

# ***Spica contribution to a panchromatic study of galaxy-scale outflows***

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OA - Roma



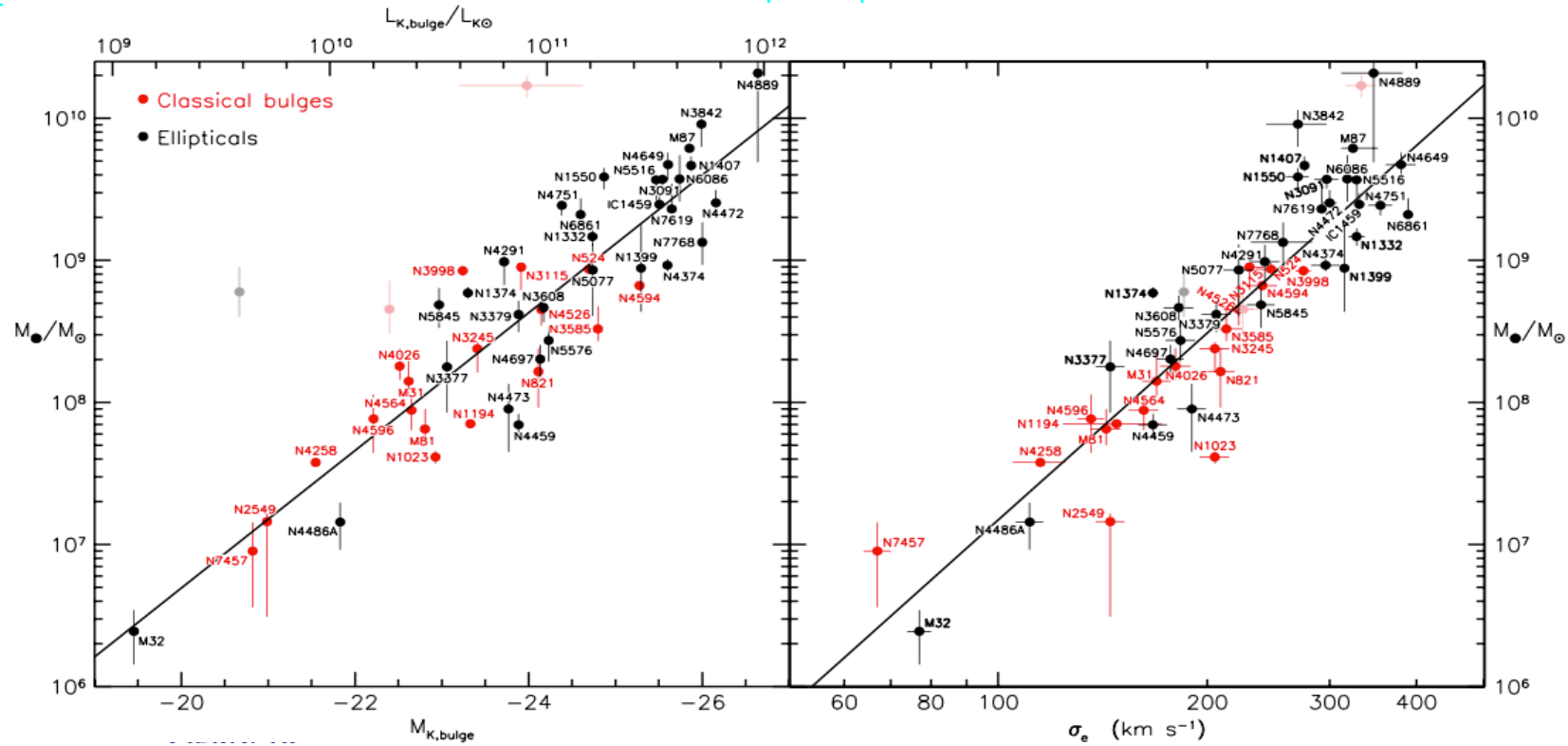
# FIVE PILLARS of AGN-GALAXY CO-EVOLUTION (I)

SMBH Scaling Relations

Cosmic Downsizing

Color

SMBH Energy budget



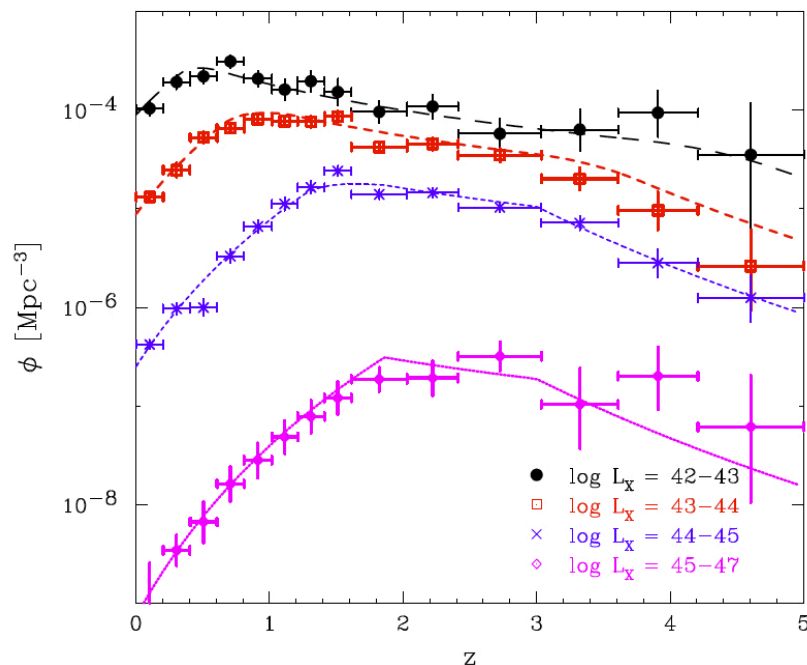
Correlations between SMBH mass and host galaxy spheroidal properties: Lum, Mass, stellar velocity dispersion

Merritt & Ferrarese 01 Haring & Rix 04 Kormendy & Ho 13

# FIVE PILLARS of AGN-GALAXY CO-EVOLUTION (II)

## SMBH Scaling Relations

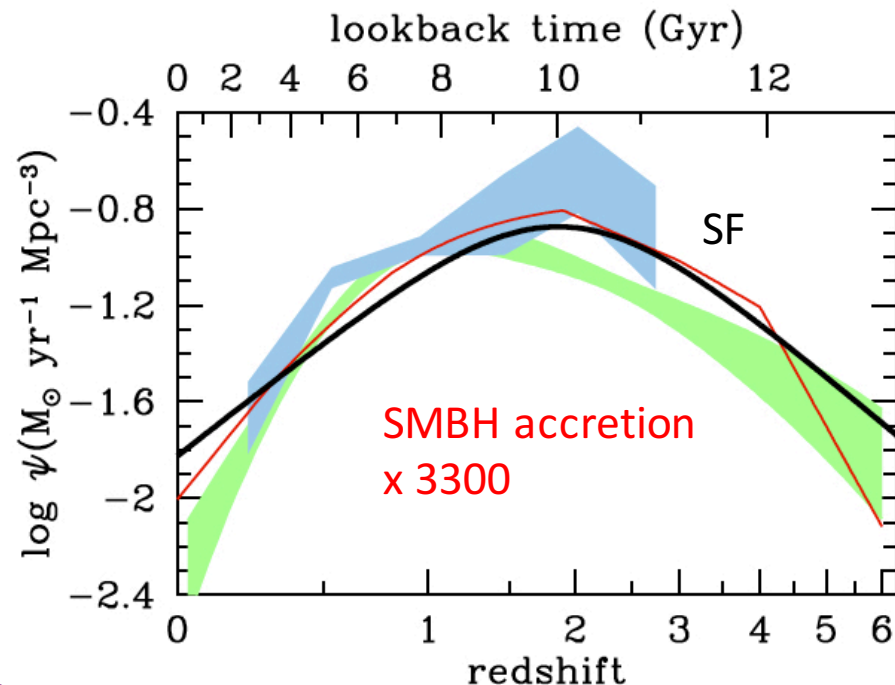
## Scaled CDM vs obs. MF



- More Luminous AGN peak at higher  $z$
- Massive Galaxies ceased star formation at  $z > 2$ , low mass galaxies continued active star formation to late epochs
- Similar SF and SMBH accretion histories

