# Blazars behind the Magellanic Clouds


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In collaboration with

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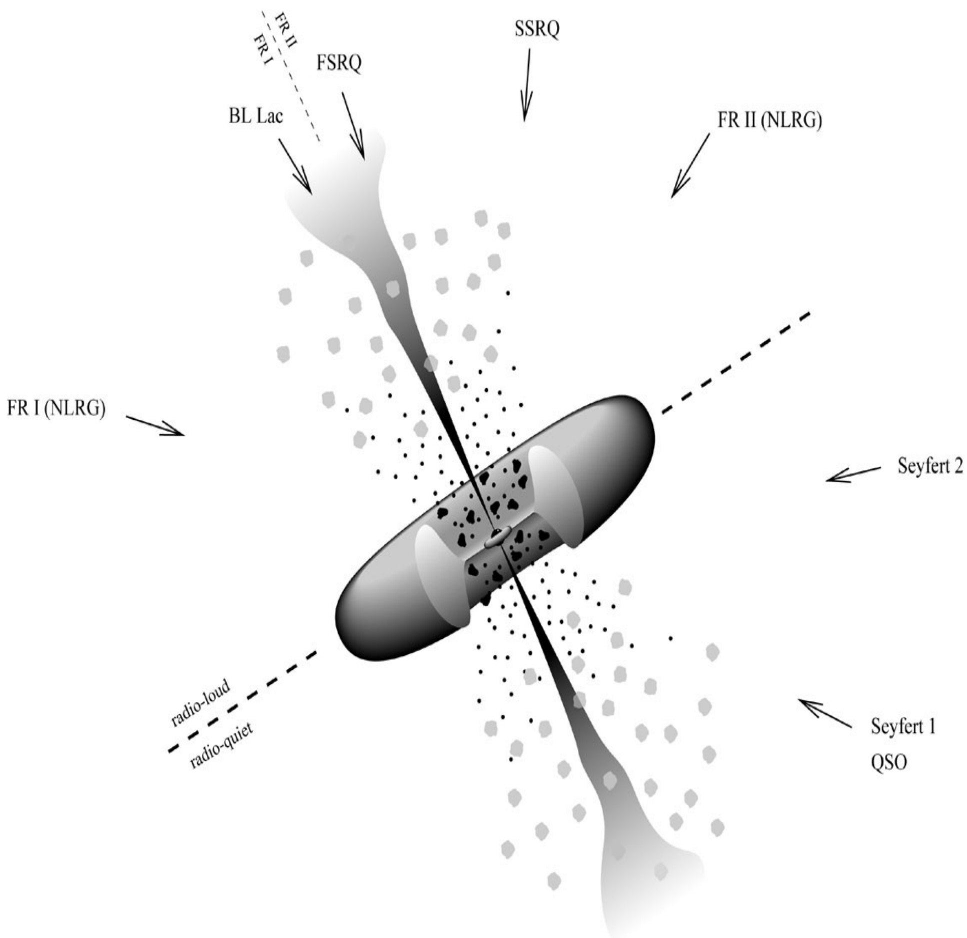
# Blazars




- Class of the AGNs
- Unification model: jets of blazars are close to line of observer's sight
- Broad range of electromagnetic radiation from radio to TeV-gamma rays emission
- Strong flat spectrum radio emission with:

$$S(\nu) \propto \nu^{\alpha}$$
$$\alpha > -0.5$$

- Significant optical polarization
- Significant flux variability in whole range
- Non-thermal continuum

Blazars are generally divided into two groups:

**BL Lacertae (BL Lac)** → no/weak emission lines

**Flat Spectrum Radio Quasar (FSRQ)** → narrow and broad emission lines

Credit: The unification model of AGNs; Urry & Padovani 1995

# OGLE
## The Optical Gravitational Lensing Experiment

The OGLE project began in 1992 under the supervision of Andrzej Udalski.

The main scientific goals:

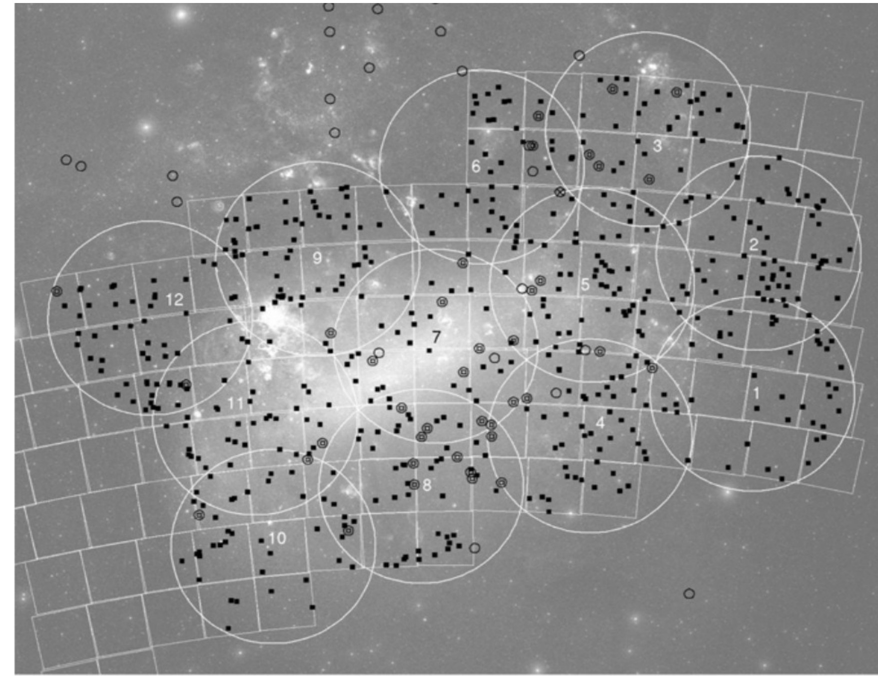
- the MCs and Galactic Bulge monitoring,
- dark matter study with microlensing phenomena,
- extrasolar planets searching,
- galactic structure study,
- analysis of different time scale variability of hundred millions regularly observed objects.

