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CHAMP Camp 2017

Radio Interferometry Lecture

Why Interferomery?

Single dishes - examples

Their resolution λ/D

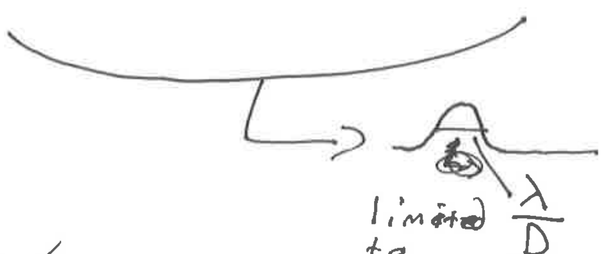
Historical Motivation: $\boxed{\text{What } \underline{\text{are}} \text{ radio "stars"??}}$

Typical dish 25m
150MHz

$$\frac{\lambda}{D} \approx 4.5^\circ = 275'$$

For Comparison
· 200" Hale

$$\frac{\lambda}{D} = 0.02''$$

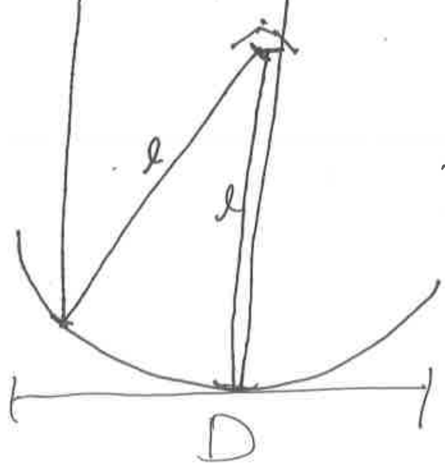


· SDSS + Single dish Res for scale.

· largest single dishes.

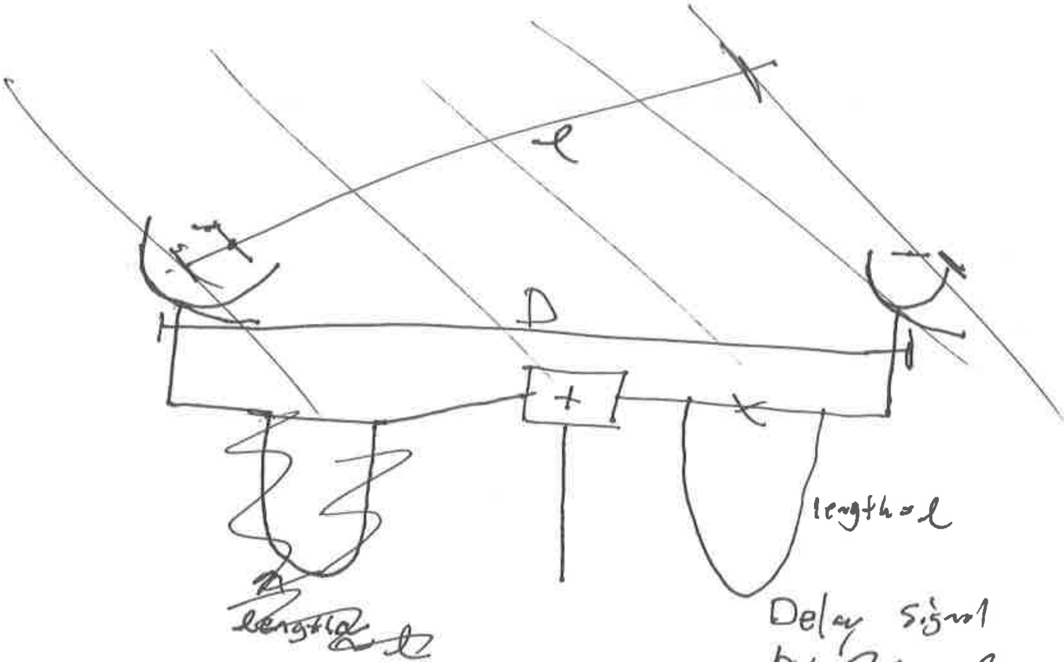
How can we do better than a single dish?

Consider the function of a the dish



Adjust the distances light travels so that wave fronts arrive simultaneously.

We can ~~do this with~~ cheat + use other means to achieve the same time delay. ☆



Delay signal by $\tau = \frac{l}{c}$

New effective resolution set by Antenna seperation.

As source drifst through beam will go in + out of phase.

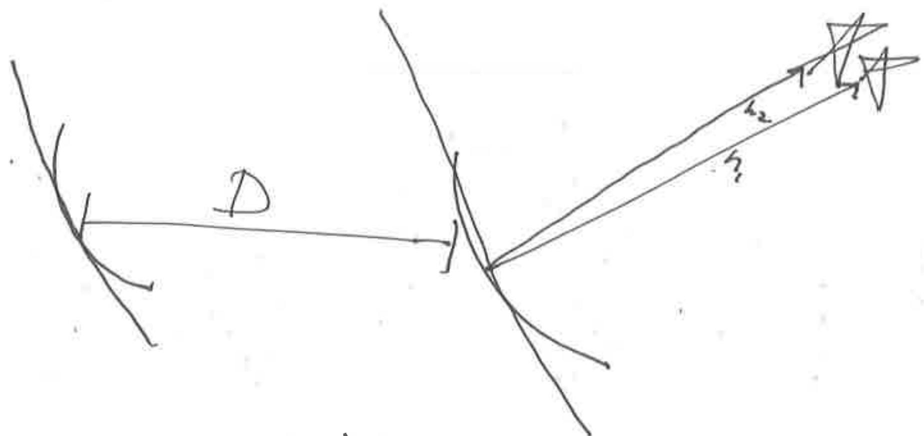
In phase

out of phase

$$|V_1 + V_2| \cancel{\propto} \boxed{\cos(h\tfrac{\lambda}{D})} \left(\times \text{ source brightness} \times \text{Dish Beam}\right)$$

~~Now I can see~~ If we only have one pt source!

If a source has multiple components @ different positions we'll get multiple sin functions.

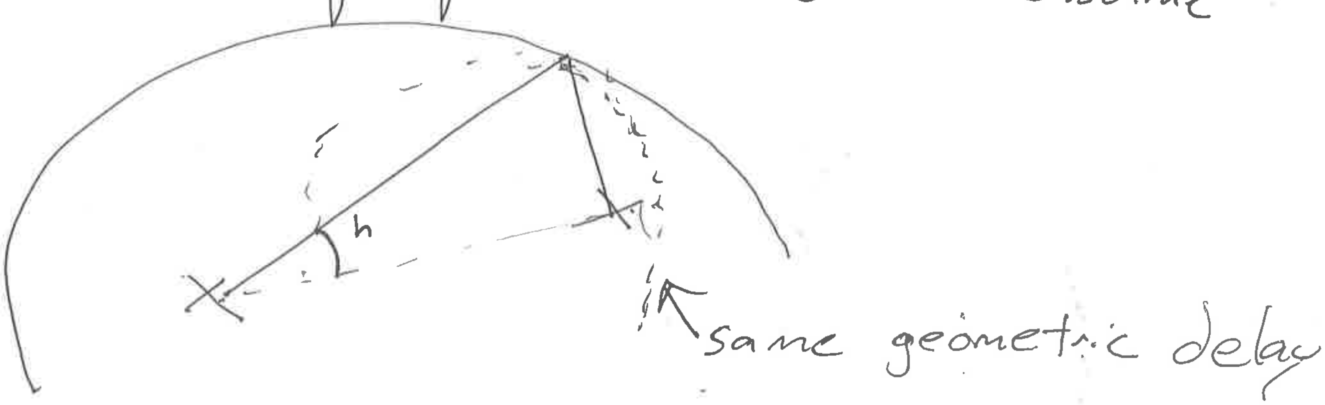


$$|V_1 + V_2| \propto \cos(h_1 \tfrac{\lambda}{D}) + \cos(h_2 \tfrac{\lambda}{D})$$

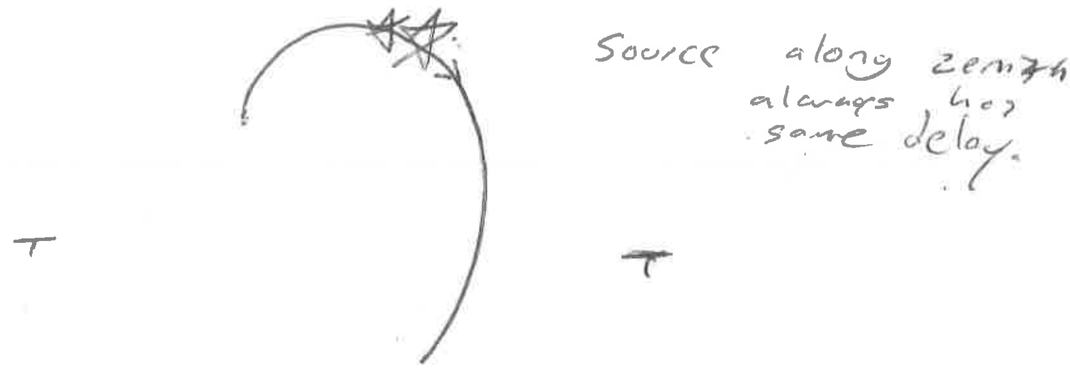
1 source

2 sources

Note! Does not constrain ~~along~~ in direction perpindicular to the baseline



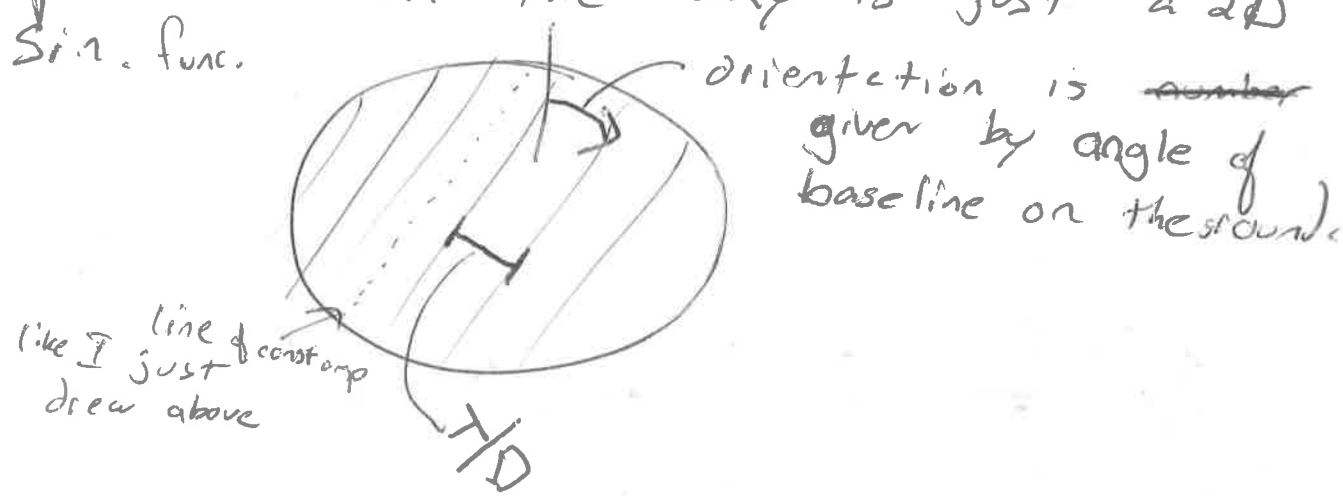
An extreme case



Two sources moving along this line will not be distinguishable.

~~You need more antennas!~~

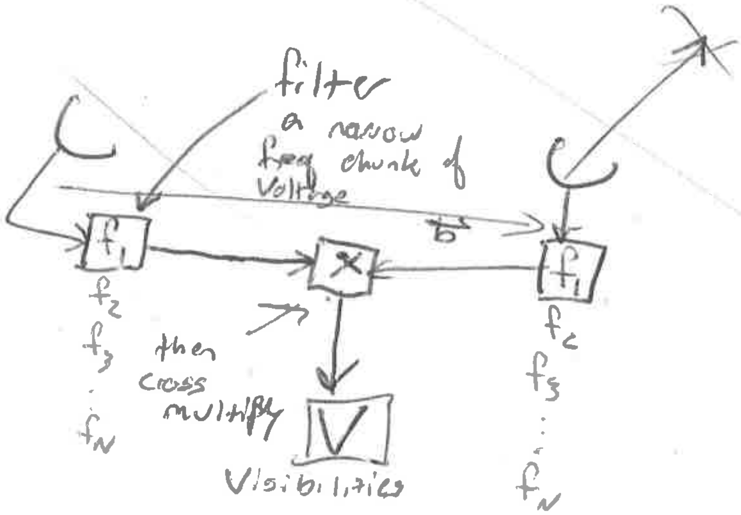
In fact the amplitude response vs. position on the sky is just a 2D Sin. func.



