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Observation of Cygnus A with a 5 m Radio-Telescope

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Abstract. During the three weeks at the institute Cygnus A has been observed with a 5 m radio-telescope located in Zürich. After finding quiet frequencies and positions, Cygnus A was measured at three frequencies: 1191 MHz, 1280 MHz and 1374 MHz. Finally the results were evaluated and compared to theoretical data.

Key words. Radioactive galaxies, nonthermal radiation, antenna temperature, system temperature, drift

1. Cygnus A

Cygnus A was the first hyper-active galaxy discovered, and it remains by far the closest of the ultra-luminous radio galaxies. This source is at a distance of 170 Mpc (for a Hubble constant of $100 \text{ km s}^{-1} \text{ Mpc}^{-1}$). As such, Cygnus A has played a fundamental role in the study of virtually all aspects of extreme activity in galaxies. These are galaxies with an active nucleus, a compact central region from which we observe substantial radiation that is not the light of stars or emission from the gas heated by them. Active nuclei emit strongly over the whole electromagnetic spectrum, including the radio, X-ray, and γ -ray regions where most galaxies hardly radiate at all. Many have luminosities exceeding $10^{12} L_{\odot}$ and are bright enough to be seen most of the way across the observable universe. After optical identification, Cygnus A was thought to be a collision of two galaxies. This was shown to be incorrect, since the radio emission is much more extended than the optical image. Cygnus A consists of two spherical regions, each of diameter 20 kpc. Within each of the radio lobes are high-brightness compact regions, so called *hot spots*; these were first found in the 1970s. As first pointed out by Hargrave and Ryle (1974), the radiative lifetimes of the relativistic electrons in these hot spots ($\approx \text{few} \cdot 10^4$ years) are less than the light travel time from the nucleus to the hot spot ($\approx 1.5 \cdot 10^5$ years, for a Hubble constant of $100 \text{ km s}^{-1} \text{ Mpc}^{-1}$), hence requiring continuous injection of a population of relativistic electrons at the hot spots. This conclusion led to the 'beam' or 'jet' model for powering double radio sources. I briefly summarize the basics of this model, which is illustrated in Fig. 1.

The radio core corresponds to the 'central engine' - the ultimate source of energy responsible for the double radio structures. The core generates a tremendous amount

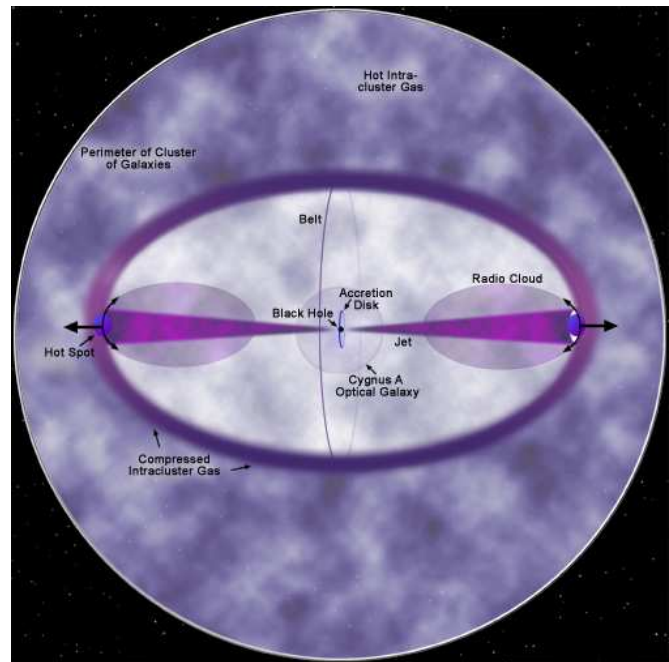


Fig. 1. Illustration of Cygnus A including the jet model

of energy, $\gg 10^{45} \text{ ergs}^{-1}$ in a very small volume ($\ll 1 \text{ pc}$ radius). Its power source is probably the energy released by gas falling into a black hole. Some of this energy can be released in the form of highly collimated, supersonic, and probably relativistic, outflows of plasma and magnetic field - the radio 'jets'. The jets propagate relatively unhindered until they terminate in a strong shock on impact with the external medium. At this point the jets convert some, perhaps most, of their bulk energy into relativistic particles (through first order Fermi acceleration), and magnetic fields (through simple shock compression, or more complex dynamo processes in the turbulent post-shock flow). This post-jet shock fluid emits copious

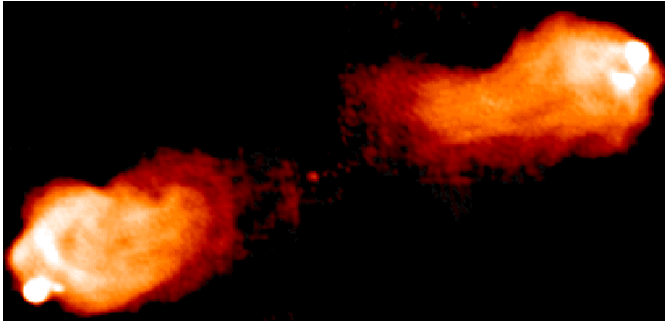


Fig. 2. A greyscale representation of the image of Cygnus A at 5 GHz made with the VLA

radio synchrotron radiation resulting in the high surface brightness radio 'hot spots'. The high pressure shocked jet material then expands out of the hot spot transversely inflating a synchrotron emitting 'cavity' in the ambient medium of waste-jet material - the radio 'lobe'. A radio image of Cygnus A is given in Fig. 2.

