Long-term Optical Variability of AGN: Exploring the Physics of the BLR

Dragana Ilić, **Luka Popović**, Alla Shapovalova*,
Andjelka Kovačević, Vahram Chavushyan, Alexander Burenkov,
Saša Simić, Nemanja Rakić, **Wolfram Kollatschny**

University of Belgrade, Astronomical Observatory Belgrade,
Special Astrophysical Observatory, INAOE, University of Goettingen

Our long-term campaign

(1941 – 2019)

- PIs: **Alla Shapovalova (Russia)**
  Vahram Chavushyan (Mexico)
- 6m + 1m telescopes - SAO RAS (Russia)
- 2.1m telescope - Guillermo Haro Observatory (Mexico)
- 2.1m telescope - Observatorio Astronómico Nacional, San Pedro Martir (Mexico)
- 3.5m + 2.2m telescopes – Calar Alto Observatory (Spain) – archival data of W.Kollatschny

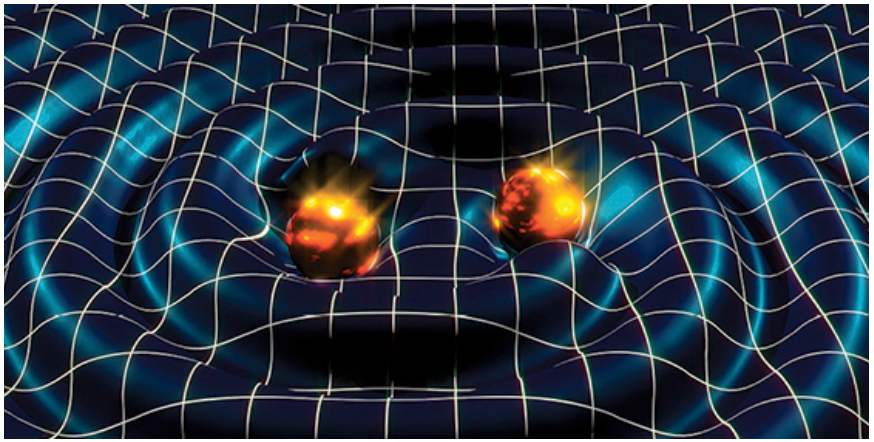
*long=decades

Importance of AGN spectral monitoring

- inner regions difficult to resolve with current optical telescopes (except w/GRAVITY, Sturm+2018)
  ➔ **spectroscopy still important tool**
- but, we can resolve it in time-domain and with spectro-polarymetry: get the BLR size, kinematics, the BH mass

EHT Collaboration, 2019

- we can search for periodicities or quasi-periodicities in AGNs, to identify supermassive binaries
  ➔ synergy with gravitational wave astronomy



What is a Broad Line Region?

→ clumpy, photoionized by the continuum coming from the accretion disk

→ probably disk-like, following Keplerian motion

→ more similar to stellar atmospheres than to the photoionized nebulae

- **physics and geometry** not known, e.g.
  - → what is the BLR temperature and density? (e.g.Ilic+2012)
  - → is it virialized to the supermassive black hole? (e.g. Popovic+2019)
  - → do we have outflows, inflows? (e.g. Wang+2017)
  - → what is the inclination? (e.g. Afanasiev+2019)

BLR gas:

$T_e \sim 10^4$ K

$N_e \sim 10^8$-10^{14} cm^{-3}

Our sample: different type 1 AGNs

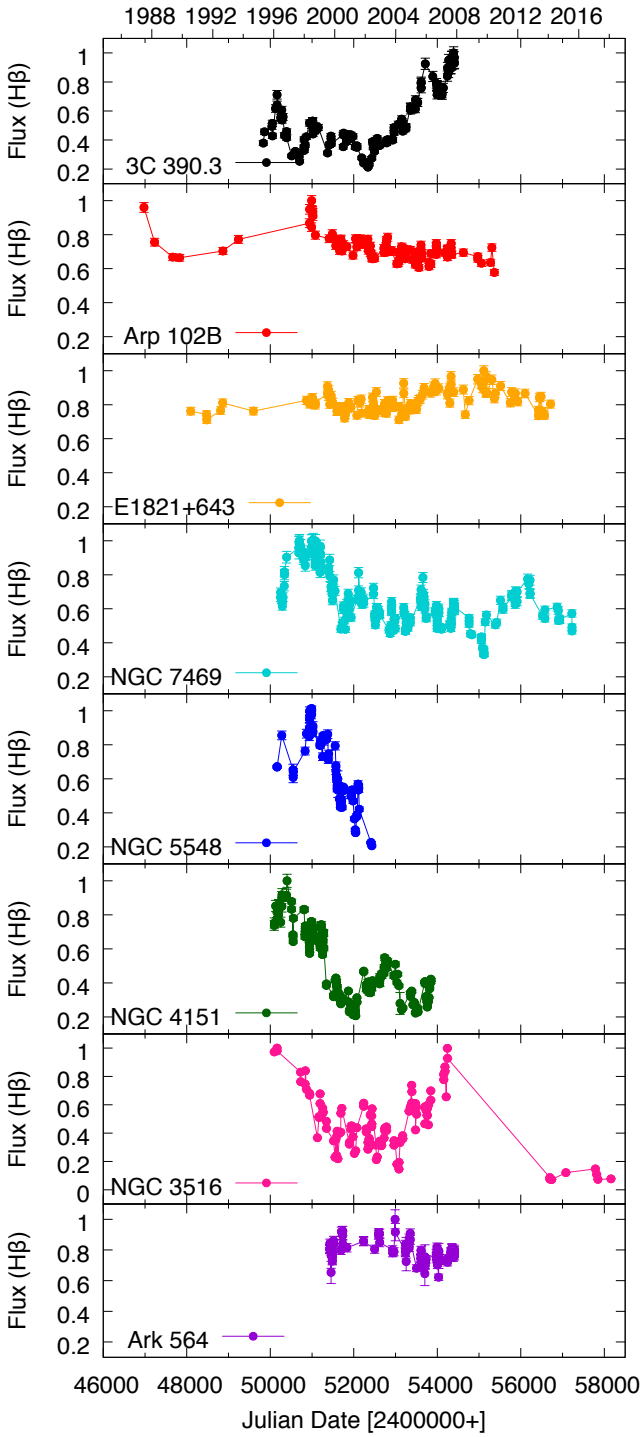
• **Seyfert 1s:**	**Main papers:**
NGC 5548 – 9 yrs	(Shapovalova+ 2004, Ilić 2007, Popović+ 2008)
NGC 4151 – 11 yrs	(Shapovalova+ 2008, 2010a, Ilić+ 2010)
NGC 7469 – 20 yrs	(Shapovalova+ 2017)
NGC 3516 – 21 yrs	(Shapovalova+2019)
• **Narrow Line Seyfert 1:**	
Ark 564 – 11 yrs	(Shapovalova+ 2011, Shapovalova+ 2012)
• **Double Peaked Line AGNs (DPLs):**	
3C 390.3 – 13 yrs	(Shapovalova+ 2001, 2010b, Popović+ 2011)
Arp 102B – 12 yrs	(Shapovalova+2013, Popović+ 2014)
• **High luminosity quasar**:	
E1821+643 – 25 yrs	(Shapovalova+2016, Kovačević+2017)

...and many other papers based on these data sets: Jovanović+ 2010, Bon+ 2012, Kovačević+ 2014, Ilić+2015, Kovačević+ 2015, Rakić+ 2017, Ilić+2017, Bon+ 2016, Kovačević+2018 ...

Summary of the results

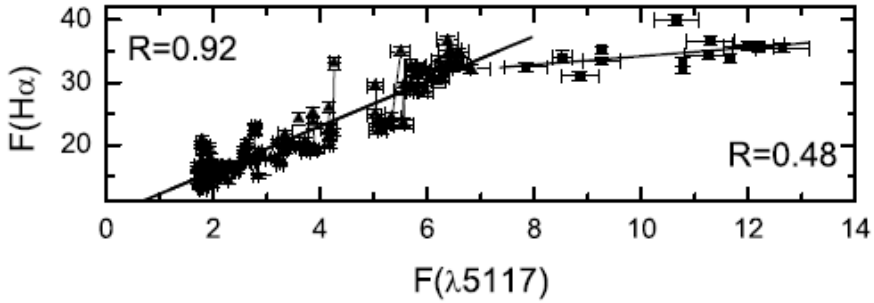
- determined BLR size and SMBH mass in 8 different type 1 AGN
- your BLR is more likely complex

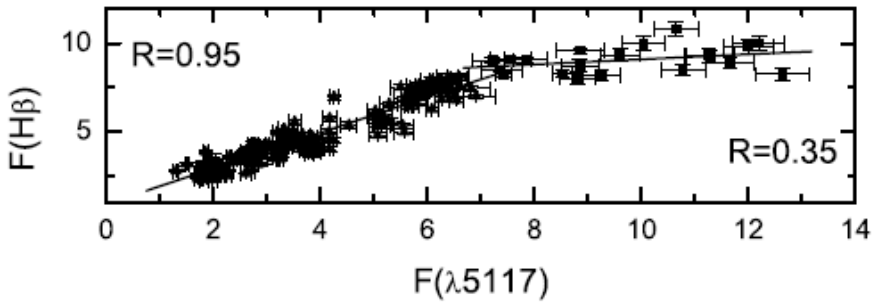
- some highlights of **long-term** monitoring:
  - different oscillations in light curves of NGC 4151, NGC 5548 (Andjelka Kovačević's talk)
  - different dynamics in 2 double-peaked line AGN: 3C390.3, Arp102b
  - discovered (confirmed) a changing-look AGN: NGC 3516

