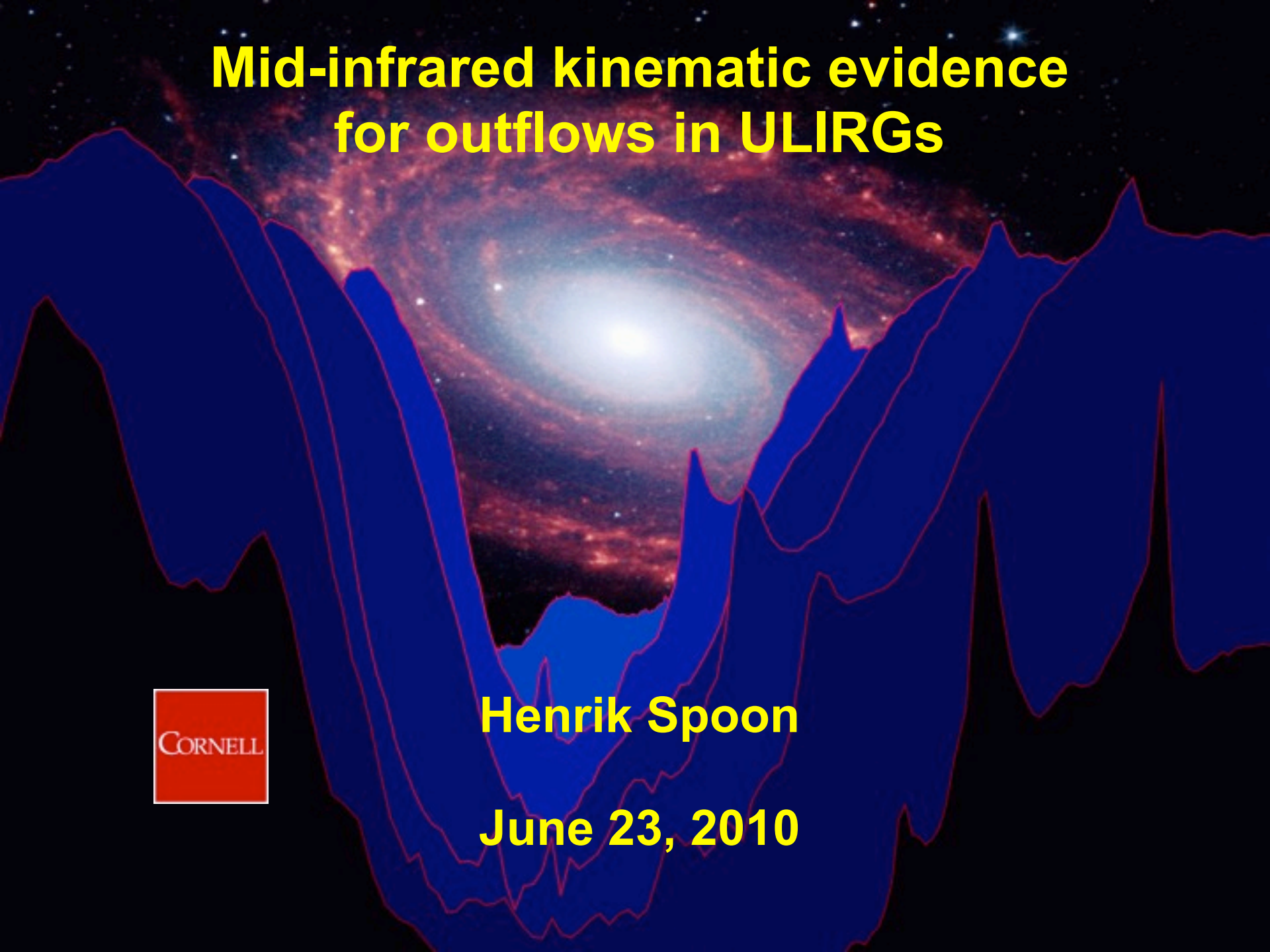
H. Spoon

Mid-infrared kinematic evidence for outflows in ULIRGs

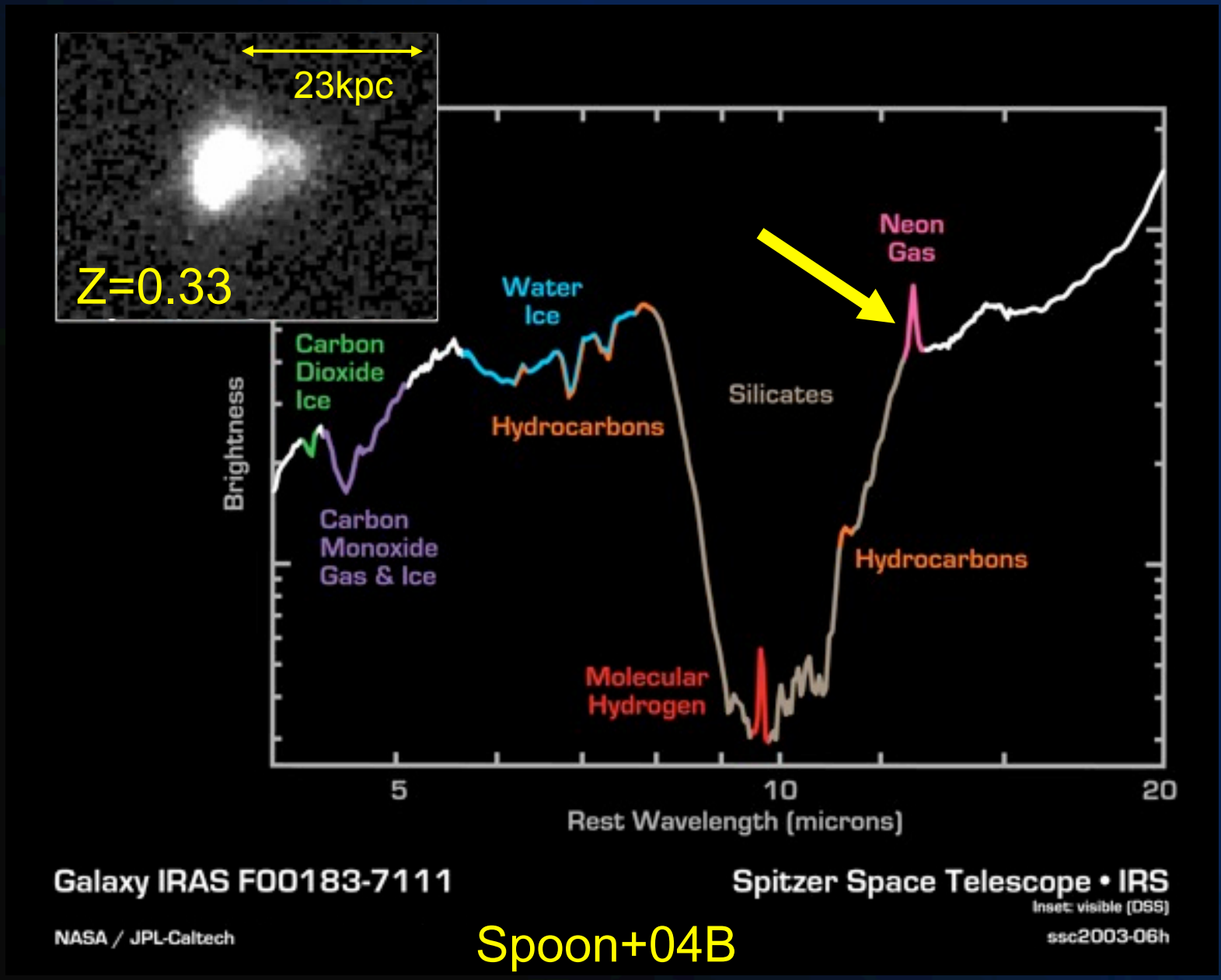
Abundant evidence exists for the presence of outflows in active and starburst galaxies. Ultraluminous infrared galaxies host both extreme starbursts and supermassive black holes accreting at high Eddington rates. Outflows are hence expected to be ubiquitous in ULIRGs. The mid-infrared wavelength range is home to a suite of strong fine-structure lines from various ionization stages of neon, spanning a range in ionization potentials of 21 to 127eV, relatively unaffected by extinction. These lines can be exploited to probe the ionization structure and origin of the outflowing gas. We report on the results of a first systematic study of the line profiles of the mid-infrared fine-structure lines of Ne+, Ne2+, Ne4+ and Ne5+ gas in a sample of 320 ULIRGs, HyLIRGs, Seyferts, LINERs, QSOs and starburst galaxies observed in by Spitzer-IRS. The sources span a range of 5 decades in [NeV] AGN luminosity and 6 decades in 21cm radio luminosity. Blue shifted [Ne III] and/or [Ne V] emission (shifted by 200 km/s or more) is found for 30% of the ULIRG sample. The incidence of blue shifted [Ne V] emission is even higher (60%) among the sources with a [Ne V] detection. A comparison of the line profiles of the neon lines reveals the ionization of the blue shifted gas to increase with blue shift, implying decelerating outflows in a stratified medium, photo-ionized by the AGN.

Mid-infrared kinematic evidence for outflows in ULIRGs

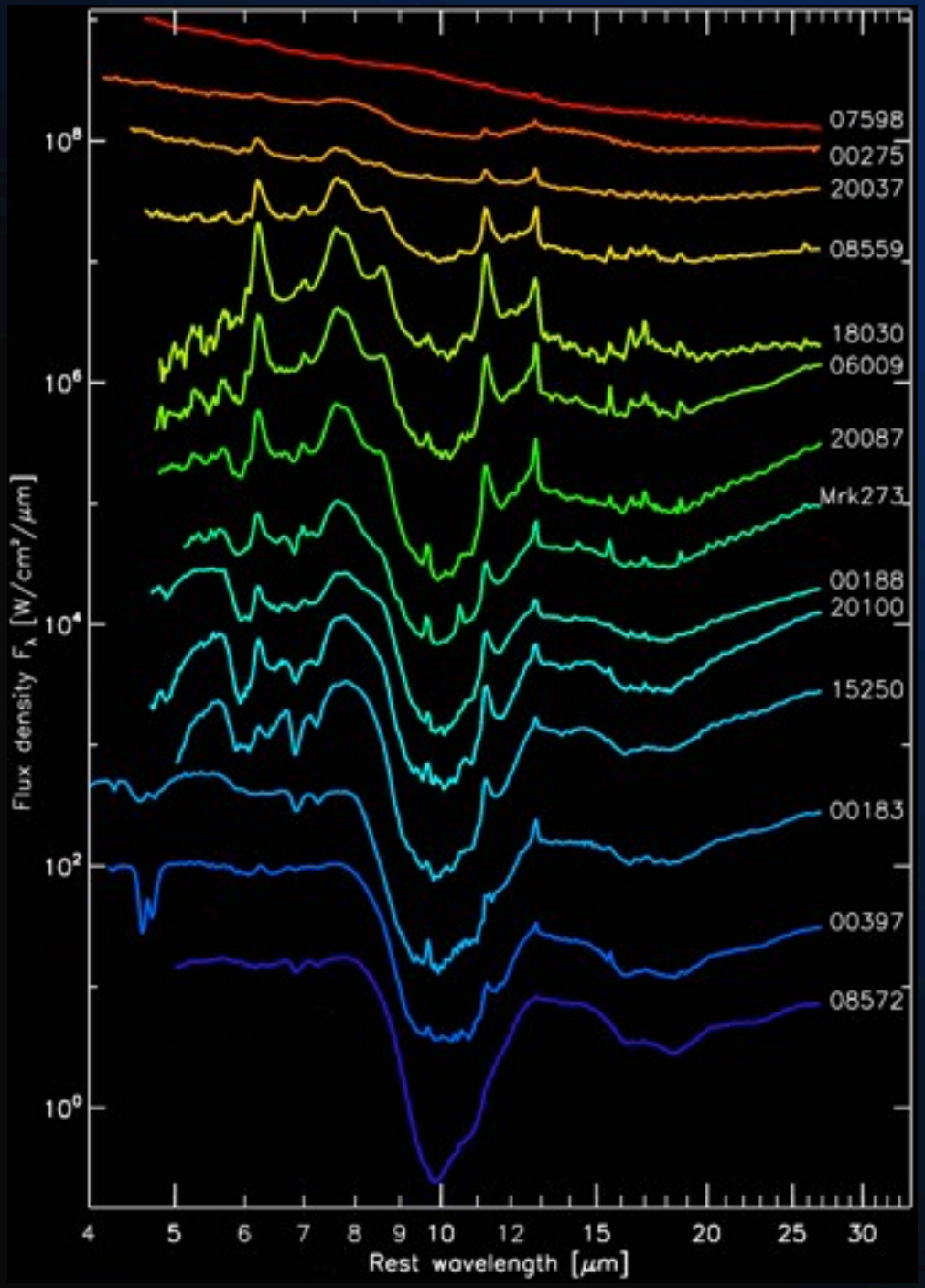


Henrik Spoon

June 23, 2010

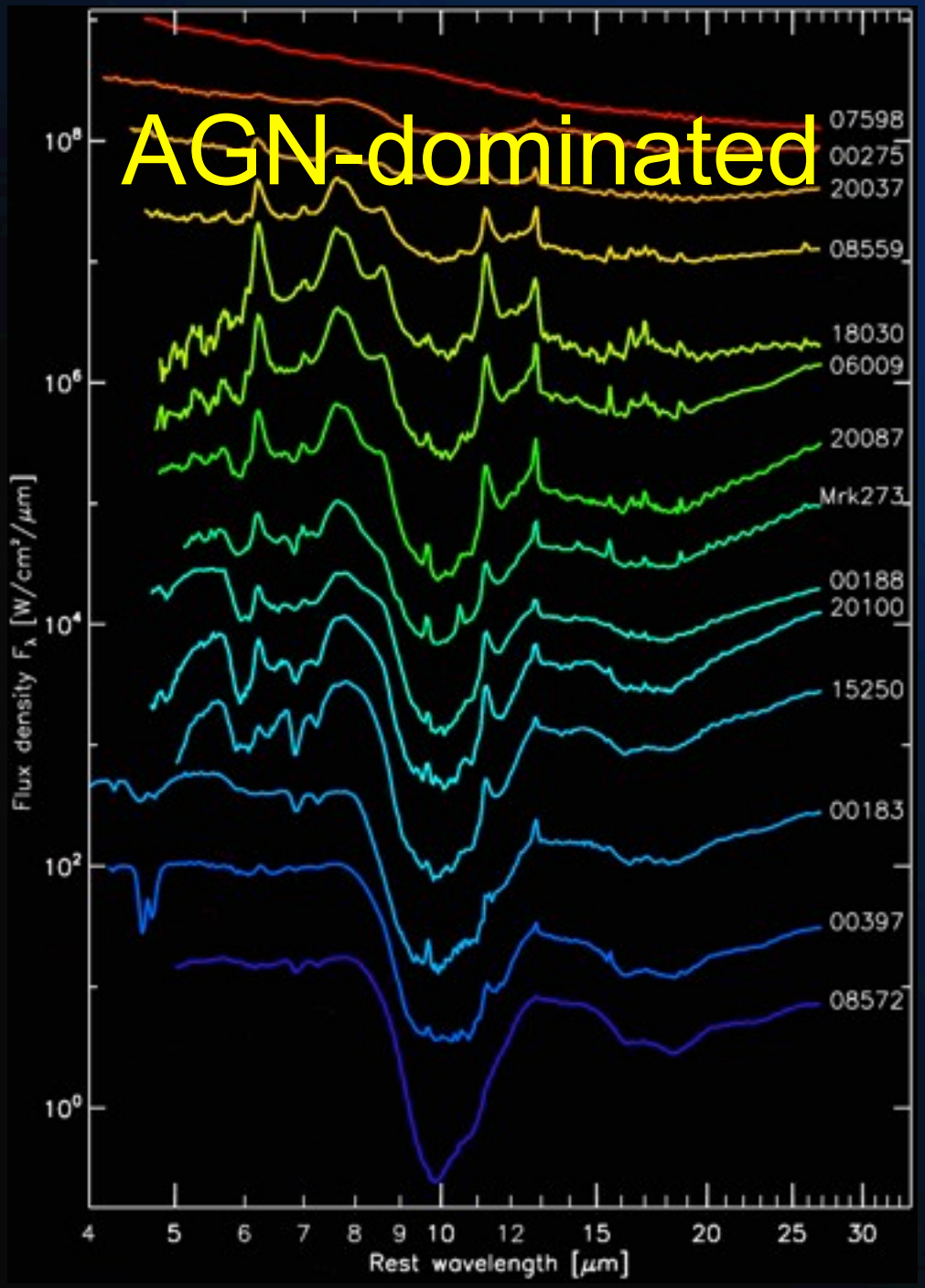

23kpc
Z=0.33
Neon
Gas
Water
Ice
Carbon
Dioxide
Ice
Hydrocarbons
Silicates
Brightness
Carbon
Monoxide
Gas & Ice
Hydrocarbons
Molecular
Hydrogen
5
10
20
Rest Wavelength (microns)
Galaxy IRAS F00183-7111
Spitzer Space Telescope • IRS
Inset: visible (DSS)
NASA / JPL-Caltech
ssc2003-06h

