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Radio astronomy in Poland: a vision based on solid scientific and engineering foundations

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Beginnings of Polish Radio Astronomy



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Krakow - former
capital city of Poland.

First Polish radio telescope



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First Polish radio telescope was built in **1954** in "Fort Rock" – currently Astronomical Observatory of the Jagiellonian University in **Kakow** (director **T. Banachewicz**).

The instrument was designed and constructed by **L. Kowalski, A. Strzałkowski, O. Czyżewski, J. de Mezer** and many others...

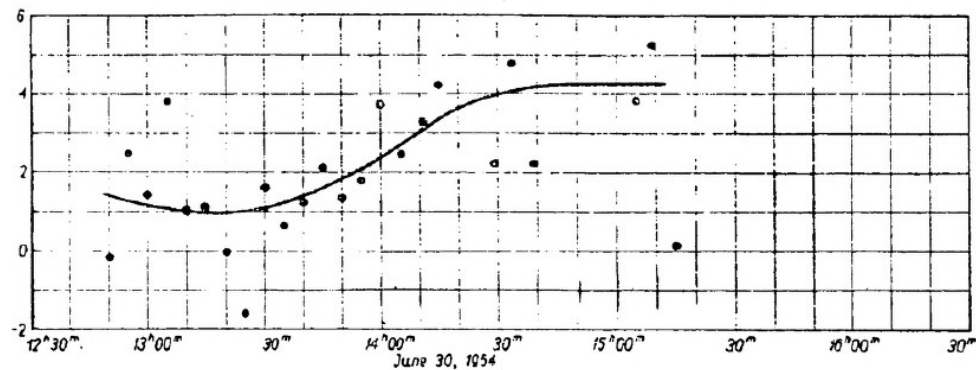
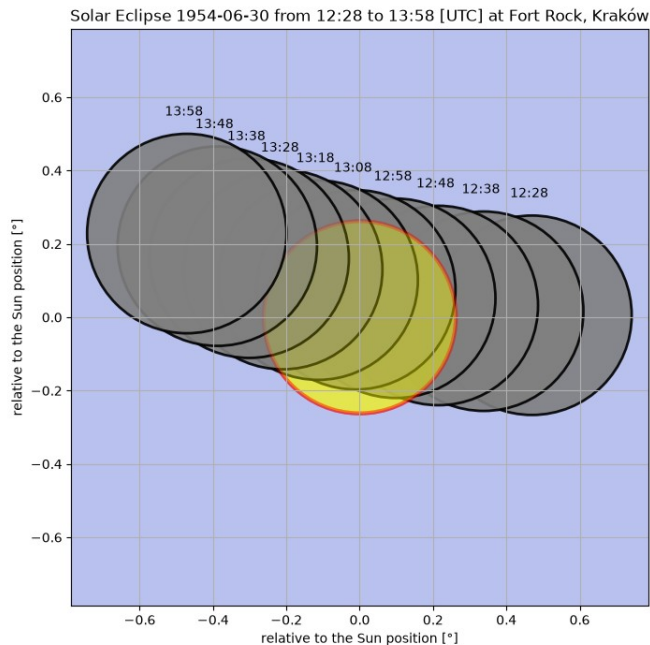
It was 5 m parabolic dish designed to work at ~ 1 m wavelength. The telescope was used for the first time on 30 of June 1954 for observations of the solar eclipse. In following years the instrument was used for regular monitoring of solar activity at 47 and 94 cm (**J. Maślowski, J. Machalski, S. Zięba, A. Michalec, A. Kułak** and others...)

Solar eclipse in 1954 – radio data



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Ryc. 8. Wyniki obserwacji promieniowania Słońca w czasie zaćmienia 30 czerwca 1954 r.

Solar eclipse in 1954 – first radio data



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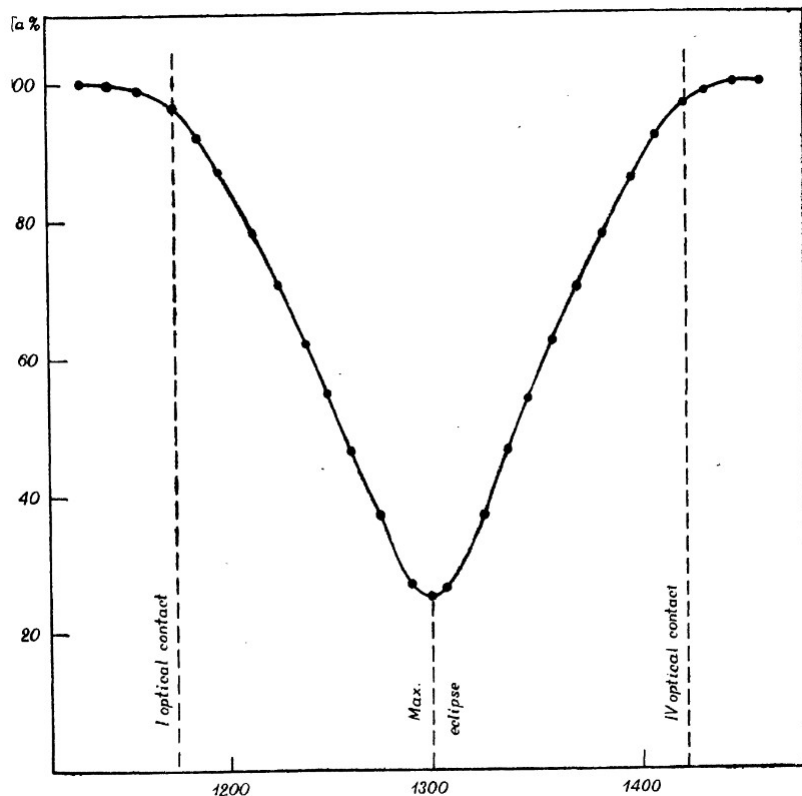


Fig. 5. The adjusted eclipse curve obtained in Bemowo on 600 MHz.

Ultimately the observations of solar radio noises were carried out on 600 MHz (50 cm) at the Military Academy of Technology in Bemowo, near Warsaw, by Eng. Lieut. Dzieciołowski, Eng. Gawroński, Eng. Lieut. Komarzyński, Eng. Lieut. Tomaszewski and Eng. Lieut. Żelazowski with the consent of Gen. Docent Gowiadkin. The results of observations were kindly sent by the Military Academy of Technology to the Polish Astronomical Society, from which the writer obtained them for a final working out²⁾

J. Maślowski Acta Astronomica 1957

Second radio telescope in Krakow



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15 m dish formally commissioned in 1965. It was intended to replace the old seven-meter radio telescope in radio observations of the Sun. It was used for example for precise measurements of radio background emission at 1300 MHz (Machalski 1973).

Third radio telescope in Krakow



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In October 1995, a new, **8-meter** radio telescope was commissioned in Krakow. This instrument with full automation and a new system for conducting observations and collecting data, without the participation and presence of an observer in the cabin, was dedicated for observations of the Sun. New observations were carried out simultaneously in 10 bands (at 10 wavelengths) ranging from 10 cm to over 1 meter.

