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SPIDER230 experiences: Cassiopea A transit at 11.2 GHz

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Doc. Vers. 1.0 del 27.03.2014

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We continue the description of the experiments realized with the radiotelescope *SPIDER230* illustrating the recording of *Cassiopea A* transit, a supernova remnant among the most interesting objects for radio astronomy, the brightest extrasolar radio source of the sky in the microwave band.

In the visible, *Cassiopea A* is very weak, since its radiation is absorbed by interstellar dust in the plane of the Milky Way. This radio source was identified in 1947 (one of the first recorded by a radio telescope) and its optical counterpart was discovered in 1950. It is thought that the supernova that gave rise to *Cassiopea A* exploded 11,000 years ago and that the light of the explosion reached Earth about 300 years ago. There is no news of a sighting of this supernova, but it is possible that the star of the sixth magnitude 3 *Cassiopeiae*, John Flamsteed cataloged by August 16, 1680, was just *Cassiopea A*.

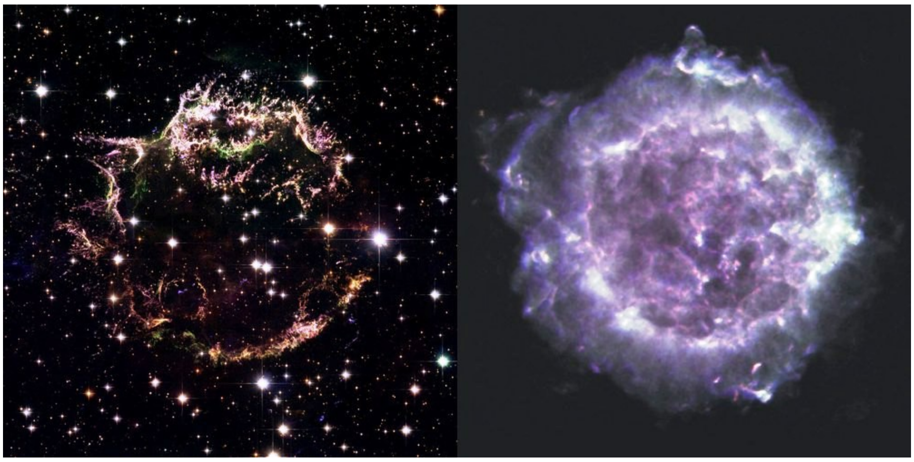


Fig. 1: *Cassiopea A* evocative images in visible band (on the left) and radio wavelenghts (on the right). The image in visible band has been taken from the Hubble Space Telescope (NASA, ESA, and the Hubble Heritage STScI/AURA-ESA/Hubble Collaboration. Acknowledgement: Robert A. Fesen (Dartmouth College, USA) and James Long (ESA/Hubble)), while the one in radio wavelenghts from VLA Radio Telescope (Image courtesy of NRAO/AUI).

Cassiopea A is one of the "sample radio sources" often used by radio astronomers to calibrate instruments and to determine the diagram of the antenna (fig.3). In fact, the procedure provides for the registration of the transit of a radio source with apparent diameter much smaller than the width of the main lobe of the antenna. This item is ideal to verify the performance of SPIDER230 and derive the amplitude of the lobe receiving our tool: in addition to being the brightest source sample, it is characterized by a straight line of the spectrum (in bi-logarithmic scale) over almost the entire radio band (fig.3), with a secular decrease in the flux density of the order of 1.1% / year. To get the value of the flux density in the *Cassiopea A* band from 20 MHz to 30 GHz using the expression:

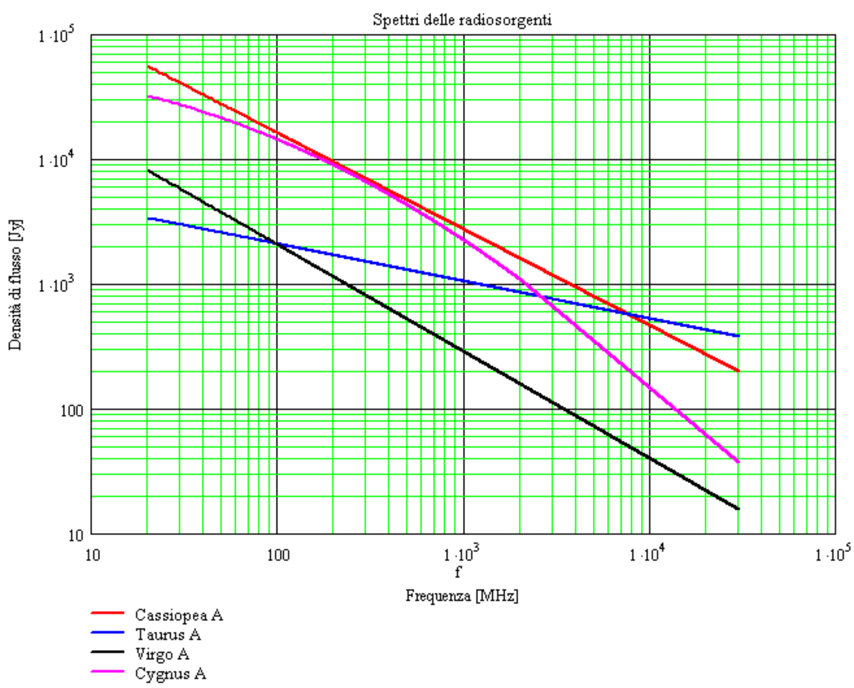
$$S(f)=A\cdot f^{n} \quad [\frac{W}{Hz\cdot m^{2}}]$$

where the value of the constant A is obtained taking into account that S*(1 GHz) = 2723 Jy* with spectral index *n = -0.77* (period 1986). The following figure shows the calculations that were performed to obtain the spectrum of *Cassiopea A* and the corresponding emission intensity at a frequency of 11.2 GHz, which is worth about 423 Jy (it is considered the secular variation of the flow).

Densità di flusso di CASSIOPEA A [Jy] quando la frequenza è espressa in [MHz]:

$Epoch := 1986$	$Anno := 2014$	Anno attuale dell'osservazione.
$Sc(f) := 10^{5.745-0.77 \cdot \log(f)}$	[Jy]	Flusso di CASSIOPEA A all'epoca 1986.
$d(f) := 0.97 - 0.30 \cdot \log\left(f \cdot 10^{3}\right)$	[% per anno]	Decremento secolare del flusso di CASSIOPEA A.
		$d(11200) = -1.1$ [% per anno a 11.2 GHz]
$Scas(f) := Sc(f) + \frac{(Anno - Epoch) \cdot d(f)}{100}$	[Jy]	Flusso di CASSIOPEA A all'epoca attuale.

Fig. 2: Calculation of the spectrum of *Cassiopea A* (flow pattern as a function of frequency) in the radio band from 20 MHz to 30 GHz (data source: "The Absolute Spectrum of Cas A: An Accurate Flux Density Scale and a Set of Secondary Calibrators" JWMM Baars, R. Genzel, IIK Pauliny-Toth, A. Witzel - Astron. Astrophys. 61.99-106 (1977)).



$Scas(11200) = 423.4$	[Jy]	Densità di flusso di CASSIOPEA A a 11.2 GHz.
$Stau(11200) = 506.2$	[Jy]	Densità di flusso di TAURUS A a 11.2 GHz.
$Svir(11200) = 36$	[Jy]	Densità di flusso di VIRGO A a 11.2 GHz.
$Scyg(11200) = 126.9$	[Jy]	Densità di flusso di CYGNUS A a 11.2 GHz.

Fig. 3: Spectrum of the most intense "radio sources sample" used by radio astronomers to calibrate their instruments. The small angular size of these objects (usually no more than 4 minutes of arc) and the relatively intense flow make them very useful as sources of evidence in order to verify the performance of radio telescopes and antennas.

