Near-infrared spectroscopy of nearby hard X-ray selected AGN

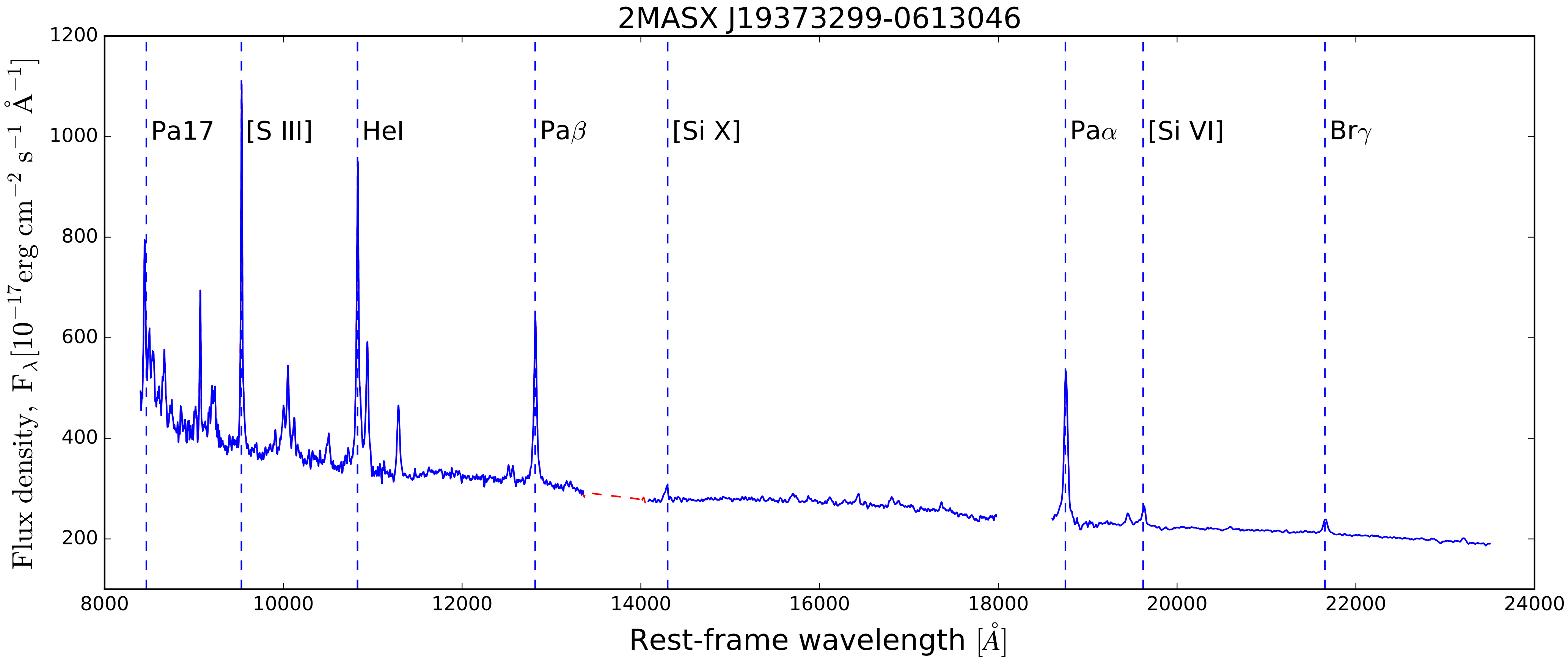
Isabella Lamperti,

Mike Koss, Benny Trakhtenbrot, Kevin Schawinski, Claudio Ricci, Kyuseok Oh, Hermine Landt, Rogério Riffel, Alberto Rodrìguez-Ardila, Neil Gehrels, Fiona Harrison, Nicola Masetti, Richard Mushotzky, Ezequiel Treister, Yoshihiro Ueda, Sylvain Veilleux

Image: NASA InfraRed Telescope Facility at Mauna Kea (planetaryweather.blogspot.co.uk)

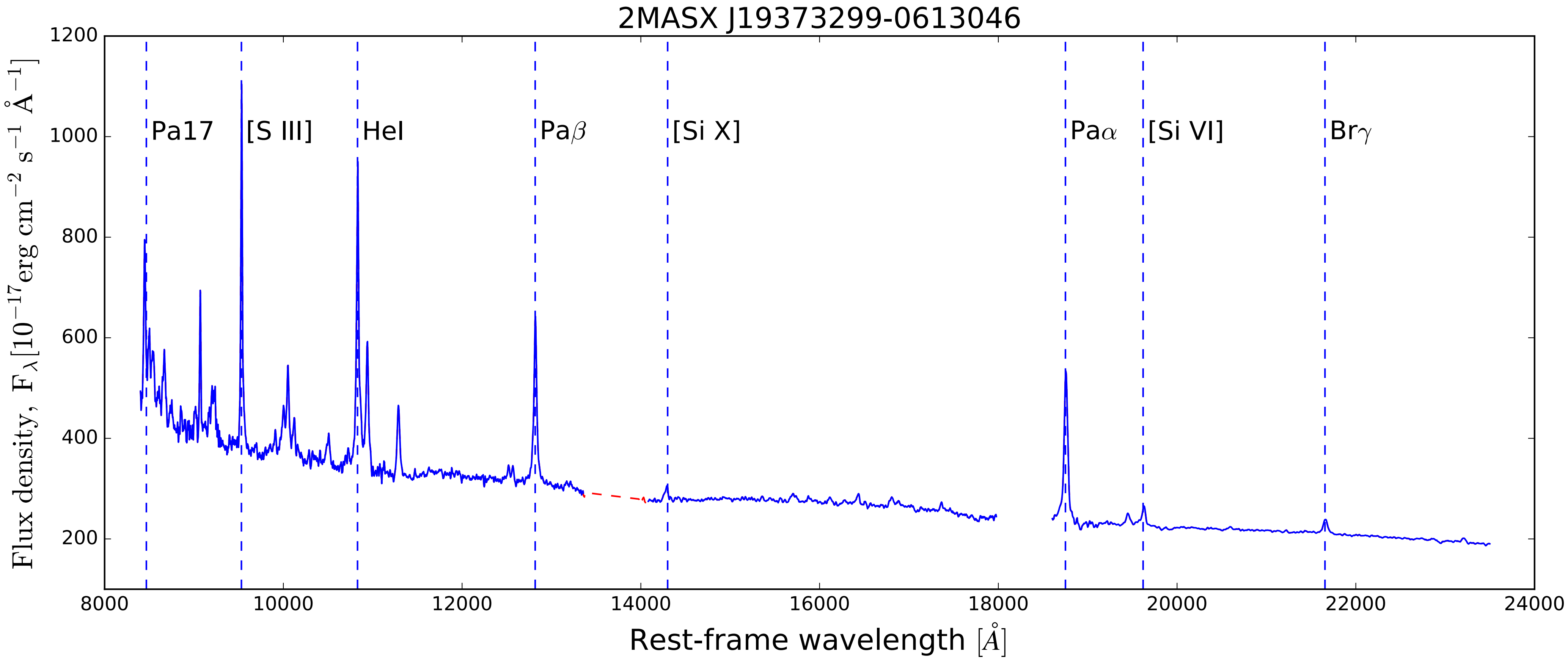
Near-Infrared spectra of AGN

- Near-infrared **~10 time less obscured** than the optical



Near-Infrared spectra of AGN

- ***Hydrogen Paschen lines***: broad emission lines can be used to measure black hole masses



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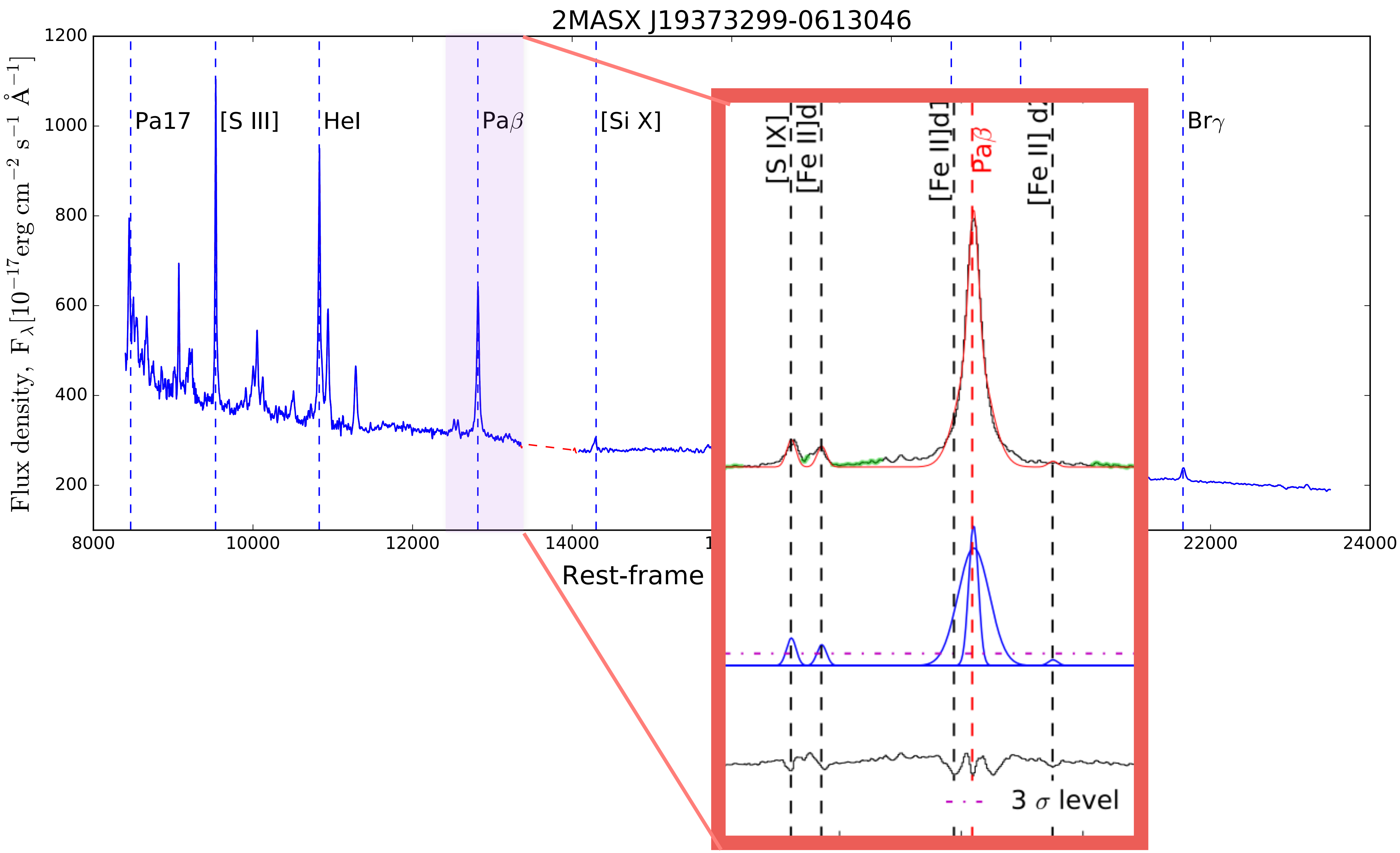
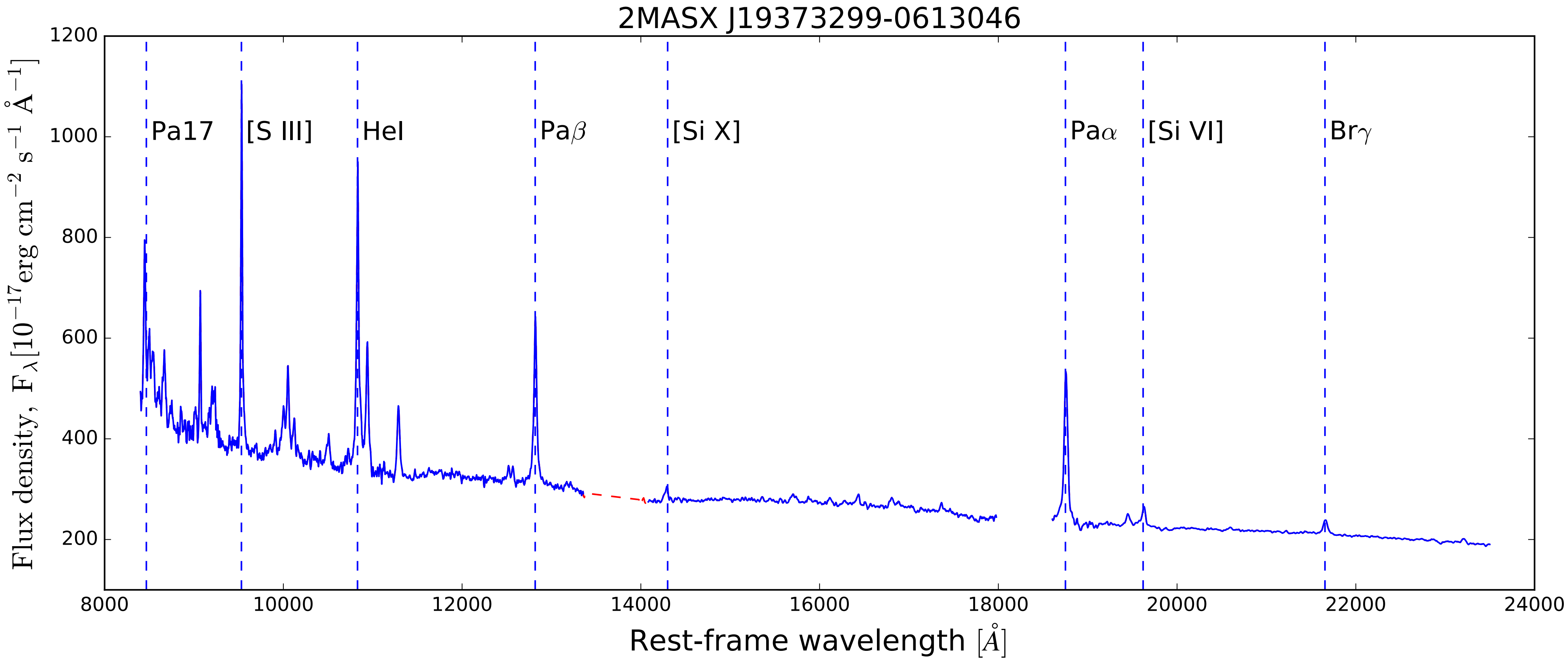


Near-Infrared spectra of AGN

- ***Coronal lines*** (ionization potential > 100 eV): indication of AGN activity



Near-Infrared spectroscopy of AGN

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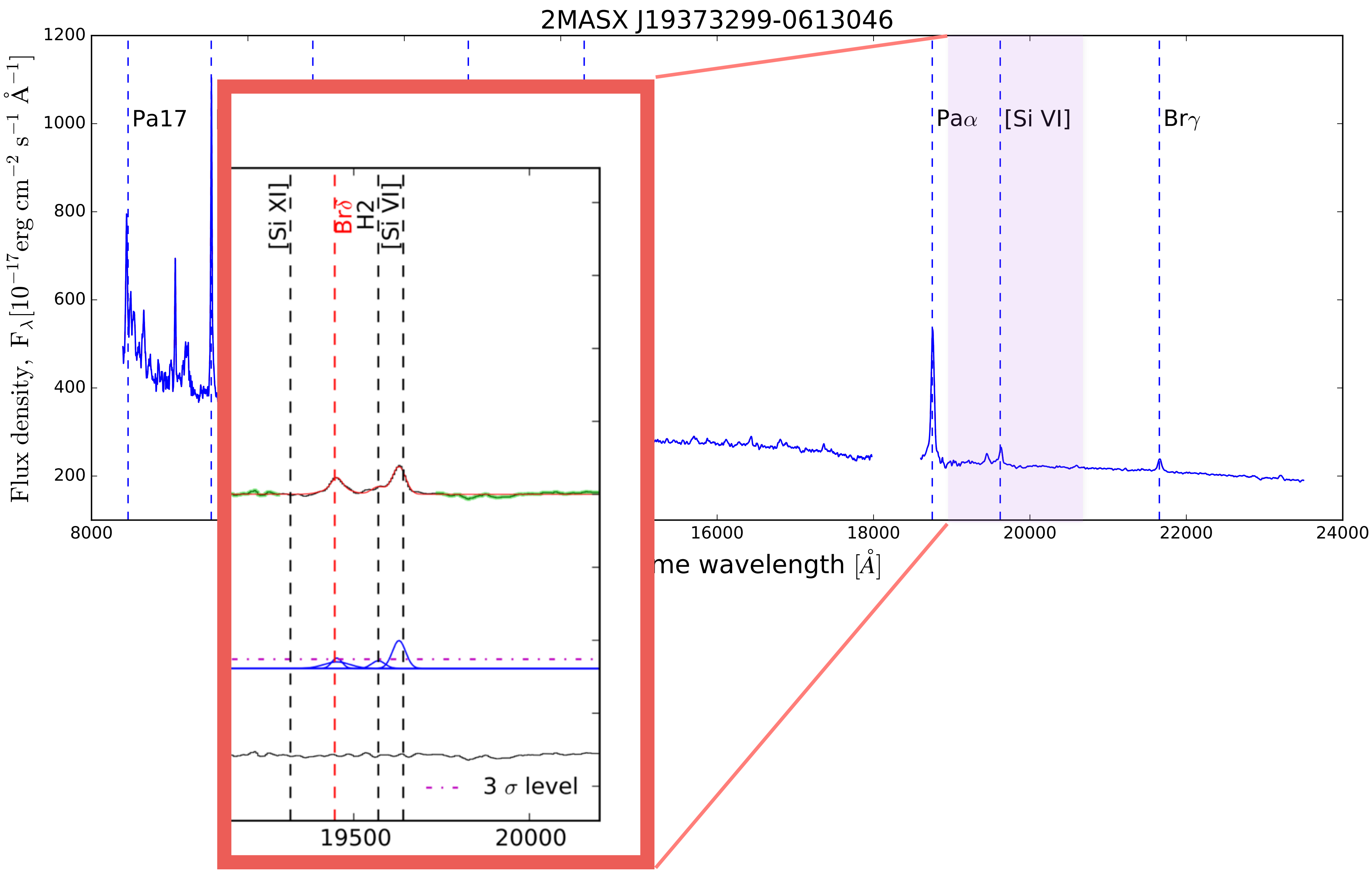
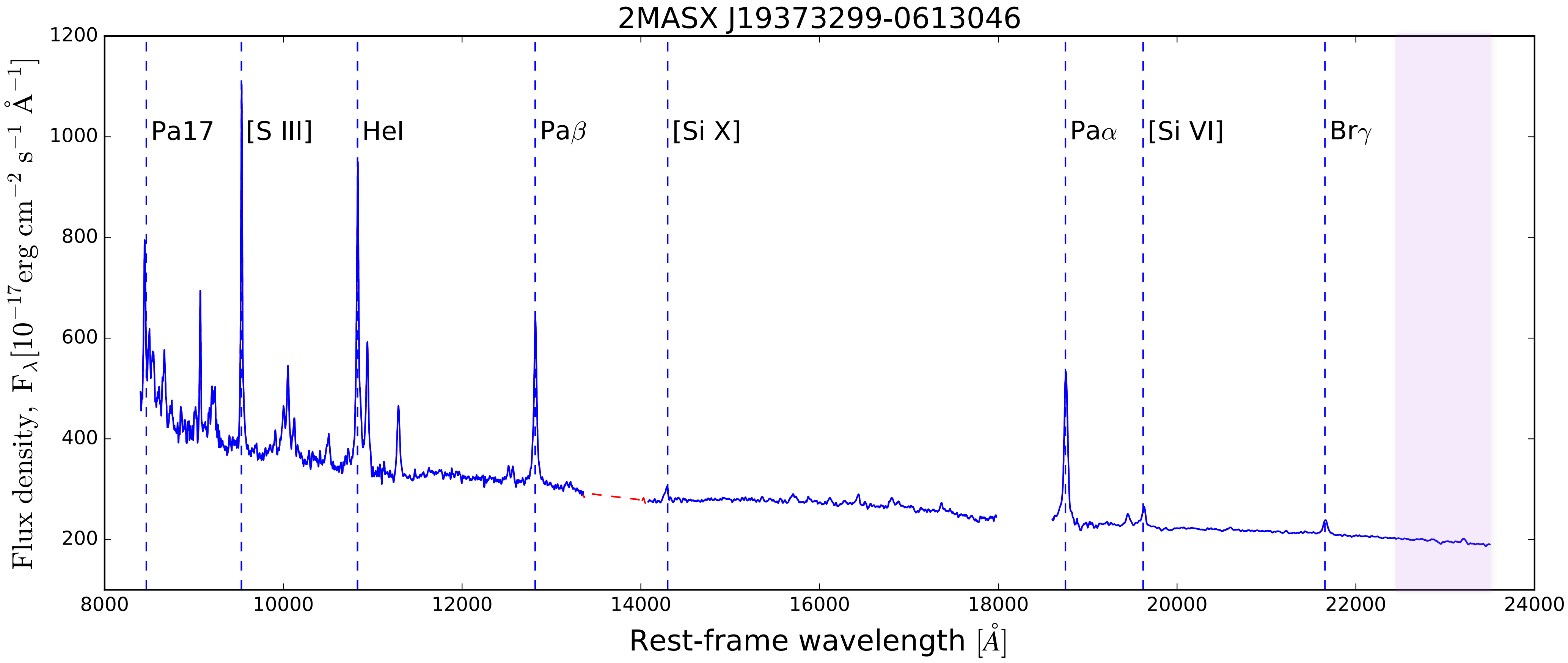


Near-Infrared spectroscopy of AGN

- ***Stellar velocity dispersion:*** from the Ca triplett and CO band-head



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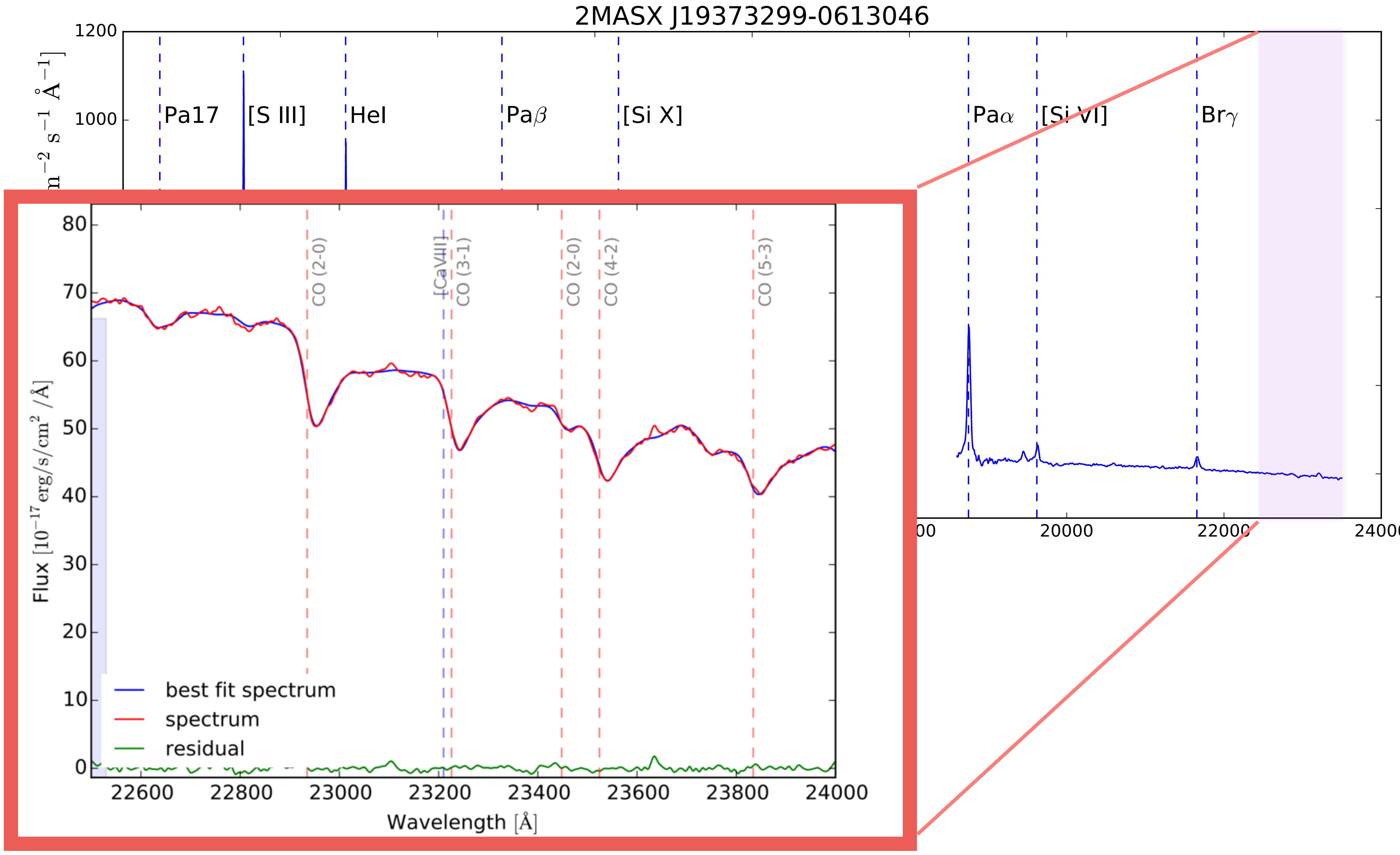

