
Main Trends of the QUASAR Main Sequence

SWAYAMTRUPTA PANDA^{1,3} • PAOLA MARZIANI² • BOŻENA CZERNY¹

¹CENTER FOR THEORETICAL PHYSICS, WARSAW

²INAF-ASTRONOMICAL OBSERVATORY OF PADOVA

³NICOLAUS COPERNICUS ASTRONOMICAL CENTER, WARSAW



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 = $f(\text{cosmic time})$** , to verify cosmological parameters.

How?

- Standard photoionisation
- Continuum fluorescence
- Collisional excitation
- Self-fluorescence among FeII transitions
- Fluorescent excitation by Ly α and Ly β 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.”

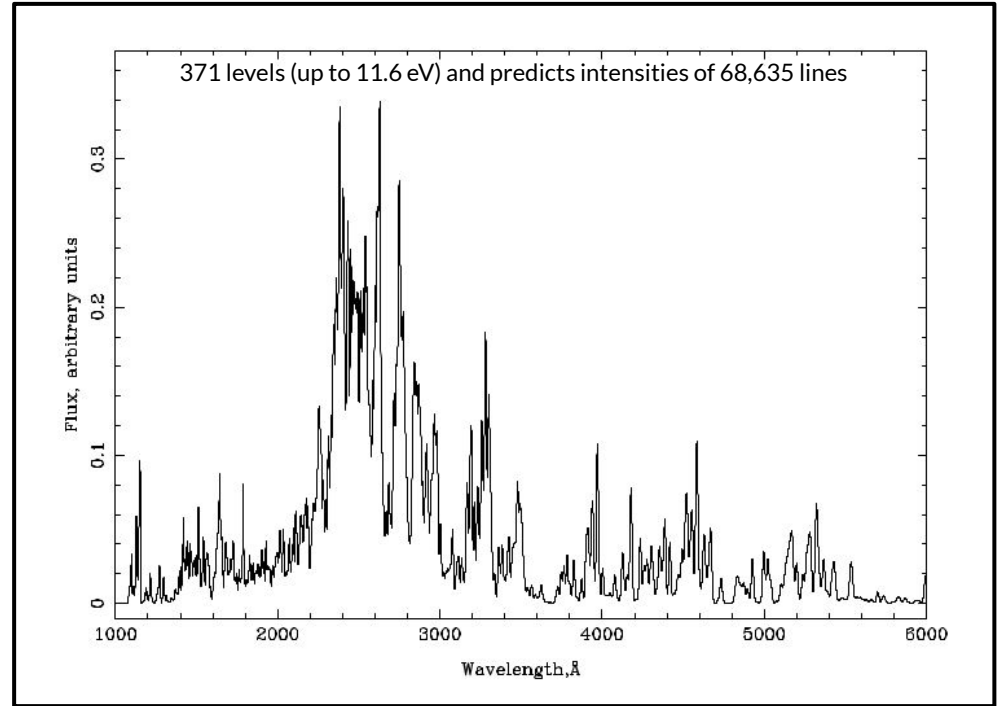
*Phillips (1978)

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] λ 5755, blend of Na I D and He I λ 5876, two intense [FeII] lines at λ 5158 and λ 5273)

- 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...



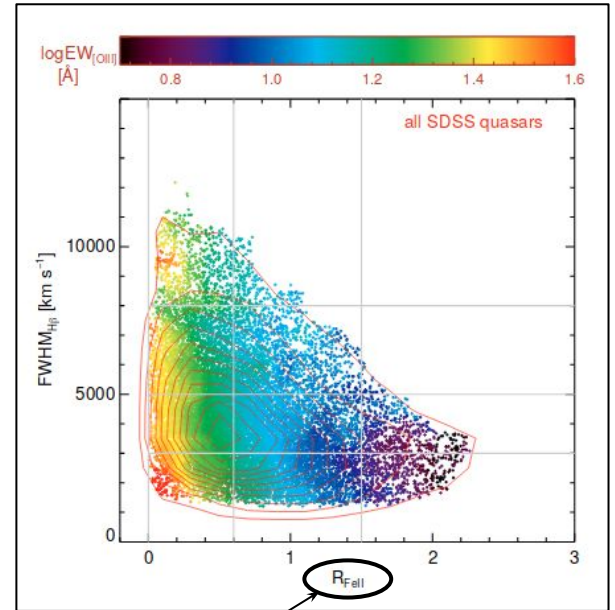
Theoretical UV and optical Fe II spectra calculated for the parameters expected in quasar broad emission line regions. The clouds are illuminated by a spectral energy distribution typical in AGNs, total hydrogen column density of 10^{24} cm^{-2} , and solar abundances: $n = 10^{12} \text{ cm}^{-3}$,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

