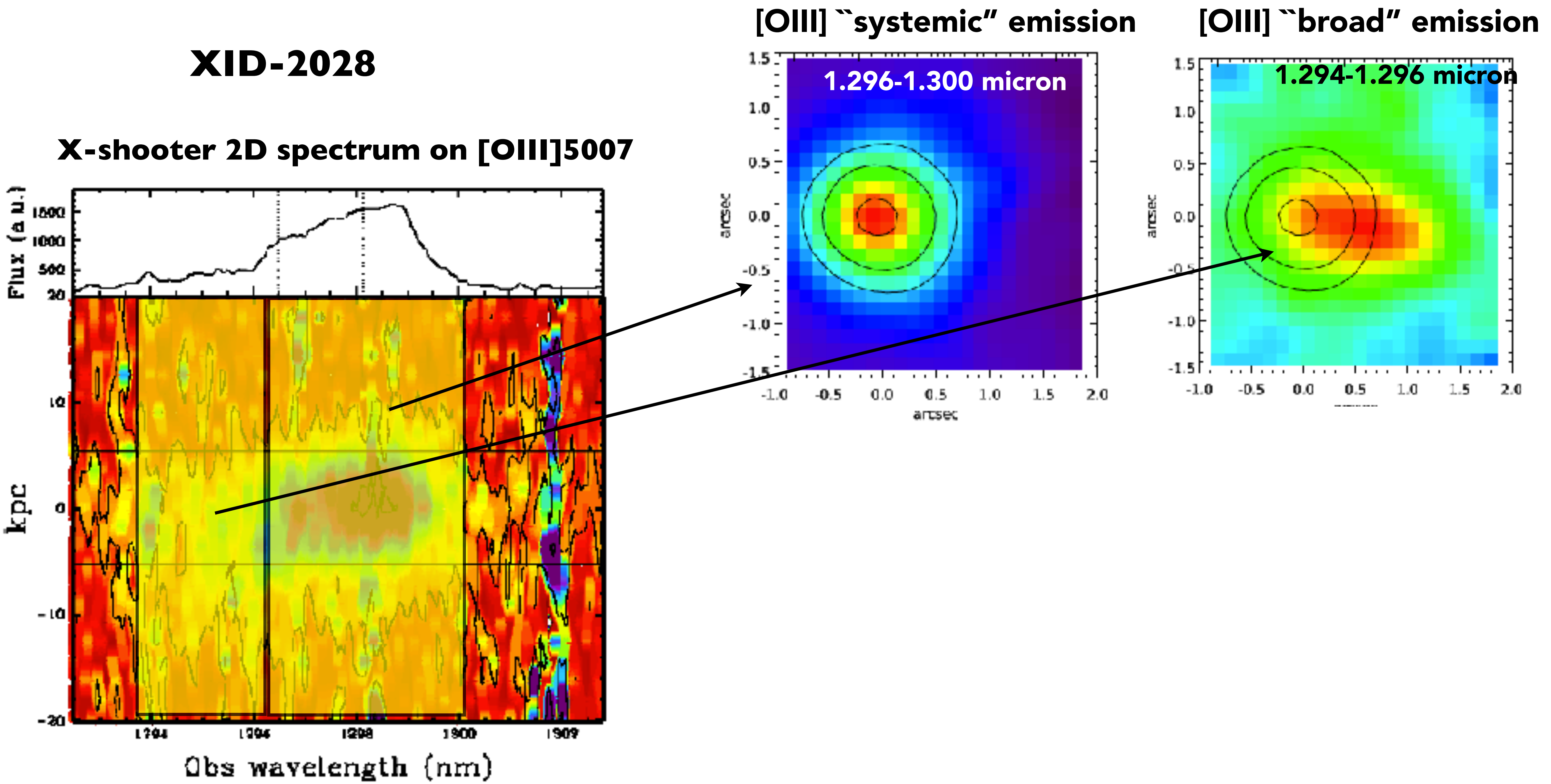
# Common features in models at high-L: "coeval" SFR and BH growth



