RESULTS OF THE LONG-TERM SPECTRAL MONITORNIG OF ACTIVE GALAXY 3c390.3

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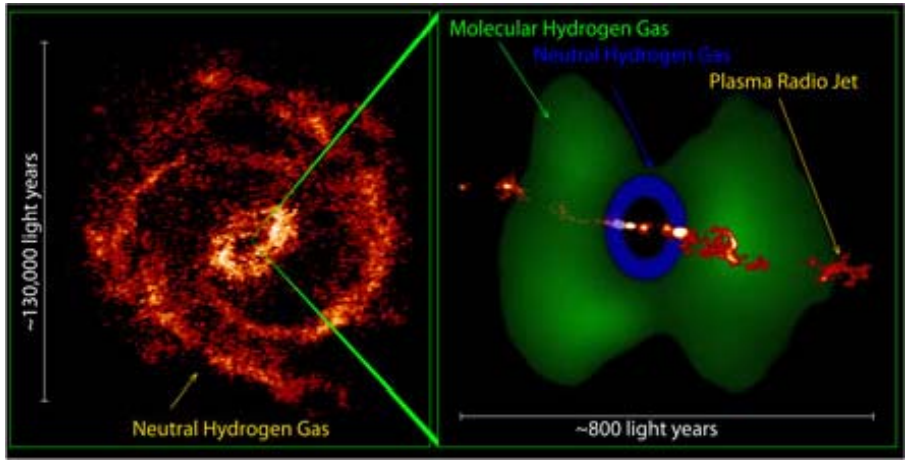
OUTLINE

- Active galactic nuclei
- The possibilities and importance of the long term monitoring of AGN
- Results for 3c390.3

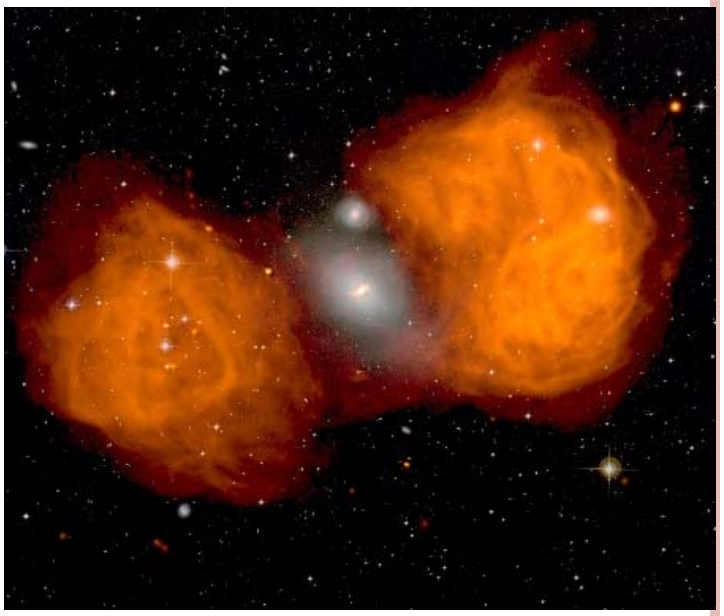


- Group of Extragalactic spectroscopy in Belgrade

EXTRAGALACTIC SPECTROSCOPY AT THE DEPARTMENT & OBSERVATORY

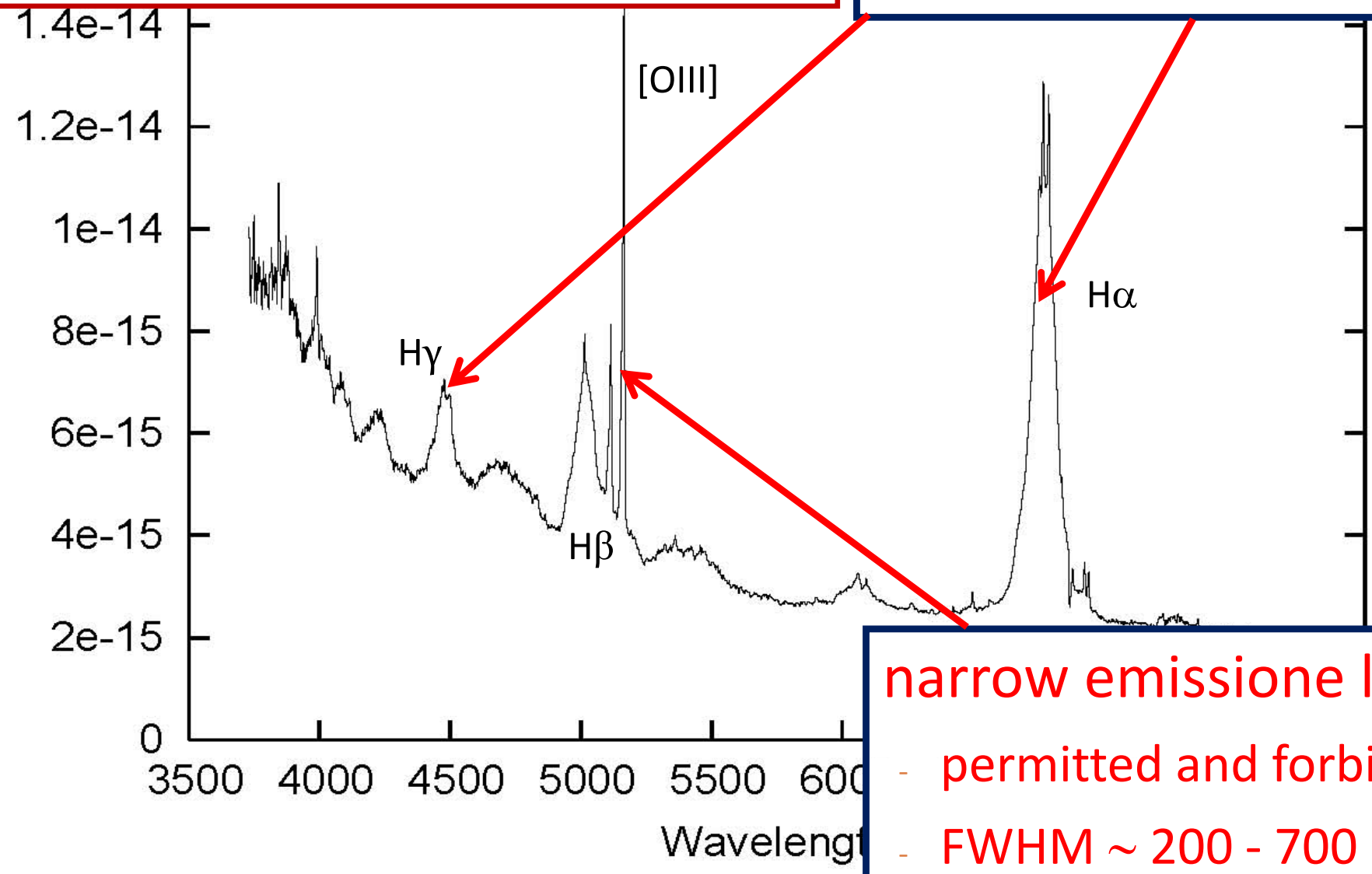
ACTIVE GALACTIC NUCLEI (AGN)

- AGN phenomenon – ubiquitous!
- AGN properties :
  - compact size
  - high luminosities:
    $L \sim 10^{42}$-10^{48}erg/s (up to 10^{15} L_{sun})
  - broad continuum
  - strong broad and narrow emission lines!!
  - strong variability(~1 day!)
  - powerful radio-sources (jets)
  - many different types



AGN EMISSION LINES

Balmer lines of AGN Mrk 817
(Ilic et al.2006)



broad emission lines

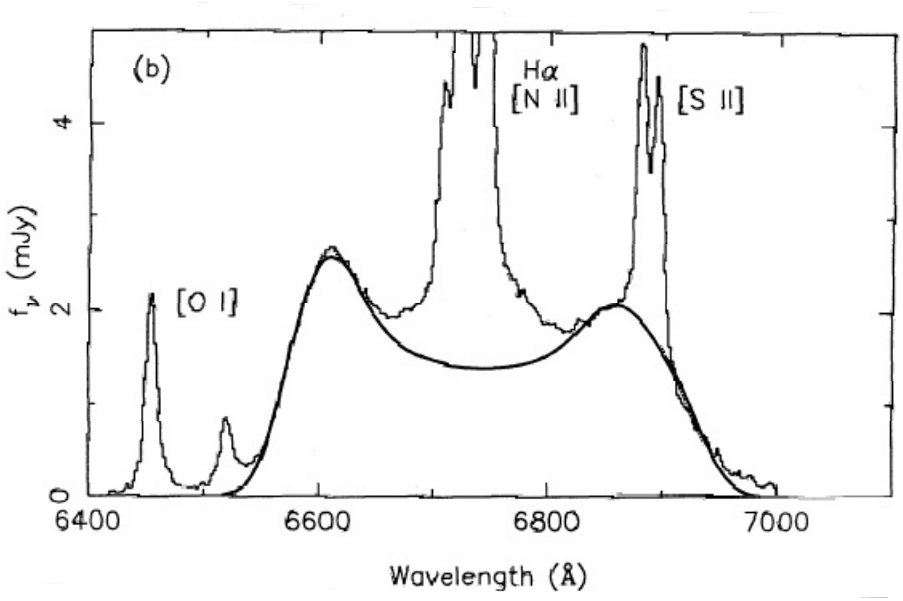
- permitted transitions
- FWHM ~ 2000 - 10000 km/s

narrow emissione lines

- permitted and forbidden
- FWHM ~ 200 - 700 km/s

What Emission Lines can tell us?

