Radio Astronomy

an introduction

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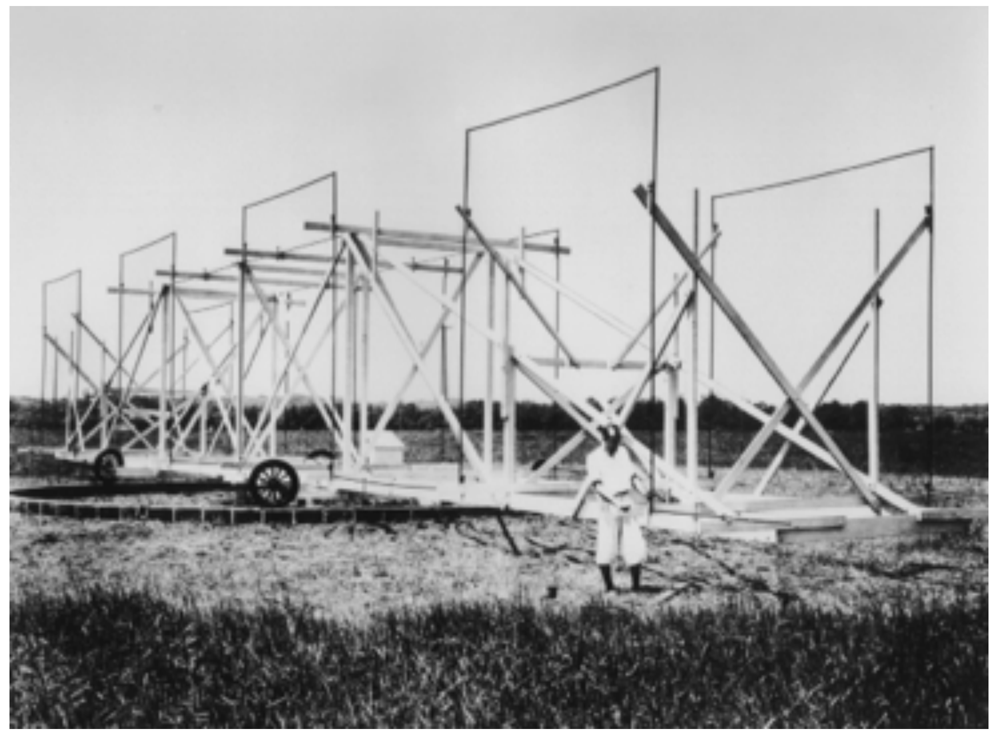
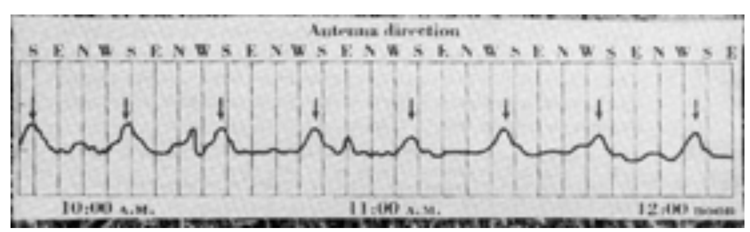
Overview

- The birth of radio astronomy
- The role of radio astronomy in astrophysics
- Basic principles and instrumentation
- FRBs: an (intriguing) operational example

The birth of radio Astronomy

1931-1933 Karl Jansky





NEW RADIO WAVES TRACED TO CENTRE OF THE MILKY WAY

Mysterious Static, Reported by K. G. Jansky, Held to Differ From Cosmic Ray.

DIRECTION IS UNCHANGING

Recorded and Tested for More Than Year to Identify It as From Earth's Galaxy.

ITS INTENSITY IS LOW

Only Delicate Receiver Is Able to Register—No Evidence of Interstellar Signaling.

Discovery of mysterious radio waves which appear to come from the centre of the Milky Way galaxy was announced yesterday by the Bell Telephone Laboratories. The discovery was made during research studies on static by Karl G. Jansky of the radio research department at Holmdel, N. J., and was described by him in a paper delivered before the International Scientific Radio Union in Washington.

The galactic radio waves, Mr. Jansky said, differ from the cosmic rays and also from the phenomenon of cosmic radiation, described last week before the American Philosophical Society at Philadelphia by Dr. Vesto M. Slipher, director of the Lowell Observatory at Flagstaff, Ariz.

Unlike the cosmic ray, which comes from all directions in space, does not vary with either the time of day or the time of the year, and may be either a photon or an electron, the galactic waves, Mr. Jansky pointed out, seem to come from a definite source in space, vary in intensity with the time of day and time of the year, and are distinctly electro-magnetic waves that can be picked up by a radio set.

New Waves Have High Frequency.

The cosmic radiation discovered by Dr. Slipher is a mysterious form of light apparently radiated independently of starlight, originating, Dr. Slipher concluded, at some distance above the earth's surface, and possibly produced by the earth's atmosphere.

The galactic radio waves, the announcement says, are short waves, 14.6 meters, at a frequency of about 20,000,000 cycles a second. The intensity of these waves is very low, so that a delicate apparatus is required for their detection.

Unlike most forms of radio disturbances, the report says, these newly found waves do not appear to be due to any terrestrial phenomena, but rather to come from some point far off in space—probably far beyond our solar system.

If these waves came from a terrestrial origin, it was reasoned, then they should have the same intensity all the year around. But their intensity varies regularly with the time of day and with the seasons, and they get much weaker when the earth, moving in its orbit, interposes itself between the radio receiver and the source.

A preliminary report, published in the Proceedings of the Institute of Radio Engineers last December, described studies which showed the presence of three separate groups of static: Static from local thunderstorms, static from distant thunderstorms, and a "steady hiss type static of unknown origin." Further studies this year determine the unknown origin of this third type to be from the direction of the centre of the Milky Way, the earth's own home galaxy.

Direction of Arrival Fixed.

The direction from which these waves arrive, the announcement asserts, has been determined by investigations carried on over a considerable period. Measurements of the horizontal component of the waves were taken on several days of each month for an entire year, and by an analysis of these readings at the end of the year their direction of arrival was disclosed.

"The position indicated," it was explained, "is very near to the point where the plane in which the earth revolves around the sun crosses the centre of the Milky Way, and also to that point toward which the solar system is moving with respect to the other stars.

"Further verification of this direction is required, but the discovery, like that of the cosmic rays and of cosmic radiation, raises many cosmological questions of extreme interest."

There is no indication of any kind, Mr. Jansky replied to a question, that these galactic radio waves constitute some kind of interstellar signalling, or that they are the result of some form of intelligence striving for intra-galactic communication.

The birth of radio Astronomy

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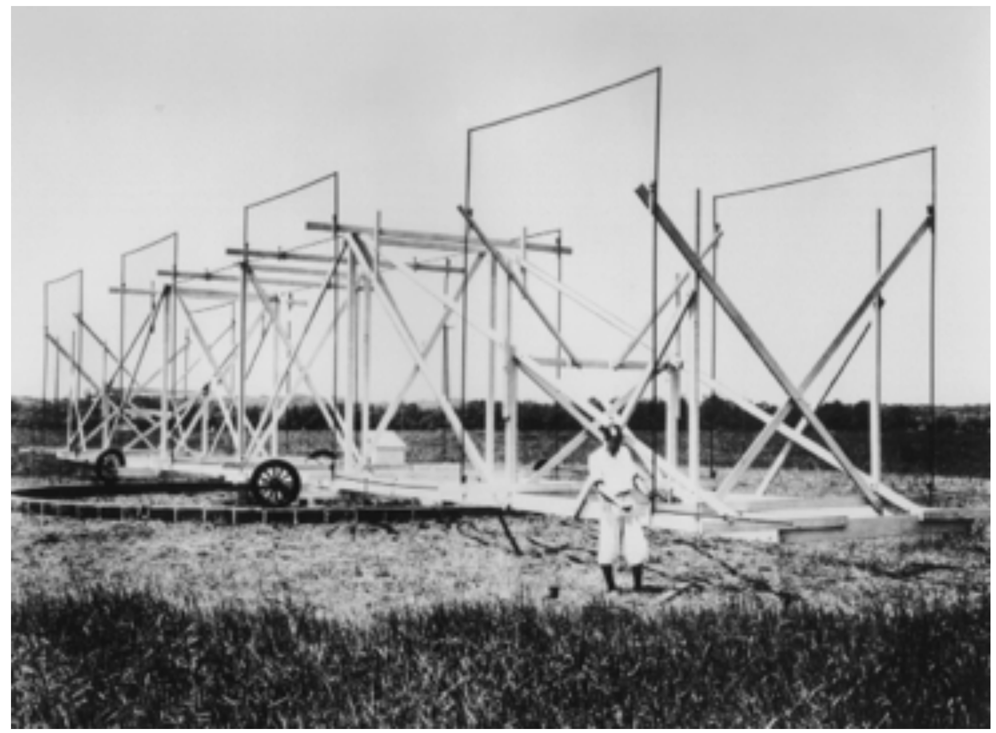

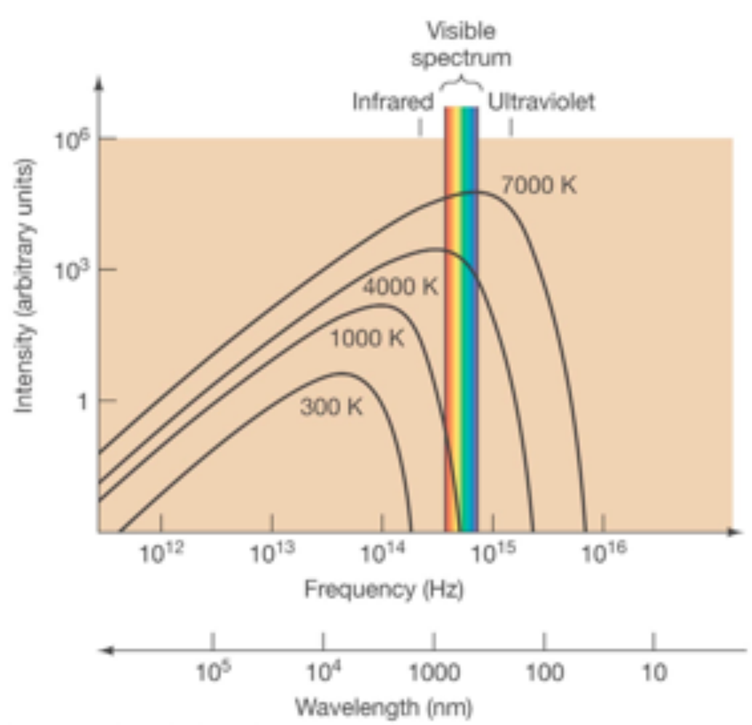

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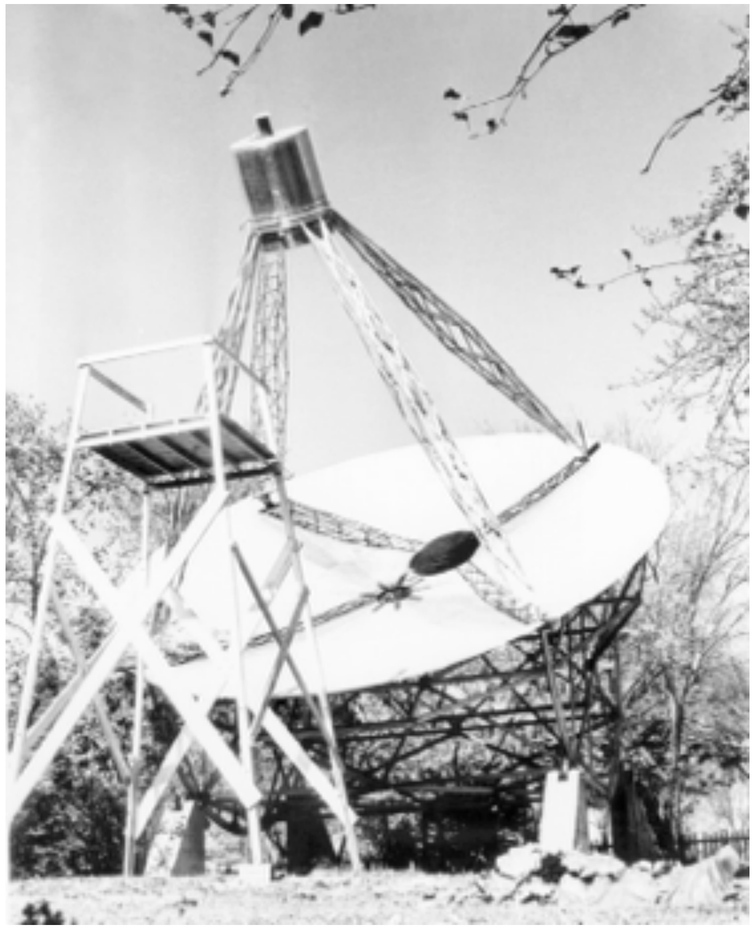
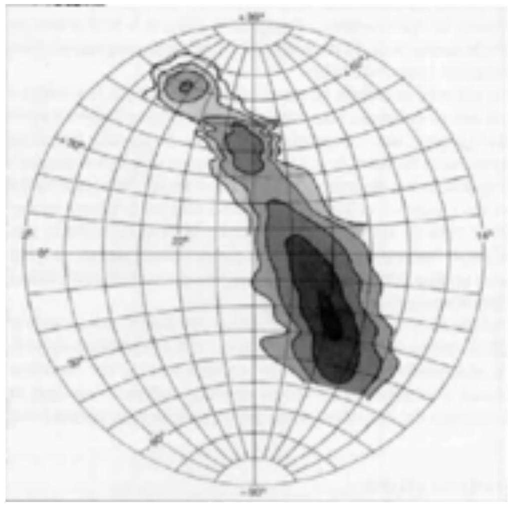
The first radio astronomer

