Main Trends of the QUASAR Main Sequence

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Overview

- **The diaspora in FeII emission**
  - mechanisms, multiplets, pseudo-continuum
- **Schema for the Eigenvector 1**
  - **Principal Component Analysis**, optical plane
  - the **Quasar Main Sequence**
- **“*Looking at it*” differently**
  - effect of viewing angle (*f*-factor), physical trends
  - the **Mass** effect
- **In progress**
  - cloud dynamics and composition
  - and something more...

The diaspora in FeII emission in AGNs

*~40-years in the making**

Why?

- To determine the Energy budget of the emitting gas, provided the emission is strong.
- Measurement of its Abundance = *f(cosmic time)*, to verify cosmological parameters.

How?

- Standard photoionisation
- Continuum fluorescence
- Collisional excitation
- Self-fluorescence among FeII transitions
- Fluorescent excitation by Lyα and Lyβ lines

Verner et al. 1999

"The atom is far from equilibrium in most emission-line objects, so the spectrum is sensitive to the detailed local conditions. A complete simulation of the physical processes affecting the Fe II spectrum would make it possible to deduce the density, temperature, and iron abundance of the emitting regions."

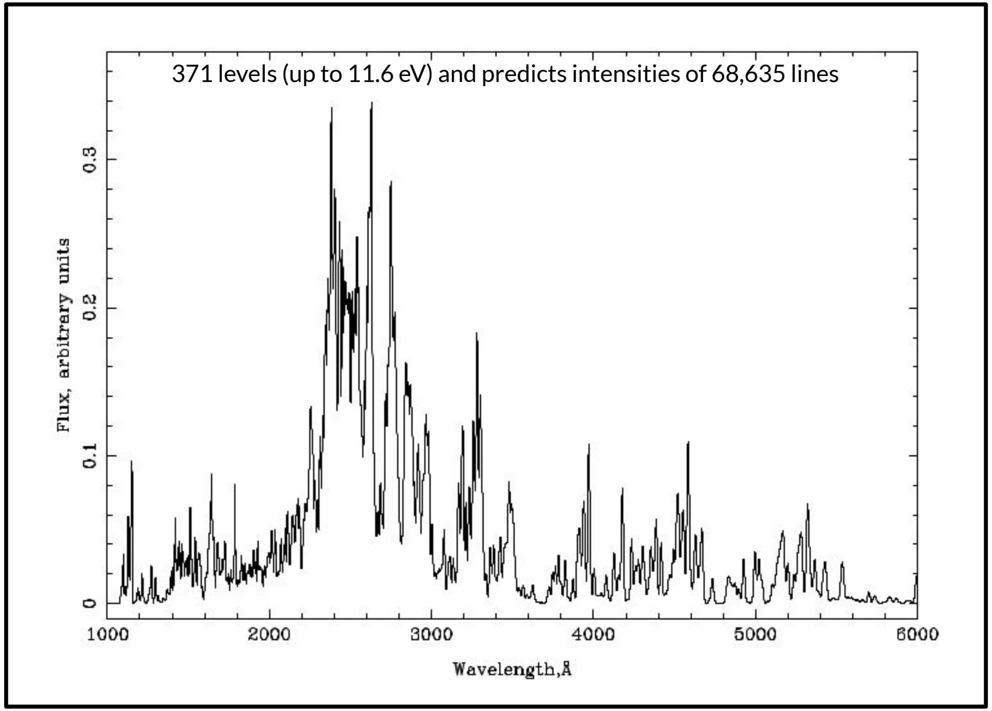
**Phillips (1978)*

Boroson & Green, 1992

- "*Make a template FeII spectrum by removing lines that are not FeII*" for PG 0050+124 (1 Zwicky 1) spectrum
- The result of their procedure was a spectrum representing only permitted FeII emission in 1 Zw 1 (removing Balmer lines, [OIII] lines, [NII] λ5755, blend of Na I D and He I λ5876, two intense [FeII] lines at λ5158 and λ5273)

- Theoretical FeII template (***Verner et al., 1999***)
- Empirical UV template (***Vestergaard & Wilkes, 2001***)
- Theoretical FeII template (***Sigut & Pradhan, 2002***)
- Semi-Empirical optical FeII template (***Véron-Cetty et al., 2003***)
- Optical FeII template based on FSG groups (***Kovacevic et. al, 2010***)
- 1Zw1-derived NIR FeII template (***Garcia-Rissmann et al., 2012***)

And others...