- Physical conditions of the region
  - temperature
  - density
  - ionization state

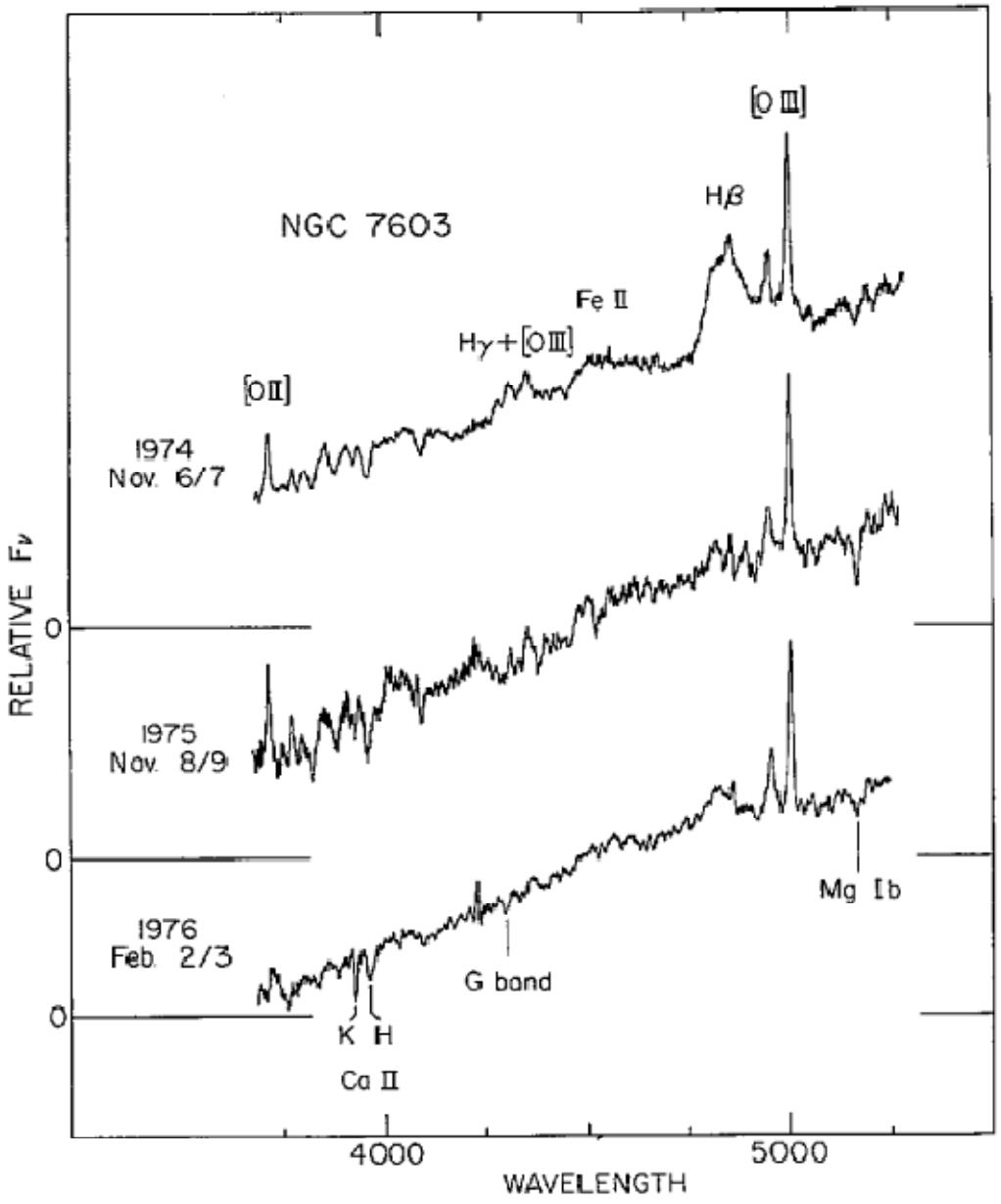


- Kinematics
  - velocities (line widths)
  - size (reverberation – time delays)
  - geometry (line shapes)

AGN – STRONG VARIABILITY!

- NGC 7603
  the change of AGN type
  Sy1 → Sy2

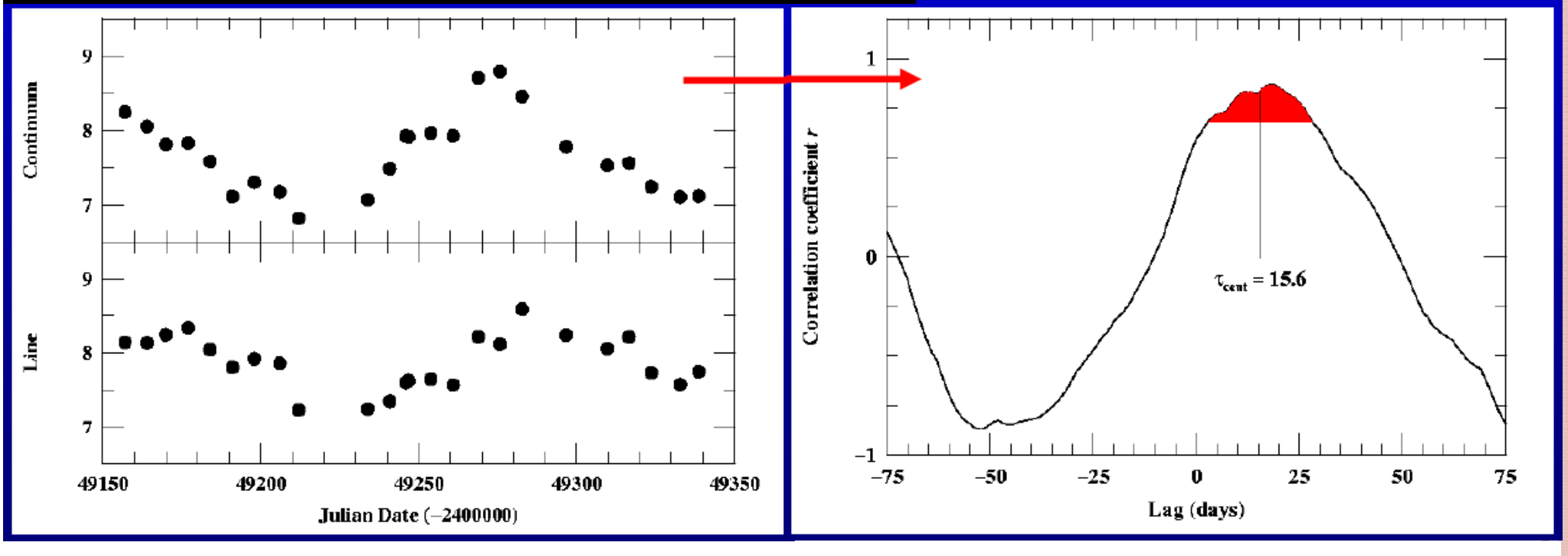
Tohline & Osterbrock 1976



Reverberation Method (RM)

$$\mathrm{CCF}(\tau) = \int_{-\infty}^{\infty} \Psi(\tau')\,\mathrm{ACF}(\tau-\tau')\,d\tau'$$

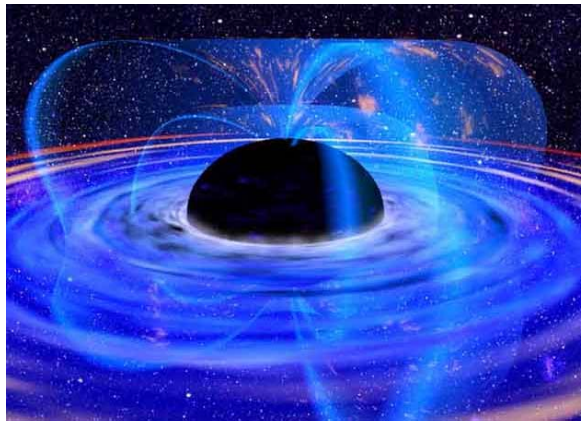
CCF= cross-correlation function



- time delay of line flux ⇒ size of the BLR

Blandford & McKee 1982, Wandel et al. 1999, Kollatschny et al. 2001, Kaspi 2000, Peterson et al. 2004, Shapovalova et al. 2008…