To Do a better localization job we need more base lines!

But we need ~~a more complete model~~ to update our model for a real correlator... (not just using cables of different lengths)

The most straight forward thing to do is ~~the~~ so called FX



the output is

$$V = \sum_i S_i \, e^{-i\pi \vec{b}\cdot\hat{s}_i}$$

flux of source @ position $\hat{s}_i$

or, for ~~each~~ smooth images like

or

$$V = \int I(\hat{s}) \, e^{-i\pi \vec{b}\cdot\hat{s}} \, ds^2$$

Integrate flux over the ~~whole~~ sky

for <u>each baseline</u>

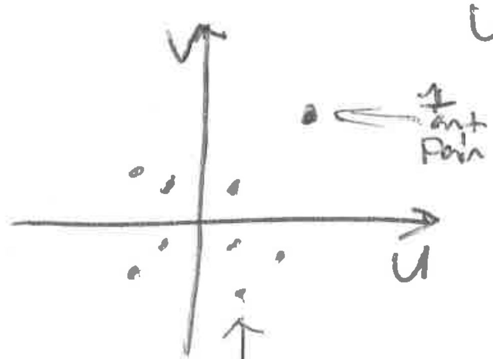
$V_{\vec{b}}$ or V_{ij}

baseline vector or antenna i to antenna j

Note the similarity to a Fourier transform.

Each $\vec{b}$ measures a different mode.

UV plane



$$\vec{b} = (u\hat{e} + v\hat{n} + w\hat{z}) \times \lambda$$

Modes plotted in a useful basis

think back to locations of delta functions in FT lecture.

Each corresponds to a differt sin mode on the sky.

This the basic procedure for <u>Synthesis Imaging</u>

1 Measure $V_{\vec{b}}$ for lots of different baselines.

2 Put those measurements in a 2D array corresponding the $\vec{b}$ vector positions

3 Take a Fourier Transform. $\boxed{\text{The rest is details...}}$

The FT of the baseline distribution tells you your Point Spread Function

i.e., what point sources will look like.

[Some examples]

Adding baselines, ~~freqs + rotation~~.

Some key points.

① UV position scales w/ wavelength

$$\frac{\vec{b} f}{c} = \frac{\vec{b}}{\lambda} = \vec{u} = u\hat{e} + v\hat{n} + w\hat{z}$$

So If I measure multiple wavelengths and am ok w/ averaging them together I could put them all in the same uv plane

This is a nice trick for getting more Fourier modes ~~increasing~~ Increasing my uv coverage.

key Points cont

(2) uv vectors rotate with time.

The Earth is moving after all

Eppur si muove!

In the uv plane, it usually looks like this

[[Examples]]

Break time!

(click here to skip warnings)

Details!

Warnings!

Several approximations were slipped in there.

1) The sky is round but ~~arrays~~ Fourier Transforms assume a flat rectilinear coordinate system.

Rules of thumb: ~~or~~ on a patch of sky >~10° coordinates of things in the image will ~~be~~ be off (if you aren't careful)

2) UV plane assumes the antenna positions are planar

Search terms: w-projection
w-stacking
w-anything

3) No element or dish has a flat response on the sky.

→ In practice what you would get ~~from solving the s~~ if you ignore that fact is an image which gets dimmer or fainter @ the ~~edges~~ $\frac{\lambda}{D}$ (D = dish diameter) distance away from the beam center.

Lesson goals

- The interferometer measures Fourier modes ~~ox~~ ~~off~~ of the sky.

- The number + distribution of the modes comes from ~~antenna locations~~ baselines samples of the UV plane.

- The FT of the baseline distribution is the shape of the image psf.

- Geometric delay + the relationship to resolution.