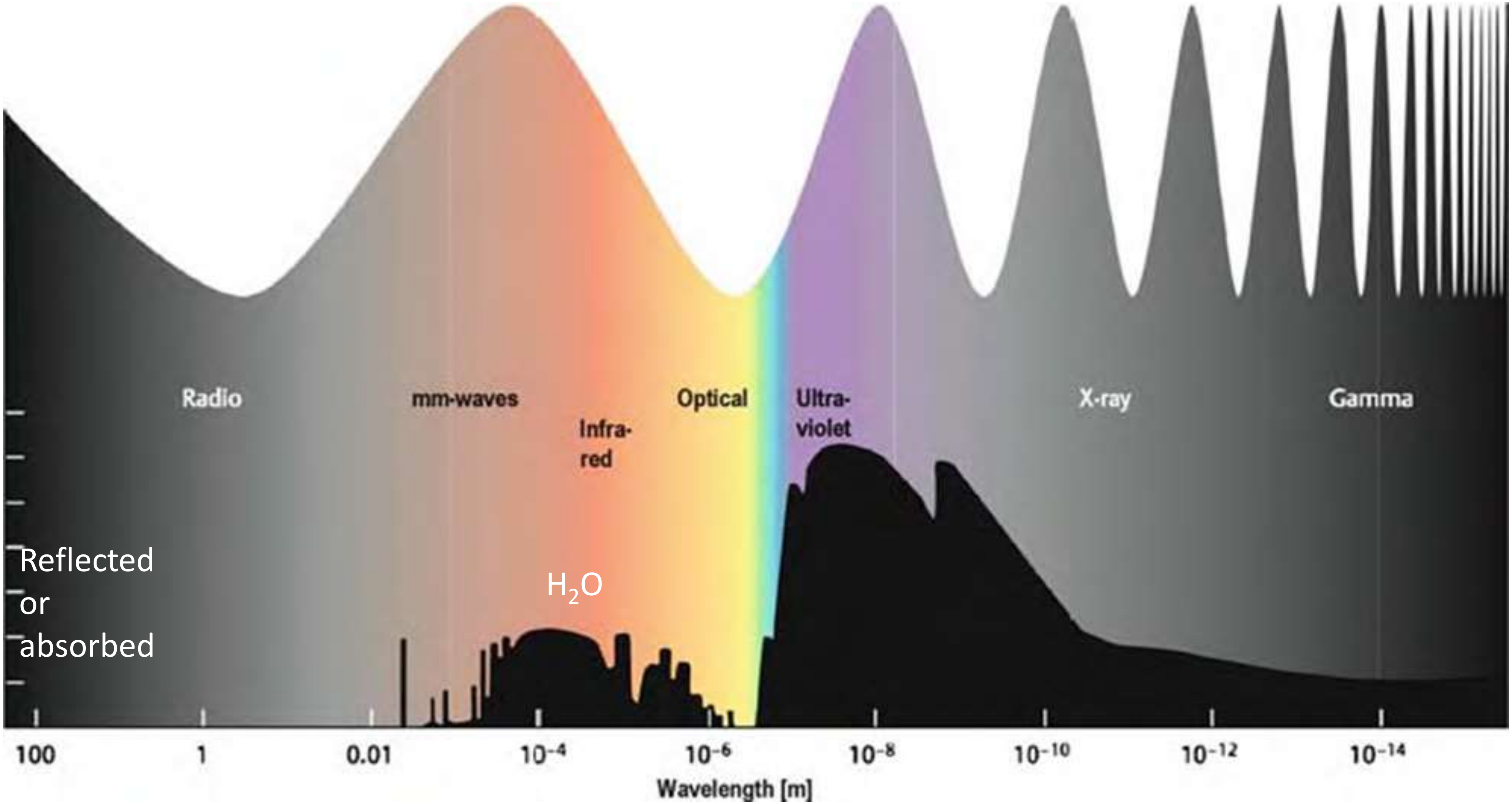
Telescópios: Radiotelescópios

Prof. Jorge Meléndez

The radio region

The radio region observable from Earth occupies a wide range within the electromagnetic spectrum.



The wavelength region in which Earth-based radio astronomy can be pursued comprises wavelengths 15 (or 20) m - 1 mm. This corresponds to frequencies of between (15) 20 MHz and 300 GHz.

Porque demorou tanto? Astrônomos sabiam demais ...

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{\exp(\frac{h\nu}{kT}) - 1}$$

Em ondas de rádio: $h\nu/(kT) \ll 1$

Replacing the exponential term in Planck's equation by its Taylor-series approximation

$$\exp\left(\frac{h\nu}{kT}\right) - 1 \approx 1 + \frac{h\nu}{kT} + ... - 1 \approx \frac{h\nu}{kT}$$

Aproximação de Rayleigh-Jeans:

$$B_\nu(T) \approx \frac{2h\nu^3}{c^2}\frac{kT}{h\nu} = \frac{2kT\nu^2}{c^2} = \frac{2kT}{\lambda^2}$$

Example: What is the flux density S_ν at $\nu = 1$ GHz of a $T = 5800$ K blackbody the size of the Sun (radius $R_\odot \approx 7 \times 10^{10}$ cm) at the distance of the nearest star, about 1 parsec ($d \approx 3 \times 10^{18}$ cm)?

$$S_\nu = B_\nu \Omega$$

$$B_\nu \approx 1.78 \times 10^{-15} \text{ erg cm}^{-2} \text{ sr}^{-1}$$

$$\Omega = \frac{\pi R_\odot^2}{d^2} \approx \frac{\pi (7 \times 10^{10} \text{ cm})^2}{(3 \times 10^{18} \text{ cm})^2} \approx 1.71 \times 10^{-15} \text{ sr}$$

$$S_\nu \approx 3.0 \times 10^{-30} \text{ erg cm}^{-2}$$

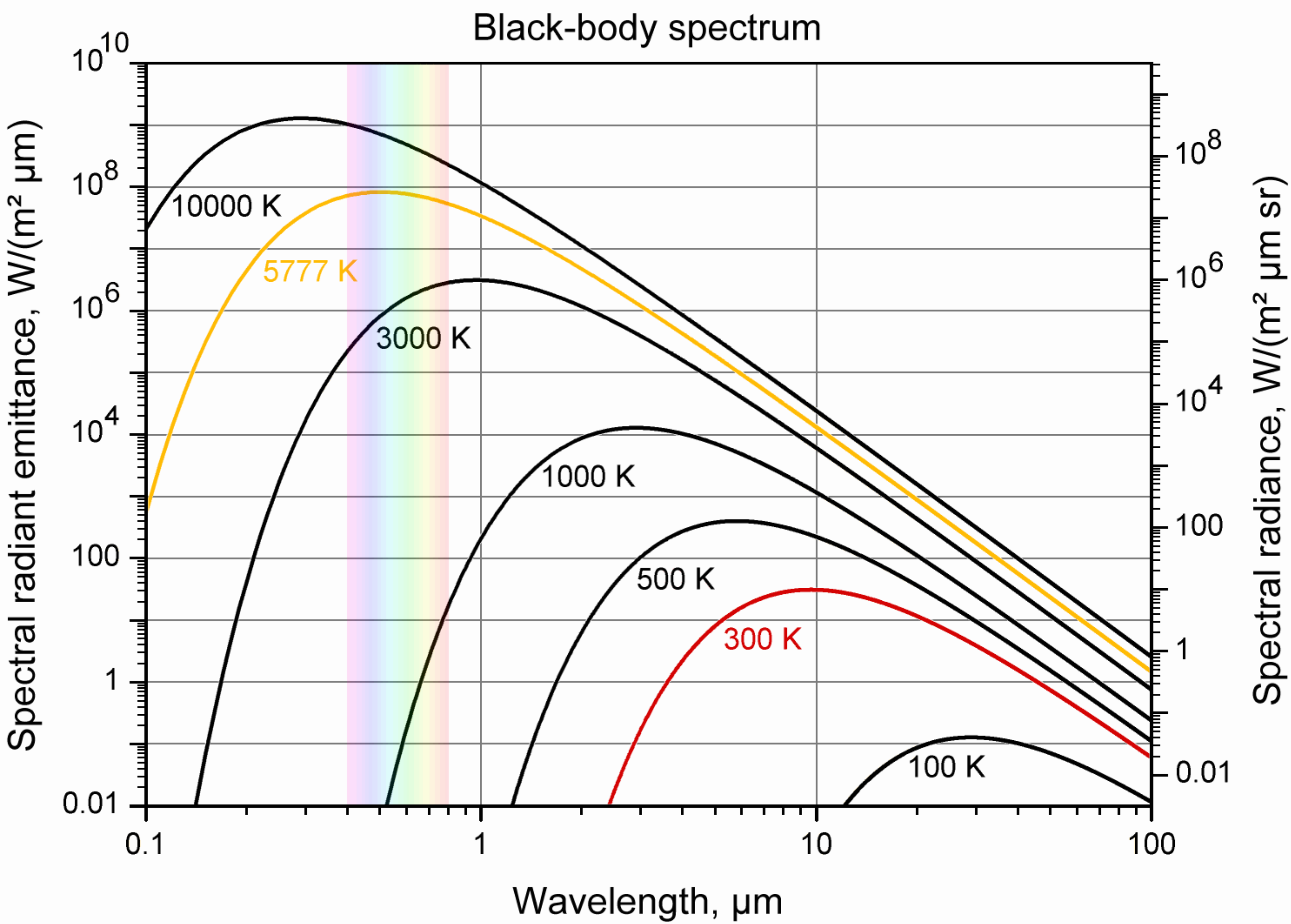
$$S_\nu \approx 3.0 \times 10^{-33} \text{ J m}^{-2} \approx 3.0 \times 10^{-33} \text{ W m}^{-2} \text{ Hz}^{-1}$$

Jansky) defined as 10^{-26} W m^{-2} Hz^{-1}

$$S_\nu \approx 0.3 \ \mu\text{Jy}$$

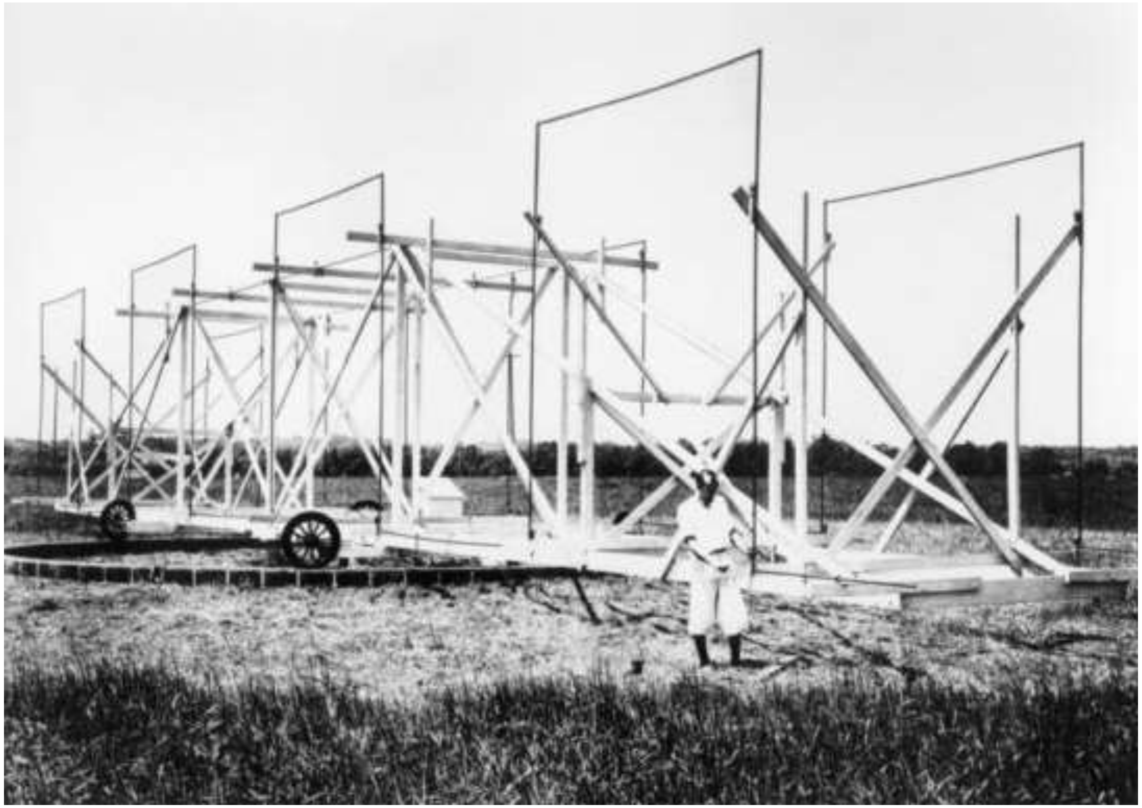
This is too faint even for modern radio telescopes, which can barely detect continuum sources as faint as $S \sim 10$ μJy.

http://www.cv.nrao.edu/course/astr534/



Black-body spectrum
Spectral radiant emittance, W/(m² μm)
Spectral radiance, W/(m² μm sr)
Wavelength, μm
10000 K
5777 K
3000 K
1000 K
500 K
300 K
100 K
0.1
1
10
100
0.01
1
100
10^4
10^6
10^8
10^10

Inicio da radioastronomia



Karl Jansky (1905-1950) and the antenna that discovered cosmic radio static at 20.5 MHz. *It rotated in azimuth on four wheels scavenged from a Ford Model T. An accurate replica of this antenna is located at the NRAO in Green Bank, WV.*

Natural radio emission from our Galaxy was detected accidentally in 1932 by Karl Guthe Jansky, a physicist working as a radio engineer for Bell Telephone Laboratories.

Electrical Disturbances Apparently of Extraterrestrial Origin

KARL G. JANSKY

the receiver. As will be seen from the figure, the horizontal component of the direction of arrival changes 360 degrees in about 24 hours, or in exactly 23 hours and 56.06 minutes

seriously considered. The point on the celestial sphere of right ascension 18 hours and declination −10 degrees, the direction from which the waves seem to come, is very near the point where the line drawn from the sun through the center of the huge galaxy of stars and nebulae of which

The New York Times of May 5, 1933

"New Radio Waves Traced to Centre of the Milky Way."

Astronomers ignored this discovery, because they couldn’t understand how that strong emission was possible. Se fosse de origem térmica, corresponderia a

$T \sim 2 \times 10^5$ K blackbody

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.

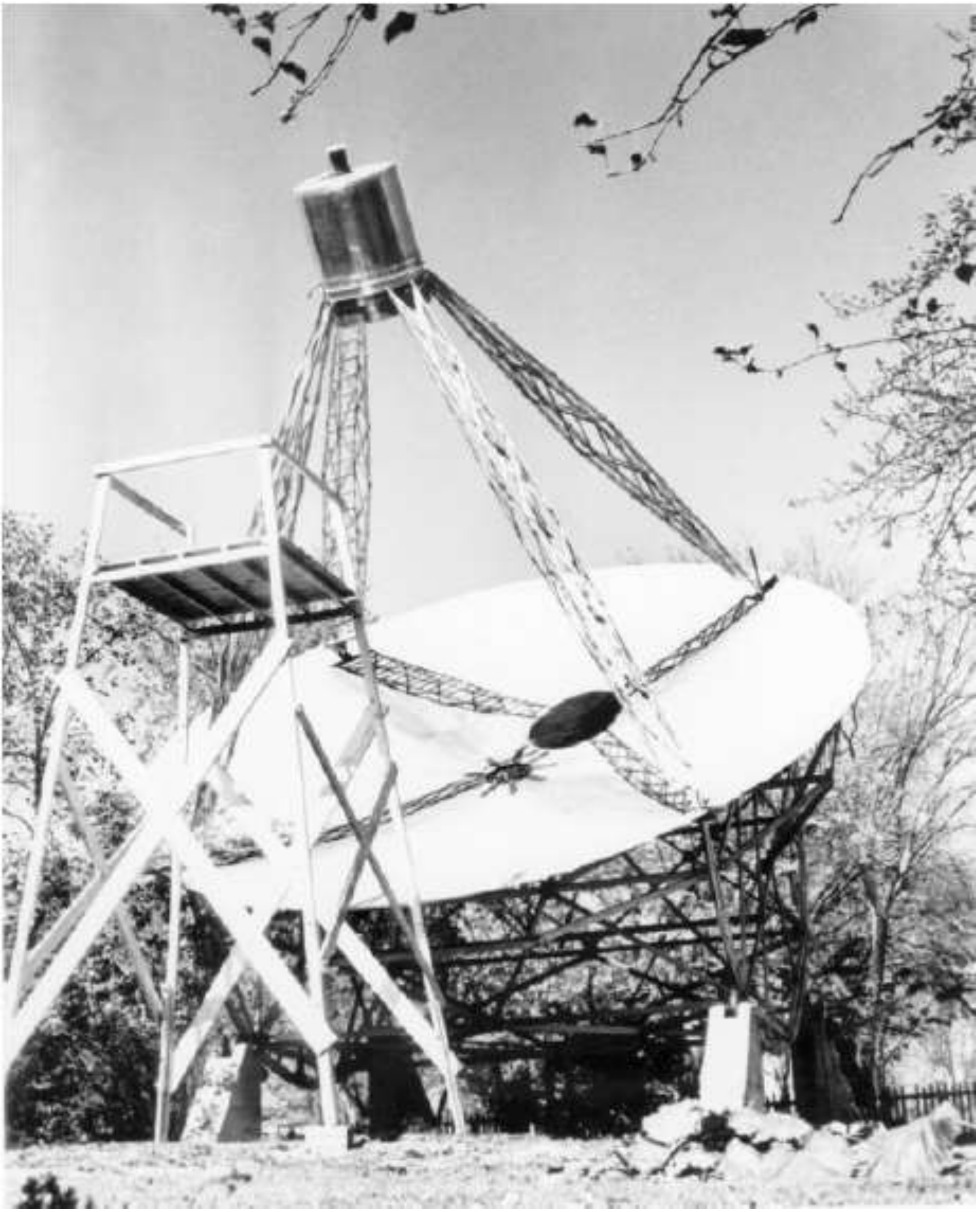
Direction of Arrival Fixed.

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.



Only **Grote Reber** took Jansky's discovery seriously. He was an amateur radio operator and professional radio engineer.

$$B_\nu(T) \approx \frac{2kT\nu^2}{c^2}$$

Grote Reber's backyard radio telescope in Wheaton, IL. The parabolic reflector is about 10 m in diameter.

Em 1937 observou em 3300 MHz, mas teve insucesso.

(Jansky observou em 20.5MHz)

Henry Ford: o insucesso é apenas uma oportunidade para recomeçar de novo

Grote Reber (22 dec 1911 – 20 dec 2002)

3300 MHz: nada
910 MHz: nada

In 1938 he finally succeeded in detecting and mapping (with about 10 degree angular resolution) the Galaxy at 162 MHz, confirming Jansky's discovery and demonstrating that the radio emission has a distinctly nonthermal spectrum

http://www.cv.nrao.edu/course/astr534/Discovery.html

Since the theory of black-body radiation predicts an intensity proportional to the square of the frequency in this range, the first tests were made at 3300 megacycles. Nothing was found at the sensitivity limit of 10^{-20} watts per square centimeter per circular degree per kilocycle band width. Improved equipment for the frequency of 900 megacycles gave no results at the limit of 10^{-22} watts per square centimeter per circular degree per kilocycle band width. The data of Figures 2 and 3 were obtained at 162 megacycles.

