SPICA
赤外線分光
による銀河形成の研究

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1．INTRODUCTION
2．星形成と [NeII],[NeIII]
3．高階電離、AGN 現象と [OIV],[NeV]
4．SAFARI
5．米国装置　WISPIR/BLISS/μ-SPEC

SPICA MIR/FIR焦点面装置に望むサイエンス

☆ Dust/PAR emission による撮像・測光

High Sensitivity L(FIR) ~ $10^{11}L_{sun}$ galaxies @ z~3

SPICA resolution ~2” == 10-20kpc @ z~1-5

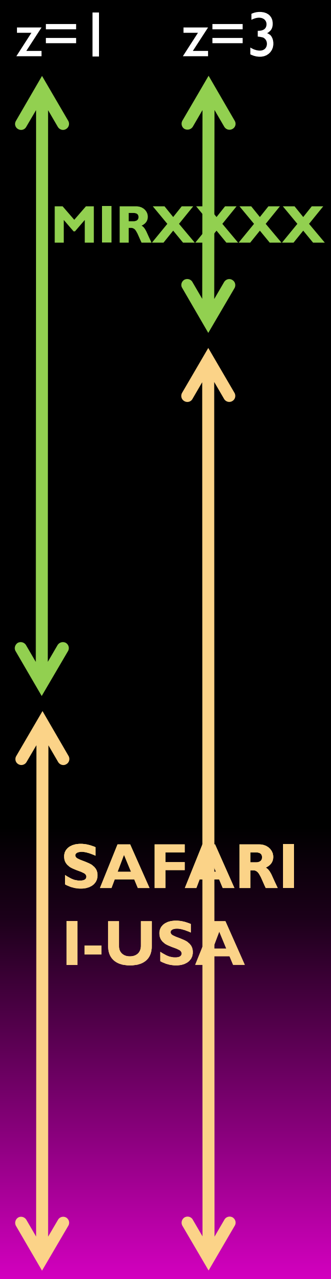
個々の銀河の内部構造は分解出来ないが
銀河相互作用は分解できる。

☆ Fine Structure Lines (微細構造輝線)

銀河星形成領域内部における電離ガス
(吸収の影響なし)
銀河中心核深部における銀河中心核起源の電離ガス

微細構造定数？

line	λ rest (μm)	Probes of
HI Br α	4.05	metallicity (H) / extinction
HI Pf α	7.46	metallicity (H) / extinction
ArII	7.0	excitation
ArIII	9.0, 21.8	excitation
NeII	12.8	SFR / excitation / metallicity
NeIII	15.6, 36.0	SFR / excitation / metallicity
NeV	14.3, 24.3	AGN indicator
SIV	10.5	Excitation
SIII	18.7, 34	Excitation
SiII	34.8	PDR
OIV	25.9	AGN indicator
OIII	51.8, 88.3	Density / metallicity
OI	63.1, 145	PDR
NII	122, 205	Metallicity
NIII	57.3	Metallicity
CI	370	Molecular gas
CII	158	PDR



代表的な微細構造輝線（電離ポテンシャルと臨界密度）

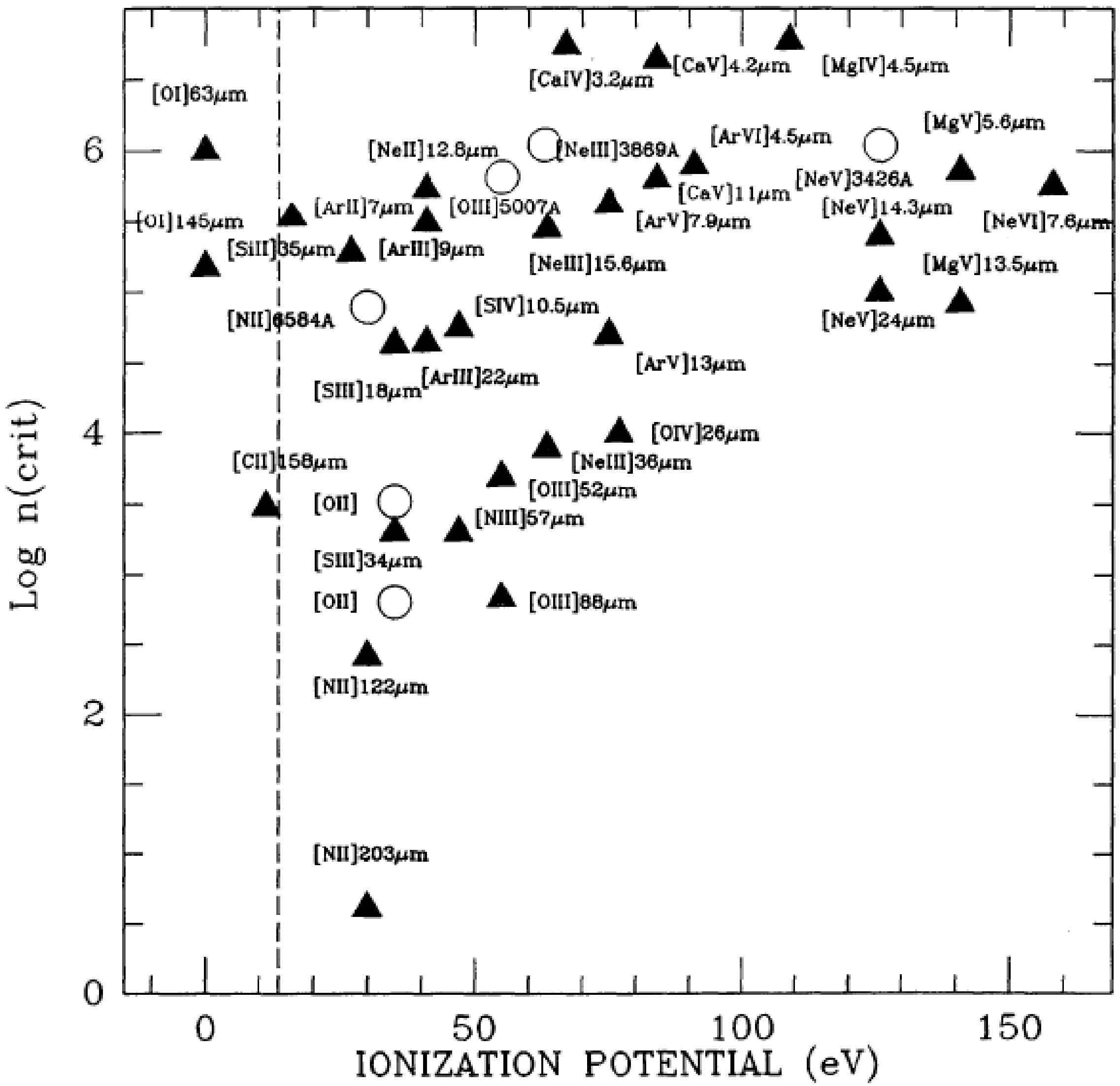


FIG. 1.—Ionization potential (in eV) vs. critical density (cm^{-3}) of the forbidden infrared lines (*filled triangles*) compared to some optical forbidden lines (open circles).

Spinoglio and Malkan (1992)

ISO-SWS によるM82 のスペクトル

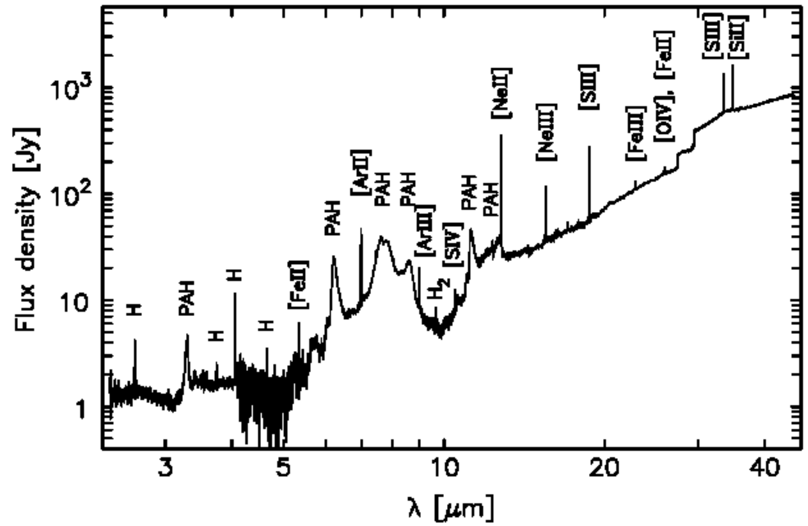
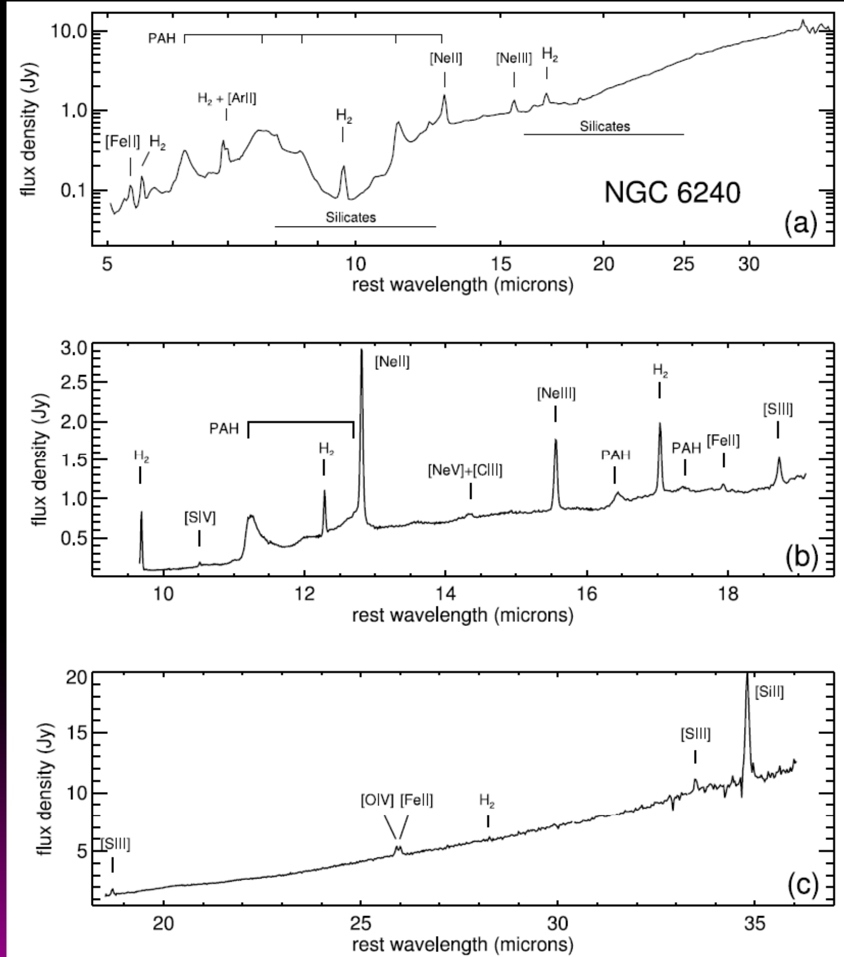


FIG. 4.—*ISO*-SWS mid-infrared spectrum of M82 (full scan AOT SWS01). The spectral resolution varies from ∼1000 at short wavelengths to ∼500 at long wavelengths. The “jumps” in the continuum level at 12.0, 27.8, and 29.5 μm are caused by the increase in aperture size and the fluctuations in the continuum, especially in the 4−5 μm region, are mainly due to noise.

