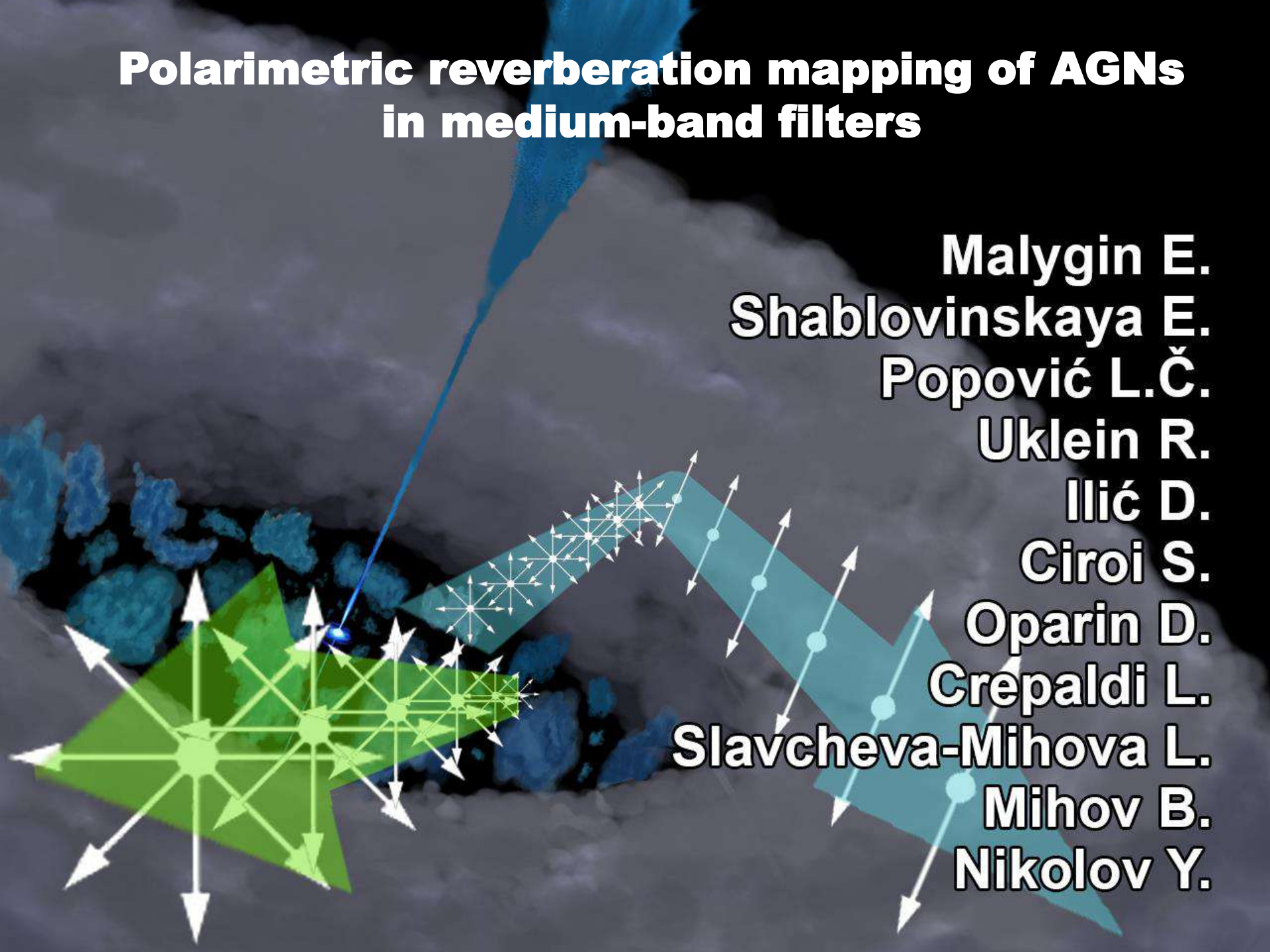
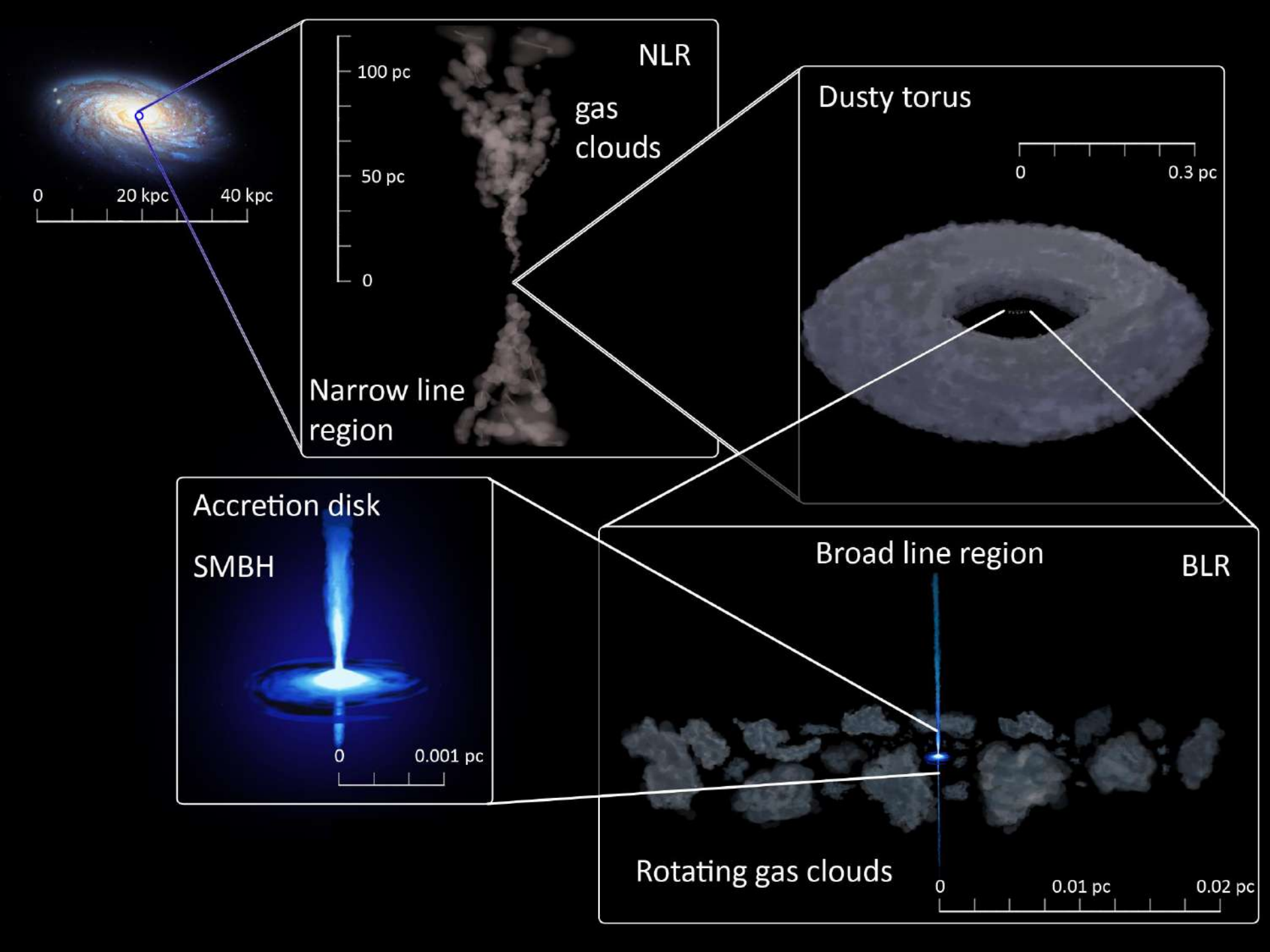
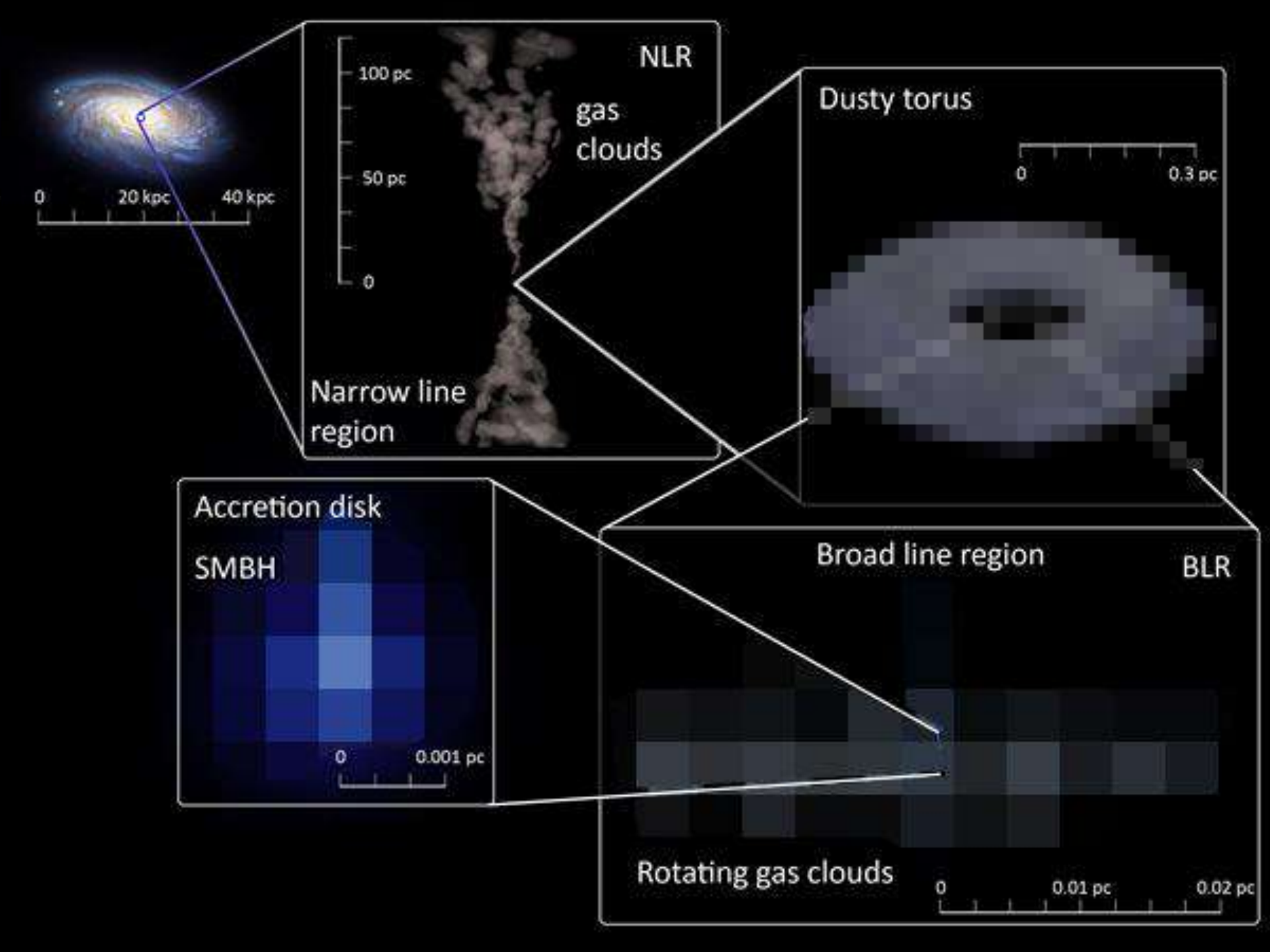
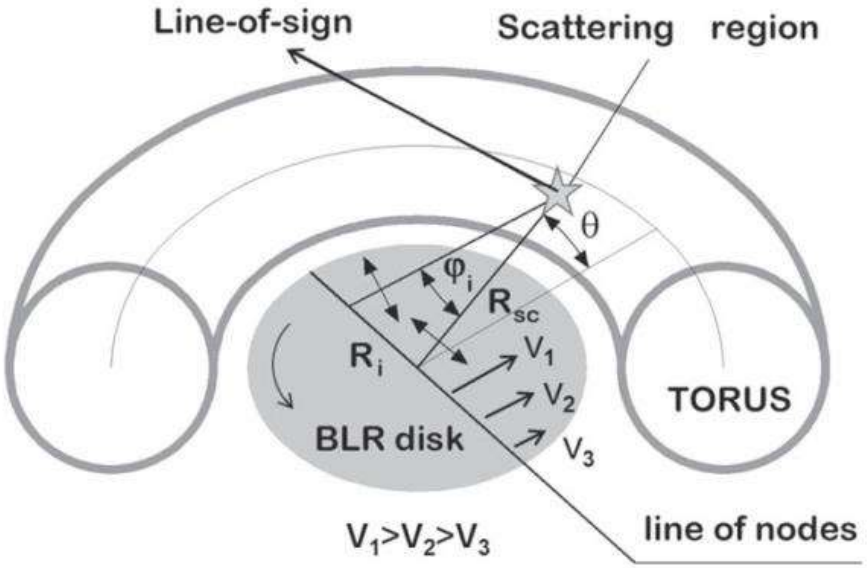
Polarimetric reverberation mapping of AGNs in medium-band filters