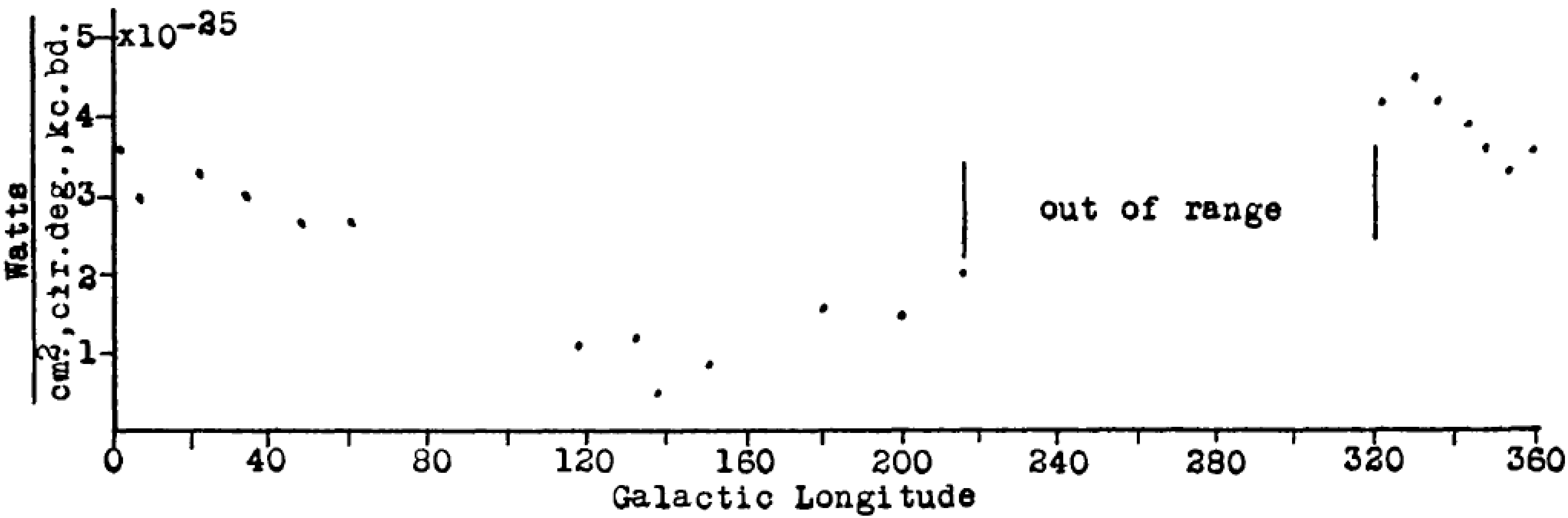
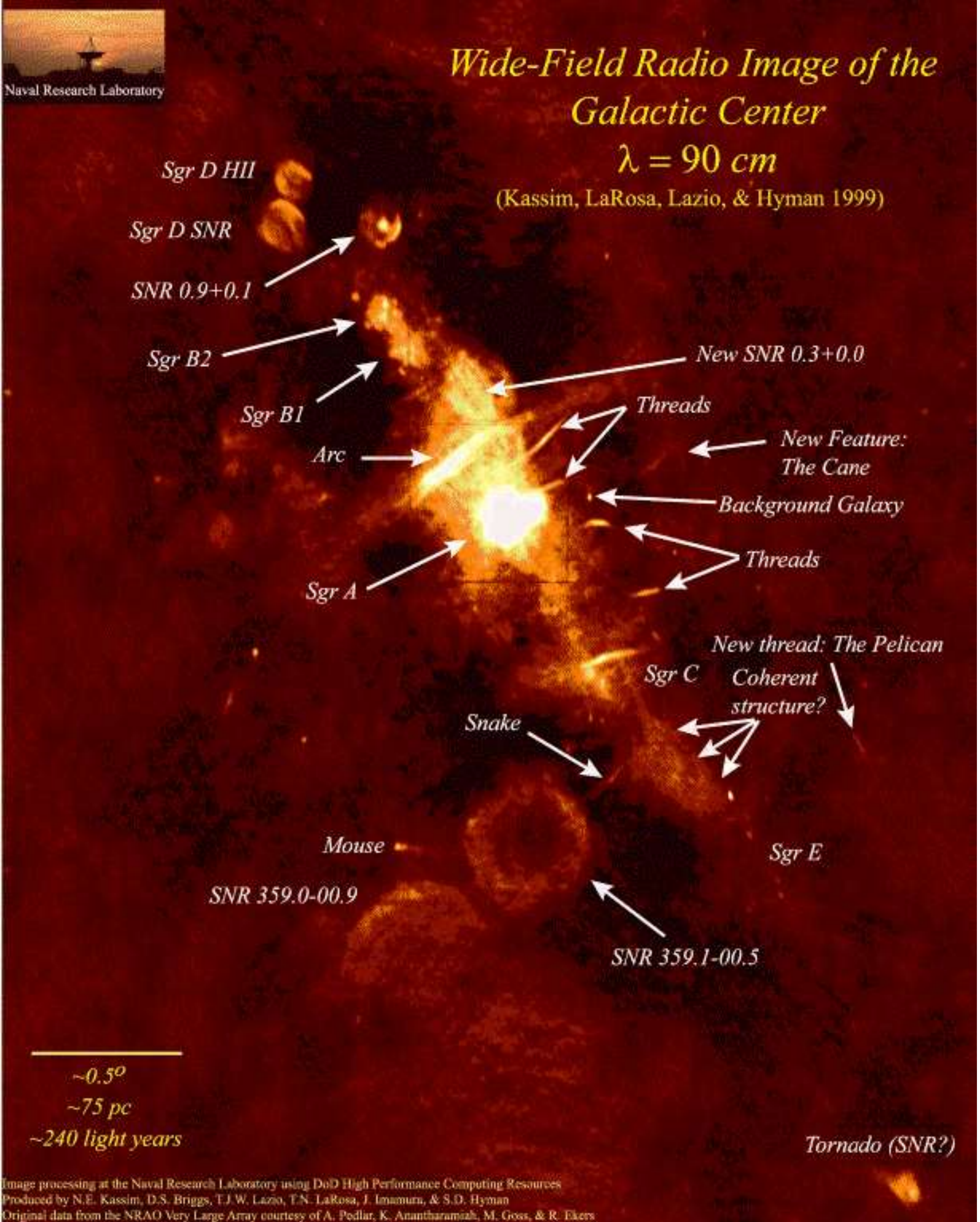


FIG. 3.—Intensity of maximum incident radiation as function of galactic longitude.

only other positive results are from the great nebula in Andromeda, with a mean of four readings, giving a maximum intensity of 8×10^{-26} watts per square centimeter per circular degree per kilocycle band

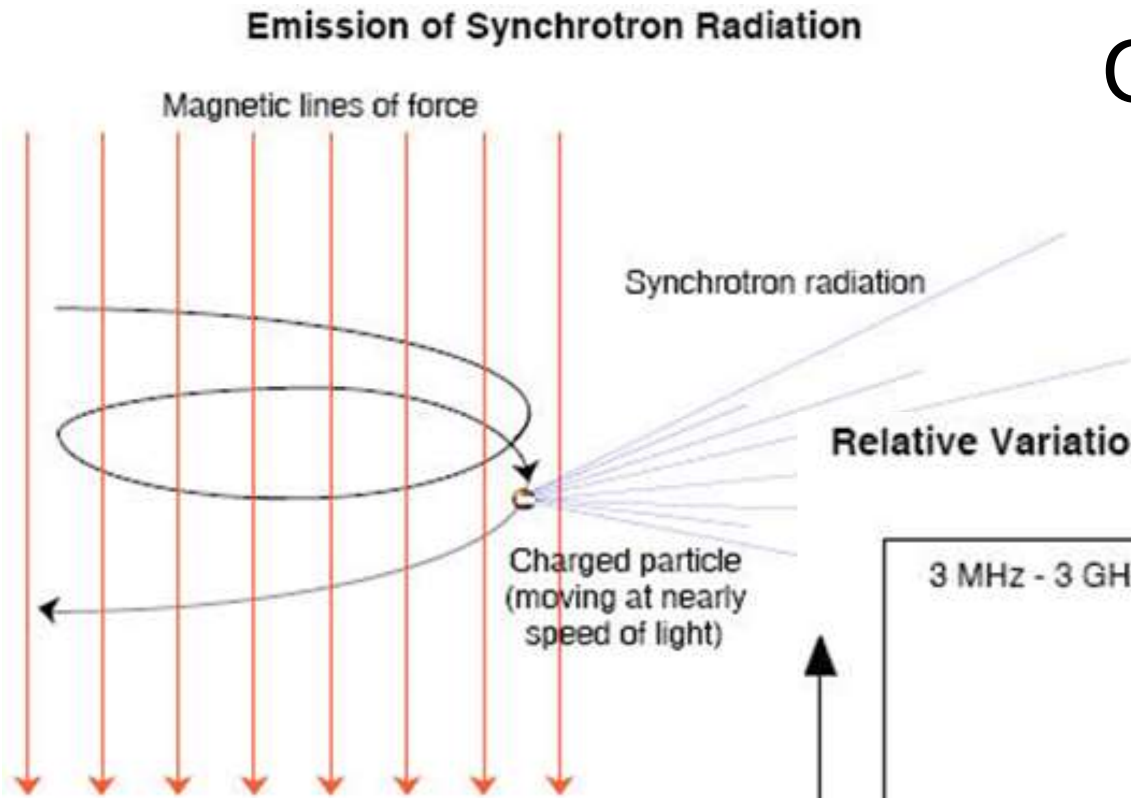
Reber, G. 1940 (ApJ, 91, 621).

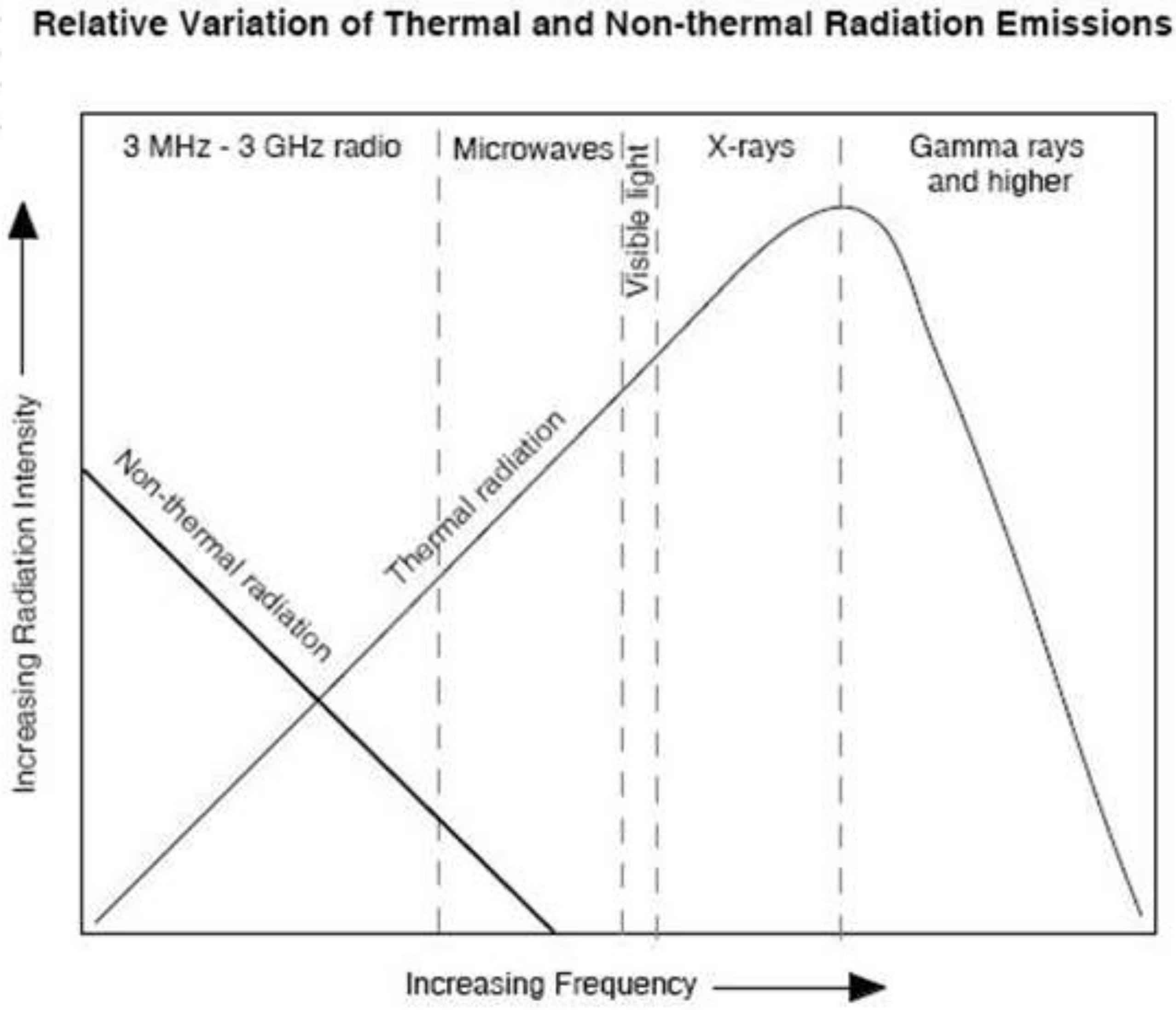


VLA image of the Galactic Center taken at a wavelength of 90 cm (Kassim et al. 1999)

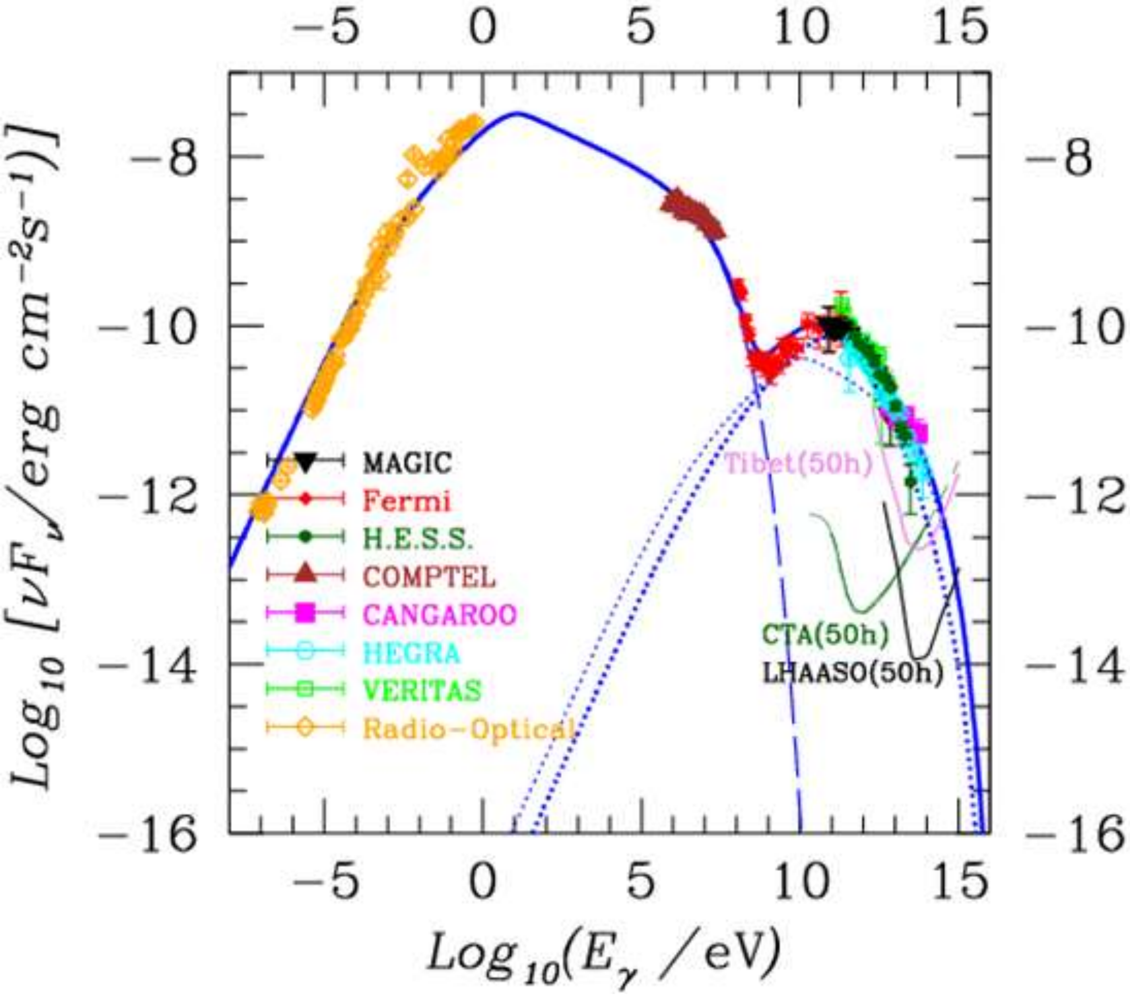
http://www.astro.ucla.edu/~tanner/gcwave.html

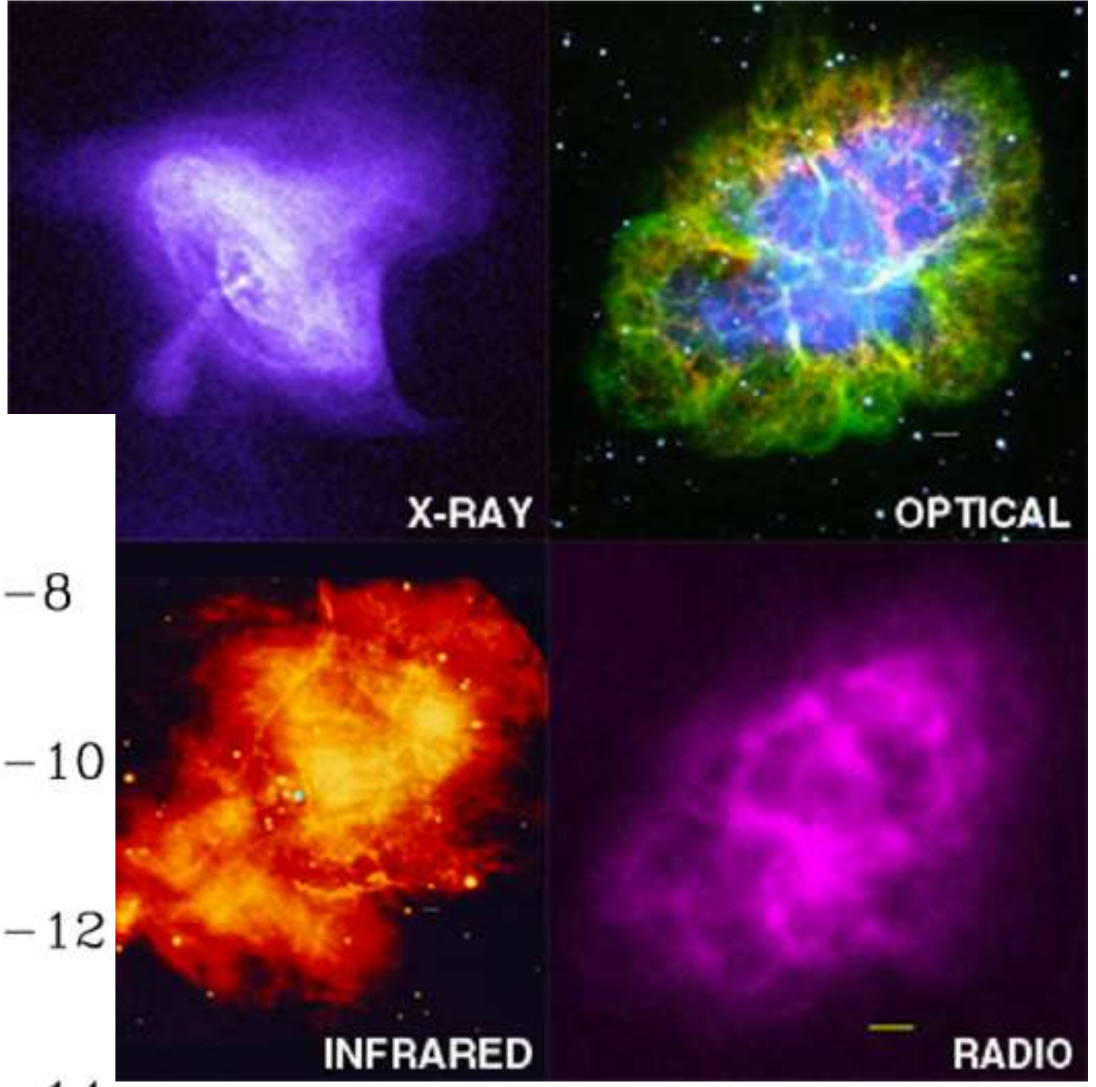
Outros mecanismos de radiação (não térmica)

