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PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE
Center of Astrophysics and Related Technologies

Astrophysics Talk UniBo

The near-infrared view of the BLR and the effect of obscuration in BLR characterisation of local hard X-ray selected AGN

F. Ricci

E. Treister, F. E. Bauer, J. Mejia-Restrepo, C. Ricci, E. Sani and BASS collaboration

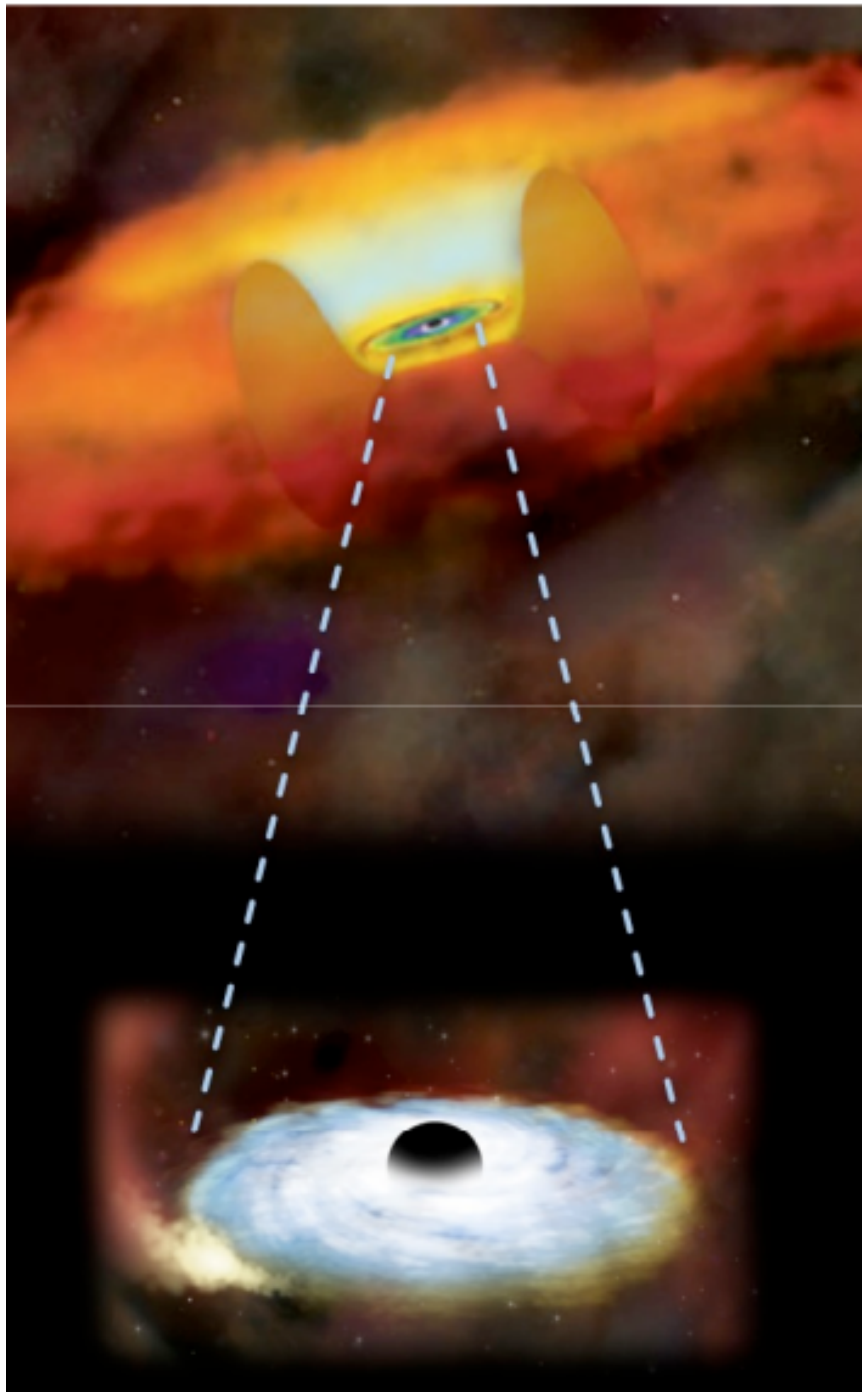
Why study BLR?

1. Understanding the structure (geometry/dynamics) of the material in the proximity of the BH, eventually feeding the BH

2. Measure the supermassive black hole masses up to the high redshift Universe

Weighting the SMBH inside an AGN

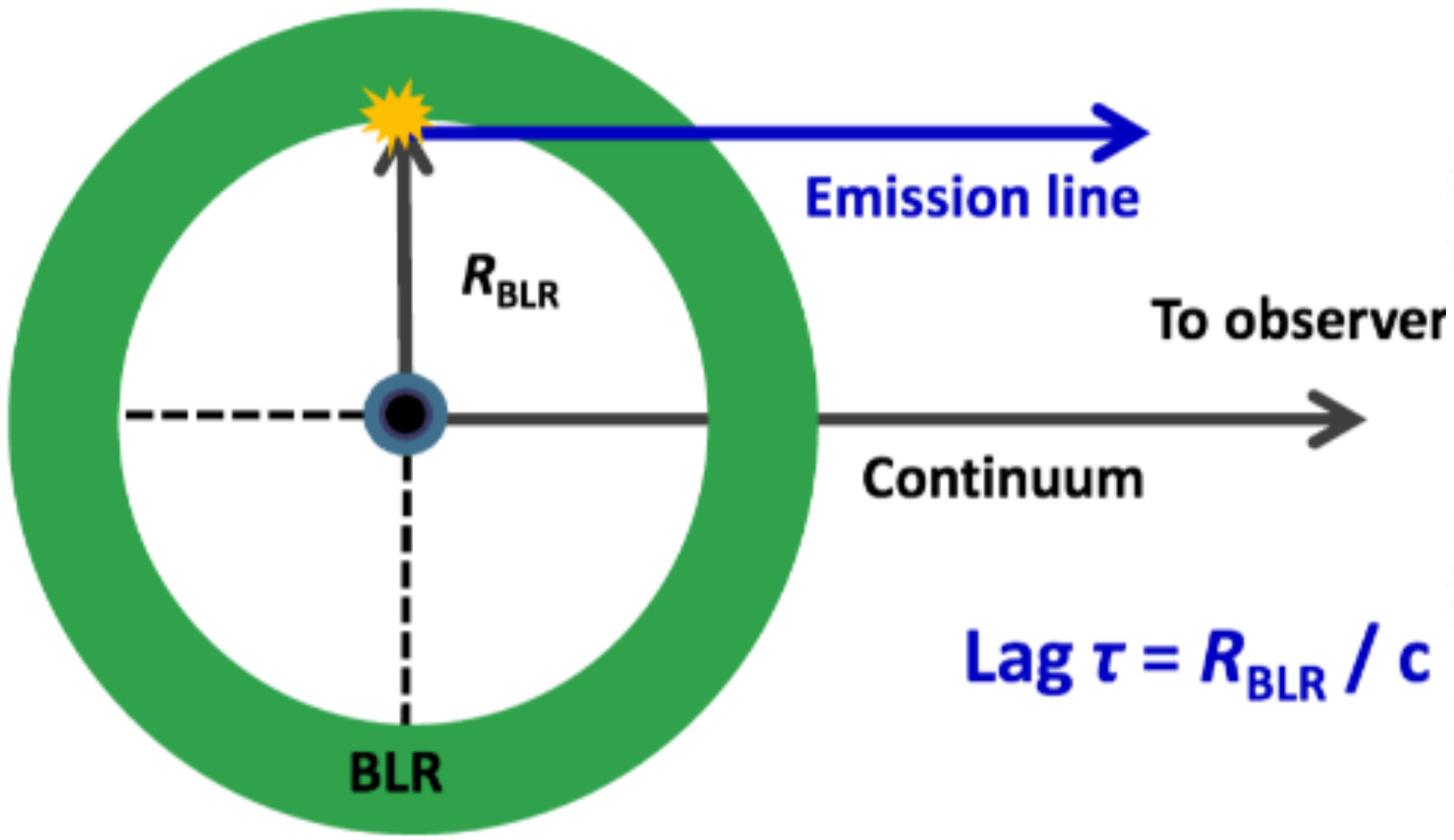
Reverberation mapping: time-resolution

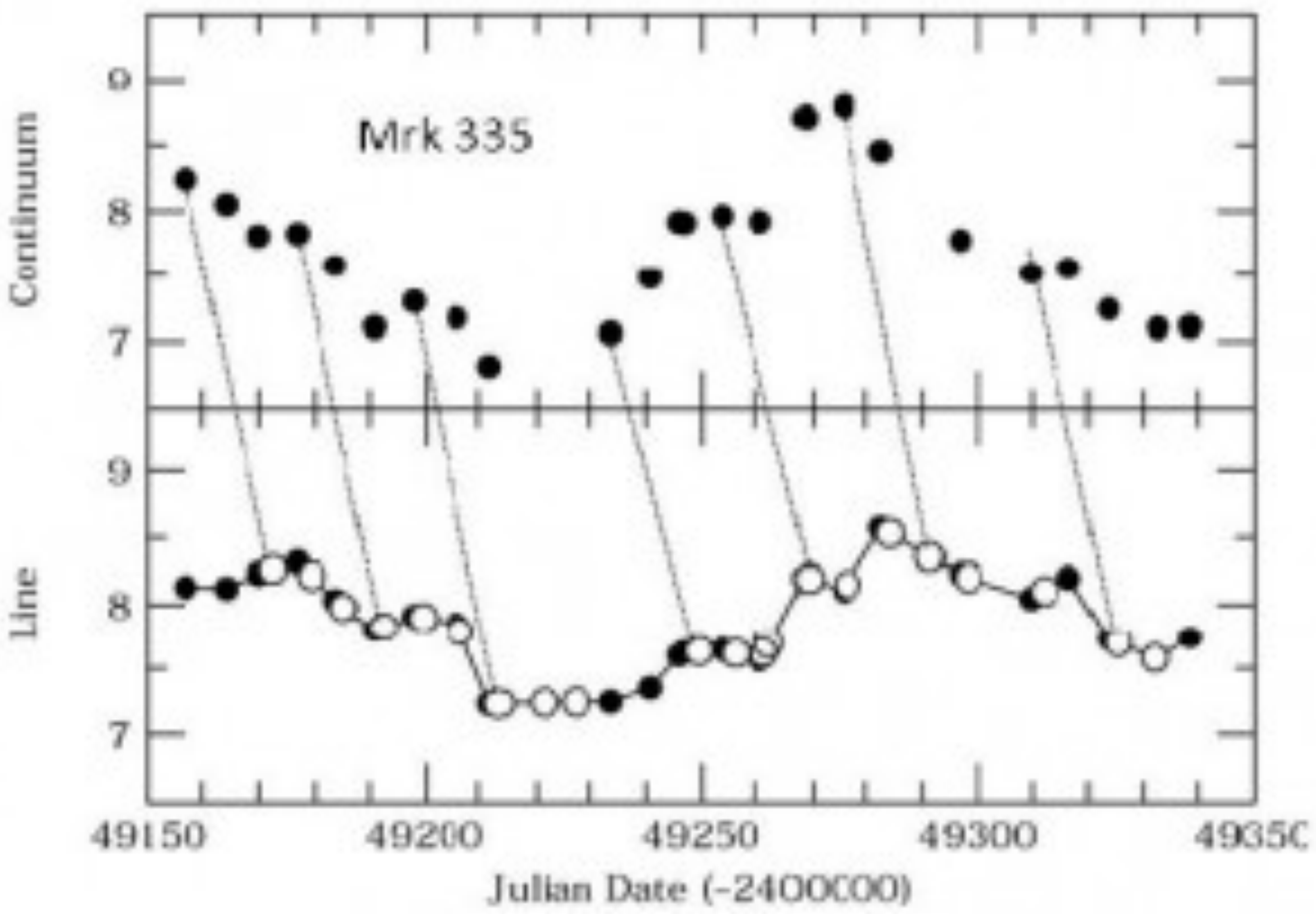


If the BLR is powered by photoionization, it is virialized and the motion is dominated by the gravity of the central compact object

$$M_{\rm RM} = \frac{V_{\rm vir}^2 R}{G} = f\frac{W^2 R}{G}$$

Measure the time lag in response of BLR clouds to changing ionizing flux from the accretion disk
Substitute spatial resolution with time resolution!

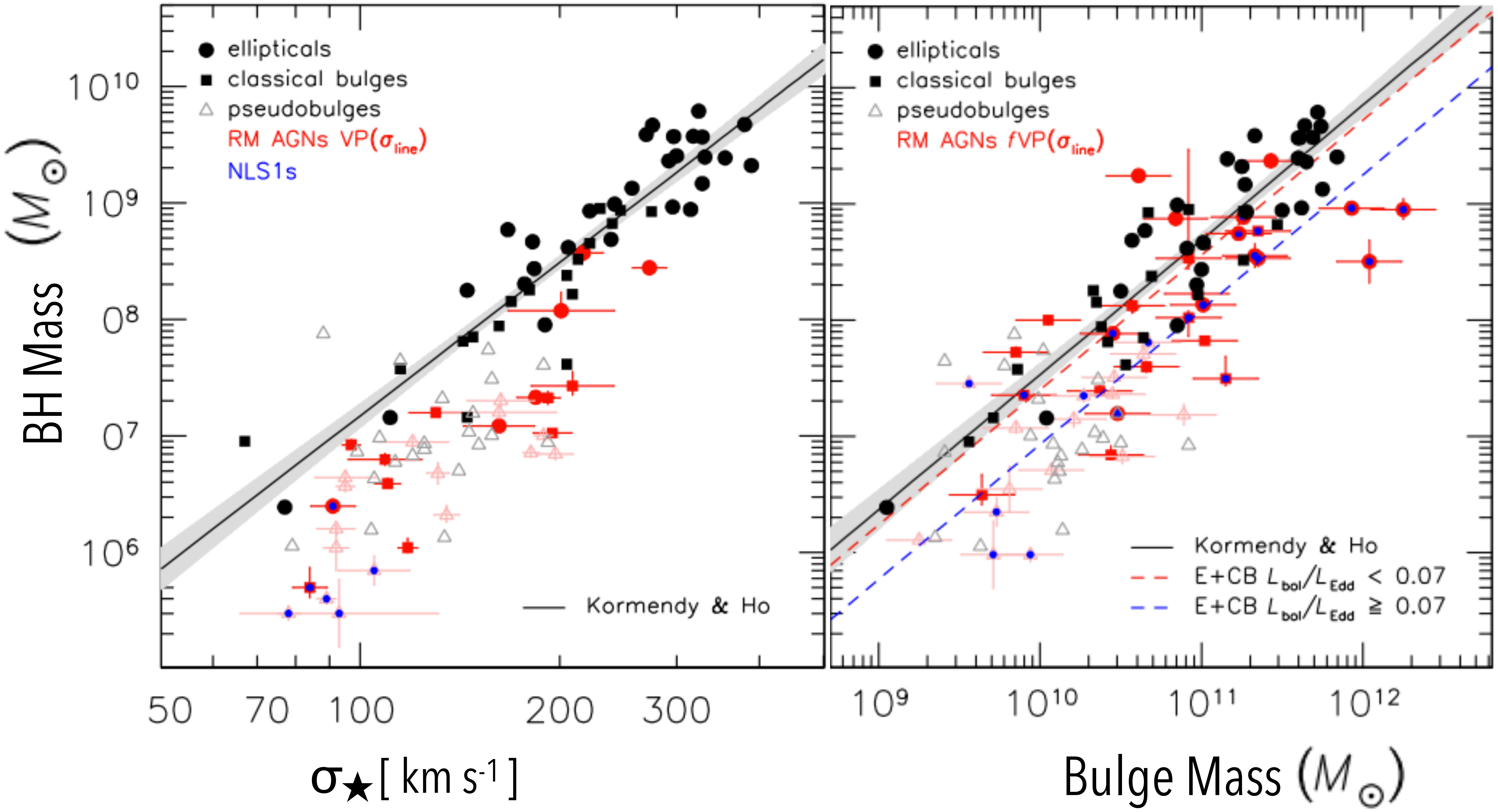




Blandfor & McKee+82; Peterson+93, +04

BLR structure encoded in the virial factor: <f>

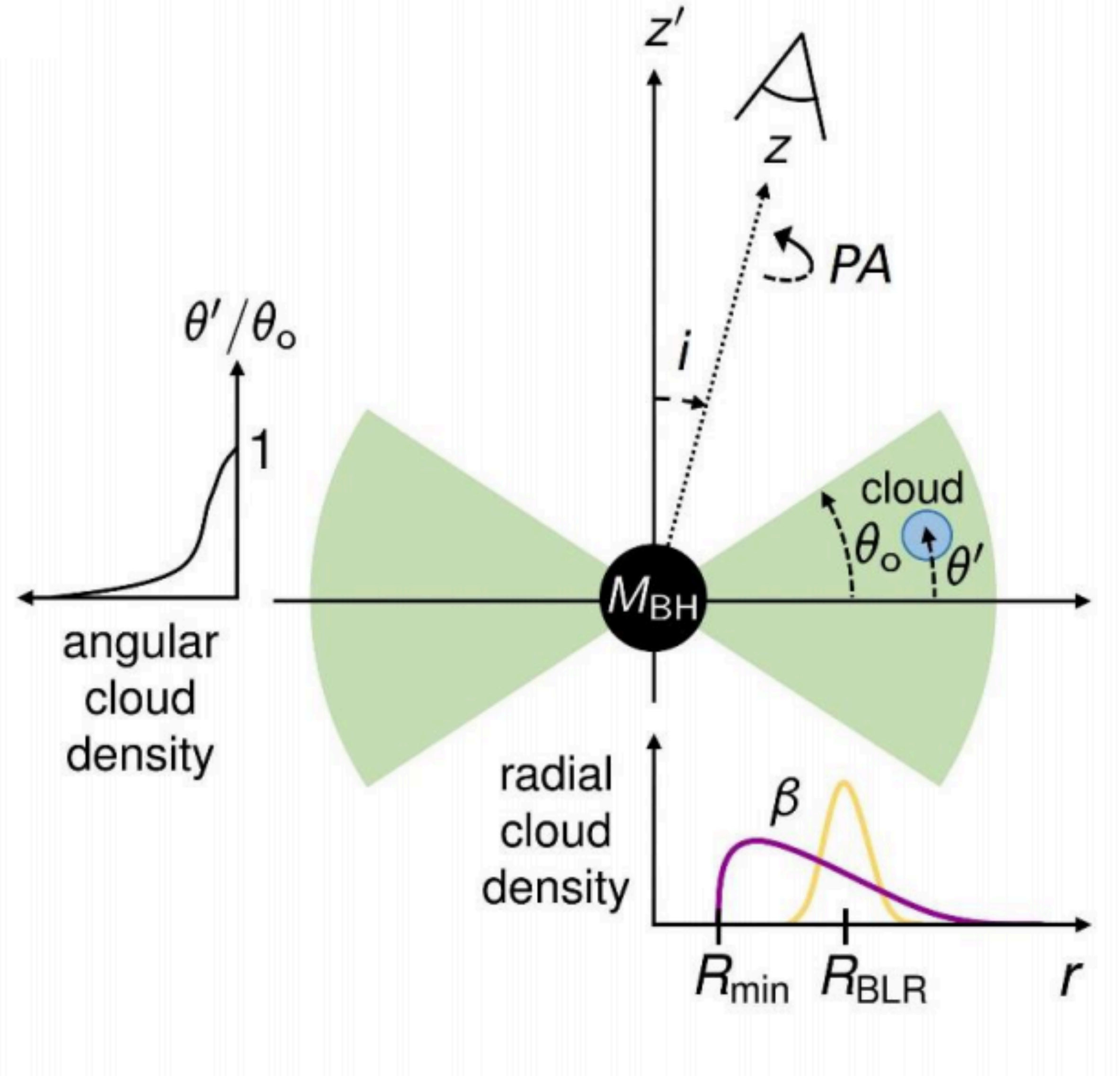
AGN are thought to follow the same scaling relations observed in quiescent galaxies with dynamically measured SMBHs. RM AGN seem to reproduce the scaling relation M_{BH} - $\sigma_\star$ once BH masses are scaled for an **average virial factor <*f*>**
(Onken+04; Woo+10; Graham+11; Park+12; Ho&Kim+14; Grier+13,+17, Batiste+17)



