Dusting Off the Secrets of the Cosmos with PRIMA Space IR Telescope

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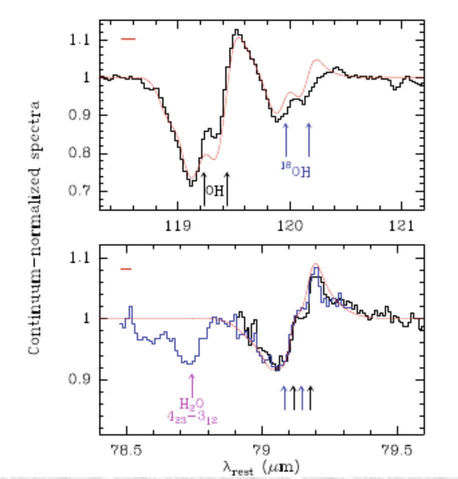
OH Outflow Energetics and the Presence of Buried Galactic Nuclei at (Nearly) Cosmic Noon

E. González-Alfonso[1], M. Pereira-Santaella[2], I. García-Bernete[3]

[1]Universidad de Alcalá
[2]Instituto de Física Fundamental, CSIC
[3]Centro de Astrobiología (CAB), CSIC-INTA
Spain

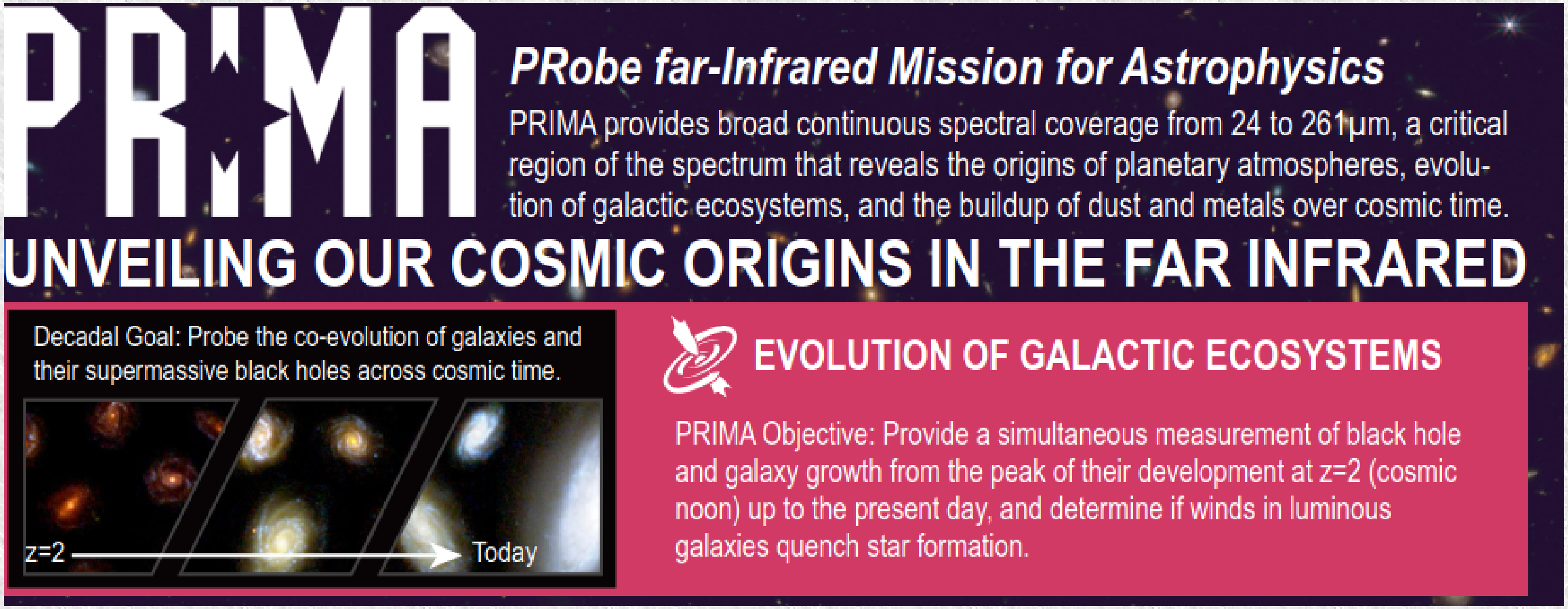


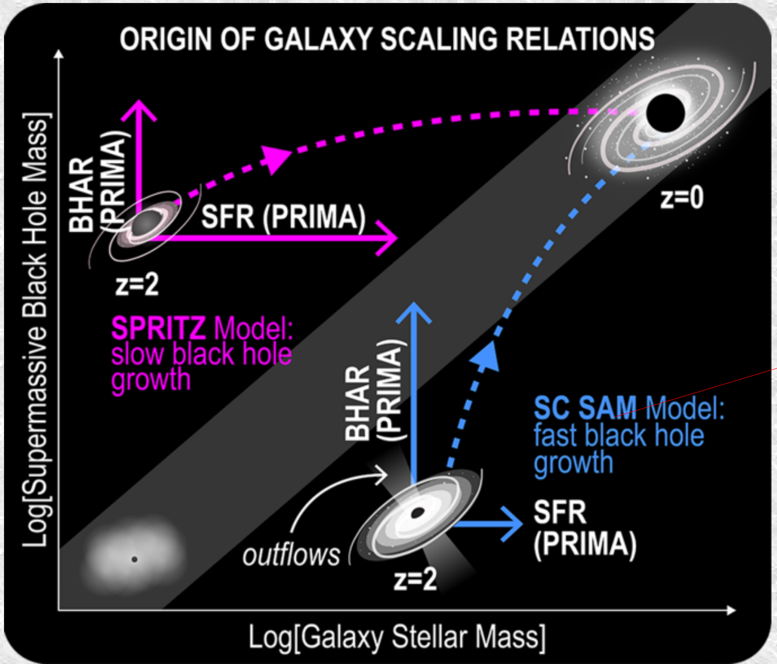
(P-Cygni OH profiles in Mrk 231; Fischer+2010)

Part I: OH outflow energetics

Introduction

PRIMA : one of the Core Science Themes, Co-Evolution of Galaxies and SMBHs Since Cosmic Noon, involves far-IR observations of galaxies up to z~2 to check for outflows & measure their energetics





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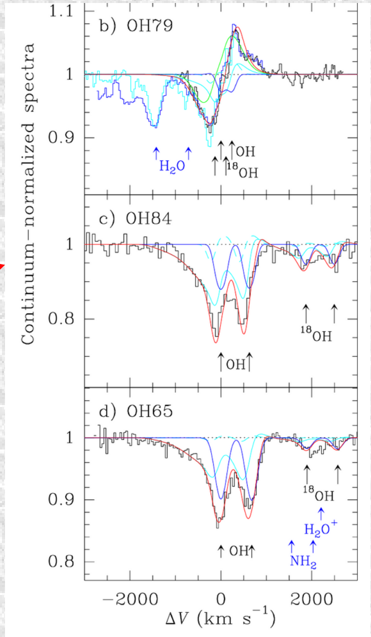
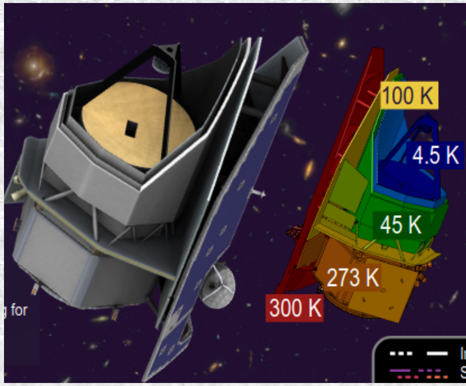
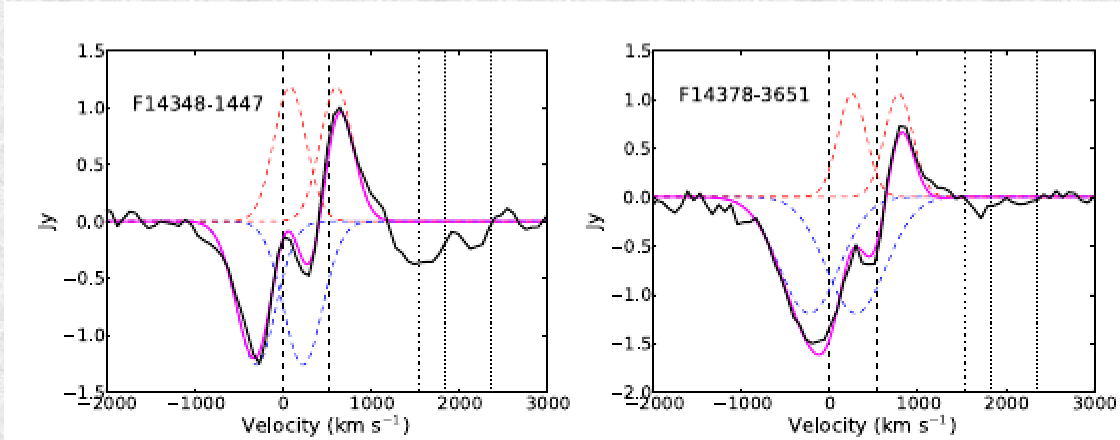




GA+14, A&A, 561, A27

P-Cygni profiles in OH119 and OH79 from Herschel : Outflows

Many local ULIRGs show P-Cygni profiles in OH119 (Sturm+11, Veilleux+13, Spoon+13):



V_{84} (OH119) is measured: 84% of the absorption produced at higher velocities

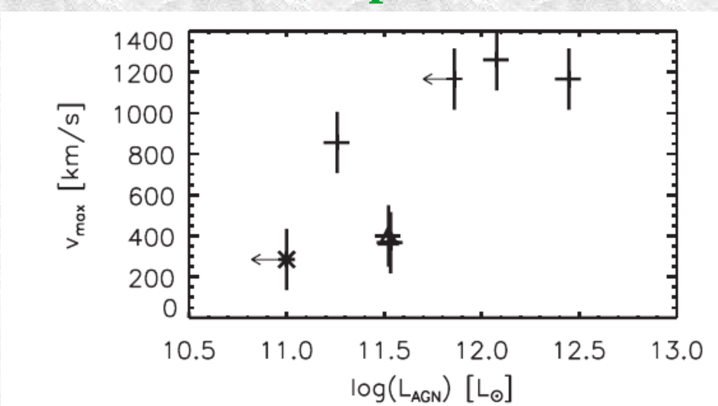
V_{84} =-509 km/s

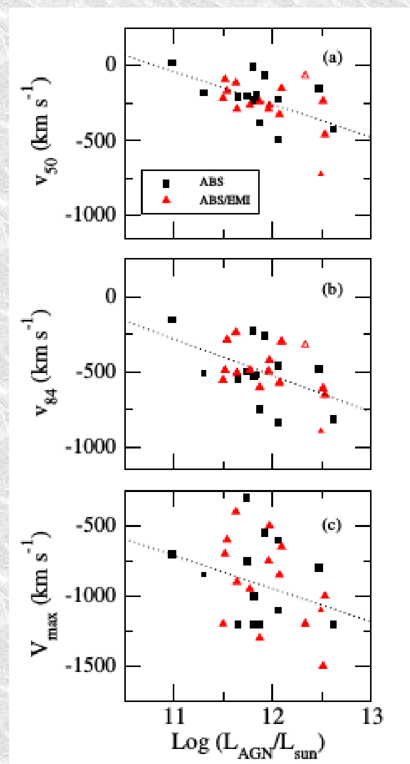
V_{84} =-556 km/s

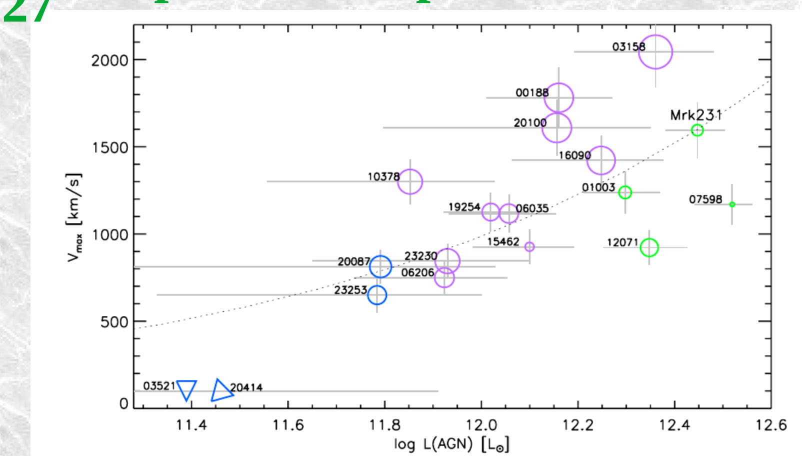
Spoon+13, ApJ, 775, 127

Veilleux+13, ApJ, 776, 27

Sturm+11, ApJ, 733, L16



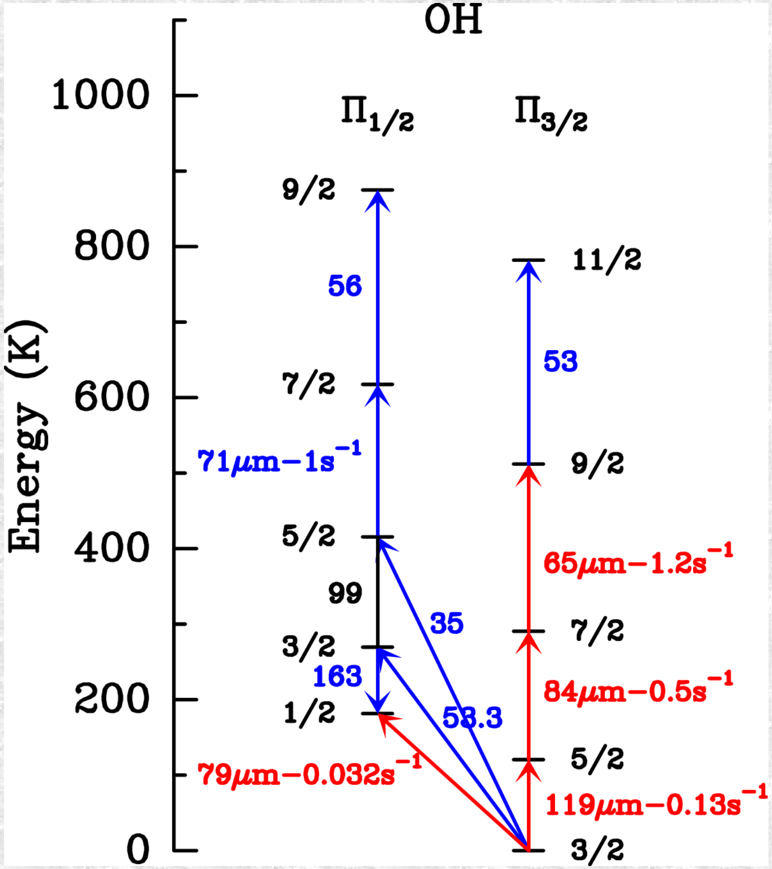




Outflows are found in 70% of ULIRGs

A trend is found of increasing Velocities with increasing L(AGN)

