The refractive and diffractive scintillation of the source B0531+194

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The observations parameters

- Central frequency: 111 MHz
- Wave bandwidth: 600 kHz
- The effective area in the zenith direction:
  20 000 – 25 000 square meters.
- The array beams system includes 16 beams and covers about 8 degrees in declination during 24 hours in right ascension.
- The time interval: from 23 June to 25 August 2011.

What is scintillations?

- Radio waves from space radio sources propagate through interplanetary plasma.

Fluctuations of plasma density cause fluctuations of source flux density. It names interplanetary scintillations.

Refractive and diffractive scintillation

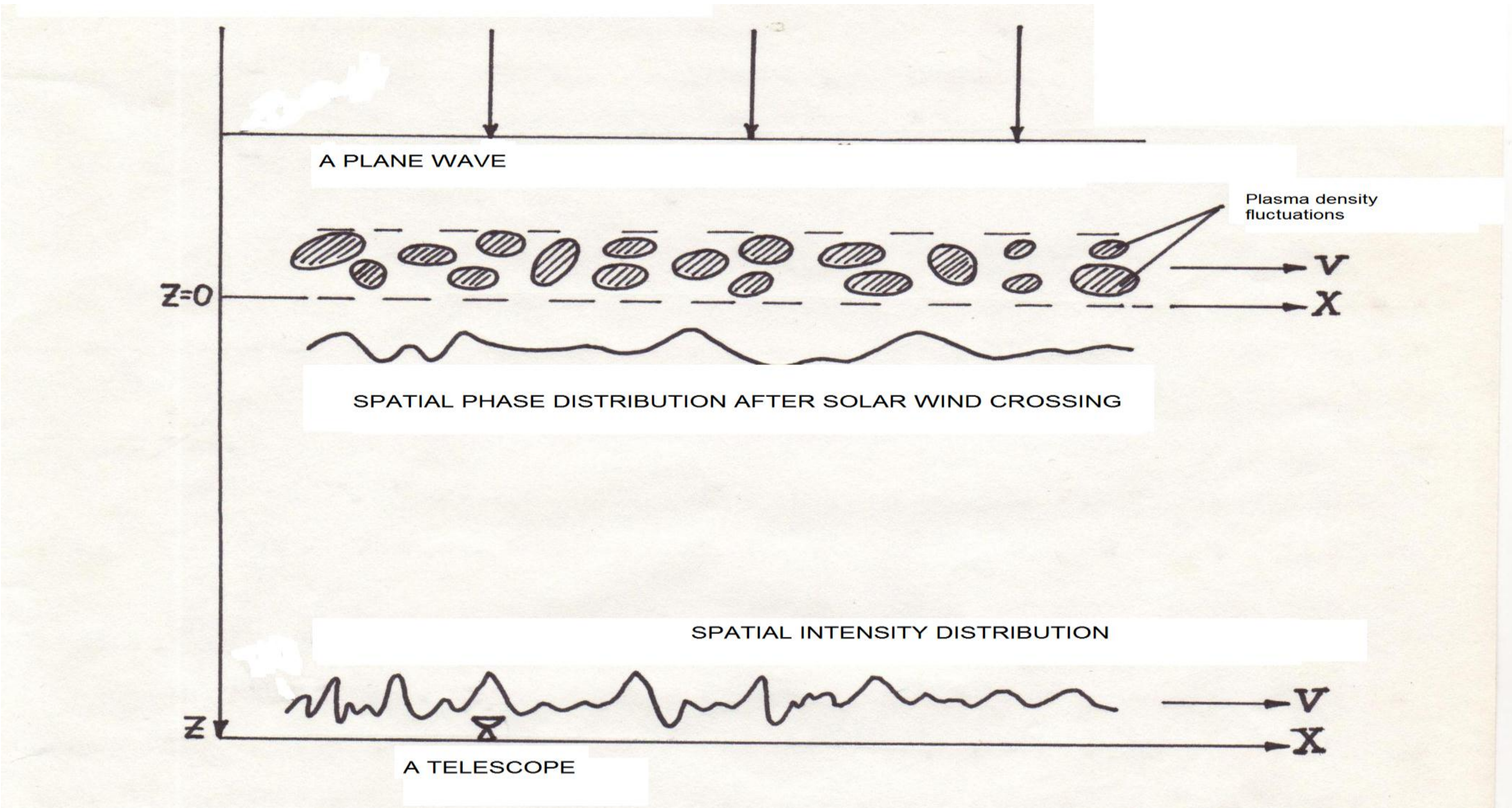
The general reason of scintillations is diffraction of radio waves on plasma. However near the Sun there is refraction on plasma too. So we have refractive and diffractive scintillations.

