Are Boltzmann plots of Hydrogen Balmer lines a tool for identifying a subclass of Type1 AGN?

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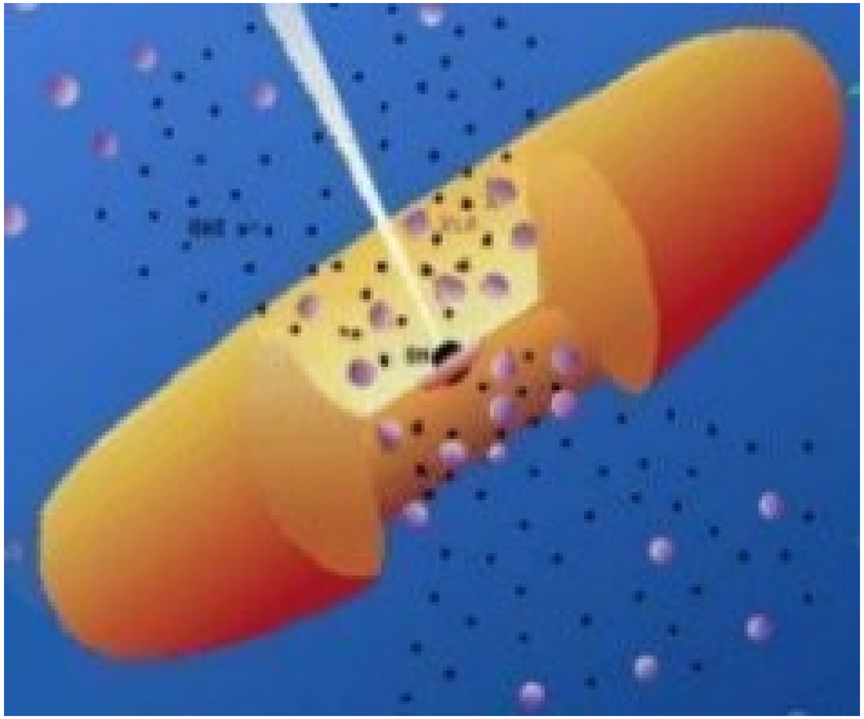
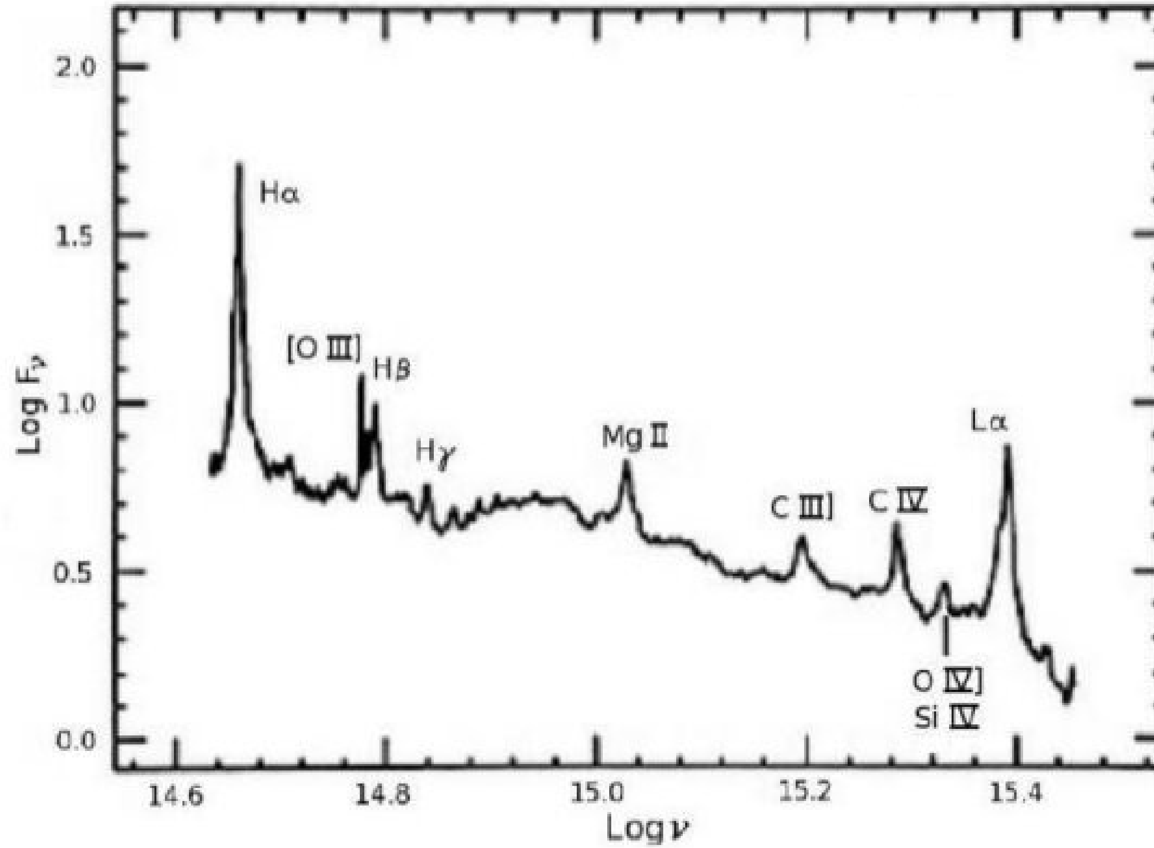
The Broad Line Region of Active Galactic Nuclei