Using these data, we simulated the *Cassiopea A* transit registered with the *SPIDER230* radiotelescope (Fig. 4). The estimates are theoretical and consider an ideal behavior of the receiving system. The brightness temperature of the radio source, of the order of 210 K, produces an increase in the temperature of the antenna equal to about 0.68 K, very "diluted" because of the difference between the apparent size and the width of the lobe of receiving radio telescope.

The calculations show that the power variation "view" at the *RAL10PL* receiver input is of the order of 0.1 dBm, with a value -52.7 dBm corresponding to the point of maximum intensity during transit. Registration simulated also shows the drift of the radiometric base line to facilitate comparison with the experimental data shown in Fig. 8.

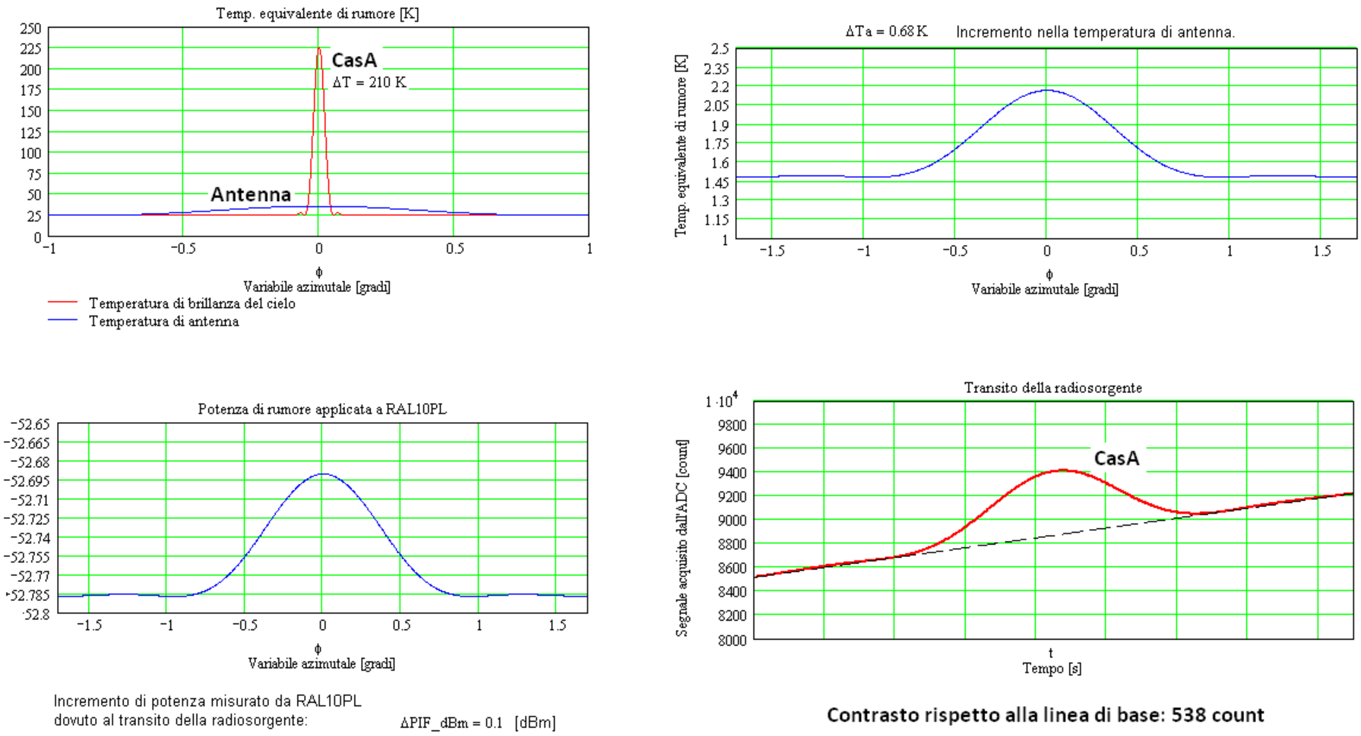


Fig. 4: Recording simulated transit of radio source *Cassiopea A (3C461)* in front of the antenna of the *SPIDER230* radio telescope.

