Fundamentals of Radio Astronomy

Lyle Hoffman, Lafayette College

ALFALFA Undergraduate Workshop

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Outline

- Sources in brief
- Radiotelescope components
- Radiotelescope characteristics

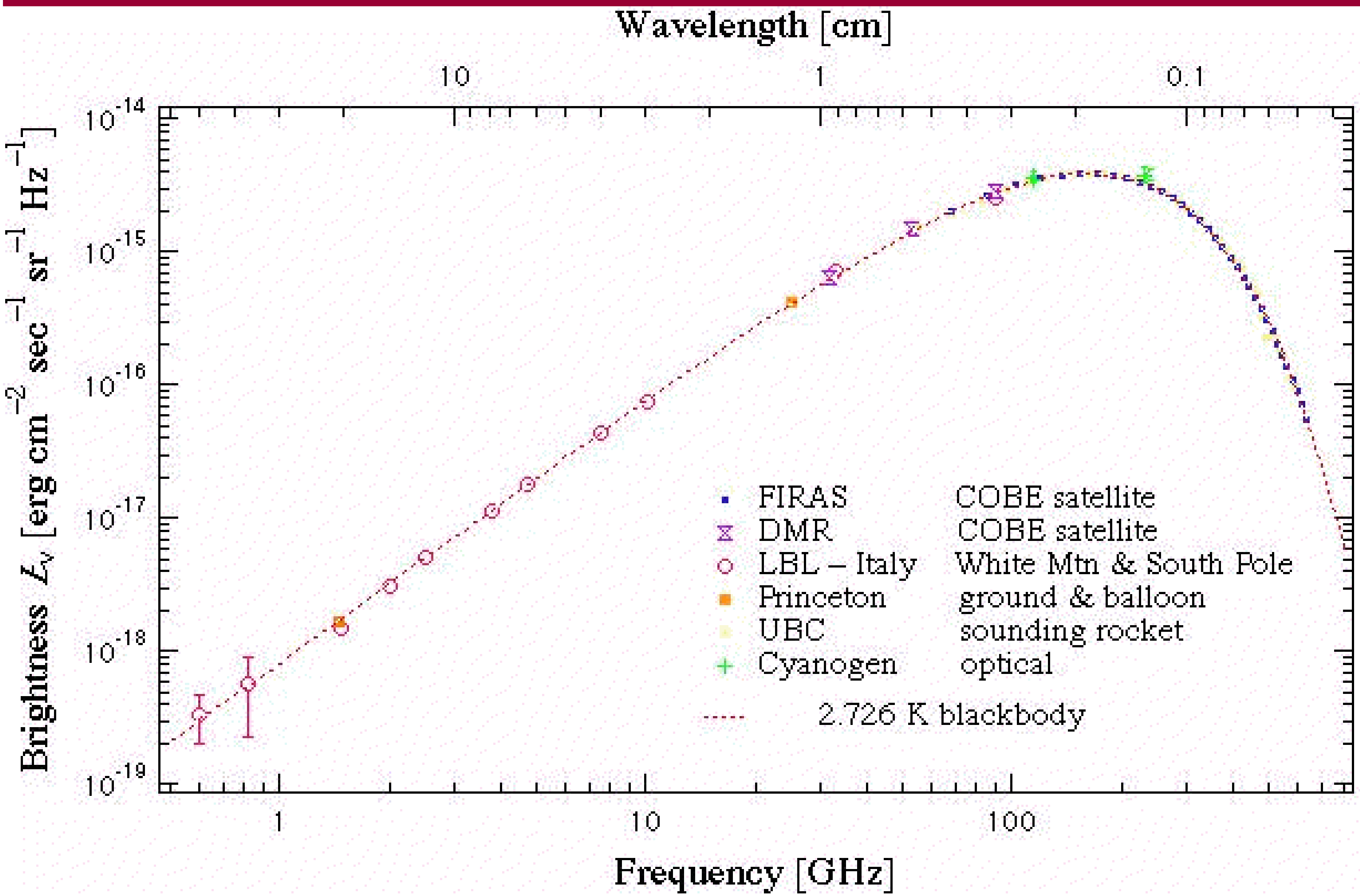
Useful Texts

Burke & Graham-Smith, *An Introduction to Radio Astronomy*
Rohlfs, *Tools of Radio Astronomy*
Stanimirovic et al., *Single-dish Radio Astronomy: Techniques and Applications*

