Basics of radio astronomy

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DAAD project

University partnerships with Iraq 2022-2023

Project: "Astro-Lab: Radio Astronomy"

Project ID: 57523935

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Aims of the Baghdad Bonn partnership

Funding is provided for

- measures to support the Iraqi higher education landscape and
- the development and strengthening of sustainable structures at the partner university through German-Iraqi university partnerships.
- **The focus is on the improvement and expansion of teaching in the partner country** as well as
- on the **intensification of scientific contacts** between German and Iraqi universities.

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Why „Basics in radio astronomy?

Radio astronomy is an applied science that uses the **modern technology of telecommunications** to explore space. In addition to science, radio astronomy also imparts a **high degree of technical education** training that ranges from **local area networks and telecommunications to the reception of satellite data**.

In 2022/23, colleagues from your College are expected to continue the lecture to complete the "Introduction to Radio Astronomy" lecture established at the University of Bonn itself, and finally **to teach it as an internal training course to lecturers in their department.**

Contents

How to receive radio waves?
- Electromagnetic radiation
- radio telescopes and their different designs

Receivers
Cables
how to observe a radio source

Active Galactic Nuclei (AGN)
Supermassive Black Holes
Nucleosynthesis
Radio Galaxies and Galaxy Clusters
Molecules in Space

Bonn: hometown of German radio astronomy

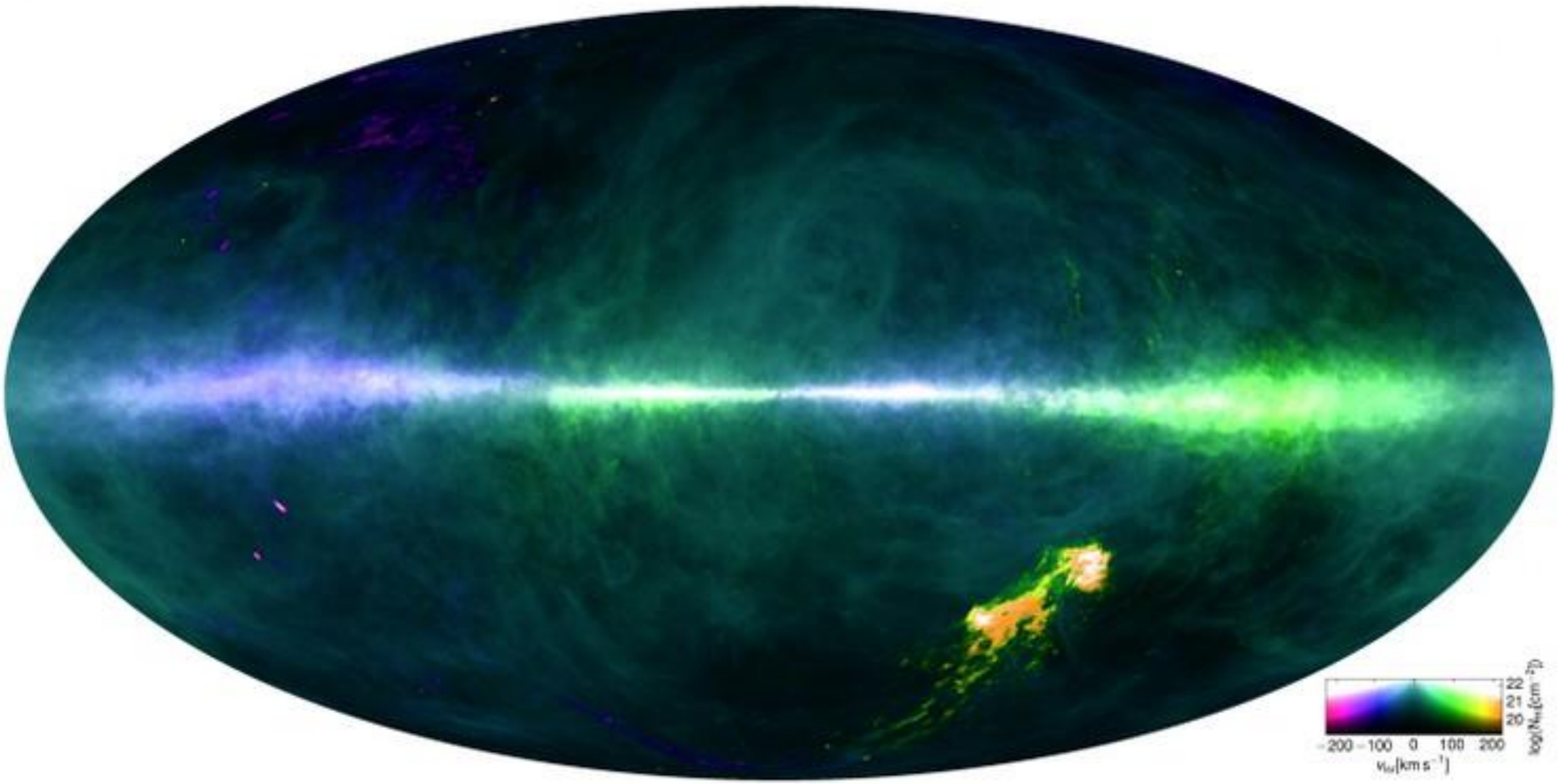
- Argelander-Institut
  - Two Professors for radio astronomiy
  - 4-m Nanten telescope Atacama desert
- Max-Planck-Institut für Radioastronomie
  - Three directors
  - One of the world‘s largest radio astronomy research facilities
  - Operation of unique instruments
    - Effelsberg 100-m-telescope
    - APEX 12-m-telescope
    - LOFAR-station at Effelsberg

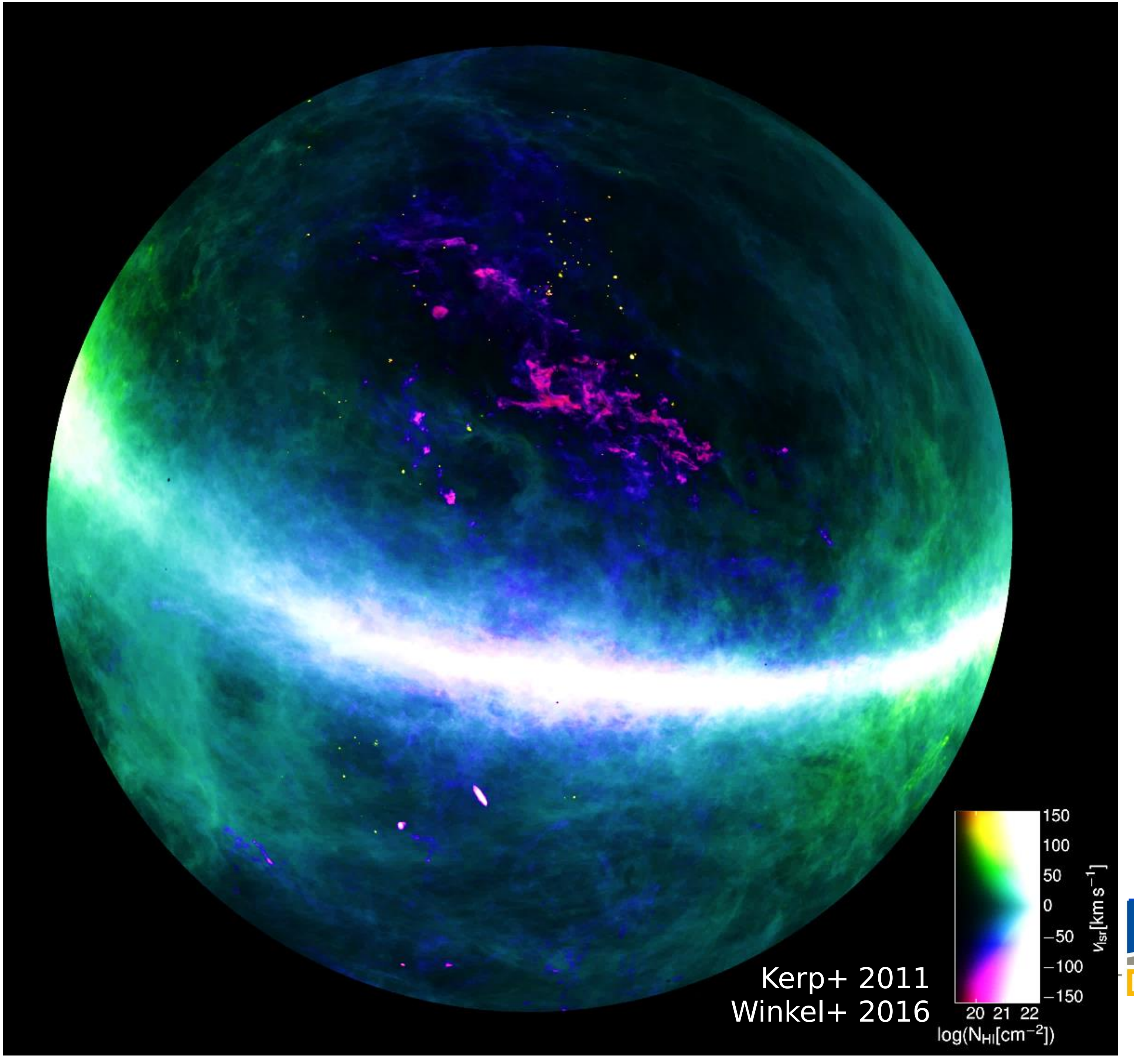
100-m-radio telescope

- The 100-m radio telescope at Bad Münstereifel-Effelsberg is one of the two fully steerable 100-m-telescopes world wide.
- It starts operation at the 12. May 1971 aiming to study the Sun's photosphere and corona down to a wavelengt of 6cm.
- Today multiple receivers cover a huge frequency range. Starting at 90cm bis zu 0.3 cm.
- There was no necessity to modify the basic construction. The surface is such as accurate that it can work down to the cut-off frequency of the Earth atmosphere.