- Do AGN follow the dynamical-based scaling relations? sphere of influence resolution-dependent bias (e.g., Bernardi +07; Gültekin +09; Batcheldor +10; Morabito & Dai +12; Shankar +16)
- Are these relations valid for obscured AGN as well? **bulk** of AGN population
- Is there a dependence on bulge morphology for active galaxies?

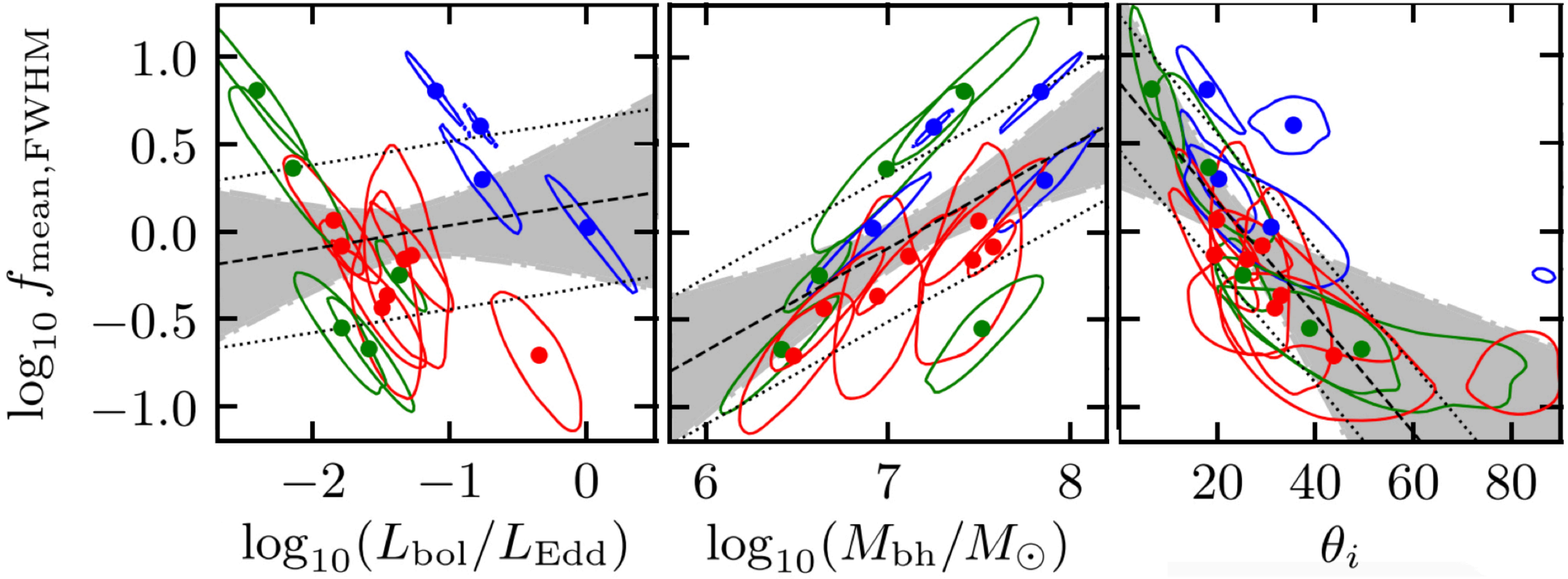
Direct f-factor measurements in RM AGN

The virial factor f can be directly inferred only for a handful (~16) RM broad-line AGN having sufficiently detailed RM data available (Pancoast+14b, Grier+17, Williams+18, Li+18)



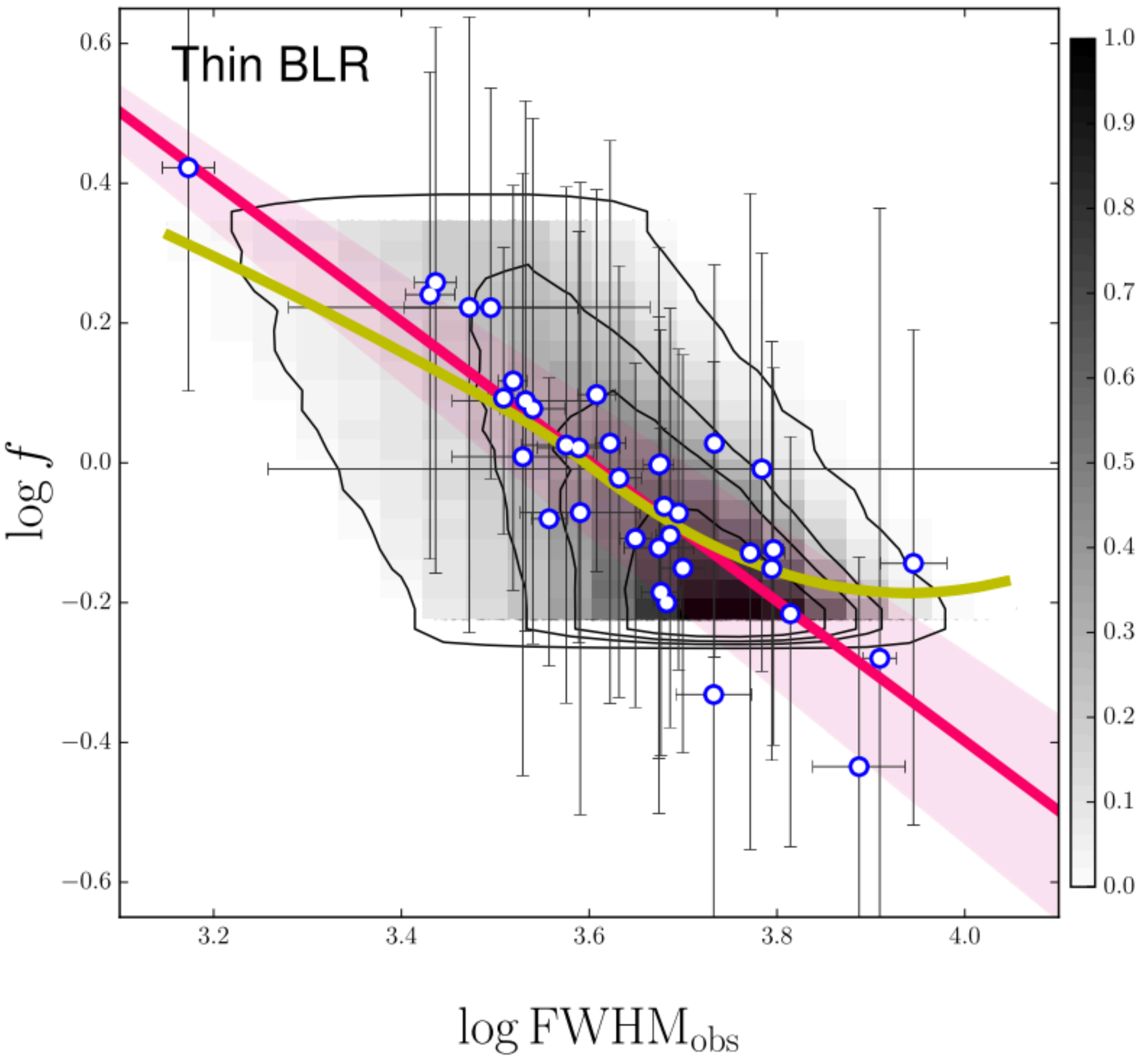
The Hβ emitting BLR is described by a thick disk BLR close to face on emitting preferentially from the far side of the BLR.
Dynamically, the orbits are both inflowing and outflowing.

The f-factor could depend on some AGN properties (Lbol, Edd ratio, M_{BH} or the inclination angle) -> **marginal evidence of M_{BH} and inclination dependence**



Statistical studies on f

Mejia-Restrepo+18



Several works used f-independent Mbh estimates to infer the virial factor and found that there is an anti-correlation between f-FWHM of Hβ, Hα, MgII and CIV (Decarli+08, Shen&Ho+14, Mejia-Restrepo+18) which is explained by the fact that the observed FWHM gets broadened with increasing los inclination (e.g., Collin+06)

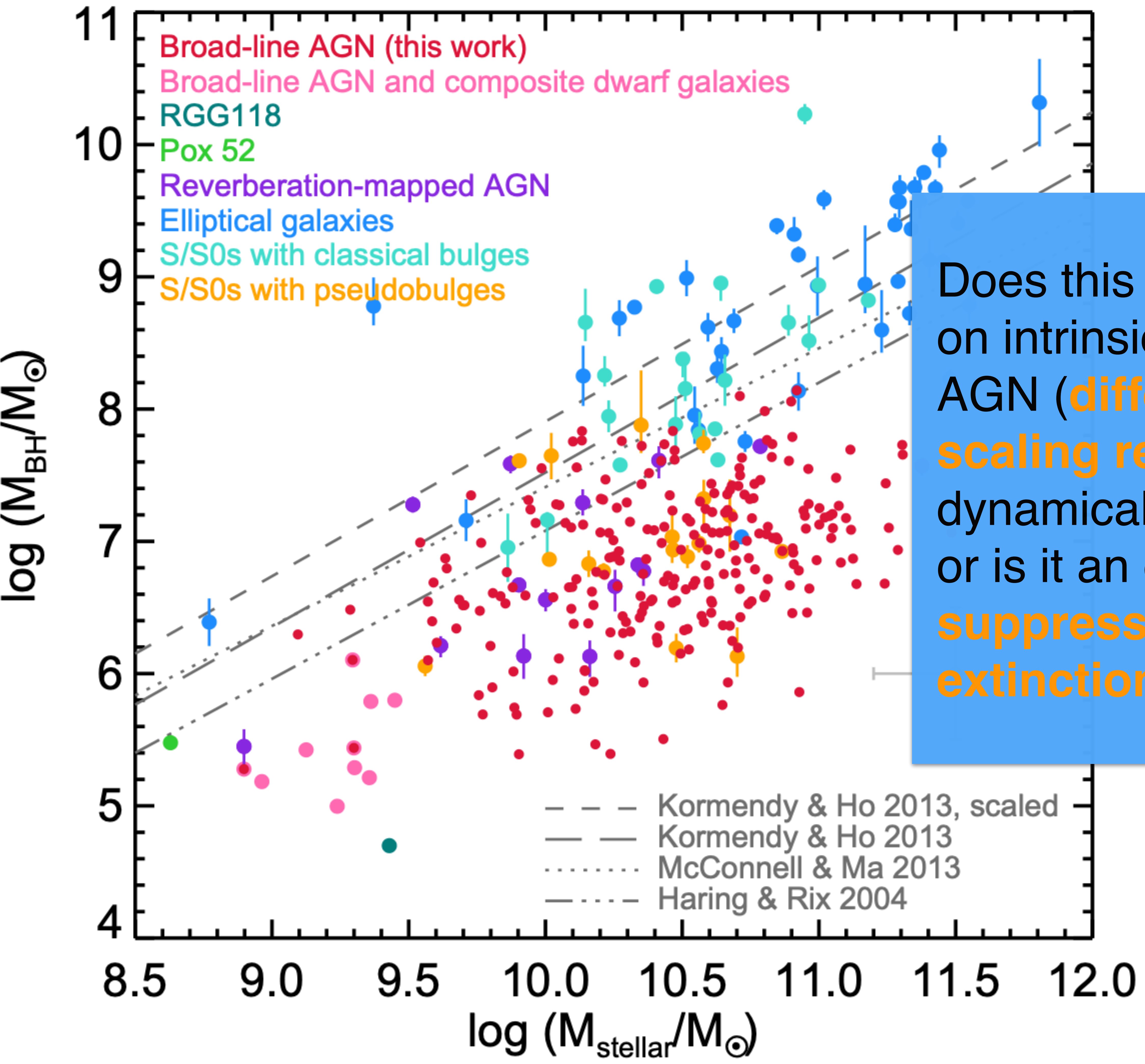
$$f = \left[4\left(\sin^2 i + (H/R_{\rm BLR})^2\right)\right]^{-1}$$

(*for a similar broadening effects on the EW[OIII] see also* Risaliti+11, Bisogni+17)

BUT! These works focused only on broad-line sources. What about the BLR in optical narrow line Seyfert 1.8-1.9-2?

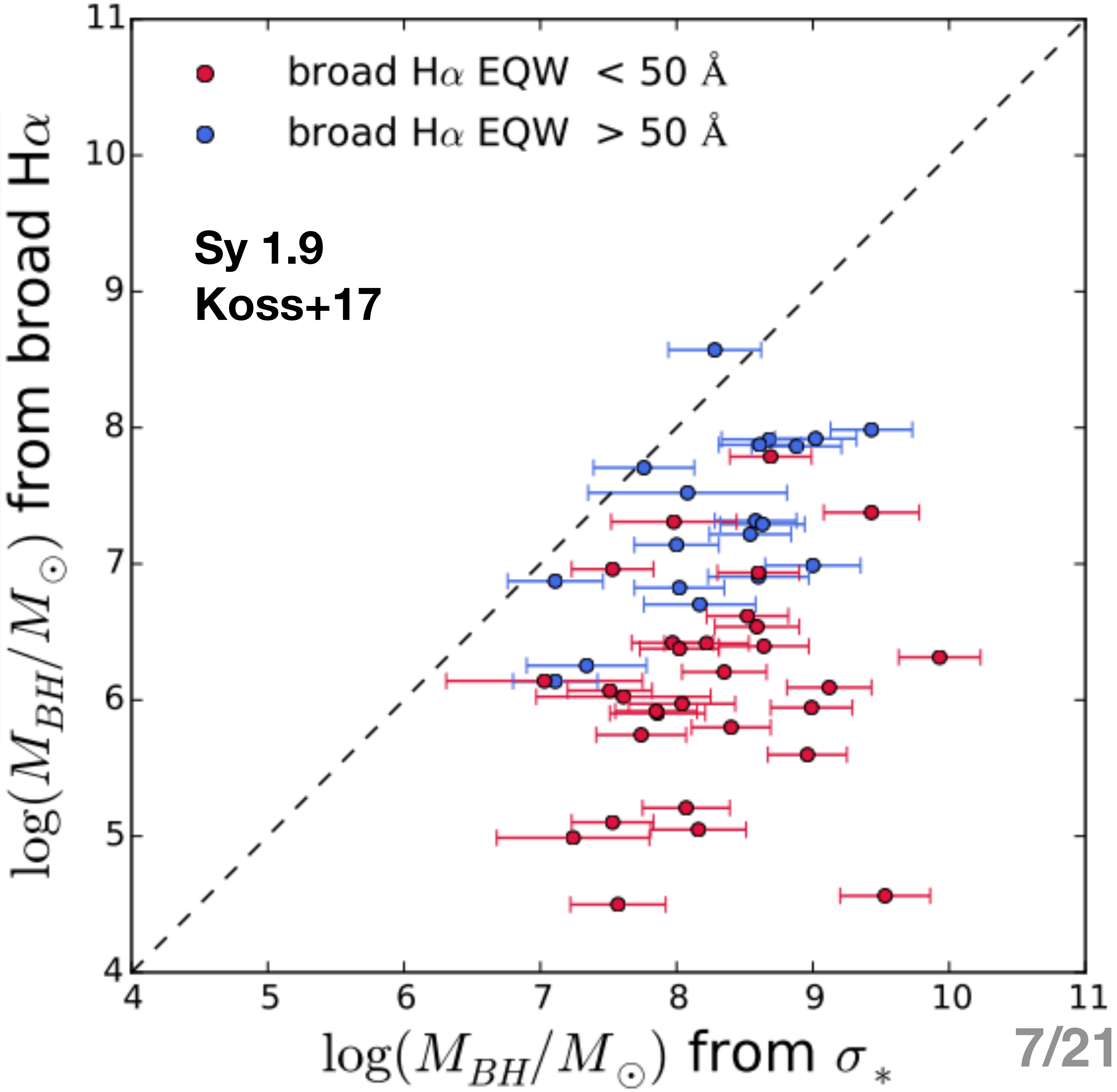
Hα in low mass BHs

It is unclear whether the Hα is completely reliable, particularly in so-called Sy 1.9 (Osterbrock+81), where the level of extinction due to dust is more relevant than what is usually experienced in optical broad line Seyferts.



