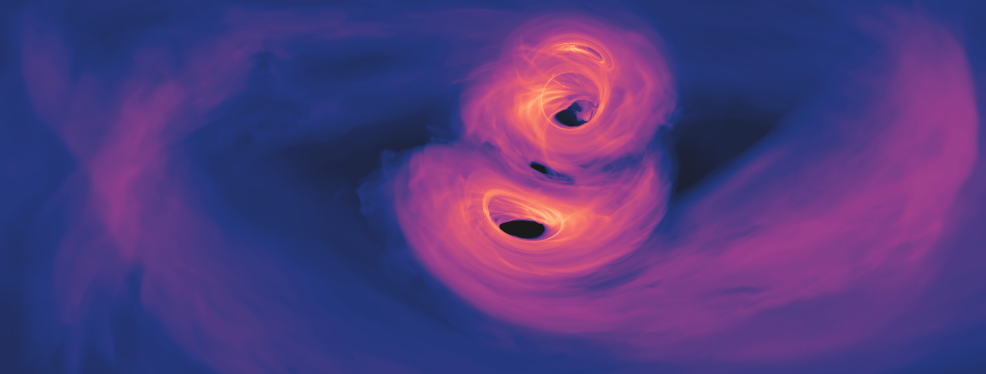
Periodic variability of Stripe 82 quasar light curves and associated changes in Mg II emission line profiles

14th Serbian Conference on Spectral Line Shapes in Astrophysics
Session: Spectral line phenomena in extragalactic objects



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Original idea: Search for small-amplitude long-term periodic variability in the SDSS Stripe 82 standards catalogue

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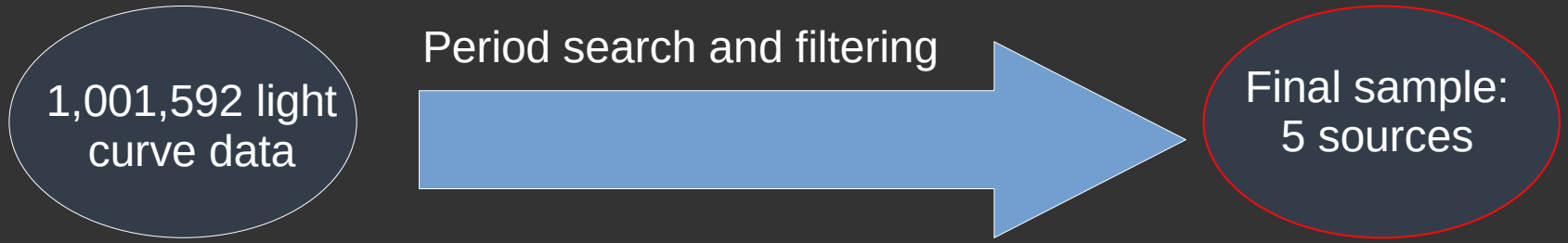
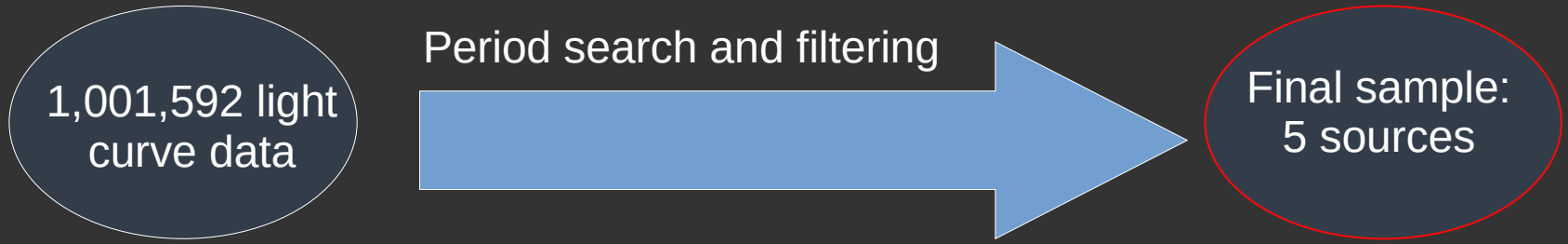
- Data:
  - SDSS Stripe 82 (York+00, Ivezić+07)
    - ($-60^\circ \leq RA \leq 60^\circ, -1.3^\circ \leq Dec \leq 1.3^\circ$)
    - Multiple visits in *ugriz* filters over 9 years
    - Enables the construction of the light curves
    - Photometric precision and long baseline
  - Standards catalogue: 1,001,592 sources (Thanjavur+21)

The results:


1,001,592 light curve data
Period search and filtering
Final sample: 5 sources

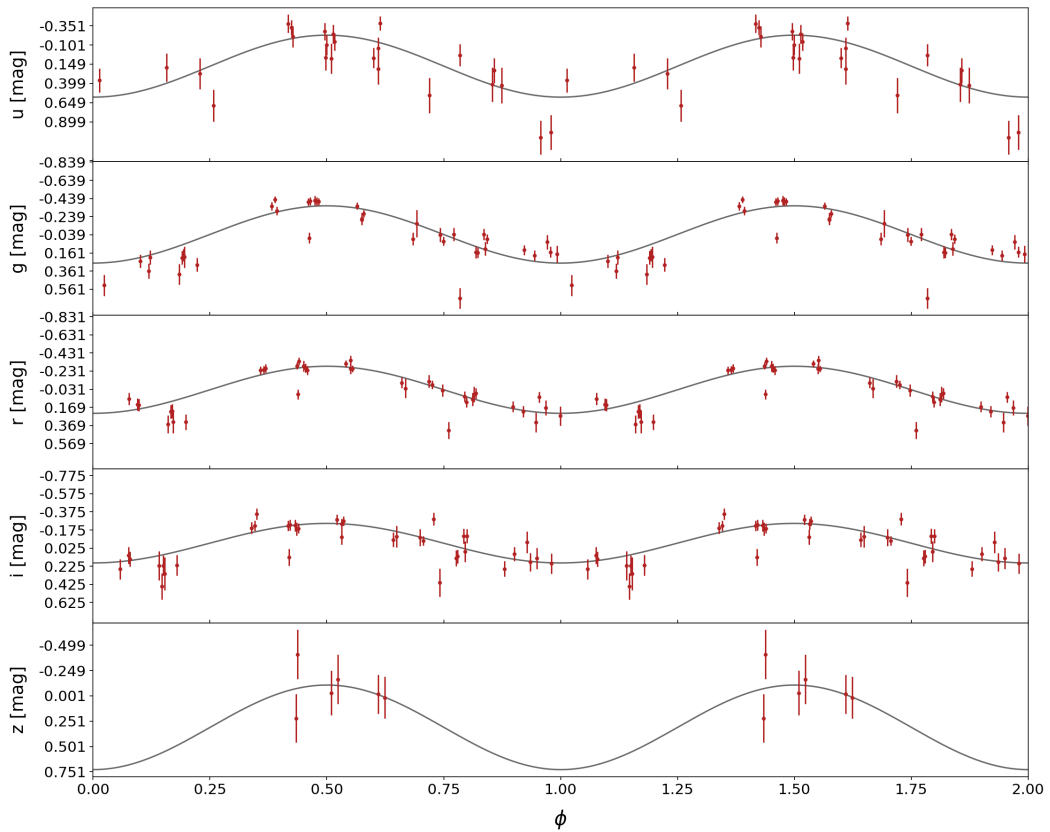
The results:

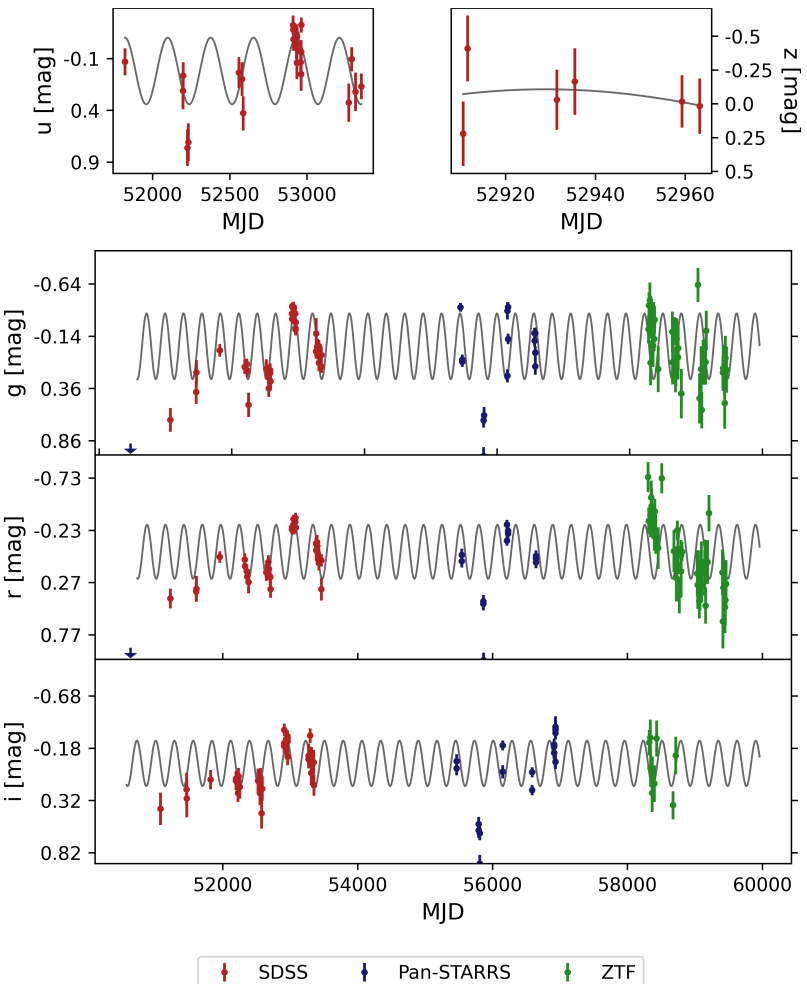


All 5 sources have SDSS spectra consistent with quasar spectra!

Representative candidate periodically variable quasar

P = 278 days → confirmed with MC simulations (Tisanić, K. et al., in prep) and 2D Hybrid method (Kovačević +18, +19, +20)





What could cause periodic behaviour in quasars?

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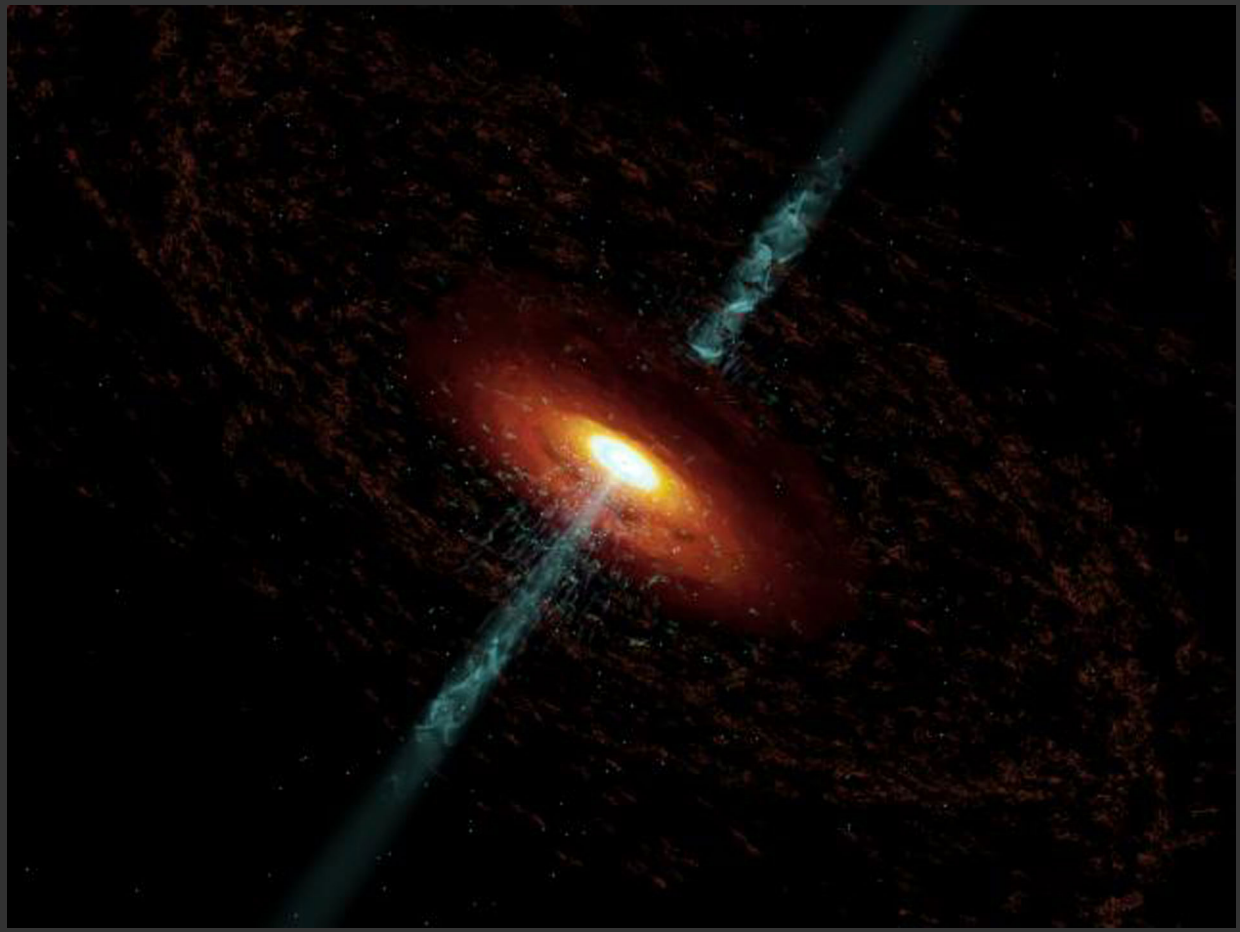
- Jet related

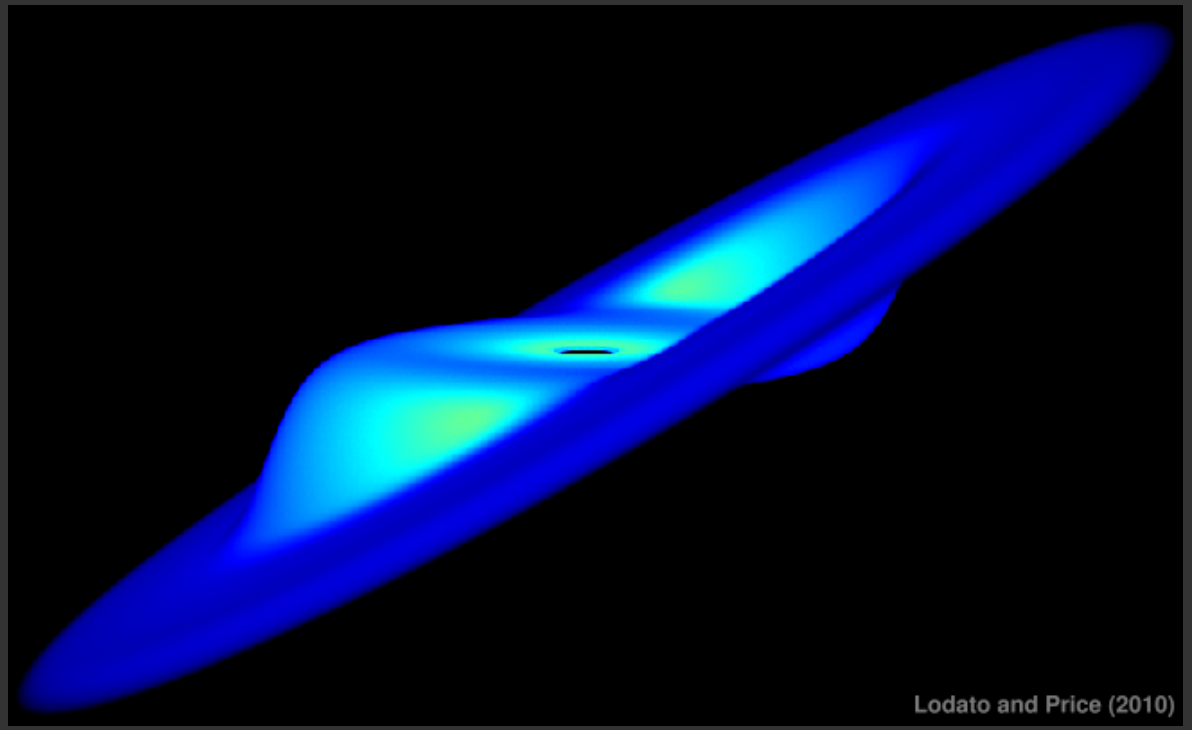
(Fan+02,Kudryavtseva+11)



What could cause periodic behaviour in quasars?

