Introduction to Radioastronomy

Observatoire astronomique
de Strasbourg

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http://astro.u-strasbg.fr/~koppen/JKHome.html

Overview

- History, Discoveries, Sources
- Equipment and Observing Techniques
- Physical Processes
- ISU Radiotelescopes and Data Reduction
- Observations (@ ISU, Illkirch)
- Data Reduction and Interpretation (Obs.)
- Interferometers and Aperture Synthesis, the Future

Literature

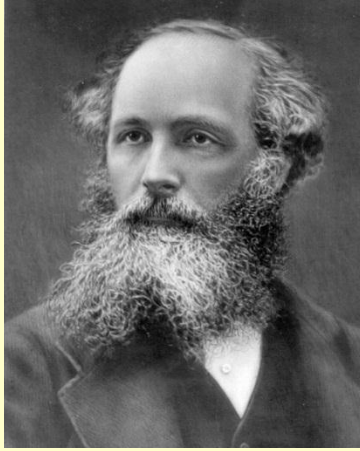
- J.D.Kraus: Radio Astronomy, Cygnus-Quasar (classic)
- K.Rohlfs, T.L.Wilson: Tools of Radioastronomy, Springer, 4th, 2003 (Obs.library, pdf@JK)
- Books on Antennas:
  - J.D.Kraus, Antennas, McGraw-Hill, 2nd, 1988
  - C.A.Balanis, Antenna Theory, Wiley, 2nd, 1992
- Lecture notes on the Web
  - Lindsay Fletcher (astro.gla.ac.uk)
  - Dale E.Gary (NJIT, interferometry)

Website for our course

- pdfs of lectures
- project instructions and links
- archive data
- infos

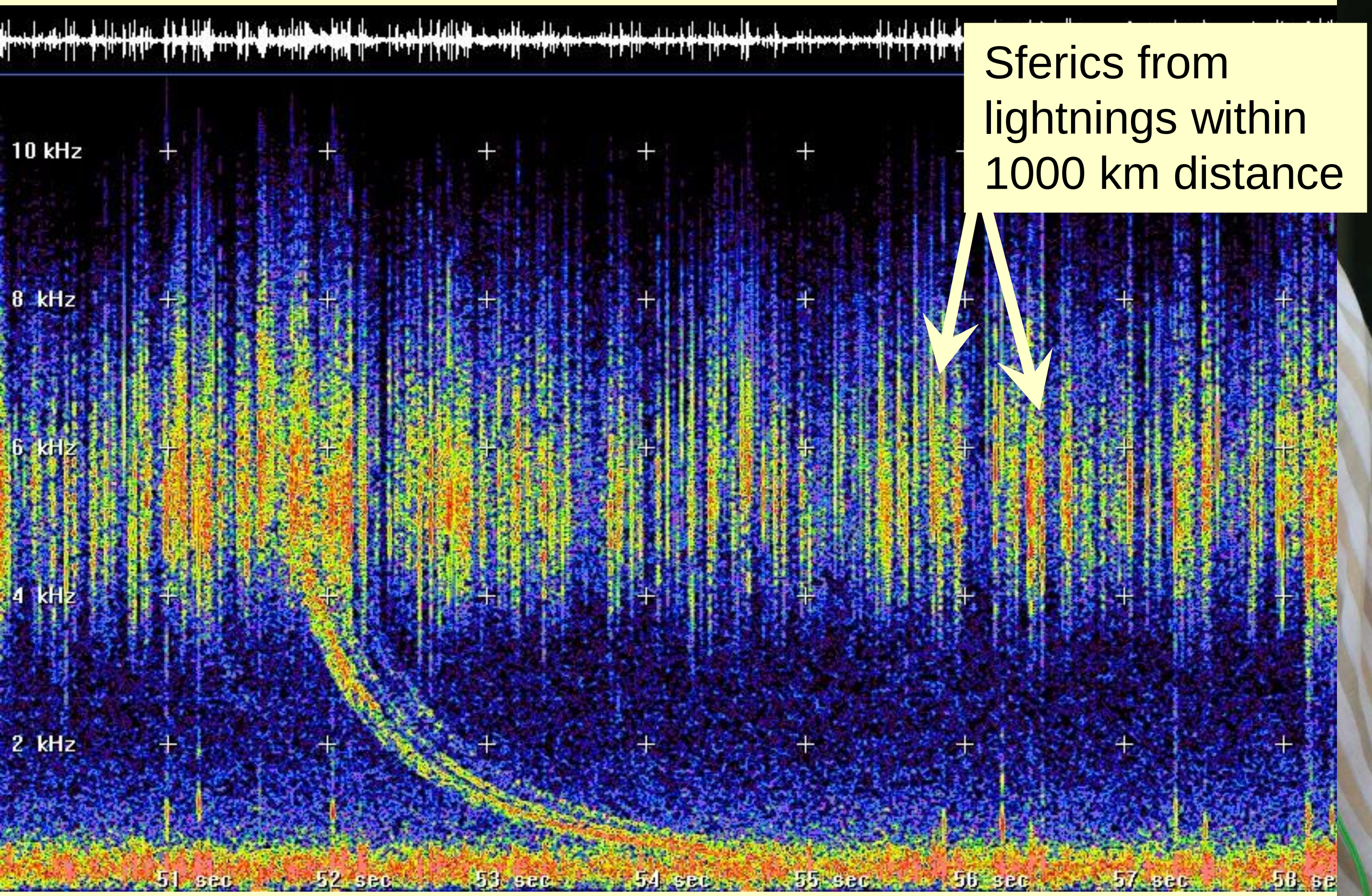
http://astro.u-strasbg.fr/~koppen/ue7e/

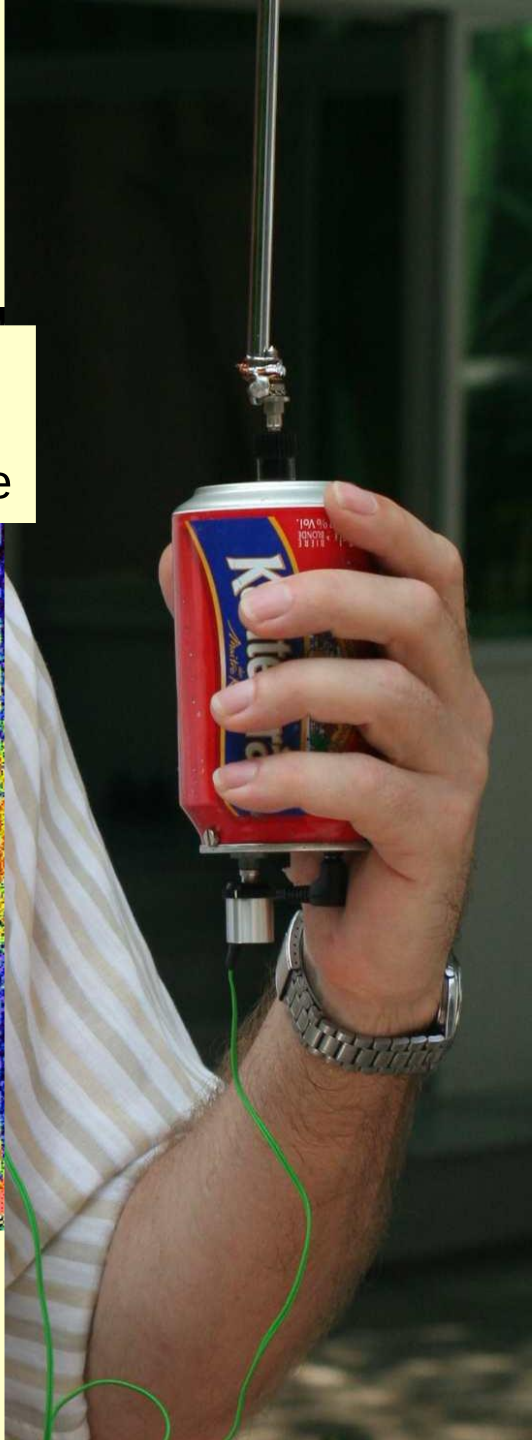
How it all began



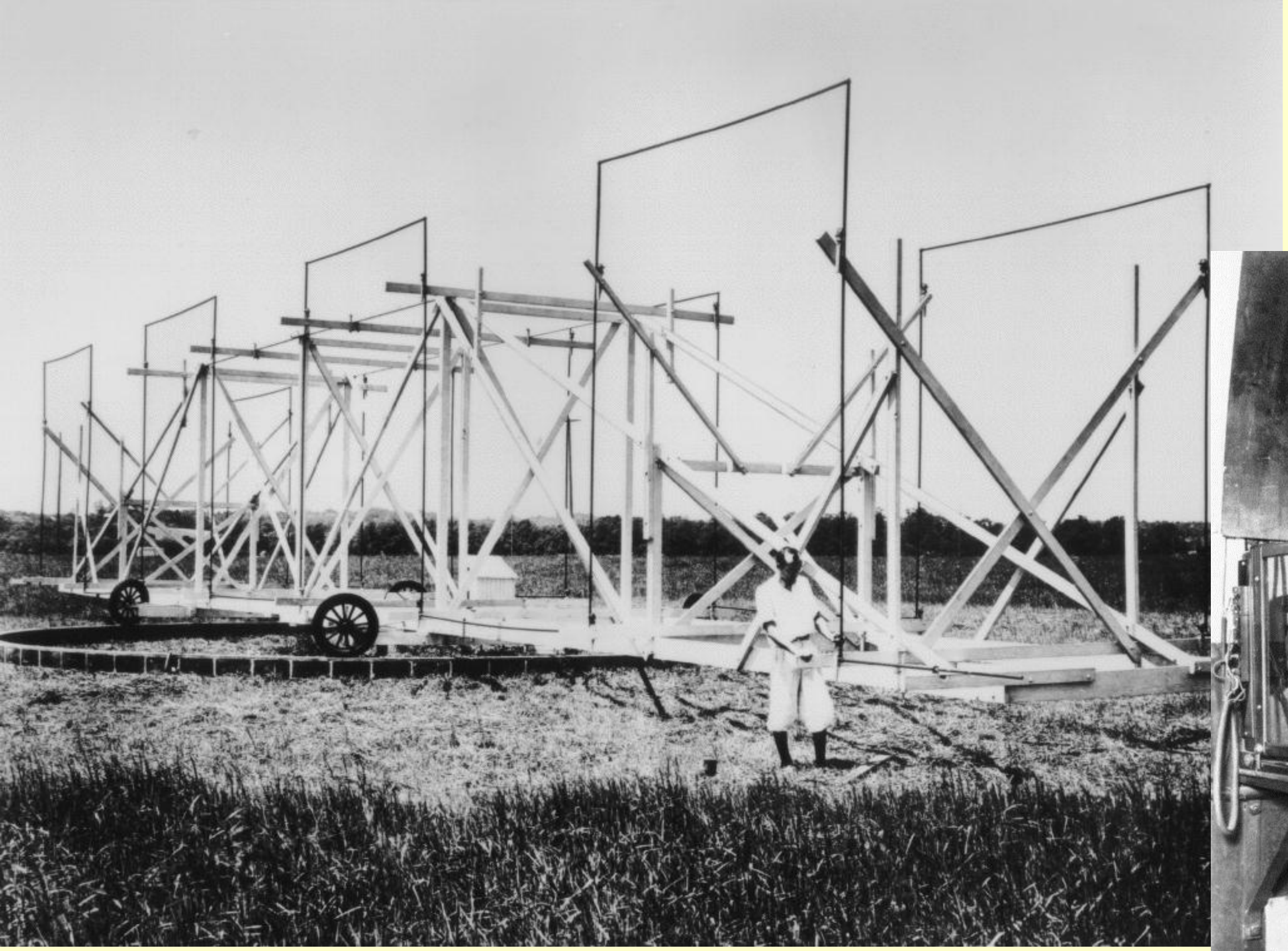
- 1861 J.C.Maxwell’s equations
  ➔ electromagnetic waves
- 1888 discovery of radio waves (H.Hertz; ‘purely academic interest, no practical use’)
- 1895 Marconi/Braun/Popov et al.: radio communication
- 1899 N.Tesla claims to have received extraterrestial signals
- WW I: noise, atmospherics, and whistling sounds on telephone lines

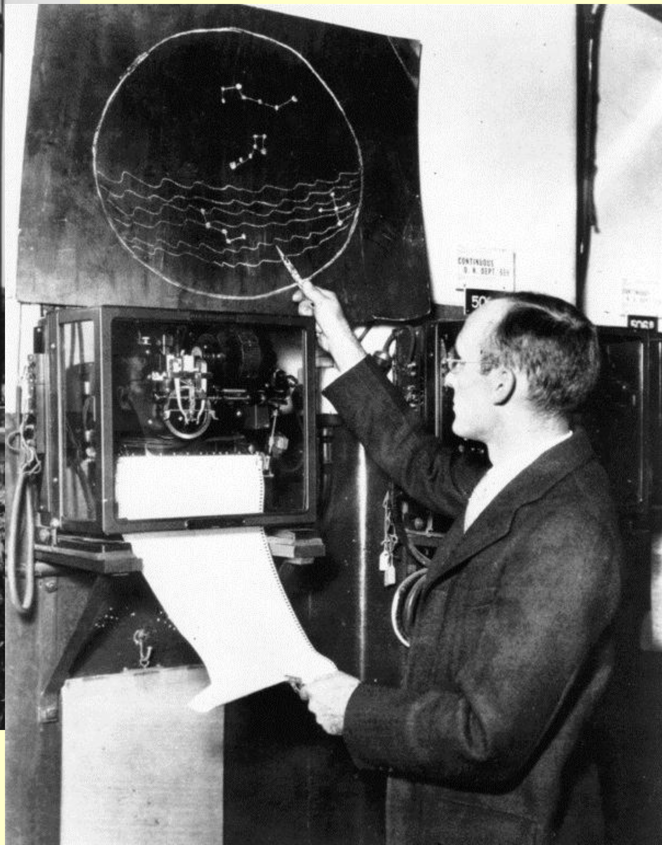
VLF: whistler from lightning in South Africa





