Dynamical inferences on Super Massive Black Holes from the spectra of broad line emitting Active Galaxies

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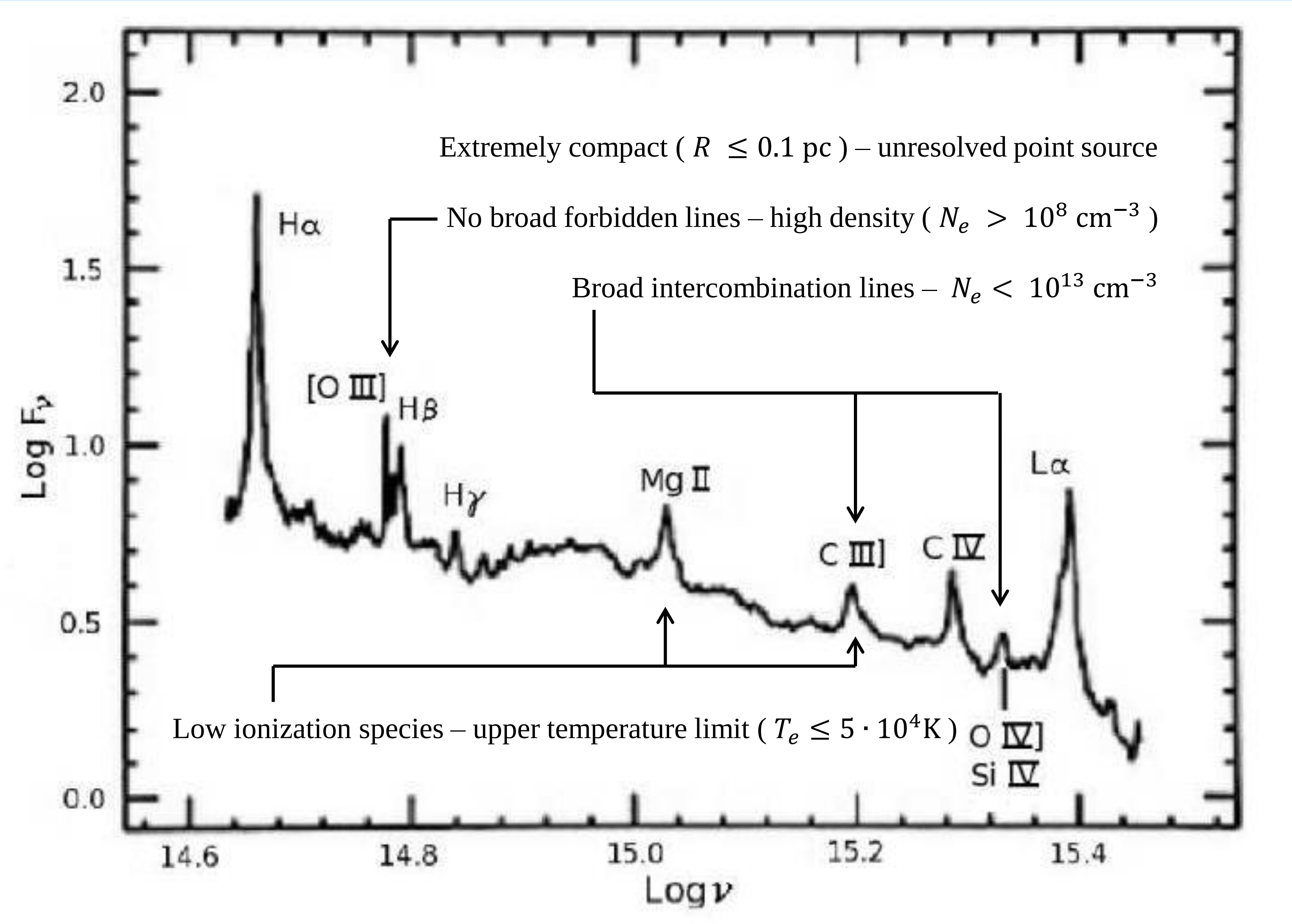
Discussion outline:

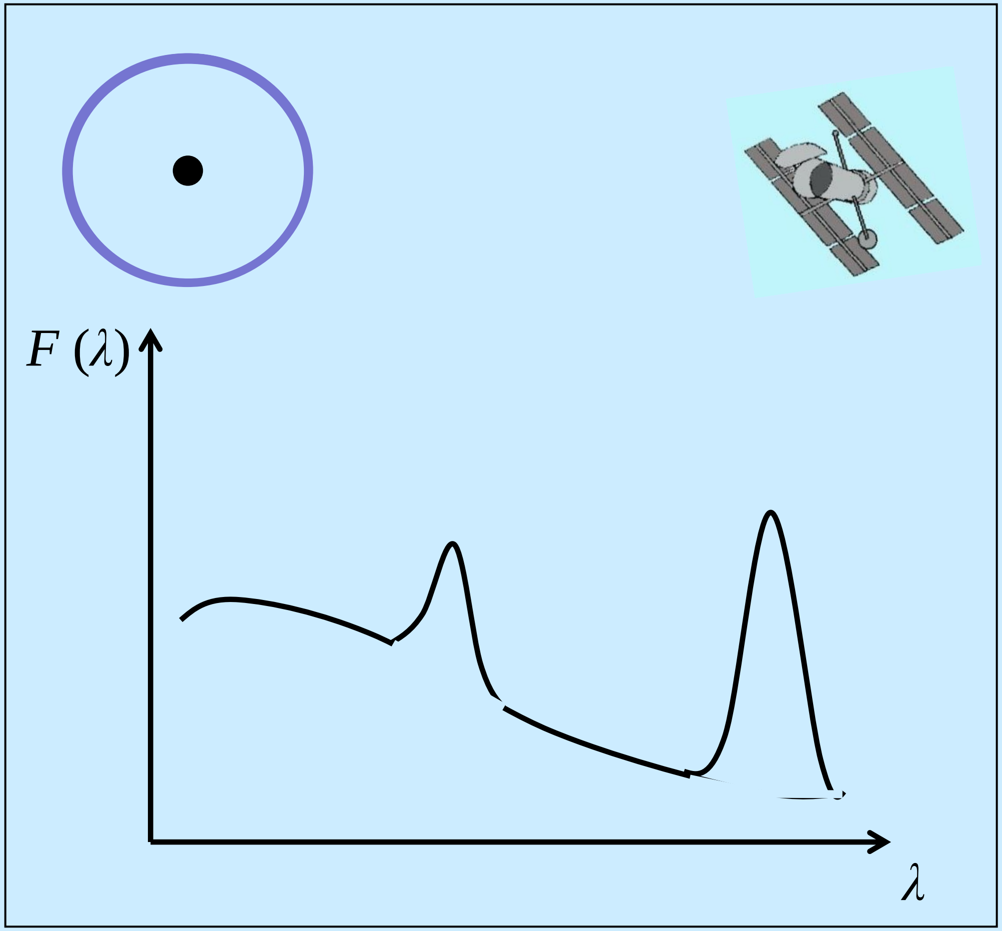
1. Physics of the Broad Emission Line Region (BELR)
2. The optical domain: continuum and emission lines
3. Data analysis threads
4. Insight to the AGN central engines
5. Concluding remarks: available tests and developing perspectives.

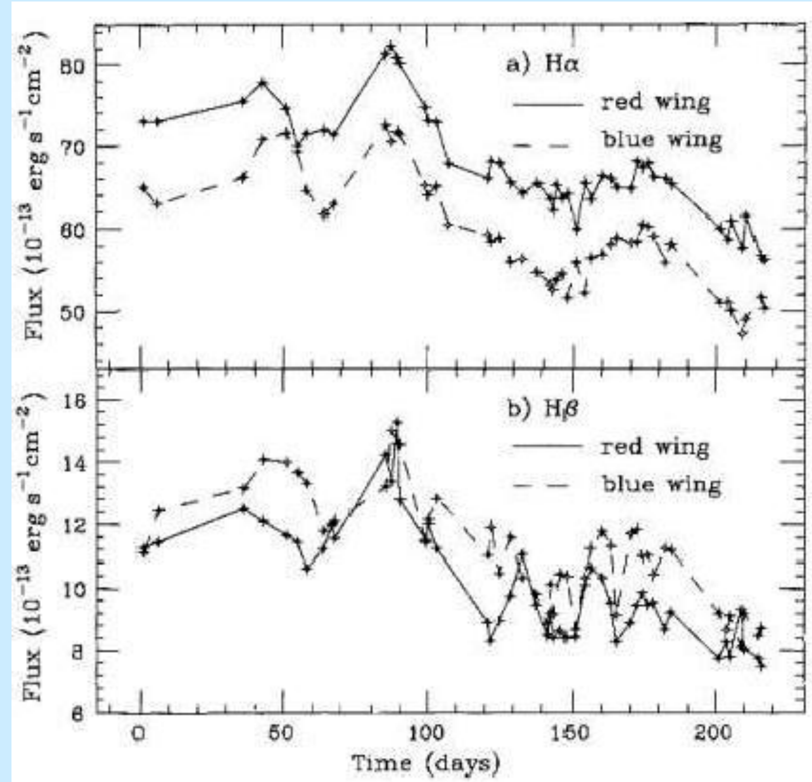
Physics of the BELR



A typical Type 1 AGN spectrum (from Netzer 1990)

Physics of the BELR





Differential emission line light curves in the spectrum of NGC 4151 (Maoz et al. 1991)

Some details of the BELR structure and kinematics can be derived from the analysis of correlated variations in the continuum and emission lines of the spectra, through the *Reverberation Mapping* (RM) technique.

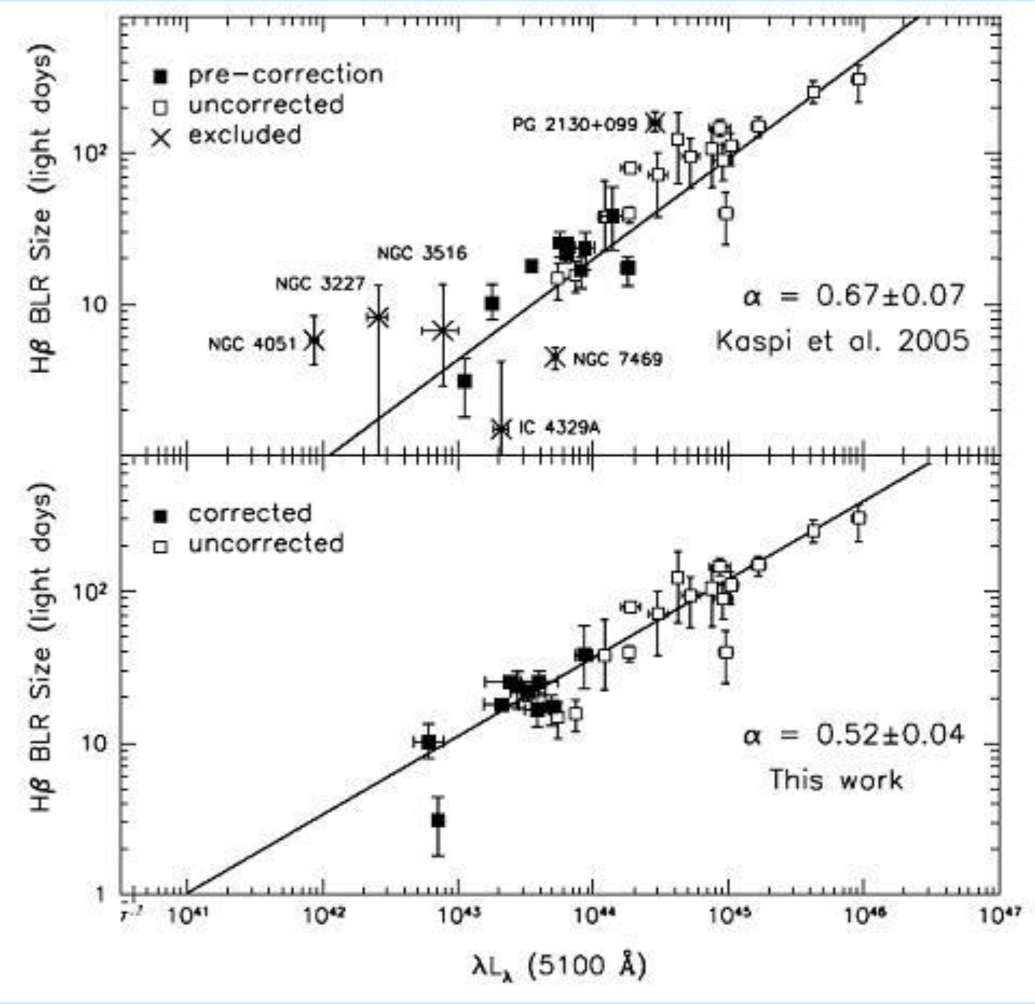
The optical domain: continuum and emission lines

Problems with RM:

- large requirements of time;
- SED variability can hardly be accounted for;
- emission line response assumed to be linear and coherent.

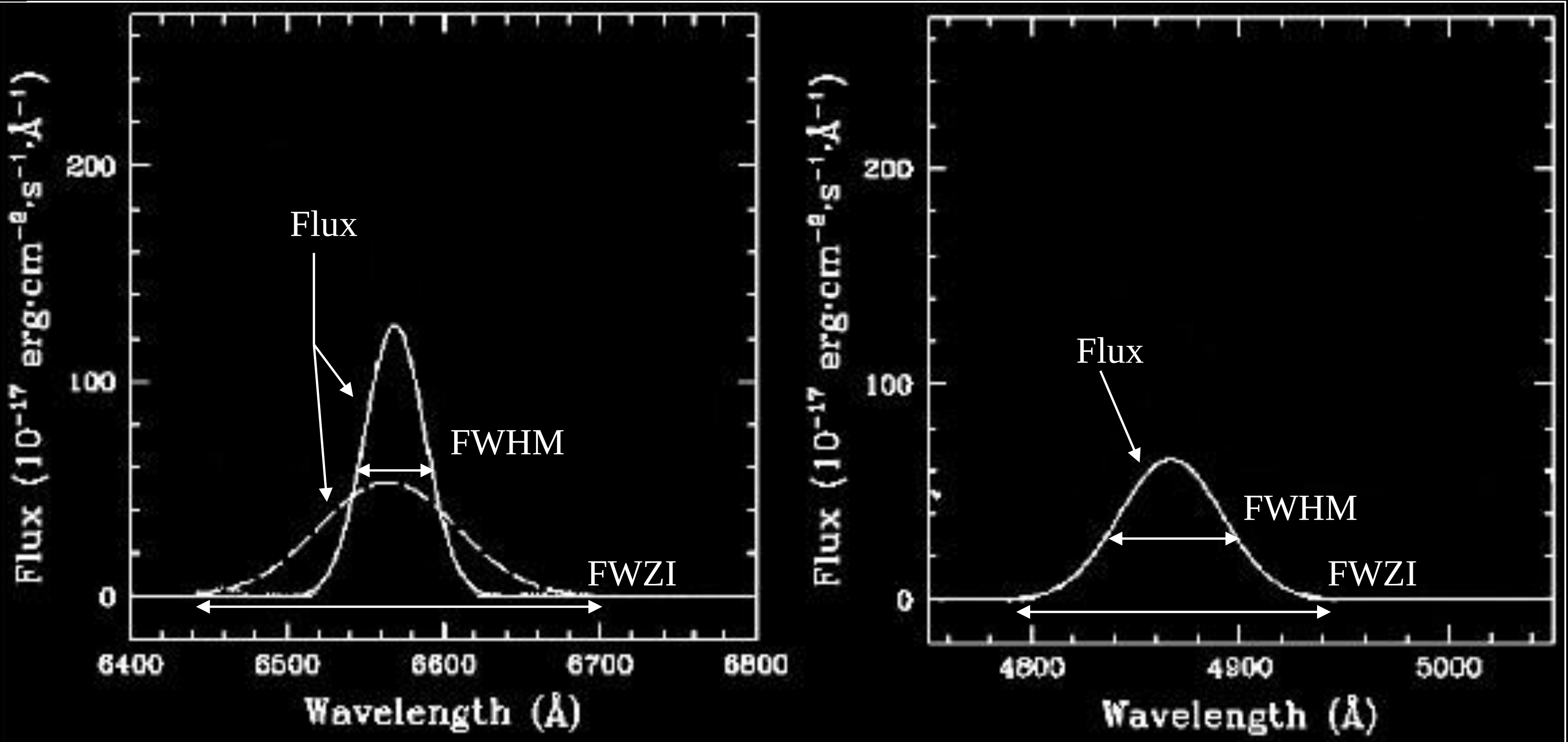
Both theoretical and empirical arguments, however, support a relation among BELR size and continuum luminosity.

Empirical relationships among the continuum source luminosity, in the optical domain, and the BELR size, estimated by means of the Hβ emission line variability lag.



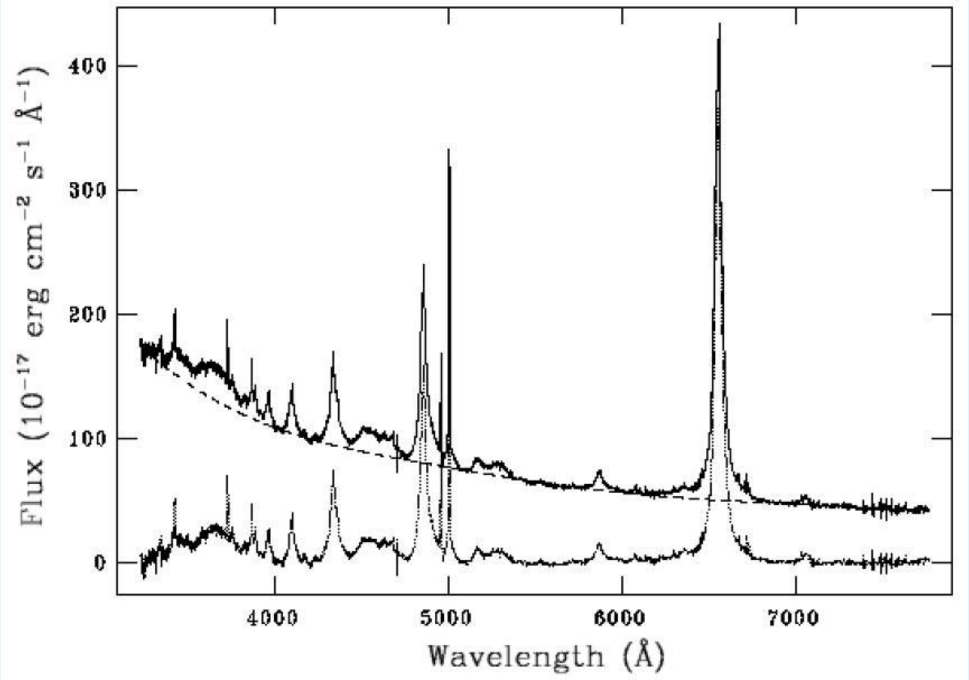
The optical domain: continuum and emission lines

With the estimated BELR size, the properties of emission lines, such as the Balmer series in the optical domain, may contribute to infer the influence played by the central engine on the surrounding medium.



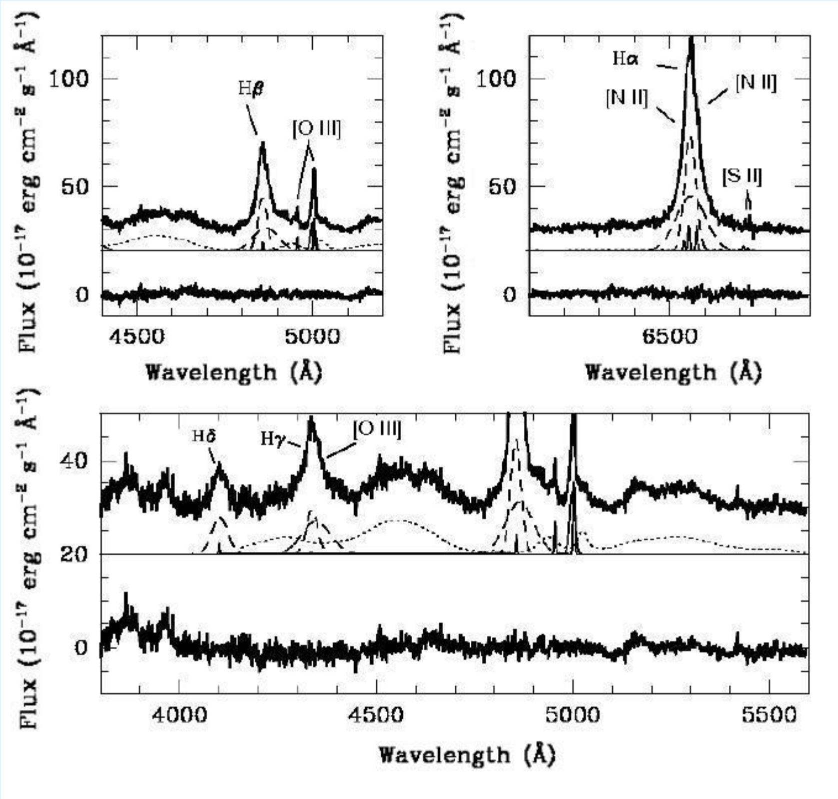
Example of the BELR contribution extraction from the Hα and Hβ emission lines in the spectrum of a broad line emitting AGN

Data analysis threads

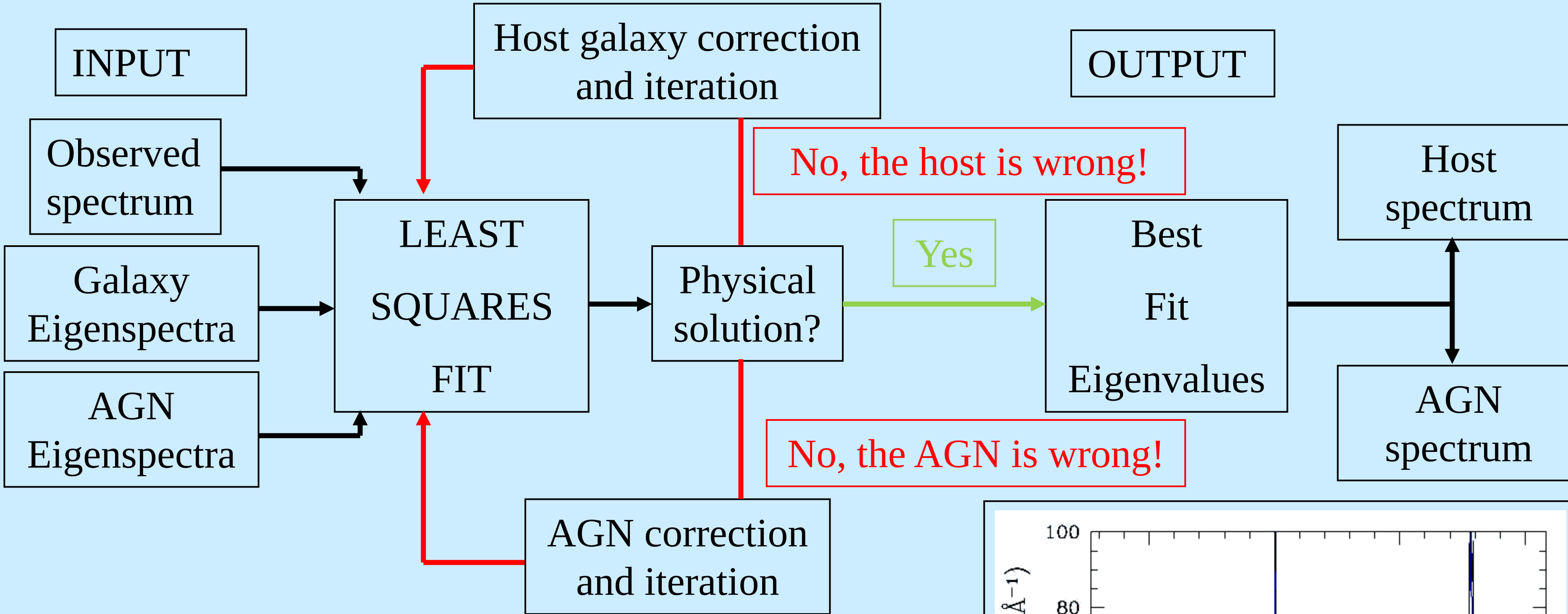


Spectroscopic observations carry several contributions, which are blended together with the BELR signal and must be accounted for, in order to study the broad emission lines. This example illustrates the subtraction of the underlying continuum in the spectrum of 2MASS J03221390+0055134.

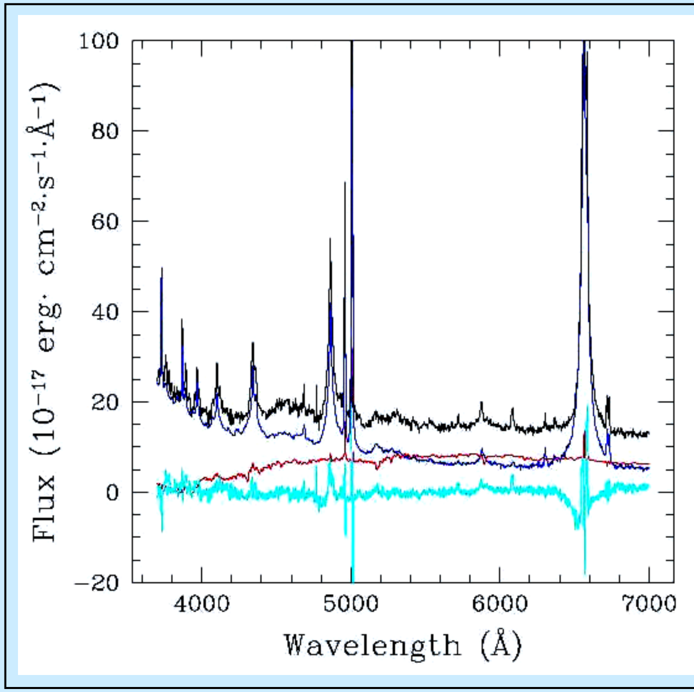
The identification of the broad spectral line component may be carried out by means of standard techniques, such as the multiple Gaussian profile fits, as it is shown in the case of PC 1014+4717 below.



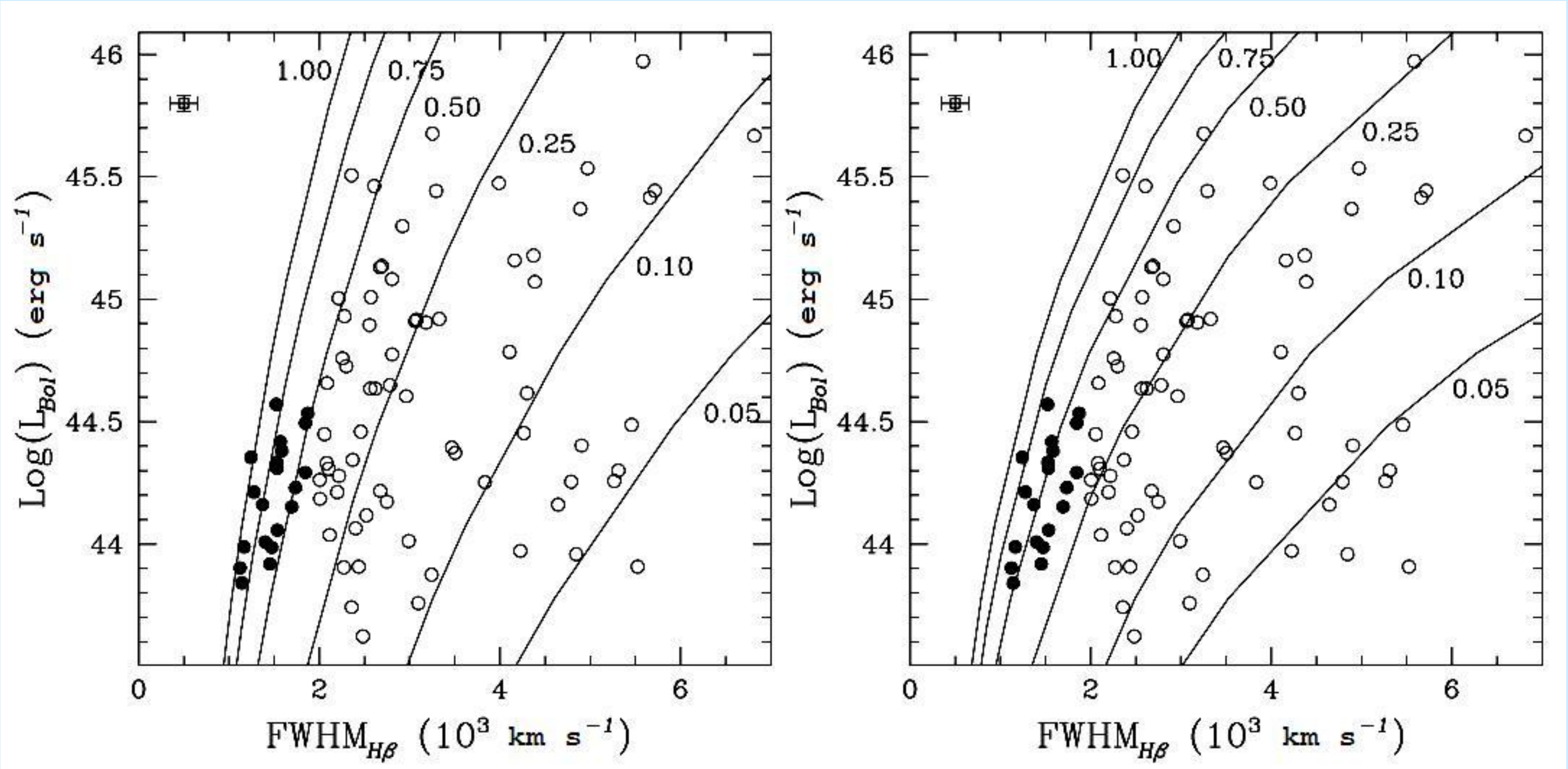
Data analysis threads



On the other hand, we need a distinction among the AGN and host galaxy spectral contributions. This is not available as a standard reduction technique and it requires the development of specific software. Exploiting an object oriented programming language, such as the C++, it is possible to apply the Principal Component Analysis, like in the steps given above, to get the results illustrated in the plot.

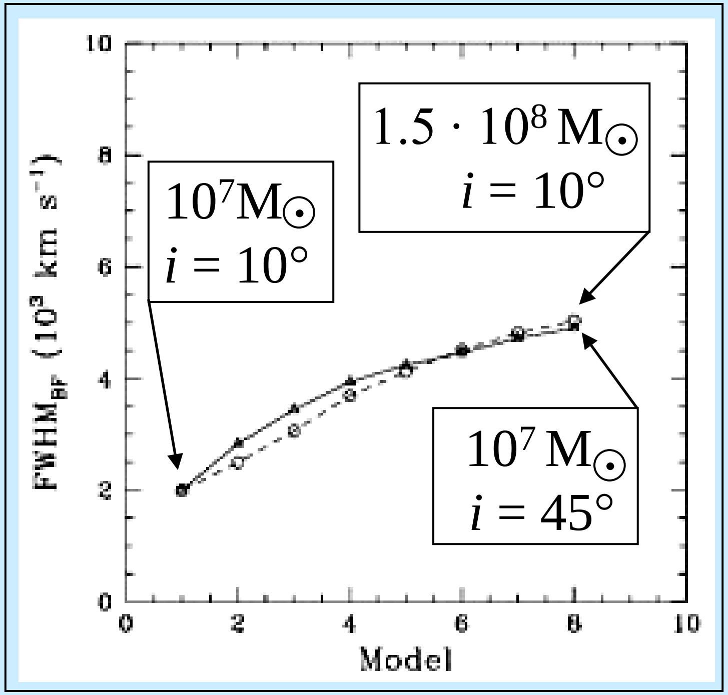


Insight to the AGN central engines

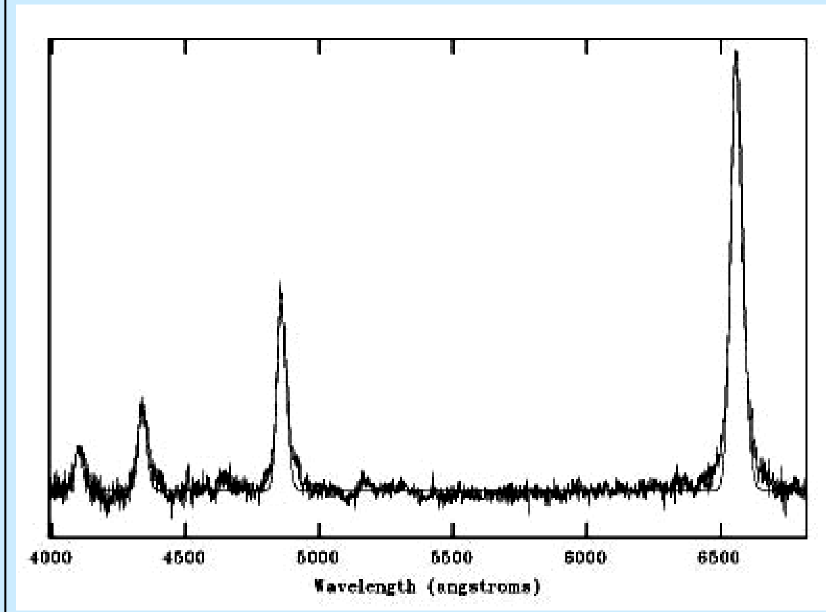


Bolometric luminosities vs. FWHM(Hβ) according to the structural models of Kaspi et al. (left panel) and Bentz et al. (right panel). Filled circles are NLS1 galaxies, while the continuous lines represent SMBH, having masses in the range from $10^6\,M_\odot$ to $10^9\,M_\odot$ and accreting at the labeled Eddington ratios. These observations suggest that objects with narrow emission lines are more commonly powered by low mass black holes working at very high accretion rates.

Insight to the AGN central engines



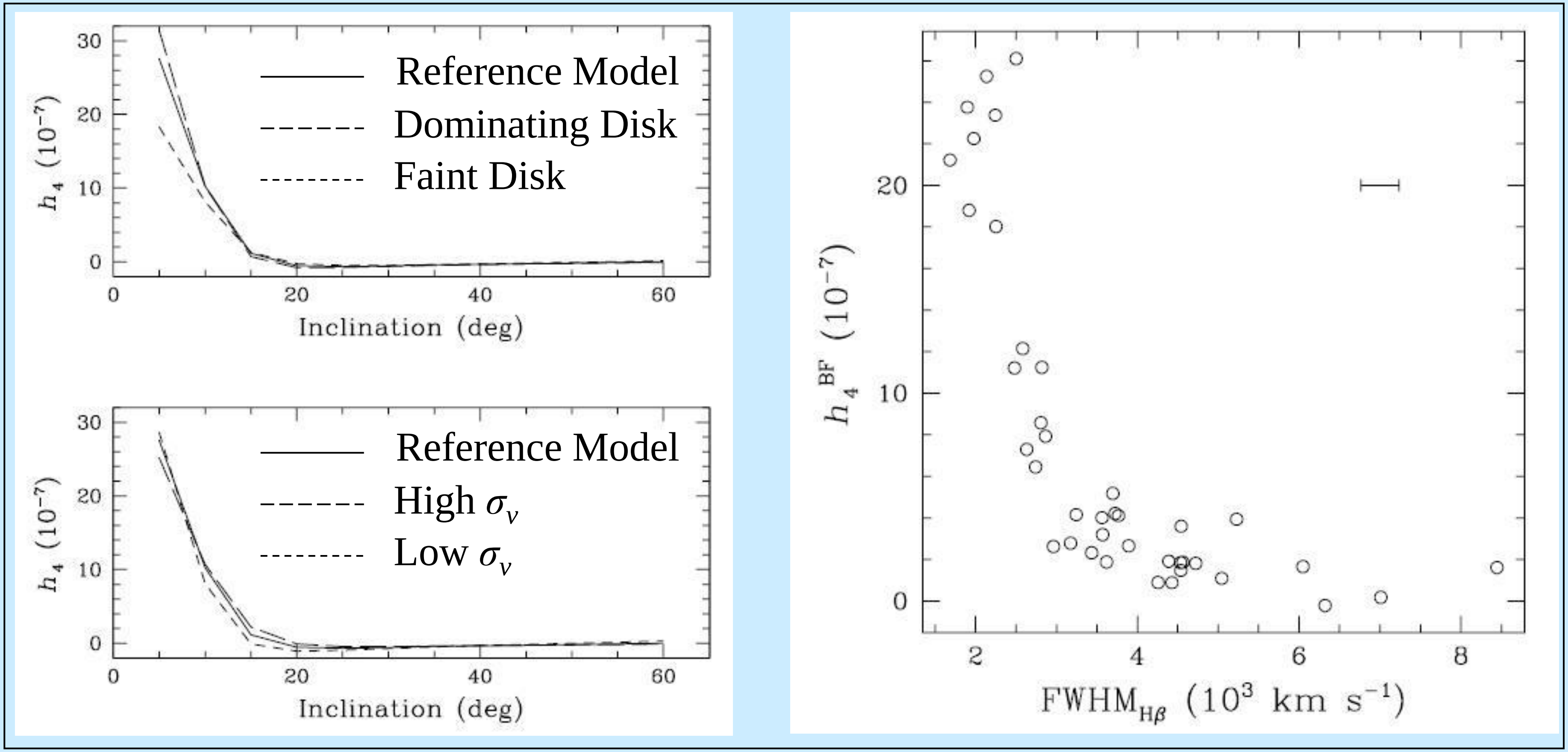
Spectrum of PC 1014+4717



Given the complex structure of the emission line region, however, the connection among the broad line profiles and the source kinematics is not straightforward. Here we introduce a composite broadening function (BF) based on the Gauss-Hermite polynomial expansion:

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

Insight to the AGN central engines



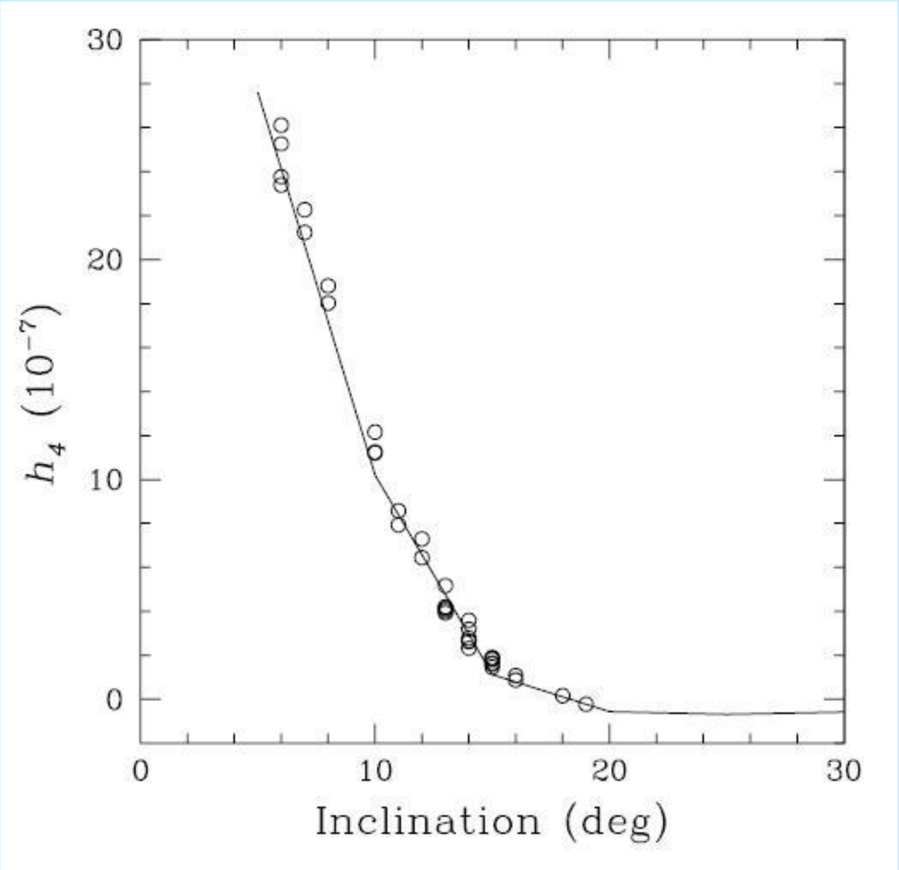
The observed line profile moments are in very good agreement with the predictions of some composite BLR structural models, involving two distinct kinematical contributions: a flat rotating disk, embedded in a surrounding distribution of line emitting material. The inclination of the disk is the main factor affecting the emission line kurtosis.

Insight to the AGN central engines

A comparison among the reference model and the observed line profiles may provide a guess to the inclination of the motion plan in a flattened BELR component.

The most common AGN spectra appear to be consistent with nearly face-on disk structures, having an inclination of $i < 20°$.

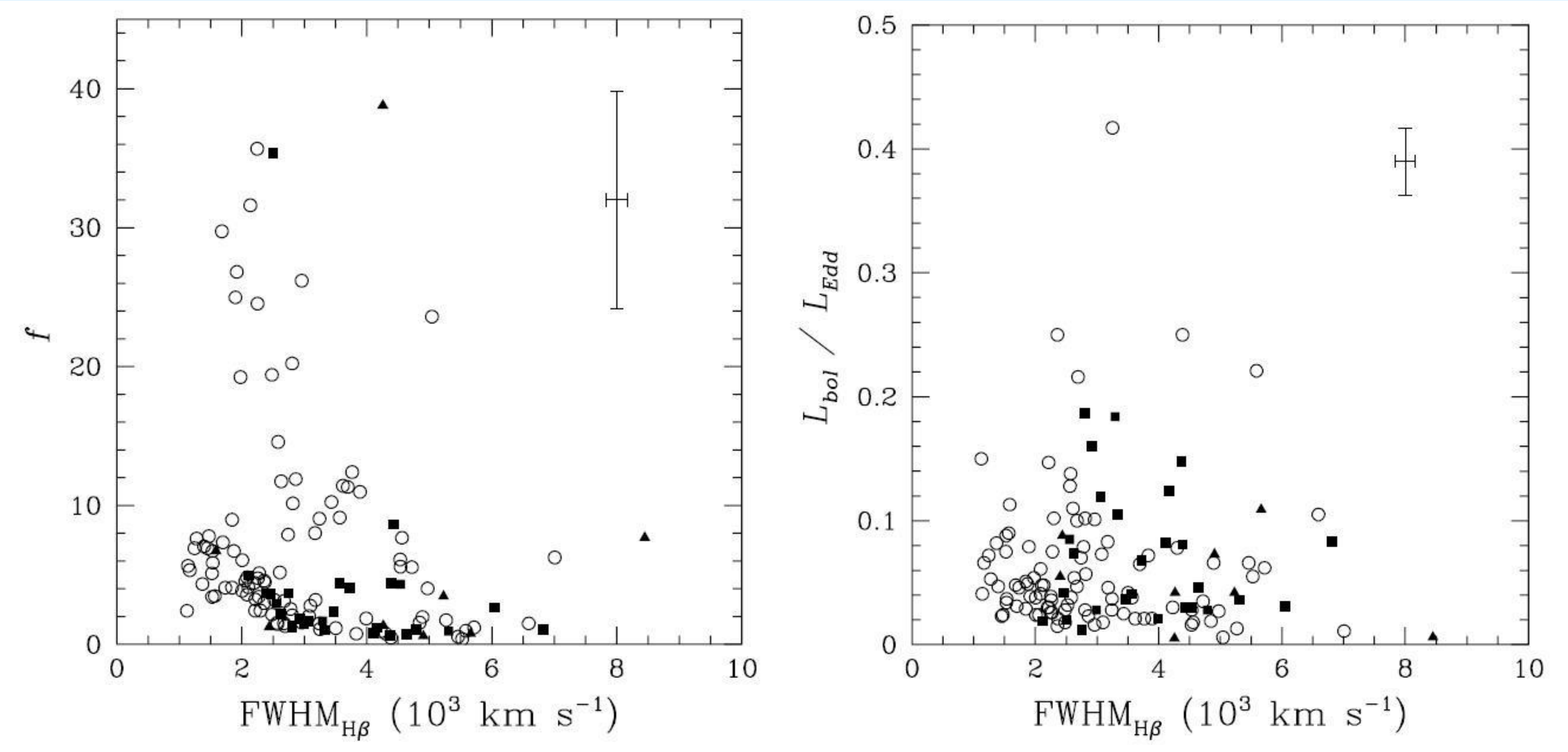
Such inclinations agree with observations concerning the rare occurrence of double peaks in the broad line profiles.



Inclination of the rotating disk component in the BELR estimated from a comparison of the line profile kurtosis with the value predicted by the reference structural model.

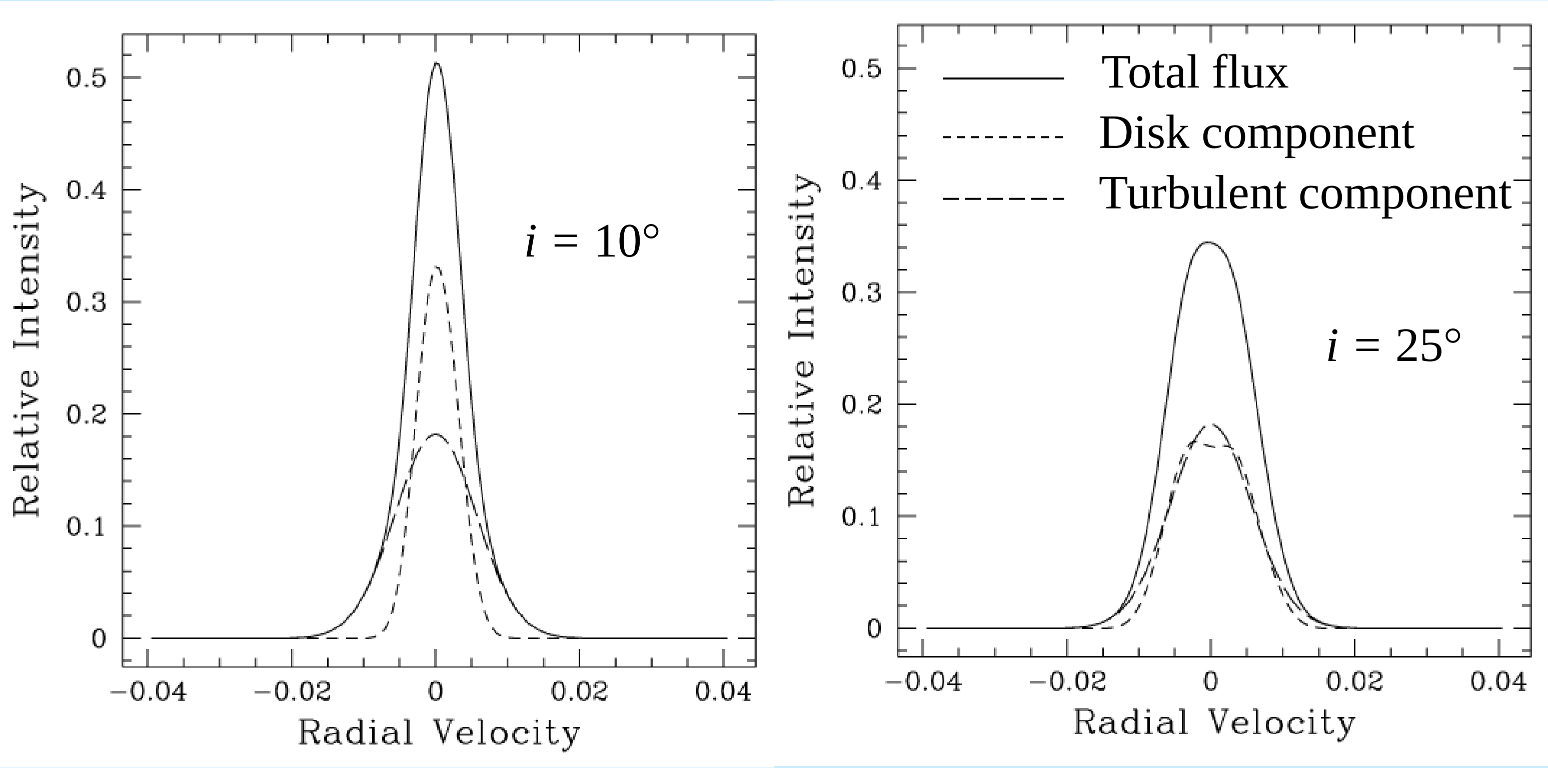
Concluding remarks

$$M_{BH} = f\,\frac{R_{BLR}v^2}{G} \qquad f \cdot v^2 = v_{eq}^2 = \frac{1}{4}\left[\frac{\sqrt{3}}{2}\mathrm{FWHM}_{Turb} + \frac{\mathrm{FWHM}_{Disk}}{4\sin i}\right]^2$$



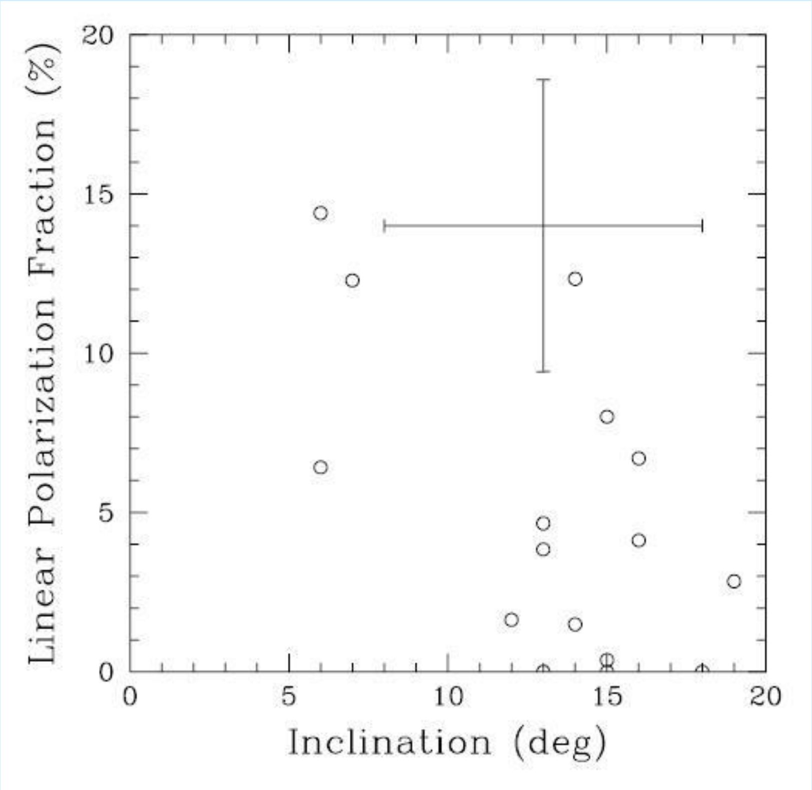
Left: Geometrical factors to estimate the SMBH mass from the profile of the Hβ emission line. Right: Accretion rates onto the SMBH, given in terms of Eddington ratios, as a function of the corresponding FWHM(Hβ).

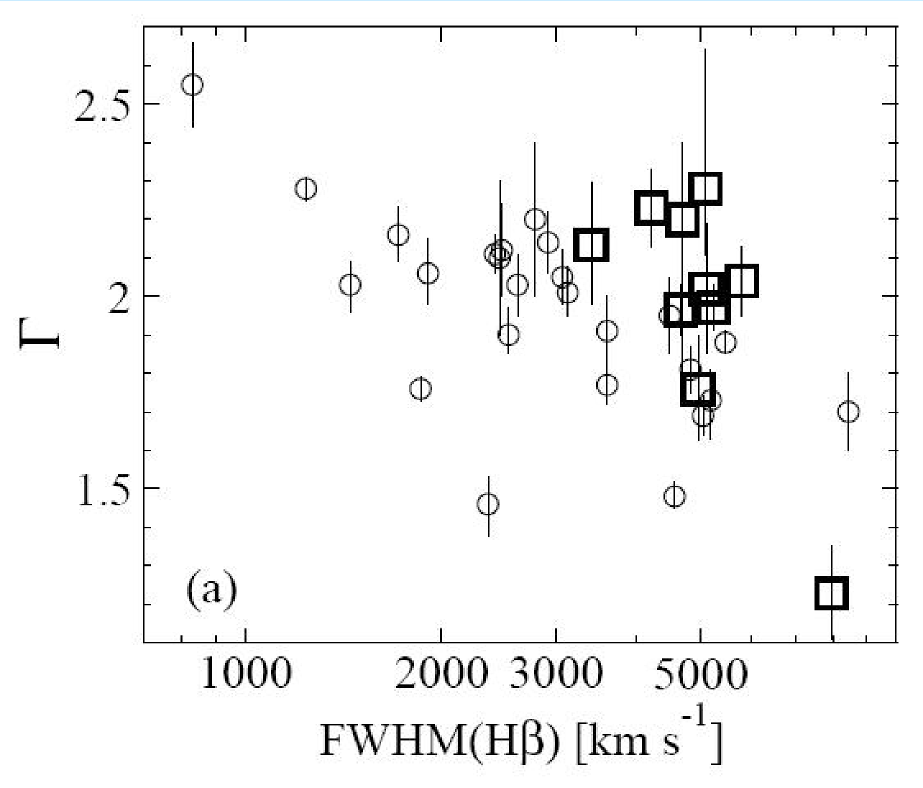
Concluding remarks



The profiles of the emission line broadening functions result from the combination of the central engine's dynamical influence and the geometrical projection effect. By modeling the broad emission line profiles it is possible to penetrate the BELR structure and to improve the analysis of AGN dynamical properties. The results achieved in the optical domain are consistent with other independent measurements at radio wavelengths.

Concluding remarks





Left: the relationship among the linear polarization degree detected in radio by the VLA FIRST survey and the estimated BLR inclination of our composite kinematical model. **Right:** the hard X-ray photon index vs. FWHM of Hβ for low luminosity nearby sources ($\nu L_\nu <\ 10^{46}$erg cm^{-1}, $z < 0.5$, circles) and for bright high redshift quasars ($\nu L_\nu >\ 10^{46}$erg cm^{-1}, $1.3 < z < 3.2$, squares)