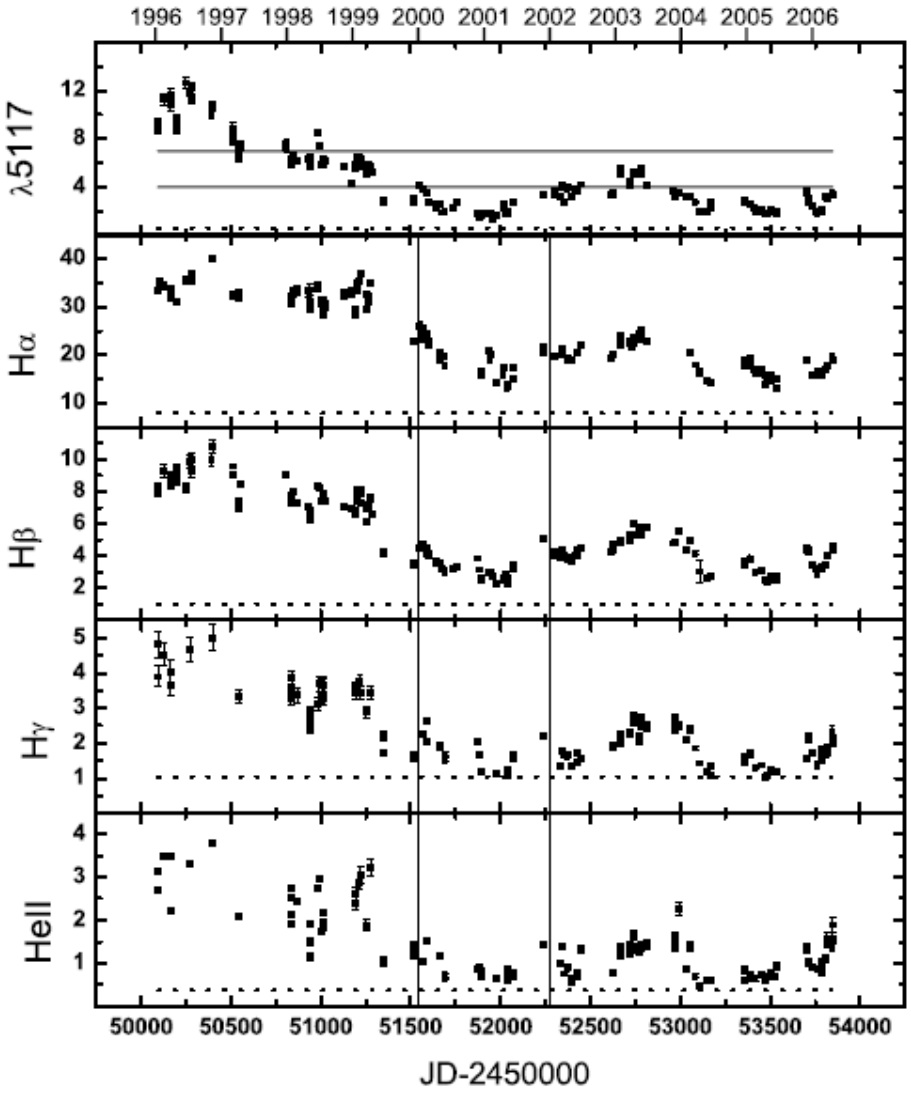


NGC 4151

- best known Seyfert 1
- data from 11 years
- strange behavior of the BLR:
  - lines saturate for high continuum
  - contribution of the non-ionizing continuum from the BLR



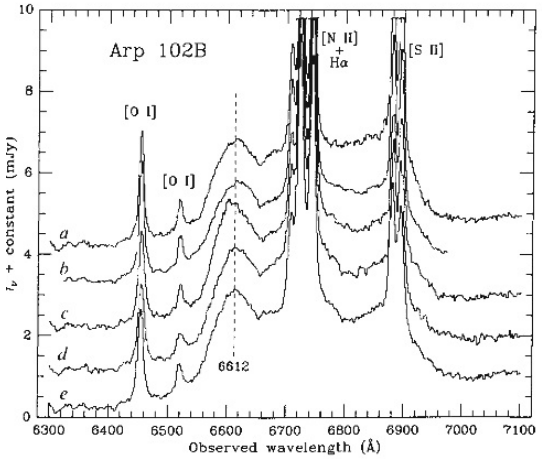




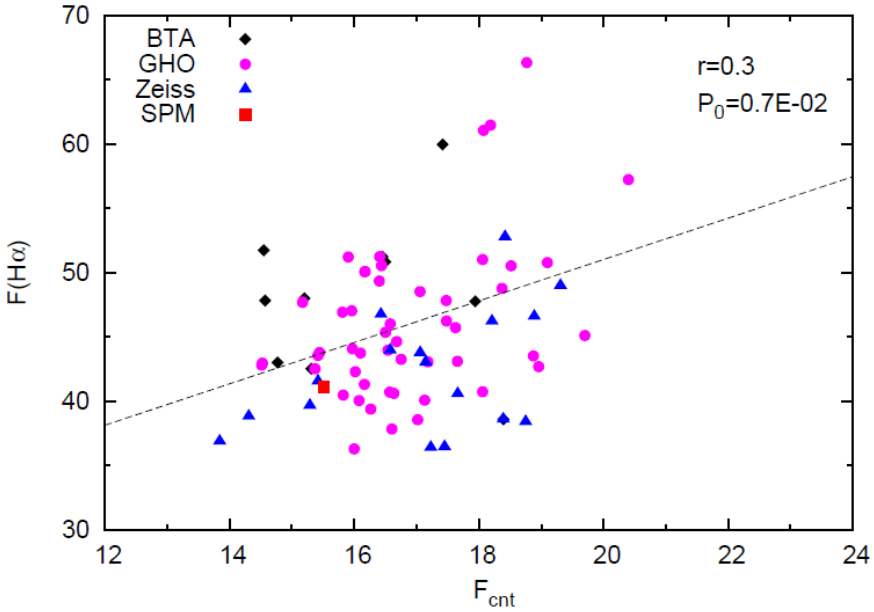
Shapovalova et al. 2008,
Shapovalova et al. 2010a

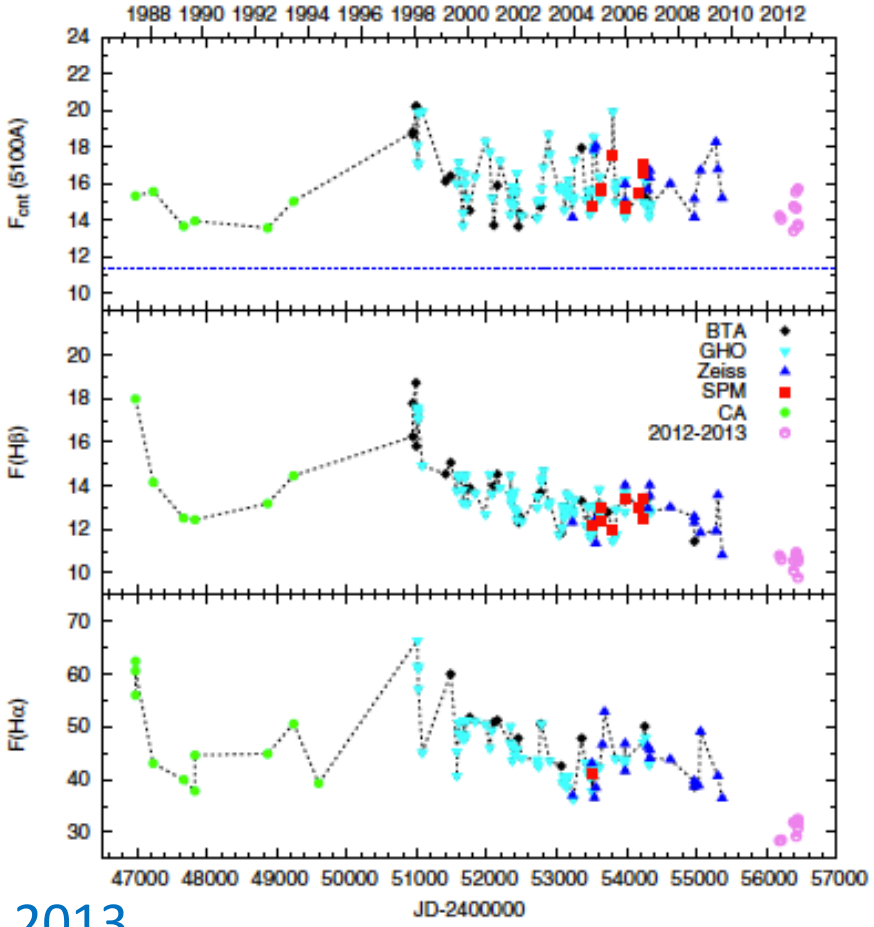
Arp 102B

Halpern & Filippenko 1991



- prototype of double-peaked broad emission lines (Hα and Hβ)
- 12 years of data
- week correlation between the line and continuum flux