- Jet related
- Warped accretion disk

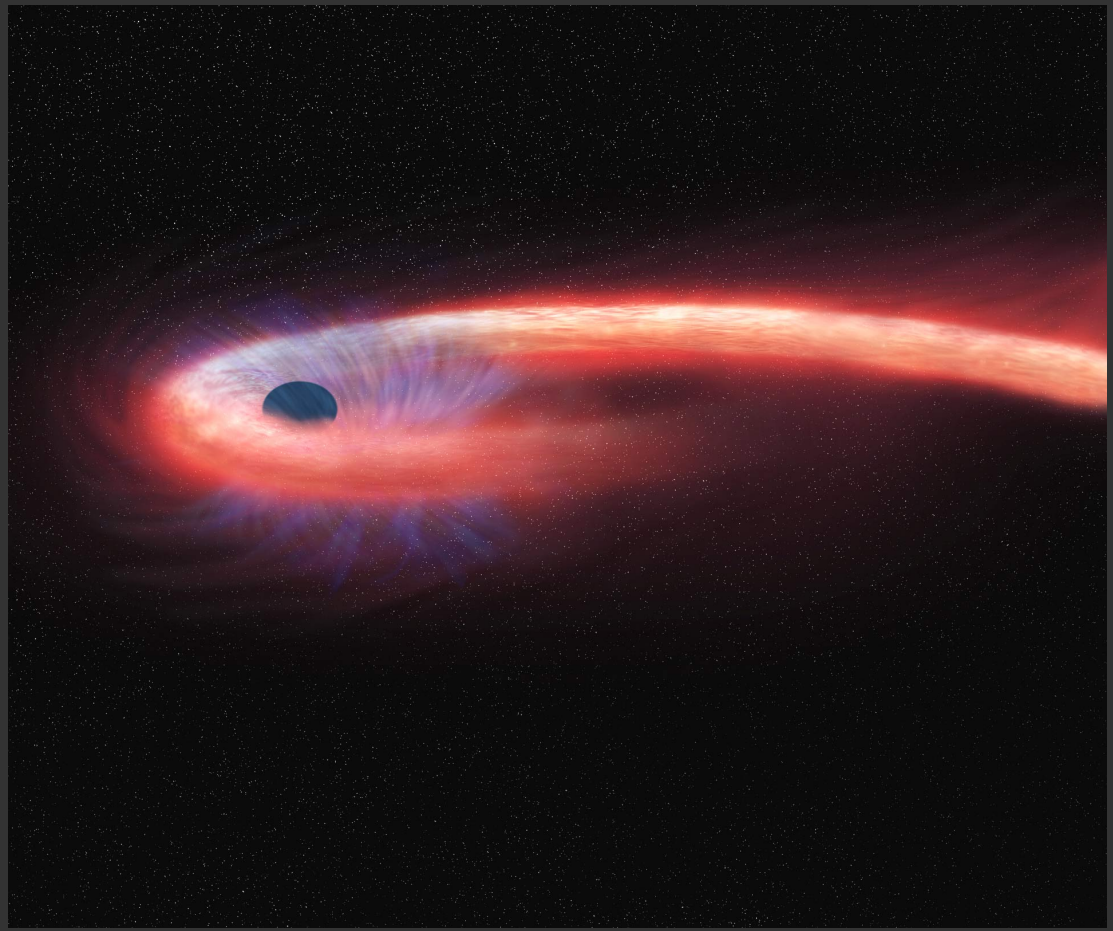
(Greenhill+03, Herrnstein+05)



What could cause periodic behaviour in quasars?

- Jet related
- Warped accretion disk
- Tidal distruption events

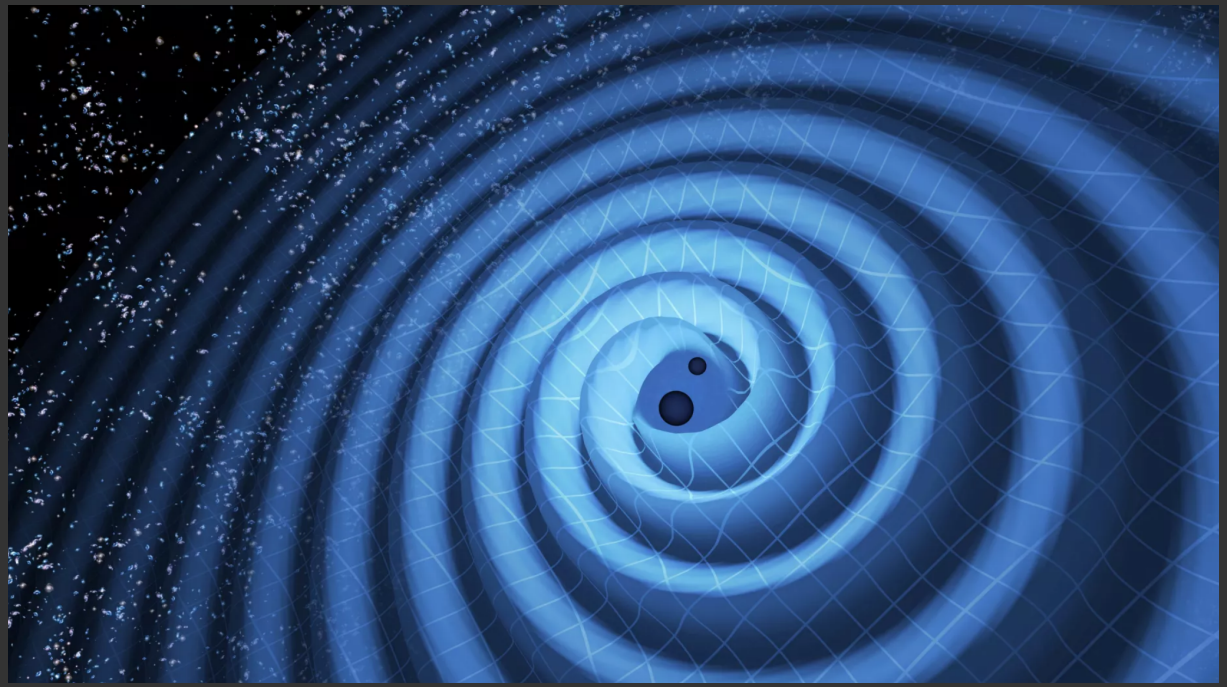
(Komossa&Greiner+99, Mandel&Levin+15)



What could cause periodic behaviour in quasars?

- Jet related
- Warped accretion disk
- Tidal distruption events
- Binary black hole system

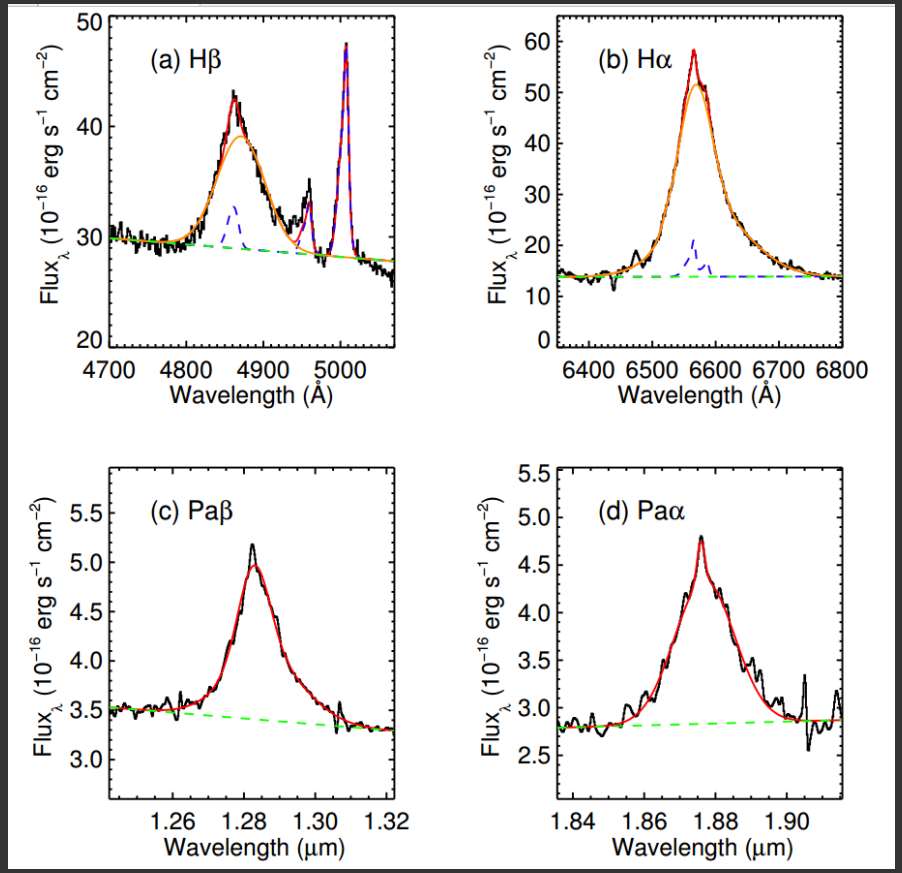
(Sillanpää+96, Graham+15**)**



What could cause periodic behaviour in quasars?

