

Radio Astronomy: an introduction

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Good reasons NOT to do astronomy with radio waves

- Astronomy is all about stars which are at 1000's of degrees and radiate in the visible region
- For radio waves, say at 1.35 cm, 22 Ghz, , the corresponding temperature is one degree Kelvin, who wants to look at such cold stuff?
- The power in radio for the Sun would be 10^{-12} of the total
- To make up, one would need a large solid angle but the space between the stars is empty, anyway

Radio waves from the Milky Way

Karl Jansky, Bell Labs, USA, 1932

wavelength 14.5 m , frequency

20 MHz

1 Jansky = 10^{-26}

Watts/metre²/Hertz

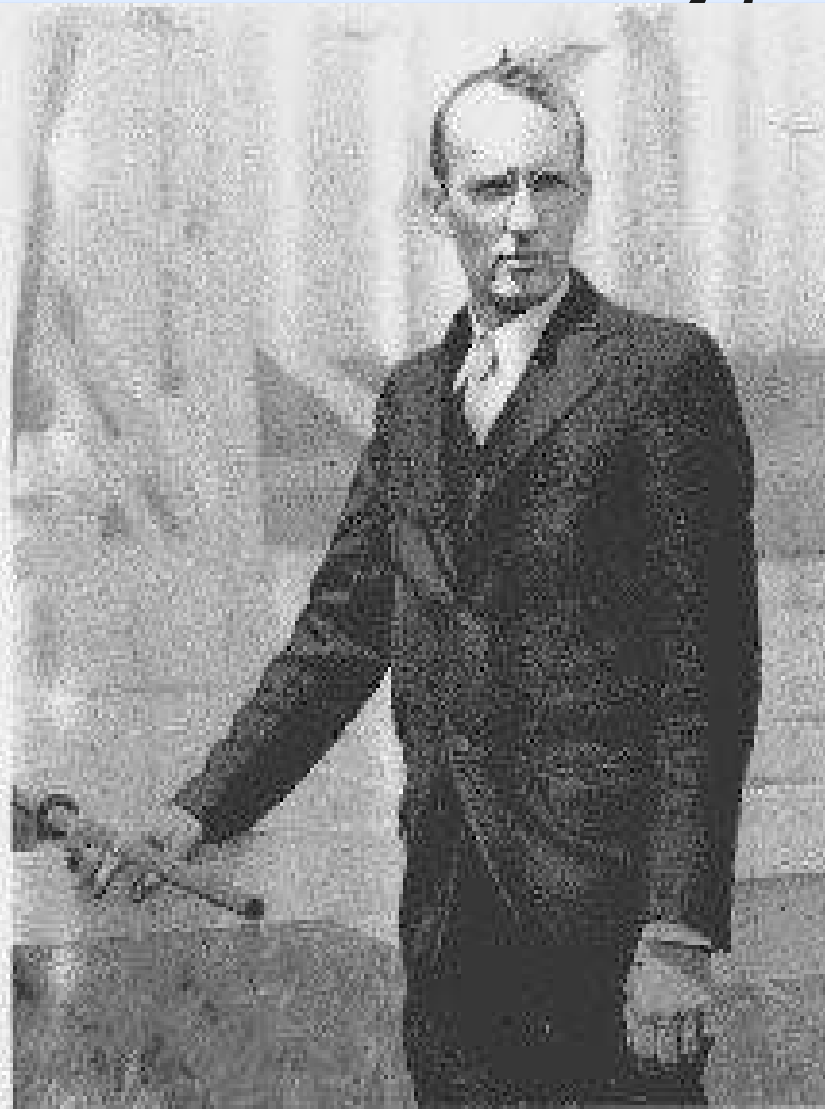
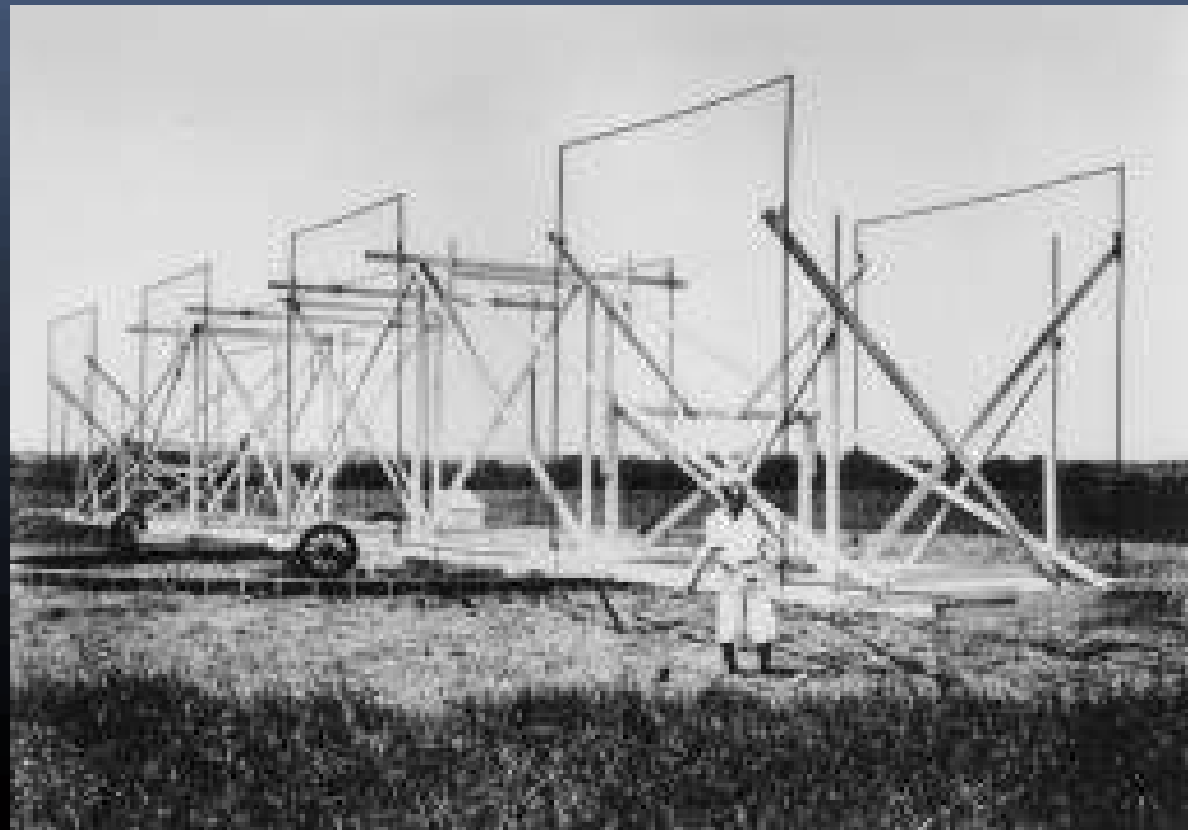


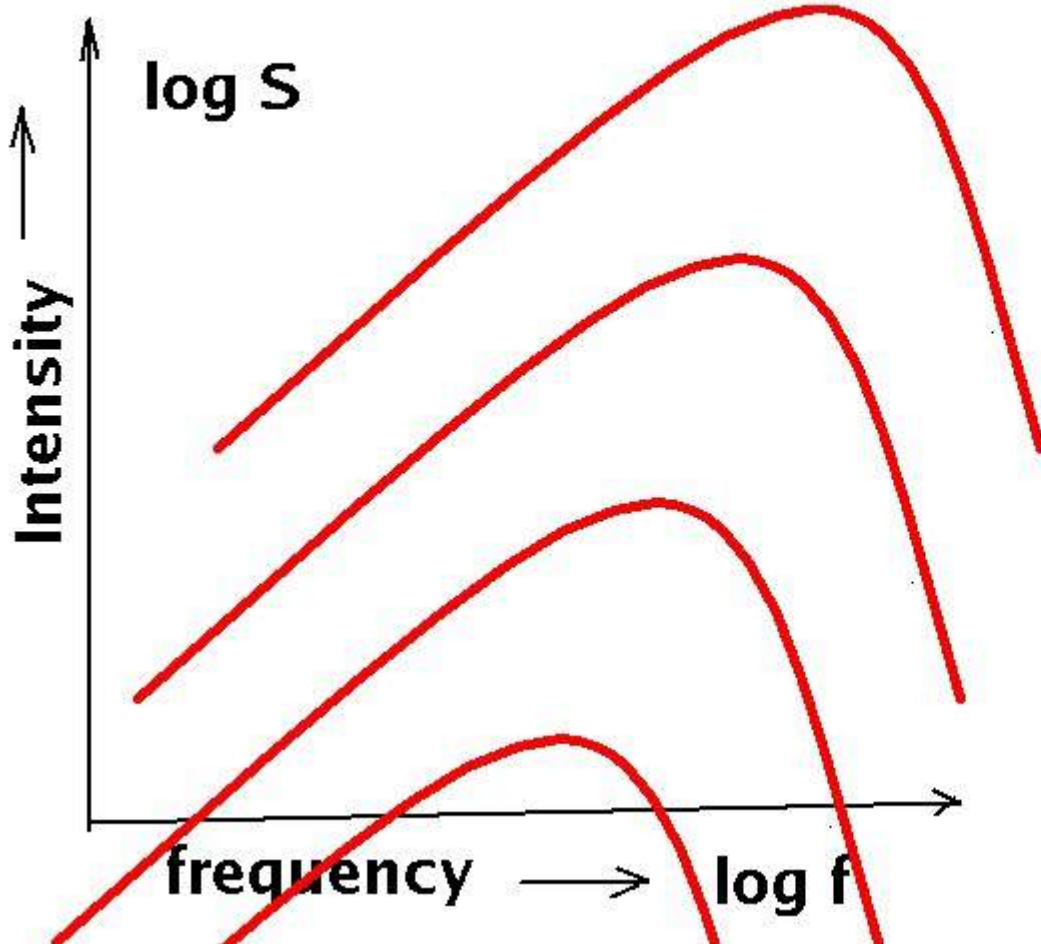
FIG. 1—Karl Gure Jansky, about 1925



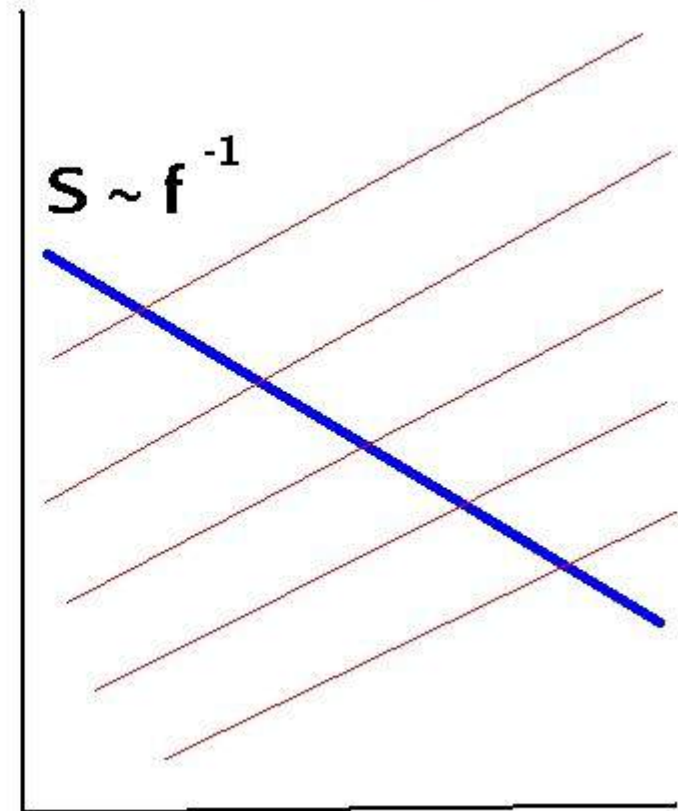
Cosmic radio waves are not like black body radiation!

The thermal

.....

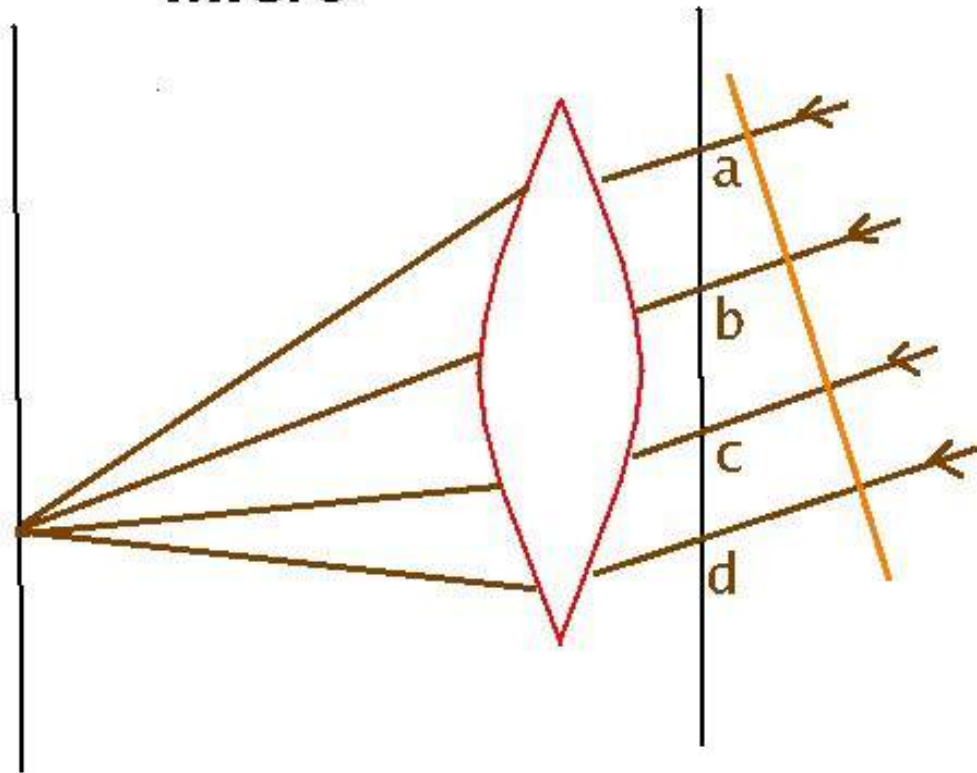


and the non-thermal



Images are made of correlations: Abbe, Zernike, Michelson....

All tele microscopes are interferometers



$$E = a + b e^{-i\phi} + c e^{-2i\phi} + d e^{-3i\phi}$$

= *Fourier transform of input field*

$$I = |E|^2 = a a^* + b b^* + \dots$$

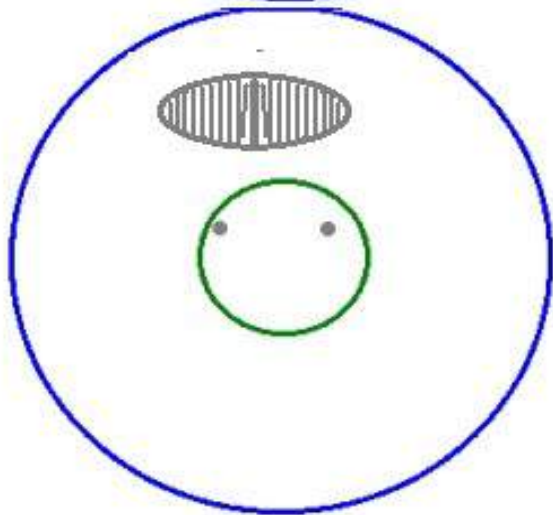
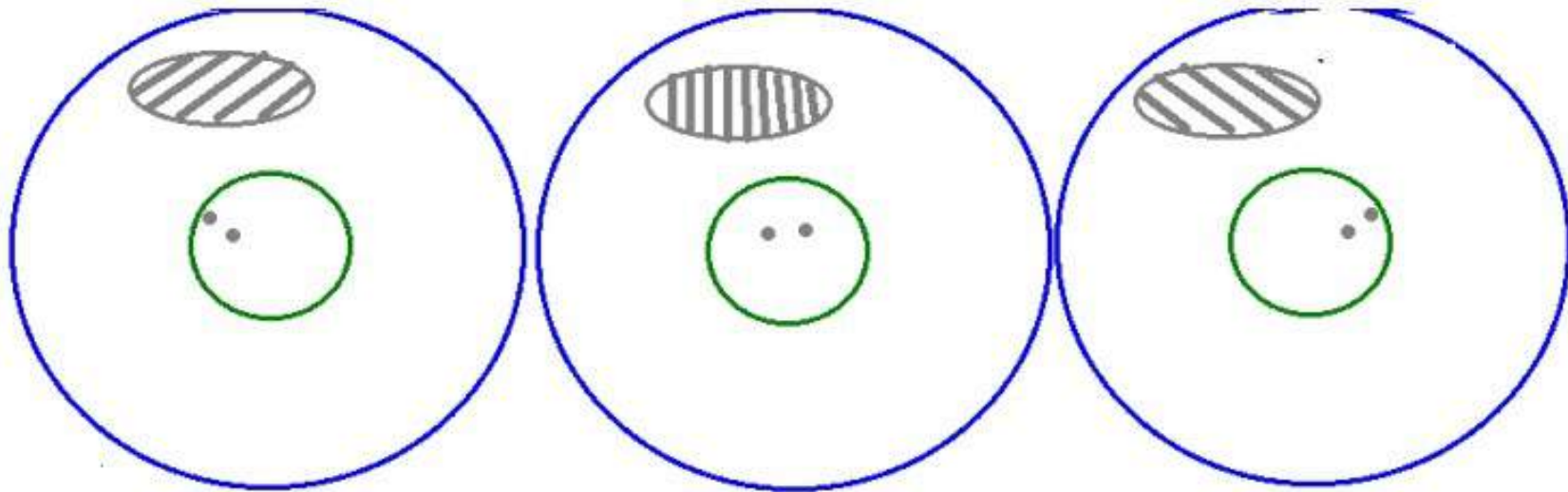
$$+ a b^* e^{i\phi} + a c^* e^{2i\phi} + \dots$$

$$+ b d^* e^{2i\phi} \dots$$

Fourier transform of input correlations

Large telescopes from small: Ryle, Cambridge, 1960

The geometry of Earth rotation aperture synthesis.....



.....and the algebra

$$E(x,y) = \sum \tilde{E}(k_x, k_y) \exp(i(k_x x + k_y y))$$

$$|\tilde{E}(k_x, k_y)|^2 = \text{I.F.T of } \langle E^*(x+u, y+v) E(x,y) \rangle$$

The Very Large Array: NRAO, New Mexico, USA



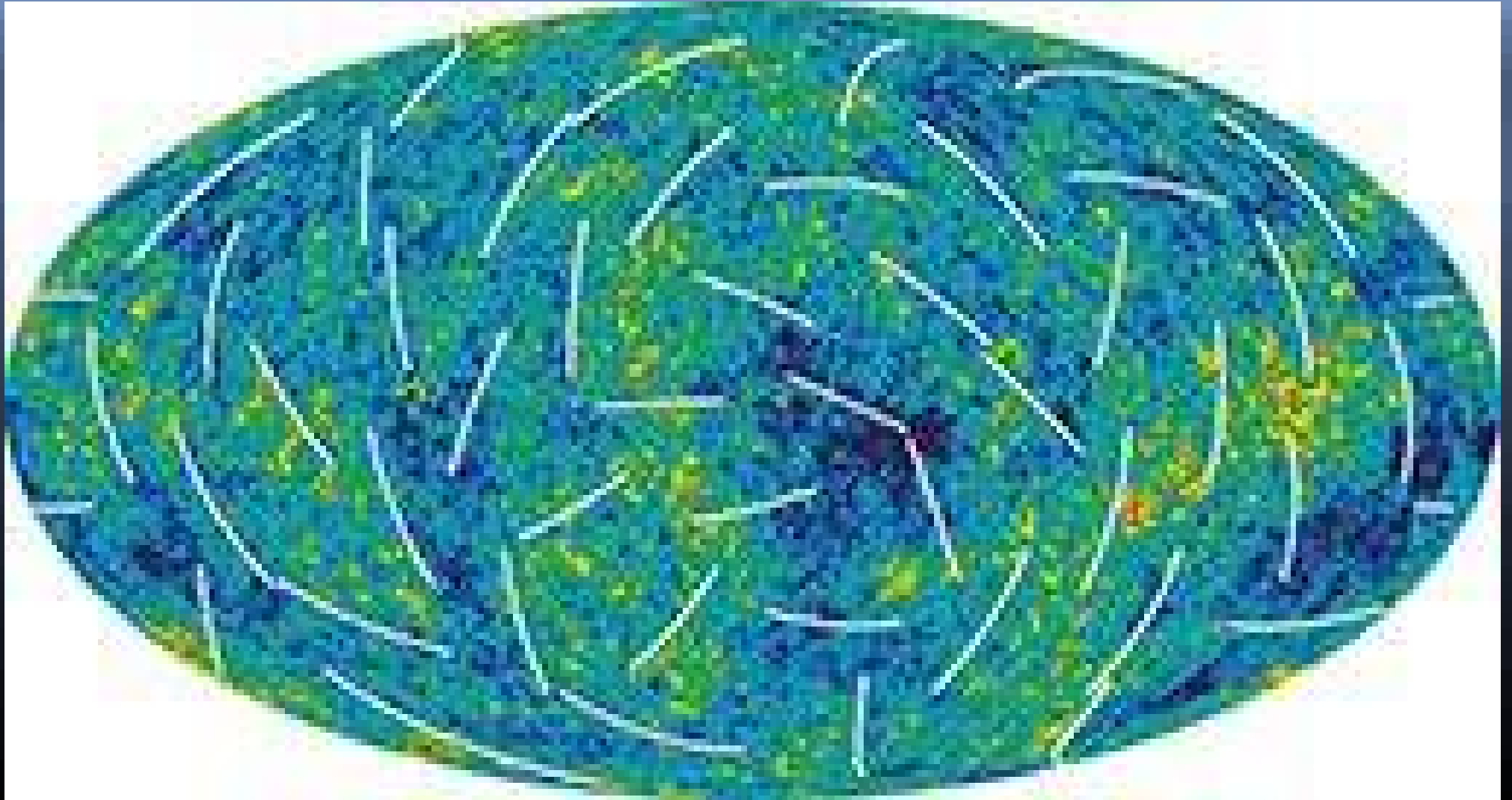




Bell Labs, 1965 – the Universe is a black body at 2.7 degrees Kelvin..almost

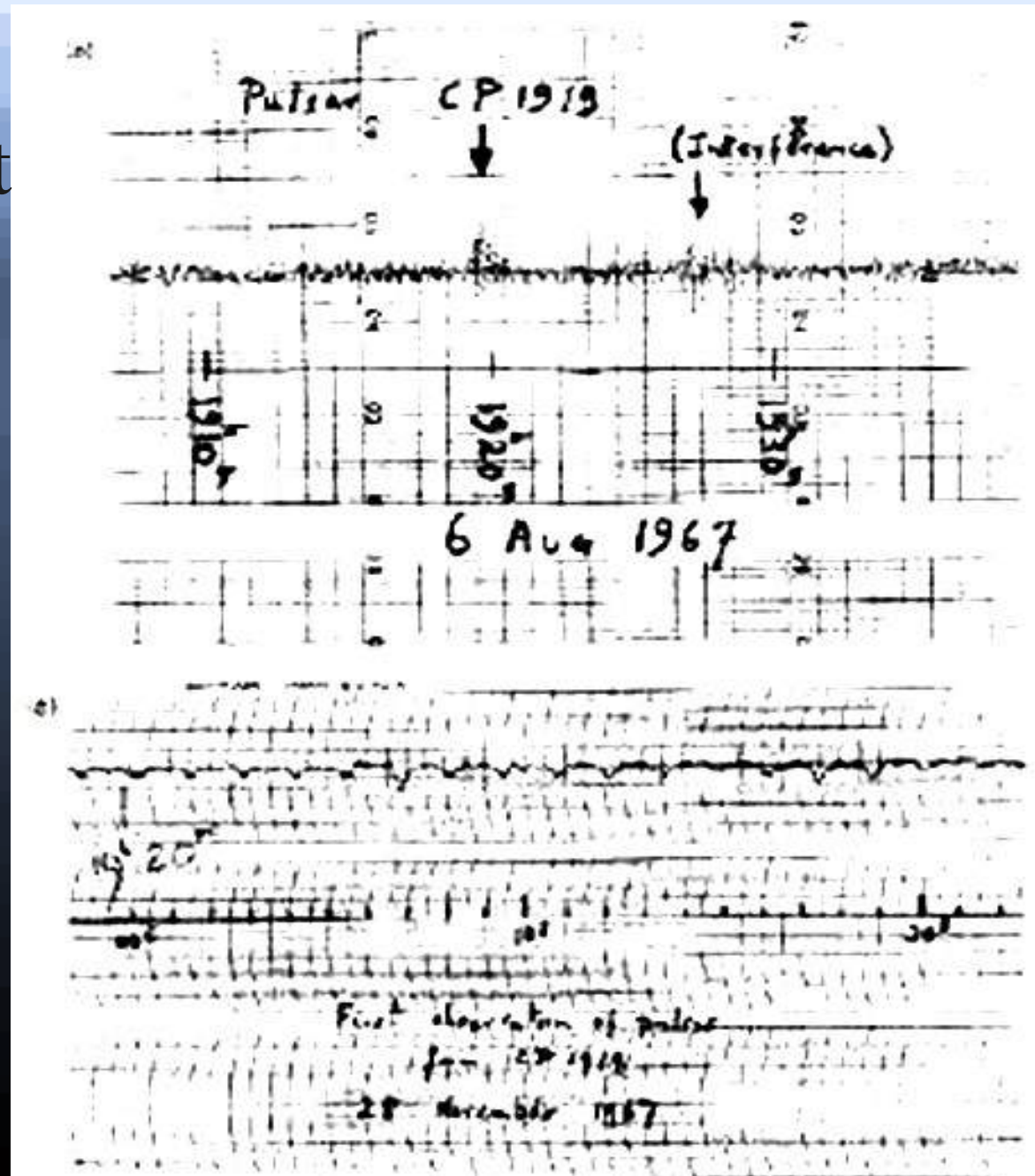


COBE and WMAP show temperature variations and polarisation of the radiation



The little green men of 1967

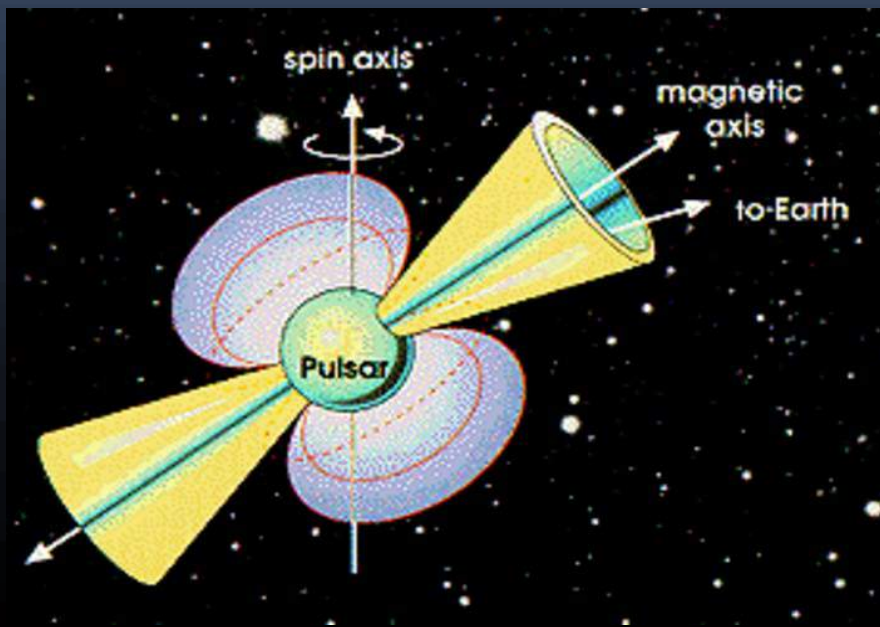
Jocelyn Bell-(Burnell)
as a research student at
Cambridge



Radio pulsars – the crash course

spinning neutron stars 20 km across with coherent radio beams fit the data

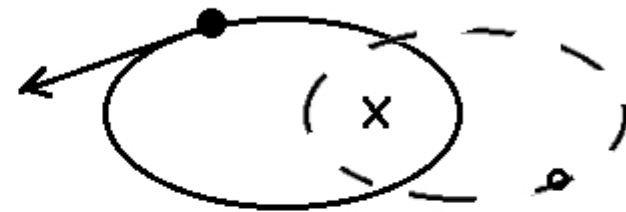
- being braked by their magnetic dipole moments
- can spin upto 0.6 kHz!
- timing their pulses helps us track their movements to about 1 km accuracy



The importance of timing pulsars

By accurate (sub microsecond) pulse timing, at earth, one measures

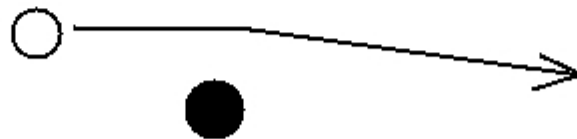
orbital parameters: period
eccentricity, projected axes



Precession



gravitational time delay



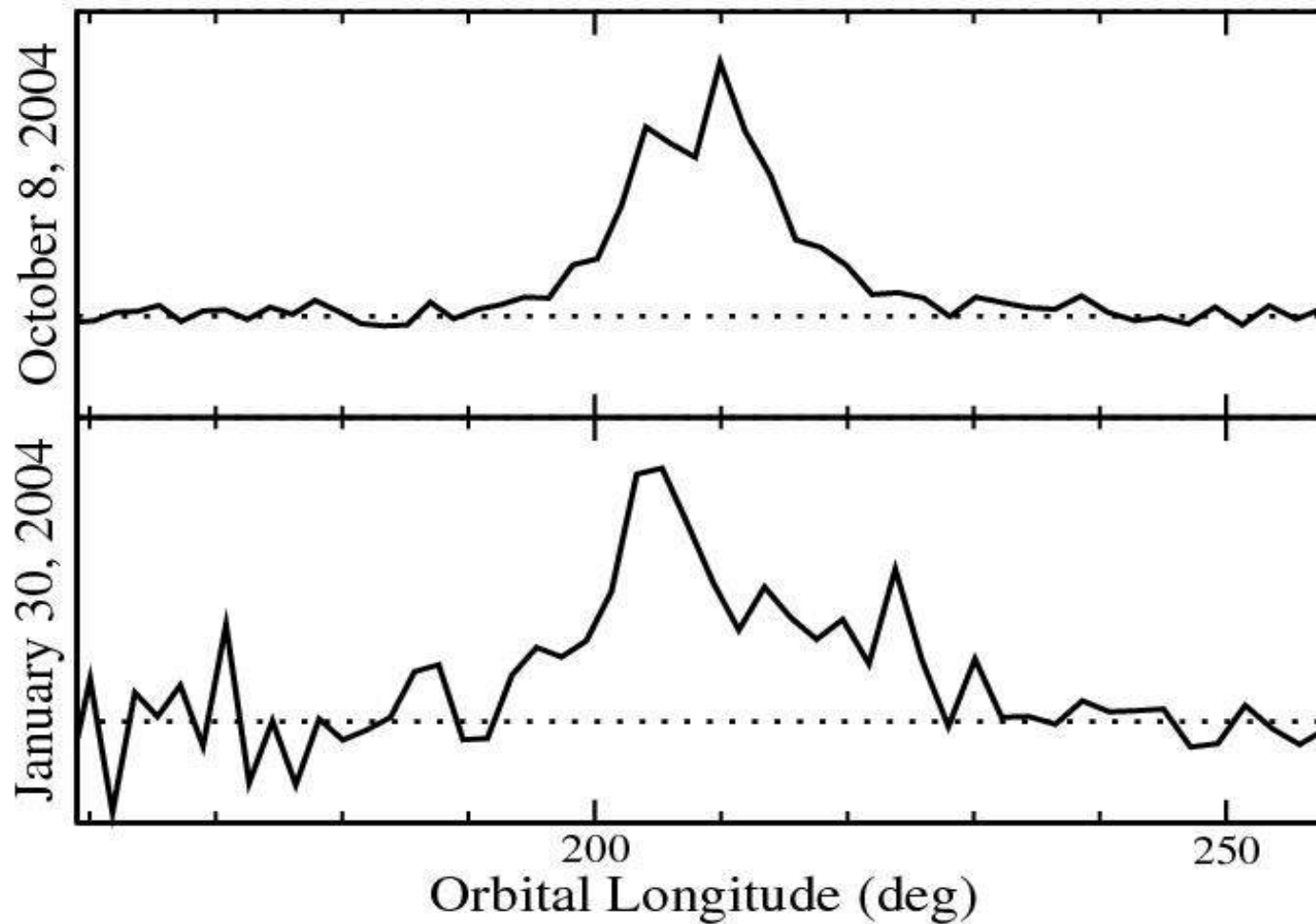
Inspiral



0737 -3039 A tale of two pulsars

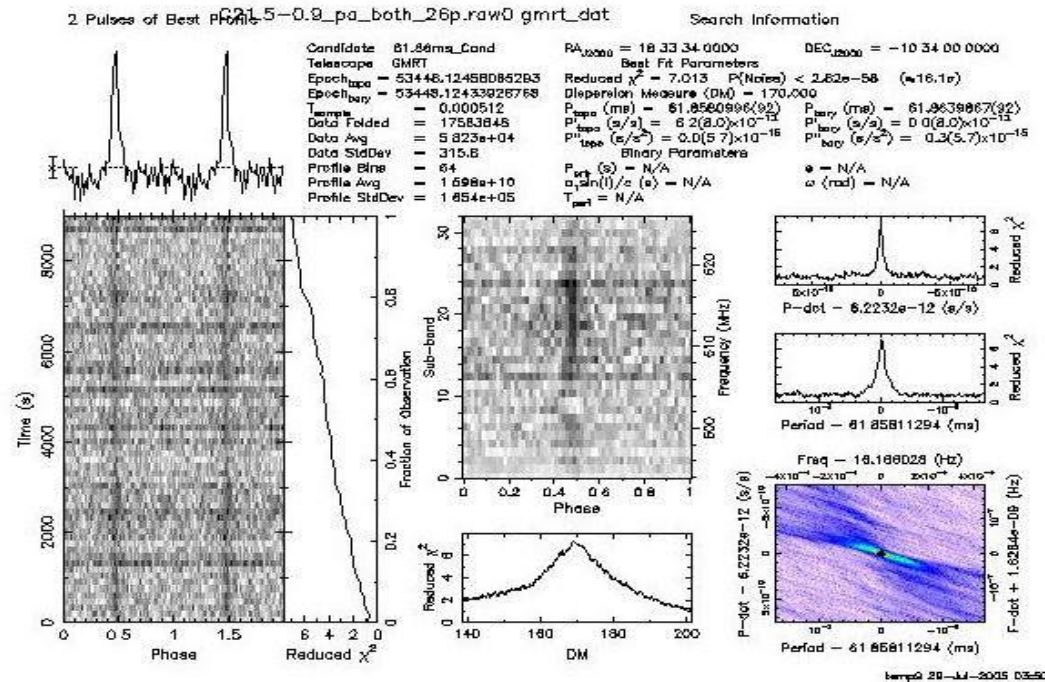
B.C. Joshi

2004



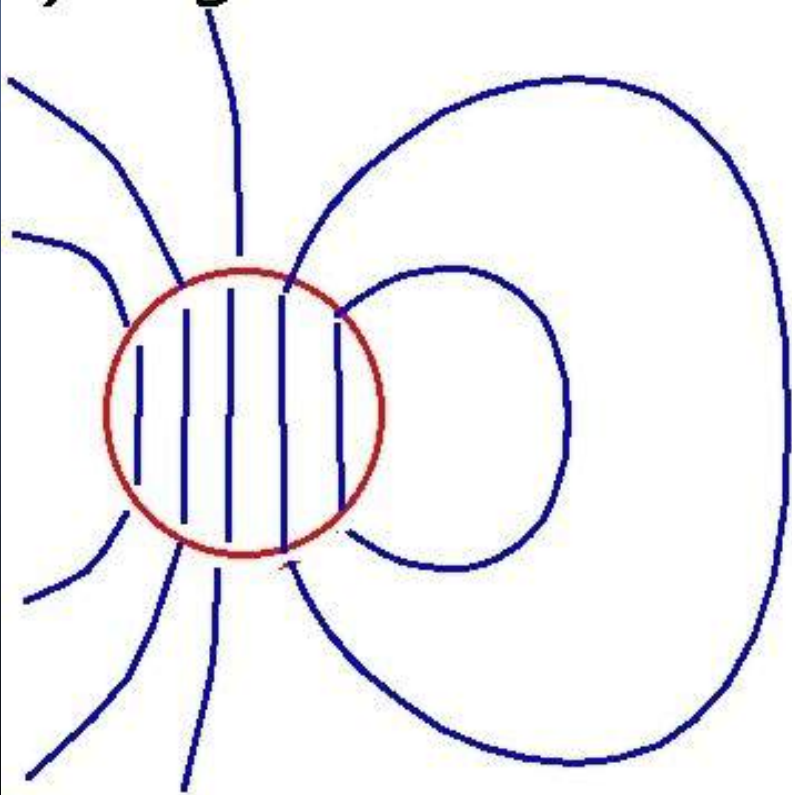
The Crab's older brother 1833 -1024

Gupta,
Green
Mitra,
Acharya
2005



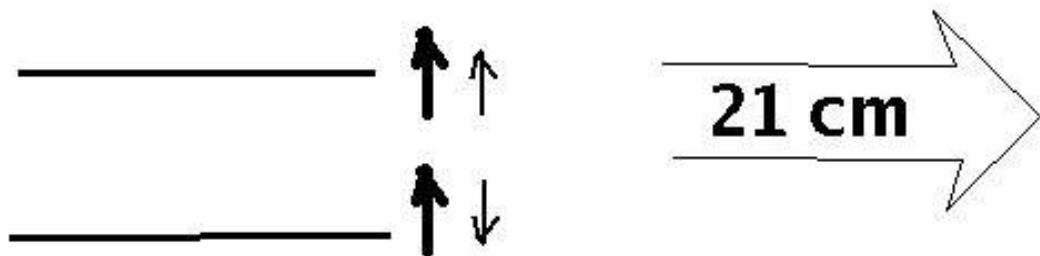
One planned discovery – van de Hulst, Oort, Netherlands, 1940's

The signature of cold, neutral, diffuse, neutral, atomic hydrogen in interstellar and intergalactic space H I

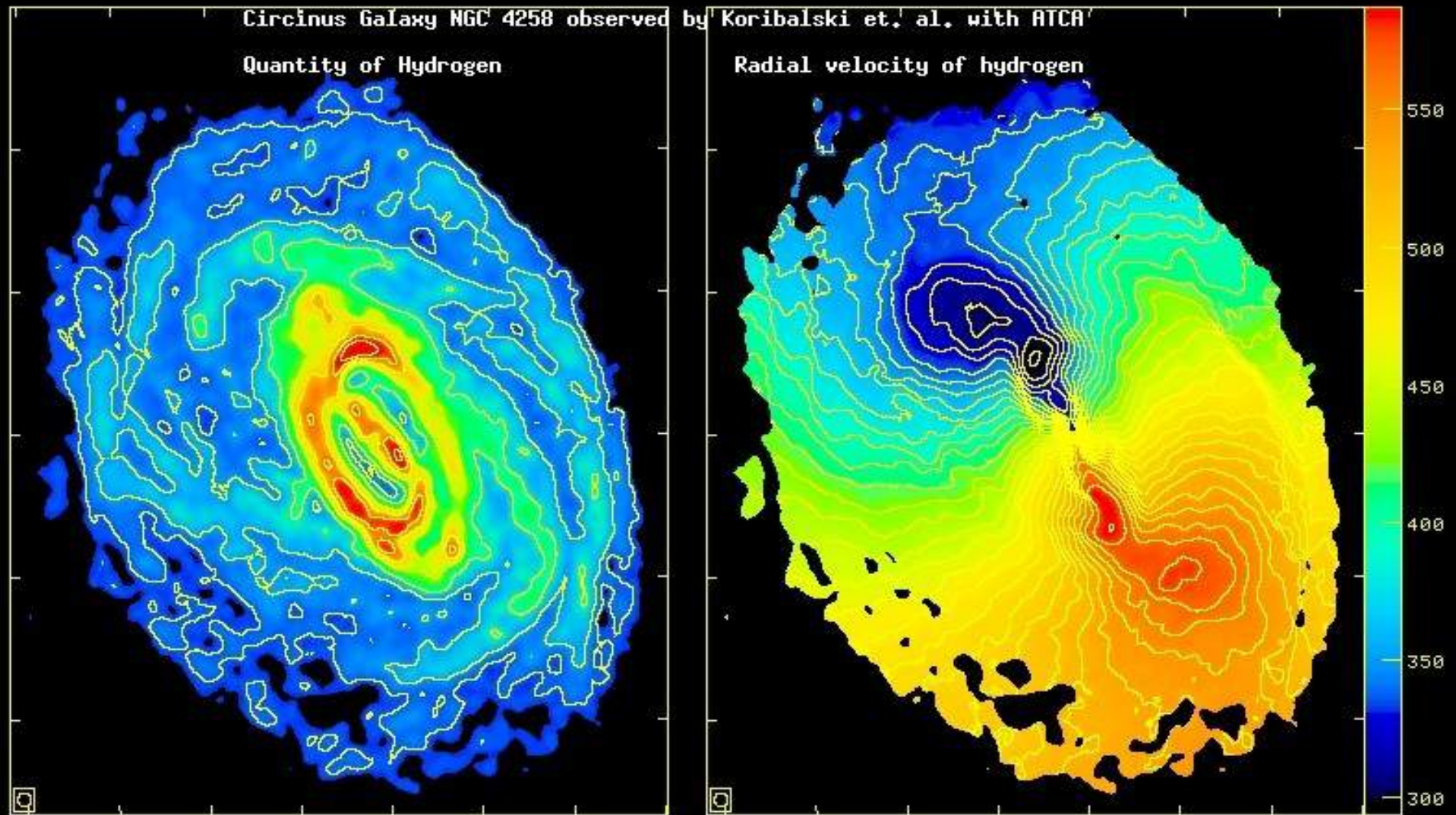


$$\frac{M_{\text{electron}}}{M_{\text{proton}}} \frac{1}{(\text{Bohr radius})^3}$$

