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ANALYSIS OF BROAD LINE REGION OF MRK 1018

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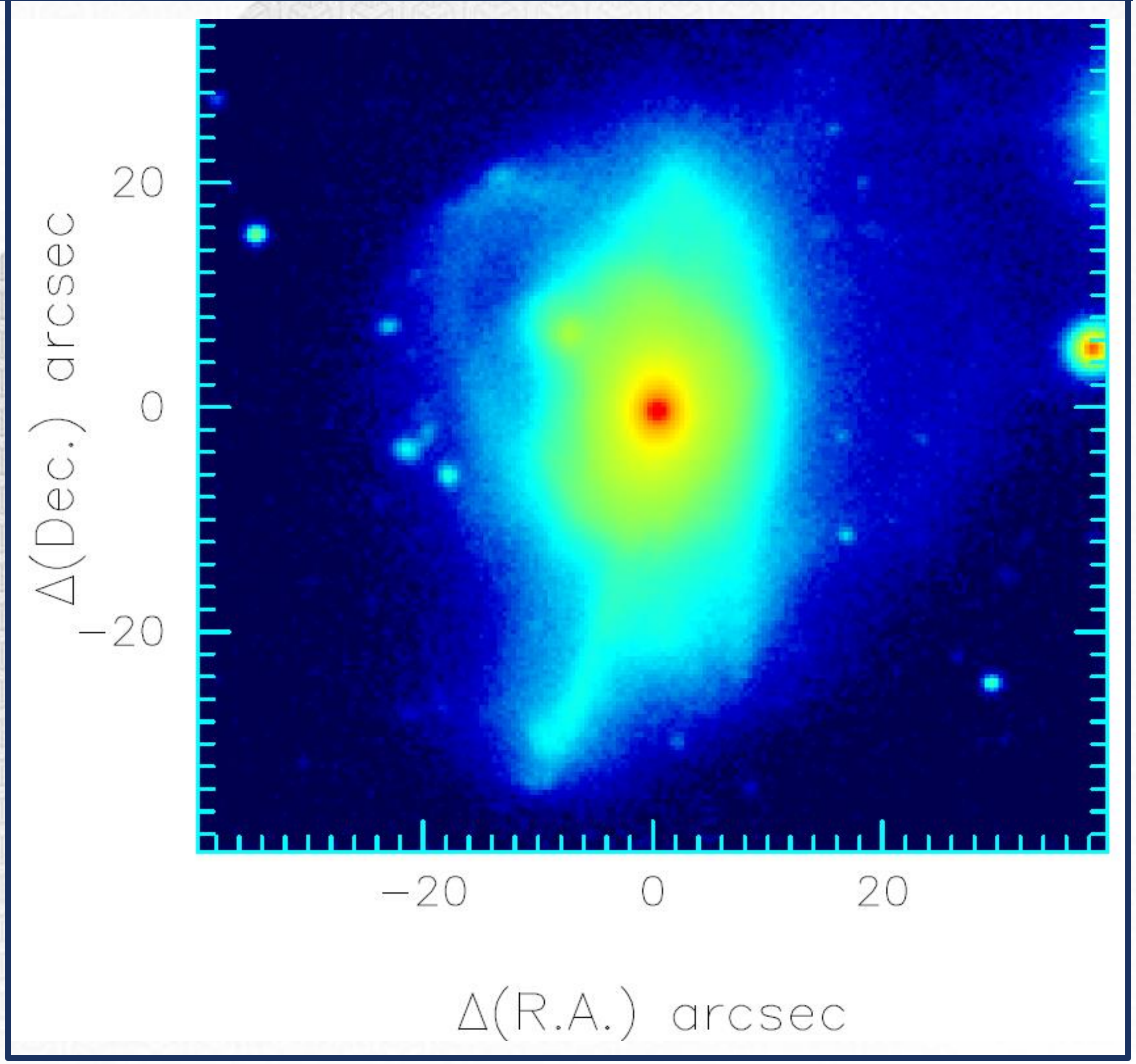
ABOUT MARKARIAN 1018

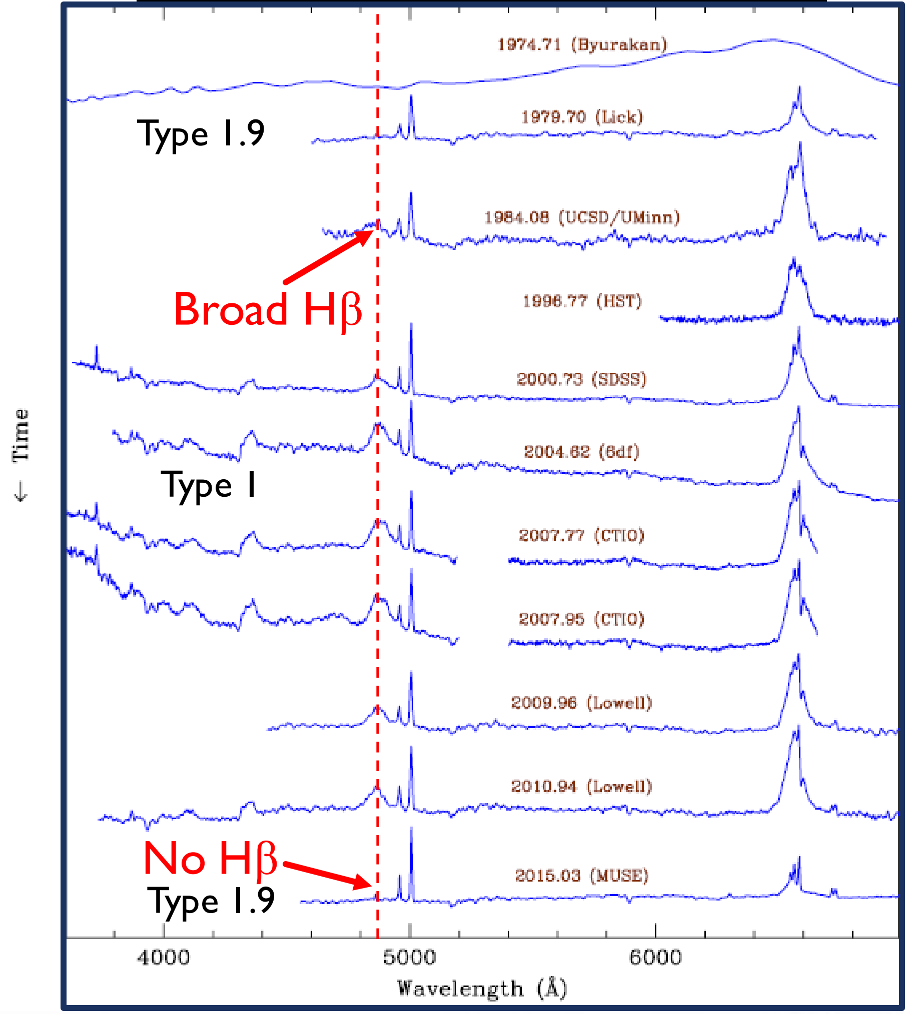
- A late-stage galaxy merger, tidal tails evident.
- In general, moderate to strong UV continuum (first in Byurakan Observatory, 1965-1978).
- Redshift, **z = 0.043 ~ 600 Mly** (first observed - Markarian et al., 1977).
- Changing look from Seyfert **Type 1.9 — Type 1 — Type 1.9**.
- CARS combines **muti-wavelength data** from Chandra, NuStar, Swift, HST, **VLT (MUSE)** and other ground-based observations.
- 2-10 keV flux **decline by ~10x from 2010-2016**.



D.C. Kim et al. (2018, APJ)

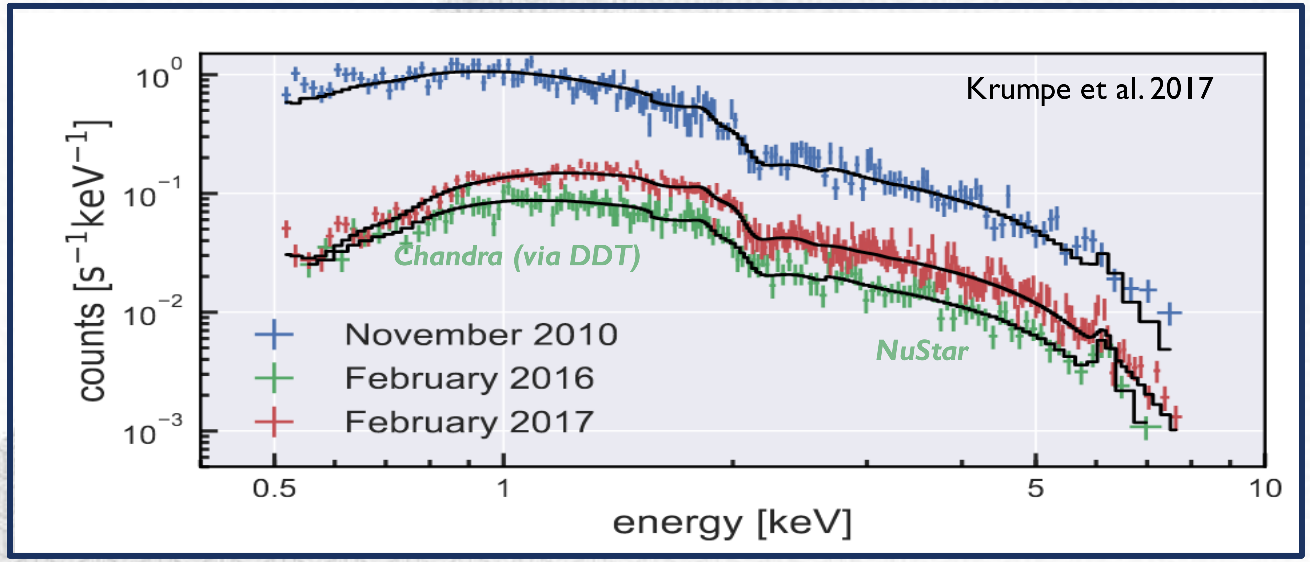
OBSERVING THE CHANGING-LOOK

Broad Hα emission over 41 years



Archival spectra normalized to same integrated flux as [OIII]λ5007Å (except for Byurakan)

