Celebrating 20 years of Swift Discoveries

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Unveiling the periodic variability patterns of the X-ray emission from the blazar PG 1553+113

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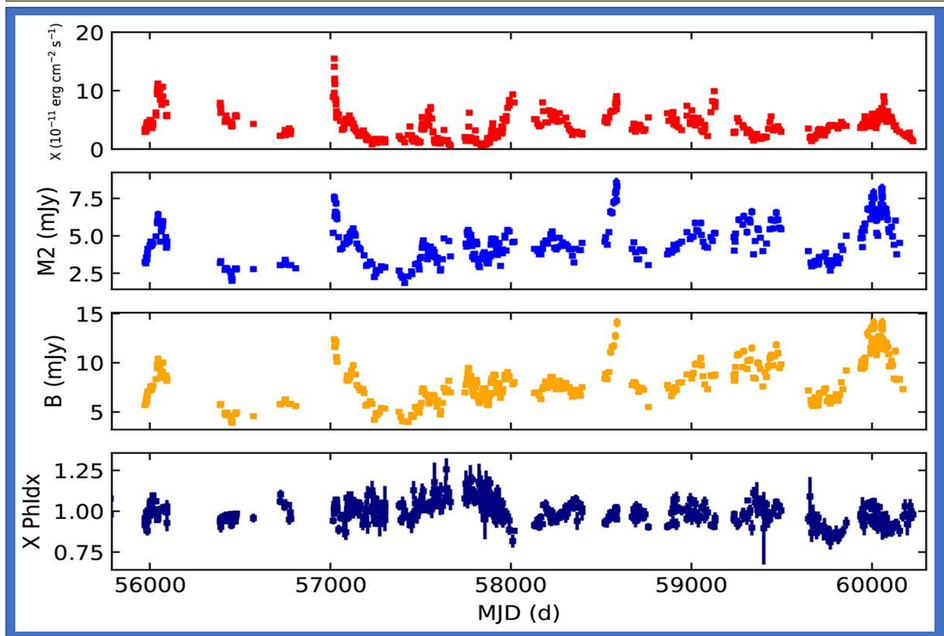
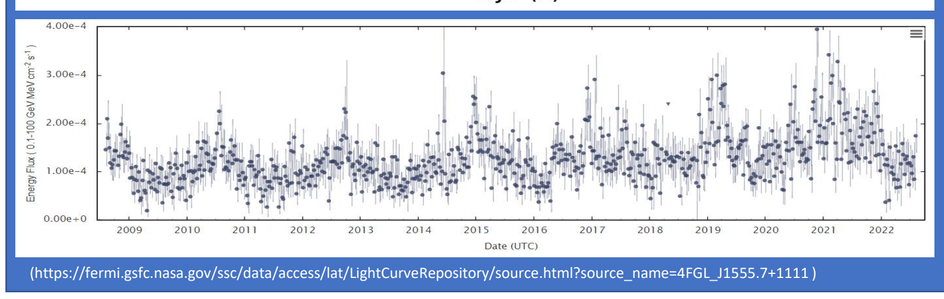
PG 1553+113 IS A BRIGHT **BL LAC OBJECT** LOCATED AT J2000 COORDINATES RA = 15H 55M 43.0S, DEC = +11° 11' 24" AND WAS DISCOVERED AS A BLUE STELLAR OBJECT BY THE PALOMAR-GREEN BRIGHT QUASAR SURVEY (PG) BETWEEN 1976 AND 1982. IN THE EARLY 1980S, IT WAS CLASSIFIED AS A BL LAC OBJECT DUE TO ITS FEATURELESS SPECTRUM. BESIDES THE OPTICAL AND THE RADIO, PG 1553+113 WAS ALSO DETECTED AS AN **X-RAY** SOURCE AND AS A TEV **Γ-RAY** EMITTER.
PG 1553+113, A BLAZAR WITH OPTICAL MAGNITUDE V ∼ 14.5 AT REDSHIFT Z ∼ 0.4 − 0.5 (**[1]**), SHOWS EVIDENCE OF A **PERIODICITY** (T ∼ 2.2 YR) IN THE Γ-RAY BAND (E ≥ 100 MEV) SAMPLED BY THE FERMI-LAT SATELLITE AND AT LOWER FREQUENCIES (R-BAND;**[2];[3]**;**[4]**). 1





