

# QPOs in Blazars

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*INR, RAS, Moscow, 2018/09/17*

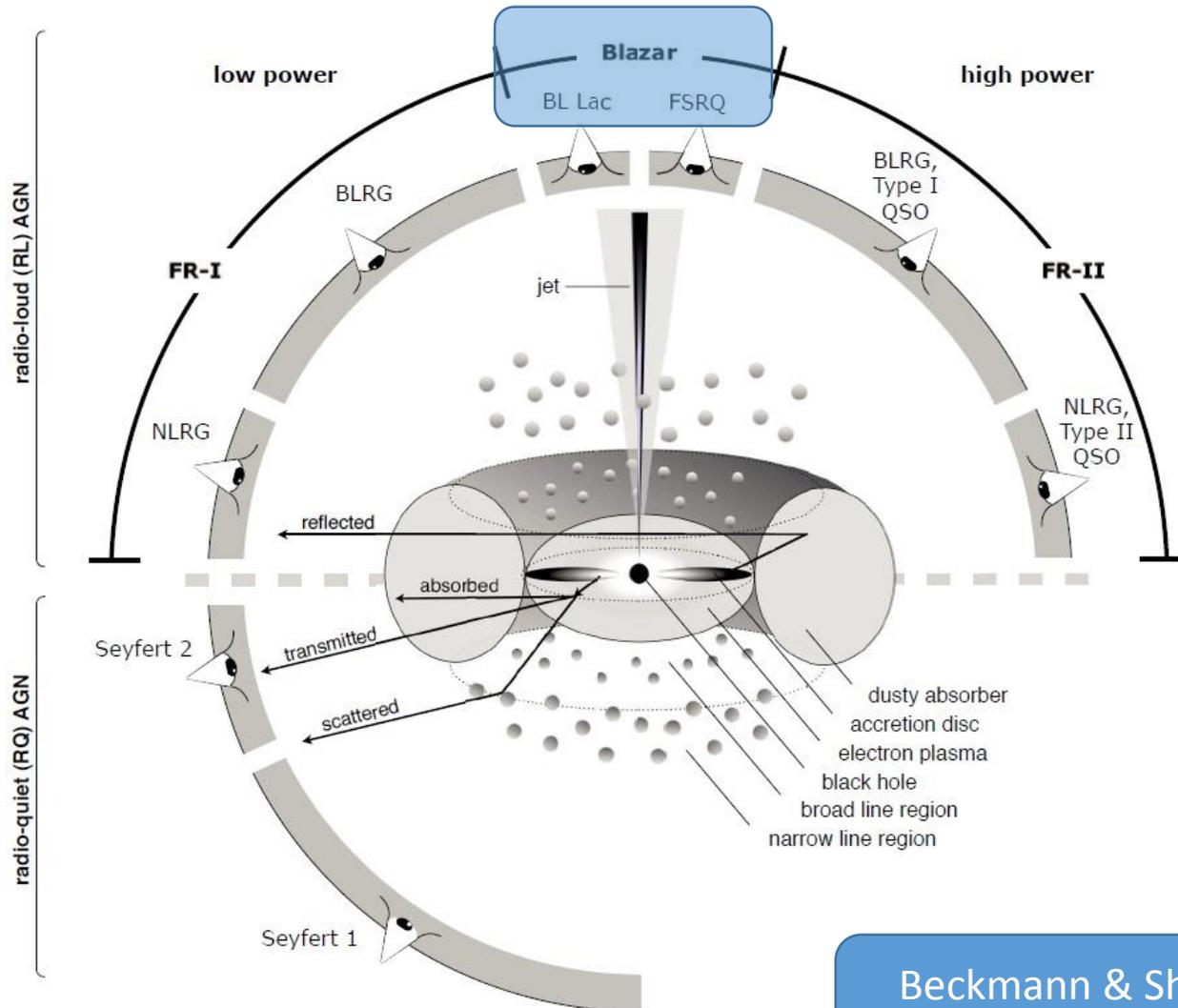
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Chinese Academy of Sciences)*

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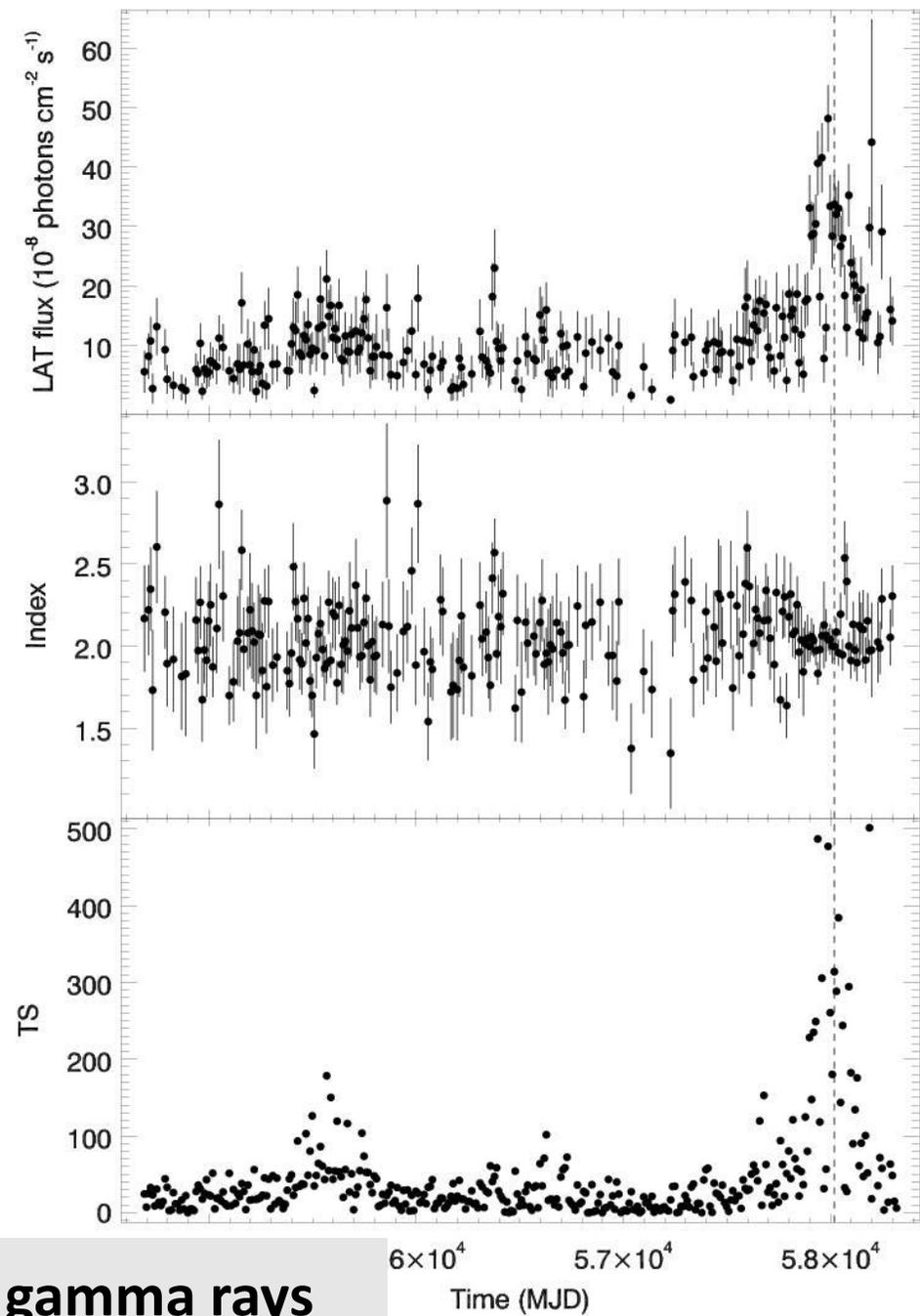
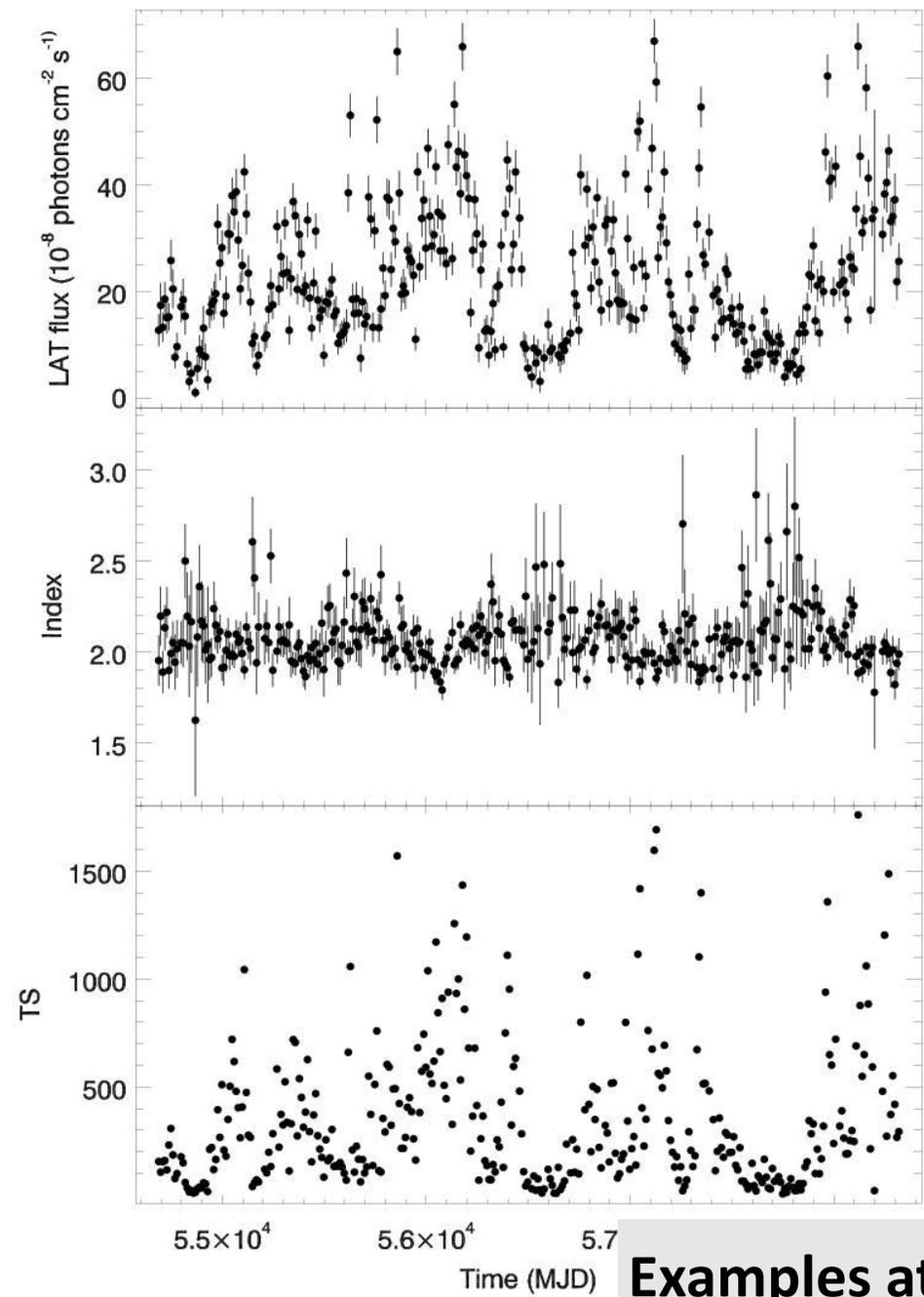
*N. Morrell (LCO, Chile), Pengfei Zhang(CAS), Jujia  
Zhang(CAS)*