Spoon+04B



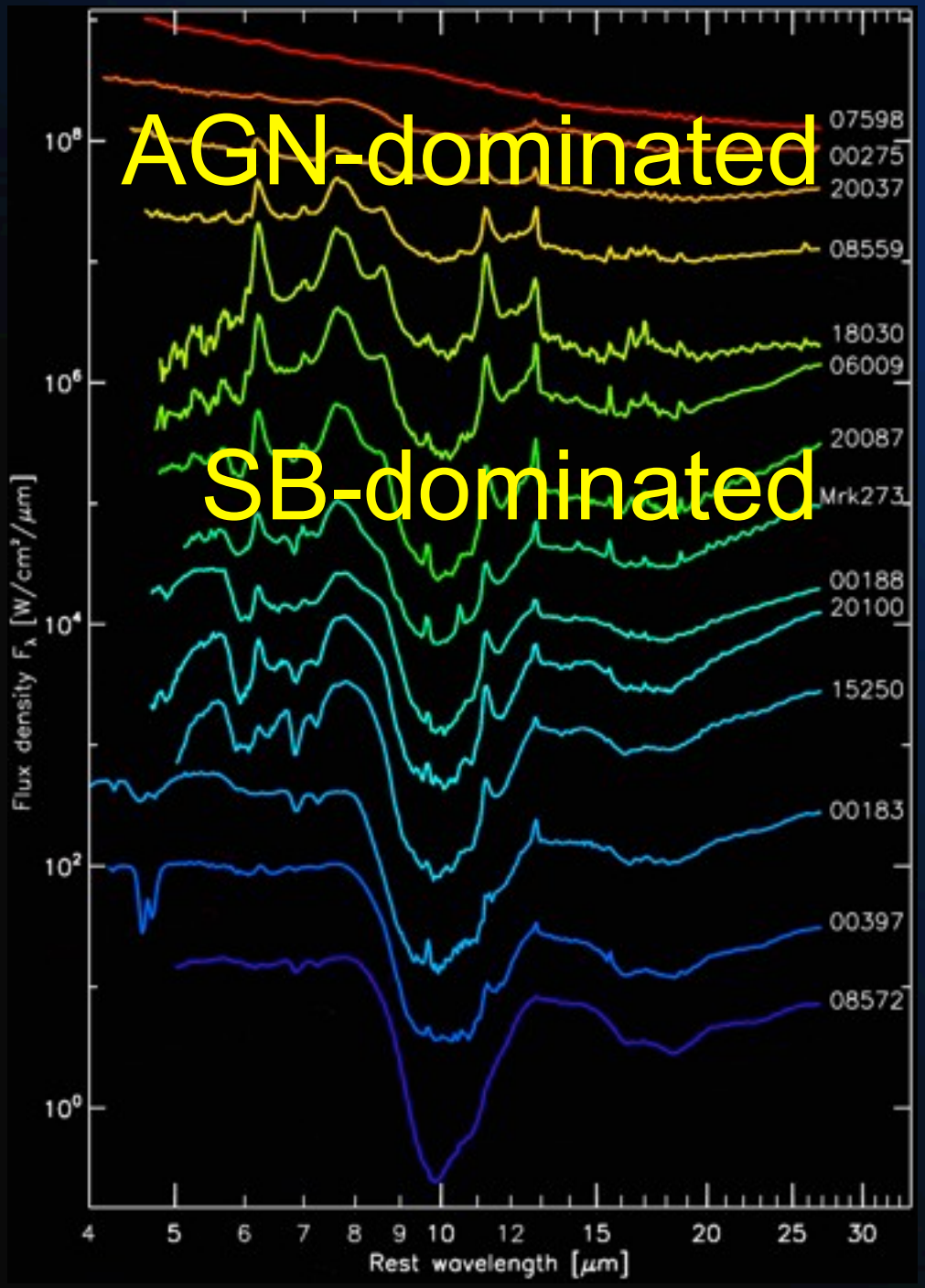
Spitzer-IRS spectra
illustrate
the diverse nature
of ULIRGs

Spoon+05+07



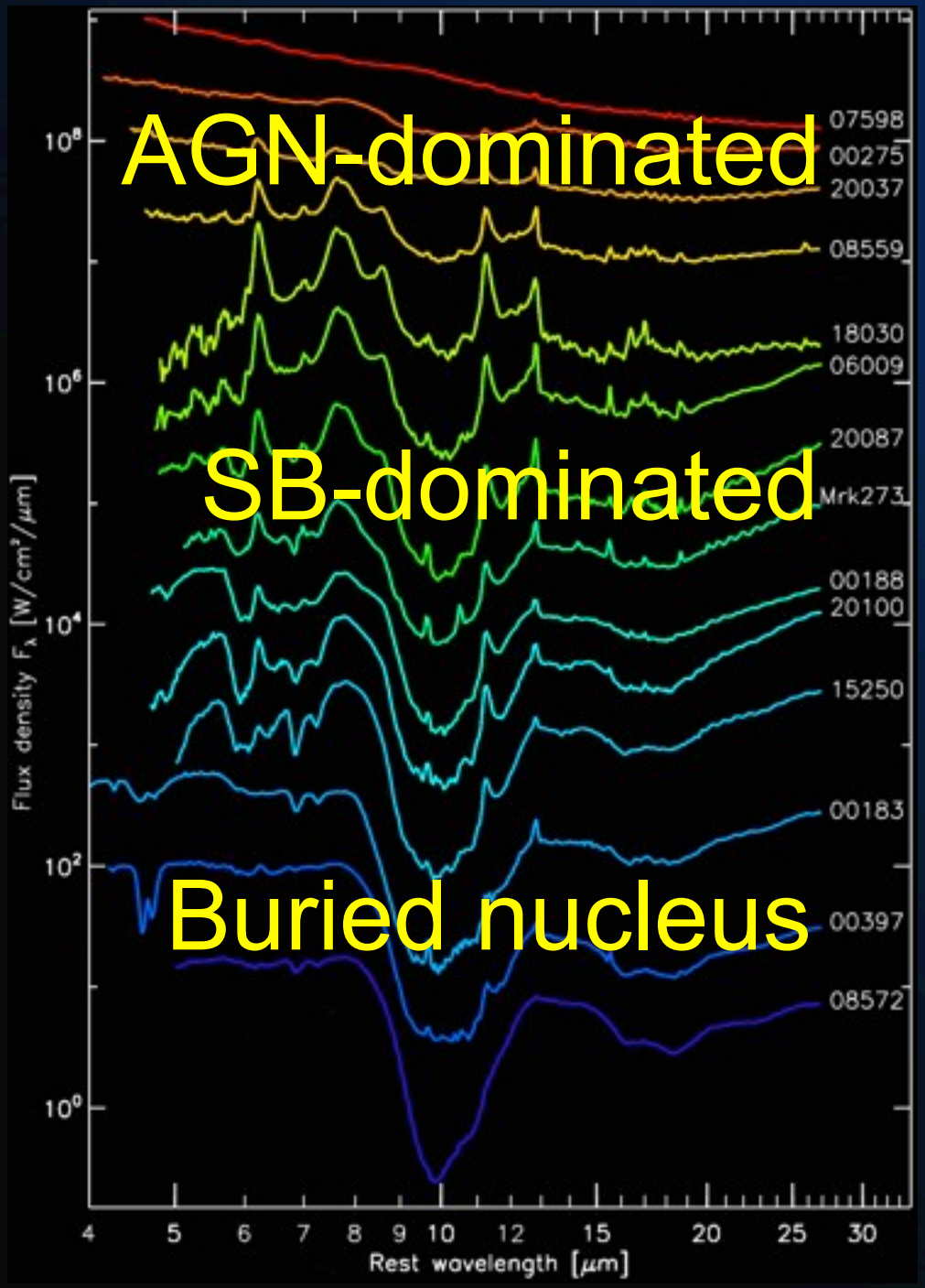
Spitzer-IRS spectra
illustrate
the diverse nature
of ULIRGs