POLFAR Polish part of LOFAR



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- **Jagiellonian University (coordinator),**
- **University of Warmia and Mazury in Olsztyn,**
- **Space Research Centre of PAS,**
- University of Zielona Góra,
- Nicolaus Copernicus University in Toruń,
- Nicolaus Copernicus Astronomical Center of PAS,
- University of Szczecin,
- Wrocław University of Environmental and Life Sciences,
- Poznań Supercomputing and Networking Center

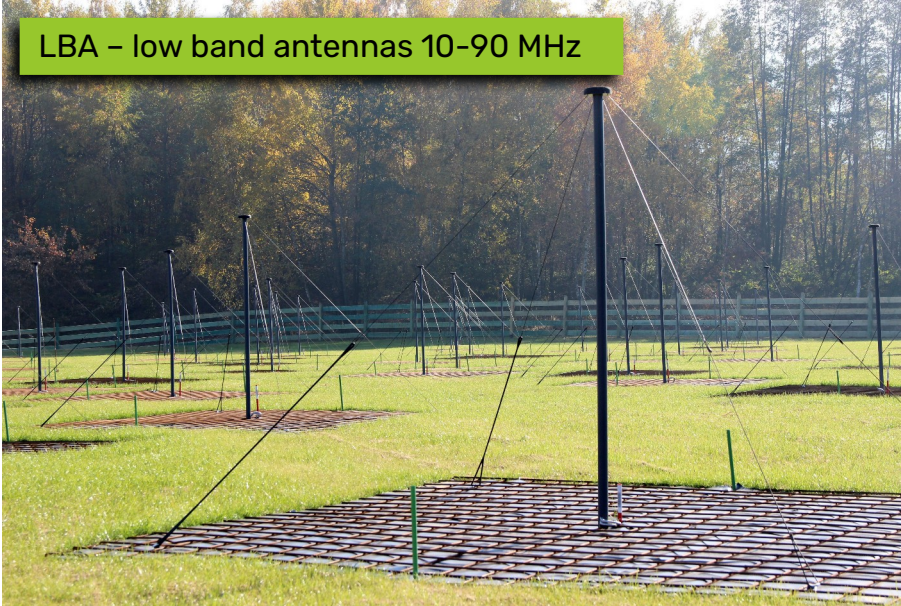
LOFAR antennas



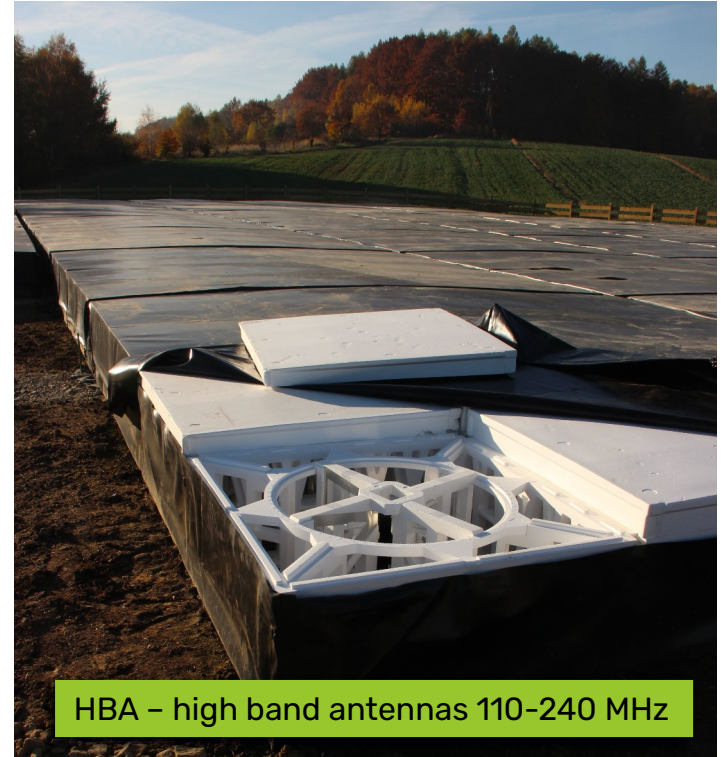
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LBA – low band antennas 10–90 MHz



LOFAR core in the Netherlands



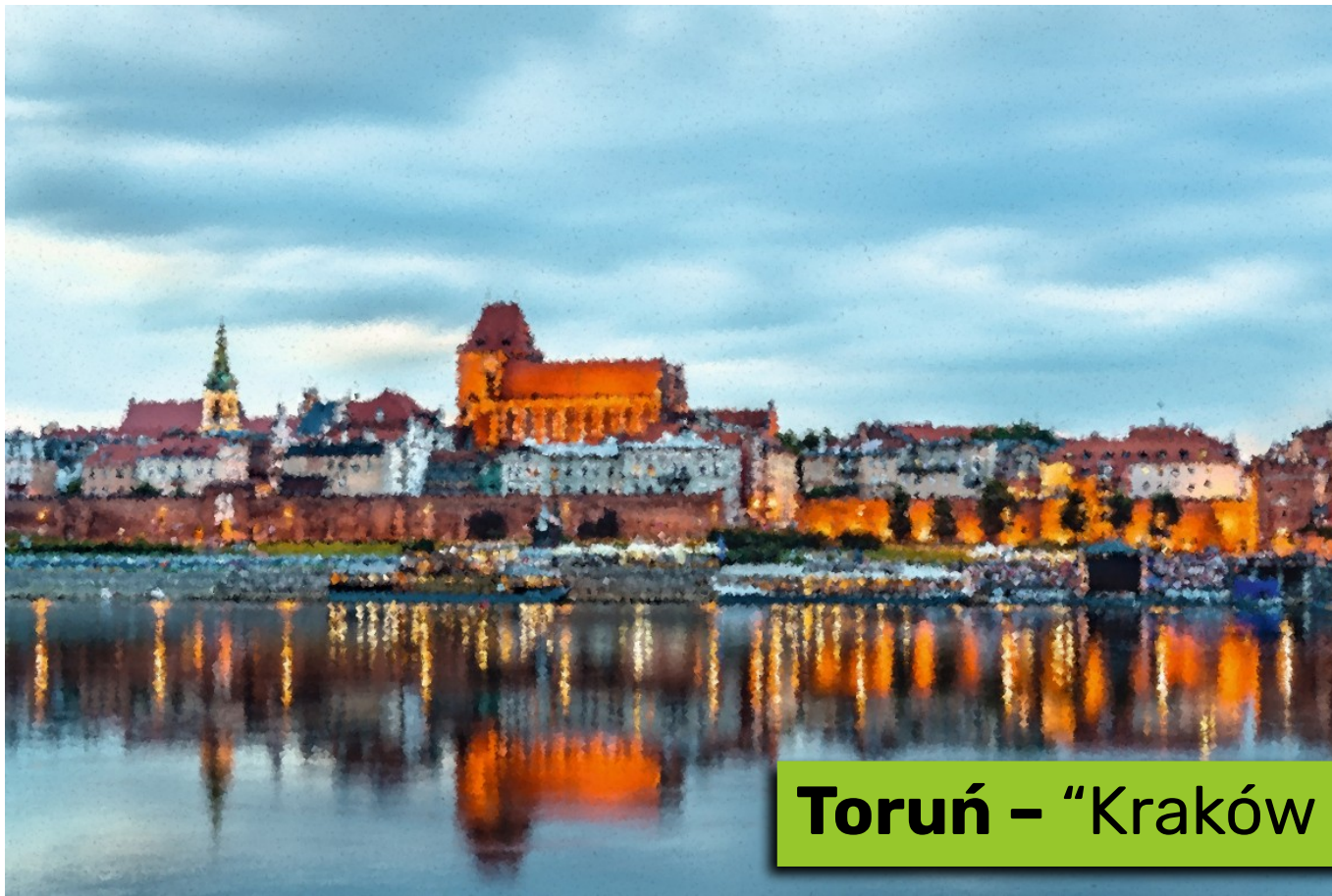
HBA – high band antennas 110–240 MHz

Beginnings of the radio astronomy in Toruń



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Toruń – “Kraków of the North”

First radio telescope in the Piwnice Observatory



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RT-1

parabolic-cylindrical antenna **12x26 m**, built in the second half of 1957. In 1958 the instrument was used to monitor solar activity. Main constructors:

**H. Iwaniszewski, S. Gorgolewski,
H. Wiśniewski, J. Hanasz**
and many others...

Second radio telescope in the Observatory



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RT-2

1958 - a hand-operated parabolic antenna, **12 m** in diameter, sensitive enough to measure the emission of a quiet Sun. It was used for daily observations during the Geophysical Year (1957/58) and for the following years. It was also used to observe the solar eclipse on February 15, 1961.