X-ray spectra



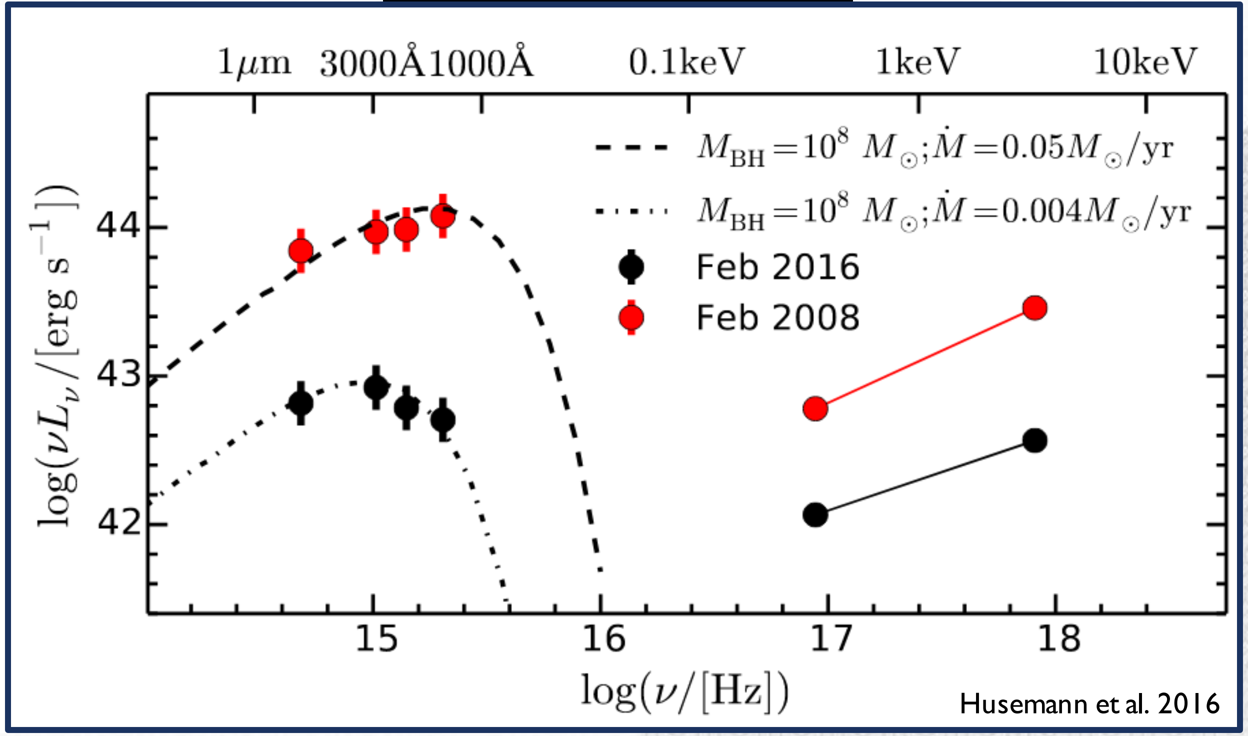
X-ray spectra consistent with no absorption.

Declining accretion disk luminosity.

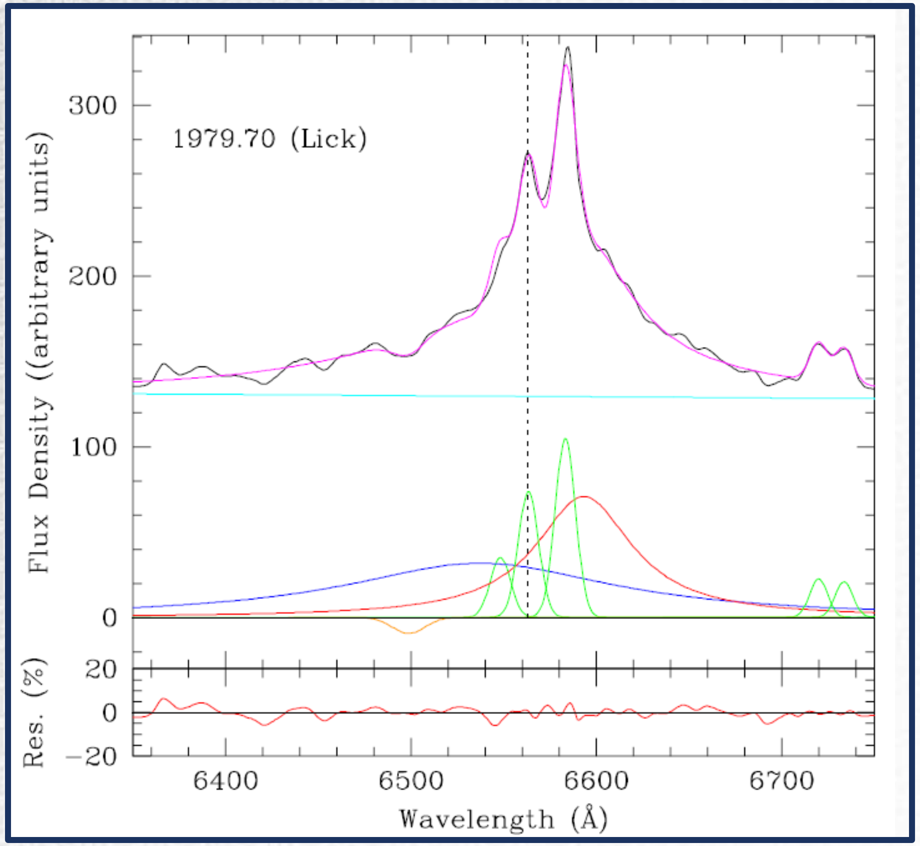
Chandra spectra fully consistent with single power-law.

OBSERVING THE CHANGING-LOOK

Optical to X-ray SED



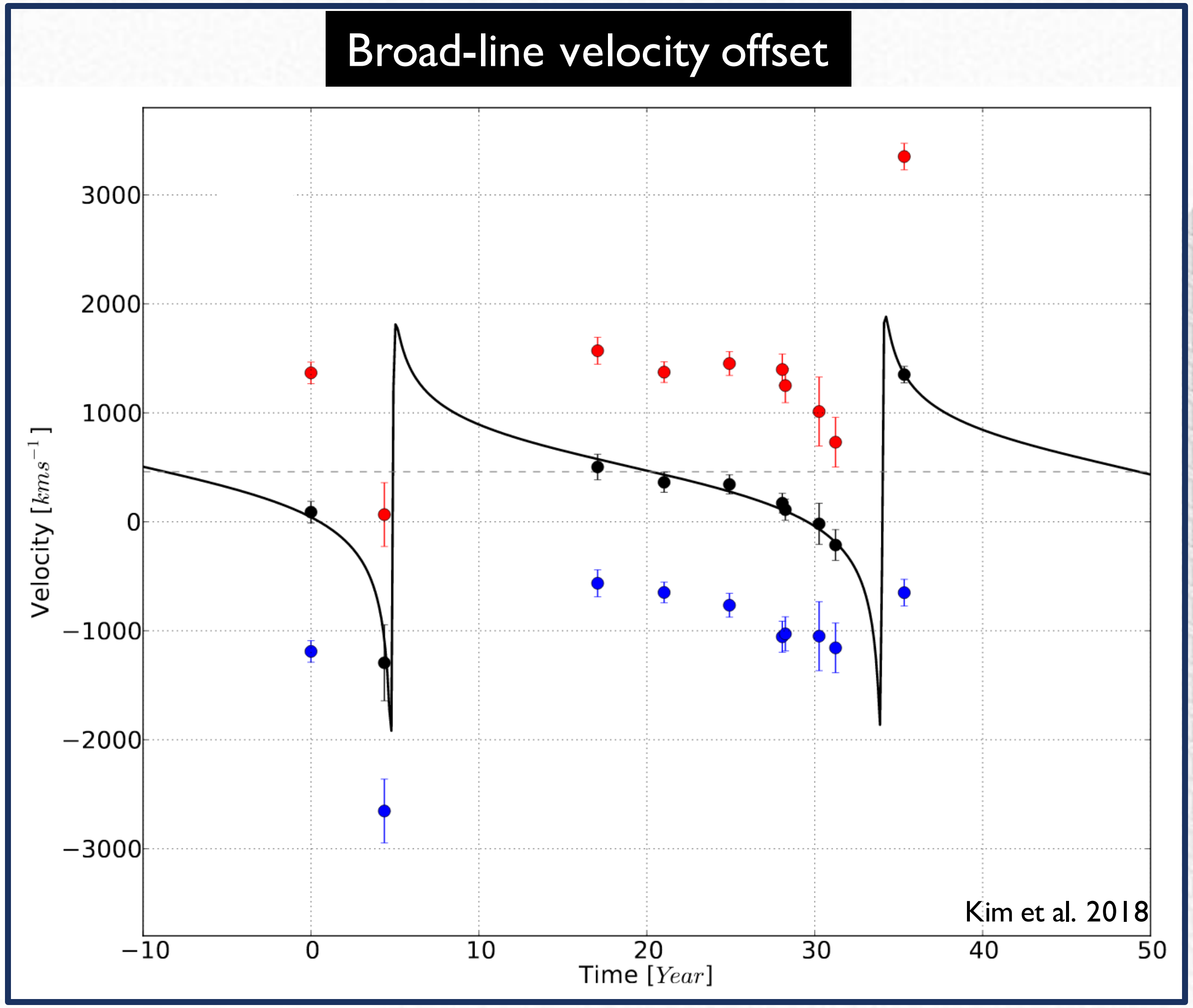
Spectral Decomposition of Hα + [N II] lines



Kim et al. 2018

- Photometry of nucleus + NUV + FUV + X-ray.
- Peak Luminosity behaves consistently with $L \sim T^4$.
- Points to relativistic geometrically thin - optically thick disk.

MAKING SENSE OF CHANGING LOOK

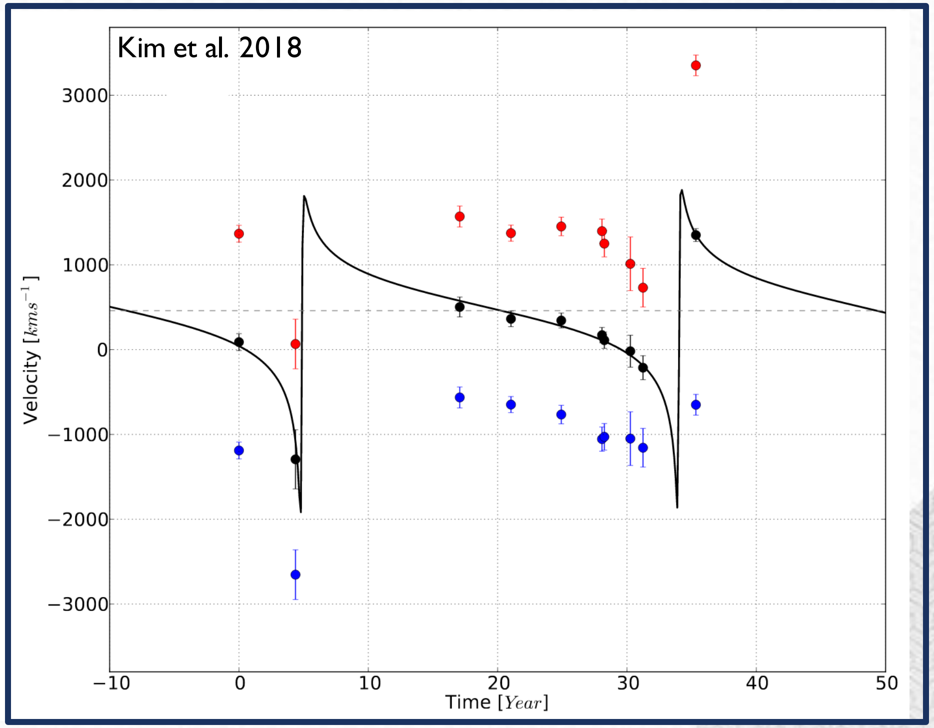


Systematic change in blue and red components ⟹ bulk motion in both components.