The verification of the theoretical evaluations was performed by Filippo Bradaschia, CEO of *PrimaLuceLab*, *RadioAstroLab* business partners in the implementation of the radio telescope *SPIDER230* that we thank for cooperation. The receiving station installed at the Polo Tecnologico di Pordenone includes the *RAL10PL* 11.2 GHz receiver Total-Power made by *RadioAstroLab* for *SPIDER230* and the antenna system (circular parabolic reflector 2.3 meters in diameter) with equatorial mount, motor and dome protection made by *PrimaluceLab*.

The instrument is fully controllable through an Ethernet line, by software *RadioUniverse*. Taking advantage of a day of "dry air", were organized observations to record the transit of *Cassiopea A*. By using an equatorial mount, the antenna of the radio telescope *SPIDER230* is very precise but, being small the apparent size of the radio source, find the object can be difficult.

To facilitate this task, it has been exploited an interesting feature of *SPIDER230*: the ability to shoot radio-images of a specific area of the sky using the *RadioUniverse* database software. By orienting the antenna of the radio telescope toward the region of the sky where there is *Cassiopea A,* there were two consecutive images at low resolution, with a size of 10 x 10 pixels radio and 0.5° resolution, in order to frame an area of sky wide 5 x 5° within which one could be reasonably sure of finding the radio source. The amplification factor of the receiver *RAL10PL* was set to the maximum value.

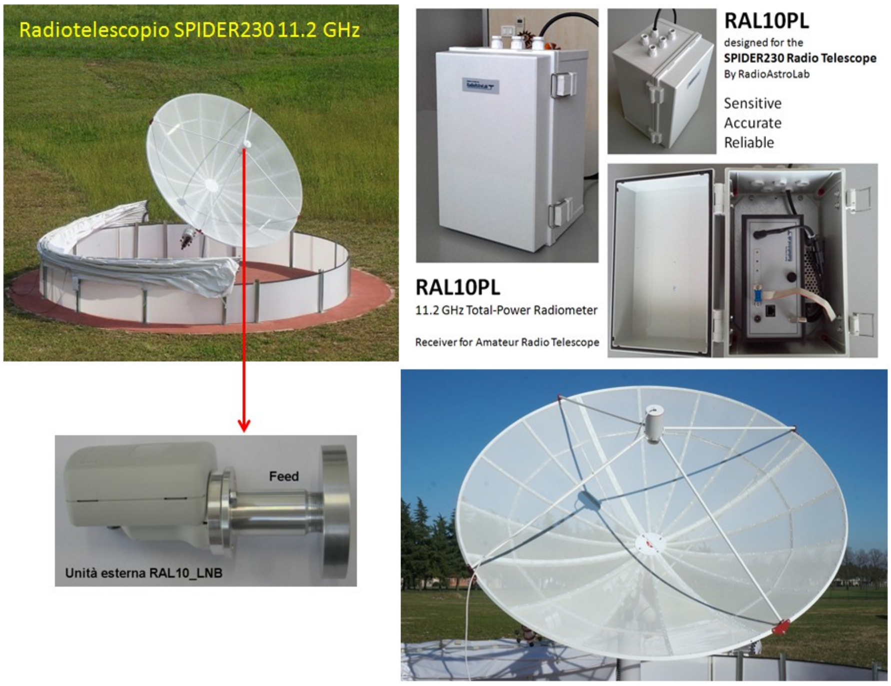


Fig. 5: The *SPIDER230* radio telescope used to record the transit of *Cassiopea A*.

