# Report on Operations and the Current Status of the Radio Telescopes at ISU

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## Summary

Both the ESA-Dresden (10 GHz) and ESA-Haystack (1.4 GHz) radio telescopes have been successfully operated for several years, and work in a stable manner. They can be used to obtain reliable observational data of the Sun, Moon, and our Milky Way Galaxy, despite the high level of electronic noise on their location on a university campus. This makes ISU one of the few educational institutions in Europe, and perhaps world-wide, where students can execute radio astronomical observations to gain quantitative and meaningful results with several instruments working on different frequencies.

While the GENSO (432 and 144 MHz) ground station might have been very useful to monitor the Solar Corona, this is made impossible by the ambient electronic noise. For the same reason, earlier operations of the RadioJove receiver (20 MHz) for solar radio bursts had to be abandoned. Natural radio emission, caused by lightning as far as from the southern hemisphere, can be recorded and analysed.

All instruments or their data have been used in workshops and projects with ISU students, astrophysics students of the Observatoire de Strasbourg, and secondary school pupils, as well as employed for demonstrations to school children and the public.

# 1. Developments at the ESA-Haystack Telescope

This telescope has been in almost continuous operation since its First Light in June 2008. One of the major problems turned out to be the proximity of a cell phone transmitter whose emission drives the preamplifier into saturation, and makes observations impossible. In 2009 this issue was cured by the construction and installation of a narrow band filter. However, the decrease in sensitivity was much stronger than should be expected from measurements of the filter on its own (i.e. from its insertion loss).

## 1.1 Completion of the First and Second Galactic Survey

Initially the system temperature was as high as 600 to 2000 K, but it seemed already worthwhile to map the emission of hydrogen gas in the Milky Way. With one of the filters a first survey could be conducted in spring 2010 with a system temperature of somewhat above 1000 K which revealed already all essential features. Further adjustments gave about 1000 K, so that in summer and autumn 2010 a second survey could successfully be completed.

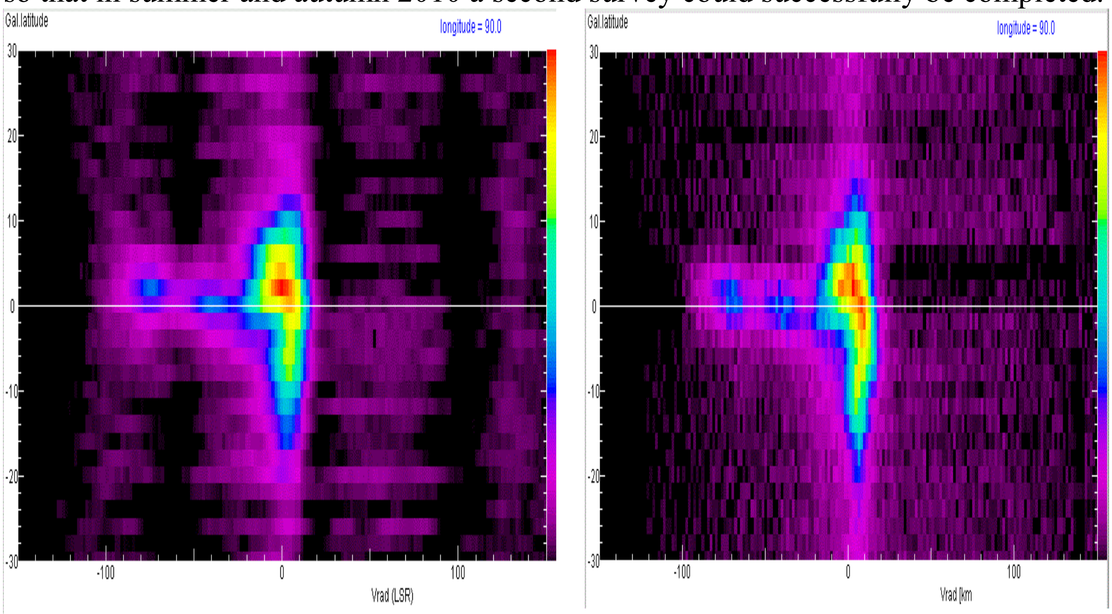


***Fig.1*** *Maps of the Galactic hydrogen emission at longitude 90° done in the First (left) and Second (right) Survey. The colour indicates the intensity of the emission measured at various radial velocities and galactic latitudes.*

## 1.2 Pushrod problems

In autumn 2010 problems became apparent with the elevation positioning, leading to the telescope getting completely stuck in elevation direction. It turned out that the linear actuator, which is labelled as maintenance-free by the manufacturer, was blocked in its operation, evidently because rain water had seeped into the inner workings and washed out the lubricant. Application of penetrating oil and repetitive operations of the device brought it back to normal functioning. In the meantime, the filter alignment could be improved, and a third survey was conducted in winter 2010/11 with a system temperature of 700 K:

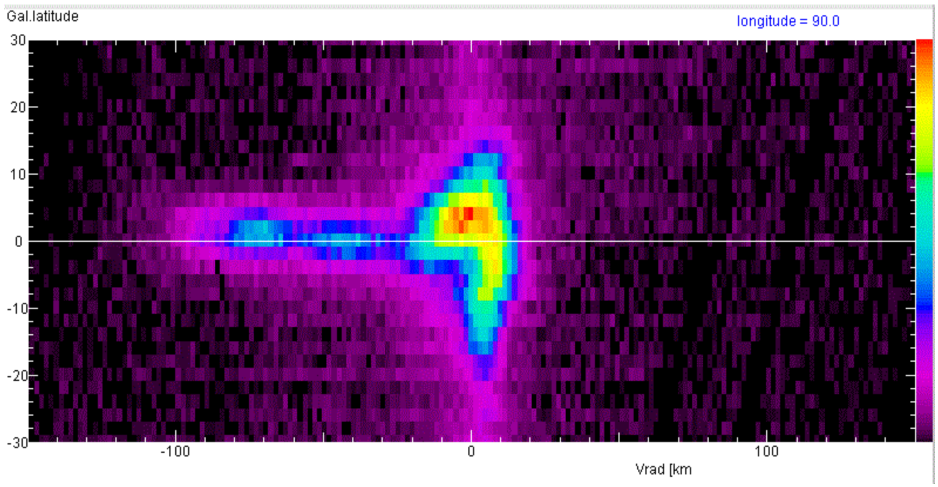


***Fig.2*** *Map of Galactic hydrogen emission at longitude 90° from the Third Survey.*

Even though the system performance was still less than should be possible, the data secured could be used as educational material. In particular, they were used in the interactive telescope simulator (see below) which students used in workshops to perform simulated but realistic observations of hydrogen gas in the Milky Way.

## 1.3 Improvements of Narrowband Filters

One of the problems with the apparently poor filter performance turned out to be the improper impedance matching of the filter to the antenna probe and to the preamplifier input. While the filter could carefully be aligned to the desired passband on the 50 Ohm system available at ISU (Hewlett-Packard 8660C swept frequency generator donated by ESA in 2008, and microwave detector by the author), the measured performance at the telescope was entirely different. By careful and systematic alignment and measurement of the entire telescope receiver system the performance could be significantly improved: in June 2011 system temperatures of 300 K and less were measured. In summer and winter 2011/12 the fifth complete survey was executed, leading to a much better signal-to-noise ratio:

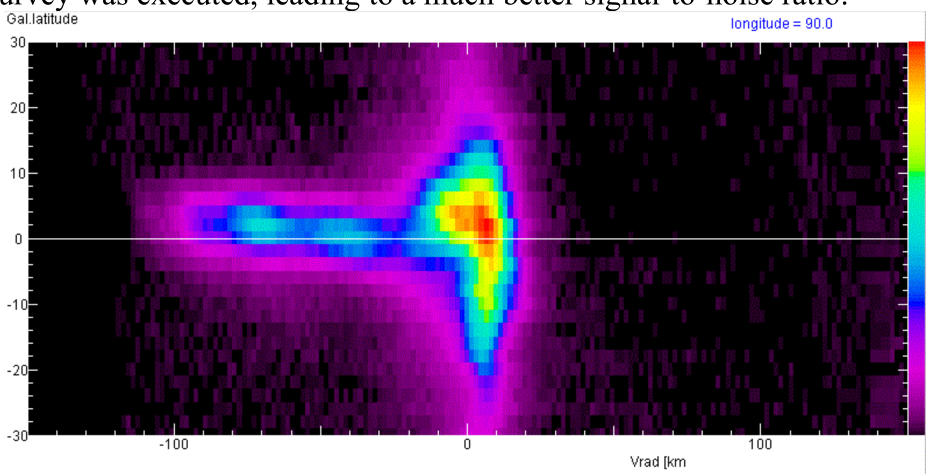


***Fig.3*** *Map of Galactic hydrogen emission at longitude 90° obtained in the Fifth Survey. One distinguishes at a radial velocity near 0 km/s hydrogen in the solar vicinity which extends to high latitudes, but also two spiral arms at negative velocity and close to the Galactic Plane. Their negative velocity indicates that they father away from the Galactic Centre than the Sun. Note also that the outer arm at -90 km/s lies above the Plane: the outer Milky Way's gas disk bents upward!*

## 1.4 Improved Mechanical Rigidity of Focal Assembly

During all these experiments and adjustments it became apparent that the telescope showed a variation of performance, which grew in time. The reason lay with the mechanical flexibility of the apparatus of the focal assembly. In particular, the two machine screws that should hold the weighty aluminium die-cast receiver box were or had become quite loose, and showed a damaged threading. Another important source of instability was that the antenna probe could move in and out of its guiding tube. Finally, to the necessary experimentation and fine-tuning the filter and the preamplifier had been tied temporarily to the receiver box, so that all components had a certain freedom to move when the telescope's elevation was changed.

