Proposal for VP-Astro-Week 2008 in Diavolezza
November 19, 2007

2-Element adding Radio-Interferometer with CALLISTO

Determination of the Diameter and the Surface Temperature of the Sun; Detection of an Amateur Satellite; Search for radio-loud Stars.

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Received November 19, 2007

ABSTRACT

Aims. We want to measure the angular diameter Φ of the Sun by means of radio interferometry. As a secondary goal, we want to capture an amateur satellite and determine the surface temperature T of the Sun by relating the total fluxes. We would like to show that α Cas and α Cyg as weaker sources of radio emission can be detected using a radio interferometer.
Methods. We use a two-element adding interferometer in connection with the spectrometer CALLISTO. The Allan variance and Allan time is measured. Three quiet frequencies have to be found. During week 2 in 2008 we measure the Sun nine times, at night we look at a satellite as well as α Cassiopeiae and α Cyngi. The fringe pattern of an interferogram gets Fourier-analysed, the peak frequency identified and the diameter Φ of the Sun inferred through the visibility. The surface temperature T in the Rayleigh-Jeans regime is deduced from a sample noise of known temperature and a satellite with fixed radiation power.
Results. We want to verify the values of $\Phi = 32.5'$ and $T = 5800$ K. A successful detection of α Cas and α Cyg is striven for.

Key words. radio interferometry – CALLISTO

1. Scientific Background

Interference can be achieved by superimposing signals from two or more telescopes. Such an interferometer gives a higher resolution than we can get with one single telescope. Interferometry is particularly useful in radio astronomy, where we deal with large wavelengths in the range of 10^{-3}m to tenths of meters.
For our observations we use a simple two-element adding interferometer. See figure 2 for a scheme.
Δs is the difference in path length which gives rise to the phase difference Ψ between the signals $V_A(t)$ and $V_B(t)$, reaching the antenna A and B, respectively. We expect the interference pattern to qualitatively look like figure 2.

2. Observation Plan

Diavolezza lies at latitude 46°24′44“, longitude 9°57′55″ and an altitude 2978 m. This position is needed for calculating the location of the measured objects. In this section we outline the roadmap for our observations. We have five days:

- Mon, 2008-01-07: Instrumental setup, search for quiet frequencies, measurement of Allan variance, calibration with noise of known temperature. Possibly during night: α Cas, α Cyg, N.0.1 and N.0.2
- Tue, 2008-01-08: Three measurements of Sun, denoted by D.1.1, D.1.2 and D.1.3. At night: N.1.1, N.1.2
- Wed, 2008-01-09: Sun D.2.1, D.2.2, D.2.3. During night: N.2.1, N.2.2
- Thu, 2008-01-10: Sun D.3.1, D.3.2, D.3.3. During night: Satellite
- Fri, 2008-01-11: No measurements planned. If necessary, one of the previous measurements is repeated. We concentrate on data reduction, the report and a presentation.

We divide the time between sunrise and sunset into three parts. During each part we measure the Sun once. The antennas point towards the position of the Sun in the middle of each of these parts. Table 1 gives the starting time of each possible measurement and the antenna orientation at the middle of the track for each measurement. If we want to change a battery about every four hours, we can replace the one indicated in the table at the beginning of a measurement. The positions for 2008-01-07 and 2008-01-11 are included for reasons of completeness.
During night, two measurements of α Cyg and α Cas are planned. From 20:00 to 04:00 we want to point towards the middle of the first star's track, from 04:00 until 08:00 the second one is measured. The longer measurement time for α Cyg is due to the fact, that the star has very low elevation, and we have to determine on-site, whether it is visible at all behind the nearby mountains. If not we could only measure the first two or three hours. Tables 2 and 3 give the coordinates of the stars, using the same conventions as for the Sun.
The ephemerides of a satellite cannot yet be determined, as the position of an active satellite can only be extrapolated for

⋆ Advisor and technical assistance

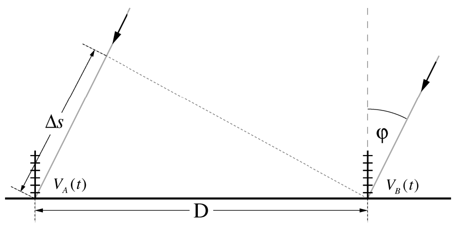

Fig. 1. Geometry of a two-element adding interferometer.

