ESPM-16

Tilt Angle of the Magnetic-field Axis of Sunspots from Microwave Observations: Method and Measurement Results

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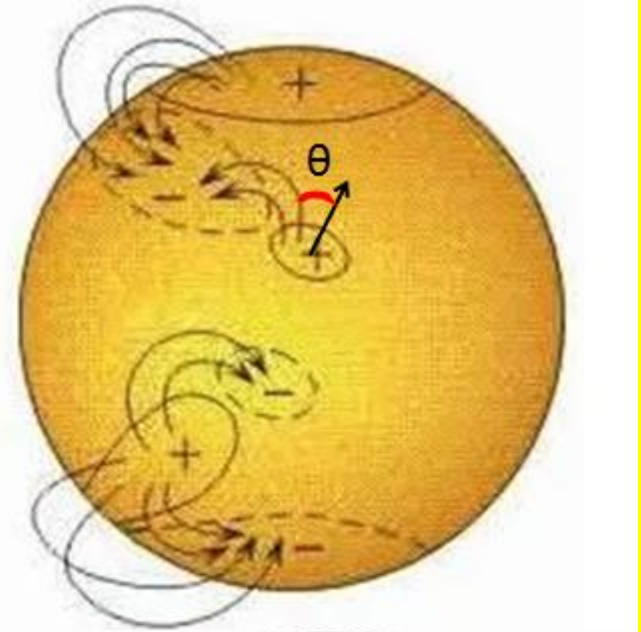
How to measure the tilt of MF



1. **Stokes parameters (I, Q, U, V) => full vector $\vec{B}$**

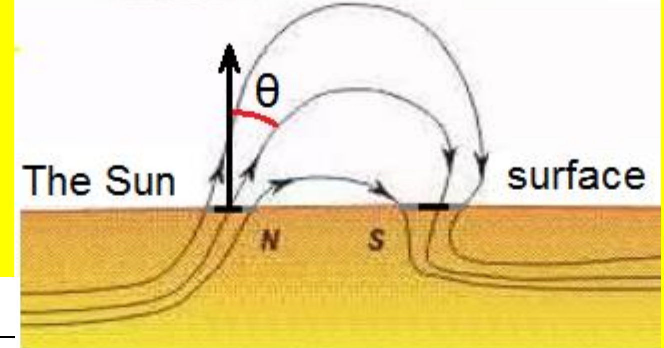
   (from line polarization observation in optics and UV)

2. **I, V => B|| + Model => $\vec{B}$**

   (MF models and/or observation from different angles)

3. **I => I + Model => $\vec{B}$**

(analysis of the fine structure of the brightness distribution: loops, arcs, brightening/darkening at different angles)



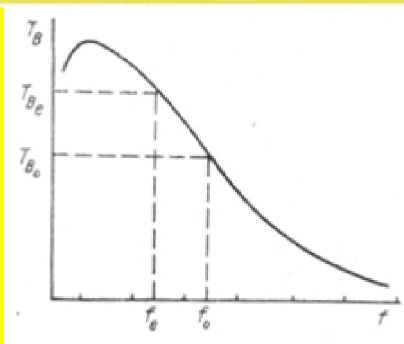
In Radio: weak MF => Thermal bremsstrahlung (like second)

$$T_b(f) = \int_0^{\tau_{max}} T_e(\tau) \times \exp(-\tau)\, d\tau$$

$$\tau_{x,o} = \int \kappa_{x,o} dl = \int \frac{\xi\, n_e \sum_i Z_i^2 n_i dl}{T_e^{3/2}(f \mp f_B\,|\cos\theta|)^2}$$

