Summary of the Results of the Radioastronomical Observations by the Students of the Course M2-UE7e

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Observing sessions

Two observing sessions, of 3 hours each, were held in the morning of 7 Dec 2011 and in the afternoon of 4 Jan 2012. In the first session, each of the three two-student teams had two runs of about 30 min. with each of the two telescopes. They observed the Sun with both telescopes, took an elevation profile of the sky background at 12.5 GHz, and obtained spectra of the HI 21 cm emission at various positions in the inner Galactic Plane in order to derive the Galactic rotation curve.

In the second session, two pairs spend about 2 hours with each telescope, observing the Moon on 12.5 GHz, along with a elevation profile of the sky background. On 1.42 GHz latitude profiles were taken at three galactic longitudes, in order to obtain cuts of a small data cube that would allow tracing out the spiral arms in 3D space. The data taken was subjected to a quick analysis using my Java software, and the results were shown to and discussed with the students.

Both sessions gave very good quality results. No interference was experienced on 1.42 GHz. The 12.5 GHz data were somewhat affected by strong winds moving the antenna.

Data reduction sessions

Following the observing, two sessions were held about the reduction and analysis of the data. In the first, the analysis of the sky noise profiles at 12.5 GHz was explained and done, followed by the analysis of the solar drift scans done with the same telescope. Nobody minded to stay much longer than the scheduled 2 hours.

The second session covered the reduction of the spectra at 1.42 GHz. The entire process from raw data to baseline-subtracted emission profiles, and the deduction of the rotational velocity was explained and done for a single galactic plane position. Again, everybody stayed beyond the scheduled 2 hours to complete the analysis.

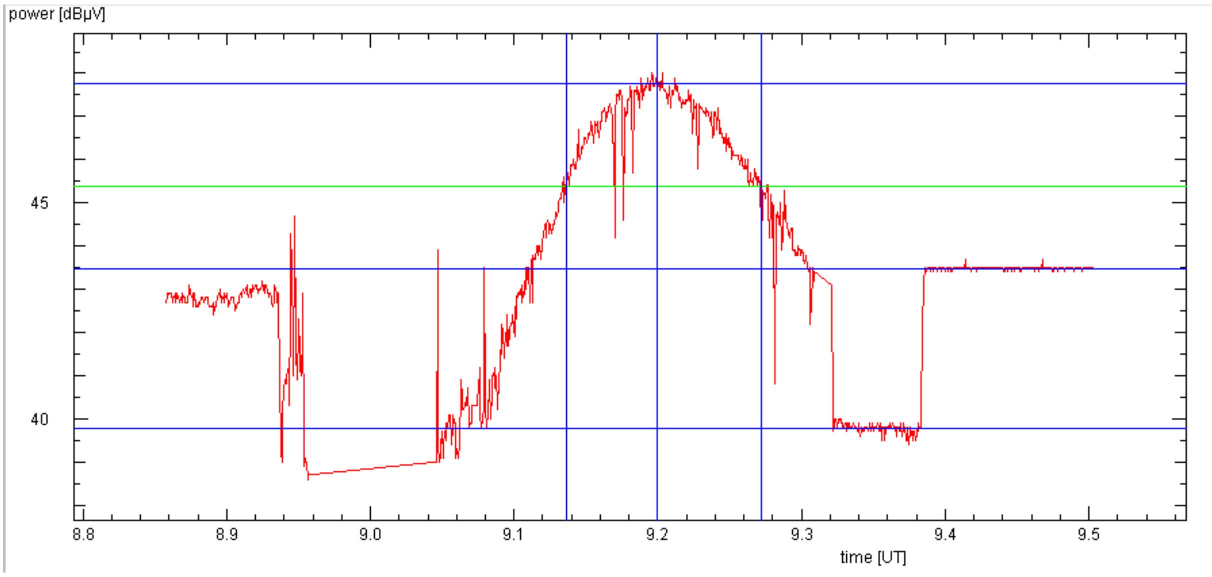
Solar observations on 12.5 and 1.42 GHz

With the ESA-Dresden telescope on 12.5 GHz, partial solar drift scans were taken of the sun by each team, giving these results:

Team	HPBW [°]	T_system [K]	T_antenna [K]	T_sun [K]
T+C	2.19	200	885	17039
JB+F	1.98	205	1116	17458
G+PA	1.98	209	996	15672
JB+F (4 Jan)	1.72	173	1065	12640

NB: The solar sky motion was not corrected for the actual solar declination, which would affect the HPBW. Also, for the solar surface temperature a solar angular diameter of 0.5° was assumed, instead of taking the actual value.

