


Why Single Dish?

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with **IMMENSE THANKS** to

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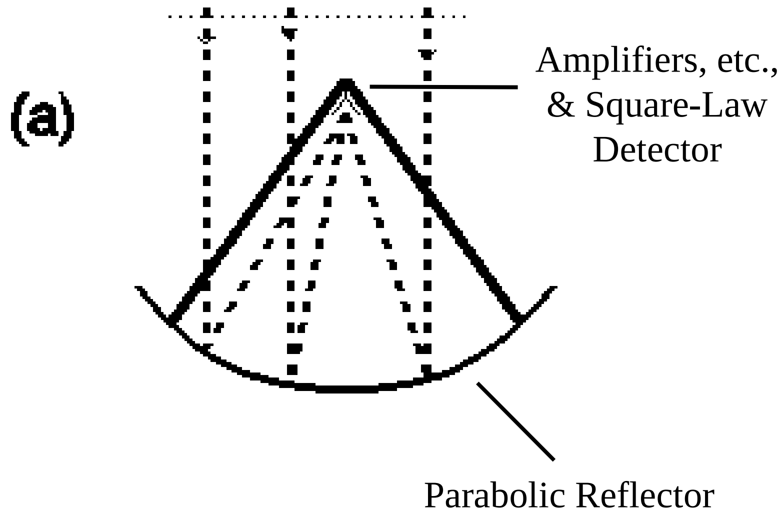
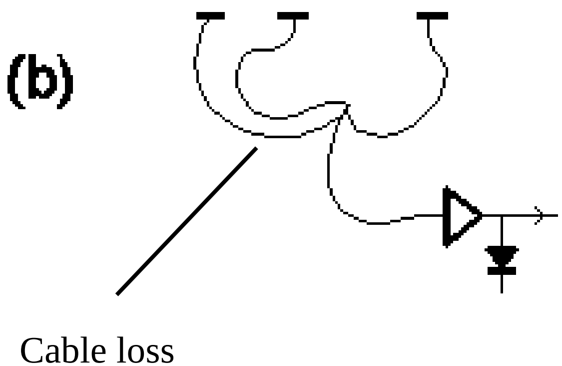
GBO/AO Single-Dish Observing School. Green Bank, Sept. 2021

What are the Alternatives to Single Dishes?



Single Dish.

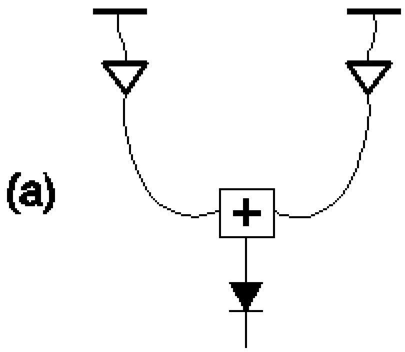
Free space propagation & reflection to bring all signals together in phase



Phased Array.

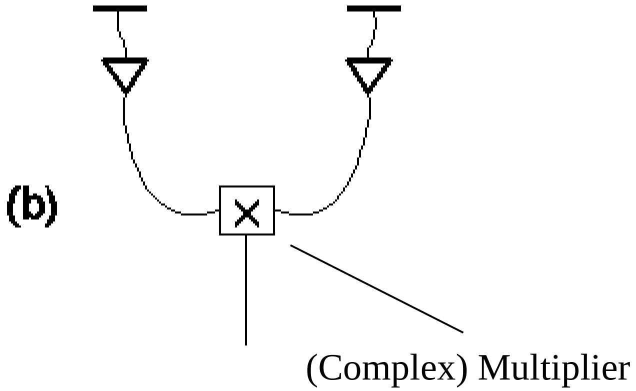
Cables of just the right length, to bring all signals together in phase

Interferometer Options



Adding Interferometer or
Phased Array

A single dish with missing metal.



Correlation or
Multiplying interferometer

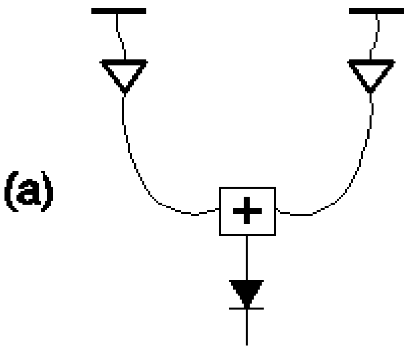
All aperture synthesis radio telescopes are made up of multiple correlation interferometers

Phased Array (Adding Interferometer) *vs.* Correlation Interferometer

2-Element Phased Array:

Signal voltage into each antenna element: **a, b**

Noise voltage of each antenna amplifier: **A, B**



Before detector:

$$(A + a) + (B + b)$$

After detector:

$$[(A+a) + (B+b)]^2$$

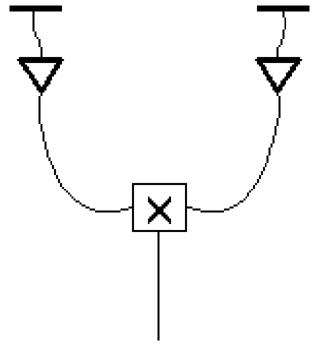
or

$$A^2 + B^2 + a^2 + b^2 + 2.(A.a + A.b + B.a + B.b + A.B + a.b)$$

Time-averaged products of uncorrelated quantities tend to zero, so this averages to just:

$$A^2 + B^2 + a^2 + b^2 + 2.a.b$$

(b)



Multiplying or Correlation Interferometer:

•After multiplier: **(A + a).(B + b)**

or

A.B + A.b + a.B + a.b

NB:
multiplication + averaging
= correlation

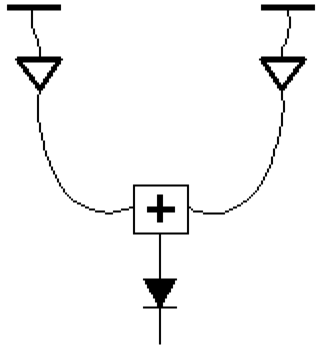
•After averaging, uncorrelated products tend to zero, so this becomes just;

a.b

The averaged output no longer depends on A or B, the internally generated amplifier noise voltages (ignoring statistical fluctuations)

In Summary

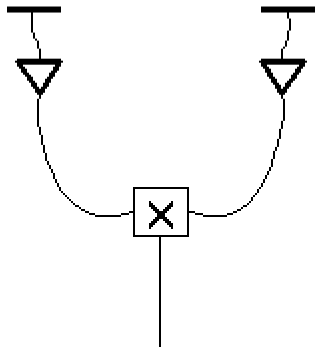
(a)



Adding Interferometer or Phased Array

- $A^2 + B^2 + a^2 + b^2 + 2.a.b$

(b)



Correlation or Multiplying Interferometer

- **a.b**

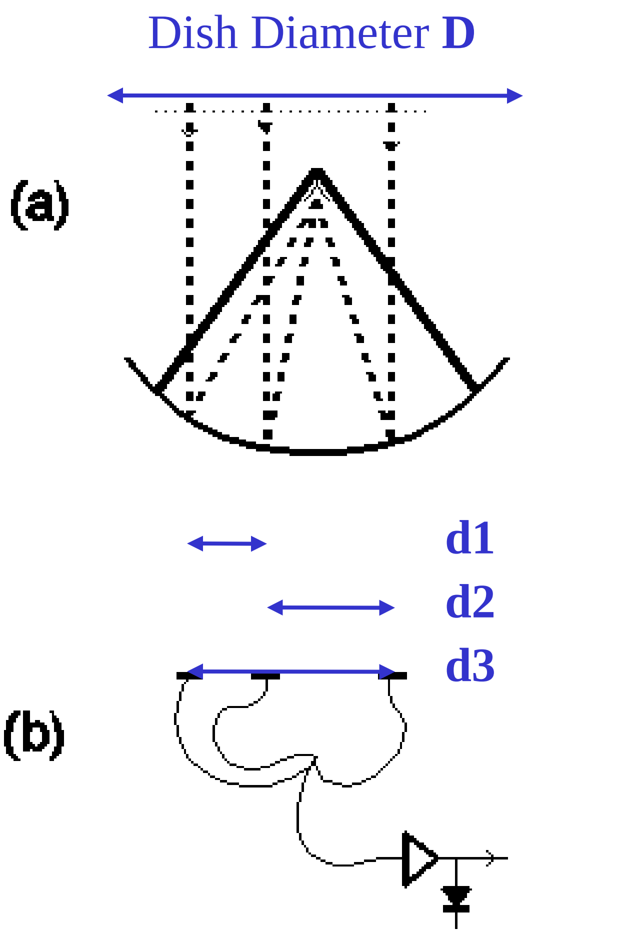
Comparison of Phased Array (Adding Interferometer) *vs.* Correlation Interferometer

- The **Phased Array (Adding Interferometer)** is the same as the **Single-dish telescope**, (just missing some metal & using more cable instead).

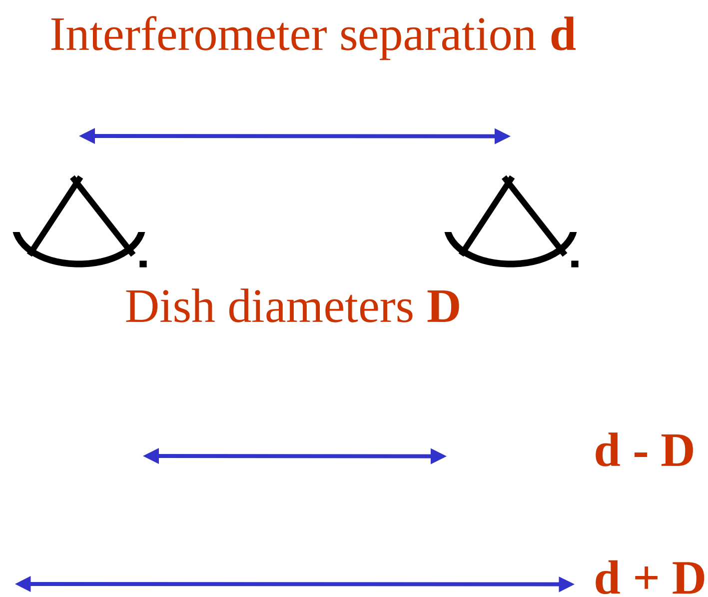
- **Single Dish/Phased Array** are ***very*** susceptible to changes in receiver gain, **and** to changes in receiver noise temperature.

- The **Correlation Interferometer** is essentially immune to receiver gain and noise changes.

- Some source distributions, or combination of sources may be ***invisible*** to the **Correlation Interferometer**. This includes angularly very extended distributions.