2. Radio astronomy

Almost everything that we know about the universe has been obtained from information brought to the observer by electromagnetic radiation. Only very small part of our knowledge stems from material information carriers, such as meteorites that hit the surface of the earth, cosmic ray particles or samples of material collected by manned or unmanned space probes.

Thousands of years, mankind was restricted to measurements of visible light. It's Jansky's discovery in 1932 of radio emission from the Milky Way which is now seen as the birth of the new science of radio astronomy. The older astronomy in the visible spectrum is now often called optical astronomy to distinguish it from the newer branch.

2.1. The radio window

The positions of optical and radio astronomy in the electromagnetic spectrum coincide with the two transparent bands of the earth's atmosphere and ionosphere. These transparent bands are commonly referred to as the optical and radio windows. There are occasional windows at infrared frequencies, allowing observations to be made from high, dry mountain sites, airplanes, balloons or satellites.

The atmosphere surrounding the earth is transparent to radio waves as long as none of its constituents is able to absorb this radiation to a noticeable extent. The radio window extends roughly from a lower frequency limit of 15 MHz to a high frequency cut-off at about 600 GHz, but these limits are not sharp; there are variations both with geographical position and with time. The high frequency cut-off occurs because the resonant absorption of the lowest rotation bands of molecules in the troposphere fall into this frequency range. There are mainly two molecules responsible for this: water vapor H_2O and O_2 . At the lowest

frequencies, the terrestrial atmosphere ceases to be transparent because the electrons in the ionosphere absorb electromagnetic radiation substantially if the frequency is below the plasma frequency ν_p given by

$$\frac{\nu_p}{kHz} = 8.97 \sqrt{\frac{N_e}{cm^{-3}}} \quad (1)$$

where N_e is the electron density in cm^{-3} and ν_p is given in kHz . But this is a problem which cannot be treated here.

In the last twenty to thirty years another detrimental effect has had an impact on the radio astronomical observing conditions. There has been a great increase in the level of man made electromagnetic interference, particularly at lower frequencies. Many sources are ground based, they range from general electrical noise interference caused by industrial complexes to telecommunication signals. These noise sources can have serious effects on measurements. Especially the environment of the antenna in Zürich is very noisy. A lot of time was invested in finding quiet frequencies as well as quiet locations and daytime (or rather nighttime).

2.2. Radio telescope antennas

A radio telescope antenna consists basically of an antenna, a receiver and a recorder. The antenna acts as a collector of radio waves. The waves are collected in the parabolic dish and focussed on the primary feed. The purpose of an antenna as a function of direction is given by the *antenna pattern*. By reciprocity this pattern is the same for both receiving and transmitting conditions. The pattern commonly consists of a number of lobes, as suggested in Fig. 3.

The lobe with the largest maximum is called the *main lobe*, while the smaller lobes are referred to as the minor lobes or side and back lobes.

The function of a radio telescope receiver is to detect and measure the radio emission of celestial sources. The signal is coupled to the receiver by the antenna and is first amplified in a radio-frequency amplifier ν_R with a certain gain. The next stage is a mixer, where the weak signal is mixed with a strong local-oscillator signal. This product of waves has a so called *intermediate frequency* ν_I . The ν_I signal power is directly proportional to the ν_R signal power. The ν_I signal is then filtered and amplified again. The ν_I amplifier is followed by a detector, which is normally a square-law device in radio telescope receivers (d-c output voltage proportional to the input voltage amplitude squared). This means that the output d-c voltage of the detector is directly proportional to the output noise power of the predetection section of the receiver. Final stages consists of an integrator and a data-recording system. The integrator integrates the observed signal power for a predetermined length of time. The actual value used, commonly of the order of seconds, is usually a compromise between too short a period, for which the output noise is excessive, and too long a period, causing excessive smoothing and loss of information.