Theoretical UV and optical Fe II spectra calculated for the parameters expected in quasar broad emission line regions. The clouds are illuminated by a spectral energy distribution typical in AGNs, total hydrogen column density of 10^{24} cm^{-2}, and solar abundances: n = 10^{12} cm^{-3}, log (Φ_H) = 20.5 cm^{-2} s^{-1}

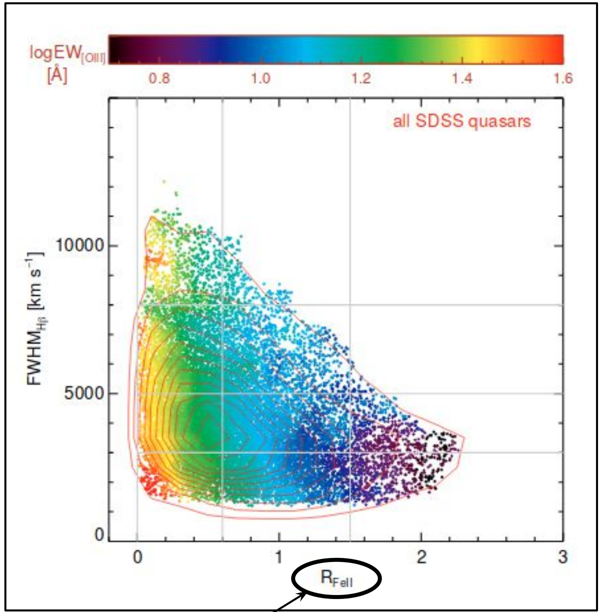
Verner et al. 1999

• Schema for the Eigenvector 1

Principal Component Analysis (PCA)

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

Boroson & Green, 1992



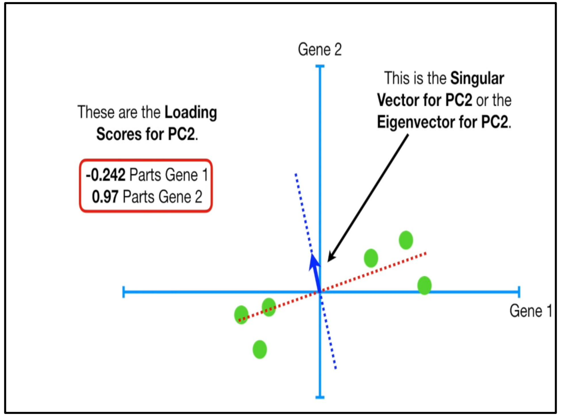
FeII emission within 4434-4684Å wrt broad Hβ

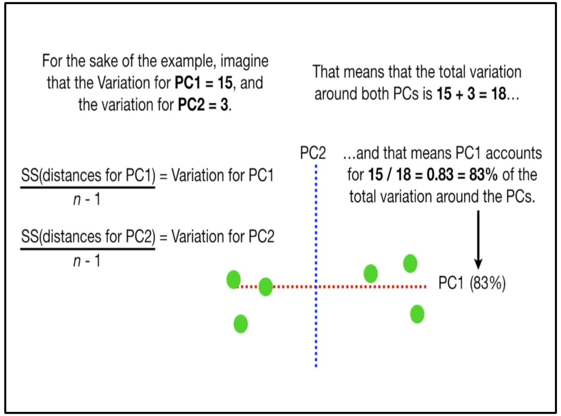
Shen & Ho, 2014

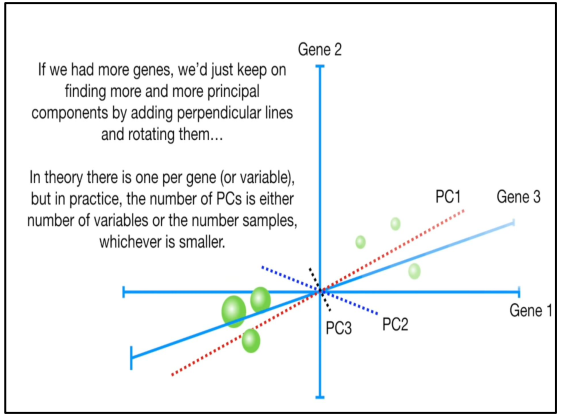
PCA in short

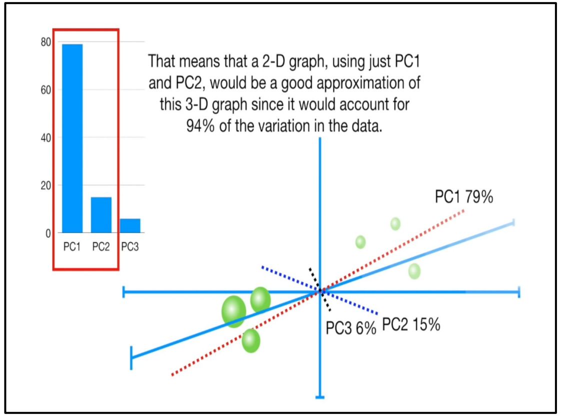
- Linear combination of variables
- Taking multi-dimensional data (> 2D) and making 2D plots
  - To show relevant clustering in data
  - To segregate parameters (principal components) based on *valuability* on clustering