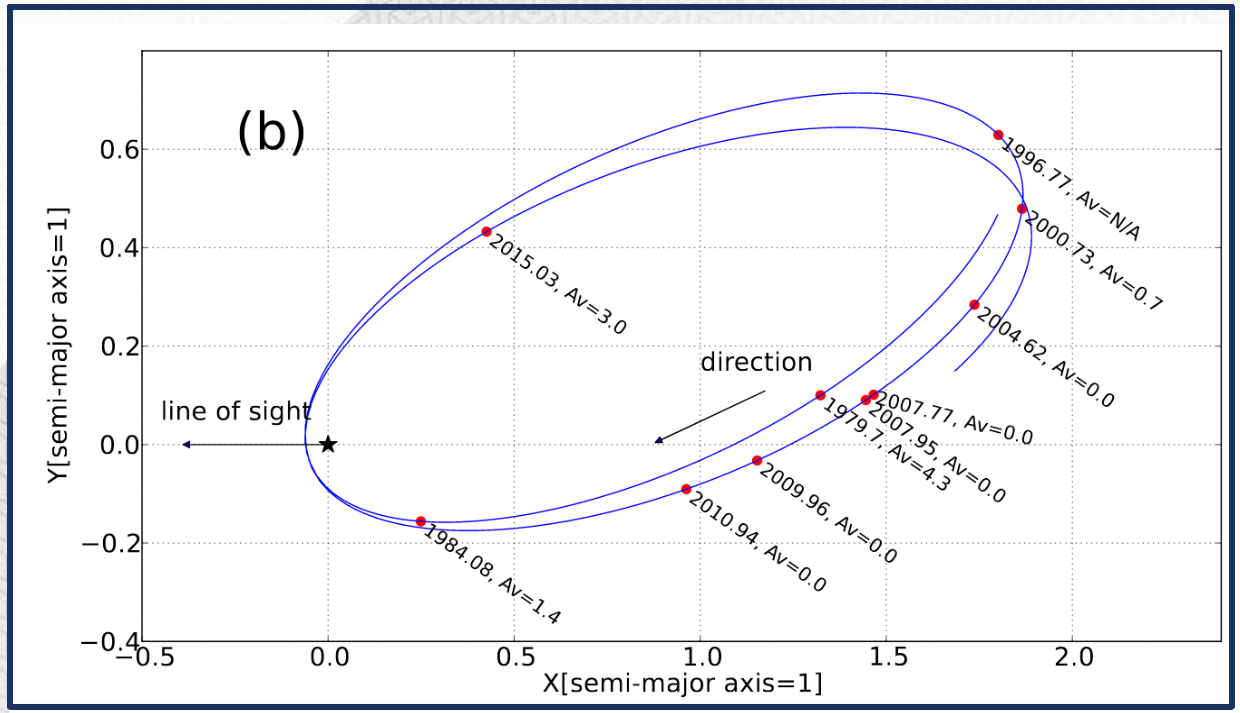
Following X-ray analysis rules out obscuring cloud as trigger for change (McElroy et al. 2016).

MAKING SENSE OF CHANGING LOOK

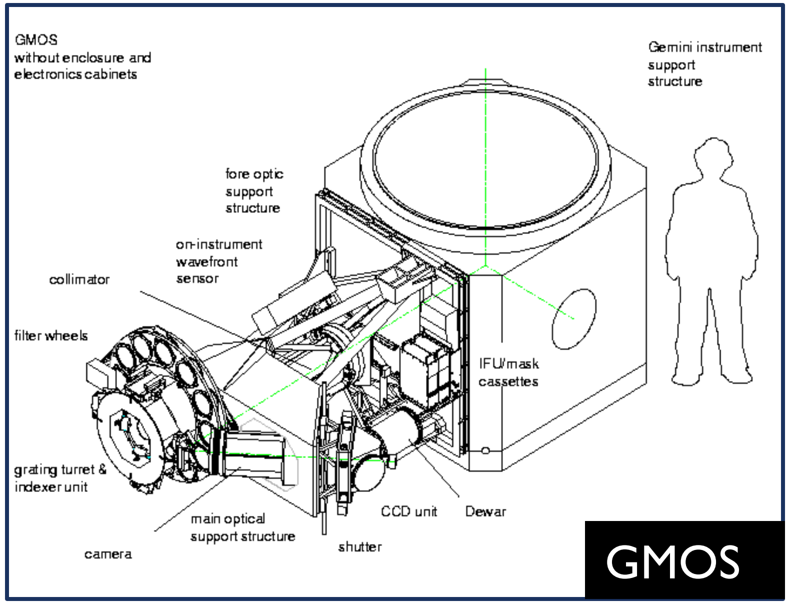
Broad-line velocity offset – BBH?



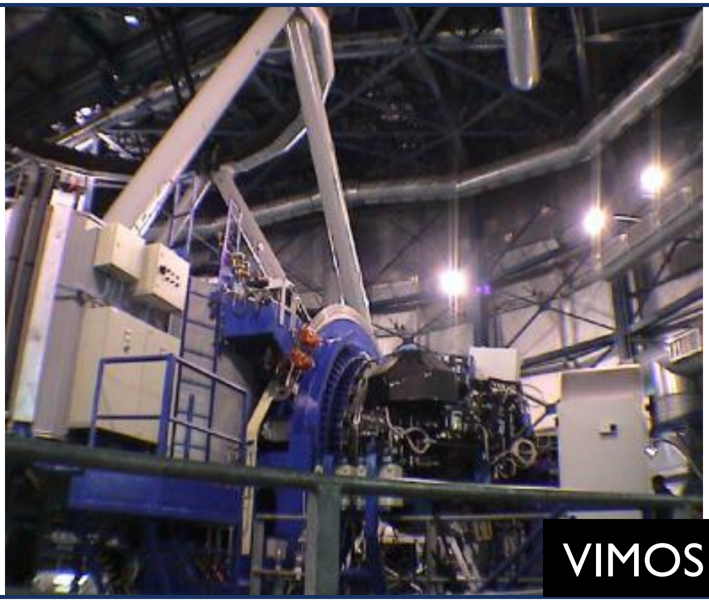
Recoiling supermassive black hole scenario



1. Rotating Binary Black Holes (BBHs)?
2. Combination of inflow + outflow?
3. 2 distinct BLRs with recoiling SMBH (rSMBH)?
4. Something else?



GMOS


VIMOS

INSTRUMENTS USED

VIMOS (VIsible Multi-Object Spectrograph)

- Visible (360 to 1000 nm) wide field imager and multi-object spectrograph.
- Four identical arms with each having FOV 7' x 8' with a 0.205" pixel size.
- Spectral resolution range from ~200-2500.
- Three modes: Imaging (**IMG**), Multi-Object Spectroscopy (**MOS**),and with Integral Field Unit (**IFU**).

GMOS (2 x Gemini Multi-Object Spectrograph)

- Visible (360 to 1030 nm) long-slit and multi-slit spectroscopy
- The Nod-and-Shuffle mode enable superior sky subtraction, is available with both GMOS-N and GMOS-S in most spectroscopic modes.
- Same modes as in VIMOS.

ANALYTICAL STEPS FOR MRK 1018

Reduced data-cubes have two positional-dimensions and one spectral-dimension from IFU Imaging modes in both VIMOS and GMOS.