In winter 2012 the receiver box was firmly attached to the focal assembly, using a sufficient number of strong cable binders. The antenna probe was fixed by forcing plastic strips into the guide tube and application of hot glue at the cable's entrance. Also the filter – now in a nearly optimal state – was firmly attached:

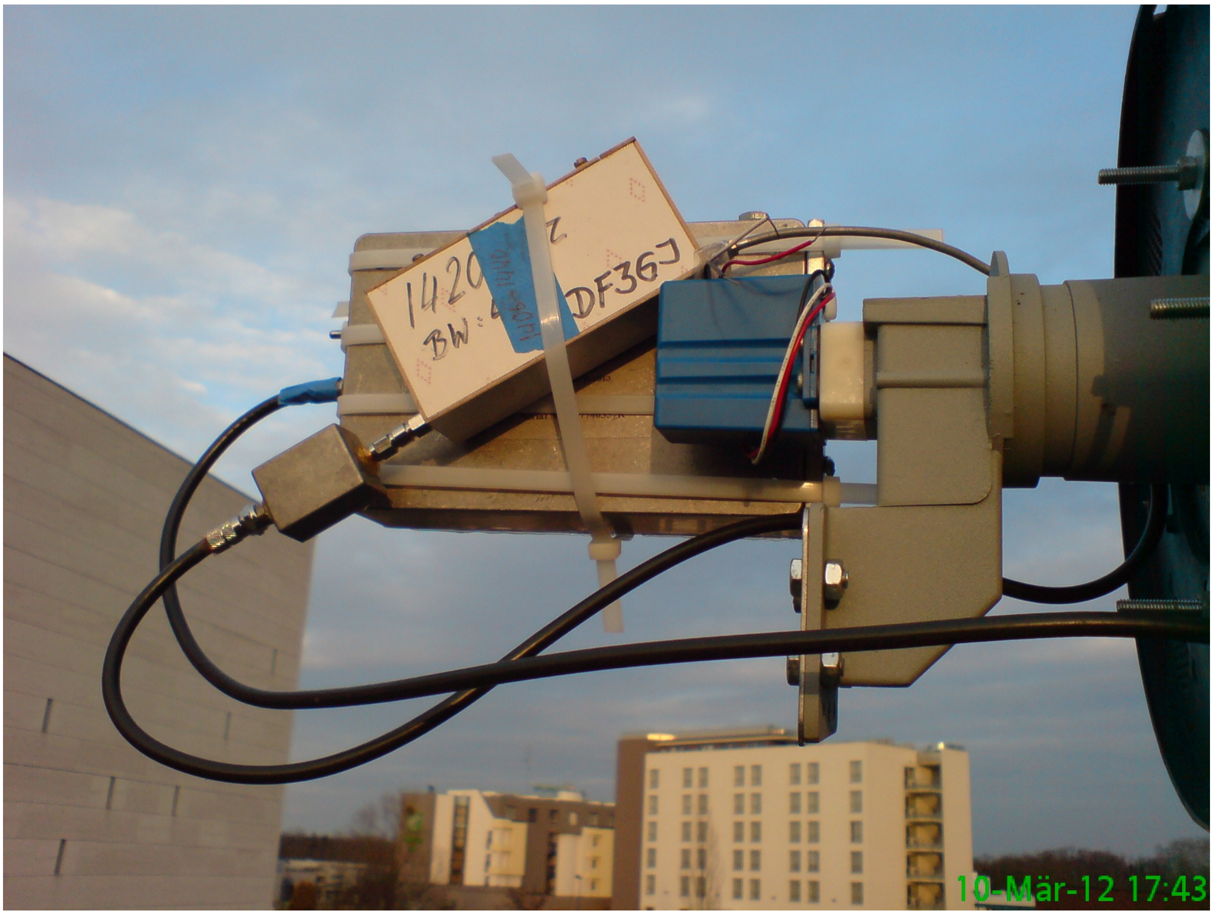


***Fig.4*** *The improved focal assembly: in the foreground are the small preamplifier and the narrow band filter, in the background the large receiver box. The blue box and the waveguide structure at right are not used.*

## 1.5 Current Status

The telescope has now been working in a stable manner for several months, and may thus be considered to be fully operational.
With a system temperature of around 300 K the performance of the telescope is better than necessary to obtain good data of the Milky Way. While even lower values have indeed been achieved, it does not seem advisable to try further improvements, as they may be at the expense of requiring an unnecessarily critical adjustment.
There is still some variation of the system temperature. At the present time, this is being monitored with the aim of making the performance as stable as possible and perhaps identifying origins of any systematic variations, such as the ambient temperature …

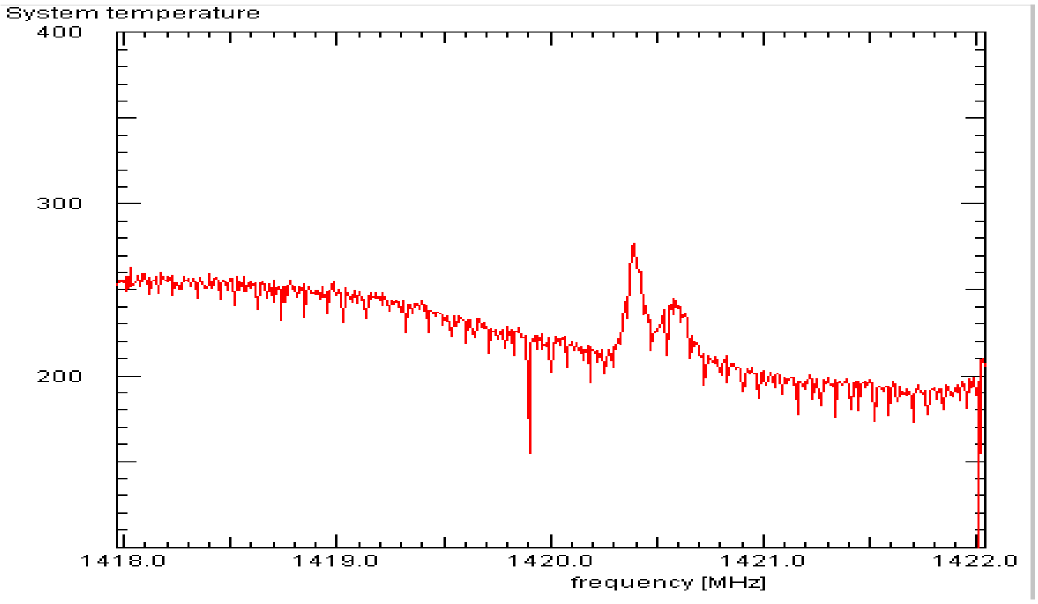


***Fig.5*** *The system temperature as a function of frequency, measured on 29 March. The feature with two bumps at 1420.5 MHz is emission from the Milky Way picked up when pointing to the sky. The closely spaced sequence of downward pointing narrow spikes is electrical interference from the lamps in the ISU library picked up when pointing towards the library wall for ground calibration.*

Recently, there came yet another interference concern: during the past year sometimes a signal appears to move in and out of the frequency range of interest. While the signal is usually not very strong, it may be overlapping with the galactic emission. The nature of this interference remains still a mystery, but it might be some digital communication occupying a 1 MHz band. There is no obvious time pattern which would allow its association with human activities. While it may wander around in frequency slowly and in jumps, it usually is below 1419 MHz, thus fortunately sufficiently away from galactic features ...

