Modeling the Solar Limb Brightening at 21 cm Wavelength Using Observations with an Interferometer of 3 Small Radio Telescopes

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Abstract

We present modeled images of the Sun from measurements of the interferometric amplitude and closure phase from a 3-baseline interferometer operating at 21 cm wavelength. The data were obtained from 9 June through 7 August 2006. During this period the solar activity was relatively quiet and the data is well fit using a model with equatorial limb brightening which contributes 30\% to the total solar radio flux density. Modeling the image with circularly symmetric brightening or polar limb brightening does not fit the measurements providing clear evidence that the limb brightening is largely equatorial. During the period of observations, the days with asymmetric images, as indicated by values of the closure phase which deviate from zero to 180 degrees, are well fit by adding from a single sunspot whose best fit position is consistent with the position of the major sunspot in the optical image for that day.

Solar Image Modeling

The Sun's radio image was modeled using weighted least squares to minimize Q, chi-squared for N observations of closure amplitude and phase on each day where

\[ Q = \sum_{ij} \left[ a_{ij} - m_{ij} \right]^2 + \sum_{ij} (\cos(\mu_{ij}) - \cos(\eta_{ij}))^2 + \sum_{ij} (\sin(\mu_{ij}) - \sin(\eta_{ij}))^2 \]

and

- \( m_{ij} \) = model amplitudes
- \( a_{ij} \) = observed amplitudes
- \( c_{ij} \) = observed closure phases
- \( \mu_{ij} \) = baseline index, 0 to 2
- \( \eta_{ij} \) = time index, 0 to N-1.

Ray Trace Modeling

In an attempt to explain the lack of limb brightening at the Sun's polar regions and find a model related to the solar environment we used numerical ray tracing with the solar electron density of Selhorts, Silva and Costa (2005) and electron temperatures of Gabriel (1992). The best fit model required the introduction of a latitude dependence to the electron density. We used

\[ h = (1 - \frac{h}{h_0})^L \]

where

- \( h \) = height above surface in km
- \( \eta \) = latitude in radians
- \( L \) = power law index
- \( h_0 \) = scale height

Conclusions

Data taken with a 3-element interferometer at 21 cm wavelength with short baselines shows clear evidence for limb brightening in the equatorial regions. Image models based on the corona density and temperature of Gabriel (1992) fit the data better than the older density profiles of the Newkirk (1961) model, but the physical models without spicules or other scattering mechanism produce more limb brightening than the best fit model.

References

McComas et al., 2000, JGR, 105, A3, 10, 419.