1937-1947: Grote Reber





built his own 9-m-diameter parabolic dish antenna in
his backyard in Wheaton, Illinois

The first spectral maps

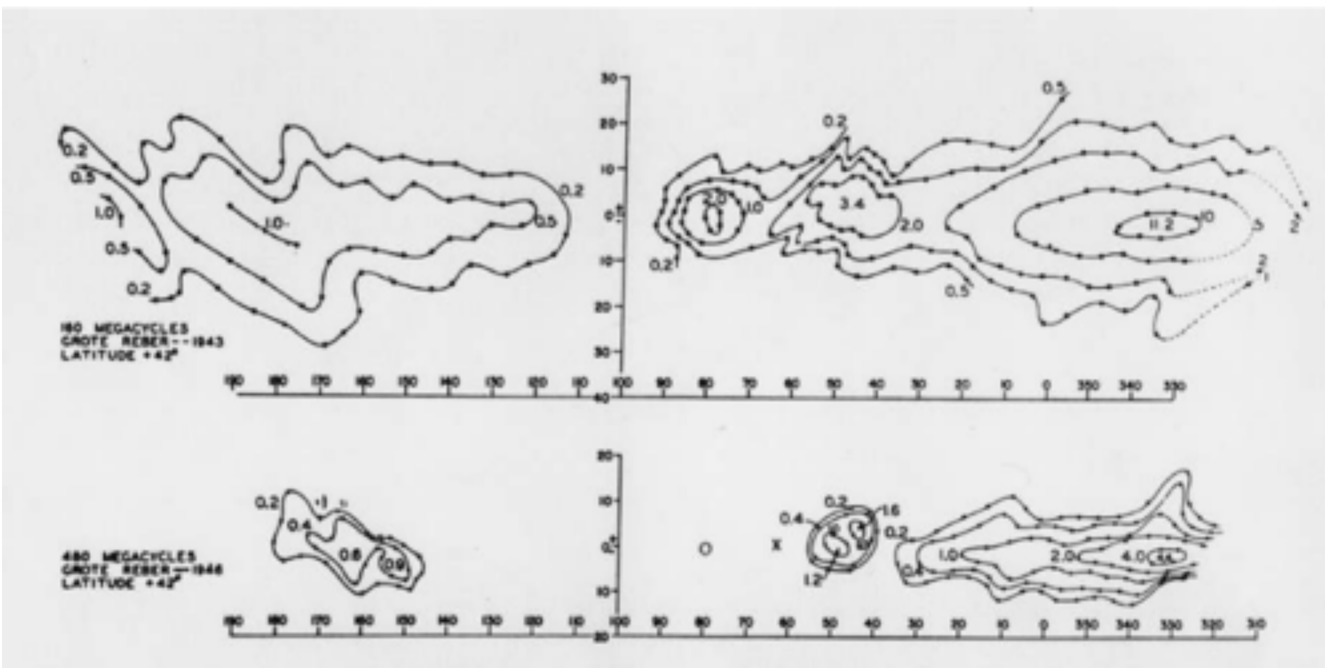
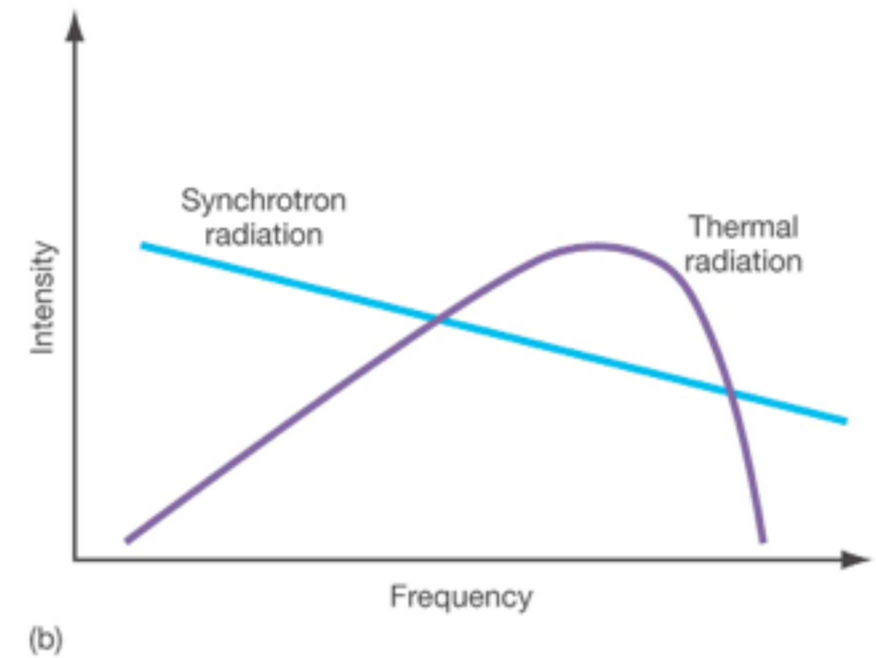
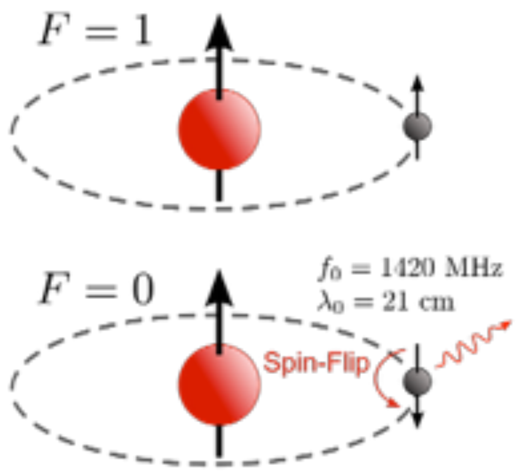


FIG. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.



Reber's multi-frequency observations revealed the non-thermal nature of radio emission (UNEXPECTED!)

Radio astronomy milestones



1945: Oort and Van de Hulst

Radio astronomy milestones

HI emission at 21 cm
on 25 march 1951 with a horn
antenna installed at Harvard

E.M. Purcell & H.W. Ewen
(Nobel 1952 for Purcell)

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Robert Dickie

was predicting a background signal
associated with the cooling of
radiation from the Big Bang

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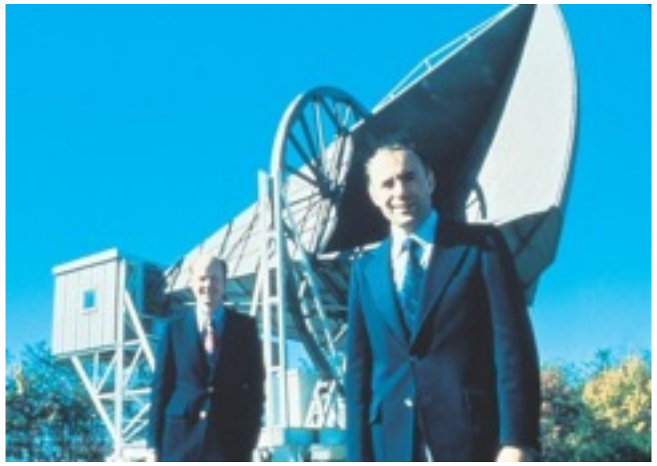


Cosmic Microwave Background
in 1965 with a horn antenna installed at Bell's Labs

A.A. Penzias & R.W. Wilson
(Nobel 1978 for Penzias + Wilson)

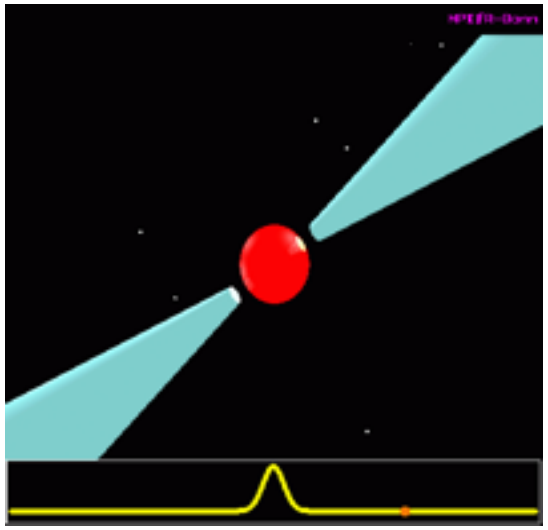
Radio astronomy milestones

1967: J. Bell and A. Hewish

Radio astronomy milestones

Discovery of the <u>radio pulsars</u> (hence of the neutron stars) on August 1967 with an antenna installed at Cambridge

J. Bell & A. Hewish
(Nobel 1973 for Hewish)



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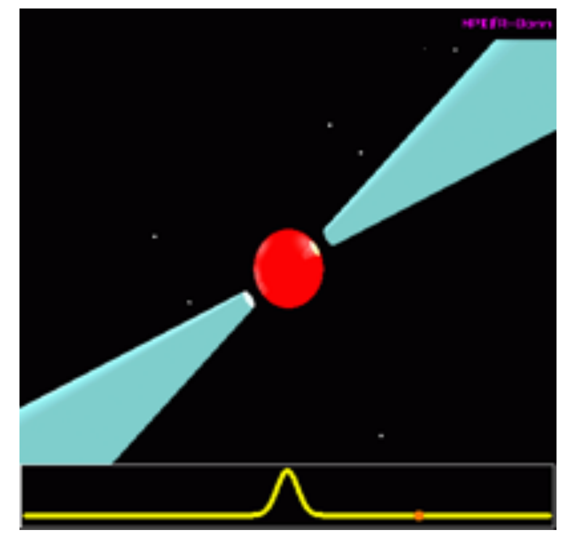

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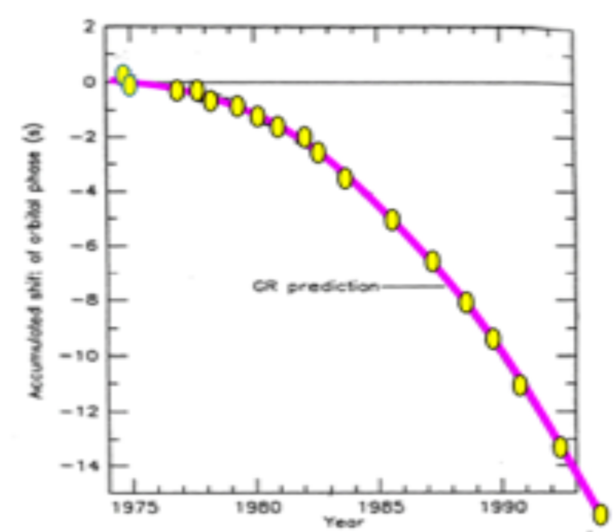
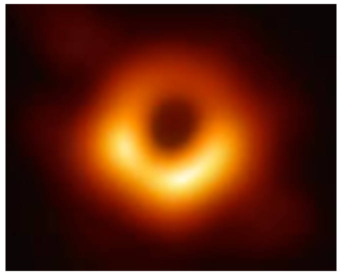
1974: Hulse & Taylor

Discovery of the binary pulsar B1913+16 on 1974 at Arecibo dish used for constraining the radiative predictions of General Relativity

R. Hulse, J. Taylor
(Nobel 1993 for Hulse+Taylor)



More discoveries



1951 Identification of the first radio galaxies (key for study of jets)

1950-1955 First radio observations of HII regions and Supernova Remnants

1963 Discovery of the first OH maser

1963 Discovery of the quasars (key for cosmology and BH studies)

1968 Discovery of ammonia lines in the interstellar medium (ISM)

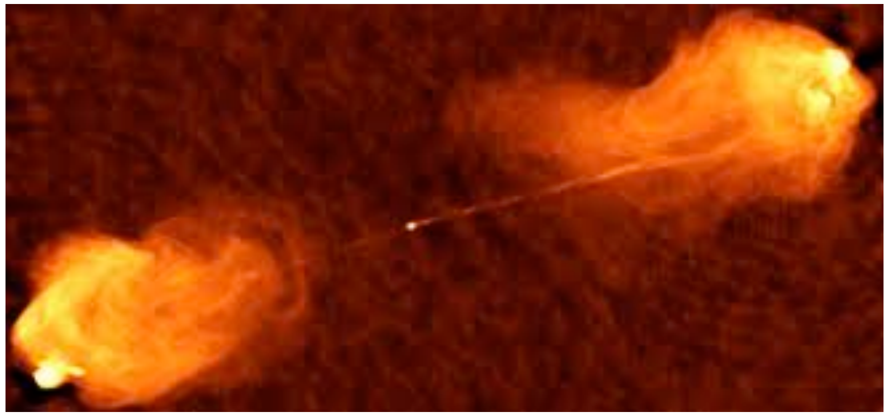
1973 Discovery of the giant molecular clouds (key for star formation)

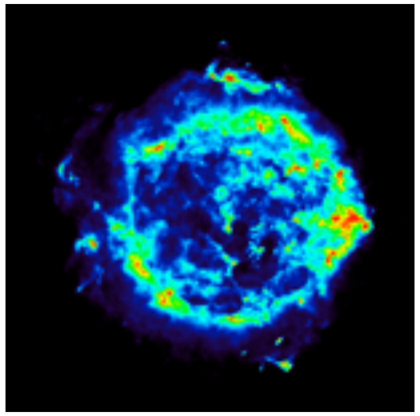
1992 Discovery of the first exo-planets (of earth and moon size!)

