PG 1553+113: the Case for a Binary Supermassive Black Hole

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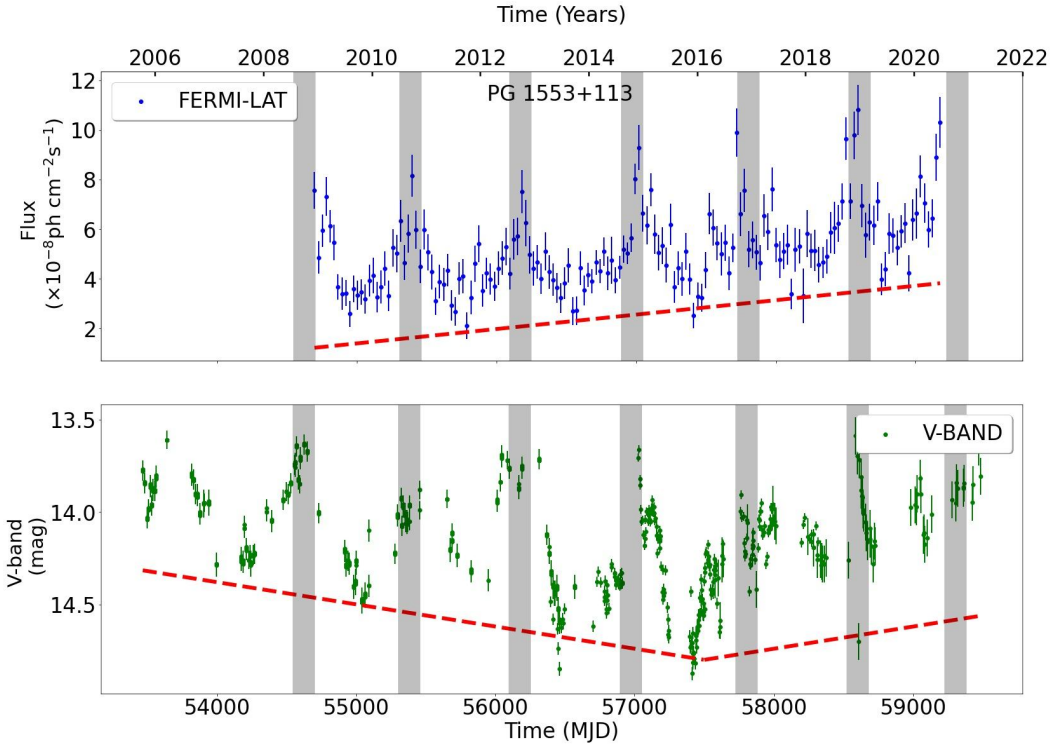
Credit: S. Ciprini

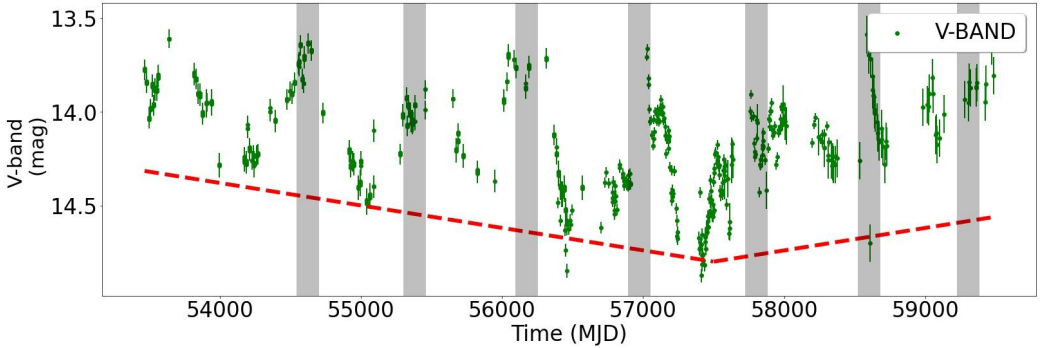
PG 1553+113

- BL Lacertae (*z=0.433*, Jones et al. , 2021)
- Among the most analyzed blazars for variability studies
- **2.2 yr** periodicity at gamma rays **(~5σ)**
  - e.g., Ackermann et al., 2015
- **A trend in multiple bands** was noticed along the light curve.
  - Peñil et al. 2023 (submitted)