● Schema for the Eigenvector 1

Principal Component Analysis (PCA)

- 13 tabulated properties
- Eigenvector 1: FeII - [OIII] anti-correlation
- Peak $\lambda 5007$ and H β FWHM correlation

Boroson & Green, 1992

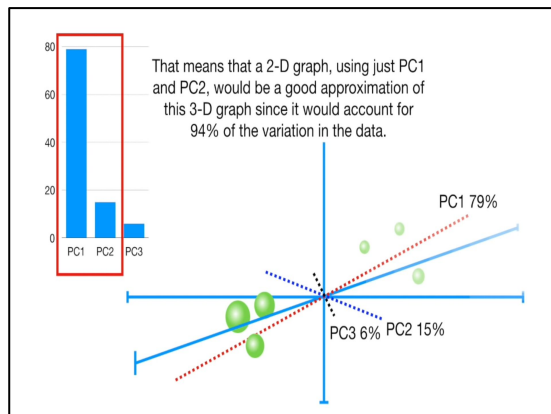
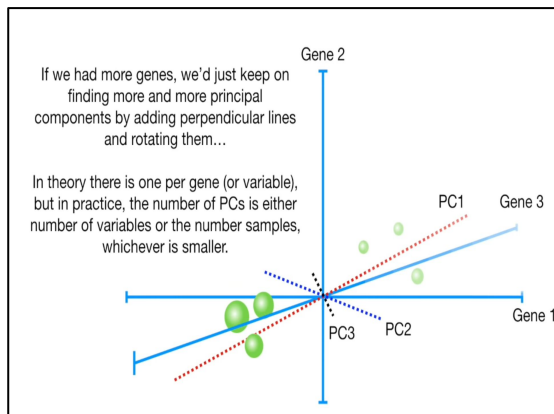
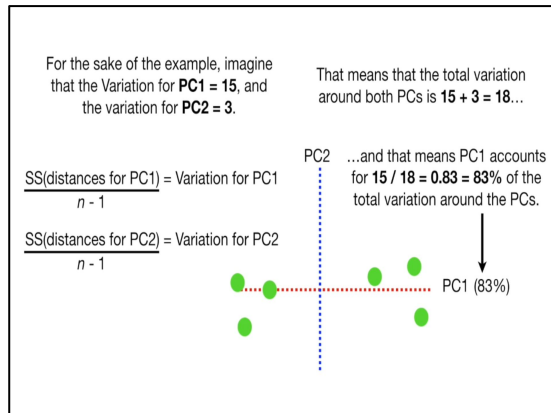
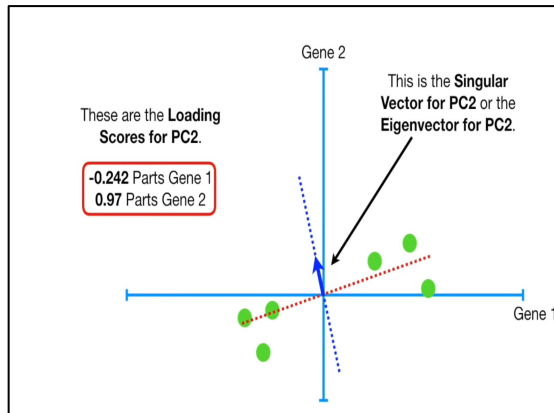


FeII emission within 4434-4684Å wrt broad H β

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**



“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)