# AGN Classification



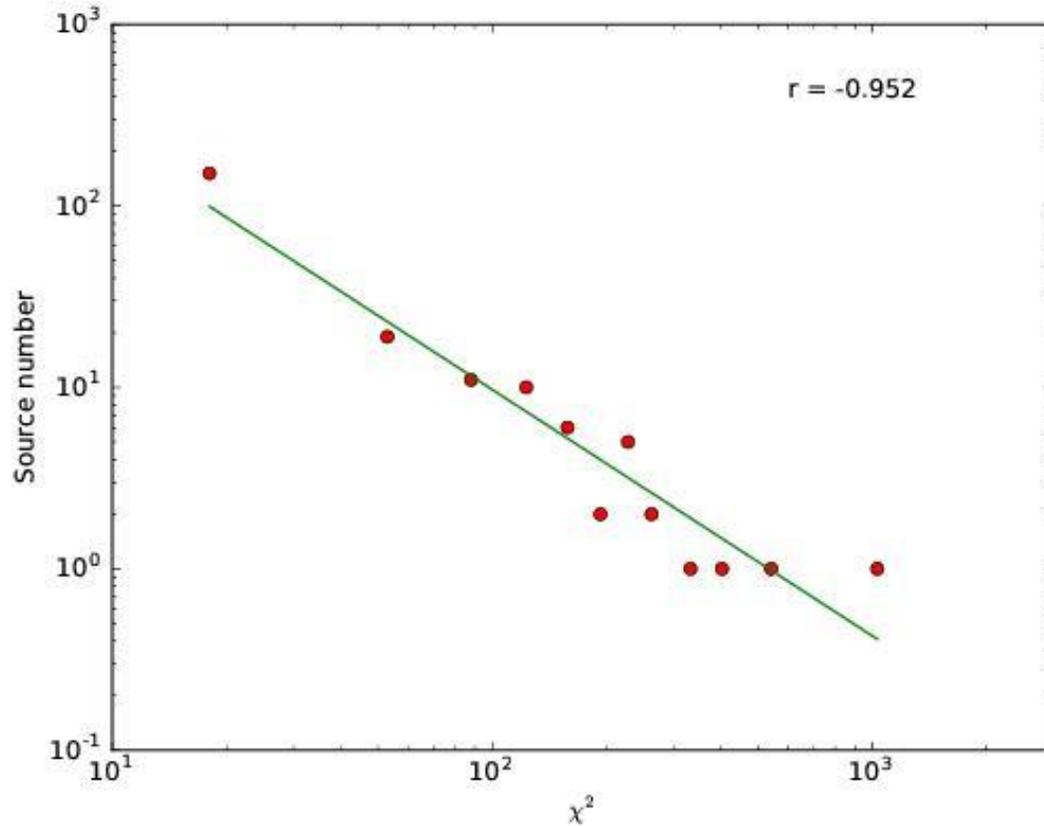
- About 10% AGN have a jet, which are classified as blazars
- In blazars, jet emission dominates because of Doppler beaming effect
- Due to beaming, blazars show rapid and large-amplitude flux variations

Beckmann & Shrader  
(2013)



