Fast Molecular Outflows in Luminous Galaxy Mergers: Evidence for Quasar Feedback from Herschel*

(*) Powerful Molecular Outflows in ULIRGs: Evidence for a Luminosity Threshold above which Quasar Feedback Becomes Dominant

Marcio Melendez

The landmark lighthouse in Noordwijk

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Outline

- Early results from the *SHINING* survey
- New results from the *extended SHINING* survey
- Multi-phase comparisons
- Summary & open issues

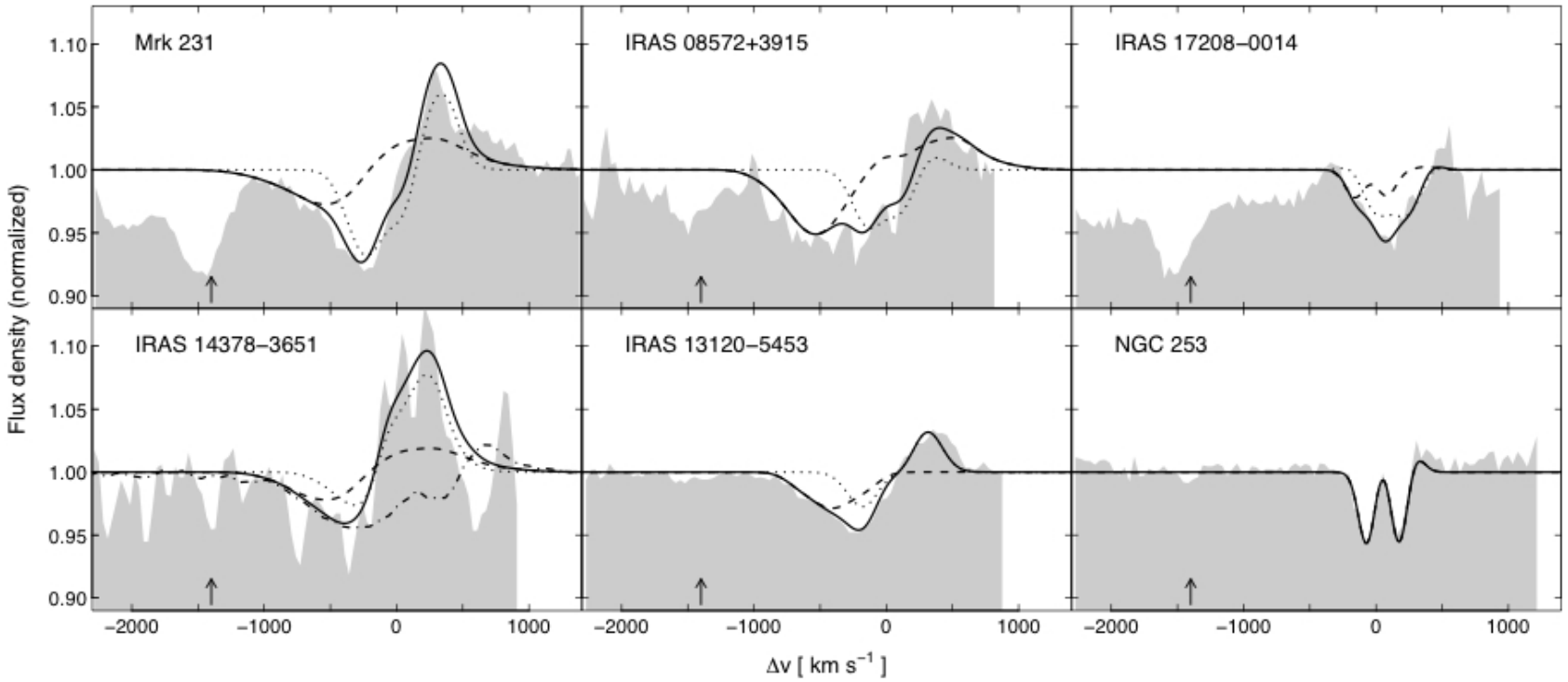
Extended SHINING Sample

- **Original *SHINING* spectroscopy sample** [PI Sturm]
  - ~10 starburst galaxies from *IRAS* Revised Bright Galaxy Sample
  - ~10 Seyfert 1s and ~10 Seyfert 2s
  - ~5 "elusive" highly obscured galaxies
  - ~30 low-metallicity galaxies
  - ~23 local ULIRGs at $z < 0.5$
  - ~5 ULIRGs at $z \sim 1$
- ***QUEST* OT1 Extension (OH 119 μm only)** [PI Veilleux]
  - 15 additional quasar-dominated ULIRGs at $z < 0.3$
- ***QUEST* OT2 Extension (OH 119 μm only)** [PI Veilleux]
  - 5 additional infrared-faint PG QSOs at $z < 0.3$
  - (All 56 BAT AGN within 50 Mpc)