It is remarkable that all observations from the first session resulted in a abnormally large HPBW of the antenna, which would normally be 1.7°. Since all teams experienced strong jumps in the drift scan profile (shown below) which are signatures of rapid shaking of the antenna due to gusts of wind, it is likely that these perturbations also caused the overestimation of the HPBW.



The overestimated HPBW values result in an overestimation of the correction factor from antenna temperature of the sun to its surface temperature, and thus in surface temperatures substantially larger than expected from earlier observations.

The drift scan taken at the start of the second session shows a much better agreement with expectations, the temperature of the lower Transition Layer. The HPBW is close to its nominal value, and hence the solar surface temperature is as expected. On this day, the sky was covered with light clouds, and no strong wind was noticed.

Finally, we note the enhanced values of the system temperatures from the first session. They are measured by comparing the signal from the flux calibrator (the Holiday Inn building) with the empty sky. The sky had a complete cover by rather dark grey clouds, and some slight rain was observed. This would cause a higher sky background, which is confirmed by the atmospheric noise level measurements (next section).

The Sun was also observed on 1.42 GHz with the ESA-Haystack telescope. Each team performed a mapping of the region about the Sun, which gave the pointing offsets in azimuth and elevation for the telescope.

Team	Offset in AZ [°]	Offset in EL [°]
G+PA	-0.4	-0.9
T+C	-0.2	-0.7
JB+F	-0.6	0.7
T+PA (4 jan)	+0.6	+0.5

The pointing offsets show differences, larger than one should expect. Due to the short time available, this point was not explored more deeply, as it would not affect significantly the results. In the second session, the offsets determined by one team were used for all galactic observations.

Then, the solar flux was measured by direct pointing, and along a measurement of the empty sky at the same elevation as well as the wall of ISU library for the flux calibration, these results (assuming an HPBW=6°, taken from the solar mapping) were obtained:

Team	T_system [K]	T_antenna [K]	T_sun [K]
G+PA	347	1557	263167
T+C	297	1453	245481
JB+F	289	1164	196712

System temperatures around 300K are good agreement with measurements taken on the same day. The origin of the variation of T_system is not yet clear.

The derived solar temperatures are close to expectations, showing the value of the lower corona.

Solar fluxes and telescope efficiencies

From the antenna temperatures of the sun and the geometric cross section of the antenna one can derive the solar fluxes at the two frequencies

