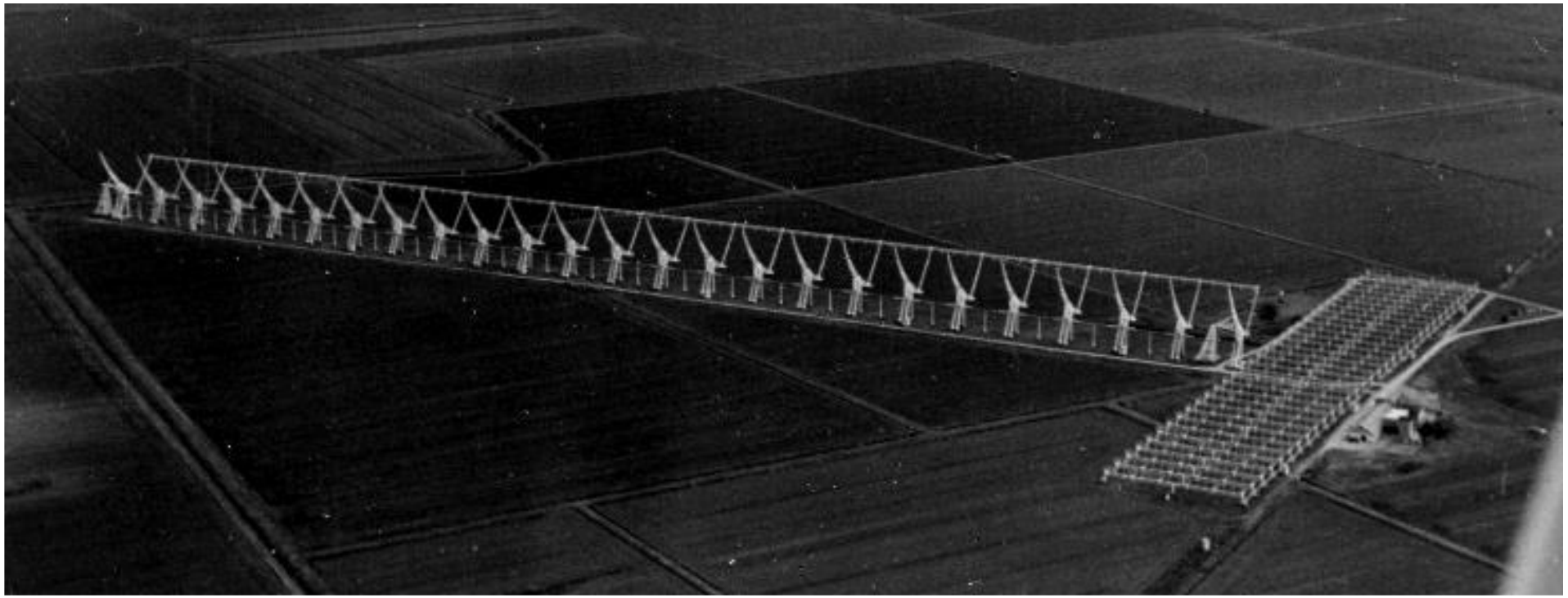
A brief history of the Northern Cross Radio Telescope

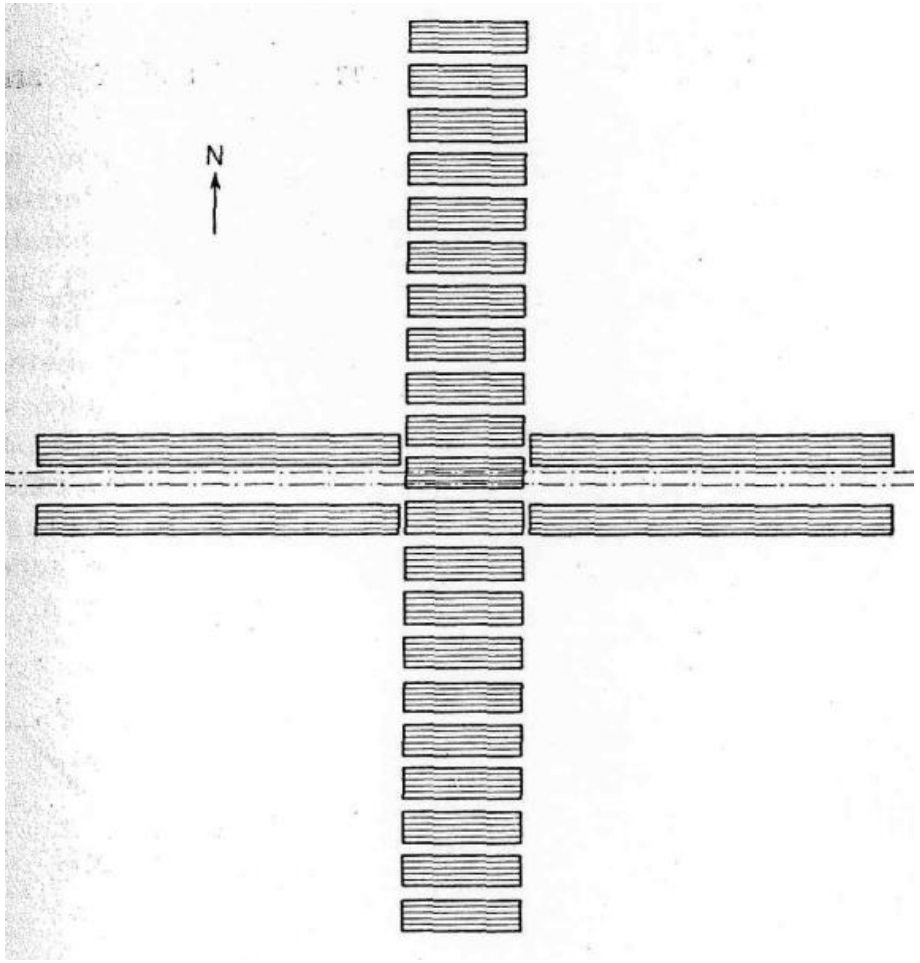
Germano Bianchi

F. Perini, G. Setti



IEEE HISTELCON Congress, 7-9 September 2023 - Firenze

The beginning…



The Northern Cross is the first Italian large radio telescope.

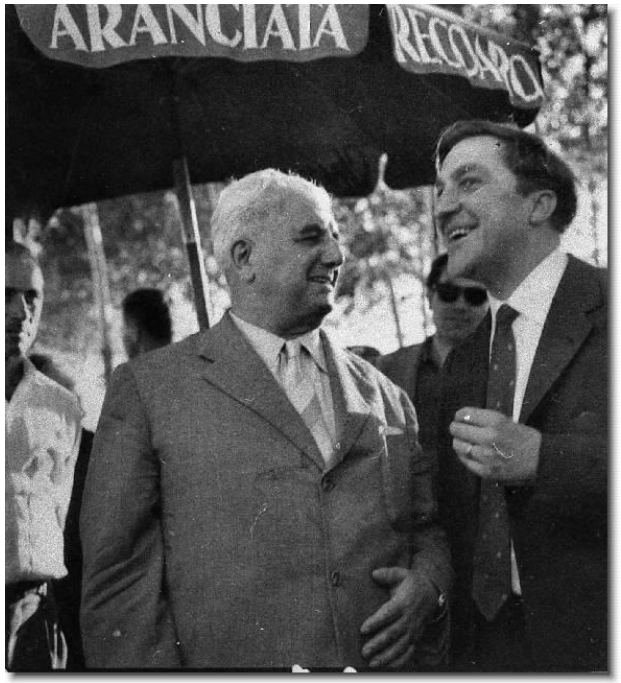
The original design was a “Mills’ cross” type configuration, with two arms of about 1.2Km, aligned in East-West and North-South directions, operating at 408MHz.

During its construction, the array was rearranged in a T shaped configuration.

The goal was to perform a large survey of extragalactic radio sources, identification of their optical counterparts and possible contribution to cosmological research.

First prototype

The project for the construction of the Northern Cross began in 1959 (responsible ***Marcello Ceccarelli,*** under the supervision of prof Puppi, director of Institute of Physics), with the construction of a trial radio telescope (***Medicinoscopio***), a 110 m long and 6.7 m wide parabolic cylinder operating at 327.4MHz, in order to gain experience with this type of antenna and related technologies.



Initial works

LETTERE ALLA REDAZIONE

The Italian Cross Radiotelescope.

I – Design of the antenna.

A. Braccesi and M. Ceccarelli

Istituto Nazionale di Fisica Nucleare - Sezione di Bologna
Laboratorio di Radioastronomia, Istituto di Fisica dell'Università - Bologna

(ricevuta il 21 Luglio 1961)

Introduction.

The telescope, which is primarily intended for identification and high resolution studies of weak radiosources, is designed to work around the frequency of 408 MHz. It will be constituted by two antennas about 1.2 km long and 30 meter wide forming a «Mills' cross» (*). This shape, or the equivalent one are, nowadays, the best compromise between resolution, sensitivity and cost for work at wavelengths around one meter.

In the following pages a general description of the instrument and the essential electromagnetic and mechanic details are given. It should be however remembered that the final accurate performance of various parts of the instrument cannot be reliably computed or measured on models, so that quite a considerable part of the design will follow the operation of components at full scale.