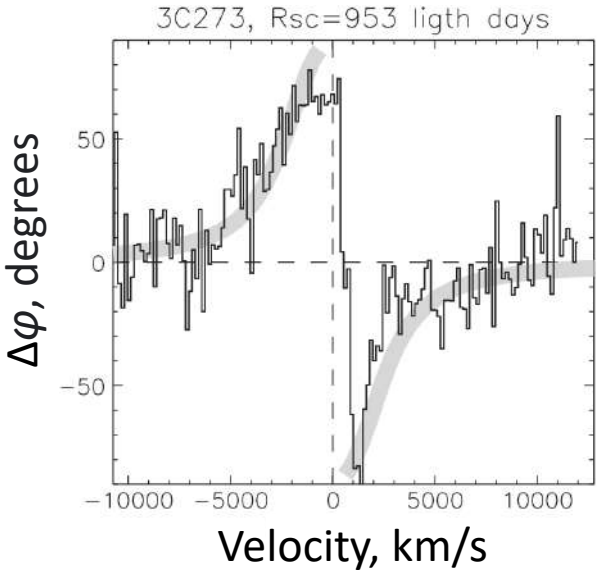


Malygin E.
Shablovinskaya E.
Popović L.Č.
Uklein R.
Ilić D.
Ciroi S.
Oparin D.
Crepaldi L.
Slavcheva-Mihova L.
Mihov B.
Nikolov Y.


0
20 kpc
40 kpc
100 pc
50 pc
0
NLR
gas
clouds
Narrow line
region
Dusty torus
0
0.3 pc
Accretion disk
SMBH
0
0.001 pc
Broad line region
BLR
Rotating gas clouds
0
0.01 pc
0.02 pc


0
20 kpc
40 kpc
100 pc
50 pc
0
NLR
gas
clouds
Narrow line
region
Dusty torus
0
0.3 pc
Accretion disk
SMBH
0
0.001 pc
Broad line region
BLR
Rotating gas clouds
0
0.01 pc
0.02 pc



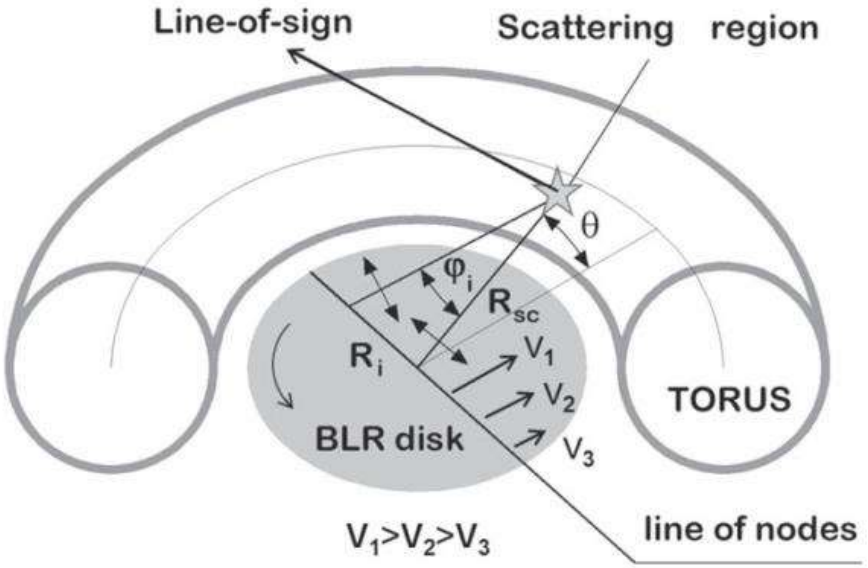


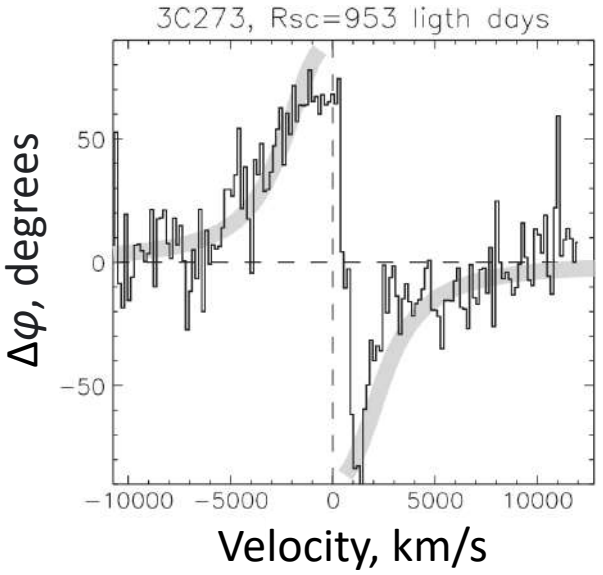
Afanasiev & Popović (2015)

New spectropolarimetric M_{SMBH} measurement method

$$\log\left(\frac{V_i}{c}\right) = a - 0.5 \cdot \log[\tan(\Delta\varphi_i)]$$

$$a = 0.5 \cdot \log\left[\frac{GM_{\mathrm{SMBH}}\cos^2(\theta)}{c^2 \boldsymbol{R_{sc}}}\right]$$





Afanasiev & Popović (2015)