$$\text{Flux} = 2\, k_B\, T_{antenna} / A_{geom}$$

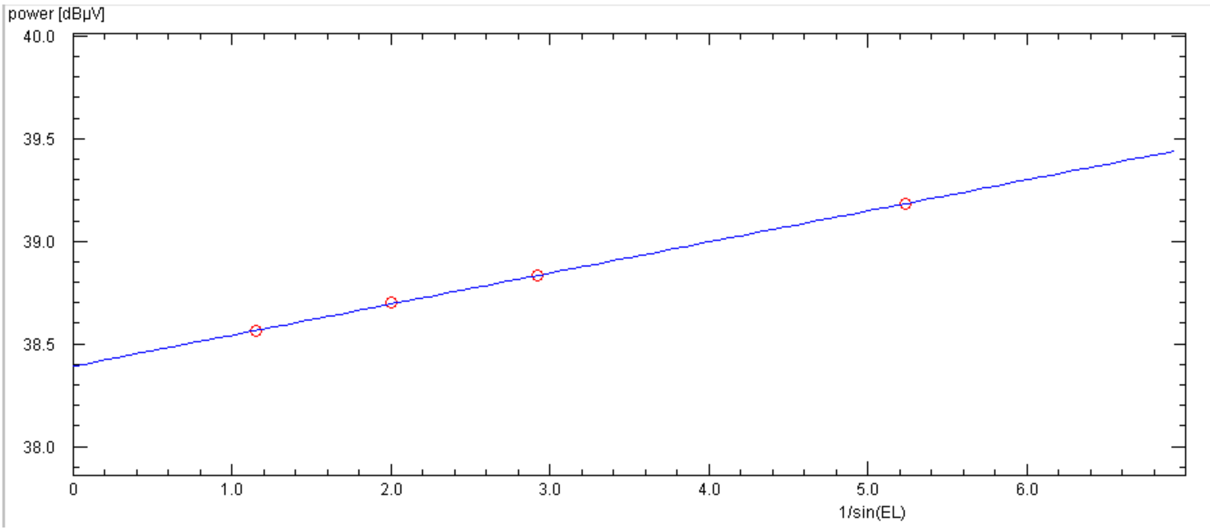
Comparison with the data from daily observations published by NOAA, the efficiencies of the telescopes can be determined $\eta = \text{Flux} / \text{Flux}_{NOAA}$:

Freq. [GHz]	Team	T_antenna [K]	Power [W]	Flux [SFU]	Efficiency
12.5	T+C	885	1.22 E-20	216	0.51
12.5	JB+F	1116	1.54 E-20	272	0.65
12.5	G+PA	996	1.37 E-20	243	0.58
8.8	NOAA (San Vito)	---	---	277	---
15.4	NOAA (San Vito)	---	---	539	---
1.42	G+PA	1557	2.15 E-20	103	0.80
1.42	T+C	1453	2.00 E-20	96	0.74
1.42	JB+F	1164	1.61 E-20	77	0.59
1.42	NOAA (San Vito)	---	---	120	---

All values obtained are reasonable and within what could be expected from such a simple approach.

Atmospheric noise on 12.5 GHz

Every team took measurements of the sky background signal at elevations of 10, 20, 30, and 60°. Linear Regression of these data, as a function of the abscissa 1/sin(elevation) permits to separate the constant contribution to the noise from the receiver (and the cosmic microwave background) from the elevation-dependent atmospheric noise:



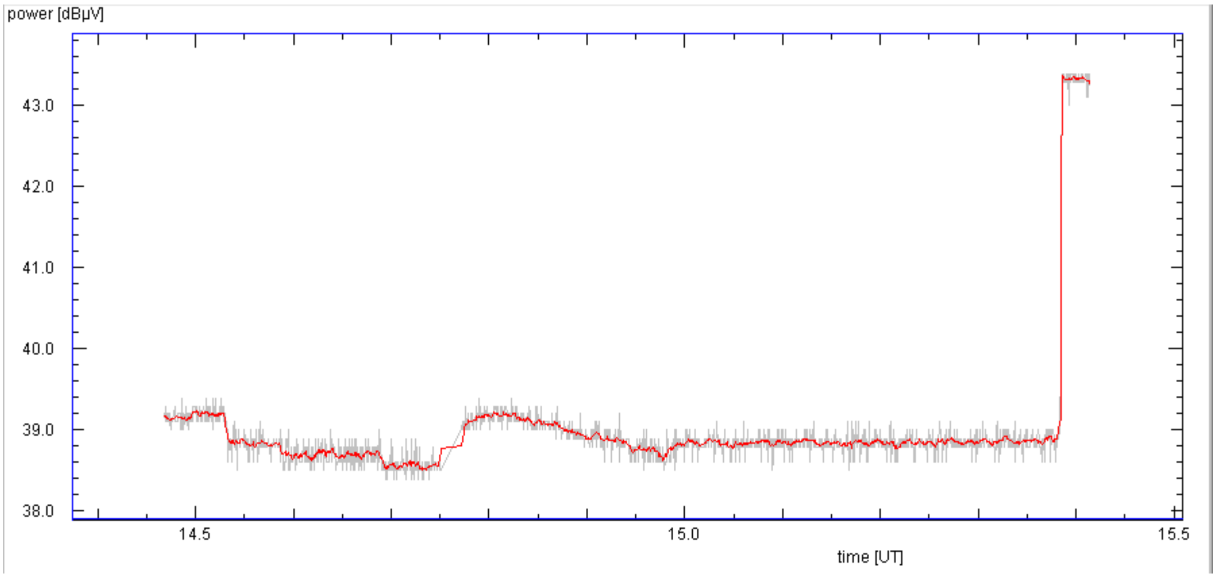
Team	RX noise level [dBµV]	Slope [dB]	Weather
JK (19 jun 2011)	+38.62	0.127	Blue skies
JK (15 nov 2011)	+39.08	0.166	Fair
T+C (7 dec 2011)	+38.34	0.455	Overcast+rainy *)
JB+F (7 dec 2011)	+38.71	0.367	Overcast+rainy *)
G+PA(7 dec 2011)	+38.64	0.346	Overcast+rainy
JB+F (4 jan 2012)	+38.39	0.151	Slight overcast
PA+T (4 jan 2012)	+38.72	0.132	Slight overcast
JK (25 jan 2012)	+38.52	0.128	Fair, some clouds

*) these teams noted that the noise level varied during observation at a fixed position. This would be caused by individual heavy clouds passing through the antenna beam.

These measurements show that the slope of the relation is well-correlated with the amount and thickness of clouds in the sky, i.e. the amount of water vapour. During the first session, the systematic decrease of the slope correlated well with the sky clearing up and becoming more stable.

Lunar observations on 12.5 GHz

During the second session the moon could be observed. Like for the Sun, a partial drift scan was done after the Moon had been found by carefully moving the telescope to the position of maximum signal. The figure below shows the lunar scan in the centre, which is preceded by an elevation profile of the sky background, and followed by the sky background and the flux calibration:



As the lunar signal is only 0.5 dB above the sky, and the fluctuations of the individual measurements are about 0.3 dB, this procedure is somewhat delicate. But after a few tries, the teams mastered the technique and obtained valid data. The deduced lunar surface temperatures are acceptable.

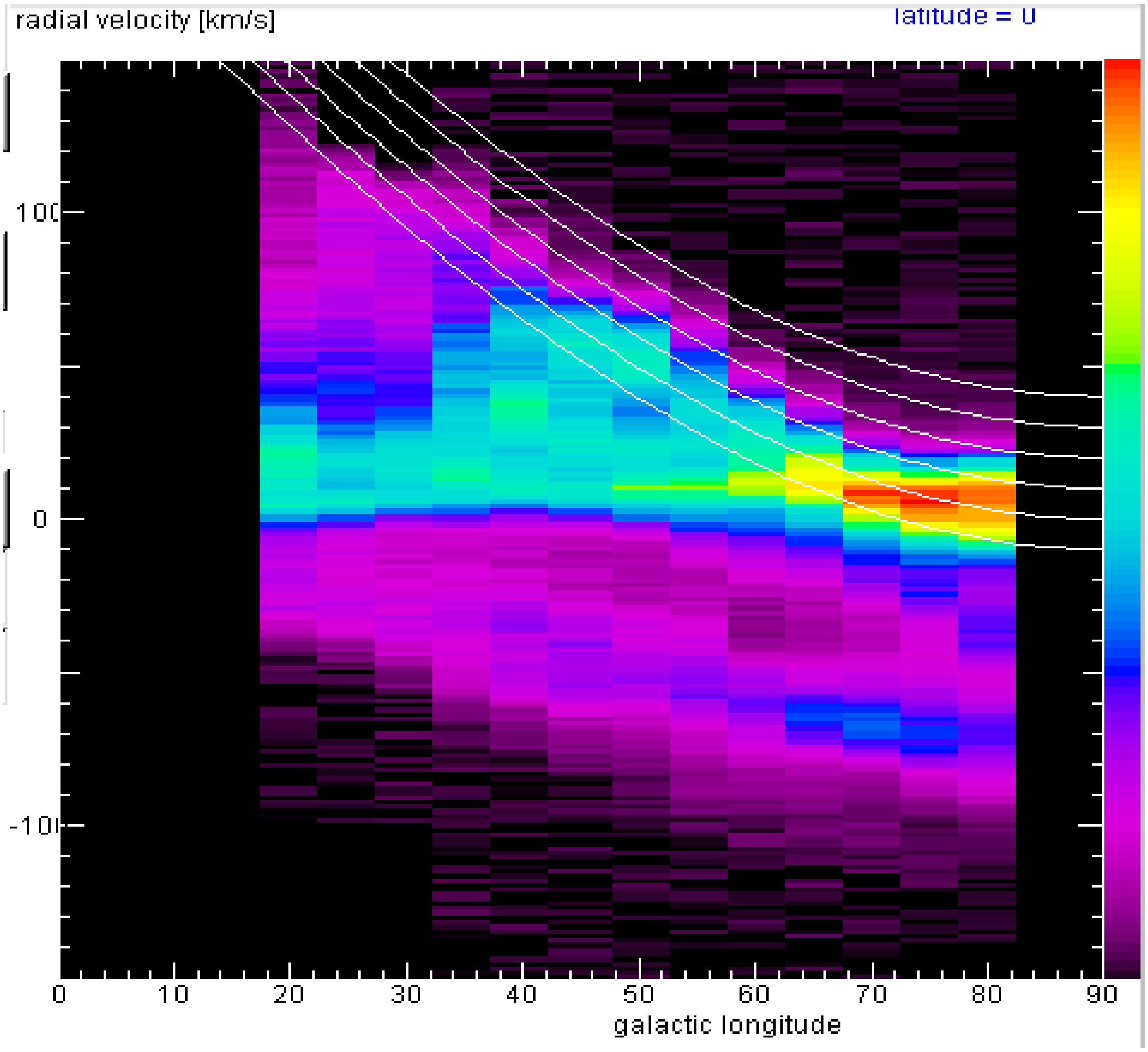
Team	T_system [K]	T_antenna [K]	T_moon [K]
JB+F	159	14	163
PA+T	158	16	188

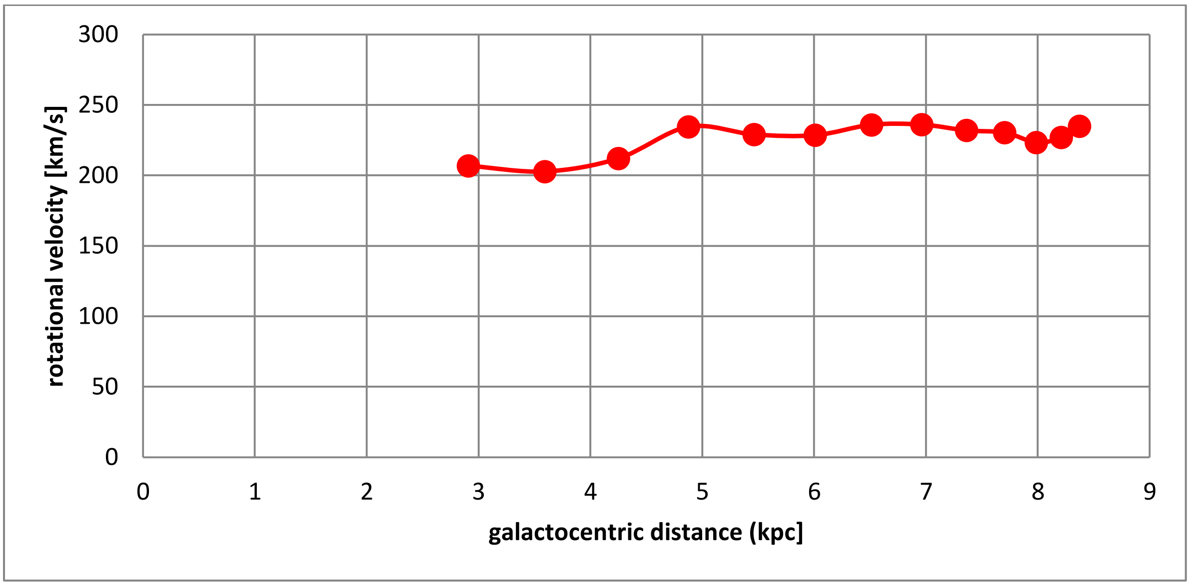
The system temperature found by both teams is rather low, normally one can expect 170 K for this telescope.