## Cosmic Downsizing

## Energy budget



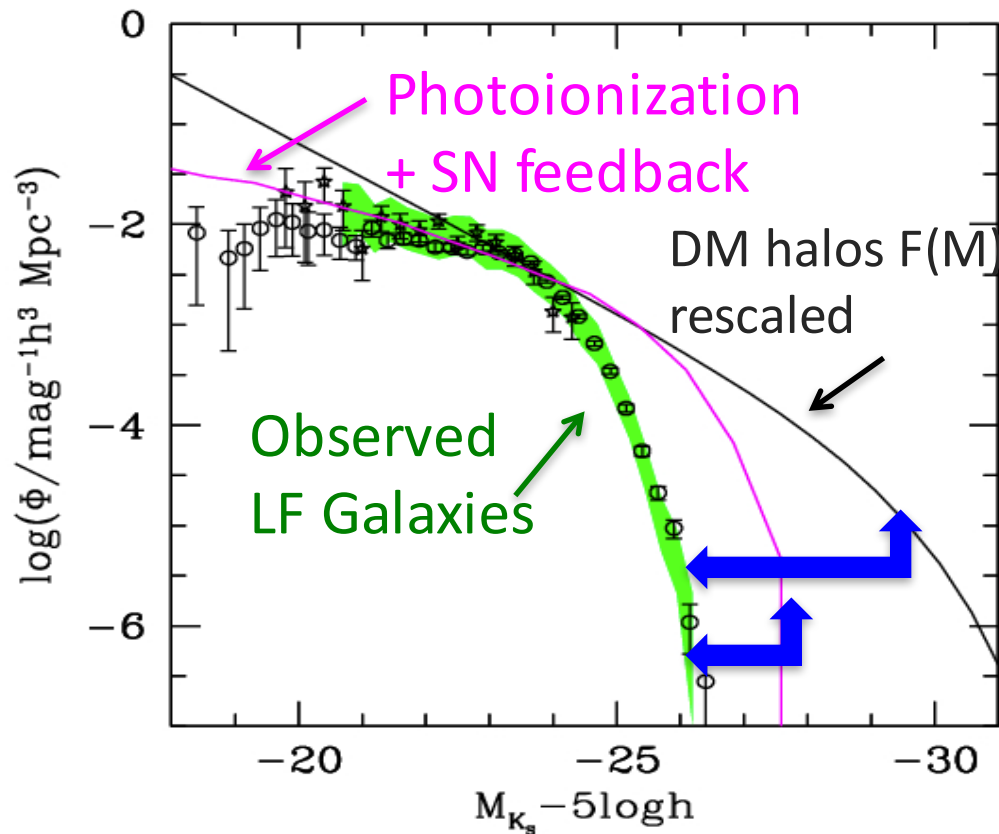
# FIVE PILLARS of AGN-GALAXY CO-EVOLUTION (III)

SMBH Scaling Relations

Cosmic Downsizing

Scaled CDM vs obs. MF

SMBH Energy budget



Theory predicts  
**too many small  
galaxies  
&  
too many big  
Galaxies**

← AGN Feedback ?

- Removing baryons
- Quenching SF



# FIVE PILLARS of AGN–GALAXY CO-EVOLUTION (IV)



SMBH Scaling Relations

Cosmic Downsizing

Scaled CDM vs obs. MF

SMBH Energy budget

$$M_{\text{SMBH}} \sim 2 \times 10^{-3} M_{\text{Bulge}}$$

*Quasar energy output*

$$E_{\text{QSO}} \sim 0.1 M_{\text{SMBH}} c^2$$

$$\sim 2 \times 10^{-4} M_{\text{Bulge}} c^2$$

*Binding energy of a bulge*

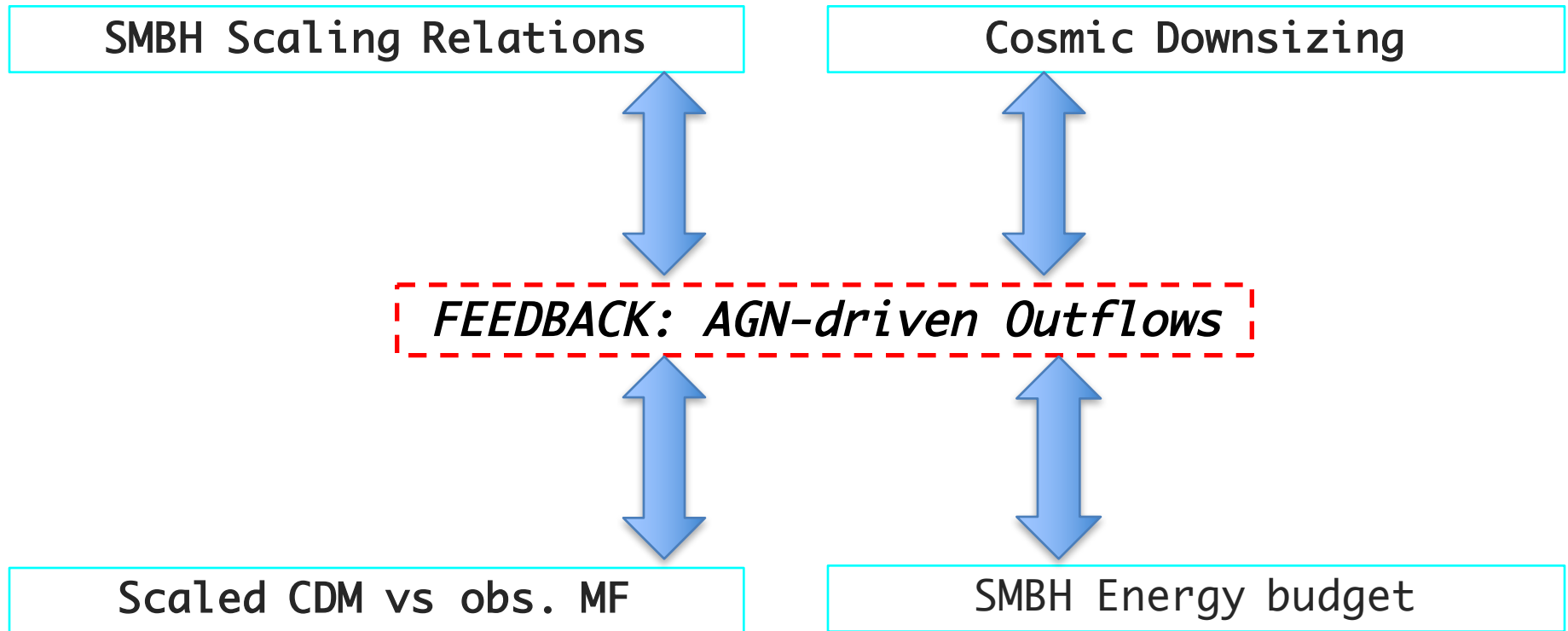
$$E_{\text{Bulge}} \sim M_{\text{Bulge}} v^2$$

$$\sim 10^{-6} M_{\text{Bulge}} c^2 \left( \frac{v}{300 \text{ km/s}} \right)^2$$