The two images obtained (Fig. 6) show the gradient of the signal caused by the contrast between the background of the sky (pixels of blue color) and the flux emitted from the ground and from the atmosphere near the horizon (pixels of red color). The angle at the lower right represents the closest point on the horizon. The presence of the *Cassiopea A* seems to be confirmed by the weak increase in brightness of the pixels shown in Fig. 6 with respect to the boundary.

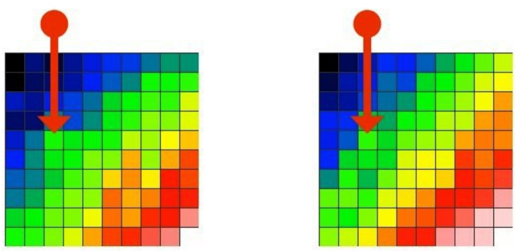


Fig. 6: Images radio consecutive recorded by *SPIDER230* in the area of sky of *Cassiopea A.*

These measures have served to align the region in the radio map where you assumed the presence of the radio source, so as to require the software *RadioUniverse* automatically record 5 consecutive transits of the *Cassiopea A*, large 8 degrees. In all the recordings it was observed a signal peak, with sufficient contrast, exactly at the point occupied by the radio source. Data have been exported for further processing with a spreadsheet.

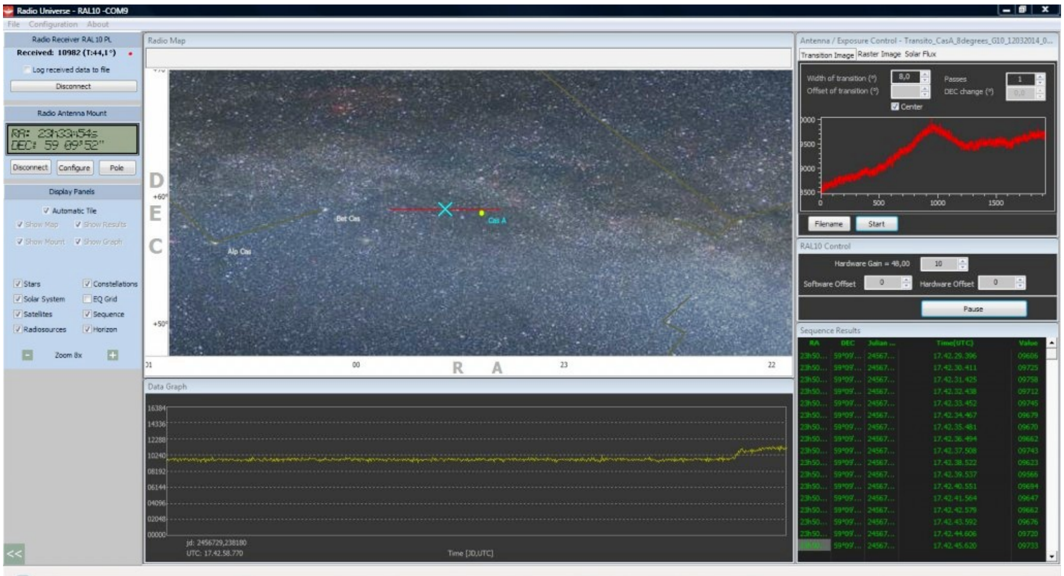


Fig. 7: Check the transit of *Cassiopea A* with the software *RadioUniverse*

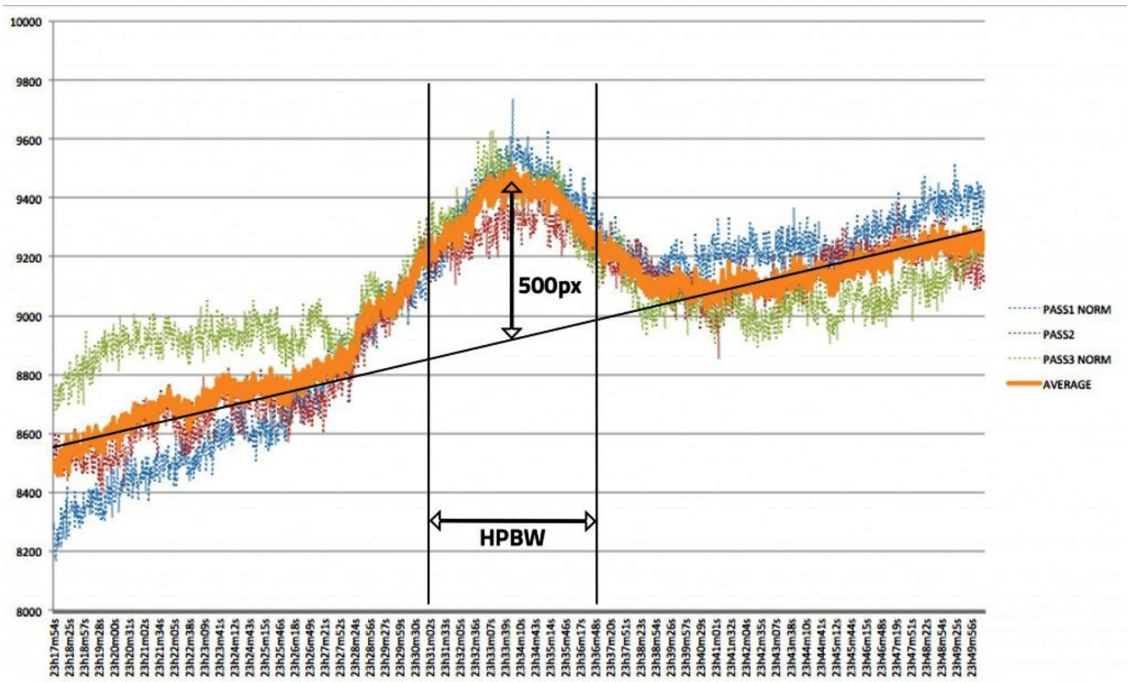


Fig. 8: Transits of the radio source *Cassiopea A.*