BLACK HOLE MASS M_{BH} ESTIMATES

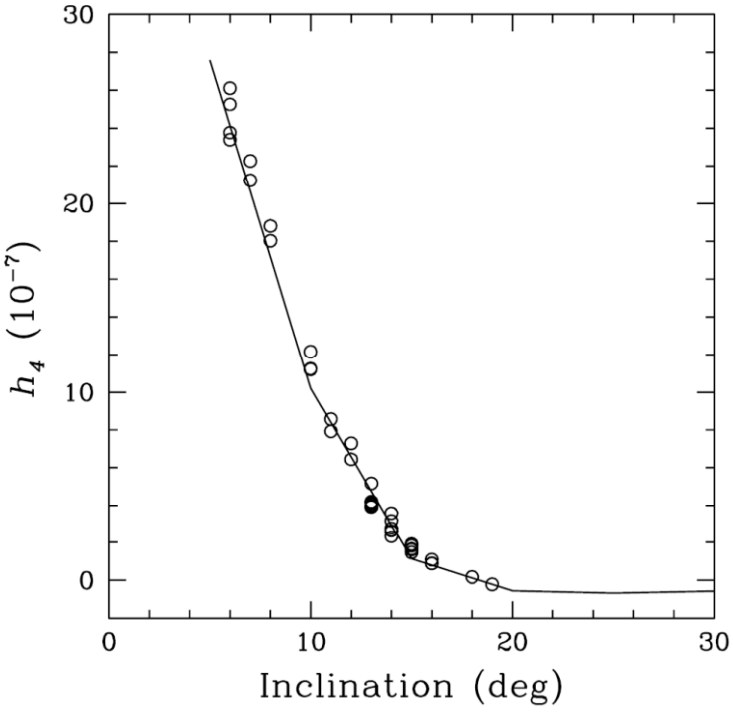


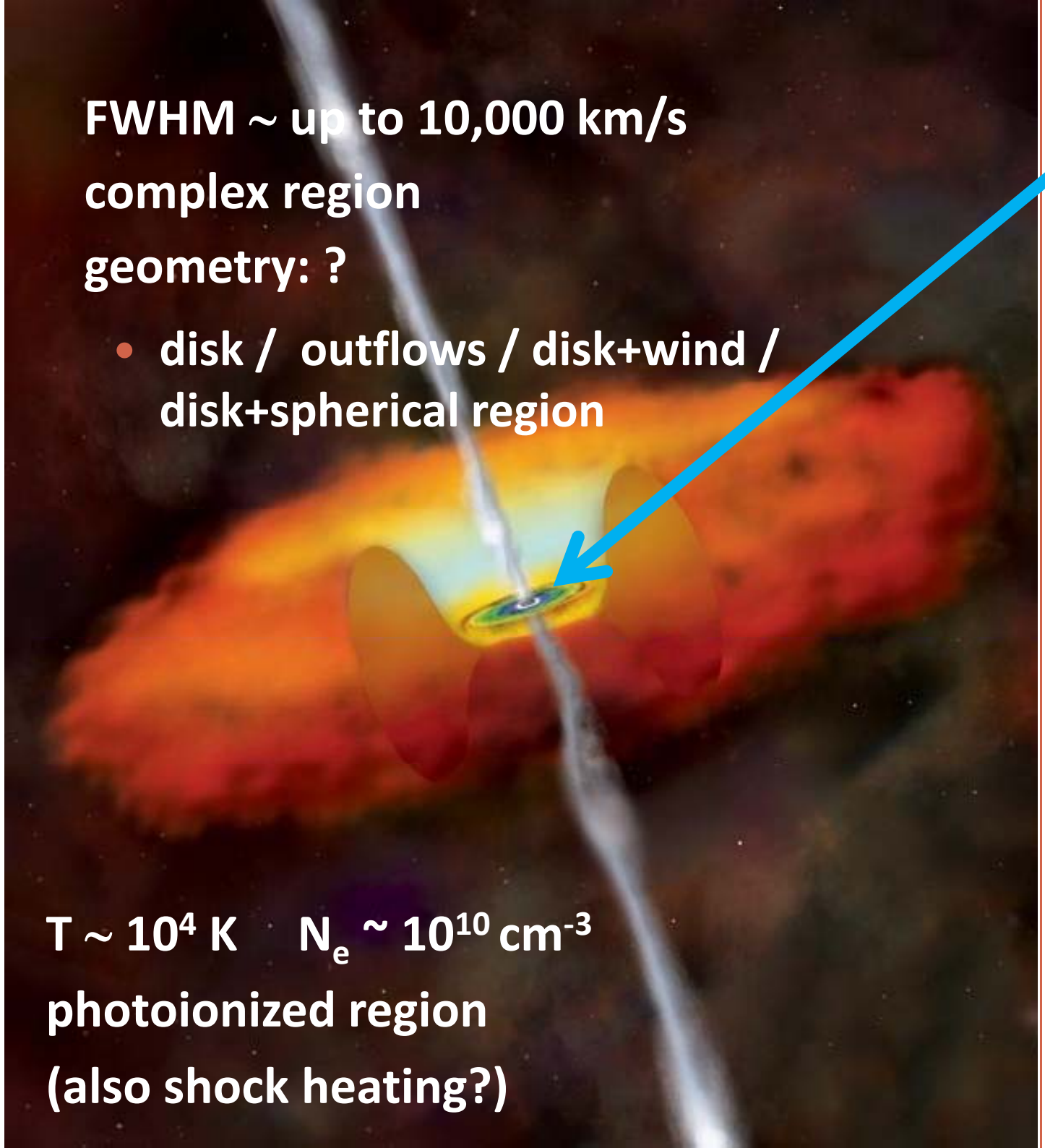
- virial theorem: $$M_{BH} = f \frac{R_{BLR} v^2}{G}$$

(Wandel+ 1999; Kaspi+ 2000, 2005; Peterson+ 2004, Bentz+ 2009)

- reverberation mapping → the BLR radius: R_{BLR} (for NGC 4151, 3c390. 3 in Shapovalova+2009, 2010)

- Problem BLR geometry : f depends on geometry and kinematics
- e.g. most common AGN spectra show i < 20° (La Mura et al. 2009, ApJ, 693, 1437)



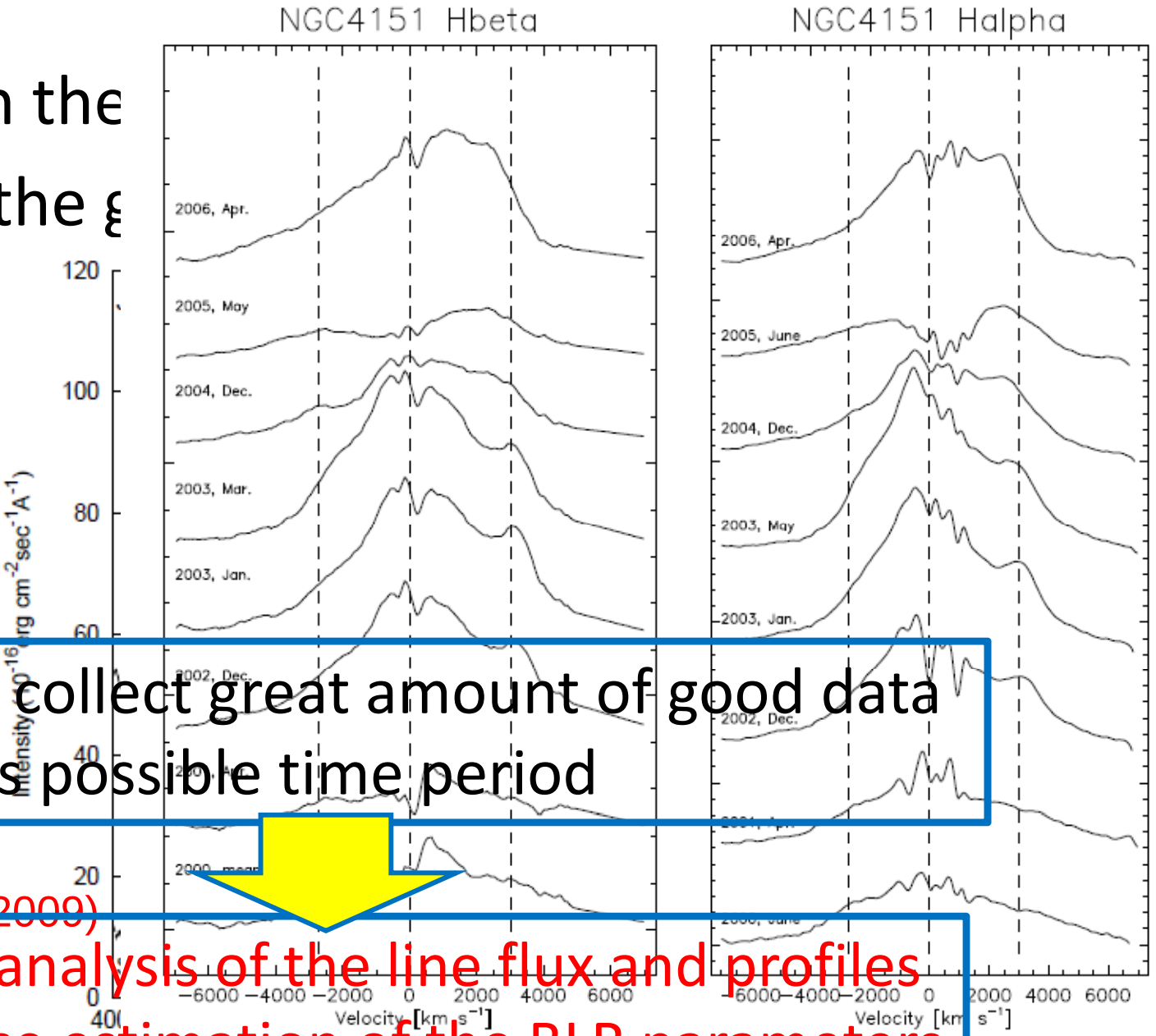


in order to estimate M_{BH} we need to know the geometry of the BLR

what do we know about BLR?