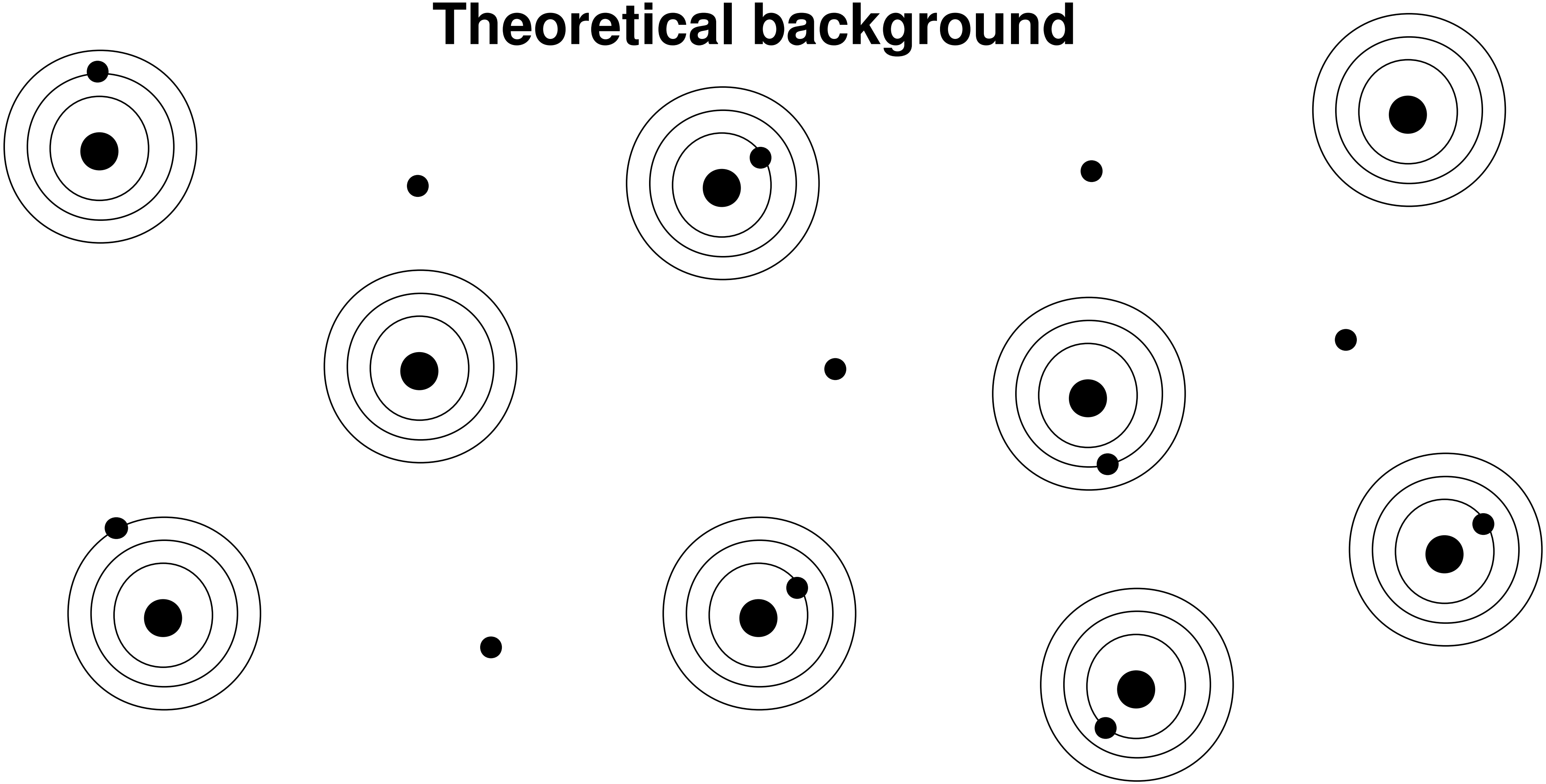


What we know: extremely compact, mainly photoionized dense plasma

What we can estimate: $T \sim 10^4$ K $\quad 10^8$ cm^{-3} $< N_e <$ 10^{14} cm^{-3}

A direct method to measure thermodynamical properties from the Broad Emission Lines (BEL) is highly desired. The **Boltzmann Plot** represents a valuable solution (see also **La Mura et al. 2007, ApJ, 671, 104; Ilić et al. 2012, A&A, 543, 142**)

Theoretical background



Given an **optically thin** plasma, the intensity of an emission line is:

$$I_{ul} = h\nu_{ul}\, g_u\, A_{ul} \int_l N_u\, dr$$

Theoretical background

If we assume that the density of the line emitting plasma is **not a function of position** and if the occupation numbers of the high excitation levels follow the **Boltzmann distribution**, it turns out:

$$I_{ul} = h\nu_{ul}\, g_u\, A_{ul}\, l\, N_1 \exp\left(-\frac{E_u}{k_B T}\right)$$

so that we can introduce a normalized line intensity, with respect to the atomic constants of the transition:

$$I_n = \frac{I_{ul}\, c}{\nu_{ul}\, g_u\, A_{ul}}$$

and find that, for the same transition series, it is:

$$\log I_n = \log(h\, l\, N_1) - \frac{E_u}{k_B T}\log e = B - A\, E_u$$

Models

How does it work? Let's consider some hypothetical calculations:

1) an optically thin plasma in Thermodynamical Equilibrium

T	N2/N1	N3/N1	N4/N1	N5/N1	N6/N1	N7/N1
100000	1.22E+000	2.21E+000	3.64E+000	5.49E+000	7.76E+000	1.04E+001
95000	1.15E+000	2.05E+000	3.37E+000	5.07E+000	7.16E+000	9.62E+000

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5000 K < T < 100000 K
10^{12} cm^{-3} < N_e < 10^{14} cm^{-3}