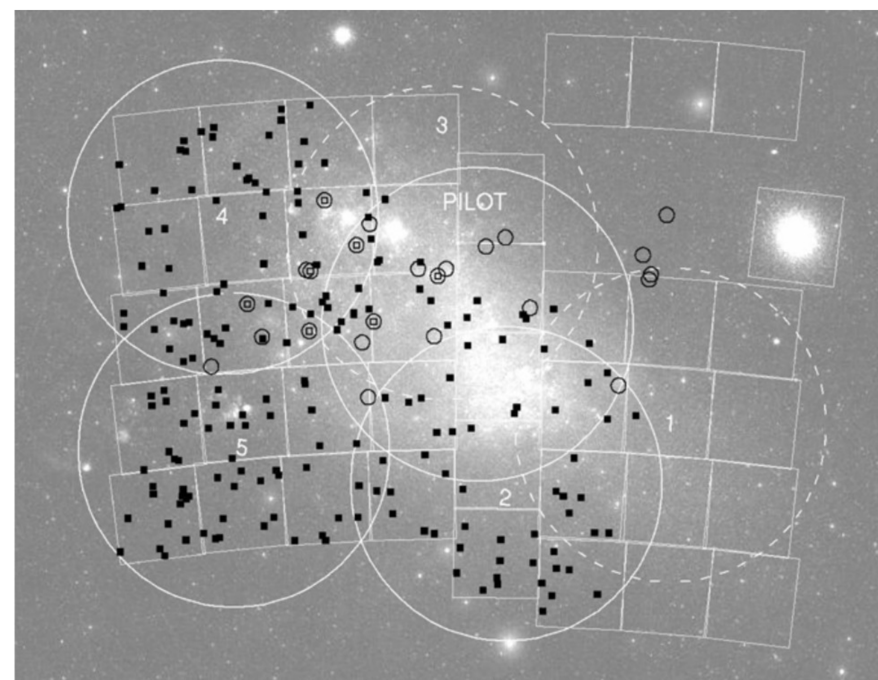
The observatory is located in Las Campanas, Atacama, Chile.


Credit: Prof. I. Soszyński

# Magellanic Quasars Survey

- All survey fields in the LMC and 70% of those in the SMC have been observed.
- The targets were selected from the third phase of the OGLE experiment based on their optical variability, mid-IR, and/or X-ray properties.
- Confirmation of 758 quasars (565 in the LMC and 193 in the SMC) behind both clouds
- 94% quasars from the MQS catalogue (527 in the LMC and 186 in the SMC) are newly identified objects

