# Blazar Flares at the Cosmic Dawn: Uncovering High-energy Processes at z>4

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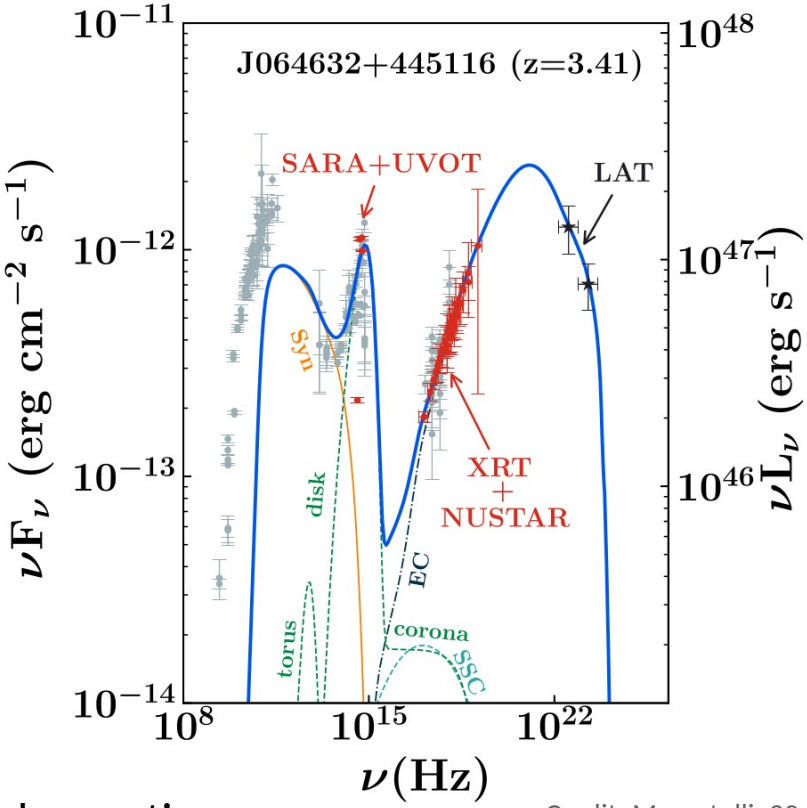
Image Credit: NASA/JPL-Caltech/GSFC

# Why are high-redshift blazars interesting?

**High-redshift blazars**

- $L_{bol.} > 10^{48}$ erg $s^{-1}$
- $M_{BH} \geq 10^{9}$ $M_{solar}$ [e.g., Ghisellini+10, Ajello+16, Paliya+16]
- Strong Compton dominance




Credit: Marcotulli+20

- High-energy hump peaks in MeV band
  → simultaneous X-ray and gamma-ray data necessary
- Accretion disk emission redshifted to optical/UV
- Individual detections allow to draw conclusions about population [e.g.,Sbarrato+14]
- High redshift → probing regions closer to SMBH with radio observations

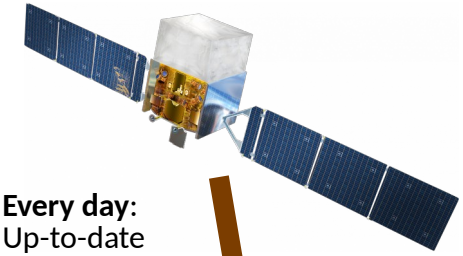
# Search for gamma rays from high-*z* sources

| | | |
|---|---|---|
| Accumulating (Fermi-LAT) data over time | → | Catalogs |
| Monitoring daily sky (LAT Flare advocates) | → | Real-time flare alerts |

**Works for most sources**

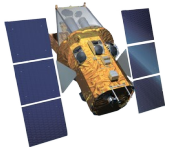
**BUT** high-redshift blazars = on average very faint with regard to LAT sensitivity

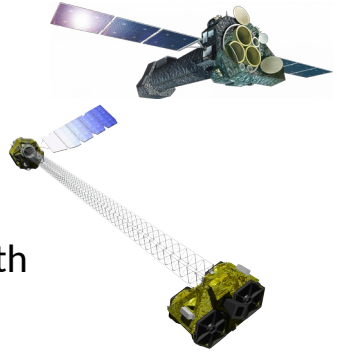
→ Real-time search for signal by $z > 3$ blazars listed in BZCAT on monthly time scales [after Kreter+20]



