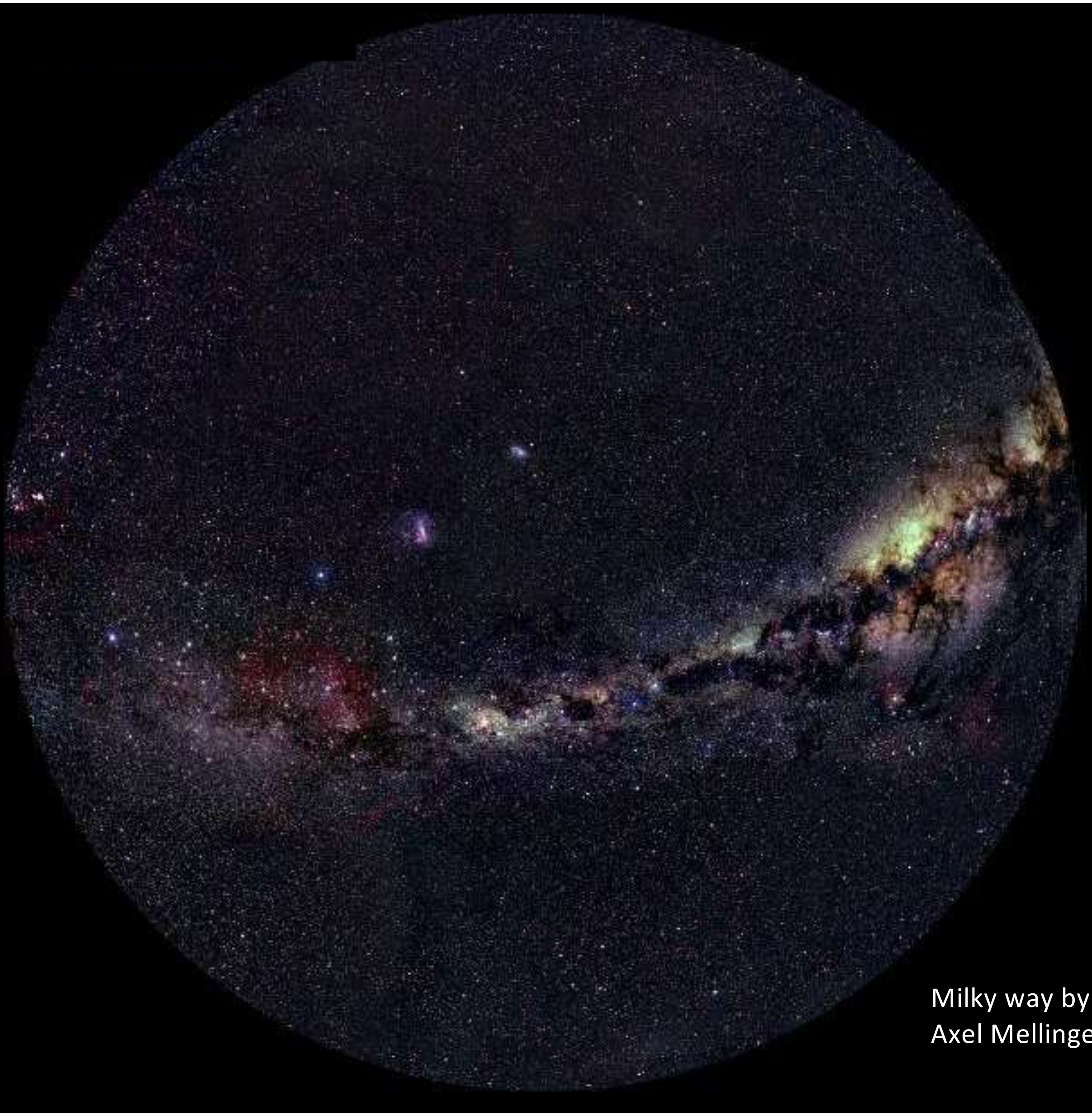
The White Giant in the Eifel

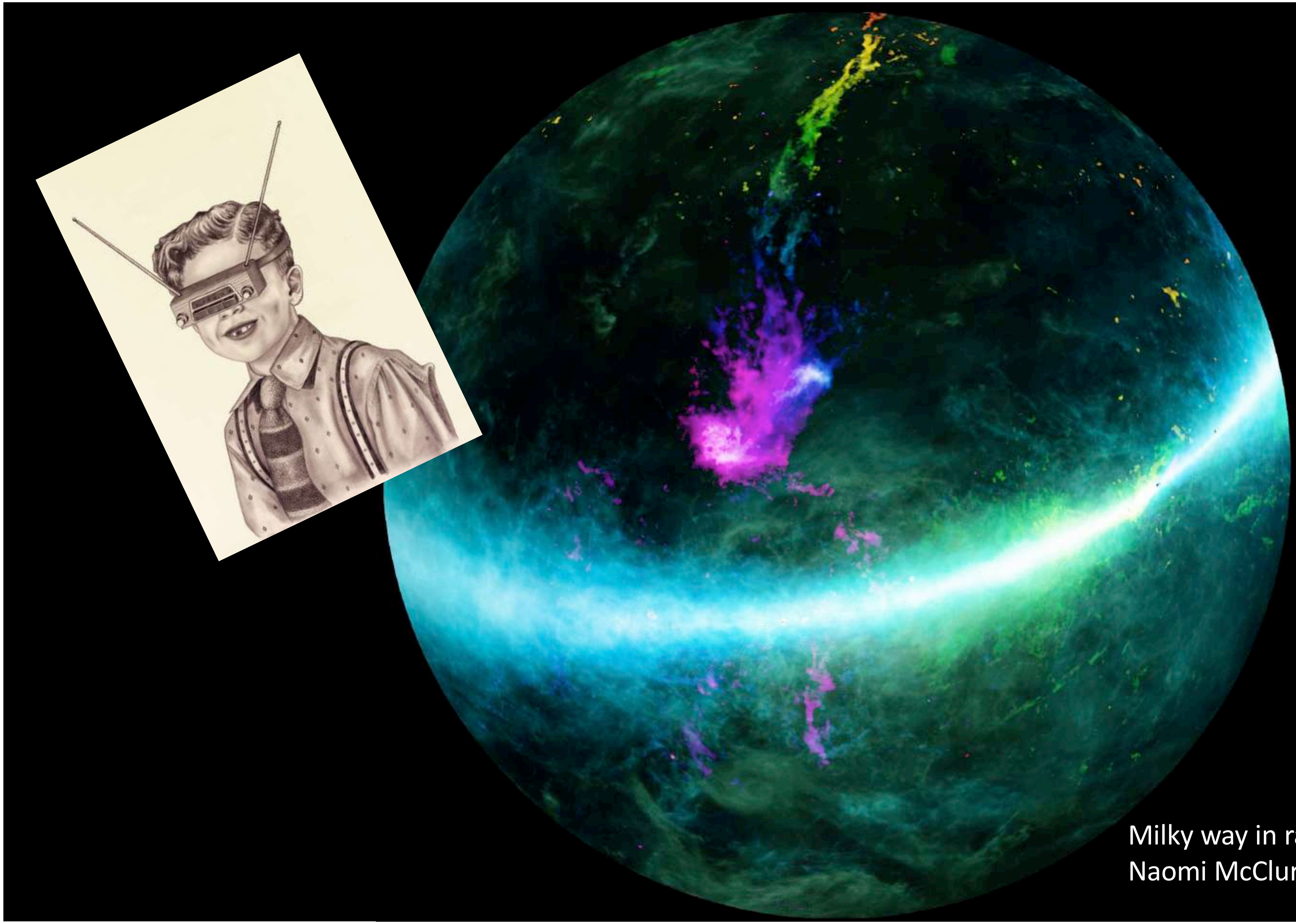
Michael Kramer

Fundamental Physics in Radio Astronomy
Max-Planck-Institut für Radioastronomie

Introduction



Milky way by
Axel Mellinger



Milky way in radio light
Naomi McClure-Griffiths

Radio astronomy is bound to make transformational discoveries

- We observe extreme and energetic processes and objects
- We get lots of photons that are easy to copy and multiply
- We can build or synthesize huge telescopes
- We can probe the complete Universe, undisturbed from dust etc.
- We can get polarization (magnetic fields!) and dynamic information (pulses!)

A brief history

1870’s: James Clerk Maxwell predicts existence of electromagnetic radiation with any wavelength!

1888: Heinrich Hertz demonstrates transmission and reception of radio waves

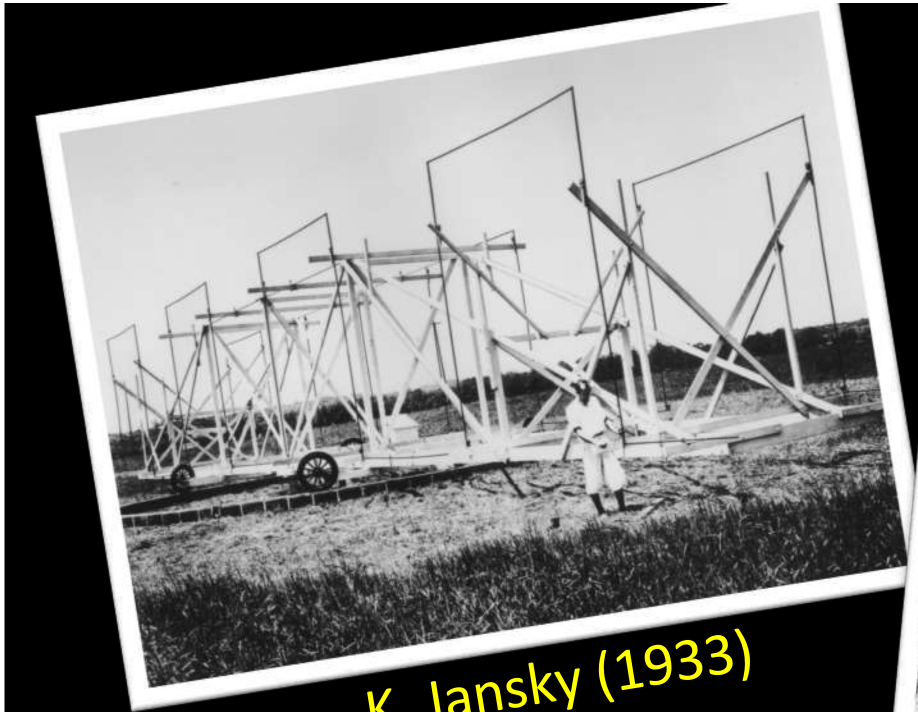
Early pioneers:

1932: Karl Jansky discovers cosmic radio waves from the galactic centre

1937-1944: Grote Reber’s First Surveys of the Radio Sky
1942: Sun discovered to be a radio source by J.S. Hey
1936-1945: Development of radar before and during world war II e.g. Sir Bernard Lovell
1944: Prediction by van der Hulst and Oort of neutral Hydrogen spectral line at 1.4GHz.

1951: Detection of neutral Hydrogen by Ewen & Purcell and van der Hulst & Oort
1956/7: Construction of the first large steerable telescopes

1960s: First radio interferometers constructed; Aperture Synthesis developed (Ryle)



K. Jansky (1933)

G. Reber (1938)

B. Lovell (1957)

Parkes (1961)

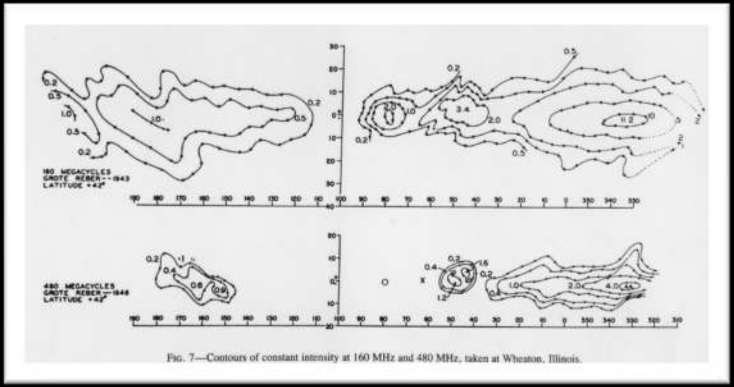


Fig. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.

First radio map of galaxy

The first radio astronomer: Grote Reber – a new cosmic window

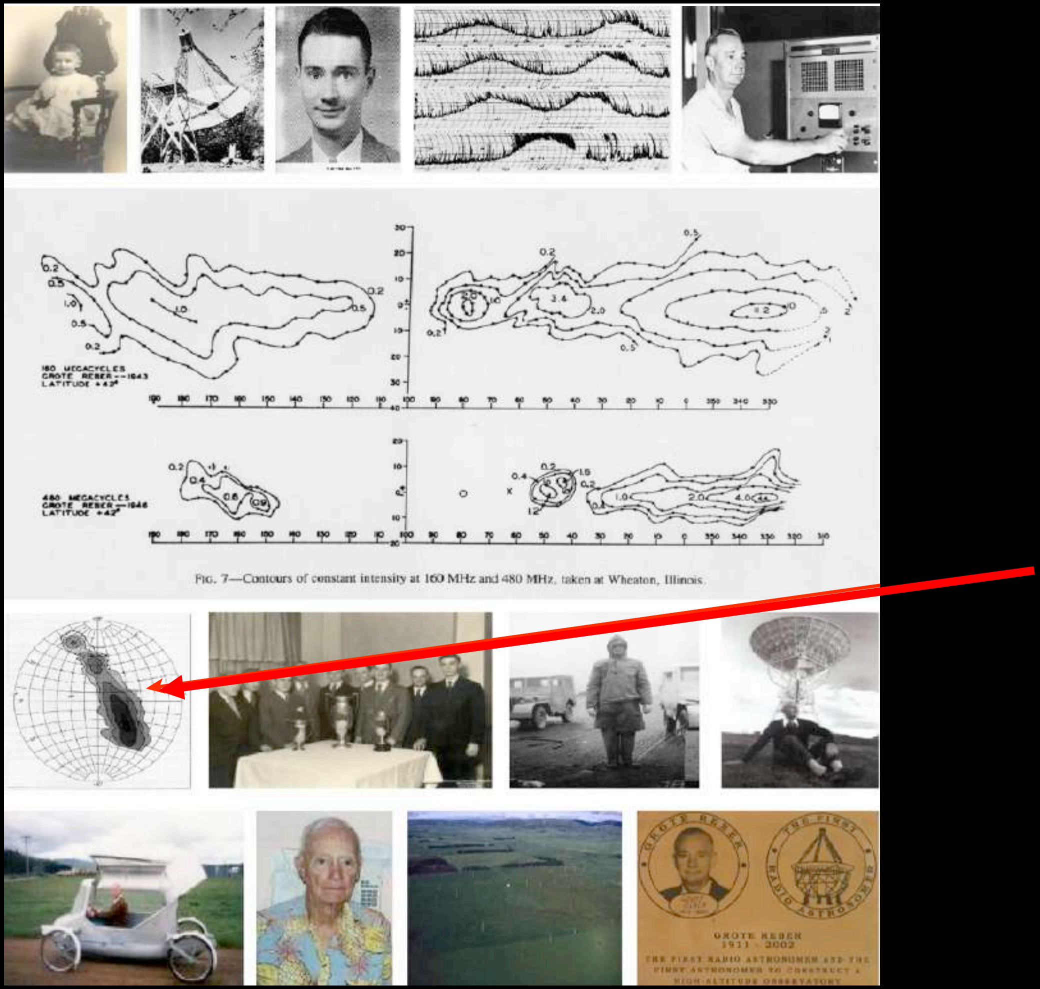


Fig. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.

He built the first parabolic radio telescope:

- "Good" angular resolution
- Good visibility of the sky
- Detected Milky Way, Sun, Cas-A, Cyg-A, Cyg-X @ 160 & 480 MHz (ca. 1939-1947).
- Published his results in ApJ
- Multi-frequency observations revealing non-thermal origin

Neutral hydrogen – The Universe’s most abundant element

van de Hulst & Oort

“We should have a colloquium on the paper by Reber; would you like to study it? And, by the way, radio astronomy can really become very important if there were at least one line in the radio spectrum.” (Oort 1944)

Plate 1.6 Van de Hulst reading his paper on the 21 cm hydrogen line. (This photograph taken in 1955 is a reconstruction of the 1944 meeting). *(By courtesy of H. C. van de Hulst, Leiden)*

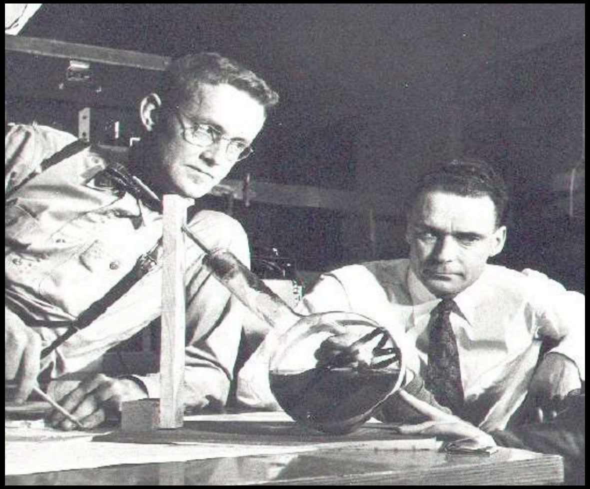
Based on Oorts suggestion, Henk van de Hulst (then a student) investigated various possibilities - his main result was that a spectral line associated with neutral hydrogen at 21 cm might be observed!

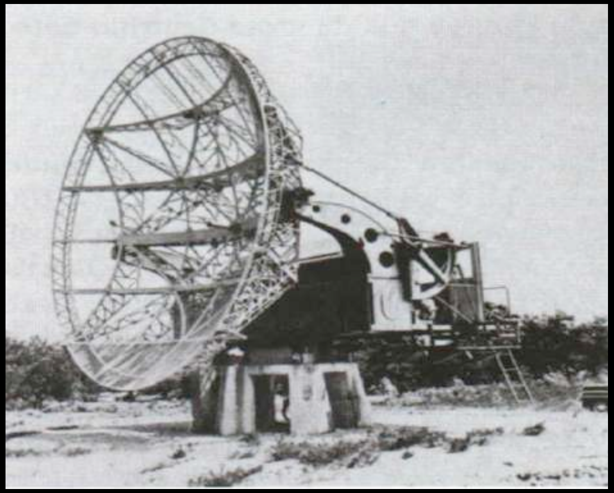
Oort was keen to try and detect the HI line but the technical expertise was not available in NL, and funding was scarce.

Eventually Oort managed to arrange observations with a disused German radar antenna.

Neutral hydrogen – The Universe's most abundant element

Meanwhile on the other side of the Atlantic, there was interest, resources and the right people. Purcell (left) and Ewen (right) built a radio antenna to search for HI.

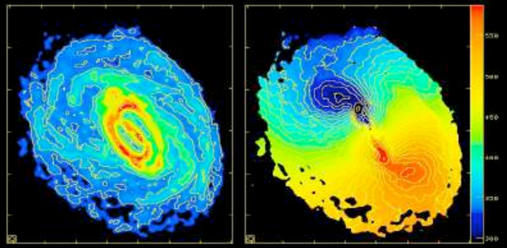




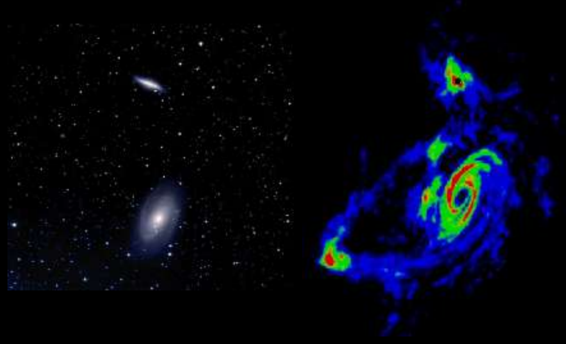
Ewen and Purcell detected HI in March1951

6 weeks later Oort & Muller detected HI using the German radar telescope at Kootwijk

The significance of HI

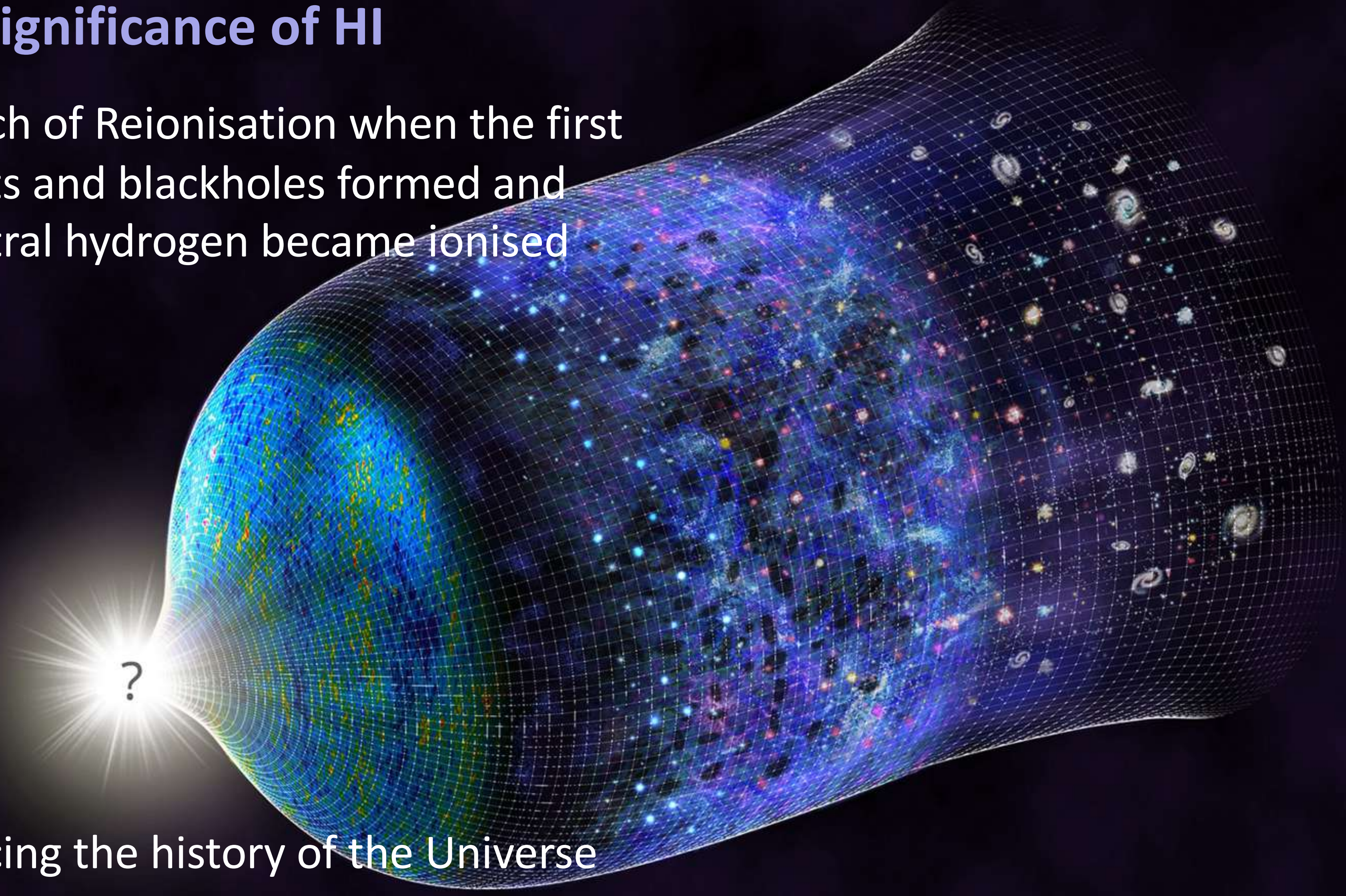


- Scale & Structure of the Milky Way
- The scale & dynamics of external galaxies
- Tracing dark matter well beyond optical extent of galaxies
- Cold HI in absorption - inflow and outflow around AGNs
- Revealing interaction of galaxies
- Probing the equation-of-state of dark energy via huge HI galaxy surveys
- Probing the dark ages: the Epoch of Reionisation



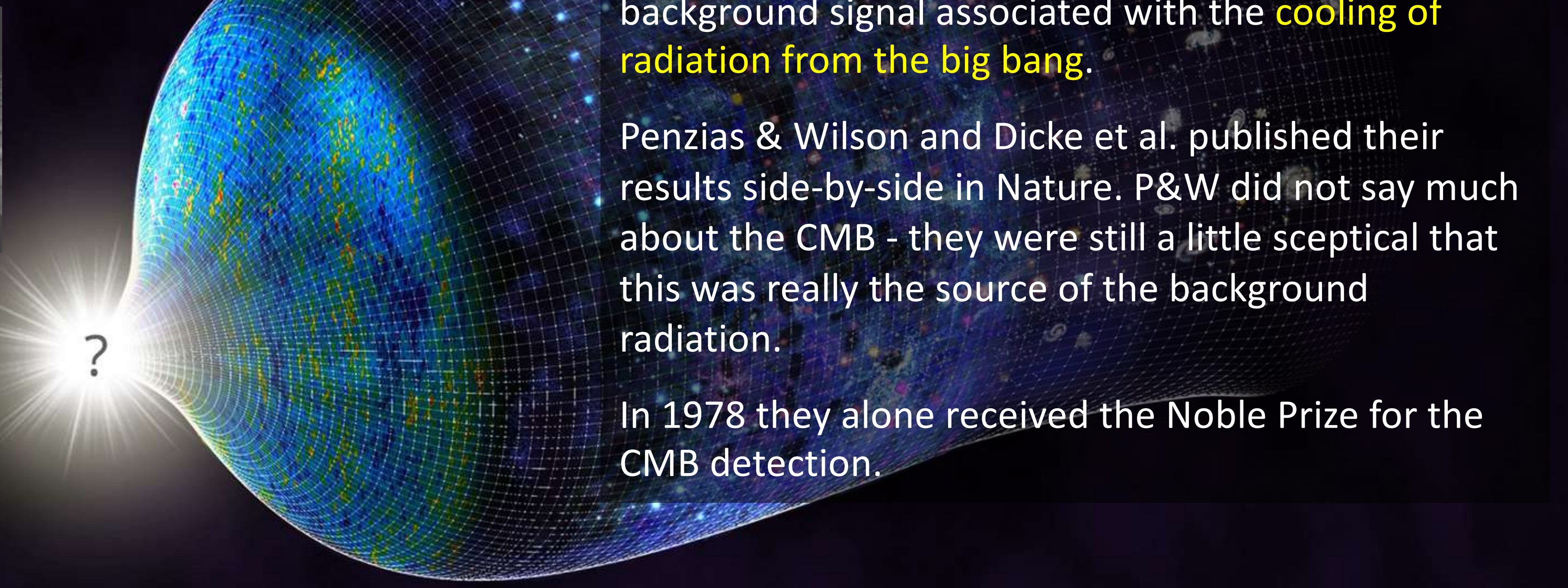
The significance of HI

- Epoch of Reionisation when the first starts and blackholes formed and neutral hydrogen became ionised



- Tracing the history of the Universe

The Cosmic Microwave Background



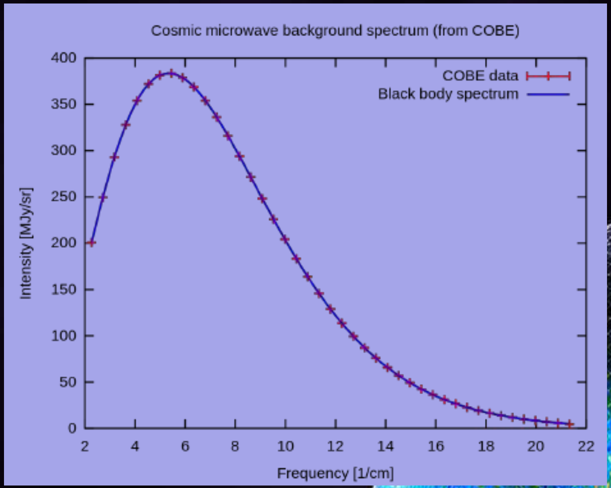
Penzias & Wilson measured an excess temperature that would not go away.

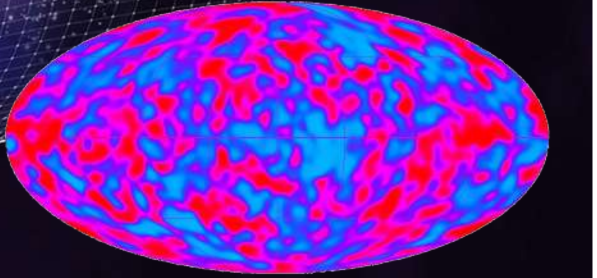
Robert Dickie at Princeton was predicting a background signal associated with the cooling of radiation from the big bang.

Penzias & Wilson and Dicke et al. published their results side-by-side in Nature. P&W did not say much about the CMB - they were still a little sceptical that this was really the source of the background radiation.

In 1978 they alone received the Noble Prize for the CMB detection.

The Cosmic Microwave Background – and its anisotropy





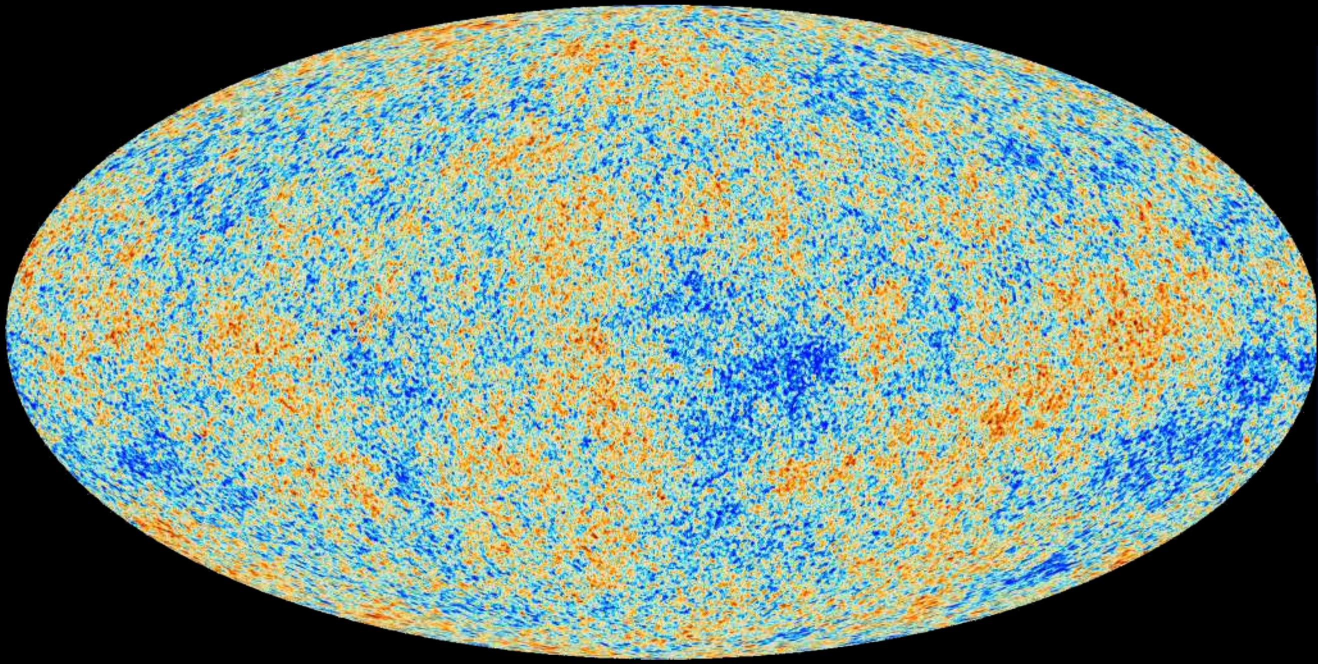
Nobel Prize for Mather & Smoot in 2006

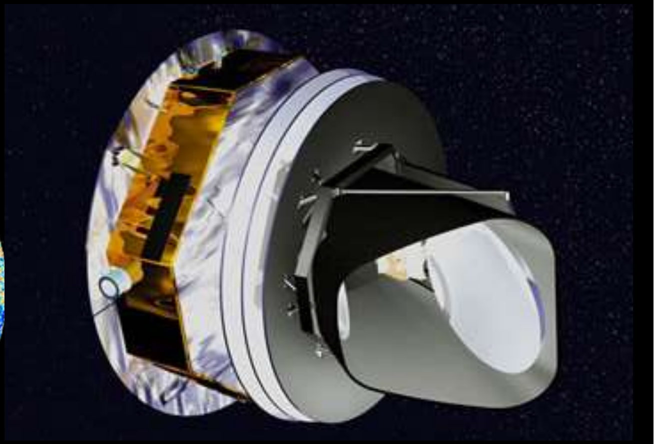
CMB after Planck

Properties of the Universe:

Age of the universe:	13.75 ± 0.11 billion years
The Universe consists of only	4.56±0.16% baryons,
compared to	22.7±1.4% "Dark Matter"
and	72.8±1.5% “Dark Energy"

We are clearly not the most important species, not even as baryons!





