EXPLAINING THE HIGH ACCRETING QUASARS FROM PHOTOIONISATION MODELLING

combining theory, observations & simulations

SWAYAMTRUPTA PANDA[1,2]

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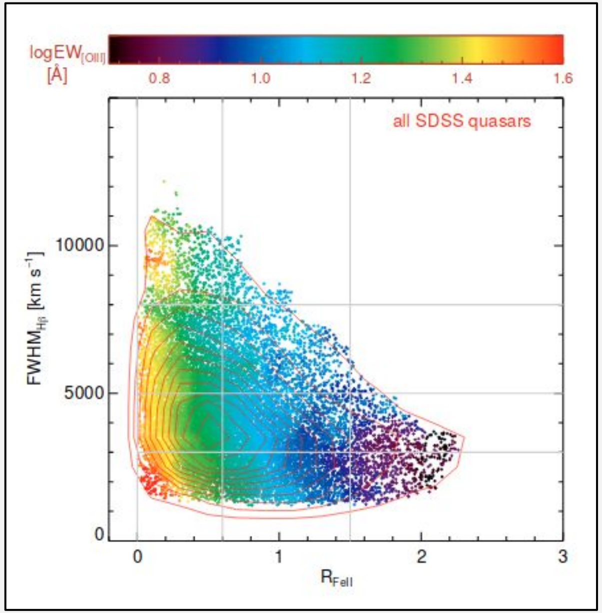
Mapping Central Regions of Active Galactic Nuclei, Guilin, China (September 19-24, 2019)

Schema for the Eigenvector 1

Boroson & Green, 1992

Principal Component Analysis (PCA)

- 13 tabulated properties
- Eigenvector 1: FeII - [OIII] anti-correlation
- Peak λ5007 and Hβ FWHM correlation



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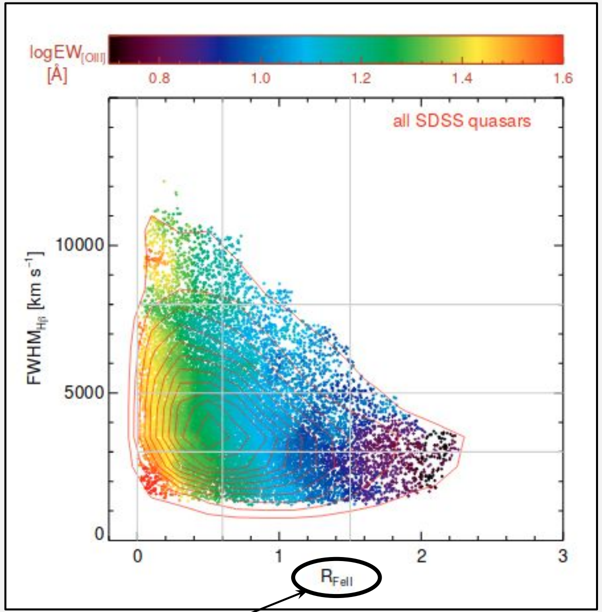


FeII emission within 4434-4684Å wrt broad Hβ

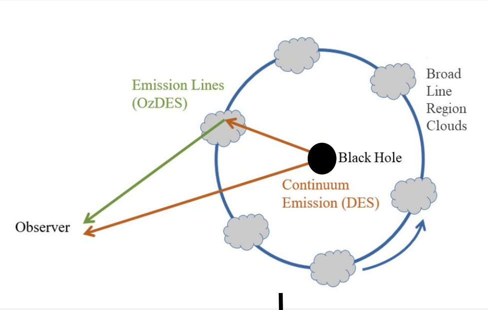
Shen & Ho, 2014

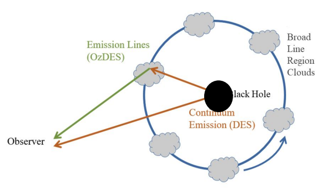
Standard radius-luminosity relation doesn't always work!

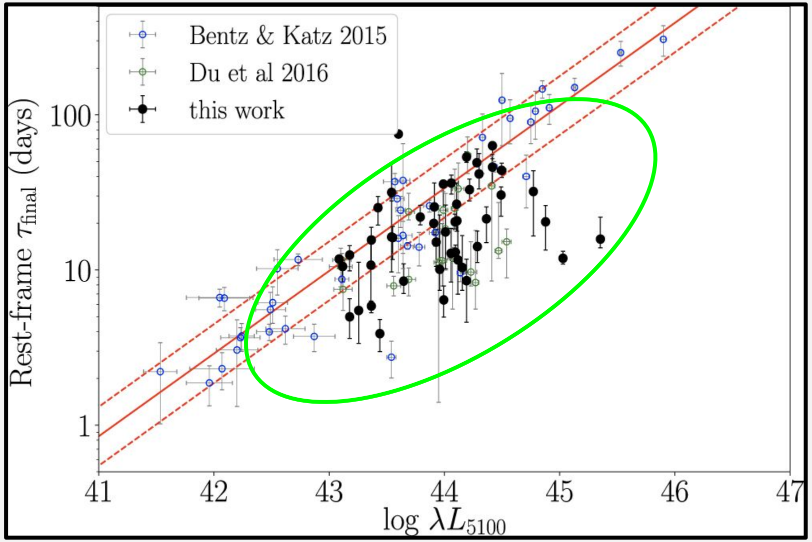
According to the standard Radius - Luminosity relation: $R_{BLR} \propto L_\lambda^{1/2}$ ← monochromatic luminosity

But, higher luminosity at the same radius ⇒ ***higher accretion rate!*** $L_\lambda \propto L_{bol} \propto \dot{M}$

And, sometimes above the Eddington limit i.e., *Super-Eddington sources* $\lambda_{Edd} = L_{bol}/L_{Edd} \propto L_{bol}/M_{BH}$

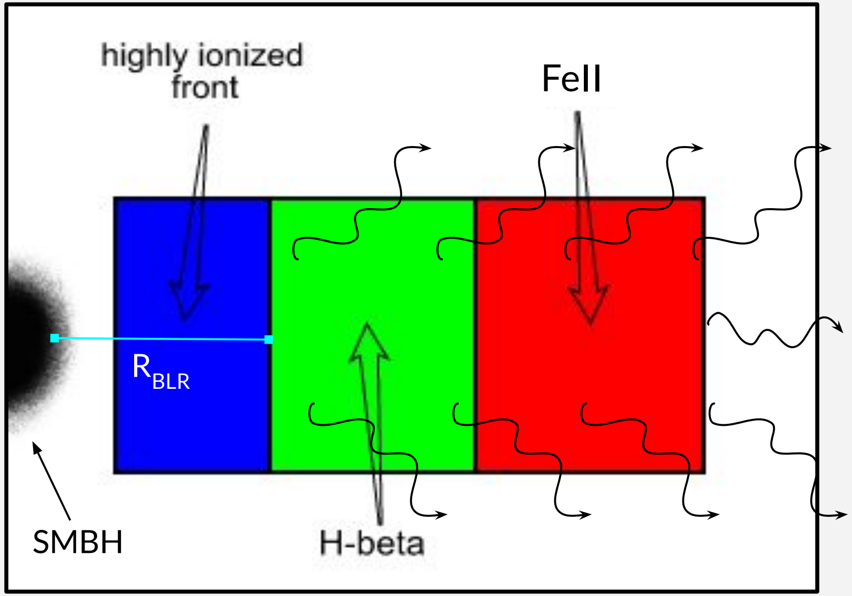






Grier et al. 2017

A simple yet 'real' model of the Broad Line Region Cloud

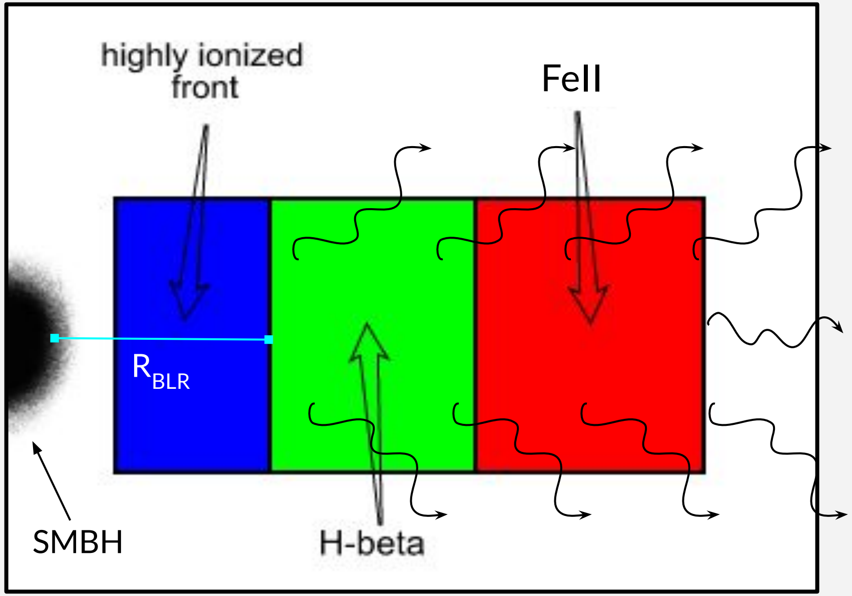


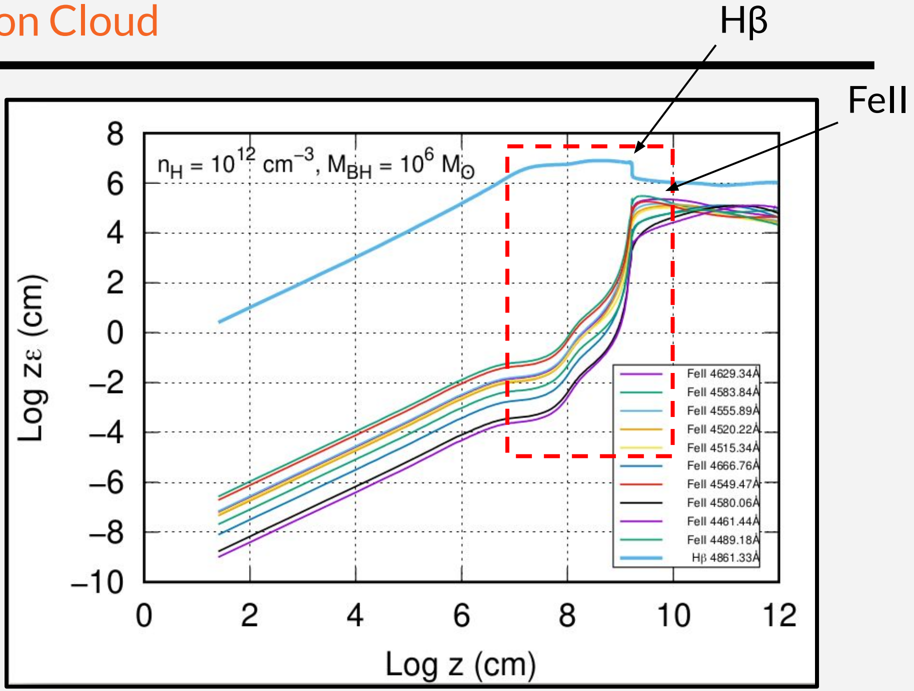
A **VERY SIMPLE** view for a Broad-Line Region (BLR) cloud. The multi-region in the cloud depict the ionization stratification - a highly ionized front-face, then the production region of Hβ, and the FeII emission at the far end of the cloud (this model is confirmed by Reverberation mapping studies). The R_{BLR} is the distance of the BLR cloud from the SMBH.

Panda et al. 2018b

Constant density single cloud model

A simple yet 'Real' model of the Broad Line Region Cloud





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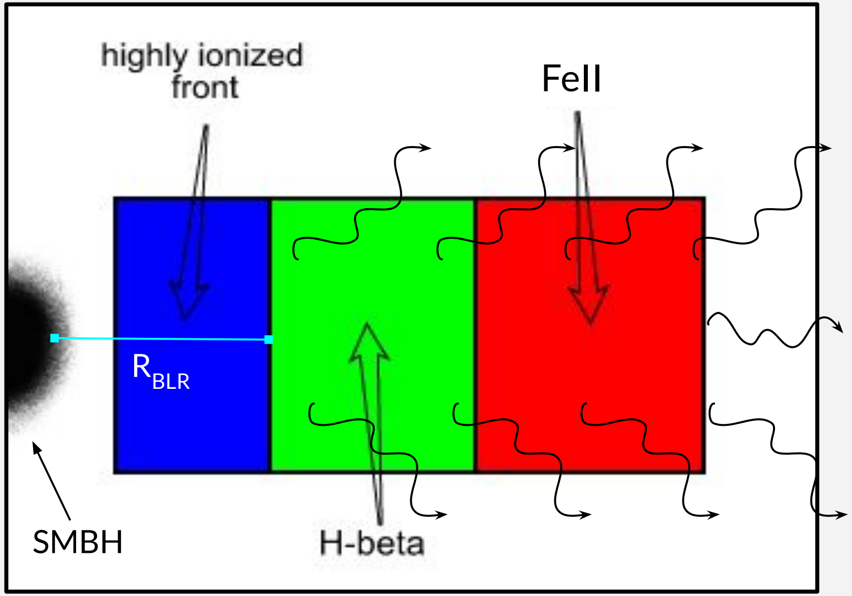
The emissivity profiles for two clouds as function of the cloud depth measured from the illuminated surface. For the low temperature cloud, the hydrogen ionization front is visible and FeII emission is dominated at the dark side of the cloud.