Binary black hole system

- Double peak in spectrum lines



(Graham+15)

What could cause periodic behaviour in quasars?

- Jet related
- Warped accretion disk
- Tidal distruption events
- Binary black hole

OR A COMBINATION!

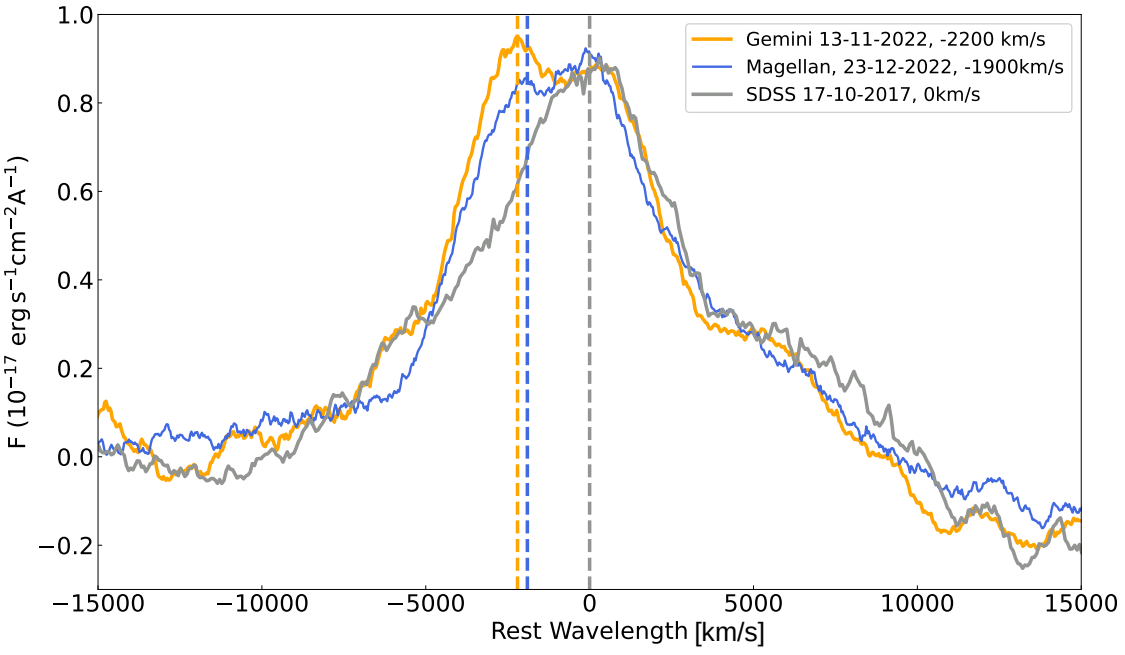
What about “our” quasar?