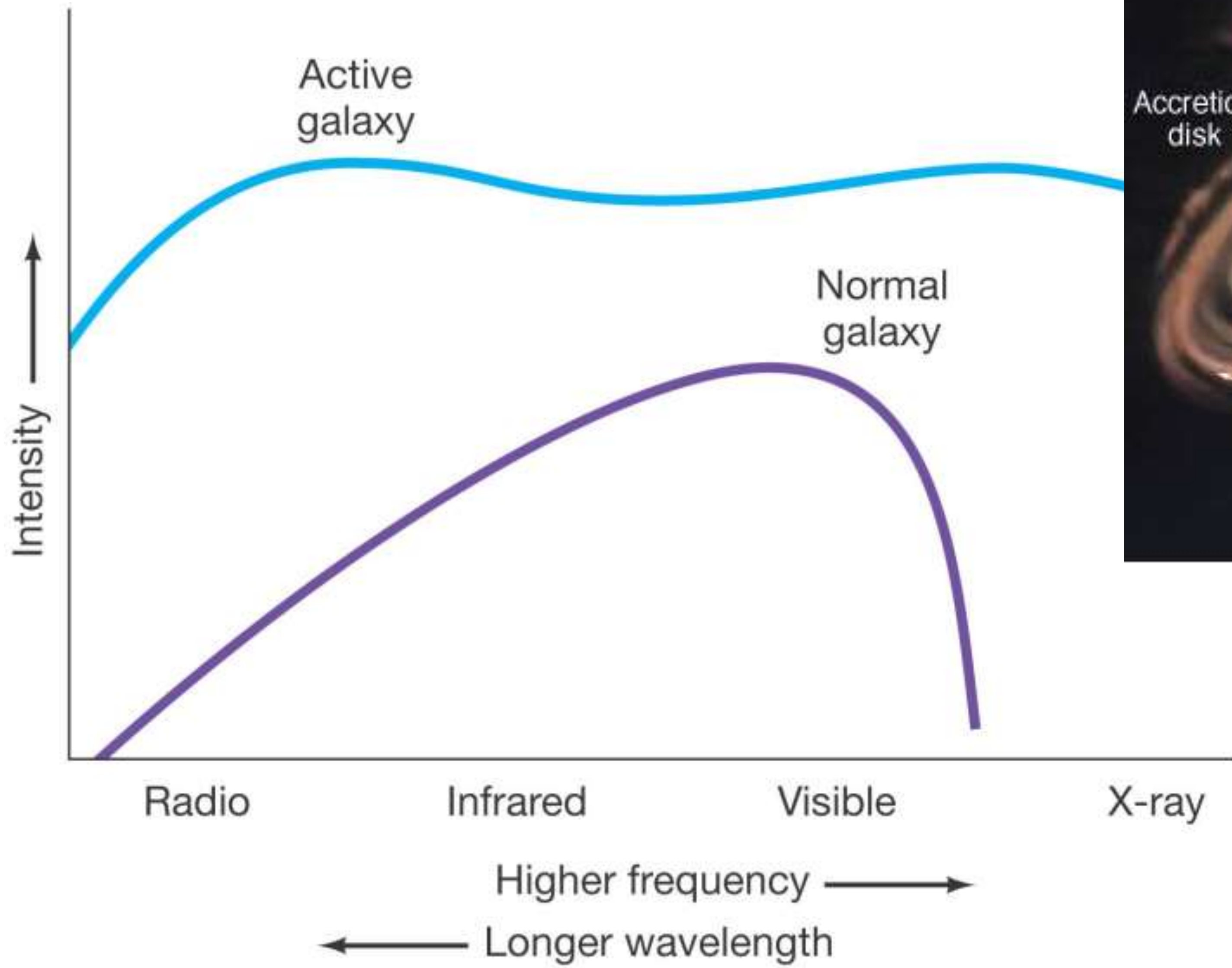


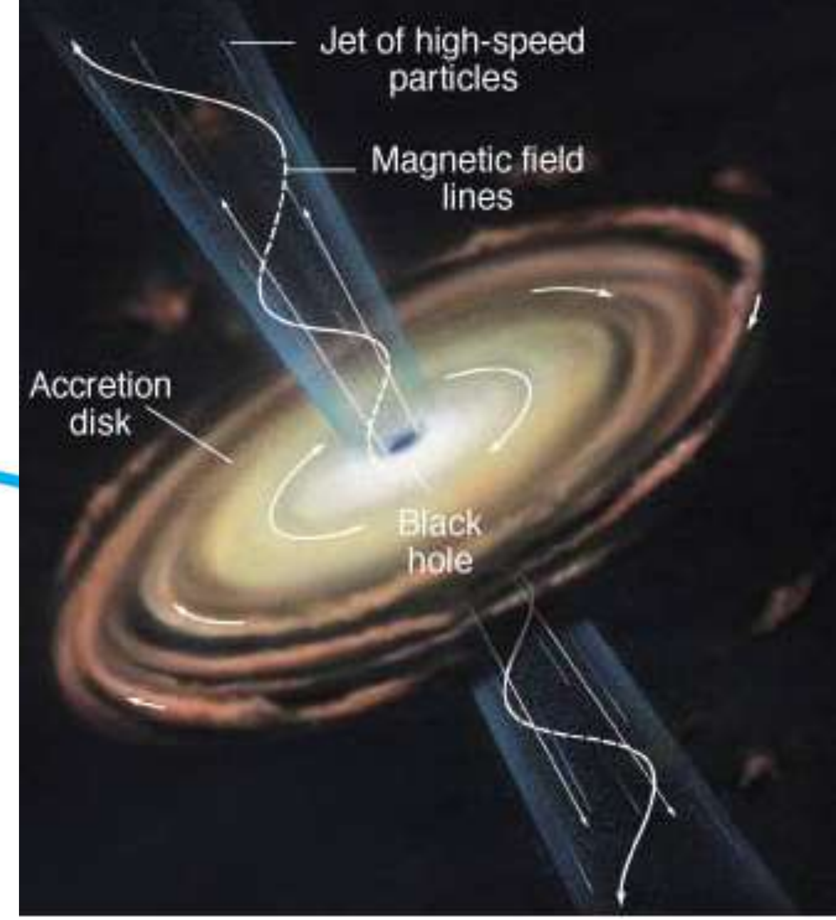


synchrotron
radiation
crab nebula






Active galaxy
Normal galaxy
Intensity
Radio
Infrared
Visible
X-ray
Higher frequency
Longer wavelength

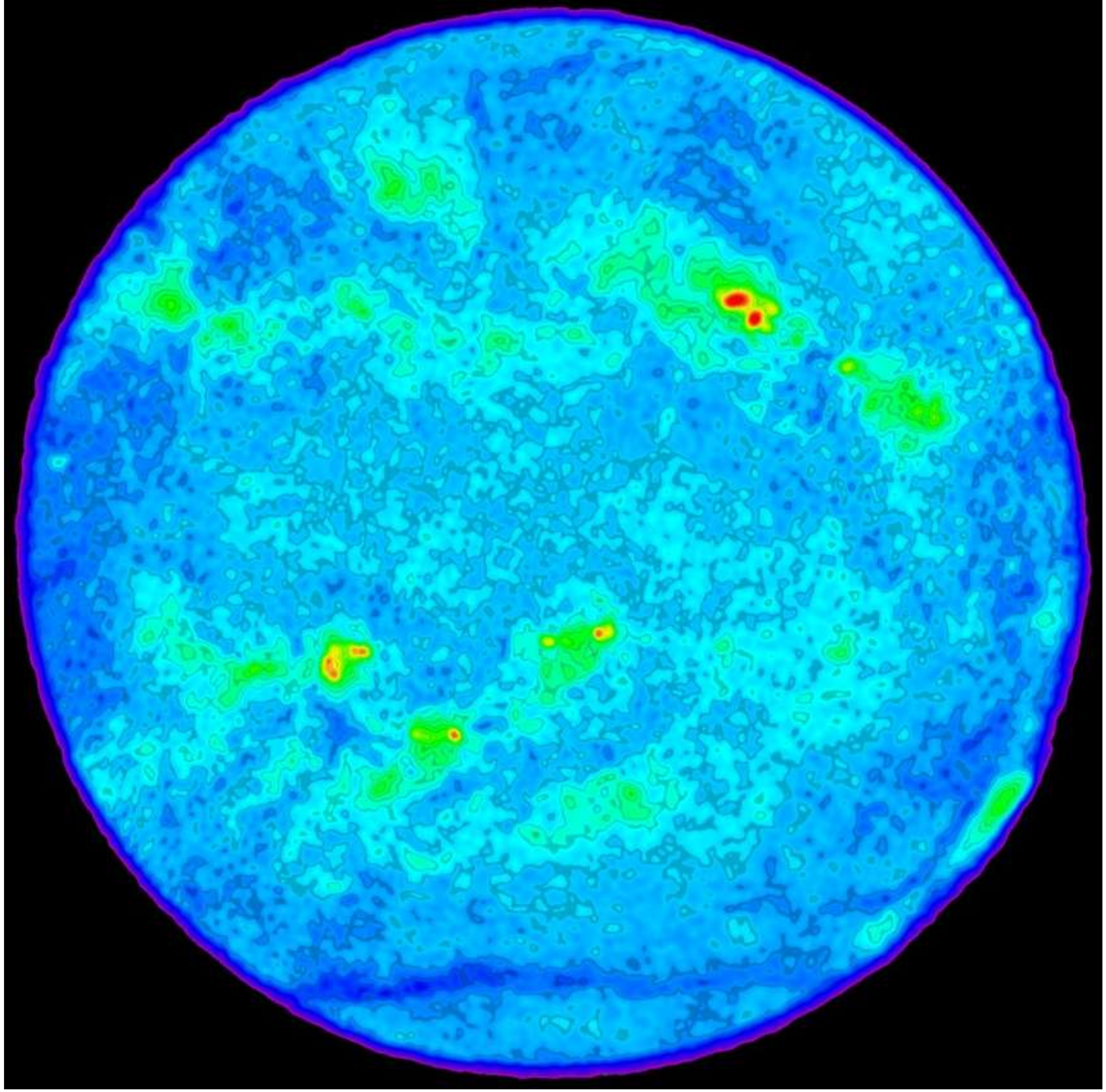

Jet of high-speed particles
Magnetic field lines
Accretion disk
Black hole

The radio sky

Céu em radio (4.85 GHz) desde Green Bank

Seen here is the radio sky over the telescopes of the National Radio Astronomy Observatory in Green Bank, VA. Note the shell-like supernova remnants and irregularly shaped star formation regions. The point-like objects are not stars but mostly distant radio galaxies. NRAO/AUI/NSF

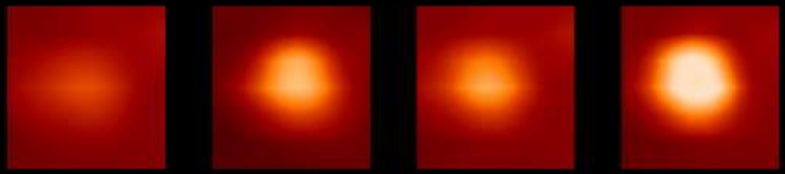
http://www.cv.nrao.edu/course/astr534/Tour.html

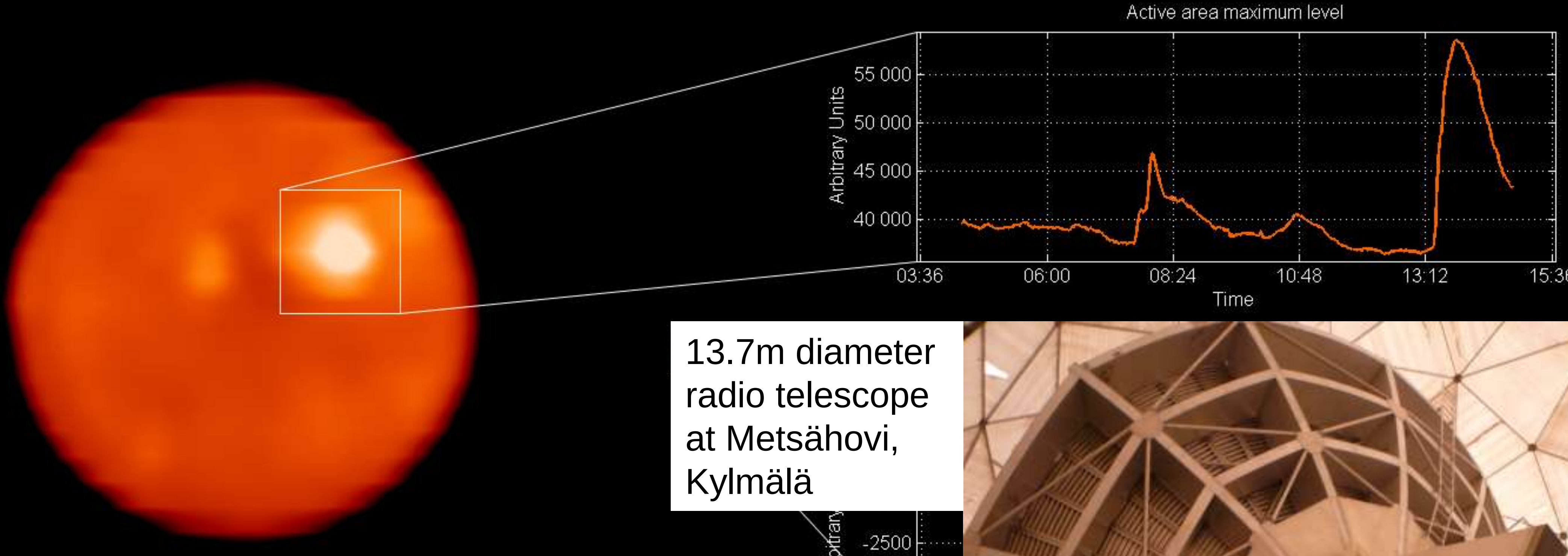


The Sun at 4.6 GHz

The quiet Sun at $\nu = 4.6$ GHz imaged by the VLA with a resolution of 12 arcsec, or about 8400 km on the surface of the Sun. The brightest features (red) in this false-color image have brightness temperatures $T_b \approx 10^6$ K and coincide with sunspots. The green features are cooler and show where the Sun's atmosphere is very dense. At this frequency the radio-emitting surface of the Sun has an average temperature of 3×10^4 K, and the dark blue features are cooler yet. The blue slash crossing the bottom of the disk is a feature called a filament channel, where the Sun's atmosphere is very thin: it marks the boundary of the South Pole of the Sun. The radio Sun is somewhat bigger than the optical Sun: the solar limb (the edge of the disk) in this image is about 20000 km above the optical limb. [*Image credit*]

MRO 37 GHz solar tracking observation
2011-08-03, 04:22:30 - 14:52:24





13.7m diameter radio telescope at Metsähovi, Kylmälä

Frequency (center) [GHz]	Wavelength [mm]	Telescope Beam size [arc min]	Estimated quiet sun level [K]	s.f.u.
22.2	13.5	4.0	9000	24.3
36.8	8.2	2.4	7800	21.1
86	3.3	1.0	7200	19.4

Table 1. Parameters of solar map measurements at Metsähovi Radio Observatory

Aalto University
School of Electrical Engineering

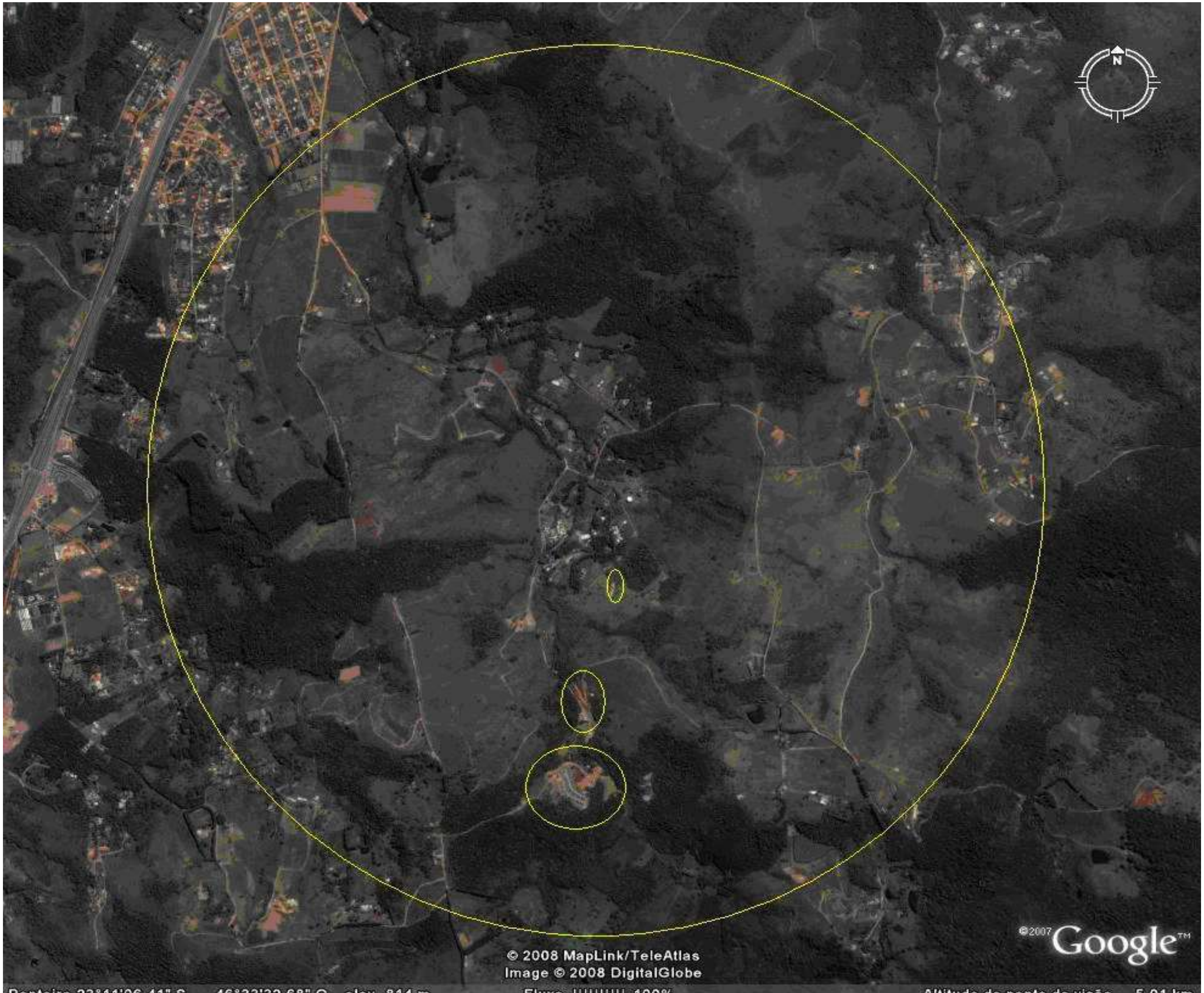
http://metsahovi.aalto.fi/en/research/projects/solar_radio/mapping_tracking/

http://www.cea.inpe.br/roi/

RADIOBSERVATÓRIO DO ITAPENTIGA

Itapetinga 13.7m radiotelescope

Zonas de Silêncio



Região de Atibaia. Ponto branco no meio é o observatório. O círculo maior é a zona de silêncio (R ~ 2 km). As elipses menores são regiões de desmatamento e degradação florestal.

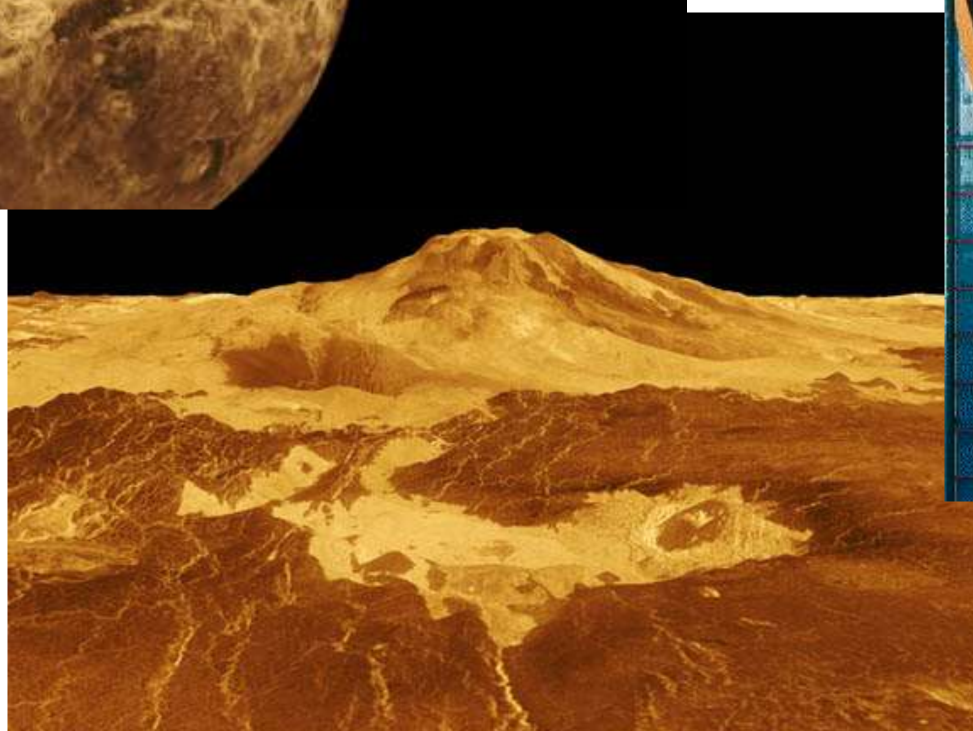
As maiores fontes de interferência são fornos de microondas, controles remotos, redes de alta tensão, walk talks, acionadores de lâmpadas fluorescentes, computadores e torres de celular.