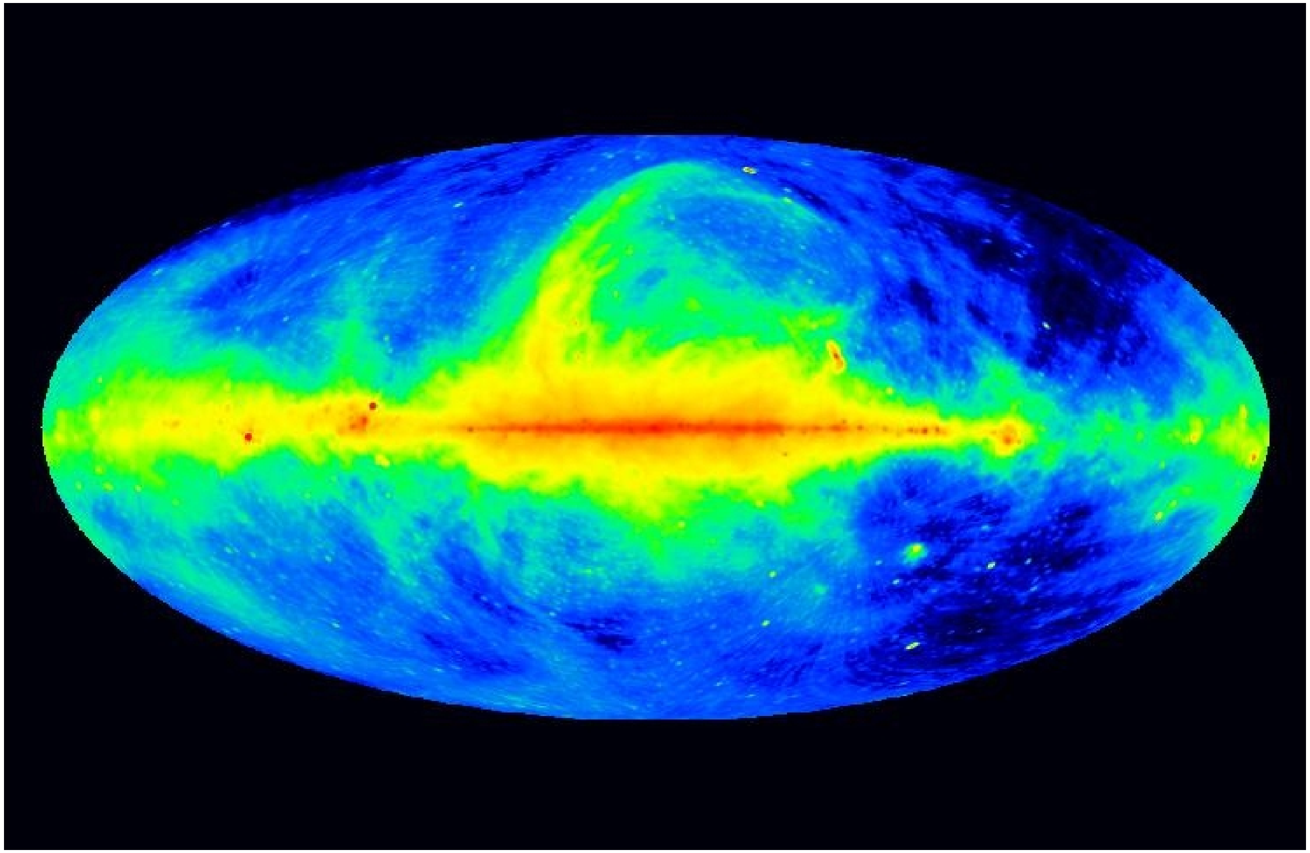


A single dish of diameter **D** includes all baselines from **0** to **D**



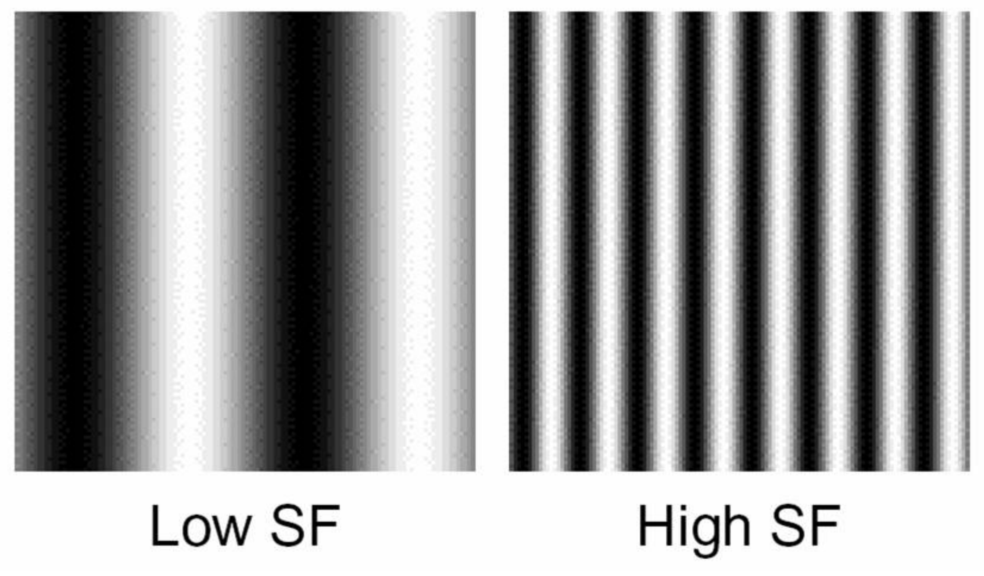
A correlation interferometer of separation **d**, using dishes of diameter **D**, includes all baselines from **d – D** to **d + D**

The Whole Radio Sky (408 MHz -- λ73 cm)



Made with 4 large single-dish telescopes. Contains all the flux in the sky (including the 3 K Cosmic Microwave Background!) Could only have been made with single dishes. (Haslam et al. 1982)