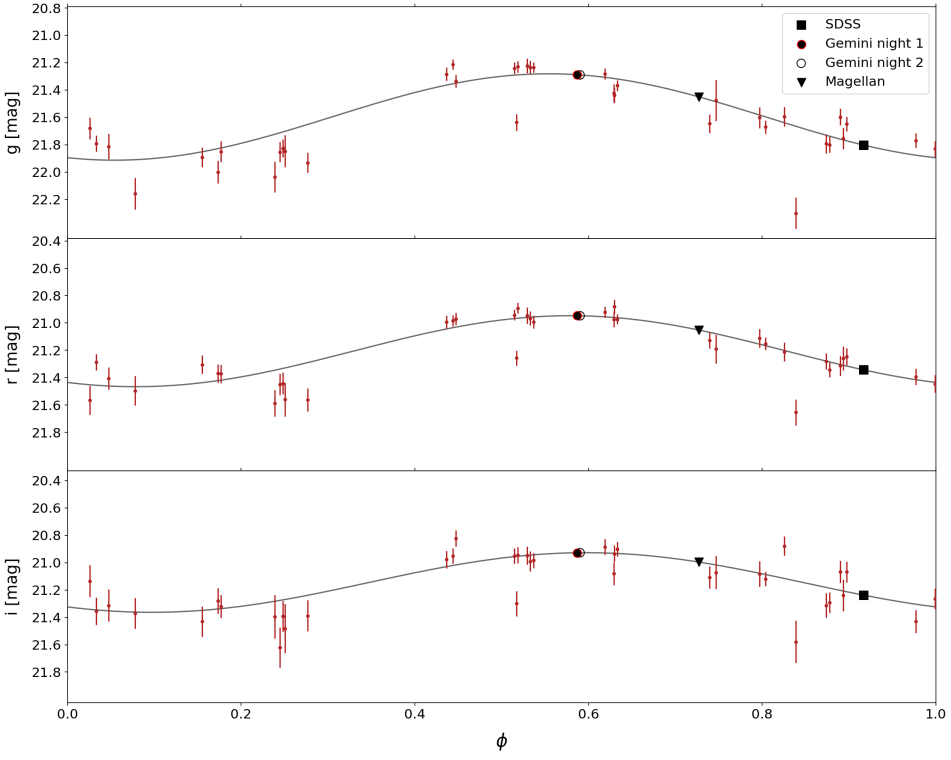
Recent observations of MgII line

Gemini South: November 13th-14th 2022

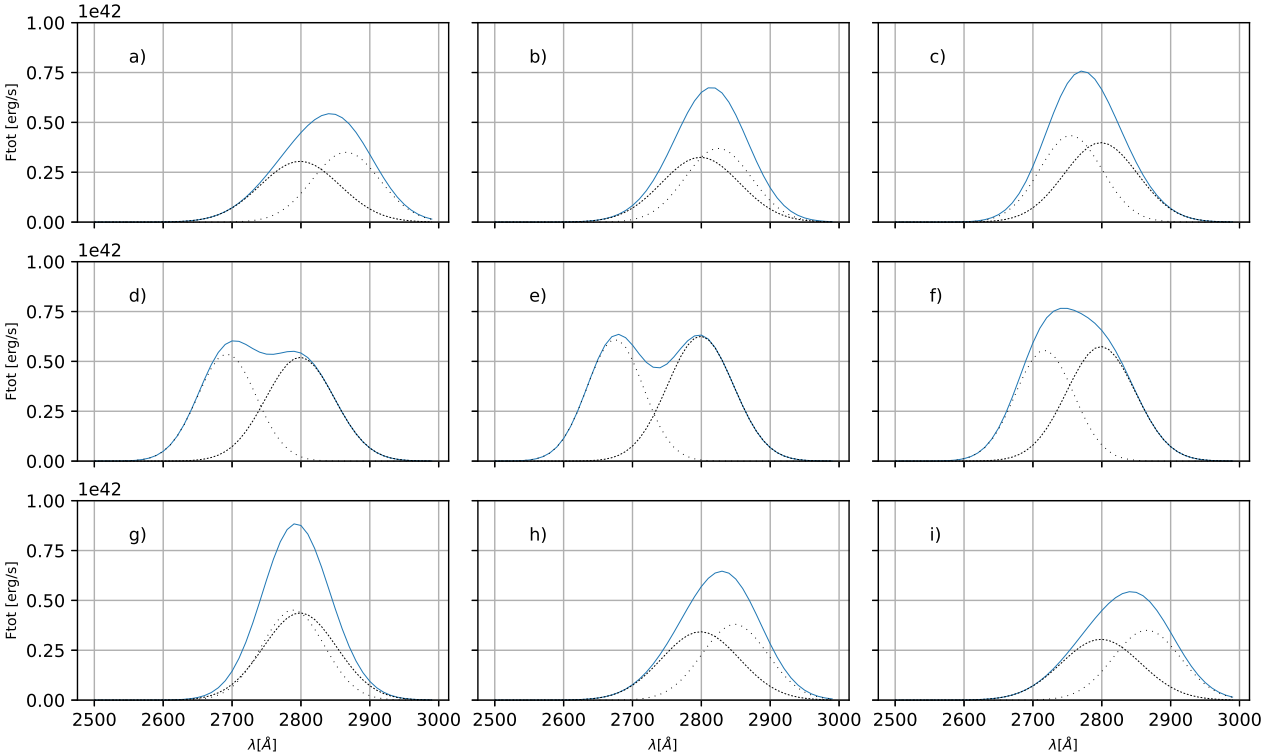
Magellan: December 22nd 2022

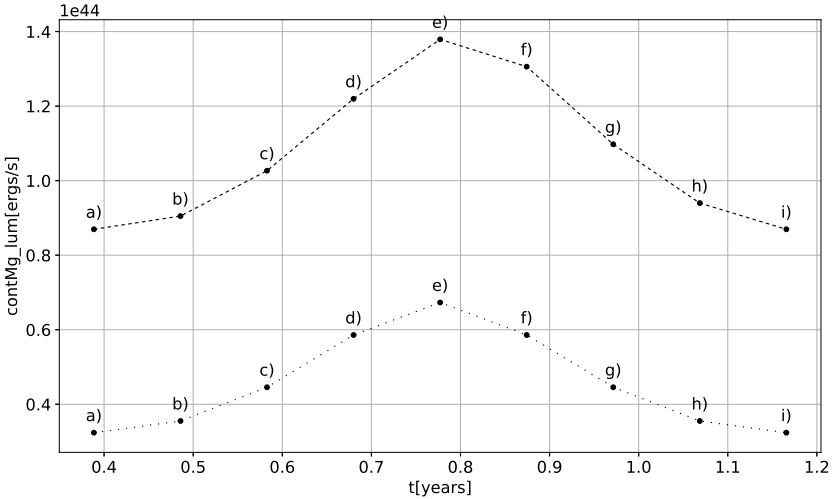
Recent observations of MgII line





Model (PoSKI) $m_1 = 10^7 M_\odot$, $m_2 = 10^8 M_\odot$, R = 0.002pc





- Shape of the MgII line for different phases during full orbit of the binary system.
- **Solid line**: total line flux, **dashed line**: contribution from cBLR, **dotted line**: contribution from BLR_1.

- Variability of continuum (dotted line) and MgII line (dashed line) during full orbit of the binary system.

Summary:

- 5 quasars with plausible periodically variable behaviour
- We chose a representative
- Follow up after observation campaign
- Strong asymmetry in MgII line – possible binary black hole system?

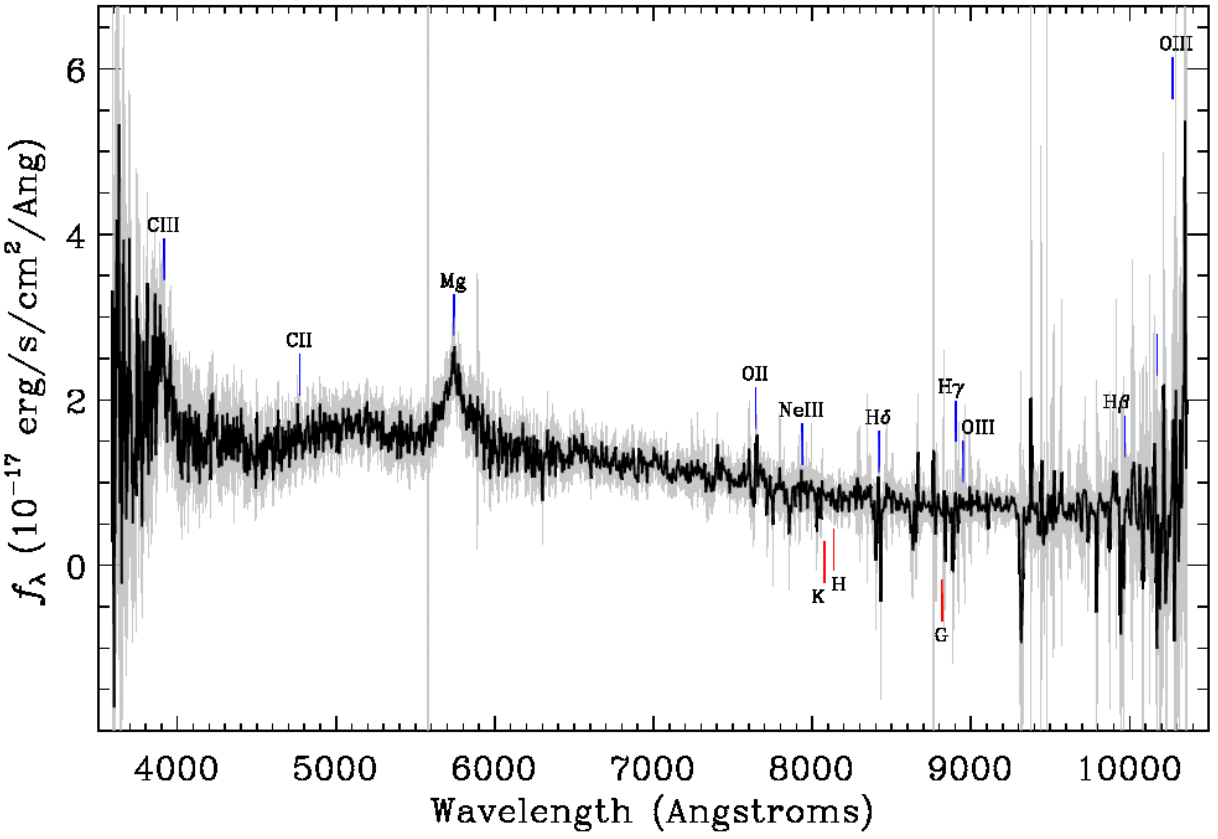
Thank you!

List of background figures references:

- NASA's Goddard Space Flight Center
- SDSS (New Mexico, USA; image source: https://sloan.org)
- Cosmovision (led by Dr. Wolfgang Steffen of the Instituto de Astronomia, UNAM, Ensenada, Mexico) for A. Marscher; NRAO/AUI/NSF
- Lodato and Price 2010
- NASA / CXC / M. Weiss
- LIGO/ T. Pyle
- Gemini Observatory/AURA
- Magellan Telescopes. (2023, February 10). In Wikipedia. https://en.wikipedia.org/wiki/Magellan_Telescopes

Additional slides

SDSS spectrum of a candidate periodically variable quasar



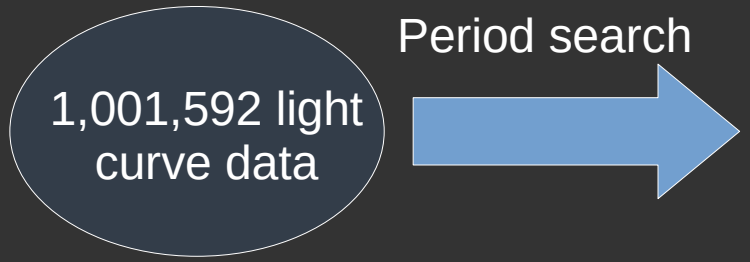
Dawson+13 , Dawson+16

The procedure:

1,001,592 light curve data

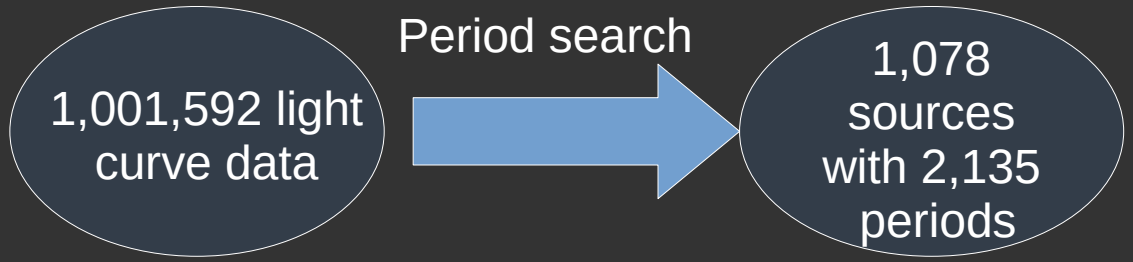
- Initial dataset of Stripe 82 standards

The procedure:

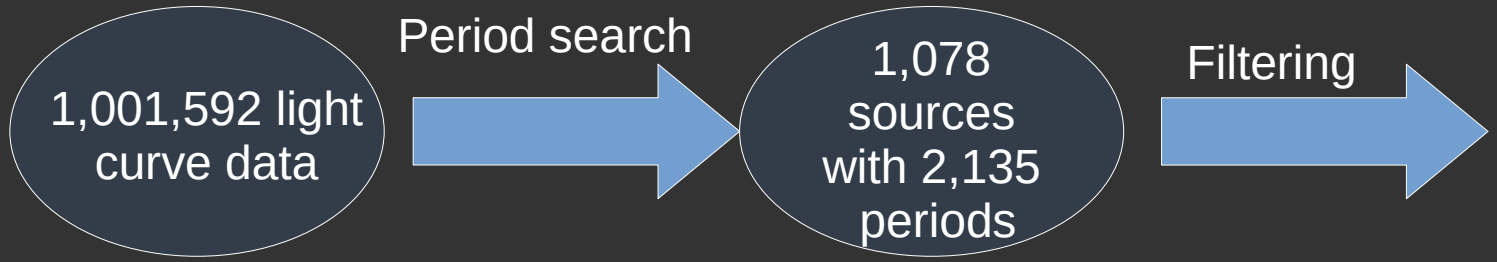


- Condition: N>25/band
- Lomb-Scargle periodogram
  - Using only *gri* filters
- Retained 3 highest peaks in the periodogram of *gri* bands for each source
- Condition: each of the *gri* periods per source agree to within 0.1%

The procedure:

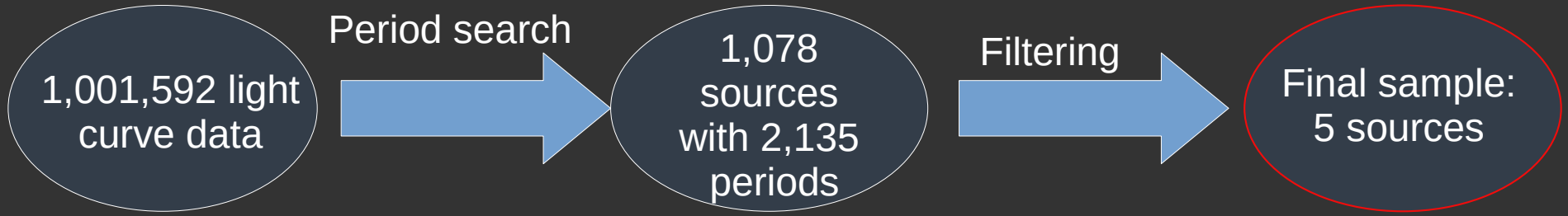


The procedure:

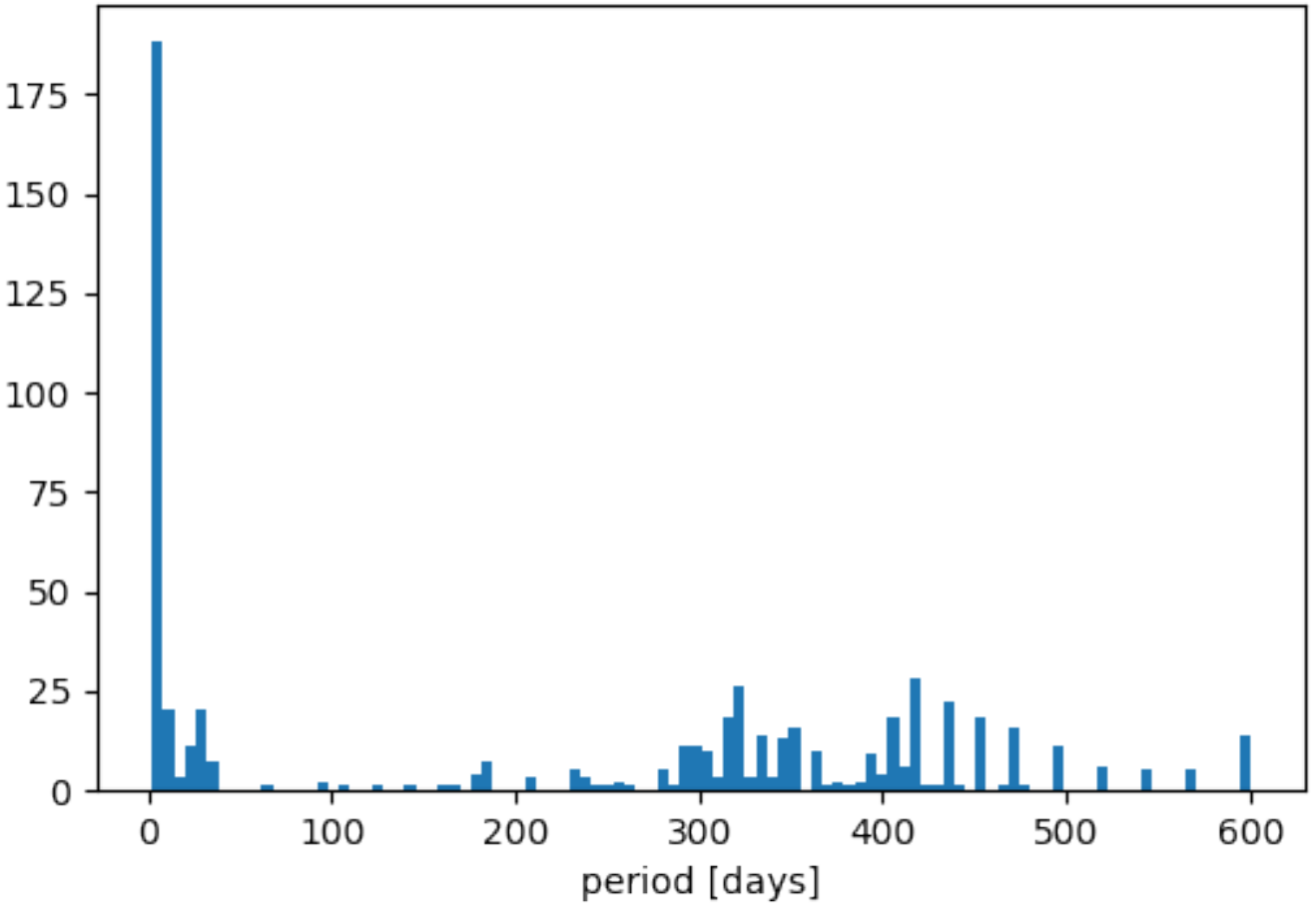


- Checked the deviation from the sinusoidal model
- Cleaned aliases
- Limit to $P \in [100d,600d]$
- Requirement: complete phase coverage
- MC simulations: derive σ_P

The procedure:



Aliases



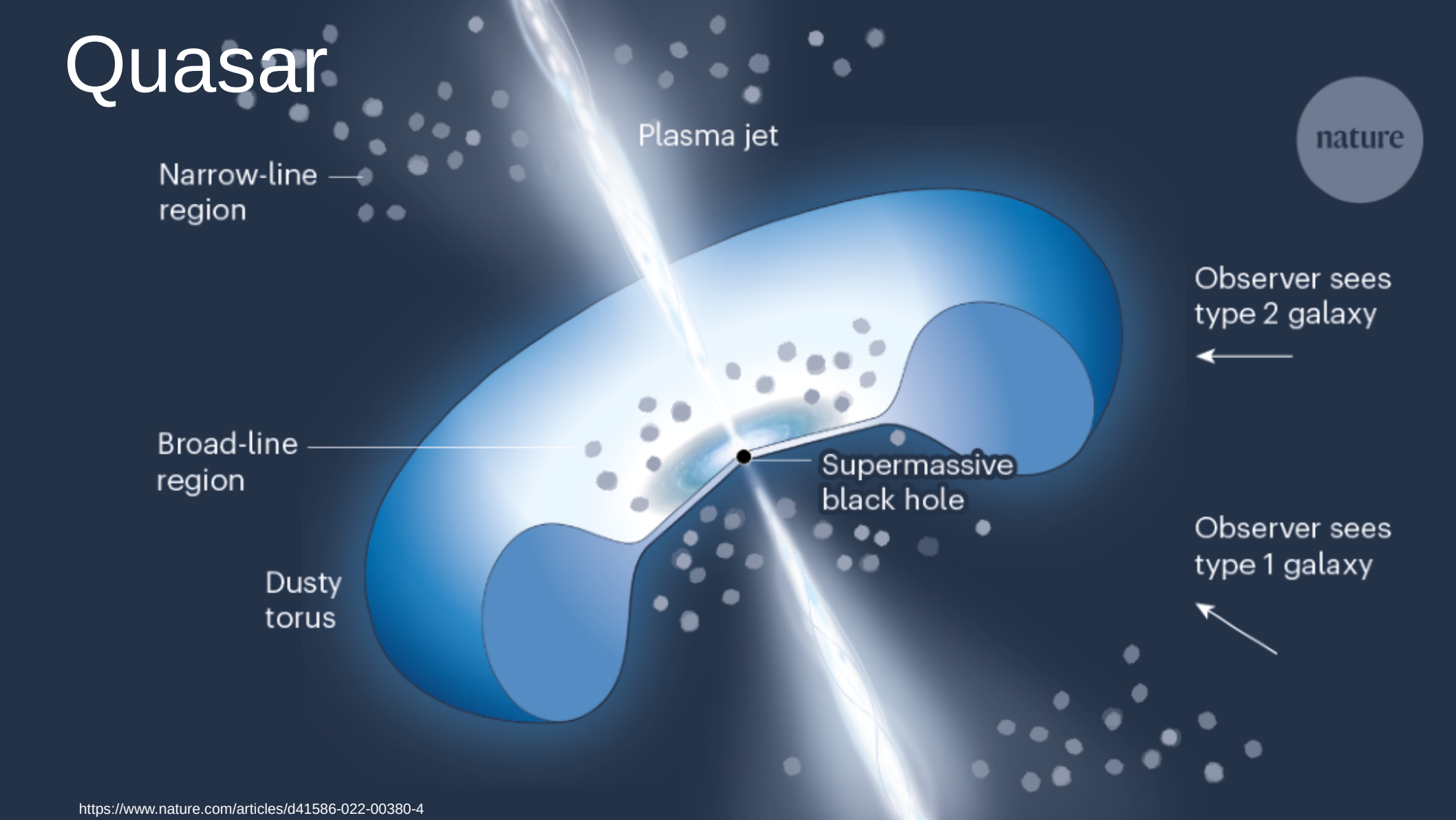
$P_a = 365 \pm k/n \cdot 365;$

$k = 1, 2;\ n = 1, 2, 3, 4, 5,$

2D Hybrid method

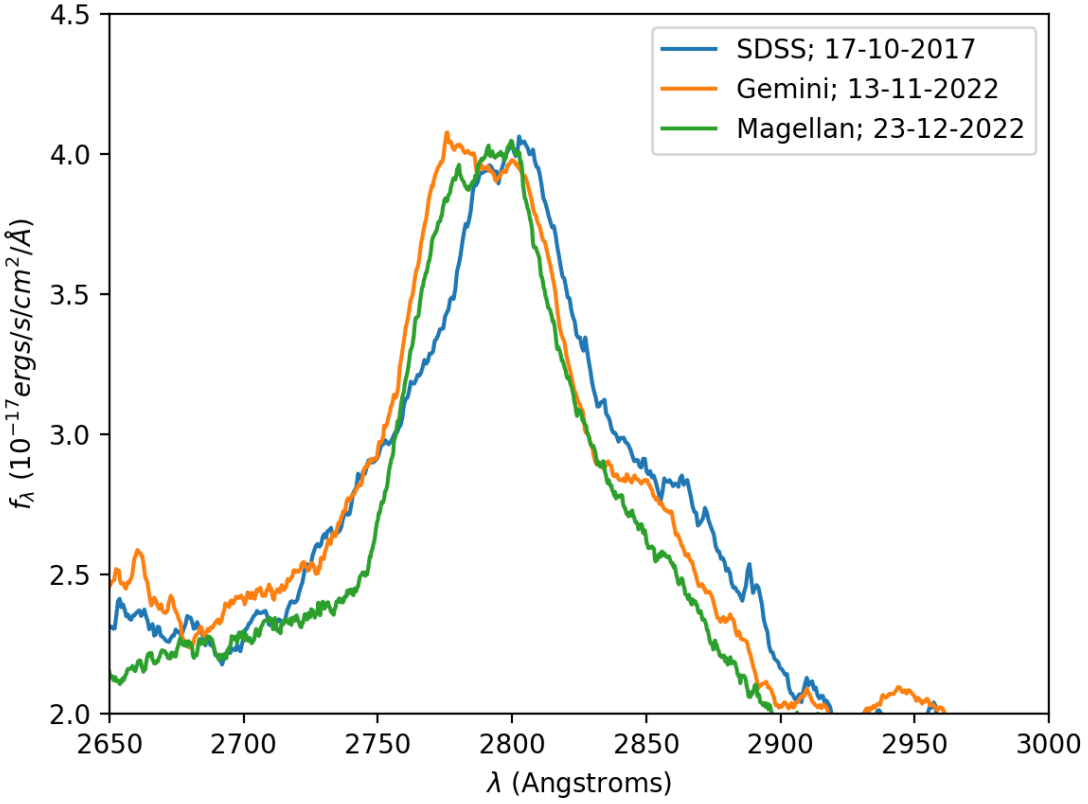
- Given two time series y_t and y'_t, we can compare their wavelet matricies (scalograms) S and S′ in order to know if they follow similar patterns.
- 2D Hybrid method uses correlation as a comparison of scalograms (Kovačević+20).
- The 2D Hybrid approach employs various wavelets, e.g. continous, discrete, Weighted Wavelet Z-transform-WWZ (Foster+96), high resolution Superlets (Moca+21), and both observed light curves and their models.
- The method generates a contour map of the intensity of (auto) correlation on a period-period plane defined by two independent period axes matching to the two time series (or one). The map is symmetric and can be integrated along any of the axes, yielding in a periodogram-like curve of the strength of correlation among oscillations (Kovačević+18,19, for more details see).