Hβ and FeII EMISSIVITY PROFILES

Panda et al. 2018b

A more comprehensive view of the BLR from theory



$$U = \frac{Q(H)}{4\pi R_{BLR}^2 n(H) c} = \frac{\Phi(H)}{n(H) c}$$

with I Zw 1 - like SED at $Z_{\odot}$

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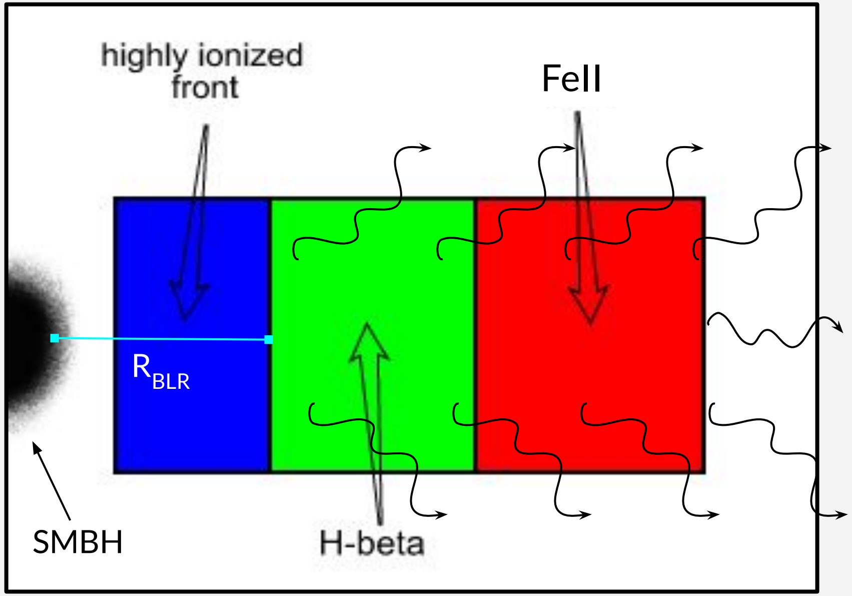

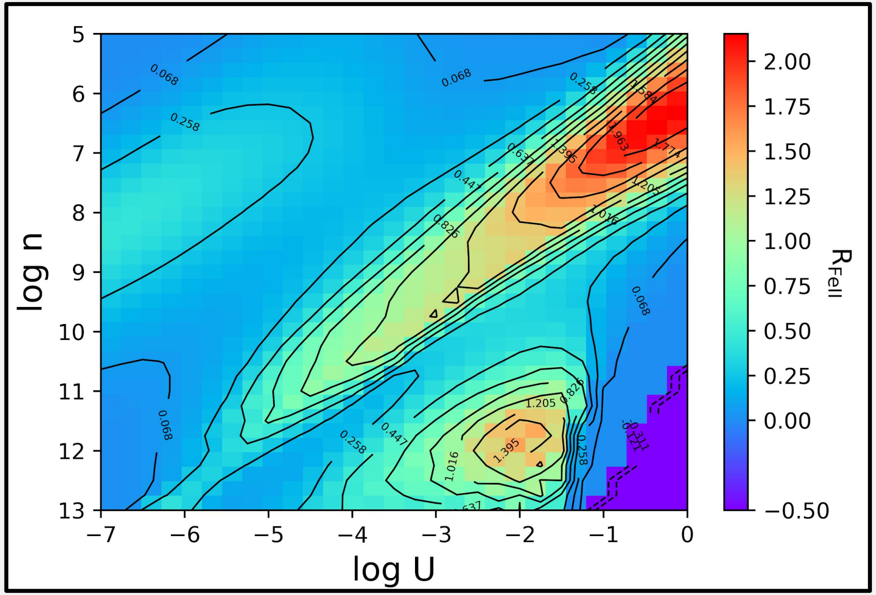

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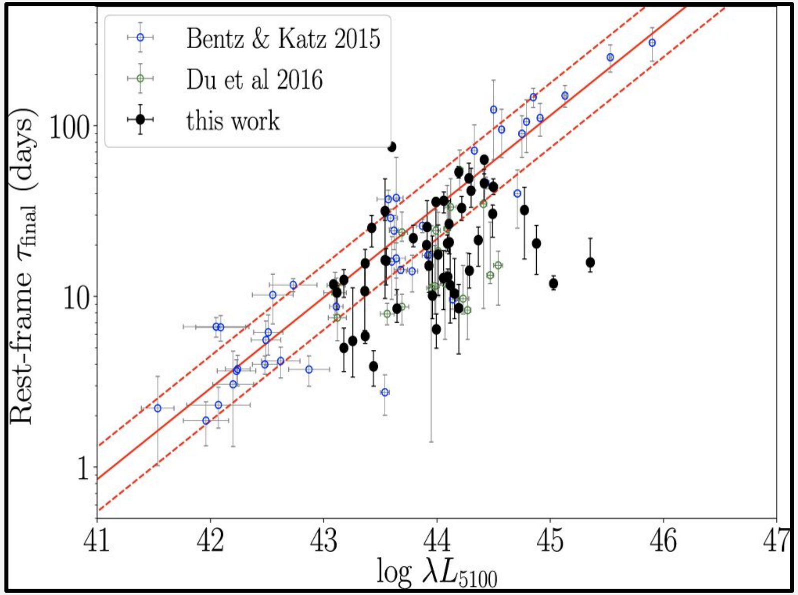
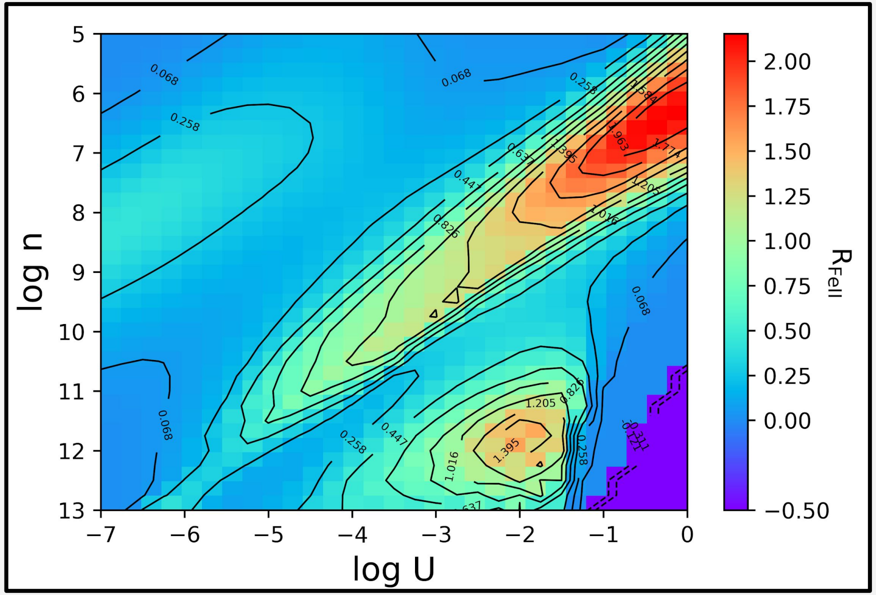
Maybe there's something here?

Panda, Martínez-Aldama & Czerny (in prep.)





Hβ radius-luminosity (monochromatic at 5100Å) with previous measurements in blue (Bentz & Katz 2015) and green (Du et al. 2016) and in black (Grier et al. 2017). The red solid and dashed lines show the best-fit relation and it's measure scatter from Bentz et al. (2013)

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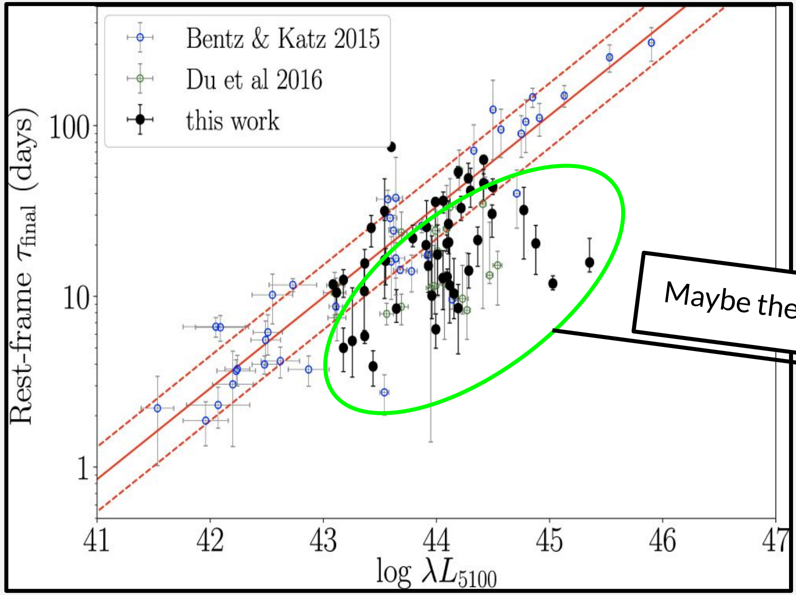
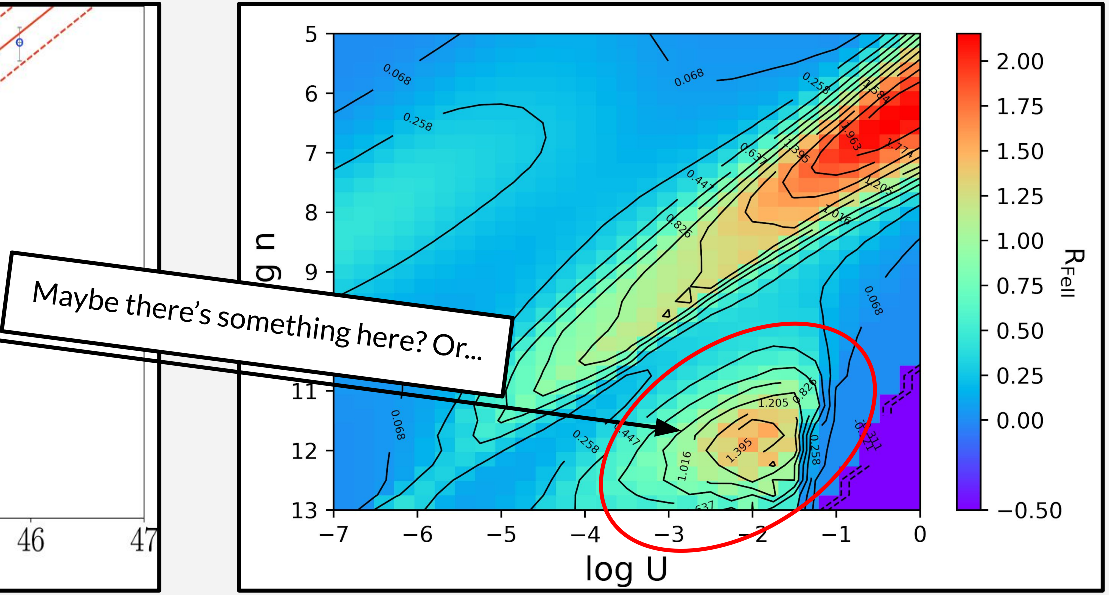
This is just the beginning...

Panda, Martínez-Aldama & Czerny (in prep.)