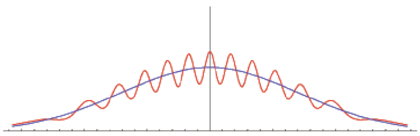

Fig. 2. Expected interference pattern.

about three weeks in advance. We have yet to find a satellite with known power output and beacon frequency, e.g. one of the AMSAT organisation. It should cross the sky in approximately east-west direction, so we don't have to change the antenna positions.

3. Experimental Setup of the 2-Element Interferometer

3.1. Adjustment of the Antennas

The two antennas are placed on an east-west orientated baseline of about 30 m length. We choose both antennas to be installed at the same base height. The appropriate position of our installation will be defined on-site when we know the local conditions. For finding the east-west line we can locate the Piz Tschierva, which is situated exactly to the west of Diavolezza (see fig. 3 and 4). Determining the direction using a compass could raise troubles because of the ferrous rock environment.

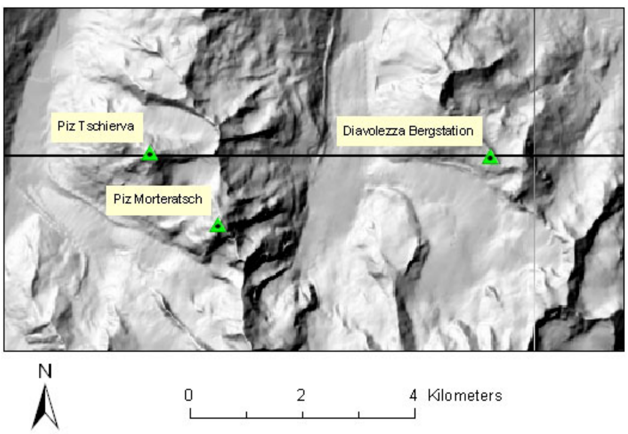

Fig. 3. Piz Tschierva and Diavolezza top station are located on an east-west line.

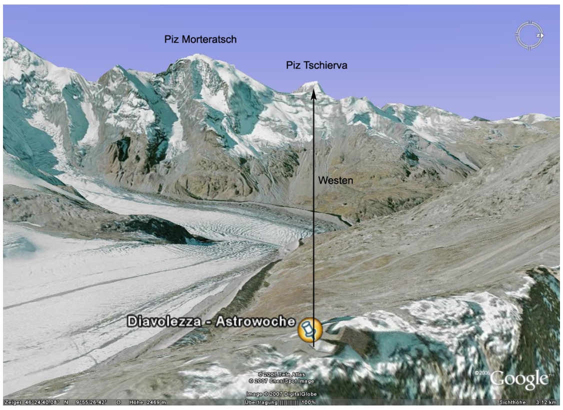

Fig. 4. View of Piz Tschierva from Diavolezza top station, located directly to the west.

3.2. Hardware Setup

We use two standard TV antennas (UHF) designed for a frequency range between 470 MHz and 530 MHz (channel 21 - 29). The received signal is amplified by a preamplifier LNA435 at both antenna outputs to compensate for signal loss in the cables. Two coaxial cables of the same length (25 m) are installed to feed the signal into the power-combiner. As power-combiner we use a $\lambda/4$-transformer; its output signal is again amplified by a broad band amplifier (10 dB) and routed through another coax-cable to the CALLISTO-spectrometer. The spectrometer is connected to a computer through a serial interface. The recorded data is downloaded and analyzed on this computer.
There are different possibilities to realize the power supply of the amplifiers:

- At the output of the power-combiner and at the output of the two LNA435 amplifiers a T-Bias is interconnected to feed the amplifiers with a 12 V voltage through the coax-cable, see figure 3.2. This model has the advantage that we only need one accumulator for the power supply of both amplifiers or that we even can connect the T-Bias input with a power supply from the hotel. However, the higher number of connections due to the T-Bias elements leads to a higher vulnerability to wetness and coldness.
- Another possibility is to supply every amplifier with an accumulator. The accus and amplifiers can be put into styrofoam boxes to protect them from snow, humidity and strong variations in temperature. As a disadvantage we need to charge the accus from time to time - for example during night - and cannot do any measurement in the meantime. A possibility to work around this problem is to charge a third accu and replace the two accus of the antennas in turn.