AGN – HIGHLY VARIABLE OBJECTS

- variation in the
- change of the g
- line profile variability



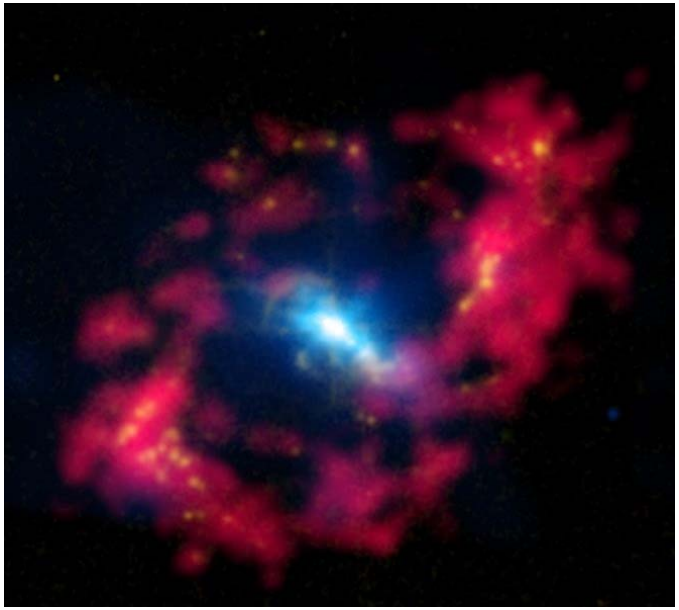
we need to collect great amount of good data in as long as possible time period

(Shapovalova et al. 2009)

detailed analysis of the line flux and profiles and precise estimation of the BLR parameters

3c390.3 (Shapovalova et al. 2010)

LONG-TERM MONITORING

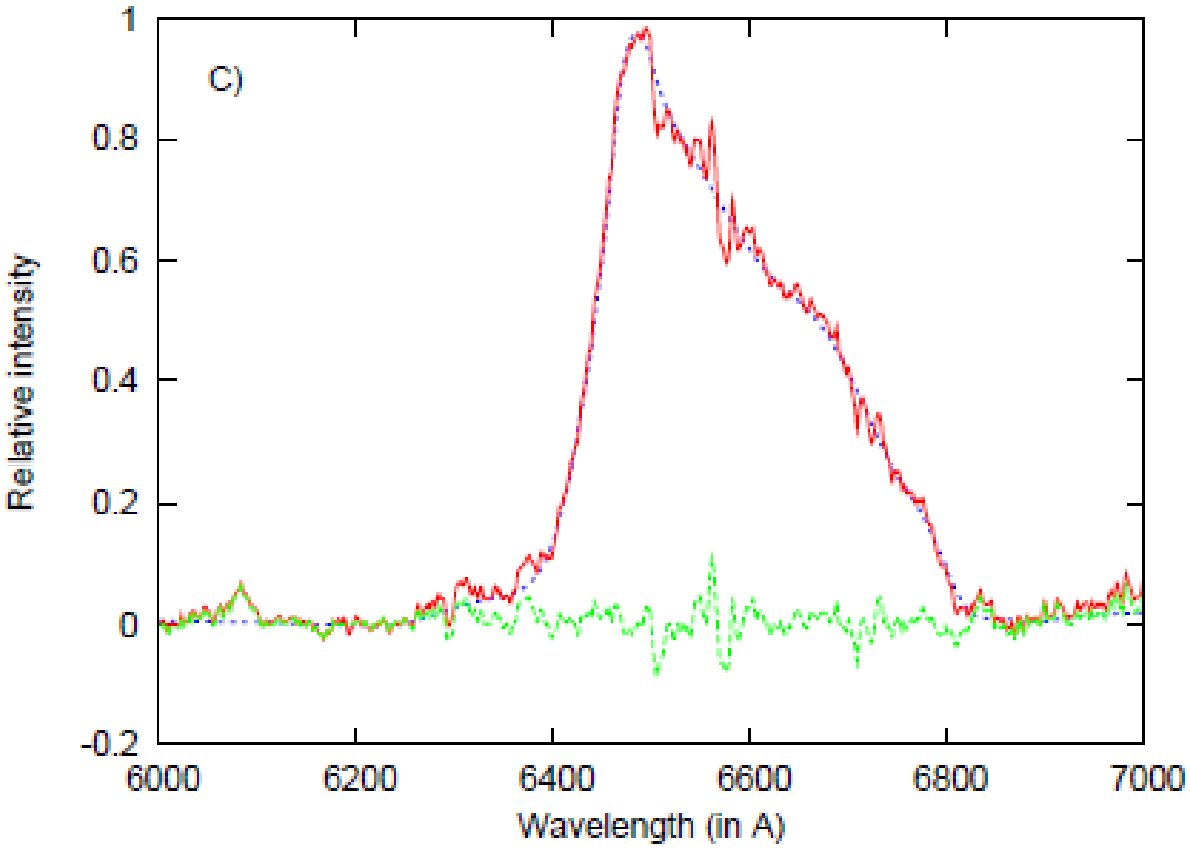


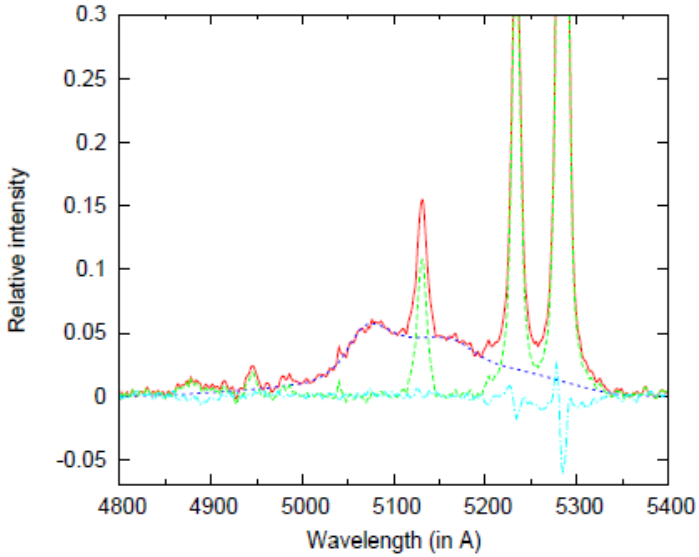
- PIs: Alla I Shapovalova (Russia)
  Vahram H. Chavushyan (Mexico)
- constantly observing well known AGN:
  - NGC 5548 – 9 years (Ilić 2007, Popović et al. 2008)
  - NGC 4151 – 11 years (Shapovalova et al. 2008, 2009, 2010a)
  - 3C390.3 – 13 years (Shapovalova et al. 2010b, Popović et al. 2011, Jovanović et al. 2010)
  - Arp 102B – 12 years (in prep.)
  - Ark 564 – 11 years (in prep.)
- variability: continuum flux, line shapes, line fluxes …
- powerful tool for emission line region diagnostics

