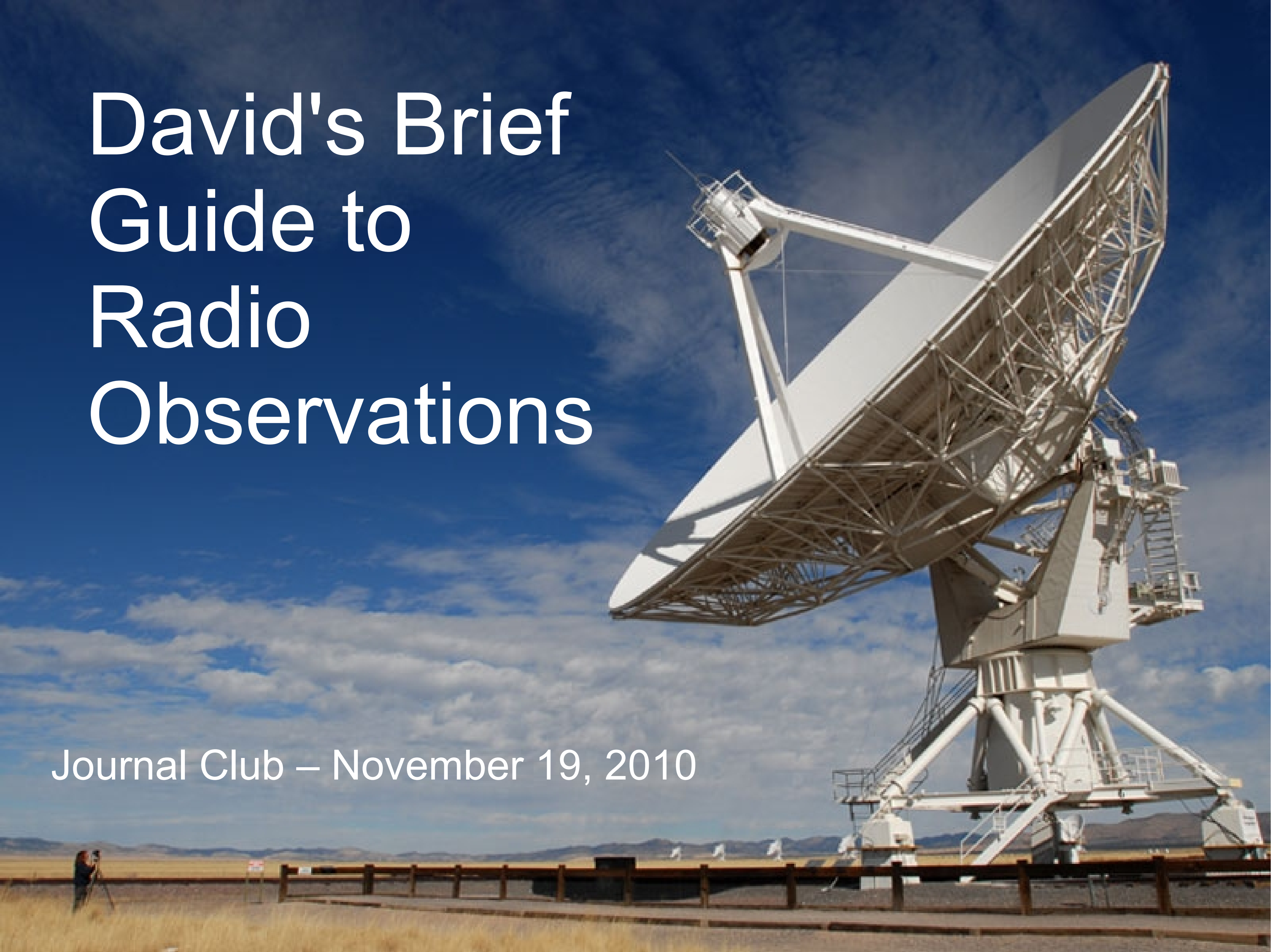
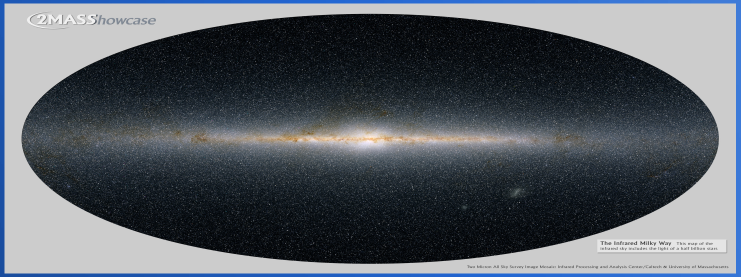
David's Brief Guide to Radio Observations