2003 Discovery of the first amino acid in space (glycine)

…

2019 Fisrt 'photo' of the shadow of a Black Hole

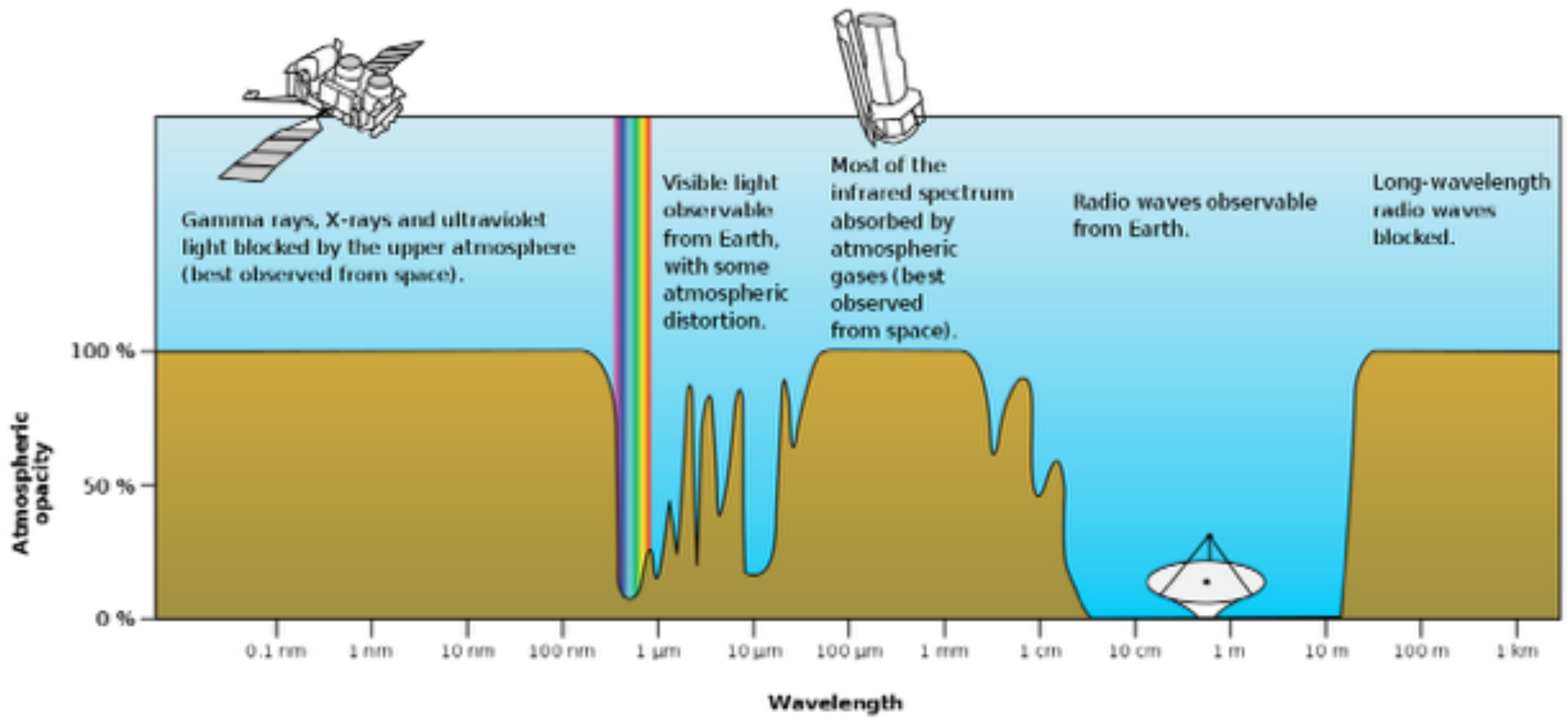




Instrumentation and techniques

Radio astronomy covers **6 decades** in frequency across the e-m spectrum

- radio and microwaves (1cm - 30m)
- millimetre (1mm to 10 mm)
- sub-millimetre (< 1mm, down to 0.3 mm)

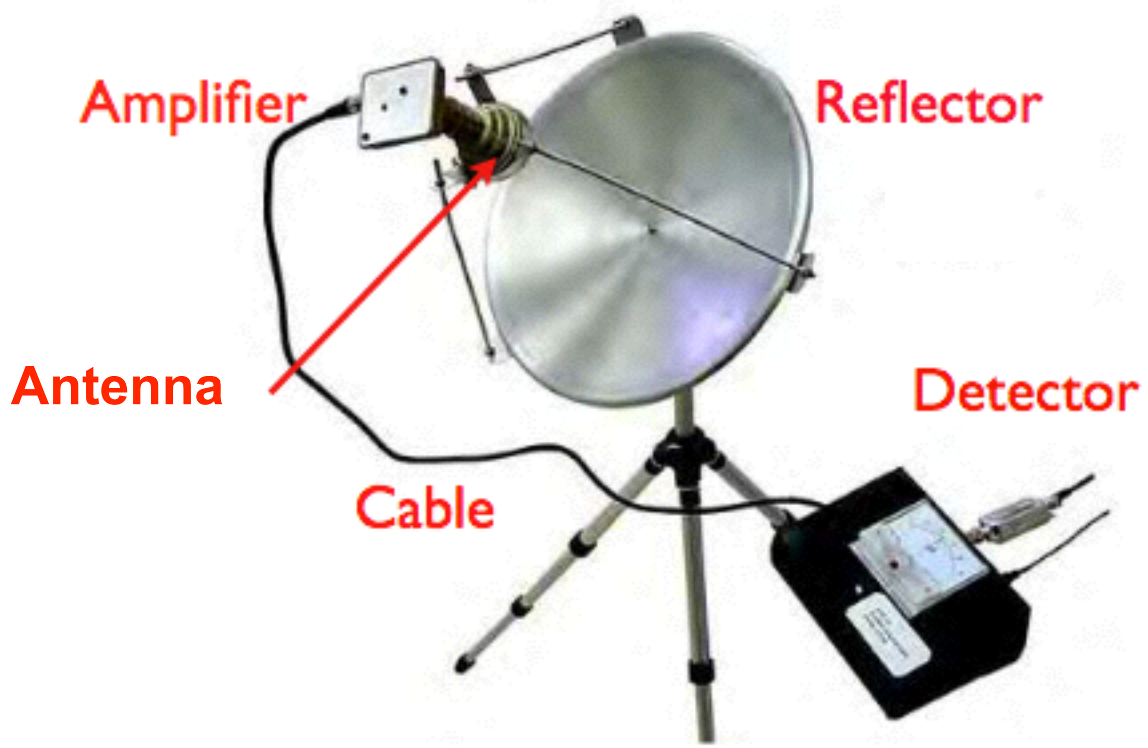


Earth’s atmosphere is transparent to radio waves from mm to decametre wavelengths

Instrumentation and techniques

Radio photons are extremely weak
optical photons of 600 nm —> 2 eV
radio photons of 1 m —> 0.000001 eV

Radio telescopes measure the voltage oscillations induced in a conductor (antenna) by the incoming EM-wave



Instrumentation and techniques

Radio telescopes measure the ***flux density*** of a source i.e. the power received (P) within a certain frequency band (dv), via a certain effective collecting area (A) with efficiency η

$$S = 2\frac{P}{\eta A d\nu}$$

The angular resolution (and FoV) is given by $\theta \sim \lambda/d$

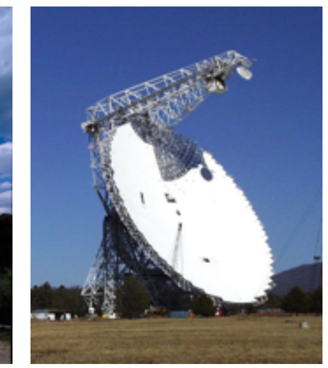
(Reber's dish had a resolution of ~ c/160MHz/9m = 11 deg)

