A multiple wavelength perspective on active galaxies

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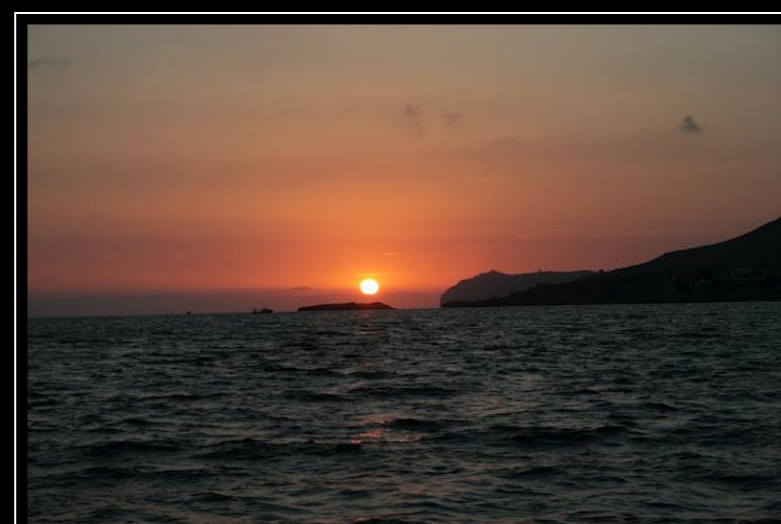
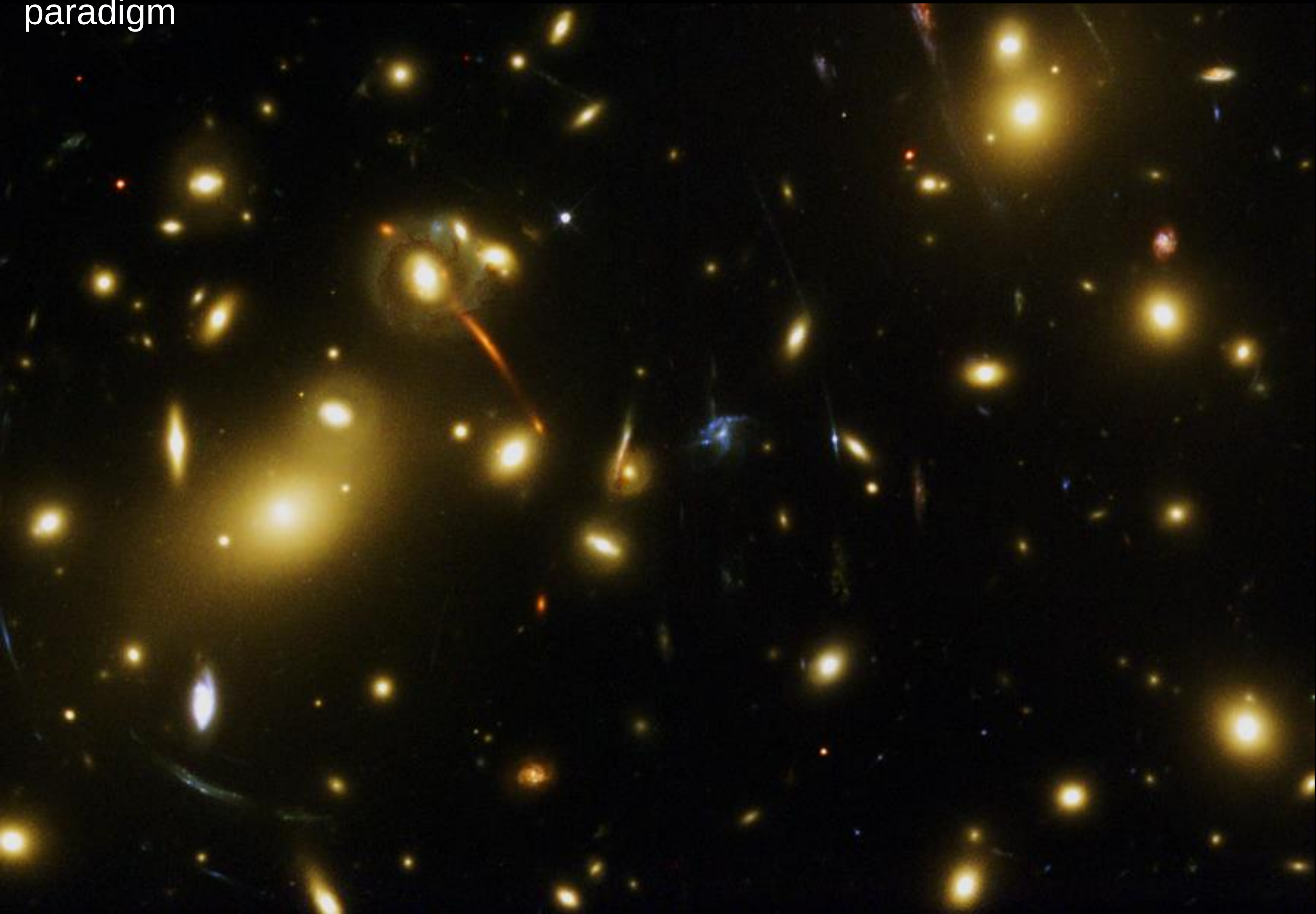
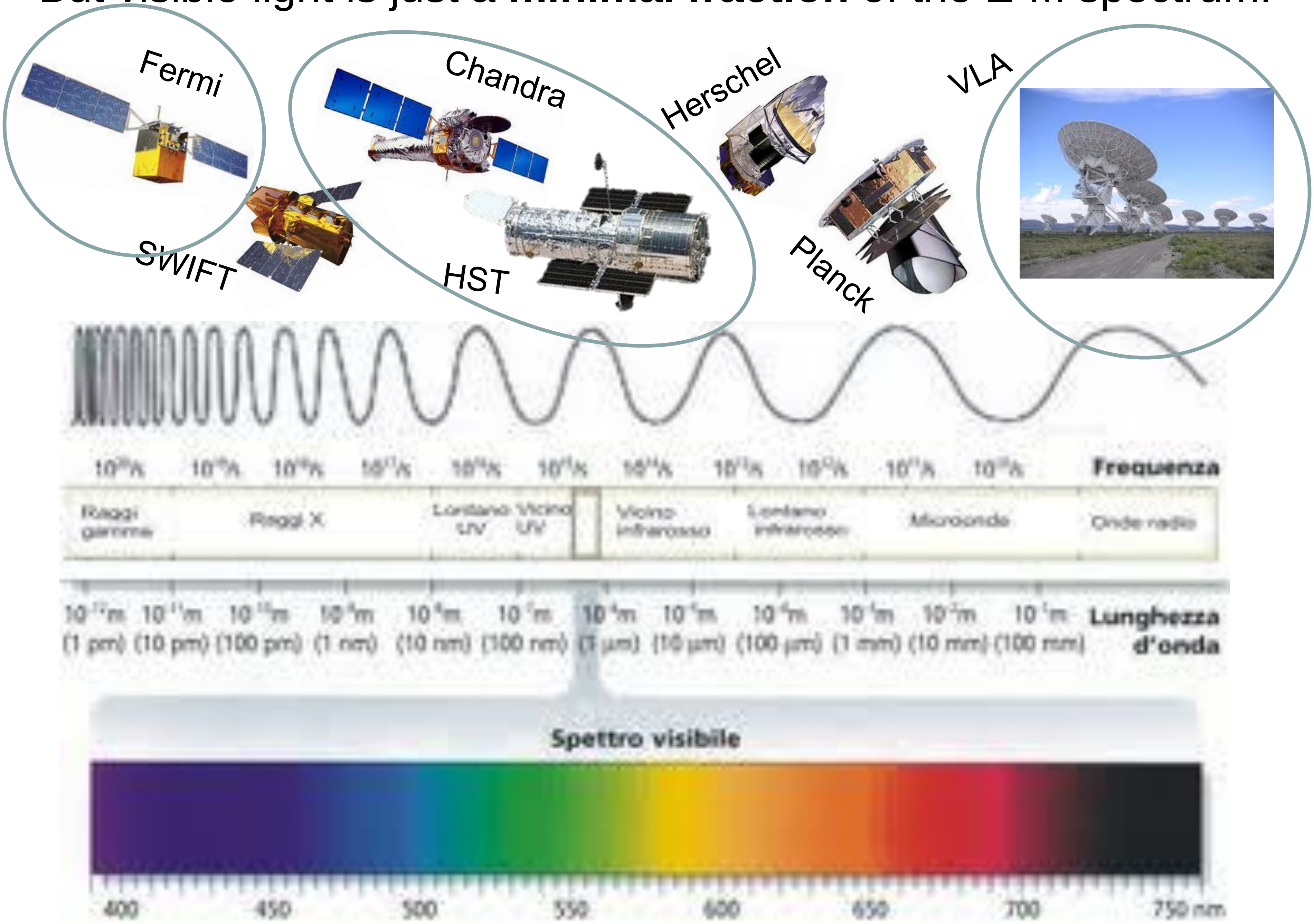
Most of light in nature comes from stars…



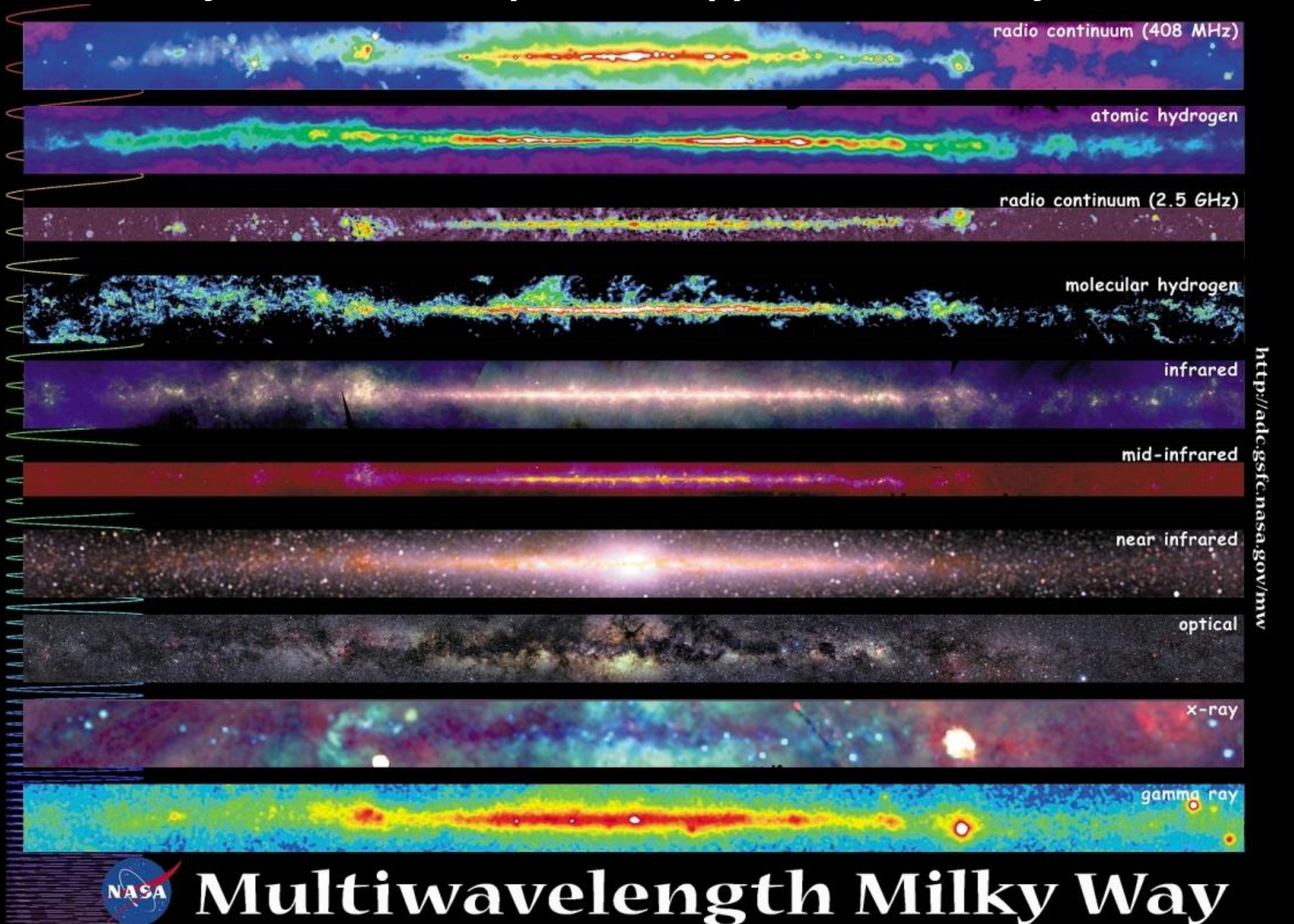
Till the first half of the 20th century, ***light = stars*** was considered a universal paradigm



But visible light is just a **minimal fraction** of the E-M spectrum!