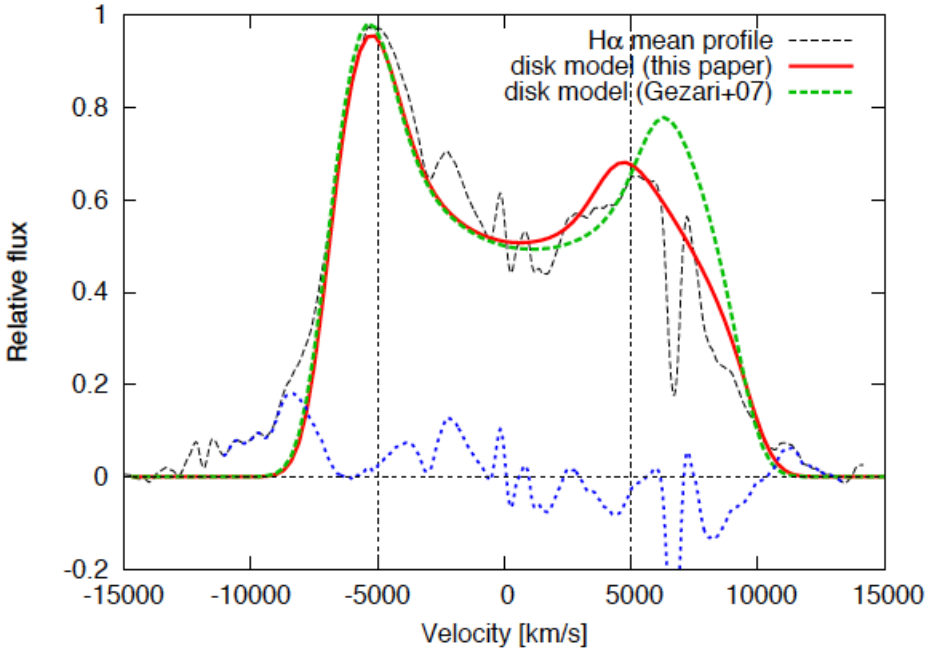


Shapovalova et al. 2013

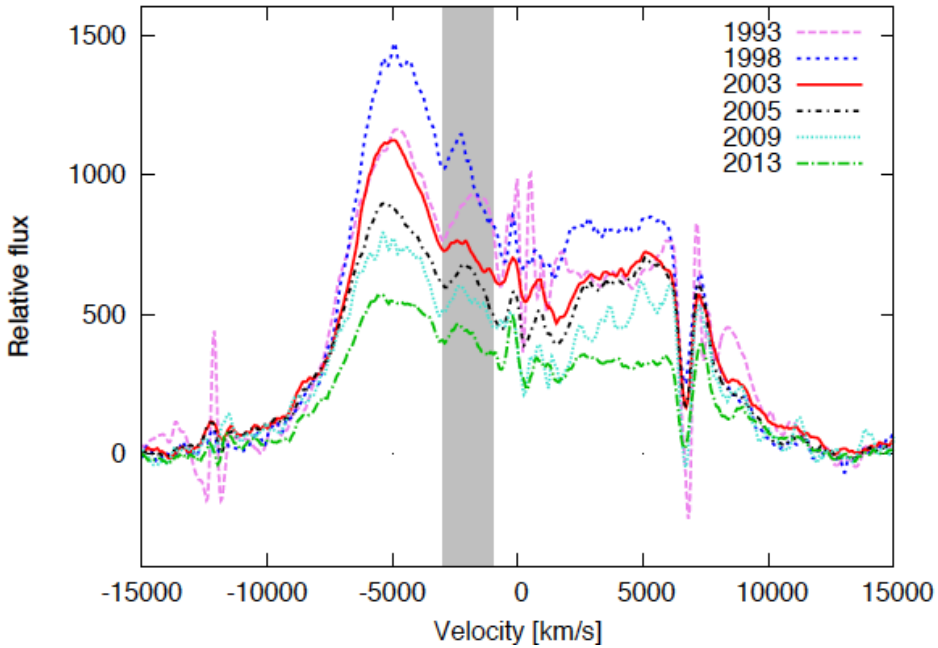
Arp 102B: is there an accretion disk seen in broad lines?

- large distance between the peaks (~ 11,000 km s^{-1}) indicates a fast rotating disk, that is probably close to the black hole

Left - the mean normalized Hα profile fitted with the disk model



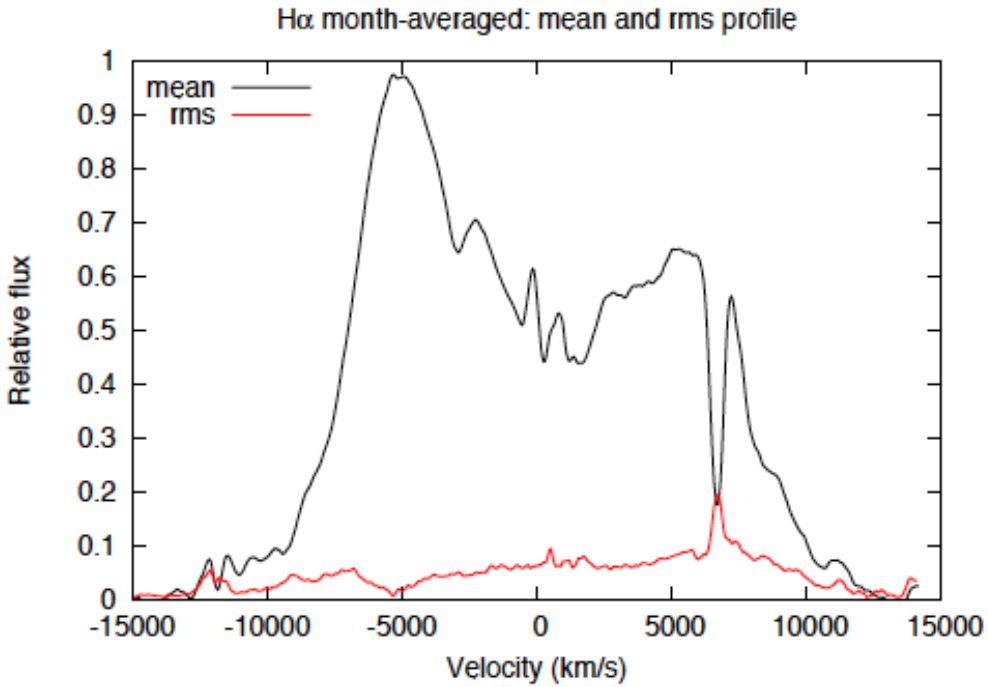
Right – bump in Hα profile at ~-2000km/s (an outflow?) during higher activity state



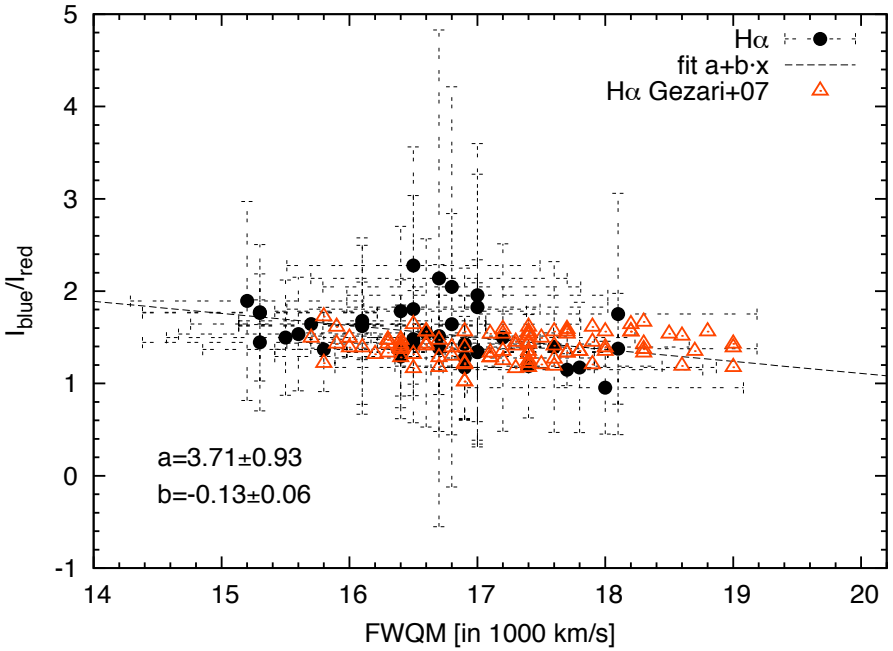
Popović, Shapovalova, Ilić, et al. 2014

Arp 102B: is there an accretion disk seen in broad lines?

- double-peaked line: disk models gives size of ~500Rg, but there is no big change in the line profile
- a stable disk?