VIMOS

Epochs 1-19 from **August 2016 – August 2017**

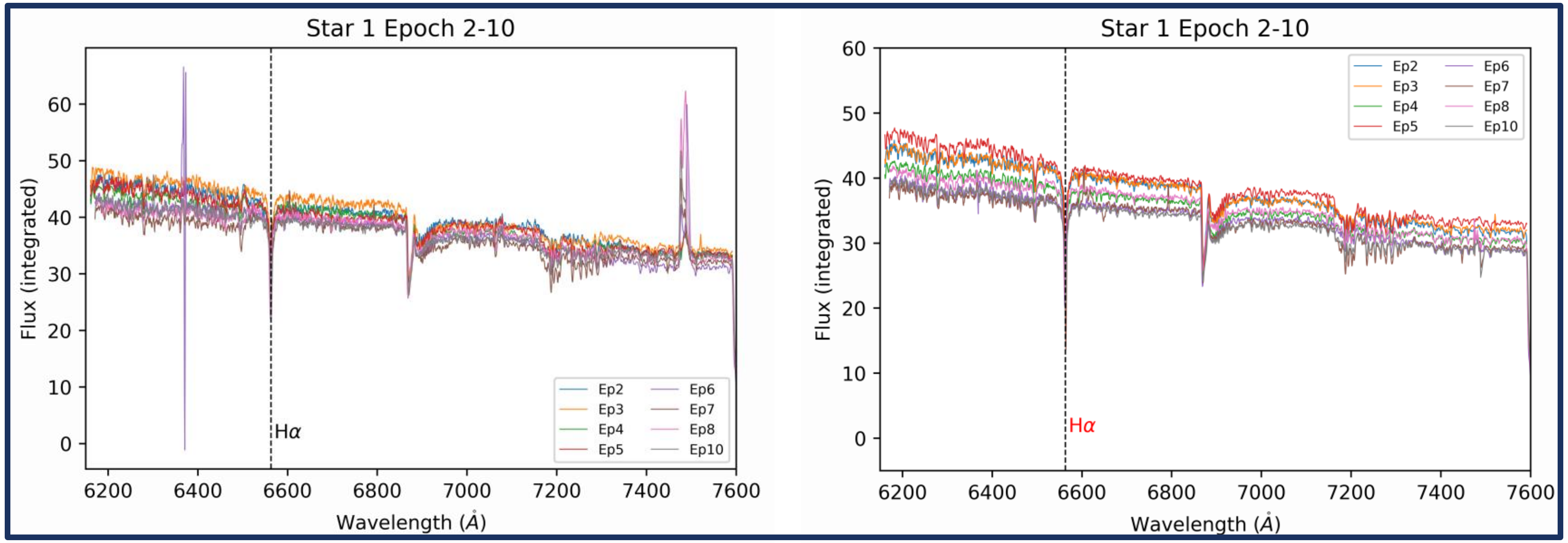
GMOS

Epochs 2-13 from **August 2017 – June 2018**

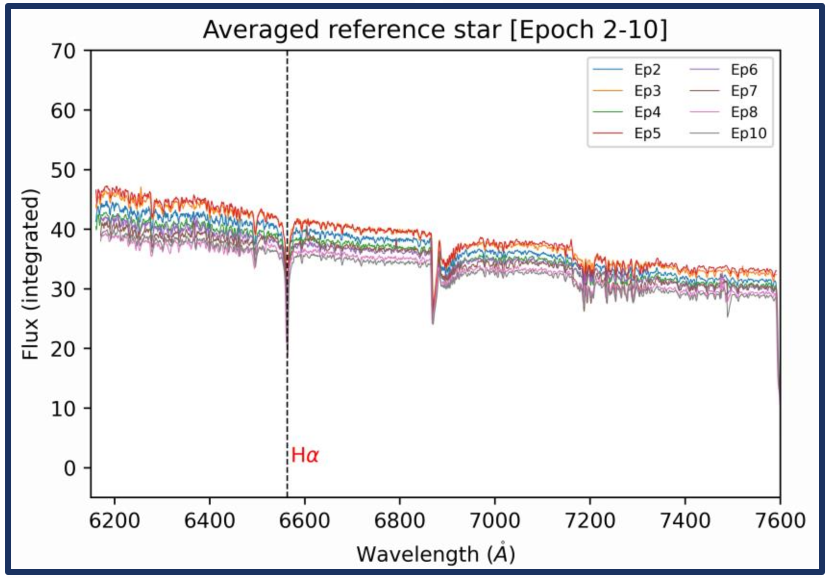
Epochs 14-21 from **October 2018 – January 2019**

1. Extracting the 2D-spectra from data-cubes and subsequent 'cleaning' of bad-pixels/noise.
2. Telluric correction with help of reference stars.
3. Absolute Spectrophotometric correction of Mrk 1018.
4. Stellar Continuum Subtraction of the host galaxy from AGN.
5. Emission-Line Fitting of Broad-Line features from H-alpha.
6. Time-delay in BLR from reverberation mapping (ongoing).

1. EXTRACTING 2D SPECTRA: REFERENCE STAR



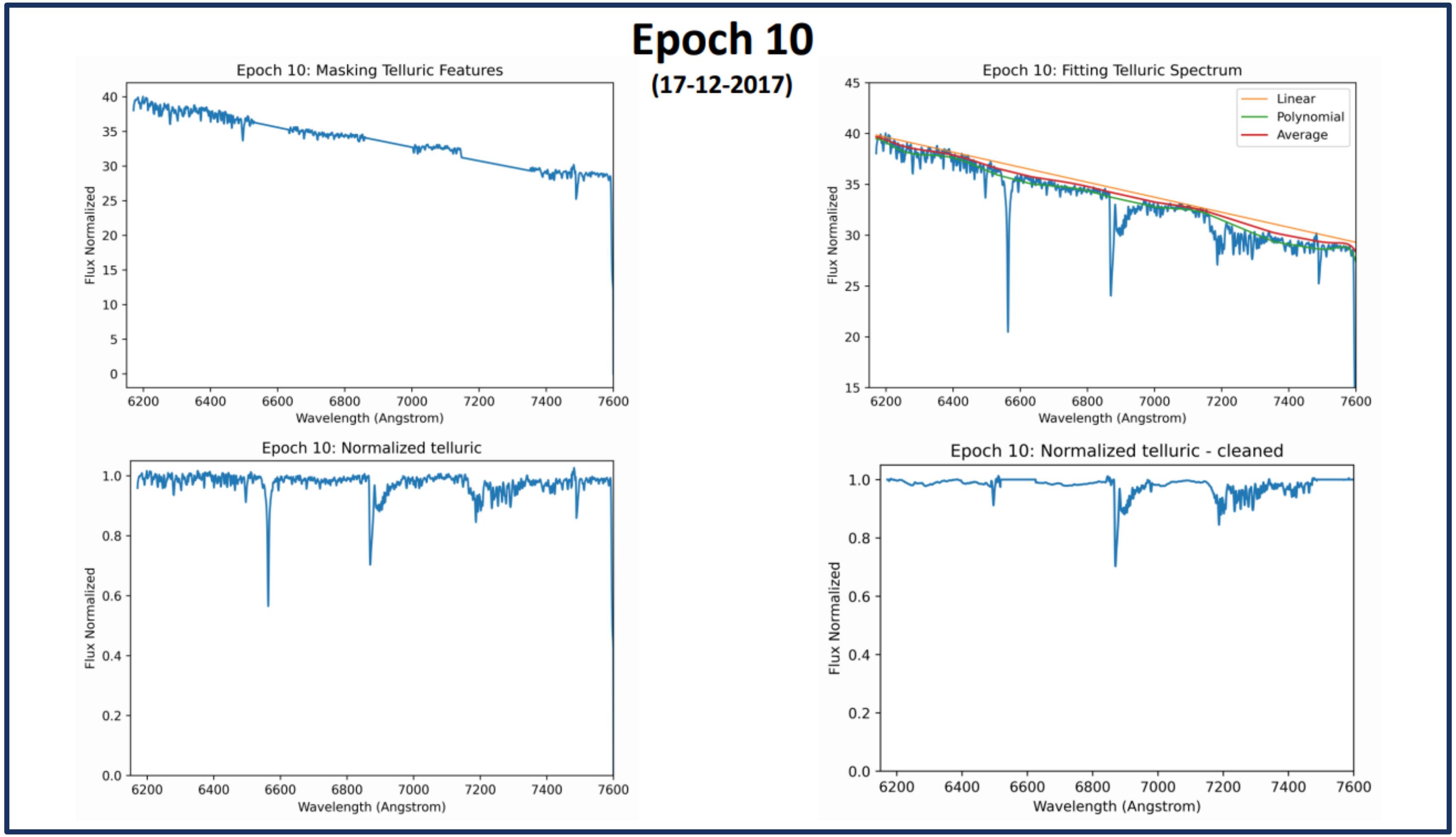
Circular aperture used to obtain integrated spectra of both star observations (before and after observing Mrk 1018) -dependent on instrument used.



Cleaned spectra are averaged and combined to have a working telluric absorption spectra for all epochs (Example below shows GMOS IFU dataset).

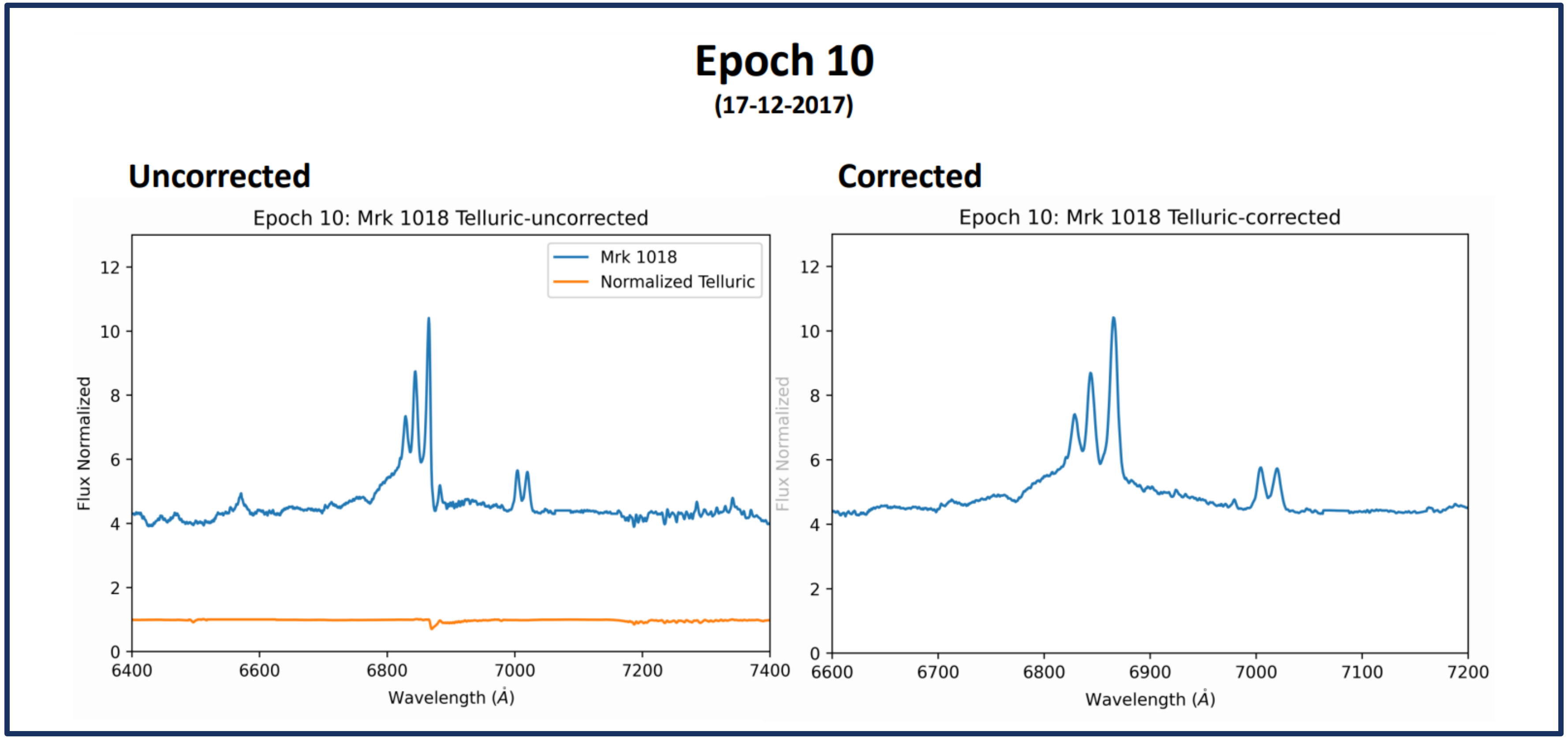
2. TELLURIC CORRECTION OF MRK 1018: NORMALIZING STAR SPECTRA

Each averaged star spectrum baseline is normalized to unity.
This is to be later scaled and subtracted from the Mrk 1018 data to correct for atmospheric contamination.



