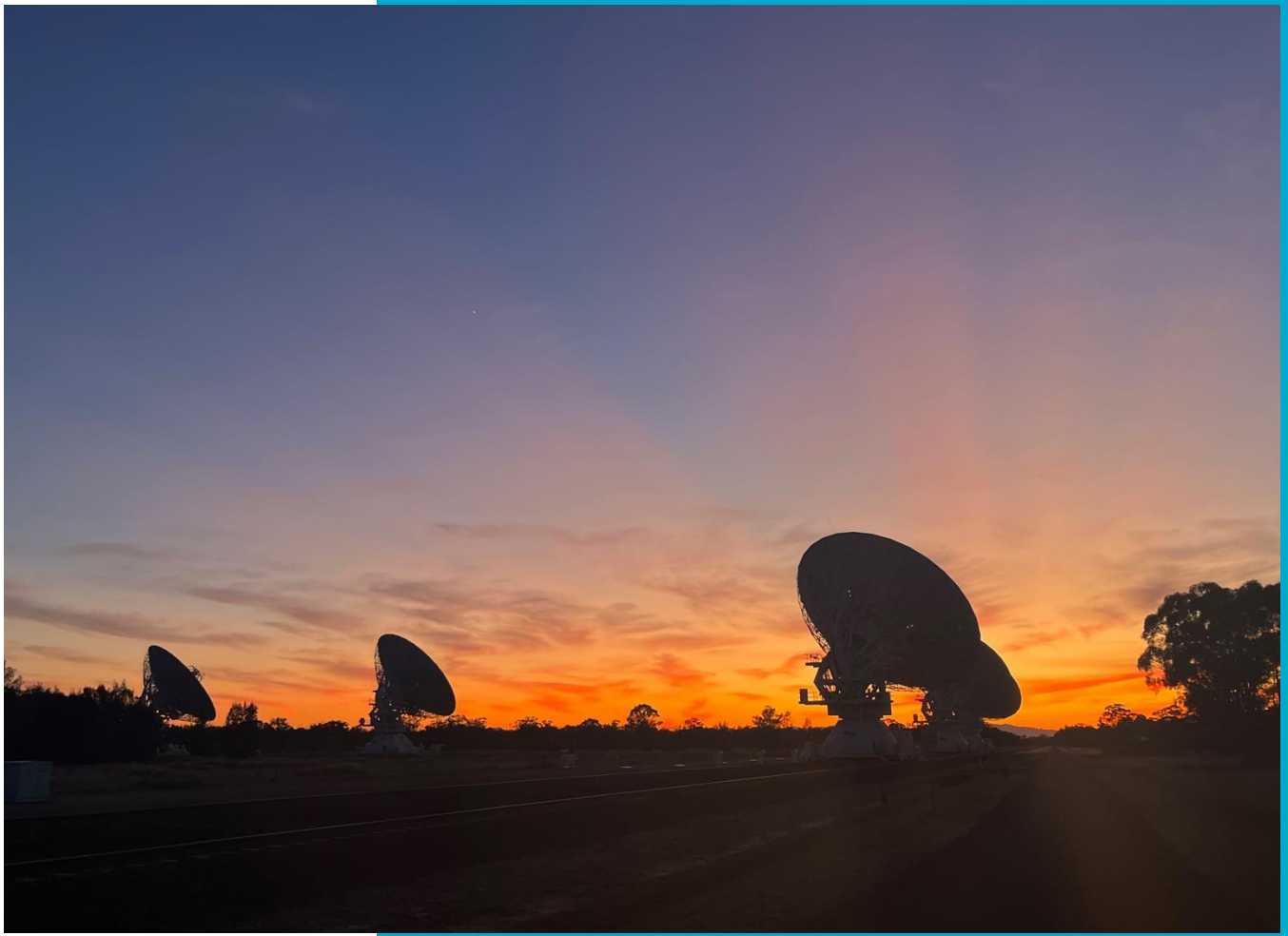
ATCA and LBA monitoring of AGN in the CTAO era