The scintillation mechanism

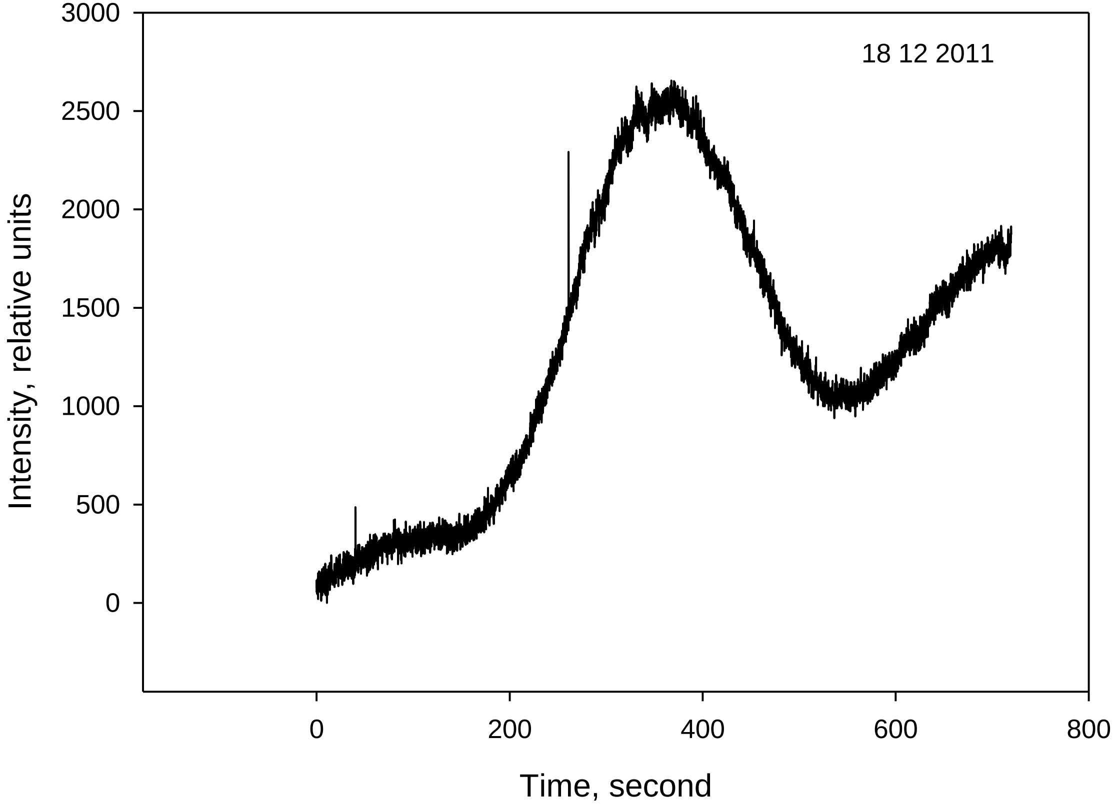
- Refraction and diffraction make spatial intensity distribution with maximums and minimums. Solar wind plasma moves relate to Earth. So this distribution moves too. A radio telescope is located

in a maximum and in a minimum by turns.

