QPO Searches in AGN with LHAASO-WCDA and RMHD Jet Simulations

Shijie Liu[1], Xufan Hu[1], Yosuke Mizuno[1], Hao Zhou[1]
[1]Tsung-Dao Lee Institute, Shanghai Jiao Tong University

1. Scientific question

We search for transient TeV quasi-periodic oscillations (QPOs) with LHAASO-WCDA. Motivated by our search results, we test kink instability as a QPO mechanism with RMHD simulations and radiation post-processing.

2. WCDA search and control tests

Sample and search

10 AGN ~ 1600 d **WCDA 2-day/8-day**

Mrk 421	**Mrk 501**	1ES 1959+650
1ES 1727+502	1ES 2344+514	BL Lacertae
4C +42.22	NGC 1275	M 87
IC 310	*Crab (control)*	—

CWT/WWZ: AR(1) red noise; 22-curve survey correction.

Mrk 421 flare

Harmonic-like hints: $\sim$ 50, 100, 150 d

Candidates remain below survey-level significance.

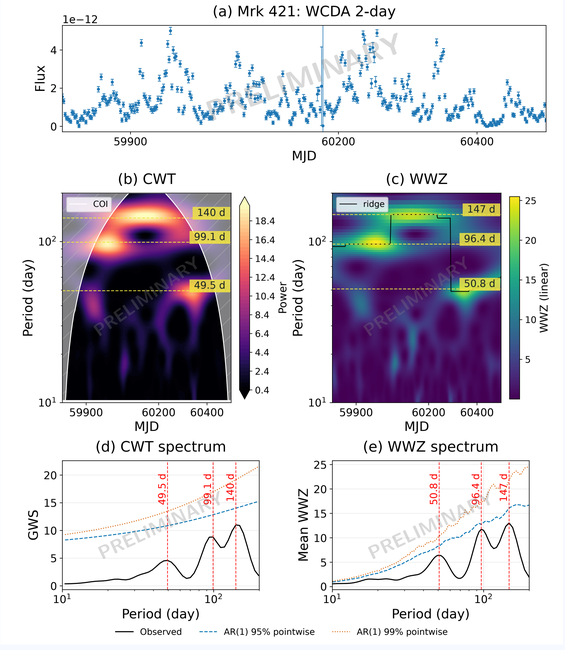


Fig. 1. Mrk 421 WCDA flare, MJD 59800–60500. 349 two-day bins; WWZ peaks: 50.8, 96.4, 147.3 d. Full-search FAP 0.380 at 147.3 d (1000 AR(1) surrogates).

Crab: response control

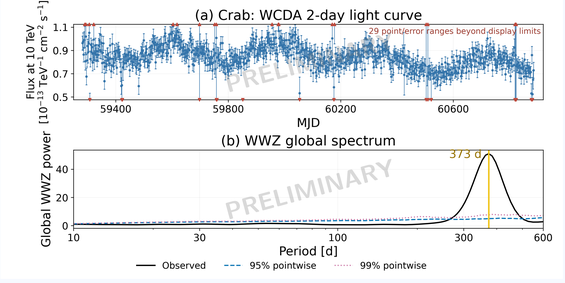
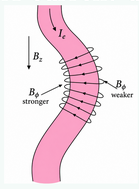


Fig. 2. Crab light curve and WWZ spectrum. 799 two-day bins. The $\sim$ 373 d feature motivates WCDA-response checks; triangles mark ranges beyond the display limits.

3. Jet simulations and radiation

A current-driven kink scenario



Triggering CD kink instability

(1) Strong toroidal magnetic field
(2) Asymmetric perturbations
→ Kink-driven jet distortions

We test whether kink-driven jet dynamics can produce quasi-periodic TeV emission.

RMHD simulation

Main dynamical peak: $45.16\, R_j/c$

WWZ of jet-center x-displacements in 3D **gPLUTO** jets ($z = 40, 45\, R_j$) also shows secondary periods of 22.58 and 25.00 R_j/c, suggesting an approximate 2:1 relation.

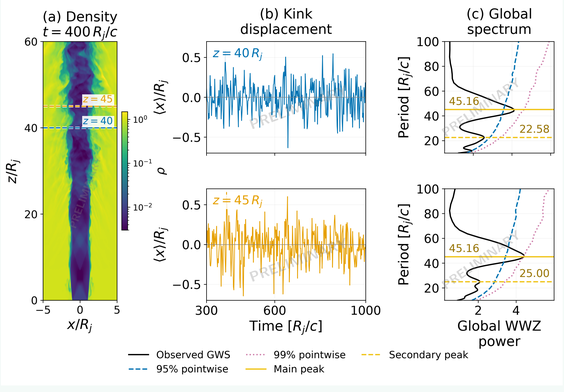


Fig. 3. Jet morphology and displacements. Density: $t = 400\, R_j/c$; $z = 40, 45\, R_j$ displacements: $t = 300$–$1000\, R_j/c$ (351 samples). GWS references are pointwise; main/secondary peaks are marked.

Radiation post-processing

gPLUTO RMHD → `kmonty` Syn+SSC → Mrk 421-like SED scaling → 0.1–3 TeV light curve

`kmonty` synchrotron+SSC SEDs guide a fixed Mrk 421-like scaling. We integrate 0.1–3 TeV flux across snapshots to construct a simulated light curve and test for kink-driven modulation.

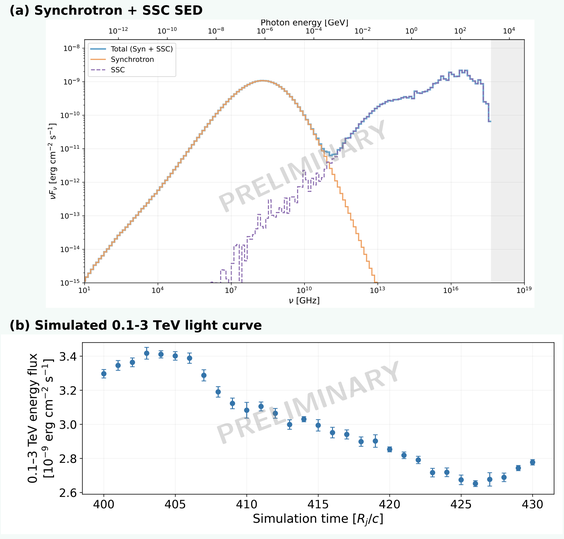


Fig. 4. Mock SED and 0.1–3 TeV light curve. (a) $t = 400\, R_j/c$, $\kappa = 8$; Syn+SSC, EC off, one seed. (b) 31 snapshots ($t = 400$–$430\, R_j/c$); $N_s = 10^7$ per seed, 8 independent seeds/epoch; MC mean ± 1 SEM. $R_j/c \simeq 6.39$ d; absorption and cooling feedback omitted.

4. Summary and future work

Observations
Mrk 421 shows harmonic-like hints; no AGN TeV QPO reaches survey-level significance.

Simulations
Harmonic-like jet distortions support kink instability as a candidate AGN QPO mechanism.

Future work
Extend the simulated TeV series and continue WCDA analysis.

Tsung-Dao Lee Institute
Contact: sjtu7181681@sjtu.edu.cn