Celestial Spatial Frequencies

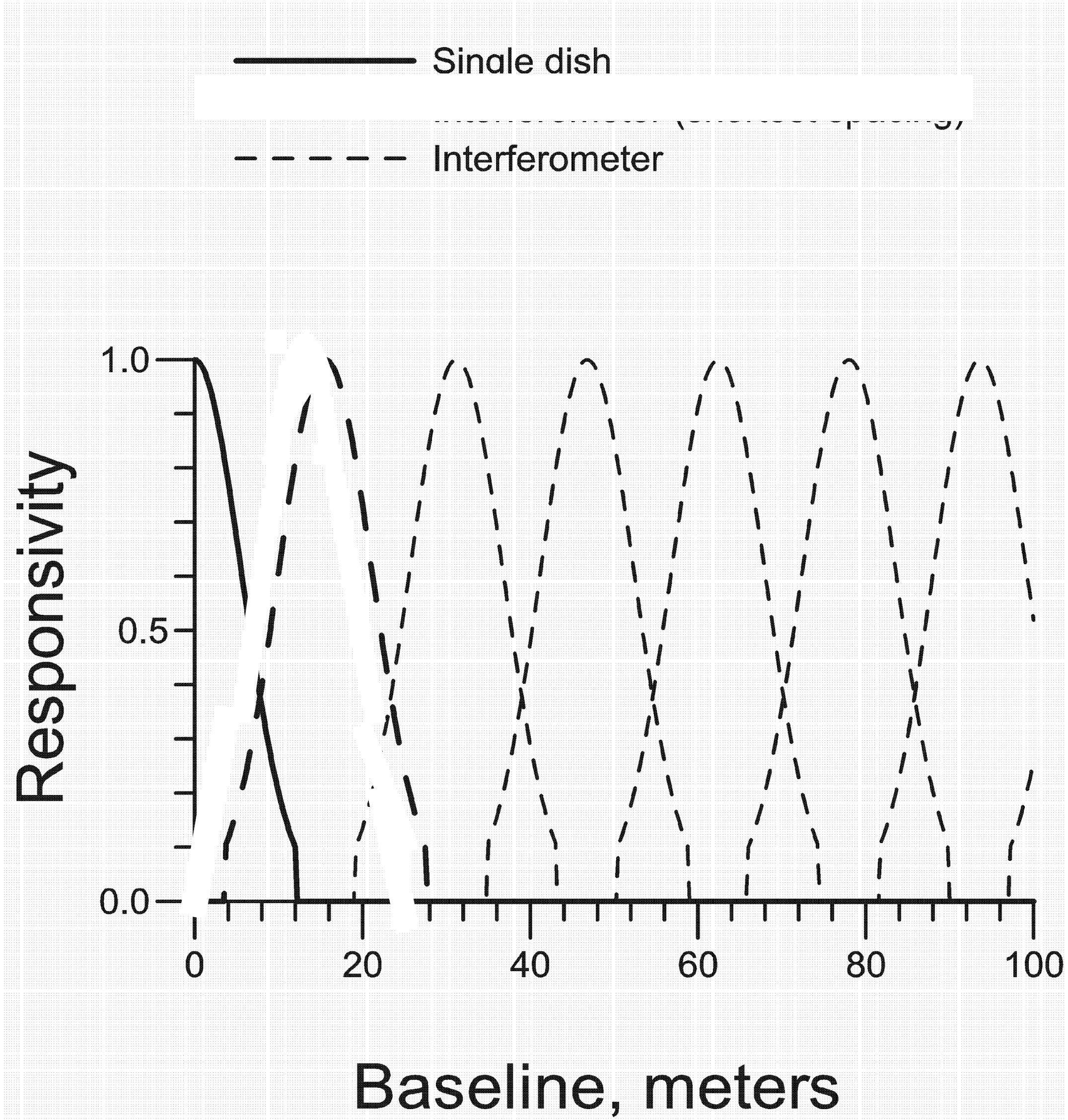


The Fourier Transform of a celestial distribution yields spatial frequencies in cycles per radian.

For a 2-element interferometer:

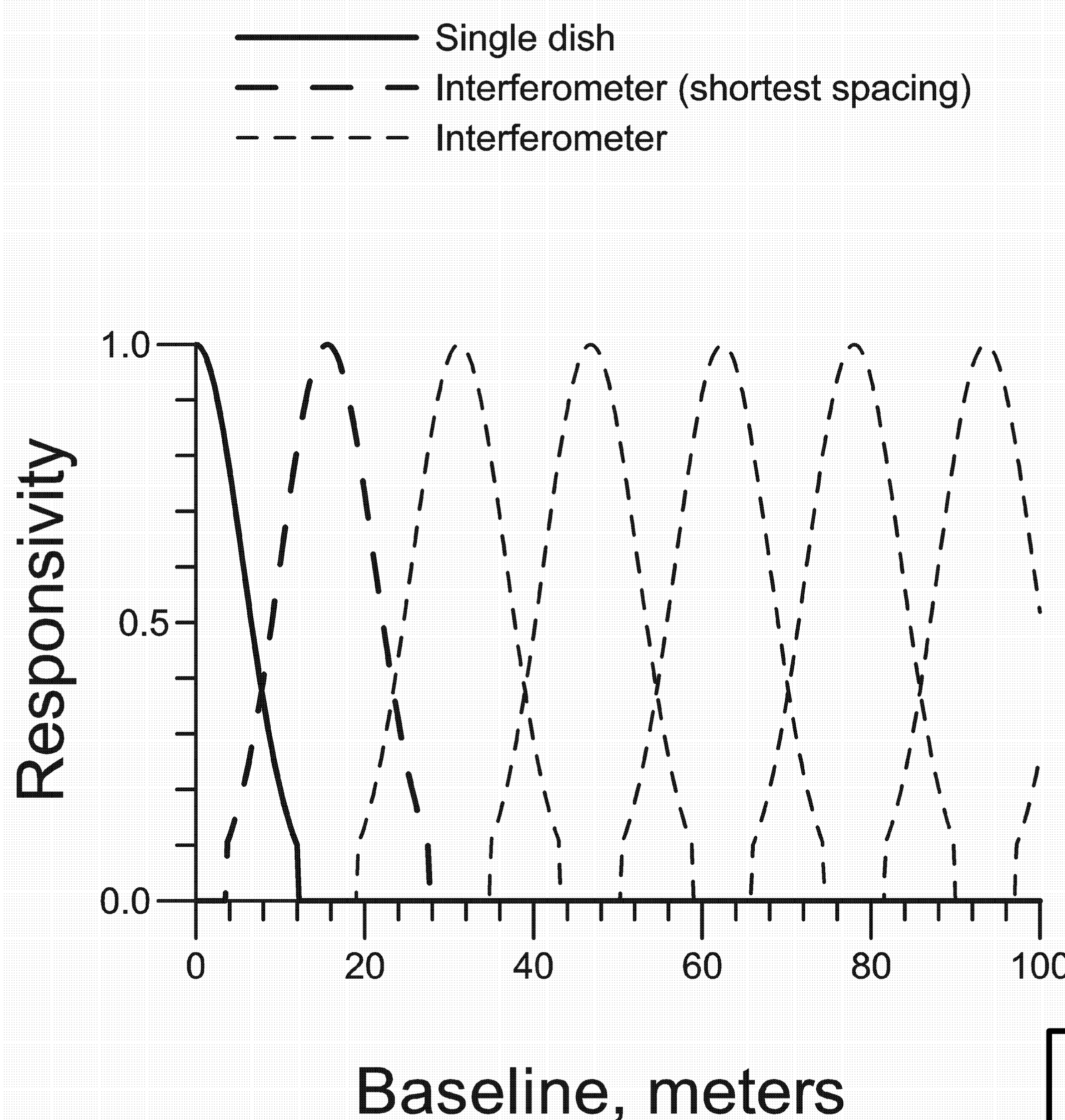
Angle on sky = (λ/Baseline) radians

Spatial Frequency to which a 2-element interferometer is sensitive is proportional to Baseline



Angle on sky = (λ/Baseline) radians

Spatial Frequency** is proportional to **Baseline

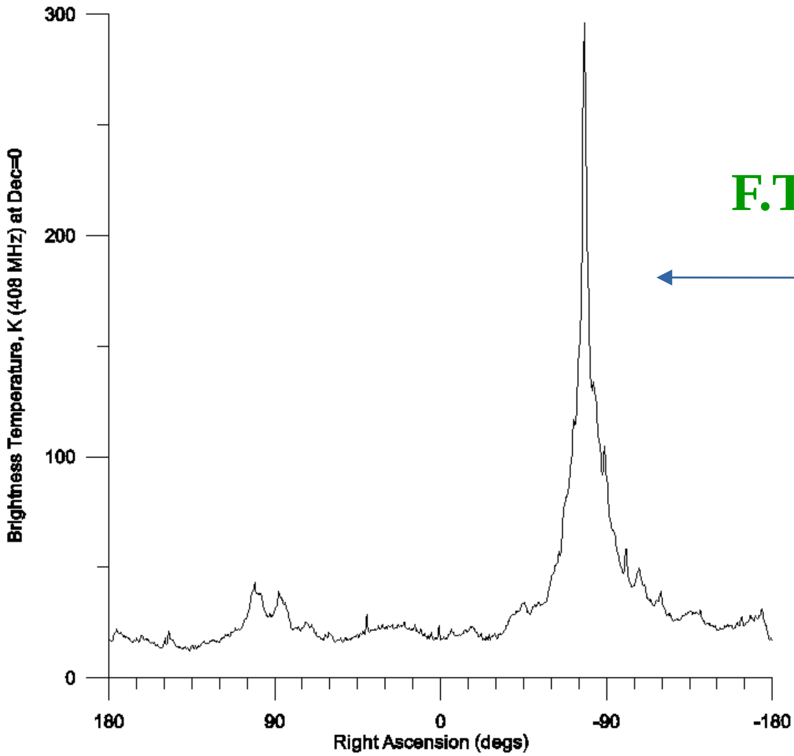


To get an accurate picture of the large scale structure and total flux density in a field, AND ALSO the fine scale detail in a source, you require a combination of both interferometric and single-dish observations.

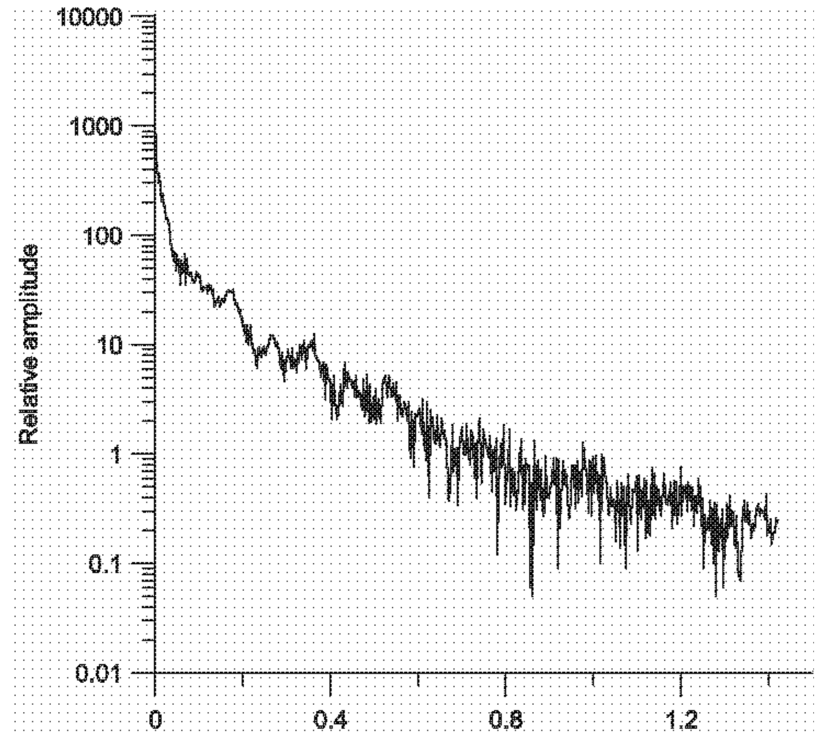
Make sure that you attend Tapasi Ghosh's talk!