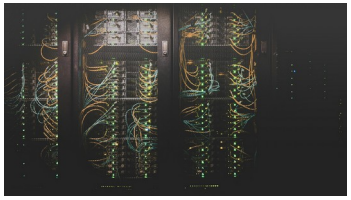
**Every day**: Up-to-date public data from *Fermi*-LAT

Additional check for real signal from the source (require TS > 25)





Multiwavelength campaign



Automated pipeline looking for signal in the last 30 days at positions of high-*z* blazars

# Flare of TXS 1508+572 ($z = 4.31$)

- Other source names:
  4FGL J1510.1+5702, GB 1508+5714
- Flare detection: February 2022
- Report in Atel #15202:
  5-day averaged flux ~25x 4FGL flux

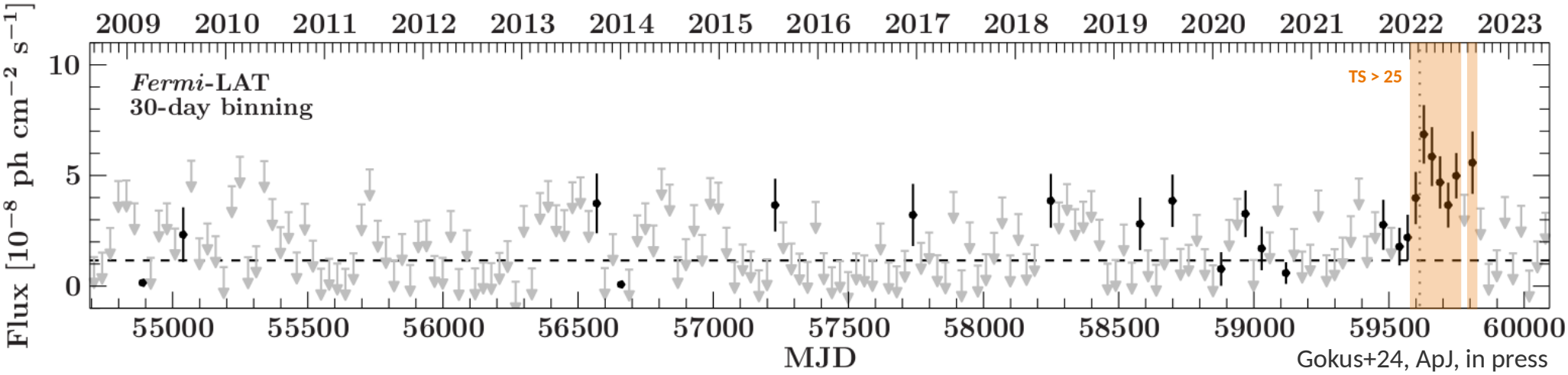
[ Previous | Next | ADS ]

**Gamma-ray flare of high-redshift blazar GB 1508+5714 detected by Fermi/LAT**

ATel #15202; *A. Gokus (Remeis-Observatory/ECAP & JMU Wuerzburg), M. Kreter (NWU), M. Kadler (JMU Wuerzburg), F. McBride (PSU), S. Buson (JMU Wuerzburg), R. Ojha (NASA), E. Ros (MPIfR), J. Sinapius (DESY), on behalf of the LAT collaboration, M. Boettcher (NWU), J. Hodgson (KASI), J. Wilms (Remeis-Observatory/ECAP)*
*on **5 Feb 2022; 16:24 UT***
*Credential Certification: Andrea Gokus (andrea.gokus@fau.de)*

Subjects: Gamma Ray, >GeV, Request for Observations, AGN, Blazar, Quasar

Long-term 30-day binned light curve (100 MeV – 300 GeV)
with upper limits for TS < 9:

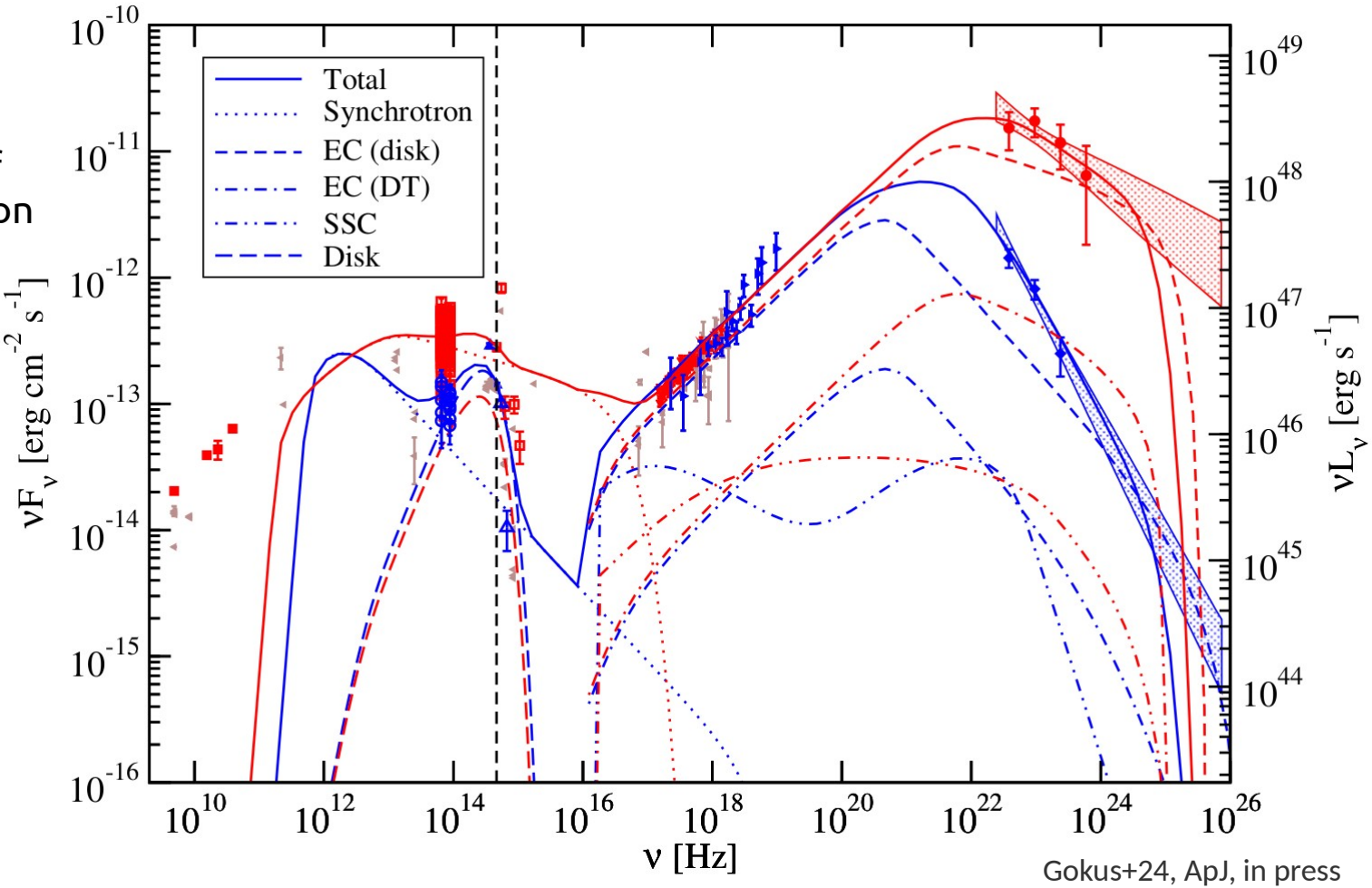



Gokus+24, ApJ, in press

# Broadband SED of TXS 1508+572

Quiescent state: **blue**
Flaring state: **red**

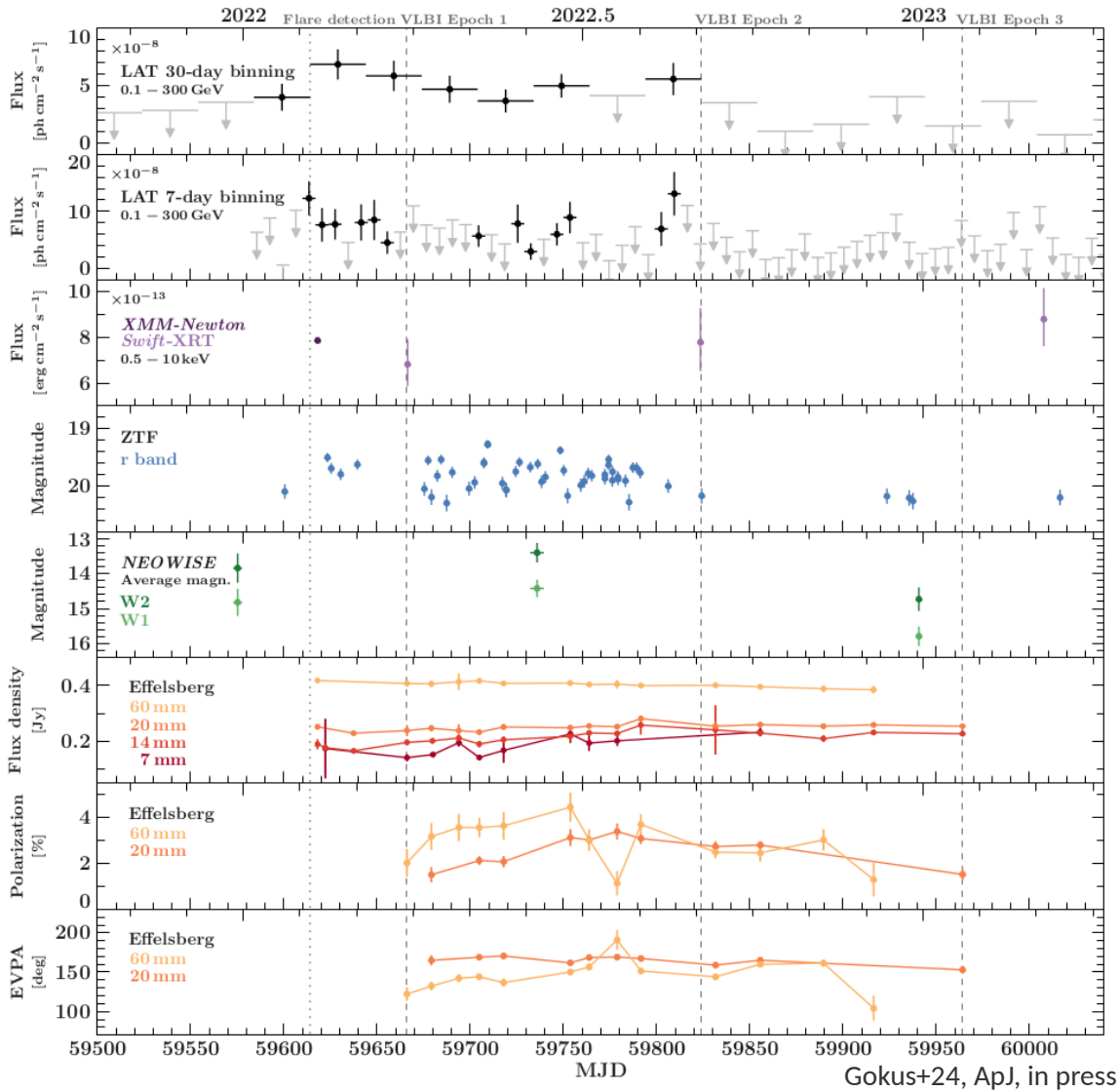
- During flare: increase of near-IR and γ-ray emission
- Single-zone leptonic model sufficient
- Lyman-α absorption starting at ~640nm → *distinction in emission from jet and accretion disk challenging*
- Optical polarization six months after flare < 3%