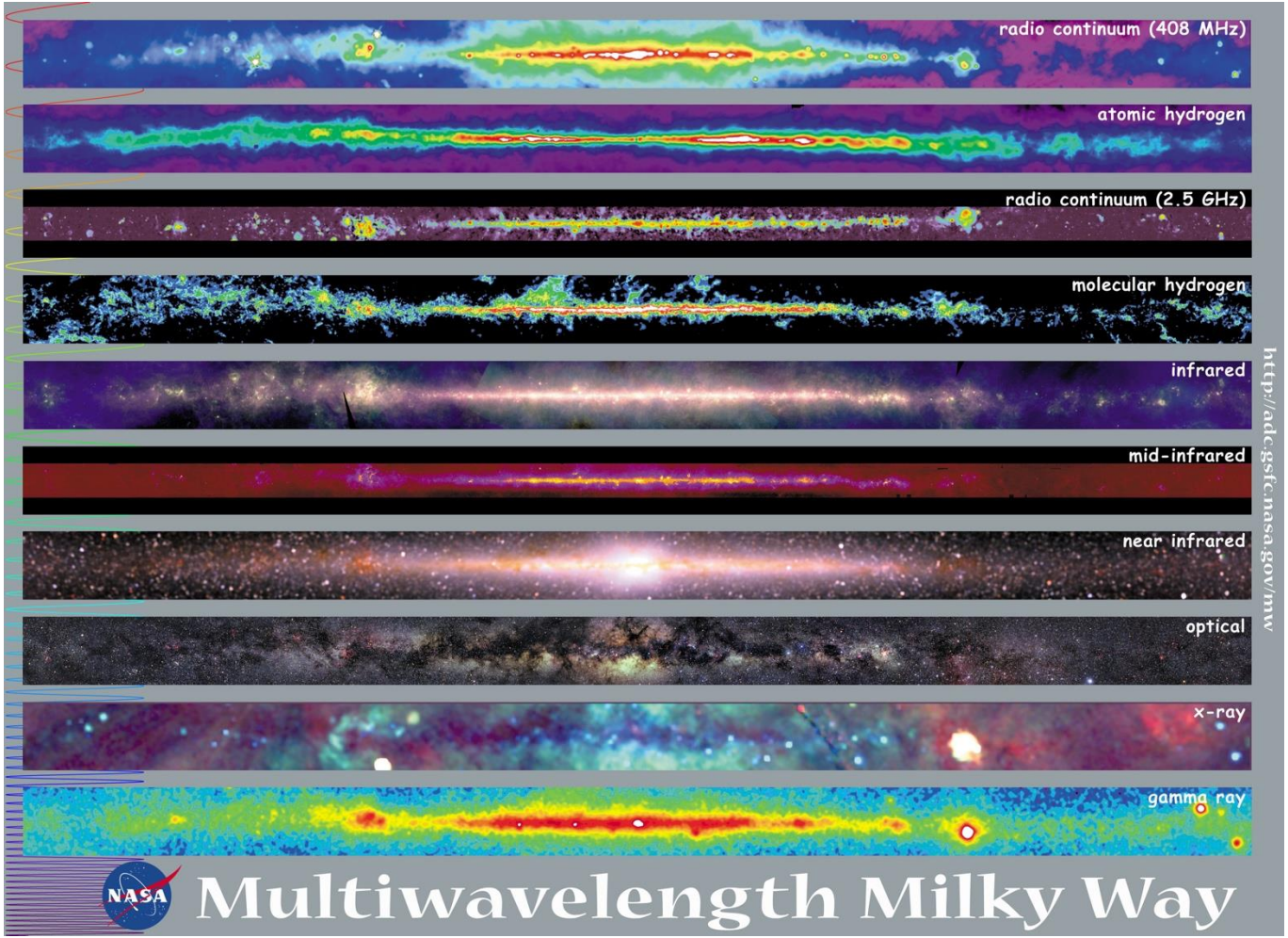
Phil Edwards | 14 Nov 2024



https://www.atnf.csiro.au/ATNF-DailyImage/archive/2023/19-Sep-2023.html

Outline

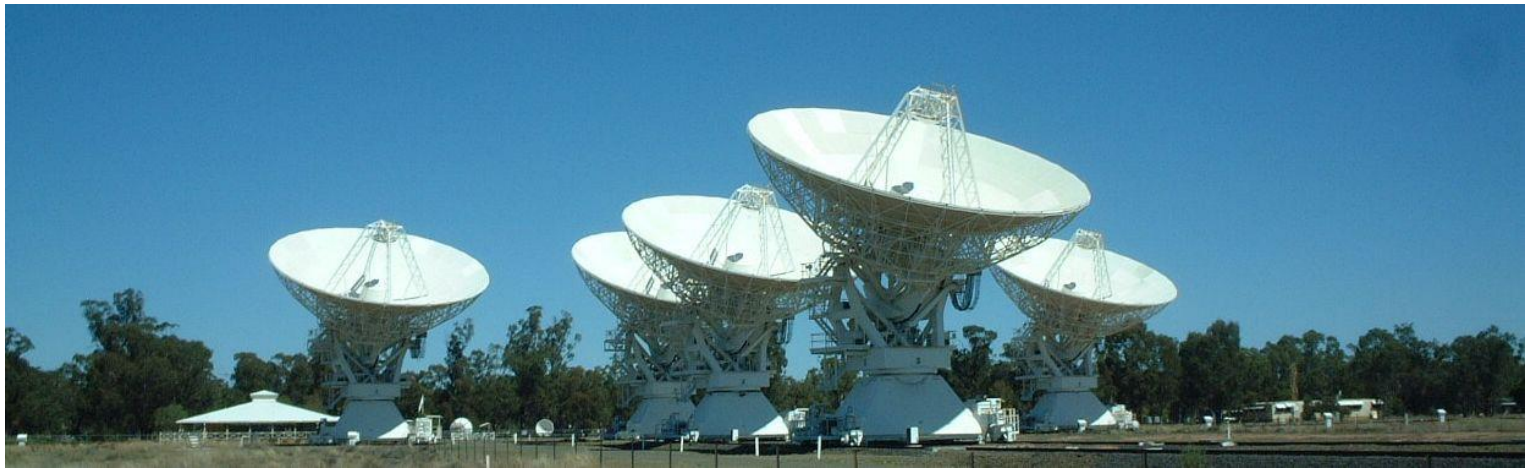
- What are the gamma-ray sources?
  - Pulsars
  - Binary systems
  - HBLs
  - Other AGN
  - NLS1s
  - Unidentified sources
- What’s the status of radio facilities?
  - ATCA
  - LBA


radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way

Source type	TeVcat 2018	TeVcat 2024
Unidentified	57	123
HBL	49	56
PWN	35	36
Shell	14	13
Binary	11	11
SNR/Molecular cloud	10	11
IBL	8	9
FSRQ	7	10
Pulsars	3	4
10 other types	20	61
Total	214	305

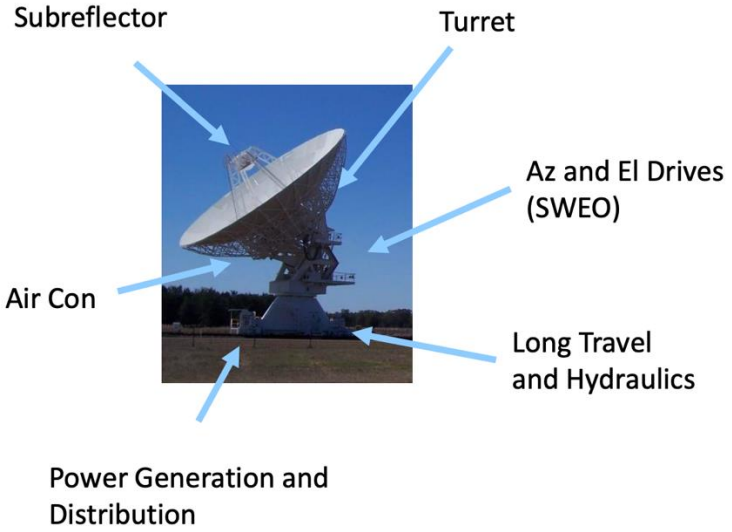
ATCA

- Ongoing flux density monitoring of Fermi AGN
- BIGCAT will replace CABB, providing more flexibility, greater reliability and greater bandwidths at higher frequencies



ATCA upgrades and improvements

- BIGCAT
- Turret, Translator & Subreflector Control
- Power supply and distribution
- Antenna hydraulics and long travel)
- Antenna Tracking (SWEO)
- Vertex Air Conditioning

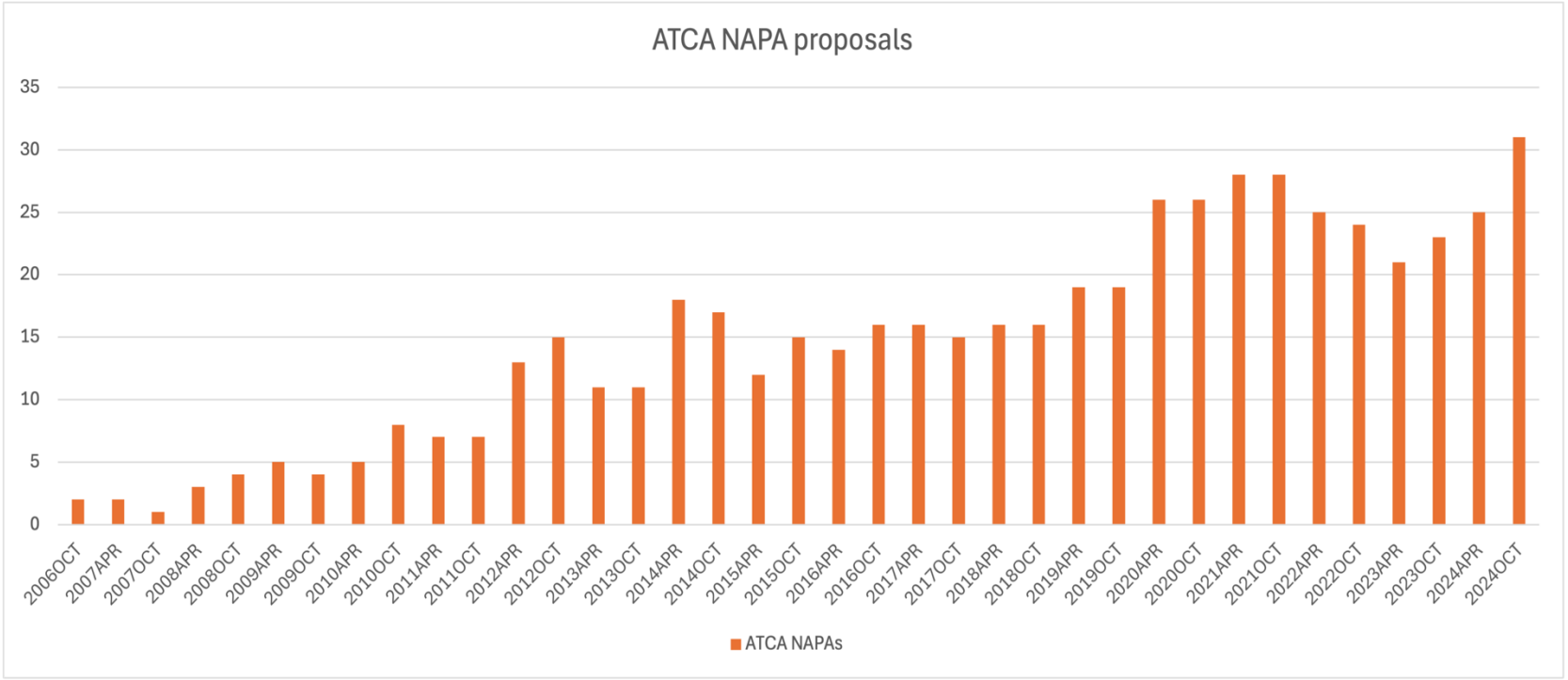


- All this being done while keeping the array operating, and with reduced staff!