**Examples at GeV gamma rays**

# Variability

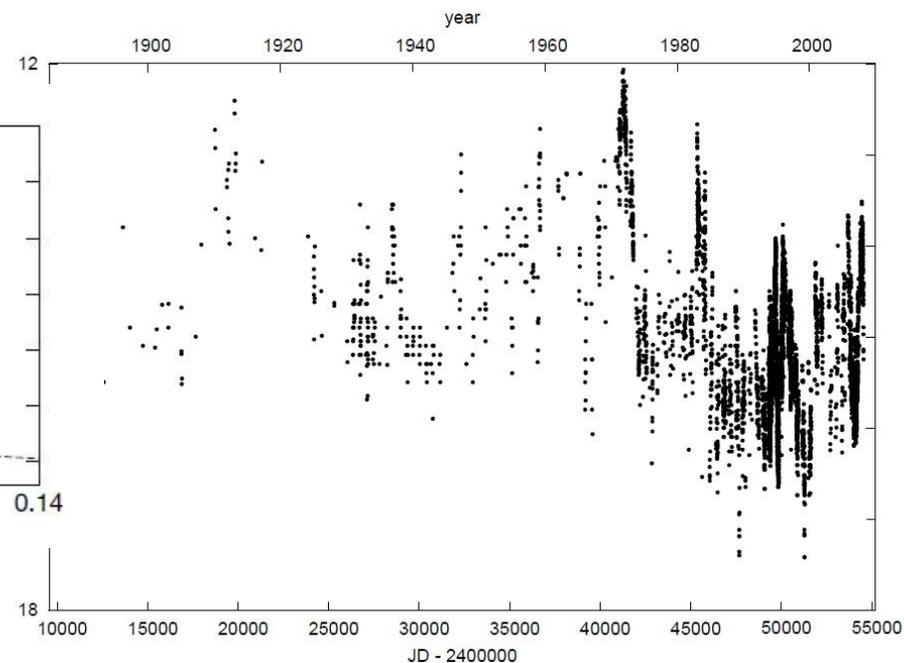
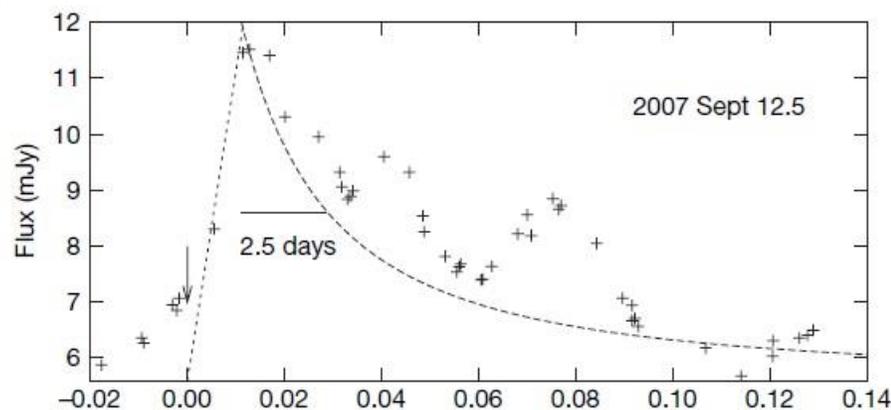
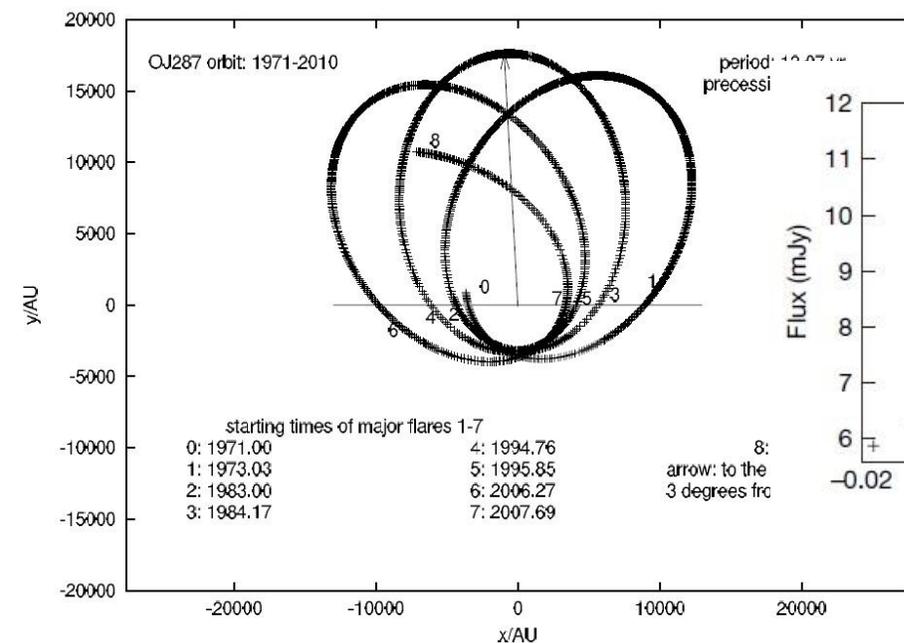


Distribution of GeV variations, obtained from  
Chi-square values of 200 Fermi blazars

# QPOs in AGN

- Variability studies of AGN are a very large field
- Although rare, one intriguing phenomenon is quasi-periodic oscillations (QPOs)
- Lots of QPOs are found at optical bands, because of easy observations conducted from the ground
  - ✓ E.g., more than 100 candidates in Catalina and Palomar transient surveys (Graham et al. 2015; Charisi et al. 2016)
  - ✓ Possible SMBH binaries
- At space, X-rays can detect different time-scale periodicities, but for long-term ones requiring very high fluxes (allowing long-term monitoring)

# OJ287

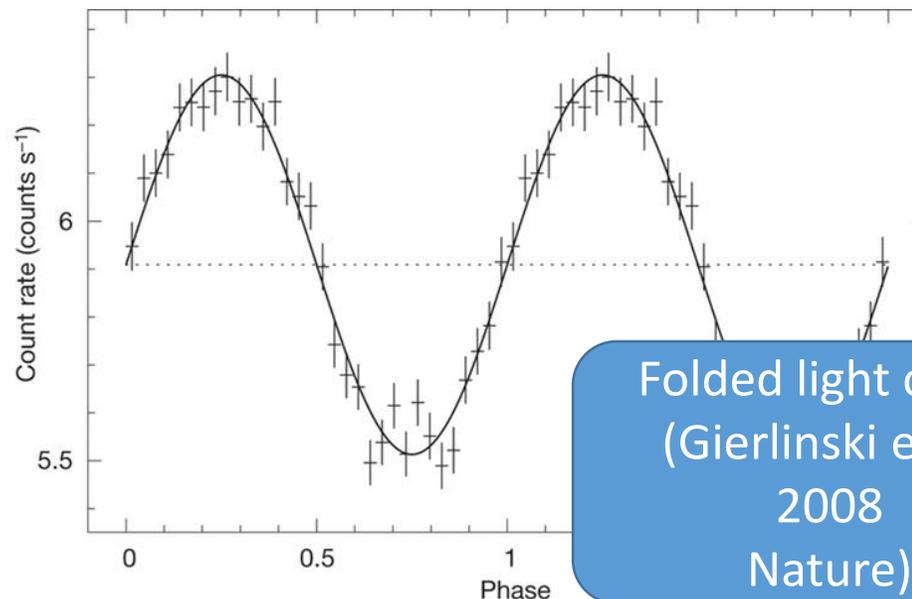
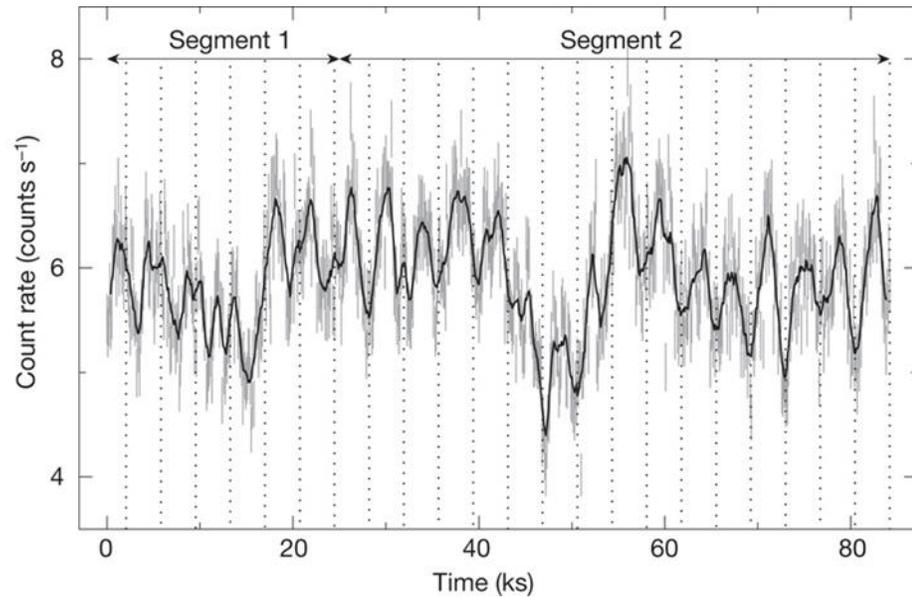


Model: a secondary BH is precessing around the primary BH, causing the modulation (Valtonen et al. 2006)

- The model successfully predicted the 2007/09 flare (Valtonen et al. 2008)

Long-term monitoring indicates a 12 year modulation in its optical light curves (Valtonen et al. 2008 Nature)