Goals:

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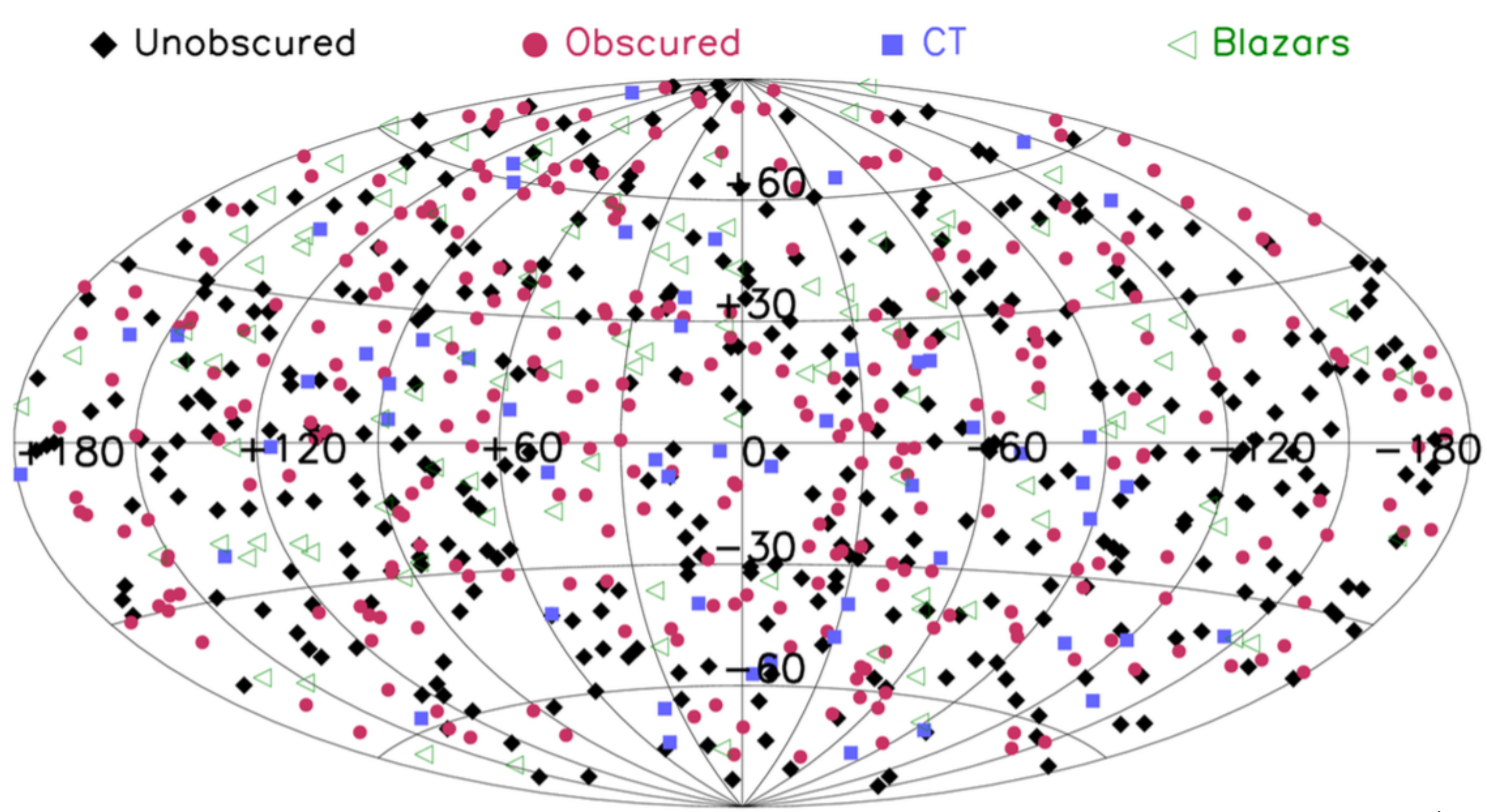
Goals:

- ★ test NIR AGN emission line **diagnostics** for hard X-ray selected AGN
- ★ look for **hidden broad line regions (BLRs)** (also in Seyfert 2)
- ★ compare different methods to estimate **black hole masses**
- ★ test whether **high ionization coronal lines** have better scaling with the X-ray than optical lines

70 month Swift-BAT survey:

- all-sky survey
- hard X-ray (14-195 keV)
- can detect highly obscured objects up to column densities > $10^{24}\mathrm{cm}^{-2}$
- 834 detected AGN



Ricci et al. (submitted)

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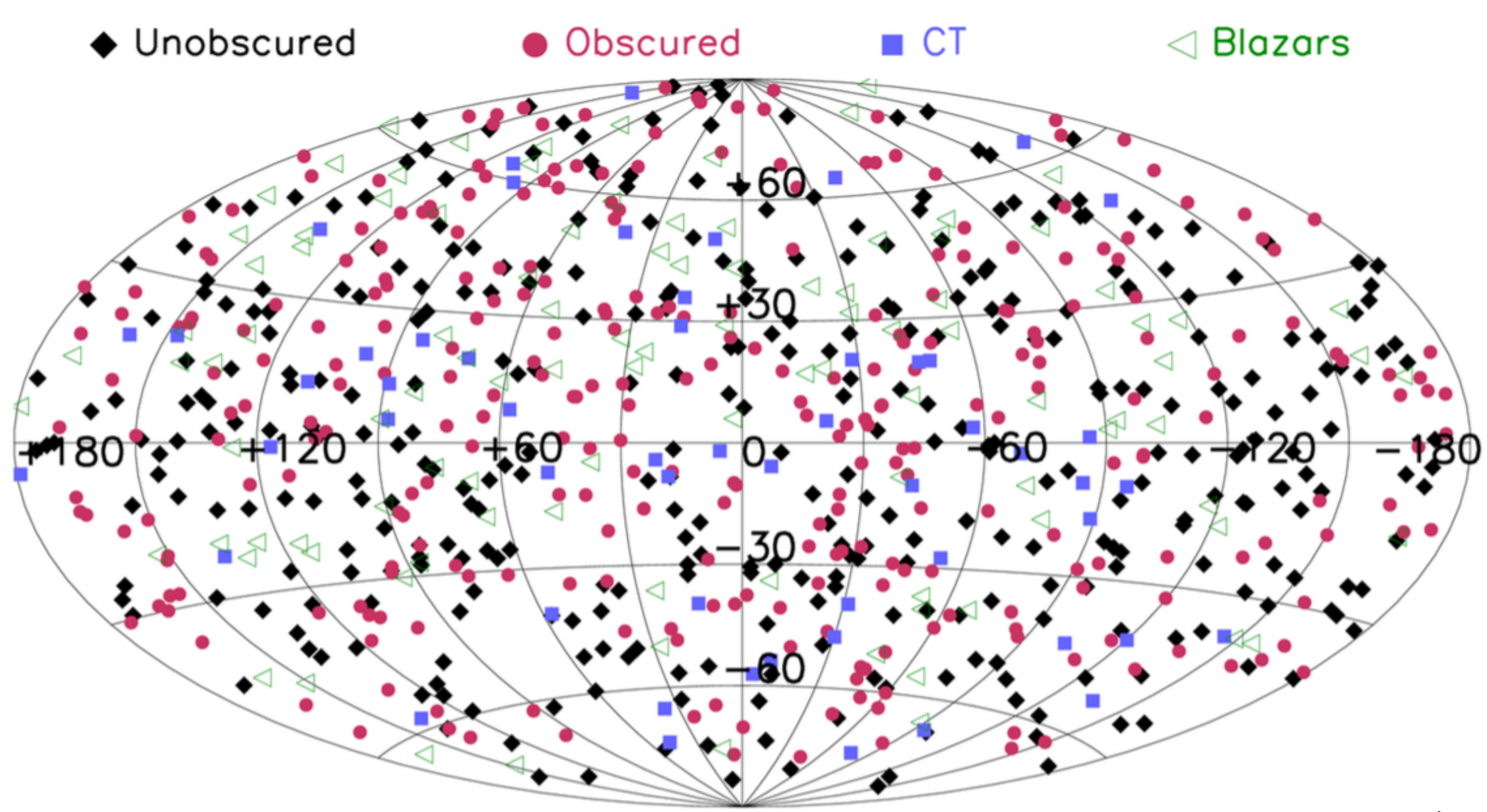
BASS: BAT AGN Spectroscopic survey: spectroscopic follow-up of the BAT AGN



Ricci et al. (submitted)

BASS: BAT AGN Spectroscopic Survey

- **optical** spectra of 642 AGN (Koss et al., submitted)
  - black hole mass estimates for 74% of the sources from:
    - broad Halpha,
    - broad Hbeta
    - stellar velocity dispersion
  - optical emission line fluxes

- **X-ray** analysis: hydrogen column density, X-ray flux 2-10 keV (Ricci et al., submitted)

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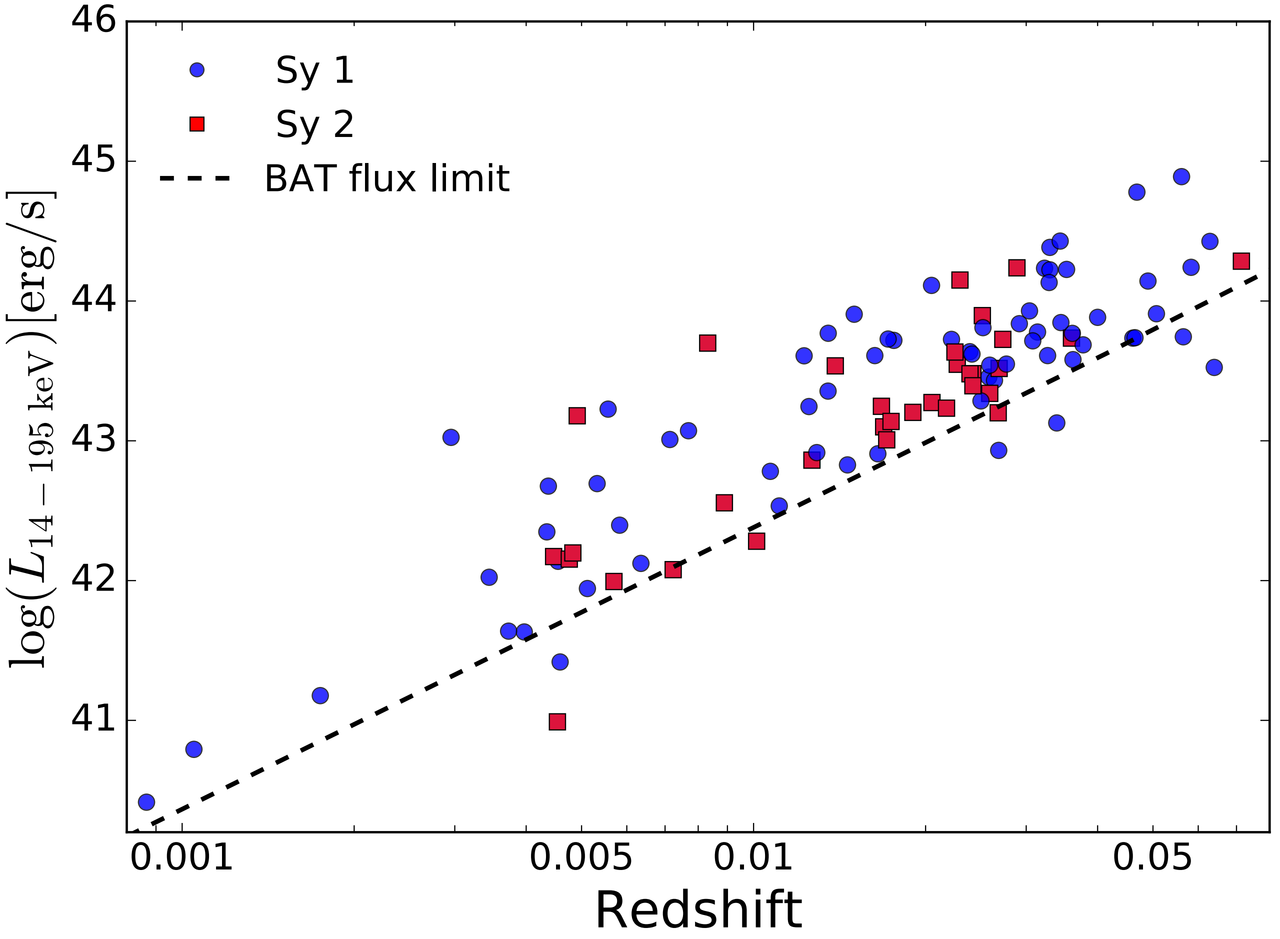
- **X-ray** analysis: hydrogen column density, X-ray flux 2-10 keV (Ricci et al., submitted)

- NIR spectroscopic information (Lamperti et al. 2017)

BASS
BAT AGN Spectroscopic Survey

Near-infrared sample:

- **102** NIR spectra of BAT AGN
  - 55 spectra from new observations (IRTF/ SpeX, Kitt Peak/Flamingos)
  - 47 spectra from the literature (IRTF/SpeX, Gemini/GNIRS)
- Wavelength range: **0.8 - 2.4 micron**
- 70% Seyfert 1 and 30% Seyfert 2



AGN diagnostic in the NIR:

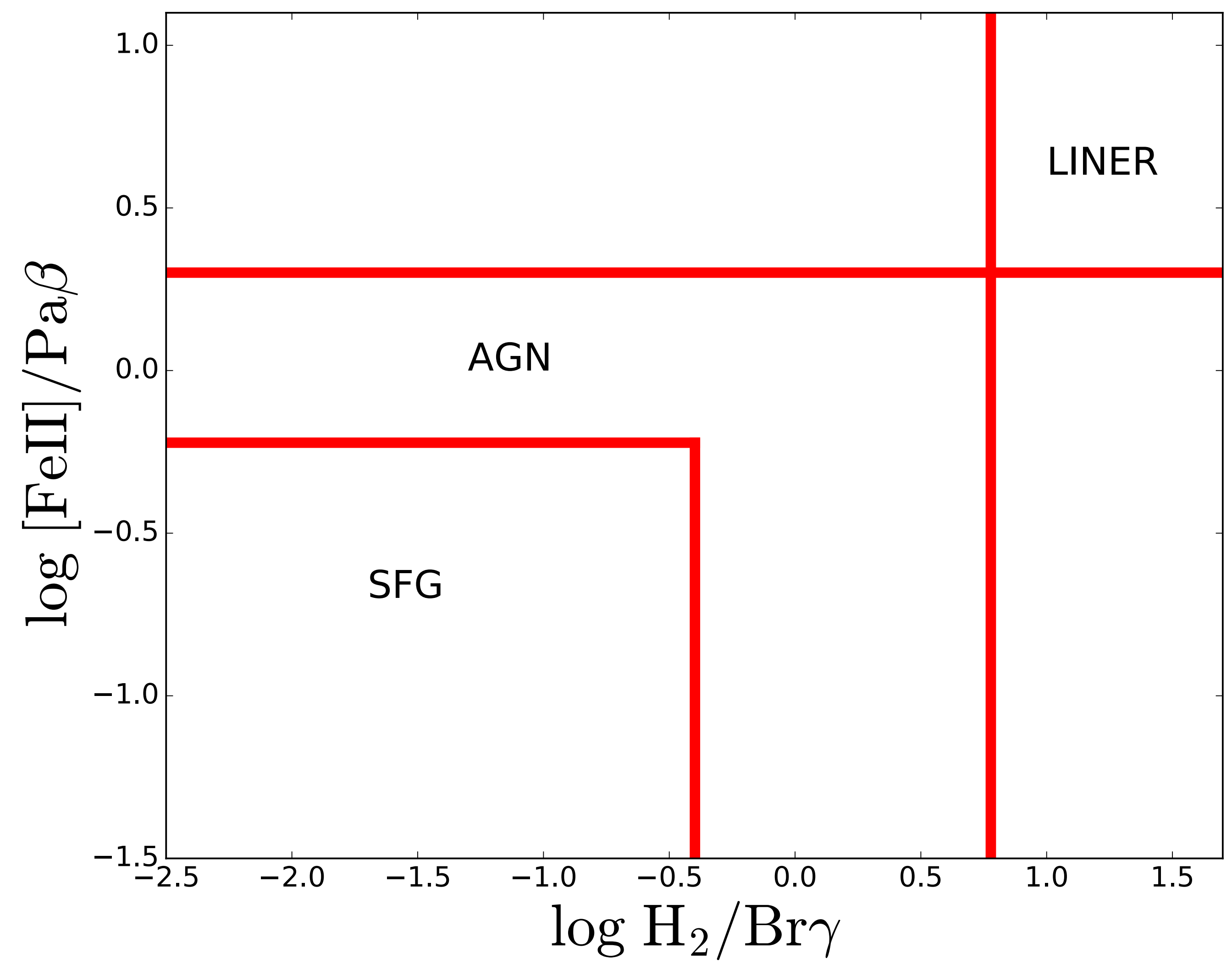
- Two potential methods for identifying AGN in the NIR:
  - emission lines diagnostic diagram
  - presence of coronal lines

NIR emission lines diagnostic diagram

First proposed by Larkin et al. 1998, refined by Rodriguez-Ardila et al. (2005)

Idea beyond this diagram:

- [FeII] and H2 excited by two mechanisms:
    - non-thermal processes (photoionization, UV fluorescence) > star-formation
    - thermal processes (X-ray heating, shocks) > mainly in AGN

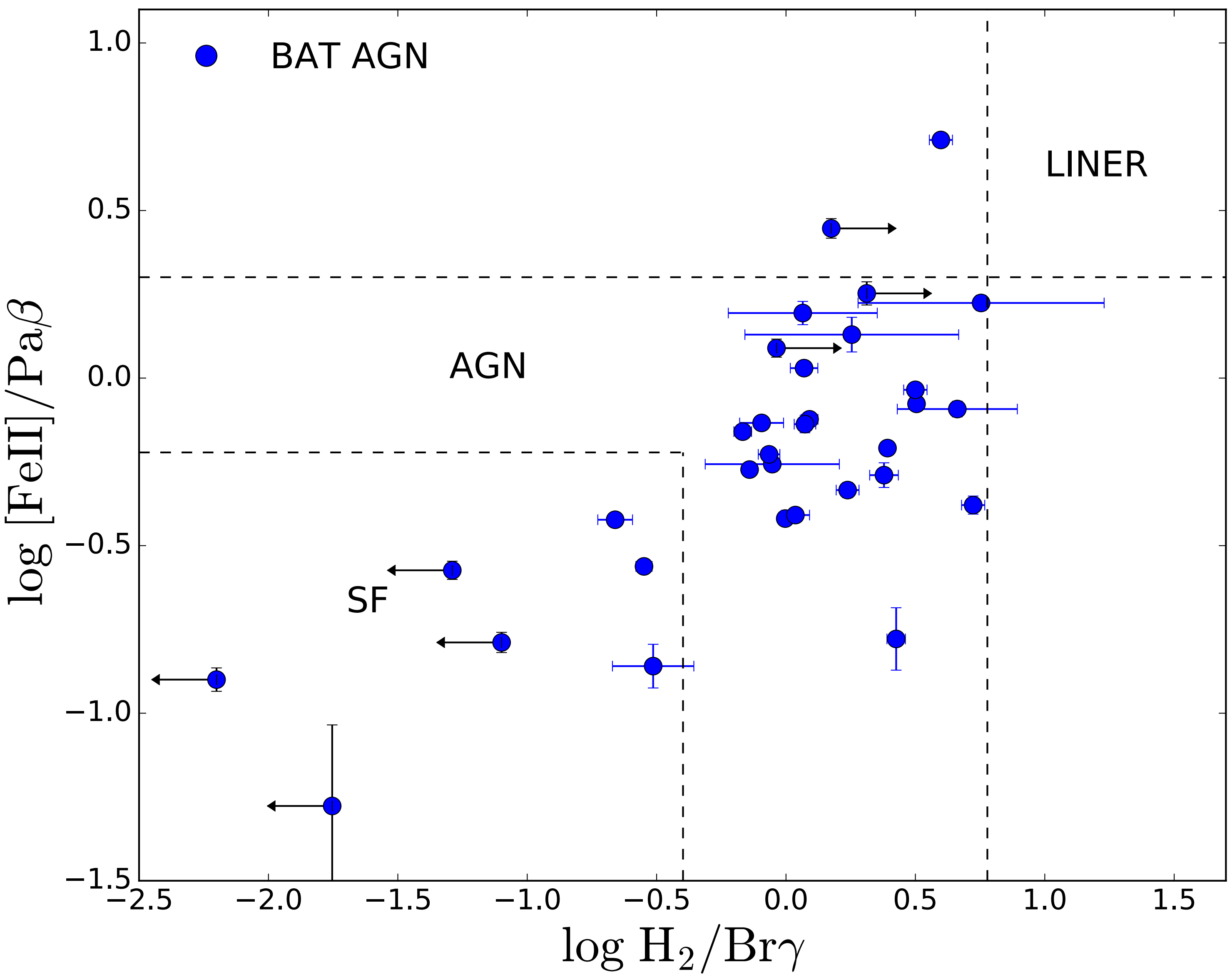


From Riffel et al. (2013)