The final power supply setup will be chosen on-site when we know the position of the antennas and the distance between the power-combiner and hotel or the closest current source respectively.

4. Data Reduction

In this section, we refer to equations from [MoMe06]. With geometrical arguments we can see that the baseline distance D can be calculated using equation (1), where δ is the actual declination and Δt is the fringe period which we receive by taking the Fourier transform of the fringe function. ω denotes the angular frequency of earth rotation, $\omega = 15°/\,\text{h}$. We can then compare

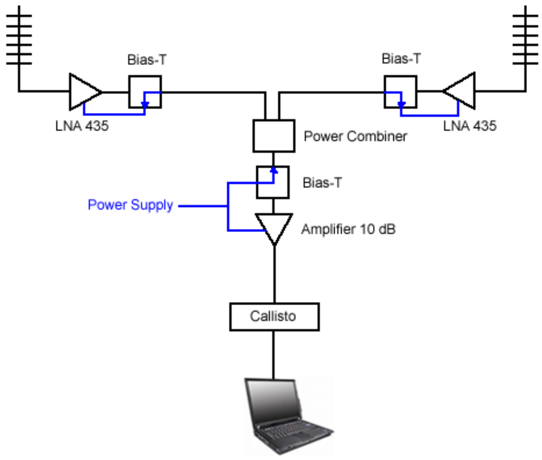

Fig. 5. Instrumental setup.

the result for the baseline to a manual measurement and use this as a check for the accuracy of the interferometer.

$$D = \frac{\lambda}{\cos(\delta)\sin(\omega\Delta t)} \tag{1}$$

We expect the interferometer pattern to look like figure 2. From this figure we can calculate the visability function v with equation (2). Note that P_{min} and P_{max} are normalized values.

$$v = \frac{P_{max} - P_{min}}{P_{max} + P_{min}} = \frac{\sin 2\pi \frac{D}{\lambda}\frac{\Phi}{2}}{2\pi \frac{D}{\lambda}\frac{\Phi}{2}} \tag{2}$$

If we solve equation (2) for Φ with a series expansion, we receive equation (3) from which we can calculate the disc diameter of the sun.

$$\Phi = \frac{\sqrt{6}}{\pi}\frac{\lambda}{D}\sqrt{1-v} \tag{3}$$

References

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Acknowledgements. We appreciate the support of ETH Zurich a lot. C. Monstein will help us a great deal with the instruments.

Table 1. Observation timetable for the Sun. Refraction is already taken into account. (http://emphemeriden.com)