Sources of Radio Emission

- Blackbody (thermal)
- Continuum sources
- Spectral line sources

Blackbody Sources

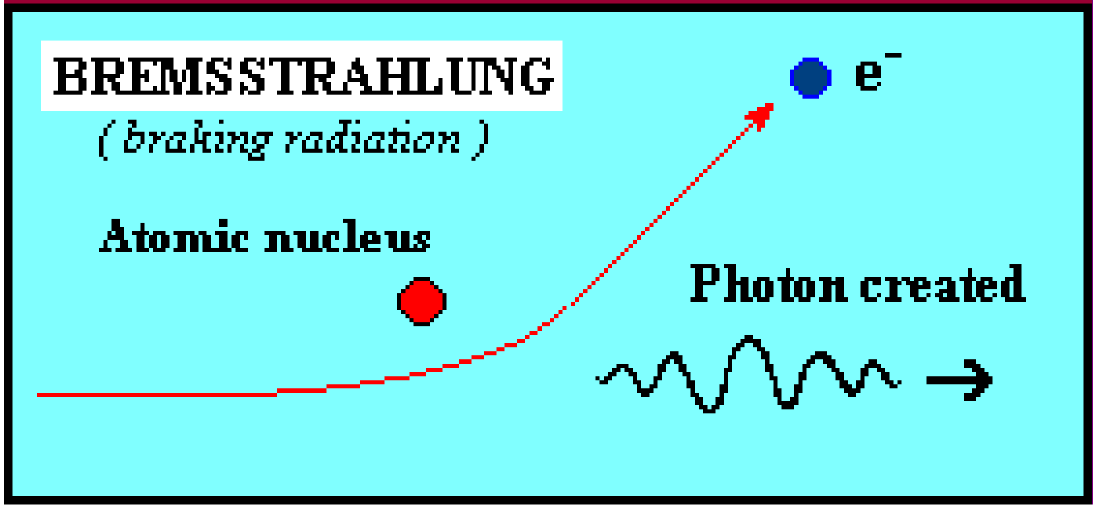


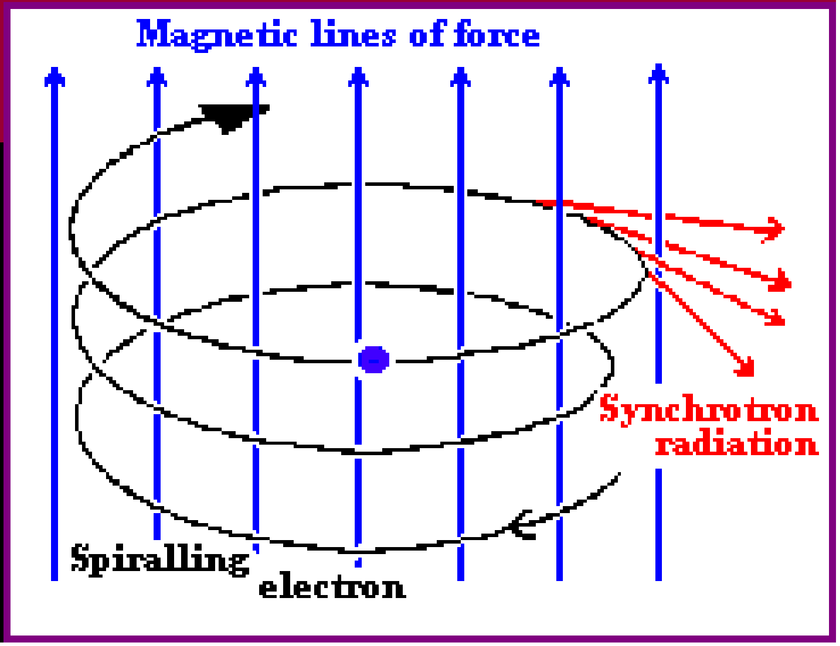
Continuum Sources

- Due to relativistic electrons:

  Synchrotron radiation

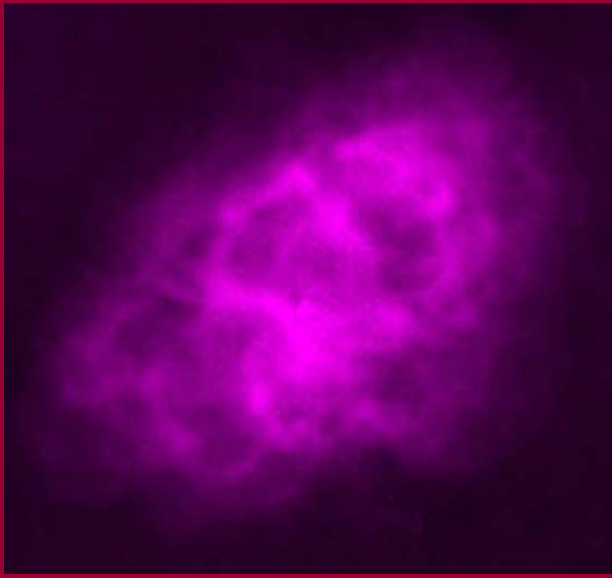
  Bremsstrahlung

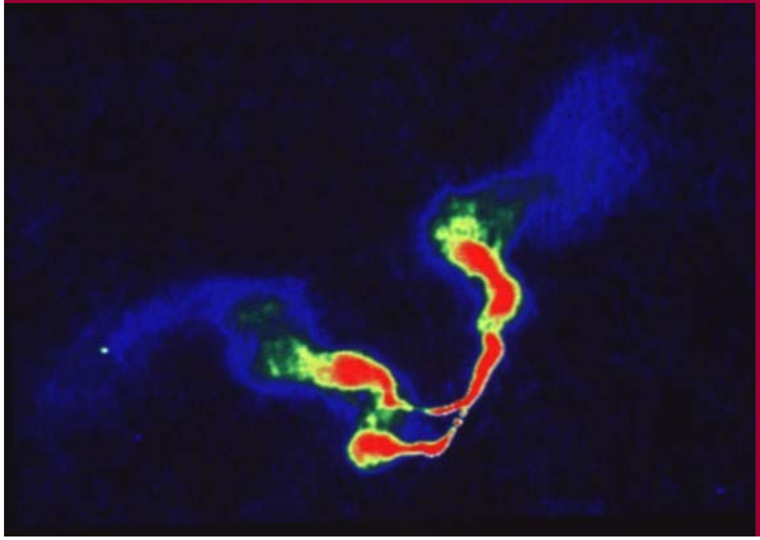


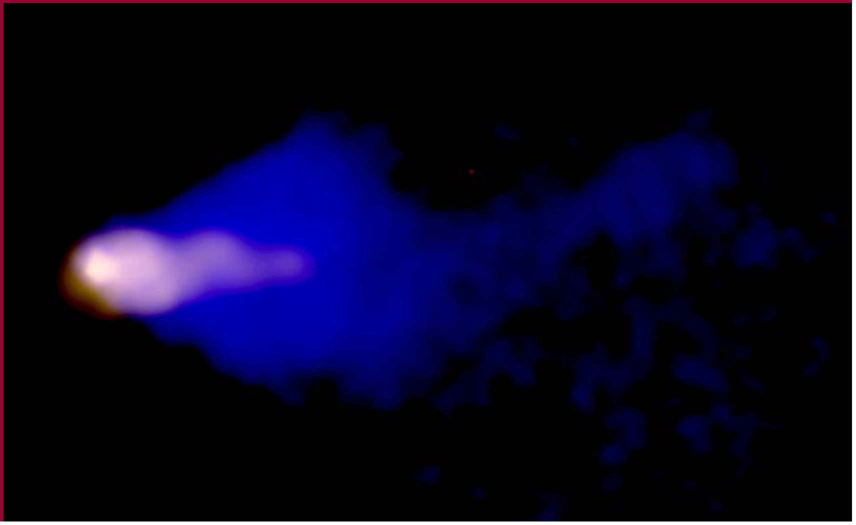


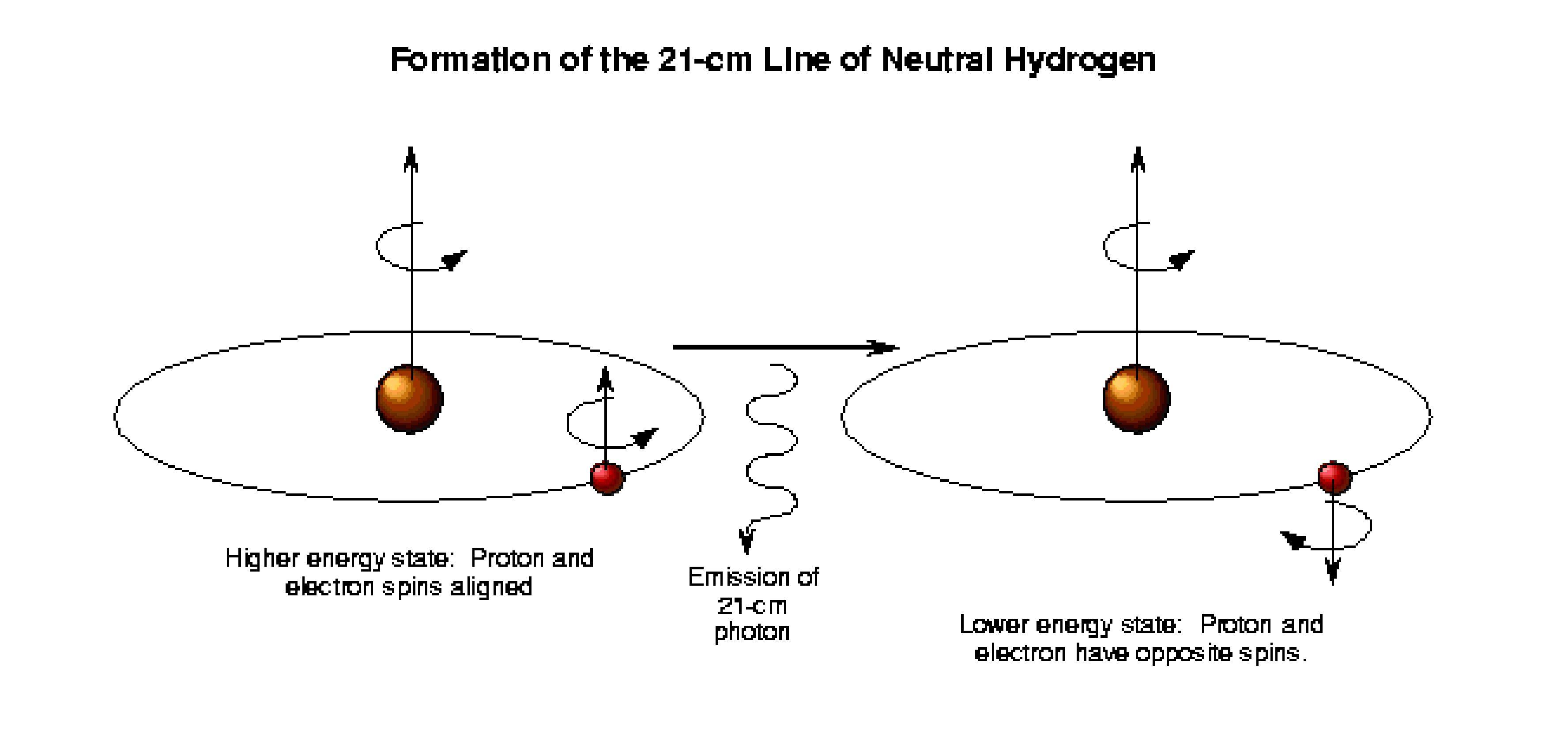
Continuum Sources

- Quasars, Active Galactic Nuclei, Pulsars, Supernova Remnants, etc.
- Used by ALFALFA for calibration