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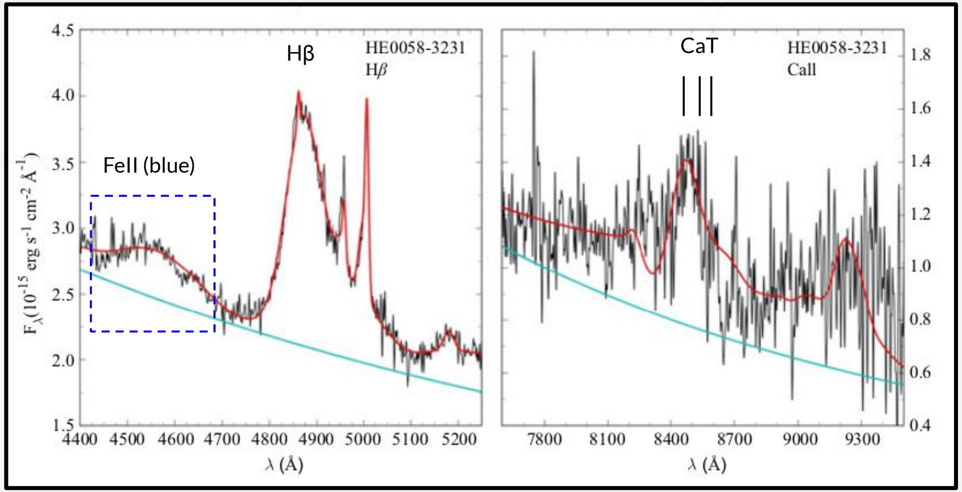
FeII and CaT zones are similar

- Given the difficulty involved with the interpretation and prediction of the FeII spectrum, the study of simpler ionic species like **CaII triplet** (emitting the IR triplet ***λ*8498**, ***λ*8542**, ***λ*8662**, hereafter CaT) is more straightforward.
- Photoionization models performed by Joly (1989) have shown that the relation between the ratios CaT/H*β* and FeII *λ*4570/H*β* provides evidence of a common origin for CaT and FeII *λ*4570.
- CaT/H*β* increases at high density and low temperature as does FeII *λ*4570/H*β* (Joly 1987).



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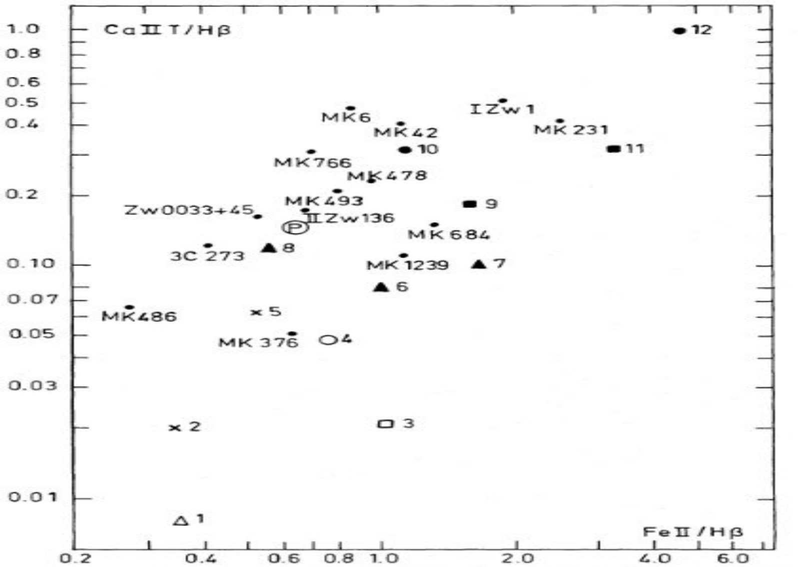


Fig. 2. Ca II T/Hβ versus Fe II/Hβ. Ca II T is the sum of the 3 lines of the IR triplet, Fe II is the blend at 5190 A, 5320 A, sum of multiplets 48, 49, 41. The observed values, located by the name of the objects, are from Persson (1988). The computed values are located by symbols according to the temperature and density of the models: open symbols are for $n = 10^{11}$ cm^{-3}, full black symbols for $n = 10^{12}$ cm^{-3} and: ○ = 6000 K, □ = 6500 K, △ = 7000 K, × = 8000 K. Ⓟ is for the photoionisation model

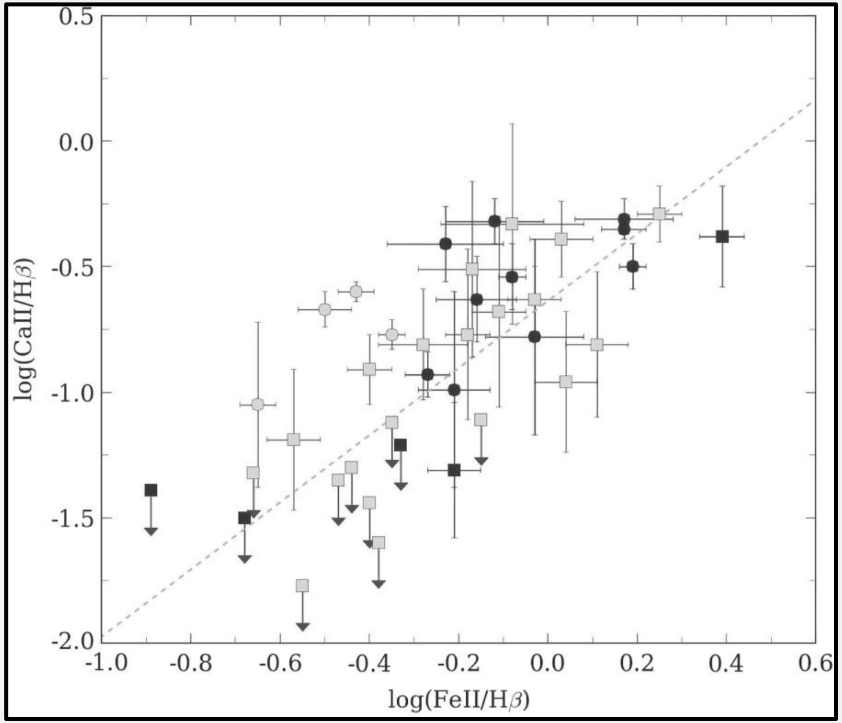
FeII and CaT zones are similar

- Data from Persson (1988) and photoionization calculations (Joly 1989) found that CaT is emitted by gas at low temperature (8000 K), high density (> 10^{11} cm^{-3}) similar to optical FeII.

- Matsuoka et al. (2007, 2008) computed photoionization models using the O I λ8446 and λ11287 lines and CaT, and found that a high density **($\sim 10^{11.5}$ cm^{-3})** and low ionization parameter **($U \sim 10^{-2.5}$)** are needed to reproduce flux ratios consistent with the physical conditions expected for optical FeII emission.

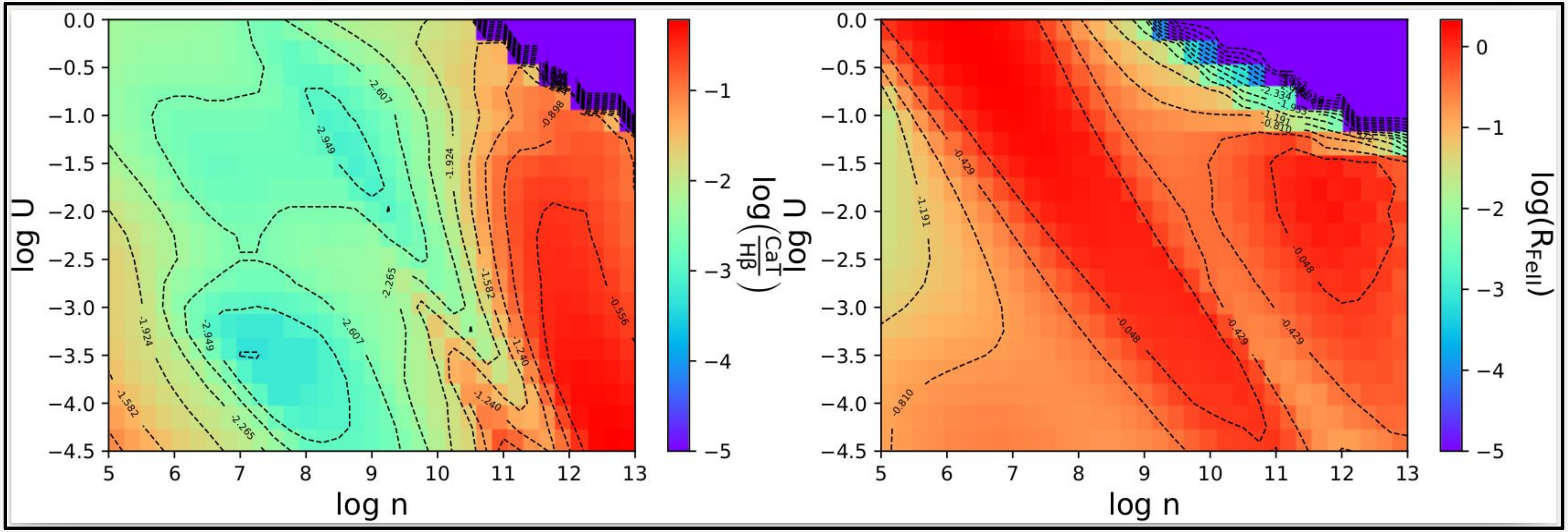
Best fit:

$$\log_{10}(\mathrm{CaT/H}\beta) \approx (\mathbf{1.33} \pm 0.23) \log_{10}(\mathrm{FeII}\ \lambda4570/\mathrm{H}\beta) - (0.63 \pm 0.07)$$



Emitting zones of CaT and FeII are similar

Panda, Martínez-Aldama & Czerny (in prep.)



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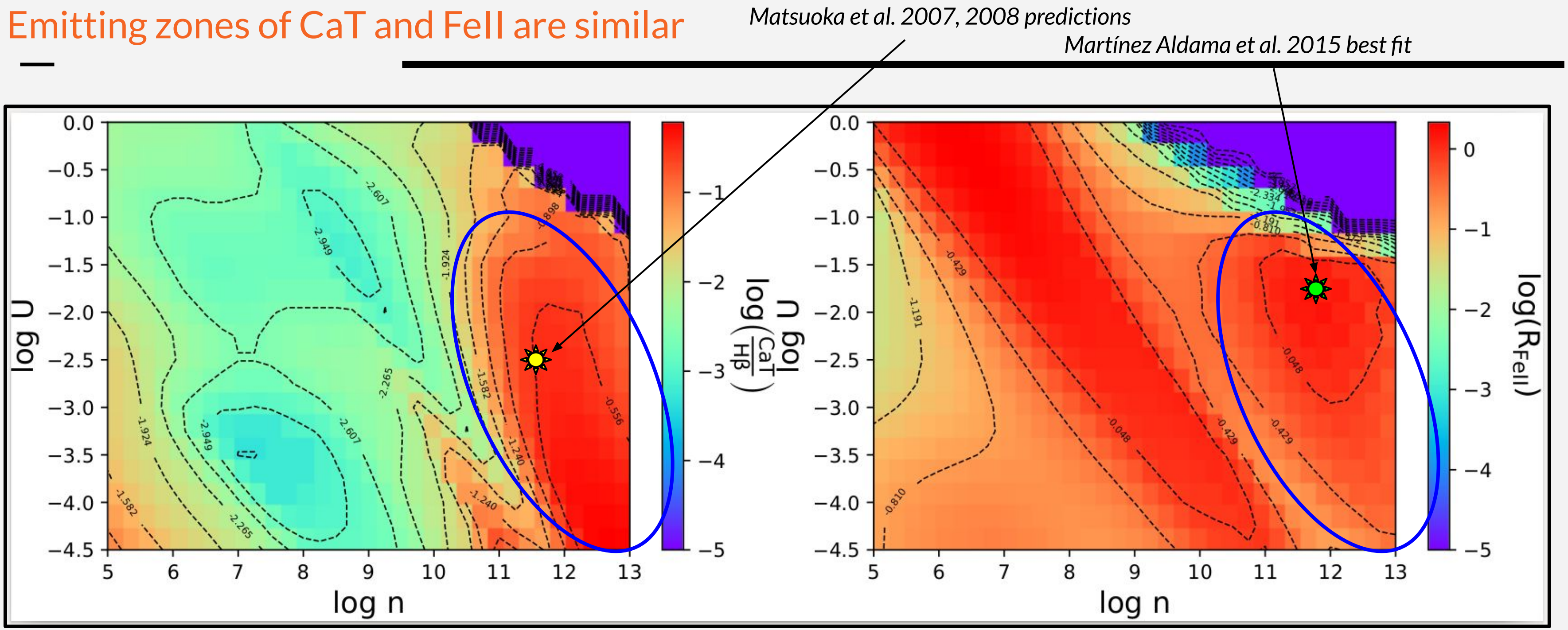

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Explaining high accreting quasars

The ingredients

$$U = \frac{Q(H)}{4\pi R_{BLR}^2 n(H) c} = \frac{\Phi(H)}{n(H) c}$$

Ionisation parameter

Explaining high accreting quasars

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$$U = \frac{Q(H)}{4\pi R_{BLR}^2 n(H) c} = \frac{\Phi(H)}{n(H) c}$$

+

$$\log\left(\frac{R_{BLR}}{1\ light-day}\right) = \kappa + \alpha \log\left(\frac{L_\lambda}{10^{44}}\right)$$

BLR radius- luminosity relation *(Bentz et al. 2013)*

Explaining high accreting quasars

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$$U = \frac{Q(H)}{4\pi R_{BLR}^2 n(H) c} = \frac{\Phi(H)}{n(H)c}$$

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➕

$$\tau_{corr}\left(\frac{L_{bol}}{L^c_{Edd}}\right) = 10^{-\Delta R_{H\beta}\left(\frac{L_{bol}}{L^c_{Edd}}\right)} . \tau_{obs}$$

Departure coefficient in the R-L relation for high accretors *(Martínez-Aldama et al. 2019)*

See **Mary Loli**'s talk later today!

