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Cover page
Bando PRIN 2019

Title of the program:
BART BAsovizza Radio Telescope
Conversion of the INAF OATs Decimetric Multichannel Solar Radio Polarimeter into an Educational Radio Telescope

Program Branch: DIV

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INAF Structures participating in the program:
INAF – Astronomical Observatory of Trieste

Program summary

INAF-OATs has been performing education and public outreach for 20 years. The main activities are the visits with schools and the general public to the Specola M. Hack, remote observation with the educational telescope of the project "stars go to schools", the interactive laboratory Esploracosmo and the participation in many science festivals and exhibitions. INAF-OATs is involved in the organization of the Italian Astronomy Olympiads also.

All the educational and public outreach activities are listed on the dedicated website http://scuole.oats.inaf.it.

Both the Specola M. Hack and the SVAS telescopes, located in the observing station of Basovizza, are optical instruments.

Recently we decided to complement the optical astronomical observations actually being offered to students with some astronomical radio experience using a commercial television satellite dish together with a satellite finder as receiver. This simple equipment lets us introduce radio basic concepts and physical effects in practice, with obvious limitations as regards sensitivity levels.

Radio Astronomy is an interesting and modern science that complements the more common optical astronomy that schools and universities commonly perform. It encompasses different disciplines such as physics, astronomy, and computer science. One major advantage is the feasibility of daytime observations, thereby allowing for its integration into regular school lessons.

Observing tools in radio astronomy, however, have not been generally or easily accessible to students, particularly at the undergraduate or pre-college levels, since the number of radio telescopes and the availability of time on these telescopes are limited.

The availability of a real radio telescope to be actually used by teachers and students to complement theoretical concepts represents a plus making a difference.

To offer easily accessible radio astronomy observations to students, we decided to convert to educational purposes the 3 meter dish antenna of the Basovizza Observing Station of INAF-OATs previously dedicated to the detection of the solar decimetric coronal radio emissions into an educational radio telescope (**BART** – **BA**sovizza **R**adio **T**elescope).

BART will introduce pupils, students and teachers to radio astronomy. It will make it possible to detect radio emission from many sources in the sky, ranging from the Sun to atomic hydrogen far away in our galaxy.

The Trieste Solar Radio System (TSRS), a set of two multi-channel solar radio polarimeters located in the Basovizza Observing Station operated by the Trieste Astronomical Observatory of the National Institute for Astrophysics (INAF), has been performing a continuous surveillance of the decimetric and metric coronal radio emissions in unattended mode till it got damaged by a lightning storm.

The two TSRS dish antennas (10m and 3m diameter) able to operate respectively in the frequency bands 100-900 MHz and 1-4 GHz have been discarded and will not be used any longer for solar radio research.

The 3m dish antenna, equipped with altazimuth mounting, is in good operating condition from an electro-mechanical point of view and can still be computer operated as regards pointing and tracking commands. Its radio chain has been heavily damaged and, considering its technological obsolescence, it is not worth the effort and cost to repair and put it into operation again as a whole. It is worthwhile instead to repair the antenna head and use it with a new radio chain including uptodate low cost high quality COTS components (LNAs, filters, YIG oscillators, SDR receivers).

A new data acquisition, storage and control system, together with a suitable Graphical User Interface (GUI) has to be designed in order to satisfy the new typical requirements of a radio telescope dedicated to education.

The technological activities will be carried out involving as much as possible the university engineering department and its graduating students, while the educational activities shall involve university Physics department and its students.

The project aims to:

- restore the damaged antenna head
- shape educational use cases
- outline educational radio telescope requirements
- update the actual computer control of the antenna according to the new educational radio telescope requirements
- design and develop an immediate and easy-to-use Graphical User Interface to interact with the instrument
- design and develop a service acquisition and storage system
- test and validate the instrument
- perform radio telescope activities in schools and for public outreach
- organize events related to radio astronomy

In summary, the proposed project aims to promote all the different technical and scientific disciplines encompassed by radio astronomy giving more attractiveness and potential in outreach and educational efforts.

General national, international and commercial context

Radio astronomy provides an excellent educational opportunity for students since it exposes them to multi-disciplinary principles found in physics, mathematics and engineering. Motivated by the potential for exciting discovery through astronomical observations, students learn through the process of making measurements, analyzing the data, and interpreting the observations.
Observing tools in radio astronomy, however, have not been generally or easily accessible to students, particularly at the undergraduate or pre-college levels, since the number of radio telescopes and the availability of time on these telescopes are limited.
The availability of a real radio telescope to be actually used by teachers and students represents a plus making a difference.