Reines&Volonteri+15 found that local Seyfert with 41.5 < log (Lbol/erg s-1) < 44.4 are **1 dex undermassive** than what expected from the M_{BH}-Mstar relation of inactive galaxies

Does this difference depend on intrinsic properties of AGN (**different BH-host scaling relations** than the dynamical inactive sample) or is it an effect of line **suppression due to dust extinction/obscuration**?



The need of a Near-infrared view

In order to have a direct view of the BLR also in obscured systems, we need to penetrate the obscuring material → NIR Paschen lines

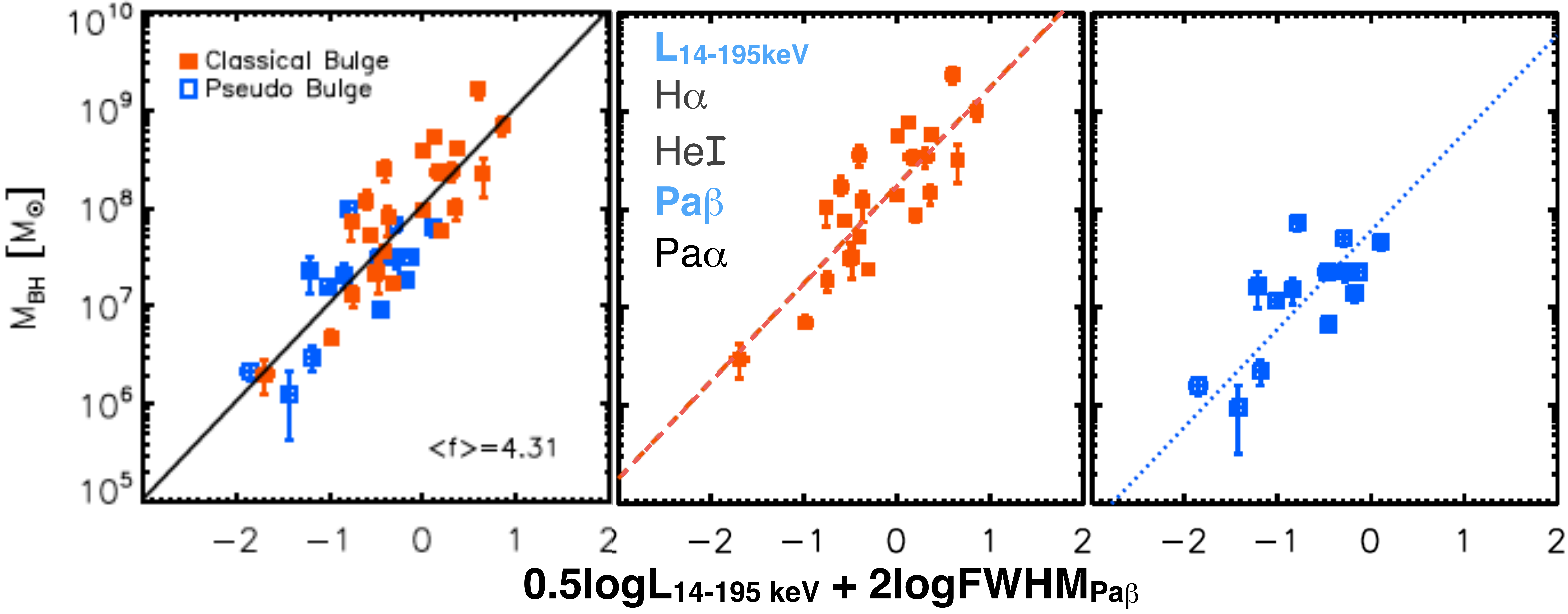
1. NIR observations of high-R and high-S/N have revealed broad Paschen lines in type 2 AGN (Veilleux+97, Riffel+06, Cai+10, Smith+14, Onori+17)
2. the dust absorption is less severe (~10 times) than in the optical (Veilleux+02)
3. Paα and Paβ are the strongest hydrogen emission lines observed in the NIR, and are almost unblended (Riffel+06, Landt+08)

A Mixed virial M_{BH} calibration for AGN

F. Ricci+17
(see also Kim+10,+18; La Franca+15; Landt+13)

NIR virial relations based on the Paβ FWHM (but also Hα, Paα, HeI1.083μm, see Greene&Ho+05; Landt+08; Shen&Liu+12; Mejia-Restrepo+16) and the hard-X $L_{14\text{-}195\ keV}$ therefore able to work with low-L AGN1 and AGN2

Goal: find the BLR in NIR in Sy 1 and Sy 2



BASS NIR data

Goals:

1. compare NIR and optical (i.e. Hα) BLR measurements in Sy 1-1.9 to understand systematics/biases in BLR characterization and thus in Hα virial-based M_{BH} estimates
2. build a statistical obscuration unbiased (=X-ray selected) sample of local Seyferts (Sy 1 and 2) with NIR broad lines to derive NIR+Lx virial based Mbh (using F. Ricci+17 calibration)

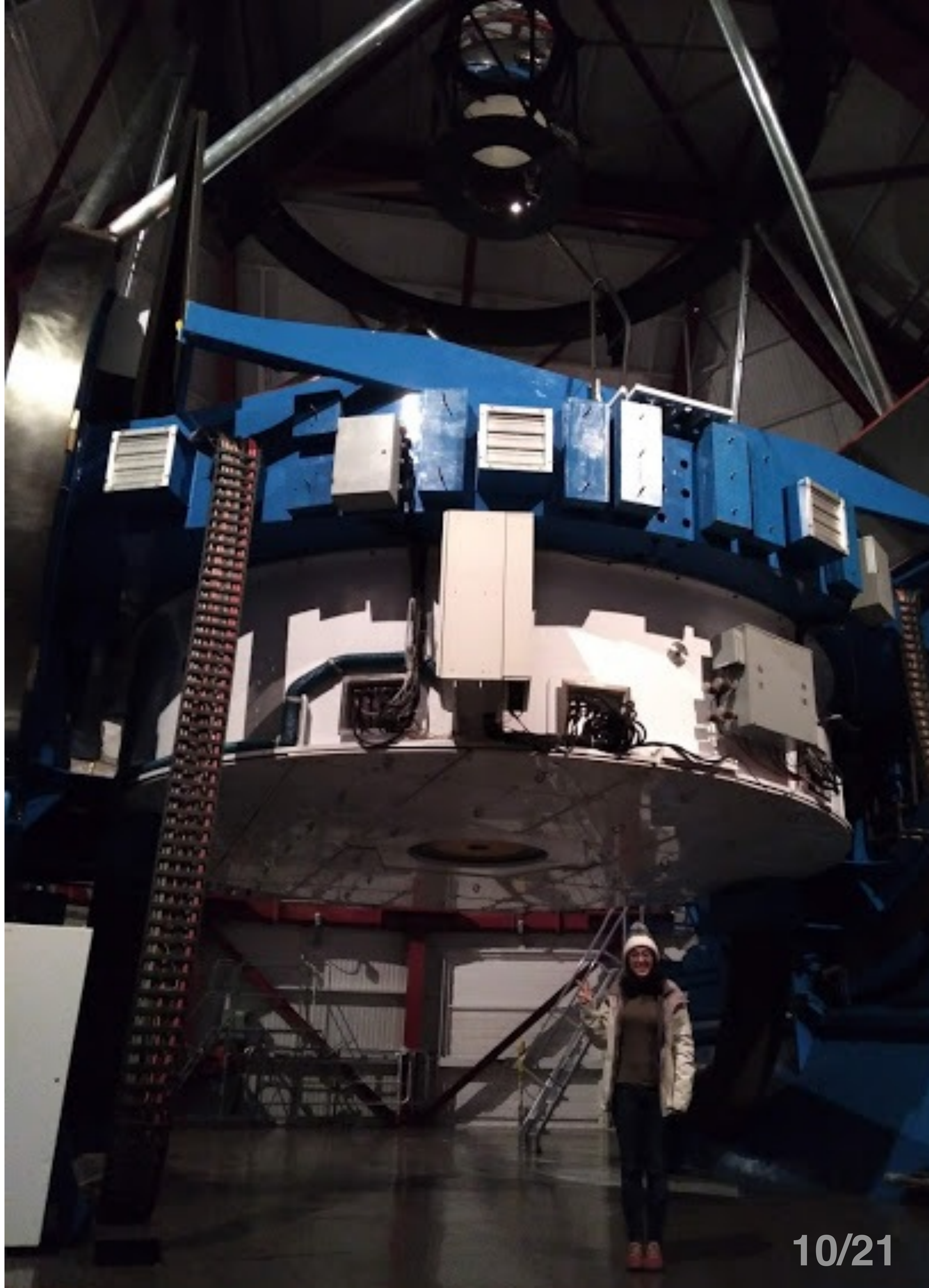
$$M(line) = f_0 \underbrace{FWHM(line)^2 L_X^{0.5}}_{M_{vir,line}}$$

- f0=6.3, <f> to put RM AGN on Kormendy&Ho+13 rel
- FWHM(line) = FWHM HeI1.0830 micron, Paβ, Paα or average NIR
- Lx 2-10 keV or 14-195 keV (using the latter)

and thus estimate the virial factor

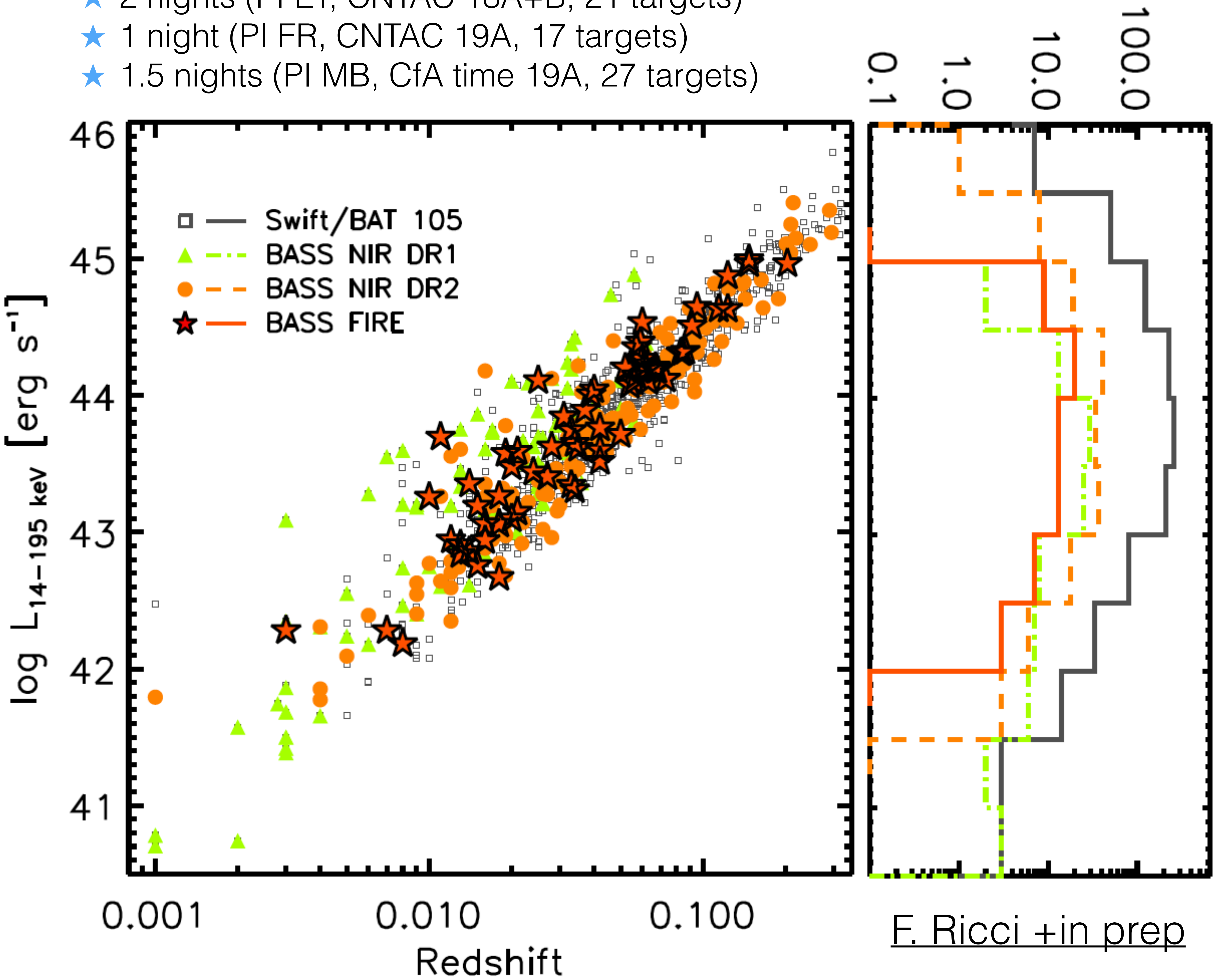
$$f = \frac{M_{BH,\sigma_\star}}{M_{vir,line}}$$

F. Ricci +in prep



BASS NIR FIRE data + BASS database!

- Magellan/FIRE (*52 Sy 1.8-1.9-2 + 13 Sy 1-1.2-1.5)*
  - ★ 2 nights (PI ET, CNTAC 18A+B, 21 targets)
  - ★ 1 night (PI FR, CNTAC 19A, 17 targets)
  - ★ 1.5 nights (PI MB, CfA time 19A, 27 targets)



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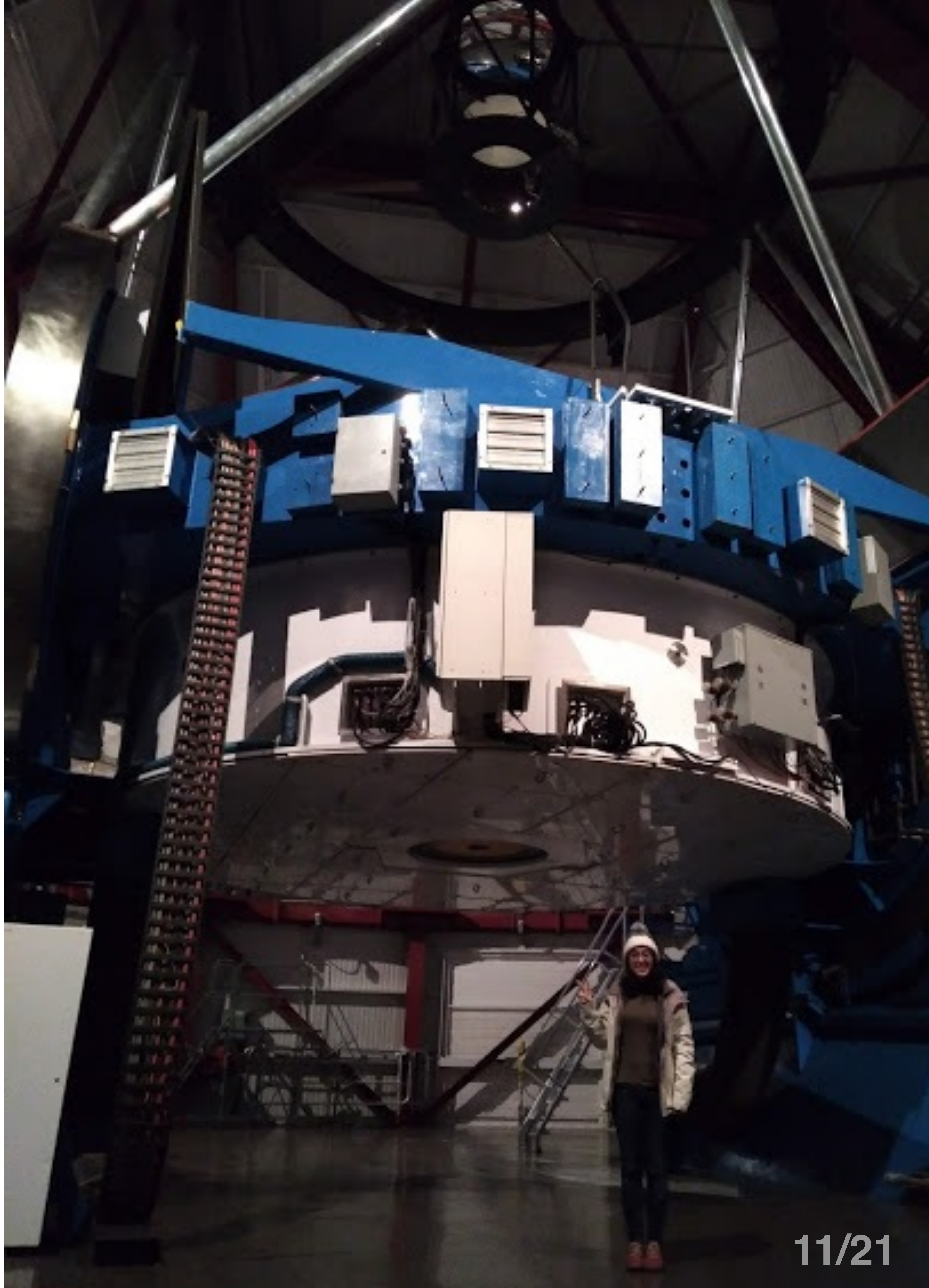