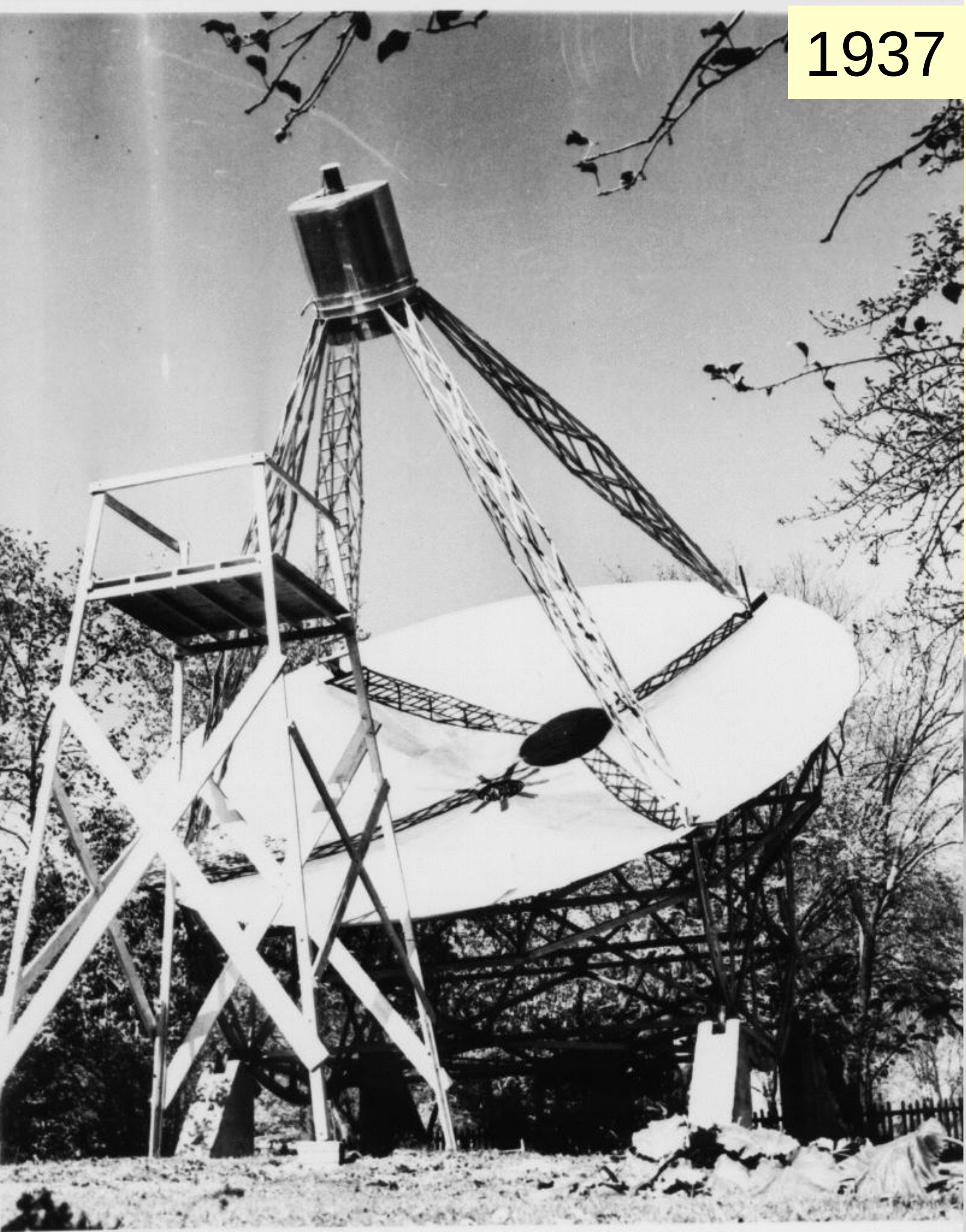
1931: there's noise on 20.5 MHz that comes from the Milky Way (C.G.Jansky)





1937 **Grote Reber**, W9GFZ, 9.5m diam. parabolic reflector antenna (160 – 3300 MHz).

- non-blackbody spectra
- sky maps
- emission from Sgr A, Cas A, Cyg A, …)
- … and the sun (solar min!



First radio maps of the Milky Way

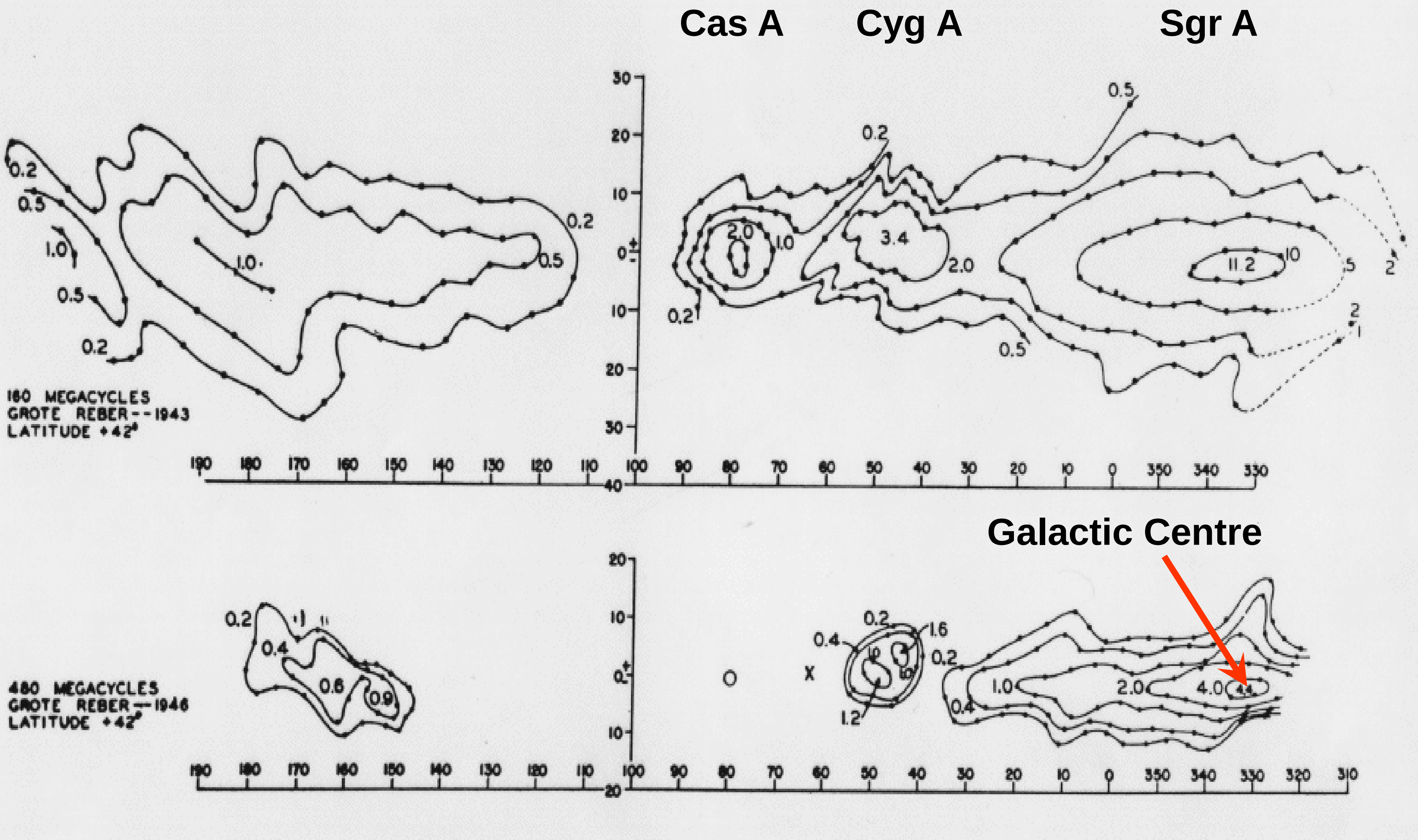
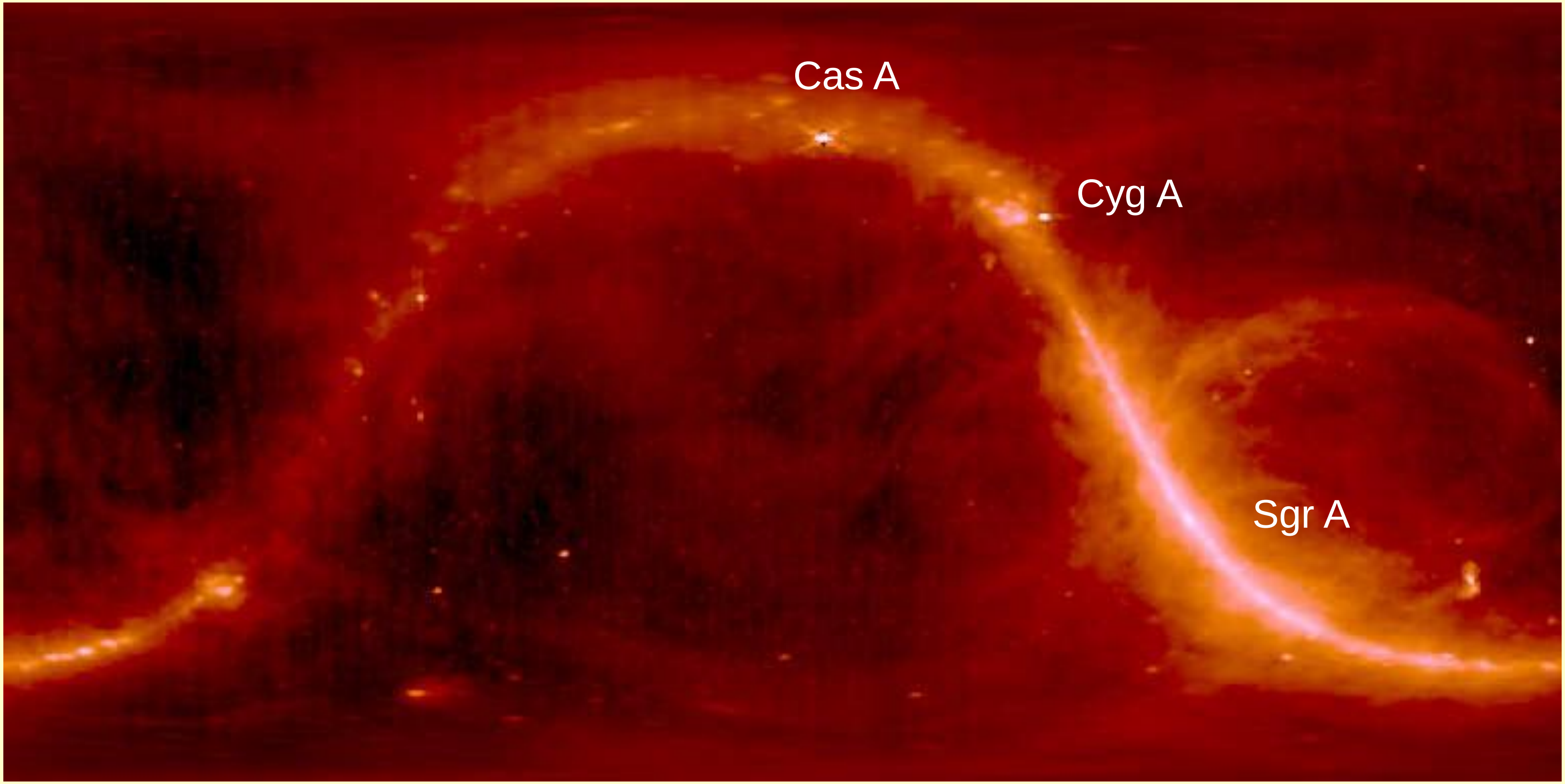
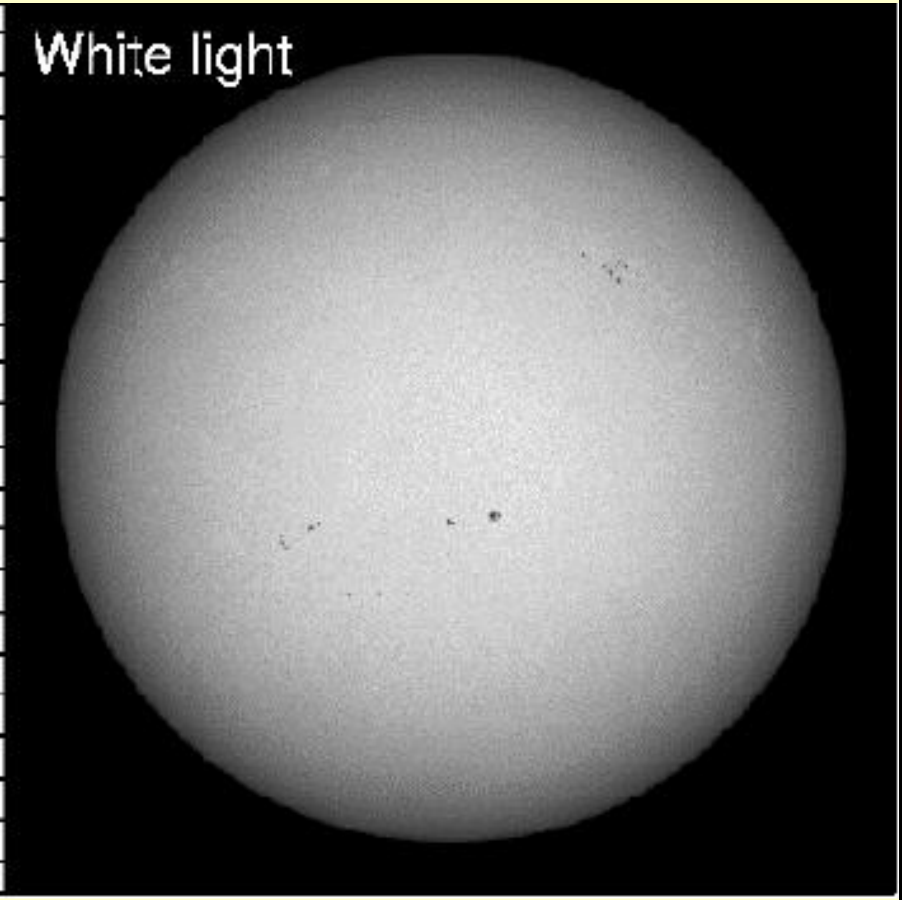