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



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

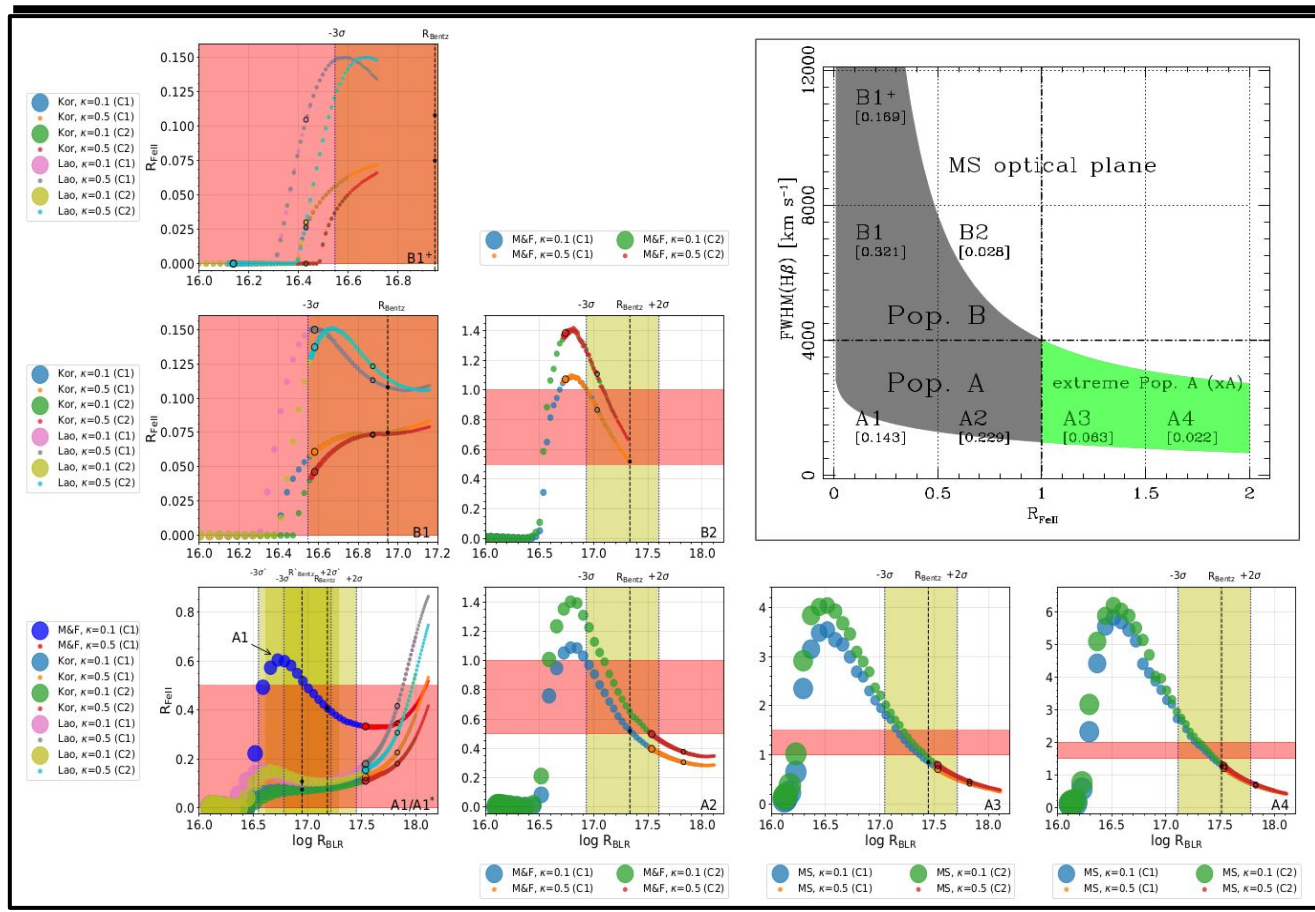


R_{FeII} dependence on $L_{\text{bol}}/L_{\text{Edd}}$

$$K = v_{\text{iso}} / v_K$$

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

Results from a set of CLOUDY simulations performed on a constant density single BLR cloud assuming $M_{\text{BH}} = 10^8 M_{\odot}$ 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 $\theta = 30^\circ$ and $\theta = 45^\circ$. The color patches (in red) in each spectral bin denote the range of R_{FeII} values as expected from observational evidences. The respective upper ($+2\sigma$) 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(H β) vs. R_{FeII}