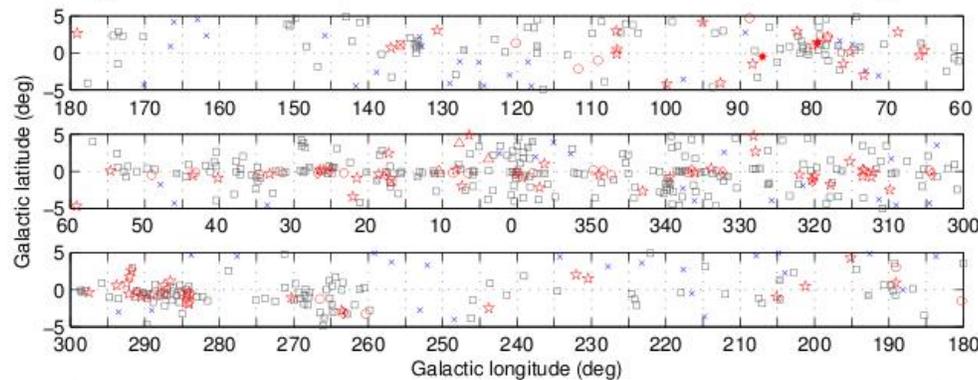
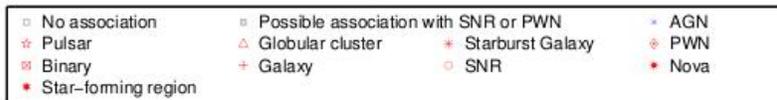
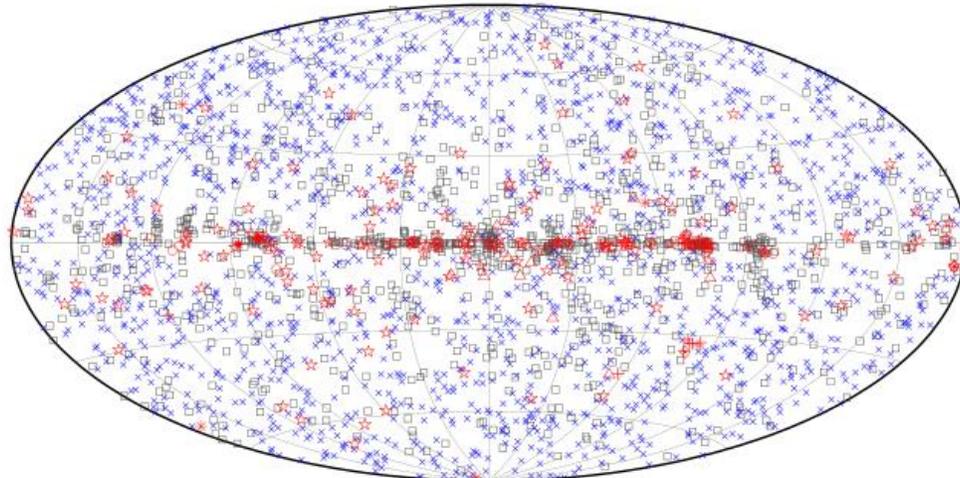
# RE J1034+396



Folded light curve  
(Gierlinski et al.  
2008  
Nature)

- Period of the QPO is 3733 sec
- The significance is 5.6sigma
- First convincing case for a QPO of AGN
- If comparing it to Galactic stellar mass black hole systems, it reflects
  - 1) the innermost stable orbit of a black hole,
  - 2) or oscillation modes of the surrounding accretion disk
- The black hole mass would be 10<sup>5</sup>-10<sup>7</sup> Solar mass

# Fermi Gamma-Ray Space Telescope



Distribution of 3000 GeV sources in the sky  
(Fermi-LAT collaboration 2015)

Goals: GRBs and Gamma-ray sources  
**GBM:** detecting gamma-ray bursts  
**LAT:** detecting sources at GeV energies

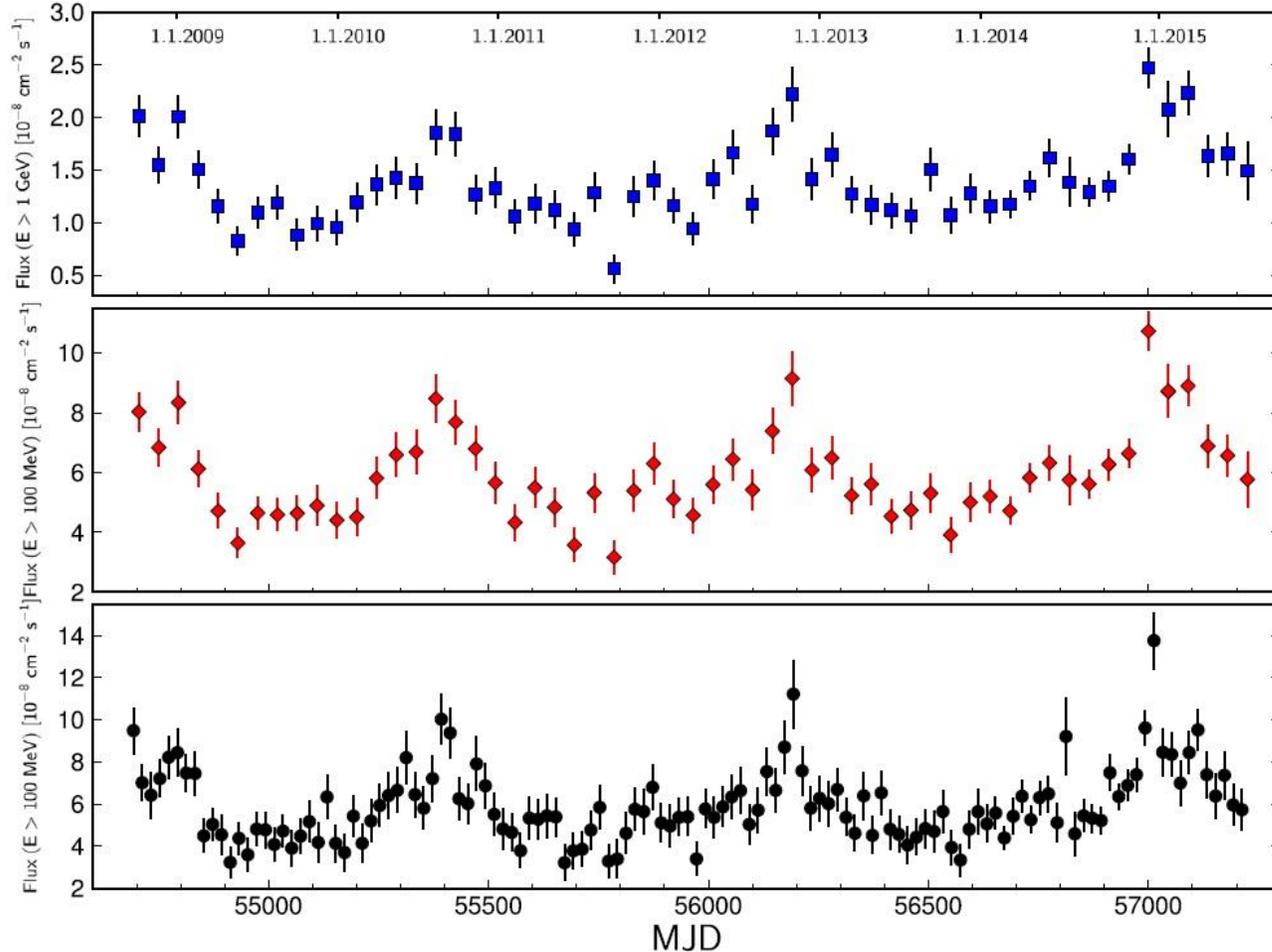
## LAT (Large Area Telescope):

- Energies: 100 MeV--300 GeV
- Spatial resolution: 0.8 deg at 1 GeV
- Time resolution: 10 micro-sec
- Observing mode: all-sky monitoring

## LAT main results:

- Found more than 3000 GeV sources
- **Most are blazars**, in Milky way, most are pulsars
- Other sources are supernova remnants, pulsar wind nebulae, gamma-ray binaries, globular clusters, and a few galaxies