(https://fermi.gsfc.nasa.gov/ssc/data/access/lat/LightCurveRepository/source.html?source_name=4FGL_J1555.7+1111)

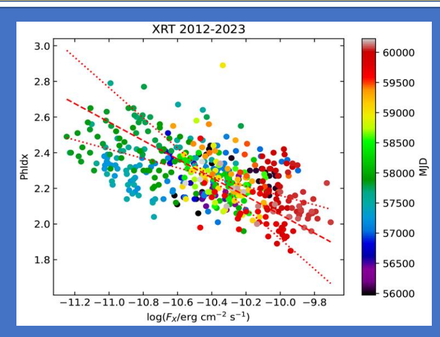
MWL LCS OF PG 1153+113 IN **B** (YELLOW DOTS), **M2** (BLUE DOTS), **X-RAY** (RED DOTS) BANDS, ALONG WITH THE X-RAY PHOTON INDEX (DARK BLUE DOTS) **FROM 2012 TO 2023 OF SWIFT SATELLITE [8]**.

THE X-RAY LC EXHIBITS DISTINCT PEAKS NOT ALWAYS MIRRORED IN OTHER BANDS. THE UV AND OPTICAL CURVES FOLLOW A SIMILAR TREND,

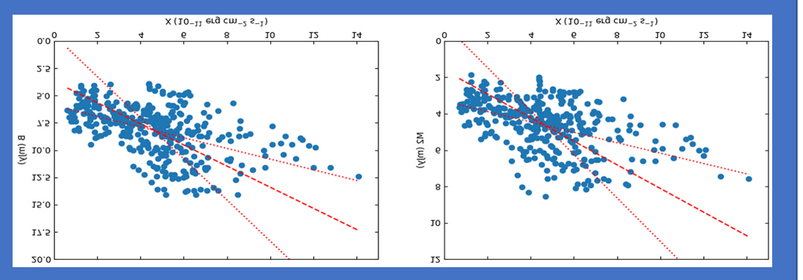
THE X-RAY FLUXES ARE IN 0.2–10 KEV BAND. B, M2, AND X-RAY'S LCS ARE SHOWN ALONG WITH THE CORRESPONDING 1Σ UNCERTAINTIES.

BELOW, THE **FERMI LAT LC** FOR APPROXIMATELY THE SAME PERIOD PROVIDES A COMPARISON IN THE Γ-RAY BAND

OUR GOAL IS TO INVESTIGATE THE EXISTENCE OF HIDDEN PERIODICITIES, POTENTIALLY DIFFERENT FROM THE Γ-RAY AND OPTICAL ONE, IN THE OTHER BANDS.



PG 1553+113 **X-RAY PHOTON INDEX–TO-FLUX CORRELATION.** THE TWO LINEAR FITS OF PHOTON INDEX VERSUS FLUX AND VICE VERSA (RED DOTTED LINES) ARE SHOWN ALONG WITH THE CORRESPONDING BISECTOR FIT (RED DASHED LINE). THE DATA POINTS ARE COLOR-CODED ON THE BASIS OF THEIR MJD **[8]**.