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

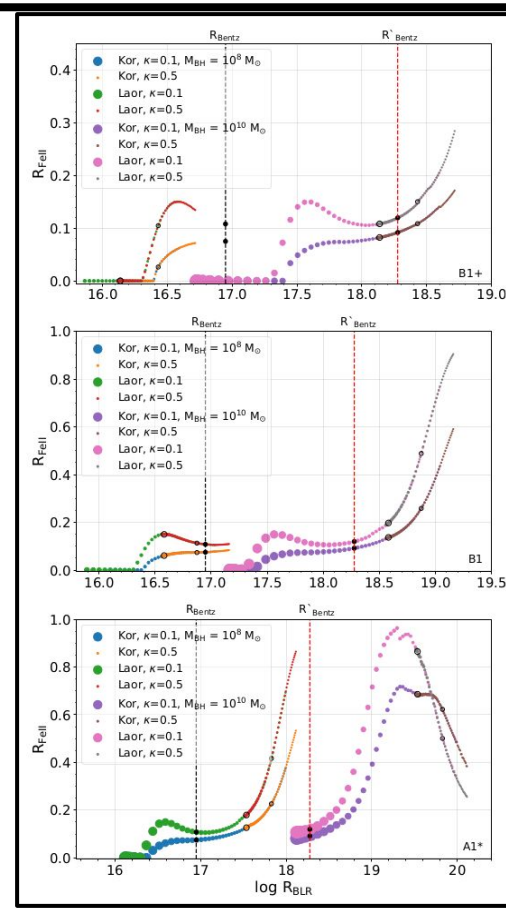
the Mass effect

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

Case	ST	Z [Z_{\odot}]	$\log n_{\text{H}}$ [cm^{-3}]	L/L_{Edd}	SED	θ^{a}	$\log R_{\text{BLR}}^{\text{b}}$		\bar{n}				
							[cm]		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	$\log n_{\text{H}}$	L/L_{Edd}	SED	θ^{a}	$\log R_{\text{BLR}}^{\text{b}}$	\bar{n}				
								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

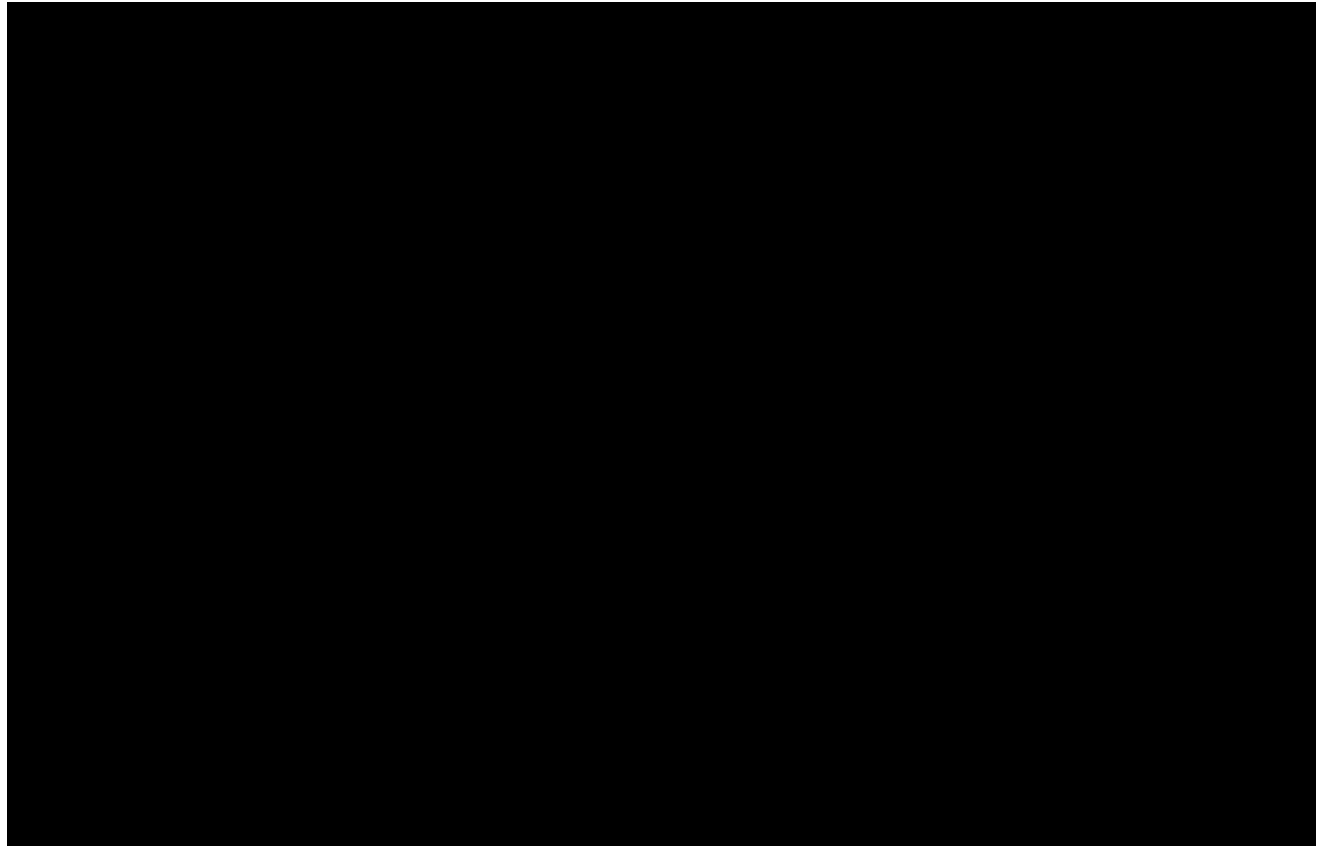
Results from a set of CLOUDY simulations performed on a constant density single BLR cloud assuming $M_{\text{BH}} = 10^8 M_{\odot}$ and $M_{\text{BH}} = 10^{10} M_{\odot}$.