~1% of the QSO liberated radiative energy is enough to unbind the galactic bulge

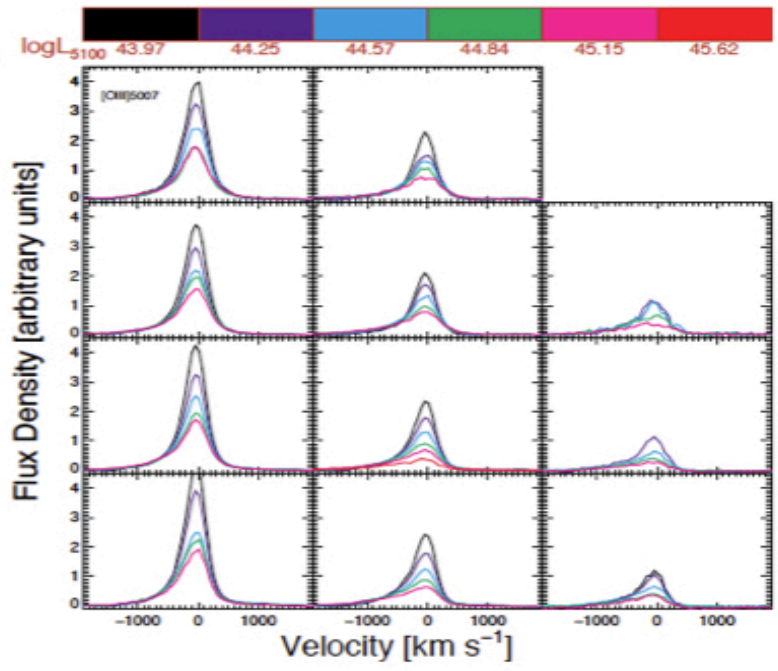
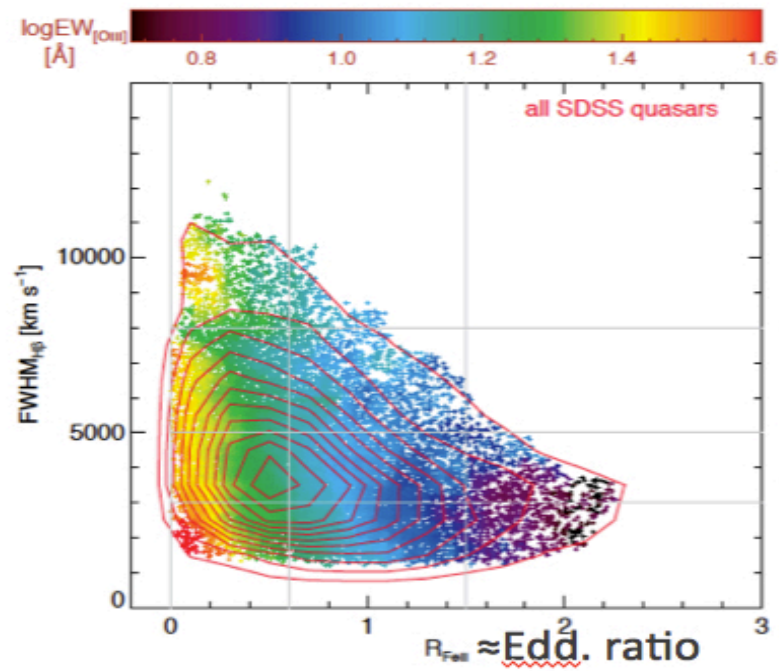
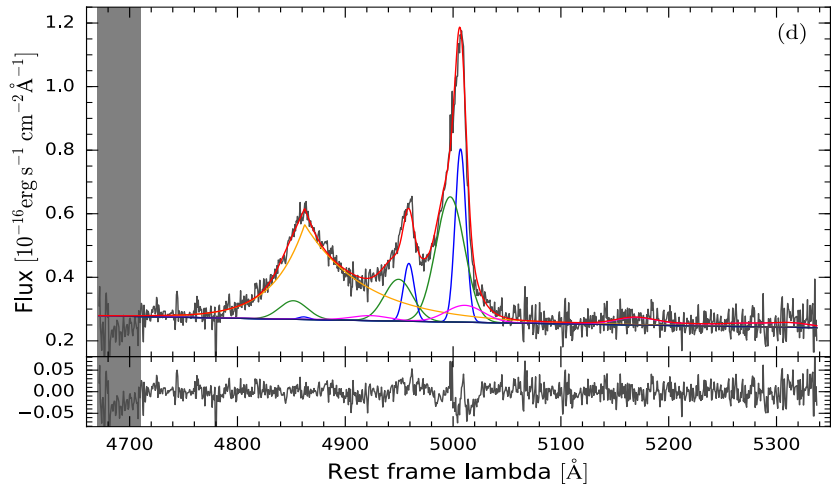
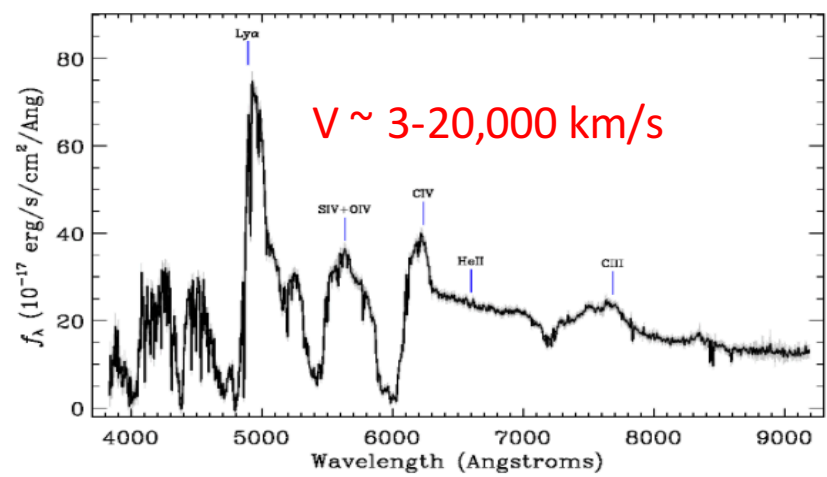
**SMBHs can regulate galaxy evolution  
(..and their own growth)!**

# FIVE PILLARS of AGN-HOST GALAXY CO-EVOLUTION



# “CLASSICAL” OUTFLOWS: OPTICAL & UV BAND

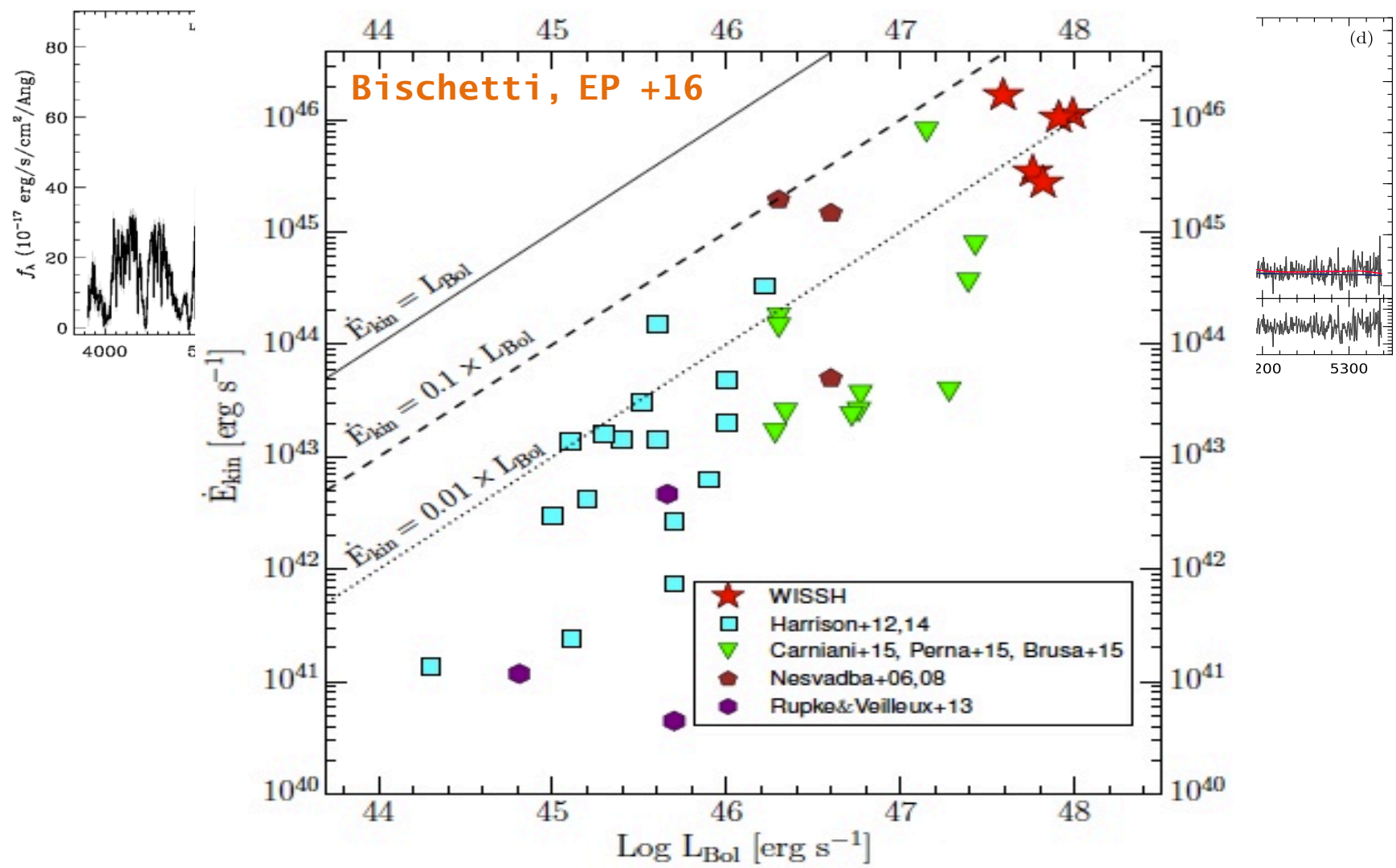
- ◆ Broad Absorption lines in 20-40% of QSOs
- ◆ “Ubiquitous” [OIII] outflows