AGN diagnostic in the NIR: diagnostic diagram

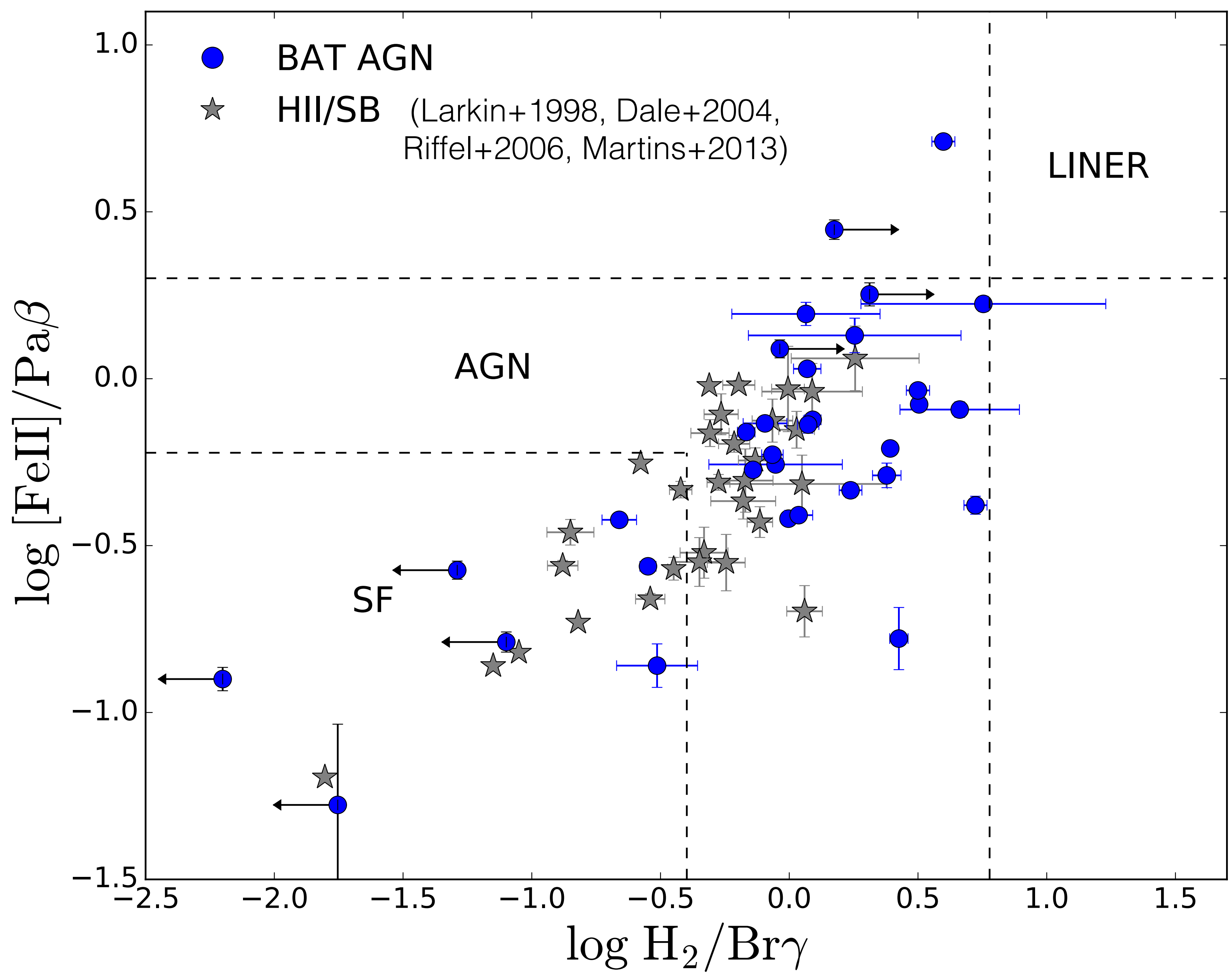
- the 4 emission lines necessary to apply the diagnostic are detected in only **31%** of our sample
- 25/31 (**78 %**) of these are in the AGN part of the diagram

  > *but these are only **25% of the total sample***



AGN diagnostic in the NIR: diagnostic diagram

- Literature values: many SF galaxies in the AGN region of the diagram

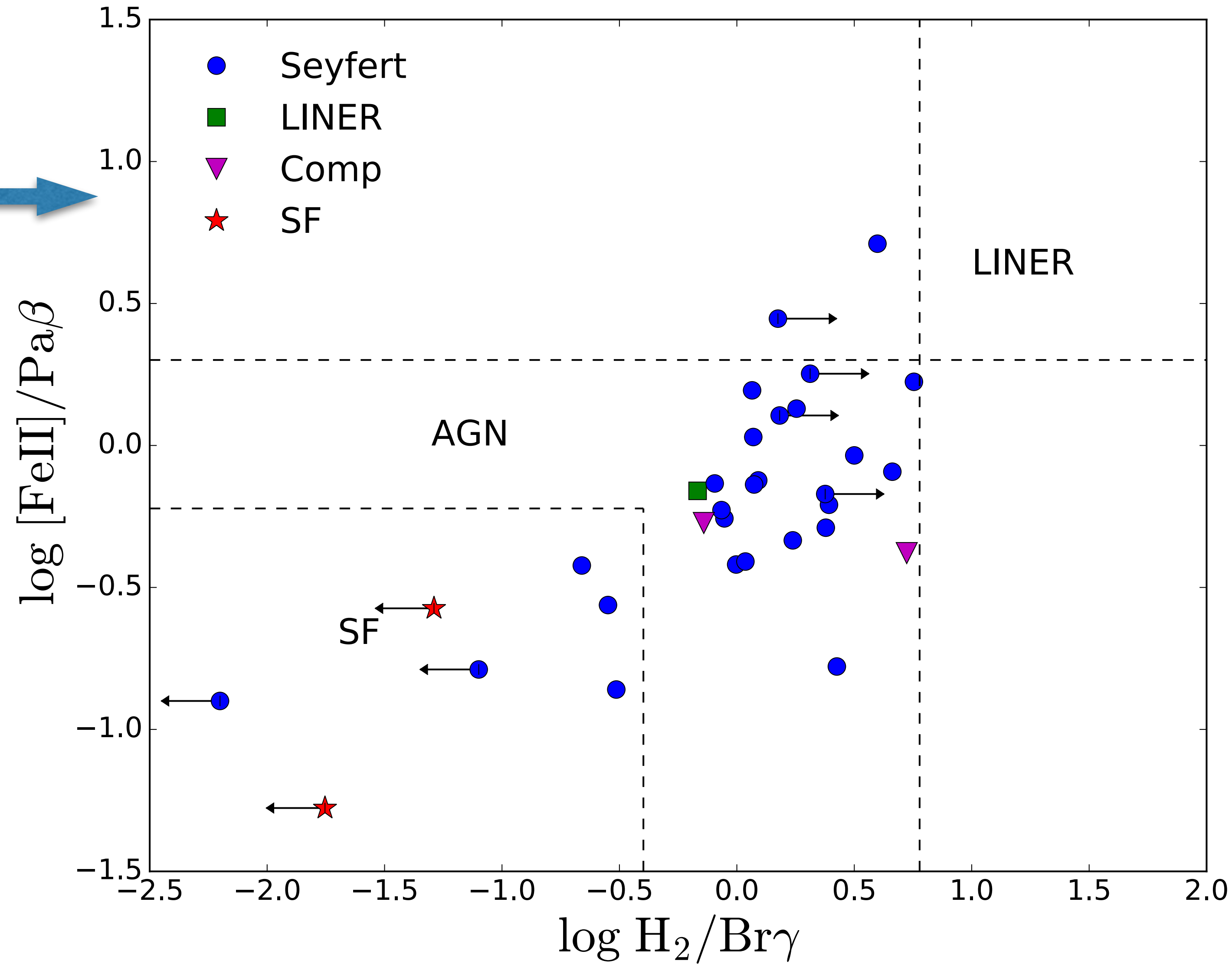


AGN diagnostic in the NIR: diagnostic diagram

- Comparison with optical BPT diagram:

~ 65% of X-ray selected AGN are in the Seyfert region of the optical BPT diagram

Classification according to the BPT diagram



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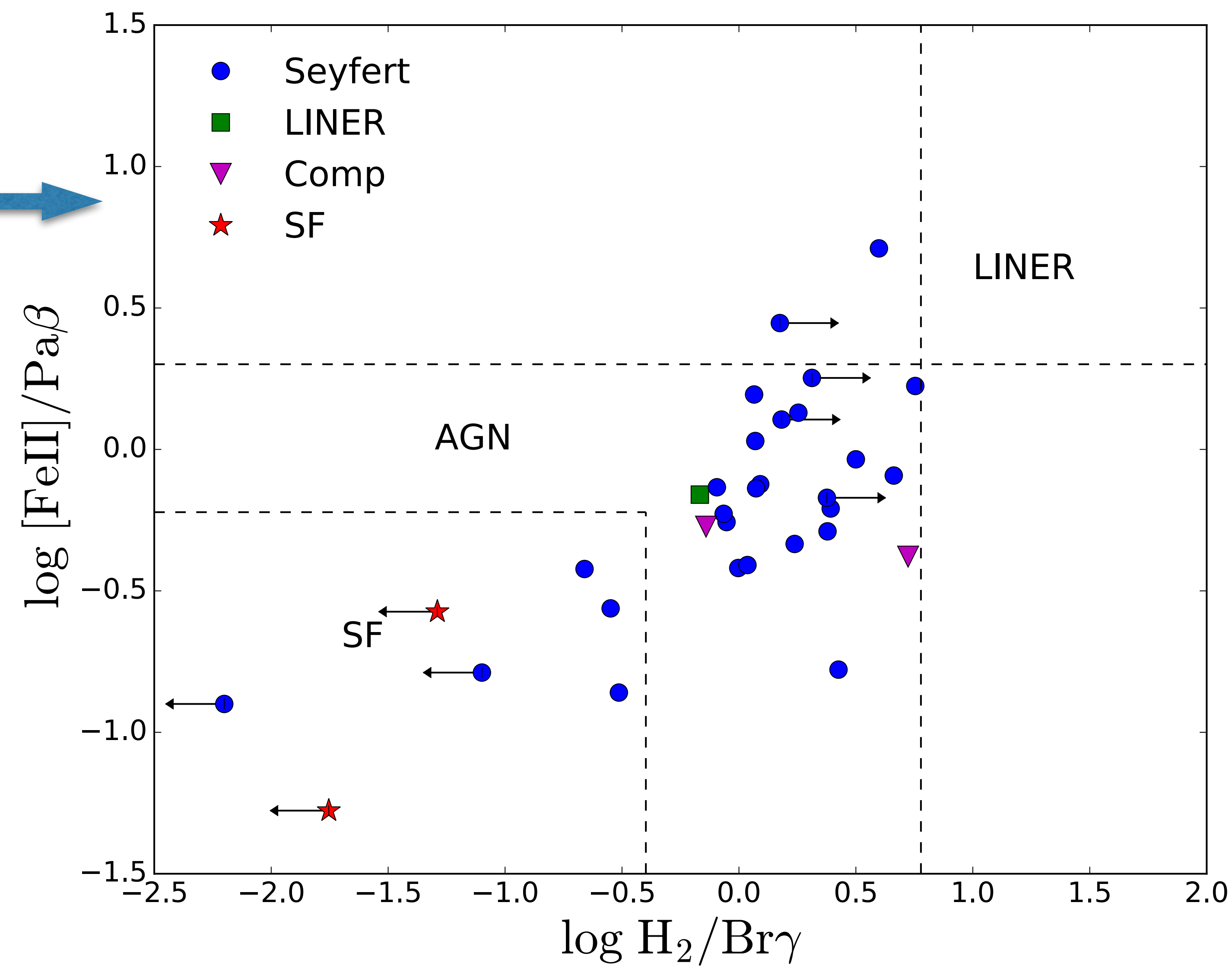
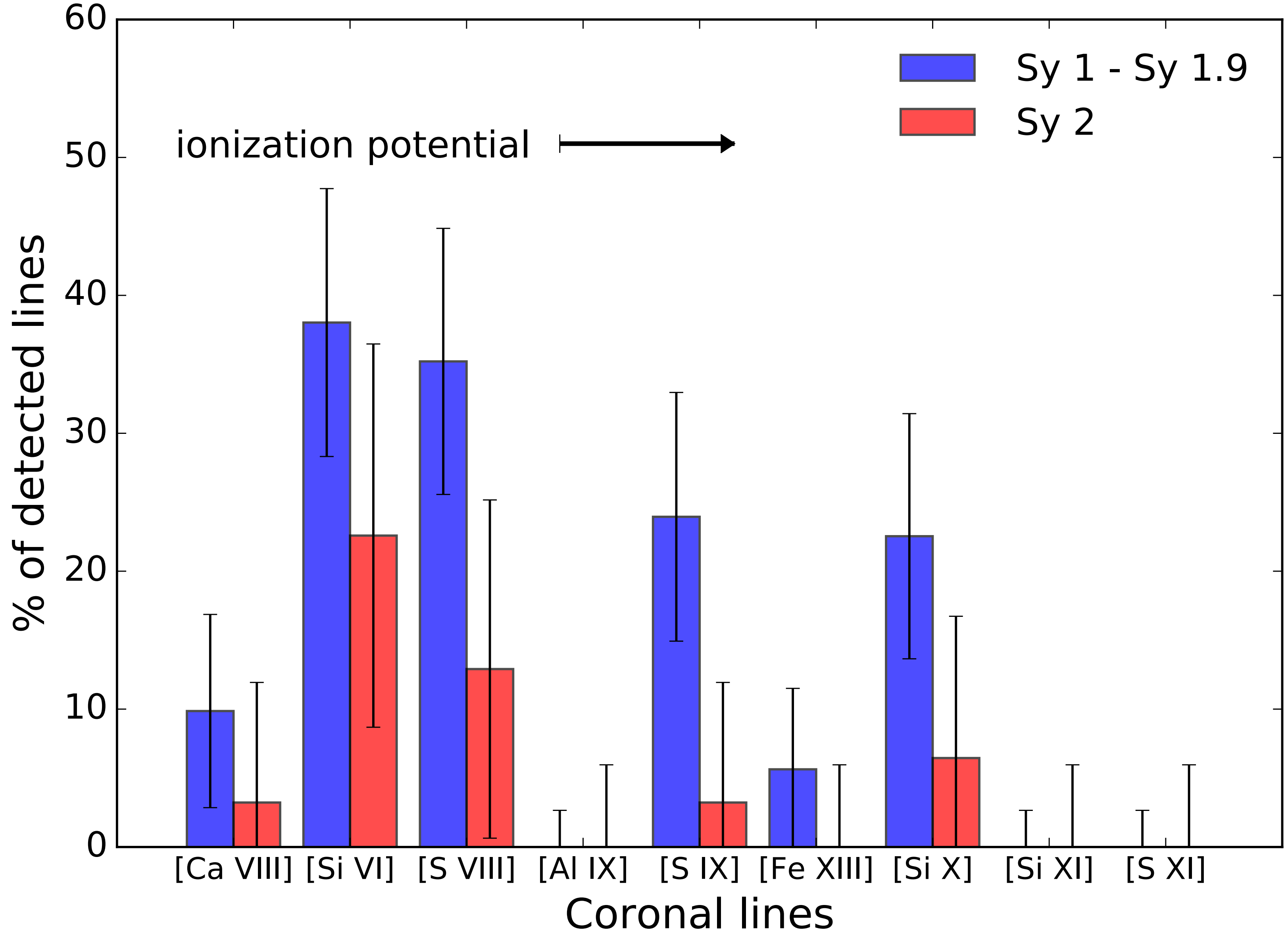


NIR diagnostic is not effective in selecting AGN

AGN diagnostic in the NIR: presence of coronal lines (CLs)

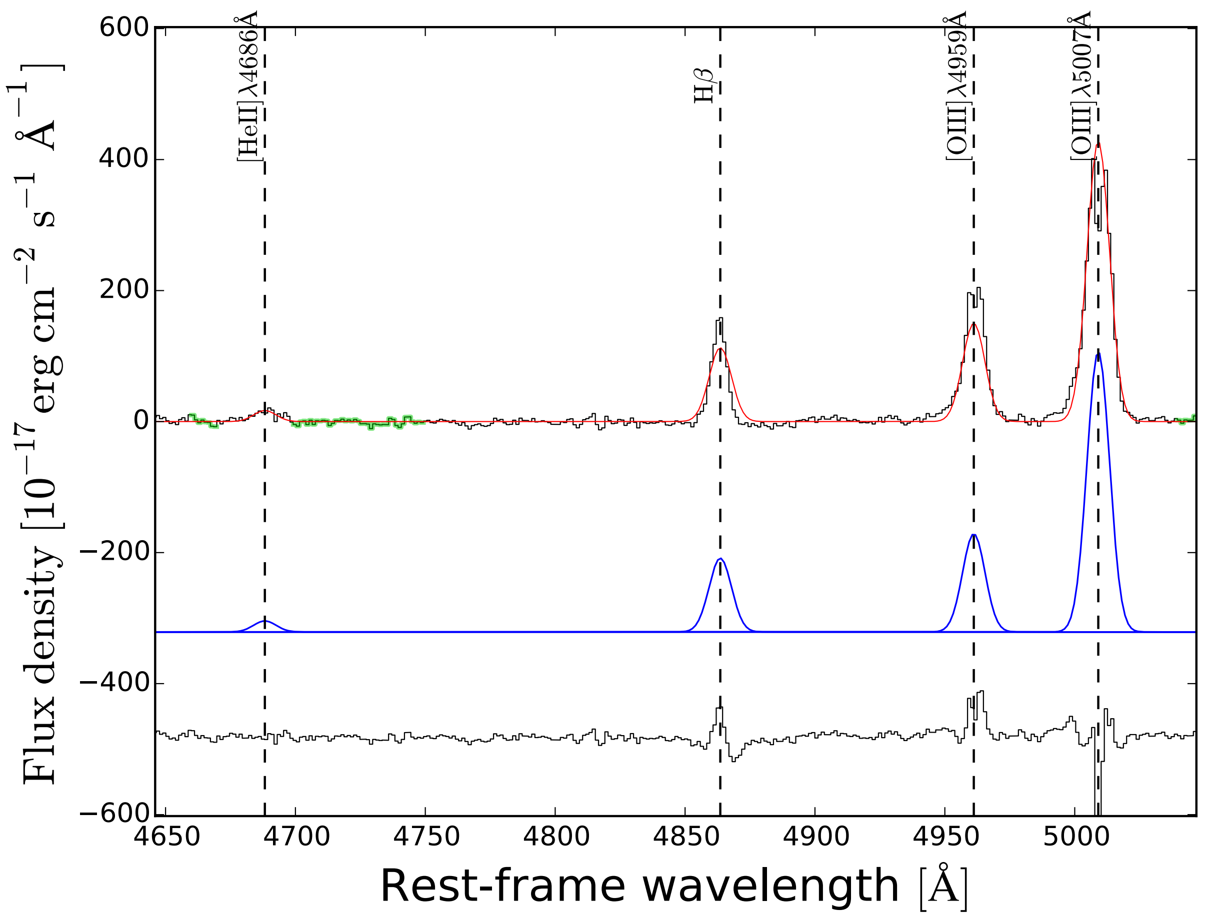
- At least **one coronal line detected** in **43 %** of the sample **(53 %** of Sy1, **20** % of Sy2)
- More coronal lines detected in Sy 1 than in Sy2 —> coronal line region obscured by the torus



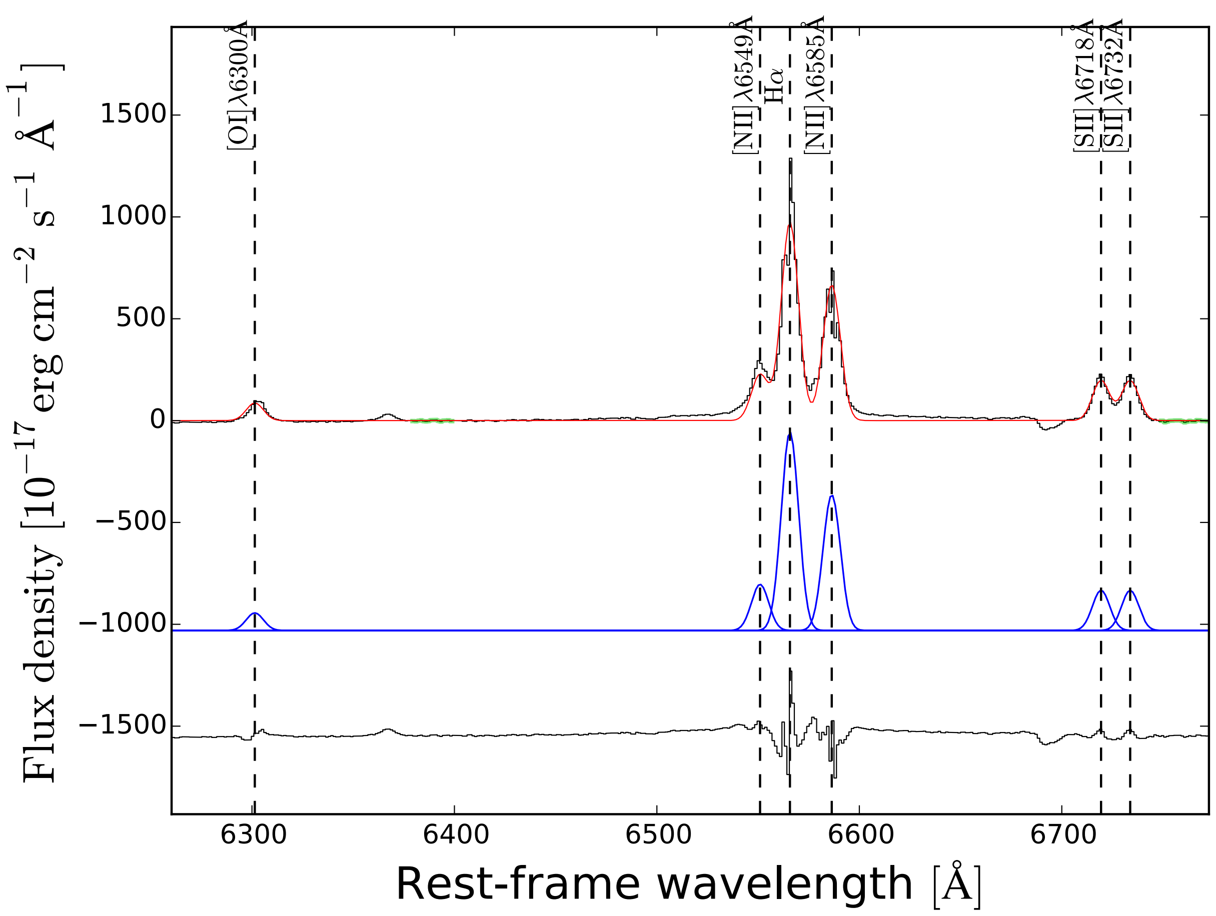
Hidden broad line region (BLR):

Optical spectrum of Mrk 520 (Seyfert 2)

Hbeta



Halpha



Hidden BLR:

