



Report

Cassiopeia A flux density measured with APRAXOS

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Cassiopeia A Flux Density Measured with APRAXOS

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Abstract

The aim of this work was to measure the radio flux of Cassiopeia A using the APRAXOS radio-telescope at the STS site in Zurich. Two observation modes, transit and ON-OFF, were applied. In order to prevent bad signal to noise ratios, the telescope was calibrated using the sun as a reference. In addition, the effective aperture of the APRAXOS telescope was determined with the Meteosat-7 weather satellite.

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1 Introduction

Cassiopeia A, the remnant of a supernova that exploded around the end of the 17th century, is actually a radio star, which means that the object is rather observable in the radio spectrum than in the visual spectrum of electromagnetic radiation. In fact, Cas A is one of the strongest astronomical radio sources in the sky. This makes it an ideal calibration source for professional radio astronomers. However, when observing Cas A in Zurich, the strong radio emissions are not that much an advantage, they are rather a condition that has to be met to get acceptable results. The reason for this lies in the noisy environment one has to deal with in Zurich: the radio-telescope APRAXOS of the Institute of Astronomy, ETHZ, lies in the midst of powerful, terrestrial radio sources. The positive point about Cas A is that its flux density is well known due to the fact that the source is often used for calibration purposes.

The calibration of the telescope was carried out by comparison of the source with the sun and not by using a noise generator. The latter calibration method would have led to a lower telescope sensitivity and would have therefore reduced the signal-to-noise ratio which is already low enough in Zurich.

2 Some Radio-Technical Terms and Formulas

This section is meant to introduce and, to some extent, try to explain the basic formulas that are used in this work.

2.1 Flux density, effective aperture

The concept of brightness, as known from the visible light spectrum, can also be applied to lower frequency ranges of electromagnetic radiation, hence, radio-waves. When describing radio emissions from the sky one may therefore use a brightness distribution B [$\text{Wm}^{-2}\text{Hz}^{-1}\text{sr}^{-1}$] which is a function of the direction in which one looks. Observing the sky with an antenna of normalized power pattern P_n will then let you measure a *flux density* of [1]

$$S = \int_{\text{source}} B(\theta, \phi) \cdot P_n(\theta, \phi) d\Omega \quad [\text{Wm}^{-2}\text{Hz}^{-1}].$$

The unit commonly used to express flux density is *Jansky* or *flux unit*¹ [Jy/fu], 1 Jy or 1 fu being equal to $10^{-26} \text{ Wm}^{-2}\text{Hz}^{-1}$. In the end, however, what the telescope measures is the power that has been induced by the incident radio signals. If the flux is almost constant over the observed bandwidth, this power calculates as [1]

¹Another unit used in this report is sfu (solar flux unit) which corresponds to 10^4 fu and is used for stronger sources, eg. the sun.

$$P = \frac{1}{2} SA_e \Delta\nu \quad [\text{W}], \quad (1)$$

where $\Delta\nu$ is the observed bandwidth and A_e is the *effective aperture* of the telescope. The factor 1/2 is necessary if random polarization is assumed. In practice, A_e is smaller than the physical aperture which is why an *antenna efficiency factor* η is introduced [1]:

$$A_e = A_{\text{phys}} \cdot \eta \quad ; \eta \text{ dimensionless}, \quad (2)$$

where $0 \leq \eta \leq 1$. Most radio-telescopes have values for η around 0.5. Many telescope relevant parameters are contained in η like, for instance, surface condition of the telescope parabola and focusing accuracy. In section 4, a way to find the antenna efficiency factor is shown and the appropriate value for the APRAXOS telescope in STS, Zurich, is calculated.

2.2 Antenna temperature

According to *Planck's Law*, a so called 'black body' radiates electromagnetic waves as a consequence of its finite temperature. For radio frequencies, where $h\nu \ll kT$ (ν : freq., h : Planck const., k : Boltzmann const., T : phys. Temperature of radiator), the *Rayleigh-Jeans approximation* of the black body radiation law may be used [1]:

$$\begin{aligned} B(\nu, T) &= \frac{2kT\nu^2}{c^2} \\ B(\lambda, T) &= \frac{2kT}{\lambda^2} \quad [\text{Wm}^{-2}\text{Hz}^{-1}\text{sr}^{-1}]. \end{aligned} \quad (3)$$

Introducing following relations [1]

$$\lambda^2 = A_e \cdot \Omega_A \quad \Omega_A \text{ is the pattern solid angle of the antenna} \quad (4)$$

$$S = B \cdot \Omega_A \quad (5)$$

into (3) yields a formula which brings flux density and temperature in correlation:

$$T_a = \frac{SA_e}{2k} \quad [\text{K}]. \quad (6)$$

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Equation (6) is the definition of the *antenna temperature* which contains not only the flux density but also the effective aperture and is thus dependent from the observing telescope. It is to be noted that the antenna temperature is proportional to the power P measured by the telescope.

3 Measuring Fluxes of Celestial Sources

This section discusses a few properties of the APRAXOS telescope and demonstrates the calibration procedure necessary for flux determination of weak sources. In section 3.5 the observation techniques used for the observations in this work are explained. In addition, the APRAXOS azimuth-HPBW is calculated in sec. 3.5.1.

For an extensive discussion of how radio-telescopes work, refer to *Kraus (Radioastronomy, ch. 6 [1])* or visit the web-site of the radioastronomy group of the ETHZ Institute of Astronomy [2].