(*) B. Mills, A. Little, K. Sheridan and O. S. Lee: Proc. Inst. Radio Engrs. **46**, 62 (1958).

1. – General design.

In a cross radiotelescope the motion of the earth provides the scanning in right ascension. In addition the beam can be tilted in declination by properly adjusting the phase of the antenna elements in the North-South arm.

The elements of this arm can be either closely spaced, as in the original Mills' cross or, alternatively, located at a certain distance from each other. In the first case the N-S arm is illuminated with continuity and hence no grating fringes are expected. On the other hand a large array of closely spaced elements requires a very large number of phase shifters thus complicating enormously its maintenance and operation.

If alternatively the N-S arm is made of elements several wavelengths wide, as for instance parabolic reflectors, a phase adjustment is needed for a much smaller number of elements. In this case however the antenna pattern contains also maxima of higher order than zero.

These can be eliminated in either of two ways:

In 1962, following the publication of the design of the antenna and of the preliminary design of the receiving system, works began on the construction of the first arm of the antenna, the East-West (E-W), 564 meters long and 35 meters wide parabolic cylinder.

IL NUOVO CIMENTO Vol. XXIII, N. 1 1° Gennaio 1962

The Italian Cross Radiotelescope.

II. – Preliminary Design of the Receiver.

G. Grueff, C. Rosatelli and G. Sinnaeglia

I.N.F.N., Istituto di Fisica dell'Università - Bologna
Comitato Nazionale Energia Nucleare - Sezione di Bologna

(ricevuta il 23 Dicembre 1961)

The receiving system that we are going to describe, is intended to operate in connection with the antenna system which has been described in part I of this paper.

The entire system (antenna plus receiver) has been conceived as a whole, functionally interdependent, and the designs of the two go on side by side. The main purposes of the receiver shall be:

a) To amplify the signals being collected by different sections of the antenna system, to convert them to a suitable intermediate frequency, and to send them to a central signal-handling station, through separate cables, so as to constitute a number of different reception «channels», each of them corresponding to a different section of the antenna.

b) To introduce on the single channels phase shifts, delays and attenuations, according to strictly controlled characteristics, in order to meet the required conditions for proper operation of the antenna system.

c) To divide each channel into a group of «subchannels» with different phase shifts, and recombine groups of properly chosen subchannels, so as to obtain new channels corresponding to a number of independent pointings of the antenna beam.

d) To multiply, in pairs, the outputs of said new channels so as to obtain different outputs corresponding to independent beams.

e) To handle these outputs, first by an analogic data process, (clippers, integrators), then by a digital one, through suitable electronic computing devices.

An integral part of the receiving system will consist of the equipment required to measure the system's performances, to check its stability, and to perform the necessary adjustments to bring the antenna beams to their desired angular positions.

The final composition of each receiving section is still under discussion. Each one will probably consist, basically, of a «parametric» amplifier, a balanced mixer and an intermediate frequency preamplifier (*).

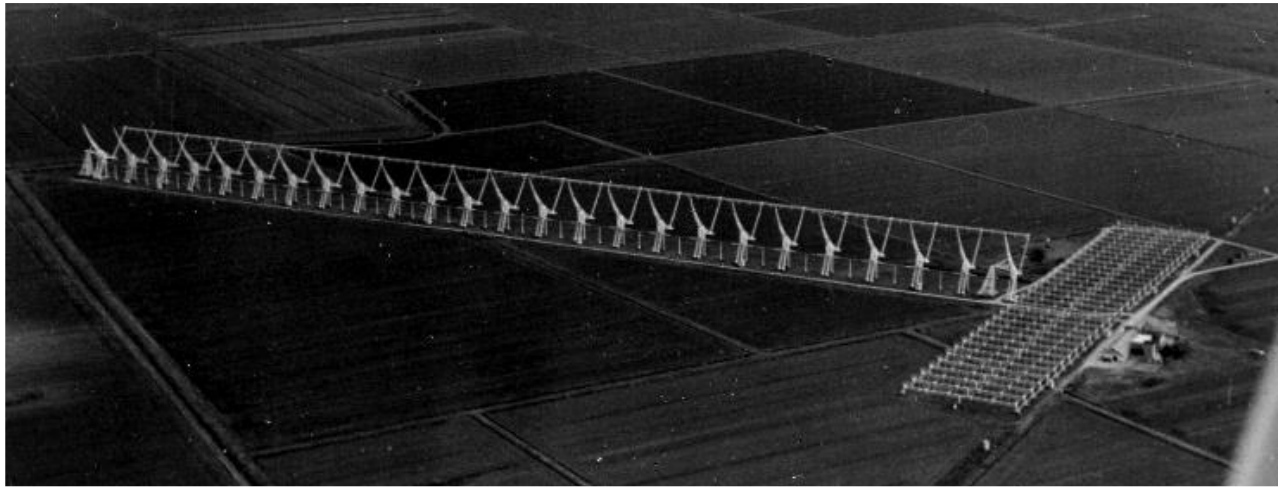
(*) In the first period of operation, ordinary converters, with cooperated crystal diodes will be most probably employed to give the I.F. frequency signal.

Inauguration

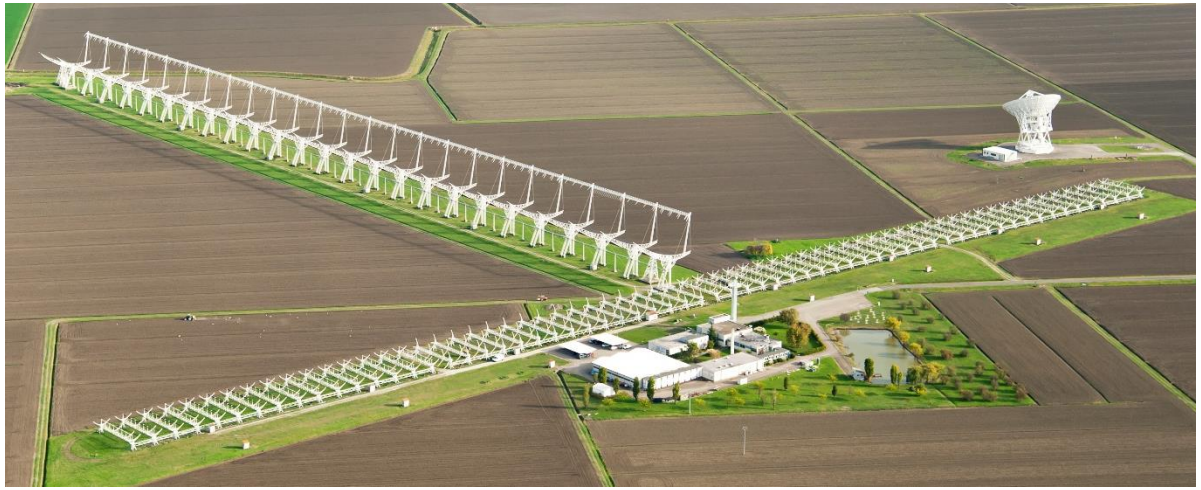
The inauguration took place on October 24, 1964.

Completion

In 1967, the North-South arm (N-S) also became operational.
It consisted of 32 cylindrical parabolic antennas, each 47 meters long and 7.5 meters wide and spaced 10 meters apart.



1967



2023

In 1975 took place the configuration rearrangement and the N-S cylinders were split into two 23.5 m long reflectors each one and respectively positioned to the North and South, in order to double the length of the North-South arm to the current 640 m.