BASS on FIRE

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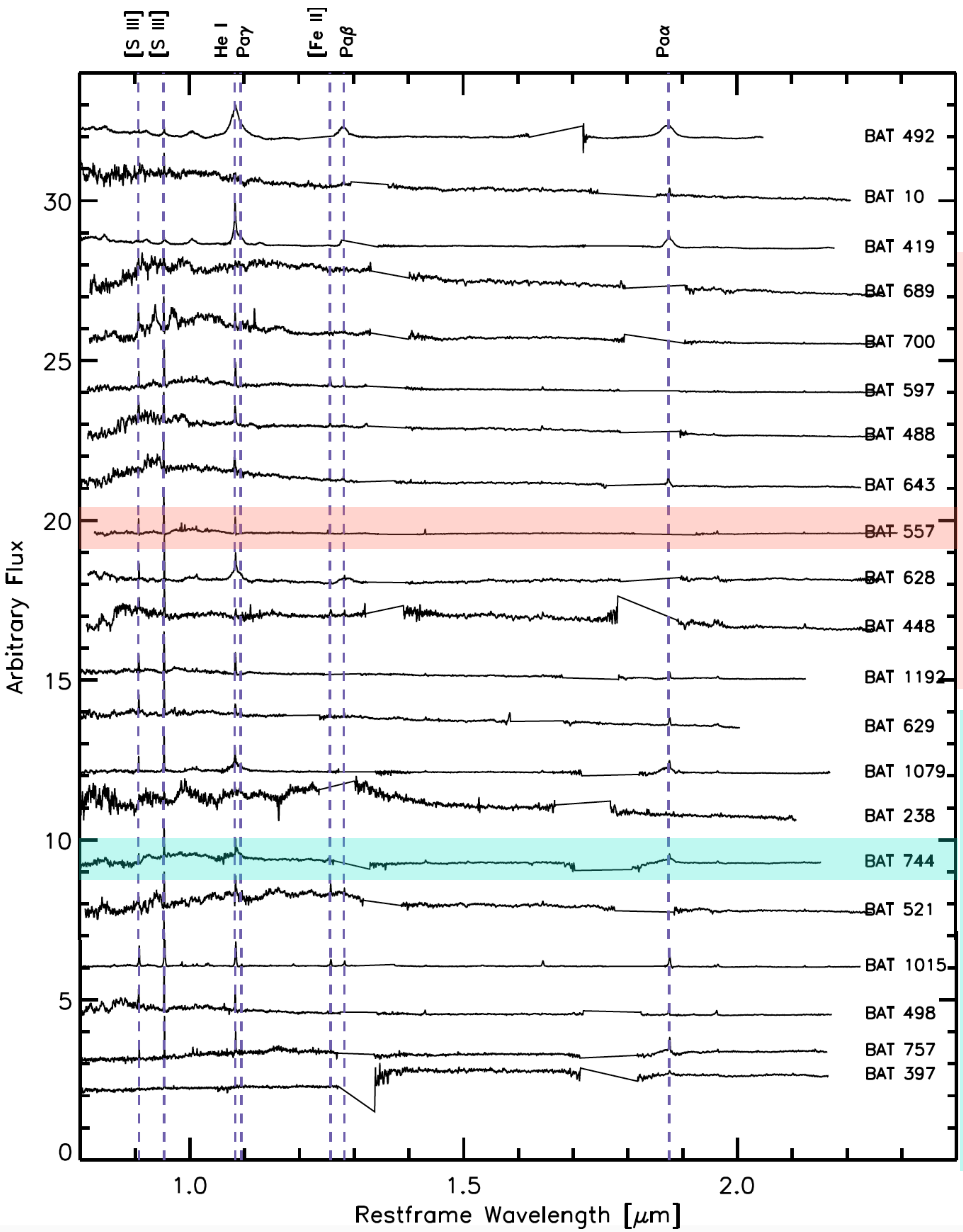

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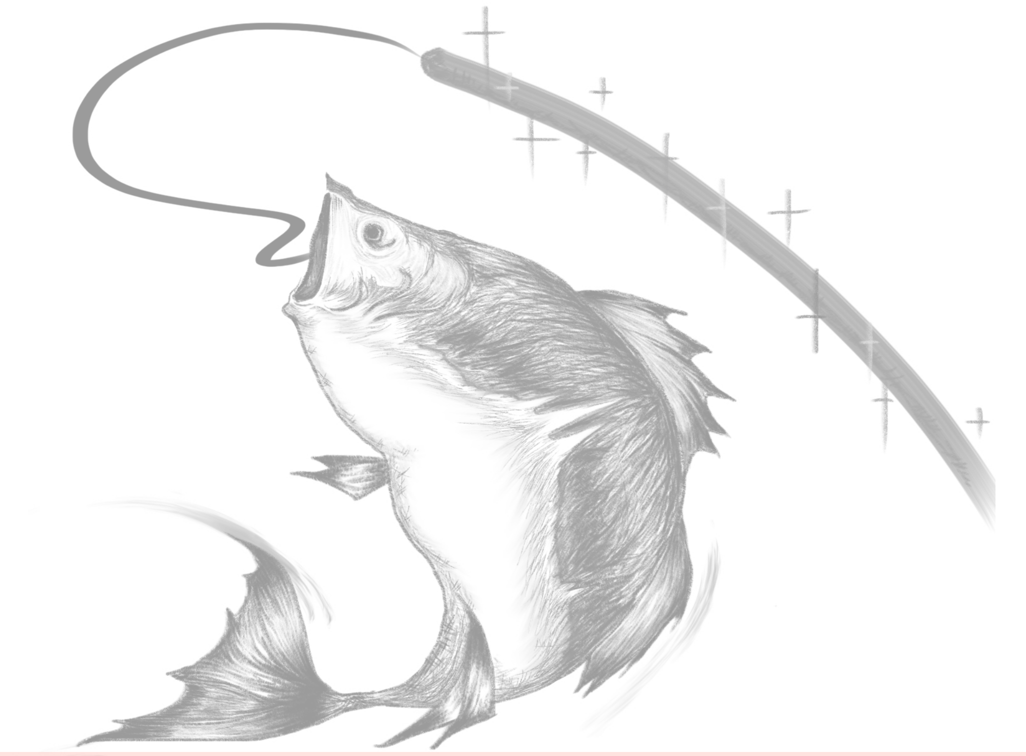
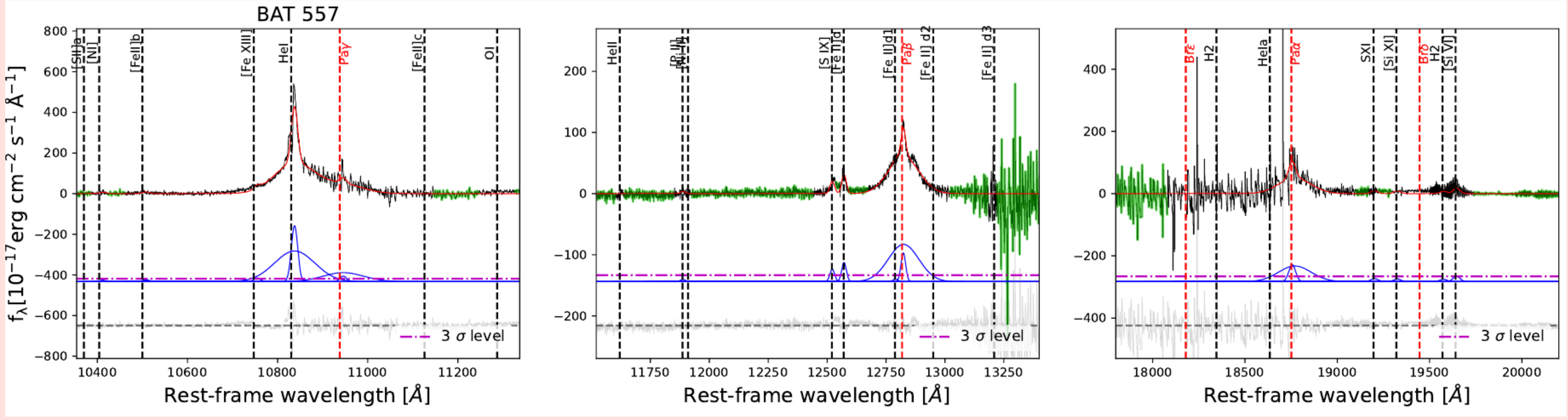
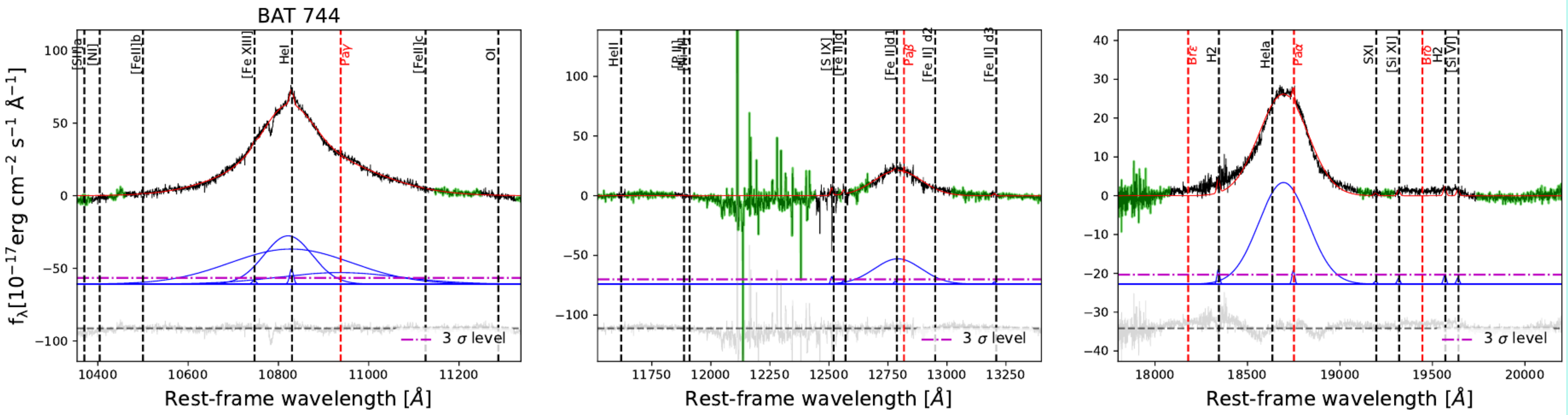
65 BASS AGN observed, mostly from 70-month