Spoon+05+07



Spitzer-IRS spectra
illustrate
the diverse nature
of ULIRGs

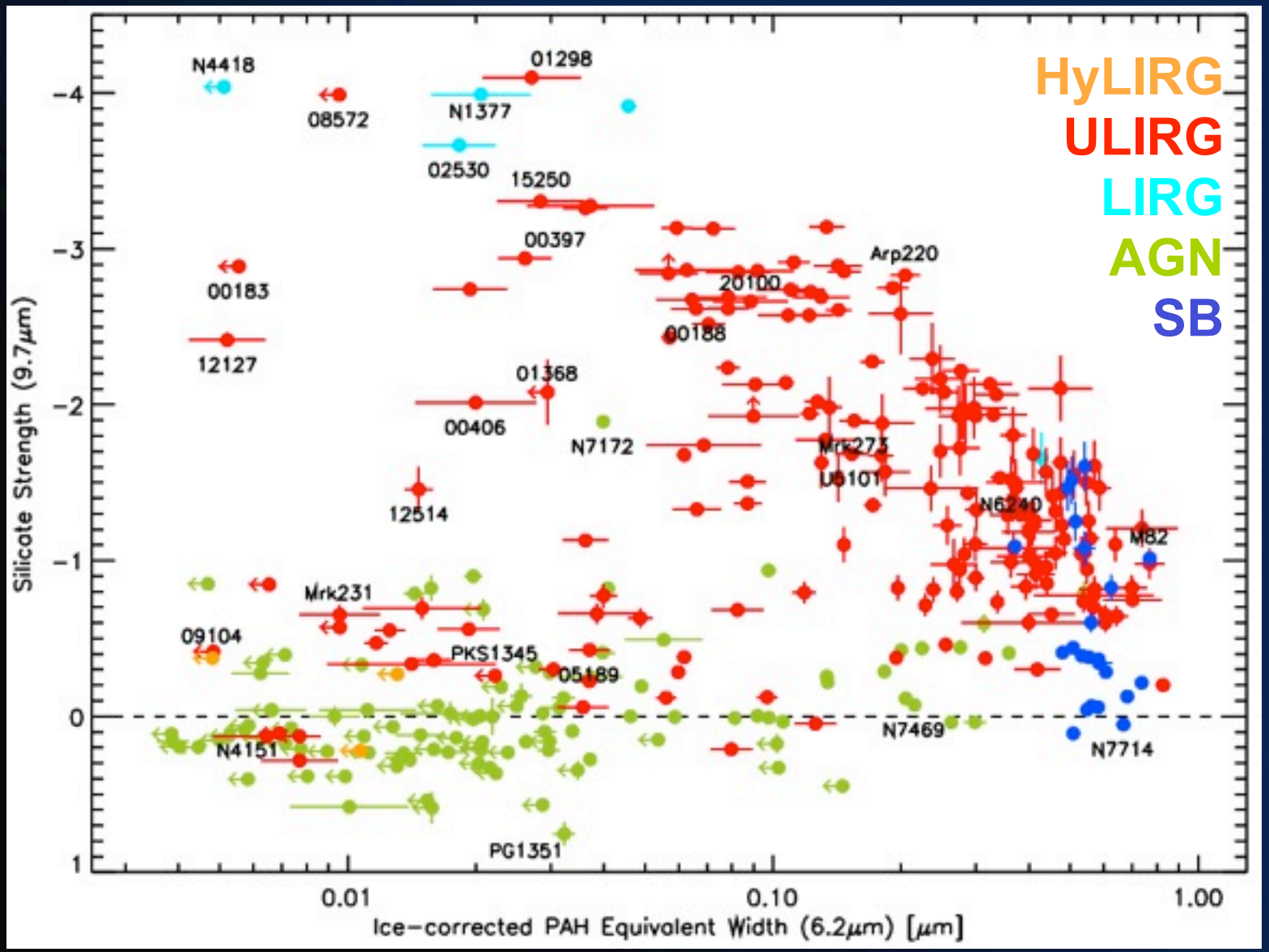
Spoon+05+07



Spitzer-IRS spectra
illustrate
the diverse nature
of ULIRGs

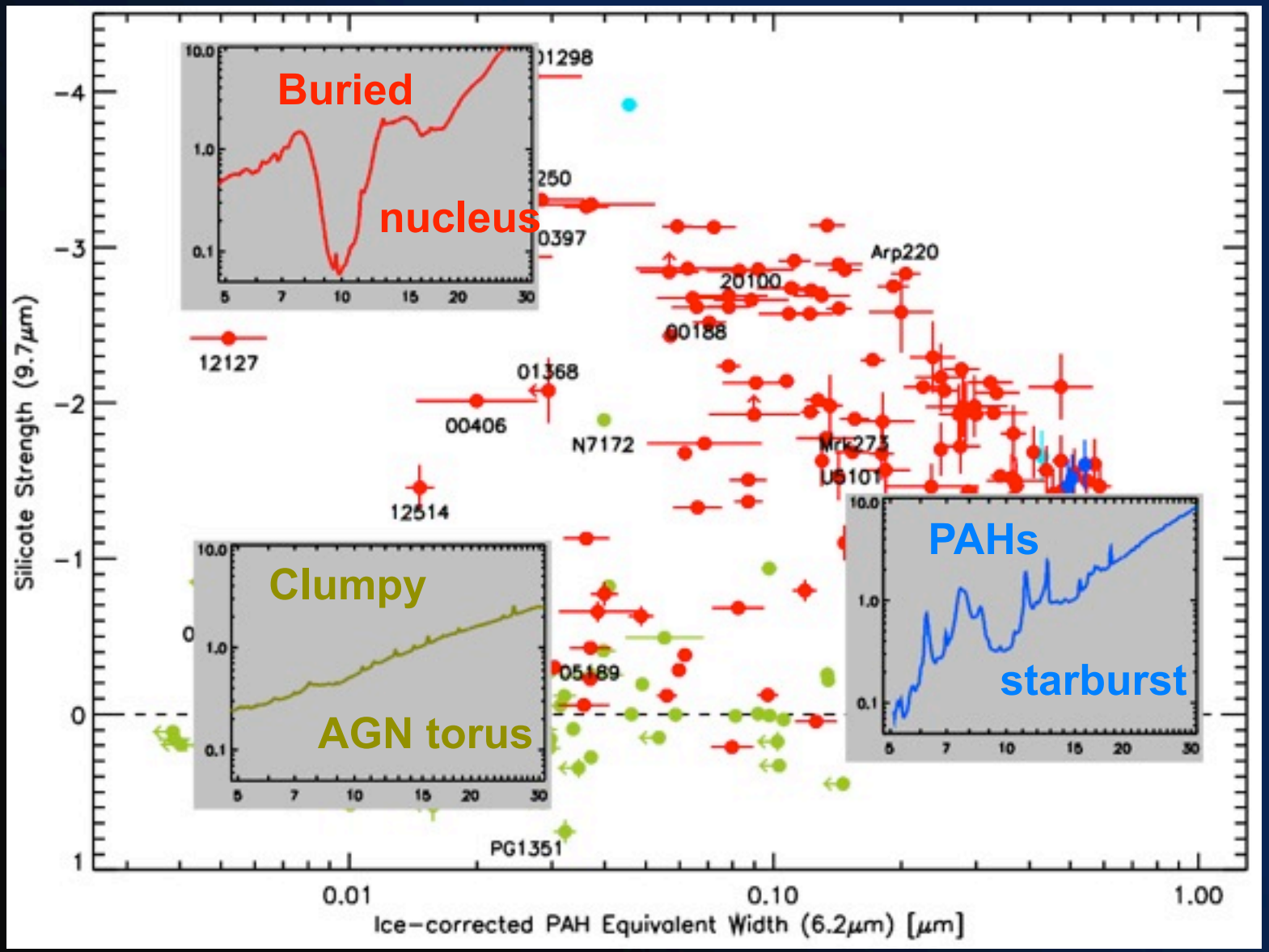
Spoon+05+07

Obscuration diagnostic diagram



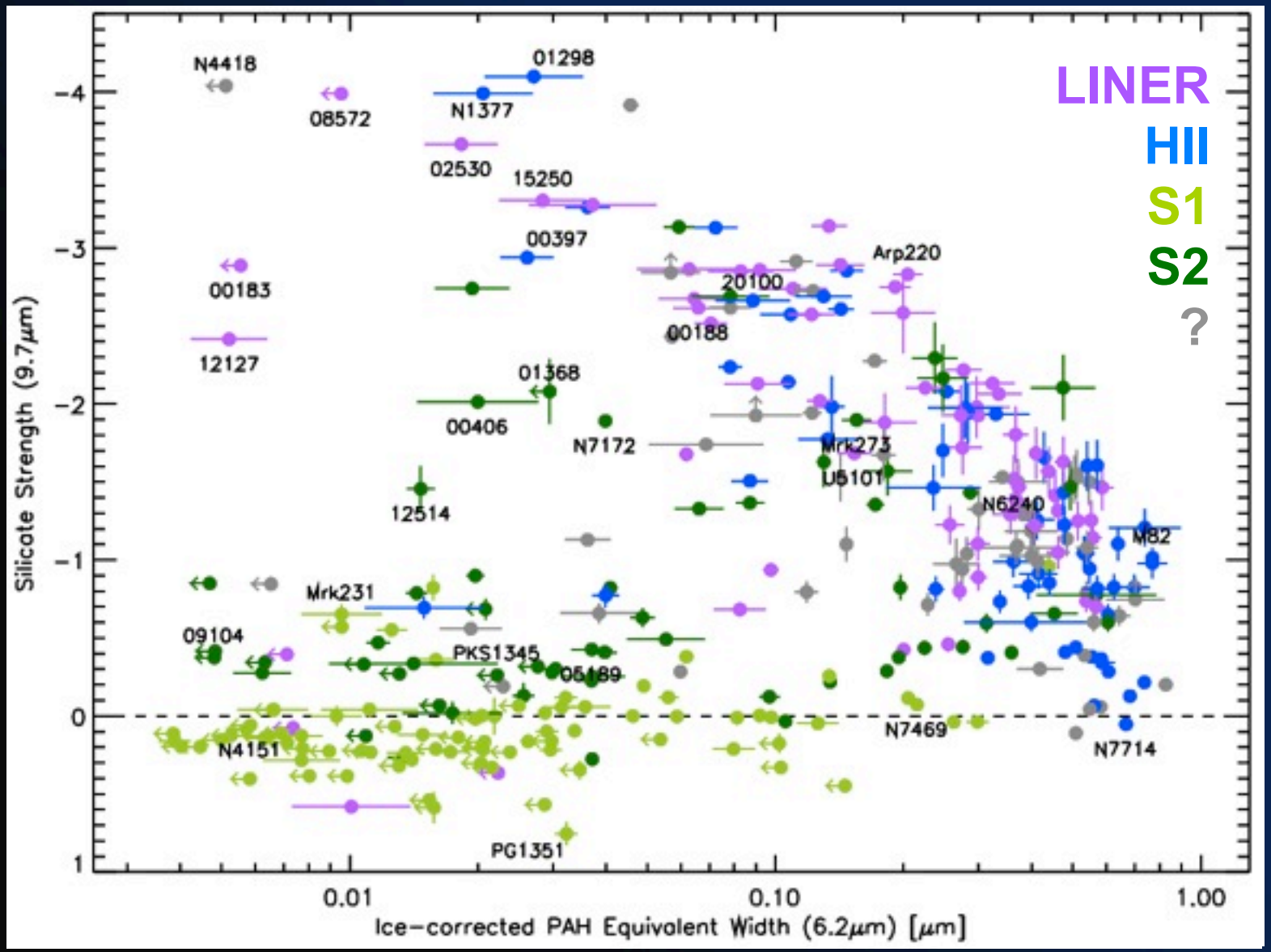
Spoon+07

Obscuration diagnostic diagram



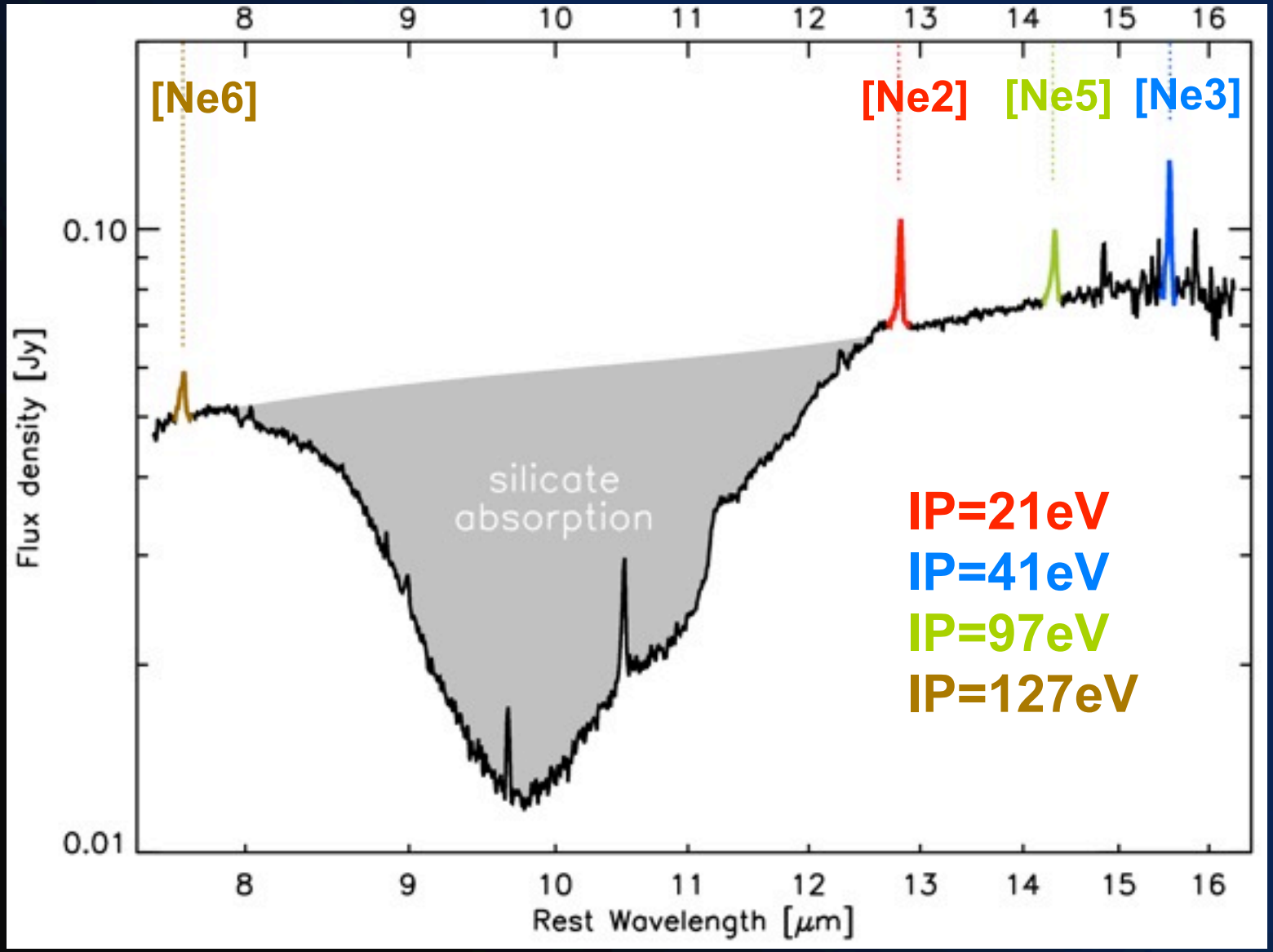
Spoon+07

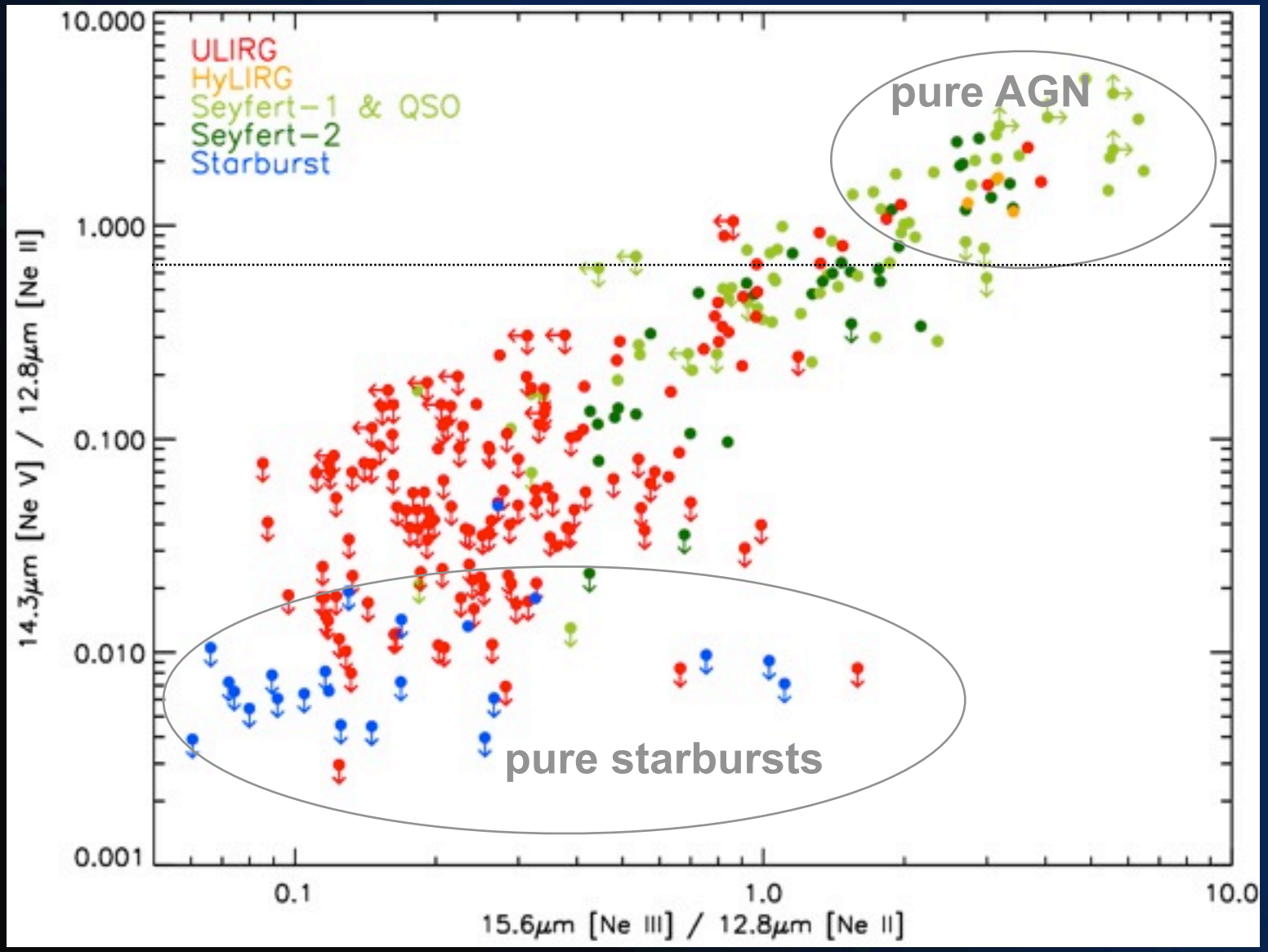
Obscuration diagnostic diagram

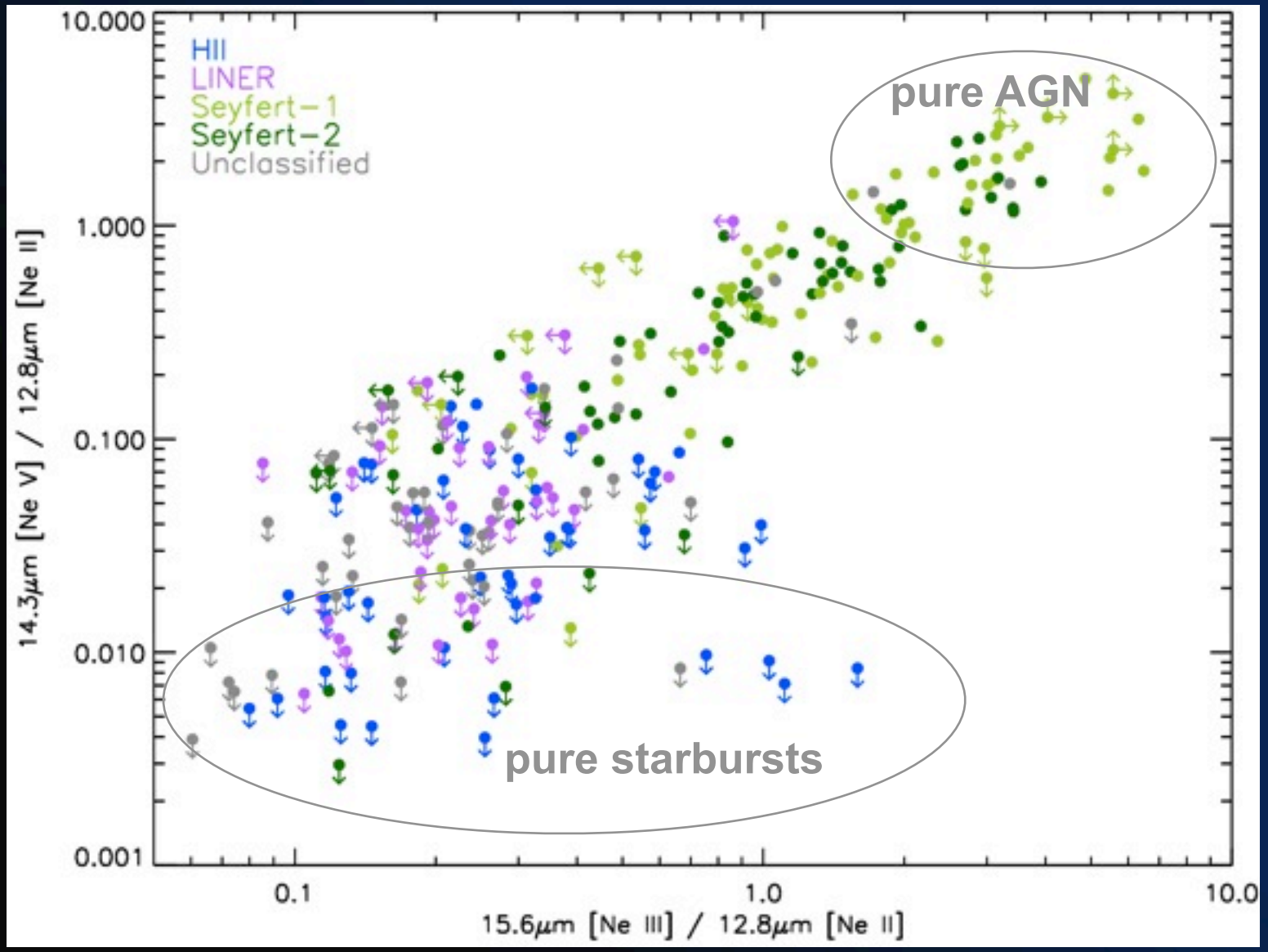


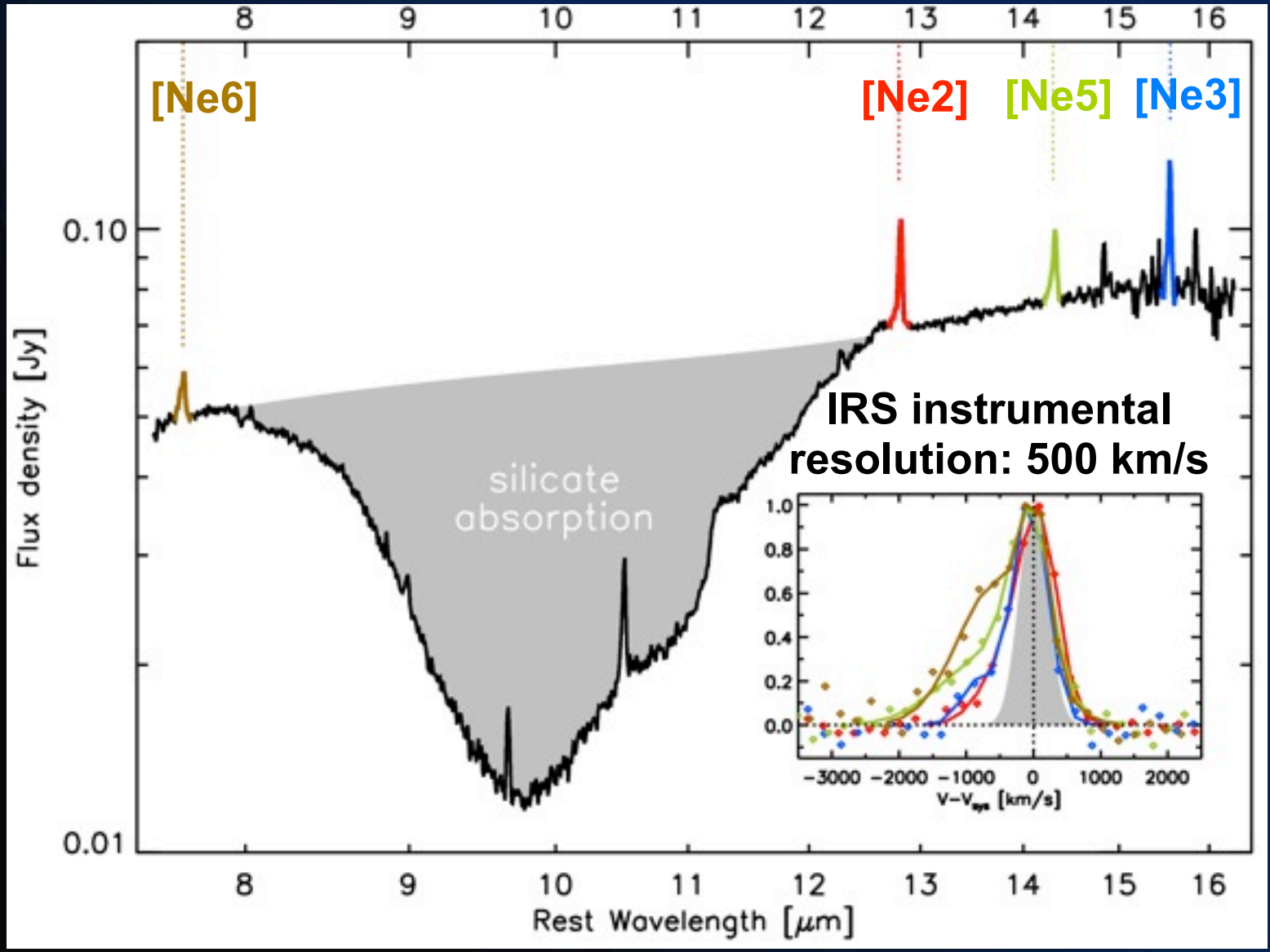
Spoon+07

Mid-IR diagnostic lines

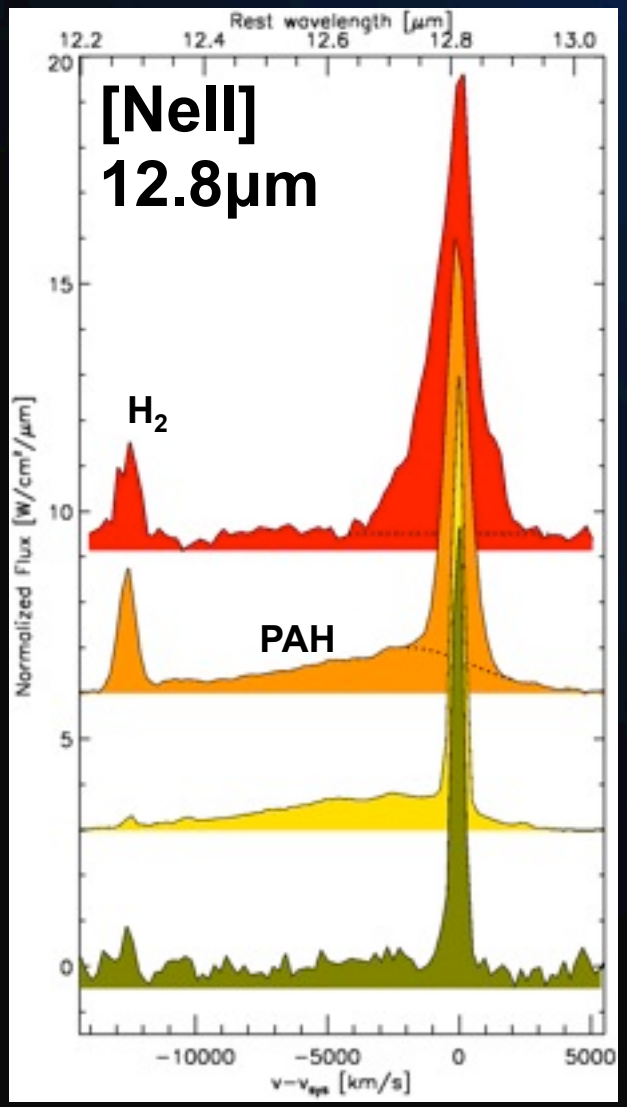