$$T_b(f) \approx T_e(\tau = 1)$$

$$f \gg f_B \;\; => V \sim B_{||} = B\,|\cos\theta|, \;\; I \approx const$$

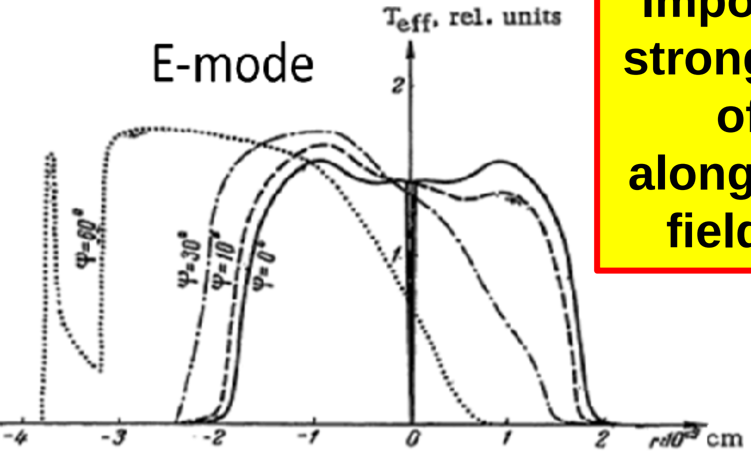


In Radio: strong MF => Cyclotron (gyro-resonance) emission (like third method)

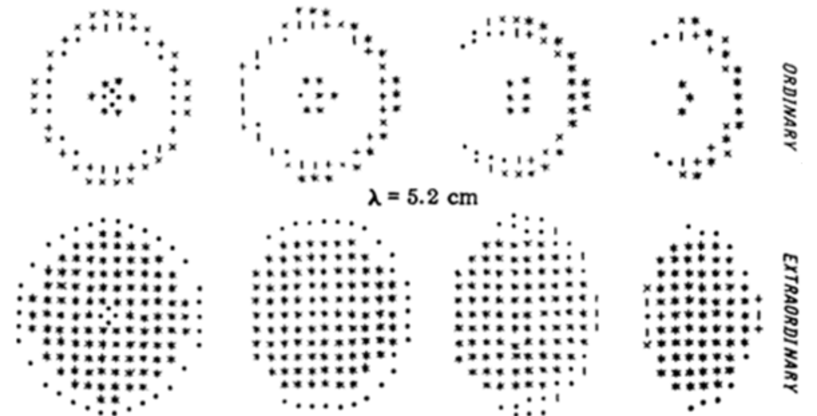
Model of sunspot cyclotron (gyro-resonance) emission

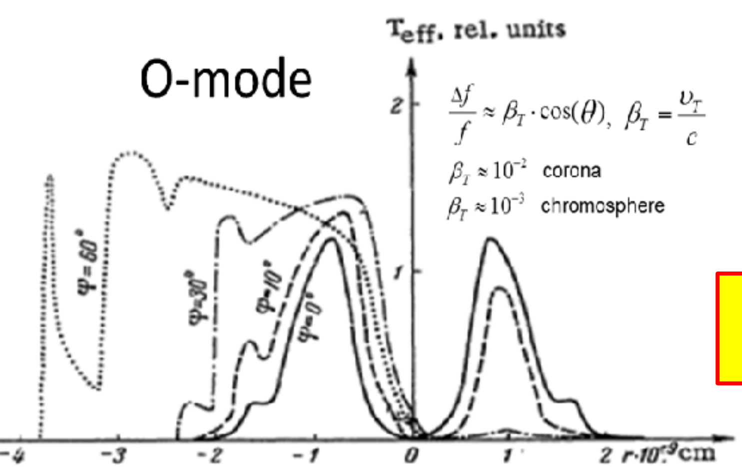
$\beta_T = \upsilon_T / c$
$u = 1 / s^2$

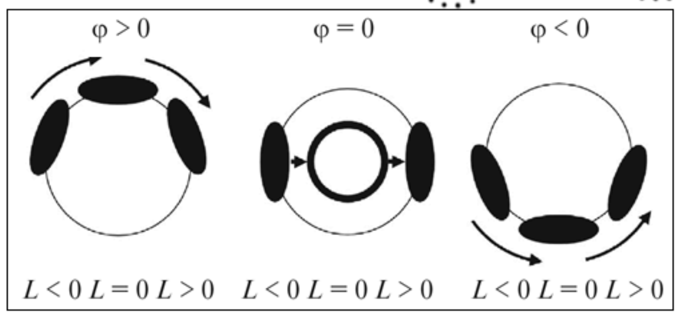
$$\tau_{js} = \frac{s^{2s}}{2^s s!}\frac{\pi e^2}{mc^2}\beta_T^{2s-2} L_H N\lambda \cdot \sin^{2s-2}\alpha \cdot \frac{(\sqrt{u}\sin^2\alpha + 2\cos^2\alpha \pm \sqrt{u\sin^4\alpha + 4\cos^2\alpha})^2}{u\sin^4\alpha + 4\cos^2\alpha \pm \sqrt{u}\sin^2\alpha\sqrt{u\sin^4\alpha + 4\cos^2\alpha}}$$