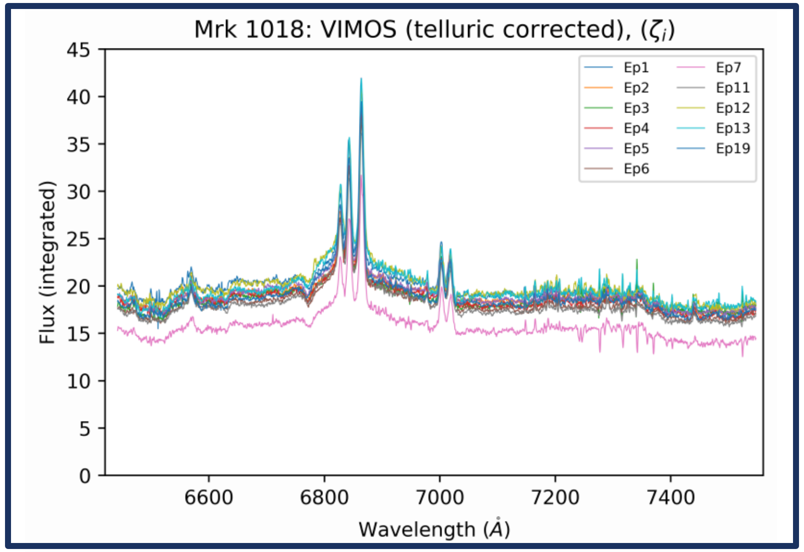
2. TELLURIC CORRECTION OF MRK 1018: CORRECTING MRK 1018

- Mrk 1018 not redshift-calibrated yet for ease of analysis.
- Scaled and subtracted from the Mrk 1018 data to correct for atmospheric contamination.

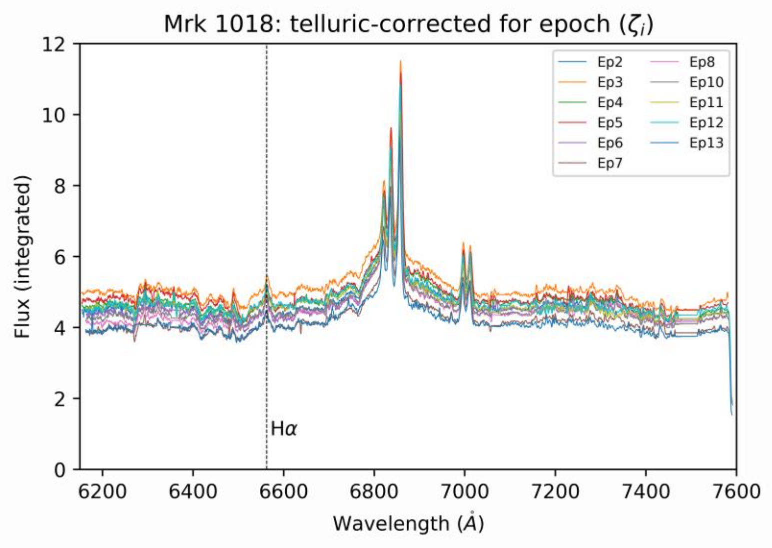


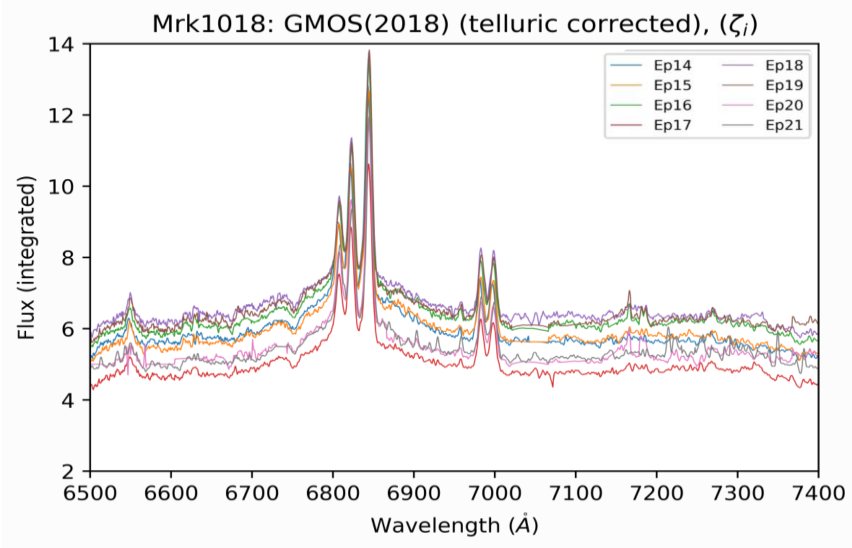
2. TELLURIC CORRECTION OF MRK 1018: CORRECTING MRK 1018