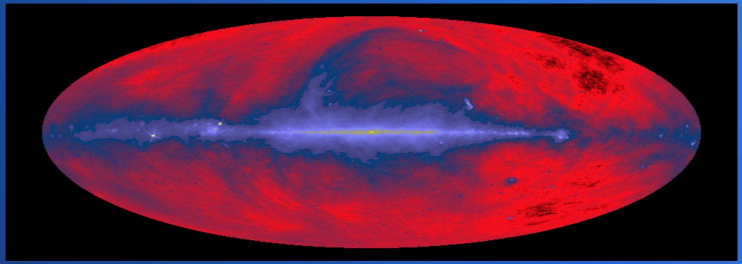


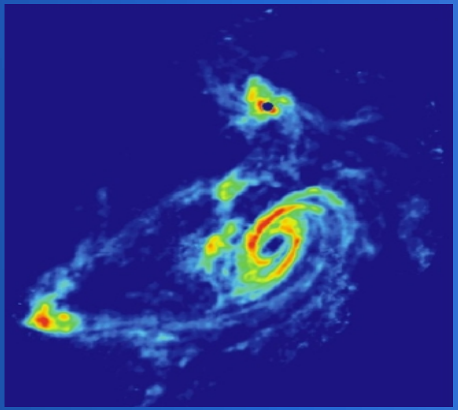
Journal Club – November 19, 2010

The Radio Regime

- Wavelengths 100 m ~ 0.1 mm
- No one single telescope ideal to effectively cover full range
- Wide variety of radiation mechanisms and low attenuation make it advantageous for study of the universe

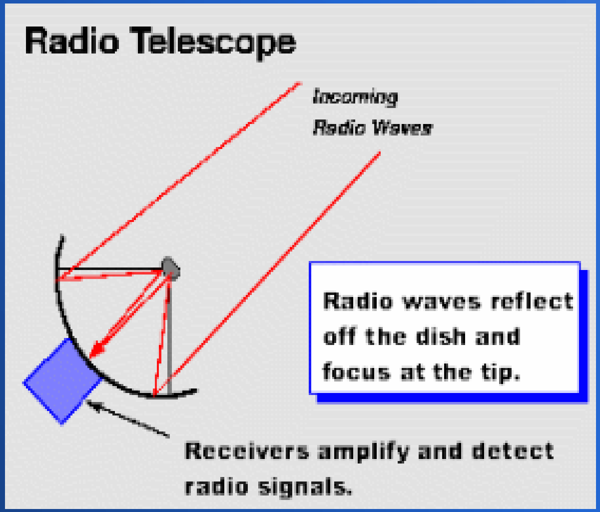


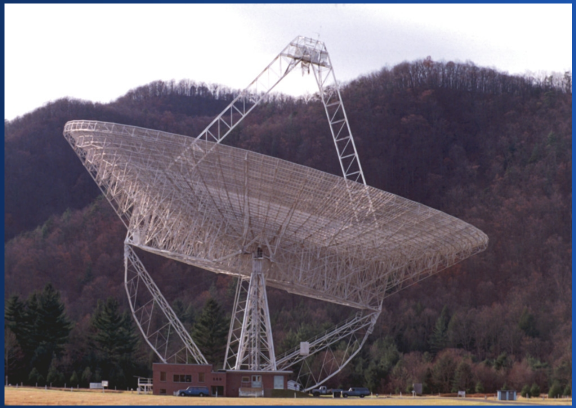




Radio Telescope Design

- Basic design similar to most optical telescopes
- These telescopes need to be big to obtain
  - Resolution ($\theta \sim \lambda/d$)
  - Sensitivity
- Size can be an issue...





Radio Telescope Design

- Certain telescopes get around this issue

SKA: Array of smaller dishes working together

Arecibo: Non-moving primary mirror

Design Considerations

- Effect of gravity on dish
  - Deformation limits available wavelengths
  - Difficult to get GBT sized mm-wave telescopes
- Secondary mirror placement:
  - Aperture blockage affects beam pattern
  - Secondary mirror plus support structure can scatter ground radiation into detector

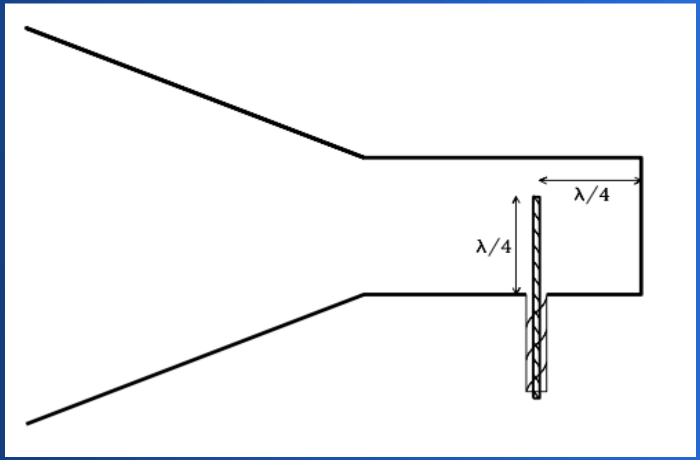
Actuators on the GBT dish counter the effects of gravity

