Characterizing the ISM in z = 1 – 2 Galaxies with PACS and Ground-Based Sub/mm Spectroscopy

Steve Hailey-Dunsheath, Caltech

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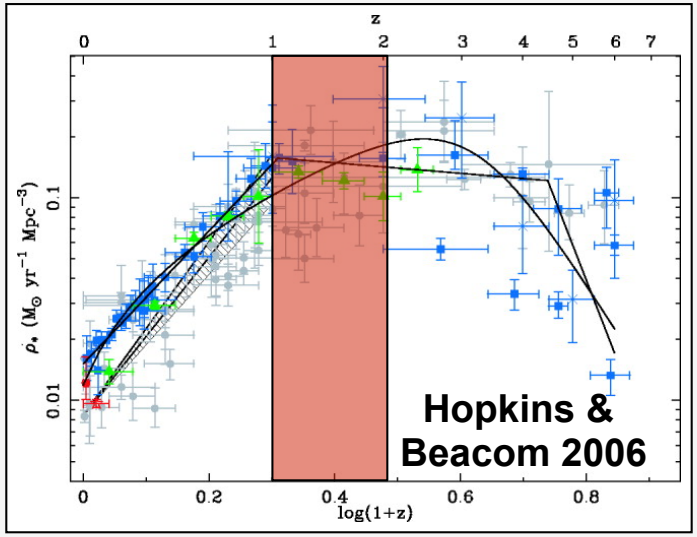
Cornell
Drew Brisbin (NRAO), Gordon Stacey, Thomas Nikola, Carl Ferkinhoff, Steve Parshley, Henrik Spoon

Oxford
Aprajita Verma

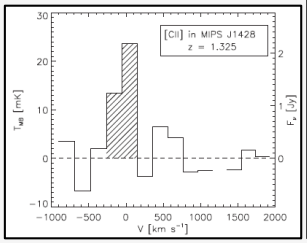
ZEUS/CSO z = 1 – 2 [CII] Survey

- **Investigates star formation near cosmic peak**
- First survey detected 13/14 sources
- Mixture of IR-selected and IR-bright quasars
- $L_{FIR} = (2 – 20) \times 10^{12} L_{sun}$

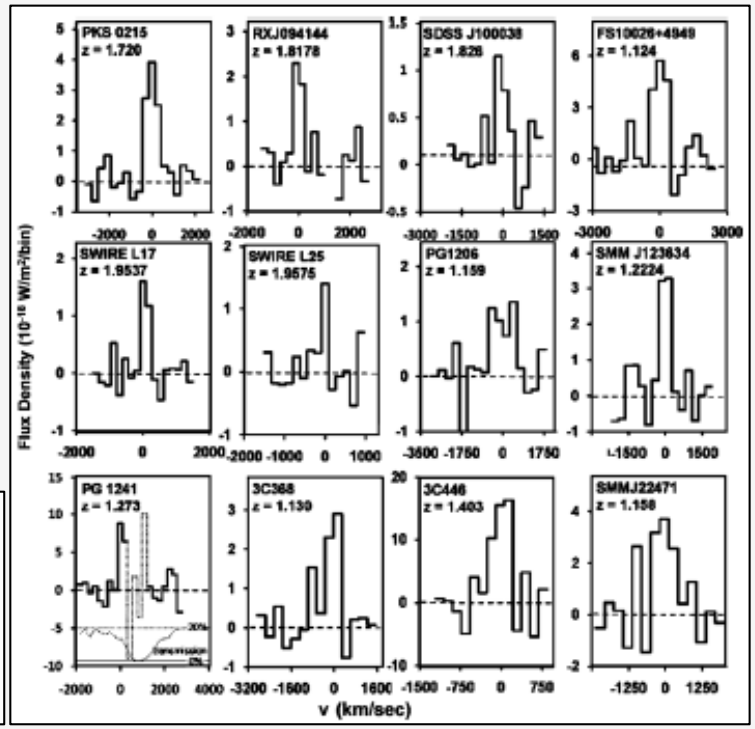


Follow up with programs

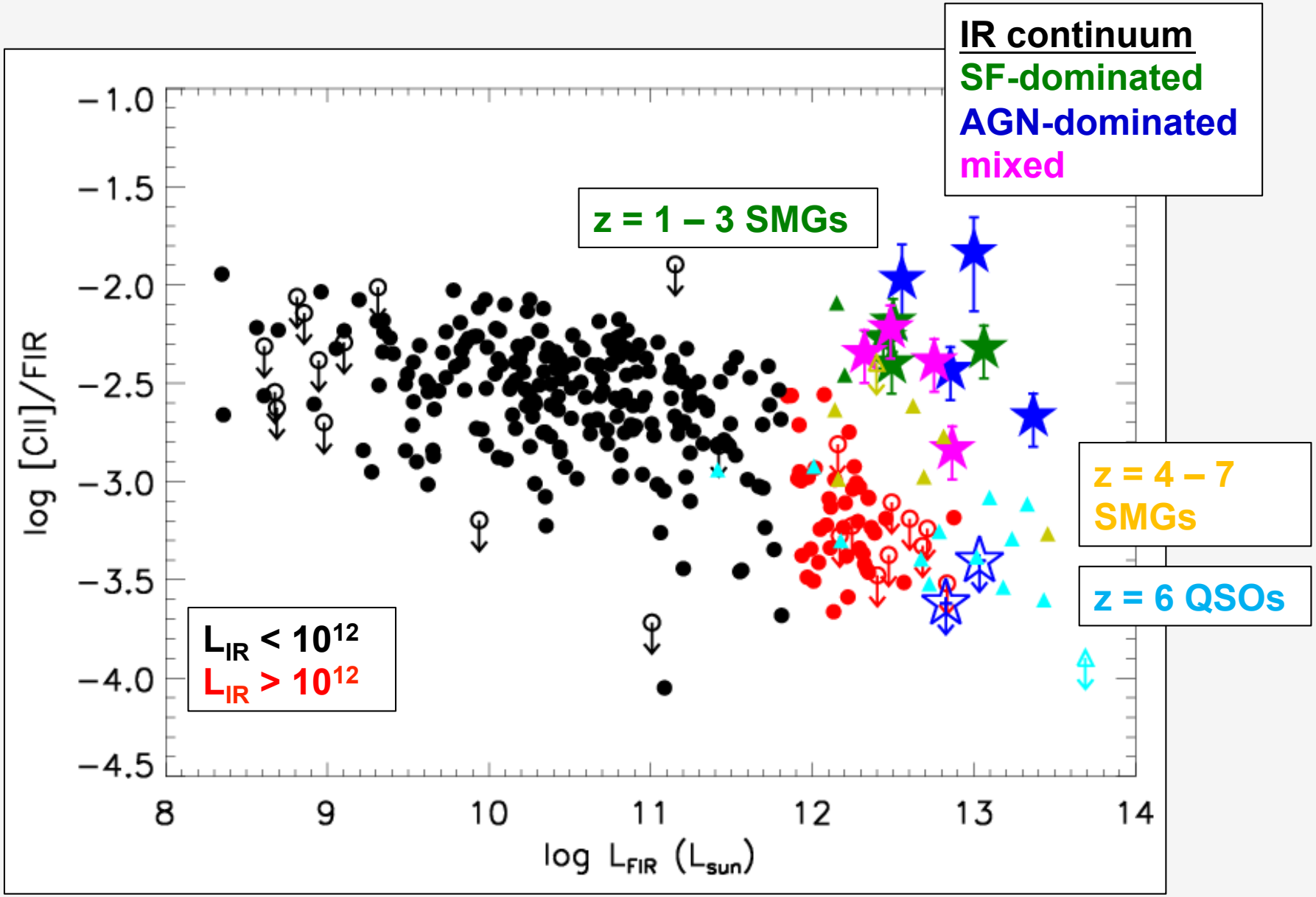
- CO observations with IRAM
- PACS observations of [OI], [OIII], [OIV]
- PACS + SPIRE photometry
- Spitzer/IRS spectroscopy



Hailey-Dunsheath+10
Stacey+10



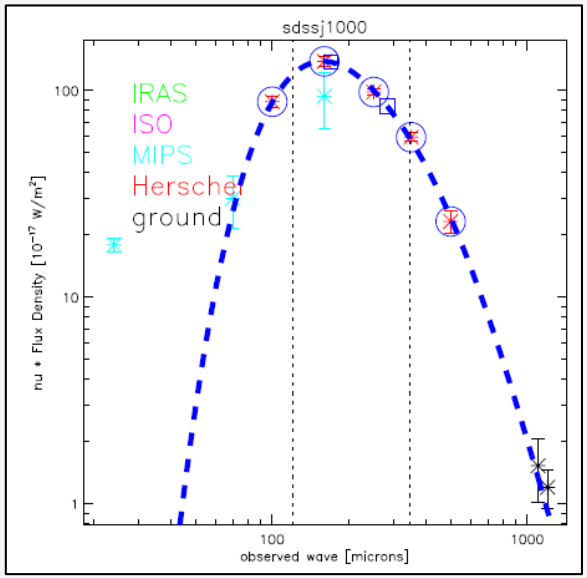
[CII]/FIR vs L_{FIR}



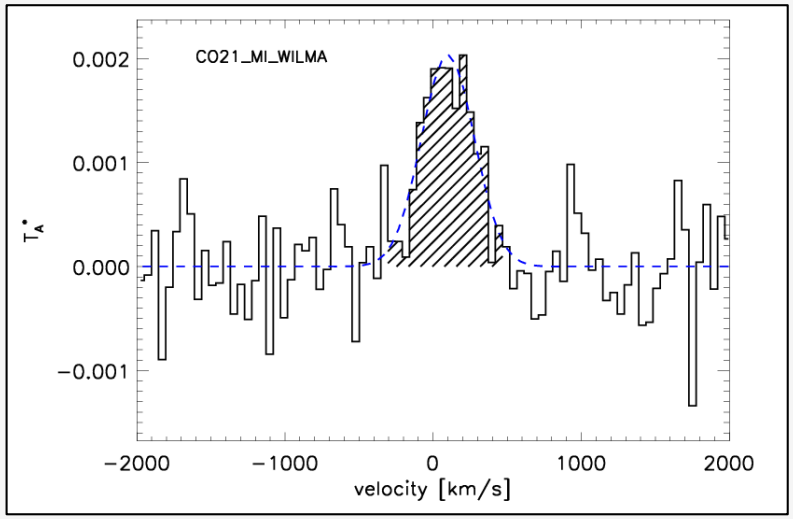
Gracia-Carpio+11, Cox+11, Swinbank+12, Venemans+12, Walter+13, Riechers+13, Wang+13, Willott+13