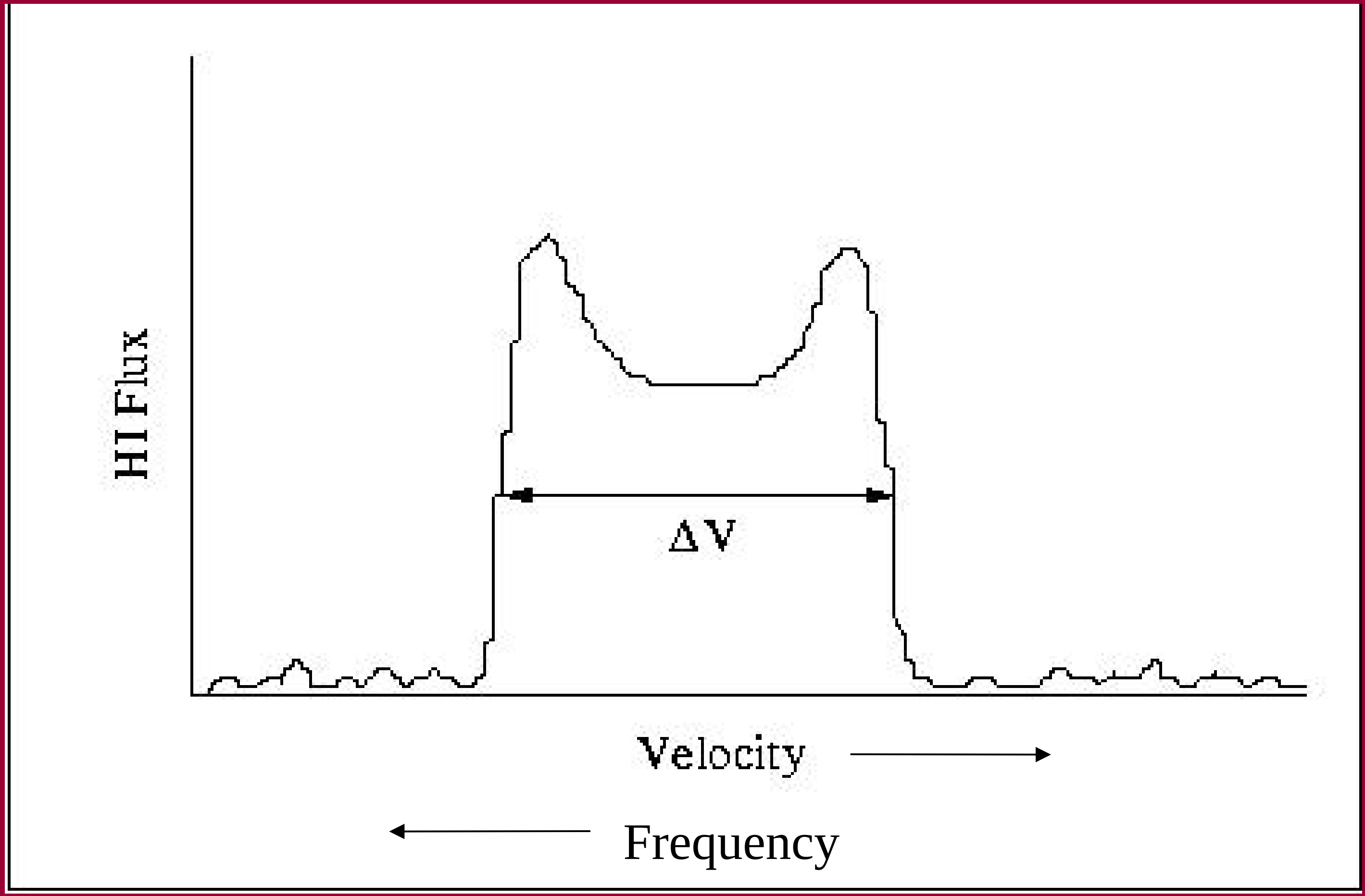


- Neutral hydrogen (H I) spin-flip transition
- Recombination lines (between high-lying atomic states)
- Molecular lines (CO, OH, etc.)