~ 1 GHz, 50 mK,
5 micro eV



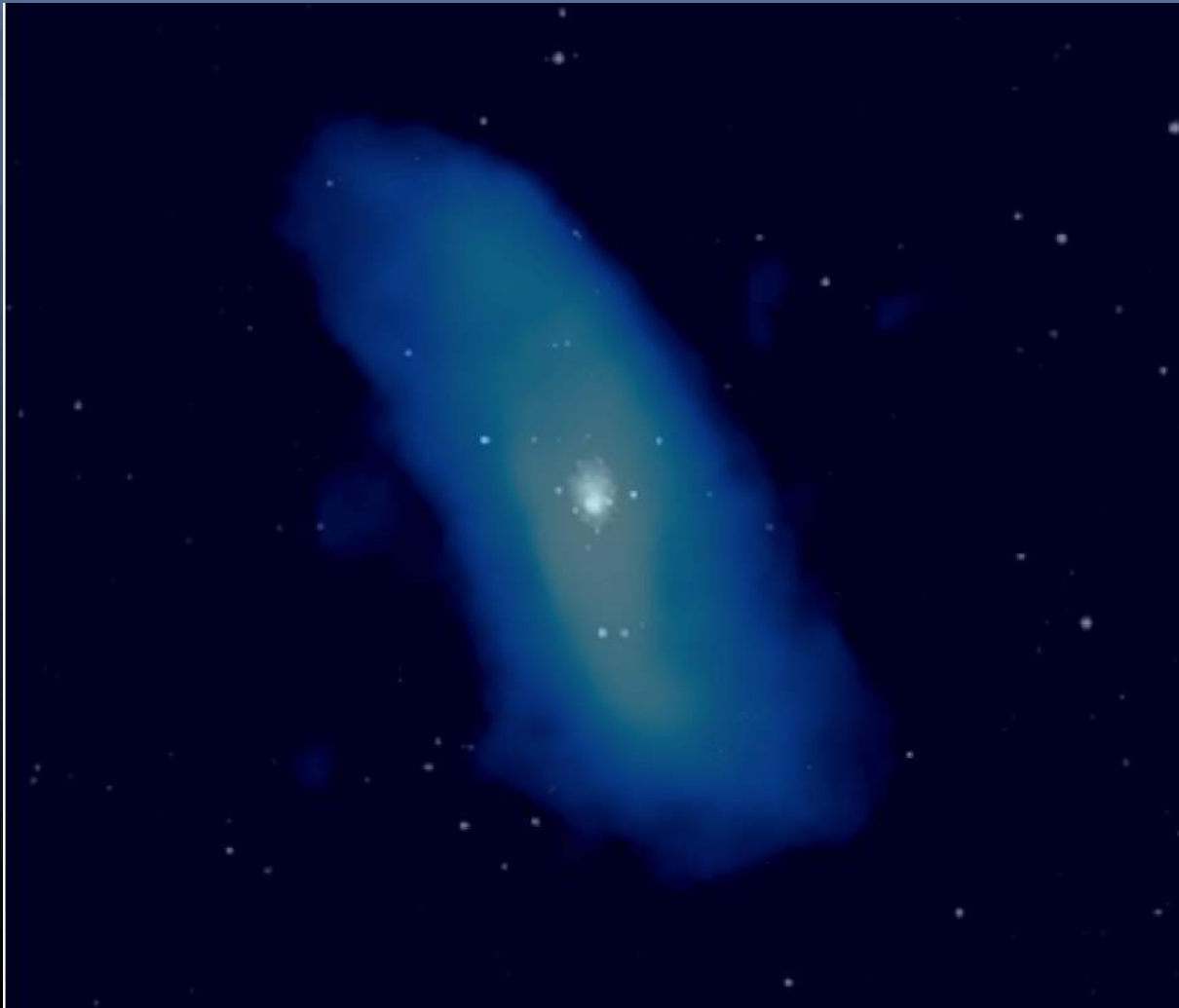
Hydrogen in NGC 4258 -e,n,p are a small minority in galaxies!



NGC 3741: A giant in dwarf's clothing:

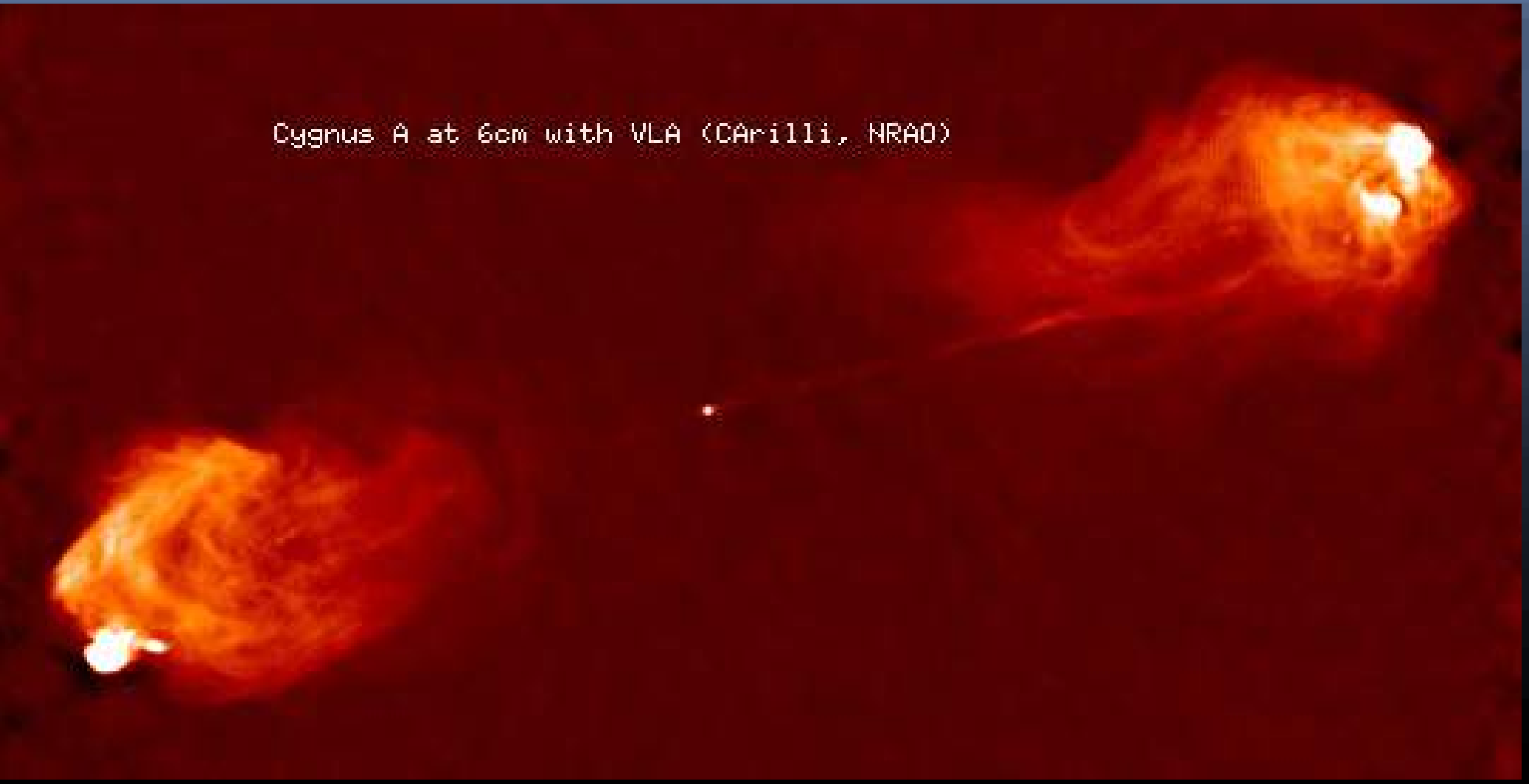
Part of a major survey FIGGS

Ayesha Begum-(Sinha) and Jayaram
Chengalur, 2005



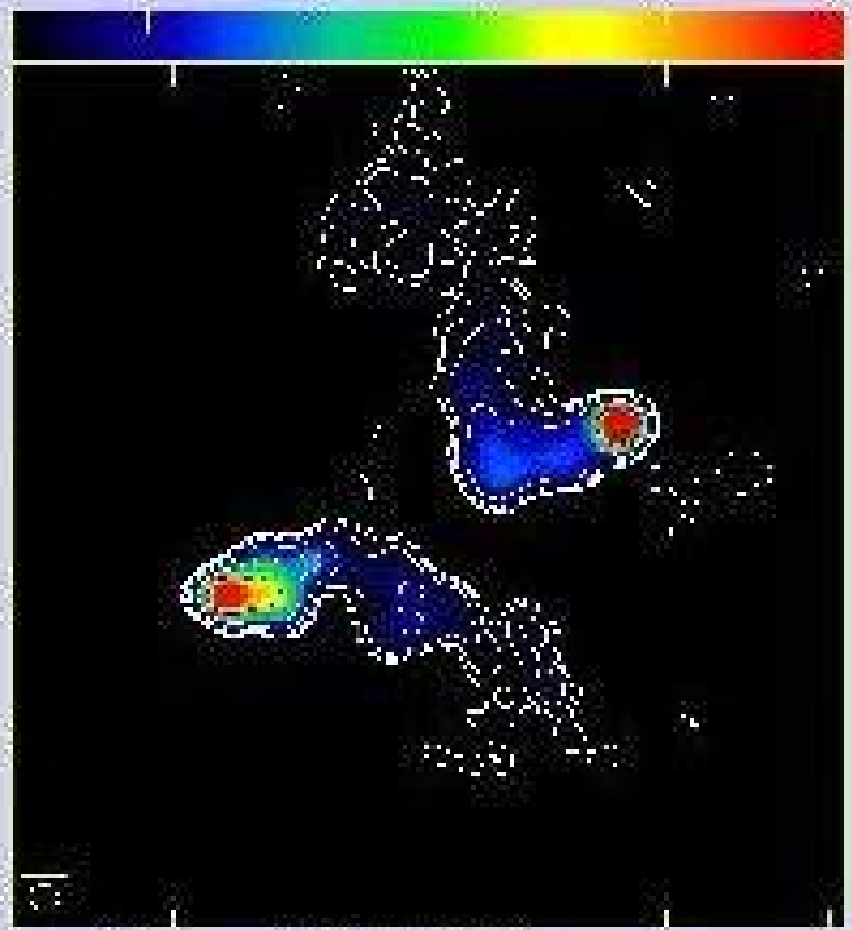
Black holes at the centres of 'active' galaxies: Cygnus A

Cygnus A at 6cm with VLA (CARilli, NRAO)



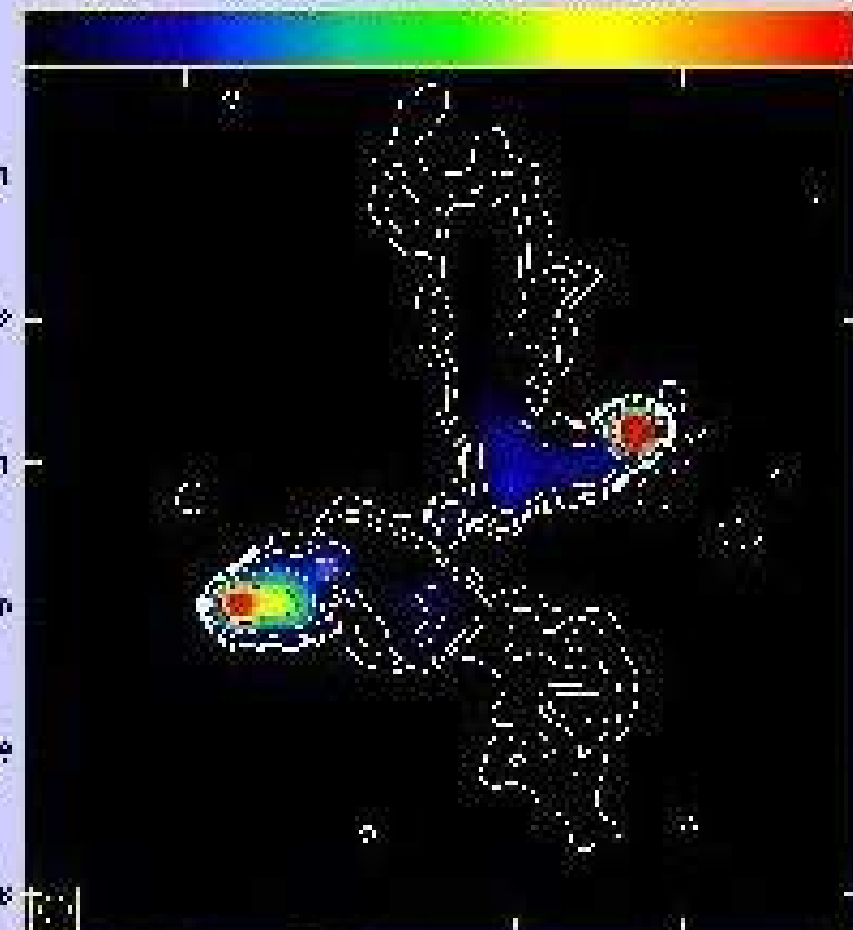
The X-files (Lal and Rao, 2004)