HI4PI: Effelsberg & Parkes Milky Way Surveys

HI4PI collaboration: 2016 A&A 594, A116




Kerp+ 2011
Winkel+ 2016
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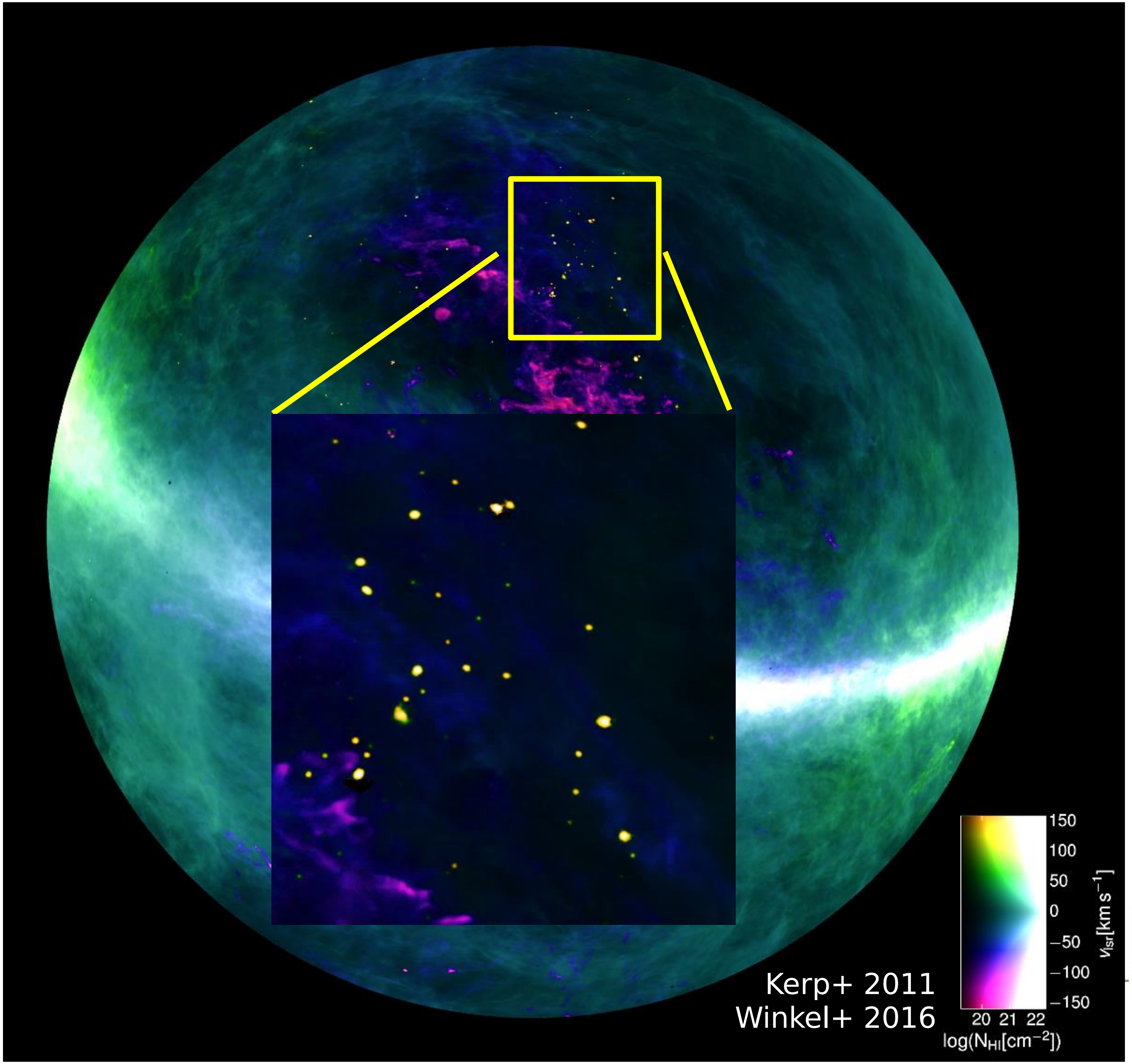
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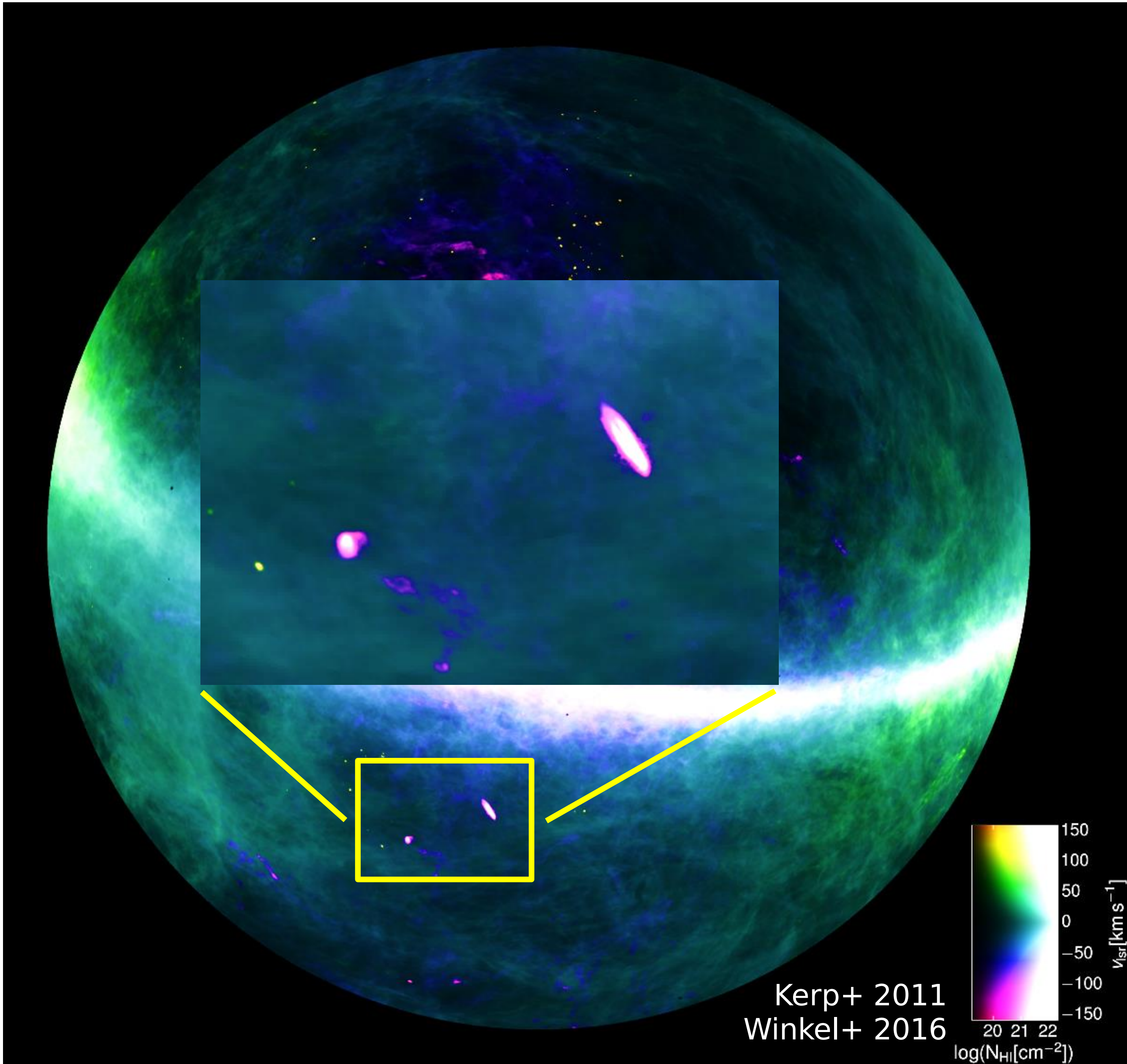

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12-m-APEX-telescope (Chajnantor)

- APEX is an acronym for Atacama Pathfinder Experiment.
- The radio telescope is located at the „Llano de Chajnantor“, in the Atacama desert in Chile. At an altitude of about 5.100m it receives radiation between 211 GHz and 1390 GHz.

4-m-Nanten-telescope (Chajnantor)

- The Universities of Cologne and Bonn operates in collaboration with the University of Nagoya (Japan) a 4-m radio dish.
- It observes cosmic objects in a frequency range between 115GHz bis 880GHz.
- The small dish is ideally suited for survey purposes, meaning measuring large portions of the sky within a short period of time.

Stockert radio telescope

Astropeiler Stockert was Germany‘s first radio telescope.
Its starts operation in 1956 and was used until 1990.
Famous are the Stockert radio surveys in radio continuum radiation.