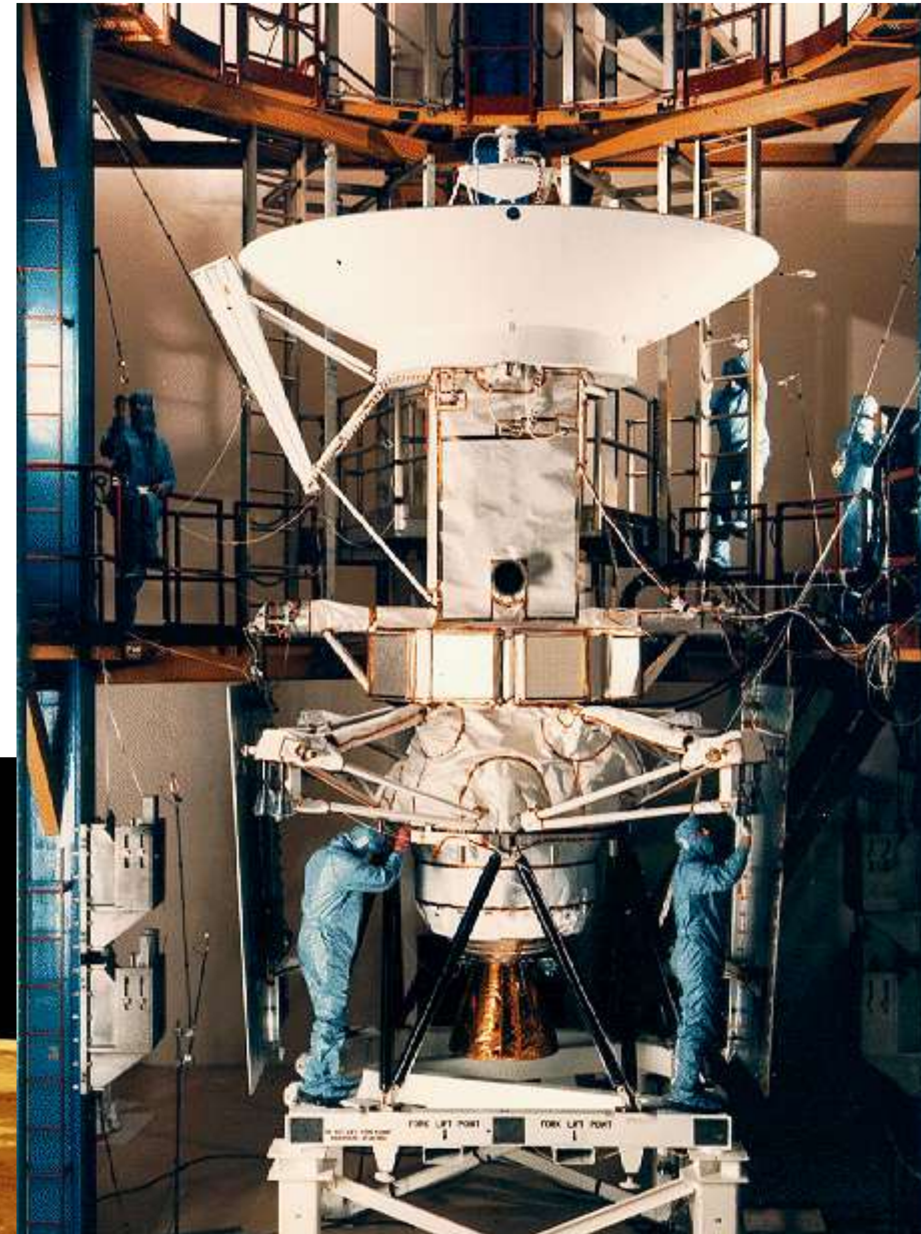
http://www.cea.inpe.br/roi/arquivos/ZonaSilencio_v2.pdf

Table 1.2.1. Radio astronomy reserved frequencies. The wave bands listed in this table are compiled from the World Administrative Radio Conference 1992 (W.A.R.C. 92) and the World Radio Conference 2000 (W.R.C. 2000). Not all frequencies are kept free in all places, some allocations are shared with other users and the allocations are continually changing. The reader should consult an up-to-date local source for specific information relative to his or her requirements. These can often be found by searching the internet.

Lower frequency	Upper frequency	Lower frequency	Upper frequency
13.36 MHz	13.41 MHz	93.07 GHz	93.27 GHz
25.55 MHz	25.67 MHz	97.88 GHz	98.08 GHz
37.50 MHz	38.25 MHz	105.00 GHz	116.00 GHz
73.00 MHz	74.60 MHz	140.69 GHz	140.98 GHz
150.05 MHz	153.00 MHz	144.68 GHz	144.98 GHz
322.00 MHz	328.60 MHz	145.45 GHz	145.75 GHz
406.10 MHz	410.00 MHz	146.82 GHz	147.12 GHz
608.00 MHz	614.00 MHz	150.00 GHz	151.00 GHz
1.330 GHz	1.427 GHz	164.00 GHz	168.00 GHz
1.660 GHz	1.670 GHz	174.42 GHz	175.02 GHz
1.7188 GHz	1.7222 GHz	177.00 GHz	177.40 GHz
2.655 GHz	2.700 GHz	178.20 GHz	178.60 GHz
3.260 GHz	3.267 GHz	181.00 GHz	181.46 GHz
3.332 GHz	3.339 GHz	182.00 GHz	185.00 GHz
3.3458 GHz	3.3525 GHz	186.20 GHz	186.6 GHz
4.800 GHz	5.000 GHz	217.00 GHz	231.00 GHz
6.650 GHz	6.6752 GHz	250.00 GHz	251.00 GHz
10.60 GHz	10.70 GHz	257.50 GHz	258.00 GHz
14.47 GHz	14.50 GHz	261.00 GHz	265.00 GHz
15.35 GHz	15.40 GHz	262.24 GHz	262.76 GHz
22.01 GHz	22.50 GHz	265.00 GHz	275.00 GHz
22.81 GHz	22.86 GHz		
23.07 GHz	23.12 GHz		
23.60 GHz	24.00 GHz		
31.10 GHz	31.80 GHz		
36.43 GHz	36.50 GHz		
42.50 GHz	43.50 GHz		
48.94 GHz	49.04 GHz		
72.77 GHz	72.91 GHz		
86.00 GHz	92.00 GHz		

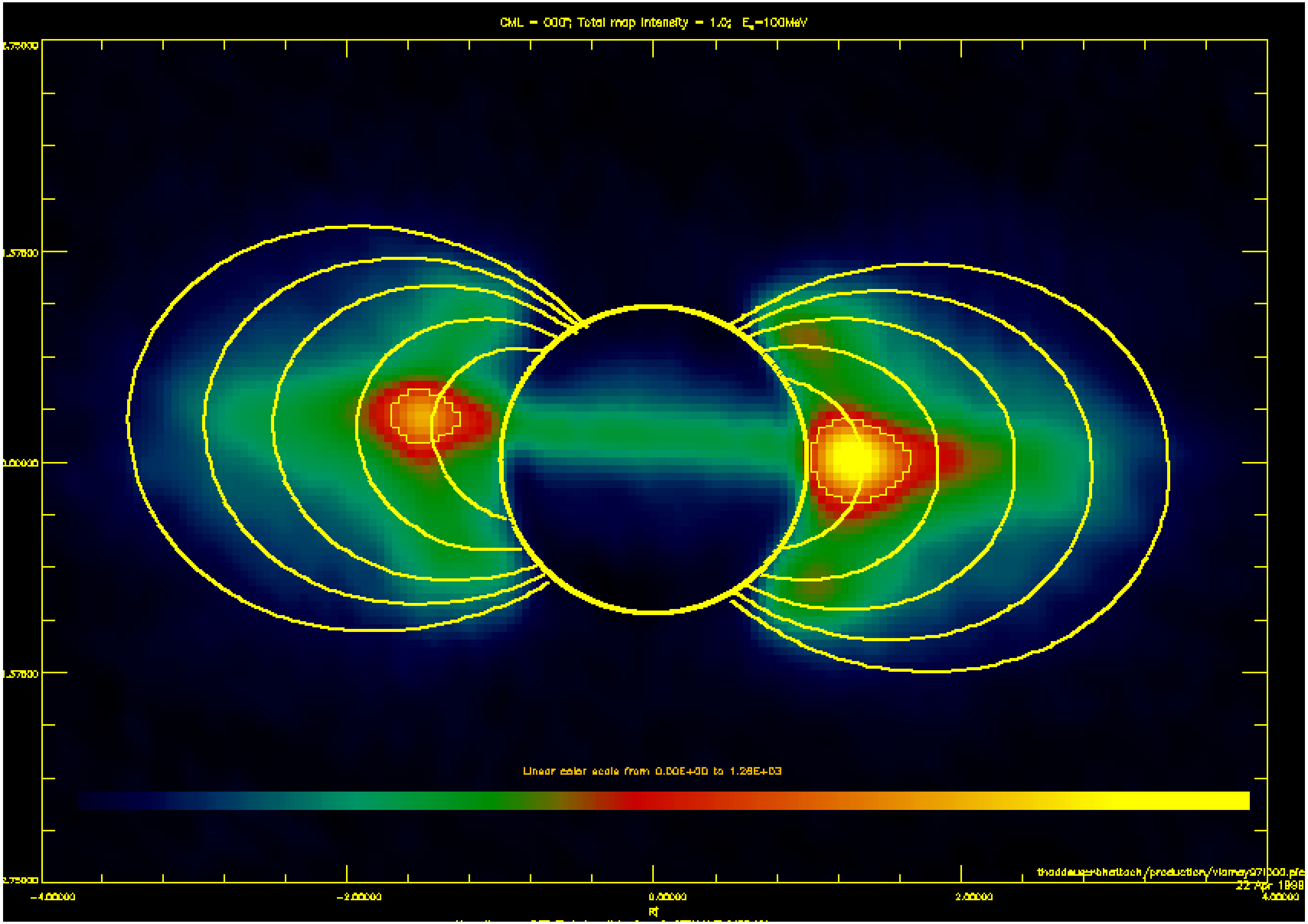
http://www2.jpl.nasa.gov/magellan/





Venus by Magellan (radar)

http://juno.wisc.edu/science_magnetosphere.html

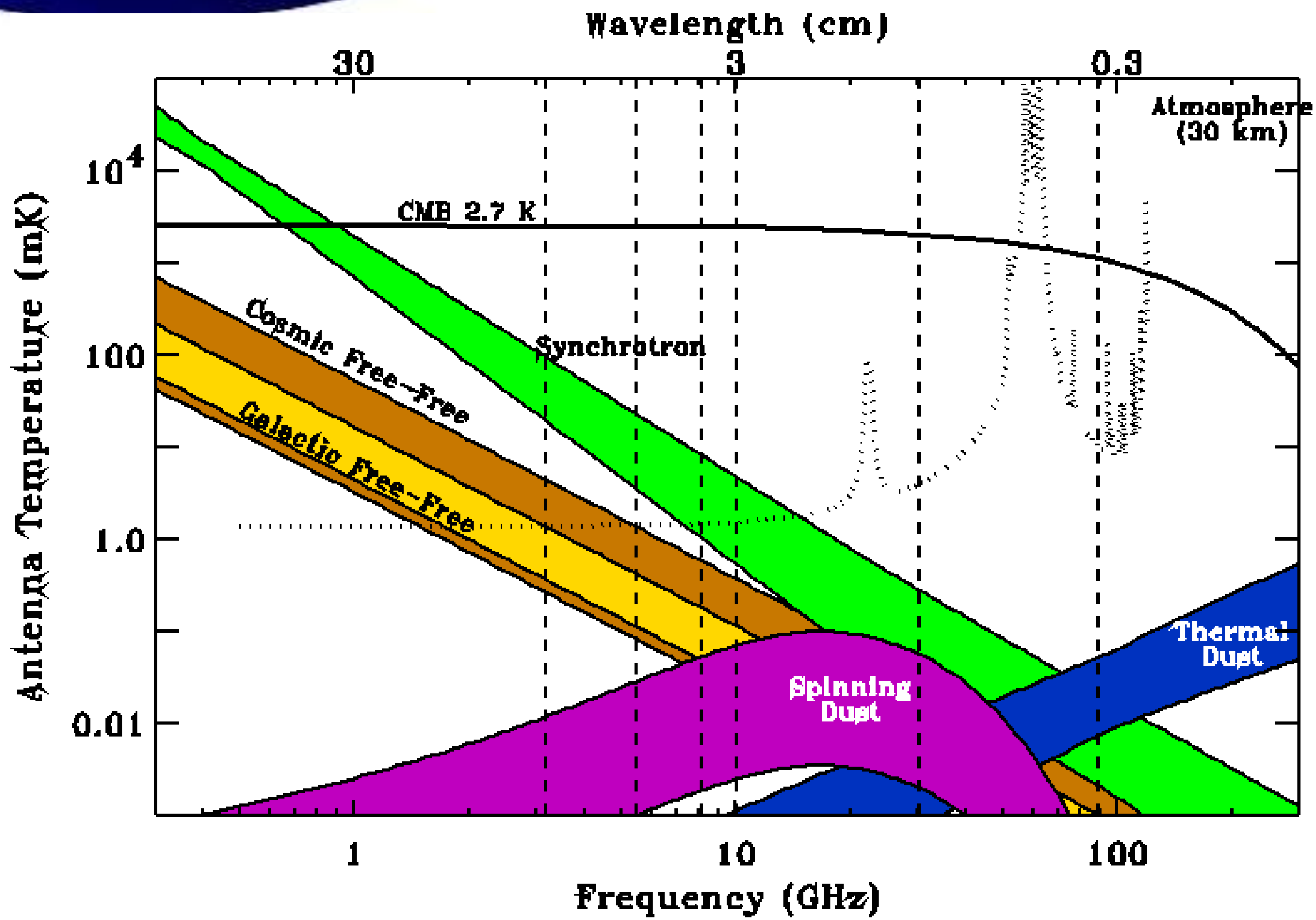


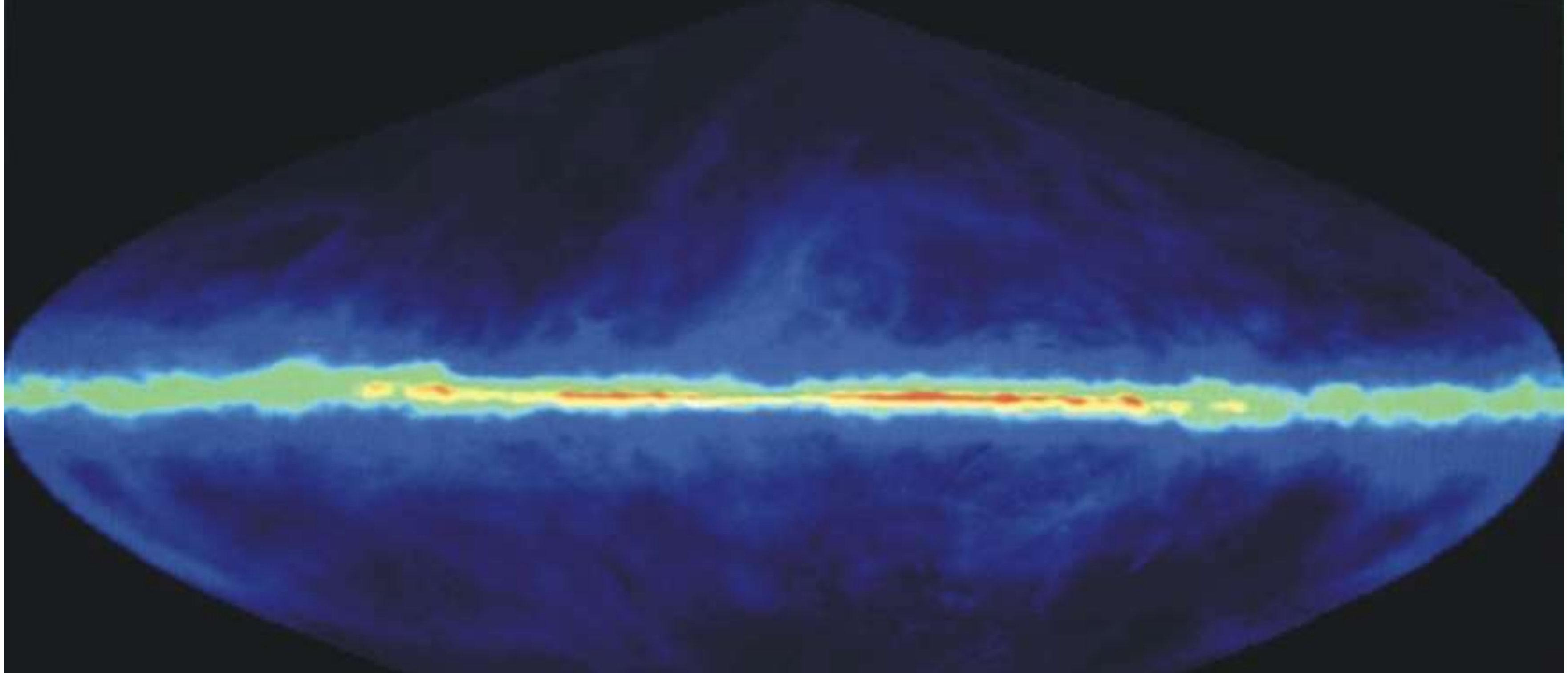
Animation of the variation of the synchrotron emission at 1400 MHz from **Jupiter** (VLA observations) with a computer model (Levin et al. 2001, Geophys. Res. Lett., 28,903) using an assumed electron distribution and magnetic field. The model simulates ground based radio observations well. The thermal emission from Jupiter has been subtracted, and representative magnetic field lines are shown. The animation covers one rotation of Jupiter, frames are 20 degrees apart in central longitude. The animation shows the East West asymmetry of the emitted radiation in the equatorial plane. The "wobble" of the emitted radiation is due to the misalignment of the rotation pole of Jupiter and the magnetic pole.