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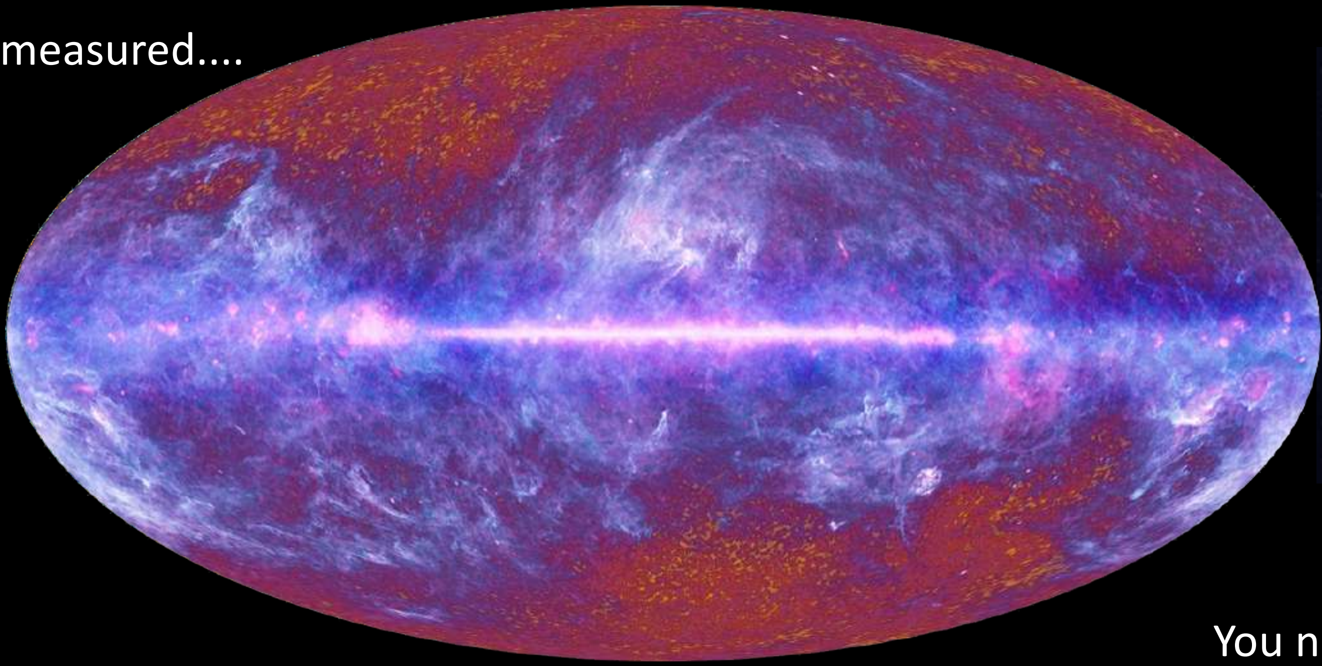
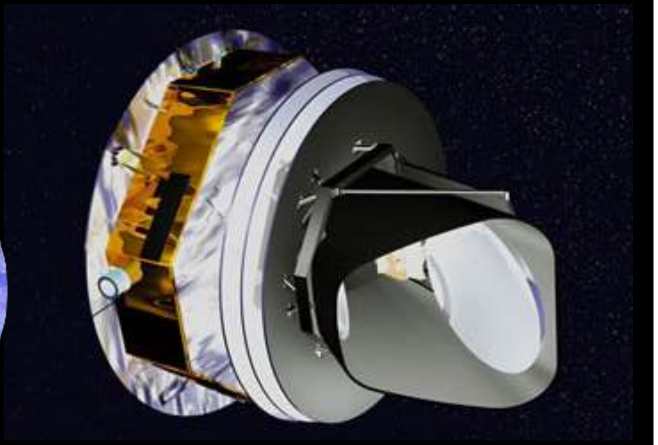
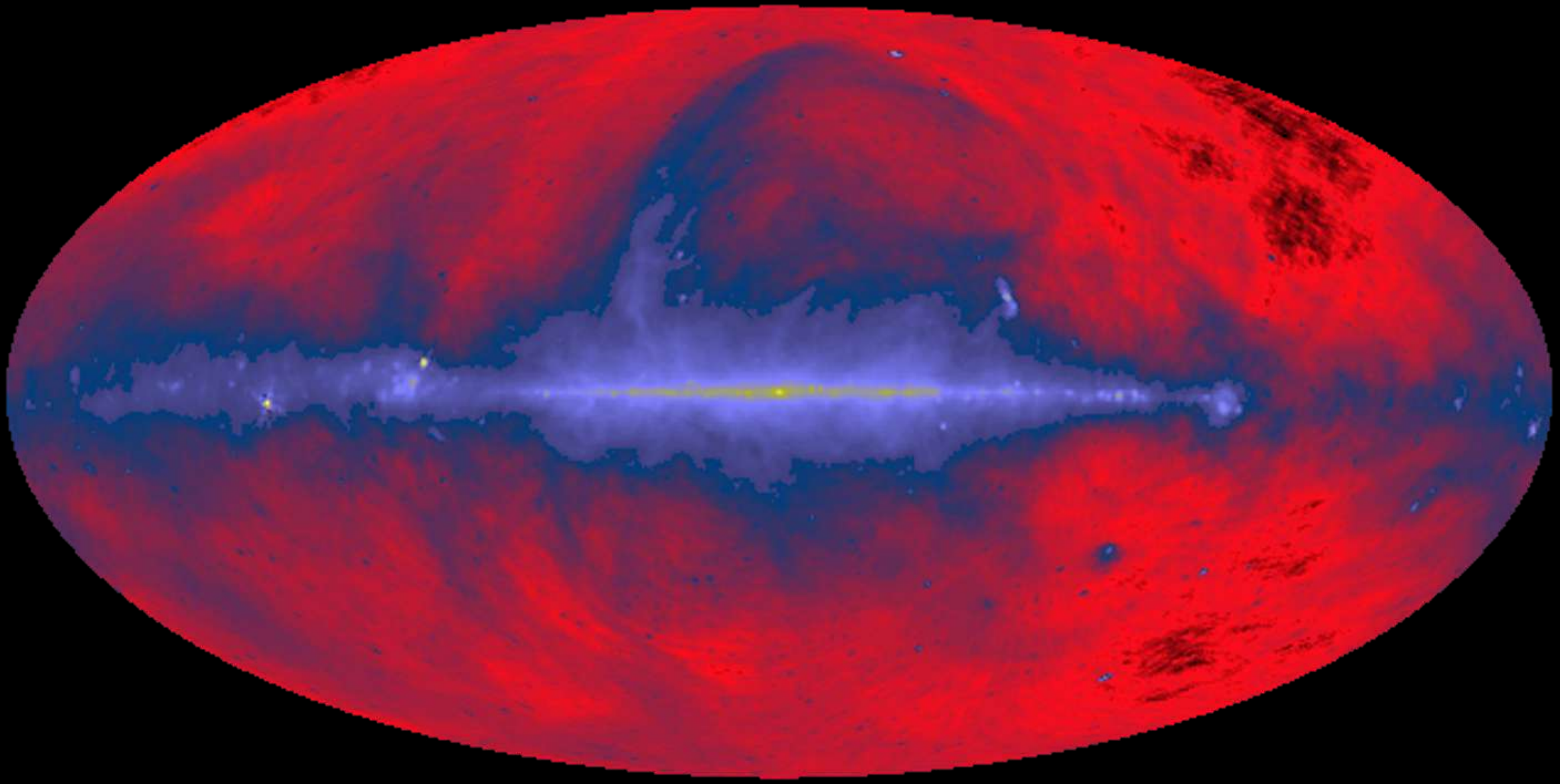
Actually measured....



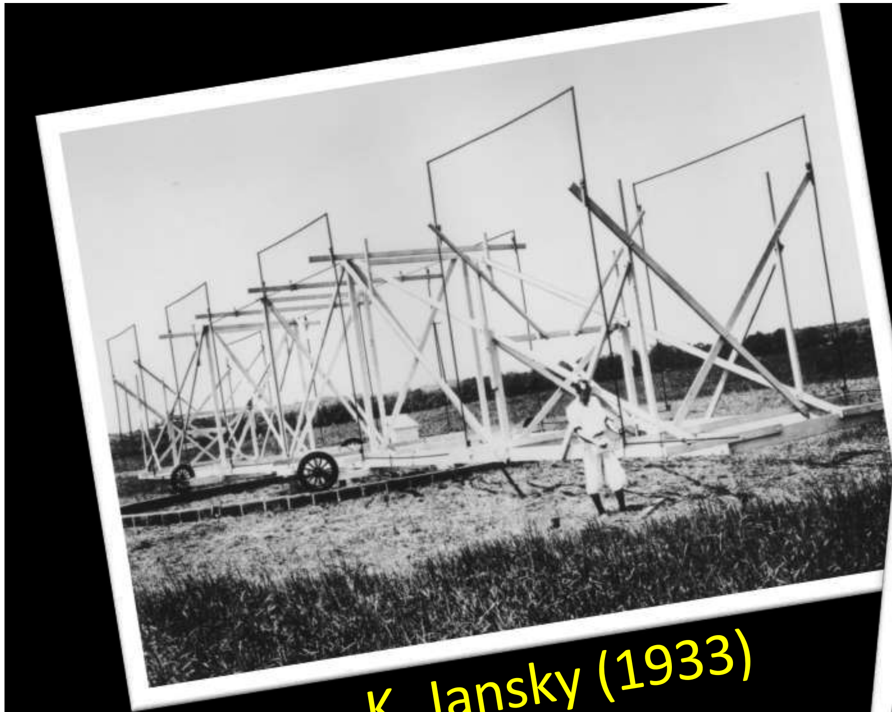


You need to correct for foreground...

The 408-MHz survey by Haslam et al.



The way to Effelsberg



K. Jansky (1933)

G. Reber (1938)

Lovell (1957)

Dwingeloo (1956)

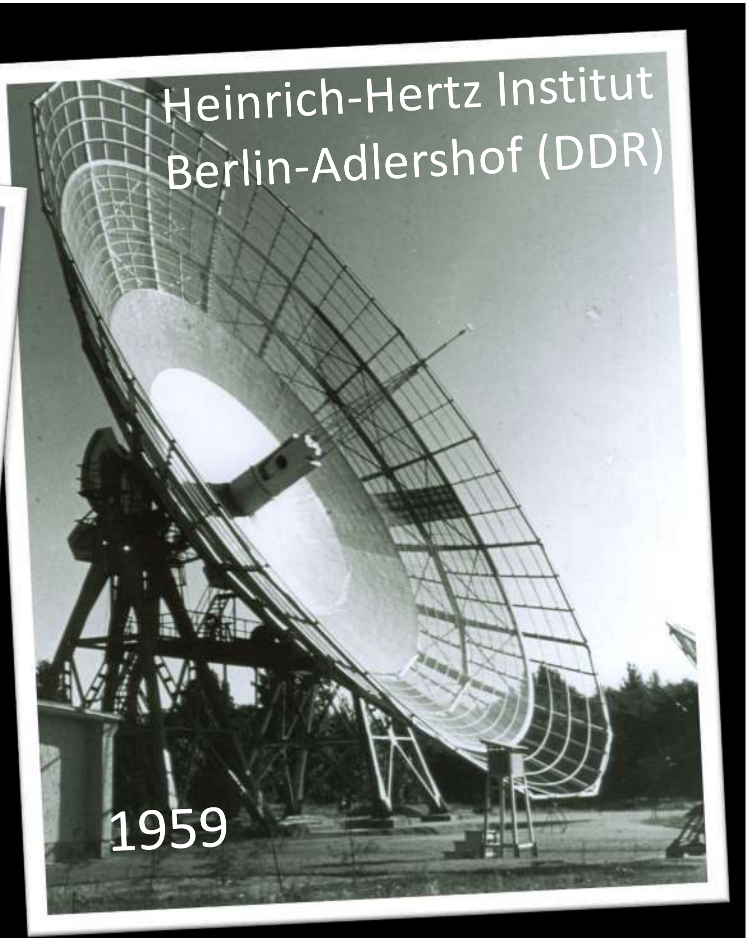
Parkes (1961)

What happened in Germany?

Meanwhile in Germany...


Universität Kiel 1953


Bonn University
Stockert (BRD)
1956

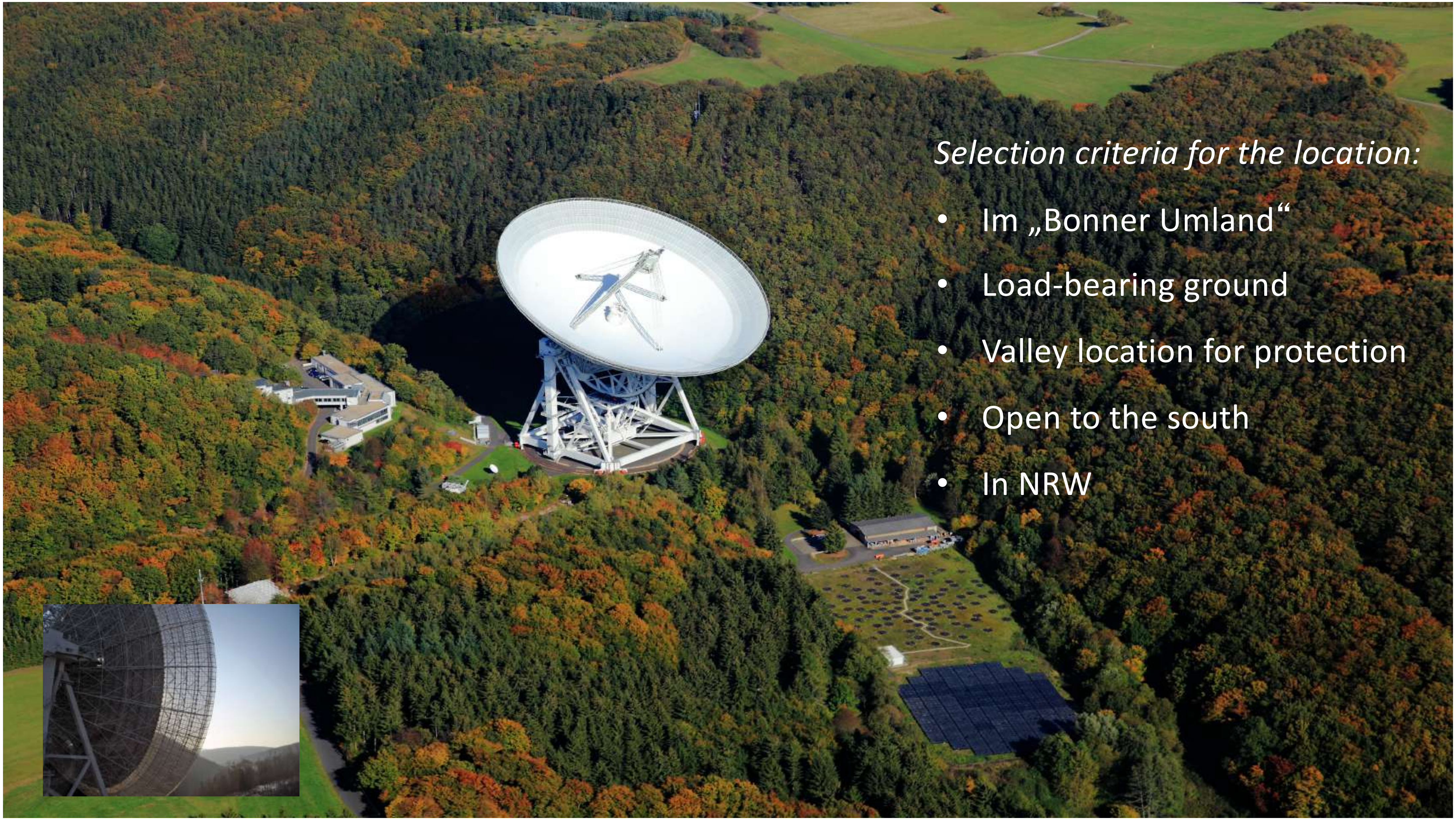

Heinrich-Hertz Institut
Berlin-Adlershof (DDR)
1959

In 1962, the “Denkschrift" recommended the construction of a large radio astronomical facility

Two competing projects:

a) A lightweight 160-m dish for low radio frequencies (Dr. Sebastian von Hoerner)
b) An 80 to 90 m dish for high radio frequencies (Prof. Dr. Otto Hachenberg)

Both with applications to the Volkswagen Foundation.
selection falls on b) and allows the construction of a larger instrument.
The state of North Rhine-Westphalia is supporting the construction.



Selection criteria for the location:

- Im „Bonner Umland“
- Load-bearing ground
- Valley location for protection
- Open to the south
- In NRW

near Germany

near Germany

near North Rhine-Westphalia —…

1 of 1

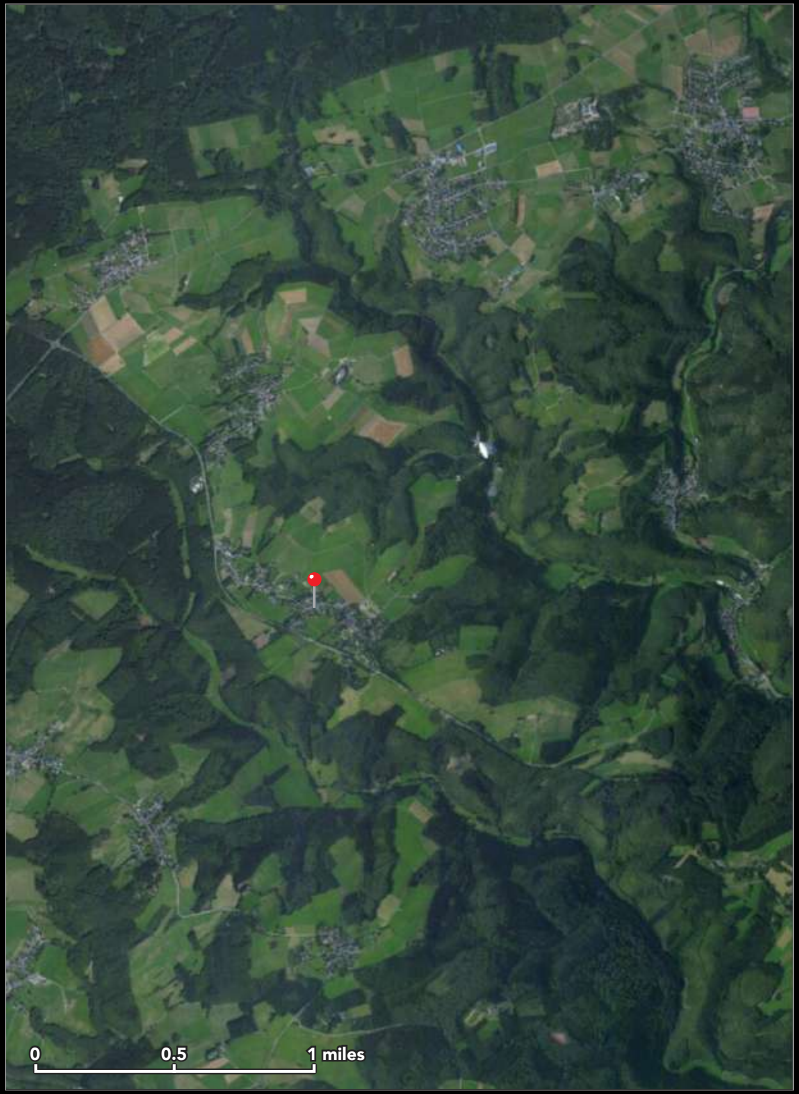
near Germany

1 of 2

near North Rhine-Westphalia — …

1 of 1

near Mutscheid — Euskirchen



1 of 1

near Mutscheid — Euskirchen

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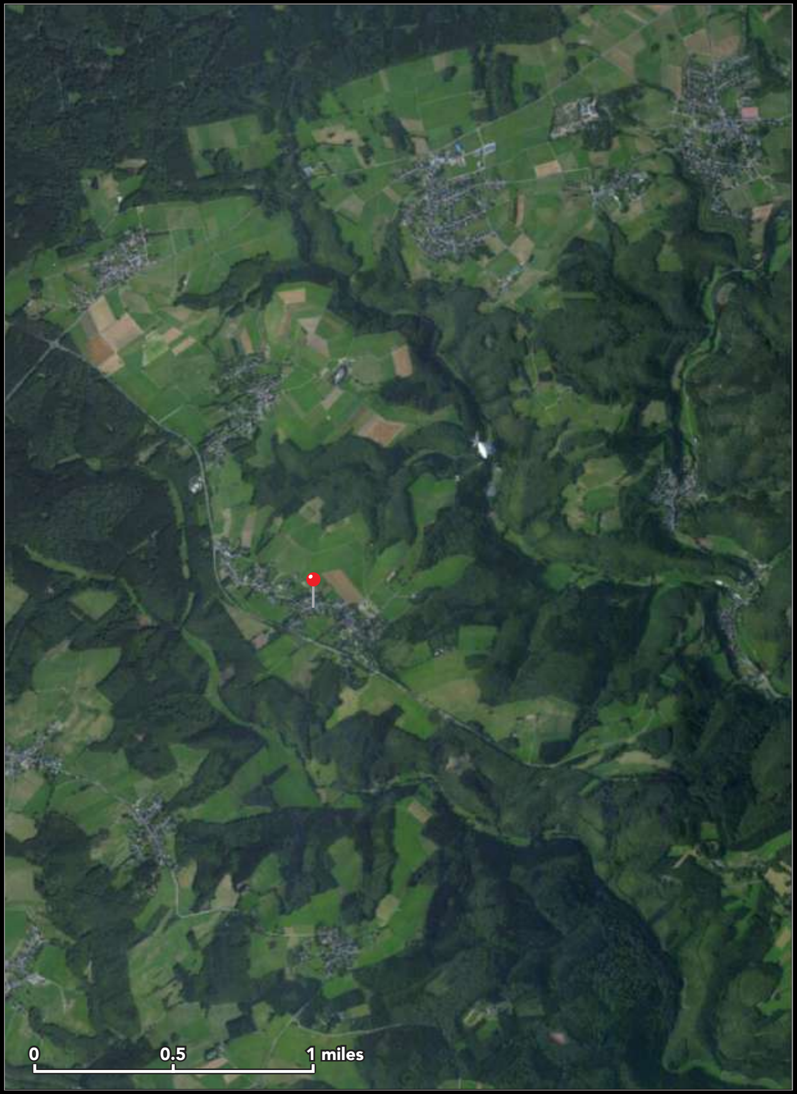
near Mutscheid — Euskirchen



1 of 1

The dish should be larger than anything else before

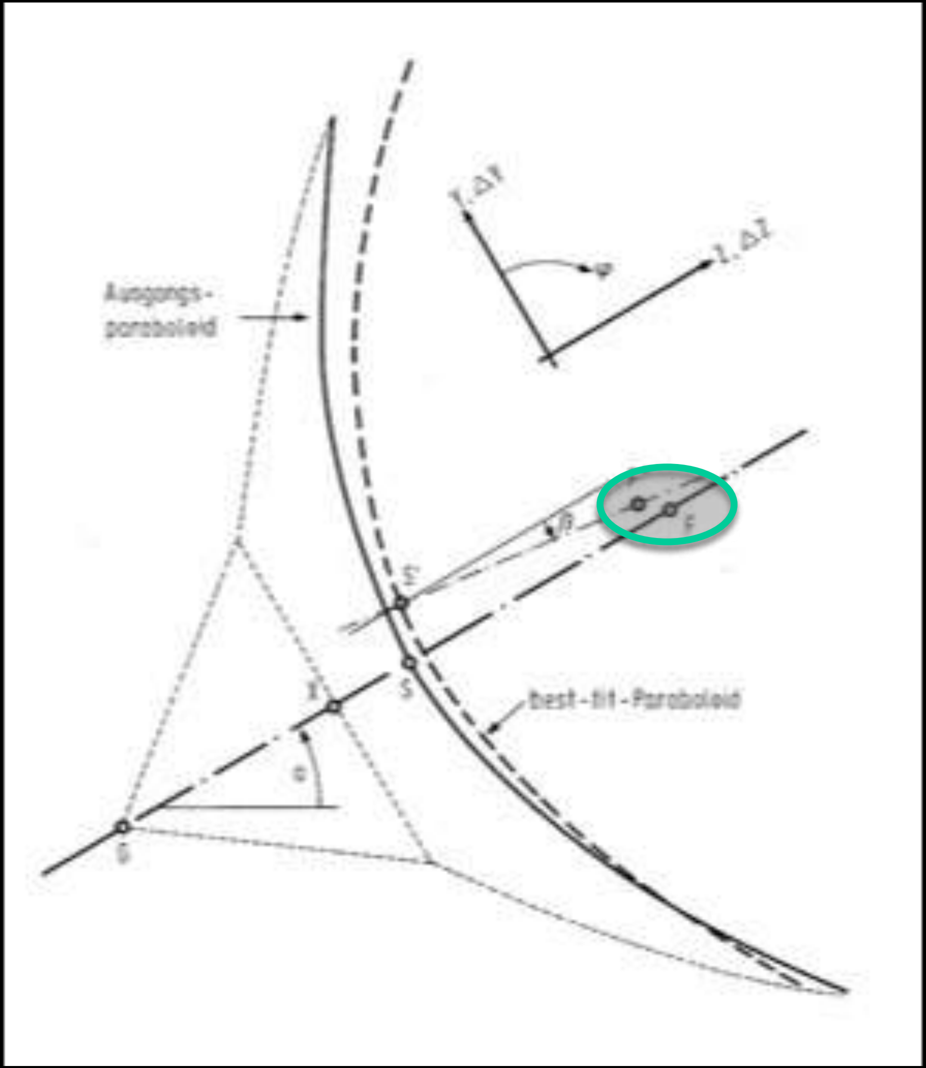
Problem: The primary mirror deforms when tilted by the influence of gravity.

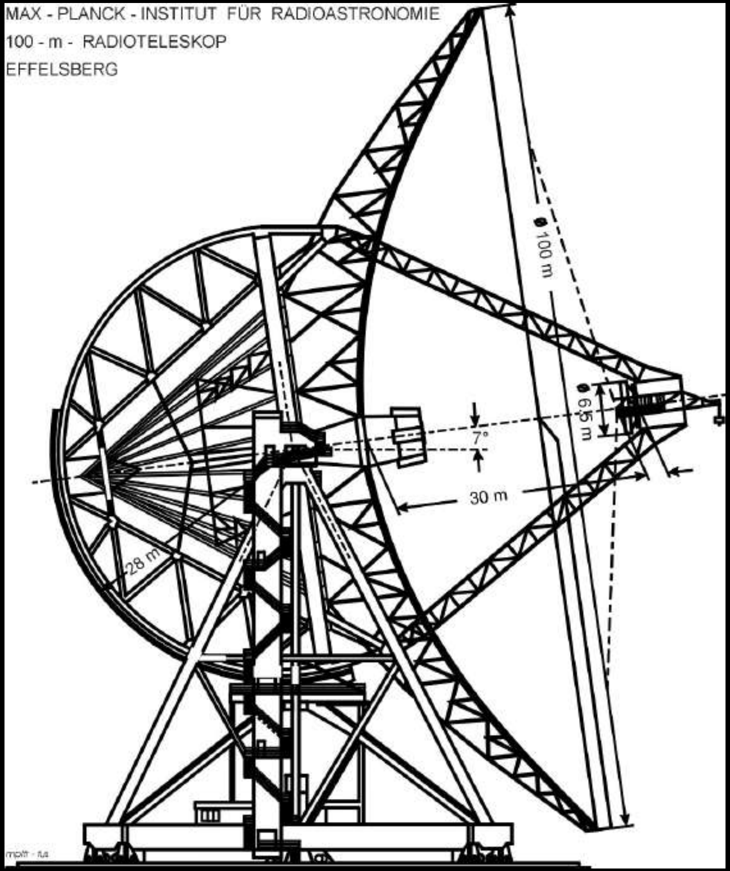
The mirror loses its defined parabolic shape and the sensitivity of the telescope decreases sharply.

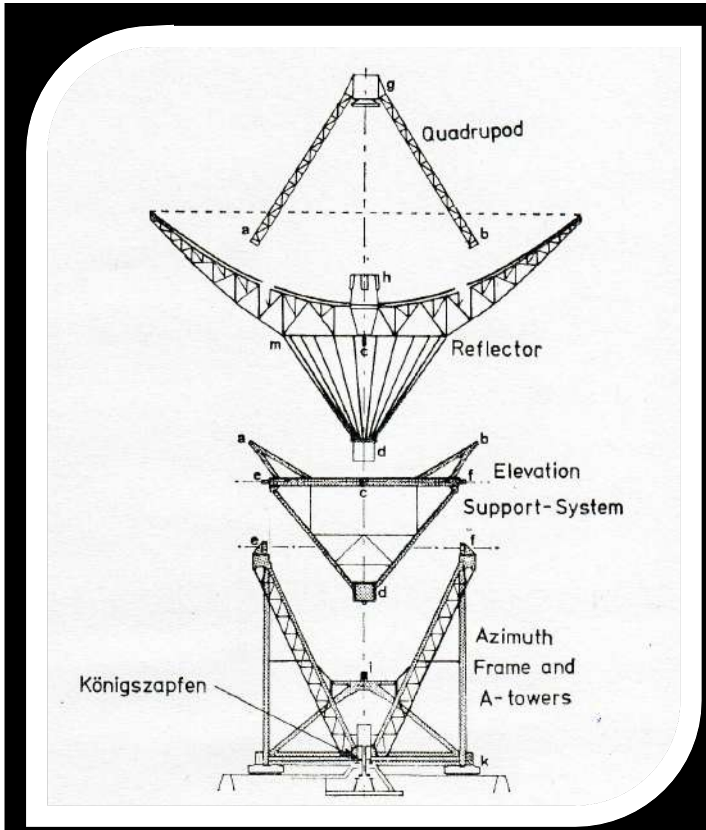
Principle of “homology” – Let it be move!

Sebastian von Hörner

Otto Hachenberg







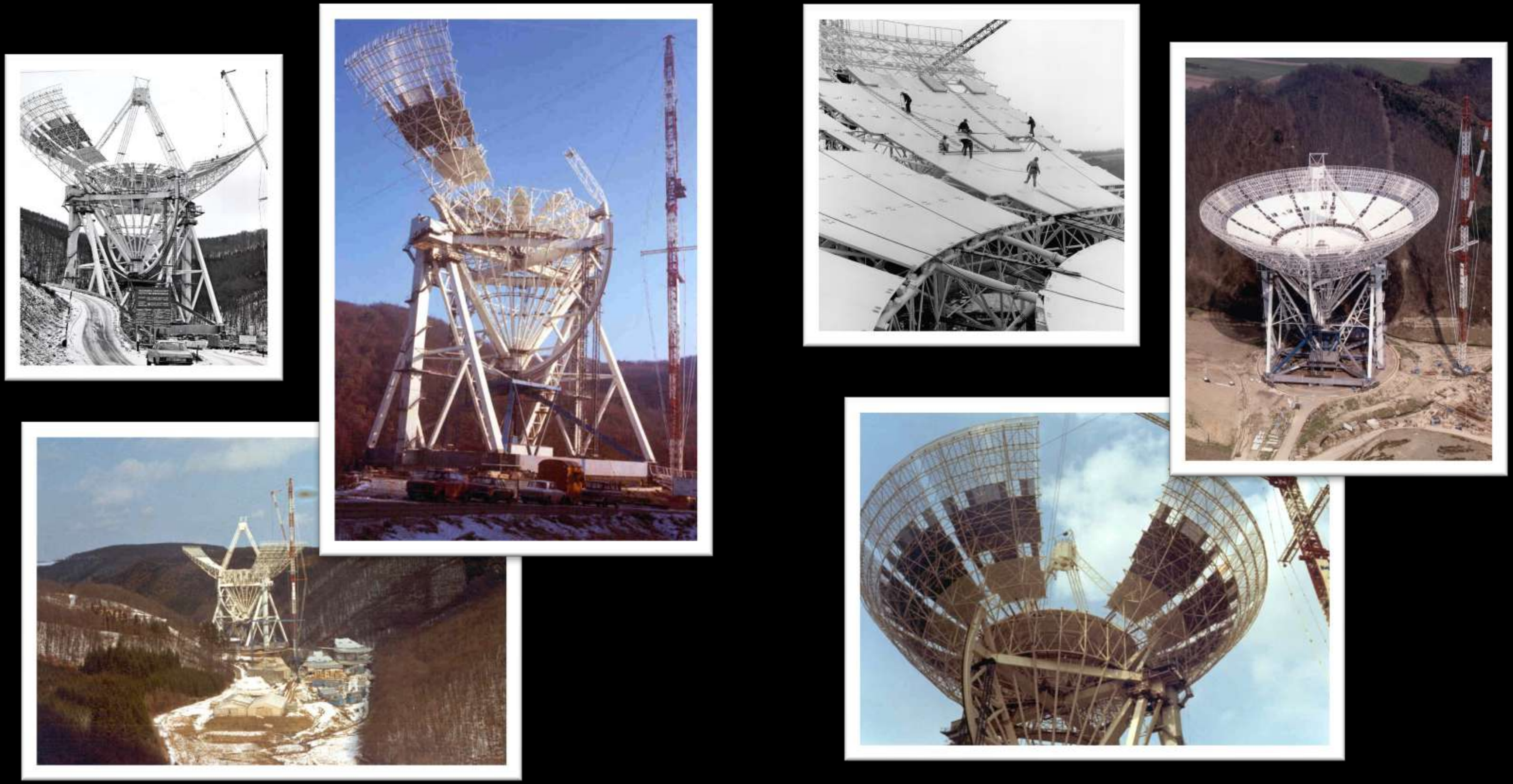
Ingenious solution: the special design of the telescope introduces a parabolic shape into the telescope when tilted.

When tilted, the focal point moves by approx. 10cm.

