Stellar Microscopy: Spectroscopic Follow-up of High Amplification Microlensing Events (TOO Mode - Continuation from 1997)

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1. Scientific Justification

Gravitational microlensing is a new technique for studying the surfaces of distant stars (e.g. Sasselov 1997). Events are detected in real time and can be followed up with precision photometry and spectroscopy (Alcock et al. 1997). This is especially efficient for red giants in the Galactic bulge. Microlensing events towards the bulge occur when a low-mass star from the disk (the lens at $D_{OL} \approx 6kpc$) crosses the line-of-sight towards a star from the bulge (the source at $D_{OS} \approx 8kpc$); typical durations are between weeks and months. While most lenses are point masses, many ($\sim 20\%$) of the sources monitored in the Galactic bulge are red giants and supergiants – their angular radii are *comparable* to the Einstein radius of a sub-solar mass lens (in the range of 50μas). In addition to being resolved by most lenses, the projected disks of bulge giants are large enough to make the probability for a lens transit very high – in fact, at least one such event (MACHO Alert 95-30) was very well observed (Alcock et al. 1997). It is likely that more such events will occur this coming season. Last season (summer 1997) our program was approved for its second half, but no events occured.

The motivation for stellar imaging via microlensing lies in its unique ability to provide center-to-limb and depth-dependent "scans" of a stellar atmosphere. The 2-D and 3-D structure of stellar atmospheres other than the Sun is not well known. Theoretical modelling relies heavily on the solar atmosphere model, but this situation is unfortunate for a number of reasons. There has been an increased demand for accurate stellar models from a number of fields. To name a few, much improved color-temperature calibrations are needed for calibrating distance indicators and determination of ages; stellar population syntheses (e.g. for high-z systems) rely critically on the accuracy of current stellar models. Our Sun is not a good zero point for most of these applications.

Stellar interferometry, eclipsing binaries, and Doppler imaging, provide valuable surface information, like limb darkening. However, by its nature, microlensing imaging is the only one which allows us to observe the center-to-limb variation in spectral lines (and their profiles). Such observations are invaluable for the construction of detailed models of the atmosphere, as it has been long known from the study of the Sun. We have developed the theoretical tools to explore this new field (Sasselov 1997; Heyrovsky, Sasselov, & Loeb 1998), and are currently analysing the spectroscopic dataset for M95-30. Gravitational microlensing offers an easily accessible, immediate, and inexpensive way to image at least some types of stars. It also offers access to stellar populations (in the Galactic bulge and Magellanic Clouds), which are beyond the reach of any interferometer. Gravitational lensing does resolve, *as well as* amplify, thus making 17 *mag* bulge giants as bright as 12 *mag* – a target easily accessible to our 60-inch FAST at FLWO.

2. Observational Considerations

A typical transit of a lens across the face of a bulge giant lasts less than one week, most likely – only a couple of days. From theoretical point of view we are most interested in the epochs of ingress and egress, because they provide the highest sensitivity in center-to-limb variation (hence depth resolution into the atmosphere). This point is illustrated in Fig. 1, which shows the equivalent width of the hydrogen Hα absorption in the red giant of M95-30 as a function of lens position with respect to the center of the giant's disk, in units of its radius (hence the limb is at 1.0). The observations (spectroscopy at Mt.Stromlo and CTIO; resolution: 4–4.6Å) began near closest approach, missed one night (at lens position 1.0), and continued for every night thereafter (Alcock et al. 1997). The solid line shows the theoretical model which was built independently of the observations.

Our Fig. 1 also illustrates the requirements for a spectroscopic follow-up of microlensing imaging events: modest spectral resolution, and one spectrum per night over a period of one week or less. Most red giants are smaller than M95-30 ($R = 60R_\odot$), and a transit will last shorter (depending also on the lens transverse velocity).

The alerts for microlensing are now provided predominantly by the MACHO collaboration on $http://darkstar.astro.washington.edu$, with the OGLE and EROS2 projects preparing to join in. Alerts for anomalous events in the process of follow-up are provided by the PLANET collaboration. One of the authors (DDS) receives e-mail from both MACHO and PLANET whenever an event is likely to result in a low impact parameter lens transit. The alert is given between 3 to 10 days before maximum amplification, thus providing ample time for planning the follow-up observations. The alerts are accompanied by good coordinates and finding charts.

Currently spectroscopic follow-up is done by the GMAN-MACHO collaboration (Alcock et al. 1997). Their impressive effort is mostly geared towards the use of extended source effects for breaking degenaracy in the microlensing solution and obtaining secure parameters for the lenses (see Gould 1994; Loeb & Sasselov 1995; Alcock et al. 1997). Our goals are different – solving the inverse problem, thus we are more interested in spectral coverage during maximum amplification.