http://asd.gsfc.nasa.gov/archive/arcade/science_galaxy.html

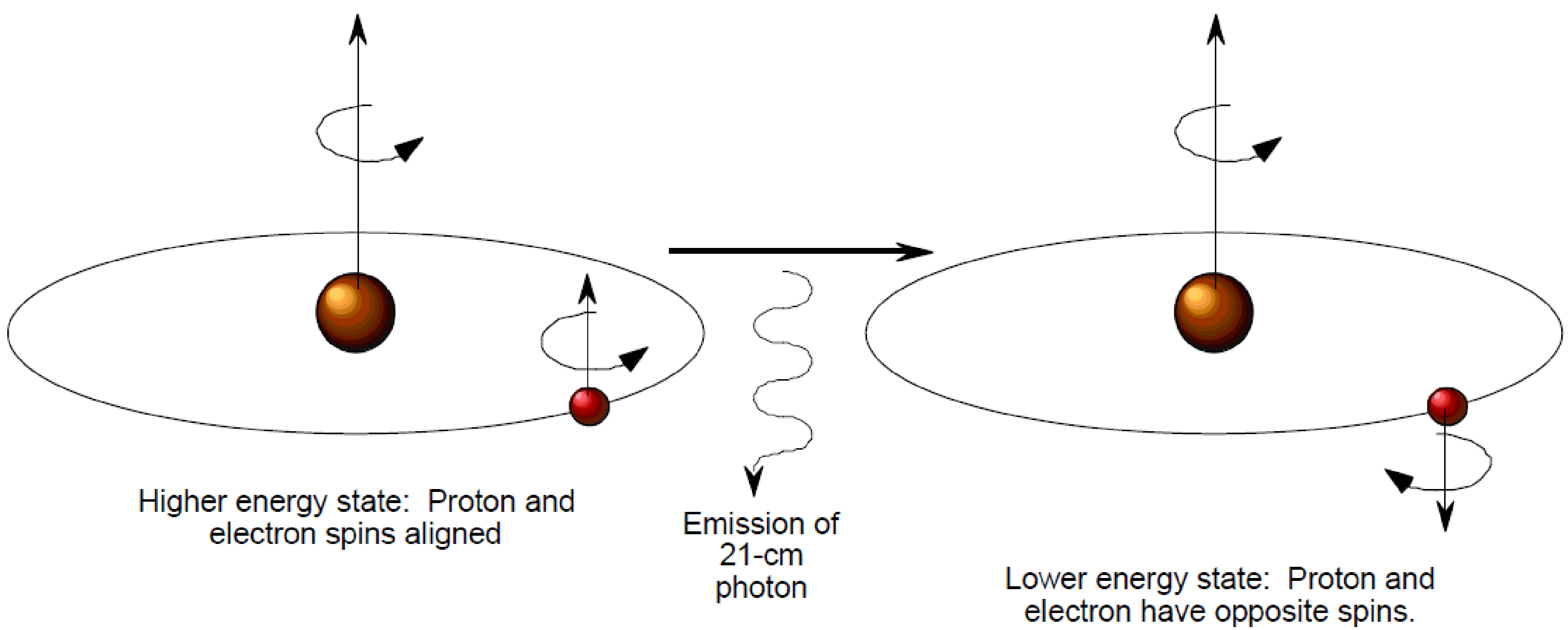
Mapa da galáxia em 408 MHz

Haslam et al. 1982, A&AS, 47, 1



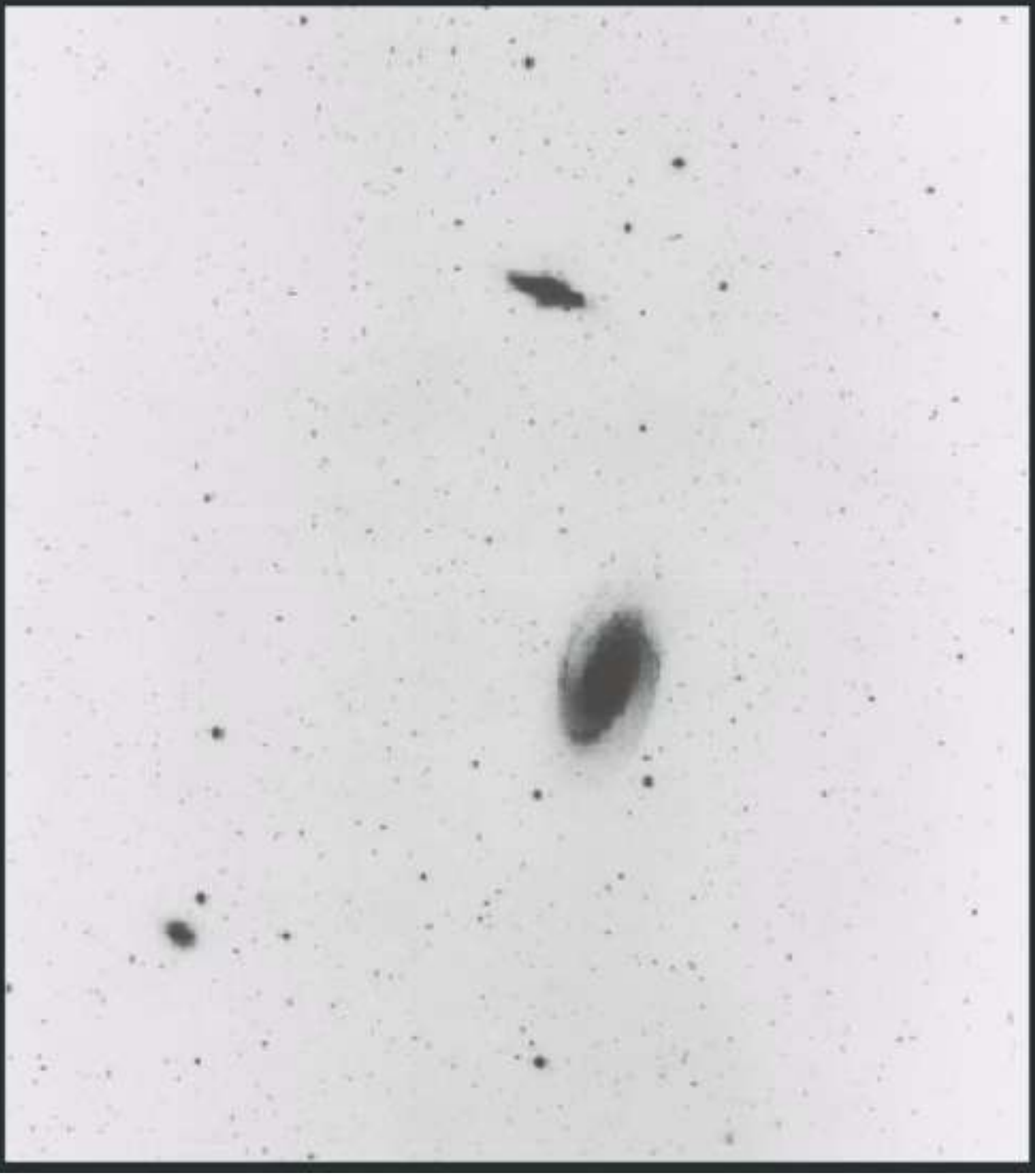


The Galaxy in the 21cm line (1420.4 MHz) of neutral H. Red indicates directions of high HI column density, while blue and black show areas with little hydrogen

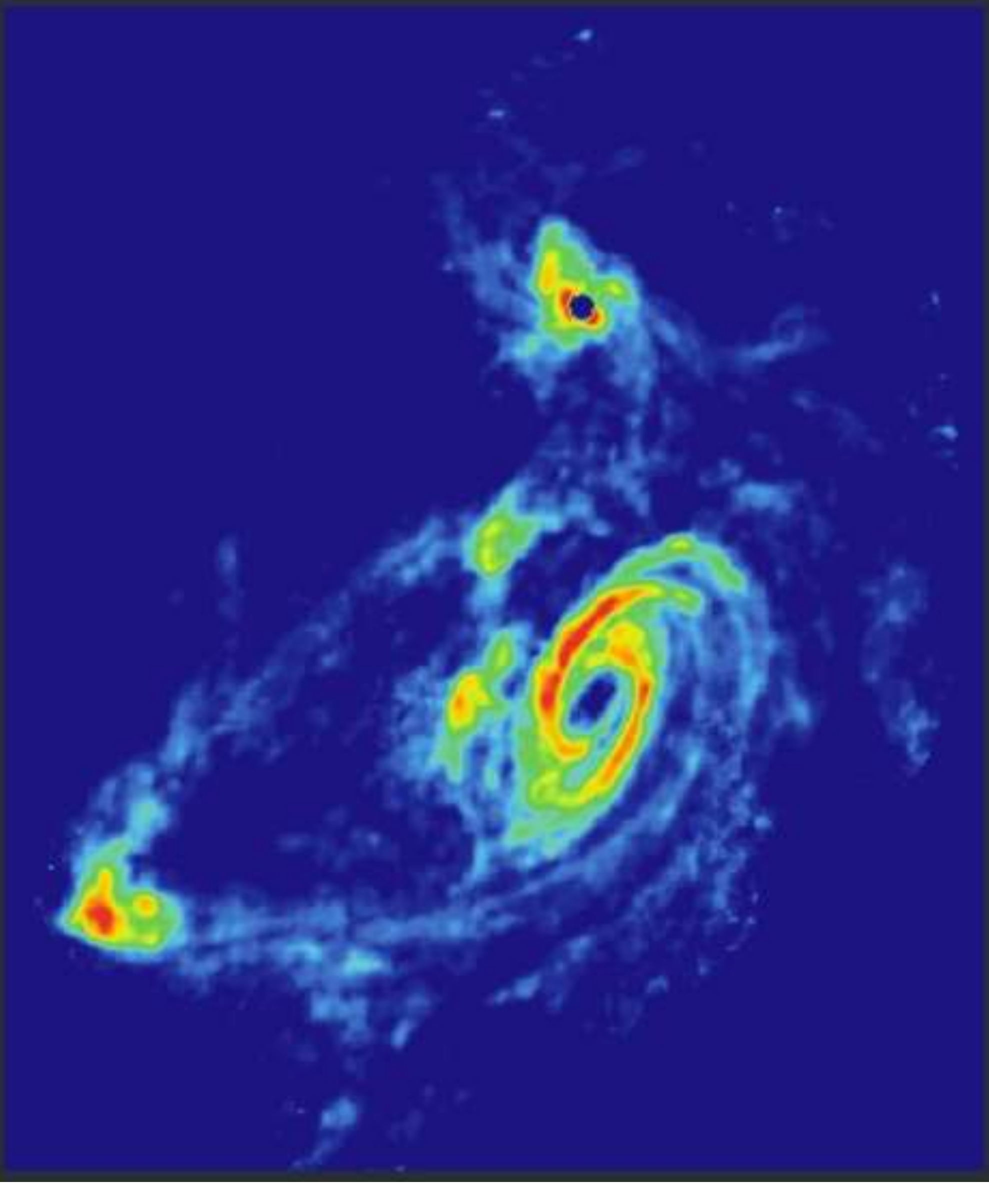


TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution



21 cm HI Distribution



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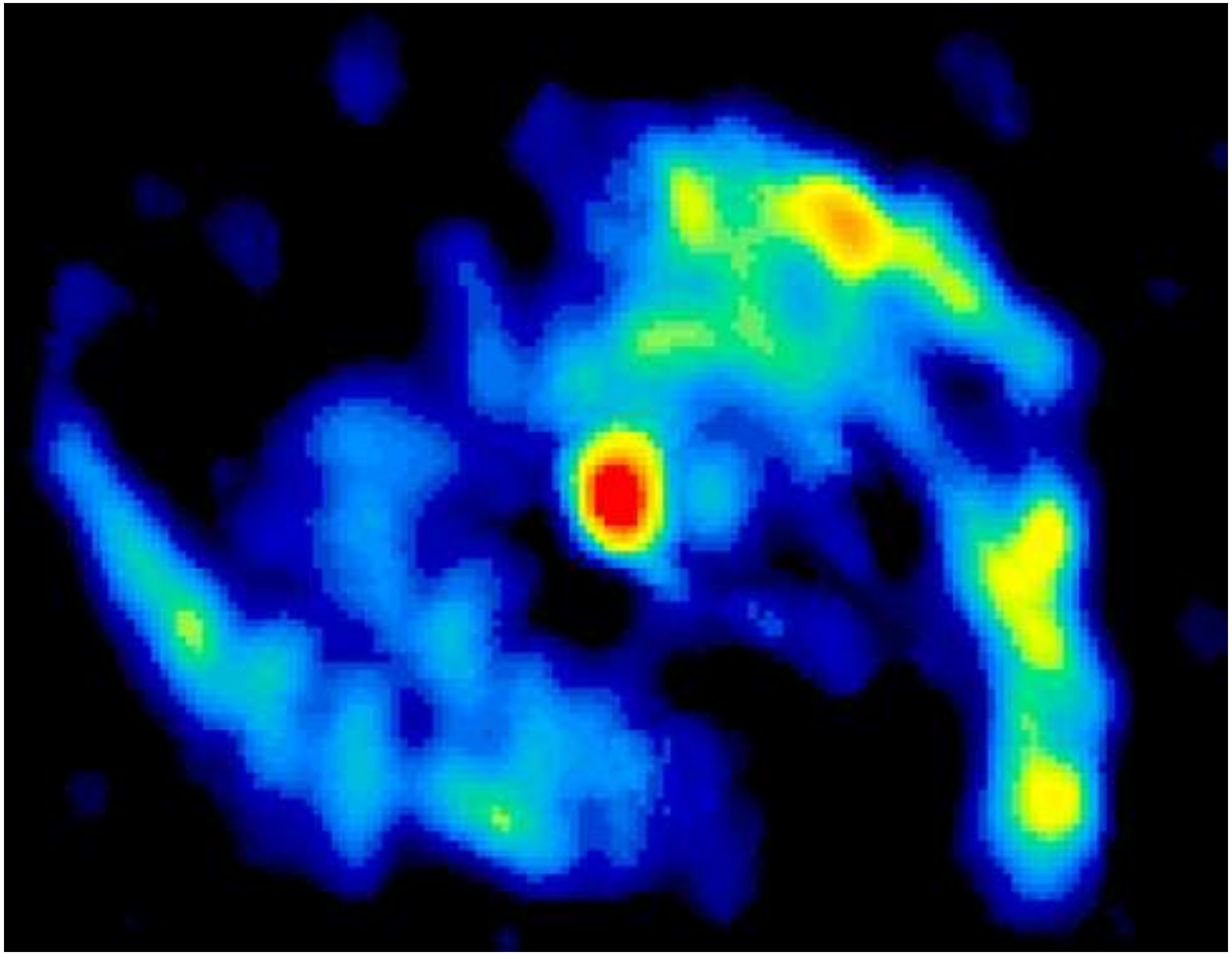
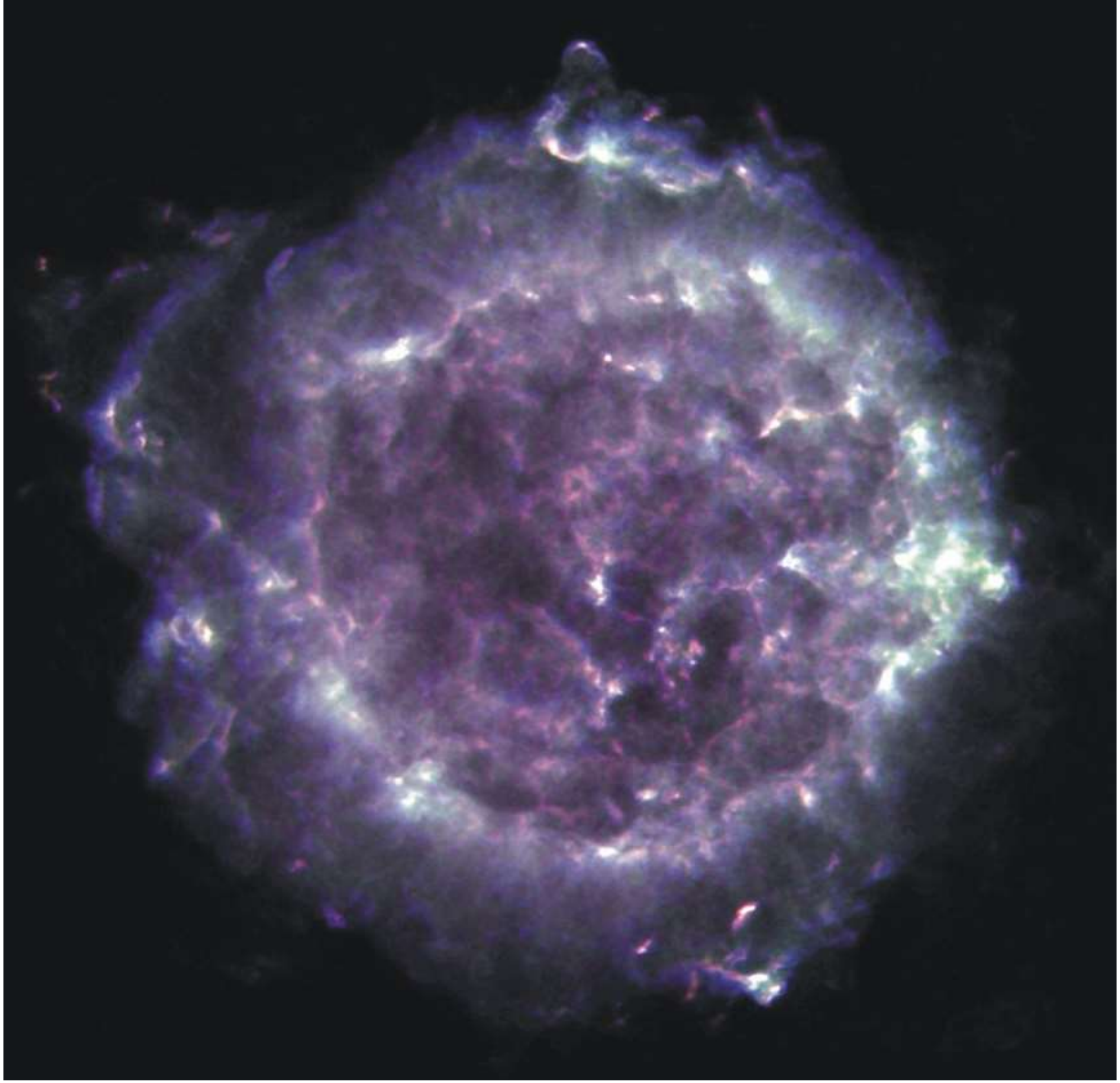


This false-color image of CO (J = 2-1) emission from the face-on spiral galaxy M51 was made with the Smithsonian Submillimeter Array (SMA). It reveals regions containing dense molecular gas, dust, and star formation that are optically obscured.

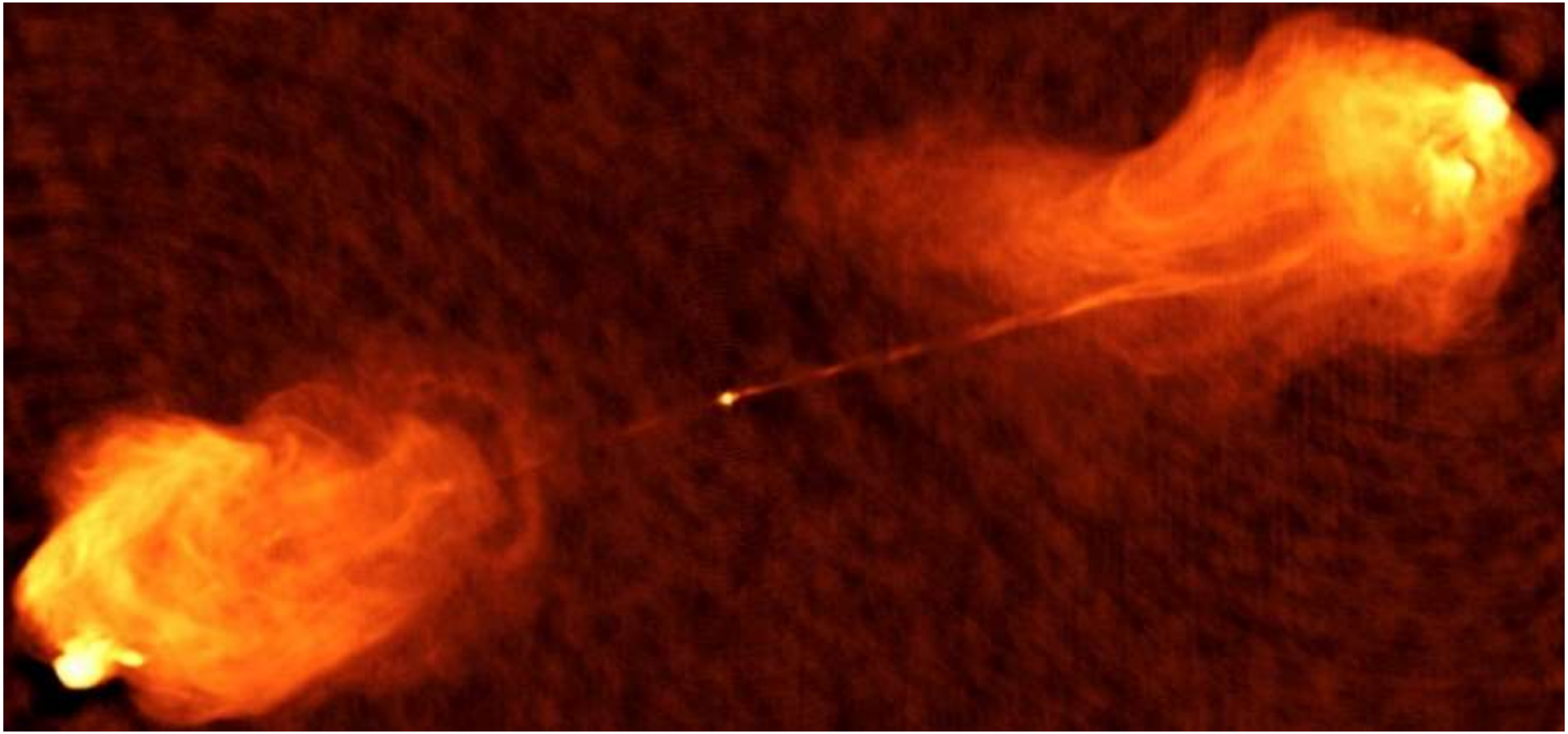
http://www.cv.nrao.edu/course/astr534/Tour.html



Cassiopeia A (Cas A)

is the remnant of a supernova explosion that occured over 300 years ago in our Galaxy, at a distance of about 11,000 light years from us. Its name is derived from the constellation in which it is seen: Cassiopeia, the Queen. A radio supernova is the explosion that occurs at the end of a massive star's life, and Cas A is the expanding shell of material that remains from such an explosion. This composite image is based on VLA data at three different frequencies: 1.4, 5.0, and 8.4 GHz. The material that was ejected from the supernova explosion can be seen in this image as bright filaments.