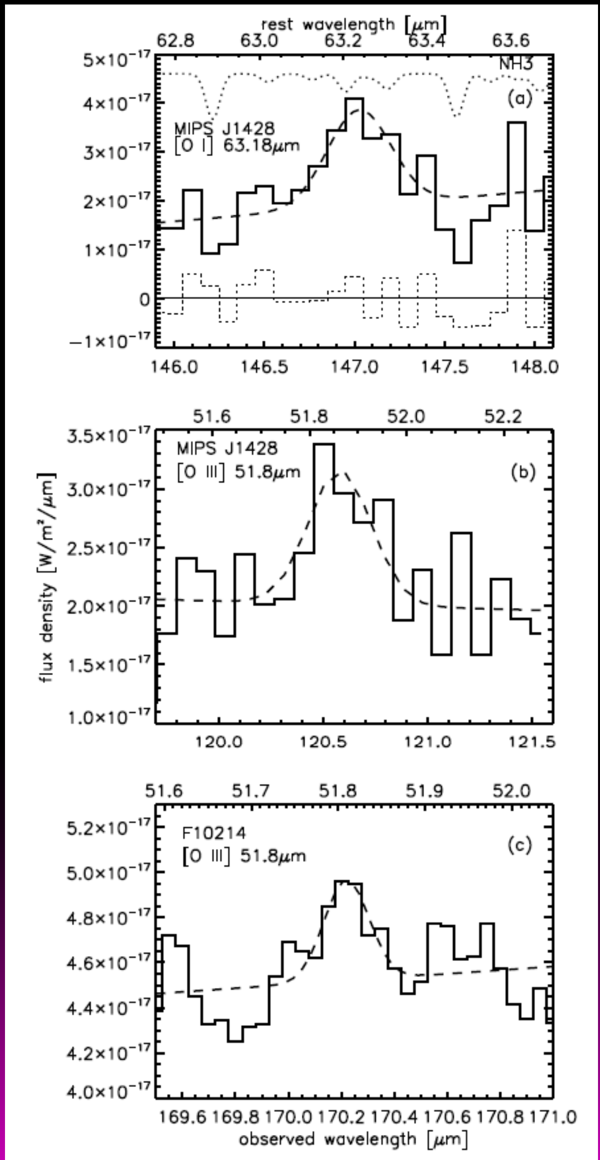
Forster-Schreiber et al. 2001

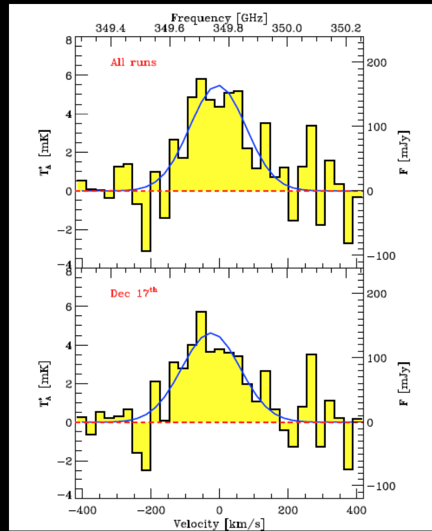
Spitzer IRS 低分散 (R~100) 及び
中分散 (R~600)による NGC6240 スペクトル



Armus et al. 2006

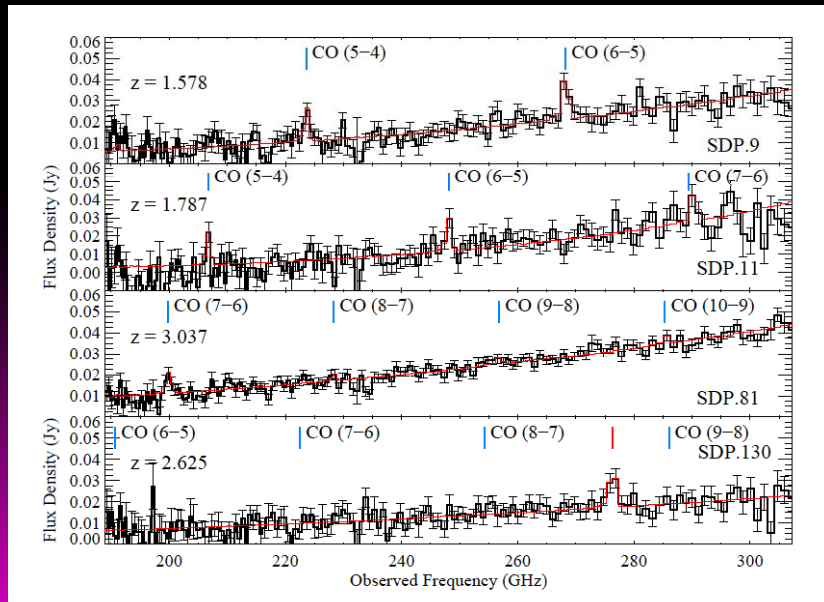
Herschel PACS による遠方銀河のスペクトル





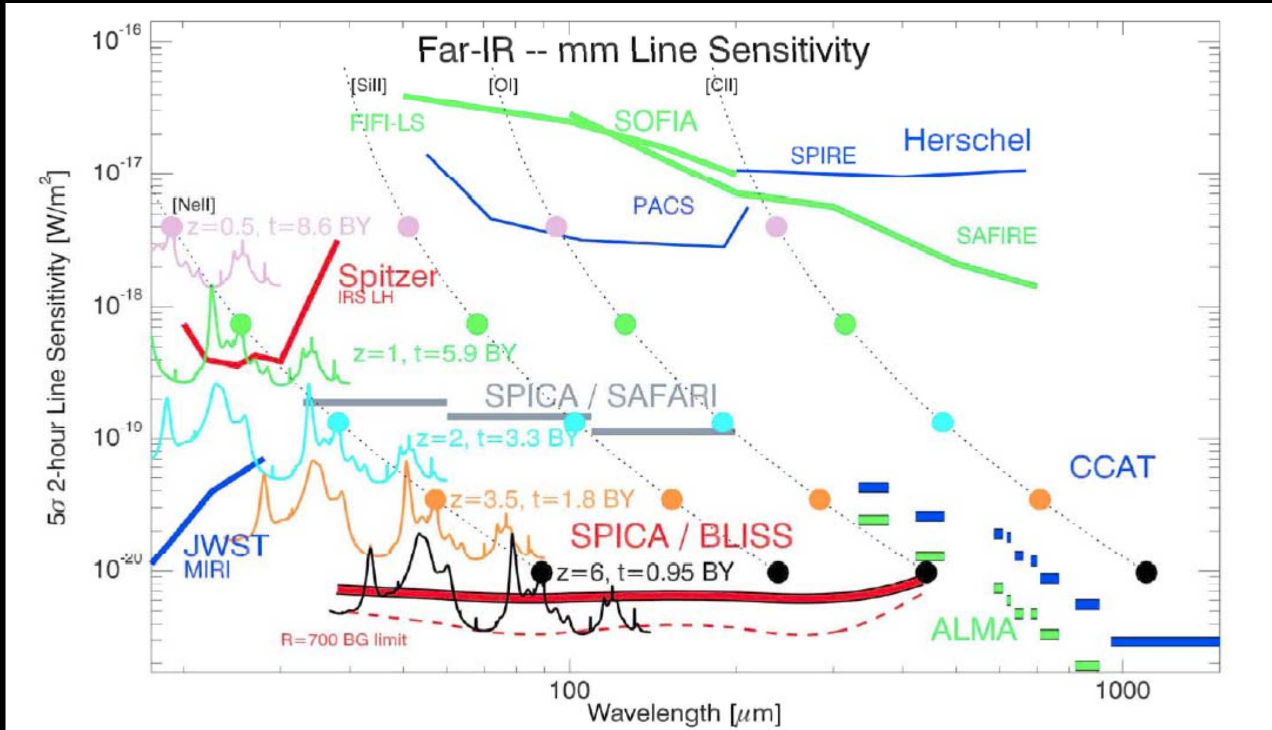
Miolino et al.
2009 APEX
[CII] lline
@z=4.43

CSO Z-Spec による遠方銀河のスペクトル



Strum et al. 2010

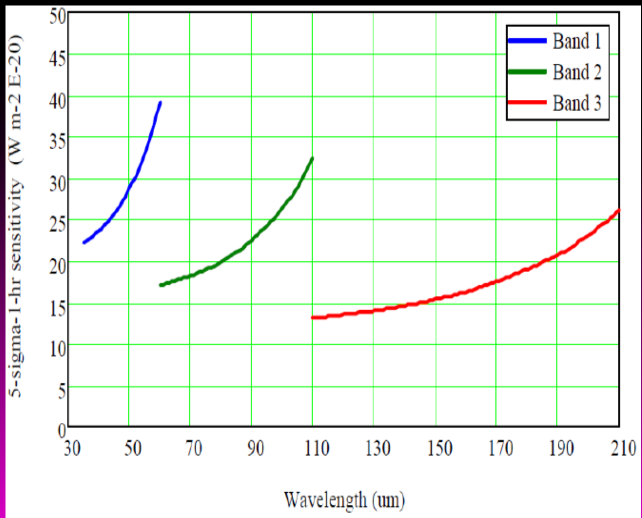
Lupu et al. (2010)

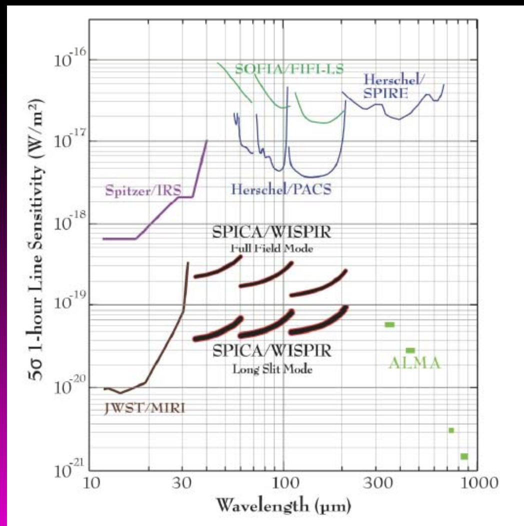


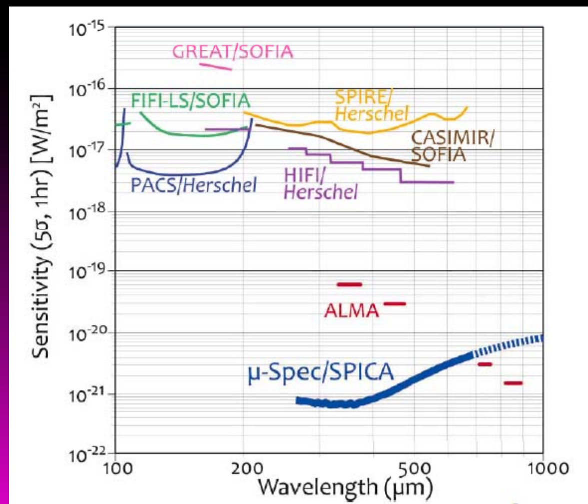
SAFARI IFS R~2000
FoV ~ 2'
~35-200μm

WISPER "longslit mode"
of SAFARI
(longslit + grating)

BLISS grating R~700
~38-433μm
single beam







SAFARI

SPICA Science Workshop で発表の機会があるたびに
言ってきたことですが・・・

遠方銀河の中間・遠赤外線分光は、
１に感度、２に感度、
３・４が無くて５に感度　あと、R~1000

$$\log L_{\mathrm{[Ne\,II]+[Ne\,III]}} = (0.98 \pm 0.069)\log L_{\mathrm{IR}} - (2.78 \pm 0.70) \quad (2)$$

