Gas Heating and Abundances from FIR spectroscopy

The Kingfish Local Galaxy Sample

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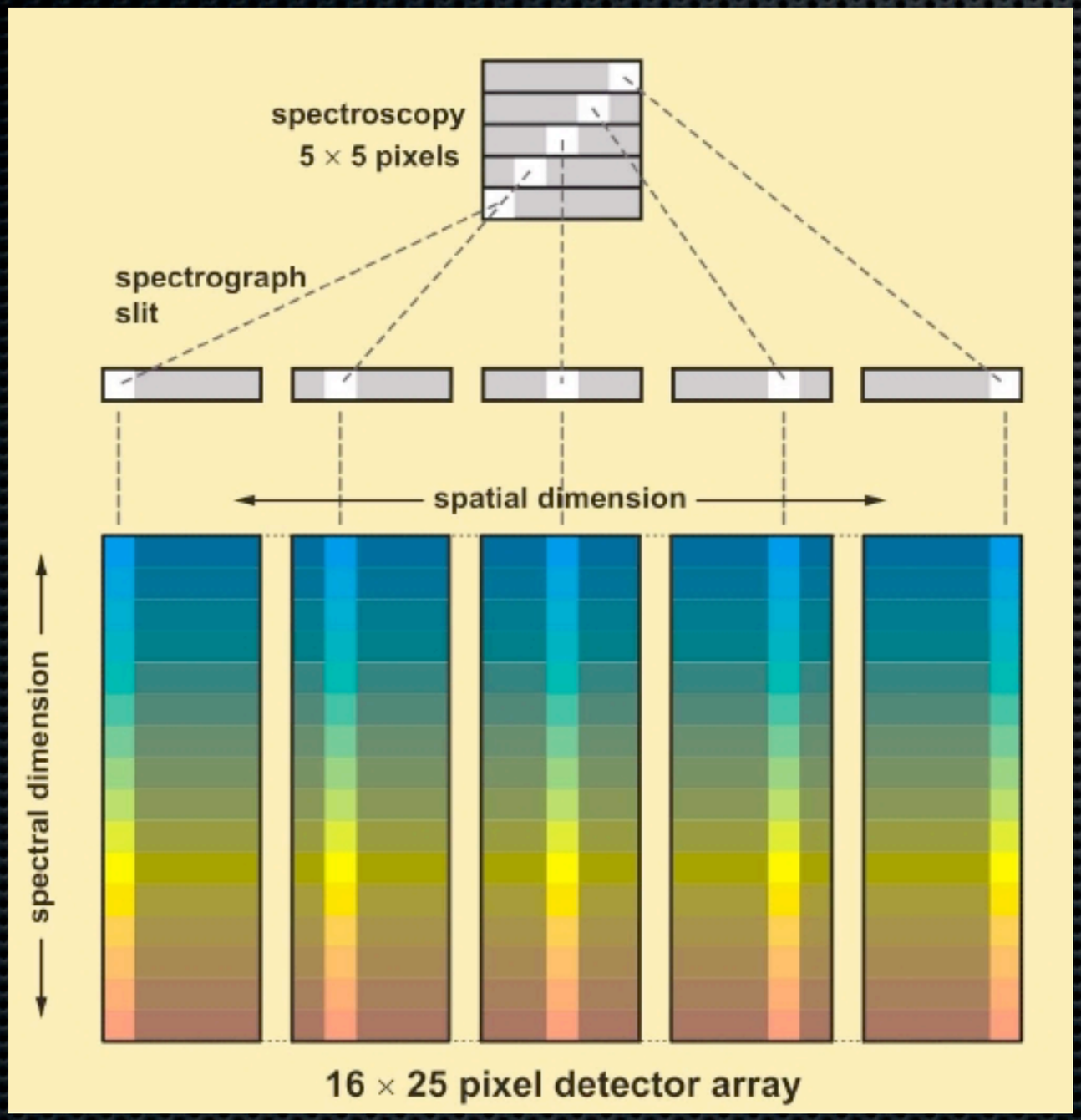
- Sundar Srinivasan
- Laurent Vigroux
- Fabian Walter
- Bradley Warren
- Christine Wilson
- Mark Wolfire
- Stefano Zibetti

Herschel PACS spectroscopy



An IFU in the far-IR.

(55 - 210 μm)

Spatial pixels 9.7″ x 9.7″

Spectral resolution of
940-5500

Kingfish (Key Insights on Nearby Galaxies: a Far-Infrared Survey with Herschel)

NGC 2841
NGC 3938
NGC 628
NGC 7793
NGC 4254
NGC 3190
NGC 4826
NGC 2976
NGC 5055
NGC 3621
NGC 5474
NGC 3265
NGC 4594
NGC 4736
NGC 7331
NGC 584
NGC 855
NGC 1482
NGC 4321
NGC 3521
NGC 3184
NGC 4579
NGC 3773
NGC 4725
NGC 5866
NGC 1404
NGC 1377
NGC 4559
NGC 6946
NGC 1316
NGC 5713
NGC 4569
NGC 1266
NGC 3627
IC 342
NGC 5457
NGC 2798
NGC 4536
NGC 925
NGC 2915
DDO 154
NGC 3077
NGC 1291
NGC 2146
NGC 3049
NGC 1097
DDO 165
NGC 5408
NGC 337
NGC 5398
NGC 4236
DDO 53
IC 2574
NGC 3351
NGC 4631
Holmberg II
Holmberg I
NGC 1512
NGC 3198
M81 Dw B
NGC 4625

Elliptical *S0* *Sa* *Sb* *Sc* *Sd*

SBa *SBb* *SBc* *SBd*

Irregular

MIPS 24 µm / PACS 100 µm / SPIRE 250 µm

[O III] line maps

Kingfish (Key Insights on Nearby Galaxies:
a Far-Infrared Survey with Herschel)

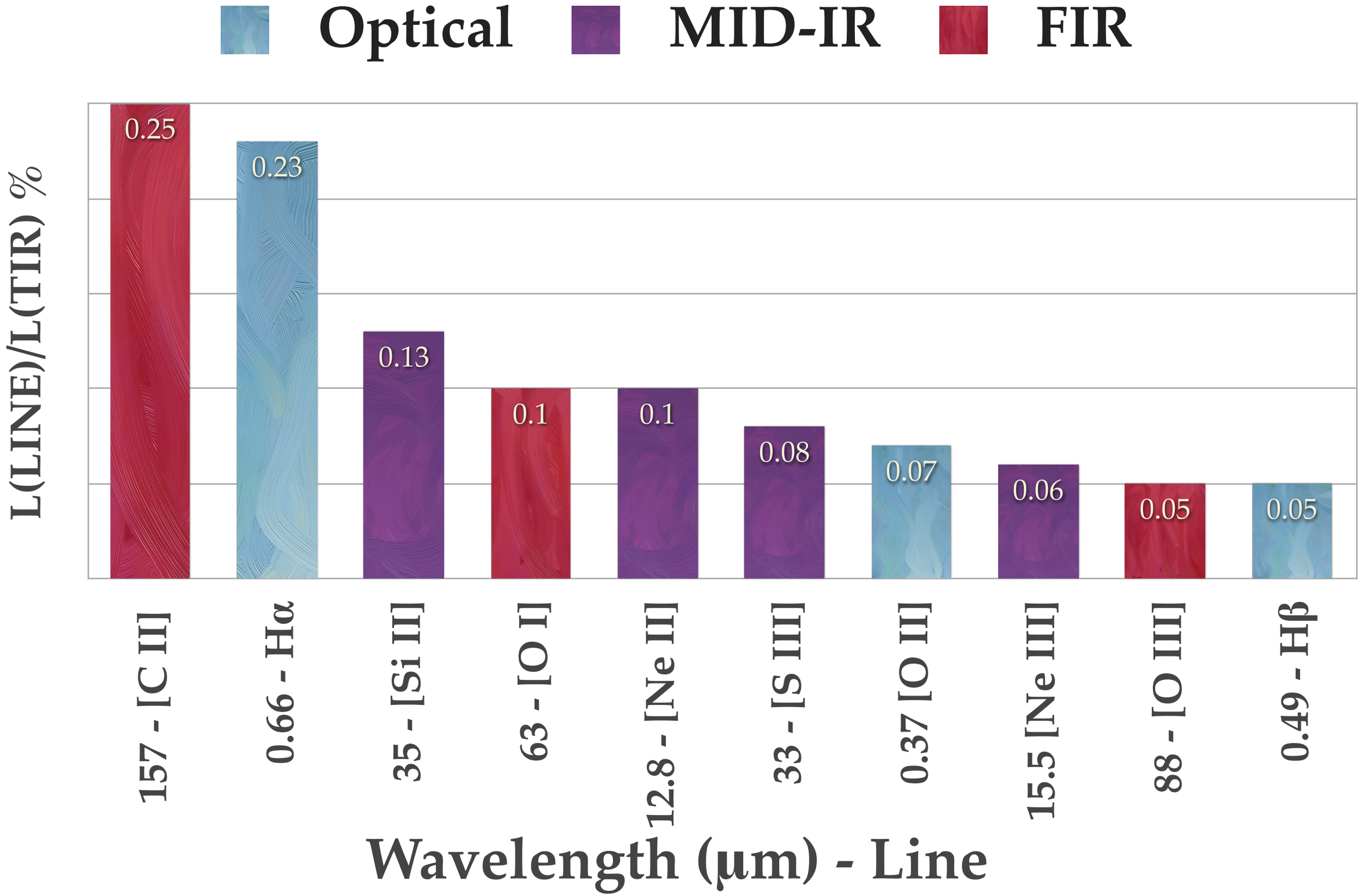
Elliptical — S0 — Sa — Sb — Sc — Sd

SBa — SBb — SBc — SBd

Irregular

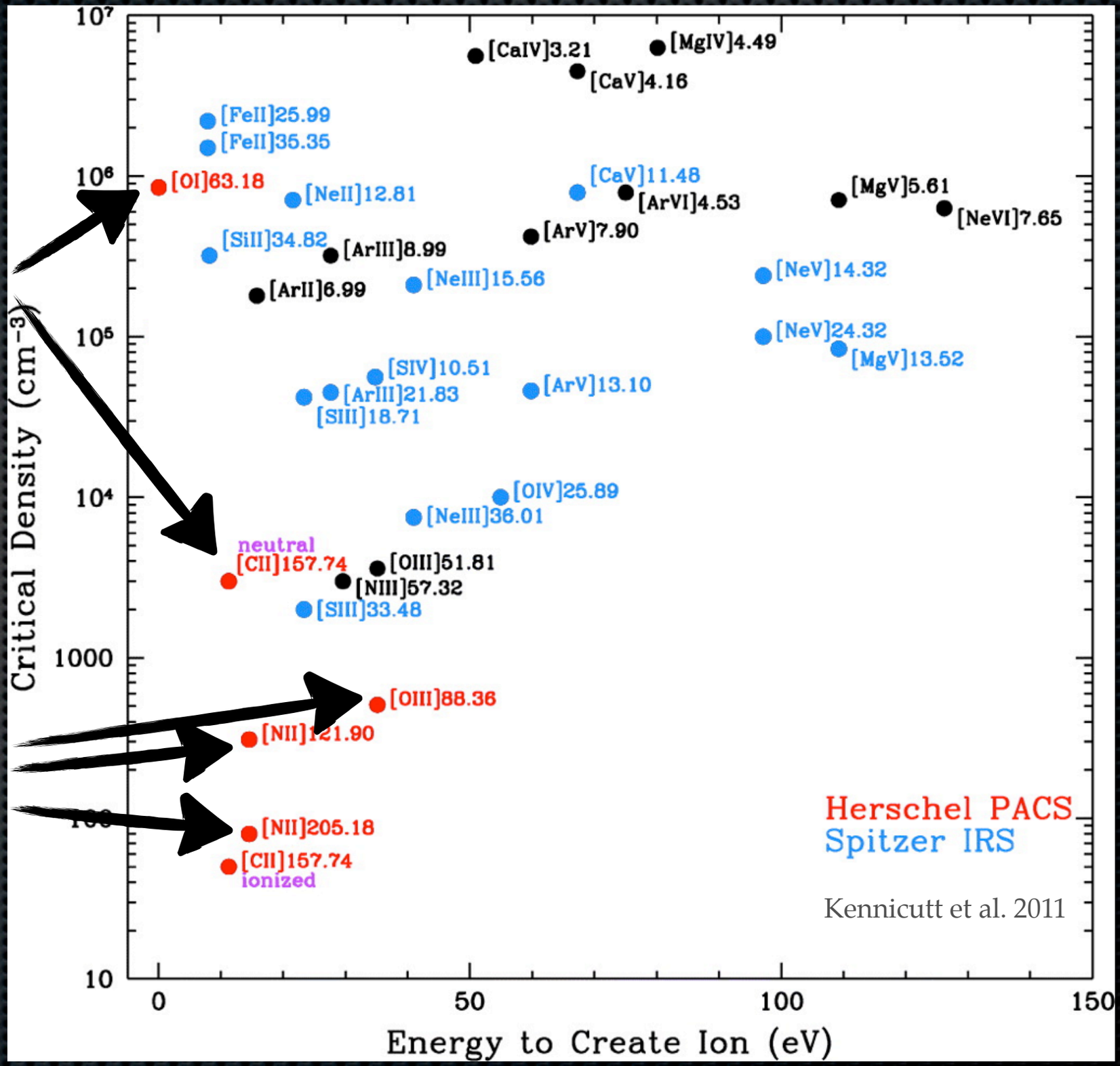
MIPS 24 μm / PACS 100 μm / SPIRE 250 μm

10 brightest (observed) spectral lines:



Principal neutral gas cooling lines

Ionized gas diagnostics

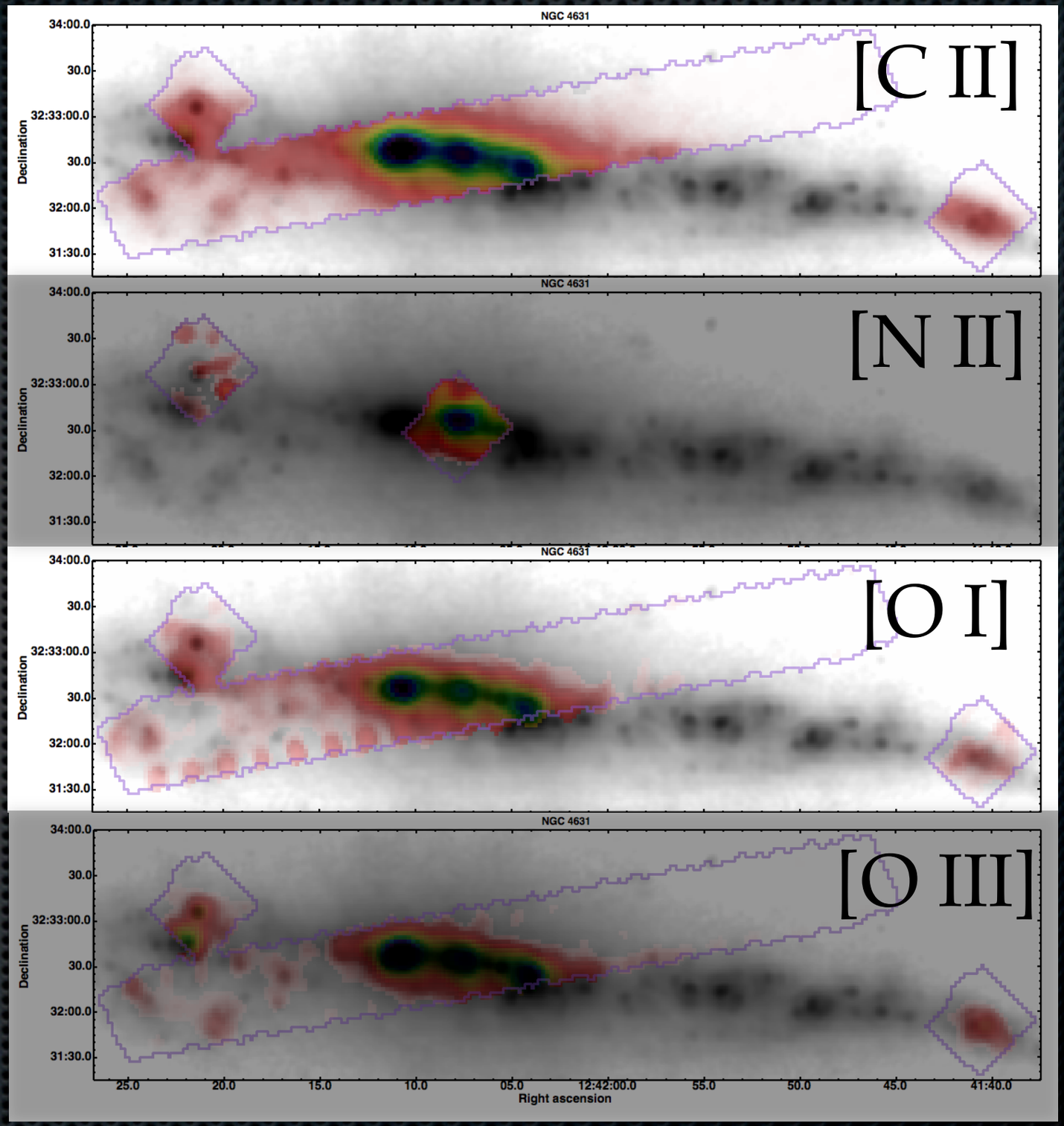


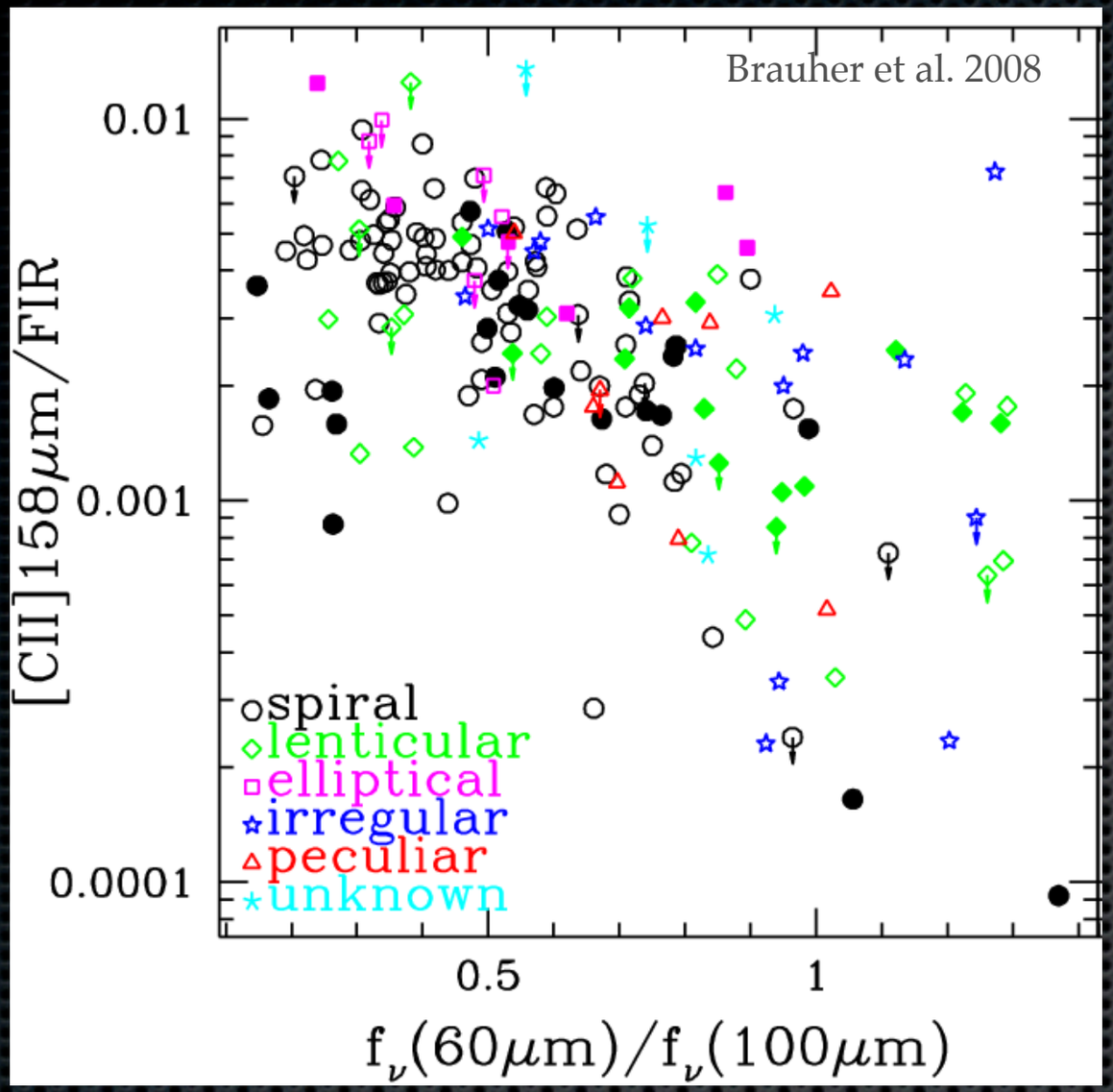
NGC 4631

<u>Goal 1:</u>

Study gas heating + cooling.

What causes [CII] deficit? Linked with PAHs?





The “[CII] deficit”

Intense radiation field

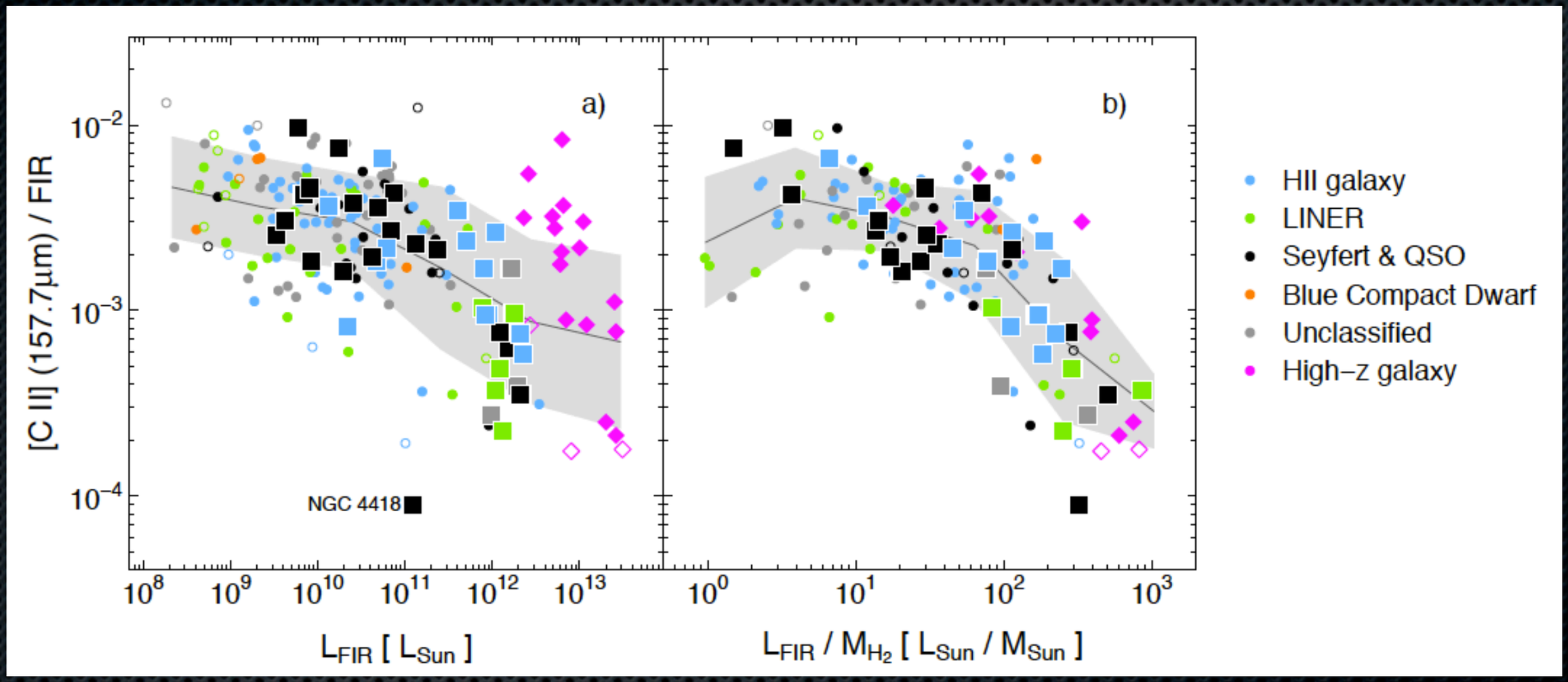
↓

Positive ionization of dust

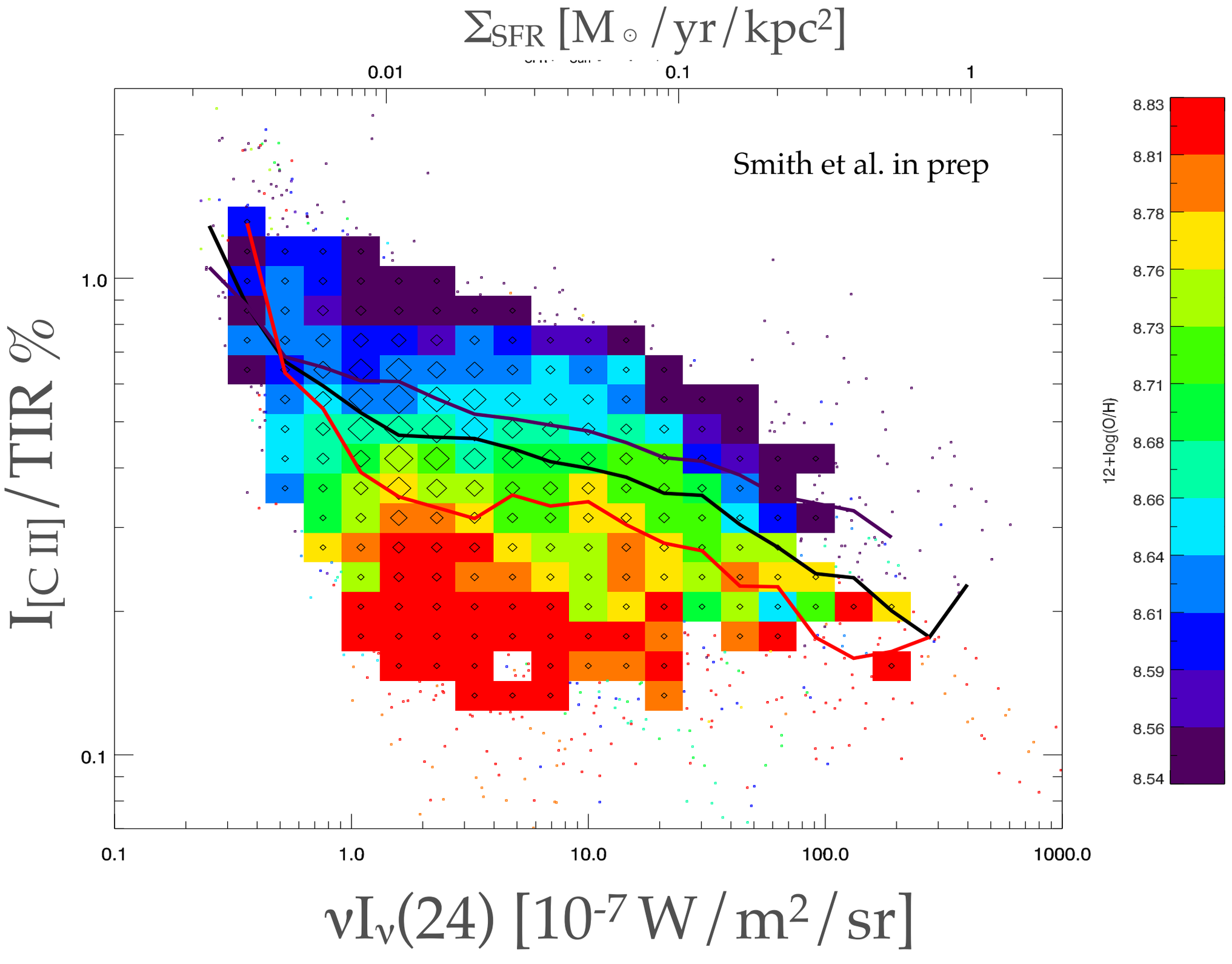
↓

Lower rate of e- ejection

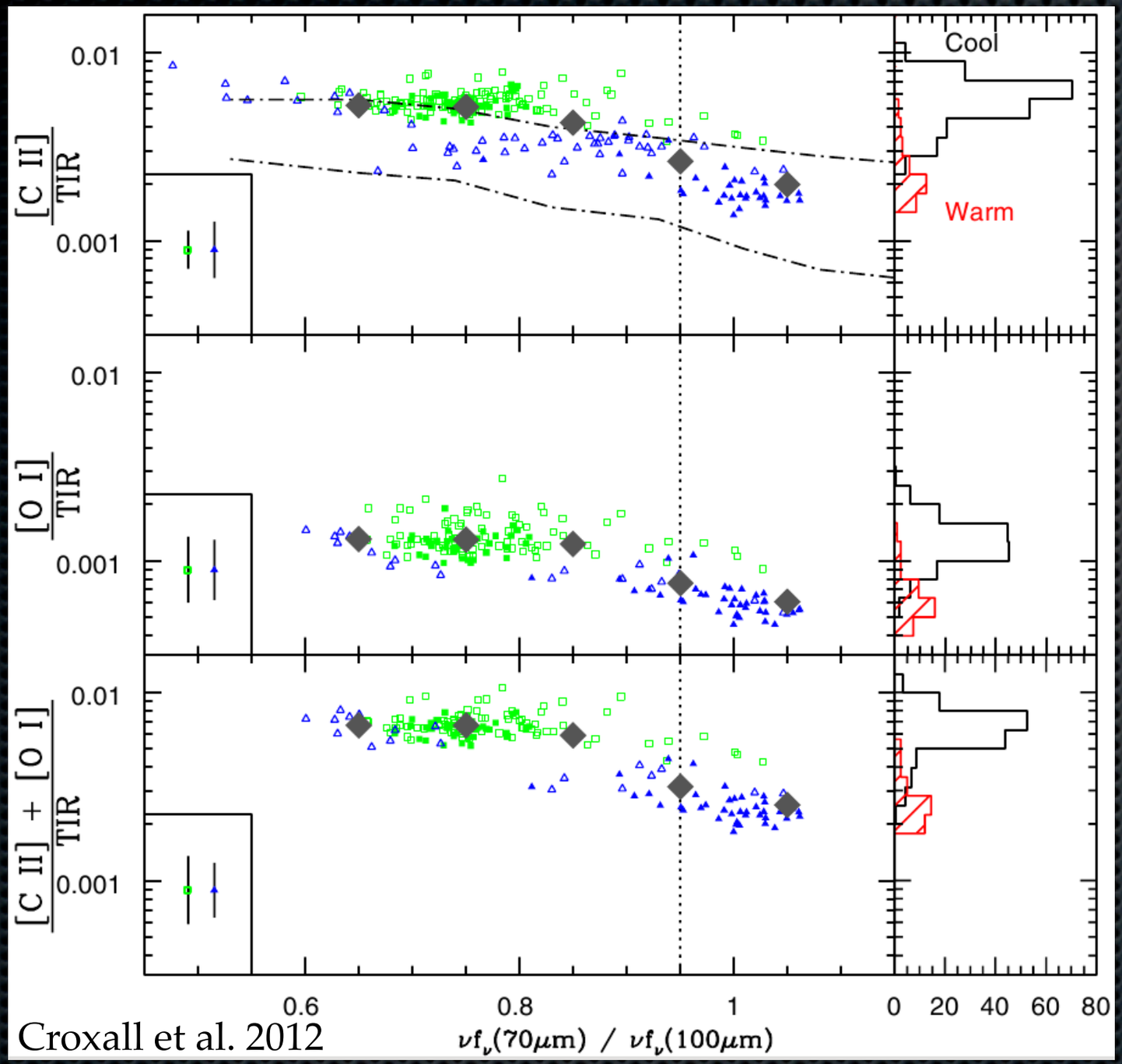
With Herschel:



Scatter is partly metallicity:



Same pattern within galaxies:



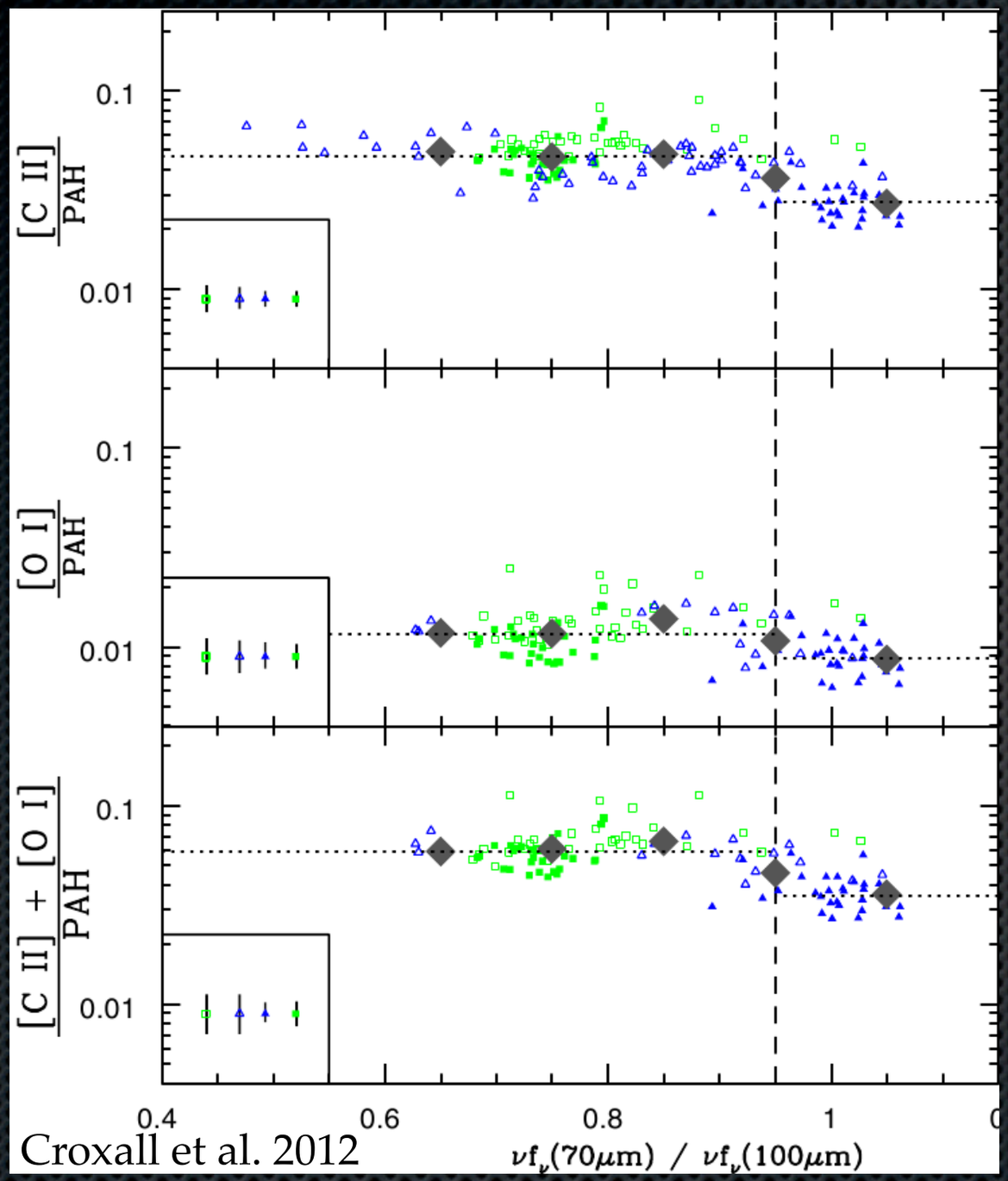
Croxall et al. 2012

NGC 4559

NGC 1097

Hardness, not just intensity of radiation field may matter.