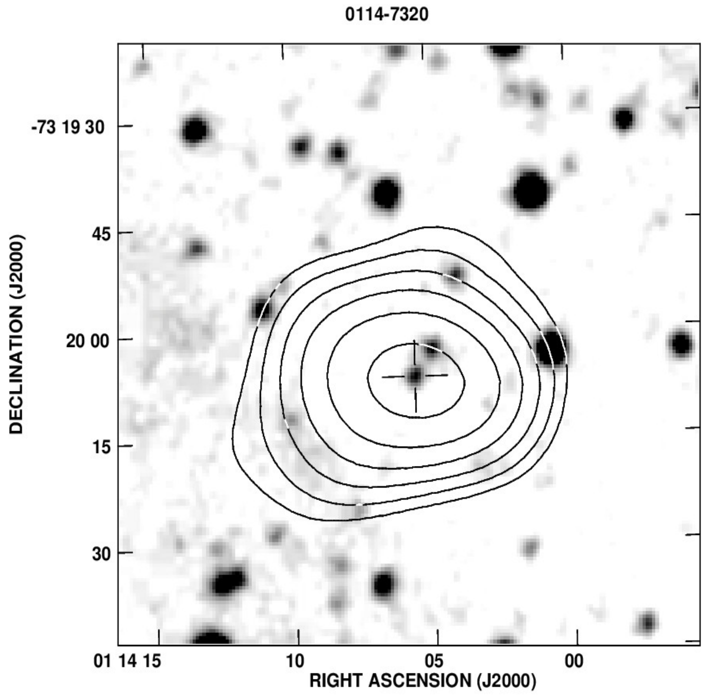



Credit: Kozłowski et al. 2013

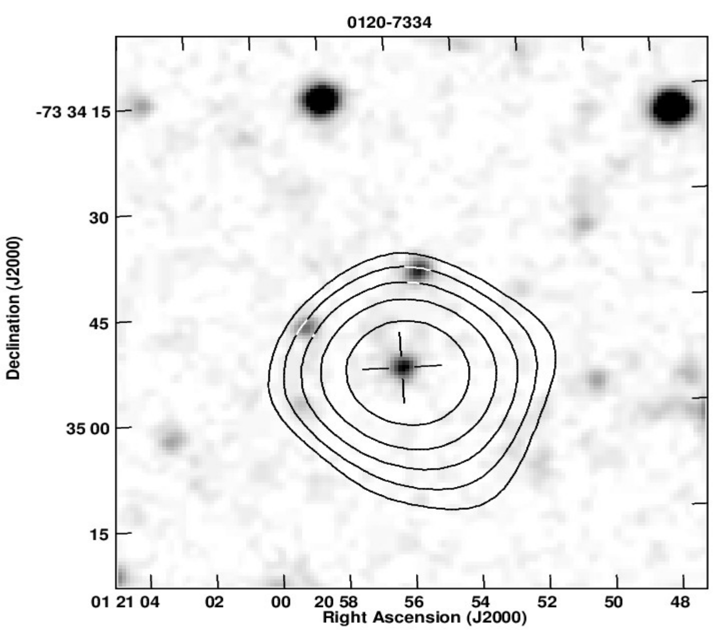
# Identification of blazars

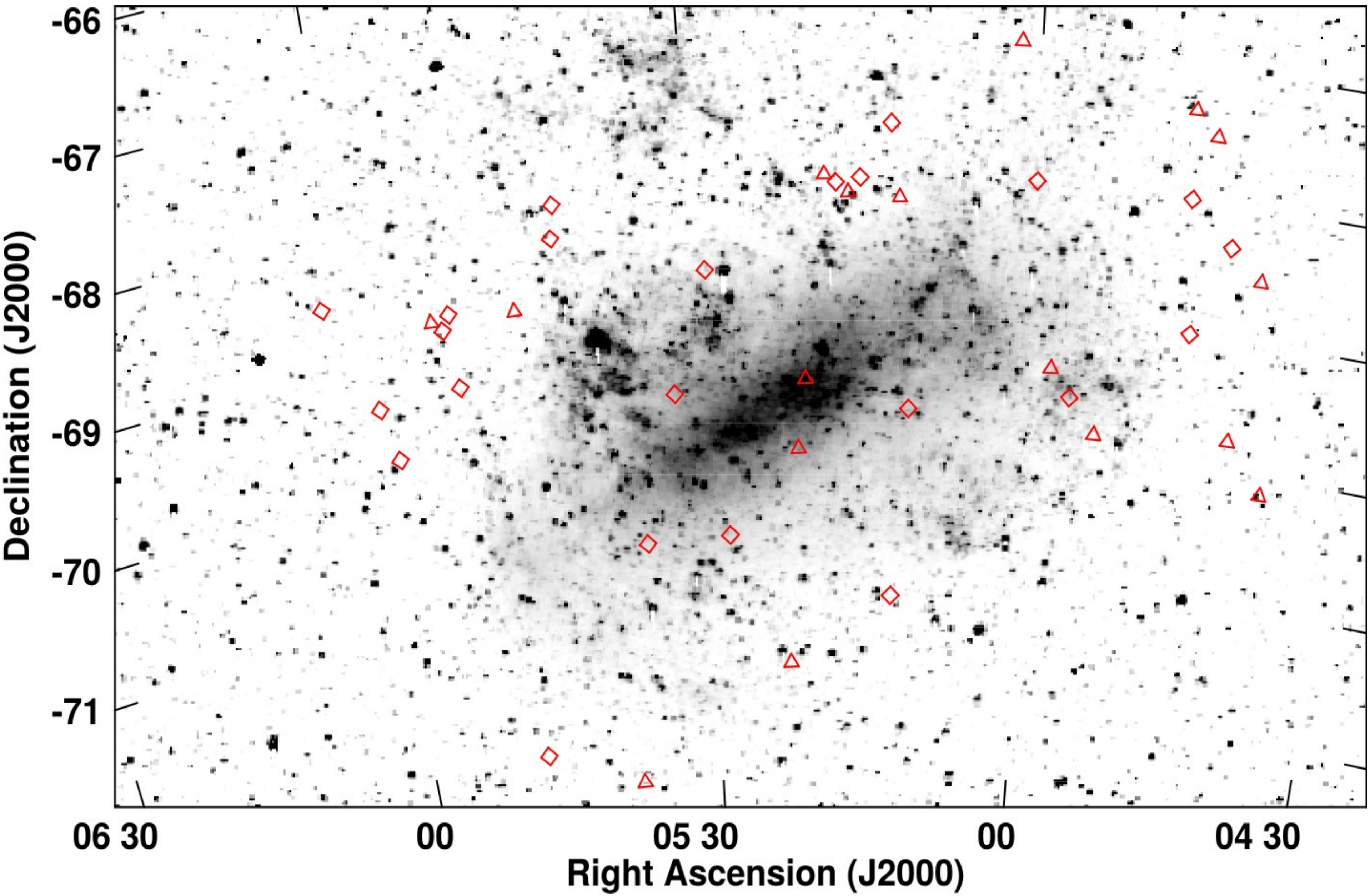
- Blazars' identification was based on the MQS optical catalogue (Kozłowski et al. 2013) and a list of "featureless spectra" (FS) objects.
- ~ 10% of catalogued quasars should be radio loud quasars (Kellermann et al. 1989) → FSRQ type blazars.
- FS list → BL Lac type blazars.
- Identification procedure was divided into two parts: cross-matching and parameters examination.



