ASTRO WÜRZBURG

# TELAMON

**Florian Eppel**
on behalf of the TELAMON Team

## Effelsberg Monitoring of AGN Jets with Very-High-Energy Astroparticle Emission

# TELAMON-Team

M. Kadler, U. Bach, P. Benke, D. Berge, S. Buson, D. Dorner, P.G. Edwards, F. Eppel, M. Giroletti, A. Gokus, O. Hervet, J. Heßdörfer, S. Koyama, A. Kraus, T.P. Krichbaum, E. Lindfors, K. Mannheim, R. de Menezes, R. Ohja, G. F. Paraschos, E. Pueschel, F. Rösch, E. Ros, B. Schleicher, J. Sinapius, J. Sitarek, J. Wilms, M. Zacharias

# TeV-Blazars

- AGN with Jets pointed directly towards Earth
- Highly variable broadband emission from radio to $\gamma$
- Typical double-humped spectrum
- Classified according to Synchroton Peak Frequency
  -> HBL and Extreme Blazars (synchr. peak > $10^{15}$ Hz)

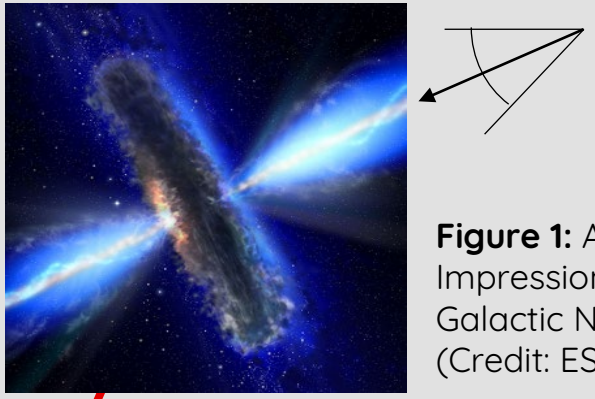


**Figure 1:** Artist's Impression of an Active Galactic Nucleus/AGN (Credit: ESA/NASA)

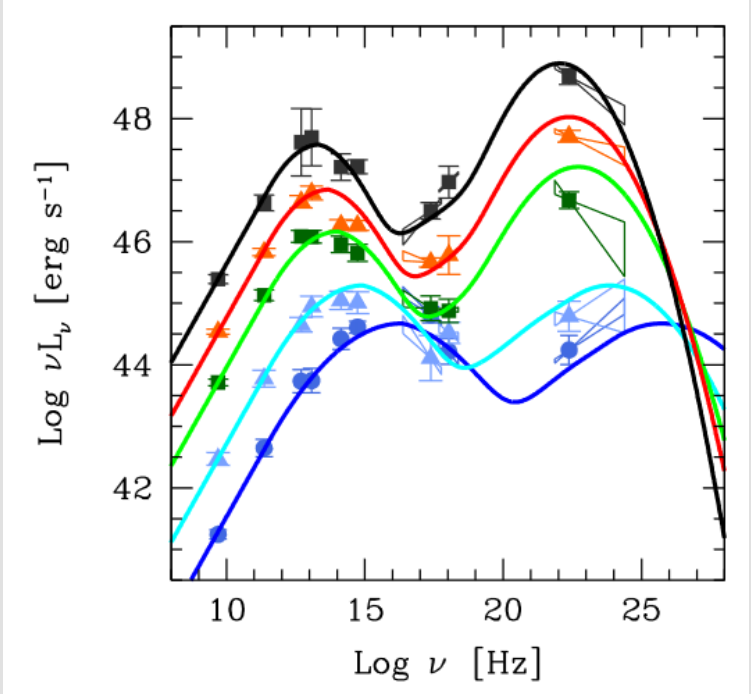



**Figure 2:** Blazar Sequence, Fosatti et al. 1998

# Radio-$\gamma$ Connection

- Known correlation of TeV and radio emission (e.g., Giroletti et al. 2016)
- Possible sources of UHE cosmic rays and neutrinos (PKS 1424-418, TXS 0506+056, PKS 1502+106)
- Blazar VLBI Flux-Neutrino Associations found (Plavin et al. 2020 & 2021, Hovatta et al. 2020, Kadler et al. 2016)

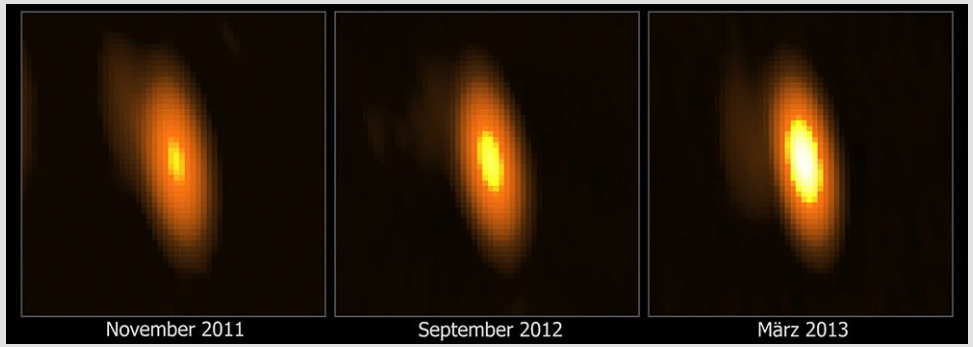



**Figure 3:** Radio Images of PKS 1424-418 before and after a possibly coincident ($2\sigma$) Neutrino Event (Kadler et al. 2016)

BUT: still no $3\sigma$ neutrino association!