- Doppler effect: frequency shift of spectral line due to relative motion of source and observer
- Closely related: redshift due to expansion of universe
- Customarily report “velocity” as

$$cz = c(f_o - f)/f_o$$

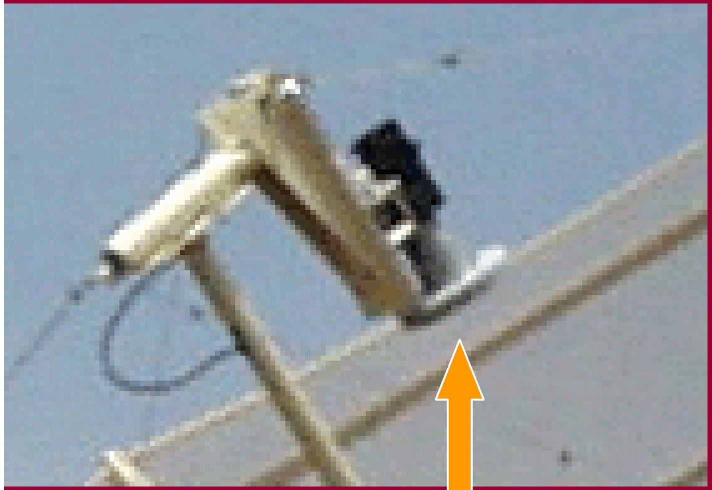
- H I spectral line from galaxy shifted by expansion of universe (“recession velocity”) and broadened by rotation



Radiotelescope Components

- Reflector(s)
- Feed horn(s)
- Low-noise amplifier
- Filter
- Downconverter
- IF Amplifier
- Spectrometer

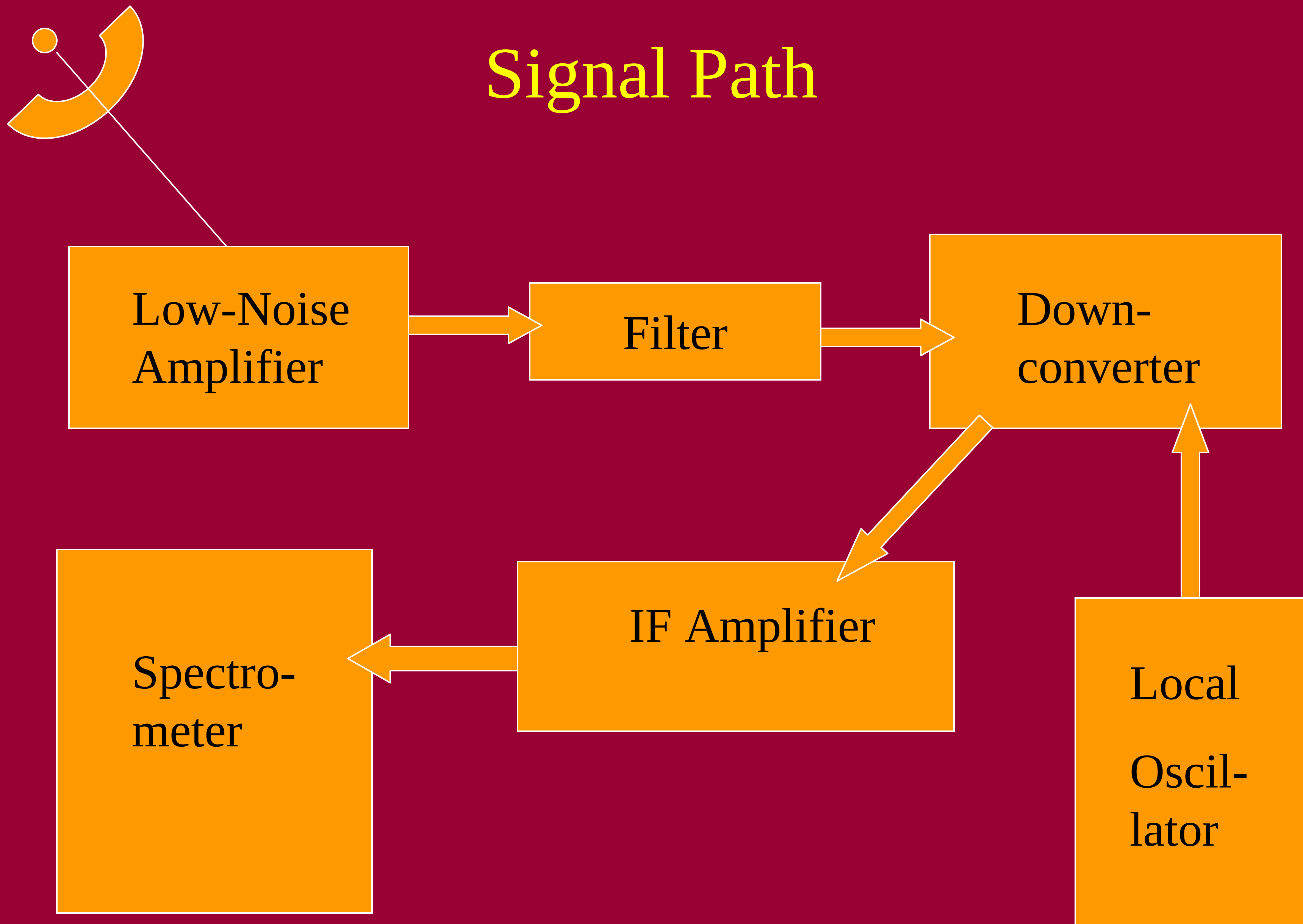
Feedhorns



4 GHz feedhorn
on LCRT

Typical cm-wave
feedhorn

Signal Path



Low-Noise Amplifier
Filter
Down-converter
IF Amplifier
Spectro-meter
Local Oscil-lator