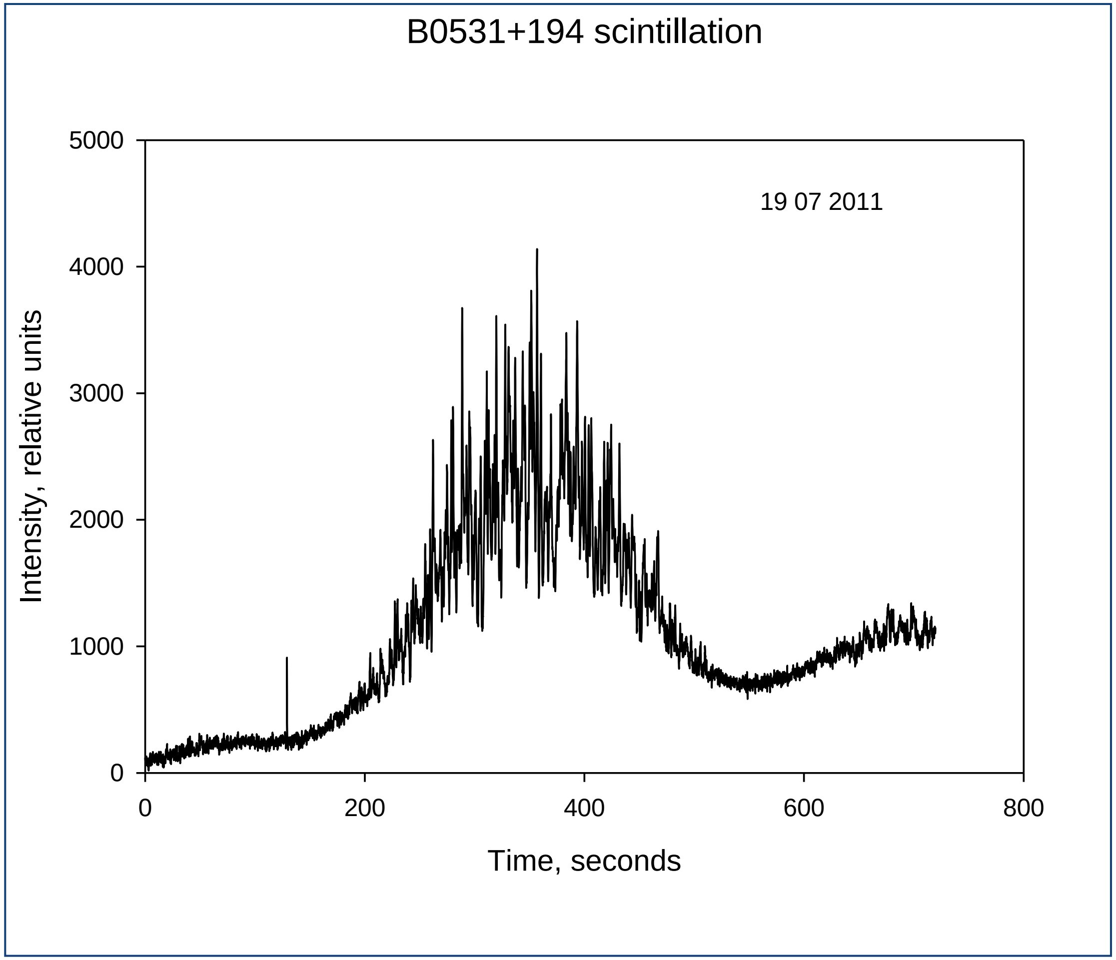
The scintillation mechanism



B0531+194 without scintillation



This intensity fluctuation is scintillation



Scintillation index

The scintillation index is the standard deviation of source intensity normalized to average intensity.