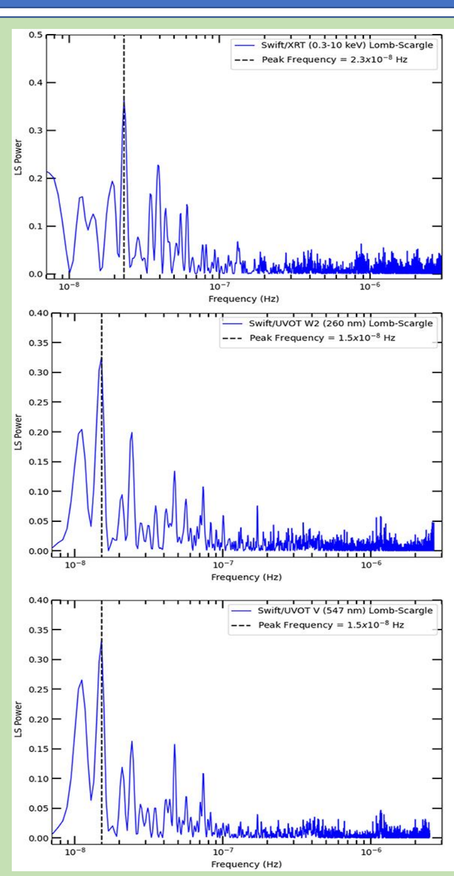
CORRELATIONS OF UV-TO-X-RAY AND OPTICAL-TO-X-RAY BANDS OF PG 1553+113 **[8]**

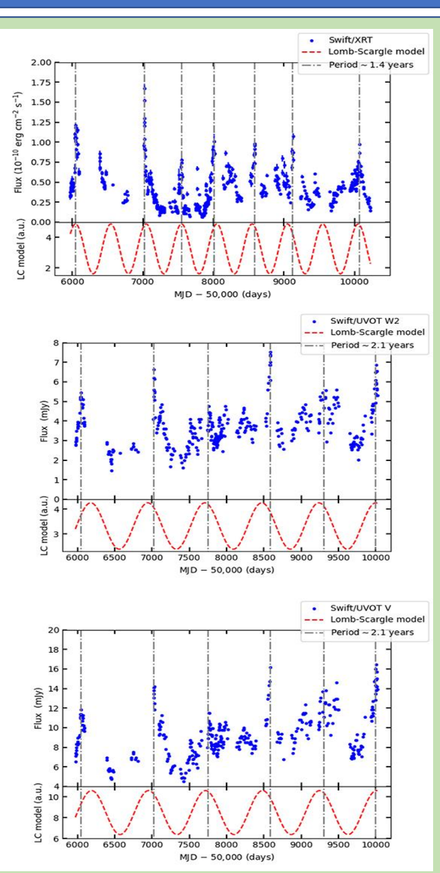
Correlation	Pearson coeff.	Degrees of freedom
U/X	0.54	265
B/X	0.50	264
V/X	0.48	254
W1/X	0.57	279
M2/X	0.58	269
W2/X	0.60	278
X PhIdx/flux	0.55	303

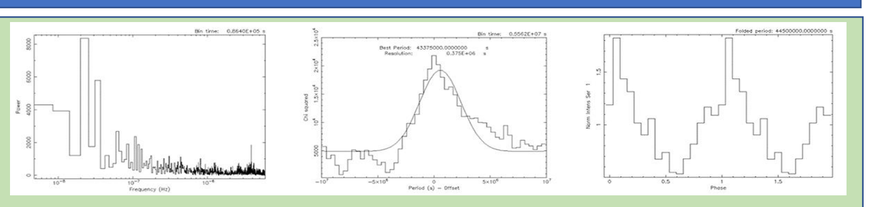
A MODERATE ANTI-CORRELATION BETWEEN PHOTON IN DEX AND X-RAY FLUX EXISTS **[8]**, INDICATING A **"HARDER-WHEN-BRIGHTER"** BEHAVIOR (AS THE FLUX INCREASES, THE SPECTRUM SHIFTS TOWARDS HIGHER ENERGIES) 2