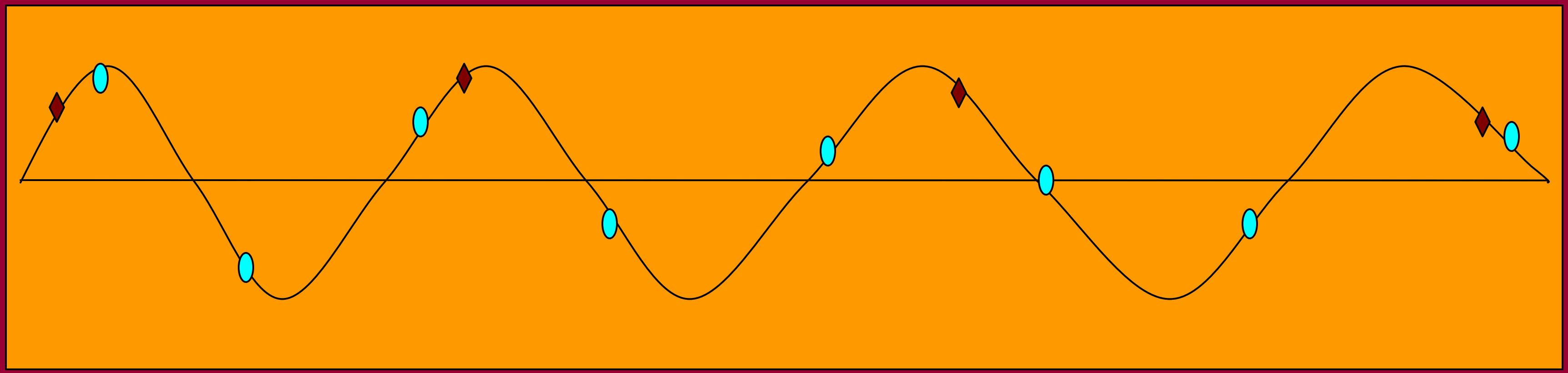
Autocorrelation Spectrometer

- Special-purpose hardware computes autocorrelation function:

  $$R_n = N^{-1}\, \Sigma_1^N\, [\upsilon(t_j)\upsilon(t_j+n\delta t)]$$

  where δt is *lag* and υ is signal voltage; integer n ranges from 0 to $(\delta t\, \delta f)^{-1}$ if frequency channels of width δf are required
- Power spectrum is discrete Fourier transform (FFT) of R_n

- Nyquist theorem: must sample at rate 2B to achieve spectrum of bandwidth B without aliassing



Diamonds: samples at rate ~B give aliassed signal near 0 Hz

Ovals: samples at rate >2B give ~correct period

Radiotelescope Characteristics

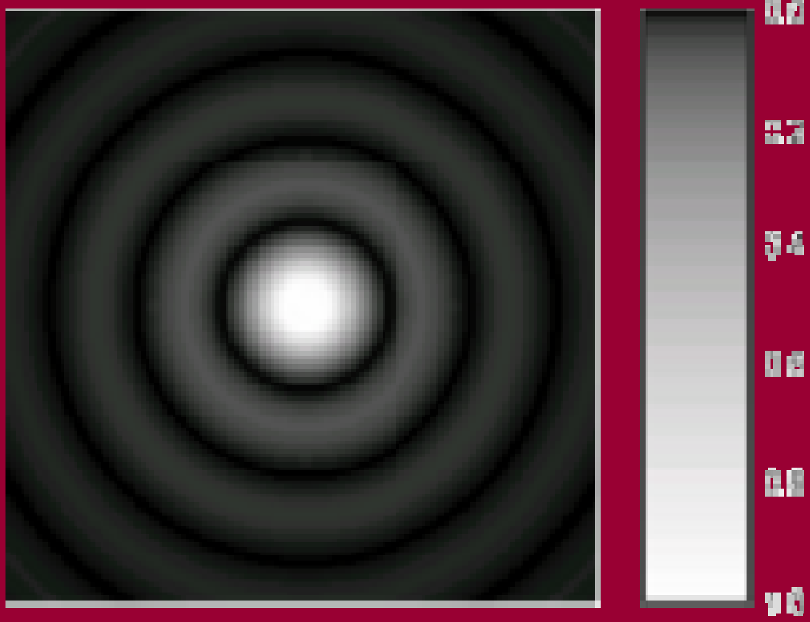
- Gain & effective area
- Beam, sidelobes, stray radiation
- Sensitivity, noise & integration time
- Polarization & Stoke’s parameters

Gain & effective area

- Received power P_{rec}
- Flux (energy per unit area per unit time) S
- Effective area $A_{eff} = P_{rec} / S$
- Gain G for transmitter is ratio of emitted flux in given direction to $P/(4\pi r^2)$
- Most emitted (received) within central diffraction max, angle ~ λ / D
- So $G = 4\pi A_{eff} / \lambda^2$