Galactic rotation curve (1.42 GHz)

In the first session, all three teams took spectral observations of Galactic Plane positions between galactic longitudes 0° and 90°. One example is shown below, as a false colour map of the brightness in the longitude-radial velocity plane. The strong emission from local HI gas at near-zero speed is seen, as well as a prominent outer spiral arm at about -70 km/s. Emission from the Milky Way inside the solar orbit is seen at positive radial velocities. This part can be used to derive the rotation curve: The five white curves indicate the loci for constant rotational velocities from 200 km/s (lowest curve) to 250 km/s.

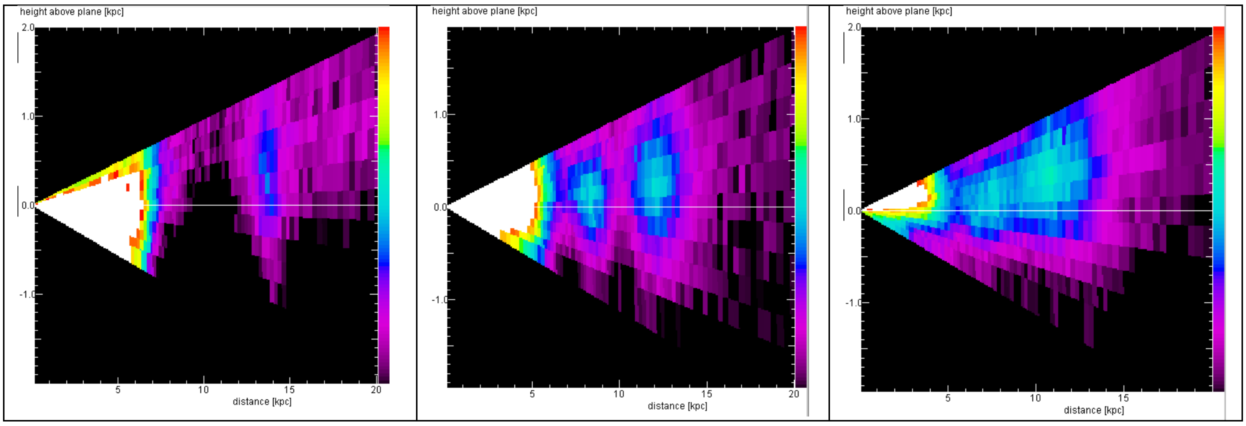
The students measured the highest radial velocities on the telescope's GUI during the observations, and some used these values to deduce the rotation curve. After the session, I processed their data and showed them that the false colour map below is proof that the data are consistent with a nearly-constant rotation curve:





Galactic warp and spiral arms (1.42 GHz)

During the second observing session, the students modified a batch file to have the telescope take vertical profiles of the HI emission at a number of galactic longitudes: l=70°, 80°, and 90°. The step in latitude was 1°, which gave a smooth view of the distribution of matter in the outer spiral arms with respect to the Galactic Plane:



The students were not required to perform the rather tedious data reduction and analysis. Instead this was done with my JAVA software, which also performed the de-projection into Cartesian maps. Apart from the strong local emission, two outer spiral arms can clearly be distinguished. While the up-bending of the outer disk is clearly evident at these longitudes, details also become apparent: at l=70° there is one arm at 14 kpc distance and 0.3 kpc above the Plane, and perhaps a fainter one at about 18 kpc and 1 kpc, at l=80° there are two bright arms at 8 and 12 kpc distance, at 90° they seem to be nearly fused into a broad one, with peak emission at 8 and 10 kpc distance.

With maps from intermediate longitudes one might well be able to construct the 3D arrangement of the arms ...