Explaining high accreting quasars

The ingredients

$$U = \frac{Q(H)}{4\pi R^2_{BLR} n(H) c} = \frac{\Phi(H)}{n(H) c}$$

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+

$$\log\ (\dot{\mathcal{M}}, L_{bol}/L_{Edd}) = \alpha + \beta \mathcal{D}_{H\beta} + \gamma R_{FeII}$$

BLR fundamental relation *(Du et al. 2016)*

FWHM/σ

Panda, Martínez-Aldama & Czerny (in prep.)

Explaining high accreting quasars

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$$U = \frac{Q(H)}{4\pi R^2_{BLR} n(H) c} = \frac{\Phi(H)}{n(H)c}$$

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$$\log\ (\dot{\mathcal{M}}, L_{bol}/L_{Edd}) = \alpha + \beta \mathcal{D}_{H\beta} + \gamma R_{\rm FeII}$$

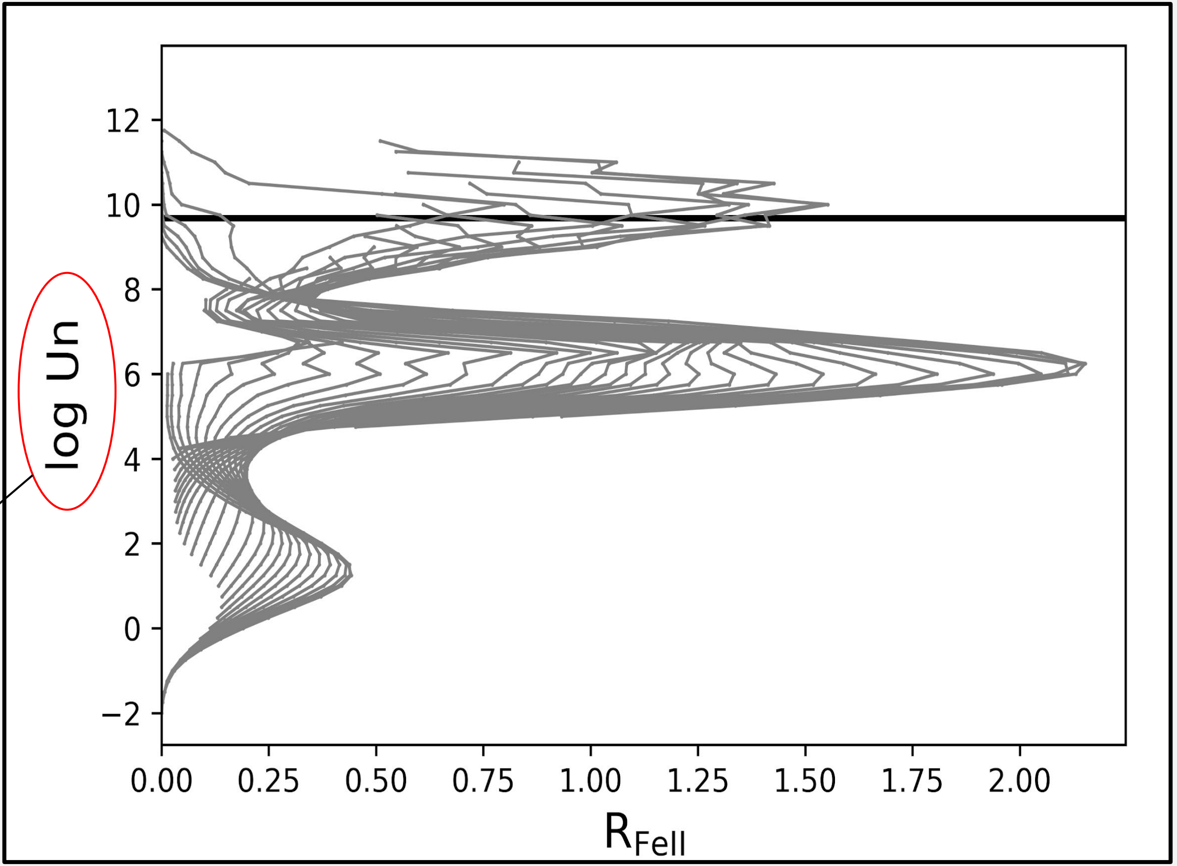
=

$$\log U = 9.683 - \log n(H) - 0.788\left[\alpha_2 + \beta_2 \mathcal{D}_{H\beta} + \gamma_2 R_{\rm FeII} - \log f^c_{BLR}\right]$$

Then...the simulation

Panda, Martínez-Aldama & Czerny (in prep.)

Results from a set of CLOUDY simulations (solid gray lines). The solid black line depicts for a *f*=1 and obeys standard *R-L* relation.



Density estimator

e.g. Marziani et al. (2014)

Next...the observations

Results from a set of CLOUDY simulations (solid gray lines) overlaid with **76 reverberation mapped sources** with $\mathbf{R_{FeII}}$ and Eddington ratio estimates. The solid black line depicts for a *f=1* and obeys standard *R-L* relation.

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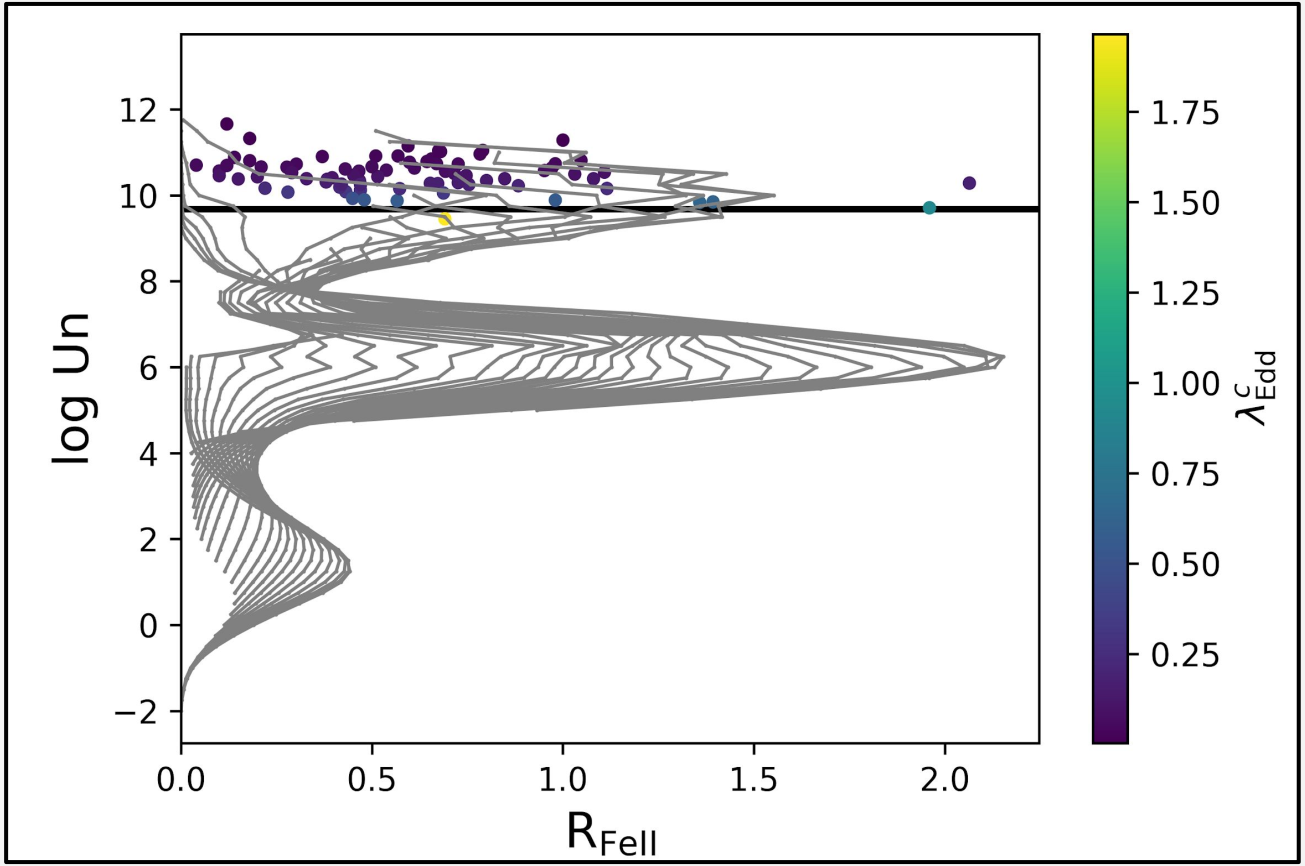

And finally...the connection!

Panda, Martínez-Aldama & Czerny (in prep.)

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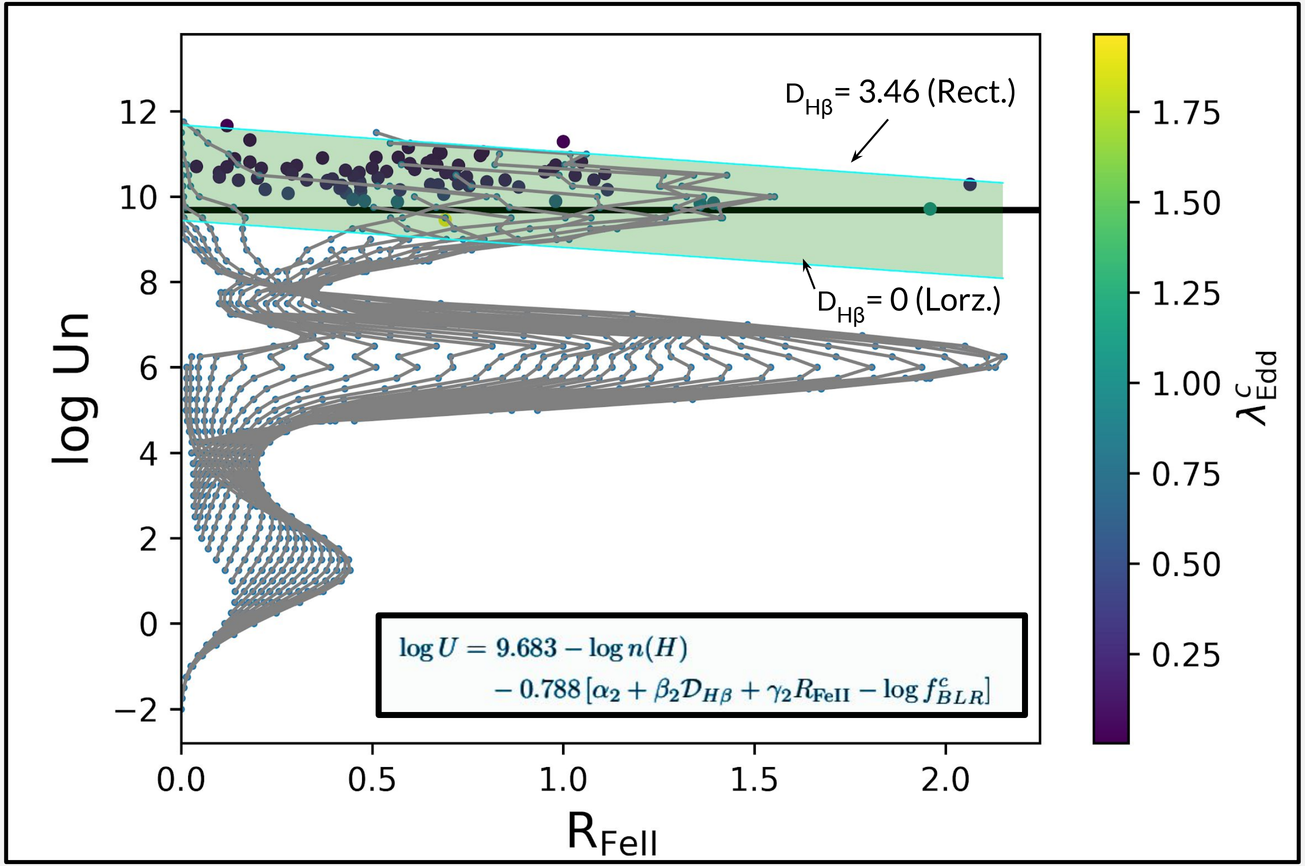
The shaded region depicts the zone that agrees with the analytical solution incorporating the correction for the departure from the *R-L* relation and the fundamental relation for the broad-line region.