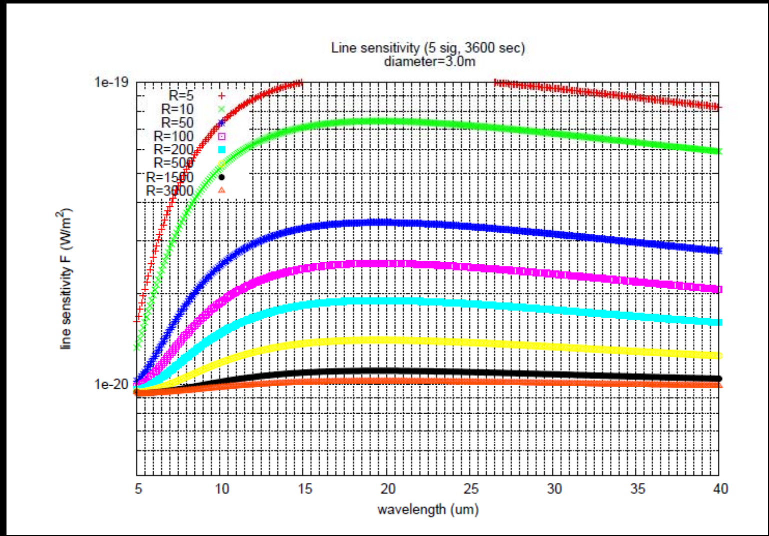
ULIRG L(IR)~10^{12} L_{sun}

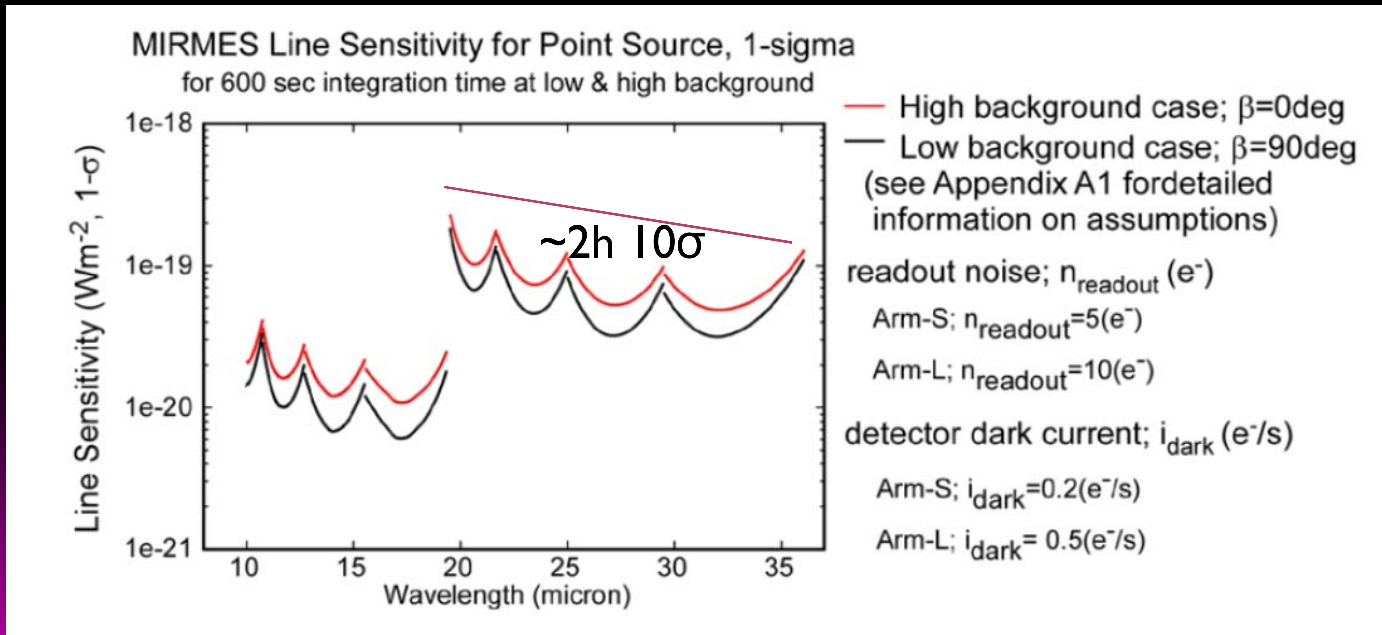
➔@ z=1 F(NeII+NeIII) ~ 8 x 10^{-19} W/m^2 MIRXXXX?

➔@ z=2 F(NeII+NeIII) ~ 1 x 10^{-19} W/m^2 SAFARI/USI?

➔@ z=3 F(NeII+NeIII) ~ 5 x 10^{-20} W/m^2 SAFARI/USI?

さらに、この比を議論するためには、約1桁+の感度が必要





MIRXXXX 600sec 1sigma Line Sensitivity

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[NeIII] (13.6μm) / [NeII] (12.8μm) Ratio

- Hardness of Ionizing radiation
  - Starburst Age
  - Upper Mass Limit in IMF
  - Metallicity (Ionizing stars / gas)
- mildly depends on Ionization Parameters
- mildly depends on Electron Density
- little depends on Extinction
- AGN can be separated by [Ne V] or [OIV]

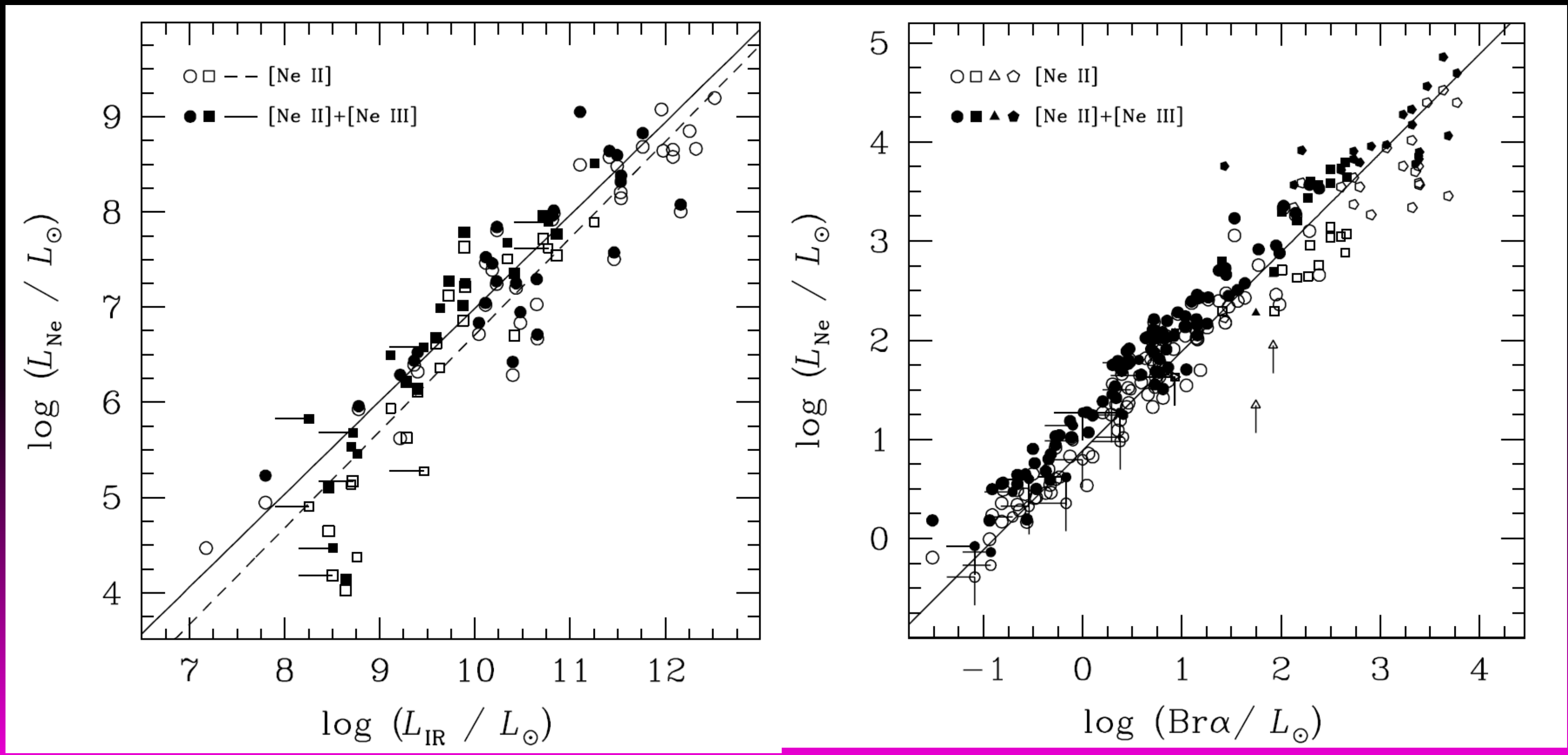
➔ **Constraining IMF of High-z Star-Forming Galaxies**

➔ **Drawing the whole demography of galaxies (observing short-timescale episodic star formation at high-z)**

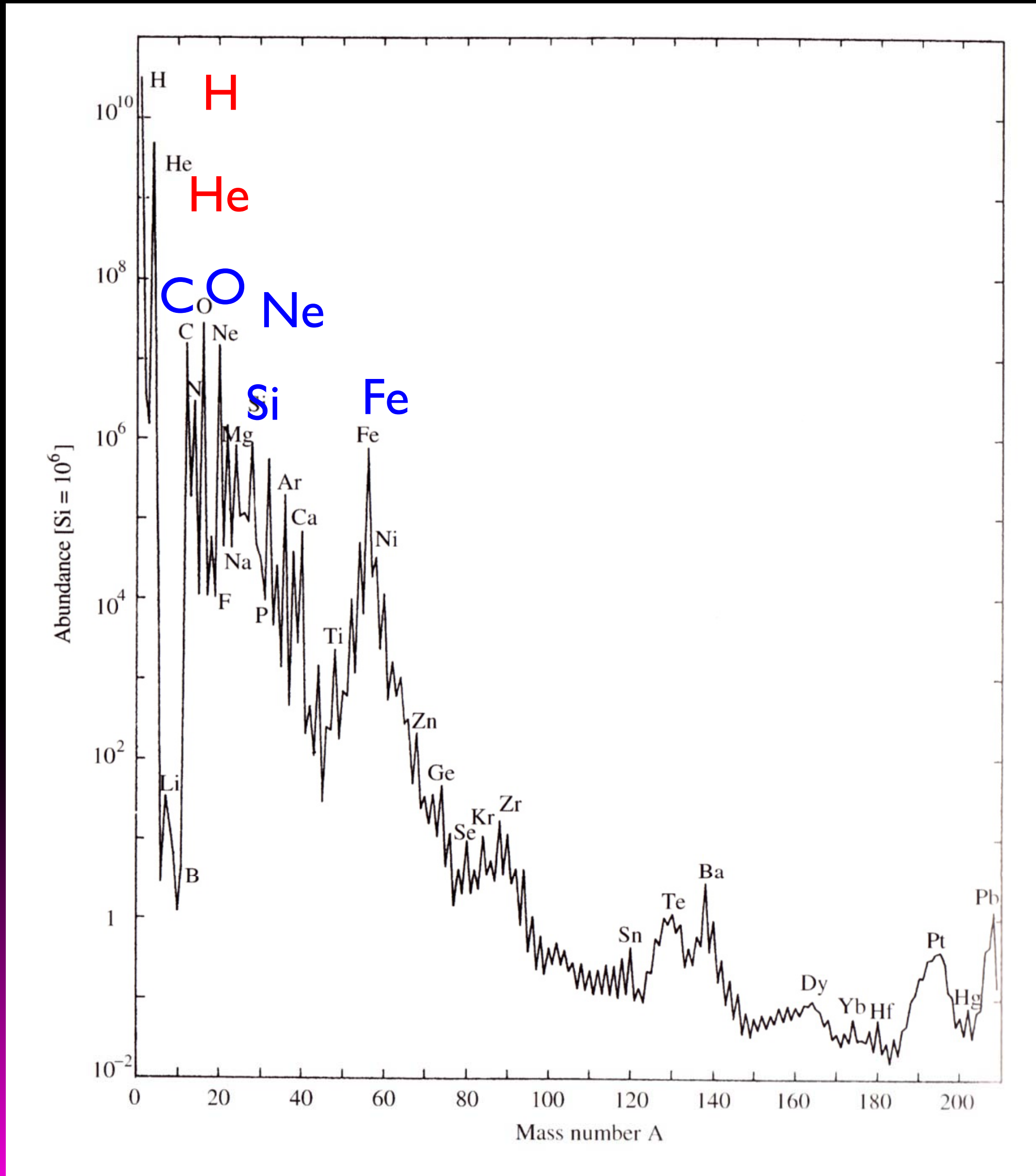
[NeII] 12.8μm-- basic indicator of star-formation/ionized gas

1. 電離ポテンシャル　21.56 eV
2. Dominant coolant in HII region
3. 大きな Critical density $4.3 \times 10^5 cm^{-3}$
4. $Ne/H = 1.2 \times 10^{-4}$ (solar) 多量に存在

Ho et al. 2007



太陽の元素組成比



H
He
C
O
Ne
Si
Fe
H
He
C
O
N
Ne
Mg
Na
F
P
Ar
Ca
Ti
Fe
Ni
Zn
Ge
Se
Kr
Zr
Li
B
Sn
Te
Ba
Dy
Yb
Hf
Pt
Hg
Pb
Abundance [Si = 10^6]
Mass number A

