The optical emission lines of X-ray bright type 1 Active Galactic Nuclei

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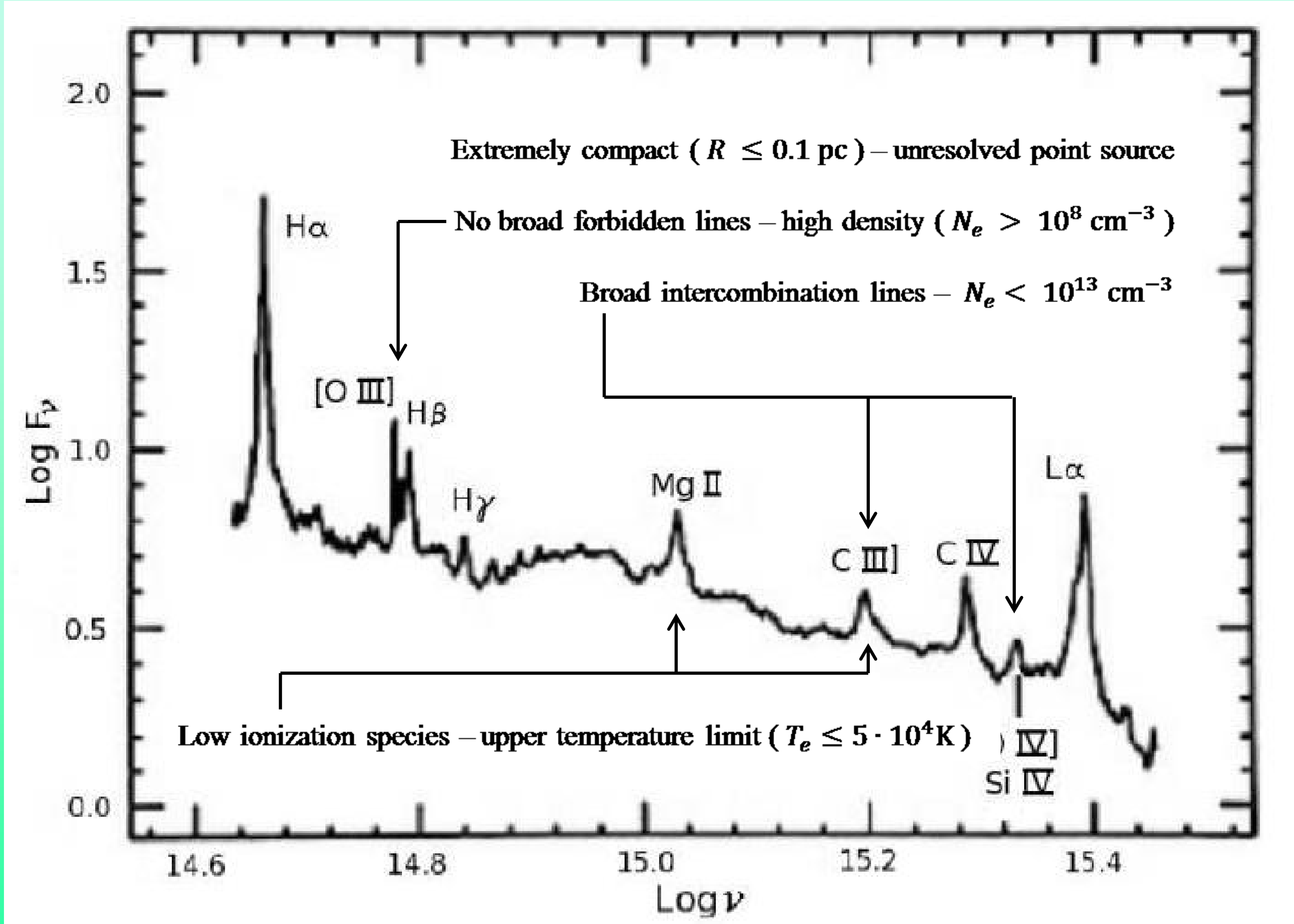
There is now convincing evidence that the nuclei of most galaxies host Super Massive Black Holes (SMBH) and that nuclear activity can be explained by accretion of matter into their gravitational field

The optical – UV spectrum of an active galaxy shows distinct components



Different spectral features can be traced back to distinct physical origins

The AGN Unified Model

There is a common framework for the interpretation of AGNs, based on:

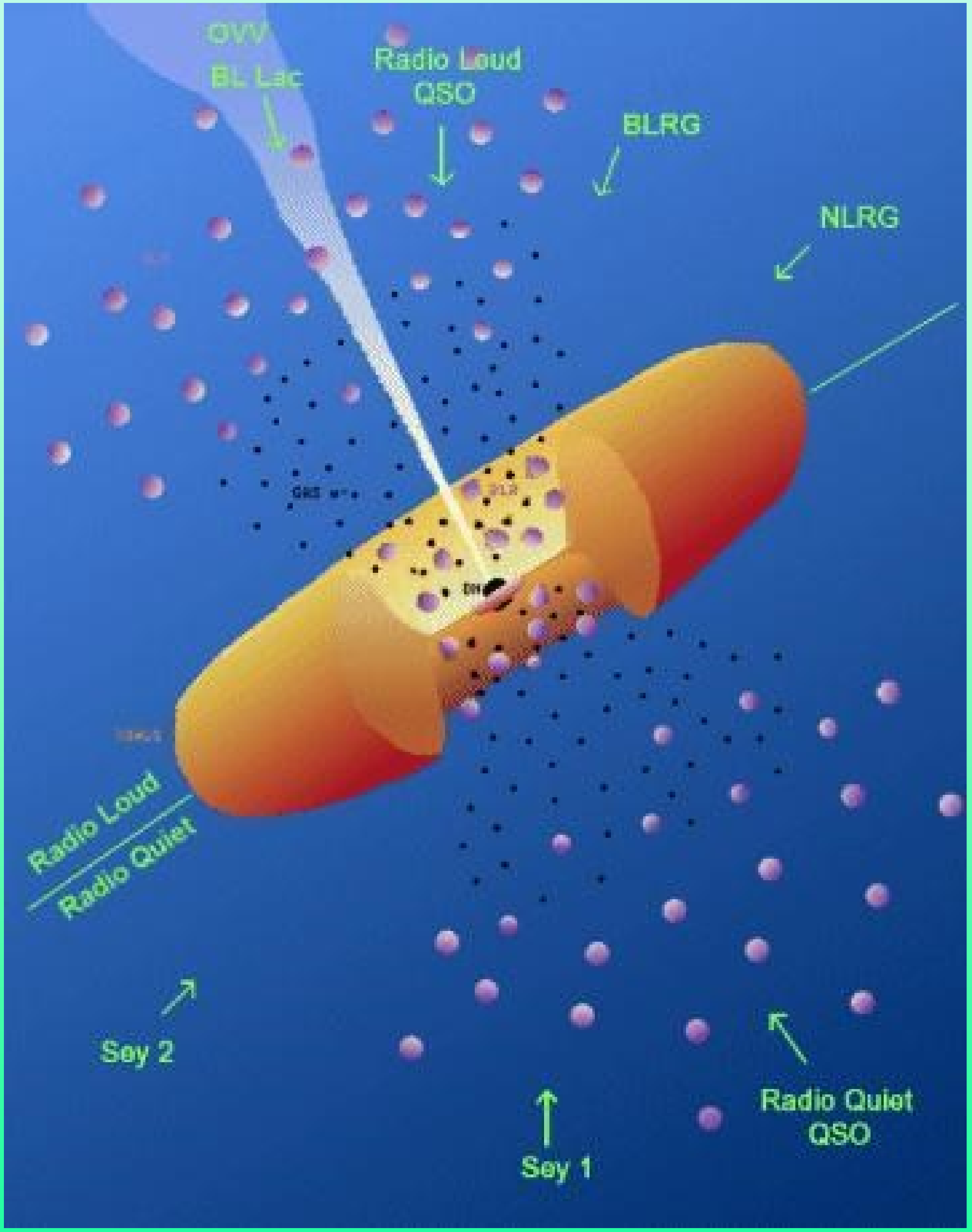
1. SMBH + disk

2. Broad Line Region (BLR), close to the black hole

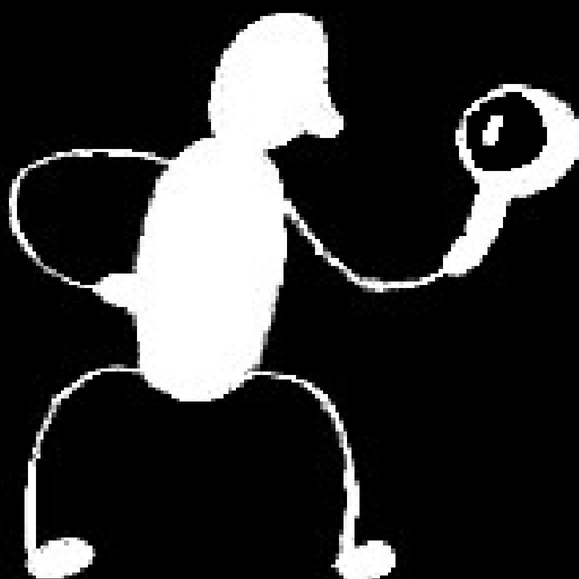
3. Narrow Line Region (NLR), farther away

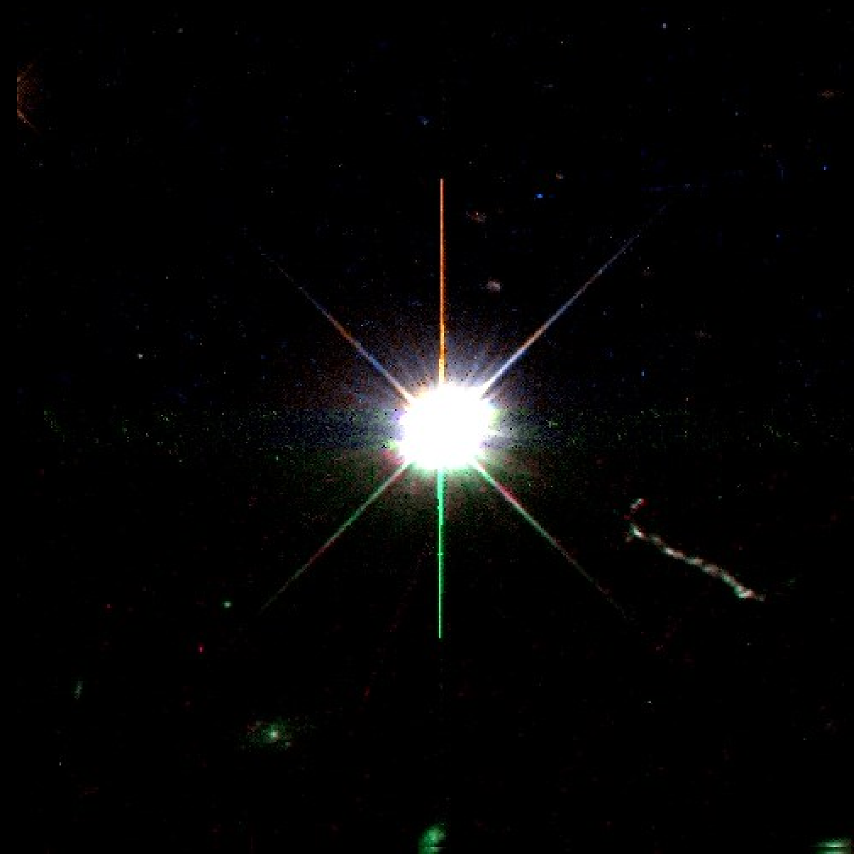
4. An obscuring equatorial structure (torus)

5. Possibly, a relativistic jet



Many efforts of AGN research have been devoted to probe the structure of the central engine, down to its smallest scales





The compact nature of the BLR (*R* ~ 0.1 pc) requires advanced investigation techniques and instrumentation

Differences between the Broad and the Narrow Line Regions

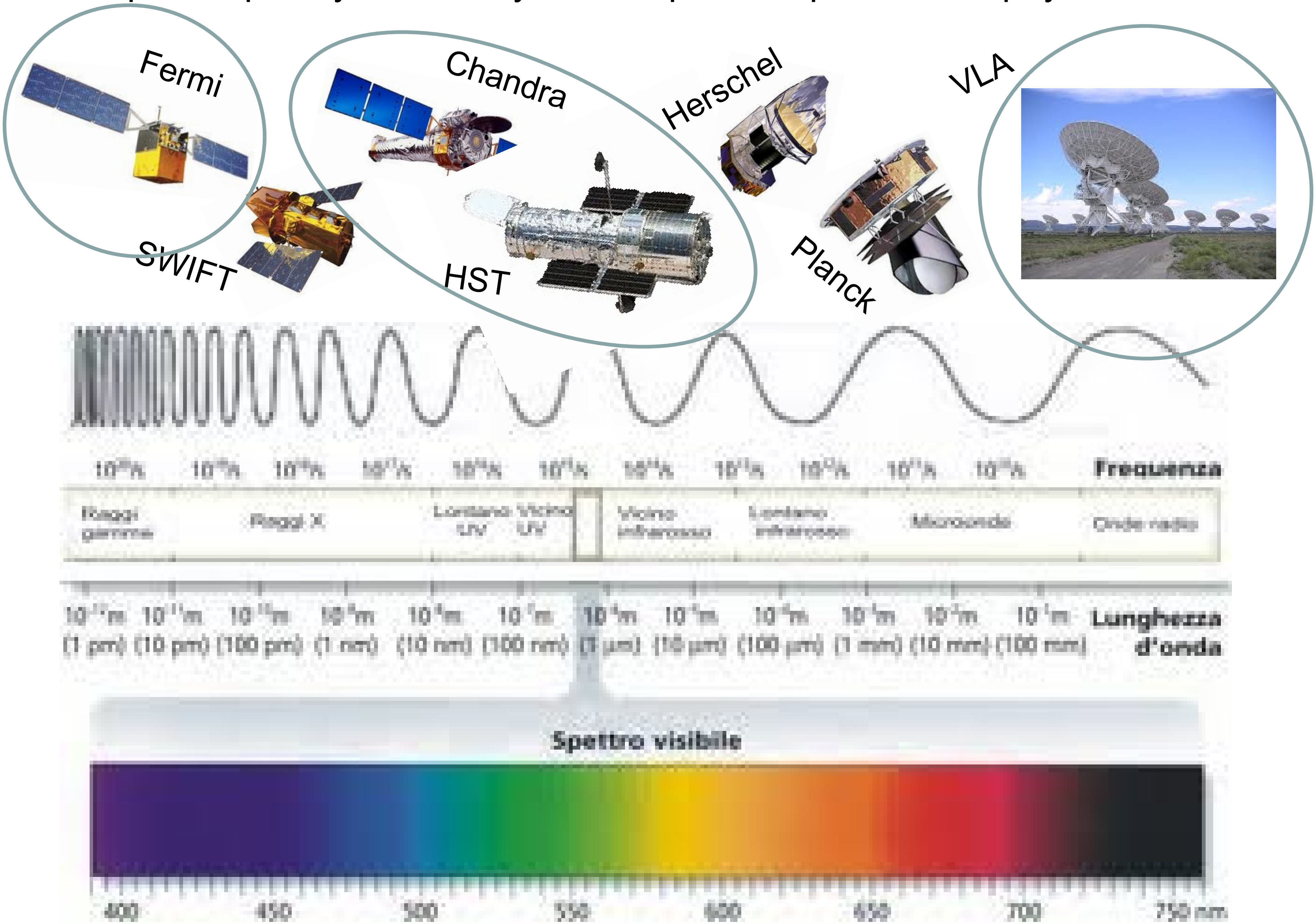
The presence of strong forbidden lines implies a low density plasma in the Narrow Line Region. In these conditions, considerations on the statistical equilibrium of the level population are possible:

$$\underbrace{N_i \sum_{j<i} A_{ij} + N_e N_i \sum_{j\neq i} Q_{ij}}_{\text{number of departures from level } i} = \underbrace{N_j \sum_{j>i} A_{ji} + N_e \sum_{j\neq i} N_j Q_{ji}}_{\text{number of arrivals to level } i}$$

From the derived deviations of level populations, with respect to thermo-dynamical equilibrium, using the critical densities of the different considered emission lines, it is, thus, possible to draw estimates of plasma DENSITY and TEMPERATURE.

In the high density Broad Line Region this does not hold anymore.

Multiple-frequency data analysis is required to probe AGN physics in detail



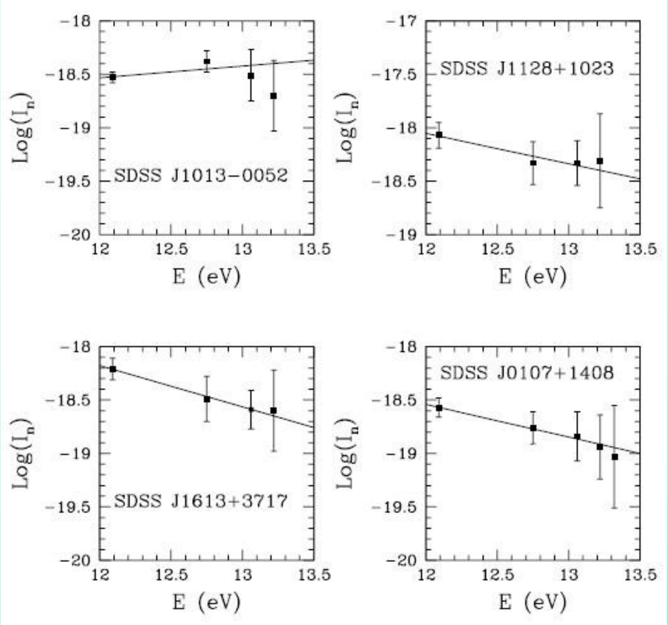
Plasma diagnostics with Boltzmann Plots

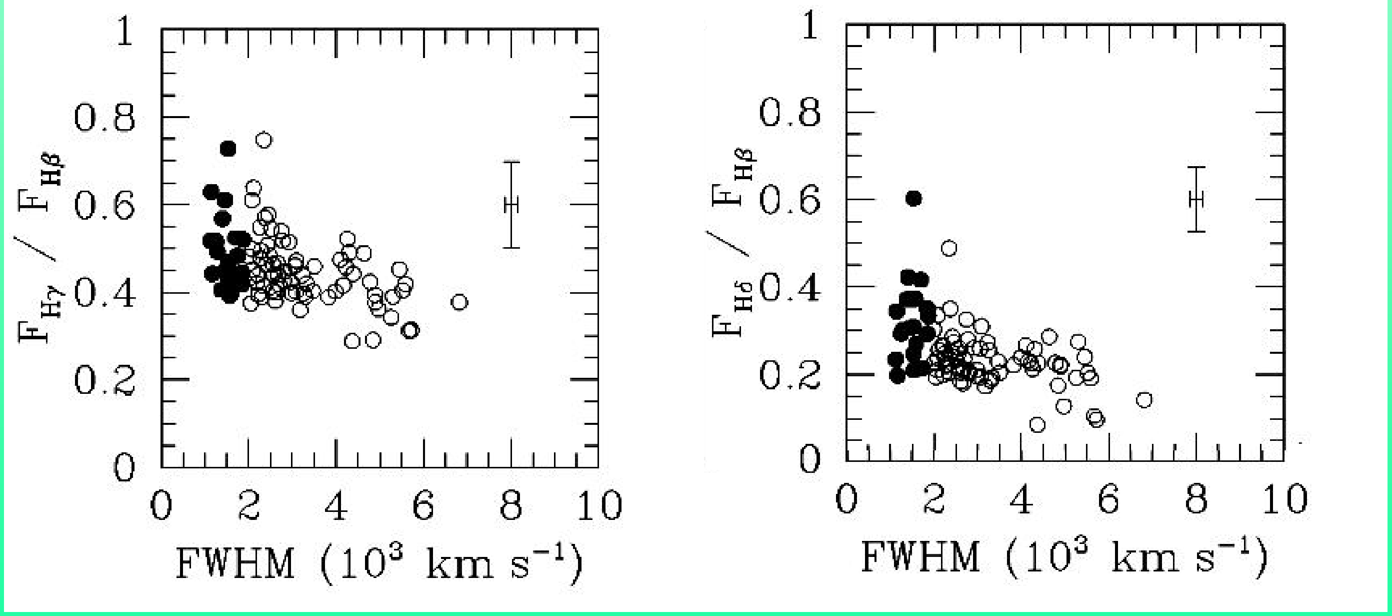
The Boltzmann Plot: given the normalized line intensity

$$I_n = \frac{\lambda_{ul} F_{ul}}{A_{ul} g_u}$$

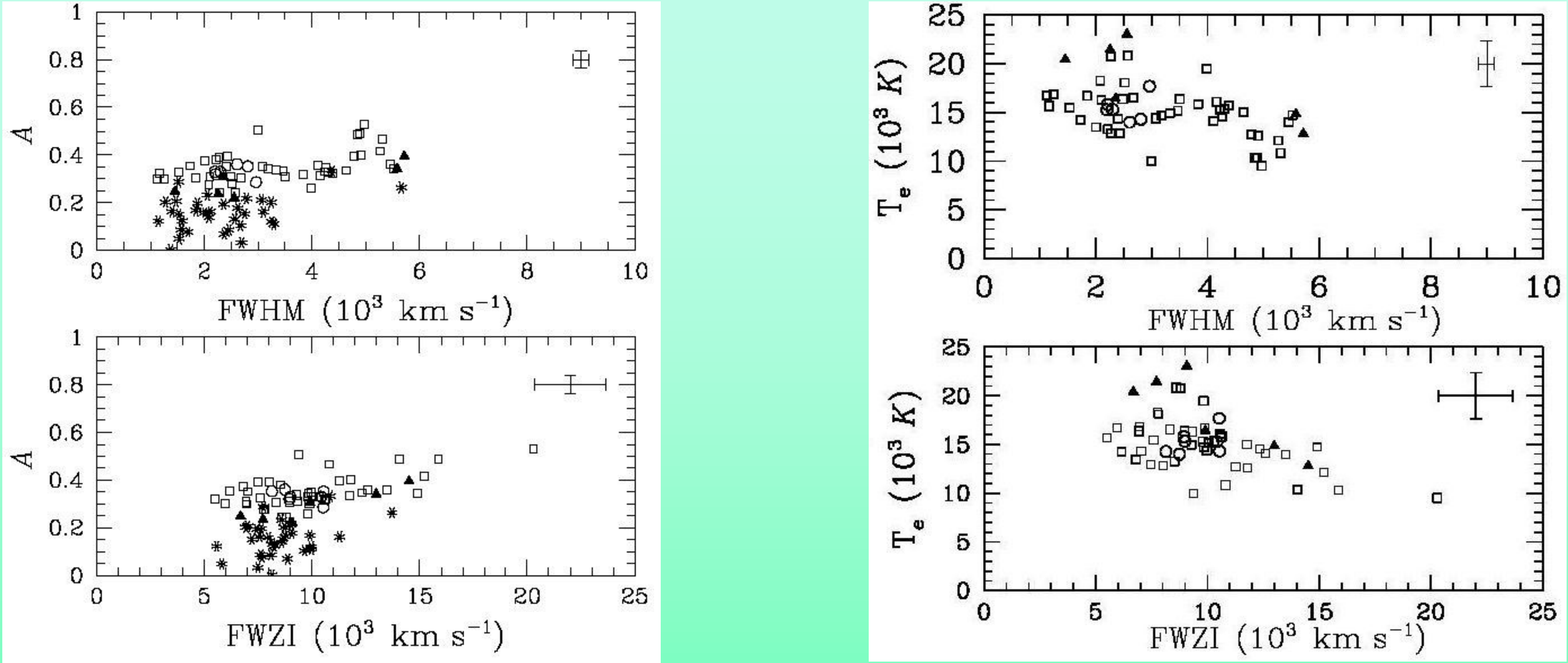
the logarithm of I_n for a particular transition series, in an optically thin plasma, is a linear function of the upper level's excitation energy, with a slope that depends on the plasma electron temperature

$$\log I_n = -\frac{\log e}{k_{\mathrm{B}} T_e} E_u + \mathrm{const.}$$





Physical conditions in the Broad Line Region

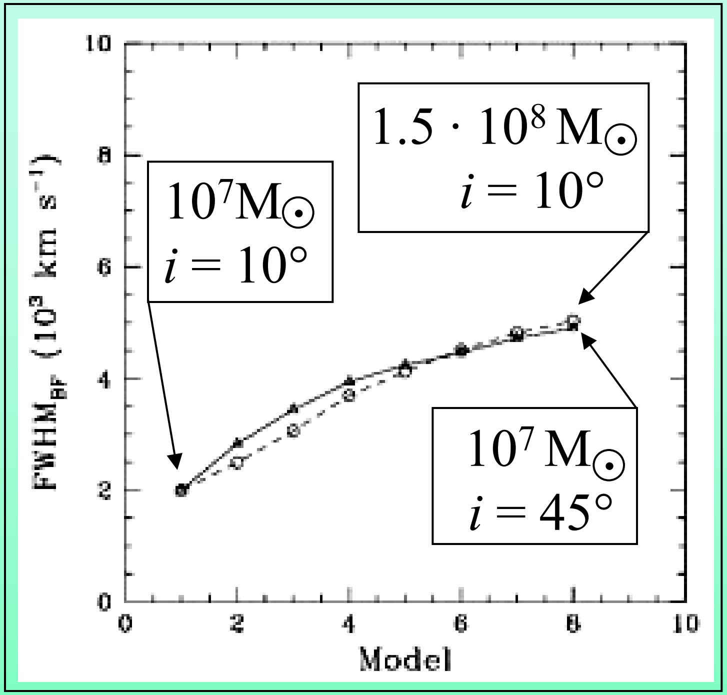


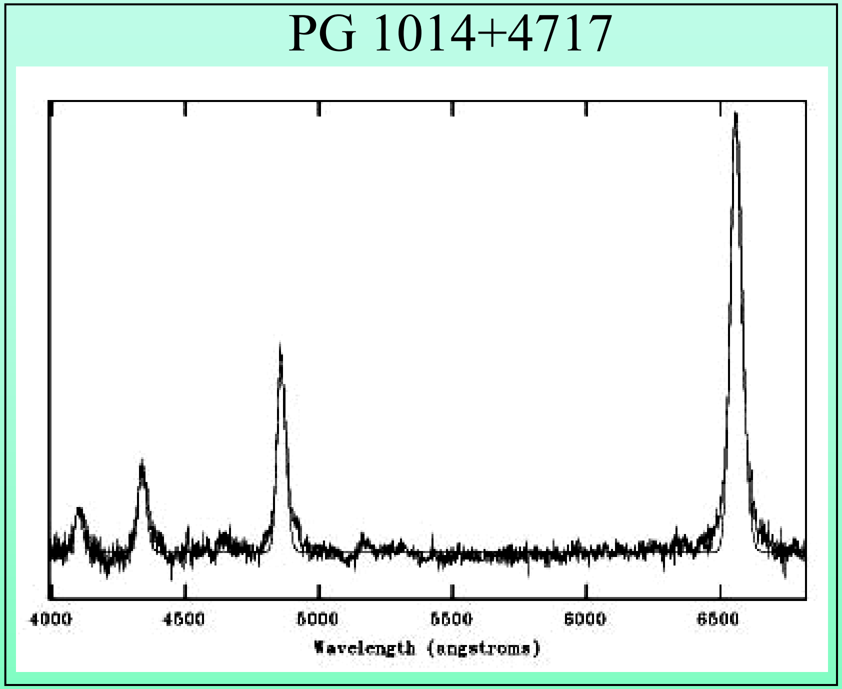
Boltzmann Plot slopes as a function of line profile widths (left panel), with the corresponding plasma temperature estimates (right panel).

The Boltzmann Plot assumptions only hold in a fraction of the selected AGN sample (~ 30%), preferably in the range of broad line emitting sources. In narrow lined objects the analysis points towards stronger ionization and higher plasma temperatures

(**La Mura et al. 2007, ApJ, 671, 104**)

Emission line profile broadening by Doppler effect

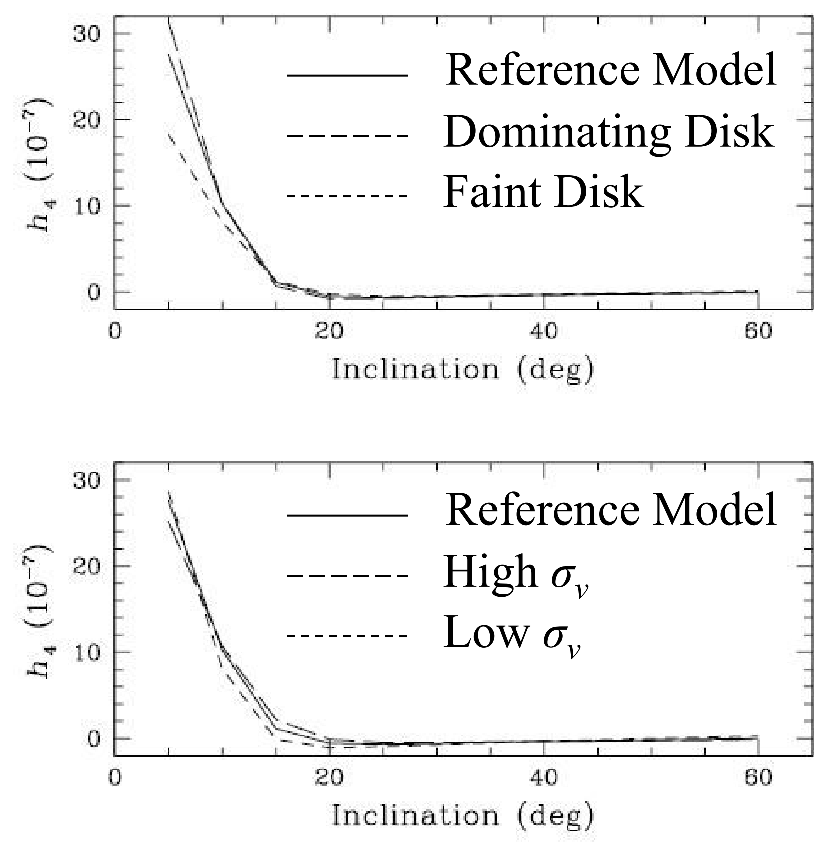


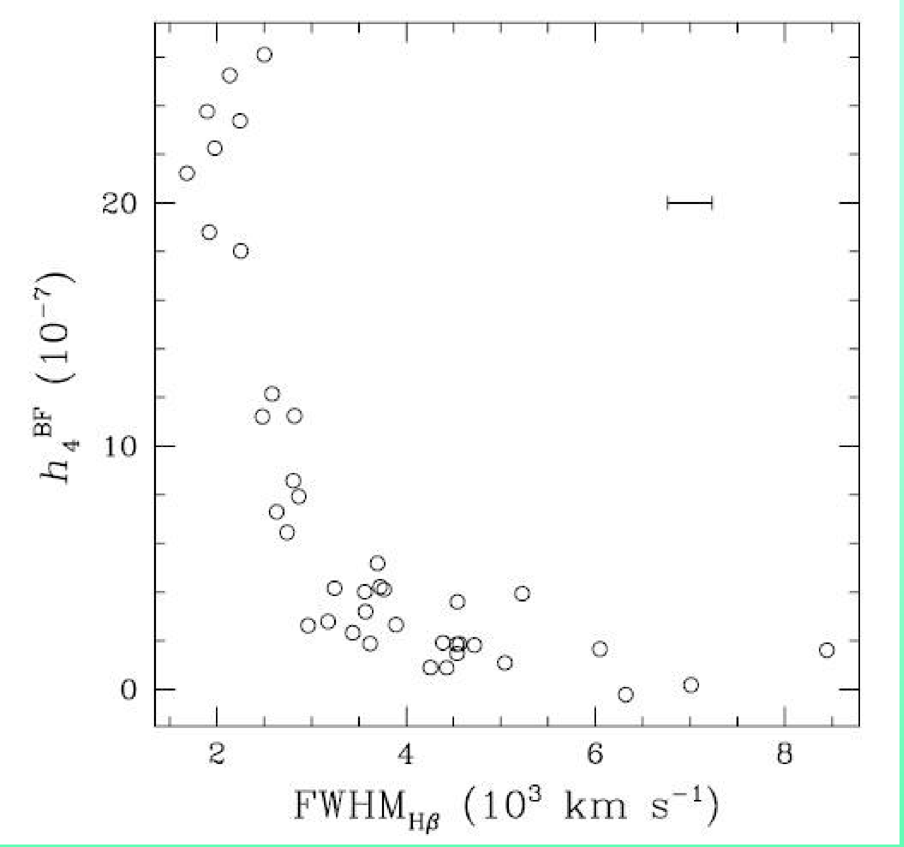


The emission line profiles only inform us about the radial projection of the actual motion field. This is related to the geometry of the source in terms of rather complex analytical solutions:

$$BF(v) = \frac{B_0}{\sqrt{2\pi}\sigma_v} \exp\left[-\frac{(v - V_{sys})^2}{2\sigma_v^{\ 2}}\right] \left\{1 + \sum_{i=3}^{N} h_i H_i (v - V_{sys})\right\}$$

Advanced line profile analysis

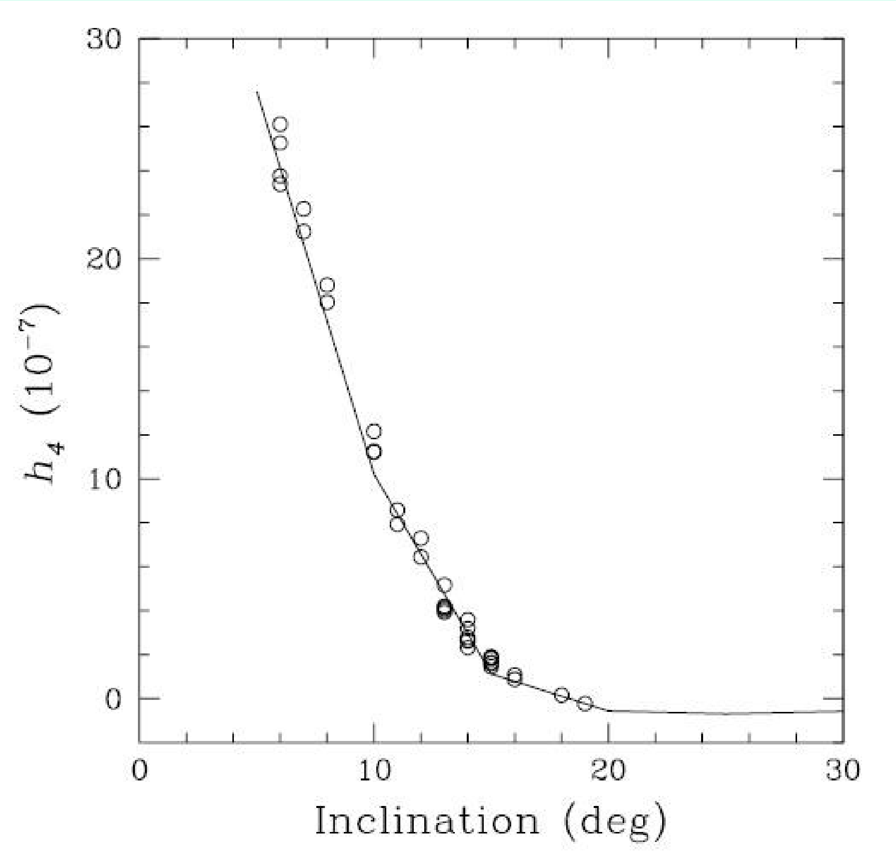


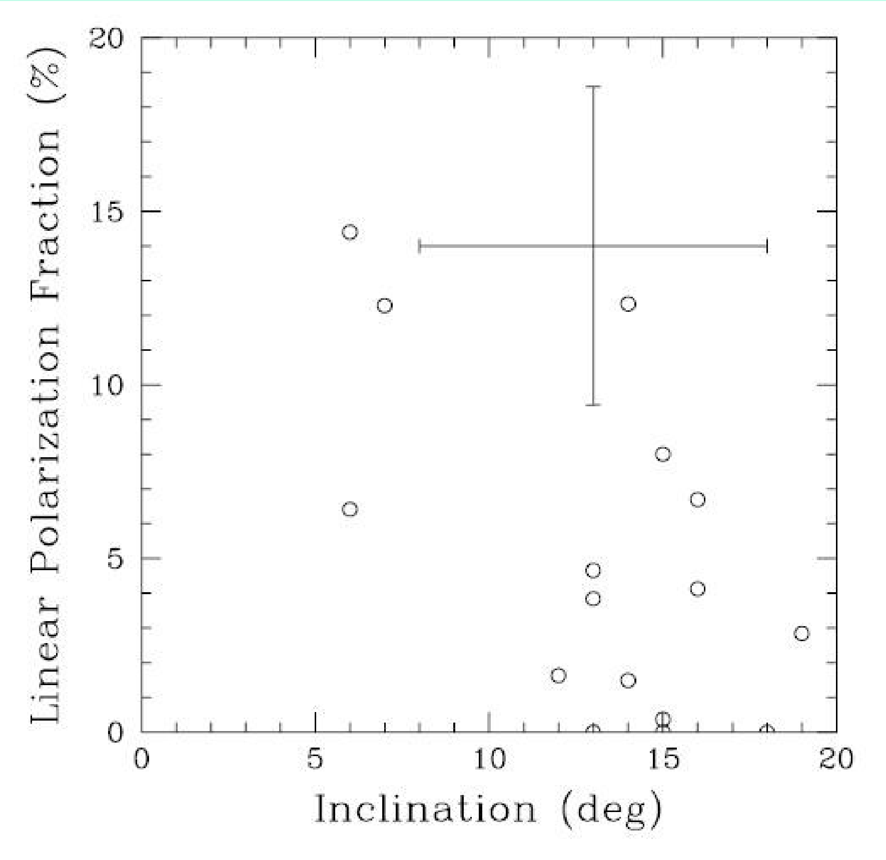


Applying composite theoretical models to the structure of the BLR, it is possible to constrain its geometry through the reconstruction of the whole line profile.

(see also **La Mura et al. 2009, ApJ, 693, 1437**)

Comparison with radio observations





Radio loud sources are likely to host a relativistic jet, arising perpendicularly to the accretion flow. Models with an accretion disk predict a high degree of radio polarization in low inclination sources (where the jet is closer to our sight line). The effect is actually seen.

A new sample

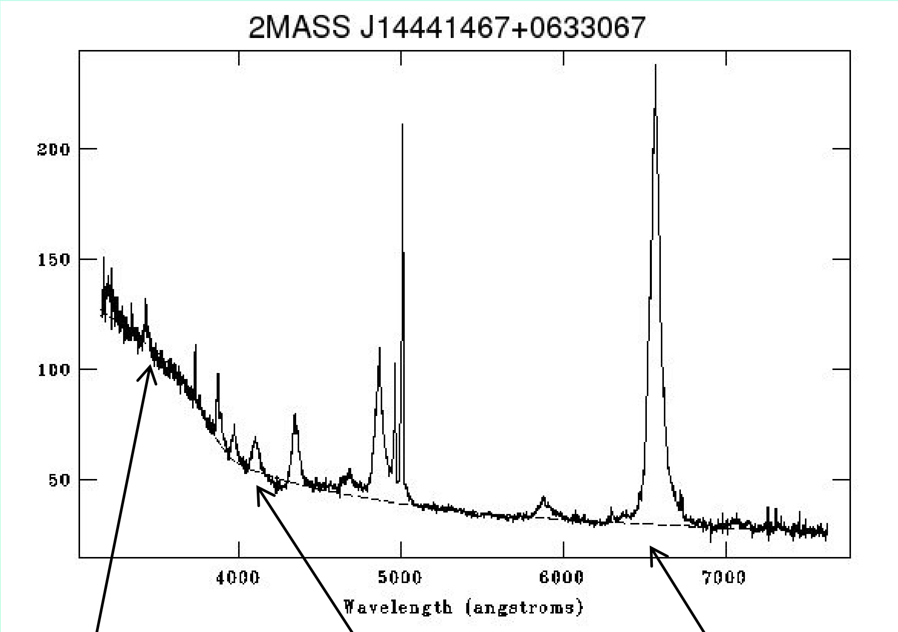
SDSS optical spectra

XMM X-ray observations

Type 1 AGN
$z < 0.35$
$g < 16$
snr (5100Å) > 10
Φ_X(0.1 – 10 keV) > 10^{-12} erg cm^{-2} s^{-1}

23 objects investigated

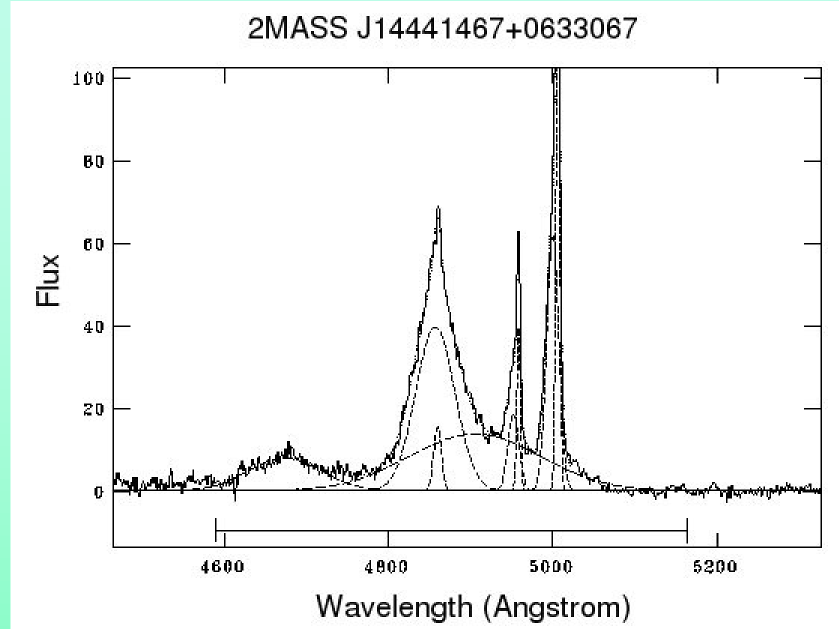
Optical observations

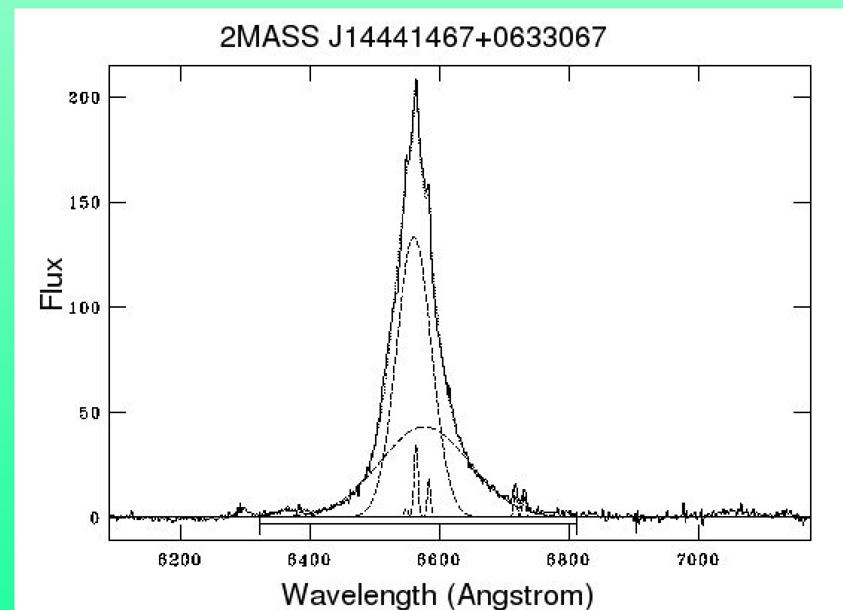


Broken warm ($T = 10^4$ K) thermal emission

Non-thermal power law

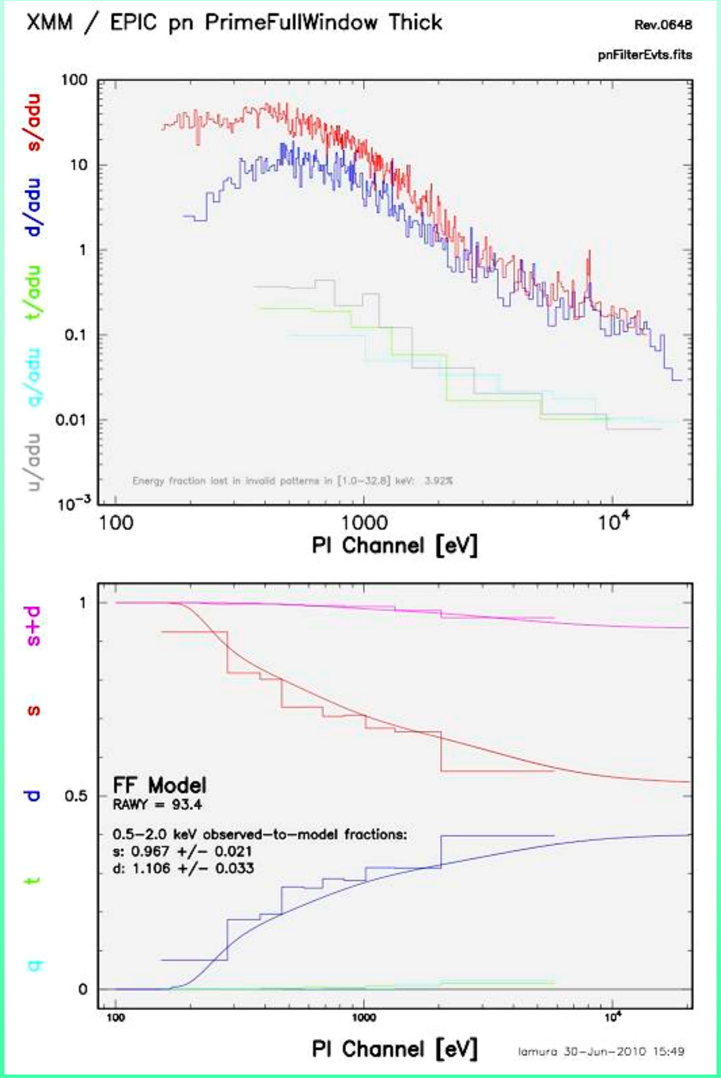
Hot ($T = 10^5$ K) thermal emission



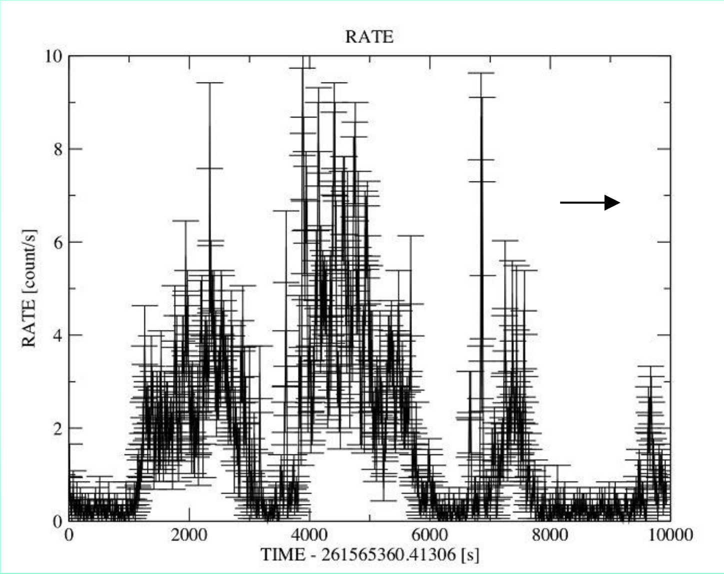


1) A physical approach to the AGN continuum fit (thermal + non-thermal)
2) Multiple Gaussian interpolation of broad emission lines

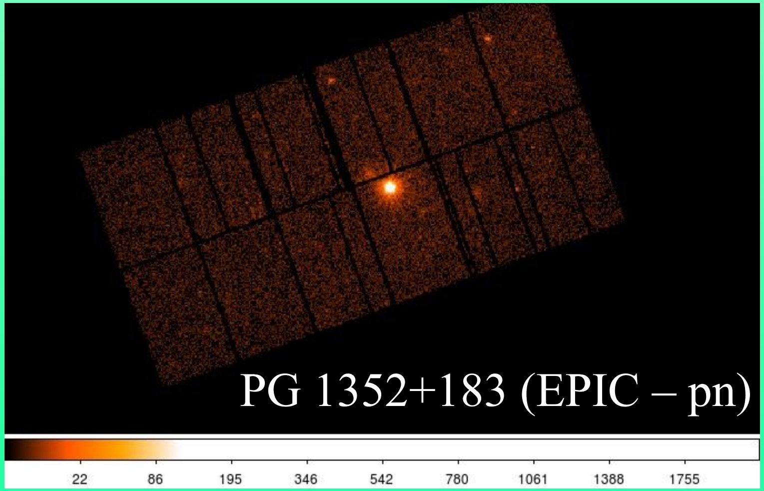
X-ray observations



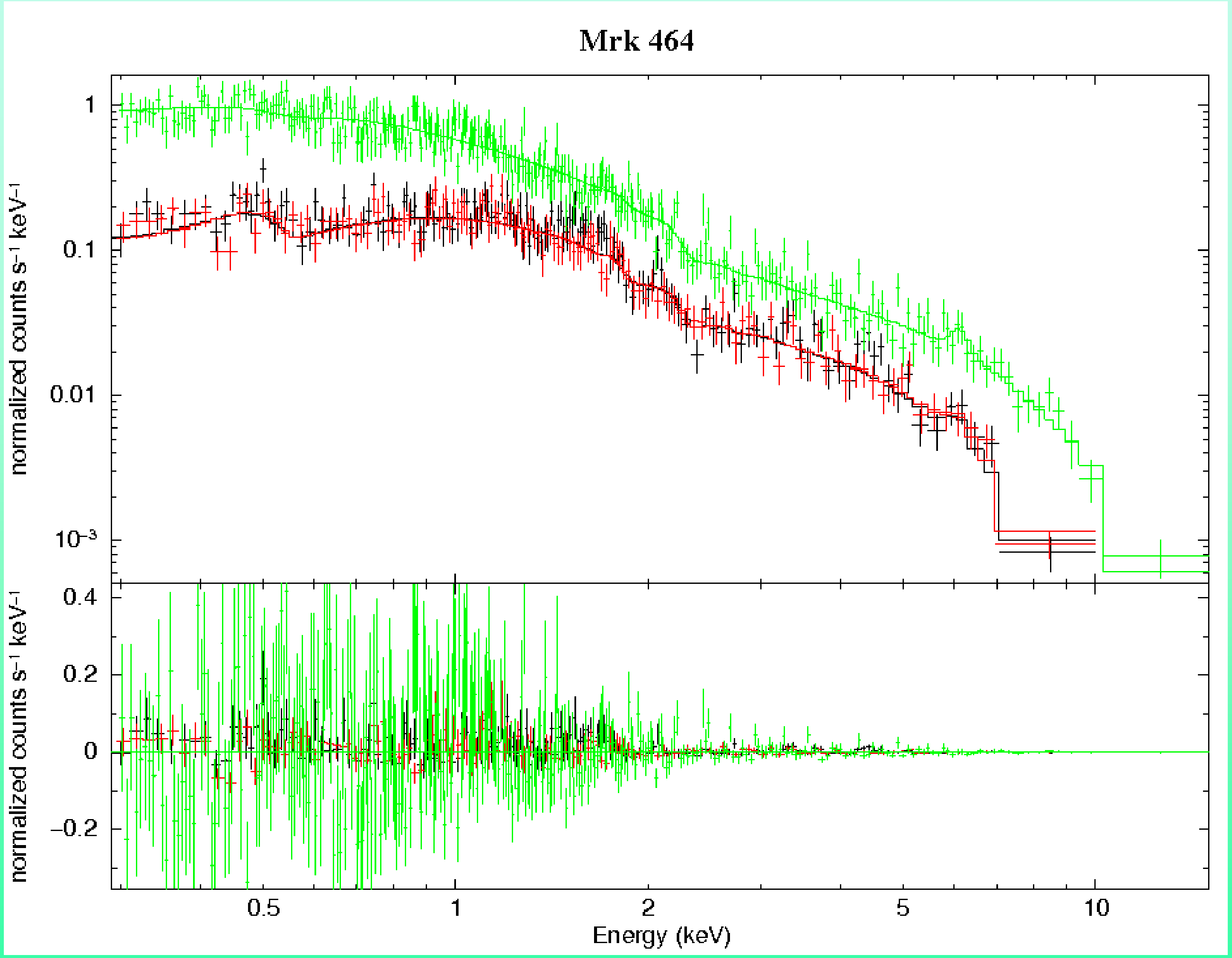
For the X-ray data we used XMM Newton observations, which provide records from multiple detectors



Space born instruments, however, may be prone to disturbing effects which seriously reduce the useful observing time

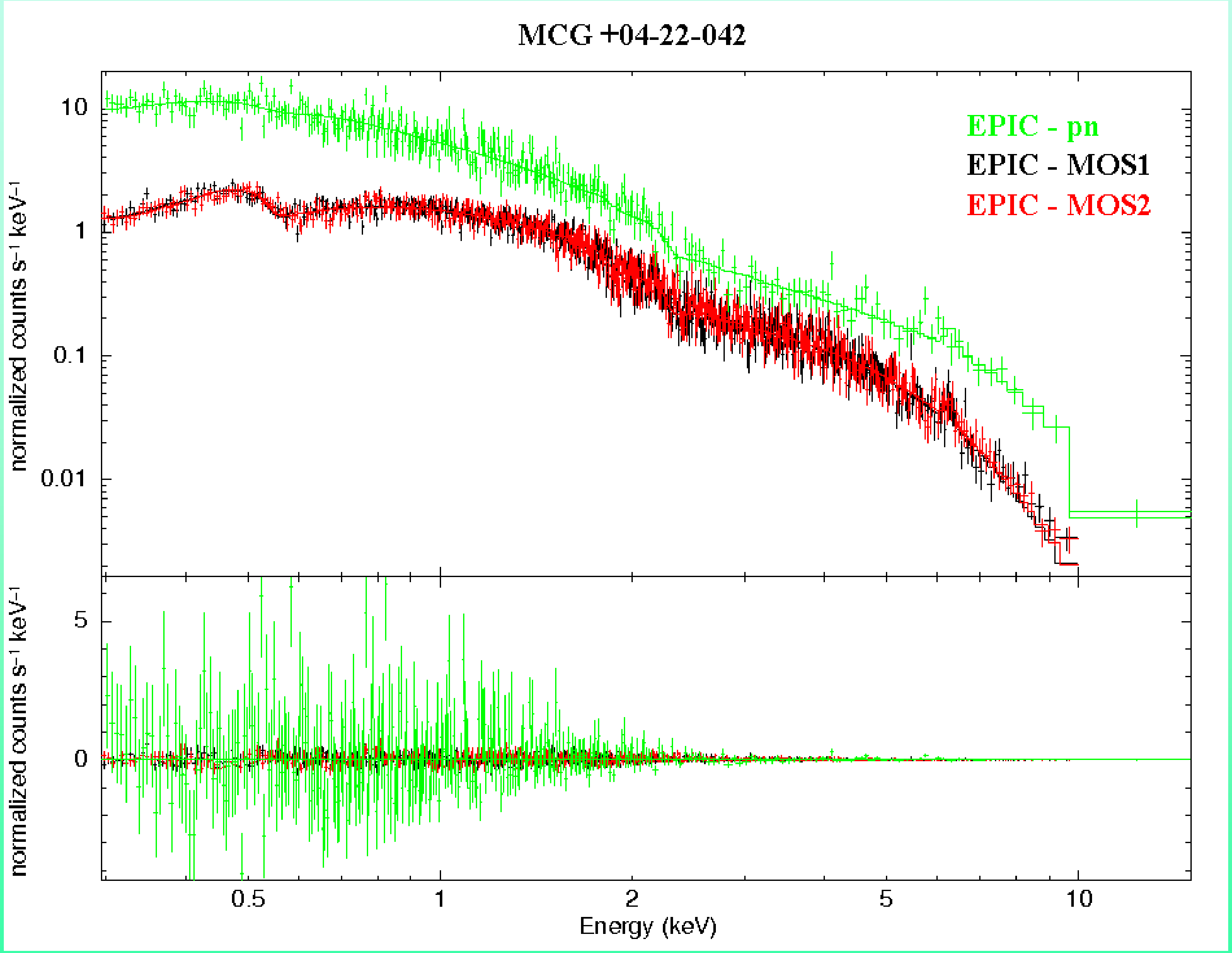


X-Ray spectra of broad line emitters



Spectral features can only be identified combining instruments with different performances. This spectrum combines thermal and non-thermal emission, little evidence for absorption and reflection from low-ionization material.

X-ray spectra of narrow line emitters



A complex thermal component, some evidence of absorption, and a steep non-thermal emission with reflection from a highly ionized medium. Such features also fit in the high accretion rate scenario, drawn from optical observations.