3.1 Sensitivity range of the feed

The feed used for observations was ZH3 (Zylinderhorn 3 [2]), with a high sensitivity range from 1690 MHz to 1750 MHz. Since Cassiopeia A radiates in a wide range of frequencies and does therefore not require at first a specific receiver antenna, the choice fell upon ZH3 in order to optimize the Meteosat-7 observations (1691.0 MHz and 1694.5 MHz) which were led to determine the antenna efficiency factor (see sec. 4).

3.2 Receiver output

Following receiver parameters can be adjusted:

- DC offset
- Gain
- Frequency
- Bandwidth

Depending on the above parameters, a DC voltage between -5 V and +5 V was applied to the ADC device. Due to a "log-device" the output in volts is proportional to the logarithm of the power induced by the flux of the observed object. The logarithmic relation was confirmed in the calibrations by making a comparison between a dB attenuation and the respective output. The correlation should be linear, which was the case (table 1).

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Calibration Date	Bandwidth	R^2
02-04-21, 1115 UT	10MHz	0.9997
02-04-23, 0840 UT	10MHz	0.9993
02-04-24, 0920 UT	220kHz	0.9993
02-04-25, 0800 UT	220kHz	0.9981
02-04-26, 0855 UT	220kHz	0.9979
02-04-27, 1400 UT	220kHz	0.9992
02-04-30, 0940 UT	10MHz	1.0000

Table 1: Linear fits of dB against output plots showed fairly nice accordance with the data.

3.3 Mechanical deviation of the feed position from the focal point of the parabola

Due to old and/or soft materials used for the suspension of the feed, the measured antenna temperature might be lower than it should be. This effect is noticed especially when observing point-like sources such as Meteosat (sec. 4.3) and therefore should be corrected. However, according to [3], the position of Meteosat in the sky might vary for angles as high as 1 deg, which is why – even after an alignment correction of the telescope – one can not conclusively say how big the mechanical deviations are.

3.4 Calibration of the telescope

A calibration has to be done in order to be able to translate the difference between the measurement of the observed source and the cold sky² into a flux density. This is achieved by comparing that difference to another difference, namely the one between a calibration source of well known flux density and the cold sky. In addition, the *system temperature*, resulting from the intrinsic noise of the radio receiver, and the *system variance* are determined. These two values are important because they give an idea about the reliability of a measurement. In figure 1 a plot of a calibration using the sun is shown. A calibration as the one explained in this section has to be made before or after every observation of an object, since many parameters relevant for the calibration may change in rather short periods of time.

The calibration process consists of several steps:

- Measurement of the cold sky (system temp. + sky temp).
- Measurement of the calibration source, eg. the sun, Cas A, etc. (system temp. + sky temp. + calibr. source temp).
- Attenuation of the calibration source by known quantities.

The last steps ensures the possibility to translate the output of the receiver (Volts) into a dB-scale. Linear interpolation makes it possible to find the dB

²The antenna temperature of the cold sky in Zurich is ~ 10 K. For our purposes, this value was assumed constant over most of the sky, away from the horizon.

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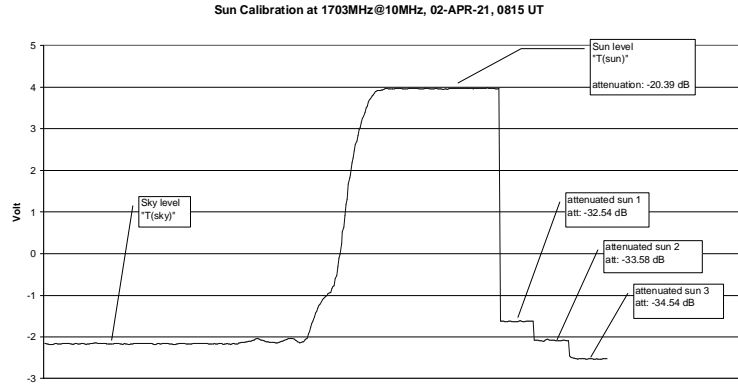


Figure 1: Example plot of a calibration using the sun.

level of the sky (see fig. 2) and, through taking the dB-difference, calculating the Y-factor of the calibration source:

$$\frac{T_{\text{sun}} + T_{\text{sys}} + T_{\text{sky}}}{T_{\text{sys}} + T_{\text{sky}}} = Y_{\text{sun}} = 10^{(T_{\text{sun}+\text{sky}+\text{sys}} [\text{dB}] - T_{\text{sky}+\text{sys}} [\text{dB}]) / 10} \quad (7)$$

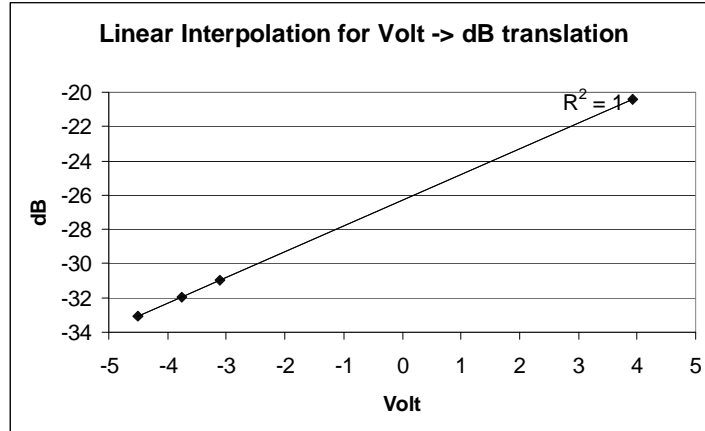


Figure 2: Translating the Volt-scale into a dB-scale through linear interpolation

3.4.1 System temperature

Using eqn. 7 we get for the system temperature

$$T_{\text{sys}} = \frac{T_{\text{sun}}}{Y_{\text{sun}} - 1} - T_{\text{sky}} \quad (8)$$

3 Measuring Fluxes of Celestial Sources

and introduction of eqn. 6 yields

$$T_{\text{sys}} = \frac{S_{\text{sun}} \cdot A_e}{2k(Y_{\text{sun}} - 1)} - T_{\text{sky}} \quad [\text{K}], \quad (9)$$

where S_{sun} is the flux density of the calibration source. In this work calibration was always performed using the sun. Solar flux densities were taken from regularly updated internet data bases [4]. An antenna efficiency of $\eta = 0.5$ was assumed and the phys. aperture was 9.82 m^2 (5m-dish).

3.4.2 System variance, radiometer equation

So far, the Volt scale has been transformed into a dB scale. By transforming – in a second step – the dB scale into a linear scale, we can now calculate the variance of the cold sky (σ). Since the cold sky was assumed to have a constant flux with respect to short periods, the obtained variance is called the **system variance** σ_{sys} . Following formula gives its value in flux units:

$$\sigma_{\text{sys}} = \frac{S_{\text{sun}}[\text{fu}] \cdot \sigma}{x_{\text{sun}} - x_{\text{sky}}} \quad [\text{fu}] \quad , \quad (10)$$

where x_{sun} and x_{sky} are the linear values of the sun and the sky respectively. Equation 10 is illustrated by fig. 3.

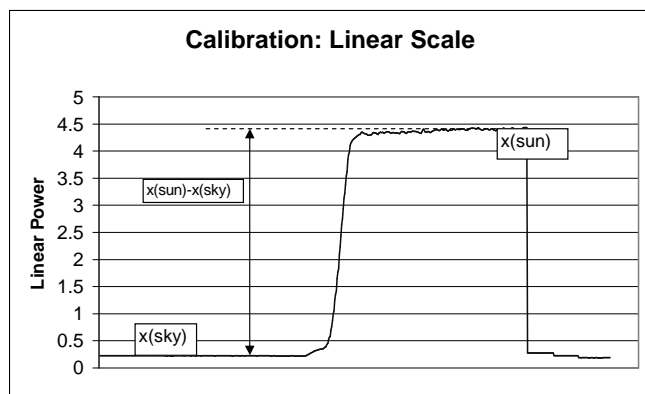


Figure 3: The difference sky to sun is used to find the value of the variance in [fu].

Two more receiver parameters are introduced:

sample time Period [ms] between the output of two data points

3 Measuring Fluxes of Celestial Sources

signal handling Indicates whether the signal should be integrated over the sample time, or whether a smoothed mean, according to the equation below should be recorded.

$$x_n = \frac{\sum_{i=1}^N x_{n-i} + x_n^{\text{input}}}{N + 1} \quad , \quad (11)$$

x_n being the newest data point recorded.

Assuming that the variance has complete random nature, statistical laws will predict that the variance should decrease with increasing integration time. This decrease is described by the *radiometer equation*:

$$\sigma_{\text{sys}} \sim \frac{1}{\sqrt{T \cdot \Delta\nu}} \quad , \quad (12)$$

where T is the integration time and $\Delta\nu$ is the observed bandwidth. Appropriate measurements have confirmed eqn. 12 only in part and there only for very short integration times, as shown in figure 4.

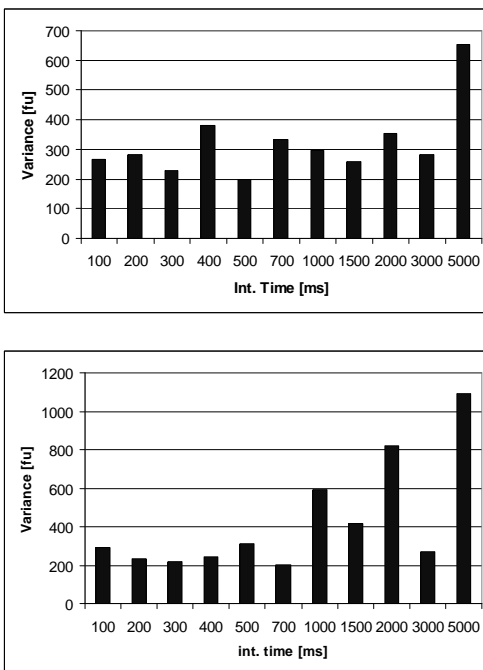


Figure 4: Variance plotted against integration time. Equation (12) is not confirmed.

A possible explanation of the divergence between the theoretical expectation and the actual observation could lie in the interferences from the telescope environment which are not only high in intensity but probably also of no complete random nature, contrarily to the assumptions of eqn. (12).

We have chosen the smoothed mean method for our observations, usually with a sample time of 3000 ms.

3 Measuring Fluxes of Celestial Sources

Reliability of an observation To have control over the quality of an observation, below listed parameters are to be indicated for every observation and should, if possible, meet the respective conditions imposed on them.

- T_{sys} : System temperature should be below 300 K.
- σ_{sys} : The ratio between the source flux density and the system variance should be around 10.