In the course of our DAAD project **we are going to use the Stocker telescope remotely for observations.**

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Why radio astronomy?

- Radio wave are penetrade dense material. You can make telephone calls from inside a building.
- The most extreme conditions of matter a bright radio sources:
  - Neutron stars → Pulsars
  - Black Holes → Accretion disks
- Most precize measurements of Doppler motions
- Highest angular resolution in astrophysics
  - local
  - global
  - satellites

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Long wavelengths vs. visible light

The discovery of radio astronomy

James Clerk Maxwell

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

James Clerk Maxwell was a genius in the natural sciences.
In 1865 Maxwell discovered that **light and the electrical and magnetic phenomena of his time are two sides of the same coin!** He could summarize the observation findings in form of four equations. Here only the electric E and the magnetic fields B enter as well as the charge ρ and the current J.
From the time derivative of the equation follows a wave equation.
Maxwell recognized already, that these electron-magnetic waves propagate with the already known speed of light c.

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Heinrich Hertz

- **Heinrich Hertz** was a physicist with very good mathematical skills. These allowed him to develop physical experiments to study Maxwell's theory of electromagnetism.

- Hertz succeeded in building transmitters and receivers of electromagnetic waves and on November 13, 1886, he was the first to generate free electromagnetic waves.

- In addition, he was able to show that electromagnetic waves propagate at the speed of light and can be refracted, diffracted and polarized in a manner analogous to light.

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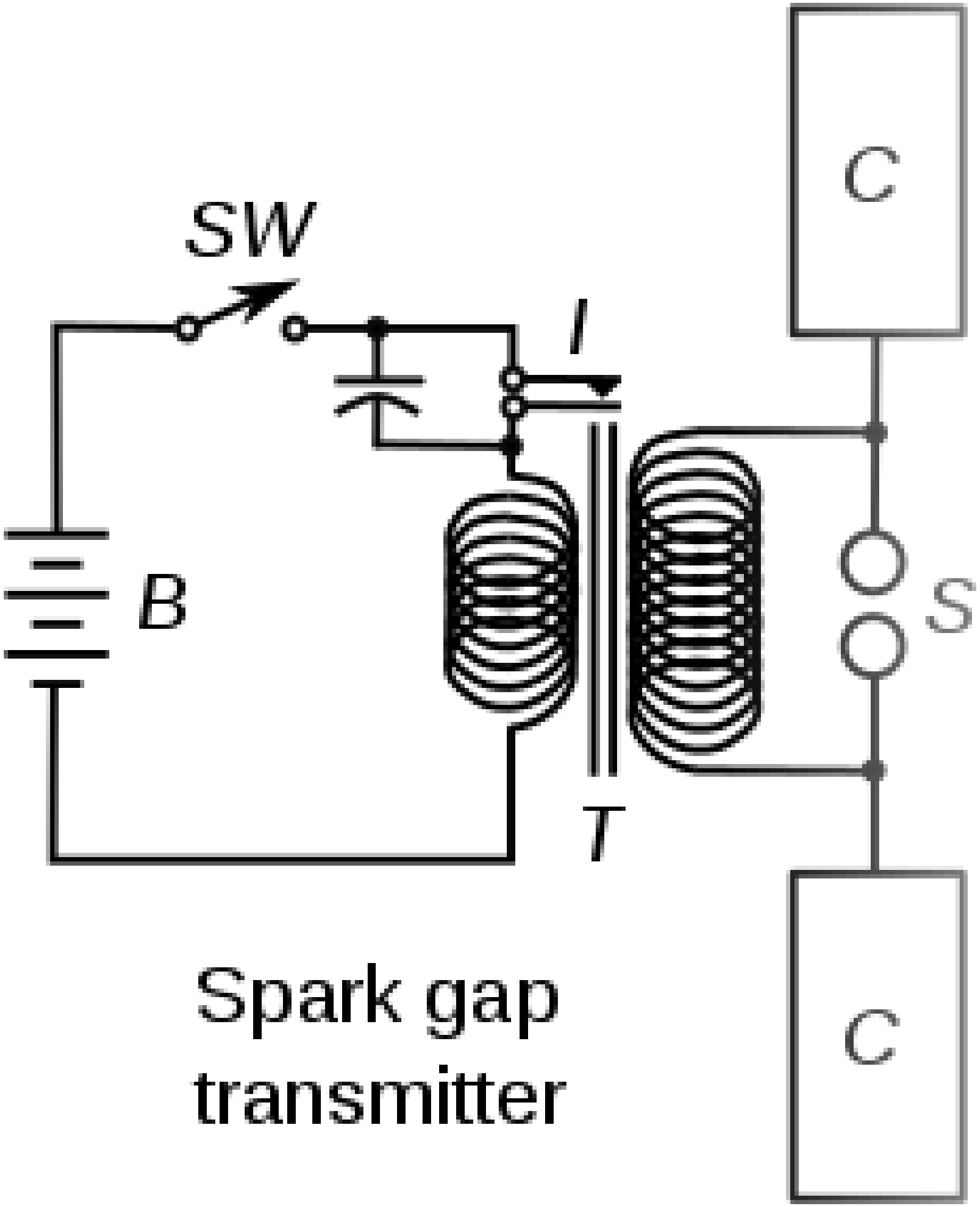

Hertz transmitter and receiver

Hertz's 1886 apparatus for generating and detecting radio waves: a spark gap transmitter (left), consisting of a dipole antenna with a spark gap (S) fed by high-voltage pulses from a Ruhmkorff coil (T), and a receiver (right), consisting of a loop antenna and a spark gap.

Guglielmo Marconi

Guglielmo Marconi was a pioneer in the use of electromagnetic radiation for sound and voice telecommunications.

He succeeded in making the first intercontinental Morse communication on December 12, 1901. Marconi's work was recognized with the Nobel Prize in Physics.

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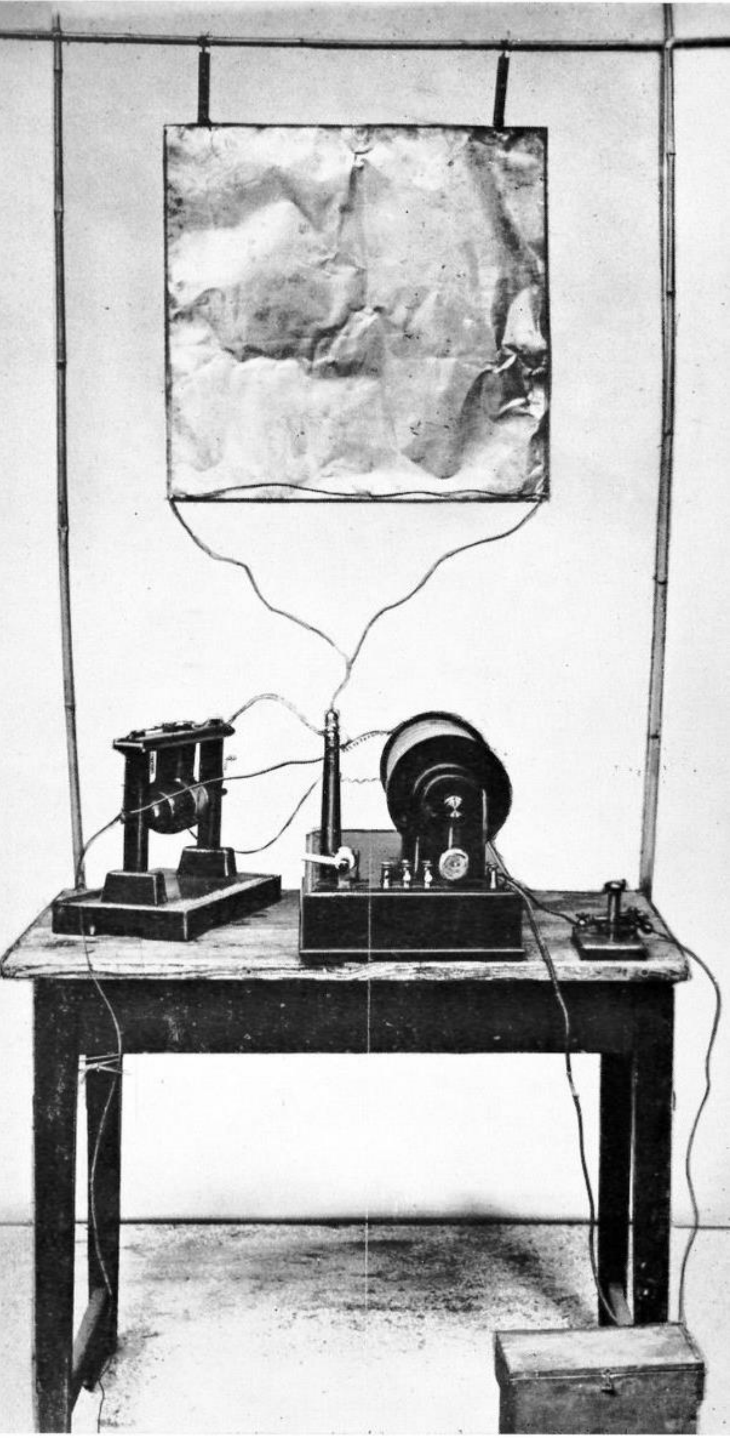

Marconi's Transmitter

- Marconi's first transmitter with a monopole antenna. It consisted of a raised copper plate (top) connected to a Righi spark gap (left) operated by an induction coil (center) with a telegraph key (right) for switching on and off to spell out text messages in Morse code.