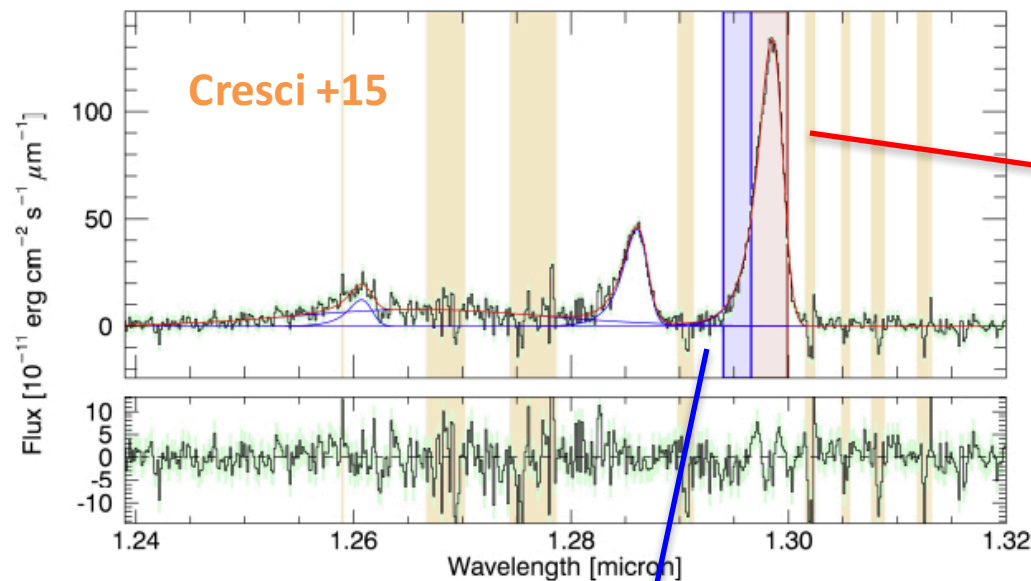
Shen & Ho 14

# “CLASSICAL” OUTFLOWS: OPTICAL & UV BAND

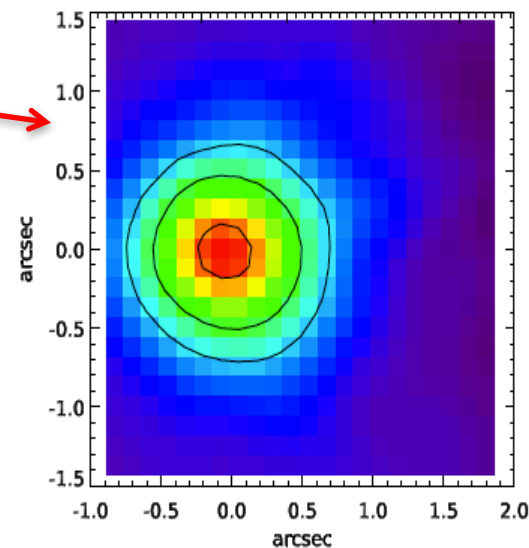
- ◆ Broad Absorption lines in 20-40% of QSOs
- ◆ “Ubiquitous” [OIII] outflows



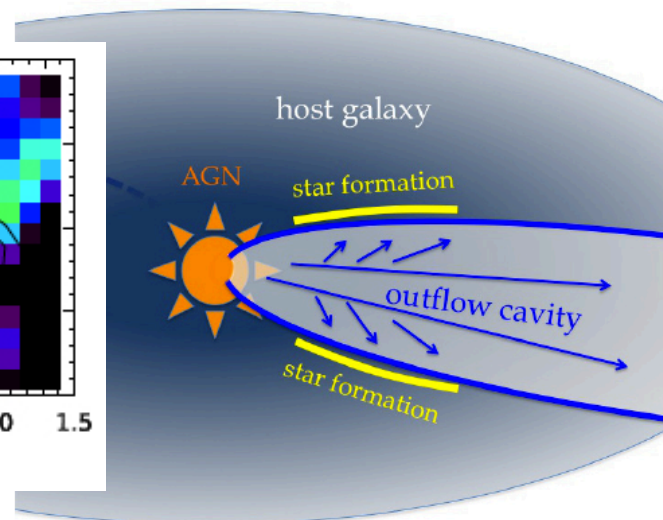
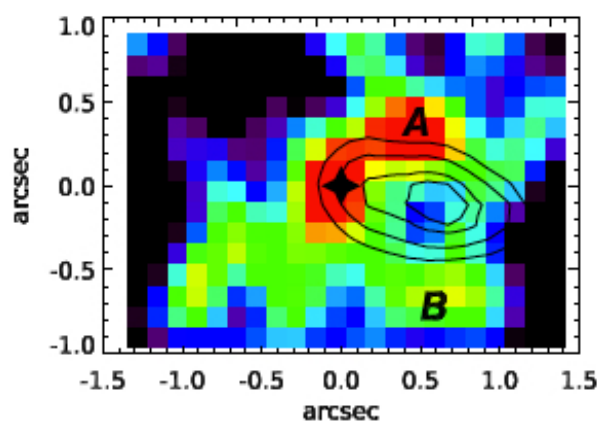
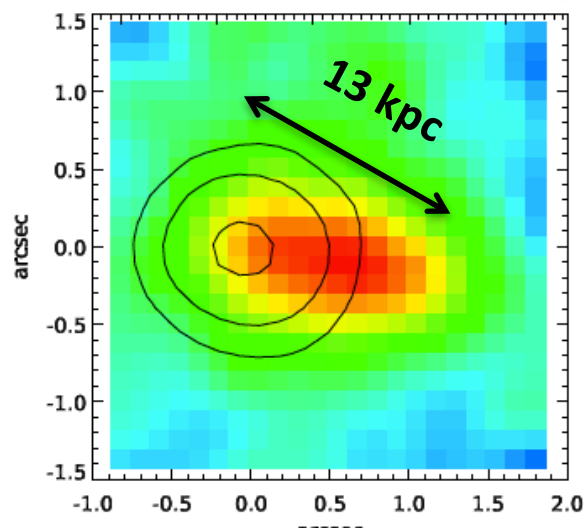
# GALAXY-WIDE IONIZED WINDS



**[OIII] core**

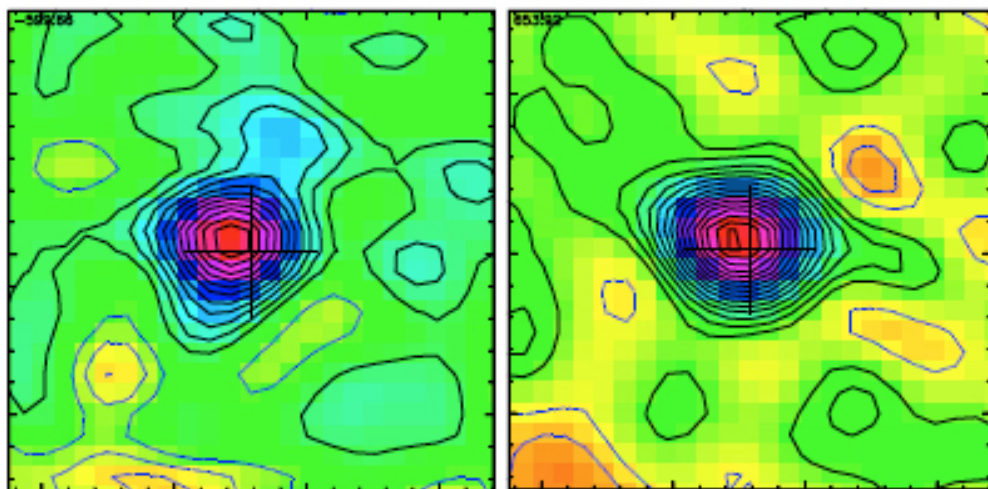
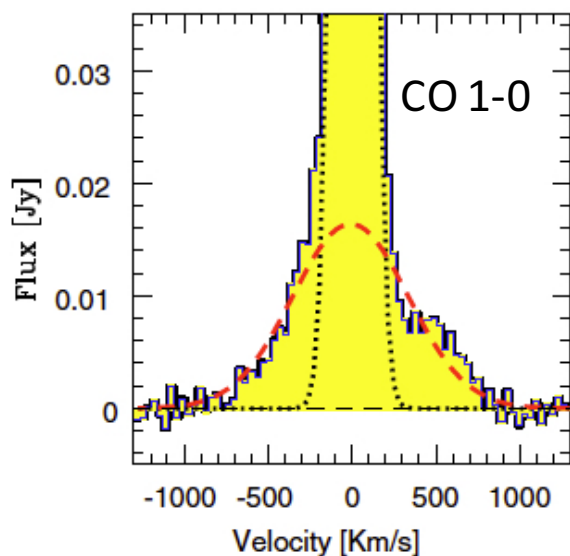


**[OIII] blue wing**



SF in blobs A&B:  $\log([\text{NII}]/\text{H}\alpha) < -1.1$

# MOLECULAR OUTFLOWS: FEEDBACK IN ACTION



BLUE WING:[-500, -700 km/s] RED WING:[500, 800 km/s]

## Feedback revealed in Mrk 231 **Feruglio, Maiolino, EP +10**

Spatially-extended emission associated with the broad wings of the CO line indicates the presence of a massive molecular outflow with velocity  $>750$  km/s and  $\dot{M} > 700$  Msun/yr  $>$  SFR

→ Expelling cold molecular gas (material for SF) from the center of the galaxy

Additional pieces of evidence published in **Feruglio +13; Bolatto +13; Cicone +14; Feruglio +15**