Persons identified on the photo:

**S. Gorgolewski, A. Buchholz,
H. Wiśniewski and J. Hanasz.**



RT-3

This instrument has a paraboloidal surface with a diameter of **15 m**. The construction of this telescope lasted from spring to autumn **1976** (project by **E. Śledziwski** and **Z. Bujakowski**, **W. Iwanowska**, **S. Gorgolewski**, **A. Kus**, **B. Krygier**, **E. Pazderski**, **A. Kępa**, **J. Mazurek** and many others). The radio telescope has an equatorial mount. In the early eighties of the twentieth century, the radio telescope was equipped with a number of receivers that allowed to record radio radiation at 2.8, 6, 18, 21, 49 and 92 cm wavelengths.

In 1981, the so-called interference fringes between the signal recorded by RT-3 and the 100-meter radio telescope in Effelsberg, Germany were obtained for the first time. It was the **beginning of Very Long-Baseline Interferometry (VLBI)** at the Observatory in Piwnice.

Fourth radio telescope in the Observatory



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RT-4 named after **Nicolaus Copernicus**

32-meter precise parabolic antenna, designed (**Z. Bujakowski** and co-workers, **S. Gorgolewski, A. Kus, B. Krygier, E. Pazderski, A. Kępa, J. Mazurek** and many others) and built in Poland in **1994**, is a fully steerable telescope with a classic azimuth-elevation mount. The main mirror consists of 336 panels, each made with an accuracy of 0.35 mm. The 32-meter antenna with high-quality instrumentation is a unique tool for Polish astronomers in space research. The telescope is part of the European and worldwide VLBI interferometric network.



RT-4 a few parameters

- Optic: Cassegrain system
- Mount: azimuth-elevation
- Elevation range: +2 to +95 deg
- Azimuth range: +-270 deg (South = 0)
- Diameter: 32 m
- Max height: 37.6 m
- Weight: ~620 tons
- L-band receiver: 1.4-1.8 GHz Tsys ~35 K
- C1-band receiver: 4.3-5.3 GHz Tsys ~35 K
- C2-band receiver: 5.9-6.9 GHz Tsys ~25 K
- X-band receiver: 8-12 GHz Tsys ~55 K
- K-band receiver: 21-25 GHz Tsys ~100 K
- Ka-band receiver: 27-33 GHz Tsys ~40 K
- **Single dish:** total power radiometry, spectroscopy, polarimetry.
- **VLBI network:** high resolution imaging, radio-astrometry, spectroscopy, polarimetry.

Renovation of RT-4 in 2020



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The renovation, which took 4.5 months, was carried out by ENERGON S.A. from Toruń - total cost **PLN 2 300 000**.



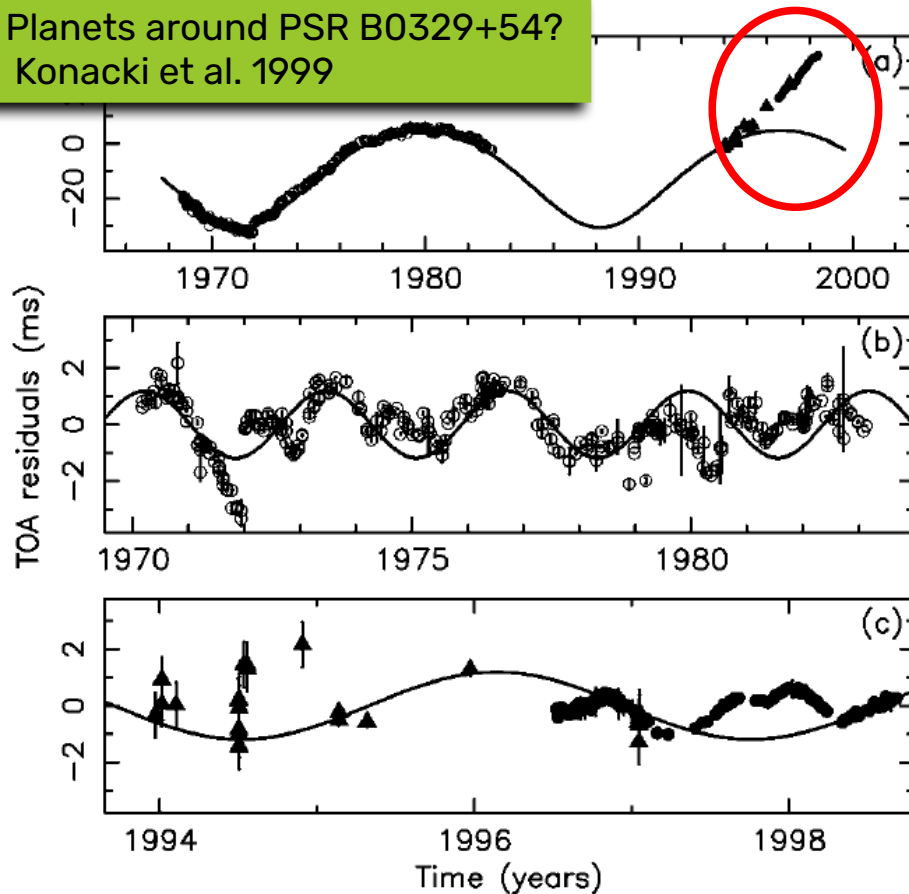
Pulsar timing program with the 32 m RT



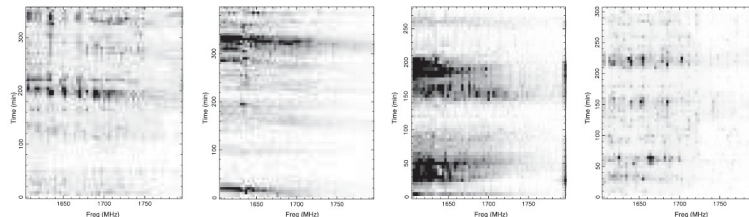
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Planets around PSR B0329+54?
Konacki et al. 1999



Regular monitoring (a measurement every few days) of about **100** strong pulsars at 1.7 GHz with the **Penn State Pulsar Machine 2** - 2 x 64 x 3 MHz channels (A. Wolszczan, M. Konacki, W. Lewandowski and many others...