**Goals**

- Investigate the radio-$\gamma$ correlation (especially with upcoming CTA)
- Pin down neutrino sources by radio flaring activity (follow up of ANTARES, IceCube, KM3NeT, ...)
- Tracing dynamical processes in pc-scale jets related to flares or $\nu$-detections.
- Characterize variability to test different emission models

**-> Use single-dish monitoring with Effelsberg 100-m Telescope -> TELAMON!**

# About

## Effelsberg 100-m Telescope

- Located in Effelsberg, Germany
- Operated by Max-Planck-Institute for Radio Astronomy in Bonn
- One of the largest fully steerable radio telescopes in the world
- Superior sensitivity compared to smaller dishes

## TELAMON

- **T**ev **E**ffelsberg **L**ong-term **A**gn **MON**itoring
- Est. Aug 2020
- Monitoring radio spectra of TeV-Blazars and candidate neutrino-assoc. AGN
- High cadence observations at high radio frequencies
  - every 2-4 weeks
  - From 14 GHz up to 44 GHz

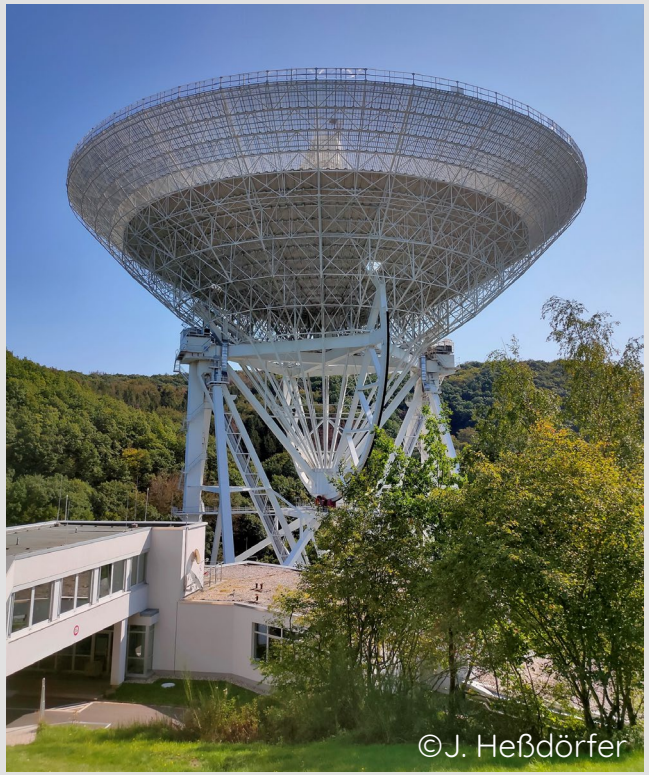
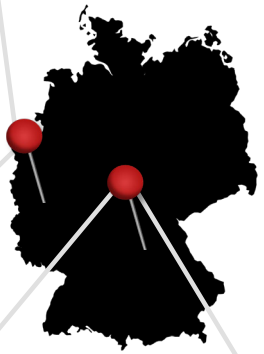



**Figure 4**: Effelsberg 100-m Telescope



FRANCI 2021

# Observational Setup

- 20mm, 14mm and 7mm receiver (secondary focus)
  -> simultaneous data at 14,16,19, 21, 23, 25, 36, 39, 41, 44 GHz
- Cross-Scans with typically 8 subscans at 20 mm and 14 mm and 16 subscans at 7 mm

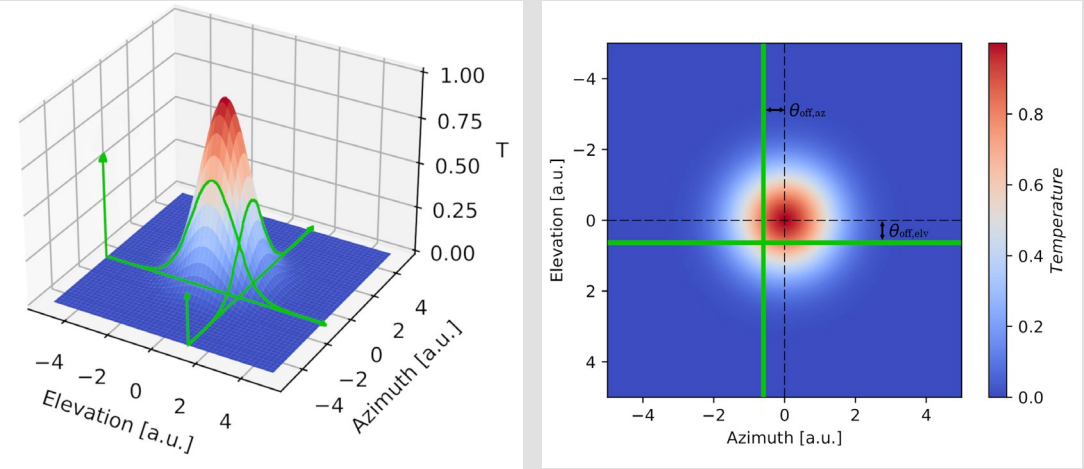
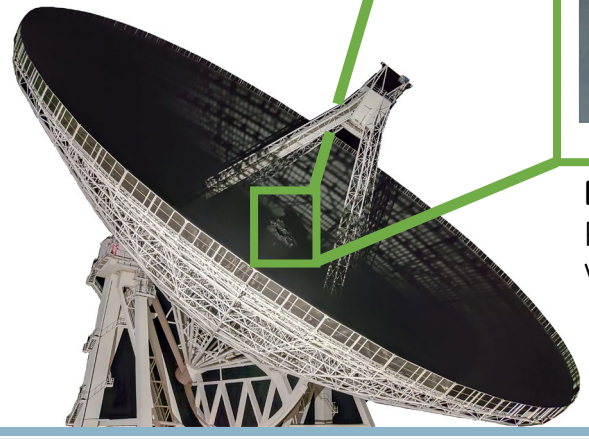