Sy 1.9

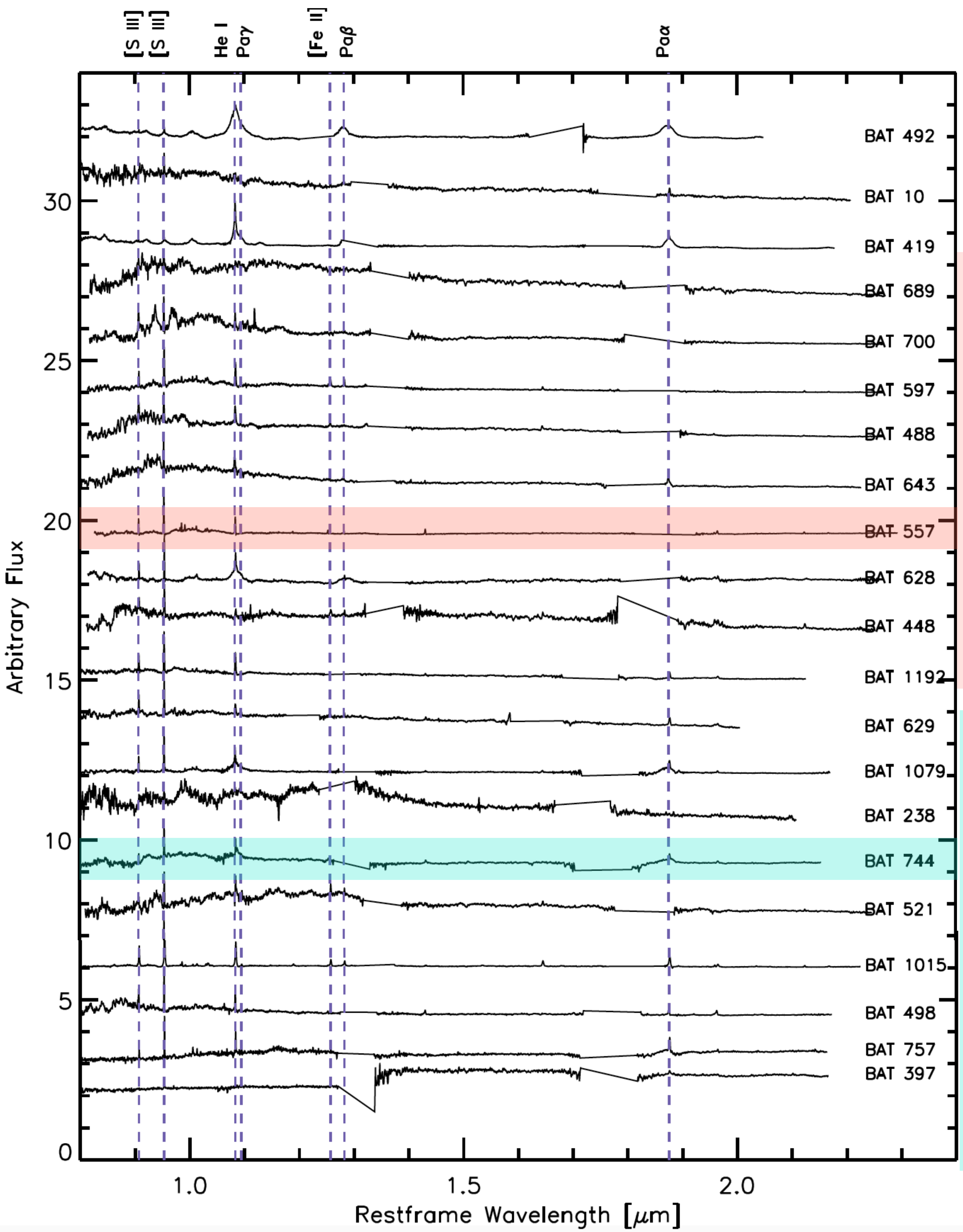


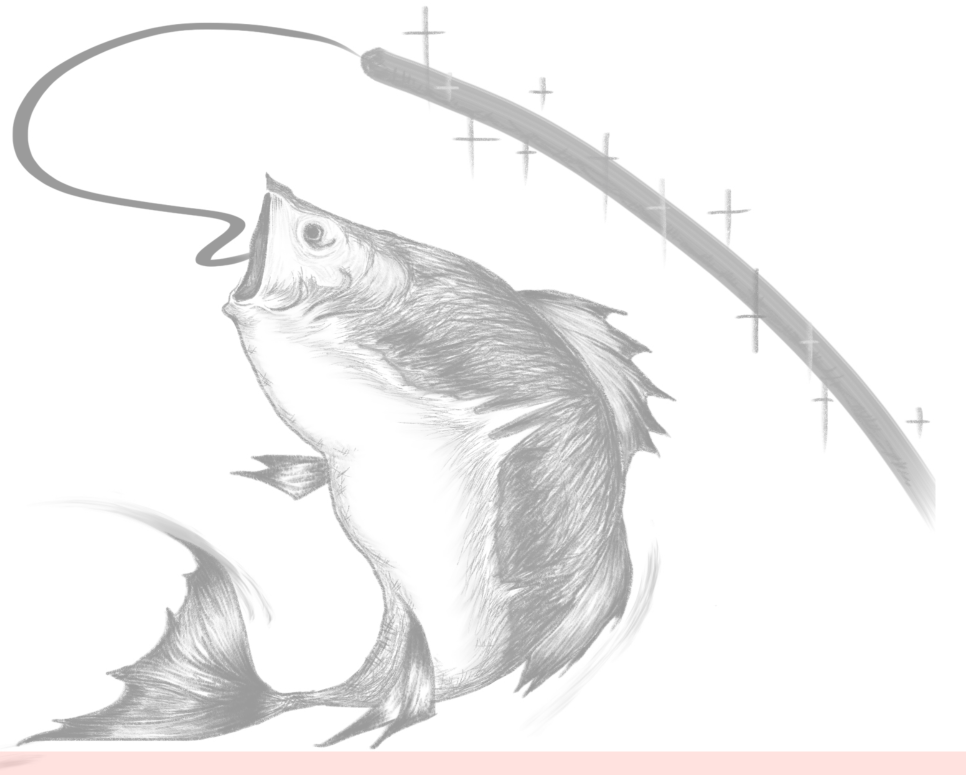
Sy 1



BASS on FIRE

F. Ricci +in prep





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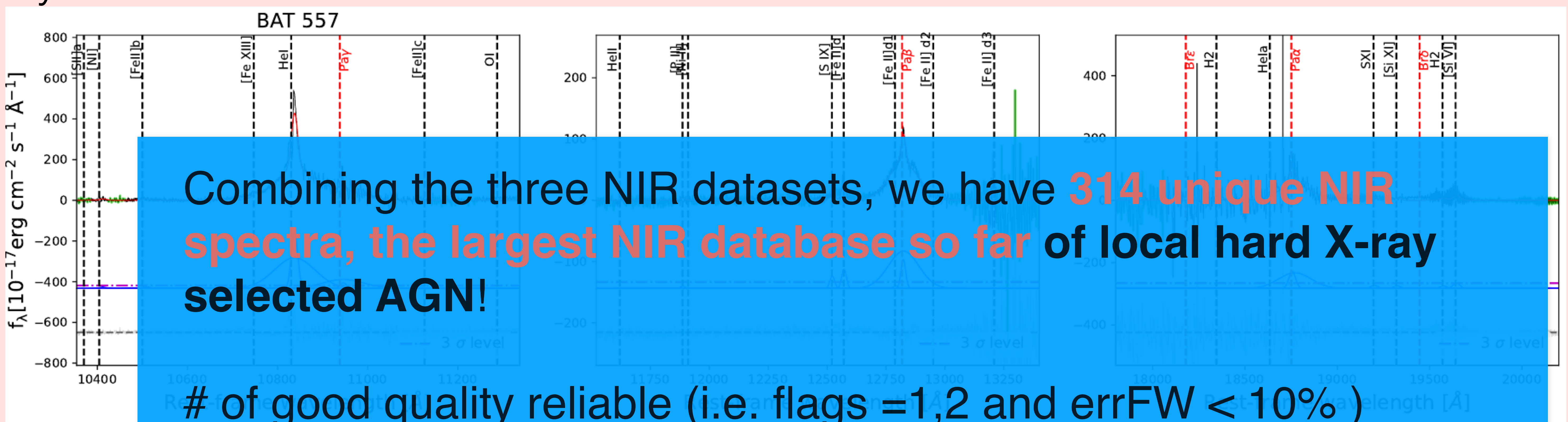
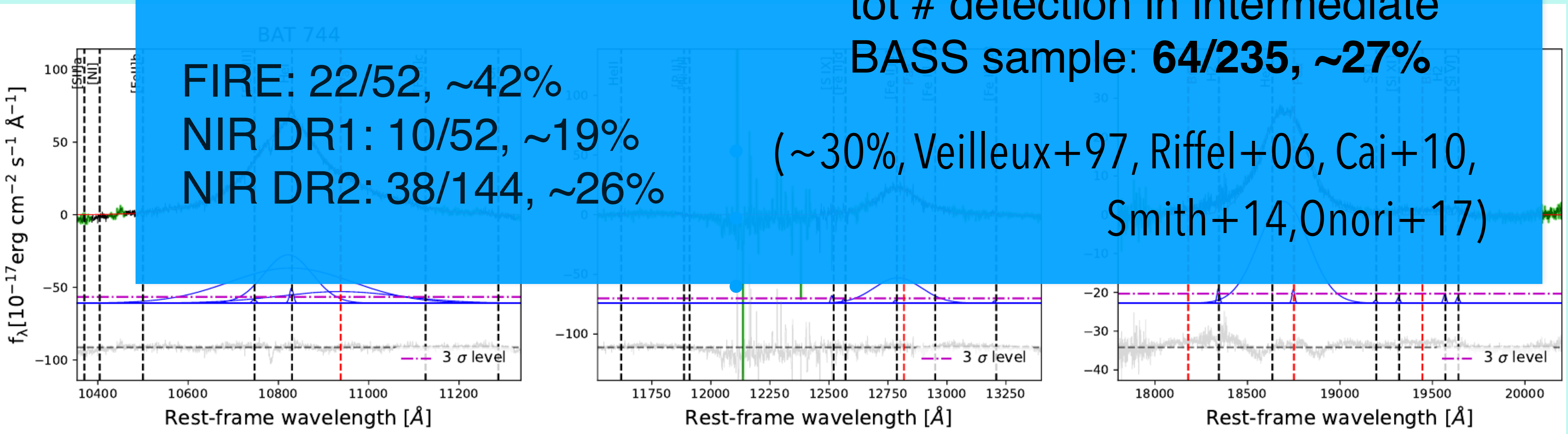
Sy 1.9



Sy 1



Combining the three NIR datasets, we have **314 unique NIR spectra, the largest NIR database so far of local hard X-ray selected AGN**!

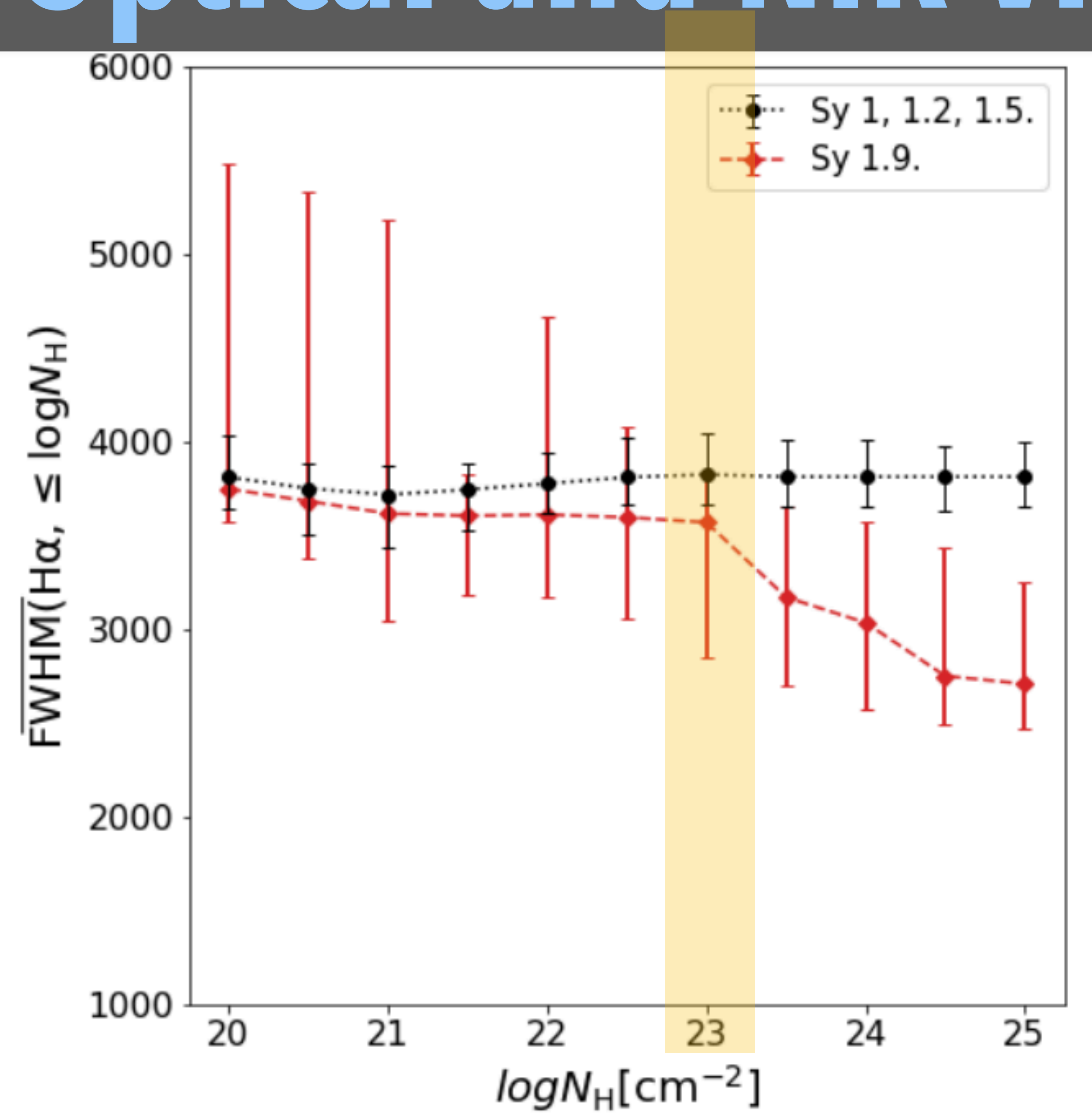
# of good quality reliable (i.e. flags =1,2 and errFW < 10%) detections of broad lines (either He I, Paβ or Paα) in intermediate Sy (Sy 1.8-1.9-2.0):

FIRE: 22/52, ~42%
NIR DR1: 10/52, ~19%
NIR DR2: 38/144, ~26%

tot # detection in intermediate BASS sample: **64/235, ~27%**

(~30%, Veilleux+97, Riffel+06, Cai+10, Smith+14,Onori+17)

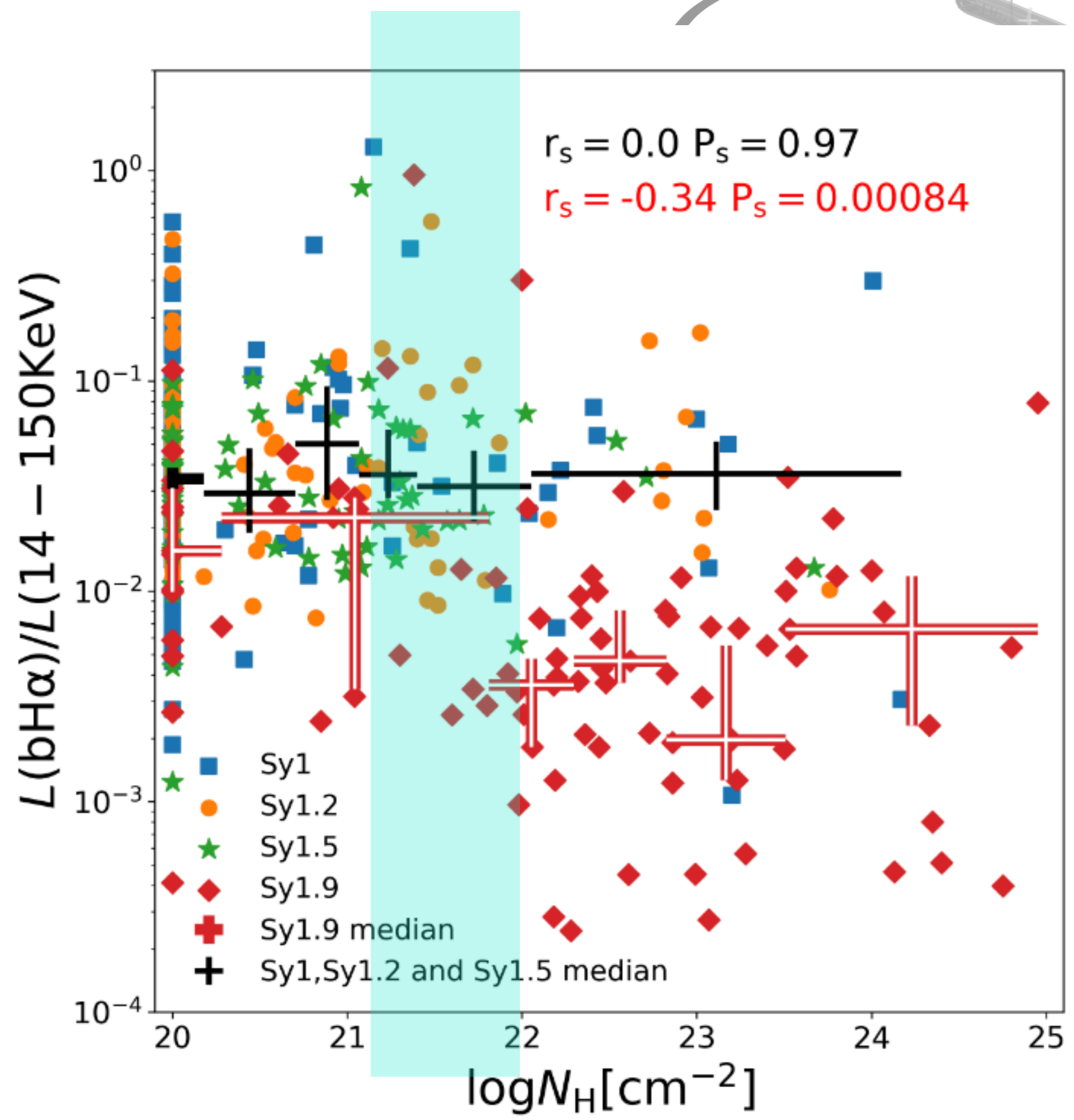
Optical and NIR view of the BLR in Sy 1-1.9



Mejia-Restrepo +in prep

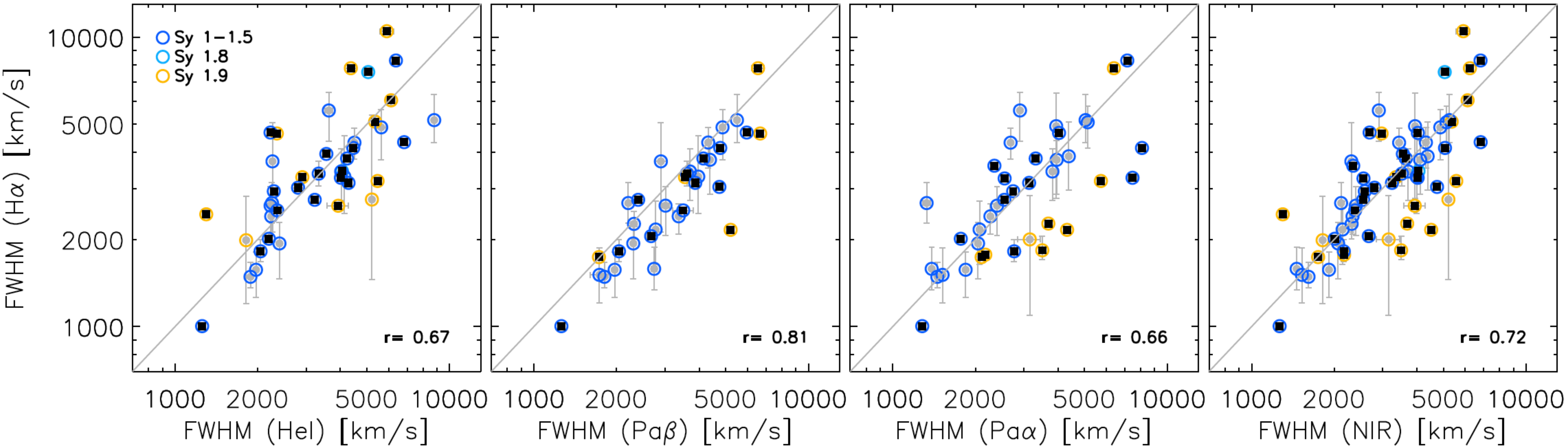
In Sy 1.9 FWHM(Hα)-N_H is almost constant up to log Nh~23 cm^{-2}
The Hα BLR velocities are not underestimated until ***log N_H <~23 cm^{-2}***.

The Hα broad line flux is biased, as the Lb(Hα)/LhardX decreases in Sy 1.9 at increasing columns, ***log N_H >~ 21-22 cm^{-2}***



✓ NIR BASS DR1+DR2+FIRE -> FWHM(line), Lx(14-195keV), M(line)
✓ OPT DR2 -> FWHM(Hα), Lb(Hα), Mbh(Hα)

What does the NIR say?



★ FWHM(Hα) consistent with FWHM from broad NIR lines

(see also, Landt+08, F.Ricci+17, Lamperti+17, Onori+17)

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Optical and NIR view of the BLR in Sy 1-1.9