ATCA infrastructure upgrade

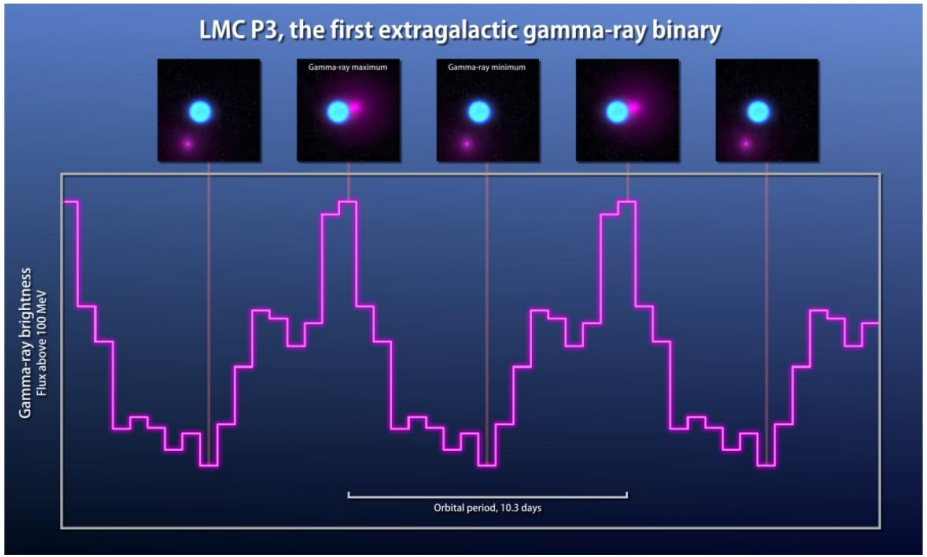
- A ~$2M upgrade of up to 35 year old equipment
- Procurement and first installations well underway
- Anticipating one 8-week shutdown in late 2025, or two 4-week shutdowns in 2025 and 2026.

ATCA NAPA proposals



ATNF Daily Astronomy Picture

24th of October 2016



First γ-ray binary in the LMC

by Phil Edwards (CASS)

Using data from NASA's Fermi Gamma-ray Space Telescope, the Australia Telescope Compact Array (ATCA), and other facilities, an international team of scientists has found the first γ-ray binary in another galaxy and the most luminous one ever seen. The dual-star system, dubbed LMC P3, contains a massive star and a crushed stellar core that interact to produce a cyclic flood of γ-rays, the highest-energy form of light. LMC P3 lies within the expanding debris of a supernova explosion located in the Large Magellanic Cloud (LMC), a small nearby galaxy about 163,000 light-years away.

http://www.atnf.csiro.au/ATNF-DailyImage/

X-ray and radio light curves roughly in phase with each other, but out of phase with the gamma-ray light curve

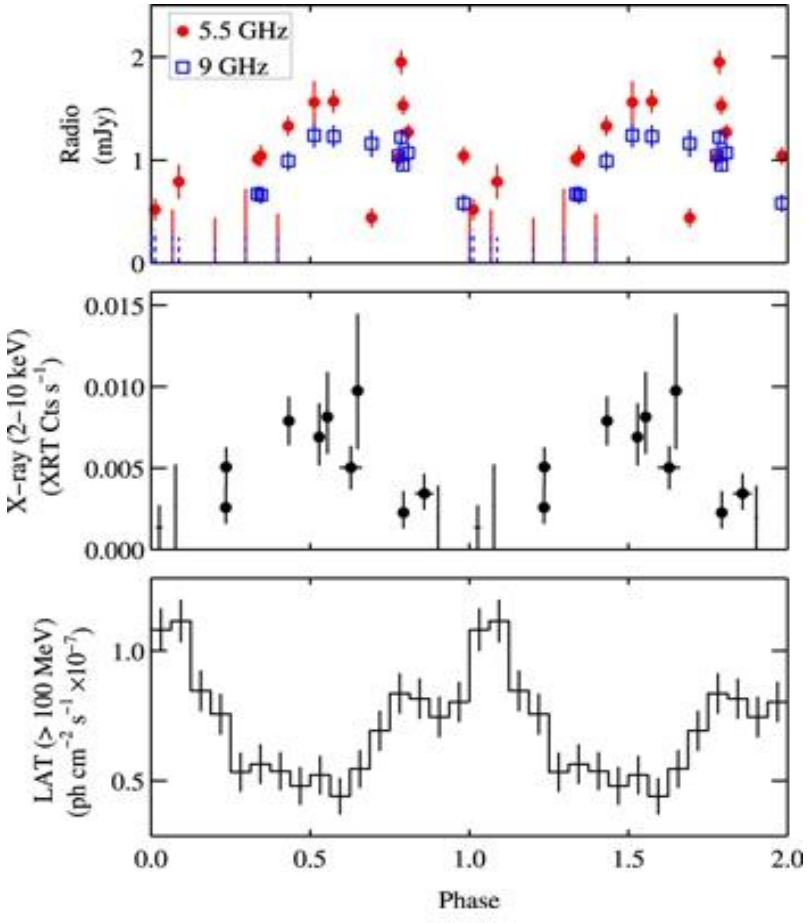
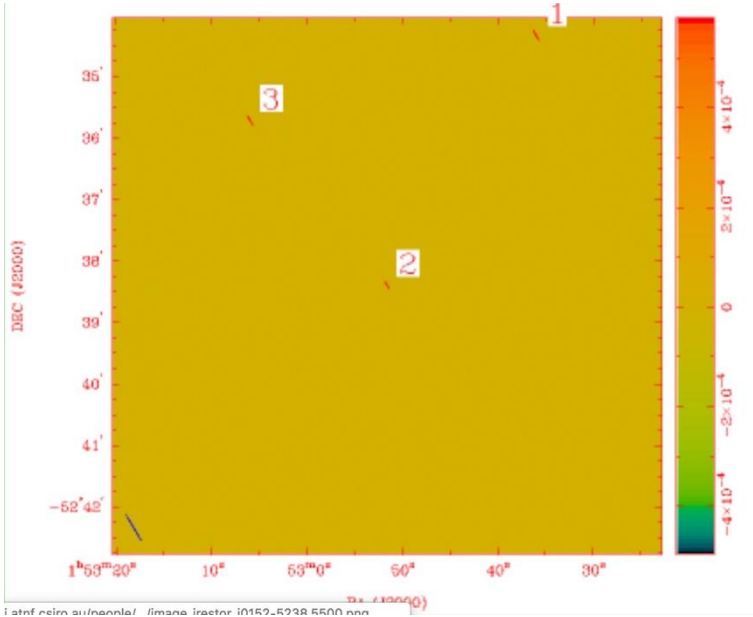


Figure 3 from A Luminous Gamma-ray Binary in the Large Magellanic Cloud
Corbet et al. 2016, ApJ, 829, 105

NLS1 galaxies

- With the increasing number of AGN detected by Fermi, new classes of object are emerging, including Narrow Line Seyfert 1 galaxies.
- These are believed to have lower mass SMBHs in their core, possibly accreting at closer to the Eddington rate
- Generally radio-quiet