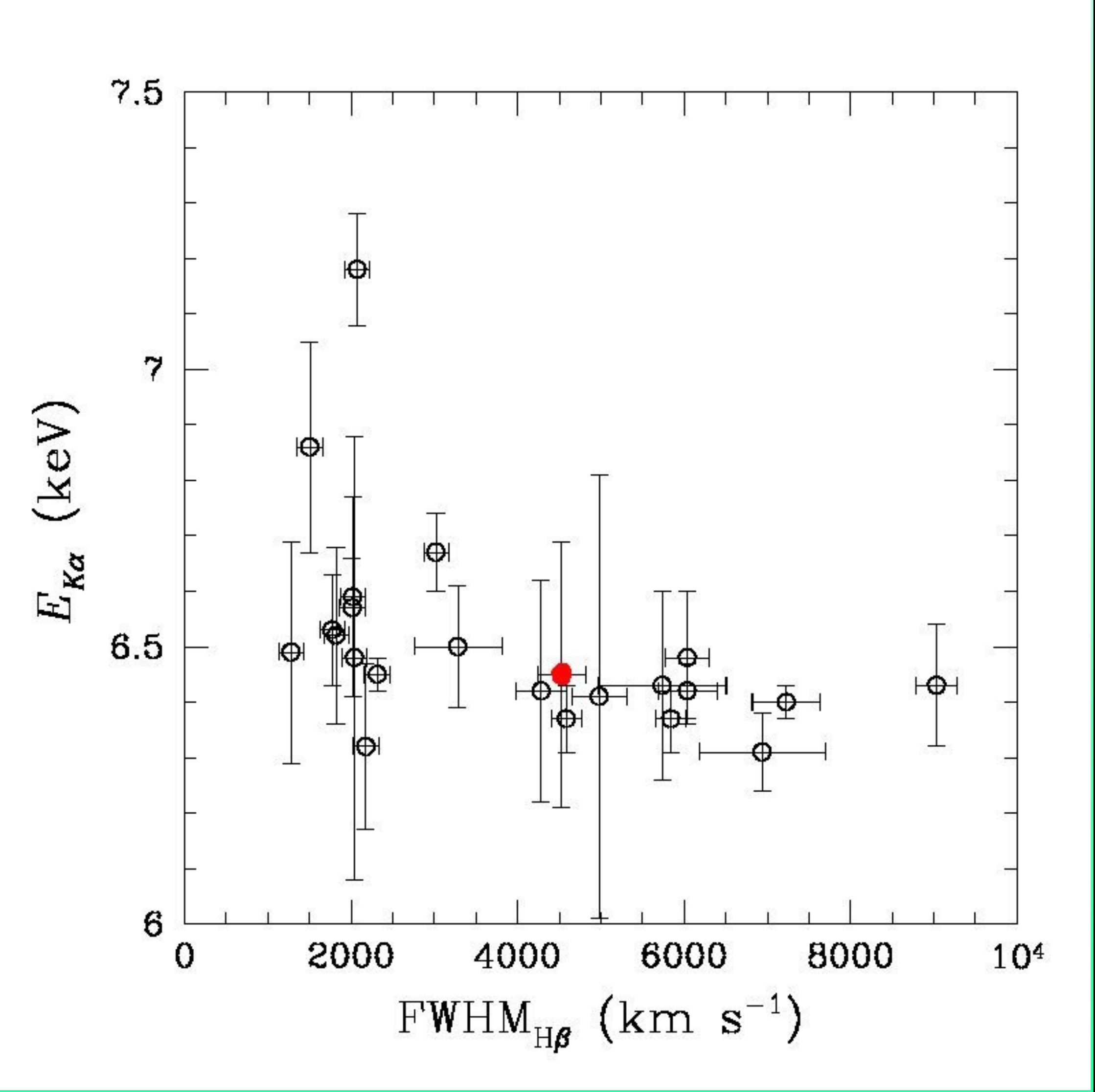
Ionization and line profiles

Fe $K\alpha$ reflection line appears to be a tracer of matter ionization

The energy of line centroid increases in objects with narrower optical line profiles ($FWHM_{H\beta} < 4000$ km s^{-1})

High ionization is only observed in the range of Narrow Line Seyfert 1 galaxies

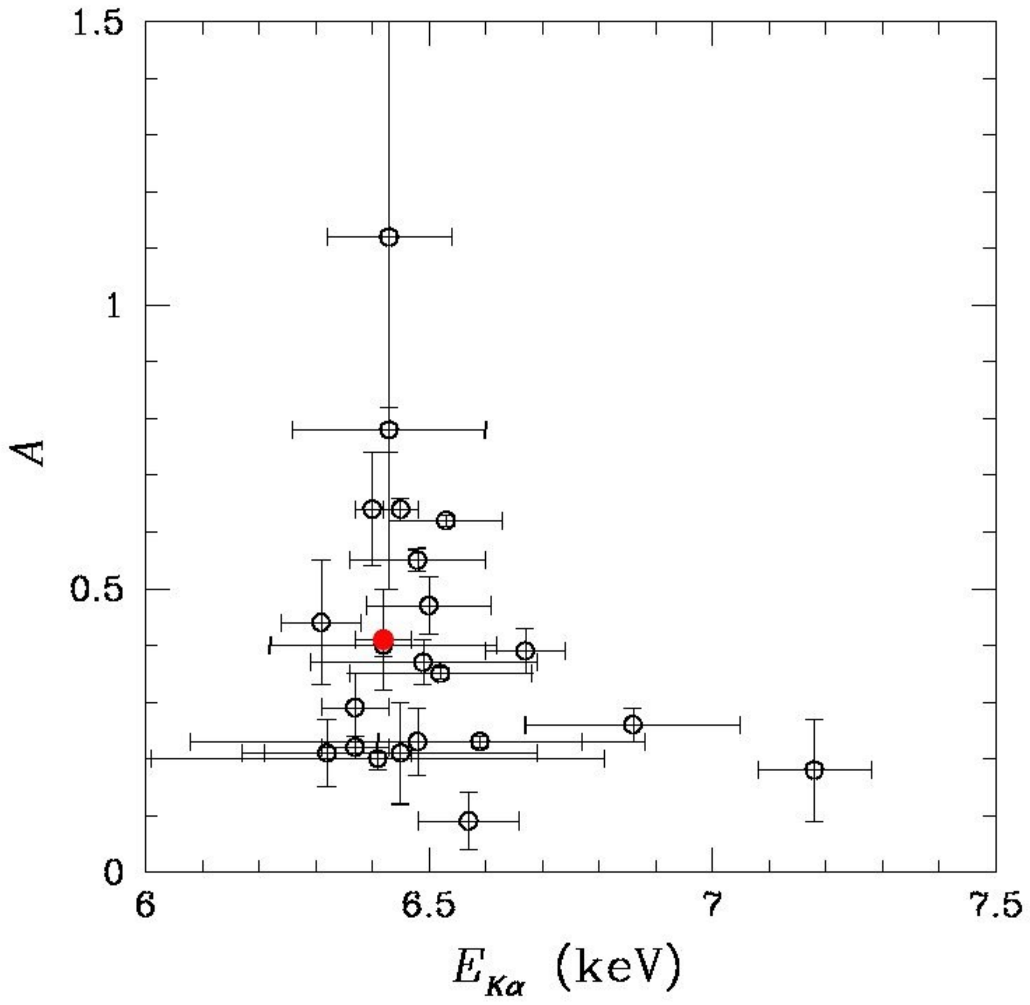
Red dot has only a guess to the position of Fe $K\alpha$



Ionization and BLR plasma physics

High degree of ionization from the X-ray spectra of NLS1 galaxies was already suggested by **Romano et al. 2002, ApJ, 564, 162**

It is here verified that the degree of ionization also affects the optical emission line ratios. This relationship is at the basis of the interpretation of the connection between broad line plasma kinematics and thermo-dynamical properties, seen at optical frequencies.



Concluding remarks

Application of multiple wavelength monitoring techniques to AGNs takes us to important conclusions on their nature. In particular it is found that:

1. The optical line profiles are related to the geometrical structure of the central source, as it is also confirmed by evidence in radio observations.
2. The plasma ionization conditions that can be inferred from the optical emission lines and the X-ray spectra are consistent with the optical indications, supporting structural interpretation of the central energy source.