Plot 1: Kaarden 1 results: 7:00PM 2001 10-25-00
 BO: P: 0105F-16 1R21 240 160 140 0105F-16 110 100 100



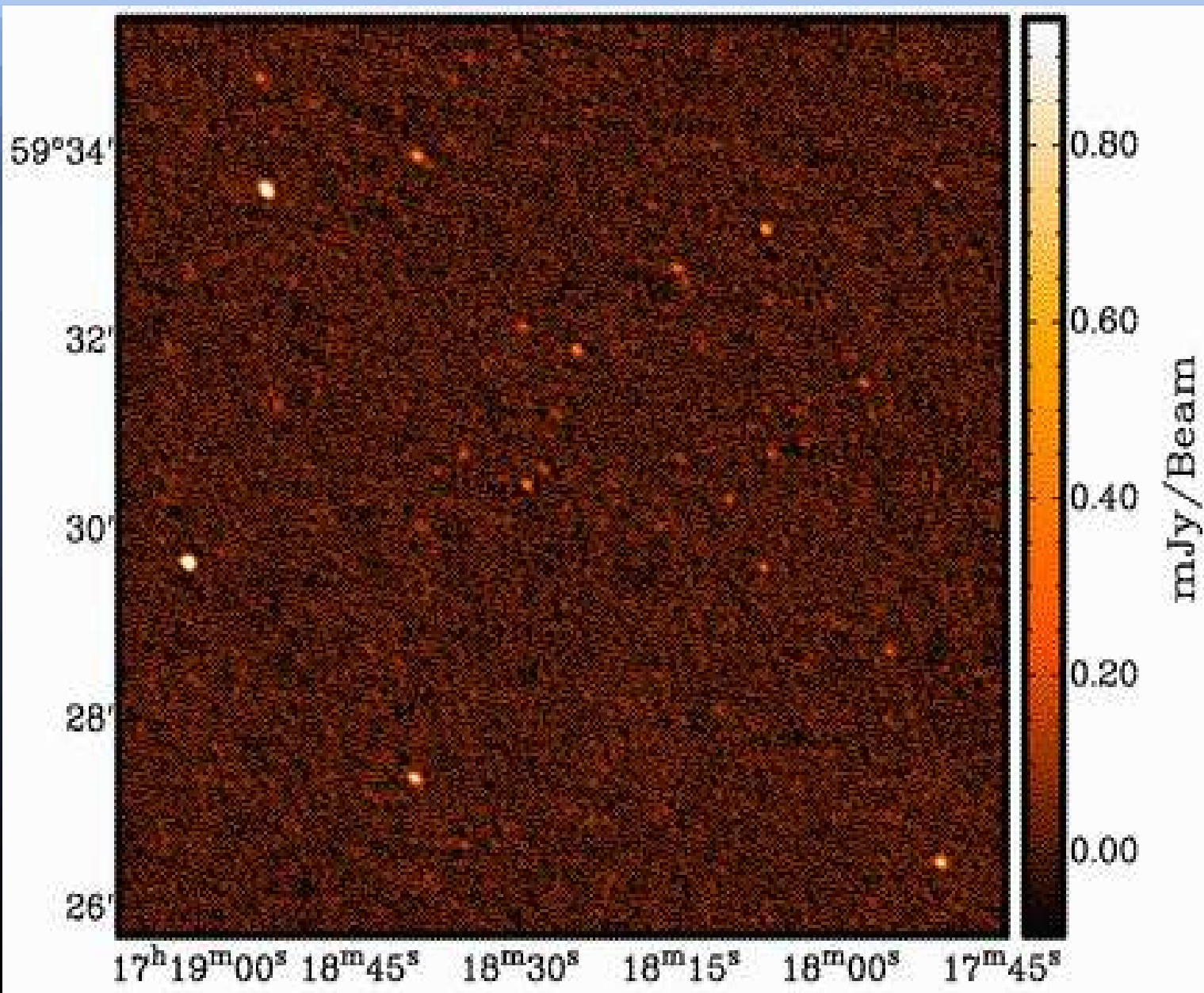
11:55:00 11:55 50 45 40
 RIGHT CHANNEL (10000)
 Gray scale: low range - 5.00 10.00 MHz - 7.00 PM
 Cont. peak: low = 0.00 10.00 MHz
 Filter = 1.00F-16 1R21 240 160 140 0105F-16 110 100 100
 0.400 1, 2, 4, 8, 16, 24, 32, 40, 48, 56