Antenna design by Krupp
A patent to Ing. H. Altmann
in 1965 construction by MAN

First plans for a large radio telescope:	1963
Foundation of the MPIfR	1 Sep. 1966
Start of earthworks in the Effelsberg Valley:	spring 1968
Start of telescope construction:	autumn 1968
First light:	spring 1971

Images by H. Kärcher (MT Mechatronics) & MPIfR



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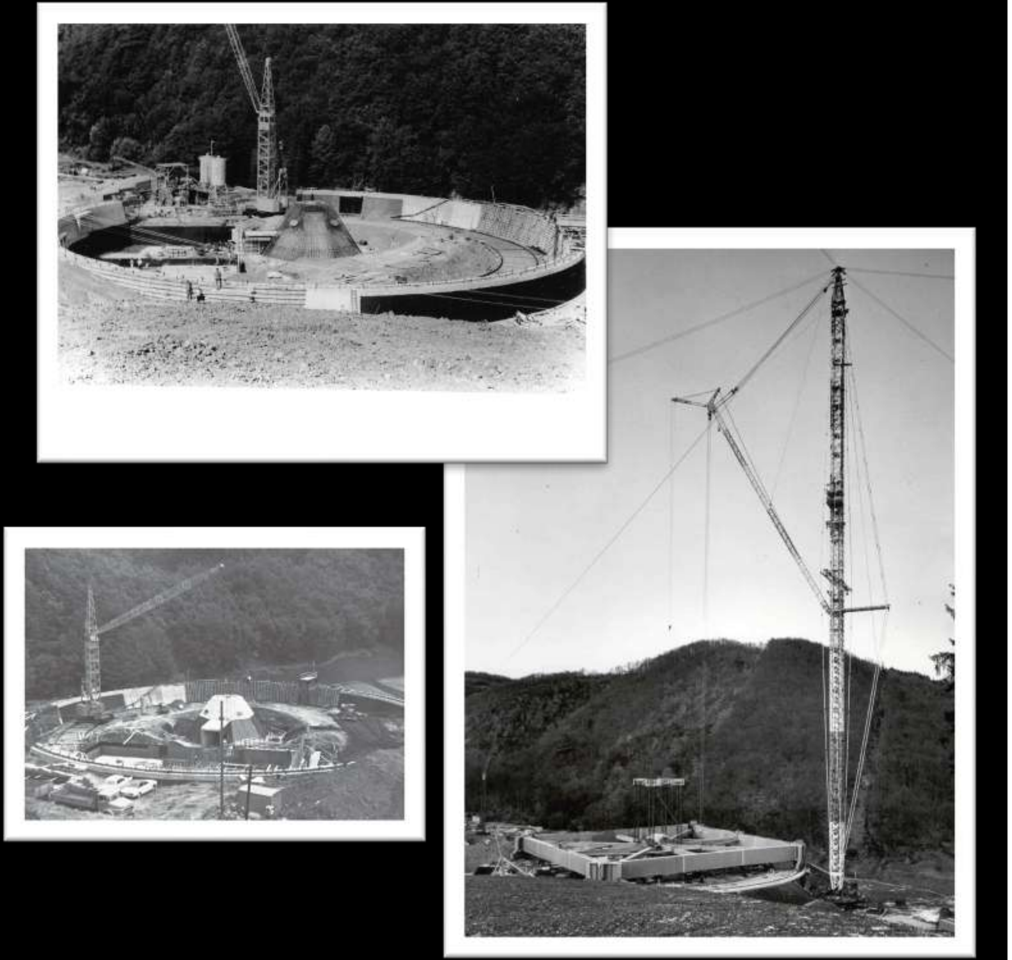

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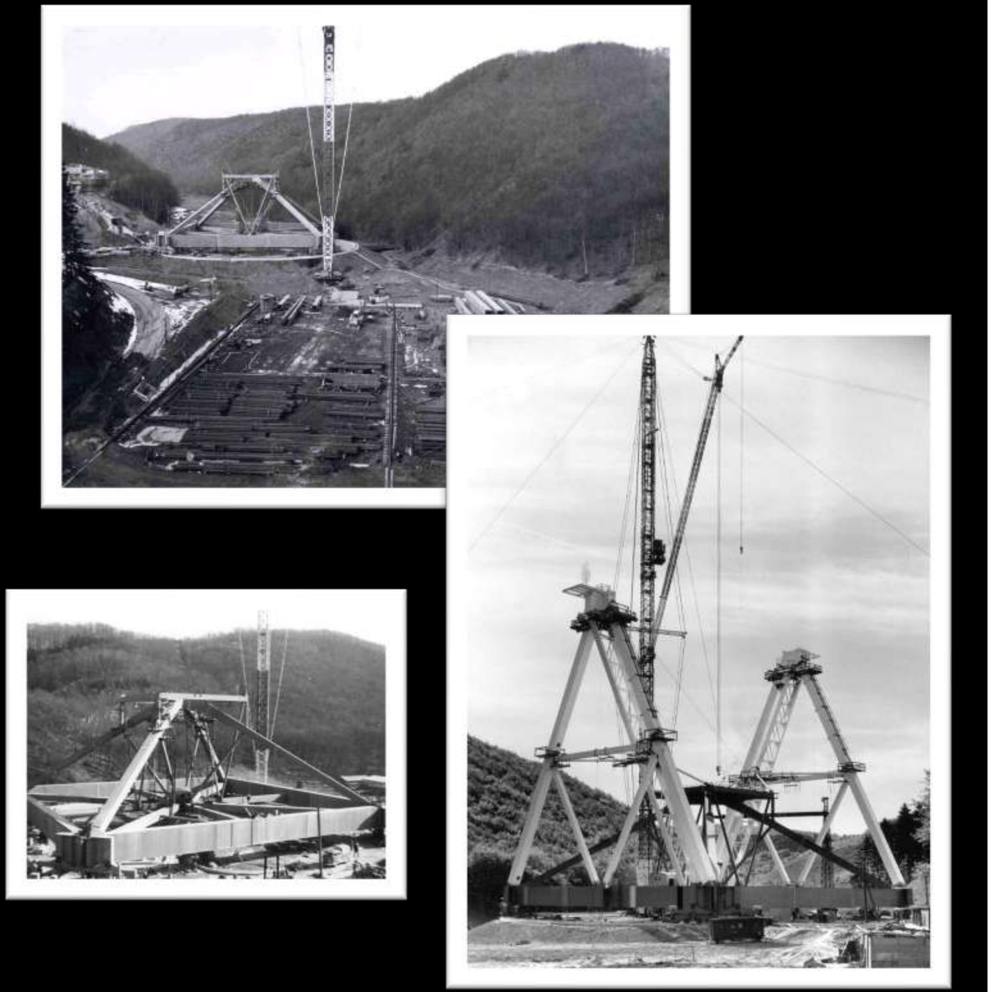

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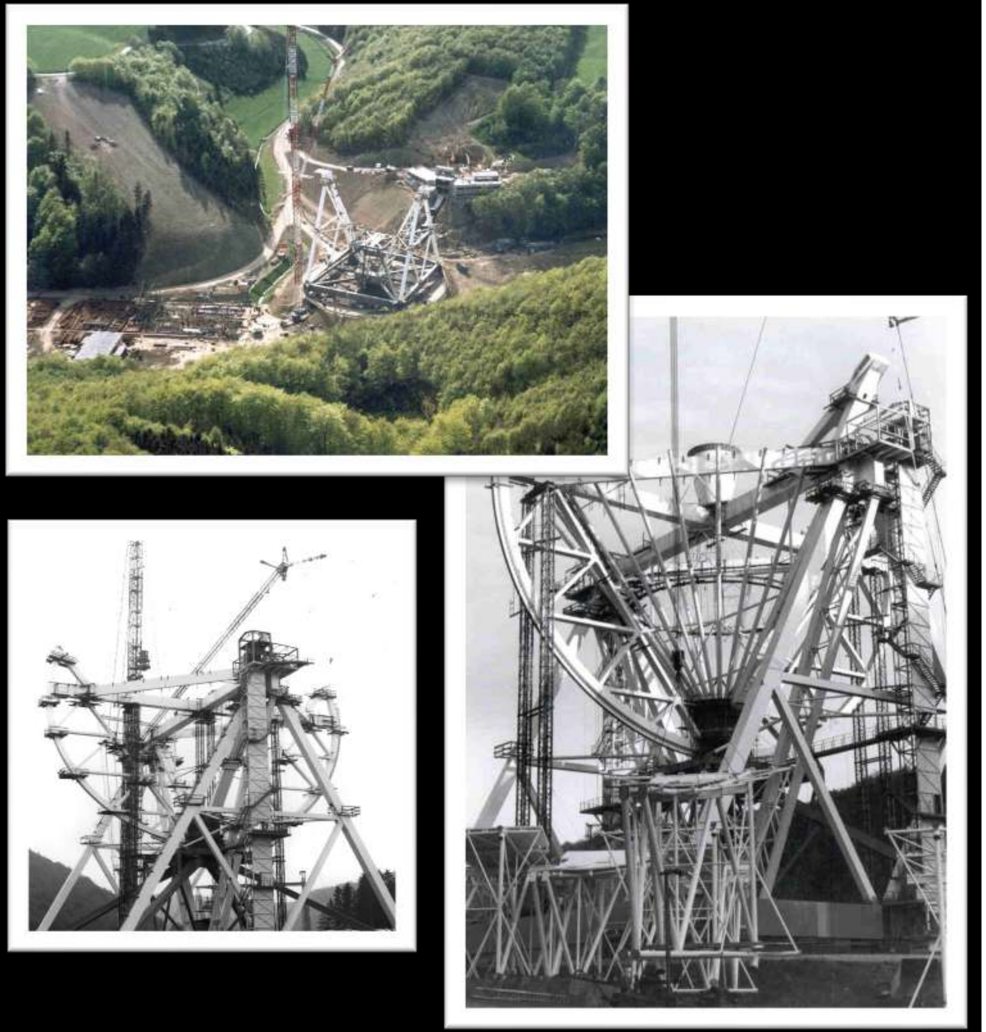

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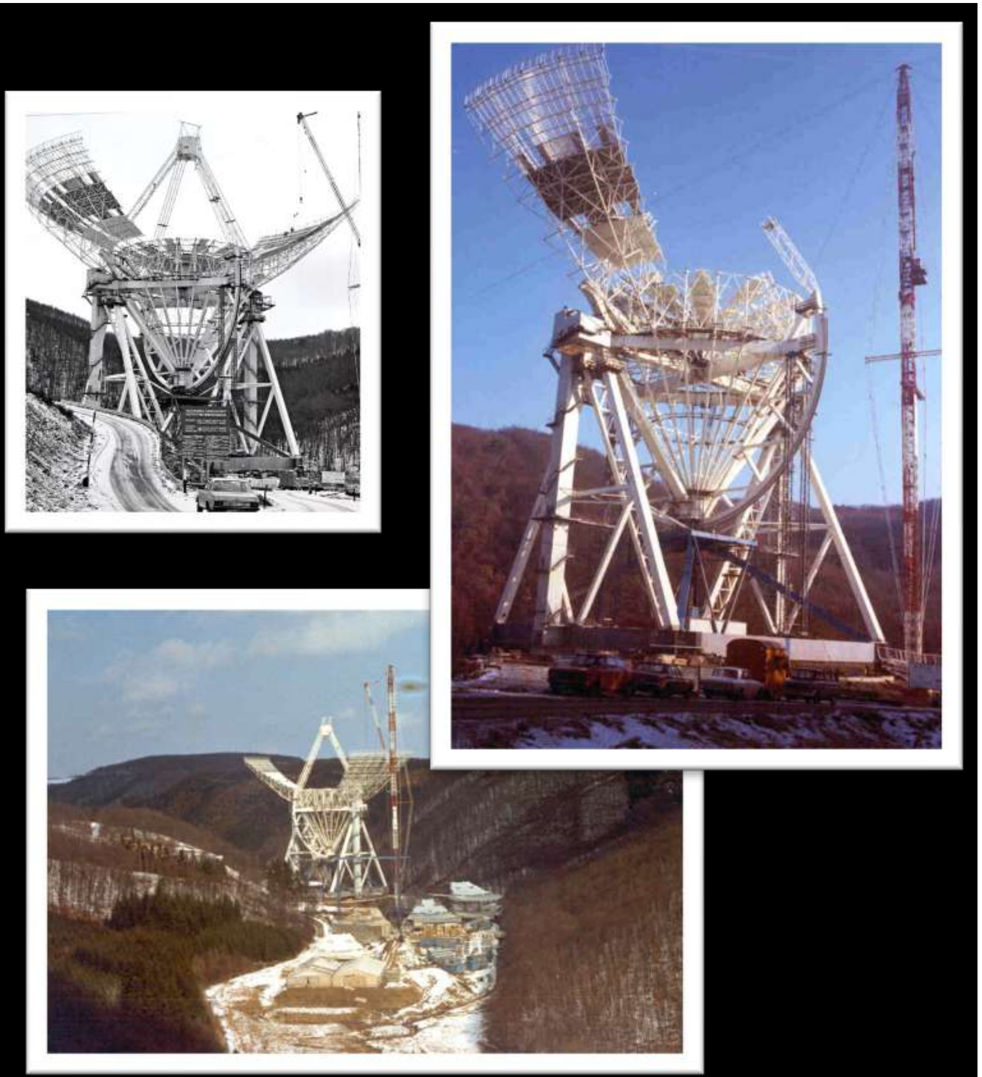

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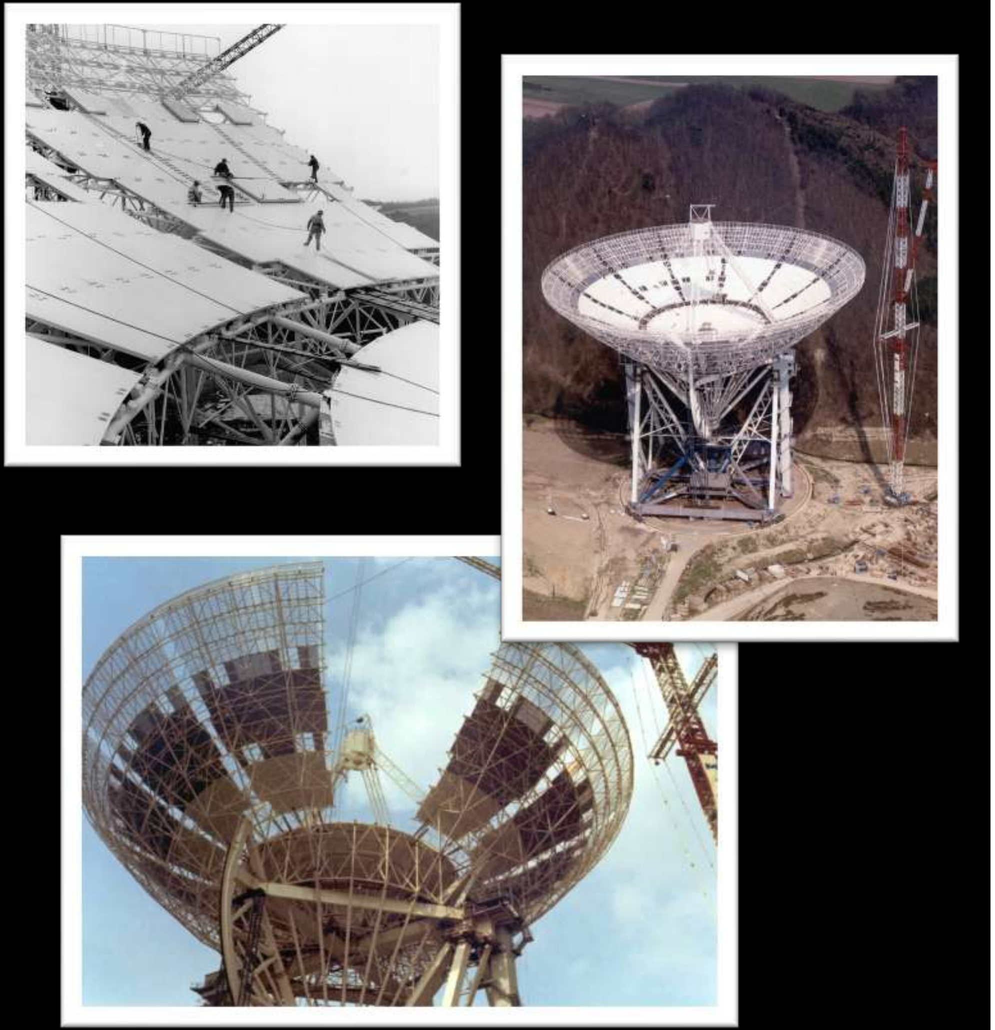


Images by H. Kärcher (MT Mechatronics) & MPIfR

Specifications

Diameter of primary mirror: (Paraboloid) 100 m

Secondary mirror diameter: (Ellipsoid) 6.5 m

Weight: 3200 t

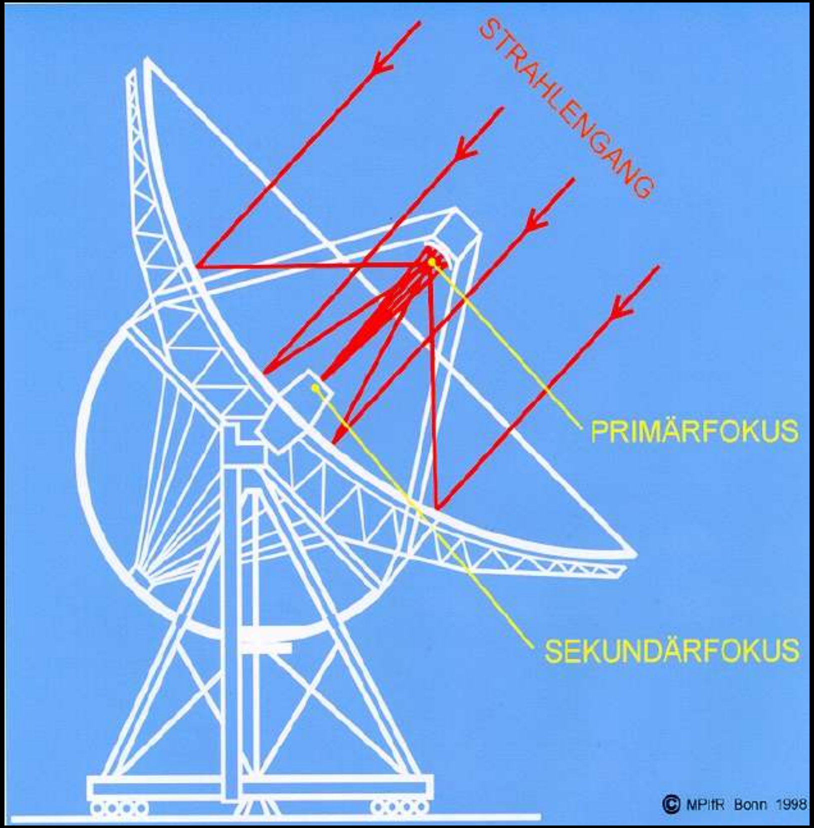
Diameter track: 64 m
Accuracy of track: approx. 0.3 mm

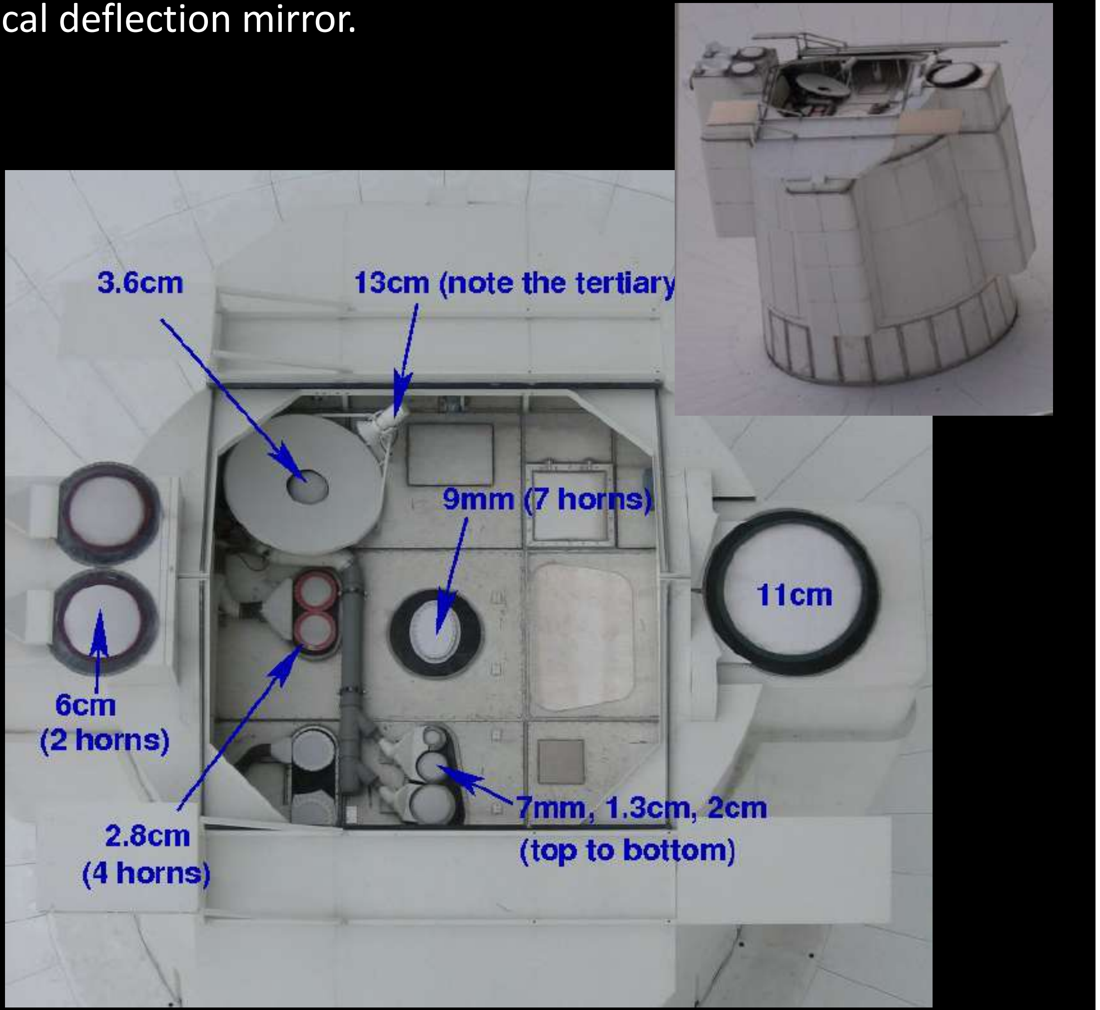
Accuracy of the surface
of the primary mirror: approx. 0.5 mm
of the deflection mirror: approx. 0.06 mm

Positioning accuracy of the telescope: 2 arc seconds ≅ 0.3mm

Optics des 100-Meter Telescope

"Gregorian Design": Parabolic primary mirror and elliptical deflection mirror.
EB: 21 receiving systems, wavelengths: 1m ... 3.5mm





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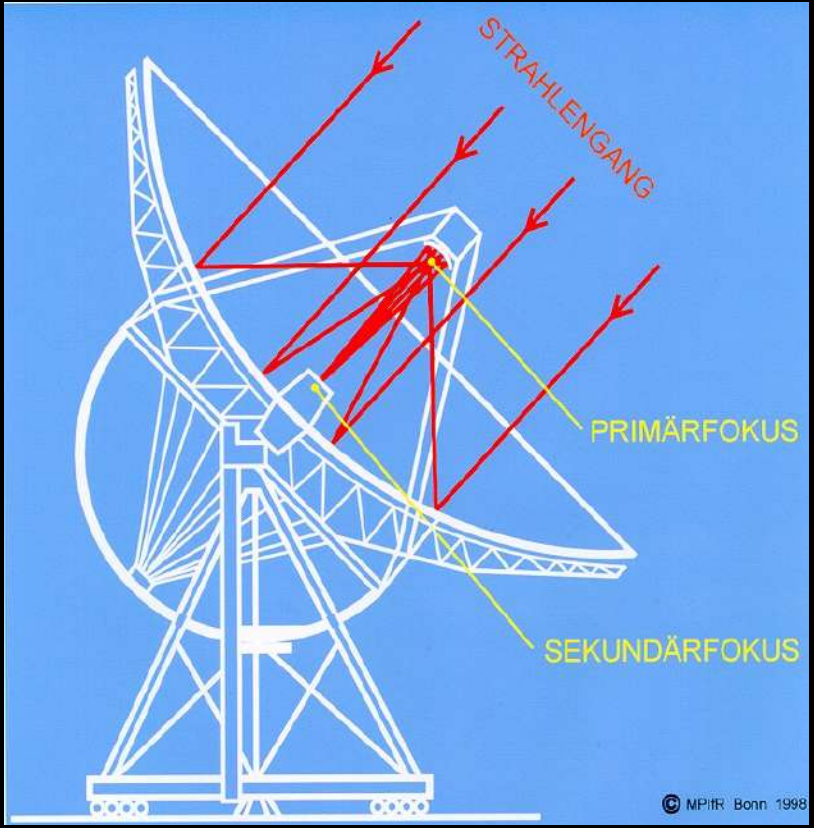
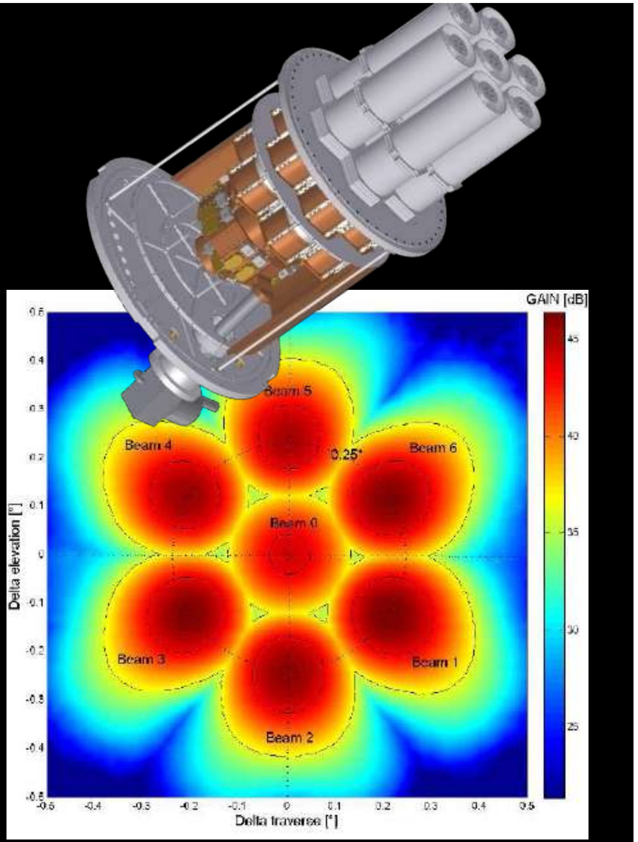




All receivers cooled to approx. 5K!

1 Jy = 0.00000000000000000000000001 W m^{-2} Hz^{-1}

A large sail

The radio telescope Effelsberg has a Surface of 9058 m2.

That's more than that four times the total sail area of the Gorch fork, the sailing school ship of the Navy.

The Gorch Fock has a total of a total of one sailing area of 2037 m^2 .

Malerarbeiten

The picture from 2007 shows painting work in the large "bowl".

The surface of the telescope covers about 9000 square meters, it is made up of 2352 individual panels.

The complete painting of the mirror surface requires quite a bit of effort!

Painting work in the backing structure

Bilder: MPIfR/N. Junkes, 30.07.13

The pictures show painters' work on the radio telescope Effelsberg in lofty height.

In 2013, the s upport structure of the telescope' turn; the Crane boom moves up to to a height of 80 m.

A complete cycle of the painting work over 15 years!

“Königszapfenraum”

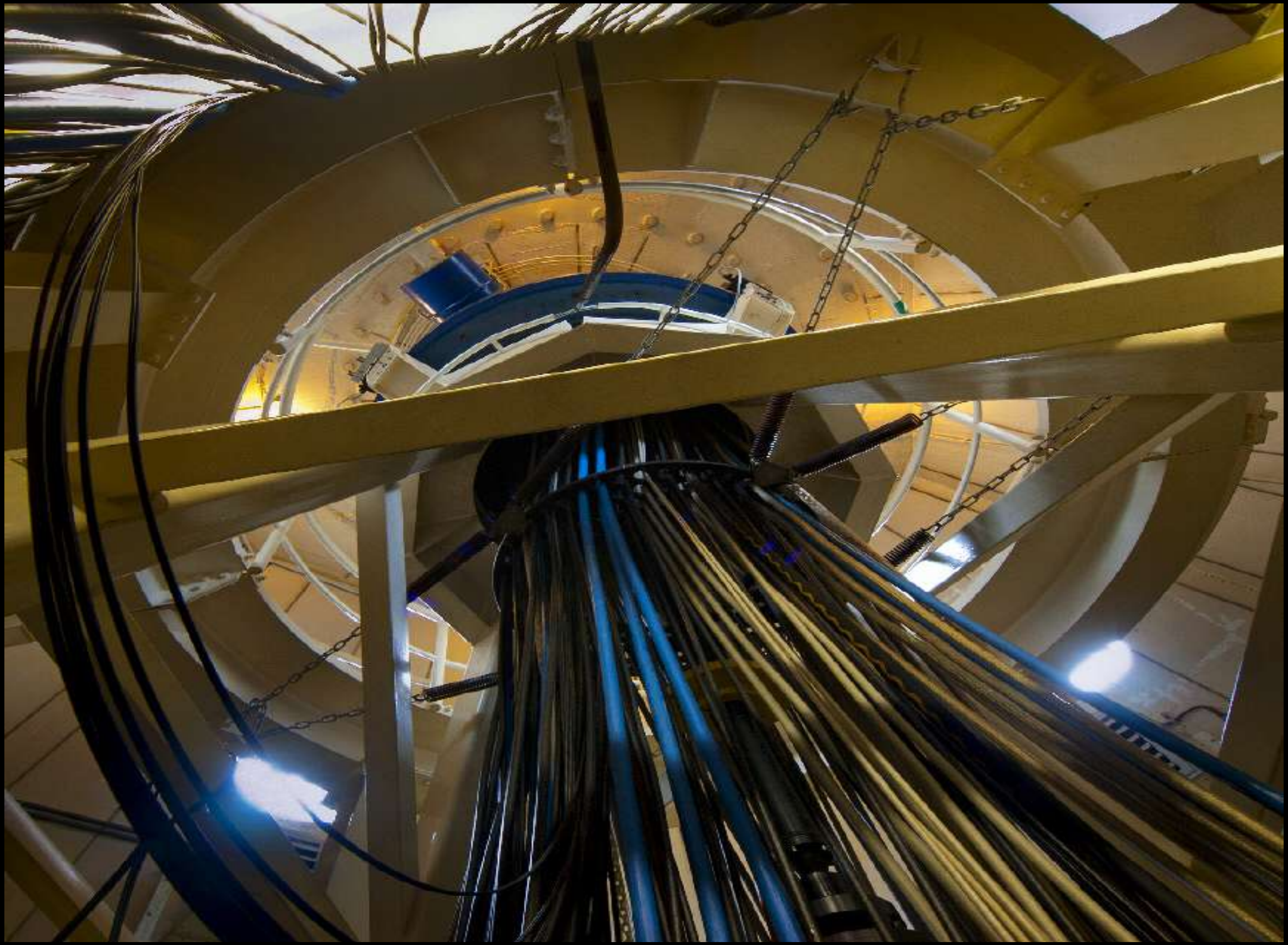
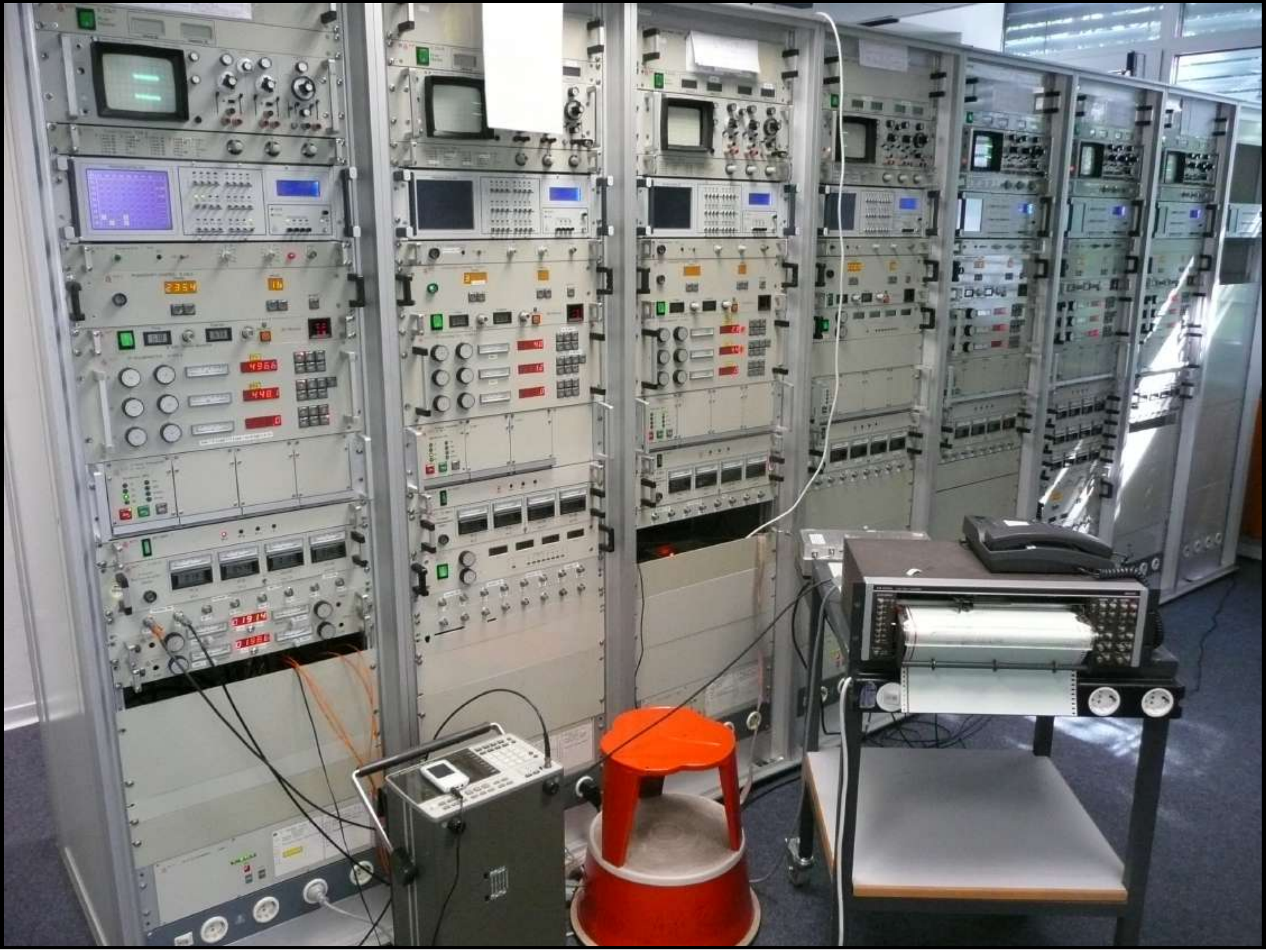


Bild: Norbert Tacken/MPIfR

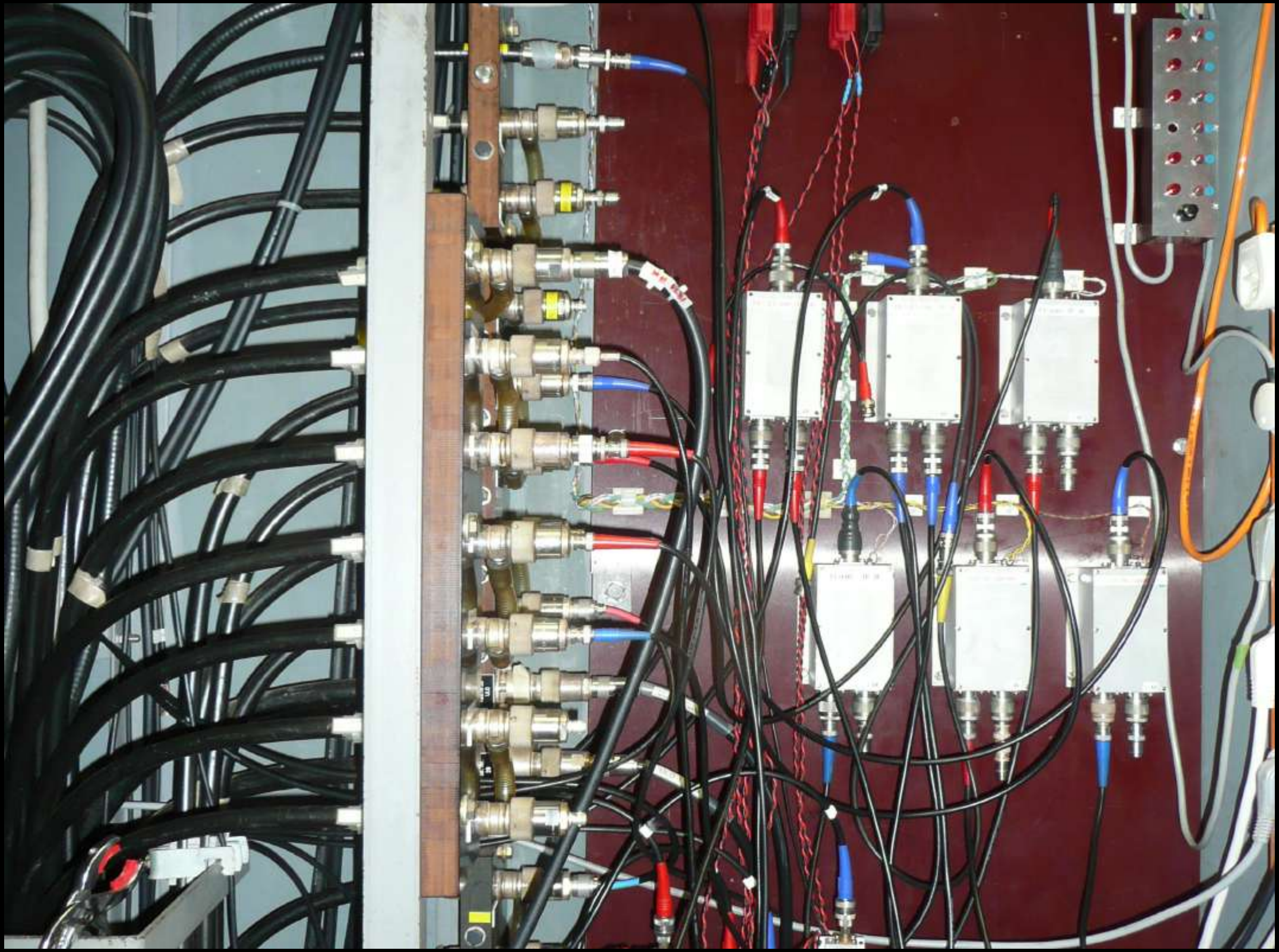
Exactly under the
central point of the
100 m radio telescope
the recipients
cable from the rotary area
into the stationary part.