Follow-up Observations

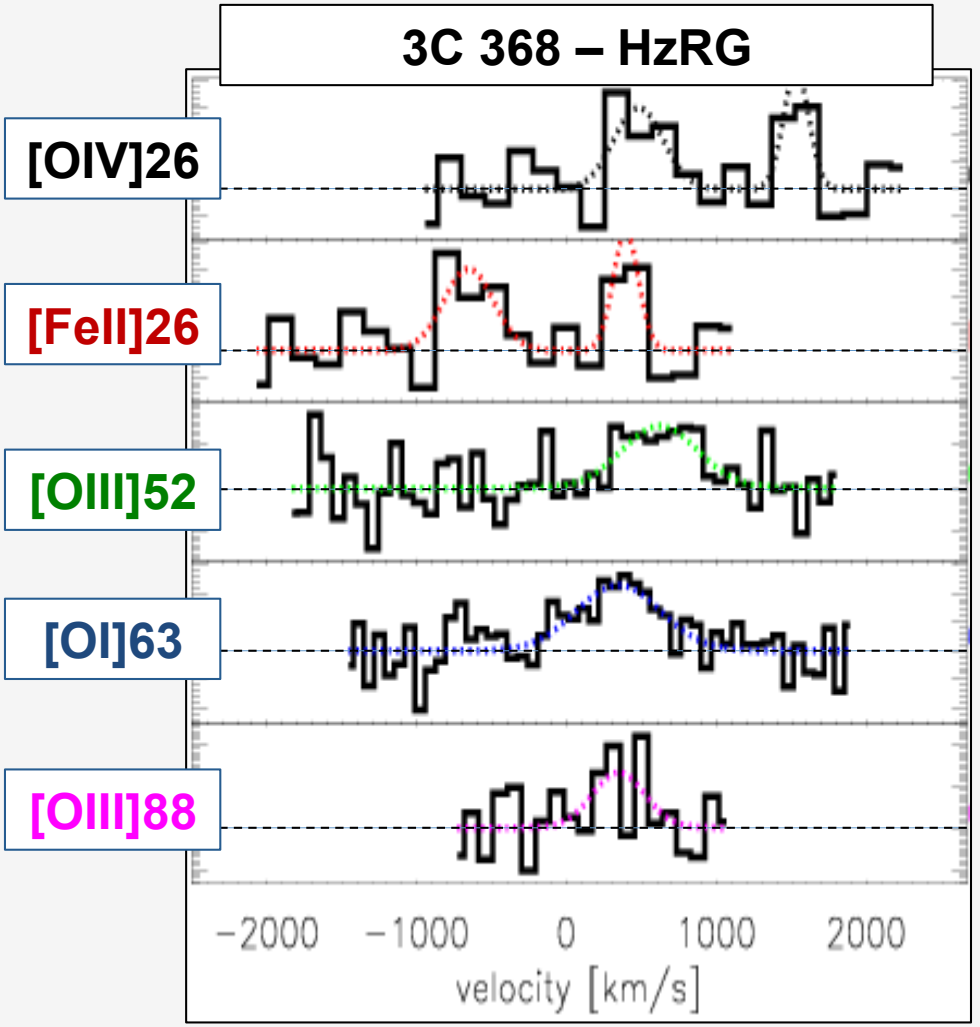
PACS+SPIRE photometry



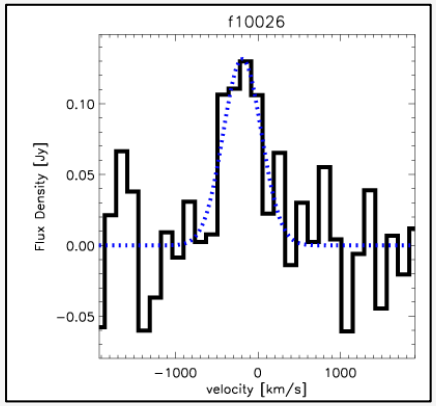
IRAM CO Spectroscopy

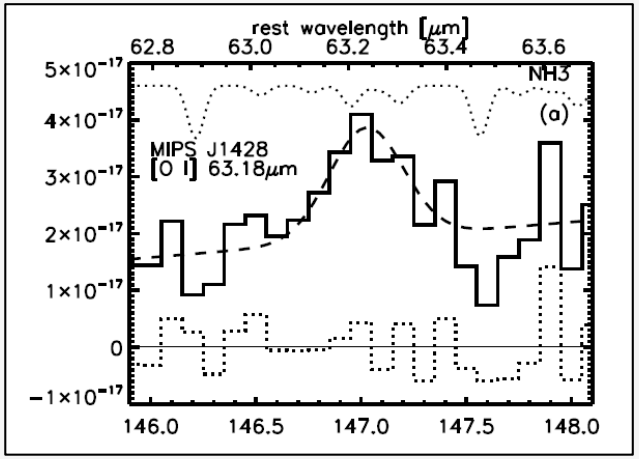


PACS Spectroscopy

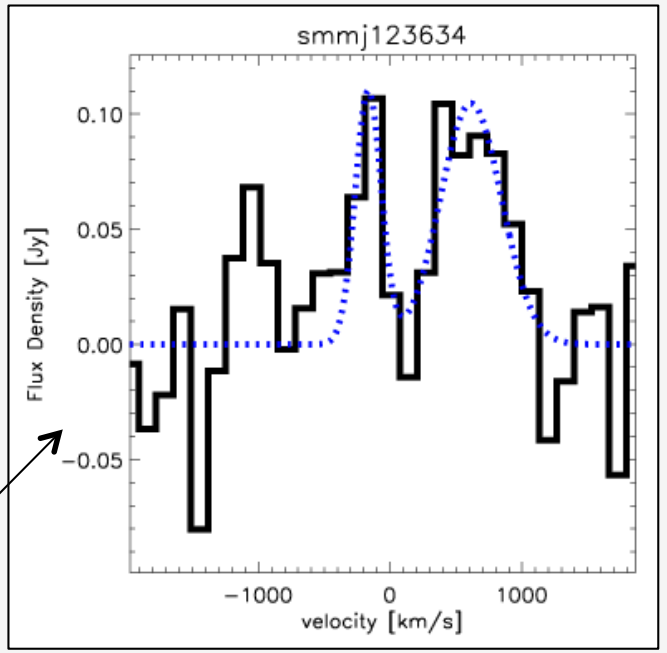


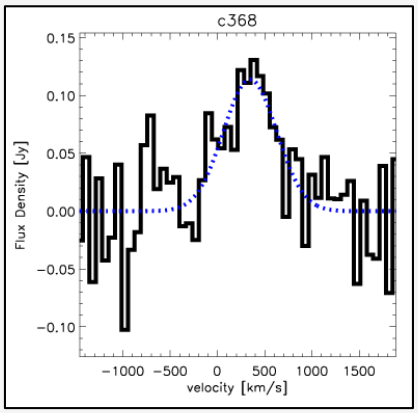
[OI] Observations