$\Delta I = I - \langle I \rangle,$

$m^2 = \langle \Delta I^2 (t) \rangle / \langle I (t) \rangle^2$

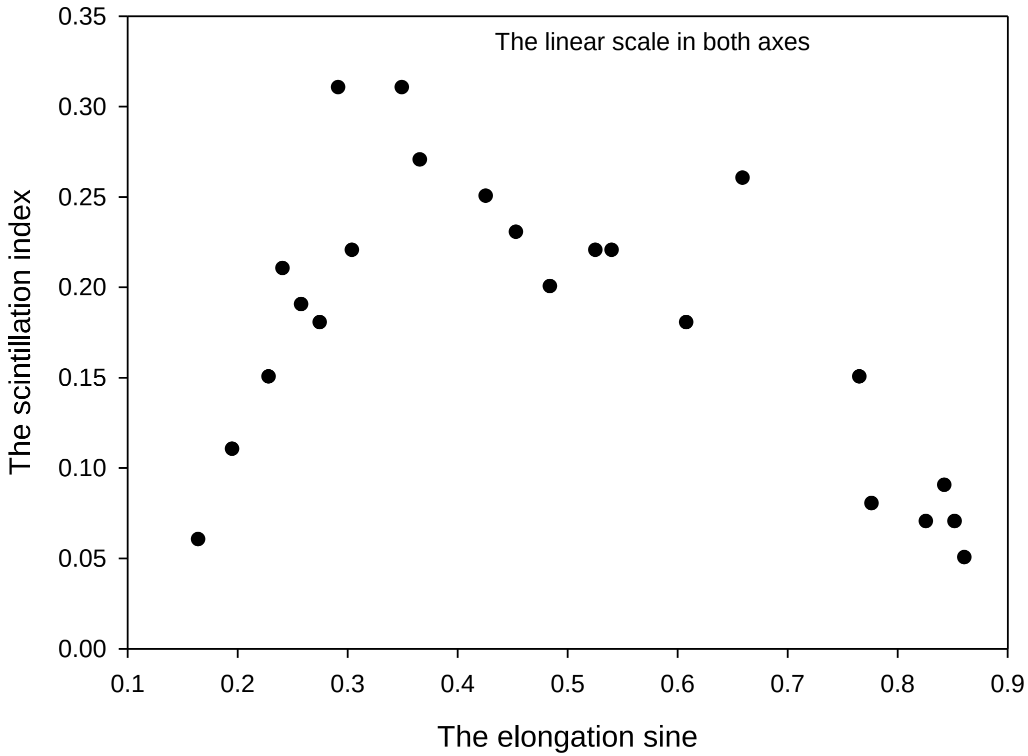
Here *I* is intensity, *t* is time, *m* is scintillation index.

Weak and saturated scintillations. Scintillation index vs. elongation

- There are two regimes of scintillations: saturated and weak. For saturated scintillations of a point source $m^2 \approx 1$ on any elongation. However for a source of finite angular size always $m < 1$ and scintillation index decrease with coming to the Sun. For week scintillating moving off the Sun because of plasma density increasing.

The curve “Scintillation index - elongation” for B0531+194

From 23 June to 25 August 2011



What are we observing scintillations for?

1. Scintillation allow to trace coronal mass ejections (CME). CME raise the plasma turbulence level in solar wind. So scintillation index sharply increase. We can trace a CME way in the sky if we observe a lot of scintillated source enough.