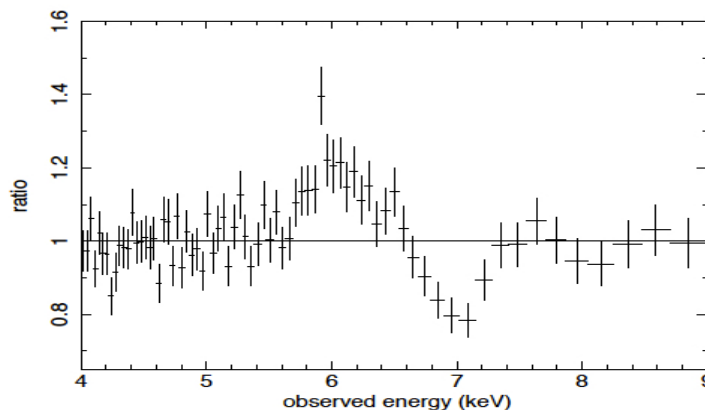
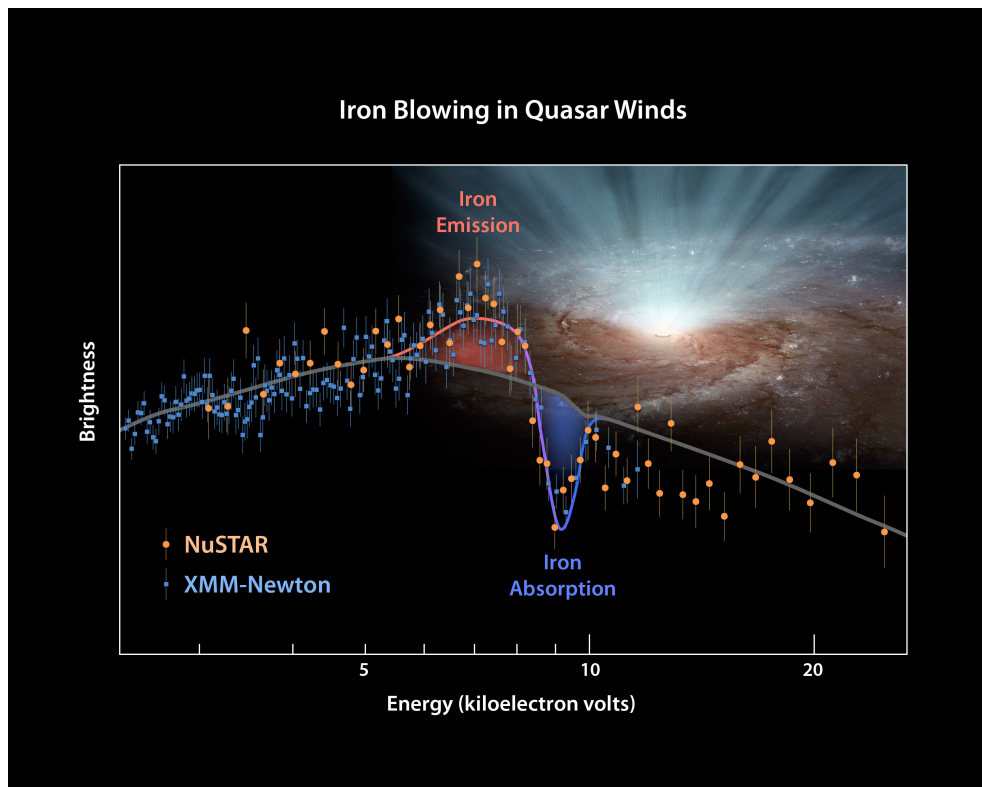


# SMBH WINDS: “X-RAY ULTRA FAST OUTFLOWS”

## SMBH winds aka UFOs (ultra-fast outflows):

- Highly-ionized (Fe XXV/XXVI), ultra-fast ( $0.1-0.4c$ ) accretion-disk ( $\ll 0.1$  pc) winds
- Mass rates:  $0.01-10 M_{\odot}/\text{yr}$  and Kinetic power:  $10^{43}-10^{45}$  erg/s

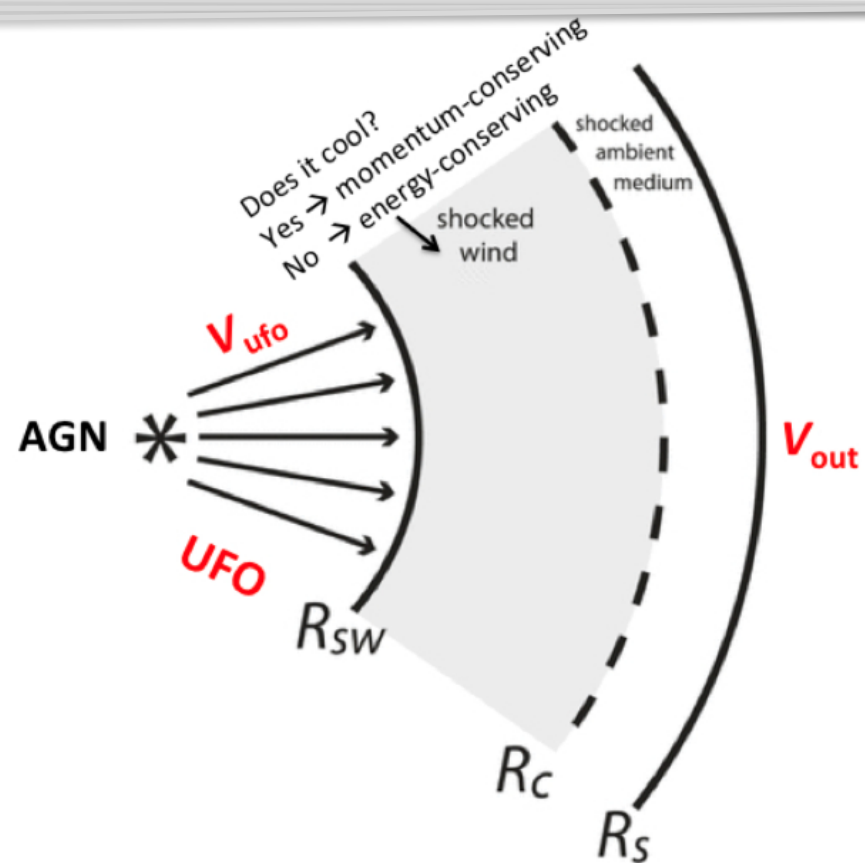
Reeves +03; Pounds +03; Markowitz +06;  
Tombesi +10; Tombesi+15; Feruglio +15



PDS 456: hyper-luminous QSO @  $z = 0.189$   
with  $L_{\text{Bol}} = L_{\text{Edd}} = 10^{47}$  erg/s

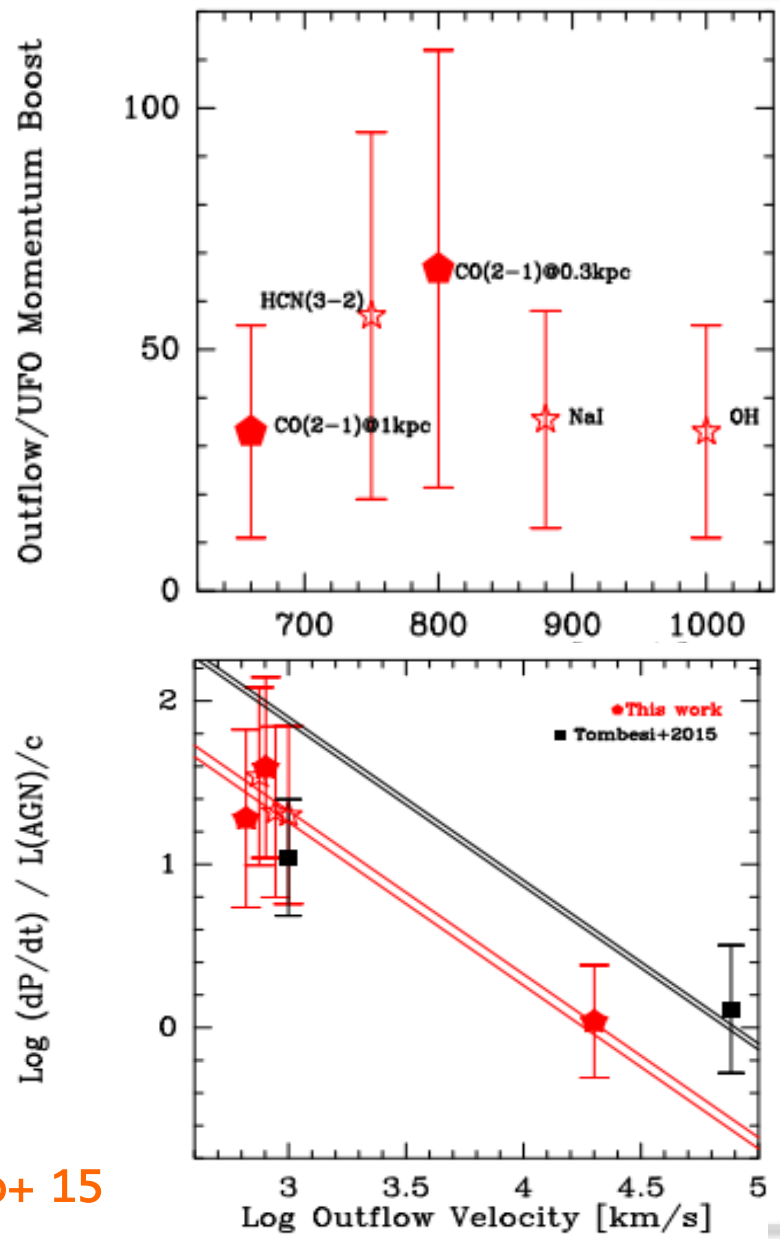
Nardini et al. 2015, *Science*,  
reveal an Fe XXVI P-Cygni-like feature  $\rightarrow$   
quasi-spherical wind with bulk velocity of  $0.25c$   
 $\dot{M} > 10 M_{\odot}/\text{yr}$   
kinetic power of  $\sim 20\% L_{\text{Bol}}$