There are 140 in total
Cables that connect with
– turning up to 480 degrees.

Receiver control room (previously)



Cable distribution (previously)



The Command Center

1974

From here, the
Observations with the
100 m radio telescope
controlled.

To the (nocturnal)
Crew at the telescope belong
astronomers and astronomers
Operators.

The picture shows the tax
Console and the big
Window with direct
View of the
100-m radio telescope.

The Command Center

Bild: Norbert Tacken

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Topics & Results

https://www.mpifr-bonn.mpg.de/471056/discovery

Research topics

All areas of modern radio astronomy: from cosmology to comets!

Especially:

Polarized radiation of cosmic electrons and cosmic magnetic fields.

Observation of neutral hydrogen and the structure of the Milky Way nd the cosmos.

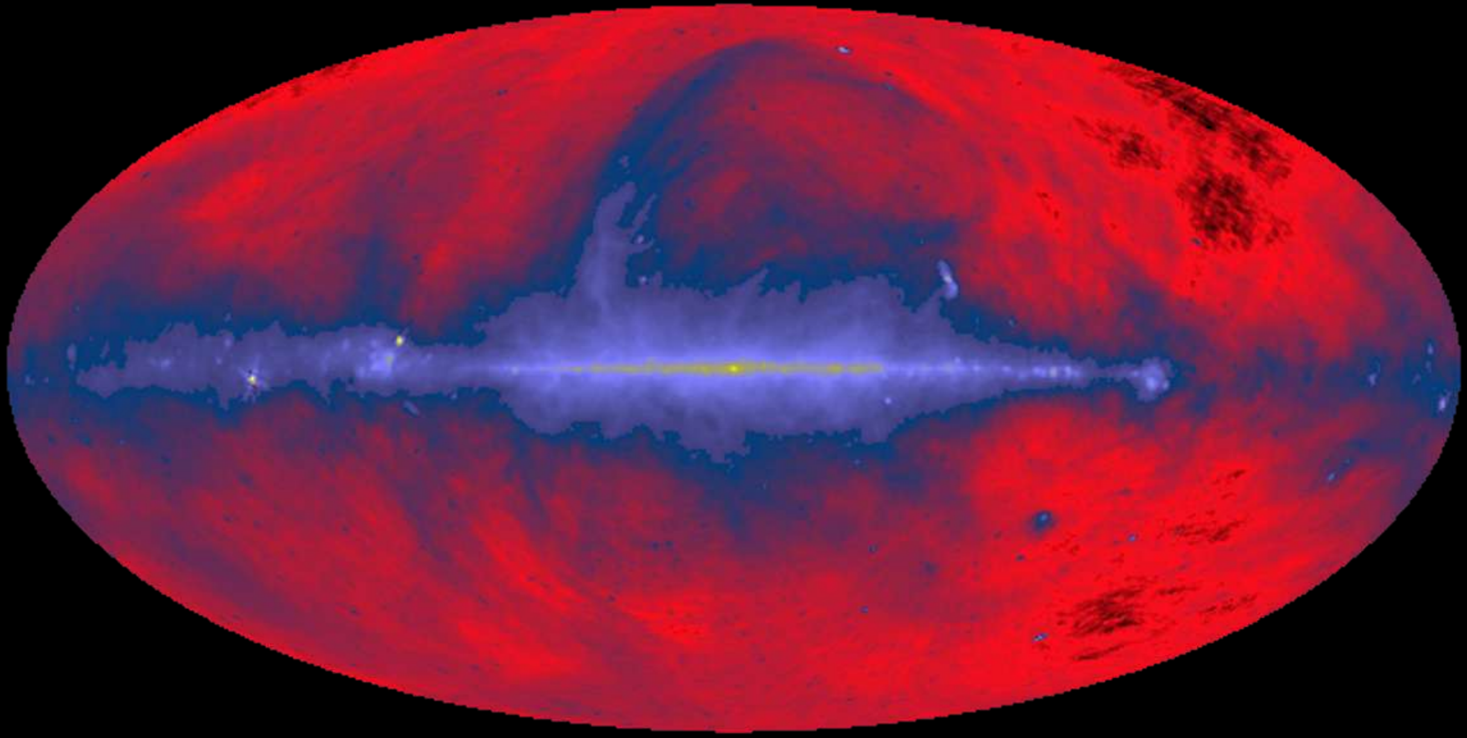
Astrochemistry and spectroscopy with investigations of molecules.

Super-massive black holes in active galactic nuclei.

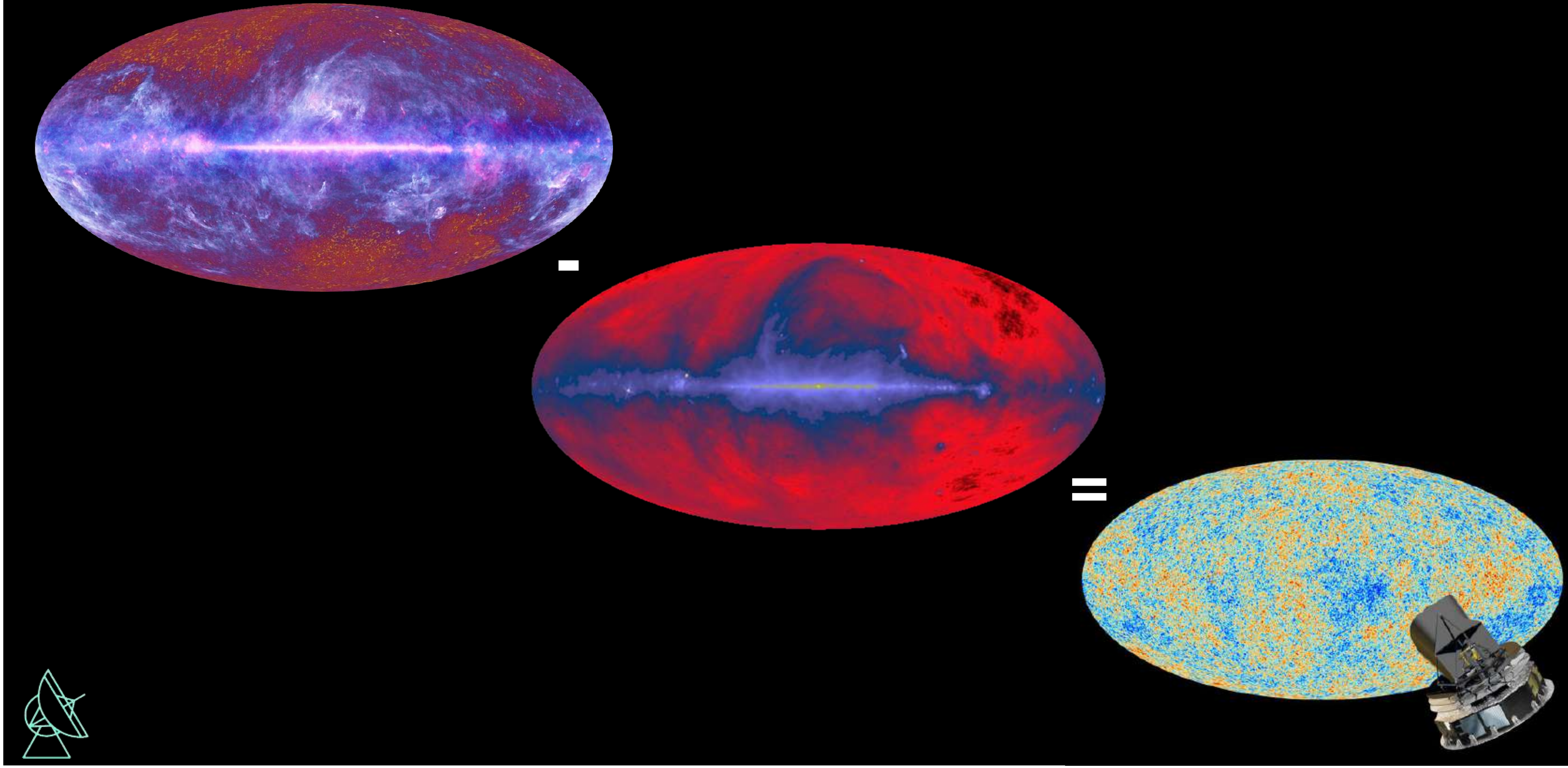
Gravitational physics, wave detection and tests of space. Theory of relativity

The radio sky

One of the most famous images in radio astronomy: 408-MHz survey by Haslam et al.

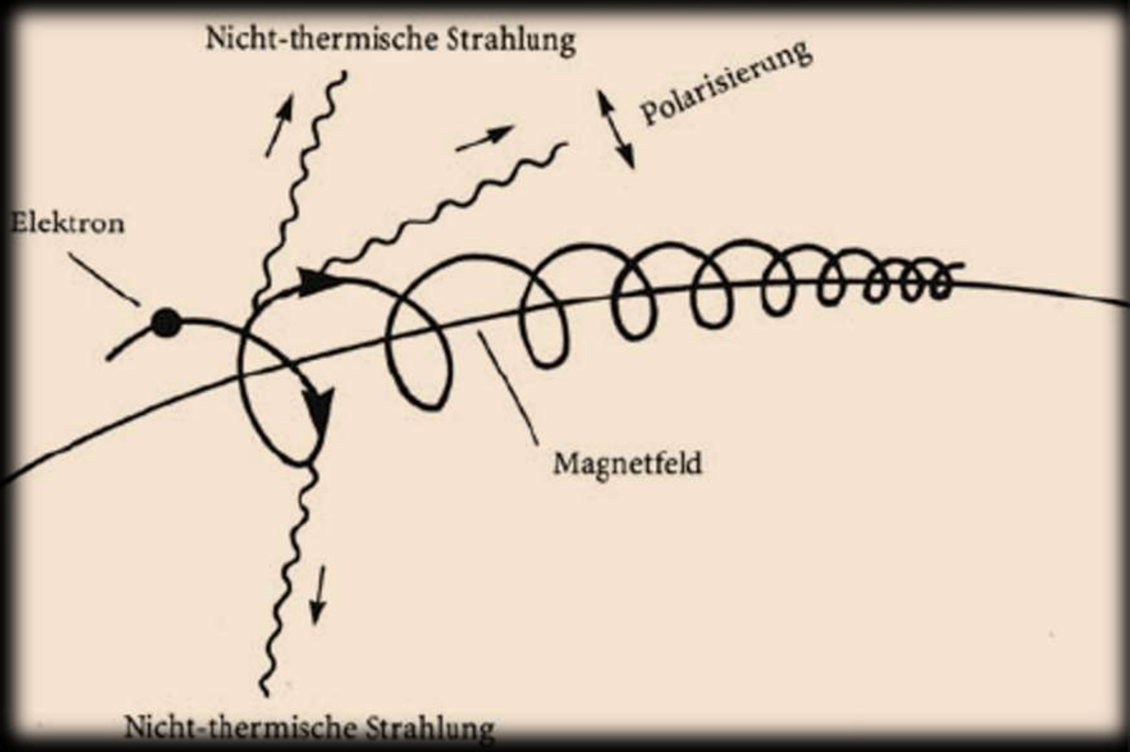


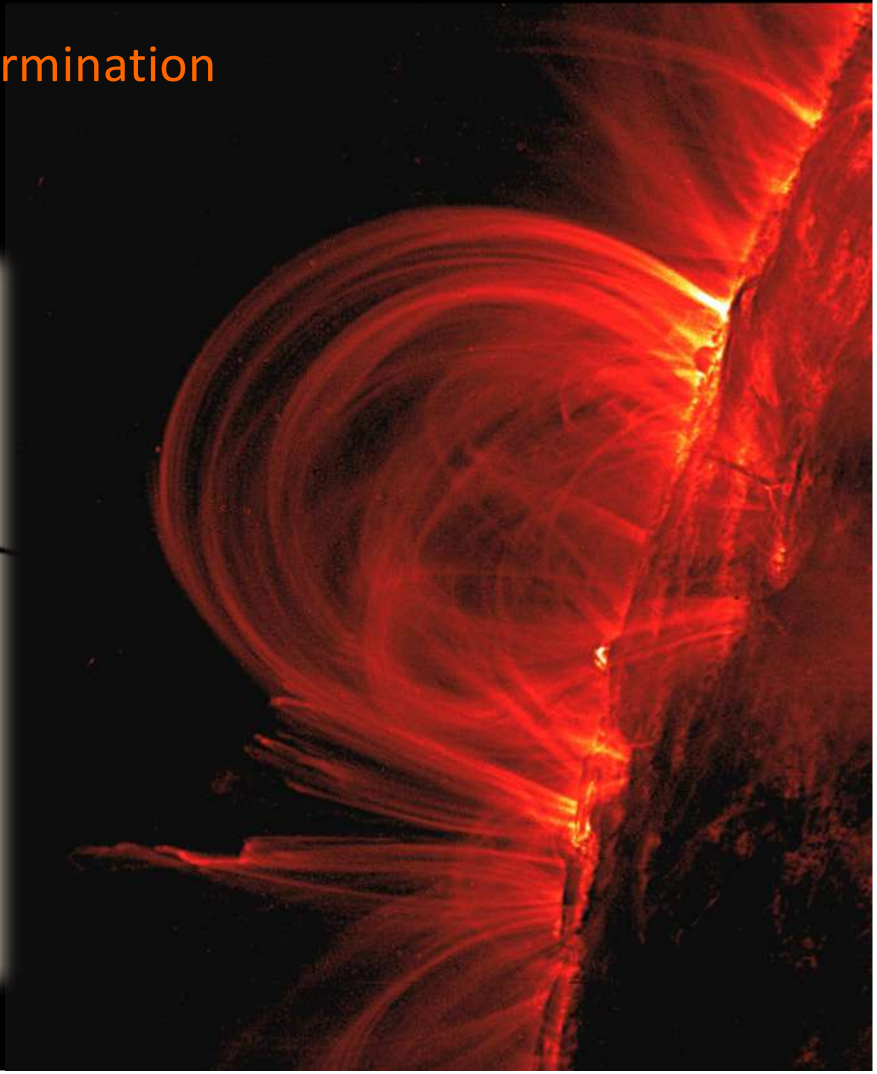
With Effelsberg to the CMB maps



Magnetfeldmessungen aus kosmischer Entfernung

The measurement of linear polarization allows the determination the strength and direction of the magnetic field.





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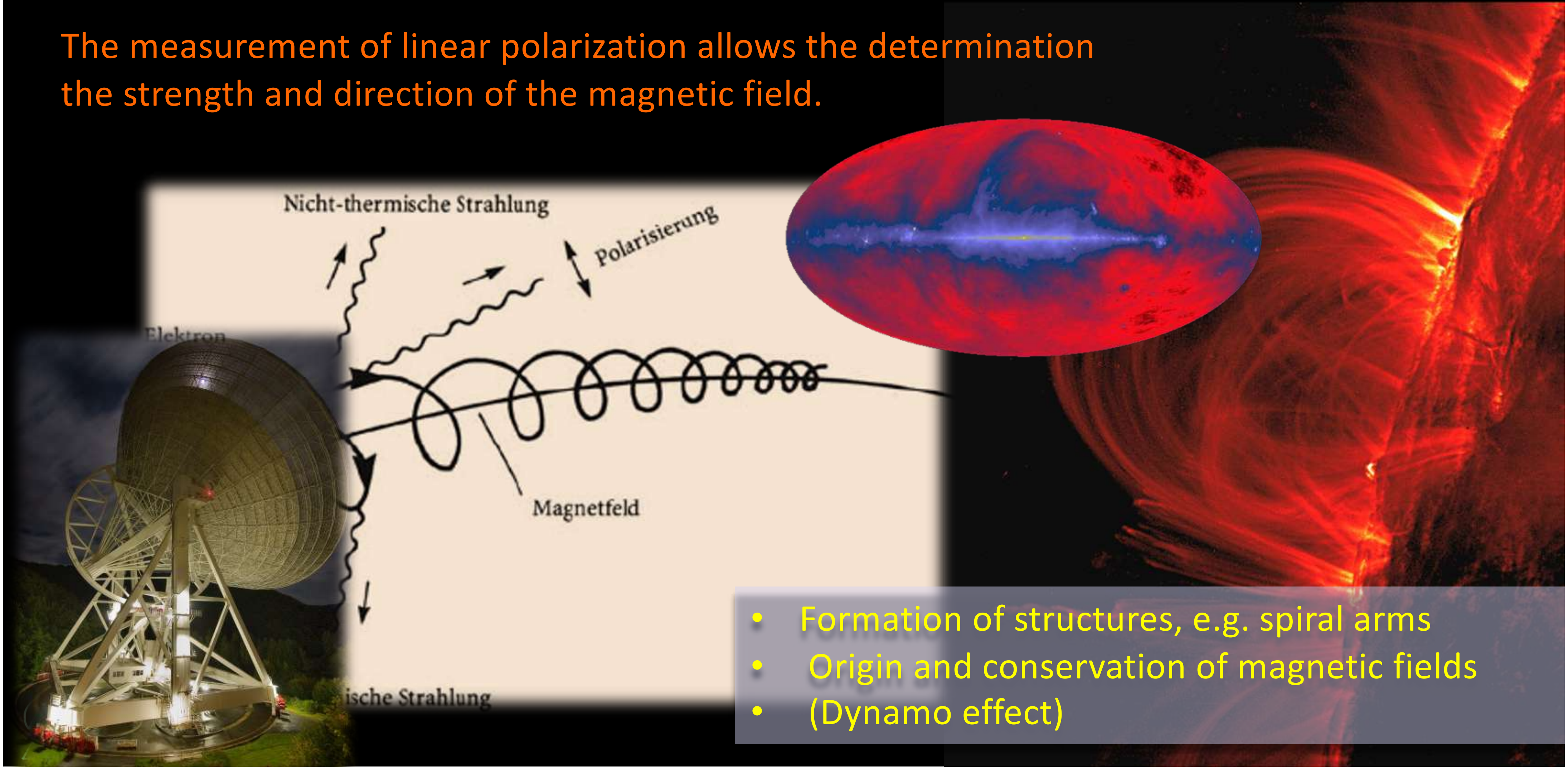
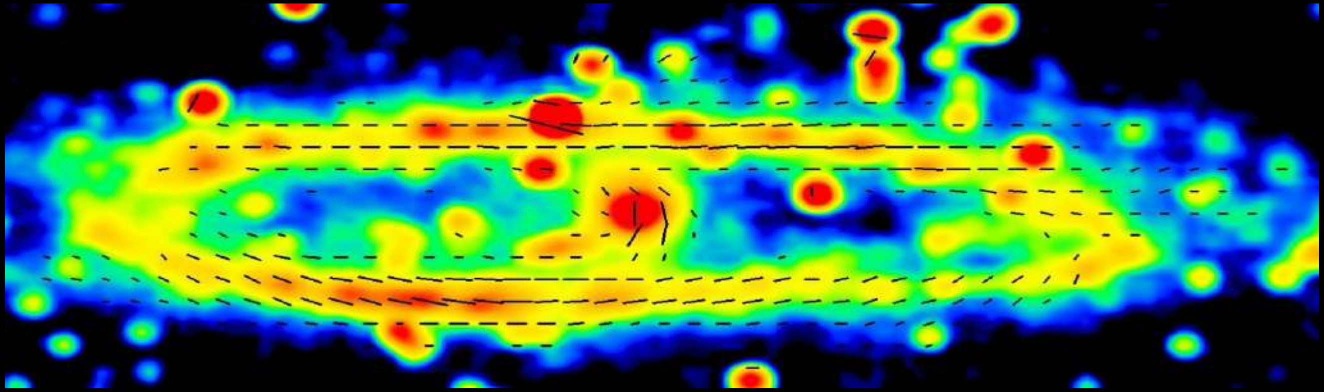


- Formation of structures, e.g. spiral arms
- Origin and conservation of magnetic fields
- (Dynamo effect)

Andromeda-Galaxy M31

a) Visible light

b) Radio emission



The Andromeda Galaxy, M31, is a twin of the Milky Way, the nearest large neighboring star system at a distance of 2.5 million light-years.

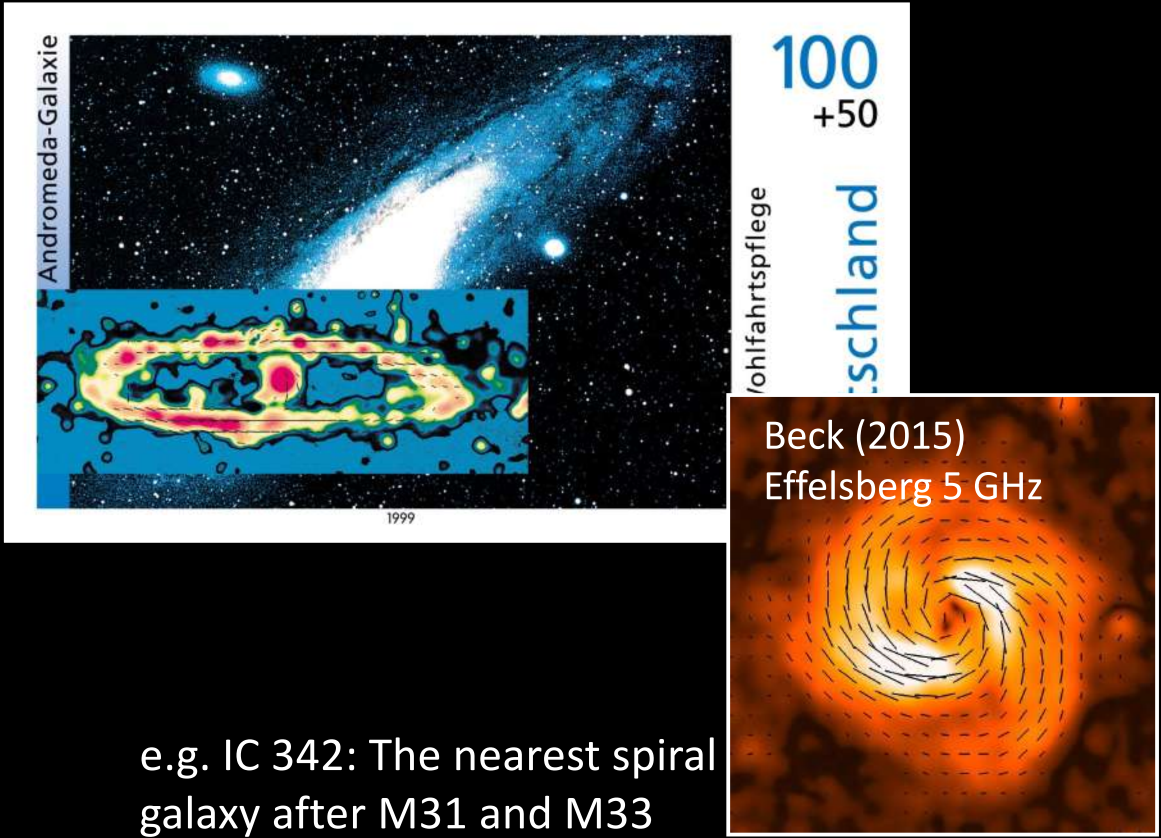
The two figures show optical light from the stars and radio waves of 6 cm wavelength.

Most stars form in the spiral arms in the outer part of this galaxy.

Images: Lick, MPIfR (Beck & Gießübel 2010)

Cosmic magnetic fields = Effelsberg

Polarisation observations established the existence of regular large-scale magnetic fields in galaxies beyond our own Milky Way.

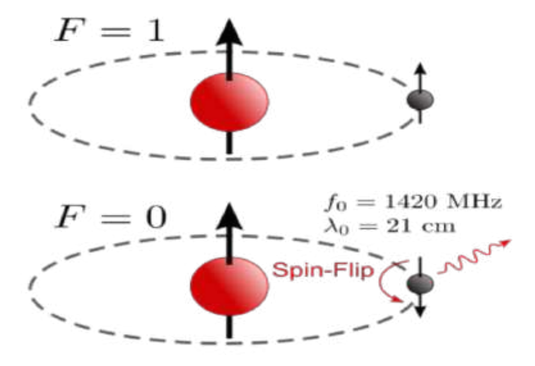


Beck (2015)
Effelsberg 5 GHz

e.g. IC 342: The nearest spiral galaxy after M31 and M33

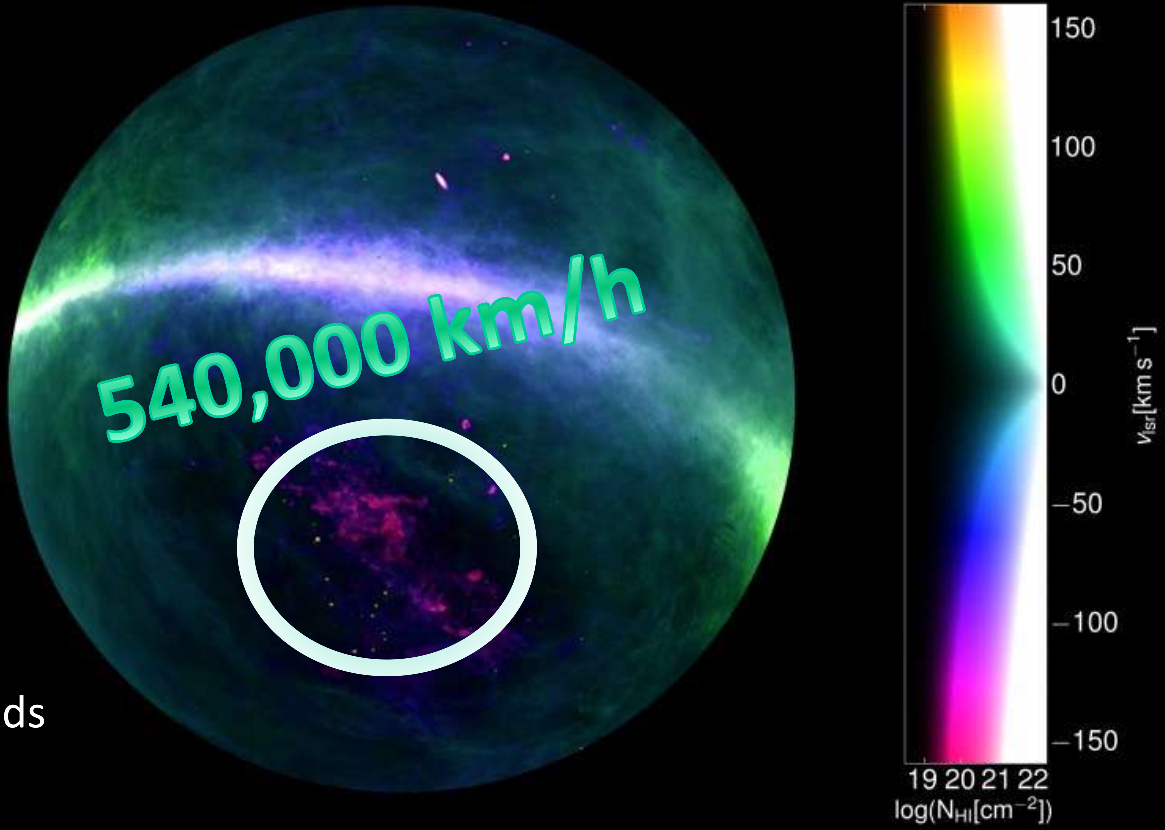
- As early as 1972, radio emission from M 31 at a wavelength of 11 was detected and at other frequencies since.
- The intensity is concentrated in a broad ring with magnetic field lines following it.
- Confirmation of the theory of the galactic dynamo, which creates galactic magnetic fields from gas motions, strong enough to support the formation of new stars and spiral arms.

The sky in the light of the HI line



Survey of the Nothern Sky
with Effelsberg

Establishment of high-verlocity clouds



540,000 km/h

Winkel, Kerp et al.

More complex molecules

Henkel et al. (2009)

Effelsberg discoveries, e.g.

Propargylimine (HC≡C–CH=NH)

Ethanolamine ($NH_2CH_2CH_2OH$)

Aminoacetonitrile (NH_2CH_2CN)

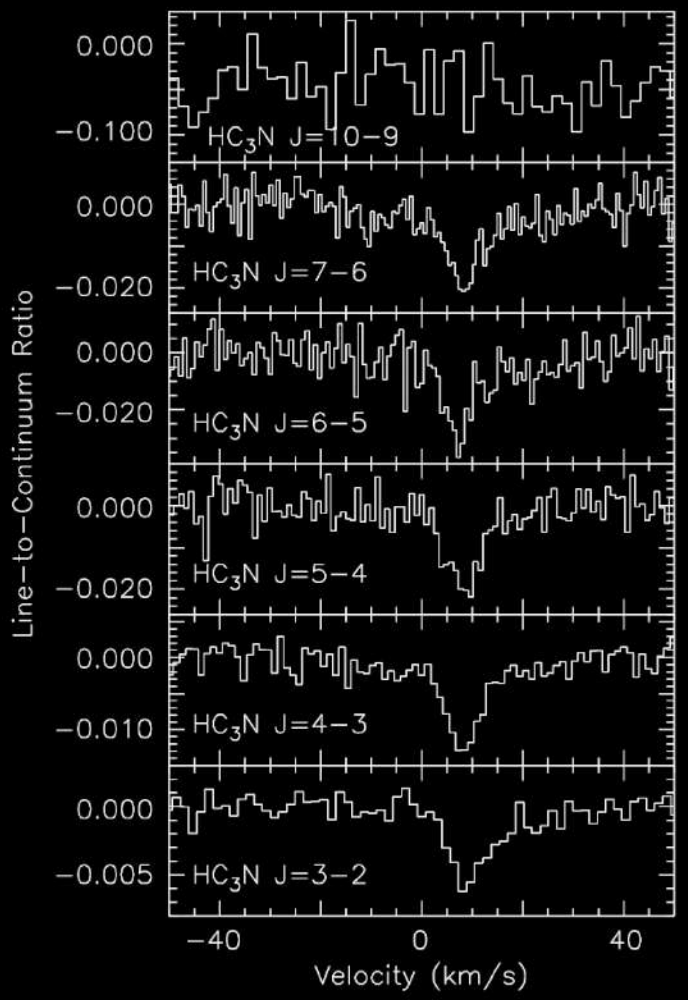
Cyanoallene (CH_2CCHCN)

Formic acid (CH_2O_2)

Methyldiacetylene (CH_3C_4H)

Acetone ($(CH_3)_2CO$)

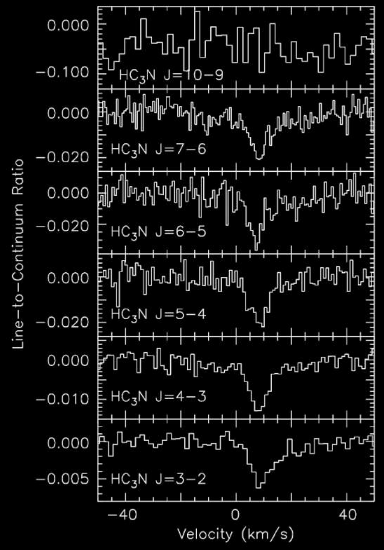
Ethyl cyanide (C_2H_5CN)

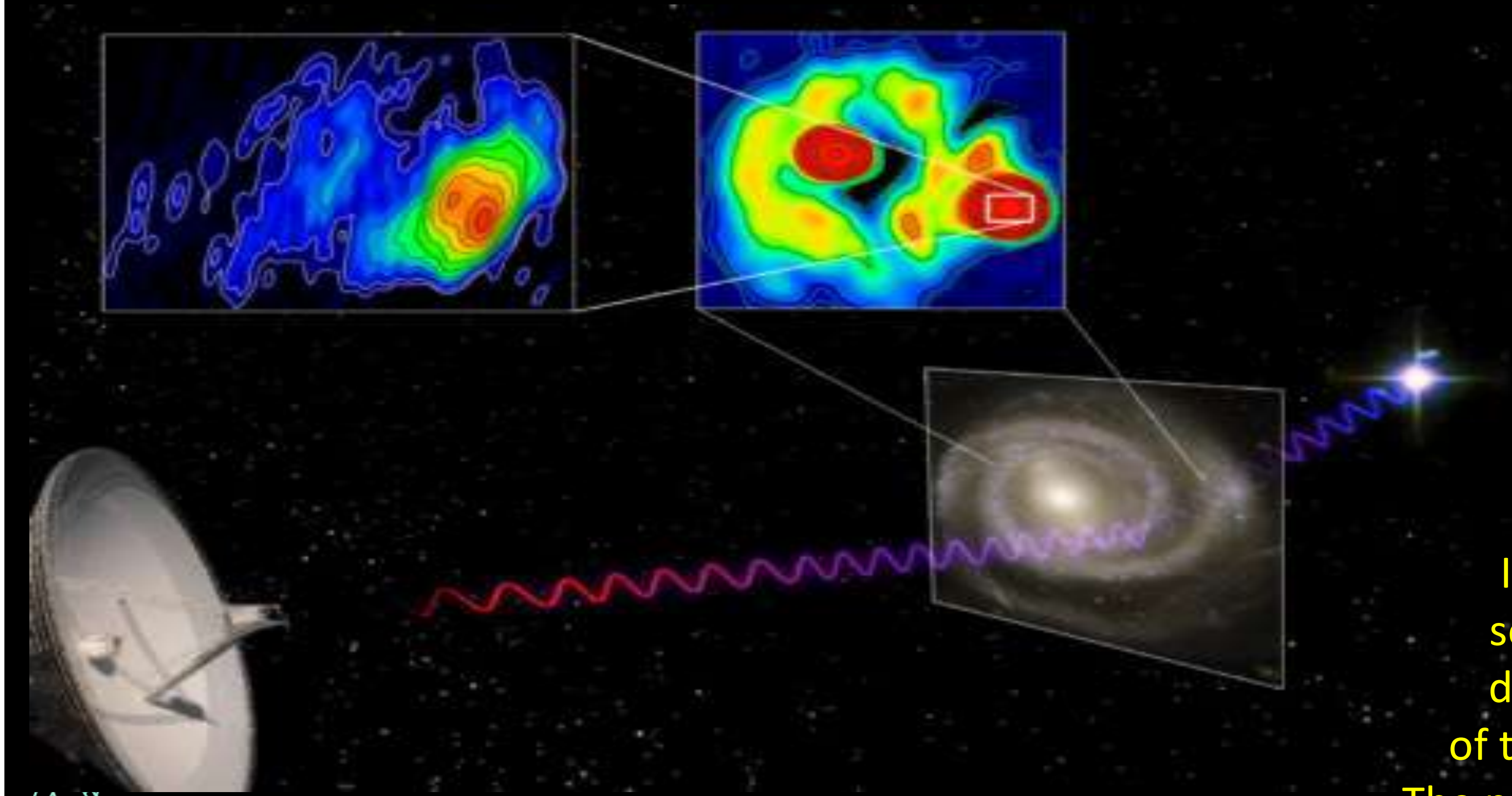


Molecules for fundamental physics

How constant are fundamental constants?