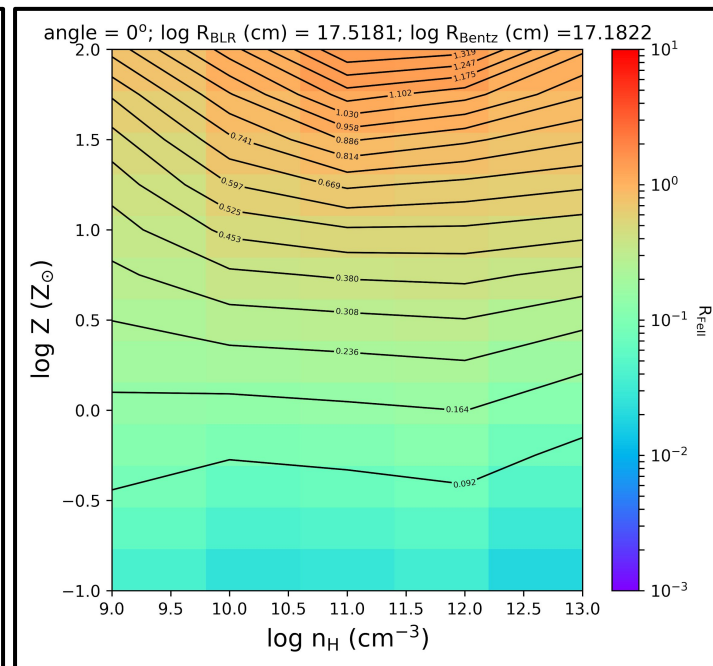
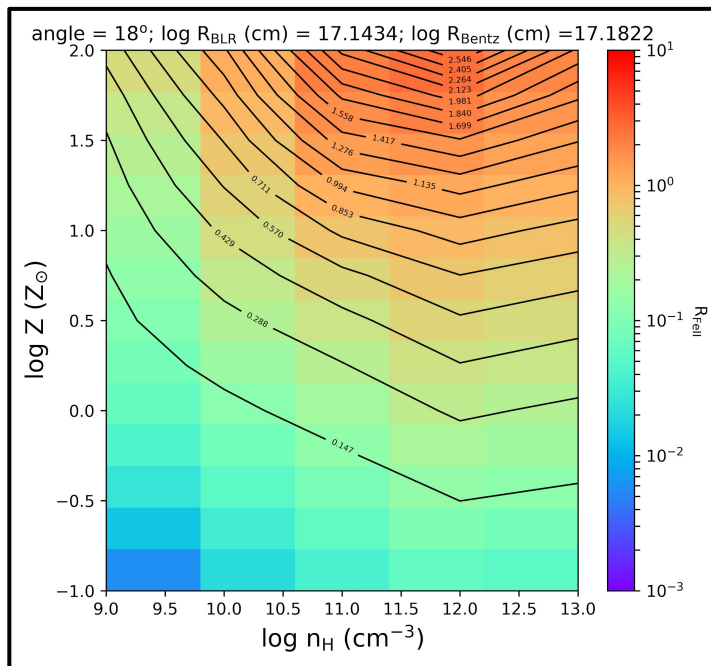
In progress