# 2. Use of the ESA-Dresden Telescope

This instrument is functional since 2007. It has been used by ISU students for their Personal Assignments seven times. Except for the occasional re-adjustment of the elevation position – usually altered by stormy weather – and the replacement of the elastic luggage holder around the azimuth motor it has not yet required any repair or encountered any serious problems.

## 2.1 The Lunar Challenge

Already in 1946 it had been discovered that the maximum radio temperature of the Moon occurs about five days after Full Moon, because the lunar surface layer consists of rather loose material ('regolith') which heats up only slowly under the solar irradiation. It had been demonstrated that with modest equipment like the ESA-Dresden telescope it is possible to measure the monthly variation of the lunar surface temperature.
A first attempt of systematic lunar observations was done by Zahrah Musa in 2008 (MSS Personal Assignment). Her work showed that the limitations of the telescope's positioning system and the use of the original software made it rather difficult to obtain reliable measurements.
The development of our own software and of a special procedure to localize this faint source resulted in a substantial improvement. In her Personal Assignment during MSS11, Mary-Anne Fobert obtained 100 individual measurements, during all lunar phase angles and at a variety of sky conditions. Her outstanding work showed that it is possible to get measurements even at overcast skies, mist, or fog. However, the scatter among the deduced temperatures was still too large to see the expected monthly variation:

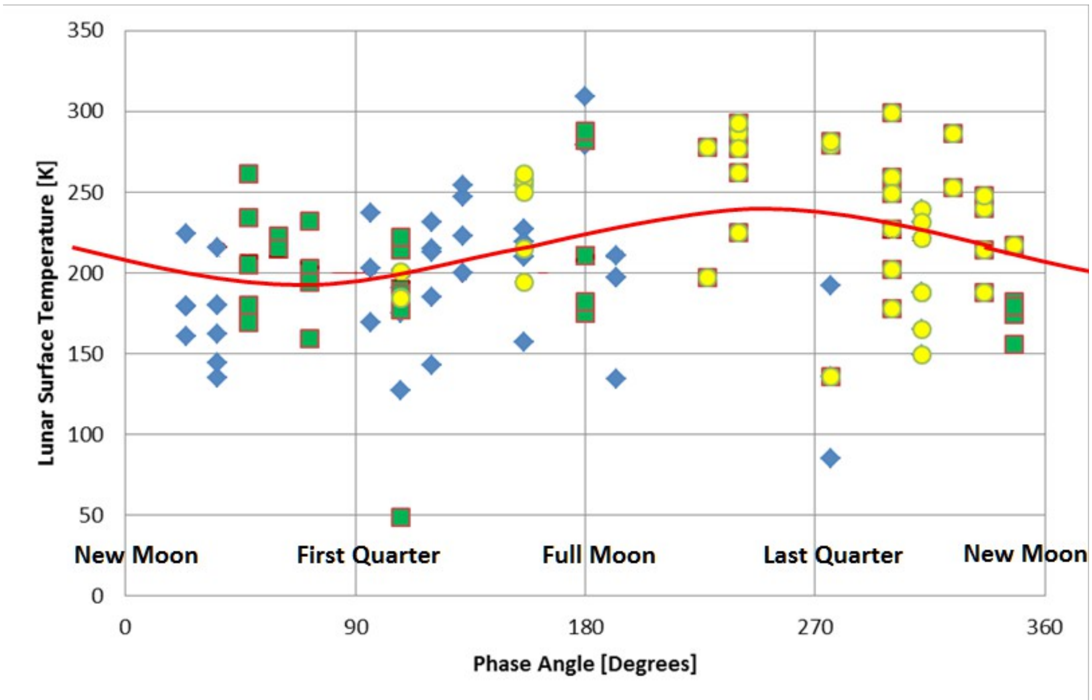


***Fig.6*** *The surface temperature of the Moon depends on the lunar phase. The expected relation is shown as a red curve, compared to our measurements: blue diamonds indicate clear skies, green squares overcast skies, fog, or mist, but all taken at elevations higher than 20°. Yellow symbols refer to observations at low elevation, circles showing clear sky conditions.*

Furthermore, she showed that the temperatures depended on the Moon's elevation angle in the sky, because our subtraction of the noise background did not yet take into account that this noise is composed of two contributions: while the receiver's internal noise is constant, the noise from the sky increases with lowering elevation, as the intercepted column of the atmosphere is larger. At 10 GHz this cannot be neglected.

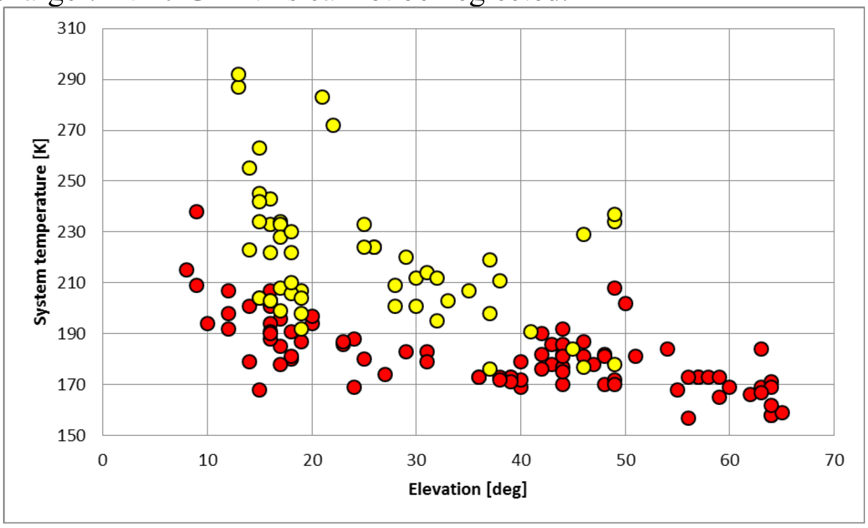


***Fig.7*** *The system temperature as measured for different elevations. Yellow dots indicate data done with the old calibrator position which underestimates the flux, red dots are data taken with by pointing at the lower, better position.*

## 2.2 Use in educational activities

⑤ The ESA-Dresden telescope was used in seven Personal Assignments focussed on various astrophysical and technical aspects. Usually, three topics are proposed in each years if the ISU Masters program.

⑤ Data obtained with the telescope has been used in regular workshops in the Masters program as well as in the Physics Department of SSP. A typical example is the analysis of the drift scans of the Sun (below) and the Moon:

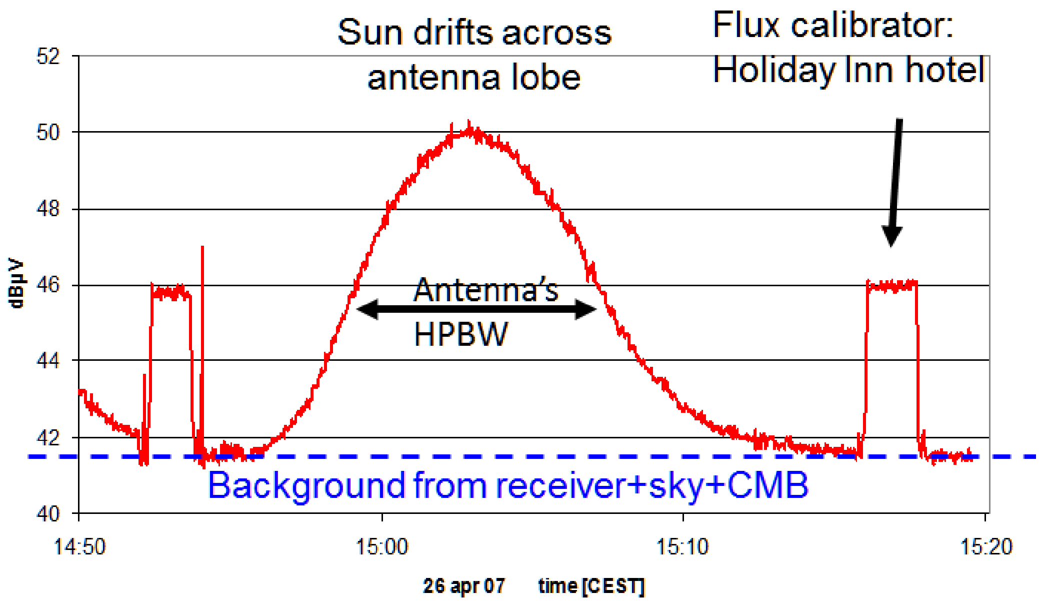

*__Fig.8__ Drift scan observation of the Sun with flux calibrations.*

⑤ In winter 2012, I gave a lecture course "Introduction to Radio Astronomy" in the M2 program at the Observatoire de Strasbourg. This consisted of 10 hours of formal lectures, 6 hours of observations with the ISU telescopes, and 4 hours of data reduction and analysis workshop. In the two observing sessions, the students were able to perform all the observations possible with the ESA-Dresden and ESA-Haystack telescopes. For example, a complete lunar measurement is shown below, along with flux calibration and the procedure to measure the sky and receiver noise.