A number of school and amateur radio telescopes already exist. Basically, radio astronomy projects can be classified into two groups:

- Absolutely low cost projects
- Semi-professional telescopes

Low Cost Projects
The telescope architecture is typically characterised by the following parameters:

- A dish with a diameter from 0.6m up to 1.5m is used, usually installed on a fixed mount without an antenna rotator
- As front-end unit, a commercial LNB is used, typically in Ku-Band for Europe
- Signal measurement is made with a simple receiver, often using a satellite finder
- Data recording is performed on request, often by using home-made instrumentation
- The system is not well calibrated

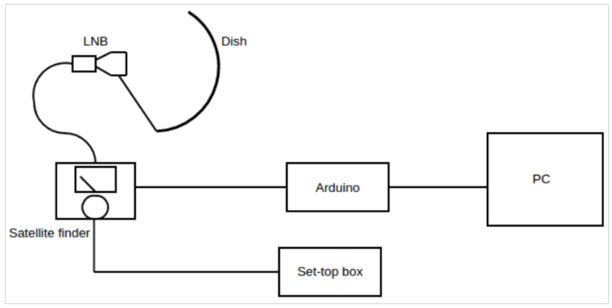
Trieste Astronomical Observatory - Itty bitty telescope

Itty bitty telescope Satellite finder used as receiver

Feasible documented observations:

- All of these telescopes were used to detect the radiation of the quiet Sun
- In some cases, Moon observations are documented

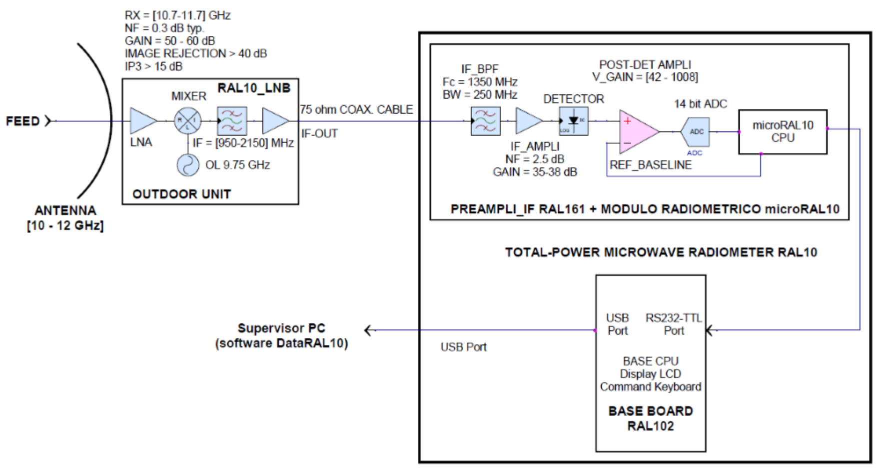
The observation of galactic point sources as well as long term observations cannot be realized due respectively to the restricted sensitivity and the lack of adequate tracking capabilities.
Despite the restricted capabilities of this school telescopes, the students learn a lot about radio astronomy and how to detect and measure signals from the sky. In addition, they can learn how to develop and use electronic circuitry aimed to acquire and process signals and to control instruments and how to process acquired data via computers and software tools.
An example of such a system is the Indian '*Everyday Radio Telescope*' which can be used to measure brightness temperature and flux of the Sun at 11.2 GHz and calculate the beam width of the antenna. The set-up uses commercially available satellite television receiving system (LNB, SatFinder), a parabolic dish antenna and an Arduino Uno controller board to digitize the intensity from the satellite finder at 10Hz sampling rate.



Everyday Radio Telescope setup

They report the detection of point sources like Saturn and extended sources like the galactic arm of the Milky way. A Python pipeline has been developed for data acquisition and visualization, available for free download.
Pointing is done manually in all the cases, by firstly looking at the source Altitude and Azimuth in the local sky at that time, using Stellarium and then rotating the dish about the two axes individually to point at the source location.

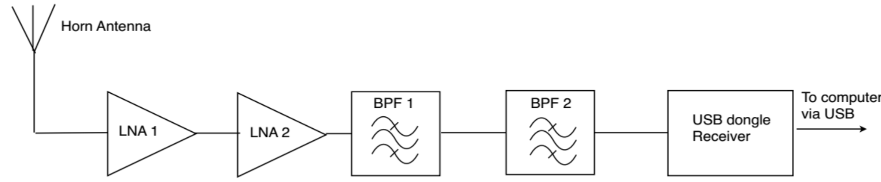
There are also some commercial products for radio astronomy such as *RAL10KIT* (www.radioastrolab.it), a starter kit for amateurs with a minimum of practice with the electronic construction, comprising a Total Power-receiver that integrates the functions of a radiometer and is programmable via software.