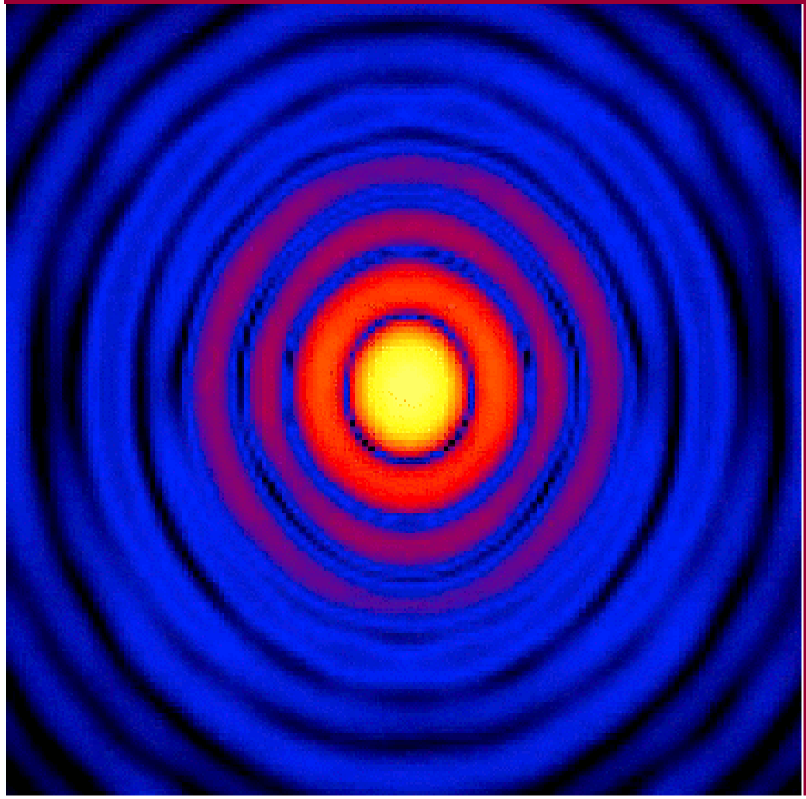
Beam & sidelobes

- Essentially diffraction pattern of telescope functioning as transmitter
- Uniformly illuminated circular aperture: central beam & sidelobe rings