Gokus+24, ApJ, in press

# Variability of TXS 1508+572

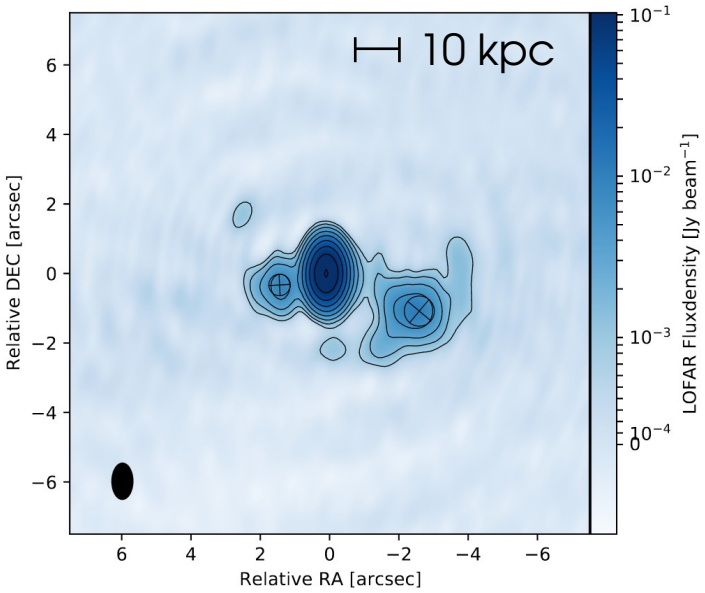
- Normalized excess variance $\sigma^2_{RMS}$ low or consistent with noise, except for near-IR and optical r-band on daily time scales
- Near-IR behaviour consistent with LSP blazars / FSRQs
- Gamma-ray spectrum significantly hardened during flare, but no change in X-ray spectra
- Isotropic gamma-ray luminosity:
  $2 \times 10^{48}$ erg/s (quiescent state)
  comparable to other $z > 3$ blazars
  → during flare: $> 5 \times 10^{49}$ erg/s, only 6 other sources with equally bright or brighter flares
  $> 10^{49}$ erg/s: PKS 0537−286, PKS 0402−362, 3C 454.3, 3C 279
  $> 10^{50}$ erg/s: CTA 102, B3 1343+451




Gokus+24, ApJ, in press

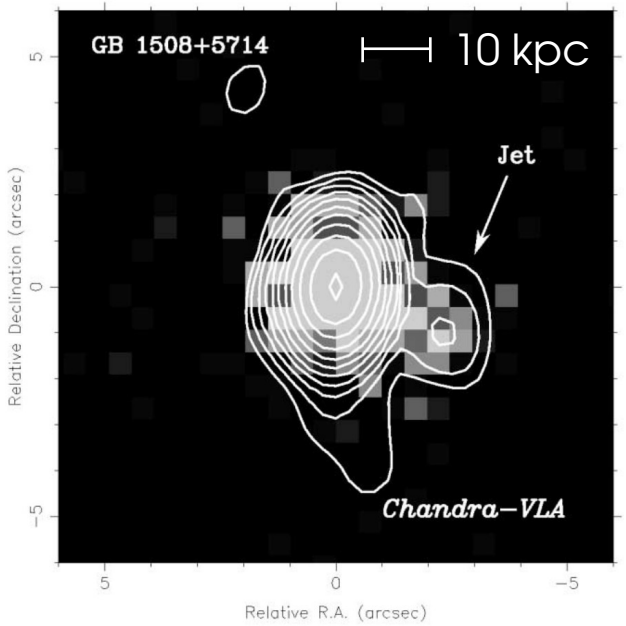
# Radio images of TXS 1508+572

## 144 MHz



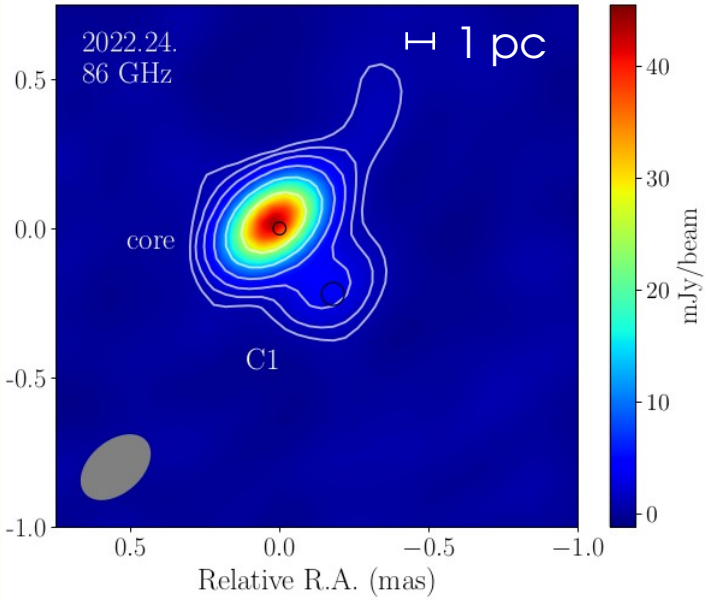

LOFAR image
(Kappes et al., 2022, *A&A* 663, A44)

## 1.4 GHz




VLA contours with
Chandra image
(Cheung, 2004, *ApJ* 600, L23)