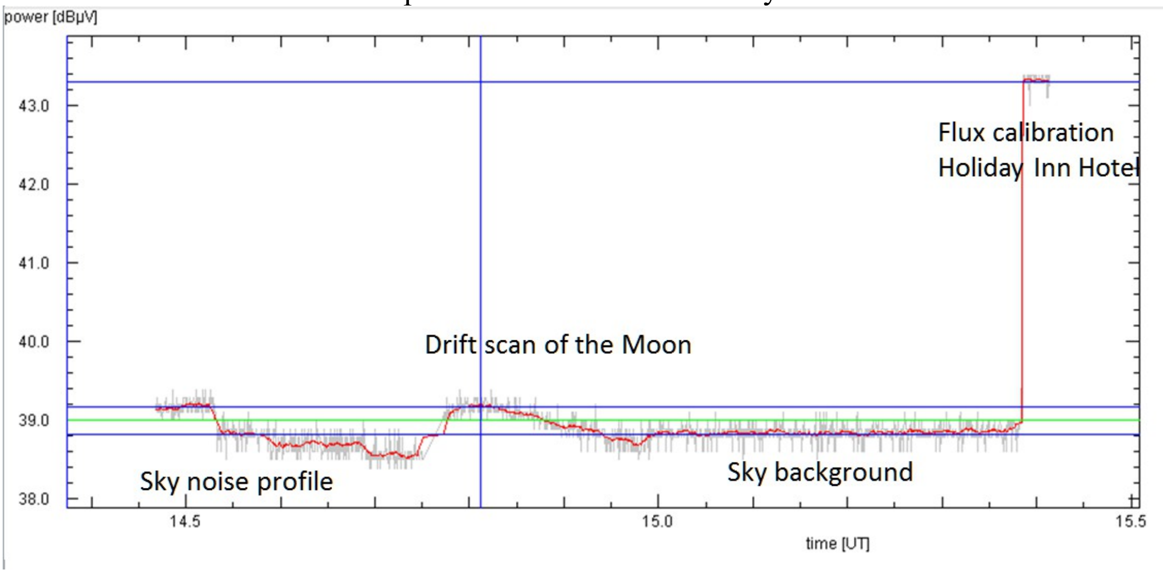


***Fig.9** Observations of the Moon by astrophysics students of the M2 programme of the Observatoire de Strasbourg: sky noise measurements are taken at several elevations, followed by the Moon drifting through the telescope's antenna beam, then measurement of the sky background and the Holiday Inn Hotel, our flux calibration source.*

⑤ The ESA-Dresden telescope was also used for demonstrations of solar observations during ISU Open Doors Day and visits of secondary school students from France, Germany, and Sweden in 2011 and 2012

## 2.3 Current Investigations

The aim of the undergoing tests is to improve further the procedures of observing the Sun and the Moon, and especially improve the subtraction of the background noise from sky and receiver.

Measurements of the noise taken at a number of elevation angles permit to separate the constant receiver noise from the elevation-dependent sky noise. It is found that the slope of the sky noise profile is well correlated with the weather:

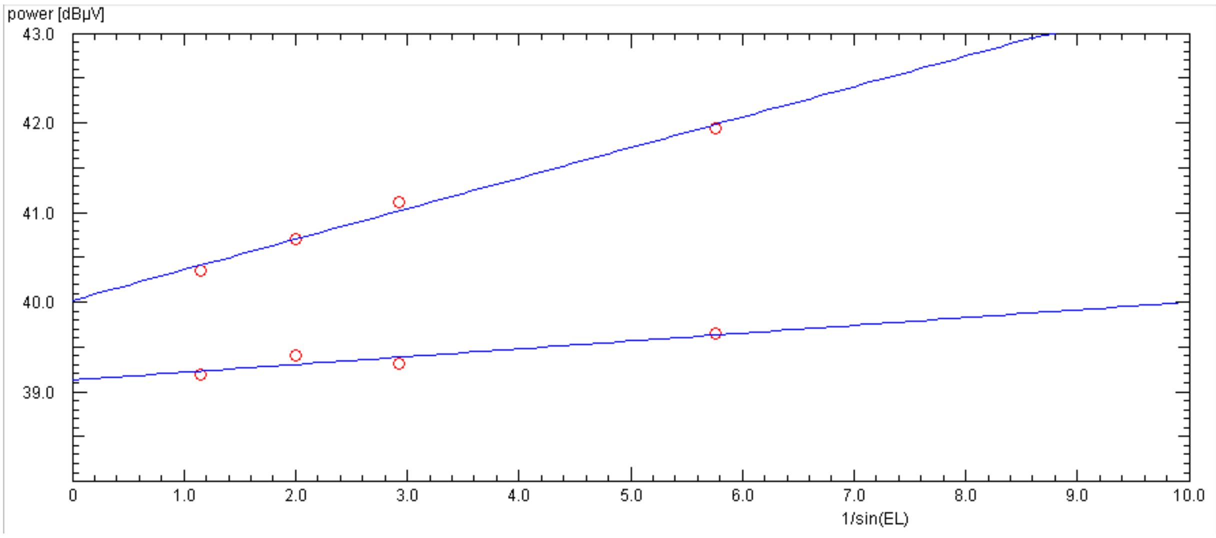


***Fig.10*** *The sky noise measured at four elevations (60, 30, 20, and 10°) on a cloudy and rainy day (top) and on a sunny day with blue skies (bottom). The different slopes of the straight line fit indicate the difference in water content of the atmosphere.*

At 10 GHz emission and absorption by water vapour in the atmosphere is no longer negligible. Hence these measurements would allow estimation of the water content in the atmosphere above Strasbourg. These measurements will be pursued systematically and under various sky conditions with the aim of establishing this correlation, and perhaps in a quantitative way.

# 3. Use of the ESA-Haystack Telescope

## 3.1 Development of Software and an Interactive Simulation Tool

As the original JAVA software lacked the full graphical interaction usually found in present software and was a bit tedious to work with, it was subjected to extensive modifications which now offer a number of features that were added and designed as a response to the needs of the observer:

- Completely graphical control
- Improvement in the plots
- Display of the horizon silhouette
- Waterfall plot to indicate any perturbations
- Interactive control of the plot scales
- Display of messages of activity
- More options for wider frequency span
- Improvements in the background subtraction and the stitching of spectral segments
- Various modifications of the program structure
- Switching over to simulation mode, with the possibility to change the time

From this software an applet version was generated which simulates the use of the telescope:

- It behaves exactly as the real user interface
- Observations of positions in the Galactic Plane are simulated in a realistic way, based on data taken with the ESA-Haystack, and with noise of the same level
- As a JAVA applet it is accessible via the Internet and will run on any platform
- Data is produced in the same format, and can be saved by the user

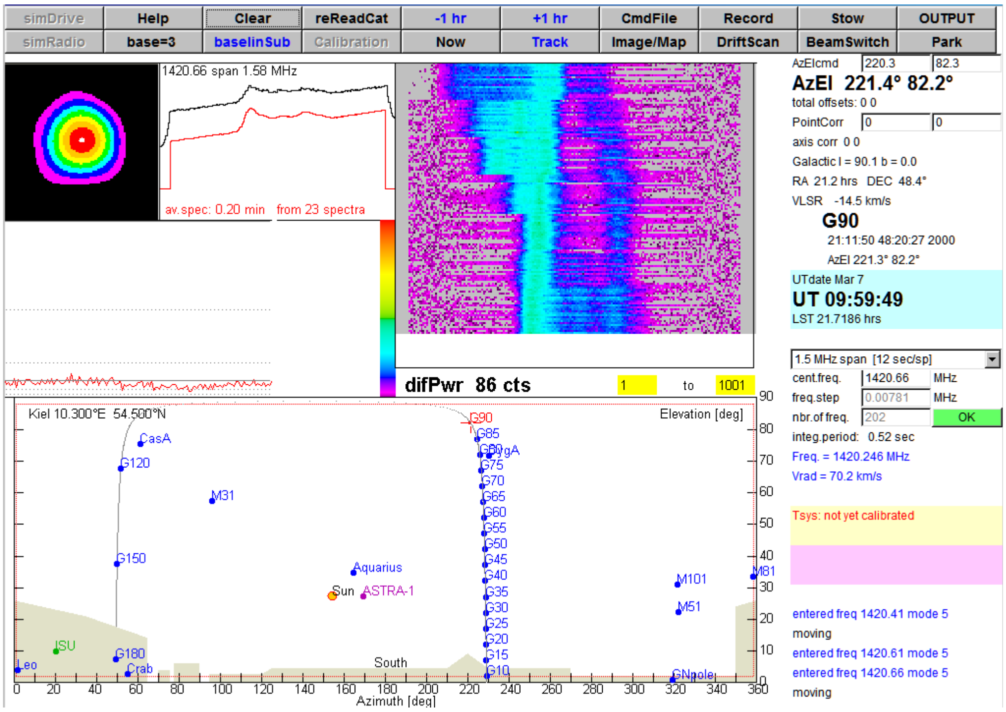


***Fig.11*** *The interactive simulation software for the ESA-Haystack telescope produces realistic data based on observations secured with the real instrument.*