Credit: Jamie Stevens

Chen et al. 2022, MNRAS, 512, 471

PMN J0948+0022

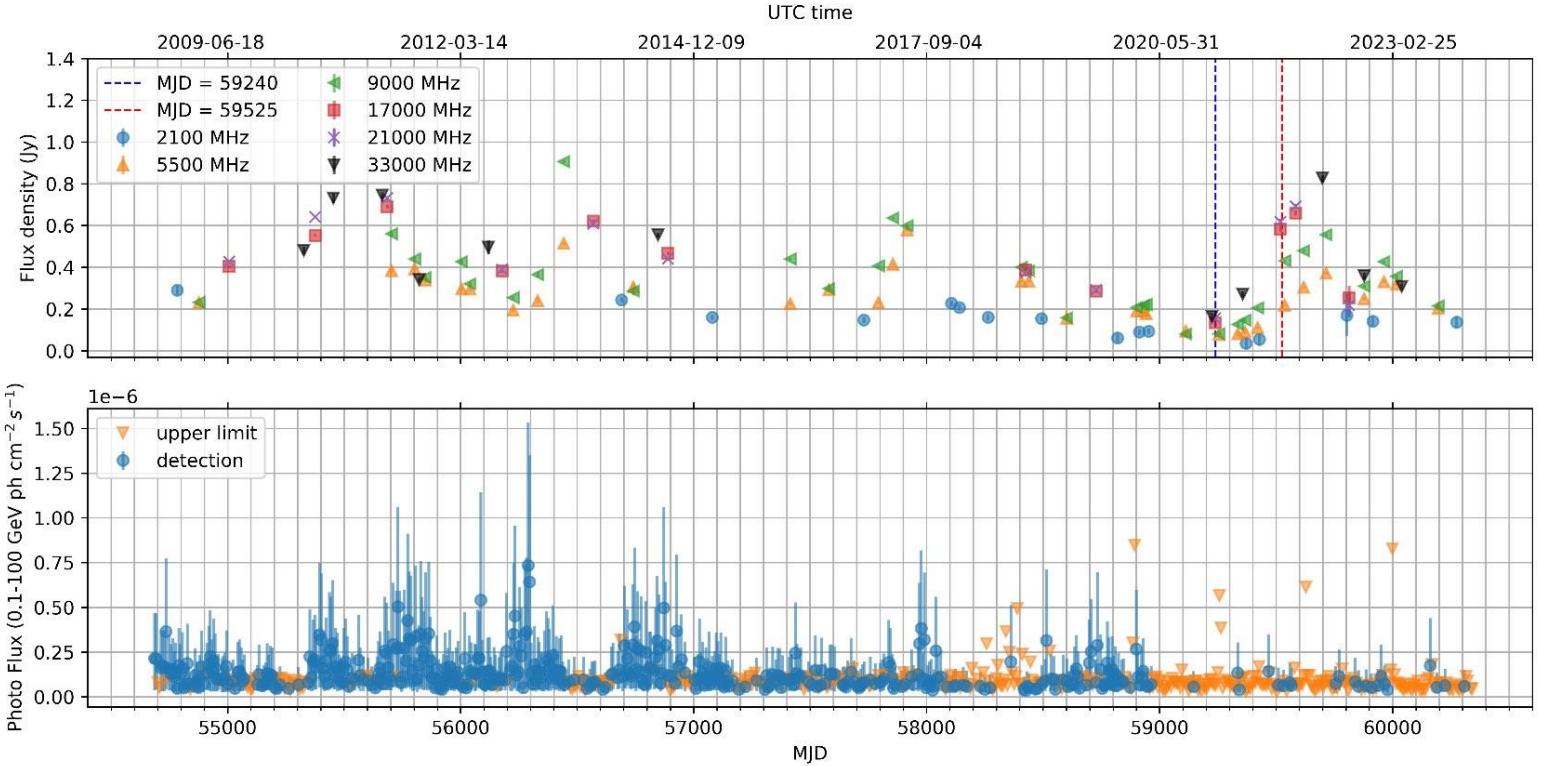


Figure 2. The radio and gamma-ray light curves of PMN J0948+0022. The dashed lines indicate the epochs for which radio spectra are shown in Figure 6.

Xi Shao et al. 2024 MNRAS

PKS 1502+036

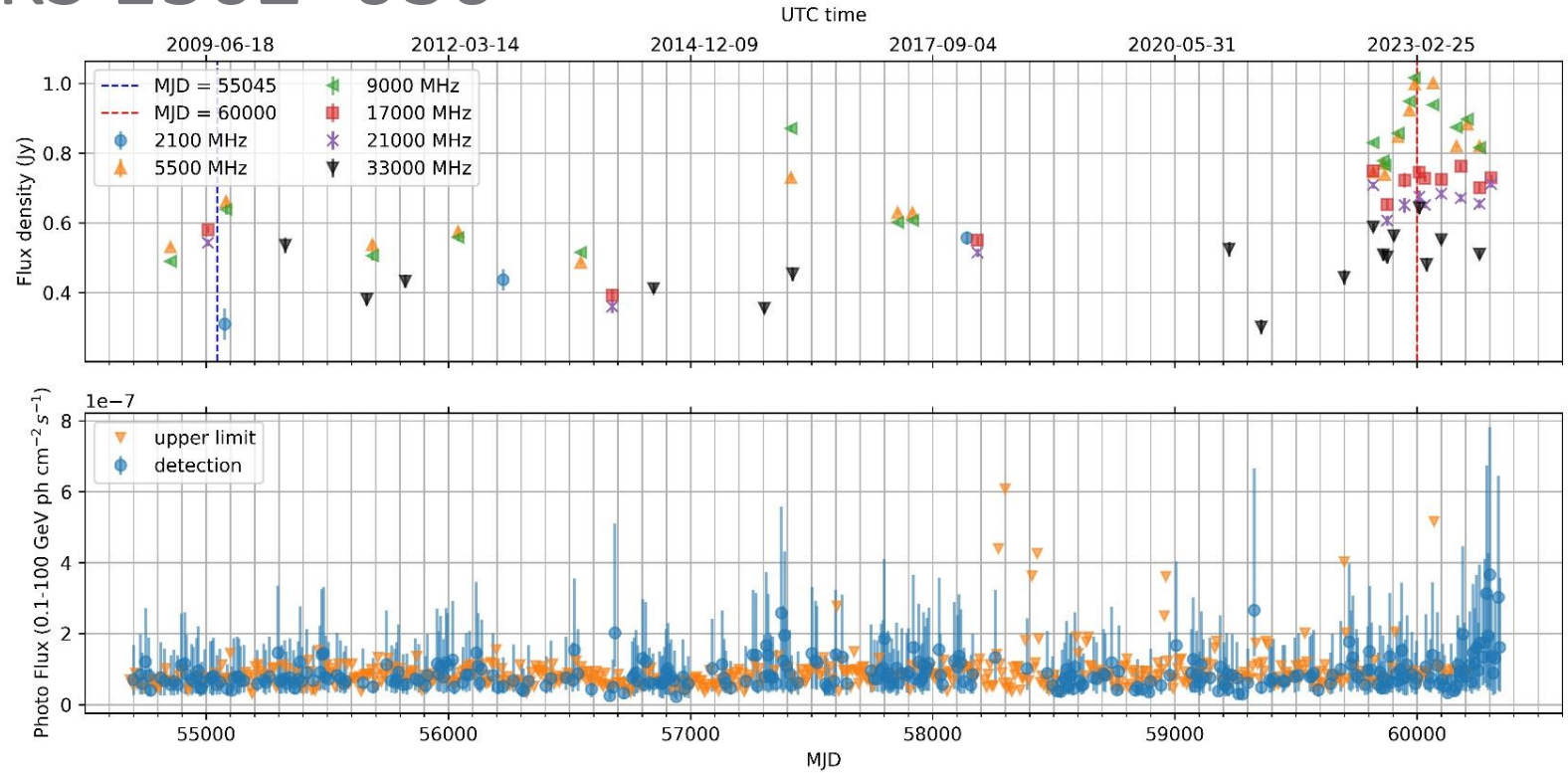
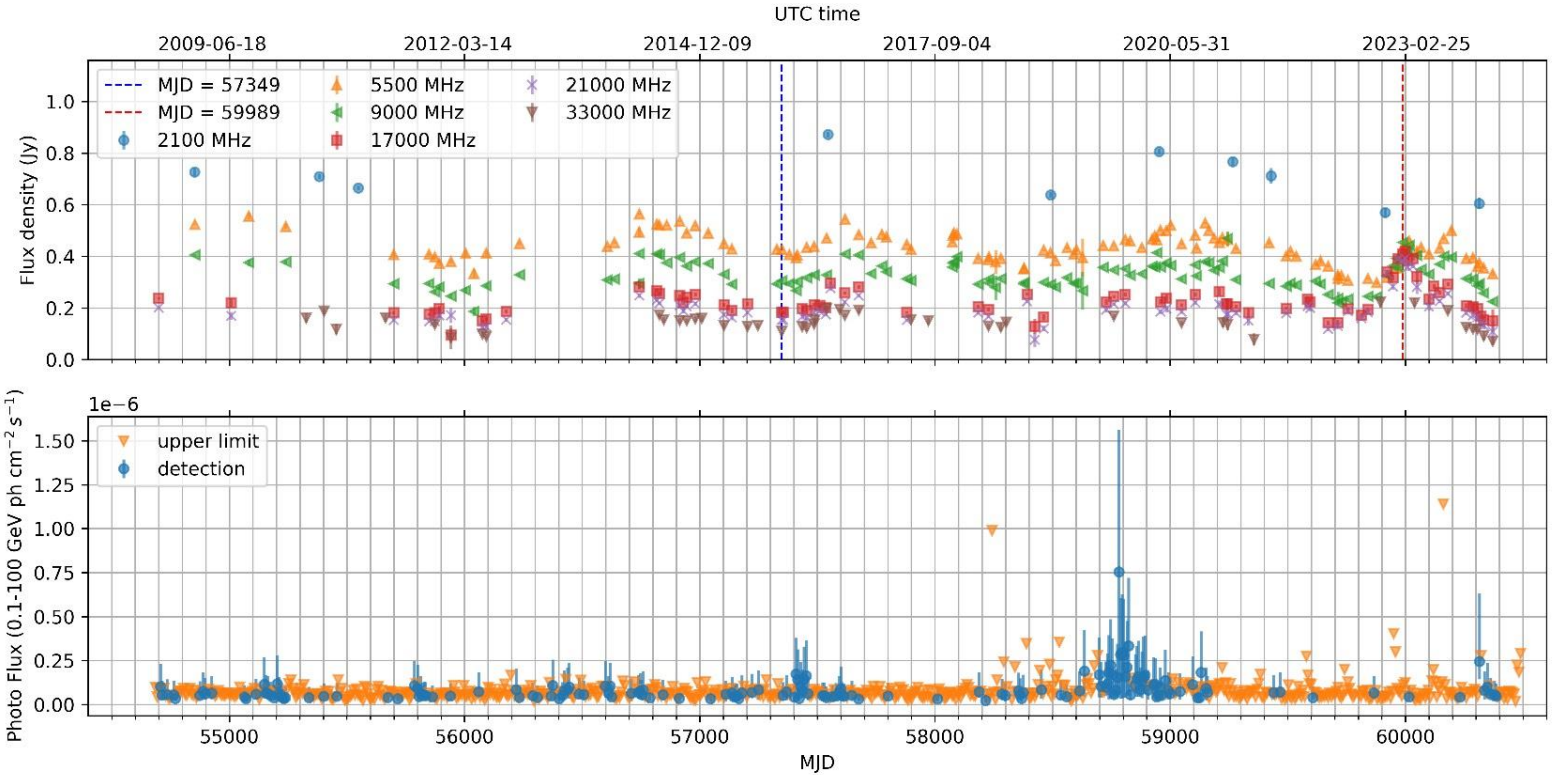