LS PERIODOGRAMS ASSOCIATED WITH THE CORRESPONDING **MWL LCS** OF PG 1553+113. LEFT PANELS: PG 1553+113 LS PERIODOGRAMS OF X-RAY, UV (W2), AND OPTICAL BANDS (V; BLUE SOLID LINES). IN EACH PANEL, THE FREQUENCY OF THE MAIN PEAK (BLACK DASHED LINE) IS HIGHLIGHTED AND ITS VALUE IS REPORTED (SEE LEGEND). RIGHT PANELS: X-RAY, UV, AND OPTICAL LCS (BLUE POINTS), ALONG WITH THE **RELATIVE SINUSOIDS OF PERIODS CORRESPONDING TO THE LS MOST SIGNIFICANT FREQUENCIES** (RED DASHED LINES). IN SUCH PANELS, THE SINUSOID MAXIMA APPROXIMATELY COINCIDING WITH FLUX PEAKS IN THE LCS (GRAY DOT-DASHED LINES) ARE MARKED, AND THE CORRESPONDING PERIOD IS REPORTED. **[8]**

SPECIFICALLY, **UV** AND **OPTICAL** BANDS SHOW A DOMINANT PEAK AT A FREQUENCY OF **~1.5 × 10⁻⁸ HZ**, CORRESPONDING TO A PERIOD OF **~2.1–2.2 YEARS**, CONSISTENT WITH THE PERIODICITY PREVIOUSLY OBSERVED.
X-RAY BAND DISPLAYS A PEAK AT A HIGHER FREQUENCY (**~2.3 × 10⁻⁸ HZ**), CORRESPONDING TO A SHORTER PERIOD OF **~1.4 YEARS**, ABOUT 35% SHORTER THAN THE OPTICAL-GAMMA PERIODICITY. THIS SUGGESTS A DISTINCT VARIABILITY MECHANISM IN X-RAYS. **[8]**

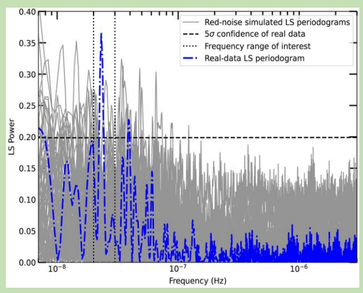






ANALYSIS RESULTS OBTAINED WITH THE **XRONOS** SOFTWARE. LEFT PANEL: PG 1553+113 PSD OF X-RAY LC OBTAINED WITH THE POWERSPEC PACKAGE OF XRONOS. MIDDLE PANEL: BEST-FIT PERIOD (SOLID LINE) OF PG 1553+113 X-RAY LC OBTAINED WITH THE EFSEARCH TASK, ALONG WITH ITS NUMERICAL VALUE IN SECONDS CORRESPONDING TO **~1.4 YEARS**. RIGHT PANEL: EPOCH FOLDING OF PG 1553+113 X-RAY LC OBTAINED WITH THE EFOLD METHOD ON THE BASIS OF THE BEST-FIT PERIOD DETERMINED BY EFSEARCH. **[8]**

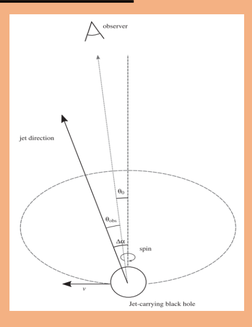
XRONOS CONFIRMED THE PRESENCE OF A SIGNIFICANT PERIODICITY IN THE X-RAY DATA OF PG 1553+113, SUPPORTING THE RESULTS OBTAINED WITH THE LOMB-SCARGLE PERIODOGRAM.