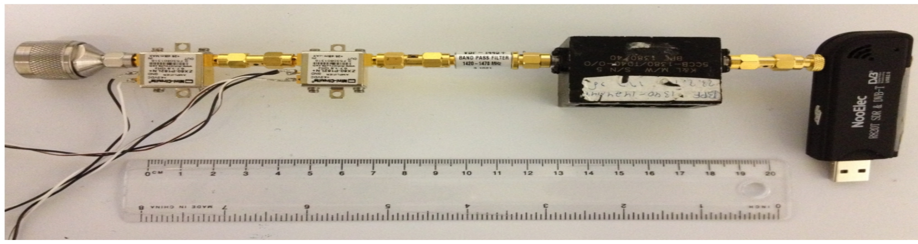


RAL10KIT diagram

It has to be used together with a Satellite TV antenna in Ku-band (10-12 GHz) or C-band (3-4.5 GHz), complete with mechanical supports, illuminator and LNB (Low Noise Block Converter). The signal received by the antenna, amplified and converted in frequency by the LNB (moves down the "receiving window" in the 900-2000 MHz band), is sent to the RAL10KIT receiver via a coaxial cable.
Any type of antenna and TV-SAT accessories can be chosen, new or recycled. The larger the antenna, the more sensitive the telescope.
The receiver amplifies and measures the received signal strength and, via an analog-digital converter (ADC) with high resolution, it converts the detected signal into digital form, by positioning the level of "zero" in the appropriate point of the scale. The critical functions of the receiver, as well as the possibility to set various operating parameters and communication with the PC via the USB interface module, are handled by a microprocessor.
The acquisition and control software, usable with all major PC platforms, is provided for free.

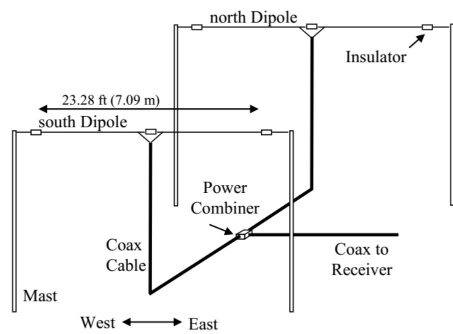
Other low-cost systems imply students' direct involvement in mechanics and electronics activities.
An example is the low-cost *21 cm horn-antenna radio telescope* for education and outreach that has been developed at Harvard entirely by students, using simple components costing less than $300. The horn has an aperture of 75 cm along the H-plane, 59 cm along the E-plane, and gain of about 20 dB. The receiver system consists of low noise amplifiers, band-pass filters and a software-defined-radio USB receiver that provides digitized samples for spectral processing in a computer. Starting from construction of the horn antenna, and ending with the measurement of the Galactic rotation curve, took about 6 weeks, as part of an undergraduate course at Harvard University.





The project can also grow towards building a two-element interferometer for follow-up studies.

The NASA Radio Jove
The NASA Radio Jove Kit is dedicated to Sun and Jupiter observations at 20.1MHz and is well suited for the observation of noise storms. Due to the low observation frequency, a dipole antenna is used instead of a satellite dish. The kit contains specific components for the receiver device and the antenna. Additional material is needed to complete the telescope. The kit itself costs $125, and for the other equipment about $130 is necessary. So it is a very low-cost system. Some skills in electronics are required for the assembly of receiver and antenna, e.g. soldering. A well-illustrated assembling manual is available on the web, as well as video sequences for some worksteps. The data are recorded and post processed. Data samples can be found on the Radio Jove Homepage. Schools without their own Radio Jove equipment, can access observation data published on the Internet.



Semi Professional Telescopes
Universities and research institutes typically operate these educational telescopes. They use professional antennas of larger size and in most cases special dedicated receivers together with digital control and processing equipment.
Their technical capabilities can be characterized as follows:

- Dishes with diameters from 3m up to 10m, installed on a fixed mount, movable in 2 axes
- As front-end units, commercial LNBs and special antennas are used in several frequency bands starting from 1.4 GHz via C-Band up to Ku-Band
- Special back-end receivers
- Data recording is performed automatically by computer, and raw data are partly published by Internet
- Systems are well calibrated

Common feasible documented observations:

- Sun, also long term Sun activity observations
- Hydrogen spectral line
- Galactic point sources (e.g. Cygnus A, Taurus A, Sagittarius A)

Unlike low cost telescopes, these university telescopes are operated in the same manner as professional ones. They are usually controlled by specialized software on a PC located in a "control room". The systems are calibrated to achieve a more accurate measurement of the received signals. Since these telescopes use larger antennas and better receivers, a better sensitivity is achieved that makes it easier to detect galactic point sources. Nevertheless they are used more for education purposes than for science.