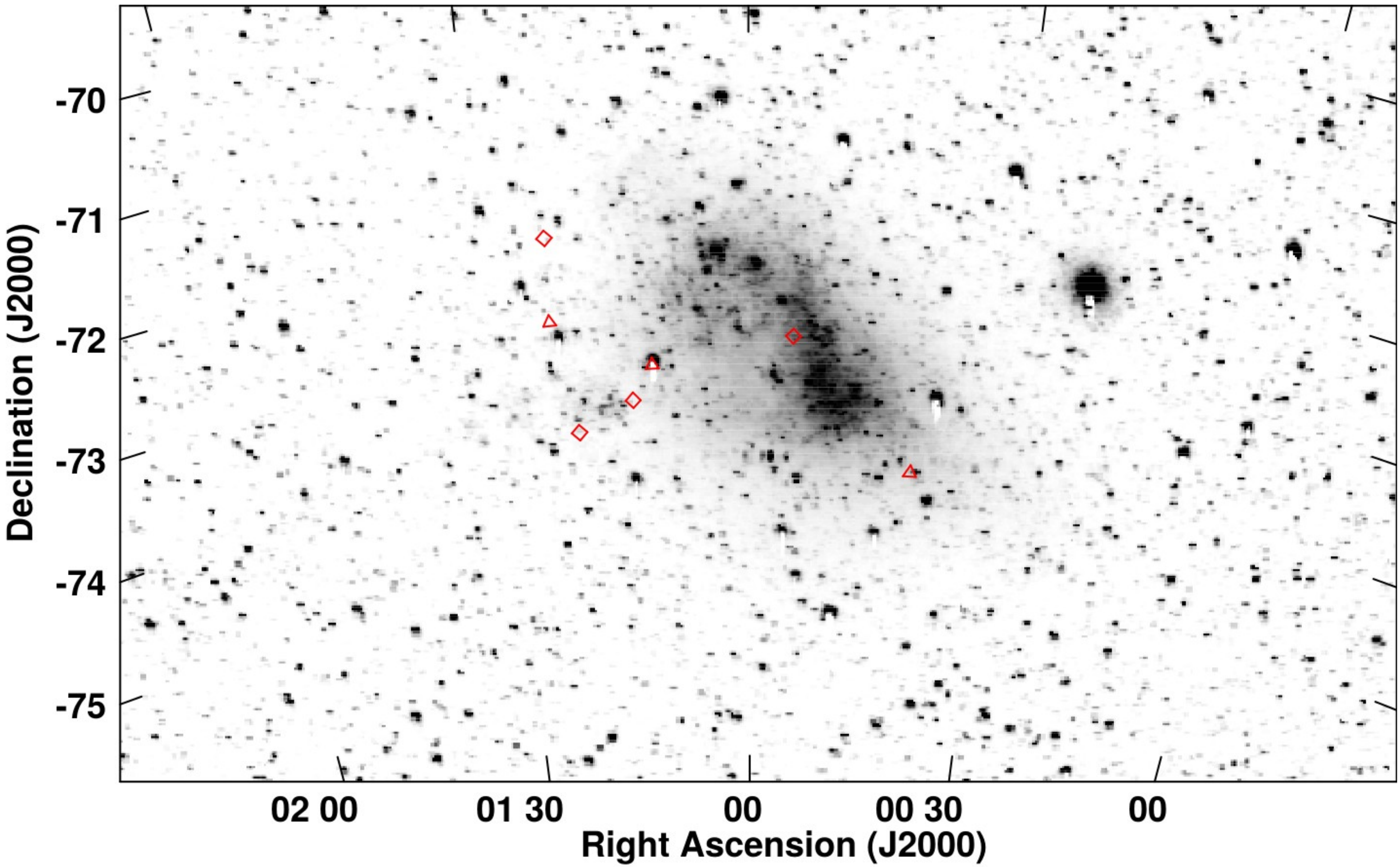

Radio surveys used in cross-matching:

- Sydney University Molonglo Sky Survey (SUMSS; Murphy et al. 2007) at 843 MHz
- Australia Telescope 20 GHz (AT20G; Murphy et al. 2010) at 5,8, and 10 GHz
- Parkes-MIT-NRAO (PMN; Condon et al. 1993) at 4.85 GHz
- Australia Telescope PMN follow-up (ATPMN; McConnell et al. 2012) at 4.8 and 8.6 GHz






Optical image: Bothun & Thompson (1988)




Optical image: Bothun & Thompson (1988)

# Parameters

Spectral index **α**: $F_\nu \propto \nu^{-\alpha}$

To indicate if a radio spectrum of a source is flat $\alpha_r < 0.5$ or steep $\alpha_r > 0.5$. The flat spectrum radio sources are identified with blazars.