New spectropolarimetric M_{SMBH} measurement method

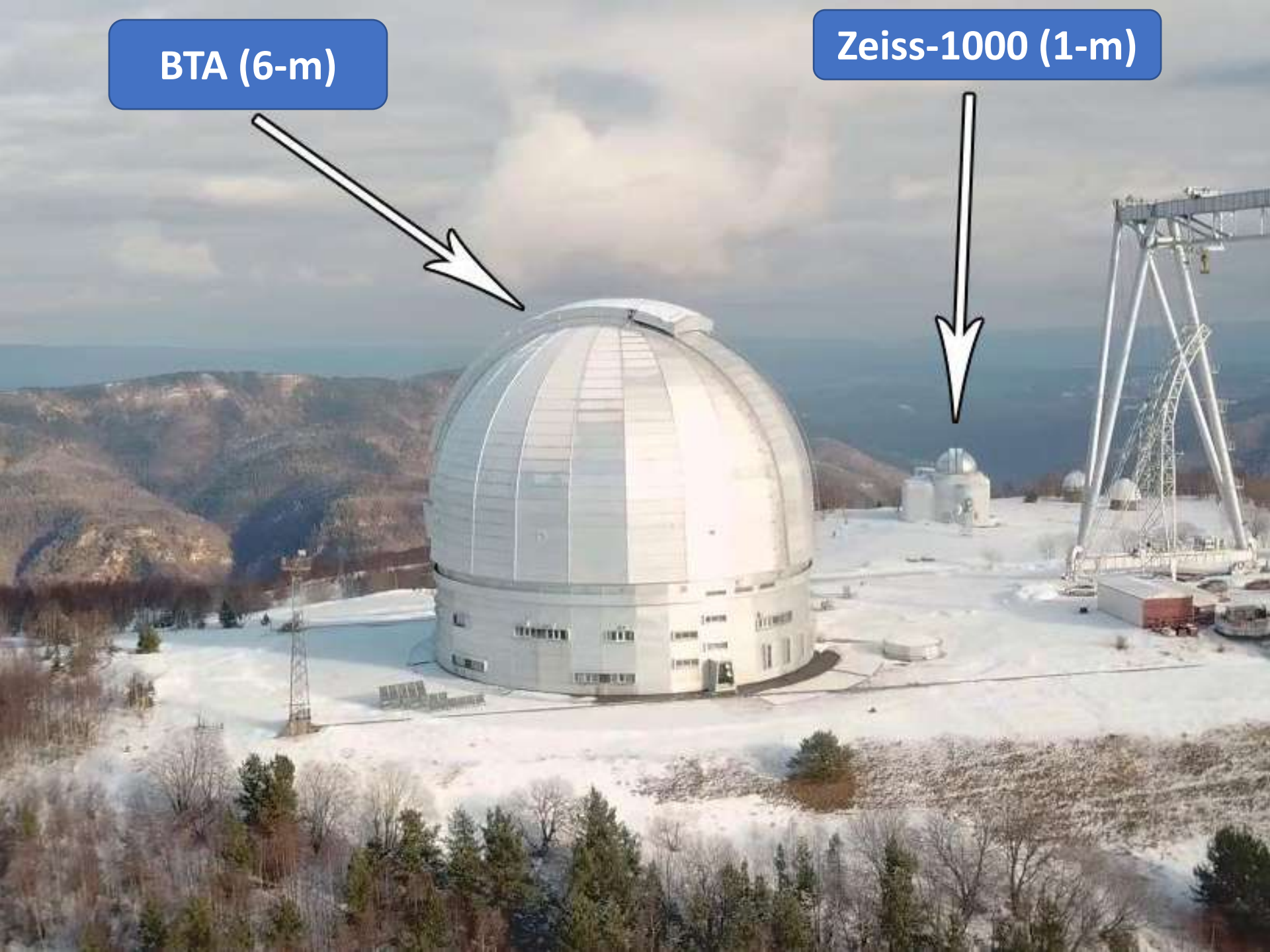
$$\log\left(\frac{V_i}{c}\right) = a - 0.5 \cdot \log[\tan(\Delta\varphi_i)]$$

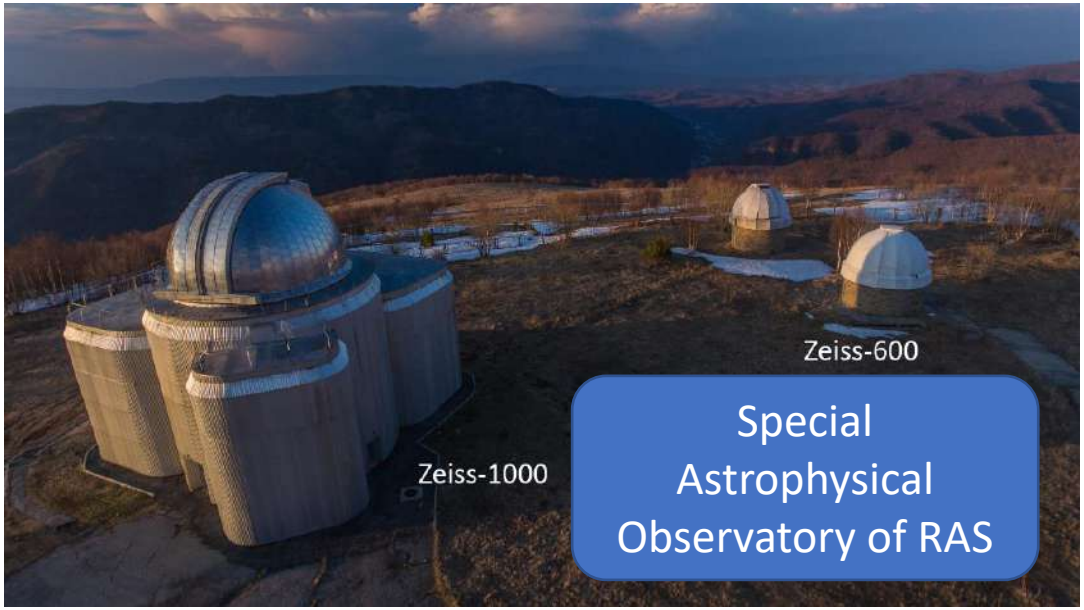
$$a = 0.5 \cdot \log\left[\frac{GM_{SMBH}\cos^2(\theta)}{c^2 \boldsymbol{R_{sc}}}\right]$$

Shablovinskaya Afanasiev Popović (2020)

New spectropolarimetric R_{sc} measurement method

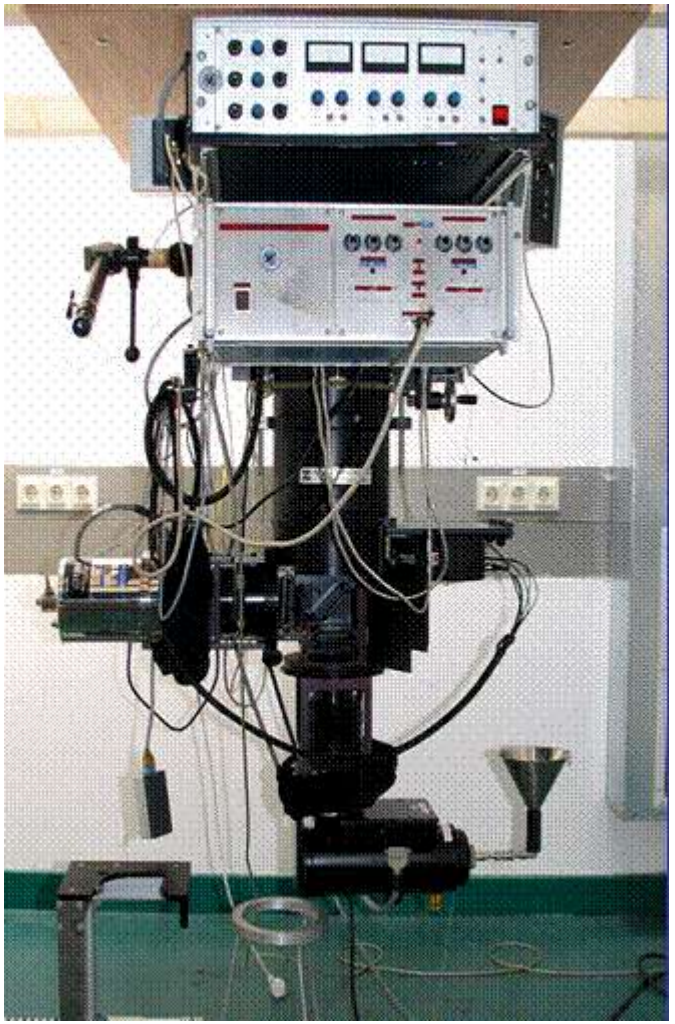
$$R_{BLR} < R_{sc} < R_{dust}$$


BTA (6-m)
Zeiss-1000 (1-m)



THE 2-M RCC TELESCOPE ROZHEN NATIONAL ASTRONOMICAL OBSERVATORY

Copernico 1.82-m telescope
Italy, Asiago
AFOSC (double WP + 100Å filters)



2-m Ritchey-Chrétien-Coudé
telescope (Bulgaria)
FeReRo2 (double WP + 30Å filters)

2020

1-m Zeiss + StoP

Afanasiev et al, 2021

Accuracy:

$\Delta P \sim \pm 0.15$ %

$\Delta\varphi \sim \pm 0.7°$

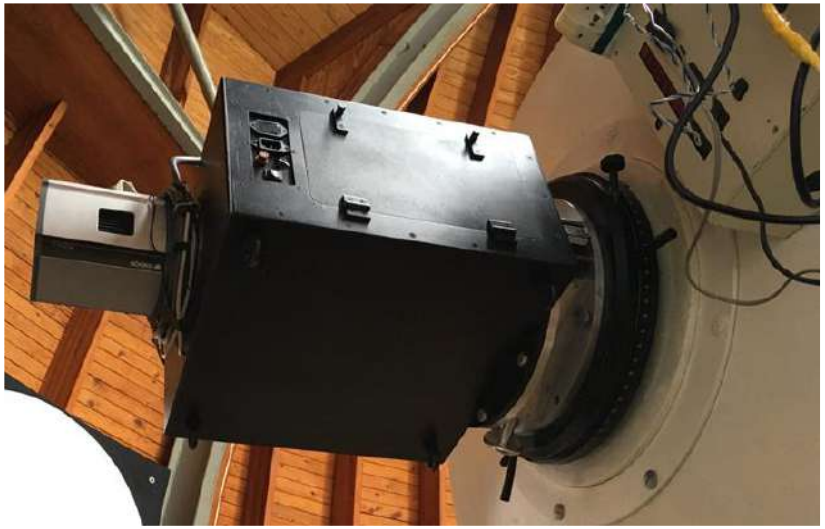
2021 - today

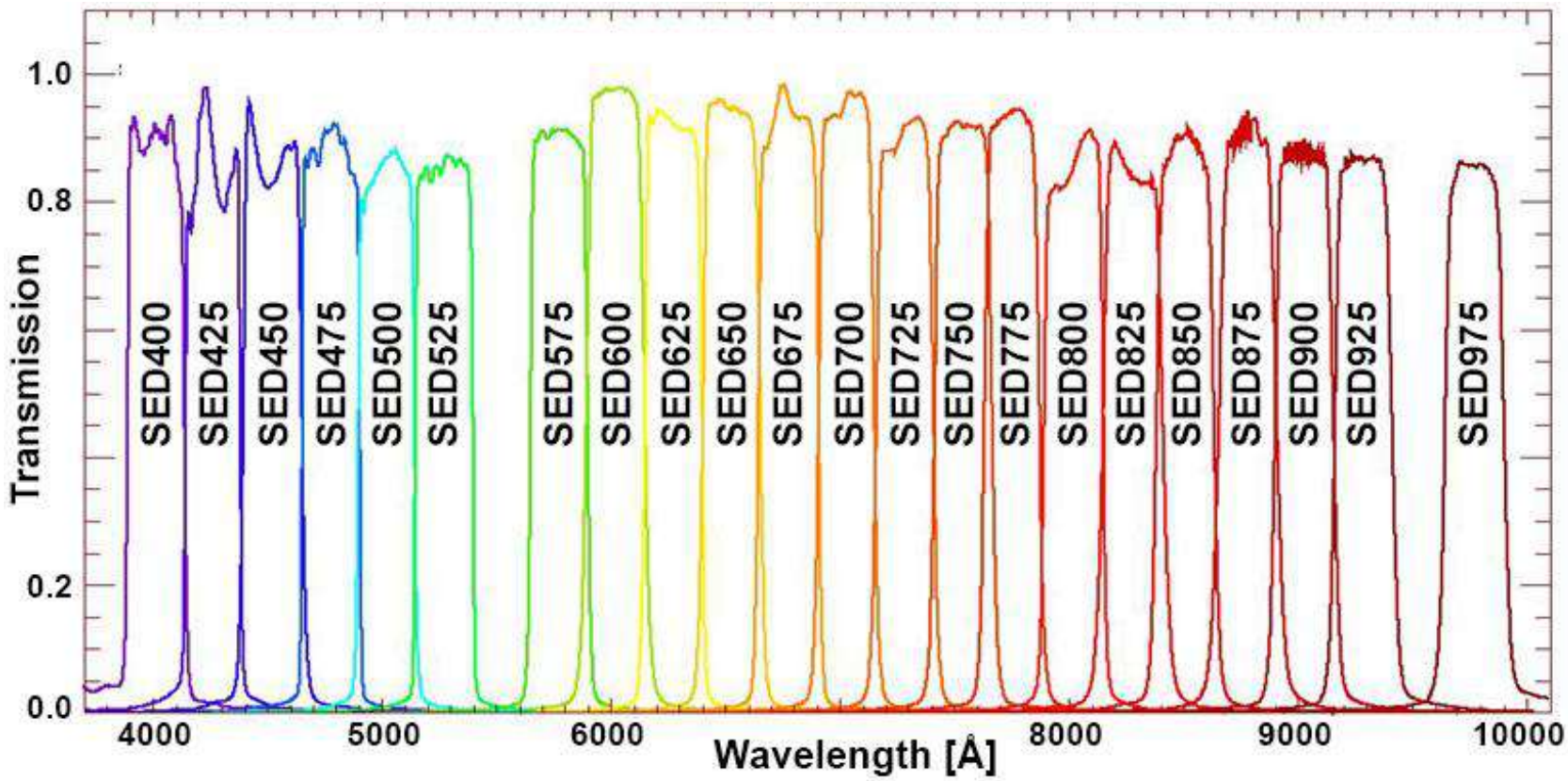
1-m Zeiss + MAGIC

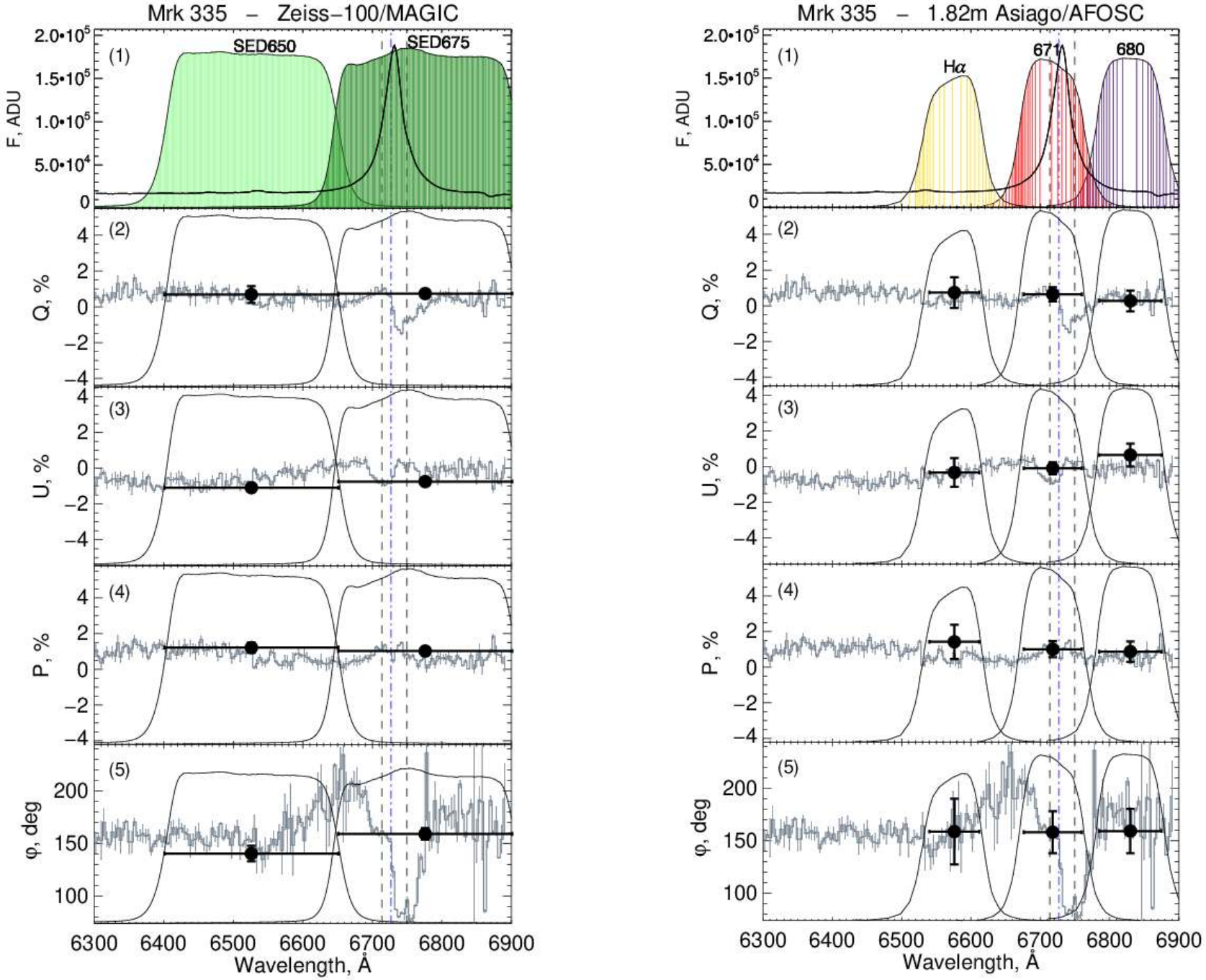
Afanasiev et al, 2022

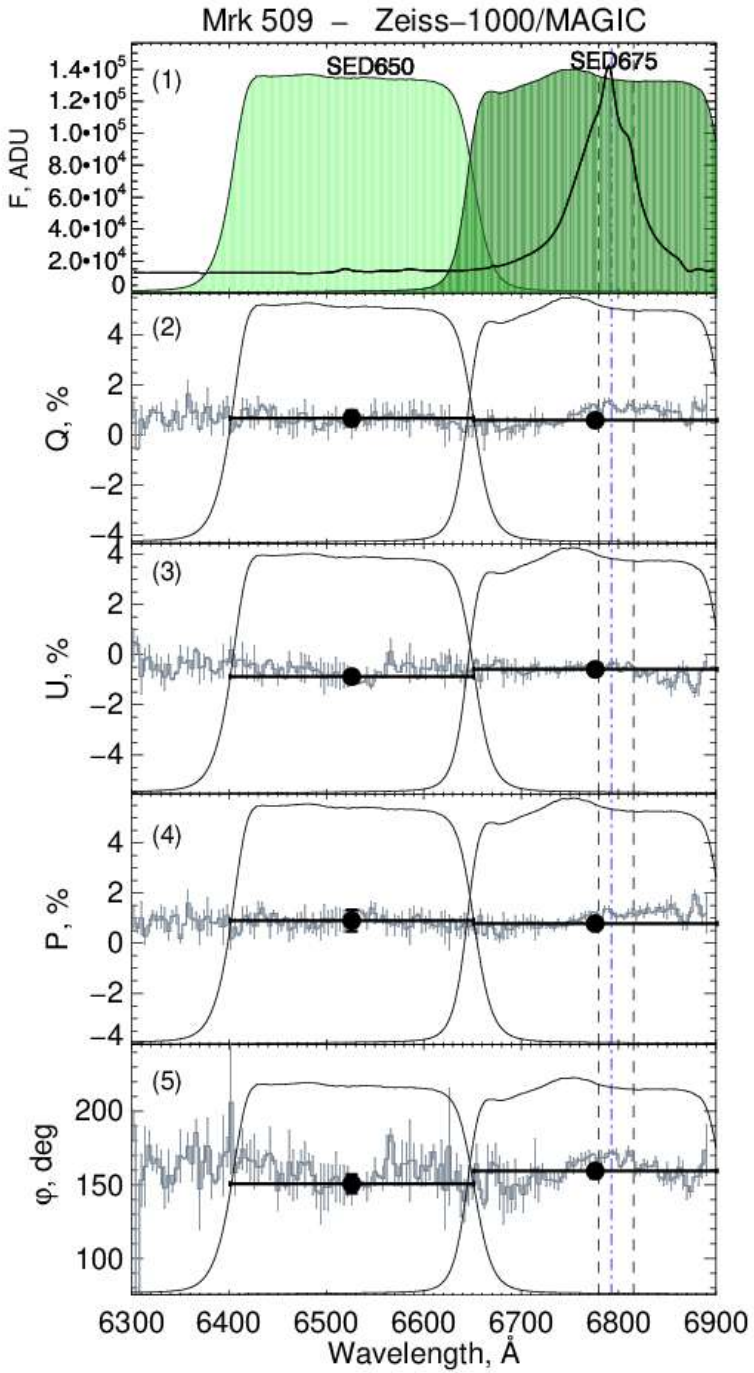
$\Delta P \sim \pm 0.18$ %

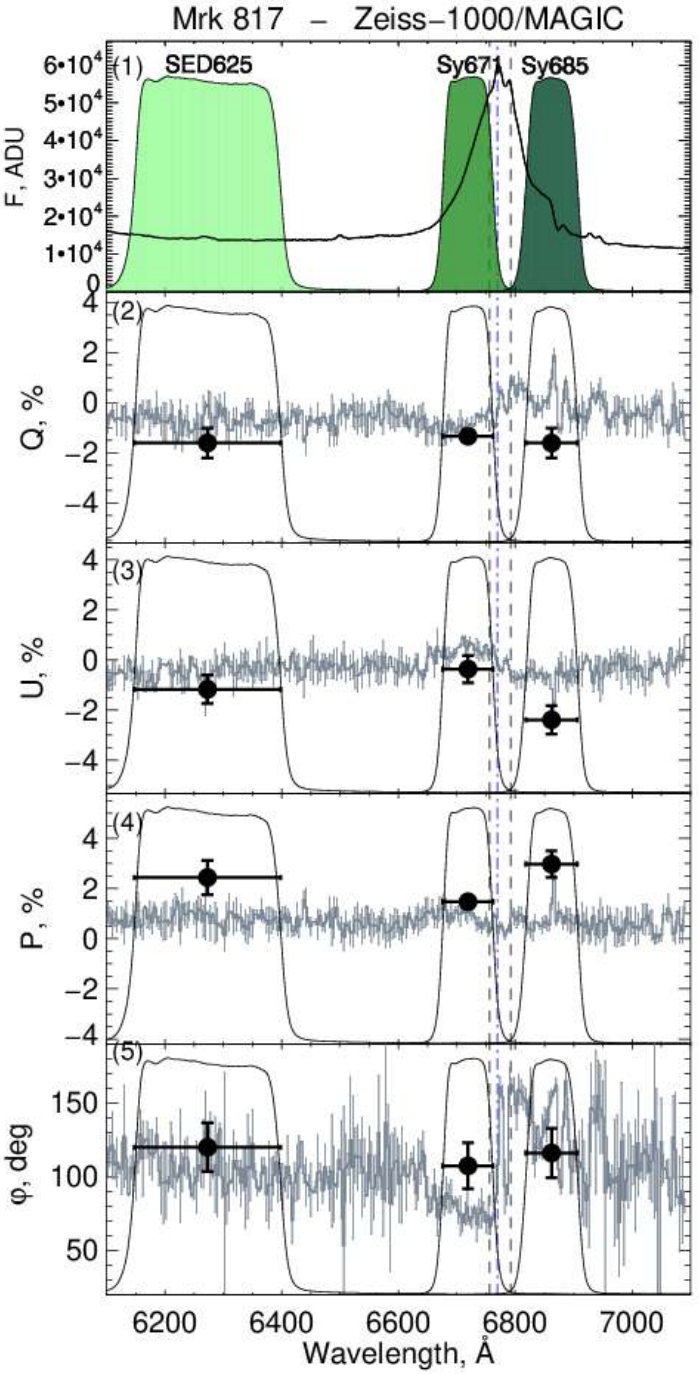
$\Delta\varphi \sim \pm 3°$



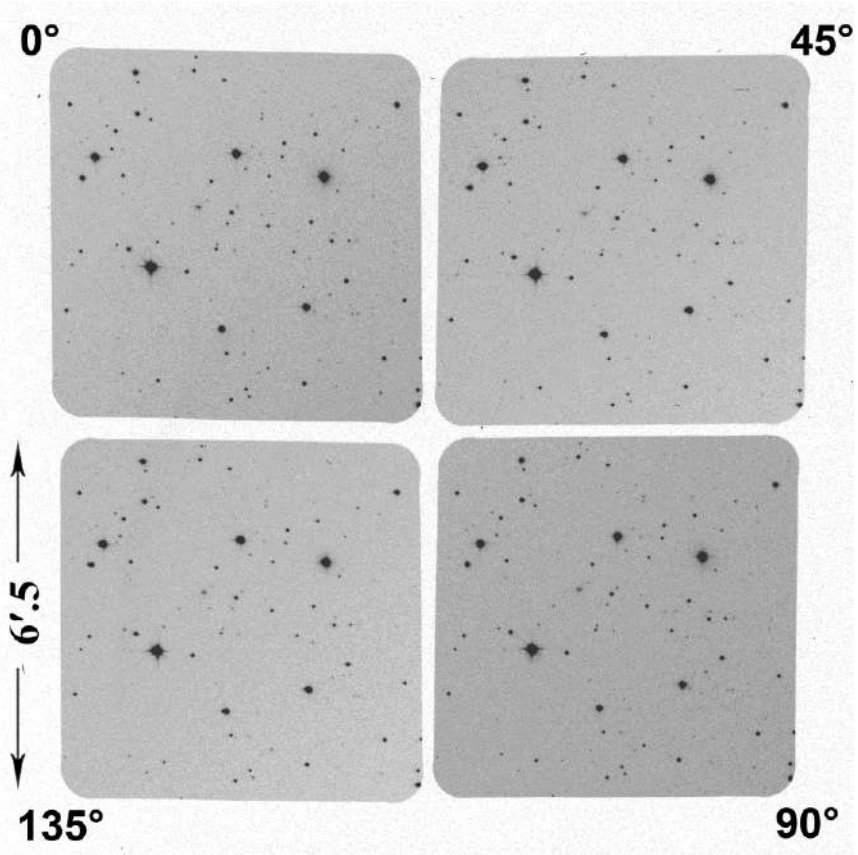

Transmission
1.0
0.8
0.2
0.0
SED400
SED425
SED450
SED475
SED500
SED525
SED575
SED600
SED625
SED650
SED675
SED700
SED725
SED750
SED775