Single dishes

Single dishes

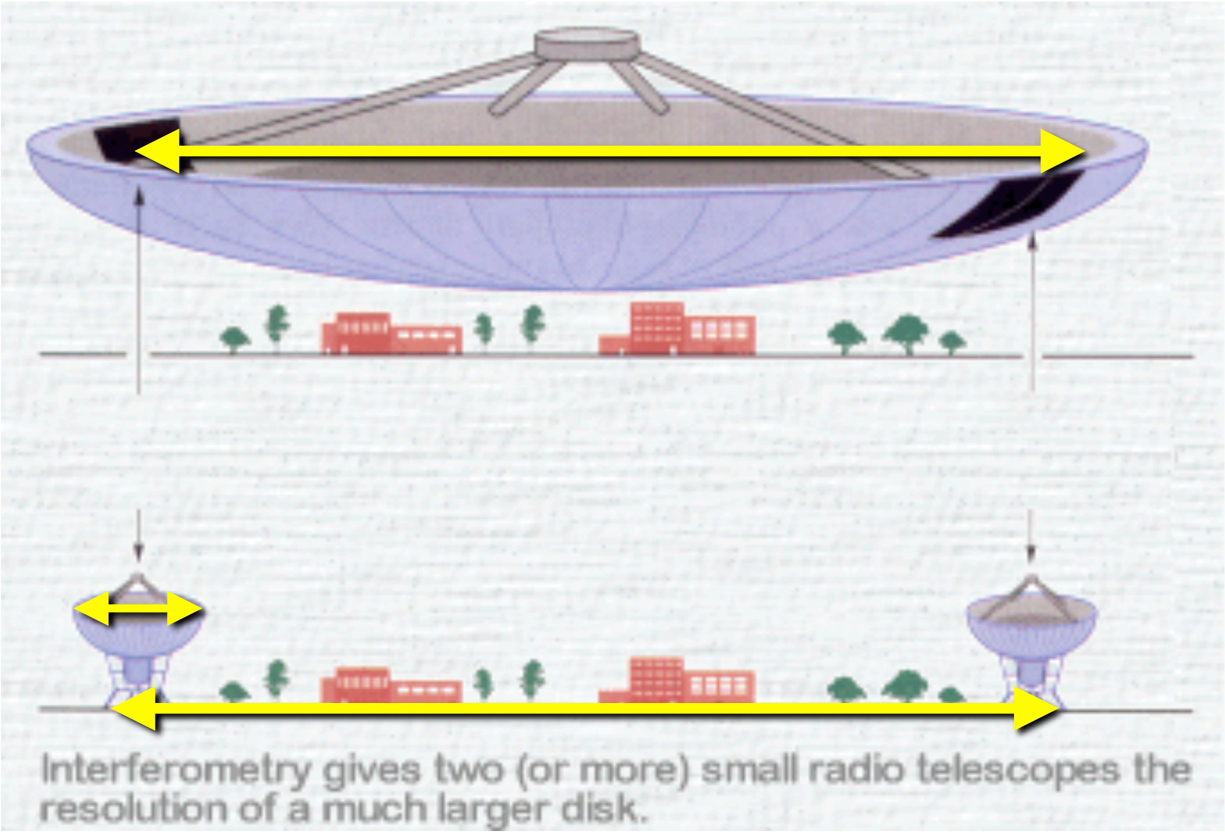
Single dishes

Single dishes



Single dishes

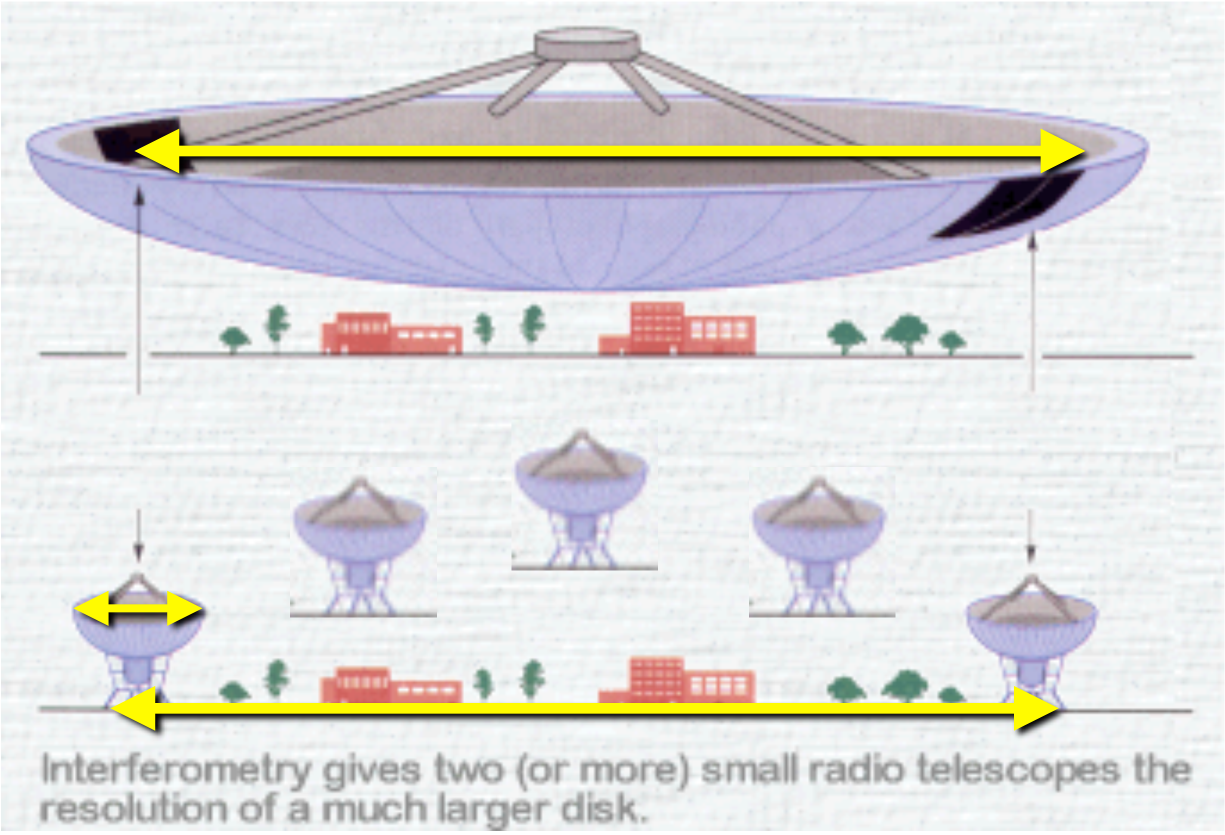
Interferometers



FoV ~ λ/d

θ ~ λ/D

Interferometers



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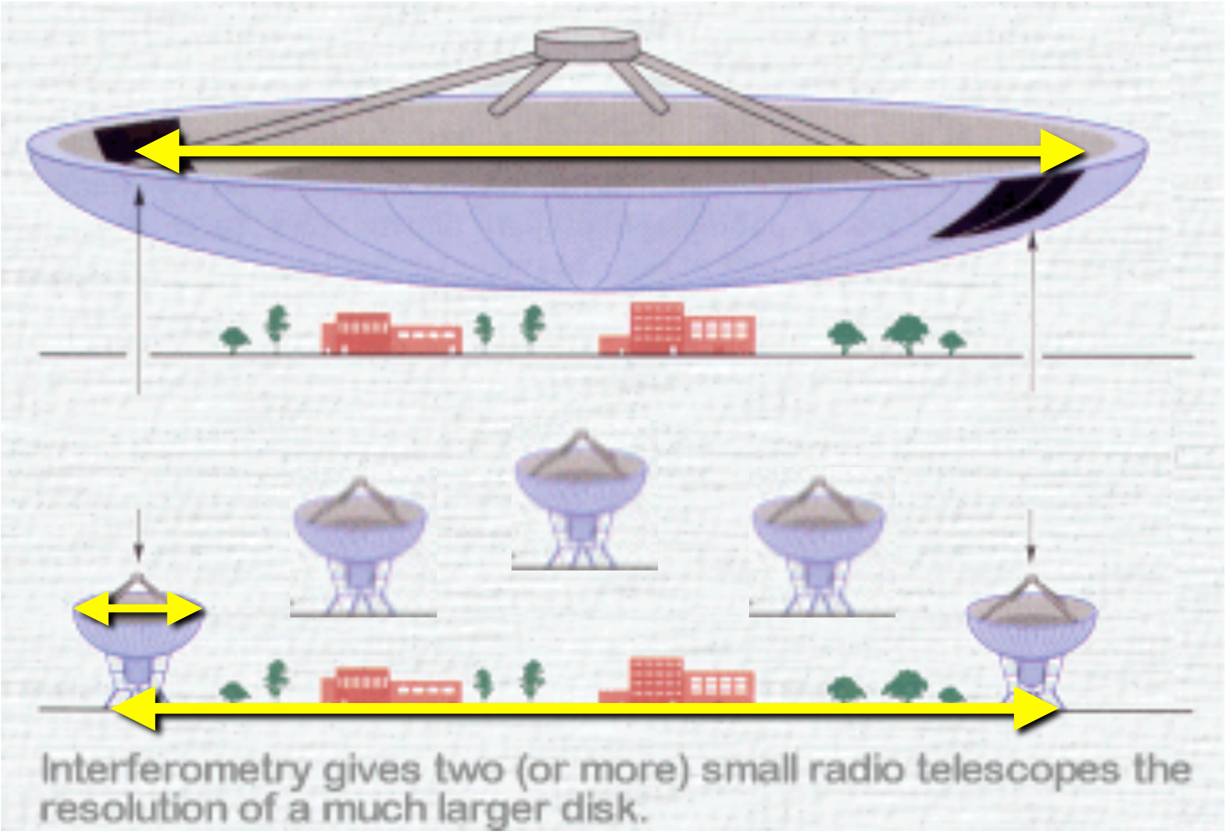

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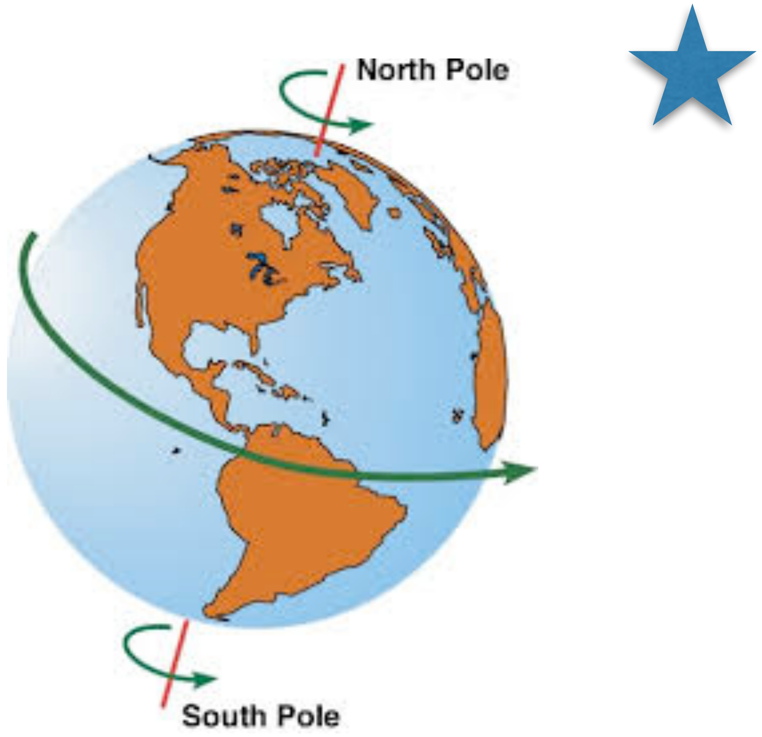

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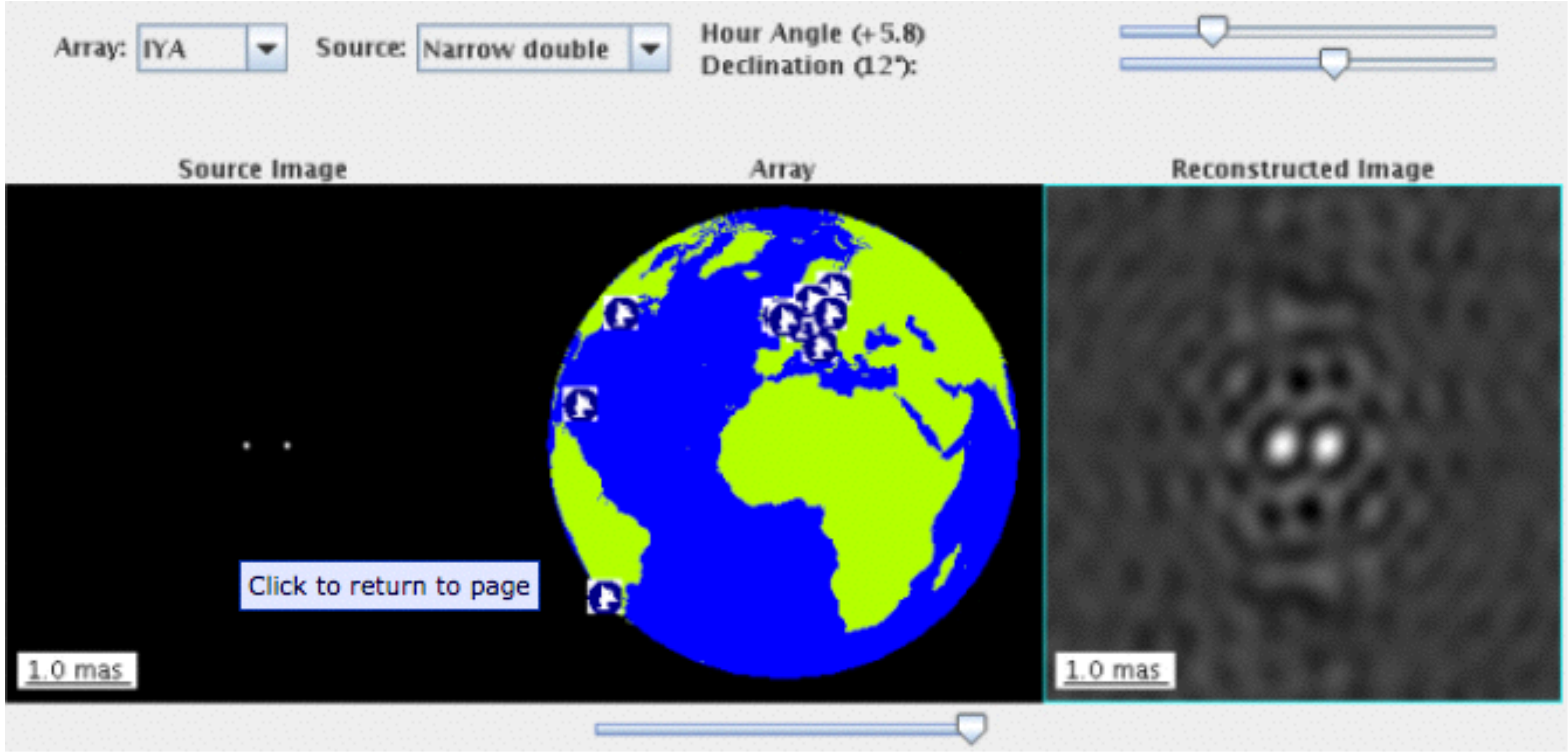
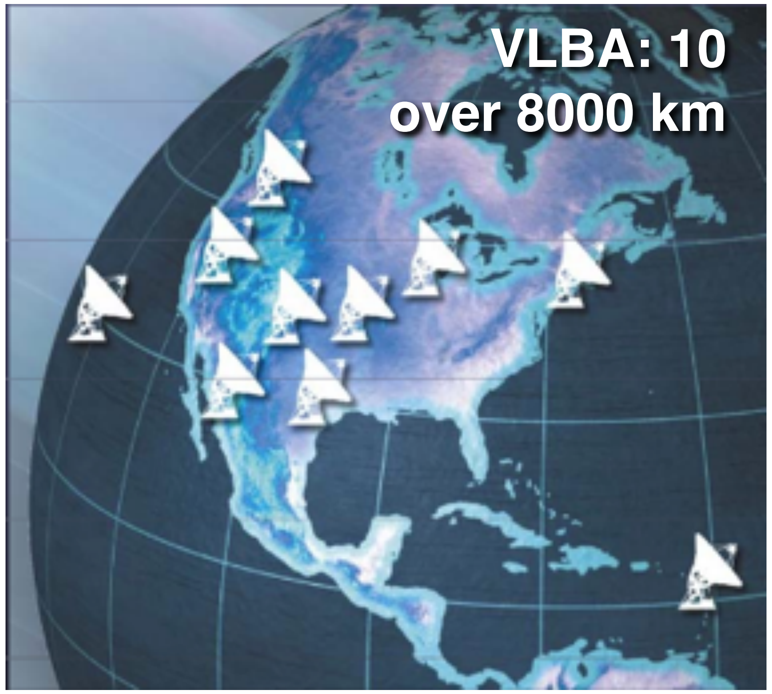