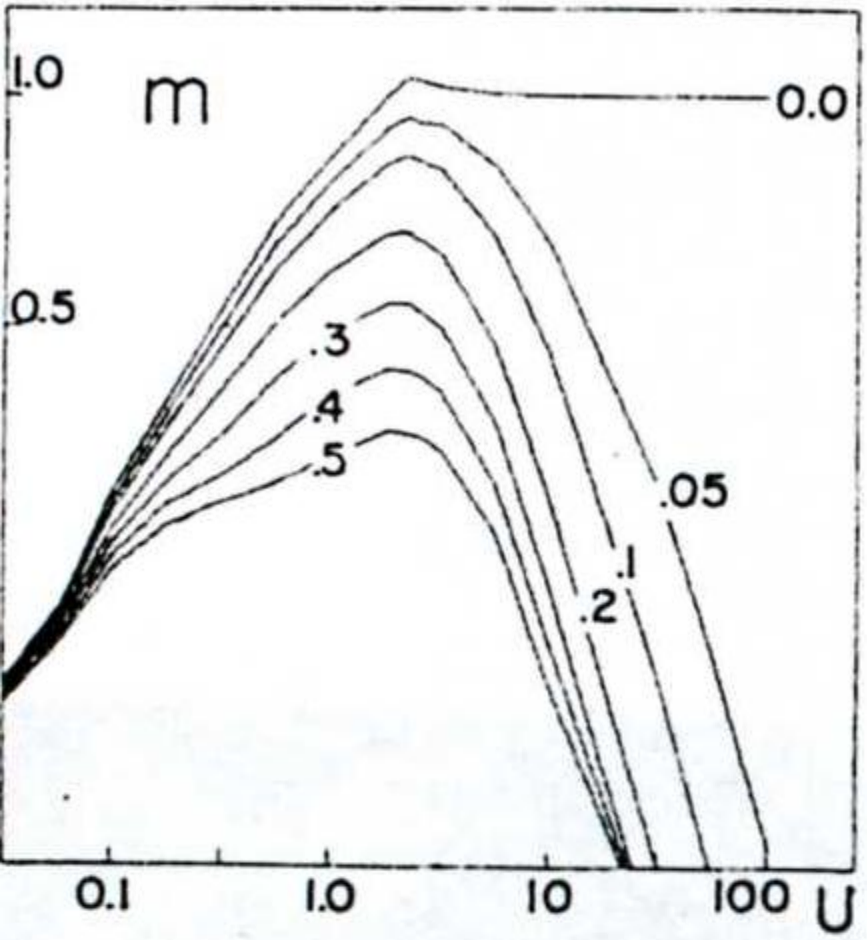
What are we observing scintillations for?

- 2. Scintillations allow to estimate a source angular size. It is very useful for low frequency. To get resolution 0.1’’ on 100 MHz by means of interferometer we need a base about 6 000 km.

Methods of size source estimation from scintillation observed

1. The curve “Scintillation index - elongation”.
2. Matching a theoretical power spectrum curve (using for weak scintillation)
3. A new method: estimation from break frequency of power spectrum in saturated regime.

1. A size source from the curve “scintillation index - elongation”



m on *U* for various angular size (arcsec), here

$U = (T\lambda \; 1 \text{ a. u. } \cos \varepsilon)^{1/2}$,

T is plasma spectrum turbulence power,

ε is elongation

[Marians, 1975].

1. A size source from the curve “scintillation index - elongation”

- However, it is showed that this curve is various in years of quiet and active the Sun [Manoharan, 2012]. So, there is the question about this method precision.

2. Matching a theoretical power spectrum curve

Power-density spectrum is Fourier transform of intensity autocorrelation function.

Here *I* is intensity, *t* is time, *B* is autocorrelation function, *M* is power-density spectrum.

$$M(f) = \int B_I(\tau) \exp(2\pi i f\tau)\, d\tau,$$

$$B_I(\tau) = \langle \delta I(t)\, \delta I(t + \tau) \rangle.$$

2. Matching a theoretical power spectrum curve

- Power spectrum of weak scintillation is

$$P(f) = 4A\lambda^2 \int \frac{dz}{\upsilon_\perp(z)} \int dq_\perp \Phi_e(q) \sin^2\left(\frac{q^2 z}{2k}\right) F^2\left(\mathbf{q}\right)\Bigg|_{q_\| = \frac{2\pi f}{\upsilon_\perp(z)}},$$

- Here $A = 5 \cdot 10^{-25}$ cm^2, z is the coordinate down the line of sight, f is the temporal frequency, $v_\perp(z)$ is the projection of the SW velocity on the plane of the sky, $\boldsymbol{q}$ is the spatial frequency, $q_{||}$ is the component of this frequency down the SW velocity, Φ_e is the quadratic spatial spectrum of plasma electron density, $F(\boldsymbol{q})$ is spatial spectrum of source, which is usually set as $F^2(\boldsymbol{q}) = \exp(- q^2 z^2 \theta_0^2 / 2)$, θ_0 is the angular size of the source [Shishov, Shishova, 1978]. But this equation is valid only for weak scintillation.