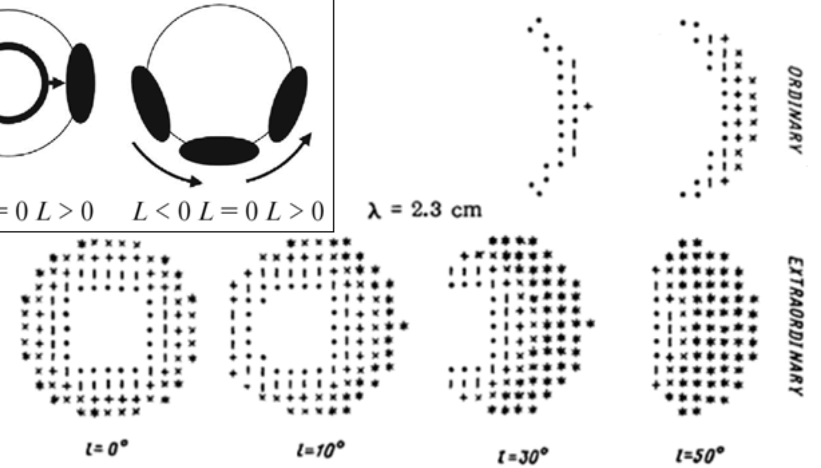
Important feature: strong suppression of radiation along the magnetic field direction!!!







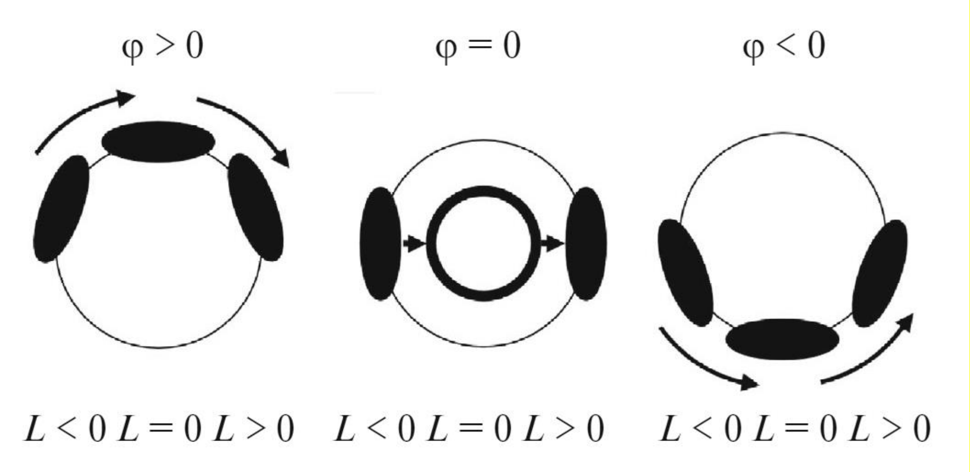
ring and crescent-shaped structures



Zlotnik E. Ya. Soviet Astron., 1968, **12,** №2, pp. 245-253 + №3, pp. 464-472.

Gelfreikh and Lubyshev, Soviet Astron., 1979, **23**, pp. 316-322.