The sky at various frequencies appears drastically different



Beyond UV-optical-IR frequencies, stars are no longer the most common light sources, nor the brightest.

3C 273, QUASAR

NGC 1316, Radiogalaxy

Active Galactic Nuclei challenge with their luminosity the brightness of entire galaxies ($10^{43} – 10^{46}$ erg/s)

NGC 1566, Seyfert 1

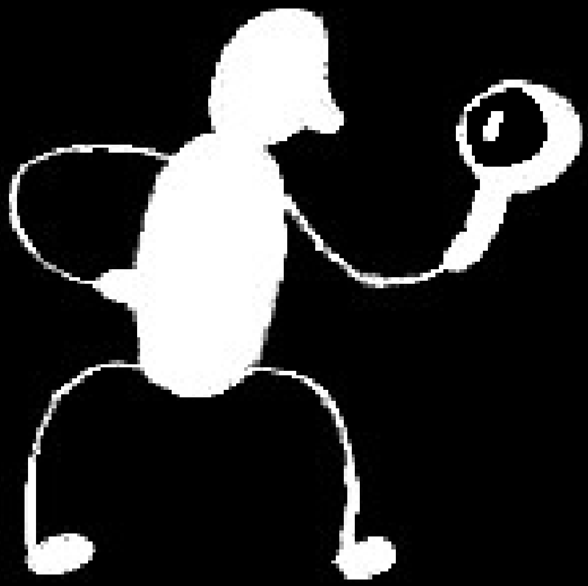
NGC 1566, Seyfert 2

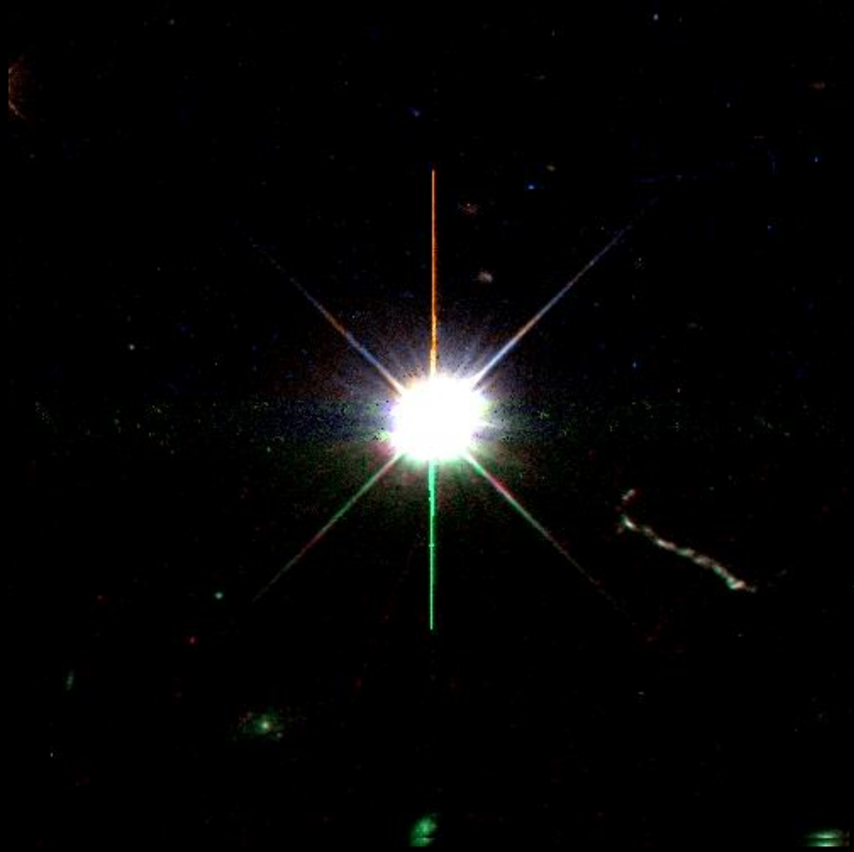
Beyond UV-optical-IR frequencies, stars are no longer the most common light sources, nor the brightest.

Active Galactic Nuclei challenge with their luminosity the brightness of entire galaxies ($10^{43} – 10^{46}$ erg/s)

There is convincing evidence that their power supply cannot be afforded by stars, but it requires accretion of matter into the gravitational field of a **Super Mssive Black Hole** ($M_{\rm BH} \sim 10^6 – 10^9\ M_\odot$)

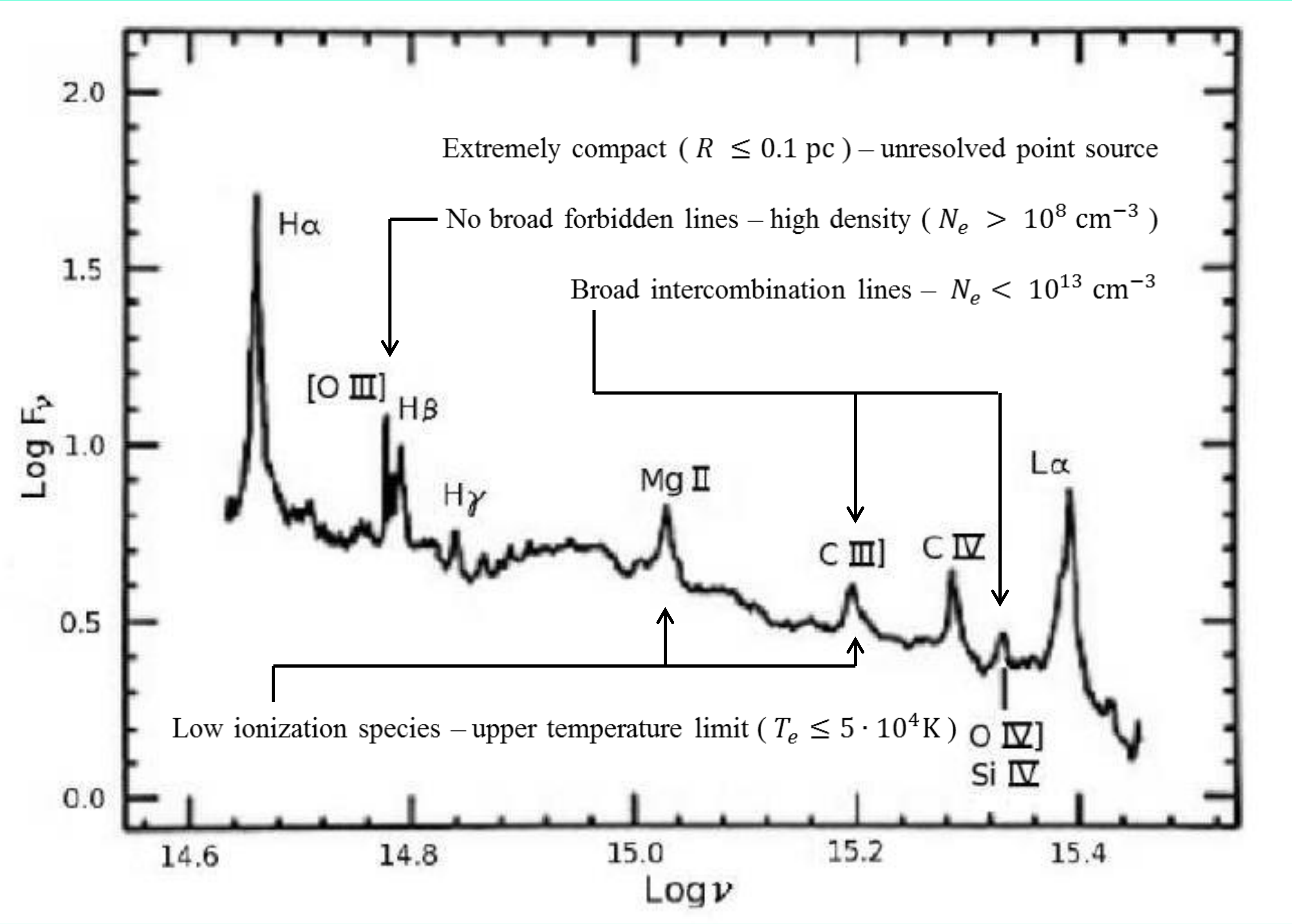
Given the extremely compact nature of the central power source ($R \sim 0.1$ pc) it is not possible to directly resolve its structure with imaging techniques.





We need to turn ourselves to some different method.

A typical AGN spectrum shows various, distinct components



Different spectal features can be traced back to different physical origins.

The AGN Unified Model

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

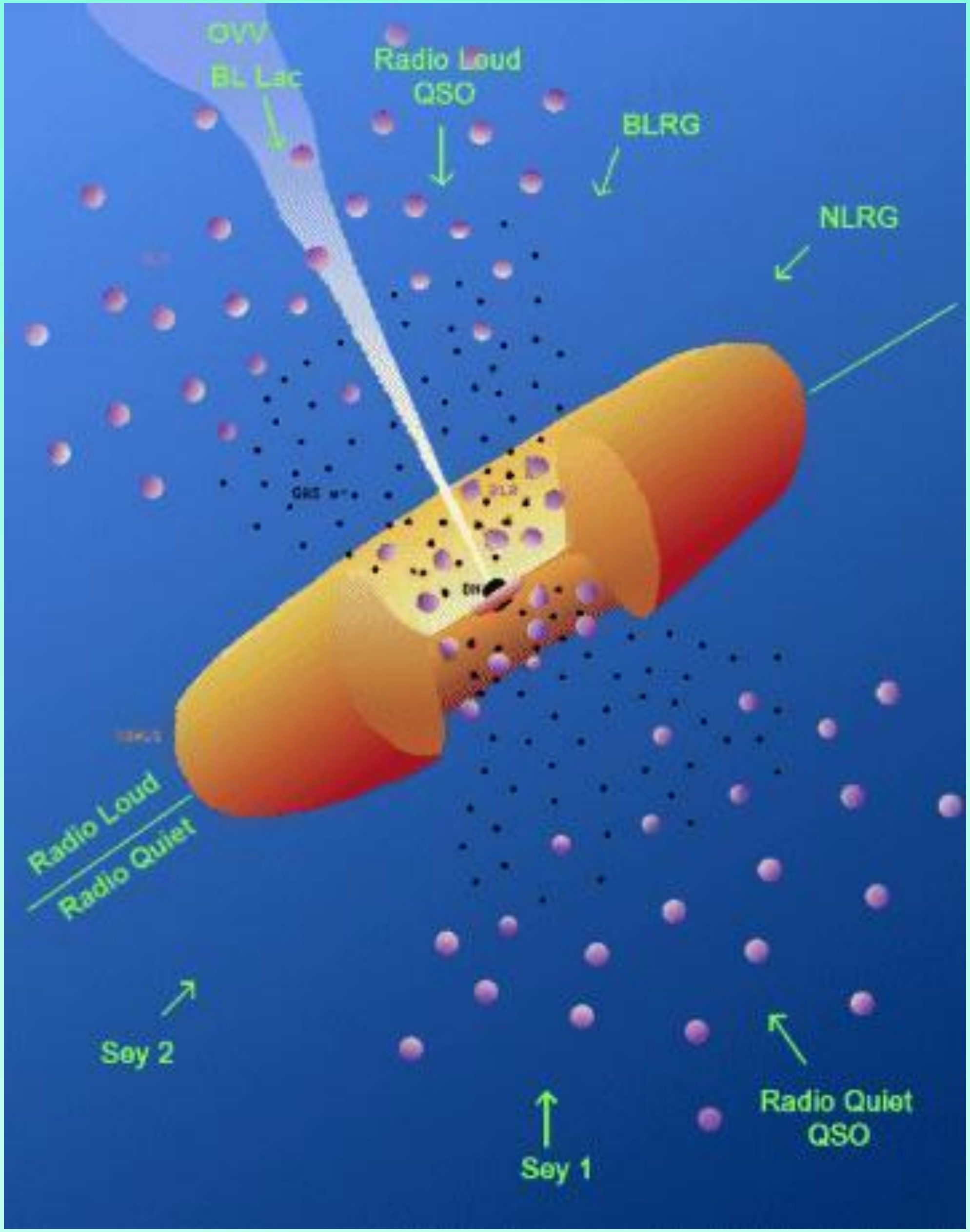
1. a black hole + disk

2. a Broad Line Region, close to the black hole

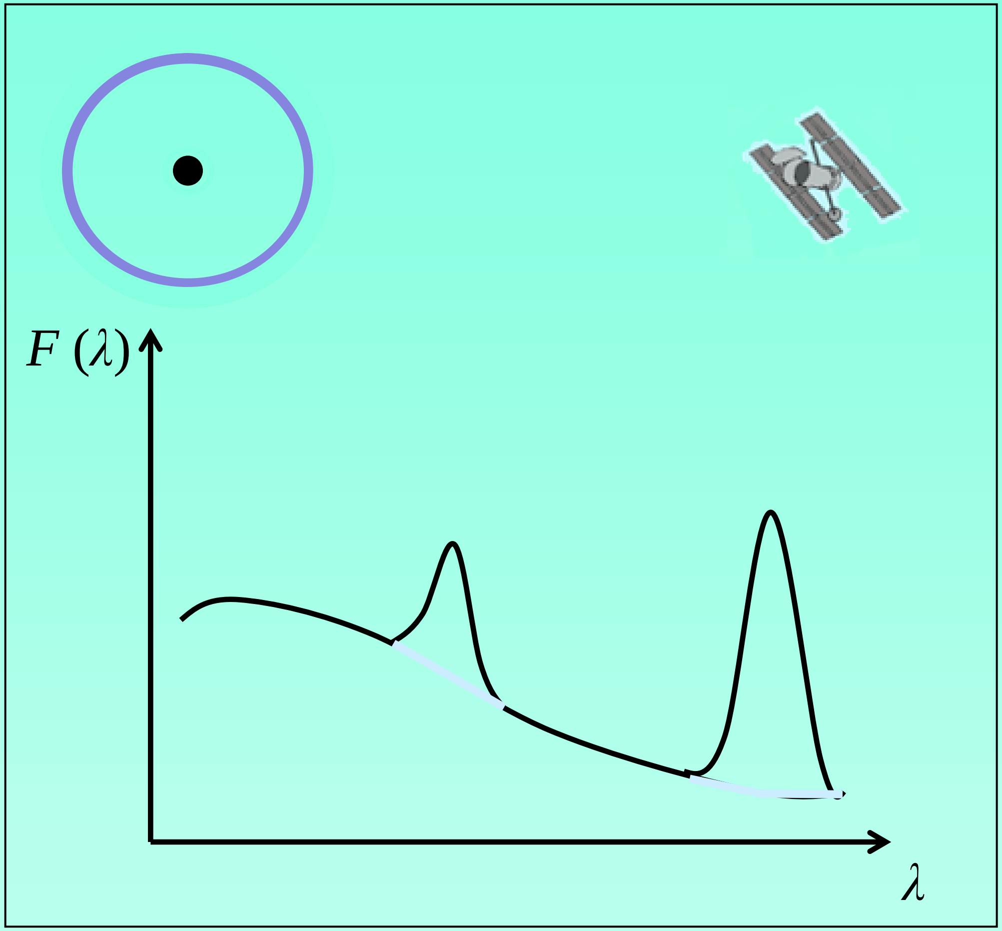
3. an extended Narrow Line Region, farther away

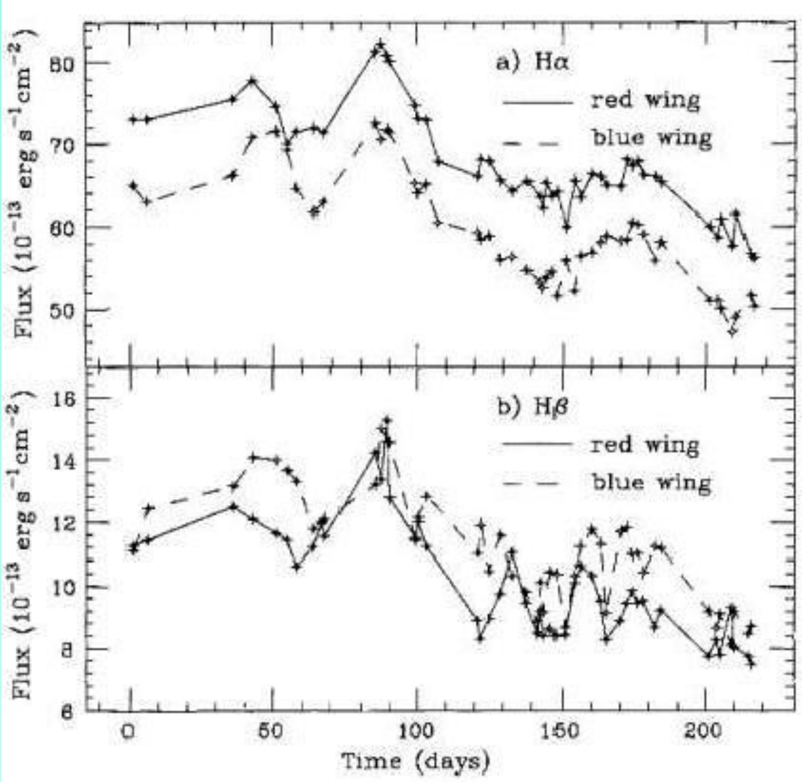
4. an obscuring equatorial structure

5. possibly, a relativistic jet



Reverberation Mapping: leveraging AGN variability





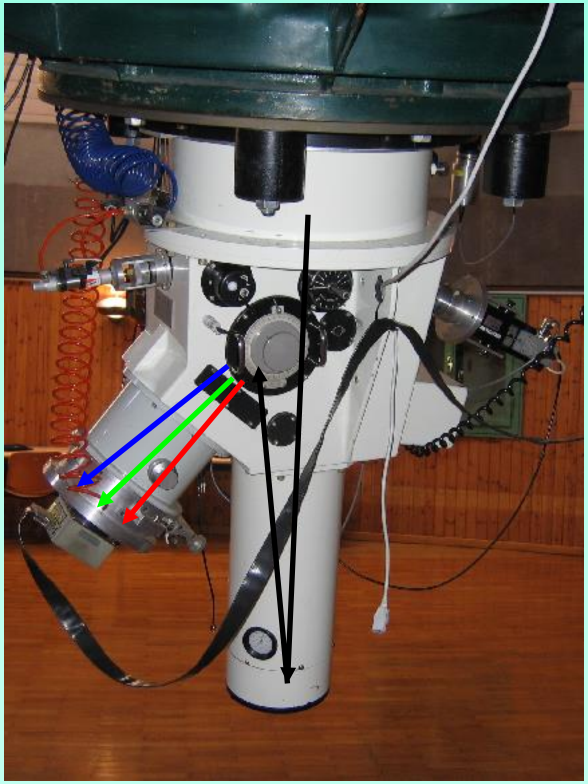
Emission line light curves of the Seyfert type 1 galaxy NGC 4151 (Maoz et al. 1991)

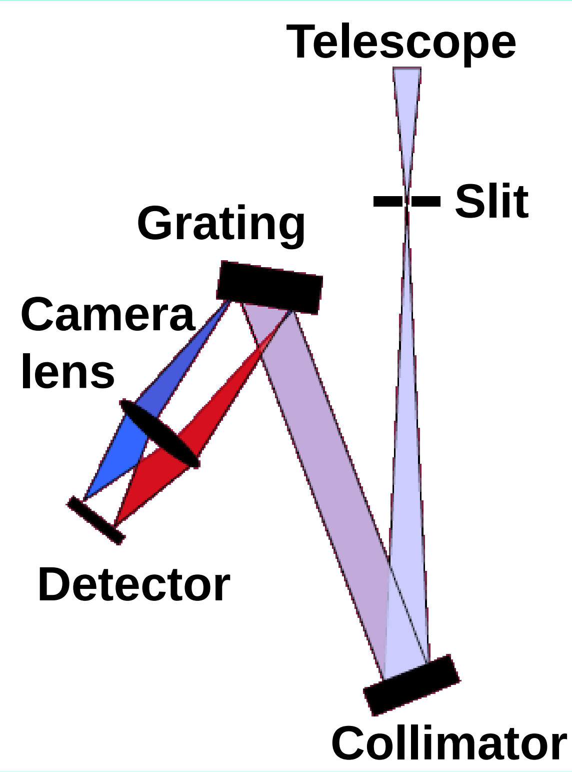
Most AGNs exhibit a short-term irregular variability. **Reverberation Mapping** studies the variations of the continuum source and the corresponding response of the line emitting gas, to understand its distribution and kinematics

Long-slit optical spectrograph setup

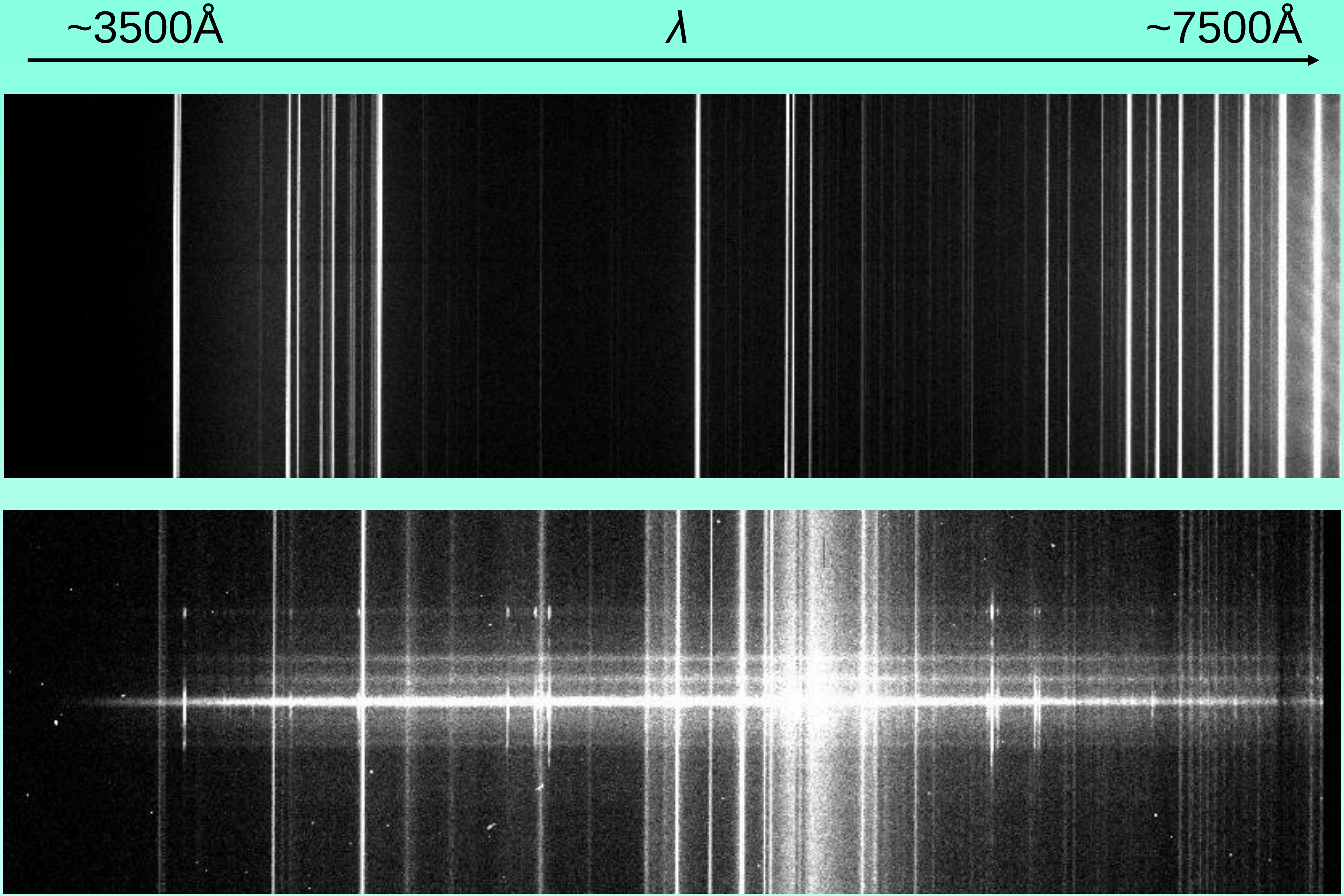
Spectrograph: slit + grating + detector

Produces 2-dimensional information:
- **spatial** (*x* – along the slit)
- **spectral** (*λ* – wavelength coordinate)

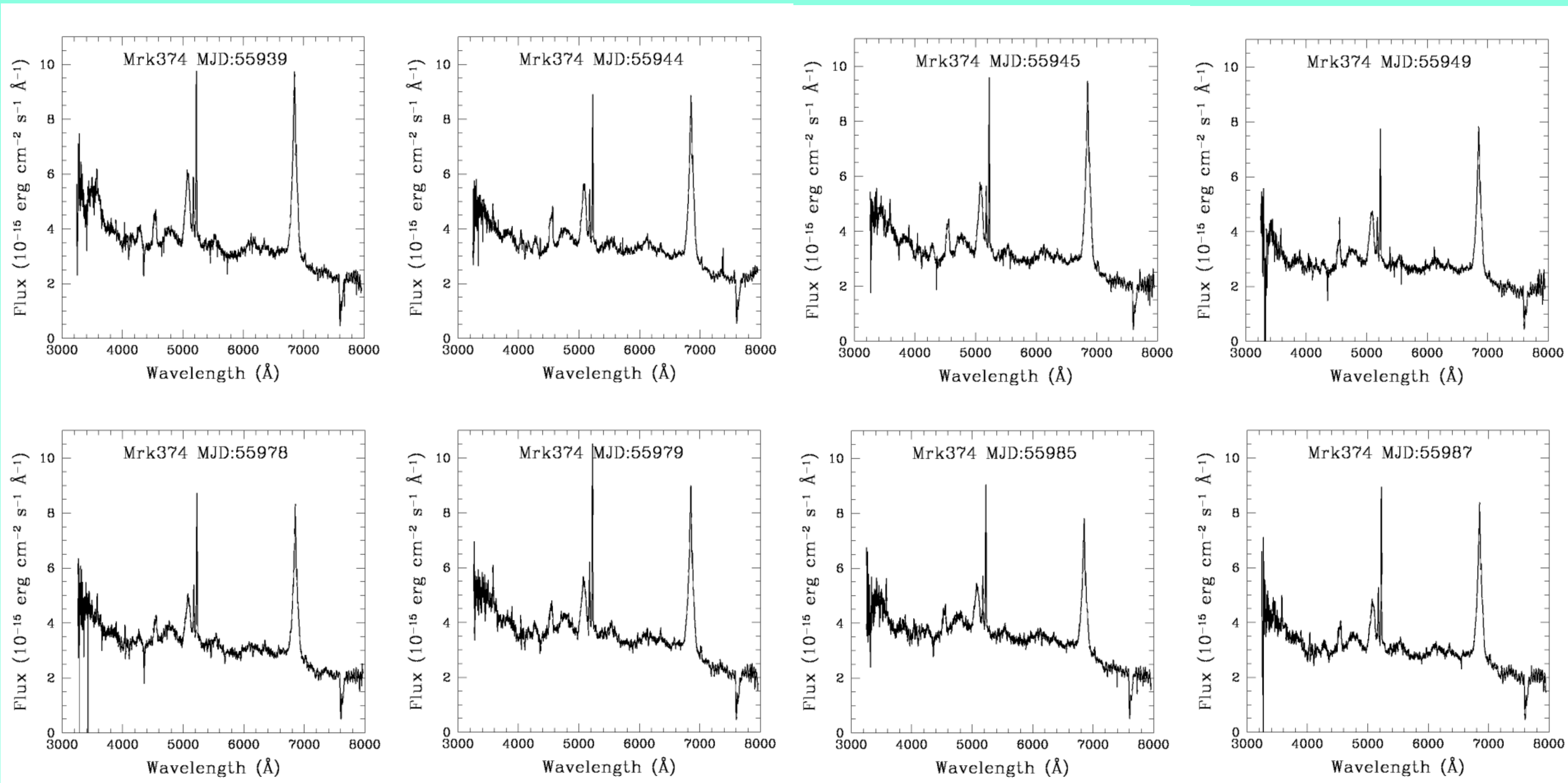




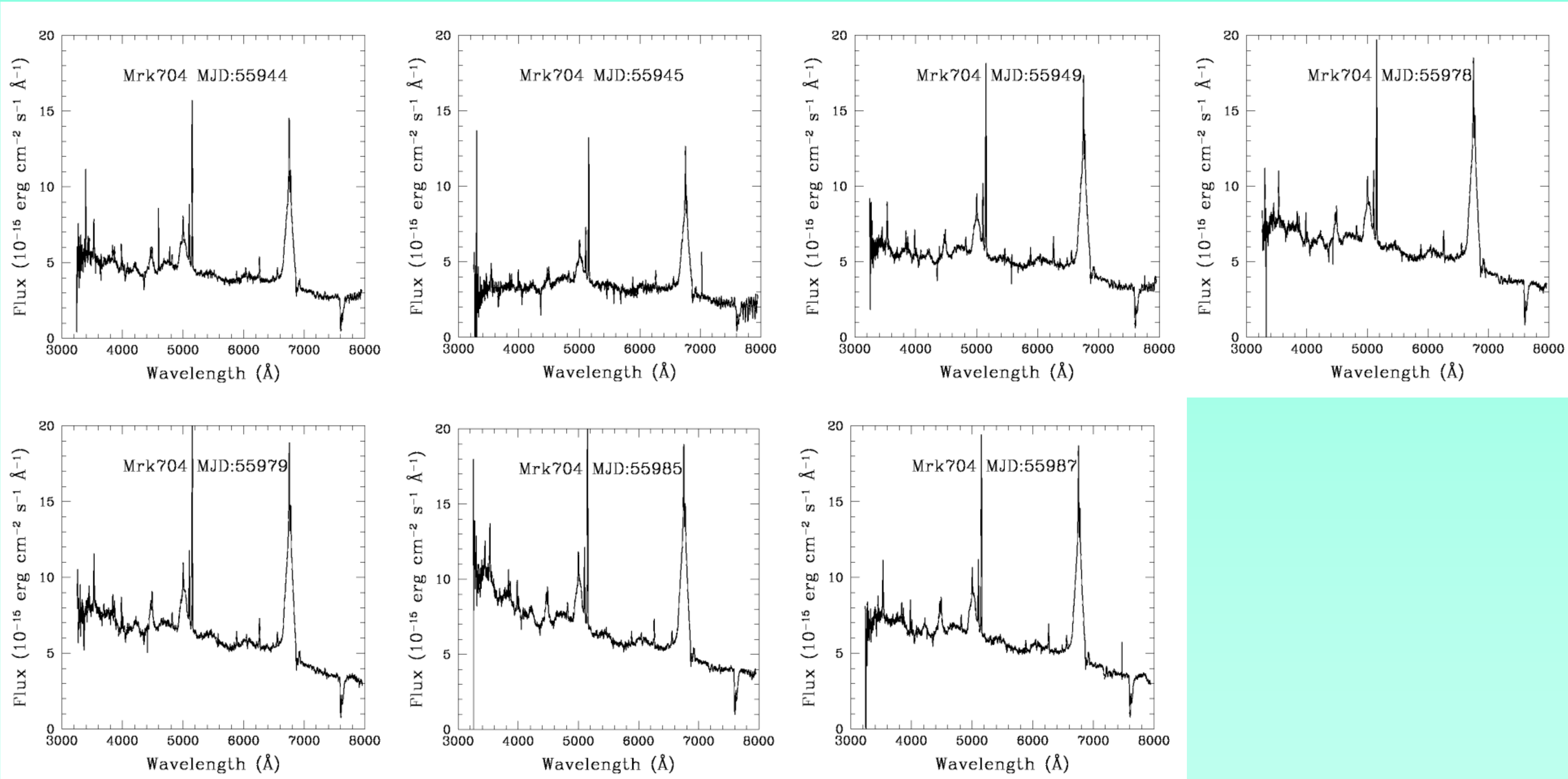
Calibration and science frames



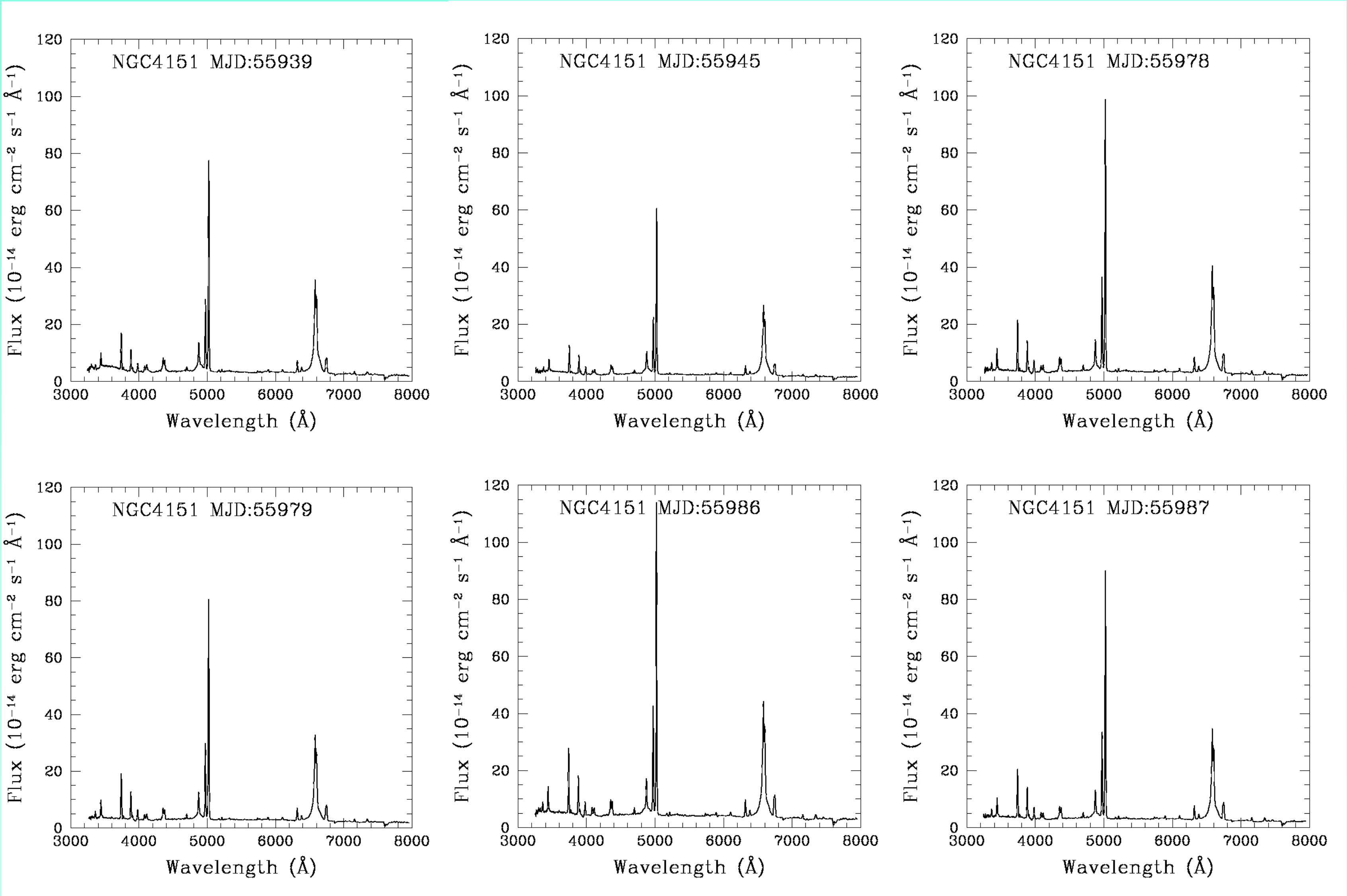
Reverberation Campaign: Mrk 374



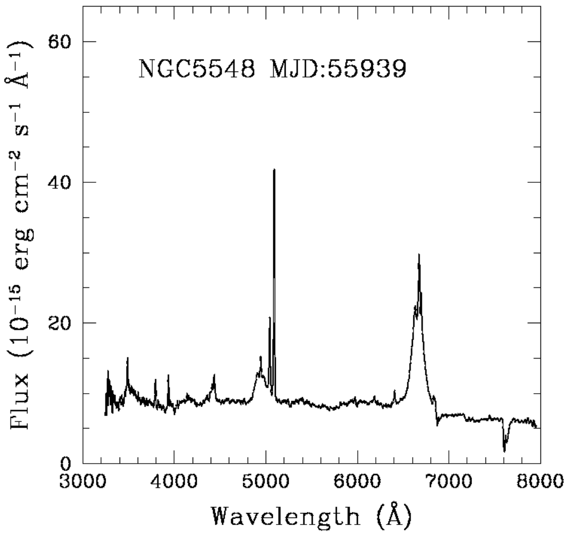
Reverberation Campaign: Mrk 704

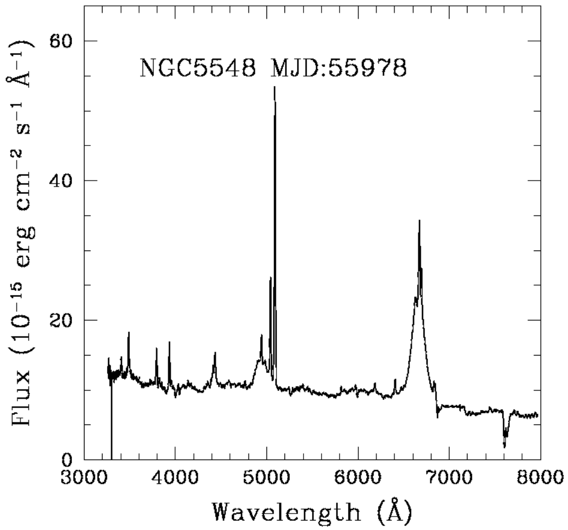


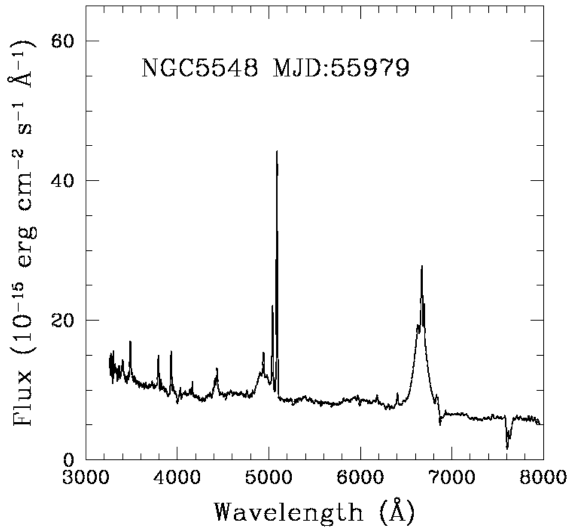
Reverberation Campaign: NGC 4151

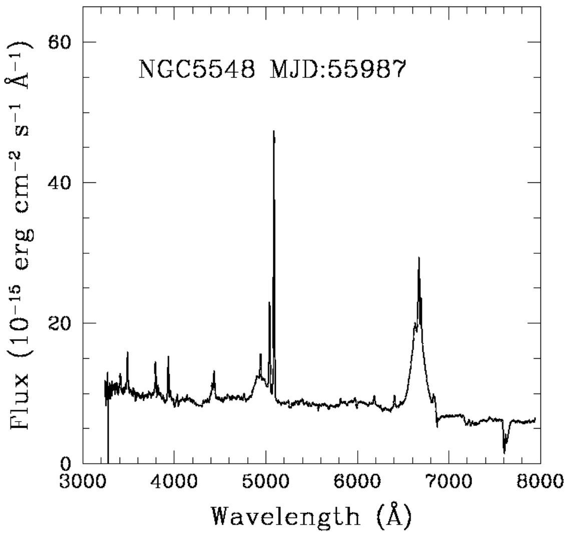


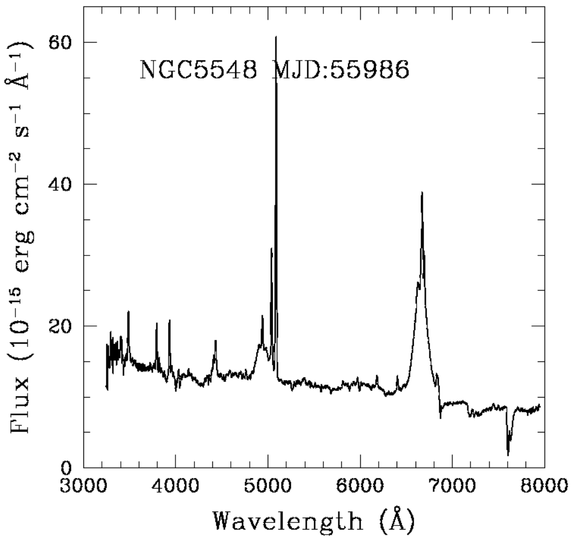
Reverberation Campaign: NGC 5548



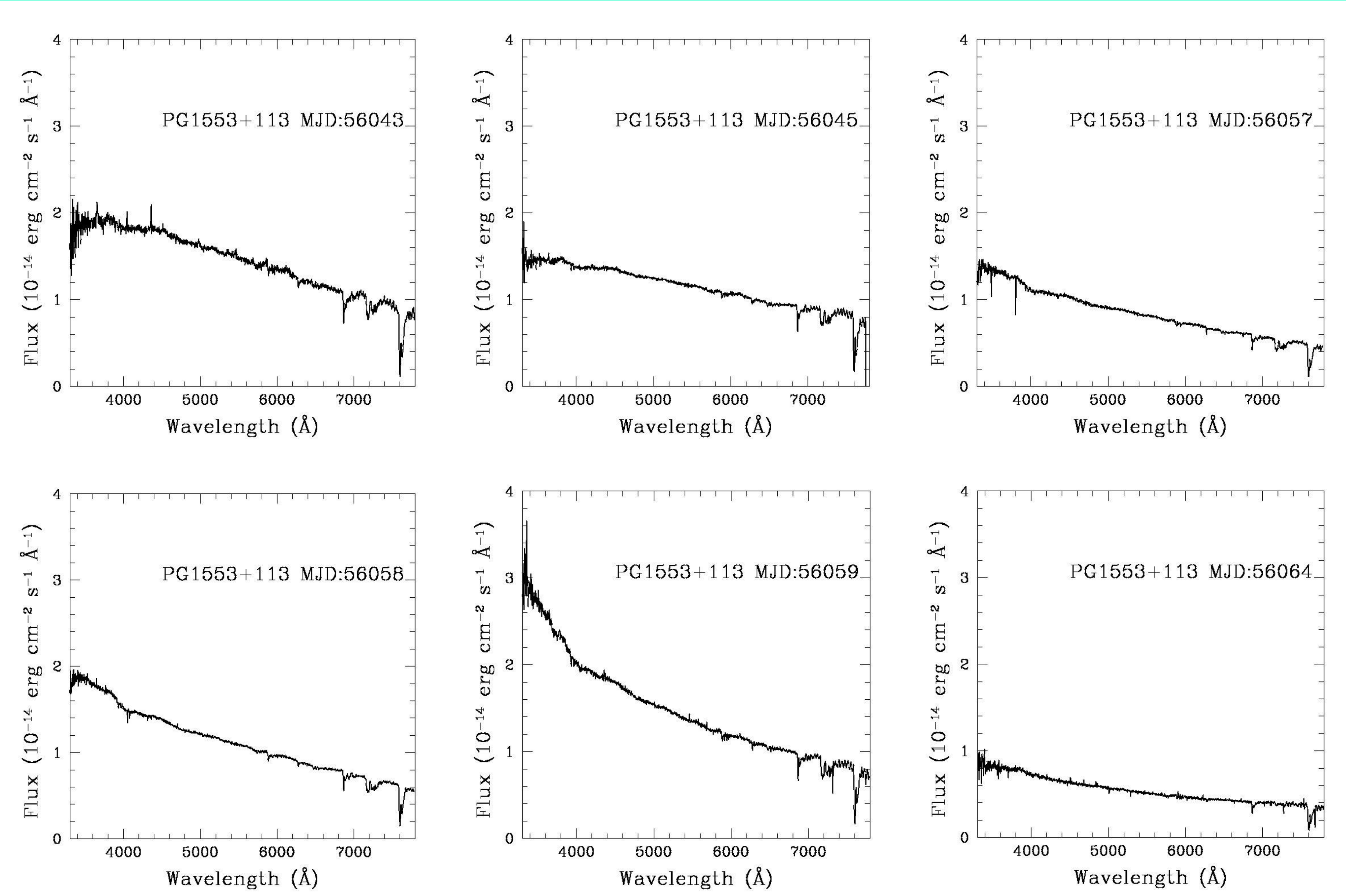




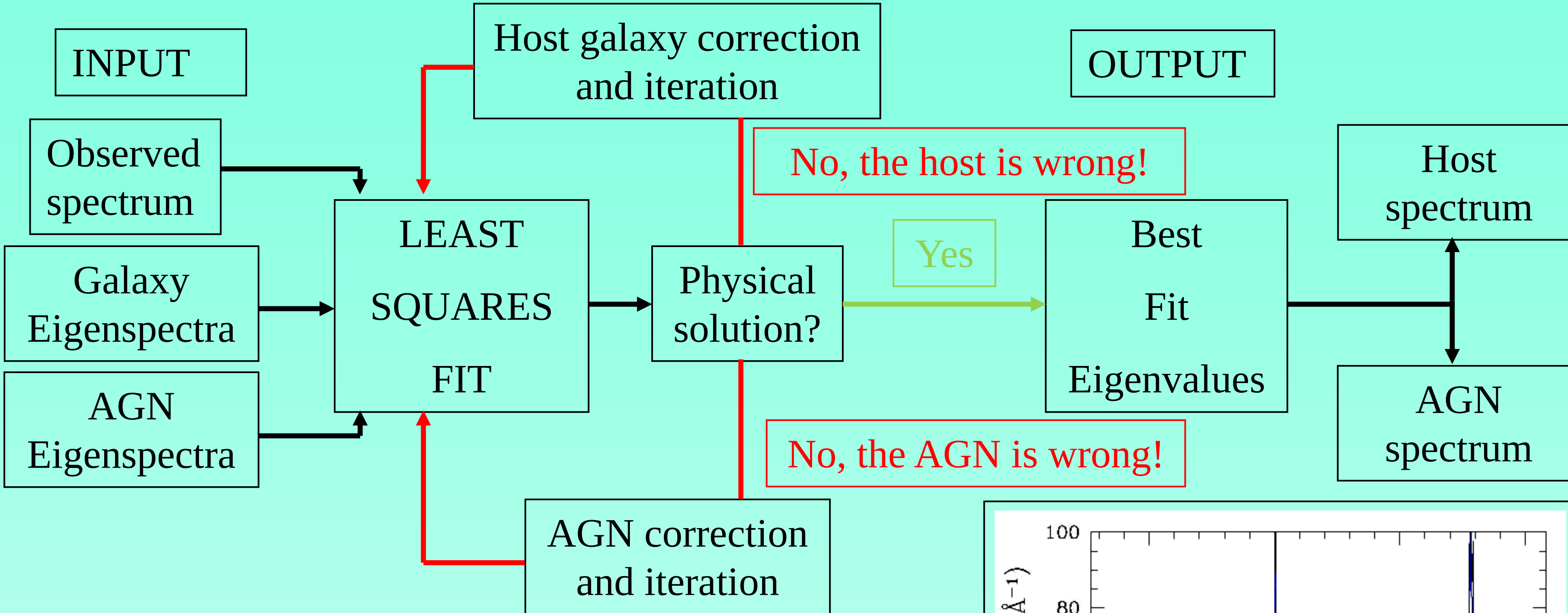




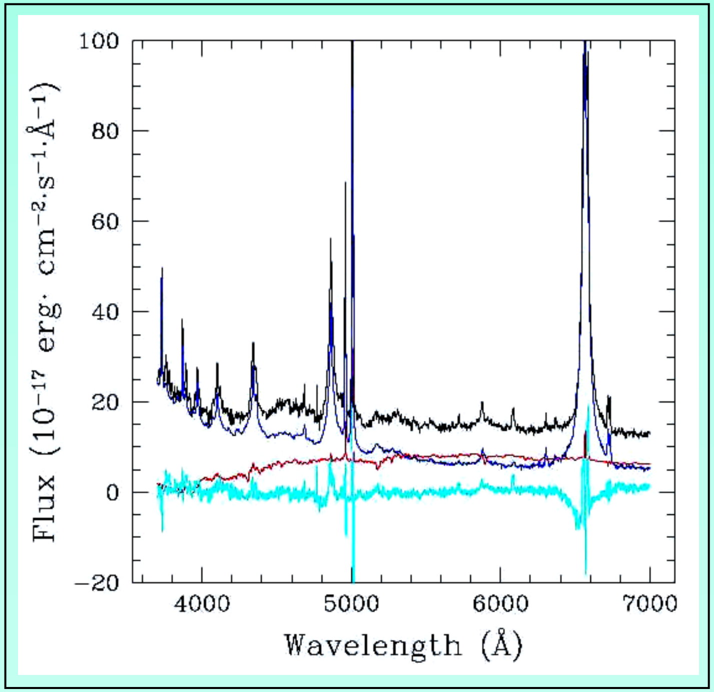
Blazar Burst monitoring program: PG 1553+113



Host galaxy spectral contamination

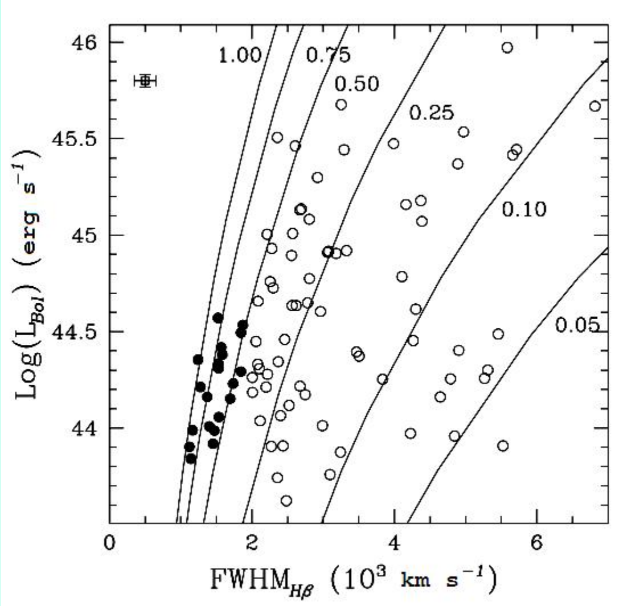


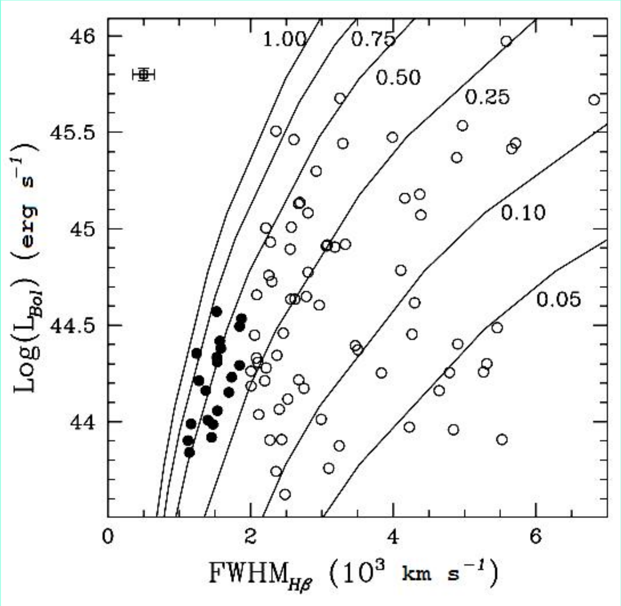
In spite of its point-like appearance, AGN light is overlapped with the underlying host contribution, that must be accounted for. The example illustrates a spectral decomposition of the different components.



Connolly et al. 1995, AJ, 110, 1071
Yip et al. 2004, AJ, 128, 585
Yip et al. 2004, AJ, 128, 2603

Properties of the Central Engine

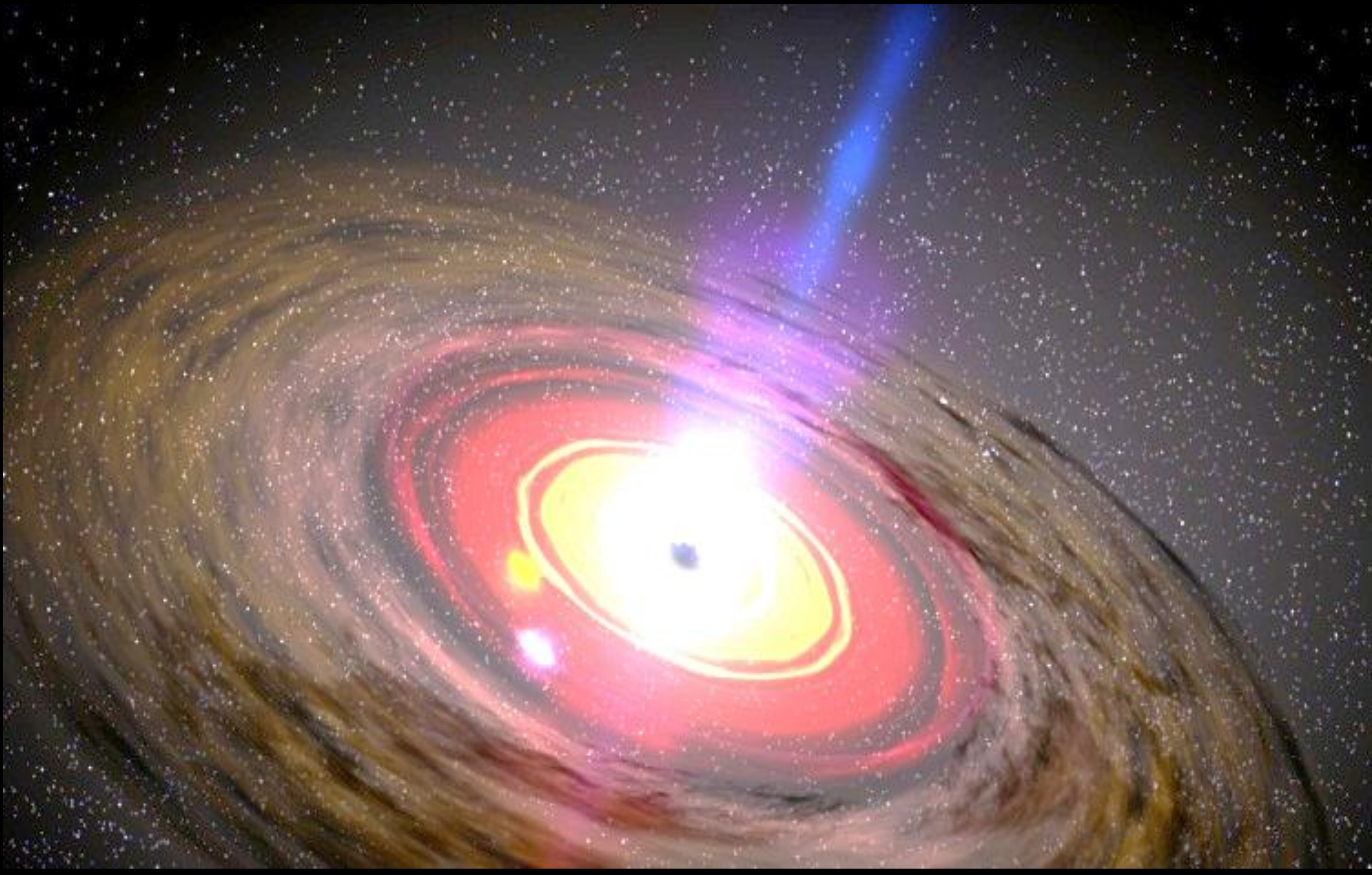




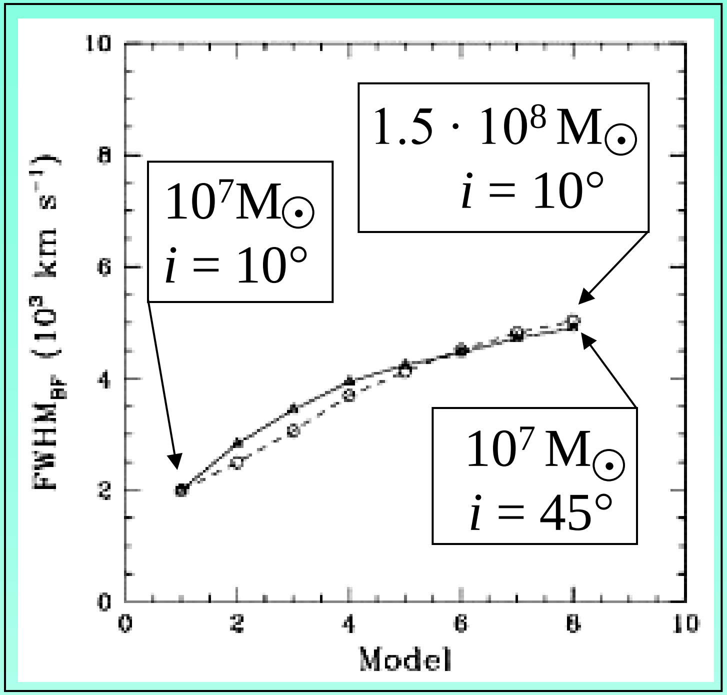
Assuming a gravitationally controlled motion pattern in the line emitting gas, it is possible to draw mass estimates for the central engine. It turns out that narrow line emitting objects are powered by relatively low masses ($M_{BH} < 10^8 M_\odot$) and must, therefore, accrete at very high rates.

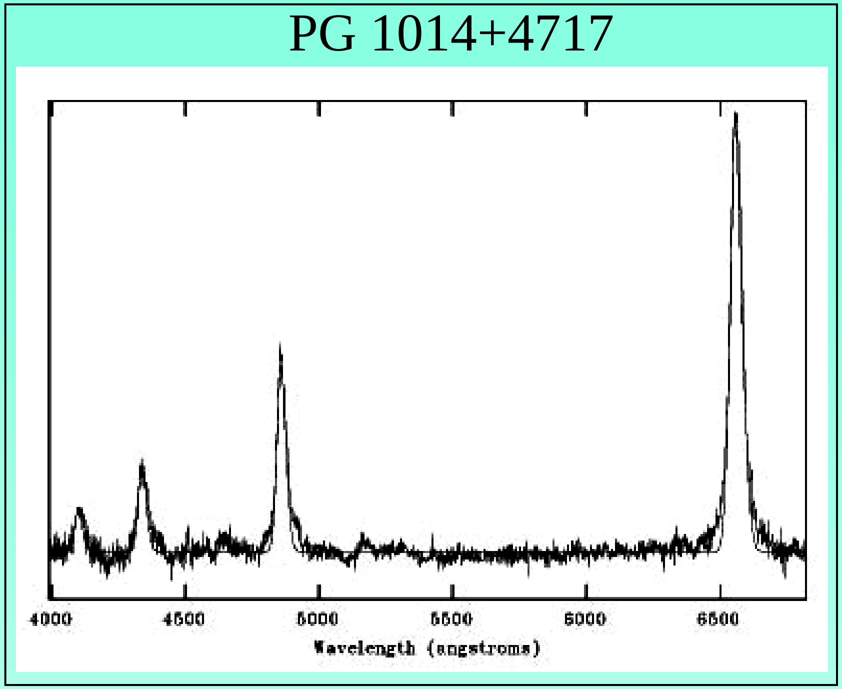
(**La Mura et al. 2007, ApJ, 671, 104**)

If this is the case, however, the structure of the line emitting region, and in particular its orientation, must be determined



Emission line profile broadening by Doppler effect

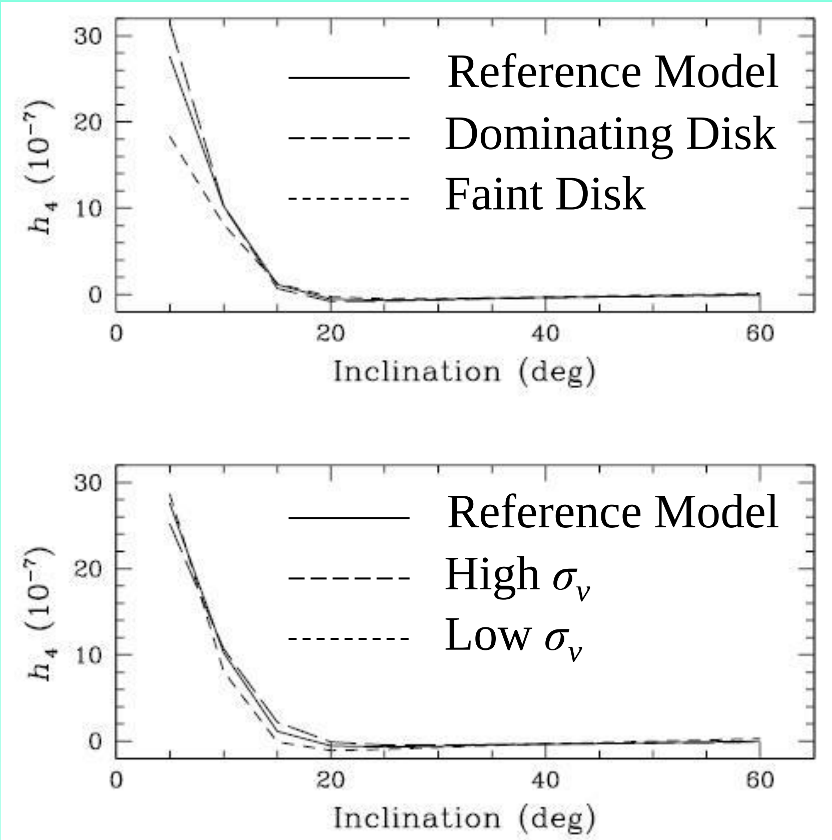


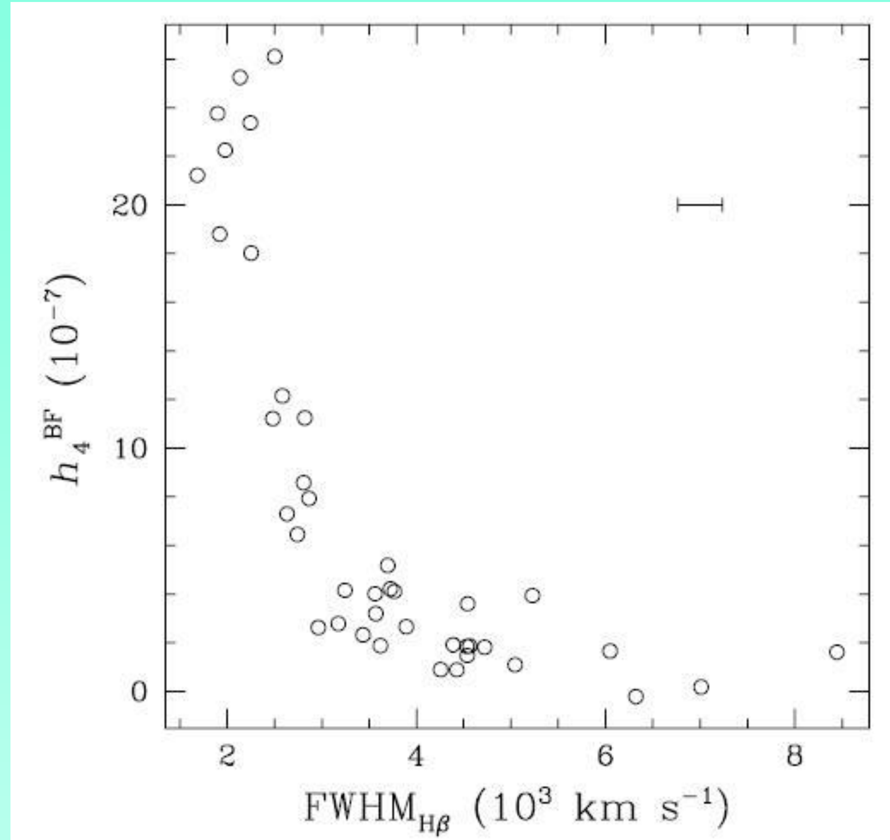


The emission line profiles only inform us about the radial projection of the actual motion field. This is related to the geometry of the source in terms of rather complex analytical solutions:

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

Advanced line profile analysis

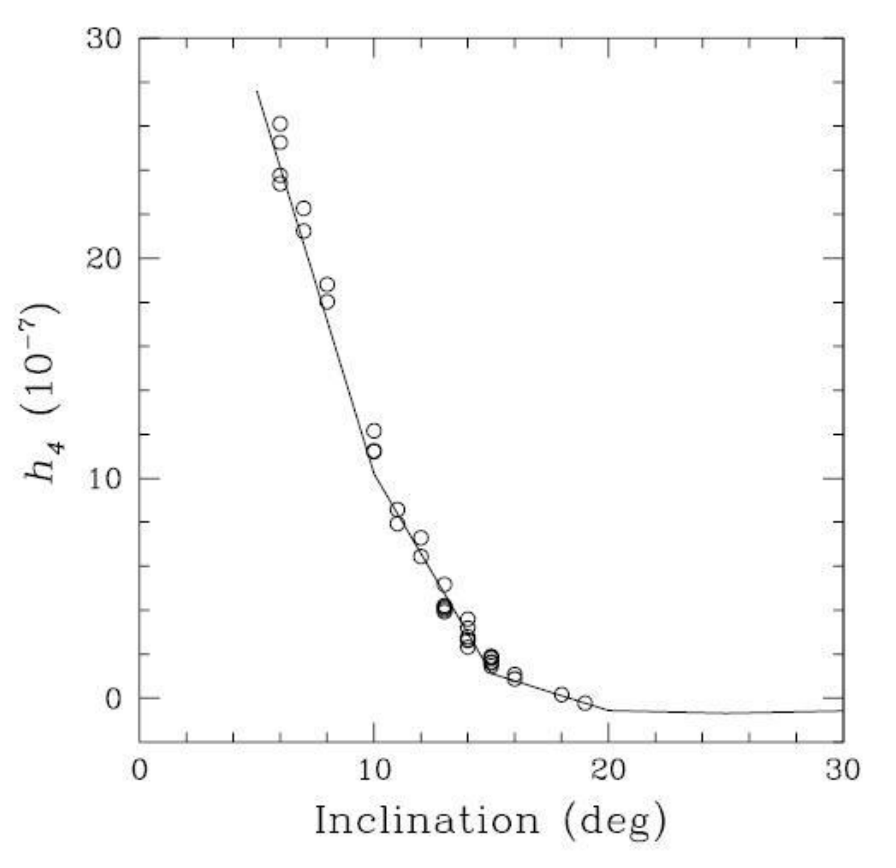


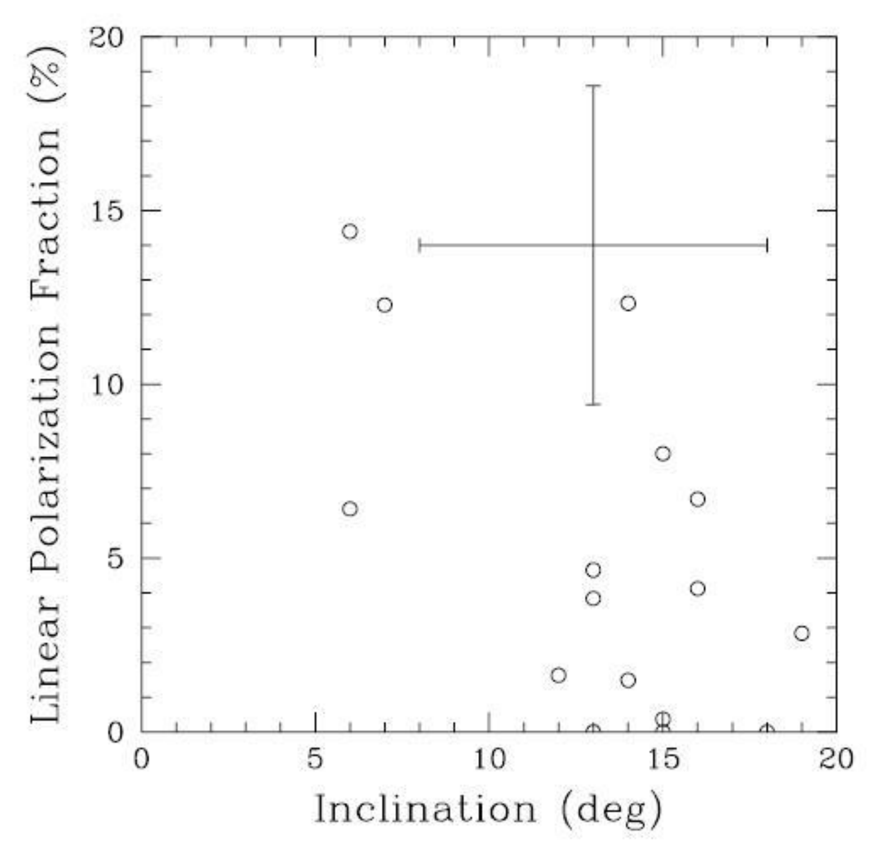


Applying composite theoretical models to the structure of the BLR, it is possible to constrain its geometry through the reconstruction of the whole line profile.