Features

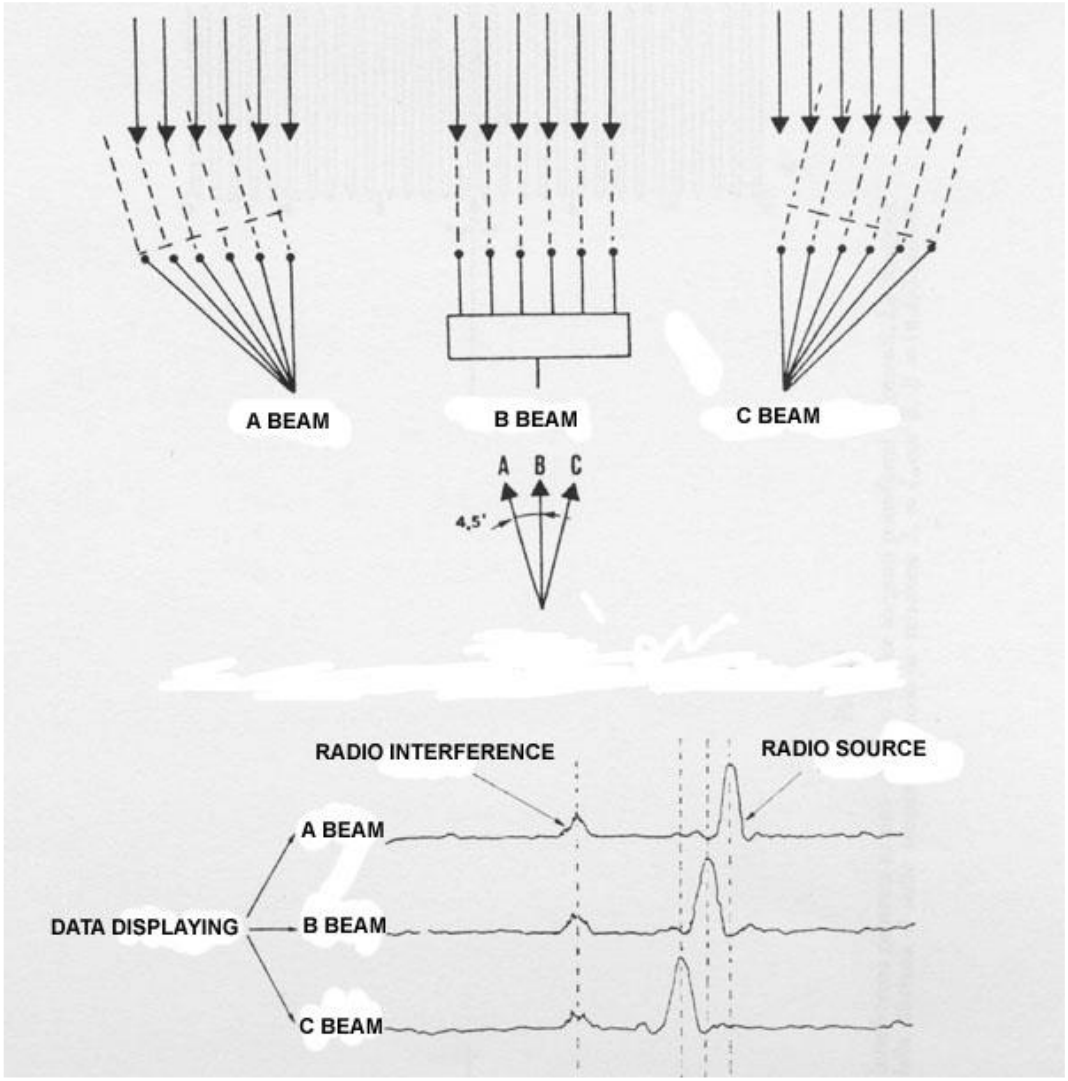
The Northern Cross is a transit instrument, mechanically steerable only in declination, so it can solely observe those objects that are culminating on the local celestial meridian.

The E-W arm is constituted by a single antenna having 1536 dipoles aligned along the focal axis.
Each cylinder reflectors of the N-S has 64 dipoles located on the focal axis.

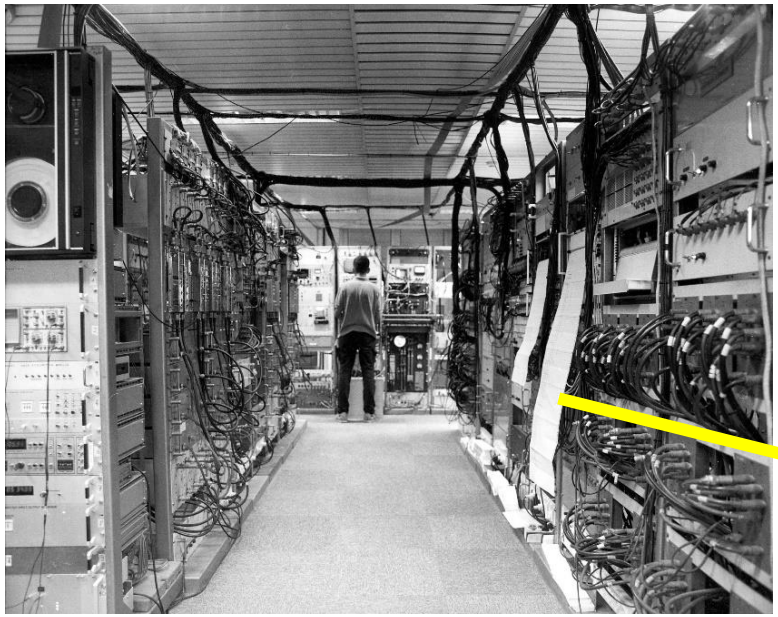
The Northern Cross receives radio waves centred at a frequency of 408 MHz.
The original RF band was only 2.7 MHz but the focal line allowed working up to 16MHz.
For this reason, by simply changing amplifiers and filters, it was possible to widen the band to 16MHz for the pulsars and FRB research.

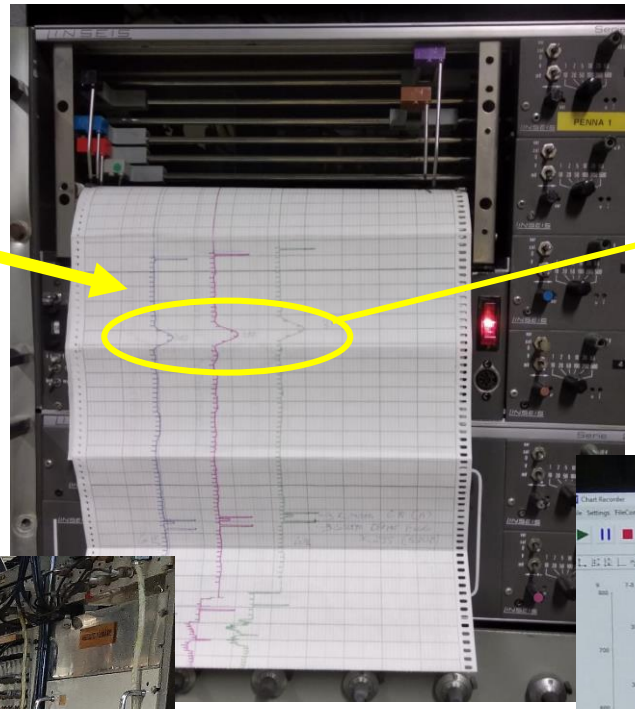
The collective area is about 27.000 m^2 and this allows to identify and measure extremely faint sources.