Several kits are available for purchase, e.g.: the *Small Radio Telescope (SRT)* from the MIT Haystack Observatory, the *PrimaLuceLab SPIDER230C and SPIDER300A, the* Poam Electronics *RTP30 3m Radio Telescope Kit.*

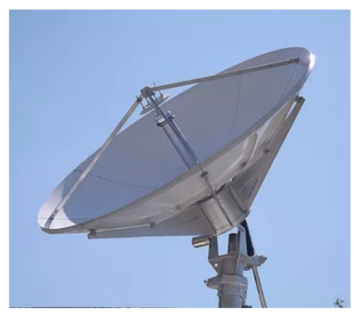
The SRT is a 2.3m radio telescope operated in L- or C-Band. The design and functionality look similar to professional telescopes, but dish size and sensitivity is more restricted. The kit costs about $6000 and can be now ordered from Europe.
The satellite dish has a diameter 2.3m, beam width 7.0 Degrees (L-band), weight with mount 72.5 kg, Azimuth and Elevation positioning. Analogue and digital receiver are available, frequency range 1.3-1.8 GHz, typical system temperature 150K, square law detector with electronic noise-source provided for calibration.
JAVA program for telescope control is available on the Internet. The look-and-feel is like that of a professional telescope and may be difficult to use for students at schools.

PrimaLuceLab SPIDER230C and SPIDER300A are radio telescopes operating at 1,42 GHz frequency; SPIDER 230C with 2.3m antenna and equatorial mount, SPIDER 300A with 3.0m antenna and weatherproof alt-az mount. SPIDER 300A is an instrument conceived for Schools, Universities, groups of amateur astronomers or generally amateurs interested in Universe exploration, searching for a complete, reliable, easy to use and expandable instrument. SPIDER 300A has been designed and developed by PrimaLuceLab, with the collaboration of the Bologna INAF Institute of Radio Astronomy, the CNR-IEIIT and several technical users with many years of experience in this field. It is equipped with a new H142-One receiver, a 1.42 GHz superheterodyne type radiometer/spectrometer, double conversion (type UP/DOWN) with 50 MHz received instantaneous bandwidth (RF =1.395MHz-1.445) and 14-bit analog to digital converter. The H142-One receiver has a 1024 channels spectrometer (61 KHz each) that are displayed and processed in real time by the control software supplied with the radio telescope. The SPIDER 300A radio telescope is reported to be able to record radio sources with a theoretical flow of at least 13 Jy. An advanced control software has been developed, offering an immediate and easy-to-use interface.

The Poam Electronics *RTP30 3m Radio Telescope Kit allows you to* to detect Sun, Moon and some strong radio sources (Many strong radio sources in the database are available for quick reference).
The main Front-End receiver of this antenna is L-Band but additionally, we can supply C, Ku and Ka band front-end receiver with this telescope as an option.

Haystack Observatory Small Radio Telescope (SRT)

PrimaLuceLab SPIDER300A



Poam Electronics RTP30

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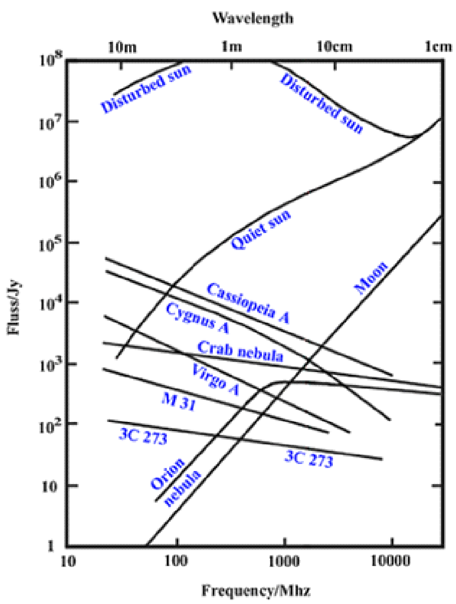
10. SALSA "Such a lovely small antenna" https://vale.oso.chalmers.se/salsa/welcome

Objectives to be achieved (max. 2 pages)

Radio astronomy provides an excellent educational opportunity for students since it exposes them to multi-disciplinary principles found in physics, mathematics and engineering. Motivated by the potential for exciting discovery through astronomical observations, students learn through the process of making measurements, analyzing the data, and interpreting the observations.