SED800
SED825
SED850
SED875
SED900
SED925
SED975
4000
5000
6000
8000
9000
10000
Wavelength [Å]


Mrk 335 – Zeiss–100/MAGIC
SED650
SED675
(1)
F, ADU
(2)
Q, %
(3)
U, %
(4)
P, %
(5)
φ, deg
Wavelength, Å
Mrk 335 – 1.82m Asiago/AFOSC
Hα
671
680
(1)
F, ADU
(2)
Q, %
(3)
U, %
(4)
P, %
(5)
φ, deg
Wavelength, Å

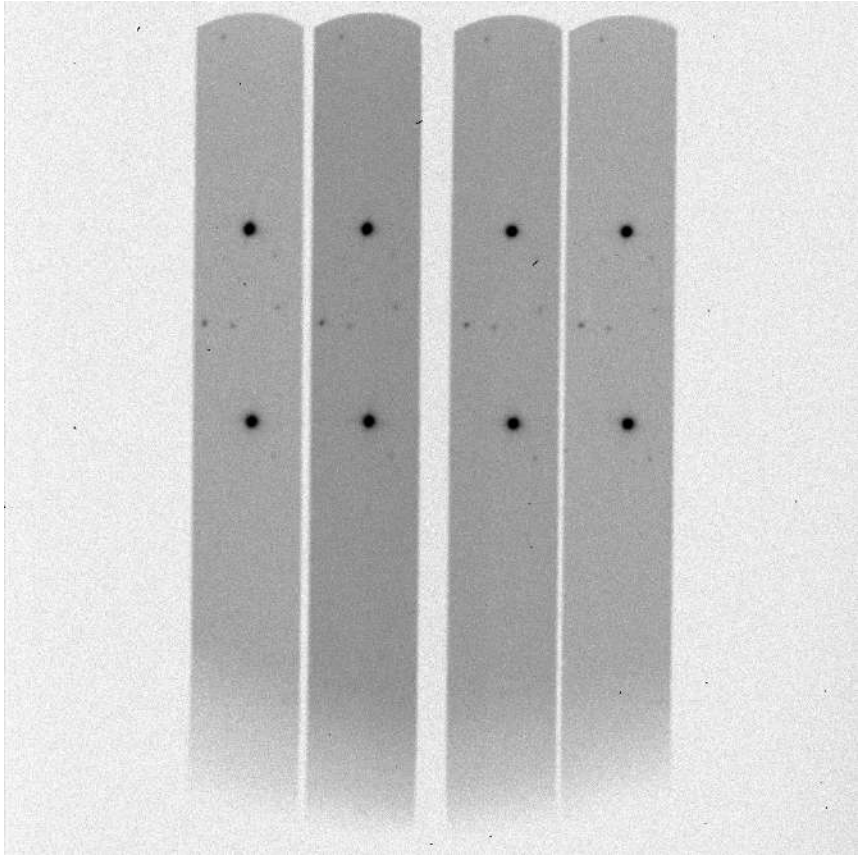

Mrk 509 – Zeiss–1000/MAGIC
SED650
SED675
(1)
F, ADU
(2)
Q, %
(3)
U, %
(4)
P, %
(5)
φ, deg
Wavelength, Å


Mrk 817 – Zeiss–1000/MAGIC
SED625
Sy671
Sy685
(1)
F, ADU
(2)
Q, %
(3)
U, %
(4)
P, %
(5)
φ, deg
Wavelength, Å