- Basic steps:
  - Data shifted to origin
  - Least-square minimization to get best fit ⟵**PC**
  - Re-scale the best-fit to unity ⟵**Eigenvector**









StatQuest with Josh Starmer

“*Looking at it*” differently

Modelling the optical plane

- Mainly as a function of black hole mass & accretion rate
- Theoretical SED shapes, local density, cloud composition

Effect of viewing angle (*f*-factor)

$\kappa = v_{iso}/v_{\kappa}$

$$M_{\rm BH} = f\,\frac{r_{\rm BLR}{\rm FWHM}^2}{G} = \frac{r_{\rm BLR}{\rm FWHM}^2}{G(4\cdot(\kappa^2+\sin^2\theta))}$$

➕

account for R_{FeII} values in each spectral type along the MS, in a way consistent with the observational trends in metallicity, density, and SED

➕

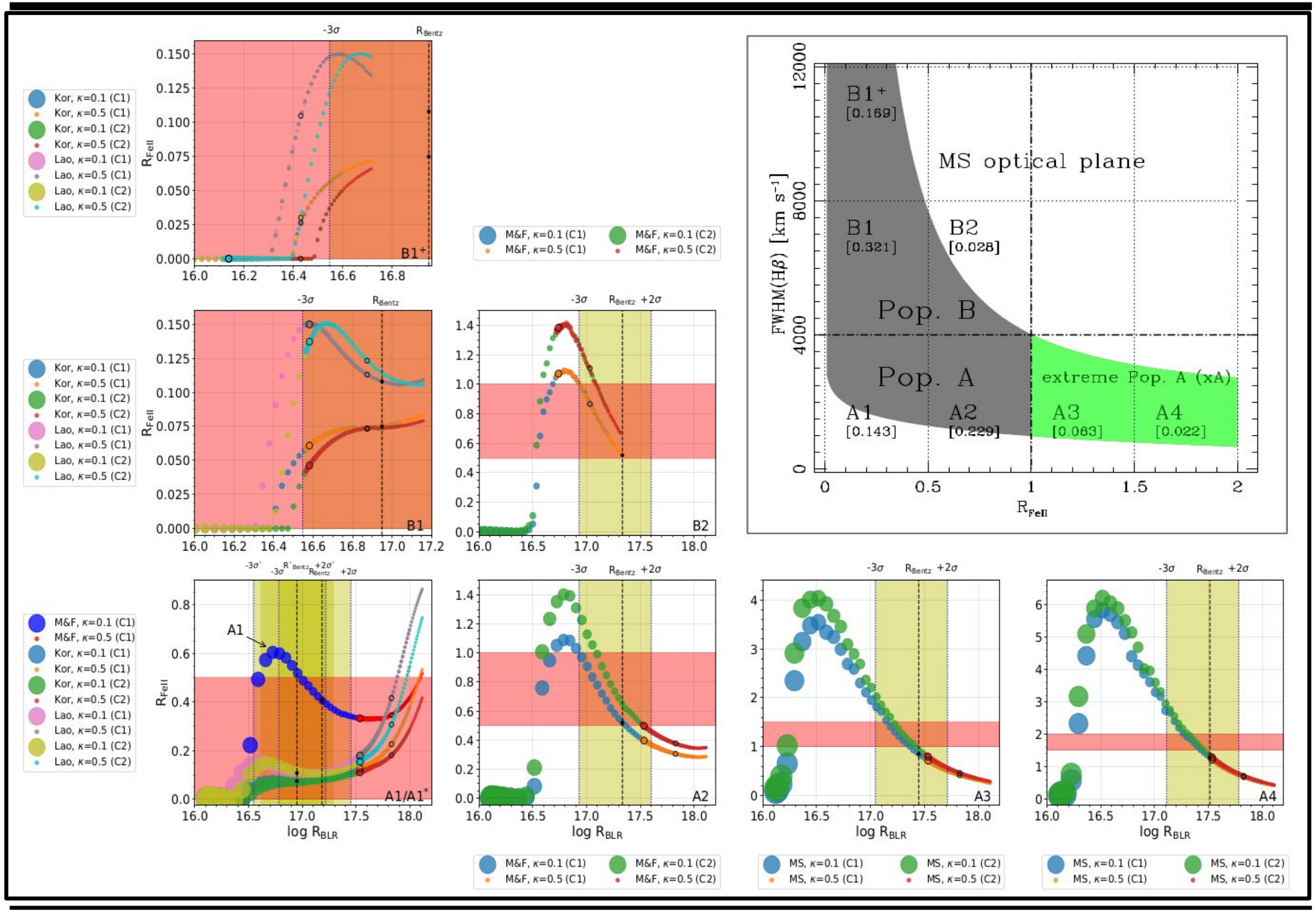
R_{FeII} dependence on L_{bol}/L_{Edd}

Panda et al. 2017, 2018, 2019

Panda, Marziani & Czerny (under-review)