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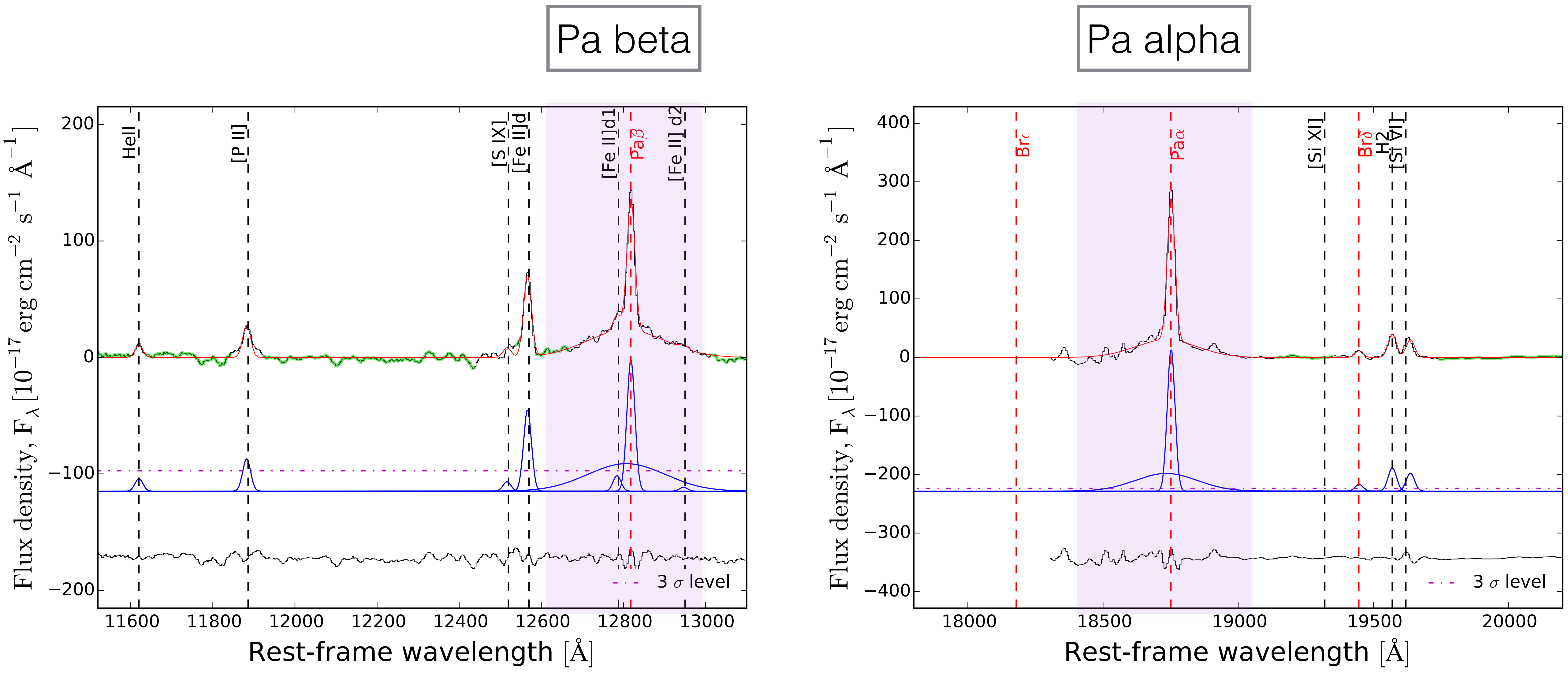
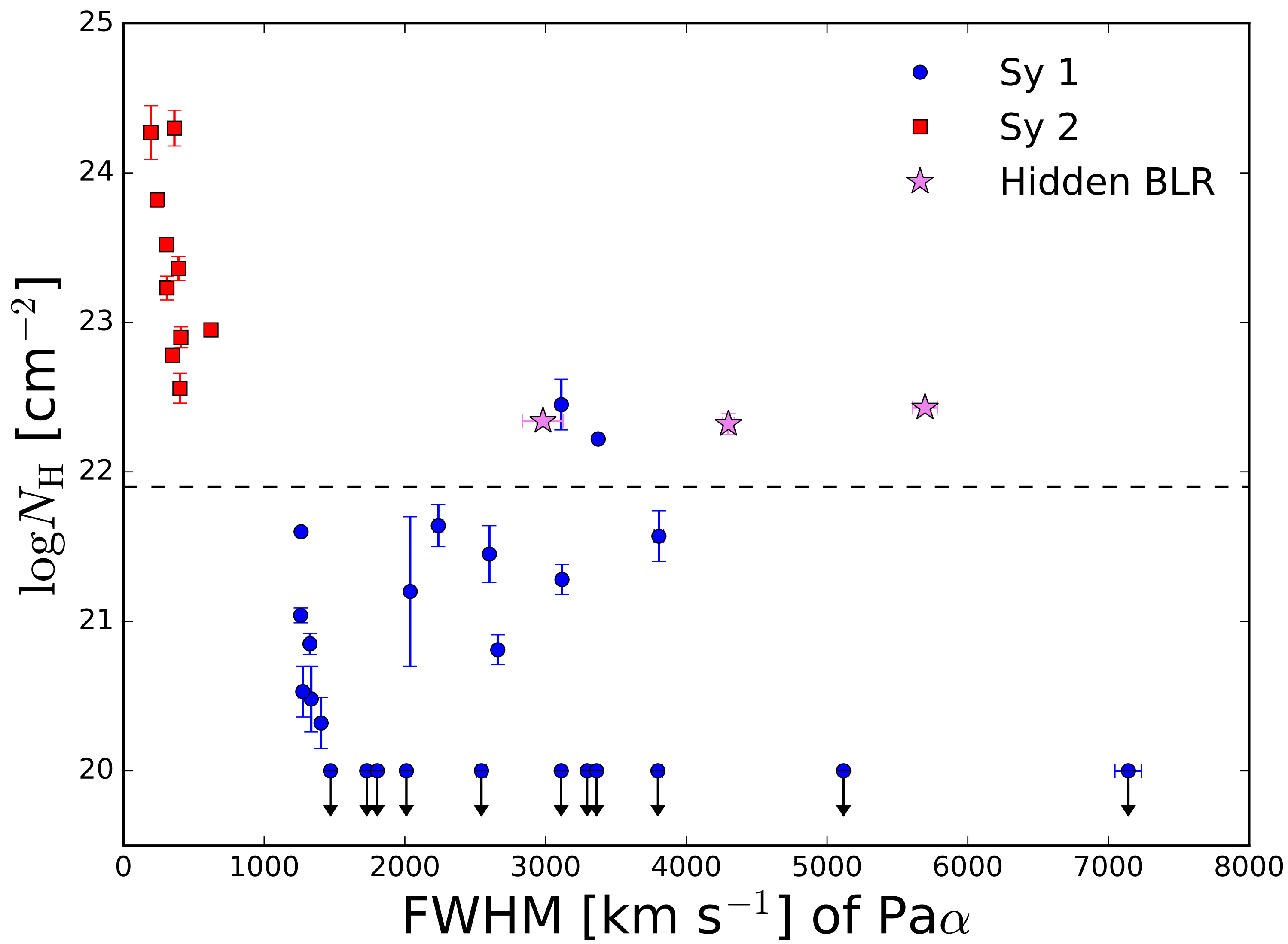
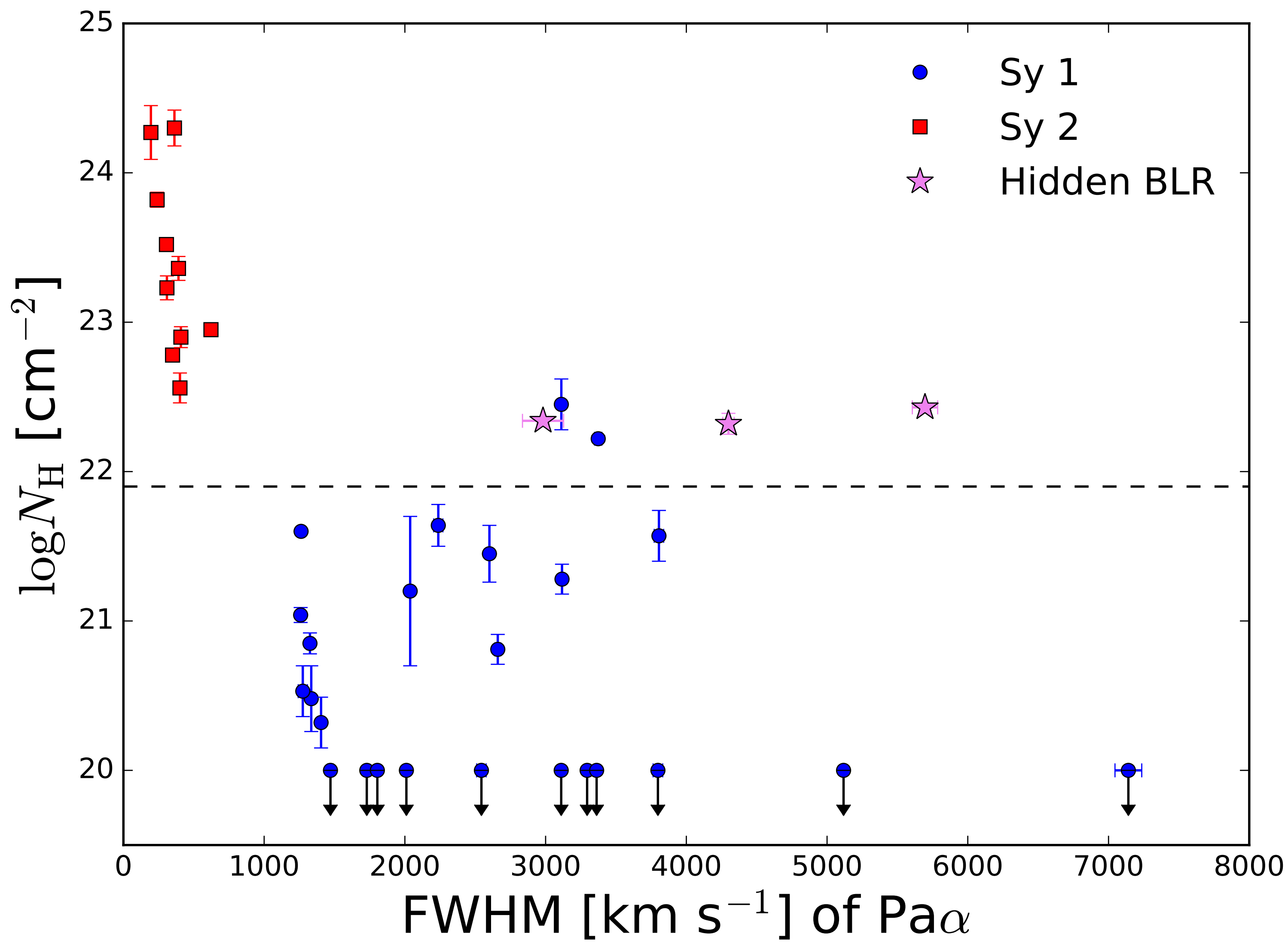


Hidden BLR:



- **10 %** of Seyfert 2s show hidden BLR
- considering also **intermediate objects (Sy 1.8-1.9): 31%** show broad lines in the NIR (similar to previous studies by Veilleux et al. 1997, Onori et al. 2014)

Hidden BLR:



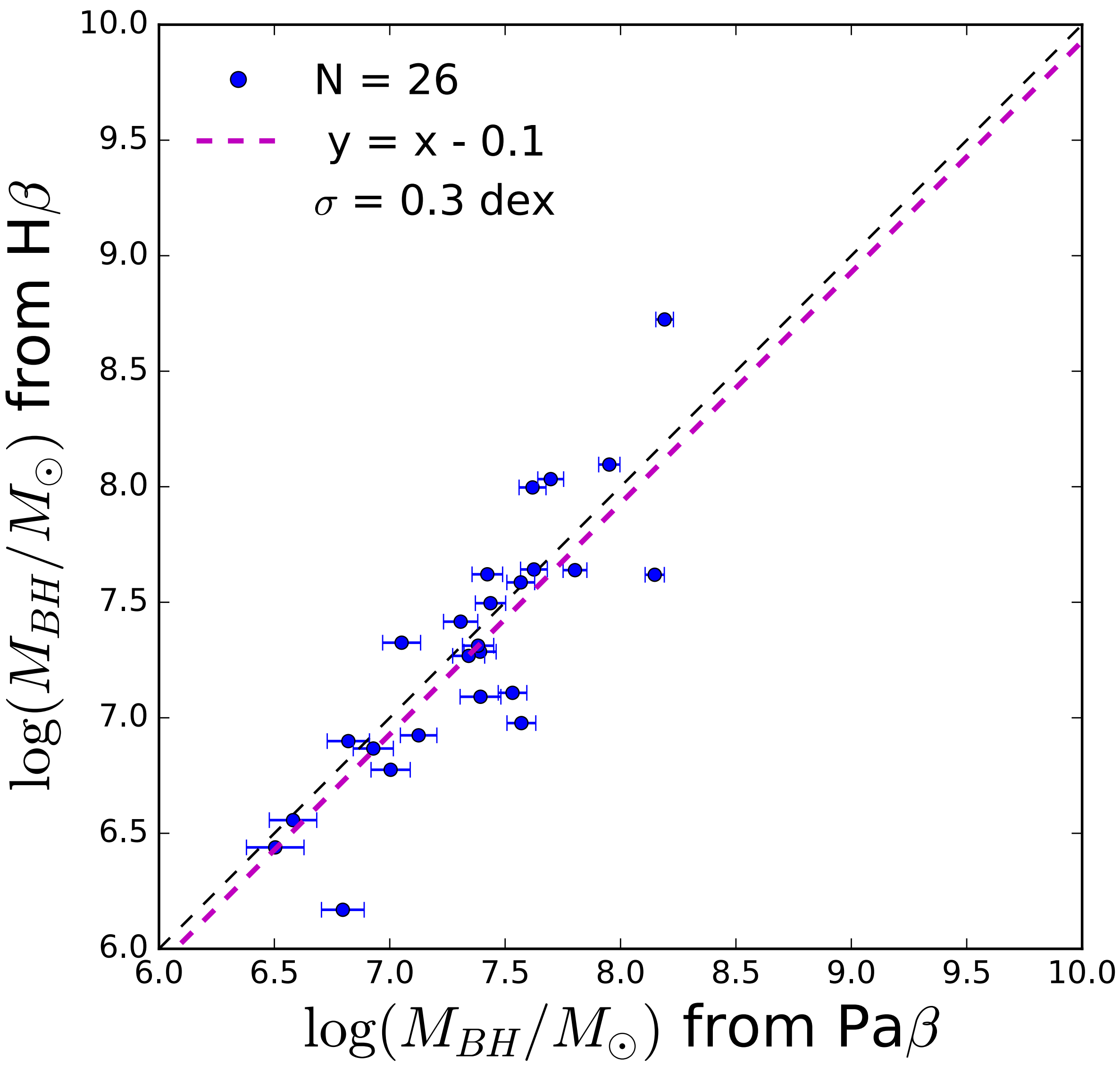
- **10 %** of Seyfert 2s show hidden BLR
- considering also **intermediate objects (Sy 1.8-1.9): 31%** show broad lines in the NIR (similar to previous studies by Veilleux et al. 1997, Onori et al. 2014)
- host galaxies of Sy2 with hidden BLR show signs of mergers or tidal features

> optical broad emission lines obscured by host galaxy dust and not by the nuclear torus.

Virial black hole masses from Paschen lines:

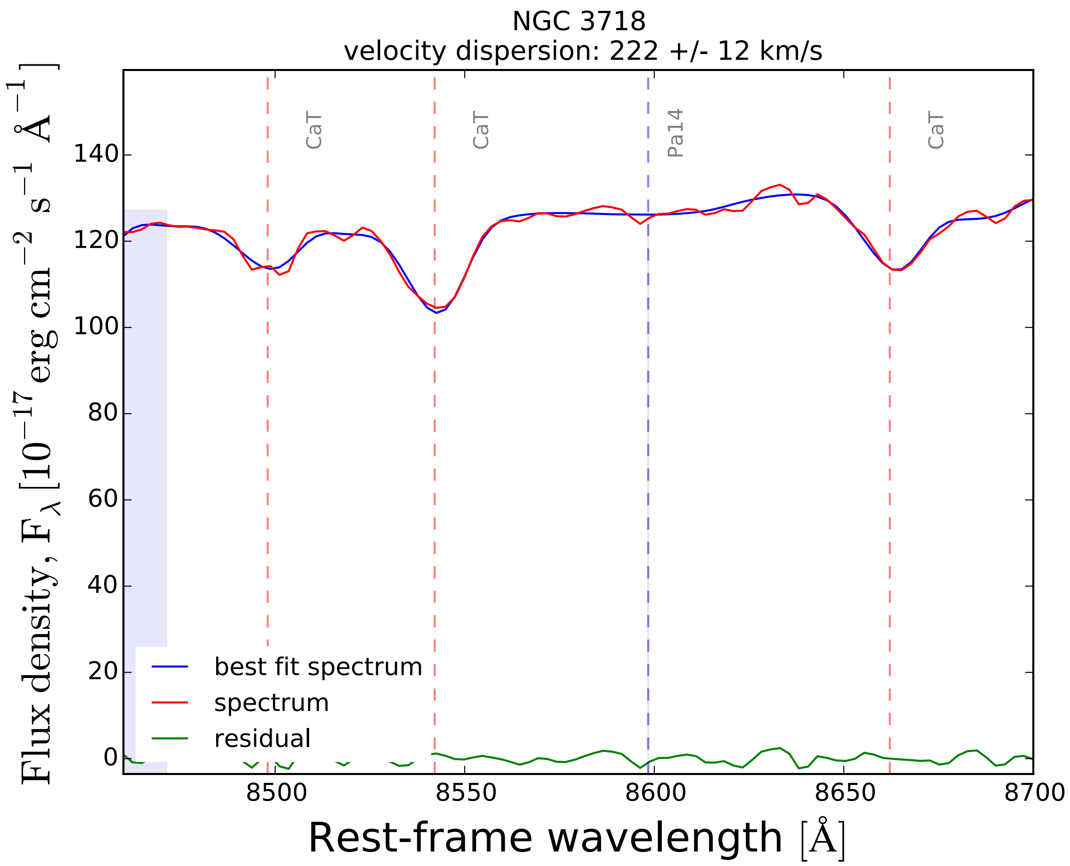
- Equation from La Franca et al. 2015:

$$\log\left(\frac{M_{BH}}{M_\odot}\right) = 0.44 \cdot \log\left(\frac{L_{Pa\beta}}{\mathrm{erg\ s^{-1}}}\right) + 1.74 \cdot \log\left(\frac{\mathrm{FWHM}_{Pa\beta}}{\mathrm{km\ s^{-1}}}\right) - 16.57$$

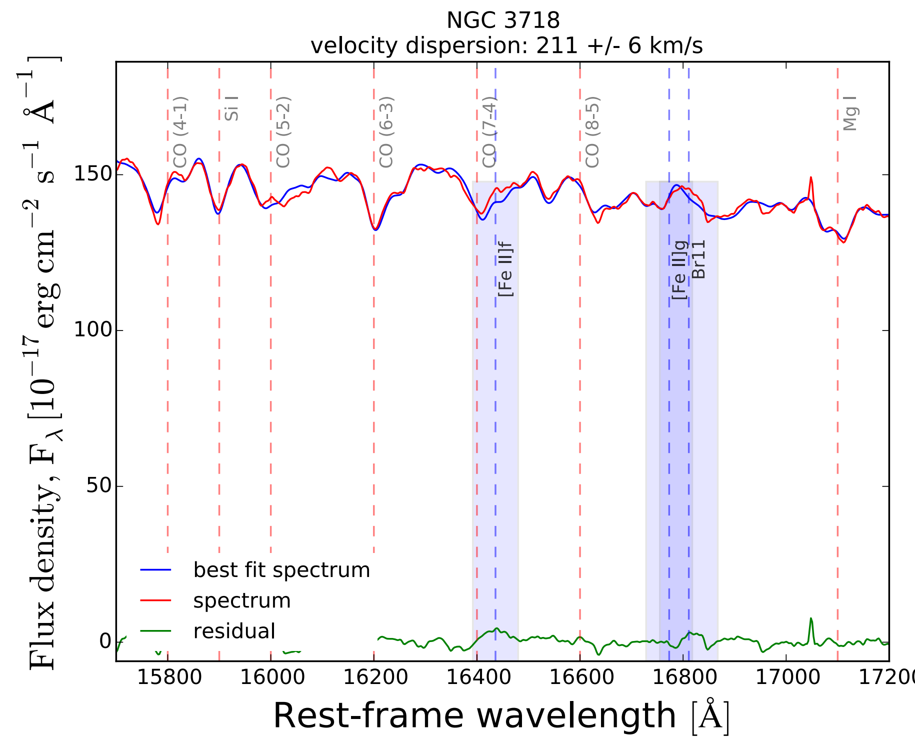


BH masses from velocity dispersion:

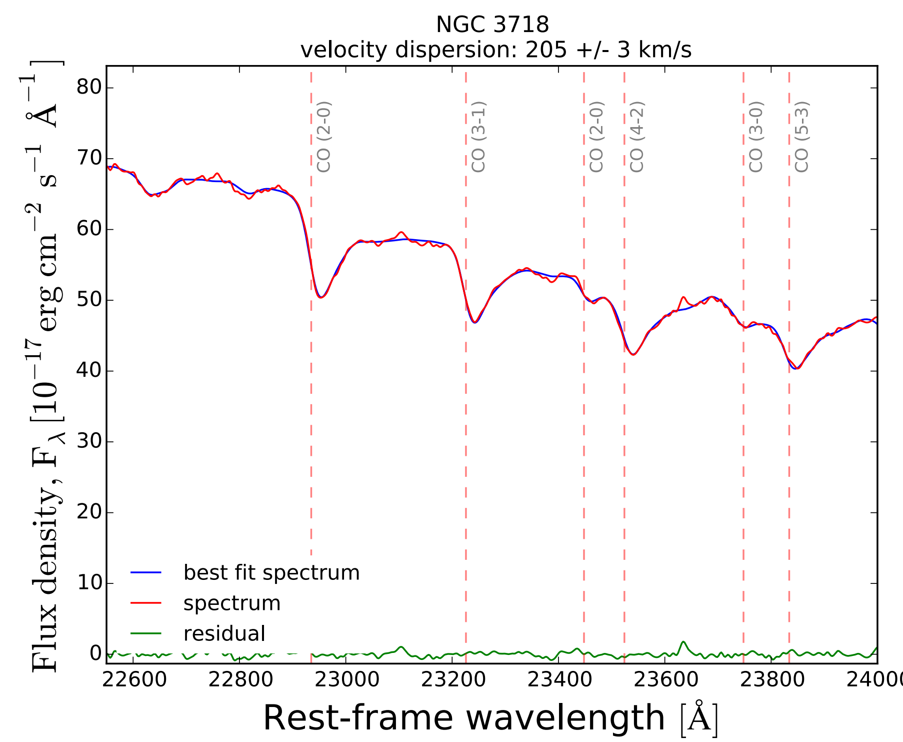
Ca triplet



CO band-heads

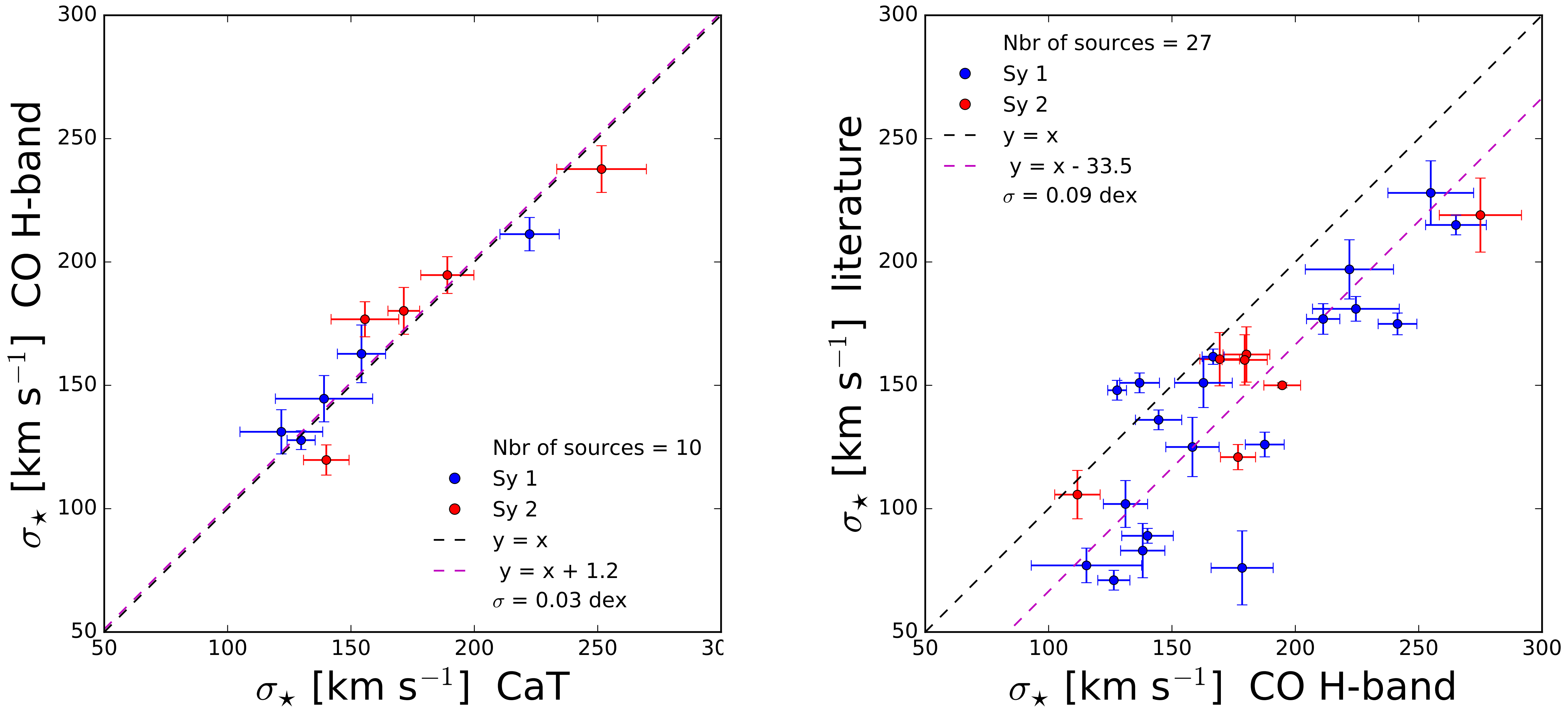


H band



K band

BH masses from velocity dispersion:



- larger velocity dispersion from the NIR spectra:

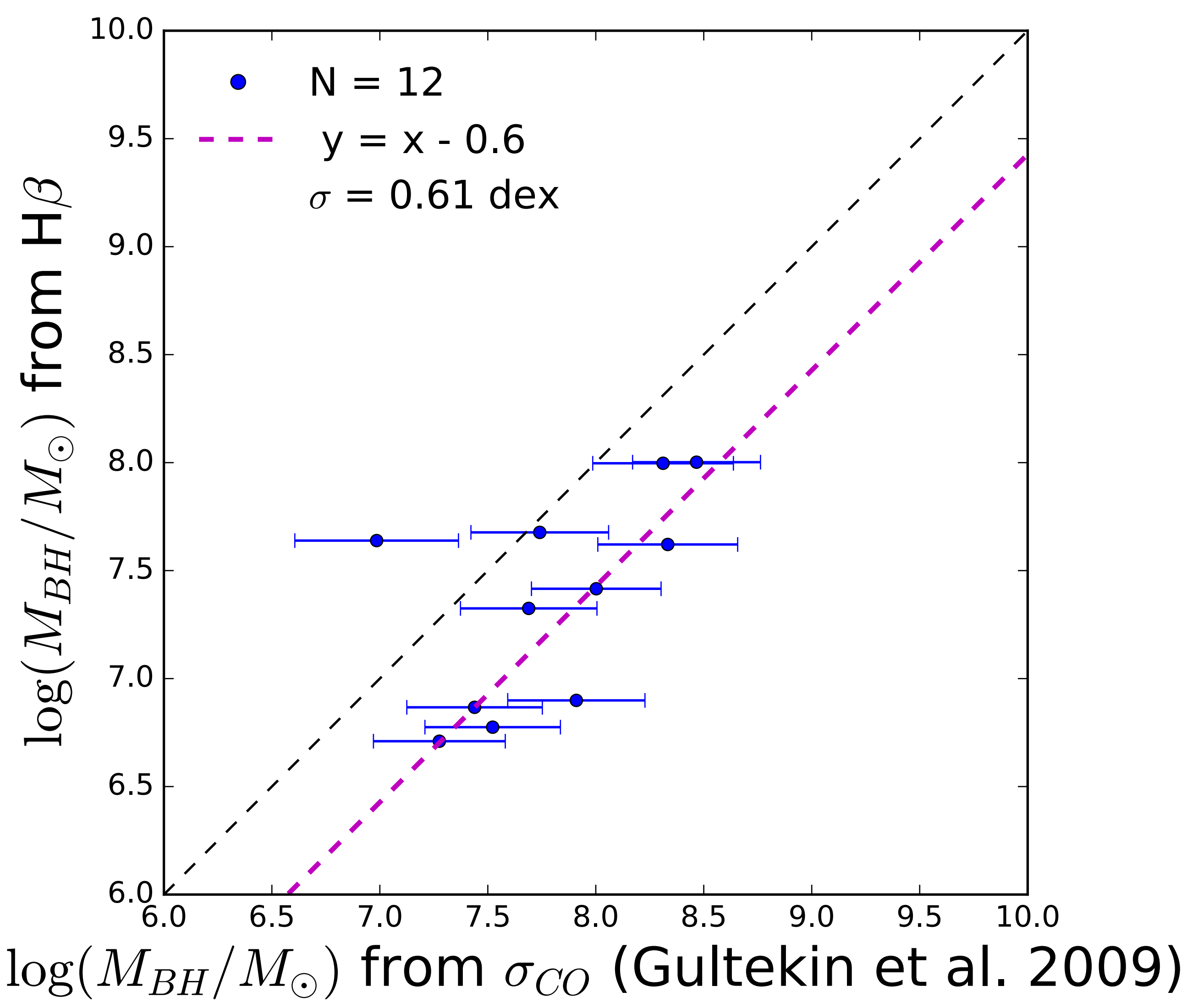
> smaller slit than in the optical: velocity dispersion from CO measured in a region closer to the BH

> no subtraction of the rotational component

BH masses from M-sigma

- Equation from Gültekin et al. (2009) : $\log\left(\frac{M_{\rm BH}}{M_\odot}\right) = 4.24 \times \log\left(\frac{\sigma_*}{200\ {\rm km\ s^{-1}}}\right) + 8.12$

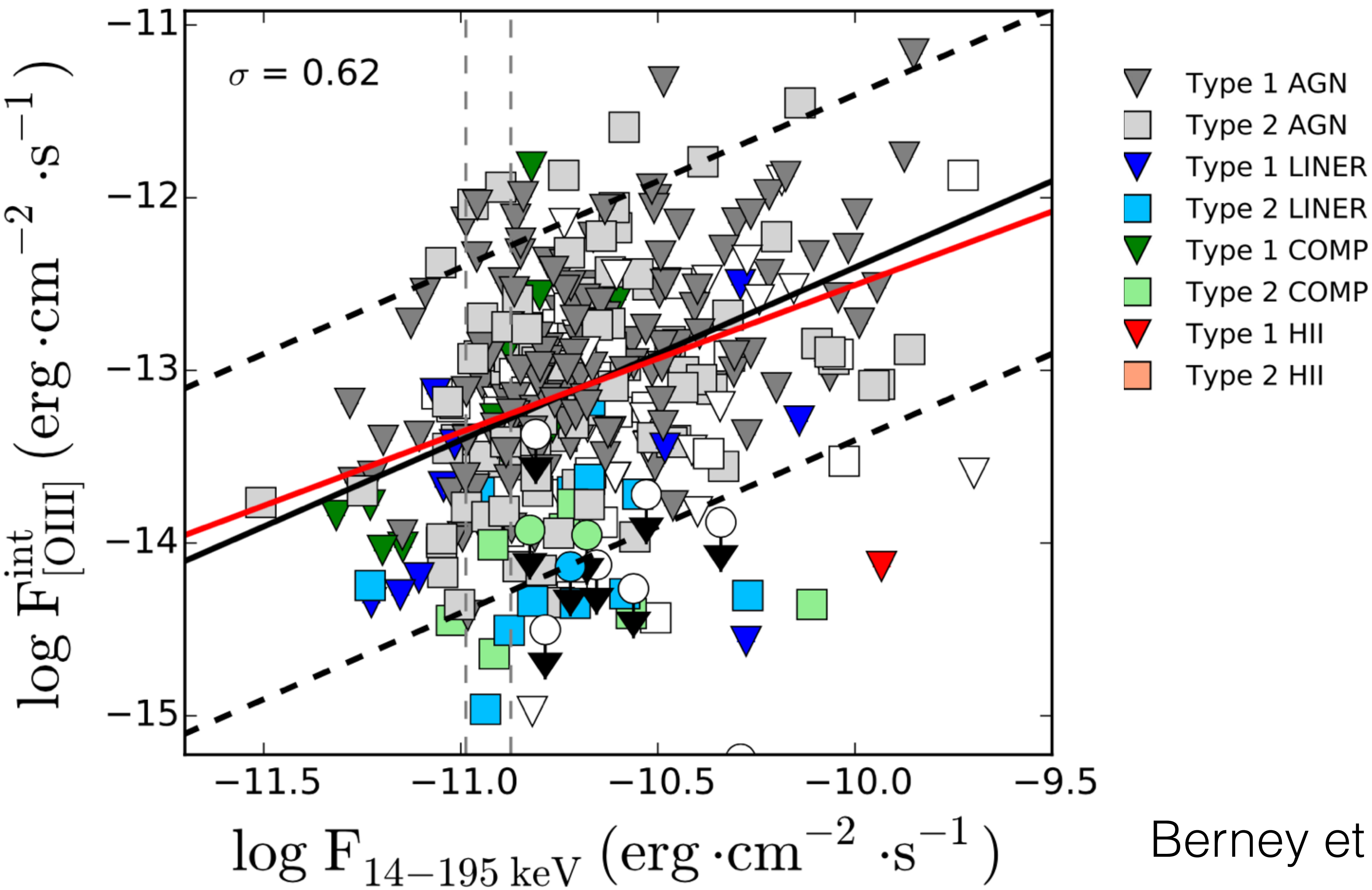
- Comparison with BH mass estimated from Hbeta:



Correlation [O III] and X-ray flux

- Both high ionization optical emission lines and X-rays are thought to be reliable tracers of the AGN bolometric luminosity (Heckman et al. 2004, LaMassa et al. 2009).

BASS sample

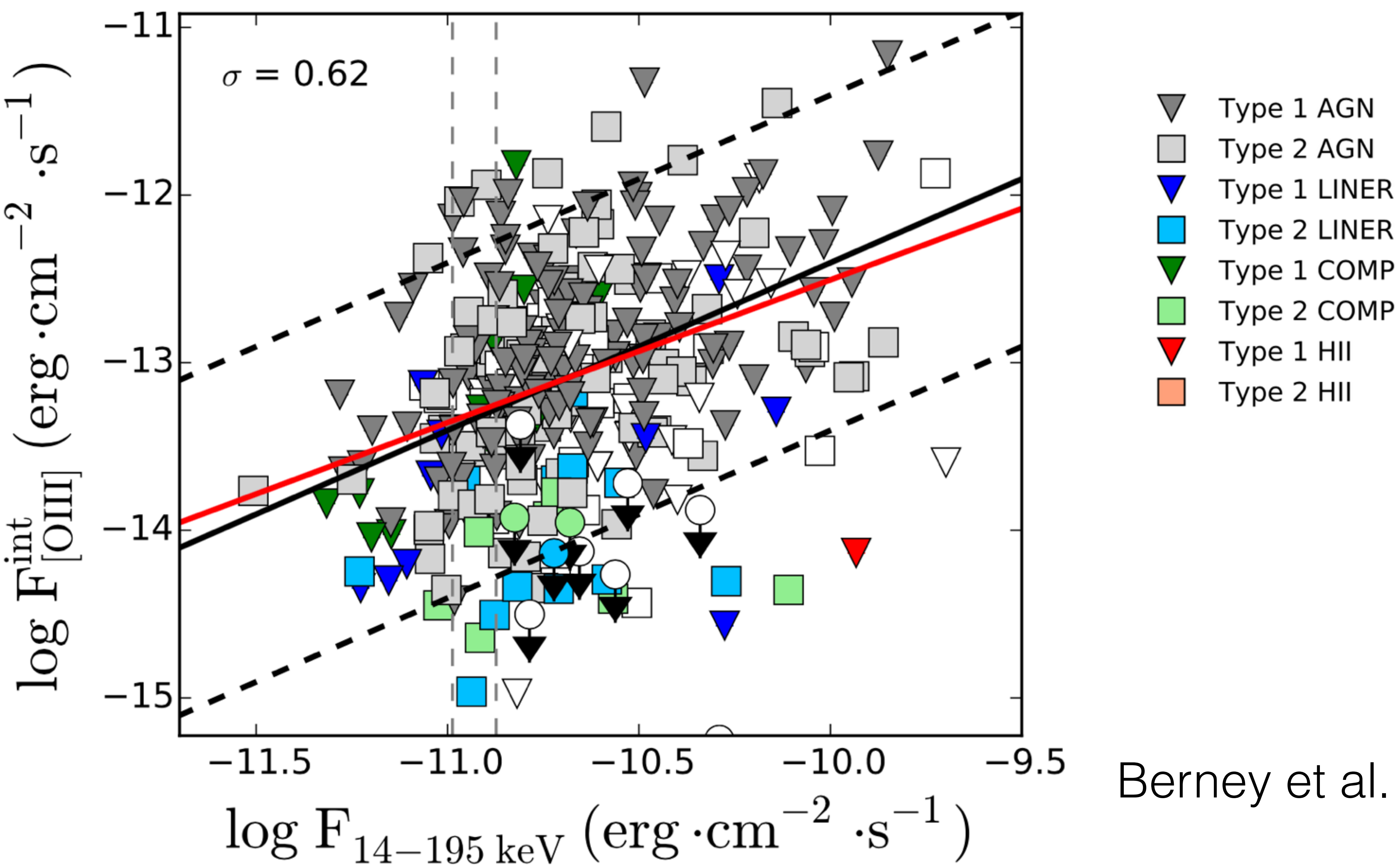


Berney et al. (2015)

Correlation [O III] and X-ray flux

★ Significant scatter in the flux vs. flux relation:

- obscuration?
- variability?
- contribution from star-formation?



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Coronal lines: better scaling with the X-ray flux?

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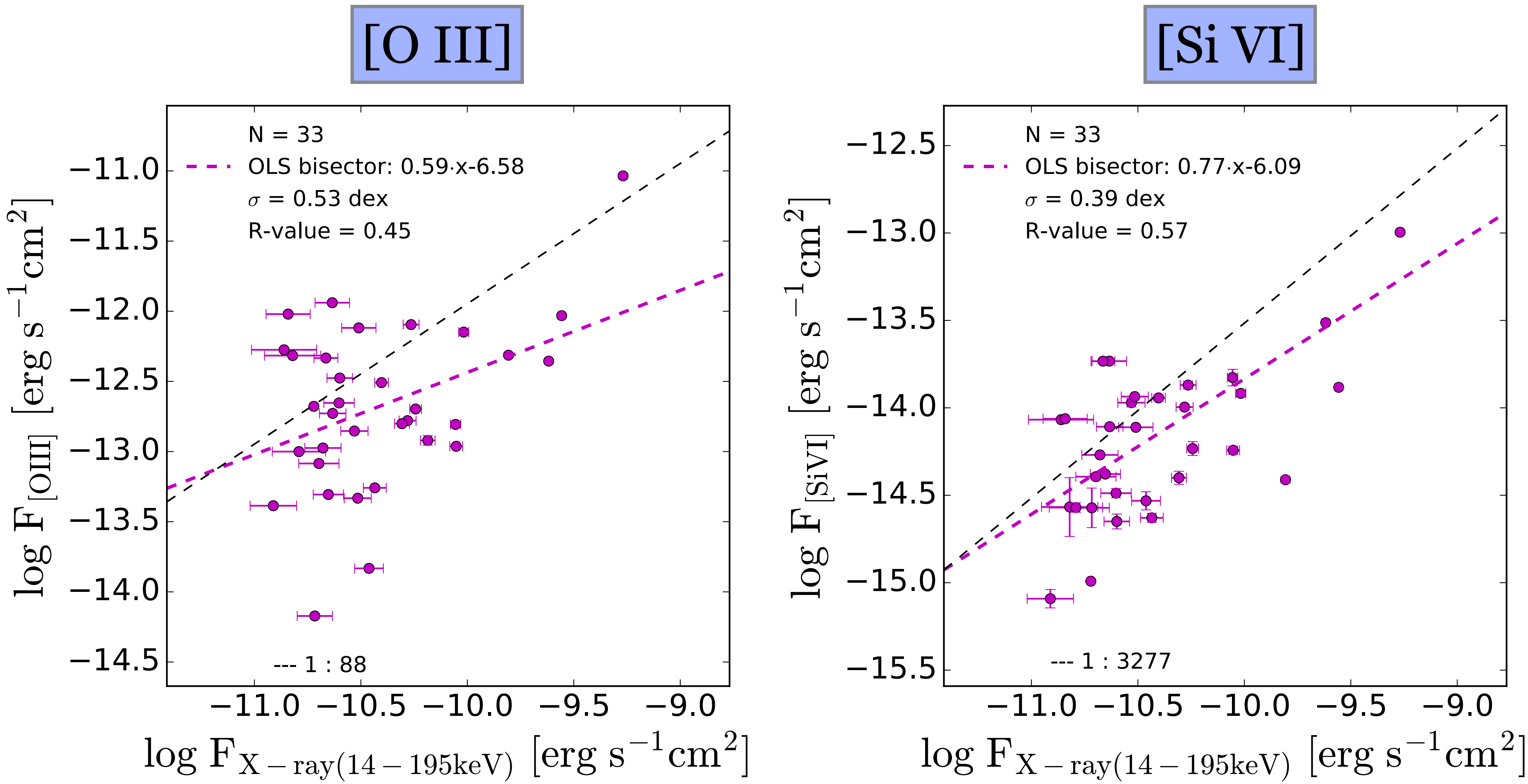
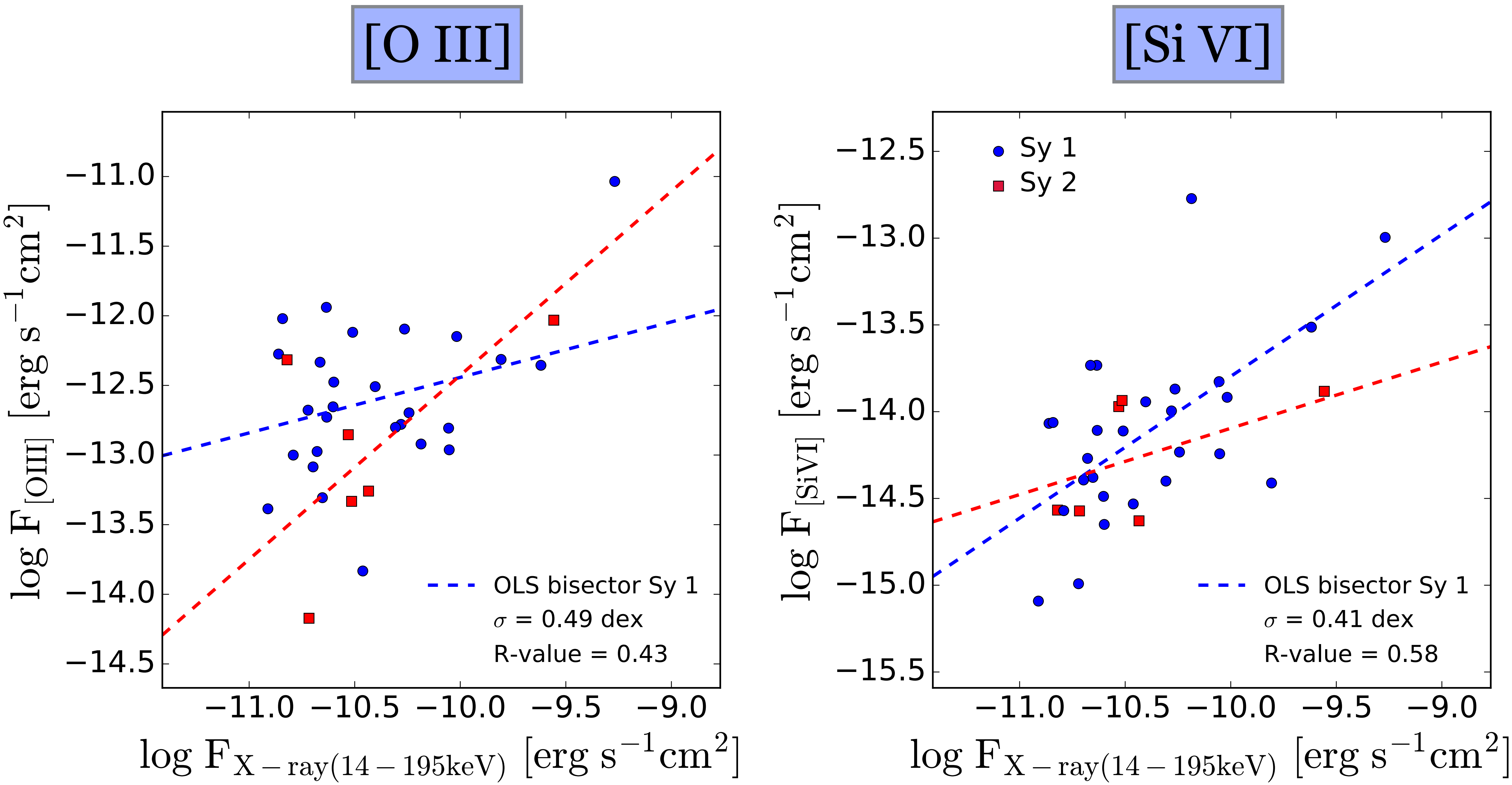


Coronal lines: better scaling with the X-ray flux?