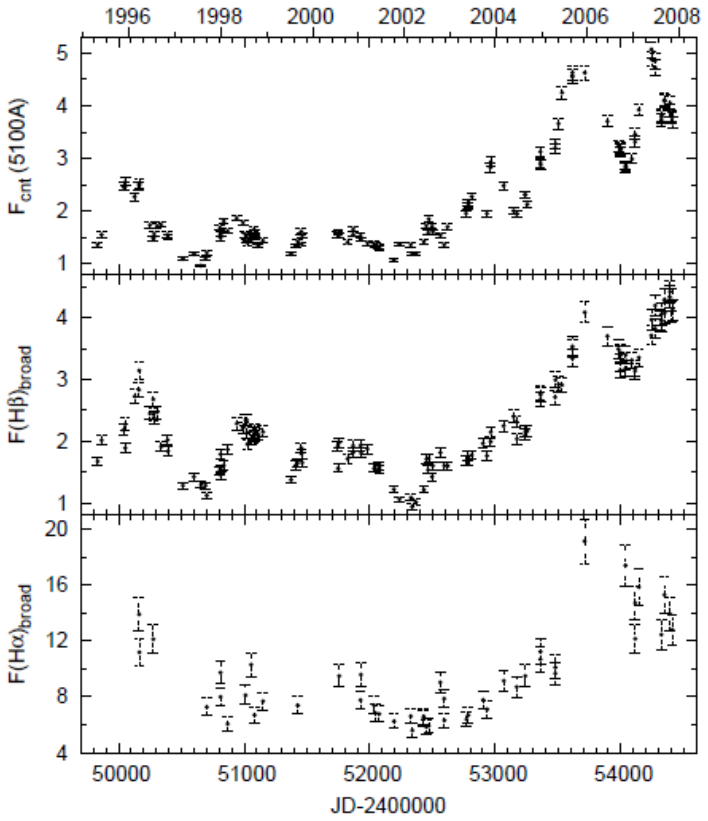
- weak anticorrelation btwn. blue-to-red peak vs. FWQM
- disk models suggest the opposite

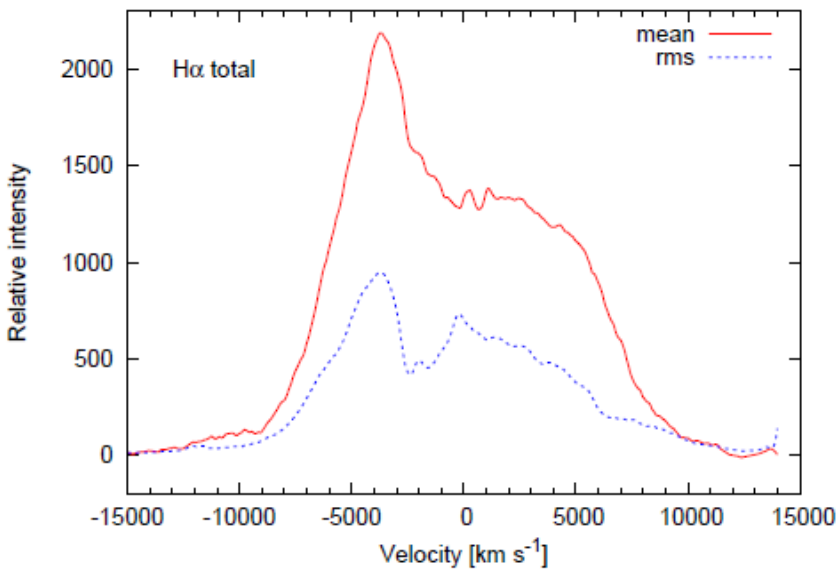


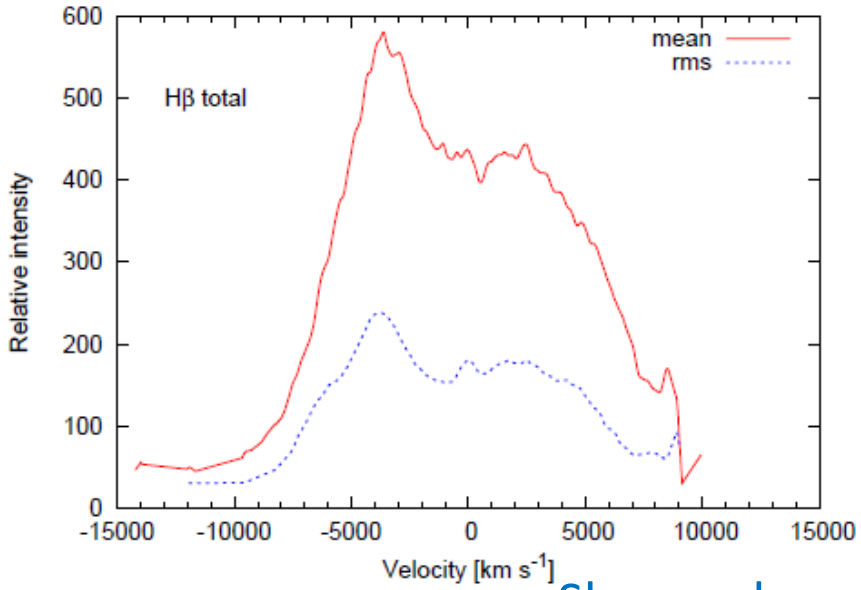
Popović, Shapovalova, Ilić, et al. 2014

3c390.3

- double-peaked broad line
  (Eracleous & Halpern 1994)
- 13 years of data
- stratified BLR (Hα ~ 120 l.d. Hβ ~ 95 l.d.)
- strongly variable line profiles ⇒ many different complex BLR models suggested: binary, disc precession, disk perturbation, etc.



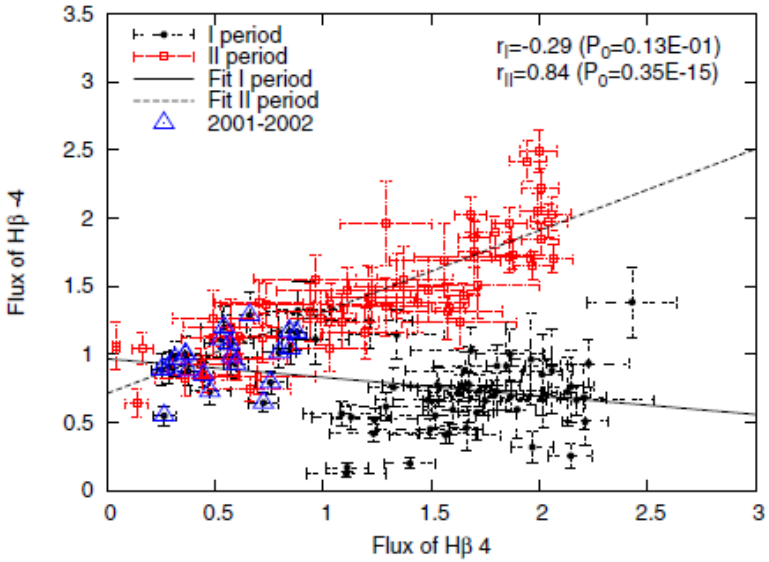




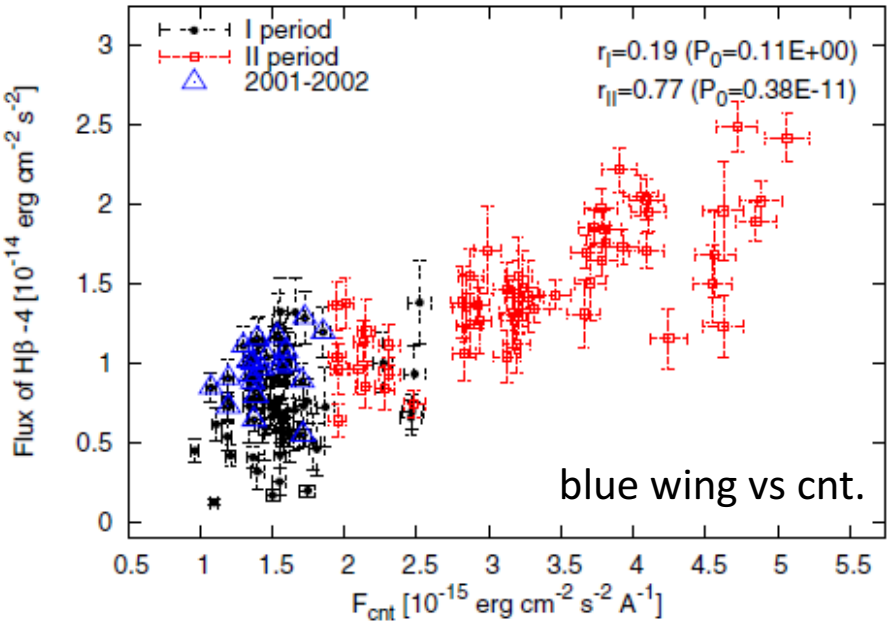
Shapovalova et al. 2010

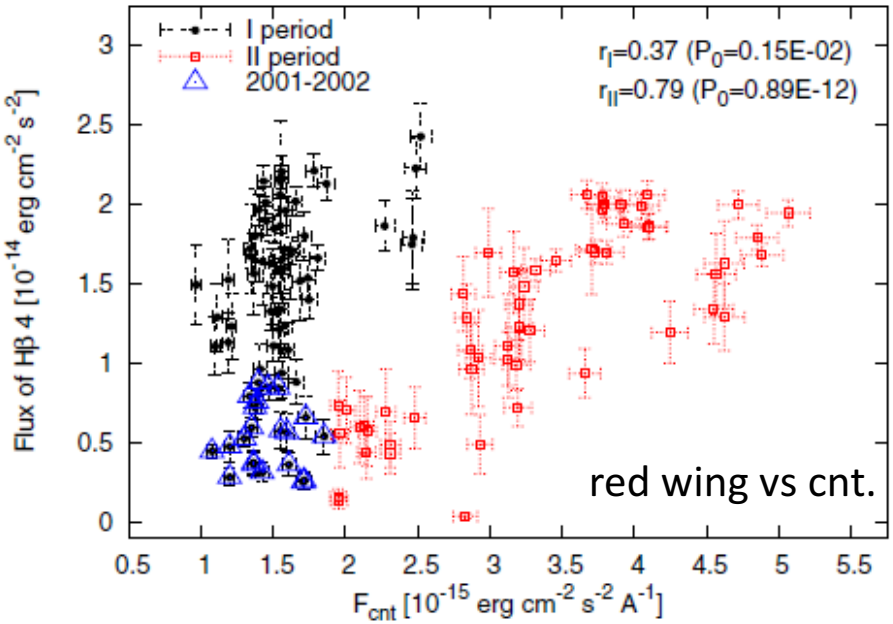
3c390.3 – Hβ line

- blue and red wings of Hβ ↔ segments -4 and +4
- Period I (**black**) and II (**red**): different response of line wings to the continuum variations