Effect of viewing angle (f-factor), physical trends

Results from a set of CLOUDY simulations performed on a constant density single BLR cloud assuming $M_{BH} = 10^8 M_\odot$ showing the distribution of changing FeII strength with changing BLR sizes computed from the virial relation. Open circles mark the R_{FeII} values expected for θ = 30° and θ = 45°. The color patches (in red) in each spectral bin denote the range of R_{FeII} values as expected from observational evidences. The respective upper (+2σ) and lower (-3σ) bounds are shown by blue dashed lines about the r_{BLR} values estimated from the Bentz et al. (2013) relation (shown by black dashed lines) and the range is shown as green shaded regions. The inset diagram shows the optical plane of the Eigenvector 1, FWHM(Hβ) vs. R_{FeII}



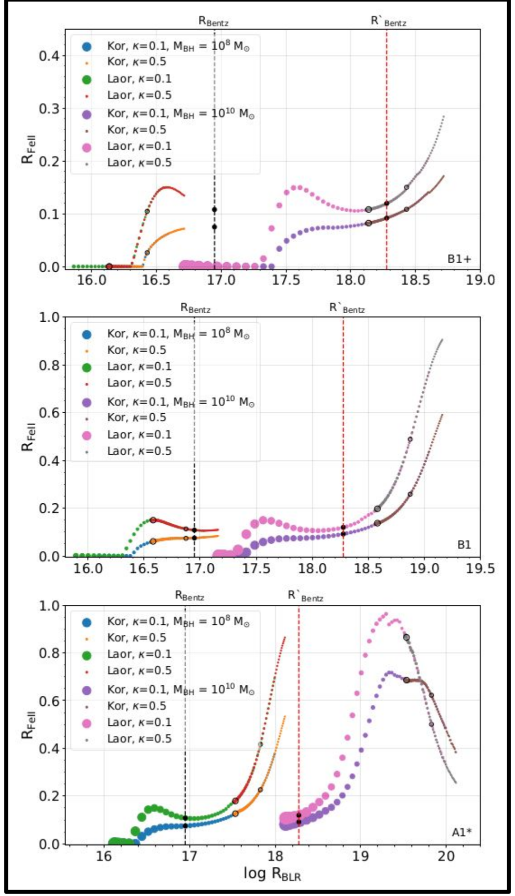
Panda, Marziani & Czerny (under-review)

Effect of viewing angle (*f*-factor), physical trends   the **Mass** effect

Excerpt of the Table 1 from our paper showing photoionization models of spectral types and associated prevalences

Case	ST	Z $[Z_\odot]$	$\log n_H$ $[\mathrm{cm}^{-3}]$	L/L_{Edd}	SED	θ[a]	$\log R_{BLR}$[b] [cm]	$\tilde{n}$ A1	A2	A3	A4	A5f[c]
C1/C2	A1	5	10.5	0.2	M&F	0 – 45	16.12 – 17.83	0.92	0.08	0.00	0.00	0.00
C1/C2	A1	5	10.5	0.2	M&F	10.9 – 26.8	16.78 – 17.45	0.26	0.05	0.00	0.00	0.00
C1	A2	5	11	0.5	M&F	0 – 45	16.12 – 17.83	0.735	0.215	0.05	0.00	0.00
C1	A2	5	11	0.5	M&F	13.51 – 32.7	16.93 – 17.60	0.25	0.20	0.00	0.00	0.00
C2	A2	5	11	0.5	M&F	0 – 45	16.12 – 17.83	0.58	0.31	0.11	0.00	0.00
C2	A2	5	11	0.5	M&F	13.5 – 32.7	16.93 – 17.60	0.09	0.30	0.05	0.00	0.00

Case	ST	Z	$\log n_H$	L/L_{Edd}	SED	θ	$\log R_{BLR}$	B1	B2	B3	B4	B5f
C1	B1	0.5	10	0.05	Kor	16 – 45	16.10 – 16.87	0.87	0.00	0.00	0.00	0.00
C1	B1	0.5	10	0.05	Kor	37.4 – 45	16.55 – 17.22	0.30	0.00	0.00	0.00	0.00
C1	B1	0.5	10	0.05	Lao	12 – 45	16.55 – 17.22	0.93	0.00	0.00	0.00	0.00
C1	B1	0.5	10	0.05	Lao	37.4 – 45	16.55 – 17.22	0.30	0.00	0.00	0.00	0.00
C2	B1	1.0	10	0.075	Kor	18 – 45	16.10 – 16.87	0.83	0.00	0.00	0.00	0.00
C2	B1	1.0	10	0.075	Kor	37.4 – 45	16.55 – 17.22	0.30	0.00	0.00	0.00	0.00