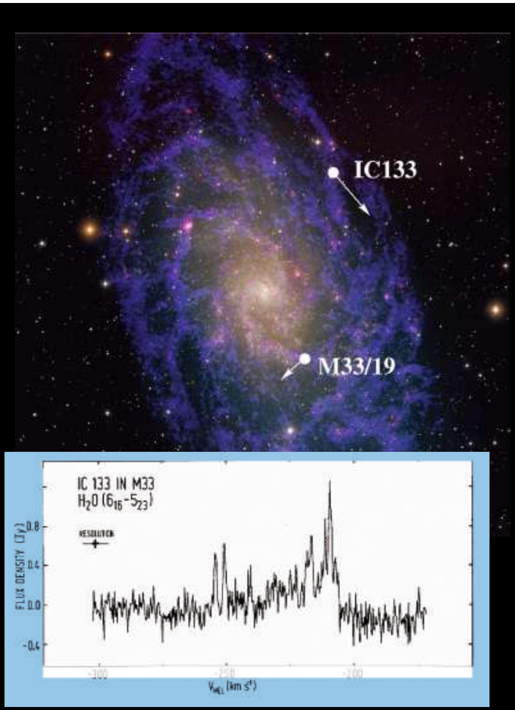
HC_3N in 1830-211 ($z = 0.89$)
Measurement $\mu = m_e/m_p$:
$\Delta\mu/\mu < 1.4 \times 10^{-6}$





It is the same value in a
several billion light years
distant galaxy as here on
of the Earth - and thus in the
The past is the same as it is today!

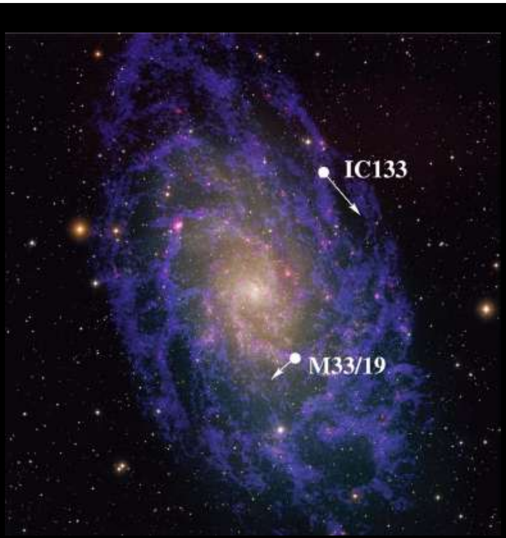
Water



- Spectral line at 1.3cm (often occurs as amaser or megamaser)

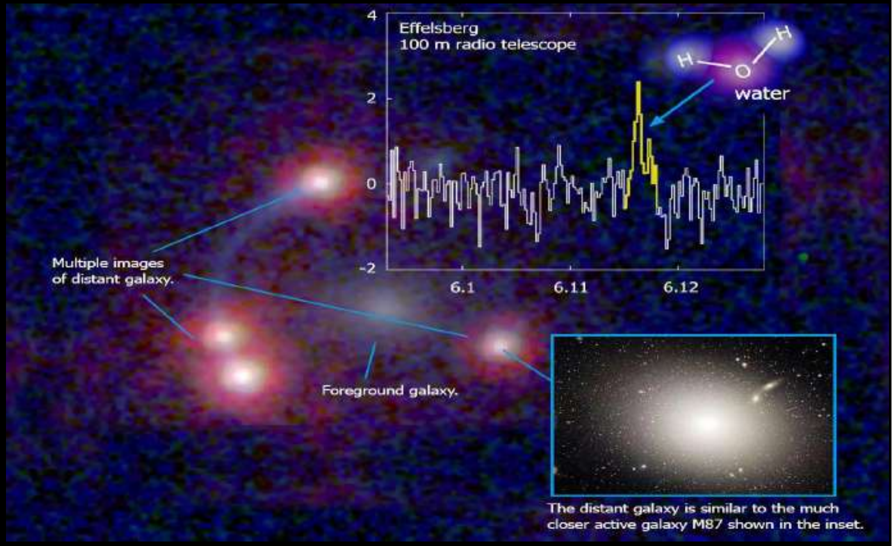
- Water discovered outside the Milky Way for the first time in 1976 (with the 100-meter telescope in M33 – distance 3 million lyr)
-
- 2002: Discovery of a water maser in 3C403 (light travel time: approx. 6 billion years)

Water



- Spectral line at 1.3cm (often occurs as amaser or megamaser)
- Water discovered outside the Milky Way for the first time in 1976 (with the 100-meter telescope in M33 – distance 3 million lyr)
-
- 2002: Discovery of a water maser in 3C403 (light travel time: approx. 6 billion years)
- 2007: Discovery of water in MG0414+0534 (z = 2.64) light travel time > 11 billion years! Redshifted to 5cm

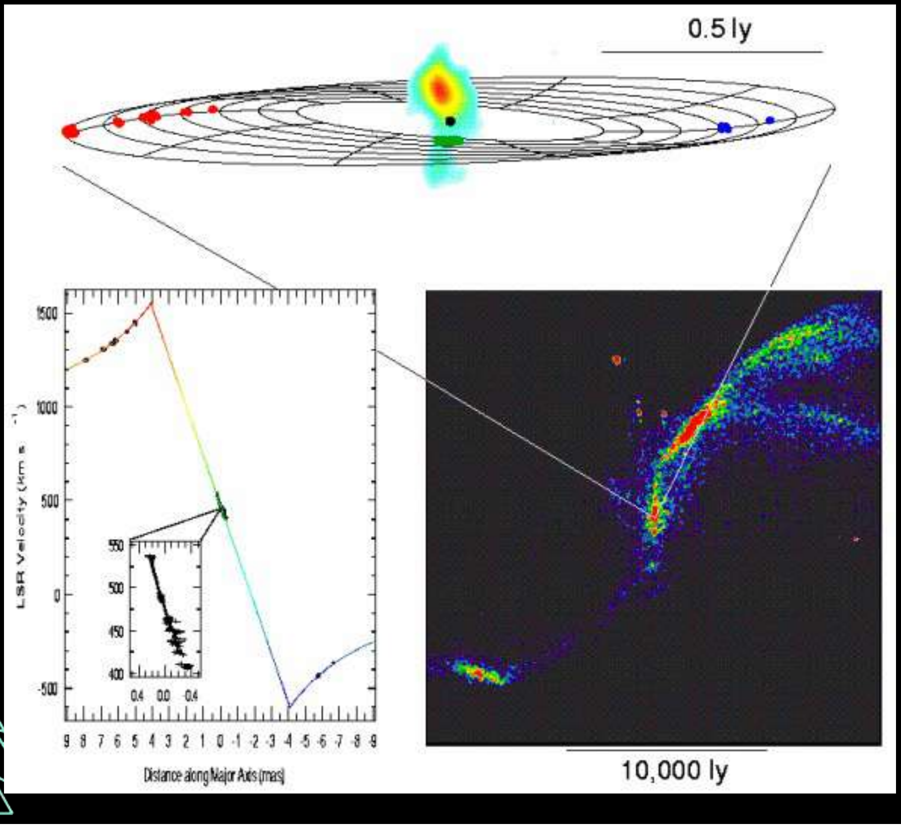
Detected using a gravitational lens

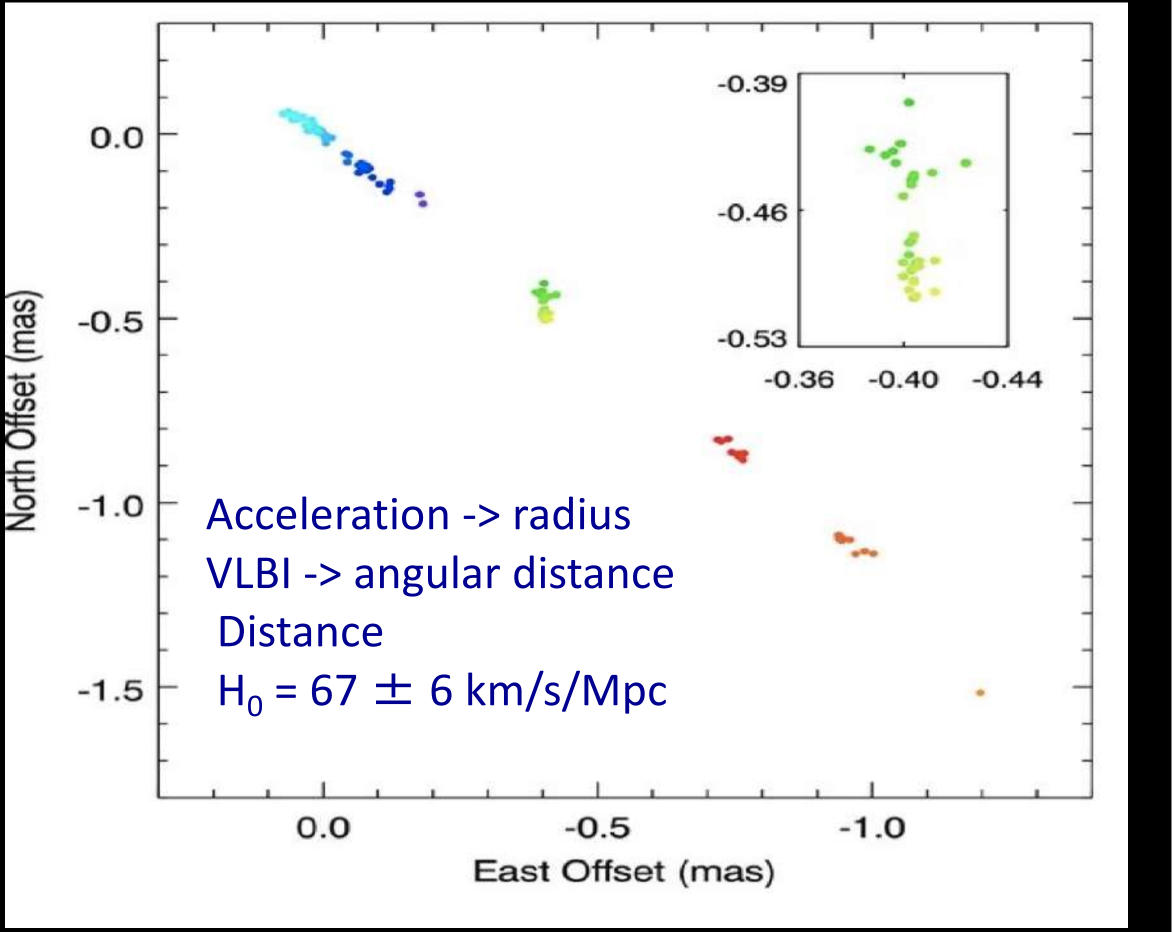


The distant galaxy is similar to the much closer active galaxy M87 shown in the inset.

Megamaser Cosmology Project

Determination of the Hubble Constant by Precise Distance Measurement of Active Galaxies: Effelsberg with VLBA, GBT and Arecibo





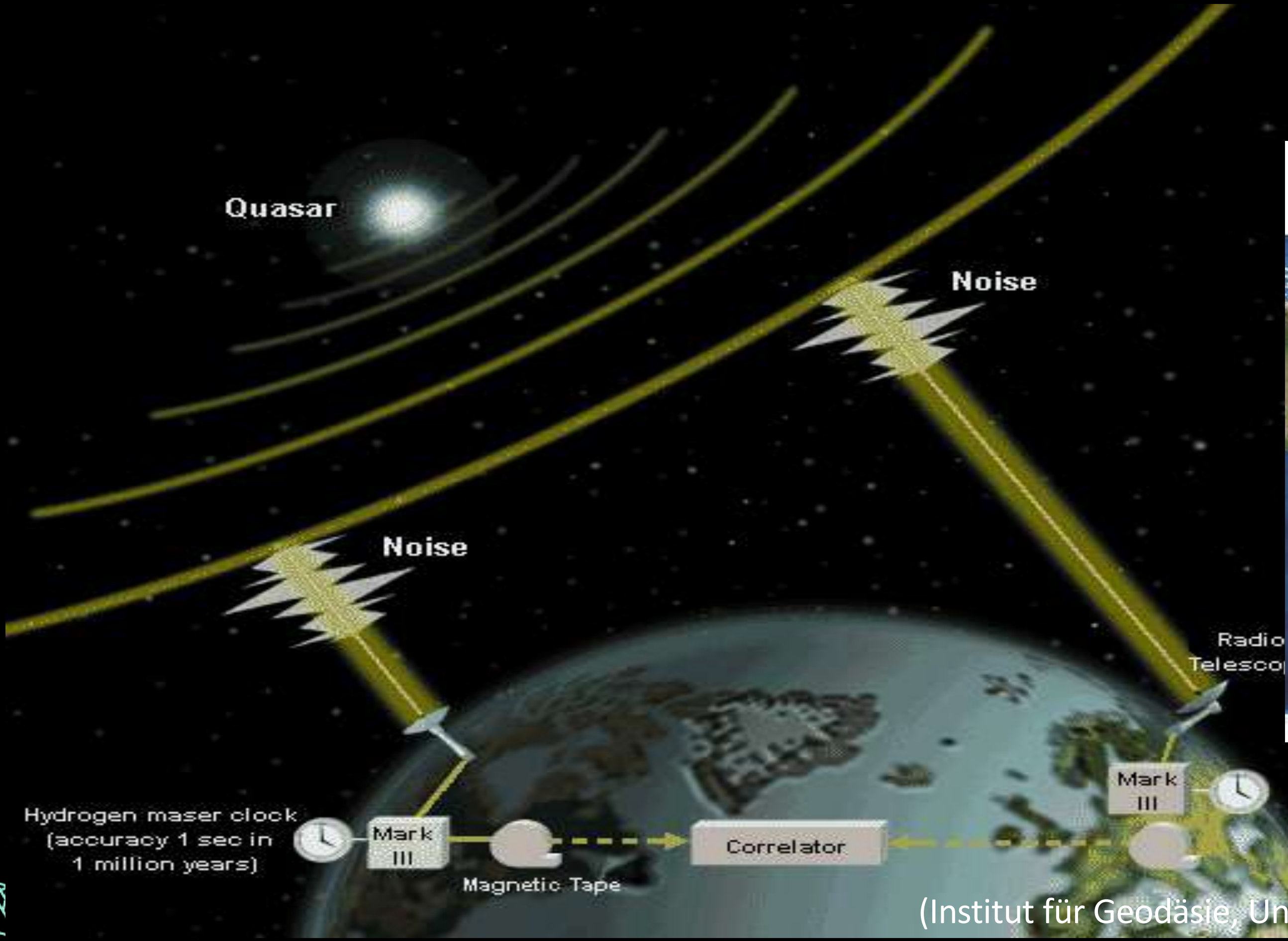
Acceleration -> radius
VLBI -> angular distance
Distance
$H_0 = 67 \pm 6$ km/s/Mpc

Water megamaser in the accretion disks of NGC4258 and NGC6323. (Henkel et al., Braatz et al.)

Very Long Baseline Interferometry (VLBI)

VLBI = Interferometry with long baselines

Resolution~
Wavelength/Antenna Distance



(Institut für Geodäsie, Uni Bonn)

Effelsberg backbone of EVN, GMVA and HSA

Space-VLBI

VLBI = interferometry with very long baselines

Resolution~
Wavelength/Antenna Distance

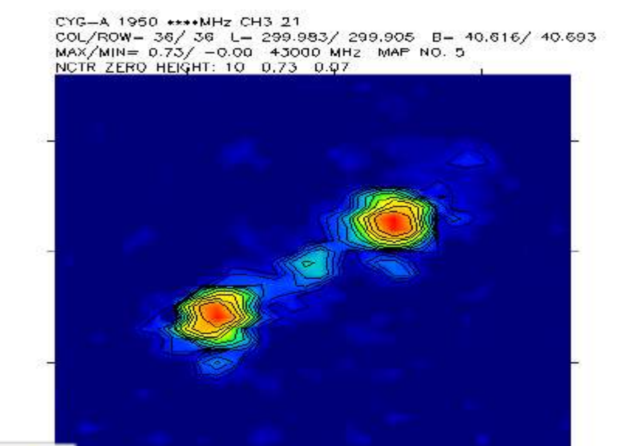
(Institut für Geodäsie, Uni Bonn)

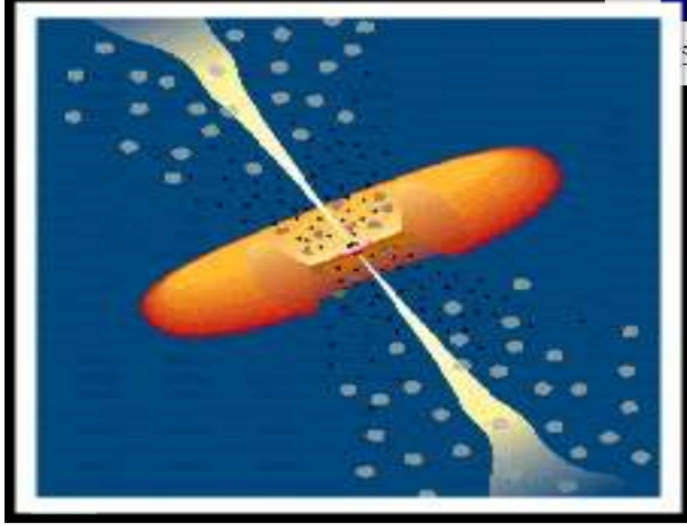
Improvement of angular resolution:
2.5 arcmin → ≈ 10-3 arcsec

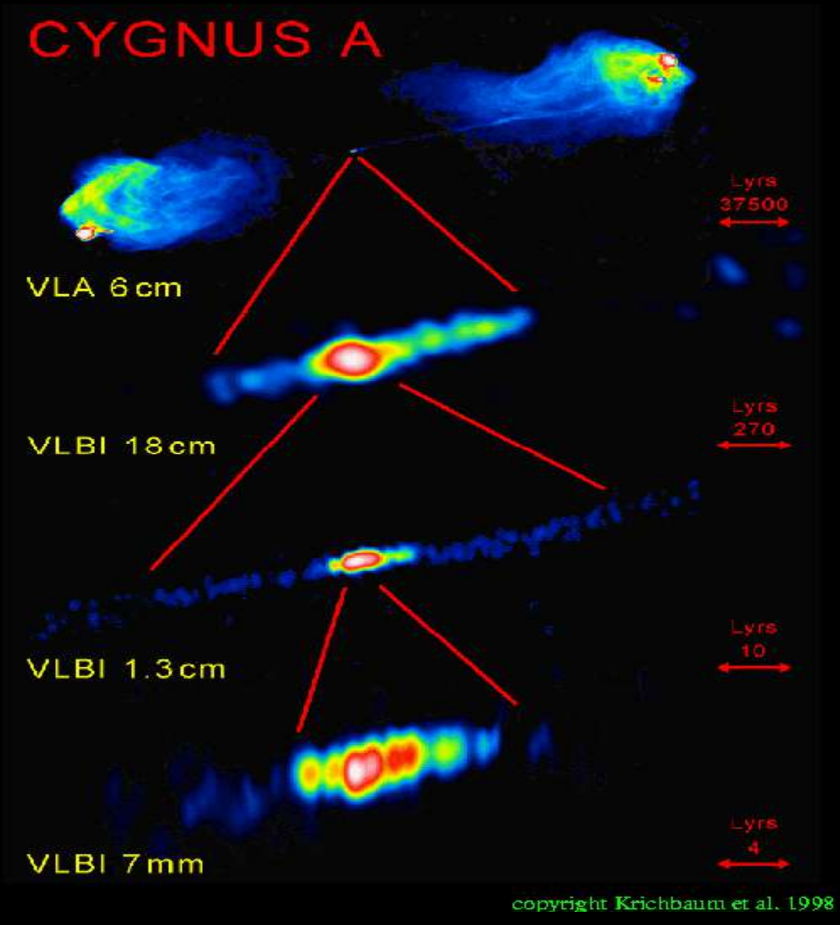
RadioAstron (Russian), 10-m telescope
Launched in July 2011
Orbit: 10,000-360,000 km
First fringes with Effelsberg

"Zoom" into the core (black hole!) of an active galaxy

VLBI is primarily used to study central regions of active galaxies



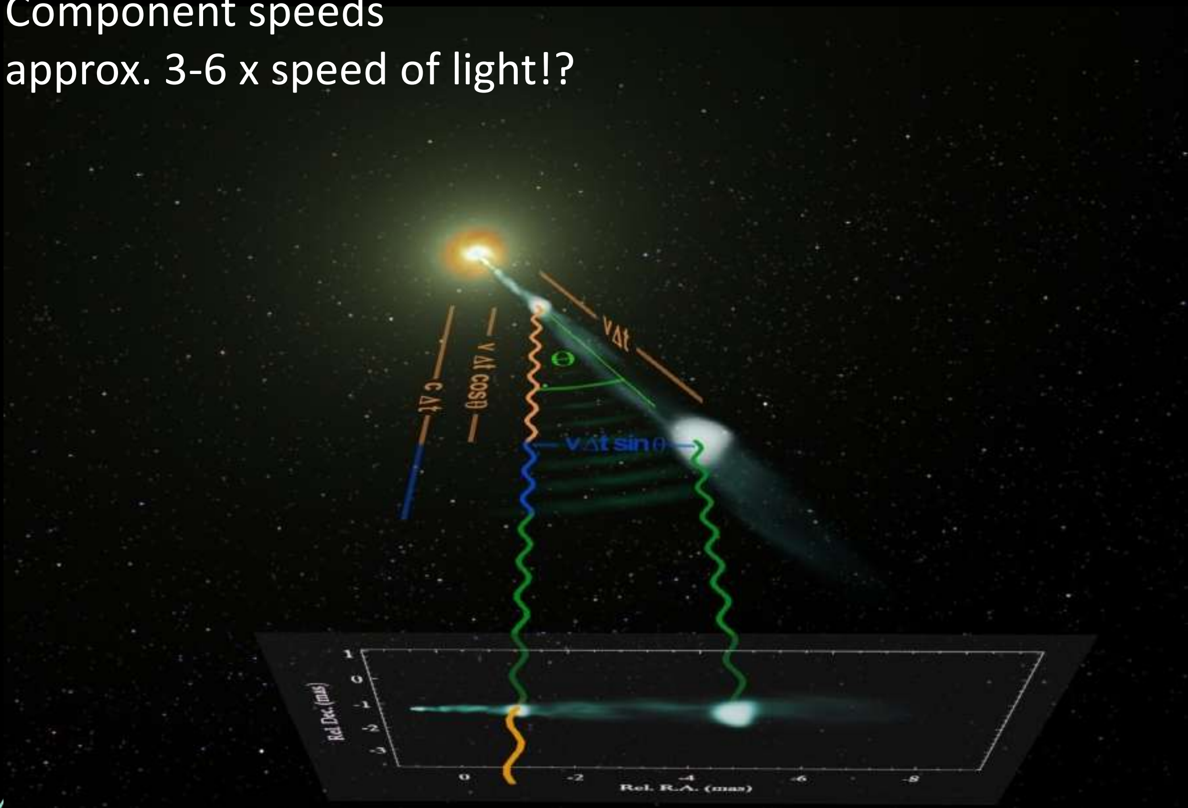




Apparent faster-than-light speeds

Radio galaxy 3C111, distance approx. 700M lyr

Component speeds
approx. 3-6 x speed of light!?

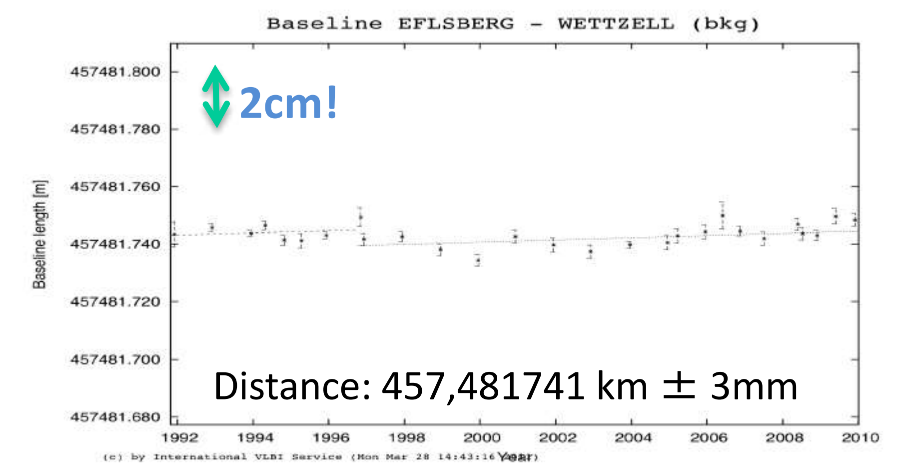


"only" a projection effect

"Jets" consist of plasma,
which moves in a highly relativistic way.

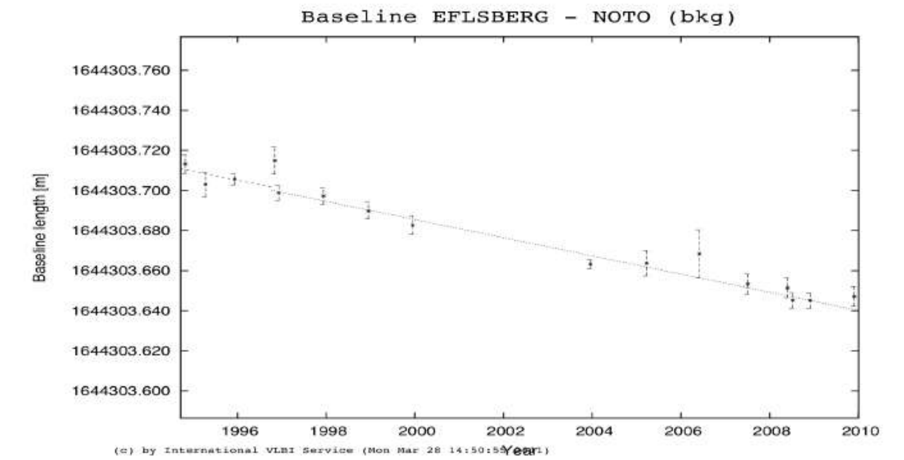
Geodetic VLBI

To study the movement of the continental plates:



2cm!

Distance: 457,481741 km ± 3mm



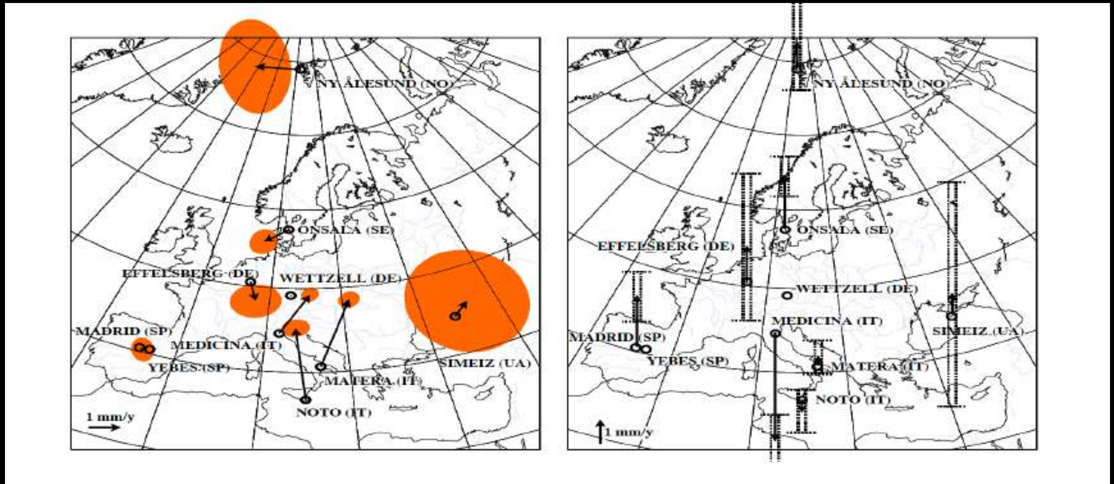


Figure 1. Observed horizontal station motion with respect to Wettzell

Figure. 2: Observed vertical station motion with respect to Wettzell

J. Campbell et al. 2000

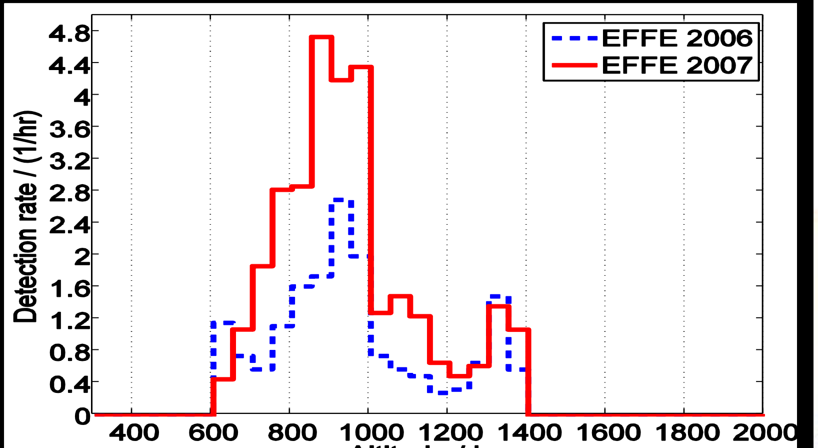
Search for Space Debris

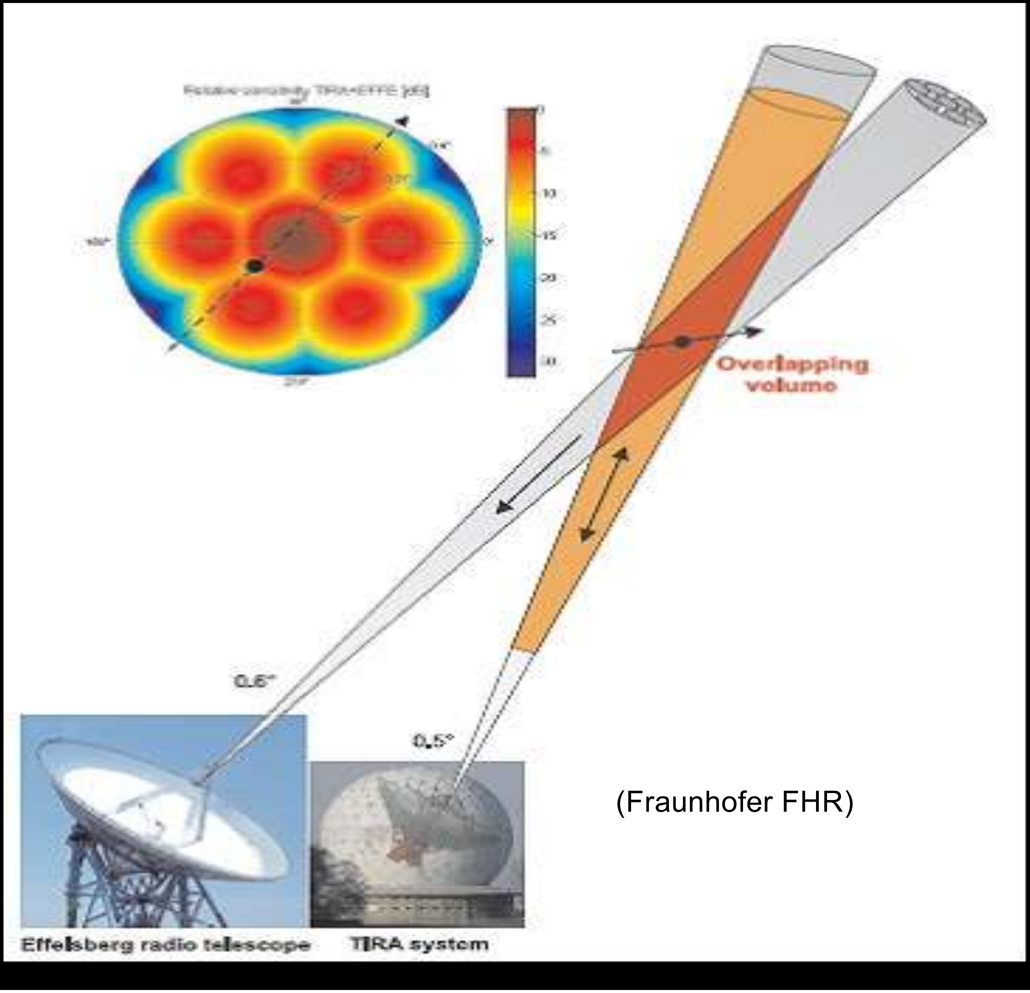
Beobachtungen mit TIRA/FHR und EB!