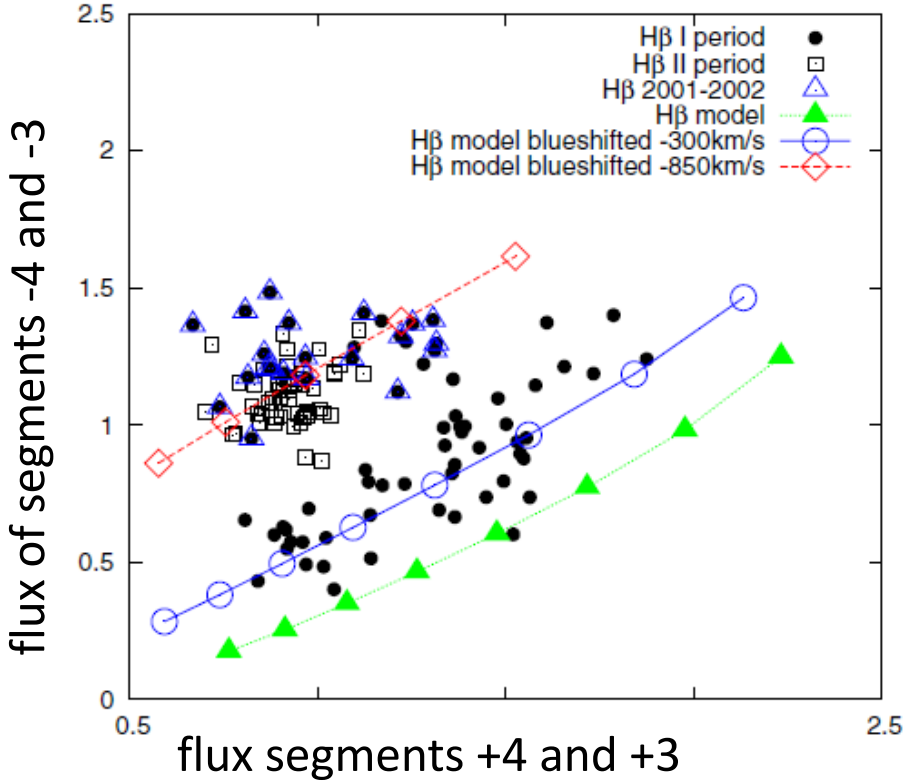
Popović, Shapovalova, Ilić, et al. 2011, A&A, 528,130



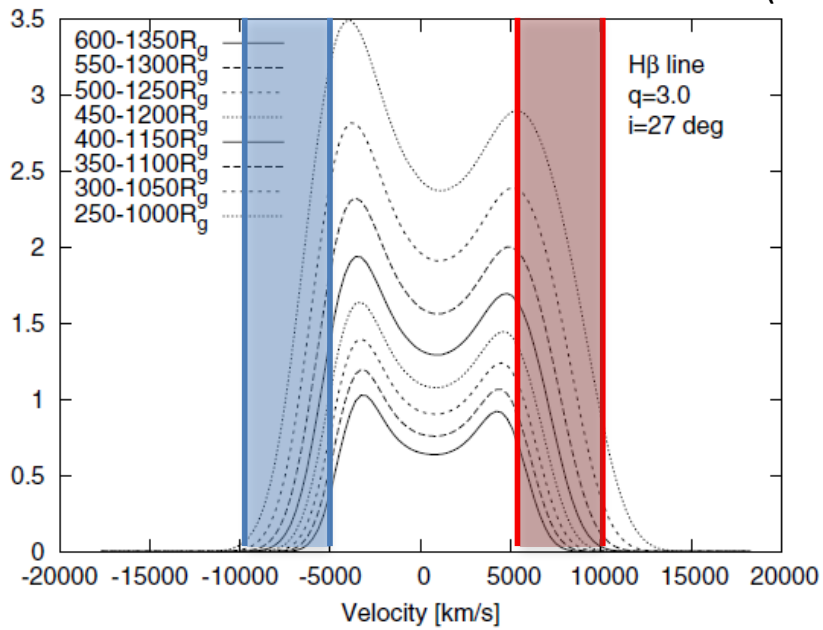


3c390.3 – models

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



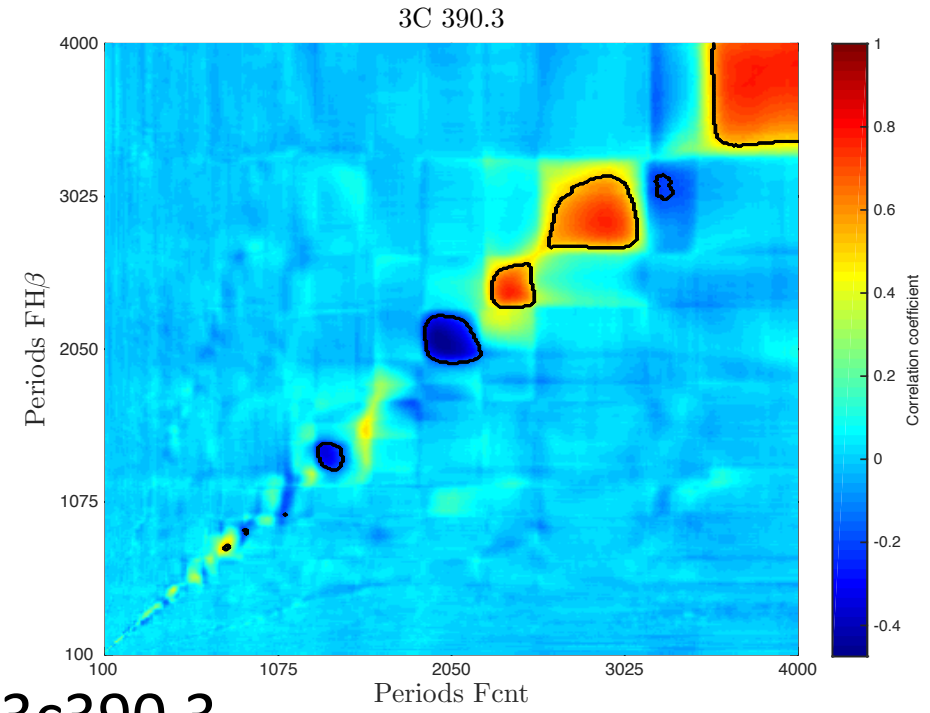
Disk model of Chen et al. (1989)



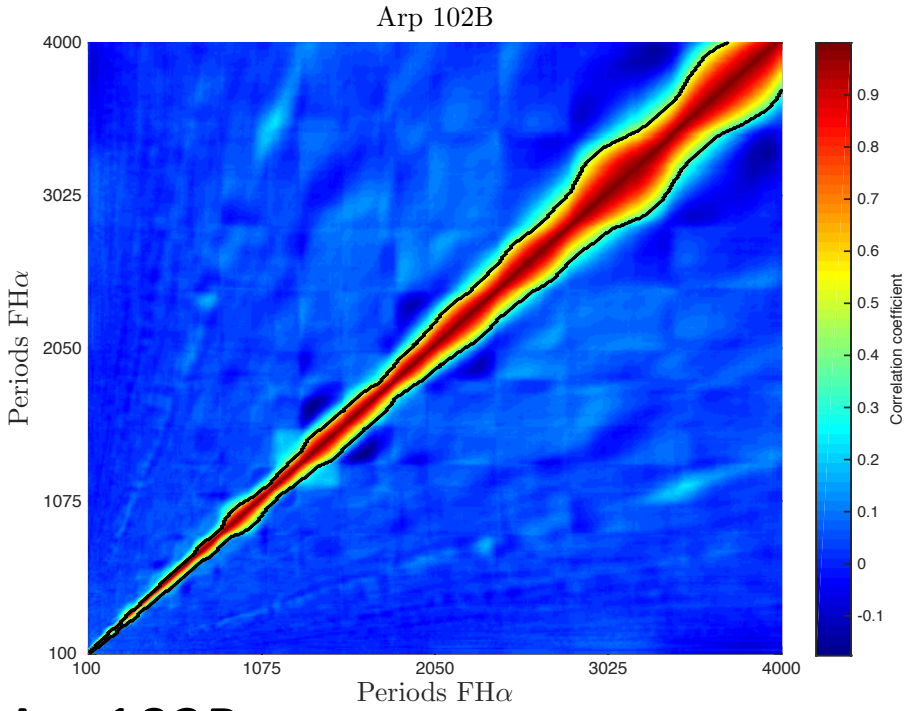
- models vs. observations
- **Period I**: the change can be explained with the change of the line-emitting disk radius
- **Period II** (when burst starts): line-emitting disc radius is fixed

Popović, Shapovalova, Ilić, et al. 2011

- new method to detect oscillatory patterns in long-term light curves (talk of A. Kovačević)