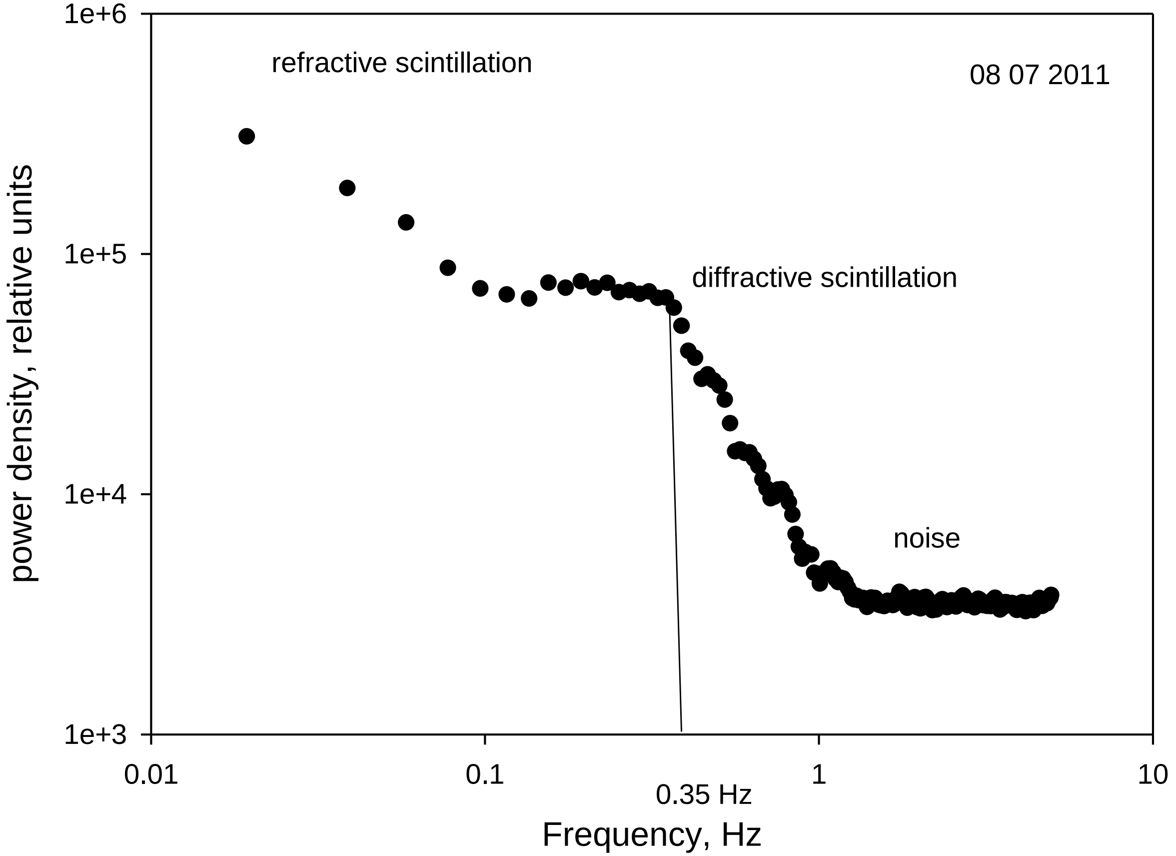
3. A new method: estimation from break frequency of power spectrum in saturated regime.

- For saturated scintillation the source angle size may be estimated from the equation

$f_b = V/(2\pi\ \theta_0 * 1\ \text{a. u.} \cos \varepsilon)$,

- here f_b is the break frequency of the power spectrum, v is the solar wind velocity, θ_0 is the source angle size, ε is the elongation.
- This method was proved for the source B0531+194.