地上 N-band 分光　[Ne II] (12.8μm)　[Ar III]　(9.0) [S IV] (10.5)
HII 銀河での「小さい」　[Ar III] / [NeII] 比

ISO の時代

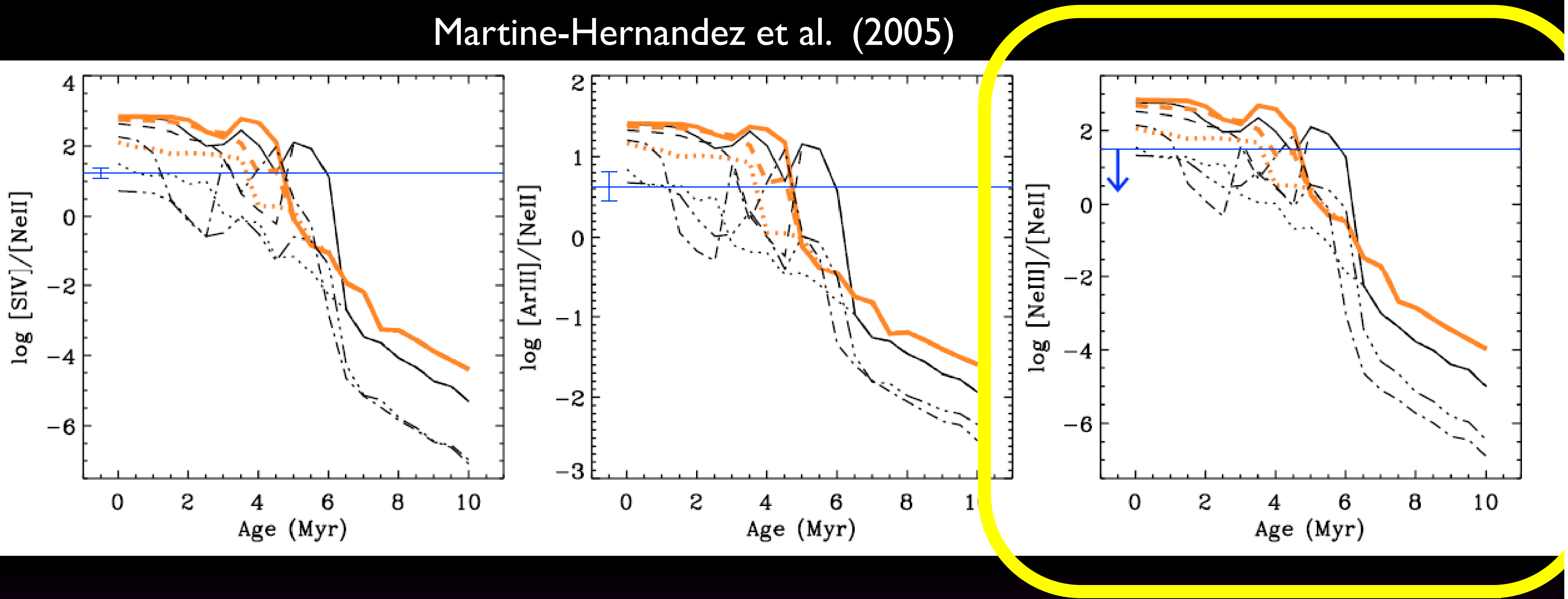
Thornley et al. 2000　Nearby Starburst Galaxies　Burst Age
Martine-Hernandez et al. 2002　Galactic HII Region　Metallicity
Rigby and Rieke 2004　Nearby Starburst　IMF Upper Mass Cut
Martine-Hernandez et al. 2005　（地上）NGC5253　Combination

Spitzer の時代

Snijders et al. 2007 Diagnostics
Beirao et al. 2008 M82　/ Brandle et al. 2006　Starburst /
Barnard-Salas et al. 2009　Starburst / Deo et al. 2007 Seyfert　/
Dale et al. 2009 Nearby Gals / Farrah et al. 2007 ULIRG /
Houck et al. 2007　10μm-sample / Inami et al. 2010　IIZw096 /
Pereira-Santaella et al. 2010a,b　/Tommasin et al. 2007 12μm /
Veilleux et al. 2010 AGN / Watson et al. 2010 GRB /
Whelan et al. 2007 Mrk297 / Willet et al. 2009 Radio Galaxies /
Wu et al. 2006 BCG

Burst Age and [NeIII]/[NeII] ratio

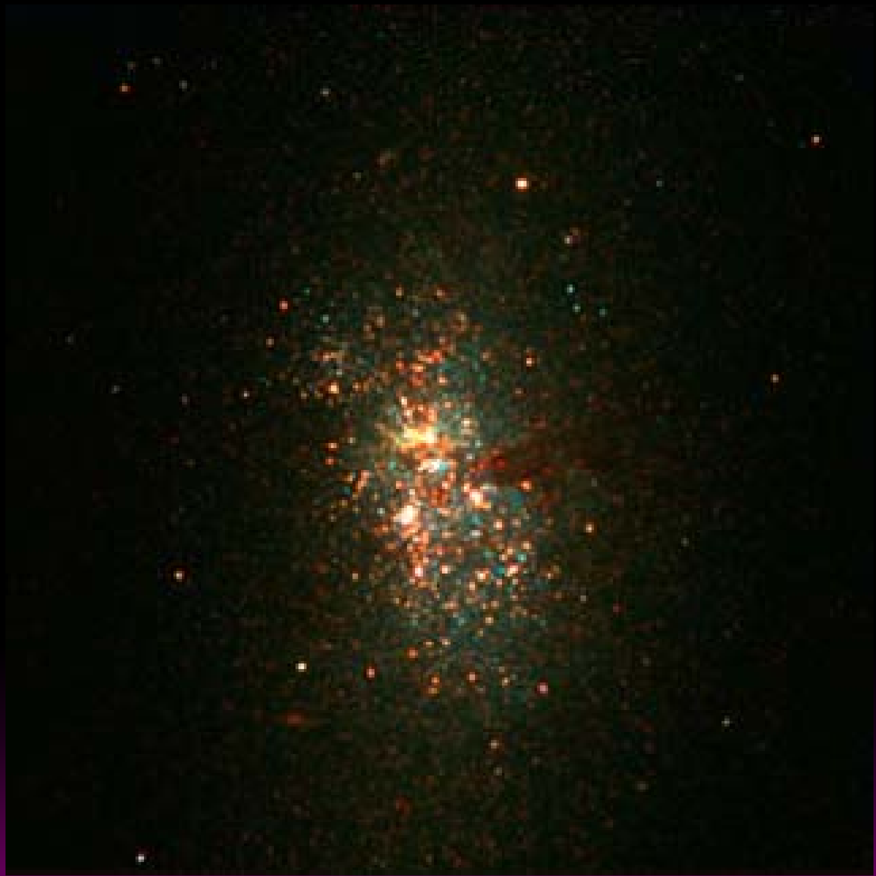
Martine-Hernandez et al. (2005)