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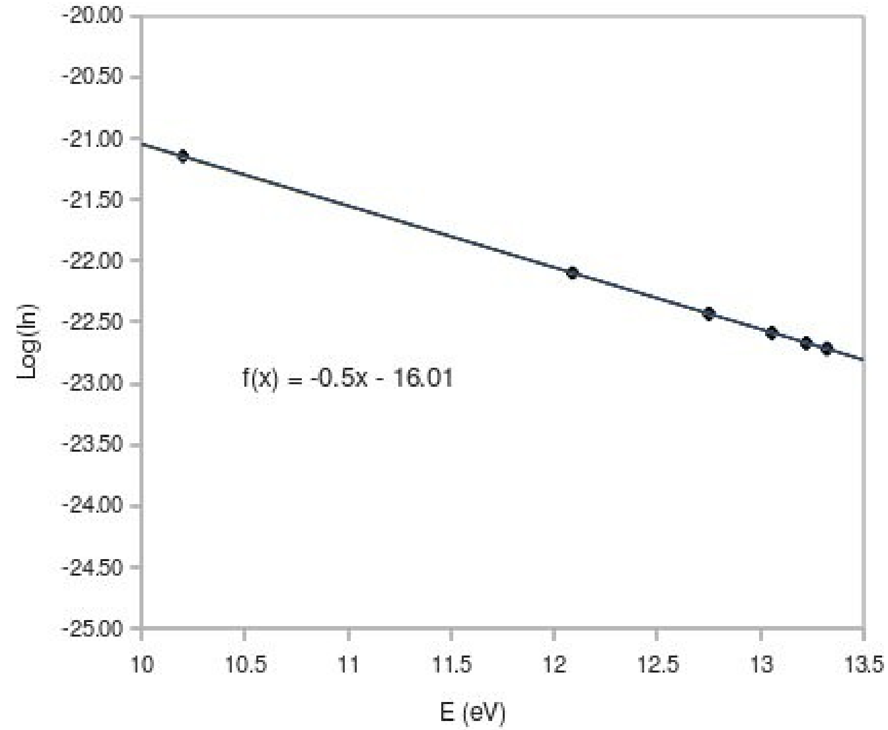
T	N2/N1	N3/N1	N4/N1	N5/N1	N6/N1	N7/N1
15000	1.49E-003	7.78E-004	8.29E-004	1.02E-003	1.30E-003	1.63E-003
10000	2.88E-005	7.23E-006	5.97E-006	6.51E-006	7.79E-006	9.44E-006
5000	2.08E-010	5.80E-012	2.23E-012	1.70E-012	1.68E-012	1.82E-012

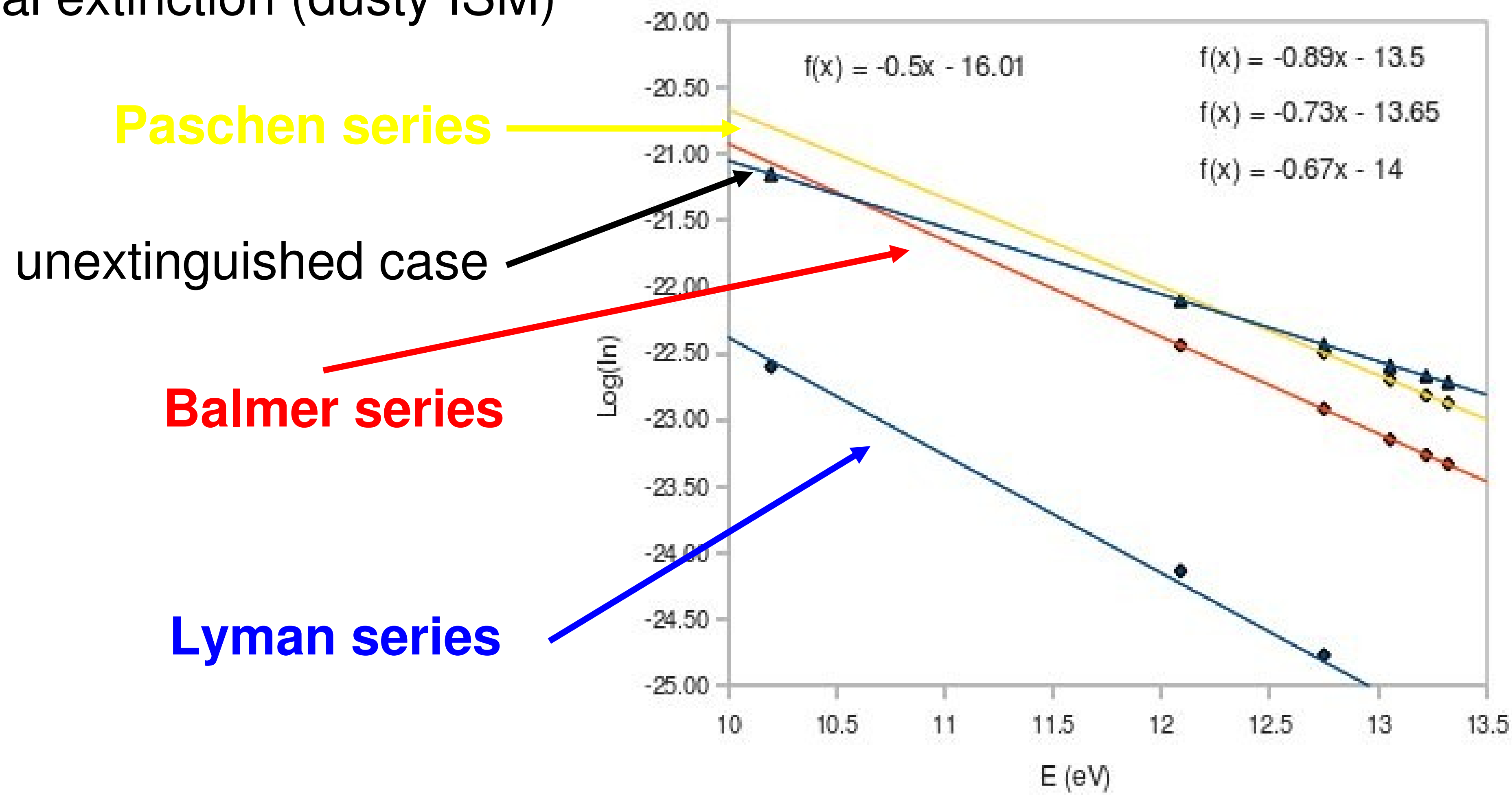


In such **purely hypotetical** situation all the emitted series of Lyman, Balmer and Paschen lie on the same function of the line excitation energies.

Models

We now want to study the situation in some more realistic conditions, introducing more complex effects.