**Figure 7:** Example cross-scan of a point-like source



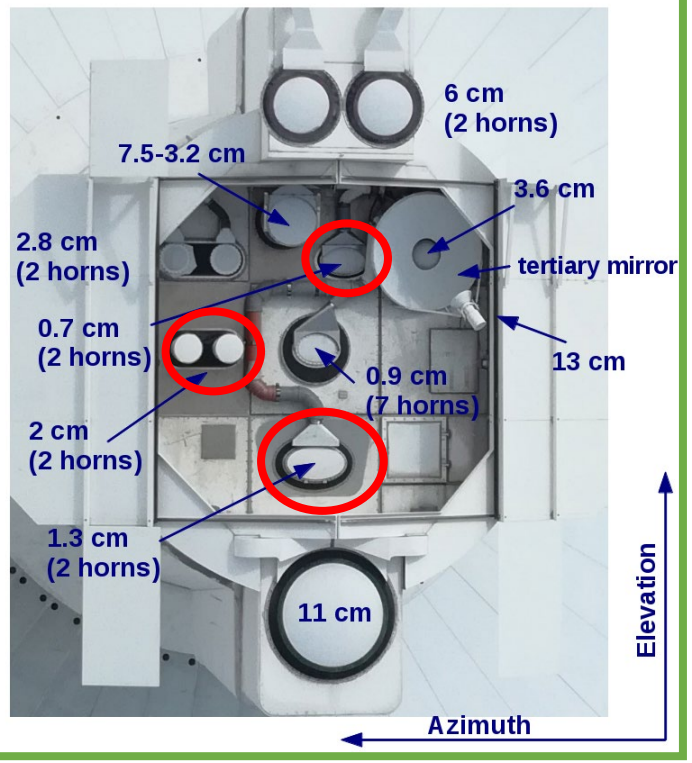



**Figure 6:** Effelsberg Secondary Focus Receivers (adapted from Effelsberg Wiki)

# Sample

- Unique sample of TeV-detected and neutrino-candidate AGN
- Main focus on HBL and Extreme BL
- Complete sample for HBLs (down to 10-20 mJy)
- Newly detected sources dynamically added

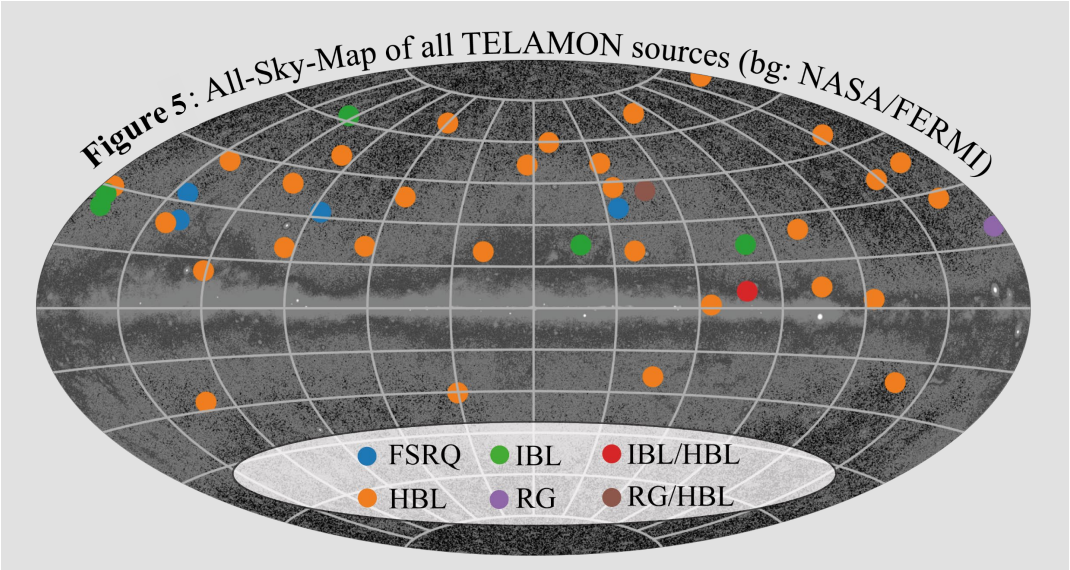



Figure 5: All-Sky-Map of all TELAMON sources (bg: NASA/FERMI)

