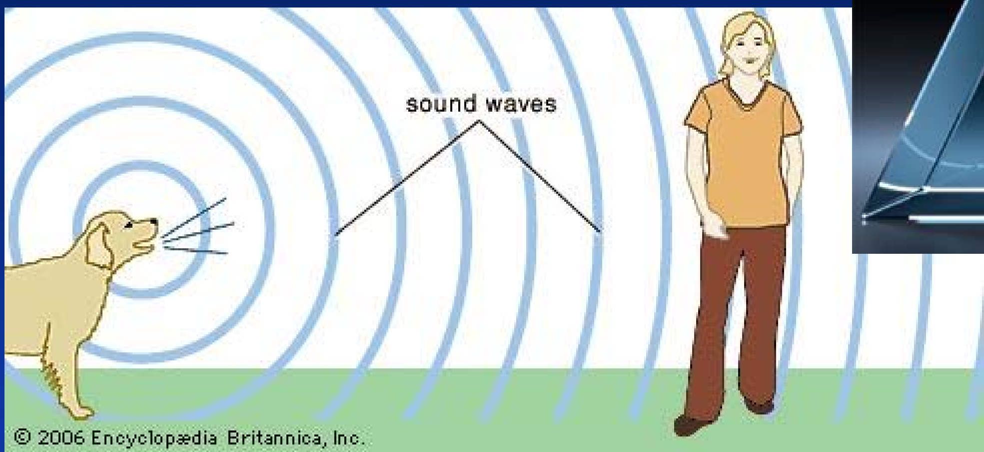
Amateur
Radio Astronomy

An Introduction

Dave Typinski, Alachua Astronomy Club Meeting, 13 Sep 2016, UF

Waves

- Water, sound, electromagnetic
  - We can see water waves and hear sound waves
  - We can see electromagnetic waves in the visible spectrum



400 THz

790 THz

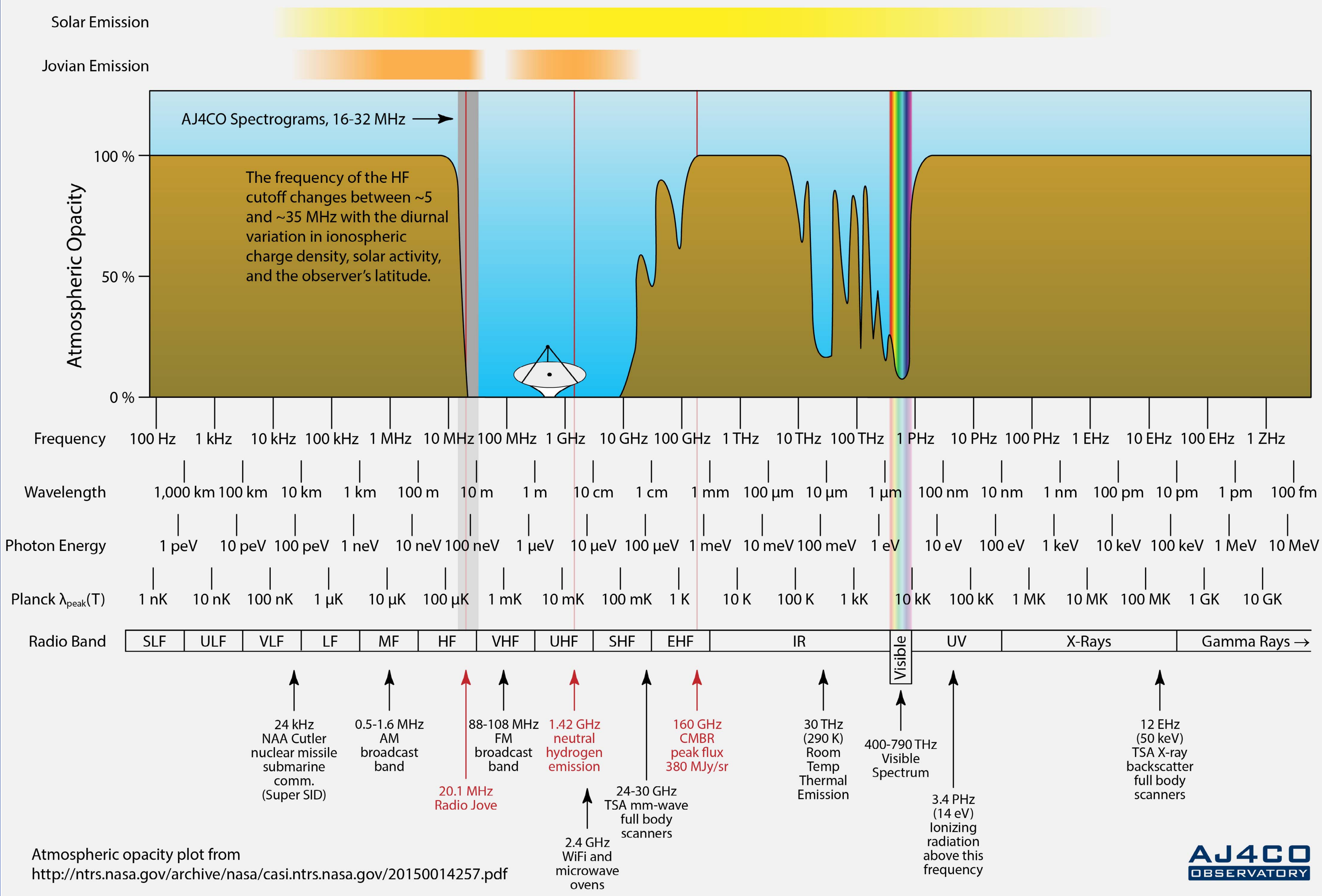
Radio Waves

- We cannot perceive electromagnetic waves outside the visible spectrum unless we convert them to sound using a radio receiver

Radio Waves

- Radio astronomers most often record voltage, not sound, because voltage is easier to analyze mathematically

The Electromagnetic Spectrum



Atmospheric opacity plot from
http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150014257.pdf

Radio Waves

- Color in the visible spectrum is the result of different electromagnetic frequencies
- A *very* loose analogy between color and some radio frequency bands:

<u>Color</u>	<u>Radio Band</u>
Red	AM broadcast band
Orange	Shortwave broadcast & HF ham radio
Yellow	FM broadcast band
Green	Cell phone bands
Blue	WiFi, microwave ovens, satellite TV
Violet	TSA mm-wave full body scanners

Radio Astronomy

- Optical astronomy looks at the universe across a narrow slice of the electromagnetic spectrum about one octave wide, from about 400 to 800 THz.

- Radio astronomy looks at the universe across the rest of the electromagnetic spectrum.

Radio Astronomy

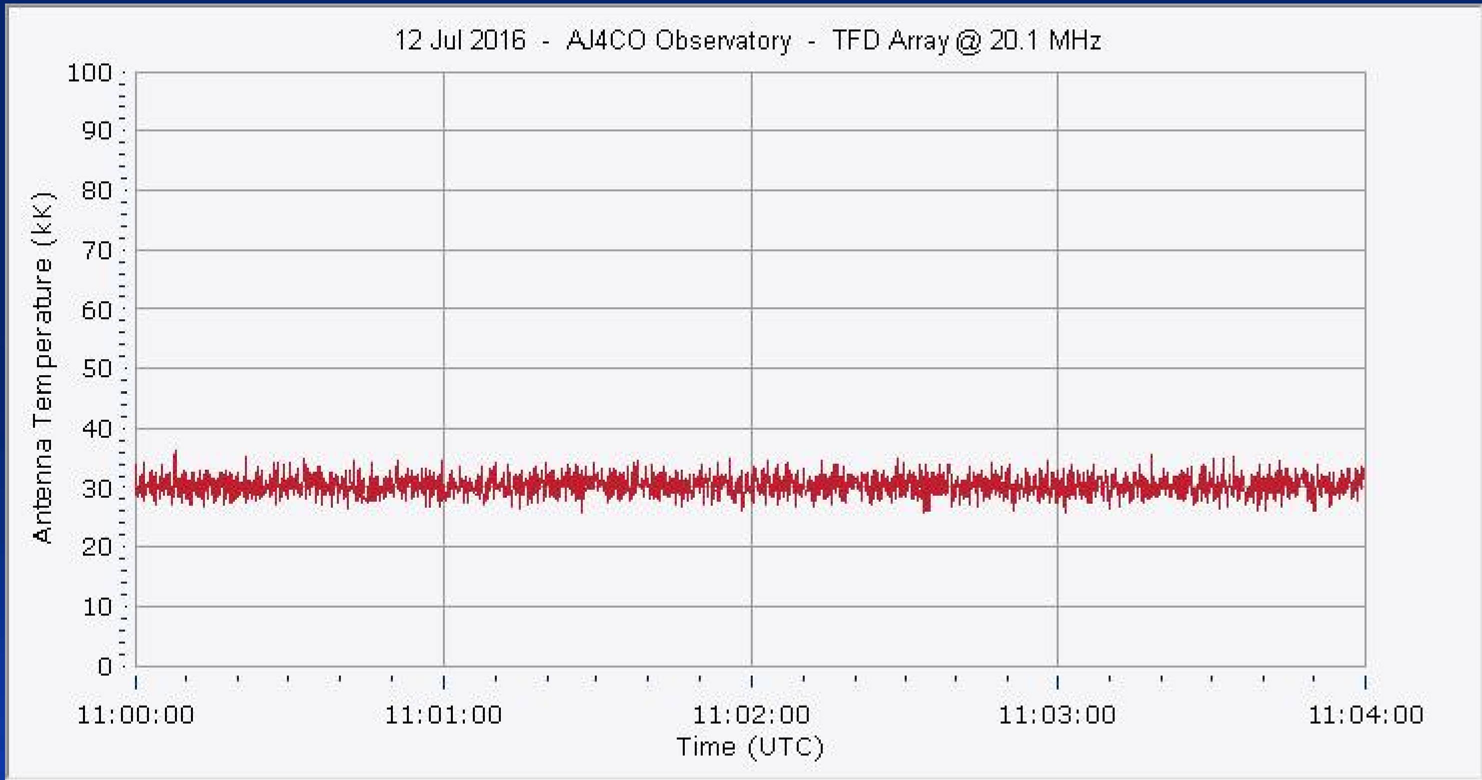
- Easy to form images with an optical telescope.
- Imaging not so easy with a radio telescope due to size of array elements.
  - Factor of 20,000,000 bigger in the HF band.
  - 1” CCD optical → 316 *miles* at HF, roughly the size of Arizona, or Georgia + Alabama, or Pennsylvania + New York.

This is **NOT** Radio Astronomy

This **IS** Radio Astronomy

Cosmic Radio Emission

- All cosmic emission is noise
  - Gaussian distribution of amplitudes around a mean



Cosmic Radio Emission

- Good noise
  - Radio emission from the source we want to observe
- Bad noise
  - Emission from other cosmic sources
  - Emission from man-made technology
  - Lightning
  - Receiver internal noise

Cosmic Radio Emission

- Since the good noise and the bad noise are both *noise*, the hard part is separating the *good* noise from the *bad* noise.