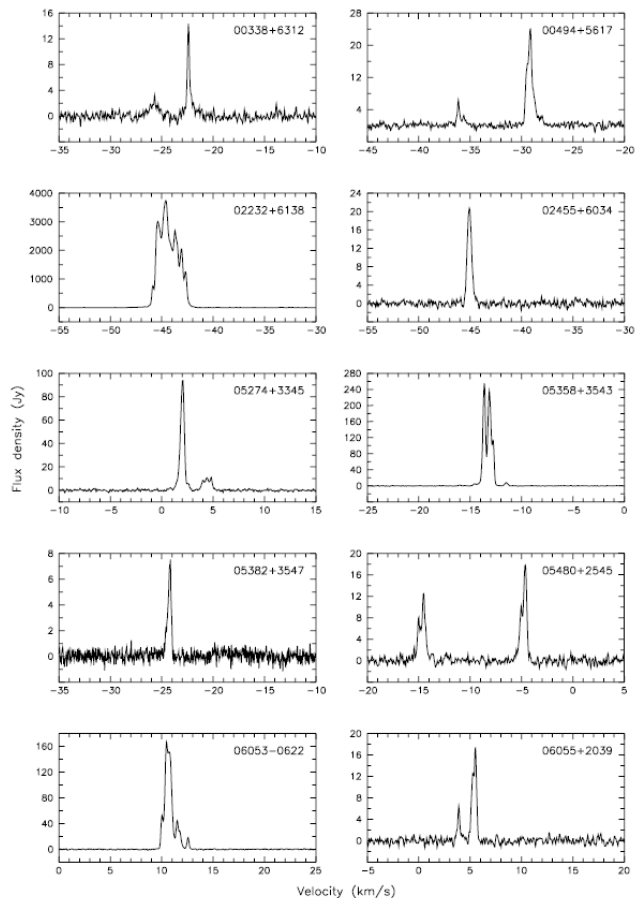
Scintillations of PSR B0823+26 - Daszuta et al. 2013.

Search for methanol maser emission



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- Search of **1399 IRAS** objects north of declination -20 deg at 6.7 GHz.
- Maser emission **was found in 182 sources**, including **70 new detections**.
- **32 new sources** were identified with objects of radio emission associated with **star-forming regions**.
- Results suggested that about 65% of methanol masers exhibit moderate or strong variations on time-scales of about 4 and 8 years.

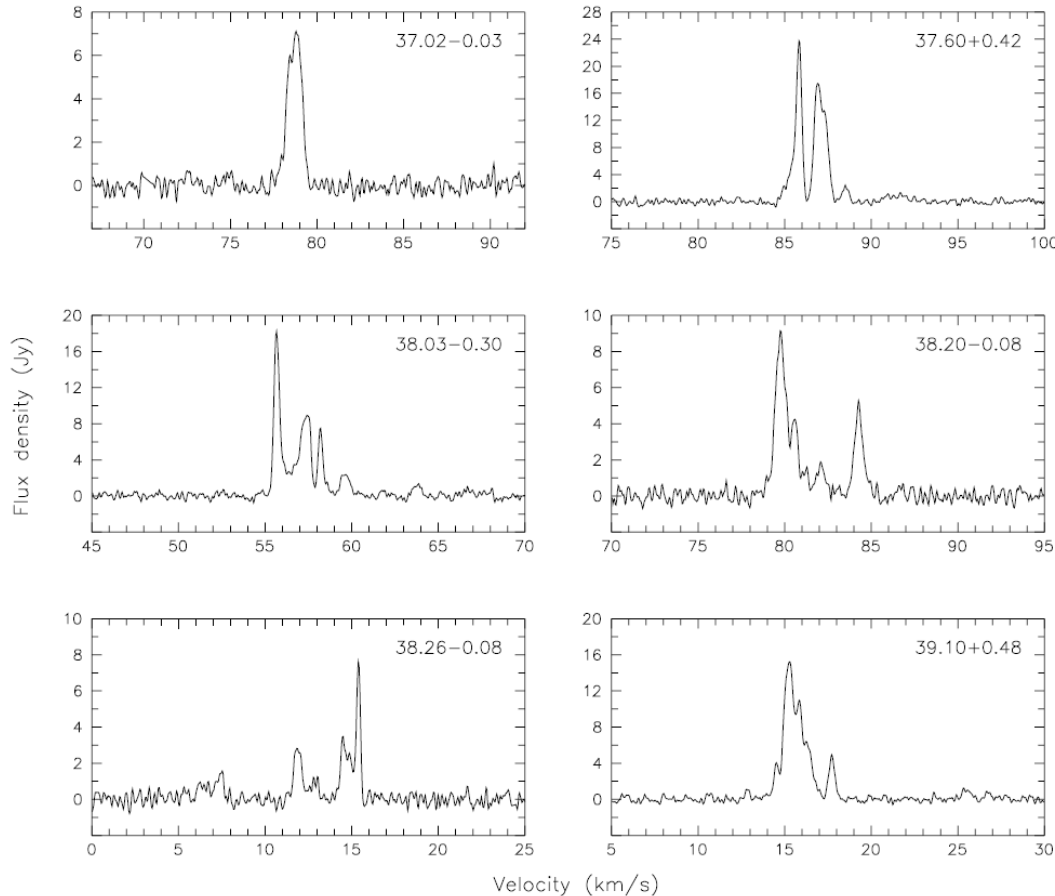
(Szymczak et al. 2000)

Blind survey of the Galactic plane



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A blind search for methanol masers sources in a strip of the Galactic plane (20 to 40 deg in longitude and ± 0.52 deg in latitude).

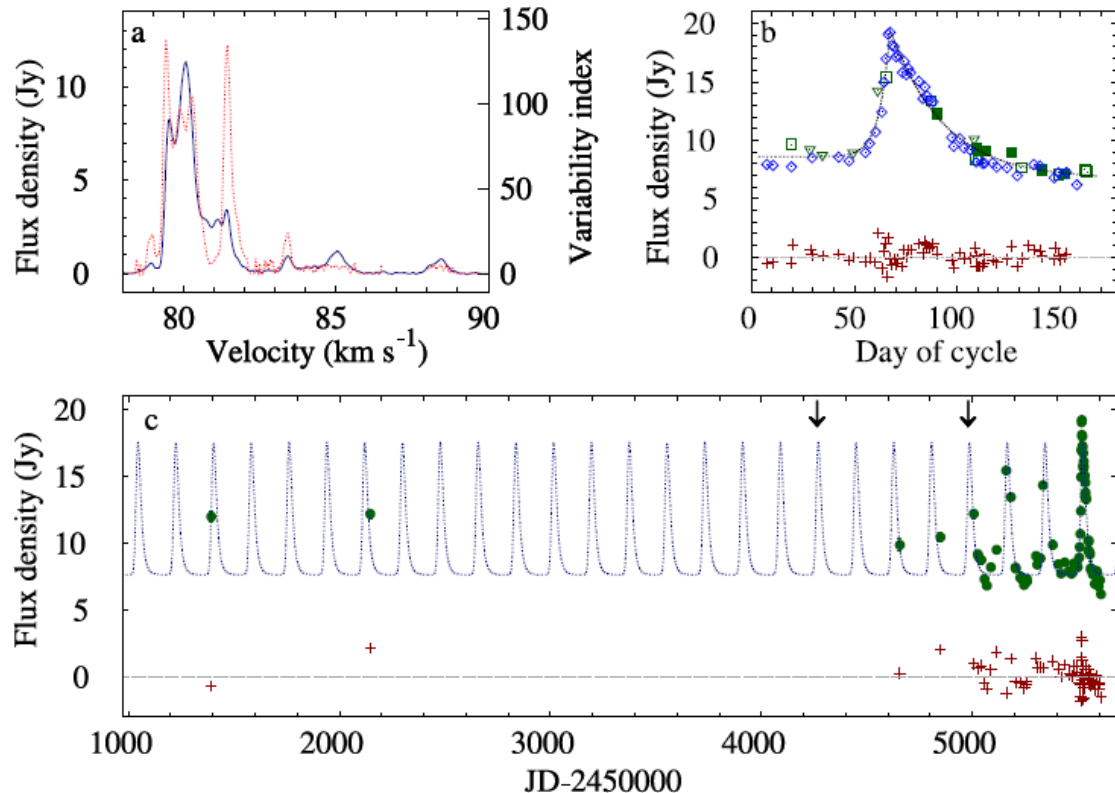
100 sources were detected in total, where **26 objects were detected for the first time.**

(Szymczak et al. 2002)

Periodic variability of methanol masers



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Periodic variability of methanol masers in G22.357+0.066. The period of the variations is about 179 days and seems to be stable in last 12 years.