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

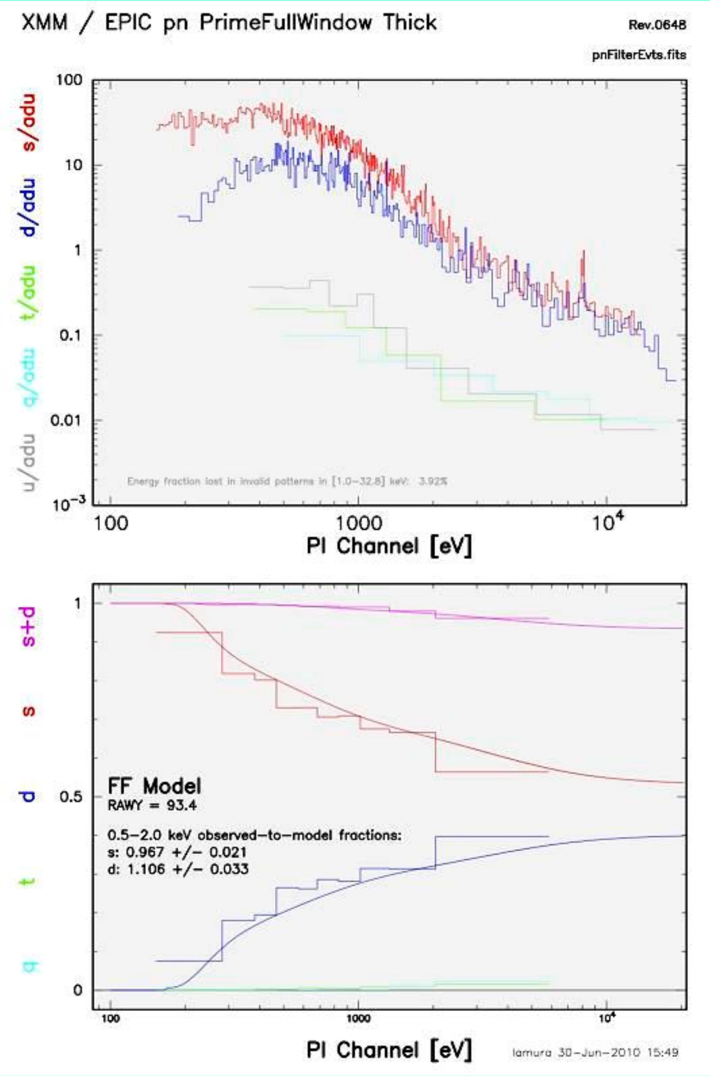
Comparison with radio observations



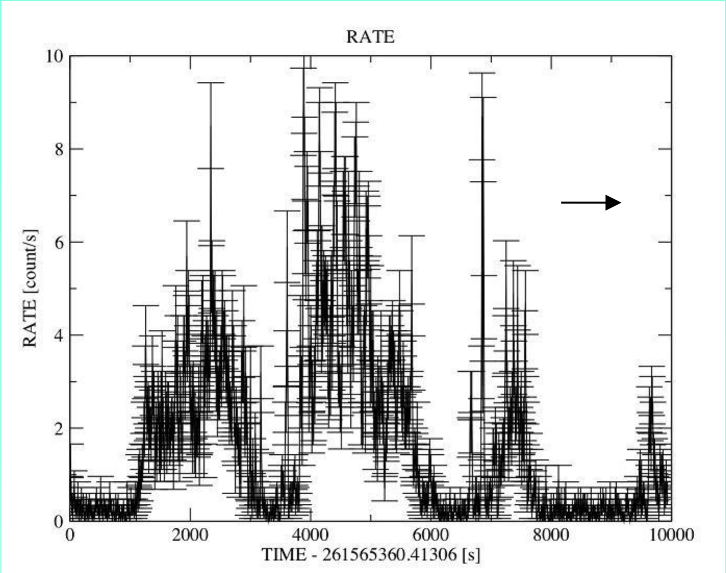


Radio loud sources are likely to host a relativistic jet, arising perpendicularly to the accretion flow. Models with an accretion disk predict a high degree of radio polarization in low inclination sources (where the jet is closer to our sight line). The effect is actually seen.

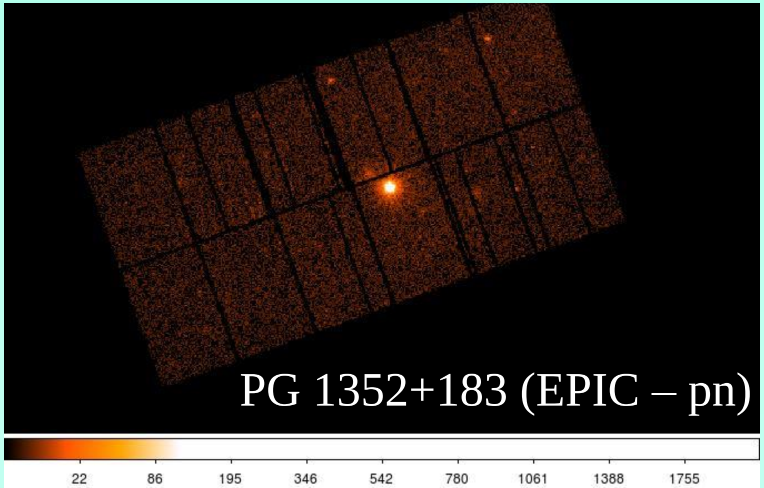
Results from X-ray observations



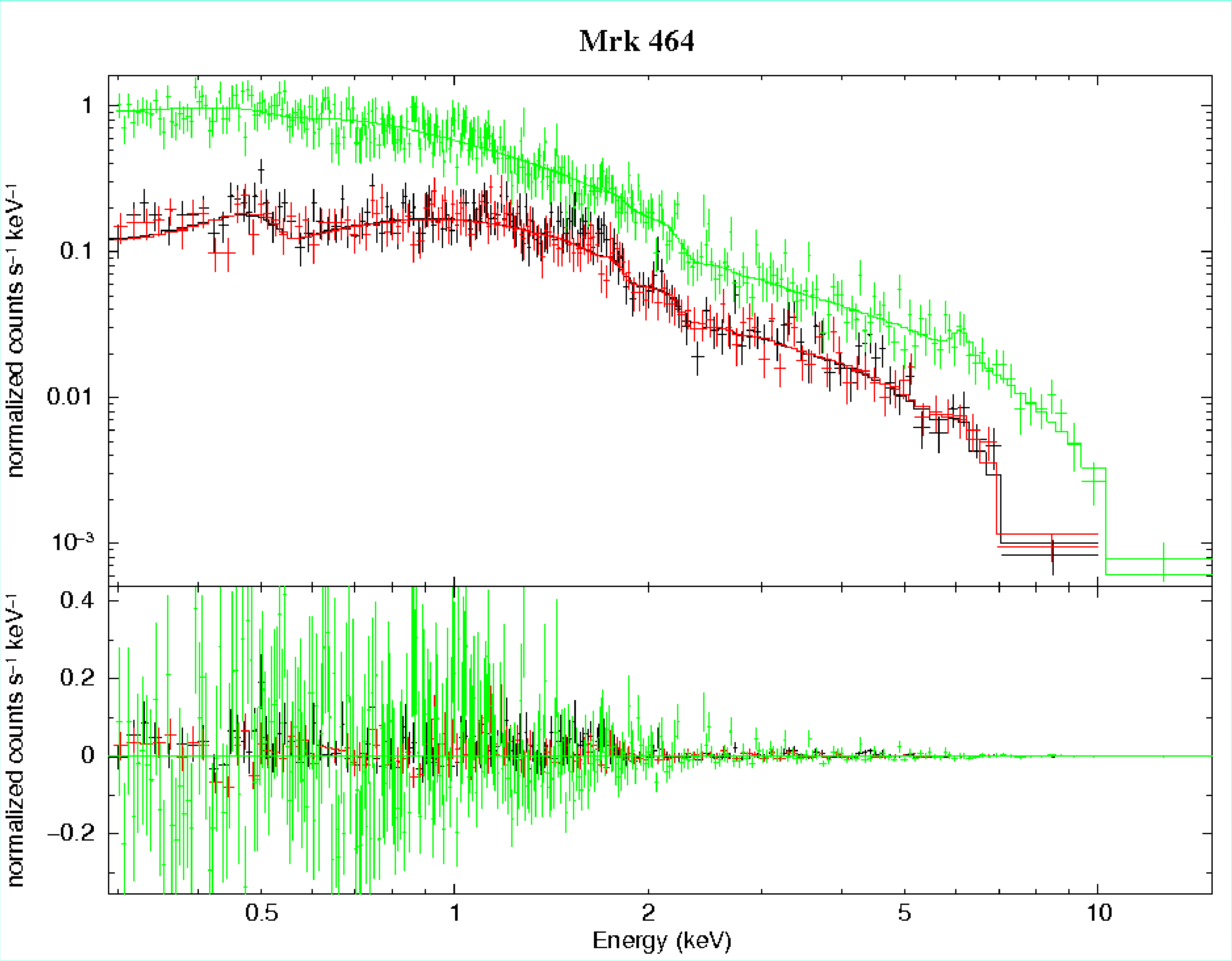
X-ray instruments must be placed in space-born observatories, requiring a different management



The technology to collect X-ray signal is different from the one used for UV-Optical-IR, and subject to various sources of noise

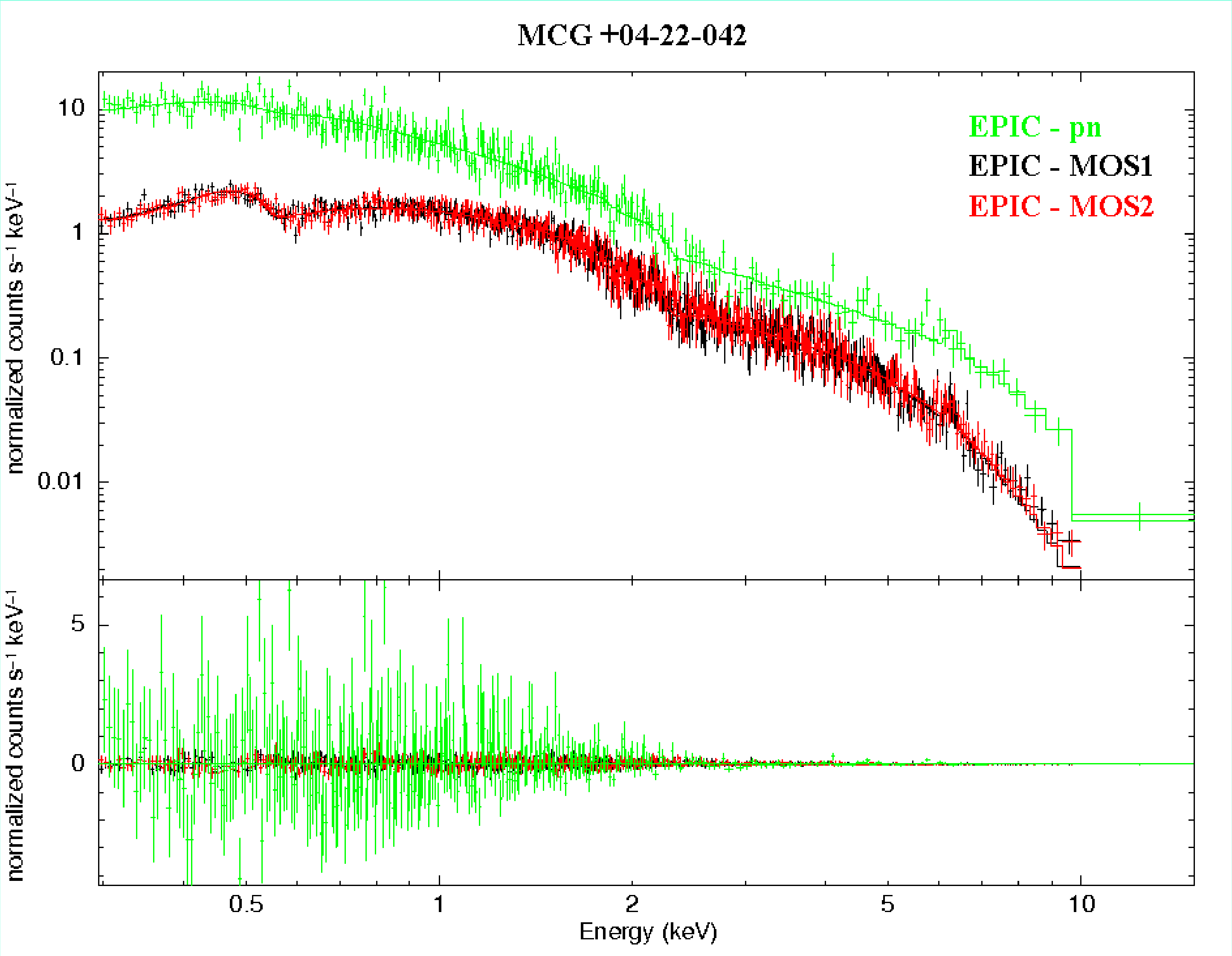


X-Ray spectra of broad line emitters



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, without evidence of absorption, is combined with a steep non-thermal emission and reflection from a highly ionized medium. Such features also fit in the high accretion rate scenario, drawn from optical observations.

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 expected accretion rates, supporting the interpretation of physics in the central energy source.