Peñil et al. 2023 (submitted)

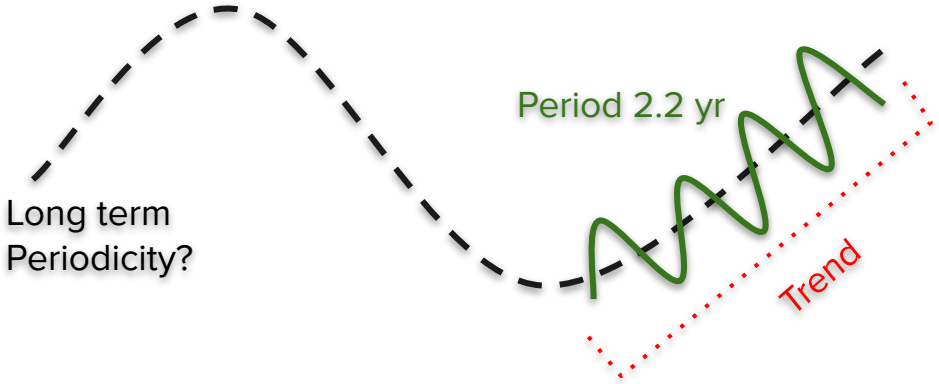
Trends in PG 1553+113



Peñil et al. 2023 (submitted)

- Trend in a few other blazars:
  - E.g., 3C 84 (Rani, 2018) and 1ES 1215+303 (Valverde et al., ApJ, 2020)

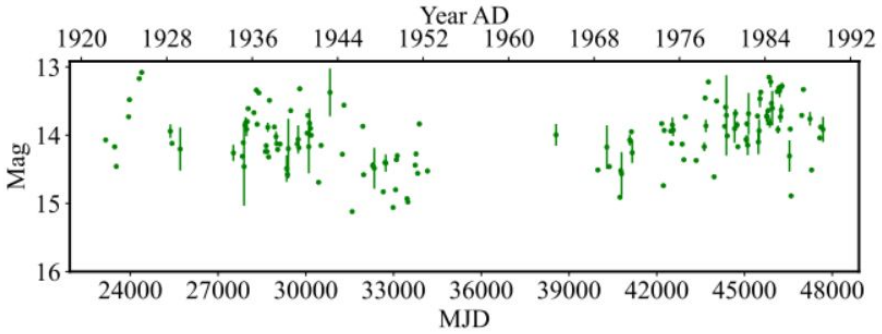
- **Hypothesis**:
  This trend may be part of a **longer period**?



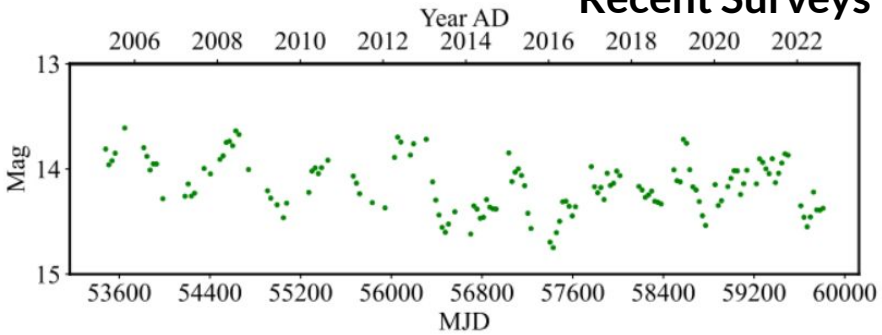
Optical Data

- DASCH:
  - >80 years of data (1920-1992)
- Recent Surveys:
  - CSS, AAVSO, ASAS-SN, ZTF (2005-2020)
- Total exposure time ≈**100 years**