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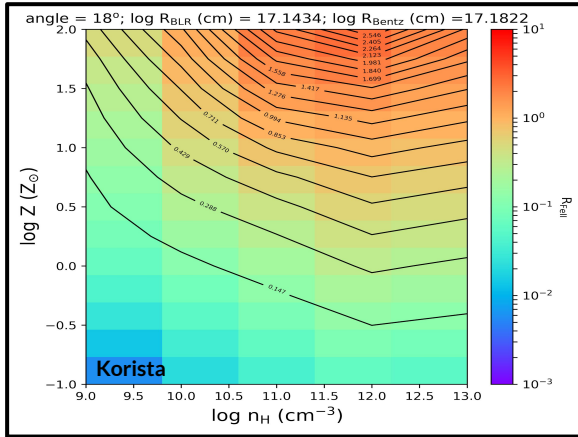
Metallicity - cloud density distribution as a function of R_{FeII} at zero turbulence. The montage is shown as a function of increasing steps in inclination angles, the corresponding BLR size computed from the virial relation. The BLR size from the Bentz et al. 2013 $R-L$ relation is shown for $\lambda_{\text{Edd}}=0.2$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



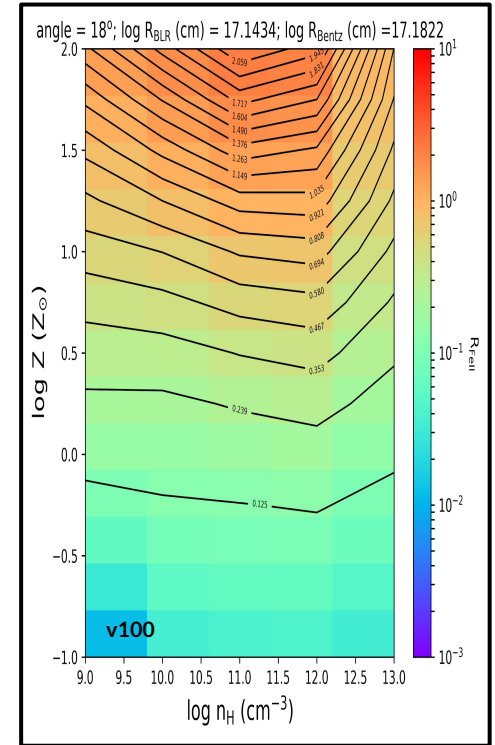
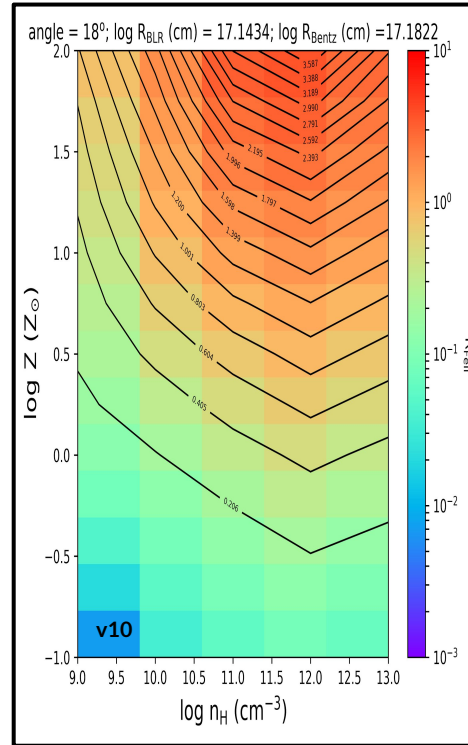
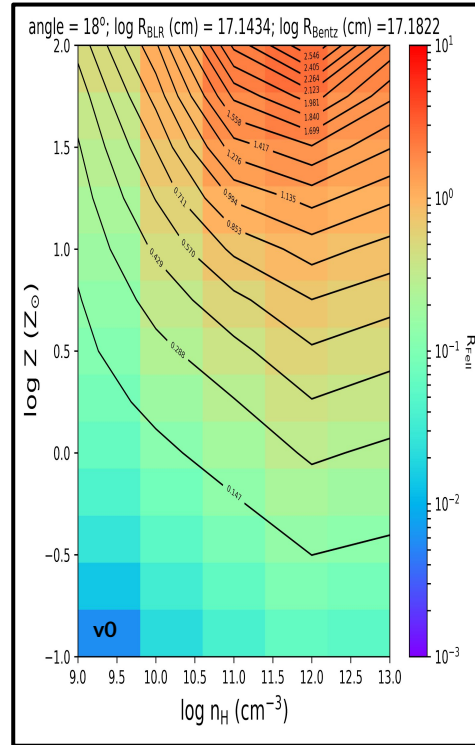
M8 k=0.1 vs k=0.5, Korista SED, Edd=0.2, A1