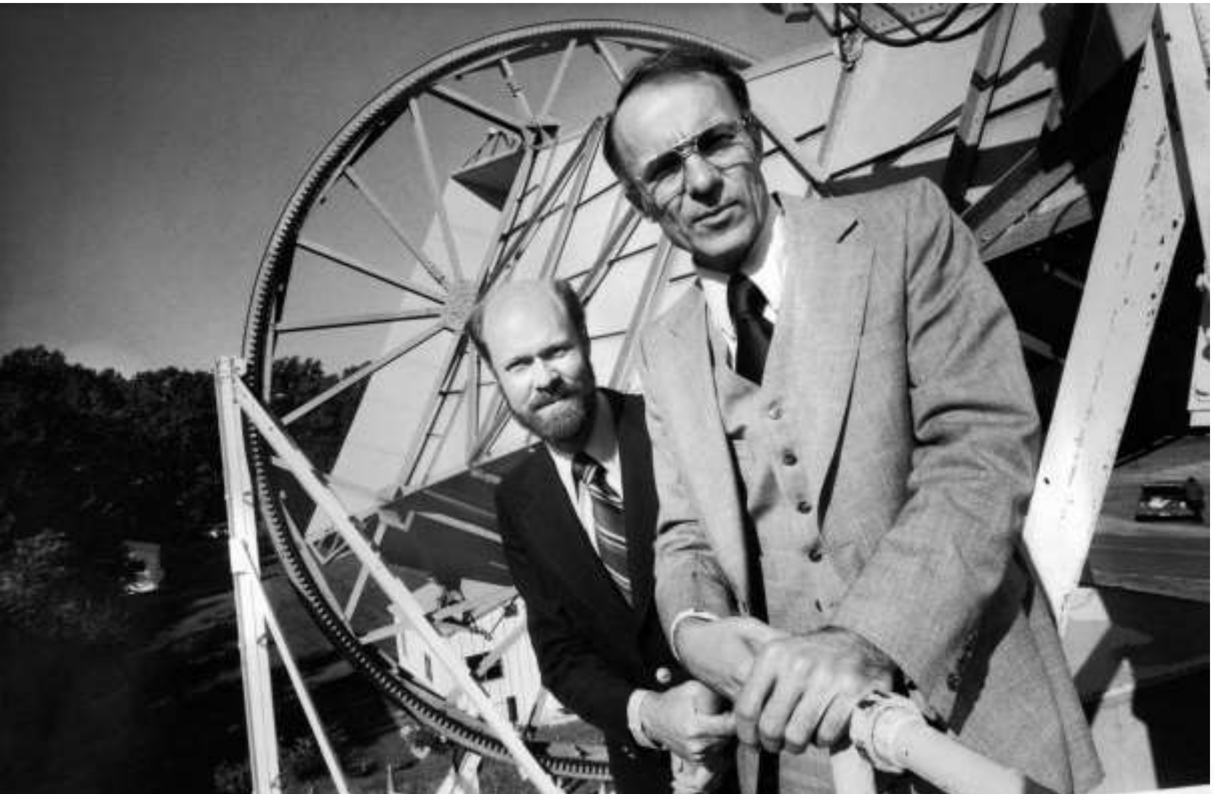
http://www.cv.nrao.edu/course/astr534/Tour.html



A high-resolution VLA image of the ***radio source Cygnus A.***
The bright central component is thought to coincide with a supermassive black hole that accelerates the relativistic electrons along two jets terminating in lobes well outside the host galaxy.

http://www.cv.nrao.edu/course/astr534/Tour.html

Radiação cósmica de fundo em micro-ondas (CMB)

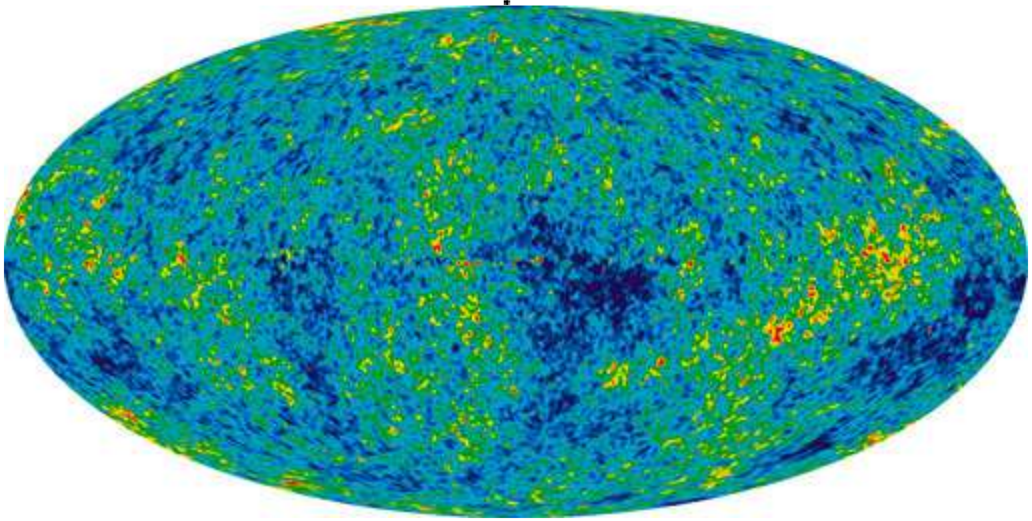


Emissão térmica a 3 K

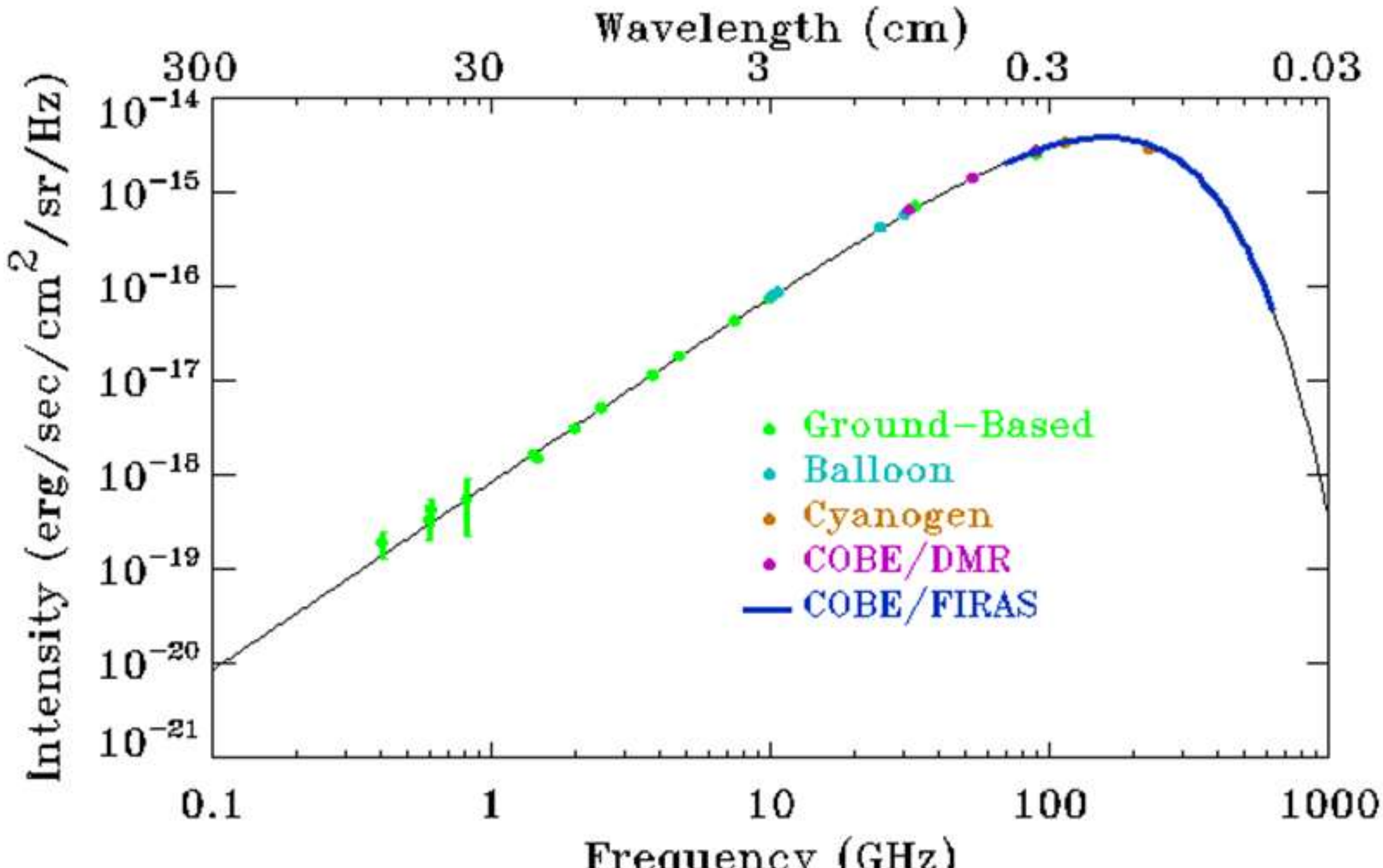
Descoberta experimentalmente em [1965](#) por [Arno Penzias](#) e [Robert Wilson](#)

Nobel prize: 1978

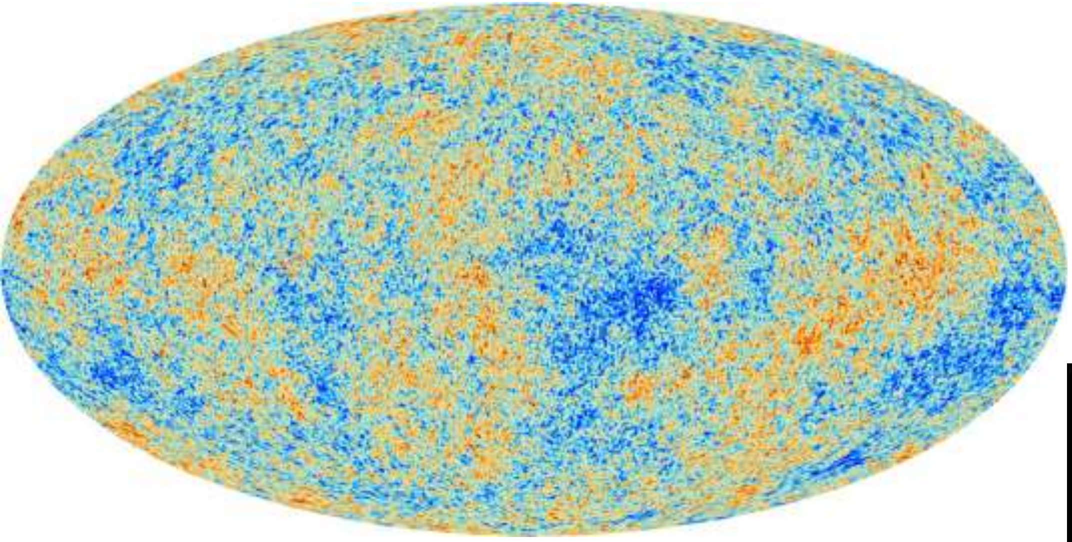
Emissão térmica



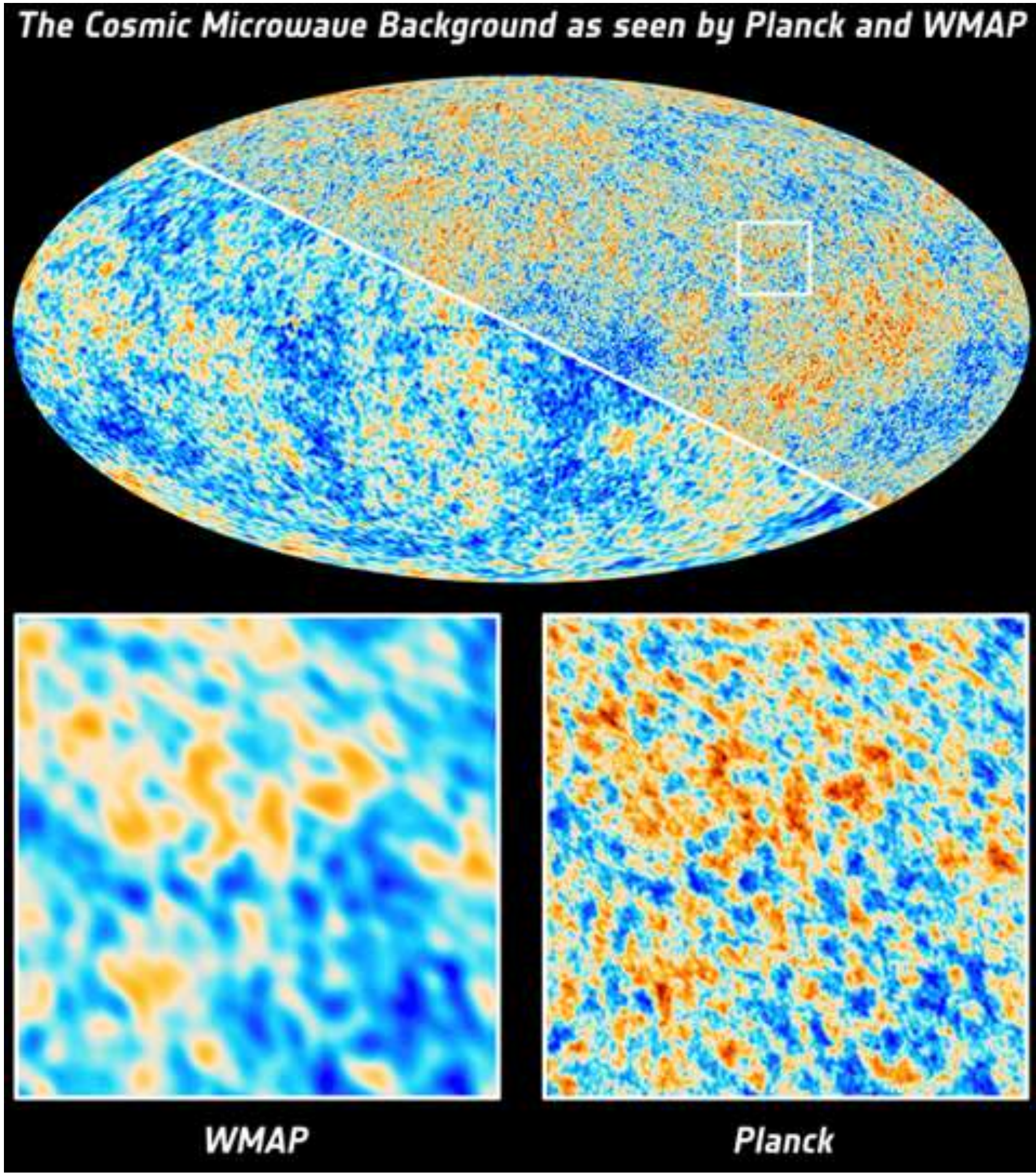
The WMAP 7-year total-intensity image of the CMB. The intensity range is only 200uK centered on the mean brightness T=2.725 K.