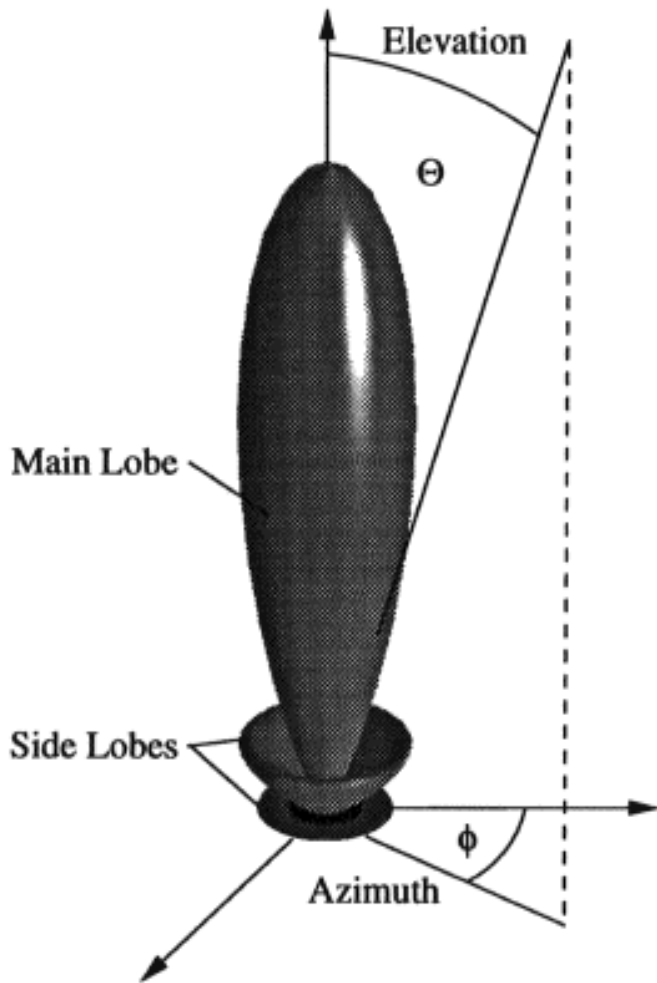


Fig. 3. Antenna pattern in polar coordinates and linear power scale

In Zurich the whole system is called *APRAXOS* (Fig. 5). *APRAXOS* consists of a 5 m diameter parabolic dish with a wide-band, linear polarized primary feed. In the so called *Fokuspak* (FOPA), the signal is first being amplified (low noise 1 GHz-4 GHz, 35 dB) before getting to the receiver AR5000, shown in Fig. 4.

The FOPA also contains two PIN-switches and a noise source (35 dB). Fig. 6 shows rather abstractly the scheme of the whole system. To increase the sensitivity of the system, we bridged the switch and connected the input feed directly to the preamplifier. The system-temperature T_{sys} after changing the connection was 0.4 dB lower than before. Please see the following pages for calculating T_{sys} .

The steering system of the antenna is independent of the receiver and controlled by a separate computer (system *ANTOS*) which determines the position of the dish through *azimut* and *elevation*. The recorded data can be easily transformed into well known formats such as EXCEL for example.



Fig. 4. AR5000 receiver



Fig. 5. 5 m diameter parabolic dish in Zurich

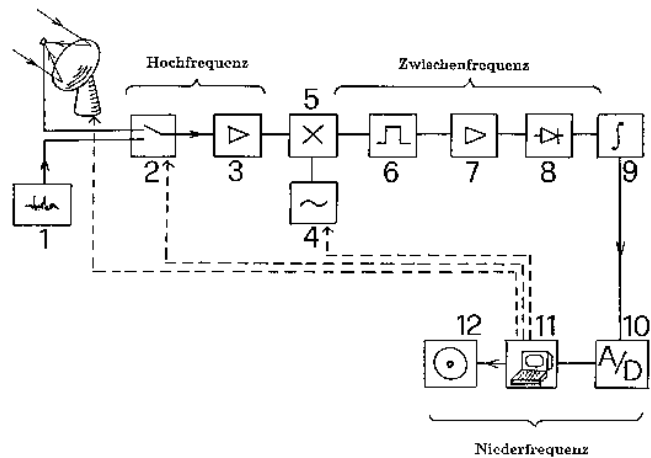


Fig. 6. Scheme of *APRAXOS*: 1 noise source 2 switch 3 preamplifier 4 local oscillator 5 mixer 6 filter 7 amplifier 8 detector 9 integrator 10 a/d converter 11 computer 12 safety copy

2.3. Feed Horns

As mentioned before, I was troubled by severe man made noise, mainly from Zürich. To cut out at least some of it, Mr. Monstein and I installed a cylindric horn at the input feed. I decided to take a horn which was designed for a frequency of 1161 MHz. With a *Network Analyzer*, that measures the standing-wave-ratio (swr), the horn was optimized by changing the length and form of the exciter inside the horn. An optimal horn would be one with a swr of 1.0. As can be seen in the plot (appendix zh05) the swr was with 1.0680 at 1163.75 MHz and 1.0879 at 1280.00 MHz quite satisfying. It can also be seen that the swr is more or less stable between ≈ 1100 MHz and ≈ 1400 MHz.

2.4. Antenna temperature and flux density

Consider electromagnetic radiation from the sky falling on a flat horizontal area A at the surface of the earth. The infinitesimal power dW from a solid angle $d\Omega$ of the sky incident on a surface of area dA is

$$dW = B \cos(\theta) d\Omega dA d\nu \quad (2)$$

where dW = infinitesimal power, B = brightness of sky at position of $d\Omega$, $d\Omega$ = infinitesimal solid angle of sky ($= \sin(\theta) d\theta d\phi$), θ = angle between $d\Omega$ and zenith, dA = infinitesimal area of surface, $d\nu$ = infinitesimal element of bandwidth.

The brightness B is a fundamental quantity of radio and optical astronomy and is a measure of the power received per unit area per unit solid angle per unit bandwidth. The element of bandwidth lies between a particular frequency ν and $\nu + d\nu$.