3c390.3



Arp102B

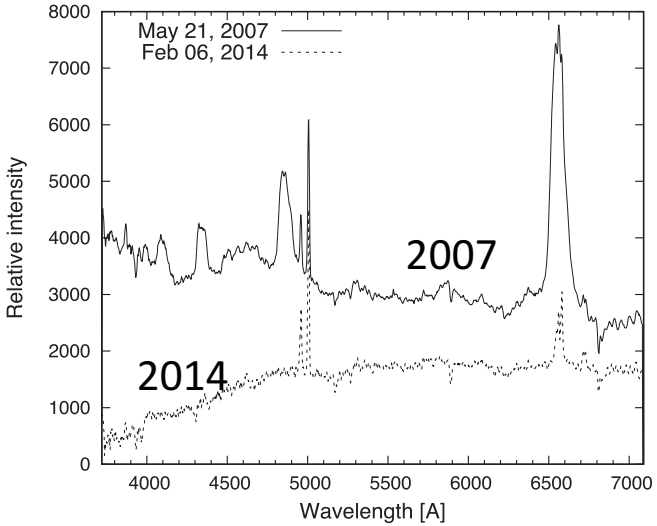
- Both are double-peaked line emitters
- The underlying topology of their oscillations mechanisms is different, suggesting different physical backgrounds

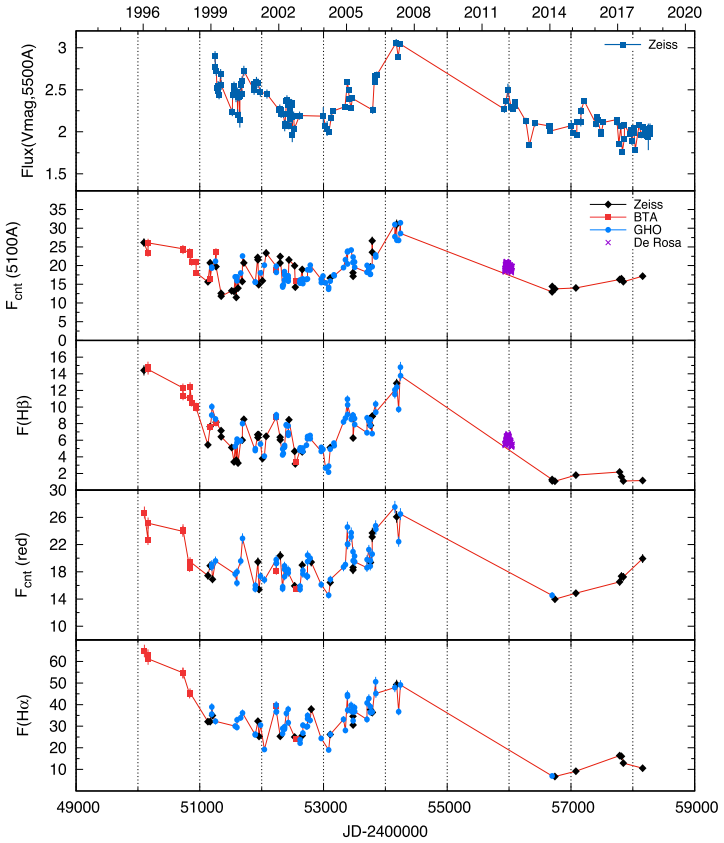
Kovačević et al. 2018, 2019

NGC 3516

- 22 years of data
- extreme variability: disappearance of broad lines in 2014

- large gap in light curves → used data until 2007
- applied Gaussian processes to get simulated light curves
- time-delays: 15-17 days for both Hα and Hβ





Shapovalova et al. 2019

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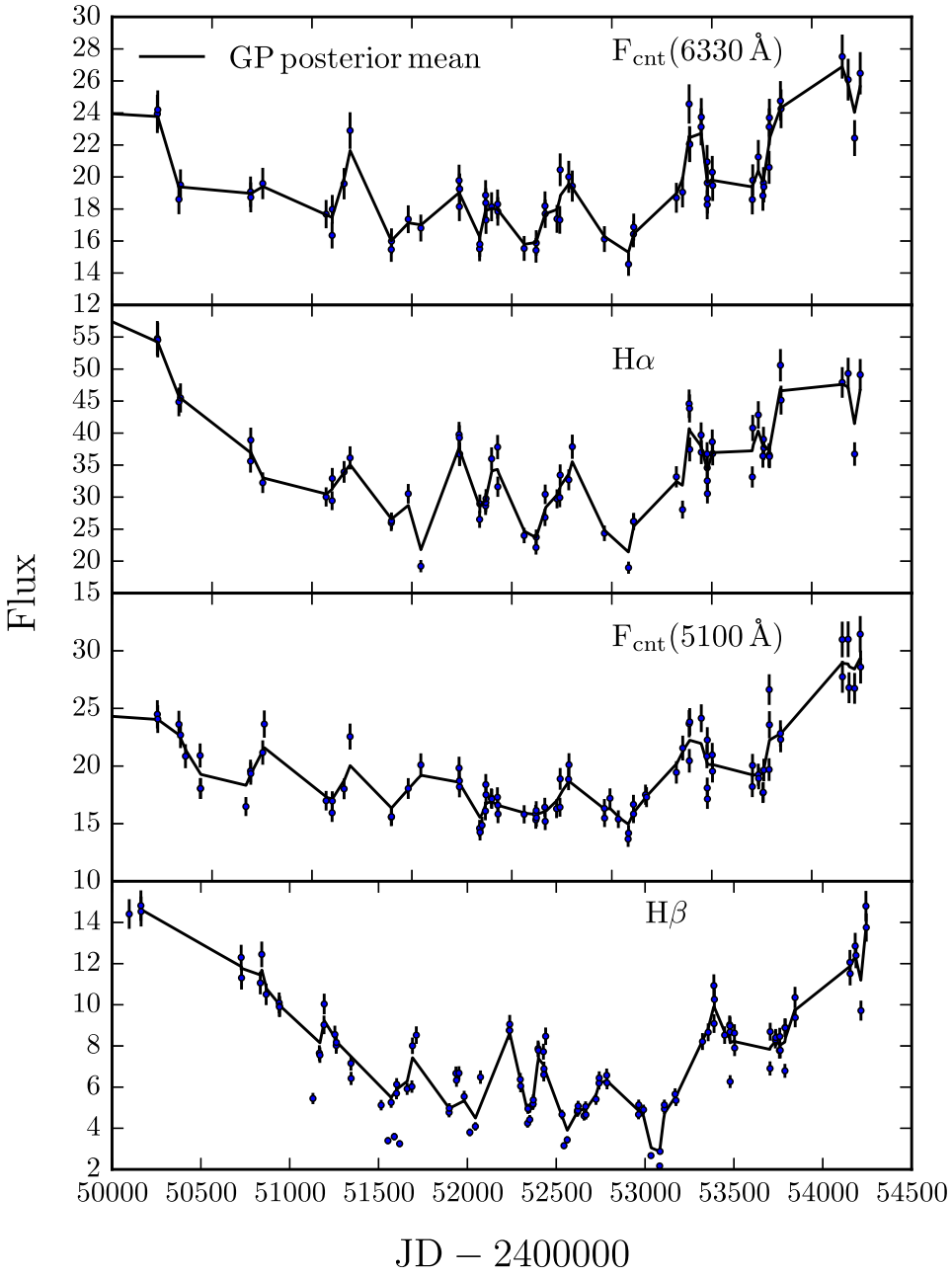
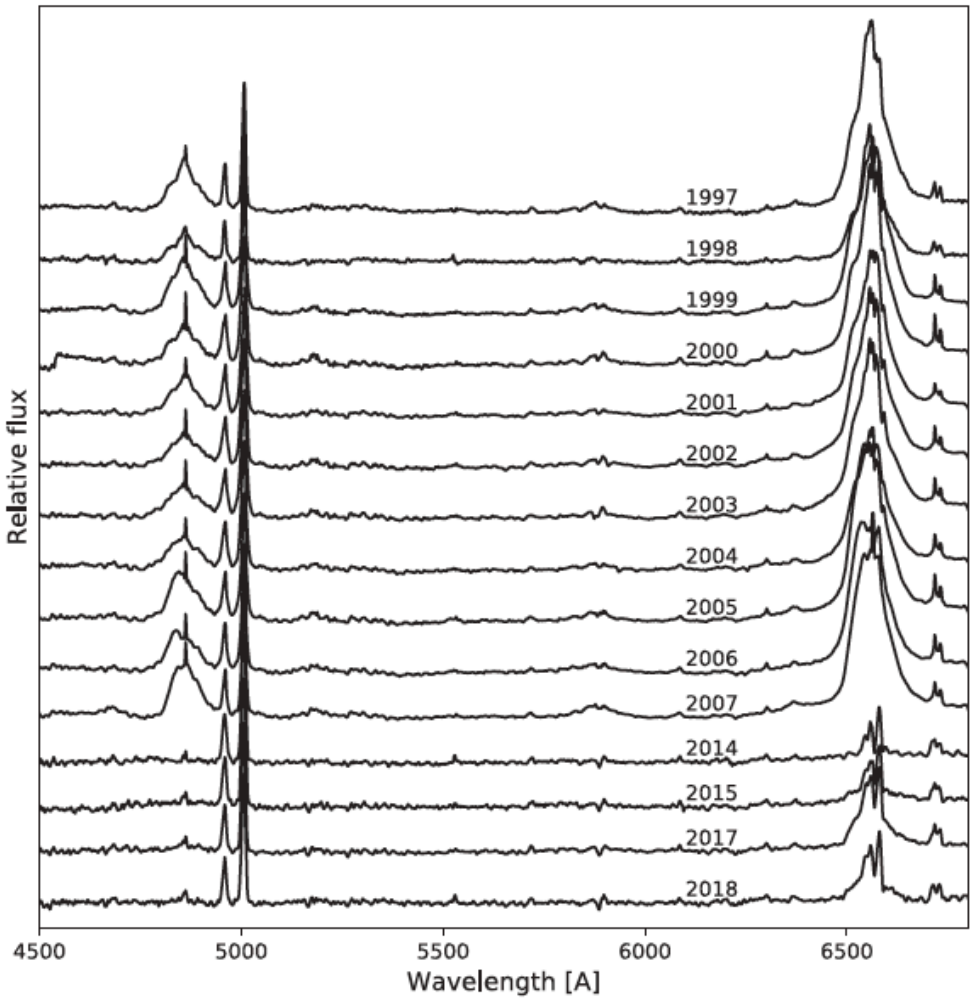