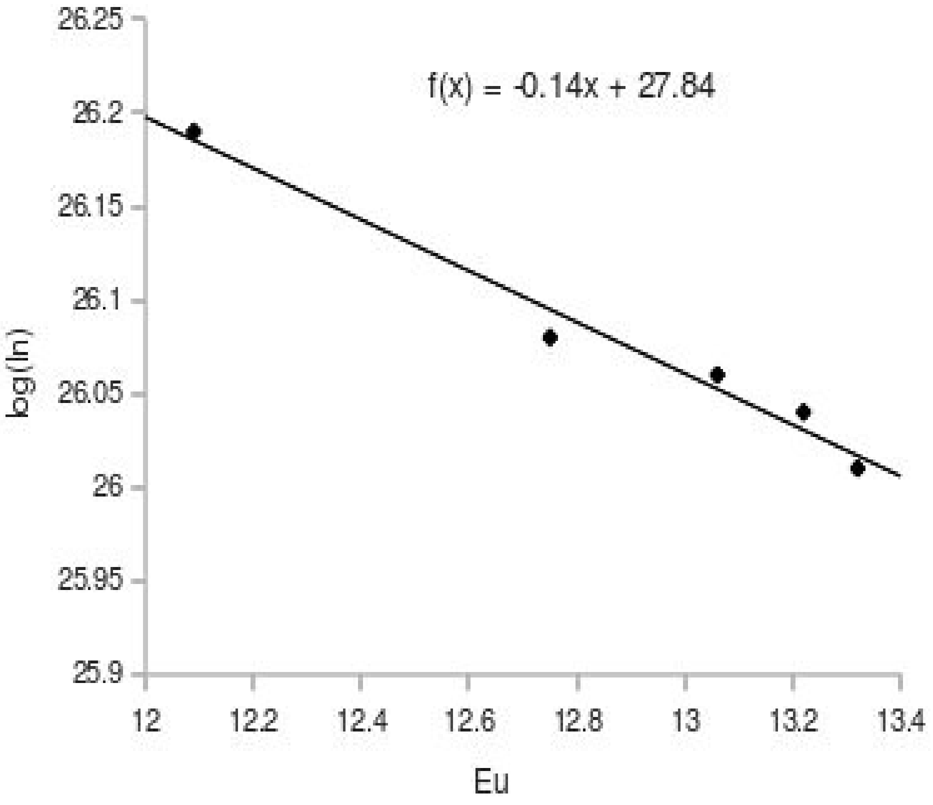
2) optically thin plasma in Thermodynamical Equilibrium, with 1 mag visual extinction (dusty ISM)

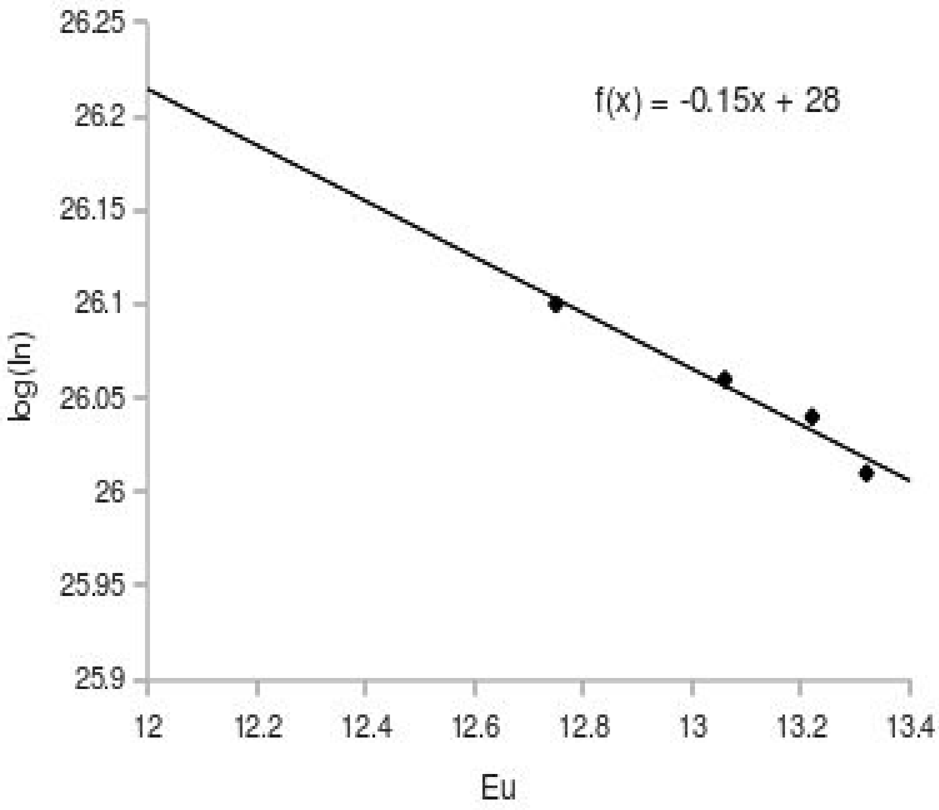


Models

More realistic models have been computed with the CLOUDY code (v. C13.01, see **Ferland et al. 2013, RevMexAA, 49, 137**) in order to reproduce the expected physical conditions of the Broad Line Region:

power law ($F_\nu \propto \nu^{-1}$) $L = 10^{44}$ erg/s $N_H = 10^9$ cm^{-3} $h = 10^{11}$ cm $R = 10^{17}$ cm