Shallower trend within PAHs:

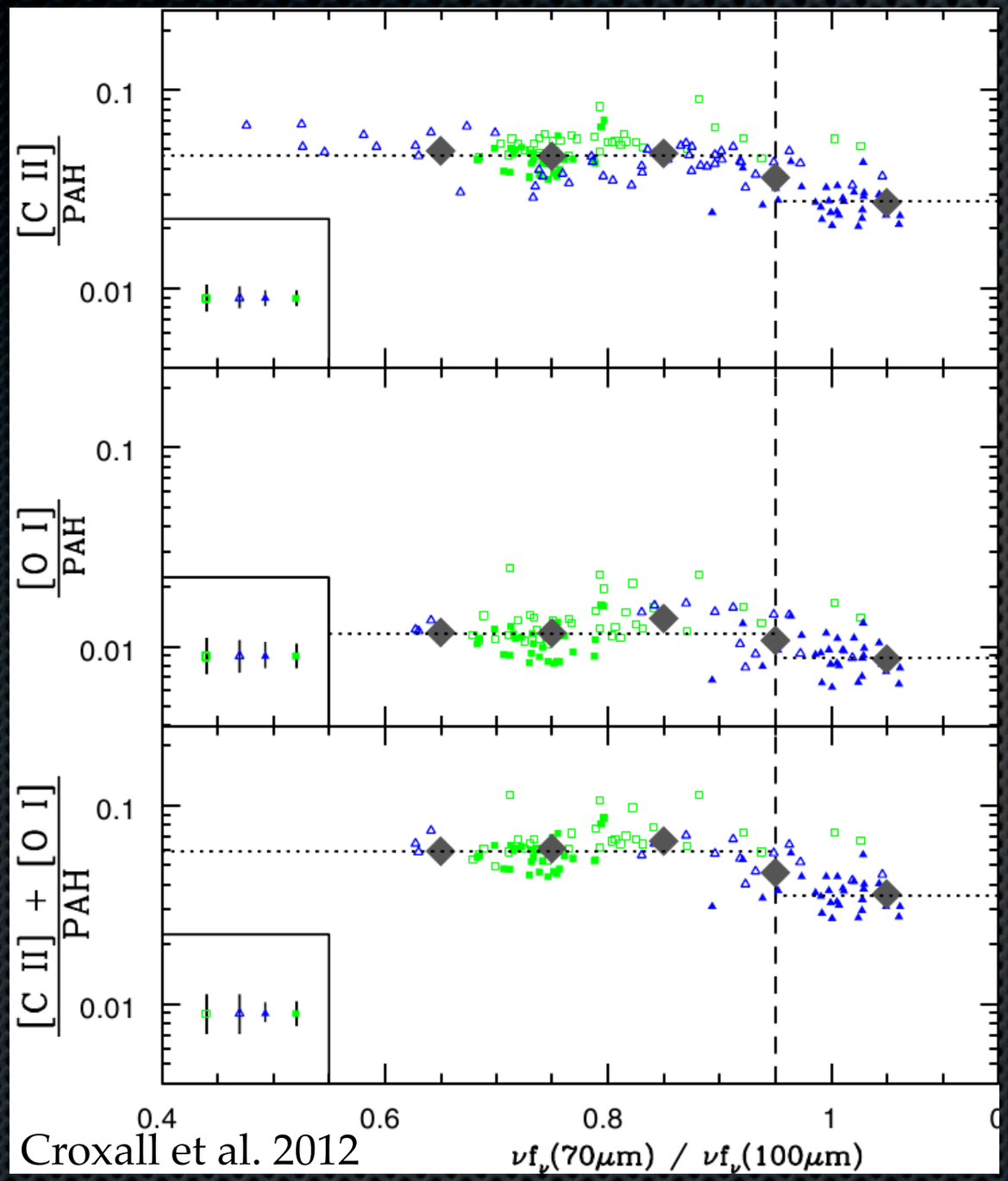


NGC 4559

NGC 1097

Croxall et al. 2012

Shallower trend within PAHs:



Croxall et al. 2012

NGC 4559

NGC 1097

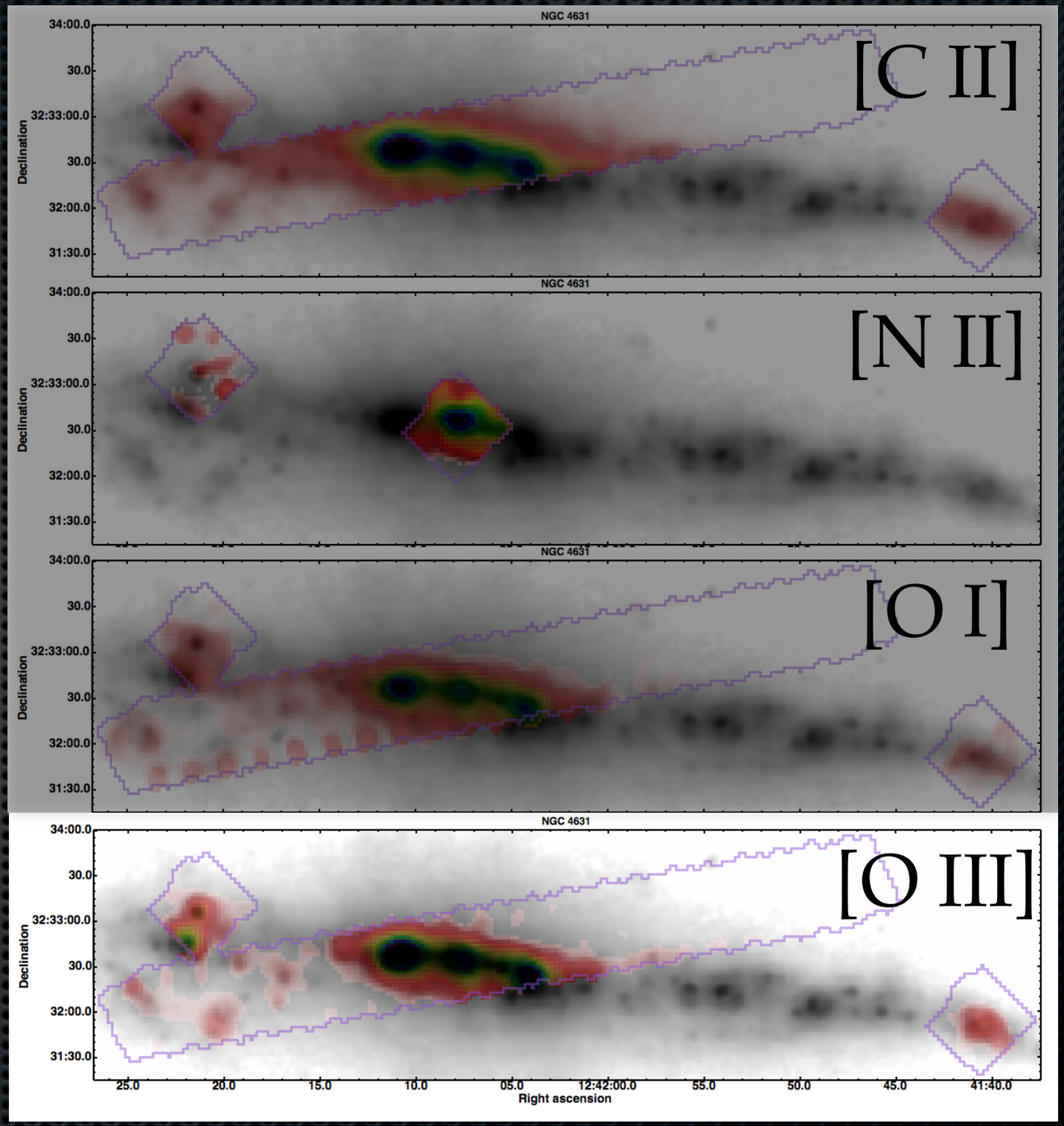
PAHs more tied to gas heating than big grains.

See Beirao et al. 2012 for hints that PAHs are ionized at high intensities.

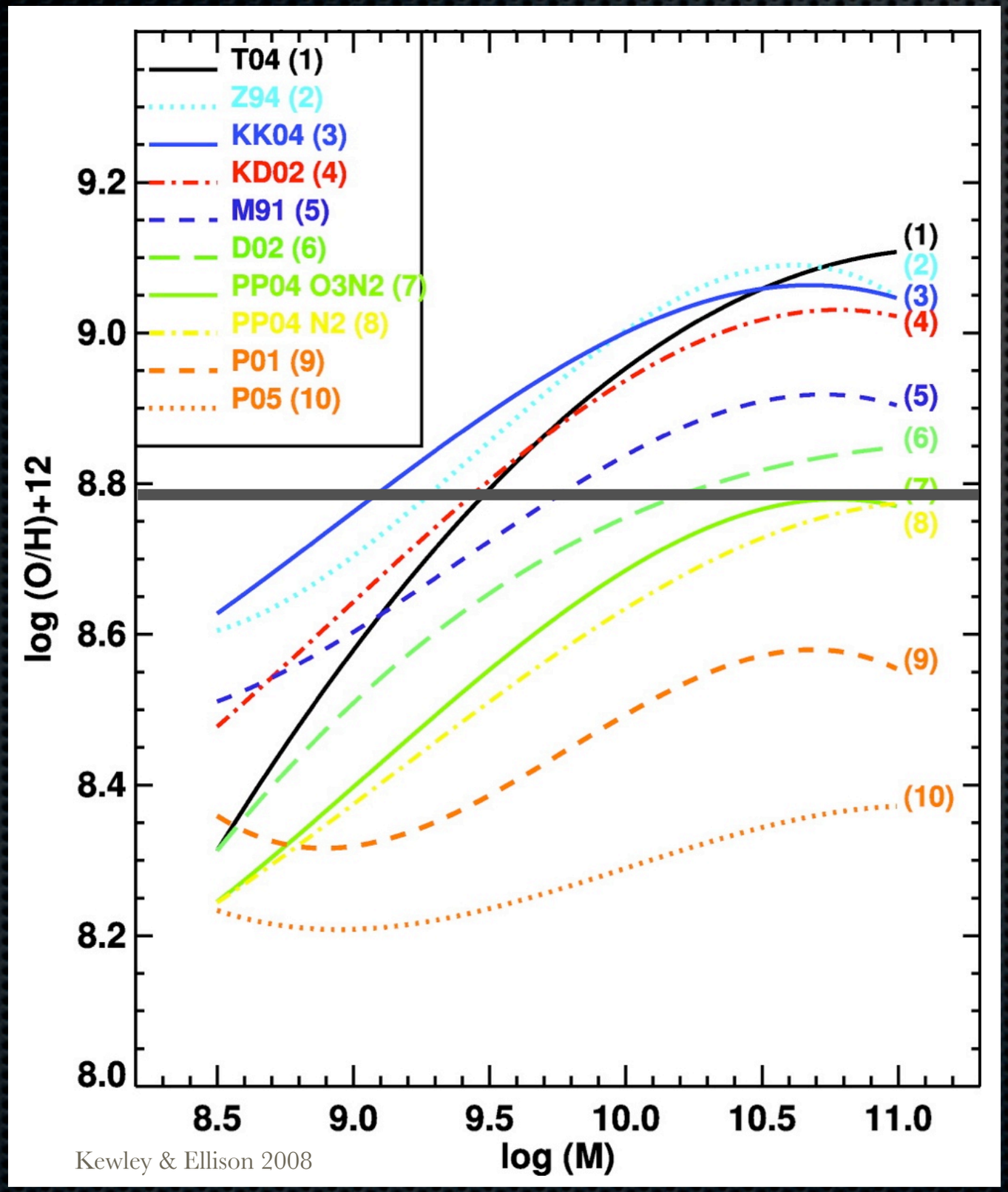
NGC 4631

<u>Goal 2:</u>

Stronger constraint on HII region metallicities.



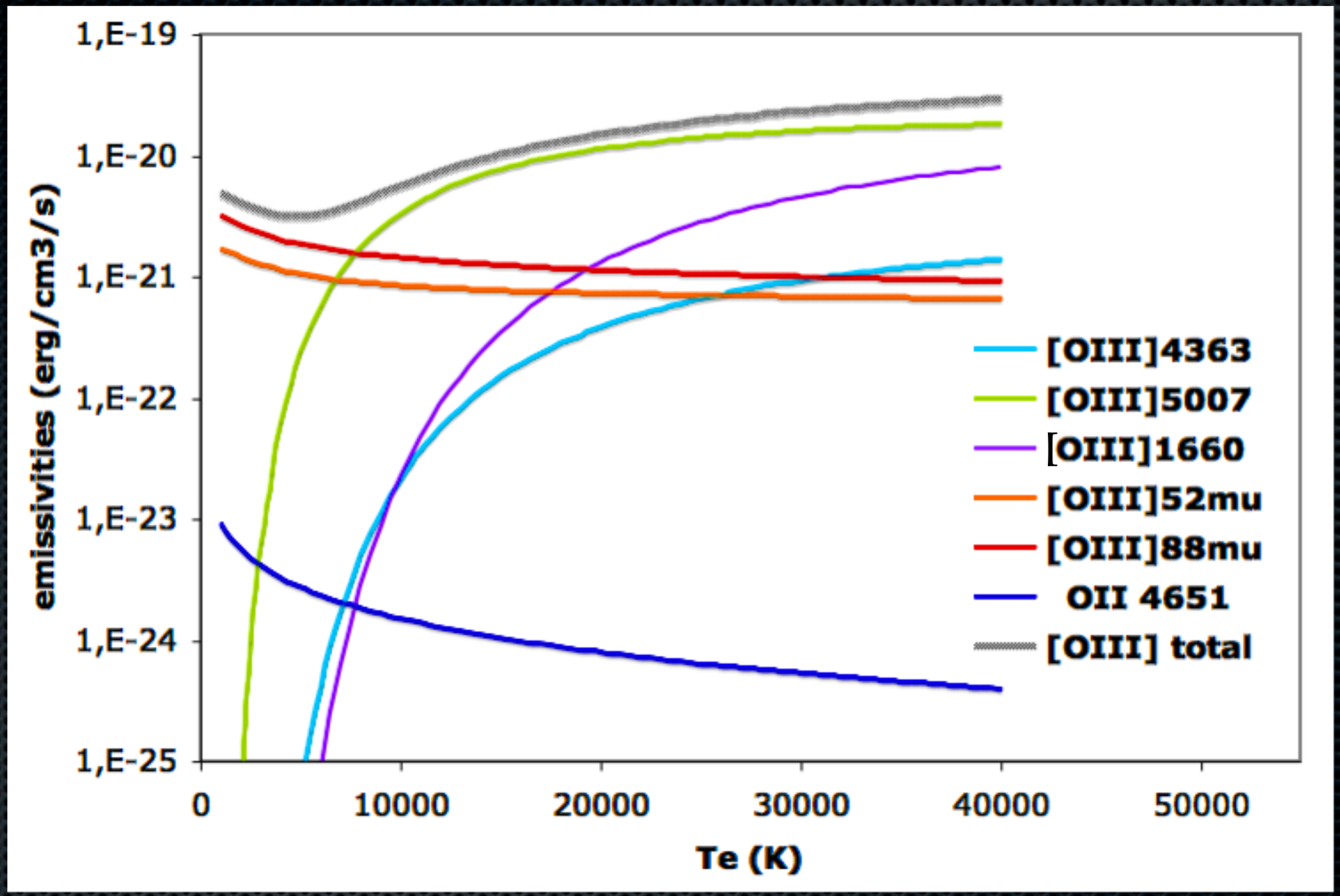
Abundances unknown...



