

Measuring Cosmic Radio Emission

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Radio Astronomy

Radio radiation

$$E: 4.2 \text{ meV} \rightarrow 41.4 \text{ peV}$$

$$\nu: 1 \text{ THz} \rightarrow 10 \text{ kHz}$$

$$\lambda: 300 \text{ } \mu\text{m} \rightarrow 3 \cdot \text{Tm}$$

The sources of radiation

Accelerated electric charges

Atoms

Molecules

Ions

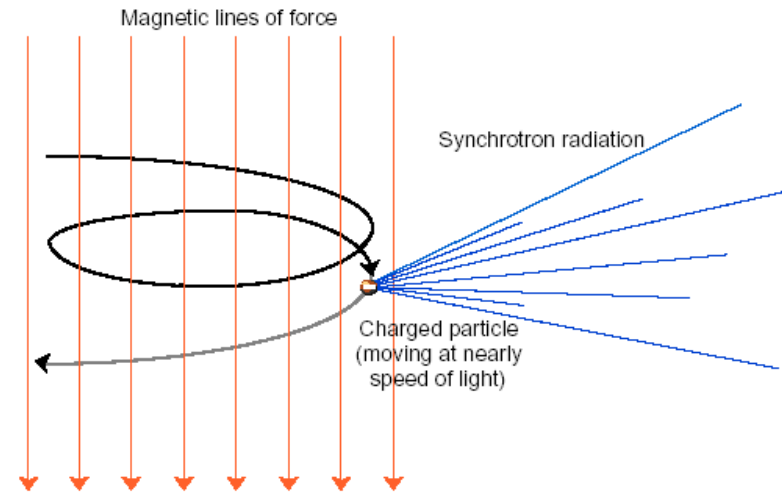
Synchrotron radiation

For extremely relativistic particles:

opening cone: $\theta = \frac{m_e c^2}{E} = \frac{1}{\gamma}$

The spectrum has its maximum at:

$$\nu_m [GHz] = 4.7 \cdot 10^{-3} B_{\perp} [10^{-10} T] (E [GeV])^2$$



At a characteristic galactic magnetic field of 10^{-10} T:

ν_{\max} [GHz]	10^{-2}	1	10^2
λ_m	30 m	30 cm	3 mm
E_e [GeV]	1.5	15	1500

The time in which an electron loses half of its energy to synchrotron radiation:

$$t_{1/2} [a] = 5.7 \cdot 10^8 (B [10^{-10} T])^{-3/2} \cdot (\nu_m [GHz])^{-1/2}$$

e.g. the Crab nebula:

$$B \sim 10^{-8} \text{ T}$$

$$\nu_m \sim 1 \text{ GHz} \quad 10^9 \text{ GHz (=X)}$$

$$t_{1/2} \sim 600000 \text{ a} \quad 20 \text{ a}$$

The synchrotron radiation is polarized

The spectrum of electrons in many sources has a power law $\sim E^{-p}$.

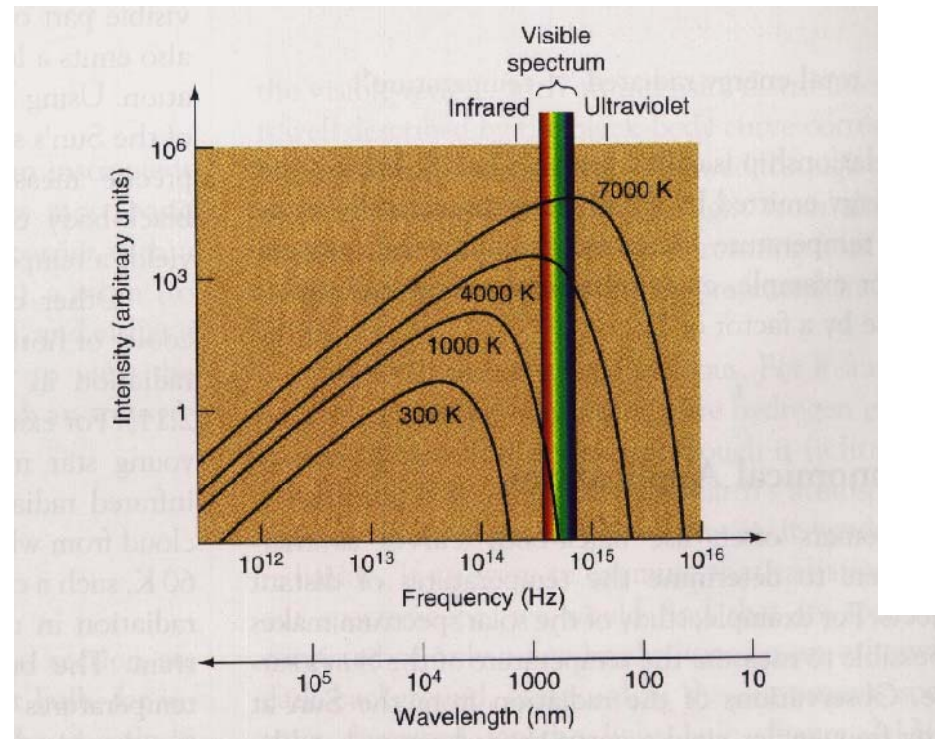
The resulting Synchrotron spectrum is then also a power law:

$$I(\nu) = (\text{const}) \cdot \kappa B^{(p+1)/2} \nu^{-(p-1)/2}$$

Black-body radiation

The intensity which is emitted by a black-body (Planck's formula) :

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

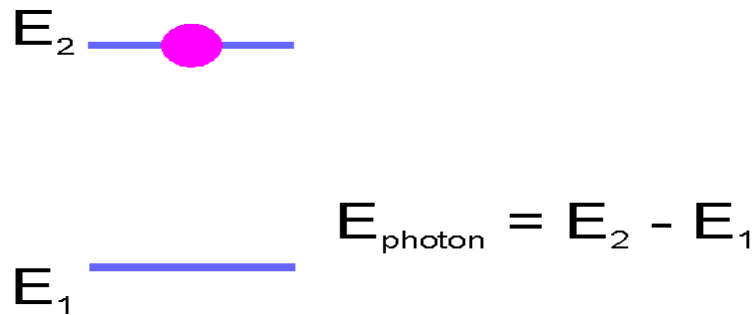


With the two limiting cases:

Wien's Law: $\frac{h\nu}{kT} \gg 1 : B_\nu(T) \approx \frac{2h\nu^3}{c^2} e^{-\frac{h\nu}{kT}}$

Rayleigh-Jeans: $\frac{h\nu}{kT} \ll 1 : B_\nu(T) \approx \frac{2\nu^2 kT}{c^2}$

Atomic and molecular levels:



Neutral hydrogen

The two hyperfine structure levels of the ground state $1s^2S_{1/2}$:

$$\Delta E = 5.9 \cdot 10^{-6} eV$$

$$\lambda_0 = 21.1 \quad \nu_0 = 1420.4 GHz$$

CO molecule (rotational level):

$$\Delta E = 4.8 \cdot 10^{-4} eV$$

$$\lambda_0 = 2.6 mm \quad \nu_0 = 115.27 GHz$$

Plasma emissions:

Oscillation

free-electron -Laser



Very intensive, because of coherent emission:



Maser:

For example OH , H_2O

Propagation of radio radiation in the ISM

Dispersion:

$$\omega_p = \sqrt{\frac{4\pi n_e e^2}{m}} \quad n(\omega) = -\sqrt{\frac{\omega_p^2}{\omega^2} - 1} \quad \longrightarrow \quad \text{group velocity: } v_{gr} = v(\omega)$$

Scattering:

The irregularities where the radio radiation is scattered must be of the order of the wavelength:

It is scattered on regions with different electron densities

Faraday rotation

When radiation traverses an interstellar magnetic field, the plane of polarization of the radio radiation will be rotated by angle Ψ :

$$\Psi = \lambda^2 \cdot RM$$

$$RM = 8.1 \cdot 10^3 \cdot \int_0^L n_e B_{\parallel} dl$$

What do we measure and what can be derived from that

Intensity and Distribution (Maps)

Continuous spectra:

From that we can distinguish the kind of radiation (thermal; nonthermal radiation)

The line spectra:

Intensity of lines \rightarrow composition of the target \rightarrow ^{12}CO , ^{13}CO , $^{12}\text{C}/^{13}\text{C}$ ratio

For $\frac{V}{c} \ll 1$:

$$\nu' = \nu \left(1 + \frac{V}{c} \right) \quad \text{Doppler effect}$$

So from shifts of the lines one can get the velocity of the matter and from the strength of the lines one can derive the density

Polarisation

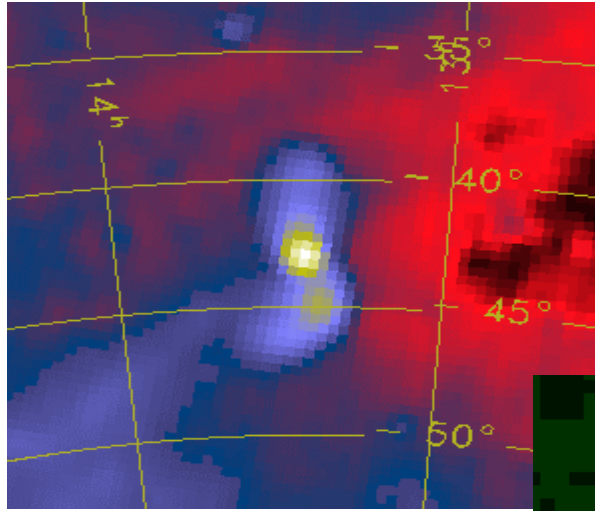
From the Faraday effect one can get the longitudinal magnetic field in the IMS

Time:

Variable sources, Pulsar emission

Historical sources

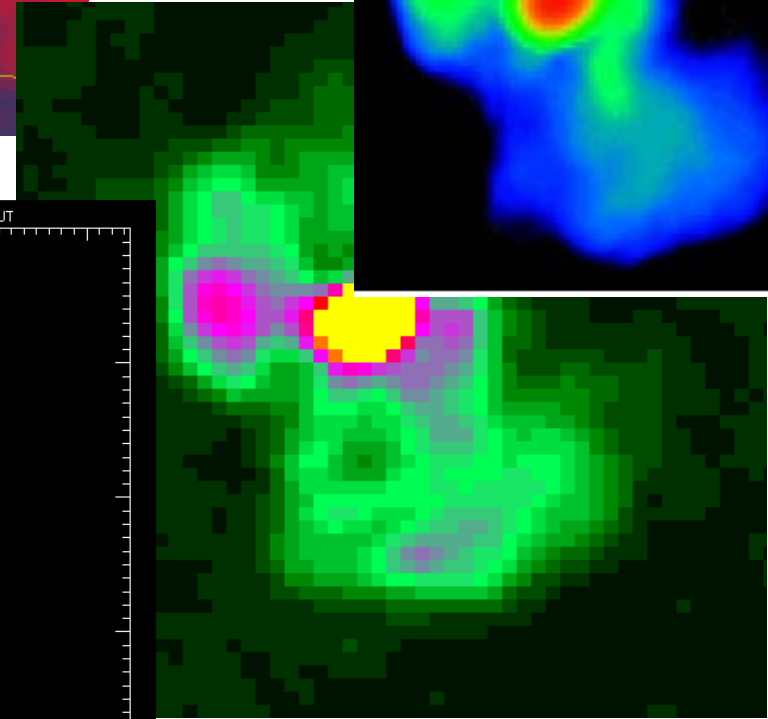
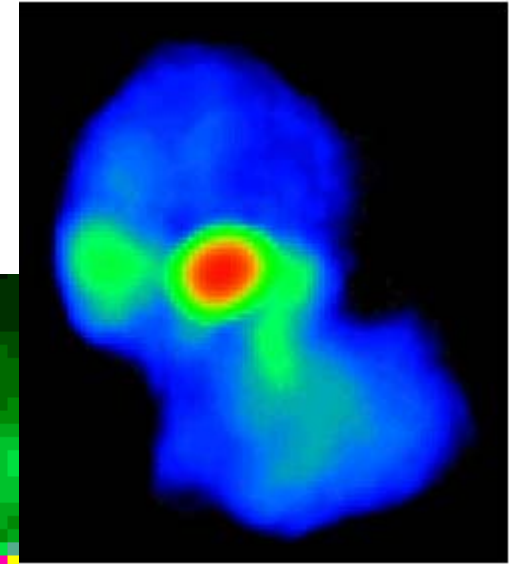
Haslam at 408 Mhz
1982



