IMPORTANCE OF SMALL TELESCOPES IN THE UNDERSTANDING OF ACTIVE HOT STARS PHYSICS

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Abstract. Active hot stars (Be stars) have been observed and studied for more than two decades. They exhibit hydrogen emission lines in the visible domain and often some emission lines of singly ionized metals. These emissions originate in a circumstellar envelope produced by a strong radiative stellar wind. Since the discovery of the prototype star of this class (γ Cas) by Father A. Secchi in 1866, the basic physical properties of these objects are still poorly known. These stars are also very bright (most of them can be found in the Bright Star Catalogue) which make them good targets for small telescopes studies. In the following I will focus on some studies that can be done using a 40 cm telescope class. Then I will explain how small telescopes can be combined in an interferometric network in order to reach one milliarcsecond (mas) angular resolution even if each telescope's aperture can be smaller than ten centimeters. With this technics it becomes possible to measure very small and faint structures on the stellar surface of stars other than our sun.

1. Effect of the Metallicity on the Be Phenomenon

The establishment and the maintainence of a circumstellar envelope around a Be star is not well understood. We know that metallic lines play an important role in the possibility of driving a radiative wind for early type stars. For cooler stars we must invoque another phenomenon to 'start' the wind since the radiative pressure itself is not sufficient to initiate a wind (Abbott, 1978). Some mechanisms like non-radial pulsations due to an iron opacity jump and thus the possibility of an instability domain between δ Sct and β Cep variables is often mentioned (Keller *et al.*, 1999). Nevertheless, the correlation between the metallicity of a globular cluster and the Be phenomenon is not well established. This kind of studies can be done thanks to small telescopes, using a very narrow spectral bandwith centred on the Hα emission line in order to detect Be stars in a given stellar field (see for instance Figure 1 and Figure 2).

2. Variability of Active Hot Stars

Be stars are variable stars. The timescale of the variability can be as short as a few minutes indicating photospheric activities such Non Radial Pulsation (see

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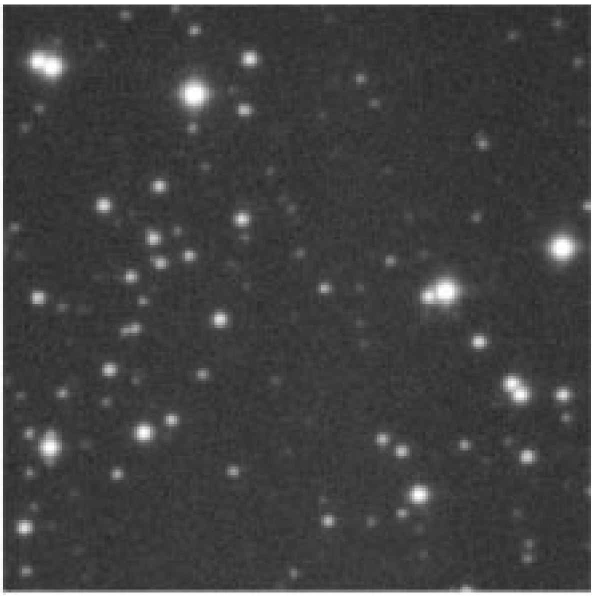

Figure 1. Open cluster NGC 663 (SMC) from David Mc David 1995, Limber Observatory observed with a 40 cm telescope.

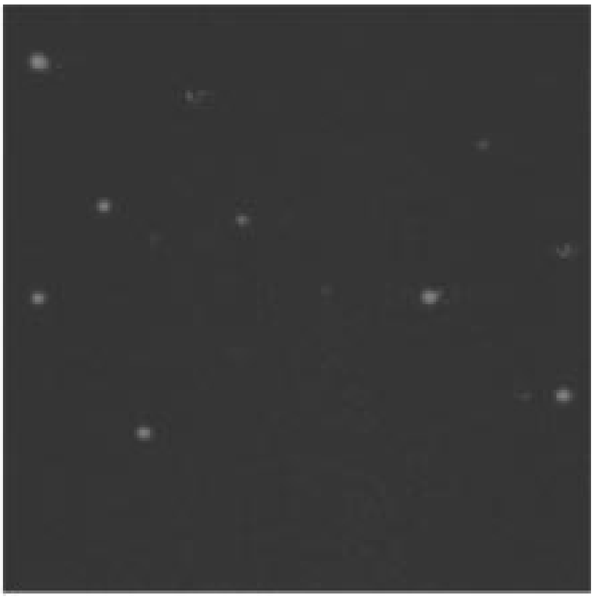

Figure 2. Be stars detected in the Open cluster NGC 663 (SMC) see. Figure 1 from David Mc David 1995, Limber Observatory with a narrow spectral bandwith centred on the Hα emission line.

