DOPPLER IMAGING OF AR LACERTAE AT THREE EPOCHS

Frederick M. Walter
CASA
University of Colorado
Boulder CO

James E. Neff
JILA
University of Colorado
Boulder CO

Jeffrey L. Linsky
JILA
University of Colorado
Boulder CO

Marcello Rodonò
Città Universitaria
Catania
Italy

ABSTRACT

Doppler imaging analysis allows use of the information contained in a time sequence of spectral line profiles to deduce the size, location, and surface flux of regions of contrasting brightness on rotating stars. We have used IUE observations to study the structure of the lower chromosphere of AR Lacertae in the light of Mg II k. We have obtained sequences of LWR/P-HI images distributed around the binary period at three epochs. We have identified discrete plage-like regions of enhanced Mg II surface flux in this system. There are temporal variations in the Mg II flux on timescales of hours as well as substantial changes in chromospheric morphology on timescales of years. Even with the limited S/N attainable with the IUE, one can map the gross structures of active stellar atmospheres. With such information, one can begin to study the true 3-D structure of the atmospheres of late-type stars.

Keywords: *Doppler Imaging; Stellar Chromospheres*

1 INTRODUCTION

The only star that presents a readily resolvable disk to us is the Sun. Consequently, we have abundant information concerning the surface morphologies of one inactive, unassuming G2 dwarf. Stars, of course, vary widely in their properties. Among the cool, solar-like stars, a number exhibit the "RS CVn phenomenon", i.e., extremely strong solar-like activity, as manifested by strong line emission from the stellar chromosphere and transition region, strong coronal X-ray emission, prominent photometric variability due to the rotational modulation of a spotted hemisphere, and radio emission in some cases. If one takes the observed solar active regions, and increases their filling factors to fill the observed solar disk, one cannot reproduce the levels of activity observed in the most active solar-like stars. In order to undertake modelling of these most active atmospheres, it is imperative that one have some grasp on the nature of the surface structures and their filling factors. Does solar analogy apply, as is usually assumed?

The technique of Doppler, or spectral, imaging uses the velocity information contained in the spectral profile of a line, together with knowledge of the stellar rotational velocity and inclination and an assumption about the surface differential rotation, to map features of contrasting brightness at a particular wavelength onto the stellar surface. In principle, the velocity of a feature relative to the rest wavelength of the line (in the frame of the star), in the absence of systematic flows, places the feature on a locus of constant radial velocity on the stellar surface. The acceleration of the feature across the line profile constrains the latitude and altitude of the feature. Further constraints are supplied by the maximum velocity observed and the fraction of the stellar rotational period the feature is visible. This technique was pioneered by Vogt and Penrod (Ref. 1), who used high S/N photospheric absorption line profiles to infer the shapes and locations of the dark photospheric spots on HR 1099.

We have used a conceptually similar technique, described in detail in Ref. 2, involving deconvolution of an emission line into its various components. Our technique is well suited to the lower S/N obtainable for the chromospheric emission lines observable with the IUE. Our target has been AR Lacertae (HD210334, G2IV+K0IV, P=1.983^d), at V=6.1 the brightest known eclipsing RS Canum Venaticorum system. We have now obtained high dispersion LWR/P spectra of the Mg II k line of AR Lac at three epochs, permitting mapping of discrete structures in the lower chromosphere at these epochs, and giving some indication of the surface morphology of a very active pair of stars.

2 OBSERVATIONS AND ANALYSIS

The number of observations and the phase coverage at each epoch are summarized in Table 1.

The analysis technique is detailed in Refs. 2 and 3. Briefly, we fit the observed Mg II k line profile with up to five gaussian components. Three of the components are well constrained in wavelength, those being the global emission from the two stars in the system and the interstellar ab-

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Table 1
Observation Log

Dates	phase range	number LW-HI	number SWP-LO
3-5 October 1983	0.85-1.64	8	9
18-19 September 1985	0.60-1.43	20	18
13-17 September 1987	0.23-2.20	34	33

sorption component (which we use as a velocity fiducial to check the IUE wavelength scale). Residuals to the fits containing these 3 components are then fit iteratively until the velocities of the global emission lines agree with those predicted from the orbital elements. The residual features traverse the global line profile as a function of binary phase, indicating that they are due to regions of contrasting surface flux on the stellar surface. Typical line profiles and fits are shown in Figure 1.