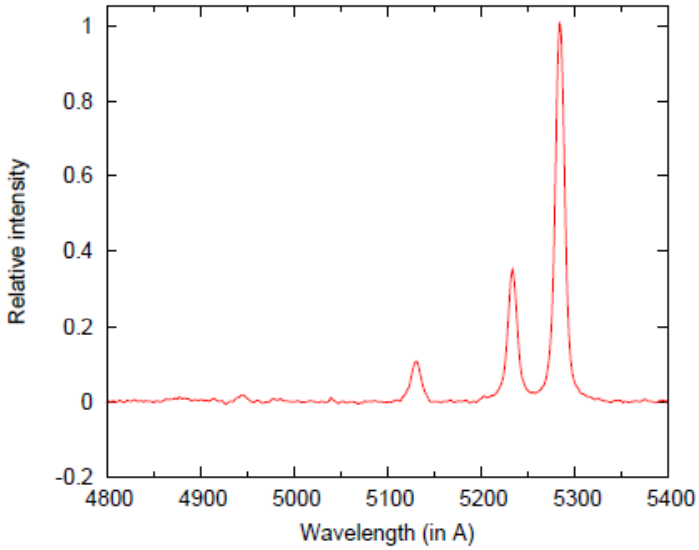
OBSERVATIONS

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

CAREFUL DATA REDUCTION AND ANALYSIS

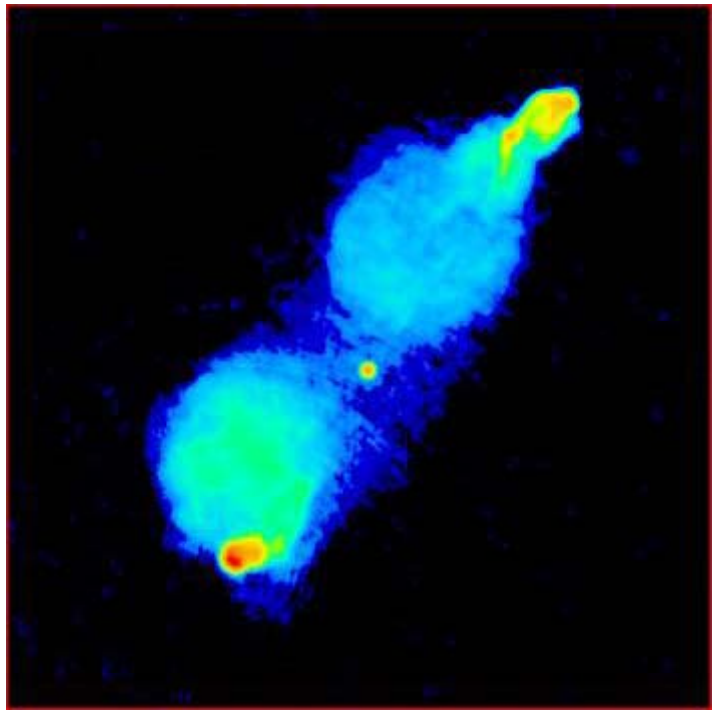




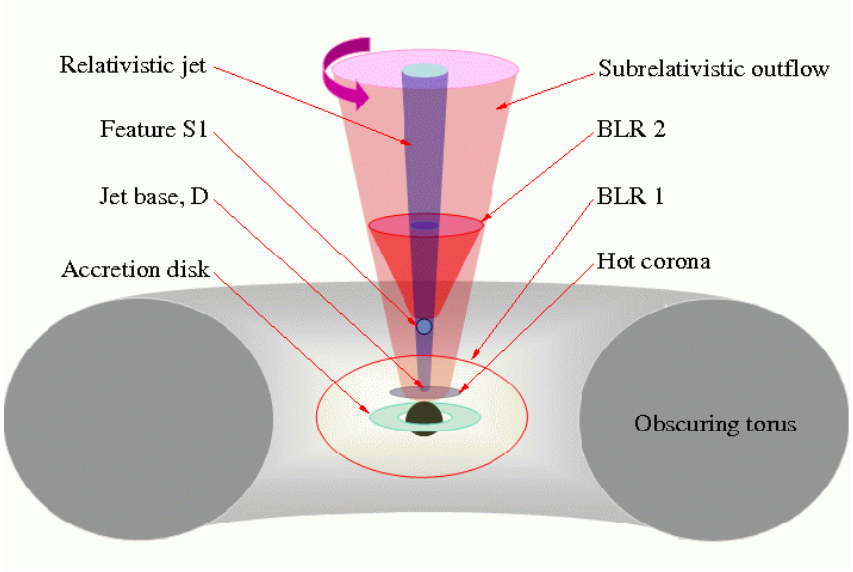


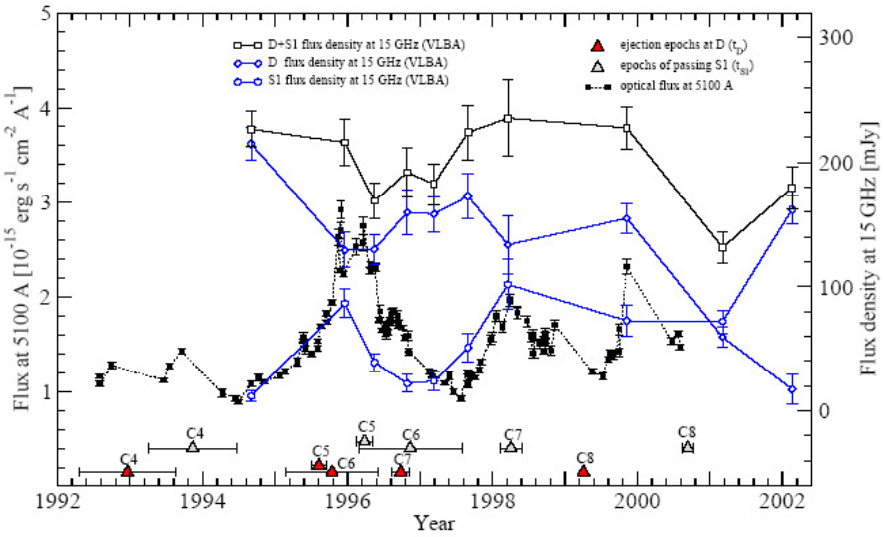
- all details in
  Shapovalova et al. 2008, A&A, 486, 99
- subtraction of the continuum and narrow lines template

3c390.3



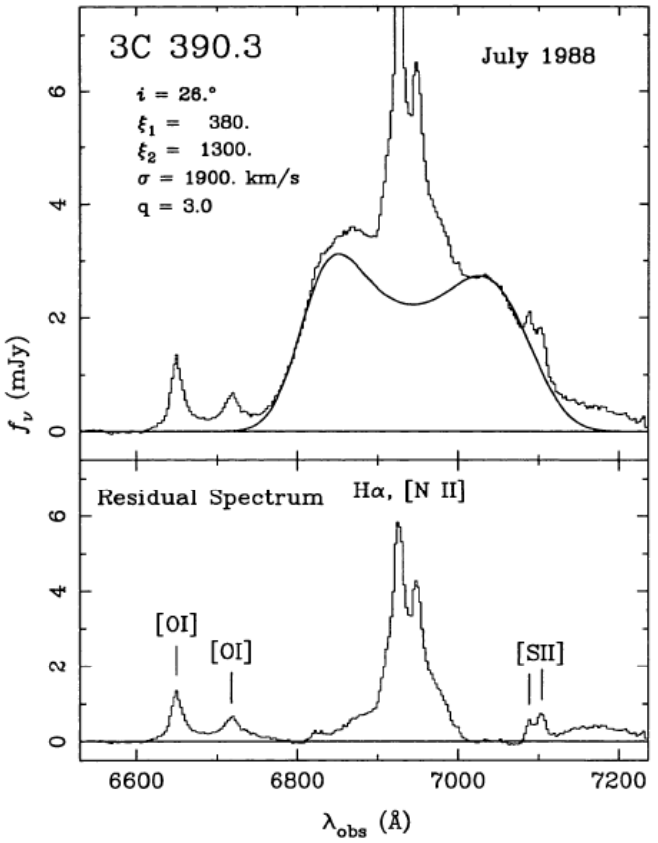
- double radio-loud galaxy with strong radio core (Leahy & Perley 1991)
- superluminal motion (v/c~4) (Alef et al. 1988; 1996)
- optical continuum emission at 5100Å is followed by emission of radio-components D & S1 in radio-jet (Arshakian et al. 2010)

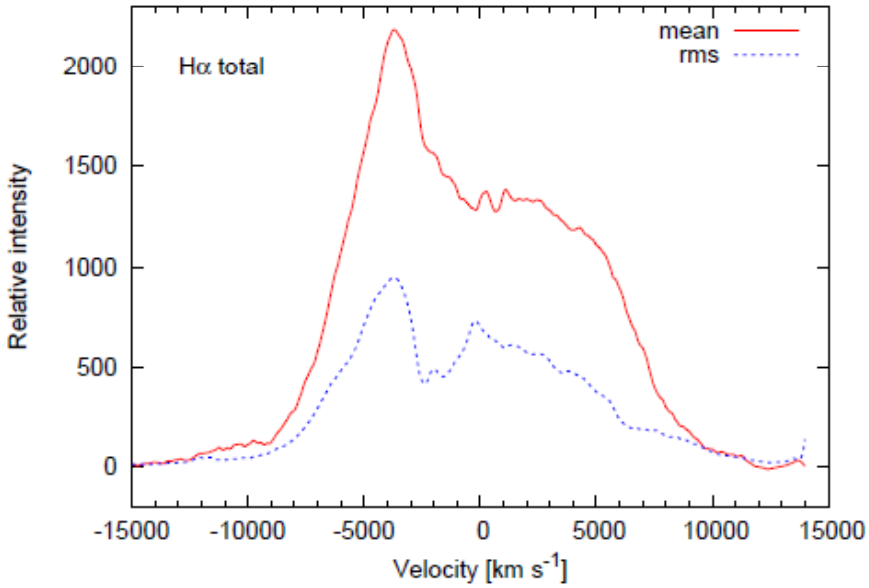


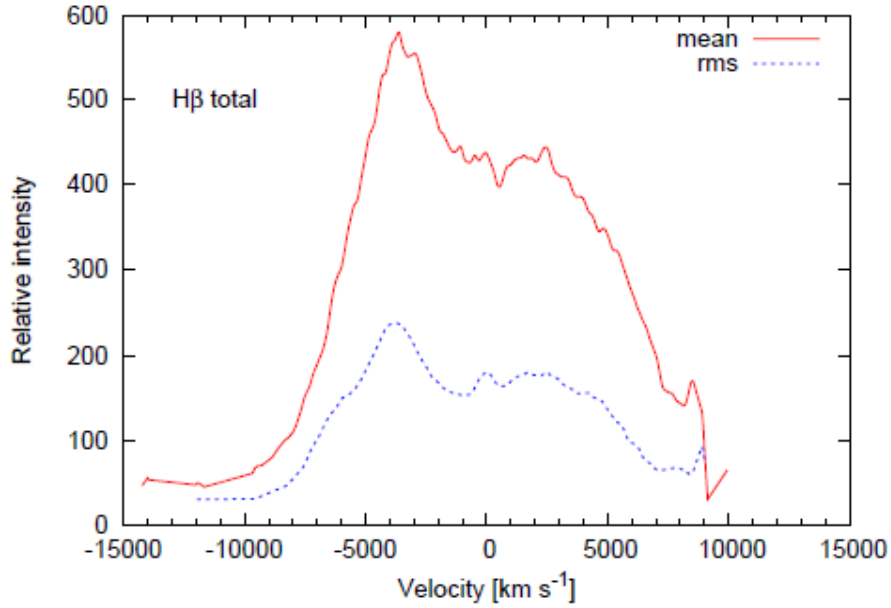


3c390.3

- double-peaked broad line (Eracleous & Halpern 1994)
- proof of the line disk-emission
- variable line profiles ⇒ different complex BLR models: binary BLR, disc precession, disk perturbation, etc.