- Considering only Seyfert 1s: the correlation is not significantly better (p-value = 0.16)



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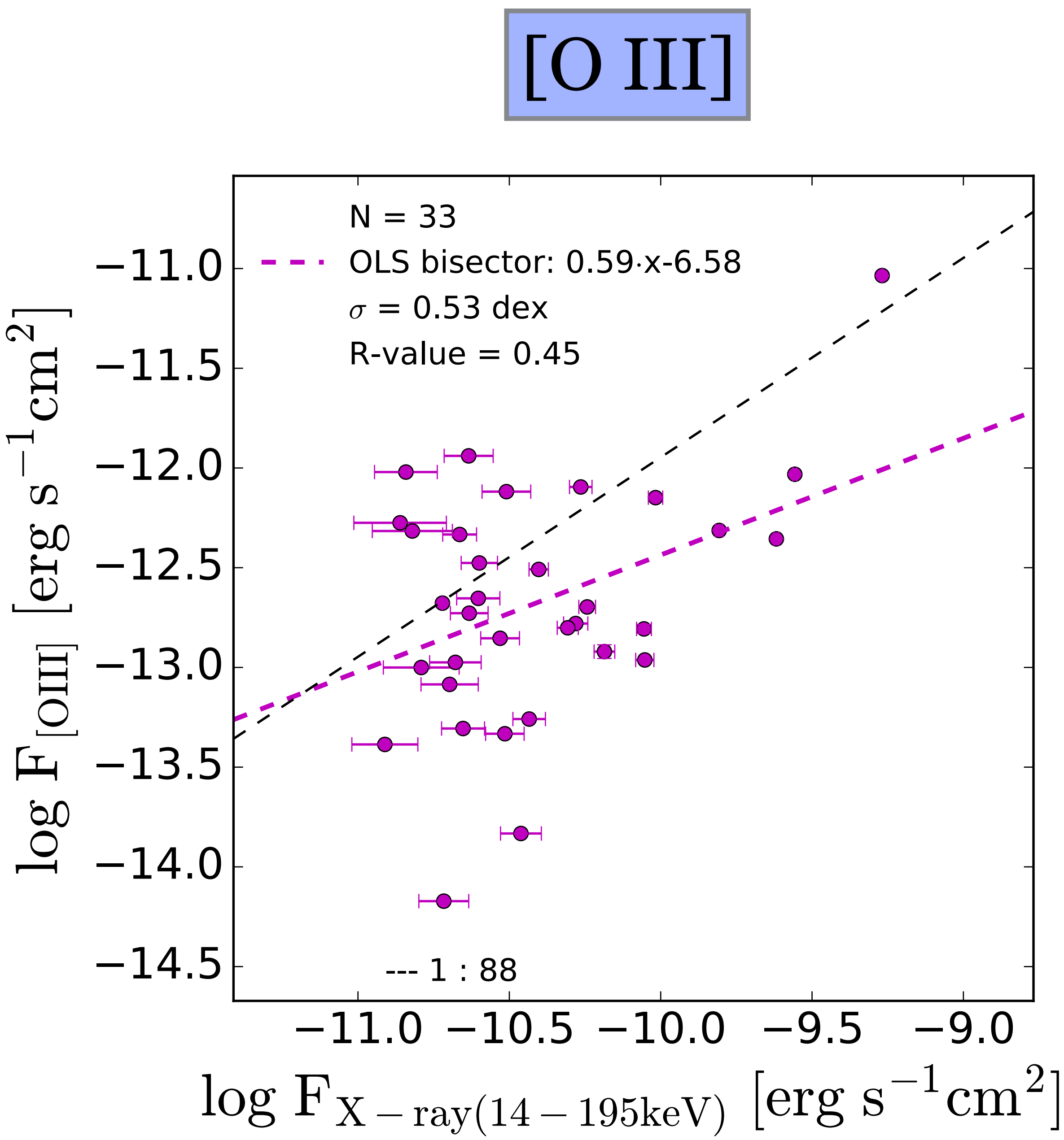
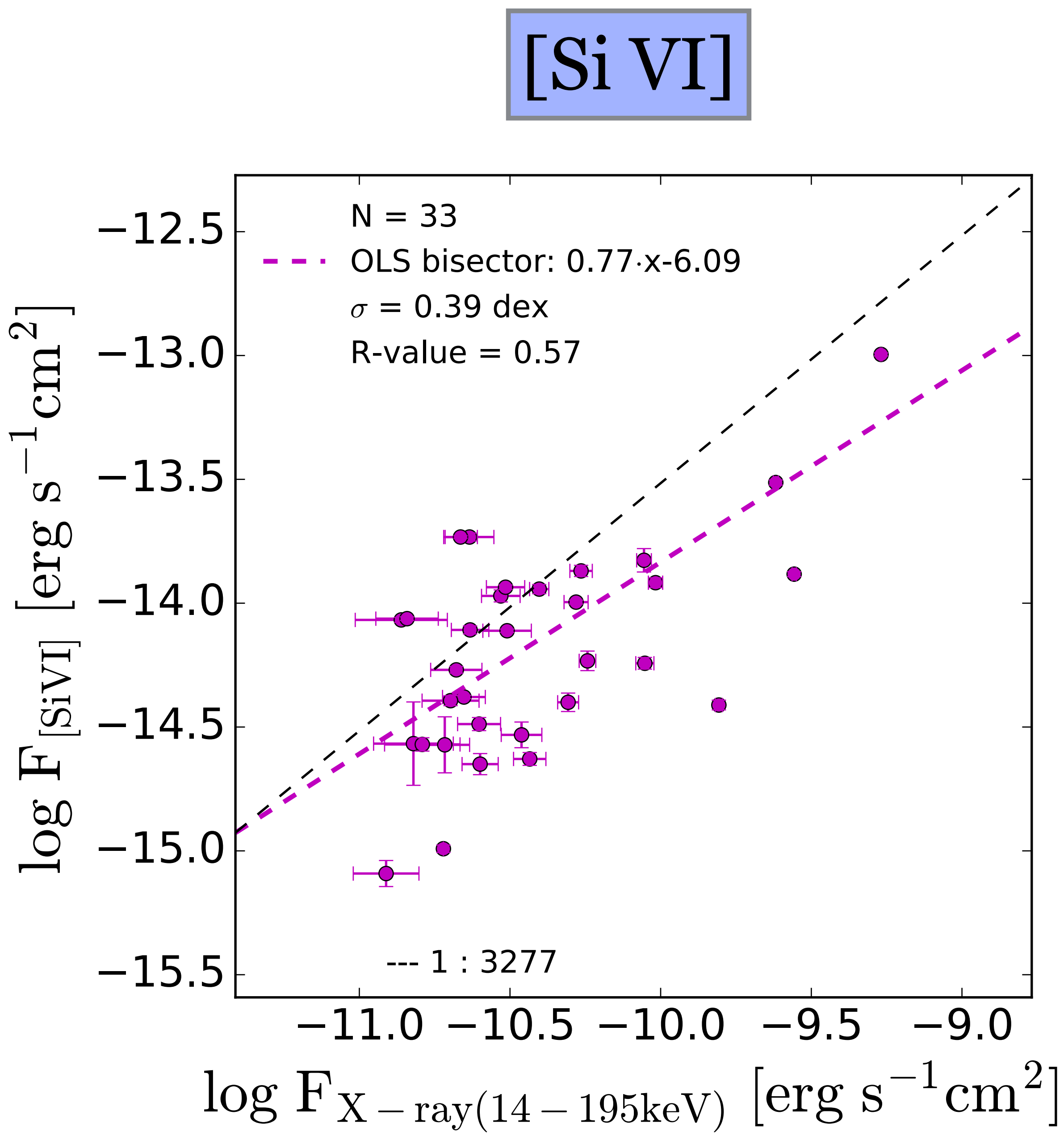


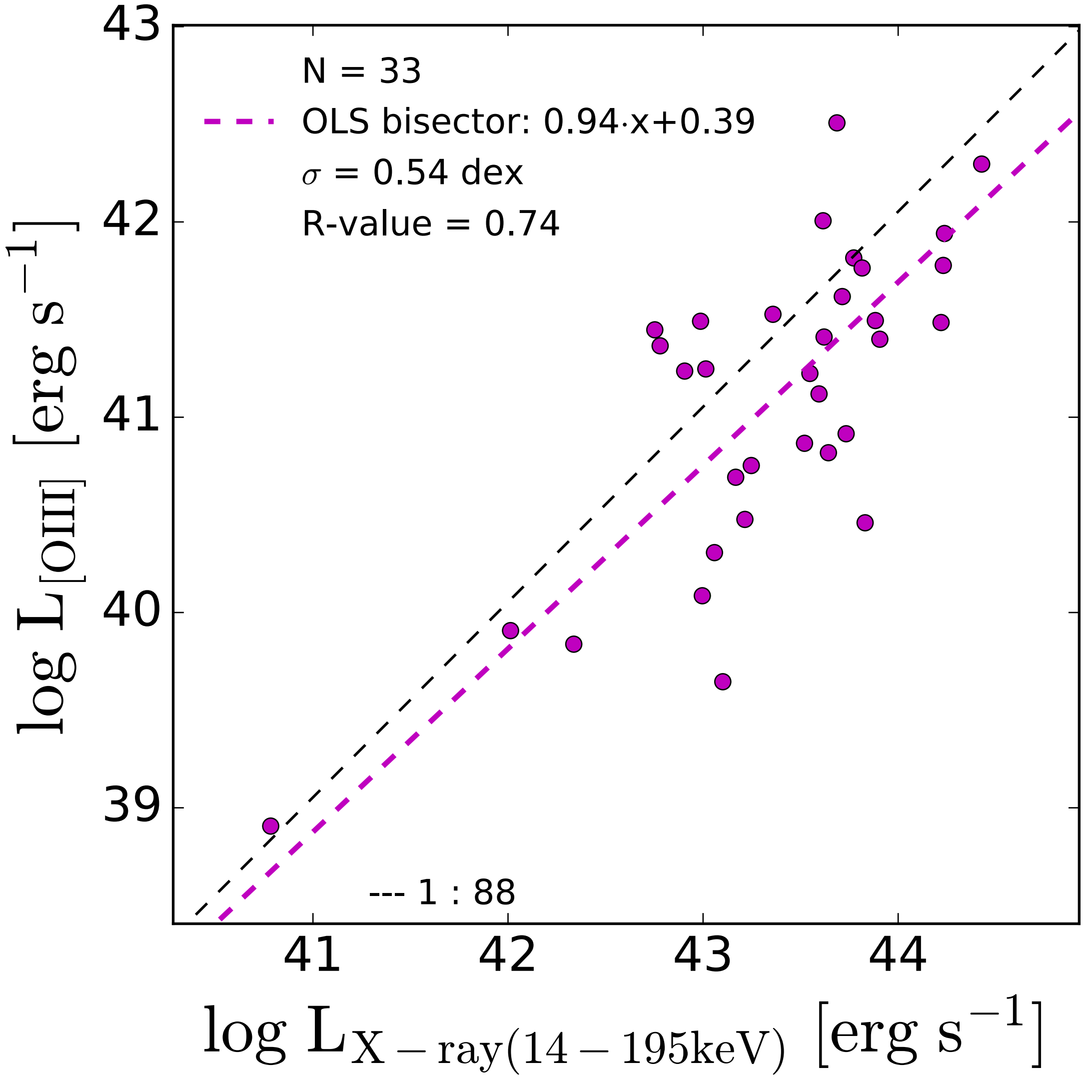


Correlation with [Si VI] not significantly stronger
> Obscuration is not the main cause of the scatter

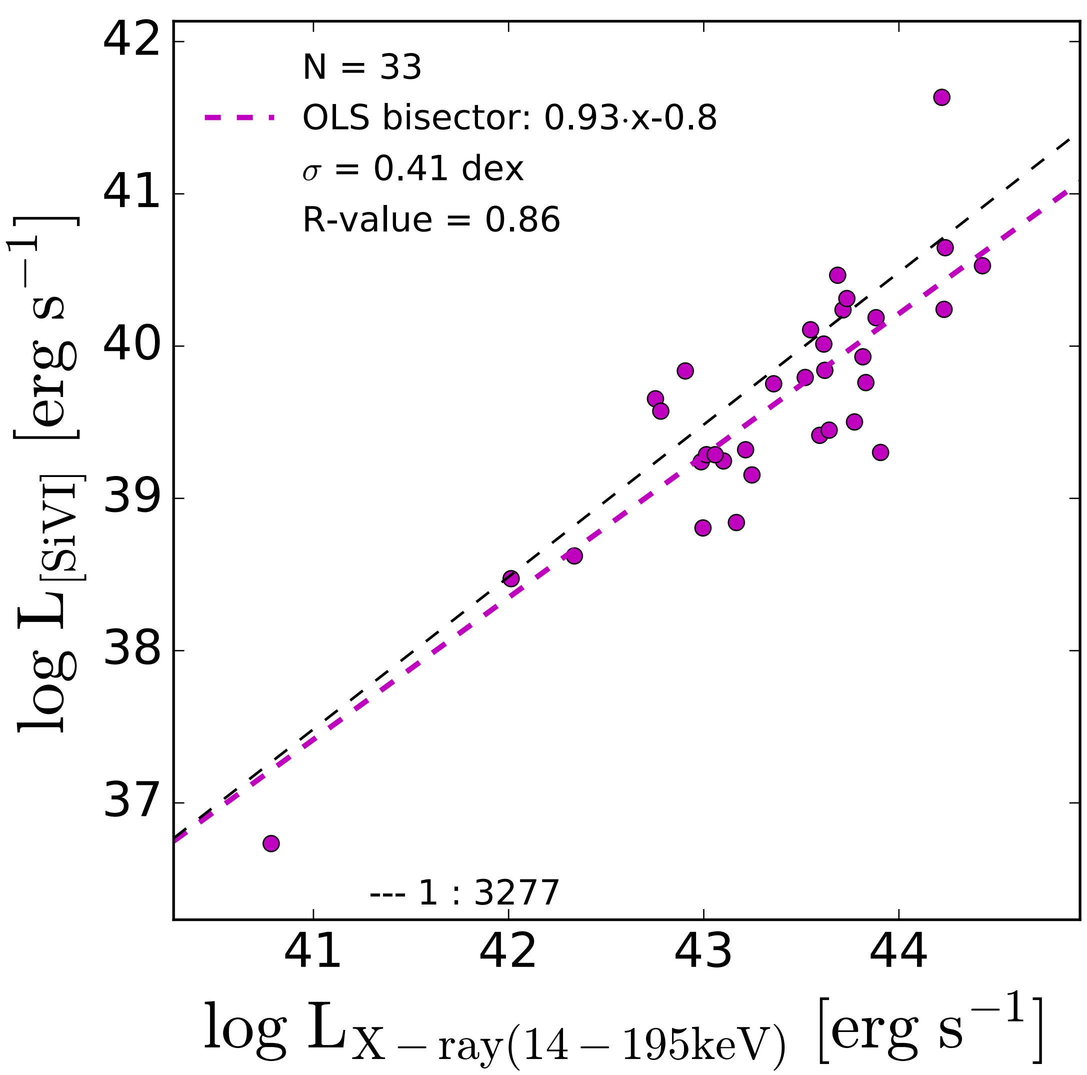
Coronal lines: luminosity correlation

- X-ray luminosity correlation with [Si VI] luminosity is stronger than with [O III] (p-value = 0.0056)

[O III]



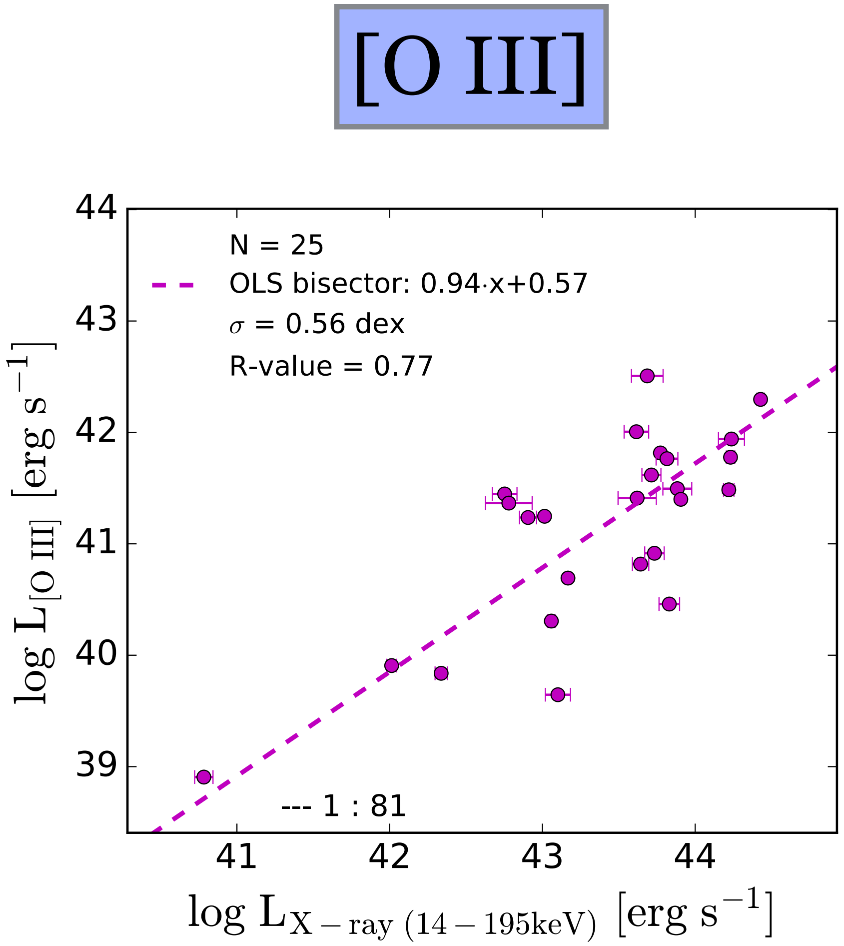
[Si VI]

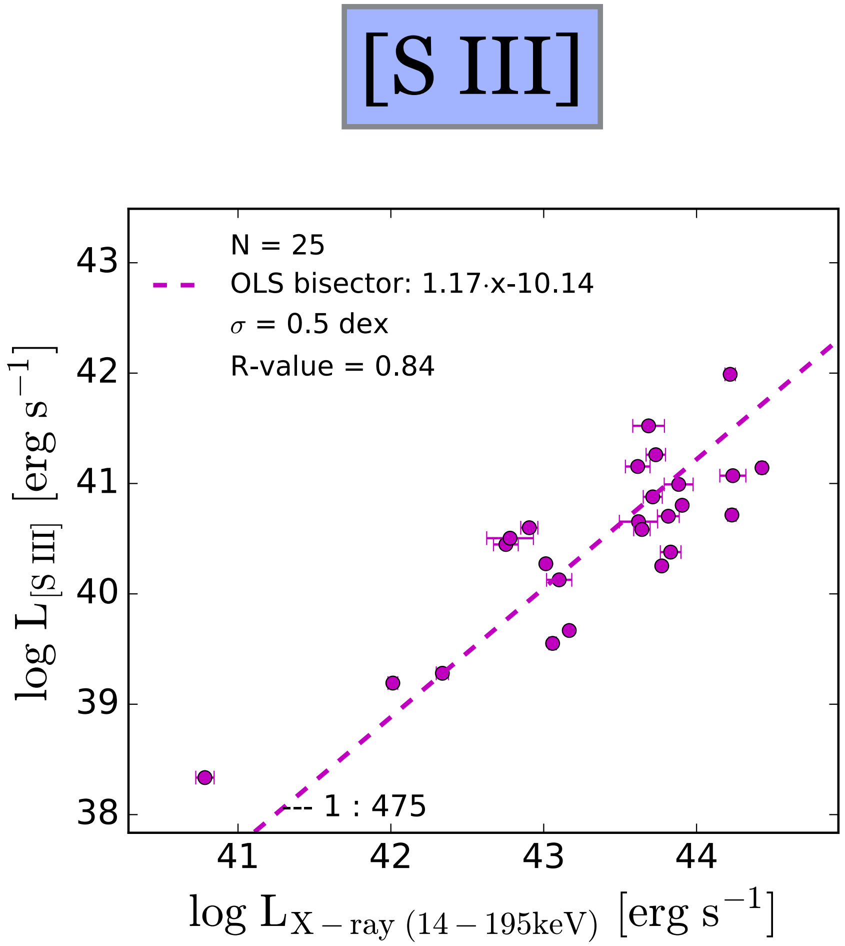


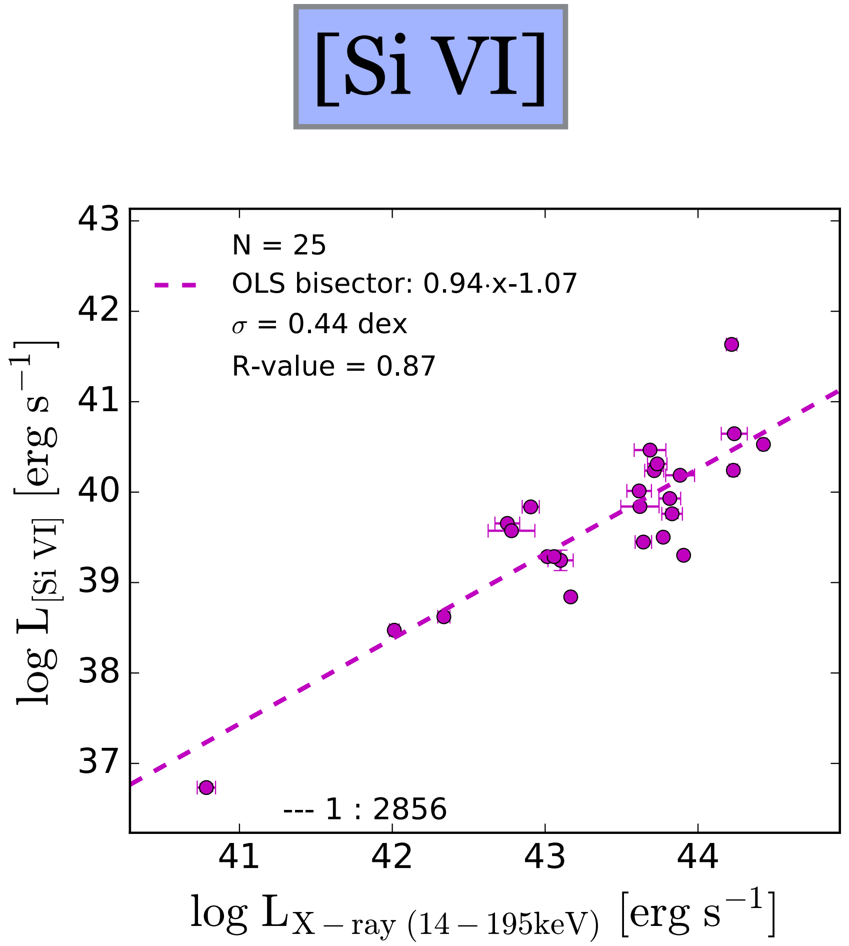
Coronal lines: better scaling with the X-ray flux?