Centaurus A:

Virgo A:
VLA image scale is 80 kpc

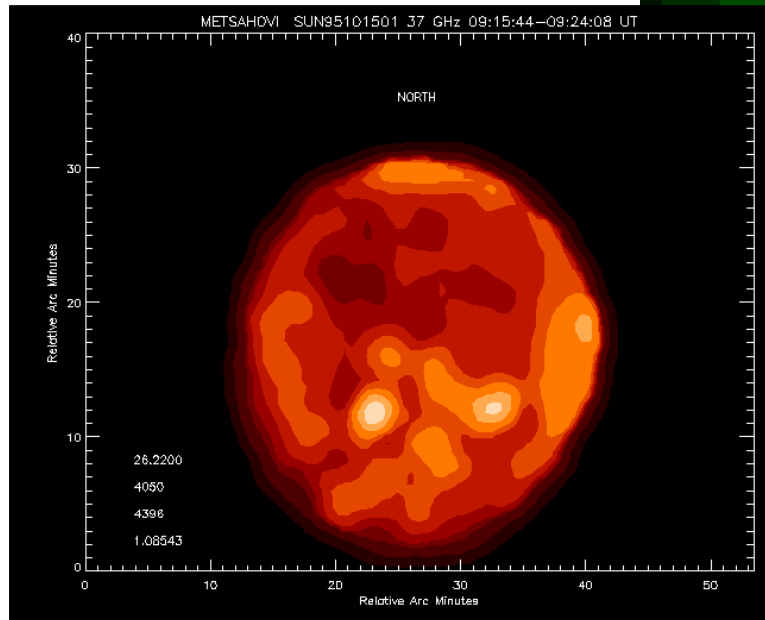
80 kpc



Virgo A
74 MHz, 60'' VLA 1998

Sun:

1995 at 37 GHz

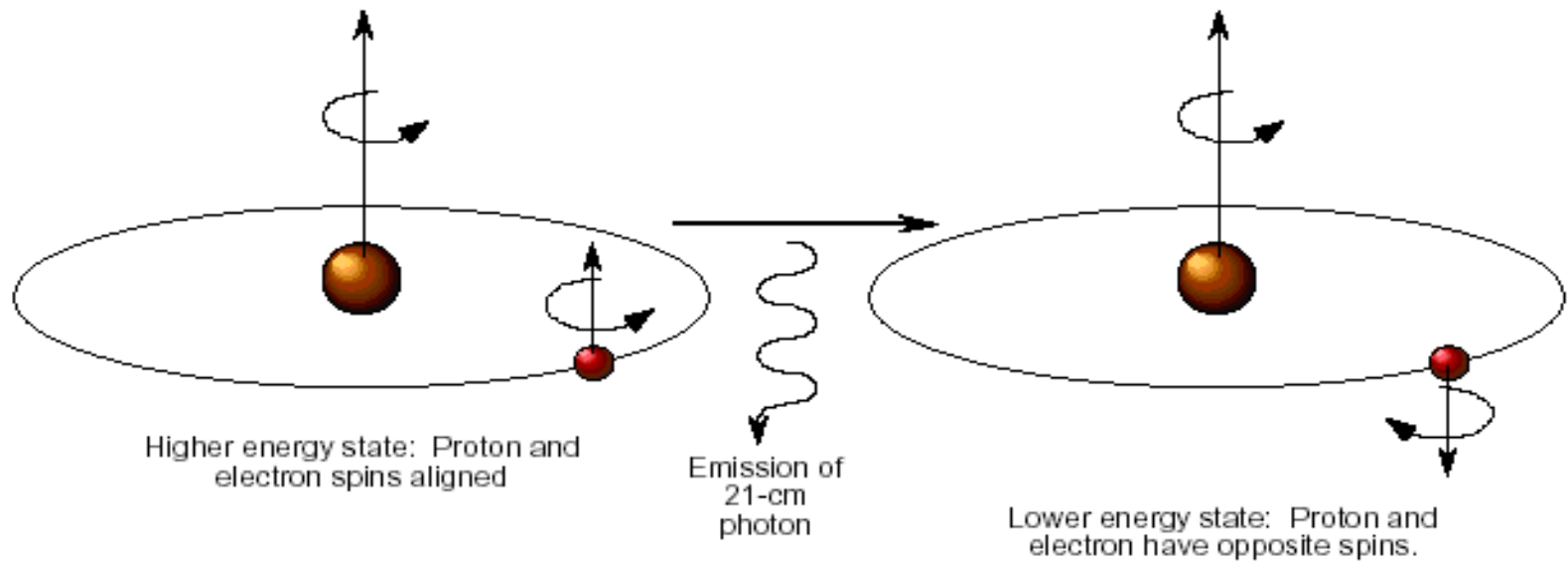


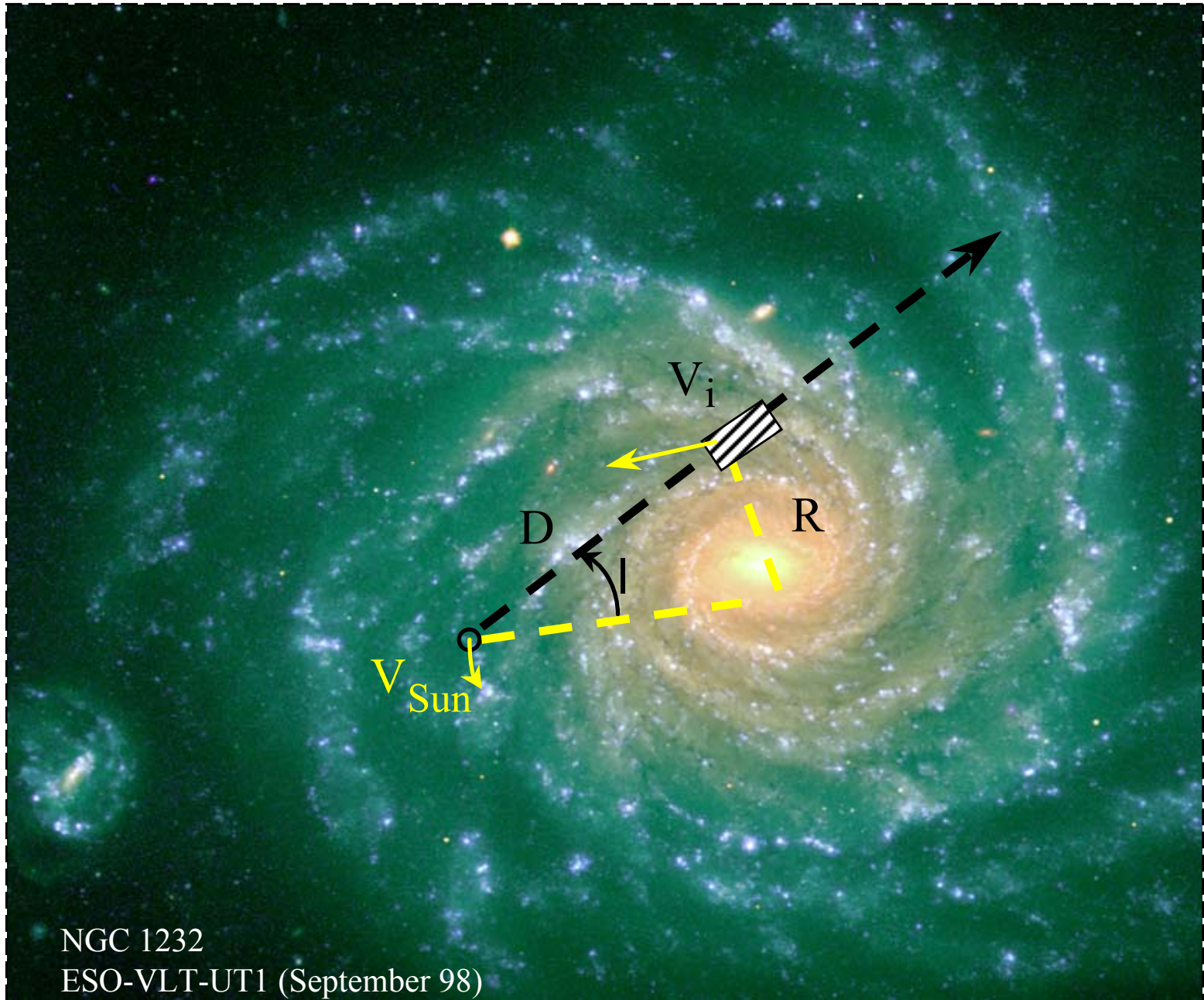
0.5 deg

Galaxy

Neutral hydrogen:

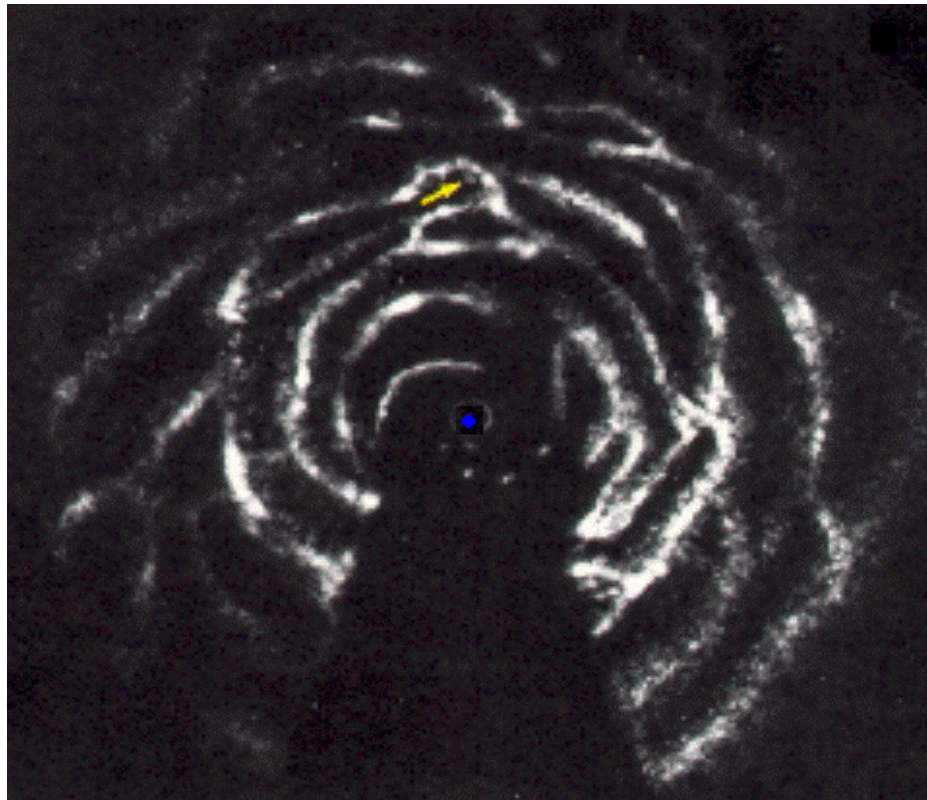
The 21.1 cm line of neutral hydrogen



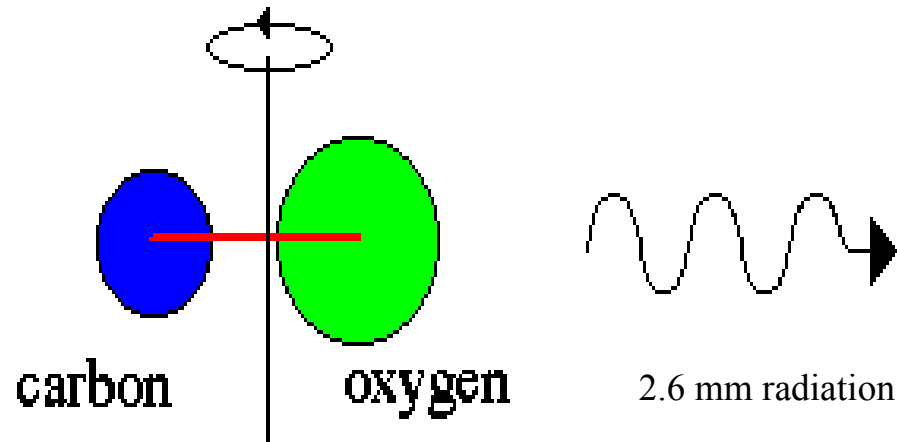


Milky Way

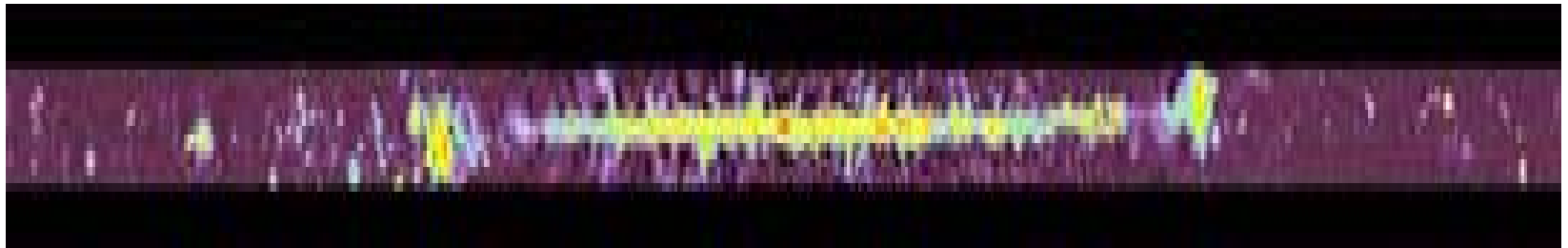
Surveys of the neutral hydrogen in the Milky Way show the spiral structure:



Radio radiation of the CO-molecule:
carbon monoxide molecule

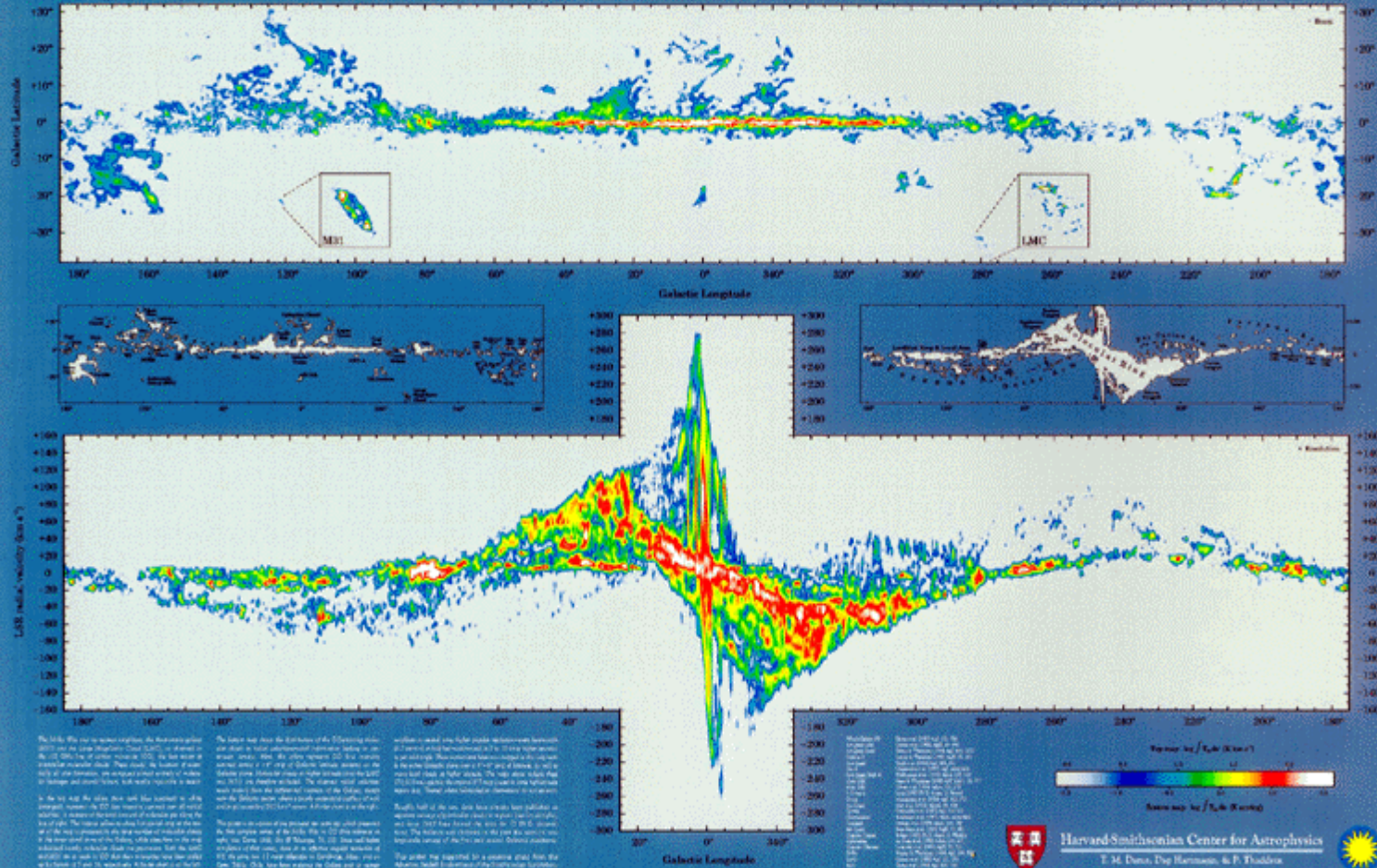


Molecular hydrogen regions in the Milky Way observed at 115 Ghz



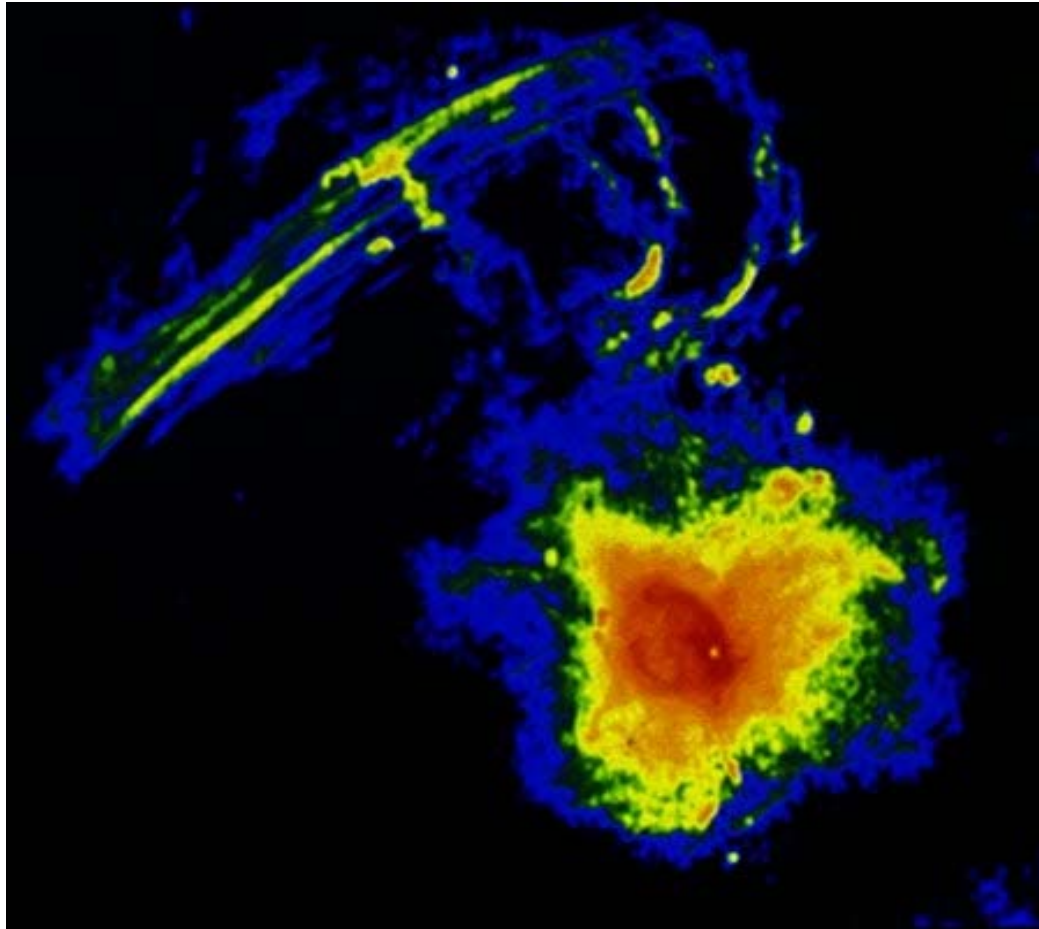
CO-surveys of the Milky Way

The Milky Way in Molecular Clouds



The center of the Milky Way

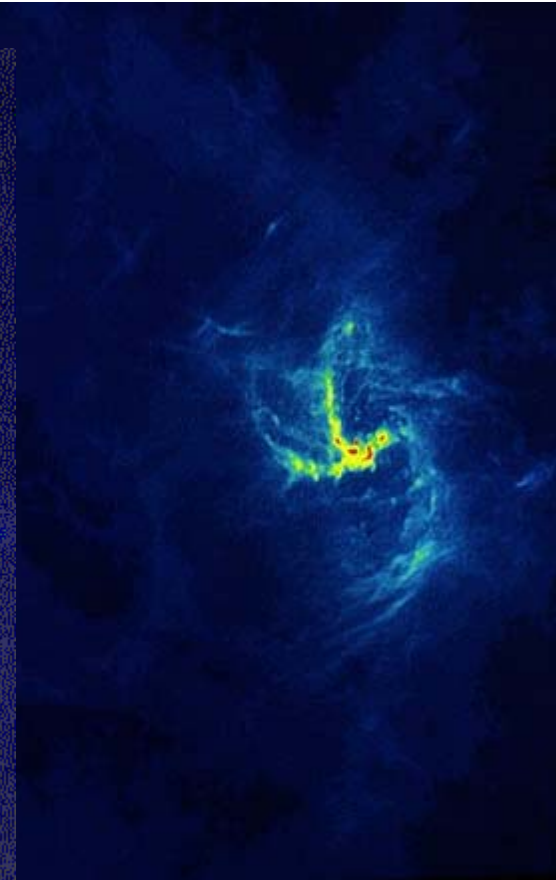
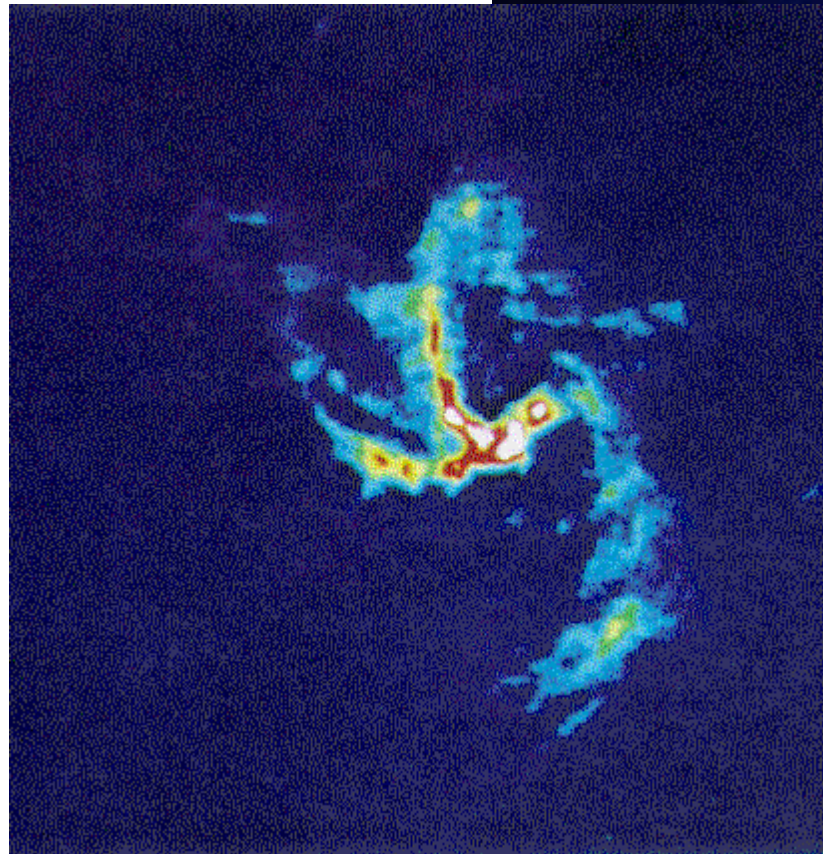
The SgrA-complex:
VLA at 20 cm (synchrotron)



Galactic Center

HII-regions: SgrA West:
(free-free emission)

Sgr a West at 6 cm ionized gas



2 pc

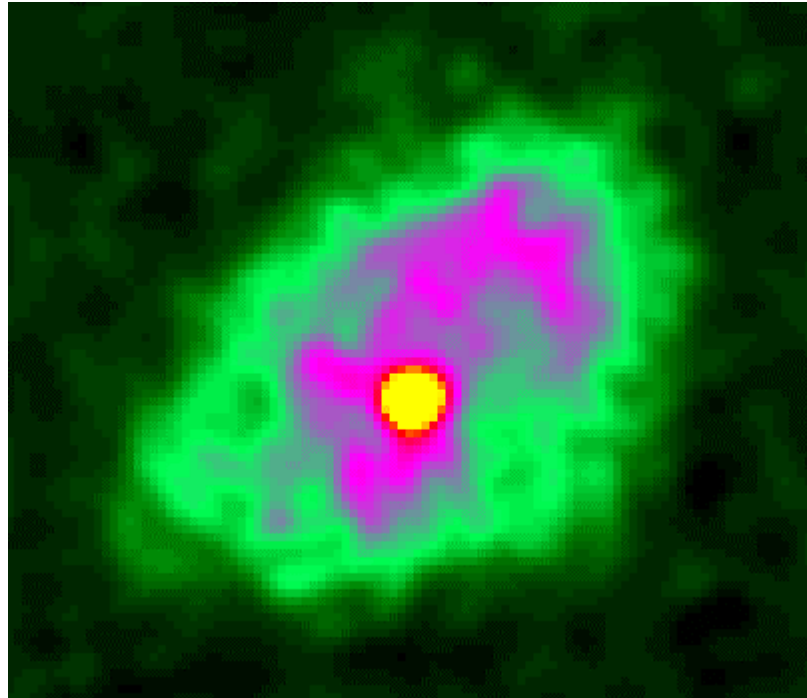


Supernova remnants

The Crab Nebula:

VLA at 74 MHz:

diameter: 6'



Pacini: Crab nebula gas ejected at by supernova explosion 1054. Centuries after the explosion is still filled with relativistic electrons.

Energy source: slowing- down of neutron star

Maser

Unusually high intensities are found for the lines of the OH radical at $\lambda = 18\text{cm}$
In terms of radiation temperature they correspond to 10^{12} K to 10^{15} K

The lines are exceedingly sharp and are emitted by a very compact sources

This can only be explained by a maser amplification mechanism

The “pump process” is not in detail understood

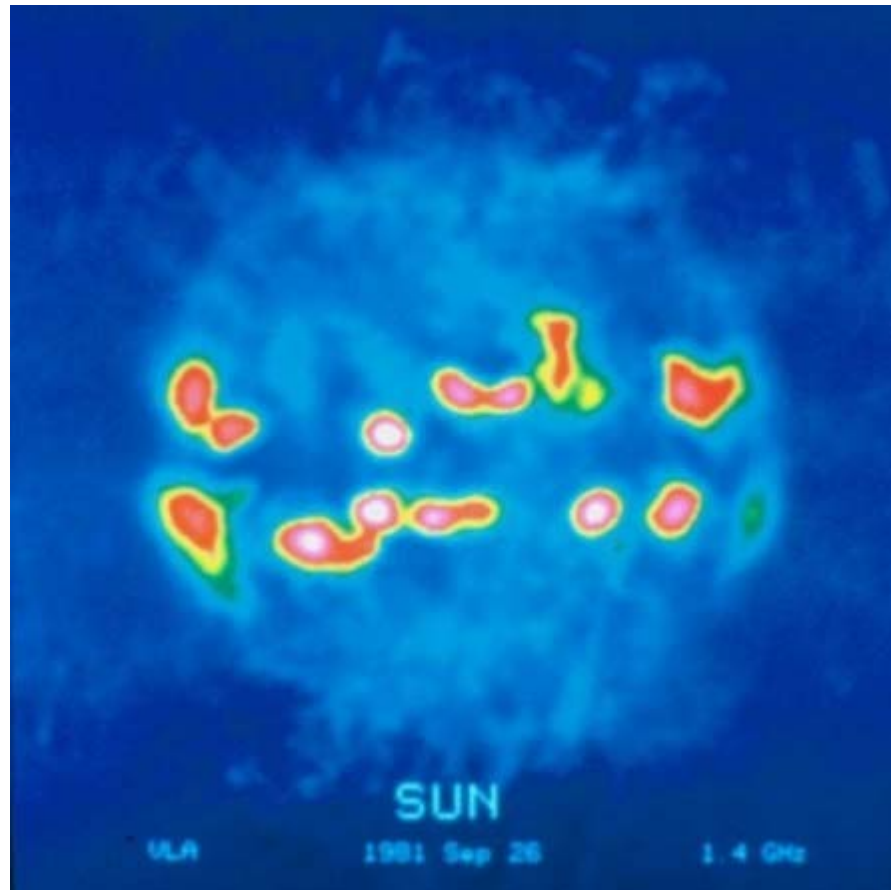
Stimulated emission is produced by a radiation field at the same frequency

Maser lines from other molecules are also observed H_2O at $\lambda = 1.35\text{cm}$

Also: SiO , H_2CO

The sun as a source of radio radiation

The sun at radio radiation of 20 cm



Sunspots:

Temperature: 4000 C

Sun: 6000 C

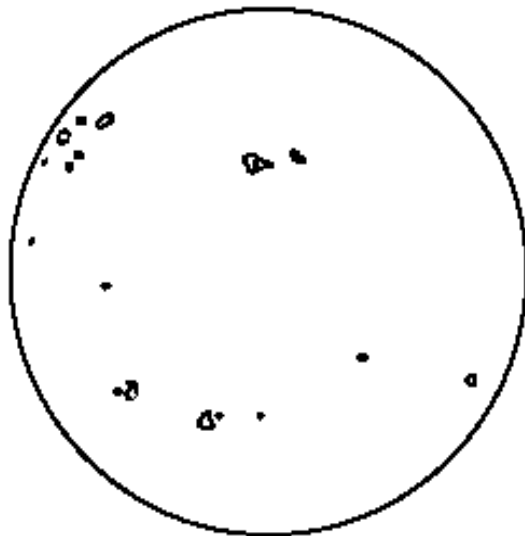
Centers of magnetic field

$B \sim 10^{-1}$ T

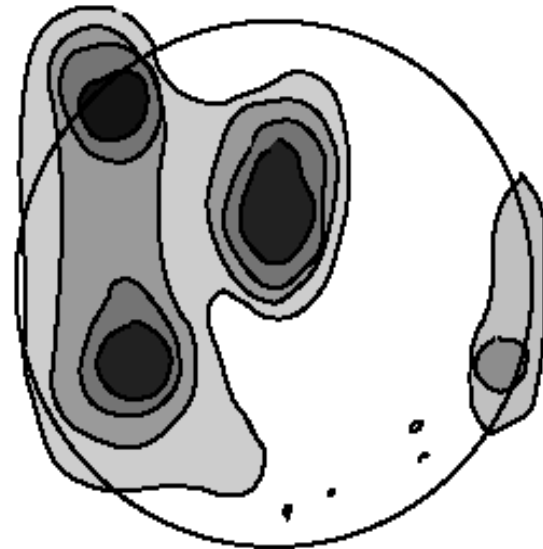
relativistic electrons

Synchrotron and
Plasma emissions

Comparison of Optical and Radio Solar Flares



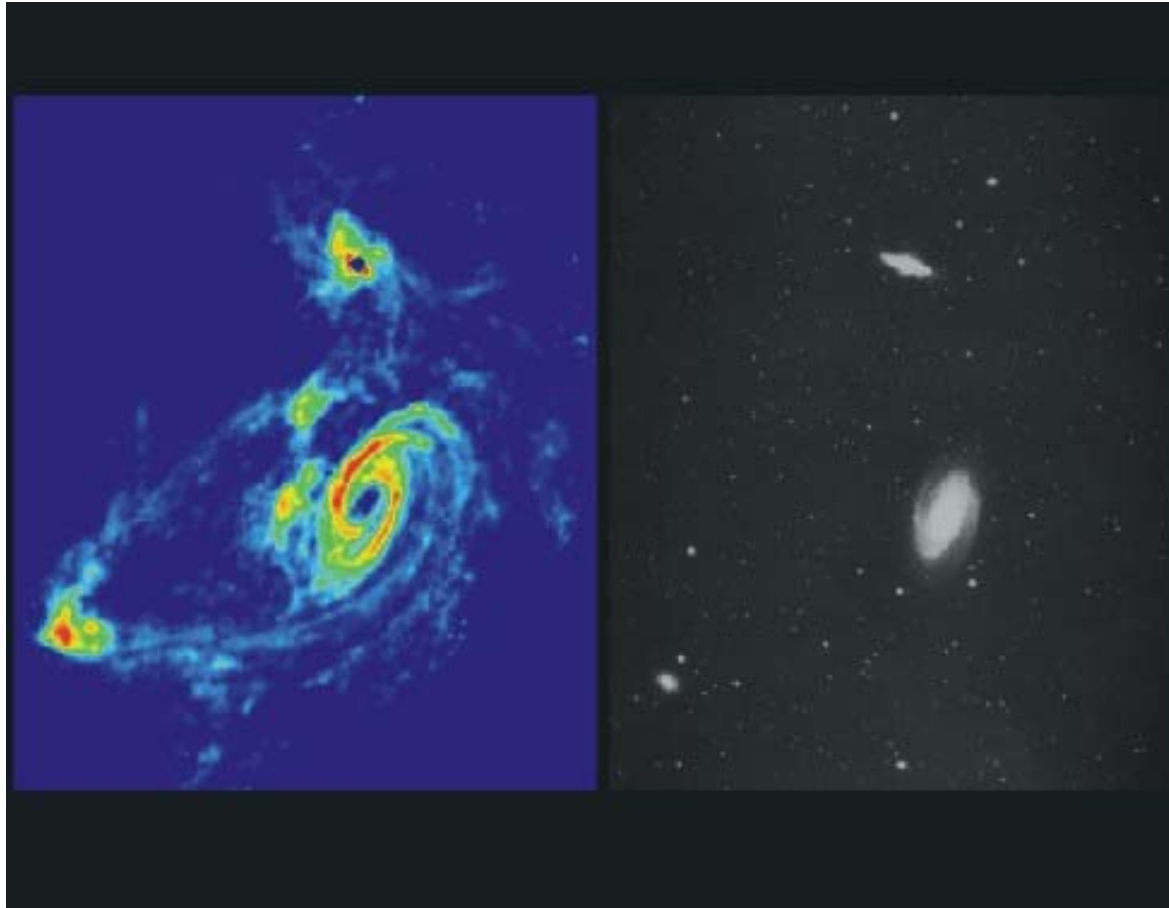
Optical View



Radio Pattern

Extragalactic Systems

M81

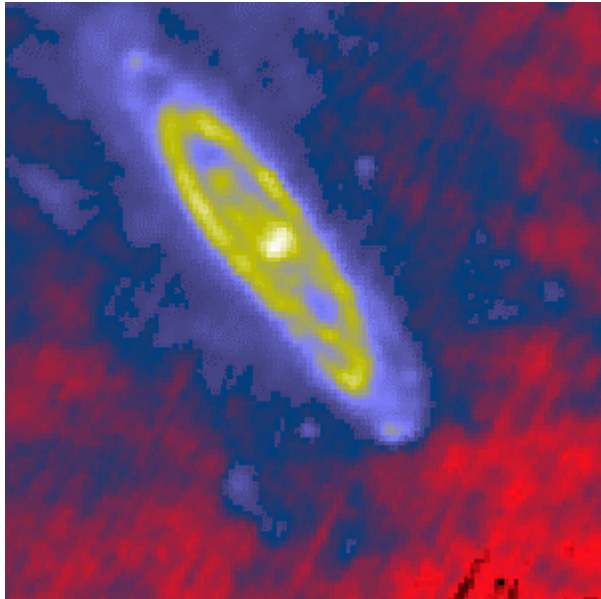


21 cm wavelength :

optical

The Andromeda galaxy (M31):

Radio image at 21 cm



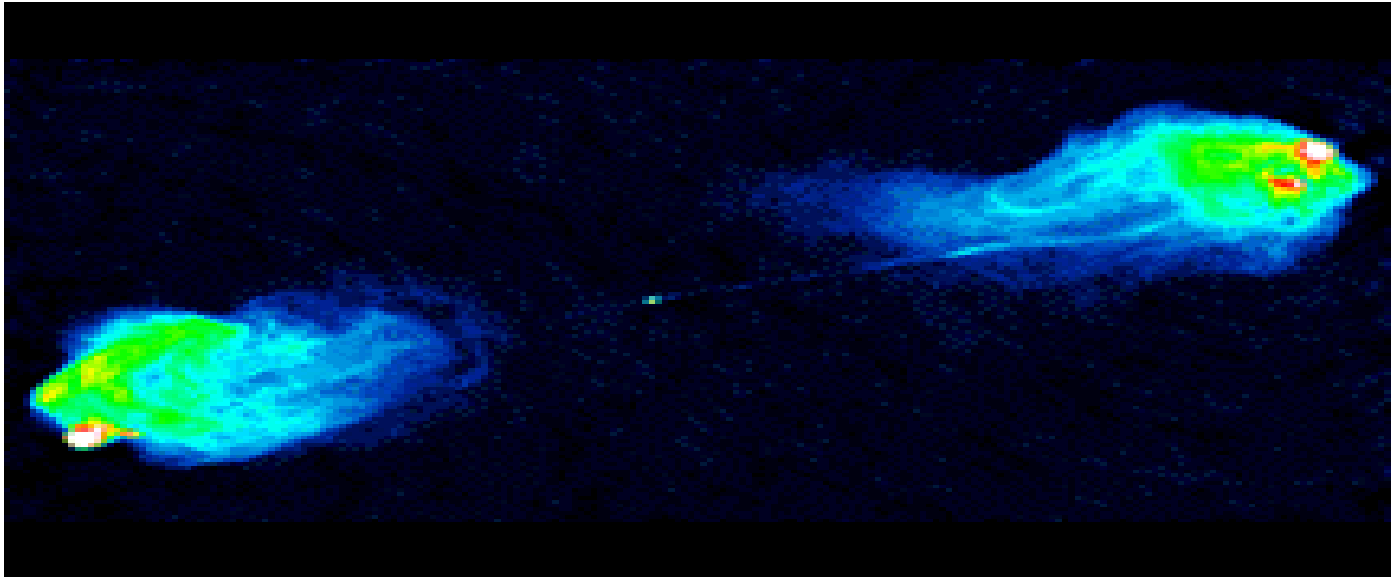
Optical image

Active Galaxies

Cygnus A: One of the strongest radio sources in the sky

At 6 cm:

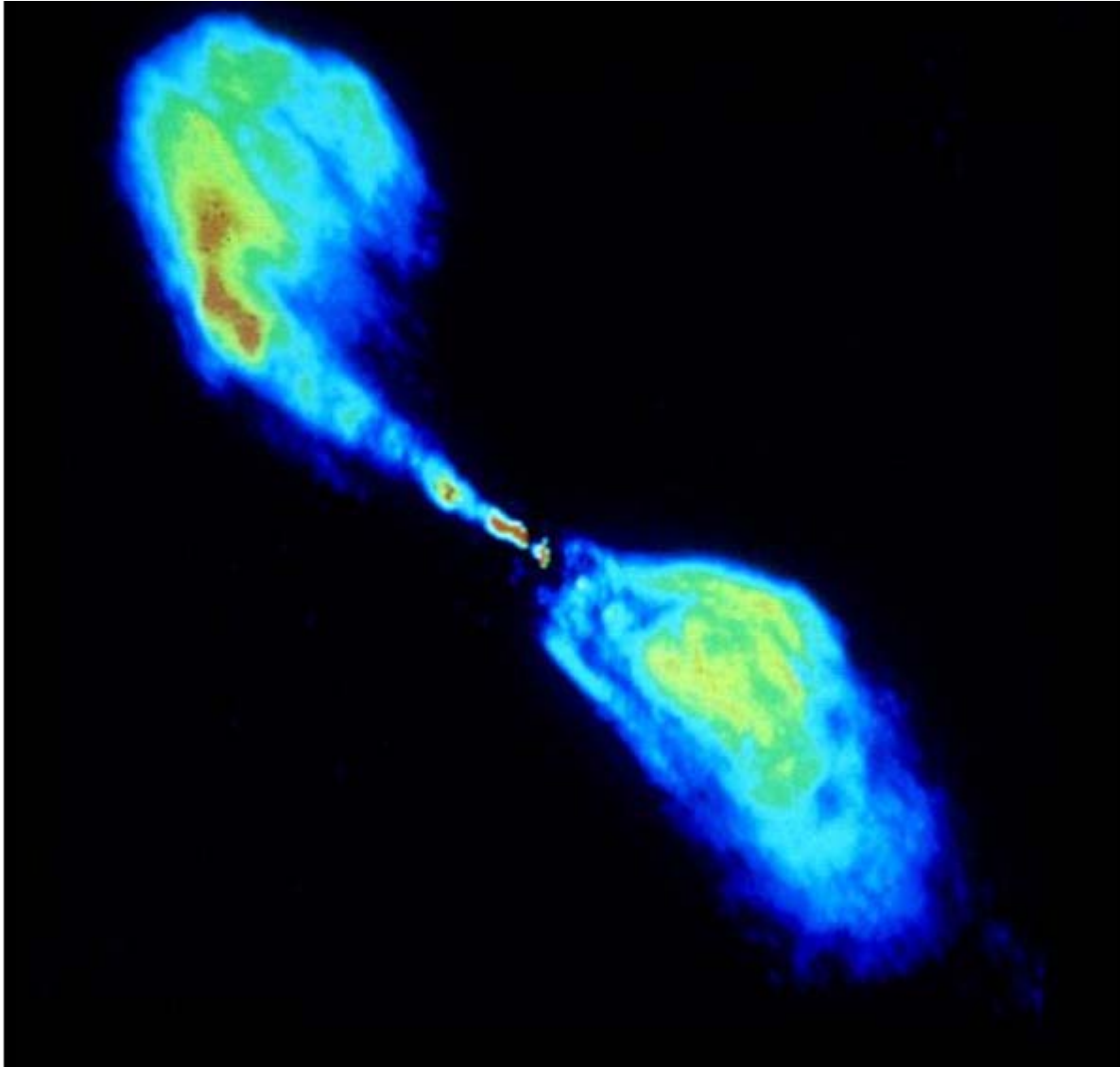
200 kpc



Two jets are emitted at the center

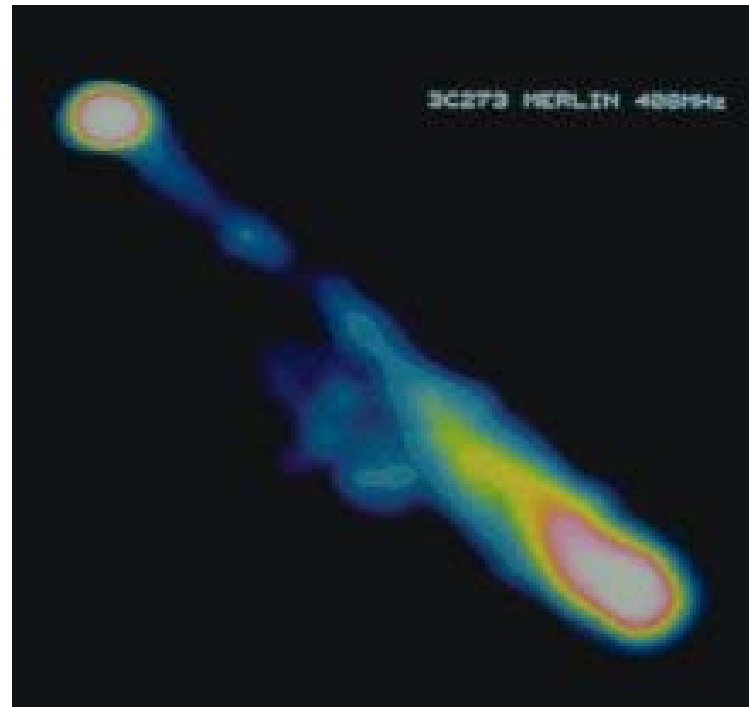
Process: Synchrotron emission
energetic electrons in magnetic fields

Centaurus A at the 6 cm radio radiation:



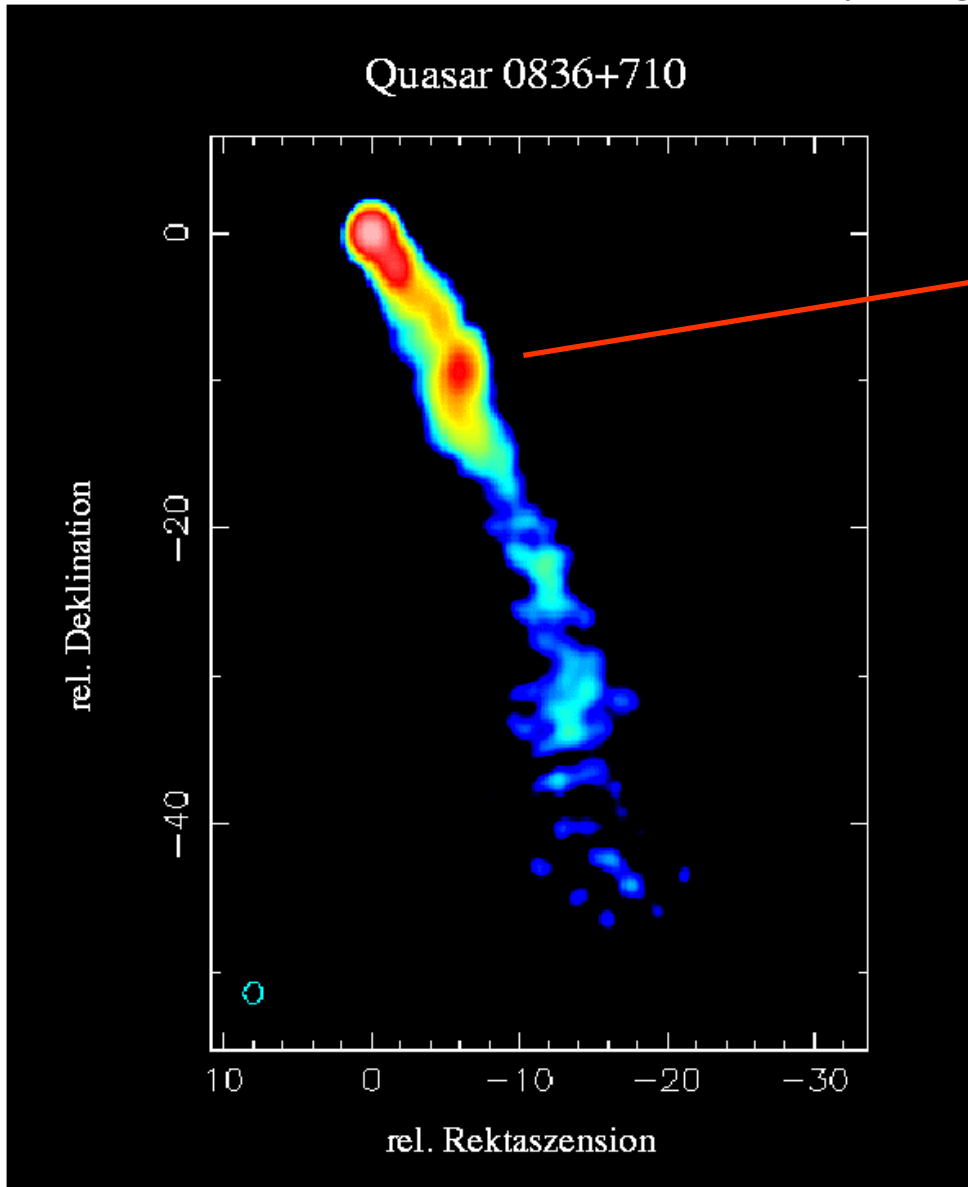
Quasars

3C273 taken from MERLIN at 408 Mhz

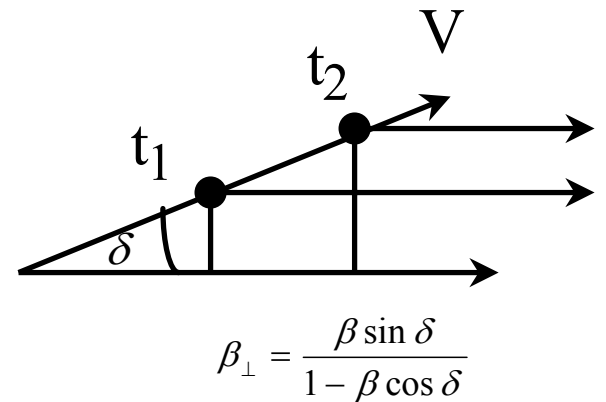


Quasar 0836+710

Radiointerferometry image at 3.6 cm



blob moves with
apparent
superluminal
velocity

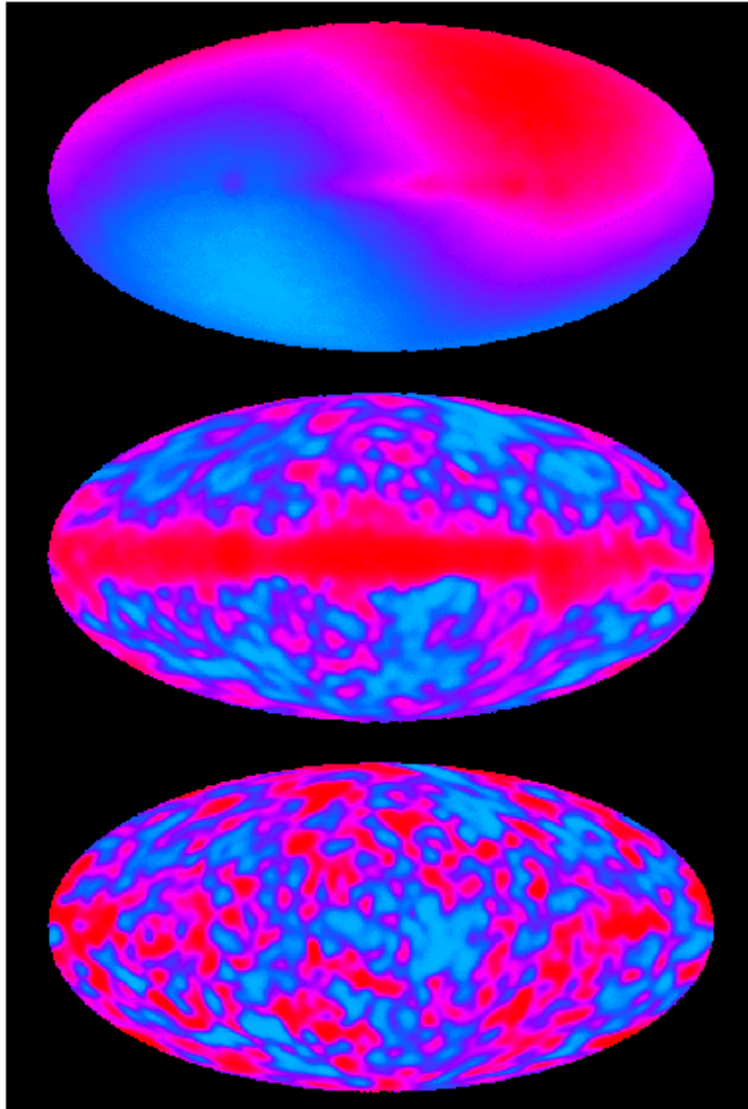


Lorentz factor:

$$\gamma \approx 5-10$$

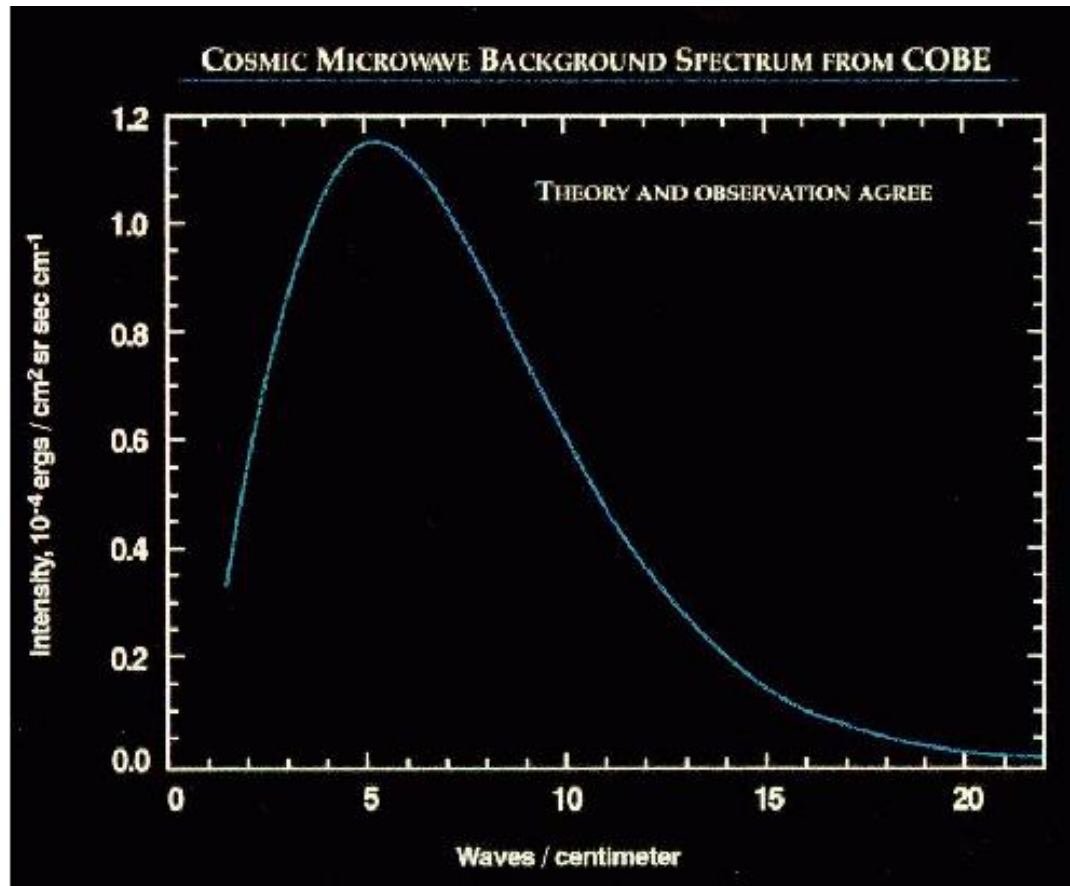
Cosmic Background Radiation

COBE



Frequencies: 31.5, 53 and 90 GHz

The COBE spectrum

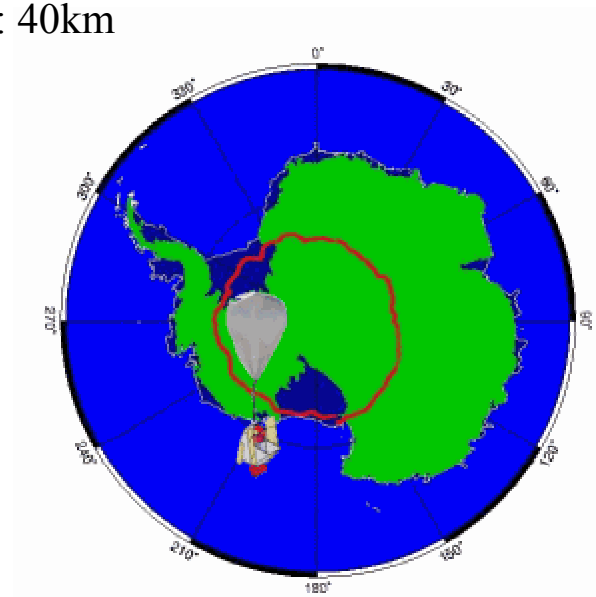
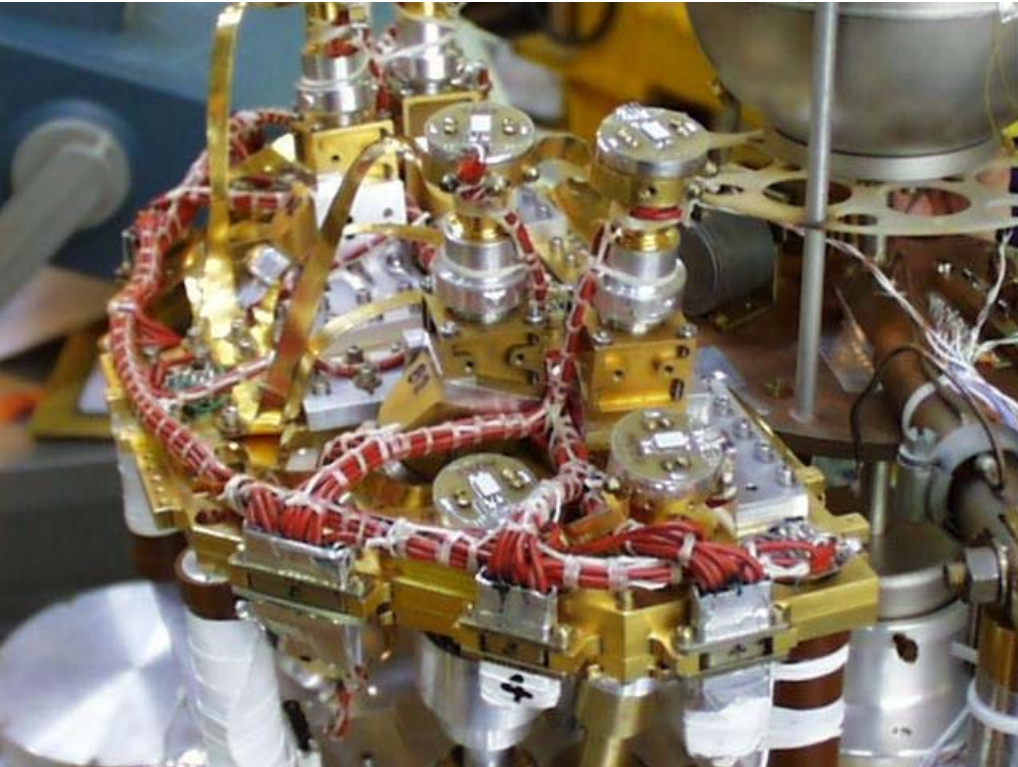


Boomerang

Dec. 29.1998

Flight time:260 hours

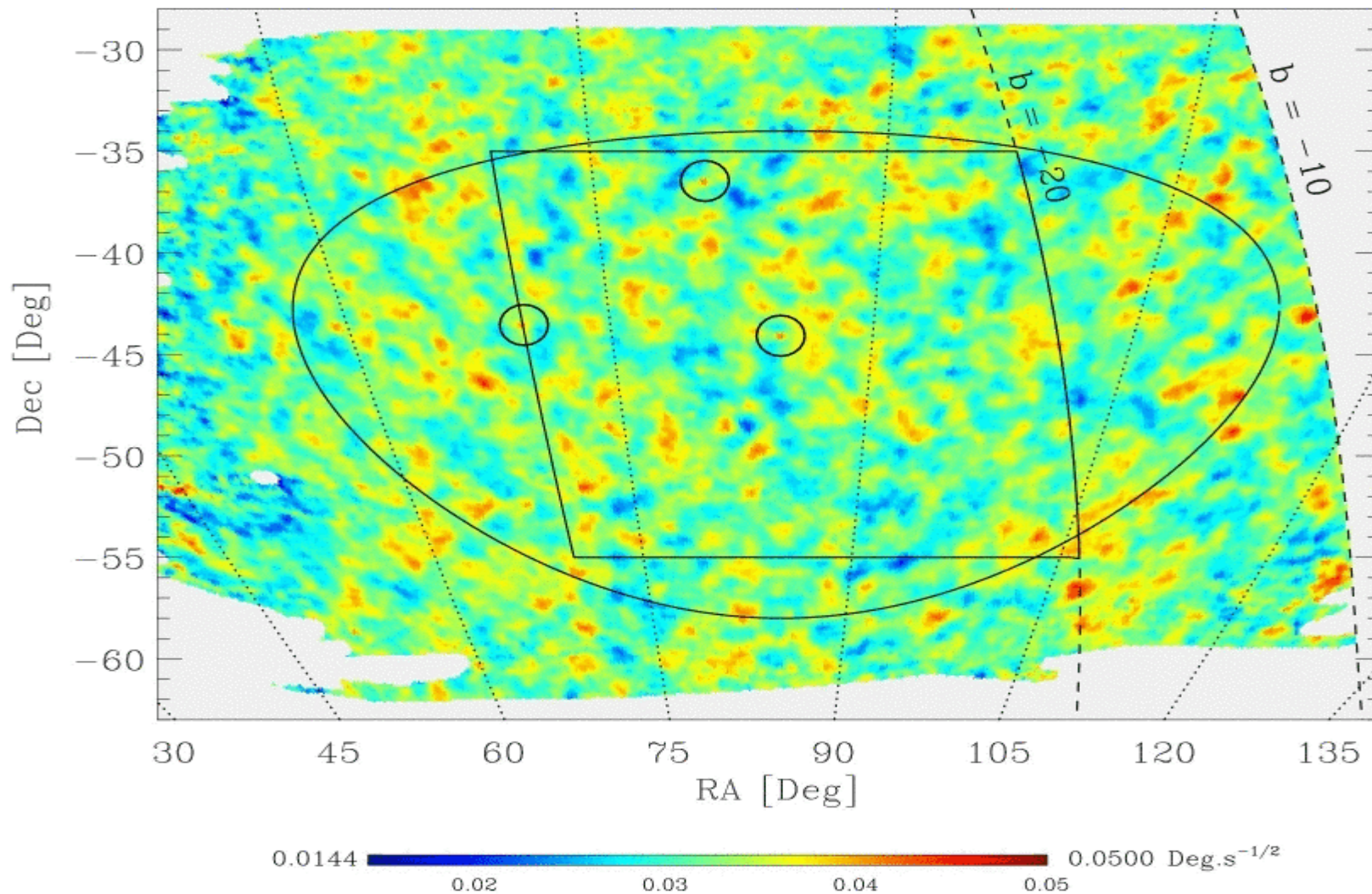
Height: 40km



focal plane where the optics, filters and detectors are located

Boomerang

Frequencies: 90, 150, 240 and 410 GHz

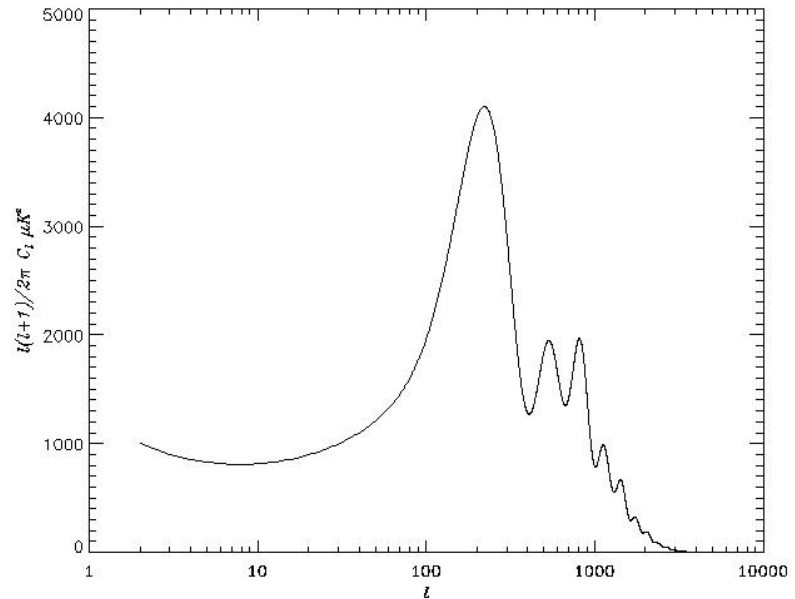
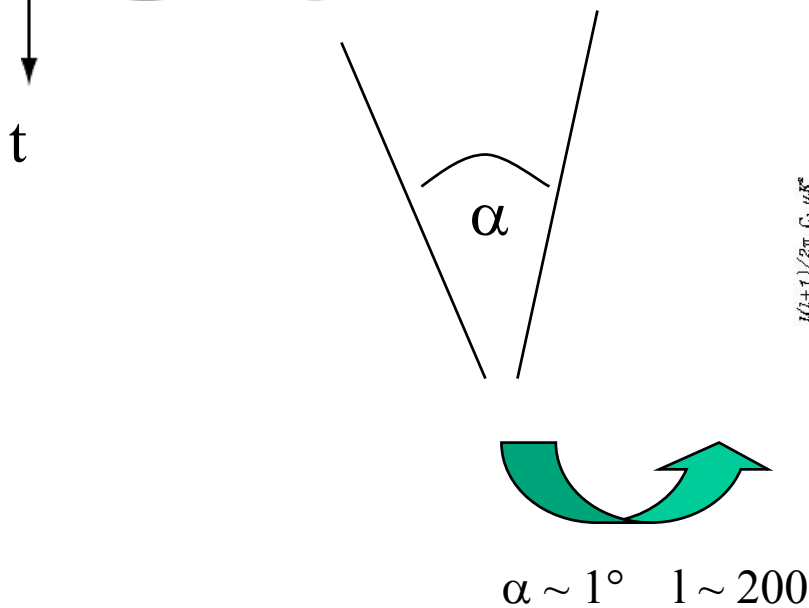
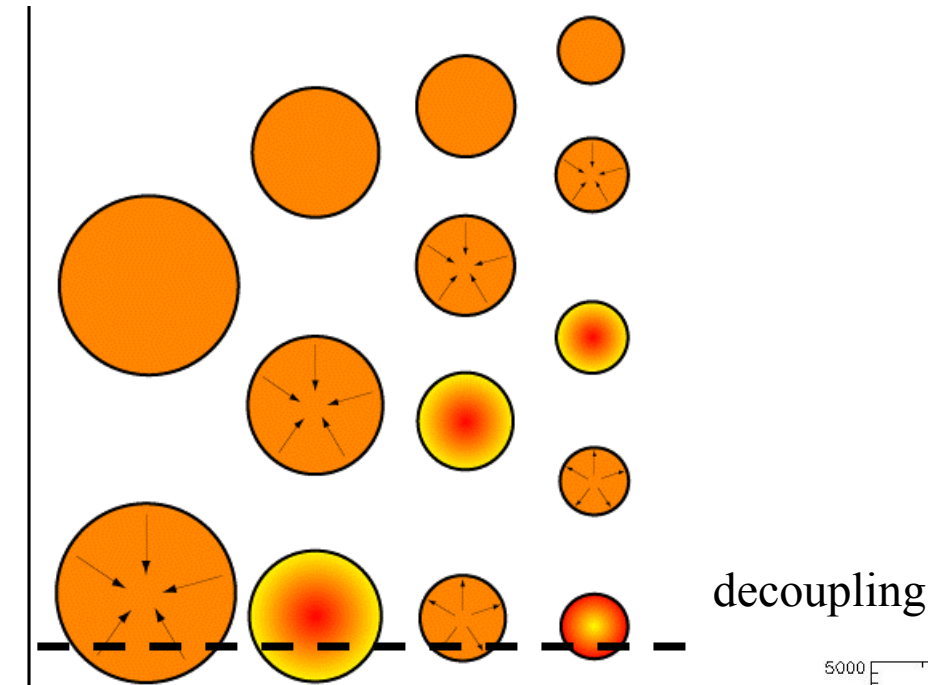