Mrk 509 observation example

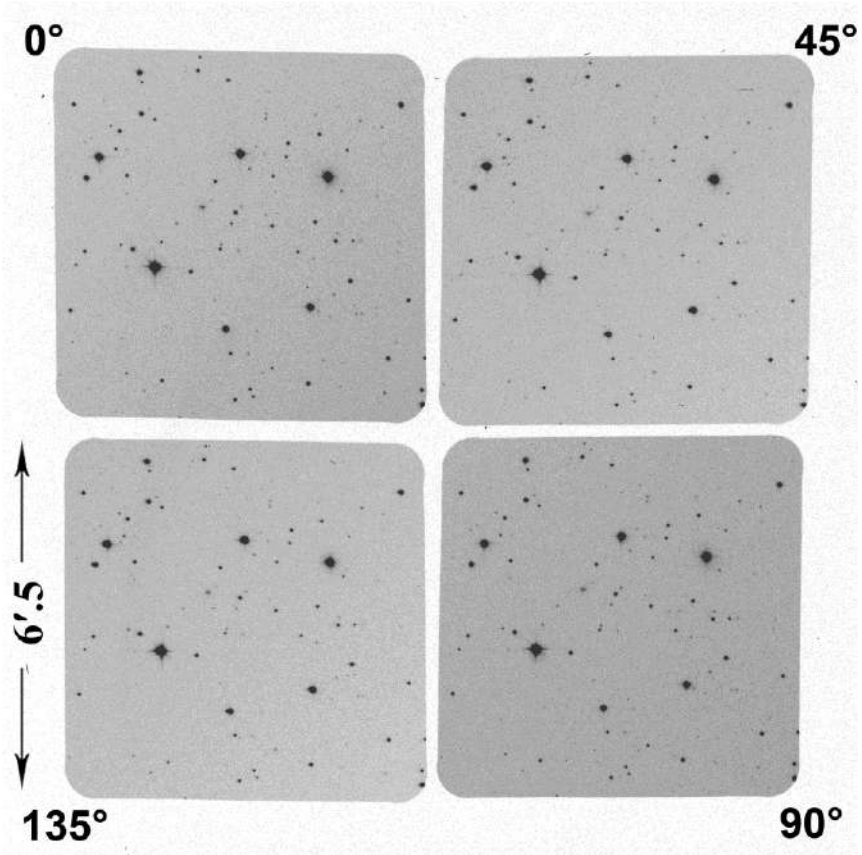


1-m Zeiss-1000 + **MAGIC** + SED675
6'.5 × 6'.5
0''.45/pix (Andor iKon-L 936 bin 1 × 1)



1-m Zeiss-1000 + **STOP** + SED675
0'.9 × 6'.1
0''.35/pix (Andor iKon-L 936 bin 2 × 2)

Mrk 509 observation example



$$I = I_0 + I_{90}K_Q + I_{45} + I_{135}K_U$$

$$Q = \frac{I_0 - I_{90}K_Q}{I_0 + I_{90}K_Q}$$

$$U = \frac{I_{45} - I_{135}K_U}{I_{45} + I_{135}K_U}$$

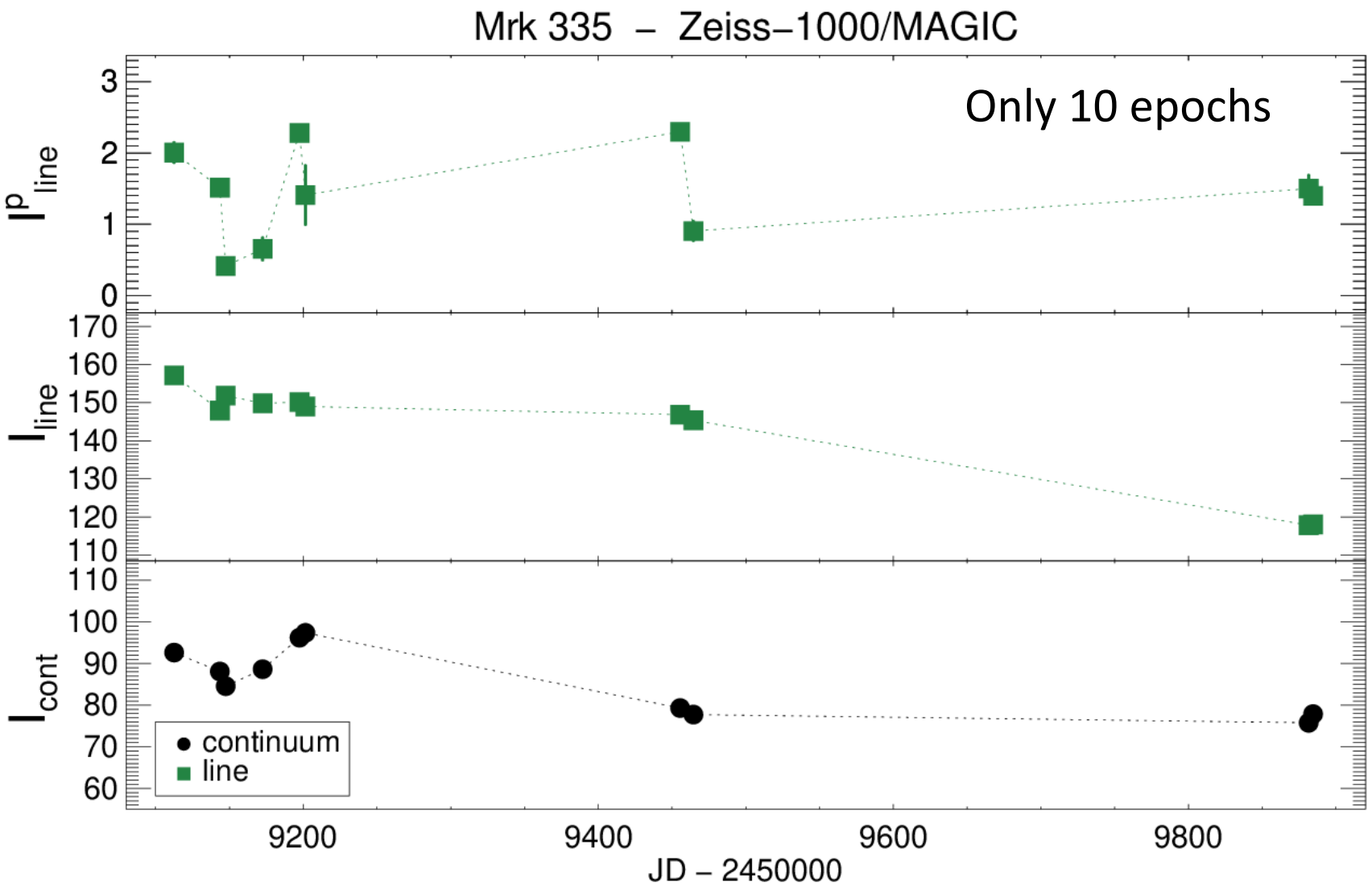
$$P = \sqrt{Q^2 + U^2}$$

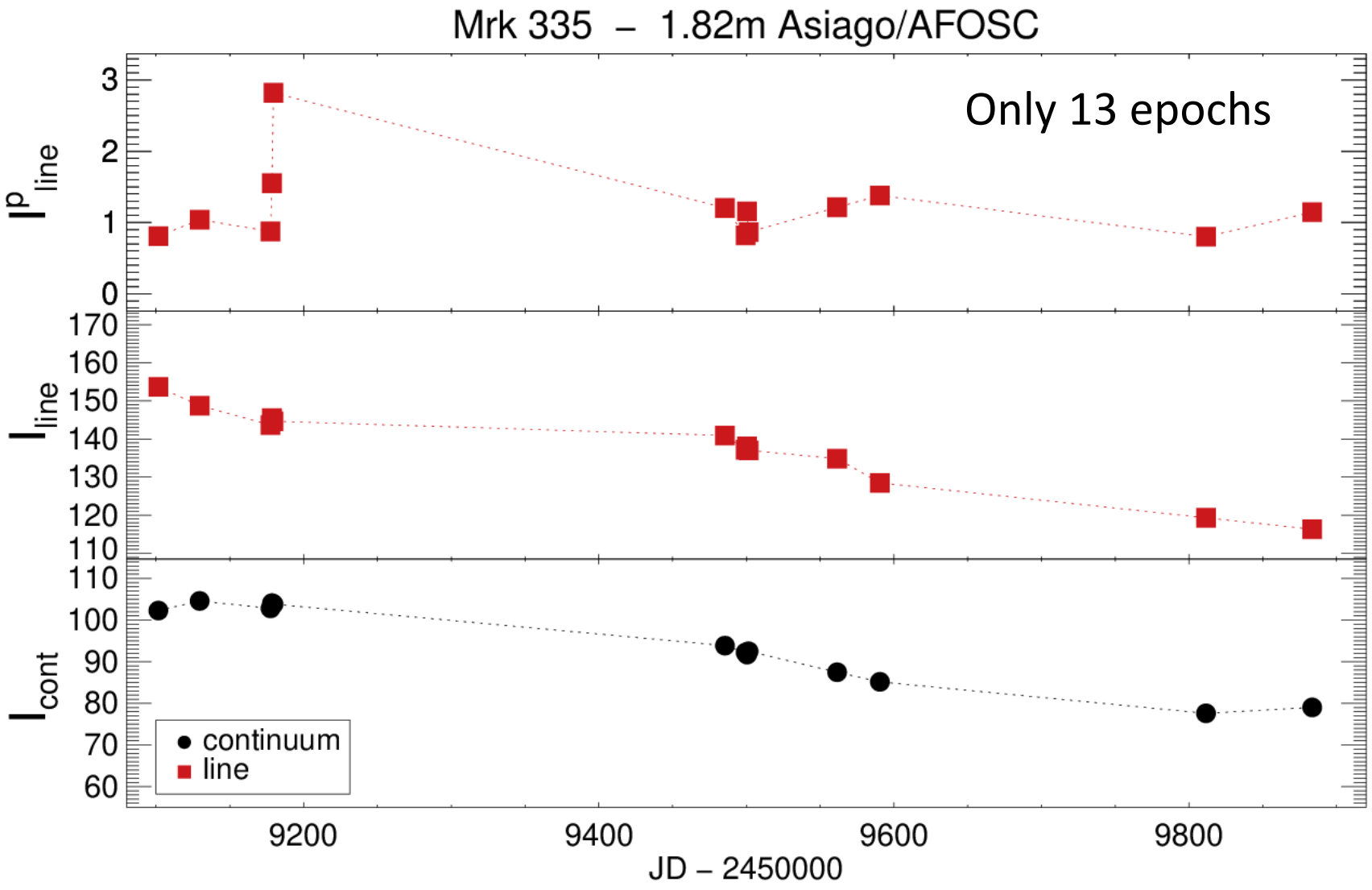
$$\varphi = \frac{1}{2}\arctan\left(\frac{U}{Q}\right)$$