But wait... there's more!

Panda, Martínez-Aldama & Czerny (in prep.)

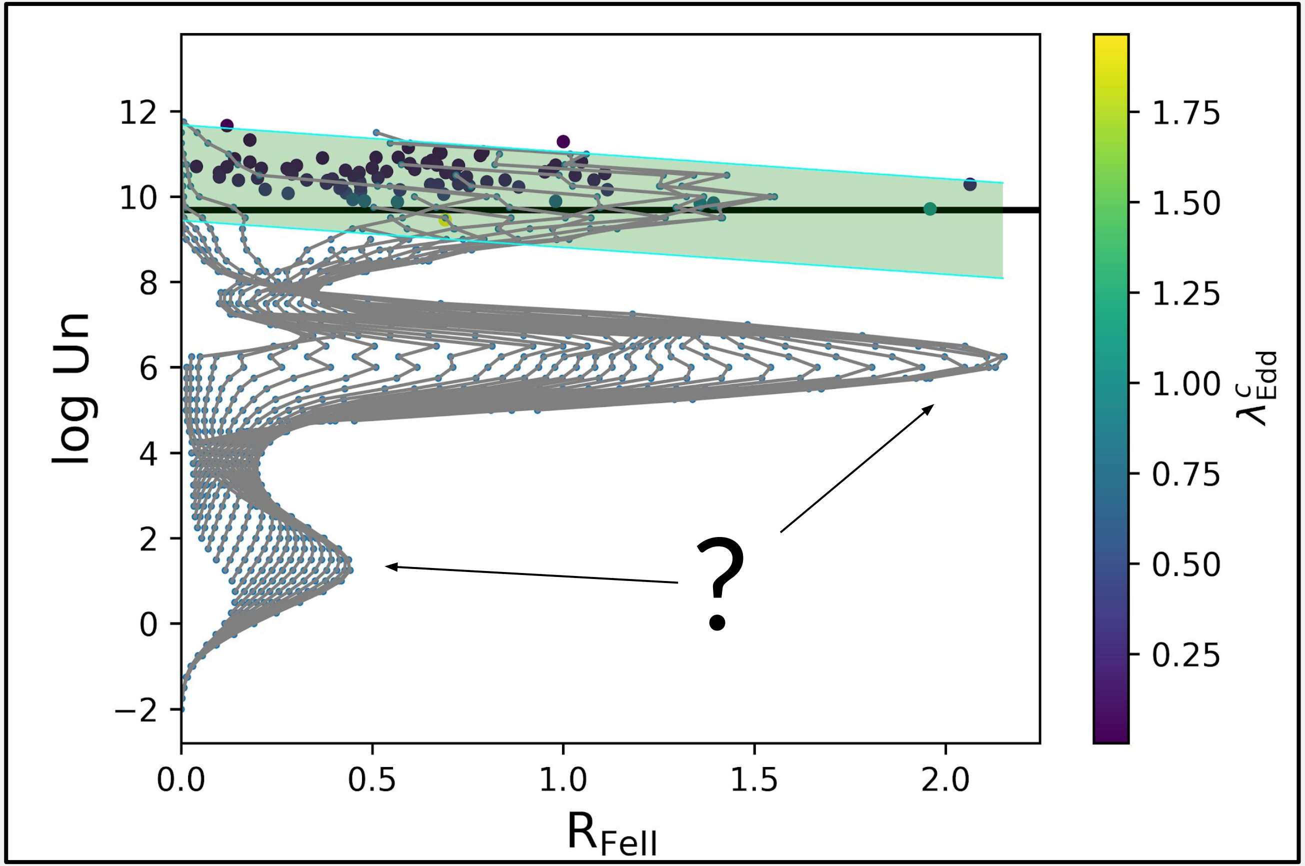
- The black solid line represents:

$\lambda_{Edd} = L_{bol}/L_{Edd} = 1$

- 9/77 sources are above this limit
- CLOUDY simulations show the presence of regions which can harbor "über-Eddington" sources, i.e.,

  $\lambda_{Edd} > 100$

- But no such quasar source is observed till now!



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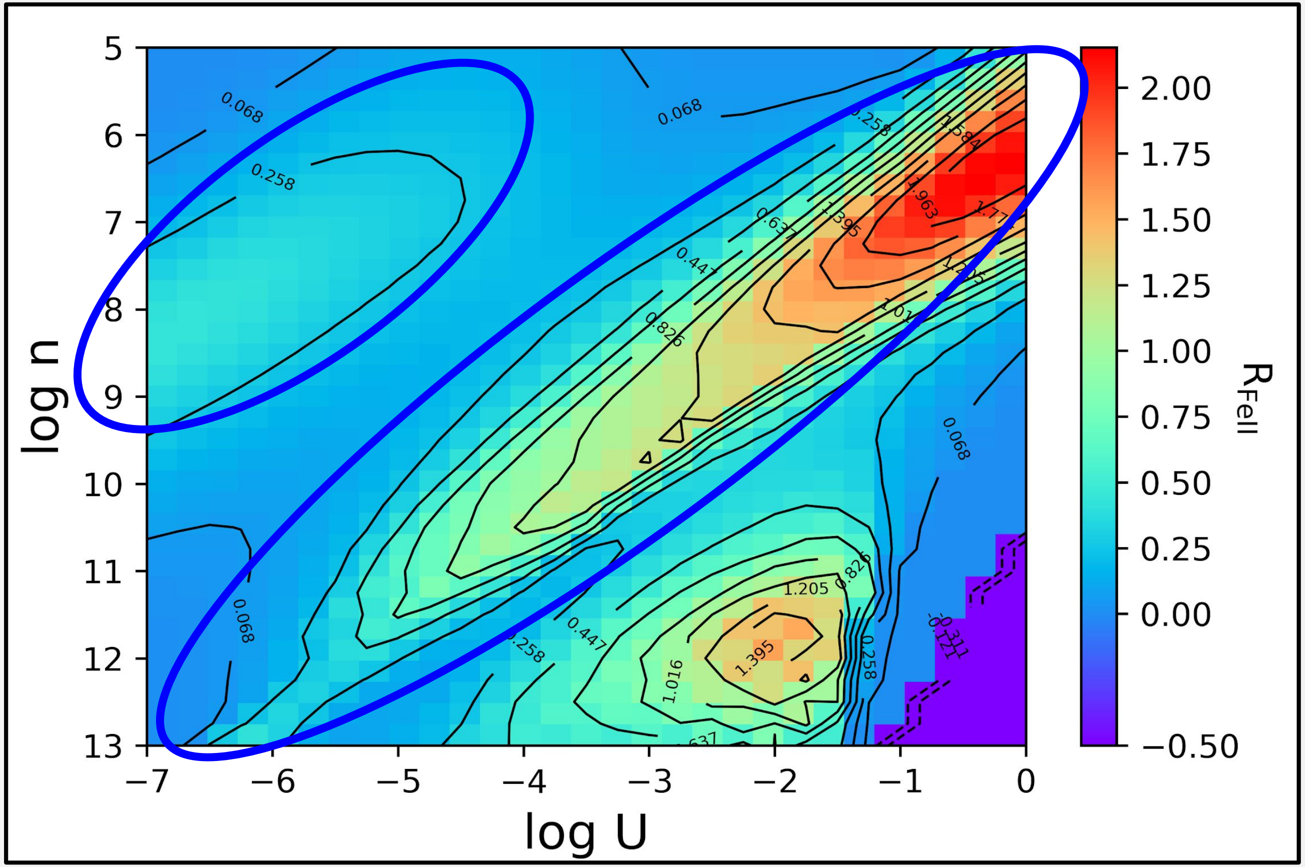

Invoking dust: Dust Sublimation radius

$$R_d = 0.4\ (L\ /\ 10^{45})^{0.5}\ [pc]$$

Nenkova et al. (2008)

$T_{dust} \approx 1500\ K$

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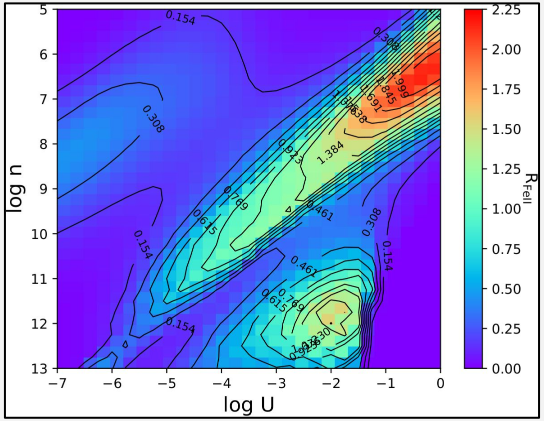

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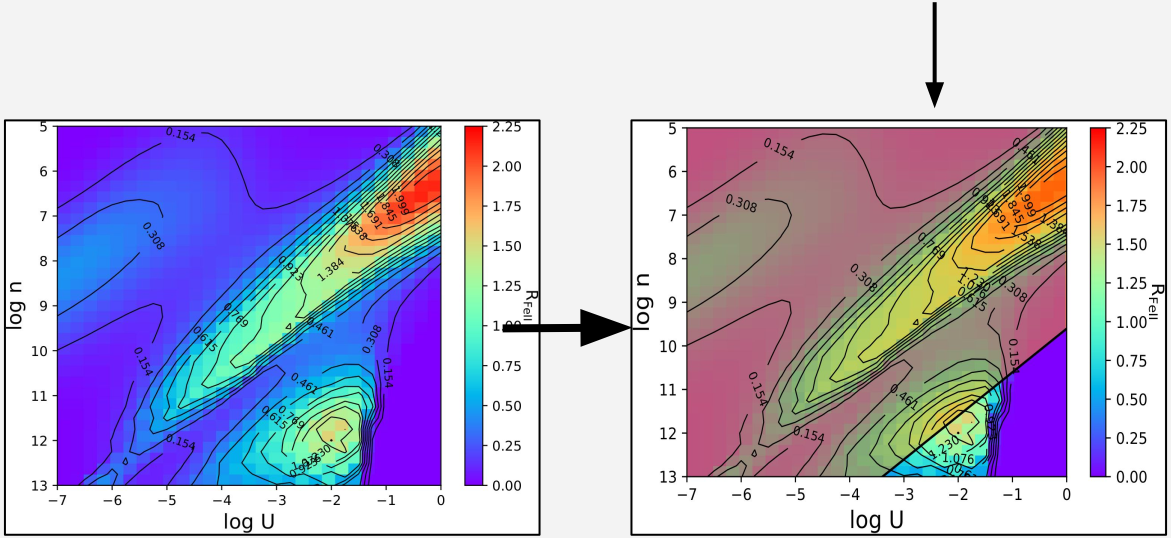