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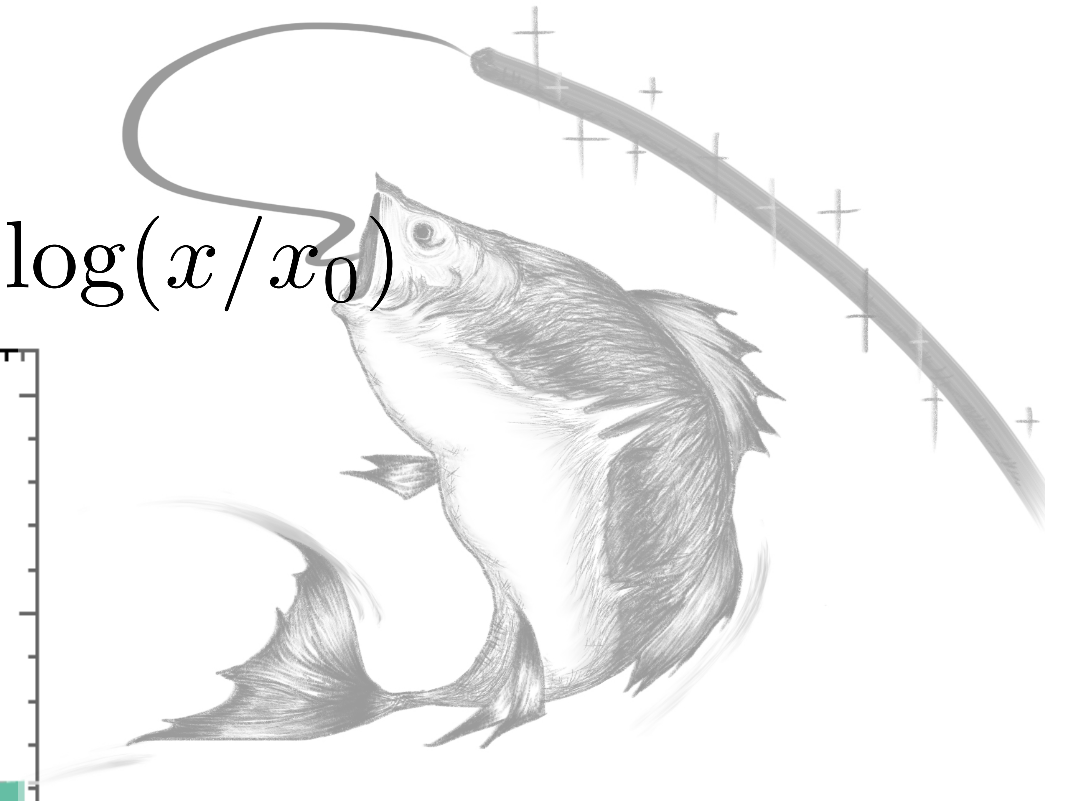
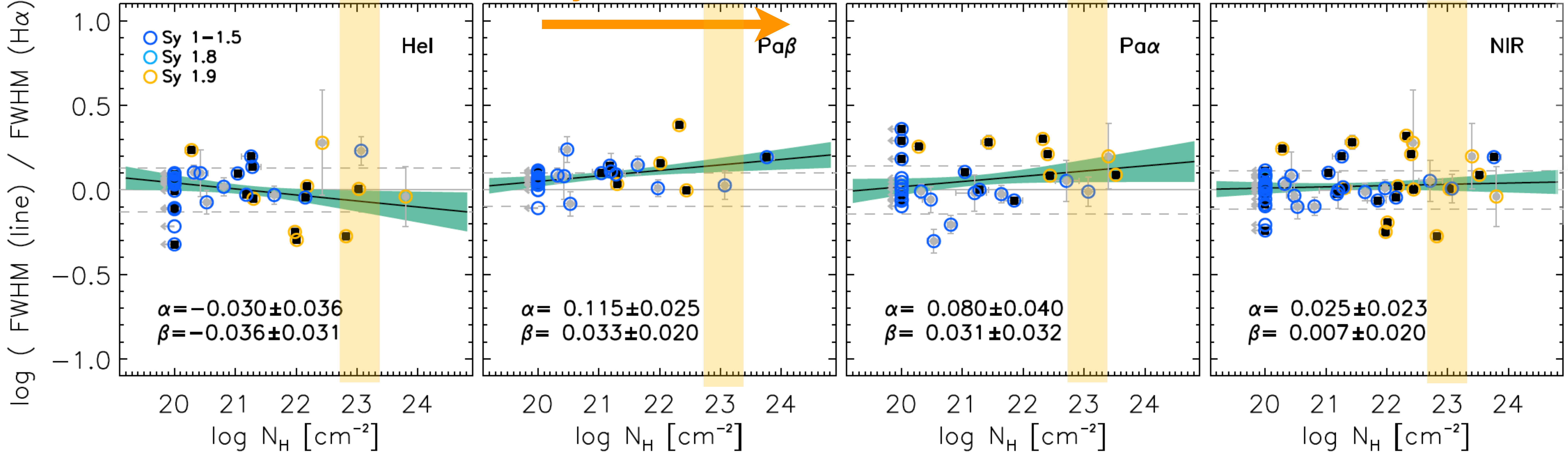
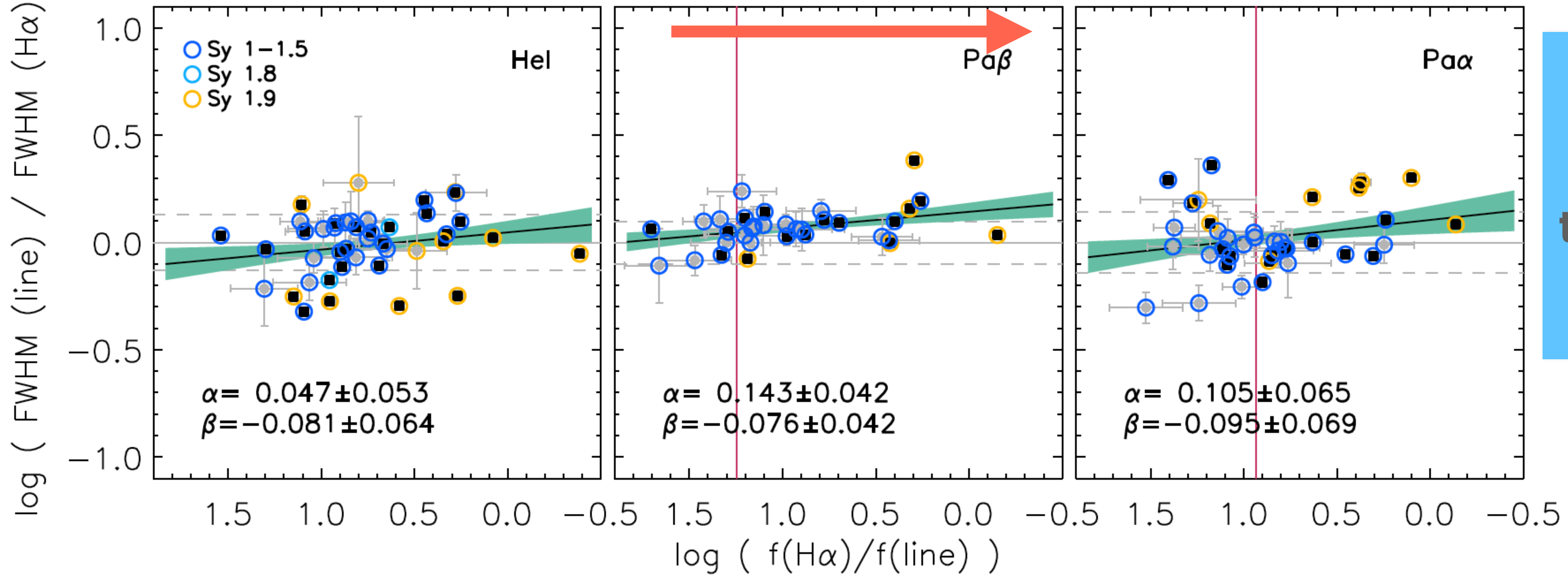
$$\log(y/y_0) = \alpha + \beta \log(x/x_0)$$



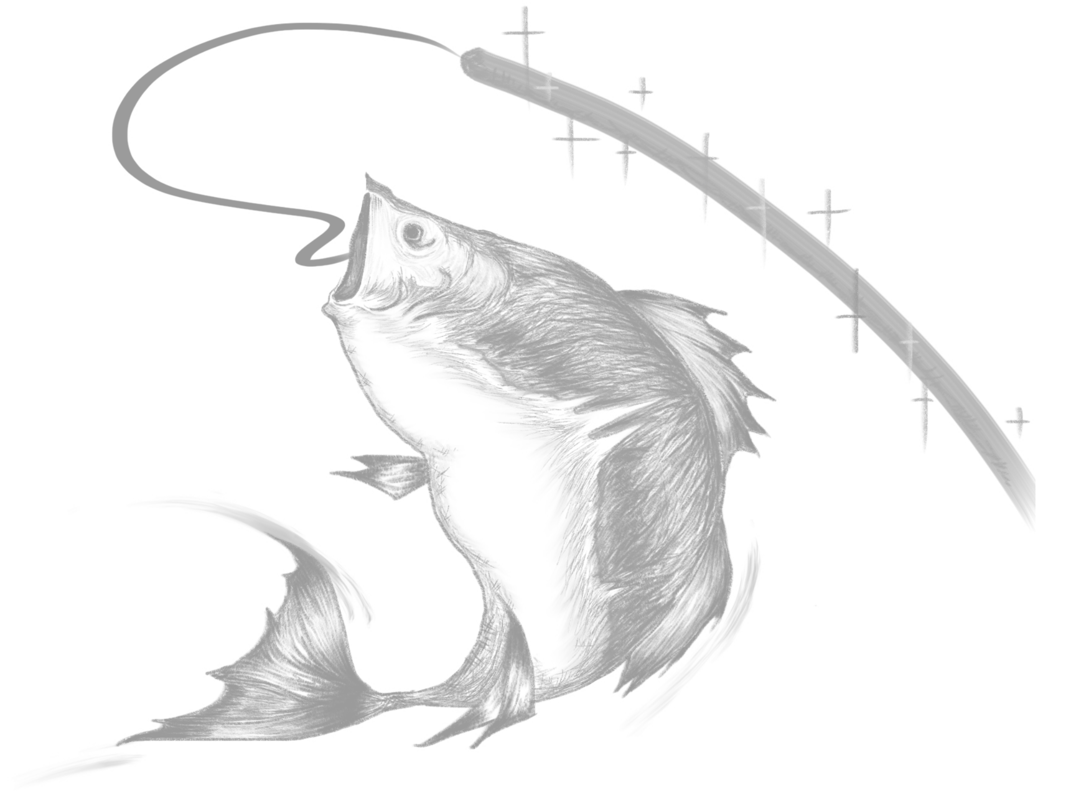
X-ray OBSCURATION

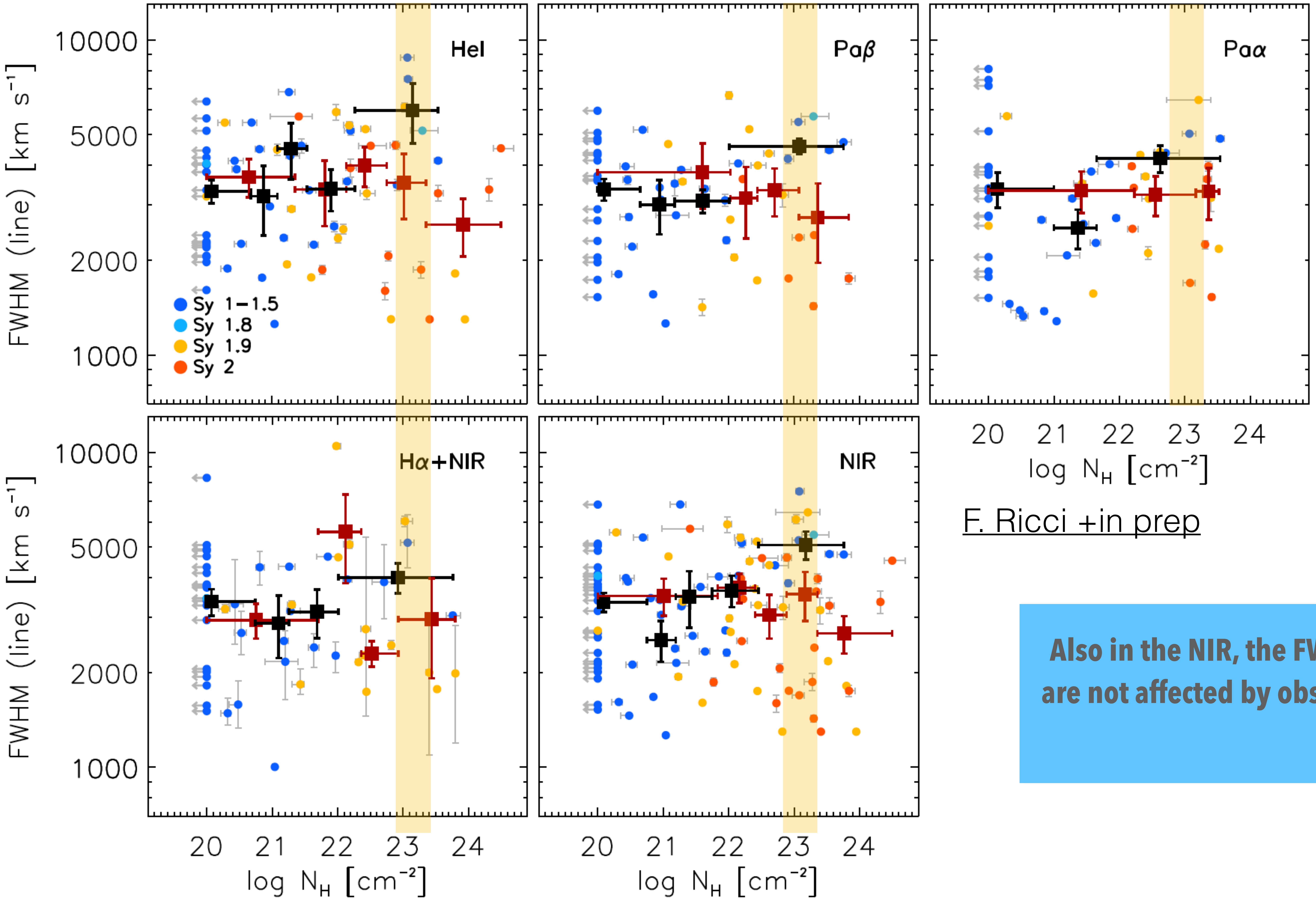


dust EXTINCTION BLR



The FWHM measurements are not affected by extinction nor obscuration once the broad Hα line is securely detected (in Sy 1-1.9) at least when log N_H <~ 23 cm-2





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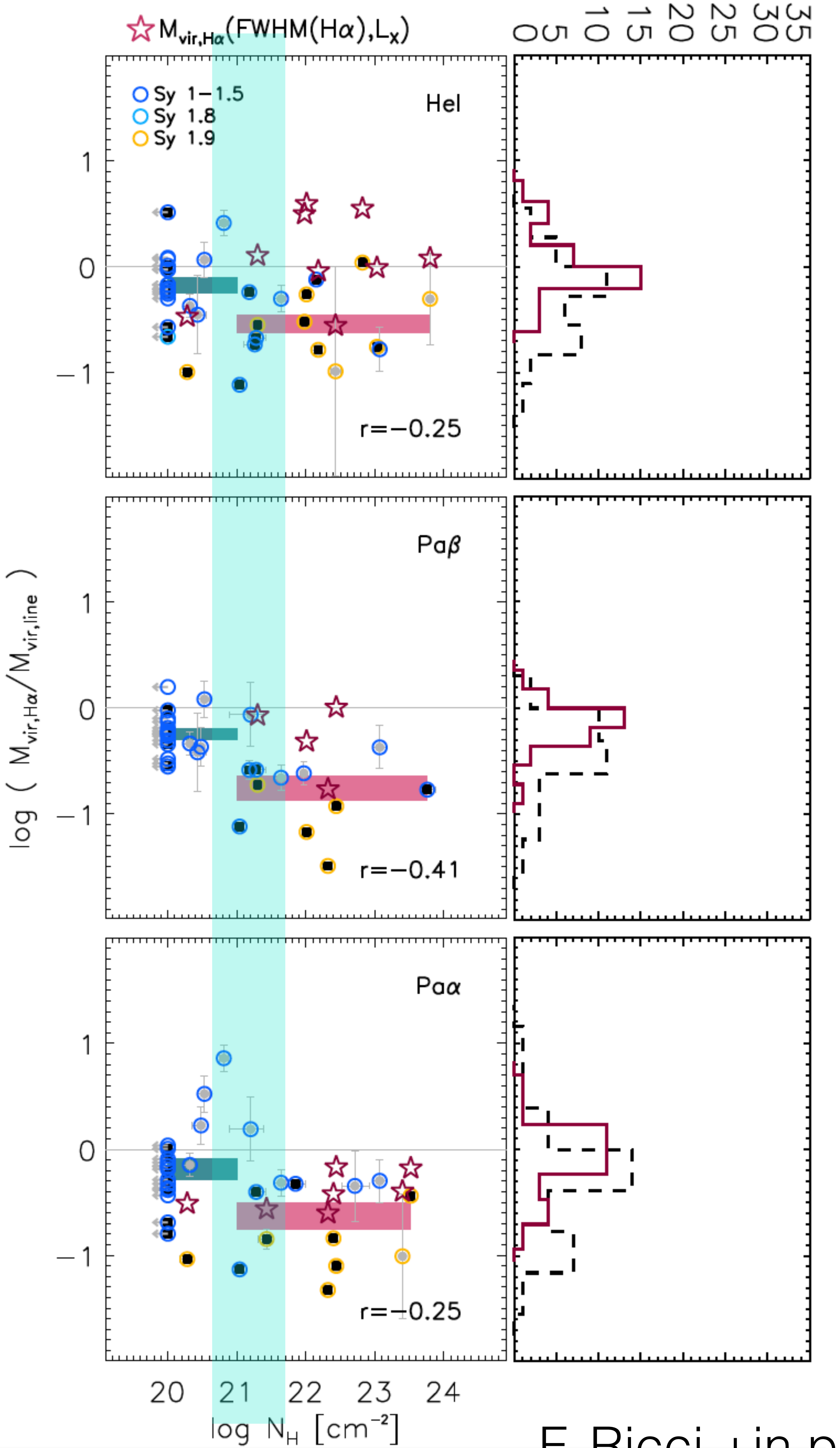
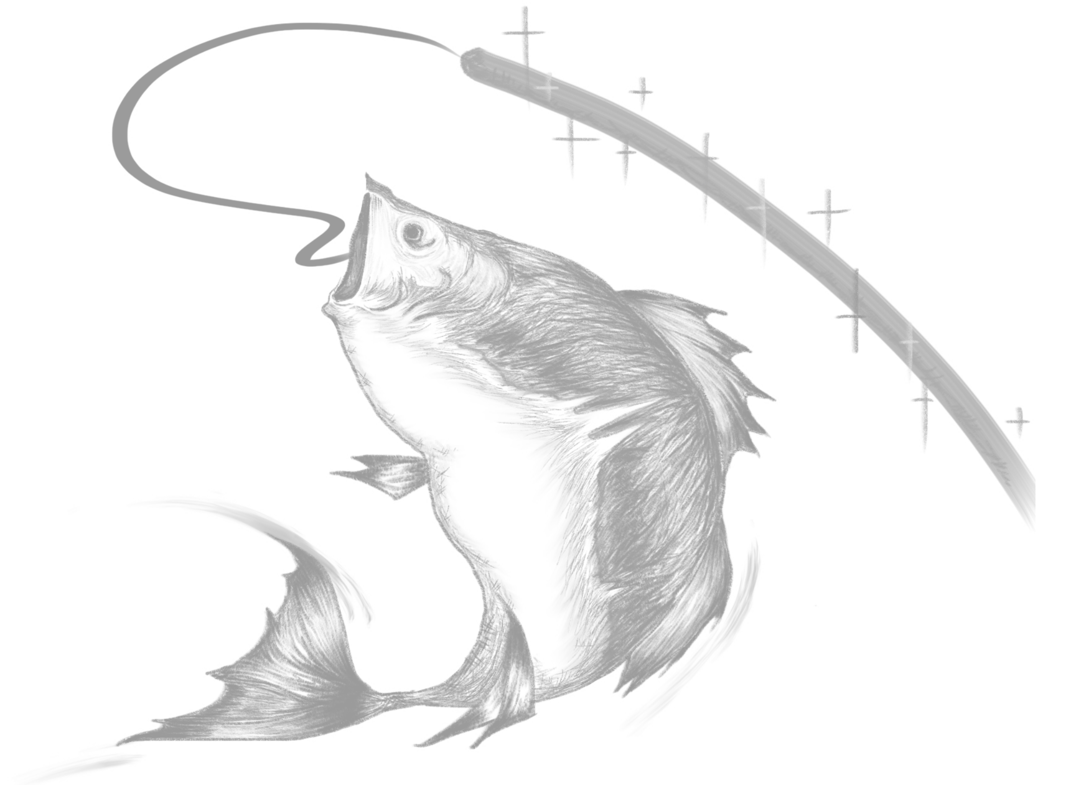
Also in the NIR, the FWHM measurements are not affected by obscuration at least up to log N_H <~23 cm^{-2}