GBT – off axis design → no blockage

Feed Horns

- Feed horns are waveguides that focus EM waves towards the antenna
- Size of waveguide wavelength dependent

L-band feed horn



Radiometers

- Radiometers measures average power received by a radio telescope a desired frequency range and time
- Basic components
  - 1) bandpass filter – only allows specific frequencies through
    - Similar concept to U,B,V,R,I
  - 2) Square-law detector ($P \sim V^2$)
  - 3) amplifier – strengthens extremely weak radio signals

GBT Receiver Room

Radiometers

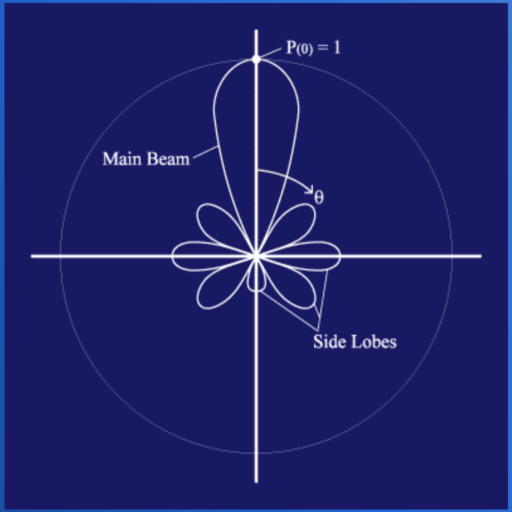
4) Integrator – average the signal over the desired period

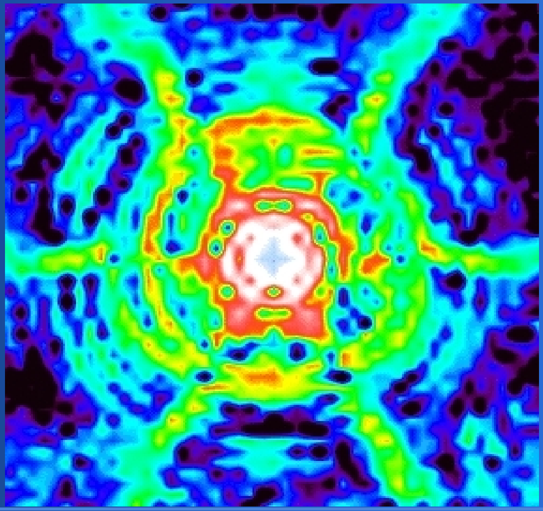
Many receivers employ a *local oscillator*

- Combines incoming signal with known tunable sinusoidal signal: result passed to rest of receiver
- Remaining components can operate at a fixed frequency

Beam Pattern

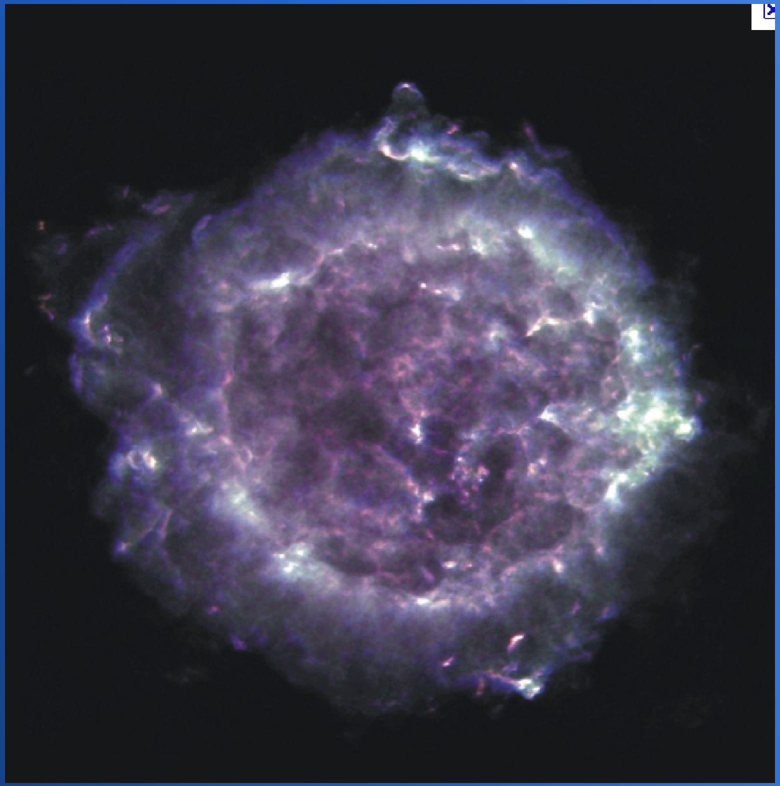
- Single-dish telescopes are effectively single-pixel cameras
- Most flux comes from ”main beam”, but flux collected from all directions (side-lobes/stray radiation)
- Low resolution
  - e.g. Arecibo at 1.4GHz: FWHM ~ 3.5'
  - e.g. IRAM 30m at 115 Ghz: FWHM ~ 22”