**Table 1:** List of all TELAMON sources

| J200 Name | Alternative Name | Class[a] | $S^{b}_{14mm}$ [mJy] | Redshift |
|---|---|---|---|---|
| 0035+5950 | 1ES 0033+595 | HBL | 75 | 0.086 |
| 0112+2244 | S2 0109+22 | IBL | 1100 | – |
| 0214+5144 | TXS 0210+515 | HBL | 150 | 0.049 |
| 0221+3556 | S3 0218+35 | FSRQ | 500 | 0.68466 |
| 0222+4302 | 3C 66A | HBL | 1000 | 0.34 |
| 0232+2017 | 1ES 0229+200 | HBL* | 40 | 0.1396 |
| 0303-2408 | PKS 0301−243 | HBL | 200 | 0.2657 |
| 0316+4119 | IC 310 | RG/HBL | 150 | 0.0189 |
| 0416+0105 | 1ES 0414+09 | HBL* | 50 | 0.287 |
| 0507+6737 | 1ES 0502+675 | HBL | 50 (1) | 0.341 |
| 0509+0541 | TXS 0506+056 | IBL/HBL | 1750 | 0.3365 |
| 0521+2121 | RGB J0521+212 | IBL | 375 | – |
| 0650+2502 | 1ES 0647+250 | HBL | 100 | – |
| 0658+0637 | NVSS J065844+063711 | HBL | 125 | – |
| 0811+0237 | 1RXS J081201.8+023735 | HBL* | 50 (1) | 0.1721 |
| 0913-2103 | MRC 0910−208 | HBL* | 135 (1) | 0.198017 |
| 0955+3551 | 3HSP J095507.9+355101 | HBL* | 10 | 0.557 |
| 1015+4926 | 1ES 1011+496 | HBL | 225 | 0.212 |
| 1058+2817 | GB6 J1058+2817 | HBL | 100 | 0.4793 |
| 1104+3812 | Mrk 421 | HBL* | 375 | 0.031 |
| 1136+7009 | Mrk 180 | HBL | 175 | 0.045278 |
| 1145+1936 | 3C 264 | RG | 325 | 0.021718 |

| J2000 Name | Alternative Name | Class[a] | $S^{b}_{14mm}$ [mJy] | Redshift |
|---|---|---|---|---|
| 1217+3007 | ON 325 | HBL | 450 | 0.131 |
| 1221+2813 | W Comae | IBL | 475 | 0.102 |
| 1221+3010 | 1ES 1218+304 | HBL* | 68 | 0.184 |
| 1230+2518 | ON 246 | IBL | 400 | 0.135 |
| 1422+3223 | OQ 334 | FSRQ | 775 | 0.681 |
| 1427+2348 | OQ 240 | HBL | 400 | 0.647 |
| 1428+4240 | 1ES 1426+428 | HBL* | 30 | 0.129 |
| 1443+2501 | PKS 1441+25 | FSRQ | 150 | 0.94 |
| 1518-2731 | TXS 1515−273 | HBL | 225 | 0.1281 |
| 1542+6129 | GB6 J1542+6129 | IBL | 115 | 0.507 |
| 1555+1111 | PG 1553+113 | HBL | 300 | 0.49 |
| 1653+3945 | Mrk 501 | HBL* | 1000 | 0.034 |
| 1728+5013 | I Zw 187 | HBL* | 125 | 0.055 |
| 1743+1935 | 1ES 1741+196 | HBL* | 175 | 0.084 |
| 1813+3144 | B2 1811+31 | FSRQ | 100 | 0.117 |
| 1943+2118 | HESS J1943+213 | HBL* | $\sim$ 20 (2) | – |
| 1958-3011 | 1RXS J195815.6−301119 | HBL* | 100 (1) | 0.119329 |
| 1959+6508 | 1ES 1959+650 | HBL* | 225 | 0.048 |
| 2018+3851 | TXS 2016+386 | HBL | 400 | – |
| 2158-3013 | PKS 2155−304 | HBL | 325 | 0.116 |
| 2243+2021 | RGB J2243+203 | HBL* | 115 (1) | 0.119329 |
| 2347+5142 | 1ES 2344+514 | HBL* | 150 | 0.044 |

# Example Source: S2 0109+22

- Continuous dynamic spectra and light curves
- Example: flaring activity with increase in flux density over ~100 days at 14mm and 7mm
- Sampling rate well suited to resolve changes
- Spectral gap at 30 GHz filled by coordinated ATCA observations