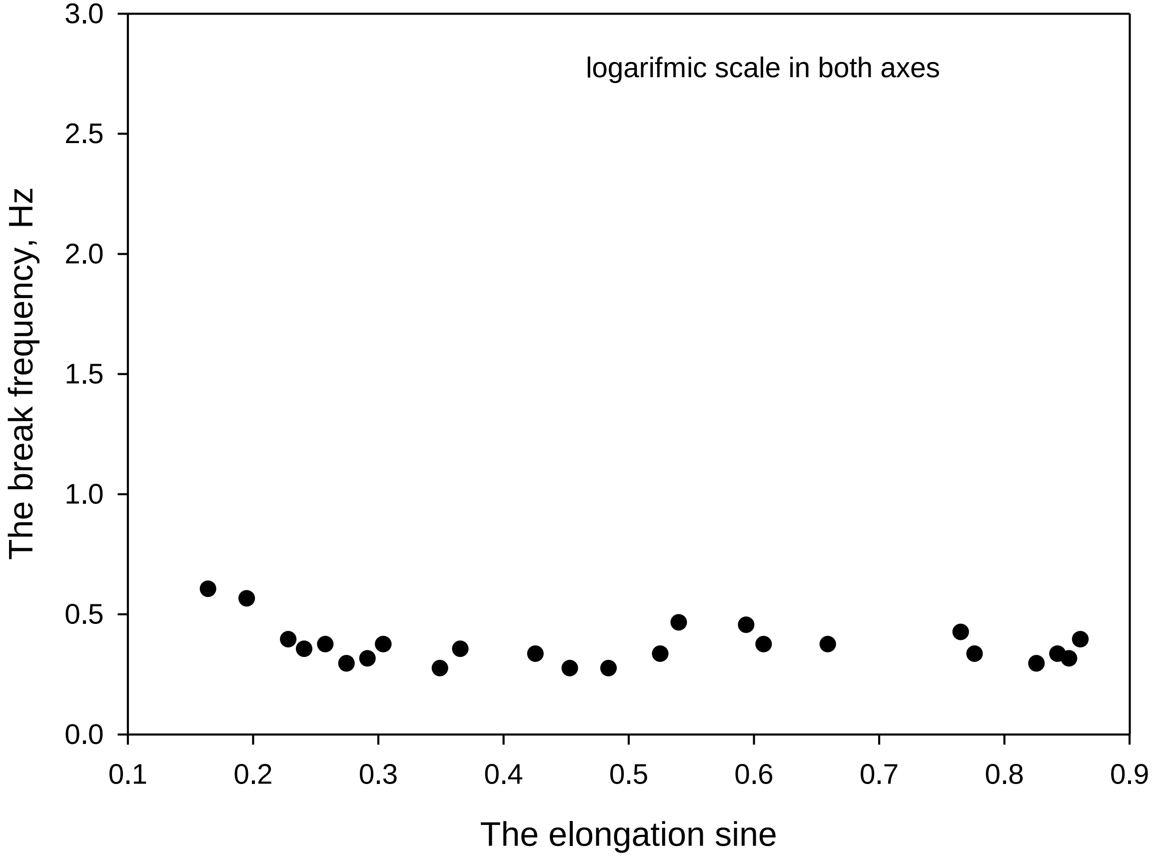
B0531+194 scintillation power spectra



The break frequency and the elongation

- For a source with a finite angular size the break frequency of saturated scintillations is determined by the source size and don’t depend on the elongation.

The break frequency and the elongation of B0531+194



Results

The solar wind velocity we take from Nagoya observatory [http://stelab.nagoya-u.ac.jp].

From 8 measurements in the saturated regime we have the angular size

0’’.24 ± 0’’.05.

The are the VLA observation at 1.4 and 5 GHz with the resolution 2’’ and 0.6’’, respectively [Perley, 1982]. The source have estimated as point.

Pro et contra

- This method have pluses and minuses. It don’t require observations in full elongation range, and it don’t sensitive to solar cycle, as opposed to the Marians’s method. It don’t also require to know a plasma turbulence parameter, as opposed to the matching a theoretical power spectrum curve. But it require source observation on small elongation (< 20 degrees) and knowledge of solar wind velocity.

Conclusion

- A new method of source angular size estimation was proposed. It is based on observation of saturated scintillation.
- The angular size of B0531+194 is estimated by means of this method as 0’’.24 ± 0’’.05. This estimate agree with other author's data.

References

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Thank you!