Jive virtual radio interferometer

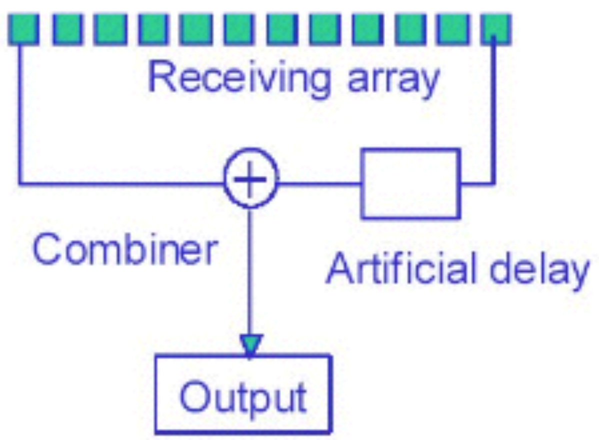
http://services.jive.nl/evlbi/diy.html

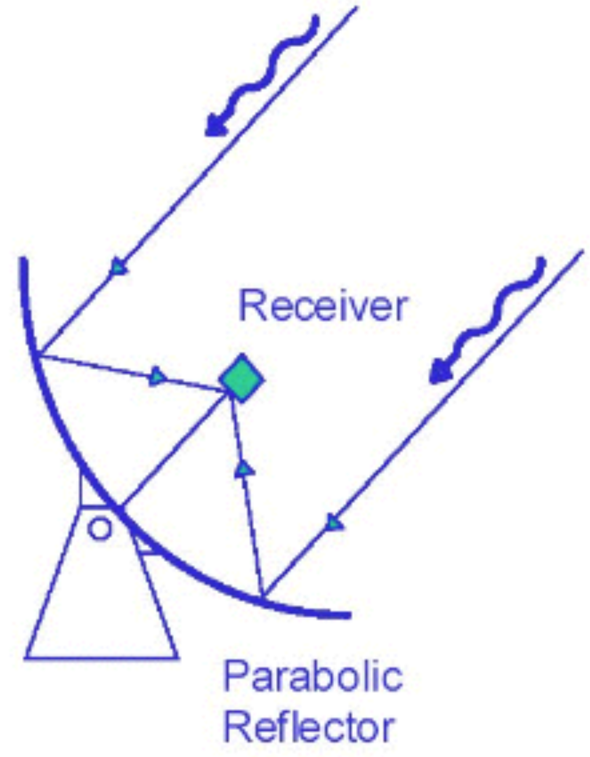
Interferometers



Aperture arrays

- For low frequency observations there is an even more efficient approach





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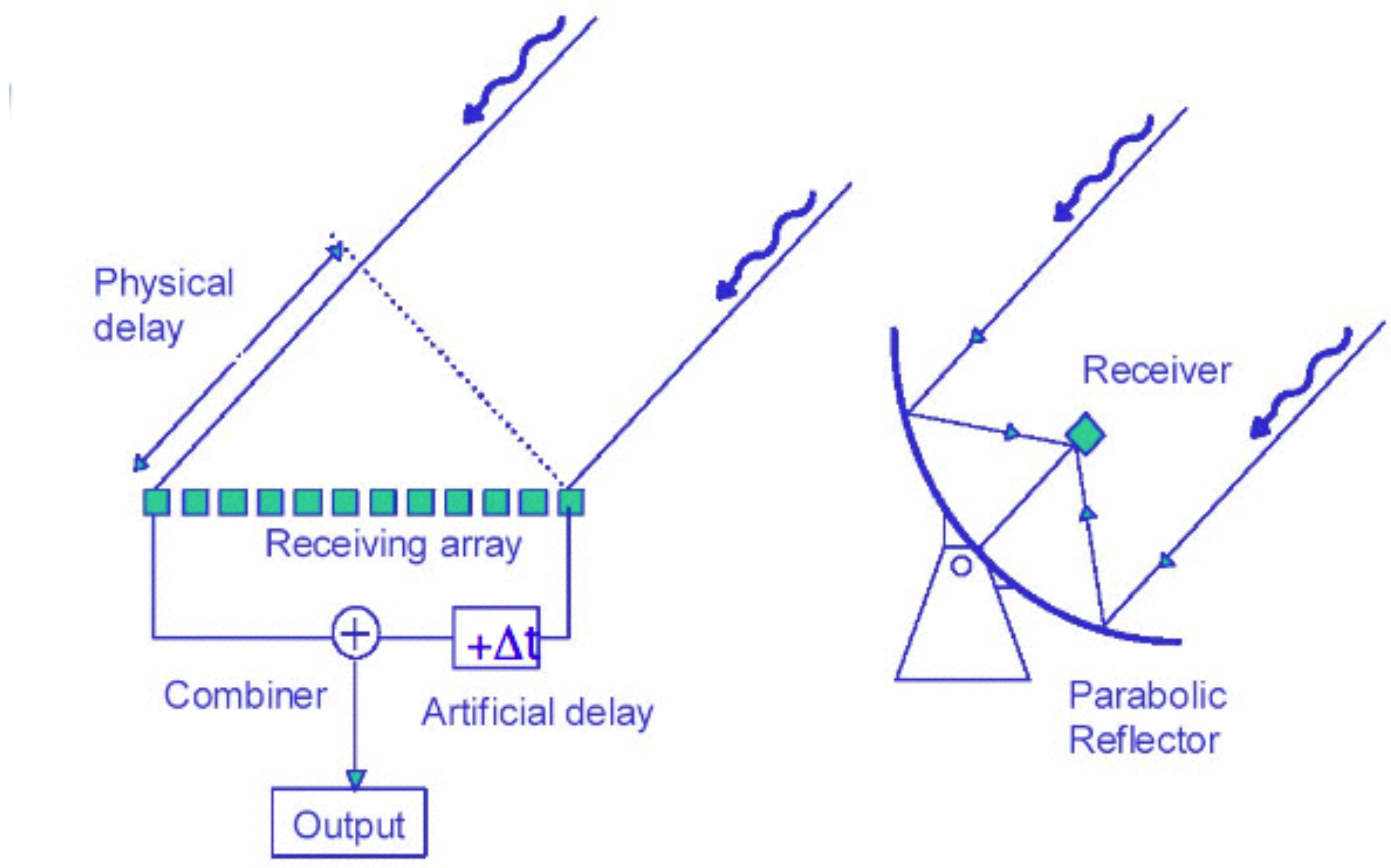

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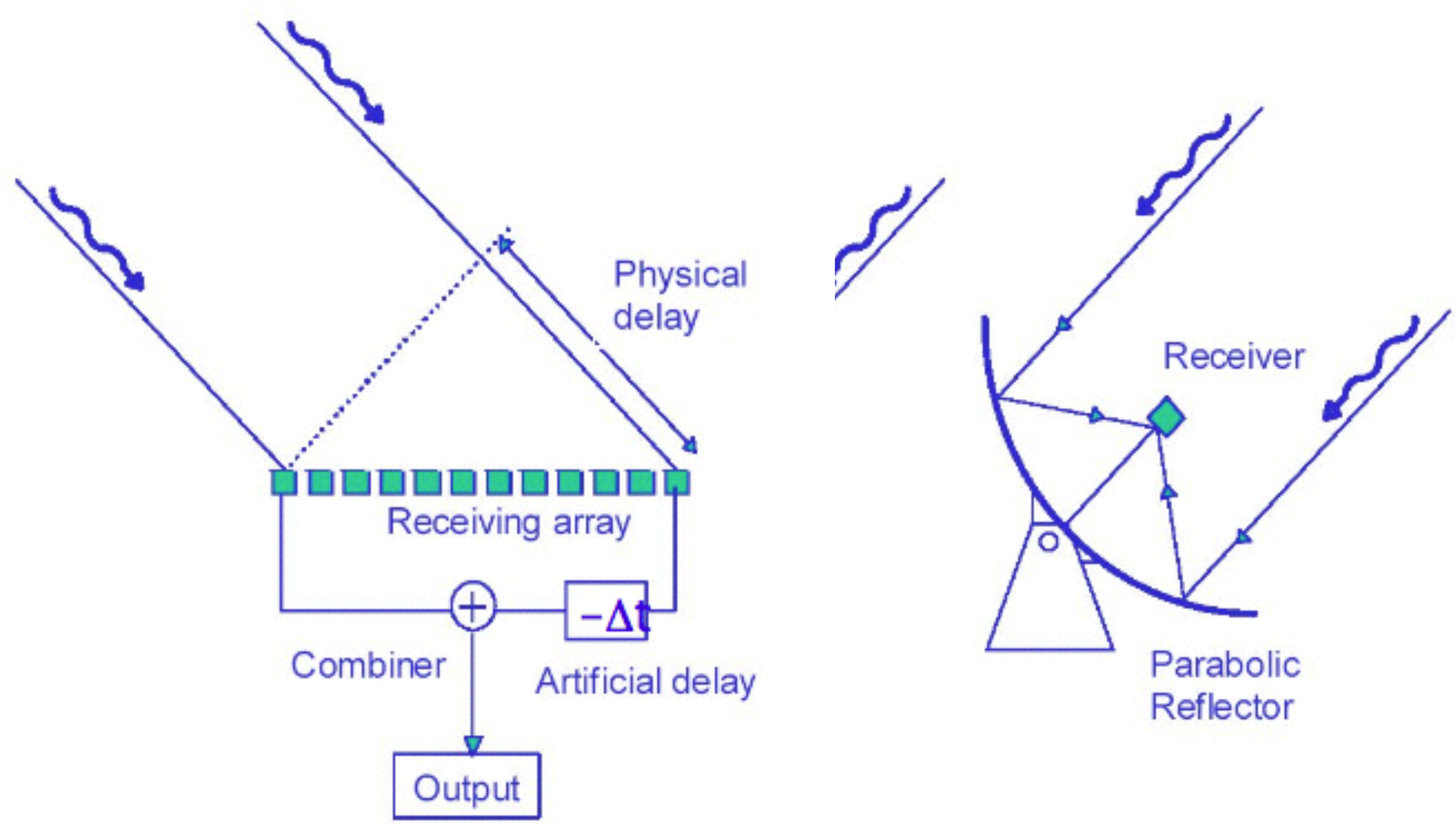

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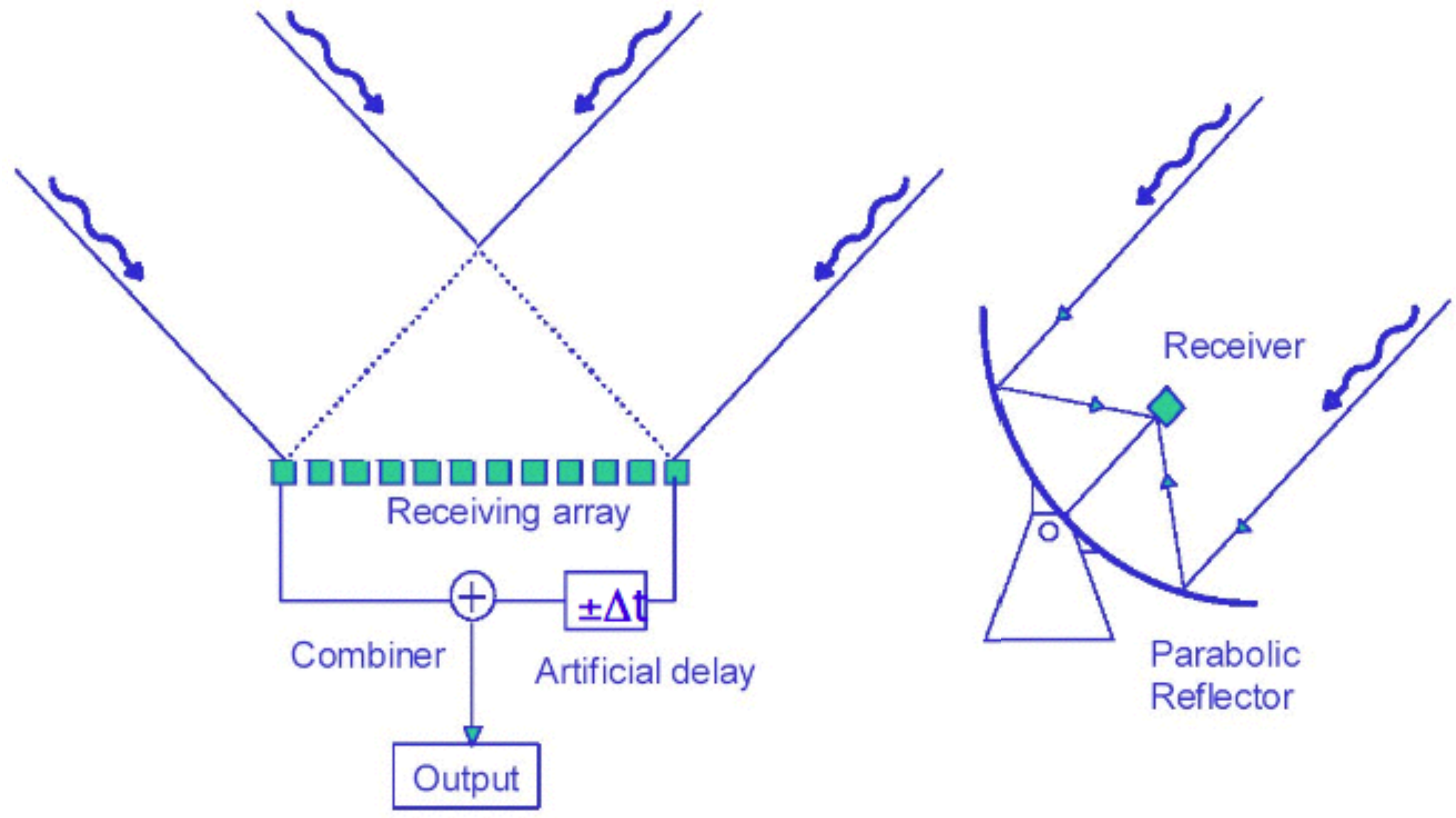