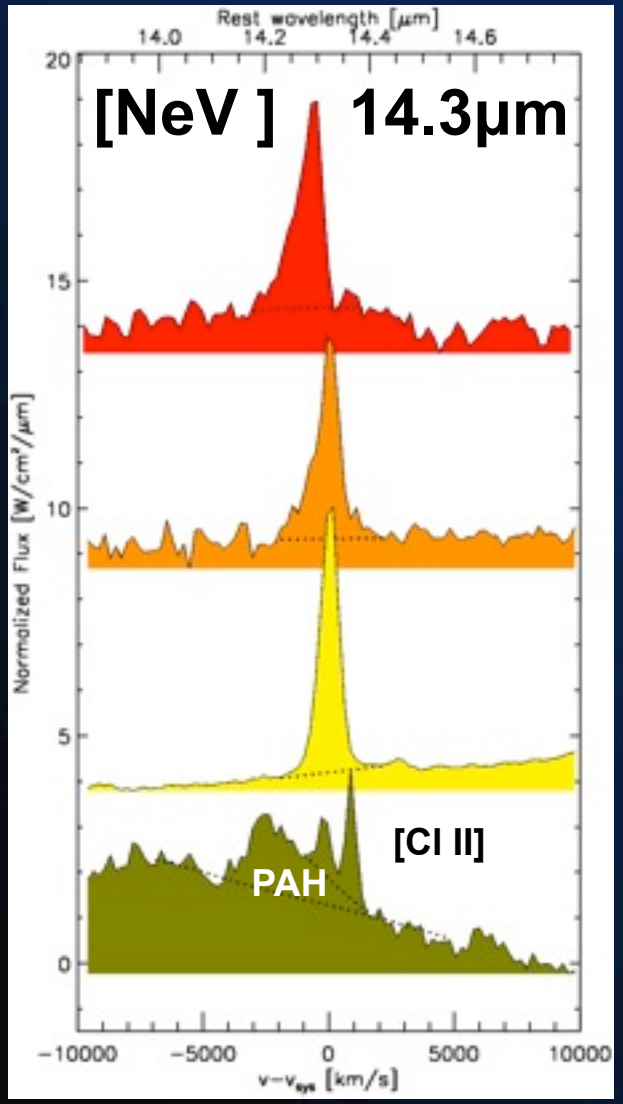

ULIRG
HyLIRG
Seyfert−1 & QSO
Seyfert−2
Starburst
pure AGN
pure starbursts
10.000
1.000
0.100
0.010
0.001
0.1
1.0
10.0
14.3μm [Ne V] / 12.8μm [Ne II]
15.6μm [Ne III] / 12.8μm [Ne II]

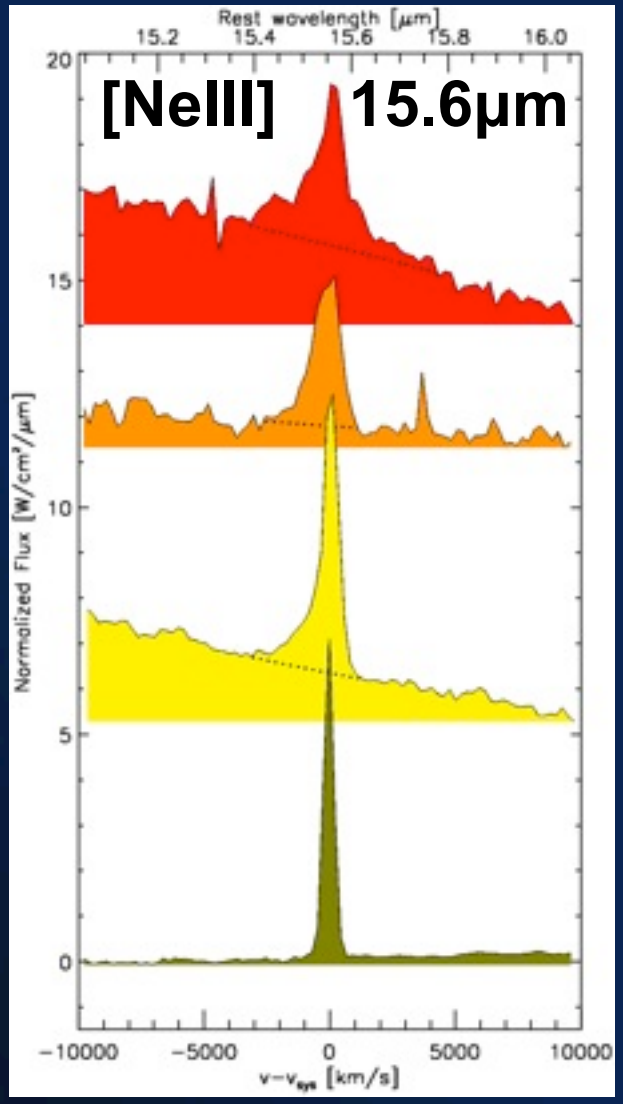

HII
LINER
Seyfert−1
Seyfert−2
Unclassified
pure AGN
pure starbursts
10.000
1.000
0.100
0.010
0.001
0.1
1.0
10.0
14.3μm [Ne V] / 12.8μm [Ne II]
15.6μm [Ne III] / 12.8μm [Ne II]


[Ne6]
[Ne2]
[Ne5]
[Ne3]
silicate absorption
IRS instrumental resolution: 500 km/s
Flux density [Jy]
0.10
0.01
Rest Wavelength [μm]
8
9
10
11
12
13
14
15
16
1.0
0.8
0.6
0.4
0.2
0.0
−3000
−2000
−1000
0
1000
2000
V−V_sys [km/s]

