Long-term monitoring of AGN: past and future

Dragana Ilić & LTRM-team
Faculty of Mathematics, University of Belgrade, Serbia
Astronomical Observatory Belgrade, Serbia
Special Astrophysical Observatory, Russia
INAOE, Mexico
University of Goettingen, Germany
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:

\[ T_e \sim 10^4 \text{ K} \]
\[ N_e \sim 10^8-10^{14} \text{ cm}^{-3} \]
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

• we can search for periodicities or quasi-periodicities in AGNs, to identify supermassive binaries
  ➔ synergy with gravitational wave astronomy
Long-term RM = LTRM

- long-term monitoring programmes of AGNs are crucial for understanding the physical aspects of AGNs (see e.g. Kovacevic et al. 2018 and reference therein)

![Graph showing light curves and time-lags from CCF for NGC 4151](Shapovalova+ 2008)
Our long-term campaign

- **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*
First AGN-GL workshop in 2010
## Our sample: different type 1 AGNs

### Seyfert 1s:
- **NGC 5548** – 9 yrs
- **NGC 4151** – 11 yrs
- **NGC 7469** – 20 yrs
- **NGC 3516** – 21 yrs

**Main papers:**
- (Shapovalova+ 2008, 2010a, Ilić+ 2010)
- (Shapovalova+ 2017)
- (Shapovalova+2019)

### Narrow Line Seyfert 1:
- **Ark 564** – 11 yrs

**Main papers:**
- (Shapovalova+ 2011, Shapovalova+ 2012)

### Double Peaked Line AGNs (DPLs):
- **3C 390.3** – 13 yrs
- **Arp 102B** – 12 yrs

**Main papers:**
- (Shapovalova+ 2001, 2010b, Popović+ 2011)
- (Shapovalova+2013, Popović+ 2014)

### High luminosity quasar:
- **E1821+643** – 25 yrs

**Main papers:**
- (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
## RM results for Hβ line

<table>
<thead>
<tr>
<th>object</th>
<th>period [years]</th>
<th>tau [days]</th>
<th>method</th>
<th>mass [M_{Sun}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 3516</td>
<td>1996-2007</td>
<td>17$^{+5}_{-0}$</td>
<td>GP+ZDCF</td>
<td>4.7x10^7</td>
</tr>
<tr>
<td>NGC 7469</td>
<td>1996-2015</td>
<td>21$^{+7}_{-0}$</td>
<td>GP+ZDCF</td>
<td>1.1x10^7</td>
</tr>
<tr>
<td>NGC 4151</td>
<td>1996-2003</td>
<td>5$^{+28}_{-5}$</td>
<td>ZDCF</td>
<td>1.6x10^8</td>
</tr>
<tr>
<td>NGC 5548</td>
<td>1996–2002</td>
<td>49$^{+19}_{-8}$</td>
<td>ZDCF</td>
<td>2.1x10^9</td>
</tr>
<tr>
<td>Arp102B</td>
<td>1987-2010</td>
<td>15$^{+20}_{-15}$</td>
<td>ZDCF</td>
<td>1.1x10^8</td>
</tr>
<tr>
<td>3c390.3</td>
<td>1995-2007</td>
<td>96$^{+28}_{-47}$</td>
<td>ZDCF</td>
<td>2.1x10^9</td>
</tr>
<tr>
<td>Ark564</td>
<td>1999–2010</td>
<td>4$^{+27}_{-4}$</td>
<td>ZDCF</td>
<td>1.0x10^6</td>
</tr>
<tr>
<td>E1821+643</td>
<td>1990-2014</td>
<td>118$^{+0.1}_{-0}$</td>
<td>GP+ZDCF</td>
<td>2.6x10^9</td>
</tr>
</tbody>
</table>

Future plans of RM campaign

- Facilities?
  - Russia
  - Mexico
  - Italy
  - Serbia

- Strategy?
  - objects
  - dynamics
  - analysis methods
  - ....
Vidojevica Observatory, Serbia

• Milutin Milankovic Telescope
• brand new
• D=1.4m, F=11.2
• photometry
• plans: spectroscopy, polarimetry
• vidojevica.aob.rs
## Objects of the SAO's monitoring programme (1996-2016)

<table>
<thead>
<tr>
<th>IAU Name</th>
<th>Objects</th>
<th>Coordinates</th>
<th>m(b)</th>
<th>M(b)</th>
<th>z</th>
<th>Sy.R.A.(1950)</th>
<th>D(1950)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0645+744</td>
<td>Mkn 6</td>
<td>06 45 43.3 +74 29 07 14 29 -20.41 0.0185 1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1103+728</td>
<td>NGC 3516</td>
<td>11 03 22.8 +72 50 20 12 45 -20.4 0.0088 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1208+396</td>
<td>NGC 4151</td>
<td>12 08 01.1 +39 41 11.13 -19.3 0.0033 1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1415+253</td>
<td>NGC 5548</td>
<td>14 15 43.5 +25 22 01 13.21 -20.9 0.0168 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1717+490</td>
<td>ARP 102-B</td>
<td>17 17 56.3 +49 01 56 14.70 -20.4 0.0256 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1821+643</td>
<td>E1821+643</td>
<td>18 21 41.9 +64 19 18 14.24 -27.1 0.297 QSO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1845+797</td>
<td>3C390.3</td>
<td>18 45 37.6 +79 43 00 15 28 -21.64 0.0556 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2240+294</td>
<td>Akn 564</td>
<td>22 40 18.3 +29 27 47 14.4 -20.9 0.0253 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2300+086</td>
<td>NGC 7469</td>
<td>23 00 44.4 +08 36 16 12.60 -21.63 0.0167 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2316-000</td>
<td>NGC 7603</td>
<td>23 16 22.9 -00 01 47 13.99 -21.46 0.0295 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>