The simulator has been used

- as a demonstration tool
- to make students familiar with the controls prior observing sessions (M2 astrophysics students)
- to perform simulated observations in a workshop with several participants. Since the real telescope operation requires one person only, the use of the simulator permits every student to do his own observations (SSP11, MSS12)
- to allow simulated observations at the student's home for their project work (TIPE by secondary students from Lycée Kléber 2012, cf. Sect. 3.3 below)

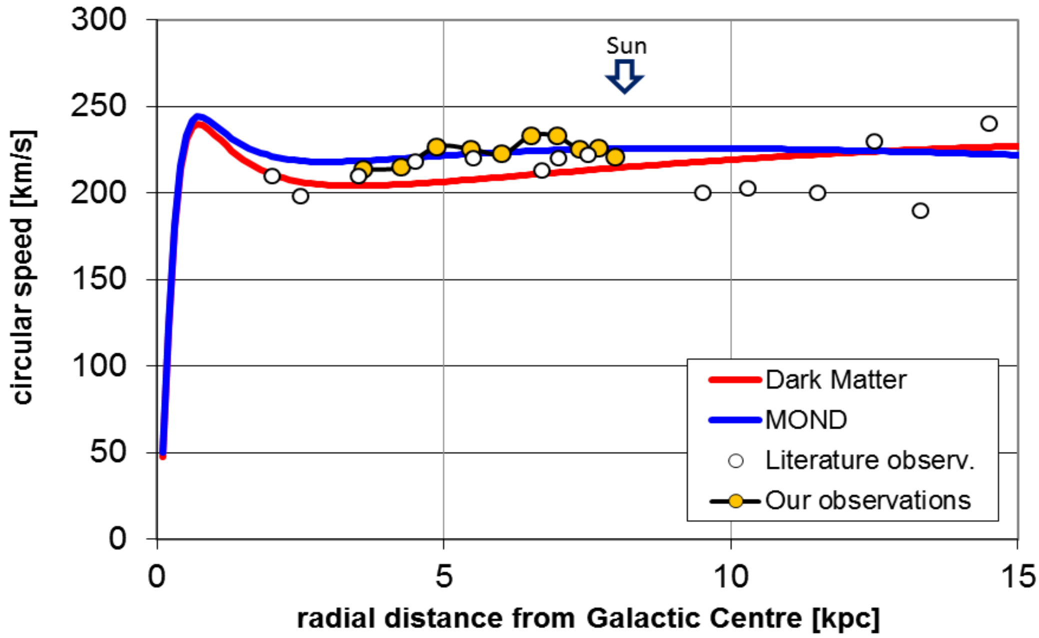


***Fig.12*** *The Galactic rotation curve obtained by ISU students using the ESA-Haystack telescope during two workshops in the Masters program 2012. In each workshop with about 25 participants, two students could operate the real telescope, while the others used the simulators. The obtained data are compared with predictions from the hypotheses of Dark Matter and Modified Newtonian Dynamics.*

## 3.2 Astrophysics Teaching at Strasbourg University

As already mentioned, in winter 2012, I gave a lecture course "Introduction to Radio Astronomy" in the M2 program at the Observatoire de Strasbourg. In the two observing sessions the students used the ESA-Haystack telescope for

- solar observations, and the determination of the temperature of the lower Corona, and comparison with the temperatures obtained with ESA-Dresden on 12.5 GHz
- Galactic Plane observations, and the derivation of the rotation curve of the Milky Way (data shown in Fig.13)
- Observations of the positions below and above the Galactic Plane near the direction into which the Sun moves, and show that the outer spiral arms lie above the Galactic Plane, evidence for the warping of the disk (shown in Fig.14)

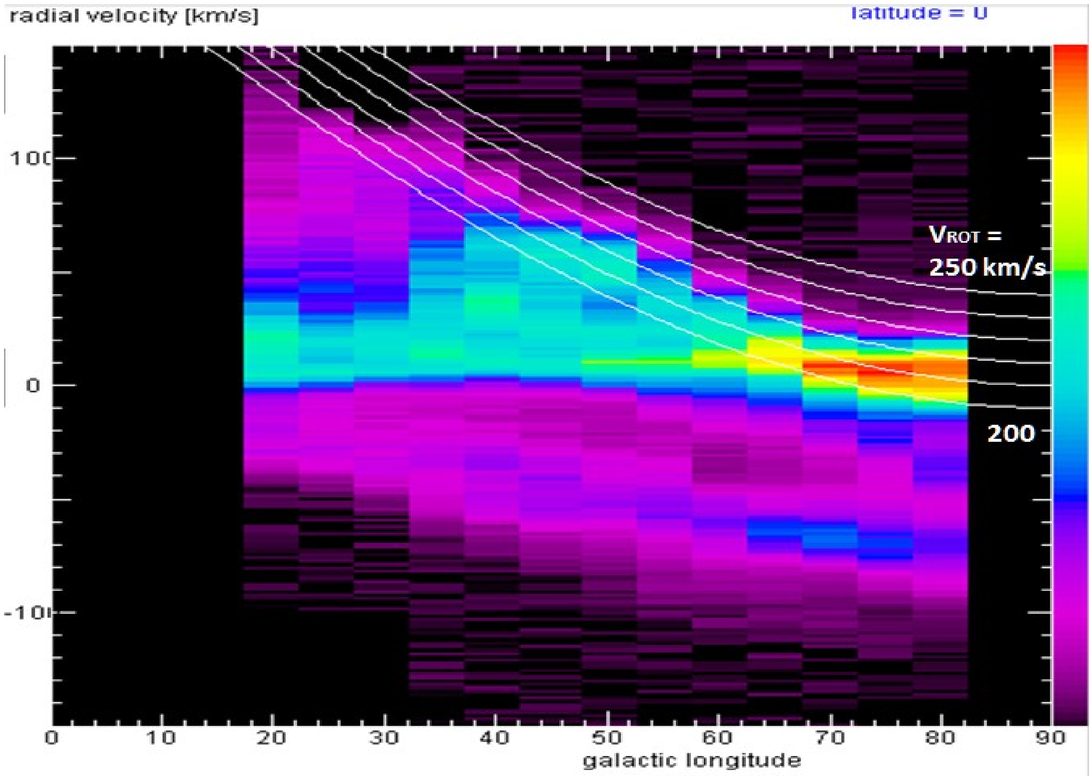


*Fig.13* *False colour position-velocity map of hydrogen emission in the Galactic Plane obtained by astrophysics students of the M2 program of the Observatoire de Strasbourg, during 30 minutes. The white curves indicate the longitude-dependence of the observable radial velocity for five values of the rotational velocity. The close correspondence of the 230 km/s curve with the extent of the emission indicates that the rotational velocity is nearly constant in the Milky Way..*

