PG 1553+113: the Case for a Binary Supermassive Black Hole
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 ($\sim 5\sigma$)
  - e.g., Ackermann et al., 2015
- A trend in multiple bands was noticed along the light curve.
  - Peñil et al. 2023 (submitted)
Trends in PG 1553+113

- 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
Long-term periodicity result

- Generalized Lomb-Scargle (Zechmeister et al., 2009)
- Weighted Wavelet Z-transform (Foster 1996)
- Long-term period of $\sim 22$ yr detected at $3\sigma$ ($1.9\sigma$ 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.
Lump periodicity?

- Lump (MacFadyen et al. 2008)
Lump Emission

- Lump period = \([5 - 10] \times \) 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 $\rightarrow$ $\gtrsim$ soft X-ray energies

Westernacher-Schneider et al. 2022
Evaluating Lump Hypothesis

- Characterization of the binary system (**reproducing both periods**):
  - **Semi-major axis** (a)
    - $a = 5 \times 10^{-3} \text{ pc}$ (Newtonian binary with orbital period 1.5 yrs)
  - **Total black hole mass** $\sim 5 \times 10^8 \text{ M}_\odot$ (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**: $h \sim 0.03$ (Eddington ratio $\sim 0.1$ (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?