Calibration

- Use a standard source (e.g. Cas A)
- Alternatively:
  - Inject a known level of noise into system
  - Cover feed with blackbody of known temperature



Cas A

Detector Sensitivity

- Noise of the system summarized by ”system temperature”
  - Side-note: radio astronomers measure noise and signals in units of temperature; proportonal to flux density

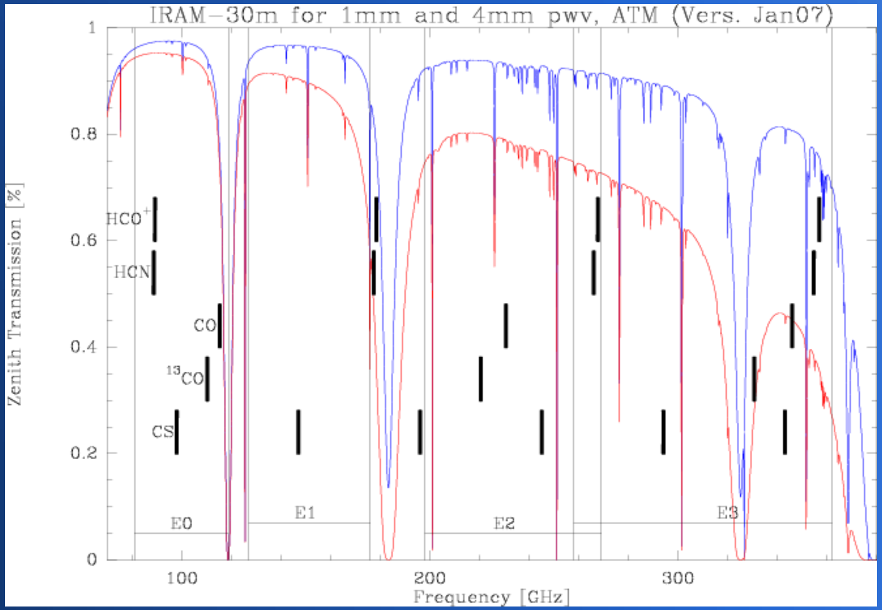
$$T_{\rm sys} = T_{\rm cmb} + \Delta T_{\rm source} + T_{\rm atm} + T_{\rm spillover} + T_{\rm rcvr} + \ \ldots$$

  - Liquid helium cooling is a must!
- Gain fluctuations
  - Reach a point where longer exposures *increase uncertainty*
  - Can reduce this by constantly calibrating telescope (Dicke Switching)

Atmospheric Transmission

- Atmospheric transmission
  - Particularly important in the sub-mm
  - Site an important factor (high and dry ideal)