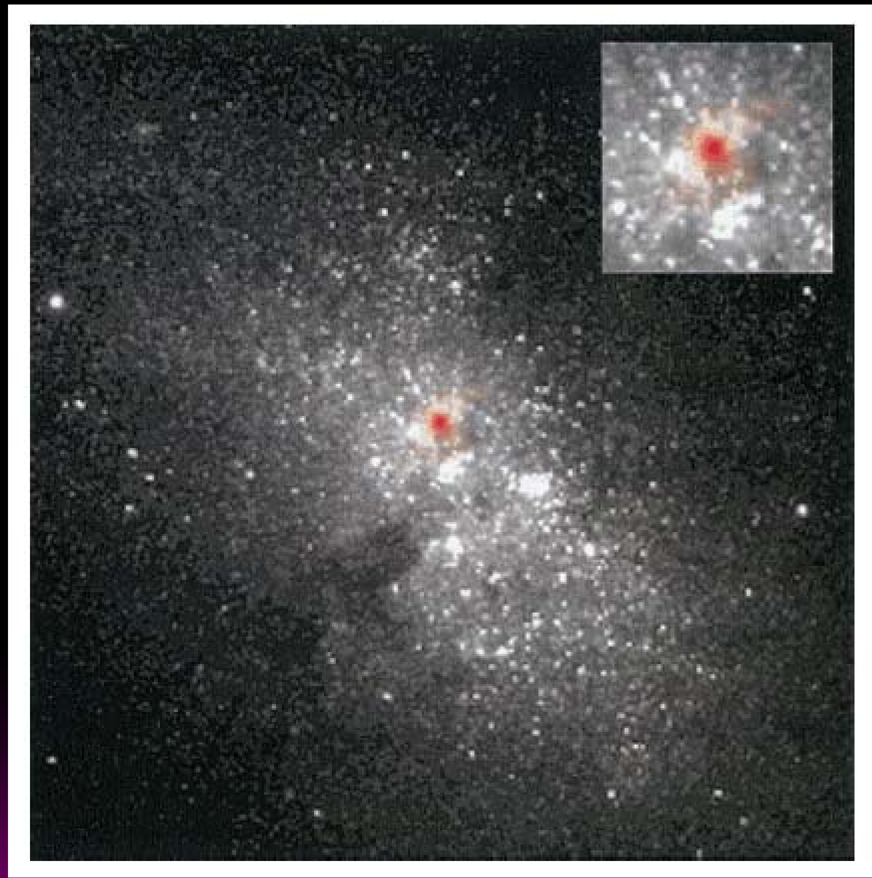


Nebulae: Z=0.004 (1/5 solar) Stars: Mu=100Msun

Nebulae:Z=0.008 (1/3 solar) Mu=100, 50, 30 Msun

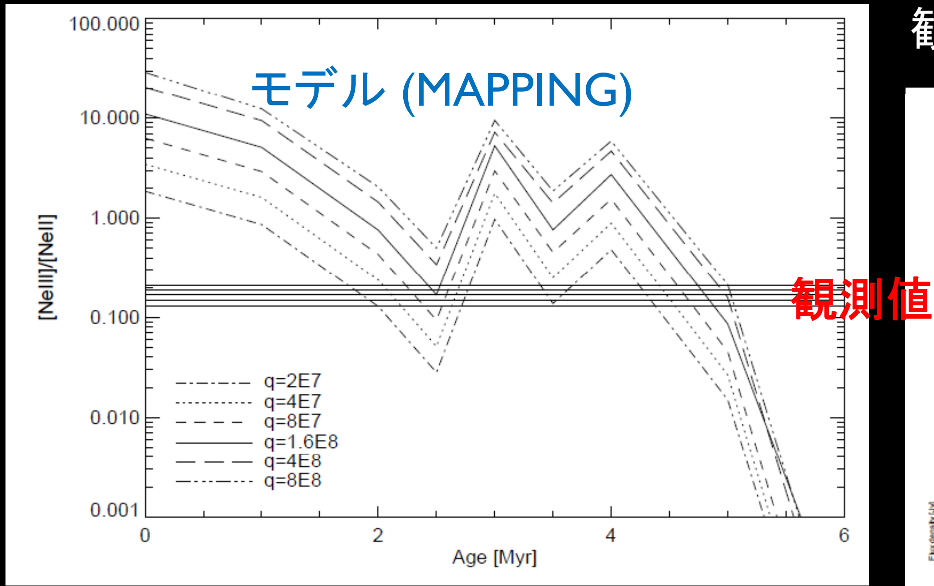
NGC5253 Super Star Cluster



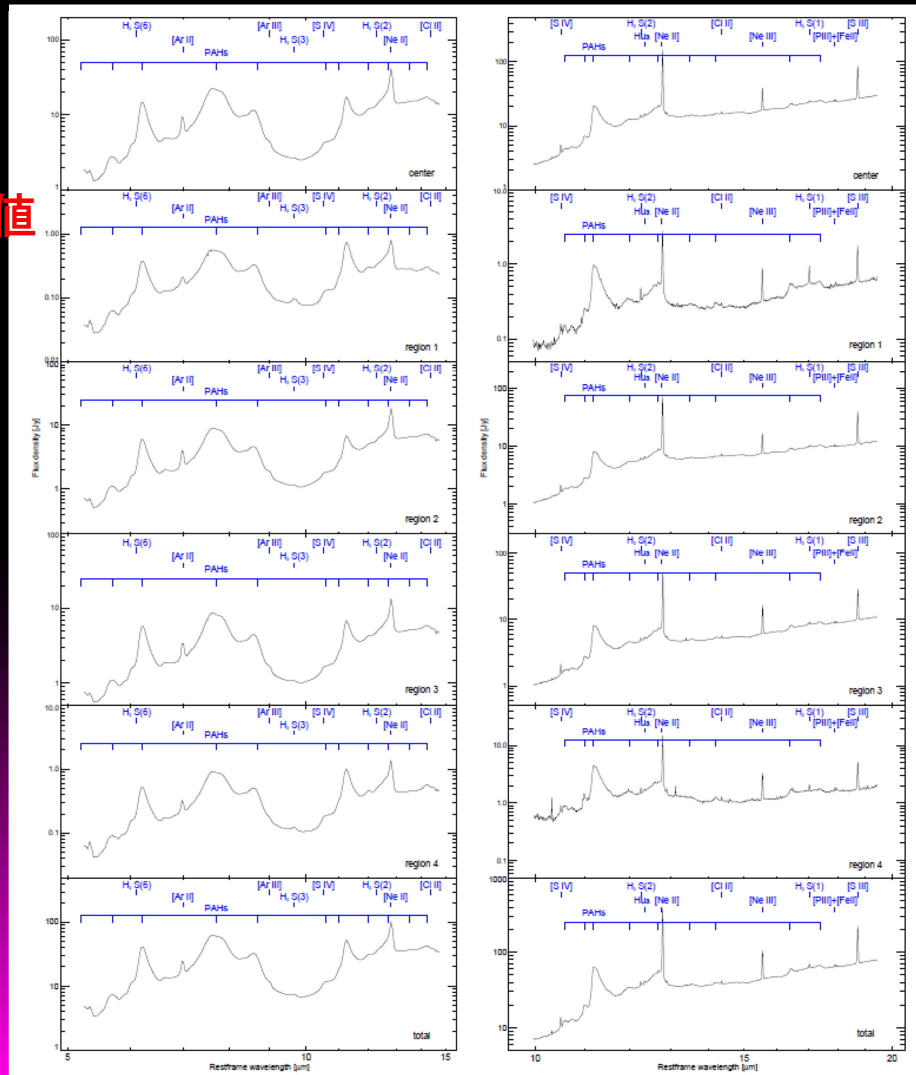


M82

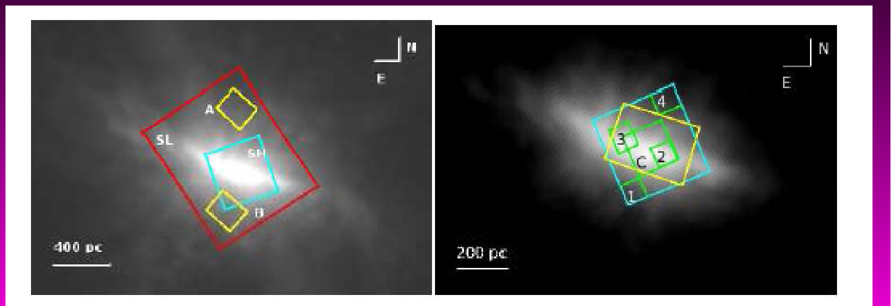
(Forster-Schreiber et al. 2001;(ISO)　Beirao et al. 2008 (Spitzer IRS)



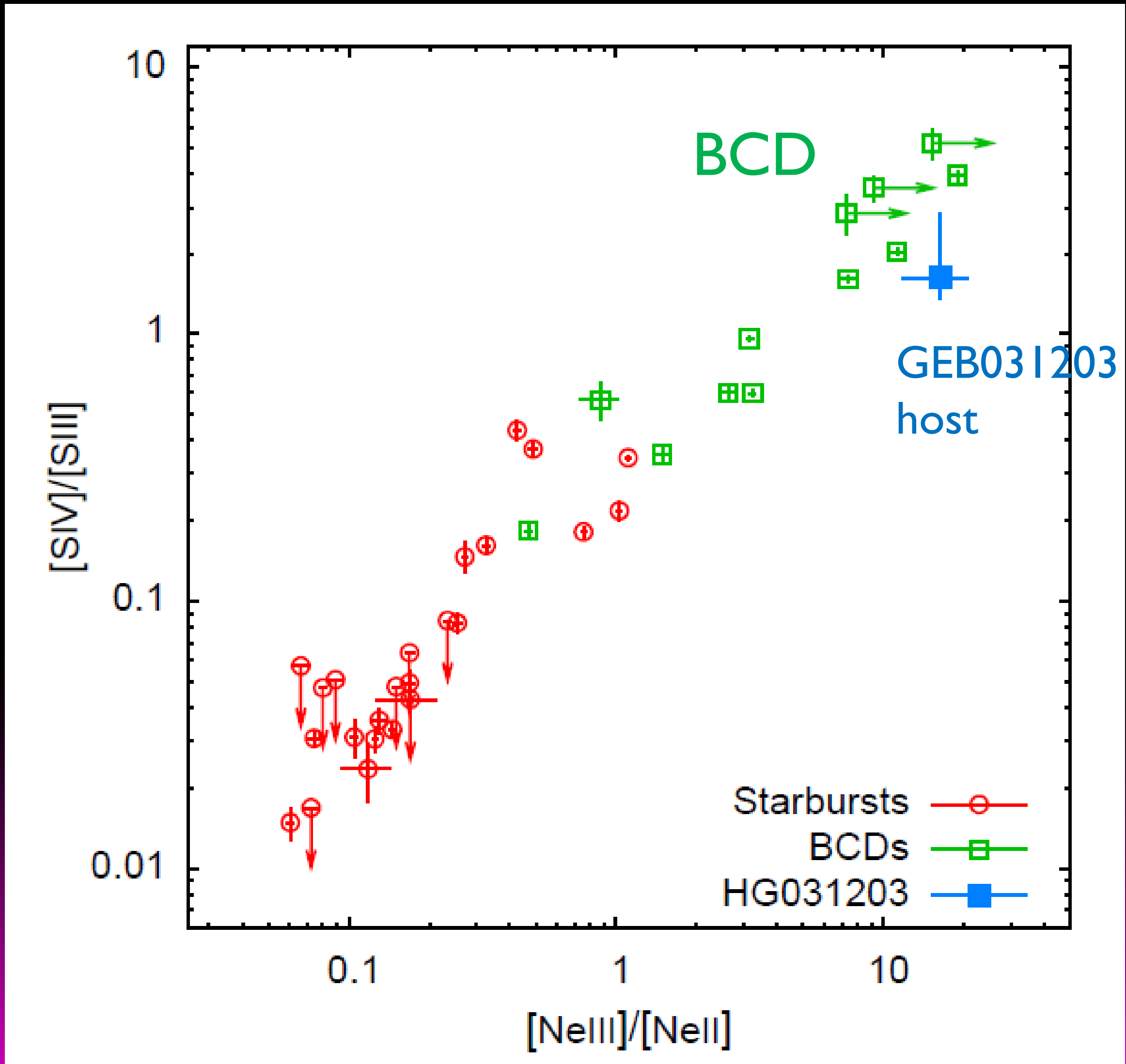
観測された低分散および中分散スペクトル

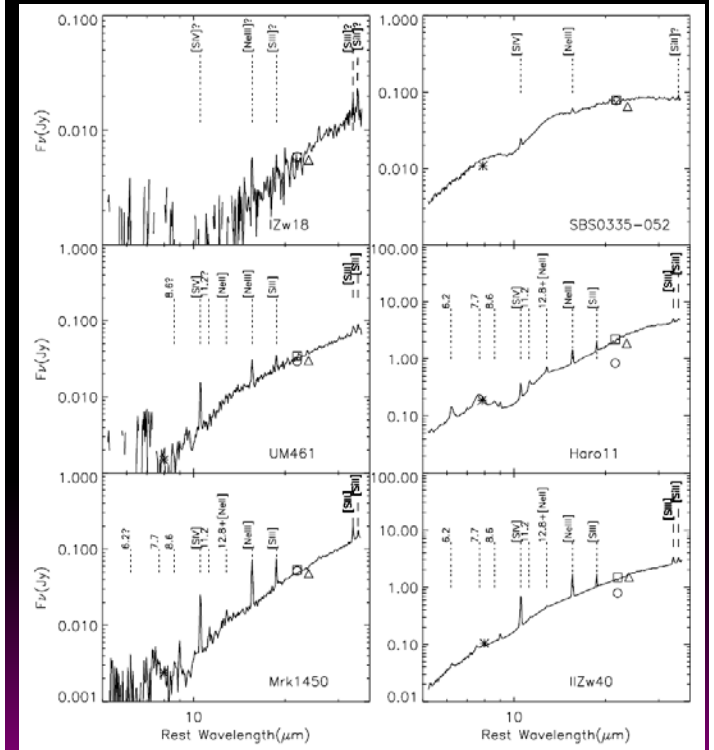


全体としては低い値 (~0.1)　Aged Sturburst?
より外側の領域の方が比が(少し)大きい
➔ ガス密度低下による電離パラメータ上昇？



Blue Compact Dwarves (e.g., Wu et al. 2006 / Watson et al. 2010)

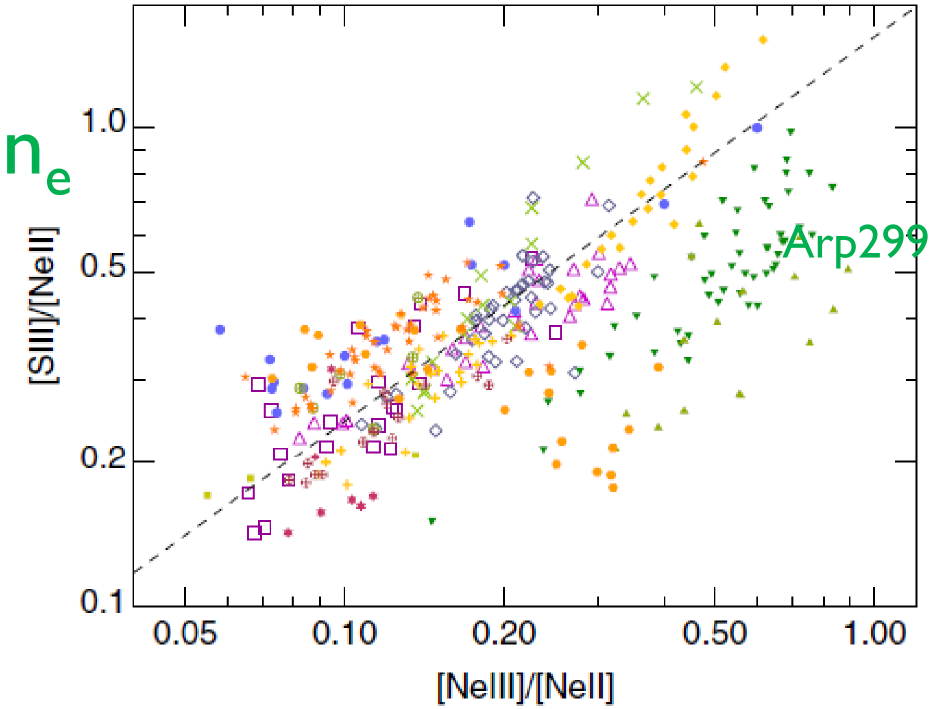




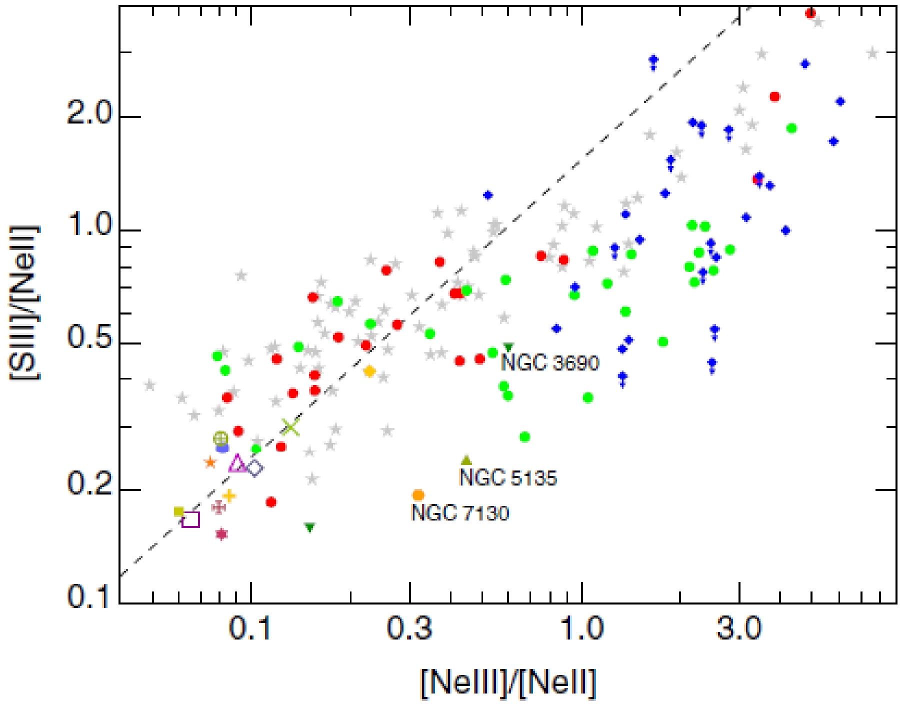
[NeIII]/[NeII] ratio for Galaxies and AGN