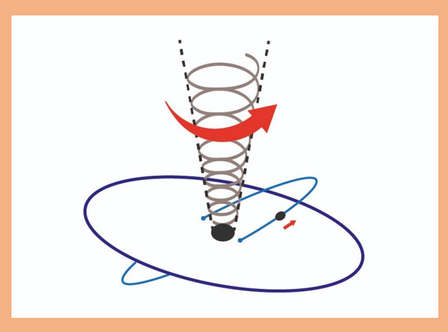
LS PERIODOGRAMS CALCULATED ON **RANDOMLY GENERATED LCS OF PURE RED NOISE**. THE SIMULATION WAS PERFORMED TO RULE OUT THE POSSIBILITY THAT THE X-RAY PEAK WAS A STATISTICAL FLUCTUATION. THE RESULTS SHOW THAT ONLY ~16% OF THE SIMULATED LIGHT CURVES EXHIBIT A PEAK AT THE SAME FREQUENCY WITH A COMPARABLE POWER, MEANING WE CAN EXCLUDE THE POSSIBILITY OF A RANDOM OCCURRENCE WITH A CONFIDENCE LEVEL OF ~84%. WE SHOW 10^2 (GRAY SOLID LINES) OUT OF THE TOTAL 10^5 REALIZATIONS, SUPERIMPOSED ON THE LS PERIODOGRAM OF THE REAL PG 1553+113 X-RAY DATA (BLUE DOT-DASHED LINE) AND THE CORRESPONDING 5Σ SIGNIFICANCE LEVEL (BLACK DASHED LINE). THE RELEVANT FREQUENCY INTERVAL FOR OUR ANALYSIS OF (2 − 3)×10−8 HZ (BLACK DOTTED LINES) IS HIGHLIGHTED. **[8]** 3

PERIODICITY MODELS

- ✓ **GEOMETRICAL MODELS** JET PRECESSION, HELICAL JET OR GRAVITATIONALLY AFFECTED JET **[3]**
- ✓ **DYNAMICAL MODELS** INSTABILITIES IN THE JET DUE TO STRESSES INDUCED BY A SECONDARY BLACK HOLE ORBITING AROUND THE JETTED BLACK HOLE (THE SMALLER BH GRAVITATIONALLY INFLUENCES THE JET OF TH LARGER SMBH); **[5]**



- ✓ **OUR MODEL**



- ✓ THE **SECONDARY BH** ORBITS AROUND THE MAIN CENTRAL ENGINE, PERTURBING THE X-RAY EMITTING REGION WITH A 1.4-YR PERIOD
- ✓ THE **JET IS CARRIED BY THE MAIN BH, AND PRECEDES** WITH A 2.2-YR PERIOD

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CONCLUSIONS

- ✓ THE PG 1553+113 X-RAY, UV, AND OPTICAL LCS ARE ALL MODERATELY CORRELATED TO EACH OTHER ACCORDING TO THE PEARSON ANALYSIS (R ∼ 0.5) **[8]**; THE X-RAY PHOTON INDEX IS CORRELATED WITH THE X-RAY FLUX IN A SIMILAR WAY. THIS BEHAVIOR IS TYPICAL OF BLAZARS, WHERE THE LIGHT IS EMITTED ALMOST ENTIRELY FROM THE JET DUE TO THE SYNCHROTRON AND IC PROCESSES (**[6] [7]**).
- ✓ THE X-RAY LC CONSTRUCTED OVER ≳10 OBSERVER-FRAME YEARS OF SWIFT-XRT DATA LIKELY (> 80% CONFIDENCE LEVEL) EXHIBITS A PERIODIC EMISSION, BUT WITH A SHORTER CHARACTERISTIC PERIOD OF T_X ∼ 1.4 YEARS **[8]** WITH RESPECT TO THAT FOUND IN THE OPTICAL AND Γ-RAY BANDS ($T_{OPT} = T_{UV} = T_\Gamma$ ∼ 2.2 YEARS; **[2] [3] [4]**.

$$T_X \sim 1.41 \pm 0.68 \text{ yr}$$

$$T_{\gamma UVopt} \sim 2.2 \text{ yr}$$

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[1] DANFORTH ET AL. 2010, APJ, 720, 976; [2] ACKERMANN ET AL. 2015, APJ, 813, L41; [3] SOBACCHI ET AL. 2017, MNRAS, 465, 161; [4] PEÑIL ET AL. 2024, MNRAS, 527, 10168; [5] HUANG ET AL. 2021, APJ, 922, 222; [6] PADOVANI & GIOMMI 1995, MNRAS, 277, 1477; [7] MARASCHI ET AL. 1992, IN PHYSICS OF ACTIVE GALACTIC NUCLEI, EDS. W. J. DUSCHL, & S. J. WAGNER, 605: [8] ANIELLO ET AL. 2024, A&A, 686, A300.