3.5 Observation Techniques

3.5.1 Transit observation

In order to increase the sensitivity of the telescope, in transit observation mode the telescope is pointed to a specific direction where, according to ephemeris calculation software [6], the source is due to pass at a specific point in time. For comparison purposes the time is always indicated in universal time [UT]. Figures 5 and 6 show a transit of Cassiopeia A and the sun respectively.

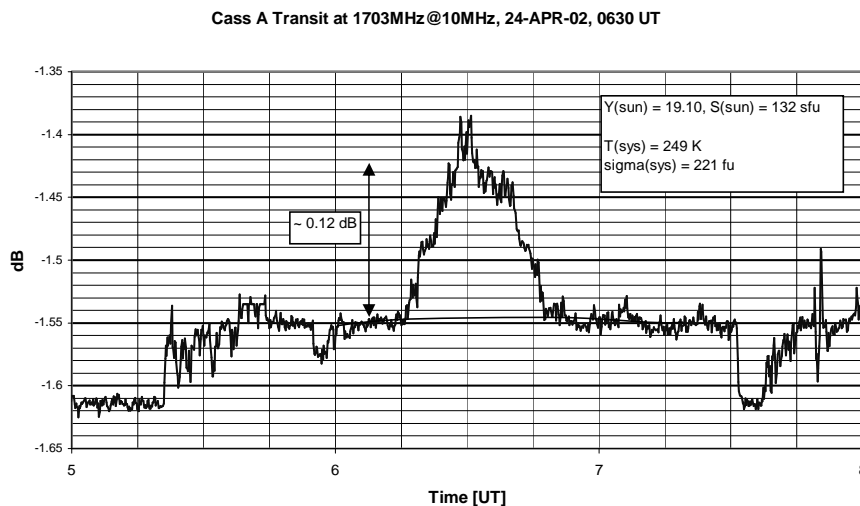


Figure 5: Example of a Cas A transit.

The Cas A flux can be calculated using eqn.'s 7 and 6:

$$\begin{aligned}
 \frac{T_{Cas} + T_{Sky} + T_{Sys}}{T_{Sky} + T_{Sys}} &= Y_{Cas} \\
 \Rightarrow T_{Cas} &= (Y_{Cas} - 1)(T_{Sys} + T_{Sky}) \\
 \Rightarrow \frac{S_{Cas} A_e}{2k} &= (Y_{Cas} - 1) \cdot \left(\frac{S_{Sun} A_e}{(Y_{Sun} - 1) 2k} \right) \\
 S_{Cas} &= \frac{Y_{Cas} - 1}{Y_{Sun} - 1} S_{Sun} \quad . \quad (13)
 \end{aligned}$$

3 Measuring Fluxes of Celestial Sources

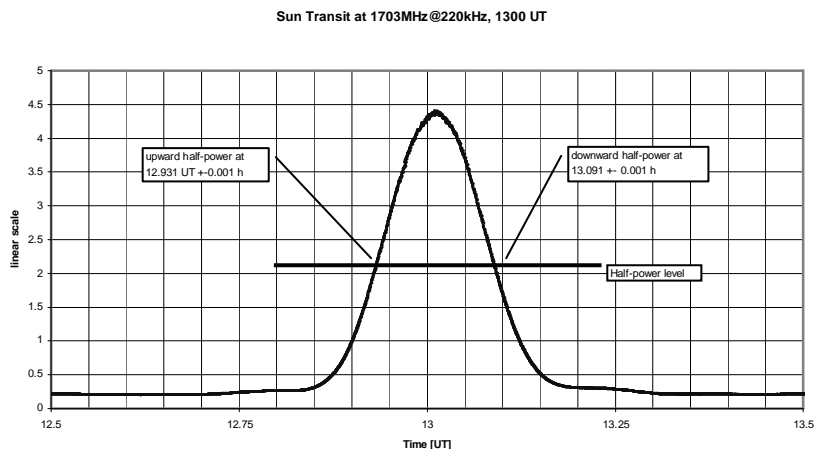


Figure 6: Transit of the sun at almost the maximum of its height above horizon.

The solar transit has been used to calculate the azimuth HPBW of the APRAXOS telescope. Since fig. 6 is scaled linearly one recognizes the upward half-power time at 12.931 UT and the downward half-power time at 13.091 UT. This yields a period of 576 ± 7 sec. Since the main lobe axis was directed to the same point in the sky (transit), the angle between halfpower points can be calculated using the siderial rotation velocity of the earth, $\omega_{\text{earth}} = 0.0048^\circ \text{ s}^{-1}$, and the declination of the sun at the time of observation, $\delta = 12.82$ deg:

$$\text{HPBW} = 576 \pm 7 \text{ s} \cdot \omega_{\text{earth}} \cdot \cos \delta = 2.70 \pm 0.03^\circ \quad . \quad (14)$$

The above indicated error is probably too small, since inaccuracies concerning the measurement of the solar induced power were ignored and the sun is not a point-like source.

3.5.2 ON-OFF observation

While basically following the sun, in ON-OFF observation mode the telescope is continuously pointed at the source for a certain period of time and then again off the source, yet still staying in the near background neighbourhood. The duration in which the telescope remains in one of above positions (either ON or OFF the source) and the angle in which it is pointed off the source are the parameters of this mode of observation. Figure 7 shows an ON-OFF observation of Cas A. As the antenna follows the source, in in ON-OFF mode the changes in the background can be seen quite clearly.

As can be seen in fig. 7, the actual difference between the background and the source increases with time as the radio star moves forth on its path towards the horizon. This may be caused by reflections or radiating objects near the horizon. To get the Y-factor of Cas A, only the smallest value of the background-CasA difference should be used.