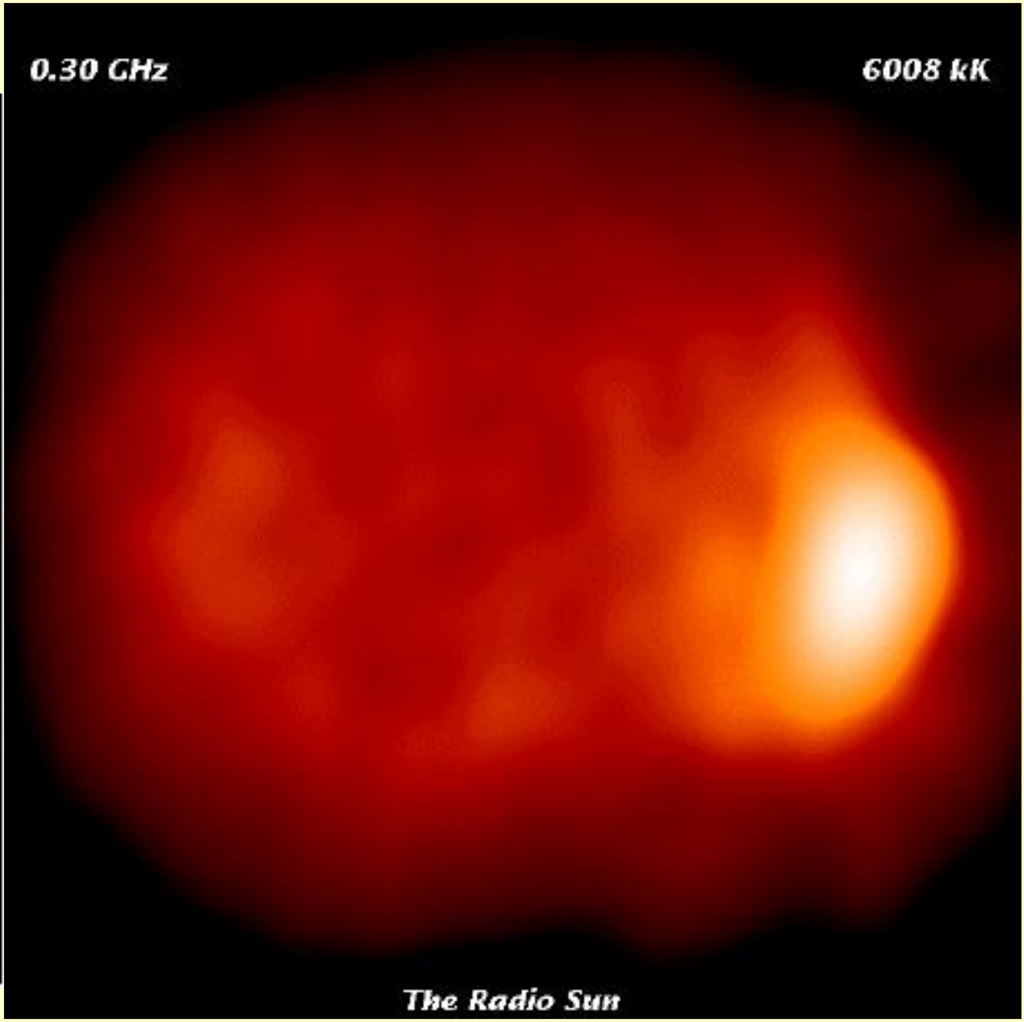
FIG. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.

The Sky at 408 MHz (λ 70 cm)



1942: noise from Sun picked up by radar equipment (J.S.Hey)



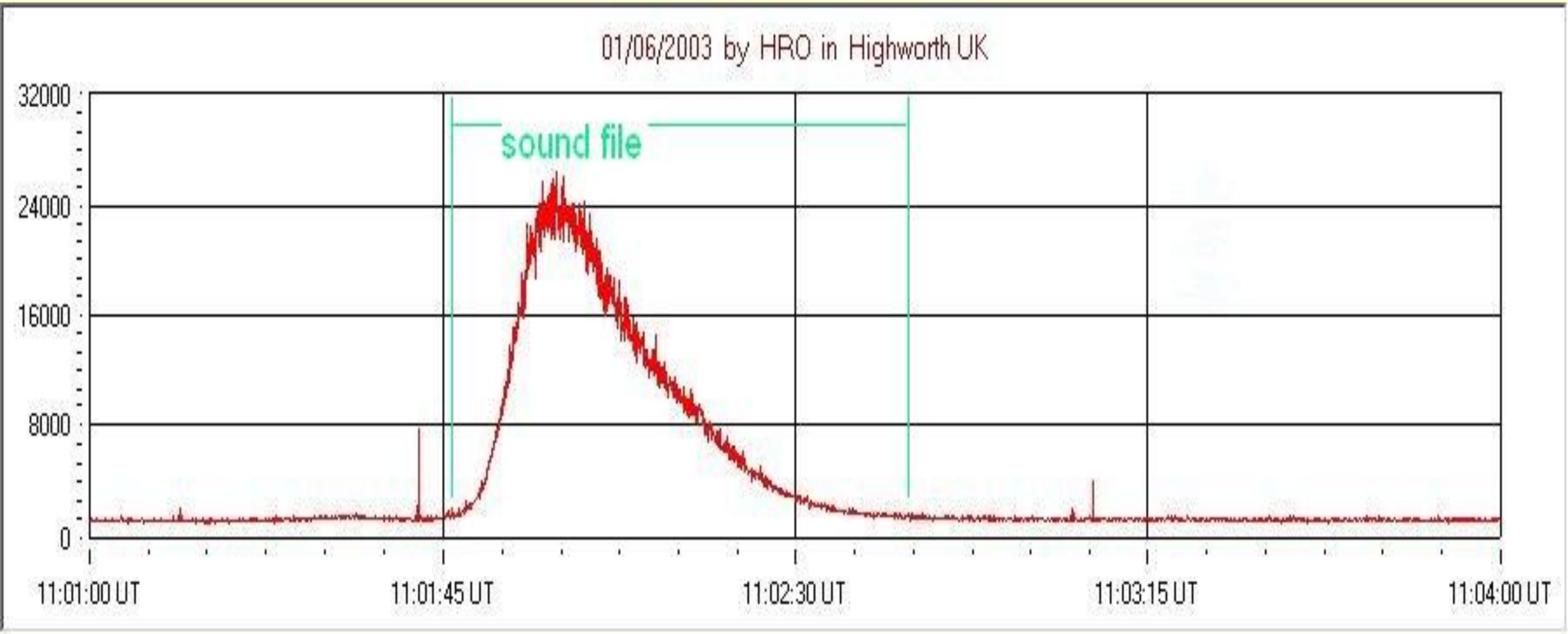


Photosphere @ 6000 K

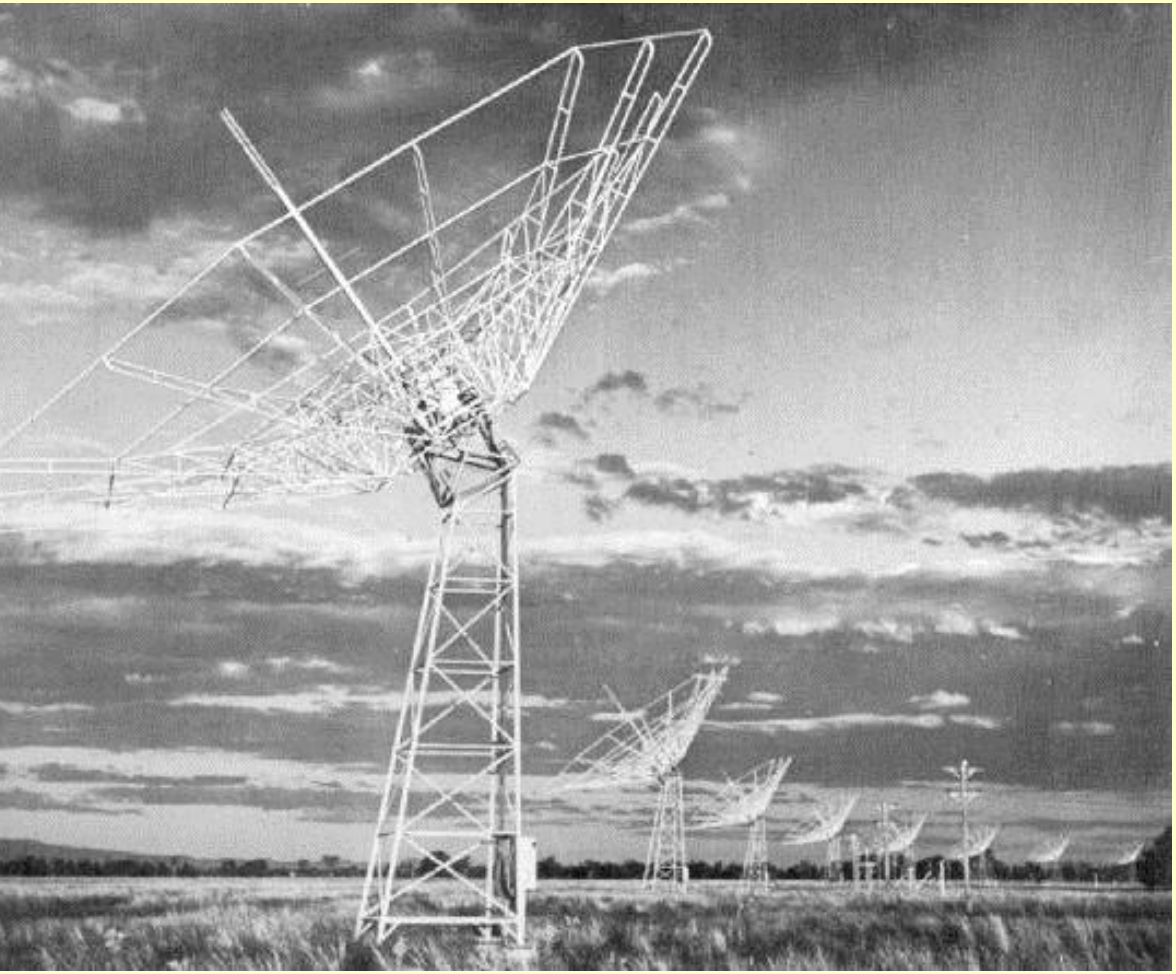
Corona @ 6 000 000 K

The sun has radio bursts

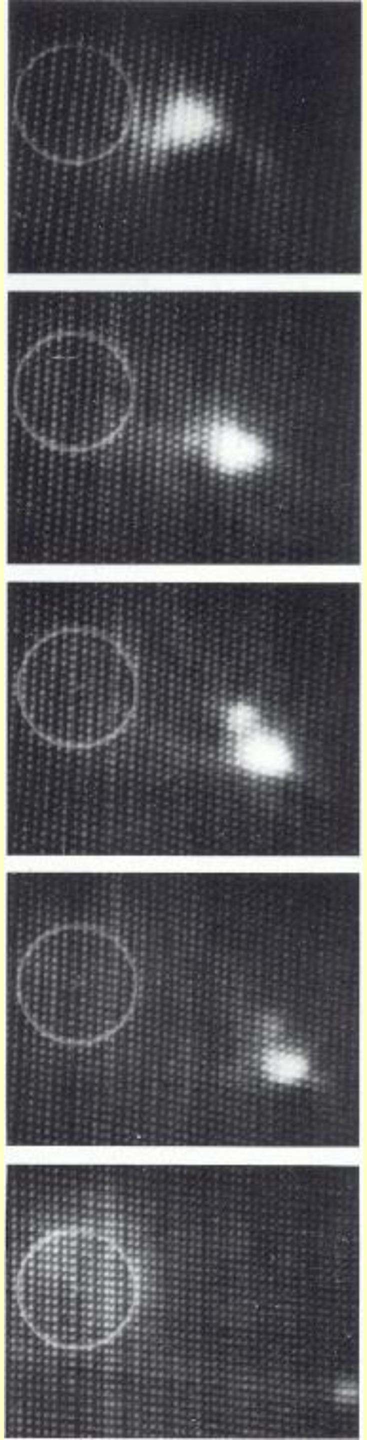
We can pick them up on 20 MHz with a shortwave receiver