3. SUMMARY OF RESULTS

The 1983 results were reported in Ref. 2. Two "plages", regions of high Mg II surface flux, were identified on the surface of the K star. A flare was observed at Mg II and in the radio (2 and 6 cm) and perhaps in N V and C IV. No discrete structures were observed on the G star, and the global fluxes from the G and K stars, exclusive of the plages and flare, did not vary significantly. The plages have filling factors of <.005 and ≈.015 of the visible hemisphere of the K star, and Mg II k surface flux enhancements of a factor of 5 or more over that of the global emission component. Phase coverage was concentrated near the eclipses and so was not optimal for a Doppler imaging study.

The 1985 results are reported in Refs. 3 and 4. With better phase coverage, we were able to identify 3 discrete plage components on the K star. One plage is at high latitude (50°). The relative sizes, fluxes, and locations of the two equatorial plages are similar to the two observed in 1983. If the same, the plages migrated about 120° towards lower longitudes relative to a purely synchronized star. Filling factors range between 2 and 9% of the visible hemisphere. The equatorial plages appear to lie about half the stellar radius above the photosphere. The G star was observed to flare in Mg II, doubling its emission flux, and the leading hemisphere of the G star was observed to be very dark in Mg II.

The observations in September 1987 were scheduled over two orbital periods in order to reduce ambiguity in interpreting slow changes in the emission fluxes as either slow secular variations or due to rotational modulation. Detailed results are not yet available. However, no flares were observed during these two orbits. The Mg II k line profile of the K star is very similar in appearance to that observed in 1985. The G star appeared to be about 50% brighter on one side, but the dark hemisphere was much brighter than observed in 1985.

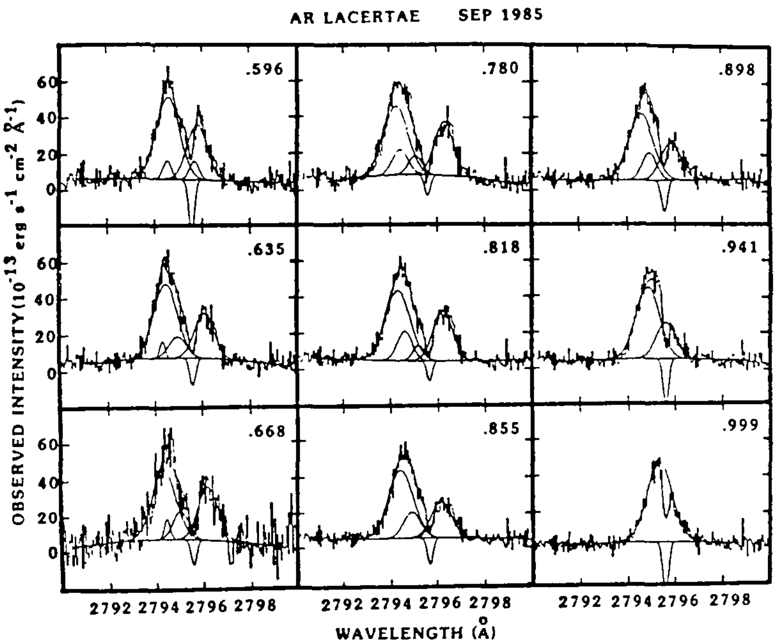

Figure 1: Typical Mg II k line profiles of AR Lac, with multicomponent fits overplotted. These spectra were cover a 19 hour period, and represent half the data obtained in 1985. Note the orbital motions of the G and K stars, plus the persistence of the smaller emission features. From Ref. 3.

4. CONCLUSIONS

It is clear that Doppler or spectral imaging observations have the potential of opening up an entirely new perspective on stars. These monochromatic images show the fallacy of modelling such stars using only one component atmospheres. Stellar surfaces are complex, as we should have anticipated from solar images, and it is likely that the solar analogy cannot be streched far enough to include the most active late type stars without major caveats.

The lower chromosphere, of course, is but one small part of the stellar atmosphere. In order to build up a true 3 dimensional picture of a stellar atmosphere, one must coordinate observations at many frequencies at the same time. How do the structures in the lower chromosphere correspond to the coronal structures inferred from X-ray observations (Refs. 5 and 6)? What spatial relations are there between the plages and the photospheric spots?

We feel it is important to continue these observations, to follow the evolution of the surface structures on AR Lac over a period comparable to the likely stellar cycle period. With the IUE we can obtain excellent phase coverage, which is necessary to discern long-lived spatial features from flares and slower secular variability. We plan to obtain a series of HST/GHRS observations with greatly improved S/N of the Mg II and C IV lines, in order to search for structures in the transition region and to study their relationship to those of the lower chromosphere. Ideally these observations can be undertaken simultaneously with the IUE, providing continuity in phase coverage, and with X-ray and radio observations, in order to yield a true three-dimensional picture of the outer atmosphere of a very active star

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