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Analisi dell'antenna a riflettore parabolico con simmetria circolare:

Si ipotizza un'antenna con diametro pari a: $D := 2.3 \cdot m$ e un'efficienza $\eta := 0.73$

si avrà un guadagno dell'ordine di: $Ga\_max := \eta \cdot \left(\frac{\pi \cdot D}{\lambda o}\right)^2$ $Ga\_max = 53121.68$

$Ga\_max\_dB := 10 \cdot \log(Ga\_max)$ $Ga\_max\_dB = 47.25$ [dB]

Gain pattern dell'antenna (modello relativo a un riflettore parabolico con simmetria circolare) che utilizza l'approssimazione dell'apertura piana circolare con illuminazione uniforme:

$$Ga(\phi) := Ga\_max \cdot if\left[\phi = 0, 1, \left(\frac{2 \cdot J1\left(\frac{\pi \cdot Deff \cdot \sin\left(\phi \cdot \frac{\pi}{180}\right)}{\lambda o}\right)}{\frac{\pi \cdot Deff \cdot \sin\left(\phi \cdot \frac{\pi}{180}\right)}{\lambda o}}\right)^2 \cdot \left(\frac{\sin\left(\phi \cdot \frac{\pi}{180}\right)}{\phi \cdot \frac{\pi}{180}}\right)^2\right]$$

$Deff := \sqrt{\eta} \cdot D$

E' definito un diametro efficace dell'antenna che tiene conto della sua efficienza [η].

$Ga\_dB(\phi) := 10 \log(Ga(\phi))$

Calcolo dell'ampiezza del fascio a metà potenza: si trova il valore angolare corrispondente a un'ampiezza del gain pattern di antenna pari a metà potenza. Tale valore, raddoppiato, sarà il parametro HPBW.