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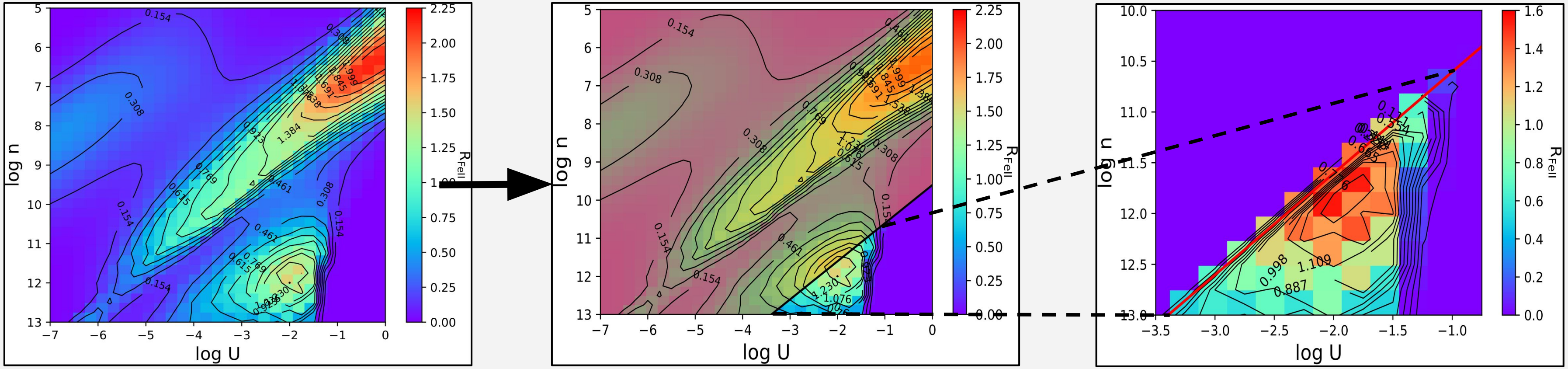
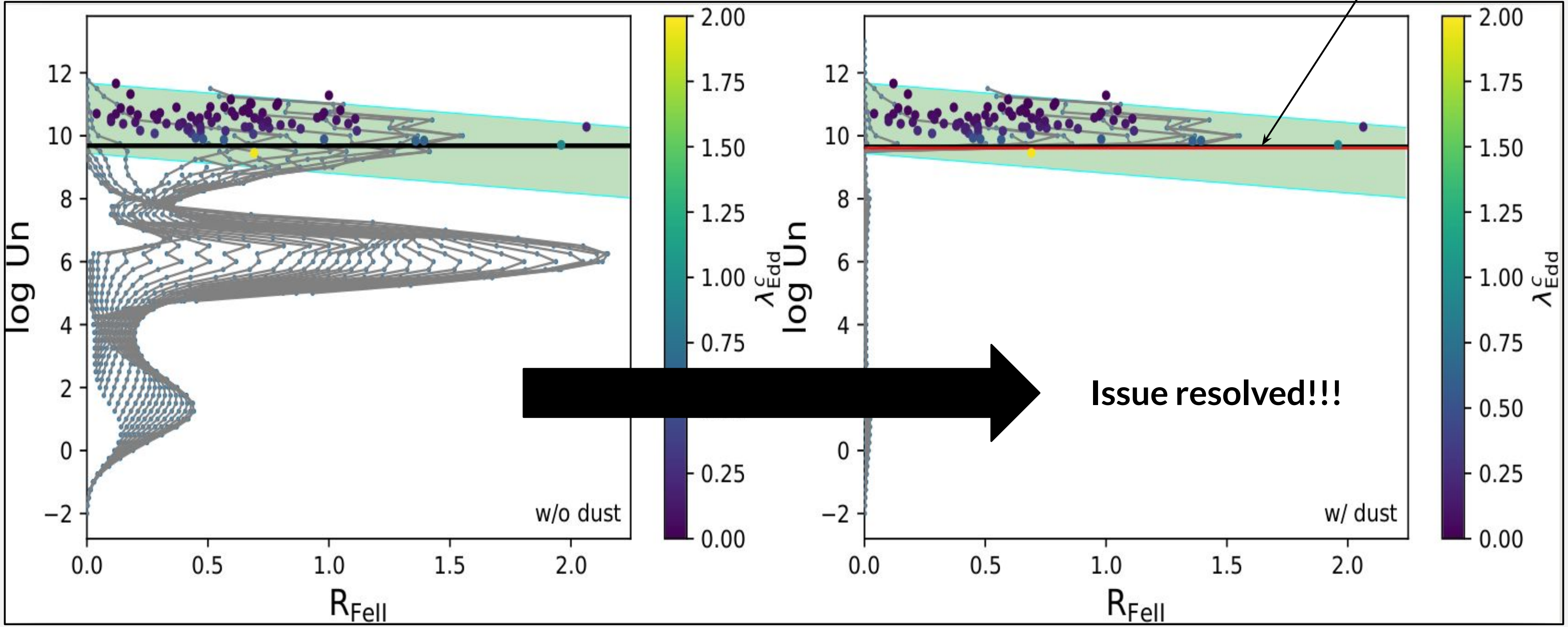
R_{FeII} confined in U - n_H space for BLR!



Inclusion of dust REMOVES those “über-Eddington” regions

Panda, Martínez-Aldama & Czerny (in prep.)

Dust sublimation



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CHECK OUR POSTER

1) A novel method to retrieve the **inclination angles** for quasars

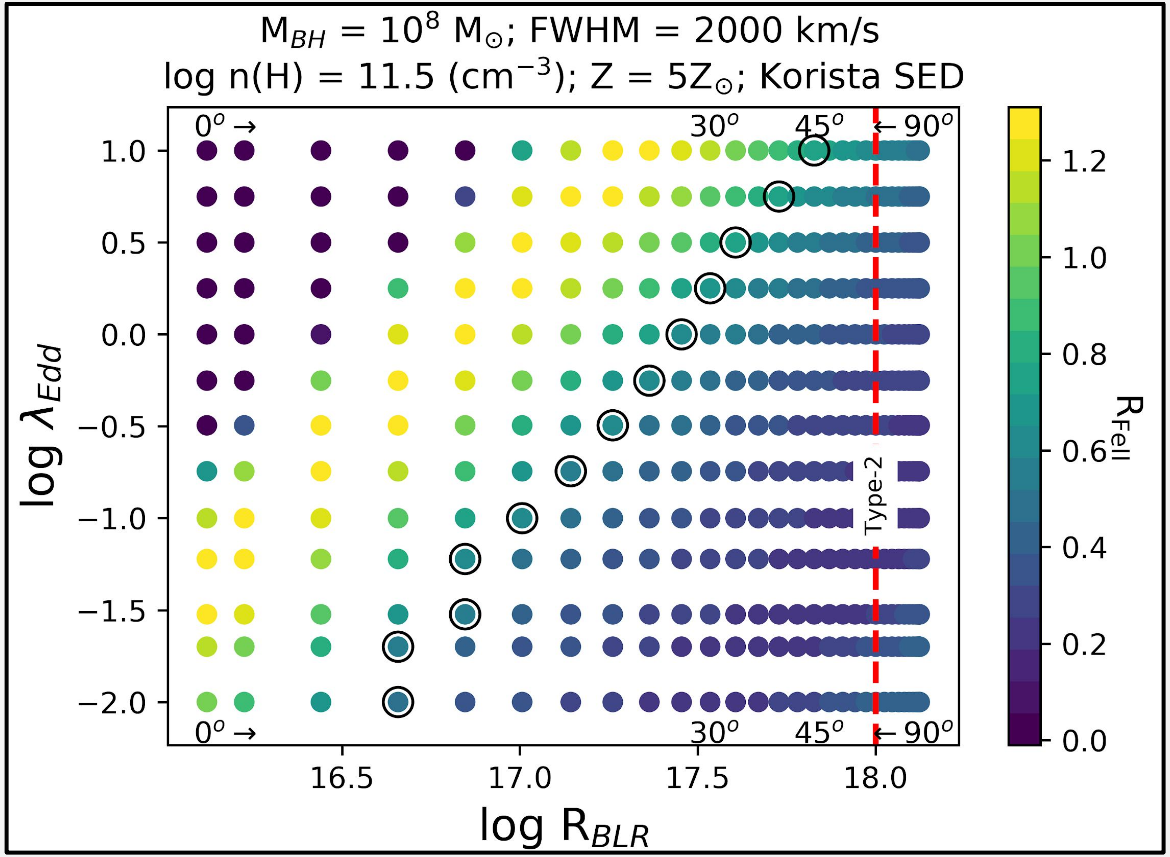
2) **R_{FeII}** is INDEED linked with the **L_{bol}/L_{Edd}**

3) ***Shorter*** **R_{BLR}** linked with ***higher*** **L_{bol}/L_{Edd}**

See our papers for more details:

Panda, Marziani & Czerny (2019b), ApJ, 882, 79 (arxiv 1905.01729)

Panda, Marziani & Czerny (2019c) (arxiv 1908.07972)



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1) A novel method to retrieve the **inclination angles** for quasars

2) $\mathbf{R_{FeII}}$ is INDEED linked with the $\mathbf{L_{bol}/L_{Edd}}$

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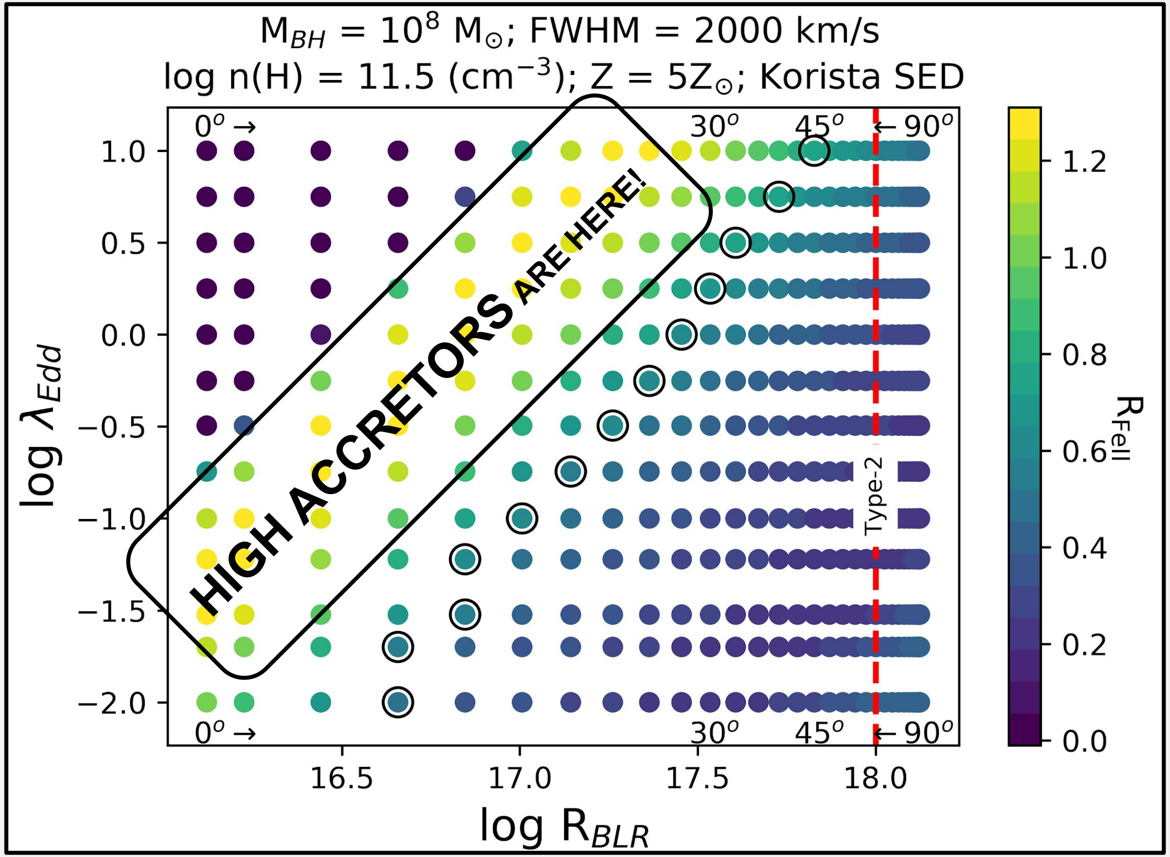

Some Answers

1. Establishing FeII confinement in terms of the physical parameters (*Ionisation parameter* and *BLR cloud density*)

2. Retrieving information about the accretion rate in terms of observables like **FeII strength**

3. Confirming the presence of dust in AGNs - from a different viewpoint

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Something to ponder upon...

1. Low-Ionization lines such as FeII - efficient tracer of the accretion process in AGNs?

2. Does the BLR fundamental plane relation still remain consistent with the newer data? A **new scaling relation**: $R_{H\beta}$ - L_{5100} *in terms of* R_{FeII} *directly*! (Du & Wang, 2019). *Need more attention...*

3. Is dust a primary reason we don't see "super" high accretors?

Thank you for your attention!

