Exploring some Limitations in Amateur Radio Astronomy

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Contents

- Antennas & Receiver properties
- Radio source strength & spectra
- **Limitations with small antennas**

Telescope Characteristics

- **Antenna properties**

Antenna Fundamentals

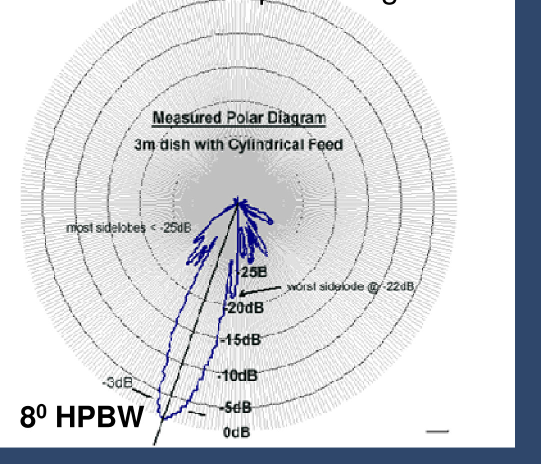
- Two fundamental properties of an antenna of concern to amateur radio astronomers
  - Gain
  - Beamwidth

- These are related – the higher the gain the smaller the beamwidth

- We want both high gain and narrow beamwidth
  - Gain = sensitivity
  - Beamwidth = spatial selectivity

Need Large antenna aperture

A 3m dia. dish polar diagram



Antenna Equations

- **Antenna Gain**

  - $G = \eta \, (4 \pi / \lambda^2) \, A$

η= Aperture efficiency

A= Antenna aperture m^2

λ = wavelength

For a reflector antenna, the area is simply the projected area.
For a circular reflector of diameter D, the area is $A = \pi D^2/4$ and the gain is

$$G = \eta \, (\pi \mathbf{D} / \lambda)^2$$

- **Antenna Beamwidth**

$$\text{HPBW} = \alpha = \kappa \lambda / D$$

κ= a factor that depends on the shape of the reflector and the method of illumination

For a typical antenna

$$G = 27{,}000/ (\alpha)^2$$

<u>Antenna diameter drives performance</u>

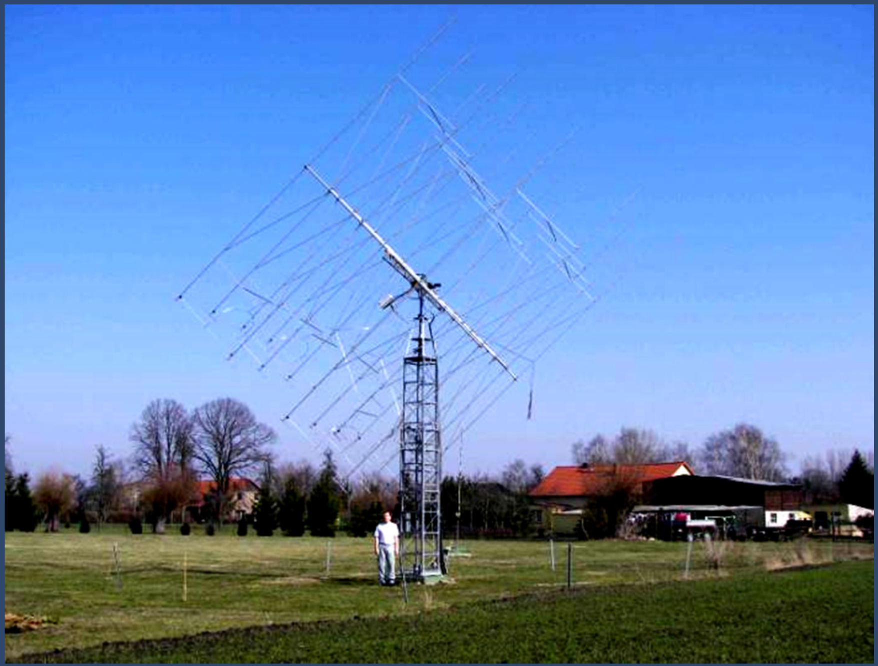
At UHF things get big

- Rare to find an amateur with a 9m antenna

John Smith (1924 -1998) with 9m dish

Yagis vs Dishes

- Would not tend to use a small dish at UHF
- Yagi arrays probably cheaper and easier to build
- But – effective aperture must be similar to dish area
- So arrays will be a few metres square
- Complicated to construct and phase together



DL7APV Array (used for EME)

Part of my 408MHz Quagi Array

Consequences

- Can have high sensitivity and good spatial resolution at 11GHz with1m antenna
  - ~40dB gain and few degrees HPBW
- Reasonable gain and resolution with 2.4m dish at C band
  - ~ 35dB gain and <5 degrees HPBW
- Workable sensitivity and resolution with 3m dish at 1.4GHz
  - eg 30dB gain and >5 degrees HPBW
- But low gain and poor spatial resolution with 3m dish at 408MHz
  - eg 19dB gain and 18 degrees HPBW
- Impractical at VHF (space & cost)

Result of Antenna limitations

L band is probably most practical, useful and affordable option for amateurs

(L Band (IEEE) = 1-2GHz)

Noise and Gain Stability

Receiver Requirements

- Band coverage
- Available bandwidths
- Detector functions
- Sensitivity
- Noise & gain stability

- Discuss the last two items

LNAs and Receivers

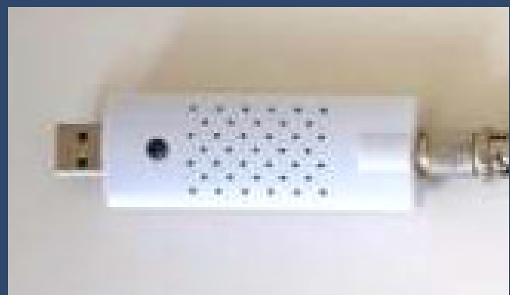
- **Receiver must have high gain and low noise**

- **System Noise figure (N_F) determined by first amplifier**
- **Low Noise Amplifiers (LNA) now capable of 0.2dB at 1.4GHz**

- **Conventional Coms receiver or SDR sensitivities are adequate when used with LNA (gains of 20 – 40dB)**

- **Noise & gain stability are crucial:**
  - **Maintain common parameters from hour to hour and day to day – to enable radio maps etc to be made.**