OH is characterized by high level spacing and high transition probabilities: it couples very well to the far-IR radiation field



We use the ground state **OH 119 µm and 79µm** doublets, and also the excited **OH 84 µm and 65µm** to characterize the high-lying molecular absorption

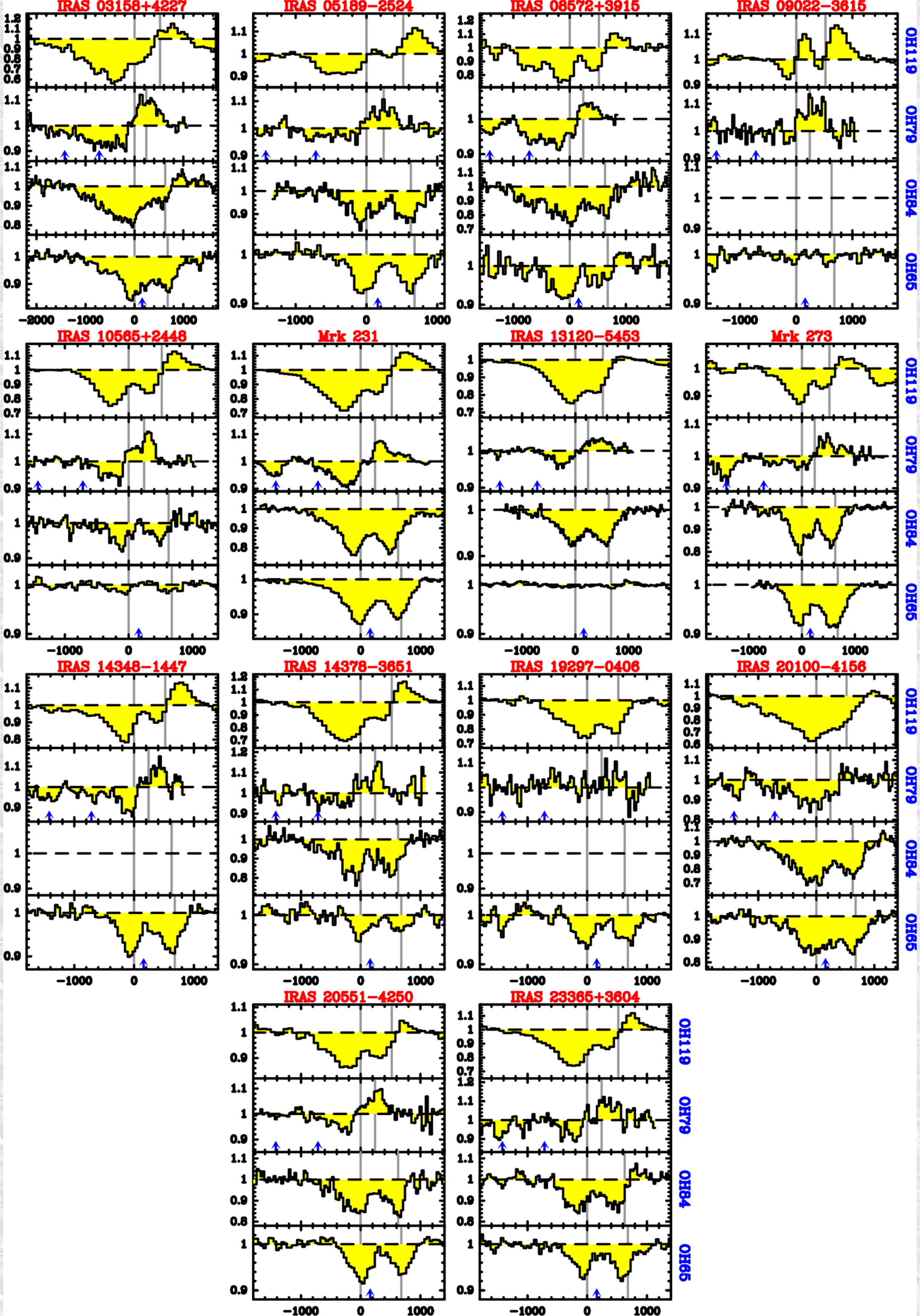
1) **OH119** is optically thick: covering factor *fc*
2) **OH79** is also ground, but optically thin: N_H
3) **OH84** is excited (Elow=120 K): compactness, *r*
4) **OH65** is high-lying (Elow=300 K): very compact and excited components, *r*

The excitation of **OH84 & OH65** is dominated by absorption of photons emitted by dust, requiring high far-IR radiation densities

Π3/2 J = 3/2 → 5/2 → 7/2 → 9/2

The size of the outflow is computed from the predicted far-IR emission, which in turn depends on the observed OH excitation

With the column density, size (and thus the outflowing mass), and the velocity field obtained from the spectra, we can estimate the outflow energetics.



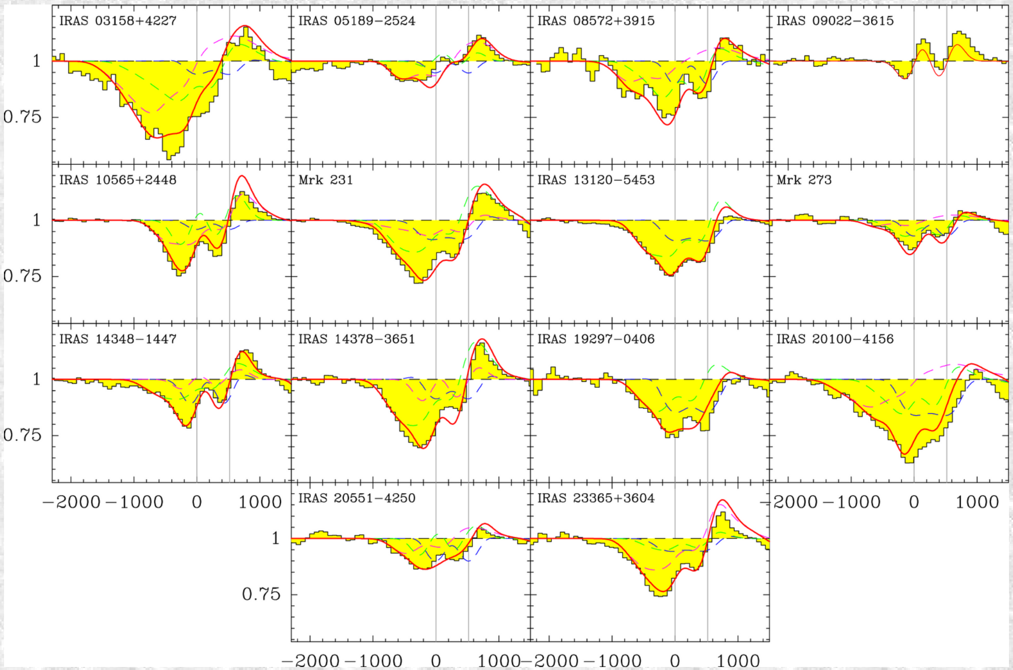
P-Cygni profiles in local ULIRGs: estimating the energetics of the outflows

GA+17, ApJ, 836, 11

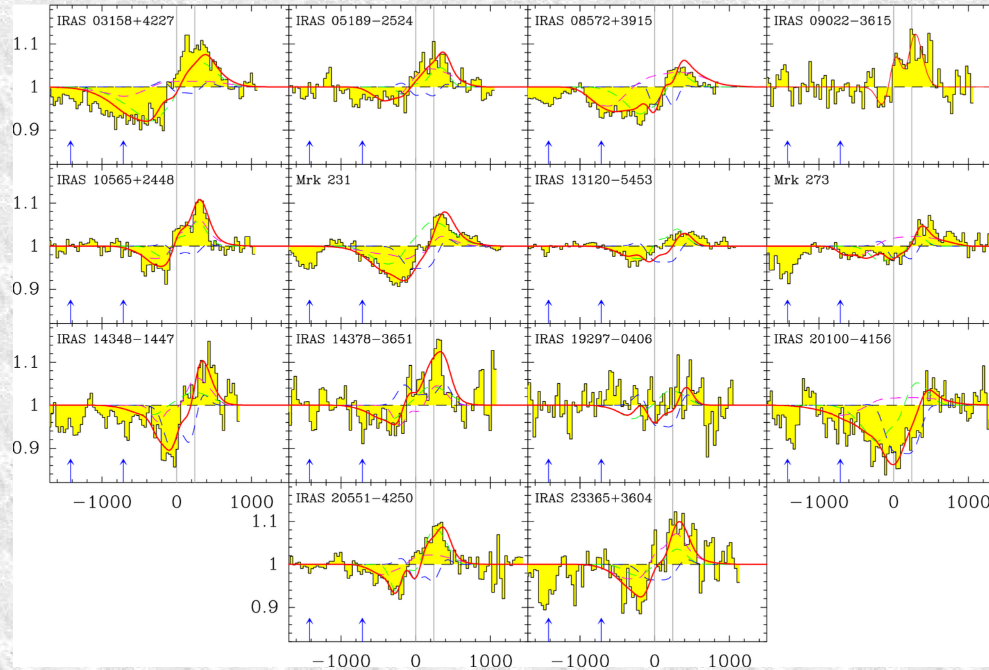
Sample: all ULIRGs with evidence for outflows in OH119 & OH79 and observed in at least 1 excited doublet (OH84 and/or OH65)