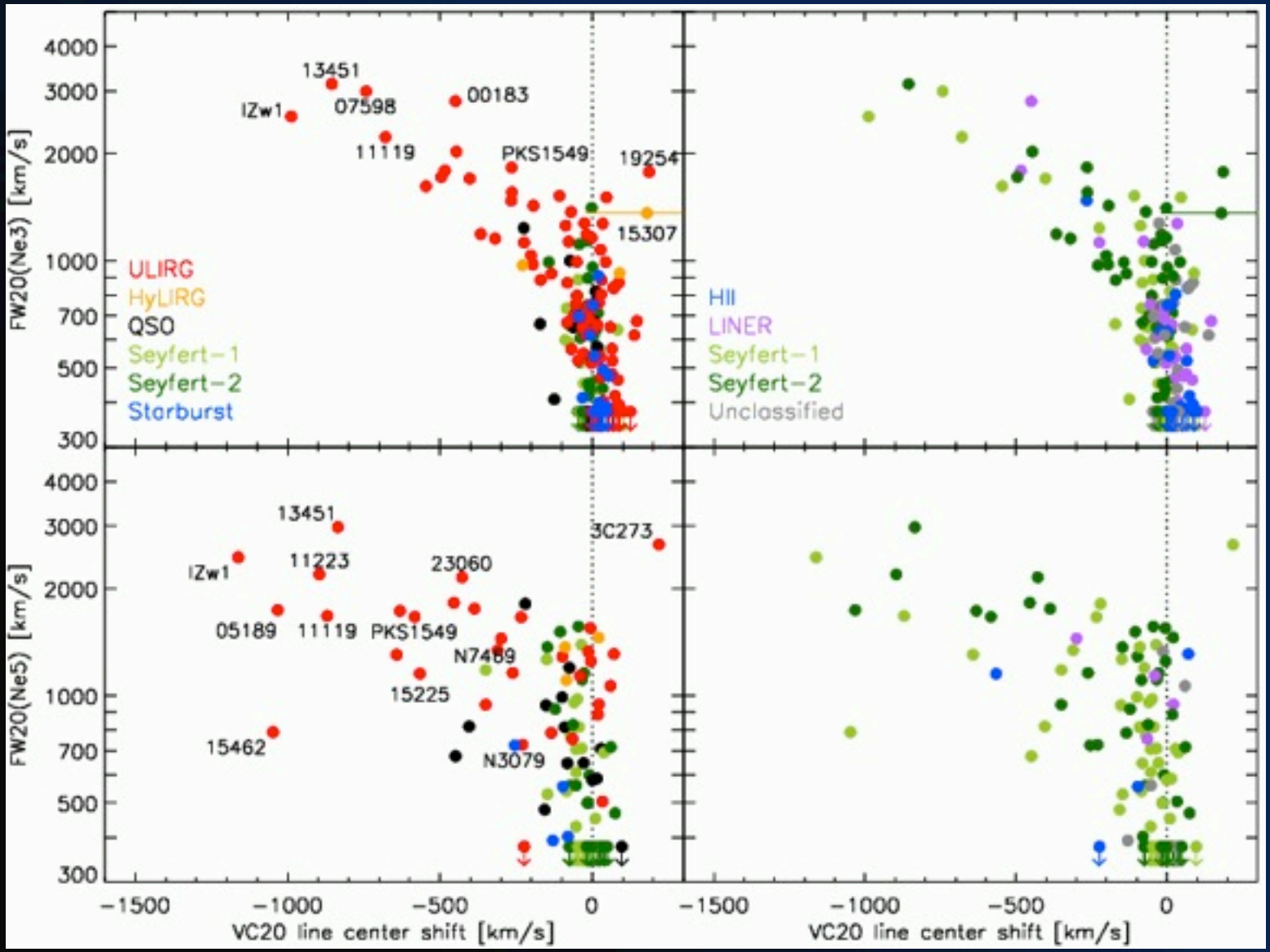
Mid-IR neon lines: easy to measure





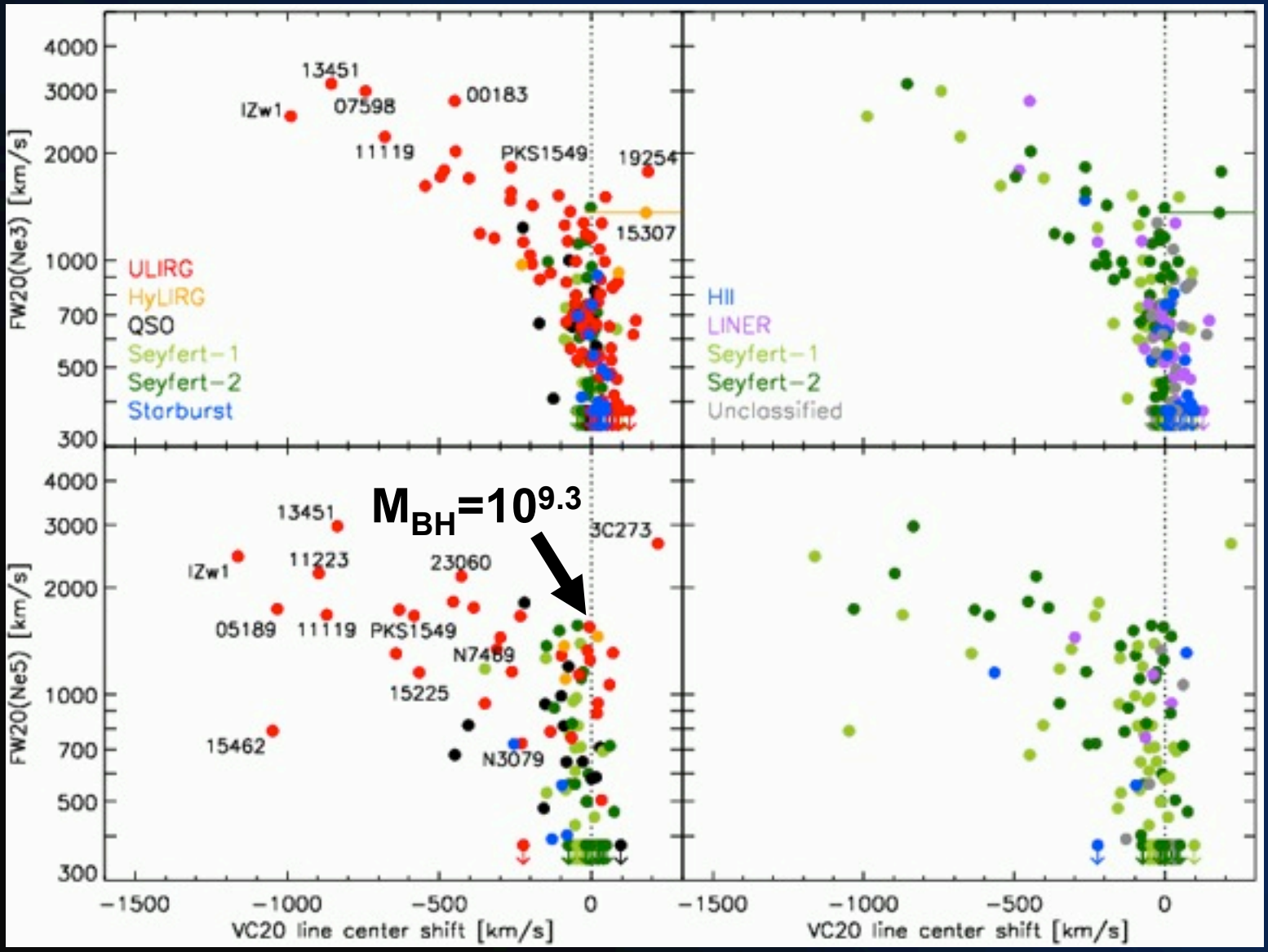


Correlation of FW20 and VC20



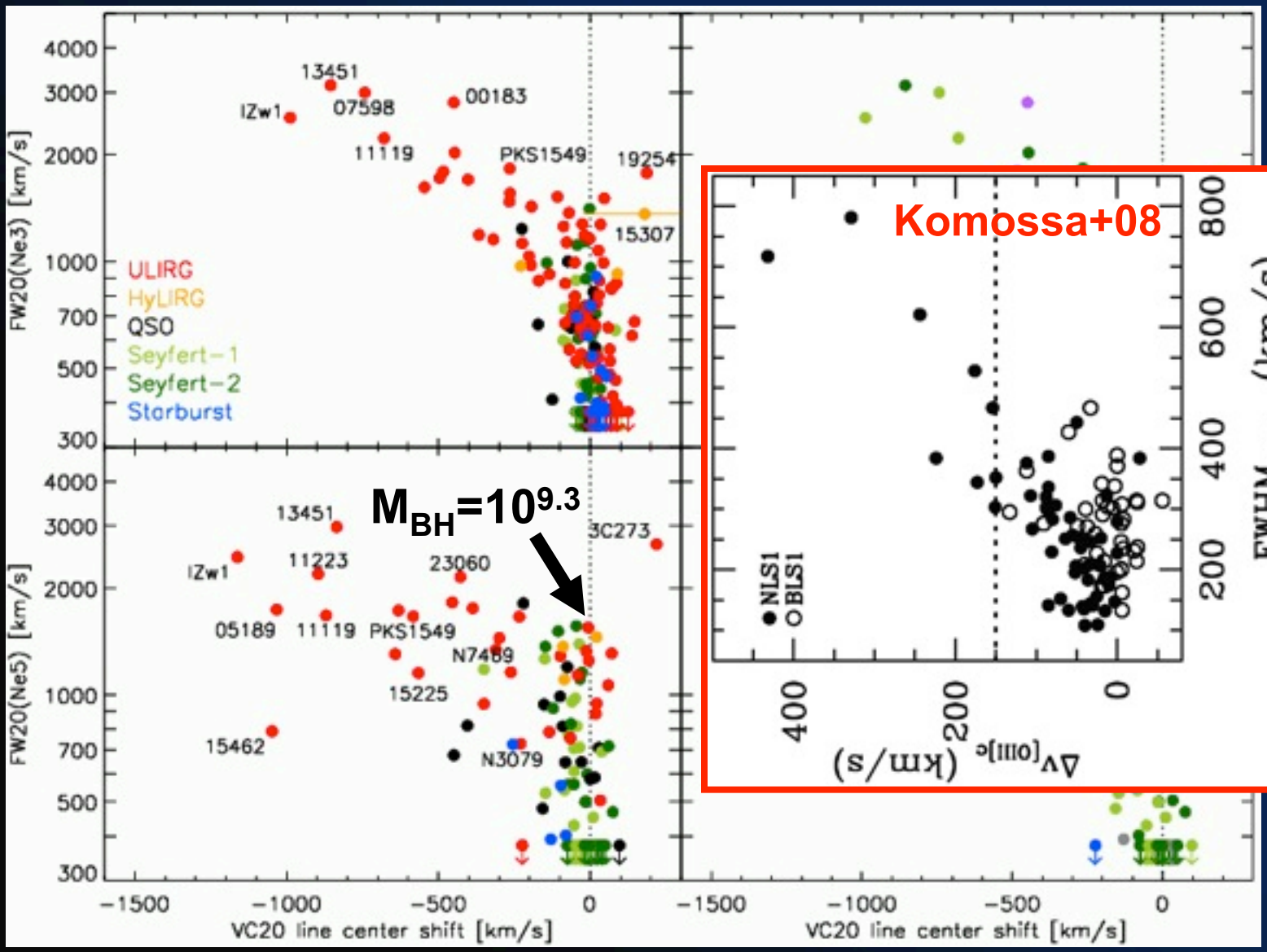
Spoon & Holt +09

Correlation of FW20 and VC20



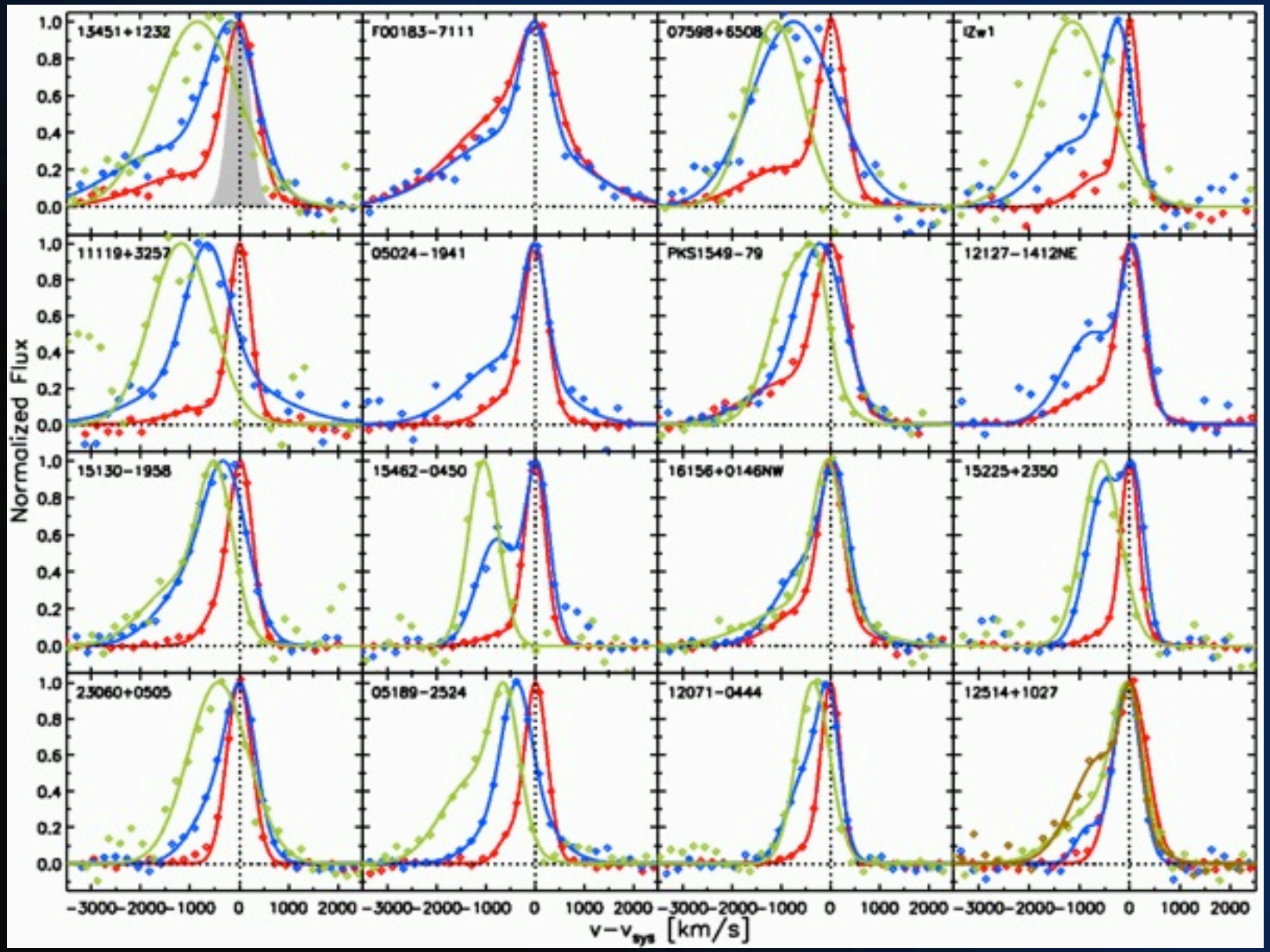
Spoon & Holt +09

Correlation of FW20 and VC20