The mid-IR spectral index: $\alpha_{IR} > 0.5$ is expected.

| Object (1) | RA (2) | DEC (3) | R (4) | z (5) | $\alpha_r$ (6) | $\alpha_{IR}$ (7) |
|---|---|---|---|---|---|---|
| FSRQ blazar type candidates | | | | | | |
| J0054-7248[a,c] | 00 54 44.70 | -72 48 13.68 | 1730 | 0.505 | | 1.89±0.50 |
| J0114-7320[b] | 01 14 05.57 | -73 20 06.50 | 246 | 0.937 | 0.58±0.31 | 1.33±0.13 |
| J0120-7334[b] | 01 20 56.05 | -73 34 53.51 | 195 | 1.565 | 0.56±0.06 | 1.88±0.07 |
| J0122-7152[c] | 01 22 58.49 | -71 52 07.00 | 267 | 0.939 | | 0.47±0.18 |
| J0442-6818[b] | 04 42 45.19 | -68 18 38.99 | 371 | 0.964 | -0.57±0.15 | 1.20±0.09 |
| J0445-6859[c] | 04 45 36.60 | -68 59 46.10 | 285 | 1.714 | | 1.73±0.02 |
| J0446-6758[c] | 04 46 33.91 | -67 58 55.88 | 169 | 1.301 | | 1.72±0.15 |
| J0455-6933 | 04 55 59.10 | -69 33 29.09 | 336 | 1.319 | 0.47±0.04 | 1.30±0.06 |
| J0459-6756[a,c] | 04 59 54.27 | -67 56 35.59 | 898 | 1.687 | | 1.45±0.14 |
| J0510-6941 | 05 10 45.85 | -69 41 26.48 | 165 | 1.061 | 0.72±0.01 | 0.60±0.02 |
| J0512-7105[d] | 05 12 21.49 | -71 05 55.61 | 489 | 0.286 | 0.79±0.00 | 1.71±0.03 |
| J0512-6732[b] | 05 12 22.48 | -67 32 20.00 | 557 | 2.557 | 0.08±0.04 | 1.99±0.09 |

Radio-loudness **R**: $R = F_5/F_B$

Radio-loud sources: $R \geq 10$.

Radio flux extrapolation assuming the radio spectral index as $\alpha_r = 0.5$.