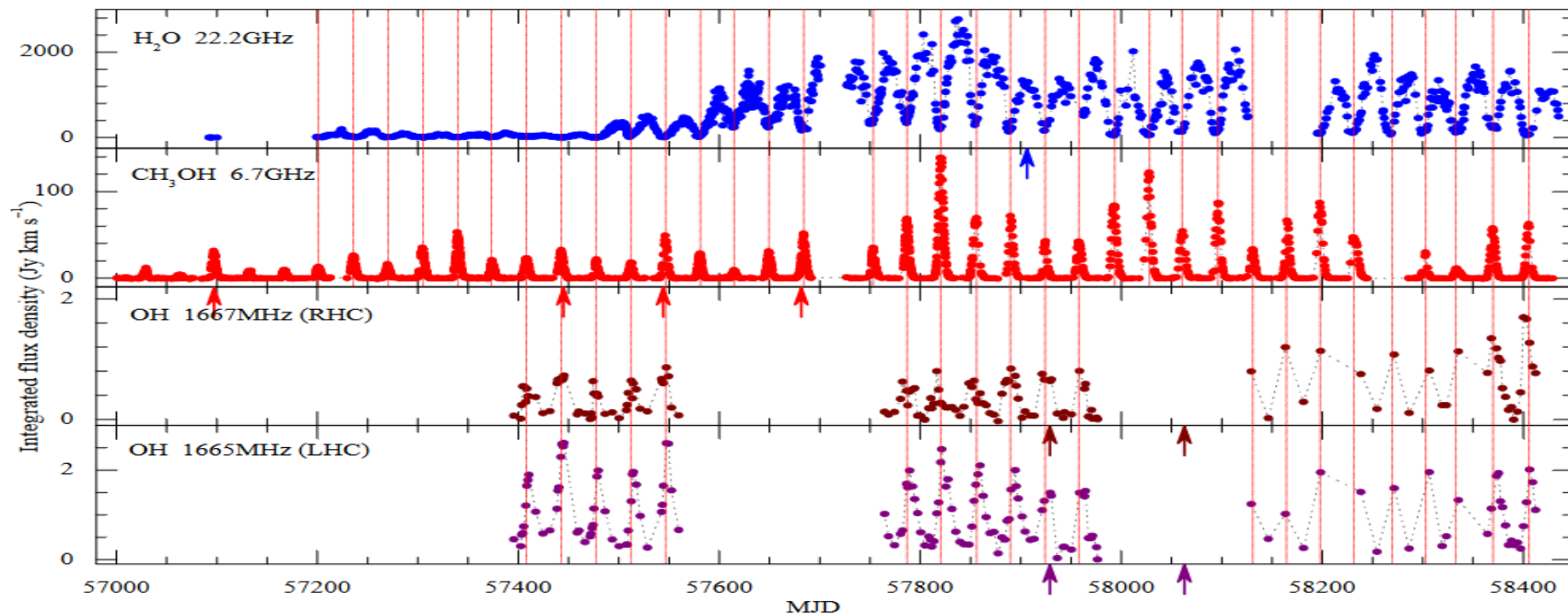
(Szymczak et al. 2011)

Alternating flares of the methanol masers



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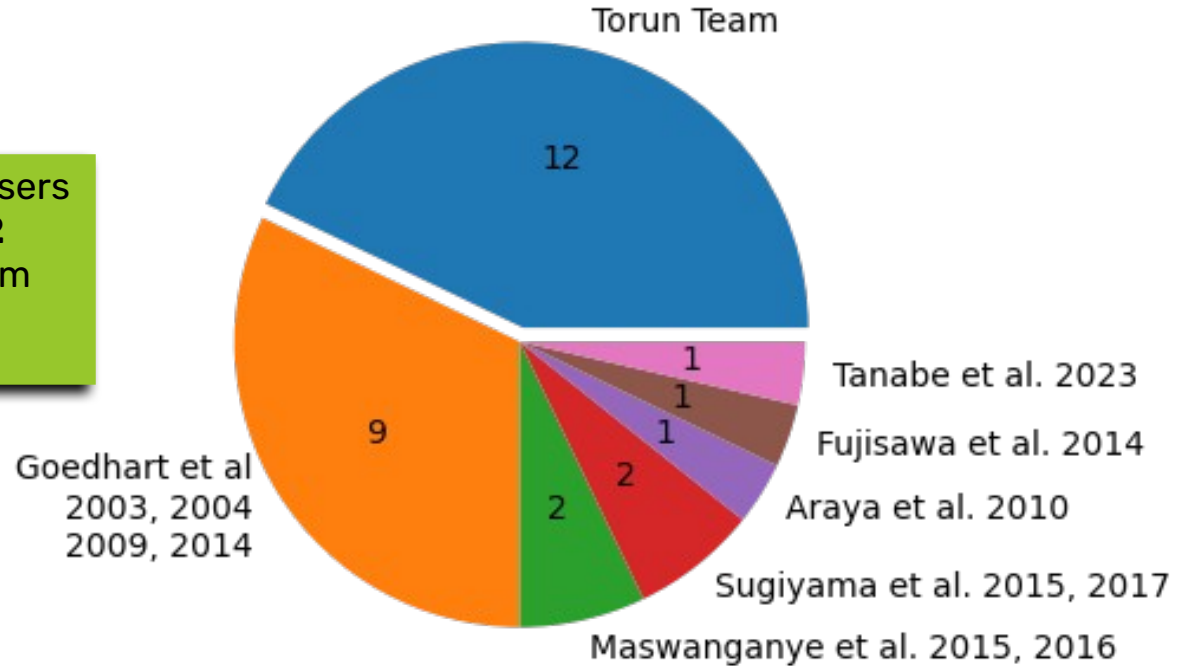
G107.298+5.639 - alternating flares of the **methanol (6.7 GHz)** and **water (22.2 GHz)** masers with a period of **34.4 days**. Periodic flares of maser emission are thought to be induced either by variations of the seed photon flux in young binary systems or the pump rate regulated by stellar and accretion luminosities (Olech et al. 2020)