Figure 4. The radio and gamma-ray light curves of PKS 1502+036. The dashed lines indicate the epochs for which radio spectra are shown in Figure 6.

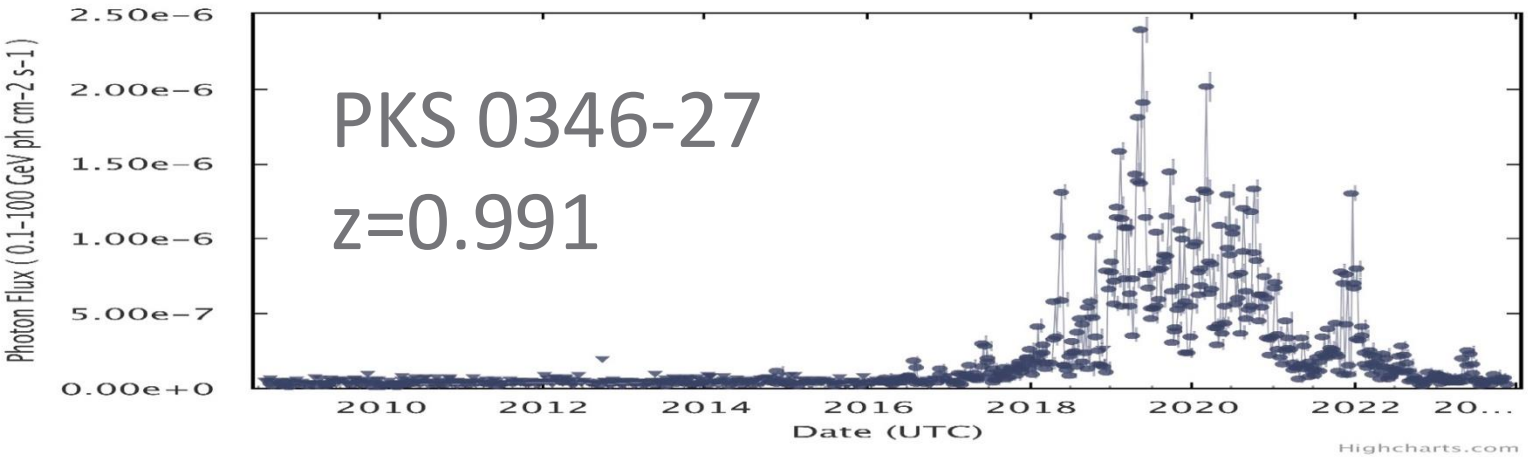
Xi Shao et al. 2024 MNRAS

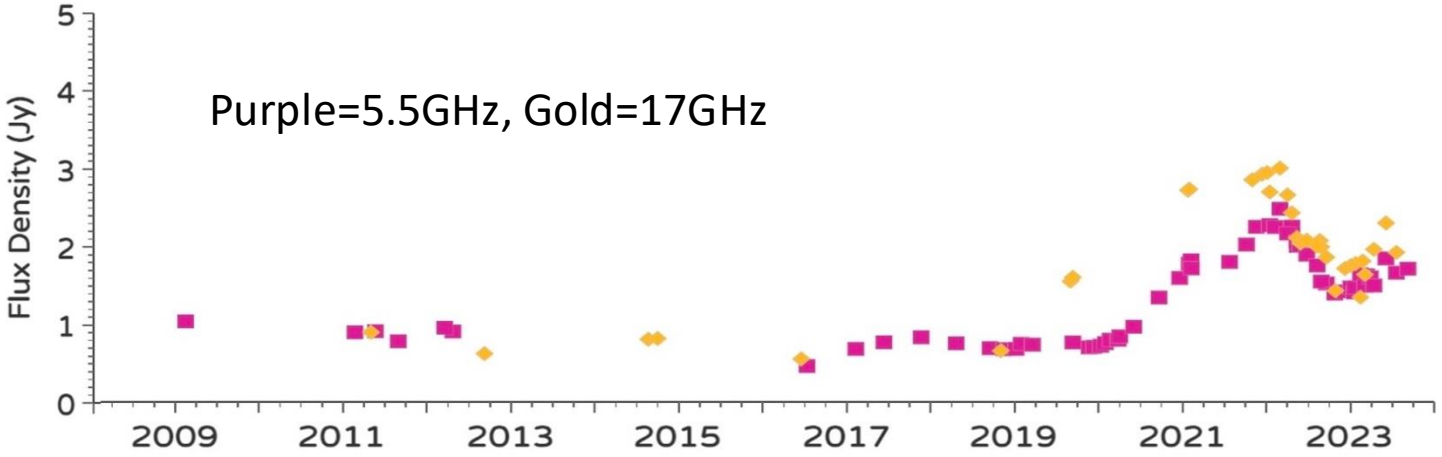
PKS 2004-447



Gokus et al. 2021 A&A, 649 A77

Xi Shao et al. 2024 MNRAS

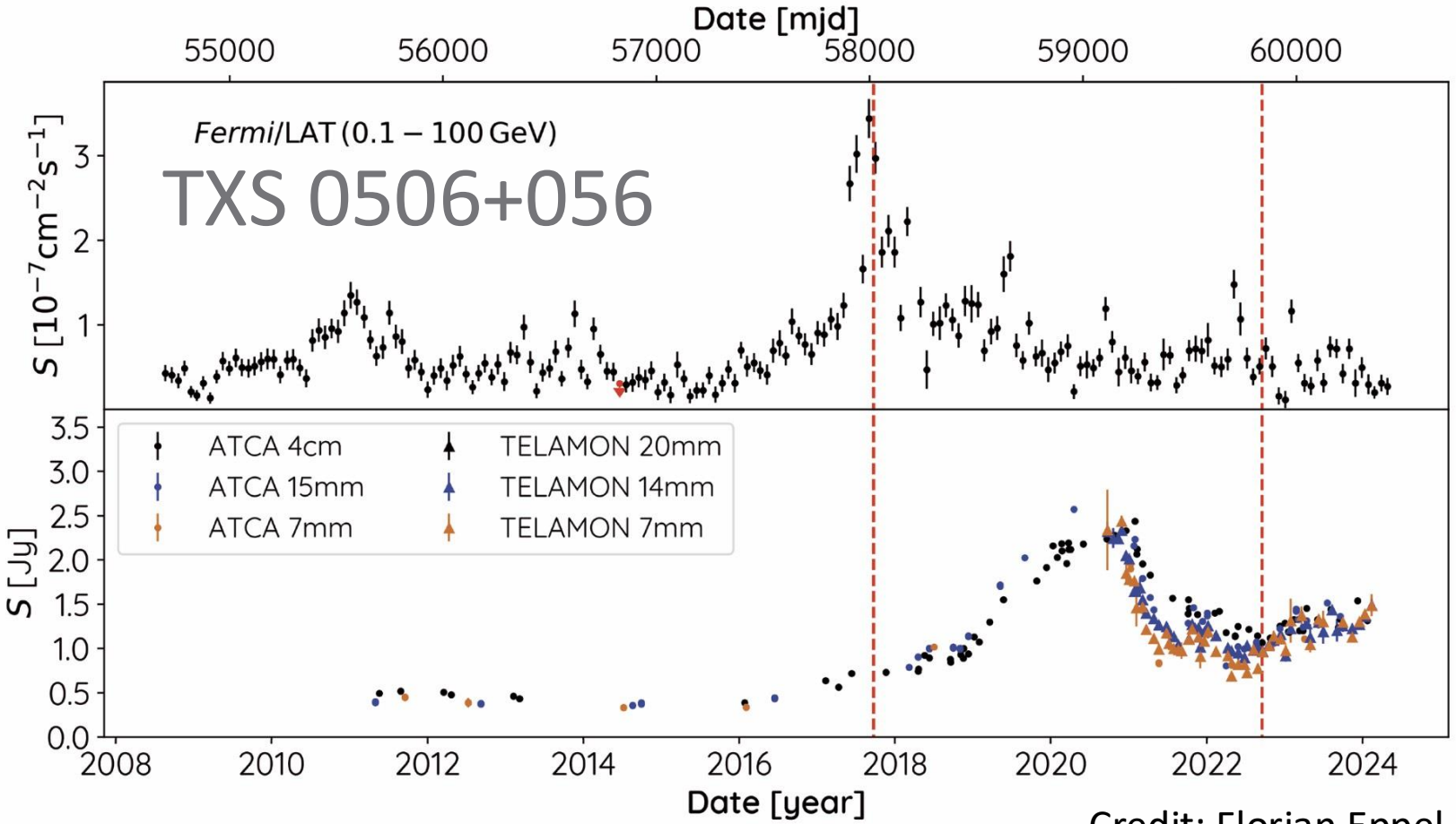

PKS 0346-27
z=0.991
Photon Flux (0.1-100 GeV ph cm-2 s-1)
2.50e−6
2.00e−6
1.50e−6
1.00e−6
5.00e−7
0.00e+0
2010
2012
2014
2016
2018
2020
2022
Date (UTC)
Highcharts.com


Purple=5.5GHz, Gold=17GHz
Flux Density (Jy)
5
4
3
2
1
0
2009
2011
2013
2015
2017
2019
2021
2023

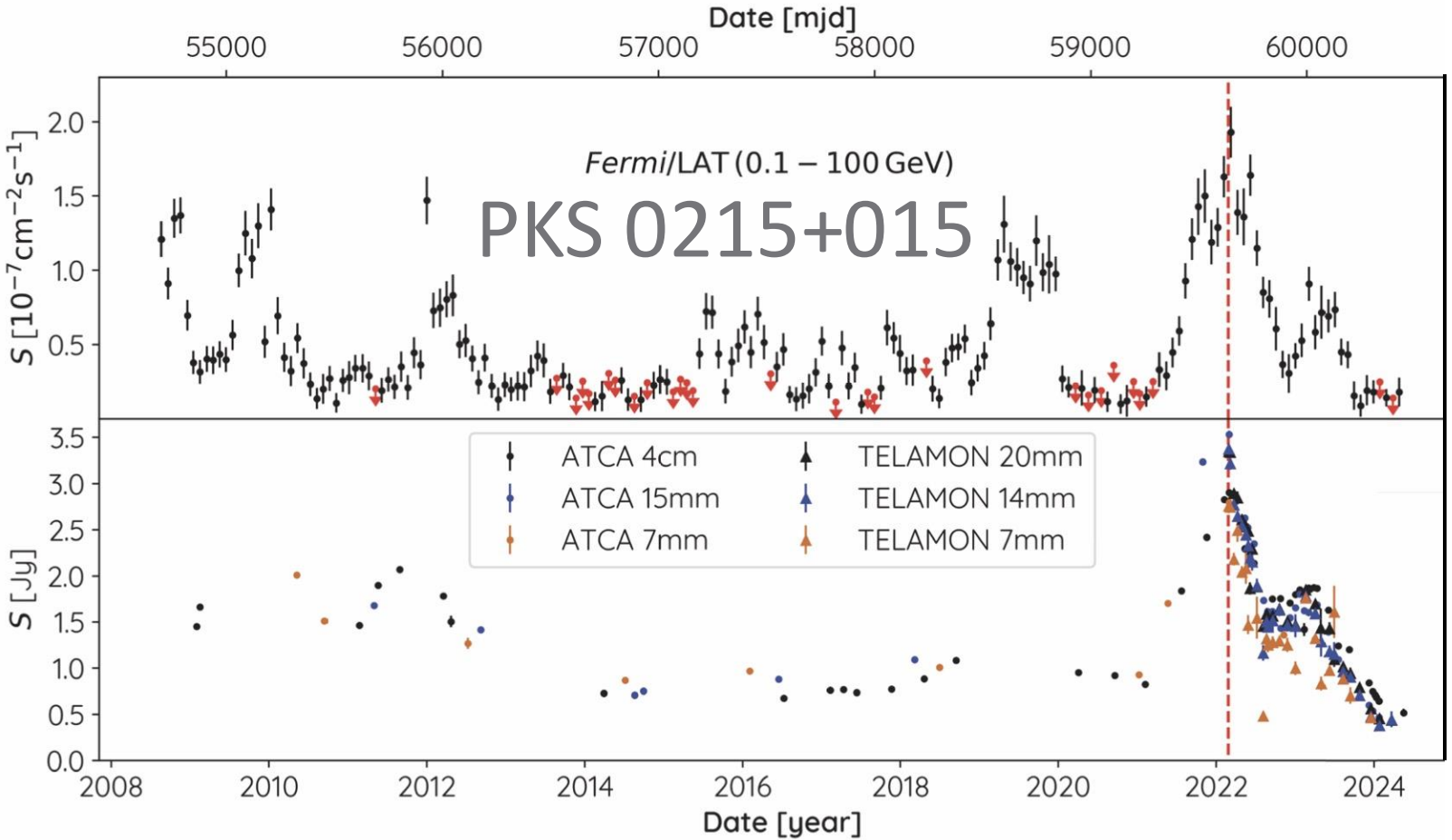
Other monitoring

- TELAMON: Effelsberg monitoring of AGN jets with very-high-energy astroparticle emission. I. Program description and sample characterization
  - Eppel et al., 2024, A&A, 684, A11

Lat. 50.5° N, Long. 6.9° E



Credit: Florian Eppel



Credit: Florian Eppel

Fermi unidentified sources

- Search for compact, flat-spectrum sources in Fermi error ellipses
- Good for identifying candidate AGN associations
  - *"ATCA observations of Fermi unassociated sources,"*
    Petrov et al. 2013, MNRAS, 432, 1294
  - *"New Associations of Gamma-Ray Sources from the Fermi Second Source Catalog,"*
    Schinzel et al 2015, ApJS, 217, 4
  - *"Radio Follow-up on All Unassociated Gamma-Ray Sources from the Third Fermi Large Area Telescope Source Catalog," Schinzel et al. 2017, ApJ, 838, 139*
- Are the RACS (Rapid ASKAP Continuum Survey) catalogs useful?
- Will EMU be more useful?