# Polarization

$P_o > 3\%$

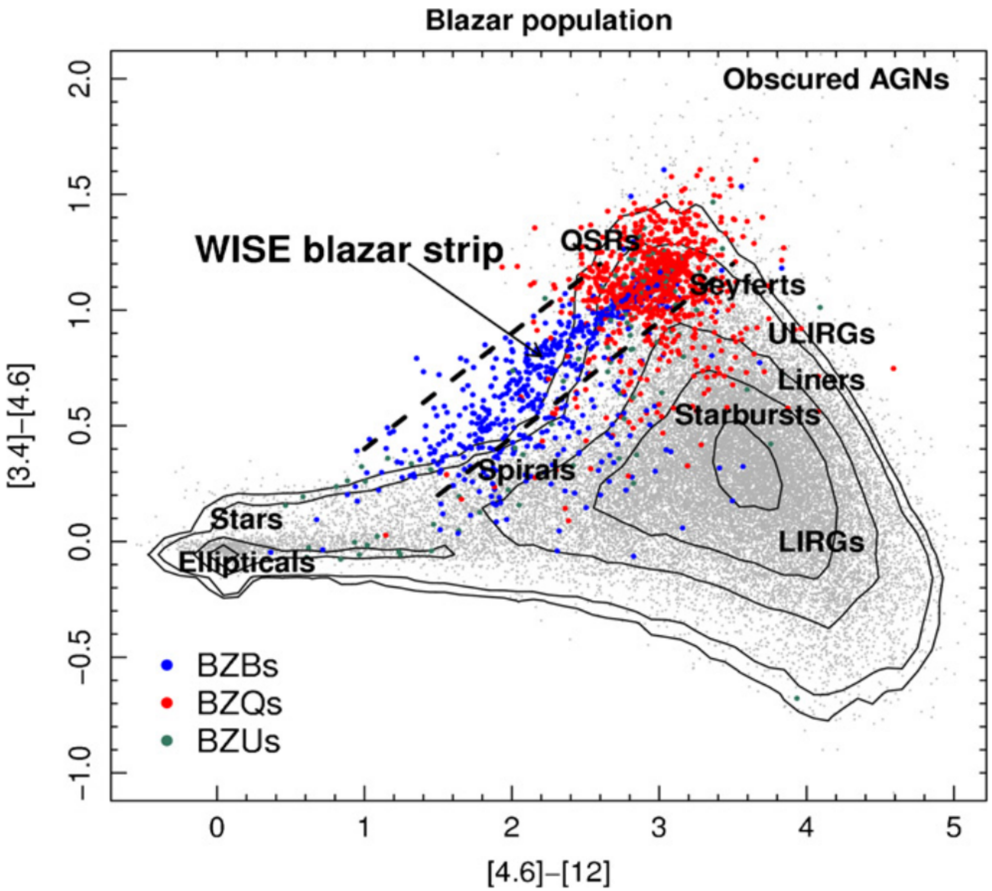
$P_{1.4\ GHz} > 1\%$

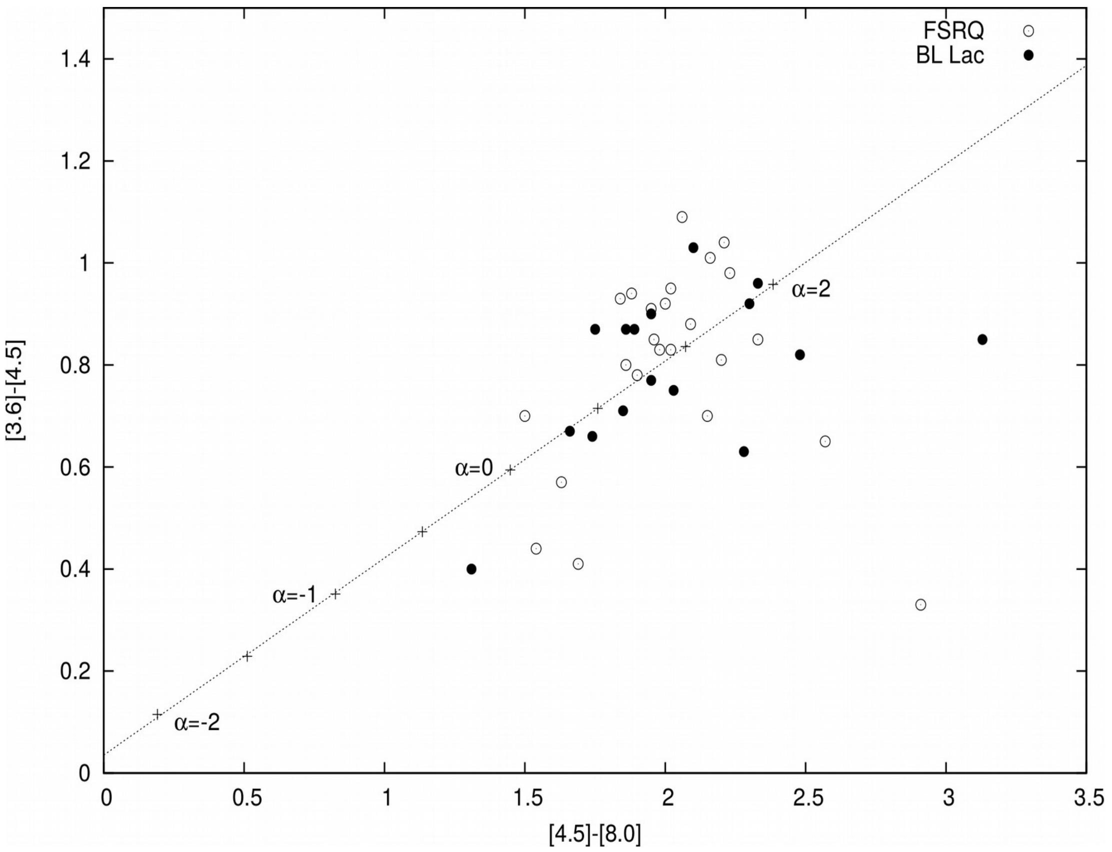
The fractional linear polarization and angle of blazar candidates based on the AT20G catalogue and polarized flux density measured on 4.8 and 8.6 GHz radio maps of both MCs.

| Object | Fractional linear Polarization | | | | | Linear Polarization Angle | |
|---|---|---|---|---|---|---|---|
| | 4.8 GHz [%] | 5 GHz [%] | 8 GHz [%] | 8.6 GHz [%] | 20 GHz [%] | 4.8 GHz [°] | 8.6 GHz [°] |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| | | | | FSRQs | | | |
| J0114-7320 | 9.5 | | | 7.0 | | 70.7 | -12.9 |
| J0120-7334 | 5.0 | | | | | -52.2 | |
| J0442-6818 | | 11.7 | 10.0 | | 8.1 | | |
| J0512-6732 | 3.3 | 12.7 | 10.7 | | 13.6 | 13.6 | |
| J0551-6916 | 7.3 | | | | | 8.3 | |
| J0551-6843 | 9.1 | | | | | -3.9 | |
| | | | | BL Lacs | | | |
| J0111-7302 | 4.1 | 8.3 | 8.3 | | 9.7 | 4.4 | |
| J0501-6653 | 10.7 | | | 22.1 | | -2.8 | -11.1 |
| J0518-6755[a] | 12.6 | | | | | -14.2 | |