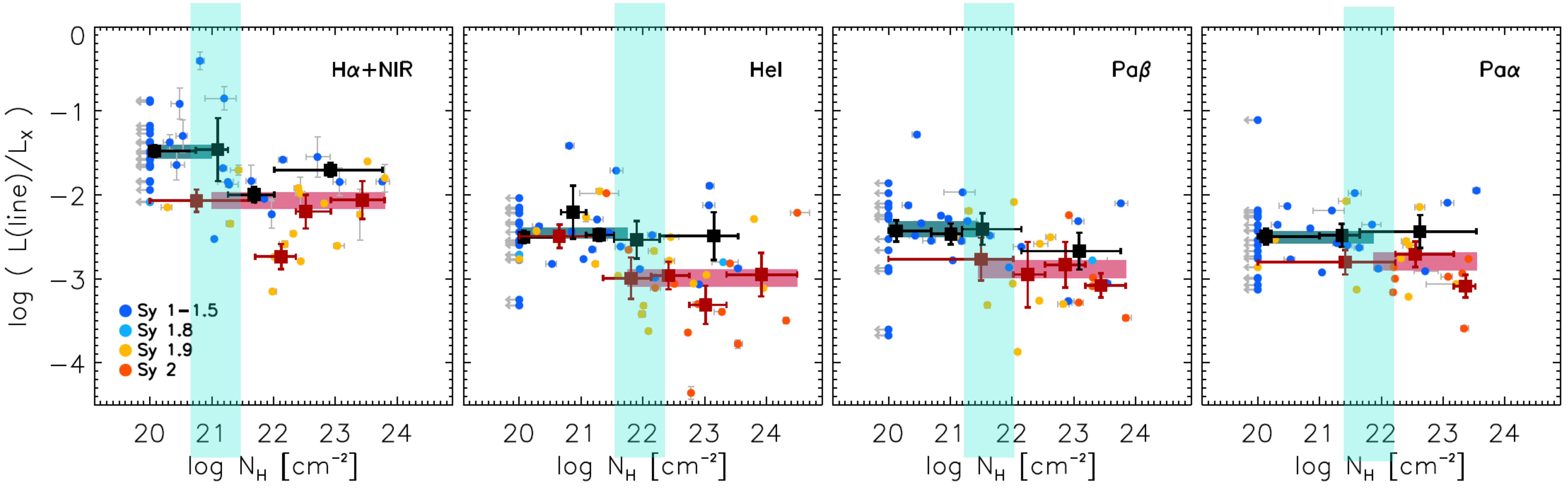




The Hα broad line intensity, i.e. the flux, is the quantity that gets suppressed with increasing obscuration, log N_H >21 cm-2 (consistent with optical results from BASS DR2)

When estimating M_{BH} using Hα, in case of Sy 1.9 or with log N_H >21 cm^{-2}, it is better to ***NOT use OPTICAL BROAD LINE luminosity*** (i.e. no Greene&Ho+05), choose a more unbiased proxy for the BLR radius (like Lx).

The IR broad line luminosities are suppressed at slightly higher N_H levels, as expected by dust extinction that becomes less relevant at longer wavelengths



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NIR view of the BLR: f

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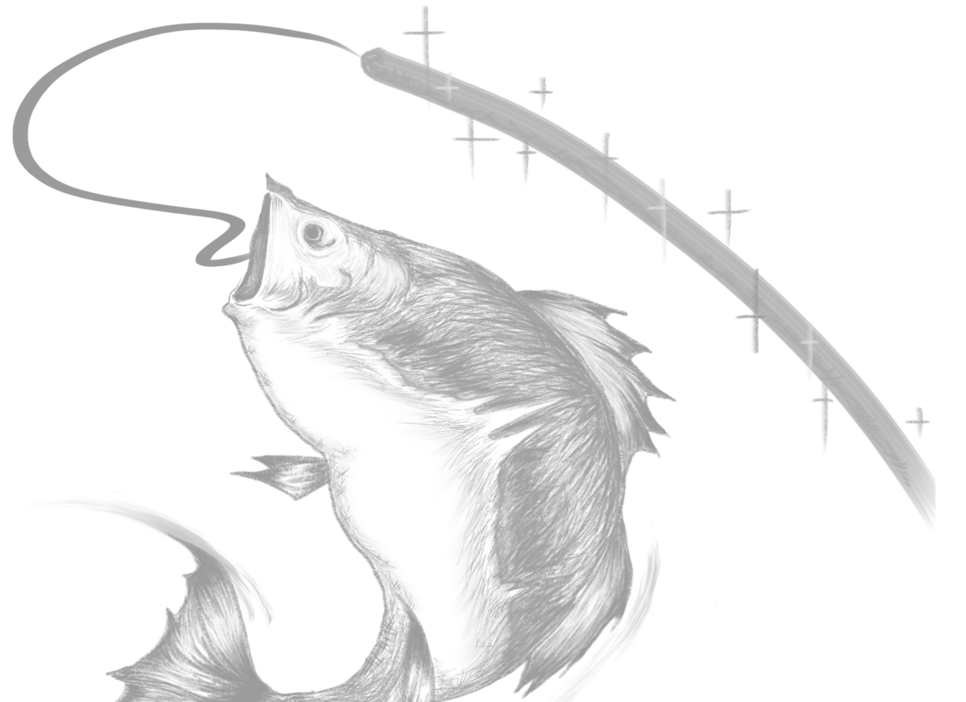
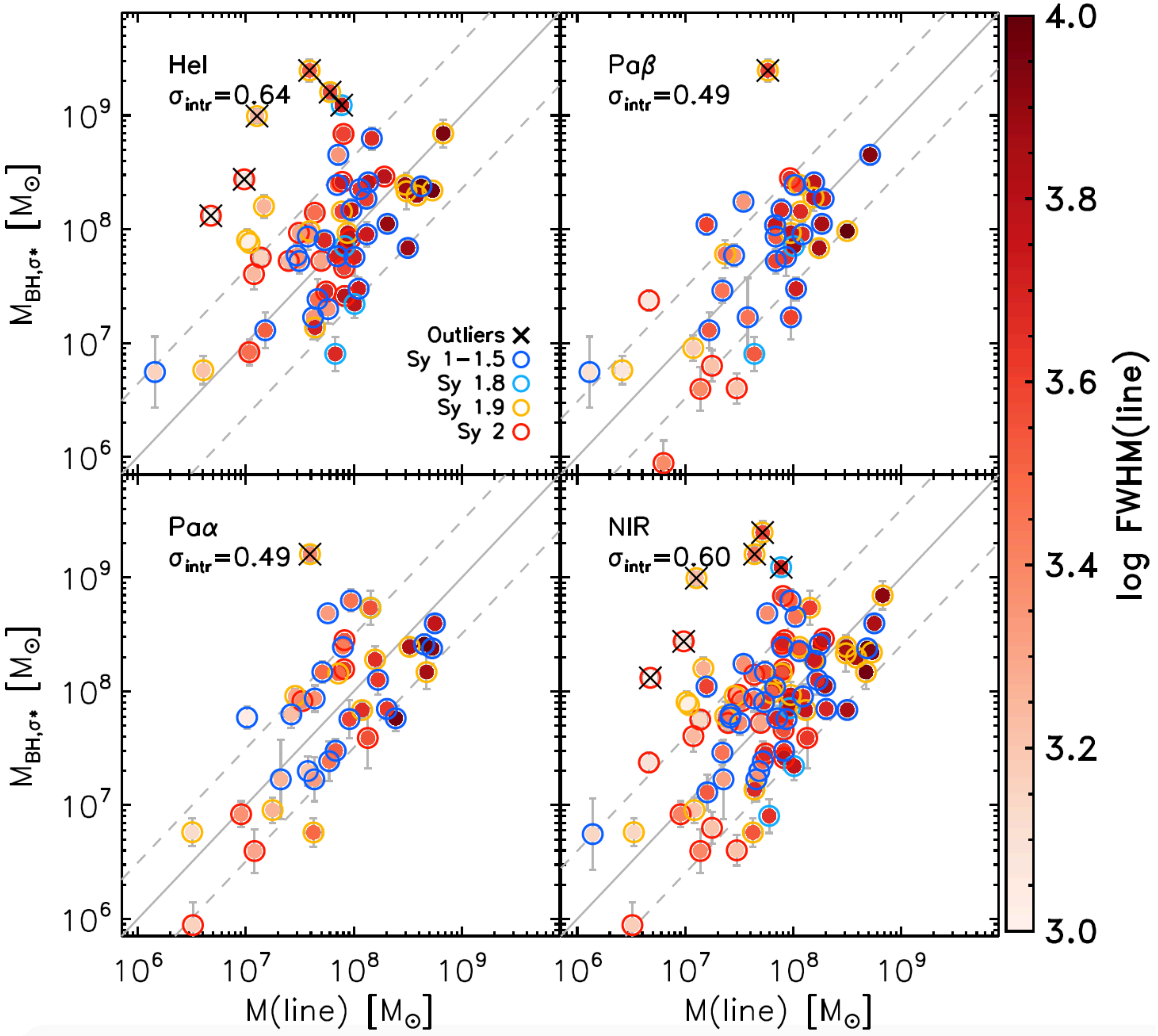
- ✓ NIR BASS DR1+DR2+FIRE -> FWHM(line), Lx(14-195keV), M(line)
- ✓ σ★ OPT DR2 -> Mbh,σ★



$$M(line) = f M_{vir,line} \Longrightarrow f_0 M_{vir,line}$$

$$M_{BH,\sigma_\star} \Longleftrightarrow M(line)$$

$$f = \frac{M_{BH,\sigma_\star}}{M_{vir,line}} \quad \log f/f_0 = \log \frac{M_{BH,\sigma_\star}}{M(line)} = \Delta \log M_{BH}$$



- ✓ The measurements are evenly distributed around the 1:1 relation with some scatter (~0.5-0.65 dex)
- ✓ Some of the scatter is driven by FWHM(line): smaller (light color) FWHMs are located above the 1:1 locus while broader lines (darker color) are below
- ✓ if FWHM gets broadened with inclination, it is expected an anti correlation between f and FWHM (see e.g. Collin+06, Decarli+08, Shen&Ho+14, Mejia-Restrepo+18, Mediavilla+19, Marculewicz+20)

Does the BH mass difference (i.e. f factor) depend on additional parameters?

NIR view of the BLR: f/f0 vs z

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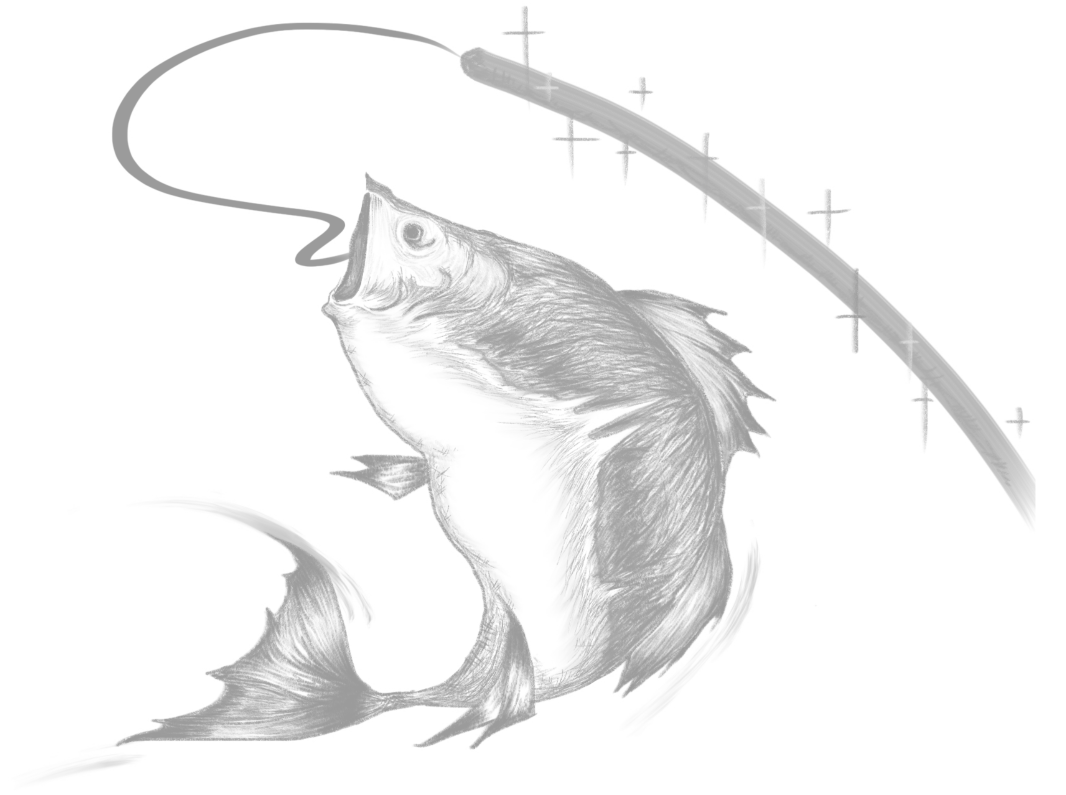

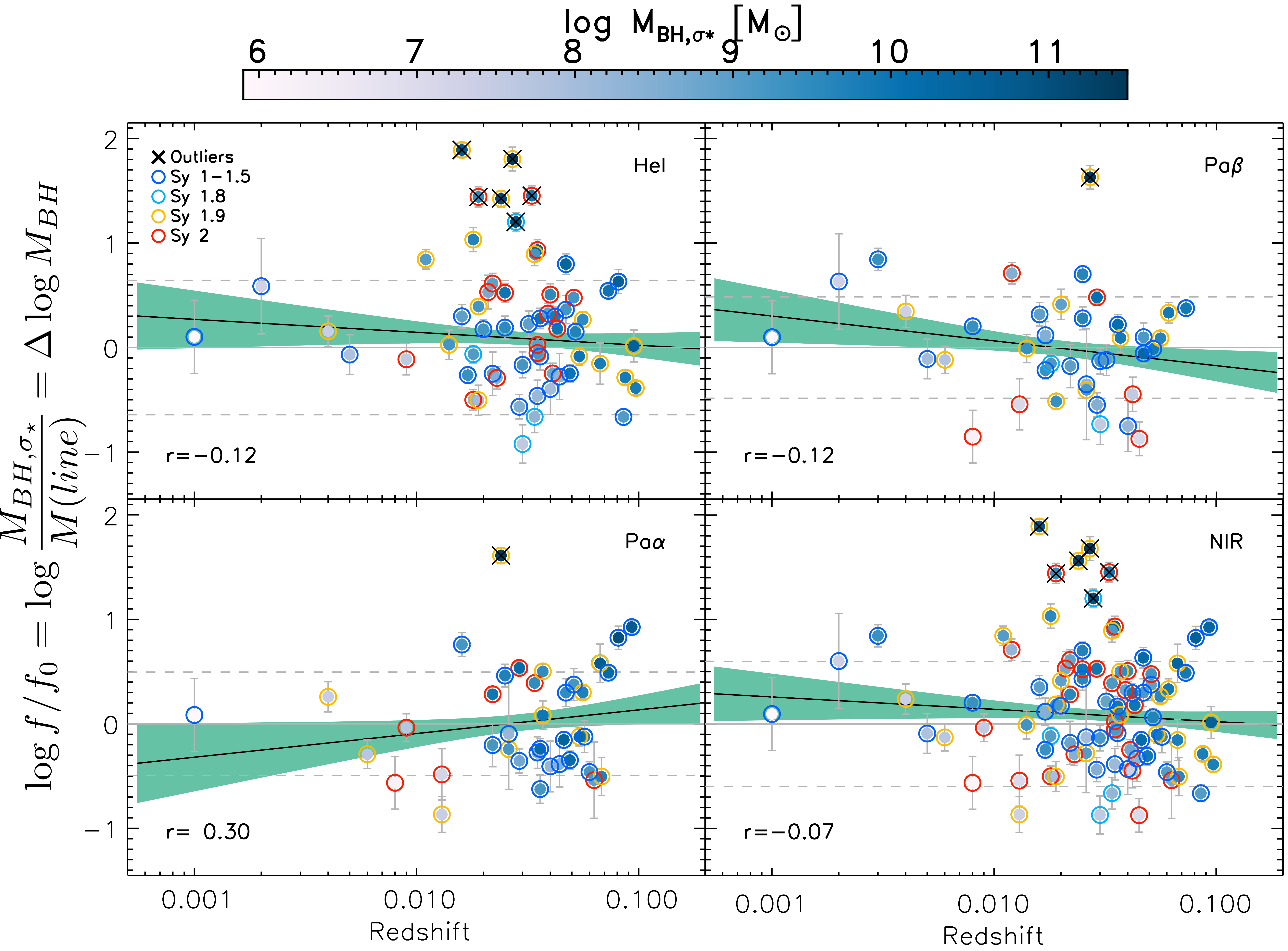

At fixed aperture, with increasing redshift a bigger part of the host bulge is sampled in 1D spectra, possibly producing an increase on the measured stellar velocity dispersion and therefore an enhancement of Mbh,$\sigma_\bigstar$

- ✓ no strong gradient of Mbh,$\sigma_\bigstar$ along the x-axis,
- ✓ some gradient along the y-axis, meaning that at each redshift there is a range of Mbh,$\sigma_\bigstar$
- ✓ weak redshift dependence, thus aperture effects should be negligible