DASCH

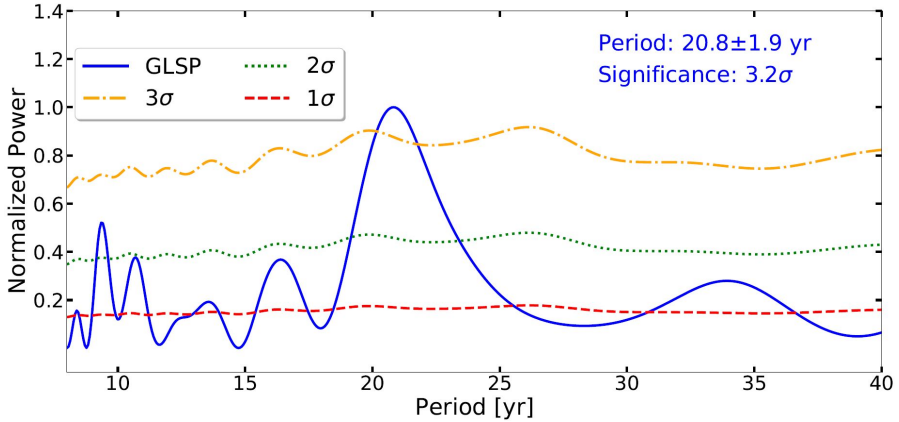


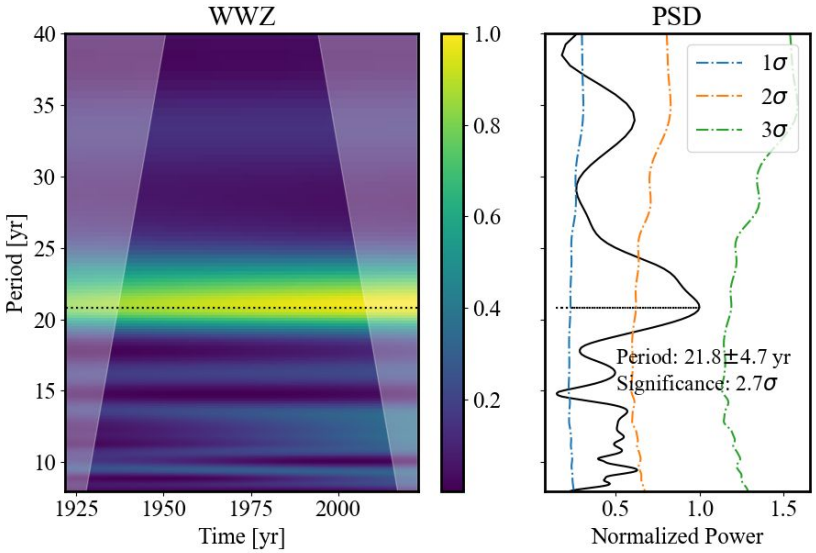
Recent Surveys



Long-term periodicity result

- Generalized Lomb-Scargle (Zechmeister et al., 2009)
- Weighted Wavelet Z-transform (Foster 1996)
- **Long-term period of ~22 yr** detected at **3σ** (1.9**σ post trial**)



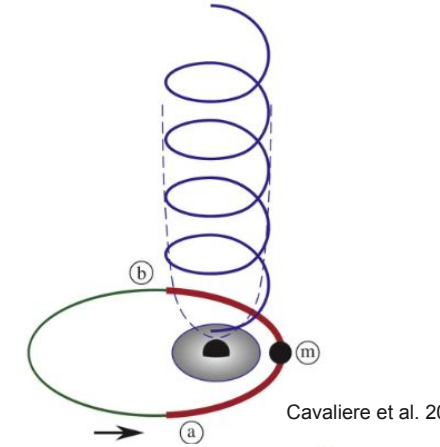


Binary Hypotheses

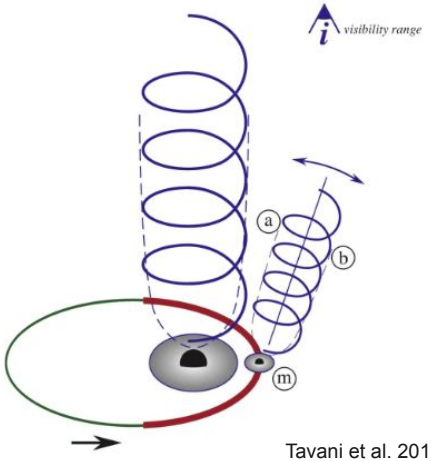
Multiple hypothesis for a binary SMBH system have been proposed to explain the quasi-periodicity of 2.2 yr.