4 Finding the Effective Aperture Using Meteosat

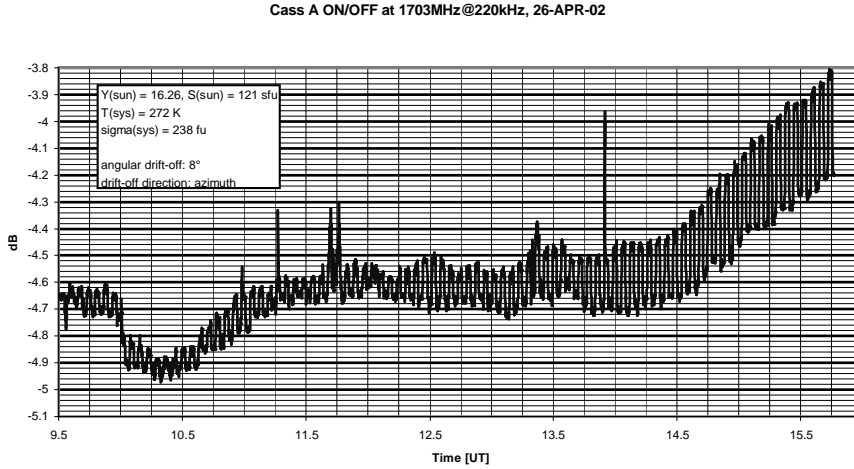


Figure 7: Example of a Cas A ON-OFF observation.

4 Finding the Effective Aperture Using Meteosat

When observing a radio source of known power flux density one has the opportunity to find the antenna efficiency factor (see sec. 2) of the observing telescope. This task is performed by

1. calibrating the *receiver* using a signal generator.
2. measuring the *telescope* response to the source.
3. comparing the measured source response with the known/calculated response.

As a source of known power flux density (PFD) at STS in Zurich we have used the geostationary weather satellite Meteosat-7. The advantages of Meteosat are its fixed position above Zurich and its high power output. Section 4.1 shows the calculation of the Meteosat-7 PFD in STS Zurich, sec. 4.2 and 4.3 deal with issues like exact satellite position and receiver bandwidth, while sec. 4.4 shows the calibration procedure which is very similar to the calibration procedure explained in sec. 3.4, and shows the efficiency factor for the APRAXOS telescope.

4.1 PFD of Meteosat-7 in STS-Zurich

Table 2 shows the data necessary for the PFD calculation:

Using a spherical coordinate system with its origin in the center of the earth and its ($\phi = 0, \vartheta = 0$)-axis through the Meteosat-7 spacecraft, we get for the distance between Meteosat and STS:

4 Finding the Effective Aperture Using Meteosat

Meteosat-7		var.	STS-Zurich		var.
Longitude	0 deg		Longitude	8°33.1 deg E	ϑ_{ZH}
Lattitude	0 deg		Lattitude	47°22.7 deg N	ϕ_{ZH}
Distance to center of earth	$42.170 \cdot 10^6$ m	R_{MET}	Altitude	543.306 m	h_{ZH}
Effective irradiated power	23.25 dBW	EIRP	Sea-level	$6.371 \cdot 10^6$ m	R_{earth}
losses					
atmospheric	-0.15 dB	Data from EUMETSAT [3] and GPS devices at the telescope site			
Roll-off	-0.25 dB				
Polarization	~1 %				

Table 2: Data used for Meteosat-7 PFD calculation.

$$D = \sqrt{(R_{MET} - R \cos \vartheta_{ZH} \cos \phi_{ZH})^2 + (R \cos \vartheta_{ZH} \sin \phi_{ZH})^2 + (R \sin \vartheta_{ZH})^2}, \quad (15)$$

where $R = R_{earth} + h_{ZH}$ ³. The PFD of Meteosat-7 at STS in Zurich therefore is:

$$S_{MET \text{ in } ZH} = \frac{\text{EIRP} - \overbrace{0.15 \text{ dB}}^{\text{atm. losses}} - \overbrace{0.25 \text{ dB}}^{\text{roll-off losses}}}{4\pi D^2} \cdot \overbrace{\cos^2 \vartheta_{ZH}}^{\text{polarization}} = 1.030 \text{ Wm}^{-2}. \quad (16)$$

4.2 Meteosat-7 signal bandwidth

In figure 8 the Meteosat-7 signal strengths are compared for different receiver bandwidth settings. Although the figure suggests a maximum for 6 kHz bandwidth, we have chosen to use 30 kHz bandwidth in order to get the complete signal band.

4.3 Meteosat-7 position in the sky

As mentioned in sec. 3.3, the telescope feed might be not exactly in the focal point of the parabola. In addition to this, according to EUMETSAT, the position of the satellite can vary for angles up to 1 deg in azimuth and elevation. In order to get a more accurate PFD measurement, a signal maximum was searched around the programmed satellite position. Figure 9 shows the result.