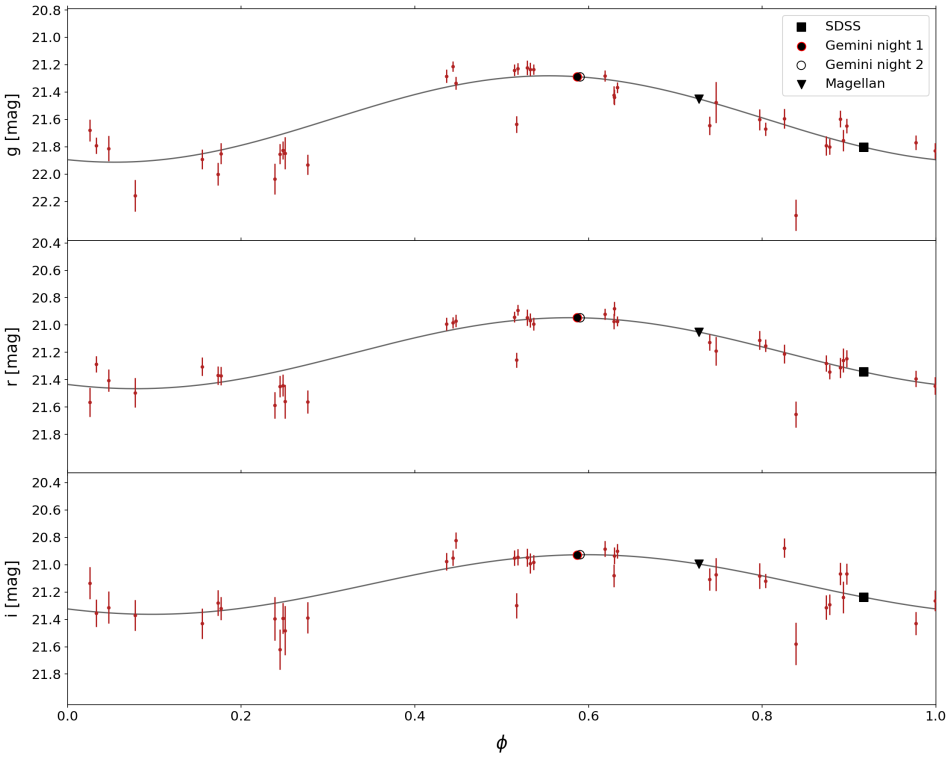
Quasar



https://www.nature.com/articles/d41586-022-00380-4

Recent observations of MgII line





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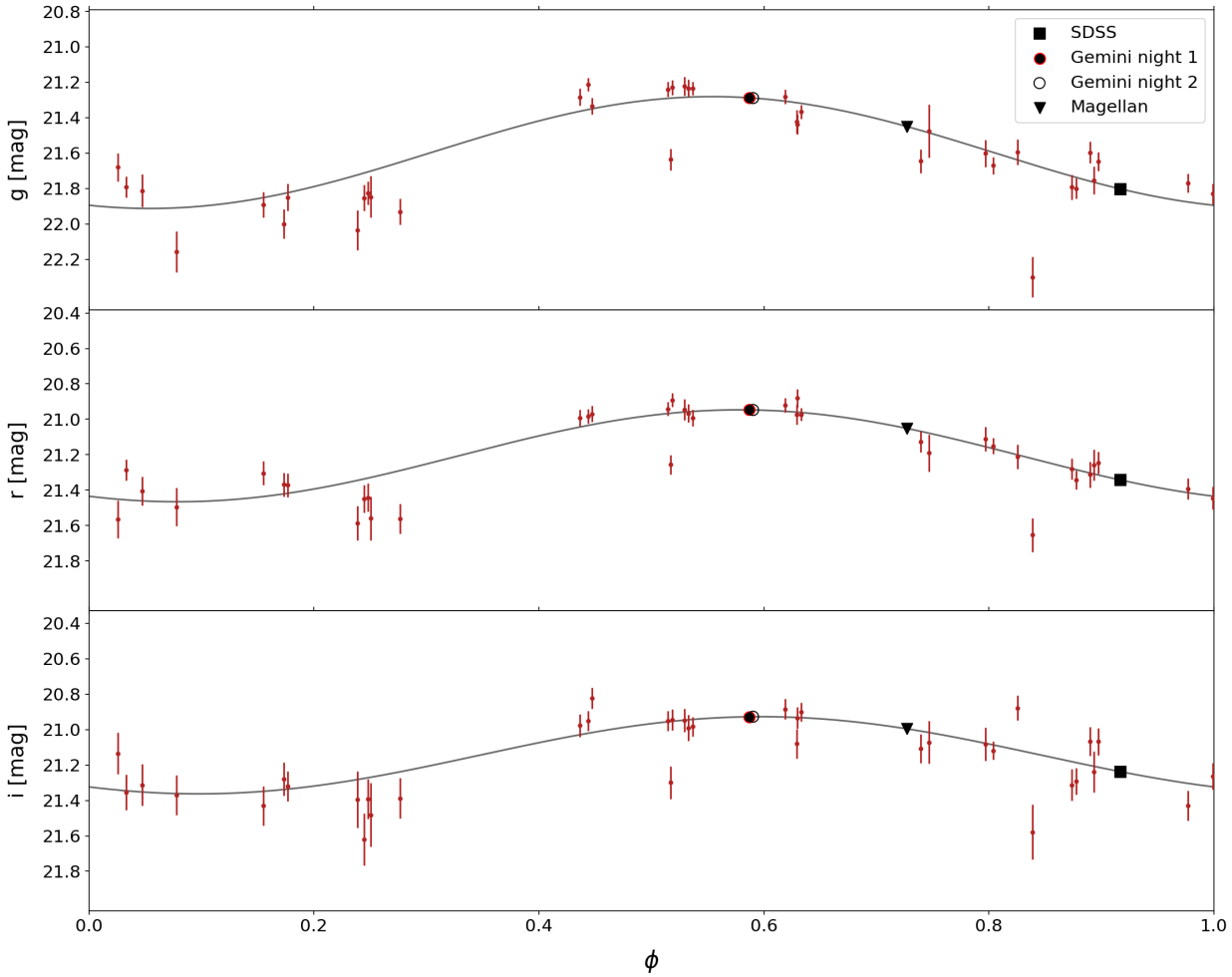
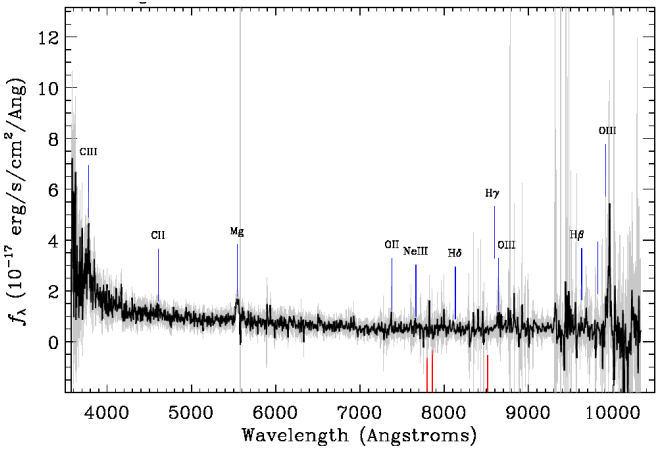
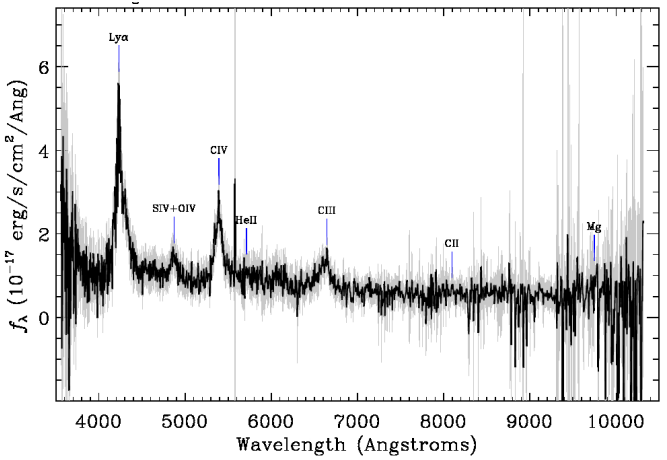
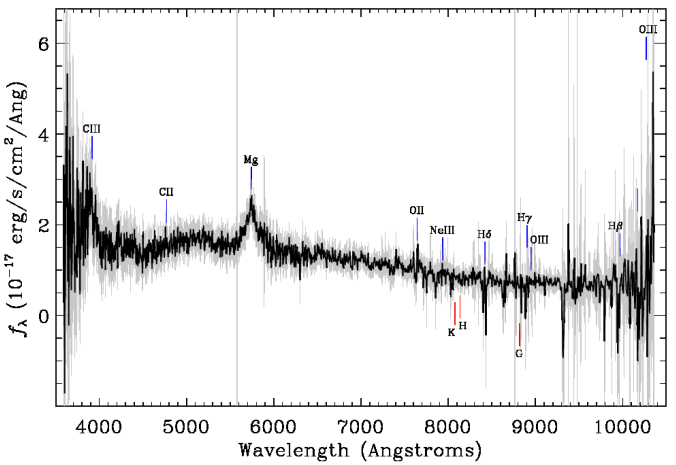
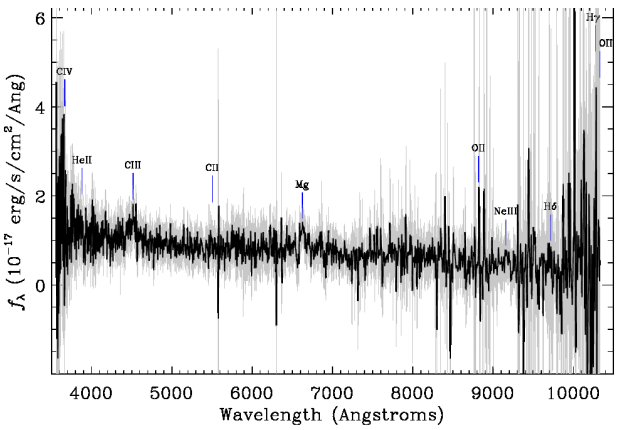


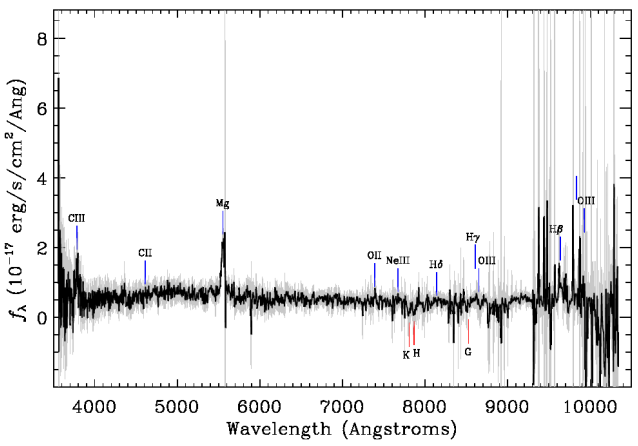
SDSS spectra of 5 candidate periodically variable quasars











Dawson+13 ,
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