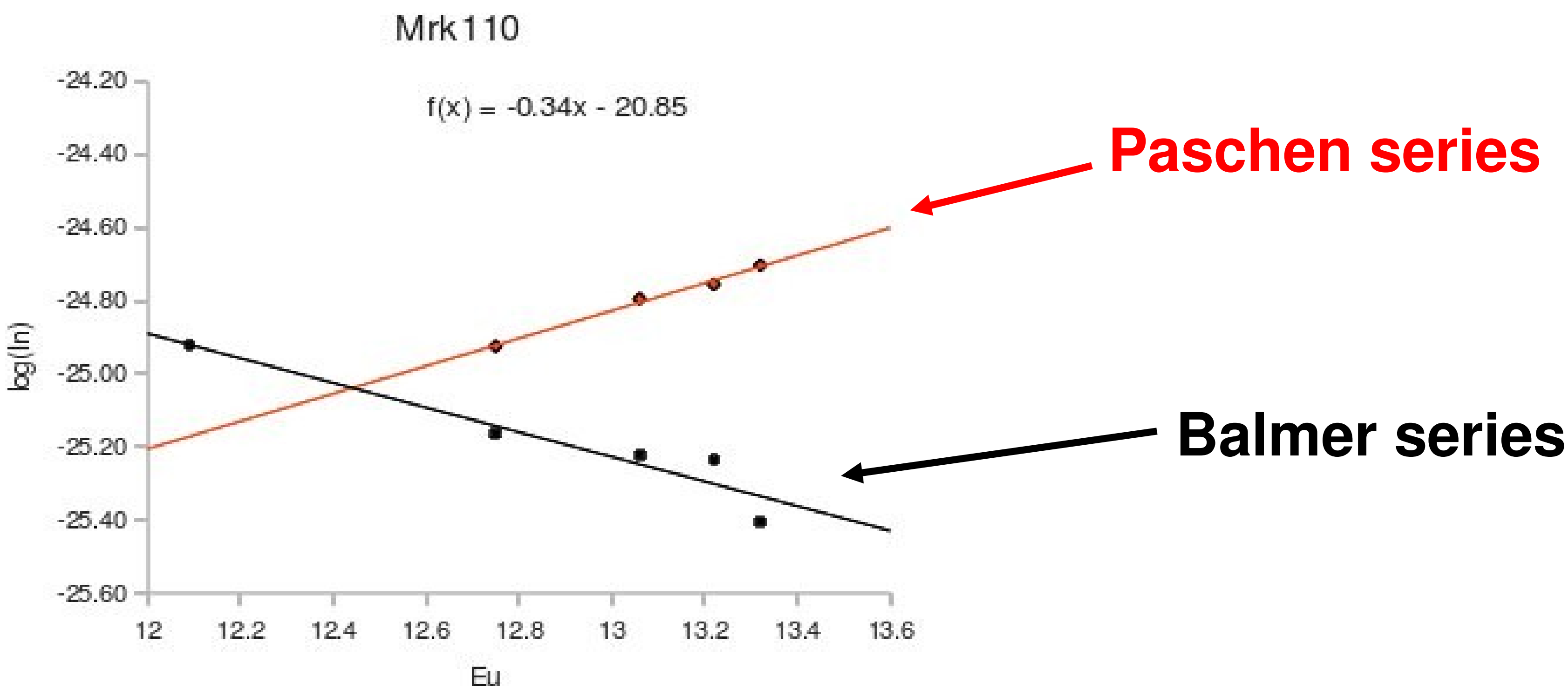




Observations: problems start here

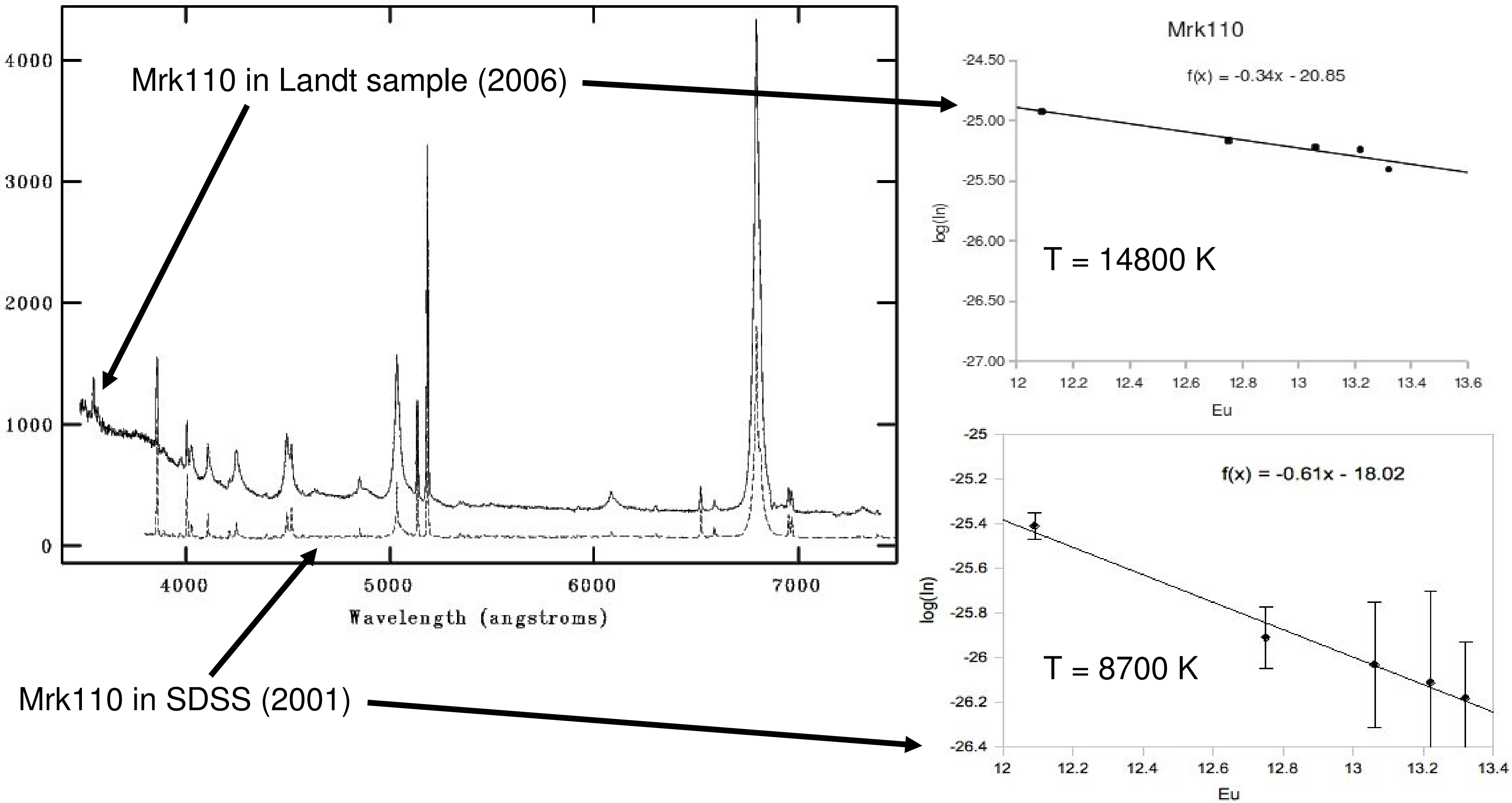
Landt et al. (2008, ApJS, 174, 282) collected a series of line flux and profile determinations, taking into account the Balmer series (up to Hγ) in the visible and the Paschen series in NIR.