If dW is independent of the position of dA on the surface, the infinitesimal power received by the entire surface A is

$$dW = AB \cos(\theta) d\Omega d\nu \quad (3)$$

Integrating (3), one can obtain the power W received over a bandwidth $\Delta\nu$ from a solid angle Ω of the sky. Thus,

$$\begin{aligned} W &= A \int_{\nu}^{\nu+\Delta\nu} \iint_{\Omega} B \cos(\theta) d\Omega d\nu \\ &\equiv A \iint_{\Omega} B' \cos(\theta) d\Omega \end{aligned} \quad (4)$$

where B' is the total brightness in the frequency band $\Delta\nu$.

In many situations the *power per unit bandwidth* is more pertinent than the power contained in an arbitrary bandwidth $\Delta\nu$. This power per unit bandwidth is often called the *spectral power*. Thus, introducing the concept of spectral power, (2) becomes

$$dw = B \cos(\theta) d\Omega dA \quad (5)$$

And the spectral power or power per unit bandwidth is

$$w = A \iint_{\Omega} B \cos(\theta) d\Omega \quad (6)$$

Since the sky brightness may vary with direction, it is, in general, a function of angle. This may be expressed explicitly by the symbol $B(\theta, \phi)$ for the brightness.

In reality the area A is replaced by the pertinent area A_e , the *effective aperture* of the antenna. The *power pattern* $P_n(\theta, \phi)$ is a response of the antenna to radiation as a function of the angles θ and ϕ . It is a dimensionless quantity and can be considered as a weighing function. In the antenna case it replaces the factor $\cos(\theta)$ of (6). Thus, introducing $B(\theta, \phi)$, A_e and $P_n(\theta, \phi)$ into (6) and consider that we measure only one polarization, we have the spectral power w .

$$w = \frac{1}{2} A_e \iint_{\Omega} B(\theta, \phi) P_n(\theta, \phi) d\Omega \quad (7)$$

If the brightness is constant, (7) becomes

$$w = \frac{1}{2} A_e B_c \iint_{\Omega} P_n(\theta, \phi) d\Omega \equiv \frac{1}{2} A_e B_c \Omega_A \quad (8)$$

where B_c = uniform or constant brightness, Ω_A = beam area.

The brightness of the radiation from a blackbody is given by *Planck's radiation law*. This law, formulated by Max Planck (1901), states that the brightness of a blackbody radiator at a temperature T and frequency ν is expressed by

$$B = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1} \quad (9)$$

where B = brightness, h = Planck's constant, ν = frequency, c = velocity of light, k = Boltzmann's constant and T = temperature.

In the region of radio wavelengths the product $h\nu$ may be very small compared to kT ($h\nu \ll kT$), so that the denominator of the second factor on the right side of Planck's blackbody-radiation law (9) can be expressed as follows

$$e^{h\nu/kT} - 1 \approx \frac{h\nu}{kT} \Rightarrow B = \frac{\nu^2}{c^2} 2kT \quad (10)$$

Equation (10) is the *Rayleigh-Jeans radiation law*, which is a useful approximation in the radio part of the spectrum. According to the Rayleigh-Jeans radiation law, the brightness varies inversely as the square of the wavelength, for

$$\lambda = \frac{c}{\nu} \Rightarrow B = \frac{2kT}{\lambda^2} \quad (11)$$

The noise power per unit bandwidth available at the terminals of a resistor of resistance R and temperature T is given by (Nyquist, 1928)

$$w = kT \quad (12)$$

where w = spectral power, k = Boltzmann's constant and T = absolute temperature of resistor.

For any discrete source, observed with an antenna of power pattern $P_n(\theta, \phi)$, the integral of the brightness and the power pattern over the source yields the total source *flux density* S :

$$S = \iint_{\Omega} B(\theta, \phi) P_n(\theta, \phi) d\Omega \quad (13)$$

The temperature of the radiation resistance is determined by the temperature of the emitting region which the antenna "sees" through its directional pattern. In other words, it is the temperature of the region within the antenna beam which determines the temperature of the radiation resistance. Assuming that the entire antenna beam area is subtended by a sky of temperature T , the radiation resistance of the antenna will then be at the temperature T and the received spectral power will be as given by (12). In such a situation the antenna and receiver of a radio telescope may be regarded as a radiometer for determining the temperature of distant regions of space coupled to the system through the radiation resistance of the antenna. The temperature of the antenna radiation resistance is called the *antenna temperature*.

If absorbing matter is present, the temperature measured may not be the source temperature but related to it. Also if the source of temperature T does not extend over the entire antenna beam area, the *measured* or *antenna temperature* T_A will be less. Thus, from (7) and (12) the received power per unit bandwidth is given by

$$w = \frac{1}{2} A_e \iint_{\Omega} B(\theta, \phi) P_n(\theta, \phi) d\Omega = k T_A \quad (14)$$

From (13) and (14) it follows that the observed flux density of a radio source or the antenna temperature may be evaluated with the aid of the following relation

$$S = \frac{2k T_A}{A_e} \quad (15)$$

2.5. Source Spectra

By measuring the flux density of a radio source over as much of a wavelength range as possible, a spectrum may be determined for the source. Sources like Cygnus A have spectra in which the flux density falls off with frequency, but for objects such as the sun the flux density increases with frequency.

According to the Rayleigh-Jeans law (10) the flux density S of an object at a wavelength λ in the radio spectrum is given by

$$S = \frac{2k}{\lambda^2} \iint T d\Omega \quad (16)$$

where k = Boltzmann's constant, T = equivalent blackbody temperature and $d\Omega$ = element of solid angle.