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Karl Guthe Jansky / 1932-1933

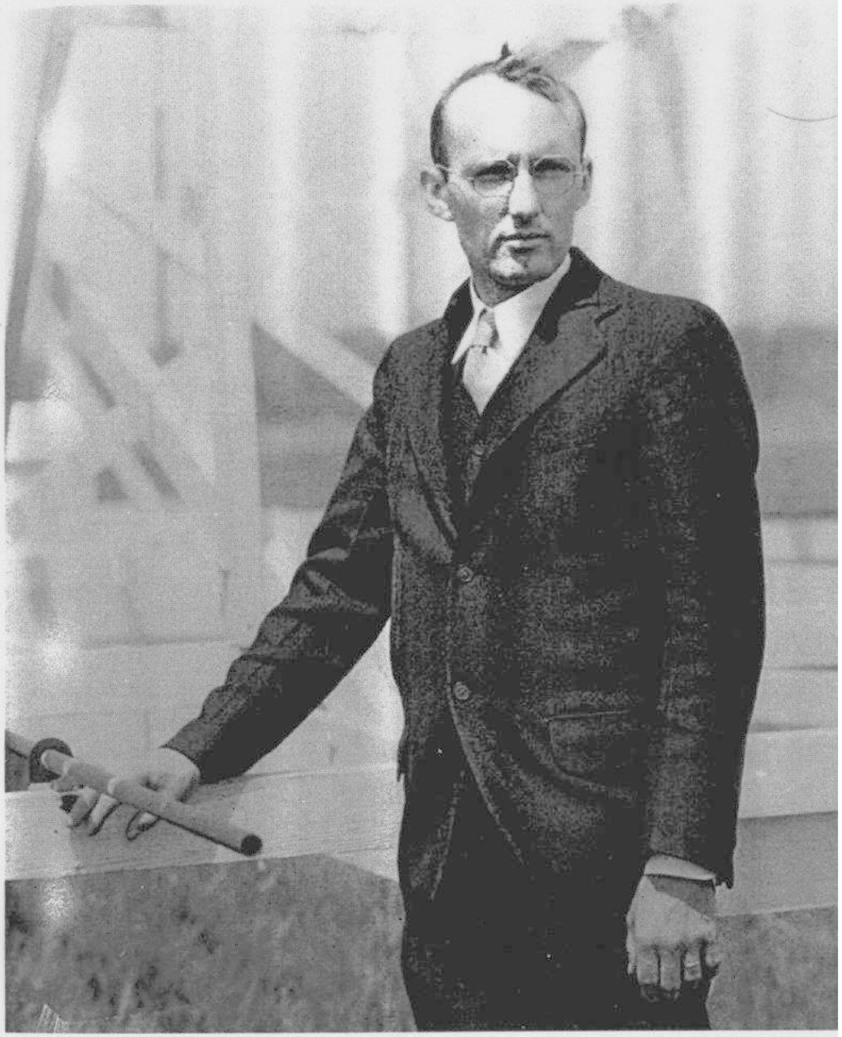

Fig. 1—Karl Guthe Jansky, about 1933.

http://www.nrao.edu

(1905-1950)

Karl Guthe Jansky, on behalf of the Bell Company, investigated the interference of radiations in telecommunications.

He found out that beside short-time disturbances (lightnings) a daily disturbance is observed at a time interval of 23 hours and 54 minutes.

This radiation originates from the Galactic Center. It is the so-called synchrotron radiation which will be physically described many years later.

Jansky's discovery was **not** the starting signal for radio astronomy

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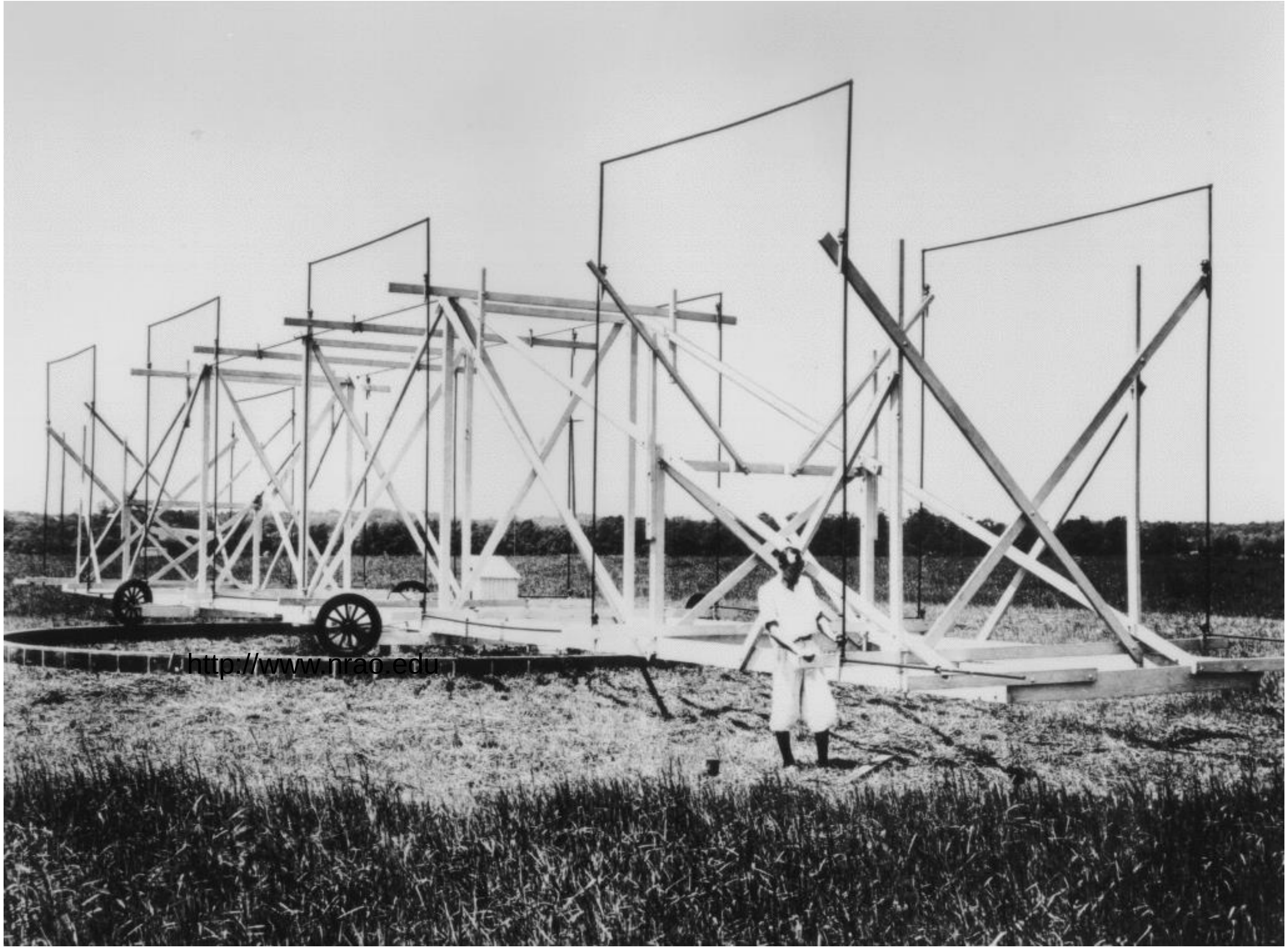
Karl Guthe Jansky / 1932-1933



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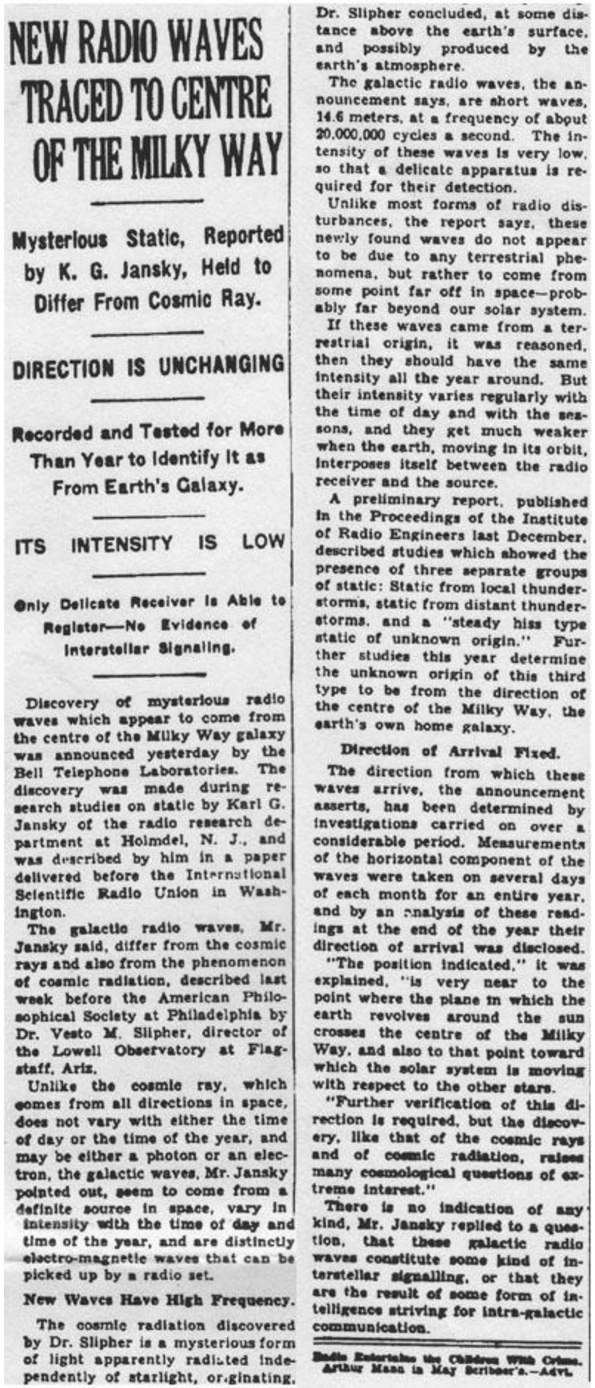

NEW RADIO WAVES TRACED TO CENTRE OF THE MILKY WAY

Mysterious Static, Reported by K. G. Jansky, Held to Differ From Cosmic Ray.