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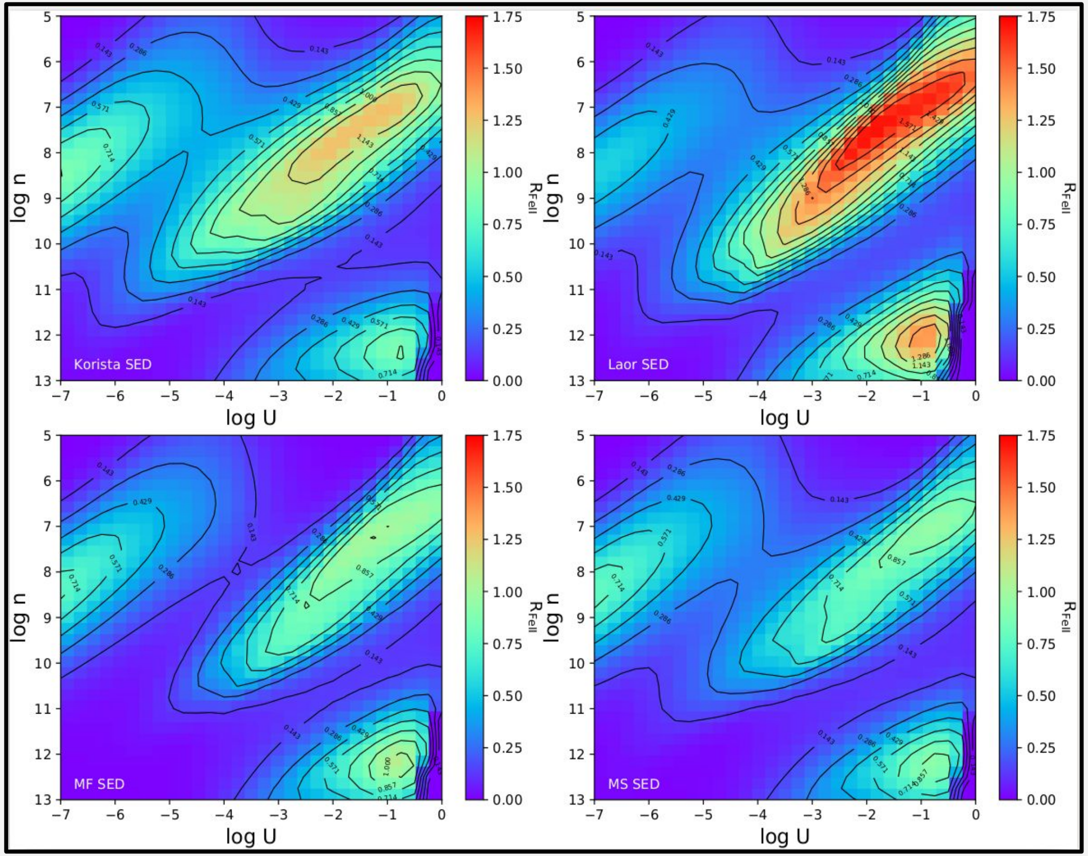
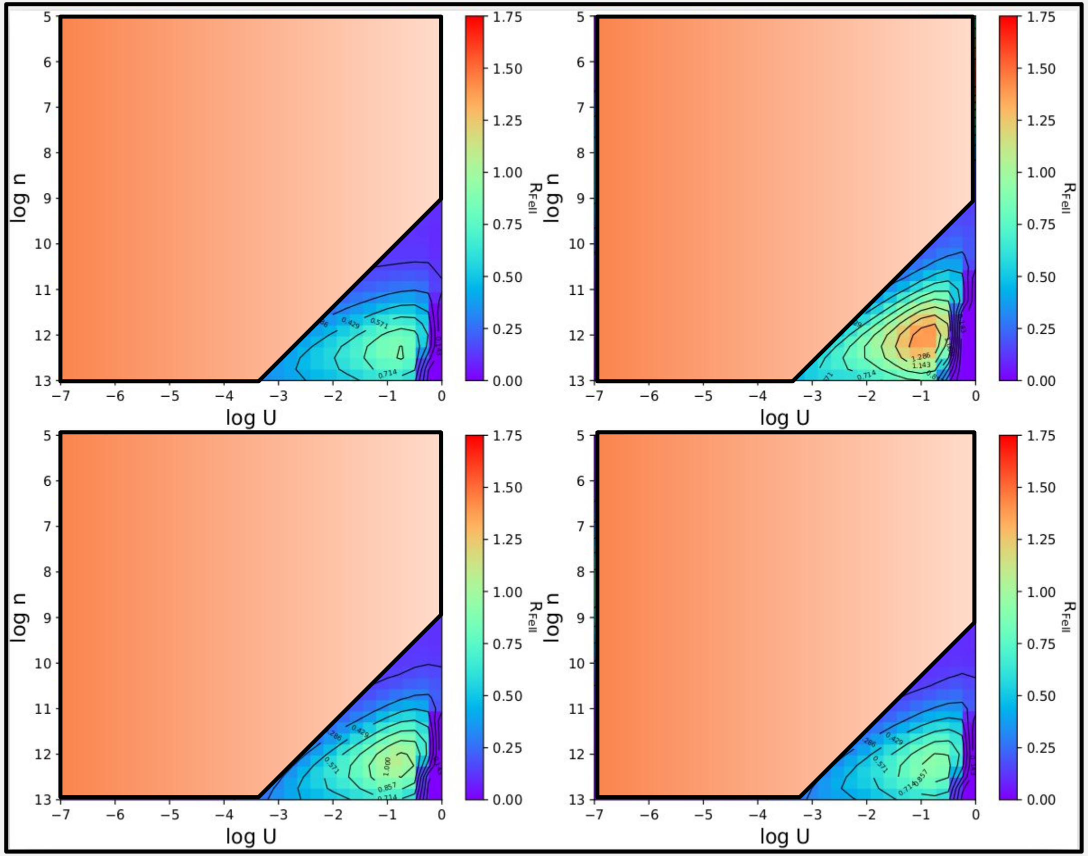
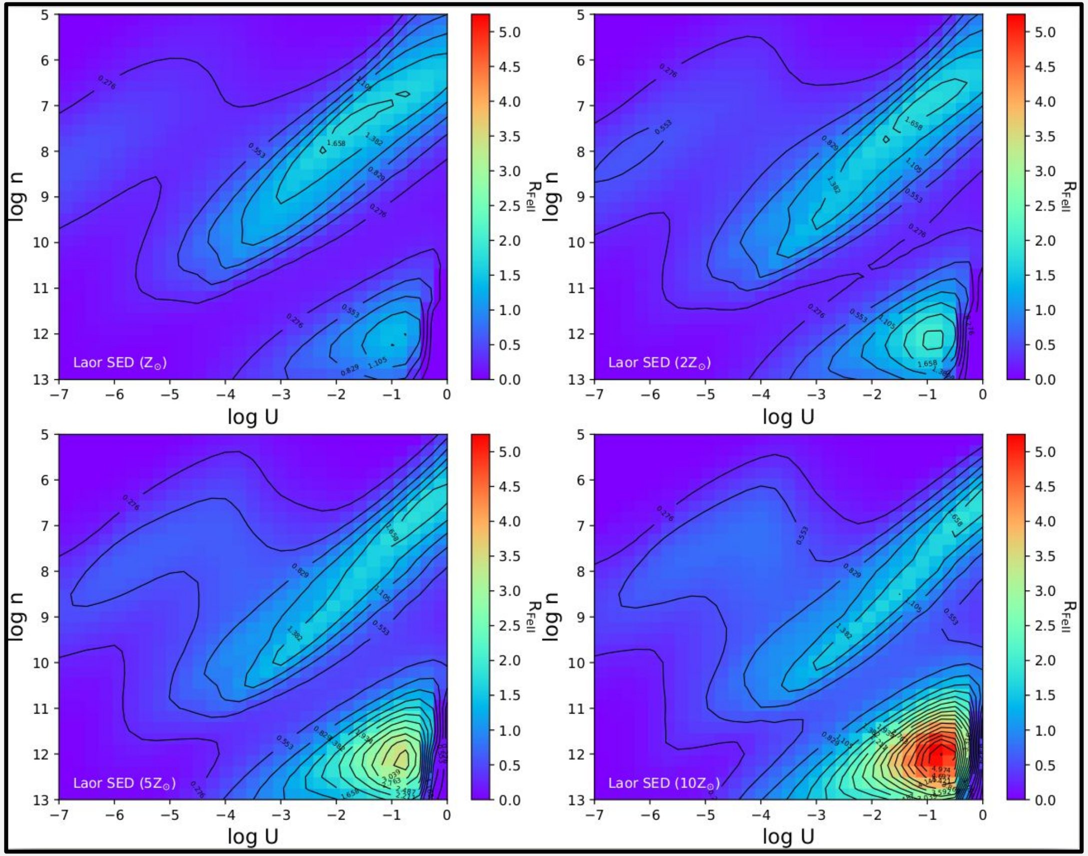
Effect of SED