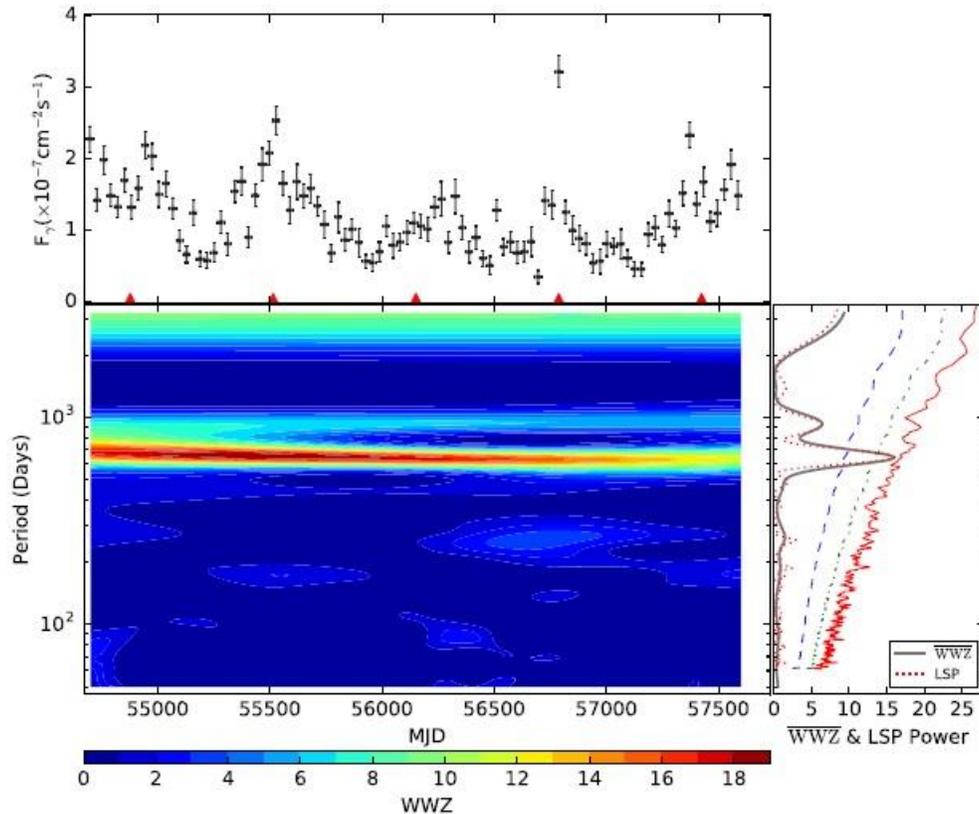
# Blazar PG 1553+113



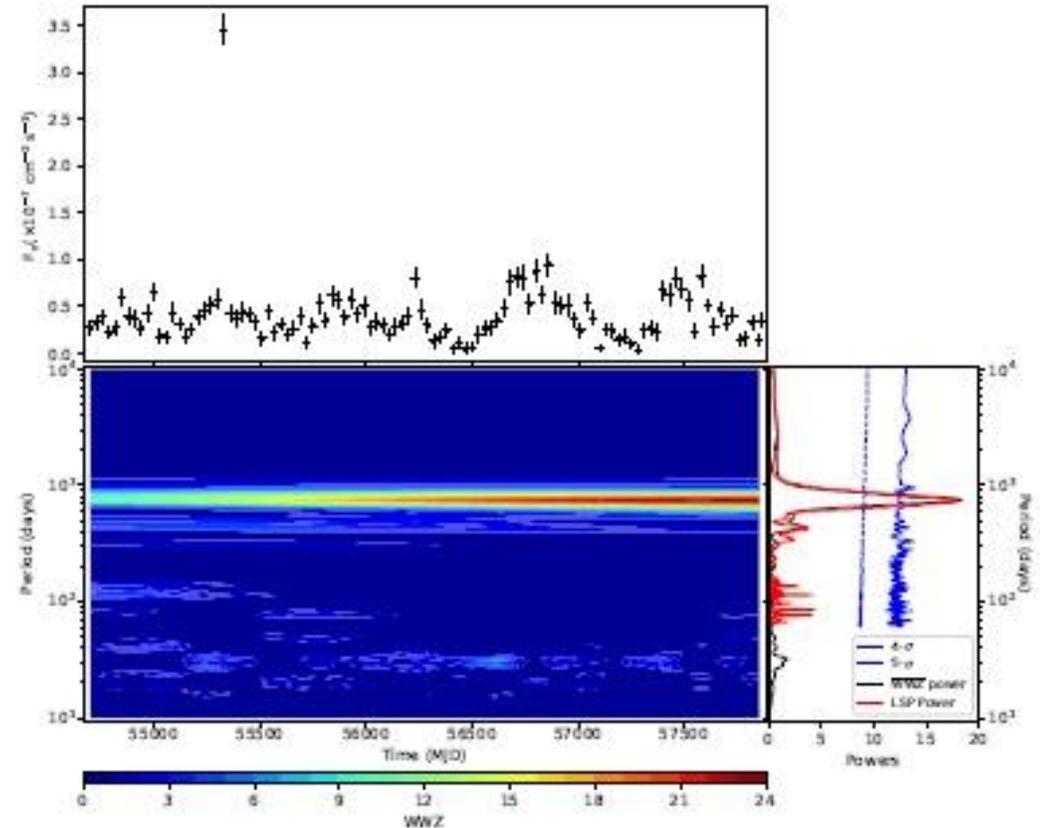
Gamma-ray modulation: 2.18 year  
(Ackermann et al. 2015, ApJL)

- Possible origins:
  - Pulsational accretion flow instabilities
  - Jet precession, rotation, or helical structure
  - Low frequency QPO such as in the Galactic stellar-mass black hole systems
  - Binary SMBH system
- Latter followups more think it's a binary SMBH system (e.g., Tavani et al. 2018)

# Other Gamma-Ray Cases

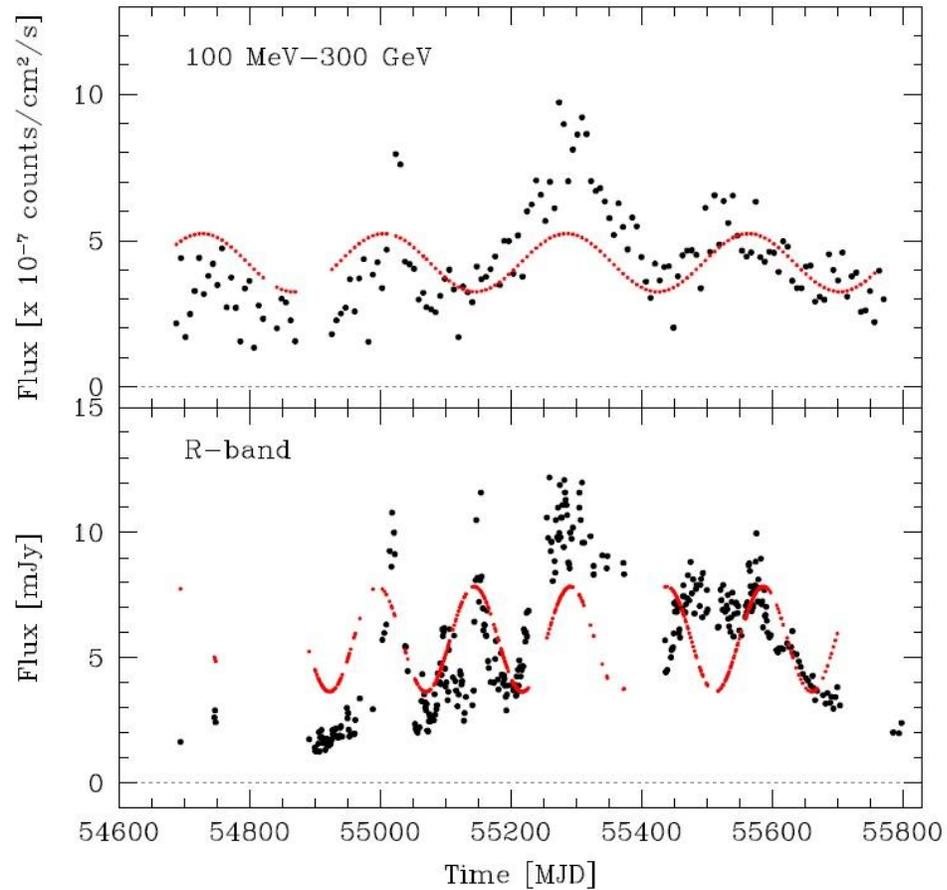


PKS 2155-304: 1.74 year period,  
4.9sigma significance (Zhang et al.  
2017)