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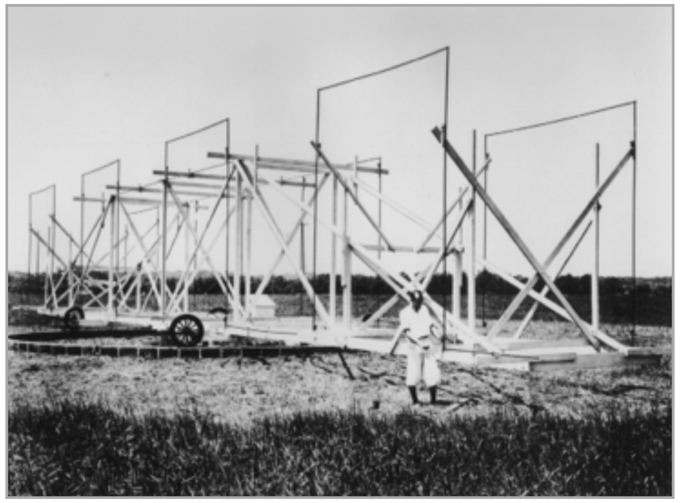
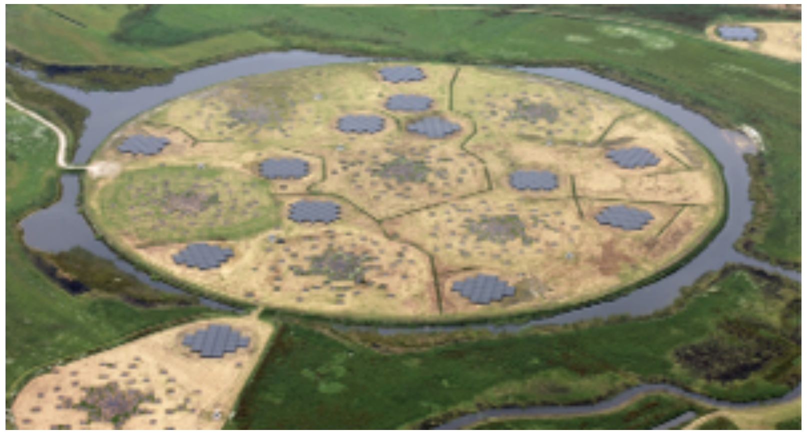
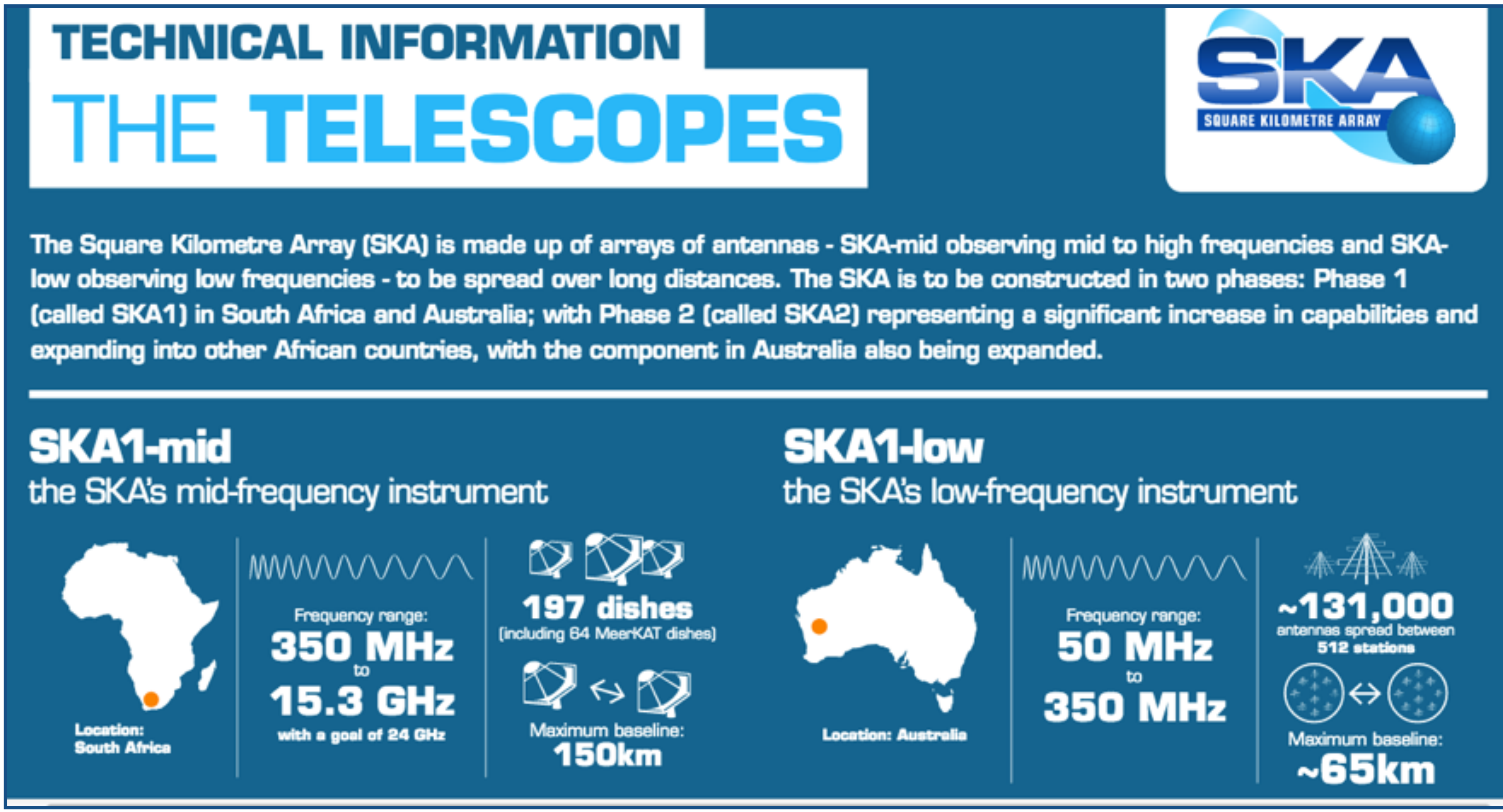




The Square Kilometre Array



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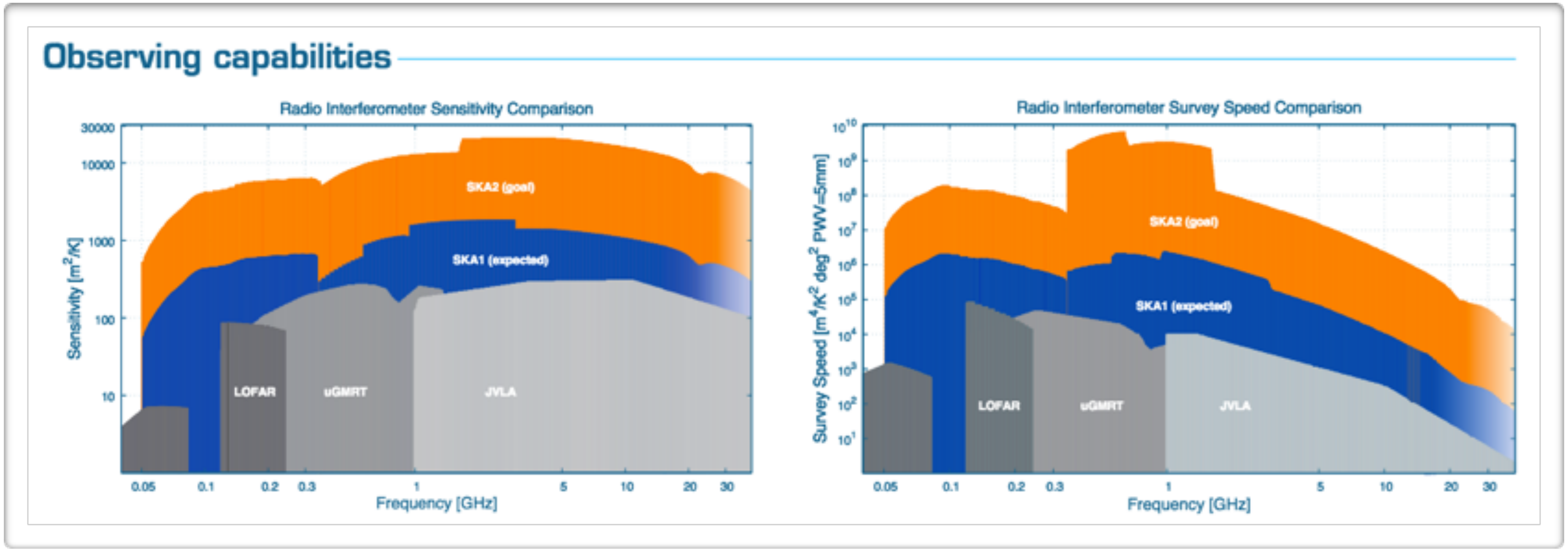
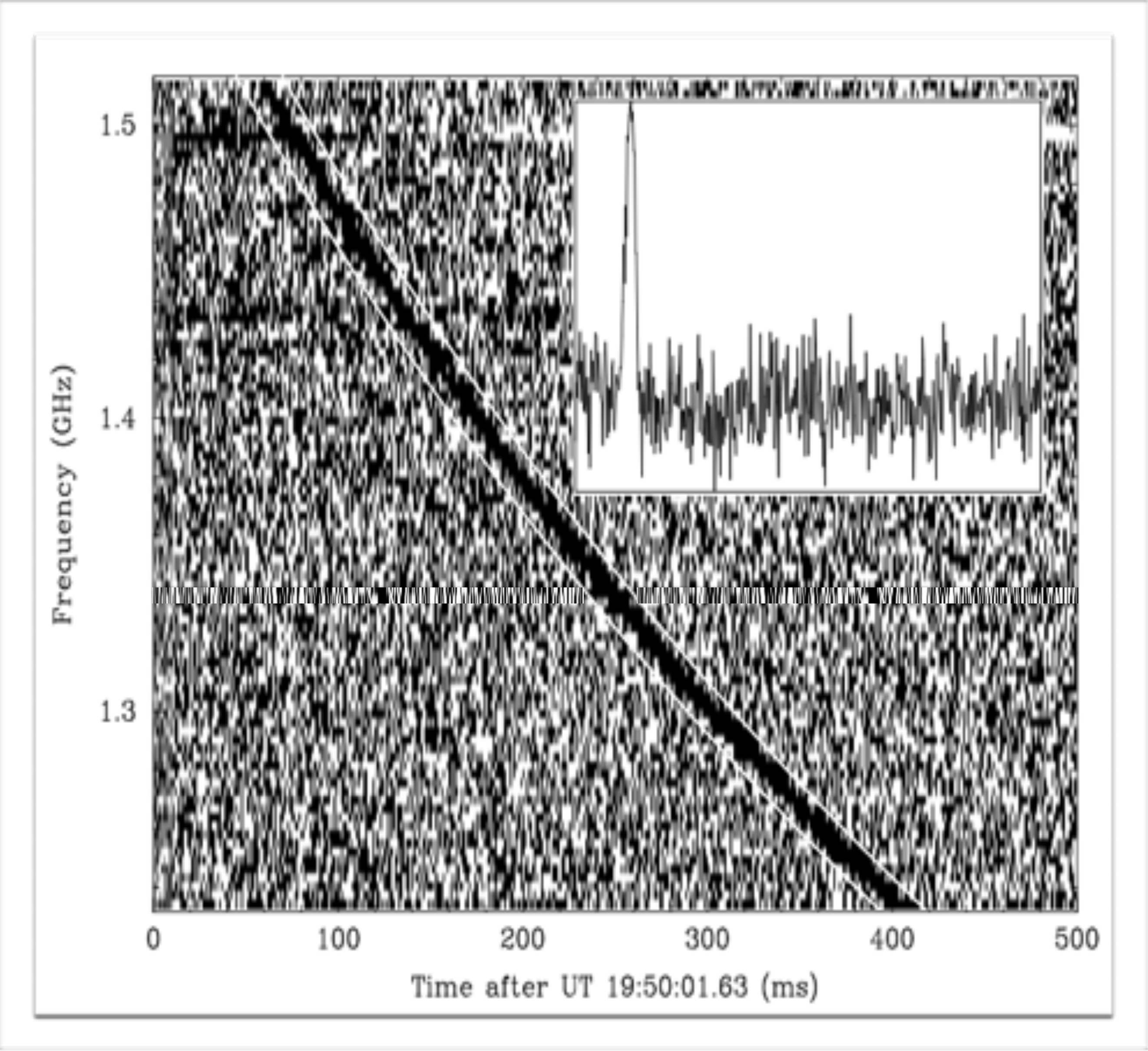


www.skatelescope.org

Fast Radio Bursts

An extraordinary pulse



Lorimer et al 2007

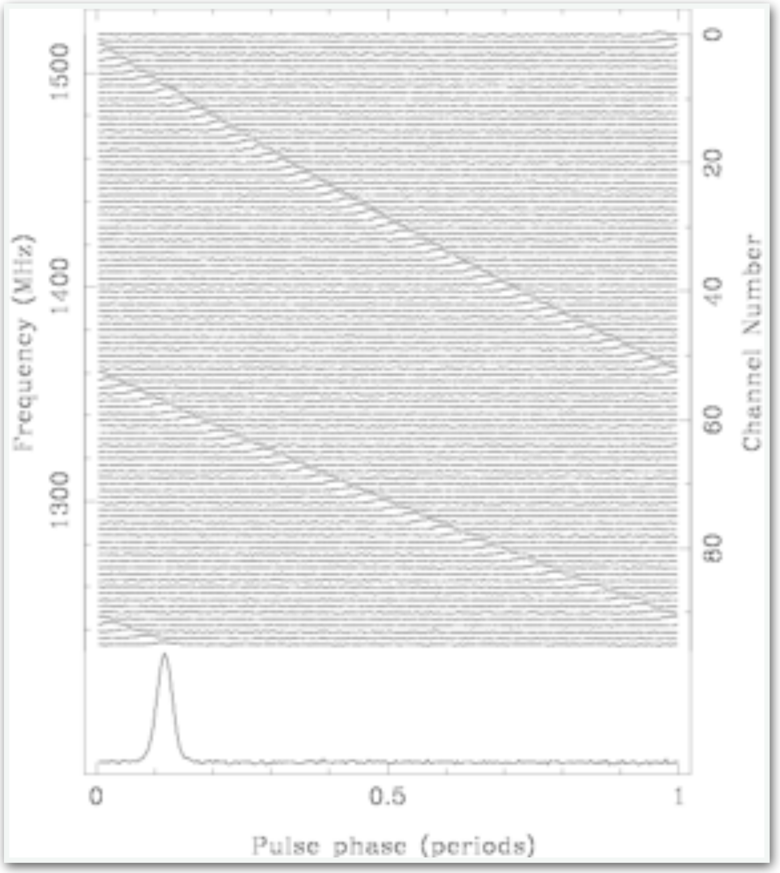
Dispersion

The group velocity of an electromagnetic wave in a plasma depends on the emission frequency ν of the signal