Shapovalova et al. 2019

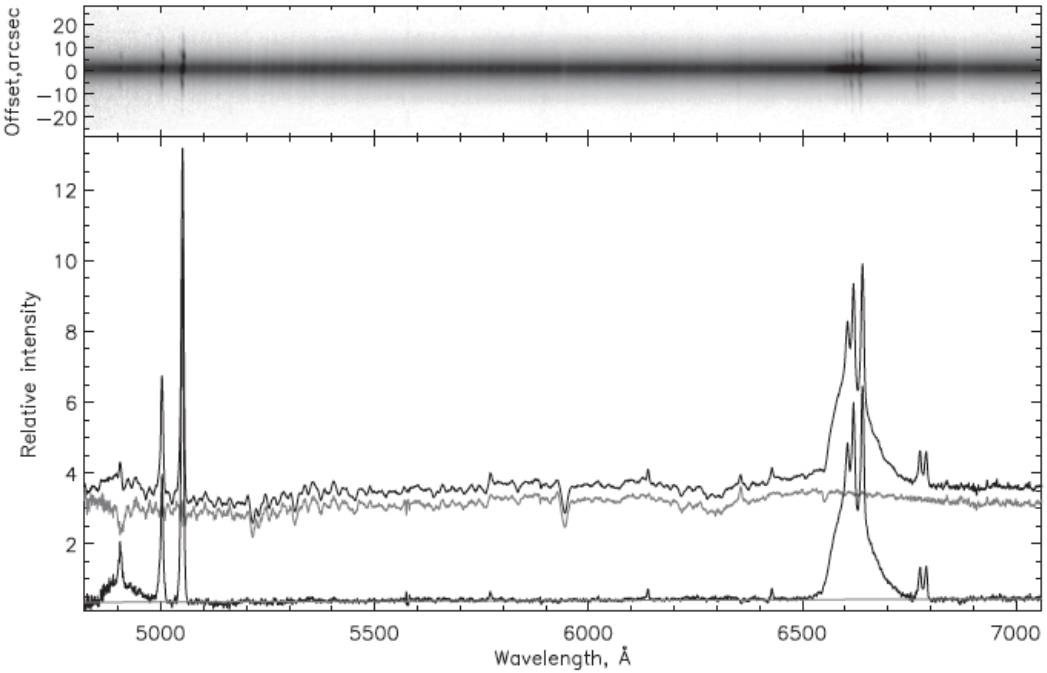
NGC 3516: changing-look AGN

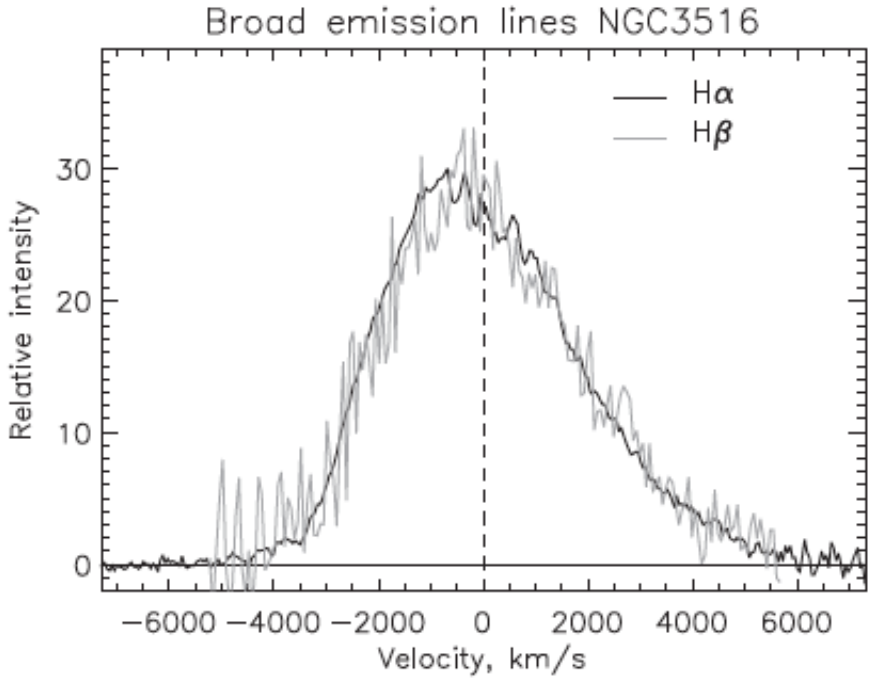
- extreme variability:
  - appearance or disappearance of broad lines within few years
- confirmed: changing-look AGN
- what is the cause?
  - variable accretion rate
  - variable obscuration
  - tidal disruption event
  - hot topic e.g. LAMOST has found 21 new CL AGN (Yang et al. 2018)
- why are important?
  - perfect cases to study the connection btw. AGN and its host galaxy
  - important to understand AGN evolution



Shapovalova et al. 2019

6m BTA observation w/SCORPIO in 2017





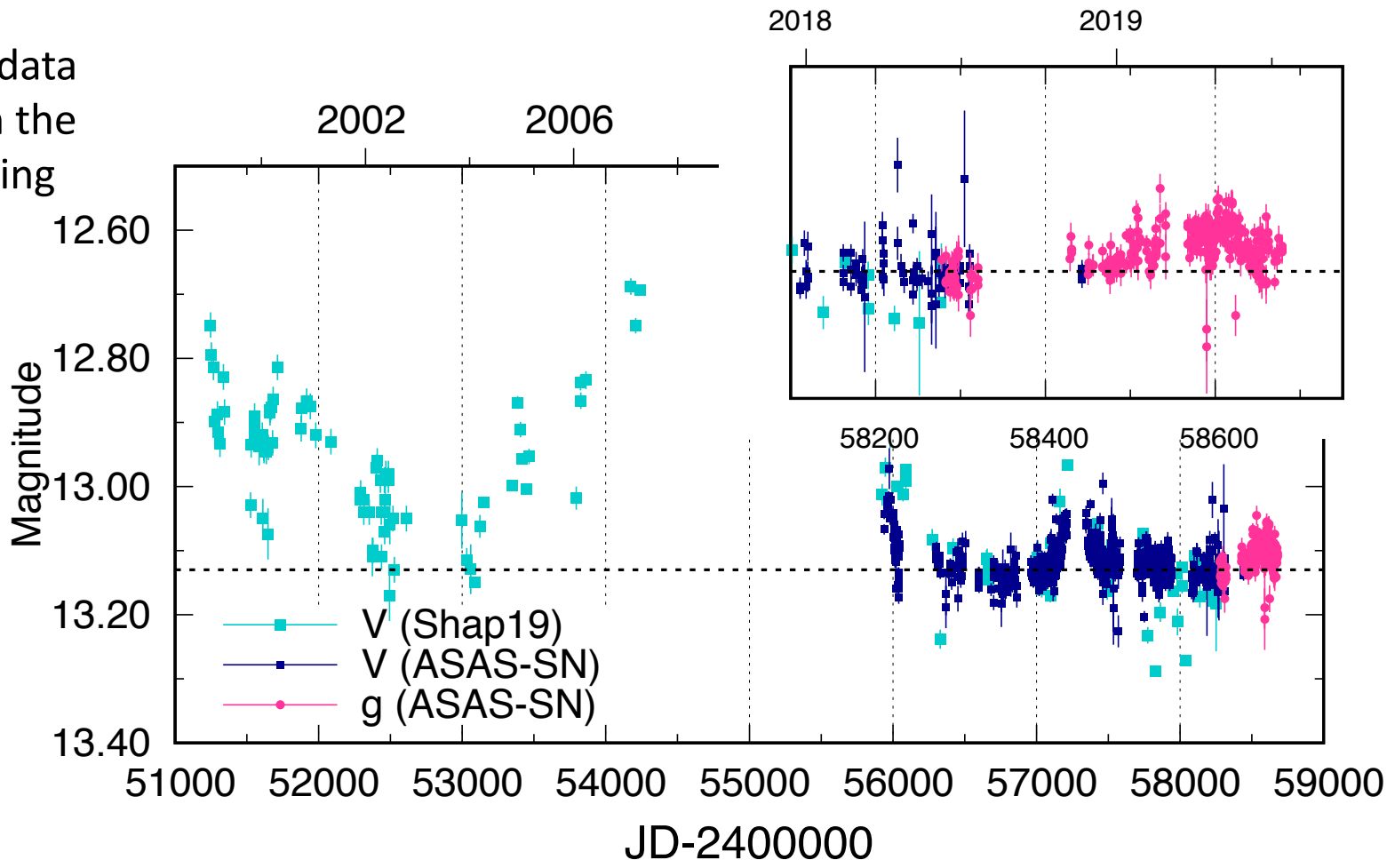
- in 2017: the object is still in low state, but broad component starts to appear
- subtracted the off-slit spectrum of the host-galaxy