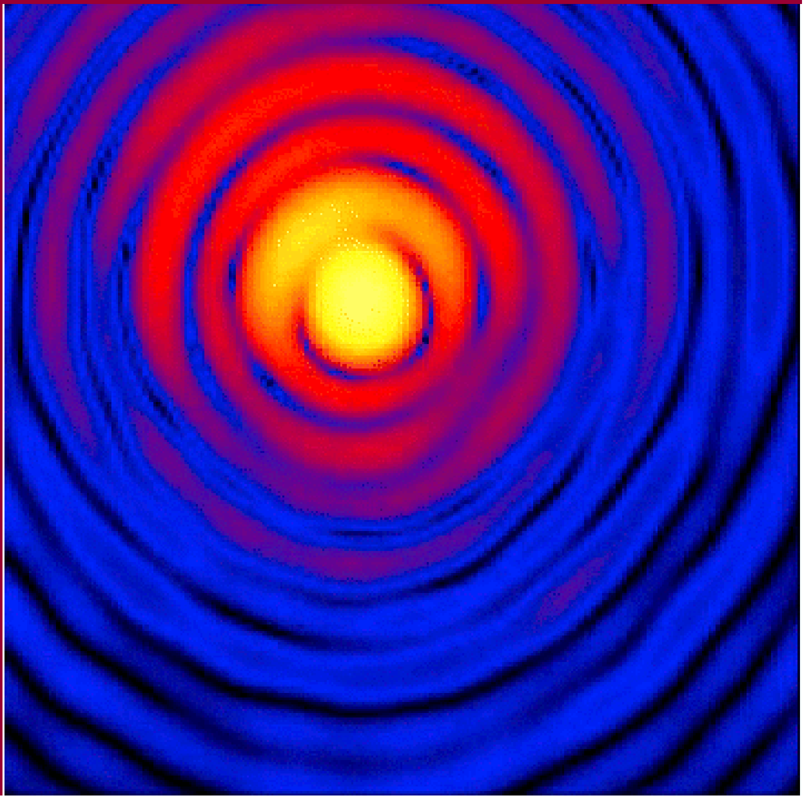


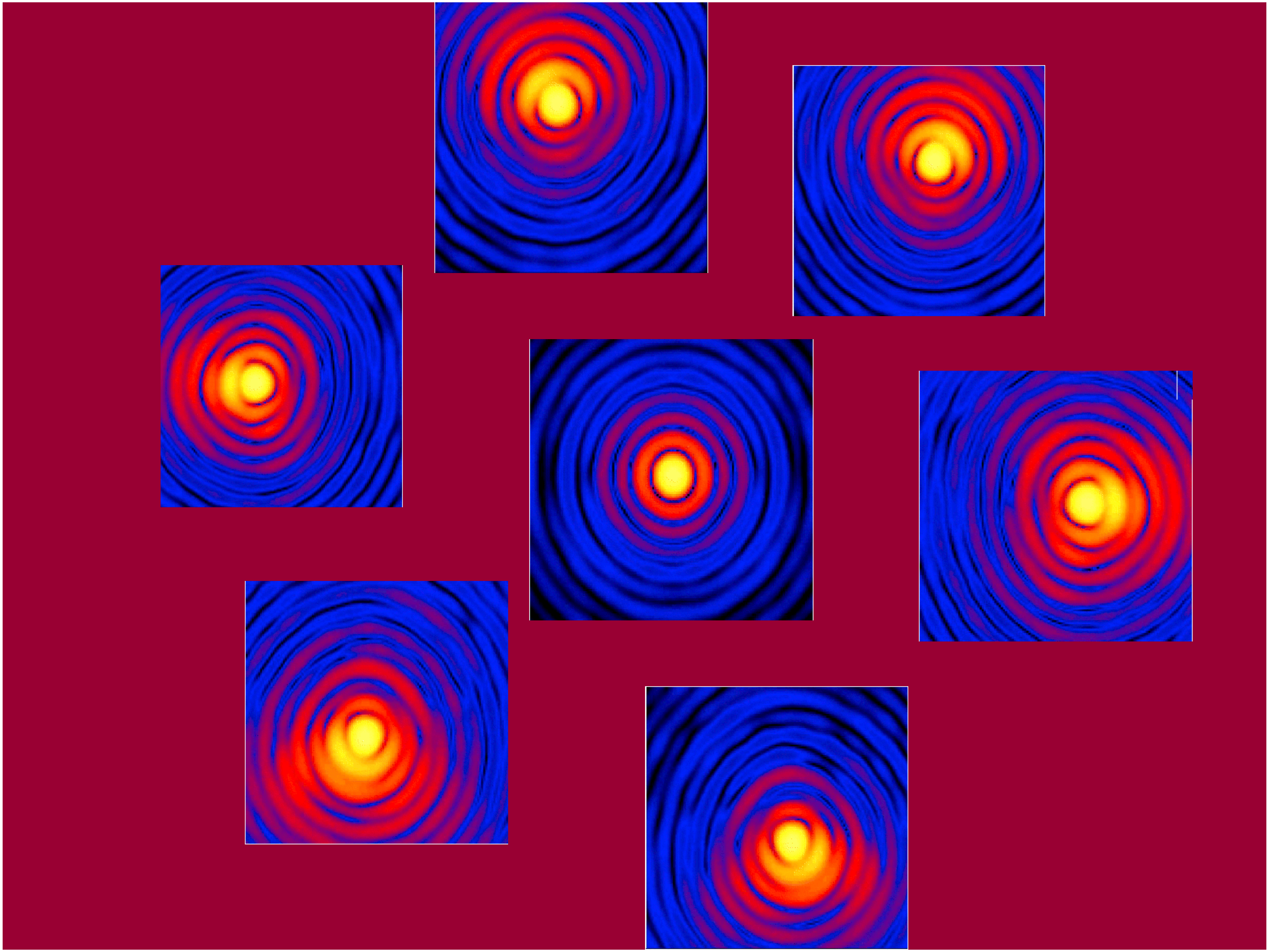
- Obstructions, non-uniform illumination by feedhorn → asymmetry and alter strengths of sidelobes vs. central beam

ALFA Center (Pixel 0)



ALFA Outer (Pixel 1)





- Emission received from pattern outside first sidelobe ring often called *stray radiation*
- FWHM of central beam is *beamwidth*
- Integrated solid angle of central beam is Ω_o
- Gain related to beam via $G = 4\pi / \Omega_o$

Sensitivity

- Limited by noise – mostly thermal noise within electronics but also from ground reflected off telescope structure into feedhorn and CMB
- System temperature: temperature of blackbody producing same power as telescope + instrumentation produces when there is no source in beam

- Often give brightness of source in temperature units: difference in effective blackbody temperature when source is in beam vs. when no source is in beam – even when source is spectral line or synchrotron radiation and brightness has little to do with actual temperature of the source
- Preferred unit (requires calibration) is Jansky:

$$1\text{Jy} = 10^{-26}\ \text{W m}^{-2}\ \text{Hz}^{-1}$$

- Limiting sensitivity for unpolarized source set by requiring signal added by source to equal rms uncertainty in T_{sys}:

$$\Delta S = 2kT_{sys}\ A_{eff}^{-1}\ (B\tau)^{-1/2}$$

(k: Boltzmann’s constant; τ: integration time)

- For spectral line work, B is set by velocity resolution required; T_{sys} and A_{eff} set by telescope and instumentation → increase sensitivity by integrating longer – but need 4 times integration time to increase sensitivity by factor of 2

Polarization

- H I sources unpolarized, but synchrotron sources are often polarized to some extent – ***E*** in plane of electron's acceleration
- Single receiver (LNA) can respond to only single polarization at any instant– either one component of linear polarization or one handedness of circular polarization
- So two receivers required to receive both polarizations

- Linear E_x and E_y with phase difference ϕ
- Stokes' parameters:

$$I = E_x^2 + E_y^2$$

$$Q = E_x^2 - E_y^2$$

$$U = 2E_xE_y\cos\phi$$

$$V = 2E_xE_y\sin\phi$$

- Unpolarized source: $E_x = E_y$ and $\phi = 0$
- So Q = 0, V = 0, and I = U for H I; usually report only Stokes' I or total flux = sum of fluxes of x and y polarizations