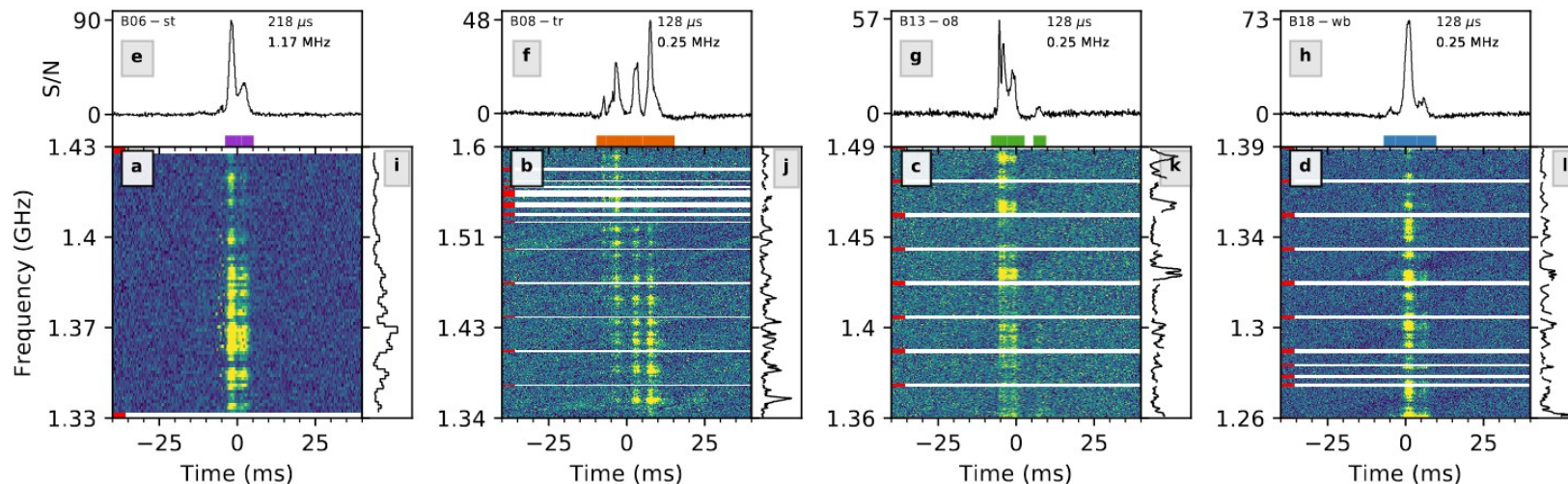
Number of known periodic maser sources



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So far only **28** periodic masers were discovered, where **12** sources were found by 32 m radio telescope in Toruń.





FRB 20201124A - observed between April 2021 and March 2022 by: 25 m telescope in Stockert, Germany; 32 m dish in Toruń, Poland; 25 m dish in Onsala, Sweden; 25 m dish in Westerbork, The Netherlands (Kirsten et al. **Nature Astronomy** 2023).

On the cover in Nature Astronomy



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a natureresearch journal

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Launched in January 2017 and publishing online monthly, *Nature Astronomy* aims to bring together astronomers, astrophysicists and planetary scientists. In addition to the latest advances in research, we offer Comment and opinion pieces on topical subjects of relevance to our community, including the societal impact of astronomy and updates on telescopes and space missions.

We are part of a portfolio of journals within Nature Research, which includes *Nature*, *Nature Geoscience*, *Nature Physics* and *Nature Communications*. Although there is some overlap in scope, each journal is editorially independent and has its own readership. Moreover, although we consider the same astronomical topics as *Nature*, *Nature Astronomy* has more space to explore theoretical, methodological and instrumental papers.



NASA/CASA; Ian Warren et al.
NORAT/FRIDWIT, NAOS/Suzaku, Design: Alex Wing

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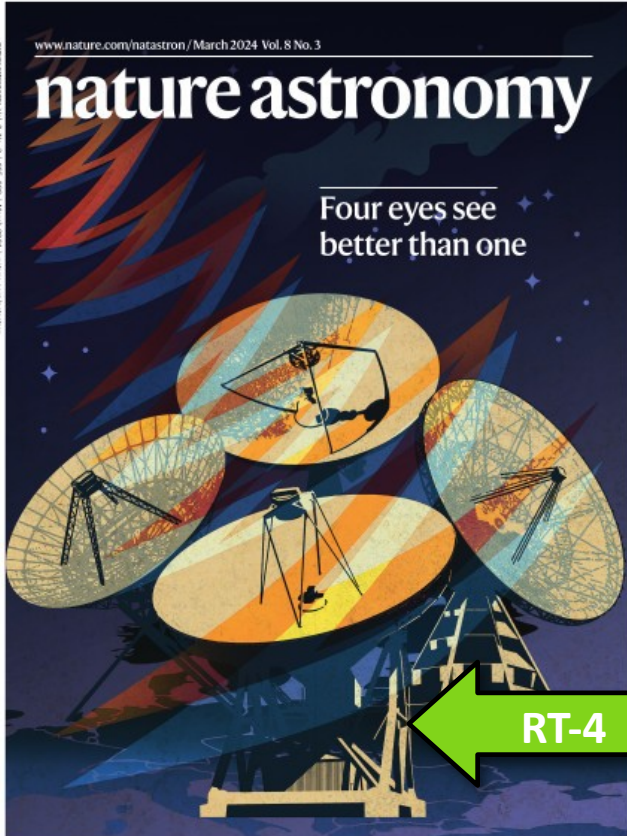
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nature astronomy