None of the NIR spectra result in a meaningful Boltzmann plot!!!



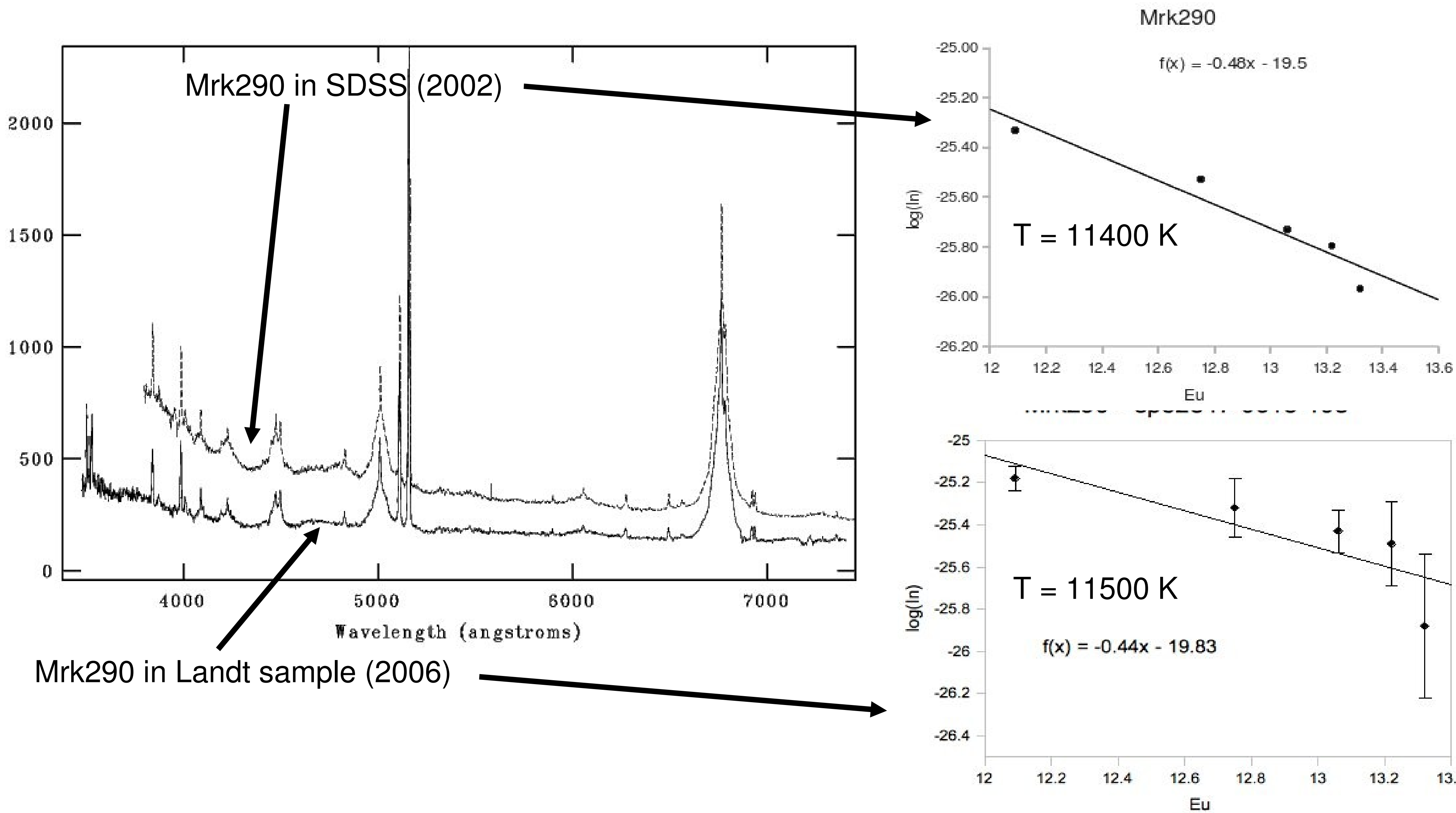
However, the NIR lines are **very difficult** to measure, due to important blends

Is AGN variability a concern?



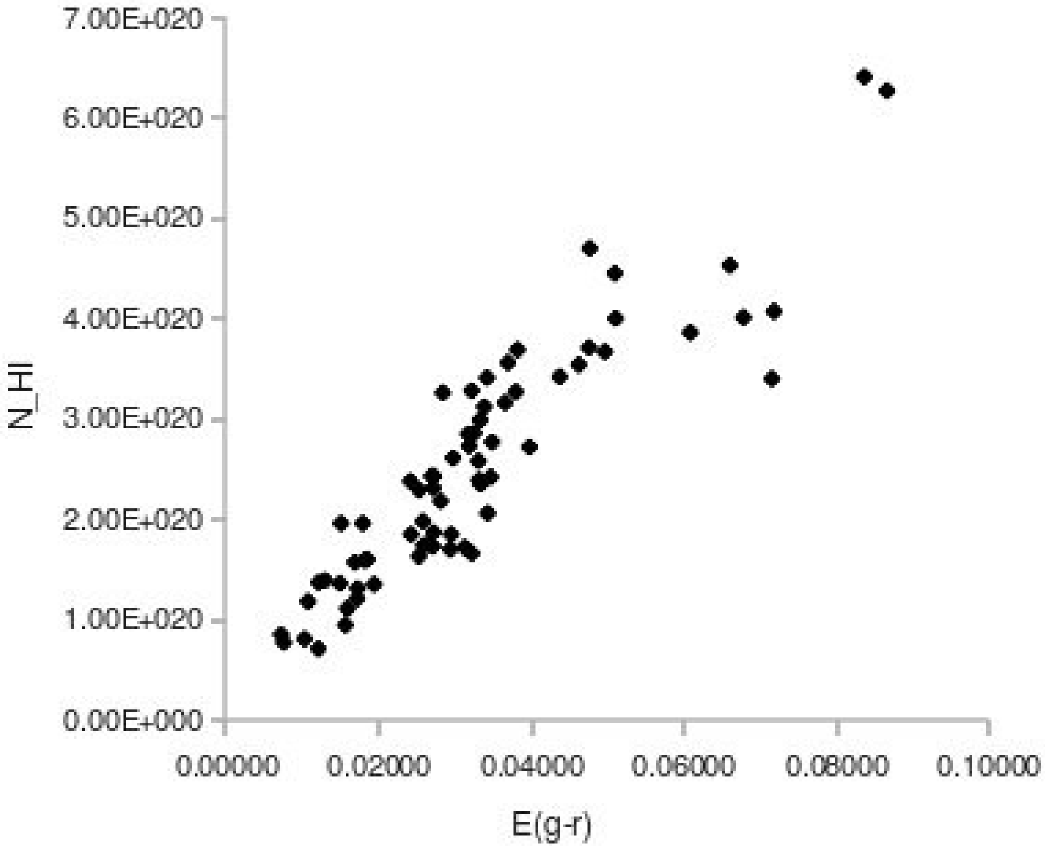
The optical Boltzmann plot is not affected in quality, but relative intensities of emission lines are sensitively influenced.