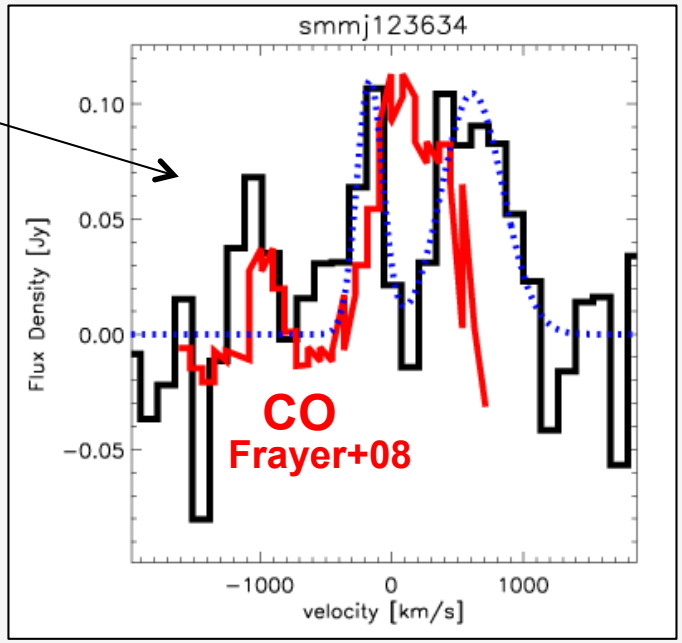


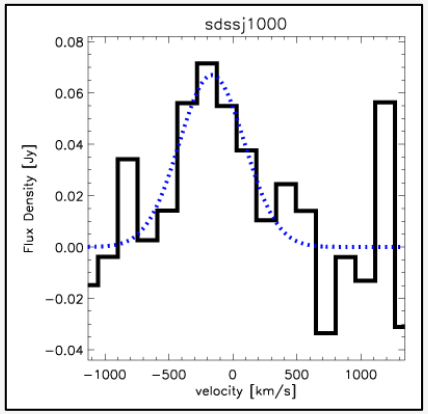
Sturm+10





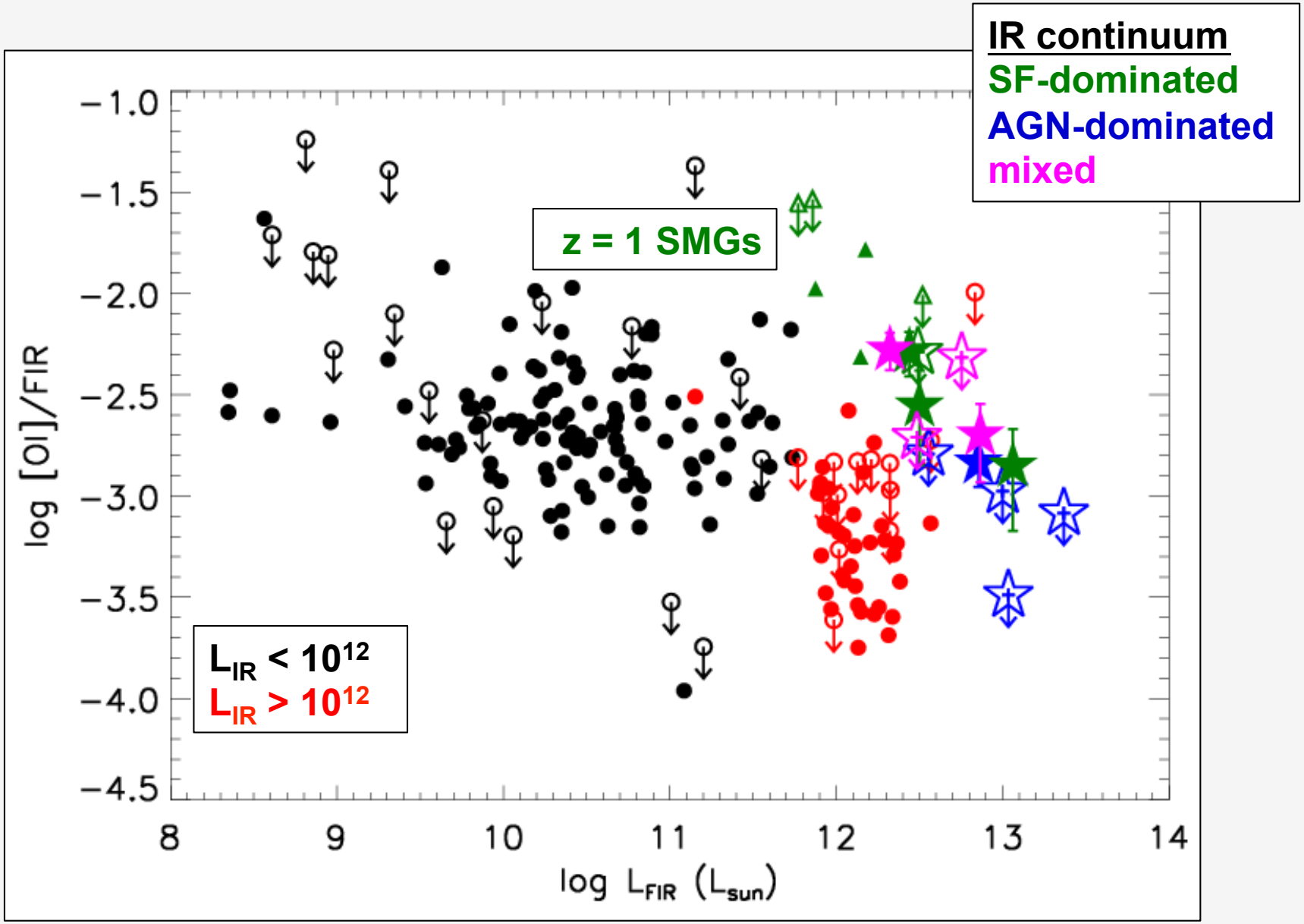
Self-absorption





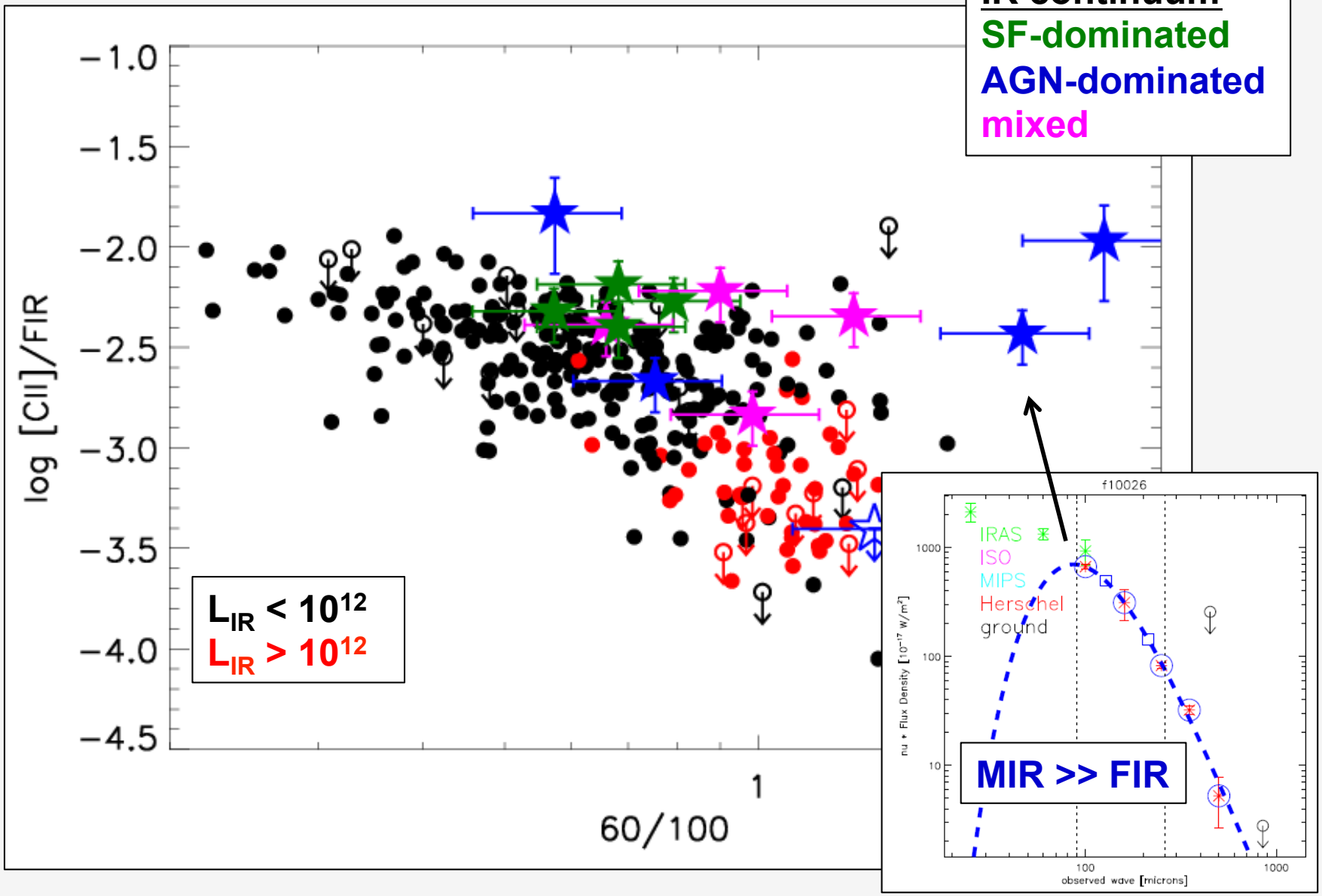
Detect 6/13 sources
4/6 SF/mixed

[OI]/FIR vs L_{FIR}



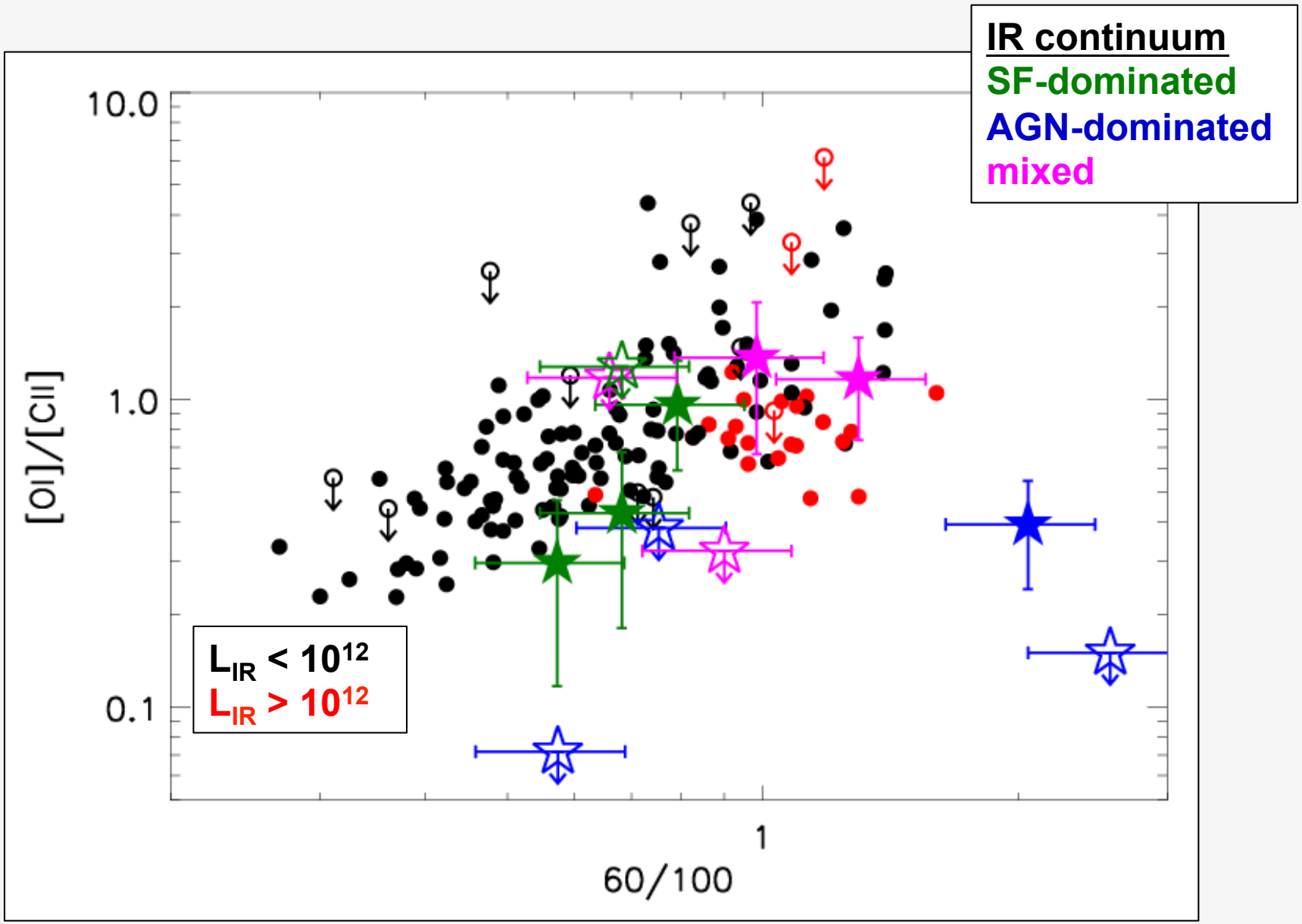
Sturm+10, Gracia-Carpio+11, Coppin+12, Farrah+13