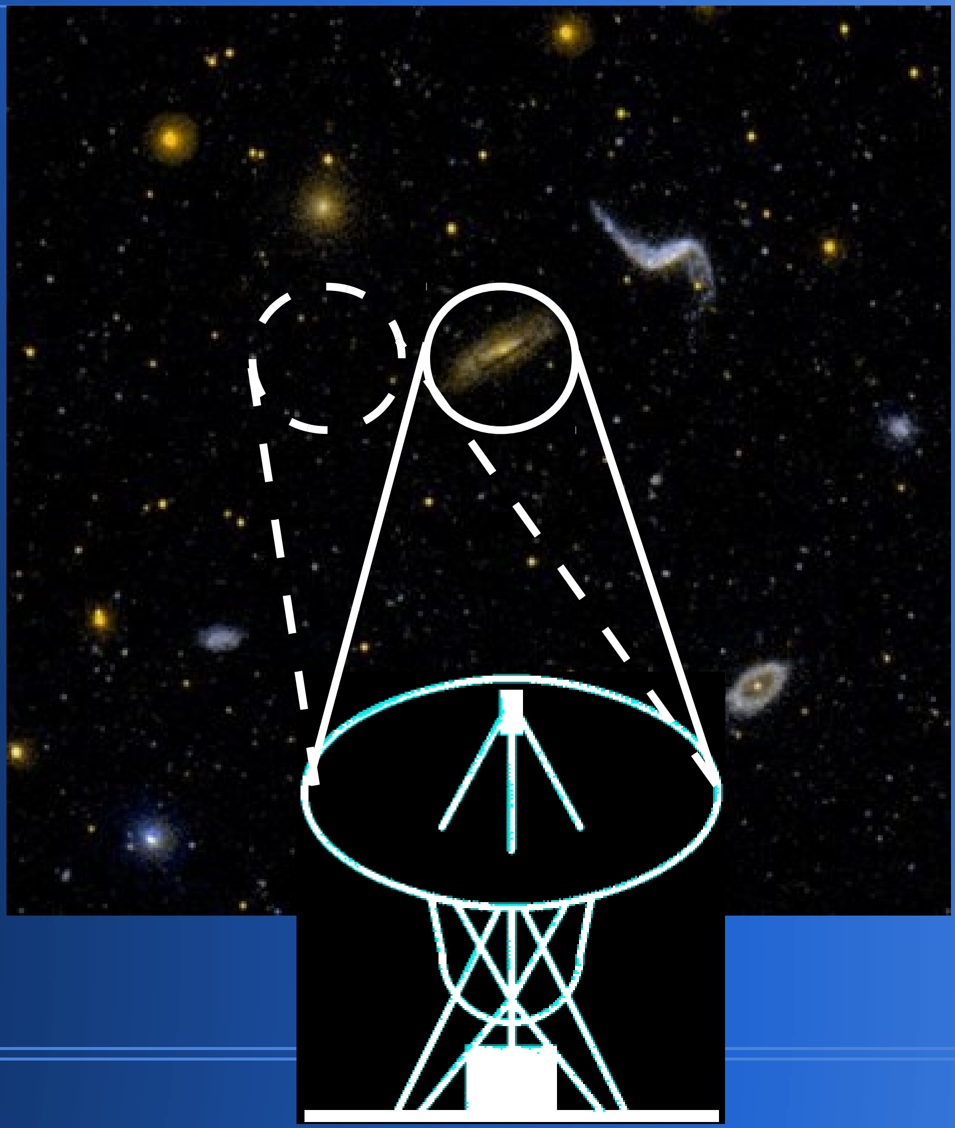
ALMA site in the Atacama Desert



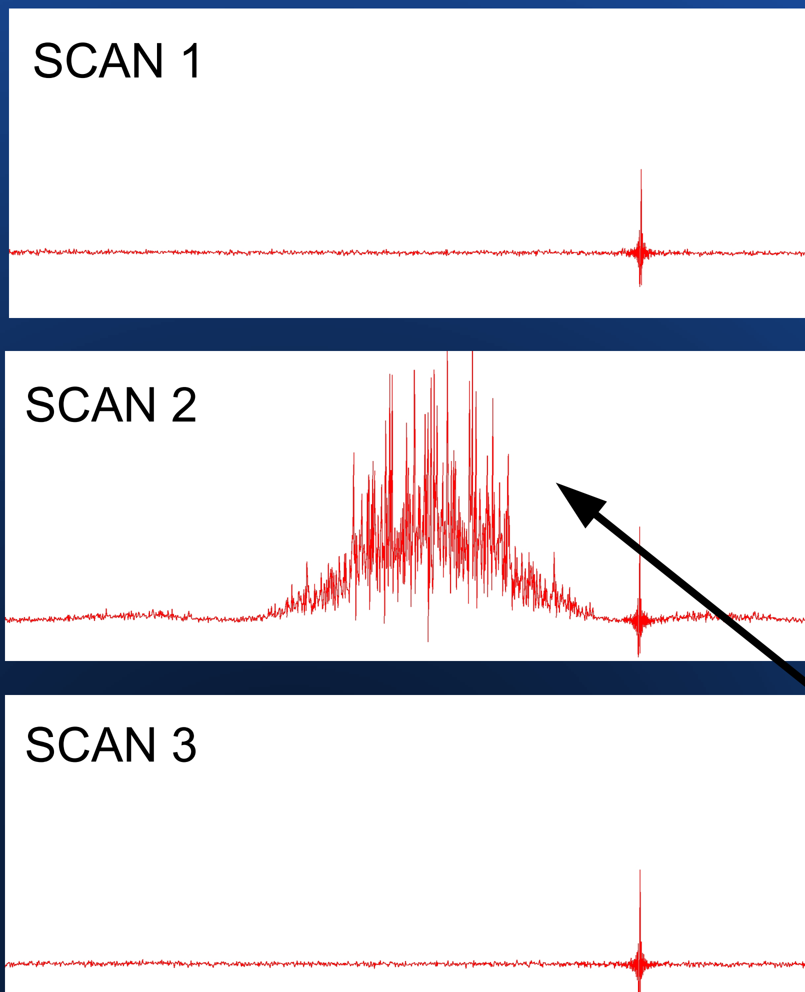
Atmospheric transmission at the IRAM 30m telescope