Emissão térmica

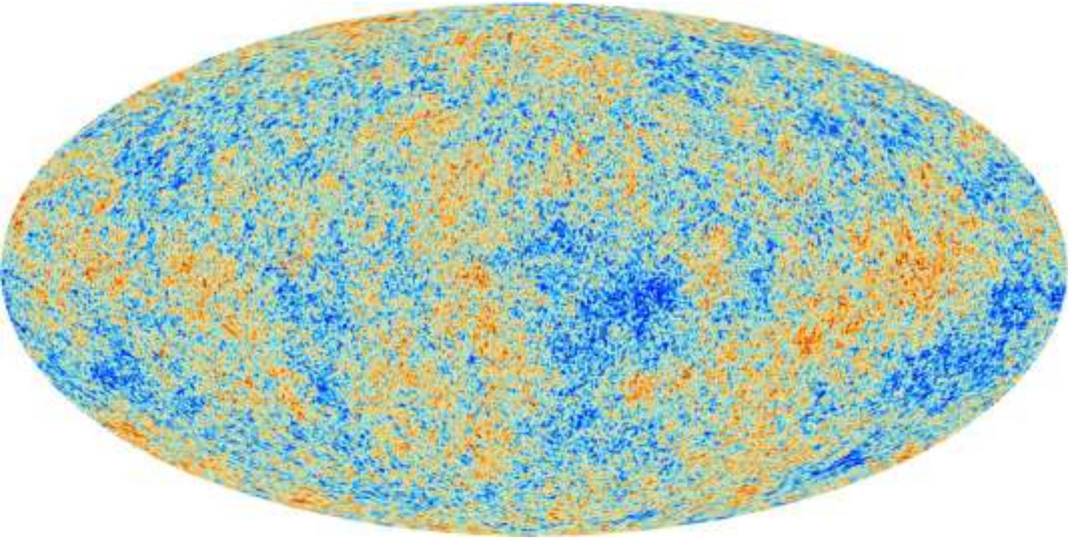


Planck observations of the CMB

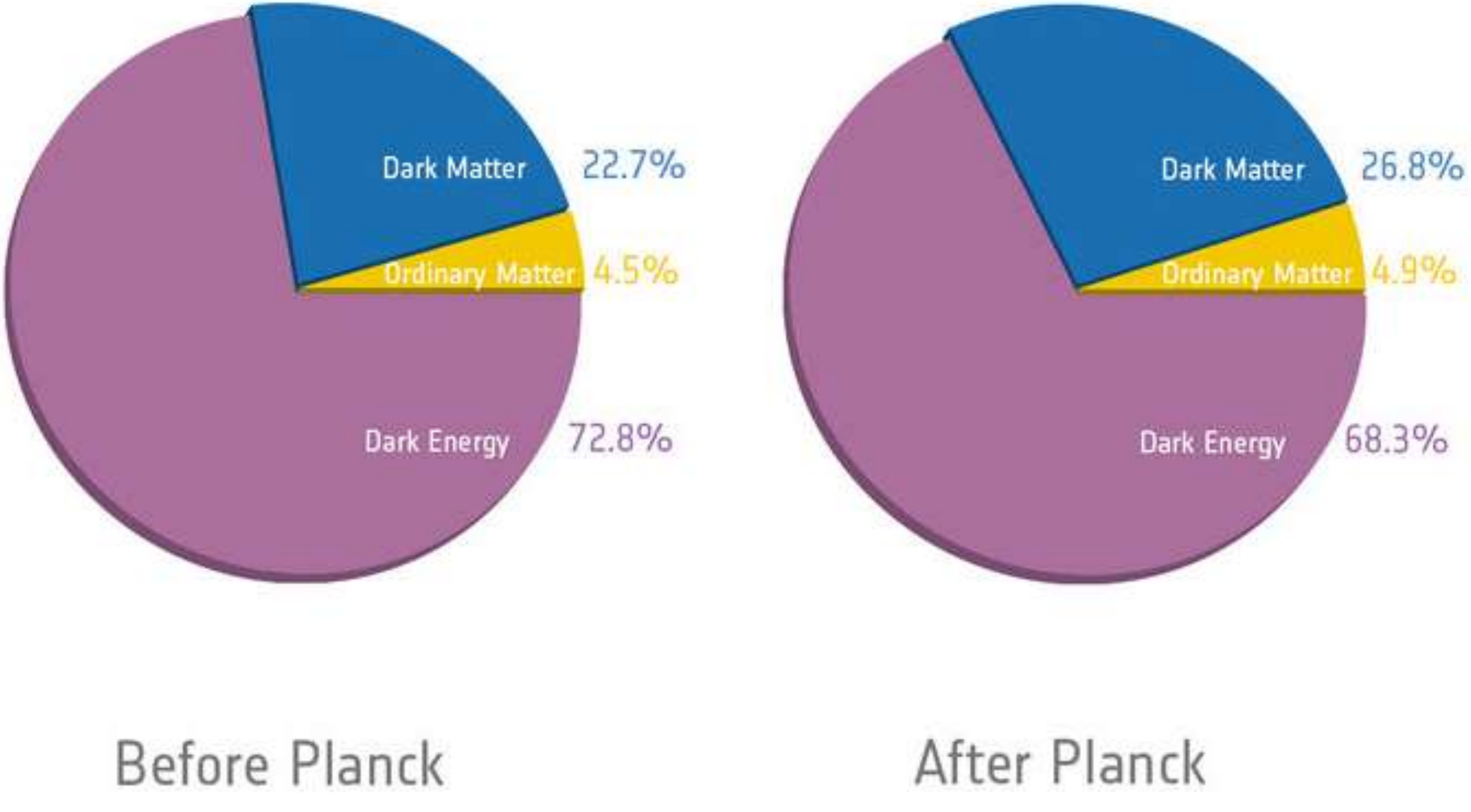


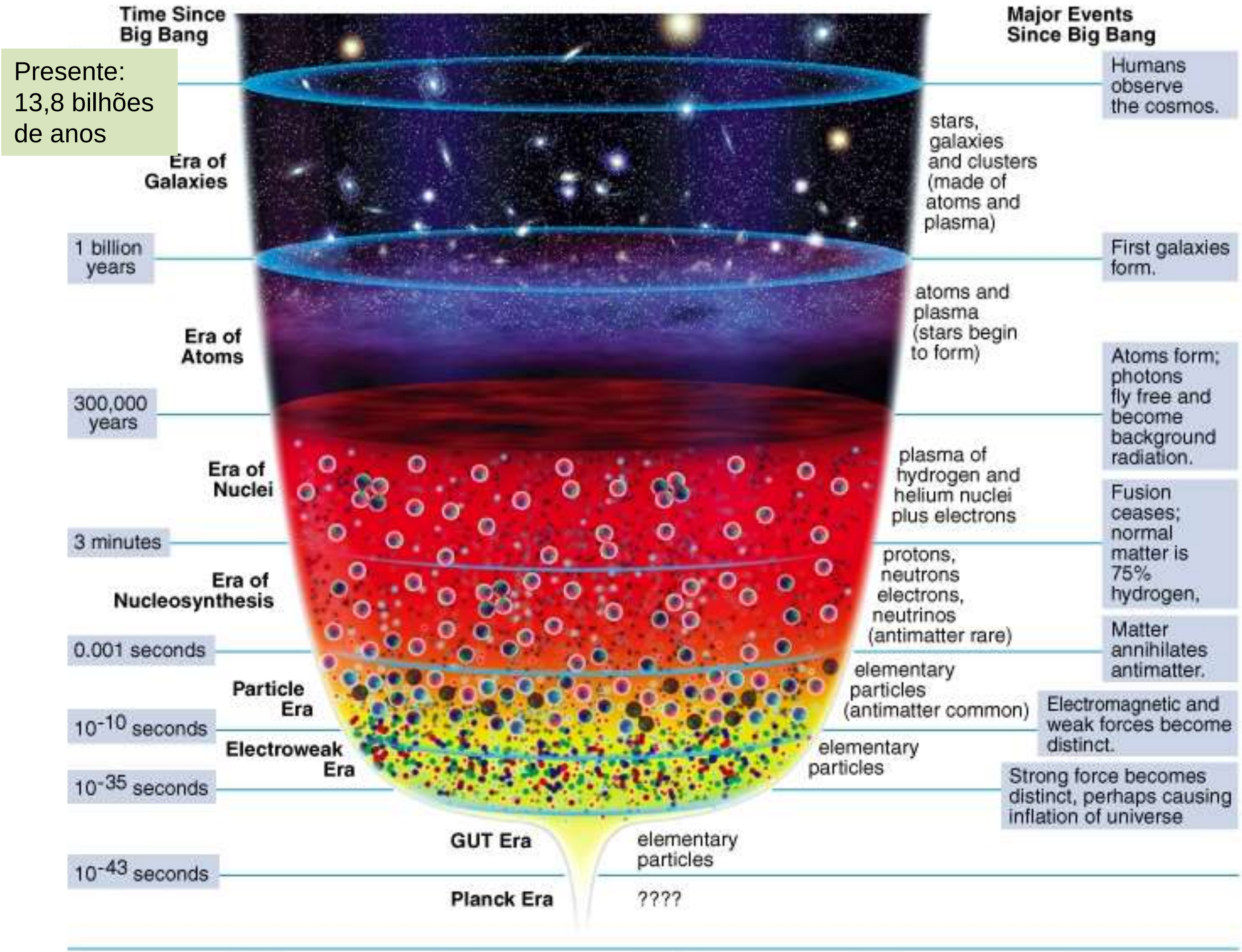
Planck março 2013:
Idade do universo: 13,82 Gyr

Emissão térmica



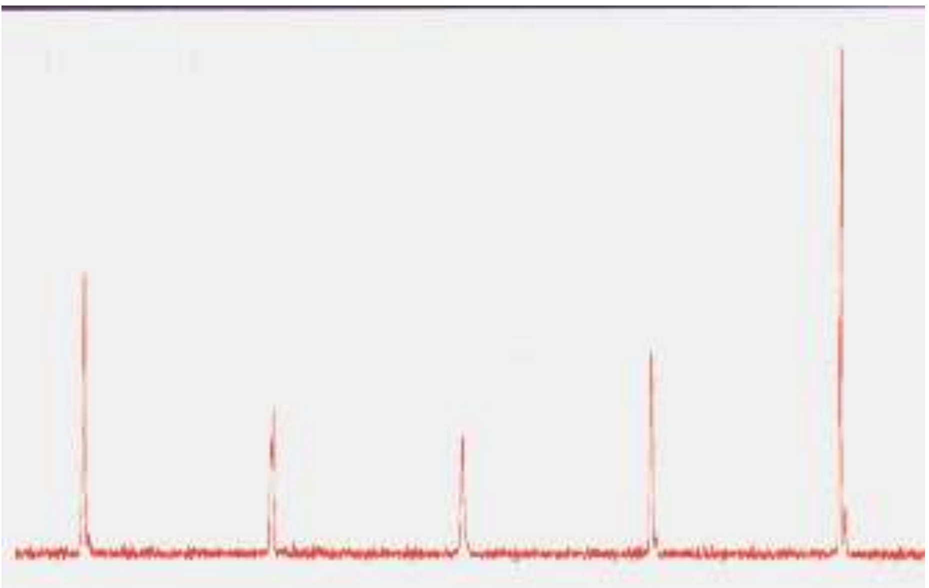
Planck observations of the CMB



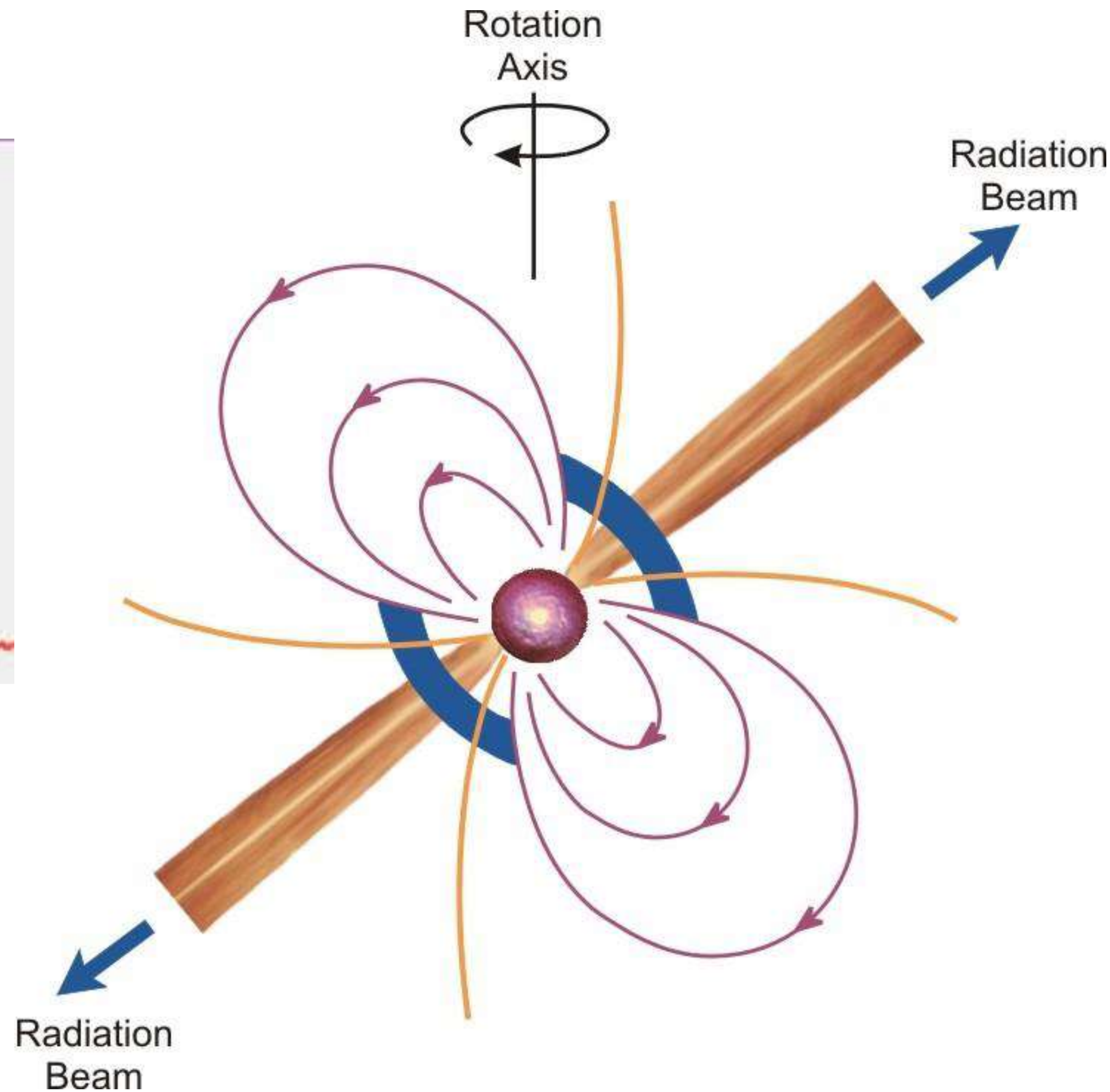


Presente: 13,8 bilhões de anos
Time Since Big Bang
Major Events Since Big Bang
Humans observe the cosmos.
Era of Galaxies
stars, galaxies and clusters (made of atoms and plasma)
1 billion years
First galaxies form.
atoms and plasma (stars begin to form)
Era of Atoms
300,000 years
Atoms form; photons fly free and become background radiation.
Era of Nuclei
plasma of hydrogen and helium nuclei plus electrons
3 minutes
Fusion ceases; normal matter is 75% hydrogen,
Era of Nucleosynthesis
protons, neutrons electrons, neutrinos (antimatter rare)
0.001 seconds
Matter annihilates antimatter.
Particle Era
elementary particles (antimatter common)
10^{-10} seconds
Electromagnetic and weak forces become distinct.
Electroweak Era
elementary particles
10^{-35} seconds
Strong force becomes distinct, perhaps causing inflation of universe
GUT Era
elementary particles
10^{-43} seconds
Planck Era
????

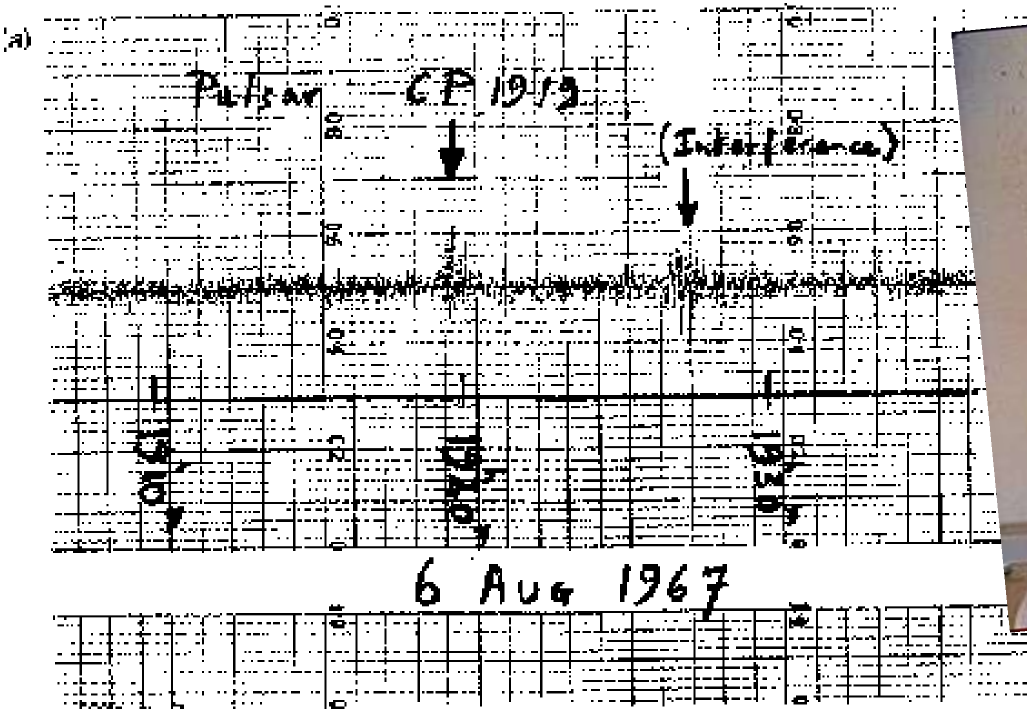
Pulsares

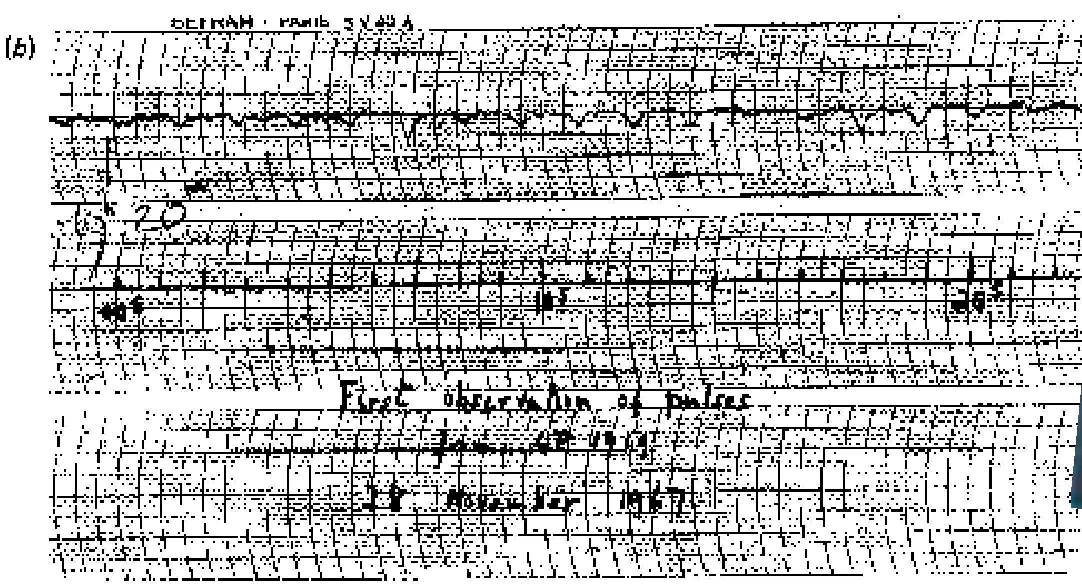


Escala Total: 3 segundos

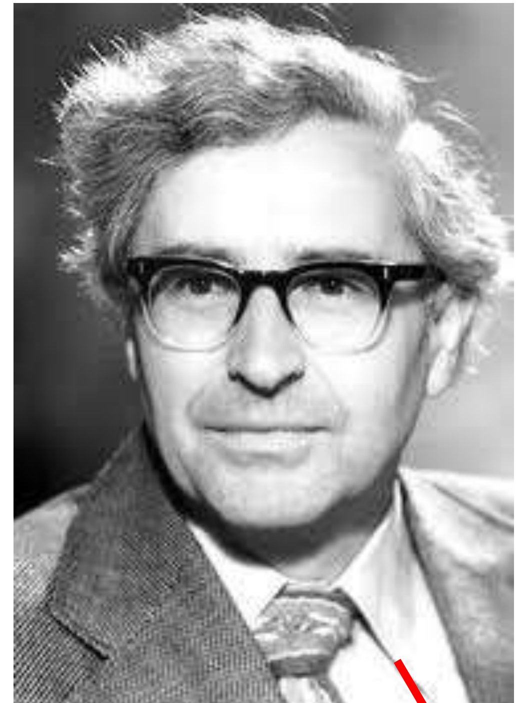


Jocelyn Bell (1943 -)



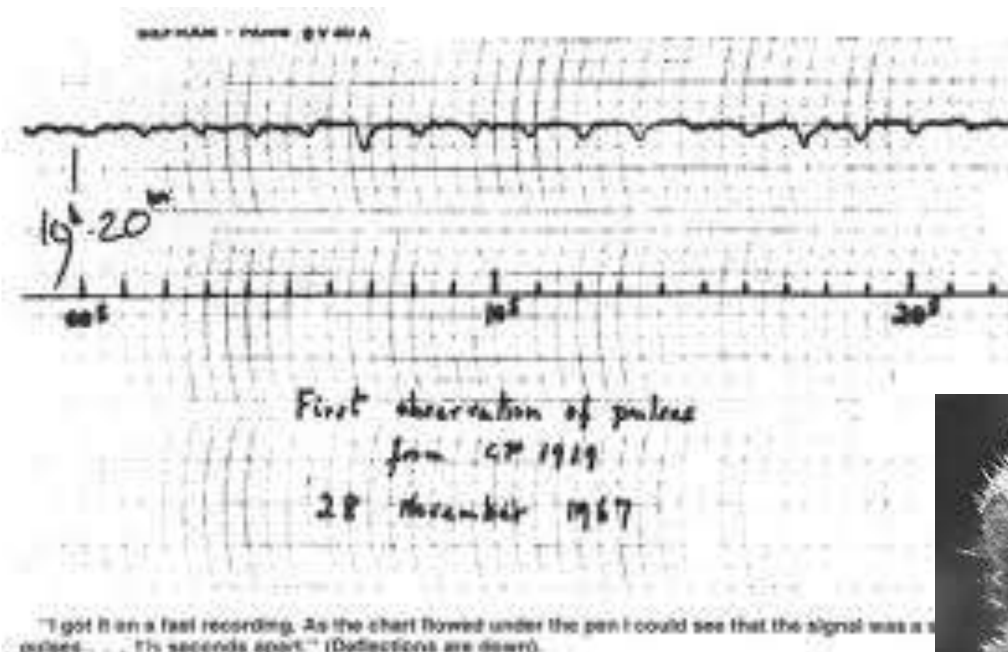


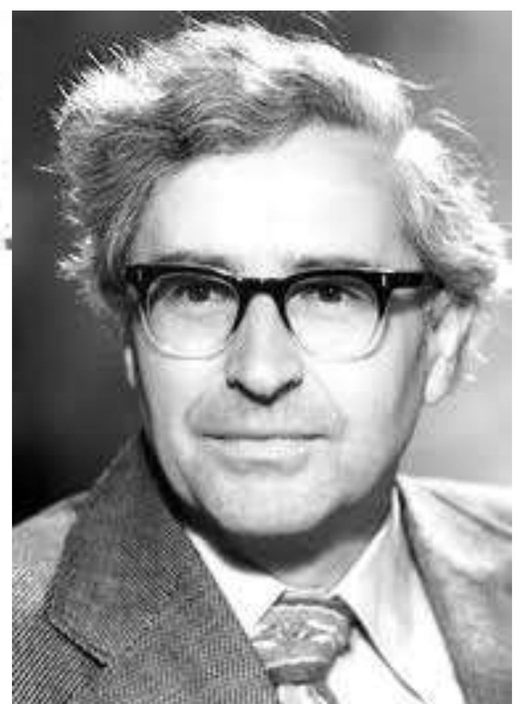
Jocelyn Bell & Antony Hewish



LGM: little green man

Jocelyn Bell achou outras fontes em 1967: they cannot be LGM





Descoberta Pulsares:

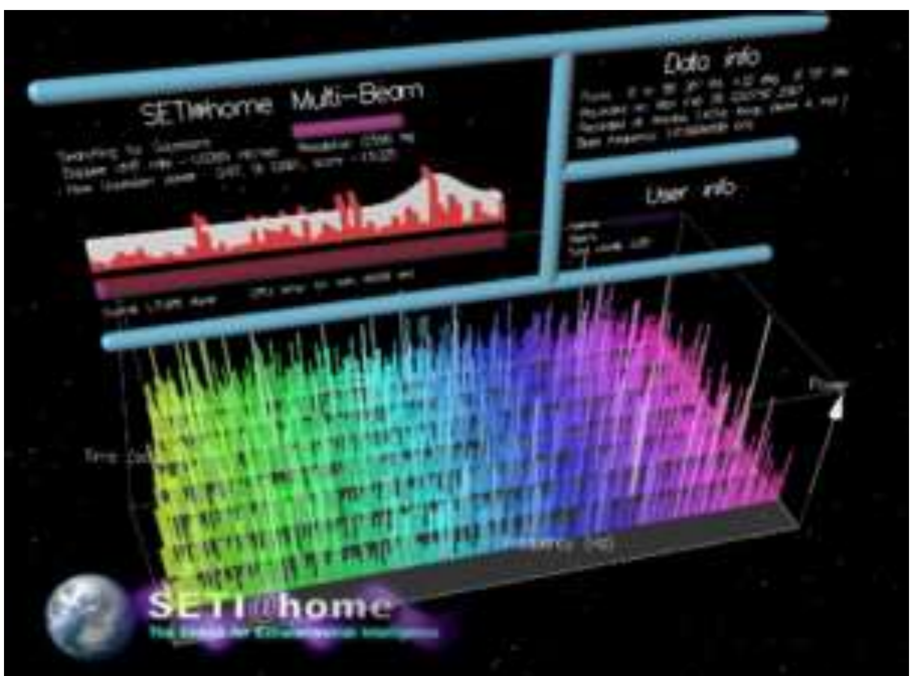
Nobel Física 1974

SETI

Arecibo

Allen telescope array 350 dishes (6m each)
Only 42 completed in 2007
(hibernation in April – Dec 2011 due to lack of funds)

Wide field 2.45° at λ = 21 cm. Instantaneous frequency coverage from 0.5 to 11.2 GHz



Resolução angular

$$\alpha = 1.22\,\lambda/d$$

λ (radio range observable from the ground) = 1mm-20mm

- Se λ = 0.1m e D = 7m, $\alpha = 1^{o}$

- Rádiotelescópios são limitados pela difração
- (lembrando...) os ópticos são limitados pelo seeing

No geral radiotelescópios não produzem imagens (detetores são unidimensionais)

⇨ as imagens são feitas por varredura

100 *Radio telescopes and techniques*

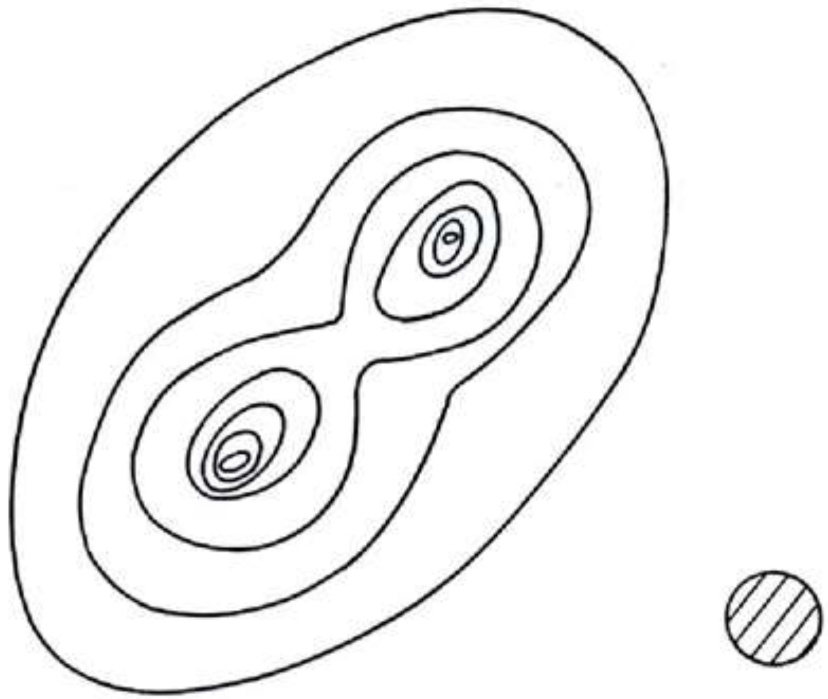


Fig. 4.1. Radio map (contours of equal intensity) of two neighbouring but resolved sources (schematic). The hatched circle represents the beamwidth of the telescope.