Early Results: Massive Molecular Outflows in ULIRGs

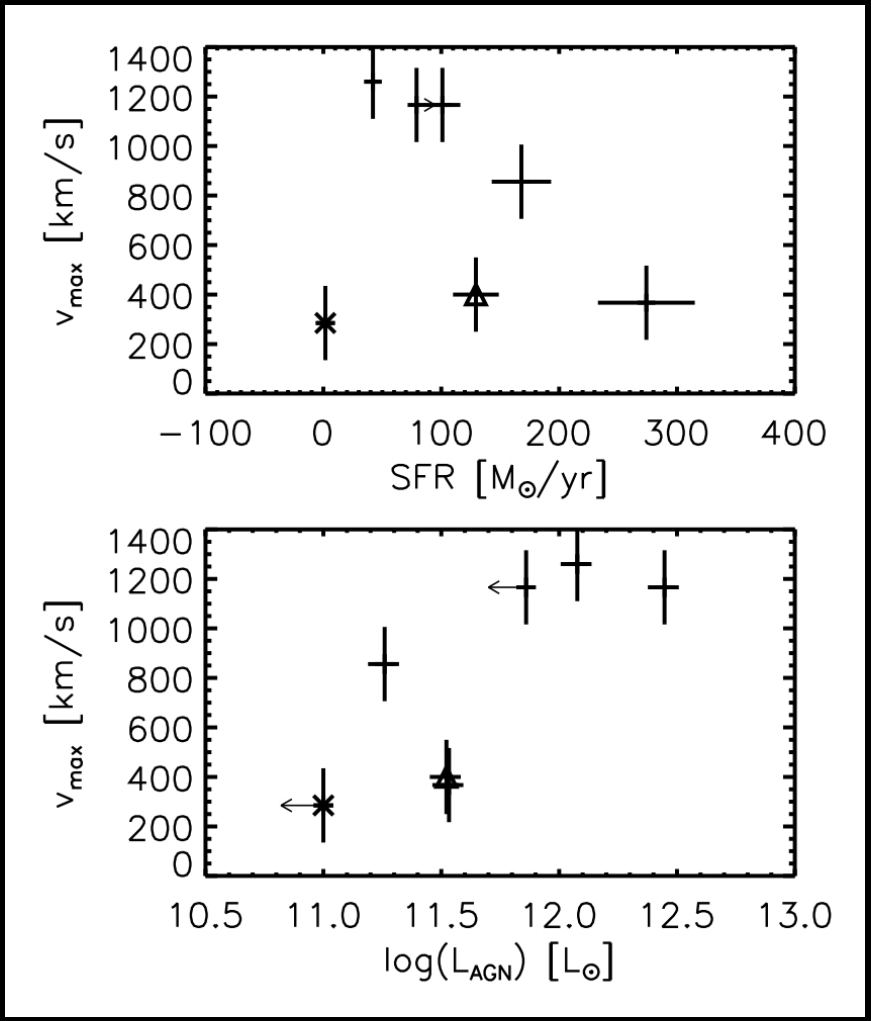
(Fischer et al. 2010; Sturm, Gonzalez-Alfonso, Veilleux, Fischer, et al. 2011)

Herschel/PACS spectra of OH 79 / 119 µm transitions: P-Cygni Profiles



Molecular Wind Kinematics: AGN Driven?

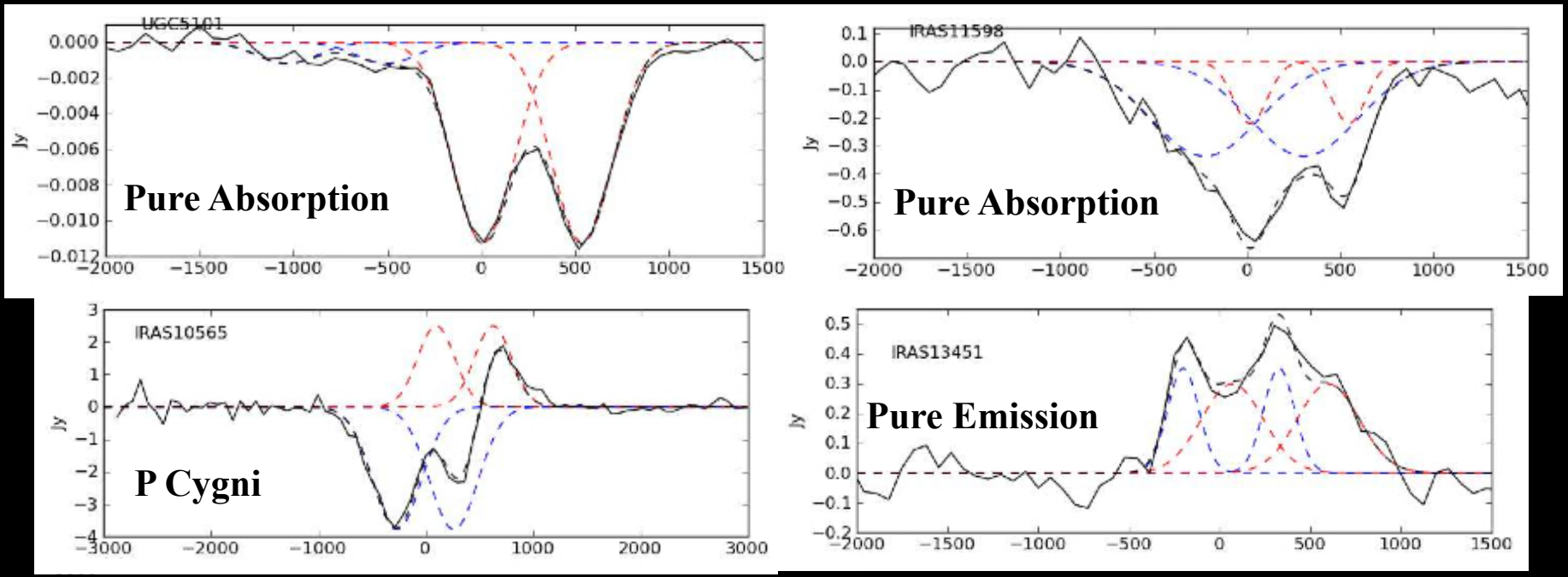
(Sturm, Gonzalez-Alfonso, Veilleux, Fischer, et al. 2011)