DIRECTION IS UNCHANGING

Recorded and Tested for More Than Year to Identify It as From Earth's Galaxy.

ITS INTENSITY IS LOW

Only Delicate Receiver Is Able to Register—No Evidence of Interstellar Signaling.

Discovery of mysterious radio waves which appear to come from the centre of the Milky Way galaxy was announced yesterday by the Bell Telephone Laboratories. The discovery was made during research studies on static by Karl G. Jansky of the radio research department at Holmdel, N. J., and was described by him in a paper delivered before the International Scientific Radio Union in Washington.

The galactic radio waves, Mr. Jansky said, differ from the cosmic rays and also from the phenomenon of cosmic radiation, described last week before the American Philosophical Society at Philadelphia by Dr. Vesto M. Slipher, director of the Lowell Observatory at Flagstaff, Ariz.

Unlike the cosmic ray, which comes from all directions in space, does not vary with either the time of day or the time of the year, and may be either a photon or an electron, the galactic waves, Mr. Jansky pointed out, seem to come from a definite source in space, vary in intensity with the time of day and time of the year, and are distinctly electro-magnetic waves that can be picked up by a radio set.

New Waves Have High Frequency.

The cosmic radiation discovered by Dr. Slipher is a mysterious form of light apparently radiated independently of starlight, originating, Dr. Slipher concluded, at some distance above the earth's surface, and possibly produced by the earth's atmosphere.

The galactic radio waves, the announcement says, are short waves, 14.6 meters, at a frequency of about 20,000,000 cycles a second. The intensity of these waves is very low, so that a delicate apparatus is required for their detection.

Unlike most forms of radio disturbances, the report says, these newly found waves do not appear to be due to any terrestrial phenomena, but rather to come from some point far off in space—probably far beyond our solar system.

If these waves came from a terrestrial origin, it was reasoned, then they should have the same intensity all the year around. But their intensity varies regularly with the time of day and with the seasons, and they get much weaker when the earth, moving in its orbit, interposes itself between the radio receiver and the source.

A preliminary report, published in the Proceedings of the Institute of Radio Engineers last December, described studies which showed the presence of three separate groups of static: Static from local thunderstorms, static from distant thunderstorms, and a "steady hiss type static of unknown origin." Further studies this year determine the unknown origin of this third type to be from the direction of the centre of the Milky Way, the earth's own home galaxy.

Direction of Arrival Fixed.

The direction from which these waves arrive, the announcement asserts, has been determined by investigations carried on over a considerable period. Measurements of the horizontal component of the waves were taken on several days of each month for an entire year, and by an analysis of these readings at the end of the year their direction of arrival was disclosed.

"The position indicated," it was explained, "is very near to the point where the plane in which the earth revolves around the sun crosses the centre of the Milky Way, and also to that point toward which the solar system is moving with respect to the other stars.

"Further verification of this direction is required, but the discovery, like that of the cosmic rays and of cosmic radiation, raises many cosmological questions of extreme interest."

There is no indication of any kind, Mr. Jansky replied to a question, that these galactic radio waves constitute some kind of interstellar signalling, or that they are the result of some form of intelligence striving for intra-galactic communication.

The discovery of radio waves coming from beyond the solar system was reported by Karl Jansky in the New York Times on March 5, 1933.

Jansky discovered radiation that is bright at low frequencies and dim at high ones.

If the spectrum of a blackbody is simply fitted to this part of the radio frequency spectrum, the radiation maximum would be a few million Kelvin according to Wien's displacement law.

Since such temperatures were not considered realistic, this radiation is also called non-thermal radio radiation.
It was not until 1944 that Ivanenko and Pomeranchuk realized that very fast electrons in magnetic fields emit this radiation, which we now call synchrotron radiation.

Grote Reber / 1937-1938

(1911-2002)

Grote Reber was a radio engineer and radio amateur who built a prototype radio telescope in his home garden.

He followed the discoveries of Jansky, but according to the radiation characteristics of a black body he started his search at high frequencies.

The radiation power of synchrotron radiation grows inversely proportional with frequency.

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Grote Reber / 1937-1938

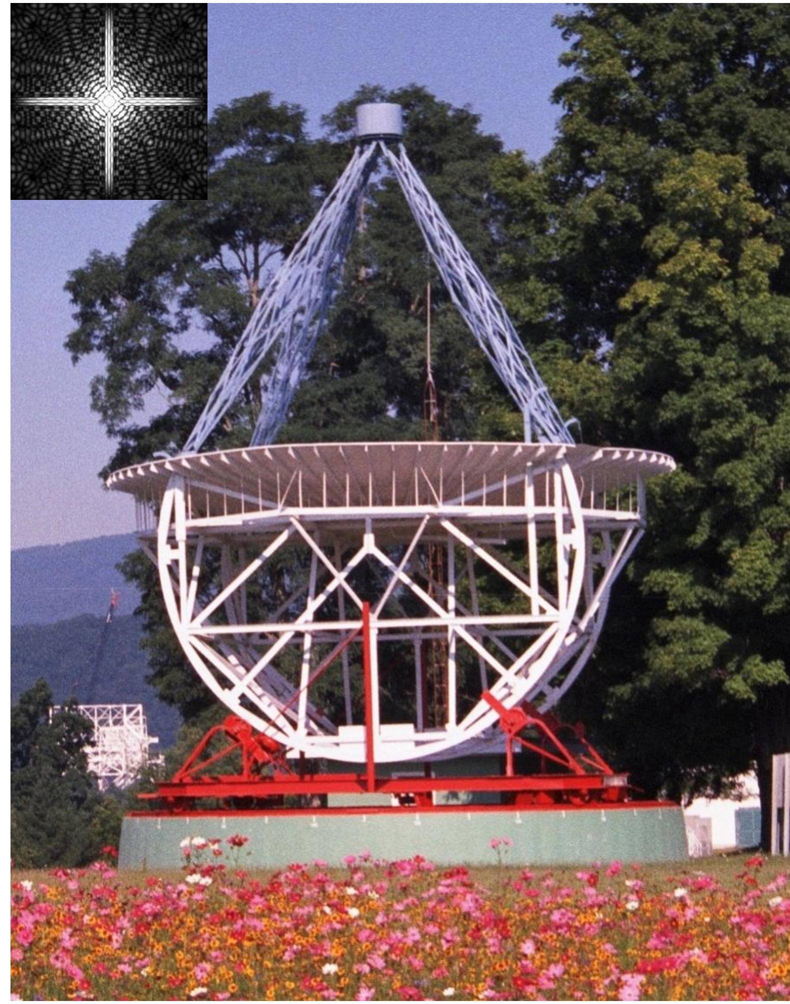
Grote Reber's telescope is the first radio telescope that used a now classical parabolic reflector.

The receiver was installed in the primary focus of the telescope.

Due to the receiver and the supporting legs, the aperture is blocked, i.e. the antenna pattern shows a wide main lobe and strong side lobes.

Because of the Rayleigh-Jeans approximation B_ν proportional to ν^2, it started at 3.3 GHz, eventually mapping the Milky Way for the first time at 160 MHz.

T_{sys}, in combination with the fact that continuous radiation is maximal at low frequencies, was the reason for Reber's evolution towards low frequencies.