Smith

“Imageamento”

O rádio telescópio é um telescópio com um “CCD” de um único pixel. → É necessário varrer a região a ser observada.

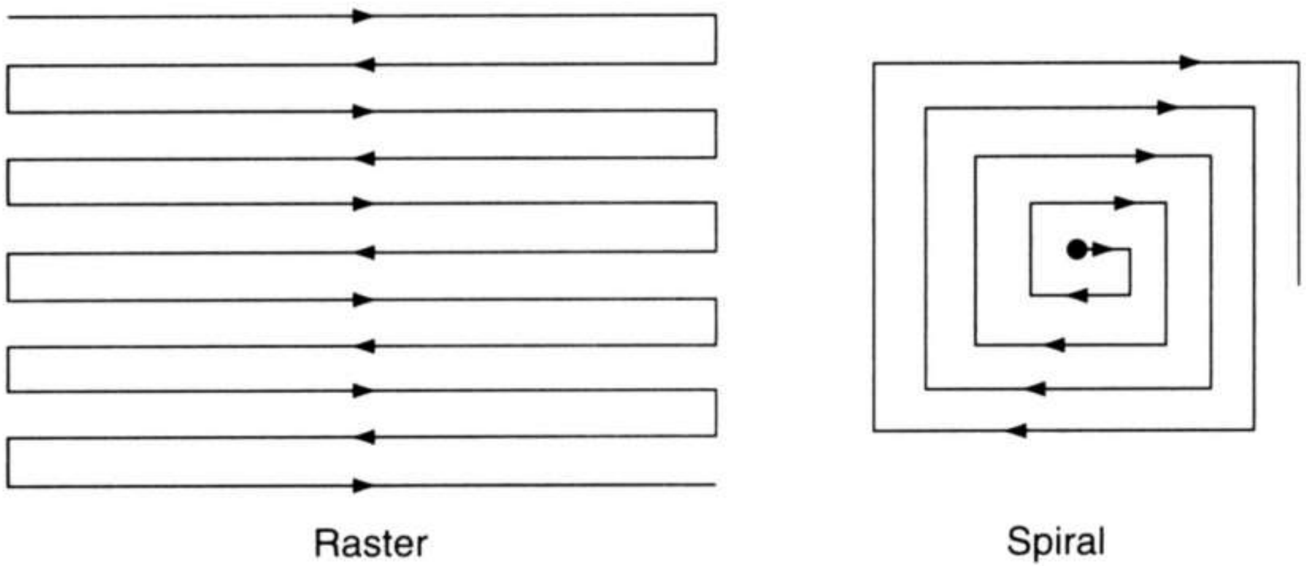
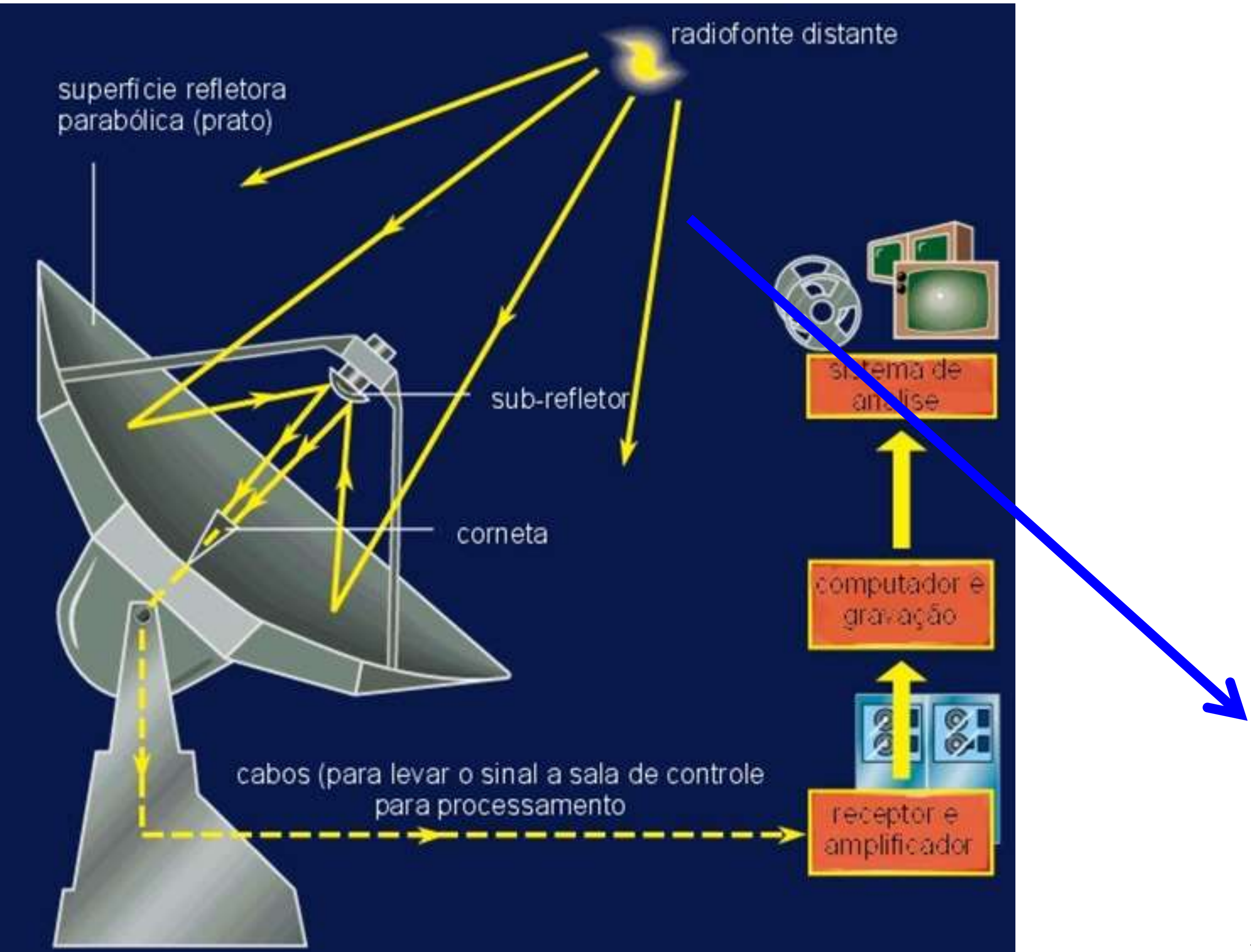


FIGURE 2.14 Scanning patterns.

Mas alguns rádio telescópios têm alimentadores múltiplos (Um CCD de mais de um pixel): O rádio telescópio de Parkes, 64 m, usa um receptor de 13 alimentadores em 21 cm, e o Five College Radio Astronomy Observatory, 14 m, usa um receptor de 32 alimentadores no milimétrico!

Elementos de um radiotelescópio



Prato
+
Antena
+
sistema de detecção

Feixe de entrada é plano-paralelo. Figura não está correta.

www.das.inpe.br

Prato: focaliza a radiação na antena

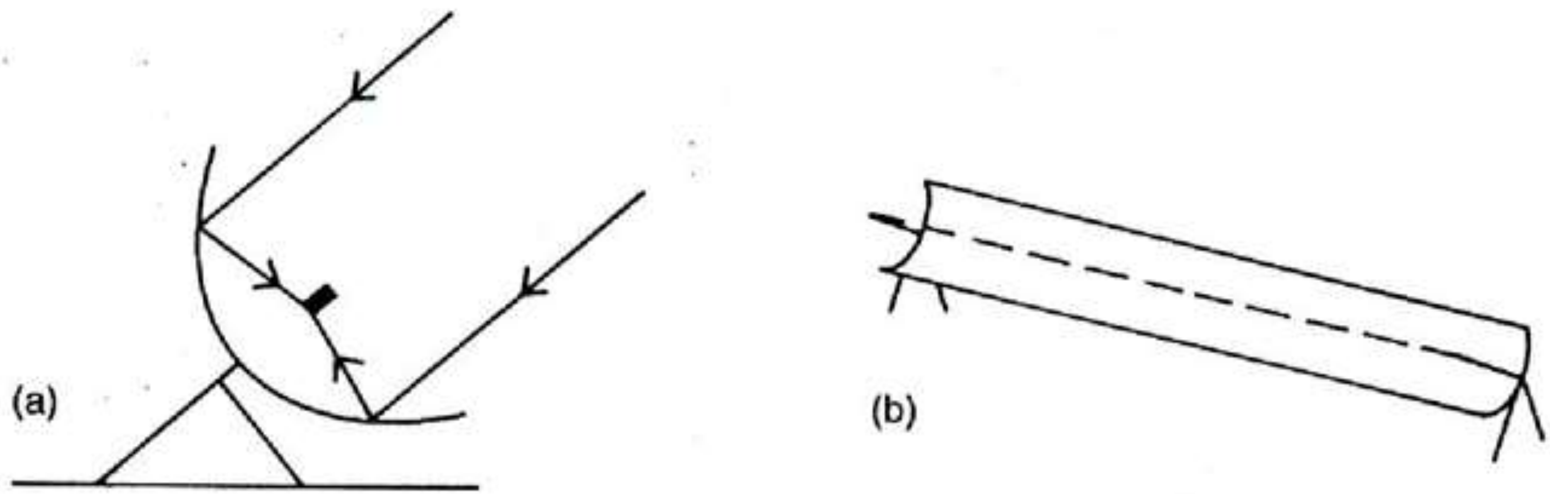


Fig. 4.3. (a) A simple parabolic dish receiver, of circular cross-section, with a prime focus feed. (b) A parabolic cylinder receiver, steerable in altitude, showing a line feed.

Smith

Rádiotelescópios não precisam ter superficies continuas

Uma das 30 antenas do GMRT na India

Rádiotelescópios tem f/# baixo

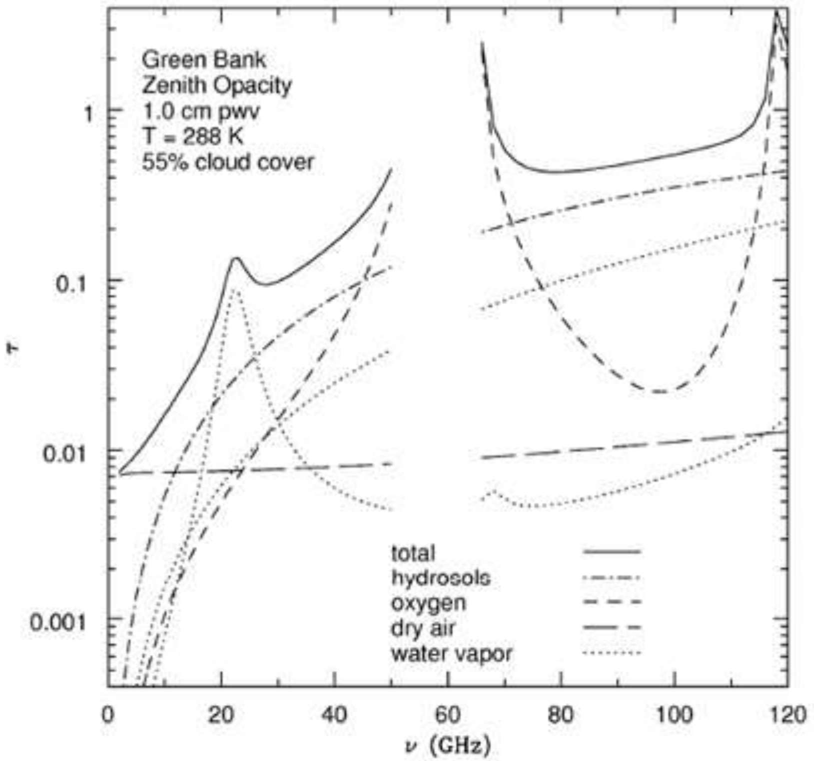
Baixa f/# ajuda a proteger do ruído

O rádio telescópio de Cambridge, com f/<1 e D=32m.

Podem ser off-focus (asimetricos, e.g. seção de parábola)

- Green bank Radiotelescope, 100x110m (F=60m), largest steerable in the world (situated in West Virginia, USA)

290 MHz to 90 GHz



The zenith atmospheric opacity for a typical summer night at Green Bank. attenuates the power received from an astronomical source by the factor oxygen and dry-air opacities are nearly constant, while the water-vapor ar droplets in clouds) contributions vary significantly with weather.


Caption: CSIRO's Parkes radio telescope. Credit: David McClenaghan, CSIRO

64-metre Parkes radio telescope in Australia.

The dish surface was physically upgraded by adding smooth metal plates to the central part to provide focusing capability for centimetre and millimetre length

Effelsberg 100-m Radio Telescope
Max Planck Institute for Radio Astronomy (Bonn)

- Located in a valley to minimize intereference

- Accuracy of the mirror surface better than 1mm

Arecibo Observatory, Puerto Rico
Diâmetro 305m

Interferometria

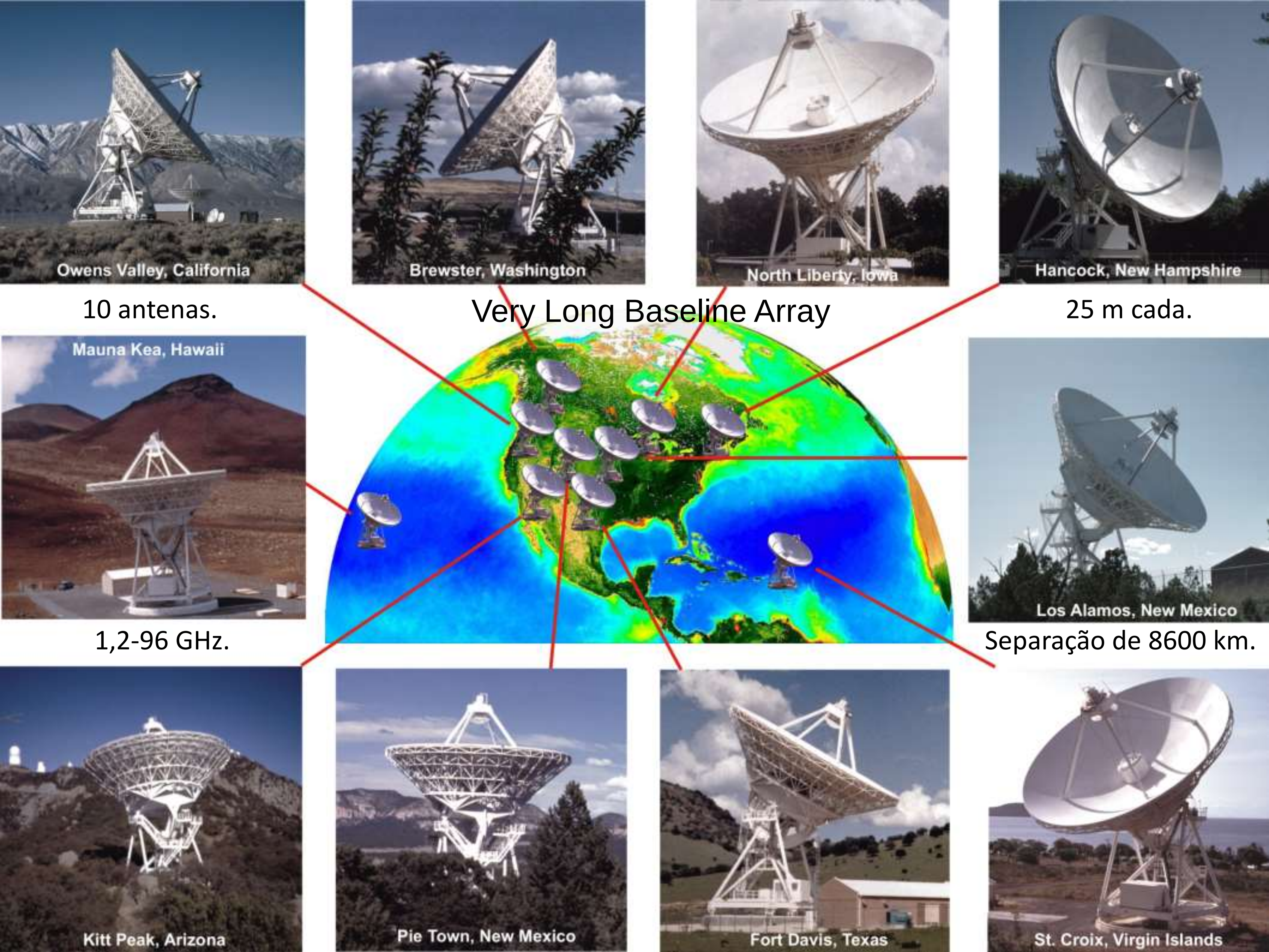
BDA

www.das.inpe.br

The 1 km configuration of the Very Large Array (VLA) of 27 25-m telescopes located on the semi-desert plains of San Augustin in New Mexico at an elevation of 7,000 feet (about 2100 m). The individual dishes can be moved to span $D =$ 1, 3.4, 11, or 36 km to synthesize apertures having those diameters and yield angular resolutions ranging from $\theta \approx 45$ arcsec at $\nu = 1.4$ GHz in the smallest configuration to $\theta \approx 0.04$ arcsec at $\nu = 43$ GHz in the largest. Coherent (phase preserving) amplifiers allow the signals from each telescope to be combined with signals from the other 26 telescopes without loss of sensitivity, a requirement for making accurate images of faint extended sources. [Image credit]

ALMA (ESO, NRAO)

- 66 antennas (50 x 12-m and 16 x 7-m)
- Wavelengths covered: from 0.3 - 3.6 mm (84 - 950 GHz)
- Top spatial resolution of 5 milli-arcseconds


Owens Valley, California
Brewster, Washington
North Liberty, Iowa
Hancock, New Hampshire
10 antenas.
Very Long Baseline Array
25 m cada.
Mauna Kea, Hawaii
Los Alamos, New Mexico
1,2-96 GHz.
Separação de 8600 km.
Kitt Peak, Arizona
Pie Town, New Mexico
Fort Davis, Texas
St. Croix, Virgin Islands