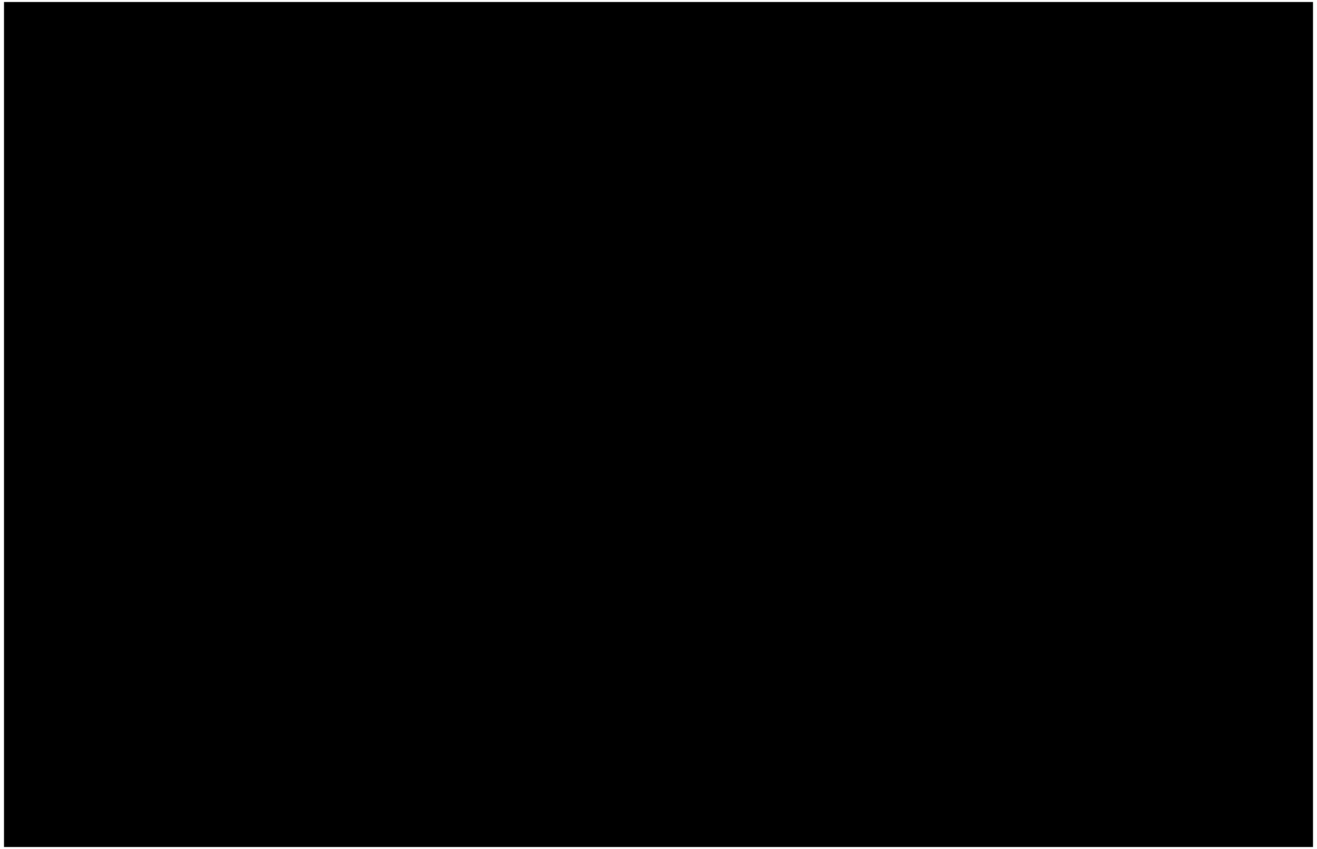
Results from a set of CLOUDY simulations performed on a constant density single BLR cloud assuming M_{BH} = 10^8 $M_\odot$ and M_{BH} = 10^{10} $M_\odot$

Panda, Marziani & Czerny (under-review)

In progress

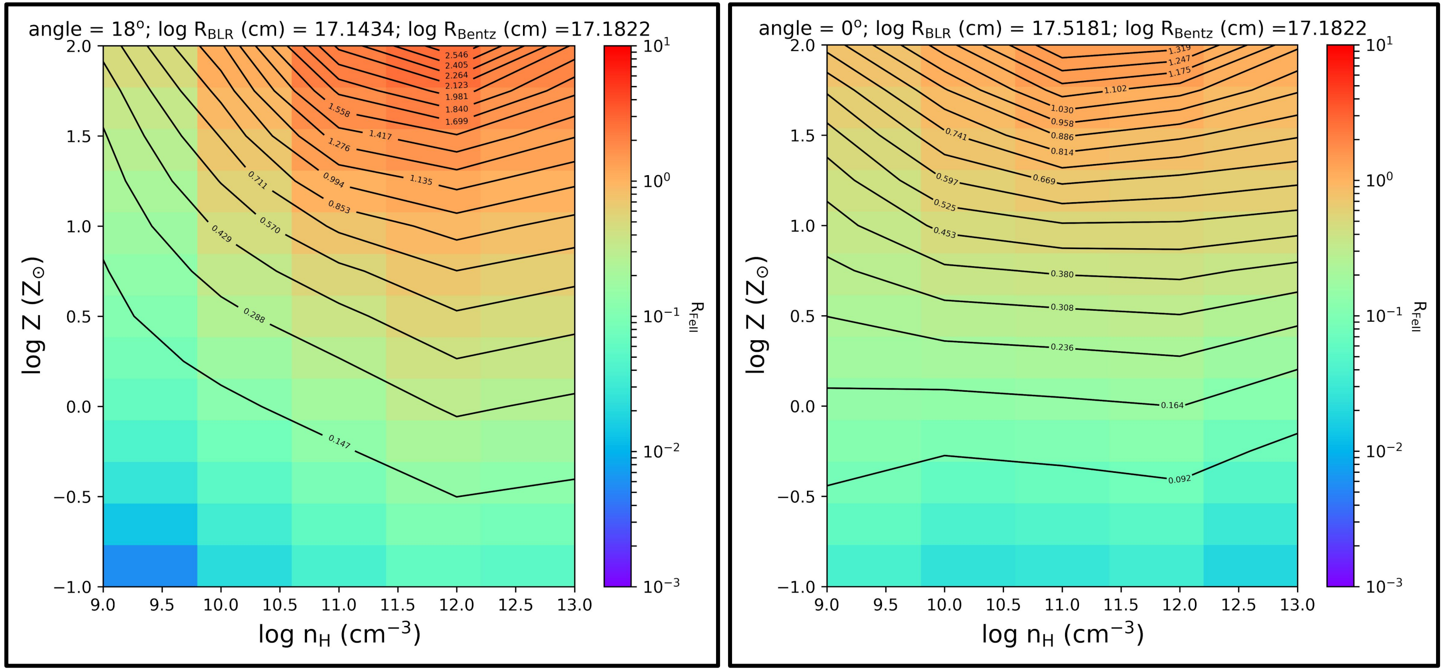
- Intra-cloud DYNAMICS and COMPOSITION
- Streamlining the FWHM DISTRIBUTION along the vertical spectral types with inclination
- Streamlining the MASS DISTRIBUTION with inclination
- Testing the model with CONSTANT BOLOMETRIC LUMINOSITY

Metallicity - cloud density distribution as a function of R_{FeII} at zero turbulence. The montage is shown as a function of increasing steps in inclination angles, the corresponding BLR size computed from the virial relation. The BLR size from the Bentz et al. 2013 *R-L* relation is shown for λ_{Edd}=0.2 and $M_{BH}=10^{10}\ M_{\odot}$. The SED shape used is taken from Korista et al. 1997. The distribution is shown for spectral type A1.



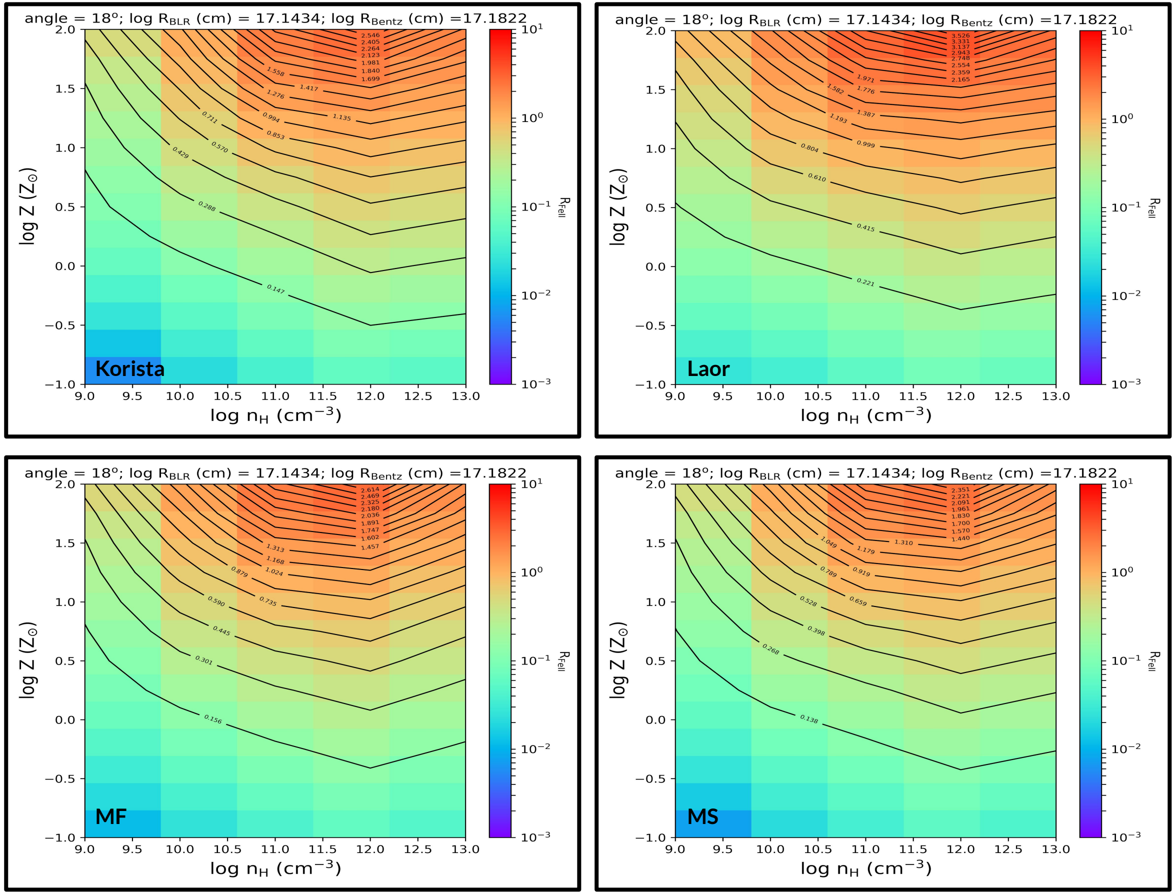
Panda et al. - in prep.