Cosmic Radio Emission

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- Solutions:
  - narrow beam antenna (i.e., larger aperture)
  - increased bandwidth
  - low-noise receiver
  - integration of signal over time
  - data folding (for periodic sources)

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$$\Delta S_{\min} = \frac{n_\sigma \, k T_{sys}}{A_{eff} \sqrt{B t n_f}}$$

Cosmic Radio Emission

$$\Delta S_{\min} = \frac{n_\sigma k T_{sys}}{A_{eff}\sqrt{B t n_f}}$$

T_{sys} includes the galactic background, receiver noise, source signal, everything

k is the Boltzmann constant, 1.38 x 10^{-23} J/K

n_σ is the number of standard deviations required for rigorous detection of a signal (usually 3 or 5)

A_{eff} is the effective aperture of the telescope

B is the pre-detection bandwidth of the receiver

t is the post-detection integration time constant

n_f is the number of folds stacked if data folding is employed, otherwise $n_f = 1$

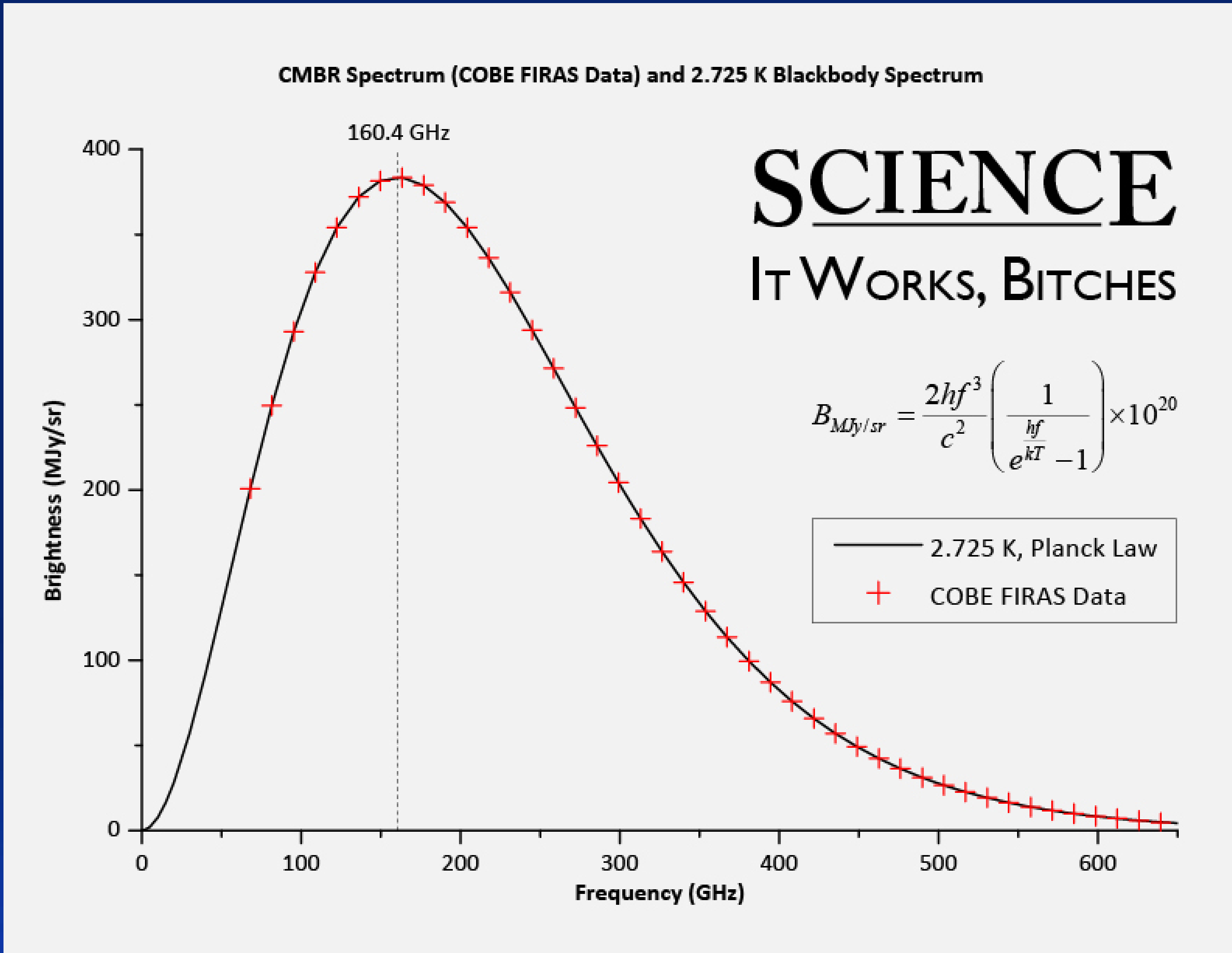
Cosmic Radio Emission

- Two kinds of noise emission
  - Thermal
    - spectrum follows the Planck law, produced by heat; i.e., a black body radiator. (CMBR)
  - Non-thermal
    - spectrum does not follow the Planck law, emission produced by other processes such as
      - synchrotron radiation (galactic background)
      - neutral hydrogen p-e spin-flip (1.42 GHz HI line)
      - cyclotron maser (Jupiter)
      - free-free electron-ion interaction (bremsstrahlung within ionized gas clouds, AGN X-ray emission)
      - pulsar emission (exact process unknown)

Thermal Radio Emission

- Planetary surface temperature measurements
- CMBR

Thermal Radio Emission



Non-Thermal Radio Emission

- HI emission (challenge, but possible)
- Pulsar emission (very difficult)
- Galactic background emission (very easy)
- Solar emission (non-thermal) (very easy)
- Planetary emission (non-thermal)
  - Jupiter (easy)
  - Saturn (impossible from Earth's surface)
  - Uranus (impossible from Earth's surface)
  - Neptune (impossible from Earth's surface)

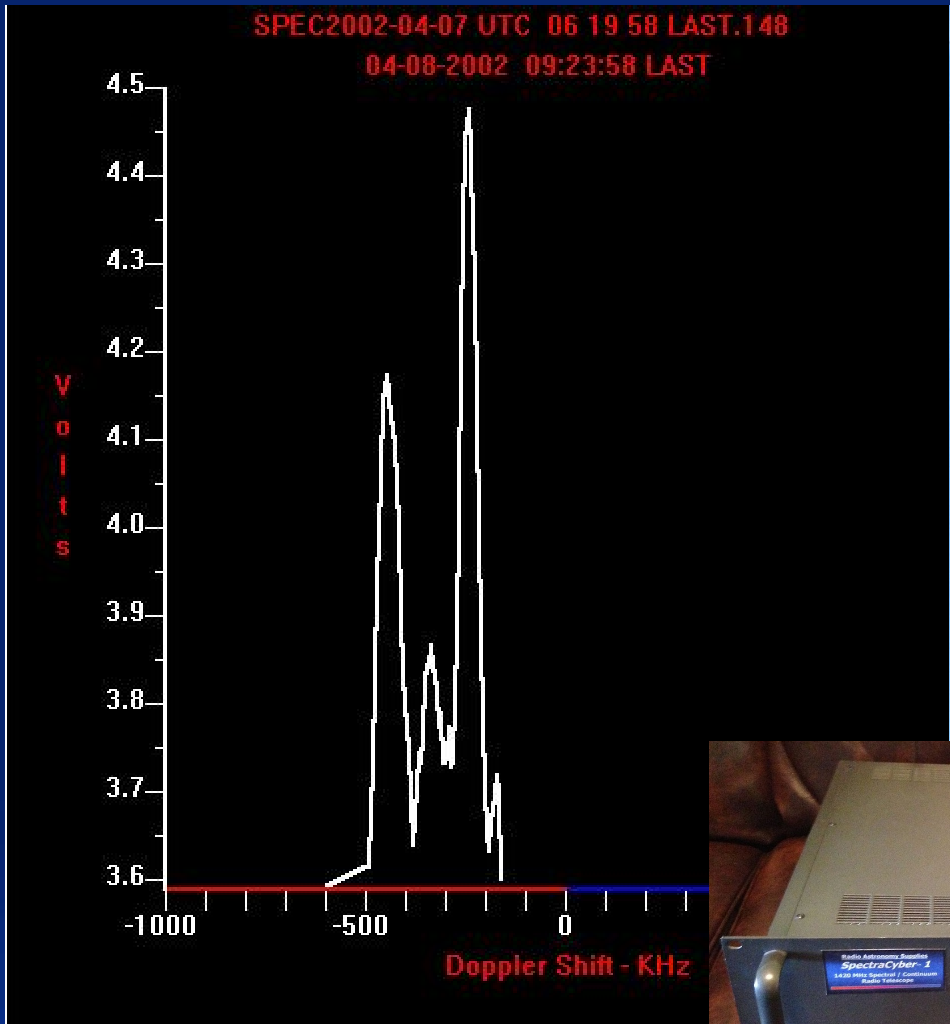
HI Emission

- Proton-electron spin-flip in neutral hydrogen (anti-parallel spins have *slightly* lower energy).
  - ΔE = 5.87 μeV
  - f = 1.4204 GHz in *rest frame* via $E = hf$
  - λ = 21.1 cm via $c = f\lambda$
- Predicted by van de Hulst in 1944 (U Leiden)
- Observed by Ewen & Purcell in 1951 (Harvard)
- Requires minimum ~ 1 meter dish, LNA and downconverter at feed point, SDR or analog receiver, software to time-integrate signal. Far easier with larger 3 meter TVRO dish.

HI Emission

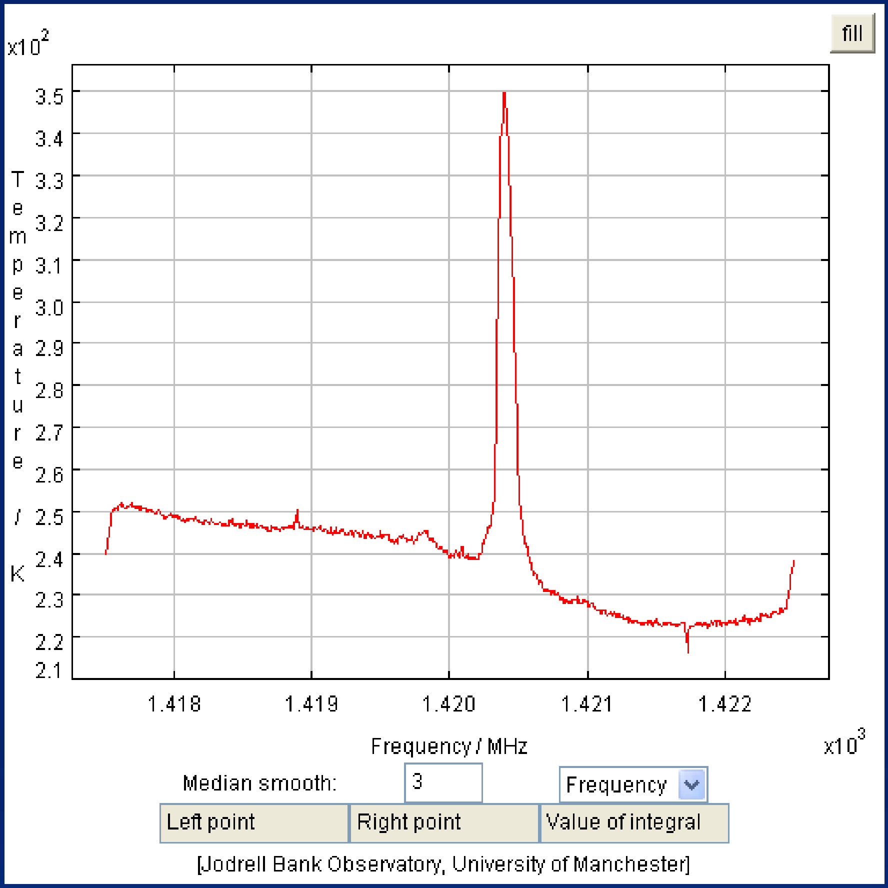
- Observed Doppler shifts showed our galaxy to be a spiral, also led to the galactic rotation curve problem and the postulation of dark matter.
- Amateur Radio Astronomers CAN DO THIS

HI Emission

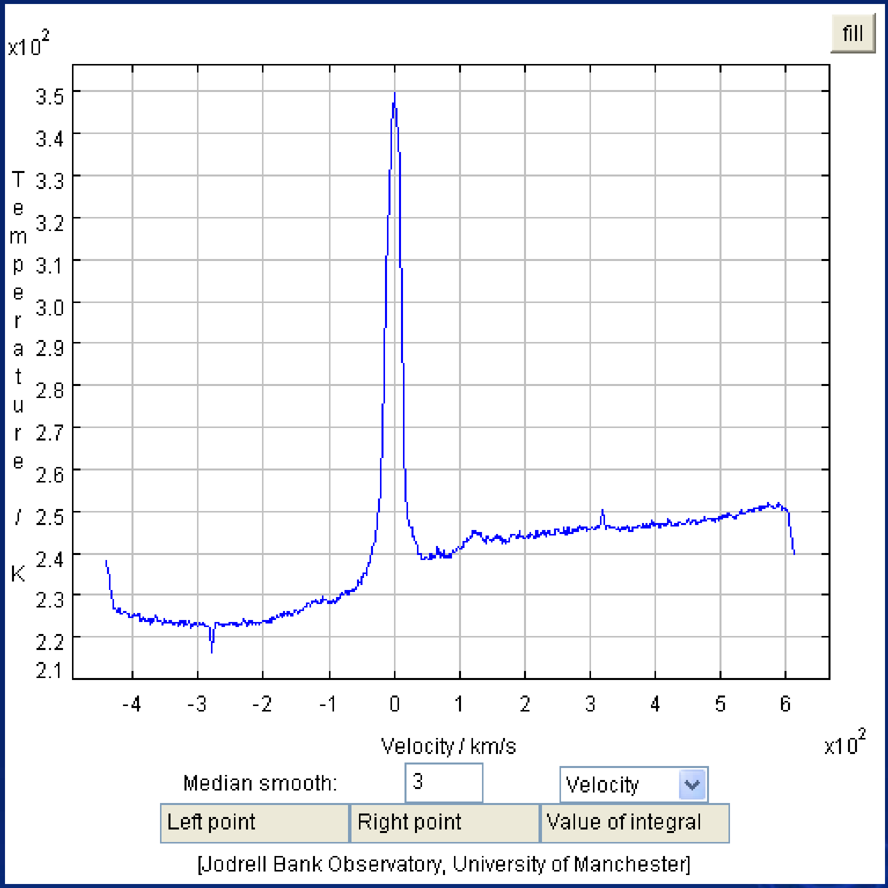


2.4 meter TVRO dish w/ special feed
Spectra Cyber 1420 MHz spectrograph & software @ MIT Haystack Observatory

HI Emission



fill
x10^2
Temperature / K
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
1.418
1.419
1.420
1.421
1.422
x10^3
Frequency / MHz
Median smooth:
3
Frequency
Left point
Right point
Value of integral
[Jodrell Bank Observatory, University of Manchester]



fill
x10^2
Temperature / K
3.5
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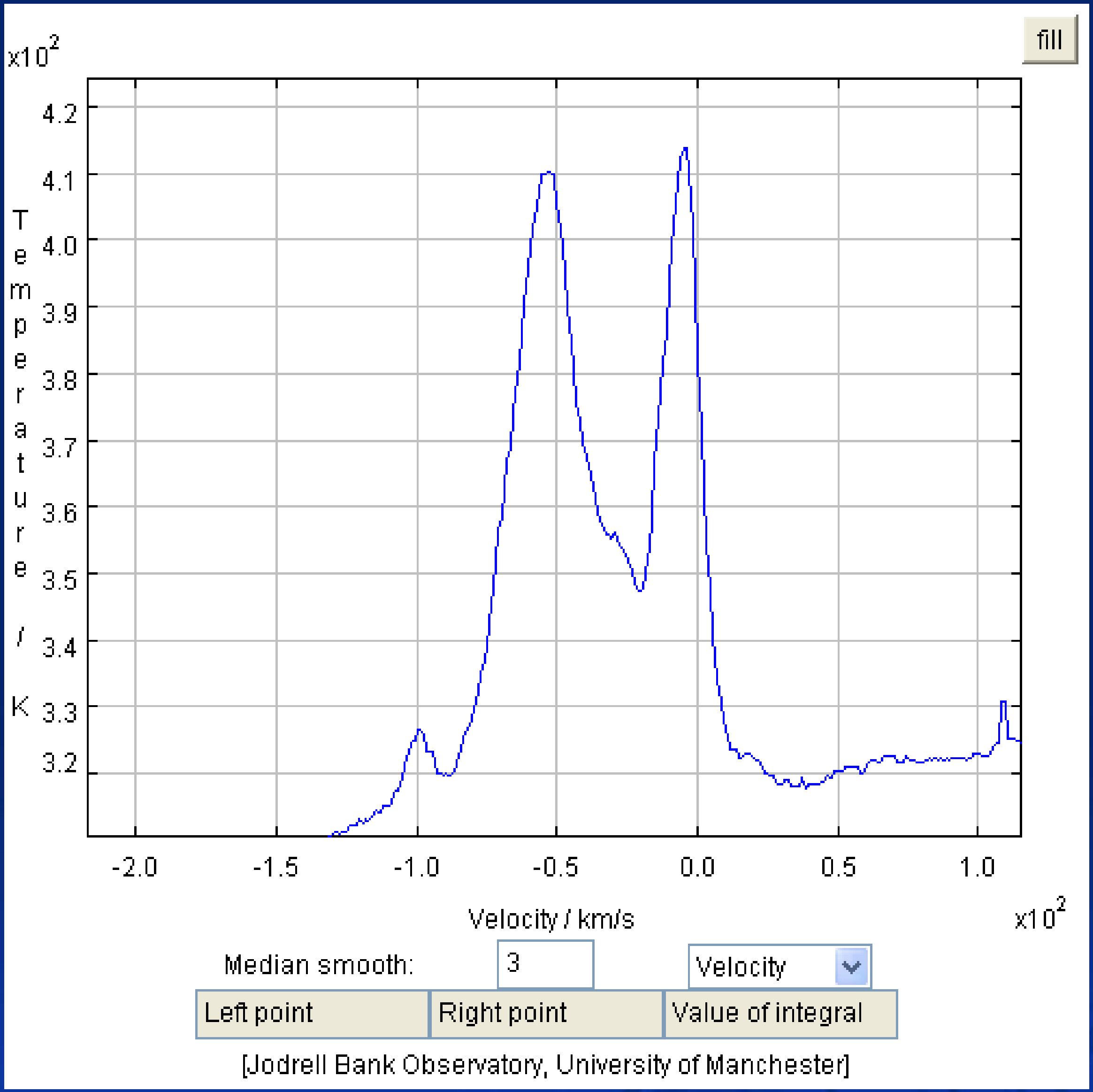
2.4
2.3
2.2
2.1
-4
-3
-2
-1
0
1
2
3
4
5
6
x10^2
Velocity / km/s
Median smooth:
3
Velocity
Left point
Right point
Value of integral
[Jodrell Bank Observatory, University of Manchester]

HI Emission

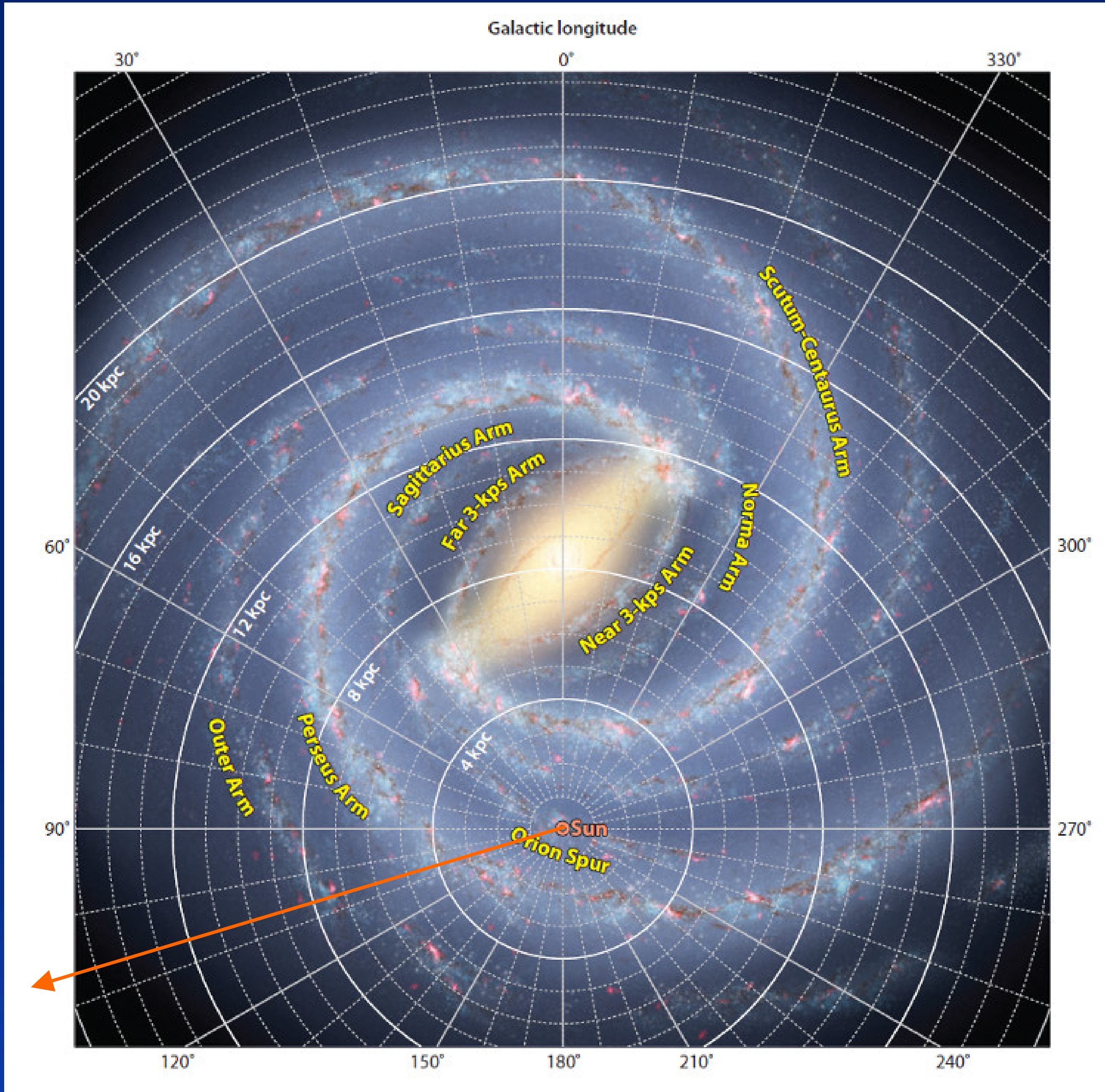


Observed spectrum with galactic coordinates
l = 106°, b = 0°
in the antenna beam.

Author's observation at
Jodrell Bank
7 meter telescope
15 May 2010

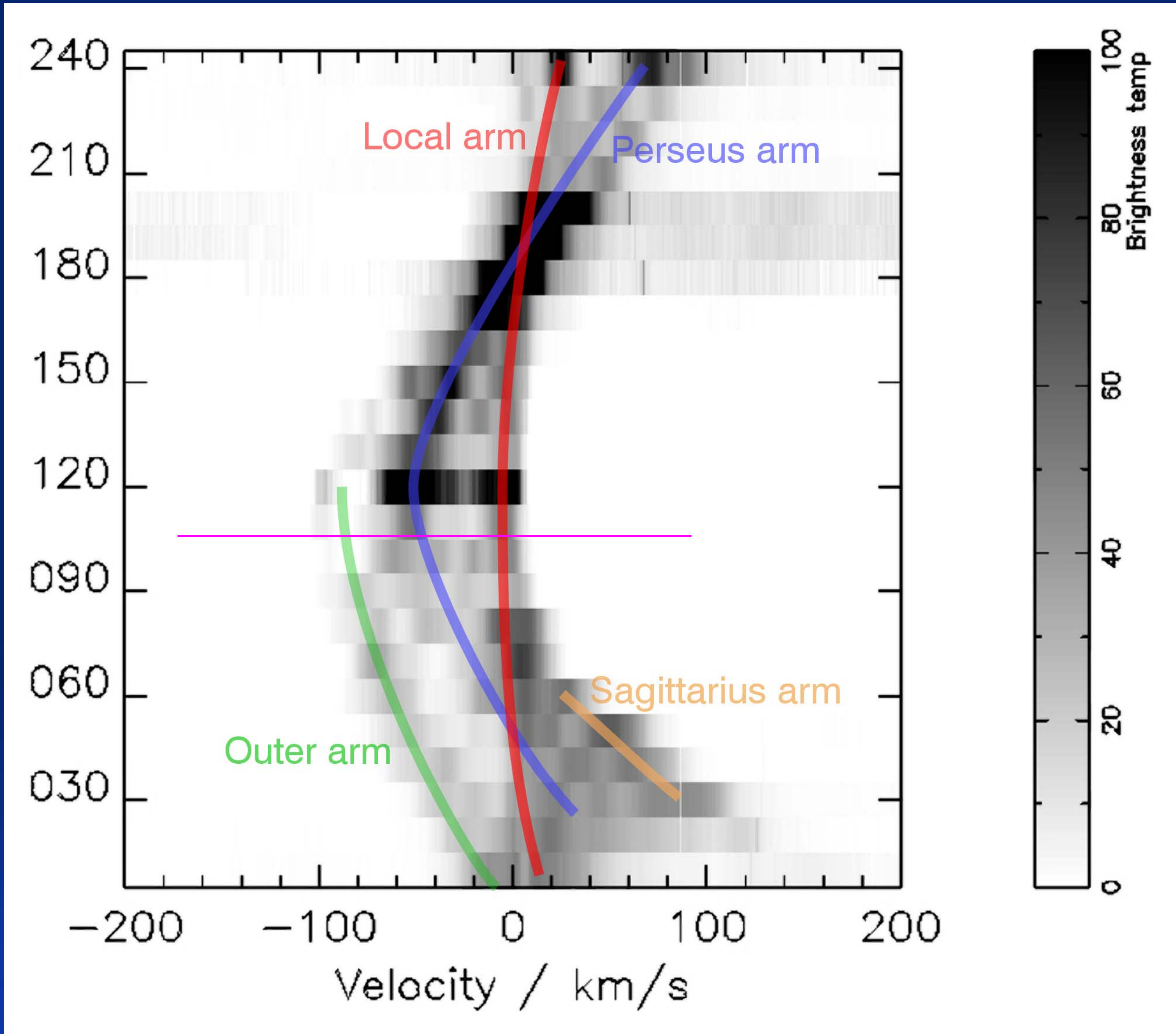
Negative velocity means the emission source and the observer are moving closer together.

HI Emission



Galactic longitude
30°
0°
330°
60°
300°
90°
270°
120°
150°
180°
210°
240°
20 kpc
16 kpc
12 kpc
8 kpc
4 kpc
Scutum-Centaurus Arm
Sagittarius Arm
Far 3-kps Arm
Norma Arm
Near 3-kps Arm
Outer Arm
Perseus Arm
Sun
Orion Spur

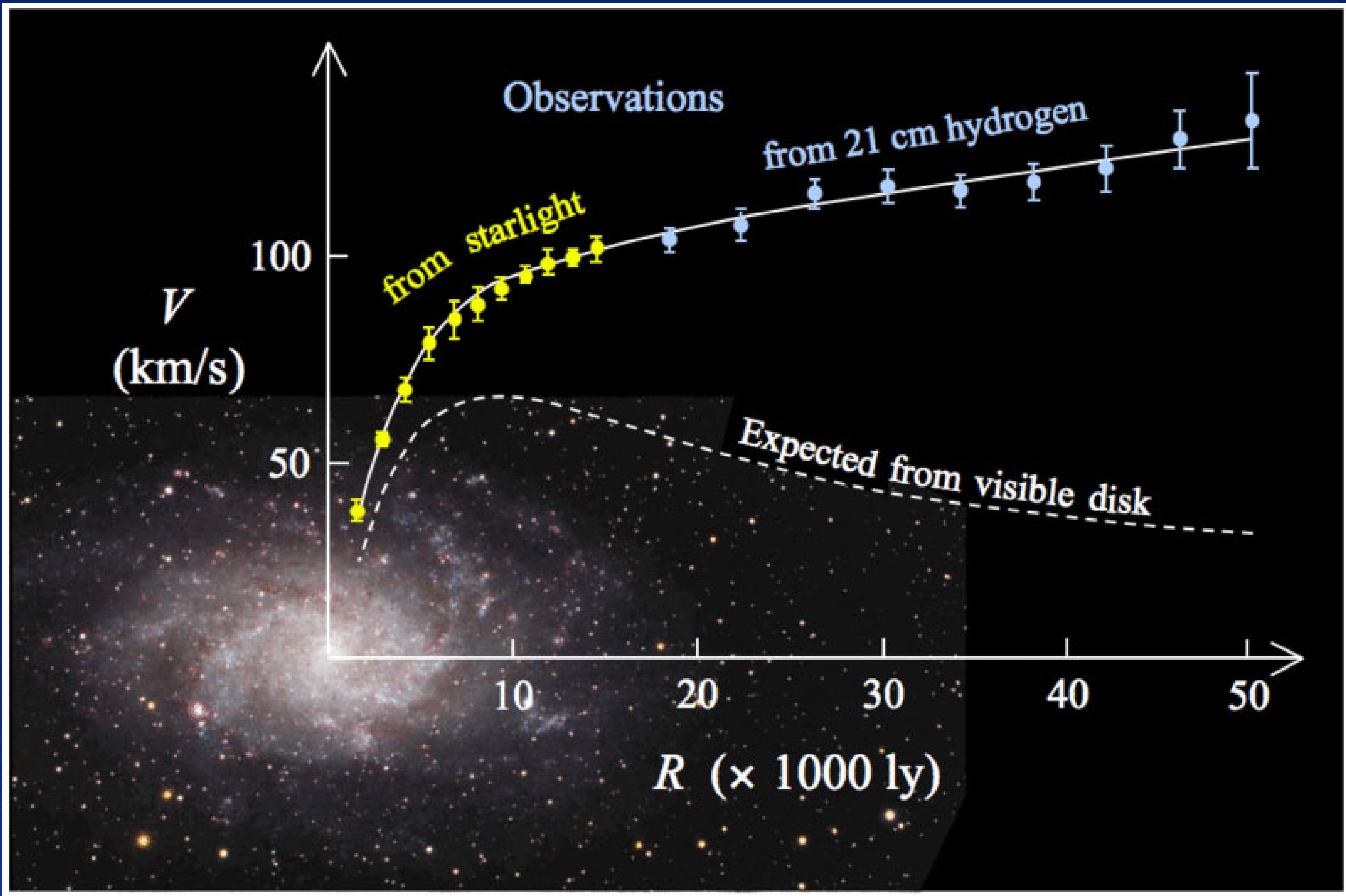
HI Emission



240
210
180
150
120
090
060
030
Local arm
Perseus arm
Sagittarius arm
Outer arm
−200
−100
0
100
200
Velocity / km/s
Brightness temp
0
20
40
60
80
100

HI Emission

The rotation curve problem and the postulation of dark matter



Pulsars

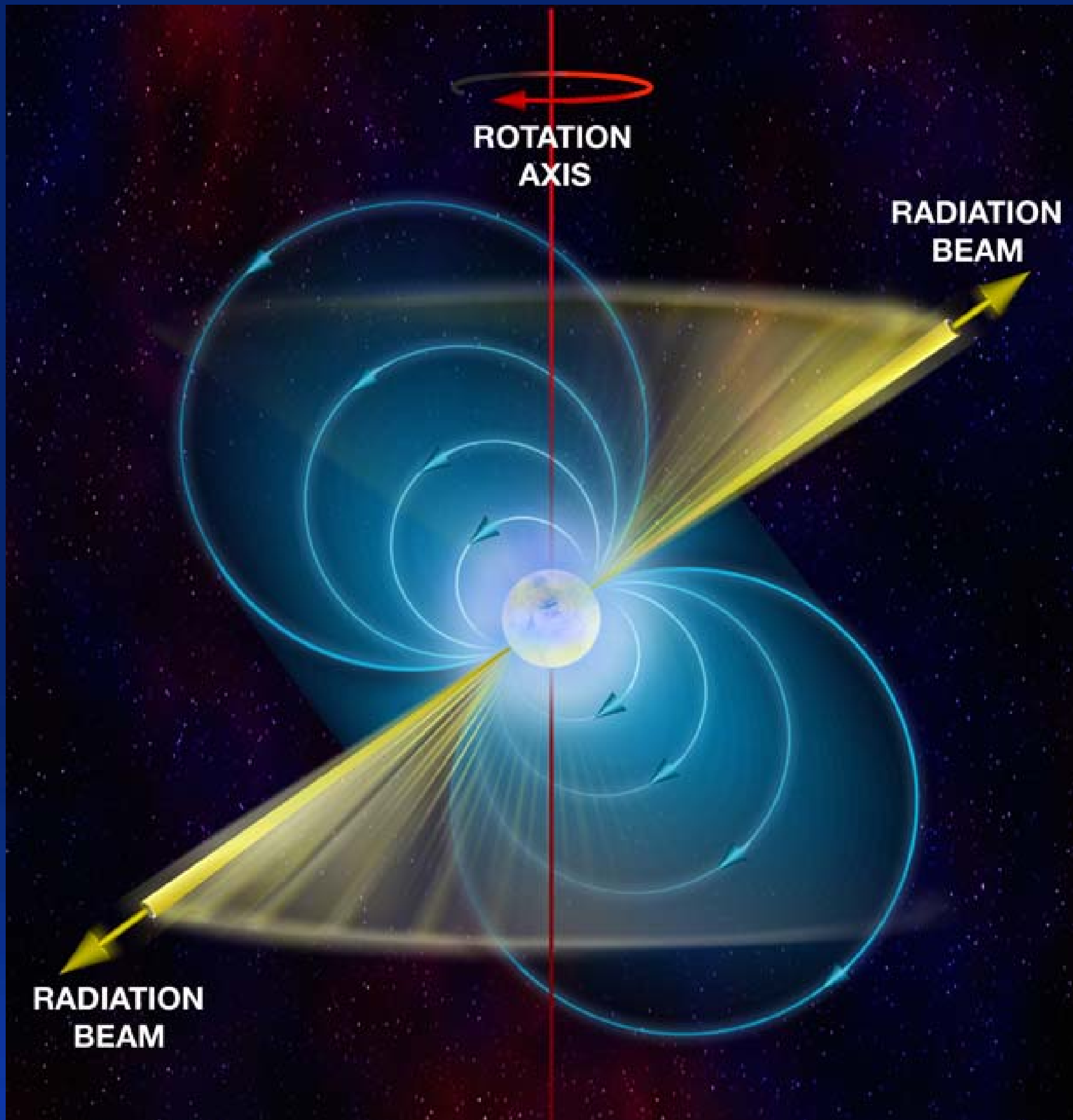


Image credit:

Bill Saxton, NRAO

Pulsars

- PSR B0329+54 aka PSR J0332+5434
- ~ 1 kpc away
- neutron star at ~ 84 RPM (1.3996 Hz)

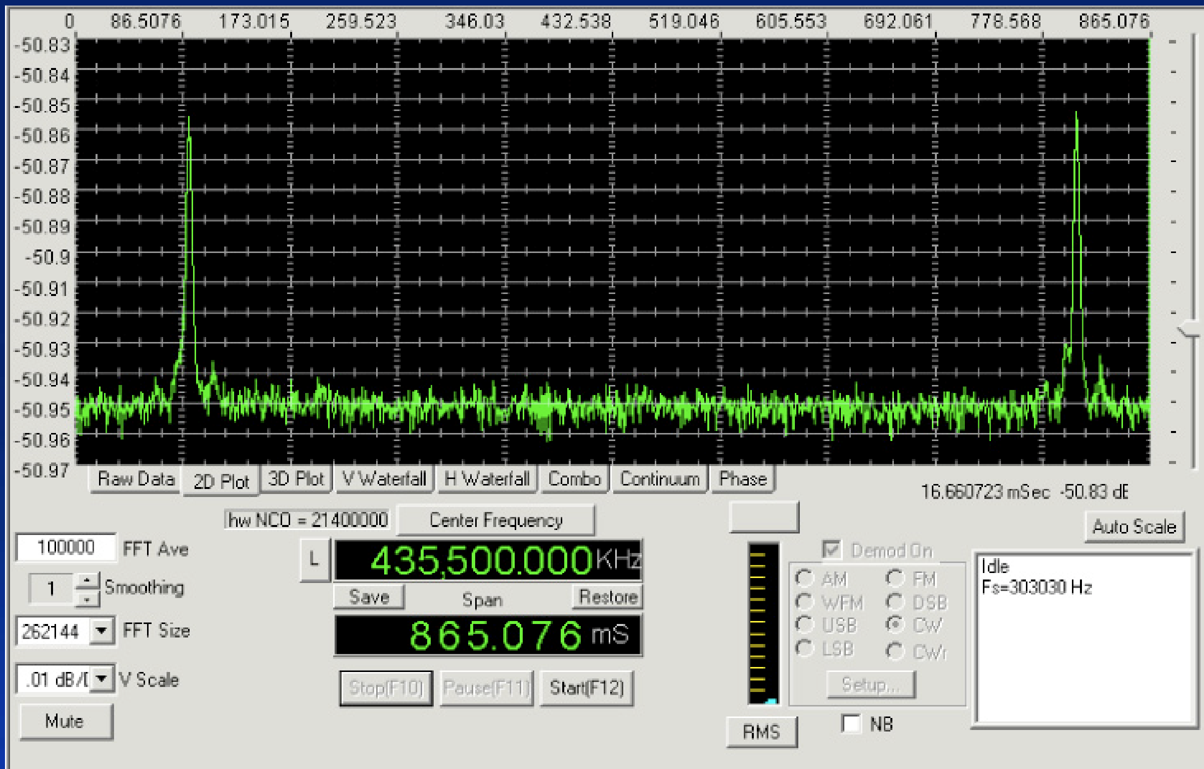


Image credit:

Joe Martin, K5SO

Pulsars

- PSR B0833-45 aka PSR J0835-4510
- in Vela SNR ~ 300 pc away
- neutron star at ~ 672 RPM (11.194 Hz)

Image credit:
NASA / GSFC
(X-ray image)

Pulsars

- PSR B0531+21 aka PSR J0534+2200
- in Crab Nebula (SNR) ~ 2200 pc away
- neutron star at ~ 1,814 RPM (30.220 Hz)

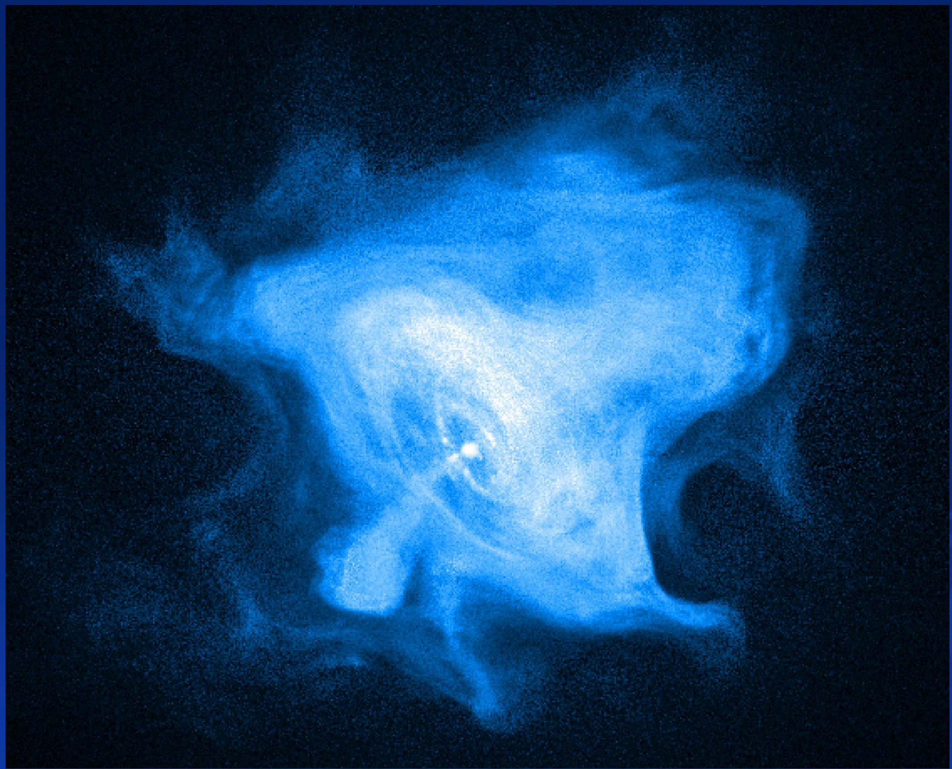


Image credit:

Smithsonian Astrophysical Observatory

(X-ray image)

Pulsars

- PSR B1937+21 aka PSR J1939+2134
- accretion spin-up
- neutron star at ~ 38,516 RPM (641.18 Hz)

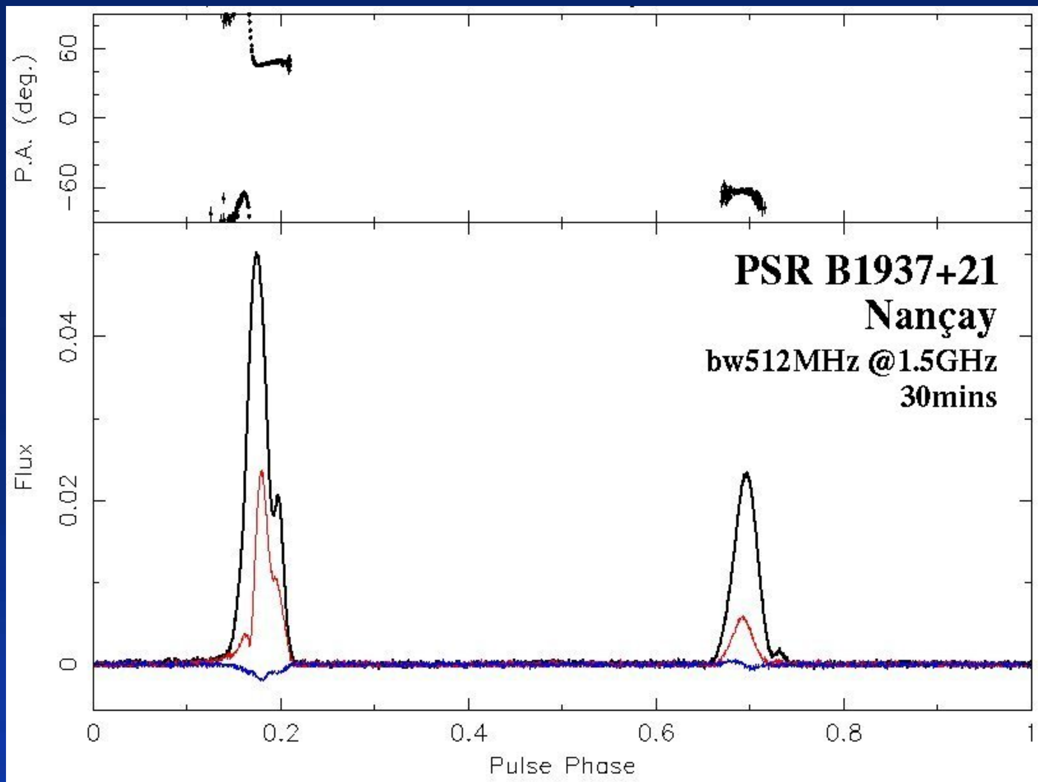


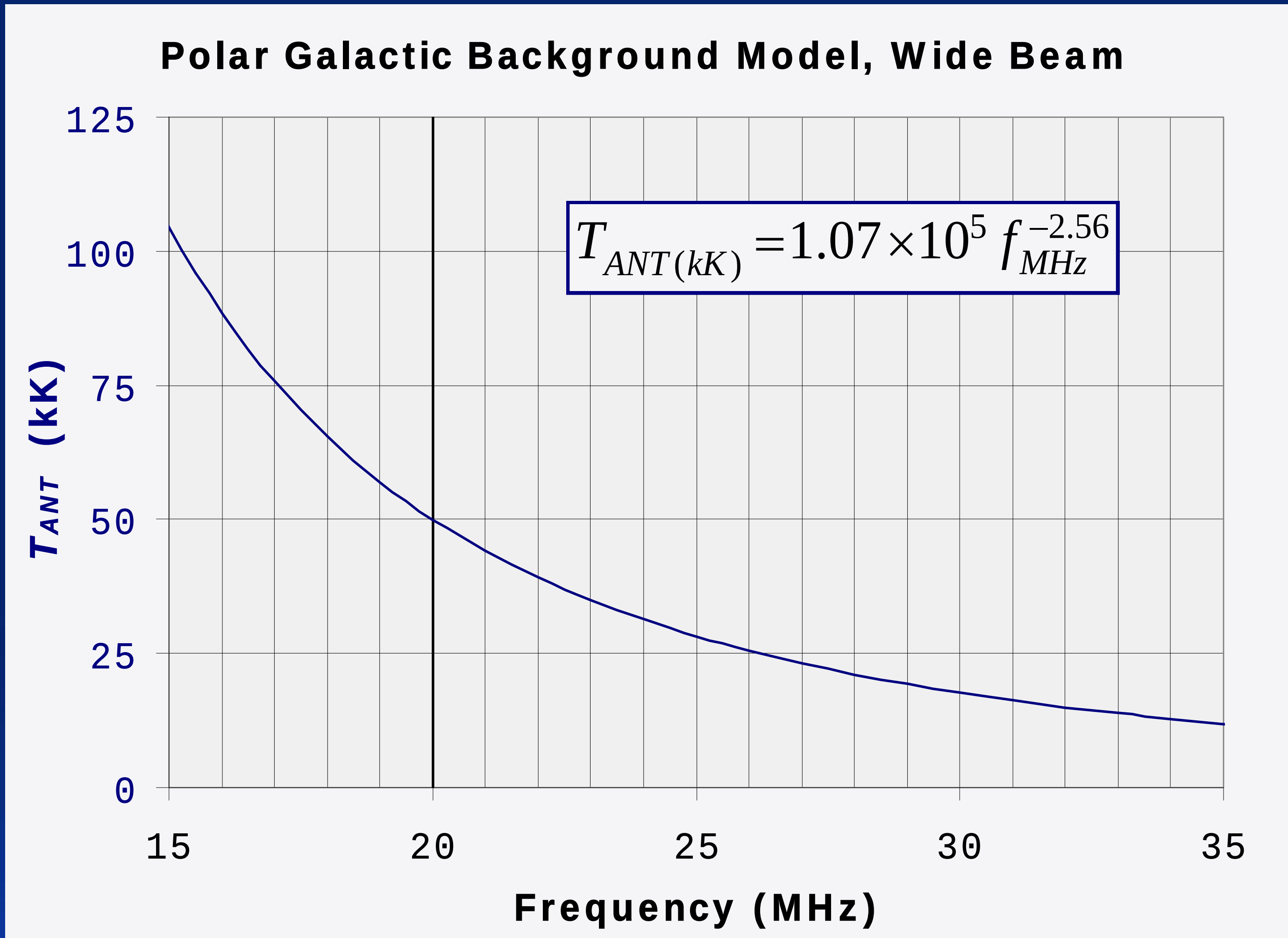
Image credit:

Paris Observatory / Nancay

Galactic Background

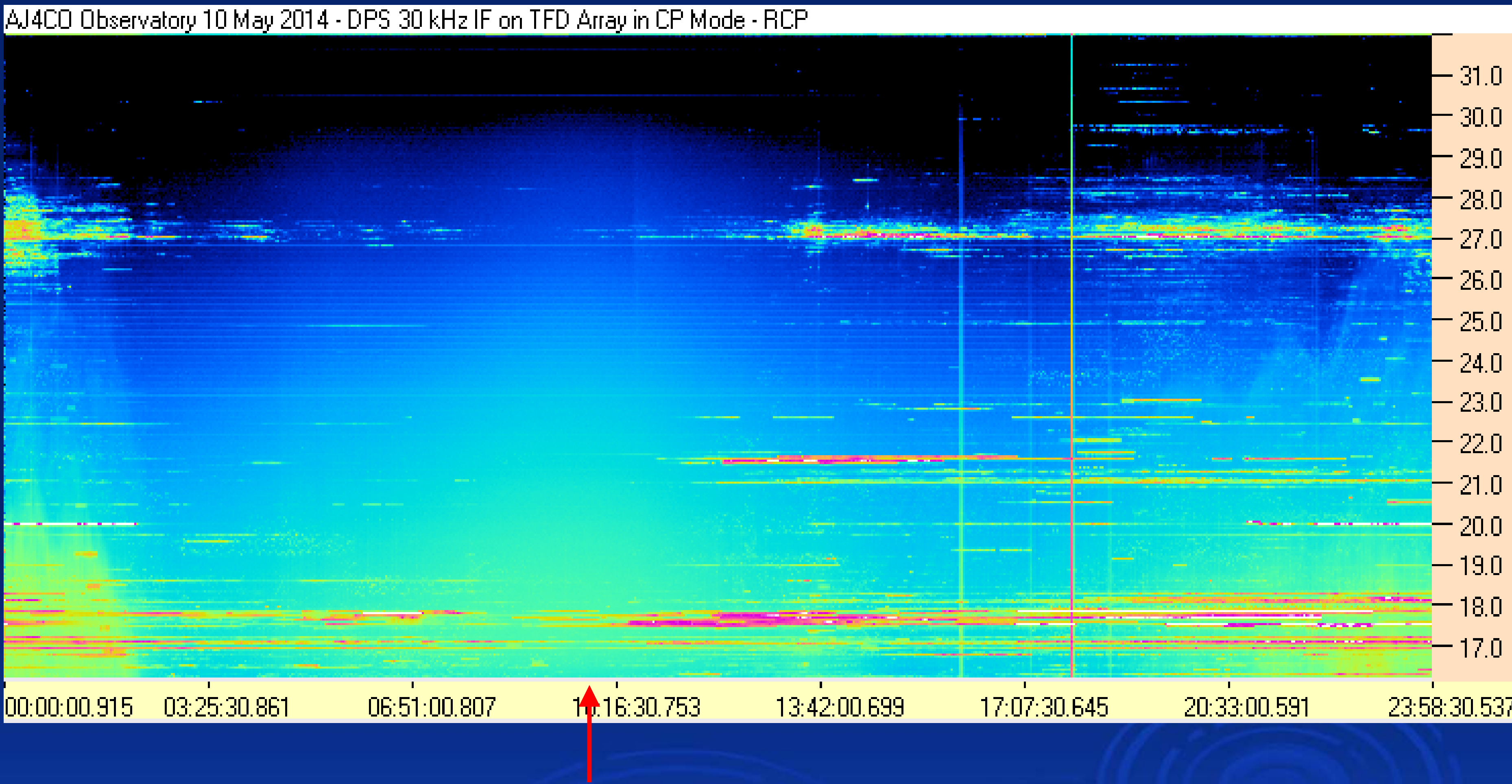
- NOT the same as the CMBR
- Produced by synchrotron process as electrons interact with the galactic magnetic field.
- Nearly pure white noise in the HF band.
- Hotter at lower frequencies; spectral index ~ -2.56.
- Normally treated as interference, but does serve well to let you know the radio telescope is working.

Galactic Background



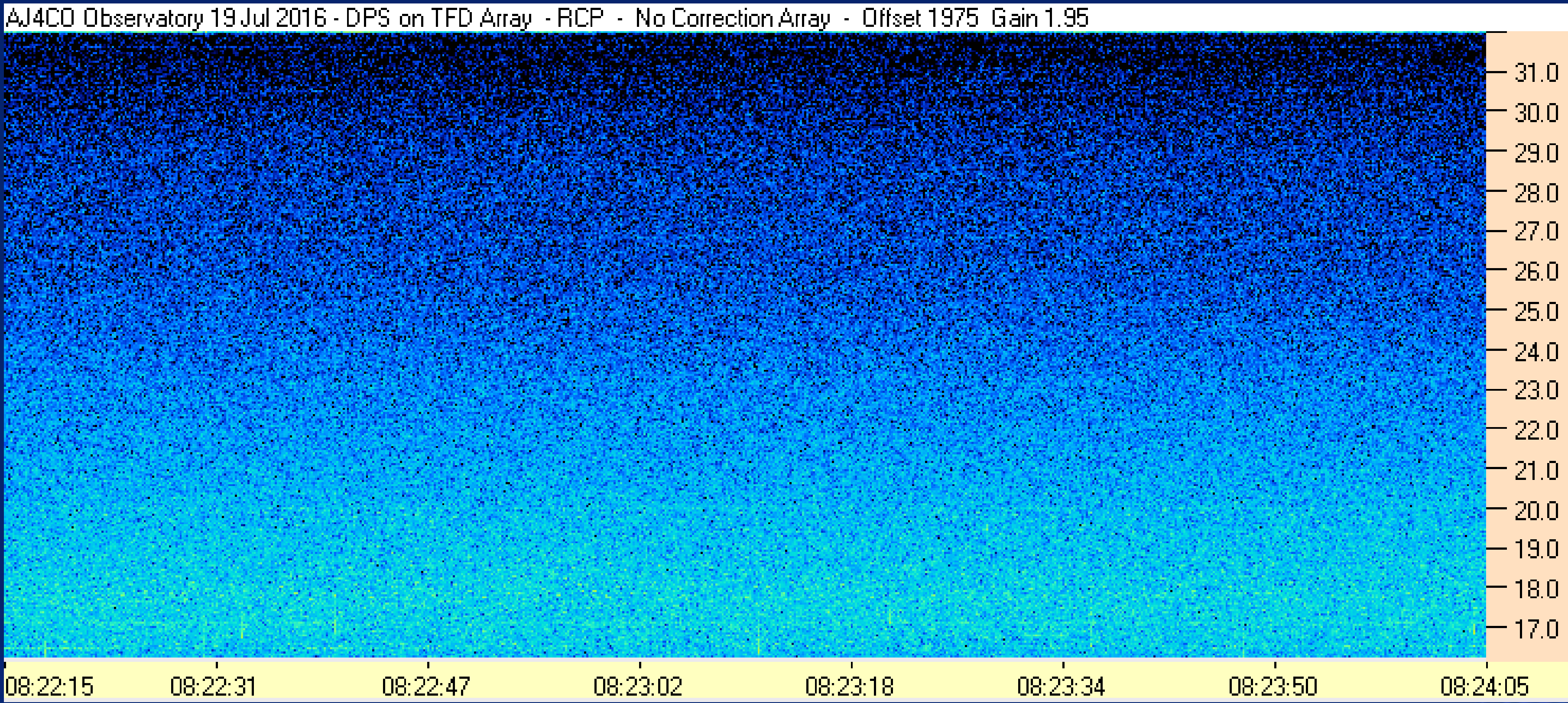
from Typinski, *The Galactic Background in the Upper HF Band*, SARAJ (2013)

Galactic Background



Galactic core transit at 1000 UTC

Galactic Background

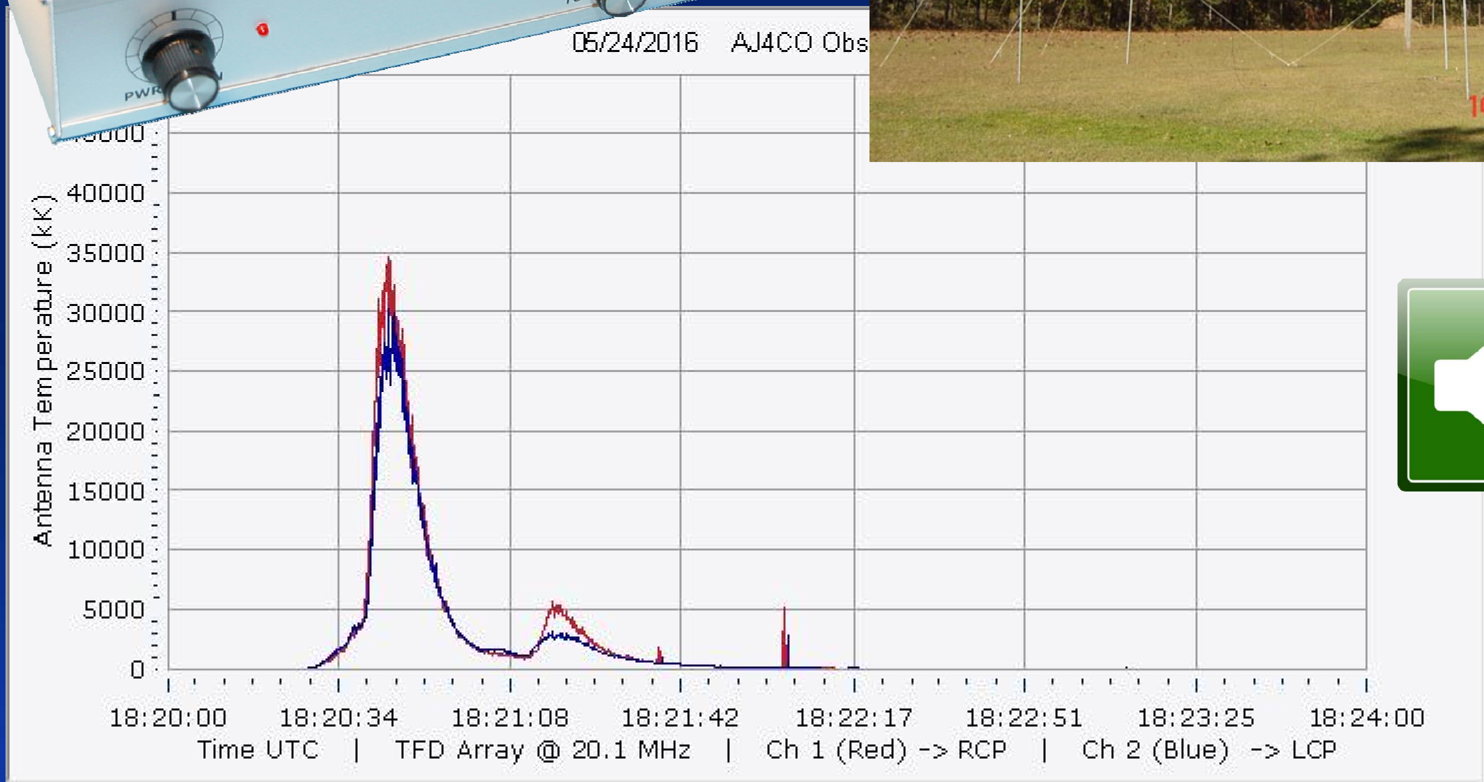


Horiz scale time UTC, Vert scale freq in MHz
Signal dropoff at higher freqs due to antenna array response.

Solar Emission

- Electrons being accelerated emit synchrotron radiation
- Exact process causing the acceleration is unknown, many theories
- Easily observable with a simple receiver and a single antenna
- Dedicated amateurs contribute scientifically useful observations and analyses