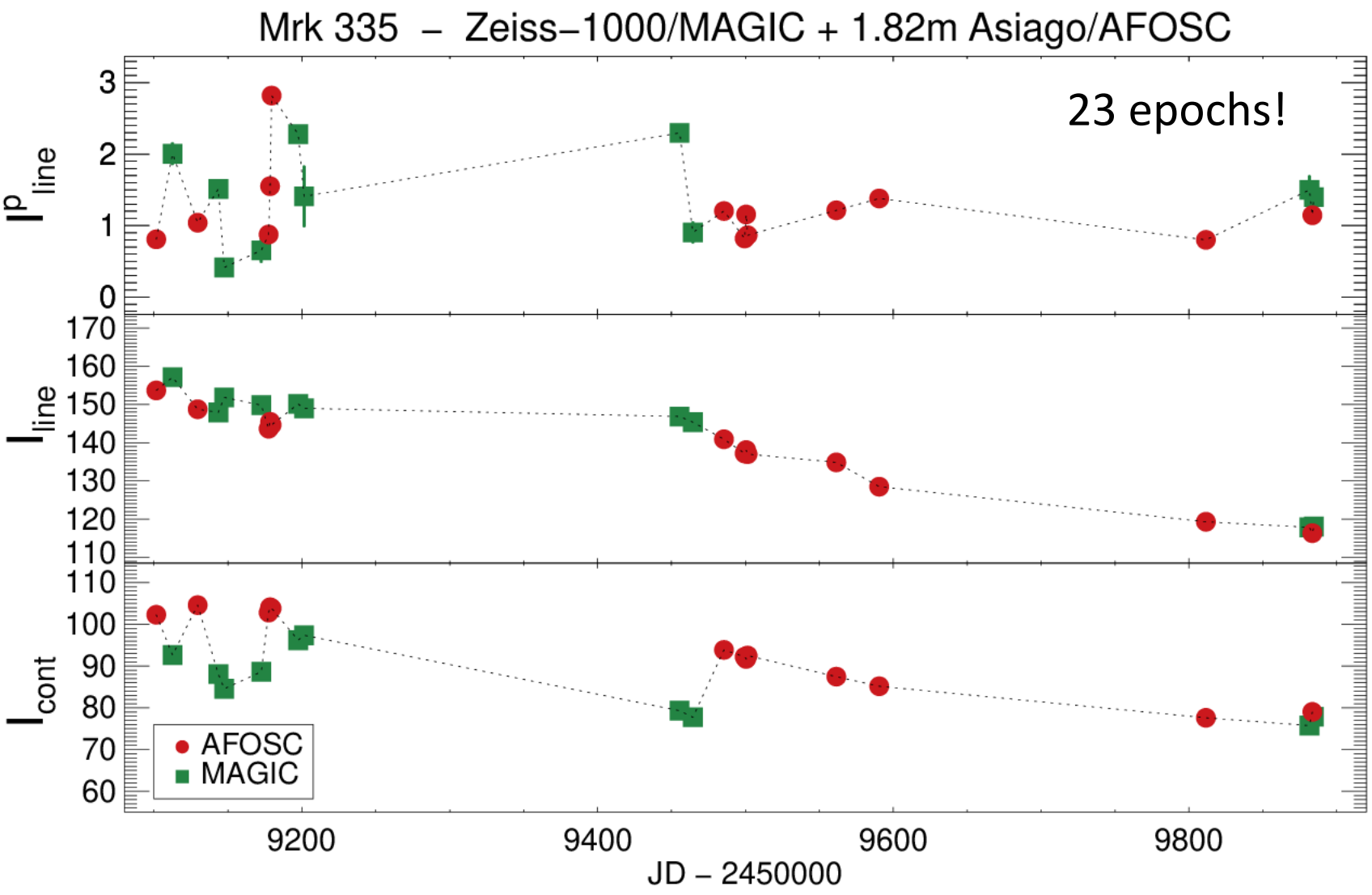
1-m Zeiss-1000 + **MAGIC** + SED675
6'.5 × 6'.5
0''.45/pix (Andor iKon-L 936 bin 1 × 1)

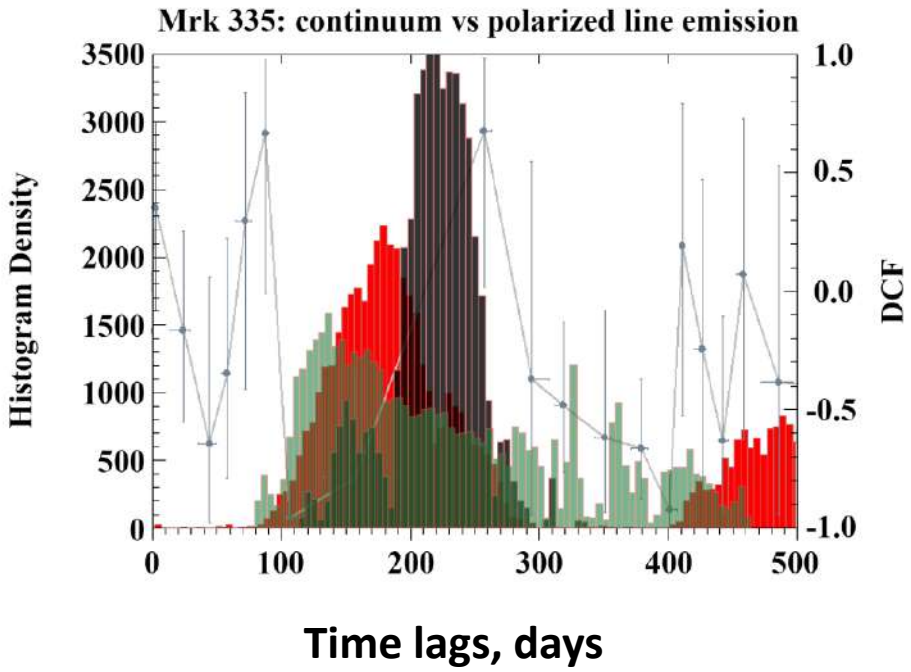
if $\sigma_P / P \gtrsim 0.7$ [*< 95% obtained data*]

then $P_{\text{unbiased}} = P \cdot \sqrt{1 - (1.41 \cdot \sigma_P / P)^2}$


Mrk 335 – Zeiss–1000/MAGIC
Only 10 epochs
I^p_{line}
I_{line}
I_{cont}
continuum
line
JD – 2450000
9200
9400
9600
9800

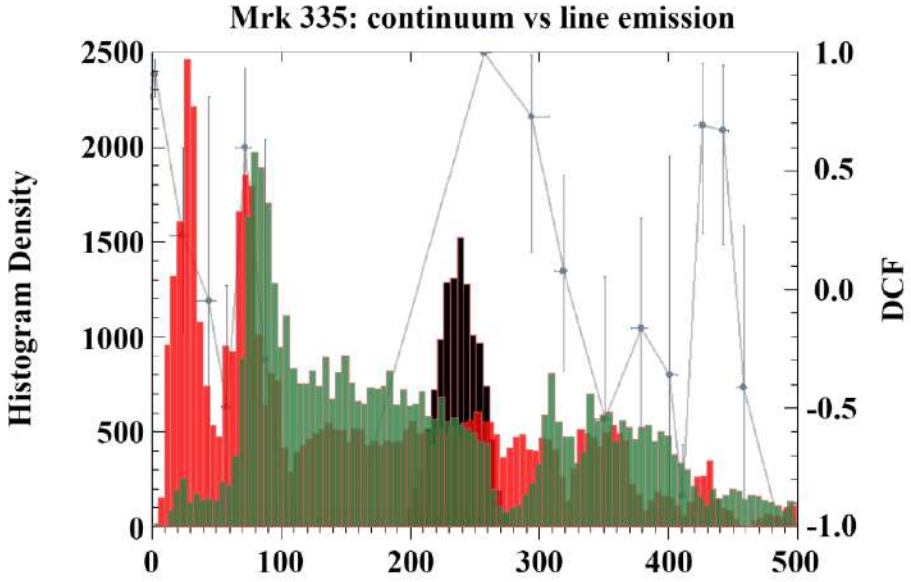

Mrk 335 – 1.82m Asiago/AFOSC
Only 13 epochs
I^p_{line}
I_{line}
I_{cont}
continuum
line
JD – 2450000
9200
9400
9600
9800


Mrk 335 – Zeiss–1000/MAGIC + 1.82m Asiago/AFOSC
23 epochs!
I^p_{line}
I_{line}
I_{cont}
AFOSC
MAGIC
JD – 2450000