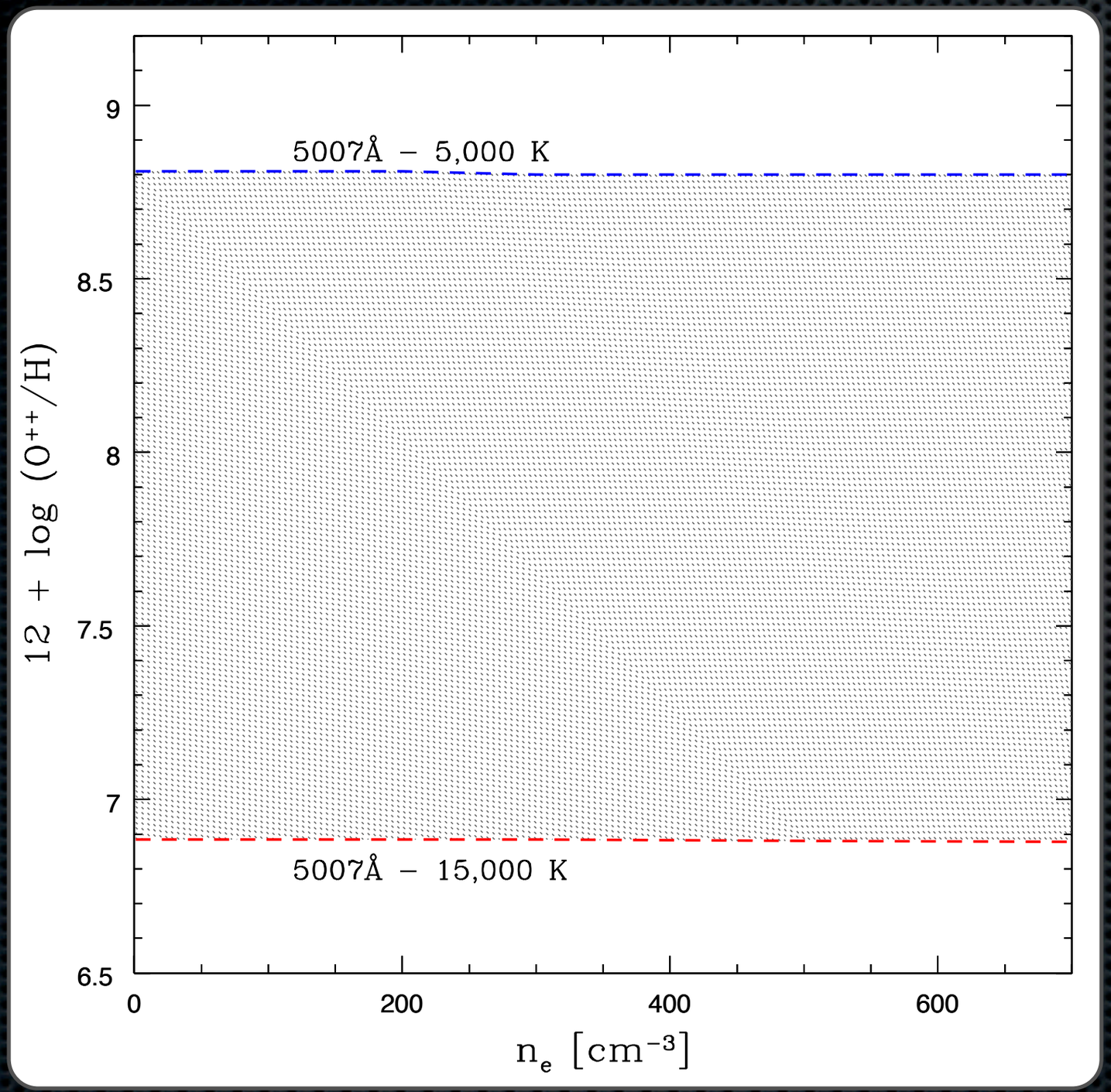
} - Photoionization models

Solar Ayres

} - Empirical Solutions

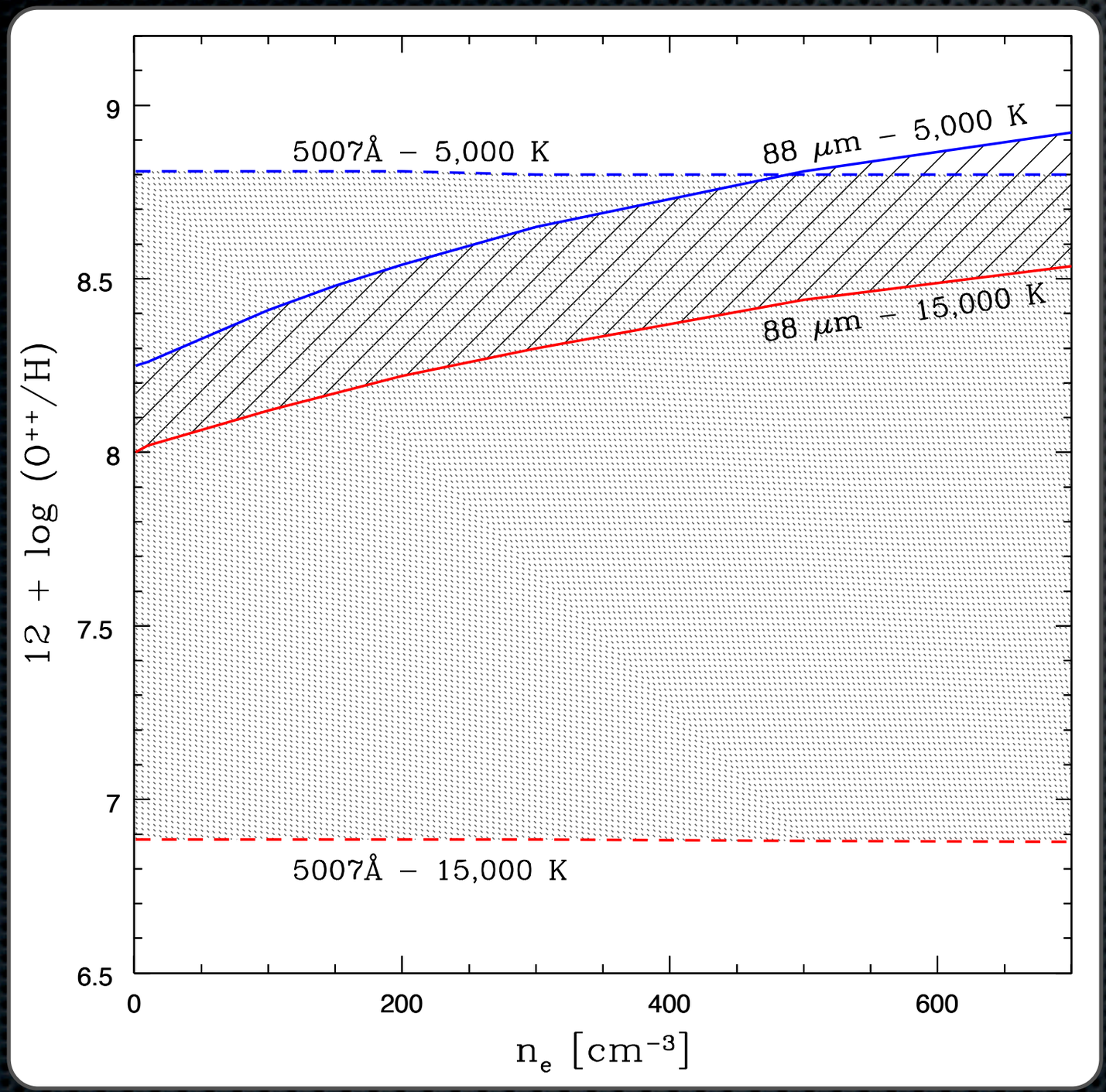


IR lines helpfully insensitive to temperature.



Using the FIR data can place stronger constraints on the abundance of (O^{++}/H)

Constraints on density further limit the uncertainty



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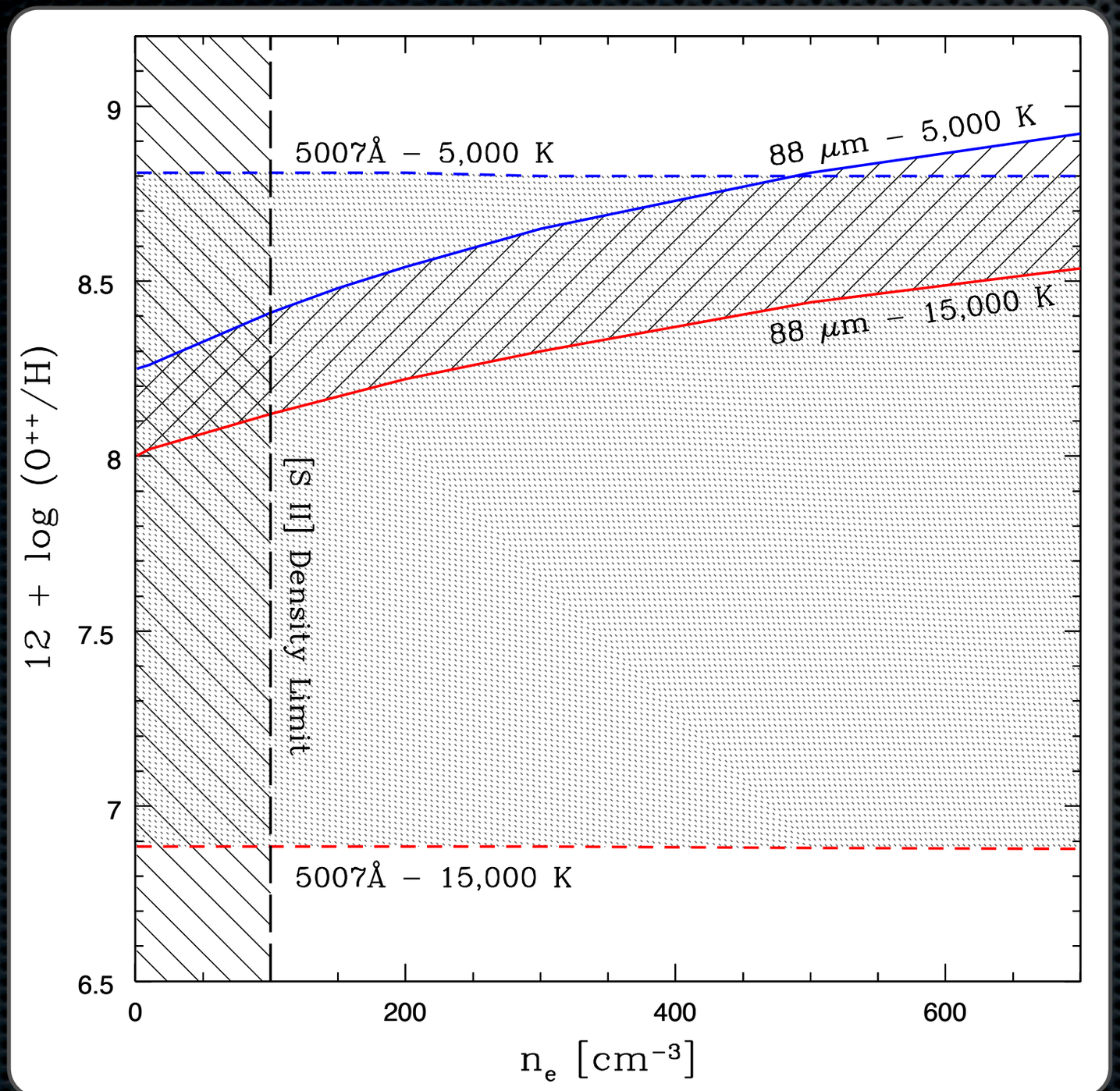

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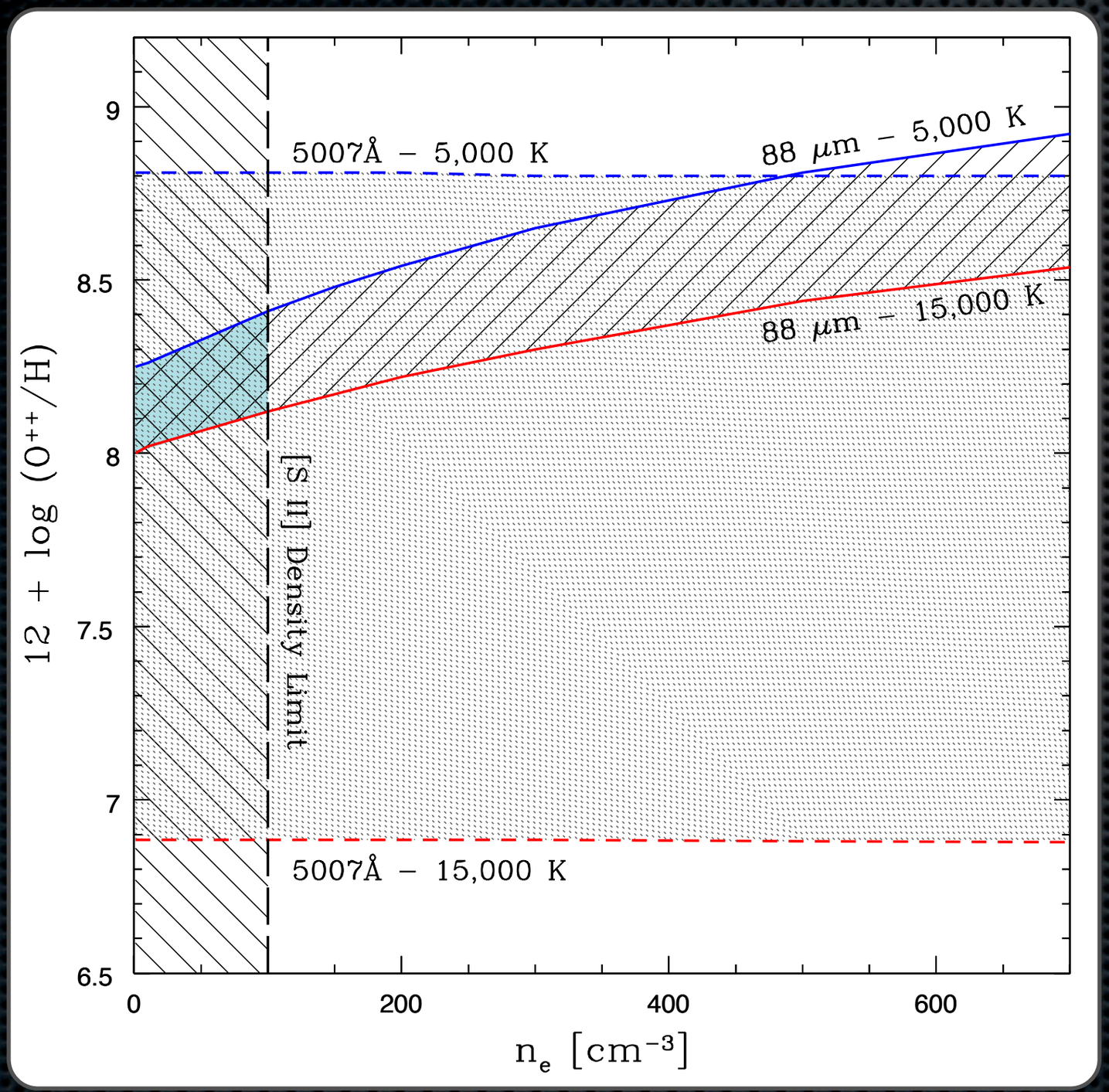


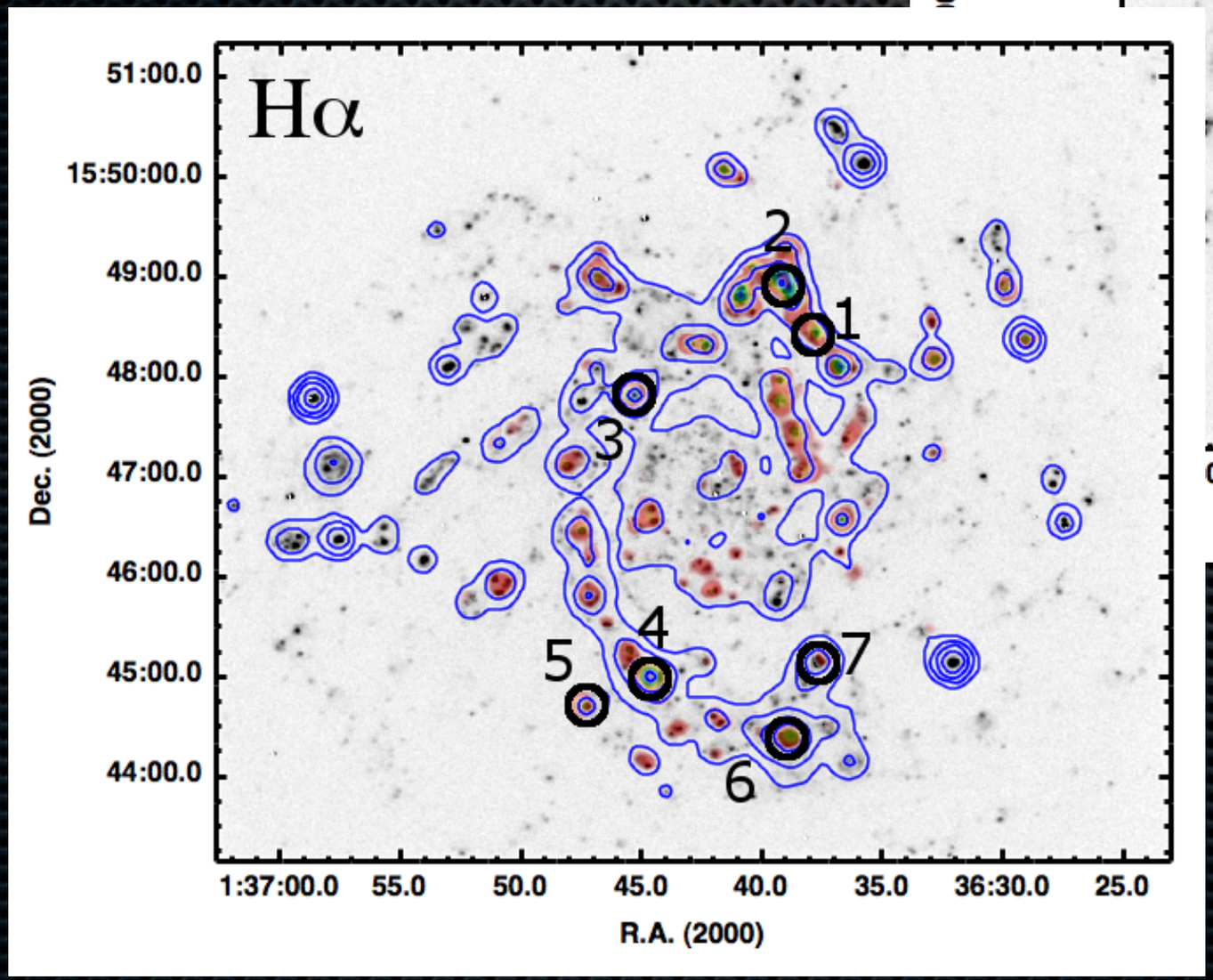
Using the FIR data can place stronger constraints on the abundance of (O^{++}/H)