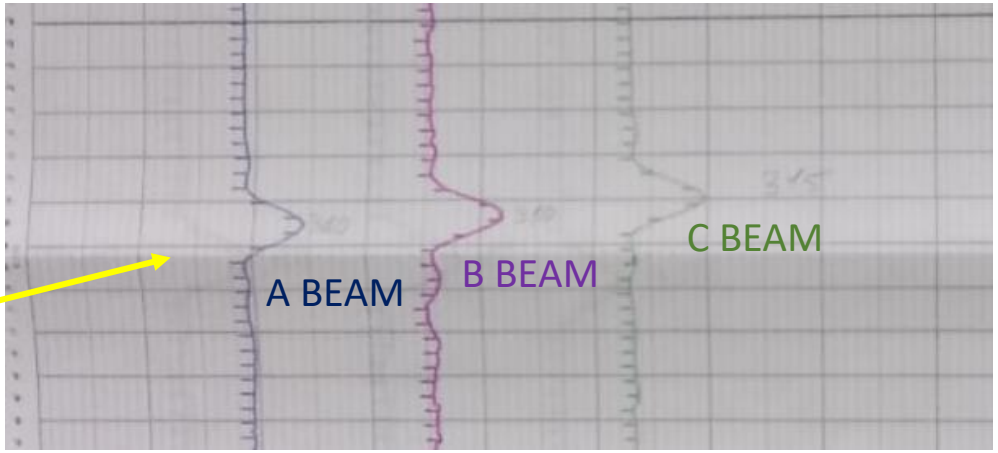
Observation method

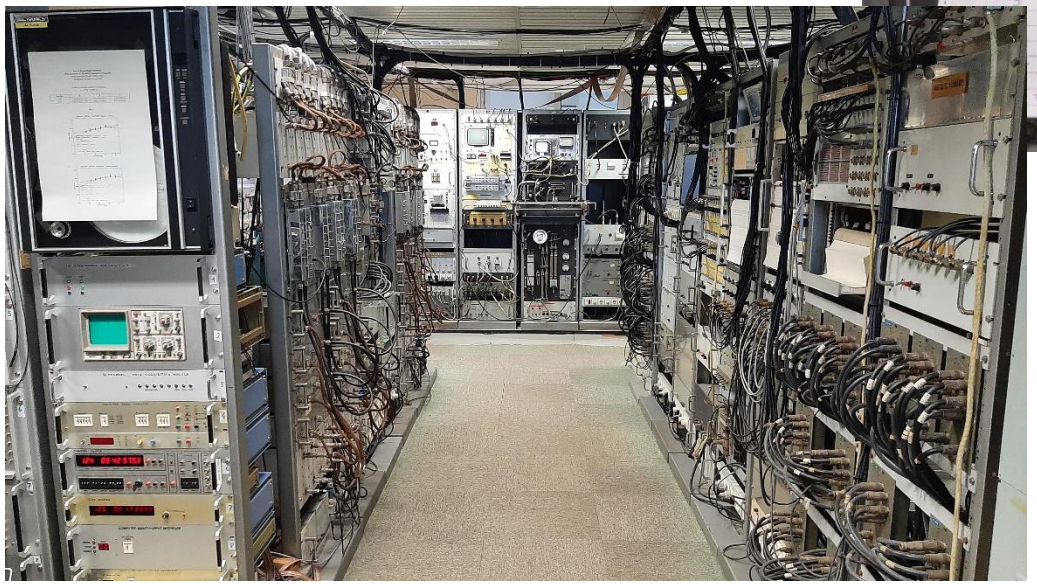


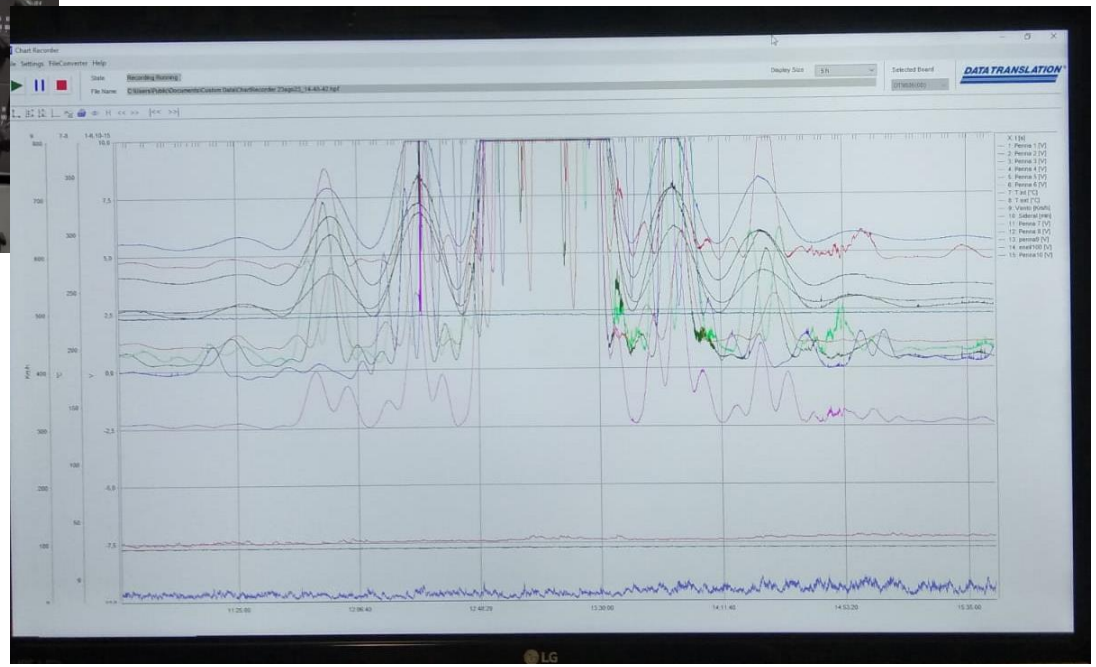
The receivers room







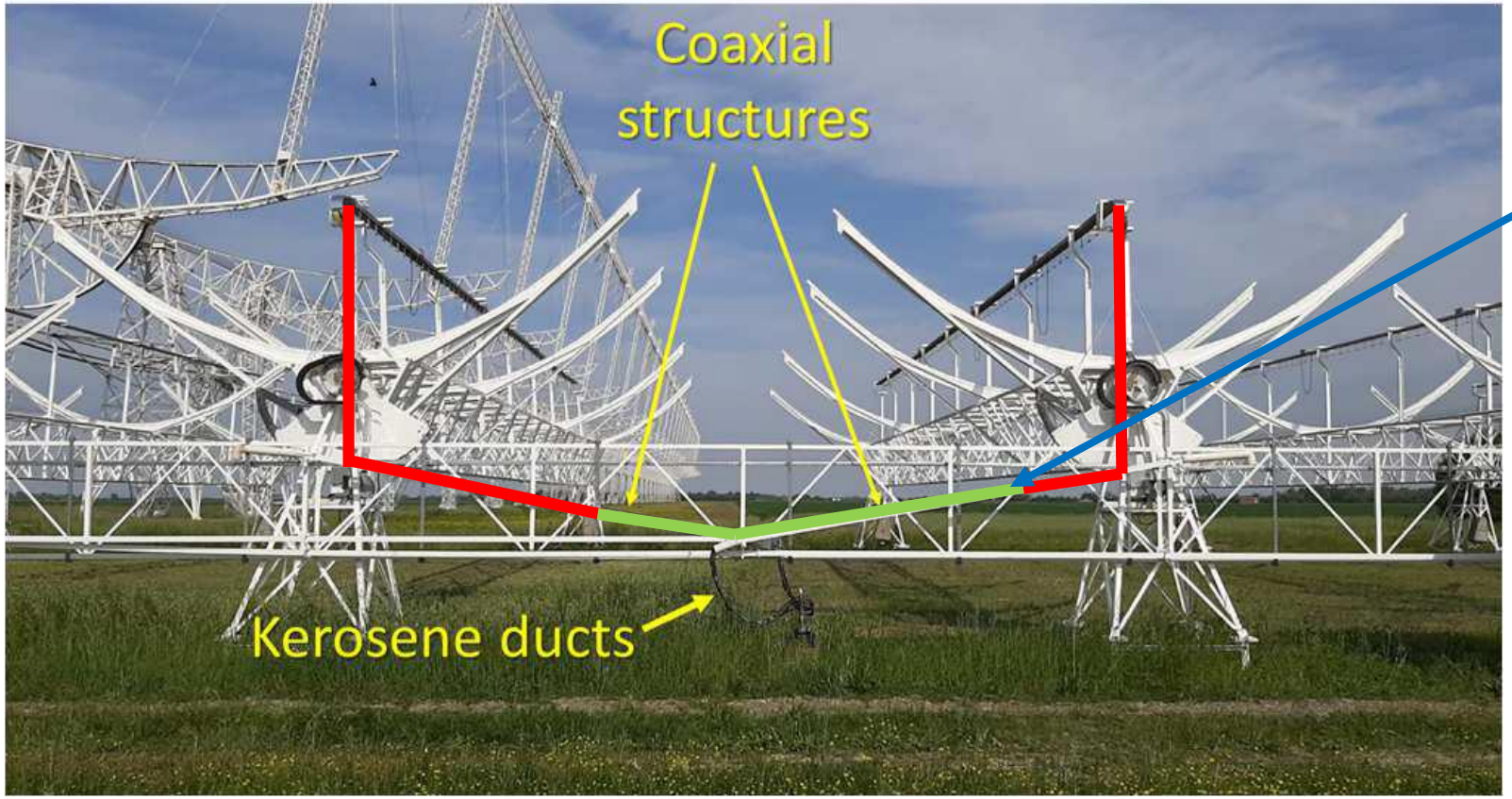


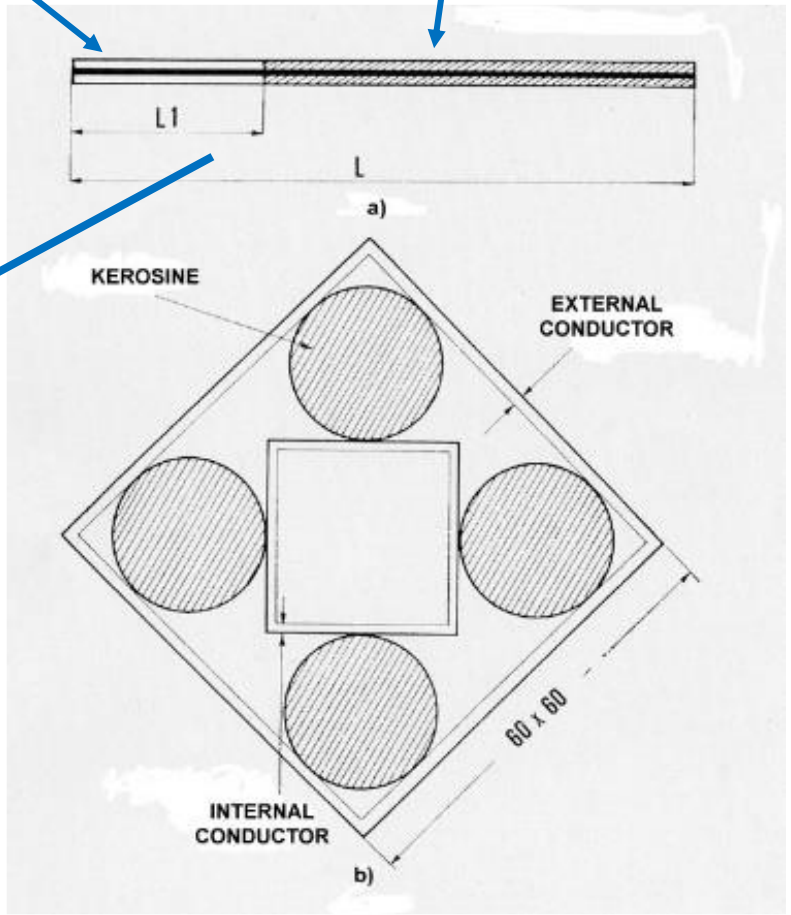


Signal phasing using kerosene

In the first part the dielectric is air

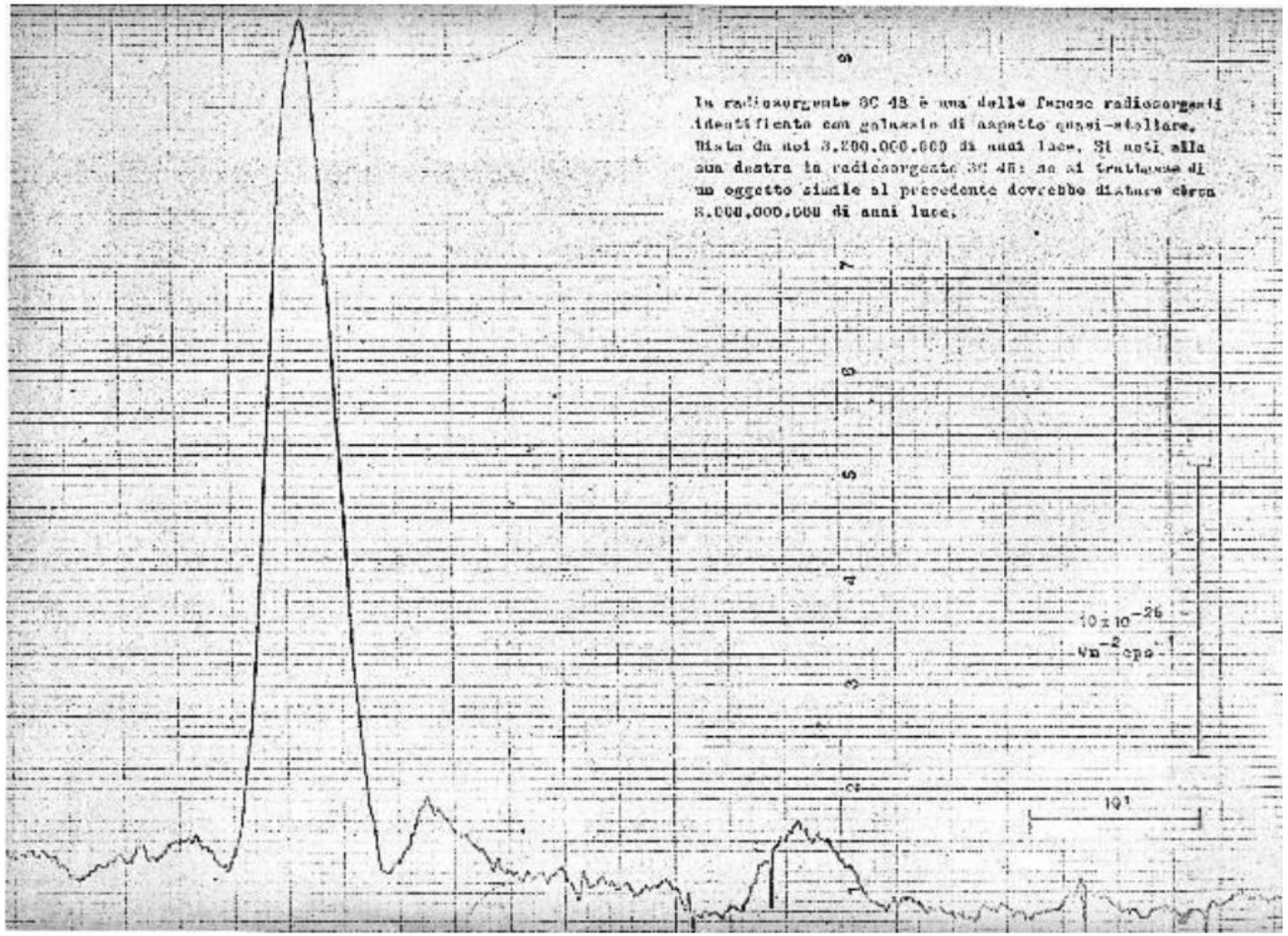
In the second part the dielectric is kerosene





Moving the level of kerosene inside the coaxial structure, it is possible to delay one RF signal respect to the other coming from another cylinder, allowing an easier and cleaver realisation of the antennas phasing.

The “first light”



In October 1964 the first signal coming from the E-W arm was successfully acquired

B catalogue

- In 1970, the B2.1 catalogue was published. It contained 3235 extragalactic radio sources and is complete down to 0.2 Jy, at least five times lower than that of the large catalogues existing at the time.

- In the following three years the systematic observations continued and the catalogues B2.2 and B2.3, both complete down to 0.25 Jy, and B2.4, complete down to 0.6 Jy, were published.

- All together the B2 catalogues have listed 9923 radio sources in a total area between declinations +21°40’ and +40°18’ and have been largely cited (about 600 citations).

- In 1967 (using also the N-S arm) a new survey was carried out leading to the publication of the B3 catalogue of radio sources. It contained 13.354 radio sources, complete to 0.1 Jy over an area between declinations +37°15’ and +47°37’.

List of published catalogues

A catalogue of 3235 radio sources at 408 MHz
Colla, G.; Fanti, C.; Ficarra, A.; Formiggini, L.; Gandolfi, E.; Grueff, G.; Lari, C.; Padrielli, L.; Roffi, G.; Tomasi, P.; Vigotti, M.