- Hα and Hβ profiles are the same
- blueshift and red asymmetry

Shapovalova et al. 2019

what NGC 3516 is doing today?

our long-term data combined with the ASAS-SN on going survey

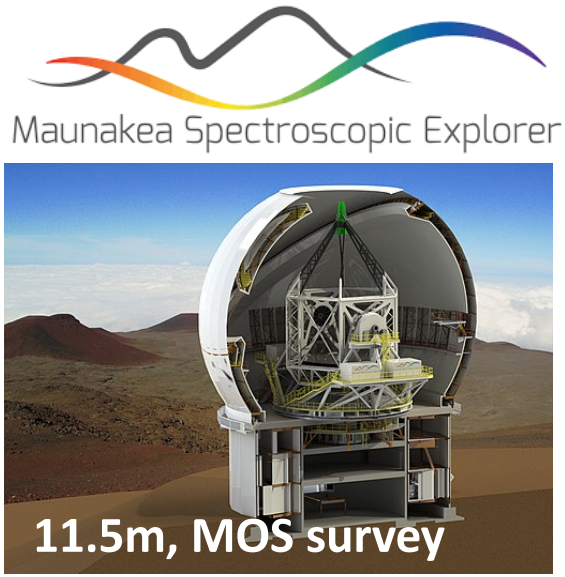


ASAS-SN data (Shappee+ 2014, Kochanek+ 2017)

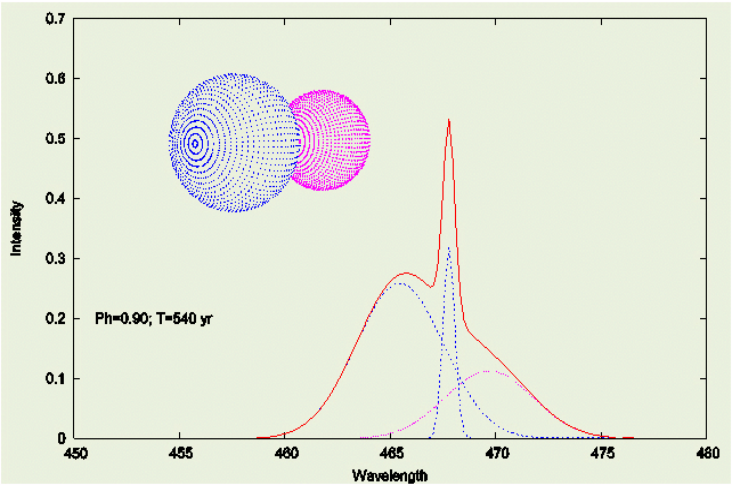
Maunakea Spectroscopic Explorer

- key science case: **reverberation mapping** campaign (~100 visits over 5yrs) of ~5000 quasars up to z~3
  - → NIR band to cover Hβ up to z~2.5
  - → robust estimates of time lags for the largest sample of quasars
  - → **Sarah Gallagher's talk**

(see White paper: Shen et al. 2019)



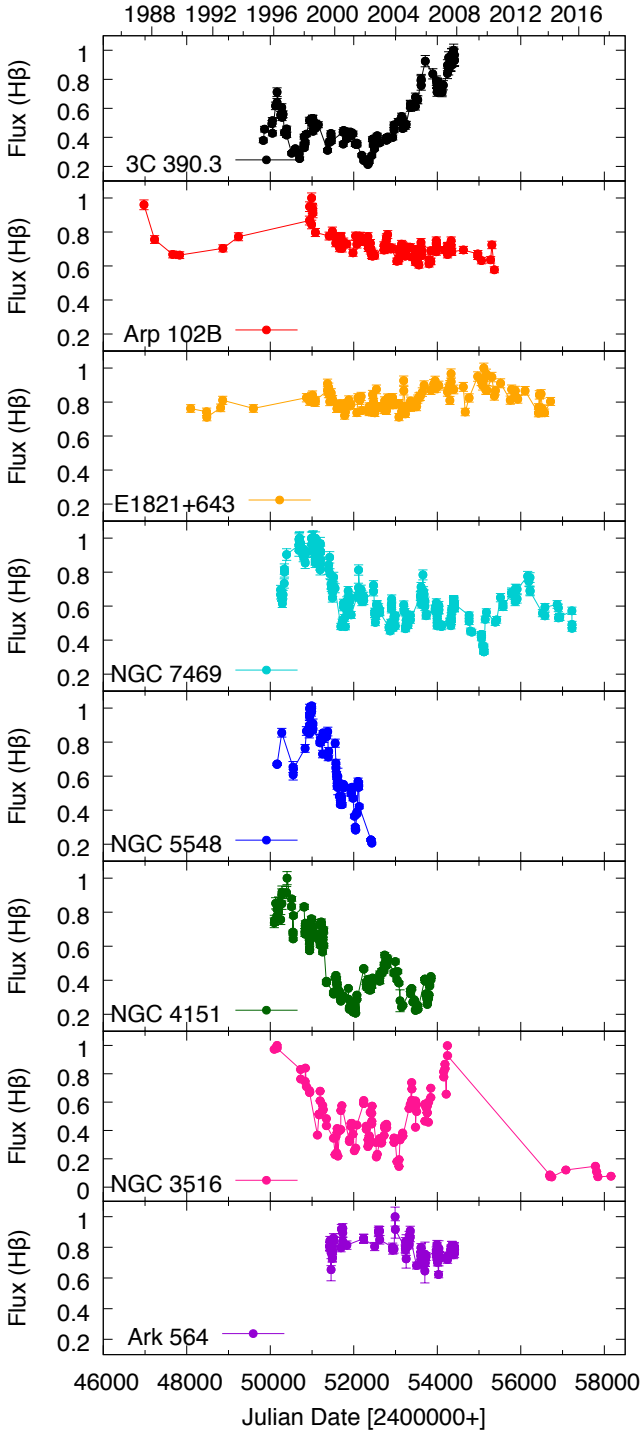
- identify new changing look AGN
  - synergy with other missions
- high-resolution spectroscopy
  - → velocity resolved reverberation mapping
  - → spectroscopically resolve the binary SMBH



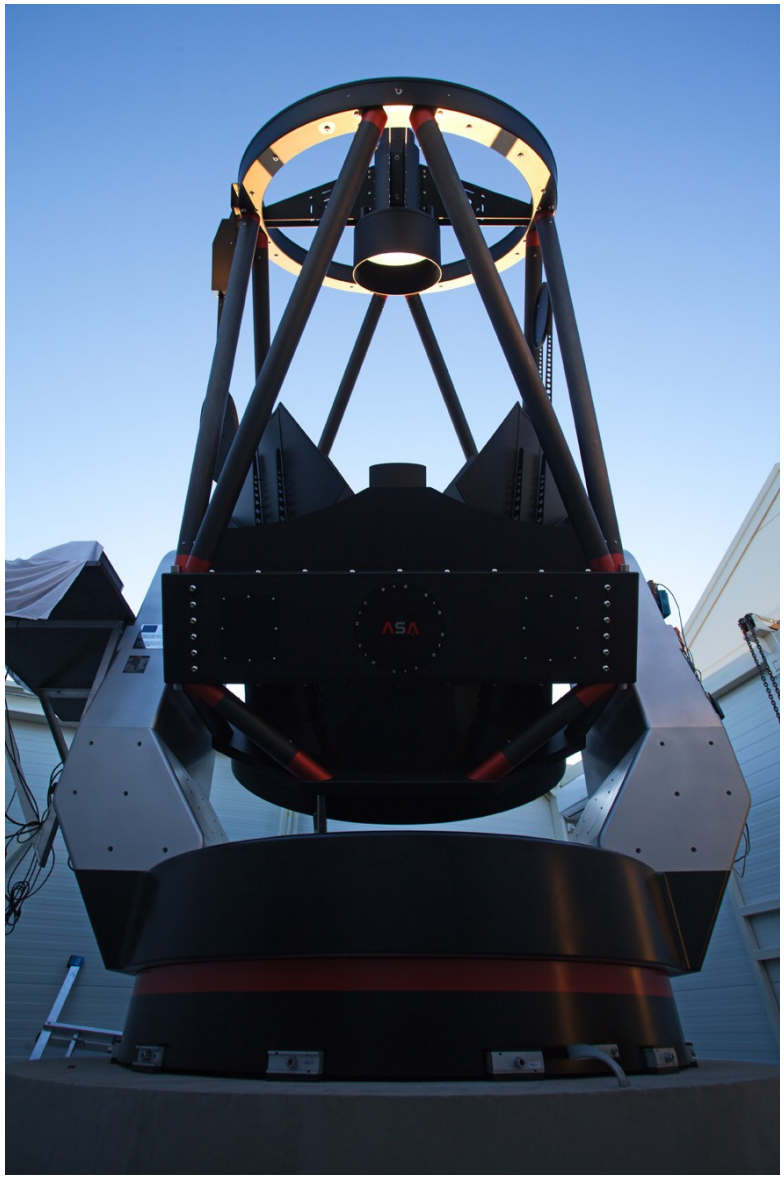
review paper, Popović 2012

Summary

- did the long-term monitoring campaign of different sub-types of type 1 AGN
  - all light curves are online and available
- determined BLR size and SMBH mass
- BLR is a complex region
- **long-term** changes in the light curves
  - hidden periodicities
  - changing-look phenomenon
- long-term monitoring is important



Vidojevica Observatory, Serbia



- Milutin Milankovic Telescope
- brand new
- D=1.4m, F=11.2
- photometry
- plans: spectroscopy, polarimetry
- vidojevica.aob.rs