- Jet instability triggered by companion black hole (Cavaliere et al. 2017)
- Jet precession due to the secondary black hole (Tavani et al. 2018)
- Double jet precession (Huang et al. 2021)

But **now we also need to explain the 22 yr period**.



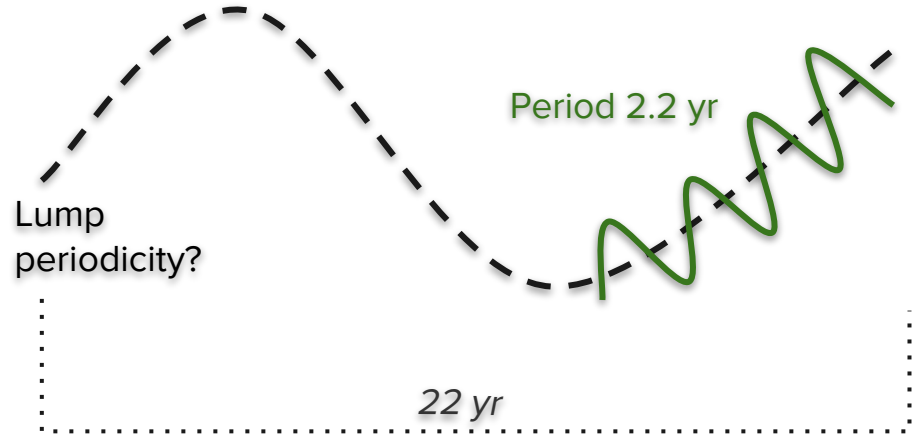
Cavaliere et al. 2017

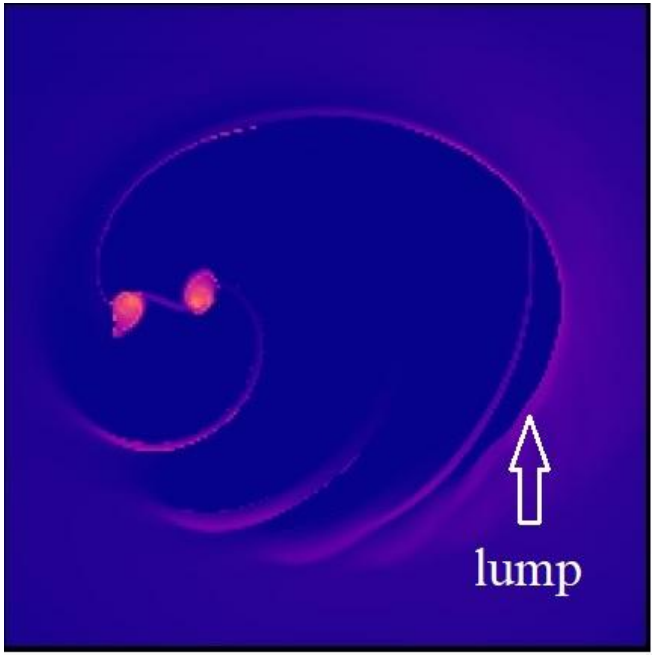


Tavani et al. 2018

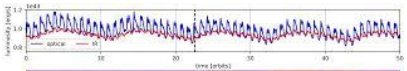
Lump periodicity?

- Lump (MacFadyen et al. 2008)