3c390.3

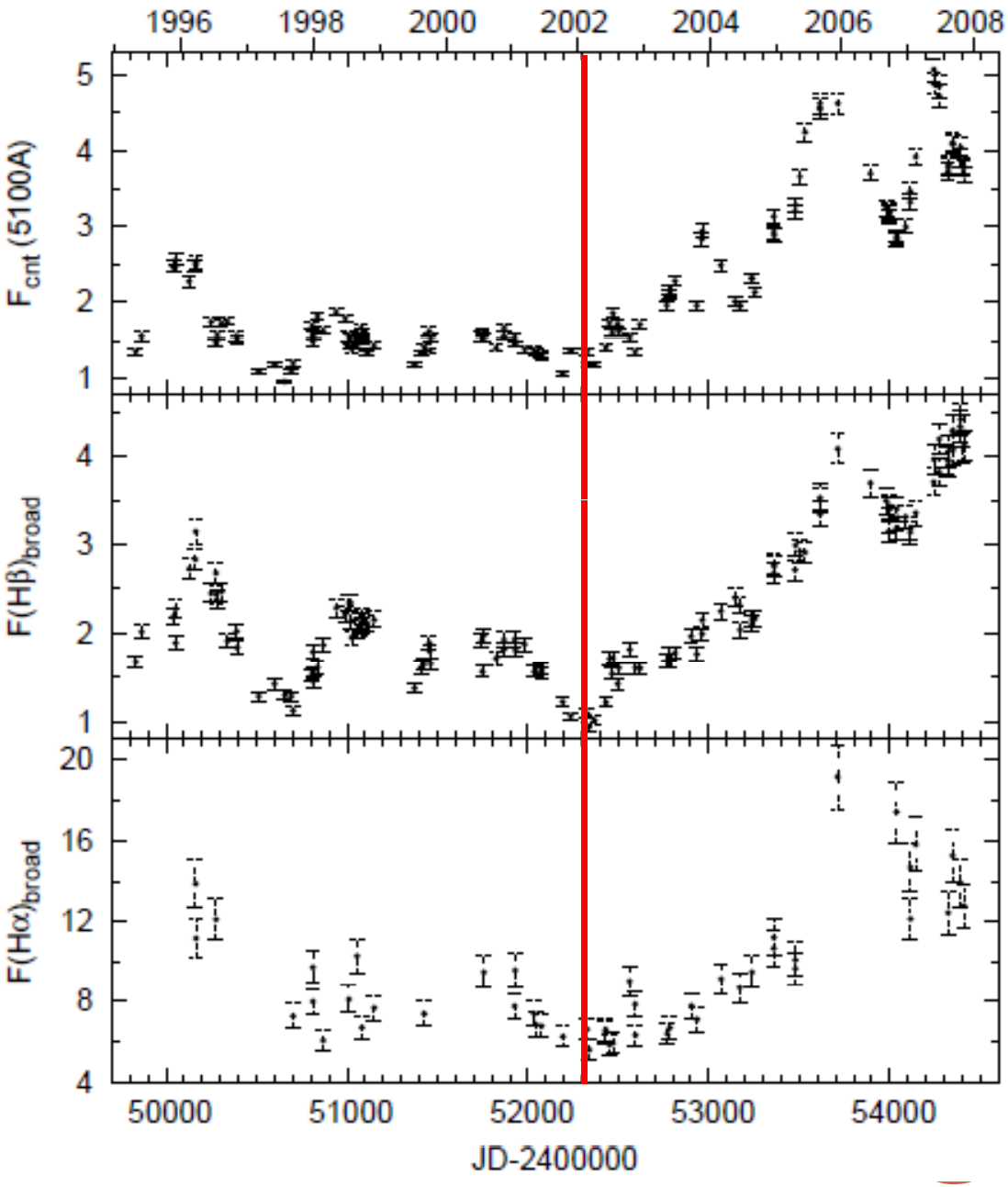
- 13-year data
- several max & min
- CCF analysis (ZDCF, ICCF)

⇒ Hα ~ 120 light days

⇒ Hβ ~ 95 light days

⇒ stratified BLR

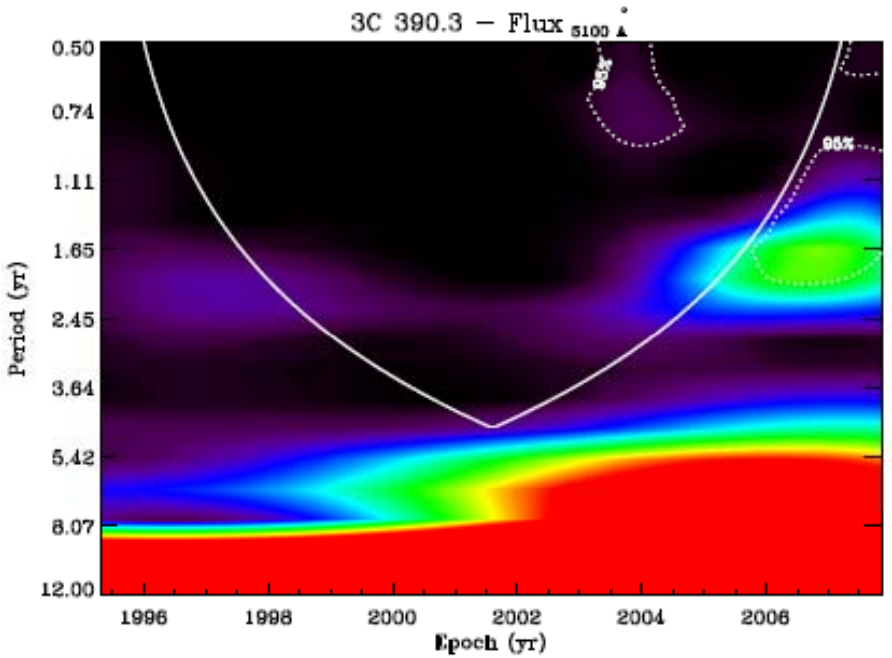
- minimum in 2002 ⇒ 2 characteristic periods

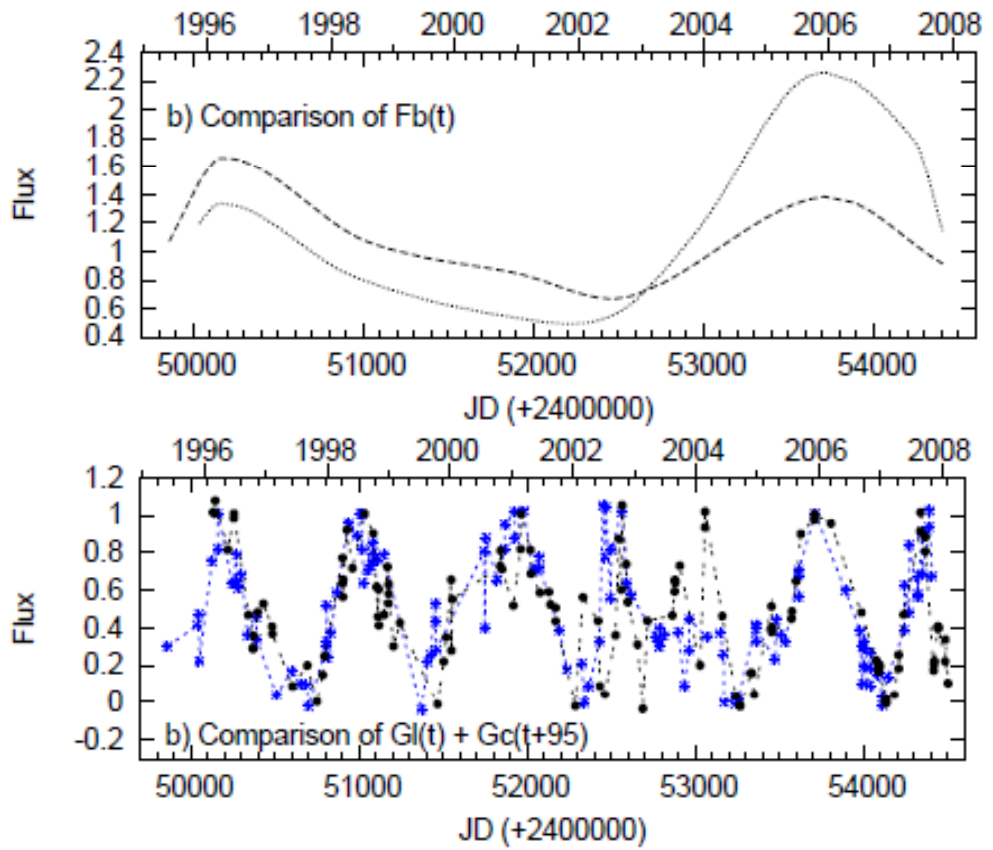


Shapovalova, Popović, Ilić, Kovačević et al. 2010b, A&A, 517, 42

3c390.3 - QPOs

- quasi-periodic oscillations (QPOs)
  - Morlet wavelet transformation
  - analysis of minima and maxima of Hβ and continuum
- QPOs with periods:
  ~ 10 years (Veilleux & Zheng 1991)
  ~ 2-4 years
- shock waves near the SMBH spreading in the outer part of the disk OR contribution of either ejection or jets to QPOs