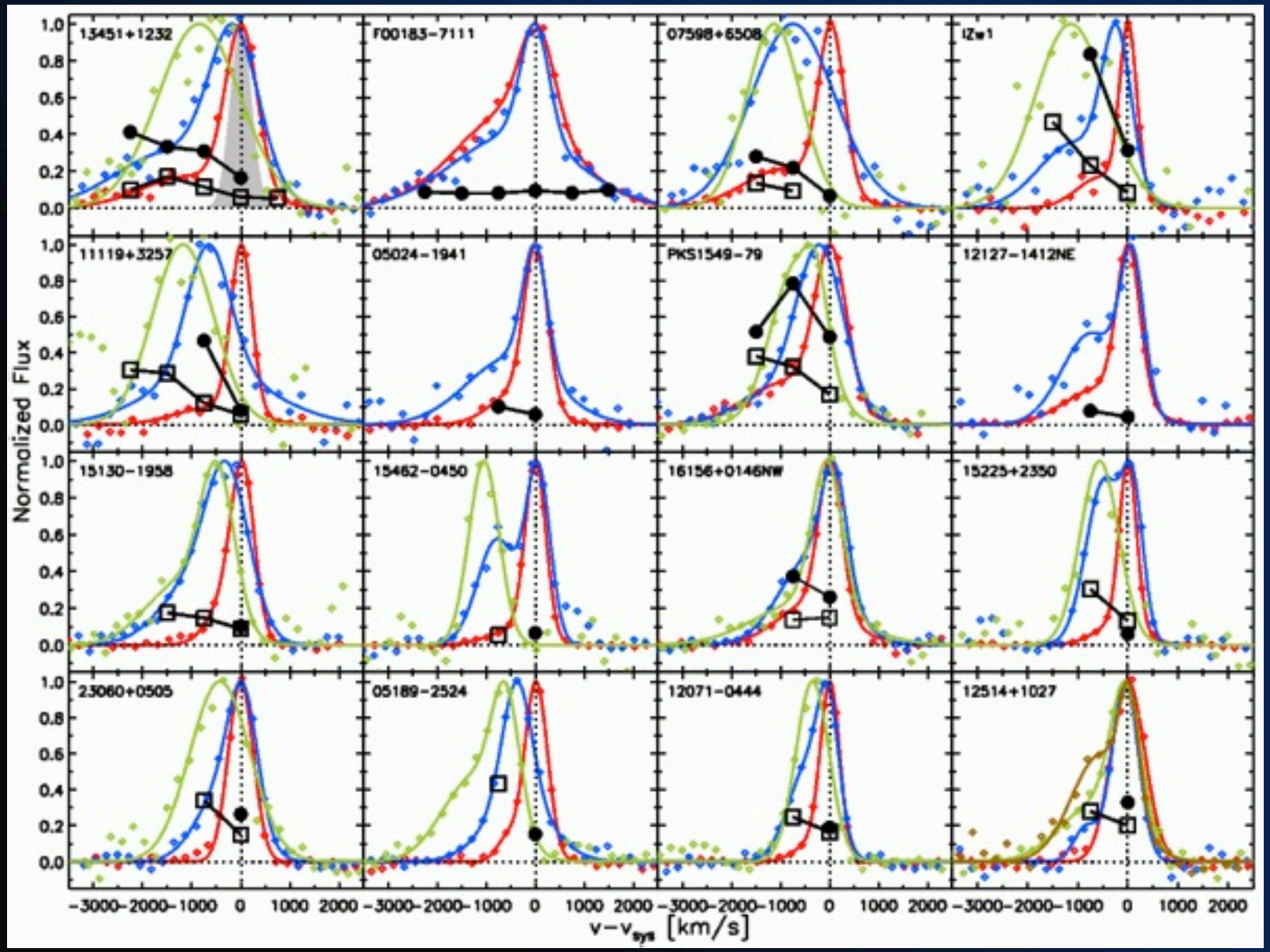
Spoon & Holt +09

[Ne2] [Ne3] [Ne5] [Ne6] IP=21-127eV



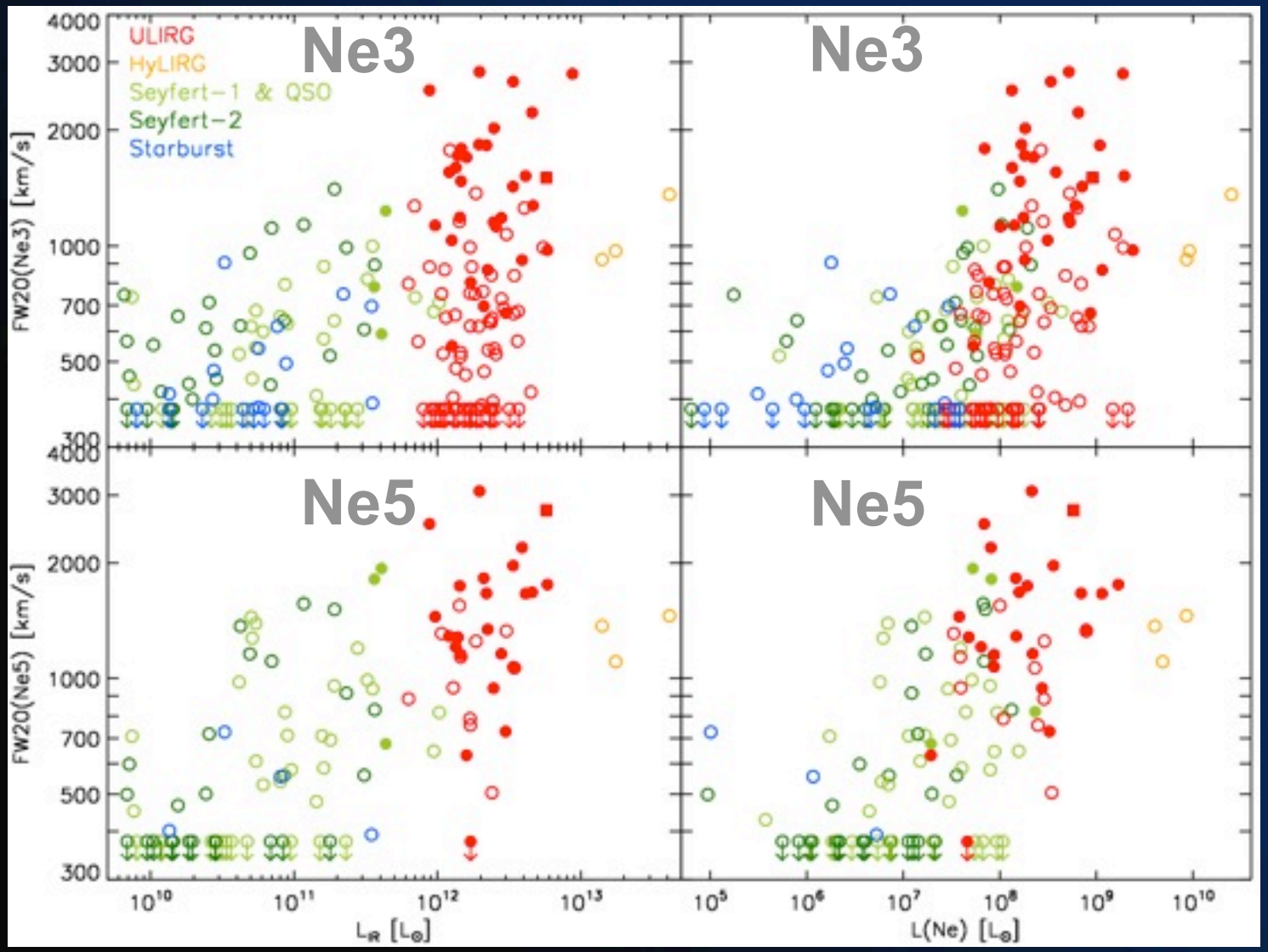
Spoon & Holt +09

[Ne2] [Ne3] [Ne5] [Ne6] IP=21-127eV

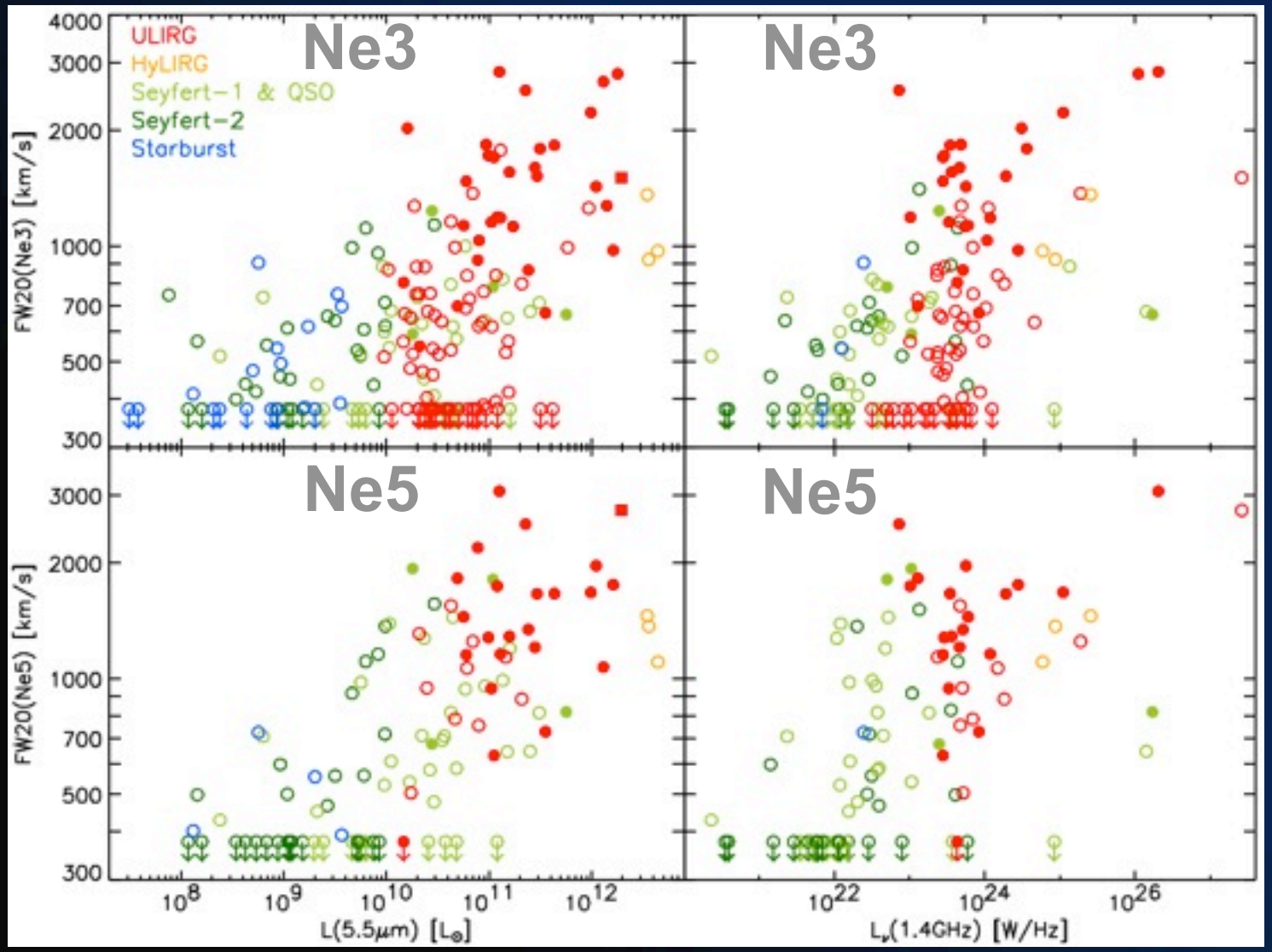


Spoon & Holt +09

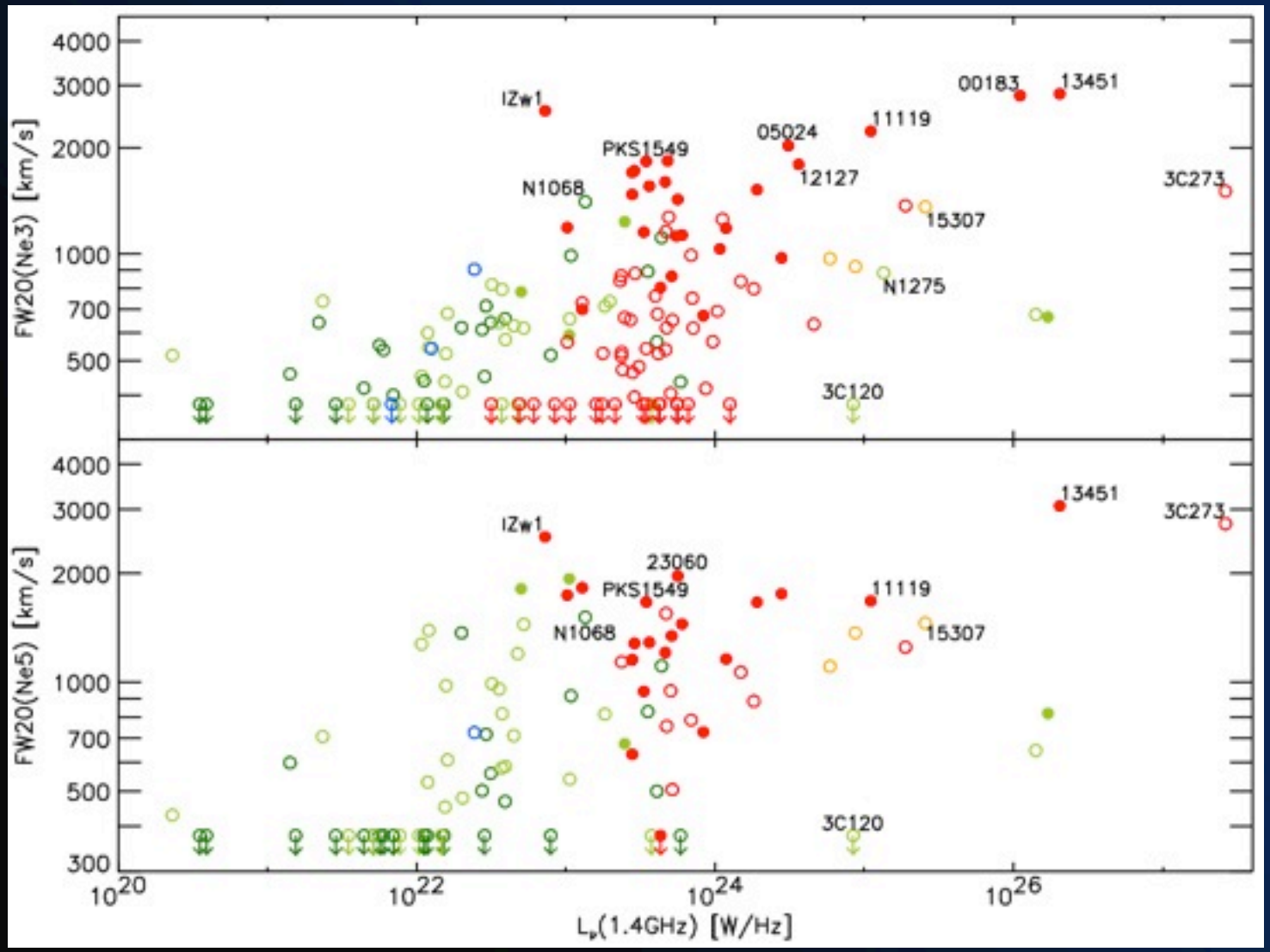
ULIRGs have largest range of neon line widths