Pereira-Santaella et al. 2010

異なるシンボルはそれぞれの銀河



▲ Seyfert ● Quasar



近傍 LIRG の銀河内のスペクトル

様々な銀河の Integrated スペクトル

[NeIII]/[NeII] ratio for Galaxies and AGN

Pereira-Santaella et al. 2010

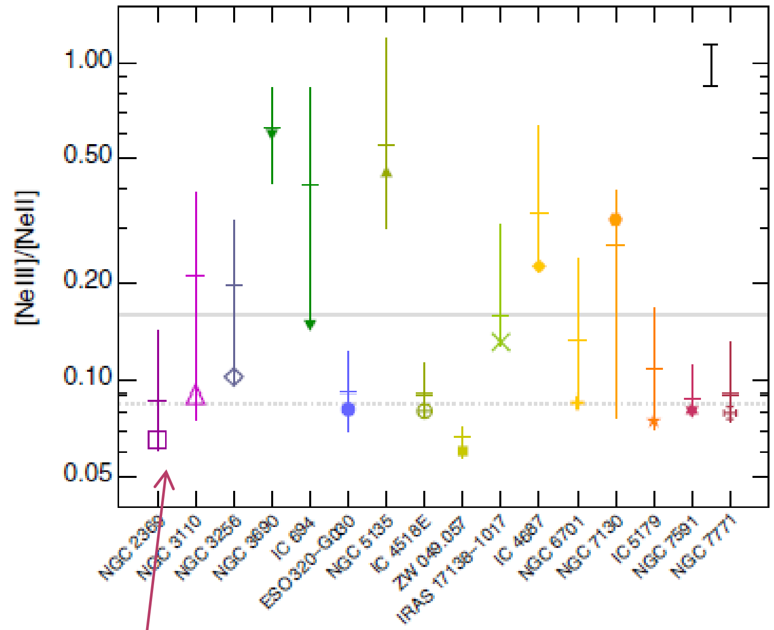


Figure 14. Range of the observed [Ne III]15.56 μm/[Ne II]12.81 μm ratio from the spectral maps. The galaxy symbol (as in Figure 12) indicates the value of the ratio in the nucleus. The horizontal mark is the median of the ratio of each galaxy. The solid gray line is the median of the medians and the dotted line is the median of the nuclear ratios. The black line indicates the typical uncertainty of the ratios.

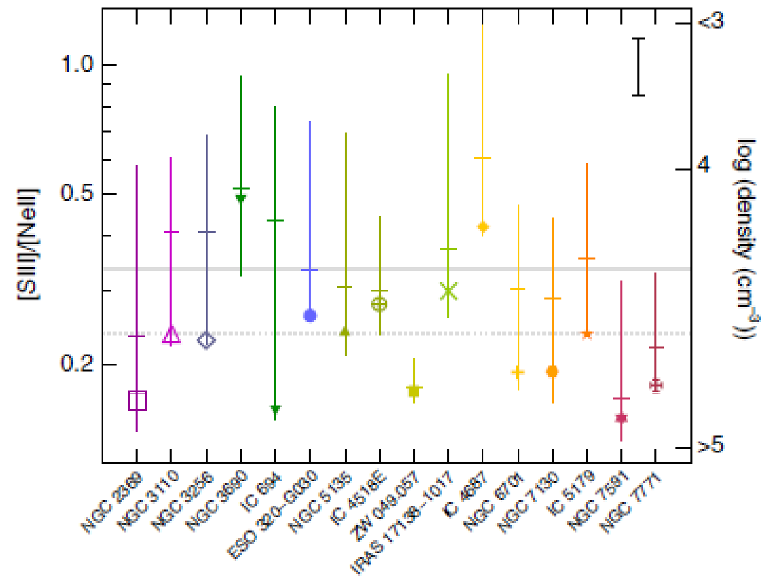
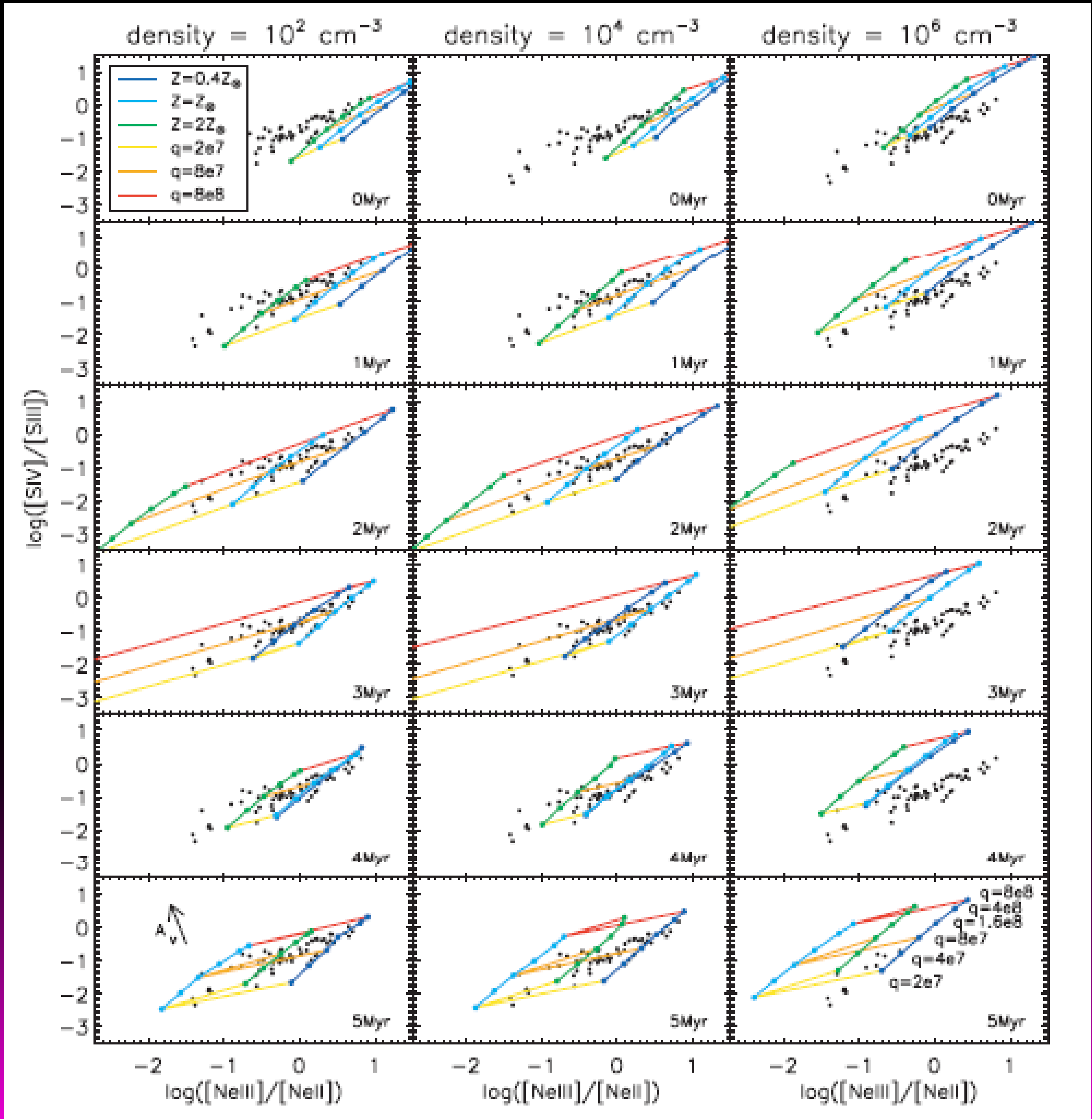


Figure 15. Range of the observed [S III]18.71 μm/[Ne II]12.81 μm ratio from the spectral maps. The symbols are as in Figure 14. The density label corresponds to the [S III]18.71 μm/[Ne II]12.81 μm ratio predicted by the Snijders et al. (2007) models for solar metallicity, $q = 1.6 \times 10^8$ and age = 5 Myr. The [Ne III]15.56 μm/[Ne II]12.81 μm ratio predicted using these parameters is ~0.1–0.2 which is in agreement with the observed ratio.

(A color version of this figure is available in the online journal.)

中心核は最も低い [NeIII] / [NeII] 比
➔ 高密度による？



Snijders et al. 2007

Log([NeIII]/[NeII])

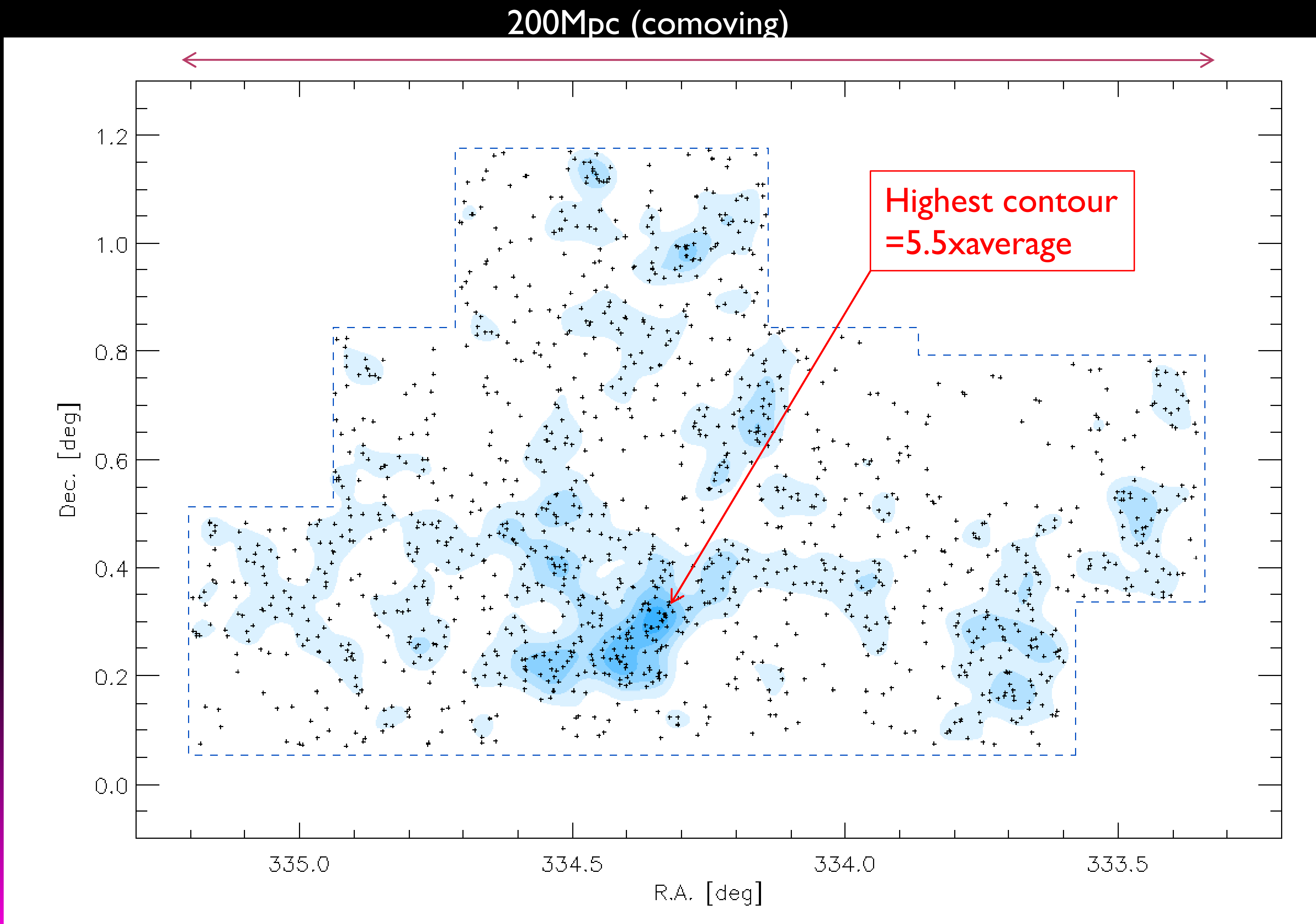
[NeIII] (13.6μm) / [NeII] (12.8μm) Ratio