Westernacher-Schneider et al. 2022

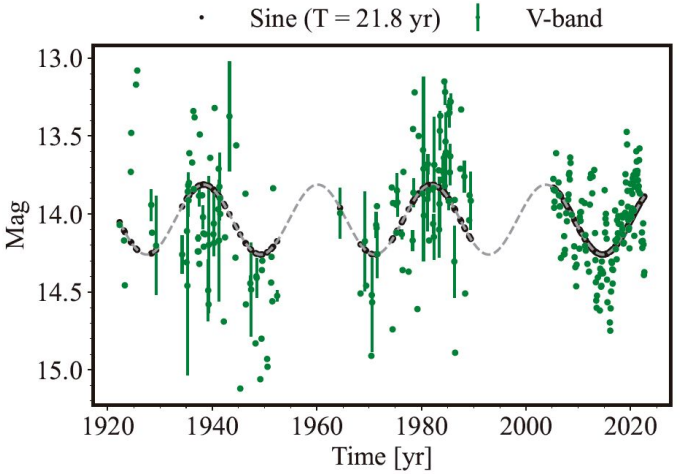


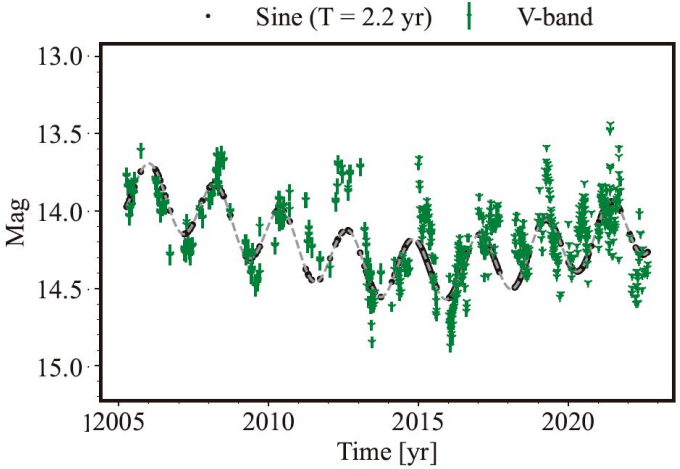
Youtube link
Credit:
R.Westernacher-Schneider

Lump Emission

- Lump period = [5 - 10] X Period binary (Westernacher-Schneider et al. 2022)

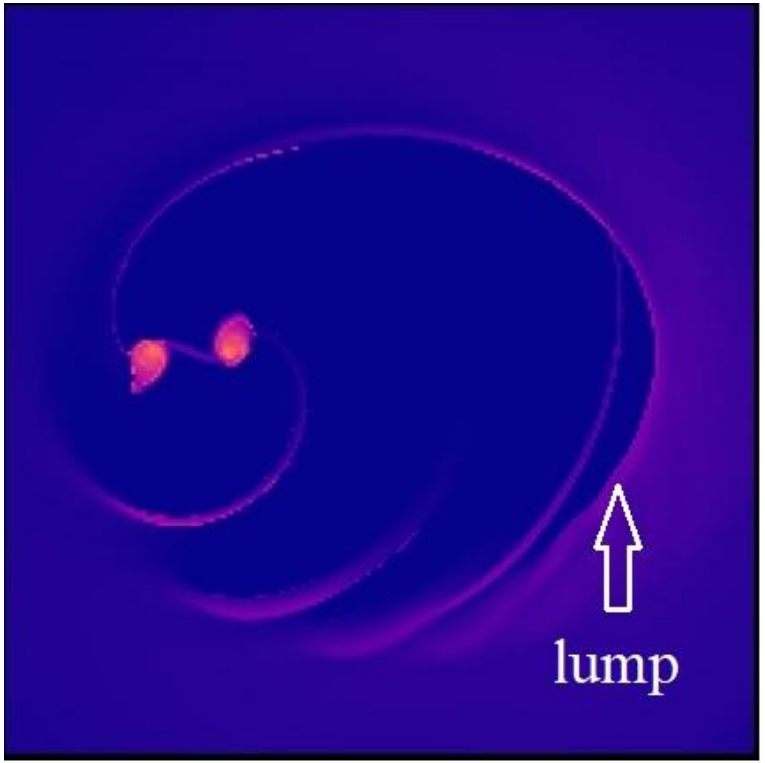
- **PG 1553+113:**
  - Period lump: 22 yr
  - Period binary: 2.2 yr
  - **Relation between both periods 10:1**
    - Lump period **plausible**





Lump: Emission Mechanisms

- **Accretion rate mechanism**:
  modulate the accretion rate of the binary system
  - Imprint upon all components of jet spectral energy distributions
- **Seed photon mechanism**:
  supply of seed (thermal) photons from the circumbinary disk (peak in the mid-infrared to optical)
  - External Inverse Compton process → $\gtrsim$ soft X-ray energies