Figure 3. Non Radial Pulsation (NRP) $l = m = 4$.

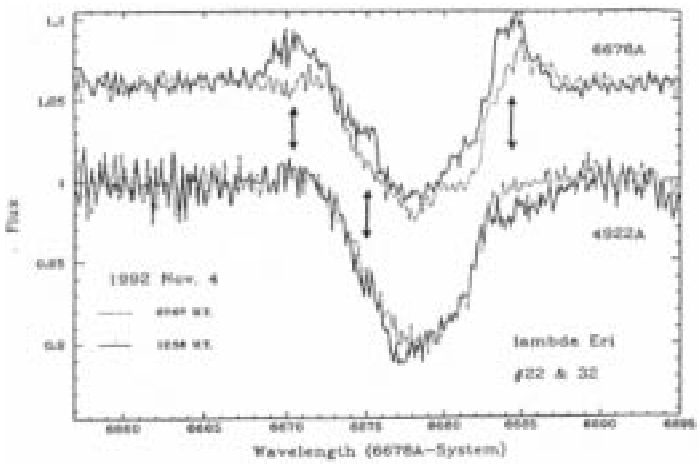

Figure 4. λ Eri Line profile variation (λ 6678) due to a mass ejection from the stellar surface. From Smith (1993), IAU Symp. 162.

Figure 3) or mass ejection (see Figure 4) from the stellar surface. These studies are more difficult to follow with small telescopes since they require a very good (and well controled) spectrograph with a spectral resolution up to 50000. Moreover a R = 50000 spectrograph is not realistic for a 40 cm telescope. The mid and long term variabilities such V/R variations (see Figure 5 and 6) or photometric variations are more suitable for small apearture telescopes. Some of Be stars present a cyclic variation between the B ‘normal’ type with a classical photospheric line

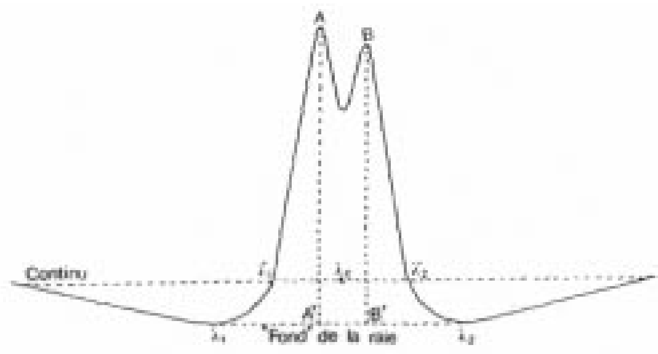

Figure 5. V/R determination: V/R = $I_A - I_{A'}/I_B - I_{B'}$.

(in absorption) see Figure 7, than, they can exhibit an emission line (and thus are showing the Be phenomenon), they can also present some shell components (with a very narrow and deep central absoption (see Figure 8) for finally returning to the initial B 'normal' stellar type. This kind of 'cycle' is not well understood and can be studied and followed with small telescopes.

3. Small Telescopes in a Network: Interferometric Observations

By using a network of small telescopes you can increase drastically your angular resolution. Even with very small telescopes (less than ten centimeters) if you separate them by a baseline of one hundred meters, you can achieve milliarsecond angular resolution observations. Then, the instrumental problems are not coming from the telescopes but from the way of controlling the metrology of the system in order to obtain interference fringes in the focal plane of the interferometer. Nevertheless, in France, amateur astronomers are bulding a small interferometer showing that this kind of intrumentation is not out of reach of Developing Countries (If you need more details on that project you can contact ADIA: Association pour le Developpement de l'Interferometrie Amateur, 1541 Bois Comtal, 69390 Millery, France.

3.1. Limb Darkening

With milliarcsecond angular resolution it will be possible to measure limb darkening of stellar photosphere. The brightest yellow and red giant stars have photospheres with diameters of several milliarcseconds, sufficiently large to be well resolved in the visible and infrared using baselines of a few tens of meters. Limb darkening can be detected through measurements of the first sidelobe of the visibility function, and to properly map the intensity across the disk an interferometer must be able to measure fringes whose contrast is less than about 10%. The observations require baselines of about twice those which resolve the star's angular