[CII]/FIR vs 60/100



Malhotra+01, Luhman+03, Gracia-Carpio+11

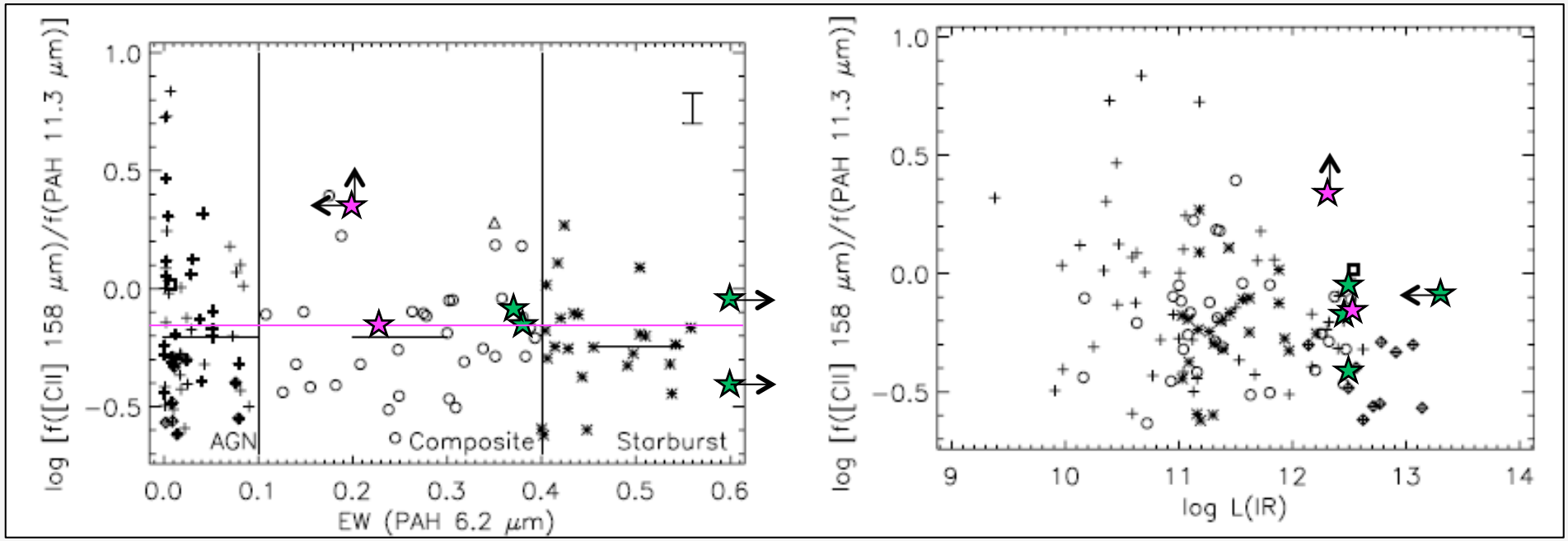
[OI]/[CII] vs 60/100



Malhotra+01, Gracia-Carpio+11

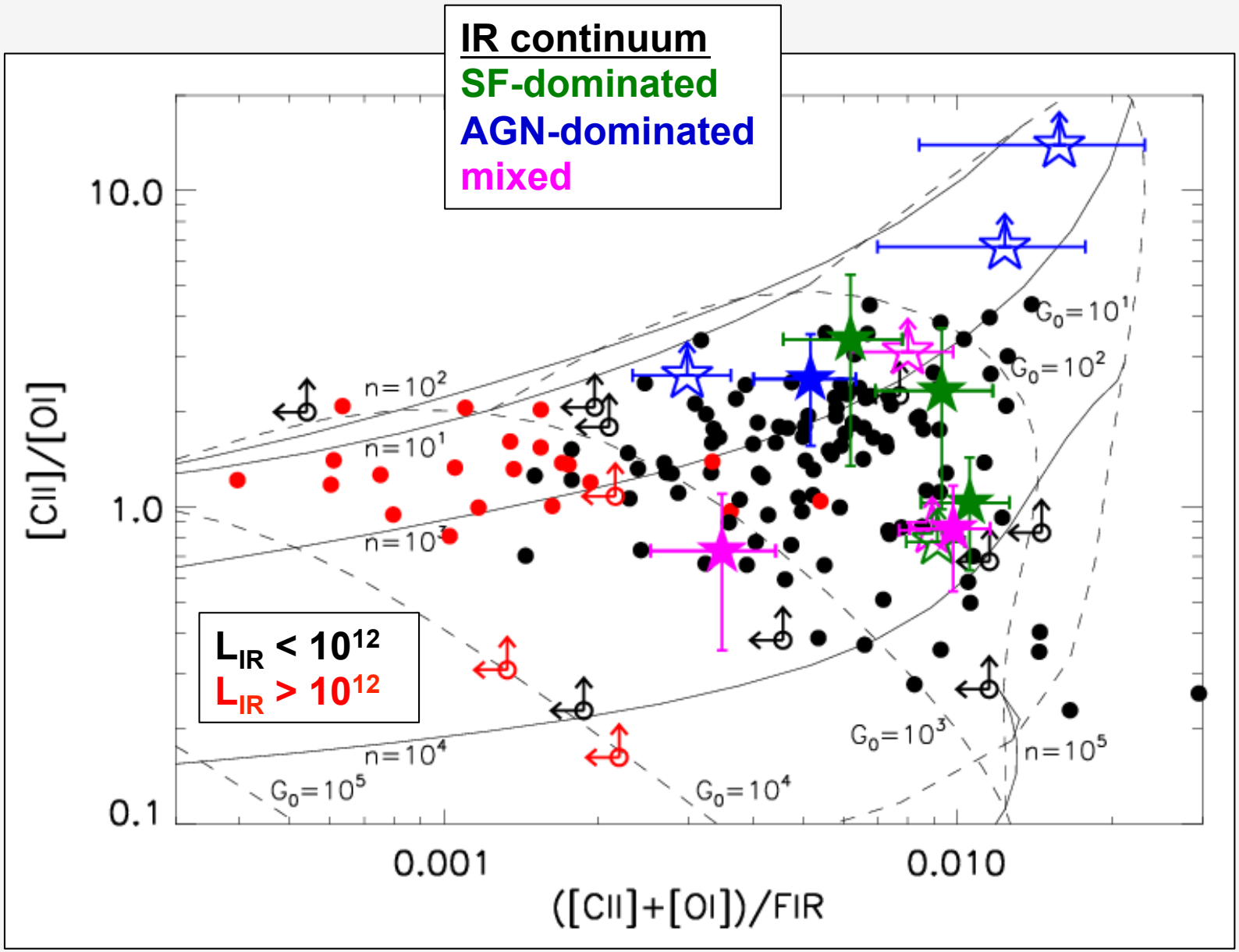
[CII]/PAH

IR continuum
SF-dominated
AGN-dominated
mixed



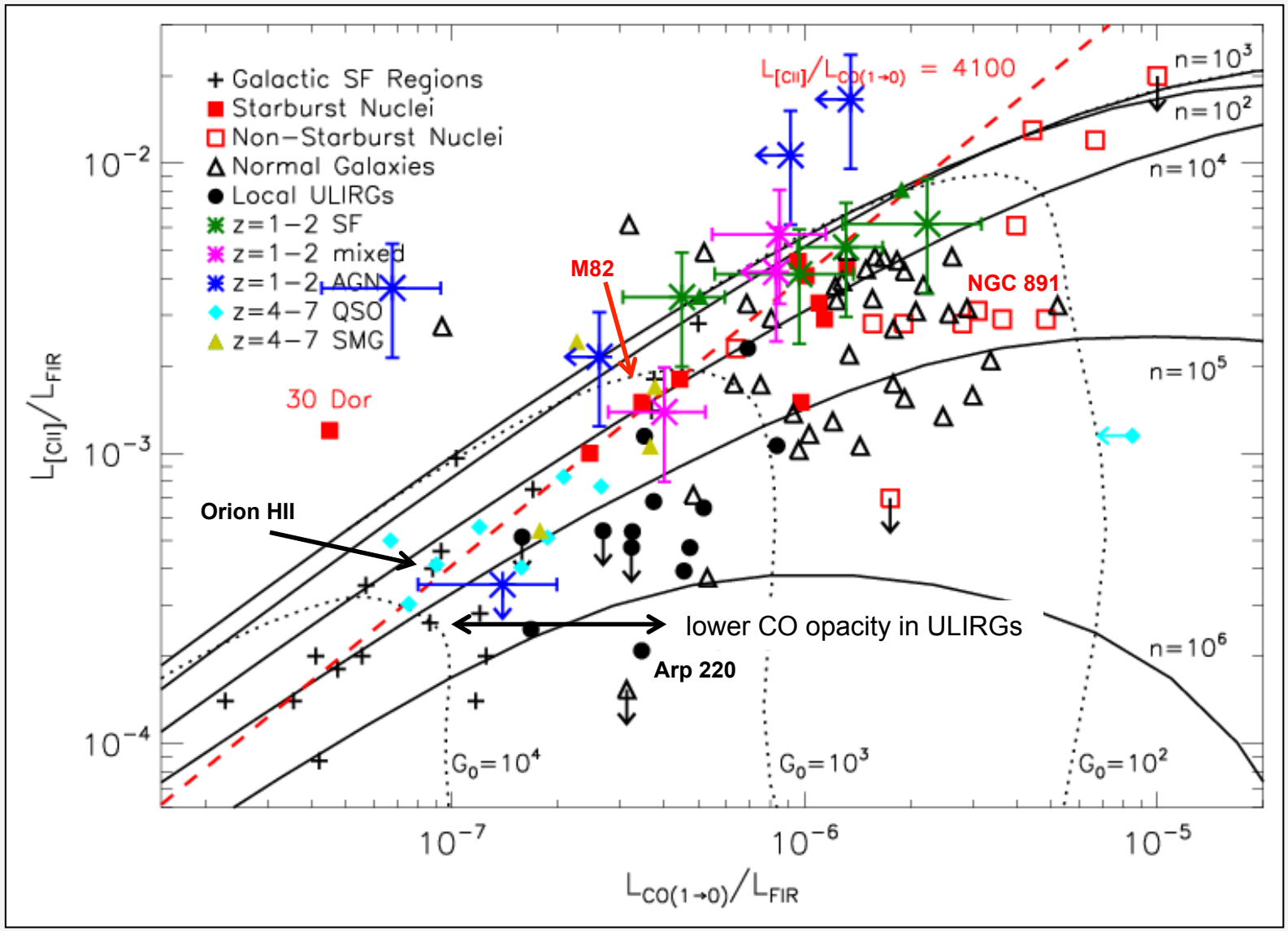
Helou+01, Sargsyan+12, Brisbin+13

[CII]/[OI] vs ([CII]+[OI])/FIR



Kaufman+99, Gracia-Carpio+11

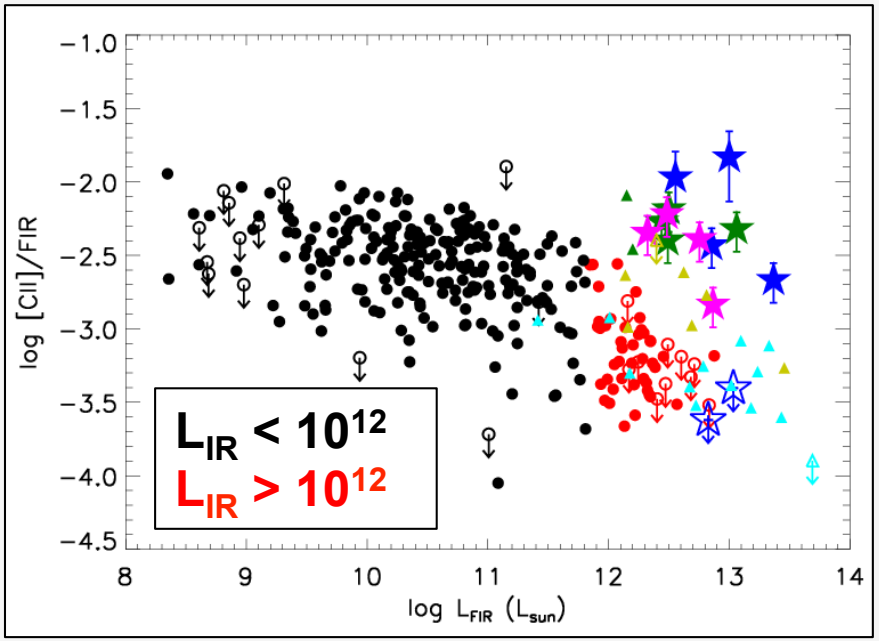
[CII]/FIR vs CO/FIR

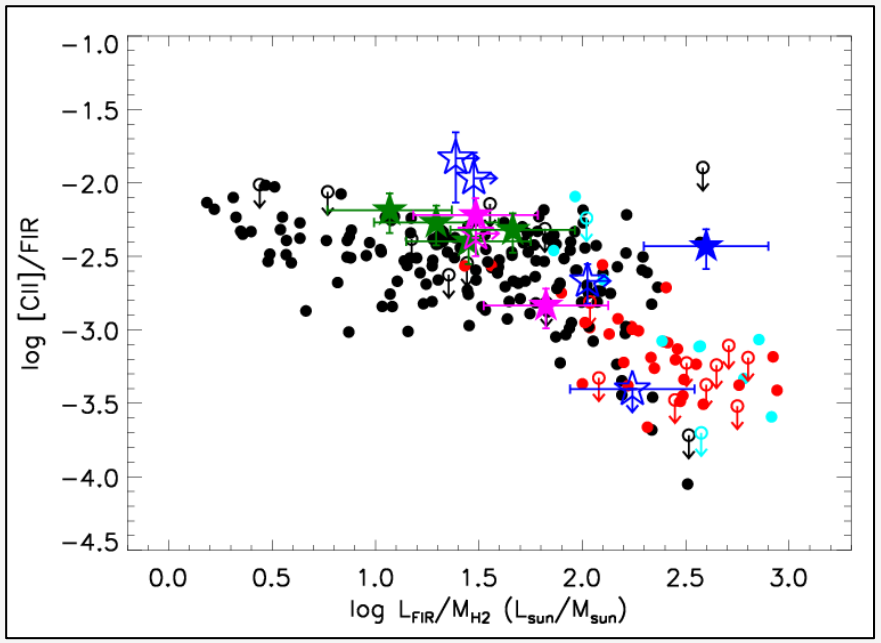


Hailey-Dunsheath+10, Stacey+10