- ☐ Hardness of Ionizing radiation
  - ● Starburst Age
  - ● Upper Mass Limit in IMF
  - ● Metallicity (Ionizing stars / gas)
- ☐ mildly depends on Ionization Parameters
- ☐ mildly depends on Electron Density
- ☐ little depends on Extinction
- ☐ AGN can be separated by [Ne V] or [OIV]

➔ Constraining IMF of High-z Star-Forming Galaxies

➔ Drawing the whole demography of galaxies (observing short-timescale episodic star formation at high-z)

Large-scale distribution of ~1500 Lyα Emitters



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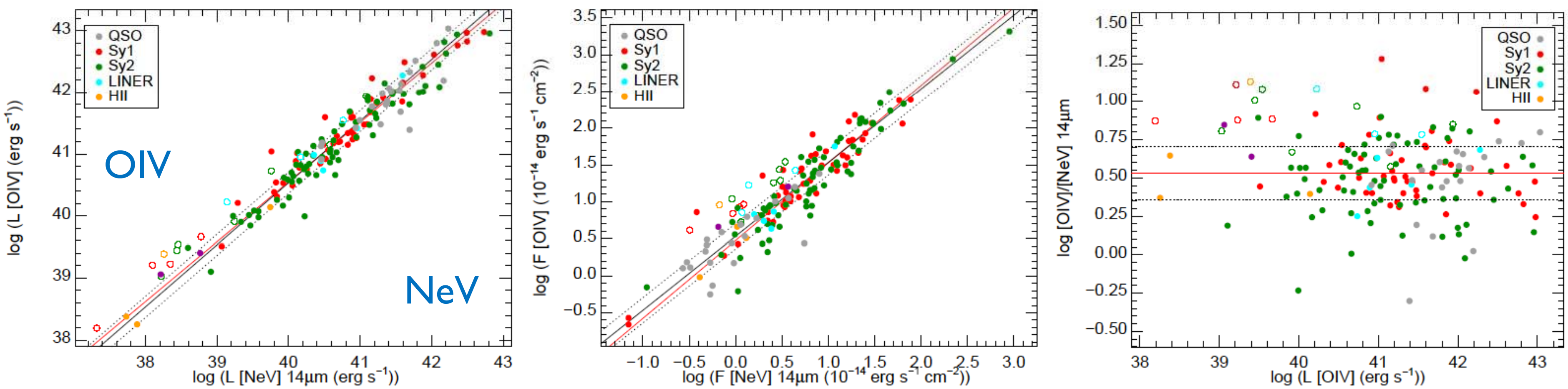
AGN による電離ガス

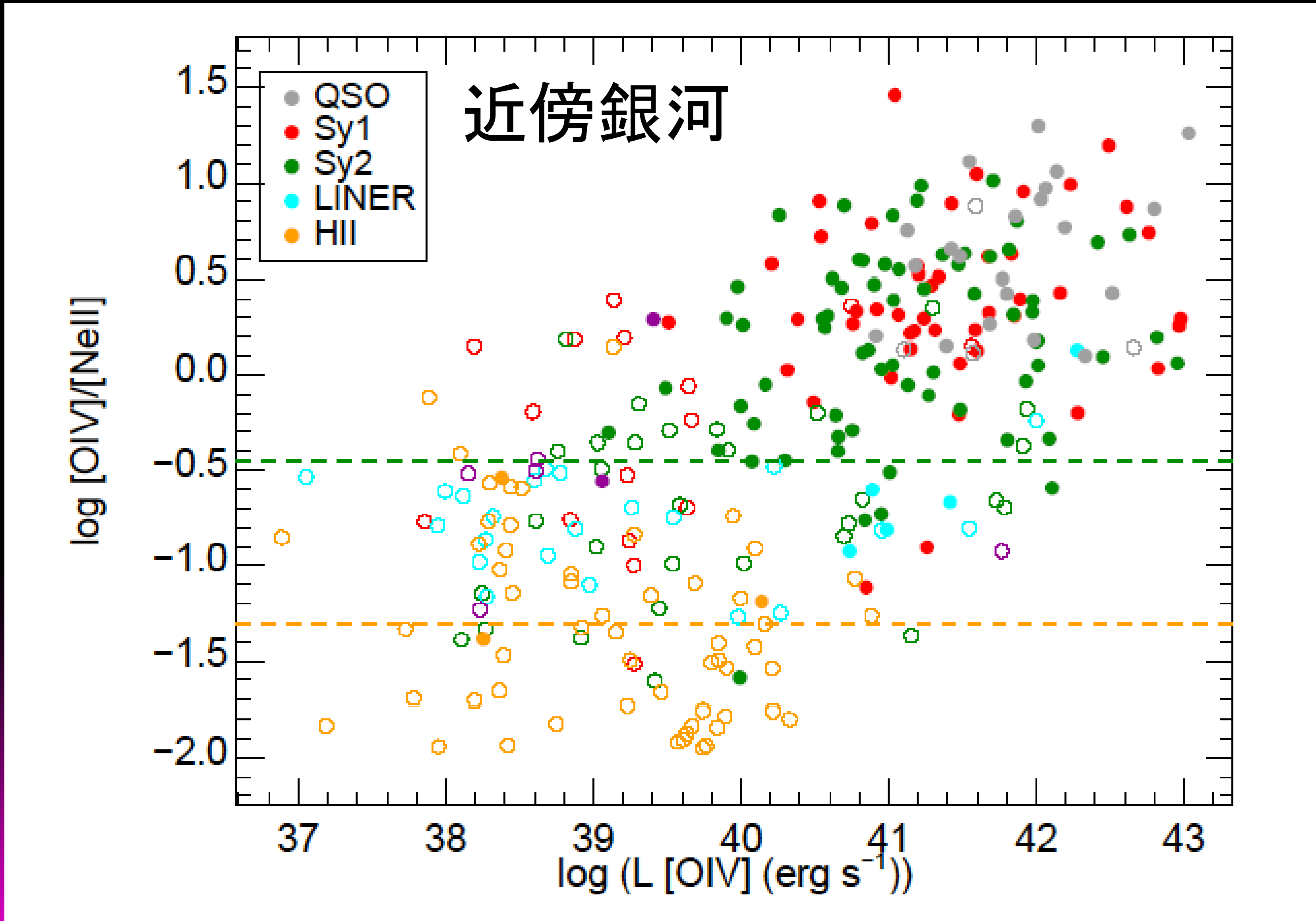
[NeV] (14.3μm) / [NeII] (12.8μm) Ratio
[O IV] (25.9μm) / [NeII] (12.8μm) Ratio 等

- AGN の存在
- Power Source AGN / Starburst Ratio

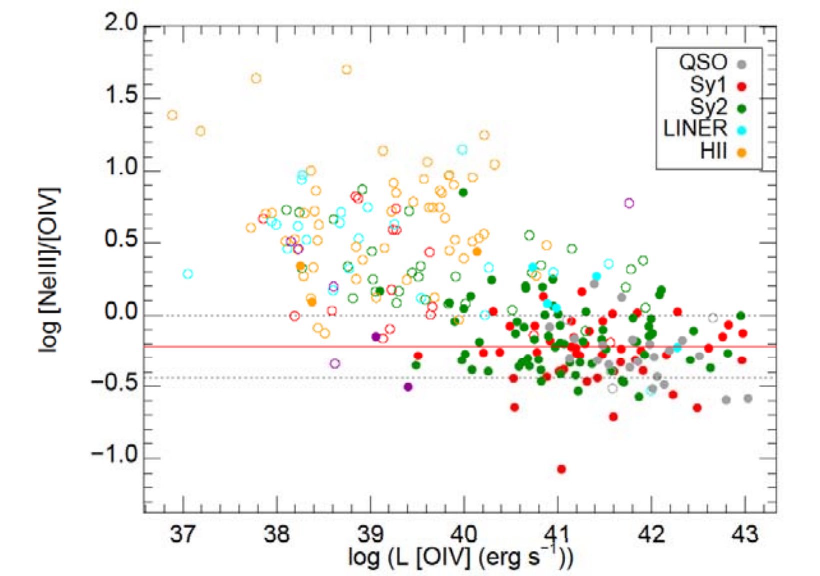
e.g., Spinoglio and Malkan 1992; Genzel et al. 1998;
Strum et al. 2002; Weedman et al. 2005;
Armus et al. 2007; Farrah et al. 2007
Tommasin et al. 2007; Veilleux et al. 2009; Pereira-Santaella et al. 2010