- Luminosity correlation:

X-ray correlation with [S III] similar to the correlation with [Si VI]





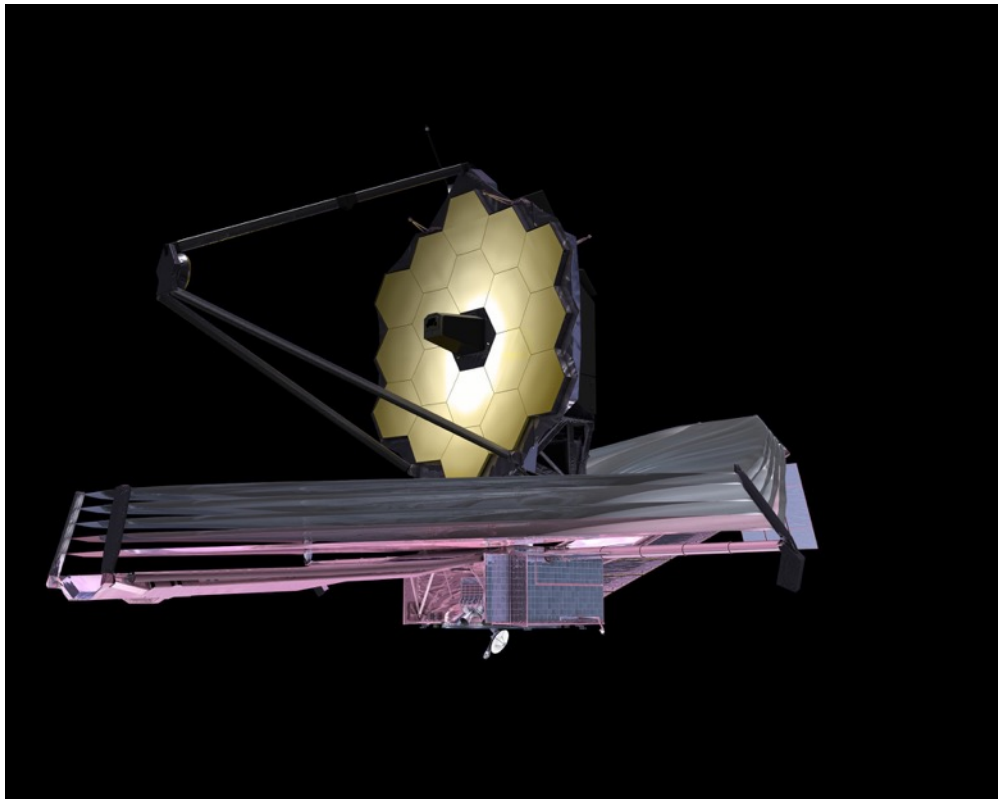


[S III] and [Si VI] luminosity can be used to estimate the X-ray and bolometric luminosity

Outlook: James Webb Space Telescope

- Near- Infrared Spectrograph (NIRSpec): wavelength 1-5 micron

  > for z~1: rest-frame wavelength 0.5-2.5 micron



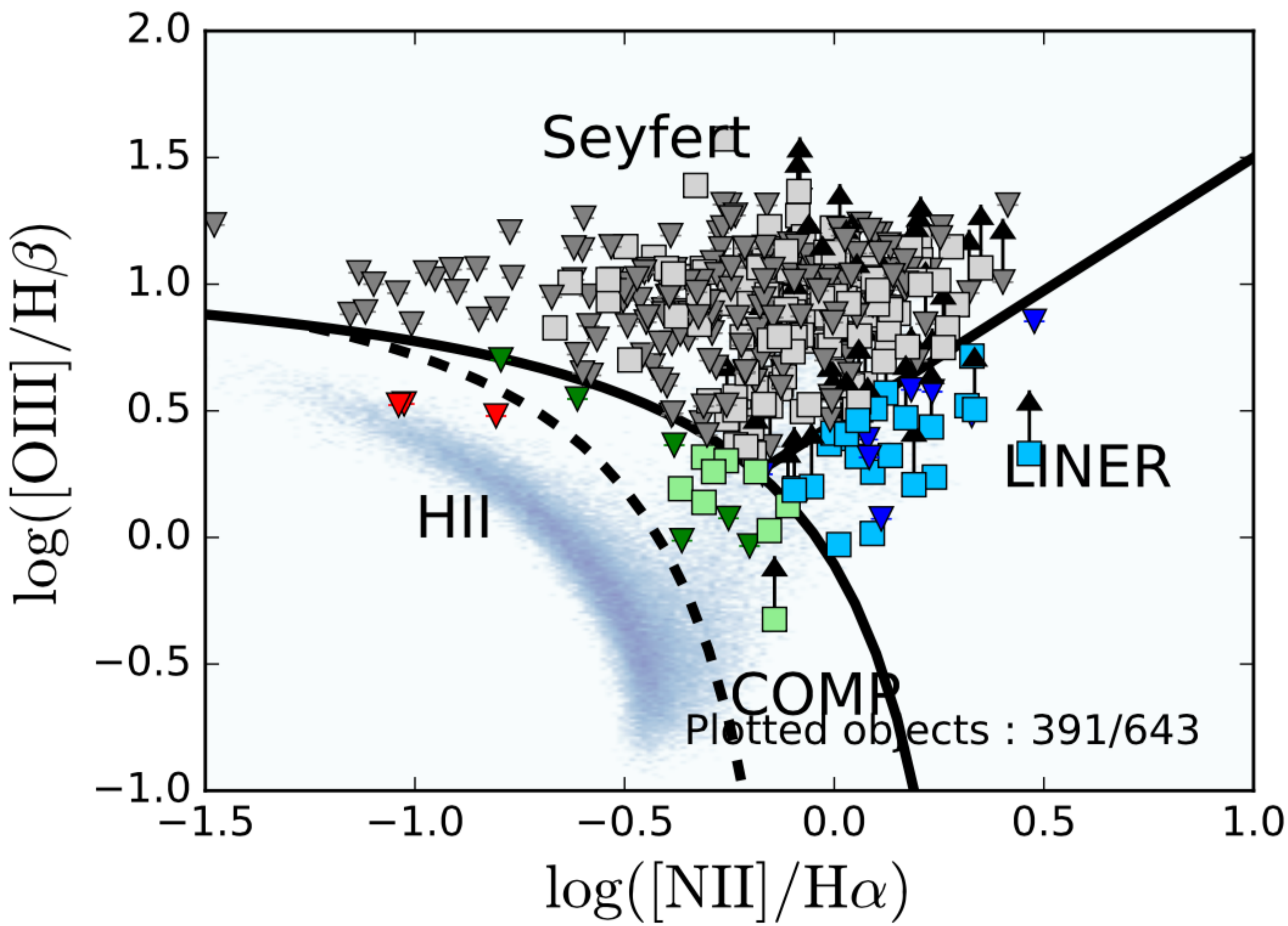
- Potential analysis for AGN at redshift z~1:
  - ✦ AGN identification through coronal lines
  - ✦ black hole masses estimates from Paschen lines
  - ✦ estimate of the bolometric luminosity from the [Si VI] or [S III] luminosity

Conclusions:

- **NIR AGN diagnostic**: 43% of objects in our sample can be identified as AGN through the presence of coronal lines
- **30%** of obscured AGN (Seyfert 1.8 - 2) show **broad lines in the NIR**
- relation between **[Si VI] and hard X-ray flux** is not significantly better than the one between [O III] and X-ray: obscuration is not the main cause of the scatter
- **JWST outlook**: JWST/NIRSpec can identify AGN through coronal lines and provide black hole mass estimates for AGN at redshift z~1.

Optical BPT diagram

BASS sample



Koss et al. (submitted)

Sample:

	Number of spectra	Telescope	Instrument	Wavelength range [micron]
New observations	48	IRTF	SpeX	0.8 - 2.4
New observations	7	Kitt Peak	Flamingos	1.0 - 1.8
Tot	55			

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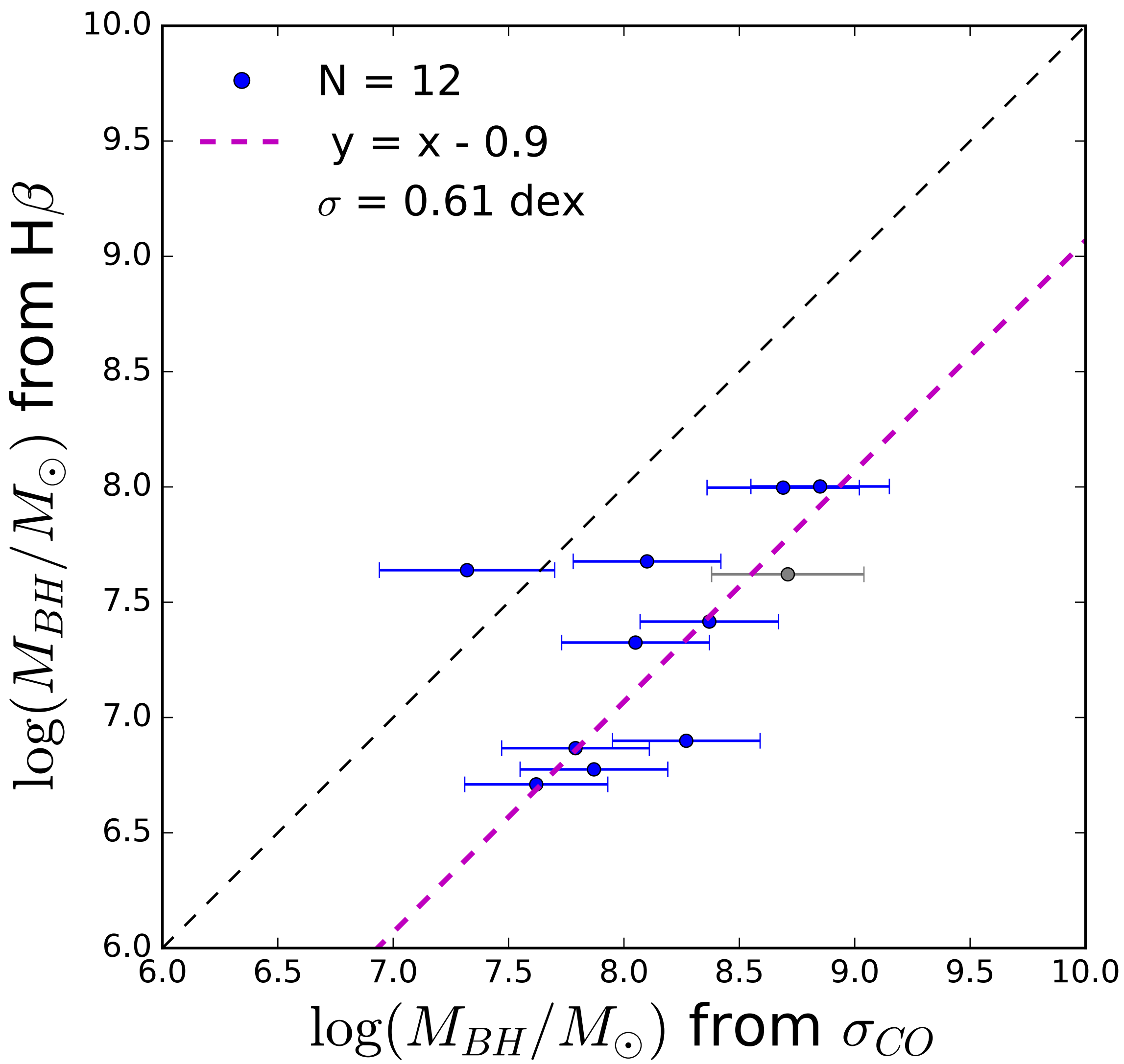
Landt et al. (2008, 2013)	17	IRTF	SpeX	0.8 - 2.4
Riffel et al. (2006, 2013)	17	IRTF	SpeX	0.8 - 2.4
Mason et al. (2015)	13	Gemini North	GNIRS	0.9 - 2.5
Tot	102			

BH masses from M-sigma

- Equation from Kormendy & Ho (2013):

$$\log\left(\frac{M_{\rm BH}}{M_\odot}\right) = 4.38 \times \log\left(\frac{\sigma_*}{200\ \rm km\ s^{-1}}\right) + 8.49$$



- Equation from Gültekin et al. (2009):

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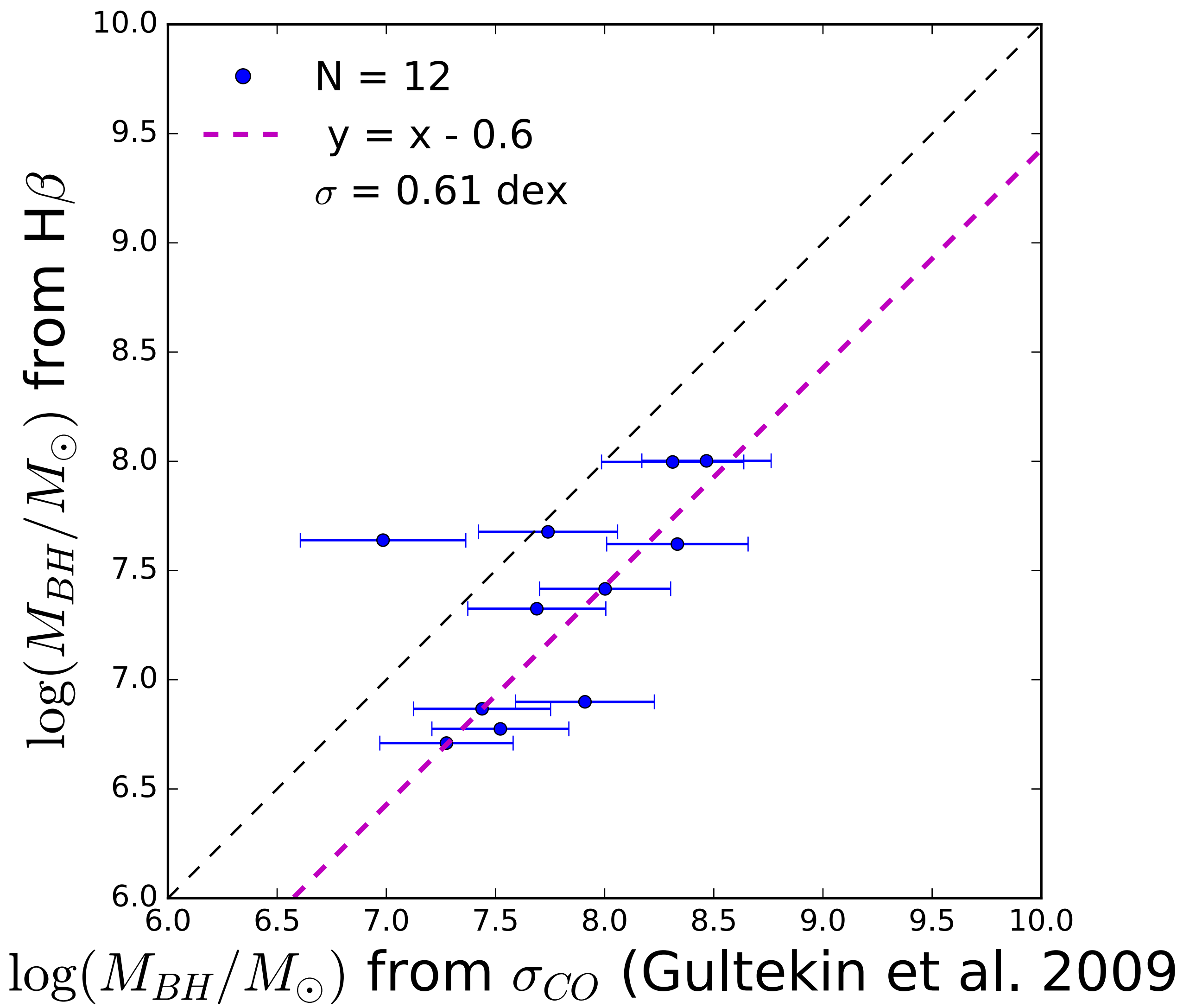
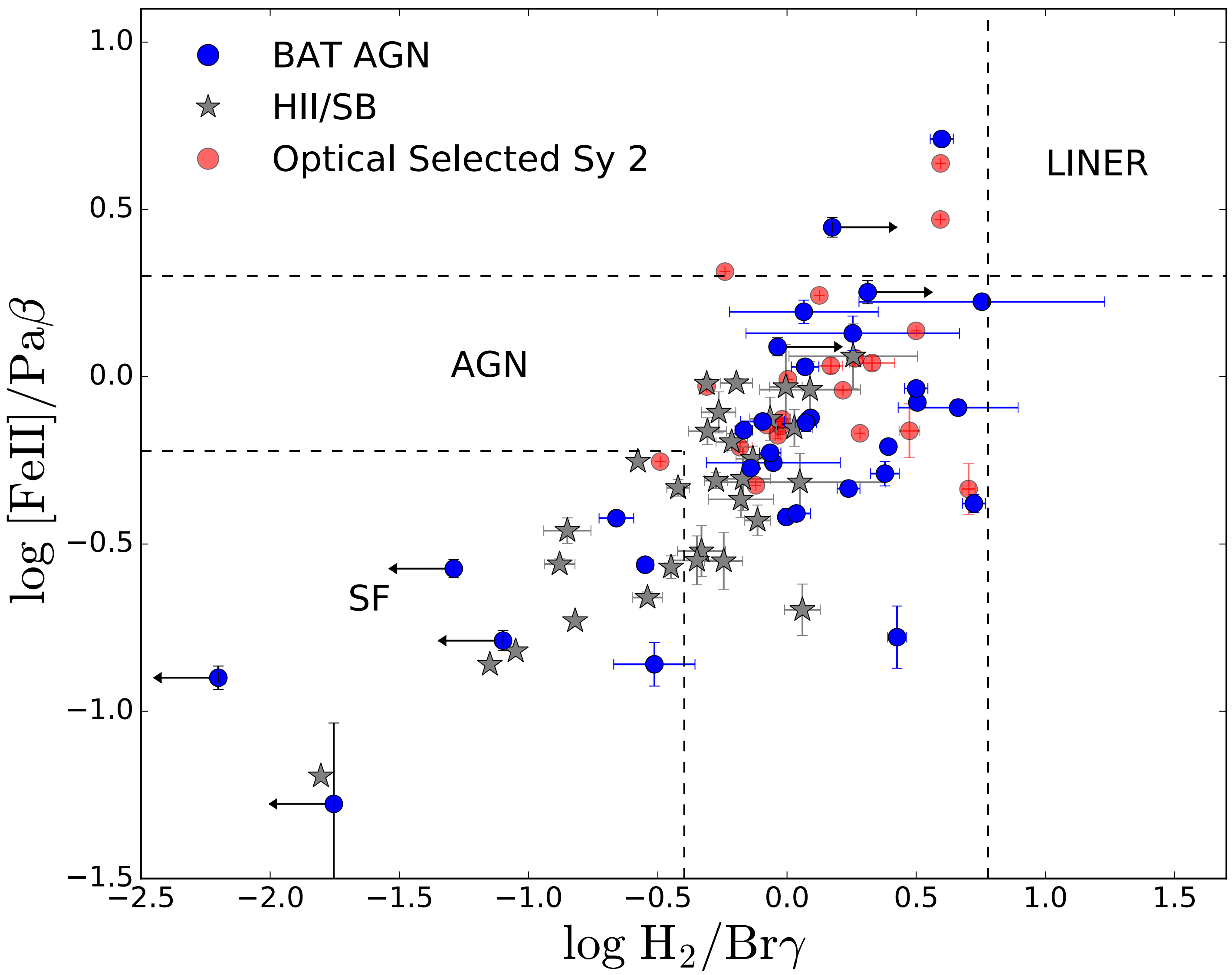


AGN diagnostic in the NIR: diagnostic diagram

- **25 %** of objects identified as AGN
- Literature values: many SF galaxies in the AGN region of the diagram
- Comparison with optical BPT diagram: **~ 65%** of X-ray selected AGN are in the Seyfert region



Virial black hole masses from Paschen lines:

- Equation from La Franca et al. 2015:

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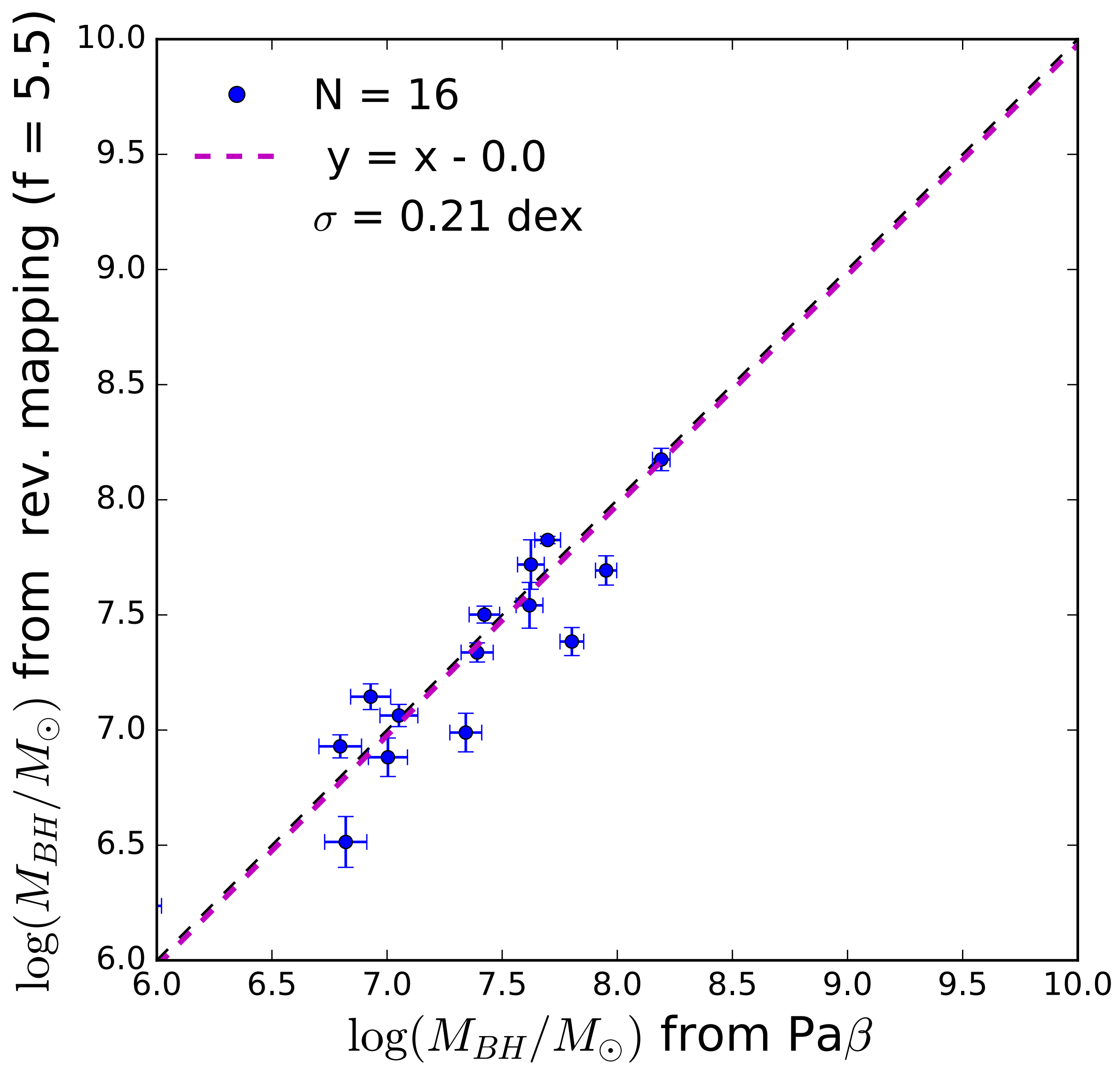

Comparison black hole masses from Paschen lines and from sigma:

- Equation from La Franca et al. 2015:

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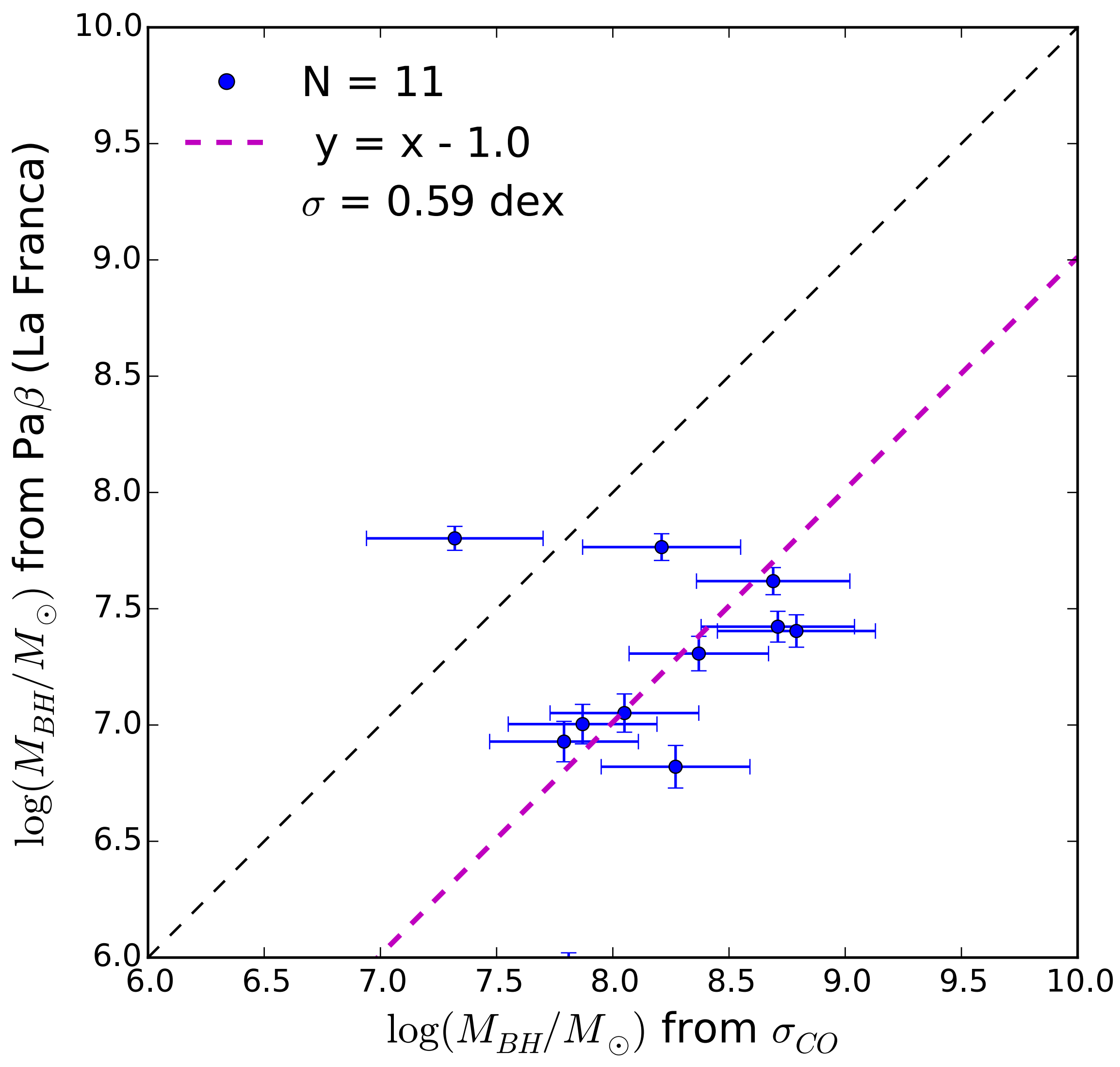
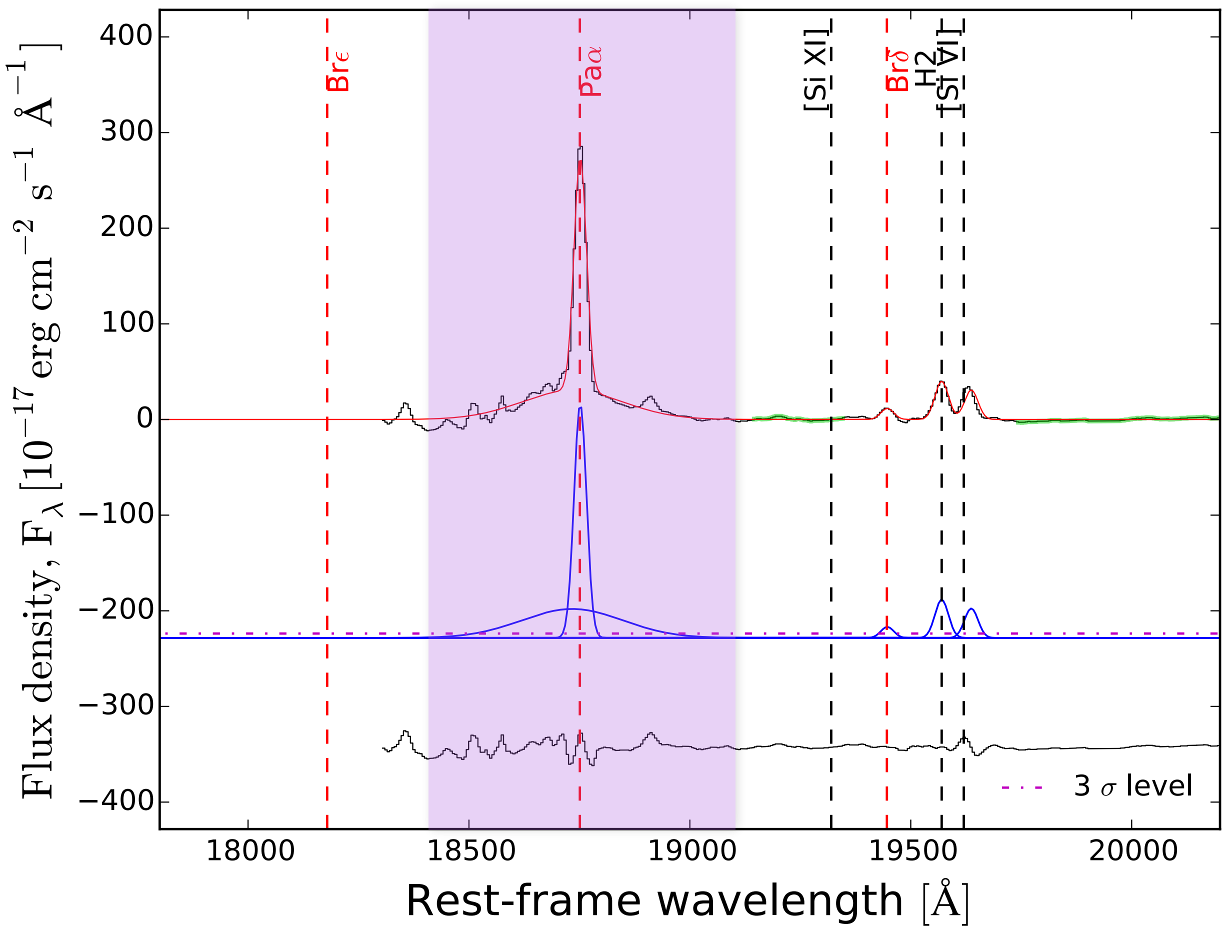


Hidden BLR:

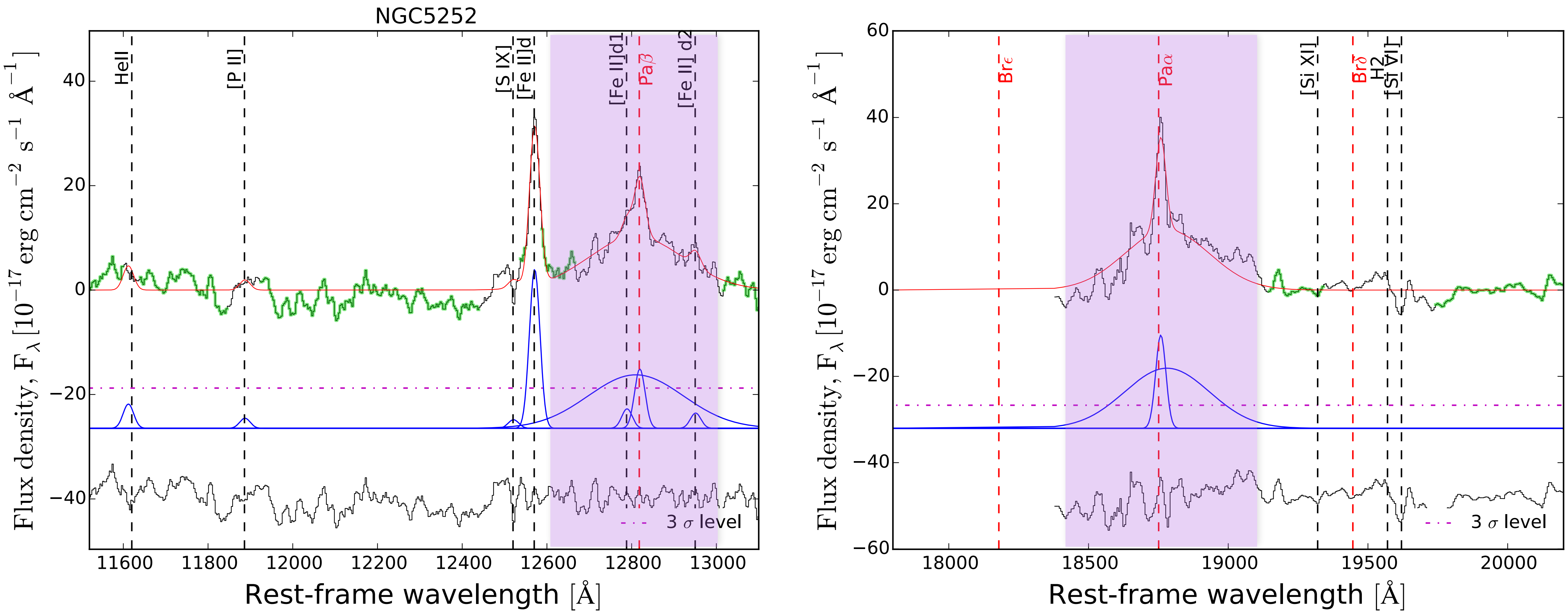
Sign of mergers or tidal features:

- Two of the Sy2 with hidden BLR (Mrk 520 and NGC 5231) are in mergers (Koss et al. (2011, 2012)
- One galaxy (NGC 5252) shows signs of tide material related to a merger (Keel et al. 2015)

> optical broad emission lines obscured by host galaxy dust and not by the nuclear torus.



Hidden BLR:



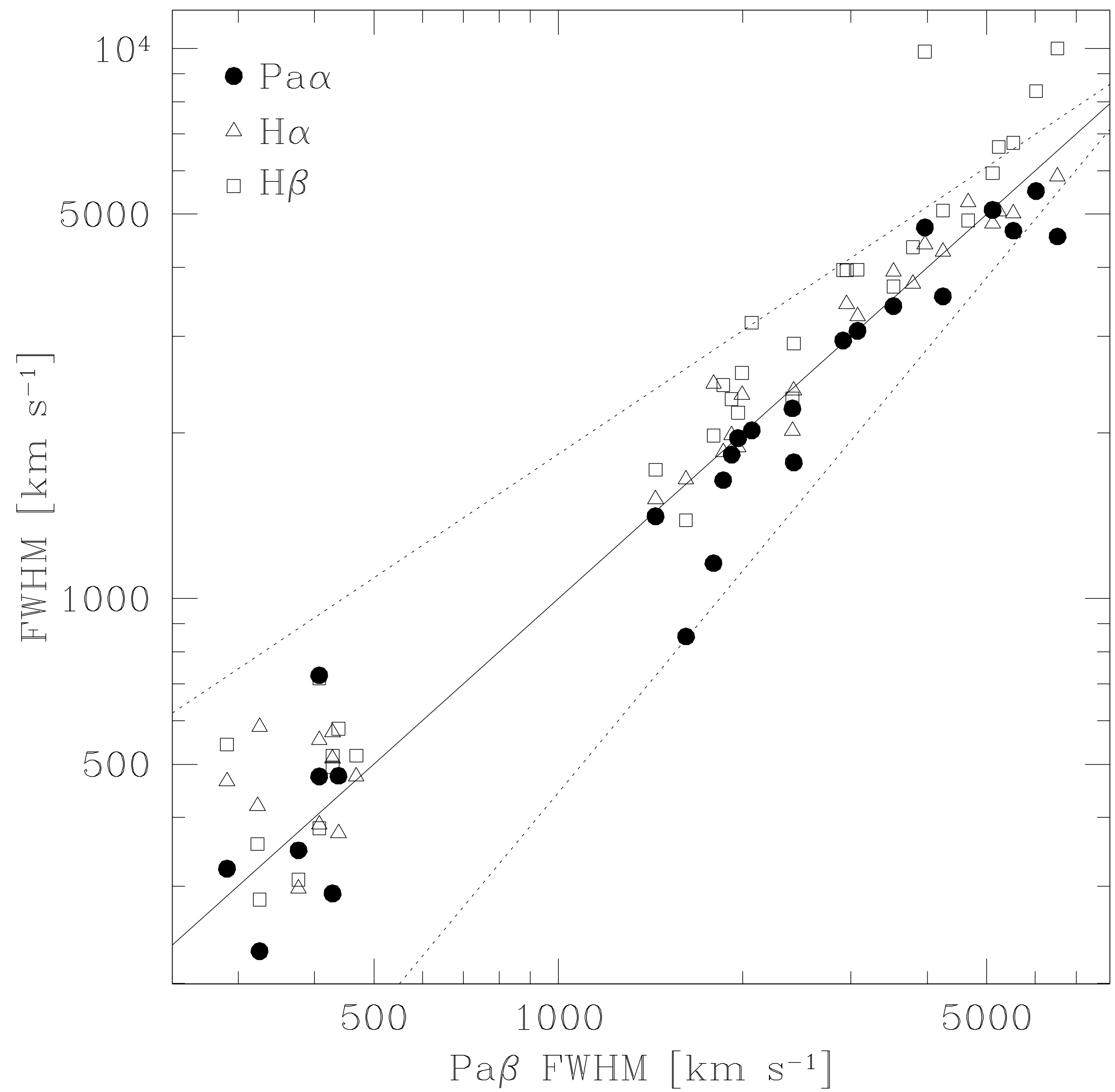
- NIR spectrum of NGC 5252 (Seyfert 2)

FWHM of broad Paschen and Balmer lines:

- Compare FWHM of Paschen and Balmer lines

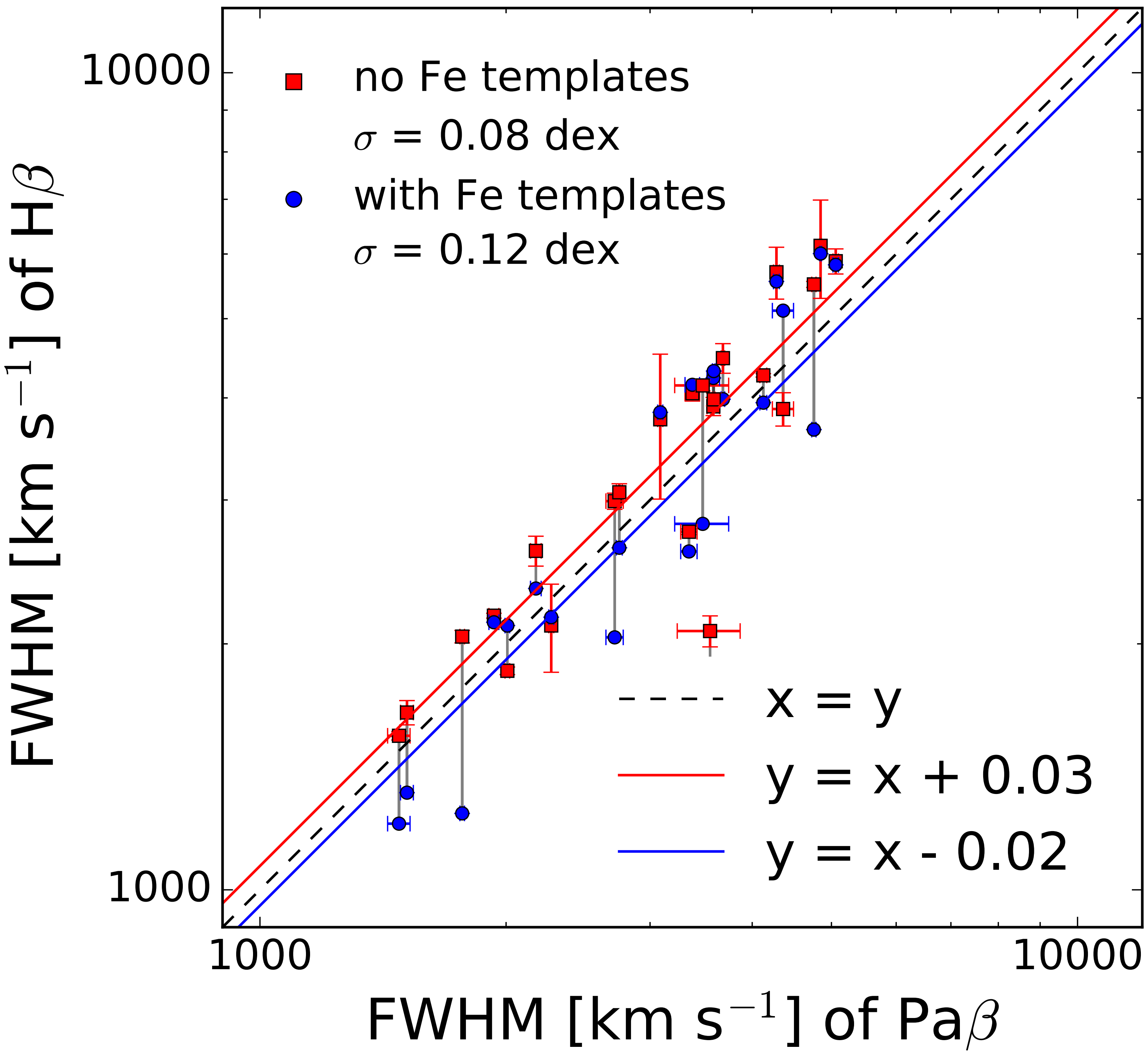
- Landt et al 2008: FWHM of Hbeta tends to be larger than FWHM of the Paschen lines.

  > possible cause: iron contamination on Hbeta

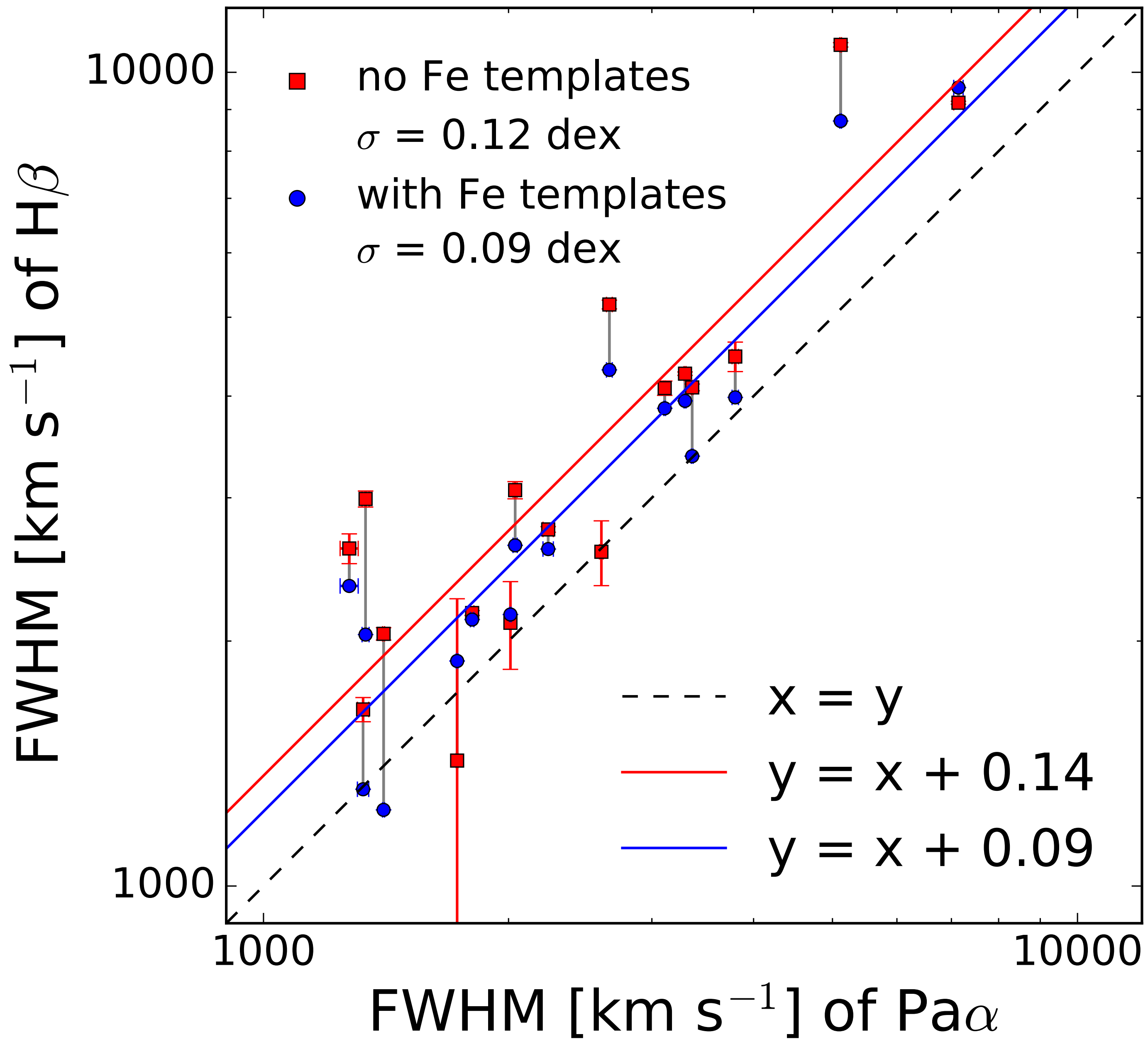


Landt et al. (2008)

FWHM of broad Paschen and Balmer lines:

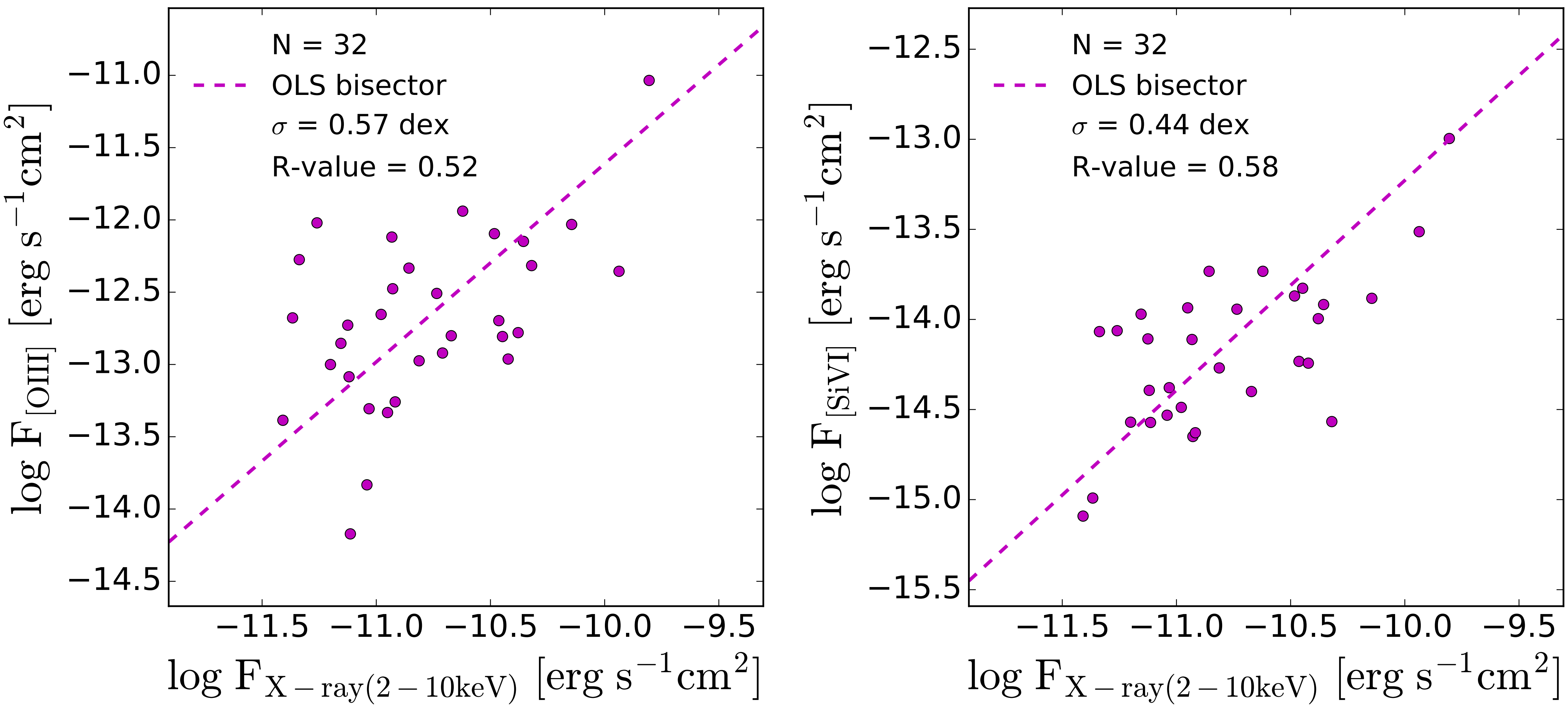


FWHM of broad Paschen and Balmer lines:



- Difference between FWHM of Hbeta and Paalpha is not statistically significant

[Si VI] vs. X-ray (2-10 keV) flux:



Example of emission line fit: