Blackburn Leisure Astronomy Society – Radio Astronomy Group.

Objectives

The objectives of the Radio Astronomy Group are:

- To introduce Radio Astronomy to BLAS and to the wider area.
- To provide resources for others to pursue this activity at the dome and at home.
- To coordinate the purchase of equipment for use by the Society.
- To broaden the appeal to include outreach activities to schools etc.
- To organise visits to and from other facilities and groups – i.e. University of Hull / York.
- To collaborate with other groups – i.e. NEMETODE, HERAS, Universities etc.

Background

The radio observations that can be made in the residential area where BLAS is situated are limited by the weak radio signals that are emitted from astronomical sources and also by the presence of man-made electrical interference from devices such as LED lights and solar panel inverters – this is a similar problem that *light pollution* is to optical astronomy.[1]

The wavelength of radio waves that are emitted by an object are governed by the underlying physical processes that create them. This, together with the relative size of the antenna that it is practical to build, determines the *gain* and *beamwidth* and affects the sensitivity and angular resolution of any measurements that we are able to make.[2]

Proposed Observations

As a result of the constraints above, we are restricted to either making indirect observations that measure the effects of an event upon external radio signals, or to observing only the stronger radio sources that are closer to the Earth.[1]

However, by both making multiple observations and applying digital processing techniques, similar to those used in astrophotography, it is possible to extract useful data from the background noise and to potentially build up maps.

Indirect Observations – *looking at the effects of an event upon an external signal.*

- Meteor Scatter
- Space Weather

- **Direct Observations** – *looking for the stronger radio sources*.
    - Jupiter / The Sun
    - 21cm Hydrogen Line

- **Advanced Techniques** – *using computer processing techniques to extract data*
    - Mapping the Galactic Rotation Curve
    - EME (Earth-Moon-Earth or “Moonbounce”)
    - Interferometry – *detecting pulsars*.

Meteor Scatter

• What are we trying to do?	To demonstrate passive *Radar Astronomy* by observing the ionised trails from meteors that are illuminated by the French GRAVES space surveillance radar.[3]
• Why are we doing this?	To introduce the idea of using radio as a means of making observations that supplement optical astronomy and to provide an alternative activity for when it is cloudy or during the day.
• What do we need?	Amateur radio equipment and antennas belonging to individual members will be used for the initial demonstrations, with the aim of purchasing (or building) a suitable antenna,[4] preamplifier and software-defined radio.[5] To install the required software on the BLAS laptops and set up a permanent antenna to remove the reliance upon personal equipment.
• How easy is it?	Extremely easy! Simply point the antenna towards France, tune to 143.049 MHz with an SSB receiver and listen for the echoes! Introducing software-defined radio into the setup provides a visual display and a means of recording and analysing meteor data without incurring significant costs.
• Other Learning	Meteor observations are narrow-band signals that are observed against the background noise that comes from a variety of sources, such as: thermal noise; leakage from the antenna side-lobes; electromagnetic interference and signals from other celestial sources.[6]
• Future Developments	To develop a system that can be left unattended and automate the detection and processing of meteor events.[7] To develop a means of calibrating the receiving equipment and making comparative measurements using the JT65 signal from the GB3VHF amateur radio beacon in Kent.[8] To develop an automated system that any amateur astronomer could easily replicate and allows data from meteor observations to be shared and accessed by other groups.[9]

Space Weather

• What are we trying to do?	To detect changes in the Sun through ***indirect observations*** of the Earth's ionosphere. This is observed by measuring short-term changes in the propagation of terrestrial Very Low Frequency (VLF) radio beacons[10] (i.e. Sudden Ionospheric Disturbances).
• Why are we doing this?	To provide a real-time indication of solar activity and an indication of events such as solar flares and coronal mass ejections for those wishing to make optical observations. To determine if there is a relationship between small changes in the Sun during the solar cycle affect terrestrial weather and the longer-term changes in the climate.[11]
• What do we need?	An antenna that is suitable for receiving the VLF radio signals, such as an inductive loop following the design from *The Radio Sky*[12] textbook or an active E-field antenna from the UK Radio Astronomy Association.[13] A dedicated PC with a suitable soundcard, or software-defined radio, with recording and processing software.
• How easy is it?	Whilst it is relatively easy to receive the signals and make observations, continuous measurements must be carried out over a timeframe that allows the normal diurnal and seasonal changes to be established so that anomalies can be detected.
• Other Learning	Knowledge of solar events and the interaction between the Sun and the Earth's magnetosphere and ionised layers within the ionosphere that affect radio-wave propagation. The development of software in the Python or MATLAB programming environments to correlate observations of space weather with data recorded by a weather station.
• Future Developments	The development of a low cost / low power platform, such as Raspberry Pi, that can be left unattended to host the processing and detection software and to distribute real-time data to the Internet and charts to the BLAS website.

Jupiter / Sun

• What are we trying to do?	To observe the various radio emissions from Jupiter that were first noted by Burke and Franklin in 1955.[14]
• Why are we doing this?	To provide a possible educational programme for BLAS that follows the lead of NASA Radio Jove in providing a solar and radio astronomy activity for school and youth groups to enhance their STEM programs.[15] Whilst the position of Jupiter in the sky and the orbit of Jupiter's moon Io can be predicted using Radio-Jupiter Pro software, it is proposed to use live images of Jupiter from one of the society's telescopes and display this alongside the radio data on a projector.
• What do we need?	The space to erect a garden-sized pair of phased dipole antennas (approx. 7m x 7m) constructed from wire and supported by lengths of PVC pipe.[16] A shortwave radio receiver tuned to 20.5 MHz can be used to listen to the signals. However, the spectrogram display provided by a software-defined radio will allow a wider portion of the radio spectrum to be observed and allow the types of emissions to be visually identified.[17] Solar Radio Bursts use the same antennas and setup but are less predictable, as an active solar event is required.[18]
• How easy is it?	The Radio Jove project is intended to provide students, teachers and amateur astronomers hands-on experience of setting up radio telescopes using inexpensive hardware and making observations, hence is ideal for beginners!
• Other Learning	The project can be used to provide hands-on experience in constructing and erecting antennas, setting up and making scientific observations using radio and optical telescopes. Registering with Project Jove gives the opportunity for BLAS to interact with both amateur and professional astronomers via the Internet and to contribute to the project.
• Future Developments	To use the lesson plans and material available on the Project Jove website to further develop the Beginners Program for BLAS to provide a practical introduction to radio astronomy. To provide educational activities for schools / Scouts / DofE To develop an automated Jupiter telescope, that any amateur astronomer could easily replicate, perhaps joining a collaborative, open science effort to share the spectrograms of the received emissions.[19]

21cm Hydrogen Line

• What are we trying to do?	To observe the 21cm (1420 MHz) *Hydrogen Line* that was first detected by Ewen and Purcell in 1951.[20]
• Why are we doing this?	To demonstrate that such observations are within the reach of amateur astronomers using home-made antennas, low-cost preamplifiers and software defined radios.[21]
• What do we need?	To either make a horn antenna from aluminium foil coated insulation foam and waveguide feed following the design from the *Open Source Radio Telescope*[22] or several stacked Yagi antennas.[23] The latter could be attached to a tracking telescope mount and would allow extended measurements to be made. A preamplifier / bandpass filter, software-defined radio receiver and computer.
• How easy is it?	Measurements of the 21cm hydrogen line have been demonstrated by Dr David Morgan using a large dish with a specially constructed feed and received using a FUNcube Dongle SDR[24] and processed using Spectrum Lab.[25] It is proposed to repeat these measurements using commodity components[26].
• Other Learning	To develop an understanding of the measurement and calibration techniques required for radio astronomy. The development of spectral analysis and post-processing scripts in GNU Radio / Python or MATLAB / Simulink.
• Future Development	To measure the Doppler shift of the 21cm Hydrogen Line and use this to determine the Galactic Rotation Curve.[27] A project suggested by the late Don Pomfret, a retired Astrophysics Lecturer from York University, was to measure the relative motion of the Andromeda galaxy.

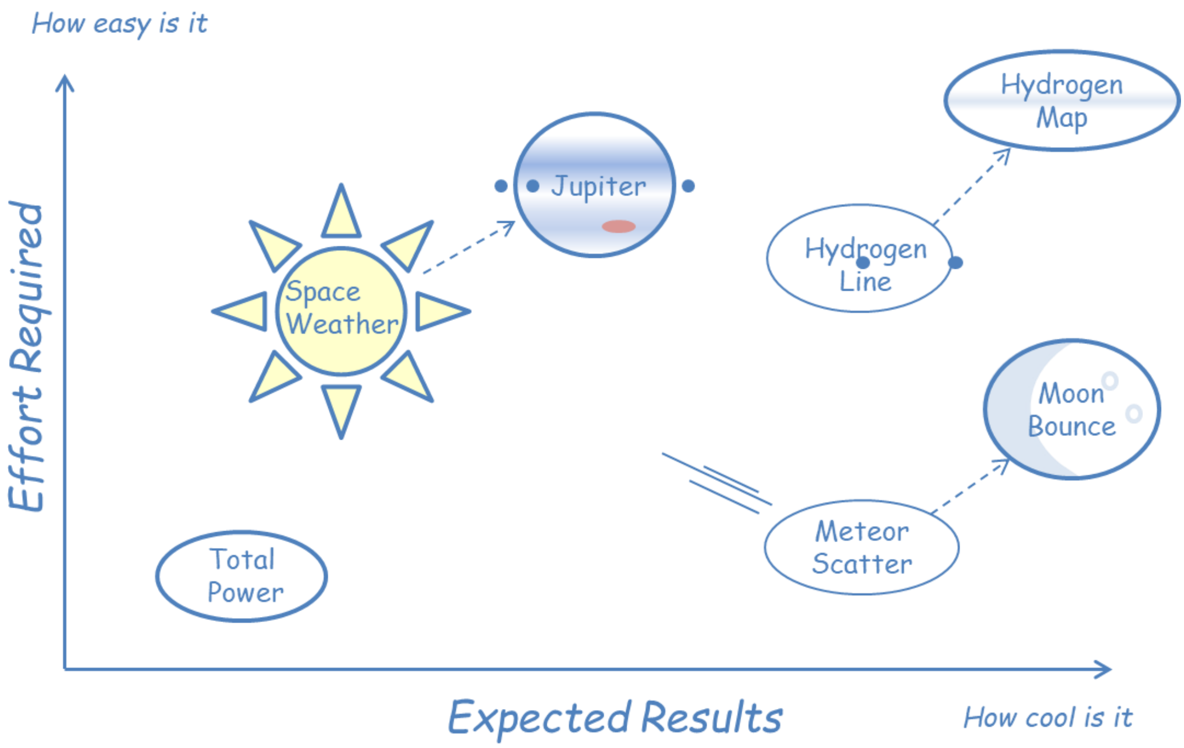
Earth-Moon-Earth (EME) Communications

• What are we trying to do?	To demonstrate the reception of lunar reflections from the GRAVES radar and amateur radio communications using JT65 on the 144 MHz and 432 MHz bands.
• Why are we doing this?	Whilst this seems an impossible feat to the uninitiated, the signals from military radar systems are sufficiently powerful to travel interplanetary distances. The lunar reflections from the GRAVES radar are capable of being received around the world. Using the moon as a calibration source builds confidence in the receiver setup and can be used outside of the recognised meteor showers.
• What do we need?	This can be achieved through incremental improvements to our meteor detection setup, such as the use of a low-noise preamplifier and low-loss coaxial cable. Transmission on the 432 MHz band can be achieved using members' amateur radio equipment and observed online using the Dwingeloo Web SDR.[28] (Note: The Dwingeloo Web SDR also monitors GRAVES)
• How easy is it?	Whilst two-way communications via EME is the pinnacle of amateur radio operation, requiring large antennas, powerful transmitters and sensitive receivers, the echoes from the GRAVES radar can be heard around the world using basic equipment. However, thanks to the techniques developed by Nobel Laureate Joe Taylor K1JT, information encoded with JT65 can be recovered from extremely weak signals and allows a relatively modest setup to be used.[29]
• Other Learning	Techniques necessary for radio astronomy: estimation of noise floor, calculation of link budgets etc.
• Future Development	Potential collaboration with other astronomical groups and amateur radio clubs.

Way Ahead

The decision to start with meteor observations was largely due to previous successes using the GRAVES radar and similar equipment and therefore results could be guaranteed with the minimal of effort and expenditure.

If we take each of the proposed observations in terms of how easy they are to achieve against the likely results, we can plot these on a graph, showing the results versus the effort required to achieve them.



Meteor Scatter

Whilst the radio observations of the Perseids meteor shower carried out in August 2019 provided useful results, they also highlighted several issues:

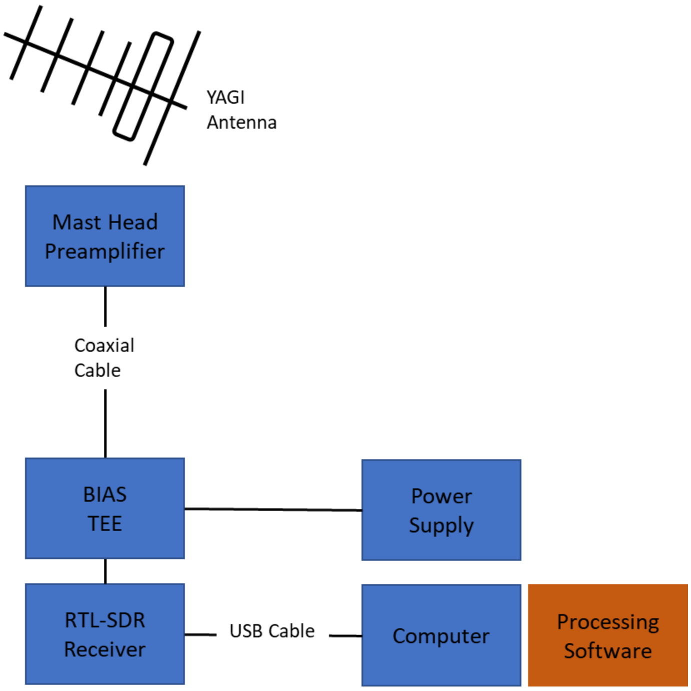
- The cost of the amateur radio equipment is a potential barrier to anyone wanting to make similar observations, and hence it is proposed to address this issue by using a software defined radio for future observations – the RTL-SDR dongle.
- The Perseids observations were carried out over a relatively short timeframe that did not coincide with the peak activity of the meteor shower, and hence a more permanent setup is required.
- Although useful data was extracted from the recording, the processing was performed manually and was laborious and time consuming, and therefore a means of automating this processing is desirable.

A masthead preamplifier may be required to match the performance of the Yaesu FT-817ND amateur transceiver, as the RealTek RTL2832U chip used in RTL-SDR dongles is optimised for digital TV reception and does not have the sensitivity or immunity to extraneous signals.

This is supported by benchtop measurements using a HP signal generator that show the sensitivity of the FUNcube Dongle is *-136dBm* (*0.03μV*) compared with *-147Bm* (*0.01μV*) for the Yaesu FT-817ND amateur radio transceiver.

As the amateur transceiver is more sensitive, it is proposed to evaluate the meteor receiving system by installing the required software on the BLAS laptops and test the receive performance with both side-by-side calibrations from the GB3VHF amateur radio beacon and meteor observations to determine if a pre-amplifier is required.

The next meteor shower is the η-Aquarids which peaks on Fri 8th / Sat 9th May at 10AM.



Moonbounce

The GRAVES radar transmits with sufficient power that reflections of the radar signal can be received from the Moon with a sensitive enough setup – making it a useful test. Provided the moon in the right area of the sky, the signal will appear as faint dotted line on a waterfall plot and is offset from the carrier frequency of 143.050 MHz by the moon's Doppler shift.

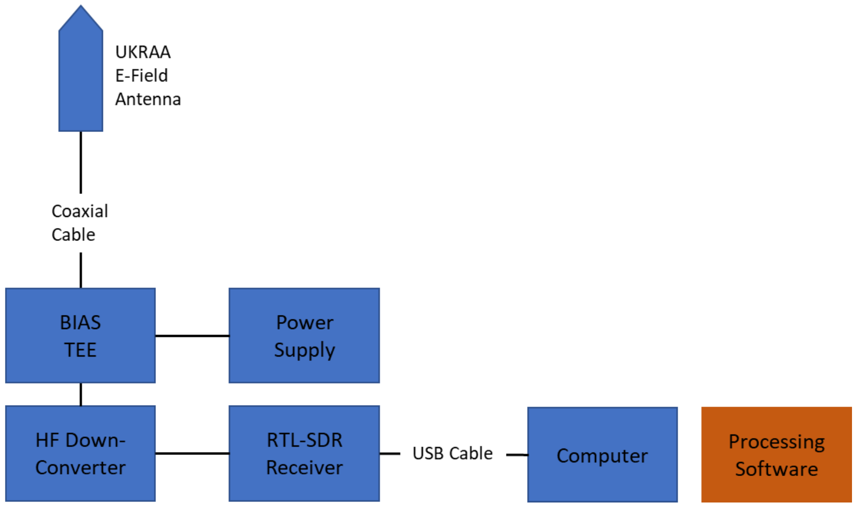
The Dwingeloo WebSDR[27] in the Netherlands has a receive antenna that is permanently setup for GRAVES meteor scatter that can be used for comparison. Furthermore, when the main 25m dish is not being used for other purposes (as shown on the status page), it is often aimed at the moon and the WebSDR can be used to receive amateur radio transmissions on the 432MHz (70cms) band.

Space Weather

Space weather is observed by monitoring short-term changes in propagation of VLF radio beacons that occur as due to changes of the ionisation of the D-Layer of the ionosphere that result from changes in solar radiation arriving on the Earth. As these observations are made against the backdrop of diurnal and seasonal changes, this is long-term project.

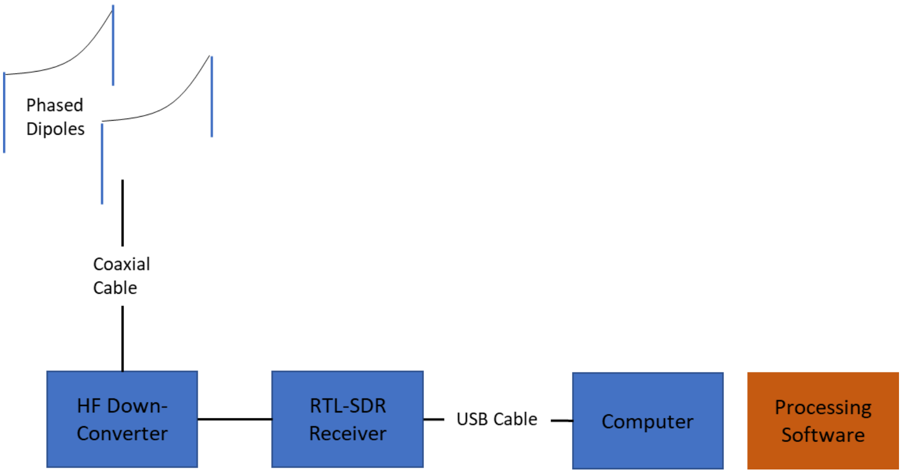
These radio beacons can either be detected using a large coil that responds to the magnetic field component or using an electric field probe that responds to the electric field component of the radio waves.

Whilst the SDRplay RSP1A and RSPduo software-defined radios can receive frequencies between 1 kHz to 2 GHz, an external frequency converter is required for both the RTL-SDR Dongle and the Airspy R2, as they do not cover the frequency range that is required for Space Weather and Jupiter observations.



Jupiter Observations

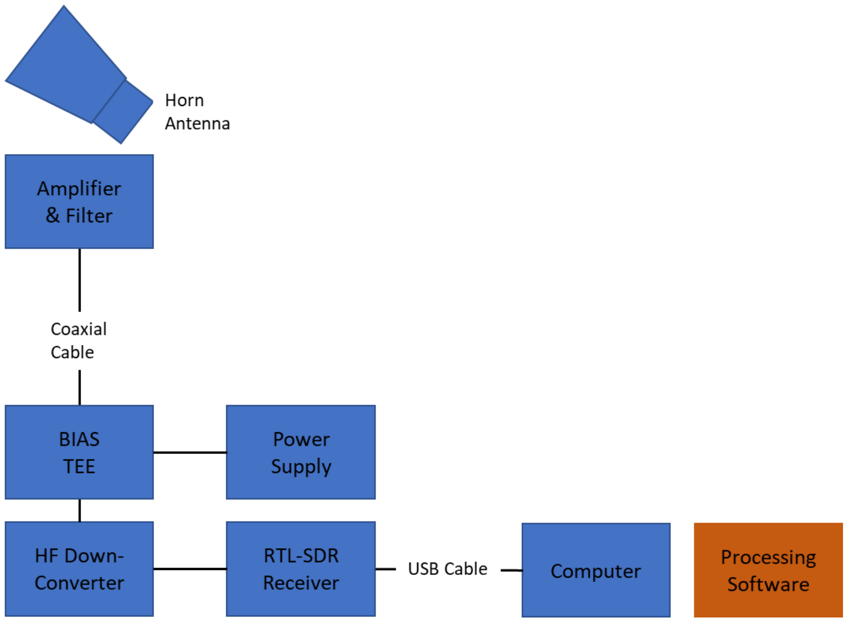
Observations of Jupiter require a wire antenna consisting of a pair of wire antennas covering an area of approximately 7m x 7m aimed at the plane of ecliptic and phased to point the beam towards Jupiter.   The larger bandwidth offered by the SDRplay and Airspy software-defined radios lend themselves to better identifying the changing radio signals that are produced during the different orbital phases of Jupiter's moon Io, and also to identifying sporadic solar radio bursts that may occur during the observation period.



21cm Hydrogen Line

Although the 21cm Hydrogen line is ubiquitous, it is extremely weak and requires a sensitive front-end amplifier and filtering to prevent interference from other radio sources which may appear in the receiver. Furthermore, the RTL-SDR was not intended to operate at this frequency range and the temperature rise in the chipset may affect the frequency stability.

The stability issues can be solved by using a GPS-locked frequency standard to provide the master clock for a software defined radio such as the RSPduo and Airspy R2 – this is essential if more than one telescope is combined together into an interferometer or longer term measurements are made.



The galactic rotation curve can be calculated by recording a number of frequency spectra measurements with the horn antenna is aimed at a fixed position in the sky and using the Earth's rotation to traverse across the Milky Way galaxy – this method was used by Dr David Morgan[26].

This requires knowledge of the Equatorial, Ecliptic and Galactic coordinate systems and how to convert between them using trigonometry, matrices (MATLAB) or a software tool or App such as Stellarium.

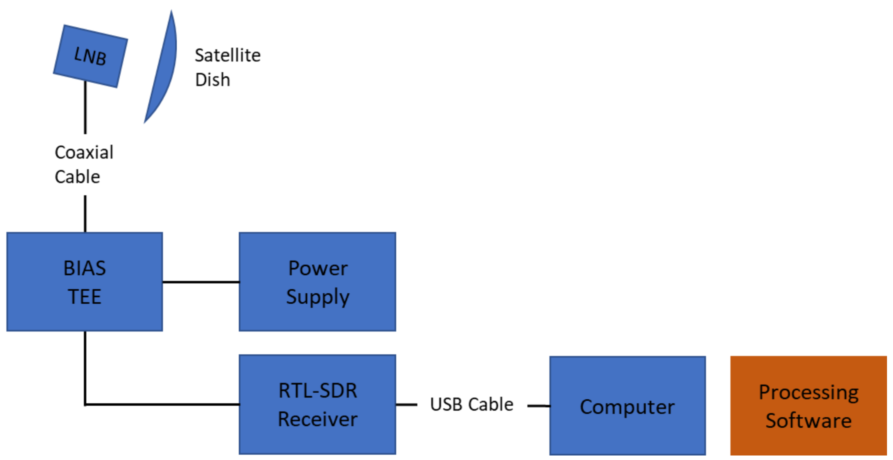
Total Power Measurements

Whilst this subject was not covered in the initial description, total power instruments can be used to measure the received broad band noise signal P_N, and relate it to the temperature of the object being observed using the relationship $P_N = k_B T\, B$. (N.B. - This only applies to thermal noise sources and not to noise generated by other means such as synchrotron radiation)

Where: P_N is the noise power in Watts,
k_B is Boltzmann's Constant (1.381×10^{-23} Joules/Kelvin),
T is the absolute temperature in Kelvin,
B is the frequency bandwidth over which the measurements are taken in Hz.

It is relatively easy to observe the sun passing in front of a satellite dish using either a satellite finder or a software defined radio and is an easy demonstration of the different ground, sky and sun temperatures and forms the basis of the calibration of the open source Hydrogen Line radio telescope.

Another recognised method makes use of an electronic noise source that provides a signal at a known level, and is usually specified as the ENR (Excess Noise Ratio) above a thermal source such as a resistor.



Low-Cost Software-Defined Radio Dongles

RTL-SDR.COM Super stable 1ppm TCXO R820T2 tuner USB Stick - Version 3 £29.99
https://shop.technofix.uk/super-stable-1ppm-tcxo-r820t2-tuner-rtl2832u-rtl-sdr-usb-stick-version-3

(Alternative SDR Dongle)

Nooelec NESDR SMArTee v2 SDR - Aluminium Enclosure, Bias Tee, 0.5ppm TCXO
https://www.nooelec.com/store/sdr/sdr-receivers/nesdr-smartee-sdr.html (US Supplier)

(BIAS TEE – a 5V supply can be injected into cable for external preamplifier / converter)

Installation Instructions for RTL-SDR Dongles and software.

https://groups.io/g/BLAS/files/Radio_Astronomy/0_Software_Defined_Radio/Instructions_for_SDR_Sharp.pdf

AIRSPY SDR Sharp: *Windows SDR Software Package*.
https://airspy.com/download

Zadig: *Windows application that installs generic USB drivers for RTL-SDR*.
https://zadig.akeo.ie

DL4YHF's Amateur Radio Software: *Audio Spectrum Analyser ("Spectrum Lab")*.
https://www.qsl.net/dl4yhf/spectra1.html

(Both SDR Sharp and Spectrum Lab are installed on BLAS Sony Vaio Laptop)

High-End Software-Defined Radios

SDRplay RSP1A Single Tuner 14-bit SDR Receiver – 1kHz to 2GHz
https://www.sdrplay.com/rsp1a/

Review
https://www.sdrplay.com/wp-content/uploads/2017/12/RSP1ARadComReviewJan2018.pdf

https://hamradiostore.co.uk/rsp-1a-rs-play-sdr-receiver-1khz-2ghz.html £94.95

SDRplay RSPduo Dual Tuner 14-bit SDR Receiver – 1kHz to 2GHz
https://www.sdrplay.com/rspduo/

Review
https://www.sdrplay.com/wp-content/uploads/2018/07/RadComRSPduoReview1.pdf

https://hamradiostore.co.uk/sdr-play-rsp-duo-new.html £239.95

Airspy Mini High Performance Miniature SDR Dongle – 24MHz to 1.7GHz
https://www.itead.cc/airspy-mini.html

Review
https://www.rtl-sdr.com/review-airspy-mini/

https://www.moonraker.eu/airspyrmini-4940
£119.99

Airspy R2 Receiver – 24MHz to 1.7GHz
https://airspy.com/airspy-r2

Review
https://airspy.com/downloads/Airspy%20RadCom%20Sep15.pdf

https://www.moonraker.eu/airspy-r2-high-peformance-sdr-receiver £209.99

Meteor Scatter

3 element GRAVES Radar LFA Yagi Antenna 143MHz £69.95
https://www.innovantennas.com/en/shop-page/553/1/vhf-uhf-ham-radio-antennas/144mhz-low-noise-lfa-yagis/3el-grave-radar-lfa-yagi-143mhzInnovAntennas

Uputronics HAB-FLT 145MHz Filtered Preamplifier £53.99
https://store.uputronics.com/index.php?route=product/product&path=59&product_id=89

Product Datasheet.
https://store.uputronics.com/files/HAB-FLT145.pdf

Space Weather

SpyVerter R2 – Upconverter (Required with RTL-SDR for Space Weather / Jupiter)
https://www.itead.cc/spyverter-r2.html (US Supplier)

https://www.moonraker.eu/airspyrmini (UK Supplier) £59.99

Review of SpyVerter v HamItUp
https://www.rtl-sdr.com/review-of-the-spyverter-upconverter/

Review of New Version
https://www.rtl-sdr.com/a-review-of-the-spyverter-r2/

Jupiter

Radio-Sky Software: *Radio-Jupiter Pro 3*.
http://www.radiosky.com/rjpro3ishere.html $19.99

Hydrogen Line

Nooelec SAWbird+ H1 Barebones - Premium SAW Filter & Cascaded Ultra-Low Noise Amplifier (LNA) Module for Hydrogen Line (21cm) Applications. (Deluxe Version is cased)
https://www.nooelec.com/store/sawbird-h1-barebones.html

GPS Locked Frequency Standard

LEO Bodnar Precision GPS Reference Clock
http://www.leobodnar.com/shop/index.php?main_page=product_info&products_id=234

Using SDR-Kits External Clock-in Cable with the SDRPlay RSPduo
http://www.sdr-kits.net/documents/SDRPlay%20RSP%20External%20Clock%20in%20Cable%20use.pdf

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Software Defined Radios

RTL-SDR.COM Dongle	£30.00				
Airspy Mini High Performance SDR		119.99			
Airspy R2 High Performance SDR			209.95		
SDRplay RSP1A				£94.95	
SDRplay RSPduo					239.95

Meteor Observations

Uputronics HAB-FLT 145MHz Filtered Preamplifier	£53.99	£53.99	£53.99	£53.99	£53.99
3 element GRAVES Radar LFA Yagi Antenna 143MHz	£69.95	£69.95	£69.95	£69.95	£69.95
Low-loss coaxial cable (50Ω) and connectors	£40.00	£40.00	£40.00	£40.00	£40.00
TOTAL	£163.94	£163.94	£163.94	£163.94	£163.94
Running Total	£193.94	£283.93	£373.89	£258.89	£403.89

Space Weather

Airspy SpyVerter R2 Up Converter	£59.95	£59.95	£59.95		
Home-made inductive loop antenna or UKRAA E-field Probe	£50.00	£50.00	£50.00	£50.00	£50.00
TOTAL	£109.95	£109.95	£109.95	£50.00	£50.00
Running Total	£303.89	£393.88	£483.84	£308.89	£453.89

Jupiter / Solar Radio Bursts

Home-made wire antenna and supports	£100.00	£100.00	£100.00	£100.00	£100.00
CATV antenna combiner / connectors	£20.00	£20.00	£20.00	£20.00	£20.00
Radio Sky Radio-Jupiter Pro 3 Software	£20.00	£20.00	£20.00	£20.00	£20.00
TOTAL	£140.00	£140.00	£140.00	£140.00	£140.00
Running Total	£443.89	£533.88	£623.84	£448.89	£593.89

21cm Hydrogen Line

NooElec SAWbird+ H1 Low-Noise Amplifier	£45.00	£45.00	£45.00	£45.00	£45.00
Materials / connectors etc.	£50.00	£50.00	£50.00	£50.00	£50.00
TOTAL	£95.00	£95.00	£95.00	£95.00	£95.00
Running Total	£538.89	£628.88	£718.84	£543.89	£688.89

Networking / Internet Access

TP-Link TL-MR6400 300 Mbps 4G Mobile Wi-Fi Router	£73.97	£73.97	£73.97	£73.97	£73.97
Three Pay As You Go Mobile Broadband 24 GB Data SIM	£42.96	£42.96	£42.96	£42.96	£42.96
TOTAL	£116.93	£116.93	£116.93	£116.93	£116.93
Running Total	£655.82	£745.81	£835.77	£660.82	£805.82

GPS Locked Frequency Standard

Leo Bodnar GPS Locked Frequency Standard			£150.00		£150.00
External GPS antenna and cable			£41.00		£41.00
RSPduo external clock cable			£6.25		£6.25
TOTAL			£197.25		£197.25
Running Total	£655.82	£745.81	£1,033.02	£660.82	£1,003.07
GRAND TOTAL	£655.82	£745.81	£1,033.02	£660.82	£1,003.07

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National Oceanographic and Atmospheric Administration.
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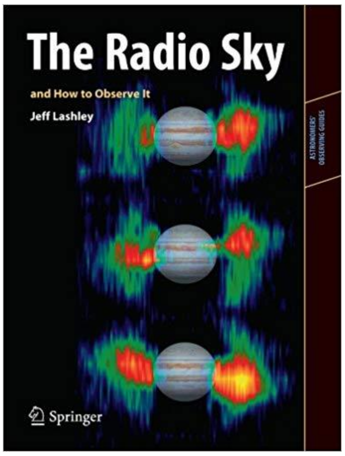

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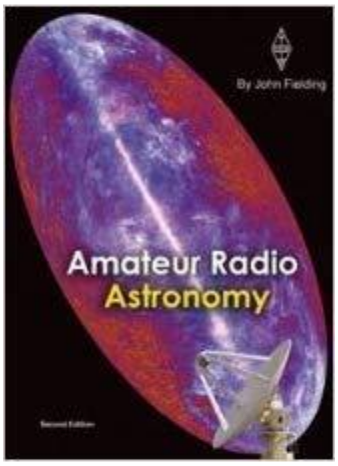

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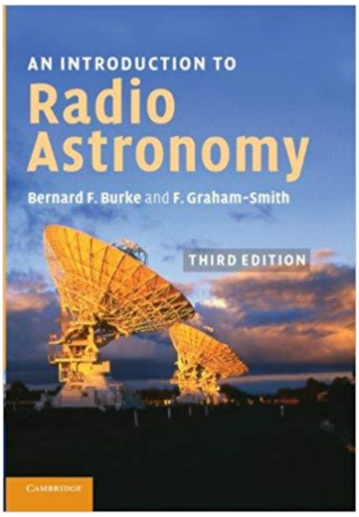

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