What and How to measure

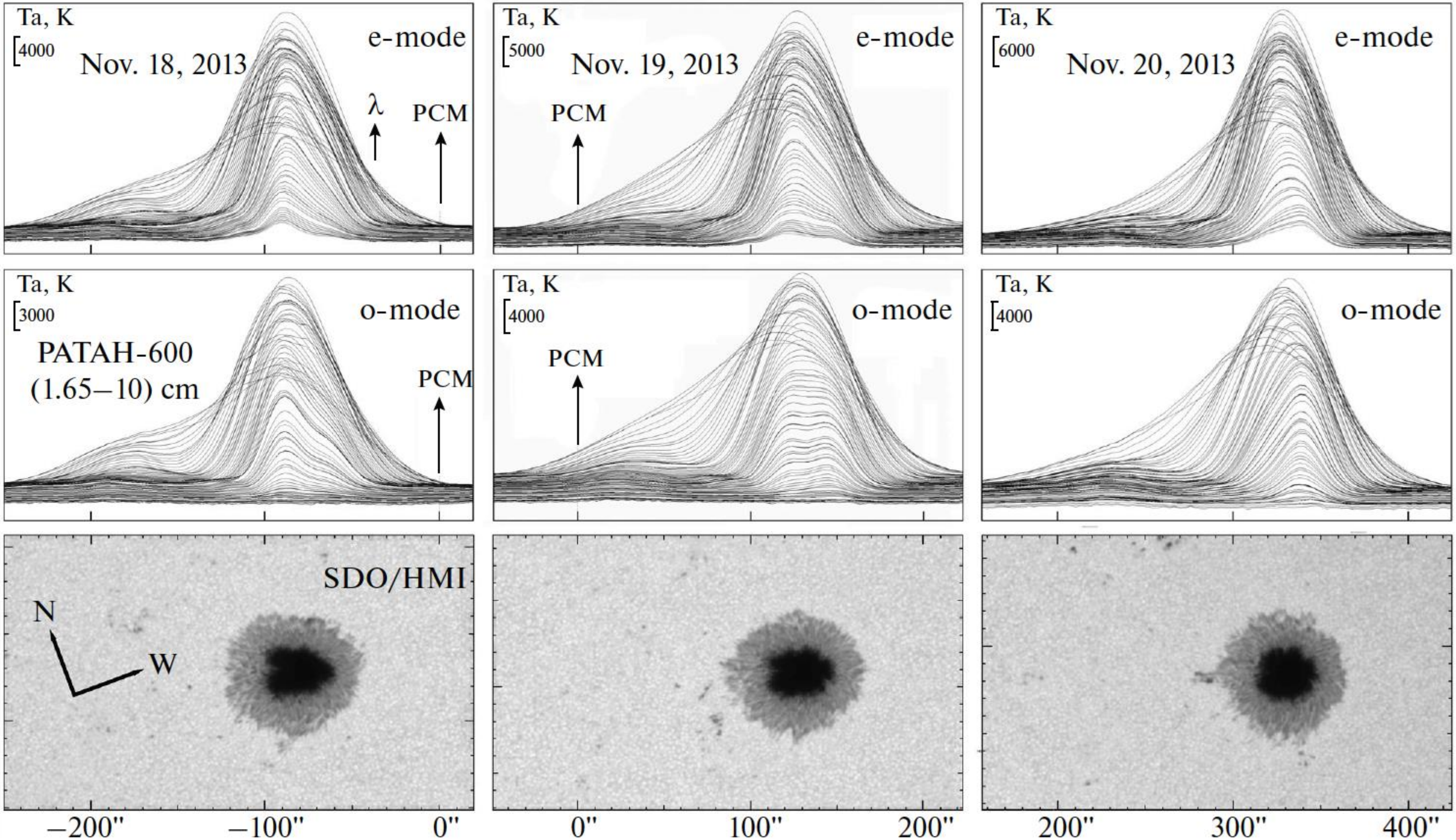


1. Real 2D image - high resolution (1-2″) - large interferometers are needed
2. Rough structure - medium resolution (10-20-30″) - large telescope
3. Integral characteristics - low resolution (>30″) - telescopes of moderate size

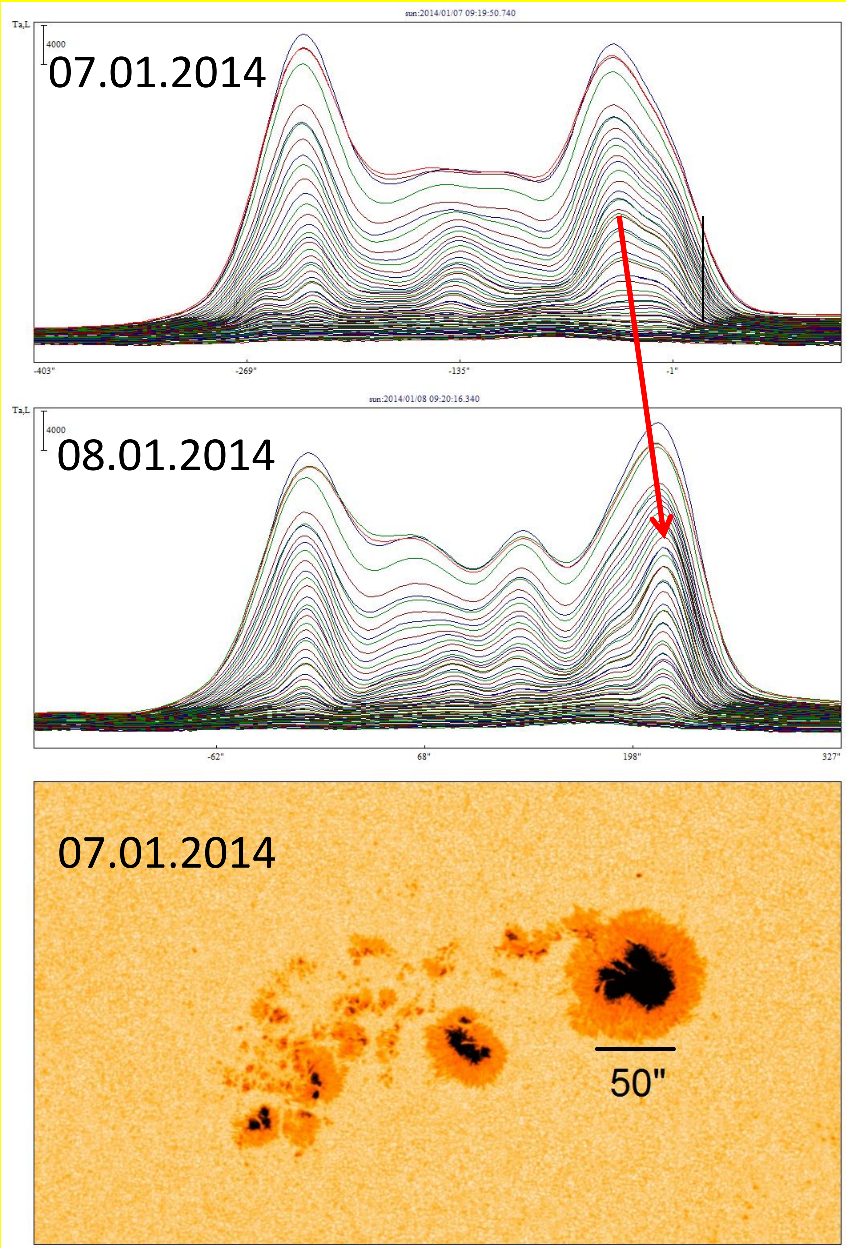
What rough characteristics can be measured :

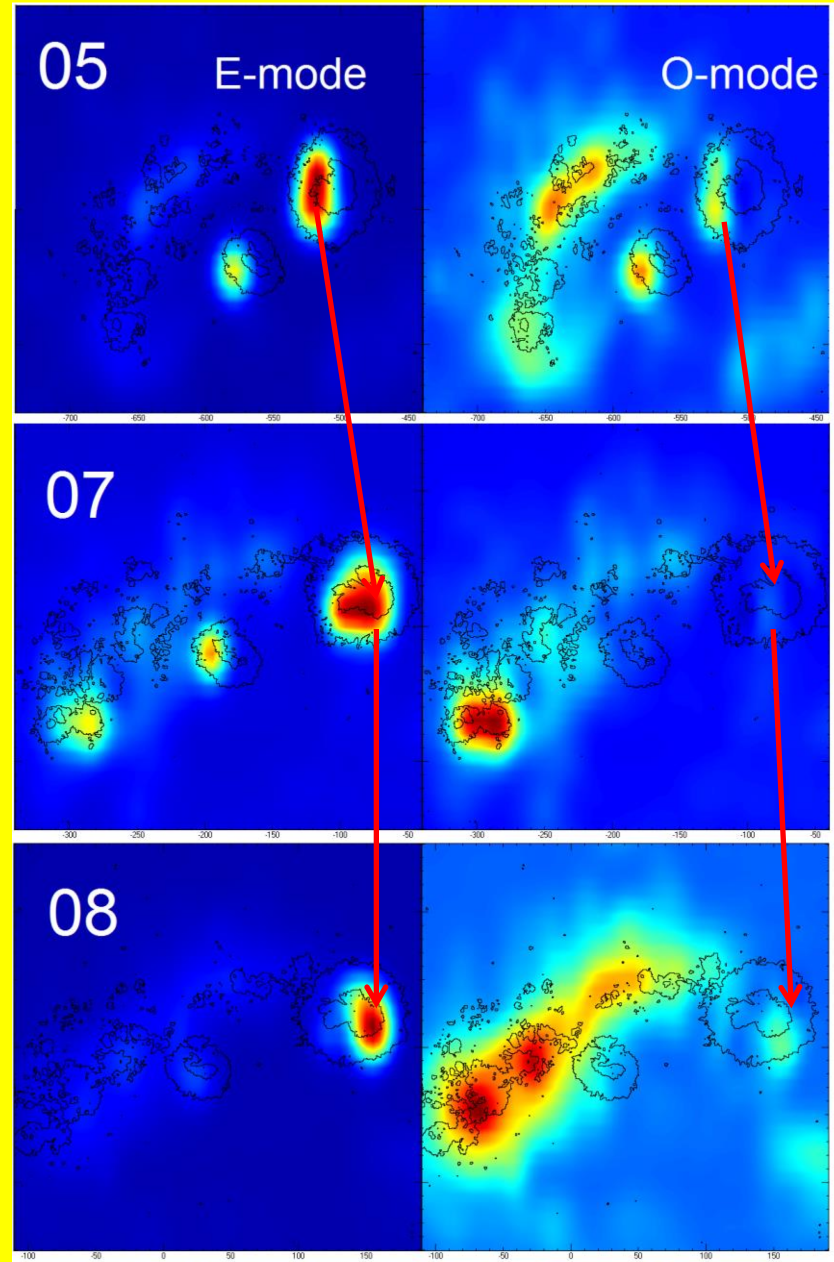
Shape – required medium resolution
Position - medium or low resolution
Flux or Intensity - low resolution (Intensity = maximum of Tb or Ta - more simple)