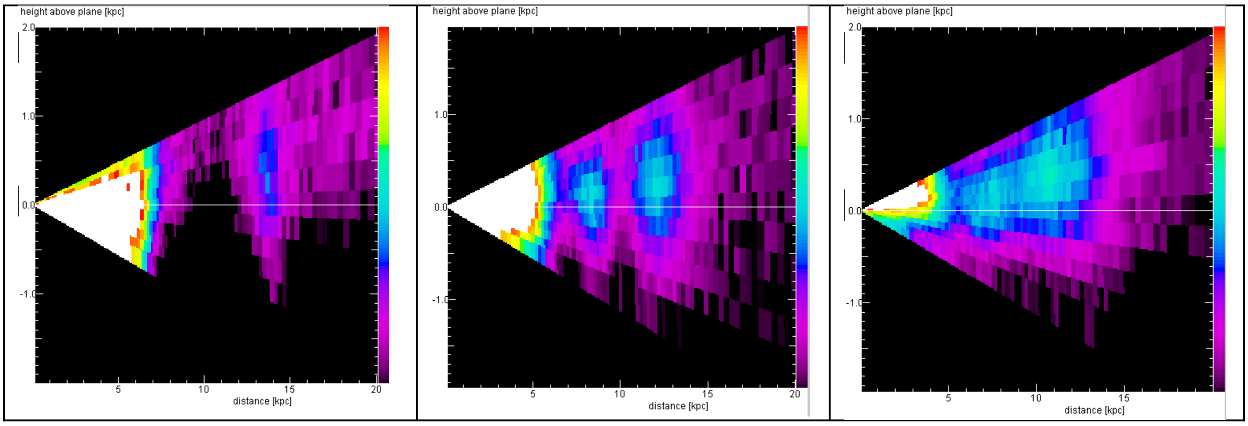


*Fig.14* *Observations of position of the outer spiral arms with respect to the Galactic Plane, at longitudes 70, 80, and 90°, obtained by astrophysics students of the M2 program of the Observatoire de Strasbourg. These show the two spiral arms outside the Sun's orbit, and that the outermost arm lies high above the Galactic Plane, the evidence of the warping of the gas disk.*

## 3.3 Projects with school students

In their work in 2012 for TIPE (Travail d'initiative personnelle encadré) on “Dark Matter” two students from Lycée Kléber have used the ESA-Haystack simulator applet to perform simulated observations, from which they derived the Milky Way’s rotation curve. The confrontation with the curve predicted by a model of the observed distribution of visible matter in our Galaxy permitted them to show the dilemma that lead to the hypothesis of dark matter, and that the amount of this matter would be substantially more than the visible matter. They also used the ESA-Haystack telescope to obtain real data …

## 3.4 Science Projects

With the low system temperature of around 300 K, the Fifth Illkirch Survey of Galactic Hydrogen (ISGH5) was completed in winter 2011/12. Hence the essential emission of our Galaxy, as far as accessible from the northern hemisphere, has been mapped with a good signal to noise ratio between Galactic longitudes 0° and 240° and latitudes between -30° and +30°, in steps of 2° in both directions.
These consistent data will permit a variety of analyses of the gas disk of our Galaxy, for example the location and structure of the spiral arms, and the deviations of the disk from a plane. These could be addressed as subjects for Individual Projects for ISU students, but also to other students.

At the present, the ESA-Haystack telescope is kept running, as to ascertain the stability of operations, in particular of the system temperature and the immunity to interference. Therefore another Galactic Survey is undertaken, now with a resolution of 1° in galactic latitude from -10° to +10°, which shall allow a more detailed study of the warping of the gas disk and lead to a reconstruction of the spiral arms in 3D:

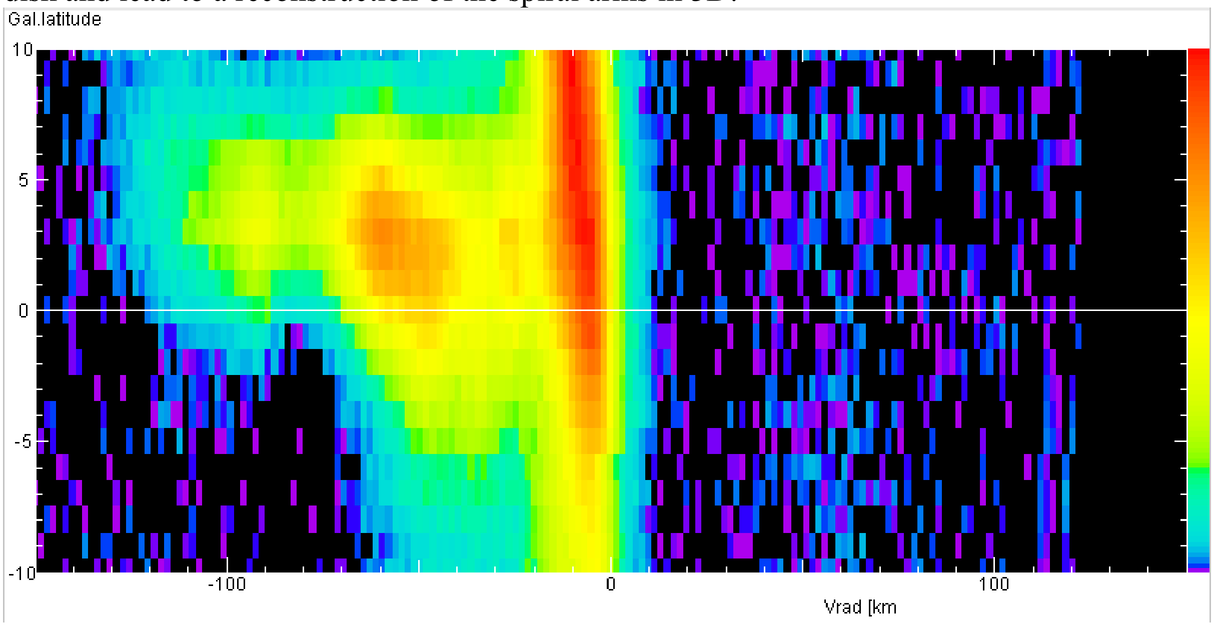


***Fig.15*** *False colour map of the hydrogen emission from the Galactic disk at longitude 104° in the on-going new Survey. Note the smooth and low background, free of spurious features.*

Since the telescope performance is rather stable, it was attempted to detect emission from the Andromeda galaxy, our neighbour and the nearest spiral galaxy. This object is at a distance of about 2 million light years, but it is rather faint and because we would pick up only the entire object, the emission from the rotation disk is spread out over a width of about 400 km/s, which corresponds to about 2 MHz. The position was observed for about 7 hours, giving about 800 spectra. The averaged spectrum is shown in Fig.16.

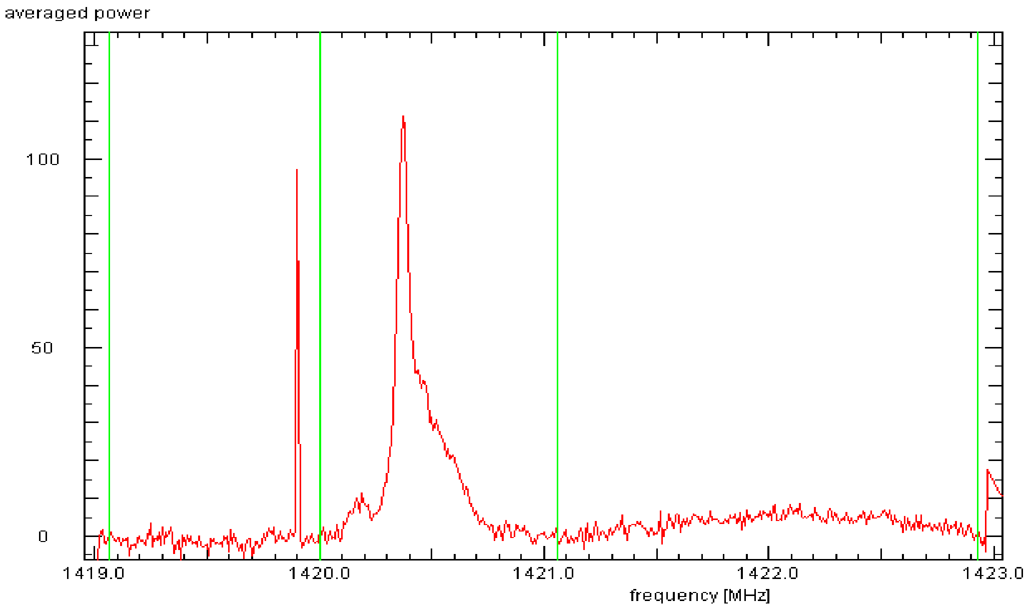


***Fig.16*** *The average spectrum at the position of the Andromeda galaxy, after subtraction of a fit for the curved baseline. The positions of the anchor points for the fit are indicated by green lines.*

While the narrow emission from our Galaxy at 1420.4 MHz comes out clearly, the broad structure that seems to be around 1422 MHz is not Andromeda: it is simply a feature of the subtraction of the non-linear baseline, whose anchor points are marked by the green lines; placing the anchors differently makes the broad feature vanish, or others appear. In the un-reduced average spectrum there is no hint for a broad feature apart from the curved baseline! Thus it must be concluded that with an instrument as small as the ESA-Haystack detection of galaxies other than the Milky Way is indeed not possible!