Let the variation of the flux density S with wavelength be expressed by the proportionality

$$S \propto \lambda^n \quad (17)$$

where n = spectral index, dimensionless and (by definition) positive for nonthermal sources.

Suppose that the temperature of a source were constant with wavelength. Then, S would vary inversely with the square of the wavelength, and for this case the spectral index n would be equal to -2 . This variation is characteristic of the *thermal radiation* from a blackbody. Since the oppositely sloping spectrum of Cygnus A suggests a different mechanism, sources with a positive index are referred to as *nonthermal* types. In nonthermal sources the synchrotron process is believed to be dominant.

3. Measurements

3.1. System temperature

In practical systems there will always be several sources of system noise. Besides the receiver itself, the atmosphere, the spillover noise of the antenna which consists of ground radiation that enters into the system through far side lobes, and noise produced by unavoidable attenuation in wave guides and coaxial cables connecting the feed to the receiver input all contribute to the receiver output.

As been discussed before, the noise power per unit bandwidth from an antenna is given by $k T_A$. The noise power from the antenna is

$$W_{NA} = k T_A \Delta\nu \quad (18)$$

where W_{NA} = antenna noise power, k = Boltzmann's constant, T_A = antenna temperature and $\Delta\nu$ = bandwidth.

The noise contributions are additive and therefore the total power at the antenna terminals is

$$W_{sys} = W_{NR} + W_{NA} = k(T_A + T_{RT}) \Delta\nu \quad (19)$$

and the total temperature referred to the antenna terminals is

$$T_{sys} = T_A + T_{RT} \quad (20)$$

where T_A = antenna temperature and T_{RT} = receiver noise temperature (including transmission line) and W_{NR} = receiver noise power referred to the antenna terminals.

In this specific measurement of Cygnus A, T_{sys} is given by

$$T_{sys(cyg)} = T_{RT} + T_{sky} + T_{cyg} \quad (21)$$

T_{RT} was determined by measuring the sun and comparing this to the measuring of the 'blank' sky. The system temperatures are

$$T_{sys(sun)} = T_{RT} + T_{sky} + T_{sun} \quad (22)$$

and

$$T_{sys(sky)} = T_{RT} + T_{sky} \quad (23)$$

The relation $\frac{T_{sys(sun)}}{T_{sys(sky)}}$ defines the so called *y-factor*, which was measured. Knowing the actual flux of the sun and therefore T_{sun} through (15) and assuming an appropriate sky temperature T_{sky} , T_{RT} can be calculated.

This has been made four times for each frequency and T_{RT} was determined by an average of these measurements. The results can be seen in the table in (3.4).

As well known from Fourier Transform theory, $\Delta\nu\Delta t = 1$ defines the time resolution for independent samples. If the total receiver bandwidth is $\Delta\nu$ then two samples taken at time intervals less than $\Delta t = 1/\Delta\nu$ apart are not independent. Then a total time τ contains $N = \tau \cdot \Delta\nu$ independent samples. Gaussian statistics shows that the total error for N samples is $1/\sqrt{N}$ of that of a single sample. Calling the error of this single sample T_{sys} we obtain

$$\Delta T = \frac{T_{sys}}{\sqrt{\Delta\nu\tau}} \quad (24)$$

This result was first obtained by Dicke (1946). Note that in practical systems T_{sys} is the noise of the *whole* system, including the source. Therefore ΔT is larger for an intense source than for a weak one. Equation (24) is the fundamental relation for system noise and RMS fluctuations: Using the given system components, no system can be better; systematic errors will only increase ΔT .

3.2. Observational Methods

There are different ways for observing sources in the sky with a radio telescope like the one in Zurich. The different methods I used are called *on-off-source*, *passage* or *drift*.

With the on-off-source method, the telescope is steered automatically and observes the source for a few seconds (on-source) and then rapidly moves away and measures the 'blank' sky (off-source). This can be repeated as many times as it is needed and the output plot will be something like a triangular shaped function shown in Fig. 7. The passage is similar to the on-off-source: here the telescopes drives from on side of the blank sky over the source to the blank sky of the other side of the source. For the time on the source is not as long as in the method before, the plot (should) look more like a sinus-curve. The curve can vary though, because the angle and the time for the passage can be determined first. An example for a plot of a passage is given in Fig. 8. The last method, simply called drift, needs a bit of time and patience, for the telescope is steered to a known location, where the source is supposed to pass by, and put in a so called parking position. Now you can only wait and hope. To see a clear result, it is recommended to start the observation at least two hours before the source is expected in the focus. If the source passes by, it should be visible on the plot with