The Varying Atmosphere

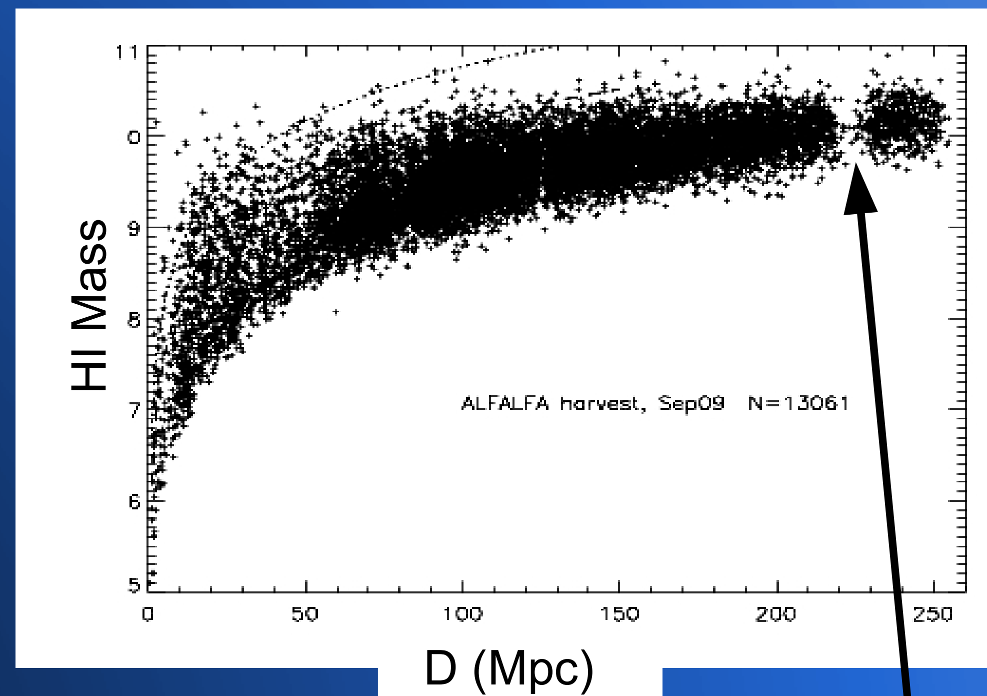
- Water vapor not well mixed with the atmosphere
  - Leads to fluctuations in sky
  - Aleviate this with *position switching* or *frequency switching*
  - ...but double you're observing time



RFI – Radio Frequency Interference



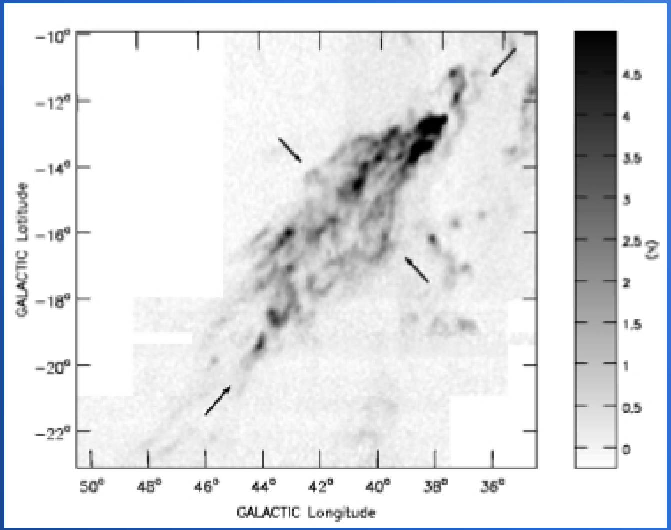
GPS satellite burst



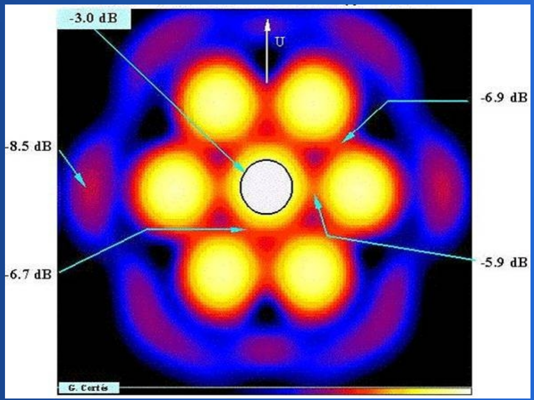
San Juan airport radar frequency

Single-Dish Mapping

- Mapping can be done ("on-the-fly"), but is very time consuming
- Low resolution means mapping limited to large targets
- Multi-beam receivers (e.g. ALFA on Arecibo or HERA on IRAM 30m) increase efficiency of mapping
  - But these are not small (don't expect any 12 megapixel radio telescopes)