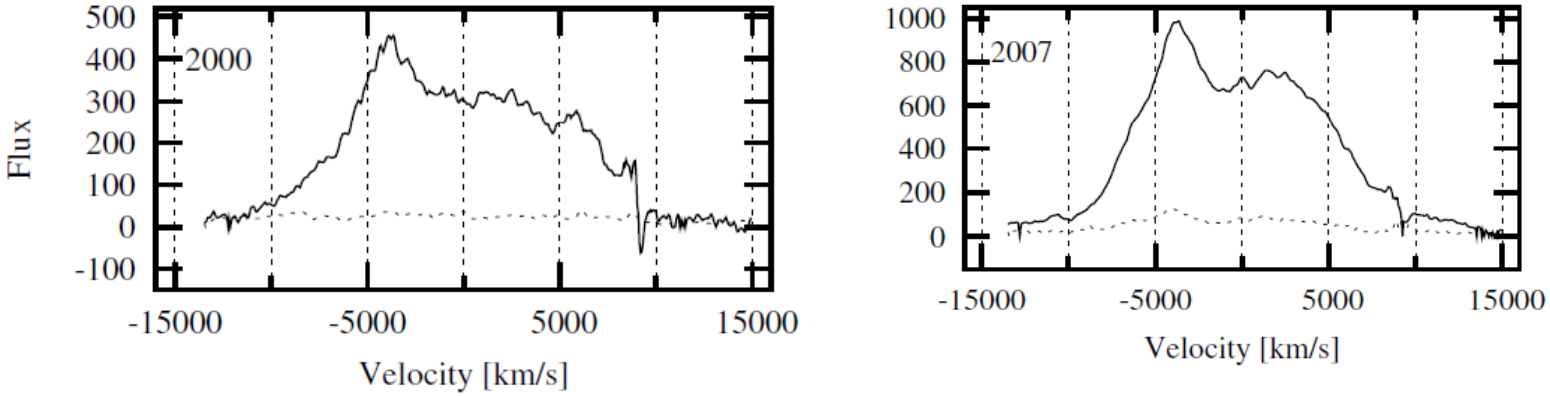




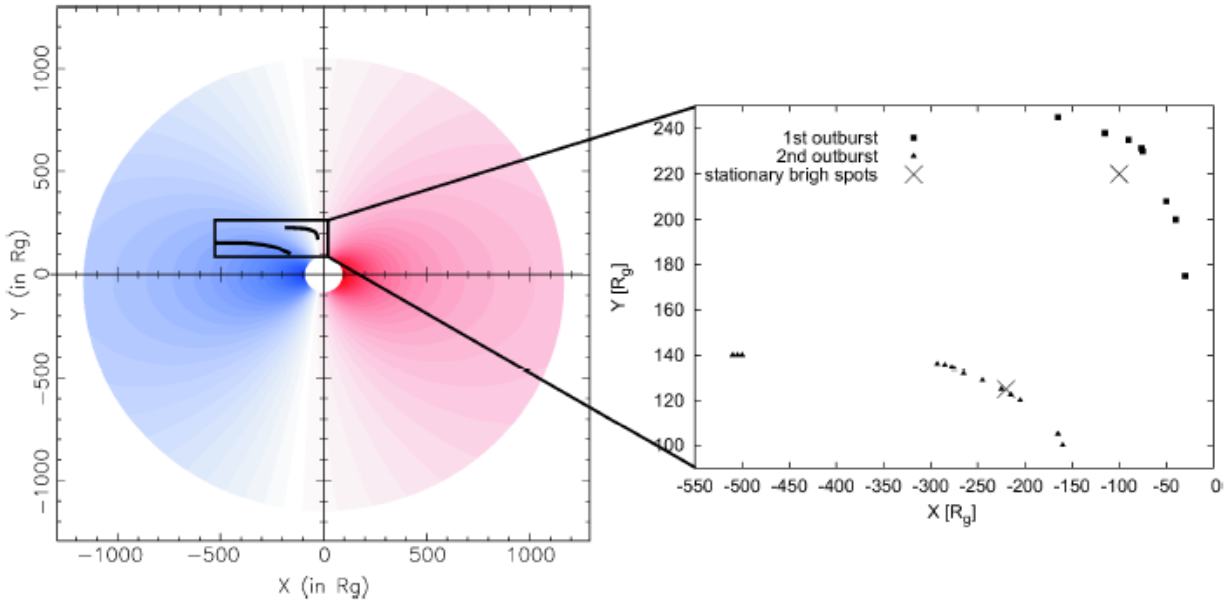
Shapovalova , Popović, Ilić, Kovačević et al. 2010b, A&A, 517, 42

3C390.3 – LINE PROFILES

- line profiles vary dramatically: disk-like profile with strong blue peak always present, BUT sometimes also the central peak appears ⇒ additional emission region



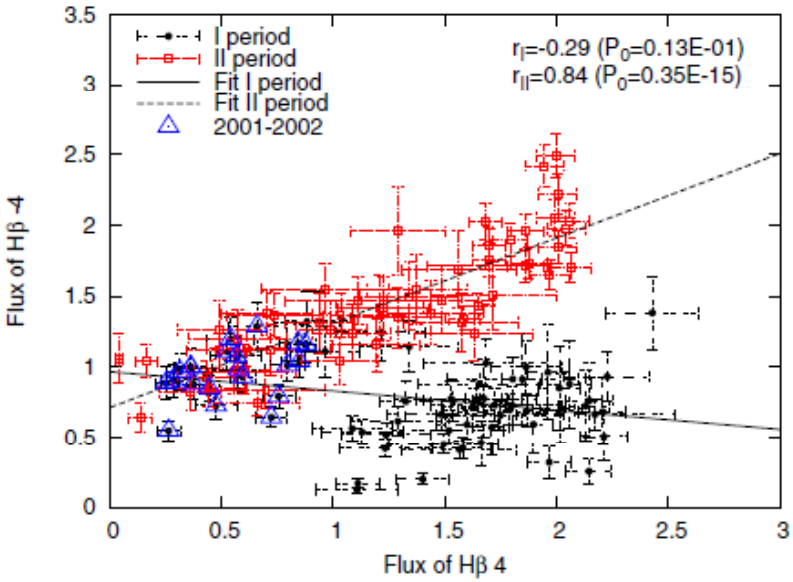
- describe the line profiles with disk perturbations



Jovanović, Popović, Stalevski, Shapovalova 2010, ApJ, 718, 168

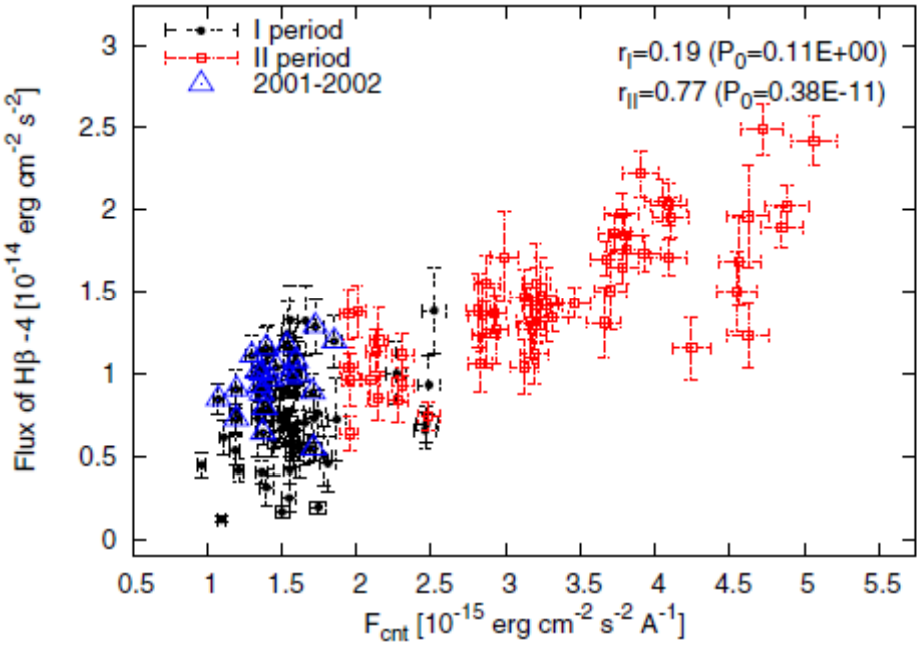
3c390.3 – Hβ LINE

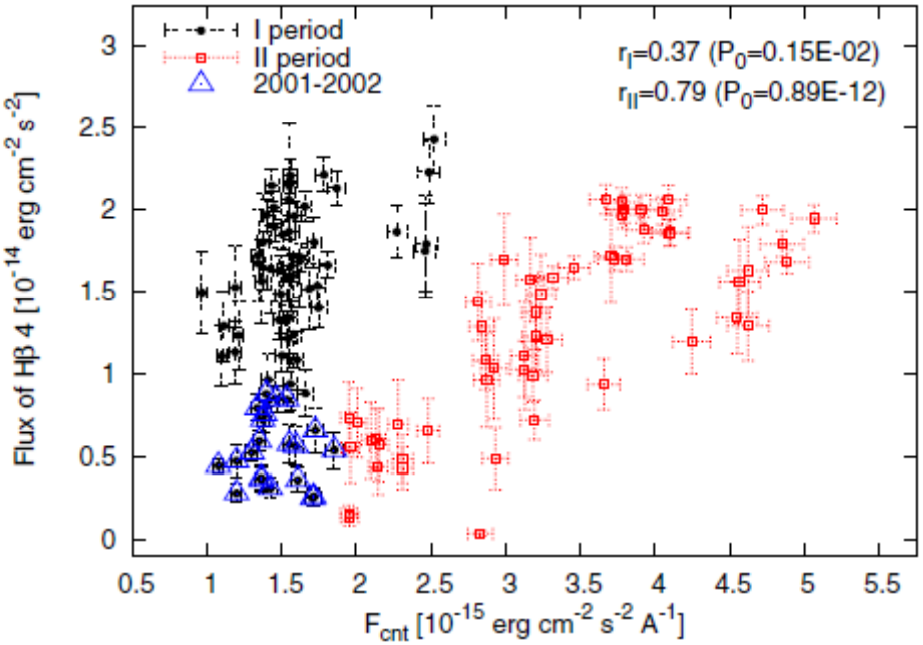
- blue and red wings of Hβ ↔ segments -4 and +4