Four eyes see better than one



RT-4

EVN and JIVE



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JIVE

Joint Institute for VLBI
ERIC

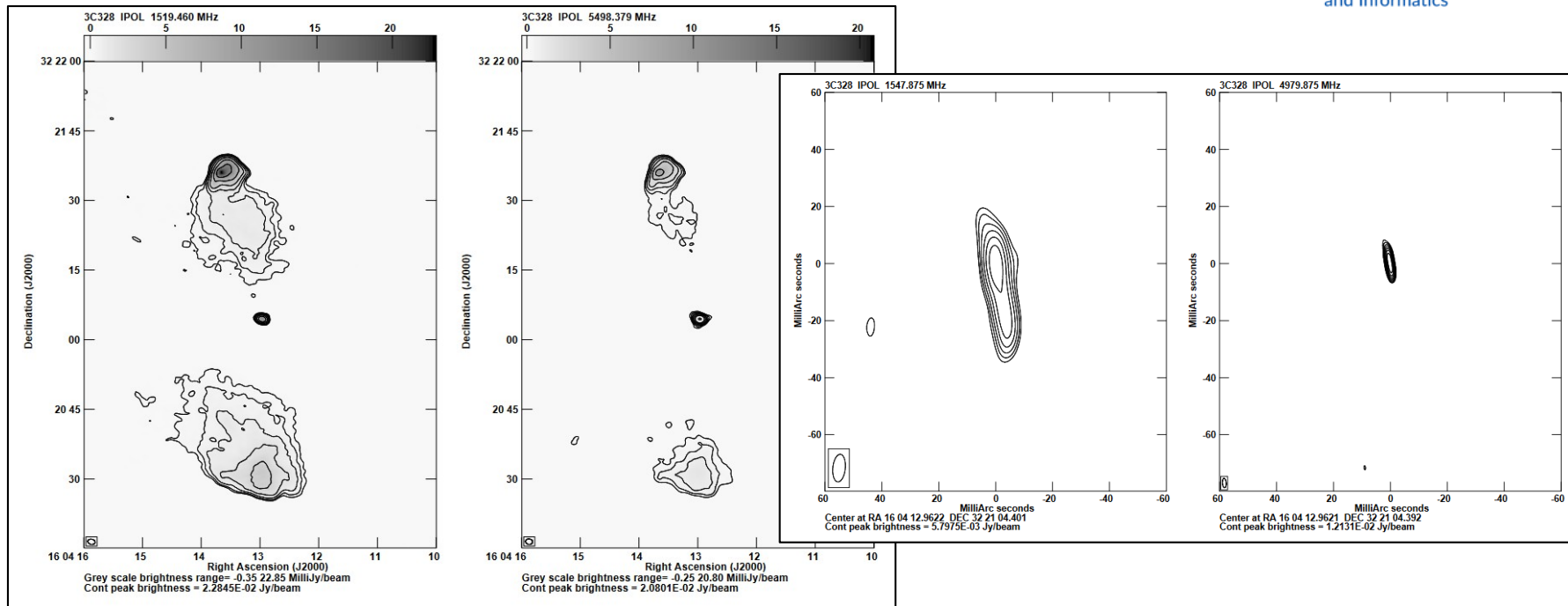


Morphology of radio galaxies



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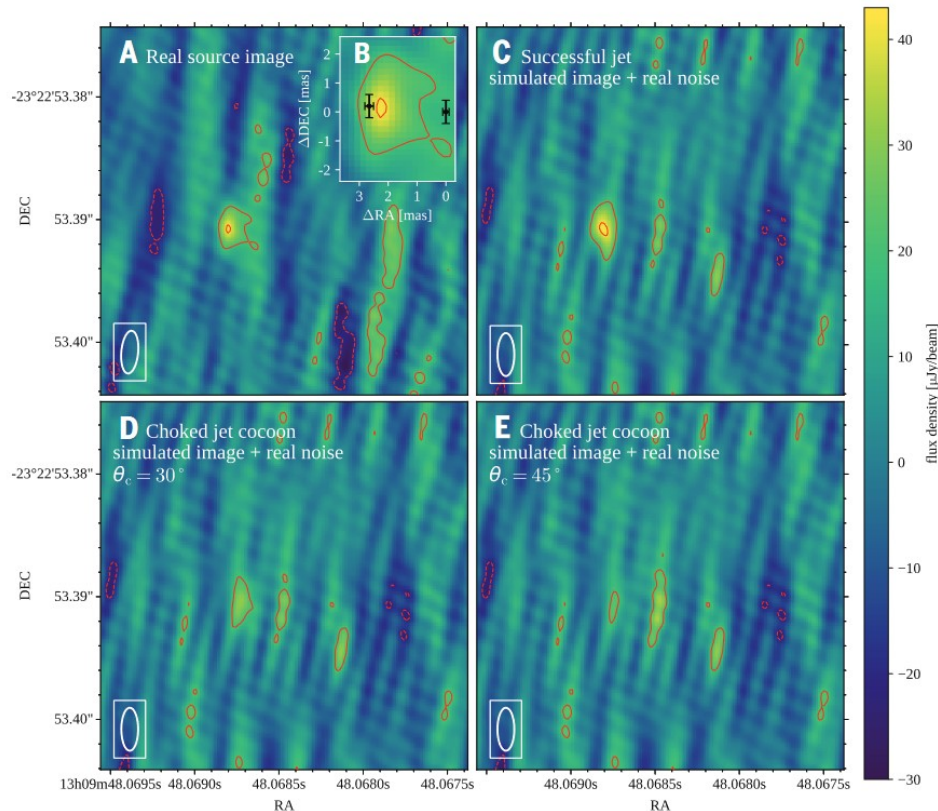
Zoom into the center of 3C 328 shows a new jets, so the source restarted activity (Marecki 2021).

Structured jet in kilonova GW170817



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The binary neutron star merger event GW170817 was detected through both electromagnetic radiation and gravitational waves. Its afterglow emission may have been produced by either a narrow relativistic jet or an isotropic outflow.

The apparent source size is constrained to be smaller than 2.5 milliarcseconds at the 90% confidence level. This excludes the isotropic outflow scenario, which would have produced a larger apparent size, indicating that GW170817 produced a structured relativistic jet.

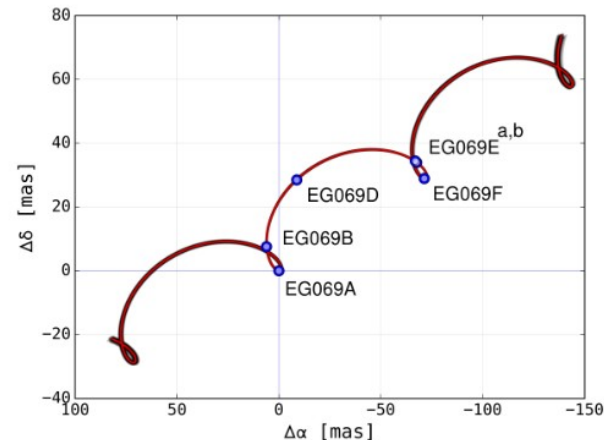
(Ghirlanda et al. **Science** 2019)

Annual parallaxes with EVN



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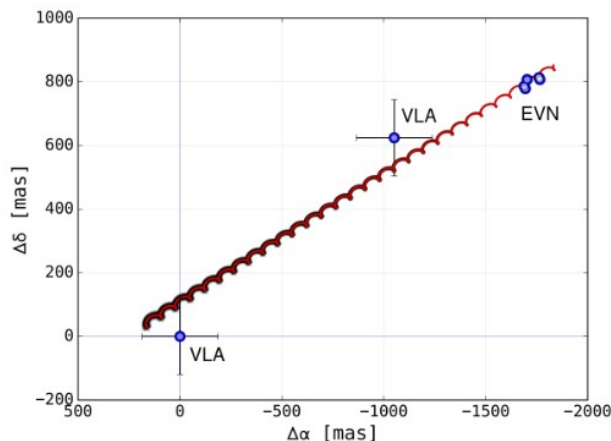
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Sky-projected parallactic motion of **AM-Herculis** - binary cataclysmic system. This particular system is formed by the magnetic white dwarf (primary) and the red dwarf (secondary) - a prototype of so-called **polars**.

A new EVN observations allowed to update the annual parallax for this system with the best precision to date (**$\pi = 11.29 \pm 0.08$ mas**), equivalent to the distance of **88.6 ± 0.6 pc** (Gawroński et al. 2018).

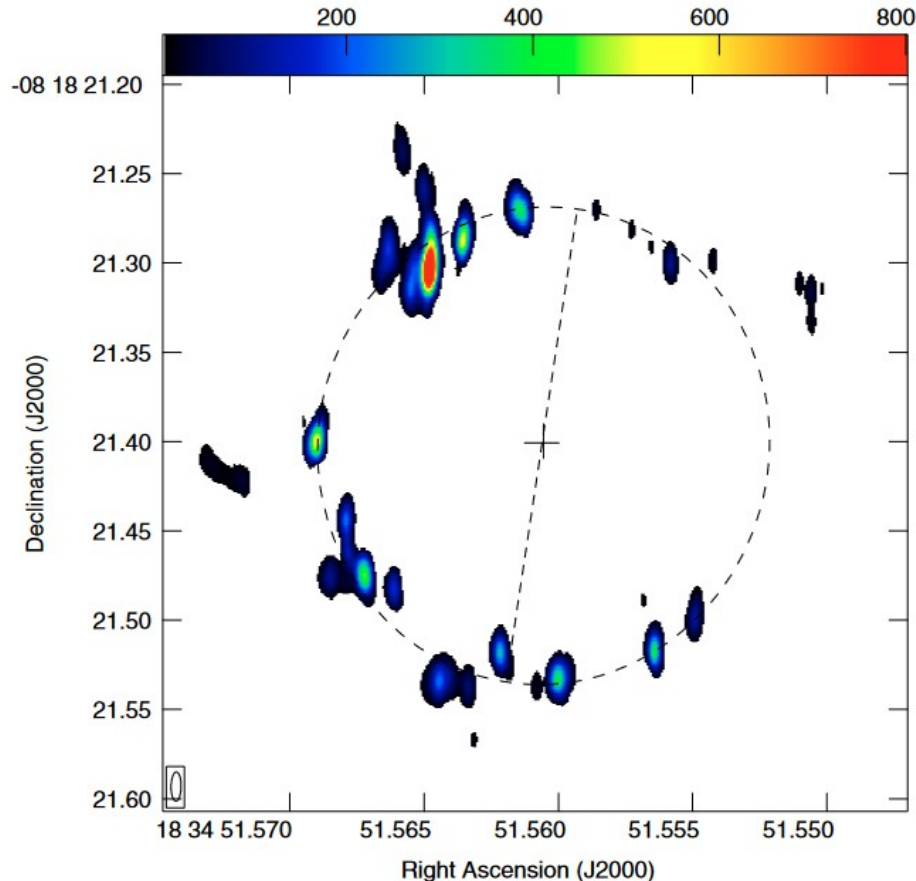
Previous estimations of this distance were in the range from **71** to **108 pc**.