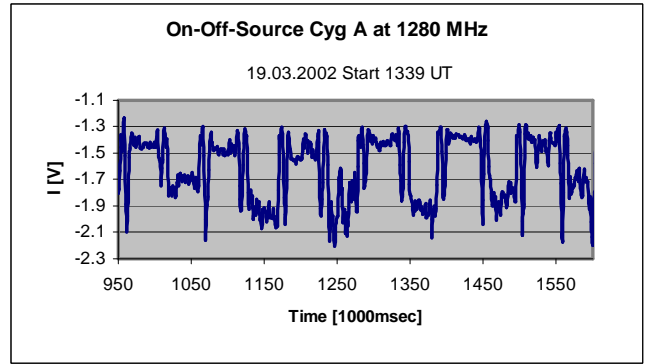


Fig. 7. Example for on-off-source: Cygnus A at 1280 MHz

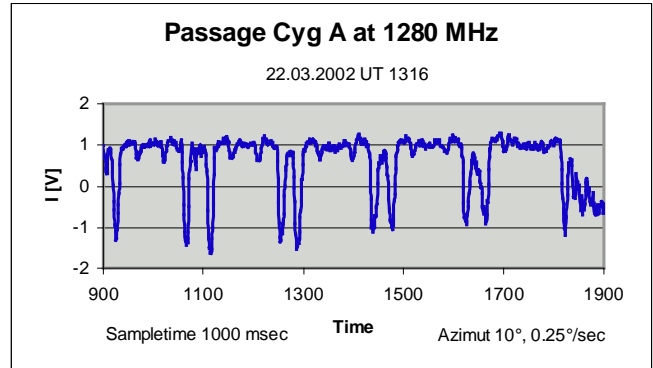


Fig. 8. Example for passage: Cygnus A at 1280 MHz

a curve similar to a gaussian. Actually this method came out to be the most efficient to measure Cygnus A, because it was easy to measure at nighttime, where the man made noise is not so dominating, and the signal could clearly be identified with Cygnus A.

If you look at Fig. 7 one could think that this is a beautiful signal as well, but calculations have shown that the flux according to the amplitude is far to big compared to theoretical data. The on-source signal must have been a nearby tree or something else that disturbed the observation. On the plot of the passage Cygnus A could be identified, but the sky temperature wasn't the same on either side of the source due to a noisy environment. This plot was somehow difficult to evaluate for the same reasons.

3.3. Frequency

As mentioned before, a lot of time has been invested in finding quiet frequencies. After choosing a horn with a frequency range of about 1100 MHz to 1400 MHz I analyzed this band in comparing the amplitude of the sun with the background and calculating a factor $\eta' \equiv \sigma/\text{amplitude}$, where σ is the standard deviation. This factor allowed me to compare the different frequencies: the smaller this factor, the better the frequency for my purpose. After com-

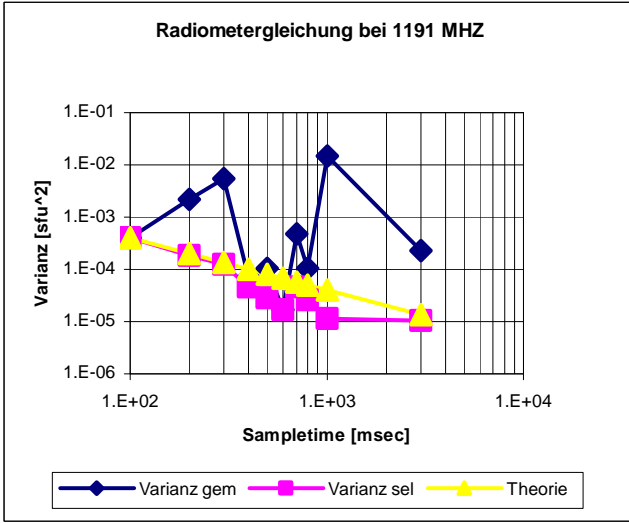


Fig. 9. Test at 1191 MHz

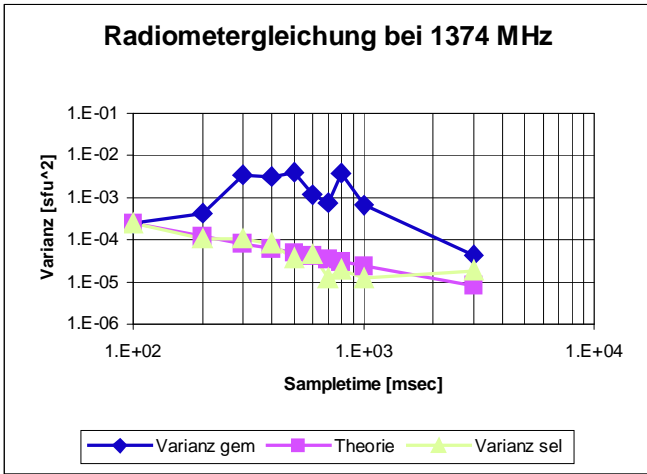


Fig. 10. Test at 1374 MHz

paring this data to the background noise I decided to measure Cygnus A at 1191 MHz, 1280 MHz and 1374 MHz.

The quality of these frequencies has been tested through the relation (24) by plotting the standard deviation squared versus the integrating time. Examples for such measurements can be found in Fig. 9 and Fig. 10.

The frequencies 1191 MHz and 1374 MHz turned out to be quite good whereas at 1280 MHz there must have been some disturbance.

Evaluating the data, we have $\sigma = 0.02$ sfu = 200 FU for 1191 MHz, $\sigma = 0.03$ sfu = 300 FU for 1374 MHz and $\sigma = 0.1$ sfu = 1000 FU for 1280 MHz.

3.4. Drift of Cygnus A

Finally Cygnus A was measured twice at each frequency. Fig. 11 to Fig. 16 show the result of such a drift.