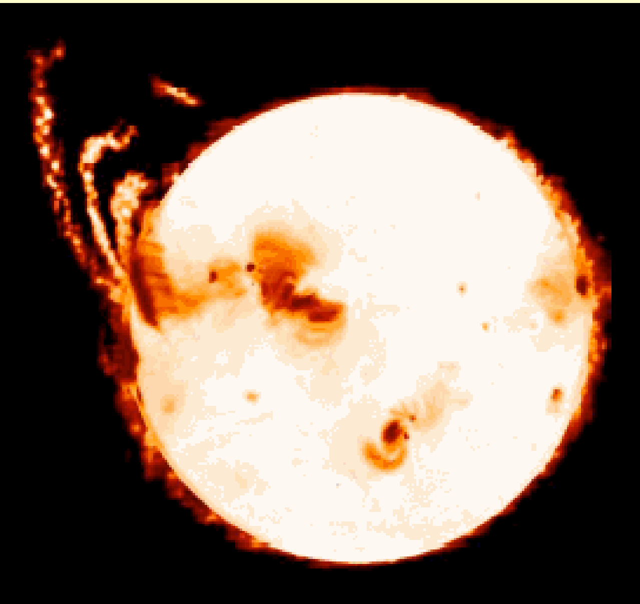
Radioheliograph, Culgoora 1967-86



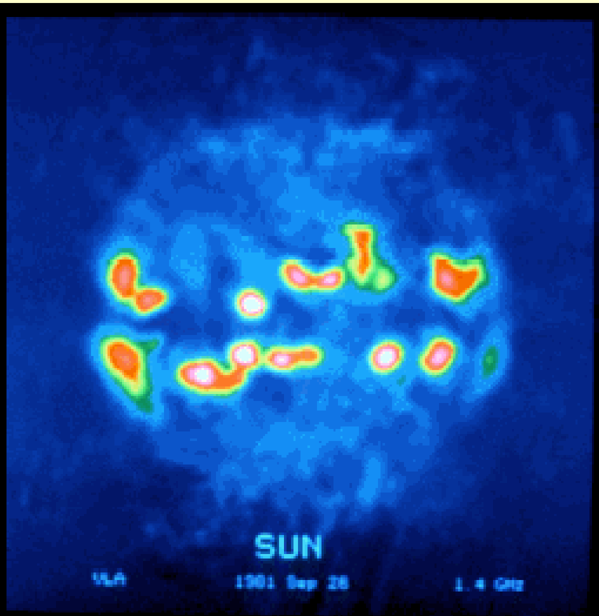
80 MHz, 96 antennas (15m diam)
in 3 km diameter circle; Res. 3.5 arcmin



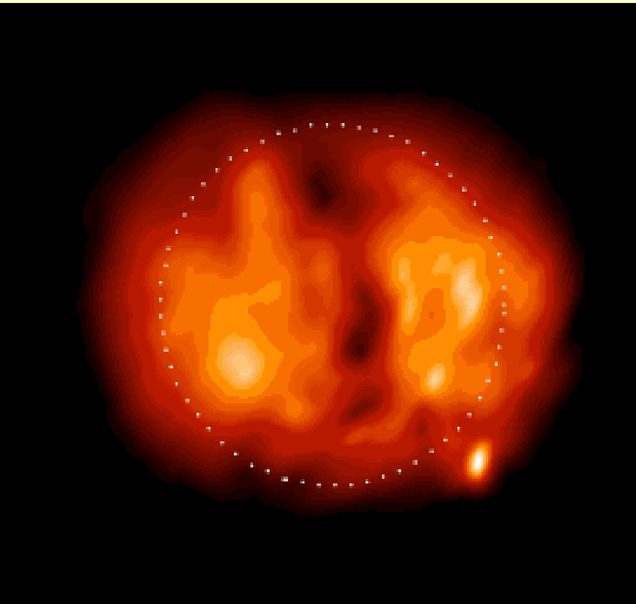
Some current spectroheliographs:



NoRH 17 GHz / 1,8 cm



VLA 1,4 GHz / 21 cm



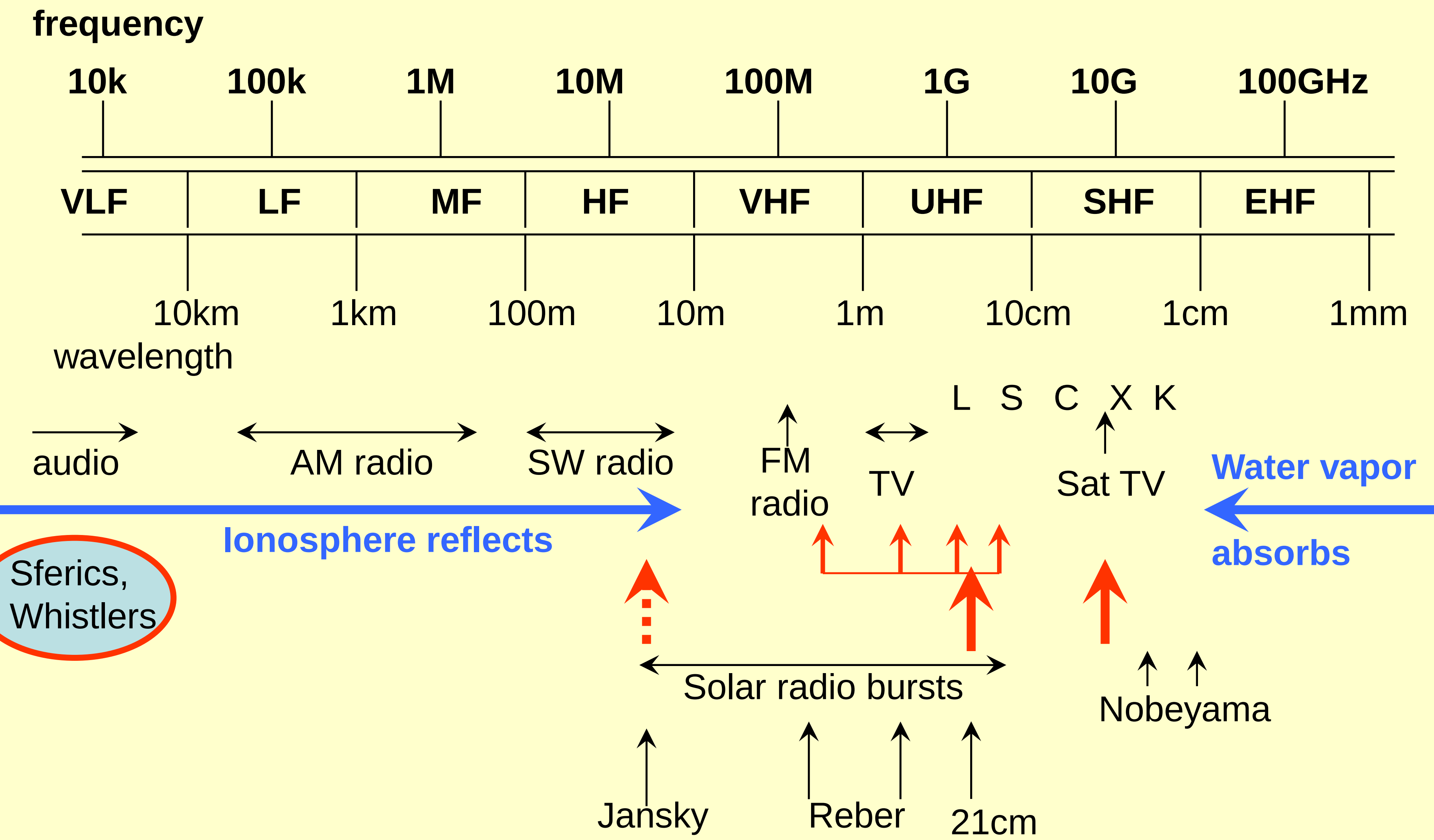
NRH 0,327 GHz / 91 cm

Nobeyama: 17 & 37 GHz

CSRH 400 km NW of Beijing

Nançay: 150 … 450 MHz

The RadioFrequency spectrum



Electromagnetic Spectrum

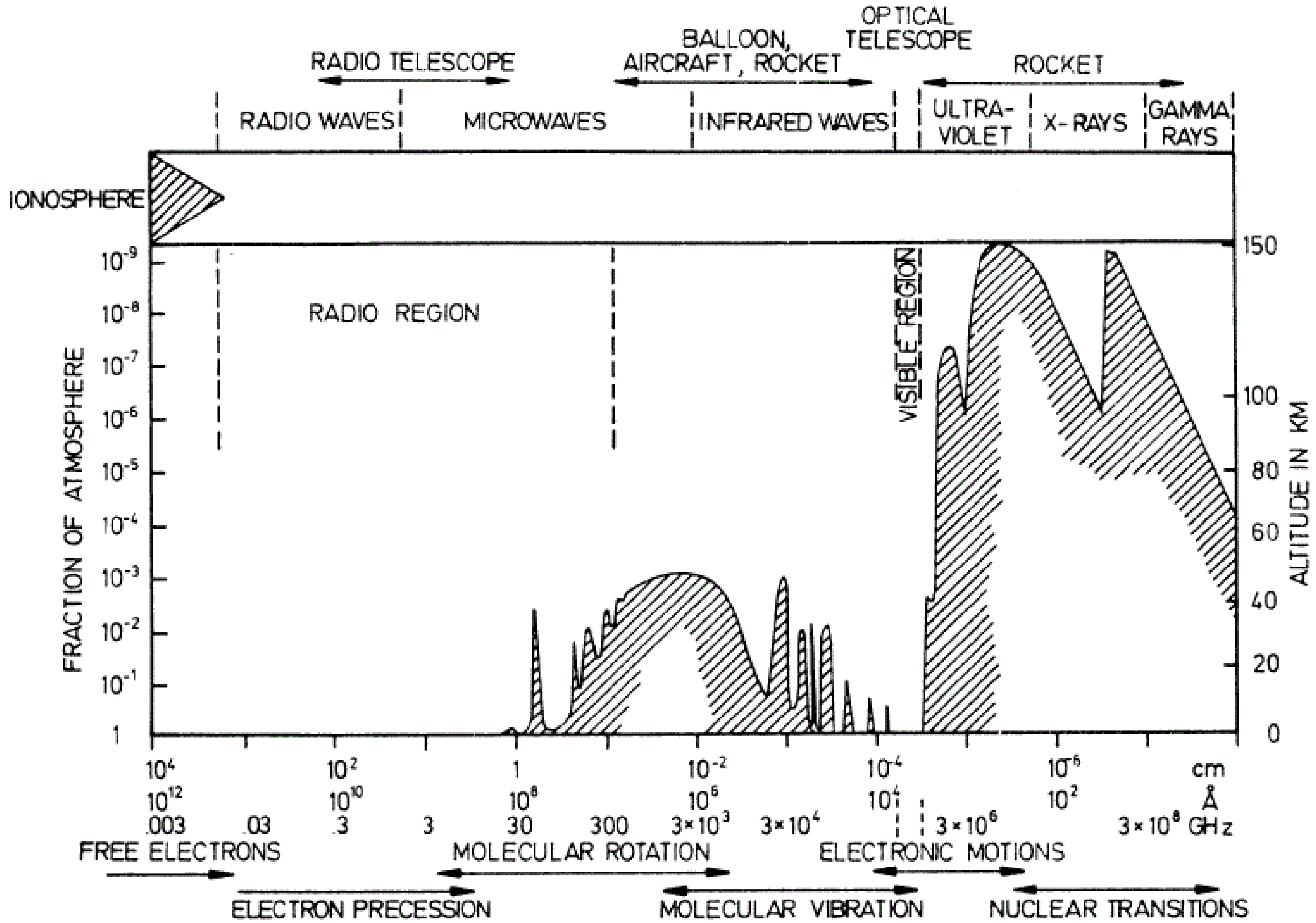


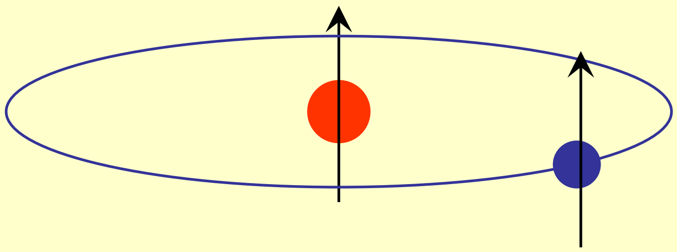
Fig. 1.1. The transmission of the earth's atmosphere for electromagnetic radiation. The diagram gives the height in the atmosphere at which the radiation is attenuated by a factor 1/2

-- Rohlfs/Wilson

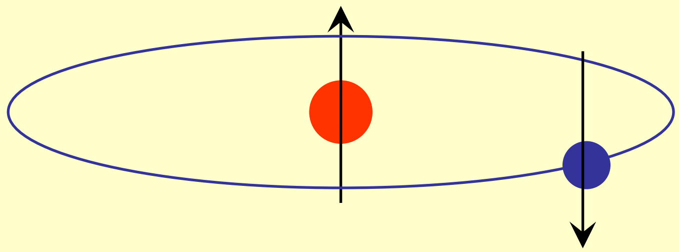
- 1944 prediction of 21 cm hydrogen line (H.C.van de Hulst ➔

- 1951 detection of 21 cm line (Ewen & Purcell)

Hydrogen: both proton and electron have a 'spin'

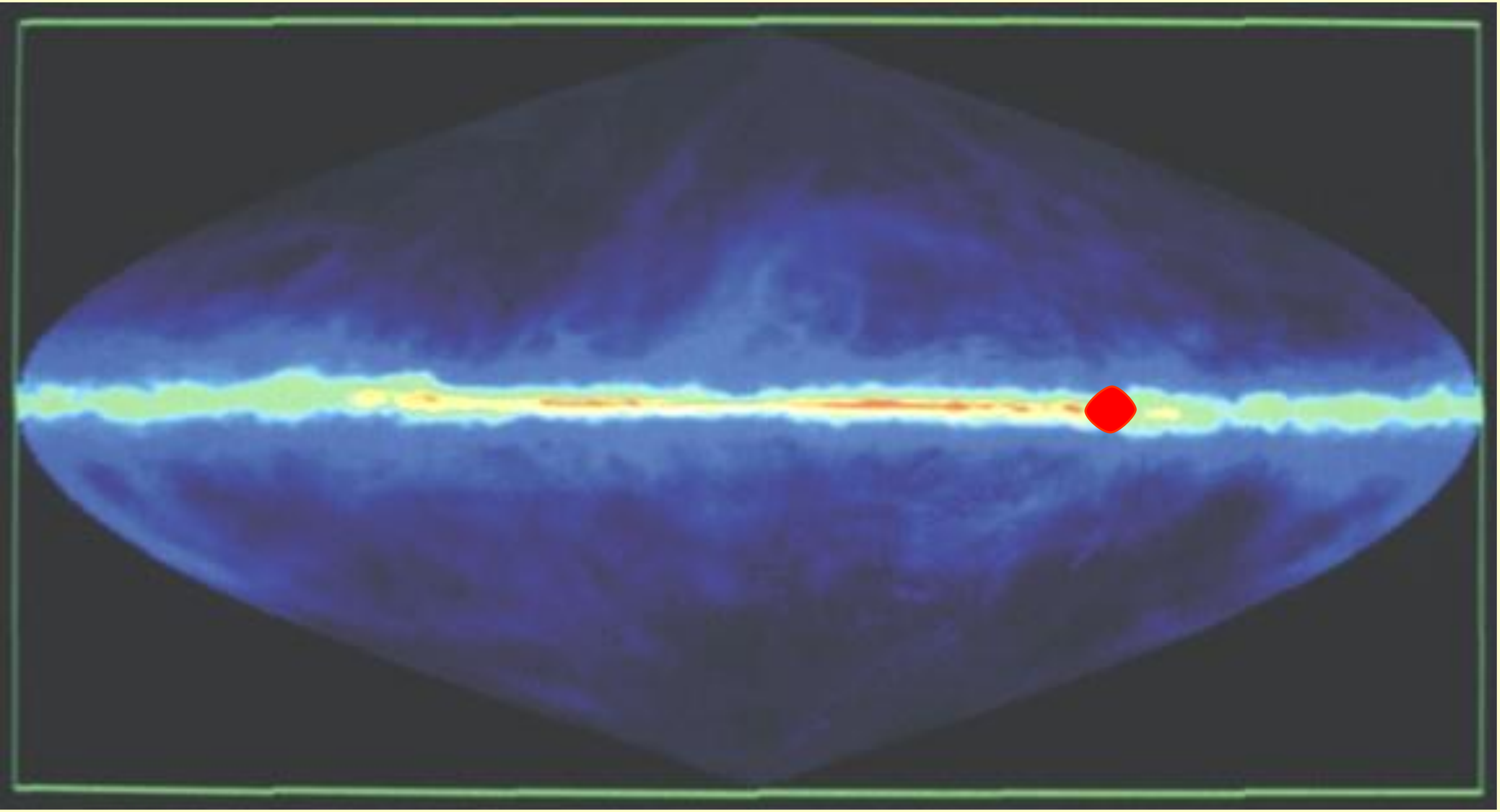


Spins parallel = higher energy
= less tightly bound

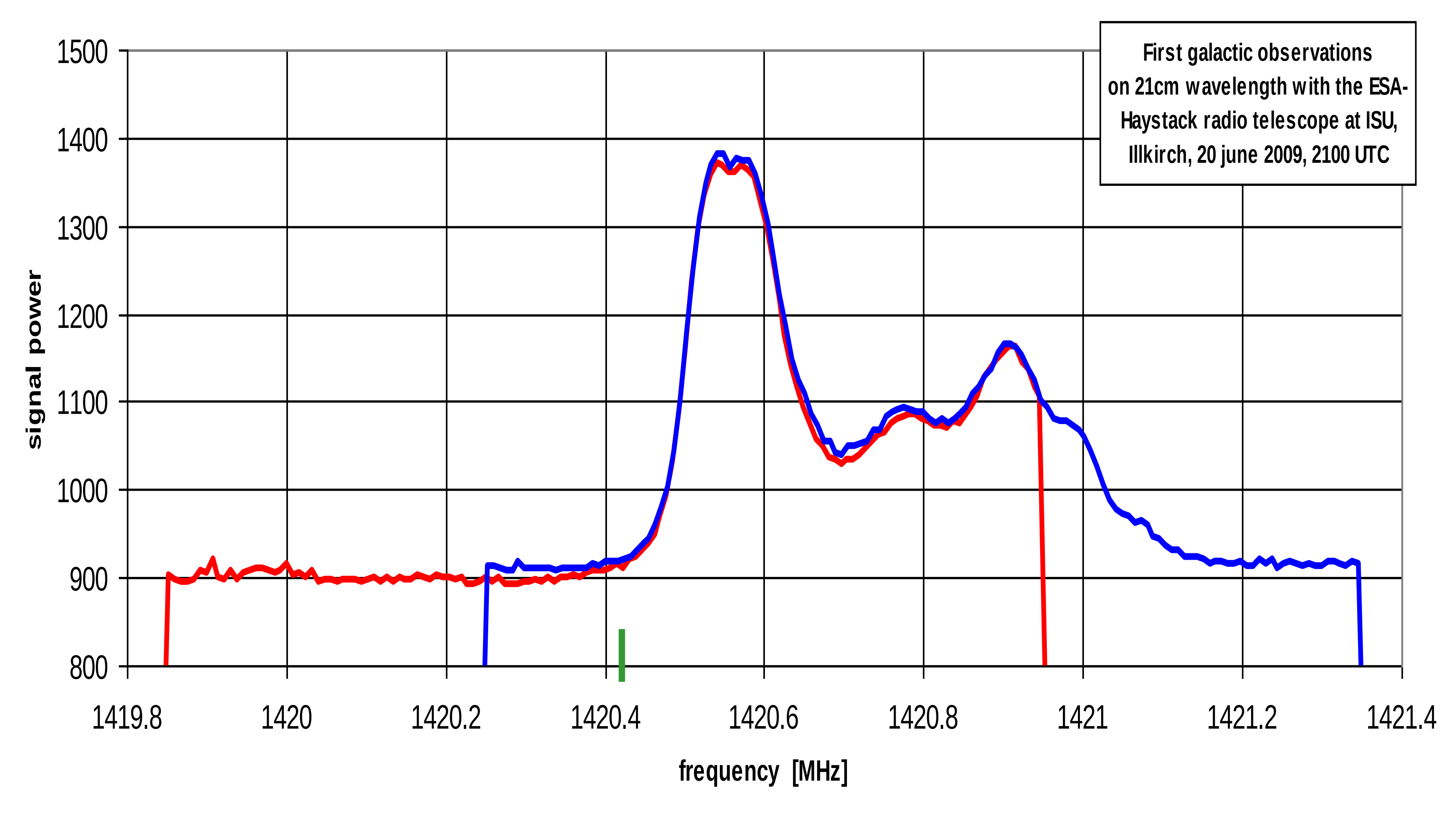


Energy difference corresponds to a line at 1420 MHz (wavelength 21 cm)

The Milky Way at 21 cm



21 cm observations from some part of the Milky Way (ℓ = 90°)



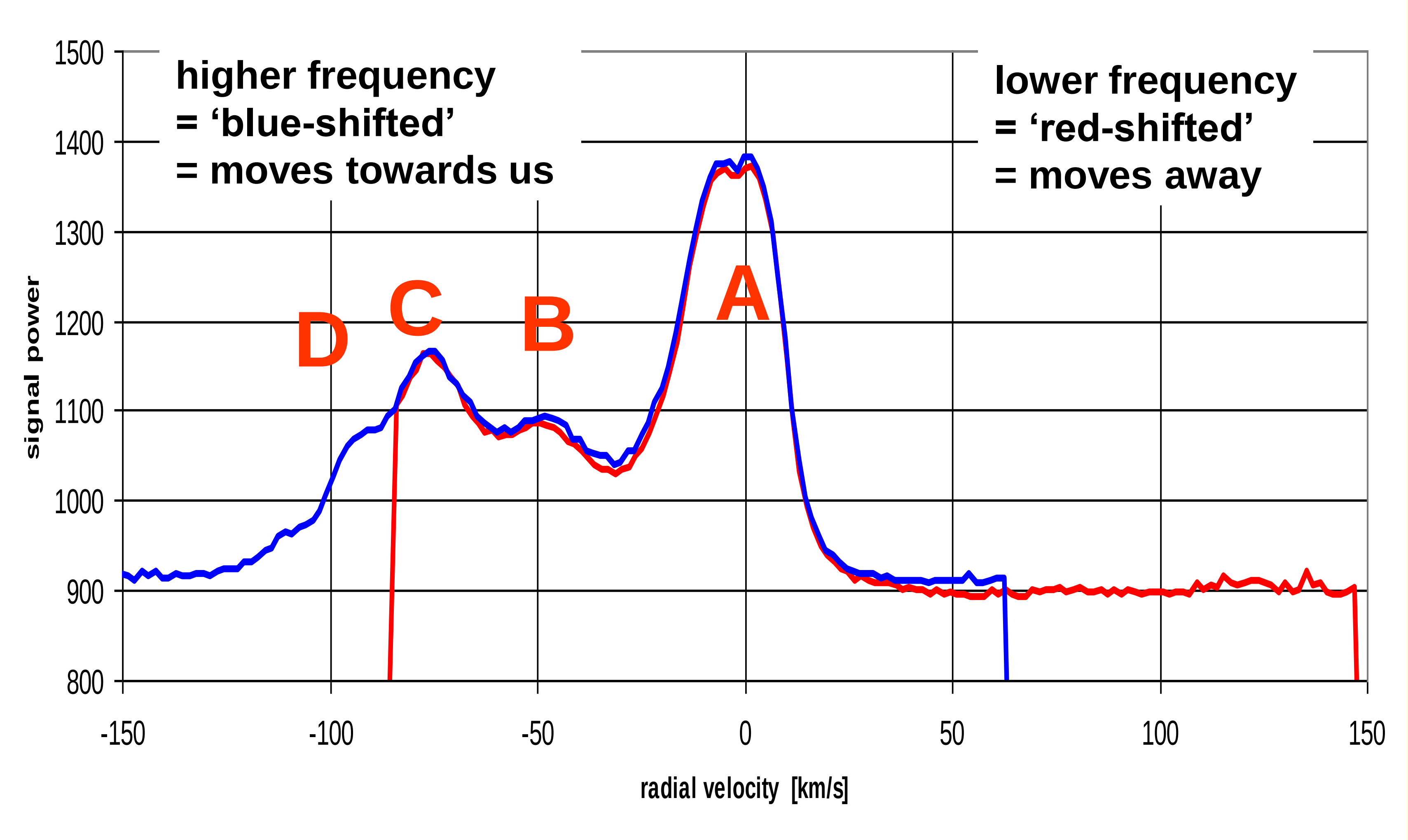
Interpretation

- The atomic line is very sharp
- The observed broad profile is produced by
  - Superposition of emission from several gas clouds …
  - … they move at different speeds relative to us
- Doppler effect places their emissions at different frequencies:

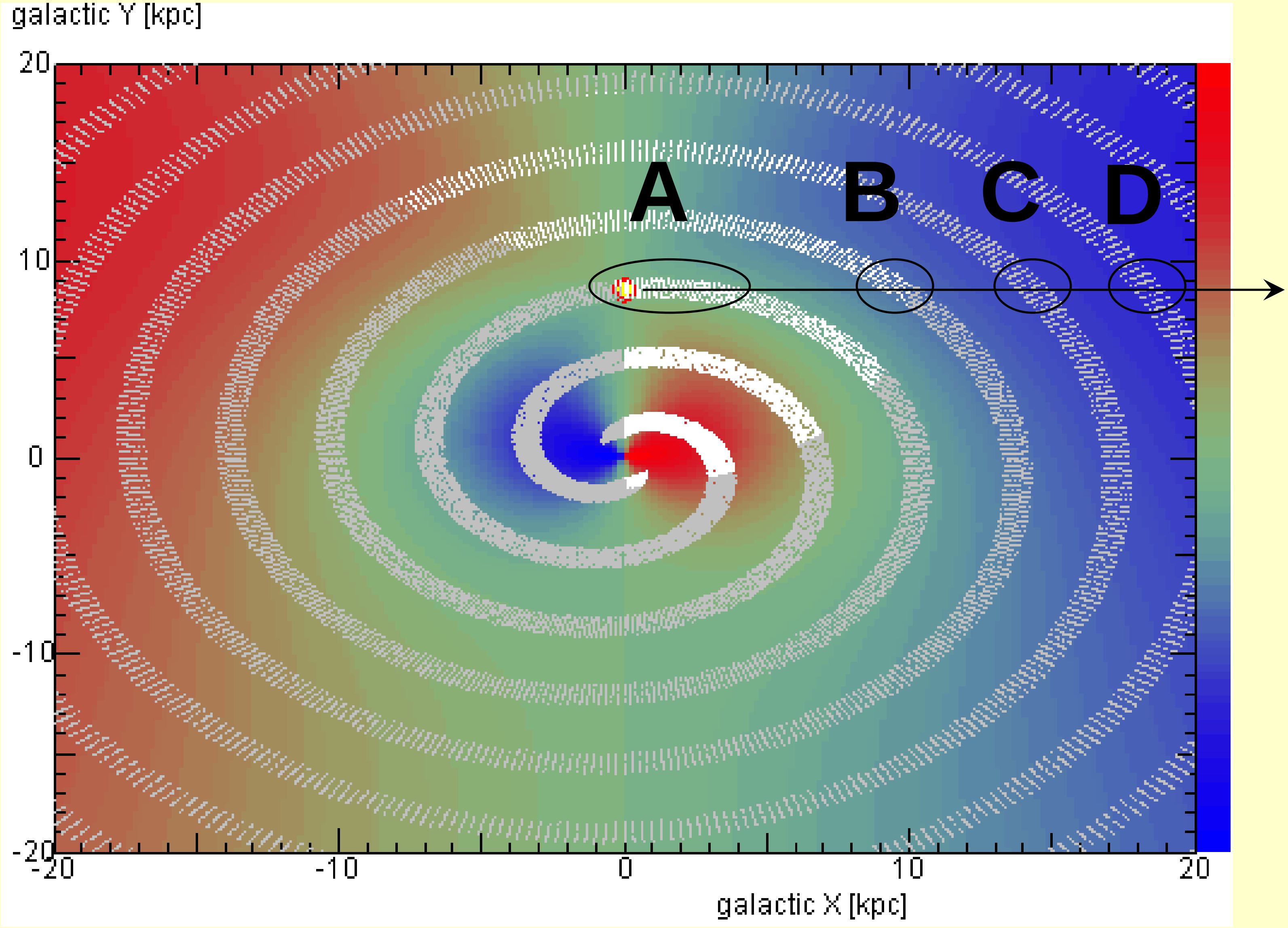
$$\Delta f/f = -v/c \qquad c = 300\,000 \text{ km/s}$$

v = speed w.r.t. us in **radial** direction

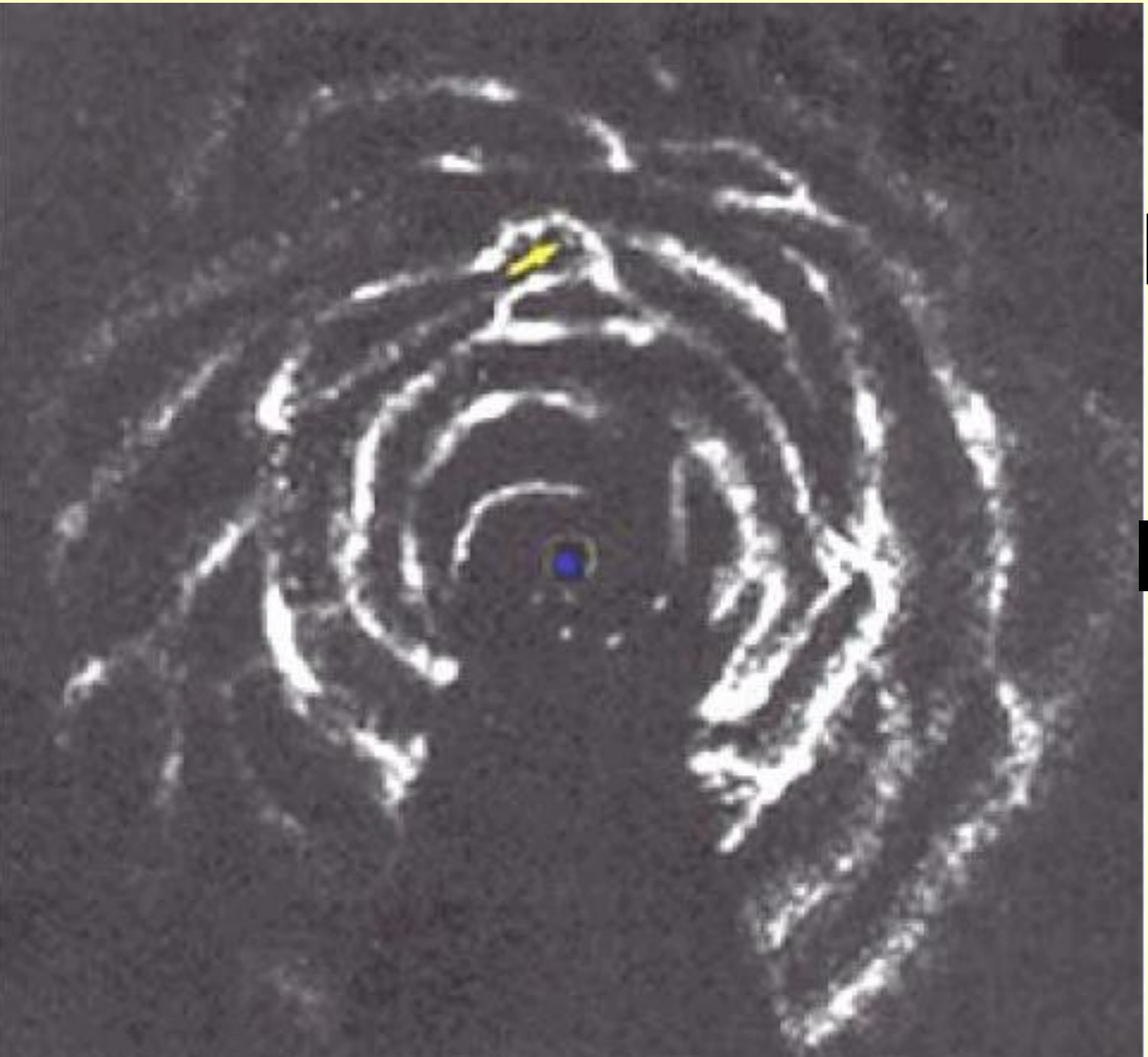
These are the spiral arms of our Milky Way



How it might look like…



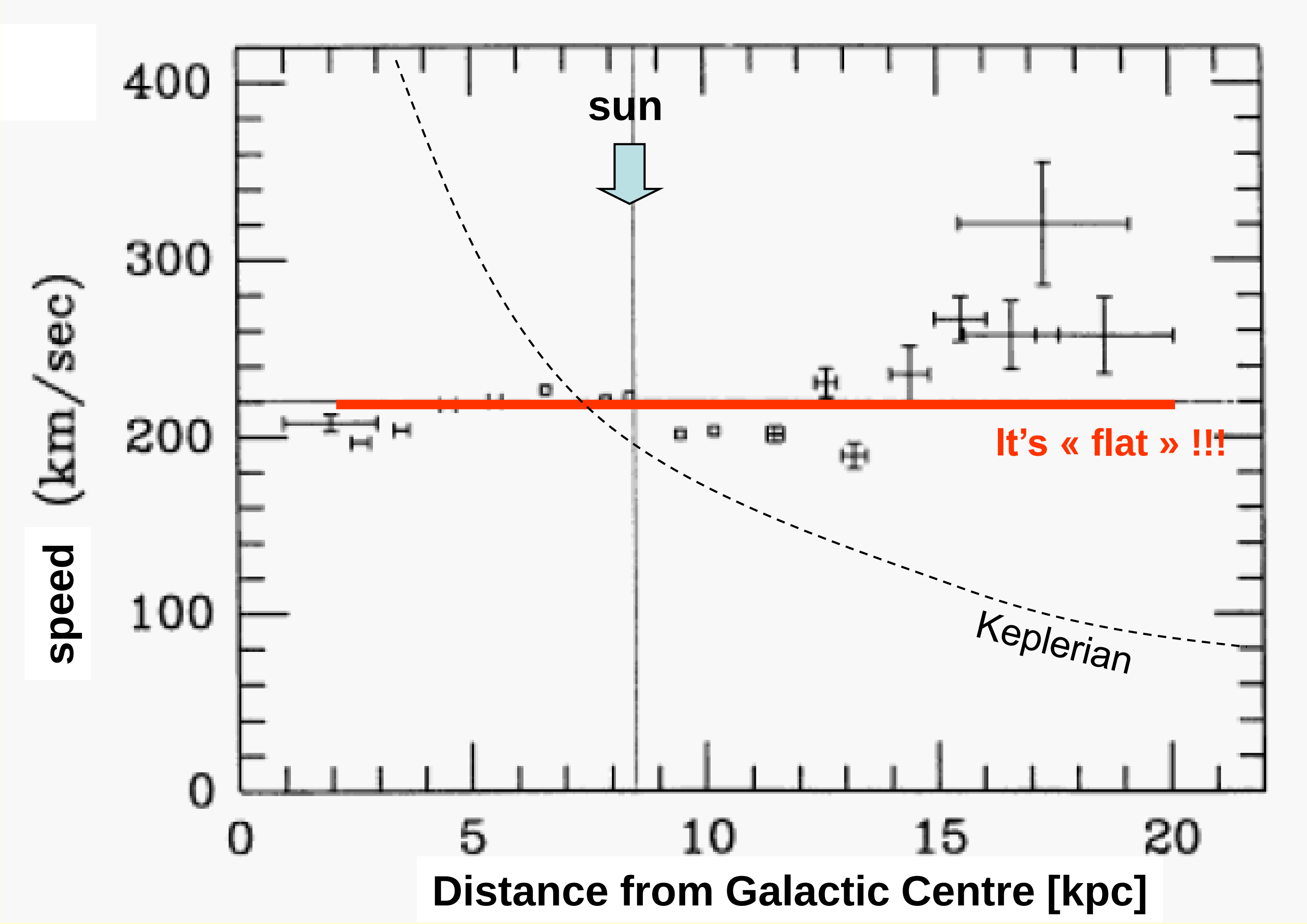
The sun is in a thin rotating disk of gas (and stars) with spiral arms



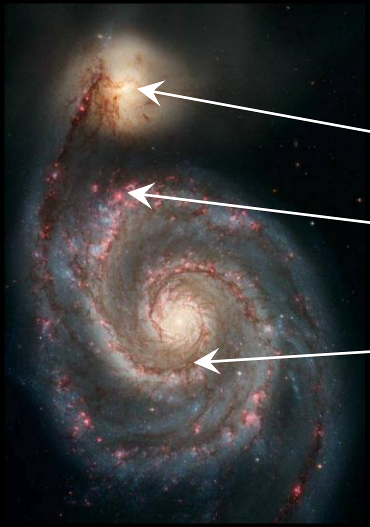
Sun

Galactic Centre (Sgr A)