# THE TWO-PHASE AGN FEEDBACK MECHANISM



Radiative forces accelerate out the Ultra-Fast Outflow from the immediate vicinity of the AGN accretion disk

It shocks against the ISM and accelerates the swept-up gas, thus producing the galactic-scale, massive molecular outflows (ENERGY CONSERVING!) **Feruglio+ 15**





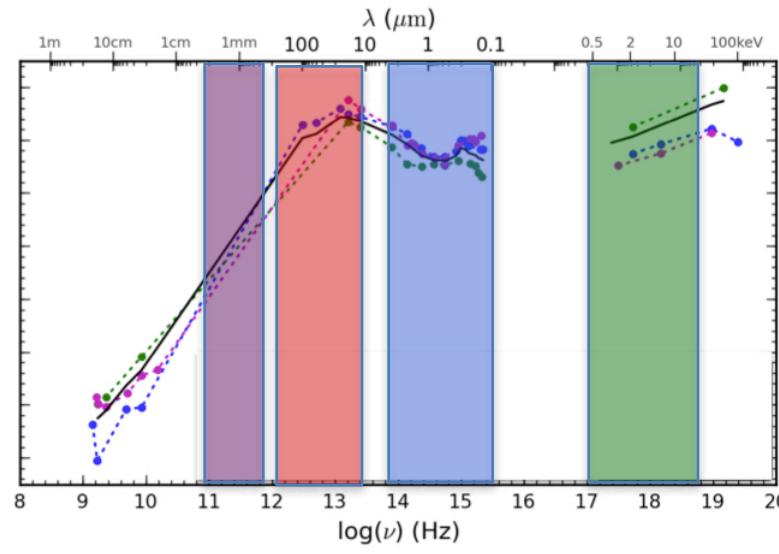
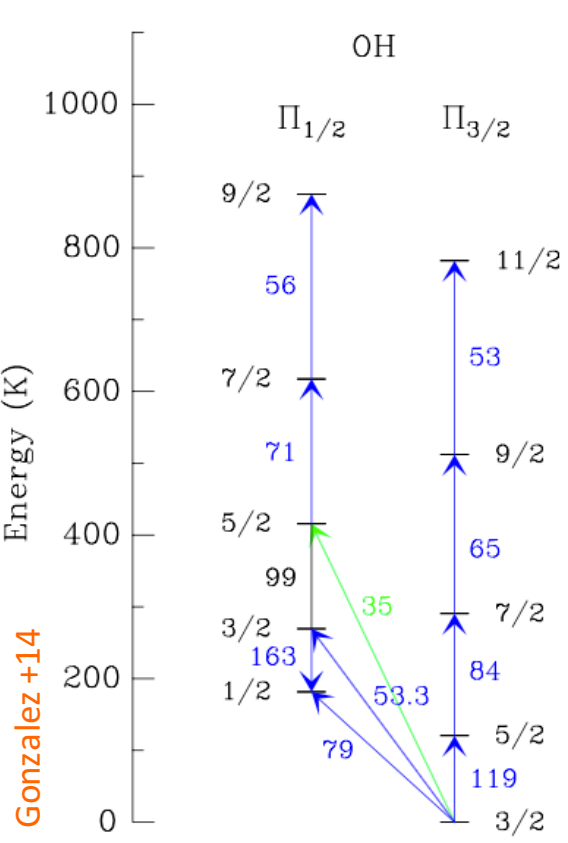
# PANCHROMATIC VIEW OF OUTFLOWS (2016)



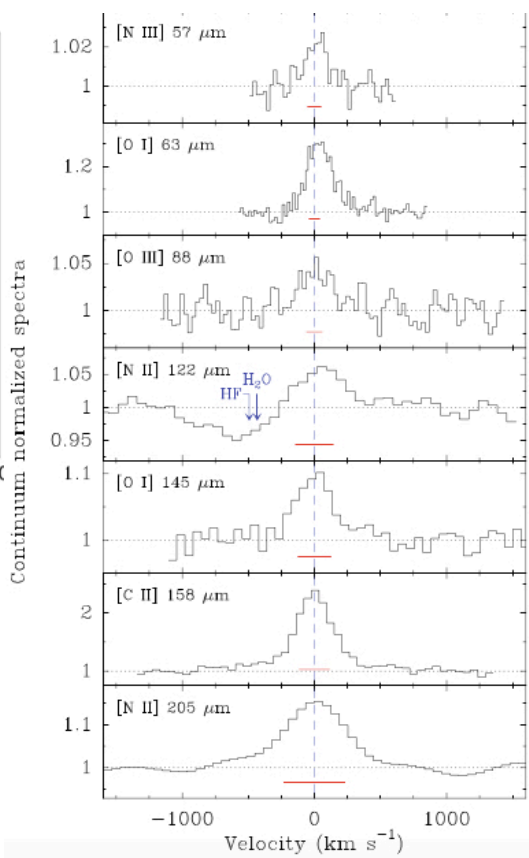
## MULTISCALE & MULTIPHASE OUTFLOWS

Different distances; Different gas phases; Different ionization states

Multi- $\lambda$  approach is mandatory

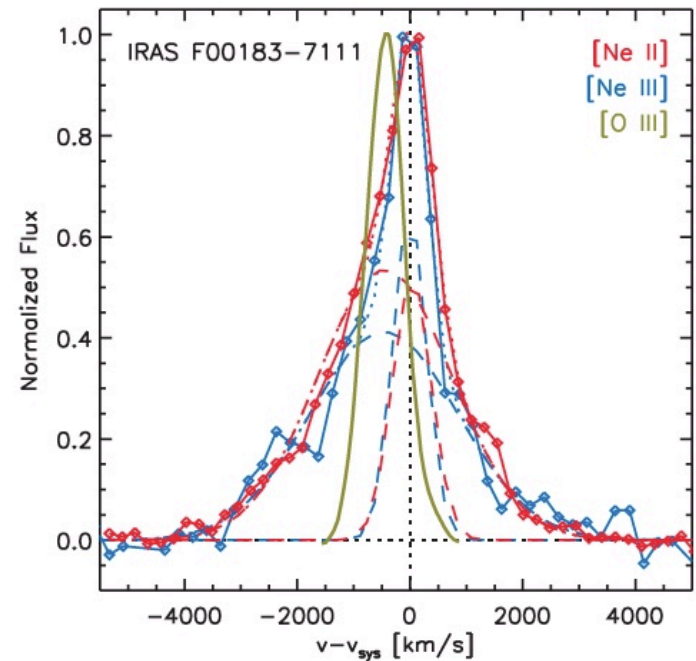
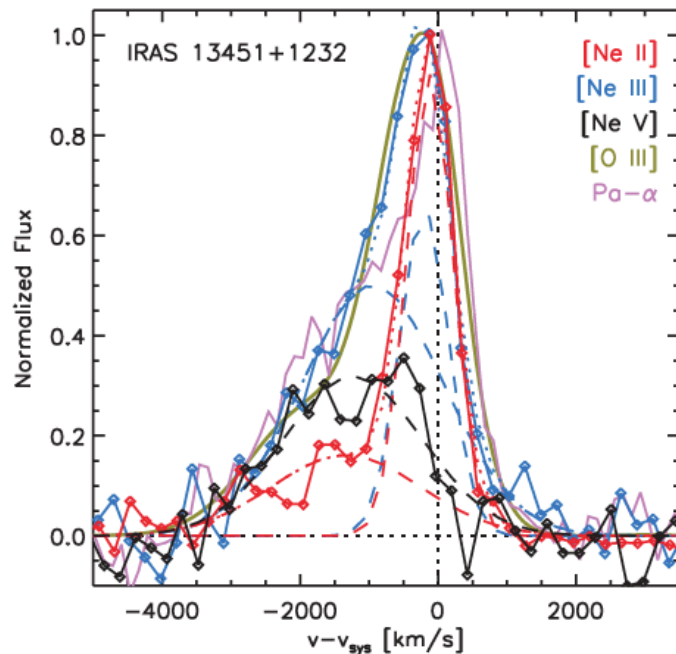


**MIR – FIR is basically not covered**  
Warm molecular gas  
OH, H<sub>2</sub>O,  
Warm atomic gas  
Fine structure lines (CII, NII,..)