# XID2028: Revealing the outflow (2)
# SINFONI J-band data (PI: V. Mainieri)




Cresci, Mainieri, MB+2015, ApJ

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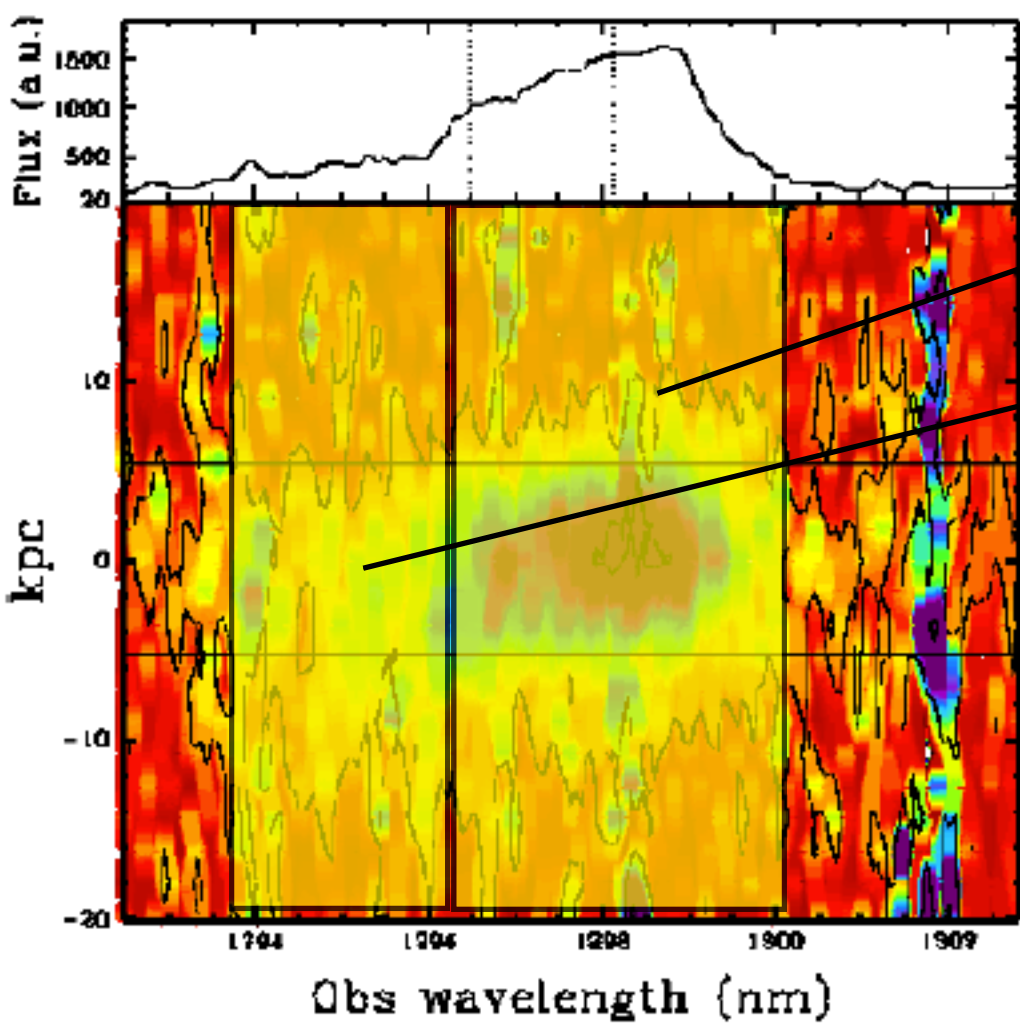
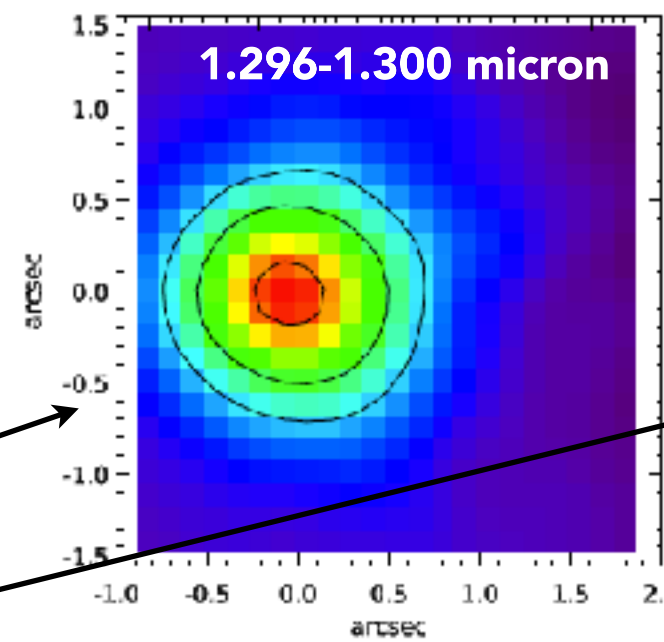
**XID-2028**