C1730

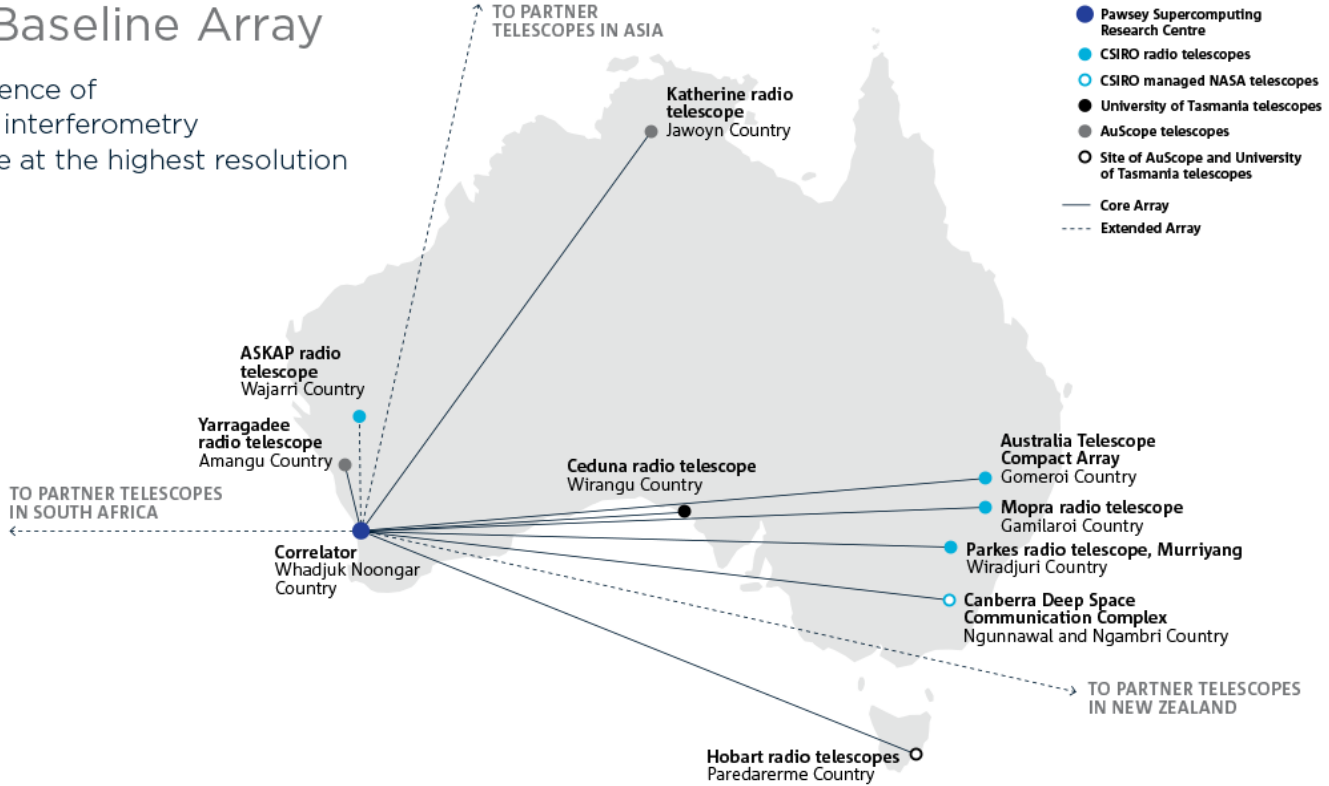
- ATNF Large Project for regular multi-frequency ATCA monitoring of high energy astrophysical sources
- C1730 has contributed to ~15 papers and ~9 ATels
- Currently ~8 hour epochs every ~3 weeks, offset in LST to provide all-sky coverage every ~6 weeks, primarily at 5.5 & 9 GHz
- Data reduction pipelined by Jamie Stevens, results promptly posted on ATNF Calibrator Database
- Band 5 on SKA-Mid is nominally 4.6 to 15.3 GHz

LBA

- Installation of UWL and CryoPAF on Murriyang/Parkes will limit LBA observing at frequencies above 4 GHz, until UWM and UWH are completed in ~3 years
- But after that, Parkes will not be limiting factor in frequency agility of the LBA. Ceduna, Hobart and Warkworth require manual receiver changes
- LBA has typically had ~4 blocks of 5~6 days per year, but there is interest in moving to more frequent, shorter blocks

The Long Baseline Array

Harnessing the science of
very long baseline interferometry
to see our Universe at the highest resolution

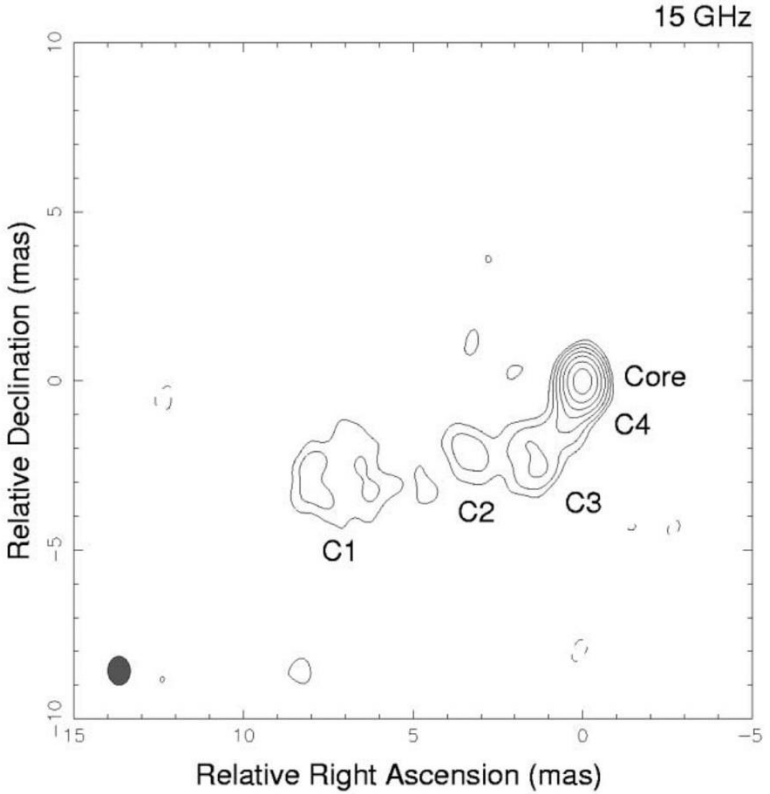


LBA Overview

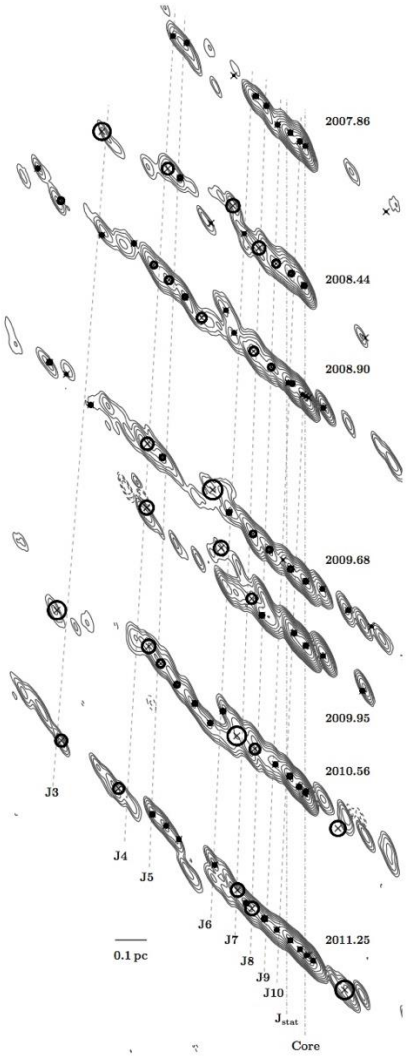
- Partnership CSIRO, UTas, AUT/SpaceOps, SARAO
- Observe in the 1.5, 2.3, 4.8, 6.7, 8.4, 22, 32, (43, 86) GHz bands
- Maximum bit rate 1 Gbps (64MHz x 2IFs x 2bits x 2pols x 2Nyquist)
- Traditionally operated in 4–5 blocks of 5–6 days per year
- Baselines from 114 km (At-Mp) to 10480 km (Ww-Hh)
- Data correlated using DiFX software correlator at the Pawsey Supercomputing Research Centre
- Continuum, spectral line, proper motion & parallax, stellar science

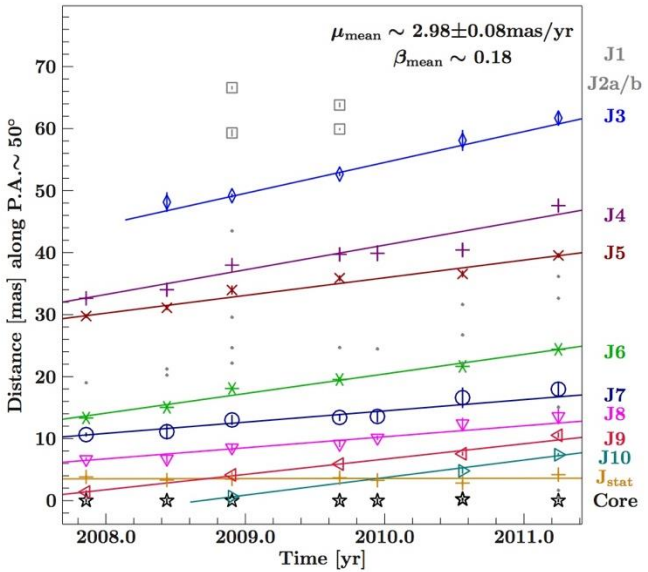
HBLs

- The inverse Compton component of the SED of HBLs can extend to TeV energies
- Early VLBI follow-up of Mkn421 (Piner et al. 1999) and Mkn501 (Edwards & Piner 2002)
- “Multi-Epoch VLBA Imaging of Twenty New TeV Blazars: Apparent Jet Speeds,” Piner & Edwards, 2018, ApJ, 853, 68
- http://whittierblazars.com/