Principle: both telescopes take fixed positions
so that the observation areas overlap
"Beam Park Experiment"

TIRA: high transmission power (1.3MW)
EB: high sensitivity

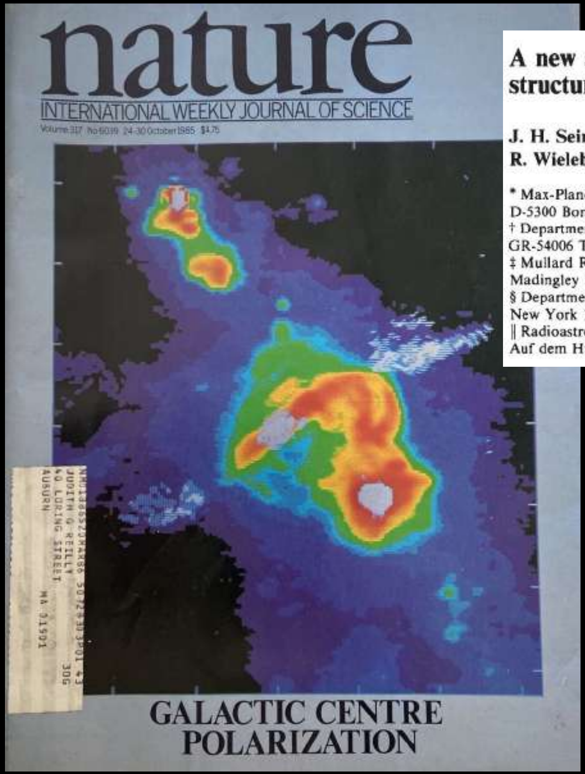
Detection limit: approx. 1cm at 1000 km altitude

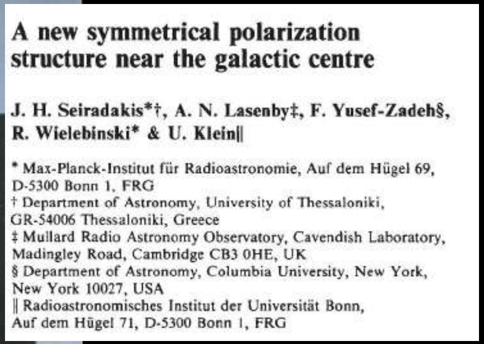




(Fraunhofer FHR)

The Galactic Centre





A new symmetrical polarization structure near the galactic centre

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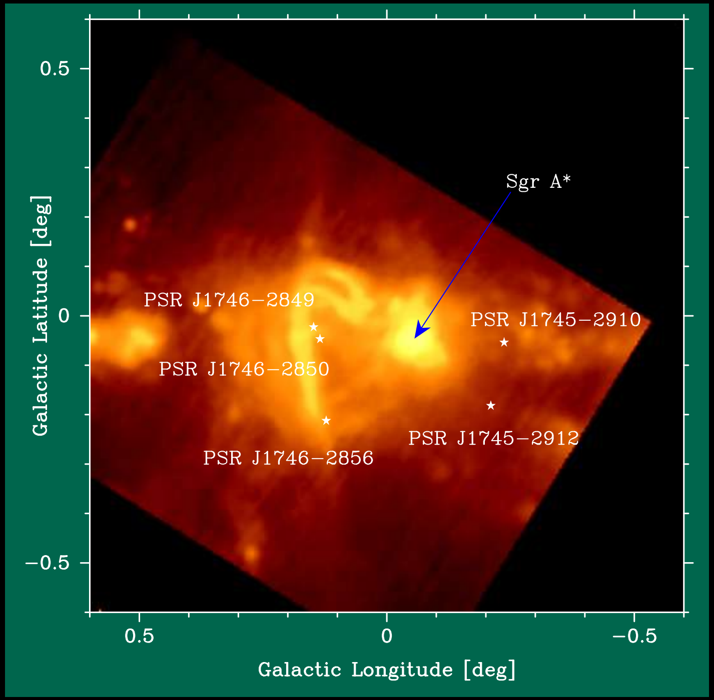
‖ Radioastronomisches Institut der Universität Bonn, Auf dem Hügel 71, D-5300 Bonn 1, FRG

(1985)



Effelsberg
10.5 GHz
(Seiradakis
et al. 1989)

The Galactic Centre – and the search for pulsars

1996ASPC..105...13K

Pulsars : Problems & Progress
ASP Conference Series, Vol. 105, 1996
S. Johnston, M. A. Walker and M. Bailes, eds.

A high frequency search for highly dispersed pulsars

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Max-Planck-Institut für Radioastronomie, Bonn, Germany

1. Introduction

The majority of known pulsars have been discovered by pulsar searches at low radio frequencies ($\nu < 1$ GHz). However, such searches are subject to various deleterious effects, viz the Galactic background radiation ($\propto \nu^{-2.8}$), dispersion smearing ($\propto \nu^{-2}$) and also scatter broadening ($\propto \nu^{-4.4}$). Dispersion smearing and, in particular, scatter broadening prohibit the detection of pulsars with high dispersion measures at low frequencies (cf. Fig. 1a). This is highlighted by the fact that all 11 known pulsars with DM>600 cm^{-3}pc have been discovered during the only two surveys performed to date above 1 GHz, i.e. at 1.4 GHz by Clifton et al. (1992) and at 1.5 GHz by Johnston et al. (1992). However, scattering is still a limiting factor at even 1.4/1.5 GHz. For example B1750–24 is observed with a double component profile at 4.85 GHz (Kijak et al. 1996), whereas at 1.4 GHz the components are completely smeared out due to scatter broadening (cf. Clifton et al. 1992). Therefore, the galactic population of highly dispersed pulsars is still not known. In order to reveal this hidden sample, we have recently started a search in Effelsberg at 4.85 GHz where limitations due to scattering are essentially not existent (see Fig. 1a). The use of this extraordinary high frequency for pulsar searches enables us to observe with a large bandwidth but a small number of filterbank channels, so that the necessary computer power is radically reduced. However, the general steepness of pulsar spectra demands a highly sensitive observing system, otherwise, only the most luminous sources can be detected. A serious disadvantage of a high frequency search is the small telescope beam requiring a lot of observing time to search even a small area of the sky. A restriction of the search area is therefore highly recommended.

2. Observing system and data analysis

We use a high sensitivity 4.85 GHz-HEMT receiver recently installed in the secondary focus of the Effelsberg 100m-radiotelescope. The system temperature was found to be less than 30K on the sky in zenith position. The gain is still large, i.e. 1.45 K/Jy, while the beamsize drops to $\sim 150''$. The total bandwidth of 480 MHz of LHC and RHC polarized signals is divided into eight channels of 60 MHz bandwidth. The outputs of all sixteen channels are detected and digitized by 2-MHz V/f-converters. A multiplexer following the filter bank pairs the channels of equal frequency digitally and compresses these eight total power outputs by a digital time-differentiation. Two adjacent channels are bit pattern encoded and supplied to the parallel inputs of the standard pulsar backend. Since we primarily expect to detect relatively young pulsars, i.e. $P \gtrsim 20$ms, the

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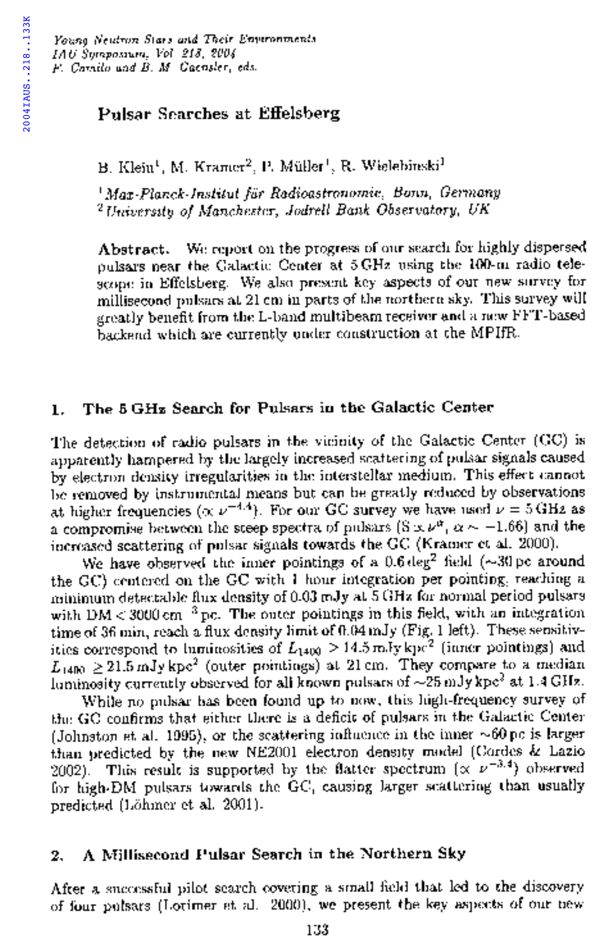

2004IAUS..218..133K

Young Neutron Stars and Their Environments
IAU Symposium, Vol. 218, 2004
F. Camilo and B. M. Gaensler, eds.

Pulsar Searches at Effelsberg

B. Klein[1], M. Kramer[2], P. Müller[1], R. Wielebinski[1]

[1] *Max-Planck-Institut für Radioastronomie, Bonn, Germany*
[2] *University of Manchester, Jodrell Bank Observatory, UK*

Abstract. We report on the progress of our search for highly dispersed pulsars near the Galactic Center at 5 GHz using the 100-m radio telescope in Effelsberg. We also present key aspects of our new survey for millisecond pulsars at 21 cm in parts of the northern sky. This survey will greatly benefit from the L-band multibeam receiver and a new FFT-based backend which are currently under construction at the MPIfR.

1. The 5 GHz Search for Pulsars in the Galactic Center

The detection of radio pulsars in the vicinity of the Galactic Center (GC) is apparently hampered by the largely increased scattering of pulsar signals caused by electron density irregularities in the interstellar medium. This effect cannot be removed by instrumental means but can be greatly reduced by observations at higher frequencies ($\propto \nu^{-4.4}$). For our GC survey we have used $\nu = 5$ GHz as a compromise between the steep spectra of pulsars ($S \propto \nu^{\alpha}$, $\alpha \sim -1.66$) and the increased scattering of pulsar signals towards the GC (Kramer et al. 2000).

We have observed the inner pointings of a 0.6 deg^2 field ($\sim$30 pc around the GC) centered on the GC with 1 hour integration per pointing, reaching a minimum detectable flux density of 0.03 mJy at 5 GHz for normal period pulsars with DM < 3000 cm^{-3} pc. The outer pointings in this field, with an integration time of 36 min, reach a flux density limit of 0.04 mJy (Fig. 1 left). These sensitivities correspond to luminosities of $L_{1400} > 14.5$ mJy kpc^2 (inner pointings) and $L_{1400} \geq 21.5$ mJy kpc^2 (outer pointings) at 21 cm. They compare to a median luminosity currently observed for all known pulsars of $\sim$25 mJy kpc^2 at 1.4 GHz.

While no pulsar has been found up to now, this high-frequency survey of the GC confirms that either there is a deficit of pulsars in the Galactic Center (Johnston et al. 1995), or the scattering influence in the inner $\sim$60 pc is larger than predicted by the new NE2001 electron density model (Cordes & Lazio 2002). This result is supported by the flatter spectrum ($\propto \nu^{-3.4}$) observed for high-DM pulsars towards the GC, causing larger scattering than usually predicted (Löhmer et al. 2001).

2. A Millisecond Pulsar Search in the Northern Sky

After a successful pilot search covering a small field that led to the discovery of four pulsars (Lorimer et al. 2000), we present the key aspects of our new

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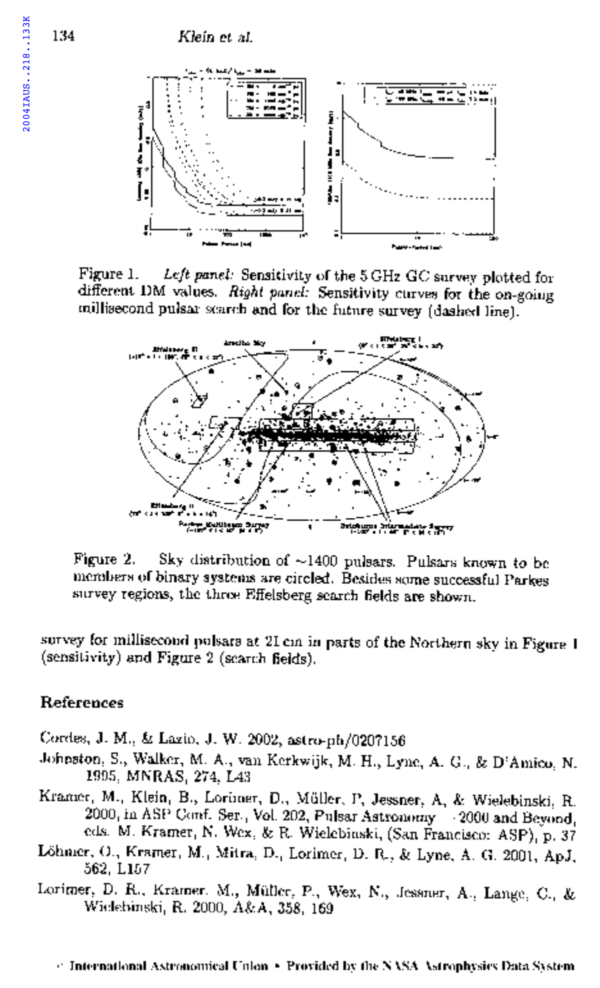

2004IAUS..218..133K

Figure 1. *Left panel:* Sensitivity of the 5 GHz GC survey plotted for different DM values. *Right panel:* Sensitivity curves for the on-going millisecond pulsar search and for the future survey (dashed line).

Figure 2. Sky distribution of ~1400 pulsars. Pulsars known to be members of binary systems are circled. Besides some successful Parkes survey regions, the three Effelsberg search fields are shown.

survey for millisecond pulsars at 21 cm in parts of the Northern sky in Figure 1 (sensitivity) and Figure 2 (search fields).

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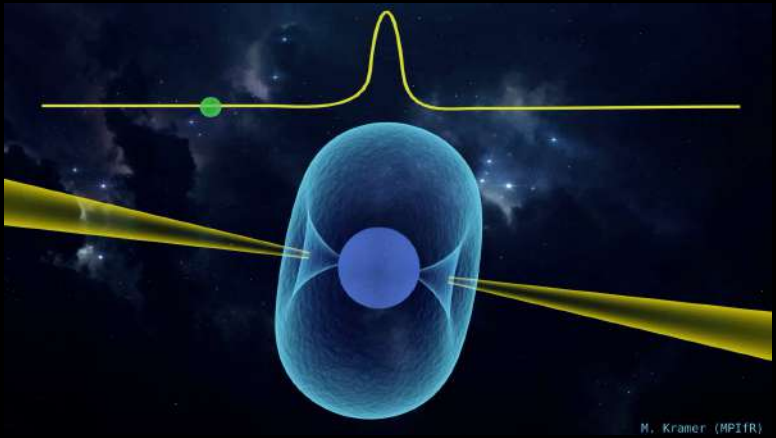
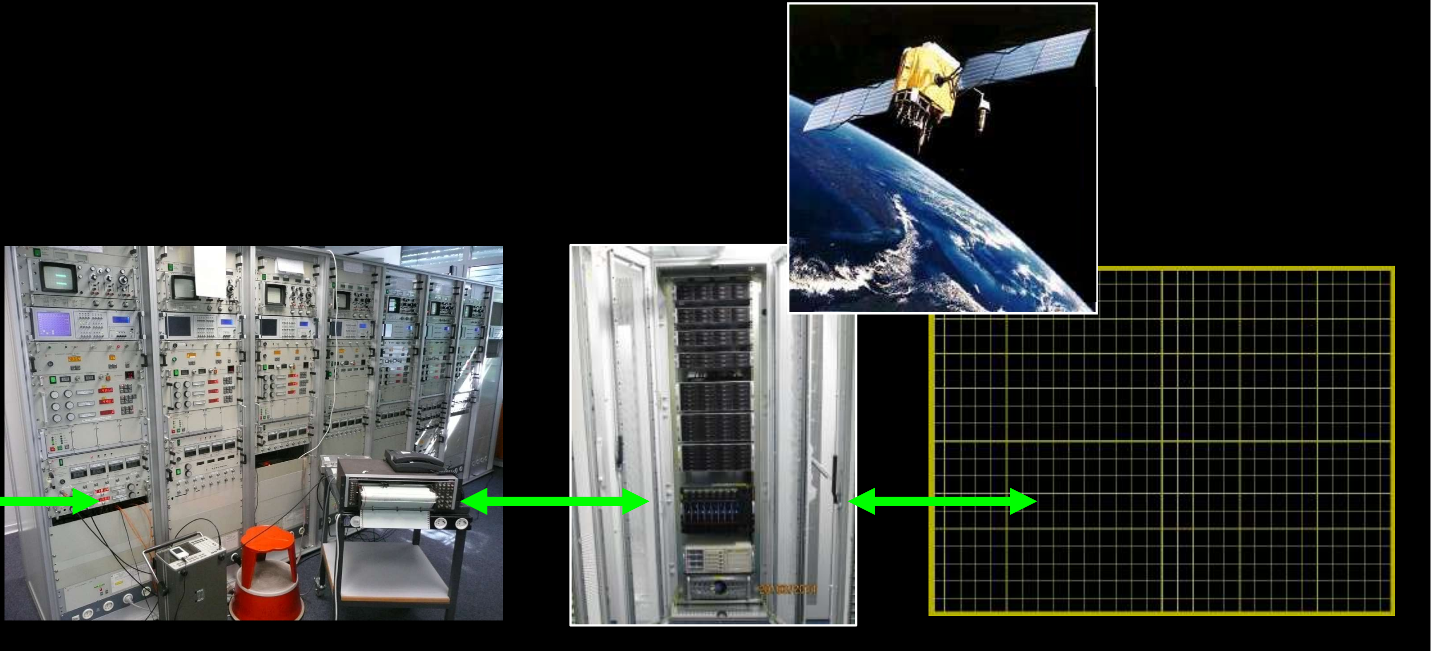
Löhmer, O., Kramer, M., Mitra, D., Lorimer, D. R., & Lyne, A. G. 2001, ApJ, 562, L157

Lorimer, D. R., Kramer, M., Müller, P., Wex, N., Jessner, A., Lange, C., & Wielebinski, R. 2000, A&A, 358, 169

Pulsars



M. Kramer (MPIfR)



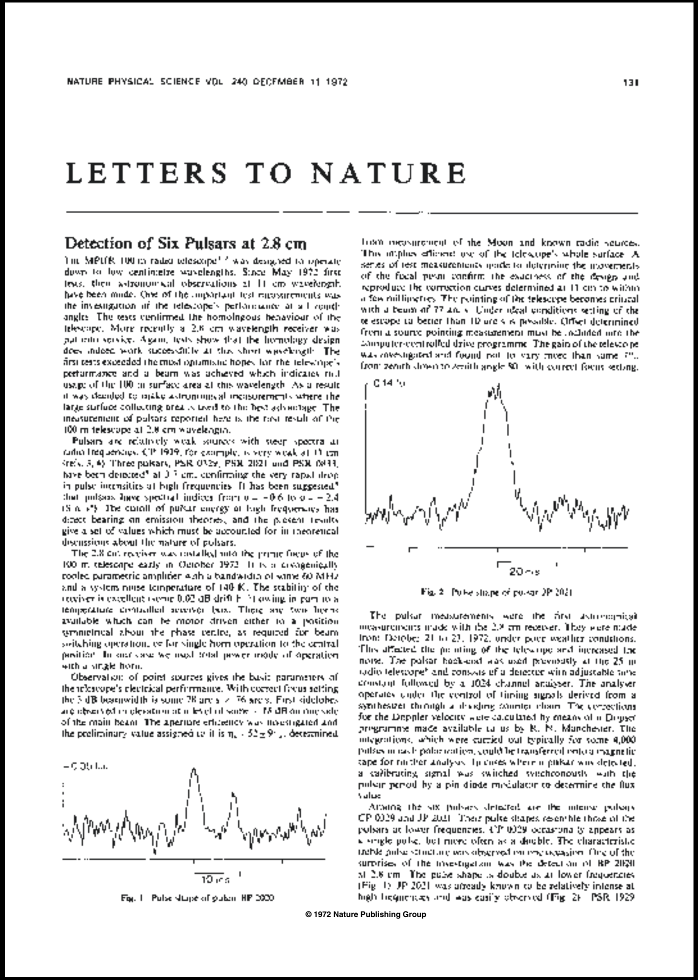
Big telescopes are useful

All the energy that would be received by a pulsar with the Effelsberg 100-m telescope in the entire lifetime of the universe (about 13 billion years) is just enough to illuminate a flashlight for one second

(Adapted from Jocelyn Bell)

Selected pulsar highlights

First Effelsberg publication was on pulsars: record-breaking detection at 2.8 cm (10.5 GHz)



NATURE PHYSICAL SCIENCE VOL 240 DECEMBER 11 1972 131

LETTERS TO NATURE

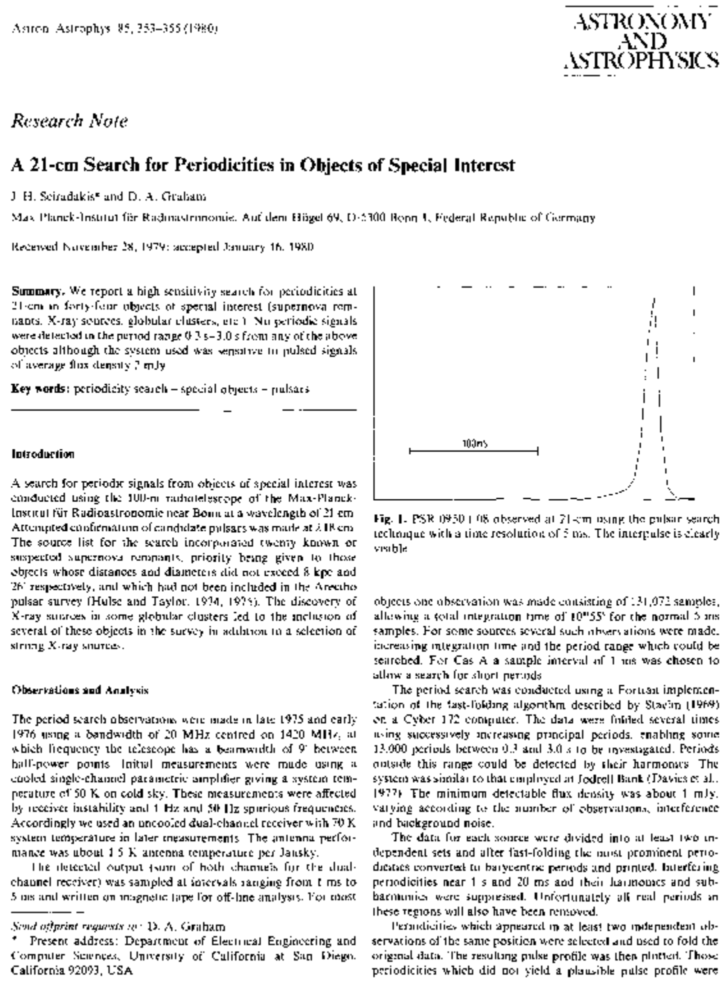
Detection of Six Pulsars at 2.8 cm

Fig. 1 Pulse shape of pulsar HP 2020

Fig. 2 Pulse shape of pulsar JP 2021

© 1972 Nature Publishing Group

Selected pulsar highlights



Astron. Astrophys. 85, 353–355 (1980)

ASTRONOMY
AND
ASTROPHYSICS

Research Note

A 21-cm Search for Periodicities in Objects of Special Interest

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Received November 28, 1979; accepted January 16, 1980

Summary. We report a high sensitivity search for periodicities at 21-cm in forty-four objects of special interest (supernova remnants, X-ray sources, globular clusters, etc.). No periodic signals were detected in the period range 0.3 s–3.0 s from any of the above objects although the system used was sensitive to pulsed signals of average flux density 2 mJy.

Key words: periodicity search – special objects – pulsars

100ms

Fig. 1. PSR 0950+08 observed at 21-cm using the pulsar search technique with a time resolution of 5 ms. The interpulse is clearly visible

Introduction

A search for periodic signals from objects of special interest was conducted using the 100-m radiotelescope of the Max-Planck-Institut für Radioastronomie near Bonn at a wavelength of 21 cm. Attempted confirmation of candidate pulsars was made at λ18 cm. The source list for the search incorporated twenty known or suspected supernova remnants, priority being given to those objects whose distances and diameters did not exceed 8 kpc and 26′ respectively, and which had not been included in the Arecibo pulsar survey (Hulse and Taylor, 1974, 1975). The discovery of X-ray sources in some globular clusters led to the inclusion of several of these objects in the survey in addition to a selection of strong X-ray sources.

Observations and Analysis

The period search observations were made in late 1975 and early 1976 using a bandwidth of 20 MHz centred on 1420 MHz, at which frequency the telescope has a beamwidth of 9′ between half-power points. Initial measurements were made using a cooled single-channel parametric amplifier giving a system temperature of 50 K on cold sky. These measurements were affected by receiver instability and 1 Hz and 50 Hz spurious frequencies. Accordingly we used an uncooled dual-channel receiver with 70 K system temperature in later measurements. The antenna performance was about 1.5 K antenna temperature per Jansky.

The detected output (sum of both channels for the dual-channel receiver) was sampled at intervals ranging from 1 ms to 5 ms and written on magnetic tape for off-line analysis. For most objects one observation was made consisting of 131,072 samples, allowing a total integration time of 10m55s for the normal 5 ms samples. For some sources several such observations were made, increasing integration time and the period range which could be searched. For Cas A a sample interval of 1 ms was chosen to allow a search for short periods.

The period search was conducted using a Fortran implementation of the fast-folding algorithm described by Staelin (1969) on a Cyber 172 computer. The data were folded several times using successively increasing principal periods, enabling some 13,000 periods between 0.3 and 3.0 s to be investigated. Periods outside this range could be detected by their harmonics. The system was similar to that employed at Jodrell Bank (Davies et al., 1977). The minimum detectable flux density was about 1 mJy, varying according to the number of observations, interference and background noise.

The data for each source were divided into at least two independent sets and after fast-folding the most prominent periodicities converted to barycentric periods and printed. Interfering periodicities near 1 s and 20 ms and their harmonics and subharmonics were suppressed. Unfortunately all real periods in these regions will also have been removed.

Periodicities which appeared in at least two independent observations of the same position were selected and used to fold the original data. The resulting pulse profile was then plotted. Those periodicities which did not yield a plausible pulse profile were

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Send offprint requests to: D. A. Graham

* Present address: Department of Electrical Engineering and Computer Sciences, University of California at San Diego, California 92093, USA

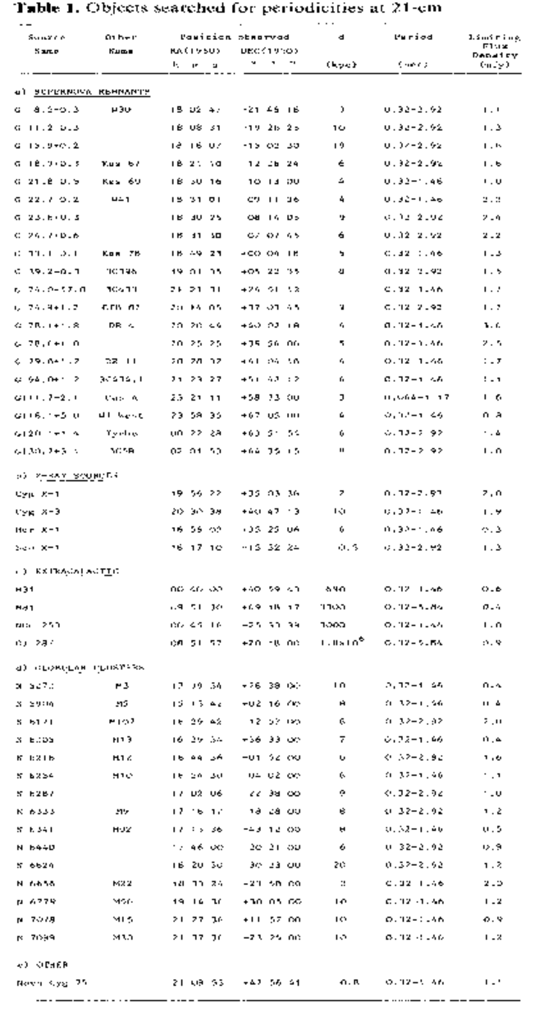
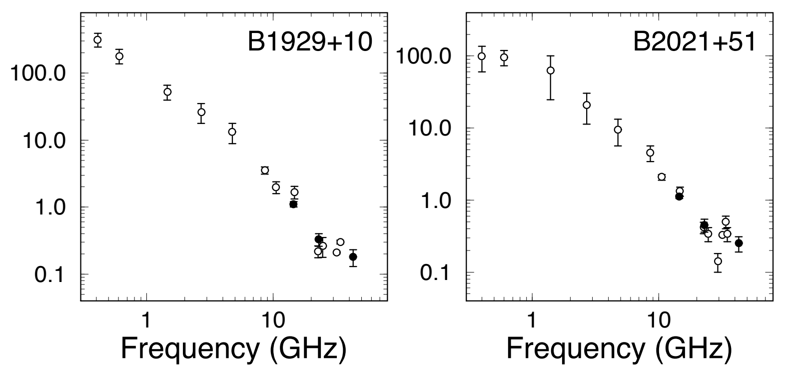


Table 1. Objects searched for periodicities at 21-cm

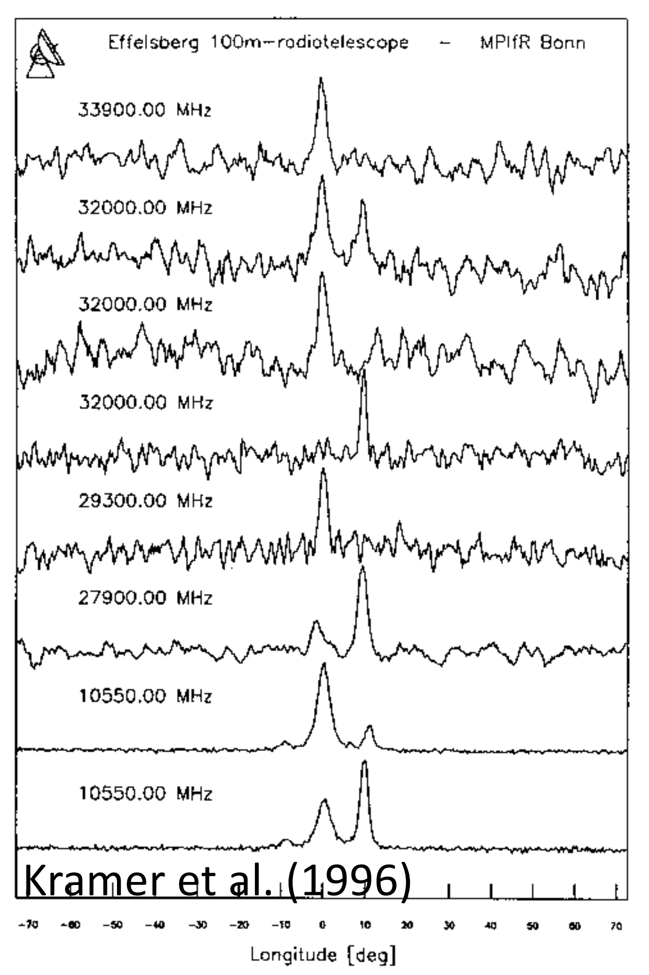
Source Name	Other Name	Position observed RA(1950) h m s	DEC(1950) ° ′ ″	d (kpc)	Period (secs)	Limiting Flux Density (mJy)
a) SUPERNOVA REMNANTS						
G 8.5-0.3	W30	18 02 47	-21 45 16	5	0.32-2.92	1.1
G 11.2-0.3		18 08 31	-19 26 25	10	0.32-2.92	1.3
G 15.9+0.2		18 16 07	-15 02 30	19	0.32-2.92	1.6
G 18.9+0.3	Kes 67	18 21 50	-12 26 24	6	0.32-2.92	1.6
G 21.8-0.5	Kes 69	18 30 16	-10 13 00	4	0.32-1.46	1.0
G 22.7-0.2	W41	18 31 01	-09 11 36	4	0.32-1.46	2.3
G 23.6+0.3		18 30 25	-08 14 05	9	0.32-2.92	2.4
G 24.7+0.6		18 31 30	-07 07 45	6	0.32-2.92	2.2
G 33.1-0.1	Kes 78	18 49 21	-00 04 18	5	0.32-1.46	1.3
G 39.2-0.3	3C396	19 01 35	+05 22 35	8	0.32-2.92	1.5
G 74.0-[illegible]	[illegible]	21 21 31	+26 01 52		0.32-1.46	1.7
G 74.9+1.2	CTB 87	20 14 05	+37 03 45	8	0.32-2.92	1.2
G 78.1+1.8	DR 4	20 20 46	+40 03 18	6	0.32-1.46	3.6
G 78.6+1.0		20 25 25	+35 56 06	5	0.32-1.46	2.5
G 79.0+1.2	DR 11	20 20 32	+41 04 50	6	0.32-1.46	1.7
G 94.0+1.2	3C434.1	21 23 27	+51 43 12	6	0.32-1.46	1.1
G111.7-2.1	Cas A	23 21 11	+58 33 00	3	0.064-1.17	1.6
G116.1+5.0	[illegible]	23 58 35	+67 05 00	4	0.32-1.46	0.8
G120.1+1.4	Tycho	00 22 28	+63 51 54	6	0.32-2.92	1.4
G130.7+3.1	3C58	02 01 53	+64 35 15	8	0.32-2.92	1.0
b) X-RAY SOURCES						
Cyg X-1		19 56 22	+35 03 36	2	0.32-2.92	2.0
Cyg X-3		20 30 38	+40 47 13	10	0.32-1.46	1.9
Her X-1		16 56 02	+35 25 06	6	0.32-1.46	0.3
Sco X-1		16 17 10	-15 32 24	0.5	0.32-2.92	1.3
c) EXTRAGALACTIC						
M31		00 40 00	+40 59 43	690	0.32-1.46	0.6
M81		09 51 30	+69 18 17	3300	0.32-5.86	0.4
NGC 253		00 45 16	-25 33 38	3000	0.32-1.46	1.0
OJ 287		08 51 57	+20 18 00	1.0×10^6	0.32-5.86	0.9
d) GLOBULAR CLUSTERS						
N 5272	M3	13 39 36	+28 38 00	10	0.32-1.46	0.6
N 5904	M5	15 13 42	+02 16 00	8	0.32-1.46	0.4
N 6171	M107	16 29 42	-12 57 00	6	0.32-2.92	2.0
N 6205	M13	16 39 54	+36 33 00	7	0.32-1.46	0.4
N 6218	M12	16 44 36	-01 52 00	6	0.32-2.92	1.6
N 6254	M10	16 54 30	-04 02 00	6	0.32-1.46	1.1
N 6287		17 02 06	-22 38 00	9	0.32-2.92	1.0
N 6333	M9	17 16 17	-18 28 00	8	0.32-2.92	1.2
N 6341	M92	17 15 36	+43 12 00	8	0.32-1.46	0.5
N 6440		17 46 00	-20 21 00	6	0.32-2.92	0.9
N 6624		18 20 30	-30 23 00	20	0.32-2.92	1.2
N 6656	M22	18 33 24	-23 56 00	3	0.32-1.46	2.5
N 6779	M56	19 14 36	+30 05 00	10	0.32-1.46	1.2
N 7078	M15	21 27 36	+11 57 00	10	0.32-1.46	0.9
N 7099	M30	21 37 30	-23 25 00	10	0.32-1.46	1.2
e) OTHER						
Nova Cyg 75		21 09 53	+47 56 41	0.8	0.32-1.46	1.1

Selected pulsar highlights

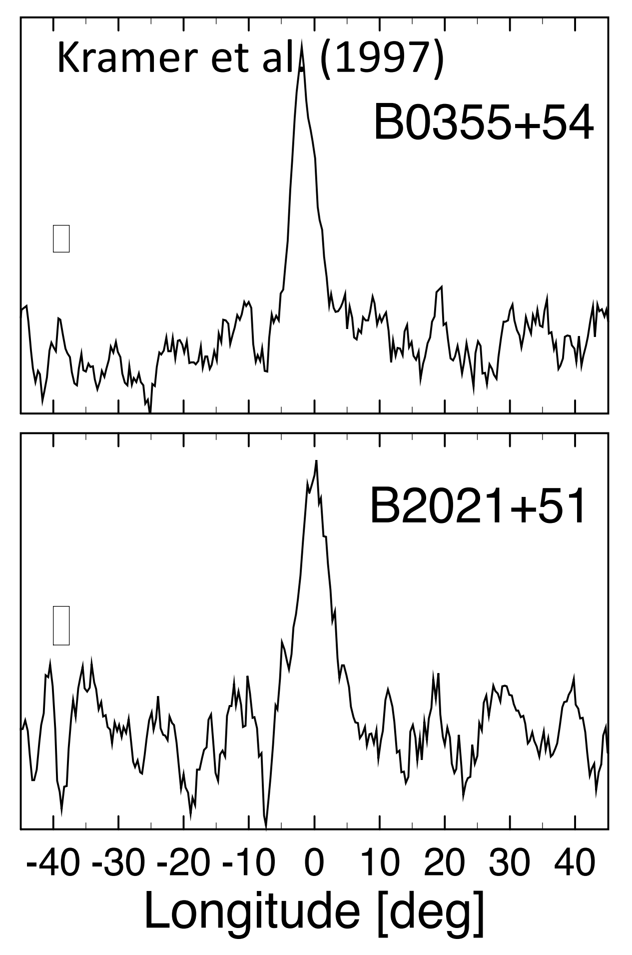
First detection of pulsars above 20 GHz, 30 GHz and 40 GHz:



There is no high-frequency cut-off, quite the opposite...