³The radius of the geostationary orbit can be calculated by

$$R_{MET} = \left(\frac{G \cdot M_E}{\omega^2} \right)^{1/3},$$

with G gravitational const., M_E mass of earth and ω sidereal rotation velocity of the earth

4 Finding the Effective Aperture Using Meteosat

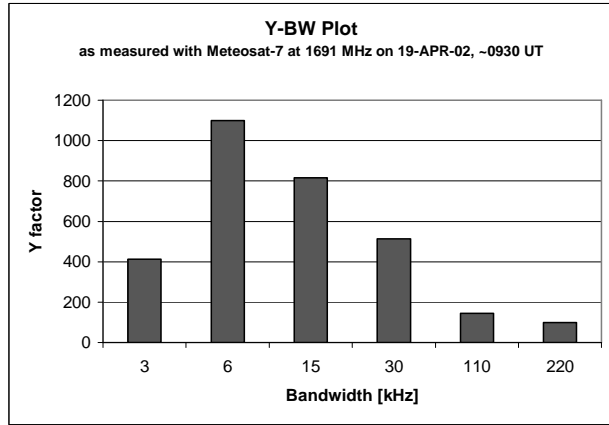
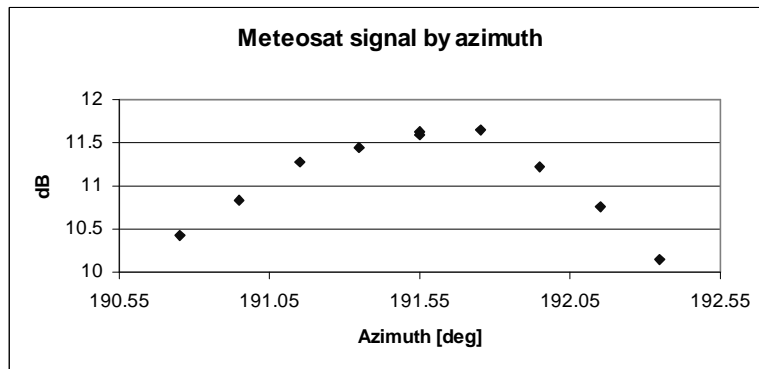
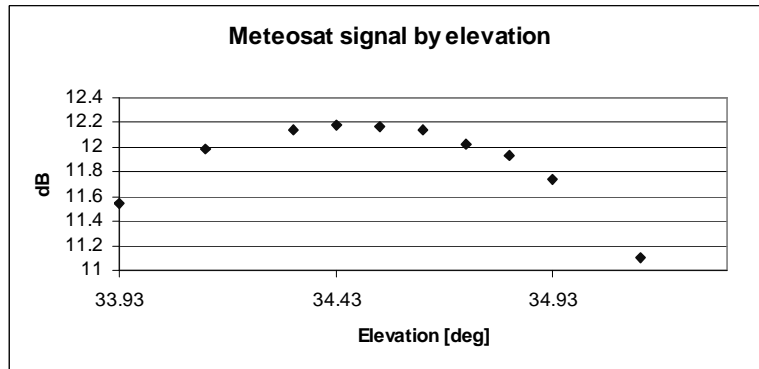


Figure 8: Meteosat signal strength for different receiver bandwidths.



	programmed pos.	pos. used for PFD meas.
Az	191.55°	191.55°
El	34.93°	34.43°

Figure 9: The search for the signal maximum was performed keeping either azimuth or elevation constant (Az=191.55°, El=34.93°) while changing the other coordinate.

4 Finding the Effective Aperture Using Meteosat

4.4 Calibration with a signal generator (SG) and calculation of η

Figure 10 shows a plot of a Meteosat observation with a calibration following right afterwards.

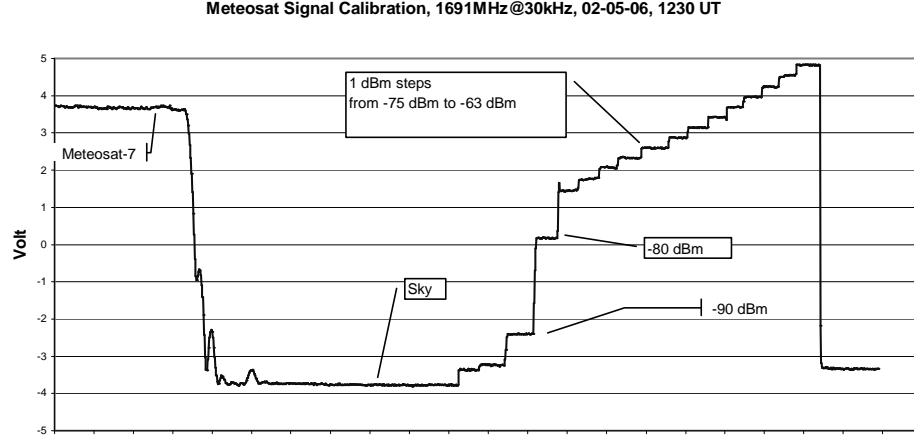


Figure 10: The left side of the plot shows a Meteosat obs. followed by a sky obs. The 'stairway' to the right was used for calibration.

The calibration goes very similar as the one with the sun and the complete procedure to find the antenna efficiency η can be summarized as follows:

- Observation of Meteosat.
- Observation of the sky.
- Connection of a signal generator to the receiver.
- Measuring receiver output for different signal strengths.
- Finding the difference Meteosat to sky by interpolation.
- Calculating η .