[CII]/FIR vs L_{FIR}/M_{H2}

IR continuum
SF-dominated
AGN-dominated
mixed

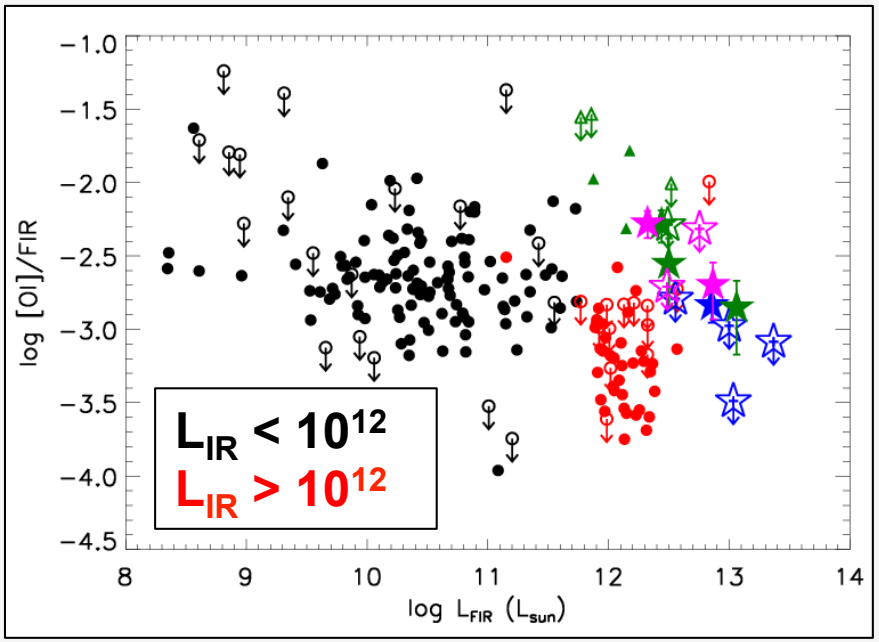


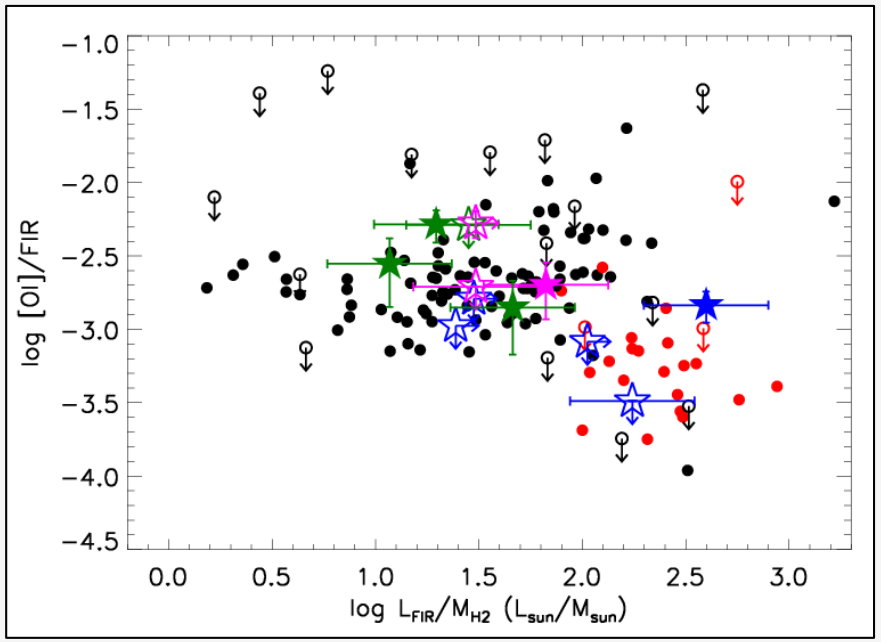


Gracia-Carpio+11, Cox+11, Swinbank+12, Venemans+12, Walter+13, Riechers+13, Wang+13, Willott+13

[OI]/FIR vs L_{FIR}/M_{H2}

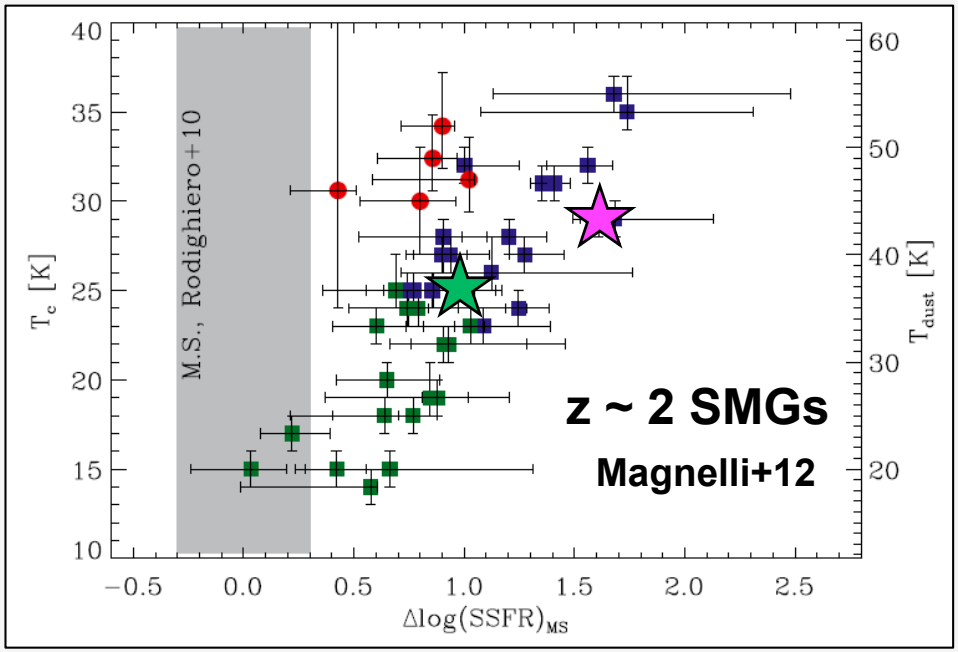
IR continuum
SF-dominated
AGN-dominated
mixed

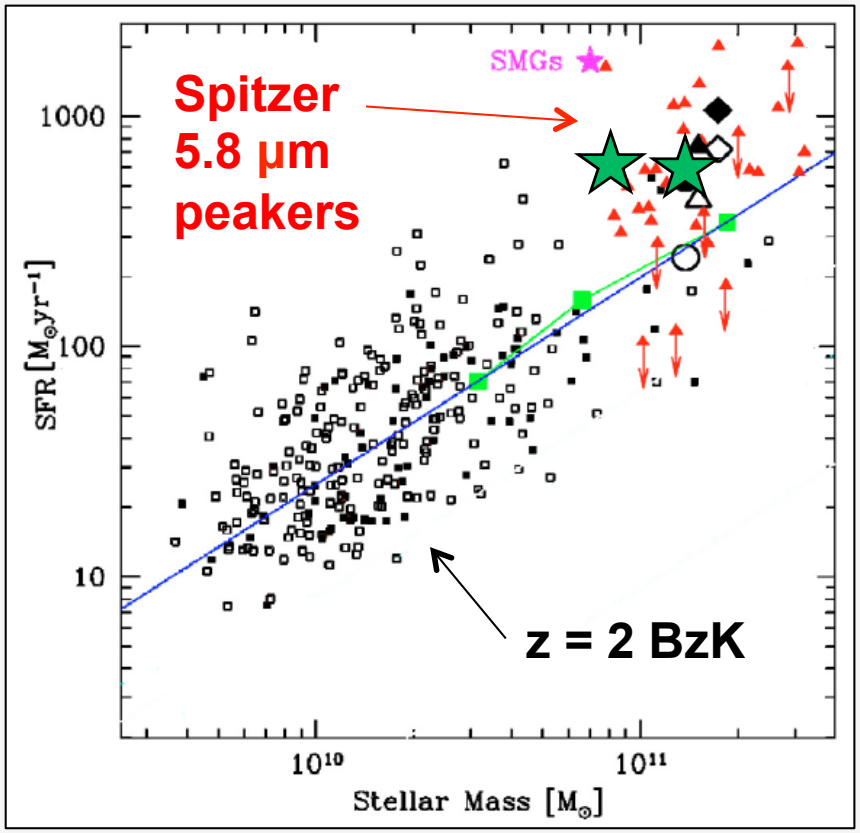




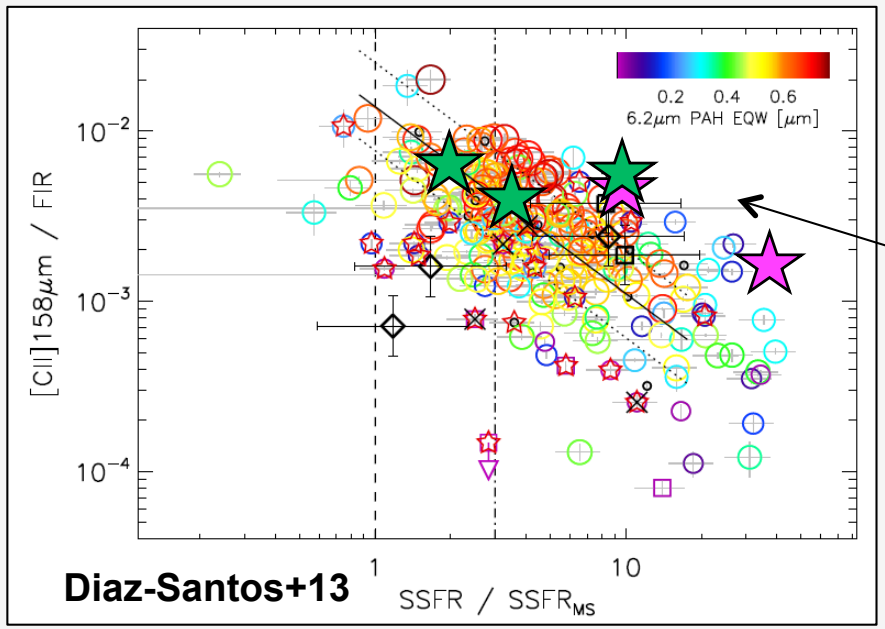
Gracia-Carpio+11, Cox+11, Swinbank+12, Venemans+12, Walter+13, Riechers+13, Wang+13, Willott+13