Westernacher-Schneider et al. 2022

Evaluating Lump Hypothesis

- 2D gas simulations with radiative cooling (**Sailfish**, Westernacher-Schneider et al. 2022).
- Characterization of the binary system (**reproducing both periods**):
  - **Semi-major axis** (a)
    - **a= 5×10^{-3} pc** (Newtonian binary with orbital period 1.5 yrs)
  - **Total black hole mass ~ 5×10^{8} $M_{\odot}$** (e.g., Cavaliere et al. 2017, Huang et al. 2021)
  - **Accretion rate mechanism (**Period of 22 yr in optical band)
  - **Eccentricity** (e):
    - **e=0** (Huang et al. 2021)
  - **Mass ratio** (q):
    - **q=0.4** (Huang et al. 2021)
  - **Accretion disk aspect ratio: h~0.03** (Eddington ratio ~ 0.1 (Ghisellini et al. 2014)

Summary

- **Long-Term period (22 yr)** in the optical band (∼100 years of observations)
- Binary Supermassive black hole hypothesis: **Lump scenario**
- Evaluation with 2D viscous gas simulations with radiative cooling:
  - **Reproduce the 10:1 double-period.**
  - **Binary model for PG 1553+113 is plausible.**

Thanks

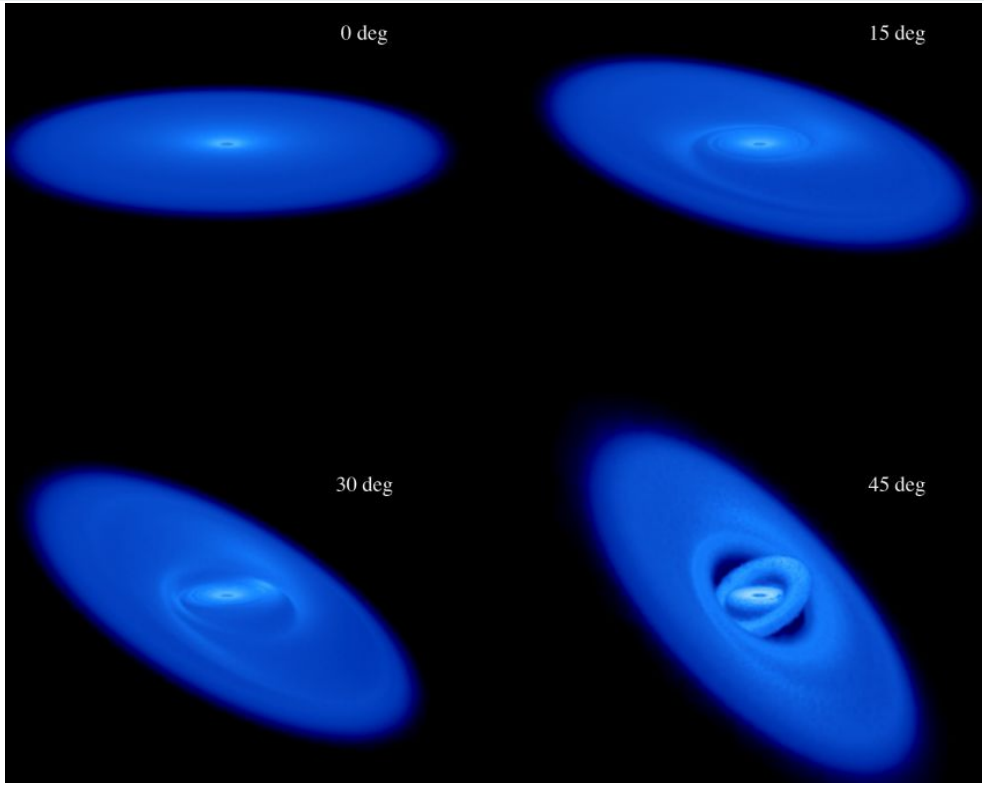
Single-BH hypotheses: E.g. relativistic precession?

- Tilted disk in a relativistic potential

  → multiple precession frequencies

  → geometric effect on the jet

- How to explain a gamma-optical delay?



Nealon et al. 2014

Gamma-Optical Delay

- Optical minimum: 2015-2016
- No minimum in gamma rays: 2-4 year?
- Simulations in (Farris et al. 2015):
  - **Accretion rate** mechanism can **LAG** **Seed photon** mechanism ≈20-30% of a lump period
- Gamma-rays:
  The **accretion rate + seed photon** mechanisms?