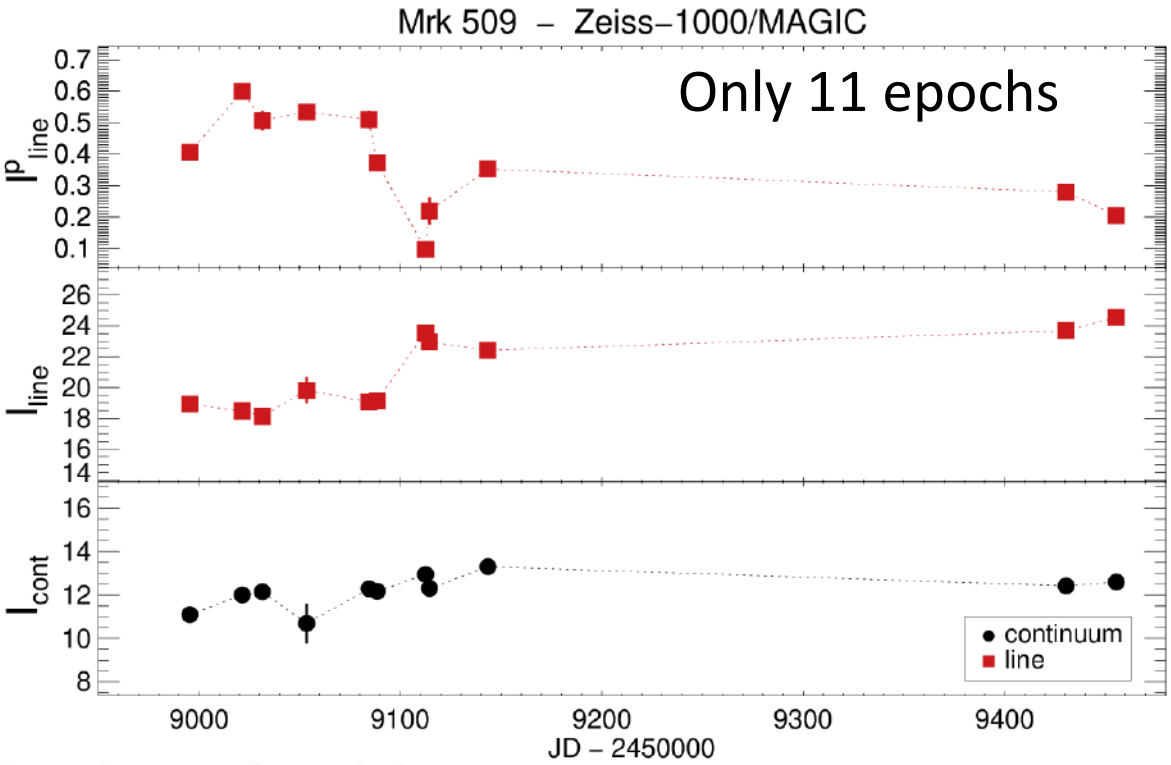
~180 days (AFOSC)

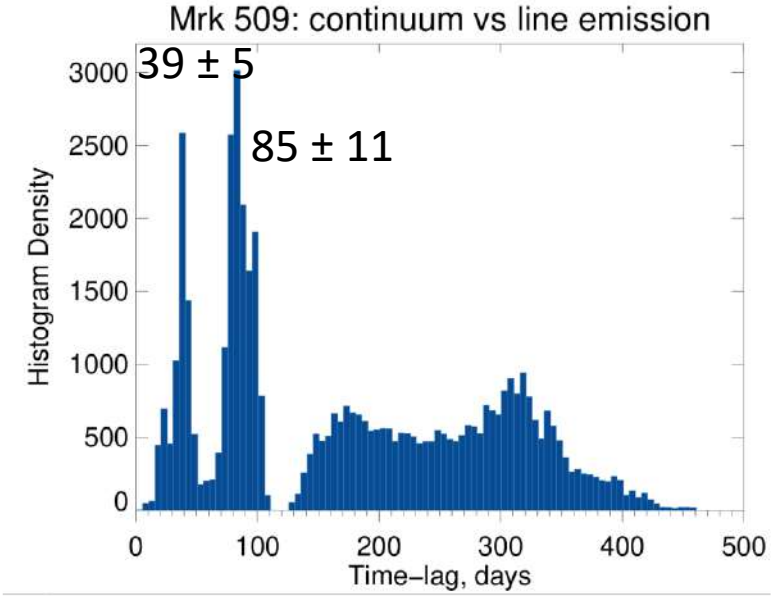
~150 days (MAGIC)

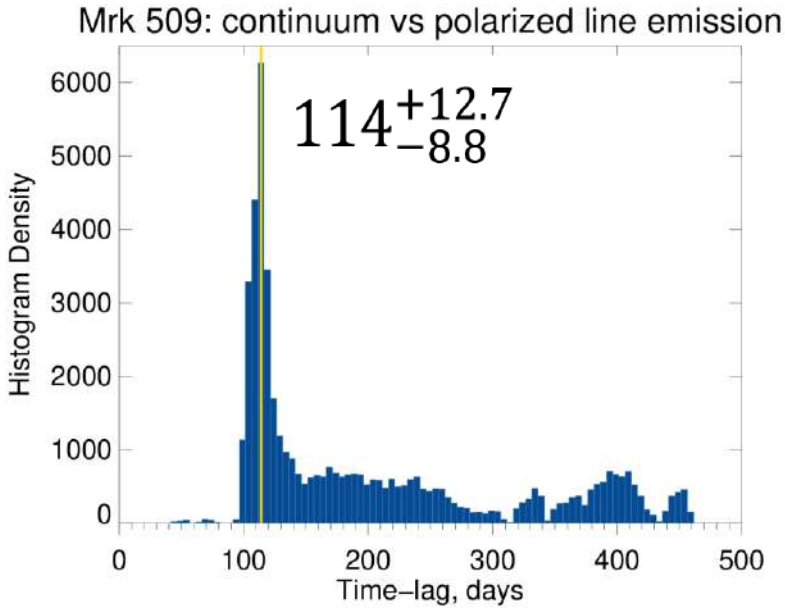


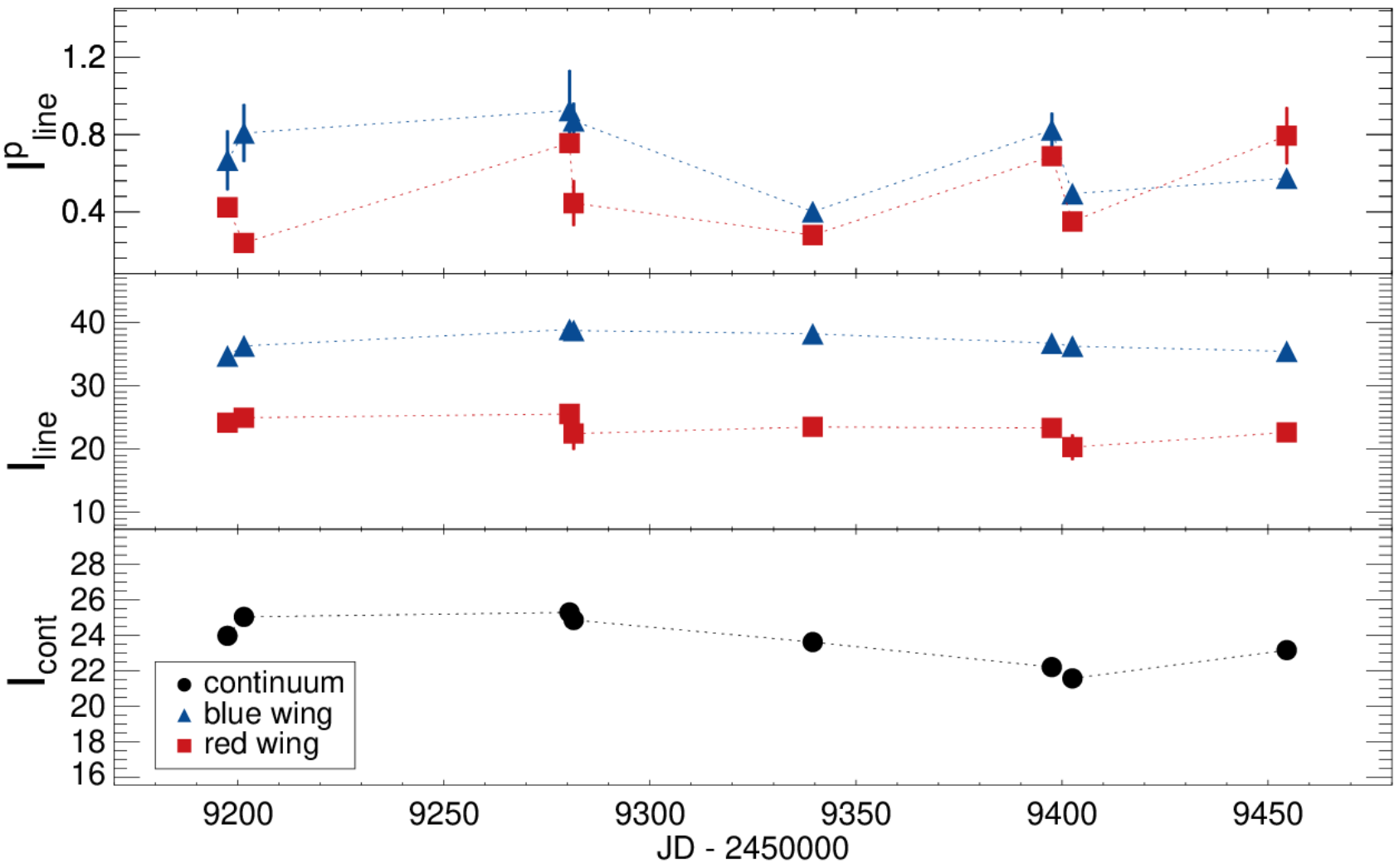
(73 ± 18) days (AFOSC)

87 ± 17 days (MAGIC)


Mrk 509 – Zeiss–1000/MAGIC
Only 11 epochs
P_{line}
I_{line}
I_{cont}
continuum
line
JD – 2450000


Mrk 509: continuum vs line emission
39 ± 5
85 ± 11
Histogram Density
Time–lag, days


Mrk 509: continuum vs polarized line emission
$114^{+12.7}_{-8.8}$
Histogram Density
Time–lag, days


Mrk 817 - Zeiss-1000/MAGIC
I^p_{line}
1.2
0.8
0.4
I_{line}
40
30
20
10
I_{cont}
28
26
24
22
20
18
16
continuum
blue wing
red wing
9200
9250
9300
9350
9400
9450
JD - 2450000

Conclusions

- The new approach of polarimetric reverberation mapping in broad lines looks promising since it can provide additional information about the size of structures in AGN, and therefore, better understand the nature of processes associated with accretion onto SMBH.

- Mrk 335 $\rightarrow R_{SC} \sim 150$-180 lt days?

  [expected from $R_{SC} = R_{BLR} \times 5.1$

  and IR-reverberation $\rightarrow R_{IR} \sim 166$ lt days]

- Mrk 509 $\rightarrow$ Rsc = $114^{+12.7}_{-8.8}$ lt days (and R_{BLR} coincides with previous estimates). GRAVITY: $R_{IRIF} \sim 296 \pm 30$ lt days!

- Astroclimate matters.

Shablovinskaya et al (2023)
Universe, 9(1), 52

- More details on the observation technique

arXiv:2301.05267