[CII]/FIR and [OI]/FIR vs SSFR





Daddi+07, Fiolet+09, Brisbin+13



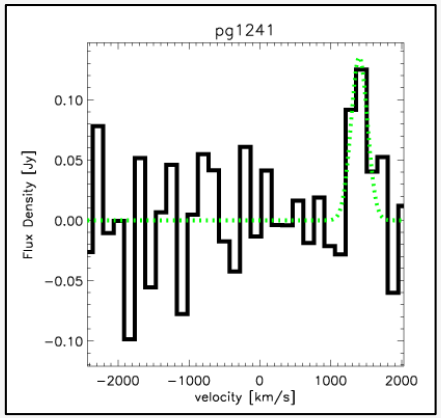
Diaz-Santos+13

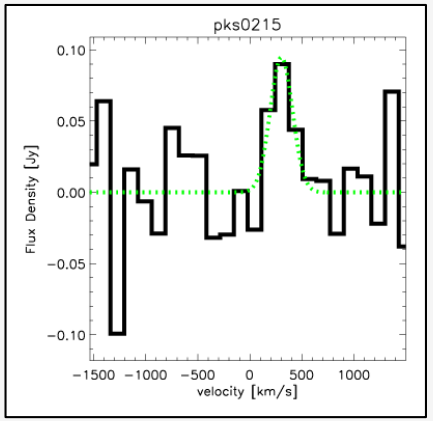
3 sources with $SSFR/SSFR_{MS} > 10$
- detected in [OI]
- moderate L_{FIR}/M_{H2}

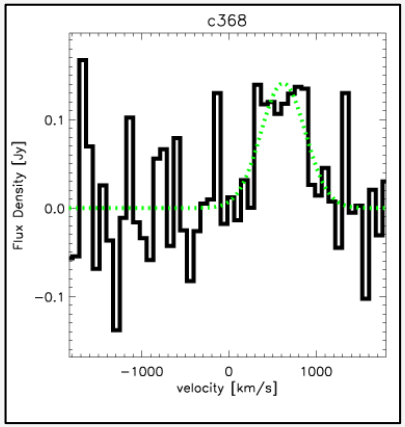
--> FIR lines traces gas properties better than SF history

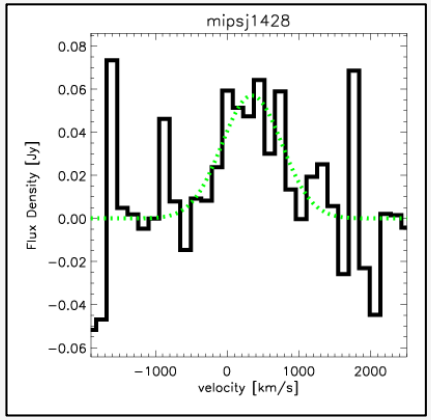
[OIII]52 and [OIV]