A cross-section through the 408-MHz All-Sky Image at Dec~0°

Spatial frequency distribution of the all-sky 408 MHz distribution



F.T.

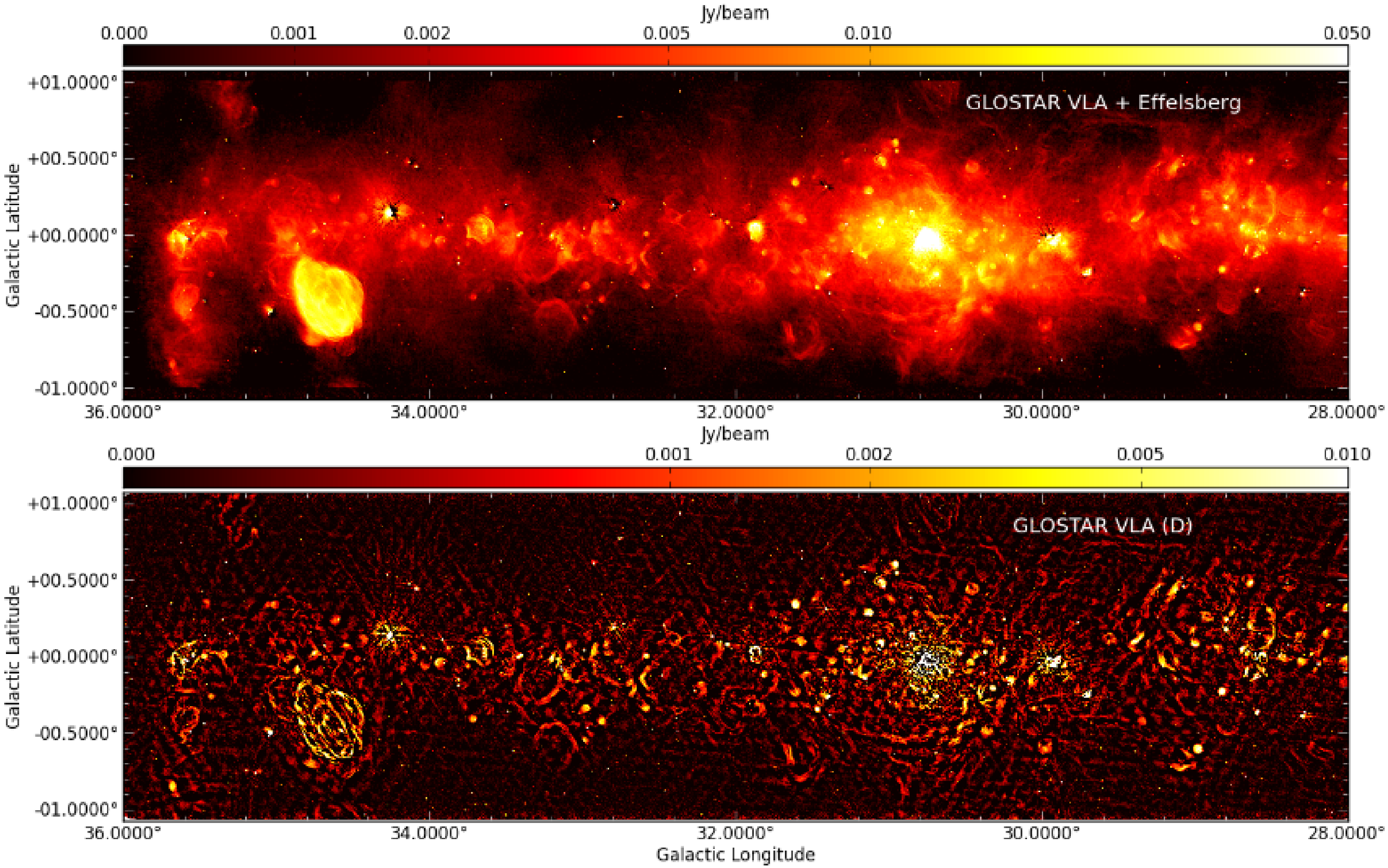


Spatial frequency (1/degrees)

Spatial Frequencies: Single Dish *vs.* Interferometer

- **Single Dish has a high-end spatial frequency cut-off in resolution set by its diameter.**
- **Interferometer has a low-end spatial frequency cut-off set by its minimum antenna separation.**
- **Sometimes, the Interferometer low frequency cut-off is advantageous.**
- **Usually, Single Dish maps are analysed in a way that removes the lowest spatial frequencies too; e.g. we don't normally want the 3 K cosmic background in our data.**
- **The relative flux in low spatial frequencies is typically far greater than that at higher spatial frequencies.**
- **For cases where we DO want large scale structure, we may HAVE TO USE a Single Dish, likely in combination with an interferometer.**

“Give Me Back My Short Spacings!”