M8 k=0.1 vs k=0.5, Korista SED, Edd=0.2, A1



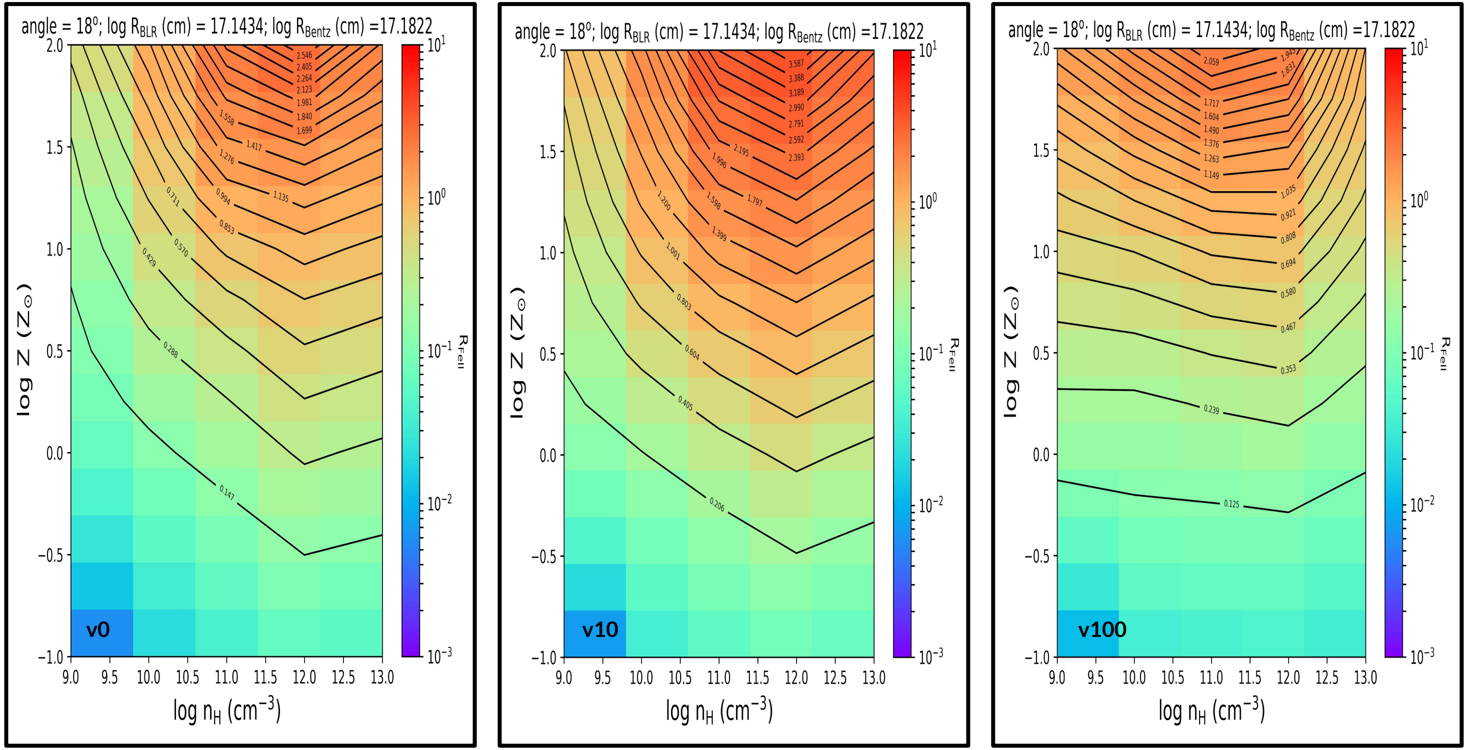
Panda et al. - in prep.