We had one successful follow-up at the 60-inch FAST at FLWO already – 97BLG10 in April 1997, which showed the feasibility of the project. Unfortunately, 97BLG10 happened to be in a very crowded field and the analysis of the spectra did not reveal resolved features. The event was also too early in the Bulge season and difficult to follow up. However, the quality of the FAST spectra and the coverage was very adequate. The 97BLG10 observations were possible thanks to the kind generosity of the Supernovae team, and P.Garnavich in particular, who added the target to their SN list. Given the many similarities between the microlensing and SN programs, we propose to be added to the COMBO FAST list of "target-of-opportunity" programs. We expect to use only a small fraction of 60-inch FAST time, because the Galactic Bulge season is not very long, and at most 2 to 3 high-level alerts are expected per season. As far as resolution is concerned, while we benefit from higher spectral resolution, the parameters commonly used by the SN team are adequate for us too. It is more important that observing nights **not** be missed during a transit, as was the case with M95-30 (Fig.1) where the most important phase (at 1.0) was omitted.

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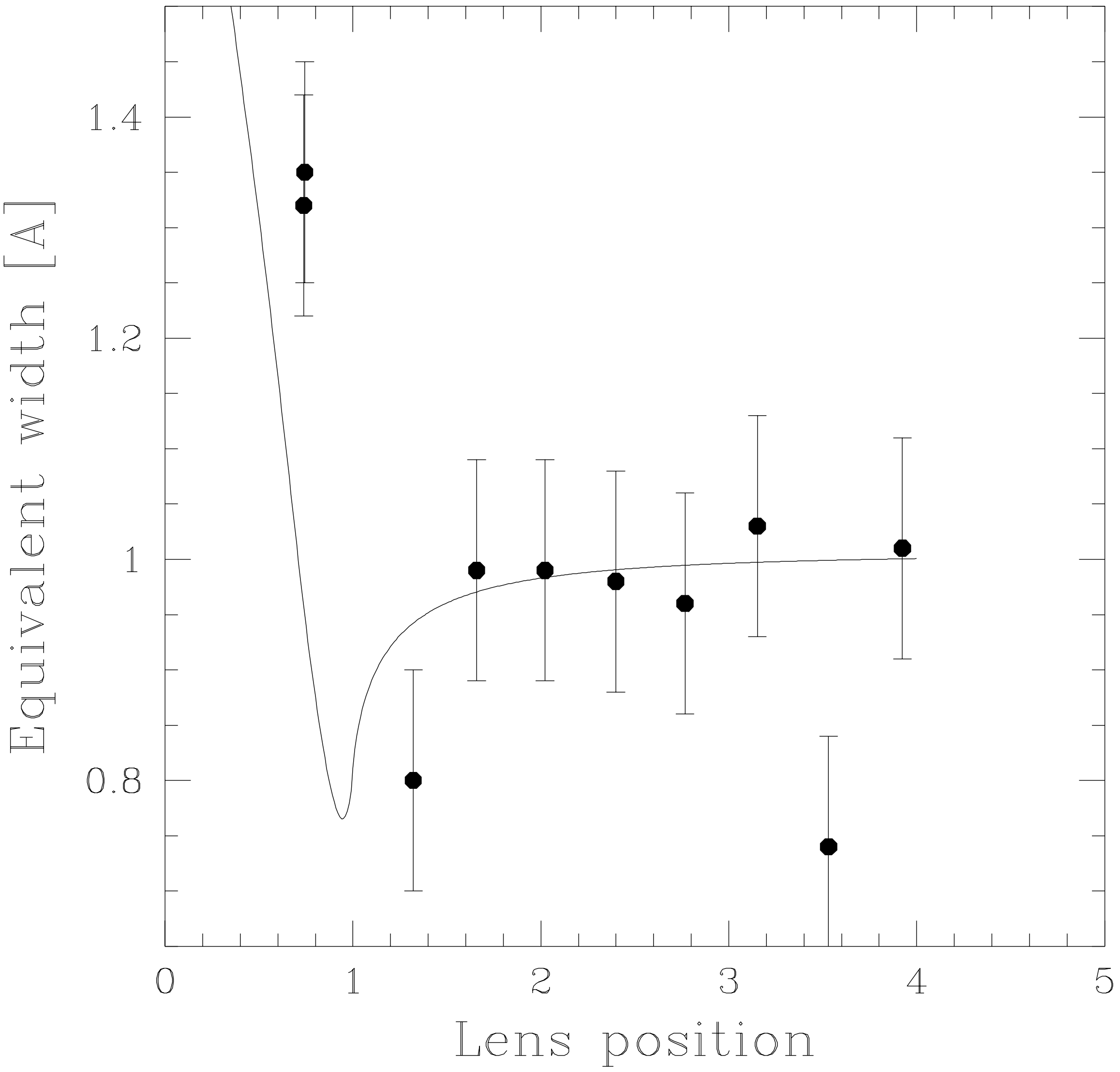

Fig. 1.— The equivalent width of the Hα line in M95-30 as a function of lens position relative to source star center (0.0); the closest approach and limb crossings (at 1.0) were not observed (Alcock et al. 1997). Solid line is model prediction (Heyrovsky, Sasselov, & Loeb 1998).