Discovery of a ring of maser emission



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6.7 GHz methanol maser emission from the candidate **high-mass protostar** G23.657-0.127.

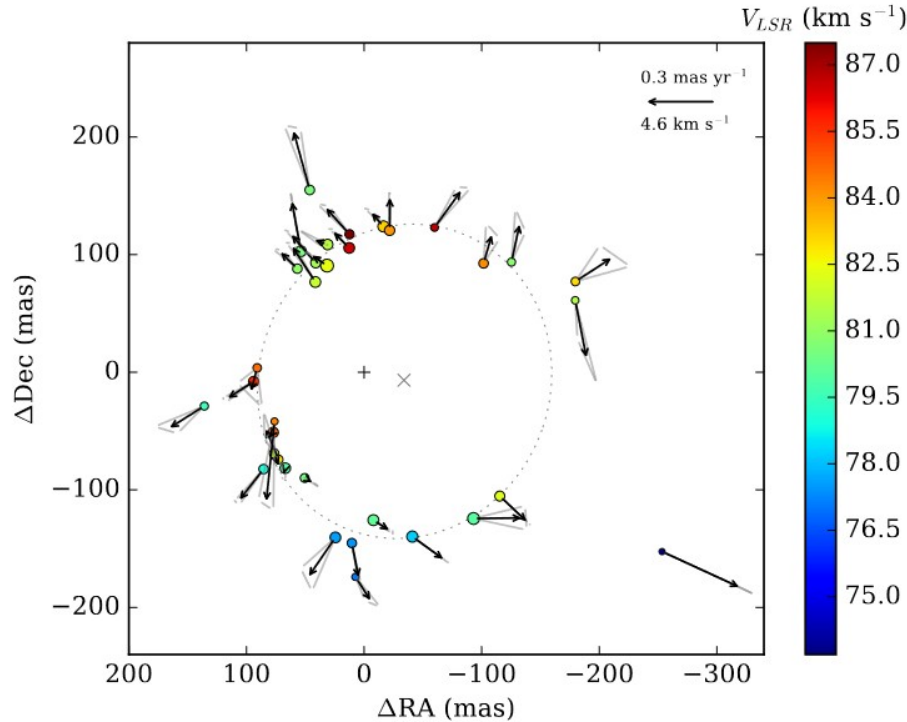
Spherical bubble or rotating disc seen nearly face-on?

(Bartkiewicz et al. 2005)

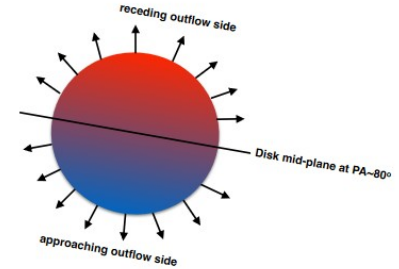
Further investigation of the maser ring



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Scenario I



Scenario II

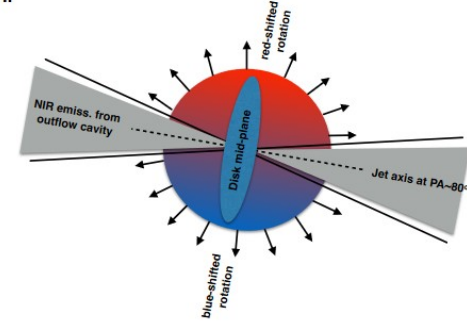


Fig. 7. Schematic models of maser expansion related to a sphere-like outflow (Scenario I) or tracing a wide angle wind at the base of the protostellar jet (Scenario II).

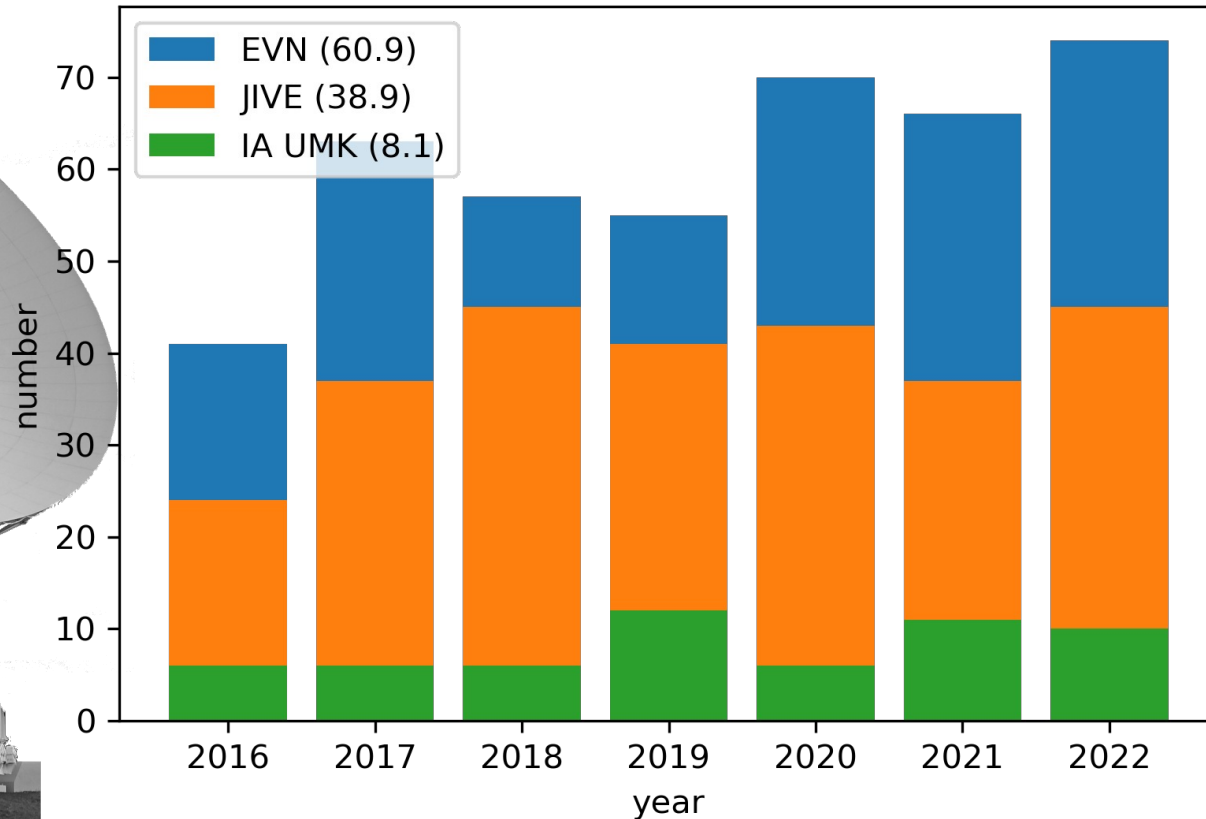
Statistic of the publications



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Refereed publications in which data from RT-4 were used



Future – SKA Observatory



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In 2025, the Polish consortium for the SKA Observatory project was established. The leader of this consortium is the **Nicolaus Copernicus University**.



Dual-use refers to technologies, software, or physical goods designed primarily for **civilian or commercial applications** that can also be adapted for **military, defence, or security purposes**.

In collaboration with institutions including the **Massachusetts Institute of Technology** (MIT) and the **University of Manchester's Jodrell Bank Observatory**, we are conducting test radar observations of satellites in geostationary orbit. These experiments are carried out as part of the **NATO SET-340 "Multistatic RF Sensing for Enhanced Space Domain Awareness"** research and development program.

Scientists from **Warsaw University of Technology** are also involved in this project in Poland.



Thank you!