Is AGN variability a concern?



This supports similar conclusions derived for NGC5548 by **Popović et al. (2008, PASJ, 60, 1)**

Possible problems: intrinsic extinction

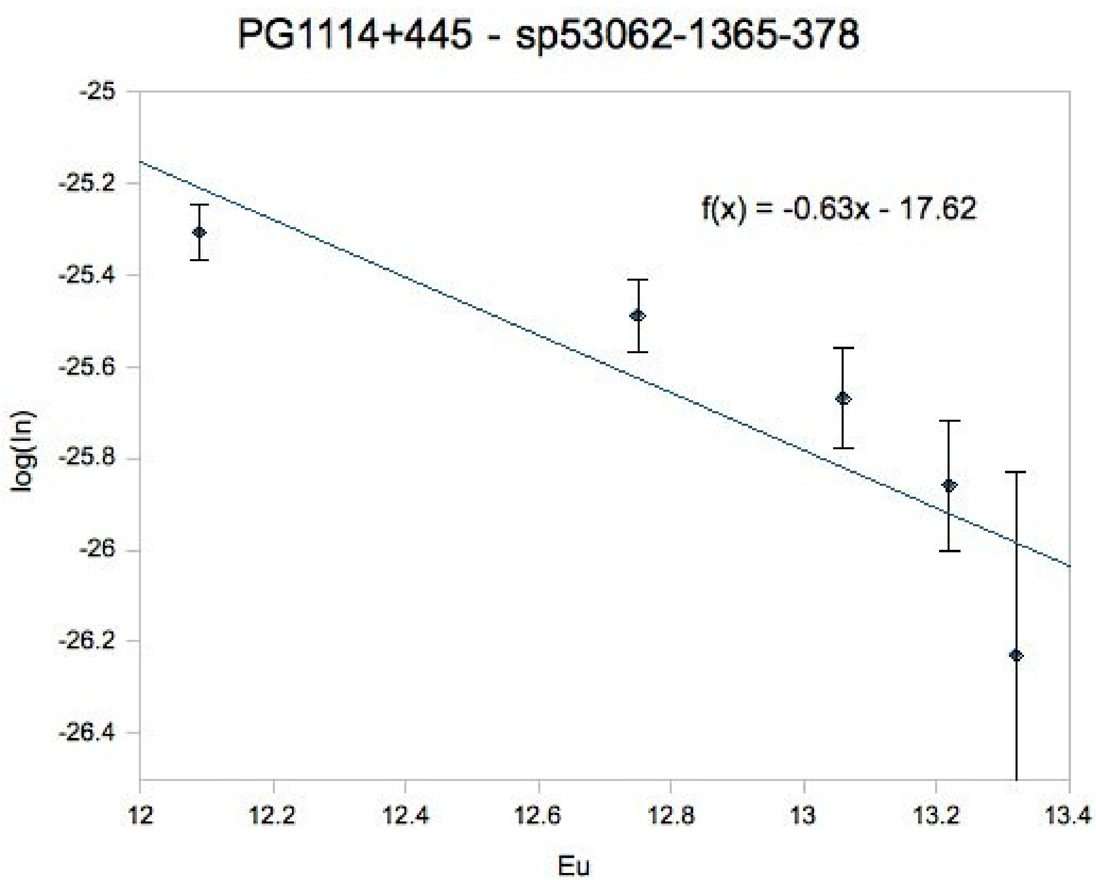


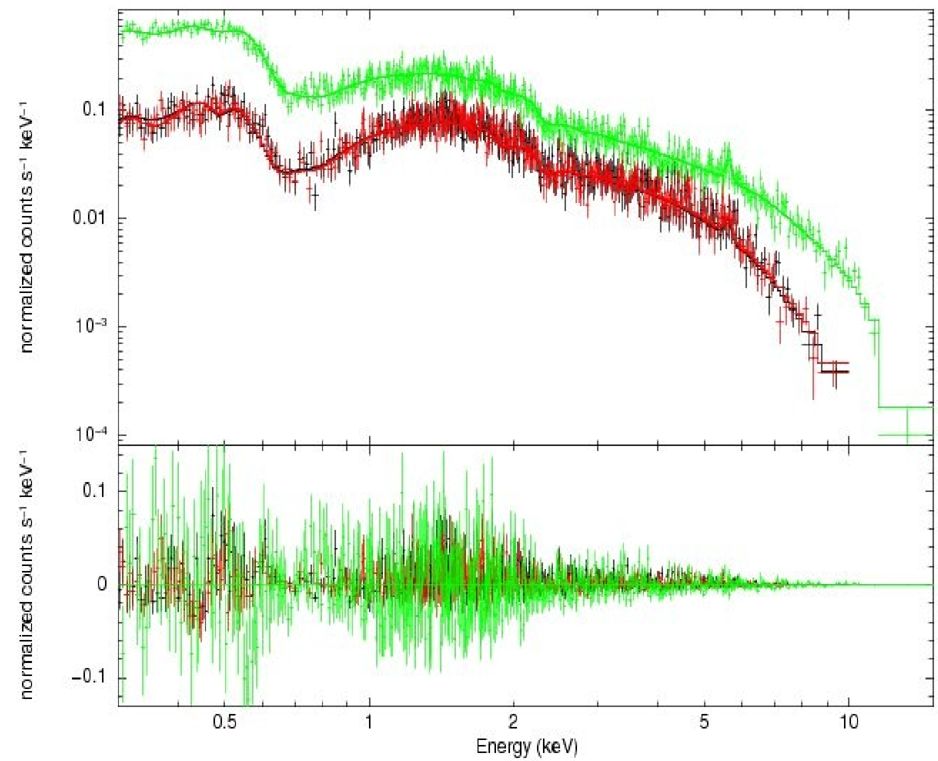
If we observe the light of an extra-galactic source, we know it is affected by some amount of foreground extinction, arising from within the Milky Way.