New Results: OH 119 µm Profiles

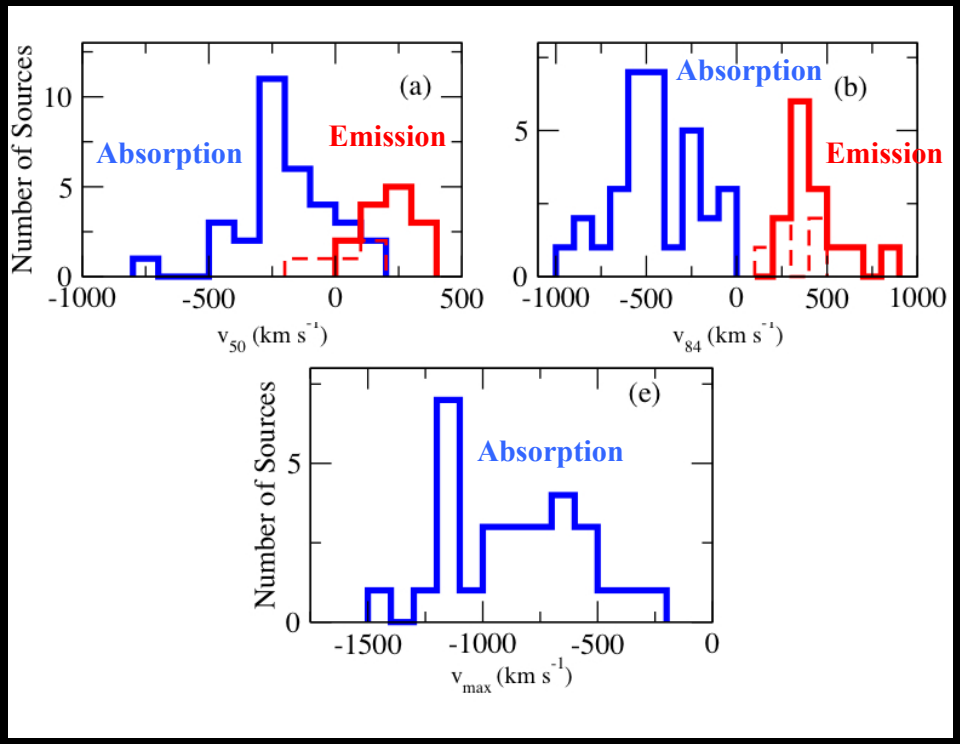
(Veilleux, Meléndez, et al. 2013)

- **A sample of 43 nearby (z < 0.3) mostly ULIRGs and QSOs.**
- **OH 119 µm feature is in emission in objects with AGN fraction above ~90%**
  (a similar trend has been seen by *Teng, SV, & Baker 2013* in GBT H I 21-cm feature)
- **OH 119 µm absorption / emission → 9.7 um silicate absorption / emission**



New Results: Kinematics (OH 119 µm)

(SV, Meléndez, et al. 2013)



- **Outflow velocities**
  - $\langle v_{50} \rangle$ (abs) ~ 200 km s^{-1}
  - $\langle v_{84} \rangle$ (abs) ~ 500 km s^{-1}
  - $\langle v_{max} \rangle$ (abs) ~ 925 km s^{-1}
- **Similar to neutral gas (Na I abs)**

(Heckman 2000; Rupke, SV, & Sanders 2002, 2005abc; Martin 2005; Rupke & SV 2011, 2013a)

New Results: OH Equivalent Widths

(SV, Meléndez, et al. 2013)