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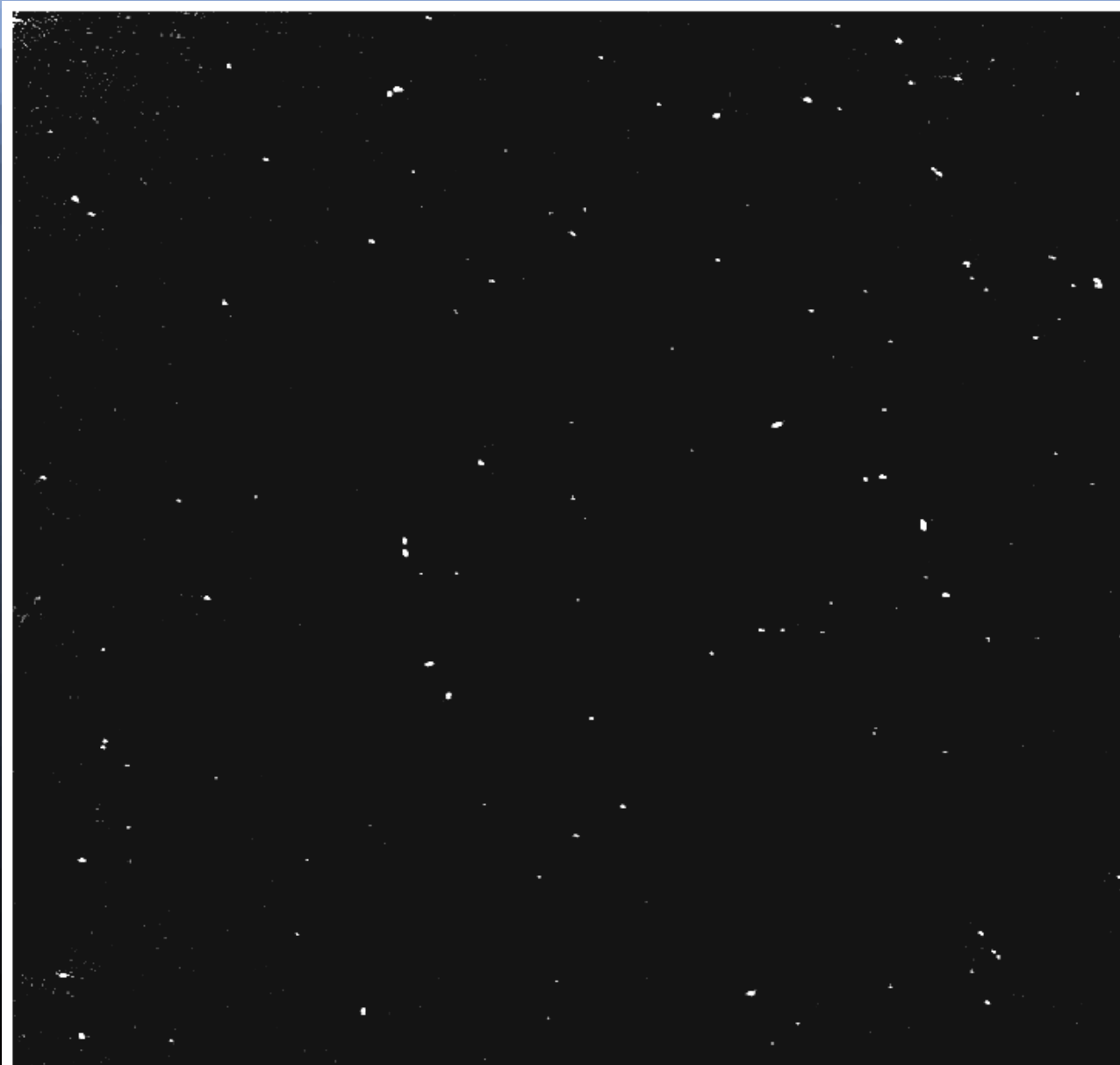
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 Filter = 1.00F-16 1R21 240 160 140 0105F-16 110 100 100
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Deep view at 610 Mhz (Green and Garn)



TGSS -all sky at 150 MHz-

Sirothia, Ishwar-Chandra, Kantharia, Gopal-Krishna



Current new directions in radio telescopes

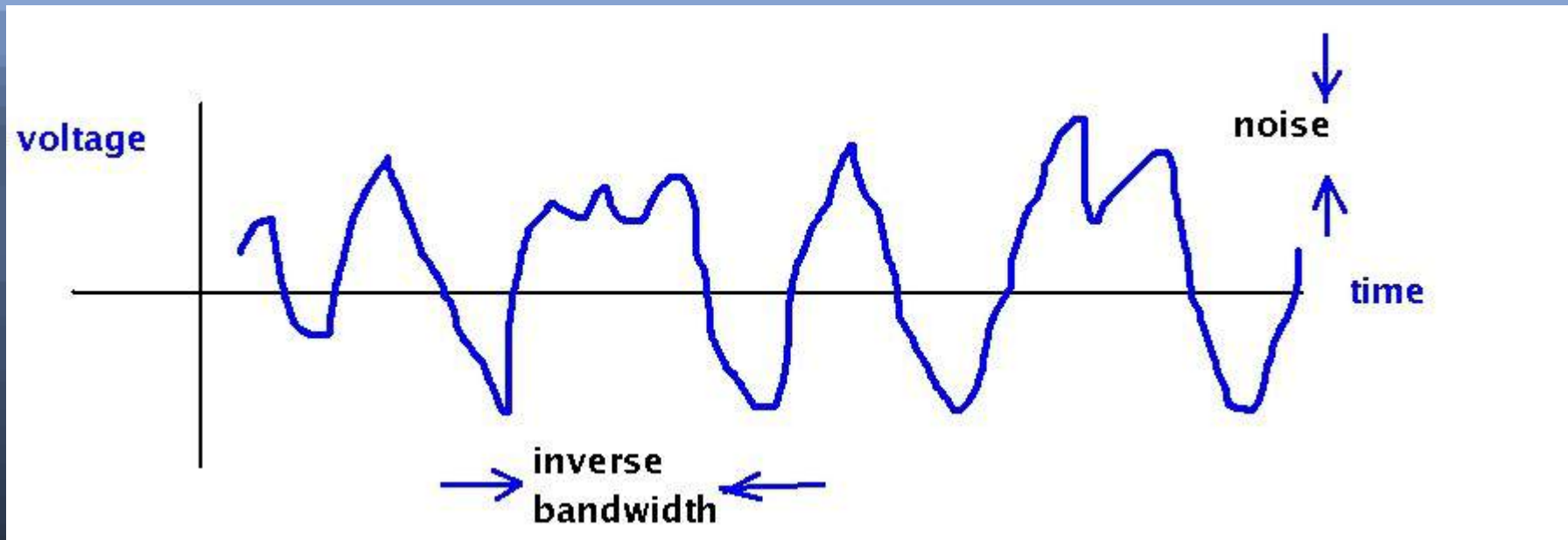
LOFAR in Netherlands: opening up 5 to 1 m

- GMRT upgrade to higher bandwidth and coverage of frequencies, in 0.2-2 (even 4) m
- ASKAP, KAT(South Africa) (0.5m-0.1m), large N small D
- e-VLA – very significant upgrade of a very successful cm wave telescope
- ALMA -millimetre wave radio astronomy – the study of molecules, hot ionised gas, and dust at far higher sensitivity and resolution than currently. Exploration of star and planet formation

The Square Kilometre Array -LHC of Radio astronomy

- International, 2 billion plus cost, 2015-2020
- two orders of magnitude hike in sensitivity
- Quiet southern sites, North Cape and Western Australia
- Significant low frequency component, to look at hydrogen atoms in the pregalactic and prestellar era
- Ultra high technology at ultra low cost - how?
- Challenges: mechanical, EM, fibre, digital hardware, software, data storage/retrival, use

The mathematical theory of communication



The signal to noise ratio is like the size of the alphabet and the Bt product is like the number of letters in the message

Shannon's way: increase bandwidth

- No uncertainty, no choice, no information
- the bit is the natural unit of information transmission, i.e. \log_2 of no. of possible messages
- there are 26^4 entries in a dictionary of four letter words, all the way from AAAA to ZZZZ
- The capacity formula looks like $(\text{Bandwidth}) \cdot \log_2(1 + \text{Signal to noise ratio})$
- Bad news for radio astronomy – e.g. CDMA