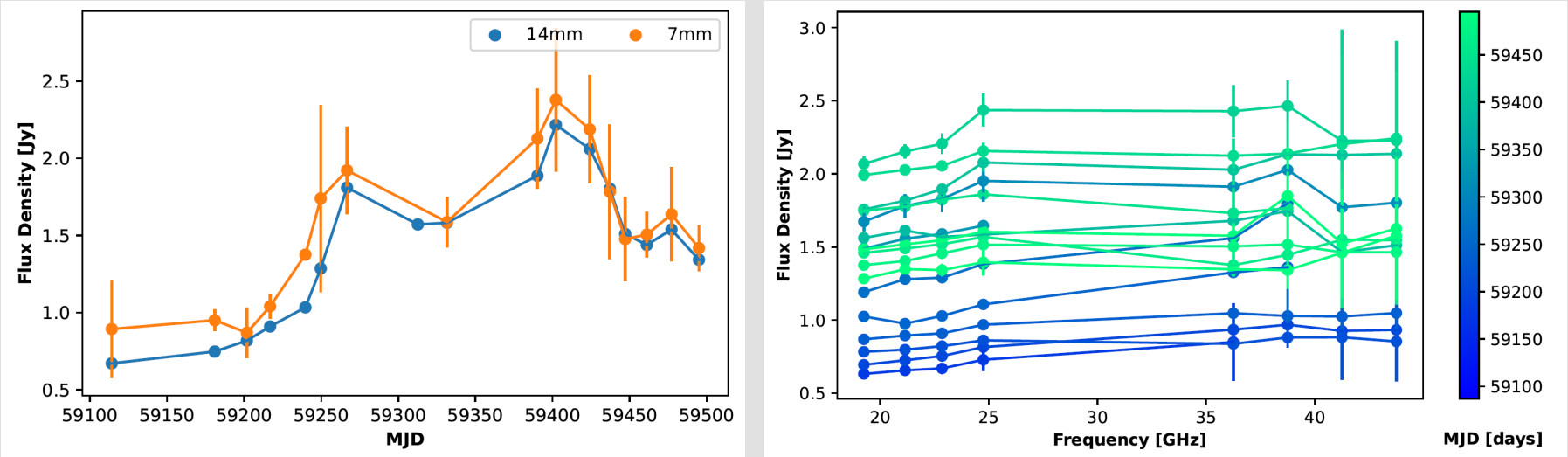
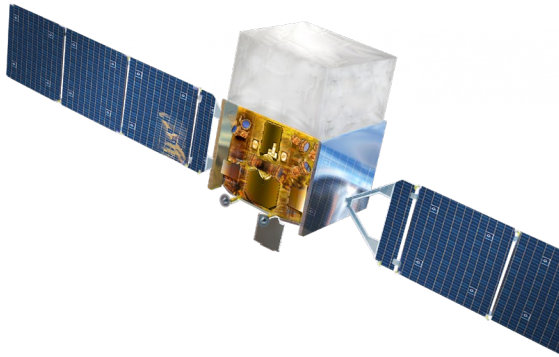



**Figure 8:** TELAMON light curve at 7 mm and 14 mm (left) and spectra (right) of the source S2 0109+22

# Collaboration with MWL Partners



- Sample includes many targets of TeV-telescopes (e.g., MAGIC, VERITAS, ...)
- Coordination with AGN groups of Fermi-LAT, FACT, H.E.S.S., MAGIC and VERITAS