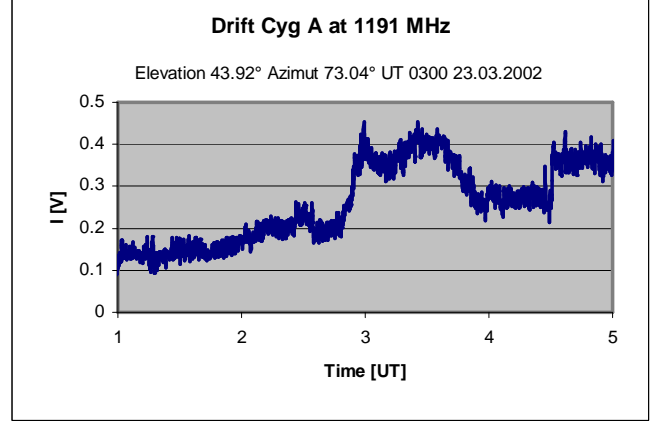


Fig. 11. Drift of Cygnus A at 1191 MHz

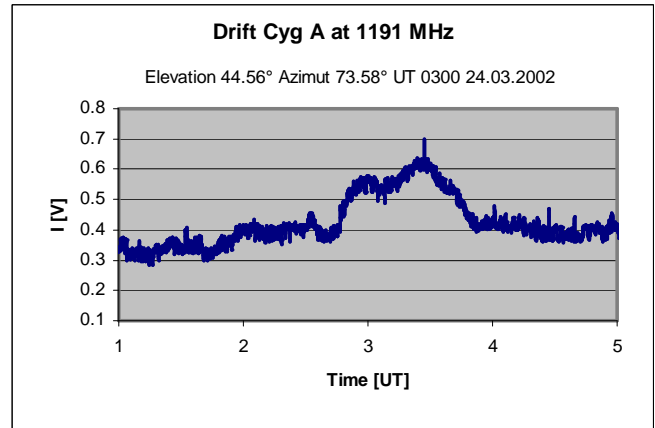


Fig. 12. Drift of Cygnus A at 1191 MHz

At 1191 MHz the position of Cygnus A at 0300 UT, when the observation was made, was 43.92 elevation and 73.04 azimuth on 23.03.2002 and 44.56 elevation and 73.58 azimuth on 24.03.2002.

At 1280 MHz the position of Cygnus A at 0300 UT was 45.20 elevation and 73.12 azimuth on 25.03.2002 and 42.64 elevation and 71.97 azimuth on 21.03.2002.

At 1374 MHz the position of Cygnus A at 0300 UT was 46.48 elevation and 75.21 azimuth on 27.03.2002 and 47.13 elevation and 75.75 azimuth on 28.03.2002.

Other daytime like early morning or afternoon showed no results because the noise by then was too strong for a weak signal like Cygnus A.

In these plots you can see two clear peaks: the first is Cygnus A, followed by the galactic background (see also Fig. 17). To evaluate an amplitude for Cygnus A I had to consider that the temperature of the galactic background is somewhat higher than the one of the blank sky. According to a radio map I assumed that the shape of the galactic background is nearly symmetrical with a slightly steeper left hand side. For the background varies between 2.7 K (cosmic background) and approx. 90 K for the selected frequencies, I assumed a temperature of