$x := 0.1$

valore angolare di partenza

Given

$$\frac{Ga\_max}{2} = Ga\_max \cdot if\left[x < 0, 0, \left(\frac{2 \cdot J1\left(\frac{\pi \cdot Deff \cdot \sin\left(x \cdot \frac{\pi}{180}\right)}{\lambda o}\right)}{\frac{\pi \cdot Deff \cdot \sin\left(x \cdot \frac{\pi}{180}\right)}{\lambda o}}\right)^2 \cdot \left(\frac{\sin\left(x \cdot \frac{\pi}{180}\right)}{x \cdot \frac{\pi}{180}}\right)^2\right]$$

$HPBW\_g := 2 \, Find(x)$

Valore angolare del beam di antenna

$HPBW\_g = 0.8$ [gradi]

Angolo solido del fascio d'antenna:

$\Omega a\_g := \pi \cdot \left(\frac{HPBW\_g}{2}\right)^2$ [gradi*gradi] $\Omega a\_g = 0.51$

$\Omega a := \left(\frac{4\pi}{41253}\right) \cdot \Omega a\_g$ [ster] $\Omega a = 0$

$lobo\_ant(\phi) := if\left(|\phi| > \frac{HPBW\_g}{2}, 0, Ga\_max\_dB - 3\right)$ Limite dell'ampiezza angolare del fascio di antenna.

$\phi := -180, -180 + 0.01 .. 180$ Angolo di azimut [gradi].

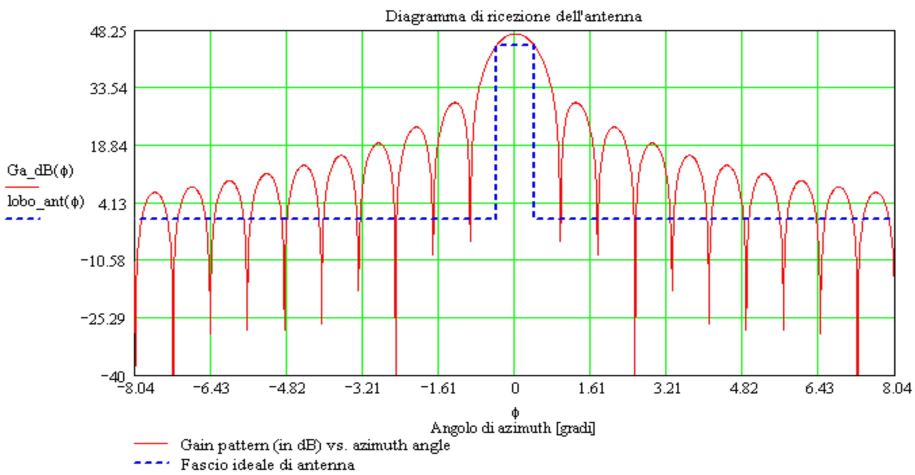

Fig. 9: A simplified model of the diagram of the antenna receive of the *SPIDER230* (parabolic reflector with circular symmetry and a diameter of 2.3 m) was approximated as a uniformly illuminated circular aperture and is given only the azimuthal variation.

As previously noted, *Cassiopea A* (object "almost punctiform") is often used as radiosource sample to verify the characteristics of the diagram of the receiving radio telescope, characterized by a lobe receiving much broader. In particular interesting obtain the *HPBW* parameter (*Half Power Beam Width*) which represents the amplitude at half power of the main lobe of the antenna (expressed in degrees). It uses the following formula:

$$HPBW = 0.25 \cdot t \cdot \cos(\delta)$$

where t is the transit time of the radio source in minutes and δ is the declination in degrees. By analyzing the recordings illustrated in figure 8 (orange trace represents the average over 5 consecutive transits) it can be seen as the time taken by *Cassiopea A* to cross the two points at half power (indicated by the vertical lines) is approximately 6 minutes. Considering that its declination is $\delta=59°$, the calculation gives:

$$HPBW = 0.25 \cdot 6 \cdot \cos(59) = 0.77\,°$$

in agreement with the value $HPBW = 0.8°$ obtained from the model of the antenna of *SPIDER230* used in the simulations (Fig. 9).

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