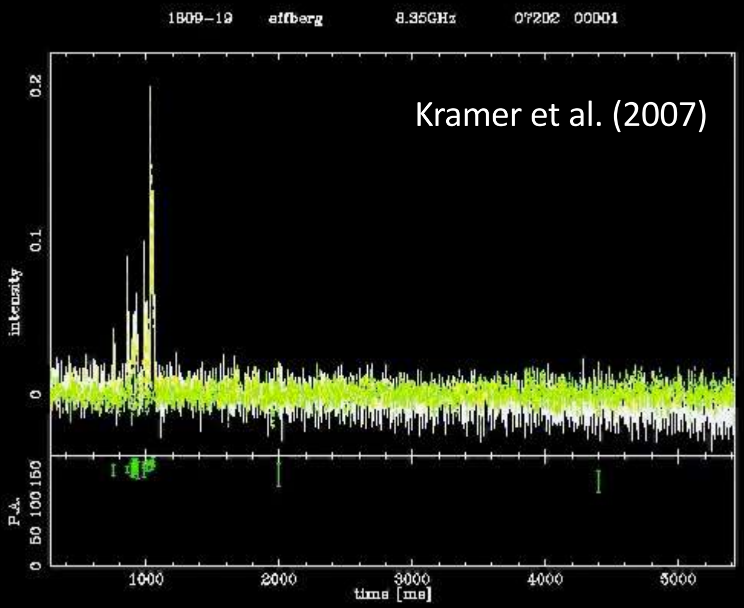
Kramer et al. (1996)



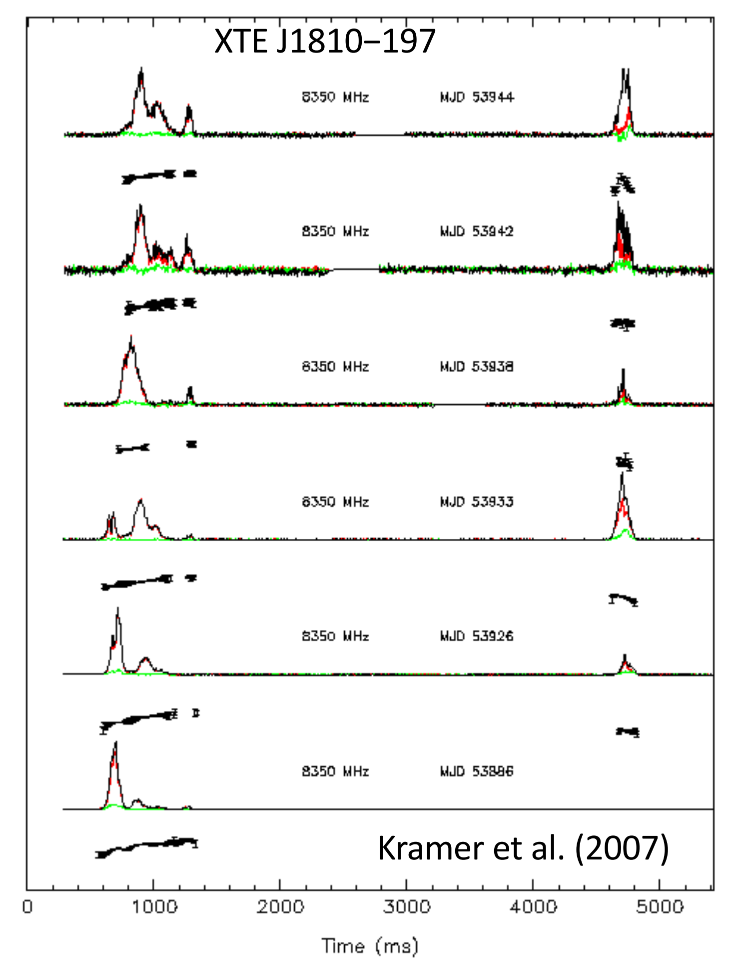
Kramer et al. (1997)

Selected pulsar highlights

First detailed polarisation study of magnetar and their single pulses



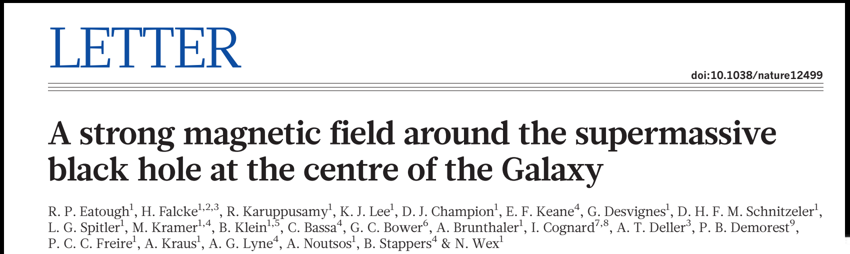
Kramer et al. (2007)



Kramer et al. (2007)

Selected pulsar highlights

Detection of radio magnetar in the Galactic Centre:

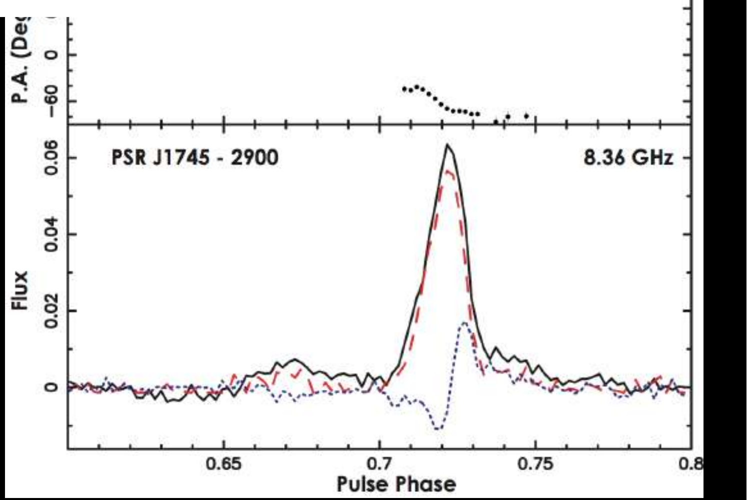


LETTER

doi:10.1038/nature12499

A strong magnetic field around the supermassive black hole at the centre of the Galaxy

R. P. Eatough[1], H. Falcke[1,2,3], R. Karuppusamy[1], K. J. Lee[1], D. J. Champion[1], E. F. Keane[4], G. Desvignes[1], D. H. F. M. Schnitzeler[1], L. G. Spitler[1], M. Kramer[1,4], B. Klein[1,5], C. Bassa[4], G. C. Bower[6], A. Brunthaler[1], I. Cognard[7,8], A. T. Deller[3], P. B. Demorest[9], P. C. C. Freire[1], A. Kraus[1], A. G. Lyne[4], A. Noutsos[1], B. Stappers[4] & N. Wex[1]



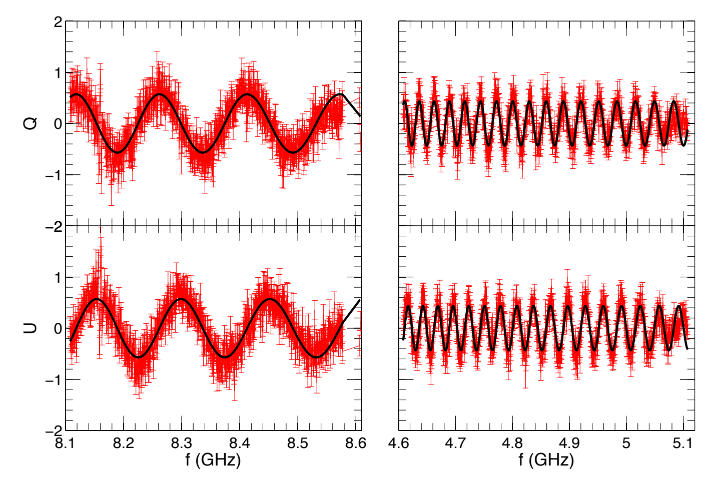
Distance of 1” to Galactic centre

Highest DM of any pulsar: DM = 1778±3 cm^{-3} pc

Source is ~ 100% linearly polarized

Rotation Measure RM = -66960±50 rad m^{-2}

- largest in Galaxy (apart from Sgr A*)



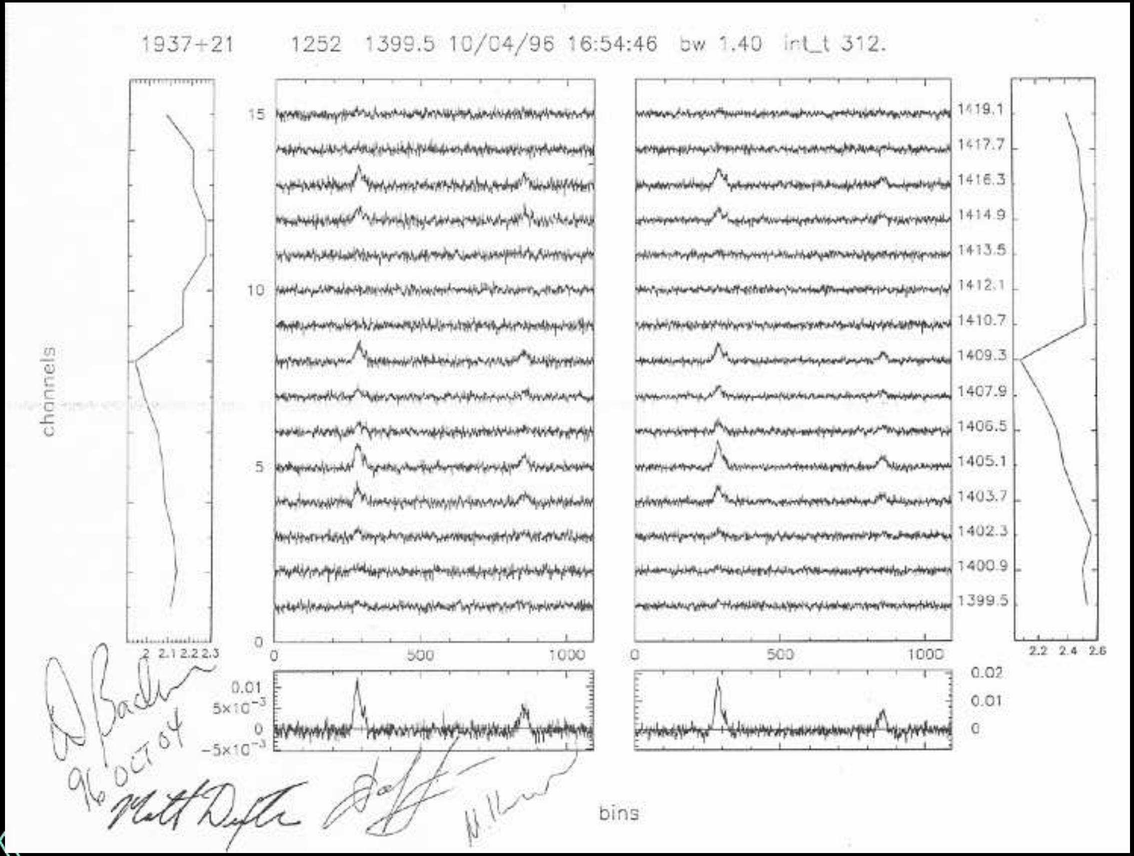
Selected pulsar highlights

Desvignes et al. (2024)

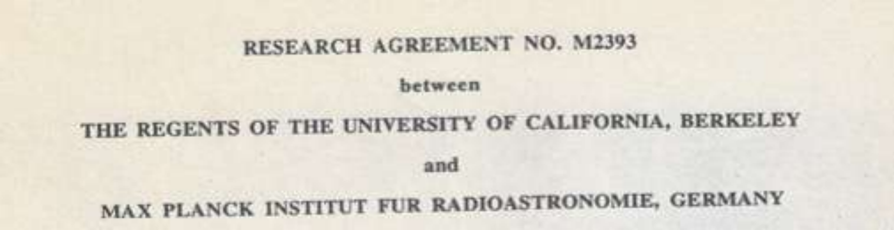
First evidence for magnetar precession:

PTA observations in Effelsberg since 1996

First light of the Effelsberg Berkeley Pulsar Processor (EBPP) – longest existing data set



Collaboration with Don Backer (UC Berkeley)



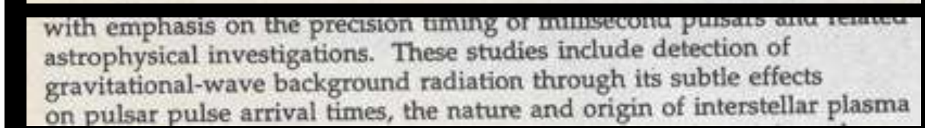
RESEARCH AGREEMENT NO. M2393

between

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA, BERKELEY

and

MAX PLANCK INSTITUT FUR RADIOASTRONOMIE, GERMANY

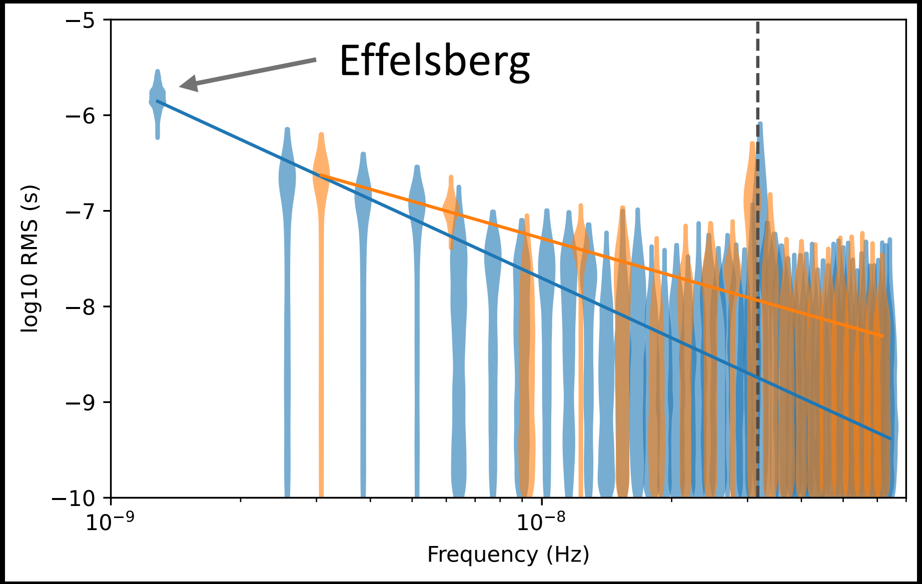


with emphasis on the precision timing of millisecond pulsars and related astrophysical investigations. These studies include detection of gravitational-wave background radiation through its subtle effects on pulsar pulse arrival times, the nature and origin of interstellar plasma

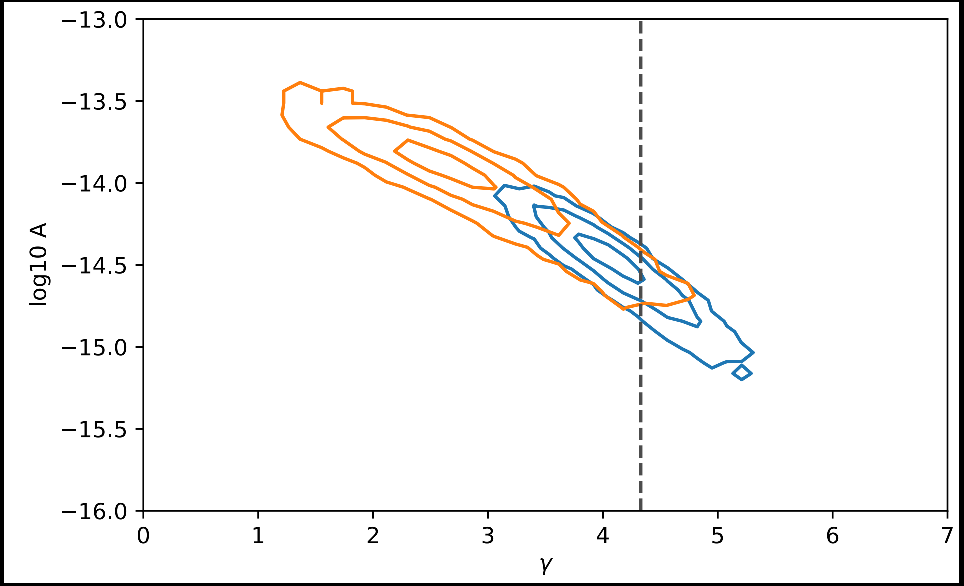
PTA observations in Effelsberg since 1996

First light of the Effelsberg Berkeley Pulsar Processor (EBPP) – longest existing data set

Spectra (with HD)

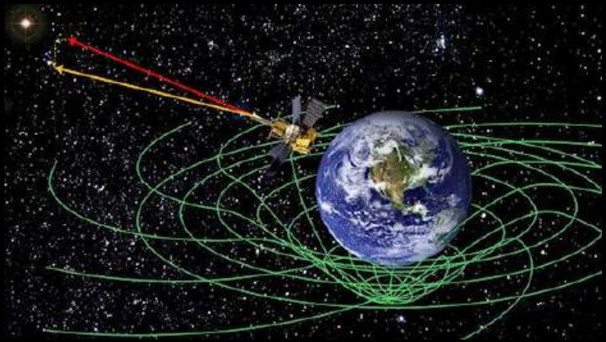


Spectral index vs amplitude



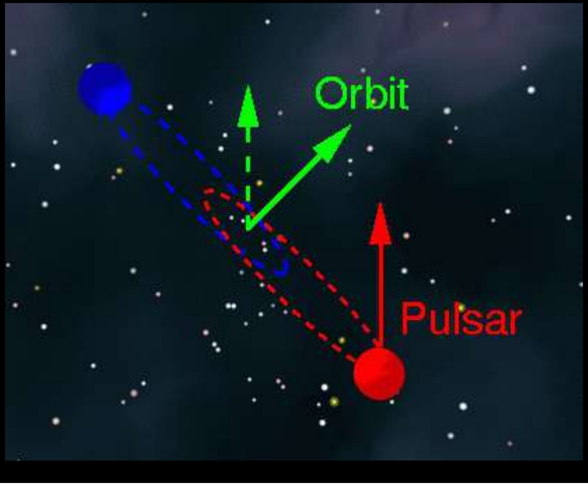
Relativistic spin precession

Due to the curvature of space-time the proper reference frame of a freely falling object suffers “geodetic precession”



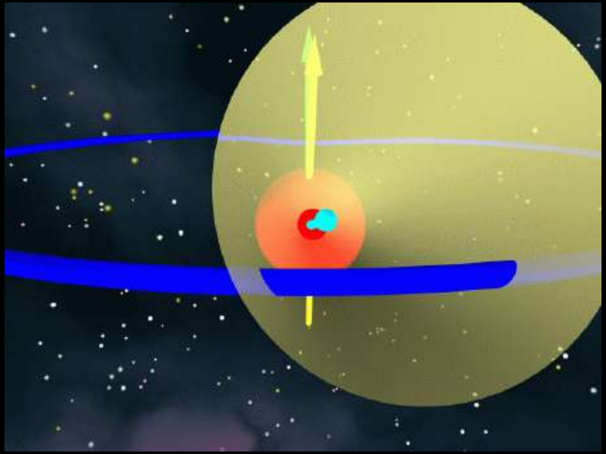
Experiments made in Solar System provide precise weak-field tests and confirm it, e.g. LLR or GRAVITY Probe-B

Effect predicted for pulsars by Damour & Ruffini (1974) immediately after the discovery of the Hulse-Taylor pulsar in 1974...

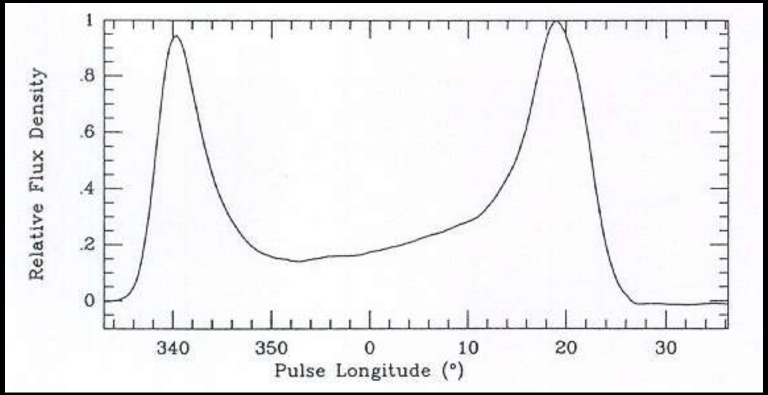


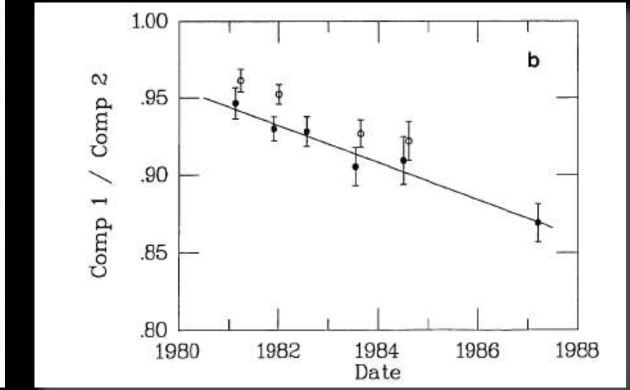
Kramer

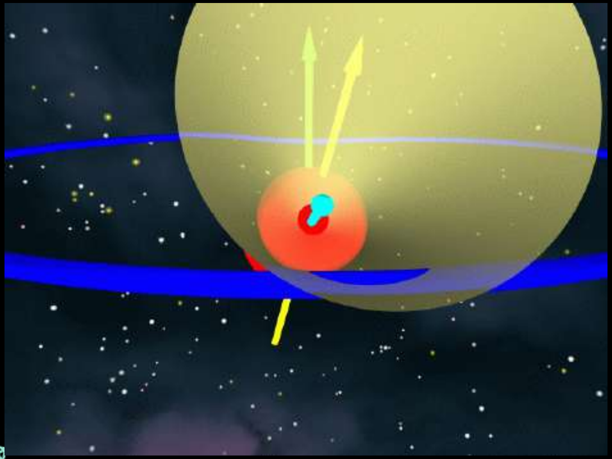
Relativistic spin precession in the Hulse-Taylor pulsar

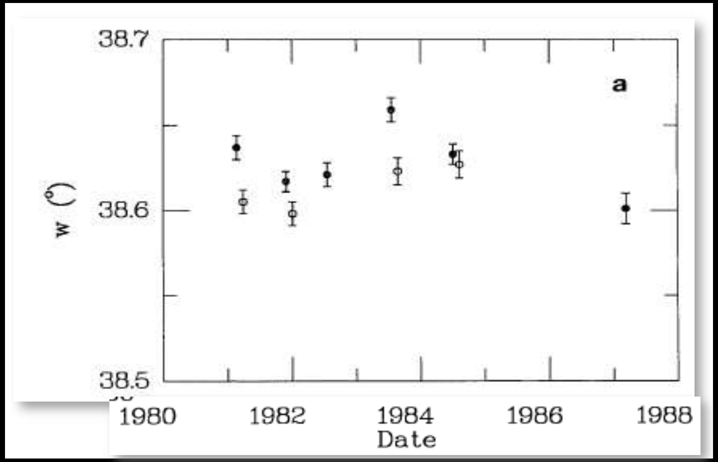


First studies by Weisberg, Romani & Taylor (1989):







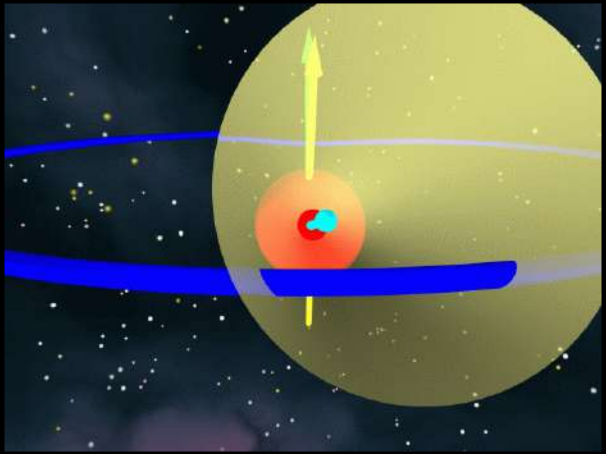


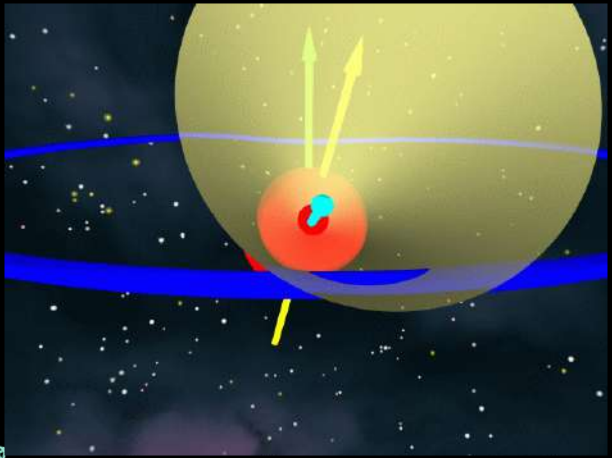
No conclusive result:

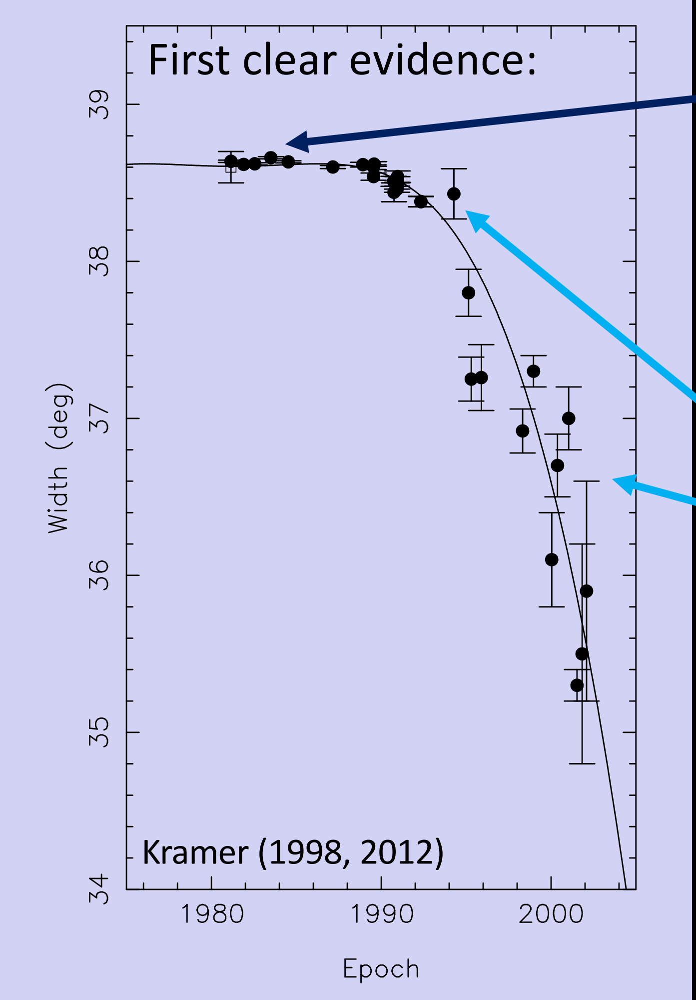
amplitude was changing slowly with time

Expected change in width was not detected!