No.	Date	Time (CET)	RA and Dec (J2000)		Azimuth and Elevation		Accu
D.0.1	2008 – 01 – 07	08 : 03 : 30	19 : 10 : 14	−22 : 26 : 38	139 : 29 : 49	10 : 42 : 19	-
D.0.2		10 : 58 : 24	19 : 11 : 13	−22 : 25 : 44	180 : 01 : 53	21 : 12 : 06	-
D.0.3		13 : 53 : 18	19 : 11 : 45	−22 : 24 : 50	220 : 34 : 01	10 : 42 : 17	-
D.1.1	2008 – 01 – 08	08 : 03 : 16	19 : 15 : 04	−22 : 19 : 02	139 : 22 : 23	10 : 46 : 56	East
D.1.2		10 : 58 : 37	19 : 15 : 36	−22 : 18 : 04	180 : 03 : 55	21 : 19 : 45	West
D.1.3		13 : 53 : 58	19 : 16 : 08	−22 : 17 : 07	220 : 45 : 17	10 : 44 : 57	East
D.2.1	2008 – 01 – 09	08 : 02 : 59	19 : 19 : 26	−22 : 10 : 59	139 : 14 : 13	10 : 51 : 38	West
D.2.2		10 : 58 : 49	19 : 19 : 58	−22 : 09 : 58	180 : 06 : 05	21 : 27 : 49	East
D.2.3		13 : 54 : 38	19 : 20 : 30	−22 : 08 : 57	220 : 57 : 05	10 : 47 : 48	West
D.3.1	2008 – 01 – 10	08 : 02 : 39	19 : 23 : 47	−22 : 02 : 30	139 : 05 : 30	10 : 56 : 32	East
D.3.2		10 : 58 : 59	19 : 24 : 19	−22 : 01 : 26	180 : 08 : 08	21 : 36 : 20	West
D.3.3		13 : 55 : 18	19 : 24 : 51	−22 : 00 : 22	221 : 09 : 13	10 : 50 : 56	East
D.4.1	2008 – 01 – 11	08 : 02 : 16	19 : 28 : 08	−21 : 53 : 36	138 : 56 : 16	11 : 01 : 39	-
D.4.2		10 : 59 : 07	19 : 28 : 40	−21 : 52 : 28	180 : 10 : 20	21 : 45 : 17	-
D.4.3		13 : 55 : 58	19 : 29 : 12	−21 : 51 : 21	221 : 21 : 55	10 : 54 : 15	-

Table 2. Observation timetable for α Cas: RA = 00 : 40 : 57, Dec = 56 : 35 : 12 (J2008). Positions for CET 06 : 00 : 00. (KStars)

No.	Date	Time (CET)	Azimuth and Elevation		Accu
N.0.2	2008 – 01 – 08	04 : 00 : 00	352 : 34 : 38	13 : 35 : 15	West
N.1.2	2008 – 01 – 09	04 : 00 : 00	353 : 07 : 44	13 : 30 : 11	East
N.2.2	2008 – 01 – 10	04 : 00 : 00	353 : 40 : 52	13 : 25 : 30	West
N.3.2	2008 – 01 – 11	04 : 00 : 00	354 : 14 : 04	13 : 21 : 12	-
N.4.2	2008 – 01 – 12	04 : 00 : 00	354 : 47 : 18	13 : 17 : 18	-

Table 3. Observation timetable for α Cyg. RA = 20 : 41 : 39, Dec = 45 : 18 : 34 (J2008). Positions for CET 00:00:00. (KStars)

No.	Date	Time (CET)	Azimuth and Elevation		Accu
N.0.1	2008 – 01 – 07	20 : 00 : 00	333 : 32 : 56	09 : 25 : 42	-
N.1.1	2008 – 01 – 08	20 : 00 : 00	331 : 09 : 49	09 : 05 : 55	West
N.2.1	2008 – 01 – 09	20 : 00 : 00	331 : 46 : 51	08 : 46 : 31	East
N.3.1	2008 – 01 – 10	20 : 00 : 00	332 : 24 : 33	08 : 27 : 16	-
N.4.1	2008 – 01 – 11	20 : 00 : 00	333 : 02 : 06	08 : 08 : 35	-

Table 4. Required devices and material

device / material	quantity
TV antennas of type EB 66 UHF	2
amplifiers LNA 435	2
broad-band amplifier with 10 dB gain	1
T-Bias elements	3
12 V accumulators	3
battery charger	1
short coax cables	3
coax cables 25 m	2
coax cable 50 m	1
$\lambda/4$-transformer (power-combiner)	1
12 V power supply unit (for the amps from the electricity network)	1
cable for the 12 V power supply from the hotel to the T-Bias element	1
spectrometer CALLISTO	1
connection cable CALLISTO → laptop	1
adapter USB ↔ RS232	1
styrophoam boxes for snow protection of accus and amplifiers	3
termination resistors / sample noise	2