In figure 11 a plot of the interpolation is given. Through that plot, to every receiver output (Volt) the correspondent SG-power in dBm can be seen. Considering the signal loss in the transmission line from the SG to the receiver, which is -35 dB, one can calculate the response to Meteosat:

$$\begin{aligned}
 P_{\text{MET}} + P_{\text{sky}} + P_{\text{sys}} &= -102.2 \text{ dBm} = 6.0256 \cdot 10^{-14} \text{ W} \\
 P_{\text{sky}} + P_{\text{sys}} &= -129.3 \text{ dBm} = 1.1749 \cdot 10^{-16} \text{ W} \\
 \Rightarrow P_{\text{MET}} &= 6.0139 \cdot 10^{-14} \text{ W} \tag{17}
 \end{aligned}$$

4 Finding the Effective Aperture Using Meteosat

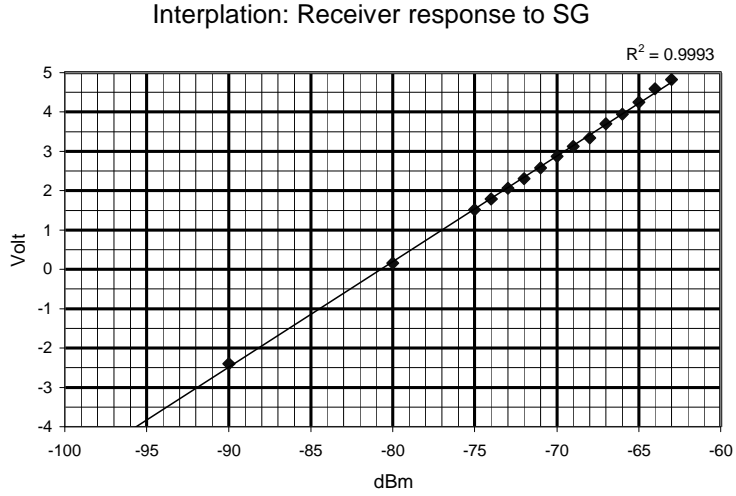


Figure 11: Receiver output plotted against SG output.

Using equations (1) (with power flux density instead of flux density) and (2), we get

$$\begin{aligned}
 P_{\text{MET}} &= S_{\text{MET}} \cdot A_e = S_{\text{MET}} \cdot A_{\text{phys}} \cdot \eta \\
 \Rightarrow \eta &= \frac{P_{\text{MET}}}{S_{\text{MET}} \cdot A_{\text{phys}}} \quad (18)
 \end{aligned}$$

For a 5m dish, as is the case for APRAXOS in STS Zurich, $A_{\text{phys}} = \pi(5 \text{ m}/2)^2 = 9.82 \text{ m}^2$. Inserting the values from 16 and 17, the antenna efficiency factor turns out to be

$$\eta = 0.59 \pm 0.015 \quad . \quad (19)$$

Error The error will mainly come from

- error in reading from the power interpolation plot (fig. 11) and
- inaccuracies in the PFD of Meteosat at the APRAXOS site.

In order to have an idea on the error for η , we have estimated the deviations of the Meteosat signals as $\pm 0.1 \text{ dB}$ and the error in reading as $\pm 0.2 \text{ dBm}$. Evaluating these errors and adding them in quadrature yields an **error of ± 0.015 for η** .

5 Cassiopeia A Flux Density

After the Calibration process has been explained in sec. 3, we can now proceed to the observations held to find the flux density of Cassiopeia A, probably a super-nova remnant and one of the strongest astronomical radio sources in the sky besides the sun.

5.1 Tabulated Cas A flux density

Since Cas A itself is used as a calibration source by radio astronomy professionals, the value and the temporal development of its flux density are very well known. According to [5], following formula can be used to calculate the Cas A flux density:

$$S_{\text{Cas A}} = 10^{5.745 - 0.77 \cdot \log \nu} \cdot \underbrace{(0.97 - 0.30 \cdot \log(\nu/1000)) \cdot (y - 1980)}_{\text{secular decrease of Cas A FD}} \text{ [fu]}, \quad (20)$$

where ν is the frequency of interest [MHz] and y is the time of observation (in decimal years). Figure 12 is a plot of the Cas A flux, showing its dependance in frequency and time.

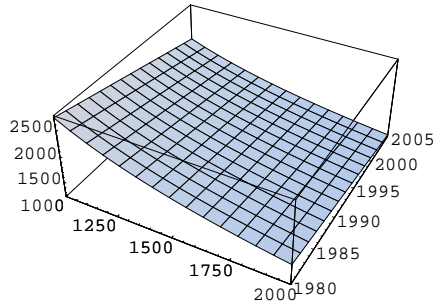


Figure 12: Cas A flux in Jy (vertical axis) depending on frequency in MHz (front axis) and time in years (side axis) [5].

As the reference time for our observations we took May 1st, 2002, which corresponds to $y = 2002.412$. According to eqn. 20, the flux density of Cas A at 1703 MHz⁴ therefore should be

$$S_{\text{Cas A}} = 1442 \text{ fu} \quad .$$

⁴This frequency was the only one in the range of the ZH3 feed which was quiet enough, also in its ± 5 MHz neighbourhood.

5.2 Measured Cas A flux density

The observations of Cas A were held as follows:

- Transit mode at 1702/1703 MHz and 10 MHz bandwidth.
- Transit mode at 1703 MHz and 220 kHz bandwidth.
- ON-OFF mode at 1703 MHz and 10 MHz bandwidth.
- ON-OFF mode at 1703 MHz and 220 kHz bandwidth.