# 4. Use of the GENSO Ground Station

A good test of the sensitivity of any VHF and UHF receiving installation is whether it can pick up the solar noise. At these frequencies, the very hot corona is a strong radio source. As solar radio emission is continuously monitored by radio observatories, the strength of this signal is well known. In summer 2010 solar noise was successfully detected on 437 MHz:

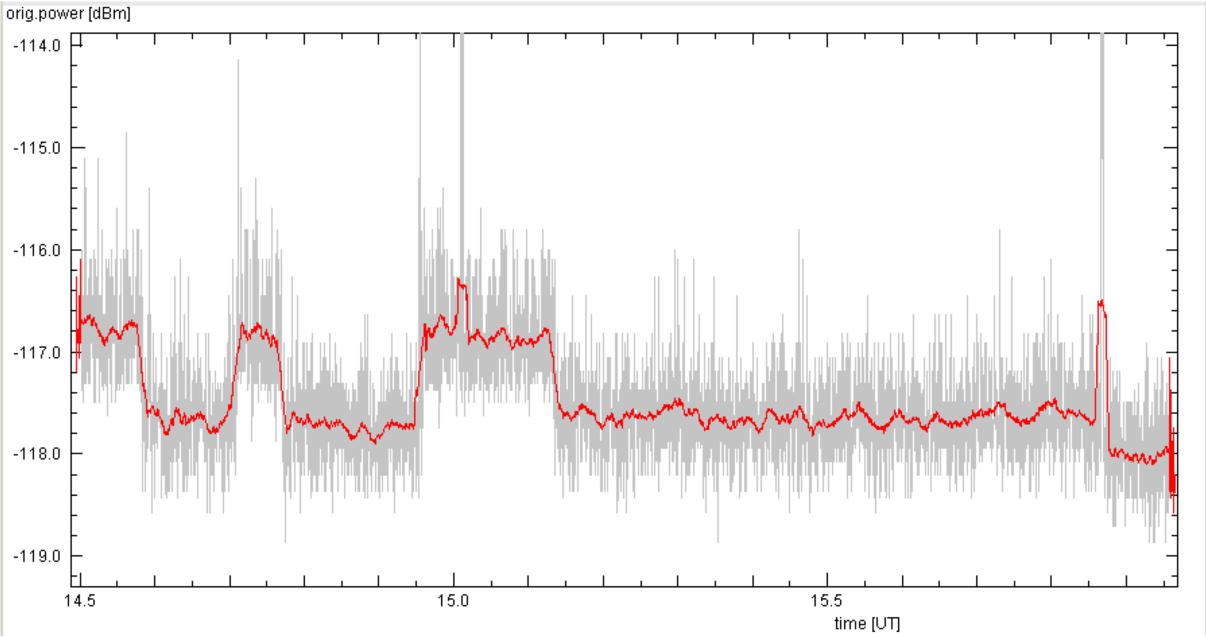


***Fig.17*** *Observation of the Sun on 437 MHz using the GENSO ground station. The antenna was pointed alternatingly to the Sun and well away from it at the empty sky.*

From the technical data of the receiver and the antenna, one would have expected the Sun's noise to be about 6 dB higher than the sky noise on UHF, and 4 dB on VHF. Instead an enhancement of only 1 dB was observed on 437 MHz and nothing was detected on 144 MHz. Evidently the ambient level of electronic noise is as strong as the solar radio flux. These measurements allowed determination of the noise level on this campus (see Sect.6).

The ground station was used in Personal Assignments for measurements of the telemetry signals of cubesats by Kaupo Voormansik (MSS2010) and Feng-Lei Wu (MSS2011). The latter established that the installation works indeed with the technical specifications of the receiver and the antenna system. Thus, the station can be used to measure the signal strength of satellites and hence to ascertain their transmitting power.

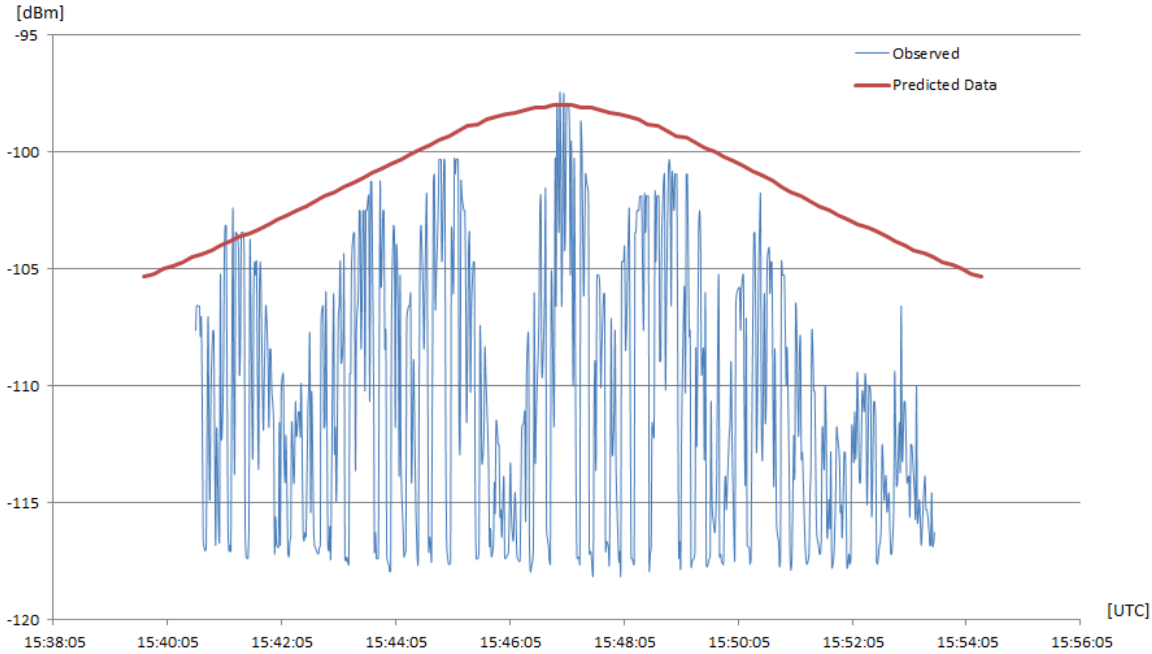

***Fig.18*** *Comparison of the measured variation of signal strength from a cubesat (blue curve) with the predicted variation while passing over the station (red curve).*

Apart from the slow variation during the satellite's pass over Strasbourg and the short pauses between the Morse code characters one finds a quasi-periodic variation of a period of about one minute. This is caused by the tumbling of the unstabilized satellite which shadows the transmitter's antenna.

In a current project, Emmanouil Detsis and Aliakbar Ebrahimi (TAs at ISU) monitor the signal strength of several satellites, in order to explore whether it would be possible to develop techniques to use these easily obtainable to determine the tumbling parameters of satellites.

# 5. Reception at Very Low Frequencies

For quite a number of years, the kit of NASA's INSPIRE receiver has been part of the activities of the SSP Physics Department. This receiver picks up radio waves at audible frequencies, emitted by lightning nearby and far away.
During MSS05 as Personal Assignment Navtej Singh designed and installed a simple VLF receiver at ISU, which proved that lightning signals could be received, despite the unavoidable mains hum. In the Personal Assignment of MSS09, Fred-Joe Nambala constructed an improved receiver. During this time, whistlers originating from lightning in southern Africa where heard and even recorded:

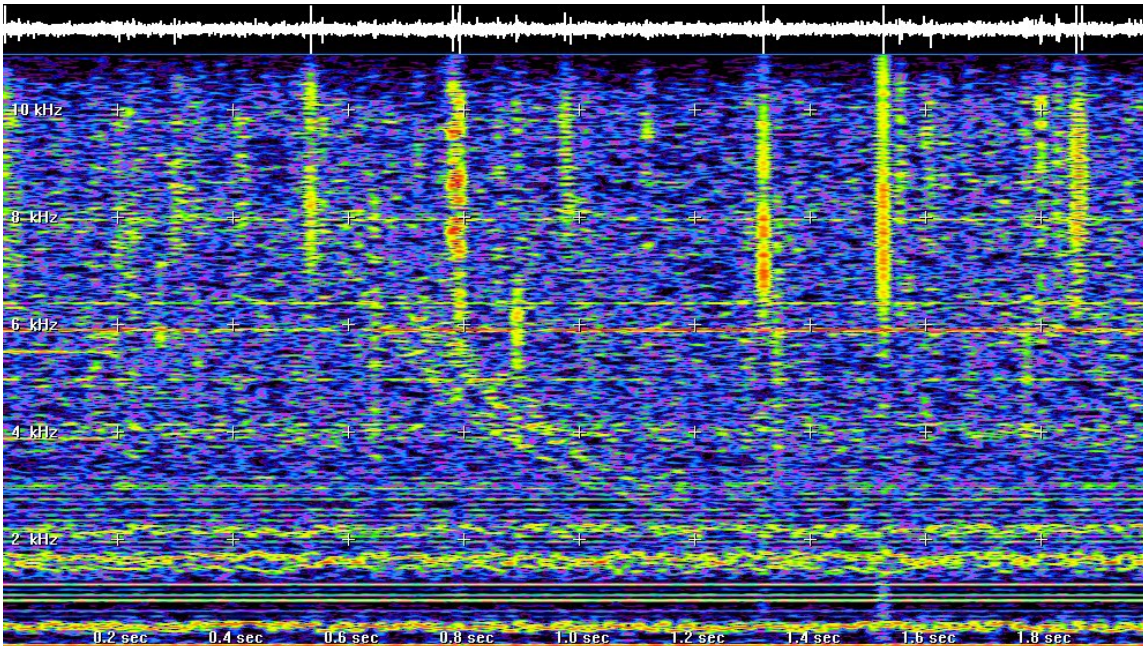


***Fig.19*** *Dynamic spectrum of a whistler recorded at ISU. The vertical structures are radio pulse from lightning in Europe, the horizontal features are from the mains electric supply, and the traces descending with time in frequency are whistler-mode radio emission caused by strong lightning discharges in southern Africa.*

# 6. Observing Conditions at ISU Campus

Using the various instruments operating on different frequencies, the level of electronic noise at our location could be measured:

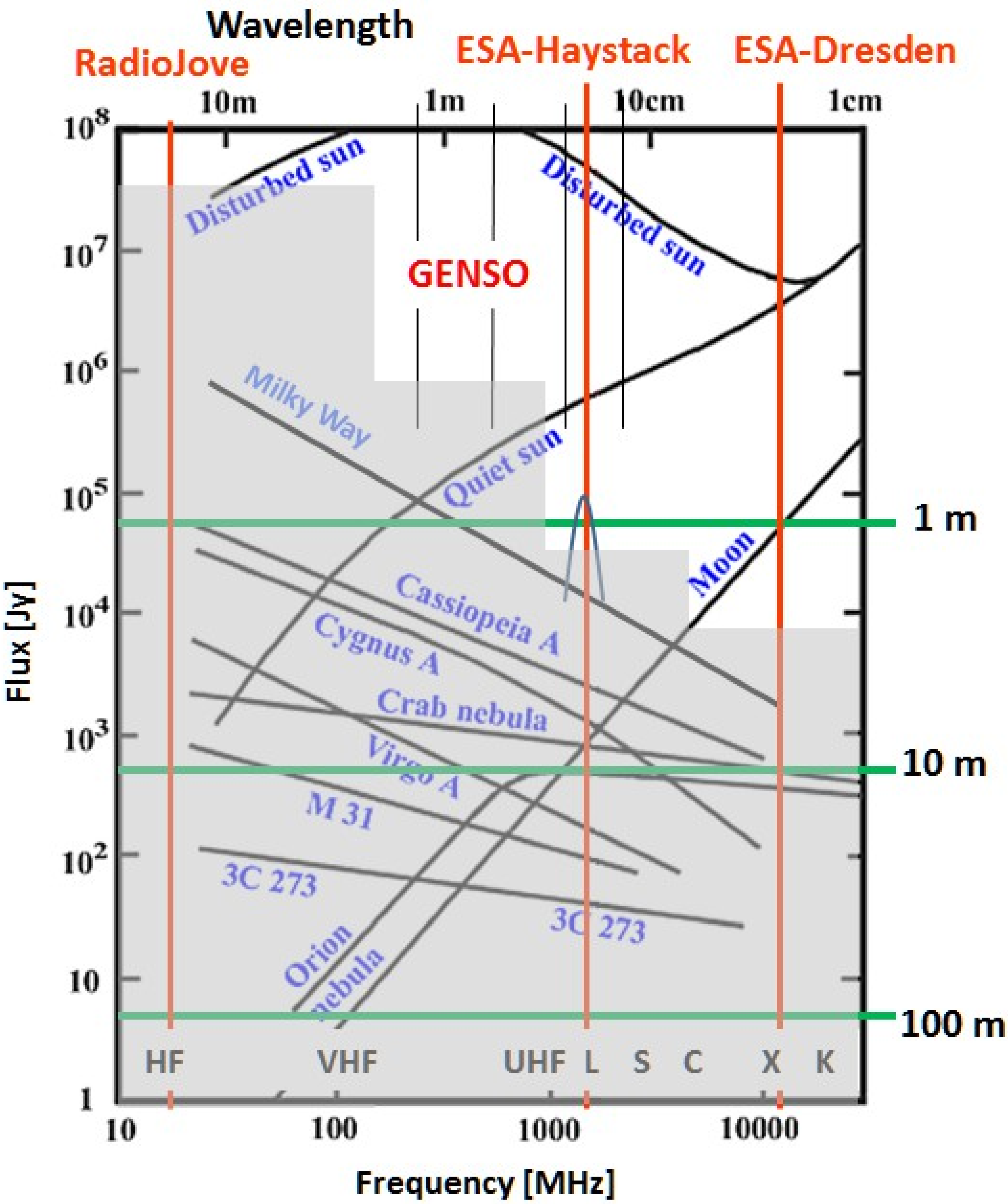


***Fig.20*** *The radio fluxes of various astronomical sources observable at various frequencies with instruments of different diameters (1m ... 100m). The frequencies of out instruments are marked by vertical lines. The grey area indicates the measured level of the electronic noise background. Note that the ESA-Haystack observes a narrow spectral line.*

Despite these non-ideal conditions at the ISU campus the students have the following possibilities to observe and measure natural radio emission of astronomical and geophysical origin:

- with **ESA-Dresden (10 GHz)** we can observe the **Sun** and also the **Moon**. From the measured continuum fluxes the **surface temperatures** of these bodies can be deduced. For the Sun one obtains the temperature of the **chromosphere**. The variation of the lunar temperature during the month provides evidence for the **lunar surface dust layer**. Furthermore, measurements of the **sky noise** permit to ascertain the **atmospheric water content**.
- with **ESA-Haystack (1.4 GHz)** we can observe the emission of **atomic hydrogen gas** in the **Milky Way Galaxy**. From the emission line at 21cm wavelength one obtains the **rotation curve** and evidence for the enigmatic **Dark Matter**, the presence and shape of the **spiral arms**, and the **warping** of the gas disk.
- with **GENSO (437 and 144 MHz)** it might have been possible to observe and monitor the **solar corona**. Unfortunately, the high level of electronic pollution permits to barely detect the quiet corona. However, strong **solar eruptions** might still be captured.
- operations with **RadioJove (20 MHz)** to observe solar radio eruptions are no longer possible because of the ambient noise.
- At **very low frequencies (1…10 kHz)** radio emission from **lightning** can successfully be detected, monitored and analysed, which includes night-time **tweeks** from lightning more than 1000 km away, as well as **whistlers** waves that had travel through the plasmas of the Van Allen radiation belts.

At ISU, two lectures are given as introduction to radio astronomy, along with a hands-on workshop involving the ESA-Haystack telescope or data from ESA-Dresden. For the Individual Projects, usually three topics each are offered involving work with ESA-Dresden and ESA-Haystack telescopes, and the GENSO station, as well as one or two topics involving the VLF receiver.

# 7. Available On-line Resources

For each of the available radio installations Websites are available, which provide full explanations and instructions for operations and data analysis, and show sample results:

ESA-Dresden: http://www.astrophysik.uni-kiel.de/~koeppen/10GHz/
ESA-Dresden simulator:
http://www.astrophysik.uni-kiel.de/~koeppen/10GHz/applets/trainer/

ESA-Haystack : http://www.astrophysik.uni-kiel.de/~koeppen/Haystack/
ESA-Haystack simulator :
http://www.astrophysik.uni-kiel.de/~koeppen/Haystack/applet/trainer/
Results of the Illkirch Surveys of Galactic Hydrogen can be inspected interactively:
Data of first Survey : http://www.astrophysik.uni-kiel.de/~koeppen/ISGH/
Data of third Survey: http://www.astrophysik.uni-kiel.de/~koeppen/ISGH3/
Data of fifth Survey : http://www.astrophysik.uni-kiel.de/~koeppen/ISGH5/

GENSO: http://www.astrophysik.uni-kiel.de/~koeppen/GENSO/

RadioJove (2003-2009): http://www.astrophysik.uni-kiel.de/~koeppen/RJove/