C-Band

(Brunthaler et al,, 2021)

Practical Advantages of Single Dish observing:

- **Spatial Frequency Response**
- **Sensitivity:**
  - Sensitivity in **Jy** (point source) depends critically on **collecting area**, SD or Interferometer.
  - Sensitivity in brightness temperature **K** (extended emission) gets WORSE as (Max.Baseline) squared, for the same collecting area – i.e. roughly as $\mathbf{(d/D)^2}$**.**
- Ability to map very extended areas quickly.
- May provide large collecting area with manageable electronic complexity.

- **Simplicity**: One receiver, not N receivers, nor N.(N-1)/2 correlations.
- BUT *relatively* easy to implement large focal-plane arrays, including bolometers, which can increase mapping speed by orders of magnitude.
- Multi-frequency receivers relatively easy investment.

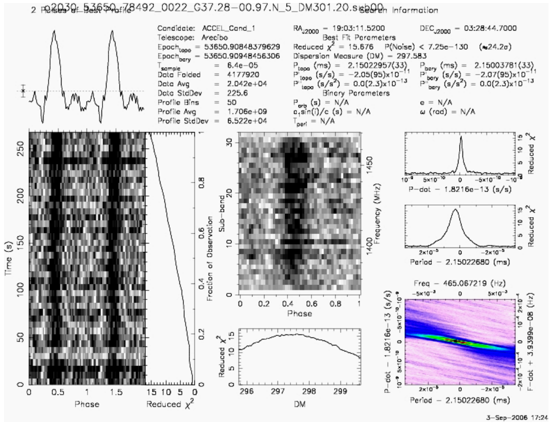
- **Flexibility**: Relative ease of upgrading/customizing hardware to an experiment.
- Relative ease of implementing radar transmitter systems.
- A single large dish can add significant sensitivity to VLBI arrays.
- Software possibly simpler: "Conceptually" easier to understand for novices.
- Use as test-bed for new receiver systems.
- User-developed equipment easily deployed for particular experiments.

- **Commensality:** Much employed at AO; also now on the GBT.

Practical Disadvantages of Single Dish Observing

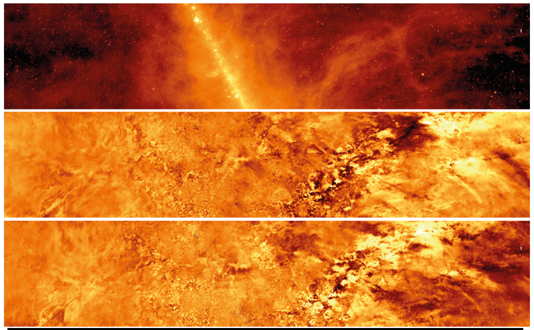
- Limited spatial-frequency response.
- Mechanical complexity often replaces electronic complexity.
- Susceptibility to instrumental drifts in gain and noise - don't have the correlation advantage of interferometers.
- Interferometers can *in principle* give high sensitivity and large total collecting area (e.g. SKA).
- Aperture synthesis imaging is a form of multi-beaming - arguably obtaining more information from the radiation falling on a telescope than is possible with a single dish.

Things Single-Dishes Do Well

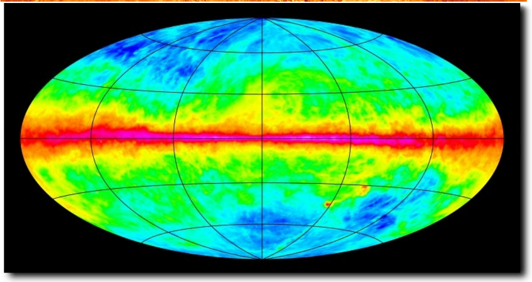


- **Pulsar searches** (~3200 known radio pulsar; the vast majority found with single dishes.)

1375-MHz Continuum I, Q & U



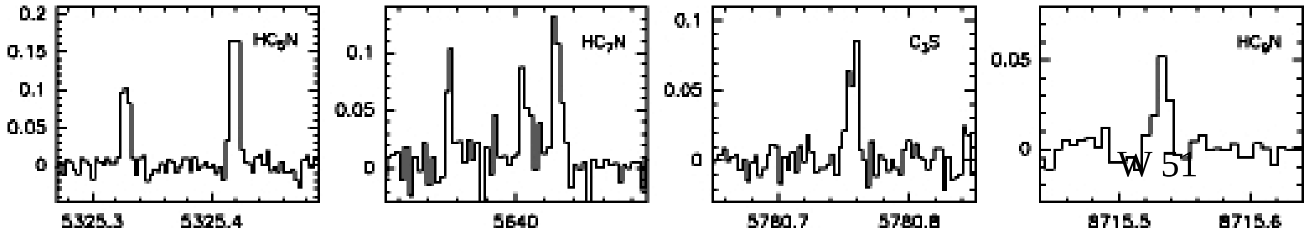
- **Large-area “background” surveys**

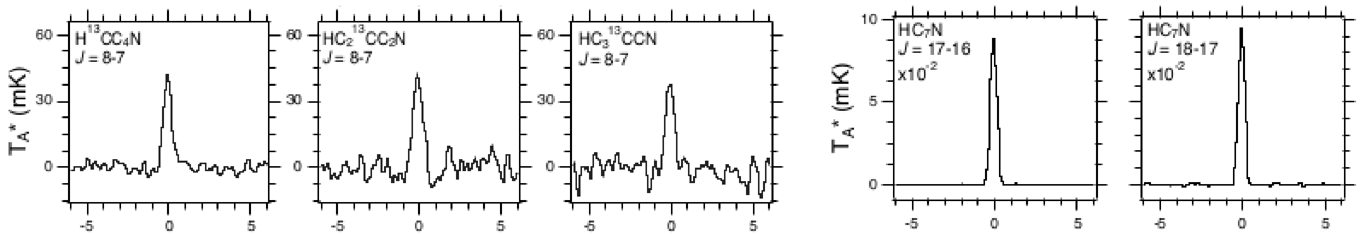


1420-MHz Neutral Hydrogen (HI)

Things Single-Dish Do Well (Cont.)