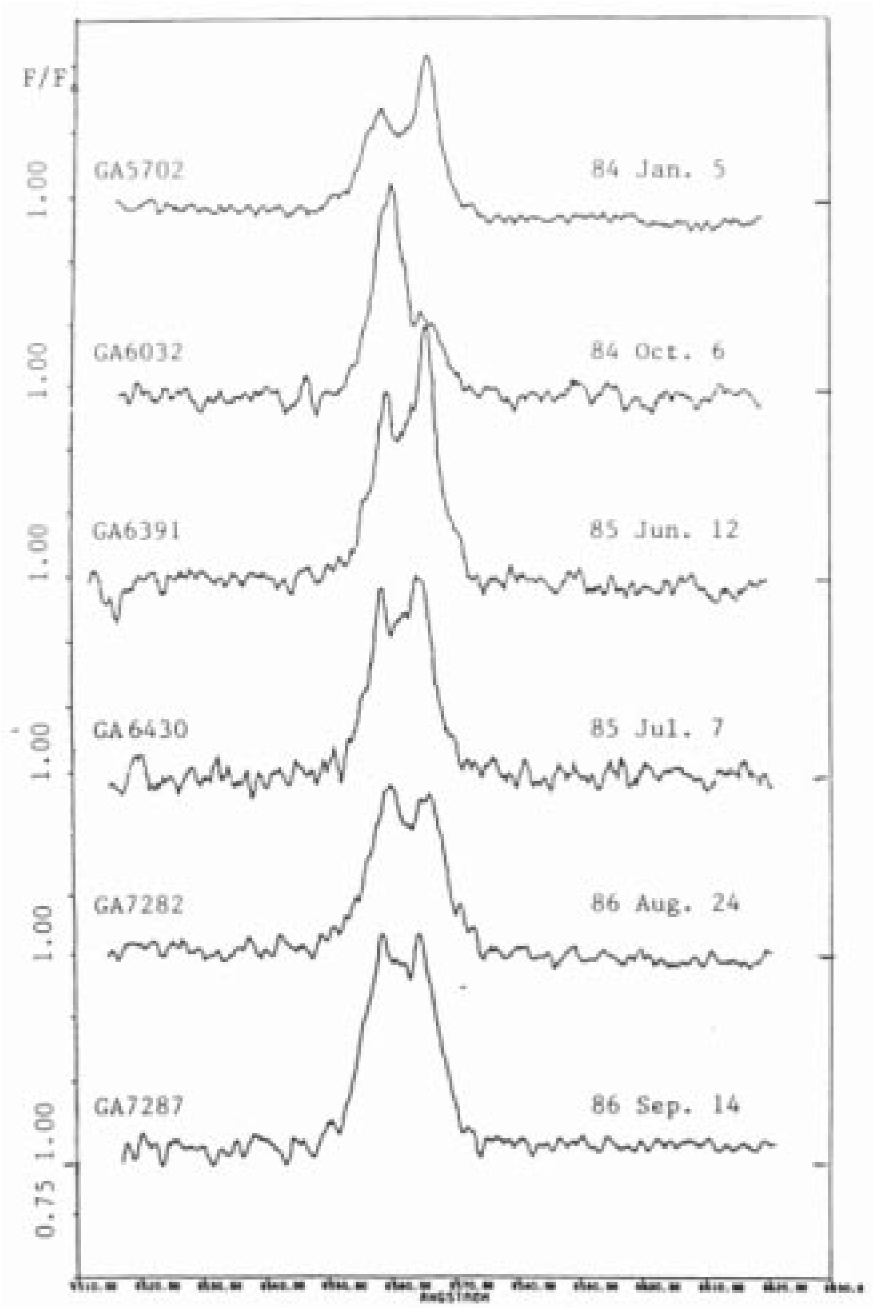

Figure 6. γ Cassiopeiae V/R variations as a function of time (months).

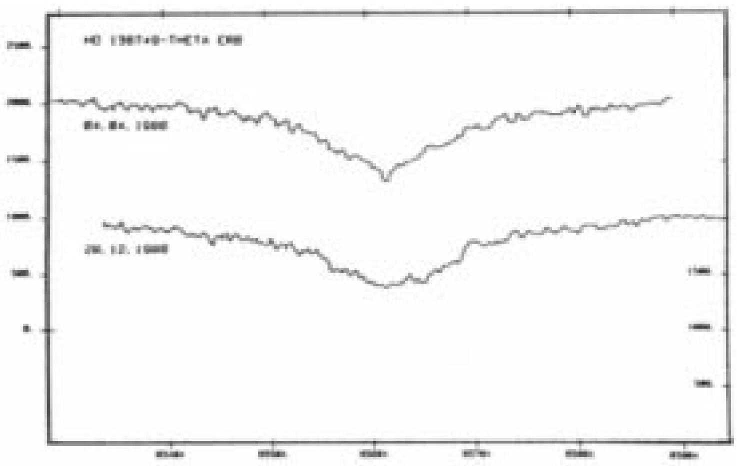

Figure 7. A ‘classical’ (in absorption) photospheric Hα line profile.