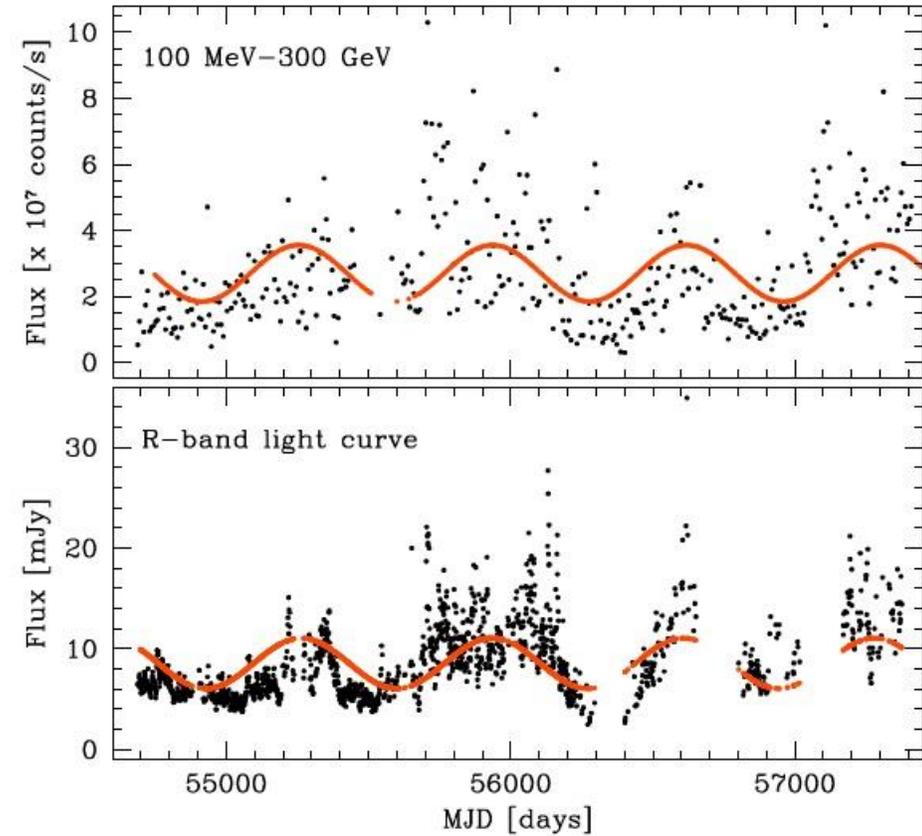


PKS 0301-243: 2.1 year period,  
 $\sim 5$ sigma significance (Zhang et al.  
2018)

# Joint Gamma-Ray and Optical



PKS 0537-441: 280 days period, 99.7% significance (Sandrinelli et al. 2016)



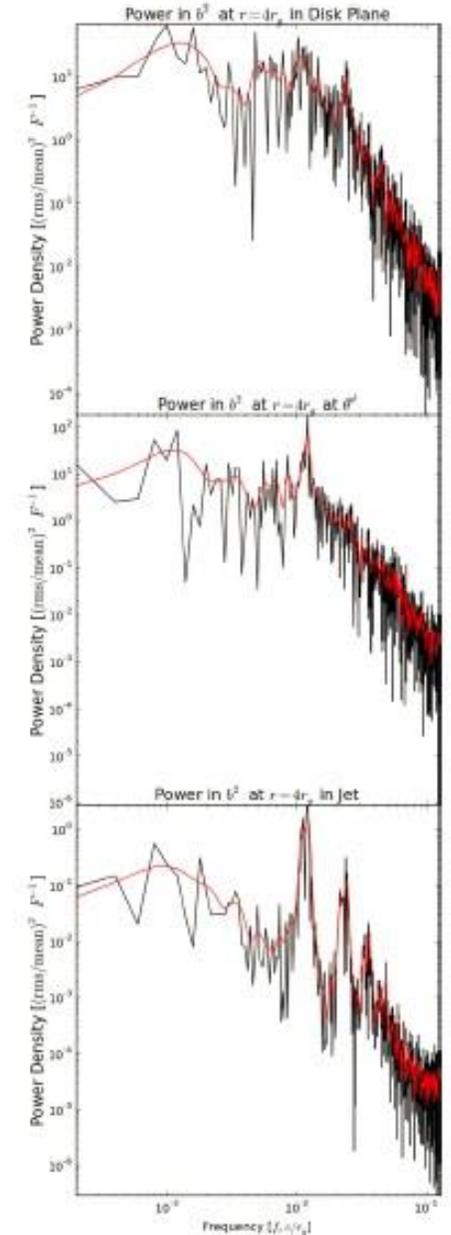
BL Lac: 680 days period, 90% significance (Sandrinelli et al. 2017)

# Summary for Gamma-ray QPOs

- Only a limited number of cases have been reported
- All have year-long periods
- Signal significances are not high: 3-5sigma

# Time Scales for Possible Blazar QPOs

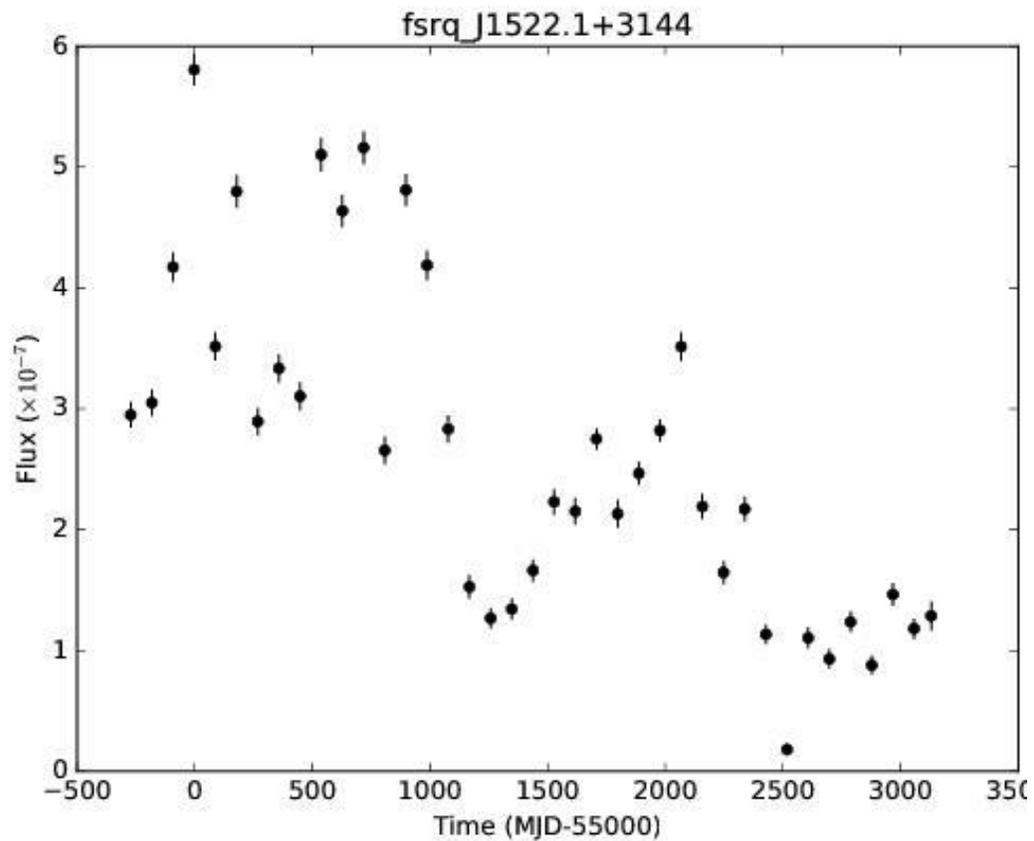
- Binary SMBH systems:
  - Orbital periods can be about **several years**, given two  $10^8$  Solar mass SMBHs
  - Precessing accretion disk (and the jet), with time scales of **hundreds of years**
- QPOs similar to those of stellar mass black holes: **sub-day variations**
- Pulsational accretion flow instabilities: **intra-day QPOs**