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Grote Reber / 1937-1938

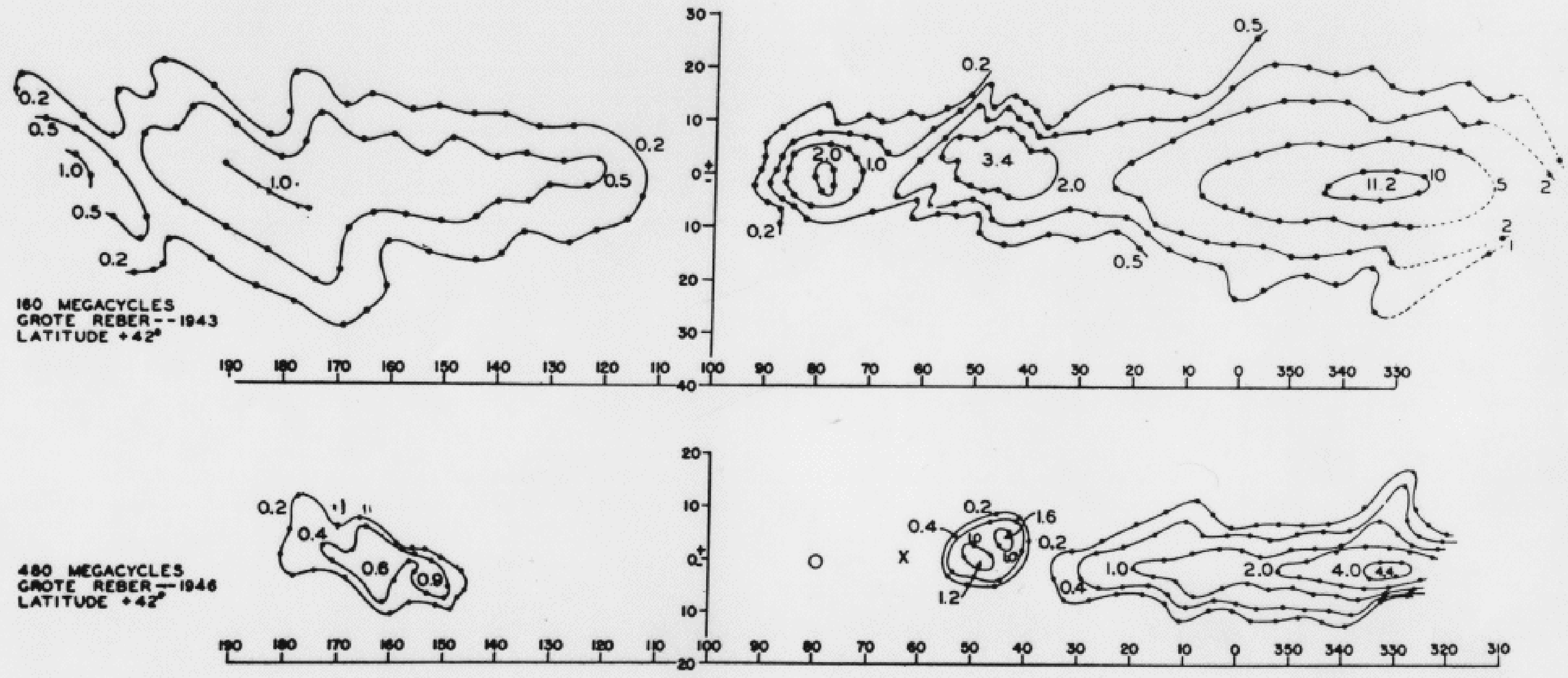


FIG. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.

http://www.nrao.edu

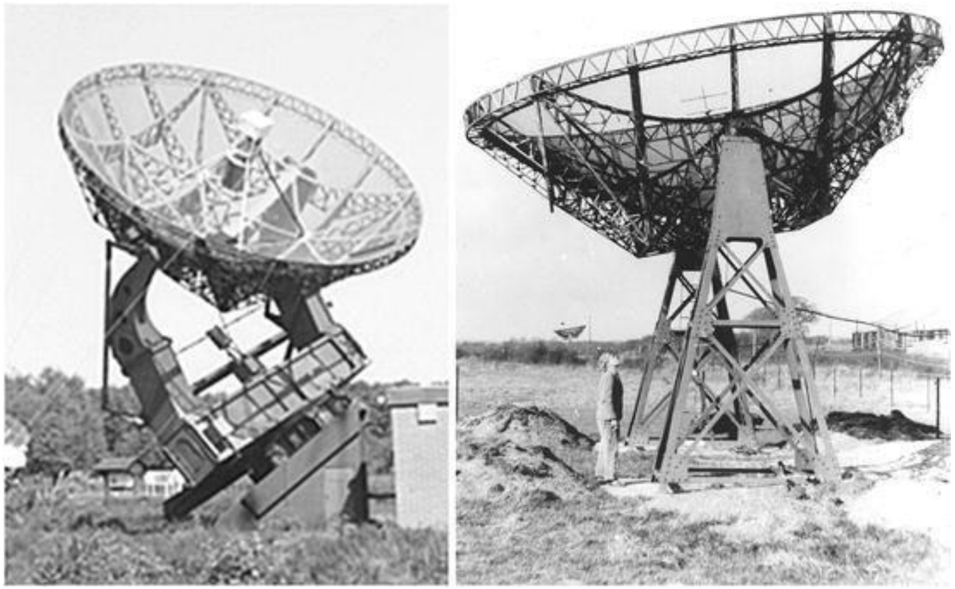
Contour maps of the Milky Way made by Grote Reber. Analogous to contour lines in geographical maps, these contours show the brightness distribution of the synchrotron radiation.

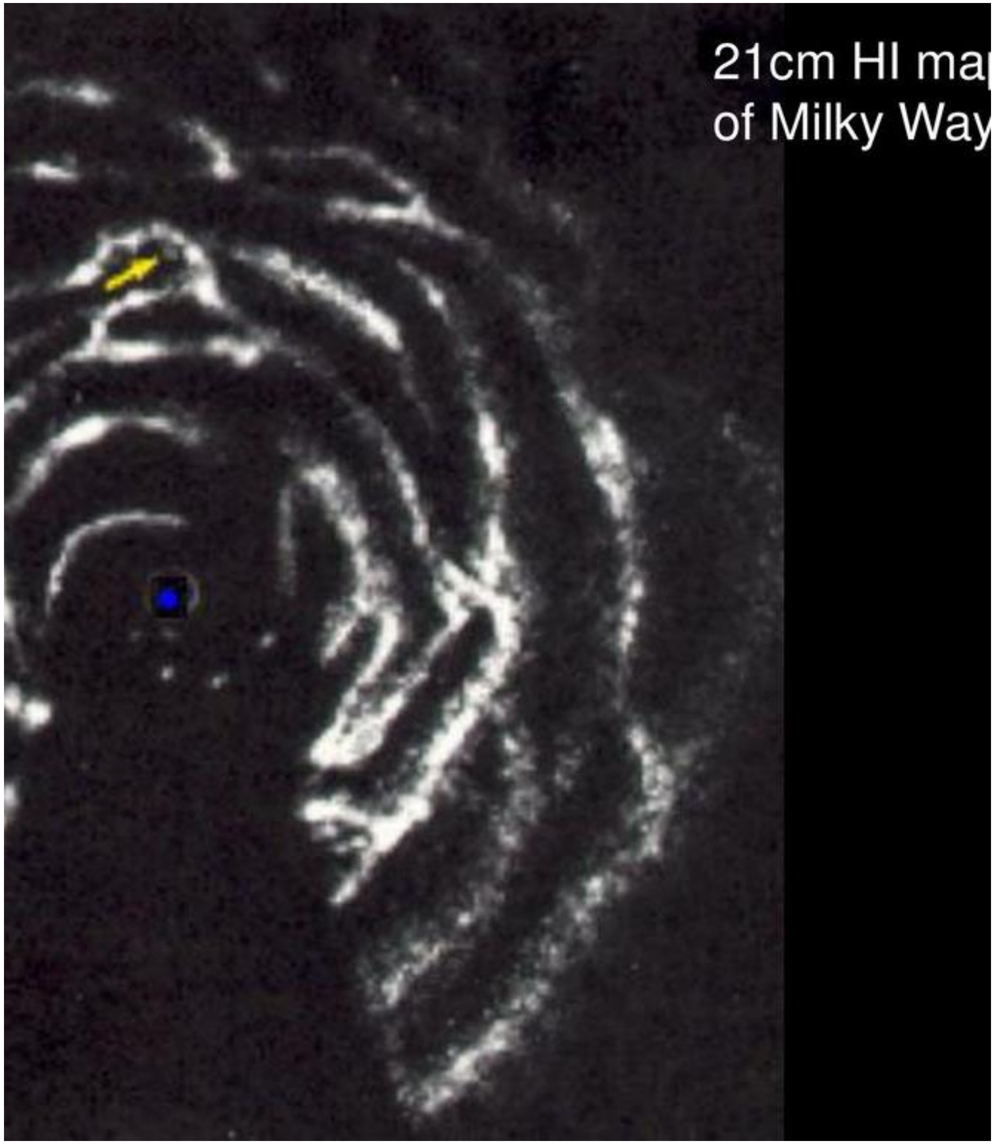
Würzburg Riese

After World War II, Europe was full of radio telescopes!

The radar technology had developed far during the war, thus the technical bases for the radio astronomy were present.

Although the so-called Würzburg Giant was available in thousands in Germany and the Nazi-occupied territories, almost all of them were melted down and processed further. Only very few specimens are still to be seen.