Astronomy & Astrophysics Supplement Series Vol. 1, no. 3, p.281, 1970

The B2 Catalogue of radio sources - second part
Colla, G.; Fanti, C.; Fanti, R.; Ficarra, A.; Formiggini, L.; Gandolfi, E.; Lari, C.; Marano, B.; Padrielli, L.; Tomasi, P.
Astronomy and Astrophysics Supplement, Vol. 7, p.1, 1972

The B2 catalogue of radio sources_- third part
Colla, G.; Fanti, C.; Fanti, R.; Ficarra, A.; Formiggini, L.; Gandolfi, E.; Gioia, I.; Lari, C.; Marano, B.; Padrielli, L.; Tomasi, P.
Astronomy and Astrophysics Supplement, Vol. 11, p.291, 1973

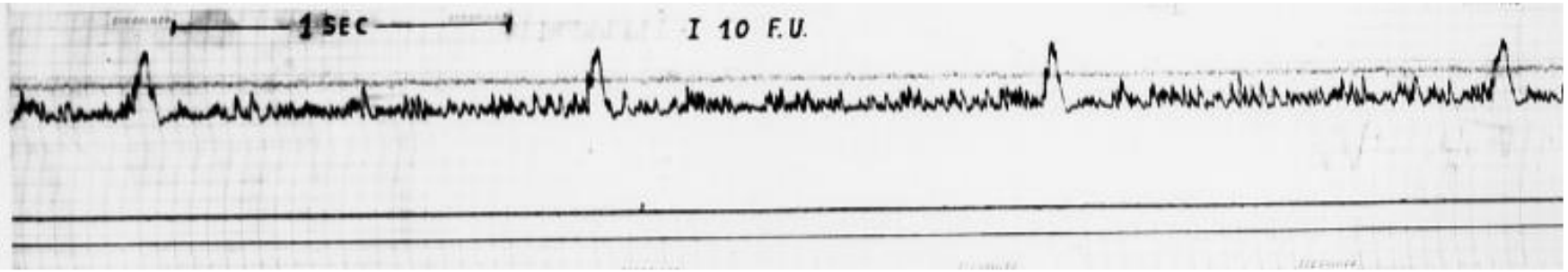
The B2 catalogue of radio sources - fourth part.
Fanti, C.; Fanti, R.; Ficarra, A.; Padrielli, L.
Astronomy and Astrophysics, Suppl. Ser., Vol. 18, p. 147 – 156, 1974

A new Bologna sky survey at 408 MHz
Ficarra, A.; Grueff, G.; Tomassetti, G.
Astronomy and Astrophysics Supplement Series, vol. 59, Feb. 1985, p. 255-347,1985

Quasars and Pulsars

- In the early 1970s, around 200 quasars were observed.

- Between 1991 and 1995, thanks to the installation of a dedicated system for the observation of millisecond and sub-millisecond pulsars, using the E-W arm was possible to observe a sample of radio pulsars in conjunction with the Compton Gamma-Ray Observatory mission. From the analysis of the pulse profiles, the values of the period, the derivative of the period, the position of 55 pulsars were obtained.



First pulsar detected by the E-W arm

SKA test bed

From 2006 to 2009 the Northern Cross has been one technological demonstrator realised in the SKADS-FP6 project.

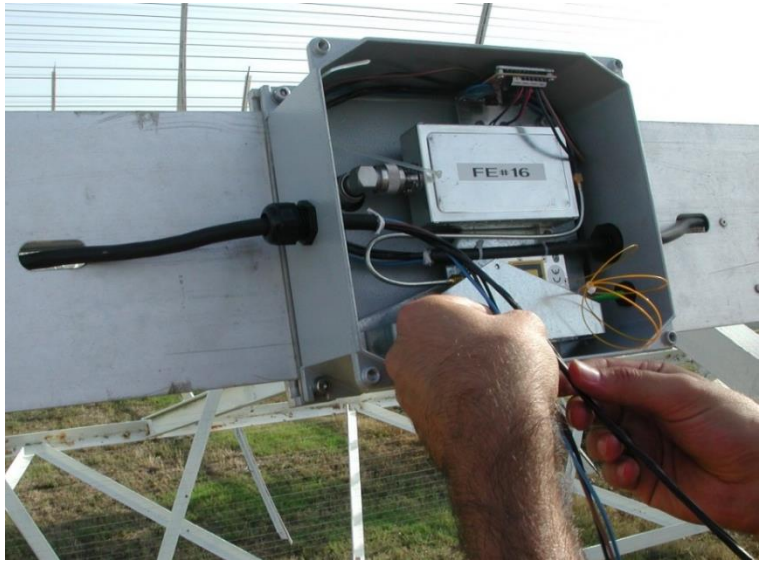
It was possible to test new technologies for the forthcoming SKA radio telescope:

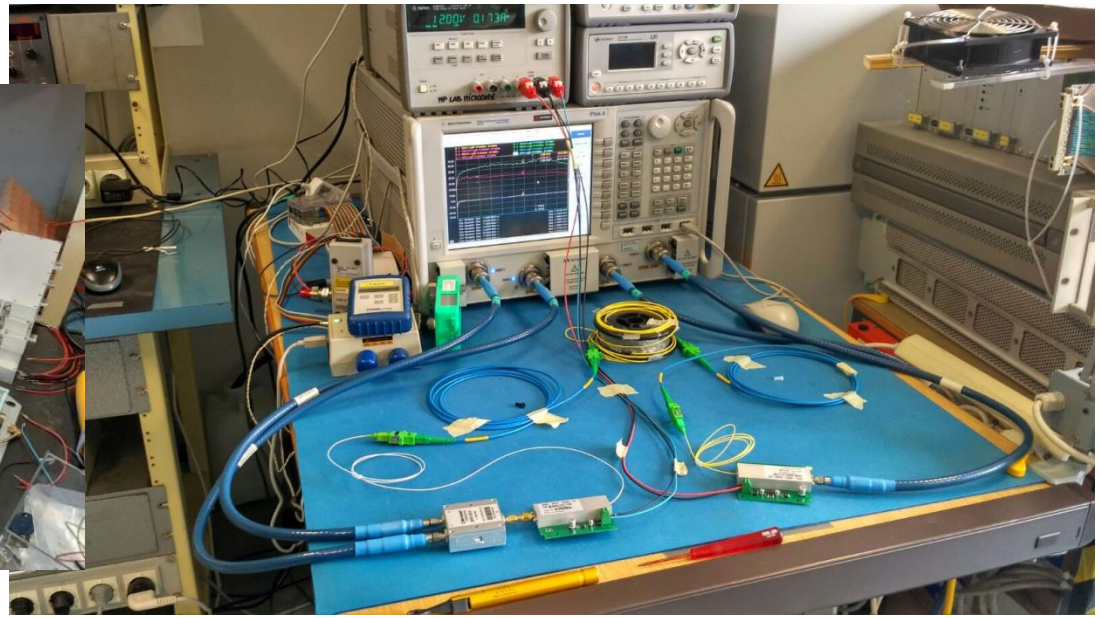
- the RFoF links to transport the signals from the focal lines directly to the receivers without frequency conversion and for long distance
- software algorithms (beamforming).

To do that, a refurbishment of 8 parabolic cylindrical reflectors of the N-S arm has been done.

Focal lines modification

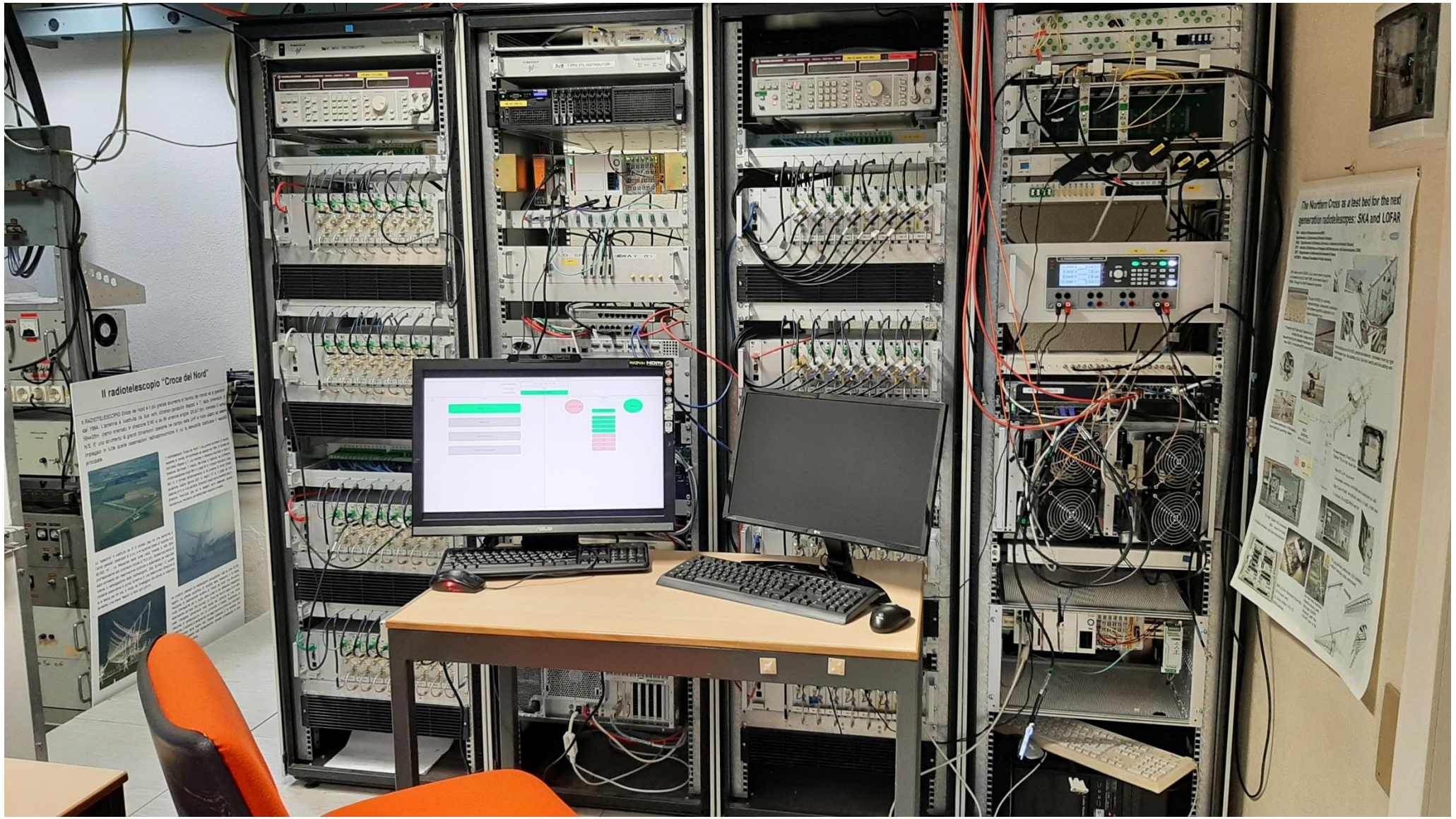
Front-end assembly, parameter measurements and installation on modified focal lines





Optical fibres installation

Back-end


Il radiotelescopio "Croce del Nord"
The Northern Cross as a test bed for the next generation radiotelescopes: SKA and LOFAR

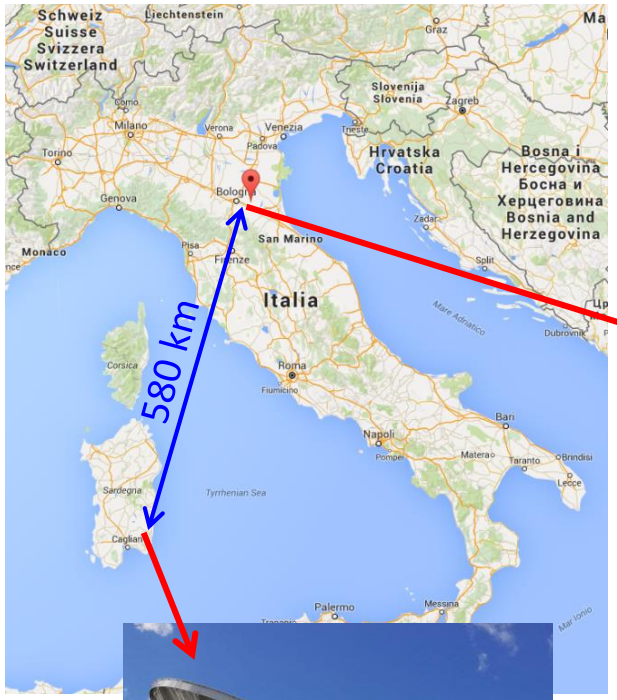
A look into the future

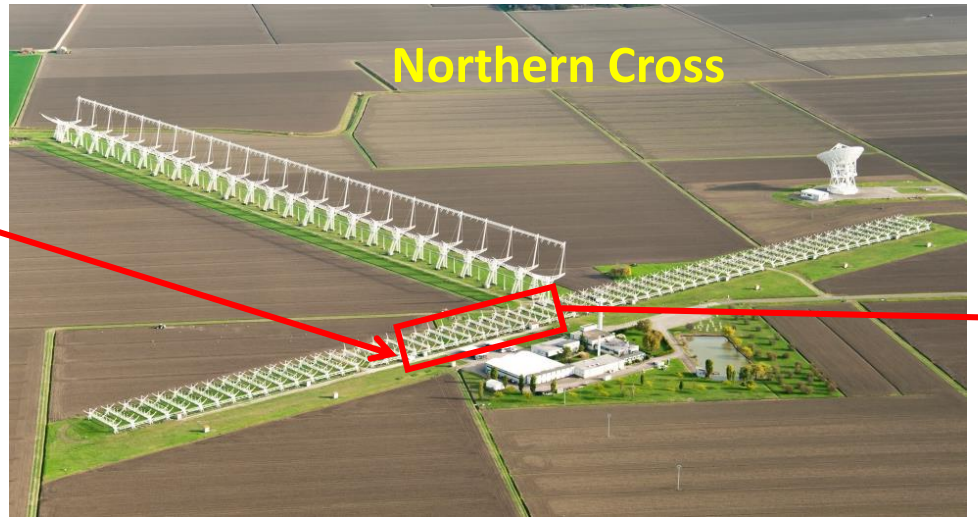
- In 2015 the Northern Cross was selected, by the European Commission, as a receiving sensor of a bi-static radar for the monitor of space debris. The N-S arm is currently part-time dedicated for the European Space Surveillance and Tracking program (EUSST). Thanks to the new funds coming from the EUSST program, all the N-S arm has been refurbished, following the same technological development already used for SKADS.

