Use of Emission Lines Databases in AGN research

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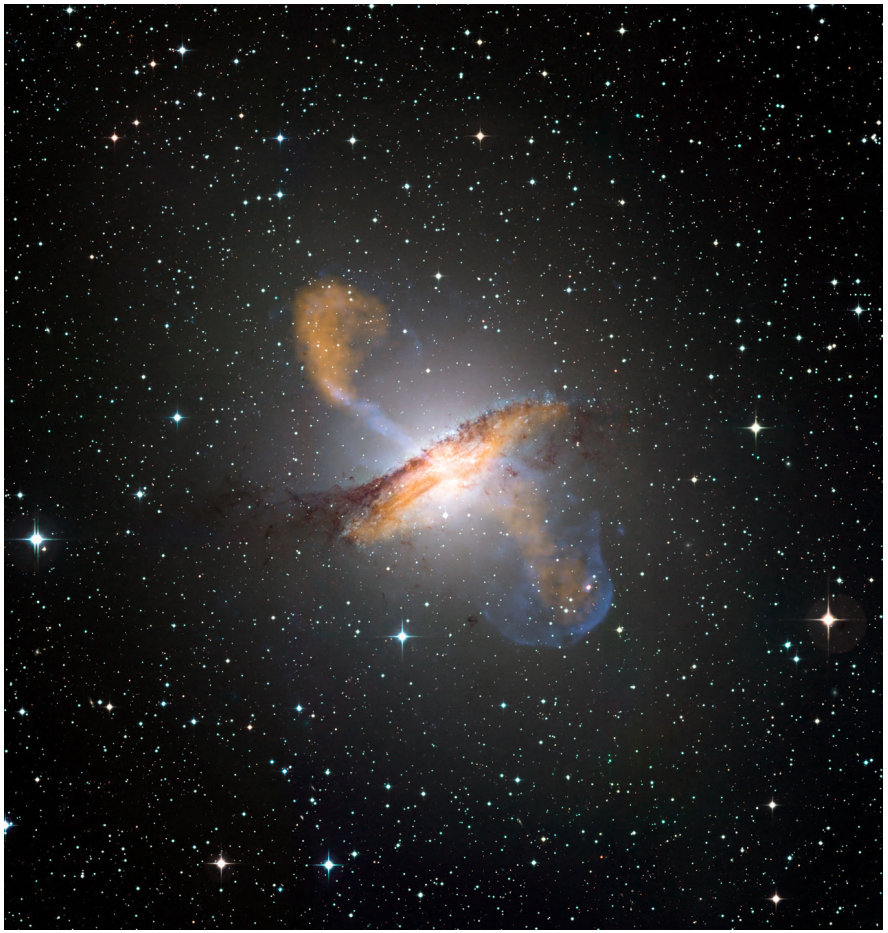
Group for astrophysical spectroscopy in Belgrade

What are Active Galactic Nuclei?

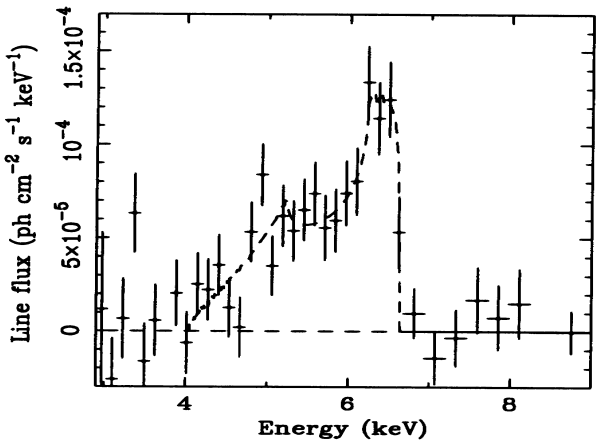
- AGN are:
  - powerful compact radiation sources: up to 10^{15} L_{sun}
  - the most luminous objects (thus, most distant) – e.g. quasars
  - emit broad band continuum and strong emission lines



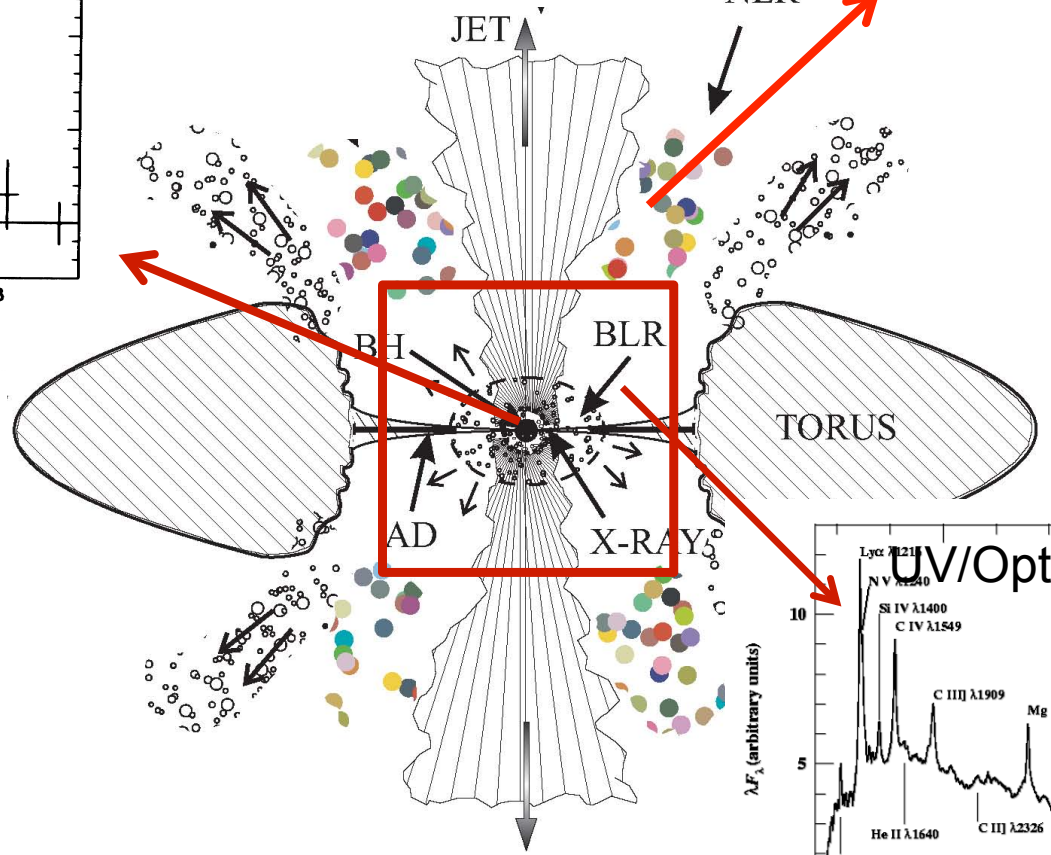
Centaurus A, composite image

Where are Emission Lines originating?

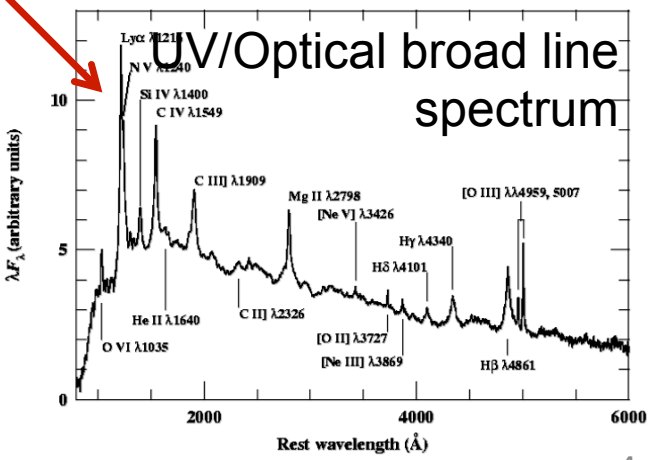
Fe Kα line in the X-ray



Narrow line spectrum
(from **Narrow Line Region**)

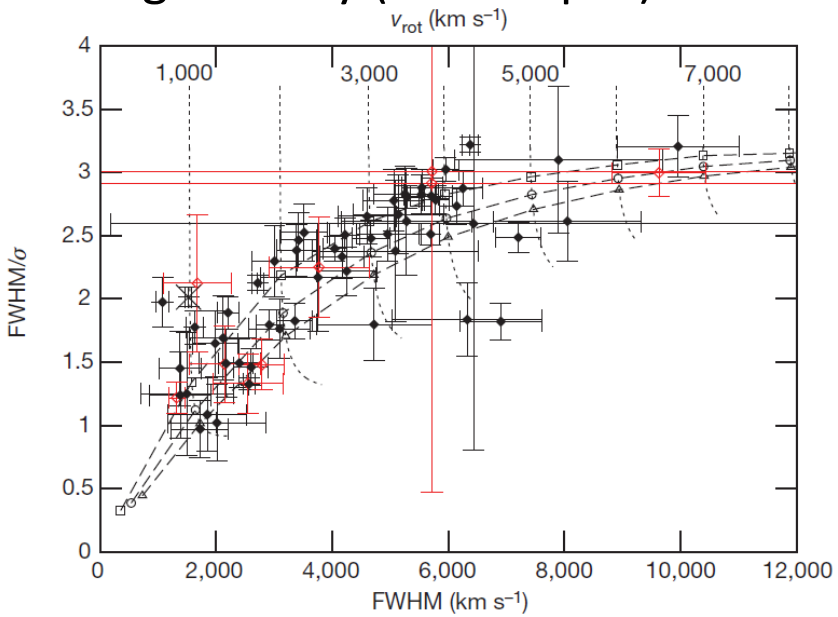


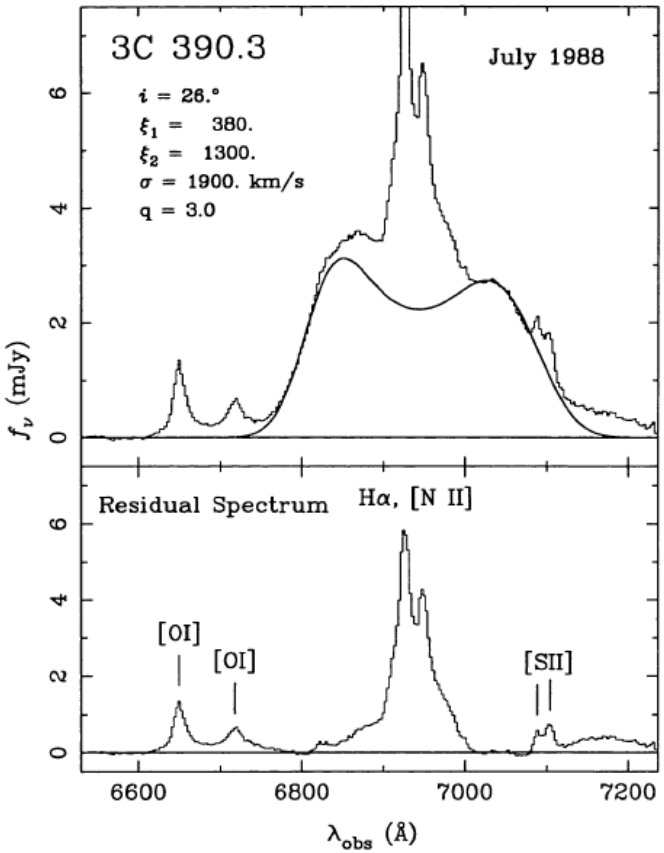
Broad Line Region (BLR)



What Emission Lines can tell us?

- Physical conditions of the region
  - temperature , density
  - ionization state
- Kinematics
  - velocities (line widths)
  - size (reverberation – time delays)
  - geometry (line shapes)





e.g. broad-line AGN rotate faster than narrow-line ones

Kollatschny & Zetzl, 2011, Nature, 470

AGN Emission Lines: Data Sources

- Sloan Digital Sky Survey
  http://www.sdss.org

- Long term monitoring campaigns
  using worldwide telescopes to observe constantly active galactic nuclei

  - SIMBAD: VizieR Data Catalog
    http://simbad.u-strasbg.fr/simbad/

  - One campaign led by Alla Shapovalova (Russia and Mexico)

SLOAN DIGITAL SKY SURVEY III

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Welcome to the DR10 site!!!

This website presents data from the Sloan Digital Sky Survey, a project to make a map of a large part of the universe. We would like to show you the beauty of the universe, and share with you our excitement as we build the largest map in the history of the world.

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The site hosts data from **Data Release 10 (DR10)**. **What's new in DR10**, **what's new on this site** and **known problems**. **More...**

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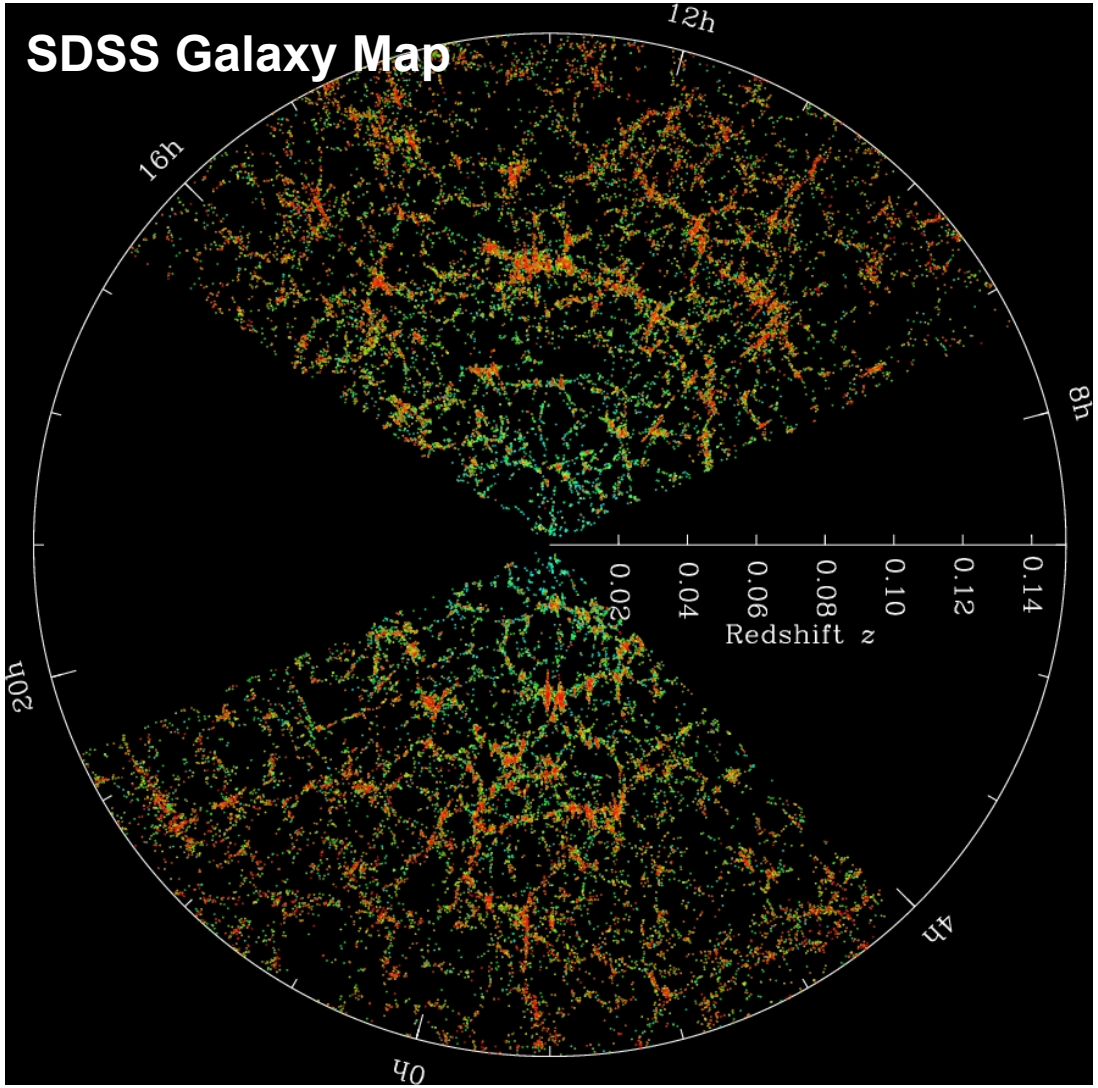
Sloan Digital Sky Survey

Mapping the Universe

- SDSS imaged 8,400 square degrees of the sky in five optical bandpasses (230 million objects)
- obtained spectra of 930,000 galaxies, 120,000 quasars, and 225,000 stars



Long-term monitoring: decades of observations

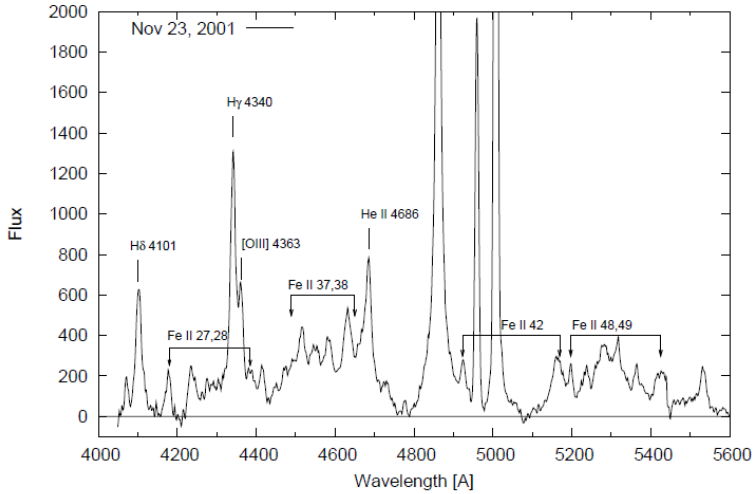
- 6m + 1m telescopes - SAO RAS (Russia)
- 2.1 m telescope - Guillermo Haro Observatory (Mexico)
- 2.1 m telescope - Observatorio Astronómico Nacional, San Pedro Martir, Baja California, Mexico

Long-term monitoring: results

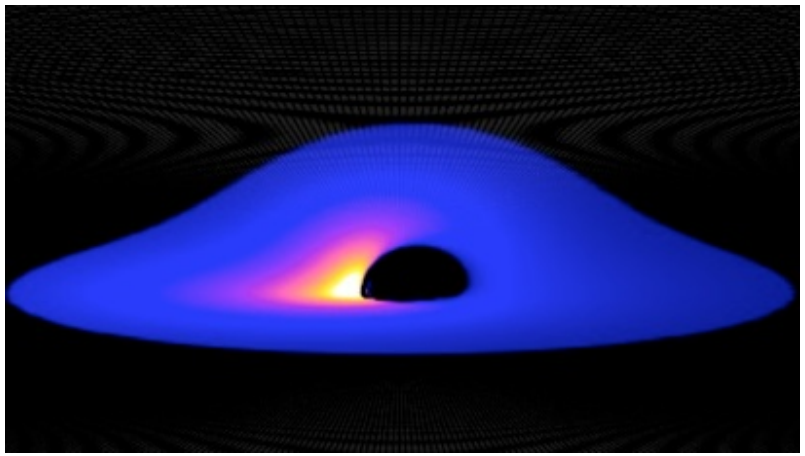
- PIs: Alla Shapovalova (Russia) and Vahram Chavushyan (Mexico)
- constantly observing Active Galactic Nuclei:
  - NGC 5548 – 9 years (Shapovalova+ 2004, Ilić 2007, Popović+2008)
  - NGC 4151 – 11 years (Shapovalova+ 2008, 2009, 2010a)
  - 3C390.3 – 13 years (Shapovalova+ 2010b, Popović+ 2011, Jovanović+ 2010)
  - Ark 564 – 11 years (Shapovalova+ 2012, ApJS)
  - Arp 102B – 12 years (Shapovalova+2013, Popović+ 2014, subm.)
  - Mrk 6 – spectro-polarimetry (Afanasieev+2014)
- Study of variability: continuum flux, line shapes, line fluxes …

Present here 2 important problems:

1. Ionized iron emission – Fe II lines origin

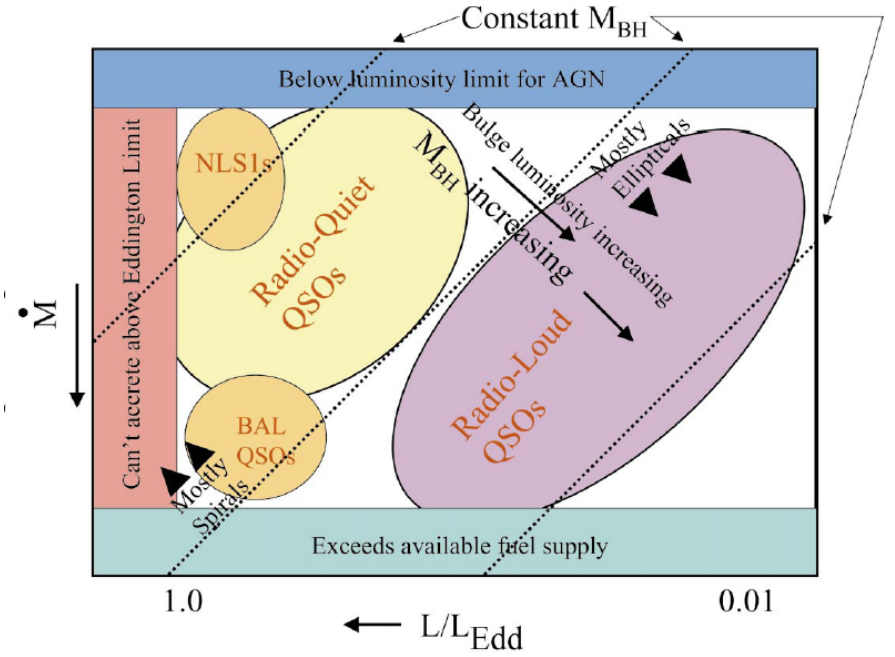


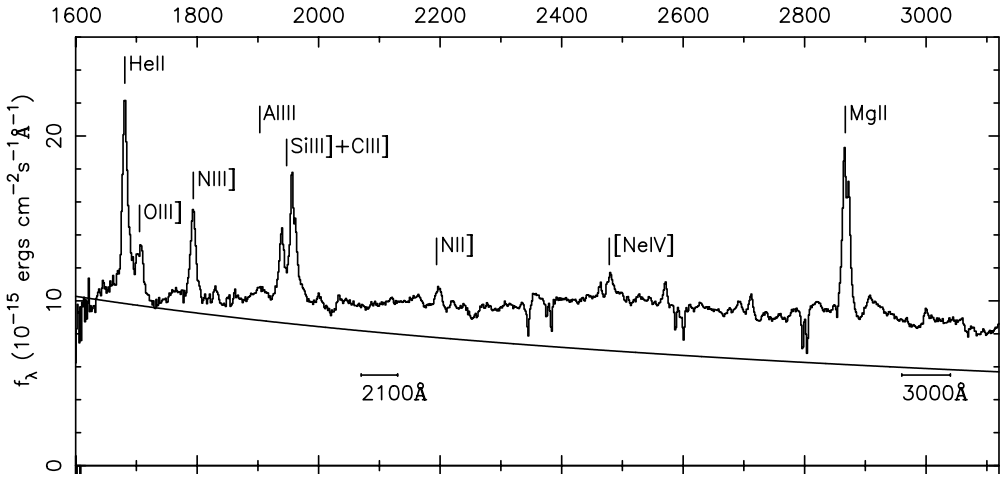
2. Estimates of the super-massive black hole (SMBH) using spectro-polarimetry

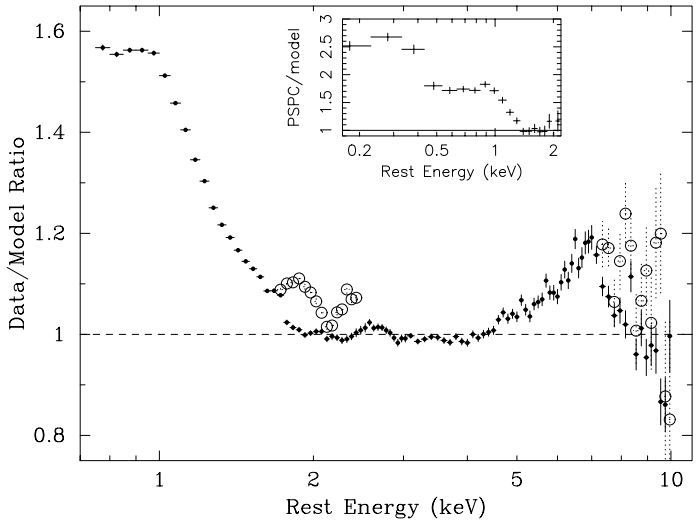


NLSy1: Ark 564

- nearby narrow-line Sy 1 galaxy (z = 0.02467)
- 11-years of observation
- X-ray bright NLS1s
- narrow permitted lines; **strong Fe II emission**





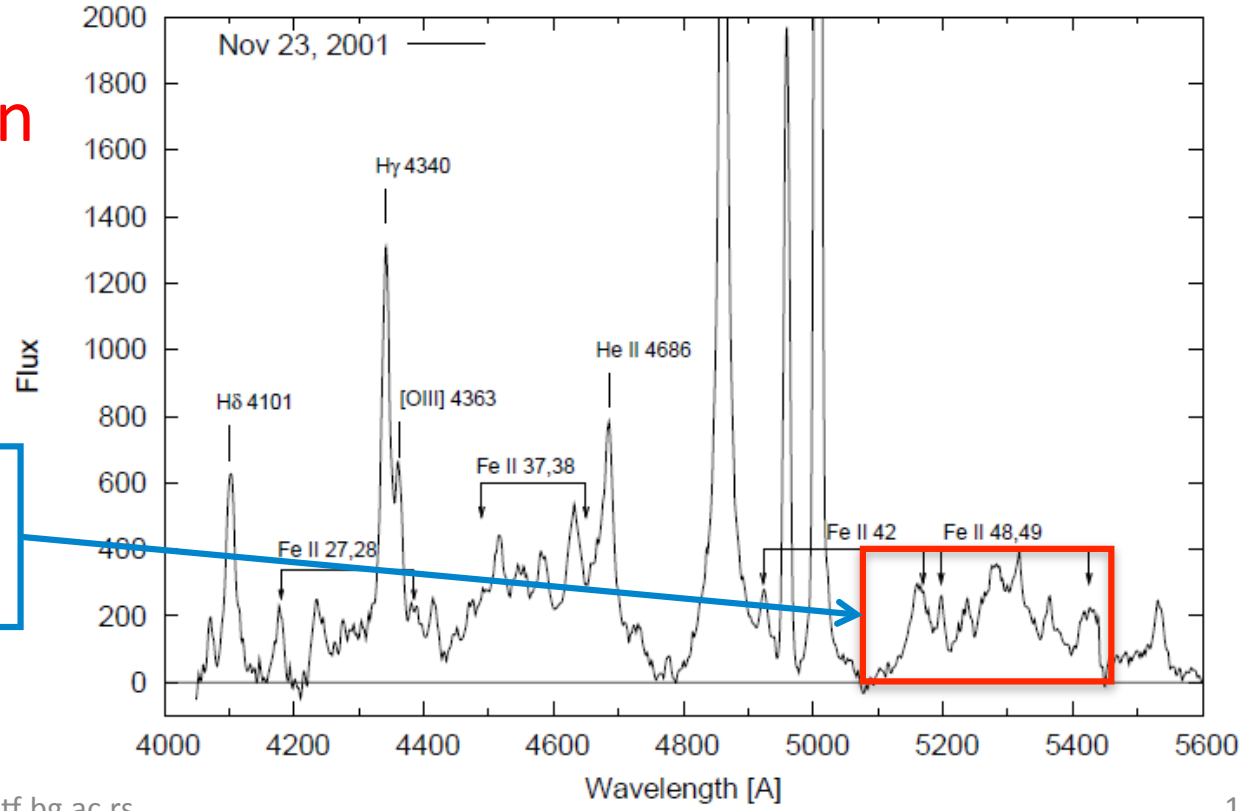


Strong Fe II emission

- strong emission; many lines - often blended
- Fe II low stage of ionization (Fe0 7.9ev) – from large partly ionized transition region of the BLR

- where is the origin and how are they produced?

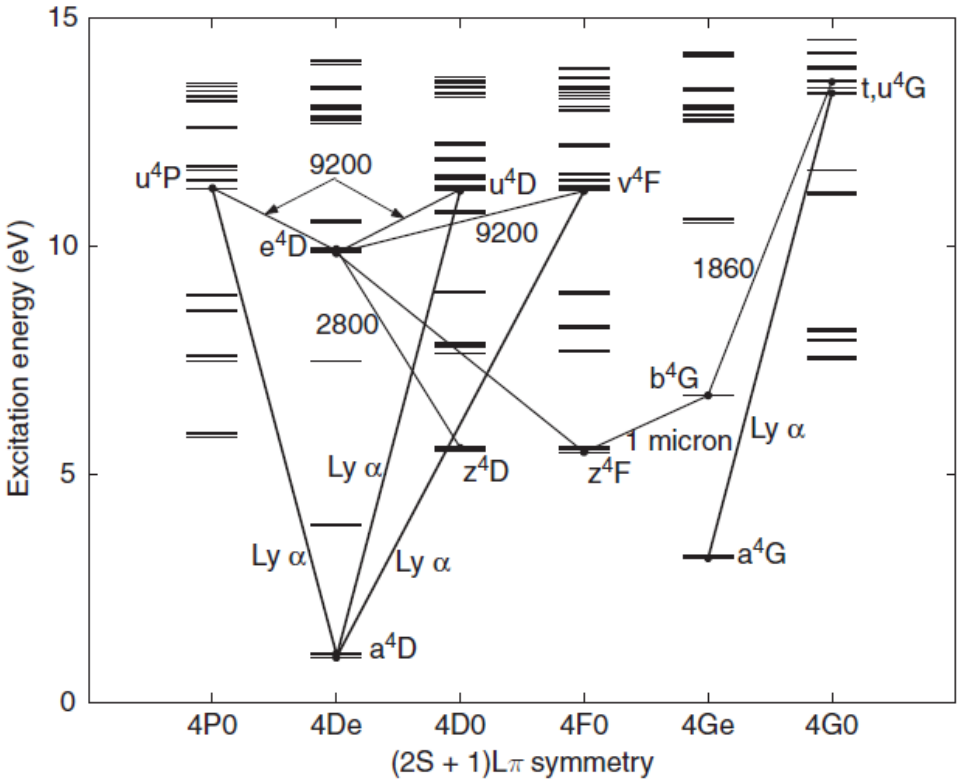
For Fe II 5100-5470:
-48,49 multiplets



Question: what is Fe II production?

- probably: collisional excitation and resonance fluorescence by continuum and HI Lyα line

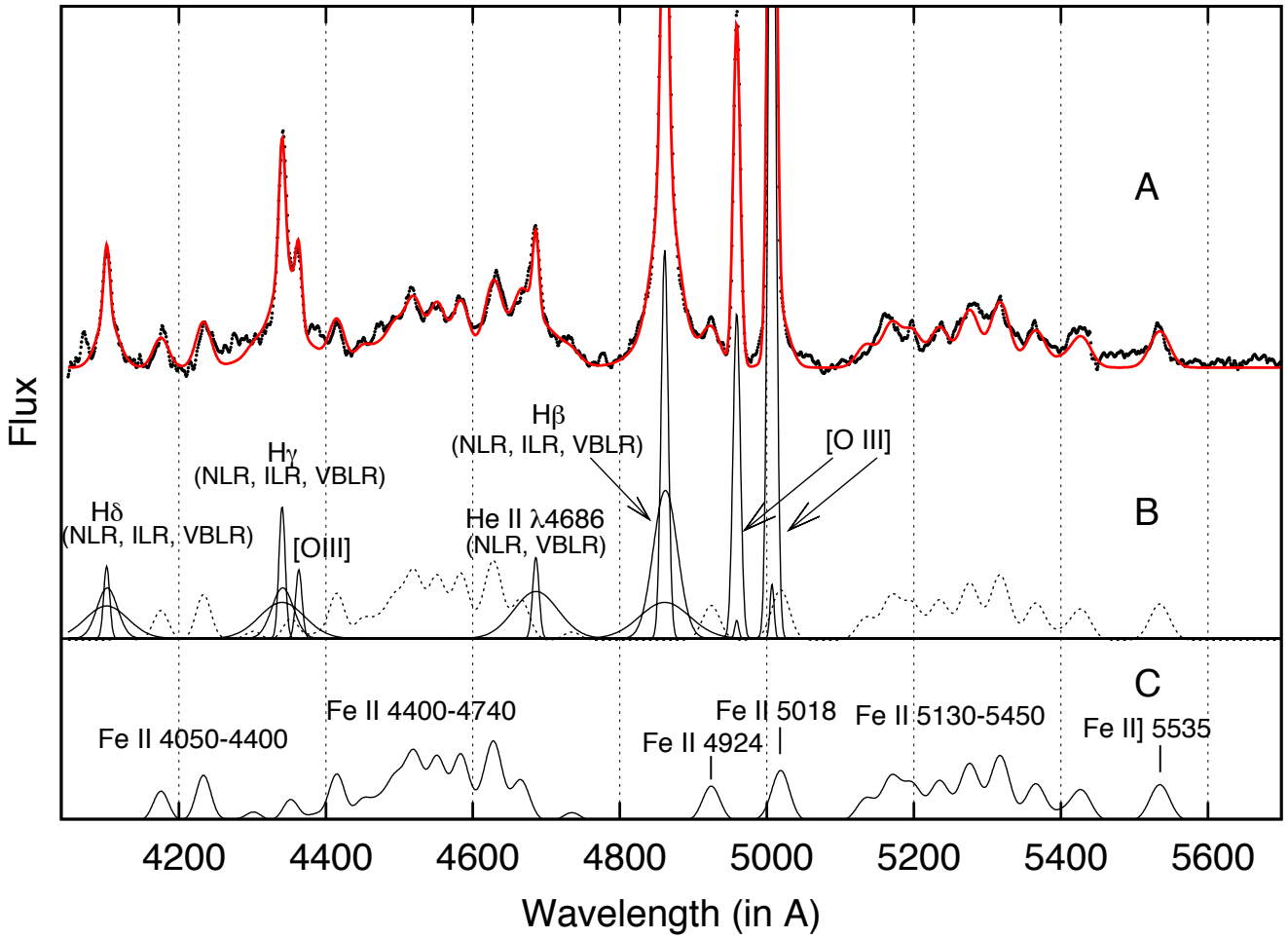
- complex calculations:
  - many energy levels
  - many transitions (radiative and collisional)
  - transition probabilities not accurately known



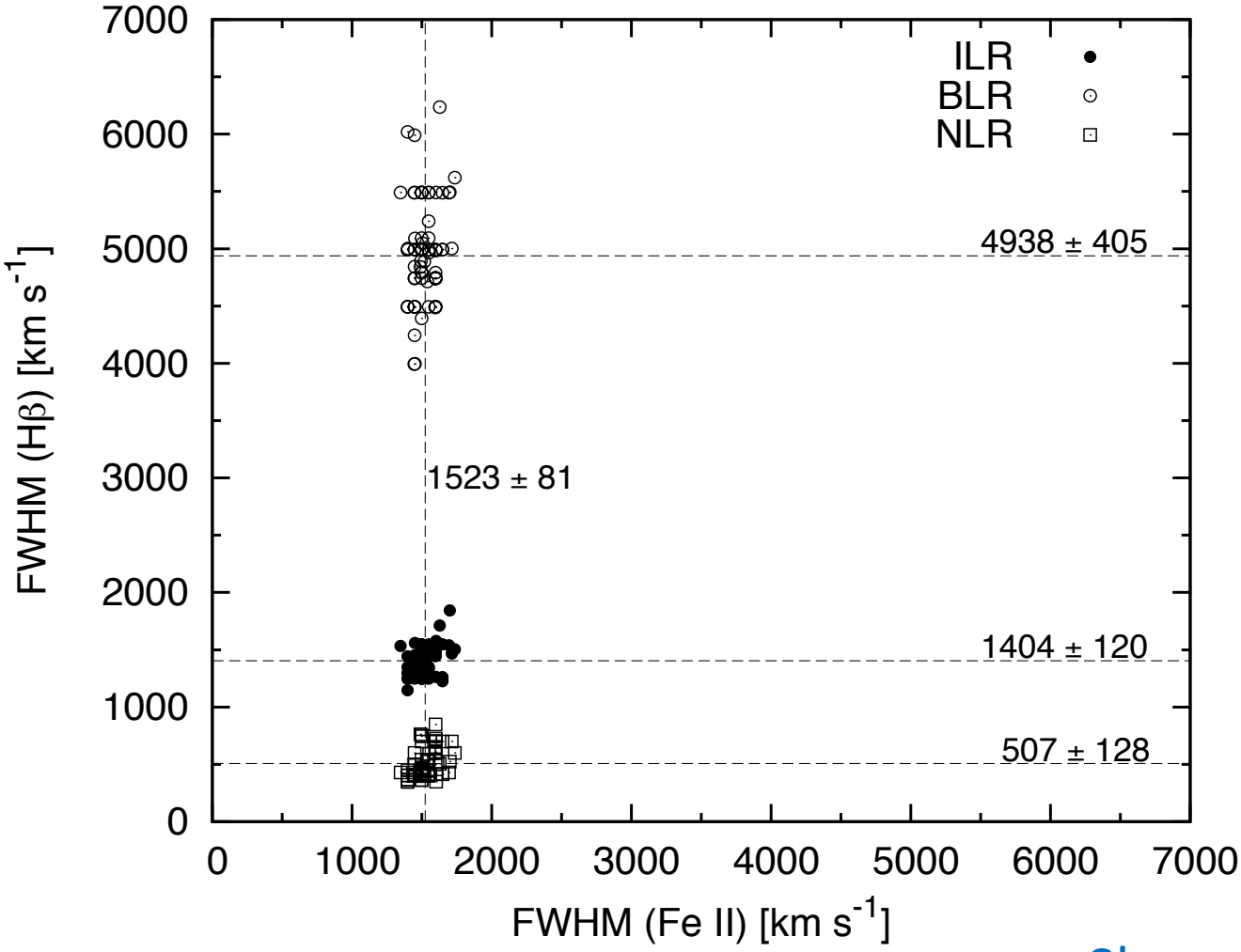
Osterbrock&Ferland 2006

Fe II fit: one example

- Hβ,Hγ,Hδ: BLR, ILR, NLR with same parameters
- HeII: BLR, NLR
- [OIII]
- Fe II template



Fe II origin: ILR

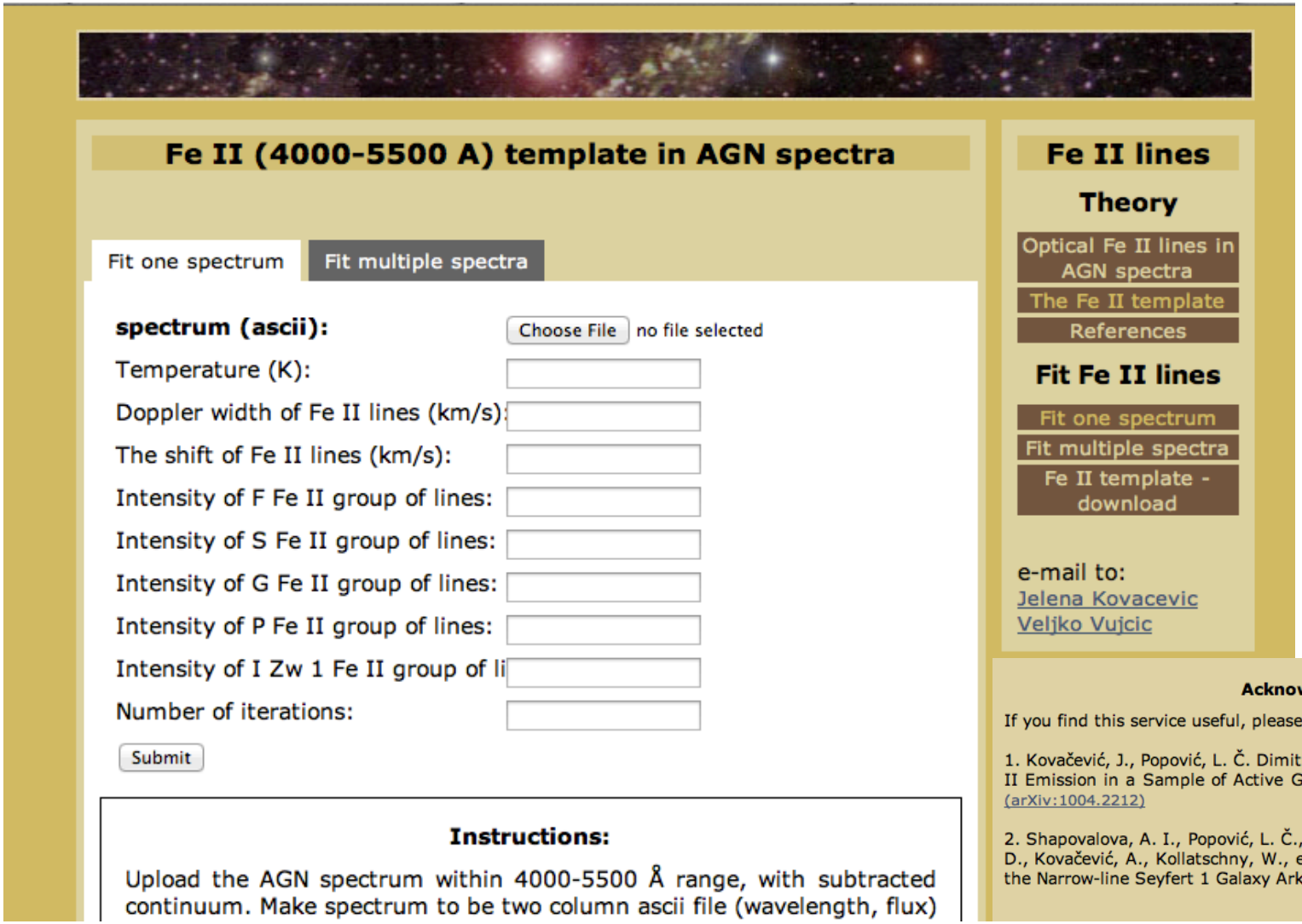


width of Fe II is the same as for Hβ ILR component

(see also e.g. Kovačević+ 2010, ApJS)

Shapovalova+ 2012, ApJS

FeII template: can fit any AGN spectrum!



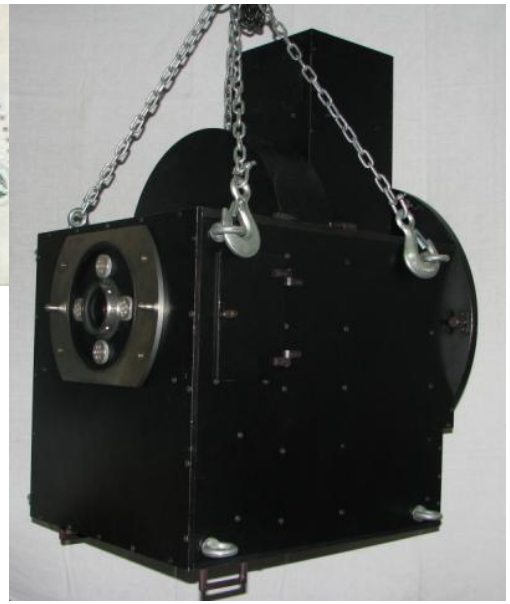
Kovacevic+ 2010
Shapovalova+ 2012

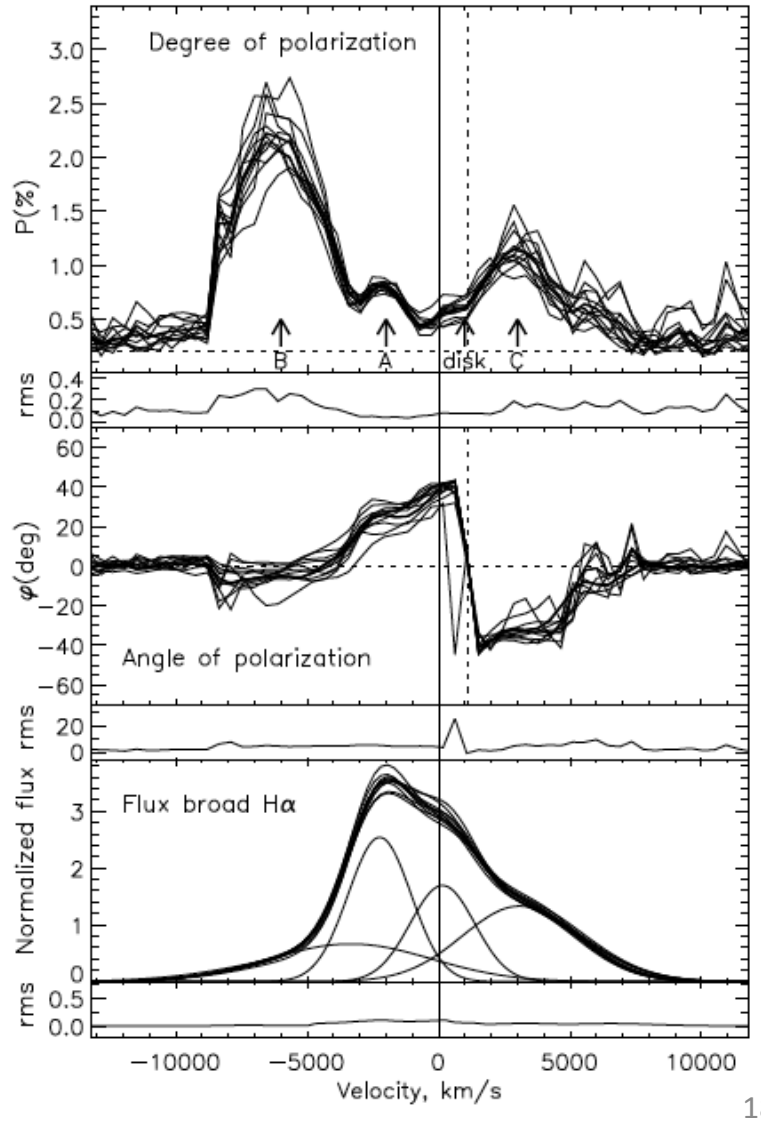
http://servo.aob.rs/FeII_AGN/

How can polarization in broad lines help?

- Example of the galaxy Mrk 6
- Spectro-polarimetric observation with 6m SAO telescope (Afanasiev+ 2014)

multi-mode focal reducer SCORPIO-2

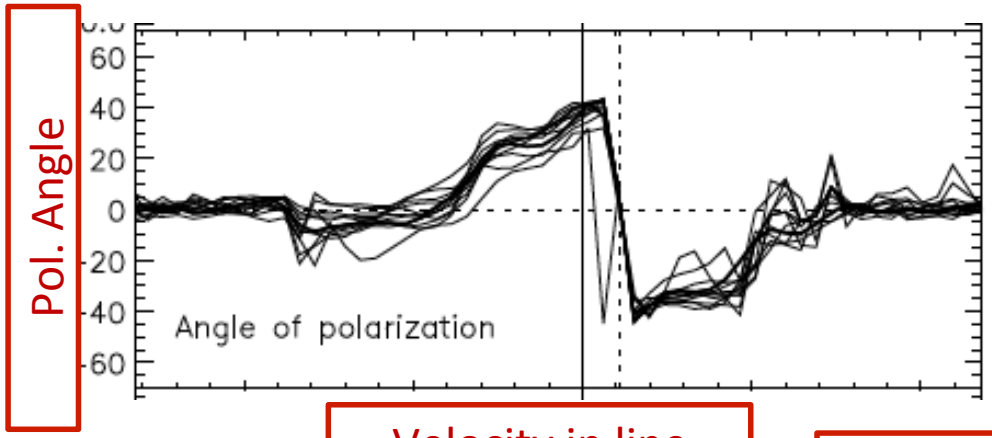




AGN polarization: some observational aims in the optical range

- comparison of polarization in the continuum and lines, both for NLR and BLR (to check the unified model)
- search for the broad lines in polarized light in Type 2 AGN
- polarization variability - jet and outflows, non-homogeneous BLR, instability in accretion disk (AD)
- dependence of the continuum polarization on wavelength – mechanisms of scattering, estimation of magnetic field in AD
- **Black hole mass estimates?**

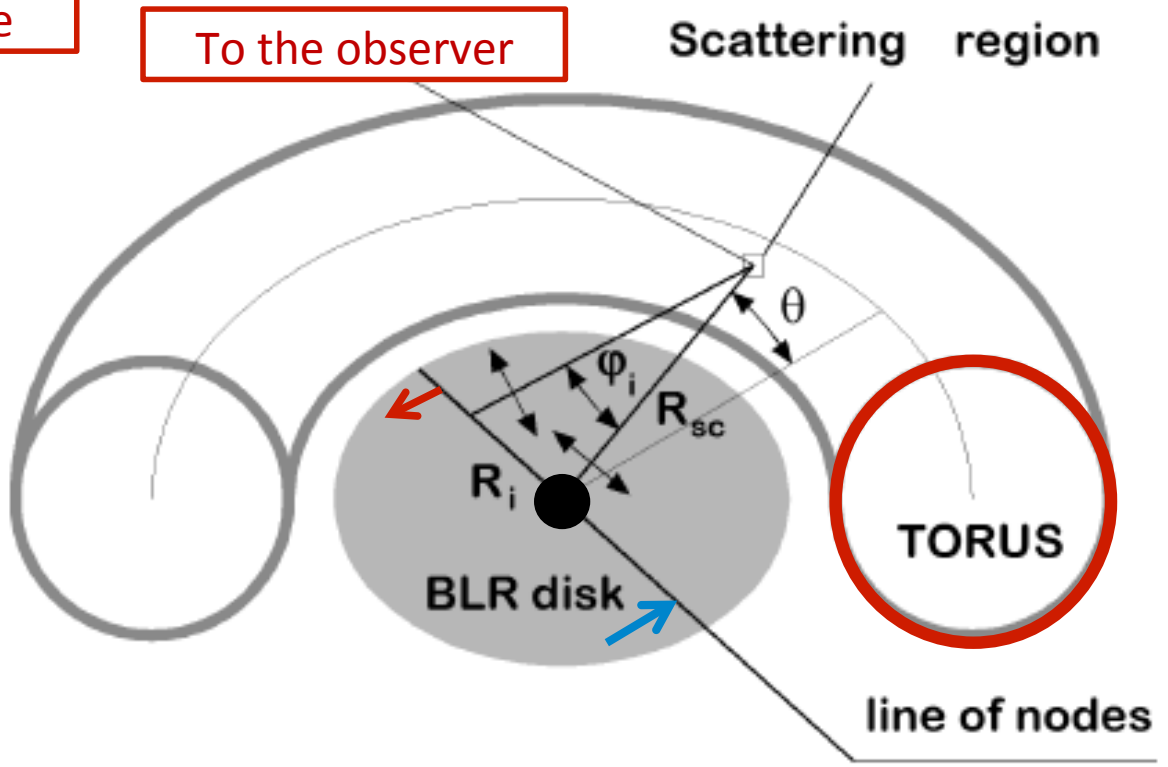
Equatorial scattering in Mrk 6



$$\log\left(\frac{V_i}{c}\right) = a - b \cdot log(\tan(\varphi_i)),$$

$$R_i = R_{sc} \cdot \tan(\varphi_i).$$

- Keplerian motion in the BLR
- Equatorial polarization: scattering region - inner part of the torus



Keplerian motion in the Mrk 6 BLR
(Afanasiev et al. 2014)

$$V_i = V_i^{rot}\cos(\theta) = \sqrt{\frac{GM_{BH}}{R_i}}\cos(\theta), \qquad (1)$$

where G is the gravitational constant and θ is the angle between the disc and polarization plane. In the case of the equatorial polarization, R_i can be connected with the corresponding polarization angle:

$$R_i = R_{sc}\cdot\tan(\varphi_i), \qquad (2)$$

where R_{sc} is the distance from the center of the disc to the scattering region.

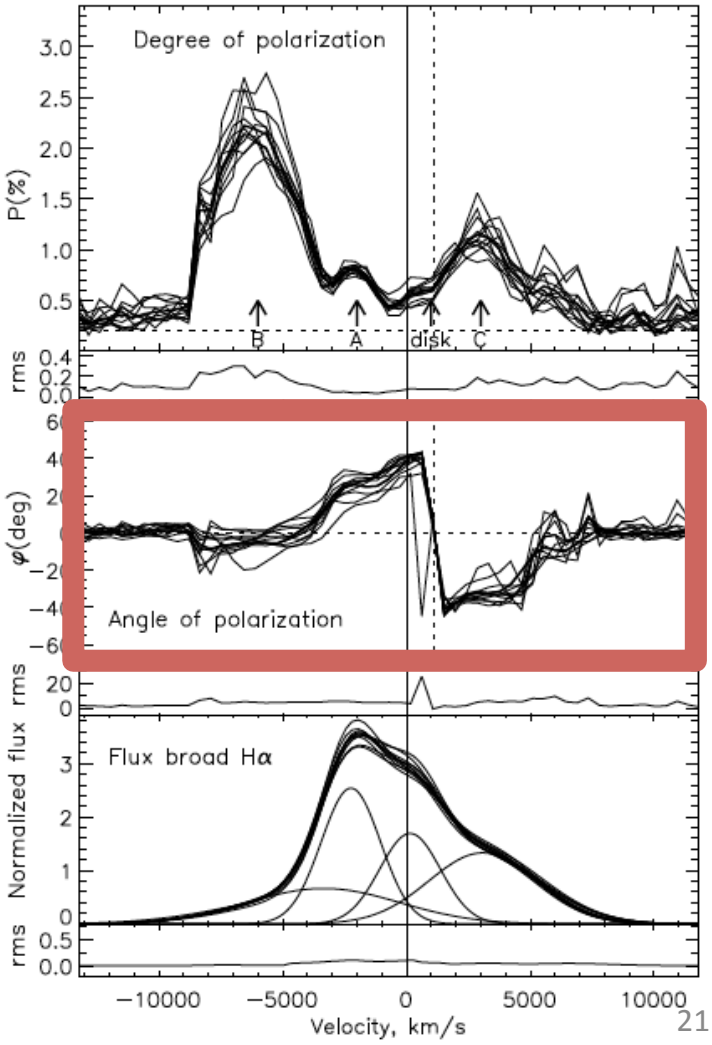
Now, Eq. 1, can be rewritten as:

$$\log(\frac{V_i}{c}) = a - b\cdot log(\tan(\varphi_i)), \qquad (4)$$

where c is the velocity of light, the constant a is

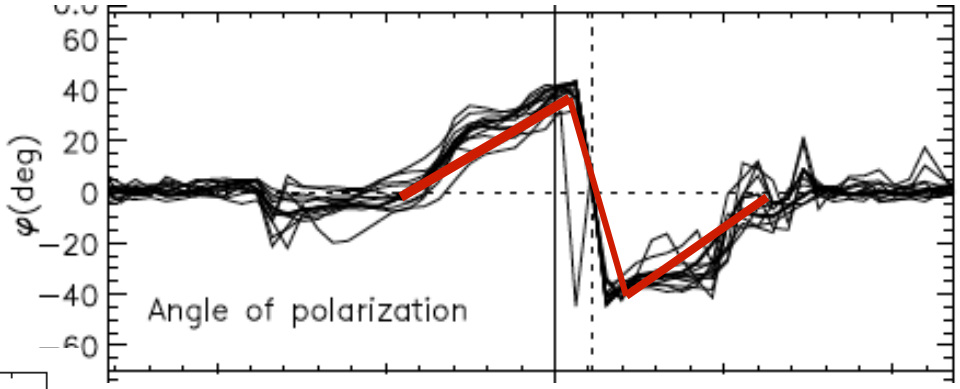
$$a = 0.5\log(\frac{GM_{BH}\cos^2(\theta)}{c^2 R_{sc}}). \qquad (5)$$

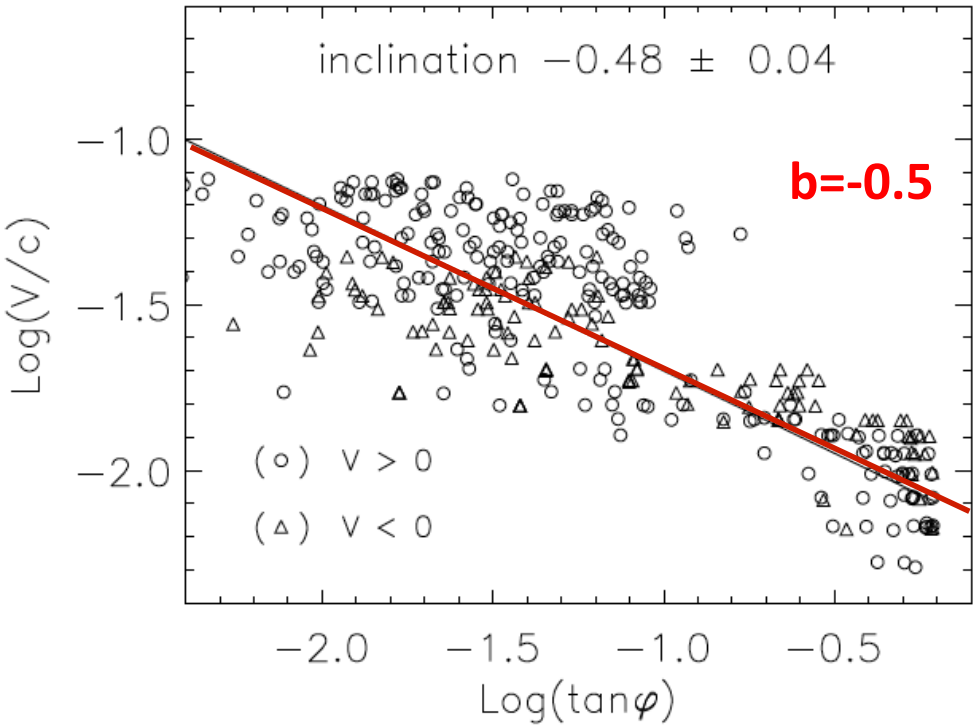
In the case of the Keplerian motion $b \approx 0.5$.



V vs. tan(ϕ) – direct evidence of Keplerian motion in the BLR of Mrk 6

$$\log\left(\frac{V_i}{c}\right) = a - b \cdot log(\tan(\varphi_i)),$$





This gives us also parameter a=-2.19

New method for the BH mass estimation

(Afanasiev, Popovic, Shapovalova, Borisov, Ilic, 2014)

$$M_{BH-kep} = 10^{2a}\frac{c^2 R_{sc}}{G\cdot\cos^2(\theta)} = 1.78\cdot 10^{2a+10}\frac{R_{sc}}{cos^2(\theta)}M_{\odot}, \quad (6)$$

where R_{sc} is in light days.

R_{sc}~ 0.18 pc ~ 220 light days (from Kishimoto et al. 2011)

Using spectro-polarimetric observations we estimated the black hole mas of Mrk 6 (low mass limit).

$$M_{BH-kep} = 1.16\times 10^{8} M_{sun}$$

Good agreement w/reverebaration value: 1.3 - 1.8 $\times 10^8 M_{sun}$

Conclusions

- there are huge amount of spectral data available online for AGN research

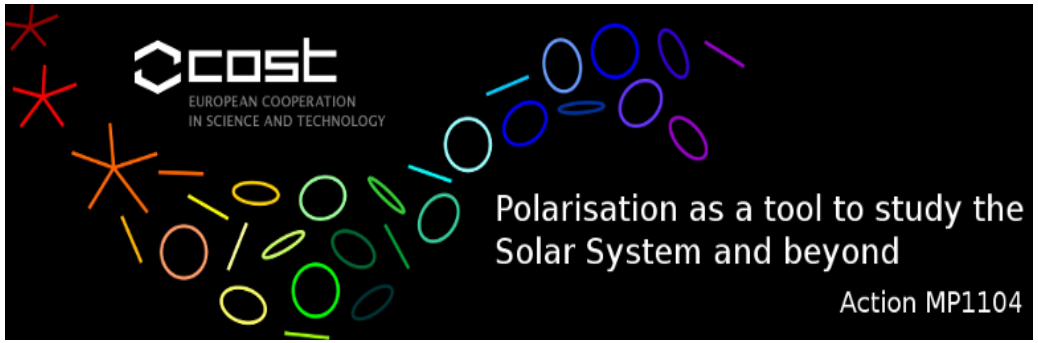
  → SDSS, long-term monitoring campaigns...

- new tools available: e.g. Fe II template for AGN spectra (http://servo.aob.rs/FeII_AGN/) - Fe II emission from ILR

- spectro-polarimetry an important tool→ M_{BH}

Thank you for your attention!

Part of this research supported by the COST Action MP1104 on **POLARIZATION**:



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