- [OIII]52μm – 5/13 detections



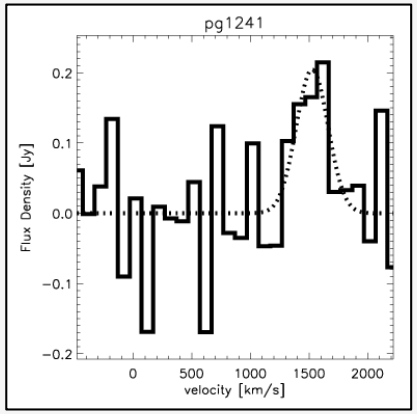


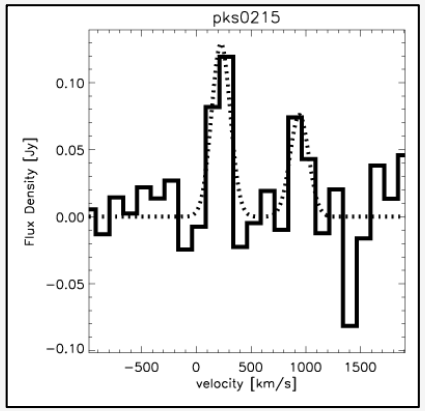


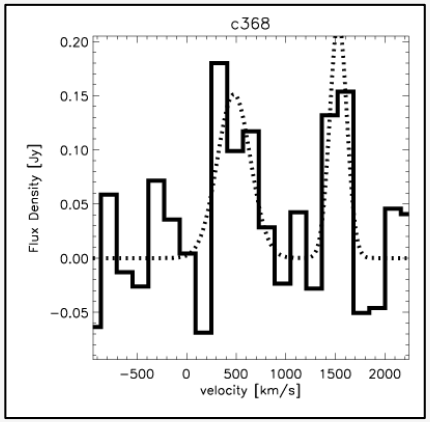


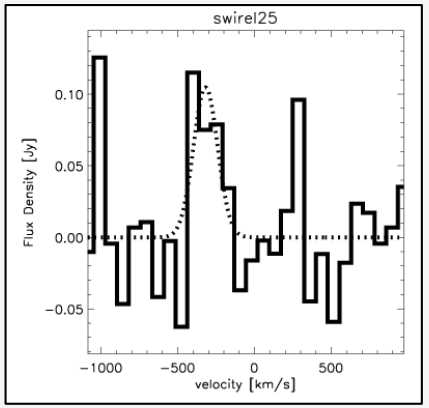
Sturm+10

- [OIV]26μm – 5/13 detections

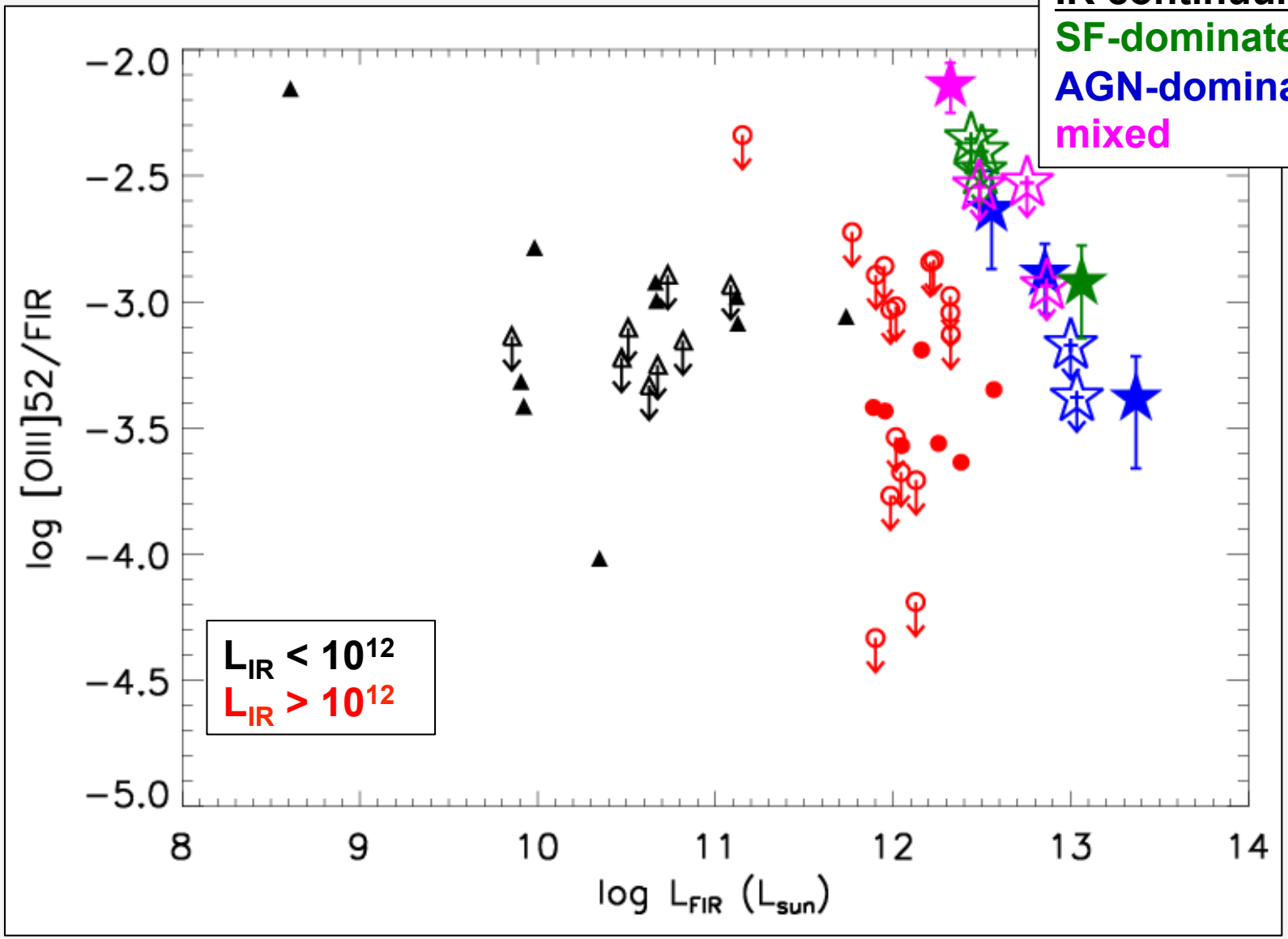








[OIII]52/FIR vs L_{FIR}



Malhotra+01, Negishi+01, Gracia-Carpio+11

[OIV]/[OIII] as AGN Indicator

- Detect [OIV] in **5/13** sources

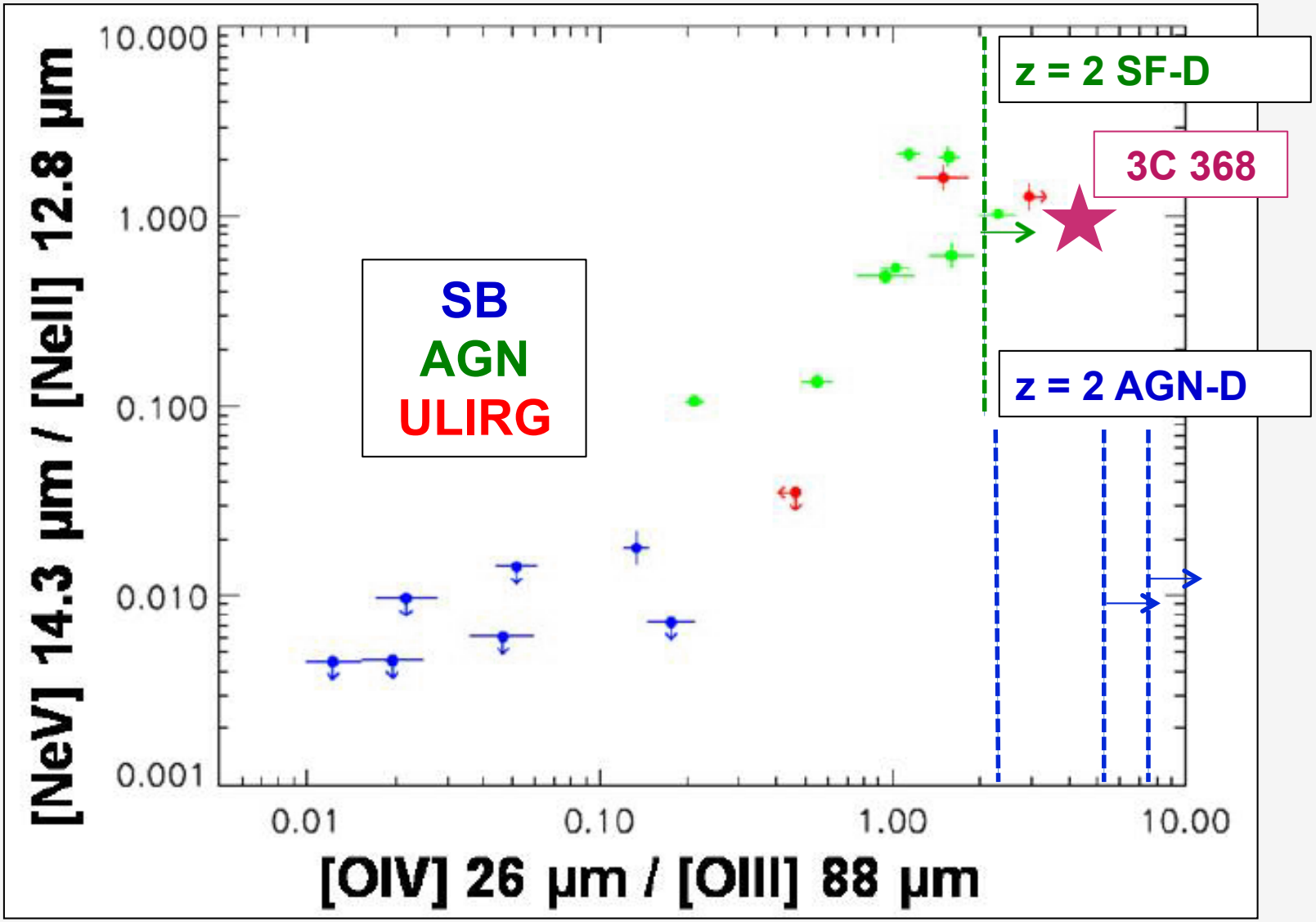
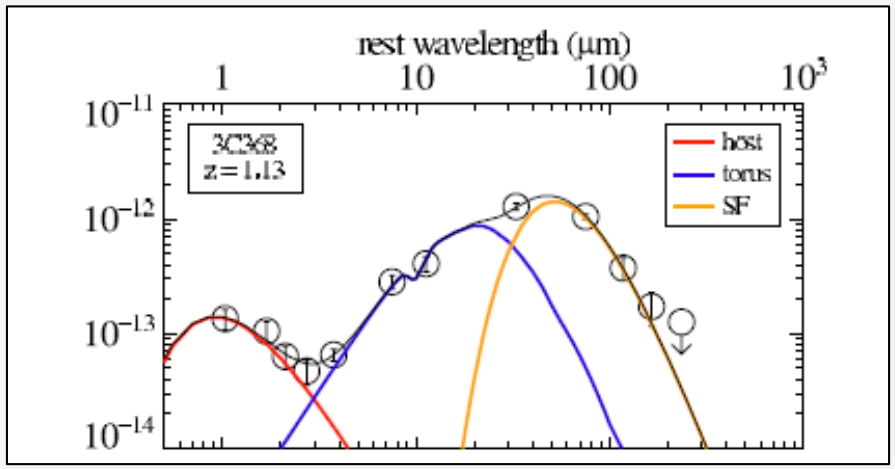
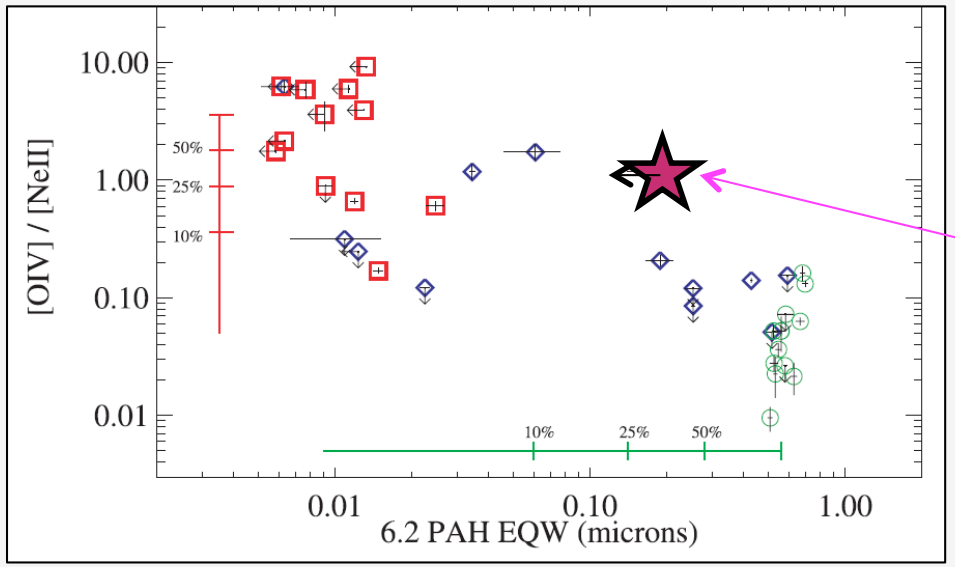