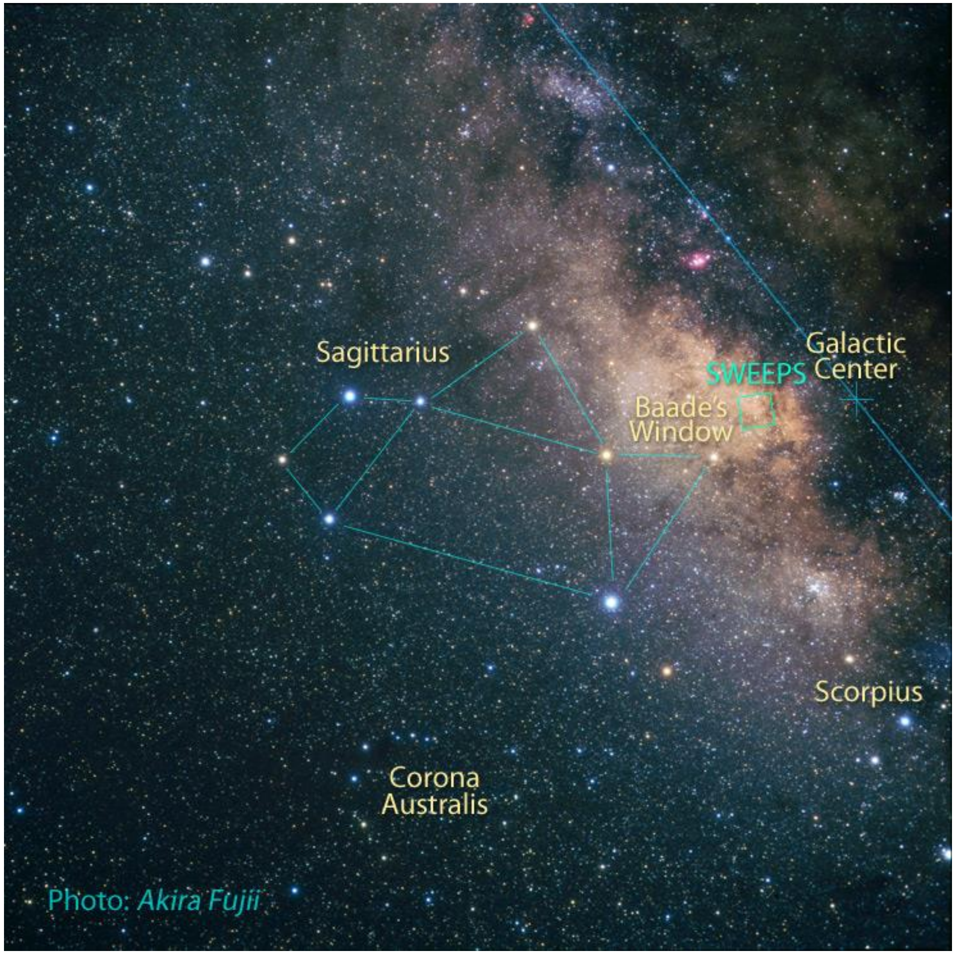


Würzburg Riese: Milky Ways spiral structure

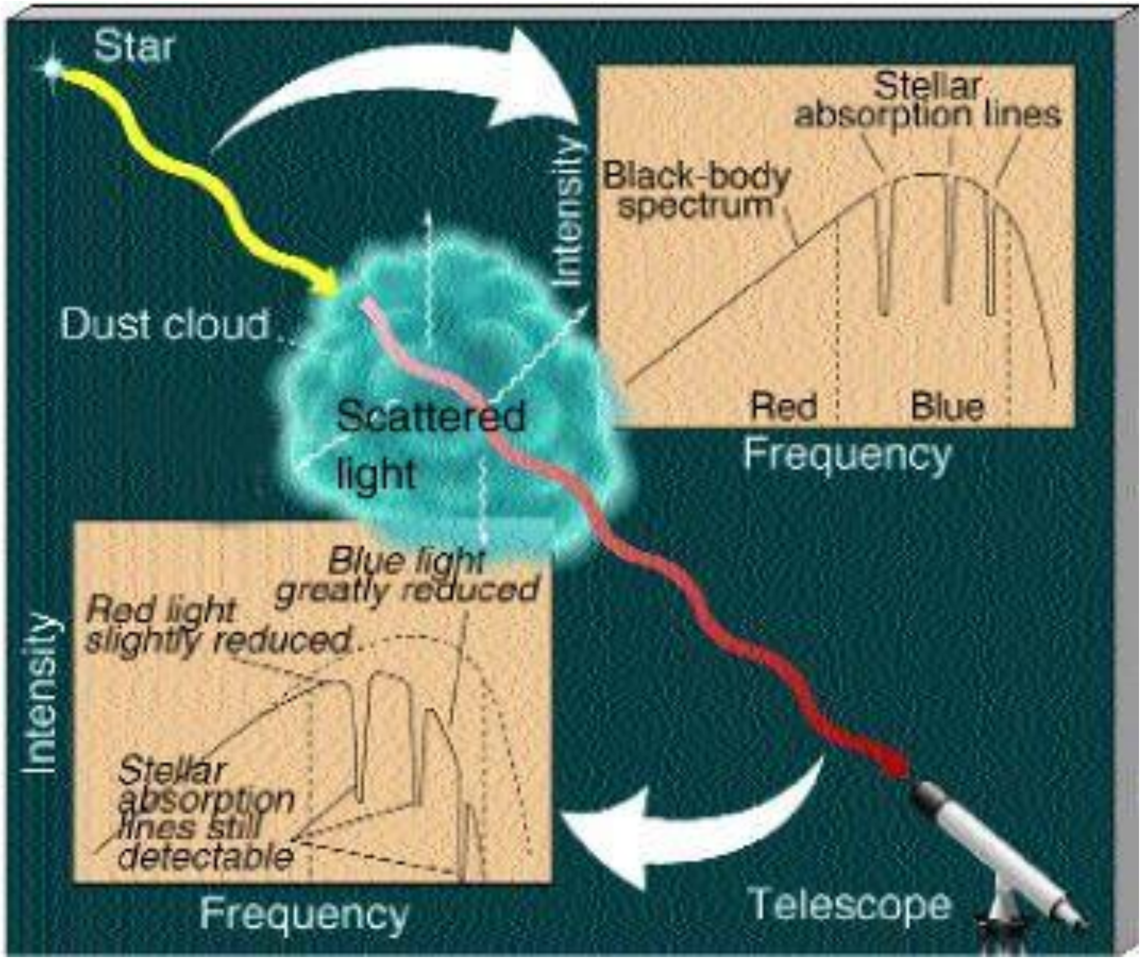
- Survey of the Milky Way with the Katwijk telescope in the Netherlands in the mid 1950's.
- The Katwijk telescope is of the type a Würzburg Riese with a 21-cm line receiver.
- Jan Hinrich Oort pushed radio astronomical research at 21-cm wavelength.

Baade's Window

- Due to the almost perfect mixing of gas and dust, the view in visible light is strongly limited.
- In the plane of the Milky Way we can look only a few kpc far in the visible spectral range. No photon from the Galactic Center reaches an optical observer.
- Walter Baade found a small gap in the dust that gave a view of stars of the Galactic Bulge. This window was initially also considered to be the center of the Milky Way.

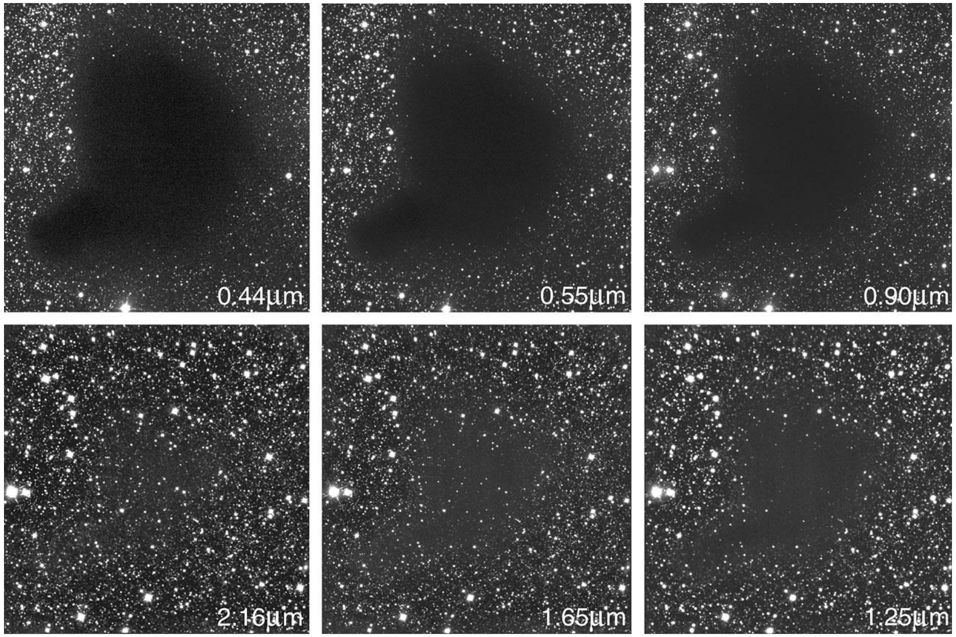


Interstellar extinction



Interstellare Extinktion

Wavelength dependence of the interstellar extinction. Shown is a dark cloud at different wavelengths. The longer this becomes, the more transparent the cloud becomes. Besides the extinction A_V there is consequently also a reddening of the visible light E(B-V).



Hole in the ground

In 1951, Bolton, Stanley and Slee built a simple radio telescope of about 22m diameter on Dover Heights in Australia during their lunch break, financed by their own funds. Metal strips from old crates served as reflectors. At its time it was one of the largest radio telescopes in the world. The receiver was aligned to a rod above the dish. In 1953, they were able to use this "hole in the ground" to determine the position of Sgr A*, the Galactic Center. Their measurement determined the position of the Galactic Coordinate System.

Hole in the ground:

Contour map in the direction of the Galactic Center, observed with the "hole in the ground" telescope on the Dover Heigths in Australia. Note the shift of the coordinate origin. At that time, optical observations were still used to determine the origin. In 1958 the International Astronomical Union decided to choose the position of this radio source as the origin.