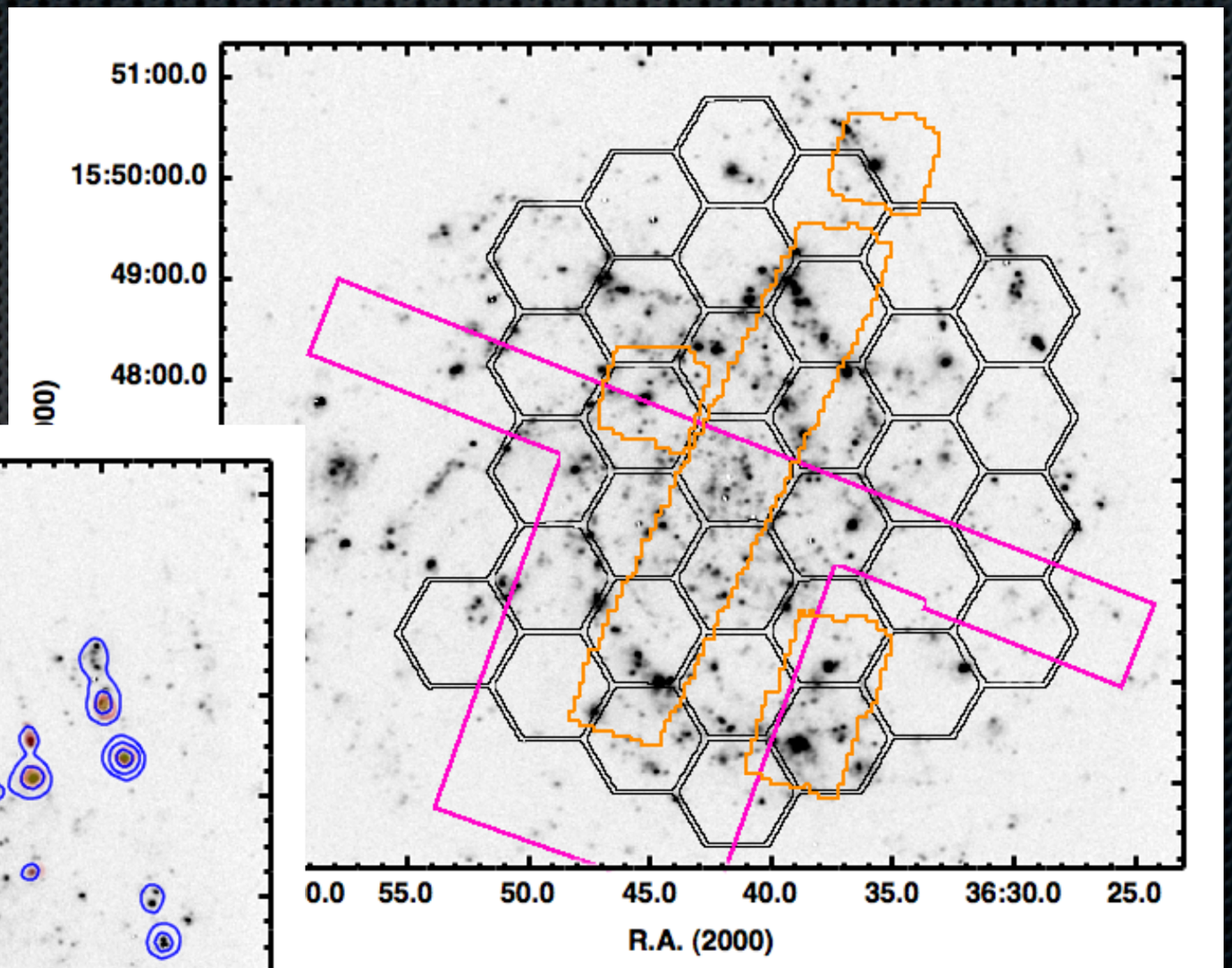
Constraints on density further limit the uncertainty

An investigation of NGC 628:

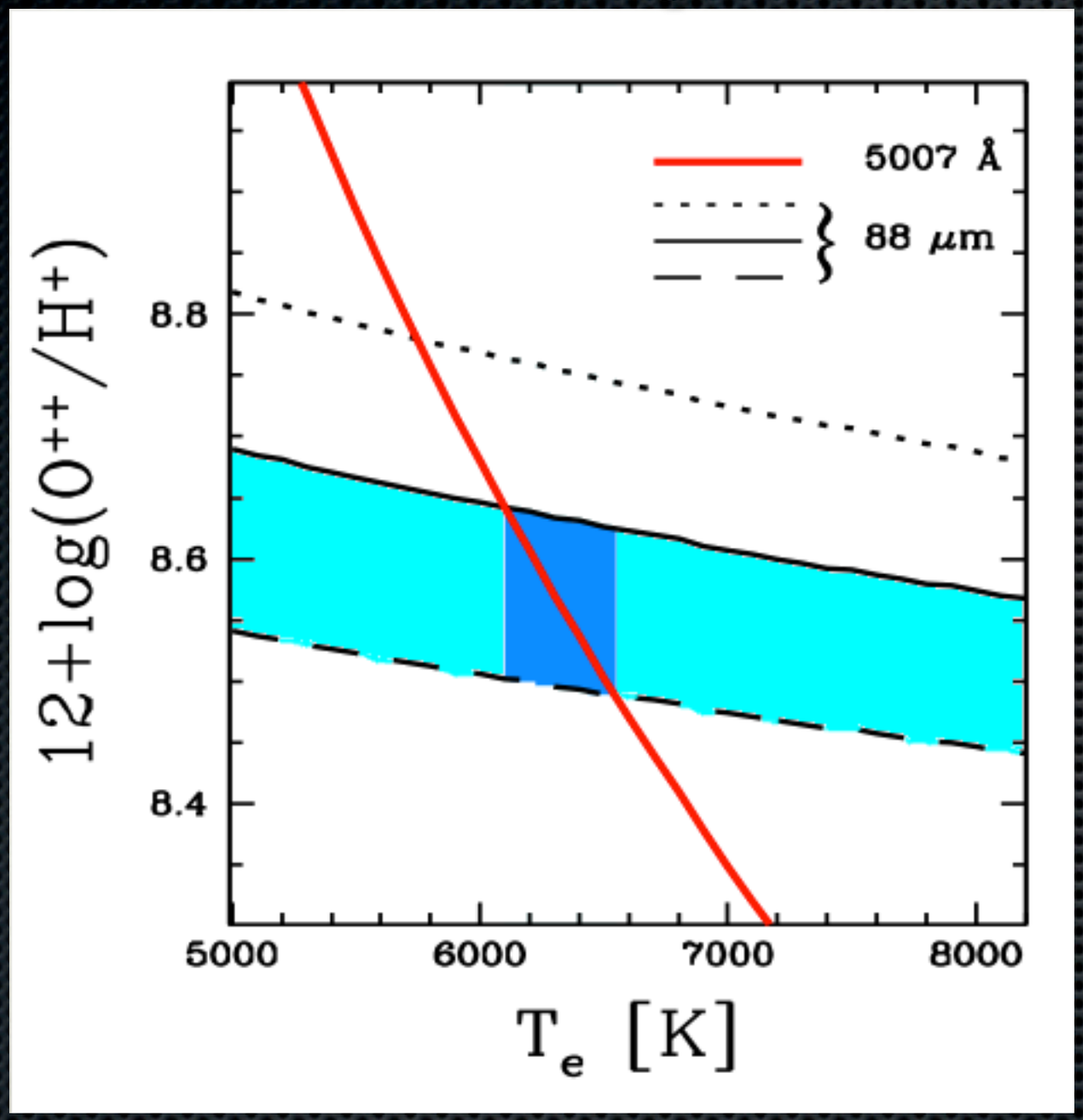
KK04 SINGS : 9.02 ± 0.01

PT05 SINGS : 8.35 ± 0.01





NGC 628 Region 7:



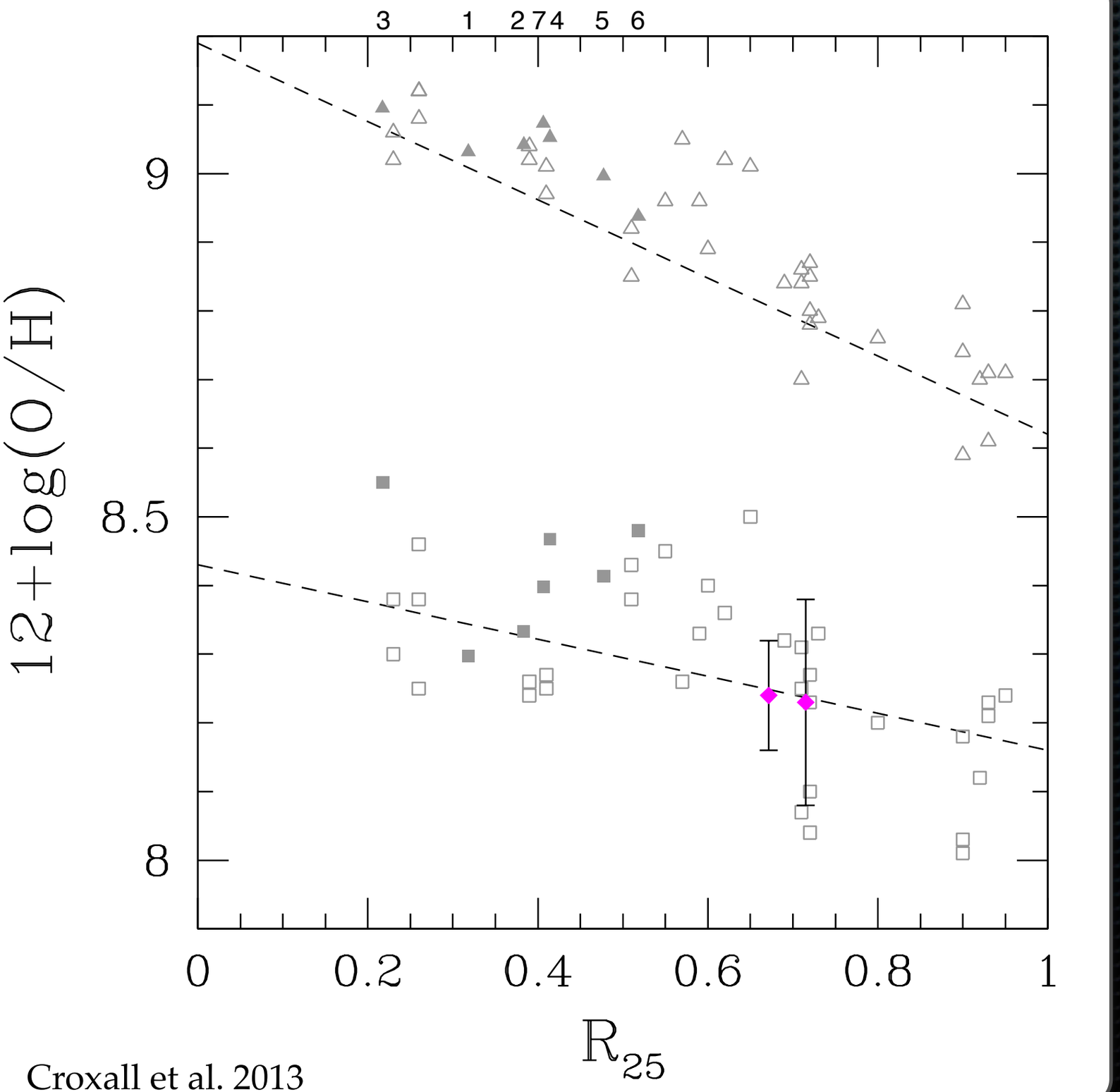
[OIII] 88 line + [SII] density constraint gives light blue band.

Add in optical [OIII] 5007Å for even narrower constraint.

KK04 (**MOD**)

PT05 (Emp)

λ4363 (Dir)



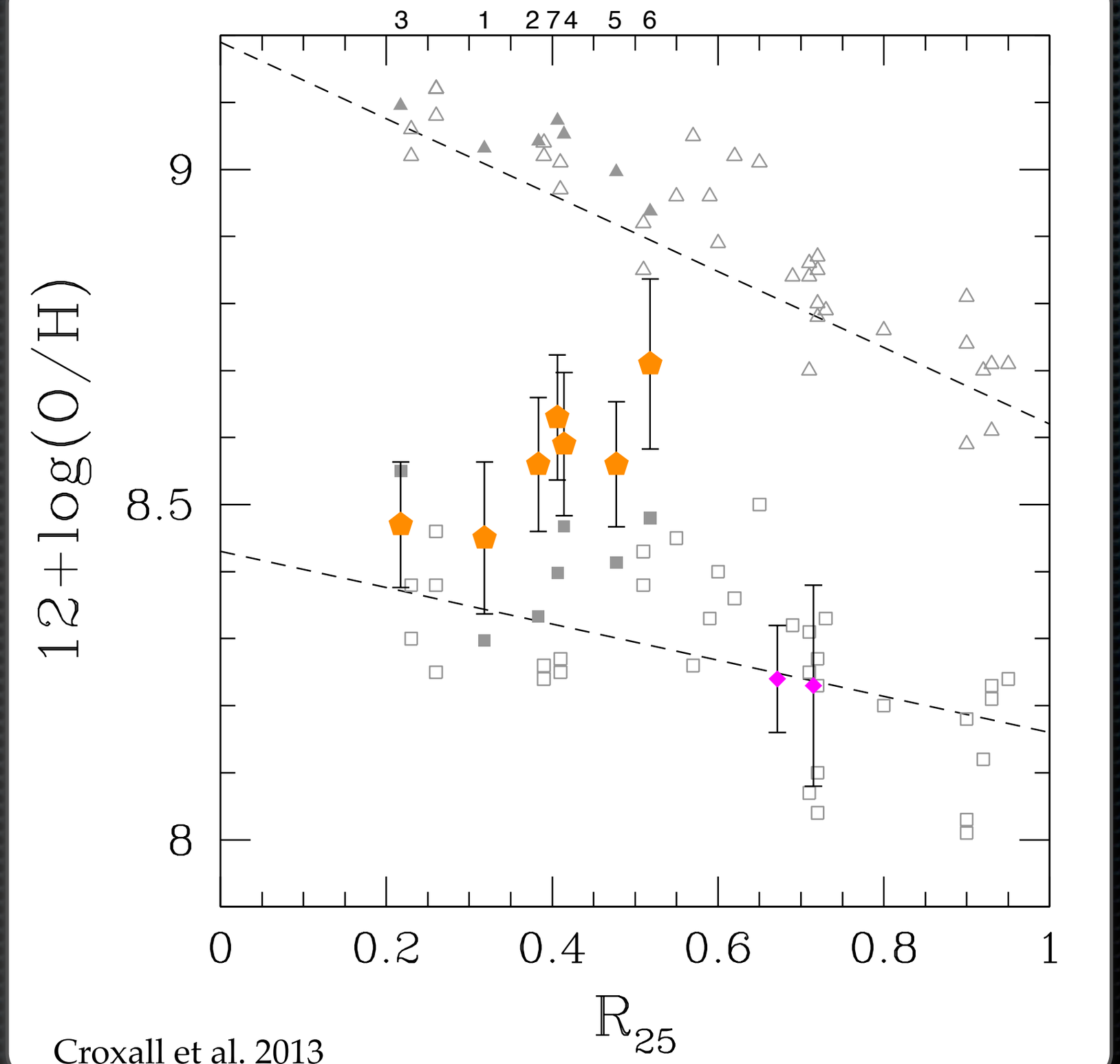
Croxall et al. 2013

FIR + Opt

KK04 (MOD)

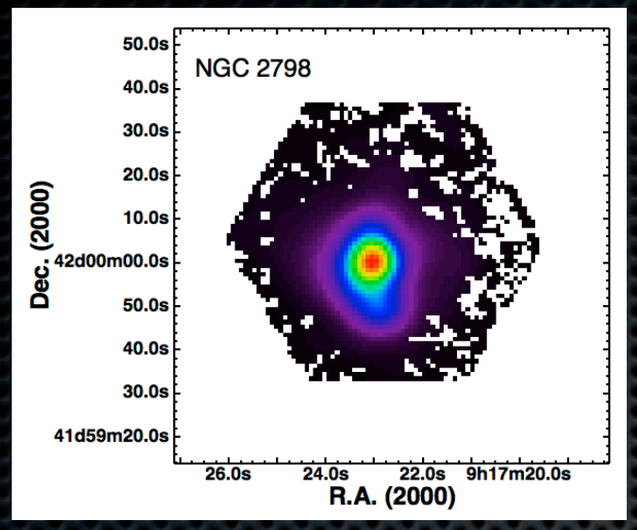
PT05 (Emp)

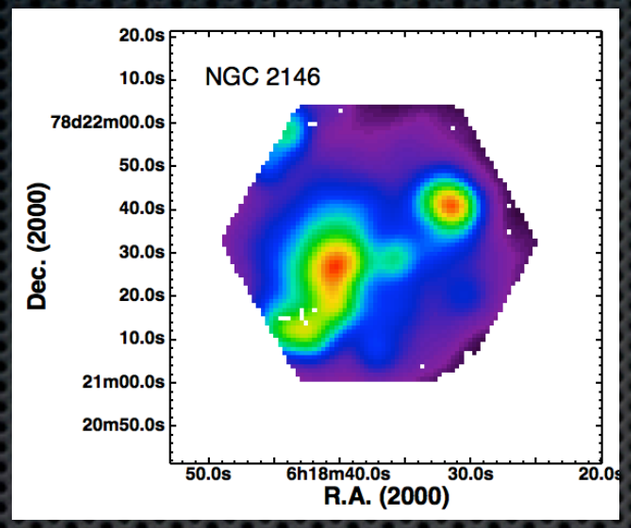
λ4363 (Dir)

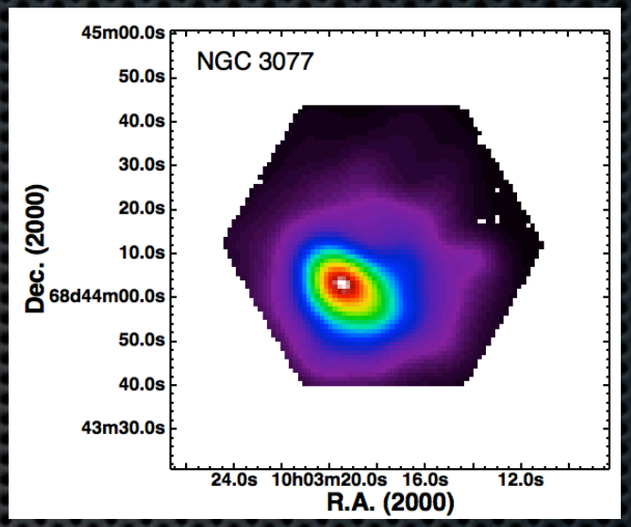


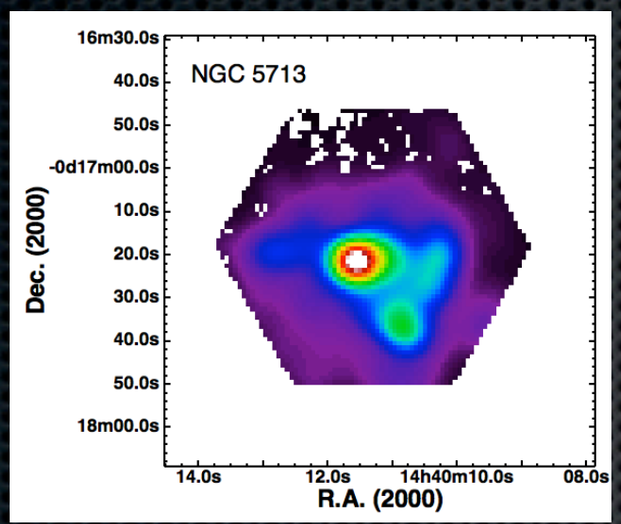
Croxall et al. 2013

Future!