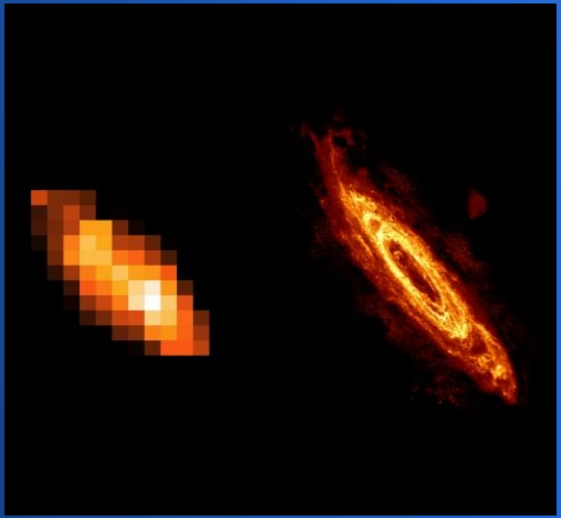
The Smith Cloud (Lockman et al. 2008) mapped with the GBT



ALFA beam pattern on Arecibo

Interferometers

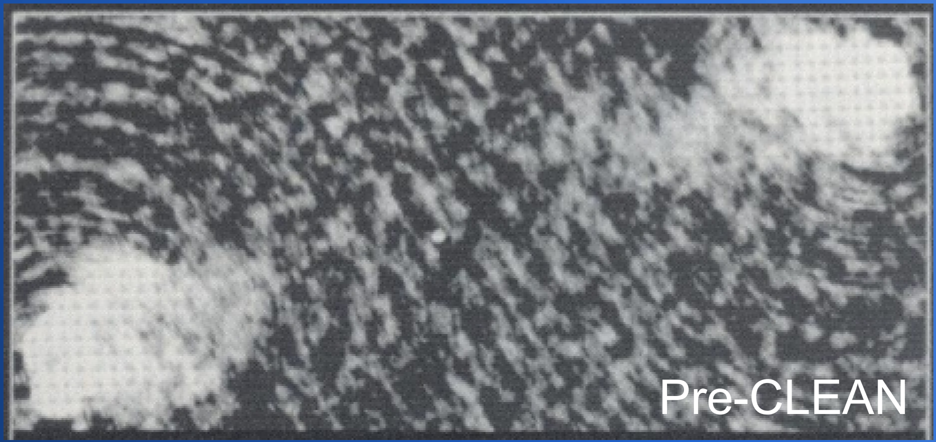
- Interferometers are becoming increasingly dominant
- **Advantages**:
  - Resolution (e.g. EVLA at 21cm = .15", ALMA at 115 Ghz = 0.03")
  - Collecting area can be arbitrarily large)
  - Simpler engineering
  - Less sensitive to gain/atmosphere fluctuations