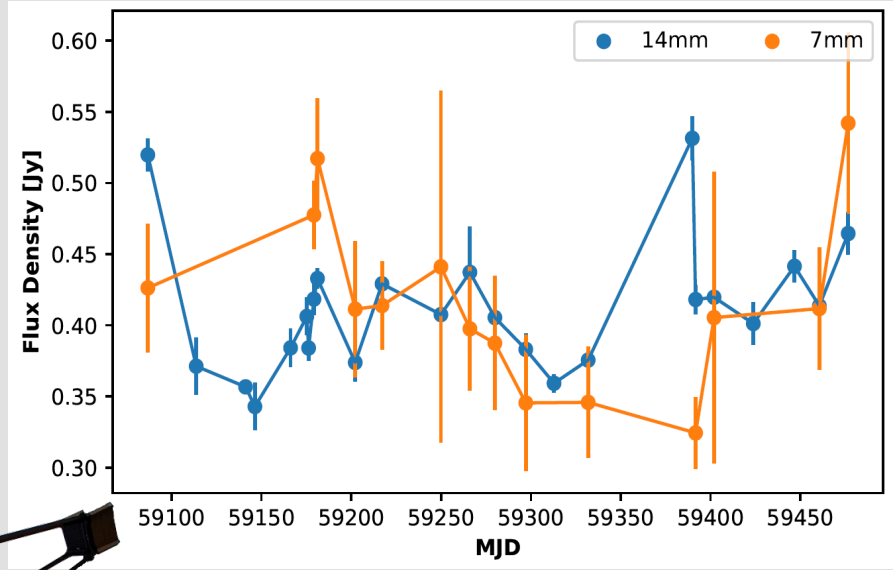



**Figure 9:** Light curve of Mrk 421

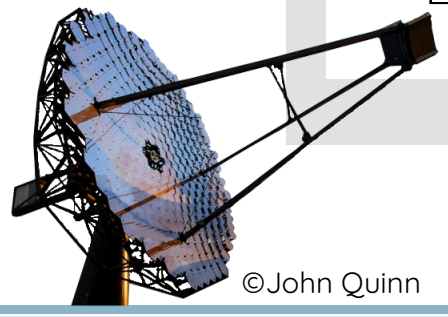


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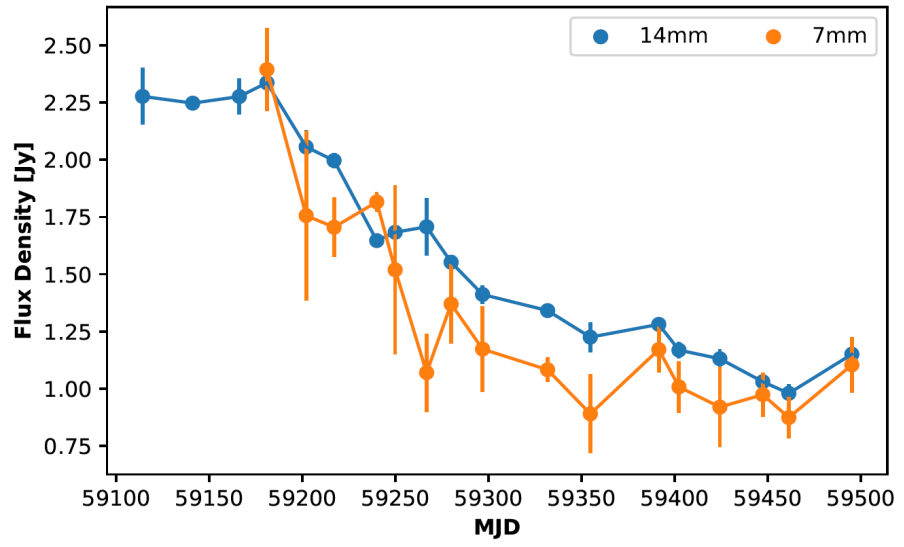
**Figure 10:** Light curve of TXS 0506+056



# Scientific Output

**Pilot Phase:**

- Two ATels
- 4 Contributions @ ICRC 2021
- 1 Bachelor Thesis just started (D. Kirchner)
- 1 Bachelor Thesis finished (J. Heßdörfer)
- 2 Master Thesis in work (F. Eppel, J. Heßdörfer)

**ATel #14191**

**Contemporary Effelsberg Observations of Two Radio Sources in the Fields of IceCube-201114A and IceCube-201115A**

ATel #14191; *Matthias Kadler (JMU Wuerzburg), Jonas Hessdoerfer (JMU Wuerzburg), Florian Eppel (JMU Wuerzburg), Uwe Bach (MPIfR), Alexander Kraus (MPIfR), Andrea Gokus (JMU Wuerzburg, FAU Erlangen), Georgios-Filippos Paraschos (MPIfR), Eduardo Ros (MPIfR), Daniela Dorner (JMU Wuerzburg), Phil G. Edwards (CSIRO), Marcello Giroletti (INAF), Shoko Koyama (ASIAA), Thomas Krichbaum (MPIfR), Elina Lindfors (FINCA, University of Turku), Karl Mannheim (JMU Wuerzburg), Roopesh Ojha (UMBC/NASA/GSFC), Florian Roesch (JMU Wuerzburg), Jonas Sinapius (JMU Wuerzburg), Bernd Schleicher (JMU Wuerzburg), Julian Sitarek (Univ. Lodz), Luis Wachter (JMU Wuerzburg), Joern Wilms (FAU Erlangen)*

on 17 Nov 2020; 20:47 UT

**ATel #14822**

**Radio Flaring of the Quasar B2 1420+32**

ATel #14822; *F. Eppel, M. Kadler, A. Gokus, J. HeÃdÃ¶rfer, F. RÃ¶sch, J. Sinapius*

on 1 Aug 2021; 12:25 UT

# Outlook

- ✓ Effelsberg Key Science Project to extend the program in the long term
- ✓ Coordination with next gen TeV & Neutrino telescopes (CTA, KM3NeT, …)
- ✓ Statistical database to test the significance of radio flaring activity with neutrino emission in Blazars
- ✓ Extract polarization data
- ✓ Coordination with VLBI monitoring observations of TeV and neutrino-candidate Blazars (TANAMI, MOJAVE)
- ✓ Multiwavelength studies with partners Fermi-LAT, FACT, H.E.S.S., MAGIC and VERITAS