VIMOS



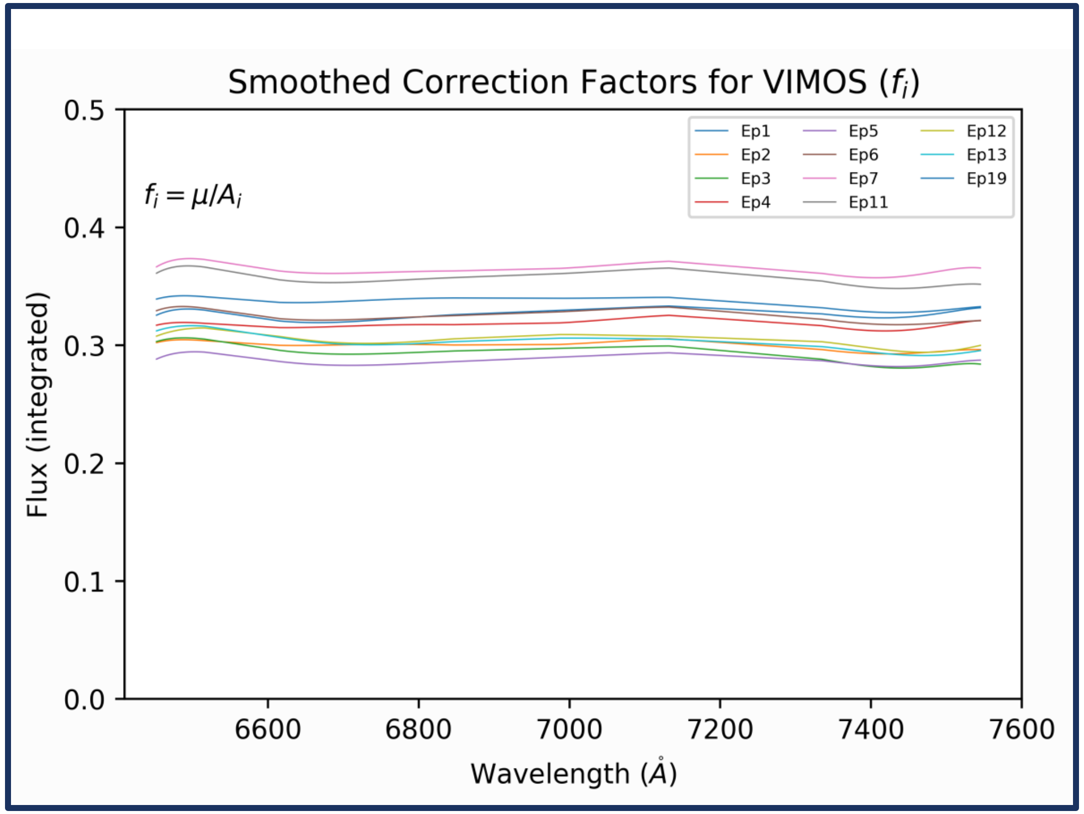
GMOS

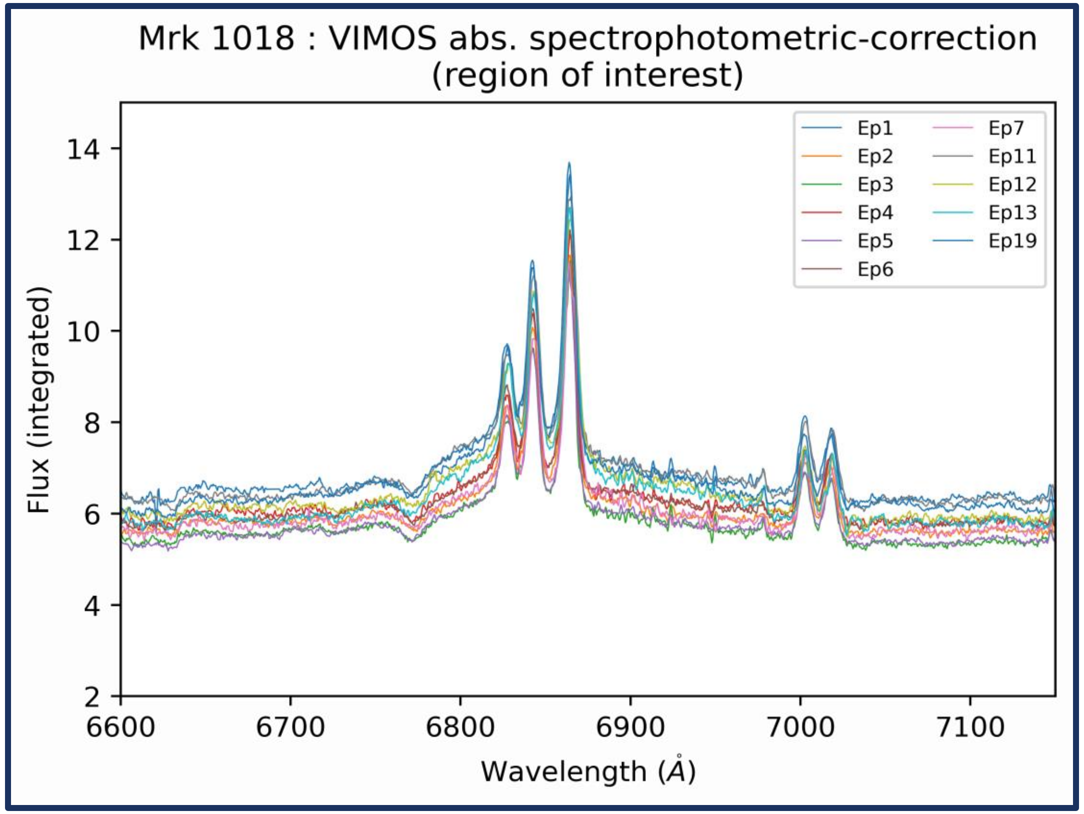




3. ABSOLUTE SPECTROPHOTOMETRIC CORRECTION OF MRK 1018

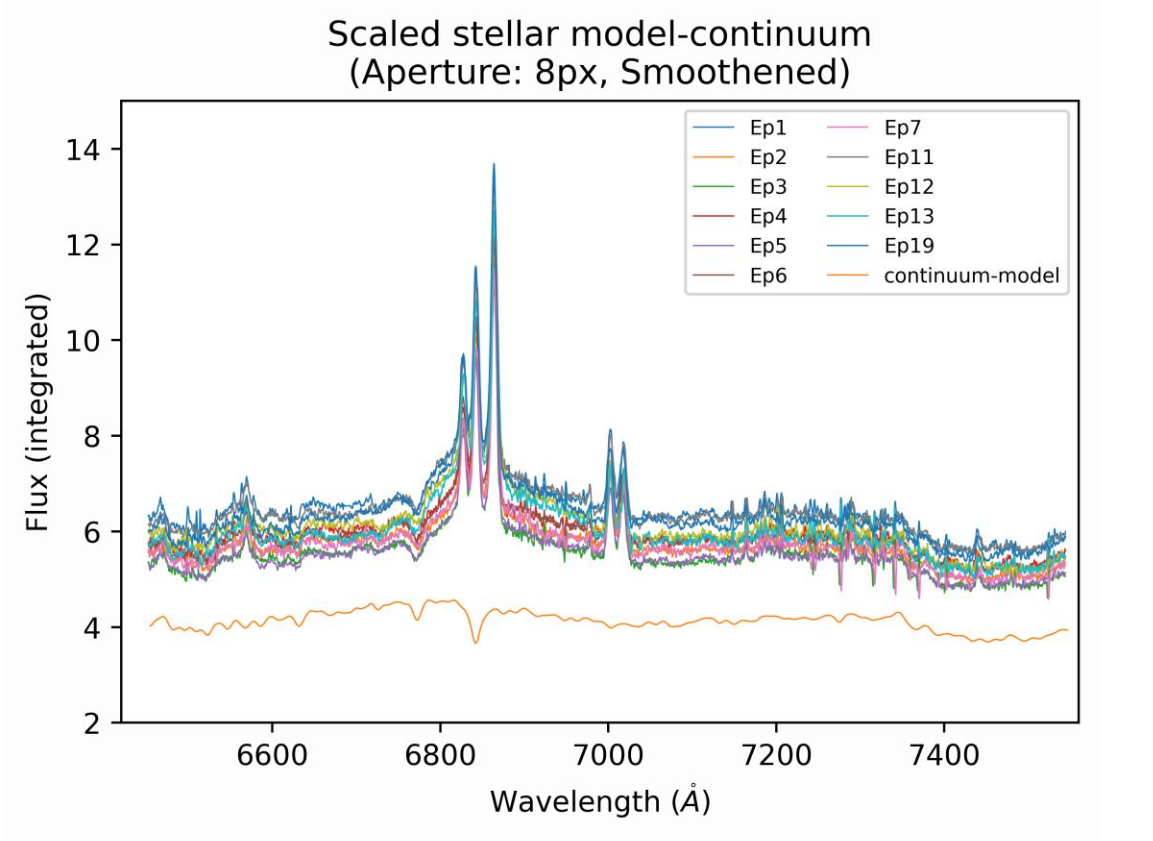
- The averaged star spectrum over all epochs is divided by individual star spectra to obtain scaling factors.
- Corrected for spectrophotometry by multiplying Mrk 1018 by the respective scaling factors.

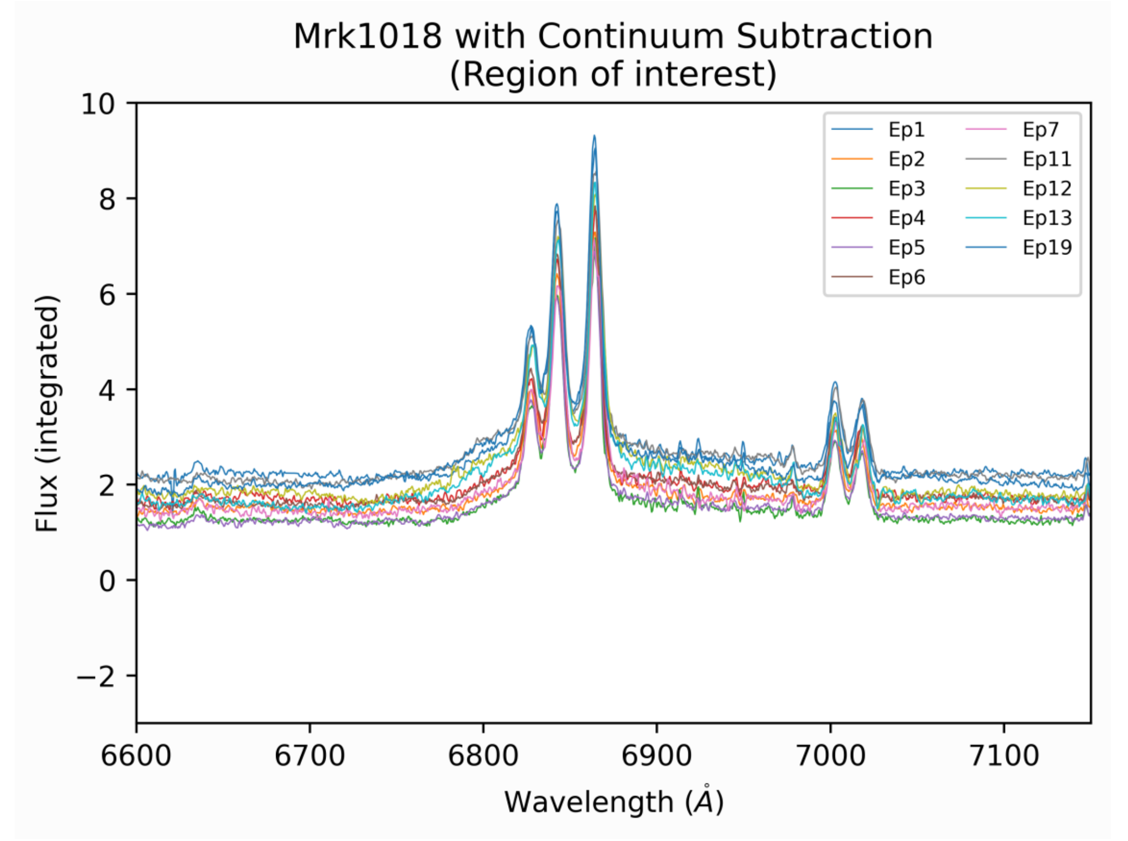




4. STELLAR CONTINUUM SUBTRACTION

- Stellar continuum model-cube (HE0203-0031) is confined to region of interest (640 – 760 nm) for Mrk 1018, which is scaled appropriately and subtracted to get rid of the stellar background from the host AGN.