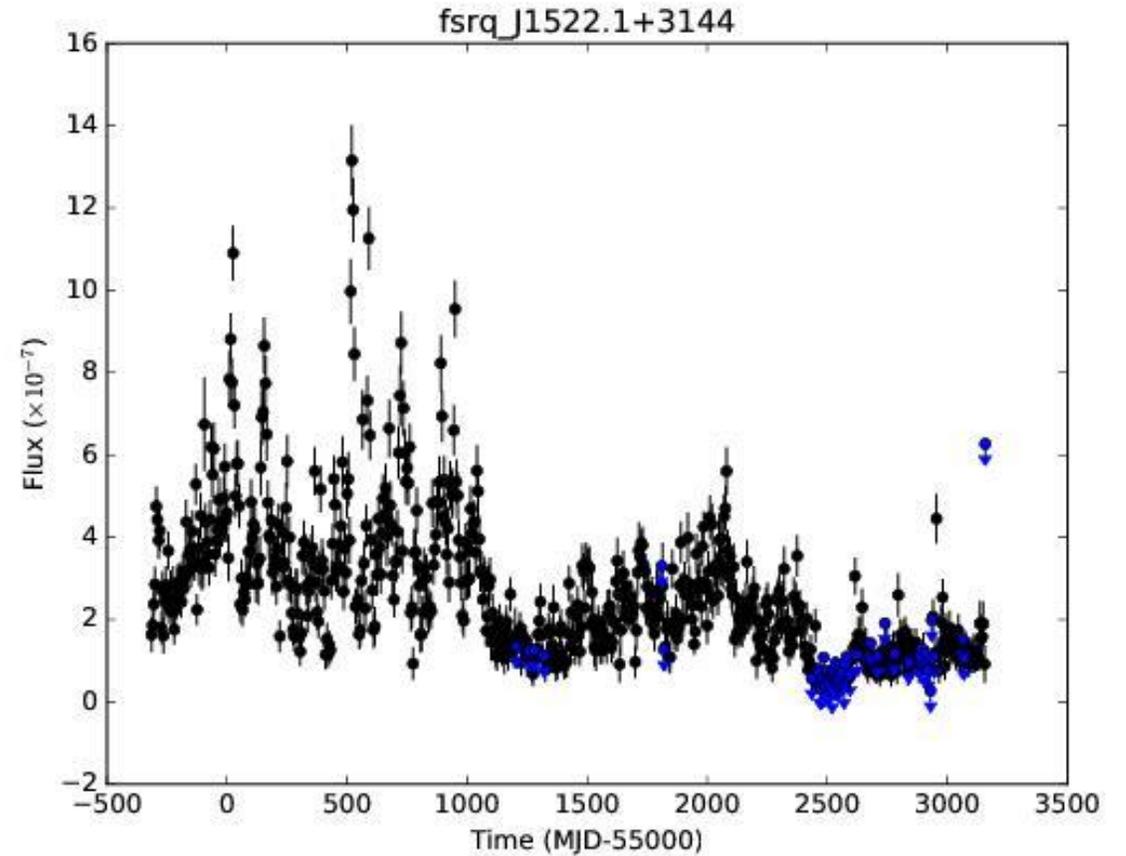
# What we at SHAO have done

1. We analyzed more than 1500 known Fermi blazars, using Fermi LAT data
2. Light curves are constructed, with focus on short time scale QPOs
3. This cannot be done without large computing power (fortunately we have)

# Examples

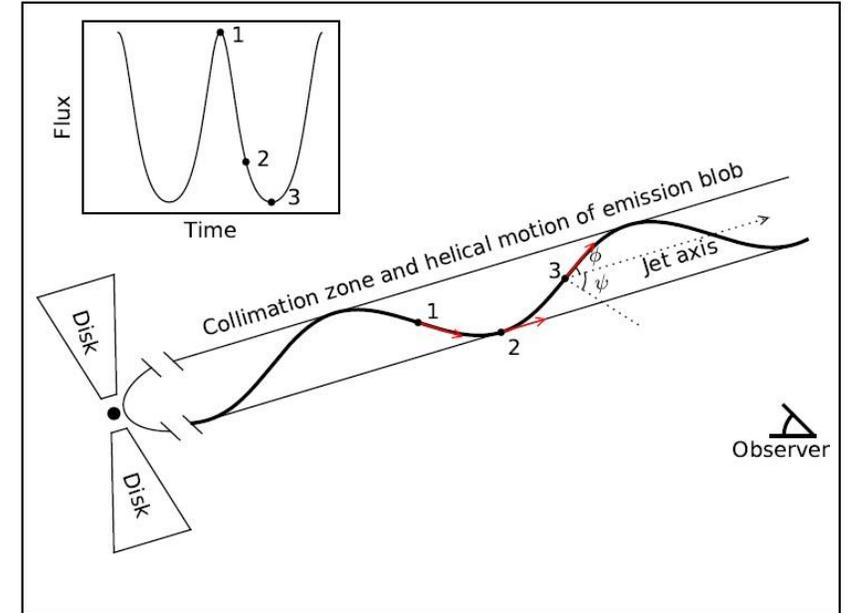
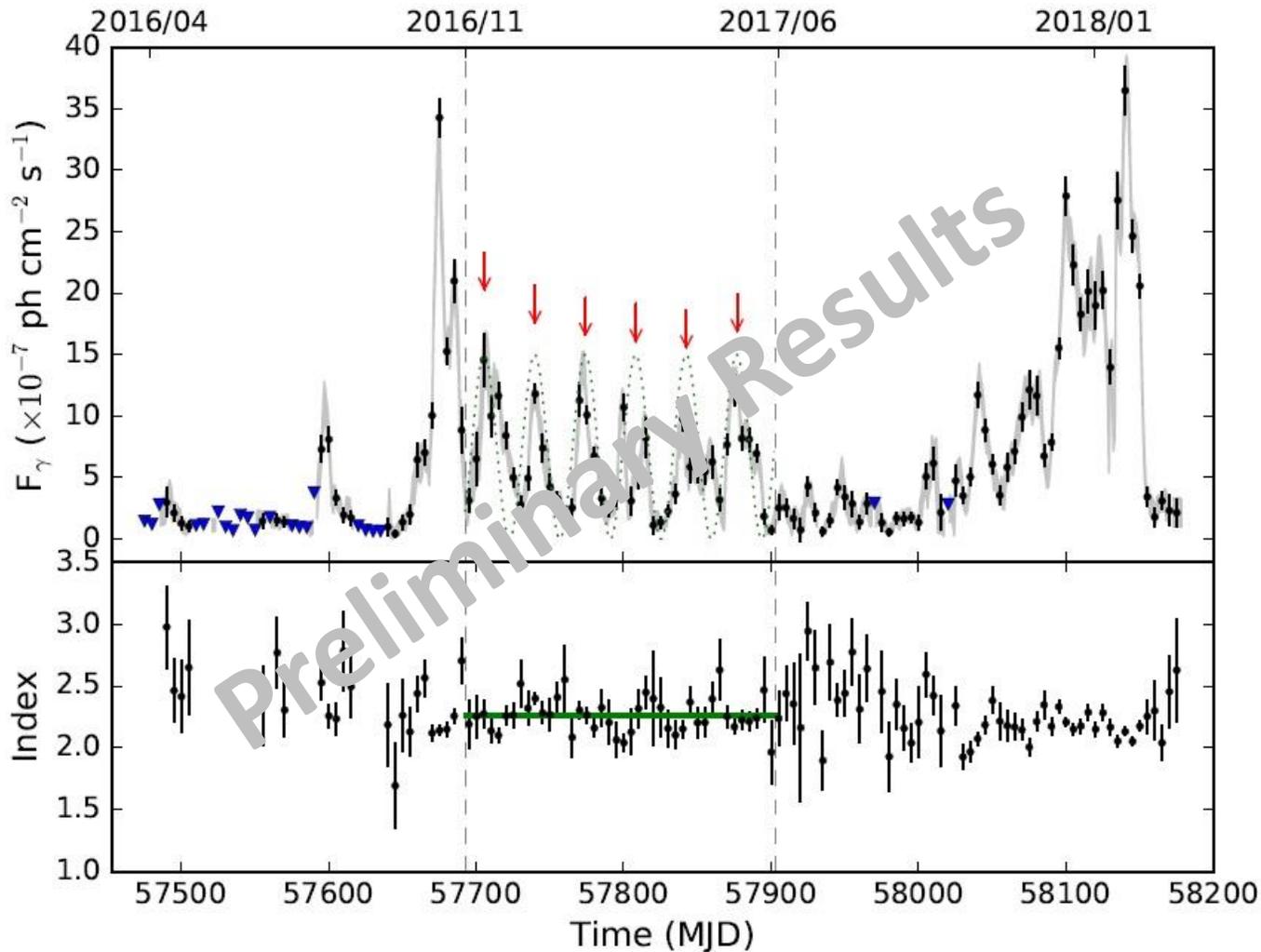