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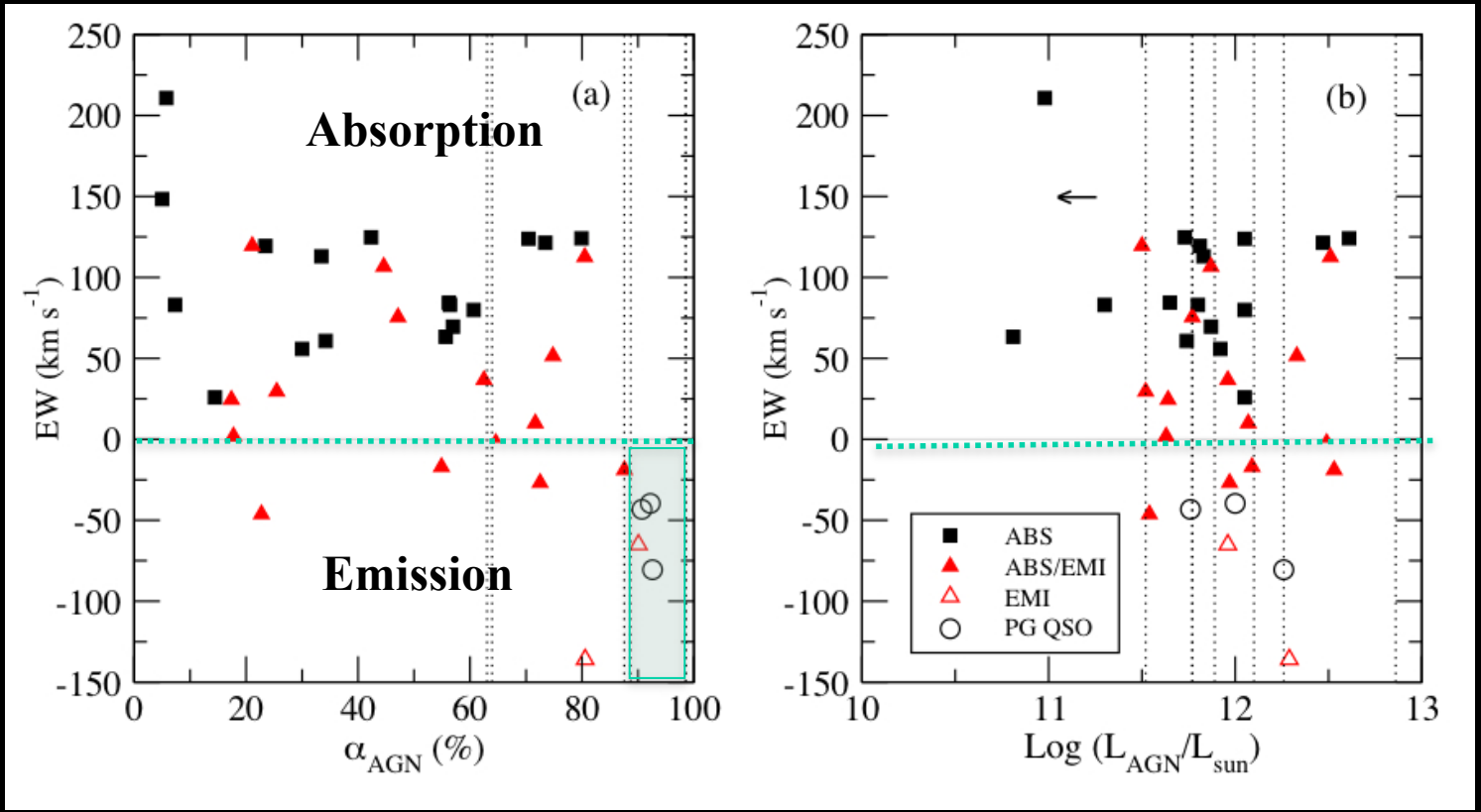