Neon line widths increase with AGN power

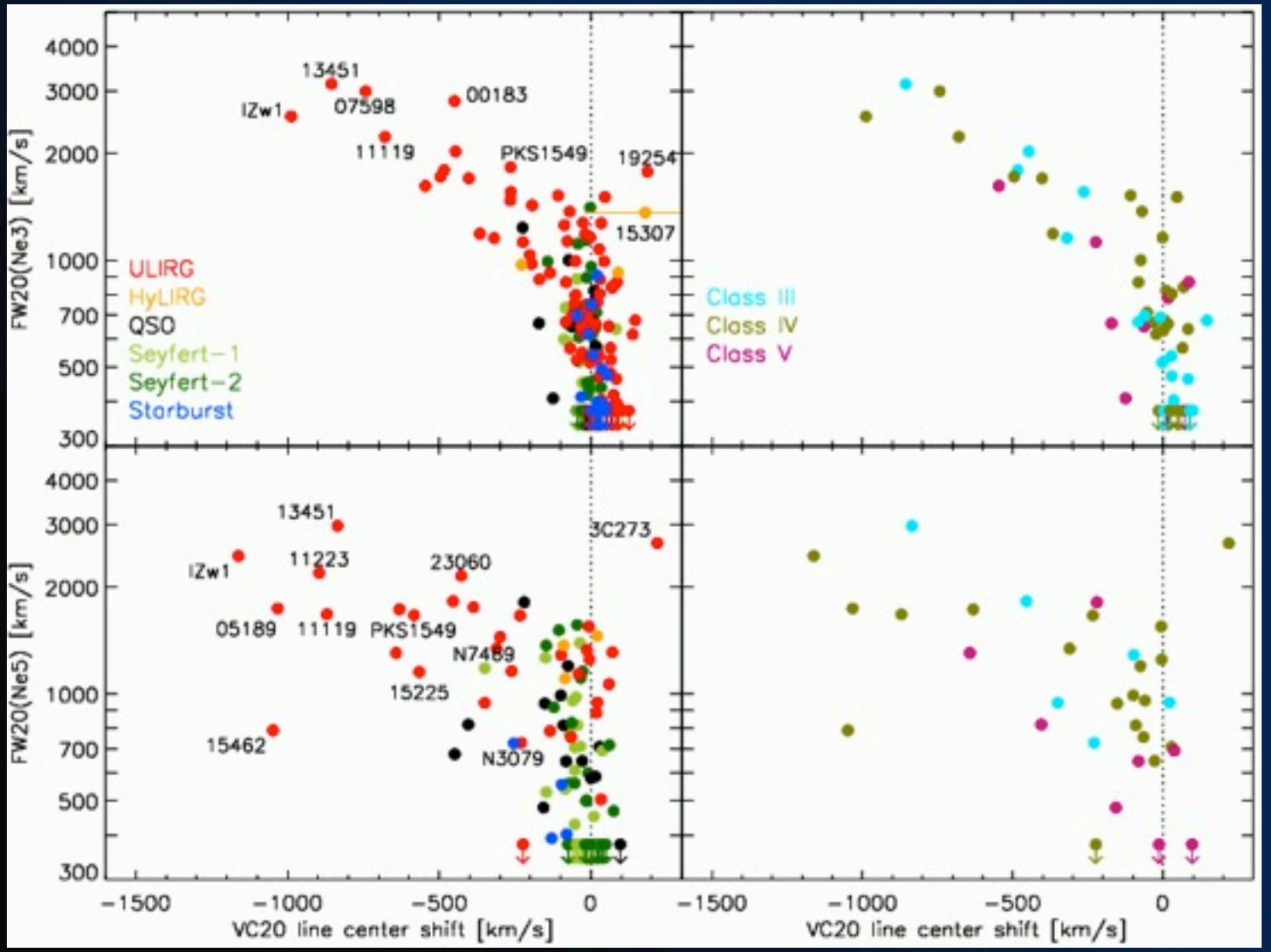


FW20(Ne3,Ne5) increases with L(radio)

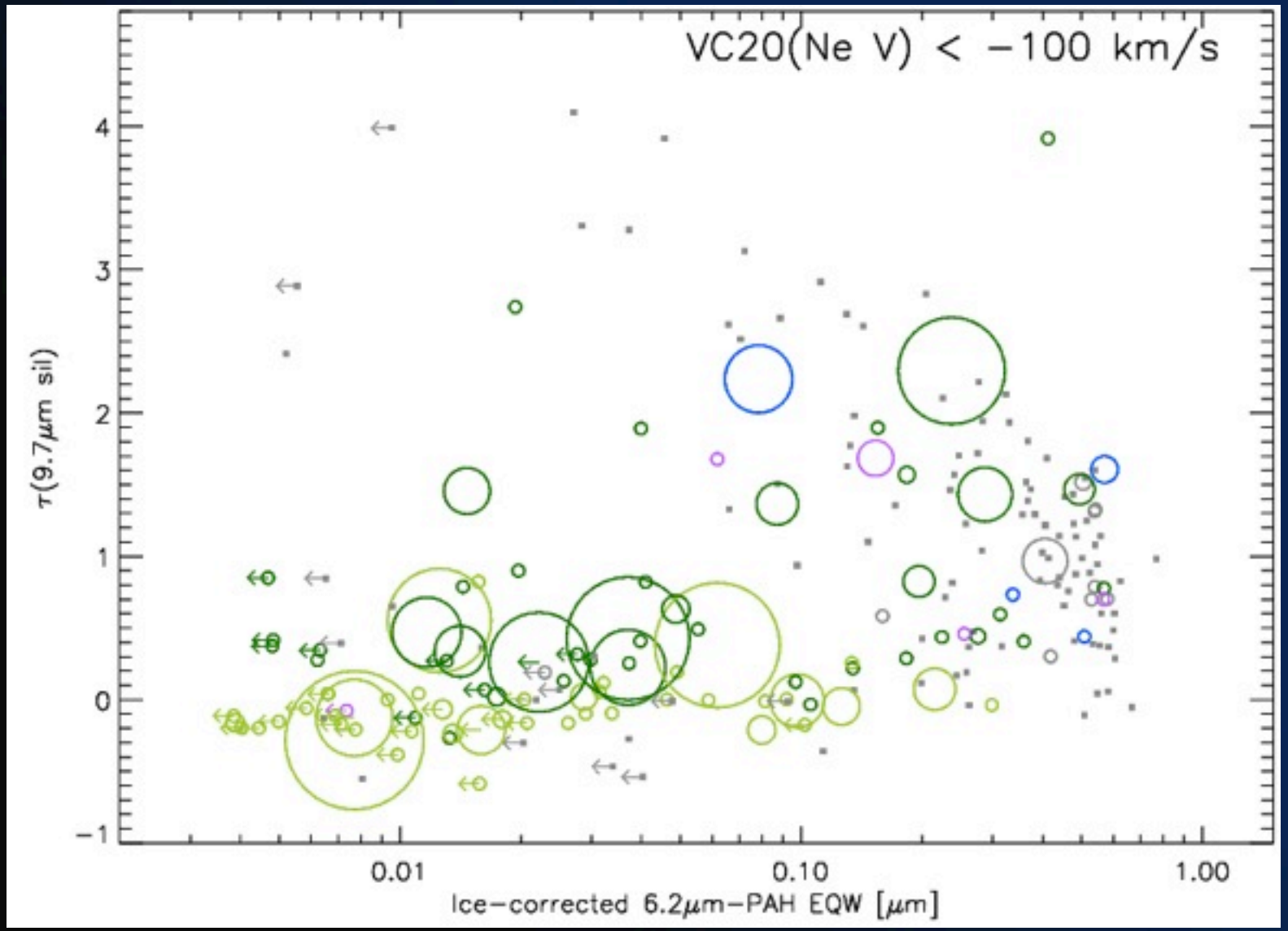


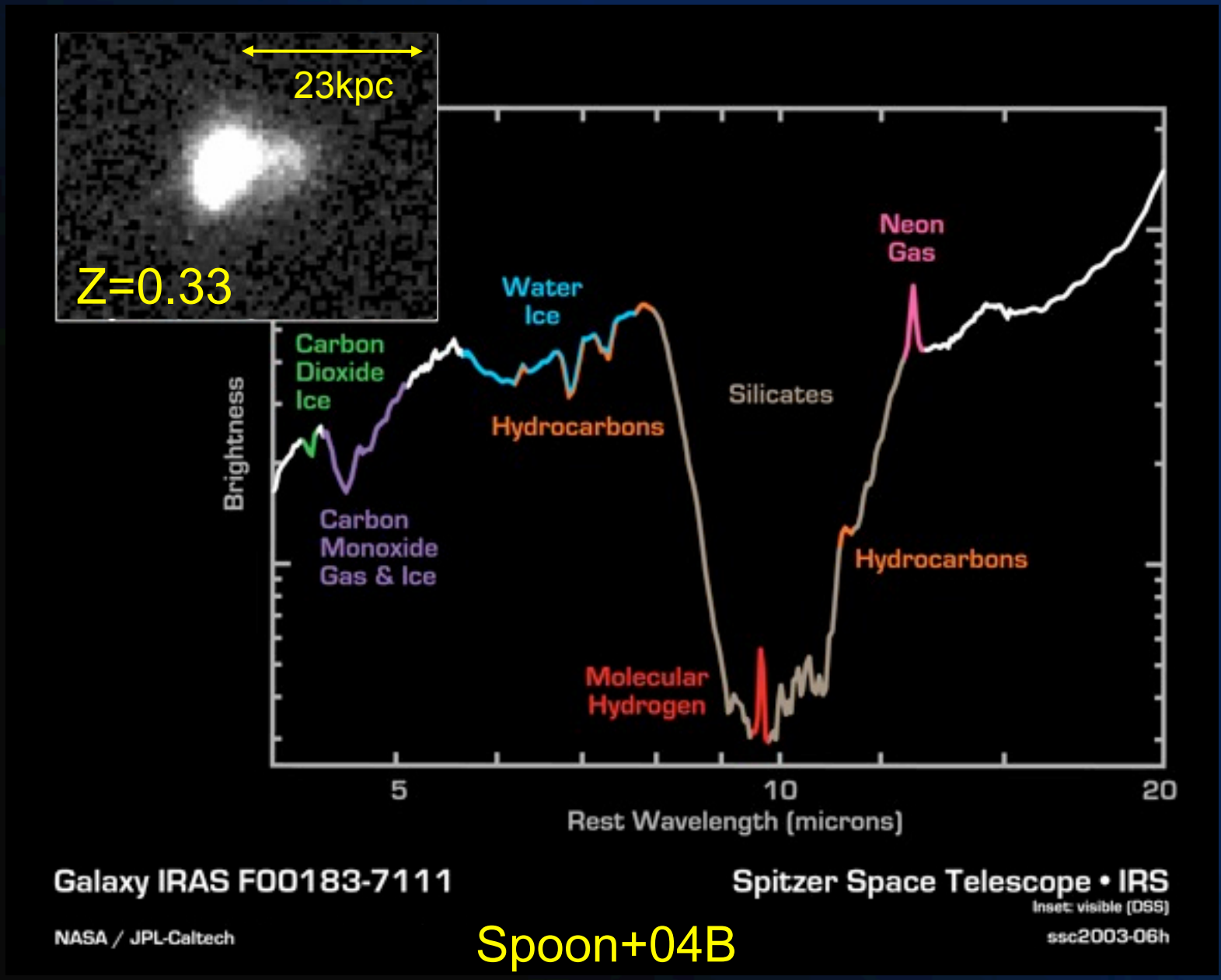
Spoon & Holt +09

No obvious correlation with interaction class

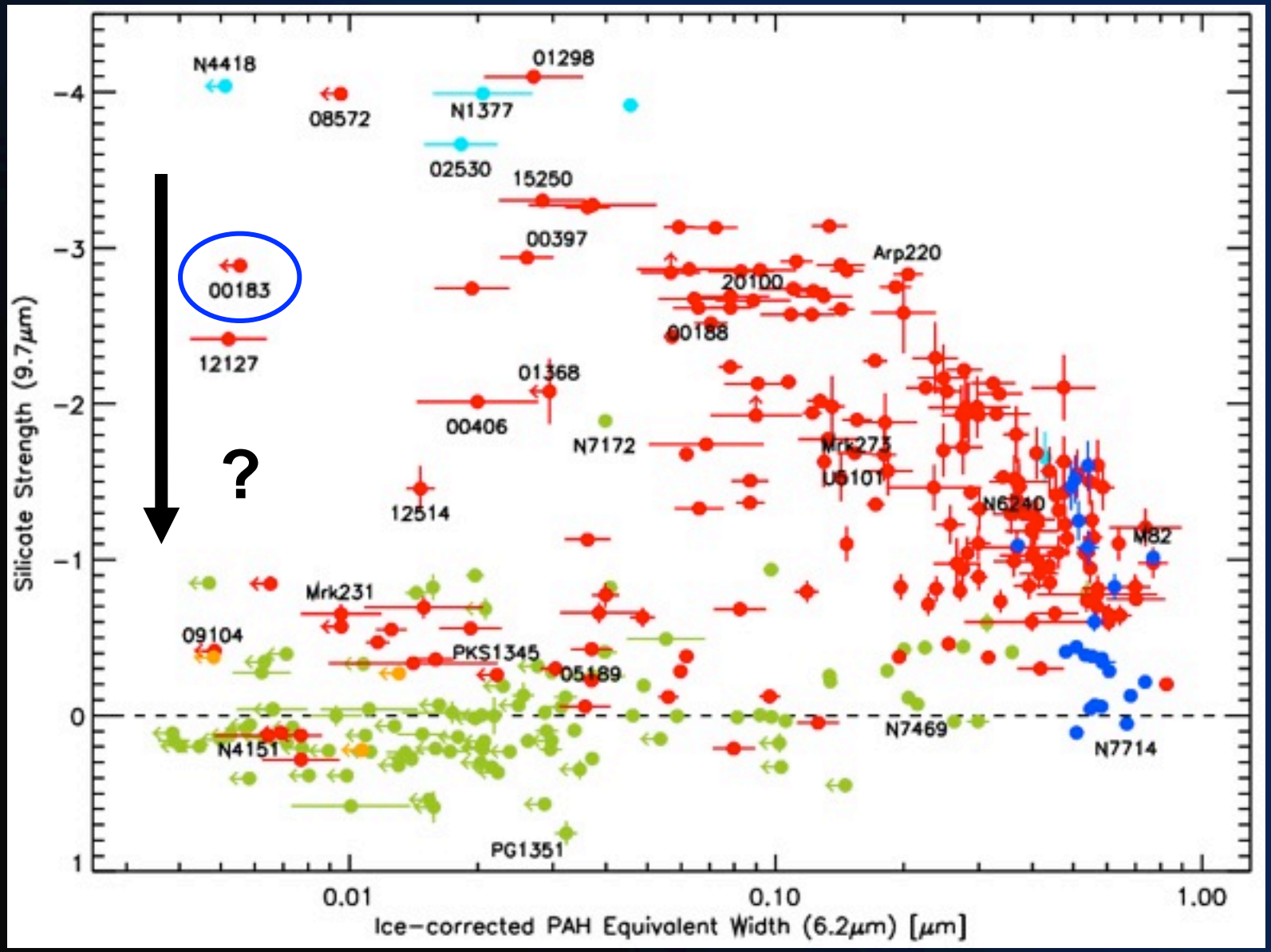


Blue shifted [Ne V] sources in fork diagram



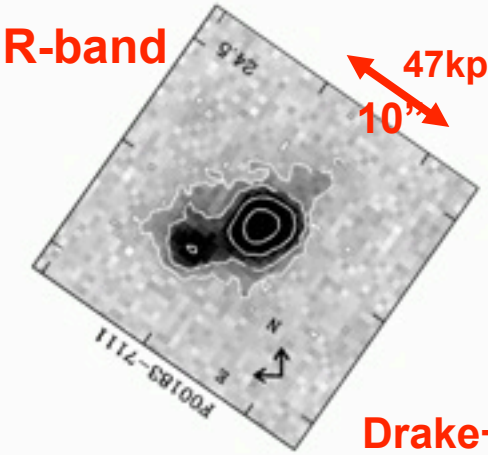

23kpc
Z=0.33
Carbon Dioxide Ice
Water Ice
Neon Gas
Silicates
Hydrocarbons
Carbon Monoxide Gas & Ice
Hydrocarbons
Molecular Hydrogen
Brightness
5
10
20
Rest Wavelength (microns)
Galaxy IRAS F00183-7111
Spitzer Space Telescope • IRS
Inset: visible (DSS)
NASA / JPL-Caltech
ssc2003-06h