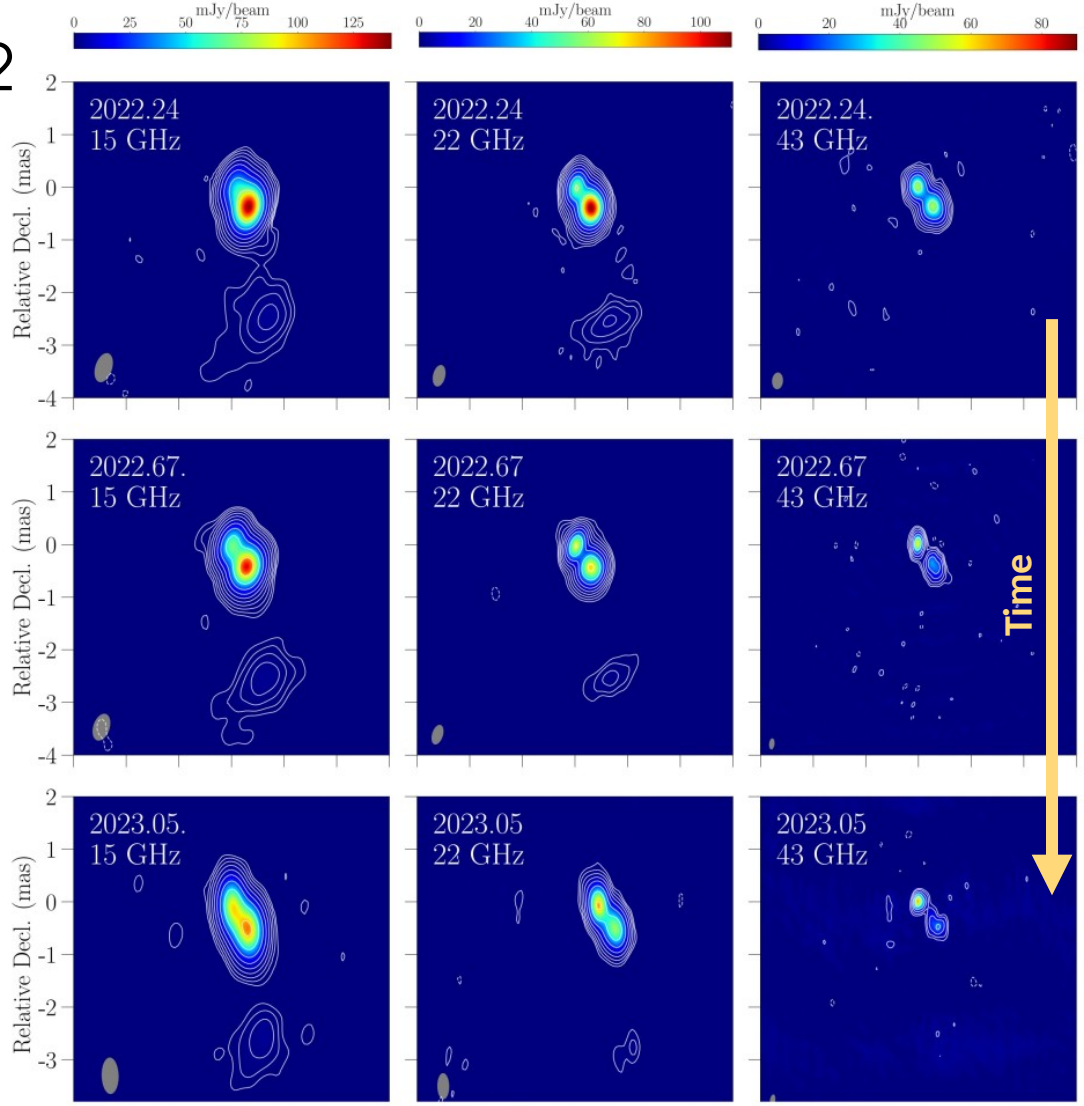
## 86 GHz




VLBA + Effelsberg + Greenbank
Telescope image
(Benke et al., 2024, *A&A*, 689, A43)

# VLBI monitoring of TXS 1508+572

- Due to high redshift, we can observe much higher source intrinsic frequencies:
  15 GHz → 80 GHz (3 epochs)
  22 GHz → 117 GHz (3 epochs)
  43 GHz → 228 GHz (3 epochs)
  86 GHz → 456 GHz (1 epoch)
- South-west component moving away from core
- Kinematic analysis yields apparent jet velocity $\beta_{app} \approx 14.3\ c - 32.2\ c$
  → agreement with bulk Lorentz factor Γ from our SED model
  → originated from core ~ 2016 – 2019
  (not connected to γ-ray flare in 2022)