- Period I and II: different response of line wings to the continuum variations

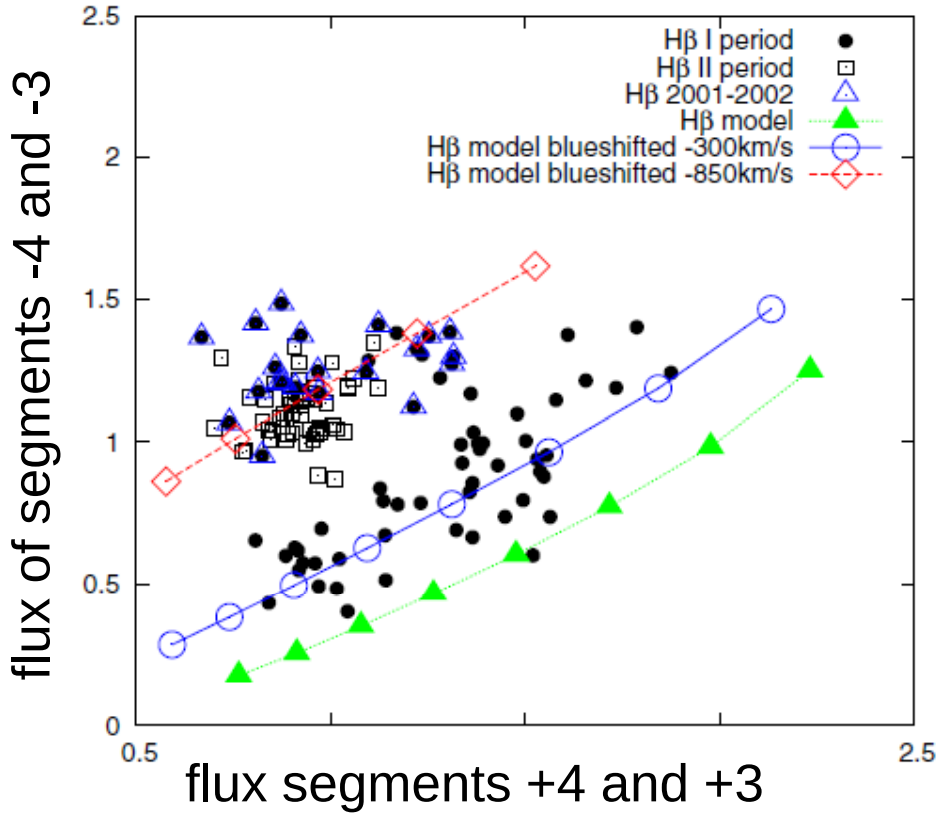
Popović et al. 2011, A&A, 528,130

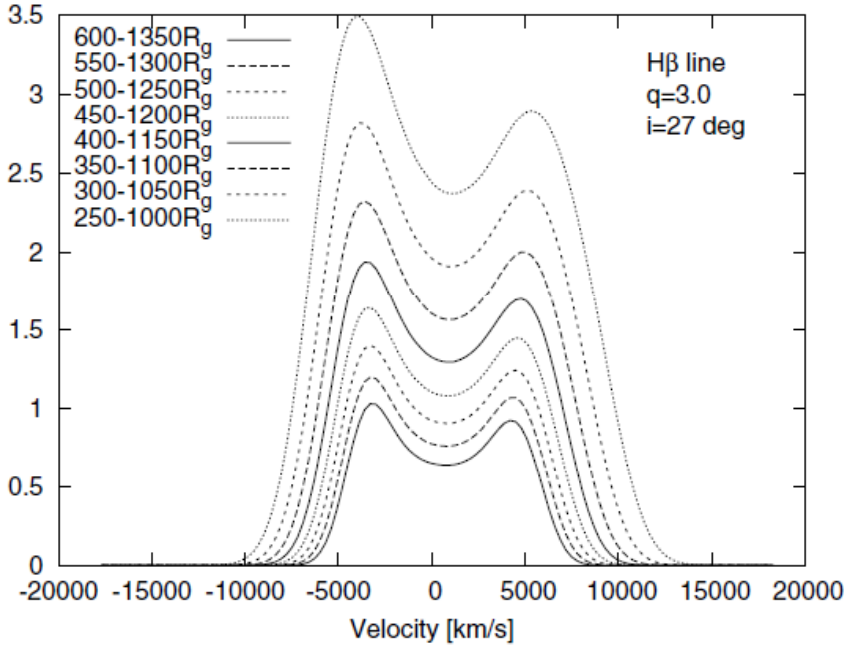




3C390.3 – MODELS

- part of the disc that is emitting lines is shifting along the radius





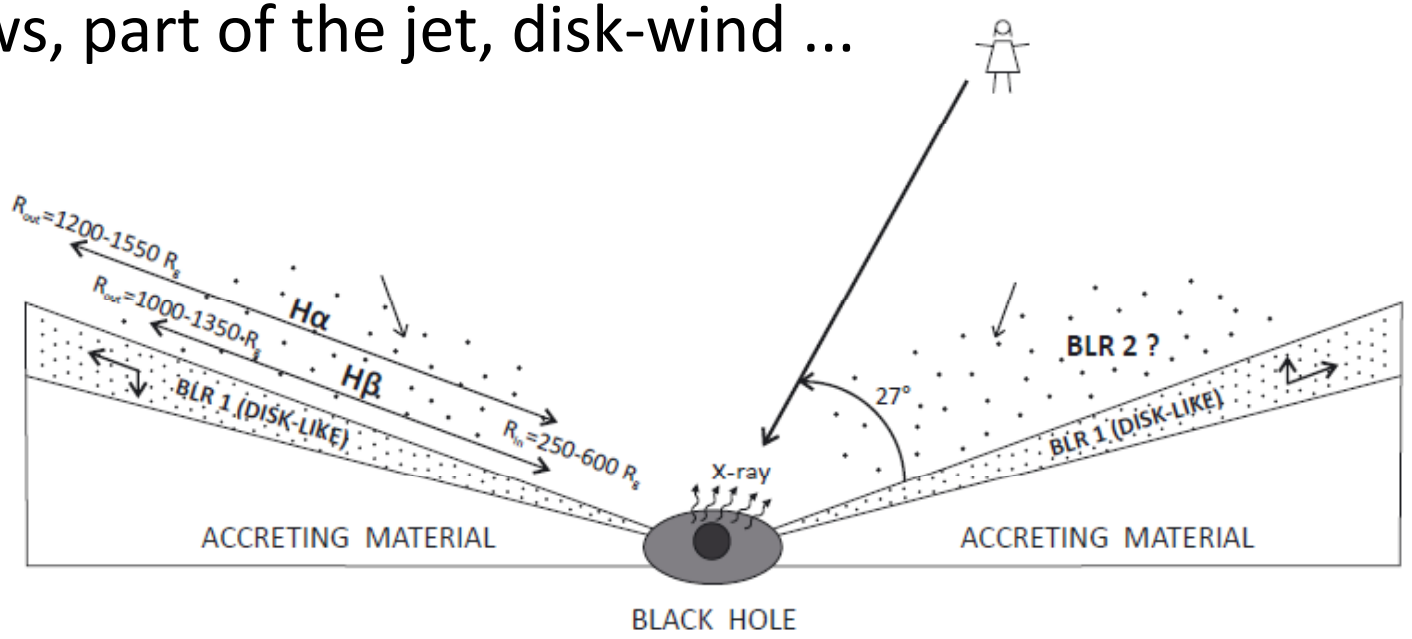
- models vs. observations
- Period I: the change can be explained with the change of the disk position with respect to the BH
- Period II (when burst starts): disc position is fixed

Popović, Shapovalova, Ilić, Kovačević et al. 2011, A&A, 528,130

3C390.3 – TWO-COMPONENT BLR

- disk-like BLR1 = optically thick accretion material, where the ionization from the central source can photoionize only the thin layer of gas above(below) the thick disk – this region follows the kinematics of the disk
  - line parameters depends on the size and position of the region with respect to the black hole in the center (variation of R_{inn} & R_{out})

- BLR2? – outflows, part of the jet, disk-wind ...



CONCLUSIONS

- the broad line region is complex!
- different components: disk, outflows...
- contribution of other mechanisms (apart from photoionization) to line formation $\Rightarrow$ reverberation method should be used with cautions for M_{BH} estimates
- possible quasi periodic oscillations like in case of stellar black holes
- possible disk perturbation: shock waves, fragmented spiral waves in the disk

Thank you!