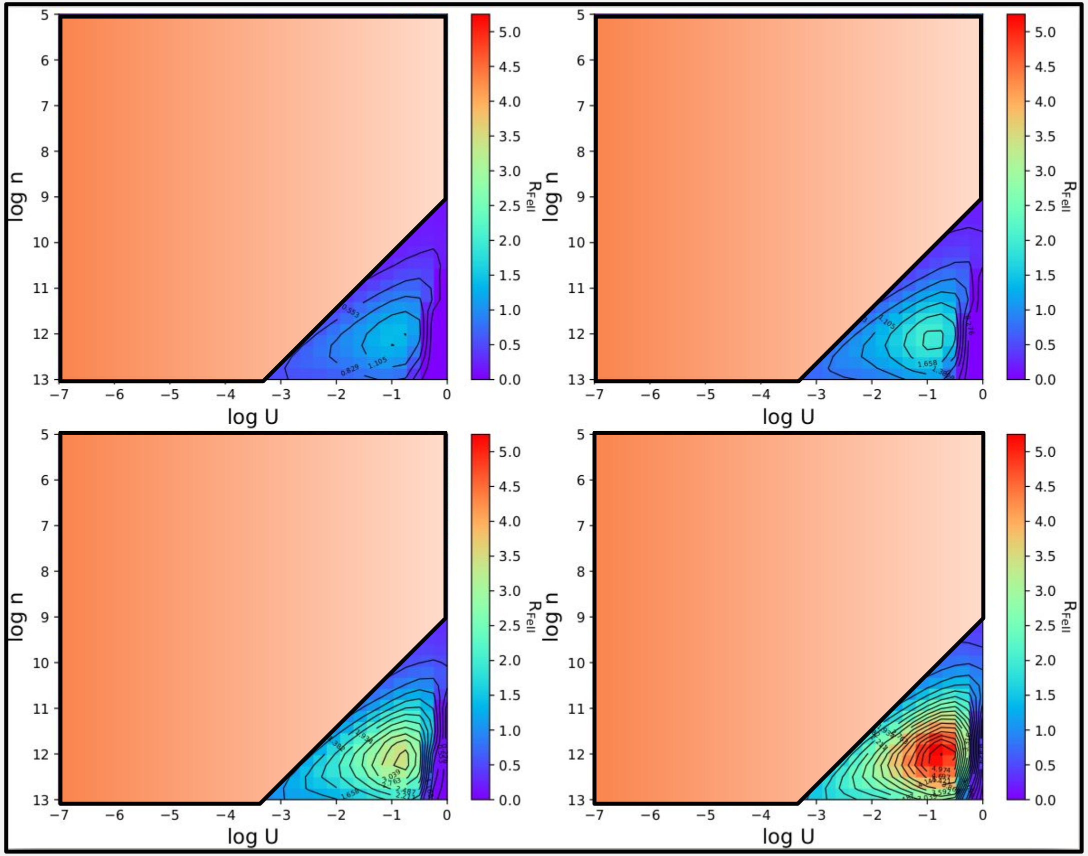
Effect of SED + dust



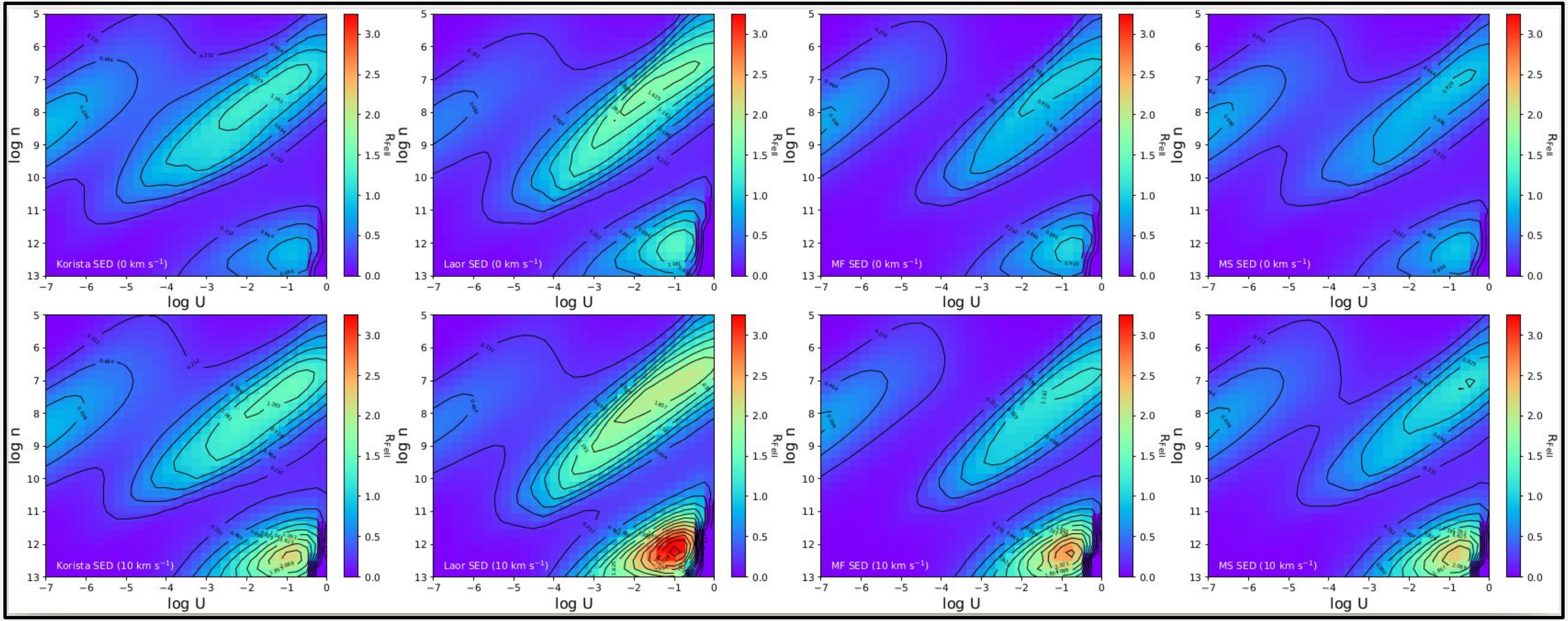
Effect of metallicity



Effect of metallicity + dust



Effect of ‘micro’-turbulence



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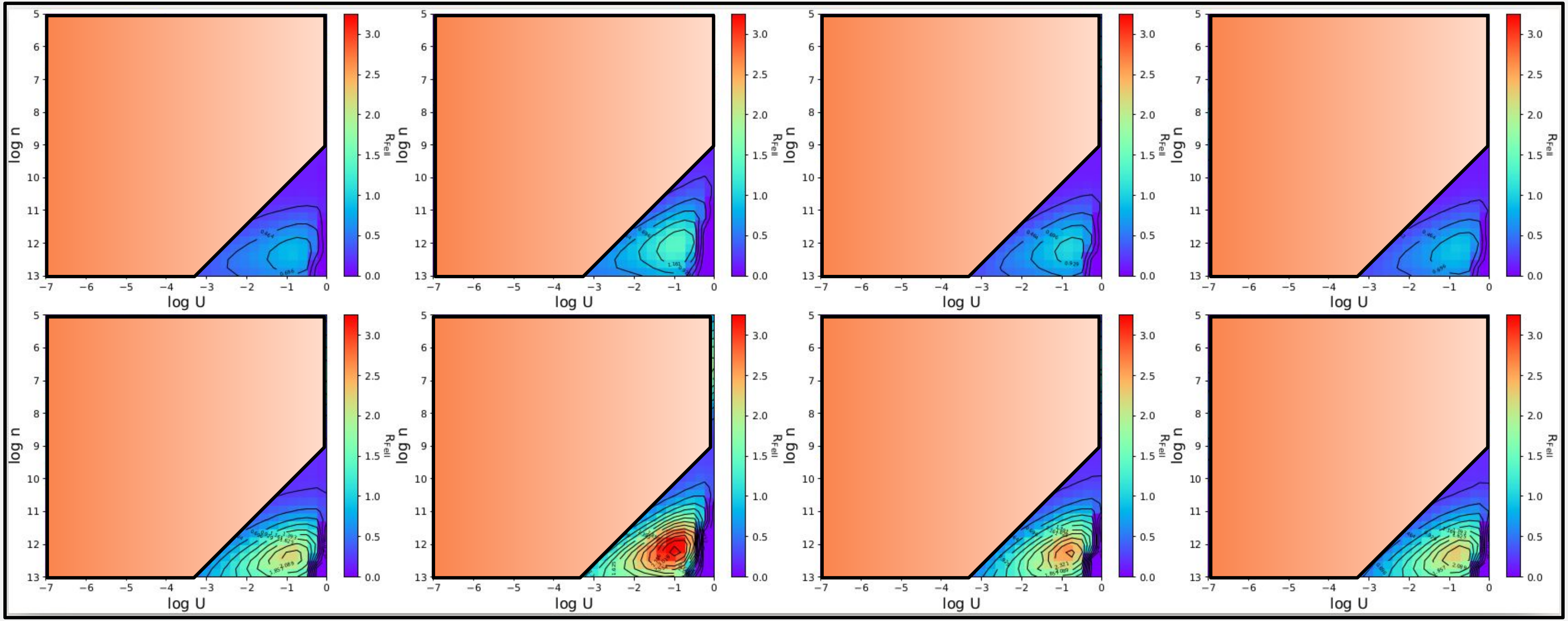

New U-n relation for $R_{H\beta}$ - L_{5100} - R_{FeII} relation?

$$\log\left(R_{\mathrm{H}\beta}/\mathrm{lt{-}days}\right) = \alpha + \beta \log \ell_{44} + \gamma \mathcal{R}_{\mathrm{Fe}}.$$

Du & Wang (2019)

Panda, Martínez-Aldama & Czerny (in prep.)

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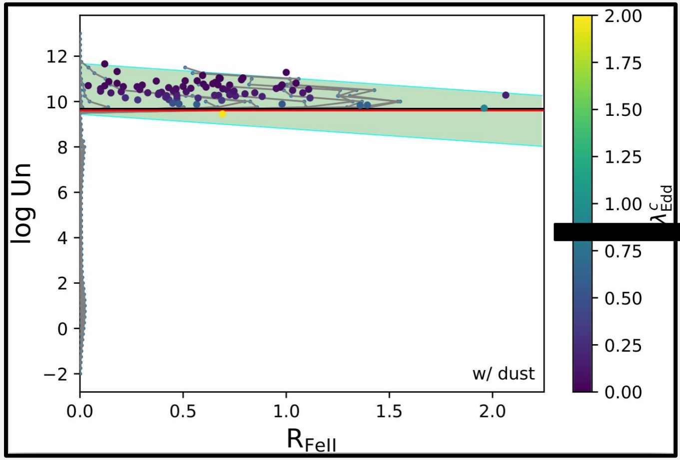

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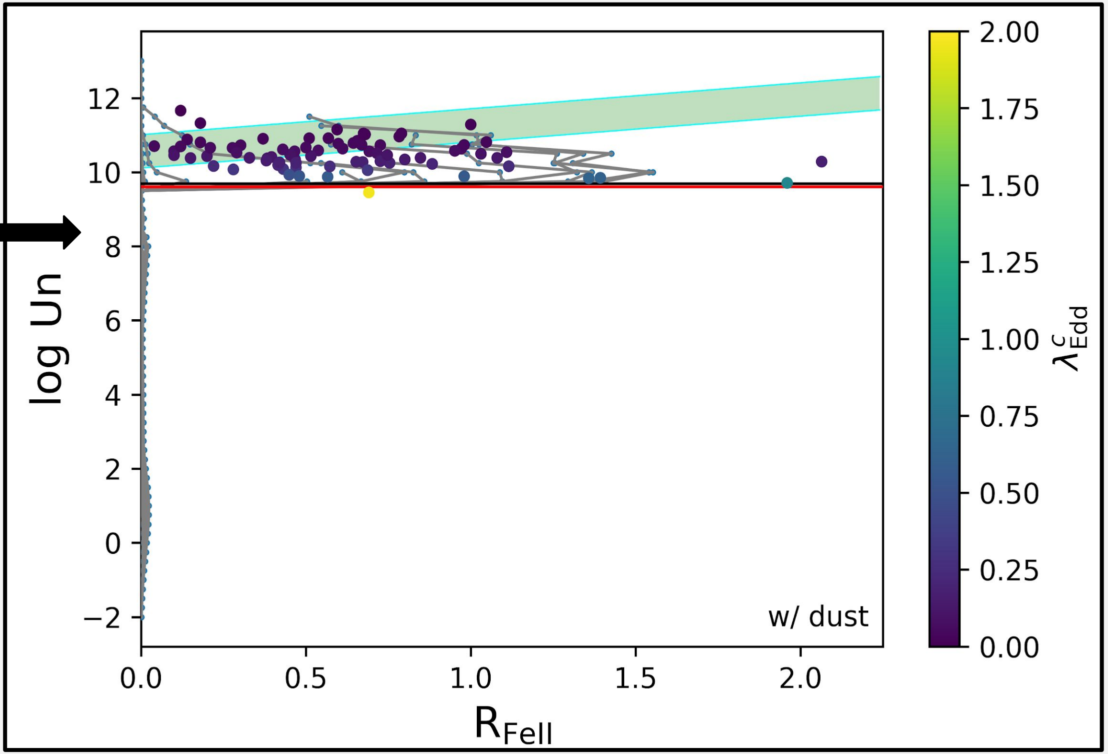
log Un = 6.31 + 0.1*log L_{5100} + 0.7 R_{FeII}



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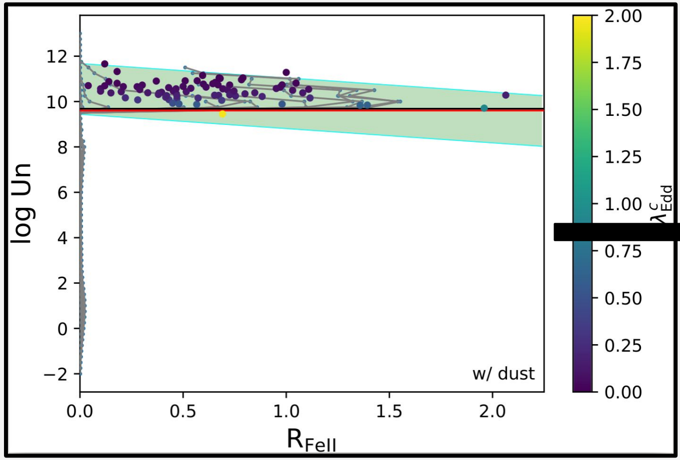

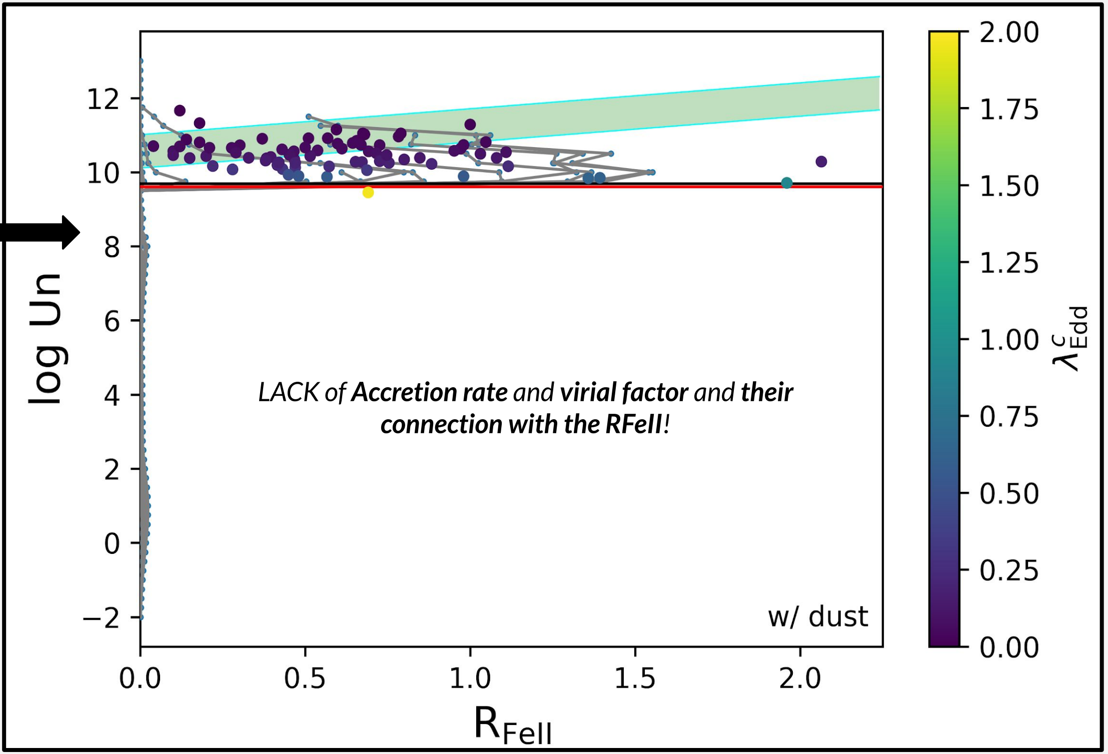

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