Fischer +10

# FOOD for SPICA: OUTFLOWS IN THE MIR



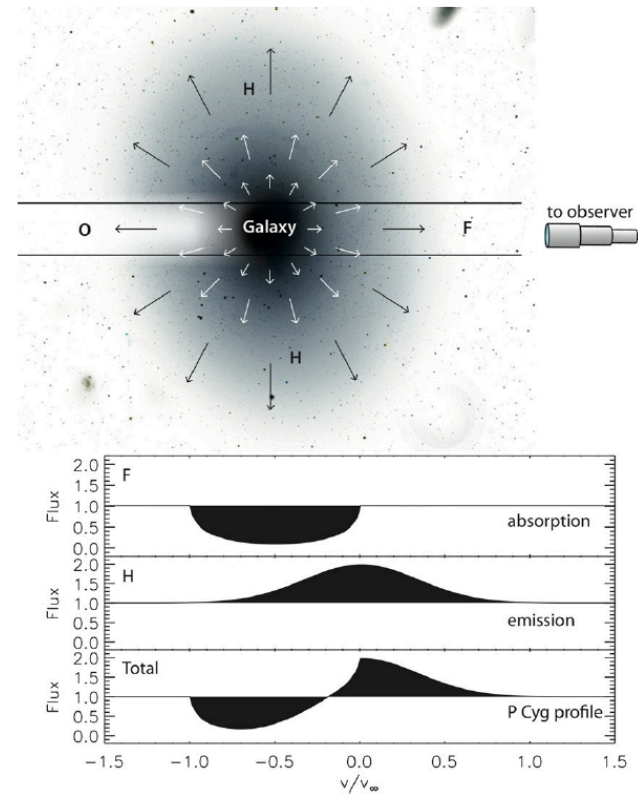
Discovery of Strongly Blueshifted MIR [Ne III] & [Ne V] Emission in AGN powered ULIRGs  
Spoon & Holt 09

High-velocity ionized gas with velocities ranging [-3500, +3000] km/s in F00183-11 Spoon +09

No evidence for similarly high- $v$  gas in forbidden lines at shorter  $\lambda$ : “Revealing the Optically Obscured Base of a Nuclear Outflow”

Highly stratified ISM, ionized by the central source

# FOOD for SPICA: OUTFLOWS IN THE FIR



OH 79 and 119  $\mu\text{m}$  doublet transitions:

Clear P-Cygni profiles, abs. & emission (max v. 100-2000 km/s)

Max velocity increases w. AGN luminosity (not w. SFR!!!)

OH emission anti-corr. with 9.7  $\mu\text{m}$  Si absorption

Fischer +10; Sturm +11; Veilleux +13; Spoon +13

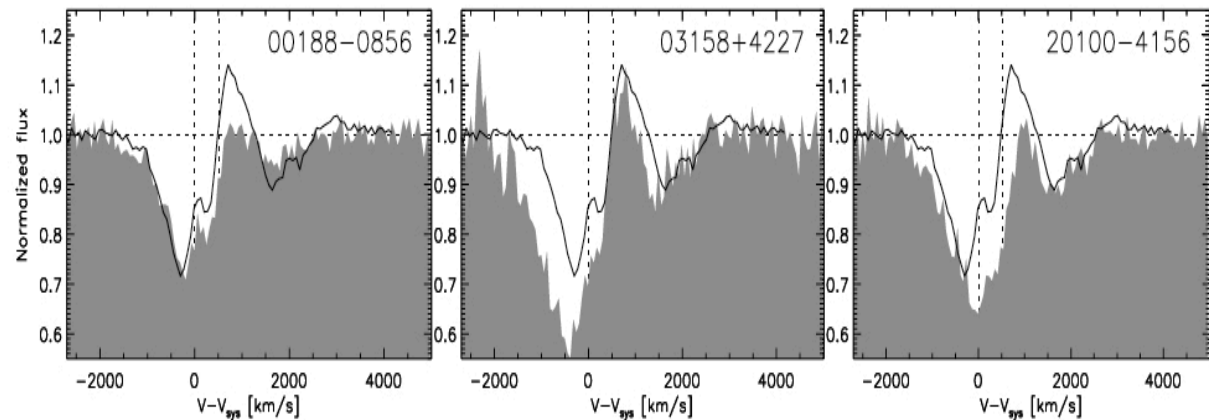


Figure 6. Comparison of the normalized OH119 profiles of IRAS 00188-0856, 03158+4227, and 20100-4156 (gray surfaces) with the OH119 profile of Mrk 231 (black line; Fischer et al. 2010).

- AGN-driven outflows
  - Estimated Outflow Masses  $10^8$ - $10^9$  Msun (many assumptions/large uncertainties..)
  - Mass rates 50-1000 Msun/yr
  - Distance: few hundred pc
- (bias: a FIR continuum is needed: if cont less extended than OH, the OH wind is not illuminated)
- Warm molecular gas close to the AGN, more compact than CO?

# [CII] 158 $\mu$ m OUTFLOWS

## [CII] 158 $\mu$ m @ z=6.4

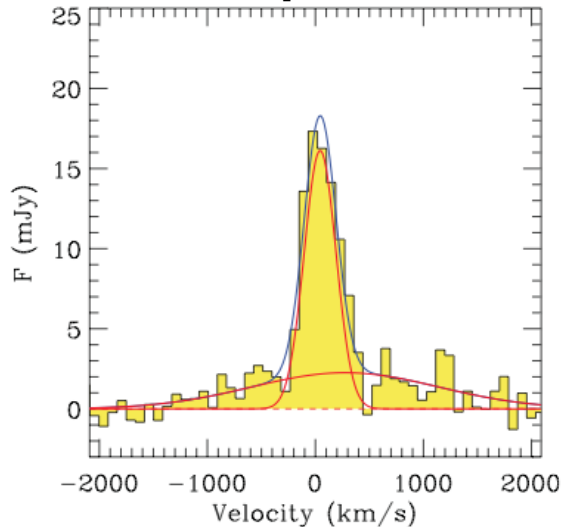
**Maiolino +12**

Ultra-powerful outflow in the early Universe

Velocity  $\sim 1300$  km/s

Size  $\sim 16$  kpc

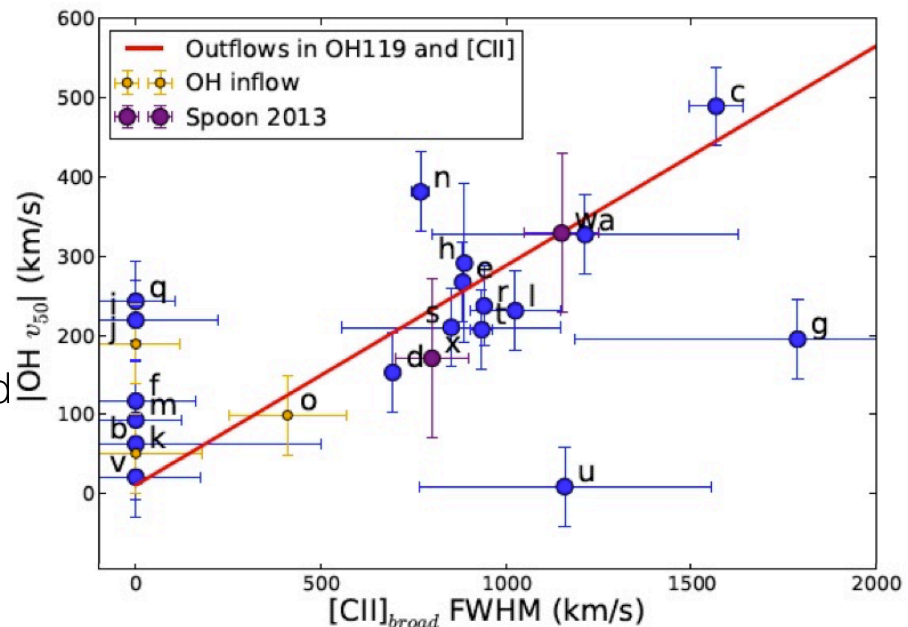
$M_{\text{outflow}} > 3500 M_{\text{sun}}/\text{yr}$



$\sim 1:1$  correlation between [CII] and OH outflow in local AGN-powered ULIRGs

FWHM [CII] correlates with OH abs. line velocity

[CII] may trace both molecular and atomic gas wind  
**Jenssen+16; Sturm+11; Rupke & Veilleux+13**



# SPICA UNIQUE CONTRIBUTION



**!! HUGE DISCOVERY SPACE !!**

Only a few tens of local ULIRGs have been observed with Herschel

**Our knowledge of molecular feedback in galaxies, even at low  $z$ , is extremely limited**

## SAFARI

**\* line sensitivity >2 orders of mag improvement wrt Herschel**

**\*simultaneous full coverage with the same sensitivity of PACS+SPIRE bands**

**\* OH doublet  $119\mu\text{m}$  + CII  $158\mu\text{m}$   
@ $z \sim 1$  in few hours  $R=3000$**

**\* OH  $79\mu\text{m}$   $84\mu\text{m}$   $65\mu\text{m}$  & OI  $63\mu\text{m}$  lines up to  $z \sim 1.5$**

**SAFARI  $35\text{--}230 \mu\text{m} \rightarrow R \sim 300/3000$**

**SMI  $17\text{--}35 \mu\text{m} \rightarrow R \sim 100/1500$**

**SMI  $12\text{--}18 \mu\text{m} \rightarrow R \sim 28000$**

**SMI (Imaging)  $\rightarrow 17\text{--}35 \mu\text{m}$**



**Systematic investigations  
of feedback & feeding in  
dust-enshrouded AGN beyond  
the local universe and  
close to their density peak**