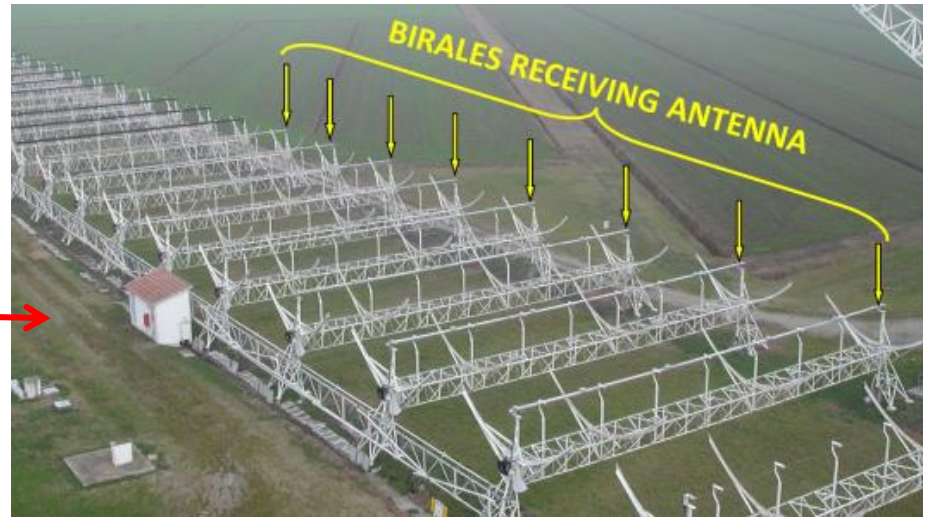
- Since 2020 the N-S arm is (in parallel) dedicated for the detection and monitoring of fast radio bursts (FRBs).

- Thanks to the Next Generation EU funds (PNRR), the E-W arm is undergoing extraordinary maintenance and technological upgrades, to respectively consolidate its mechanical structure and adapt the antenna to modern technologies.

Space debris monitoring



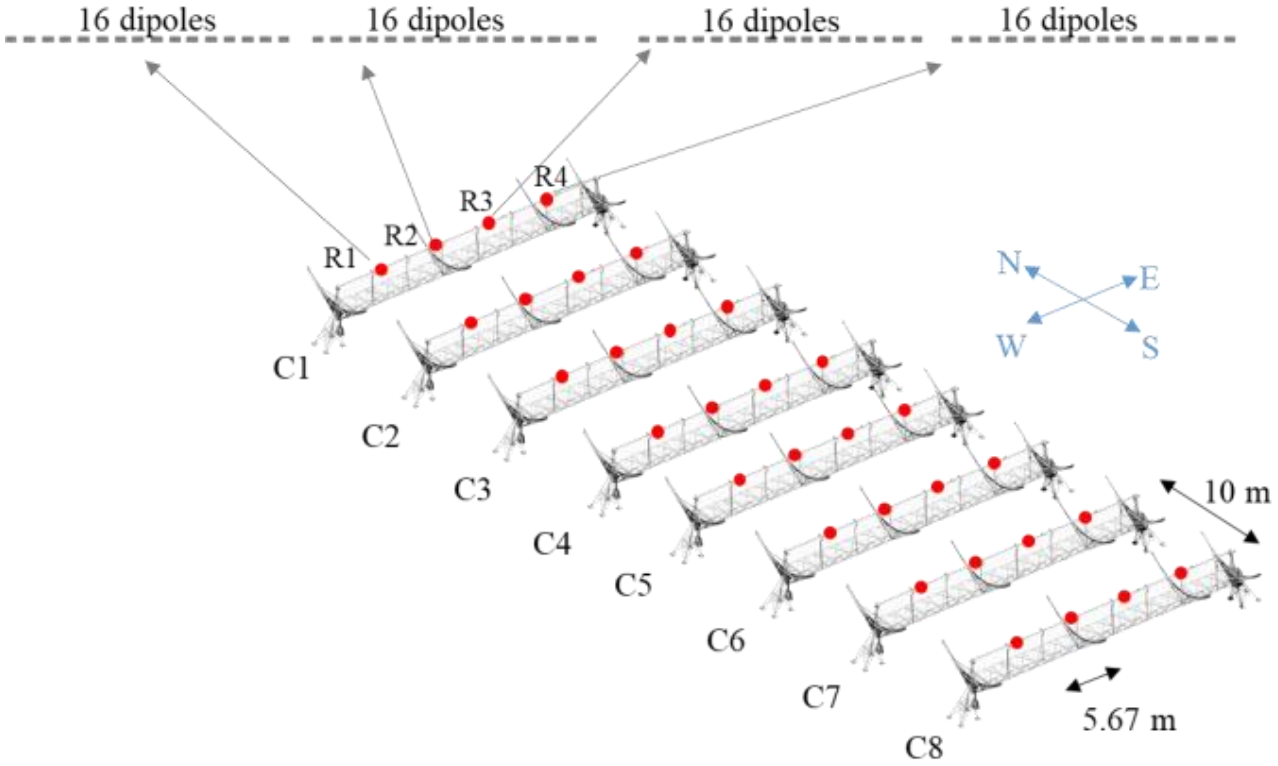


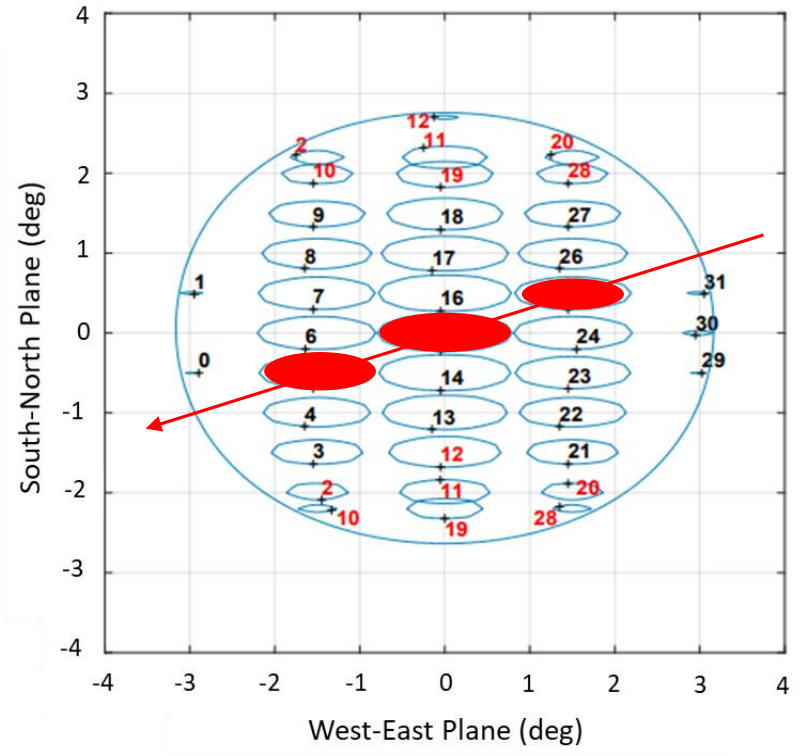


Operating frequency	410-415 MHz
Tx antenna gain	26 dBi
Rx antenna gain	45.3 dBi
Maximun tx power	10 kW

Range accuracy	< 50 m
Angular accuracy	10^{-2} deg
Sensitivity	Able to detect object with a size of 10 cm @ 1000km
Feld of View	5.7 deg x 6.6 deg