# Mid-IR Strip

## Non-thermal emission

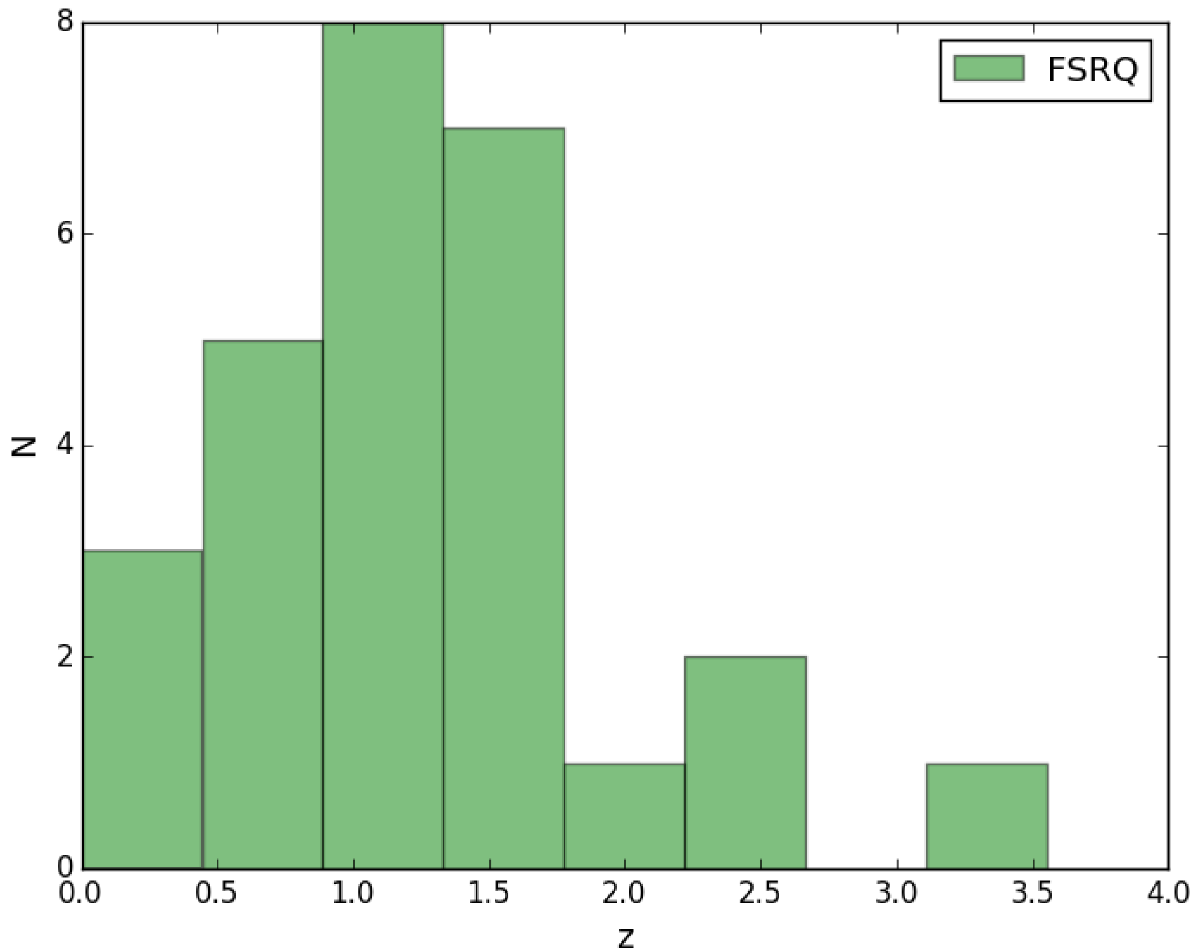



Credit: Massaro et al. 2011

# Conclusions

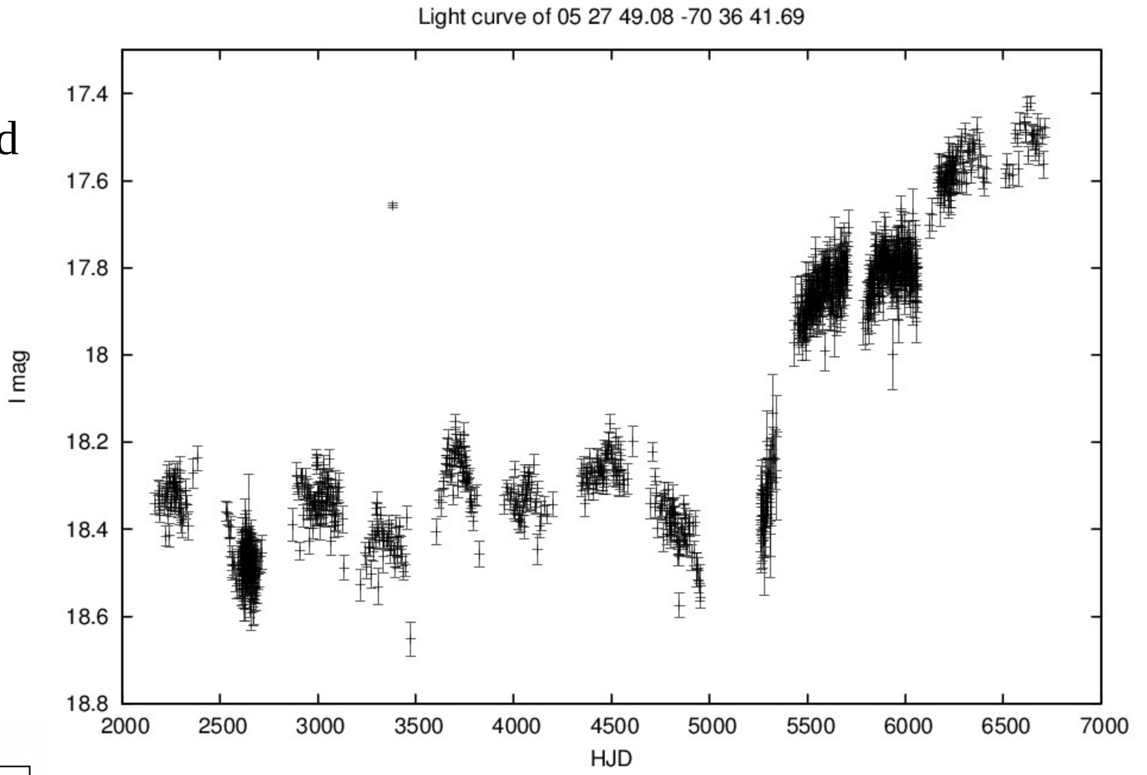
- Two lists of 44 objects: 27 FSRQs and 17 BL Lacs type blazars,
- most significant amount of the blazar candidates, 22 FSRQs and 17 BL Lacs, were found in the SUMSS catalogue,
- all objects are optically faint with the V band mag level between 18 and 22.
- all FSRQ blazar candidates are distant with redshifts up to ~3.3.

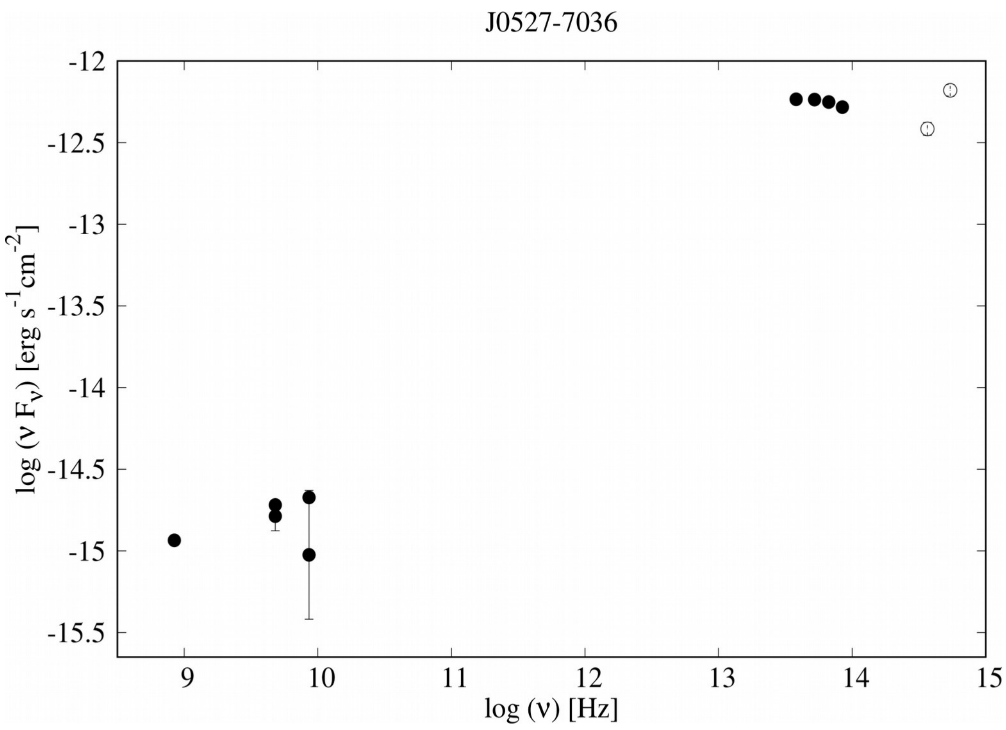


# Further directions

Optical variability study of both blazar candidates is based on data from OGLE-III and -IV projects, giving a temporal coverage of 13 years.

OGLE-III data consists of ~500 sampling points in I filter and ~50 in V filter observed within 8 years (2001-2009).
OGLE-IV data consists of ~500 points in I filter I and ~100 in V filter observed between 2010 and 2013.




- Optical variability study for all blazar candidates
- Time scales recognition
- SED modelling
- Magnetic field study of the MCs with Faraday rotation measure (RM)

# Further directions

## Possible Fermi-LAT coincidences