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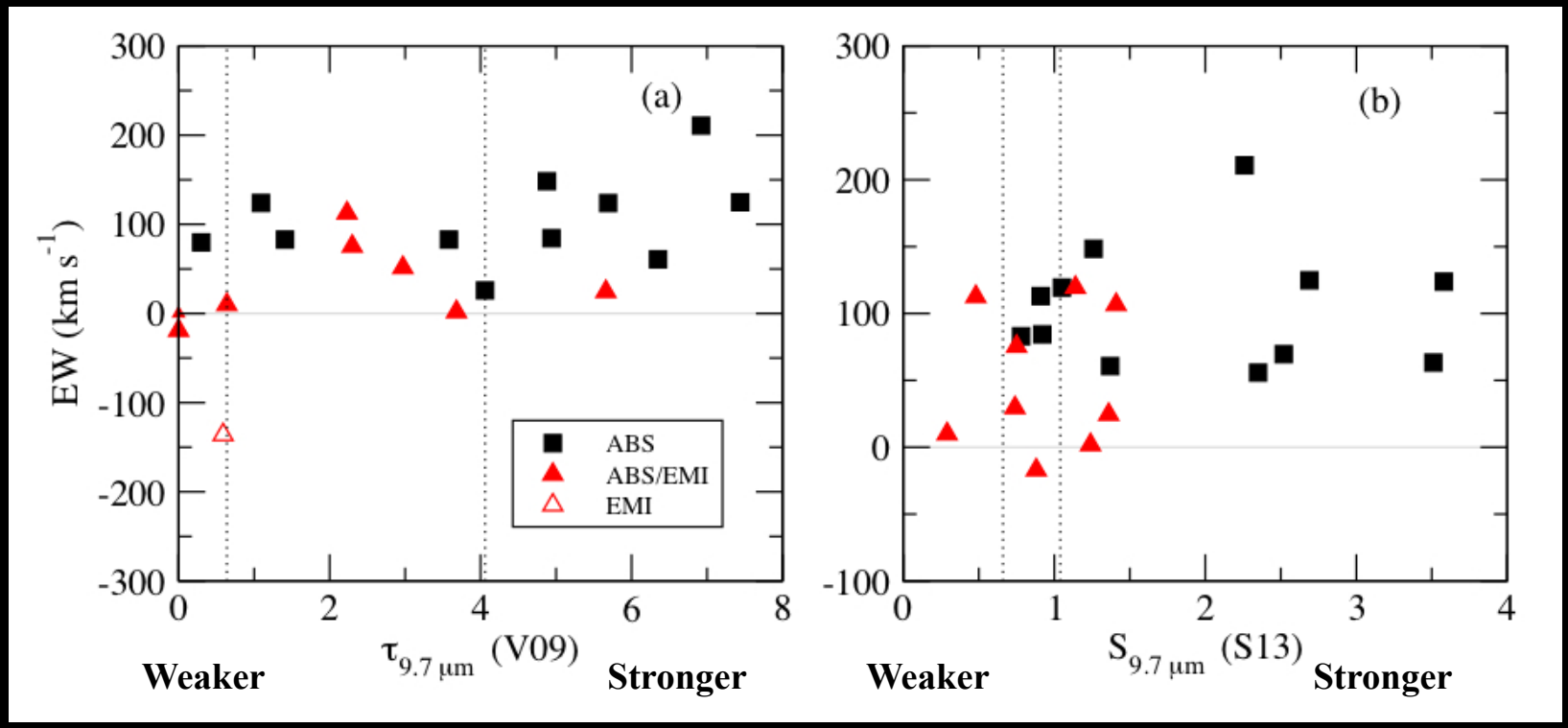
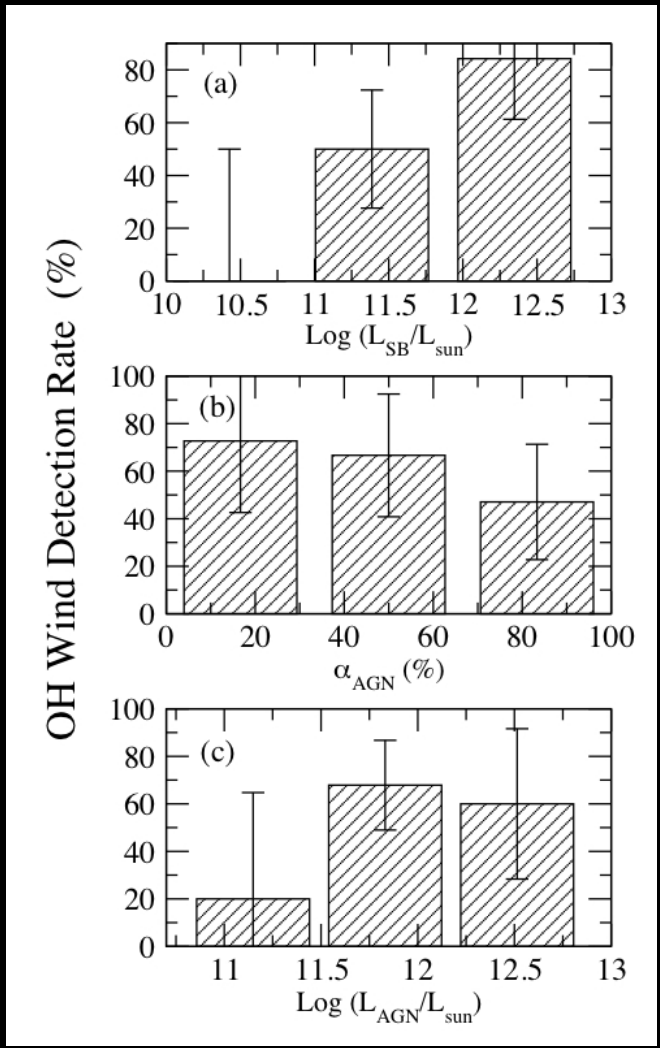