3 month binned light curve



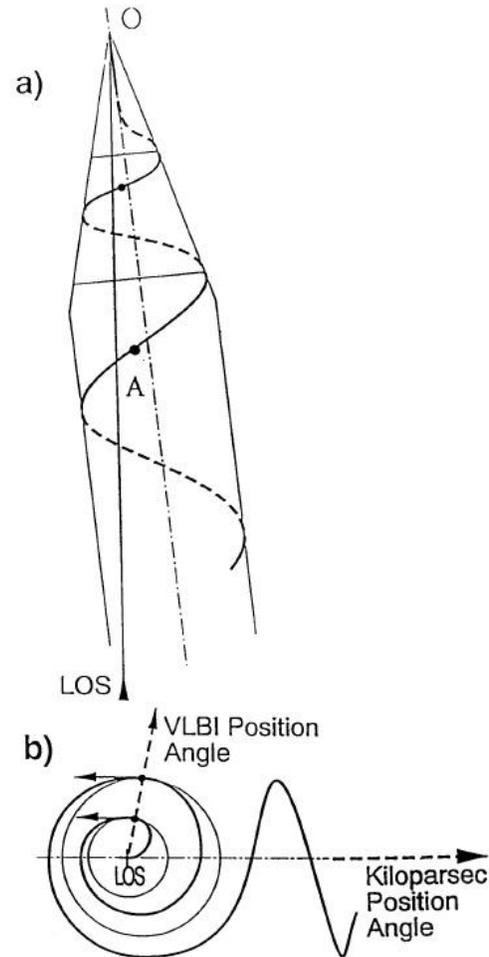
5 day binned light curve

# Our Discovery with Fermi

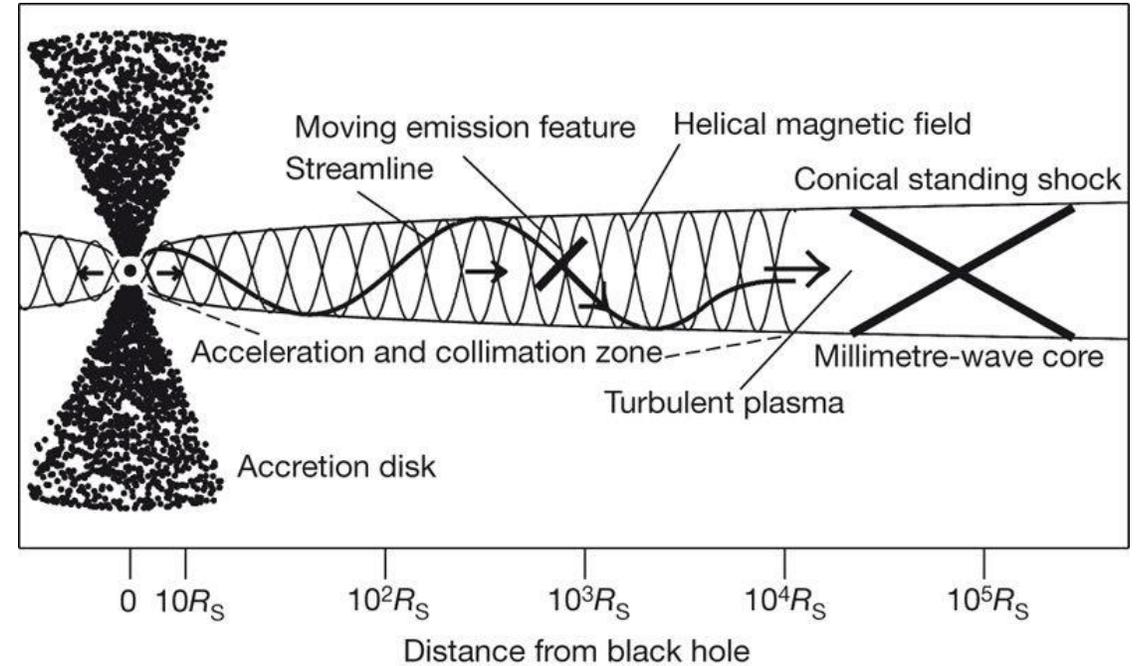


- **First month-long QPO at gamma-rays:  $P \sim 35$  days**
- We propose a helical jet scenario to explain the modulation
- Submitted to Nature Communications (Zhou, Wang, Chen et al. 2018)

# Helical Structure in Jets



Radio evidence: misalignment between parsec scale cores and kiloparsec structures (Conway & Murphy 1993)

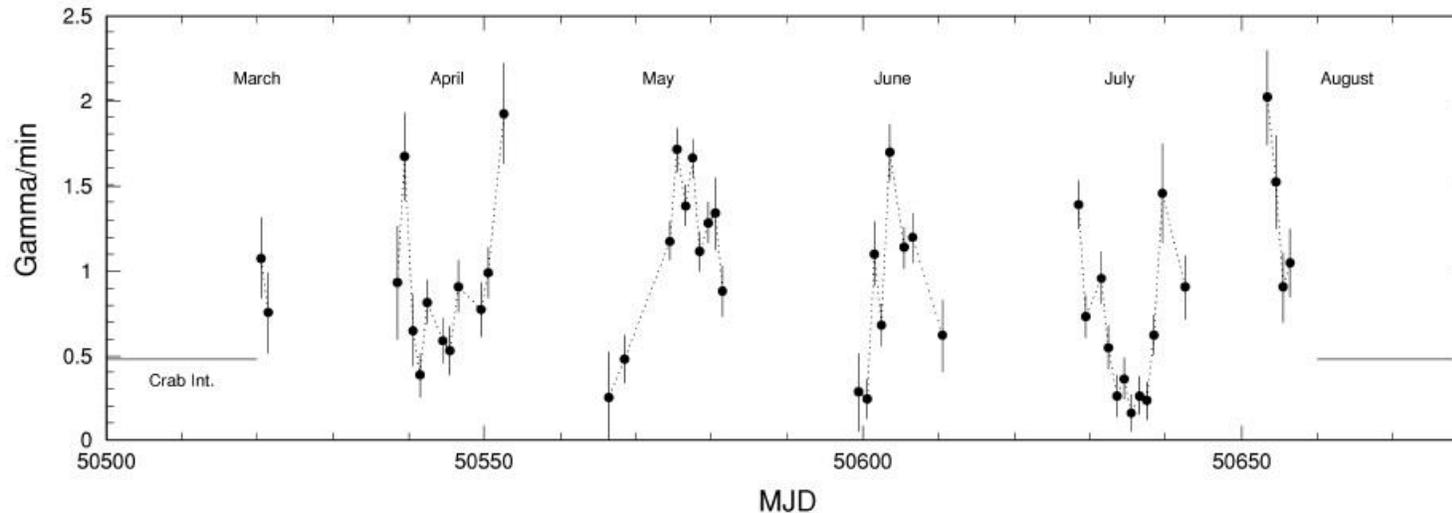


Optical polarization measurements (Marscher et al. 2008)

# Summary

- A month-long modulation, **a first such clear case**, is seen in a jet from a blazar
- Probably the first time seeing a helical structure through high-energy flux modulation
- Suggesting a new window onto jet structures
- We have looked for similar modulation in more than 1500 Fermi blazars, for the purpose of checking the appearance frequency of similar QPOs at gamma-rays
- **This case thus far has been the only one based on our search**

# A TeV QPO case



- A 23 day QPO was possibly detected in a flare from Mrk 501 with Telescope array prototype (Uath TA; Hayashida et al. 1998)
- The case seems convincing based on Uath TA, HEGRA, and RXTE/ASM observations (Osoné 2006), but suffers low significance

**LHAASO, with its monitoring capability at TeV energies, may be able to explore this area deeply**