Bi-static observations



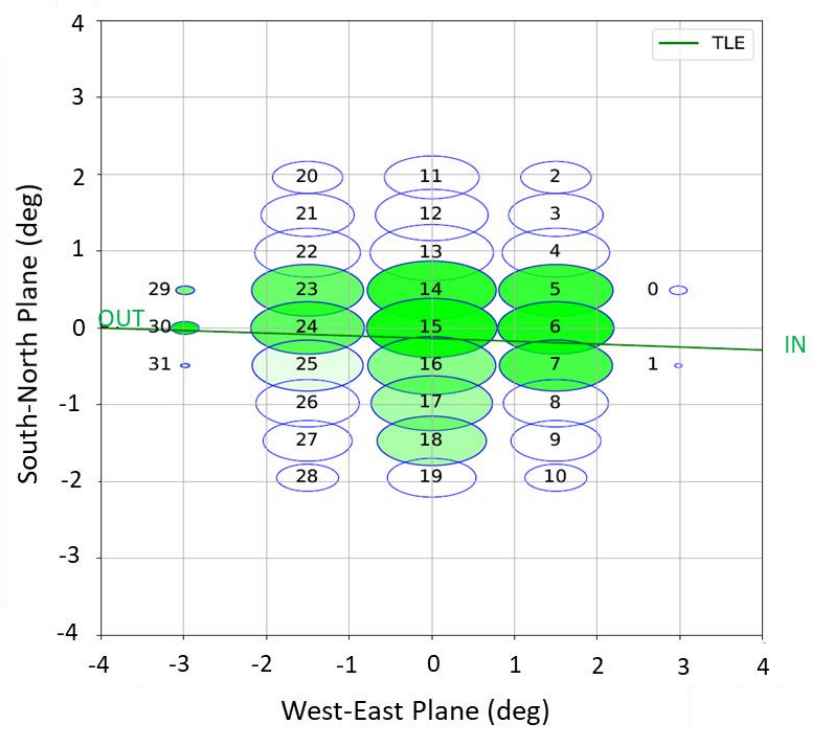


Re-entry campaign

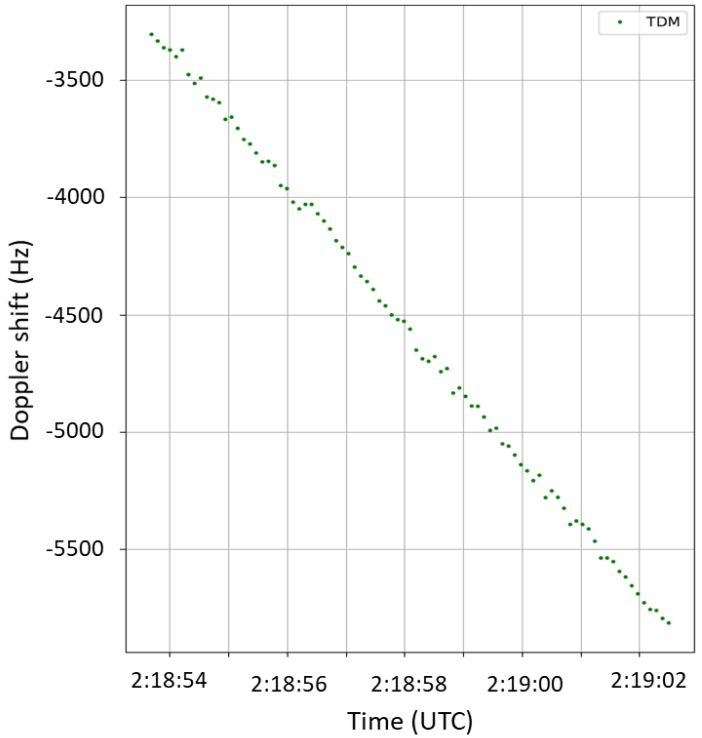
Long March CZ-5B R/B/2021-035B

From 3rd to 9th May 2021 (day of the re-entry), the N-S made measurements at every passage of the rocket over Italy and provided fundamental contributions for national and European safety. Using the measures of the track, doppler and slant range, it was possible to update the object's orbit and the re-entry window autonomously.

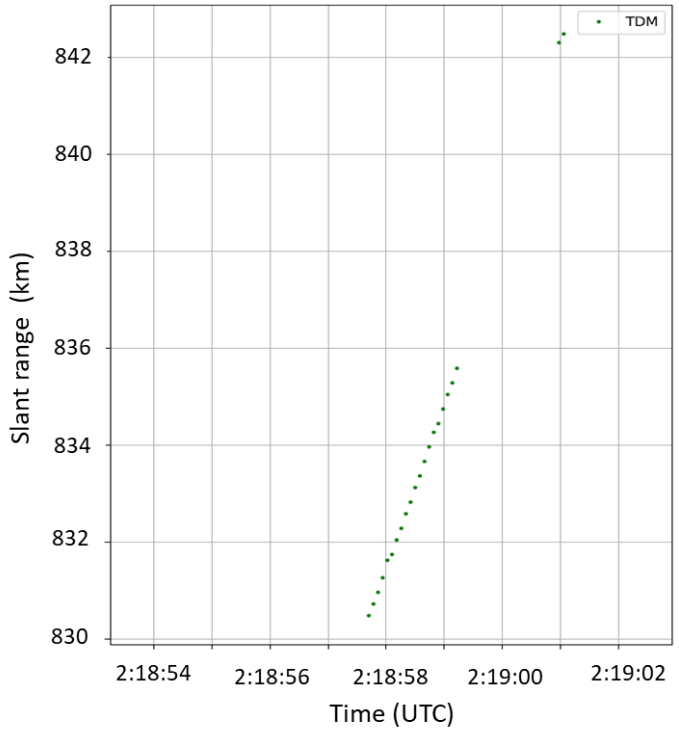
TRACK



DOPPLER



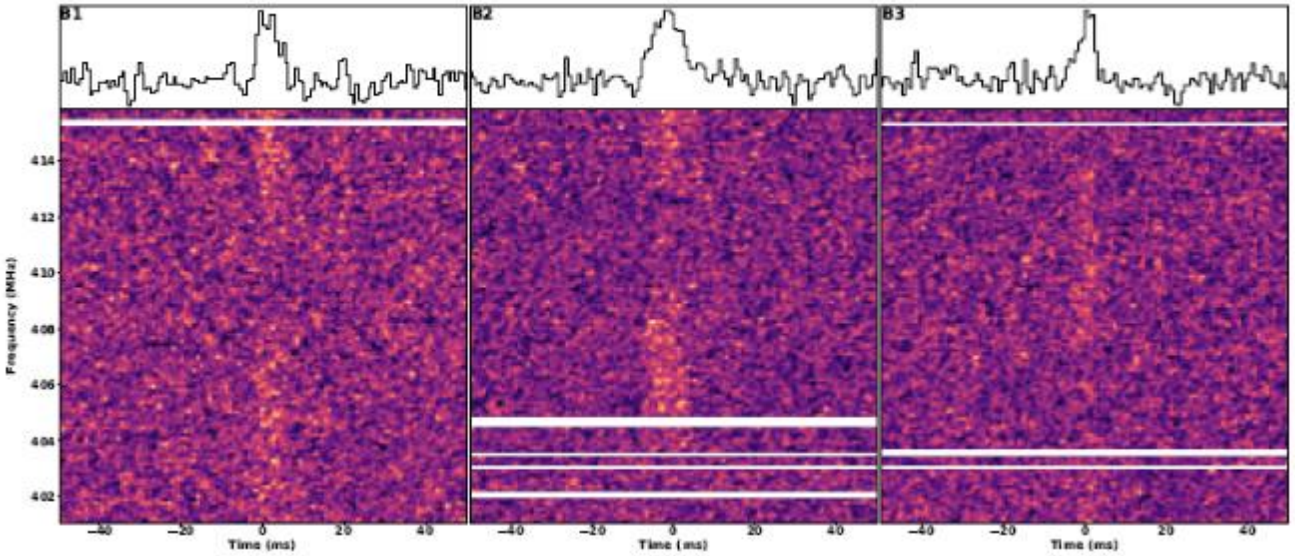
SLANTE RANGE



Data gathered during the third observation on May 5, 2021

Fast Radio Burst research

Observations of FRBs with the Northern Cross have already led different publications, but much better scientific outcomes are expected from the planned refurbishment of the antenna. The sensitivity will be greatly improved and the FoV will become much larger, thus accomplishing the two major requirements for an antenna to be an efficient detector of FRBs.



The first FRB observed with the Northern Cross

MNRAS 000, 1–10 (2021) Preprint 1 February 2022 Compiled using MNRAS LATEX style file v3.0

The Northern Cross Fast Radio Burst project - II. Monitoring of repeating FRB 20180916B, 20181030A, 20200120E and 20201124A

M. Trudu[1,2★], M. Pilia[2], G. Bernardi[3,4,5], A. Addis[6], G. Bianchi[3], A. Magro[7], G. Naldi[3], D. Pelliciari[3,8], G. Pupillo[3], G. Setti[3,8], C. Bortolotti[3], C. Casentini[9,10], D. Dallacasa[3,8], V. Gajjar[11], N. Locatelli[12], R. Lulli[3], G. Maccaferri[3], A. Mattana[3], D. Michilli[13,14], F. Perini[3], A. Possenti[1,2], M. Roma[3], M. Schiaffino[3], M. Tavani[9,15] and F. Verrecchia[16,17]

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[4]South African Radio Astronomy Observatory, Black River Park, 2 Fir Street, Observatory, Cape Town, 7925, South Africa
[5]Department of Physics and Electronics, Rhodes University, PO Box 94, Makhanda, 6140, South Africa
[6]INAF-Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, Via Piero Gobetti, 93/3, 40129, Bologna, Italy
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[17]INAF-Osservatorio Astronomico di Roma, via Frascati 33, 00078 Monte Porzio Catone (RM), Italy

Accepted XXX. Received YYY; in original form ZZZ

Conclusions

- The Northern Cross radio telescope has fully corresponded to the scientific objectives for which it was designed.
- It has introduced Italian astronomy in the field of international radio astronomy research, of which the IRA (Institute for Radio Astronomy) is the recognized Italian referent.
- It has also allowed the acquisition of scientific and technical knowledge that paved the way for the use of other large radio telescopes (VLA, WSRT, etc.) and for large international collaborations (VLBI, LOFAR and SKA).

Finally, next year the Northern Cross will be 60 years old, but is still one of the world's competitive radio telescopes for scientific research…and not only.

Thank you!