(SV, Rupke, et al. 2009) *(Stierwalt, Armus, et al. 2013)*

New Results: OH Wind Detection Rates

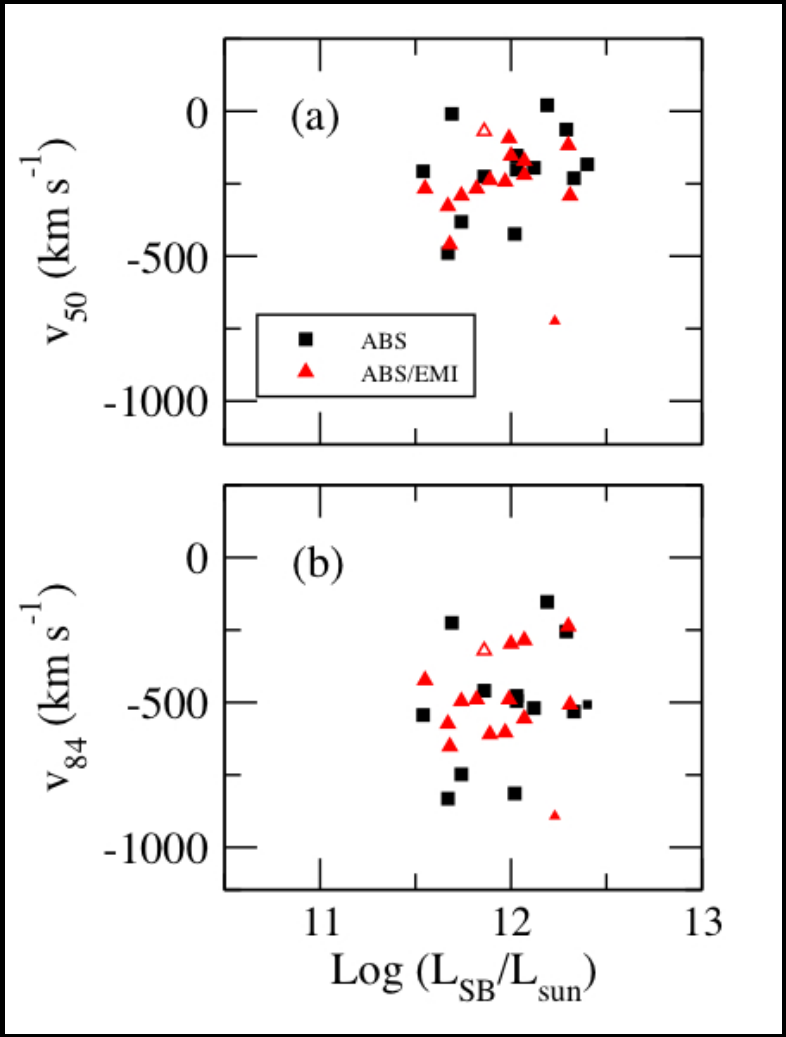
(SV, Meléndez, et al. 2013)



- ***Criterion***: v_{50}(abs) < -50 km s^{-1}
- Winds are detected in 26 (70%) of the 37 objects with OH 119 µm
  - ➔ Wide-angle outflows (145°)
- No significant trend with *SFR*, AGN fractions, and L_{AGN}
- Infall with v_{50}(abs) > +50 km s^{-1} is detected in only 4 objects
  - ➔ thin disk / filament geometry

New Results: Kinematics (OH 119 µm)

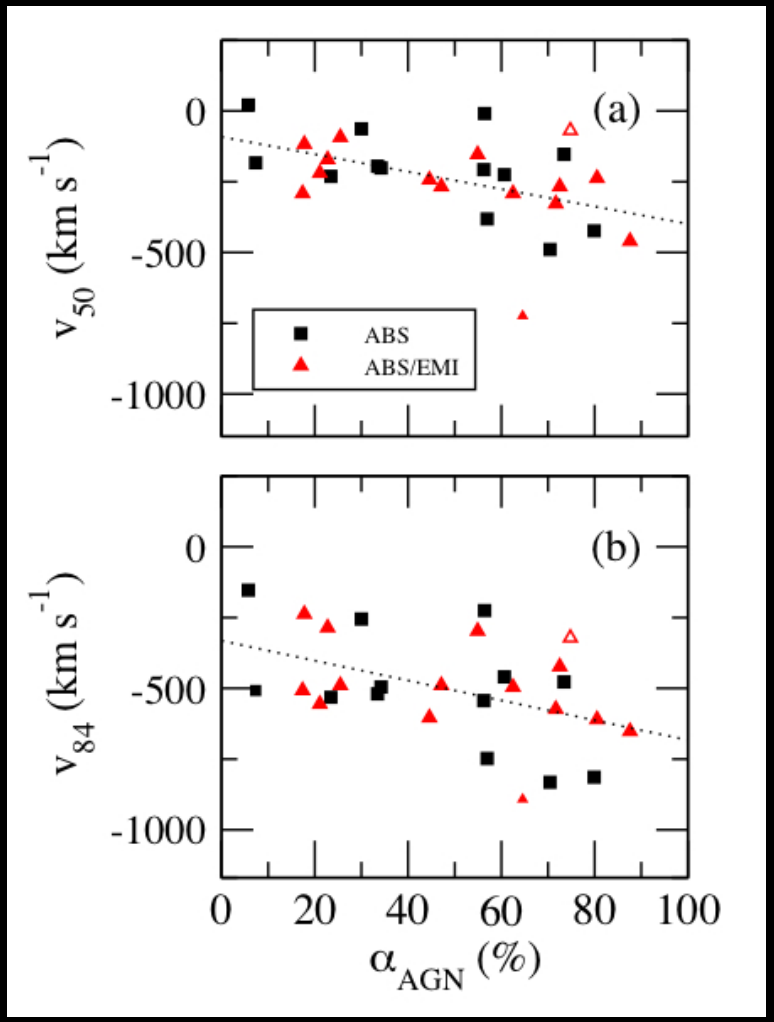
(SV, Meléndez, et al. 2013)



- No significant correlation between the OH velocities and the starburst luminosities (~ SFR), host stellar velocity dispersions, or stellar masses
- Contrary to Na I studies
- Range in L_{SB} too narrow?