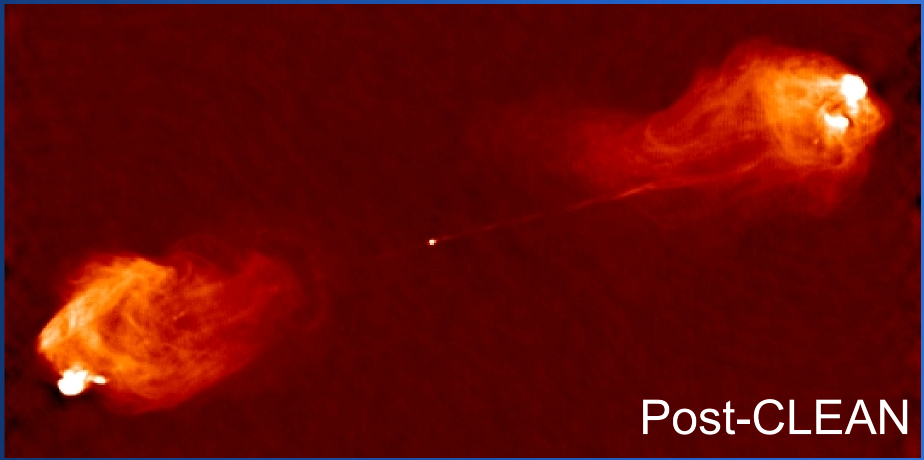


Single-dish versus interferometer resolution

Interferometers

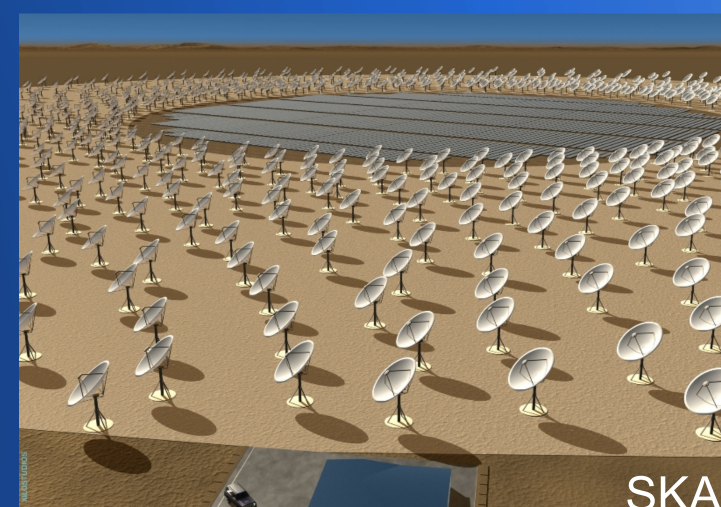
- **Disadvantages:**
- Traditionally less sensitive
  - Small filling factors of large baselines
  - Minimum spacing of dishes (miss flux at scales > λ/D_{min})
- Demanding data analysis due to more artifacts (e.g. Side-lobe effects)





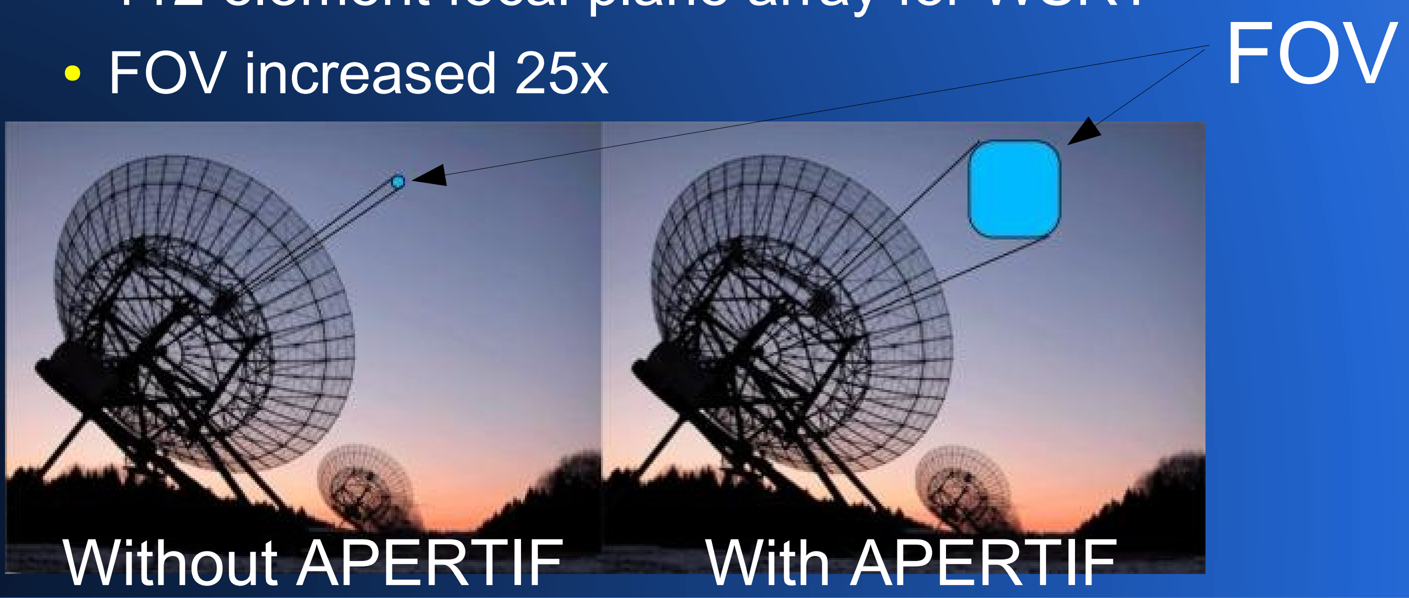
What's New in Radio Astronomy

- Massive arrays dominating current radio projects (e.g. ALMA, SKA and its precursers)
  - Designed with compact (for flux recovery) and dispersed (for resolution) configurations
  - Higher sensitivity (by factors of ~10-20) and resolution (possibly better than HST)
  - Wider window in the submm



What's New in Radio Astronomy

- More advanced multi-pixel receivers
  - Yield much faster imaging
  - e.g. APERTIF
    - 112 element focal plane array for WSRT
    - FOV increased 25x



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