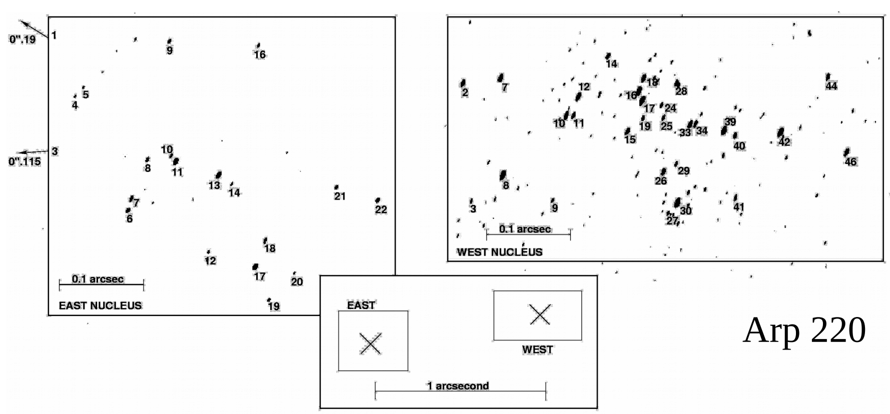
- **Molecular line studies & searches**





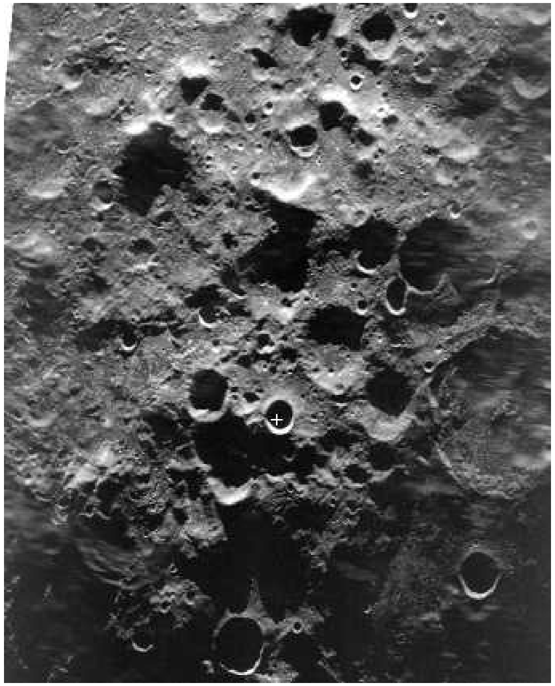
TMC 1

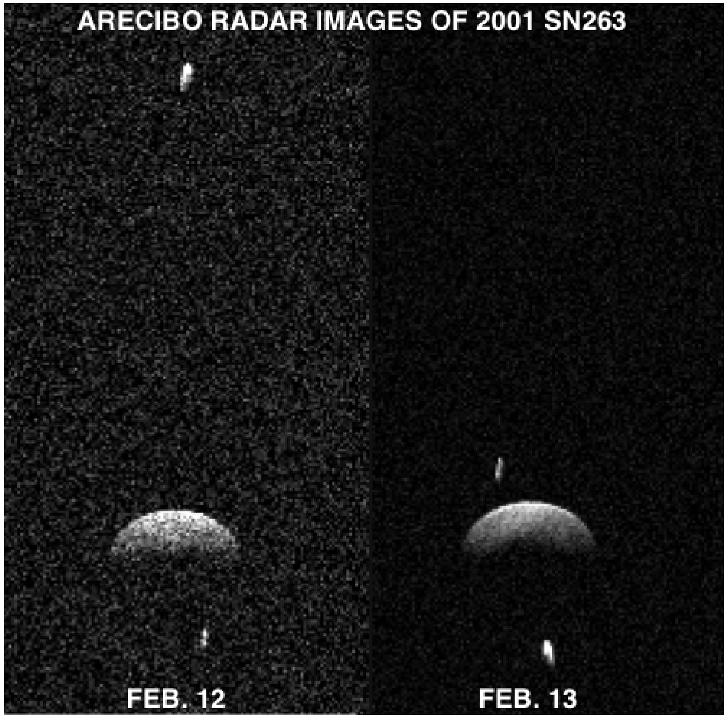
- **High-sensitivity VLBI**



Things Single-Dish Do Well (Cont.)

- **Solar System Radar**





- **Win Nobel Prizes! (1974, 1978, 1993 & 2006)**

Single-Dishes: New or Under Construction

- The Large Millimeter Telescope (**LMT/GTM**) of 50-m diameter in Mexico of INAOE & Umass. In service since 2013.

- Sardinia Radio Telescope (**SRT**) of 64-m diameter working to 115 GHz. In service from 2011.

- The Five hundred meter Aperture Spherical Telescope (**FAST**) of 500-m diameter built in China for frequencies to ~3 GHz. First light 2016.

- The 6-m sub-mm **CCAT-P** (Cerro Chajnantor Atacama Telescope)/FYST. First light planned for 2023.