New Results: Kinematics (OH 119 µm)

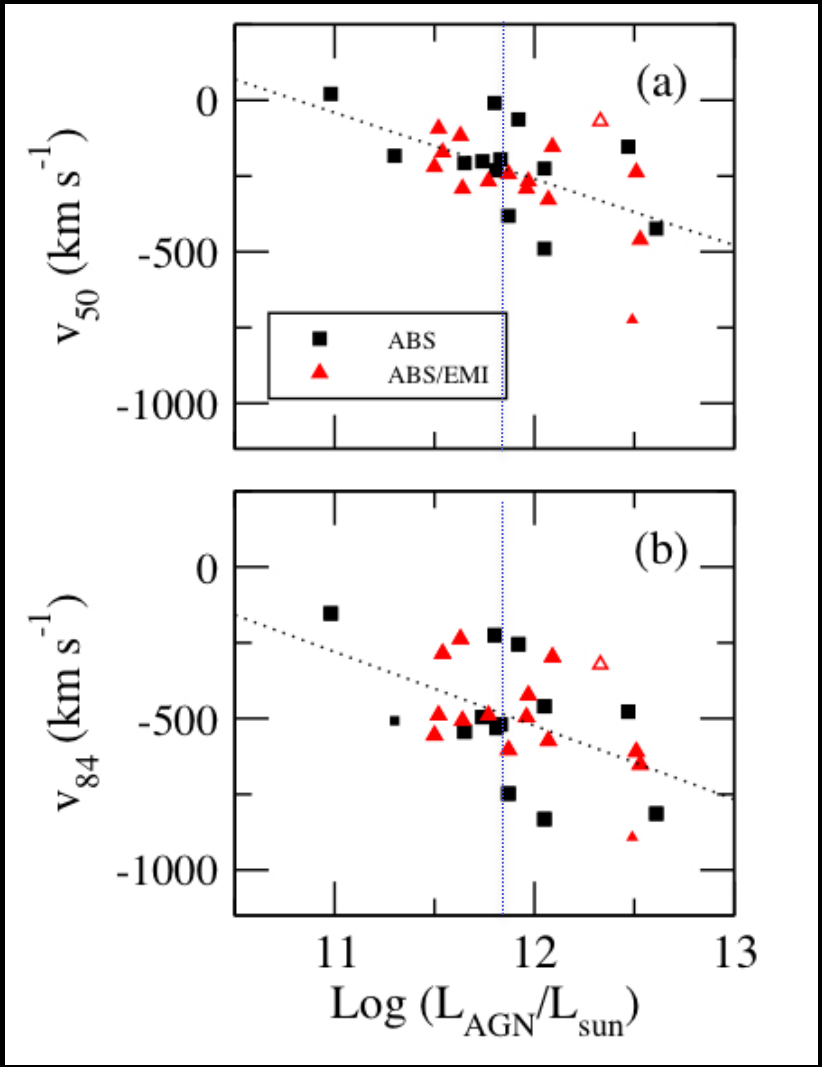
(SV, Meléndez, et al. 2013)



- A trend is present with AGN fractions
- This does not necessarily imply AGN driving
- Alternative explanation: decreasing dust obscuration → easier to see the AGN and central high-velocity gas?

New Results: Kinematics (OH 119 µm)

(SV, Meléndez, et al. 2013)



- A stronger trend is present with the AGN luminosities L_{AGN}

AGN becomes dominant driver of molecular outflow above:

$$L_{AGN}^{break} = 10^{11.8 \pm 0.3}\, L_{sun}$$

- Similar to neutral / ionized gas

$$L_{AGN}^{break} \sim 10^{11.7}\, L_{sun}$$

(*Rupke & SV 2011, 2013a* [Gemini IFU])