Observing tools in radio astronomy, however, have not been generally or easily accessible to students, particularly at the undergraduate or pre-college levels, since the number of radio telescopes and the availability of time on these telescopes are limited. To offer easily accessible radio astronomy observations to students, we decided to convert to educational purposes the small radio telescope of the Basovizza observing station of INAF-OATs (BART – BAsovizza Radio Telescope).

BART will introduce pupils, students and teachers to the marvels of radio astronomy. The sensitive receiver makes it possible to detect radio emission from many sources in the sky, ranging from the Sun to atomic hydrogen far away in our galaxy.



Spectral energy distribution of sky objects in the radio region (from J.D.Kraus)

In our plans the main target of BART observations will be atomic hydrogen: from these measurements, students will learn about the kinematics and distribution of gas in our galaxy, the Milky Way.

The aim here is to detect emission from hydrogen gas emitting at frequencies close to 1420.4 MHz. More in detail, we will review with the students some properties of the Milky Way, starting by describing the Galactic coordinate system and the geometry of a rotating disk. Then, we will describe how to use data from BART to understand how fast gas rotates at different distances from the galactic center, i.e. how to make a rotation curve. Finally, we will teach the students how to use additional measurements, and the knowledge of the kinematics, to make a map of the spiral arms.

Although BART will be primarily designed for observing galactic hydrogen, there are a few other ways to use the telescope.

The Sun is a bright radio source and will be detected easily with SALSA, together with some bright extragalactic radio sources. Observations of the Sun can be used to characterize the BART antenna.

Progress in space sciences and exploration of the universe, begun in the 1960s, caused many satellites started to appear at the Earth's orbit at altitudes from 2000 to 20 000 km. Such artificial objects are used in many different fields of science and engineering such as telecommunication, meteorology, environmental monitoring or navigation. The latter is realized through a so-called Global Navigation Satellite Systems (GNSS). BART will able to detect signals emitted from GNSS satellite also.

5. Personnel FTE and roles

Name	Status	FTE	Tasks
Alessandro Marassi	Technologist	0.5+0.5	Dish technological update Electronics and control software design and development Graphical User Interface (GUI) design and development
Massimo Ramella	Associate Astronomer	0.3+0.3	Educational radio telescope requirements Educational use cases development (on how to achieve the foreseen experimental results) Activities in schools and public outreach Events organization
Giulia Iafrate	Technologist	0.3+0.3	Educational radio telescope requirements Educational use cases development (on how to achieve the foreseen experimental results) Activities in schools and public outreach Events organization

The project will also take advantage of the expertise and support of some specialized company involved in electronics, electromechanical and radio systems design and development.

6. Costi: investimento, consumo, calcolo, missioni, spese per assegni di ricerca, borse di studio e personale a Tempo Determinato, spese per pubblicazioni

	Description of the requested items	Request (euro)
Equipment	Antenna head Antenna computer control Power plant revision and upgrade with Surge Protection Devices (SPD) Service acquisition and storage system Radio receiver (version A)/(version B)	3000 3400 2000 3500 2500/14400
Personnel	Activation of a research grant for 1 year (technological/application activities)	26000
Travels	Participations in international meetings to share the results of the project	2000
Contract	specialized company technical support	5000
Total		**47400/59300**

The two total amounts of 47400 and 59300 are alternative, considering two different solutions as regards the radio receiver: version A considers the purchase of a basic Software Defined Radio (SDR) receiver to be configured, while version B includes a turnkey solution with receiver + instrument software.

7. INAF Instrumental and financial resources

The main instrumental resources offered by INAF – Astronomical Observatory of Trieste will be the existing antenna structure, the network facilities and the power plant.

As for additional funds, we will apply to the next MIUR call for the dissemination of Scientific Culture (ex Lege 6/2000), and we hope to reach funds from the President Communication Office (usually assigned to the observatories to cover researcher participation in science festival and meetings) and funds from FOE for some workshops and missions.

8.Dichiarazione, datata e firmata, di accettazione da parte del Direttore della Struttura INAF di afferenza del Coordinatore Scientifico Nazionale e nulla osta da parte dei Direttori di Struttura dei partecipanti al programma

10.Assenso del Coordinatore Scientifico Nazionale alla diffusione via Internet delle informazioni relative ai progetti finanziati e alla diffusione presso gli eventuali valutatori esterni, all'esclusivo scopo della valutazione stessa, delle informazioni riguardanti i progetti presentati; dichiarazione ai sensi del D. Lgs. n. 196/2003 di consenso al trattamento dei dati sensibili e non.

Il Coordinatore Scientifico Nazionale **Data: 30 novembre 2019**

dott. Alessandro Marassi