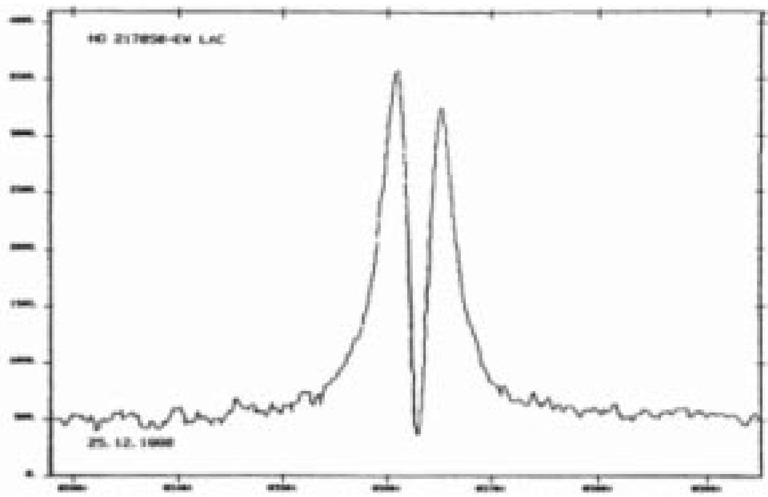

Figure 8. A typical Hα shell line profile.

diameter. Usually, limb darkening of a stellar disk is predicted by modeling the emission in the continuum or photospheric lines. An important test of these predictions is the comparison with interferometric measurements of the star’s intensity distribution.

3.2. ENVELOPES OF BE STARS

Interferometry can also provide strong constraints on circumstellar models.

As a star evolves it follows a path through the HR diagram that is dependent on its mass, and at some stage will exhibit a radiative stellar wind. The mechanisms that produce a stellar wind depend on the effective temperature and spectral class of the star, and may include the following:

1. Thermal pressure, as in the case of the solar wind.
2. Radiative pressure on both continuum and lines, for hot stars with effective temperatures of $\sim$ 15000–50000 K.
3. Radiative pressure on dust for relatively cool stars.
4. Other physical phenomena such as magnetic fields or stellar rotation.

The way in which long baseline interferometry can be used to constrain different models will be illustrated in the following.

Be stars are presumed to be fast rotators spinning at 0.5 to 0.9 of their critical velocity and have a large stellar wind and high mass loss. This stellar wind seems to be at the origin of what is usually called a *two component* envelope, which is characterized by

1. An equatorial plane with high density and low expansion where the Balmer emission lines are formed.
2. A polar region with low density and high expansion where the UV absorption line profiles are Doppler shifted with velocities up to 2000 km s^{-1}.

This envelope is also responsible for a linear polarization by free electrons of about $\sim$ 1.0–1.5%, and an IR excess that has been measured by IRAS. Based on this, many ad-hoc models have been computed which usually attempt to fit some Balmer line profiles and possibly the continuum emission flux. However, none of these reproduce intensity maps as a function of wavelength or incorporate high angular resolution data by computing theoretical visibilities.

3.3. A MODEL OF γ CAS TO INTERPRET INTERFEROMETRIC MEASUREMENTS

We have built a code (SIMECA) which reproduces both spectroscopic and interferometric data that have been measured with the GI2T interferometer. It is a latitude-dependent radiative wind model for Be stars which clearly shows that the morphology of the circumstellar envelope depends strongly on the central observational wavelength and bandwidth (Araújo and Freitas Pacheco, 1989; Araújo *et al.*, 1994; Stee and Araújo, 1994; Stee *et al.*, 1995). We have modified this code in order to build a possible scenario for the Be star γ Cas which has been observed with GI2T during an international observational campaign in autumn 1993. The model indicates that a radiative wind, driven mainly by optically thin lines at the equator, is a likely scenario for γ Cas. This is discussed in greater depth in Stee *et al.* (1995, 1996, 1998). The SIMECA code is charge-free and can be used by people interested in the modelling and the study of active hot star. If you need a copy of this code please contact me.

4. Conclusion

There is a lot of very interesting astrophysical programs on active hot stars that can be run using small telescopes. The study of the origin of the Be phenomenon in open cluster as well as the variability of these objects is very promising. Observations with interferometers will provide insight and open new horizons in problems of stellar astrophysics. The solution of these problems requires high spatial resolution, obtainable through long baseline measurements. These must be tied into stellar models and we are ready to help Developing Countries to use our code (SIMECA) that we have developped to interpret their future spectroscopic, photometric and interferometric observations.

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