Multi-Phase Comparisons

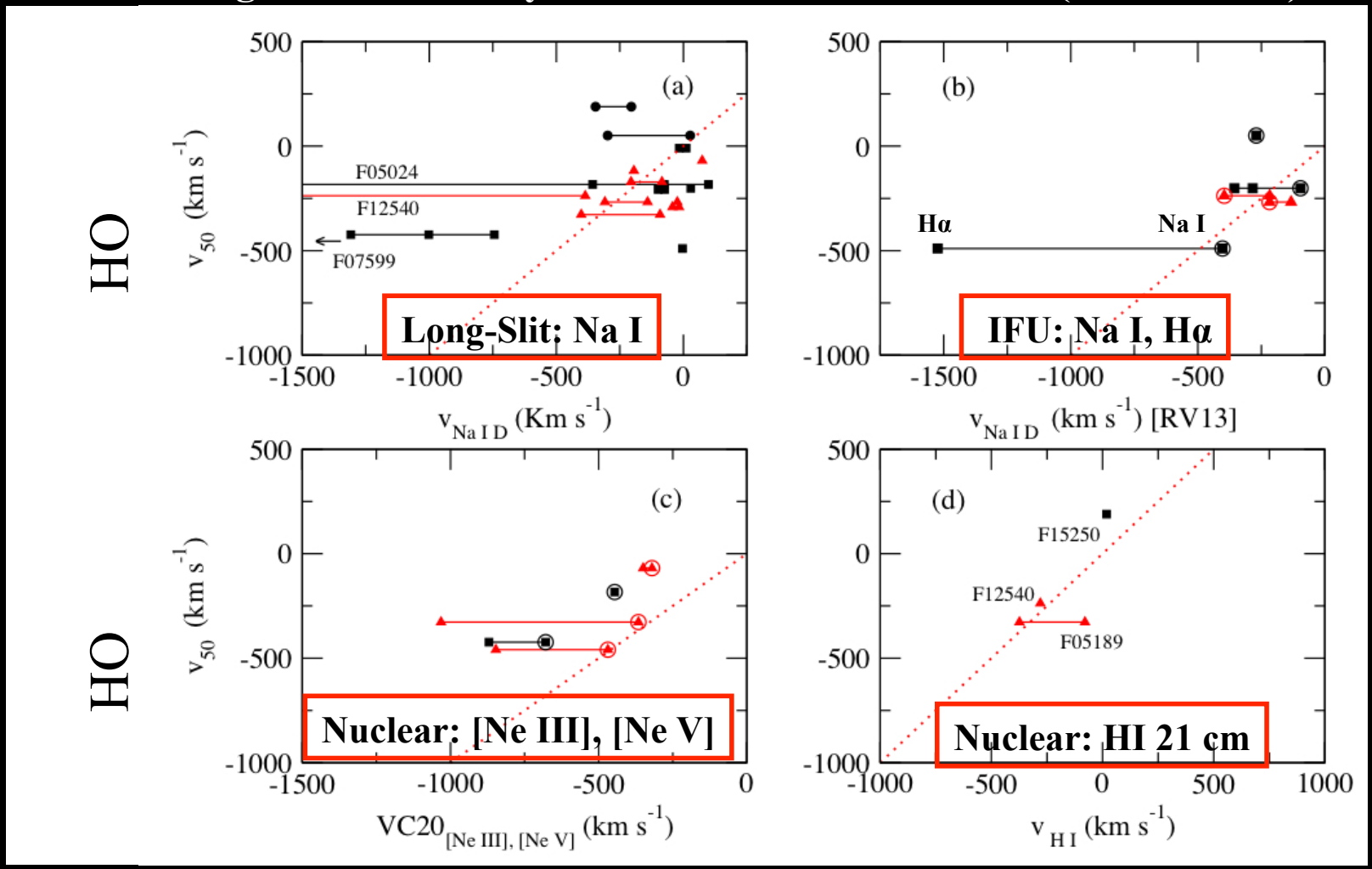
- **Molecular gas phase: OH (*Herschel*) [also CO, HCN, … (IRAM, ALMA)]**
- **Other gas phases:**
  - **Long-slit neutral Na I (Keck, Mayall): *Rupke, SV, & Sanders 2005abc; Krug, SV, et al. 2010, 2013 in prep.***
  - **IFU neutral Na I & warm ionized Hα (Gemini): *Rupke & SV 2011, 2013a***
  - **Nuclear neutral H I 21-cm (GBT): *Teng, SV, & Baker 2013***
  - **Nuclear warm ionized [Ne III] and [Ne V] (*Spitzer*): *Spoon & Holt 2009***
  - **AO IFU H_2 warm molecular gas (Gemini, Keck): *Rupke & SV 2013b***
  - **Warm-hot ionized FUV Lyα, O VI, N V (*HST* COS): *SV, Trippe, et al. 2013; Trippe, SV, et al. 2013 in prep; Hamann, SV, et al. 2013 in prep.***
  - **Hot ionized X-rays (*Chandra* LP on Mrk 231): *SV, Teng, et al. 2013 in prep.***

Multi-Phase Comparisons

Molecular (OH) *vs* Neutral (Na I, H I) *vs* Ionized (Hα, [Ne III], [N V])

(SV, Meléndez, et al. 2013)

- Molecular gas has a velocity that is similar to that of the (non-nuclear) neutral gas



Summary & Open Issues

- **What are the basics properties of molecular winds?**

- Statistics: The OH 119 feature was detected in 86% of the sample where 70 % of local ULIRGs have molecular outflows v < -50 km s-1.
- Outflow velocities: $<v_{50}>$, $<v_{84}>$, $<v_{max}>$ ~ 200,500, 925 km s^{-1}

- **Who is driving these winds: starburst or AGN?**

- Kinematics trend with LAGN suggests that the AGN is playing a dominant role in local ULIRGs when $L_{AGN}>10^{11.8+/-0.3}$ L_{sun}
- There is no obvious dependence of the properties of host galaxies, SFR and outflows velocities.