# Thanks for your attention!

Questions

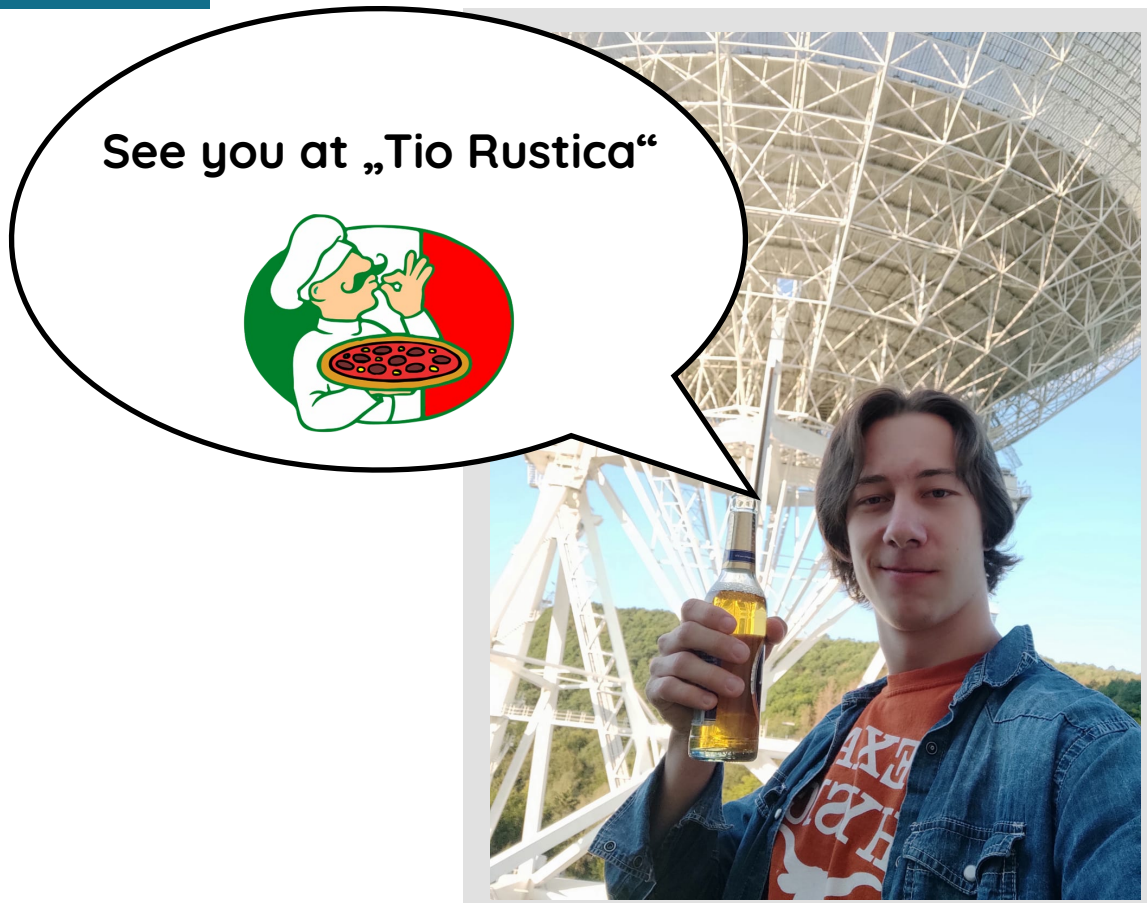
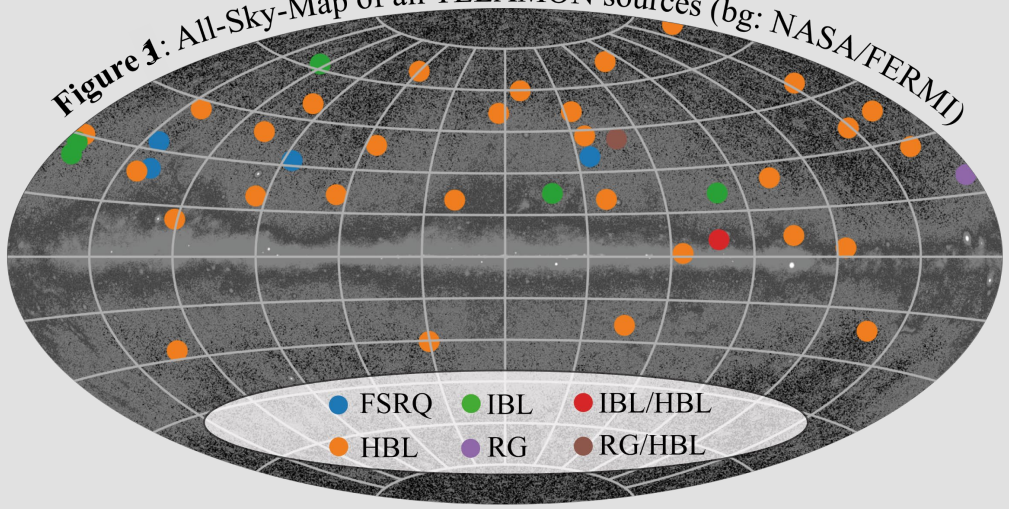



**Figure 11**: Florian Eppel, thirsty & hungry

# Selection Criteria

- Excluding low peak blazars
  -> already well covered
- Sources whose low-state flux density < 500 mJy
- Complete sample for HBLs (down to 10-20 mJy)
- Other sources for comparison
- Newly detected sources dynamically added

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| 2243+2021 | RGB J2243+203 | HBL* | 115 (1) | 0.119329 |
| 2347+5142 | 1ES 2344+514 | HBL* | 150 | 0.044 |

# Neutrino Candidate Follow-up

- Target list dynamically updated with new $\nu$-detections
- Example 1: NVSS J065844+063711 three days after IC 201114A event
- Often uncertainty region of Neutrino alert too large
  - Radio data can yield independent information to judge possible associations
  - TXS 2016+386: radio flaring after neutrino detection IC 201120A