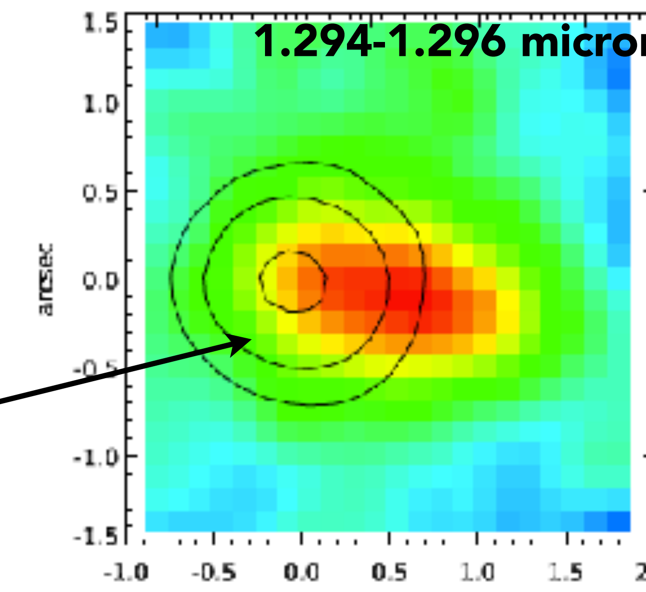
**X-shooter 2D spectrum on [OIII]5007**



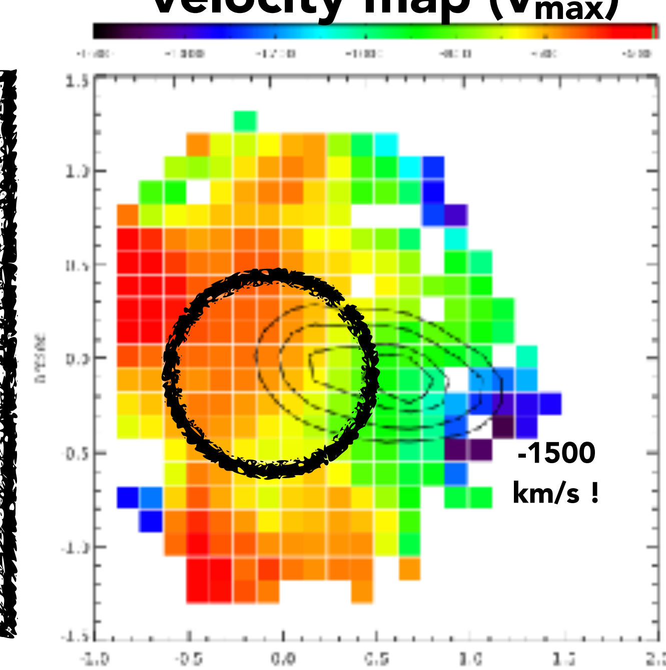

**[OIII] "systemic" emission**




**[OIII] "broad" emission**




**velocity map ($v_{max}$)**




*Ionised* Outflow is:

**massive** ($\dot{M}$>250 M⊙/yr; Cresci+2015)
($\dot{M}$>500 M⊙/yr; Perna+2015)

**fast** (v>1500 km/s)

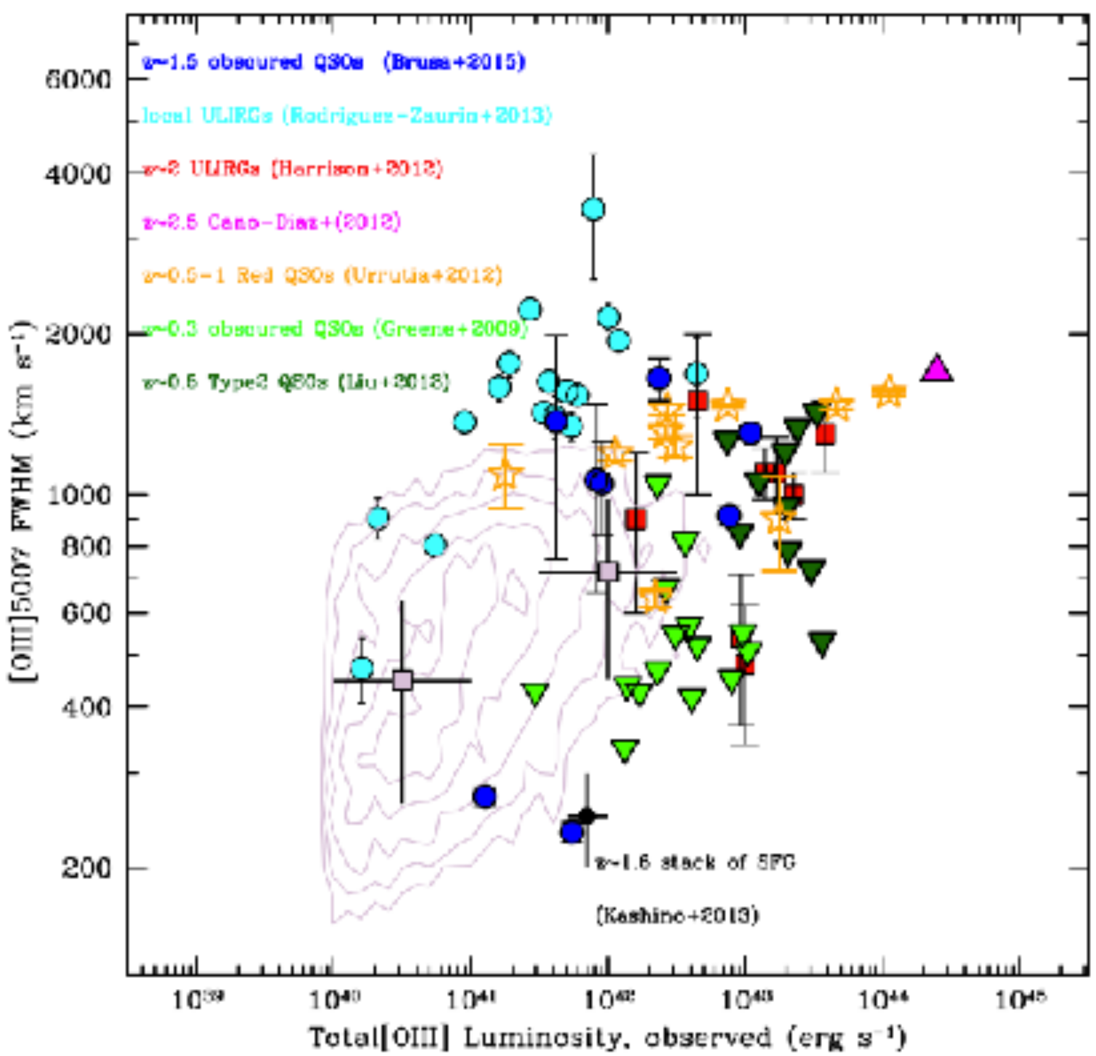
**large** (r~13 kpc in the galaxy)