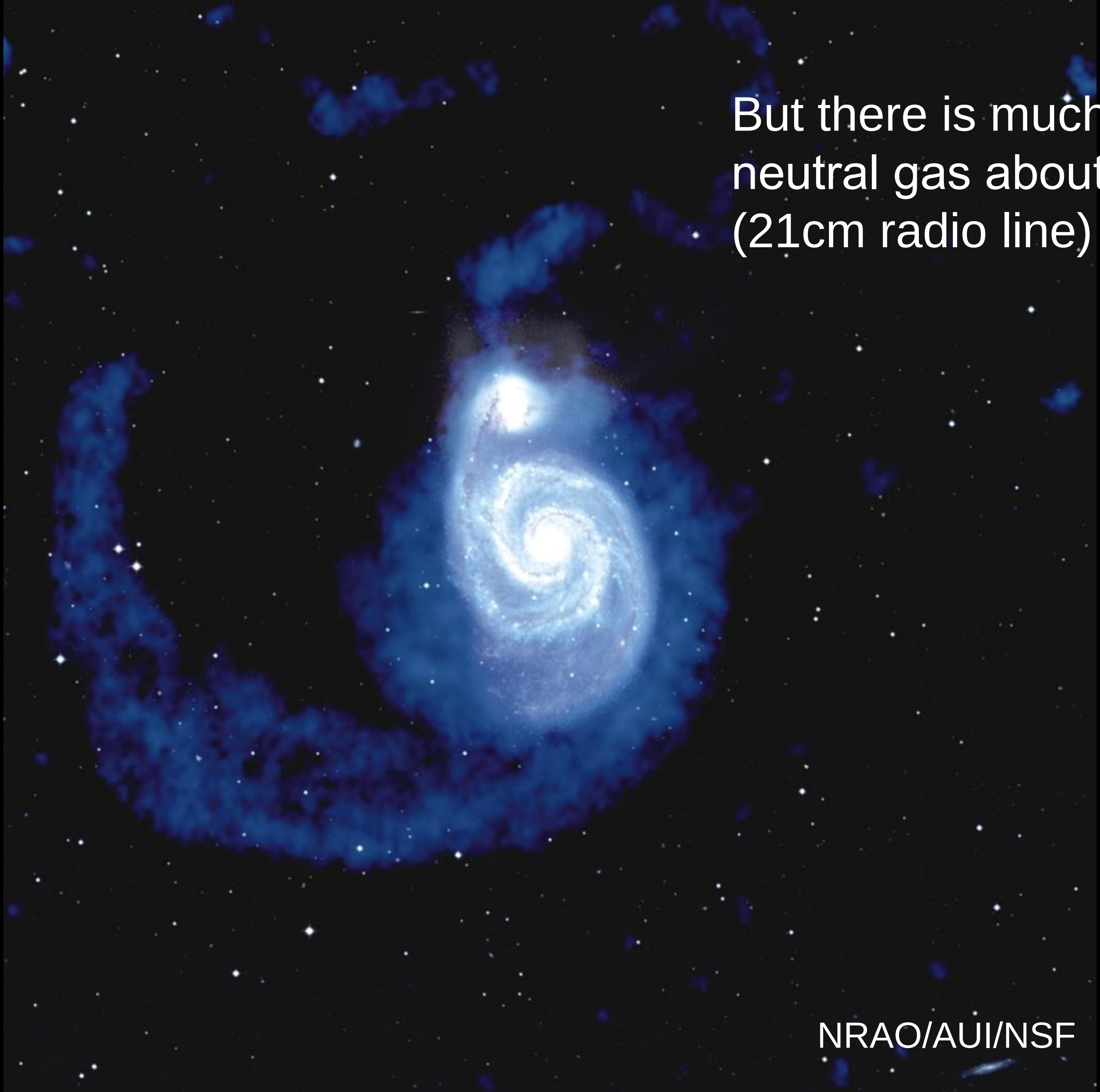
We also get the disk rotation curve



The optical (HST) shows
a lot of a spiral galaxy:

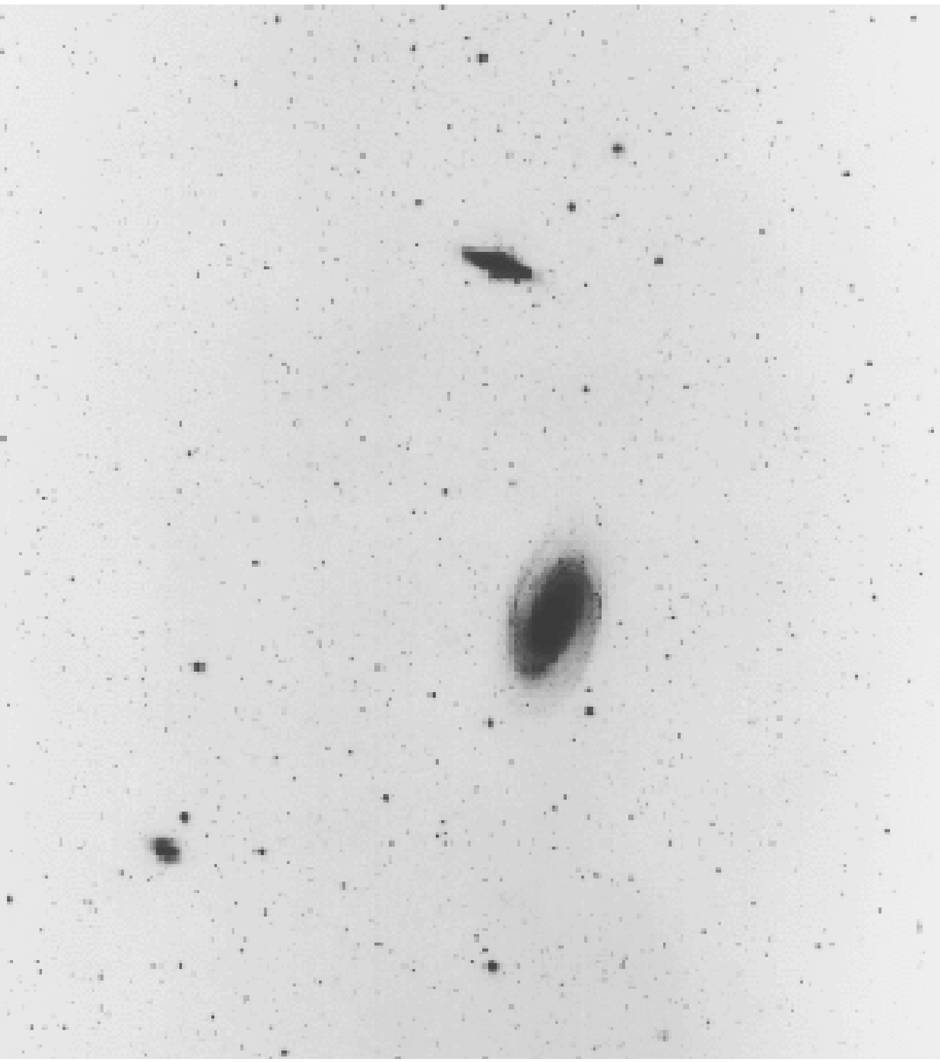


stars
ionized gas
dust

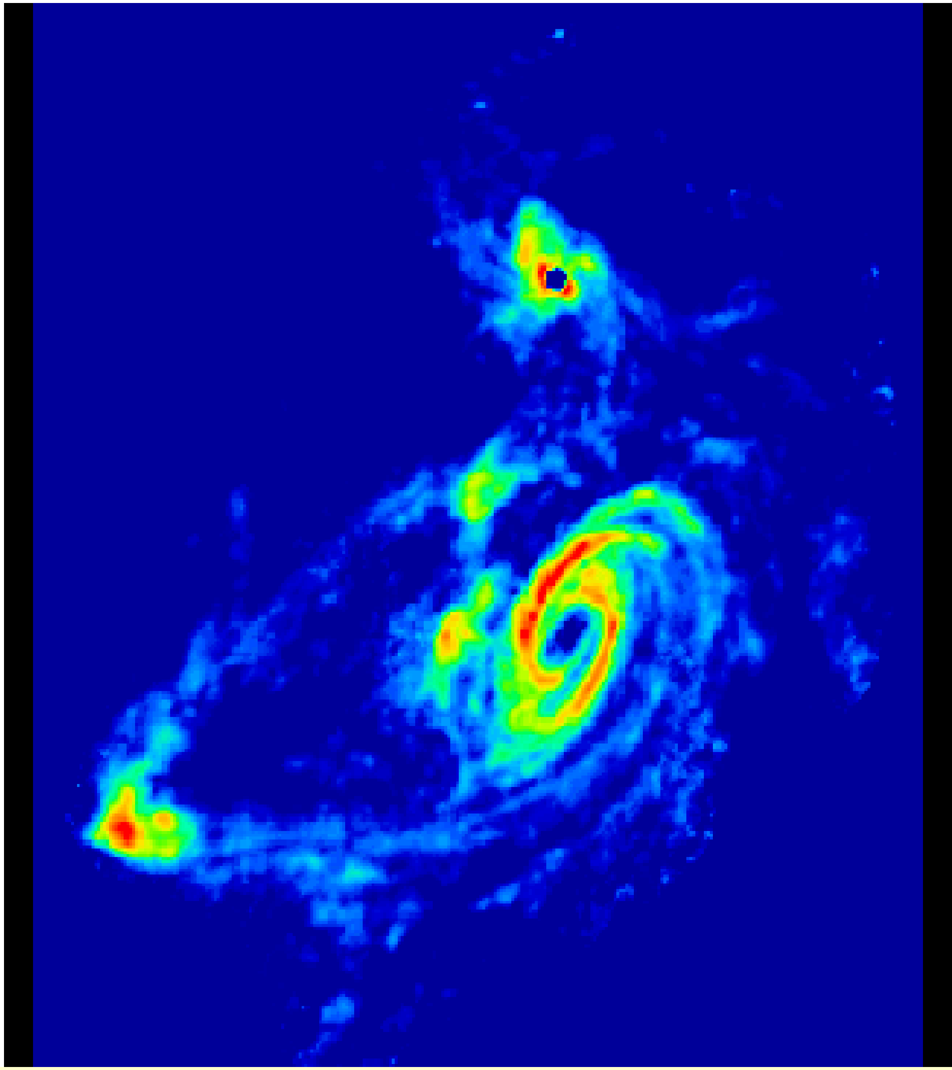

But there is much more
neutral gas about …
(21cm radio line)
NRAO/AUI/NSF

Tidal Interactions in M81 group of galaxies:

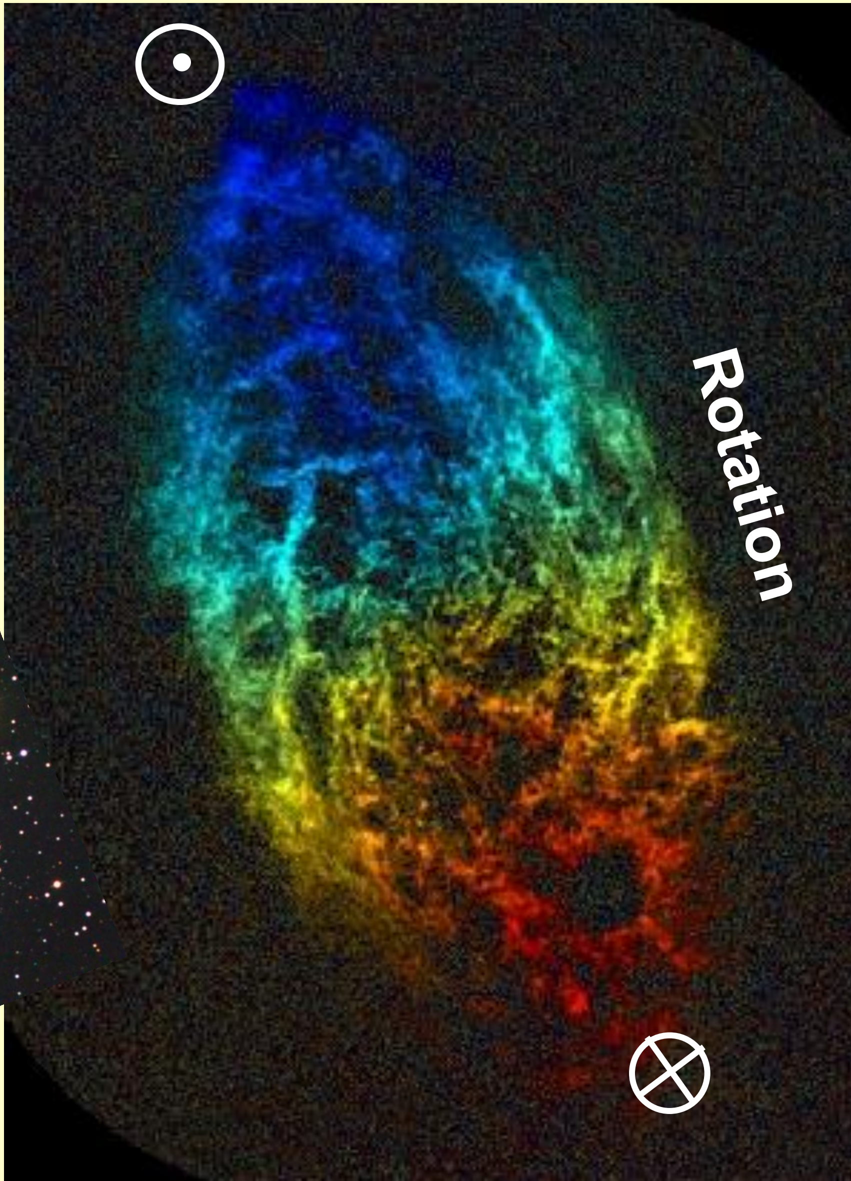
Stellar Light Distribution



21cm HI Distribution



Velocity structure of spiral M33



Other lines? YES! Lots of organic **molecules** in interstellar clouds:

Number of Atoms										
2	3	4	5	6	7	8	9	10	11	12+
H_2	C_3	c-C_3H	C_5	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N?	HC_9N	C_6H_6
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$		$HC_{11}N$
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH?	$(CH_3)_2O$	NH_2CH_2COOH?		PAHs
C_2	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH			C_{60}^+?
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	$HCOCH_3$	H_2C_6	HC_7N			
CH^+	HCN	C_2H_2	CH_2CN	CH_3OH	NH_2CH_3	$HOCH_2CHO$	C_8H			
CN	HCO	CH_2D^+?	CH_4	CH_3SH	c-C_2H_4O					
CO	HCO^+	HCCN	HC_3N	HC_3NH^+						
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO						
CP	HOC^+	HNCO	HCOOH	NH_2CHO						
CSi	H_2O	HNCS	H_2CHN	C_5N						
HCl	H_2S	$HOCO^+$	H_2C_2O							
KCl	HNC	H_2CO	H_2NCN							
NH	HNO	H_2CN	HNC_3							
NO	MgCN	H_2CS	SiH_4							
NS	MgNC	H_3O^+	H_2COH^+							
NaCl	N_2H^+	NH_3								
OH	N_2O	SiC_3								
PN	NaCN	CH_3								
SO	OCS									
SO^+	SO_2									
SiN	c-SiC_2									
SiO	CO_2									
SiS	NH_2									
CS	H_3^+									
HF	H_2D^+									

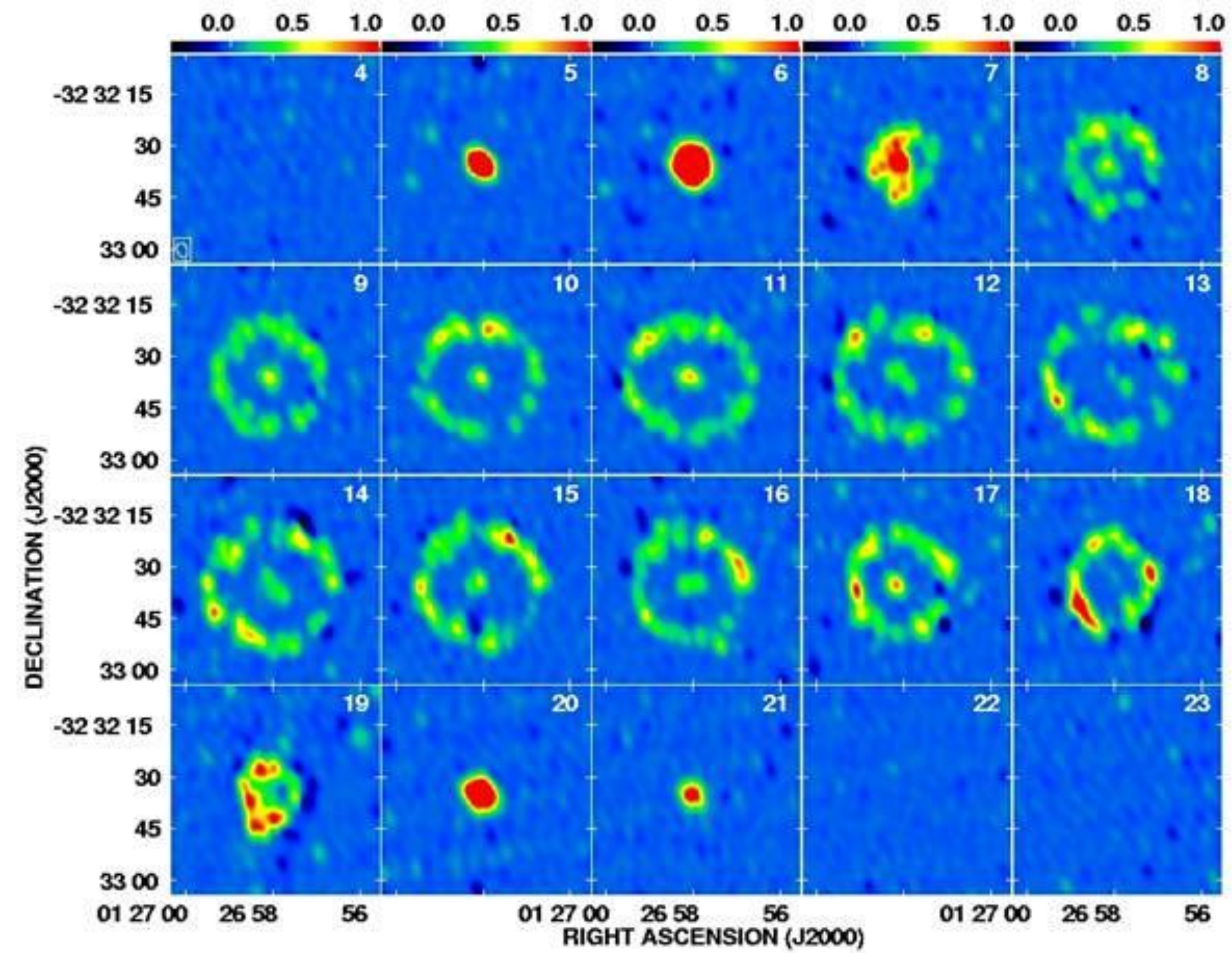
Ethanol

Carbon monoxide

molecules can
- rotate (➔ radio lines)
- vibrate (➔ IR lines)

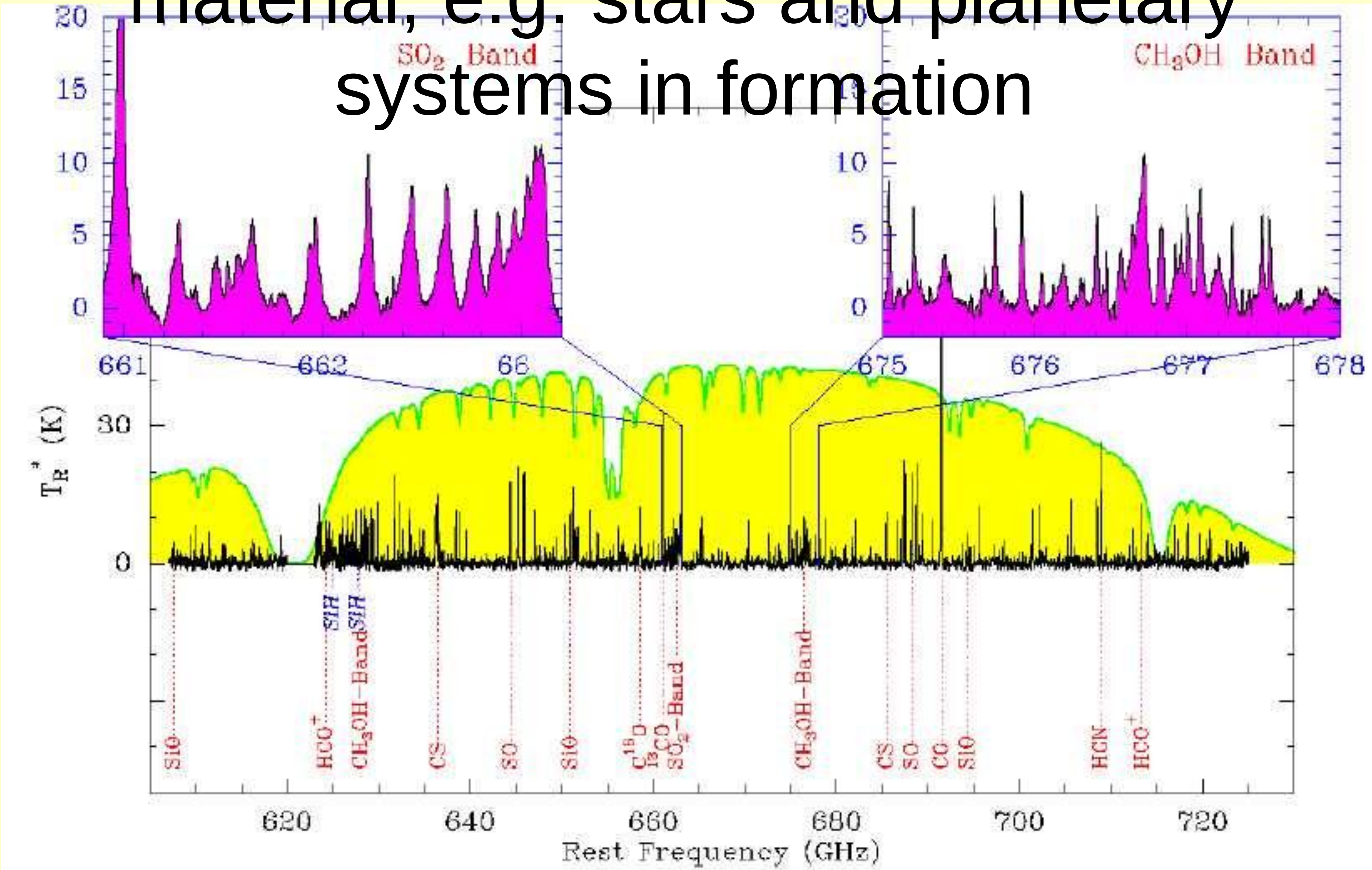
for more, e.g. http://www.cv.nrao.edu/~awotten/allmols.html

An expanding shell of CO molecules around the star R Sculptoris

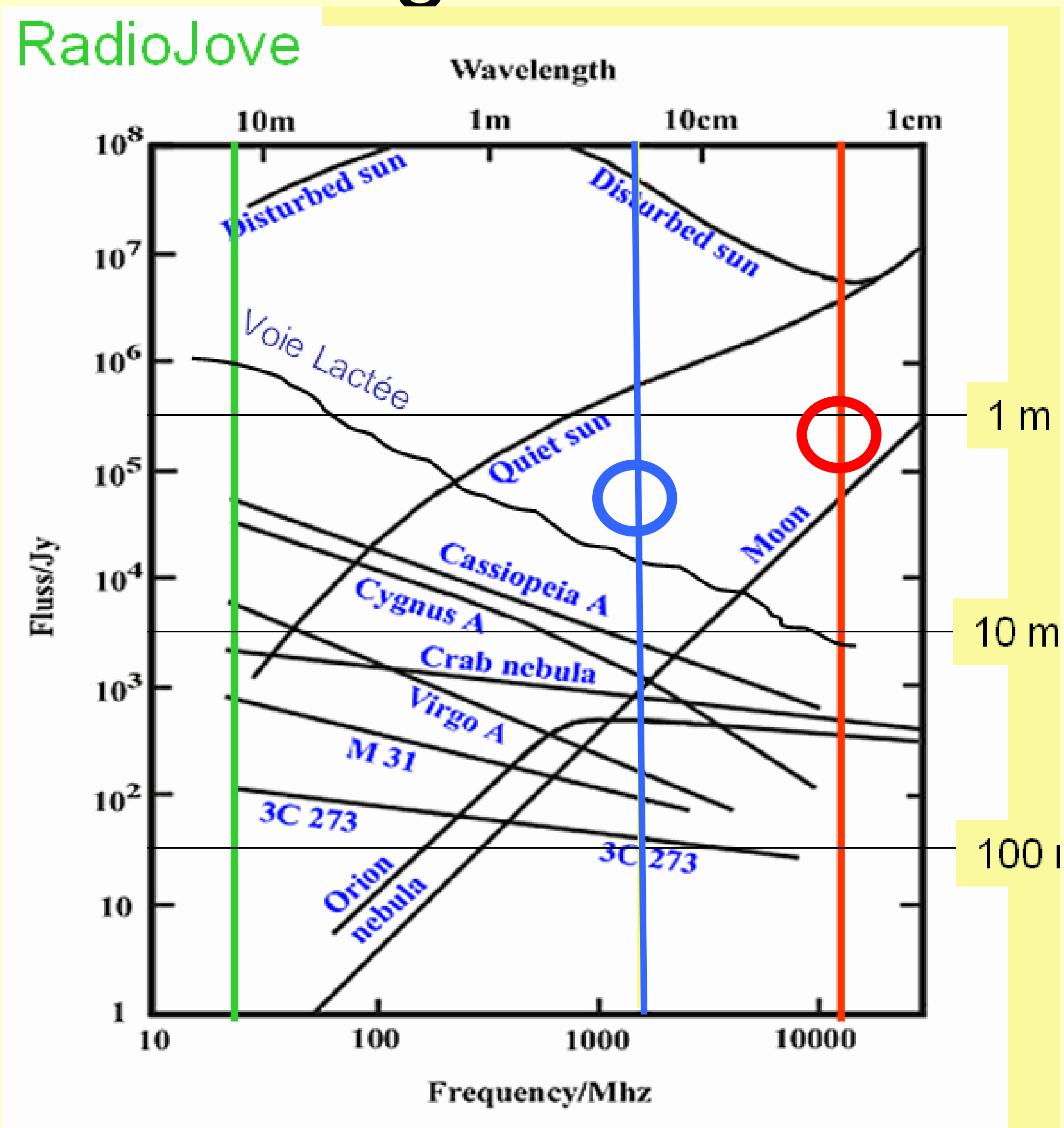


Each image shows the emission at a different wavelength, i.e. a different radial speed → we see an expanding envelope

Molecules: signatures of cool material, e.g. stars and planetary systems in formation



What we can ‘see’ depends on wavelength and telescope size:



Minimum telescope diameter for detection

Jodrell Bank, Effelsberg

Arecibo