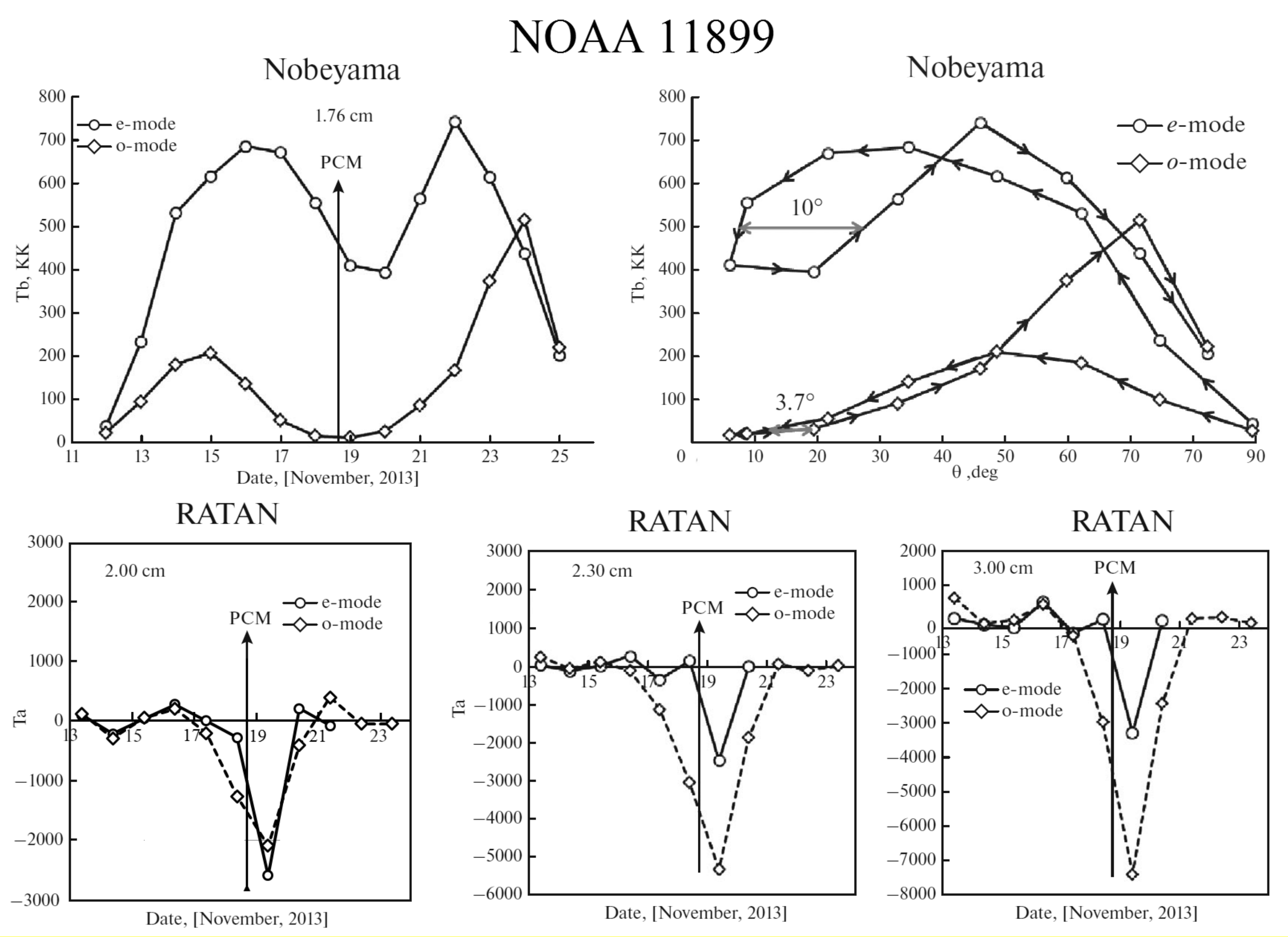
RATAN scans of NOAA 11899 in the 1.65 - 10 cm range for three days (18-19-20) .11.2013 near the PCM moment