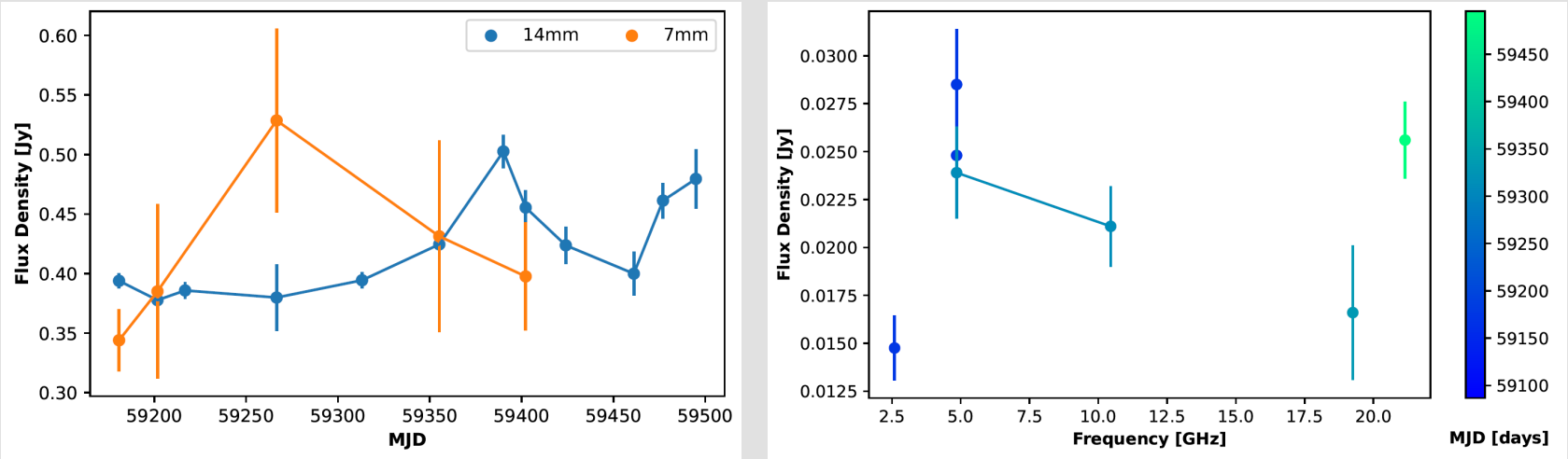


**Figure 12:** TELAMON light curve of TXS 2016+386 (left) and spectrum of NVSS J065844+063711 (right)

# Subband Averaging

- Logarithmic spectral fit for each receiver
- Average flux density from fit
- Min/Max flux density from min/max fits

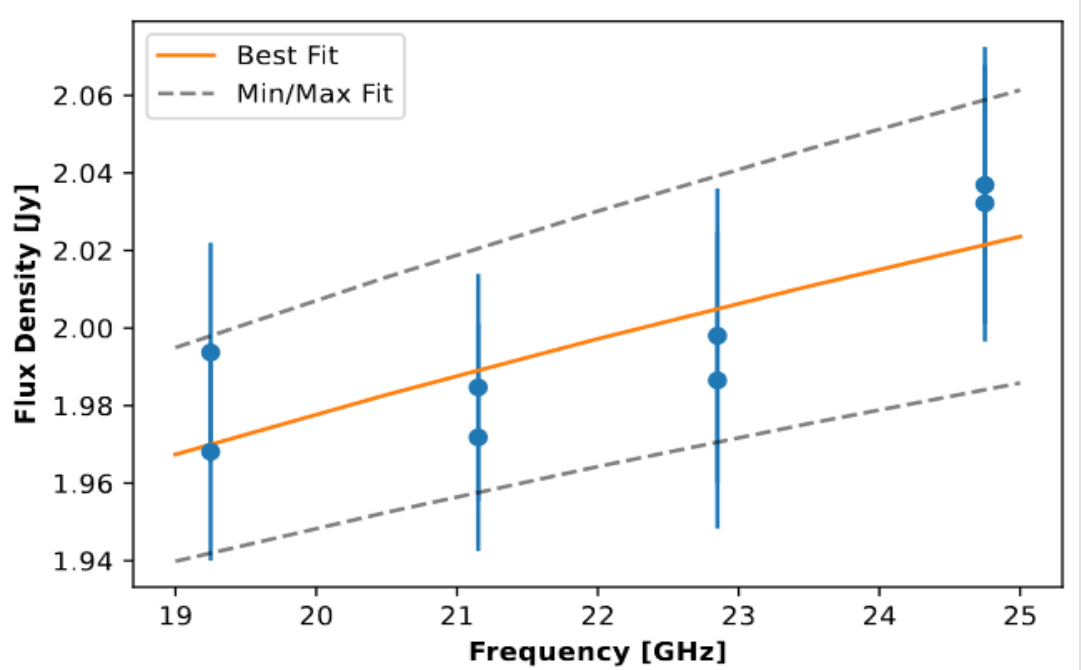


**Figure 13:** Example of the sub-band averaging process (TXS 0506+056 on Jan 2, 2021 at 14 mm). The average flux density is calculated by taking the integral of the best fit between 19 GHz and 25 GHz. The errors are determined by integrating the Min/Max fits