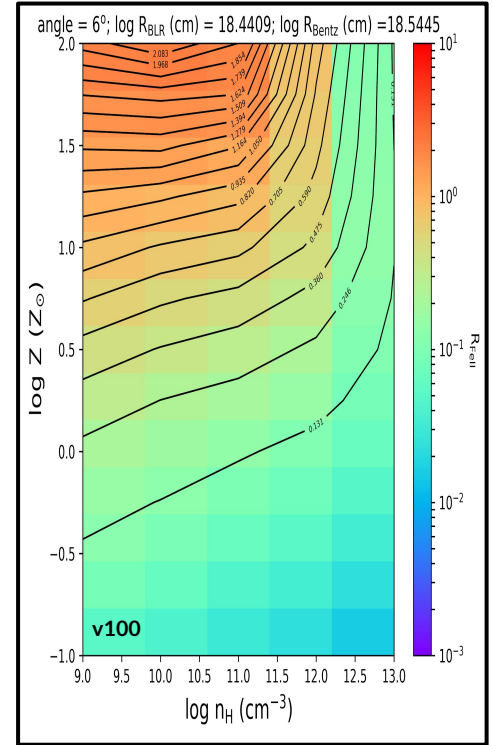
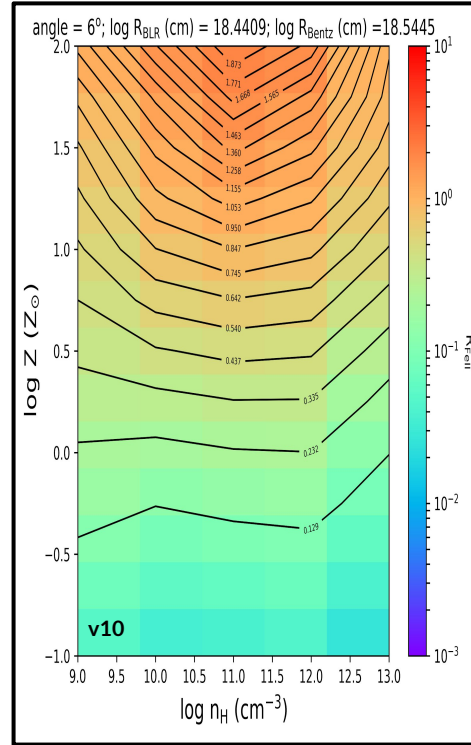
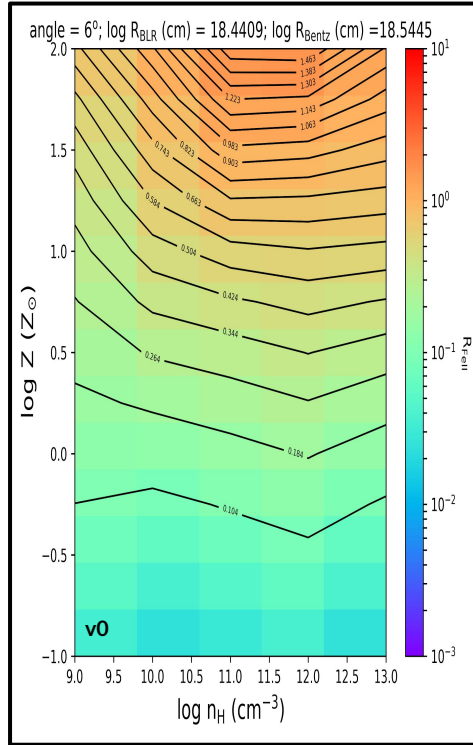
M8 SED compare, A1 vturb 0



M8 vturb O, 10, 100, Kor, A1



M10 vturb 0, 10, 100, Kor, A1



Thank you for your attention!

1. **Fell** is a complex species with numerous emission mechanisms.
2. The **Eigenvector 1 diagram** holds a key to understand the Fell emission and the rarity of strong Fell emitters
3. Combining M_{BH} , dM/dt and Θ^* with a comprehensive Fell 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**.