ICOM IC-R7000 Receiver

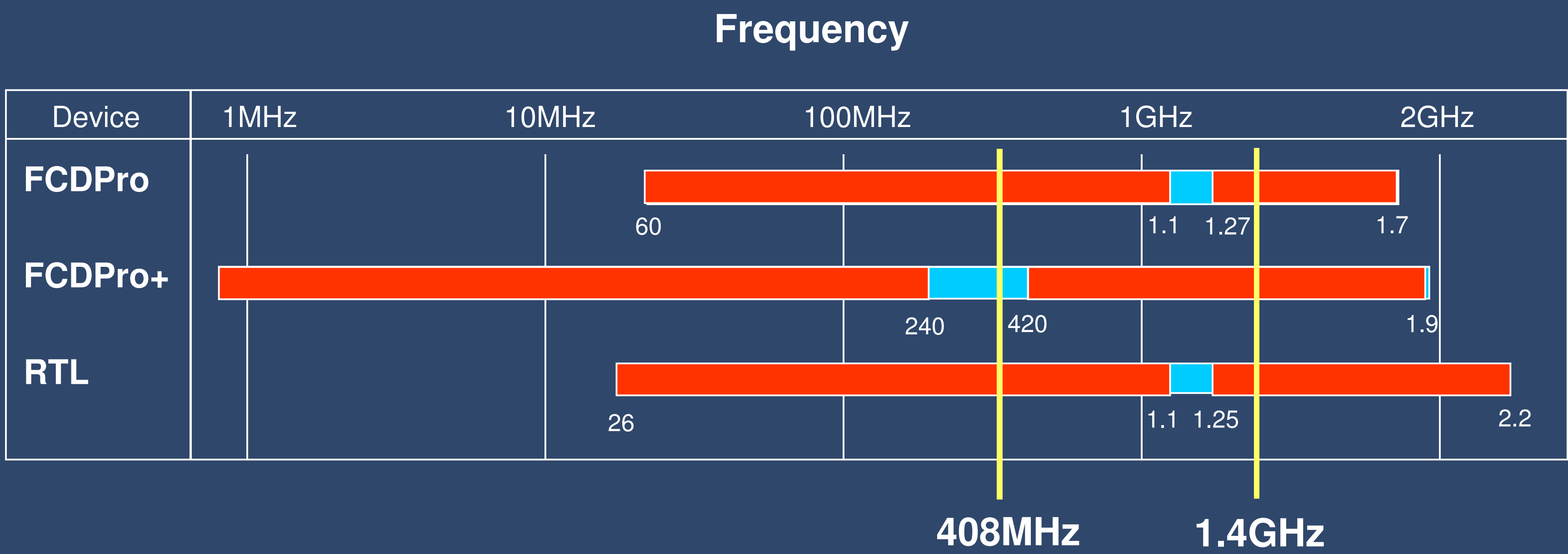


Realtek RTL2832U DVB-TV dongle

FunCube Dongle SDR

SDR Dongle Receivers

- **The common SDR Dongles have gaps in frequency coverage**

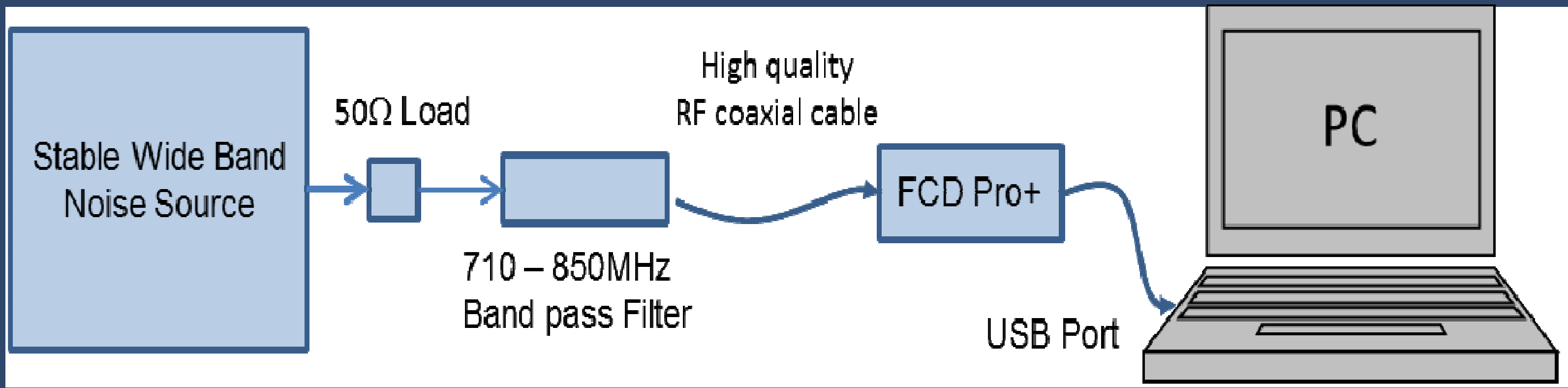


Frequency Coverage for FCD & RTL Dongle Devices

Coverage Gaps

Noise /Gain Stability

- **FunCube Dongle Pro + :**
- **Stability is better than 0.05dB over 3 hours**



- **Cheap stable SDR receivers widely available**
- **No important receiver limitations**

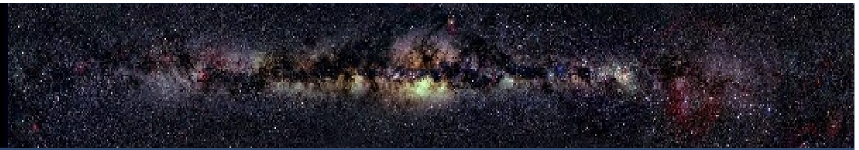
- **Astronomical Radio Sources**

- **What sources are in the Northern Hemisphere ?**
- **How strong are they ? – are they detectable by Amateurs ?**
- **What spectrum do they have ?**
- **Are they discrete or spatially distributed ?**

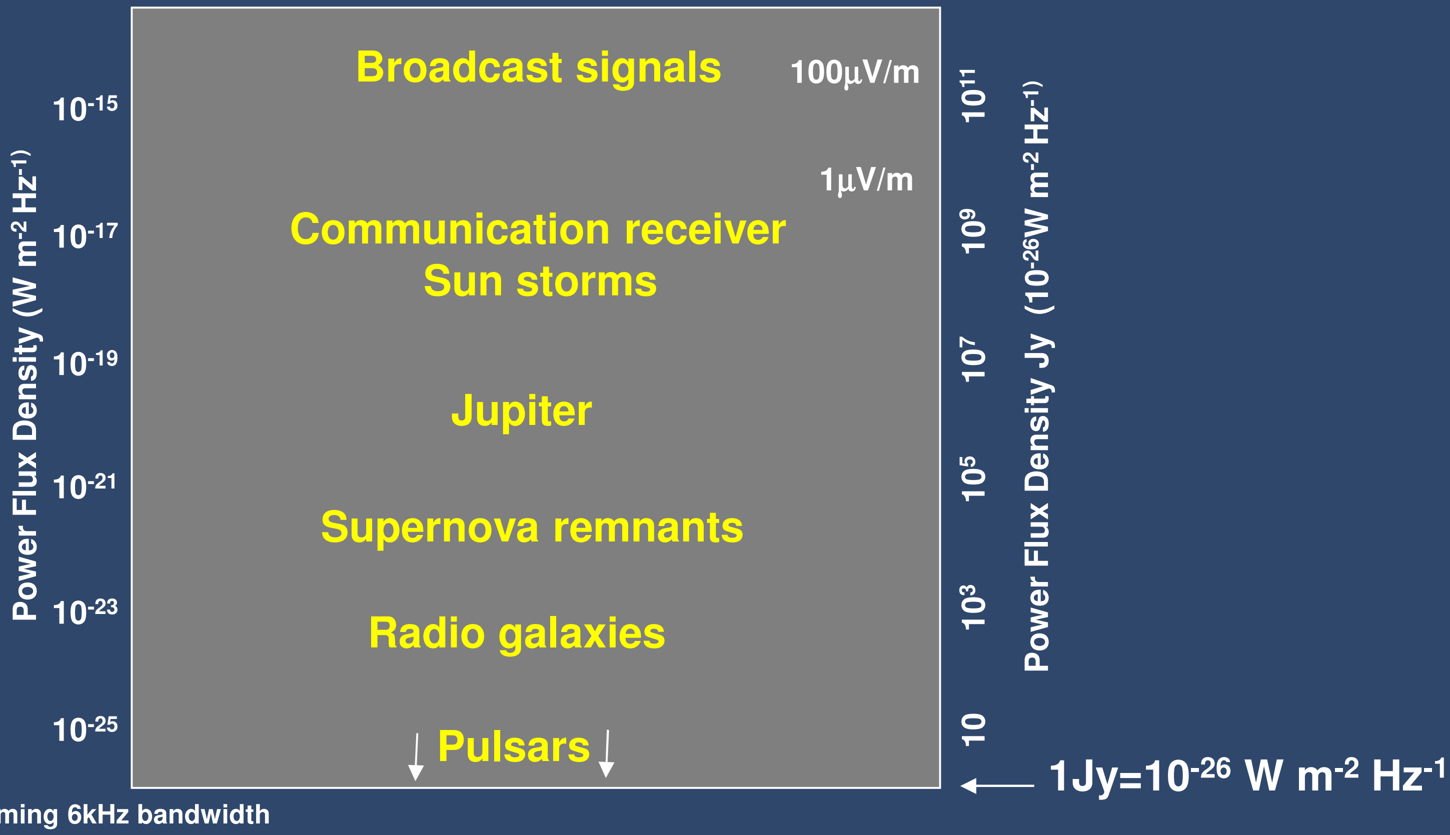
Key parameters

Source Flux **Spectrum** **Angular Size**

Source Signal Strengths

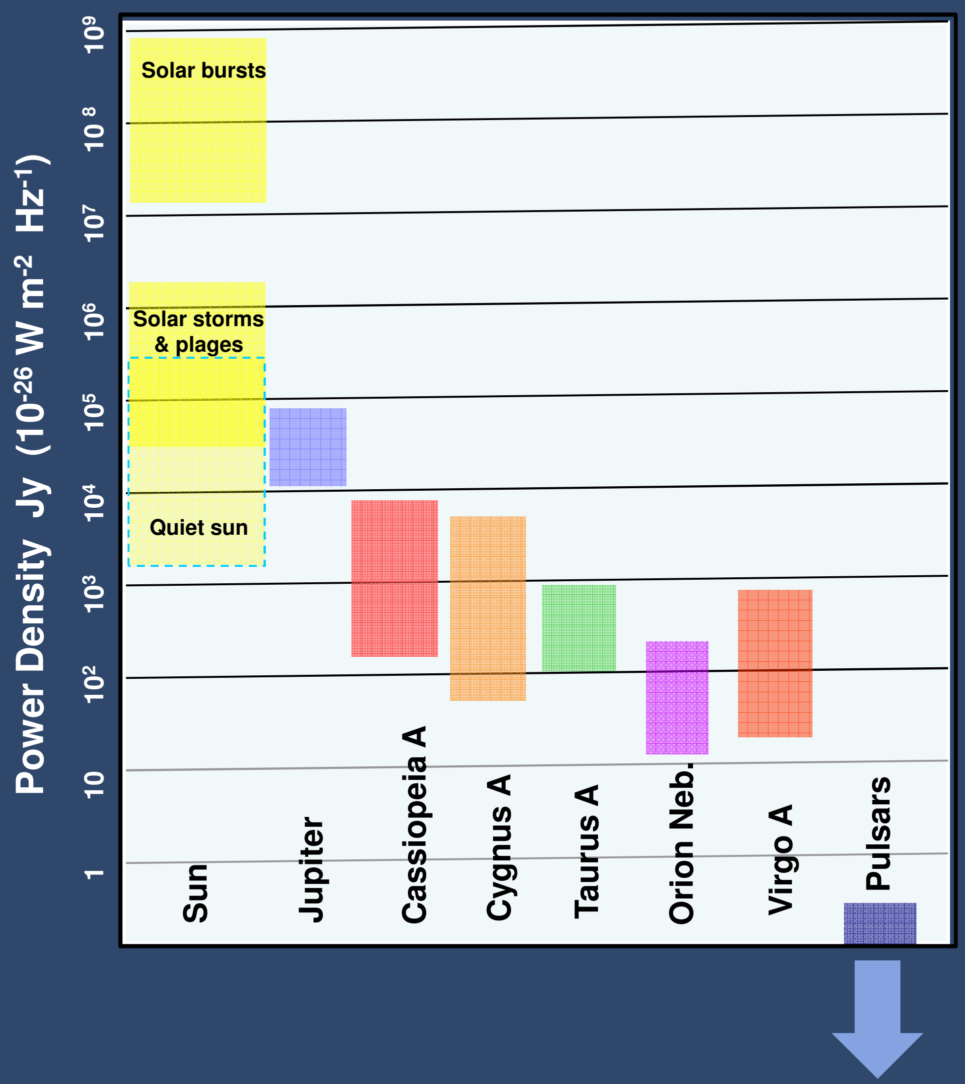


- **Look at typical source signal strength**



Radio Sources – signal strengths

- **In more detail**

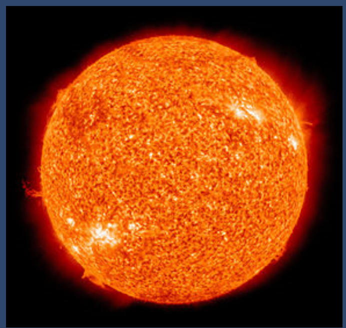


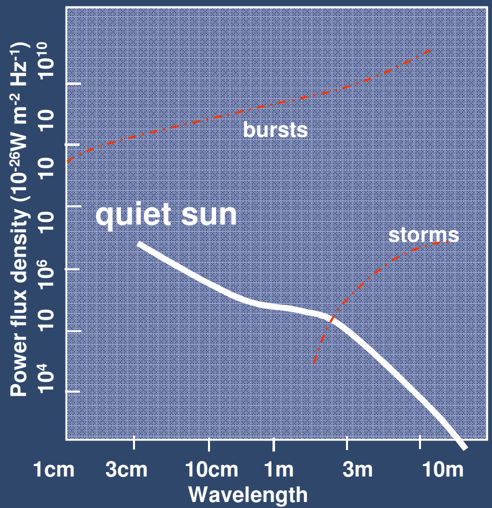
These are 'continuous' sources – not dealing with radio transients

Source Spectrum drives receiver frequency

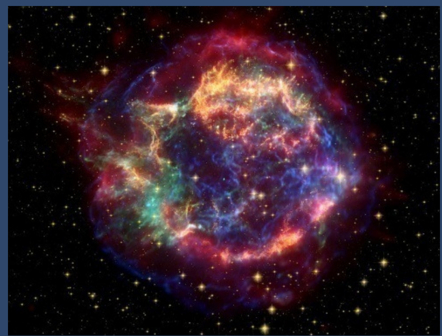
- Each source has its own predominant radiation mechanism
- This determines the emission spectrum
- The source spectrum drives the telescope configuration
  - eg Frequency of operation, Gain & Antenna size

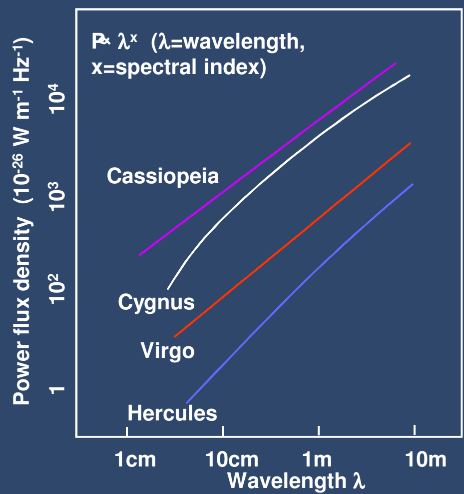
SUN : Thermal Source



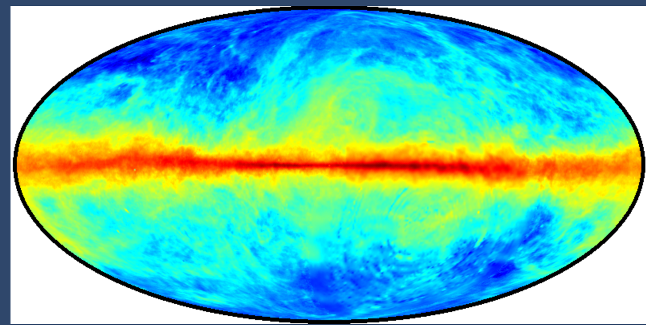


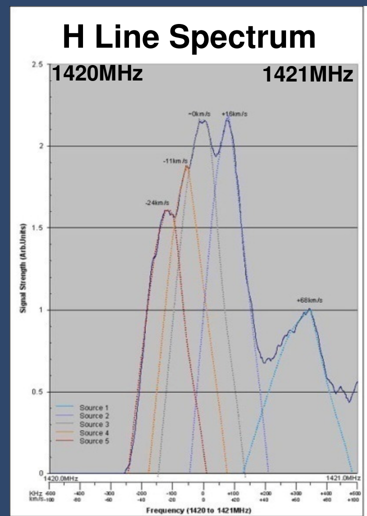
SNR : Synchrotron Source



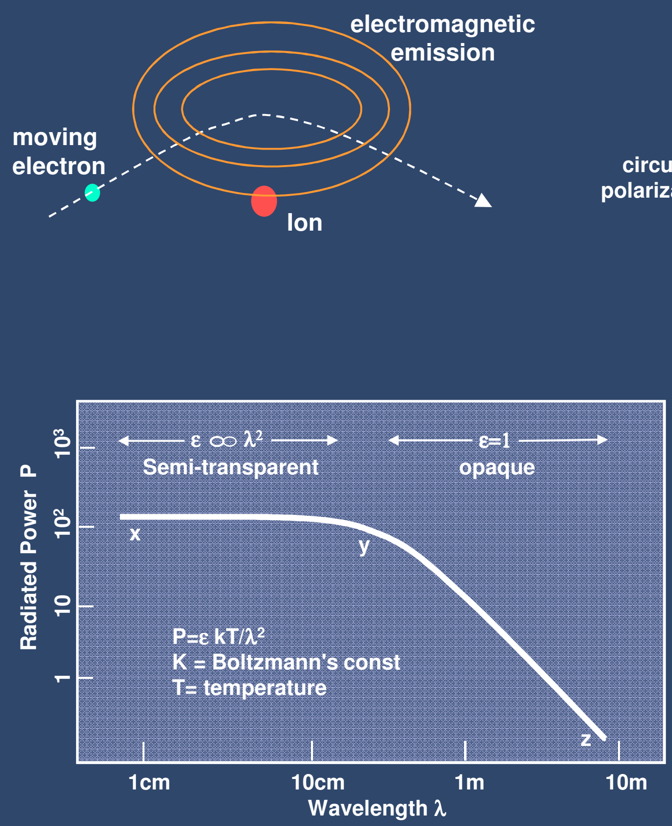


Galactic Hydrogen : Line Source

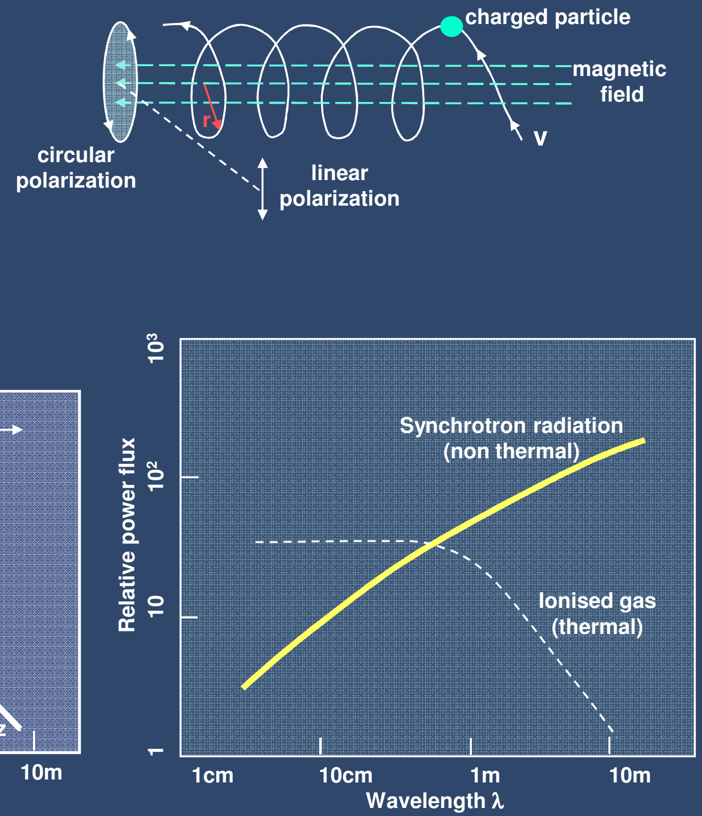




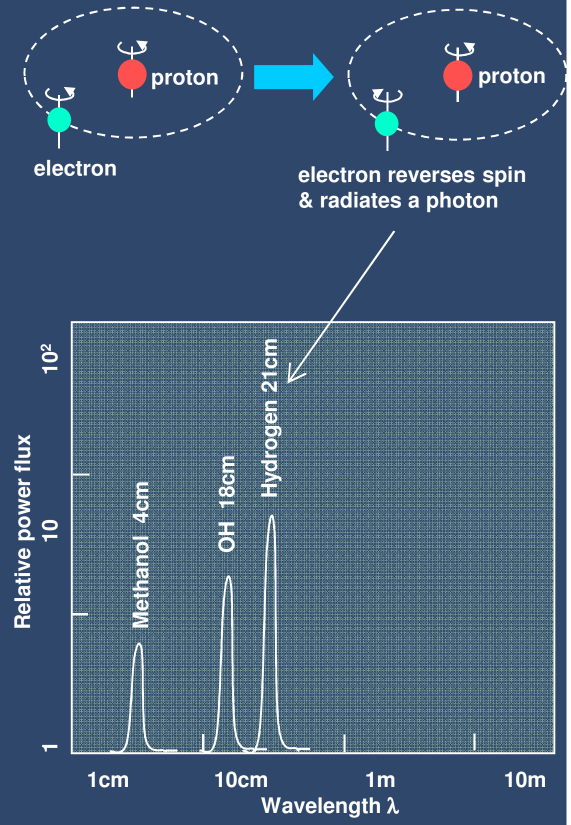
- **Source Spectra : Three mechanisms – Three spectra**



Thermal Spectrum



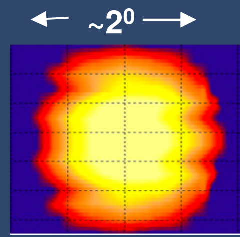
Synchrotron Spectrum



Line spectrum

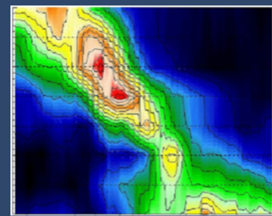
What can amateurs measure? – some examples

- **Use microwave receiver for thermal sources**
  - **Few interesting objects to detect**
  - **Small objects < 0.5^0 diameter - eg SUN & Moon**
  - **Measurements will be HPBW limited ($\sim 2^0$)**



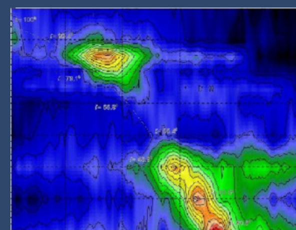
11GHz image of SUN

- **Using L band for H line**
  - **Measuring Doppler shifts & mapping galaxy**
  - **Reasonable spatial resolution achievable**



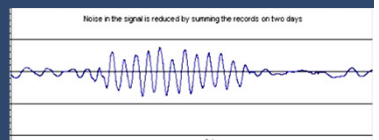
Galactic H line

- **Use L Band for Synchrotron emission**
  - **Galactic emission can be mapped**
  - **Reasonable spatial resolution achievable**
  - **SNRs are discrete sources – smeared out by large HPBW**
  - **This makes SNRs difficult to detect**



Galactic Synchrotron

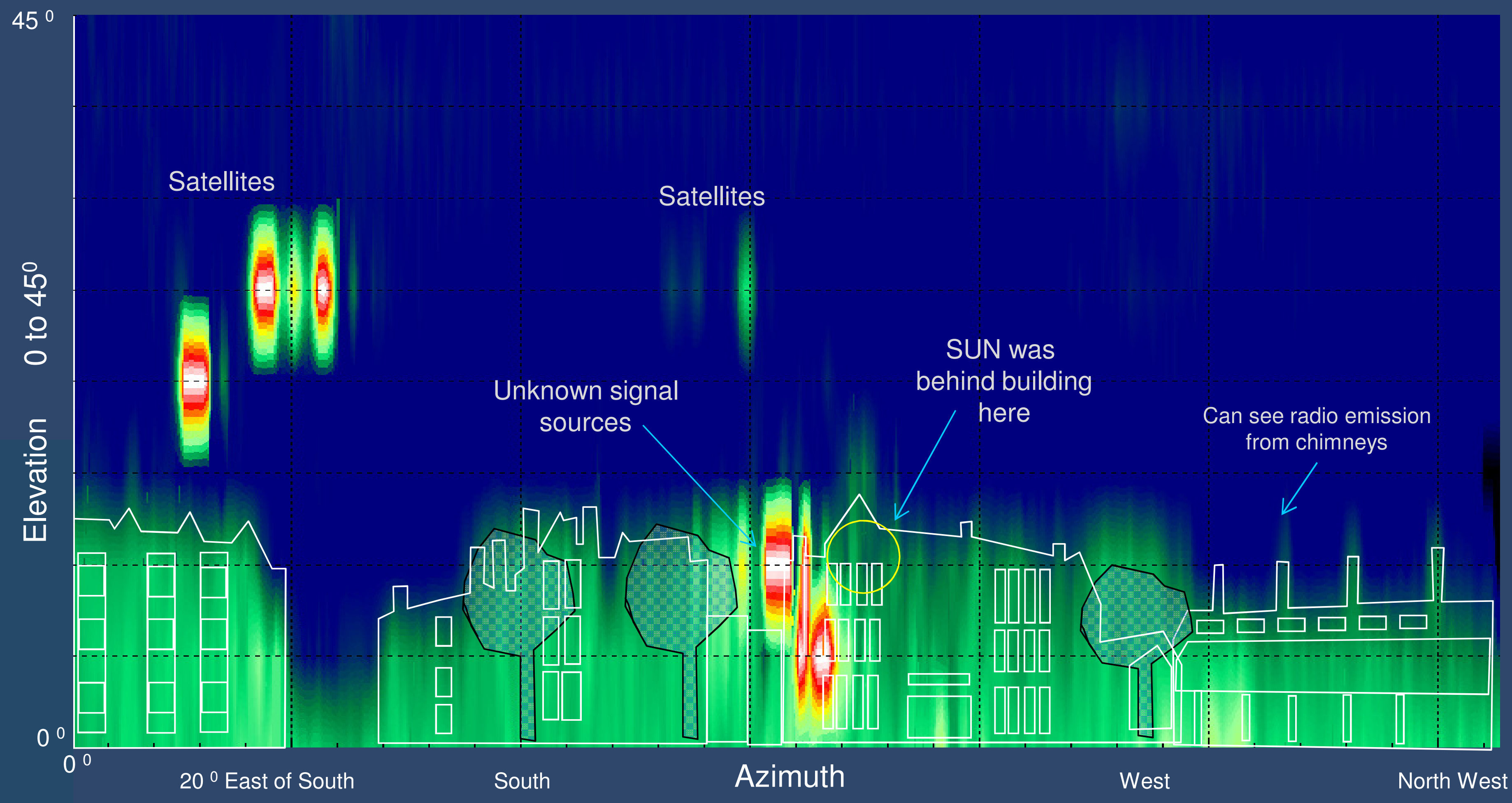
- **Try using UHF for Synchrotron emissions**
  - **Higher signal but worse antenna gain – no improvement**
  - **HPBW rather poor – limited spatial resolution**



Extra galactic interferometry

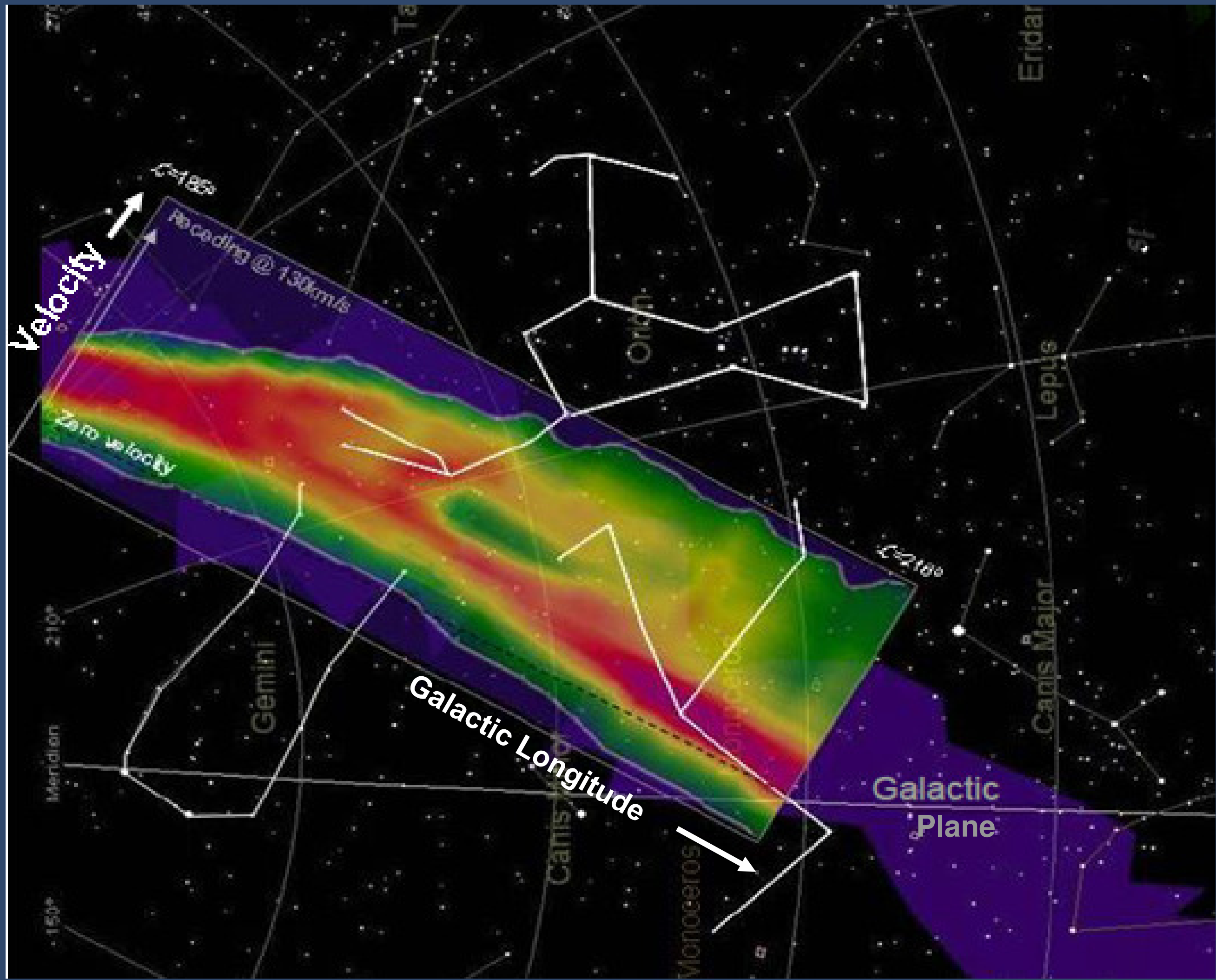
11 GHz Radiometer image

- **School Radiometer project – show some principles of Radio Astronomy**



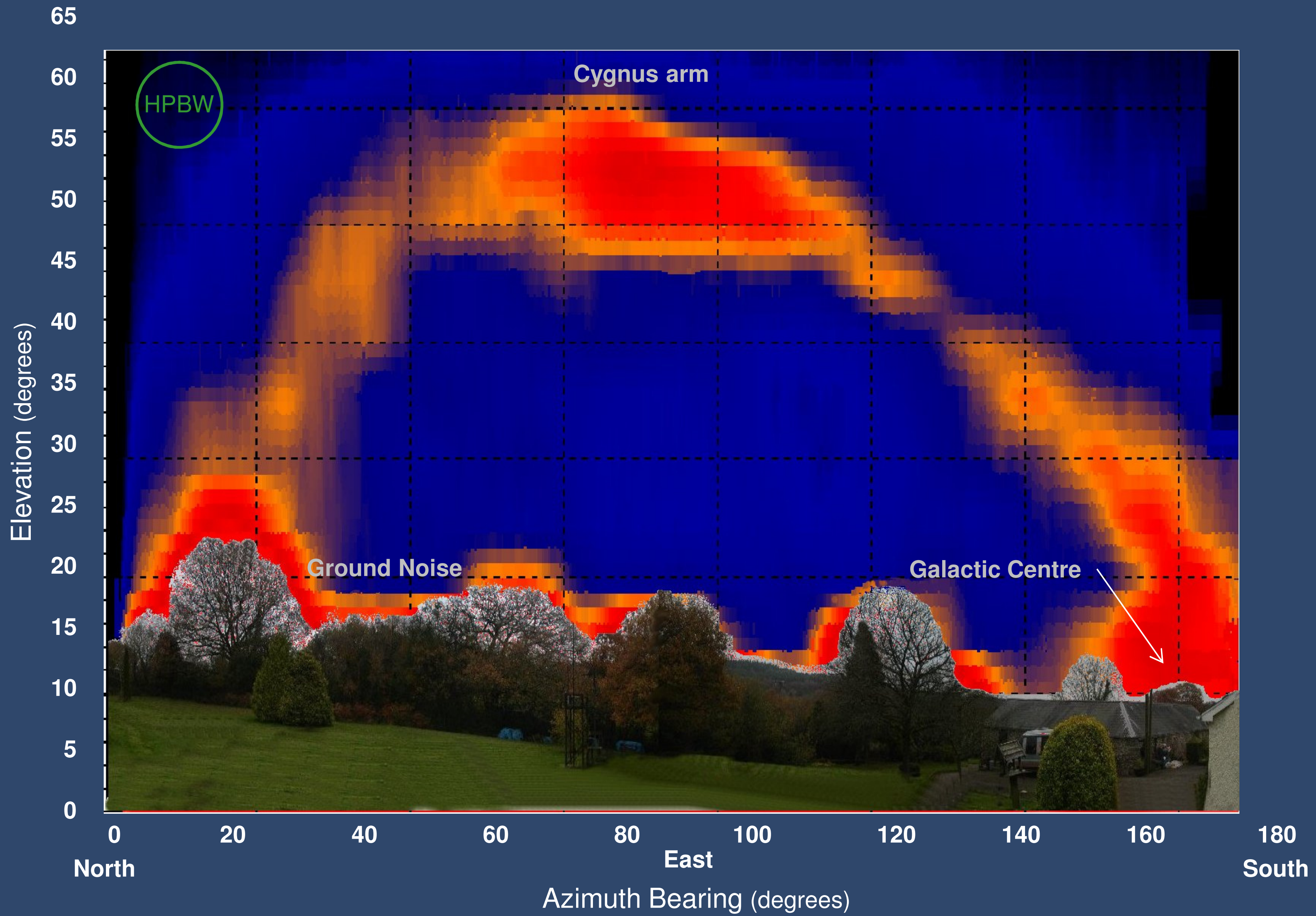
Hydrogen Line Velocity Distribution

- **As amateurs we can measure the intensity, spatial distribution and velocities of Hydrogen in the galactic plane.**

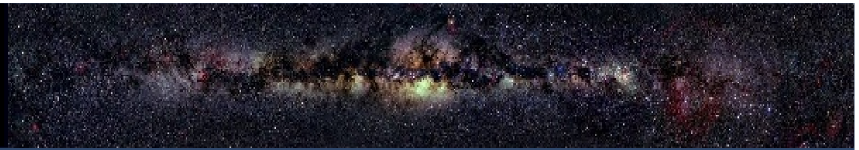


1420.4MHz Image of Milky Way

13.08 GMT 28/11/2013



What is difficult for amateurs?



- **Difficult to detect discrete sources at UHF / VHF**
  - **We are limited by using small antennas**
  - **Only moderate gain**
  - **Relatively wide beamwidths**
  - **Discrete sources << beamwidth**
  - **Leads to source intensity loss & spatial smearing**

- **How significant is the effect for discrete sources ?**

Wide beams & point sources

- **Evaluating loss of signal and point source smearing**
  - **Antenna temperature relationship with source flux density**

$$T_A = \frac{A_e S}{2k}$$

T_A = 'Antenna Temperature' , S = Source flux
A_e = Effective Area , k = 1.38×10^{-23} J K^{-1}
(1^0 K=$1.38_x 10^{-23}$ W Hz^{-1})

$$\Omega_A \equiv \int_{MB} P_n(\theta, \phi) d\Omega$$

Ω_A = Antenna beam solid angle, P_n = polar response

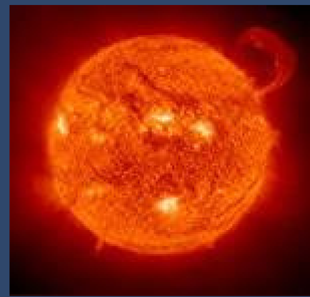
$$T_A \approx T_B \frac{\Omega_S}{\Omega_A}$$

T_B = source brightness Temp, Ω_S = source solid angle

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

Two examples

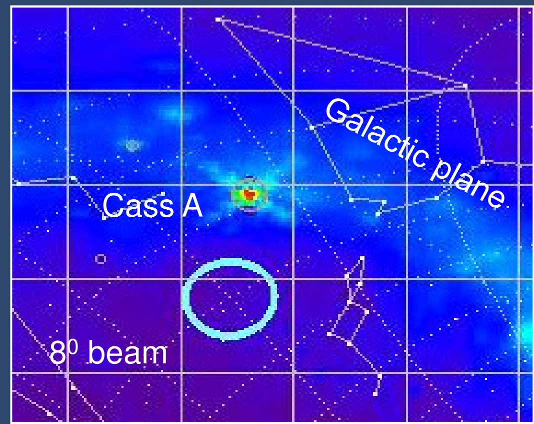
Example: SUN



- For a hot source like the SUN, TB~10^4 K
- Angular diameter = 0.5^0
- With a 5^0 HPBW antenna beam
- Source will only add 100K to the antenna temperature.

Example: Cass A

Using an antenna main beam HPBW = 8^0
Angular diameter = 5 arc min, T_B= 3792^0K
Background galactic plane Temp = 86^0K



Cass A example

- For Cass A set in the galactic plane background

Cass A

→ 5 arc min ←

- Contribution from Cass A $_{Temp}$ = 0.411^0 K
- Background GP temp = 86^0 K
- So Cass A is hardly detectable against 86^0K background with a 'Total Power' system
- Detection of 'point' sources requires very narrow beams

Discrete Source is lost in background

- **Must have a larger antenna with a narrower beam to detect SNRs or extra galactic objects when using a Total Power System**
- **Requires Antenna HPBW of < 1^0 at UHF (Synchrotron Sources)**
- **Better than 20m diameter required.**

Without access to a large antenna the only practical way for amateurs to observe point sources is with Interferometry

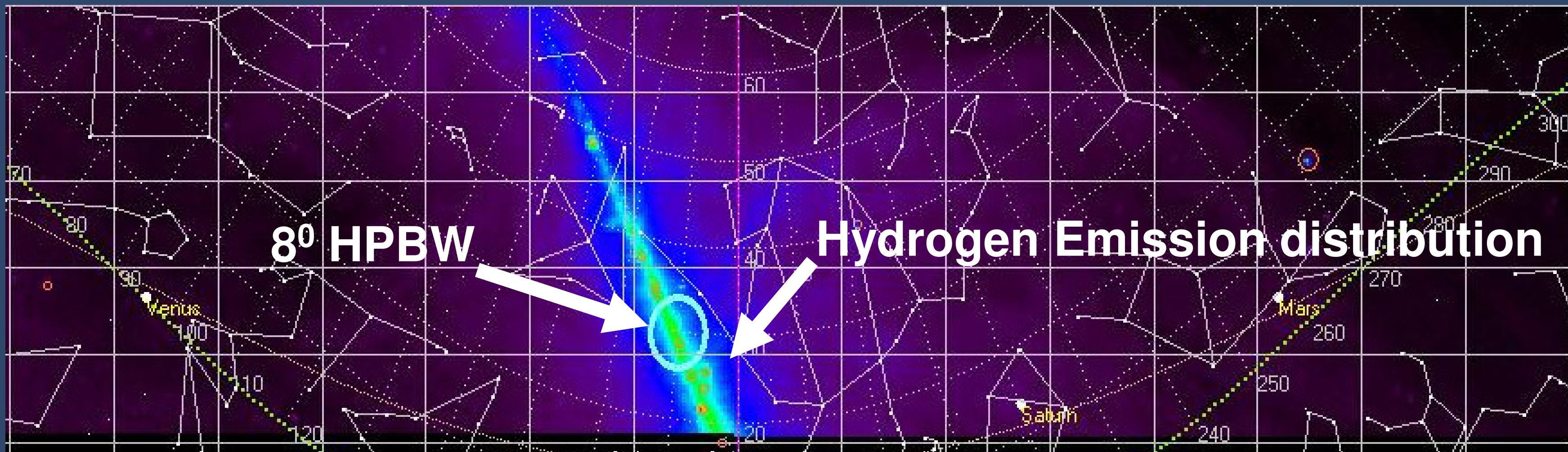
H Line is best target for amateurs

- **This table summarises the issues when restricted to <u>small antennas</u>**

Frequency	Performance	Possible Sources	Remarks
KU Band 11GHz	High gain, narrow beams ($<2^{0}$)	Few of interest (thermal only)	'High performance' system but little of interest to detect
C Band 4 GHz	Medium gain, reasonable beam	As above	No 'available' sources
L Band 1.4 -1.6GHz	Satisfactory gain, rather wide beam (5^{0} -8^{0})	Galactic H Line	Low spatial resolution but OK for Galactic Hydrogen work
UHF 408MHz	Low gain, poor beamwidth	Many synchrotron SNRs, galaxies etc	Many sources, but poor sensitivity and resolution
VHF 150MHz	Need very large antenna	Many SNRs and Pulsars	Not really practical for amateurs

Hydrogen Line measurements

- So as amateurs with modest antennas we can do a good job of measuring H Line emission - as Galactic features fill the beam
- ($T_A = T_B$) with only a little spatial smearing



Big Aspirations ?

- Where does this leave UK amateur radio astronomers?
  - Each of us is working with small antennas
- >10m dia antenna too expensive for an individual

- Clubs or groups unlikely to have funds, commitment & discipline to collaborate on large scale project

- However – it has been done !
  - Dwingeloo telescope in Holland
  - Stockert telescope in Germany
  - Now in service for Amateur Radio Astronomers & EME

Dwingeloo

Stockert

- What are the chances of a similar UK project ?
- What a challenge that would be ……..

Possible amateur radio astronomy at Goonhilly (Cornwall)

- **Two large dishes at Goonhilly will soon be used for professional Radio Astronomy – amateurs may be able to play a part ??**

Goonhilly 1 (L band)

Goonhilly 3 (C band)

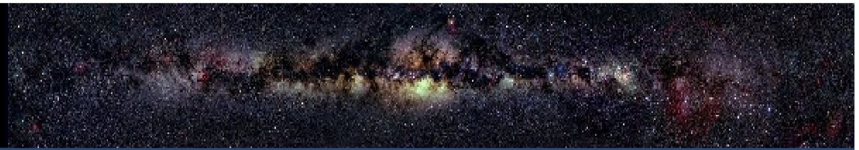
Getting Involved at Goonhilly

Would you like to consider participating in Amateur Radio Astronomy at Goonhilly ?