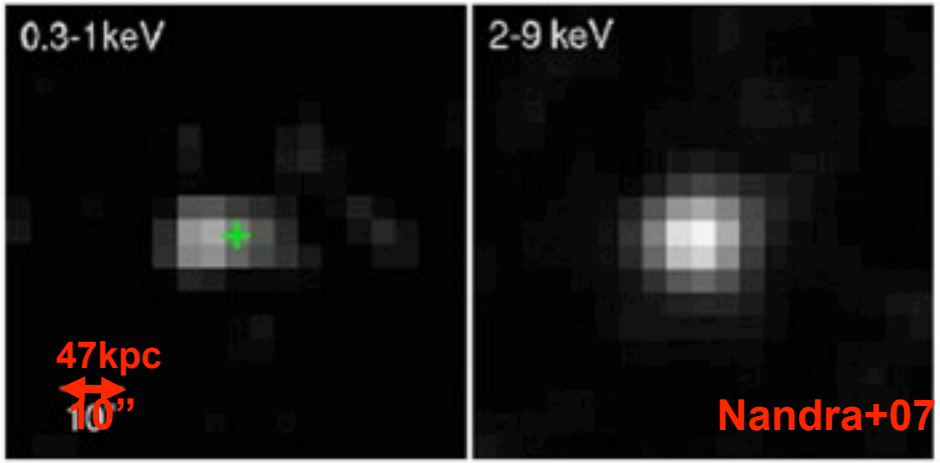
Spoon+04B

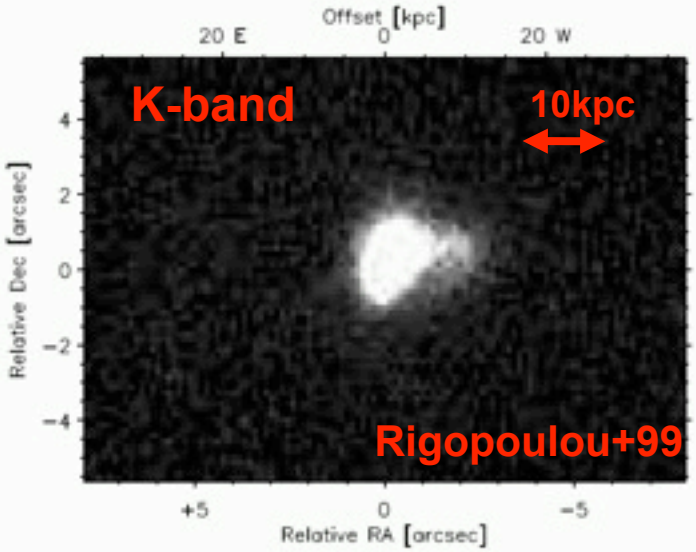

N4418
08572
01298
N1377
02530
15250
00397
Arp220
20100
00188
00183
12127
01368
00406
N7172
Mrk273
U6101
N6240
M82
12514
?
Mrk231
09104
PKS1345
05189
N4151
N7469
N7714
PG1351
Silicote Strength (9.7μm)
Ice-corrected PAH Equivalent Width (6.2μm) [μm]
0.01
0.10
1.00
-4
-3
-2
-1
0
1

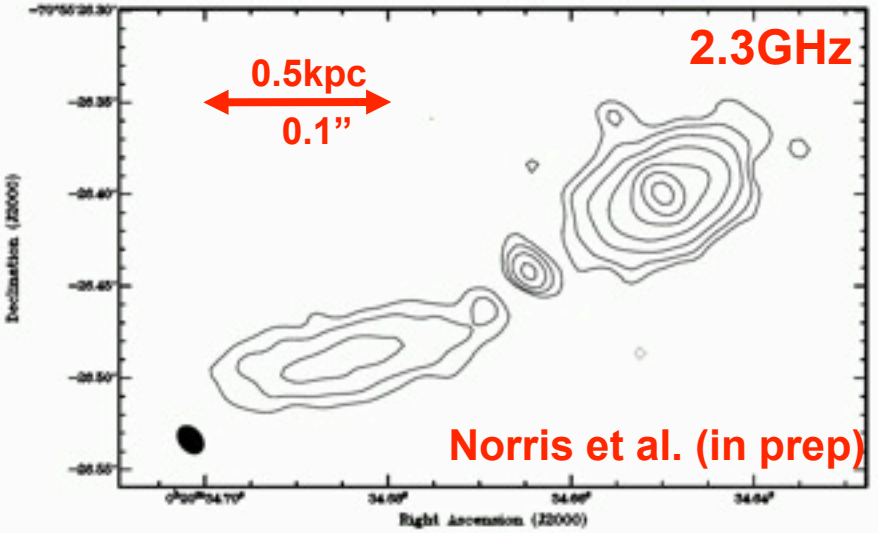
Spoon+09A

IRAS F00183-7111: young radio galaxy?

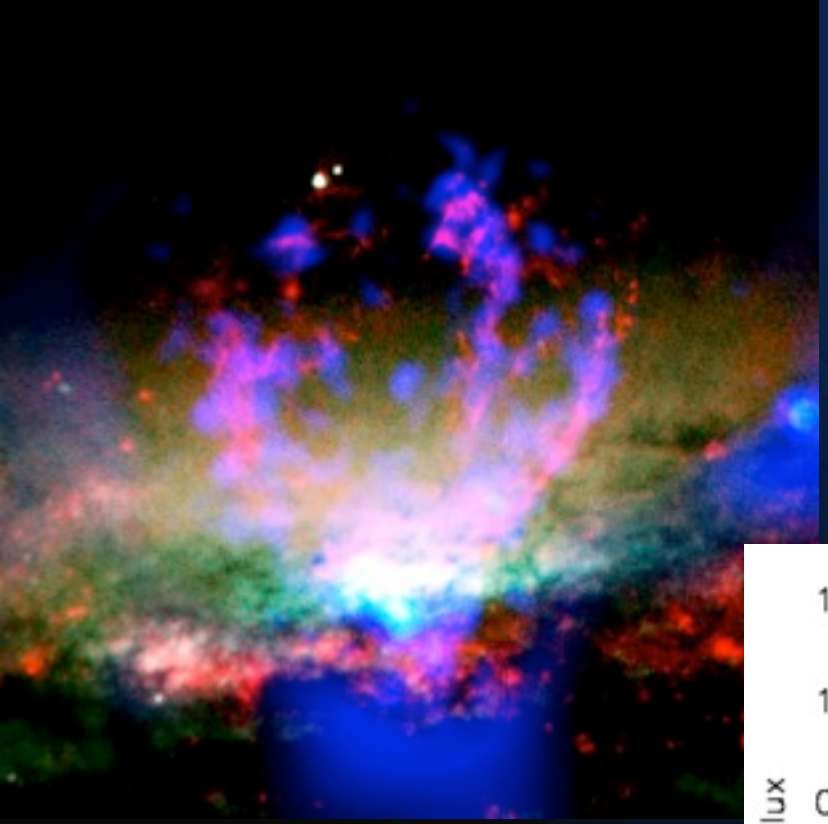






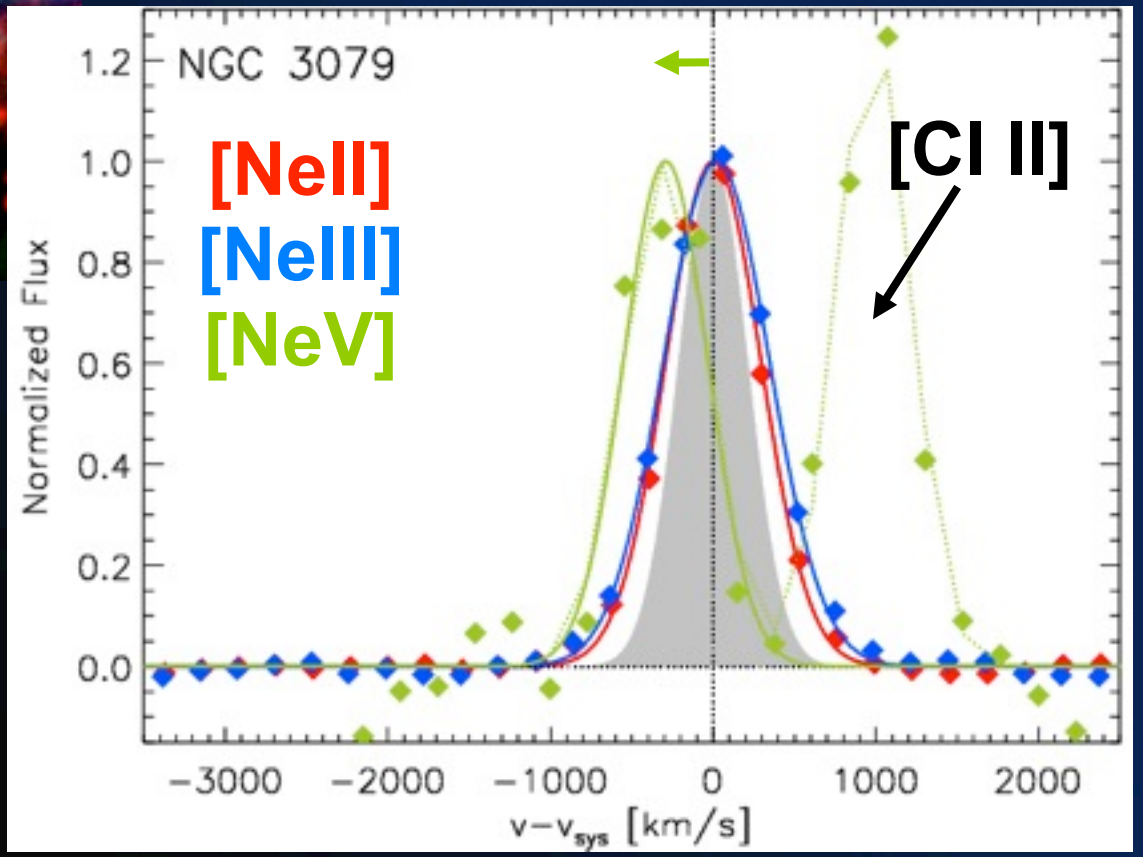


L(1.4GHz)=1.1 x 10^{26} W/Hz



NGC 3079

[NeV] line is blue shifted by 270±50 km/s



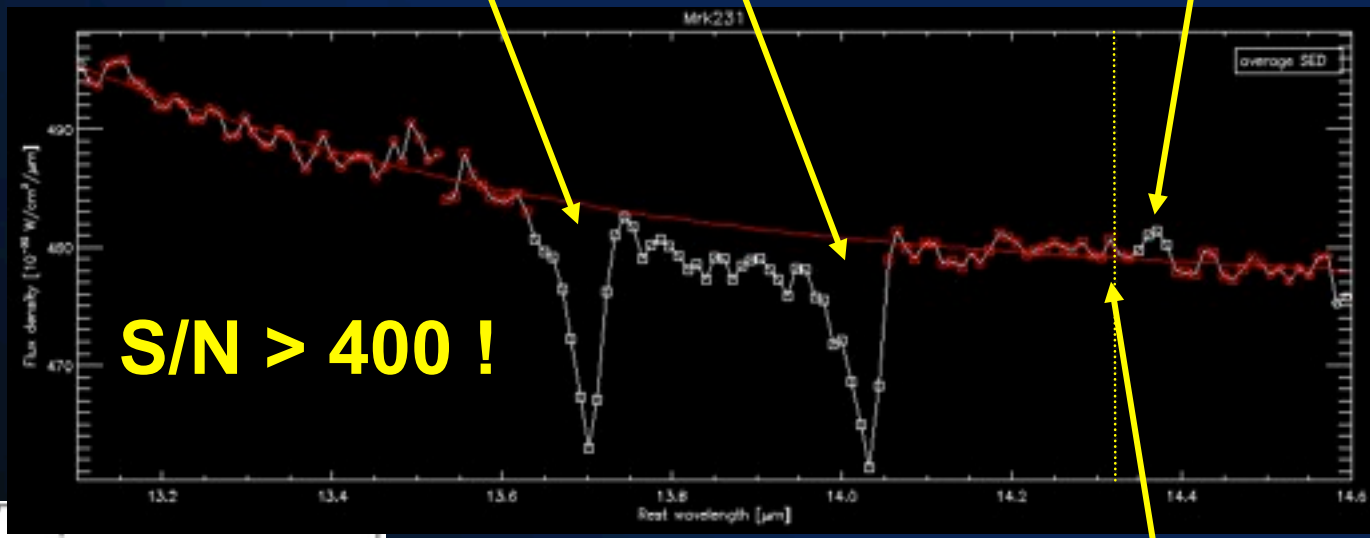
Starburst-driven outflow ionized by the AGN?

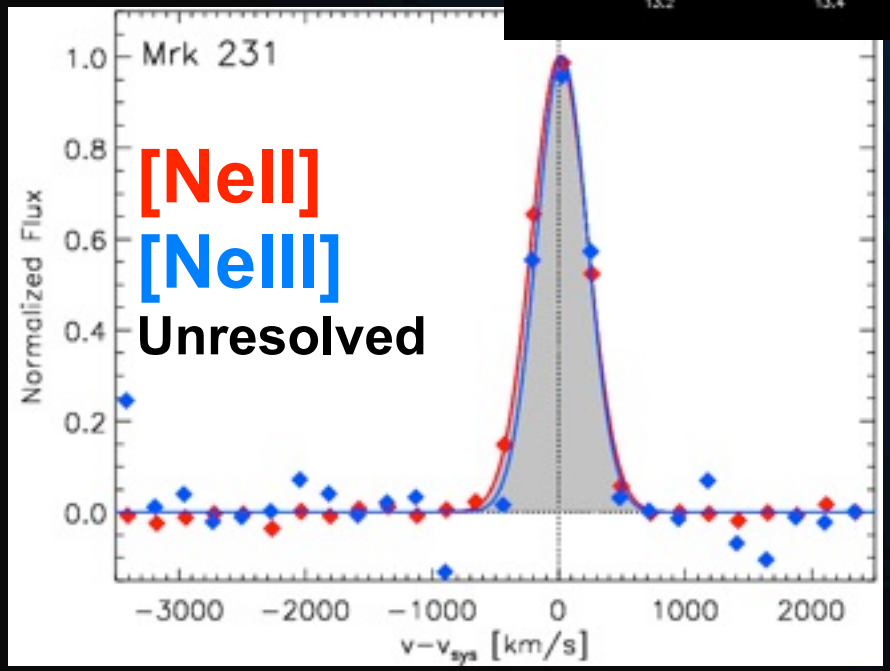
Mrk231

Neon lines are unresolved by Spitzer-IRS: FW20 < 400 km/s

C_2H_2 & HCN gas

[Cl II] ?





No [Ne V] ==> no NLR ?

Fisher et al+10: powerful molecular outflow detected

Future directions

- **Include earlier interaction stages (I + II) in study**
- **Compare to studies of:**
  - **ionized gas in optical / UV**
  - **neutral gas (Na I D) absorption lines**
  - **molecular gas (Herschel: OH) absorption lines**
- **Check for presence of linear radio structures**
- **JWST**

Conclusions

- Clearly blue shifted neon lines seen in 28/82 ULIRGs (30%)
- >90% of these are optically classified as Seyferts/QSOs
- Absence of red shifted component ➔ strong obscuration on counter outflow, even in mid-IR !
- FW20(Ne3,5) increases with L(Ne3,5), L(radio) and L(5.5μm)
- FW20(Ne3,5) correlated with VC20(Ne3,5)

- <u>Subsample of 16 most blue shifted ULIRGs:</u>
- Ionization increases with blue shift ➔ stratified medium
- Interaction of young expanding radio jets with dense ISM may explain outflow kinematics in radio-loud ULIRGs
- The origin of the outflows in other ULIRGs remains speculative at this time (radiatively accelerated clouds, jets)


gettyimages