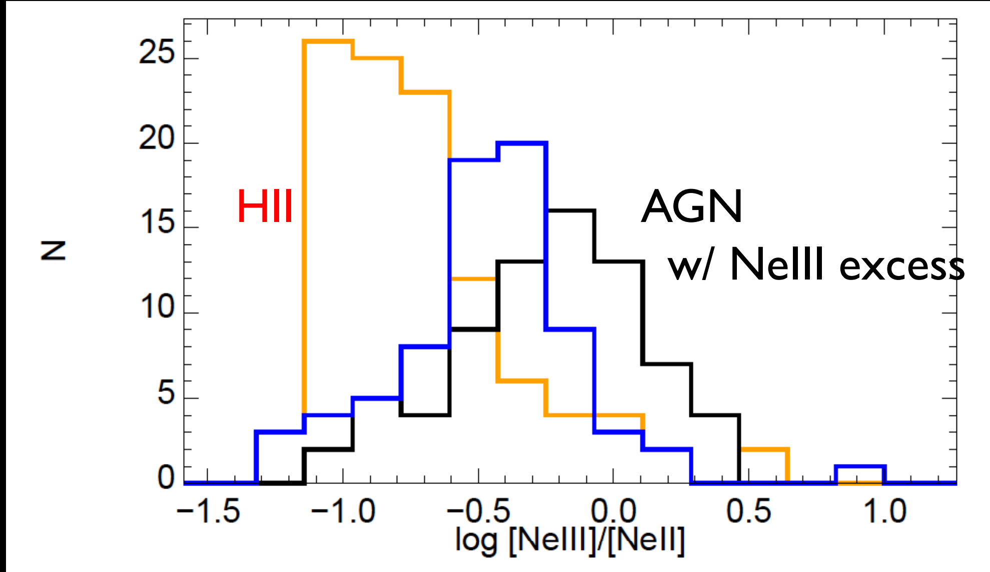


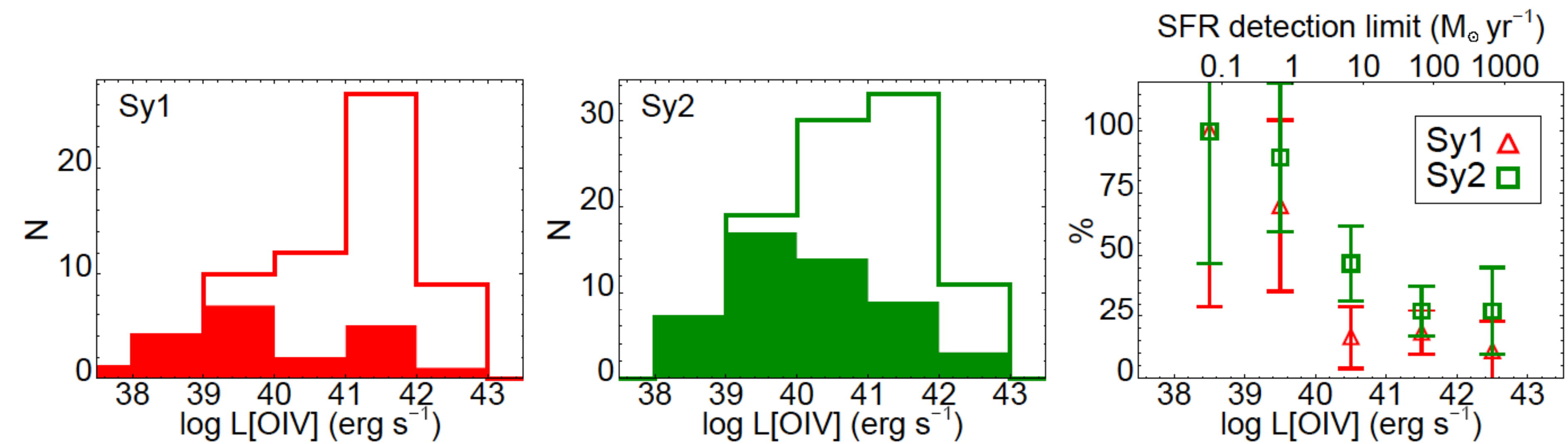
Pereira-Santaella et al. 2010 from IRS Obs 426 Galaxies



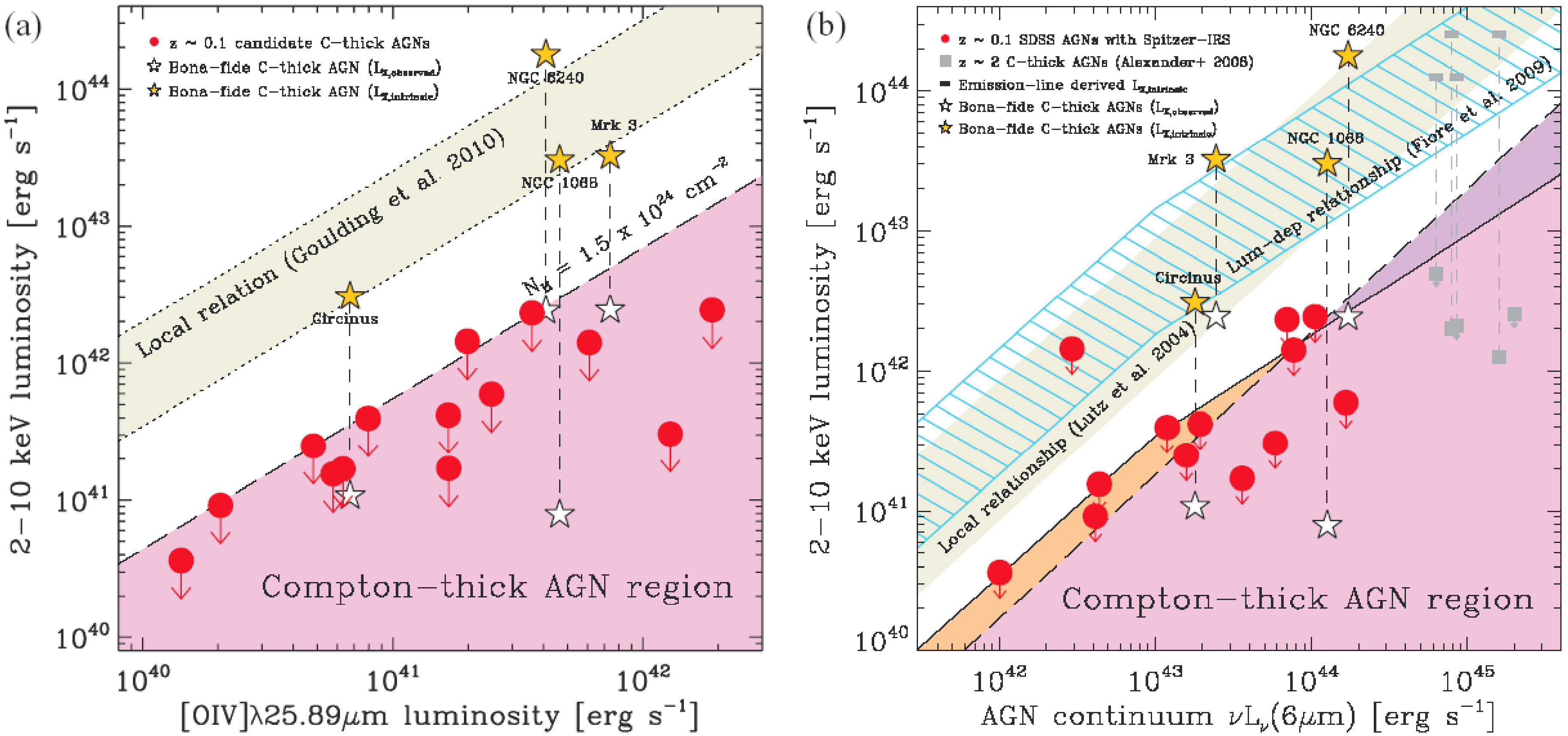
応用：[NeIII] “excess” by Starburst Component







Observing Compton-thick AGN (in forming galaxies)



Gouldings et al. 2010

SDSS → AGN XMM → undetected

AGN による電離ガス

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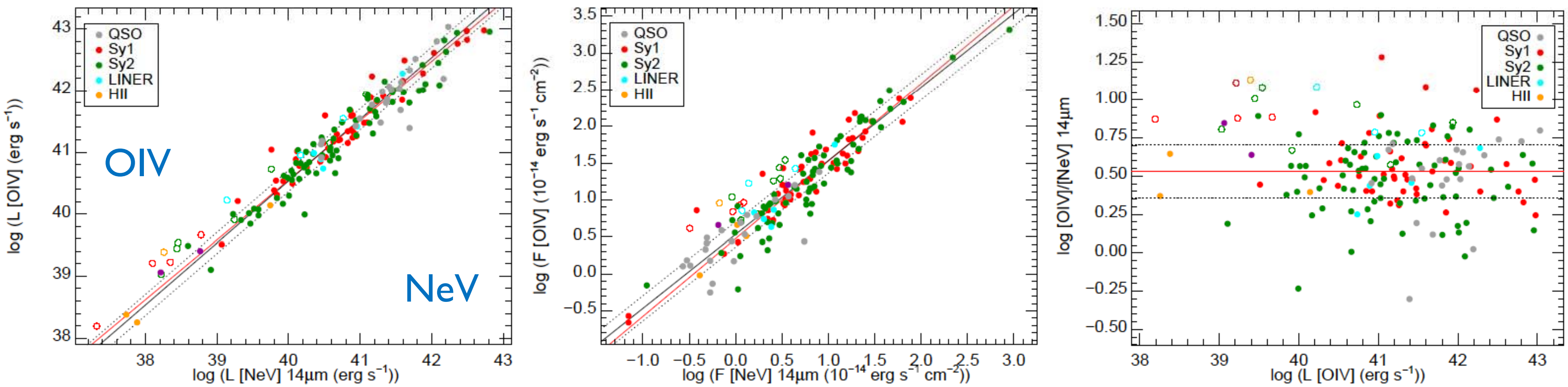

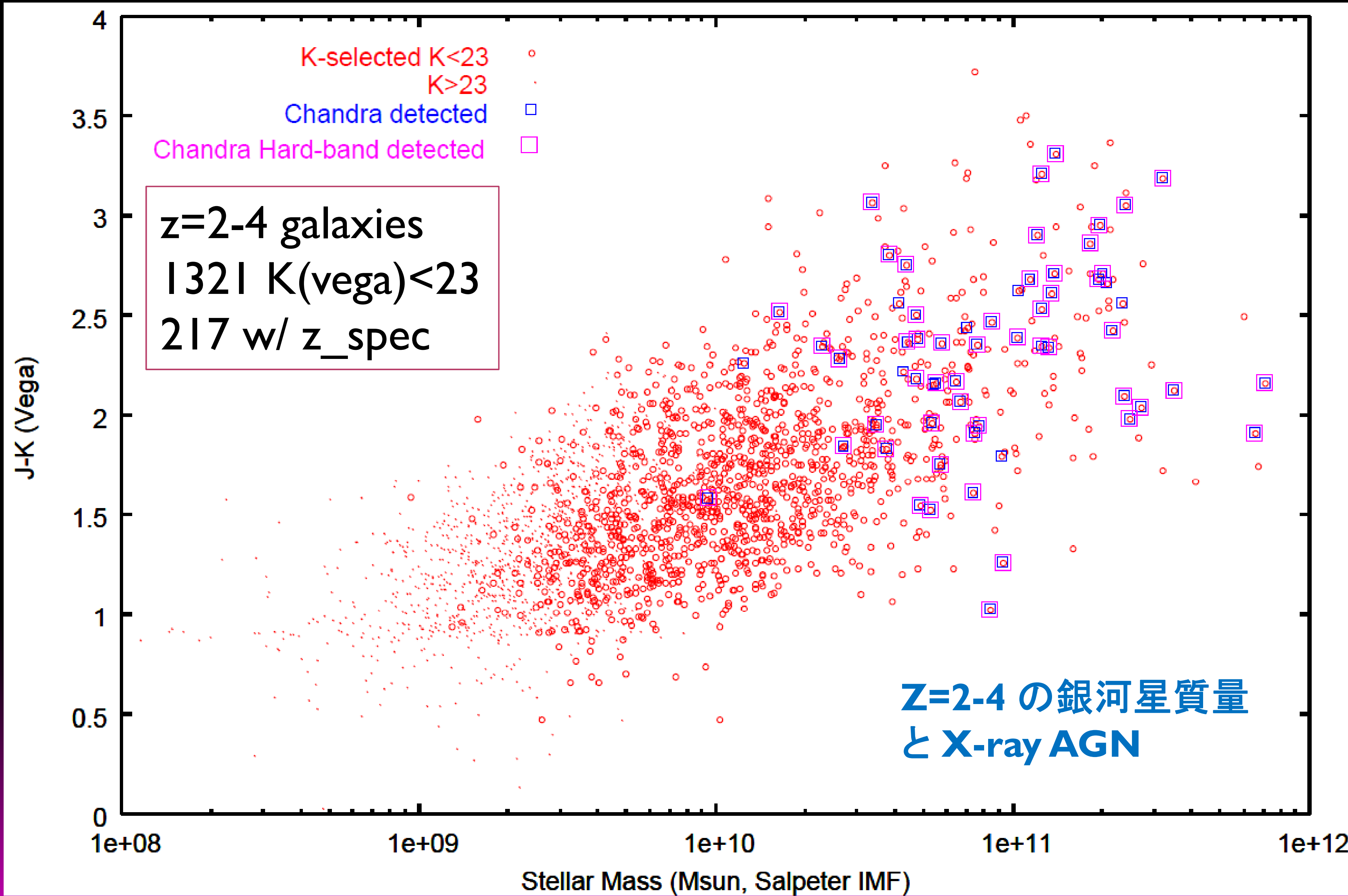

Salpeter IMF

Yamada et al. 2009

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SAFARI

Merit

Relatively Large FoV, simultaneous
(serendipitous discovery expected)

Demerit

感度が低い（遠方のおもしろい銀河にとって）。
高赤方偏移 (z>1) では、非常に明るい
天体のみ。

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米国装置

BLISS / WISPIR は万難を排して搭載するべき。

感度的には BLISS が SPICA に当初期待された
科学的観測能力をもたらし得る。

WISPIR でも z~2-3 銀河の微細構造輝線
診断観測は可能。