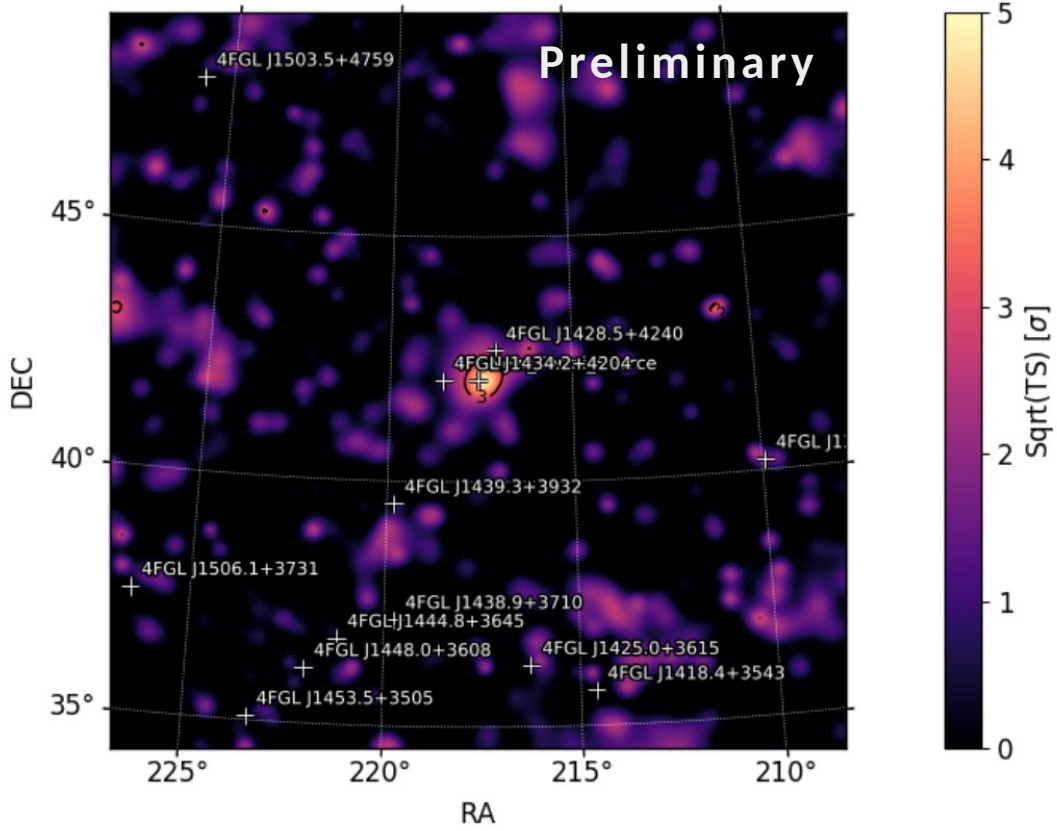



Benke+24, A&A, 689, A43

# Flare of B3 1428+422 ($z$ = 4.72)

- Other source name: 5BZQ J1430+4204
- Flare detection: December 2023
- Source not listed in 4FGL, but reported as γ-ray emitter by Liao+18 and Kreter+20
- Tested that emission is not coming from neighbouring sources
- Hard X-ray emission elevated by ~50% compared to previous observation
- Optical polarization during flare at ~ 8% → contribution from jet
- Current MWL analysis on-going

TS map for B3 1428+422, with the emission from the source visible in the center



# Summary & Conclusions


- High-redshift blazar flares rare (on average 1 per 14 months)
- We can observe very luminous gamma-ray flares from the early Universe
- VLBI monitoring allows us to probe high-*z* jets at much higher frequencies

- Status of high-z blazar projects:
  - Both papers about TXS 1508+572 in press at ApJ / A&A:
    Gokus A. et al., 2024, arXiv:2406.07635 (MWL analysis)
    Benke P., et al., 2024, A&A, 689, A43 (VLBI campaign)
  - Study of flare by B3 1428+422 currently on-going

Postdoc for Hire:
Looking for a new position starting end of 2025