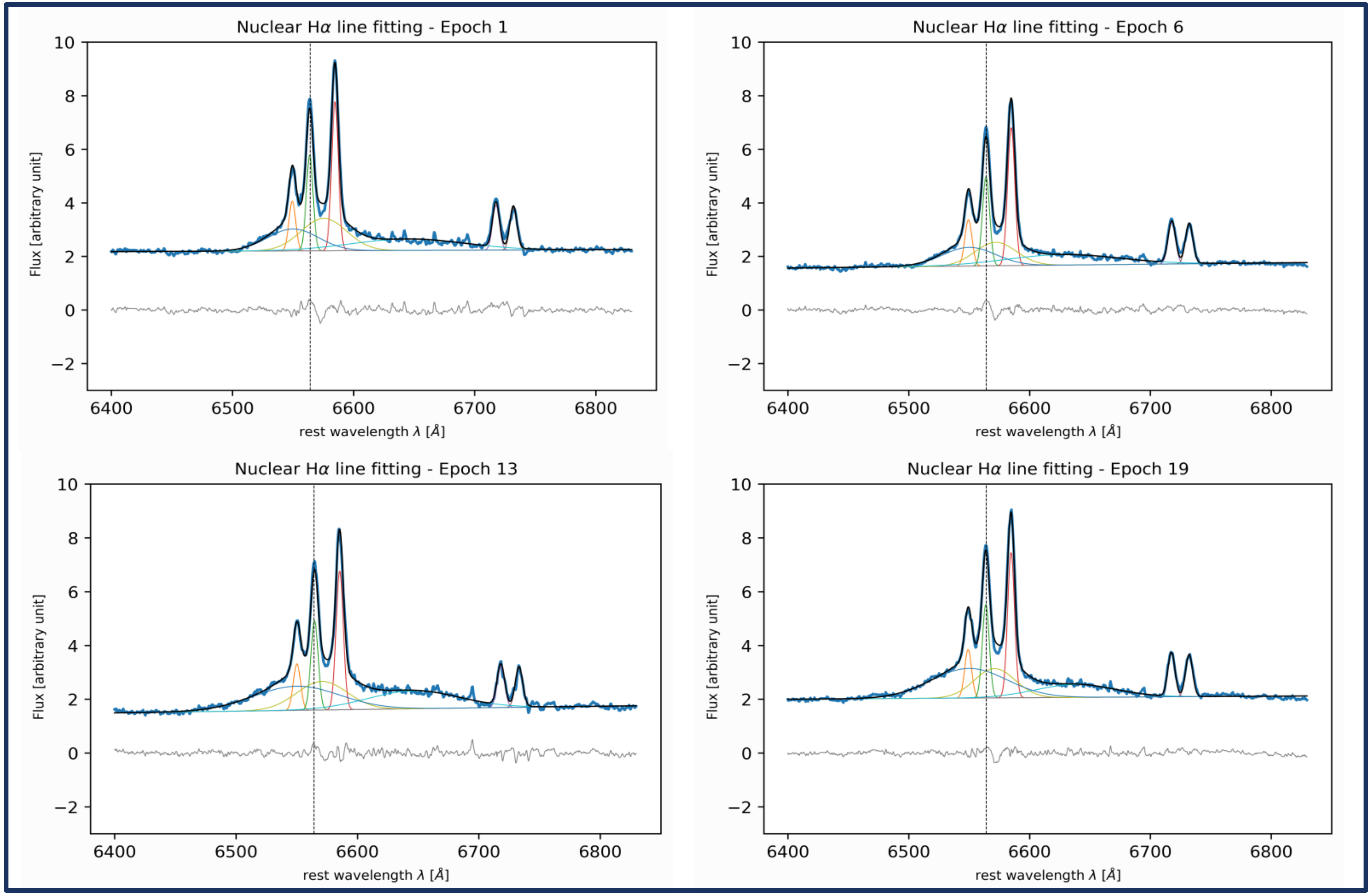




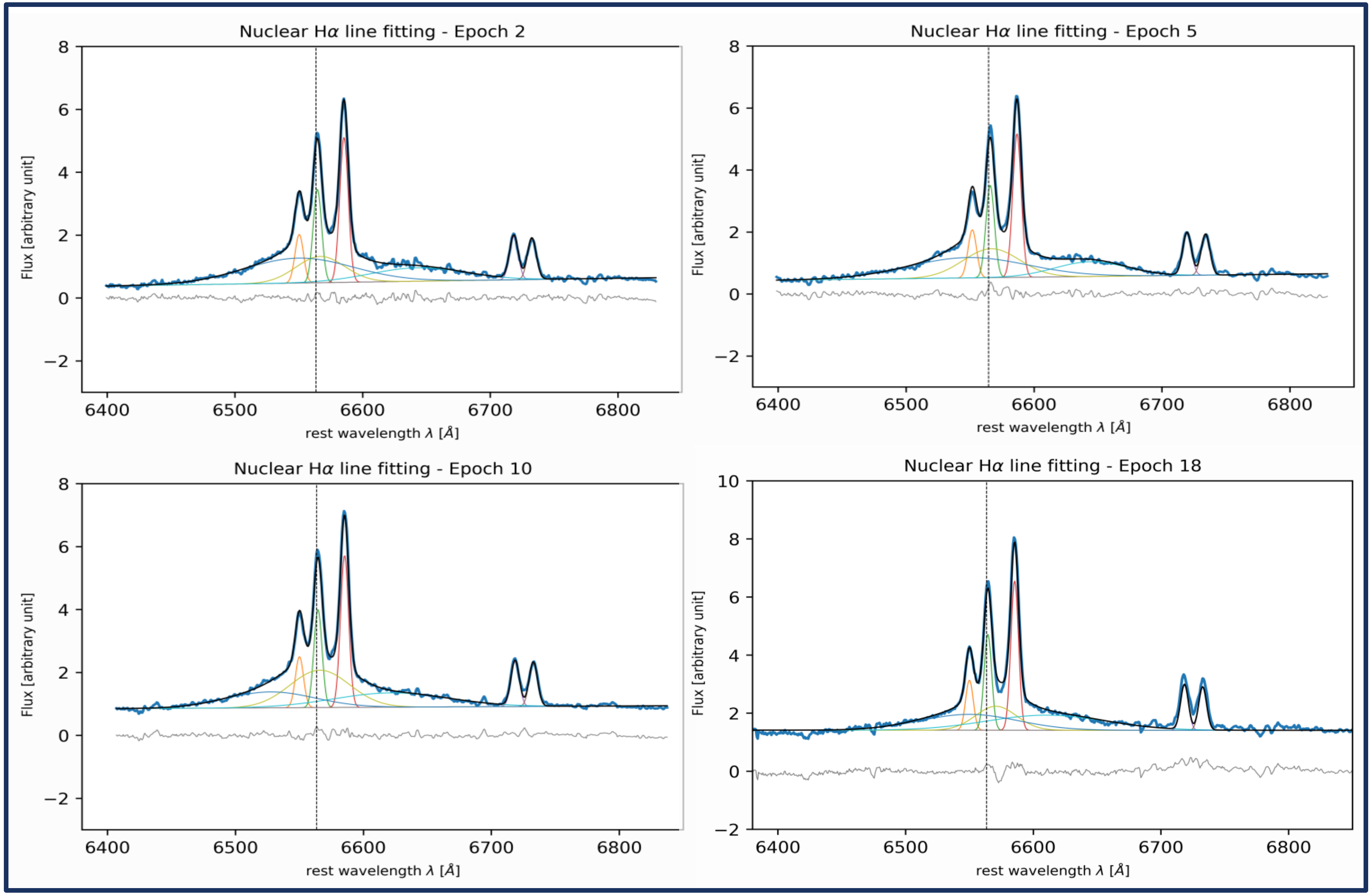
5. BROAD LINE EMISSION FITTING

- Broad-line features of Mrk 1018 can now be evaluated by fitting emission lines on the corrected data.
- Types of fits initially performed: **Lorentzian** and **Gaussian** fits on the **broad line** component of Mrk 1018.
- Two- and three-component fits are performed with both Lorentzian and Gaussian profiles. However, the difference in the fitting does not show substantial deviation from one another.
- **Gaussian fits** are more tightly bound and well-behaved. Moreover, **three components are optimal** to fully be able to explain the broad line emission profile of Mrk 1018.

