

# **QPOs in Blazars**

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## **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 largeamplitude flux variations



#### Variability



Distribution of GeV variations, obtained from Chisquare 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)





(Valtonen et al. 2006)

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

## RE J1034+396



- 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 10^5-10^7 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 <u>GBM:</u> detecting gamma-ray bursts <u>LAT:</u> detecting sources at GeV energies

#### LAT(Large Area Telescope):

Energies: 100MeV--300GeV
Spatial resolution: 0.8 deg at 1GeV
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



- 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)

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

#### **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, ~5sigma 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: intraday QPOs



McKinney et al. 2012

## 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



#### Helical Structure in Jets



scale cores and kiloparsec structures (Conway & Murphy 1993)

## 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



#### Thanks for your Attention!

- 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 (Osone 2006), but suffers low significance

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