M8 SED compare, A1 vturb 0



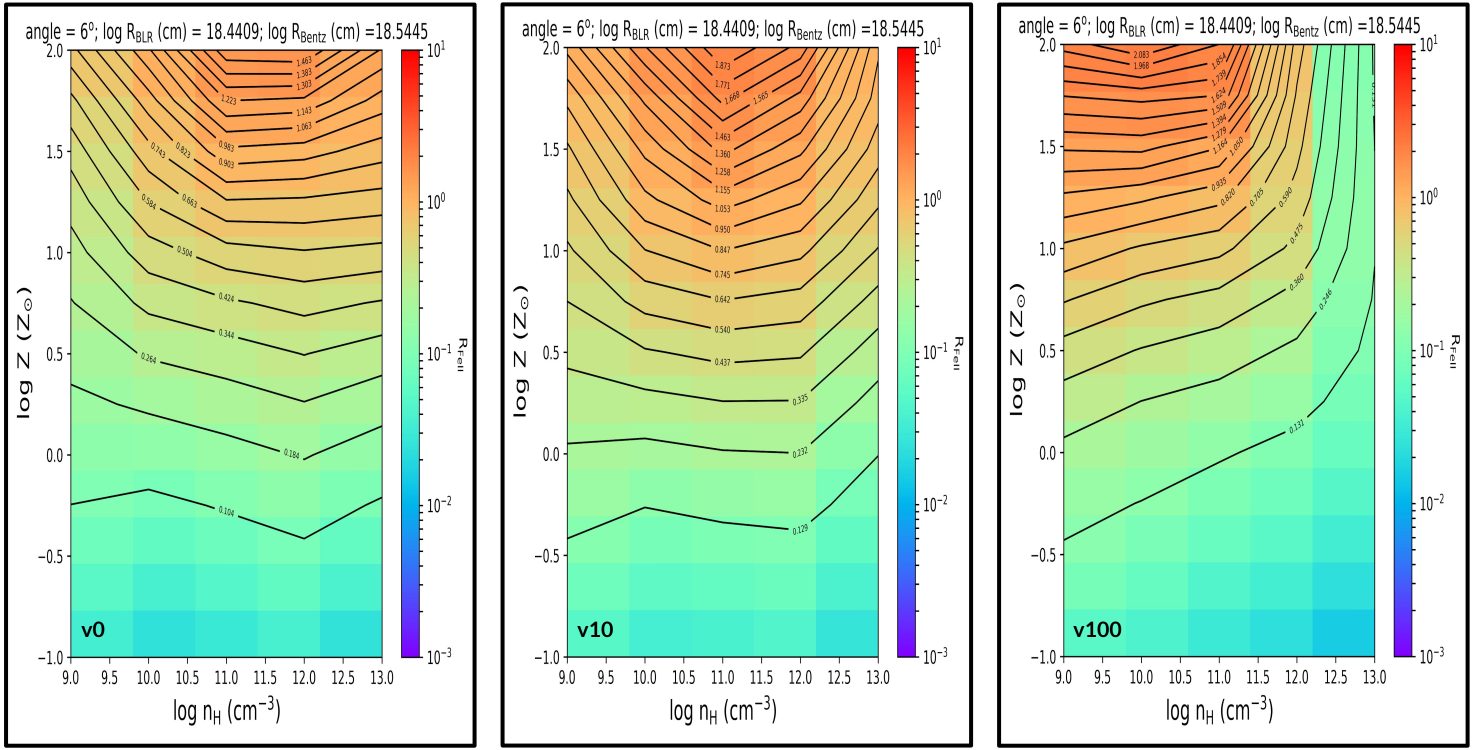
Panda et al. - in prep.

M8 vturb 0, 10, 100, Kor, A1



Panda et al. - in prep.

M10 vturb 0, 10, 100, Kor, A1



Panda et al. - in prep.

Thank you for your attention!

1. **FeII** is a complex species with numerous emission mechanisms.
2. The **Eigenvector 1 diagram** holds a key to understand the FeII emission and the rarity of strong FeII emitters
3. Combining $\mathbf{M_{BH}}$, **dM/dt** and **ϴ*** with a comprehensive FeII model
4. Constraining physical parameter space with observational trends
5. As a predictive tool for reverberation mapping studies
6. To explain xA quasars as ***standard Eddington candles*** as a probe for **Cosmology**.

**holy-trinity of quasars*