Put your contact details in the book

Thank You

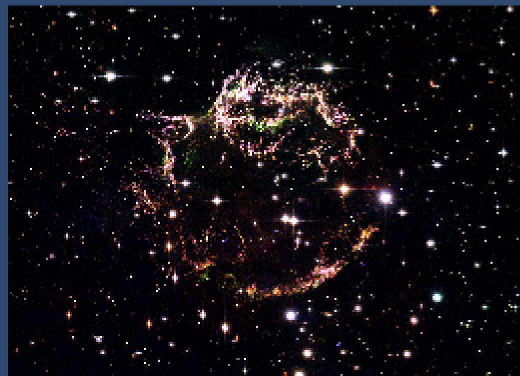
Cass A example



- **For Cass A set in the galactic plane background**
- **Discrete source lost in the background with an 8^0 beam**

$$\text{Cass A}_{Temp} = \underset{T_{CassA}}{3792} \times \underset{\Omega_A}{0.0153} / \underset{\Omega_S}{0.00000166}$$

Cass A



5 arc min

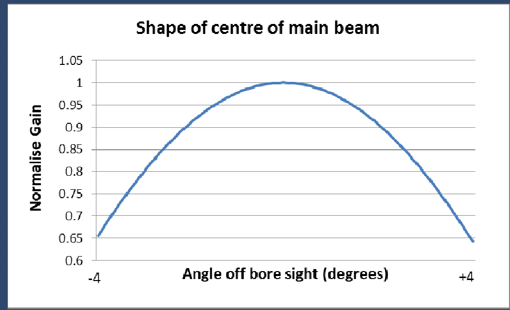
- **Cass A $_{Temp}$ = 0.411^0 K**
- **Background GP temp = 86^0 K**
- **So Cass A is hardly detectable against 86^0K background with a 'Total Power' system**
- **Detection of 'point' sources requires very narrow beams**

Look at a simple spreadsheet model of the situation

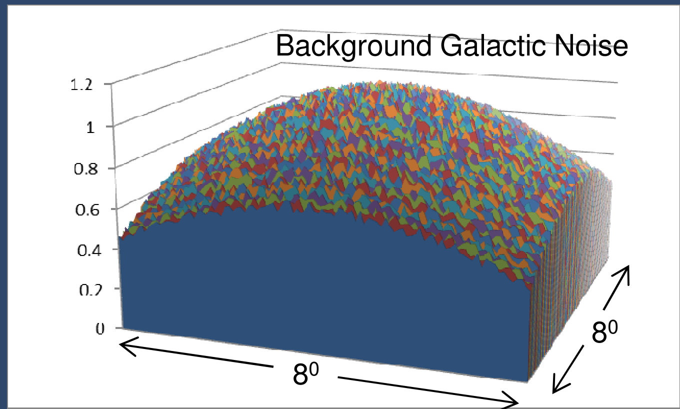
Simple spread sheet model

- **Use Excel to model point source in a wide beam**

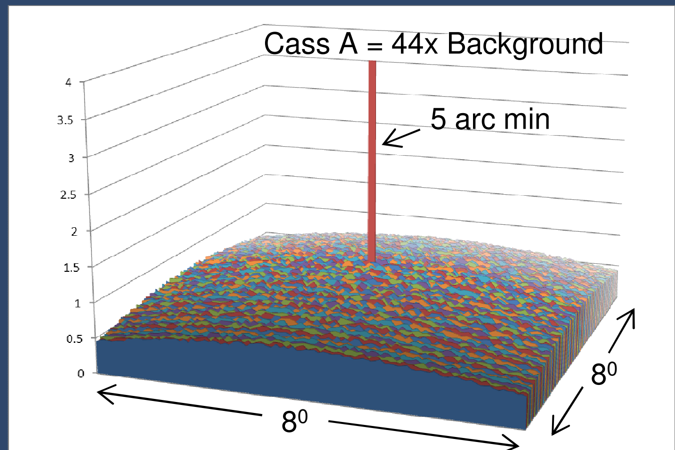
Create a beam profile



Generate a 'slightly noisy' background level



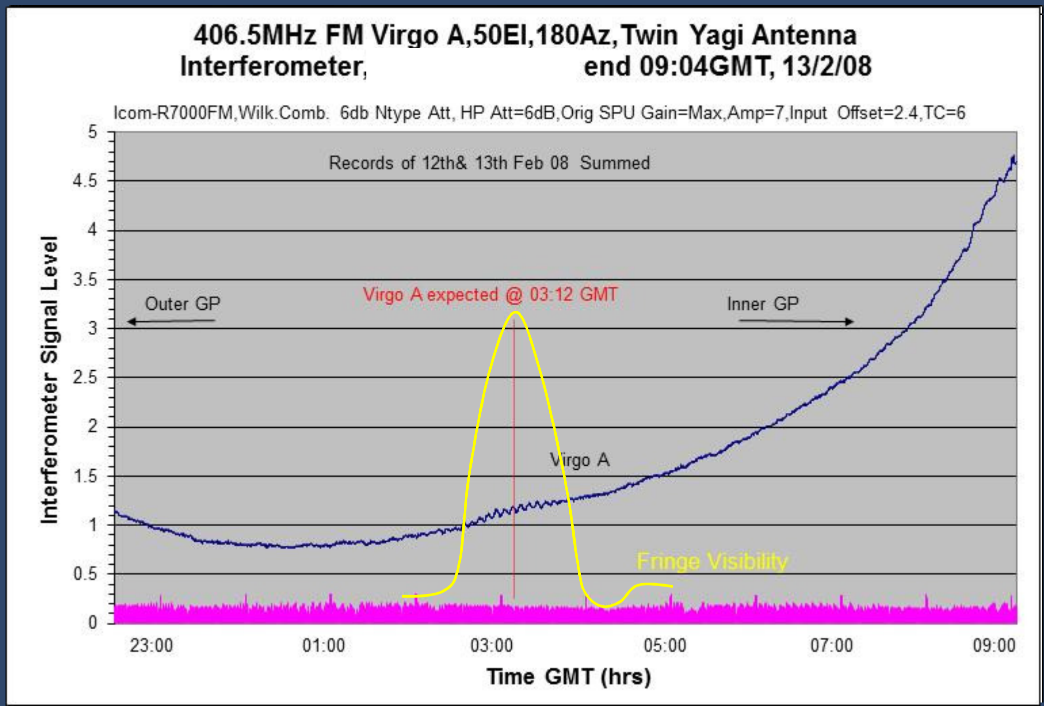
Add in Cass A ' point source'

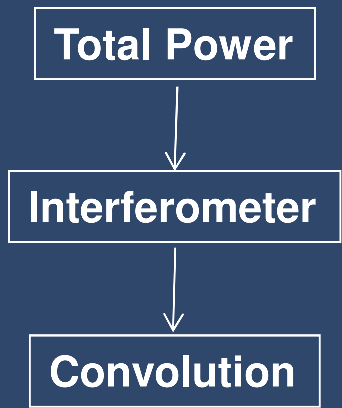


Sum the background noise power
Sum the noise power + 'point' source
Calculate % change with point source

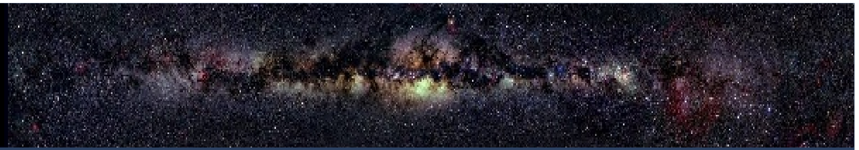
Discrete extra galactic objects - interferometry

- **Observing extragalactic synchrotron objects at UHF with small antennas results in poor spatial resolution (HPBW ~18^0 - 3m A_E)**
  - **Example: M87 / Virgo A galaxy**
  - **Only ~ 100Jy at 408MHz**
  - **Fortunately it is out of GP – less obscured**
  - **Still difficult to determine as a point source with Total Power receiver**





H Line – Sky View



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