$$v_g = c\left[1 - \frac{1}{2}\left(\frac{\nu_p}{\nu}\right)^2\right]$$

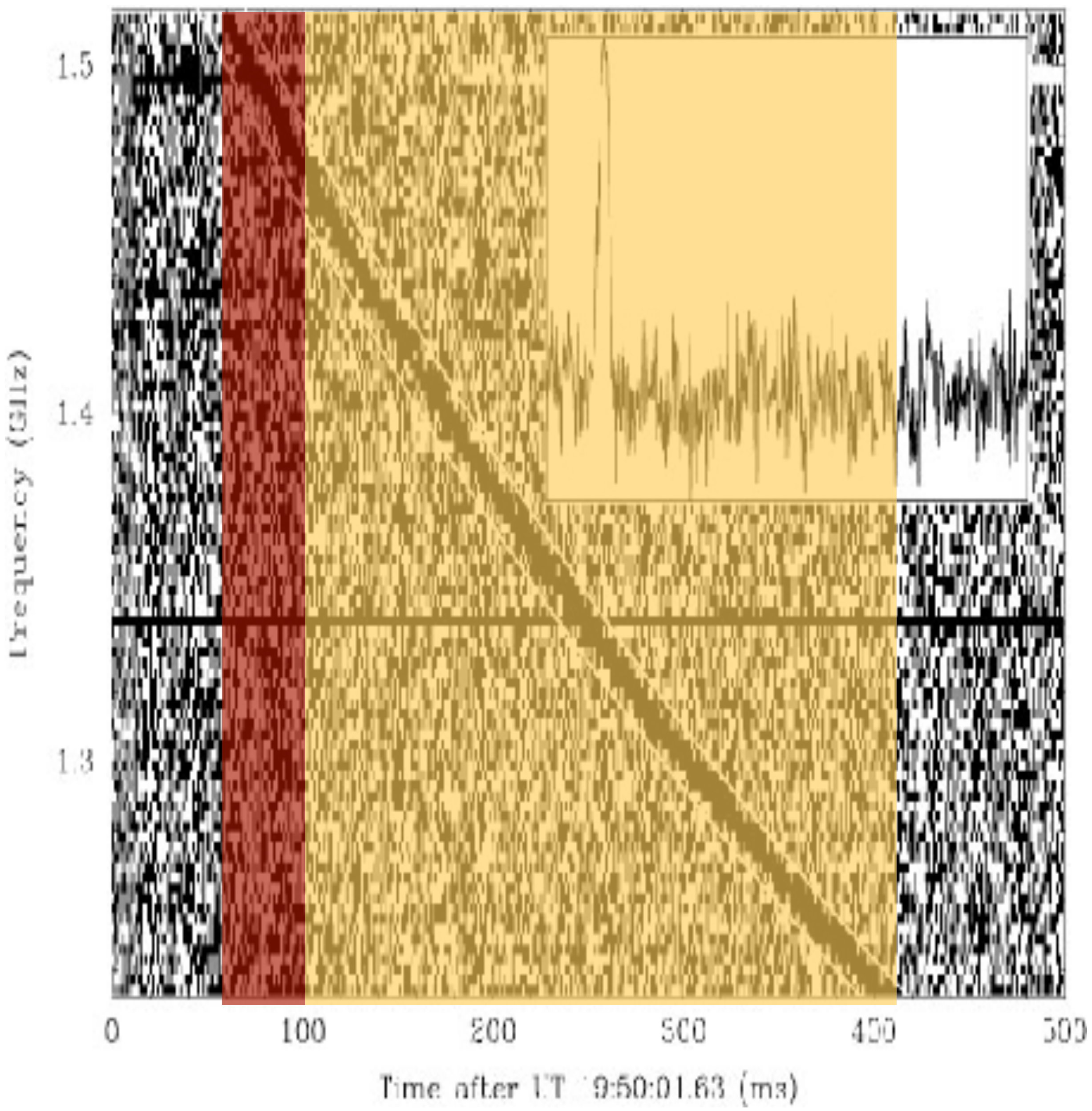
$$t = \int_0^d \frac{dl}{v_g} \sim \frac{d}{c} + \frac{1}{2}\frac{e^2}{\pi m_e c}\frac{1}{\nu^2} DM$$

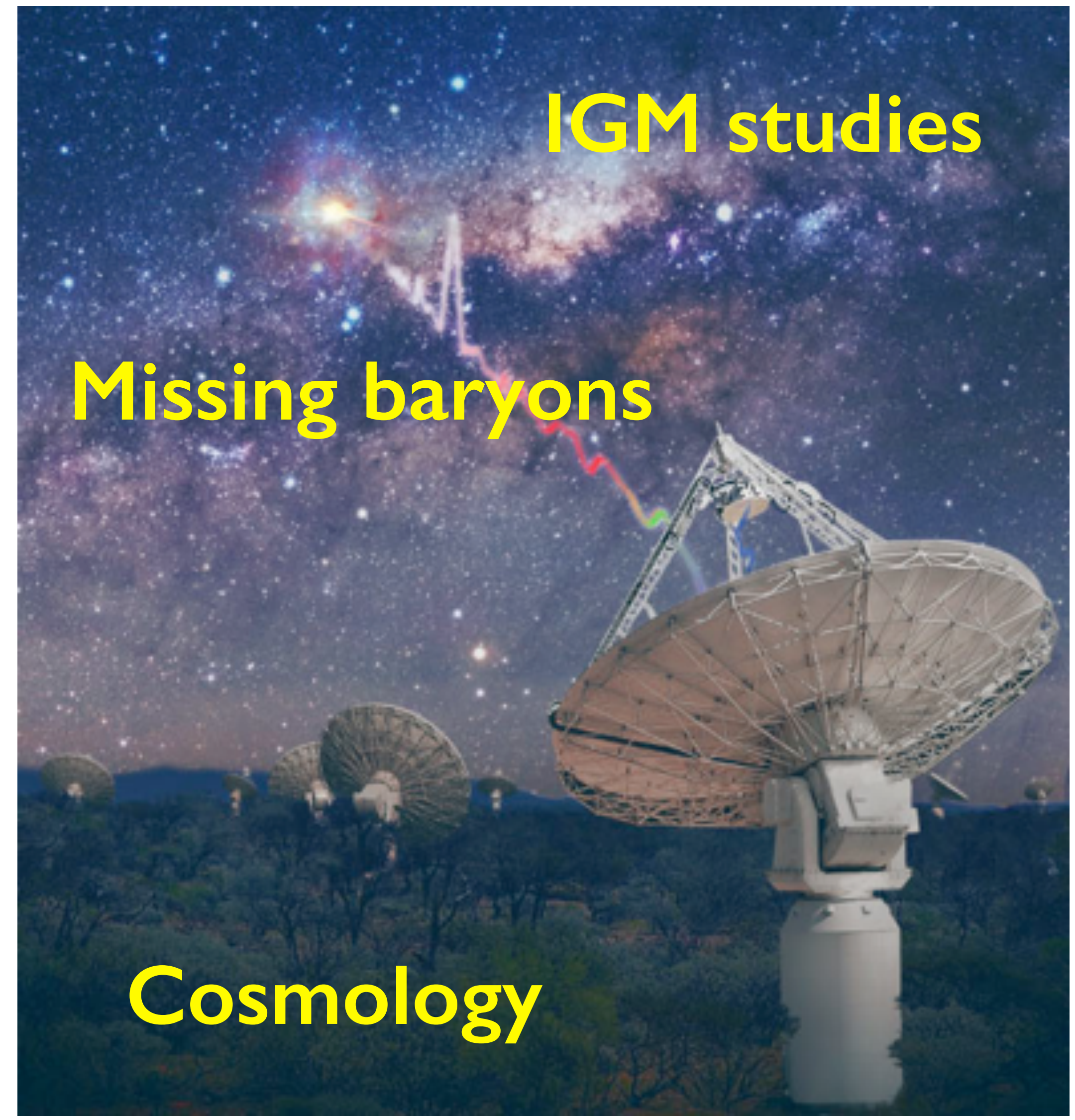
$$DM = \int_0^d n_e dl$$



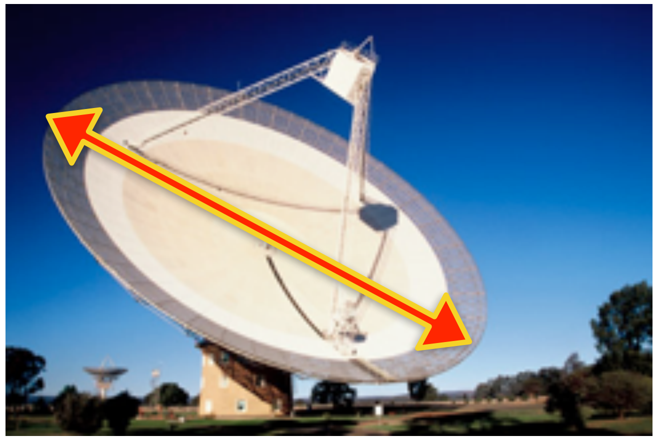
Radio waves emitted at lower frequencies arrive later

FRBs


1.5
1.4
1.3
Frequency (GHz)
0
100
200
300
400
500
Time after UT 19:50:01.63 (ms)