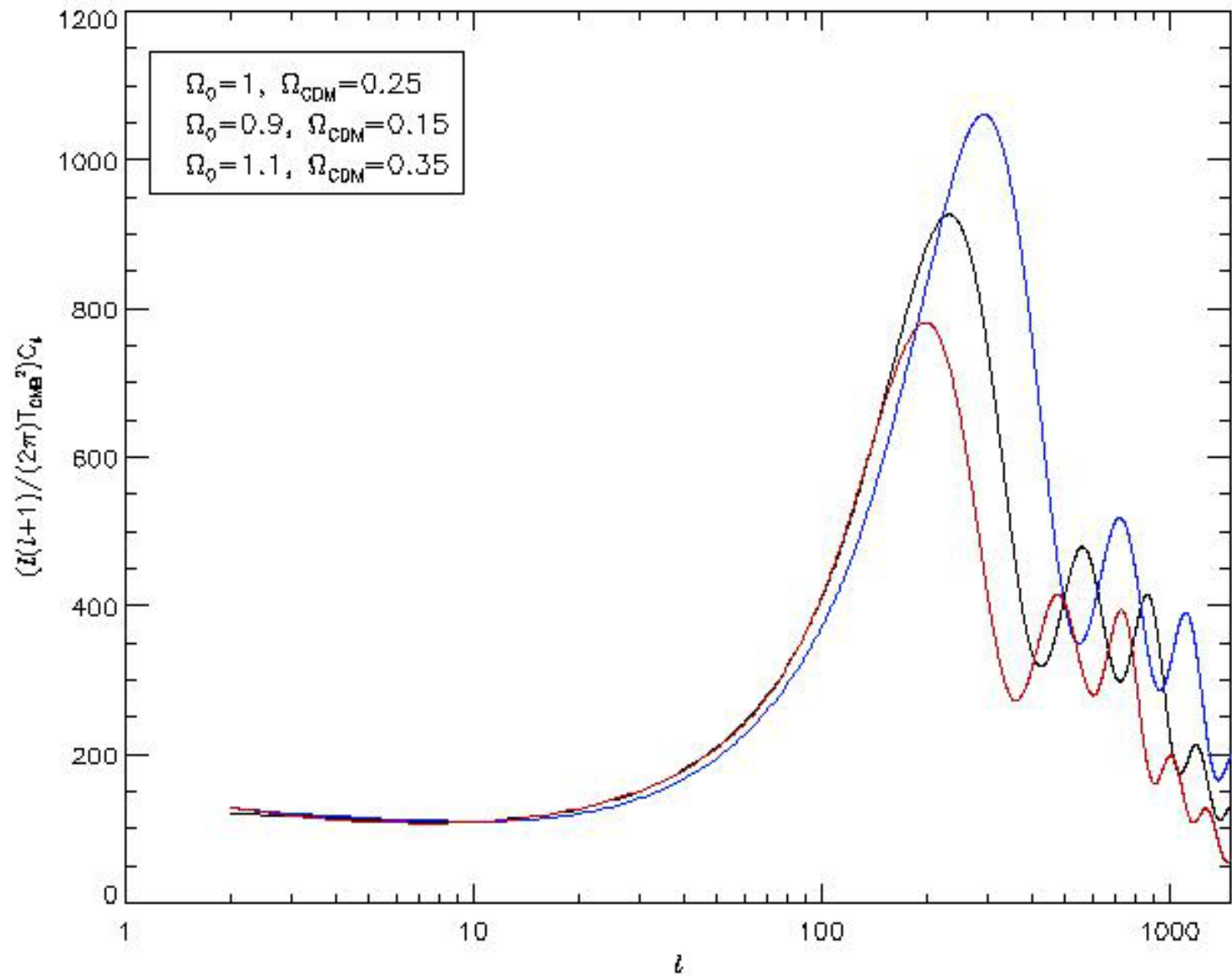
Map Description in terms of spherical functions:

$$\Delta T/T \sim \text{Sum}(\alpha_{lm} * Y_{lm}(\delta, \phi))$$

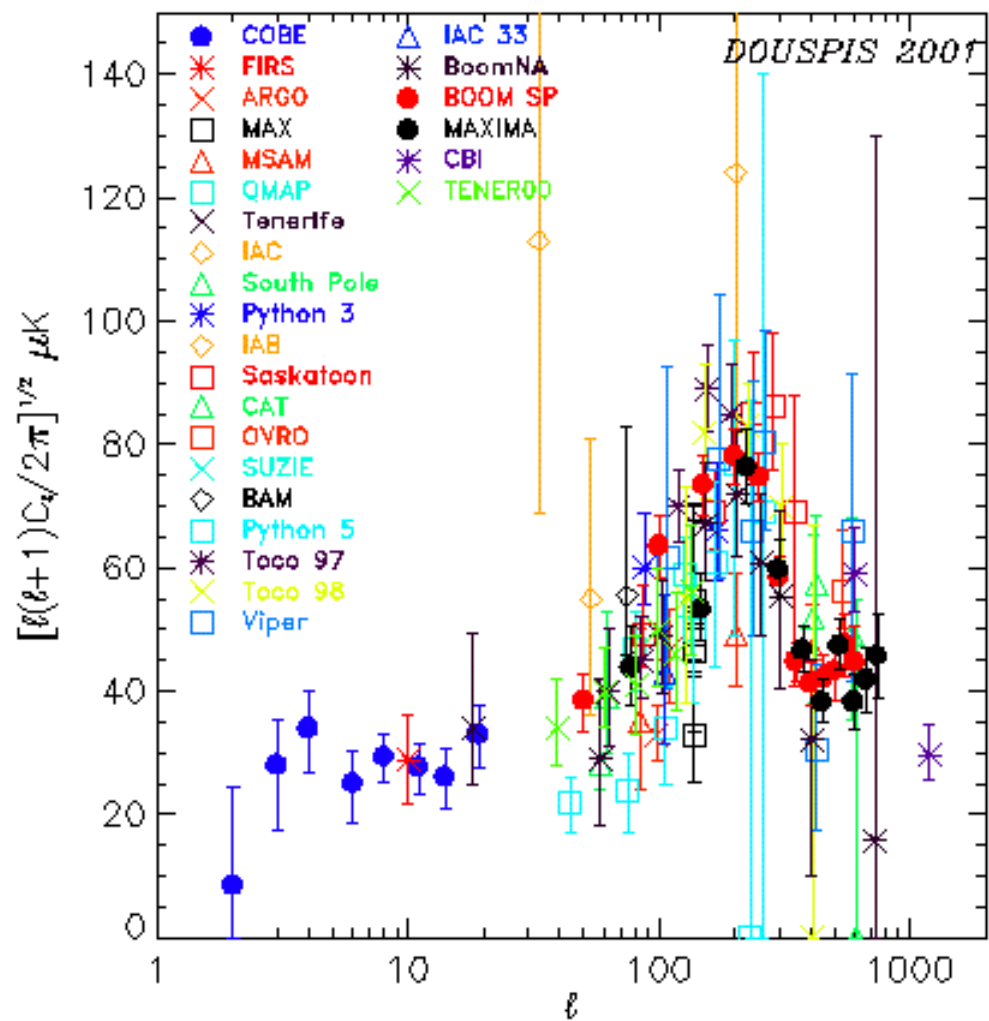
$$C_l \sim |\alpha_{lm}|^2$$

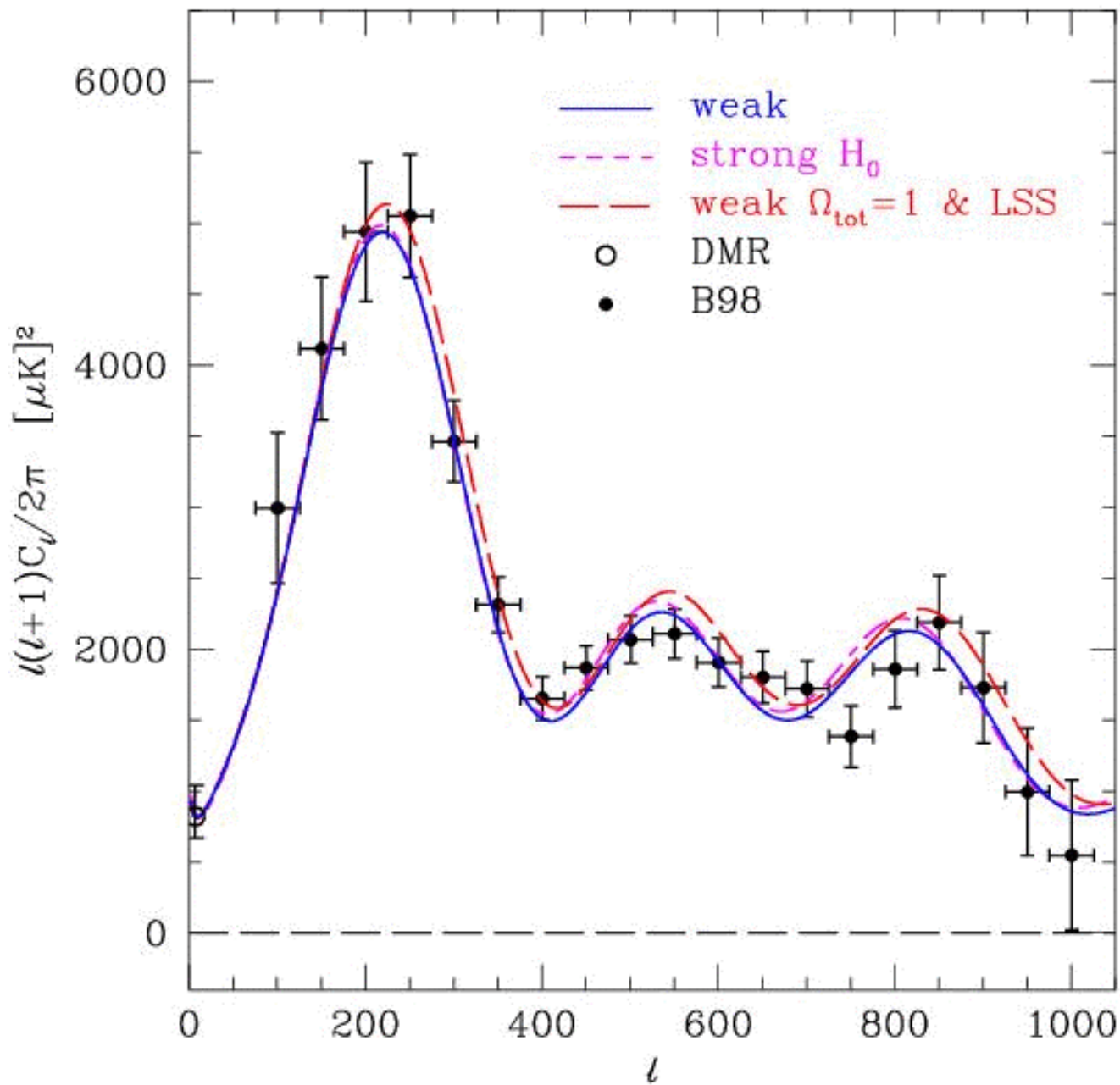
strength of fluctuations on angular scale $\delta \sim 180^\circ/l$





Data set







Launch ~2007