RT models : overall modeling results

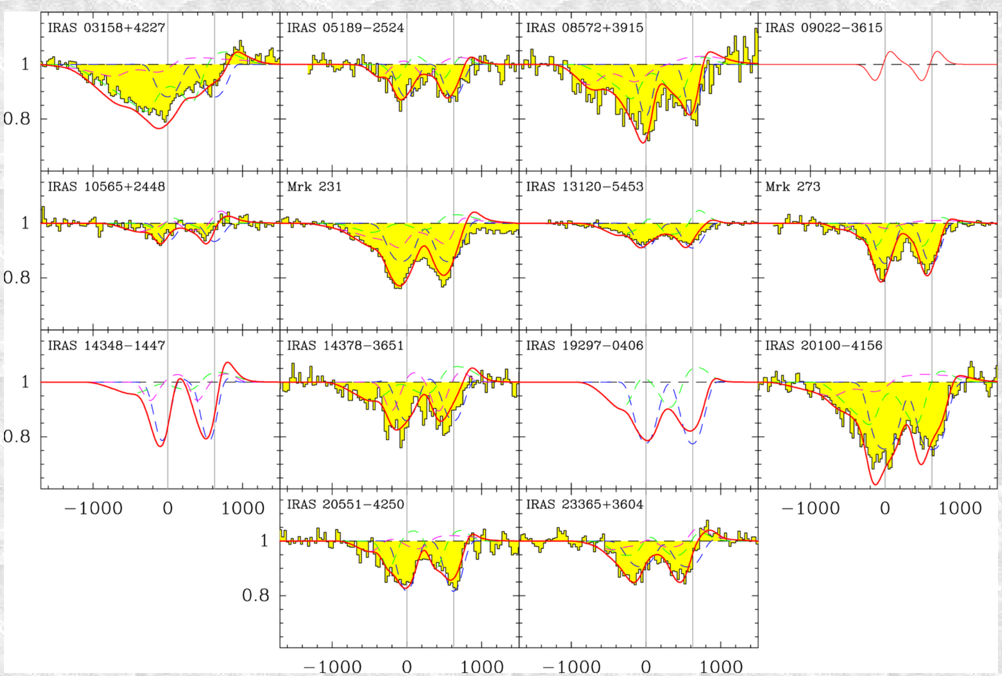
OH119



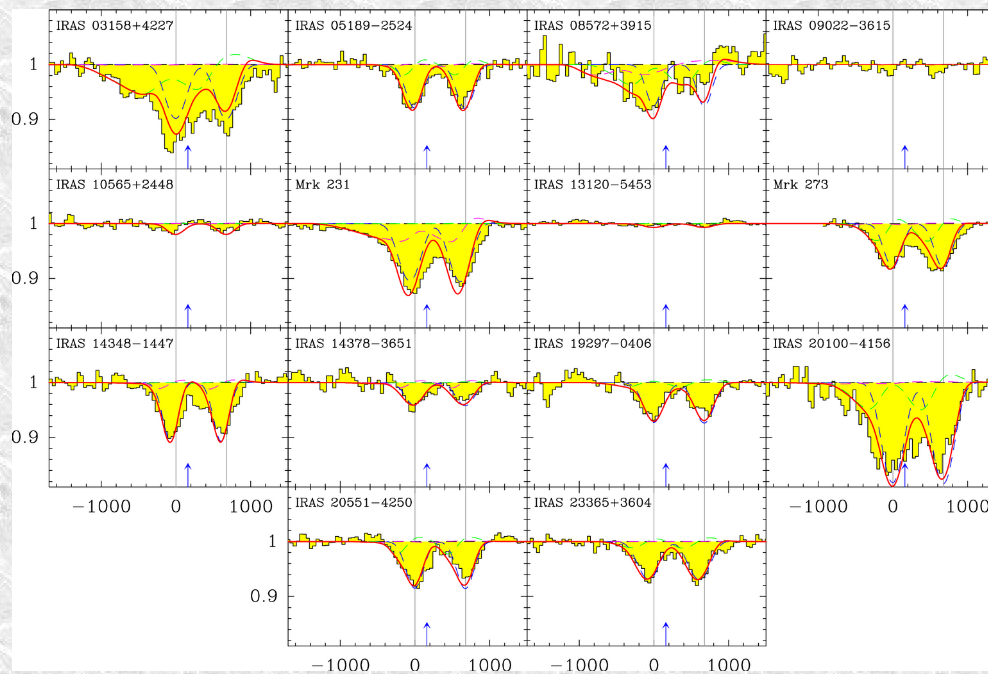
OH79



OH84

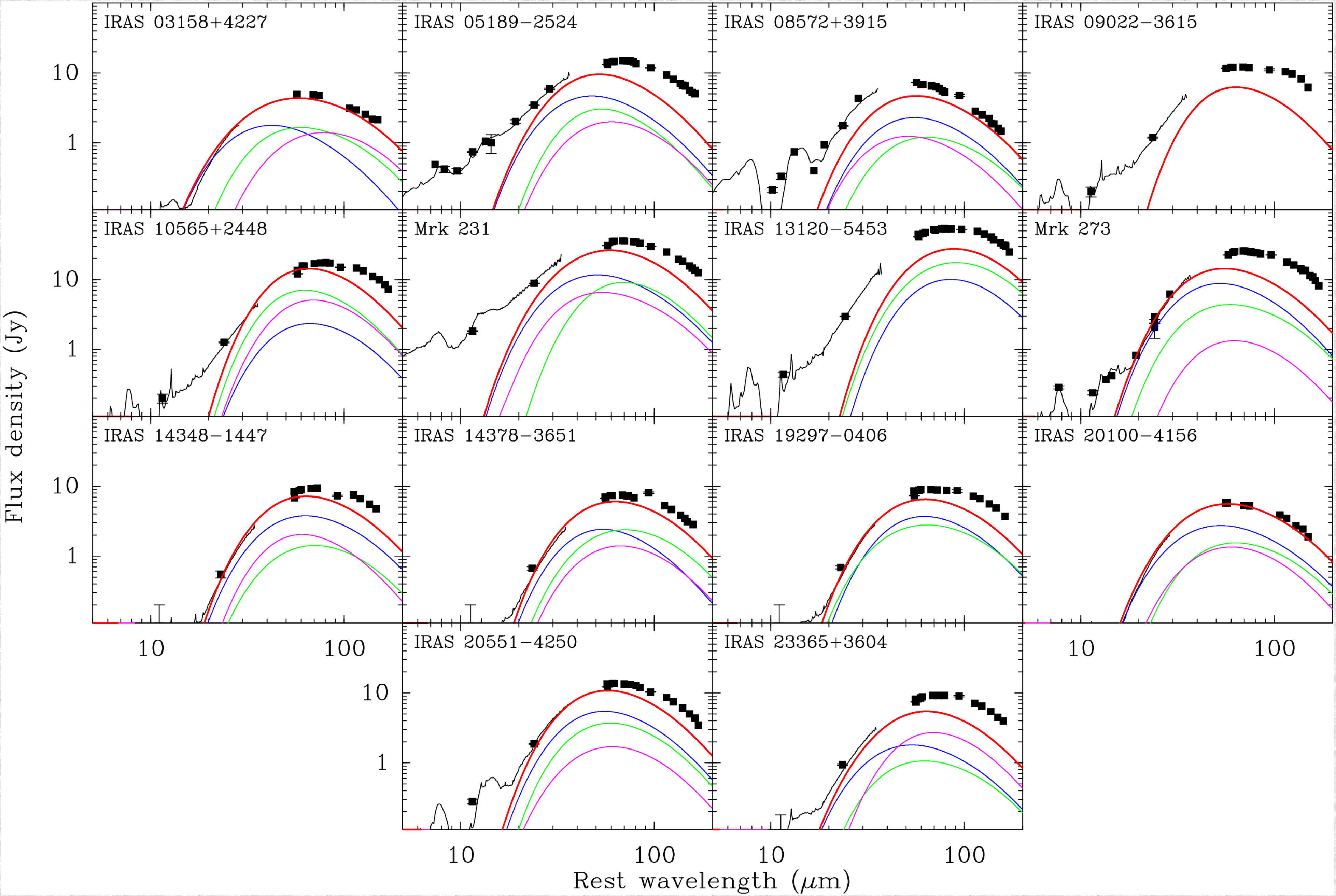


OH65



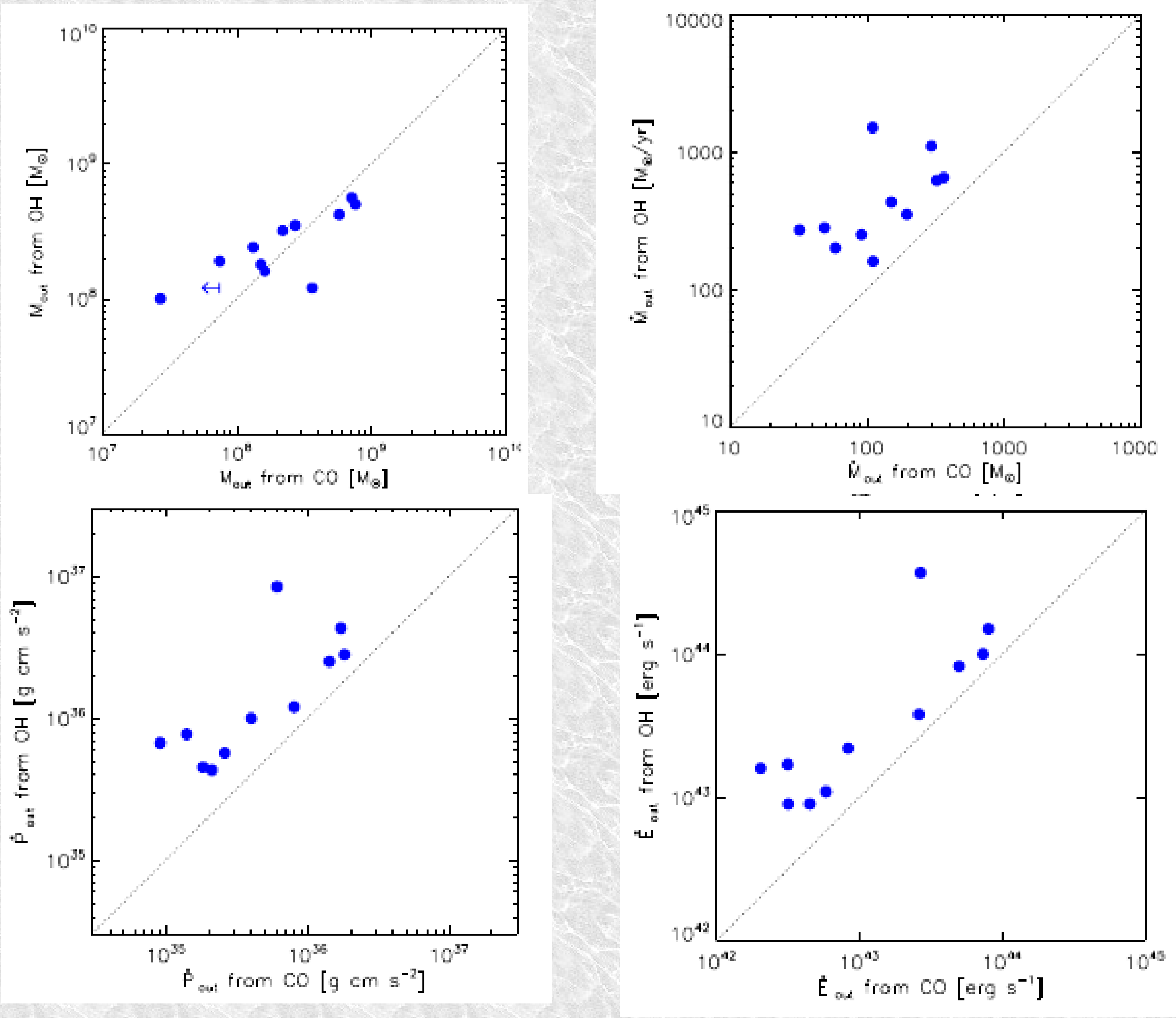
RT models : overall modeling results

Predictions for the far-IR continuum (red is total):
a fraction of the far-IR emission is associated with the OH



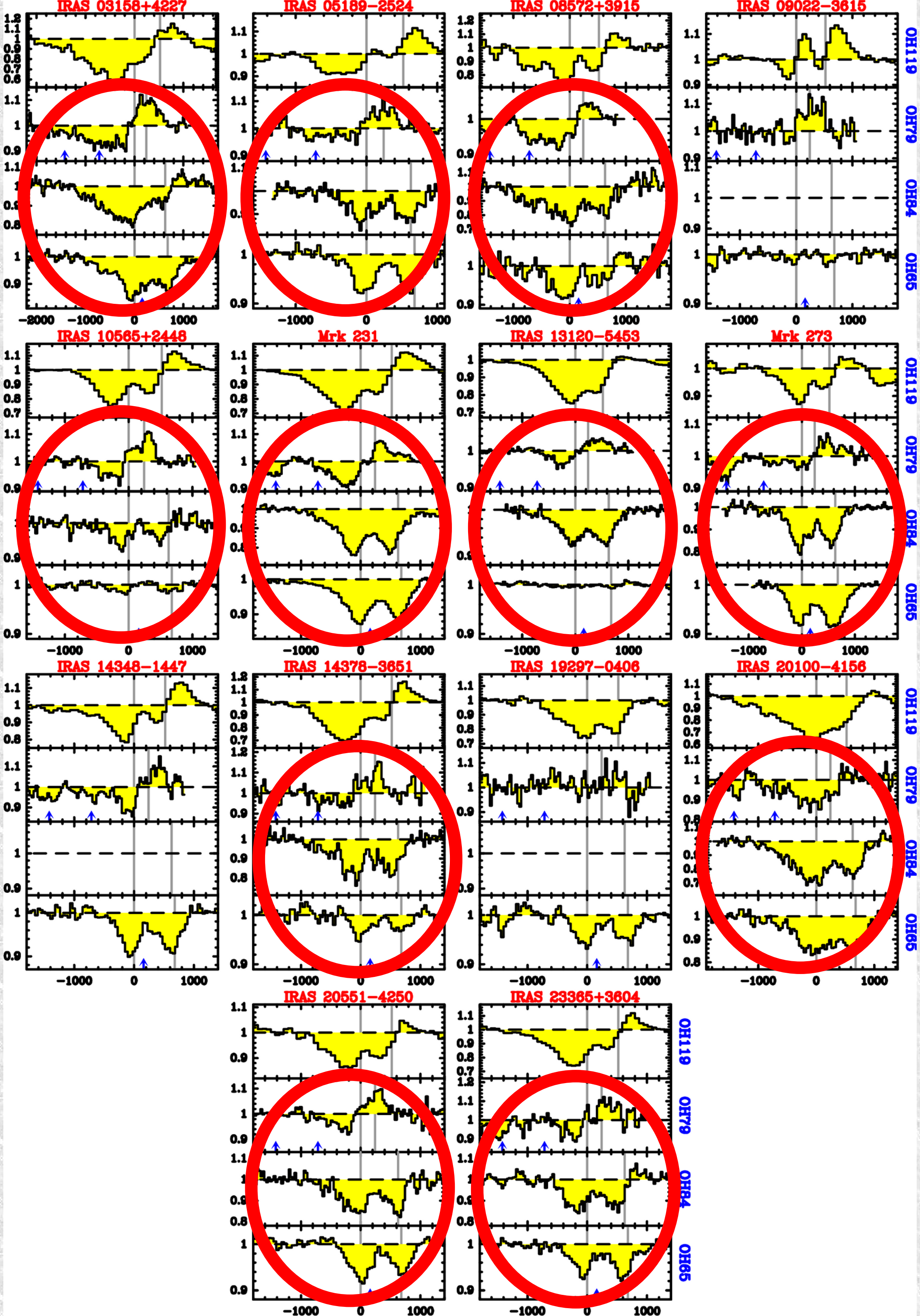
Comparison with CO

Lutz et al 2020, A&A, 633, A134



Potential Problem: with PRIMA, OH119 will not be available at z>1

We have to deal with OH79, OH84, and OH65: how will be affected the outflow energetics?