NGC 2798
Dec. (2000)
50.0s
40.0s
30.0s
20.0s
10.0s
42d00m00.0s
50.0s
40.0s
30.0s
41d59m20.0s
26.0s
24.0s
22.0s
9h17m20.0s
R.A. (2000)


NGC 2146
Dec. (2000)
20.0s
10.0s
78d22m00.0s
50.0s
40.0s
30.0s
20.0s
10.0s
21m00.0s
20m50.0s
50.0s
6h18m40.0s
30.0s
20.0s
R.A. (2000)


NGC 3077
Dec. (2000)
45m00.0s
50.0s
40.0s
30.0s
20.0s
10.0s
68d44m00.0s
50.0s
40.0s
43m30.0s
24.0s
10h03m20.0s
16.0s
12.0s
R.A. (2000)


NGC 5713
Dec. (2000)
16m30.0s
40.0s
50.0s
-0d17m00.0s
10.0s
20.0s
30.0s
40.0s
50.0s
18m00.0s
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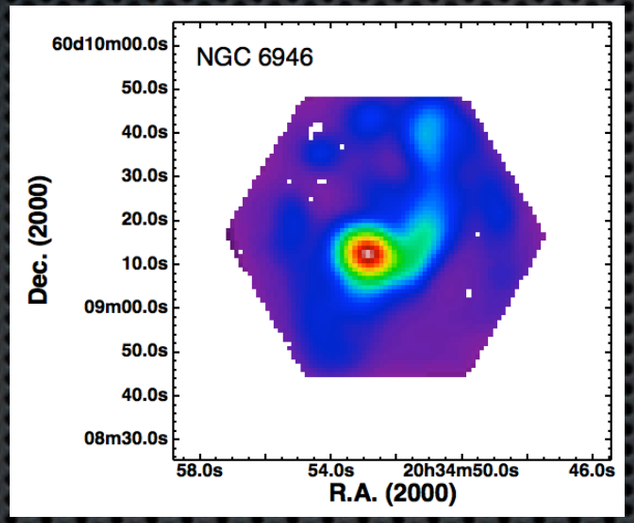
12.0s
14h40m10.0s
08.0s
R.A. (2000)


NGC 6946
Dec. (2000)
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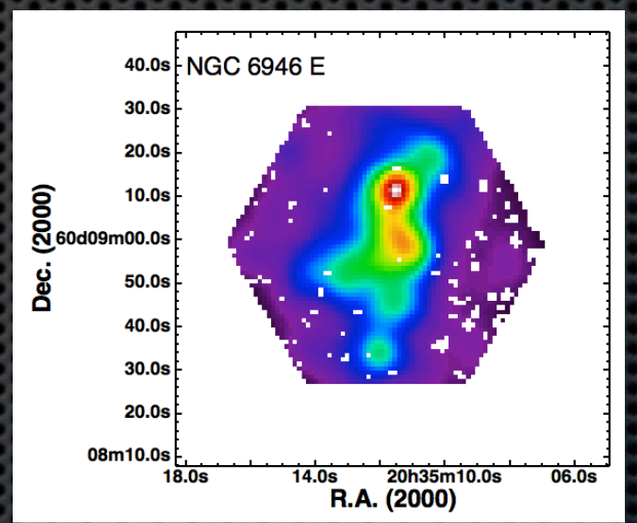
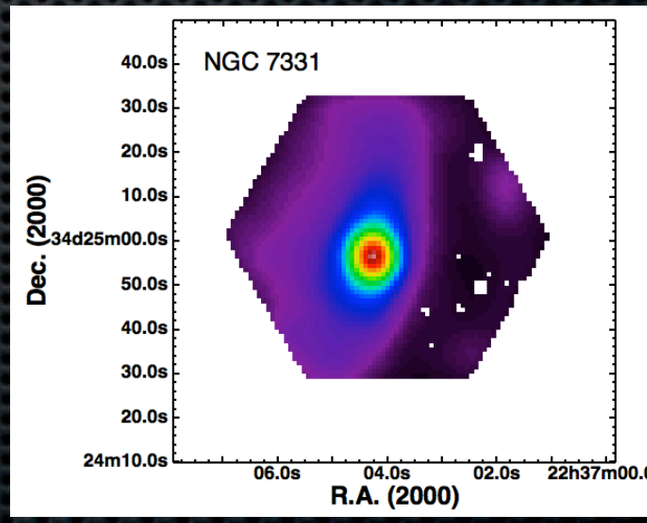
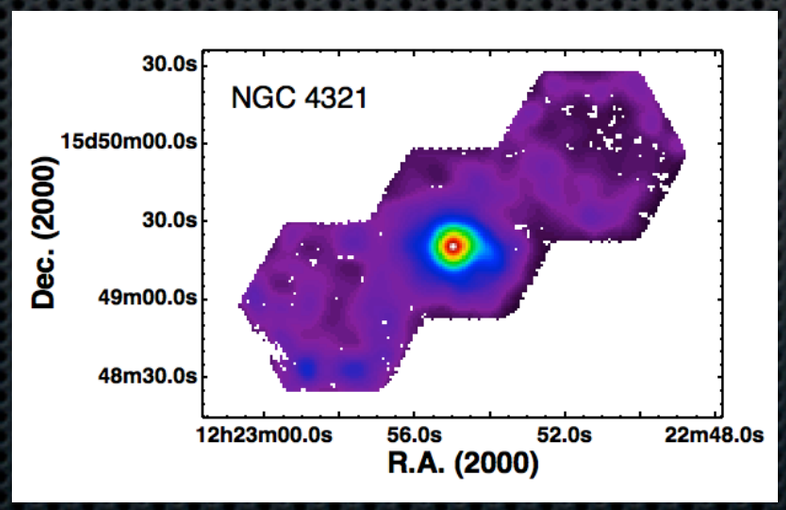
50.0s
40.0s
30.0s
20.0s
10.0s
09m00.0s
50.0s
40.0s
08m30.0s
58.0s
54.0s
20h34m50.0s
46.0s
R.A. (2000)


NGC 6946 E
Dec. (2000)
40.0s
30.0s
20.0s
10.0s
60d09m00.0s
50.0s
40.0s
30.0s
20.0s
08m10.0s
18.0s
14.0s
20h35m10.0s
06.0s
R.A. (2000)


NGC 7331
Dec. (2000)
40.0s
30.0s
20.0s
10.0s
34d25m00.0s
50.0s
40.0s
30.0s
20.0s
24m10.0s
06.0s
04.0s
02.0s
22h37m00.0s
R.A. (2000)


NGC 4321
Dec. (2000)
30.0s
15d50m00.0s
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48m30.0s
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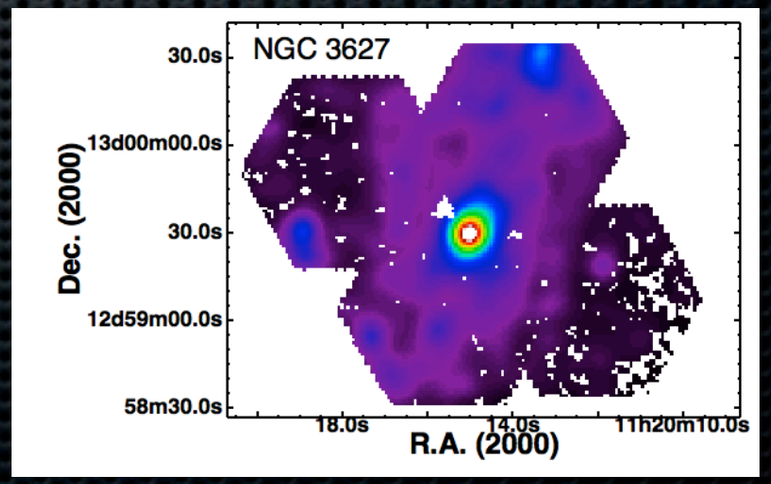
52.0s
22m48.0s
R.A. (2000)


NGC 3627
Dec. (2000)
30.0s
13d00m00.0s
30.0s
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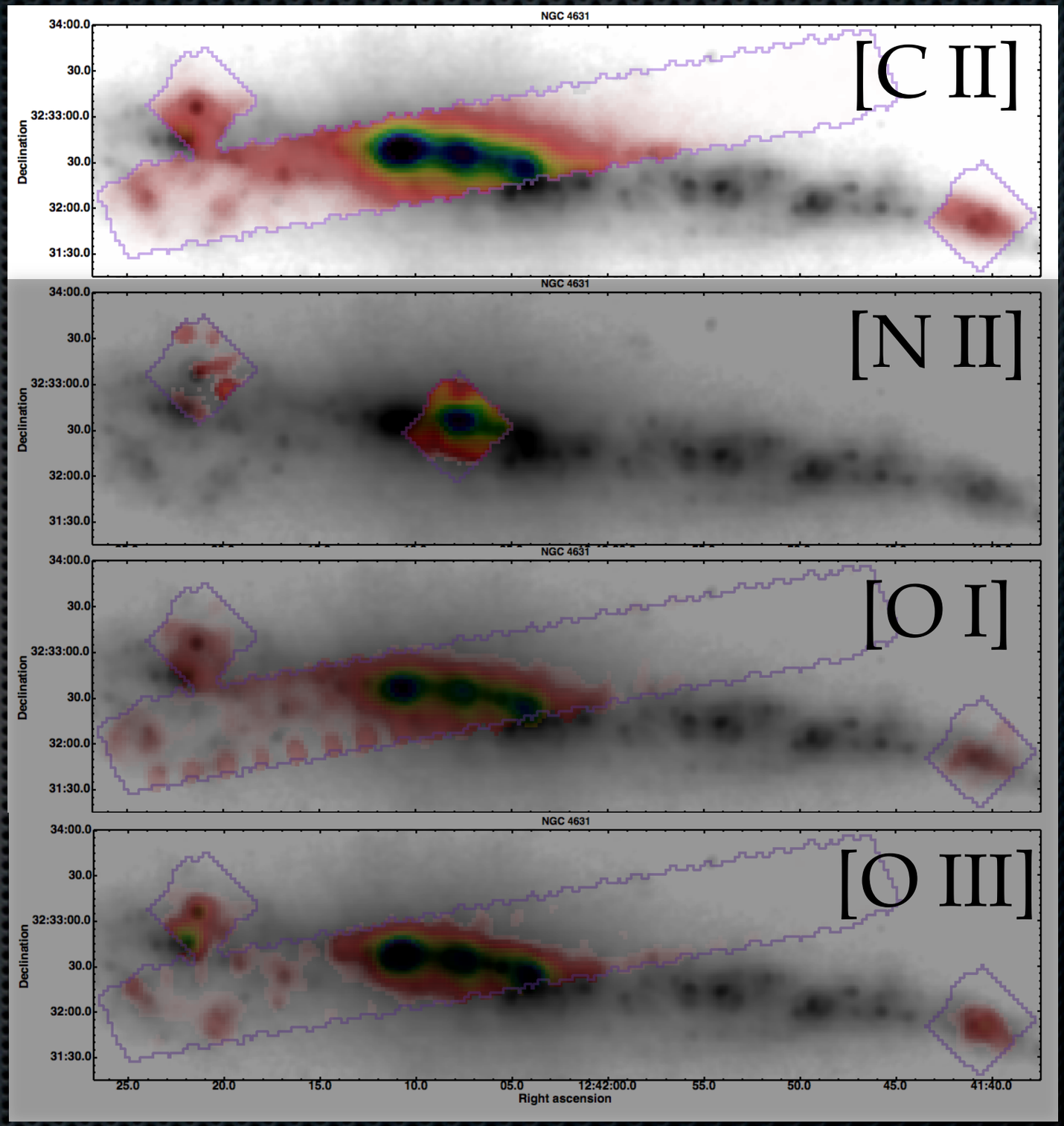
18.0s
14.0s
11h20m10.0s
R.A. (2000)

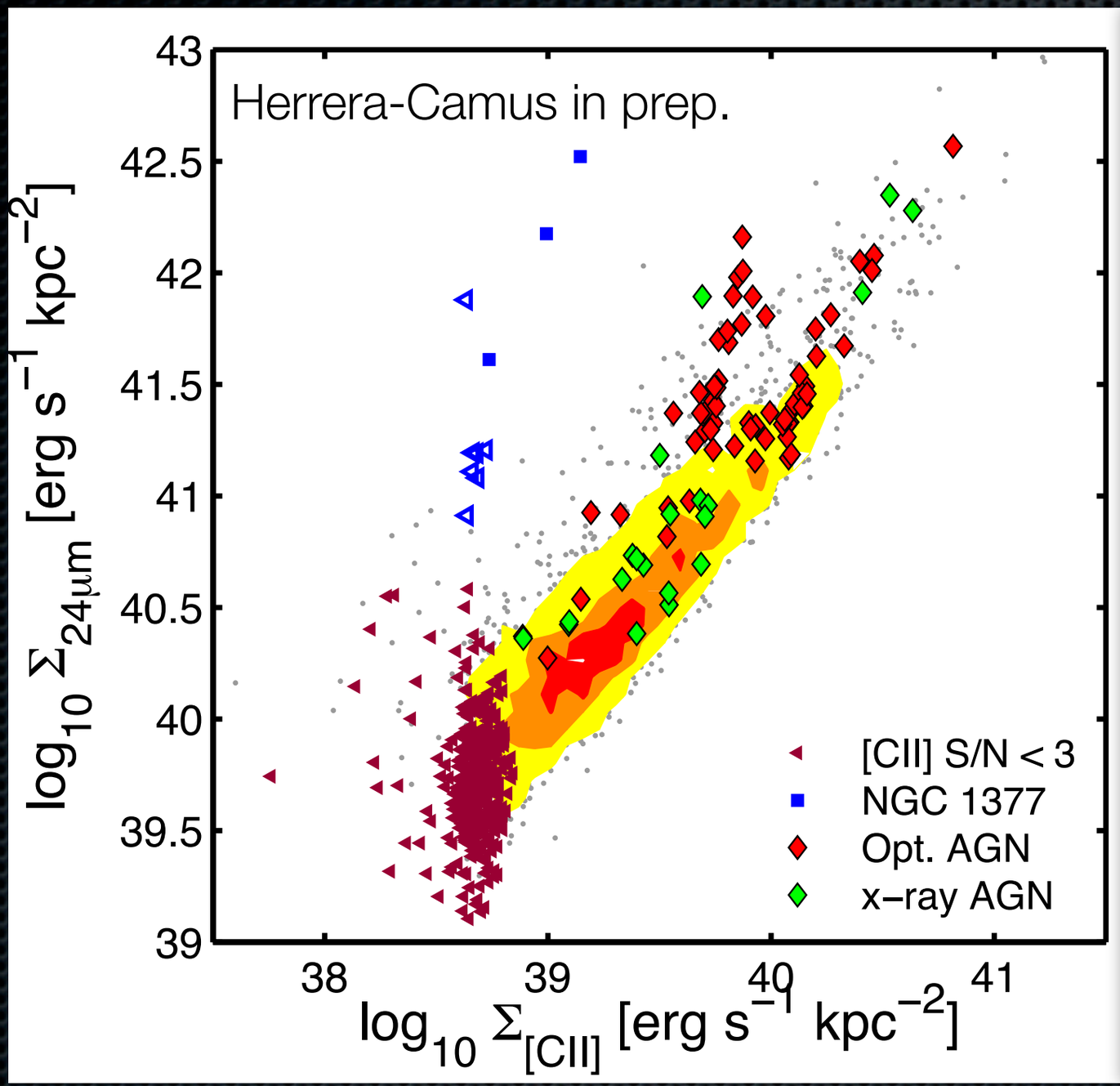
NGC 4631

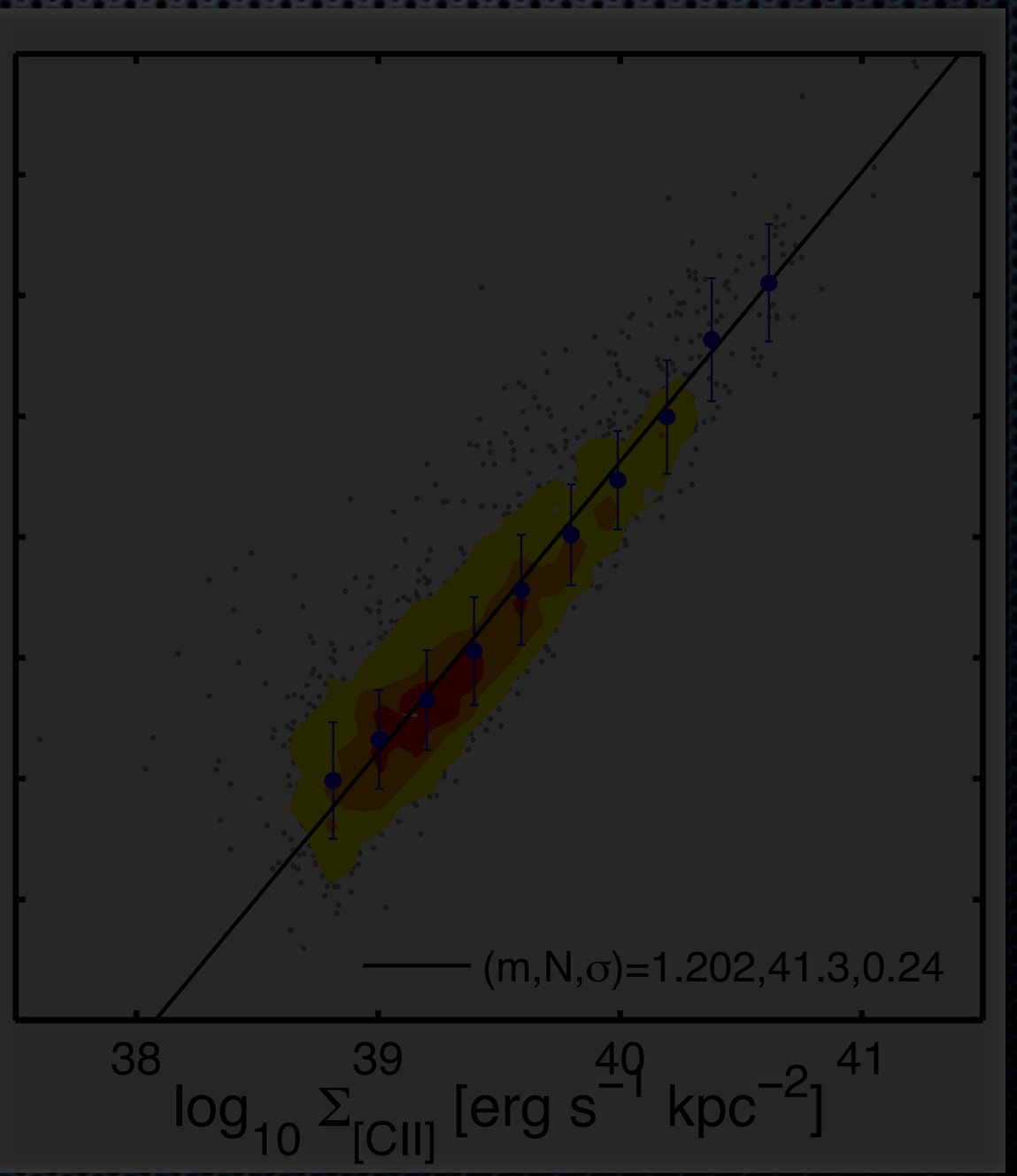


Goal 3:

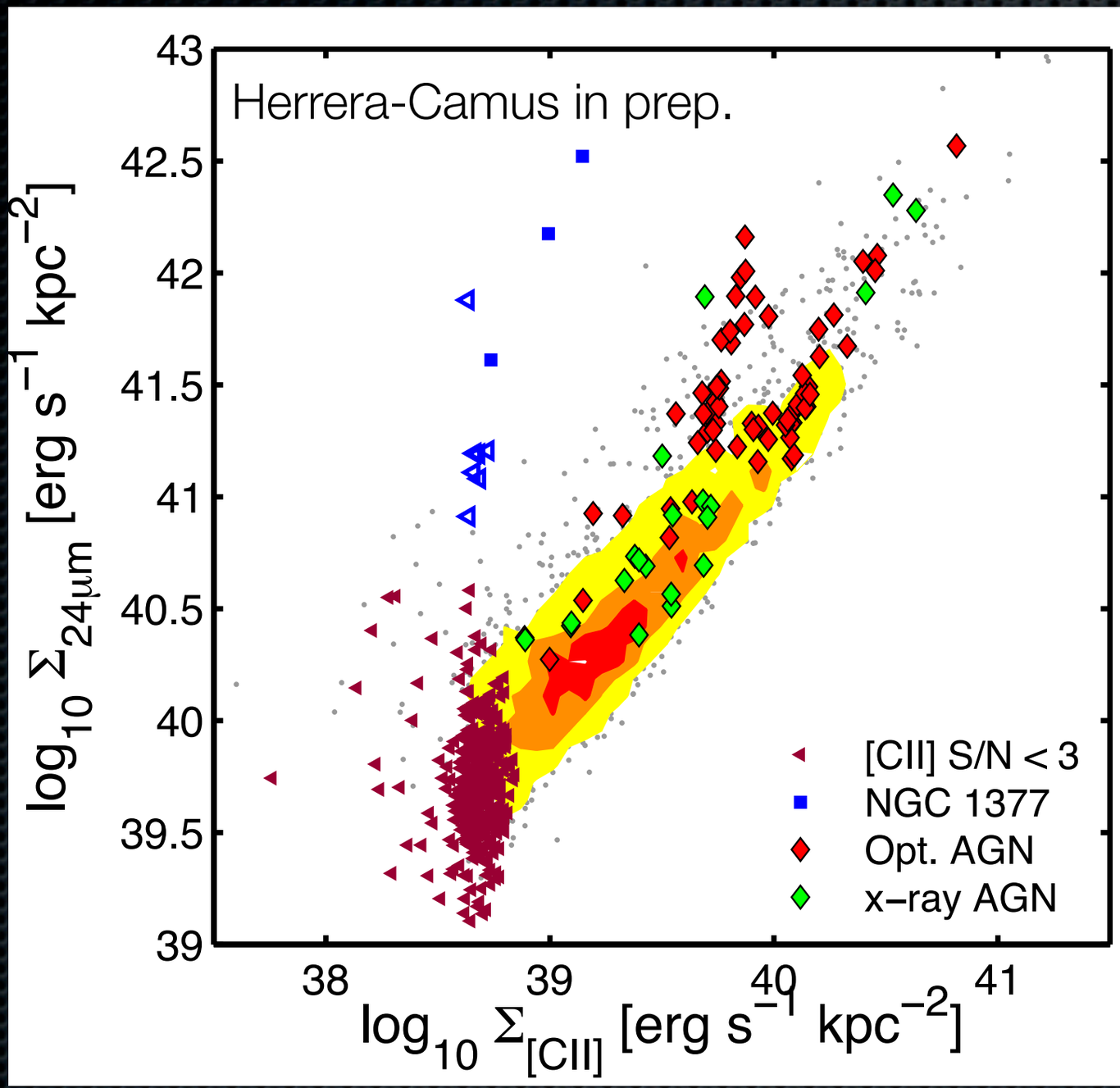
Calibrate/investigate [CII] as a SFR tracer.

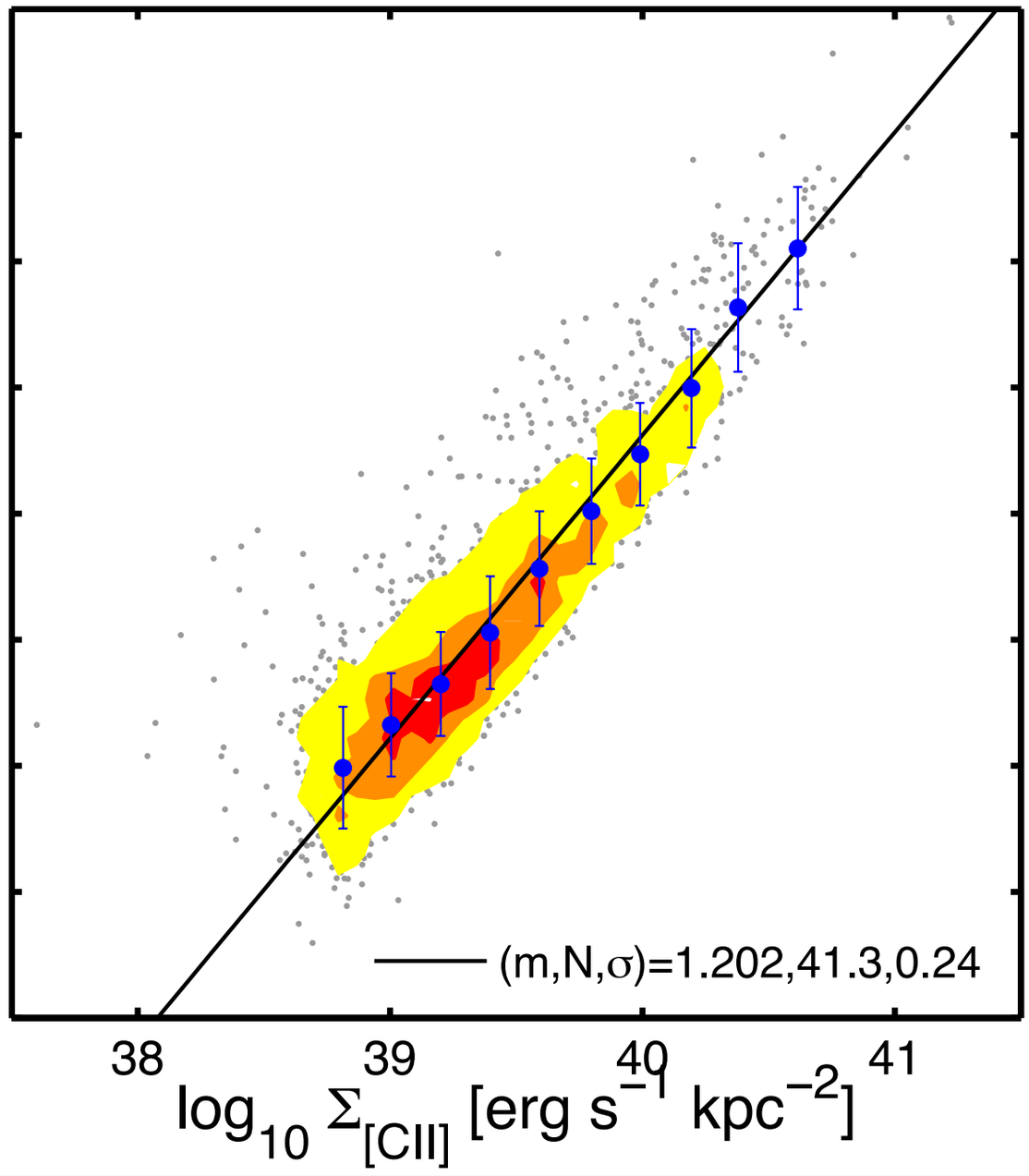
[CII] as a star-formation rate indicator:





[CII] as a star-formation rate indicator:



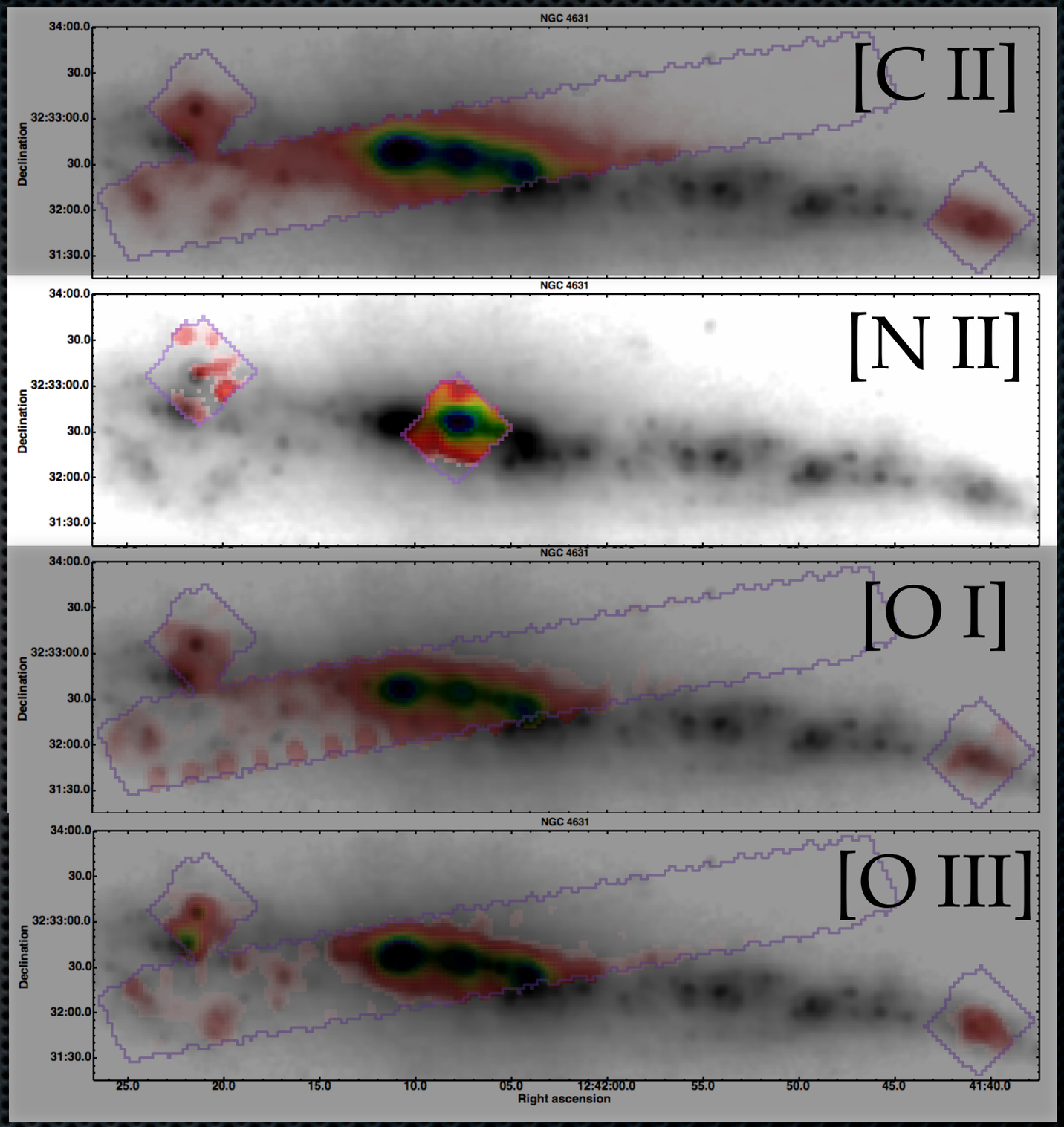


Ok if you remove your AGN + crazy-dense starbursts...

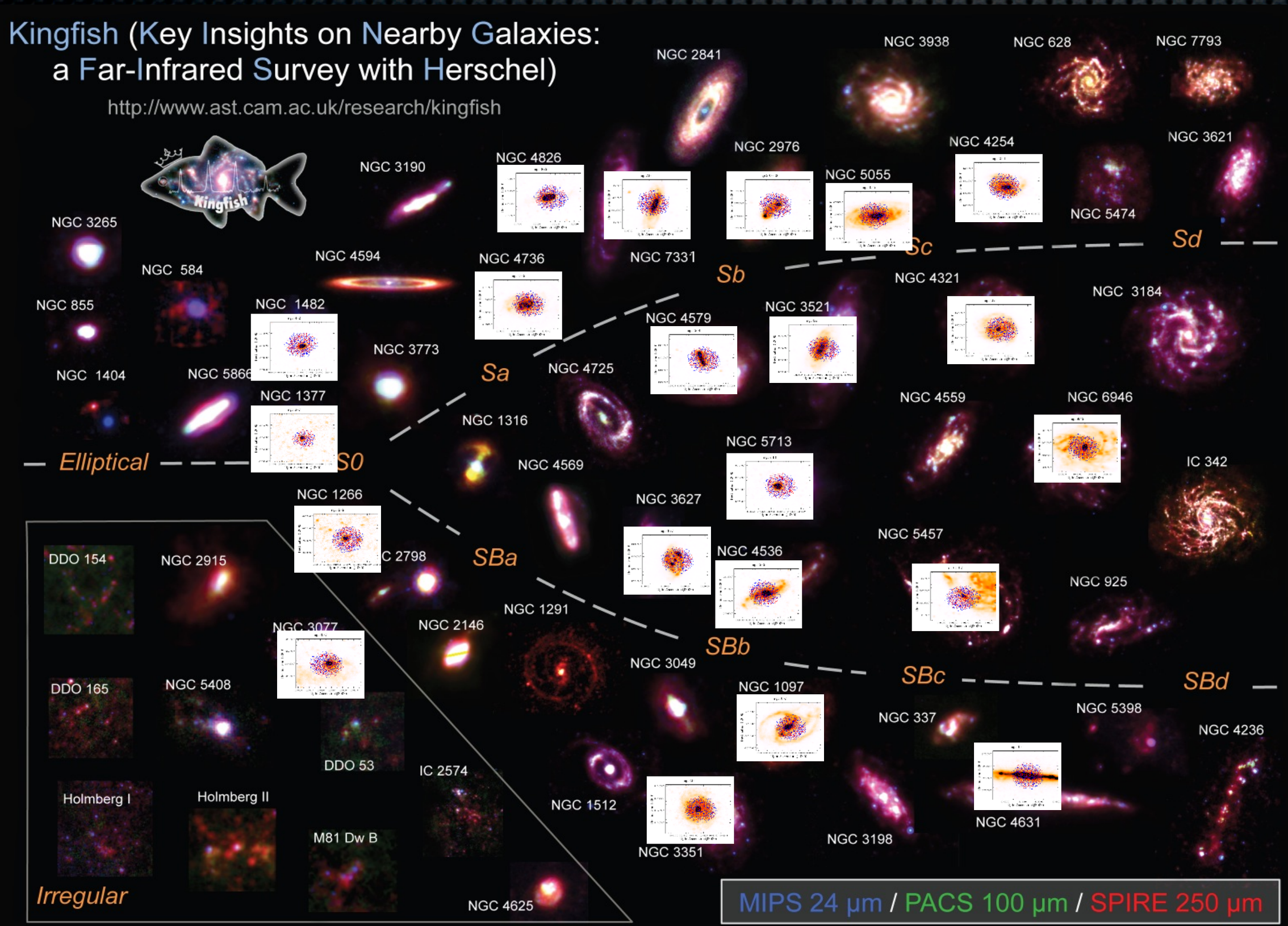
NGC 4631

<u>Goal 4:</u>

Determine gas densities...