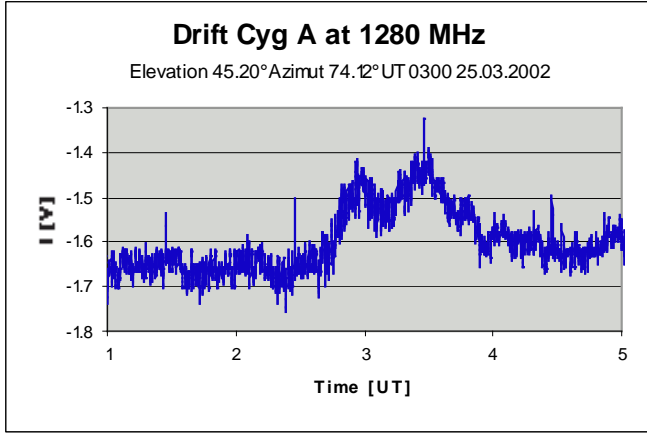


Fig. 13. Drift of Cygnus A at 1280 MHz

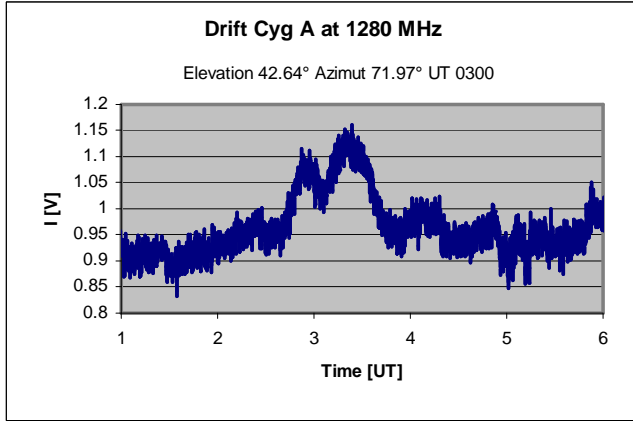


Fig. 14. Drift of Cygnus A at 1280 MHz

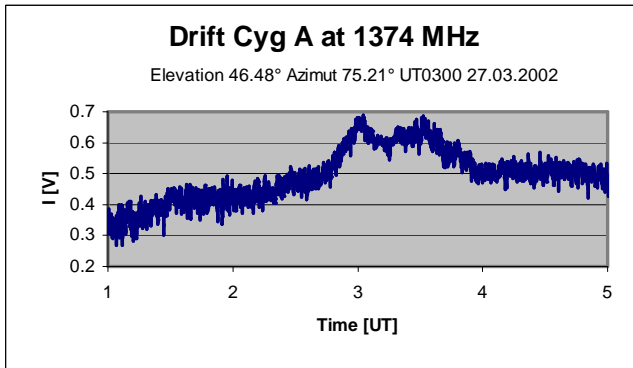


Fig. 15. Drift of Cygnus A at 1374 MHz

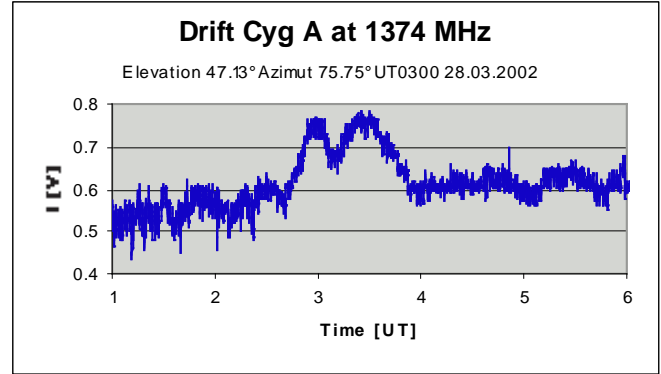


Fig. 16. Drift of Cygnus A at 1374 MHz

Frequency [MHz]	Amplitude [dB]	T_{RT} [K]
1191	0.16	223.558
1280	0.145	189.822
1374	0.135	187.398

T_{cyg} [K]	Flux S [W/m ² /Hz]	Theoretical Flux
9.516	2229.846	1872.203
7.463	1748.892	1740.070
6.864	1608.455	1617.968

where S was calculated by using the relation

$$S = \frac{2kT_{cyg}}{A\eta} \quad (25)$$

The theoretical flux S of Cygnus A is given by

$$\log S = a + b \log \nu + c \log^2 \nu \quad (26)$$

where $a = 4.695$, $b = 0.085$ and $c = -0.178$ according to *J.W.M. Baars et al.* for the given frequencies.

If we want to determine the efficiency factor η , we can use the theoretical flux and (25):

$$\eta = \frac{2kT_{cyg}}{AS_{th}} \quad (27)$$

This leads to an average efficiency factor of $\eta_{1191} = 0.715$ for 1191 MHz, $\eta_{1280} = 0.603$ for 1280 MHz and $\eta_{1374} = 0.597$ for 1374 MHz.

Finally the so called *signal to noise ratio* $q = \frac{S}{\sigma}$ can be calculated. Using the results of (3.3) and (3.4) we have $q_{1191} = 11.15$ for 1191 MHz, $q_{1280} = 1.75$ for 1280 MHz and $q_{1374} = 5.36$, which is not too bad for the frequencies 1191 MHz and 1374 MHz and a little bit too small for 1280 MHz.

Mr. Monstein was so kind to cumulate the data of these six measurements by cutting out the 'worst' peaks of noise with the effect that the curves of Cygnus A and the galactic background can be seen even more clearly. The plot of this culmination can be seen in Fig. 18.

30 K. An evaluation of these plots can be seen in the following tables, where I assumed an efficiency factor η of 0.6.

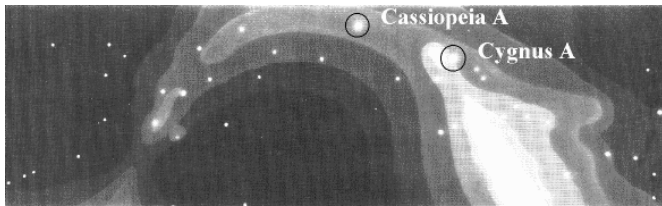


Fig. 17. galactic background

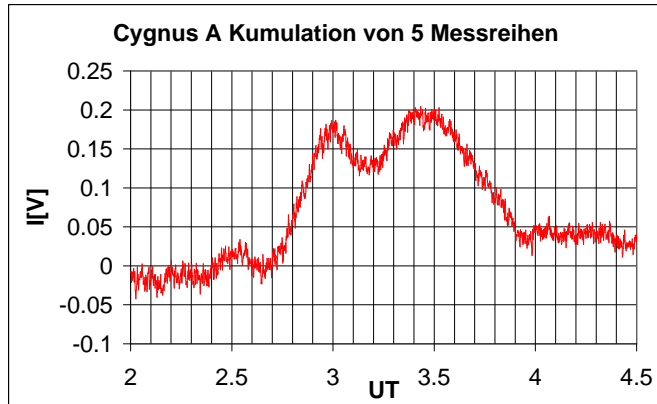


Fig. 18. Cumulation of all drifts of Cygnus A

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