**AGN driven**

**Cresci, Mainieri, MB+2015, ApJ**

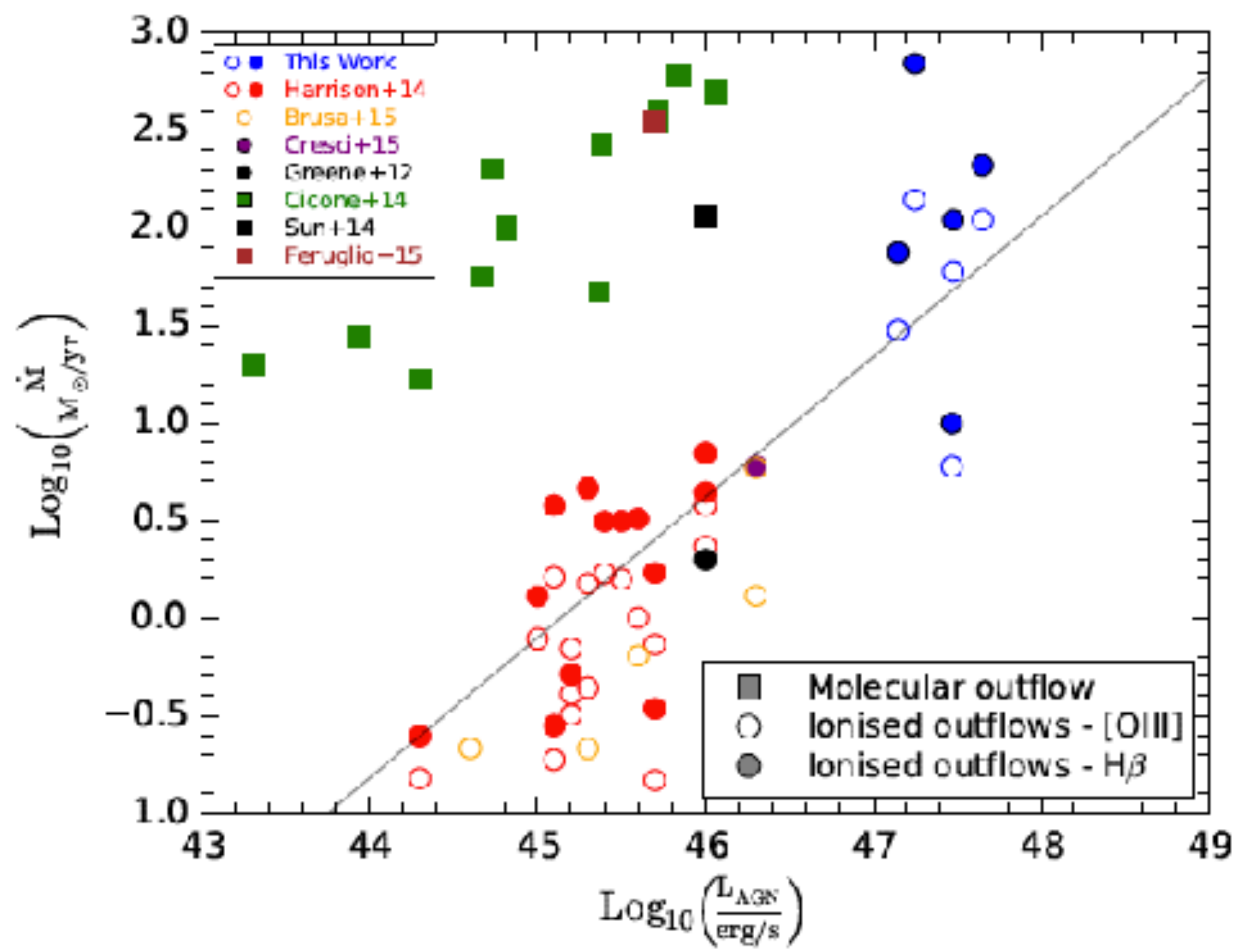
# Outflow properties vs. Luminosities

**Brusa et al. 2015a, MNRAS**




**Trend FWHM vs. Lbol**
**Higher luminosity / larger widths**

**Carniani et al. 2015**




**Mdot correlates with Lbol**
**ionised gas** ~1-10% of **molecular gas**
(but see SDSS1356,Greene+2012, Sun+2014)
--> are the outflows episodes related at all?