Relativistic spin precession in the Hulse-Taylor pulsar

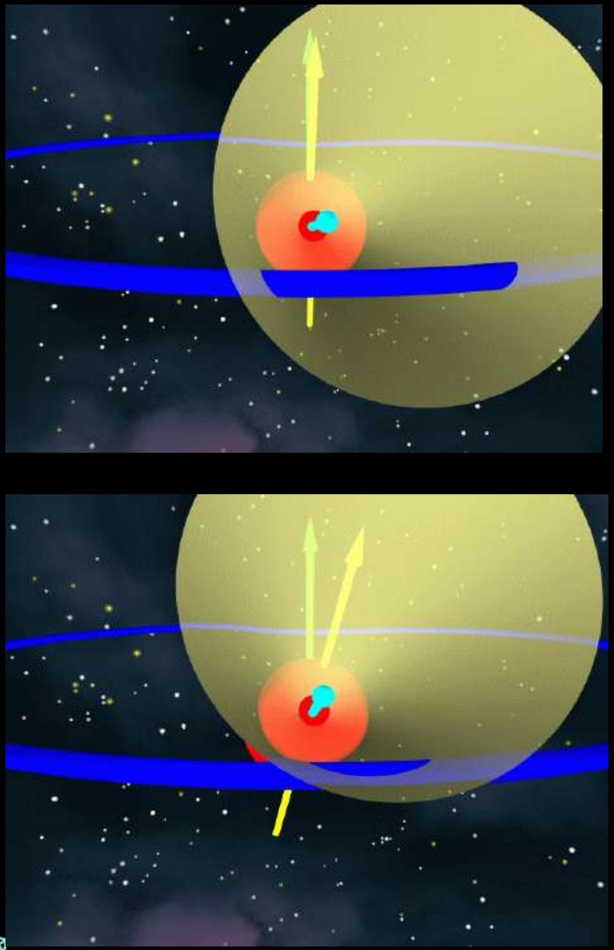




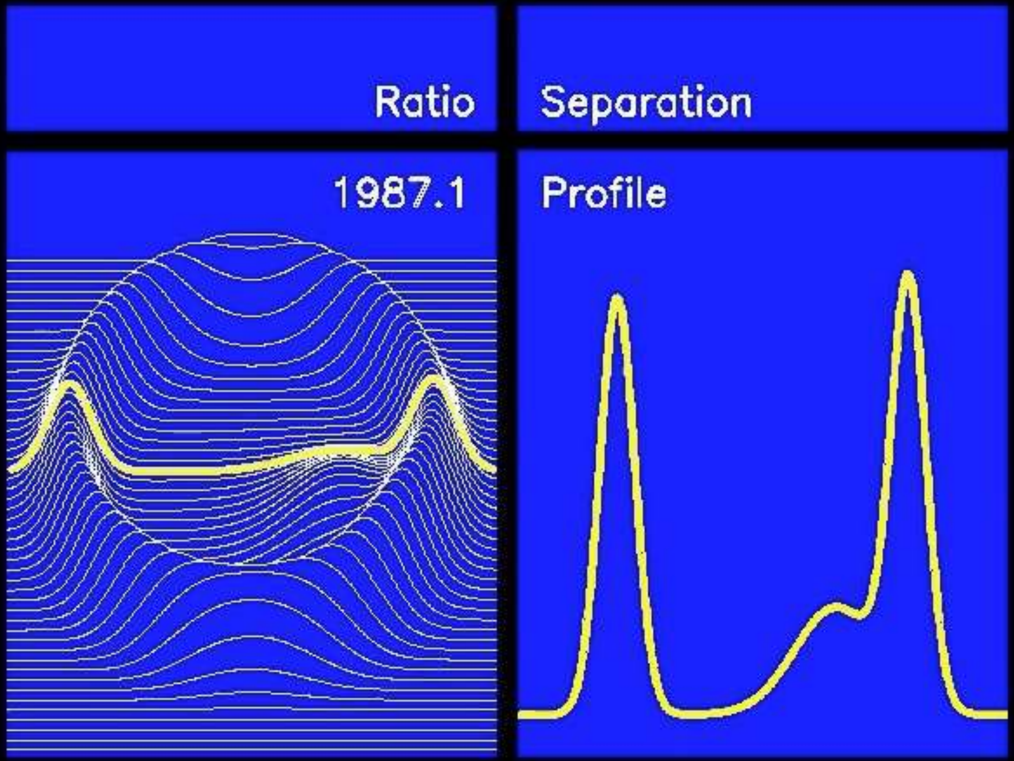

First clear evidence:

Kramer (1998, 2012)

Relativistic spin precession in the Hulse-Taylor pulsar

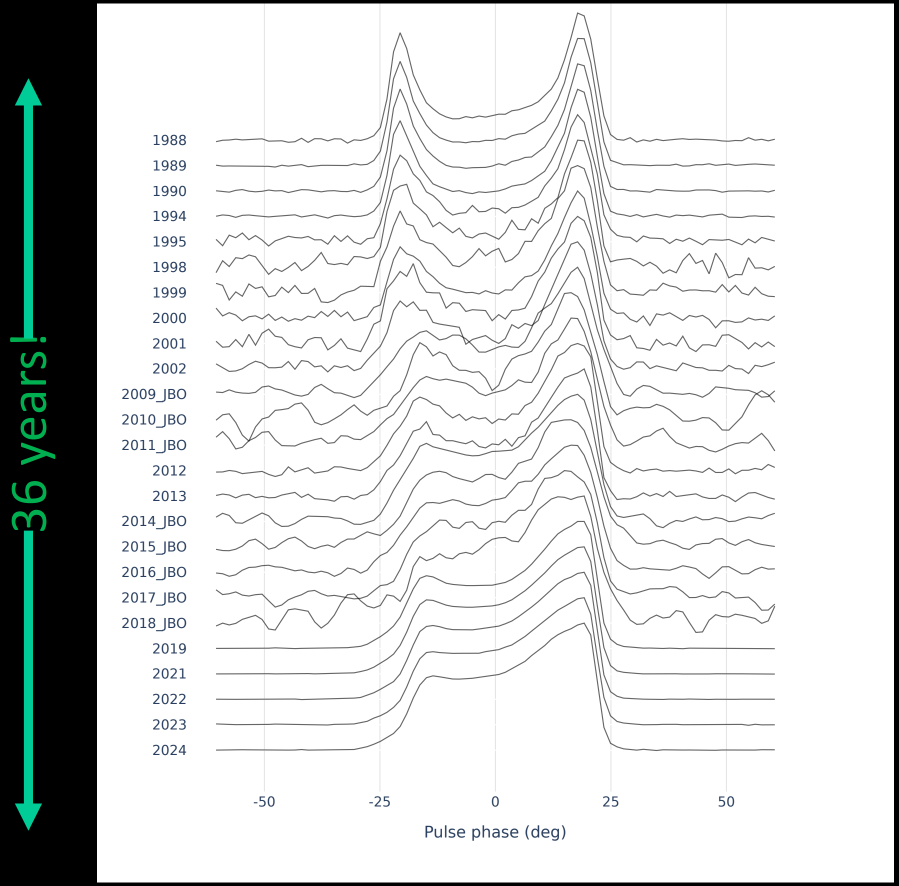


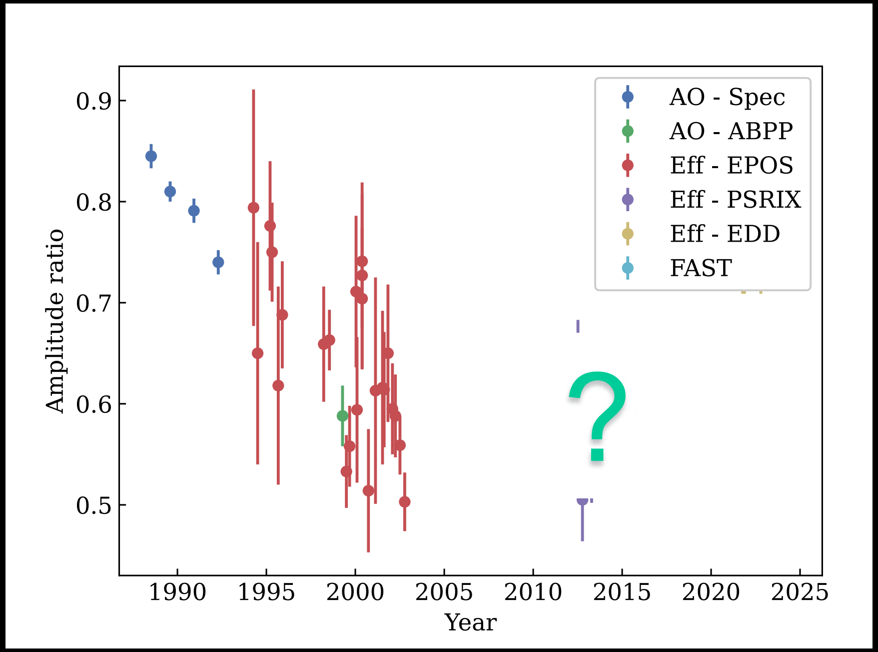
Some prediction about 25 years ago (Kramer 2000):



Relativistic spin precession in the Hulse-Taylor pulsar - Update

Graikou, Desvignes et al. (in prep.)





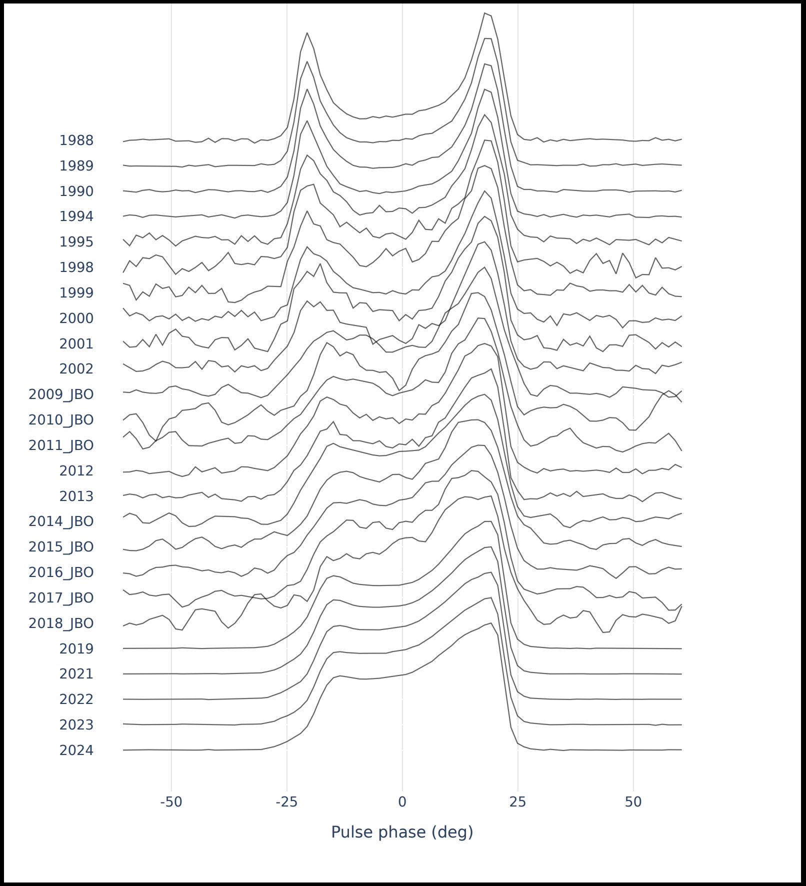
The amplitude ratio is not really increasing but flattening out – not as predicted by Kramer (2000)

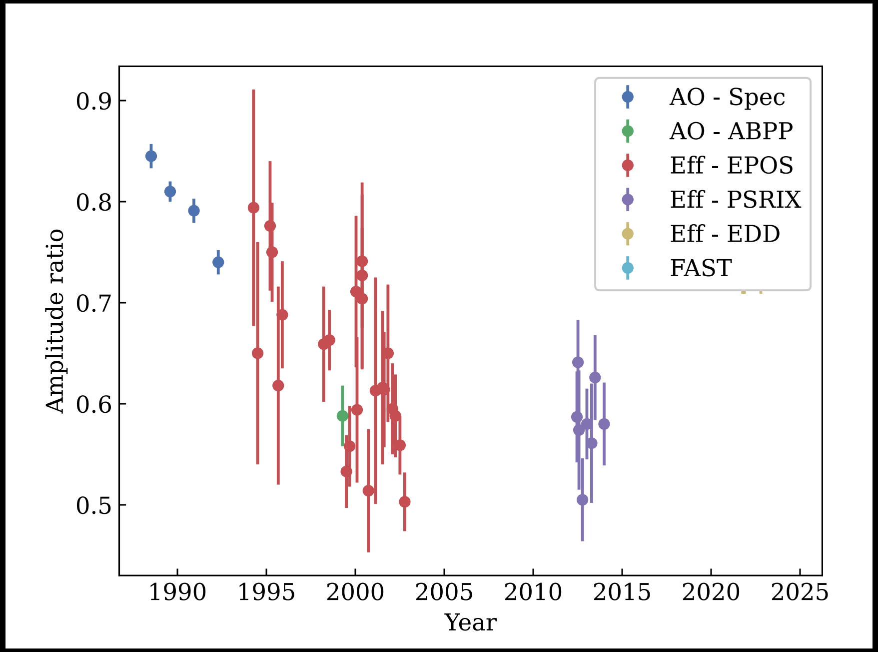
Arecibo, Effelsberg, FAST, Lovell combined!!

Relativistic spin precession in the Hulse-Taylor pulsar - Update

Graikou, Desvignes et al. (in prep.)

36 years!





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Relativistic spin precession in the Hulse-Taylor pulsar - Update

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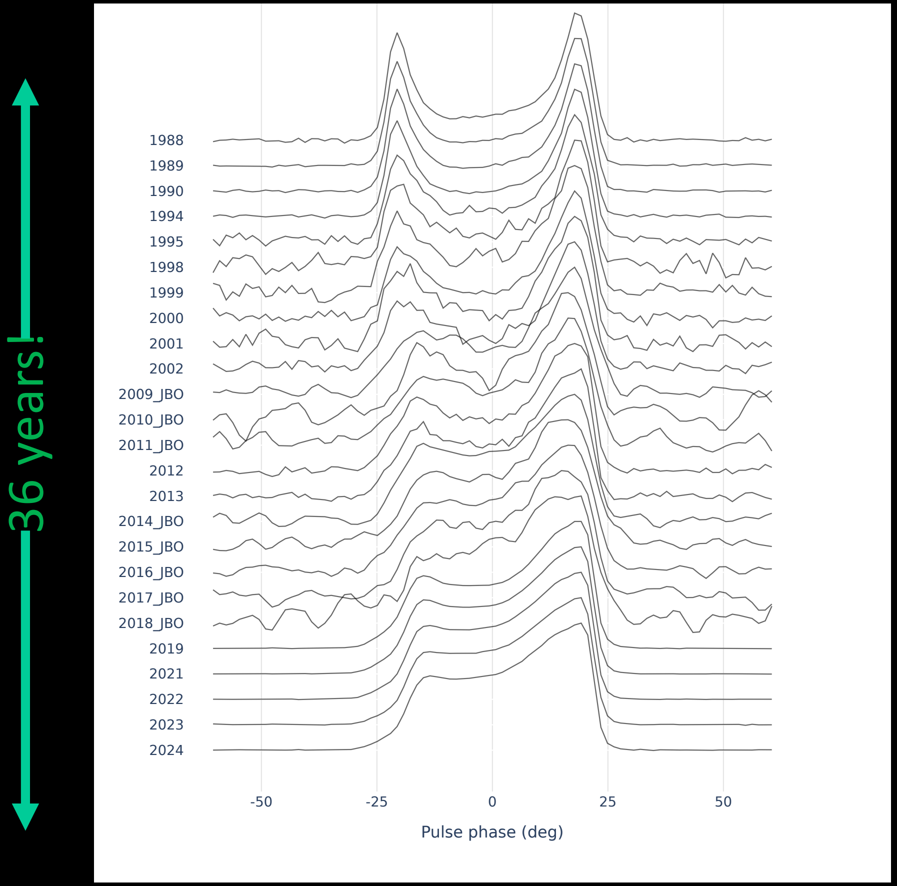
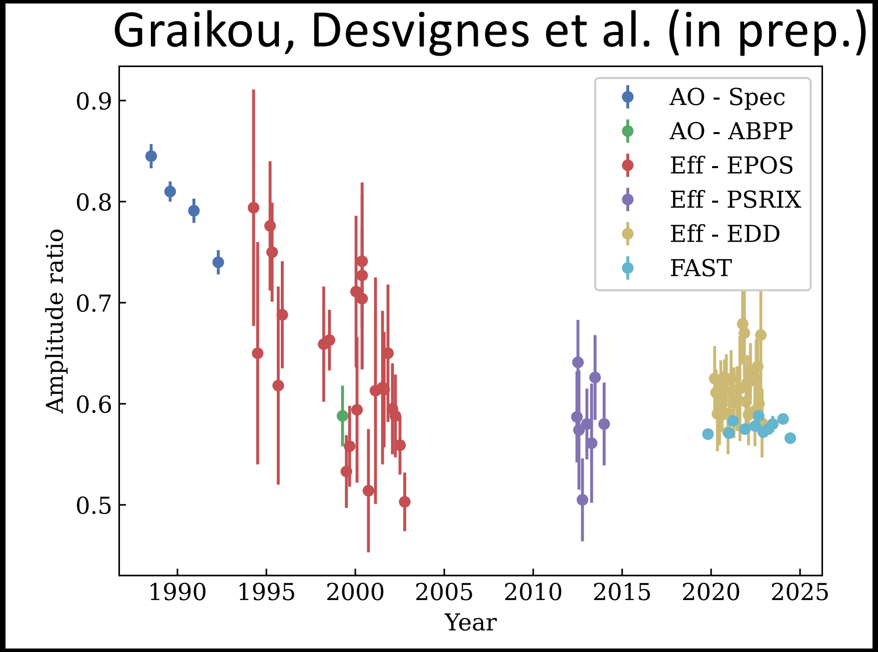


36 years!



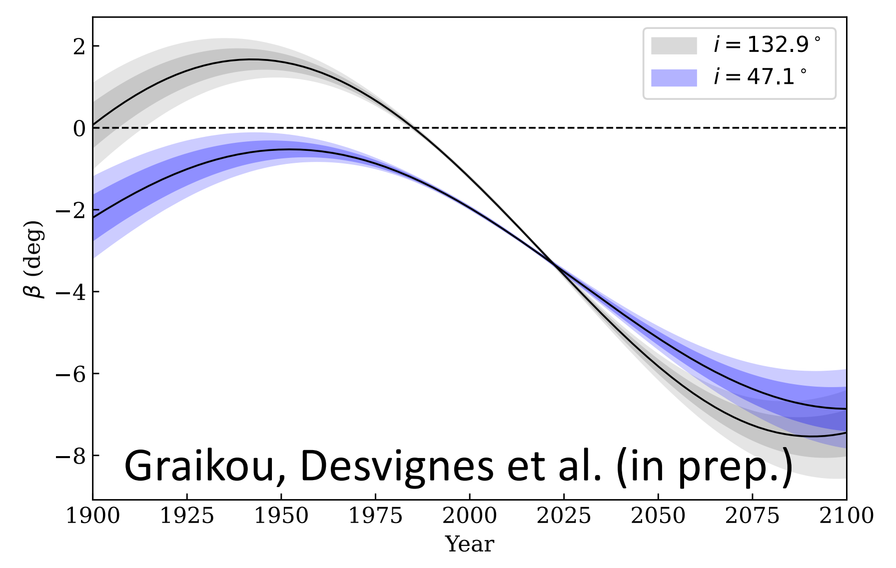
Graikou, Desvignes et al. (in prep.)

The amplitude ratio is not really increasing but flattening out – not as predicted by Kramer (2000)

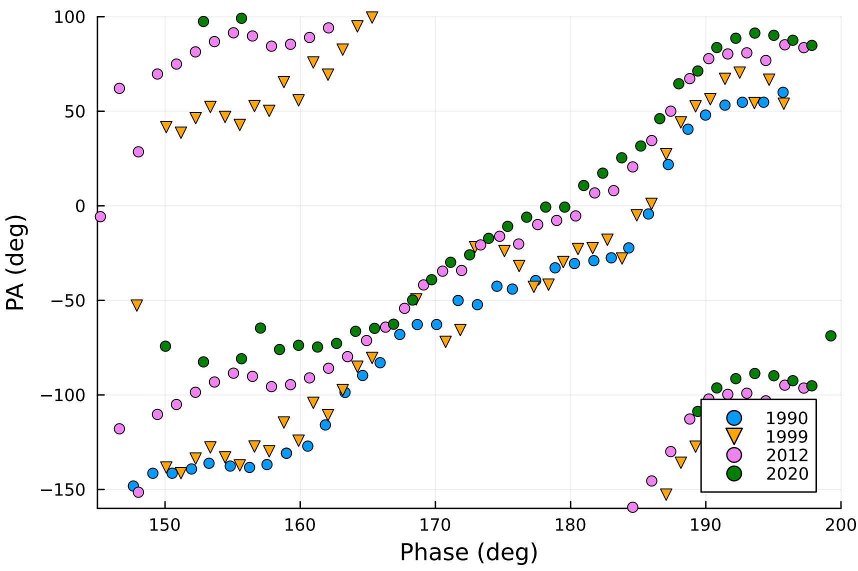
Arecibo, Effelsberg, FAST, Lovell combined!!

Relativistic spin precession in the Hulse-Taylor pulsar - Update

But geometry from polarisation in complete agreement with modelling of Kramer (1998):
λ and α agree within 1 deg!
Spin axis misaligned to orbit
by λ = 21(2) deg.



Graikou, Desvignes et al. (in prep.)



Graikou, Desvignes et al. (in prep.)

Mystery solved: there was no pole crossing.

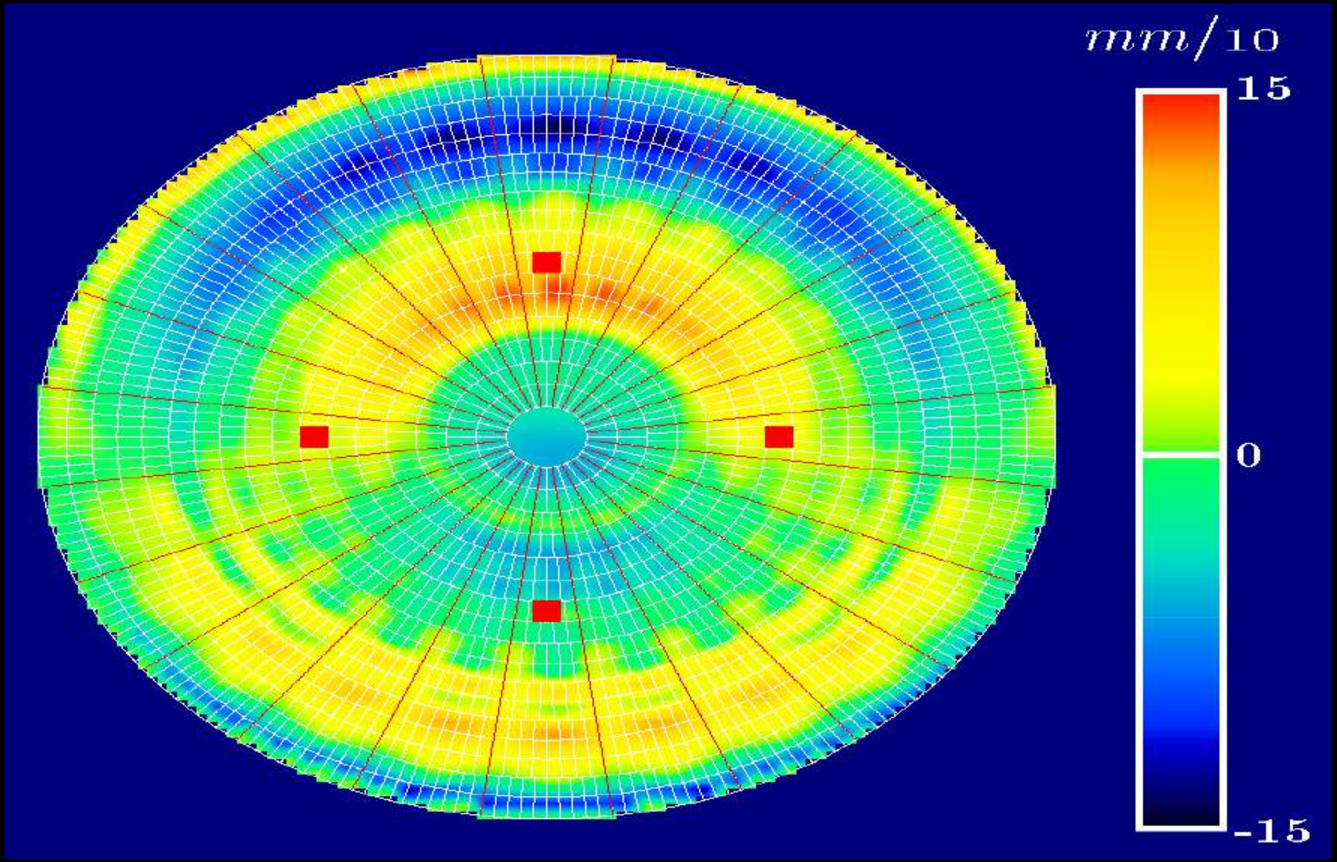
Good news: pulsar may not disappear, but that dependson extent of the pulsar beam - which is certainly not circular

Constant improvements

Structure

Track

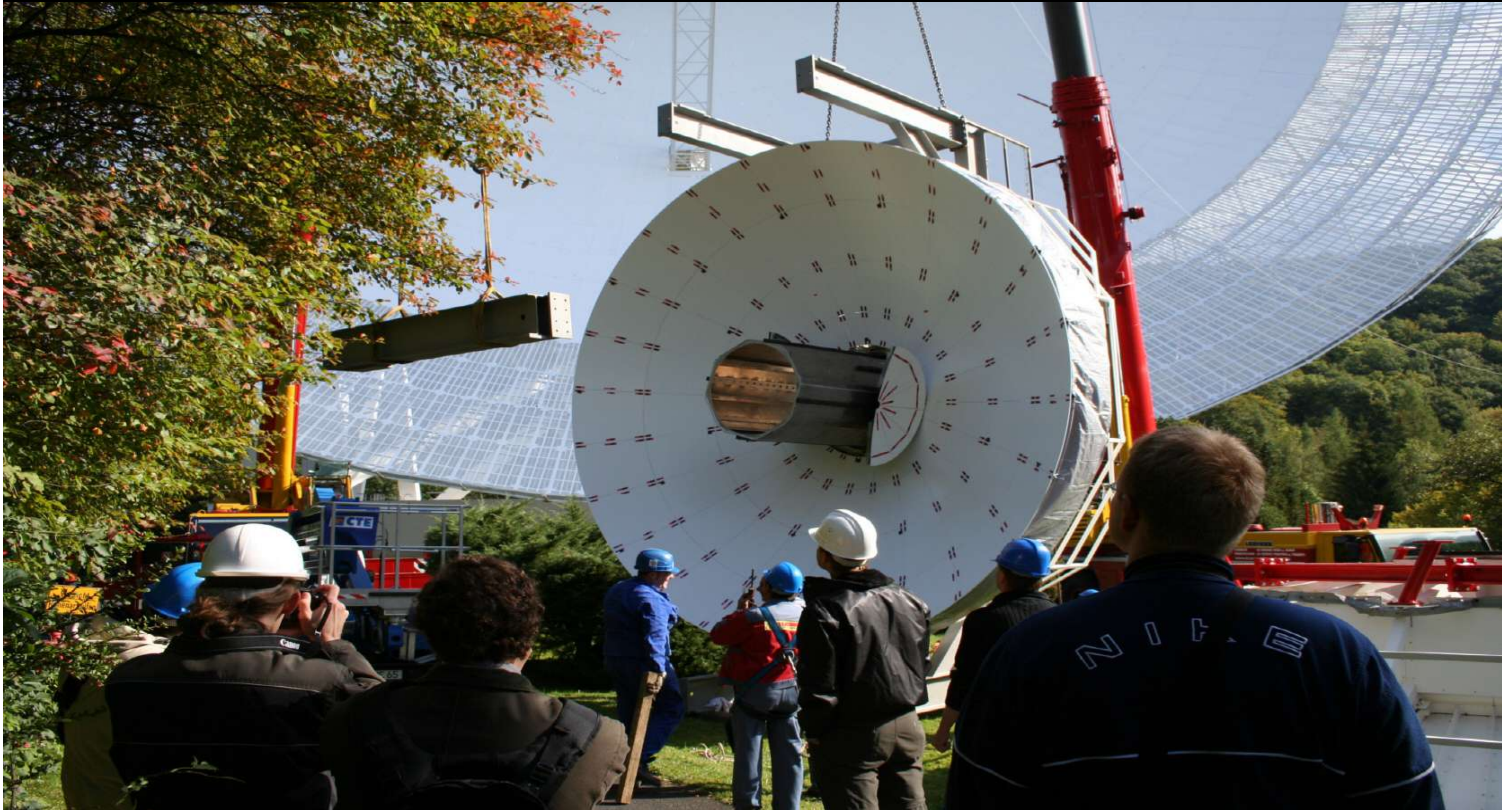
Surface



Deviations from the upper area of the ideal shape of a parabola at 70° Elevation.

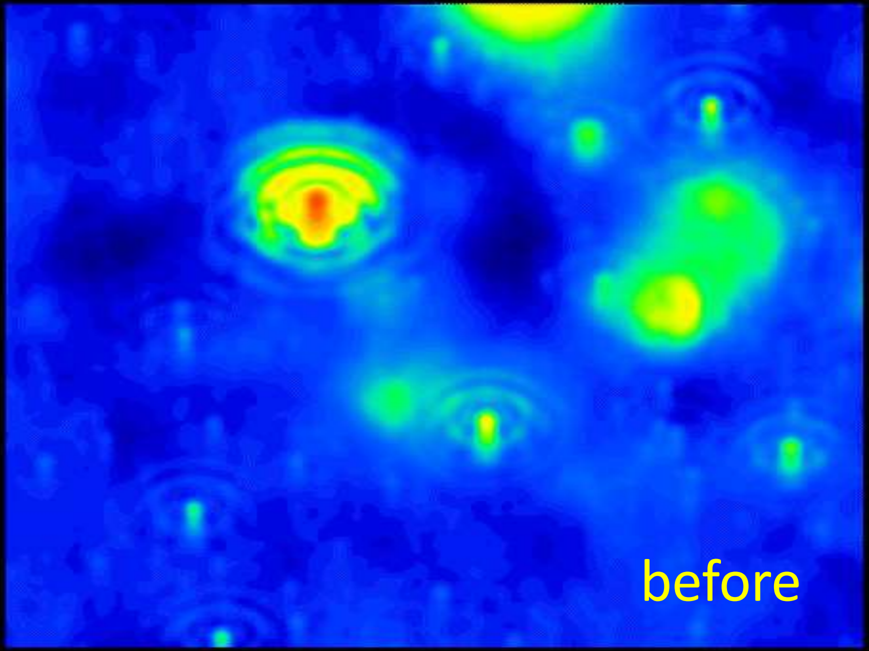
These discrepancies are a result of the not quite perfect Homology of the main Mirror.

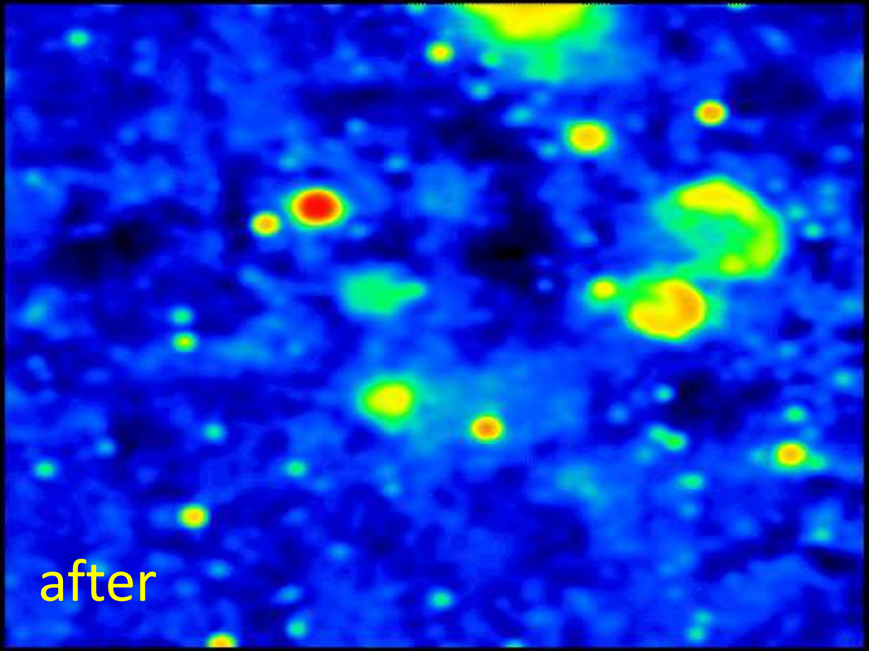
They could be replaced by a active surface of the secondary mirror be compensated.


CTE
Canon
NIKE

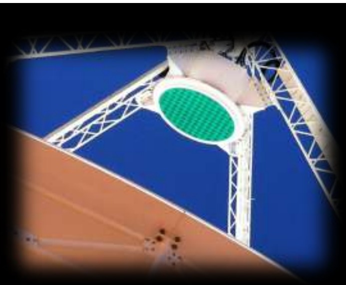

SALGERT

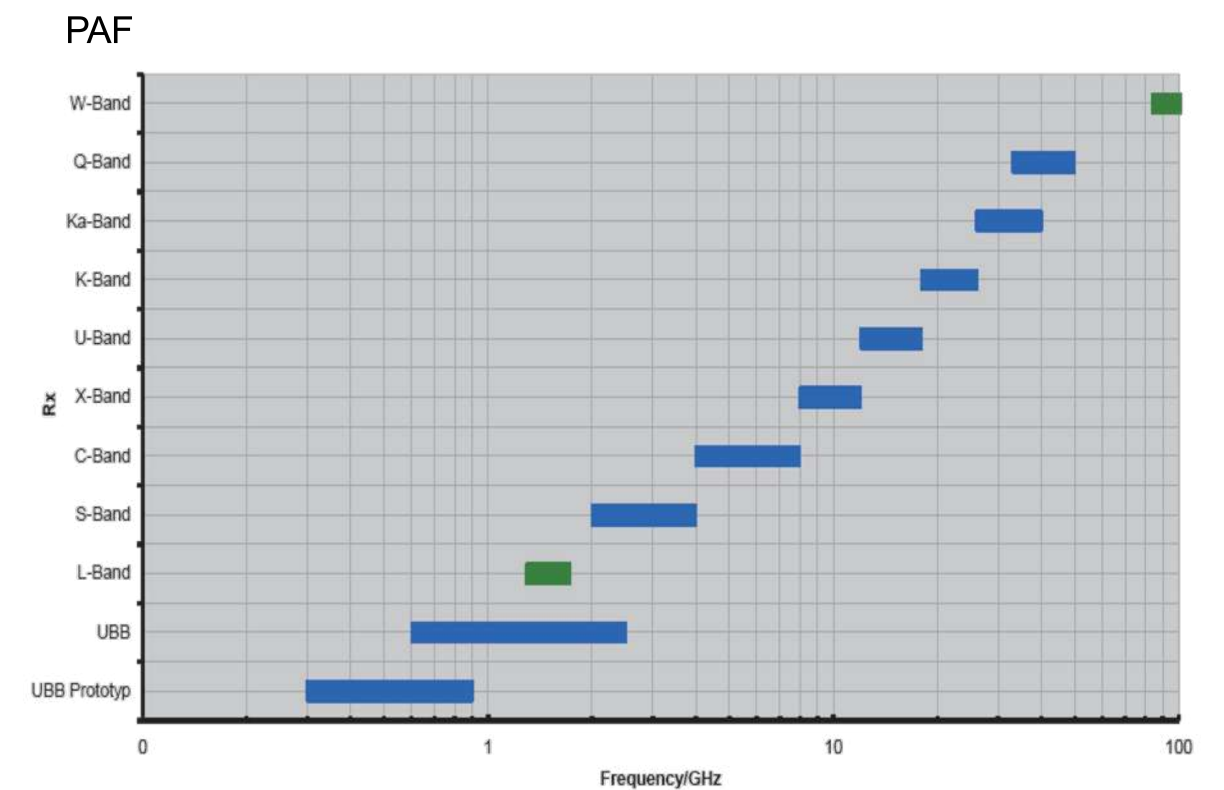
Active optics


before


after

Receivers and Backends





- Dense frequency coverage (with LOFAR to 10 MHz)
- First Broadband receiver (UBB)
- Signal path fully digital (EDD)
- First cryoPAF at 11cm
- Dark fiber to MPCDF
- Massive local compute power
- Possible connection to EU clock network

More discoveries to come!