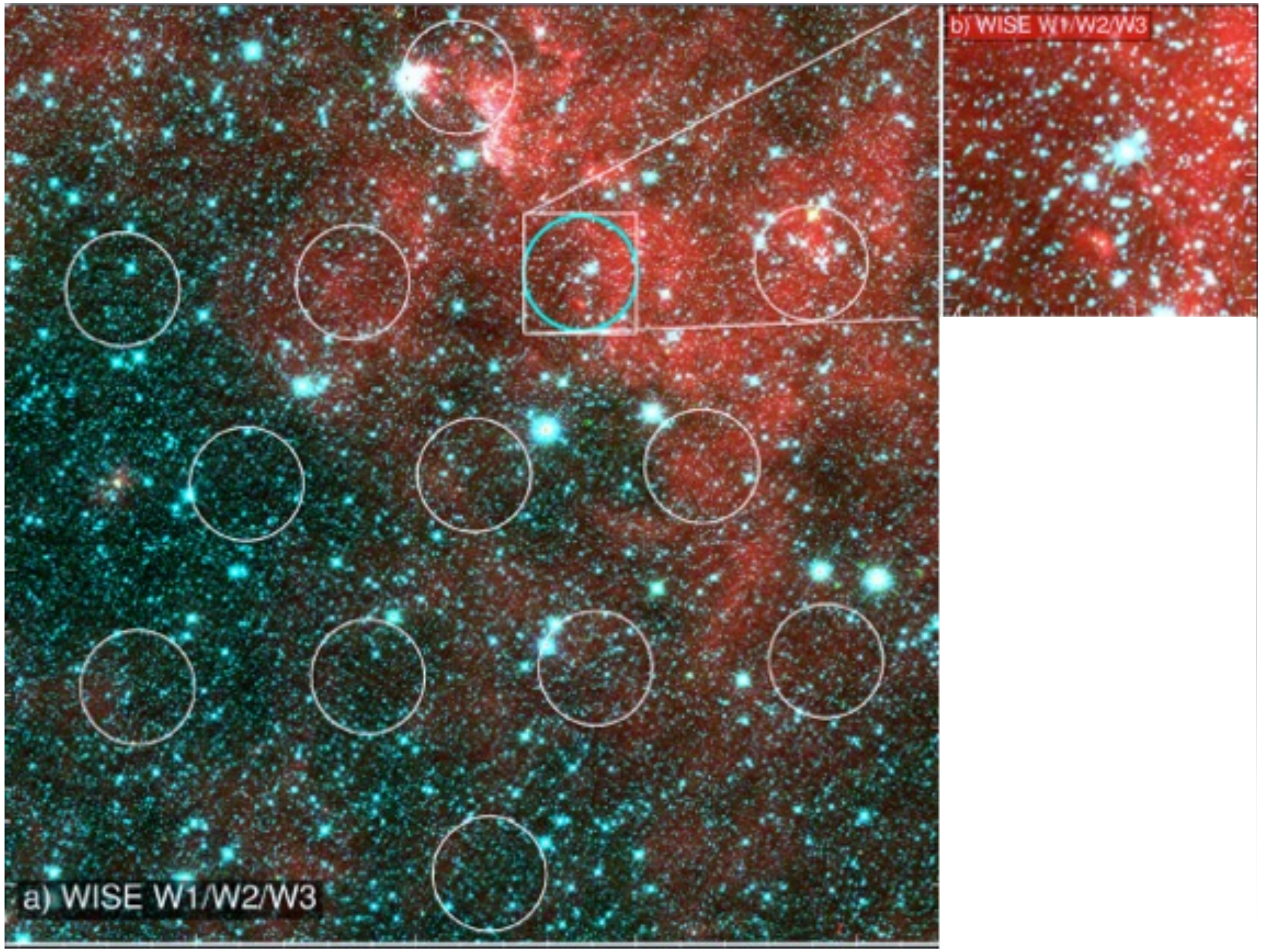

IGM studies
Missing baryons
Cosmology

Localizing FRBs

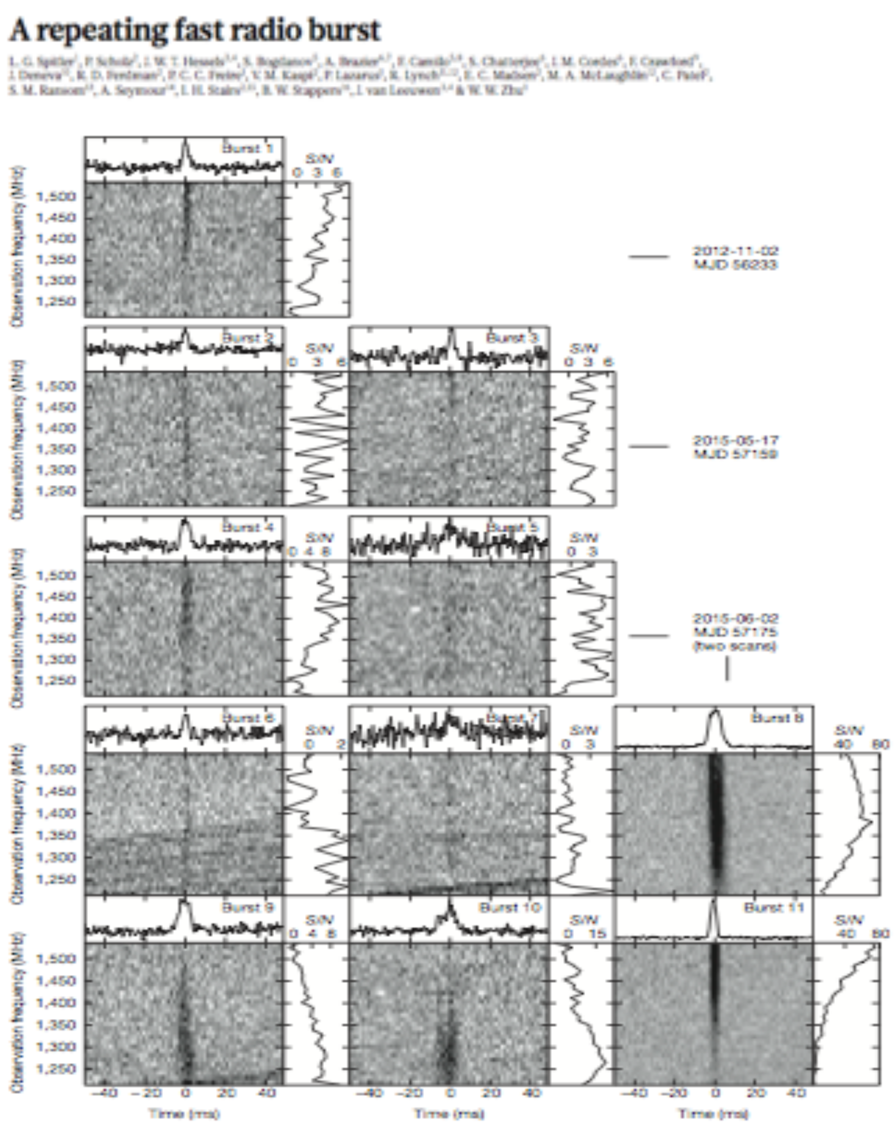


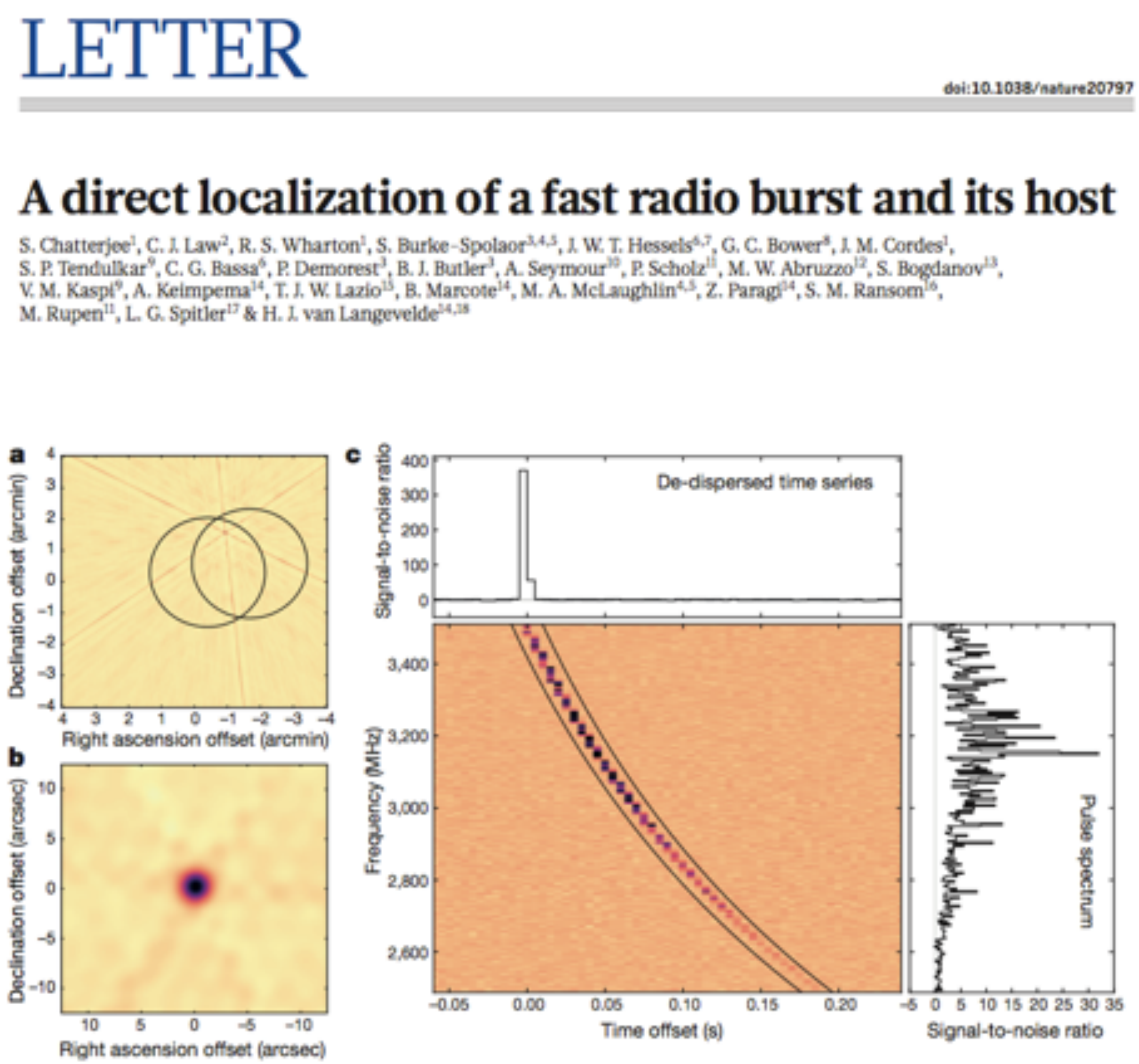
21cm/64m = 11arcmin x13

21cm/36km = 1arcsec



FRB 121102


A repeating fast radio burst
Burst 1
Burst 2
Burst 3
Burst 4
Burst 5
Burst 6
Burst 7
Burst 8
Burst 9
Burst 10
Burst 11
S/N
Observation frequency (MHz)
2012-11-02
MJD 56233
2015-05-17
MJD 57159
2015-06-02
MJD 57175
(two scans)
Time (ms)


LETTER
doi:10.1038/nature20797
A direct localization of a fast radio burst and its host
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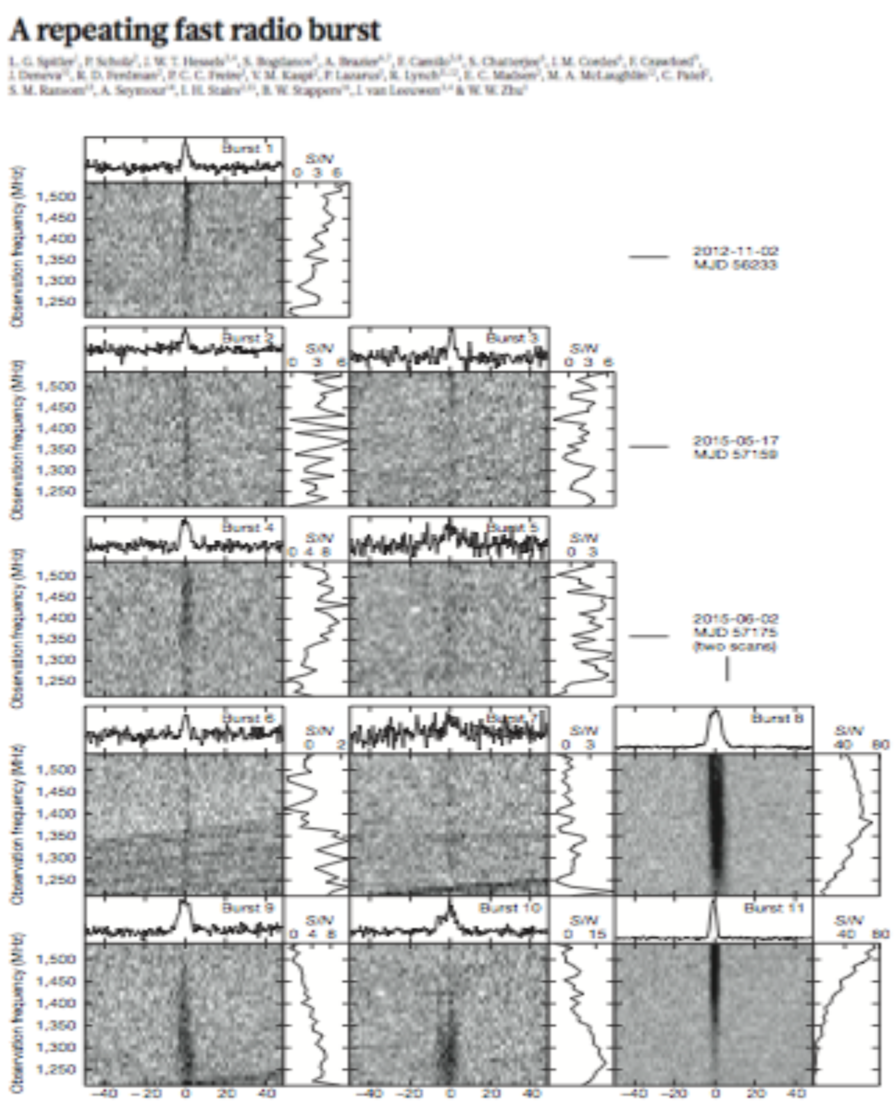
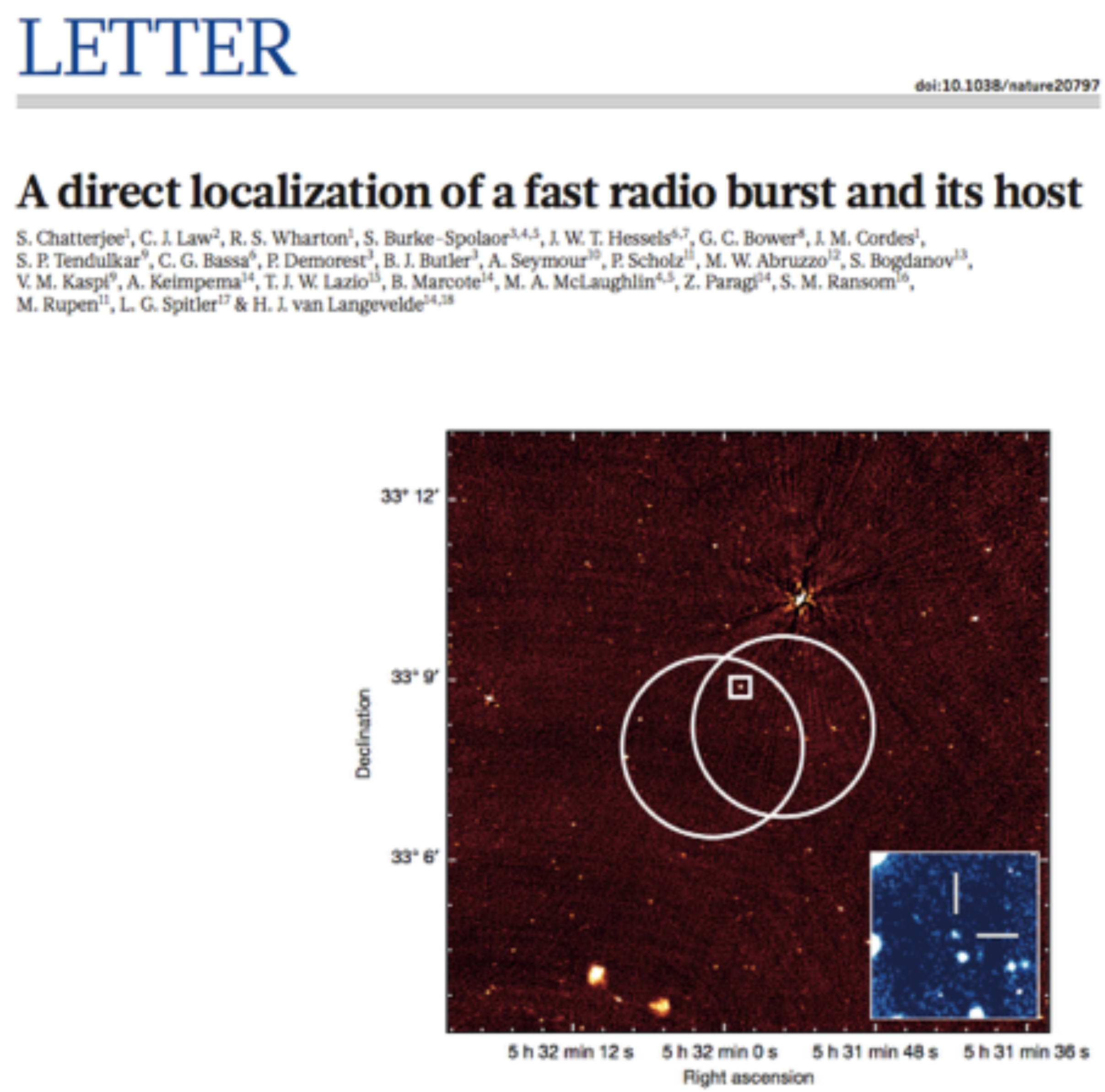
a
b
c
Declination offset (arcmin)
Right ascension offset (arcmin)
Declination offset (arcsec)
Right ascension offset (arcsec)
Signal-to-noise ratio
De-dispersed time series
Frequency (MHz)
Time offset (s)
Pulse spectrum
Signal-to-noise ratio

FRB 121102



A repeating fast radio burst



LETTER

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FRBs: the next generation

CHIME

HIRAX

PAF - Apertif

MeerKAT, ASKAP, SKA

HERA

UTMOST 2-D

Realfast @VLA

… stay tuned!

Thank you for your attention.
Questions?

Acknowledgements & Resources

- Leiden Uni radio astronomy course (Garret, Val Langevelde, Morabito)
  https://www.strw.leidenuniv.nl/radioastronomy/doku.php?id=ra_2015

- NRAO Essential Radio Astronomy course (Condon & Ransom)
  https://www.cv.nrao.edu/course/astr534/

- ERIS school 2017 Introduction to radio astronomy (McKean)
  https://www.astron.nl/eris2017/Documents/ERIS2017_L1_McKean.pdf

- Fast Radio Bursts review (Petroff, Hessels & Lorimer)
  https://arxiv.org/abs/1904.07947