TANAMI
Tracking Active Galactic Nuclei with Austral Milliarcsecond Interferometry
Mopra 22m
ATCA 5 x 22m
Parkes 64m
Ceduna 30m
Tidbinbilla 70m
TIGO 6m
Hartebeesthoek 26m
Hobart 26m
O'Higgins 9m



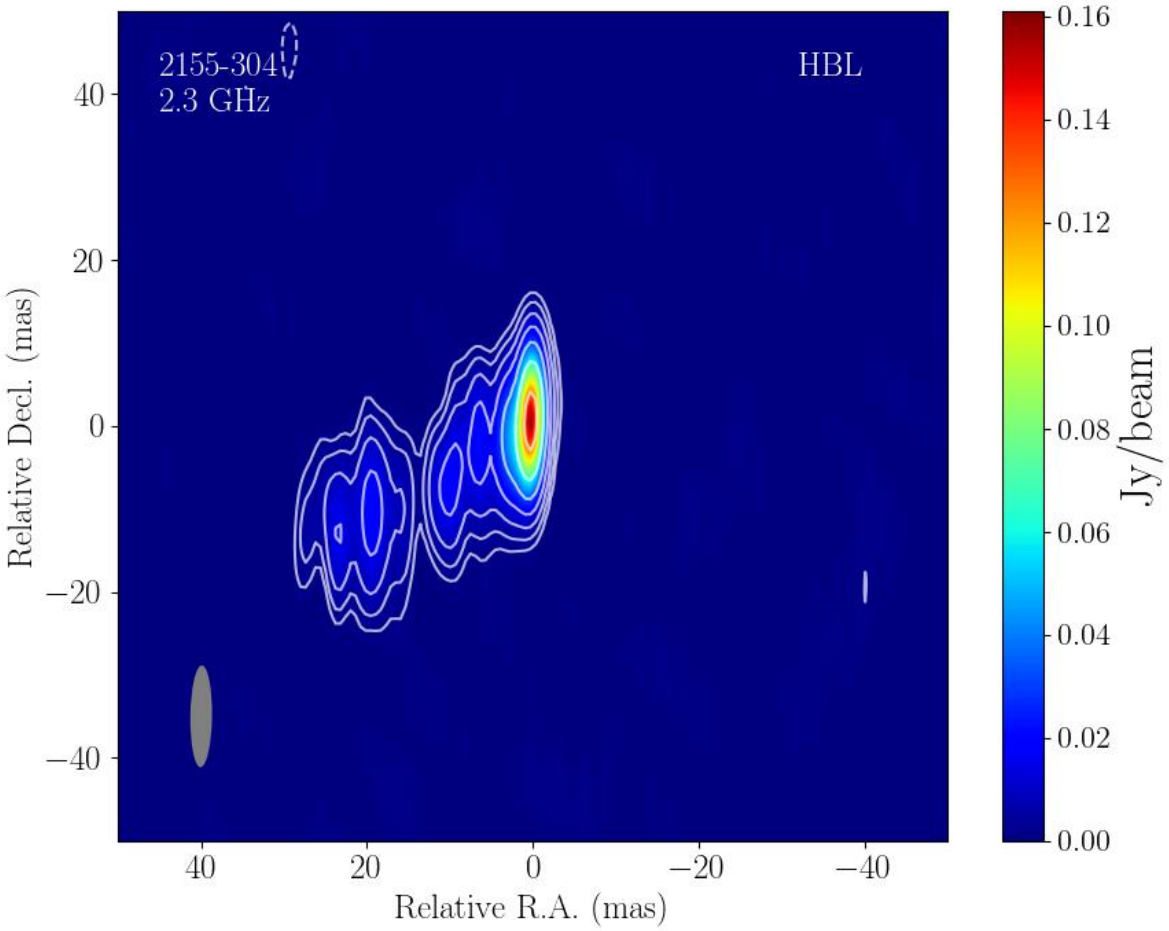


Centaurus A
Müller et al. 2014 A&A, 569, A115

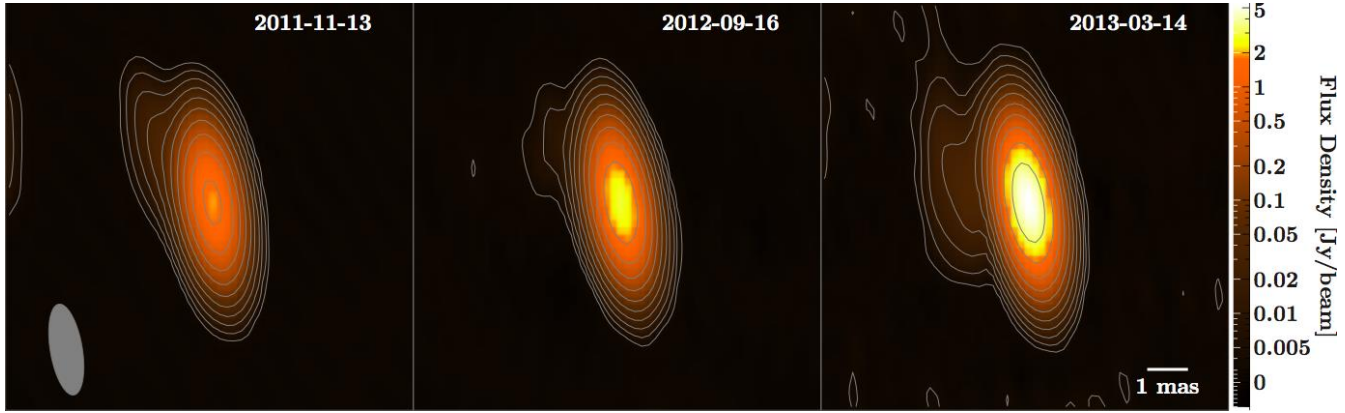
TANAMI recent results

- First very long baseline interferometry detection of Fornax A
  - Paraschos et al., 2024, A&A, 687, L6
- TANAMI: Tracking active galactic nuclei with austral milliarcsecond interferometry. III. First-epoch S band images
  - Benke et al., 2024 A&A, 681, A69
- Gamma-ray emission in radio galaxies under the VLBI scope. II. The relationship between γ-ray emission and parsec-scale jets in radio galaxies
  - Angioni et al., 2020, A&A, 641, A152
- Gamma-ray emission in radio galaxies under the VLBI scope. I. Parsec-scale jet kinematics and high-energy properties of gamma-ray-detected TANAMI radio galaxies
  - Angioni et al., 2019, A&A, 627, A148

PKS 2155-304


2155-304
2.3 GHz
HBL
Relative Decl. (mas)
Relative R.A. (mas)
Jy/beam
40
20
0
−20
−40
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00

PKS 1424-418



- Possible coincidence with IceCube PeV neutrino – Kadler et al. 2016 Nat. Phys.
- No measured component speed (yet)

Conclusions (2018)

- We've come a long way since "the astronomy of one source"….
- There are strong links between the opposite ends of the electromagnetic spectrum
- Radio monitoring and imaging of diverse classes of sources, including pulsars, binaries, various classes of AGN, and unidentified sources, will aid in the identification of counterparts and modeling of the physical processes at work
- We can expect CTA to revolutionise TeV gamma-ray astronomy in the same way Fermi has done at GeV energies

Concluding thoughts (2024)

- How can we better coordinate radio monitoring with TeV observing schedules?
- Should we request c1730 schedules be aligned with the lunar month for quasi-simultaneous observations?
- How to deal with non-point-like AGN?
- Extracting polarization information from c1730 (and modifying observing strategy, if required)
- How to best add TeV sources to TANAMI schedules?
- An ATCA program focusing on TeV unidentified sources? eROSITA??
- How to keep ATCA and LBA alive into the CTAO era!

Thank you

CSIRO Space and Astronomy
Phil Edwards
Lead Scientist, Long Baseline Array

Philip.Edwards@csiro.au
www.csiro.au/atnf