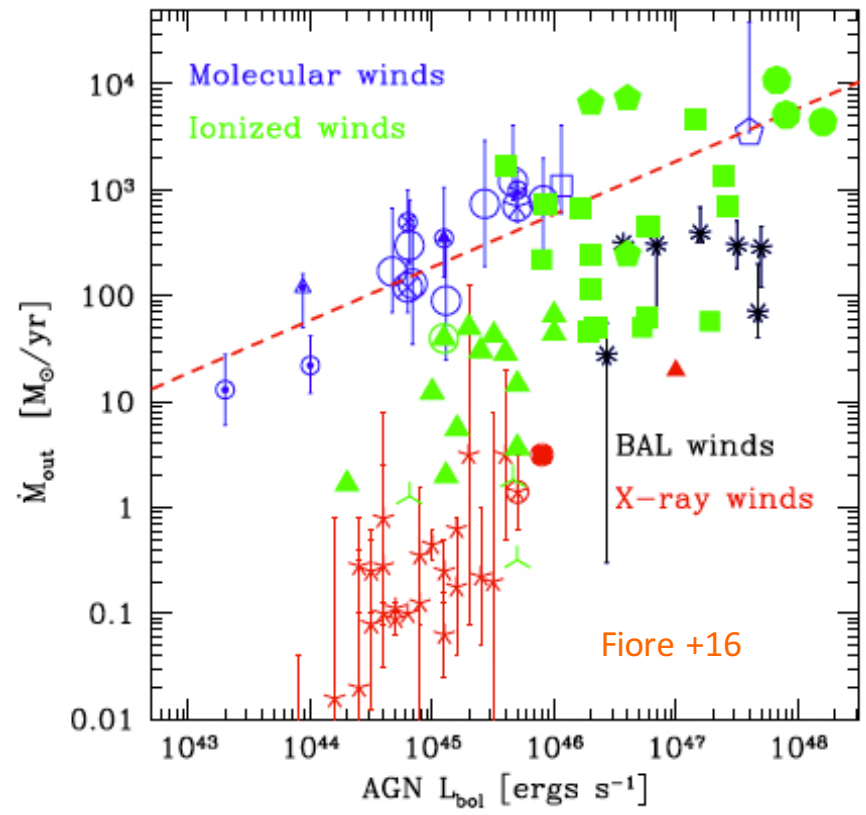
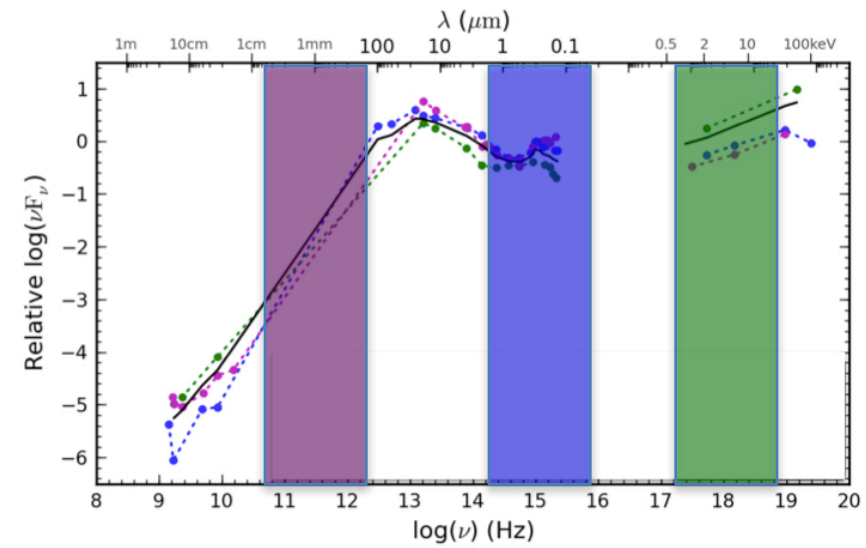
# AGN WINDS: Perspectives

MULTISCALE & MULTIPHASE OUTFLOWS:

**Accretion Disk wind (< 1pc)**  
**Highly ionized atomic UFOs**  
**X-rays: ATHENA**

**Cold molecular gas winds ~ 1kpc**  
**MM/sub-mm: ALMA/NOEMA**

**Galaxy-wide (>> kpc) Ionized atomic outflows**  
**OPTICAL/NIR IFU**



# Filling the gap with SPICA

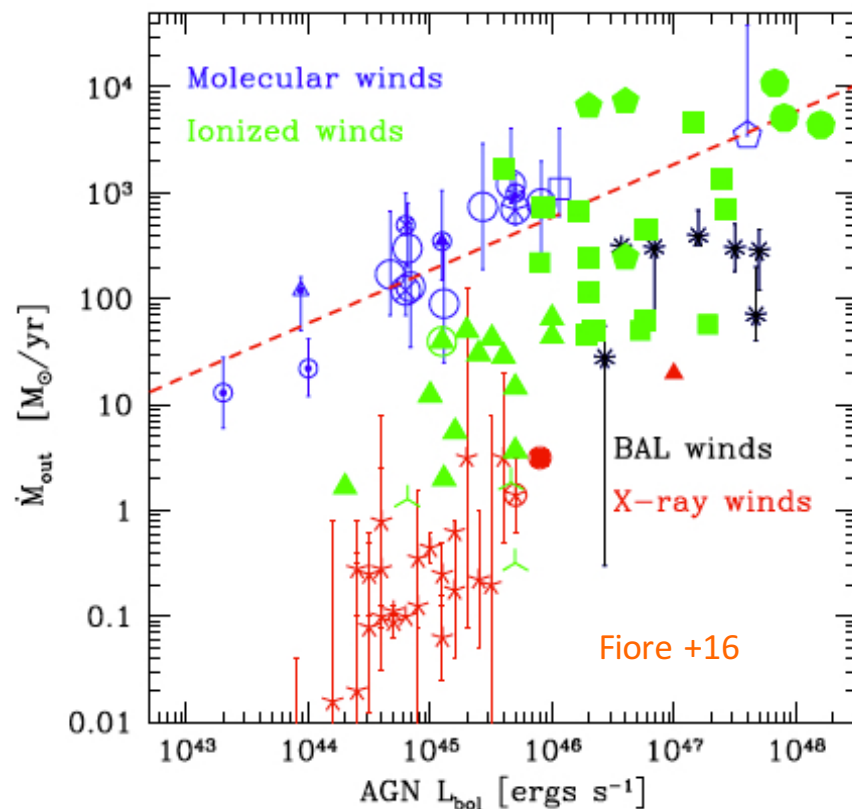
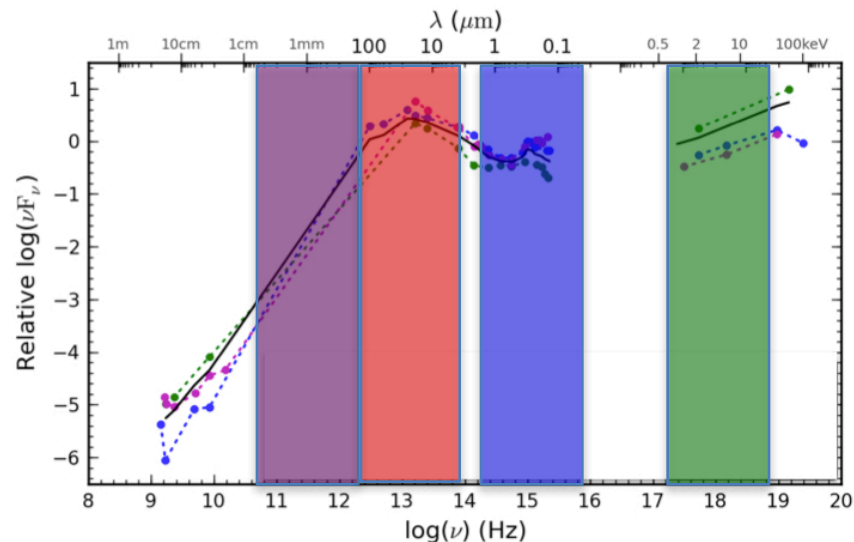
## MULTISCALE & MULTIPHASE OUTFLOWS:

**Accretion Disk winds (< 1pc)**  
**Highly ionized atomic UFOs**  
**X-rays: ATHENA**

**Warm molecular winds (10-100 pc)**  
**Warm ISM phase**  
**Close to the AGN/shock**  
**or destruction of CO into atomic ionized gas?**  
**(unexplored issue)**  
**SPICA can do a crucial job!**

**Cold molecular gas winds ~ 1kpc**  
**MM/sub-mm: ALMA/NOEMA**

**Galaxy-wide (>> kpc) Ionized atomic outflows**  
**OPTICAL/NIR IFU**





# Thank you!