1D (RATAN) & 2D (NoRH) NOAA 11944 sunspot image efolution

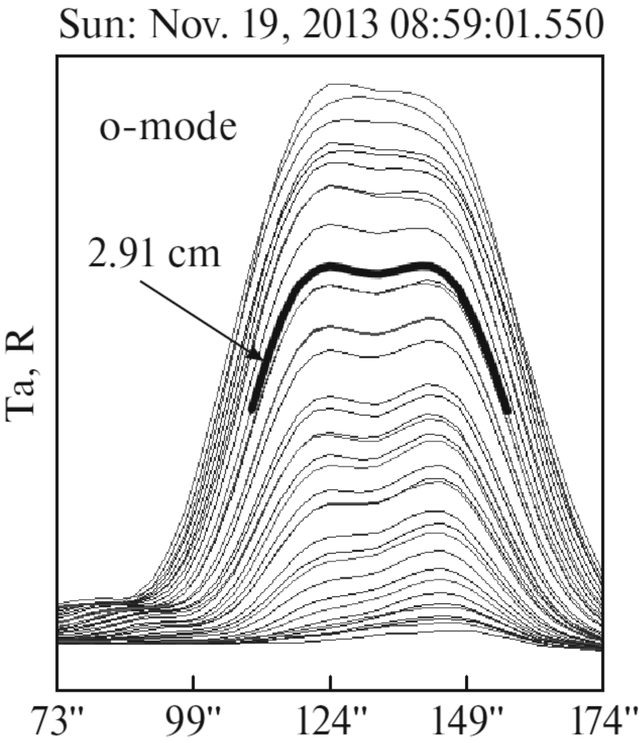


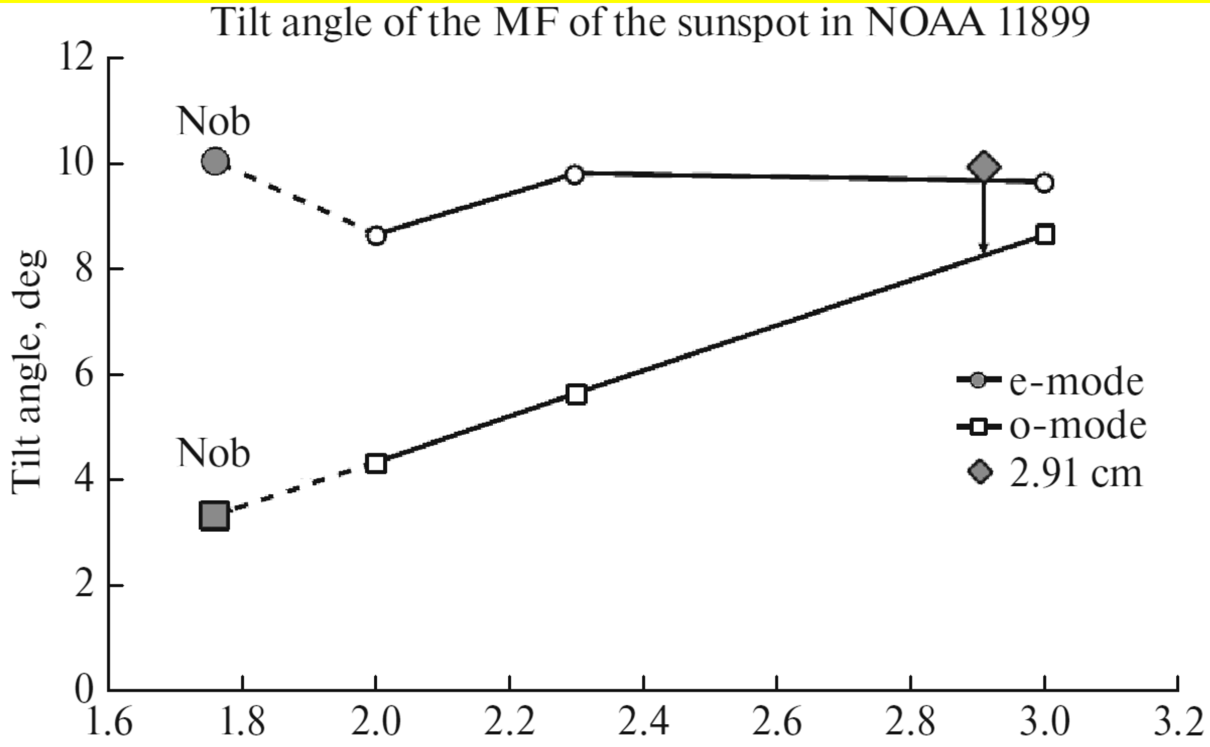




At the top right is the observed dynamics of the maximum brightness temperature Tb for Nobeyama depending on the sunspot position. The arrows show how it changed over time.

At the top left and the bottom row shows the changes in maximum Tb and Ta depending on time for Nobeyama and RATAN observations.





Right figure: dependence of the tilt angle on the wavelength for the leading sunspot of AR 11899 according to the combined RATAN-600 and NoRH data.

The arrow indicates that the diamond belongs to measurement in o-mode at a wave where the distribution of Ta is symmetric (left figure).

In addition to the above active regions, 10 active regions of various morphological structures were tested. Some results are given in the articles:

1. N.G. Peterova and N.A. Topchilo "The Gelfreikh–Lubyshev effect according to microwave observations of sunspots" // Astrophysical Bulletin, 2016, Vol. 71, No. 2. pp. 232-240.

2. N.A. Topchilo and N.G. Peterova "Tilt Angle of the Magnetic-Field Axis of Sunspots from Microwave Observations: Method and Measurement Results" // Geomagnetism and Aeronomy, 2020, Vol. 60, No. 7, pp. 881–888.

Conclusions

A new very simple technique was developed and tested for measuring the tilt-angle of the sunspots magnetic field axis. The method is based on the analysis of the temporal dynamics of the radio brightness distribution of a cyclotron source associated with the sunspot during the period of its passage through the central meridian of the Sun.

- The applicability of the method is shown for regular daily one-dimensional (RATAN-600) and two-dimensional (NoRH) observations, with an angle measurement accuracy of about 1°.
- For the investigated sunspots, the tilt angle in the microwave range is not large (1-10 °) and does not depend on the AR morphology.
- The MF of the leading sunspots is directed to the E-limb of the Sun, which could be expected, since the MF usually closes on the tail part of the AR. The deviation from this rule is explained by the presence of neighboring ARs.
- The tilt angle increases with increasing wavelength, i.e. increases with height, which is consistent with the loop model.

Thank you for your attention