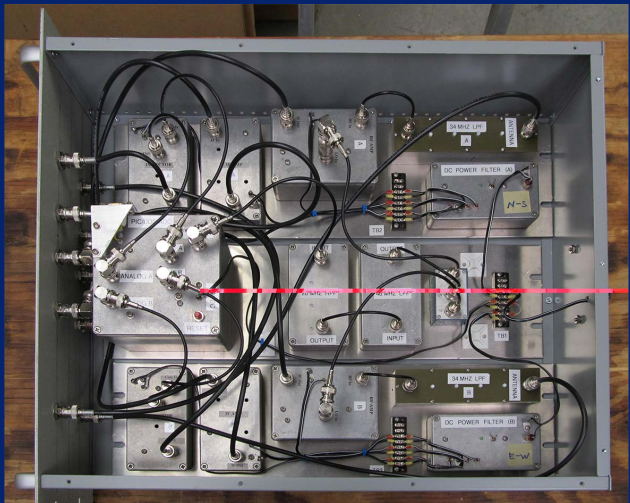
Solar Emission

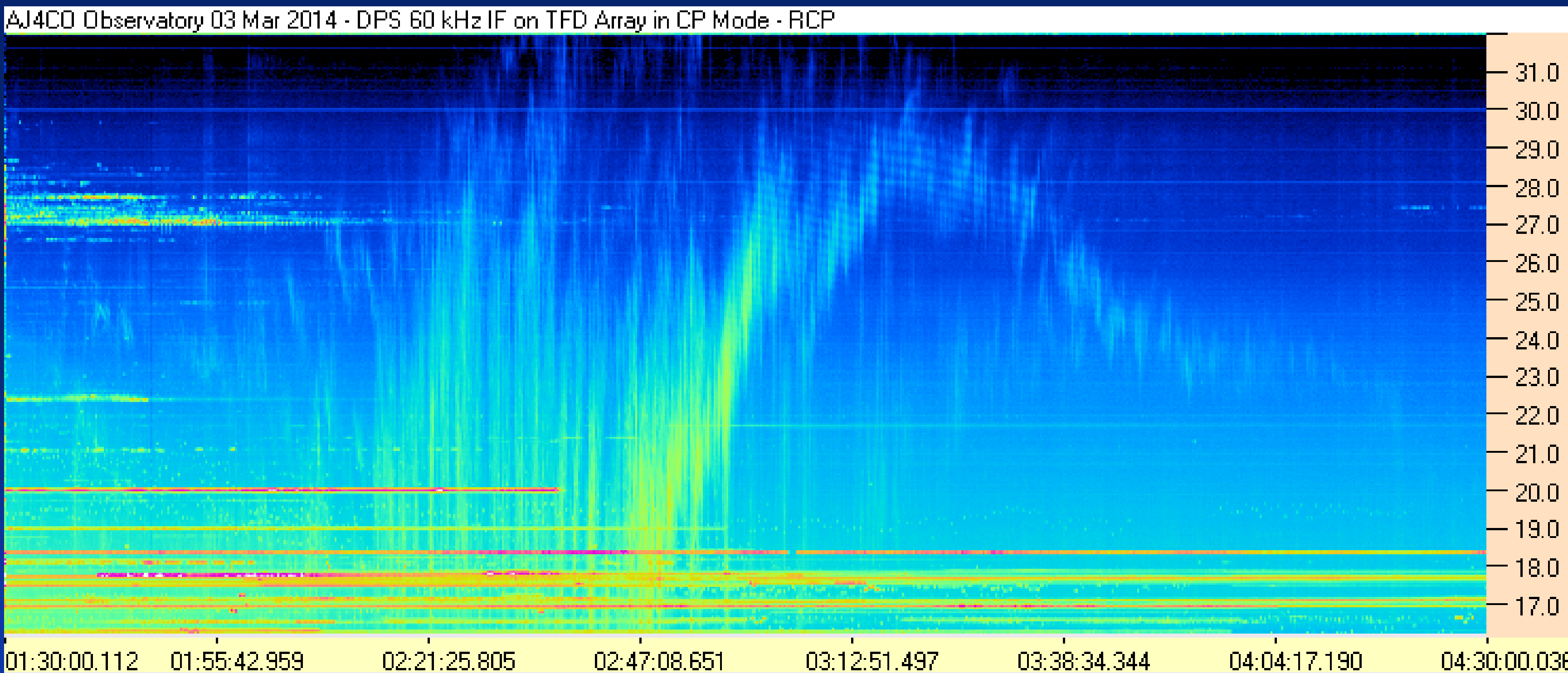


Jovian Emission

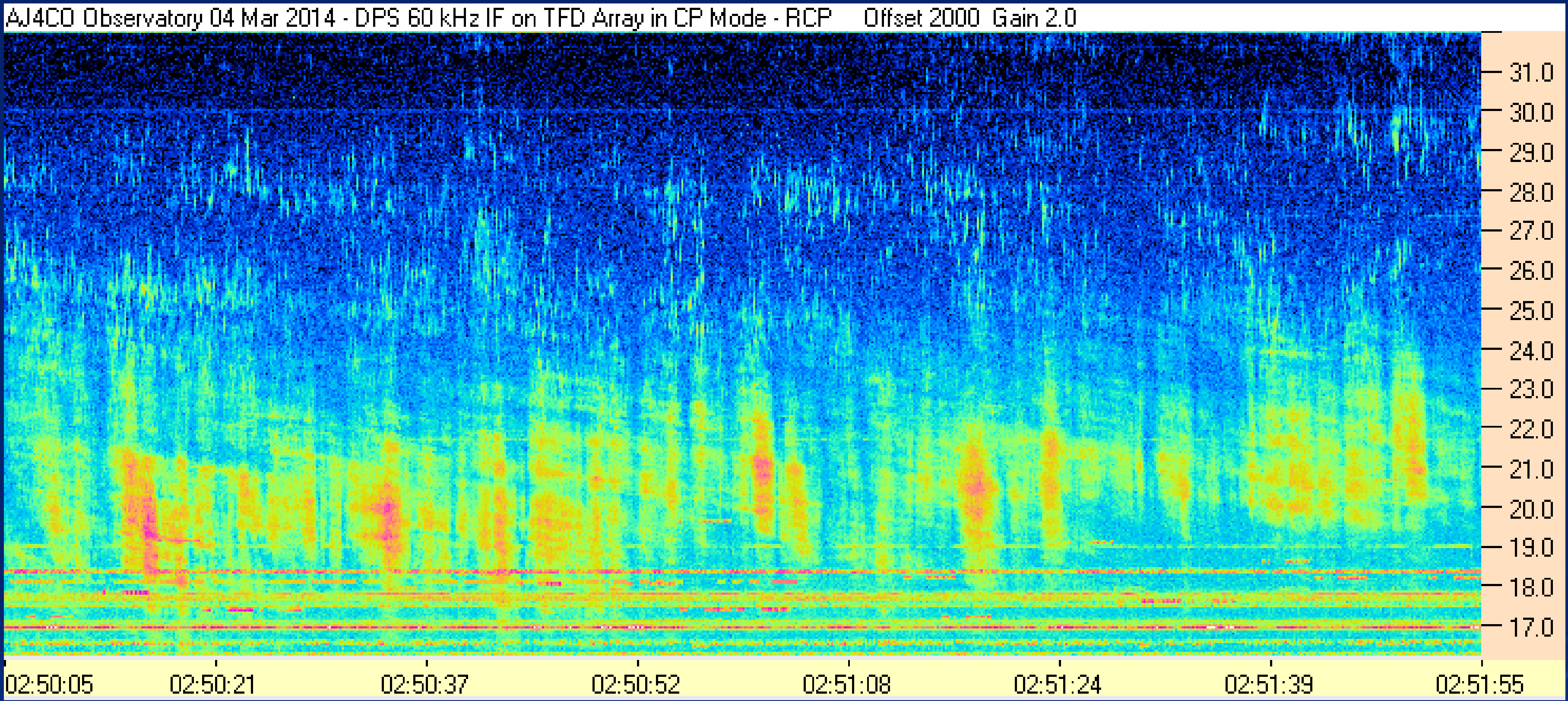
- Cyclotron maser instability (we think)
- Easily observable with modest radio telescope
- Dedicated amateurs contribute scientifically useful observations and analyses

Jovian Emission





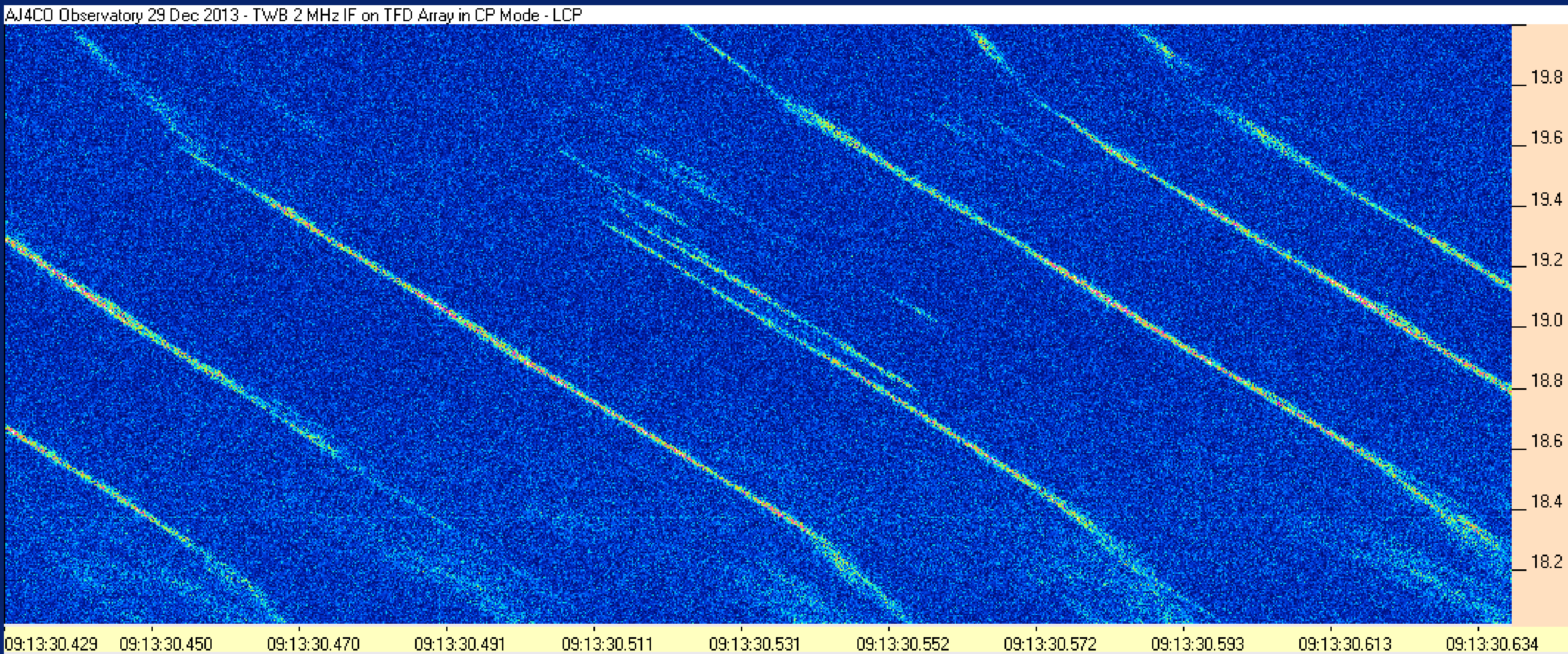
Jovian Emission



L Bursts:

S Bursts:

Jovian Emission – S Bursts



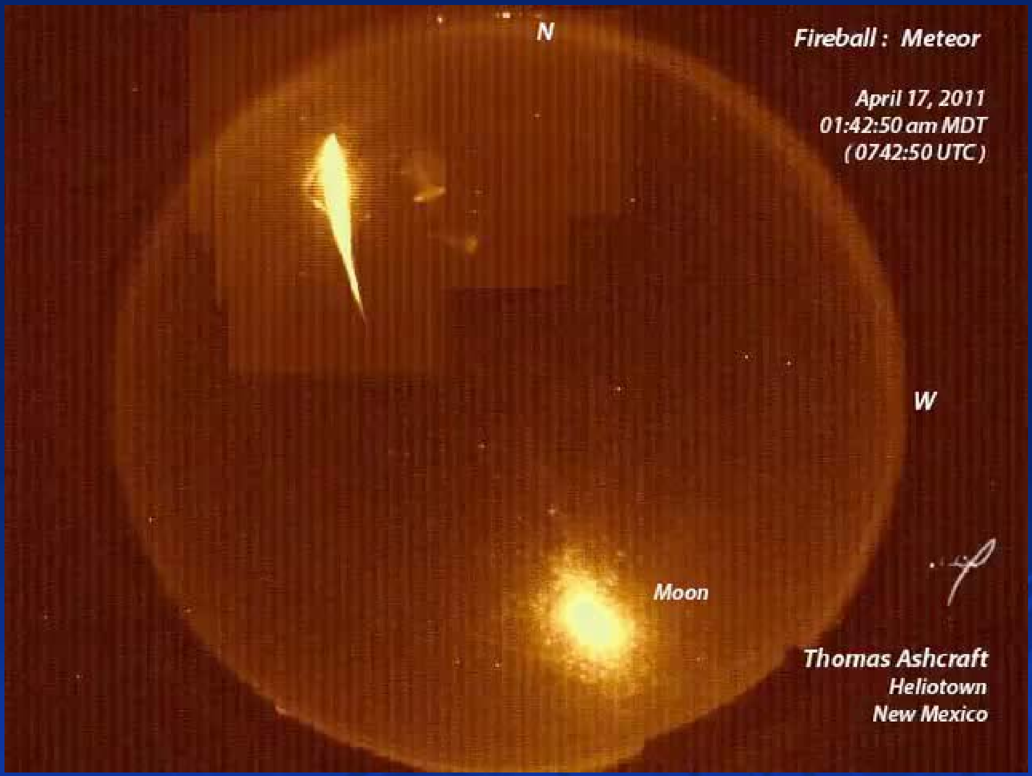
S Bursts slowed 128X:

Meteor Scatter

- The forward-scatter detection method is to monitor for sudden reception of a terrestrial transmitter signal that is not normally able to be received.
- Was once possible using the NAVSPASUR / USAF AN/FPS-133 “space fence” radar system at 217 MHz; but, that was turned off in 2013.
- Was once possible using VHF analog TV transmitter stations (54 to 82 MHz). With the advent of DTV and the shuttering of analog TV transmitters, this is no longer possible (DTV signals are much weaker). A few analog TV stations in Mexico are still transmitting, but not for much longer – and to use them for meteor detection, you have to be in California, Arizona, New Mexico, or Texas.
- Still possible using WWV at 20 MHz, but Florida’s distance from Fort Collins (WWV transmitter site) makes it rather difficult. Not impossible; just takes a lot of time and effort.

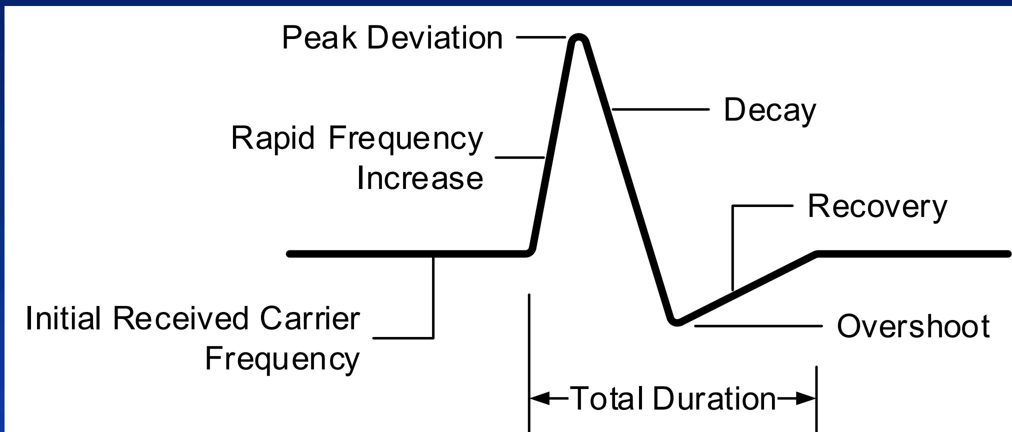
Meteor Scatter

- Example from Tom Ashcraft, New Mexico http://www.heliotown.com



Sudden Frequency Deviations

- First described in 1960 and extensively studied throughout 1960s.
- Frequency deviation caused by Doppler shift due to change in path length via abrupt change in ionospheric electron density caused by solar X-ray flares.