This can be estimated and accounted for.

A **much more complicated situation** concerns the amount of **intrinsic extinction** from within the source. An estimate of the amount of absorbing material in the source itself is instead required.

An absorption excess in non-BP?





High excitation lines are strongly under-luminous

There is strong evidence for intrinsic absorption

It is only 1 example: excess absorption implies non-BP, but vice-versa is not granted

First guess to the question

The overall quality of a Boltzmann plot does not appear to depend on the degree of activity of the nucleus, though the thermo-dynamical properties of the plasma certainly do.

There are indications that severe absorption effects can be a reason for plots deviating from the linear behavior, but the opposite is not granted.

A good Boltzmann plot, however, represents an important constraint to the physics of the BLR, in the sense that:

1) no excess intervening absorption should be expect to arise outside the BLR

2) the cloud densities and sizes are constrained in a narrow range of optical depths for the Balmer series, while still leaving Paschen photons to escape free.

What makes a Boltzmann plot work

The fundamental assumptions of the method are prone to critical conditions on:

1) optical depth

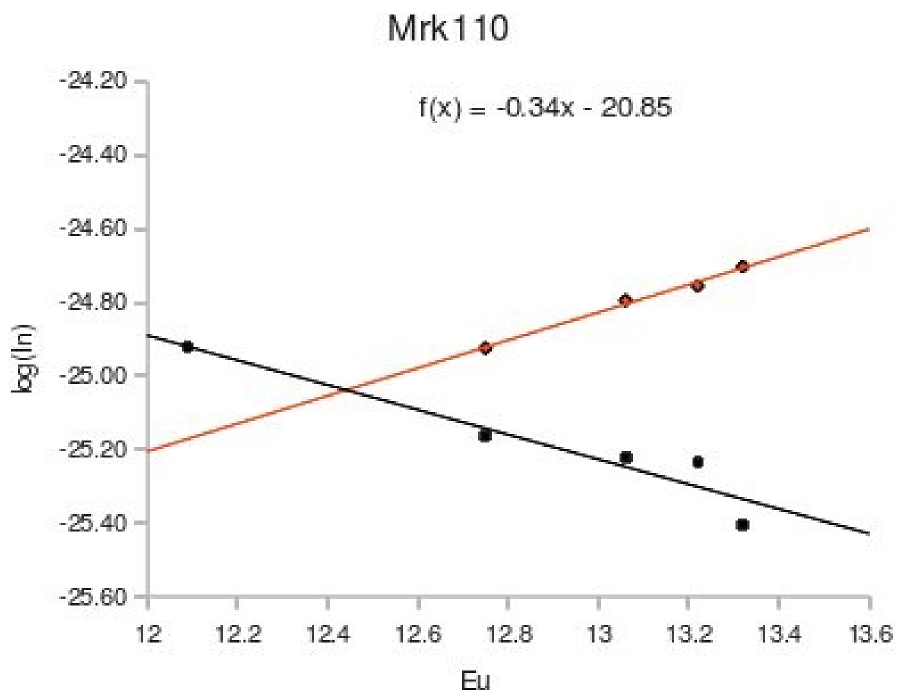
2) level population

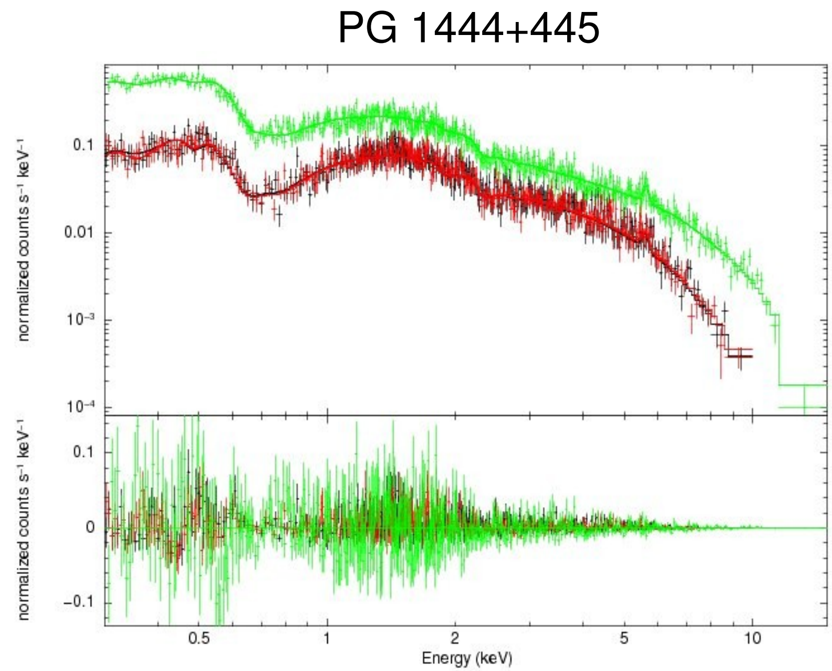
The comparison of optical to NIR data suggests that photons of the Balmer series can be affected by scattering, while the plasma is optically thin to Paschen lines.

This results in an over-population of high energy levels, that is seen clearly in the Paschen emission line ratios, while part of the Balmer photons are lost.

In such situation the BP appears to be satisfied, but it deviates from the actual plasma temperature.

Concluding remarks: need for broad band observations





The problem of what allows the Boltzmann plot to hold or not in a specific AGN is still an open question requiring further investigation.

Intrinsic absorption plays certainly a fundamental role, but the BP remains a useful tool for BLR dyagnostics.

More data, carrying out a **real broad band simultaneous coverage** of the spectrum, are needed, in order to solve this question.