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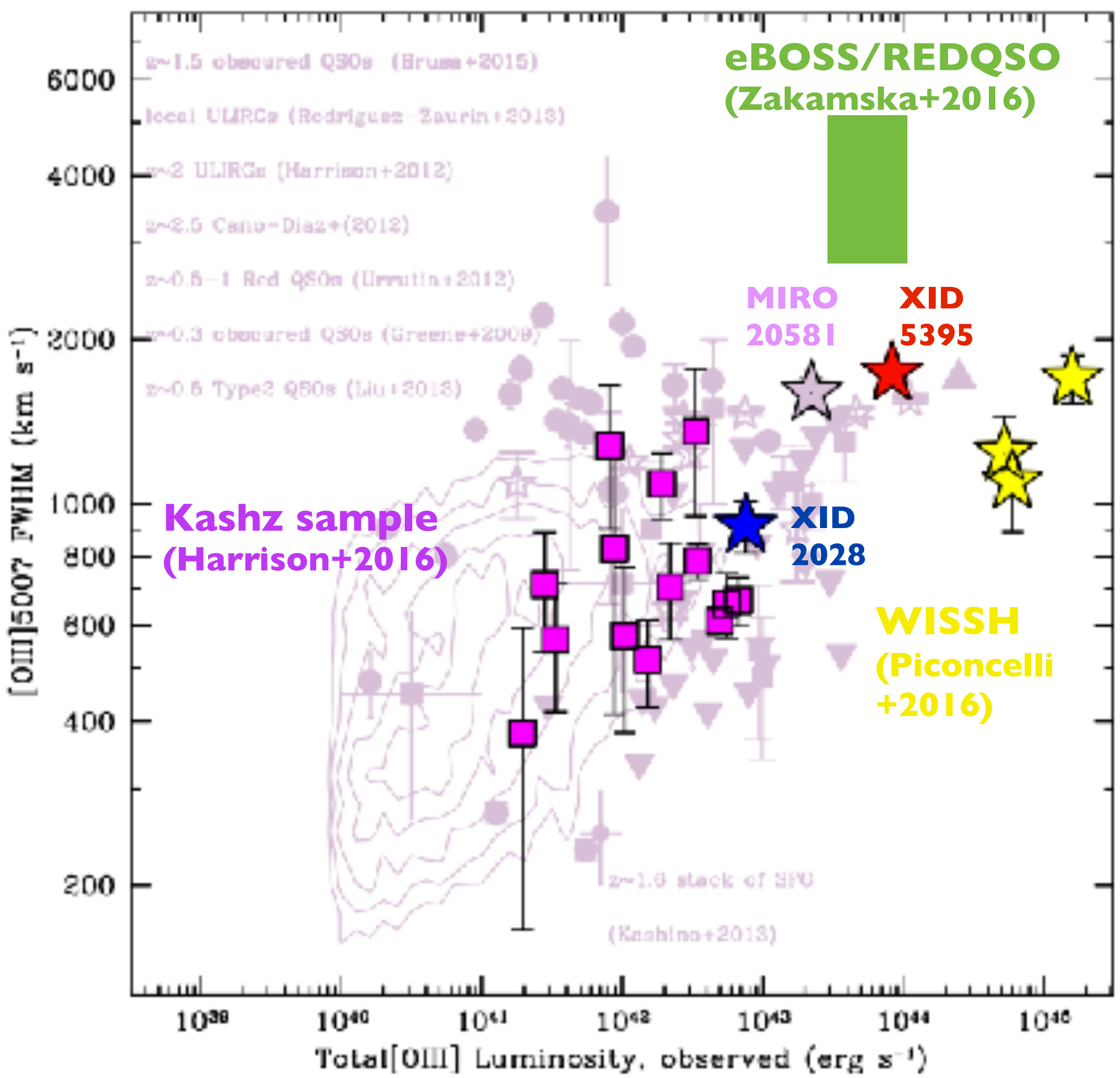