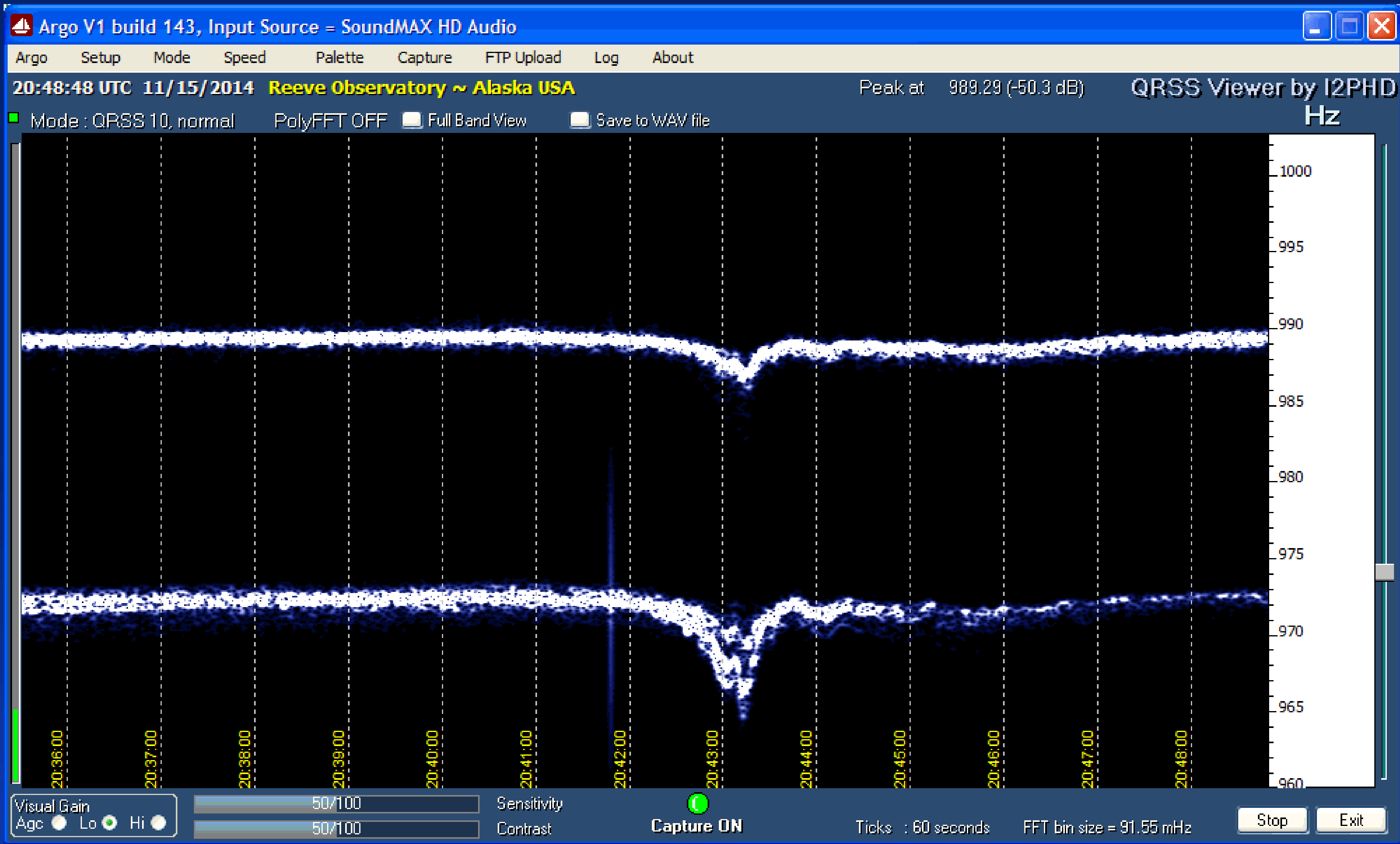


$$\Delta f = -\frac{f}{c} \cdot \left[n \cdot \frac{ds}{dt} + s \cdot \frac{dn}{dt} \right]$$

f = Carrier frequency (Hz)
c = Speed of light ($3 \cdot 10^8$ m/s)
n = Medium's Index of refraction
s = Total path length (m)
t = Time (s)

Sudden Frequency Deviations

- WWV at 15 and 20 MHz is a good carrier to monitor when terrestrial propagation conditions permit it.



Amateur Radio Astronomy Organizations

- Radio Jove
  - http://radiojove.gsfc.nasa.gov/
  - http://radiojove.org/
- Society of Amateur Radio Astronomers
  - http://radio-astronomy.org/

Further Reading

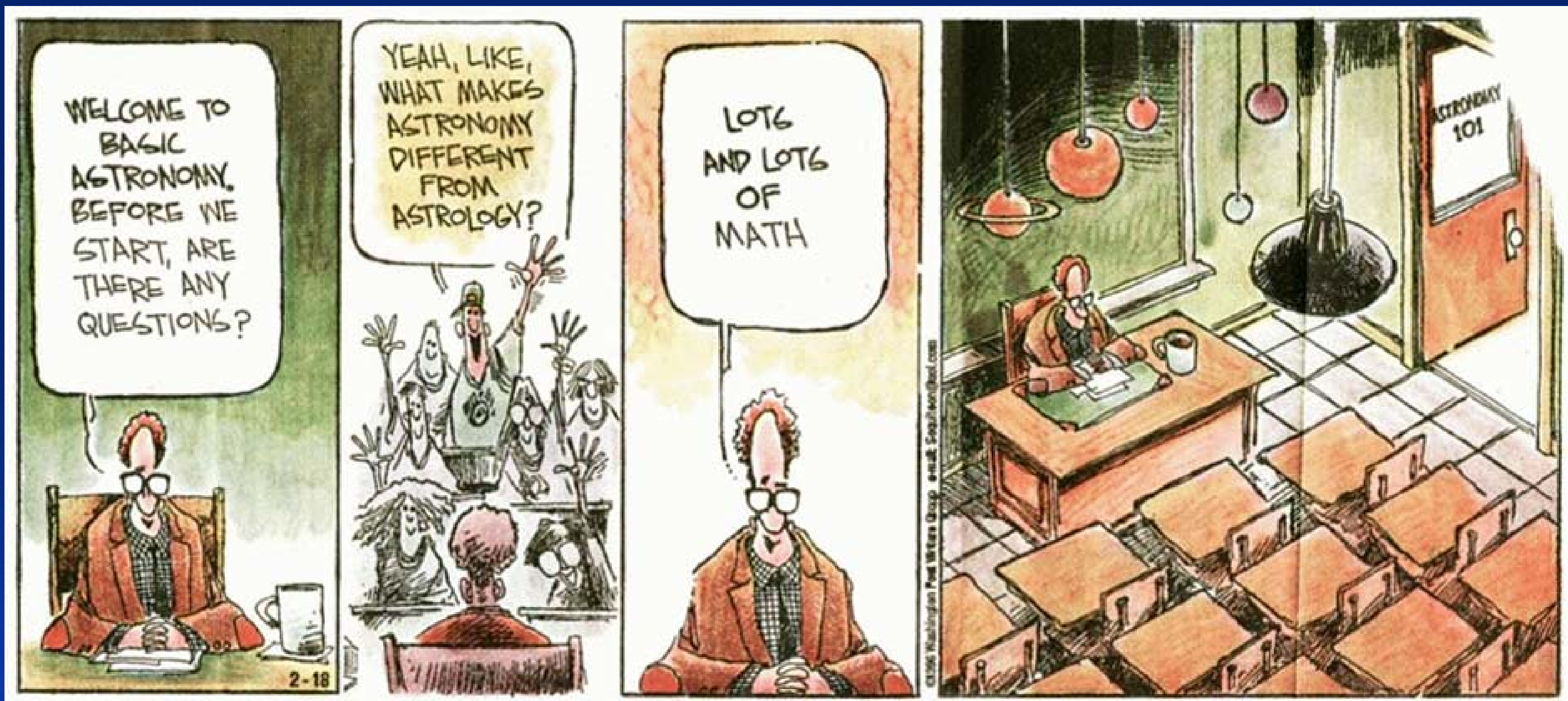
- Introductory, little to no math
  - Smith & Carr, *Radio Exploration of the Planetary System*, Van Nostrand (1964)
  - Flagg, *Listening to Jupiter*, 2nd Edn., Radio Sky Publishing (2005)
  - Smith, *Radio Exploration of the Sun*, Van Nostrand (1967)
  - Piddington, *Radio Astronomy*, Harper (1961)
  - Kraus, *Big Ear Two*, Cygnus-Quasar (1995)

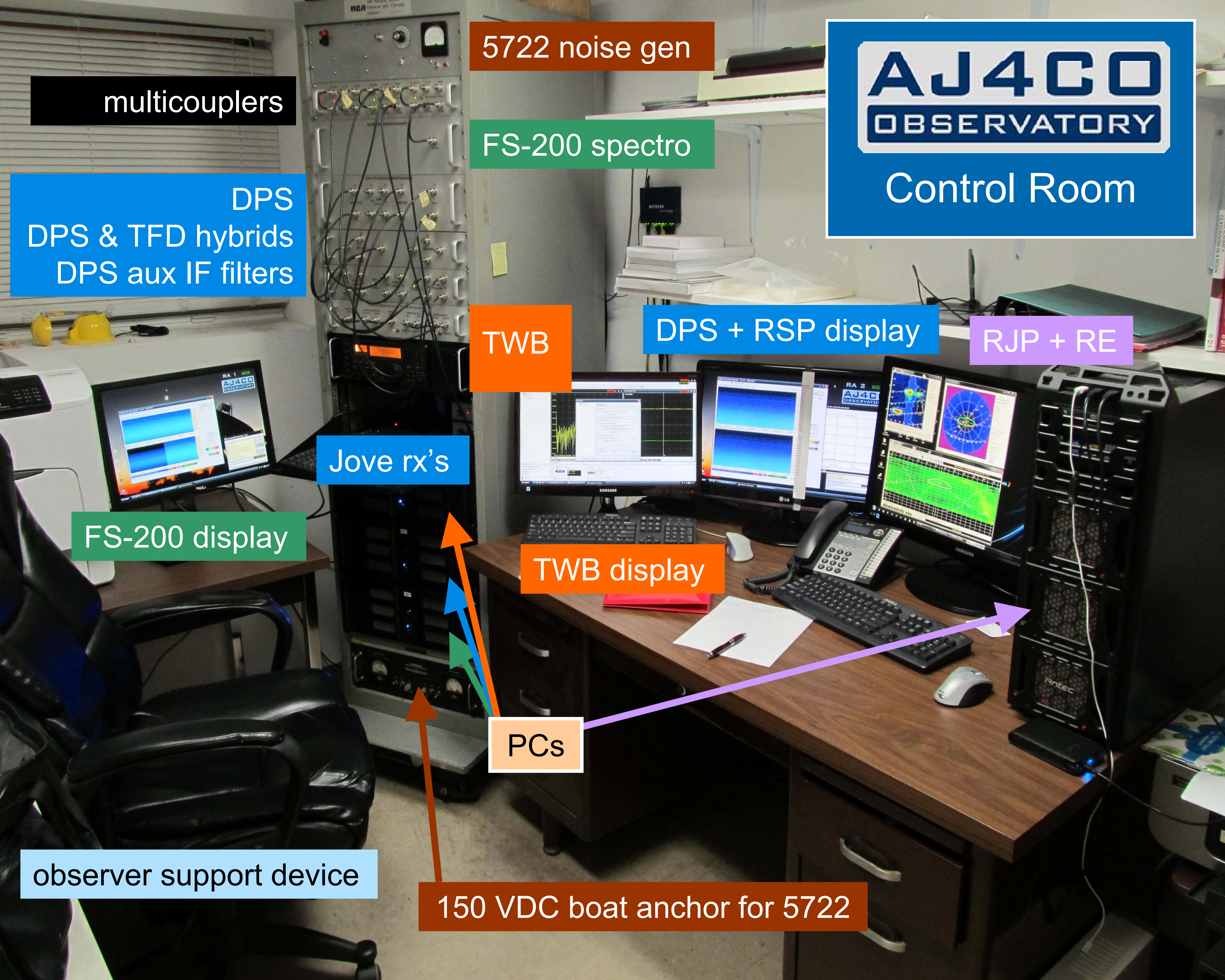
- College level texts with math
  - Christiansen, *Radiotelescopes*, 2nd Edn., Cambridje, (1985)
  - WIlson, *Tools of Radio Astronomy*, 5th Edn, Springer (2009)
  - Burke, *An Introduction to Radio Astronomy, 3rd Edn*., Cambridge (2010)
  - Marr, *Fundamentals of Radio Astronomy*, CRC Press (2016)

- The gold standards, graduate level texts with lots of math
  - Kraus, *Radio Astronomy*, McGraw-Hill (1966)
  - Kraus, *Antennas*, 2nd Edn., McGraw-Hill (1988)
  - Condon, *Essential Radio Astronomy*, NRAO (2016)

The Real World

- THEORY is when we know everything but nothing works.
- PRACTICE is when everything works but nobody knows why.
- In the real world, we use THEORY and PRACTICE:
- NOTHING WORKS AND NOBODY KNOWS WHY.




AJ4CO OBSERVATORY
Control Room
5722 noise gen
multicouplers
FS-200 spectro
DPS
DPS & TFD hybrids
DPS aux IF filters
TWB
DPS + RSP display
RJP + RE
Jove rx's
FS-200 display
TWB display
PCs
observer support device
150 VDC boat anchor for 5722

- Presenter
  - Dave Typinski is a professional businessman and amateur scientist who has been tinkering with things electrical and mechanical since he was old enough to hold a soldering iron and a Crescent wrench. He is an active member of the Radio Jove project, operating AJ4CO Observatory in High Springs, Florida.
- Contact Info
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  - http://www.typnet.net/AJ4CO