figure from H. Spoon

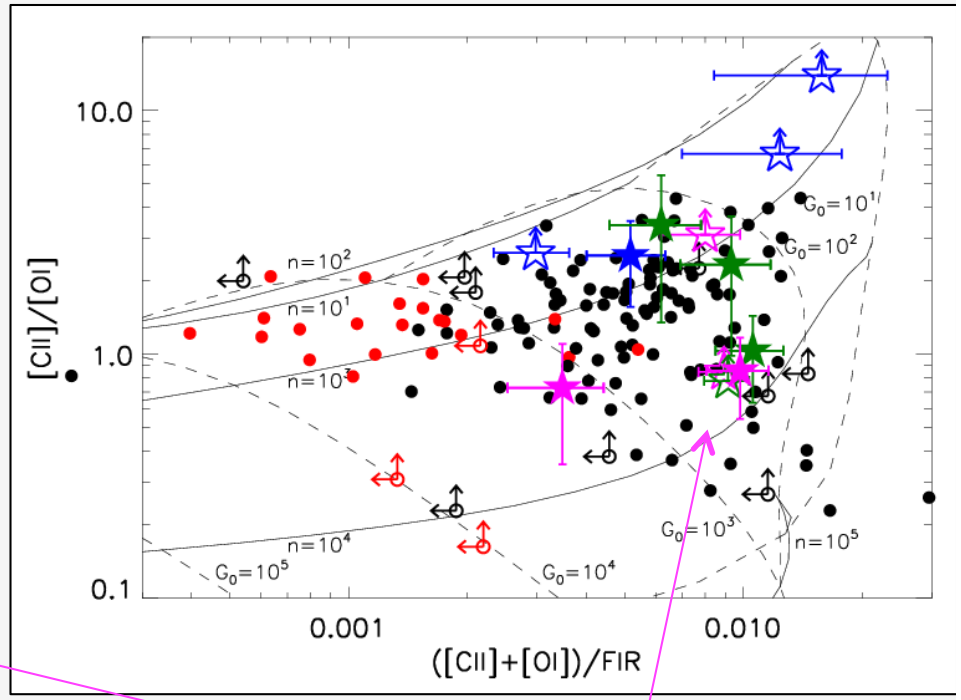
3C 368 – a HzRG



Barthel+12



Armus+07



3C 368
MIR: Pure AGN
FIR: Normal SF

Summary

- First high-z survey of [CII]158 μm and [OI]63 μm – dominant coolants of the neutral medium
- [CII]/[OI]/CO/FIR/PAH consistent with normal PDR emission – implies high SFR with low intensity in extended geometry
- [CII]/FIR and [OI]/FIR strongly anti-correlated with L_{FIR}/M_{H2}
  - Better than with SSFR
- [OIII]52 and [OIV]26 commonly detected, particularly in QSOs

End