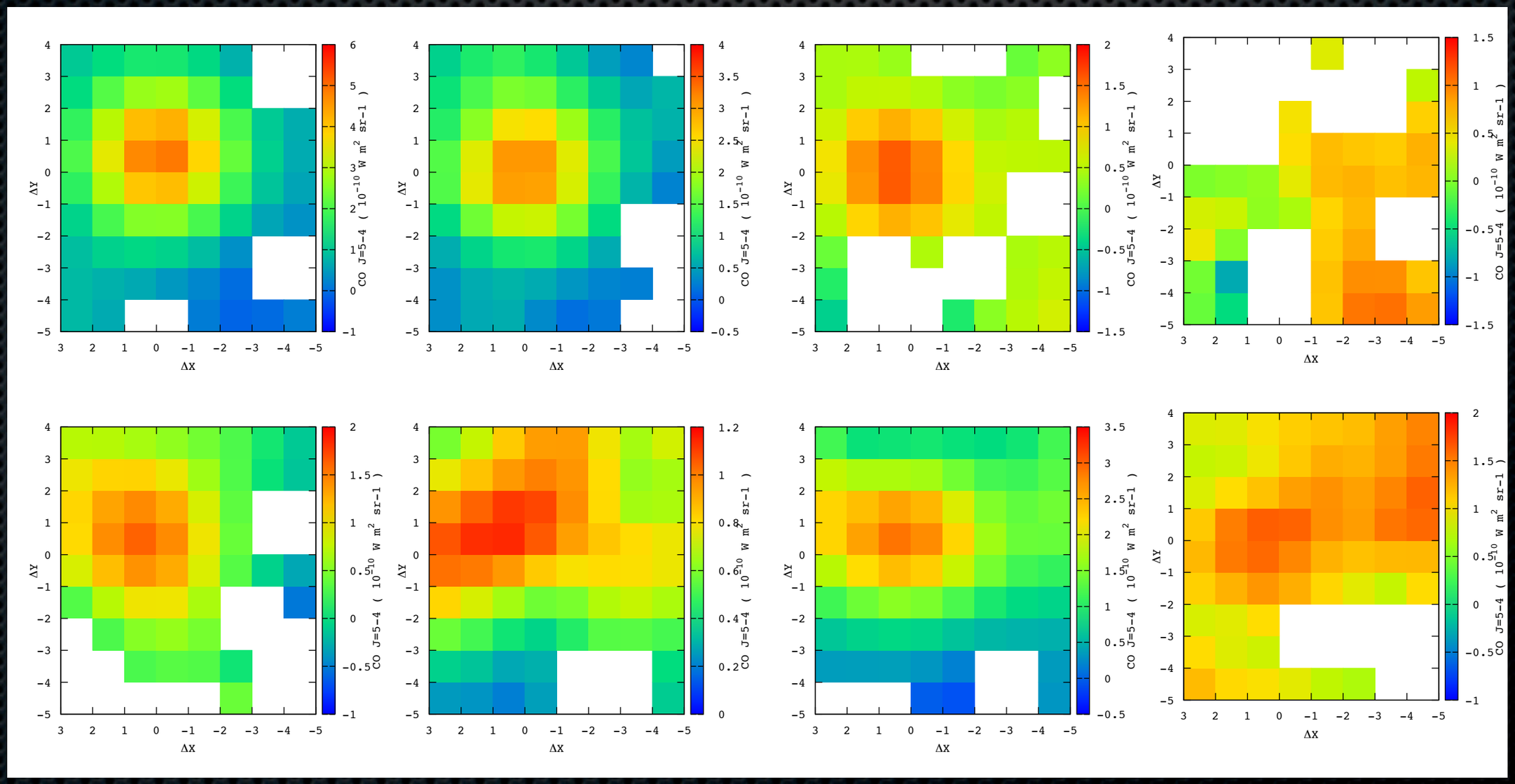
Beyond the Peak Survey:

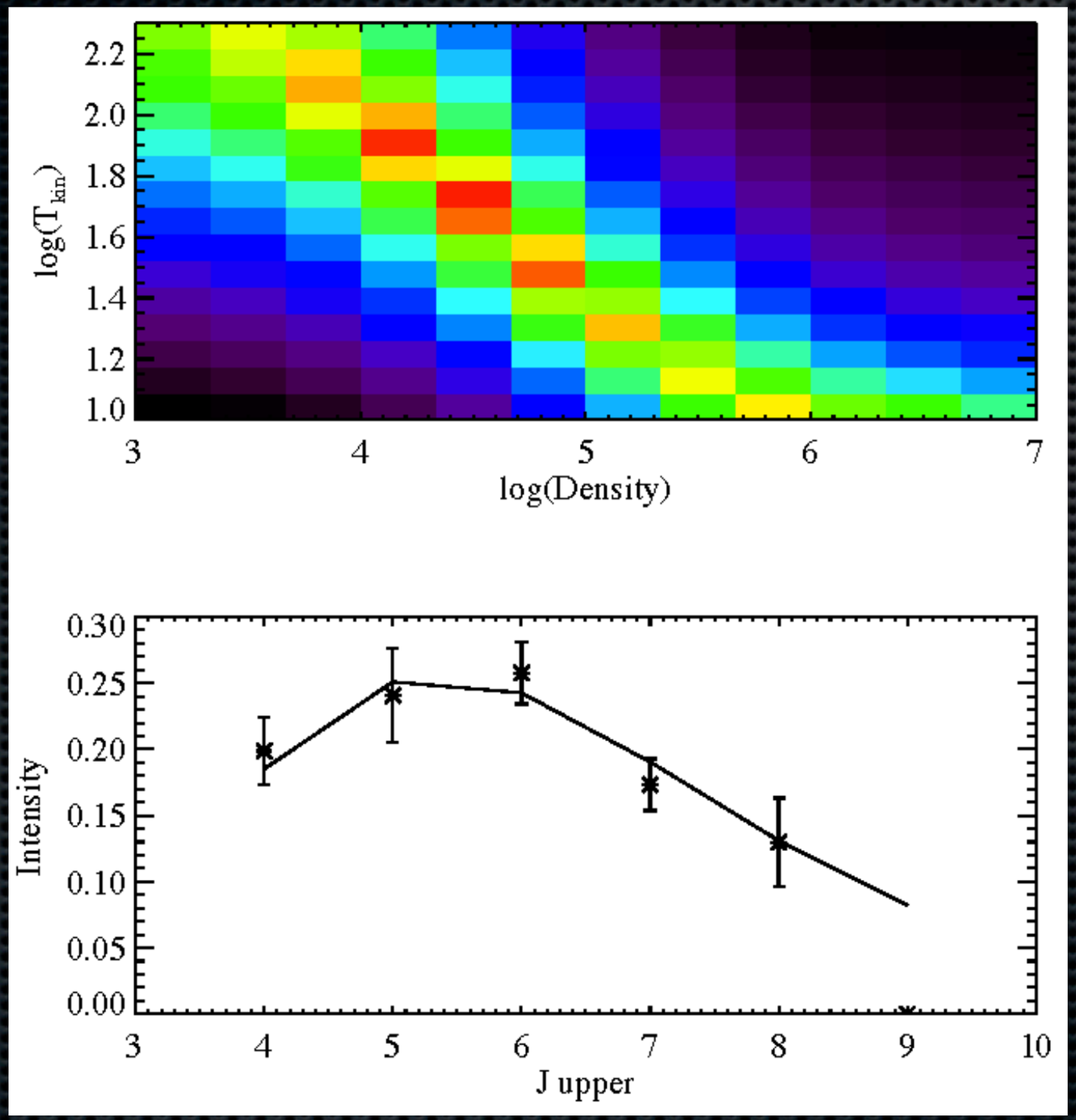


Beyond the Peak Survey:

- CO, [CI], [NII] 205 line mapping with SPIRE FTS instrument on Herschel

CO(J=5-4) maps:



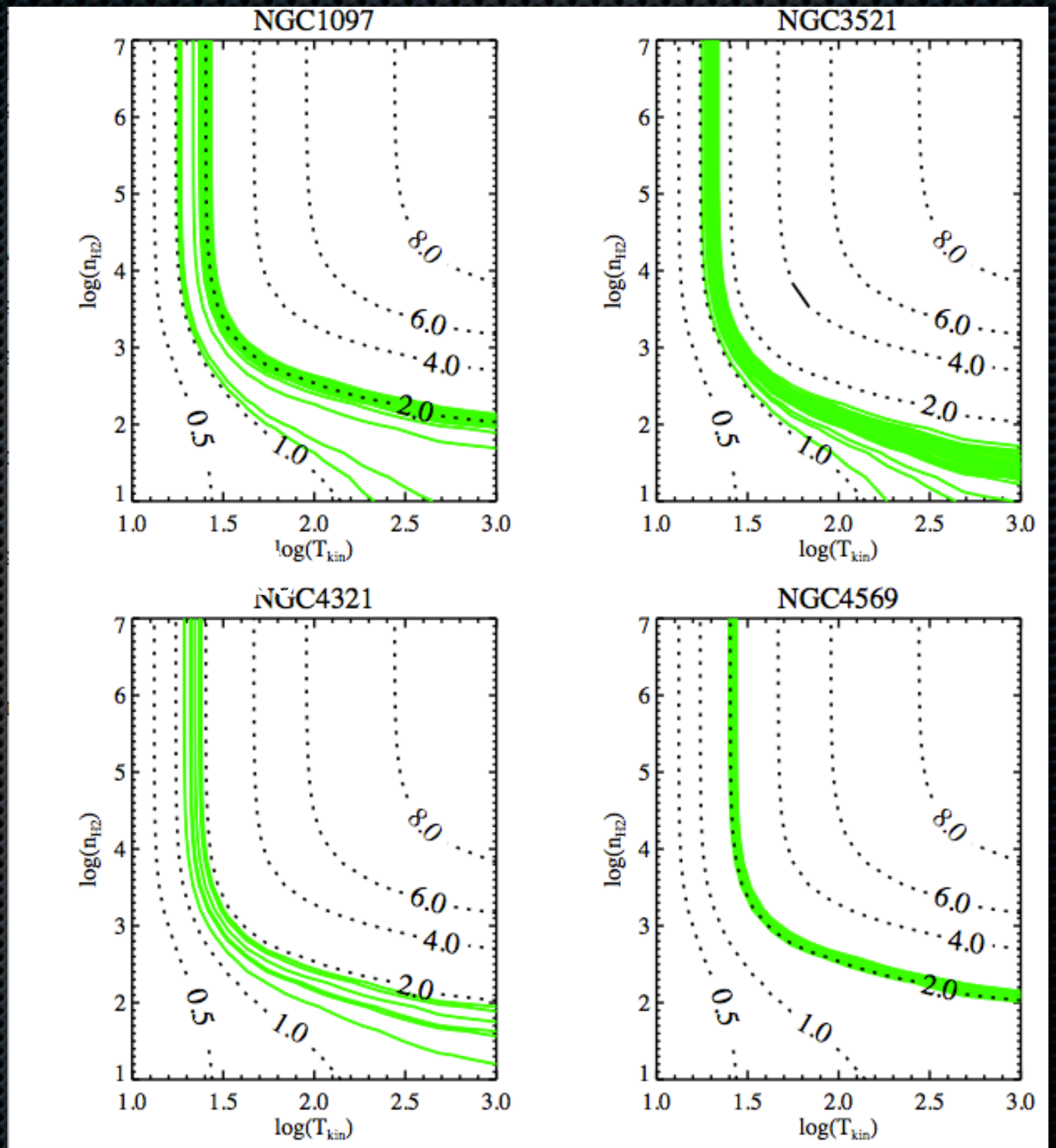


Color = χ^2 value at the specified H_2 density and kinetic temperature.

CO SLED and best fit RADEX model

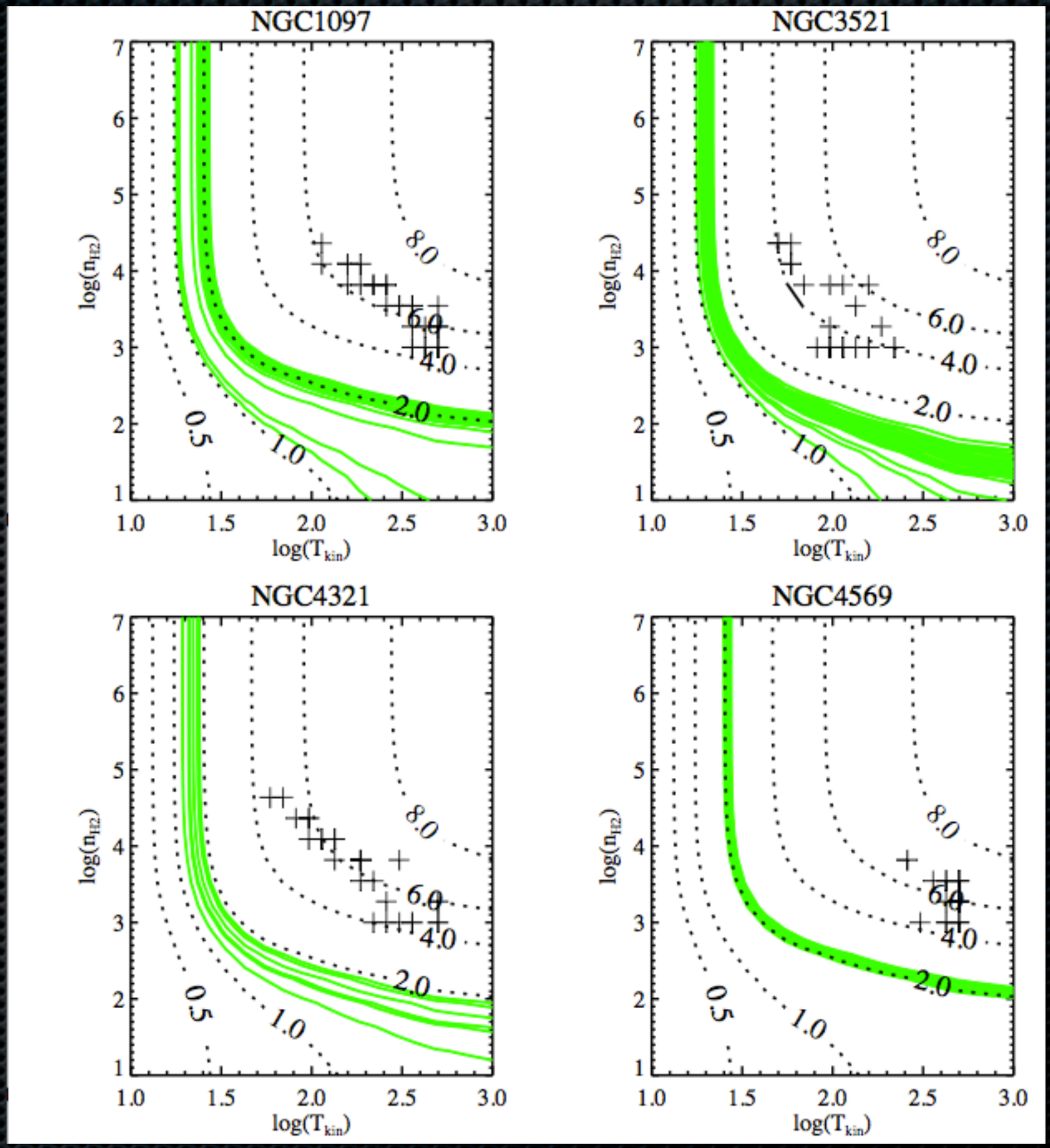
Two [CI] lines can also (partly) determine gas parameters.

CI conditions



CI conditions

+ Best-fit CO conditions

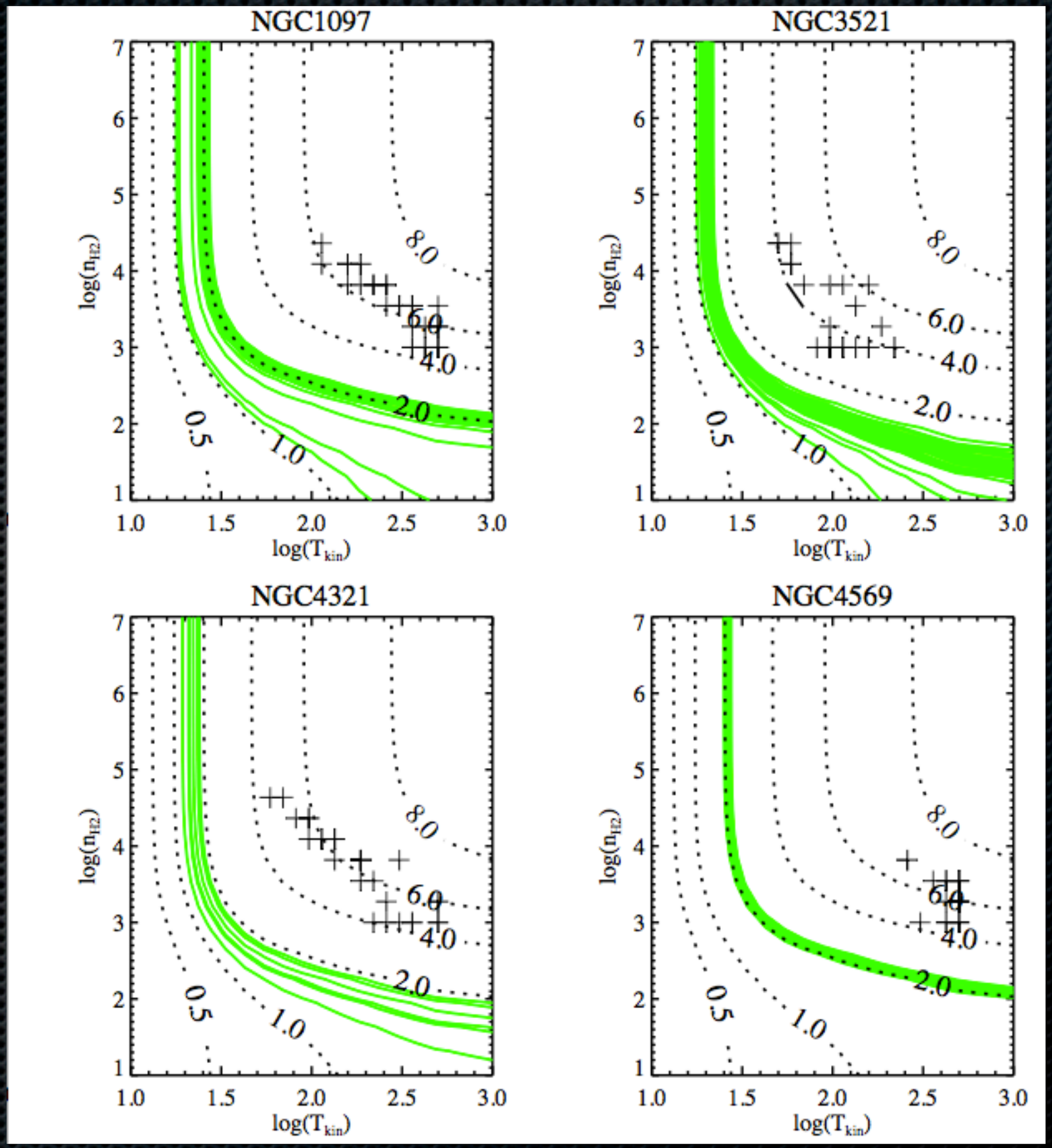


No match in any galaxy.

[CI] does not trace same H_2 component as mid-J CO.

— CI conditions

\+ Best-fit CO conditions



Conclusions

- KINGFISH and Beyond the Peak are permitting the study of spatially resolved line emission in nearby galaxies thanks to Herschel PACS and SPIRE FTS
- Numerous aspects of gas physics:
  - photoelectric heating efficiencies
  - star formation
  - CO excitation
- [OIII] 88 μm emission is insensitive to the temperature, allowing a FIR calibration of metallicity