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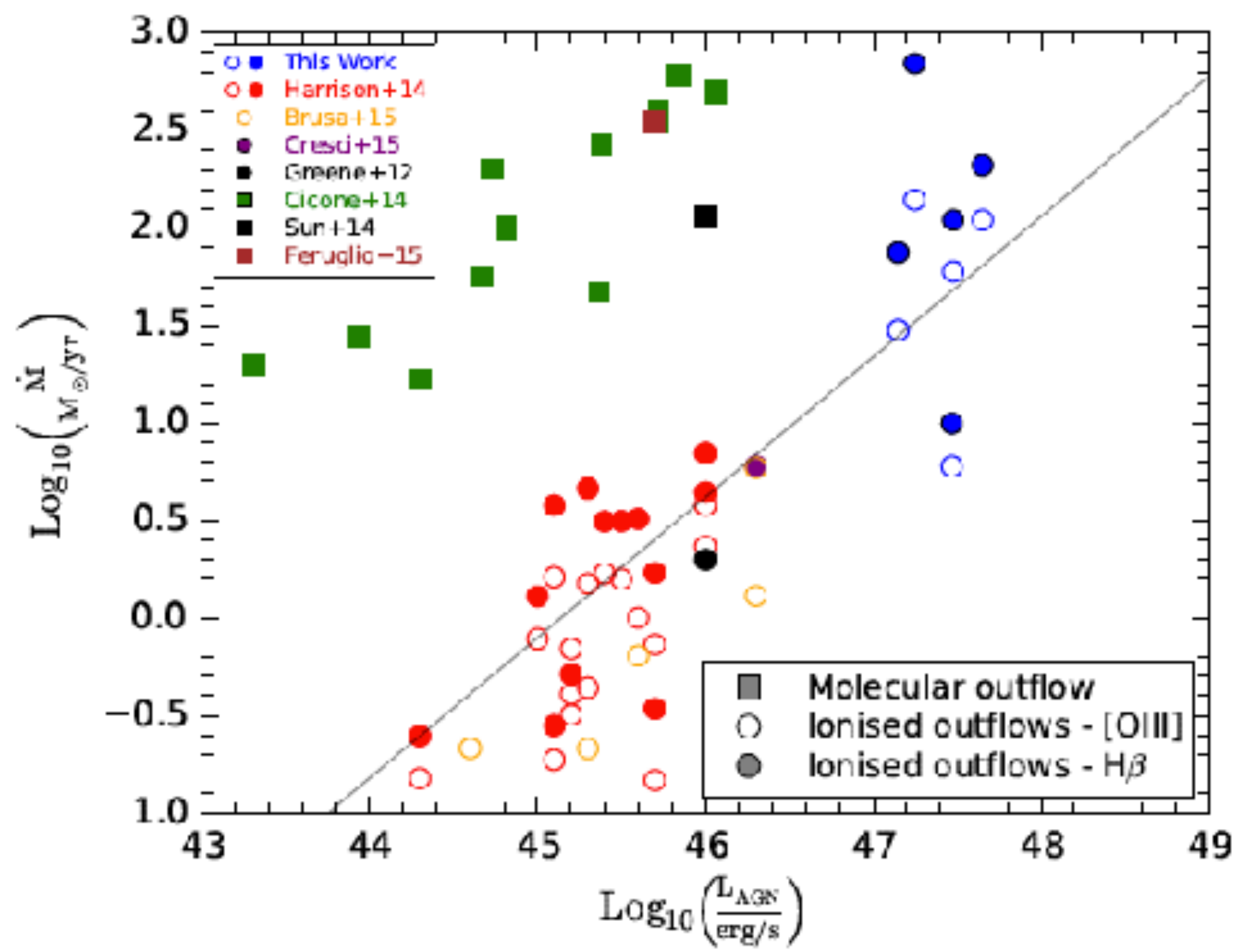


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