Cas A can be regarded as a circumpolar object. An observation of Cas A renders difficult since the STS tower is located to the north of the APRAXOS telescope and the freedom of movement of the telescope is therefore restricted. Considering the spherical area where the telescope can move freely, and the fact that a maximum angular distance from the observation point to the horizon is desirable, showed that the ideal point in the path of Cas A that was accessible by the telescope was at ~ 0600 UT and ~ 1000 UT, where the first point lied to the east of the tower and the second one was to the west of it. The later point turned out to yield less reliable results, maybe because of a cell-phone antenna in the wider view-field of the telescope. Table 3 summarizes the obtained data from selected observations. The data was found as indicated in sec. 3. From tab. 3 one recognizes that the observations at 10 MHz bandwidth seem less reliable and less stable, which is probably due to the increased probability of catching interferences (see also sec. 3.4.2, *Allen variance*).

BW=10 MHz							
Transit				ON-OFF			
Date	T_{sys}	σ_{sys}	$S_{\text{Cas A}}$	Starting date	T_{sys}	σ_{sys}	$S_{\text{Cas A}}$
*02-04-21; 0630 UT	223 K	515 fu	1346 fu	02-04-30; 0950 UT	257 K	149 fu	1472 fu
*02-04-22; 0630 UT	242 K	426 fu	1712 fu				
*02-04-23; 0630 UT	215 K	782 fu	1517 fu				
02-04-24; 0630 UT	249 K	221 fu	2188 fu				
BW=220 kHz							
Transit				ON-OFF			
Date	T_{sys}	σ_{sys}	$S_{\text{Cas A}}$	Starting date	T_{sys}	σ_{sys}	$S_{\text{Cas A}}$
02-04-25; 0630 UT	244 K	389 fu	1535 fu	02-04-25; 1000 UT	244 K	389 fu	1754 fu
02-04-27; 0630 UT	236 K	296 fu	1381 fu	02-04-26; 0930 UT	272 K	238 fu	1557 fu
02-04-28; 0630 UT	236 K	296 fu	1657 fu				
02-04-28; 1030 UT	236 K	296 fu	1381 fu				
02-04-29; 0600 UT	251 K	230 fu	1104 fu				
02-04-30; 0600 UT	261 K	271 fu	1674 fu				

Table 3: Values resulting from transit observations at 1703 MHz (except for *: 1702 MHz).

The fluxes received in transit mode with 220 kHz BW were taken to calculate a weighted mean, taking into account that low system variances increase the reliability of a measurement. The mean value was calculated by weighting the fluxes inversely proportional to the system variance of the respective observation:

5 Cassiopeia A Flux Density

$$\begin{aligned} \text{weighting factor: } w_i &= \frac{\frac{1}{\sigma_i}}{\sum_j \frac{1}{\sigma_j}} \rightarrow \sum_j w_j = 1 \\ \text{weighted mean } \bar{S} &= \sum_i w_i \cdot S_i \end{aligned} \quad (21)$$

where σ_i and S_i are the variance and the measured flux of the i^{th} observation. Using (21) yields a Cas A flux of

$$S_{\text{Cas A}} = 1439 \pm 100 \text{ fu} \quad ,$$

at 1703 MHz and 220 kHz BW. The good accordance with the tabulated flux of 1442 fu is probably more due to chance than to exact measurement. The error limit has been set empirically by comparing the variances with the appropriate transit plots. Since the Y-factor is determined 'by the eye', greater systematic mistakes (such as a shift caused by an intruding signal) can be prevented.

Figure 13 shows a normalized superposition of 5 Cas A transits, all recorded with a sample time of 3000 ms. The plot reveals that the background level behind Cas A (with respect to its movement in the sky) is lower than in front of it. Since the antenna was pointed to the same direction of the sky throughout the source transit, the behavior of the background must be a result of either reflections of other moving sources (eg. the sun) or actual changes in the galactic background radiation, according to a radio intensity contour-map in *Kraus* [1] at 250 MHz. Cas A lies in a point in the sky where there is a significant brightness gradient.

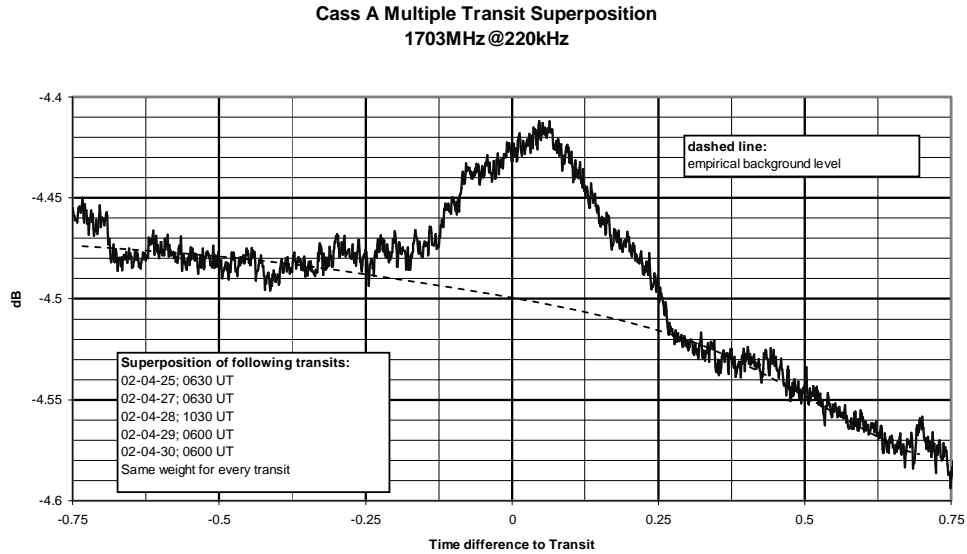


Figure 13: Five selected Cas A transits were superposed to get this plot. Horizontal axis is in decimal hours.

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