NIR view of the BLR: f/f0 vs Nh

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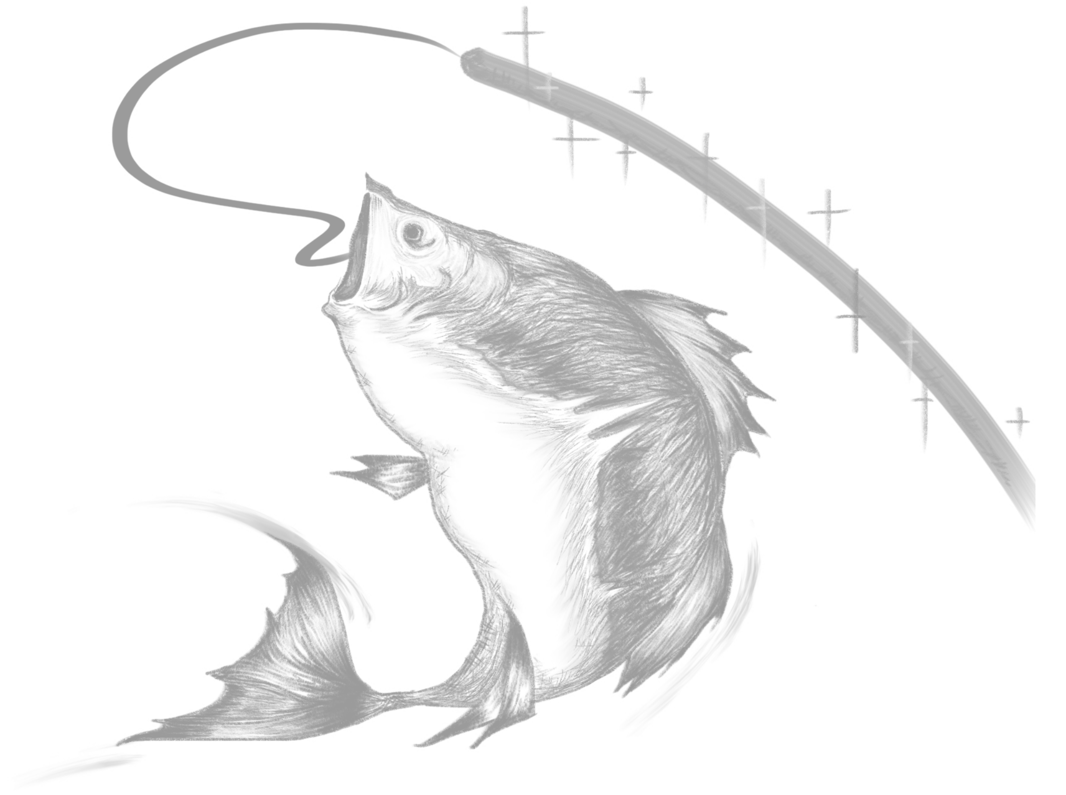

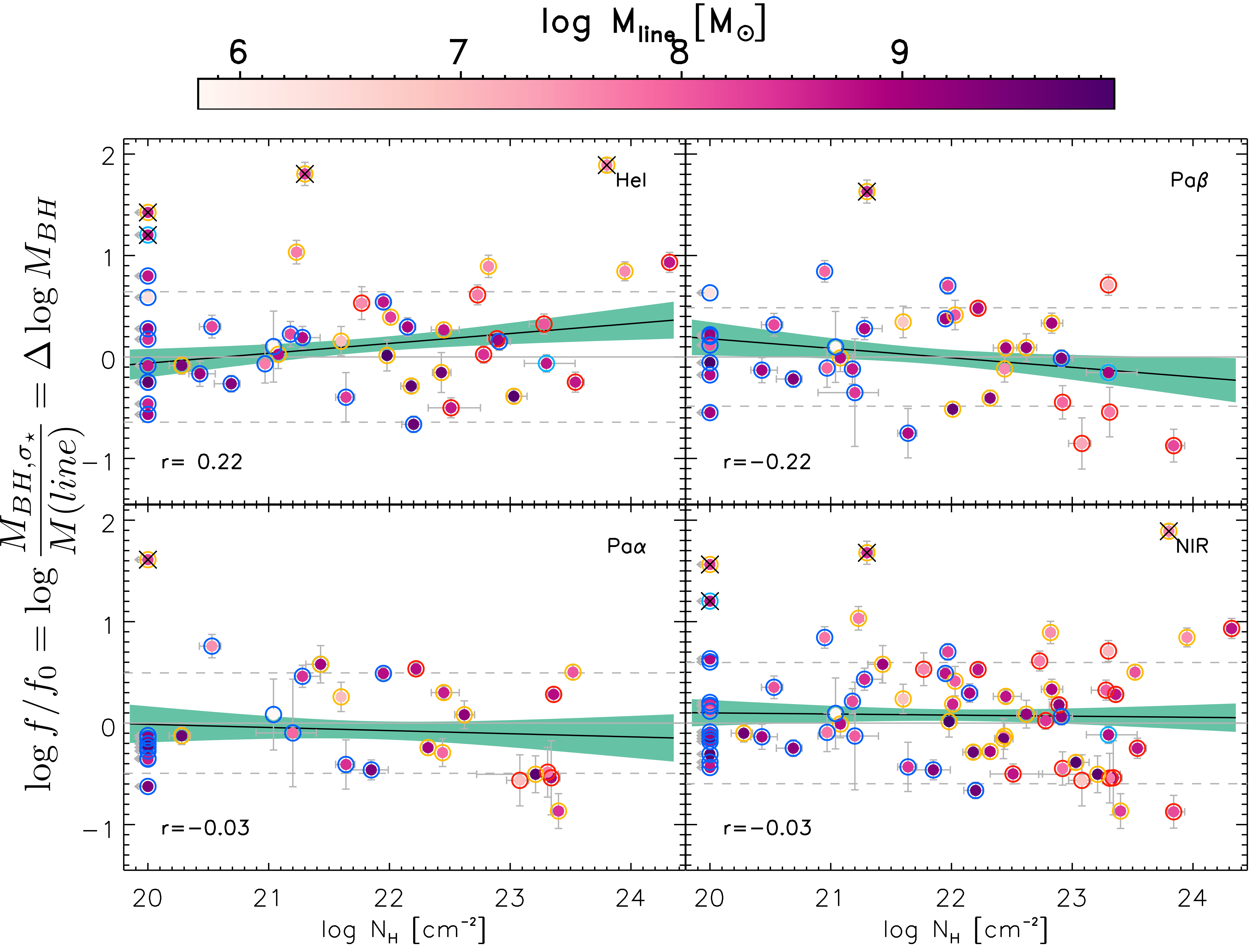

The offset f/f0 might depend on obscuration, such that, at fixed Mbh,$\sigma_\star$, the NIR virial-based estimate is biased low.

If that were the case

- ✓ the sample should exhibit a gradient with M(line) as a function of the X-ray column (lighter the higher the Nh)-> NOT SEEN
- ✓ positive correlation between the f/f0 and the column density -> NOT SEEN

NIR view of the BLR: f/f0 vs M(line)

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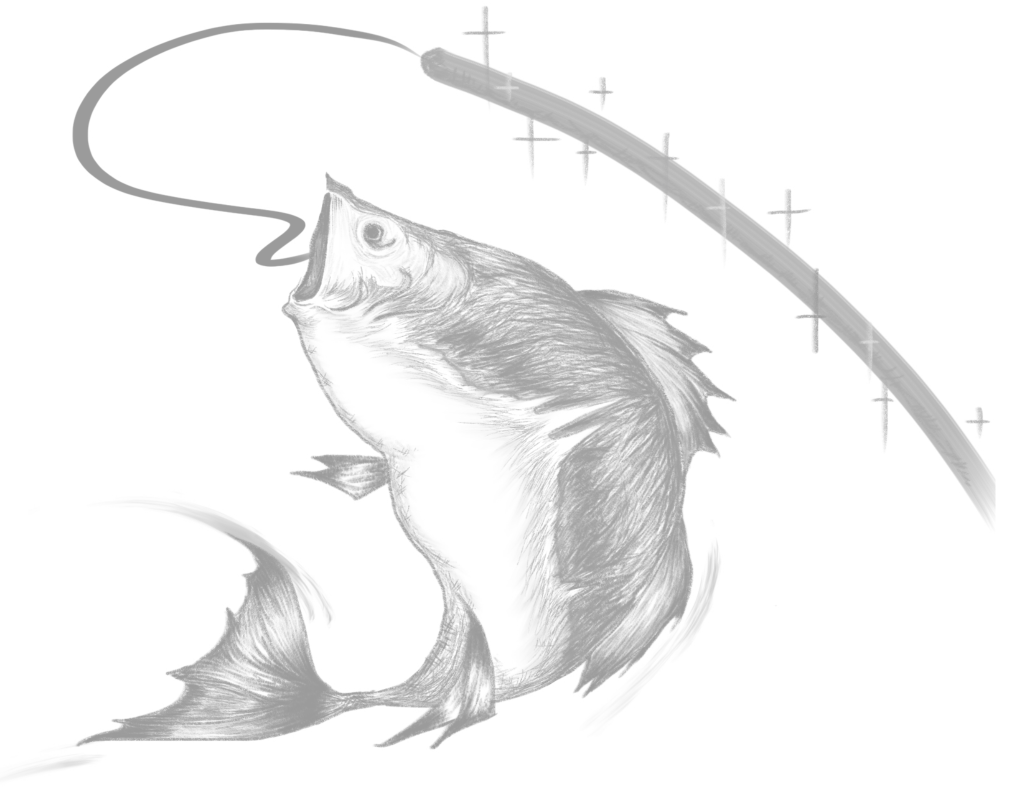
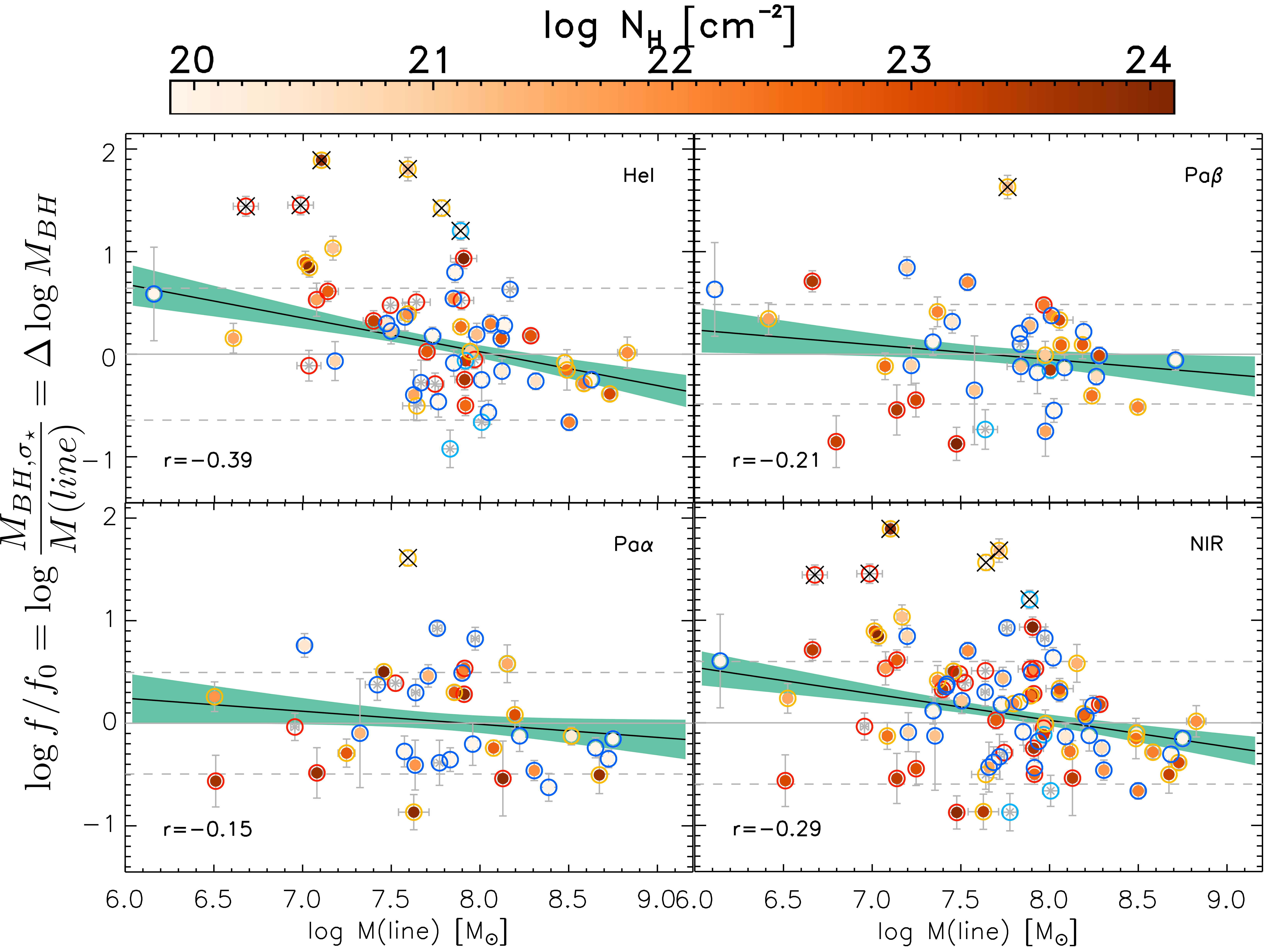




The offset f/f0 might depend on Mline. Expected an anti correlation by definition.

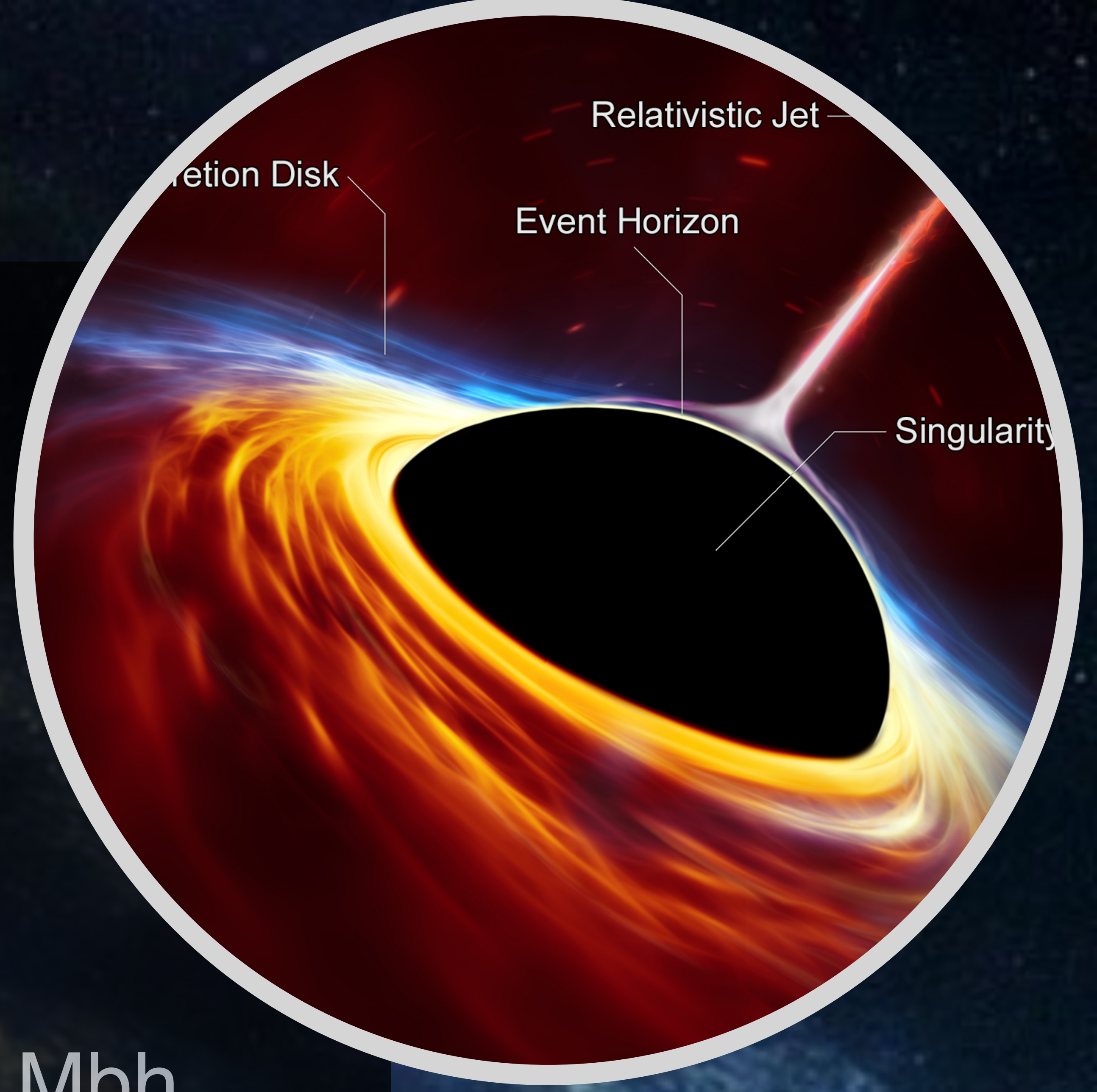
$$f \propto M(line)^{-1}$$

- ✓ there is indeed an anti correlation, but the slope is flatter than -1
- ✓ in all cases the slope is statistically ≠ -1 (p<1E-7) and ≠ 0 (p<4E-3) only for HeI and NIR samples

This anti-correlation might be driven by a more fundamental relation with the FWHM, since

$$M(line) \propto FWHM(line)^2$$

Take home messages



1. FWHM measured from Hα and near-infrared lines are consistent in Sy 1 up to Sy 1.9

2. FWHM measures do not depend on gas absorption or dust extinction

3. The broad line intensity gets suppressed:
   - Hα broad line luminosity is biased when log N_H >~ 21 cm^{-2}-> bias in the Mbh estimates based on the broad Hα line luminosity when log N_H >~ 21 cm^{-2}
   - NIR broad line luminosities gets suppressed but at slightly higher N_H, log N_H >~ 22 cm^{-2}
   - SOLUTION: use an obscuration unbiased proxy for the BLR radius (=Lx)

4. The Mbh based on stellar velocity dispersions and those based on a mixed Lx+NIR virial estimate are in general agreement, with a scatter of ~0.5-0.65 dex

5. The normalized virial factor f/f0 is not biased with redshift, X-ray absorption but does mildly depend on M(line)

Thanks!