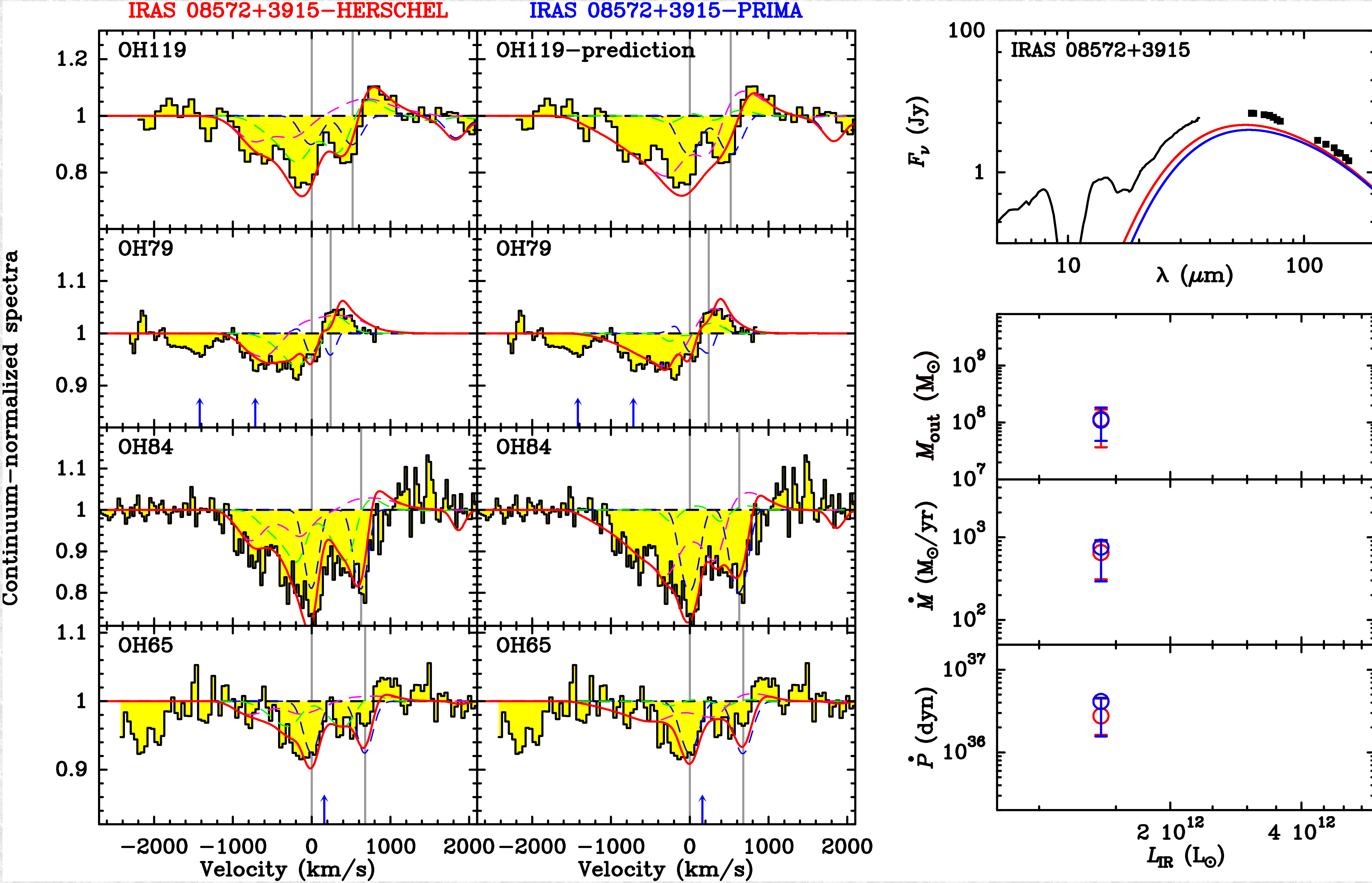


I have used the same model grid as with Herschel data to fit the OH profiles in all 11 sources where OH79, OH84, and OH65 are available, using only these 3 doublets (i.e. disregarding OH119): PRIMA-fits.

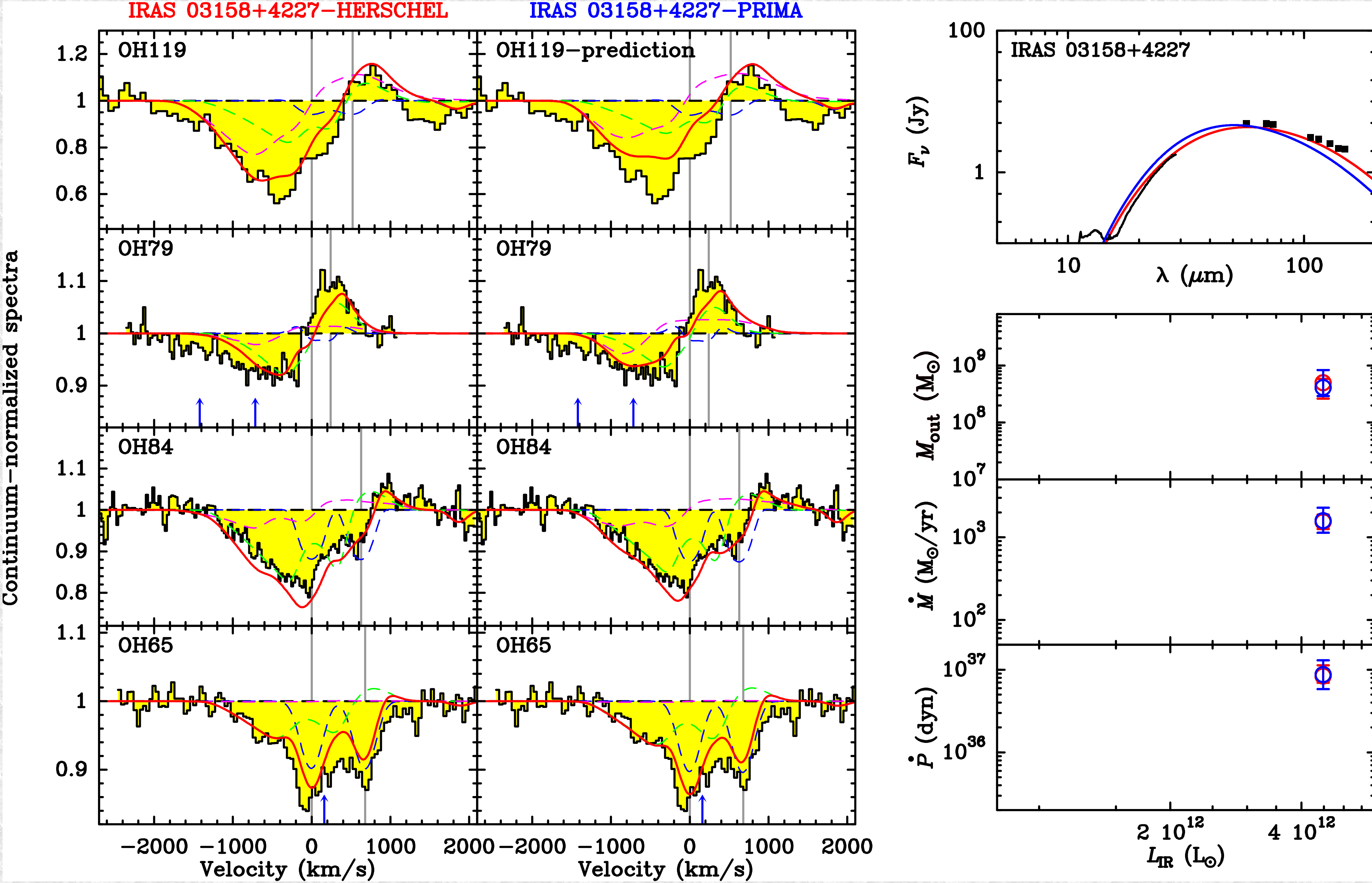
Energetics are obtained from these new PRIMA-fits, and compared with the energetics that are obtained using the 4 doublets (Herschel-fits).

One additional constraint for PRIMA-fits: the sum of the covering factors of all components cannot exceed 1 for any transition.

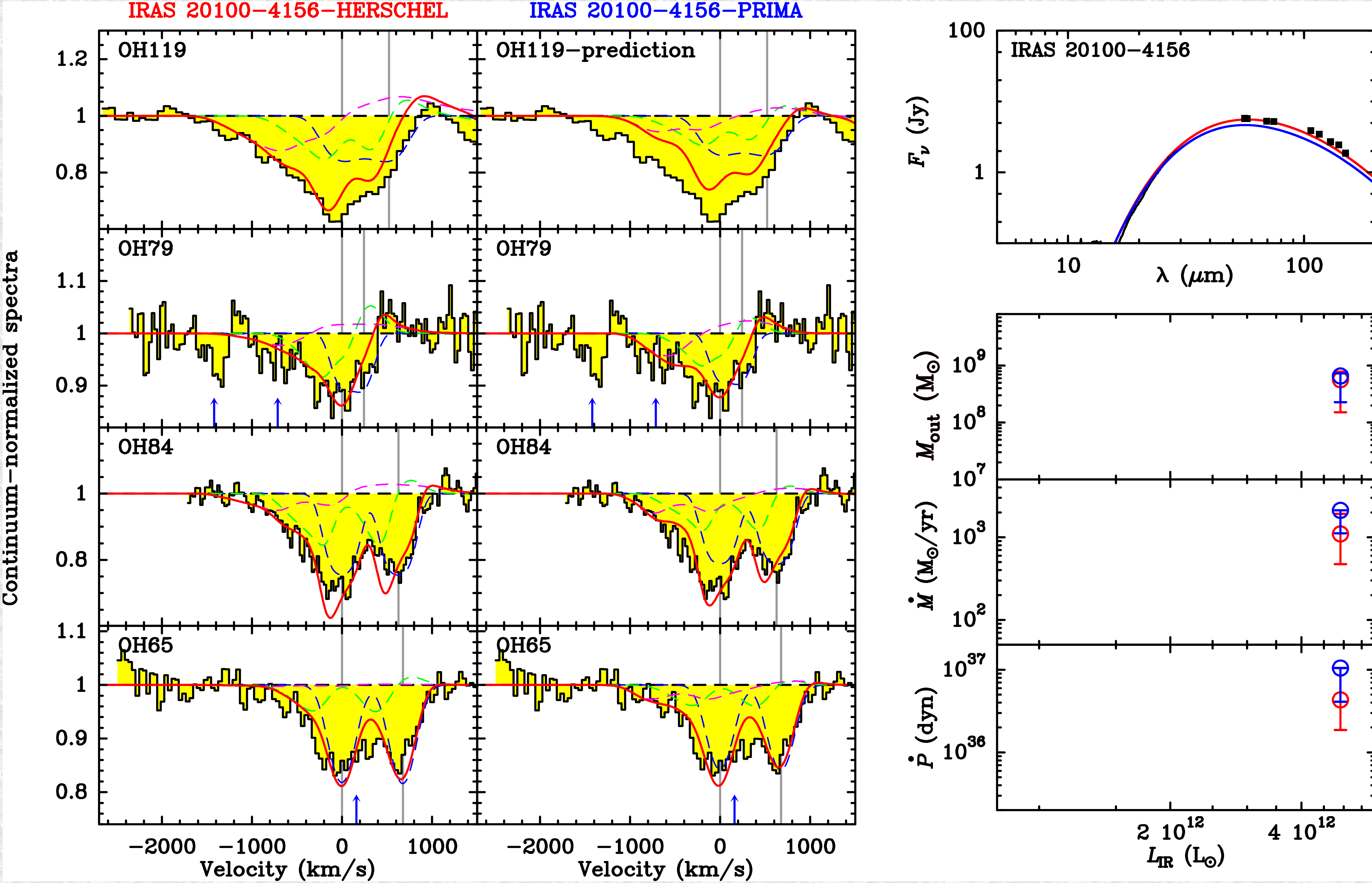
IRAS 08572+3915: comparison



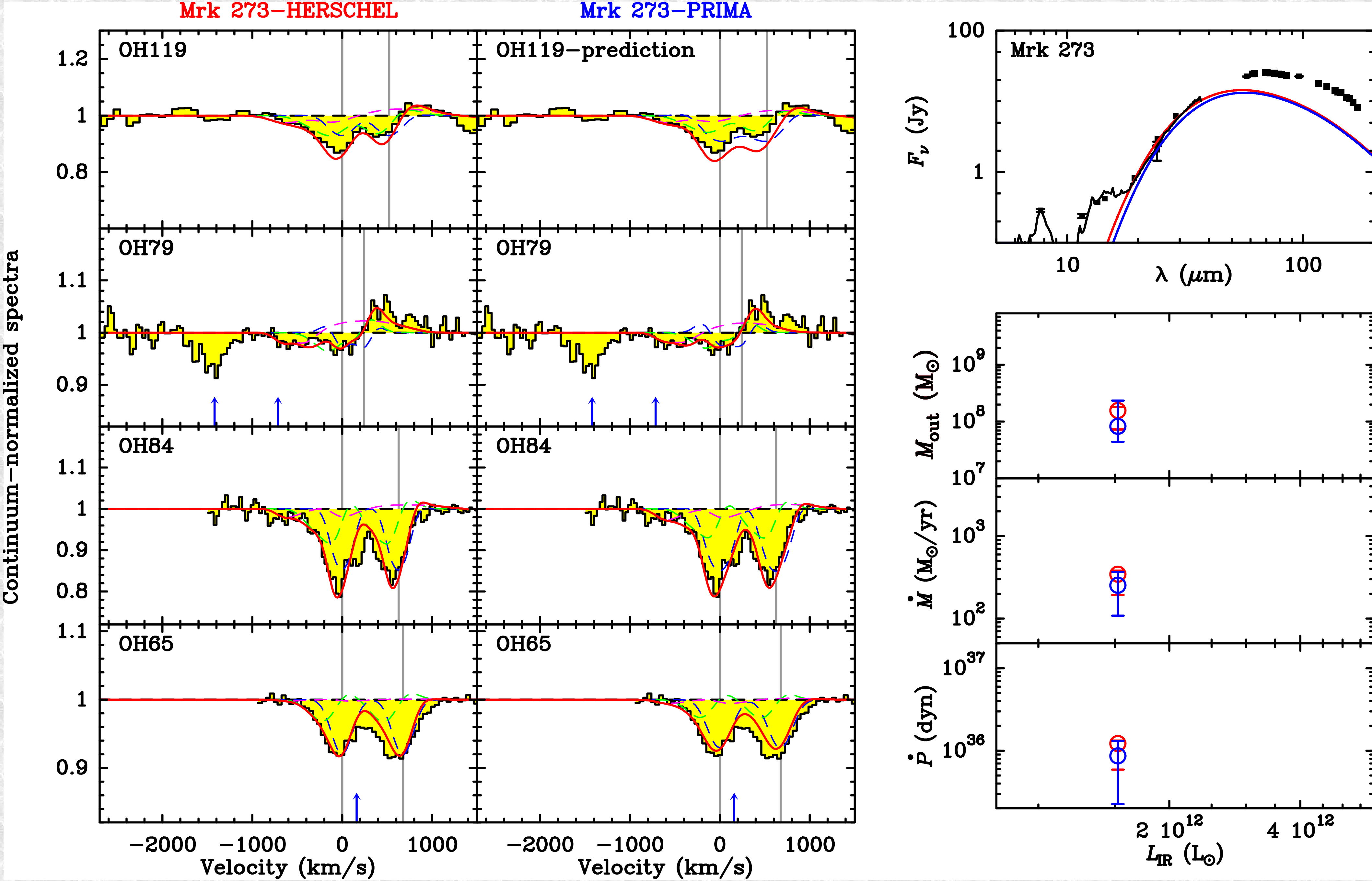
IRAS 03158+4227: comparison



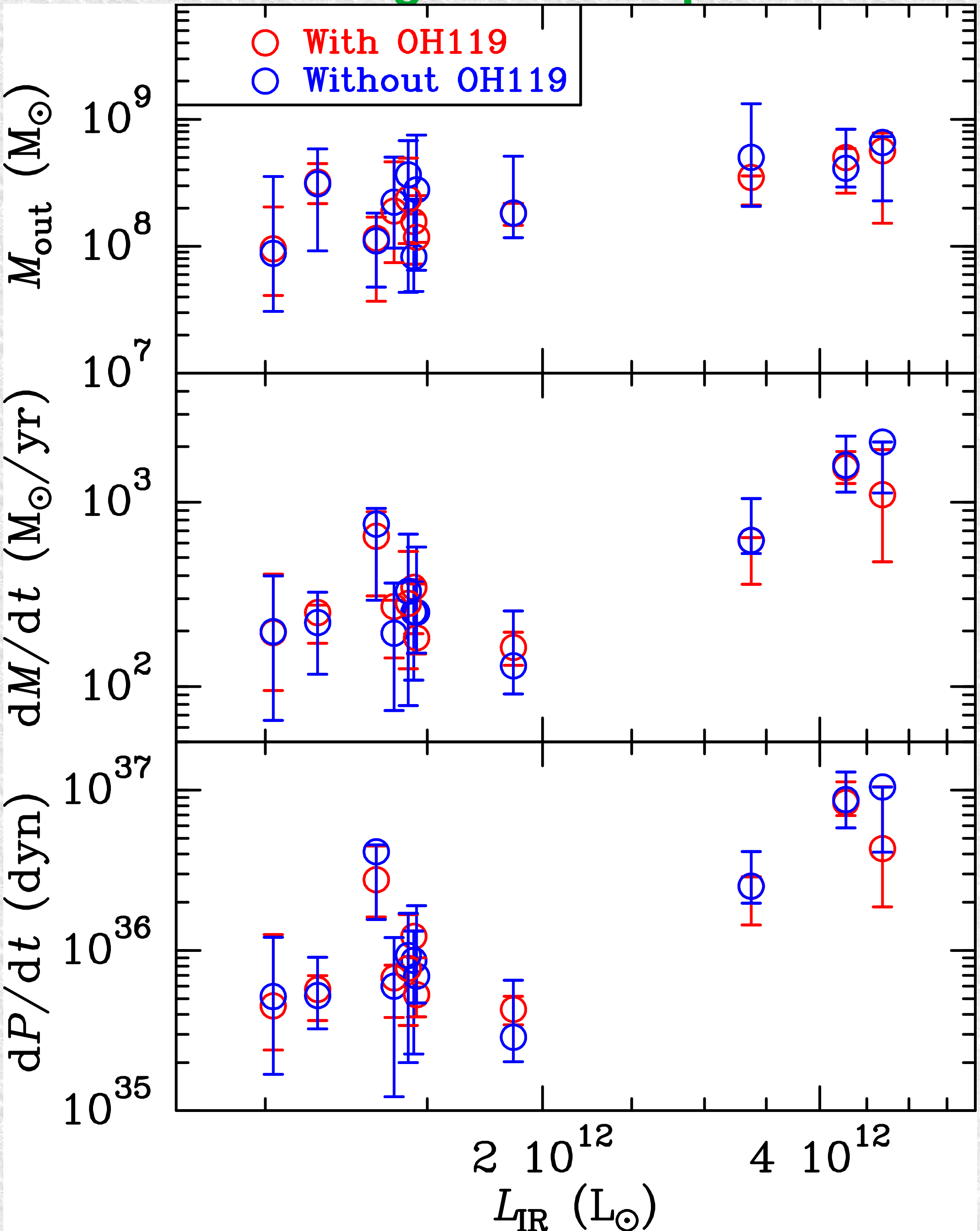
IRAS 20100-4156: comparison



Mrk 273: comparison



Energetics: comparison



Herschel-fits

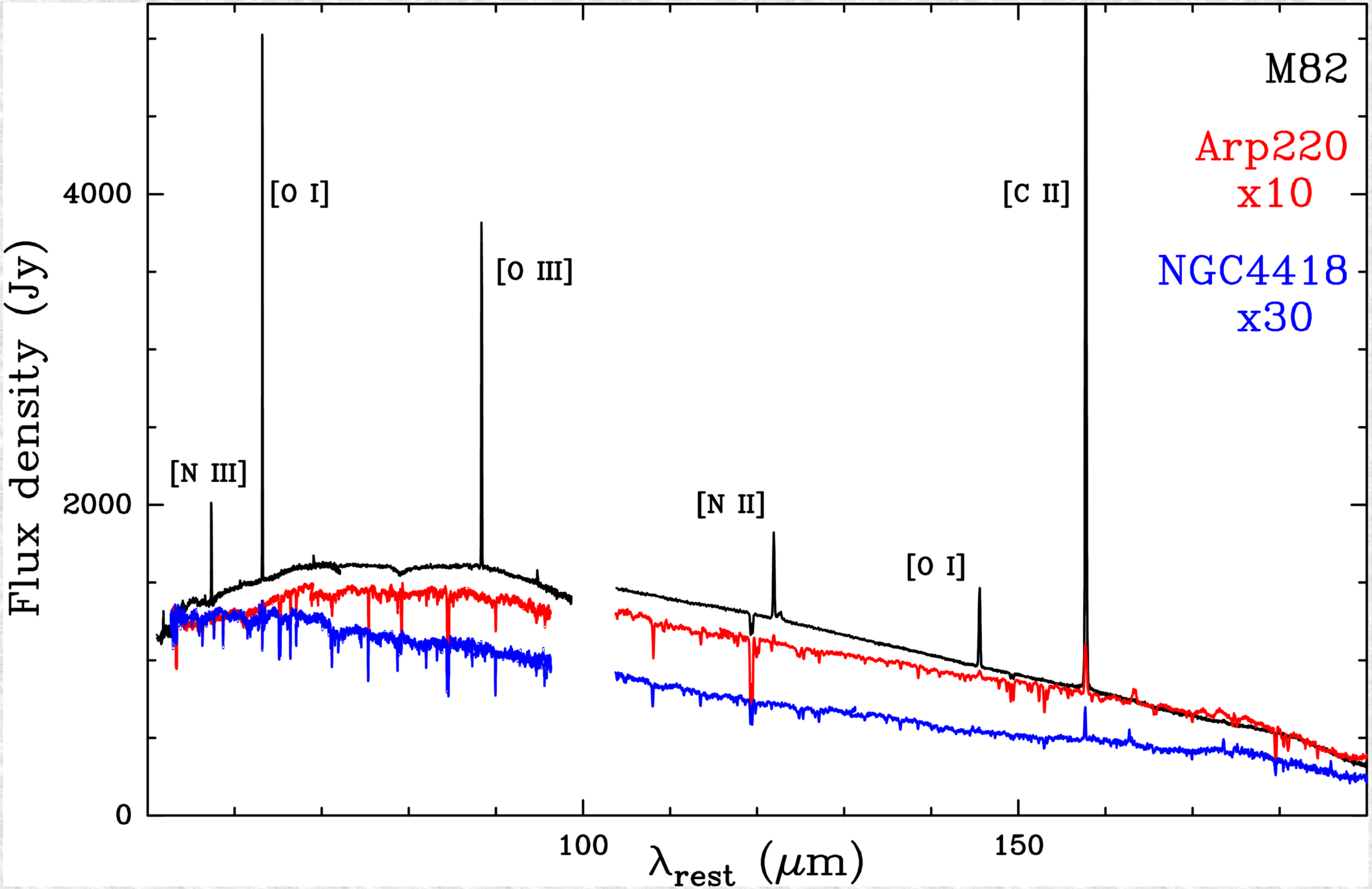
PRIMA-fits

Part II: Buried Galactic Nuclei at (Nearly) Cosmic Noon

Introduction

ABSTRACTION LINES: Herschel/PACS

LOCAL (U)LIRGs with high far-IR radiation densities have far-IR spectra (50-200 μm) dominated by absorption in molecular lines

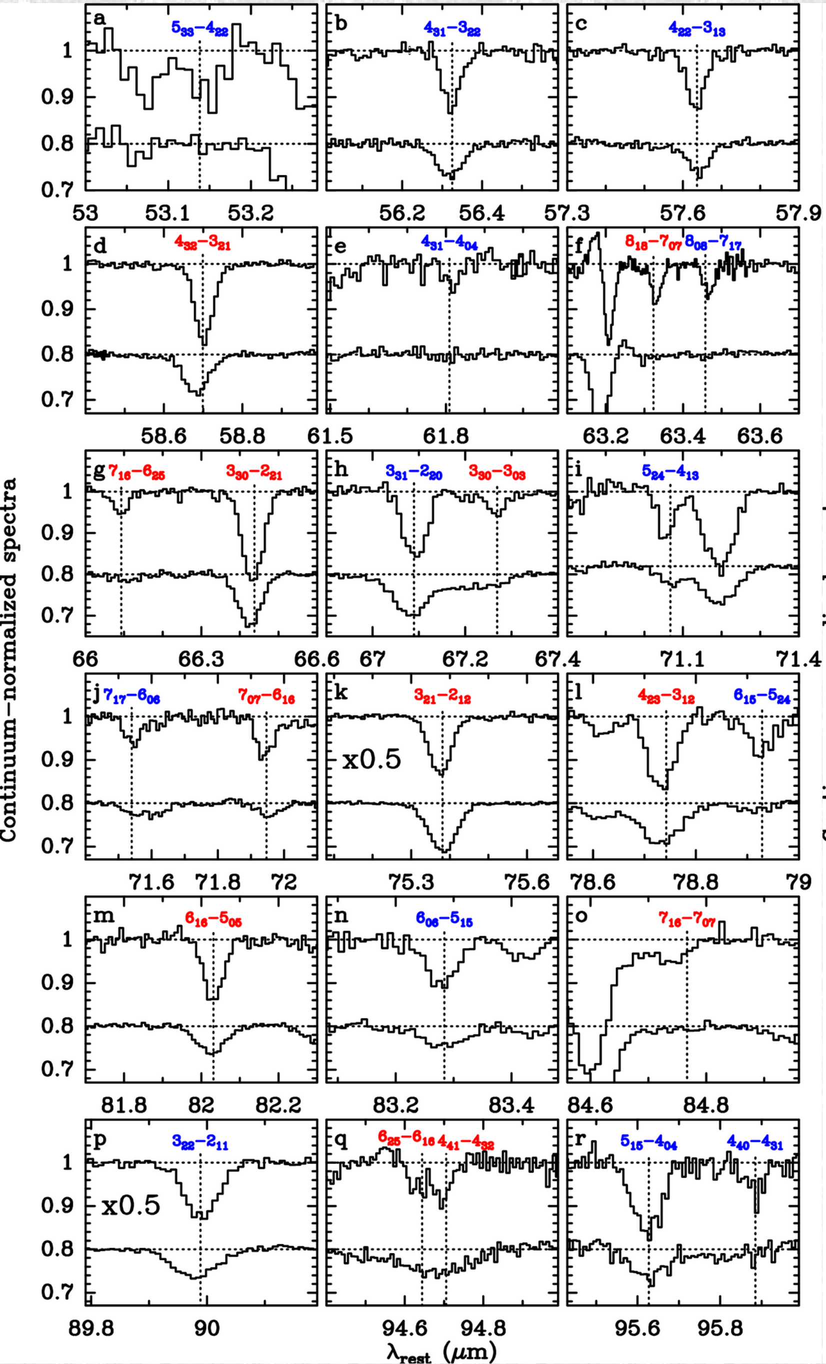


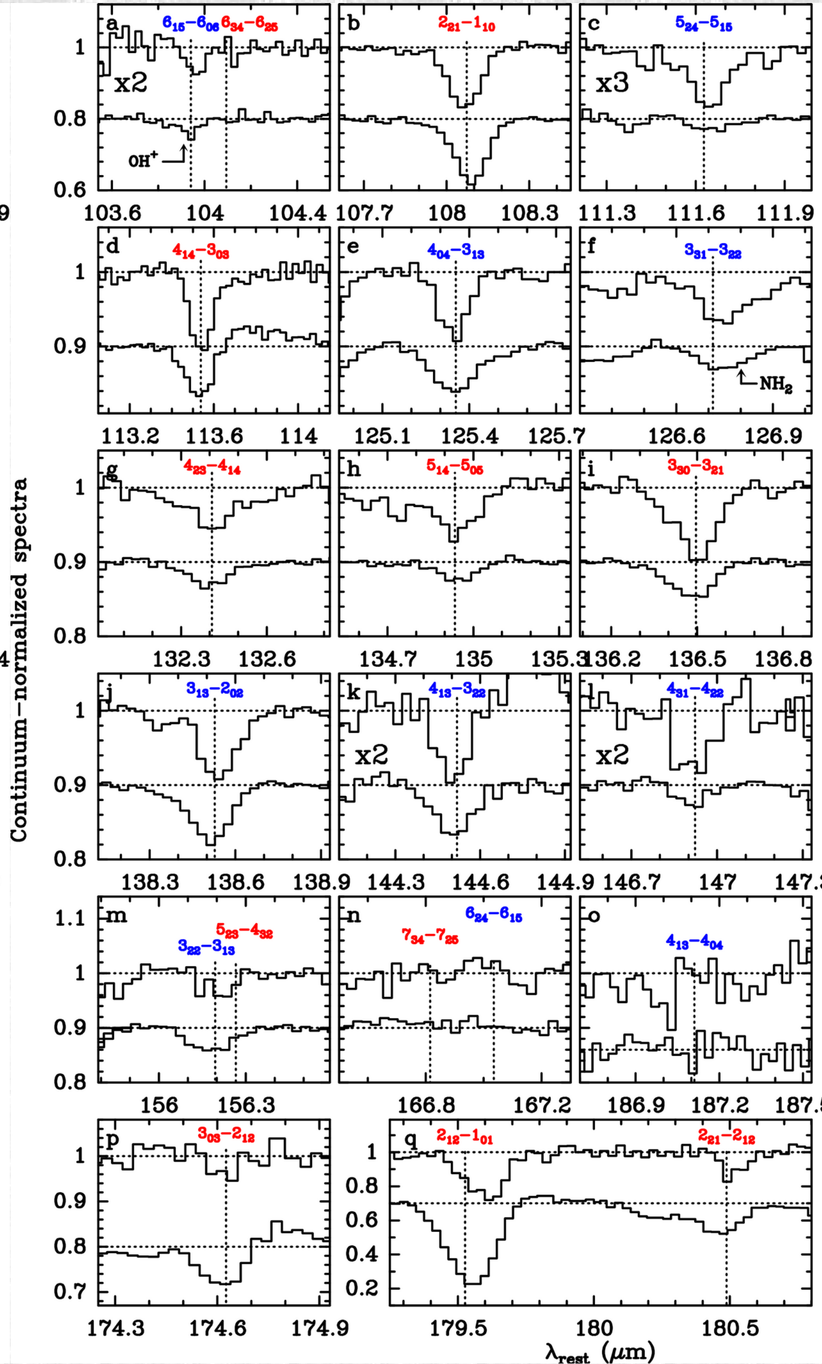
Mostly light hydrides: H2O, OH, NH, NH2, NH3, HF, H2S, CH, CH+, OH+, H2O+, H3O+

ABSORPTION LINES

H_2O lines in NGC 4418 & Arp 220 (GA+12, A&A, 541, A4)

Upper spectra:NGC 4418
Lower spectra: Arp 220

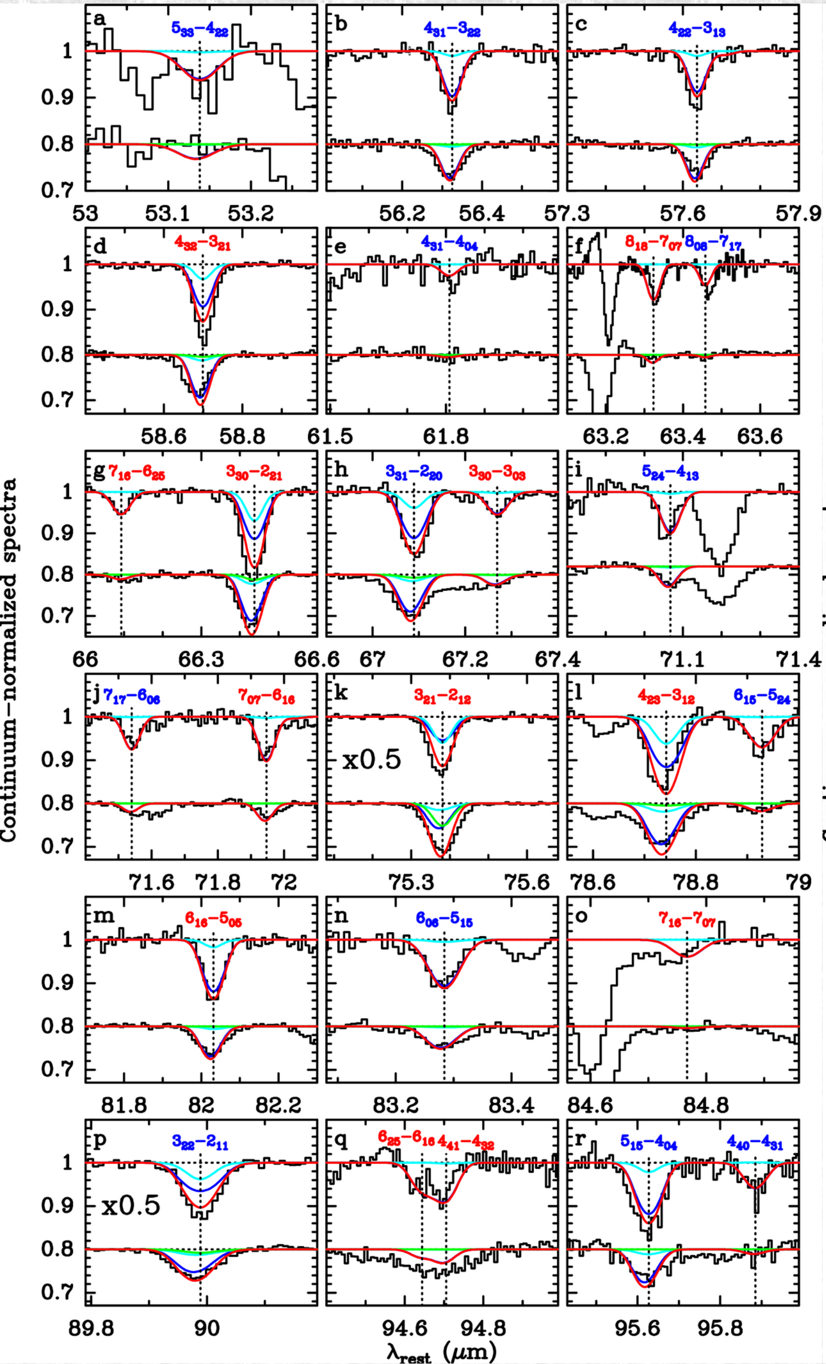


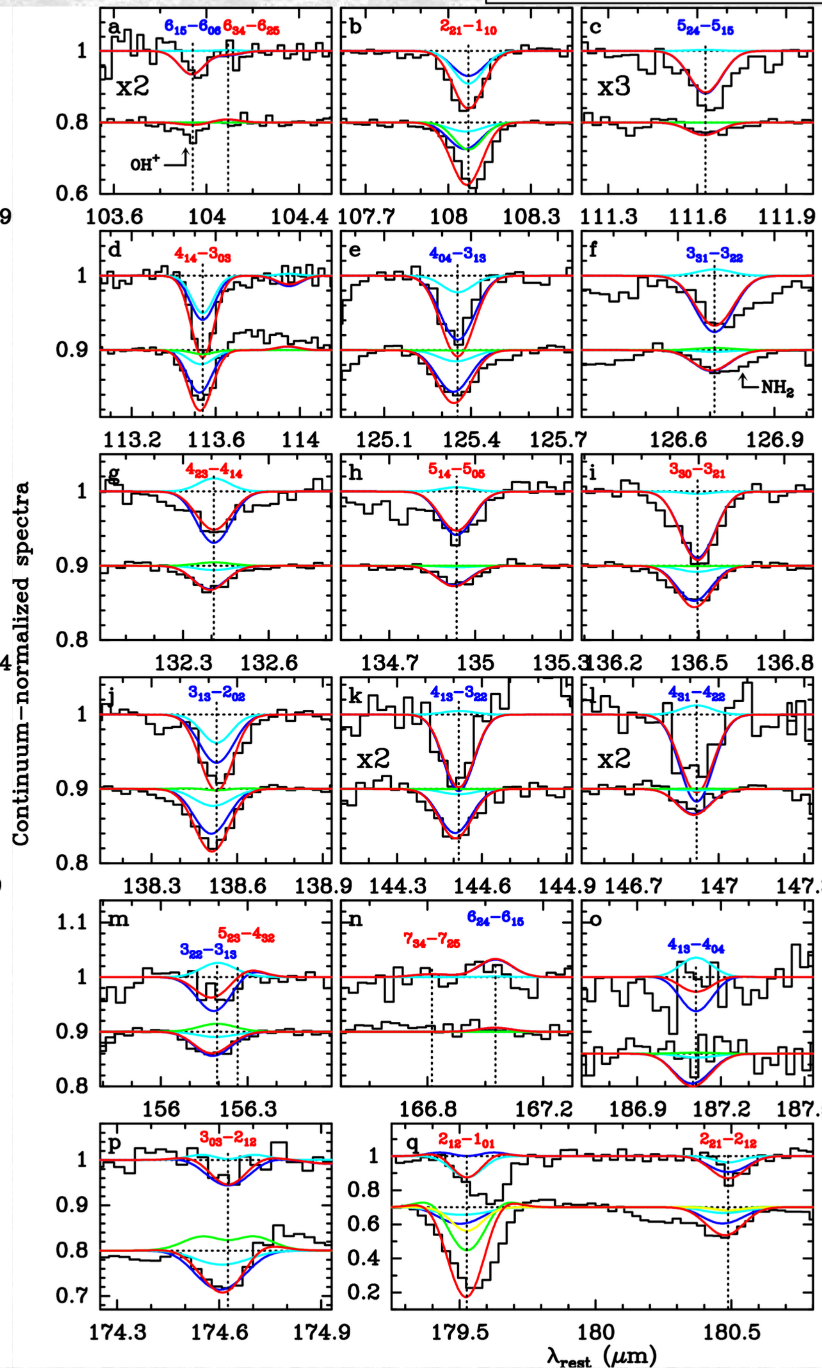


Red: ortho
Blue: para

A forest of absorption H_2O lines (GA+12)

Nuclear (warm *T*dust)
Nuclear (moderate *T*dust)
Extended region
Total





Red: ortho
Blue: para

Nuclear regions:

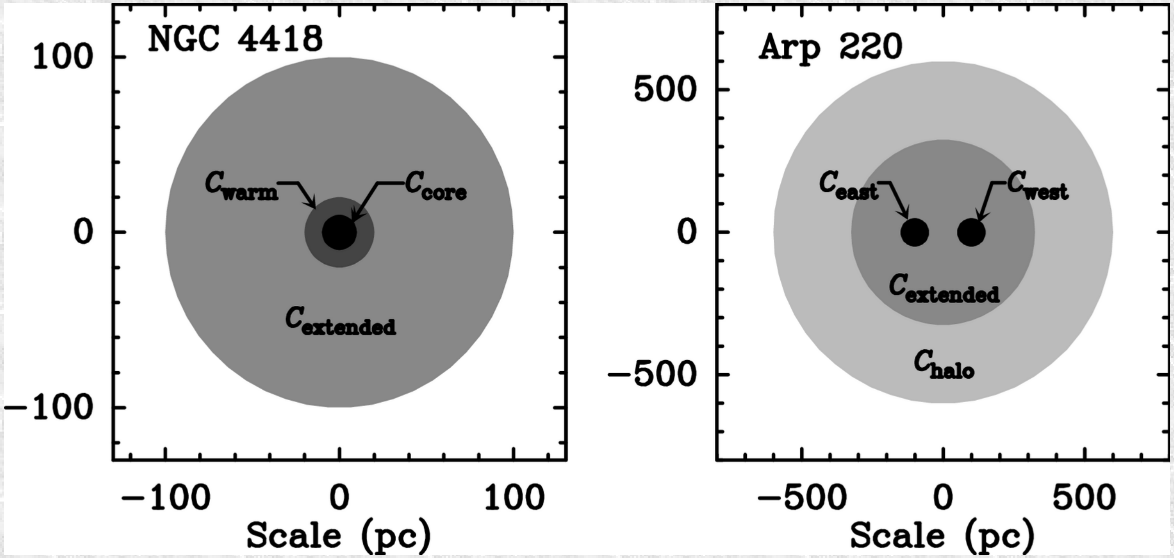
NGC 4418:
Tdust~130-150 K
$N(H_2O)/\tau_{50}$~ $(2\text{-}6)\times10^{18}$ cm^{-2}

Arp 220:
Tdust~90-110 K
$N(H_2O)/\tau_{50}$~ $(0.8\text{-}6)\times10^{18}$ cm^{-2}

mantle-free dust grains

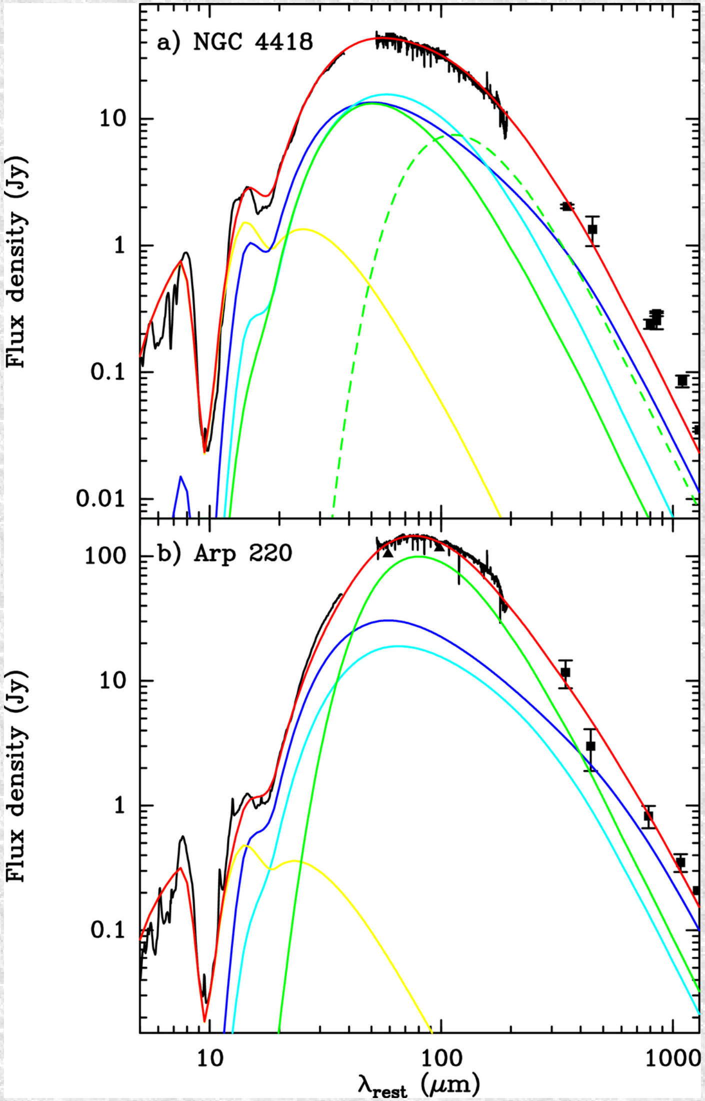
or "undepleted chemistry"

H_2O emission/absorption probes the source structure (GA+12)



**The optically thick and compact nuclei are responsible for the high-lying H2O absorption lines.*
**The more optically thin, more extended Cextended dominate the emission in the submm H2O emission lines*

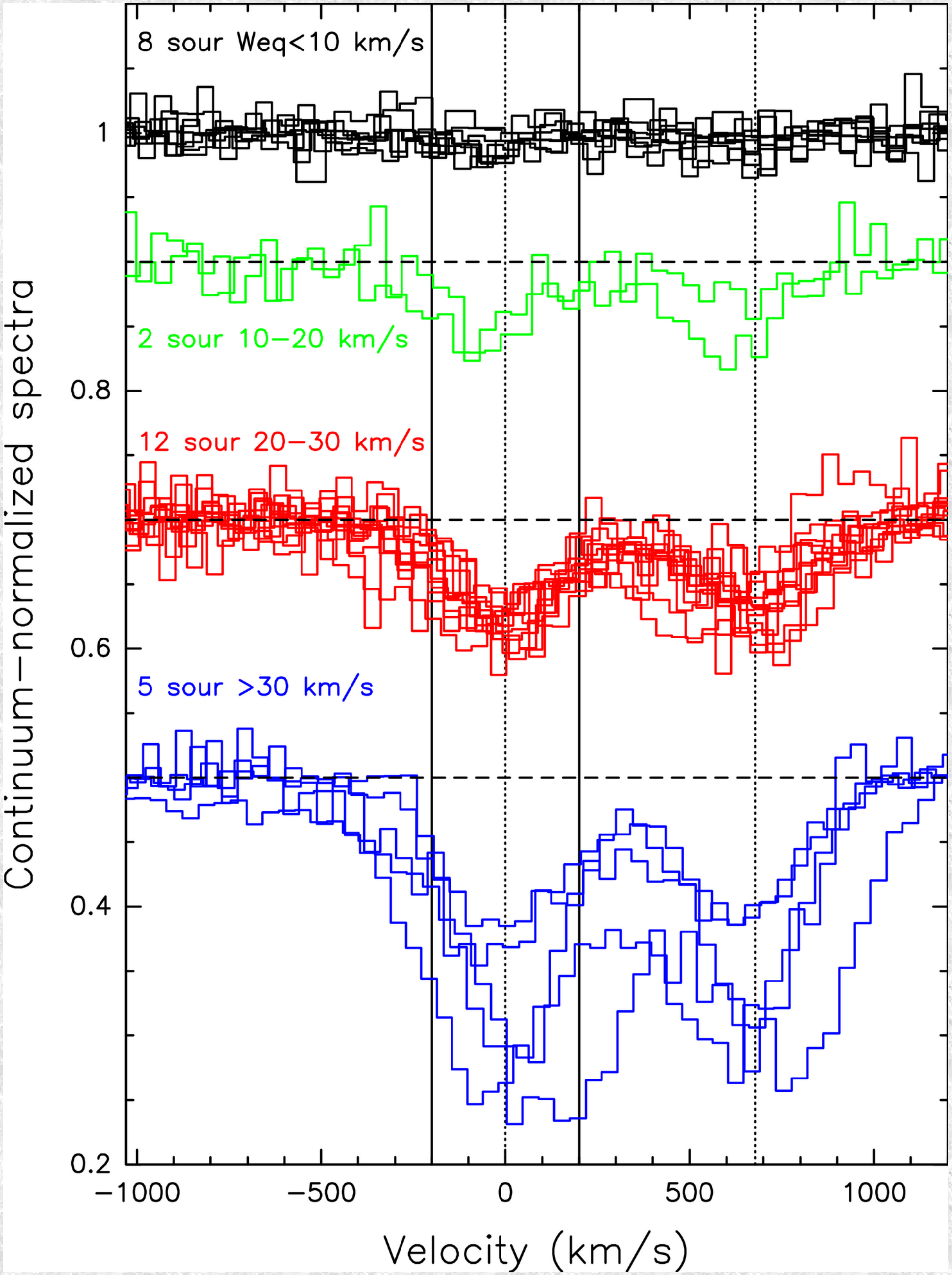
The far-IR continuum



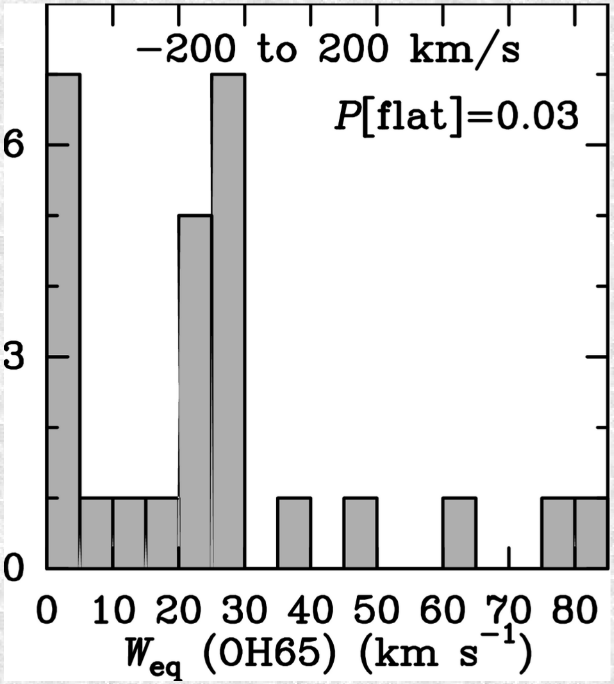
The nuclear and extended regions may have different SEDs

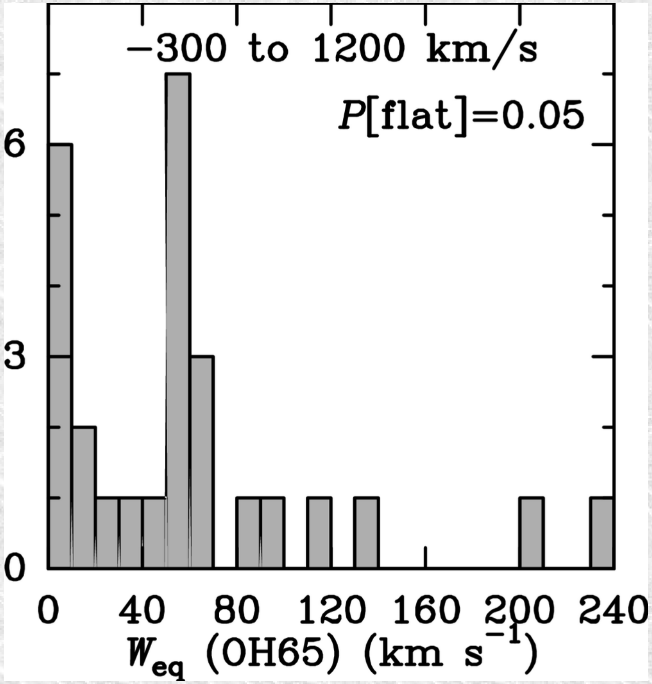
We understand better the SEDs… from the lines

THE OH 65μm *HERSCHEL*/PACS SPECTRA



Bimodality in OH65

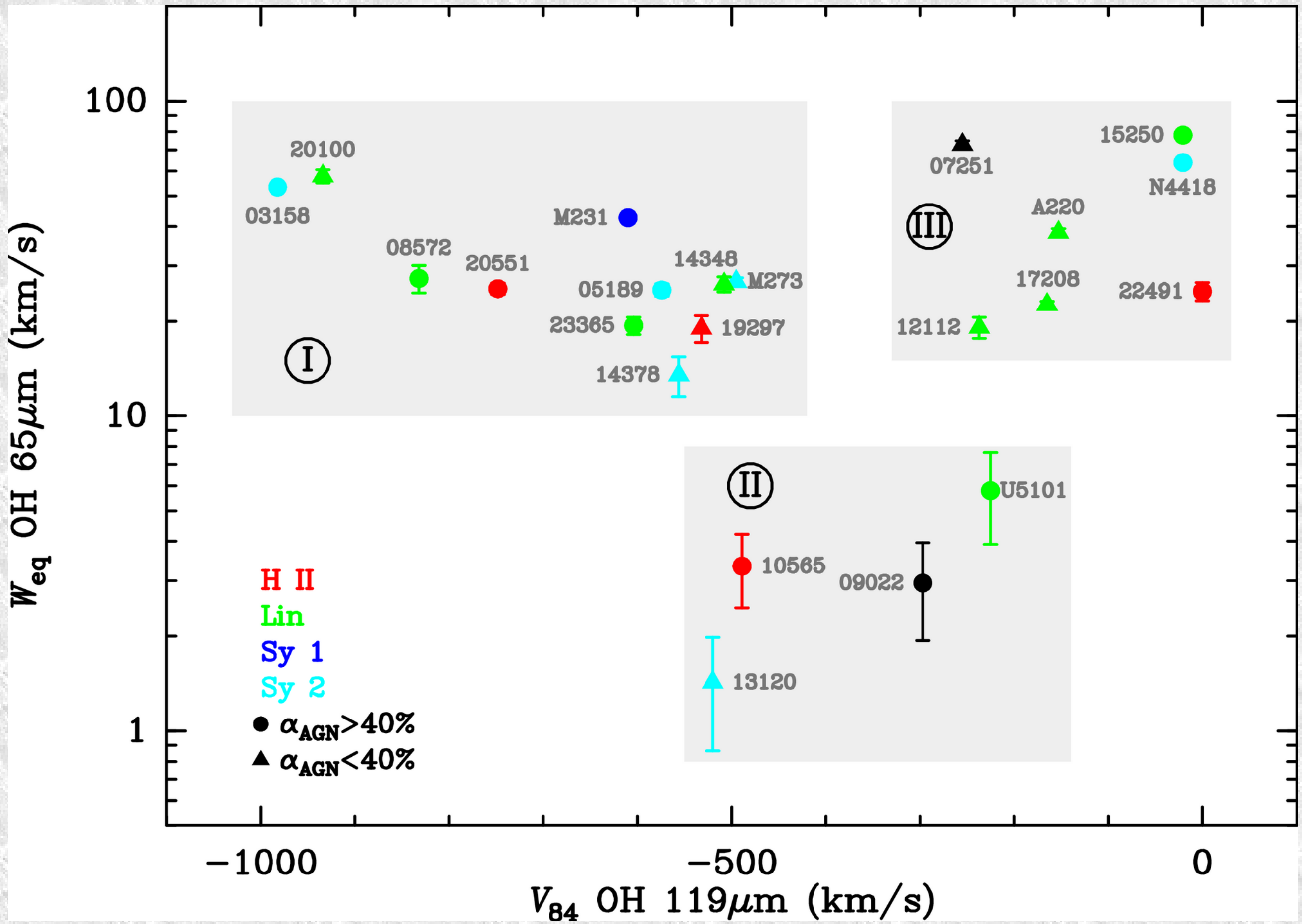




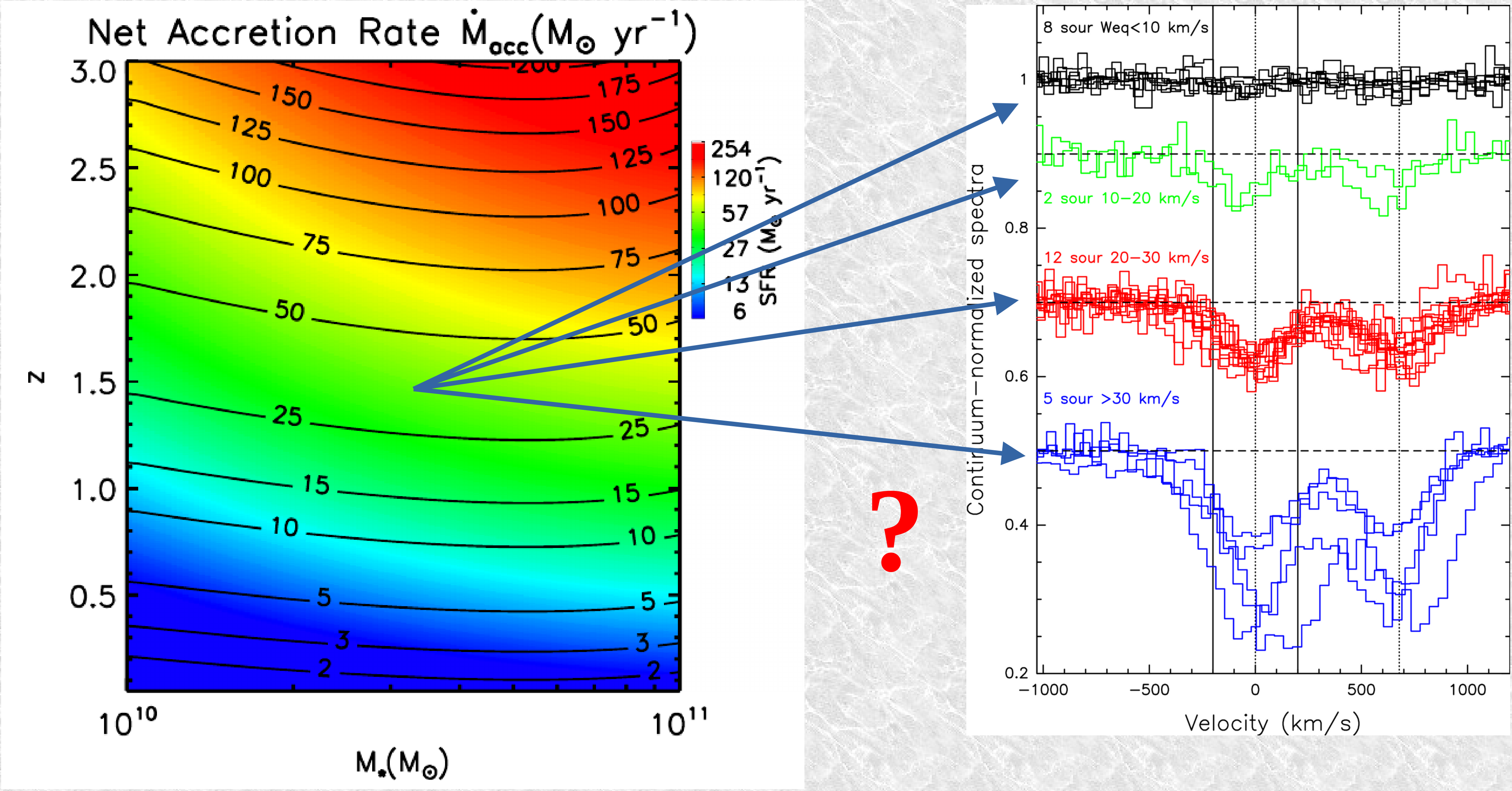
(GA+15, ApJ, 800, 69)

CONNECTING THE OH 65μm ABSORPTION WITH THE OUTFLOWS

Highest outflowing velocities are found in buried sources
(the opposite is not true)



At redshift ~1.5, the SFR of galaxies ≳MS is ≳30 M⊙/yr, and is probably maintained by accretion of intergalactic gas, which drives galaxy evolution (Scoville et al. 2017, ApJ, 837, 150)

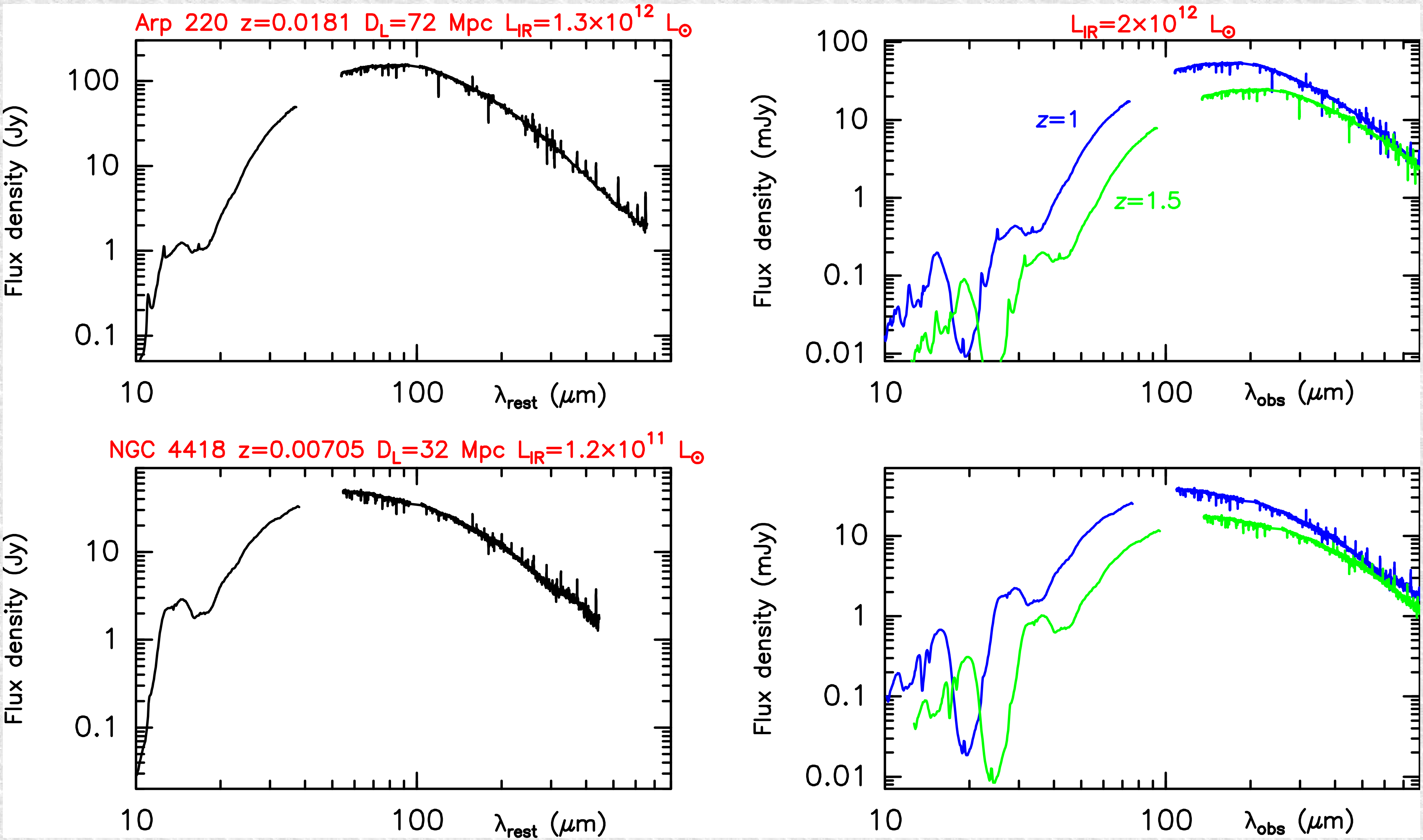


How is this gas accreted? How does it fall onto the galaxies?
Is it forming spatially extended structures (disks) with low Σ_{SFR}? (no excited absorption)
Or is (part of) it falling towards the galaxy nucleus? (with excited absorption)
Do galaxies at (nearly) cosmic noon have local-(U)LIRG structure?

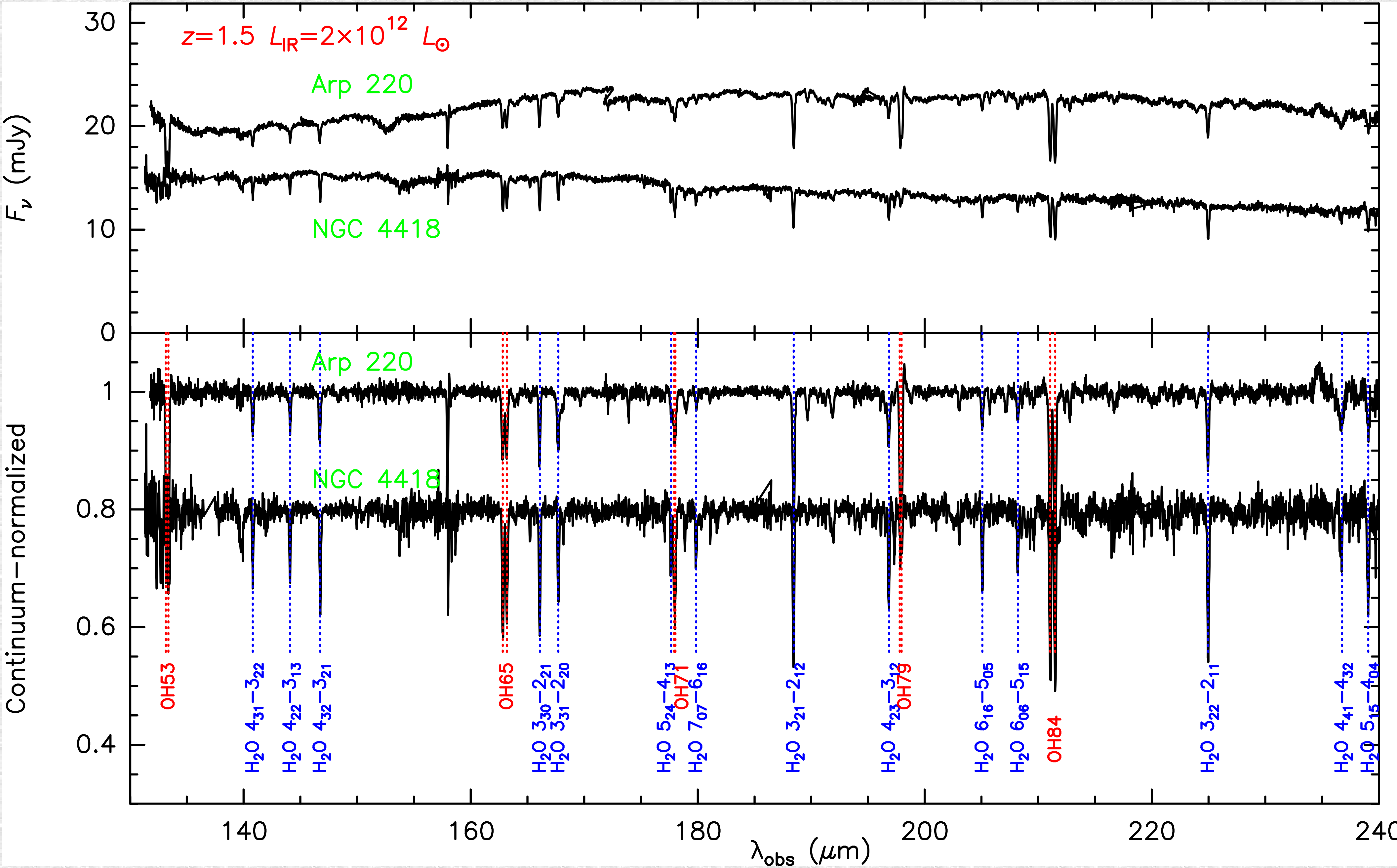
ABSORPTION LINES: Probing chemistry, excitation, ionization, columns, compactness, SED, structure, radiation field, and kinematics.

Buried Galactic Nuclei: can we detect them, if they are present, at (Nearly) Cosmic Noon?

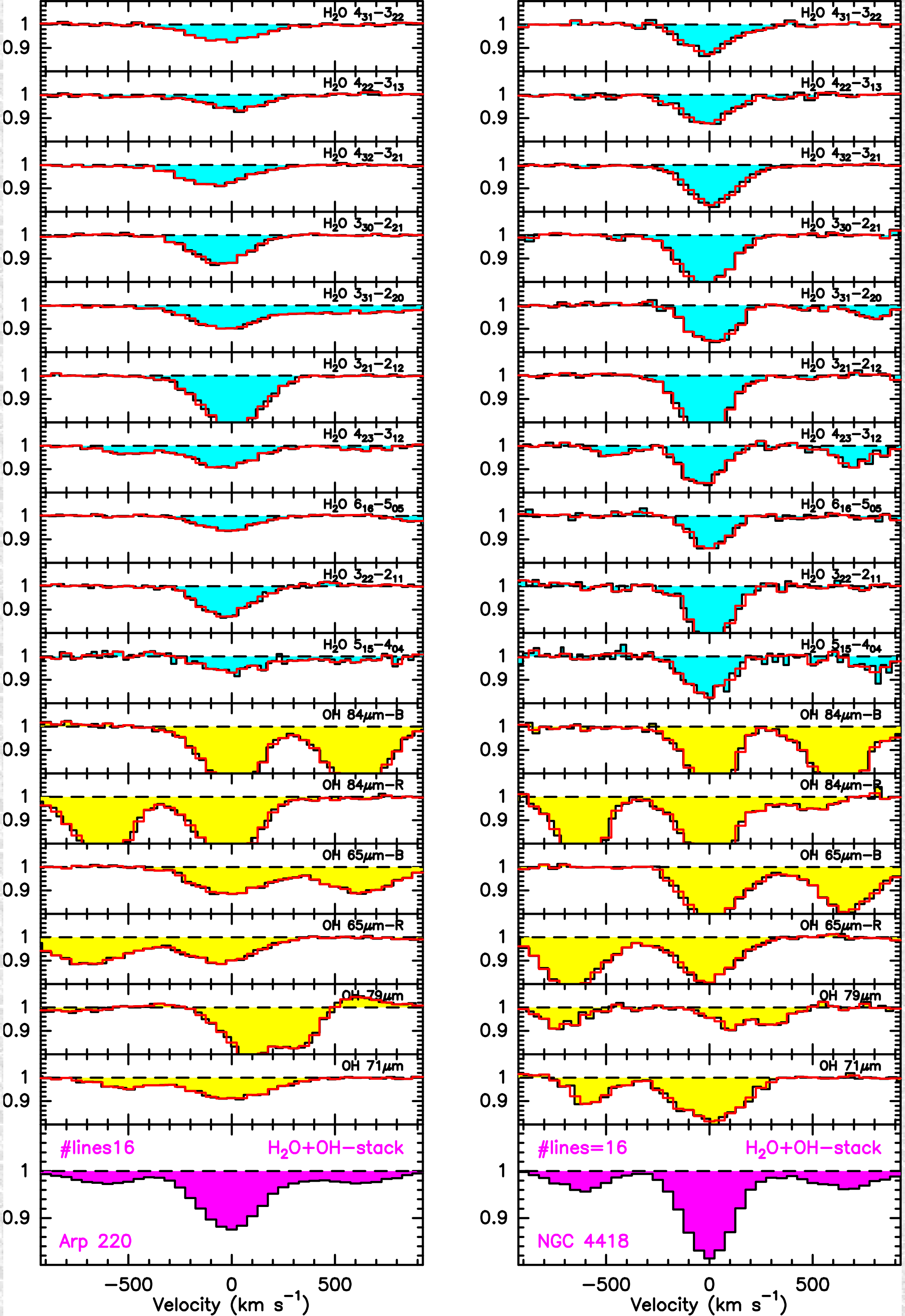
Scaling Arp 220 and NGC 4418 @ z=1-1.5 & $L_{IR}=2\times10^{12}\ L_\odot$



Identifying the strongest lines



Stacking Lines to improve SNR



We can expect a peak absorption of 12-18% of the continuum for Arp220 & NGC 4418 with N_{lines} = 16

EW=44-54 km/s for the stacked line [-300,300] km/s

Estimating observing time for 1 source @ z=1-2 with $L_{IR}=2\times10^{12}\ L_\odot$

FIRESS low-res point source ETC, for N_{lines}=16

z	F_{mJy}	F_{SL} (W/m^2)	t_{ETC} (h)	t_{ETC}/N_{lines} (h)
1.0	40	1.05×10^{-19}	3.27	**0.20**
1.5	20	5.26×10^{-20}	13.05	**0.82**
1.7	14	3.68×10^{-20}	26.66	**1.67**
2.0	8	2.11×10^{-20}	81.09	**5.07**

The flux of the stacked line is

$$F_{SL}=10^{-20}\lambda_{\mu m}^{-1}F_{mJy}EW_{km\,s^{-1}}W/m^2$$

where

$$\lambda_{\mu m}\sim190$$

$$EW_{km\,s^{-1}}\sim50$$

Spectral stacking can be combined with source stacking @ *z*=1.5-2.0 to approach as much as possible the MS.

Conclusions

* **Outflow energetics will be reliably estimated from OH doublets @ 79, 84, and 65 μm**

* **Buried galactic nuclei in galaxies at z$\lesssim$1.5 and L_{IR}~2×10^{12} $L_\odot$ might be spectroscopically identified from spectral stacking and FIRESS low-resolution in $\lesssim$1 hour.**
Source stacking is worth considering for z~1.5-2.

Thank you.