5. BROAD LINE EMISSION FITTING: VIMOS BEST-FITS

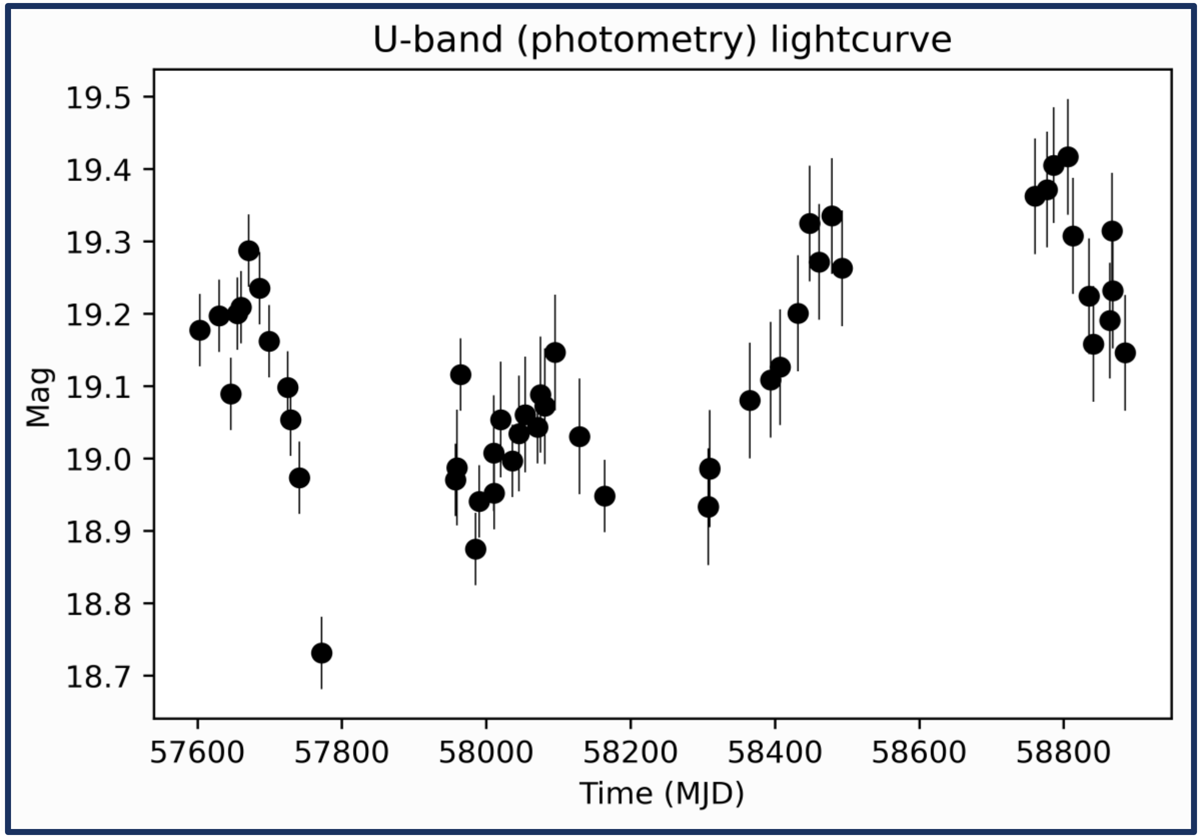


5. BROAD LINE EMISSION FITTING: GMOS BEST-FITS

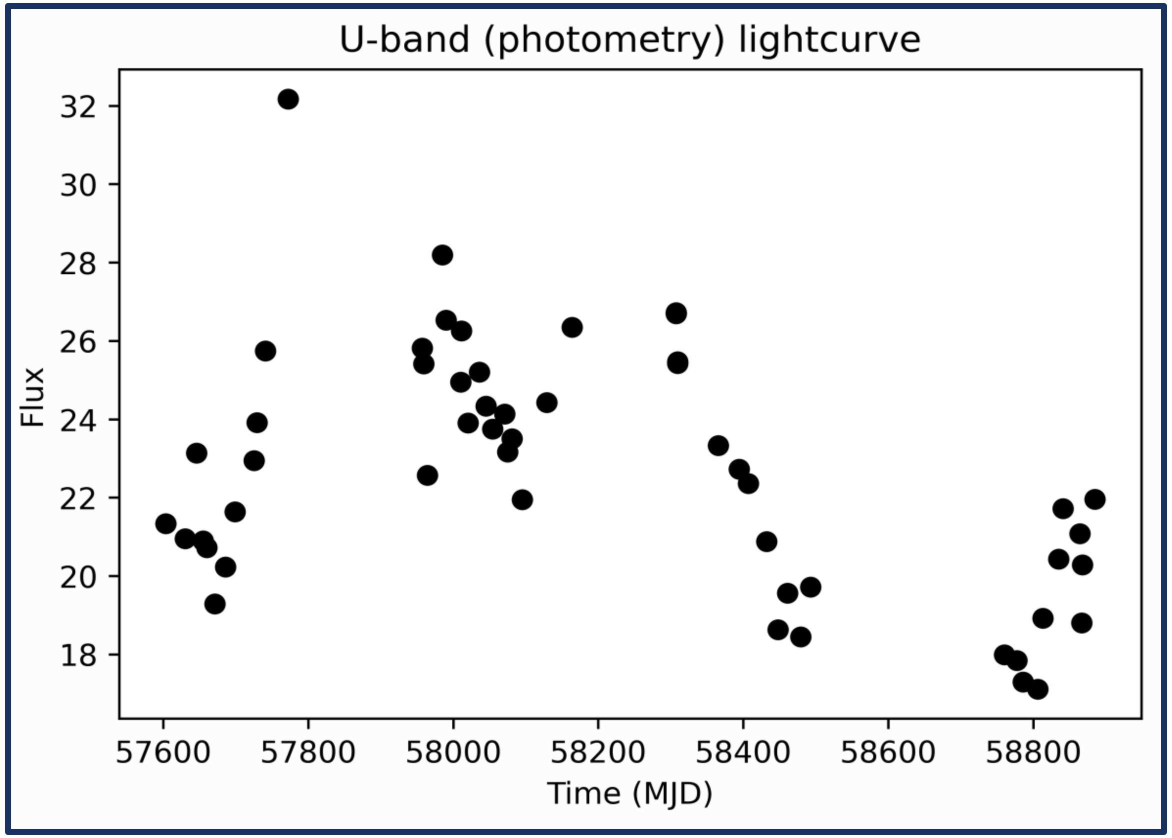


U-BAND CONTINUUM

MAGNITUDE

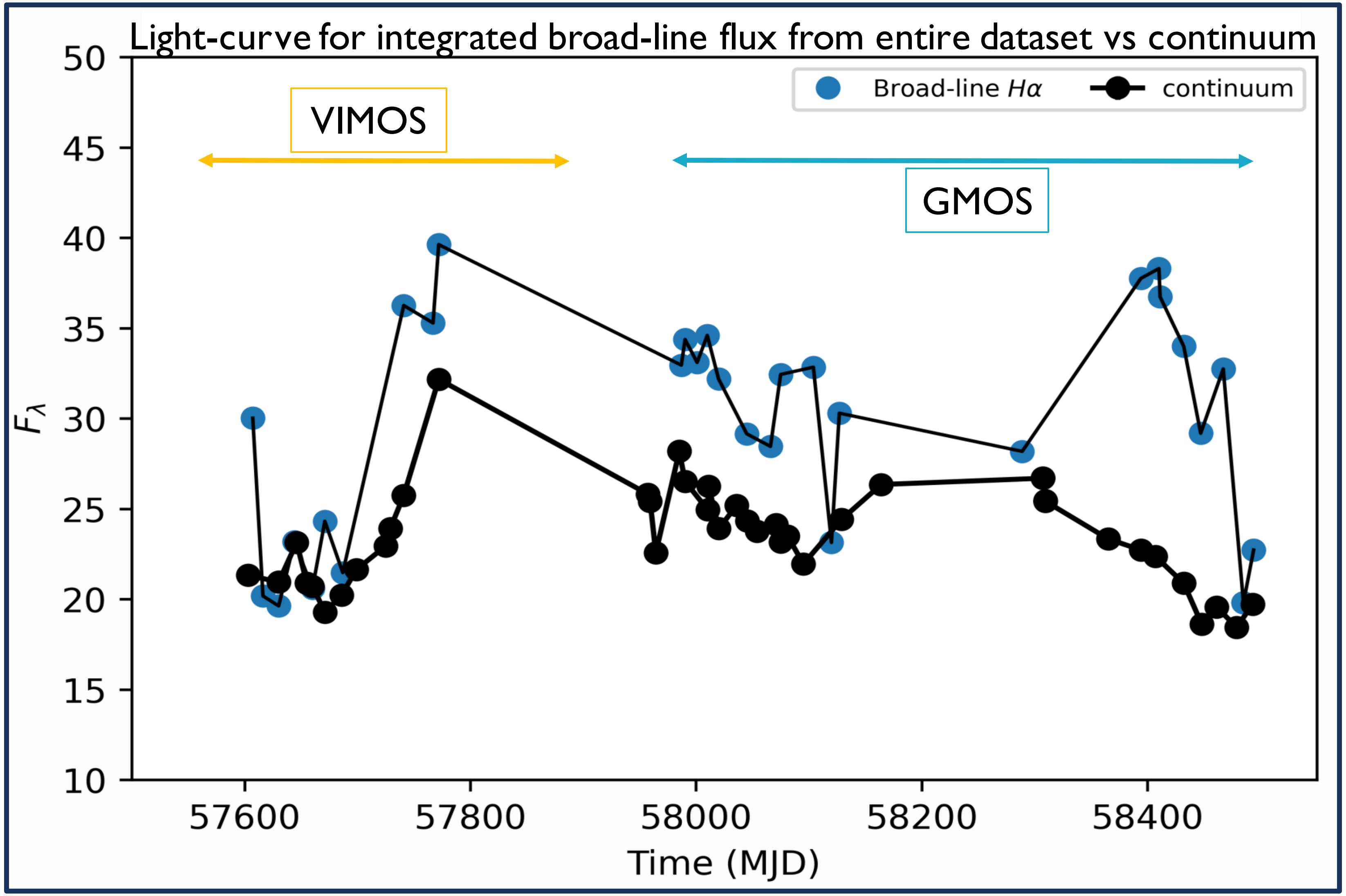


FLUX



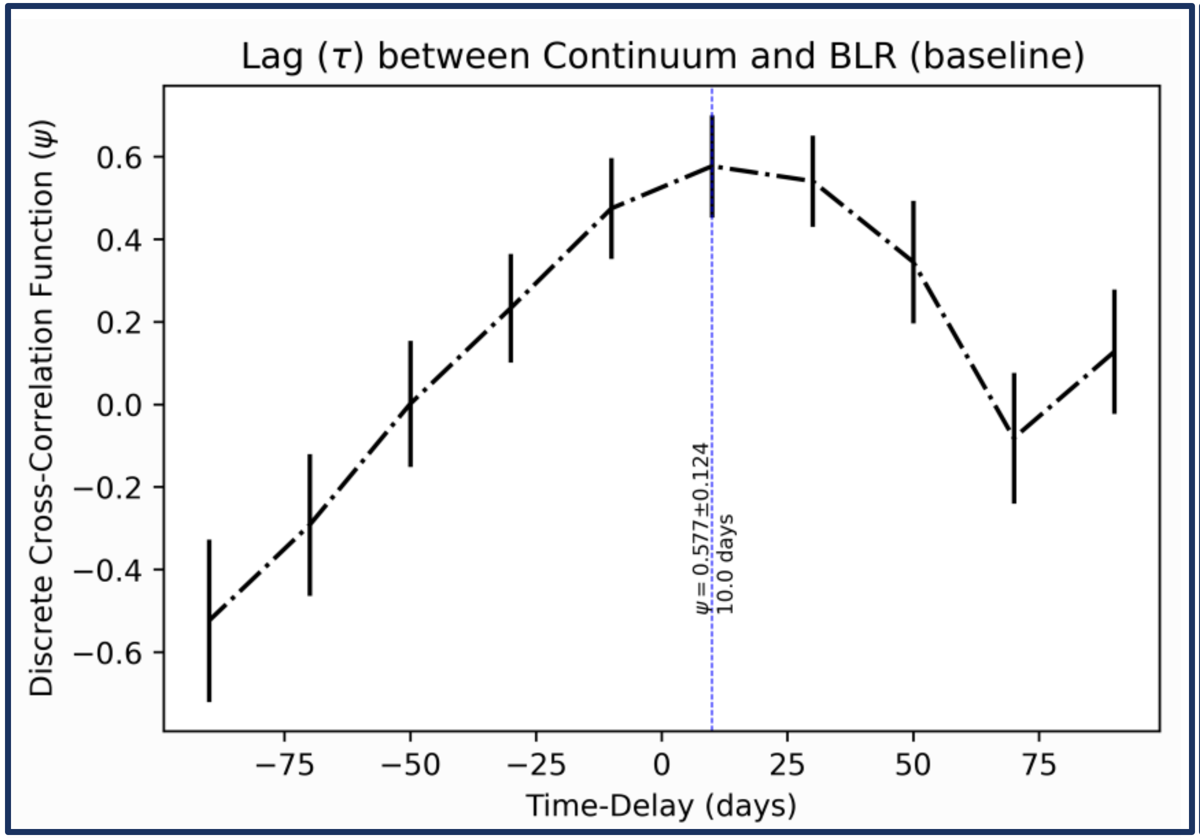
$$f = 10^{\frac{22.12 - m}{2.5}}$$

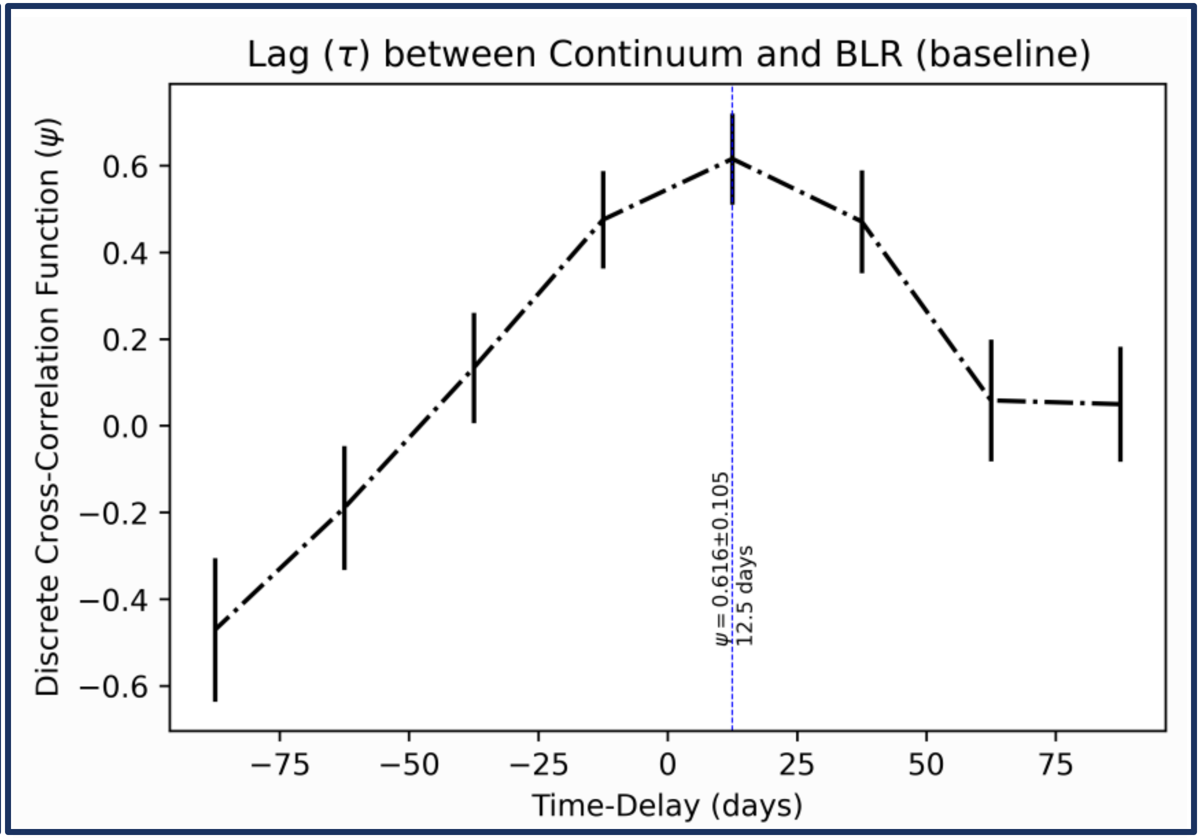
MRK 1018 BROAD-LINE Hα COMBINED (2016-2019)



6. TIME-DELAY FROM DCCF – REVERBERATION MAPPING (ONGOING)

Input parameters for binning and range give slightly varying time-delays from cross-correlation over entire baseline





REMARKS

- Mrk 1018 is a unique AGN to challenge fundamental principles of AGN physics.
- Reverberation Mapping gives an approximate **BLR radius of ~10-13 light-days**.
- Continuous monitoring from **radio to X-rays** is needed.
- Model credibility depends on **predictive power**.
- If trend follows, Mrk 1018 may become **Type-1 Seyfert again in mid 2020's?**

THANK YOU