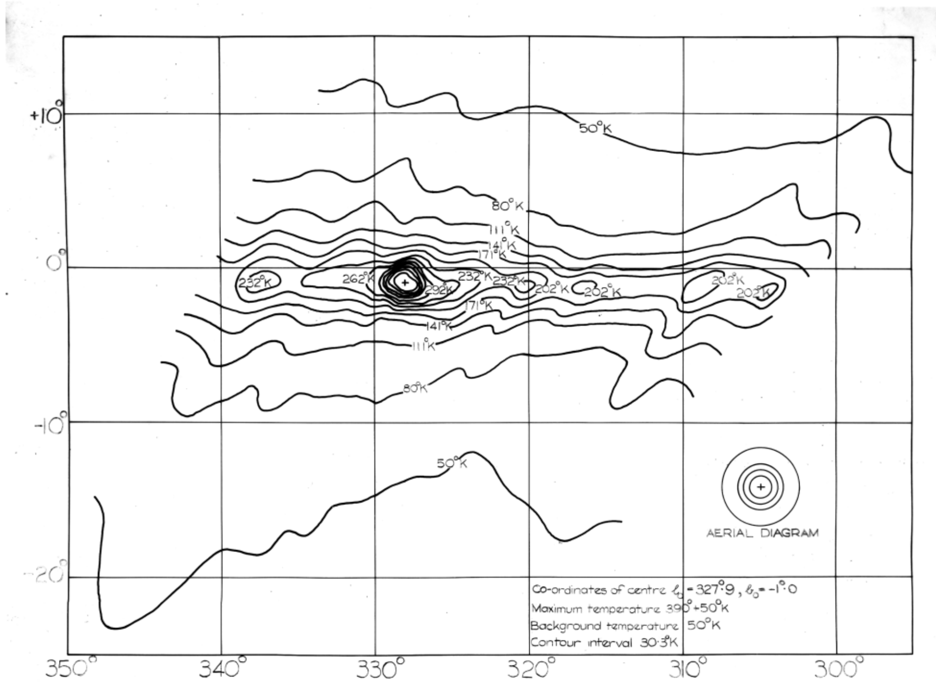


FIG. I

CONTOURS OF AERIAL TEMPERATURE OBSERVED AT 400 Mc/s.


SARAO (South Africa Radio Astronomy)

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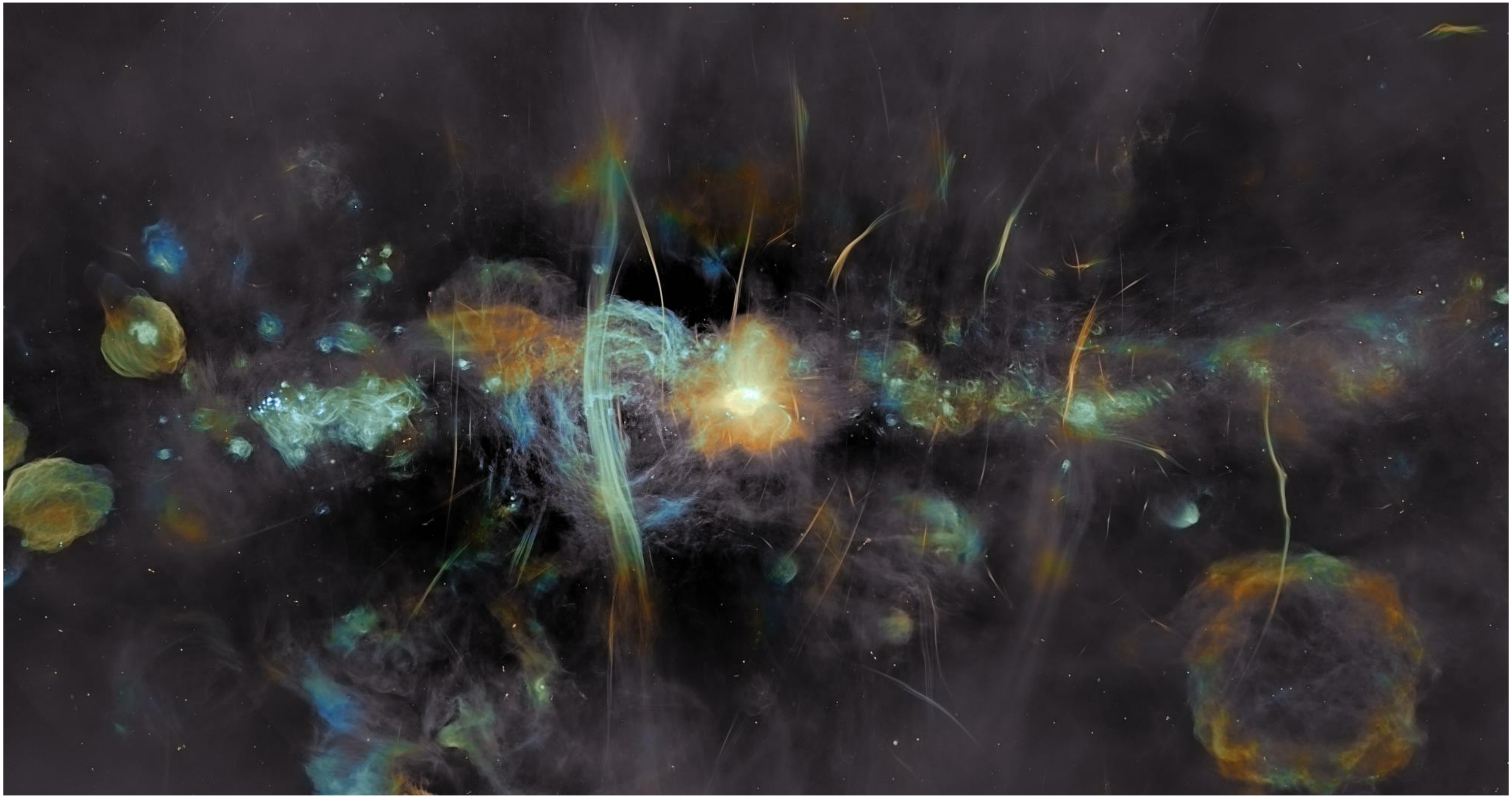

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1 light day: size of the solar system

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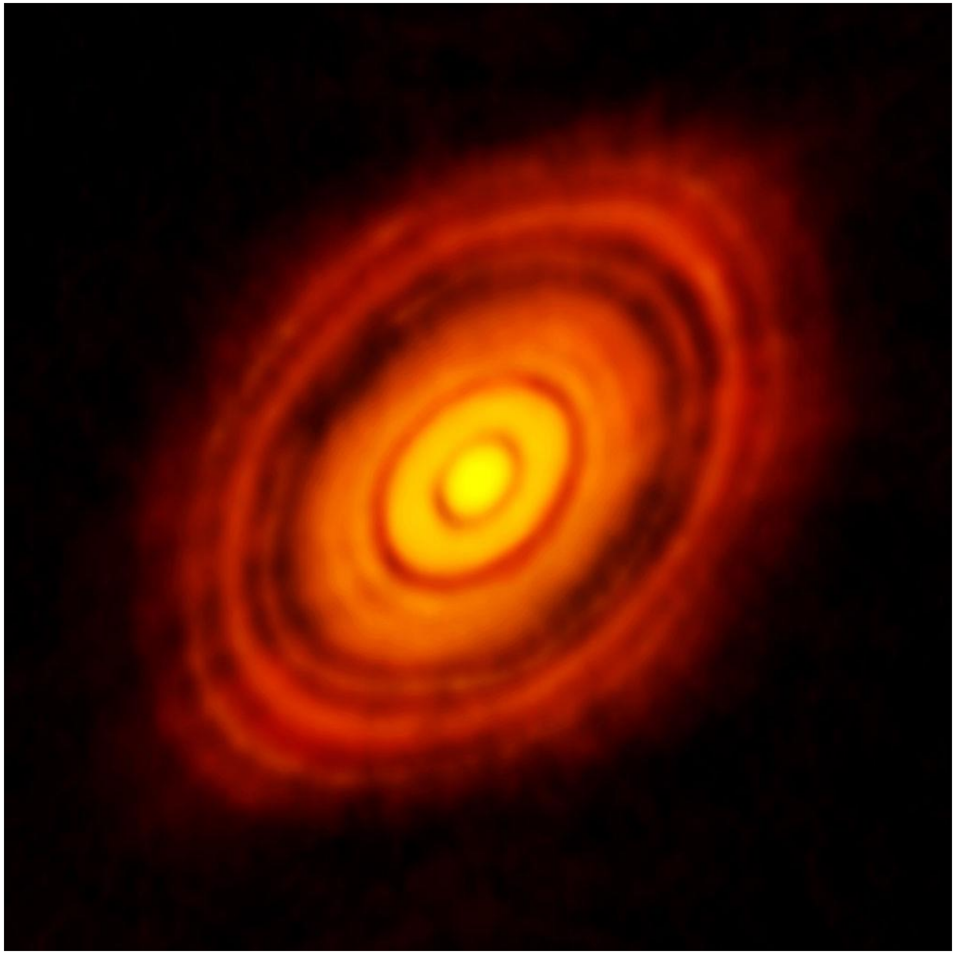

We are on the way to the radio Universe

Thank you!

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