Delta Scorpii 2011 periastron passage observing campaign

The periastron passage in delta Sco may lead to exciting interactions between the two stars and between the stars and the stars and the circumstellar matter (the latter manifests itself through emission lines such as in H_alpha). Since the orbital period of delta Sco is of order 10 years, and similarly eccentric systems with an early B-type primary are not common, the 2011 event will be a rare opportunity to gain deep insights into the physical responses to such an event. Delta Scorpii is also one of the closest Be stars (parallax 8.12 mas) enabling to resolve the disk and its distortions interferometricly.

Through observations permitting sufficiently accurate radial-velocity measurements, it will be possible to substantially improve on the uncertainties of the predicted date of the periastron. Such an improvement will enable us to use scarce resources at some of the world's premiere observatories much more effectively by scheduling the observations for exactly the moment when the main action is expected to happen.

If you find this an interesting project to support, you will below find some recommendations on how to best organize such observations and their reduction. Any contribution of the kind described will be a great help, and we will be very grateful for everyone of them.

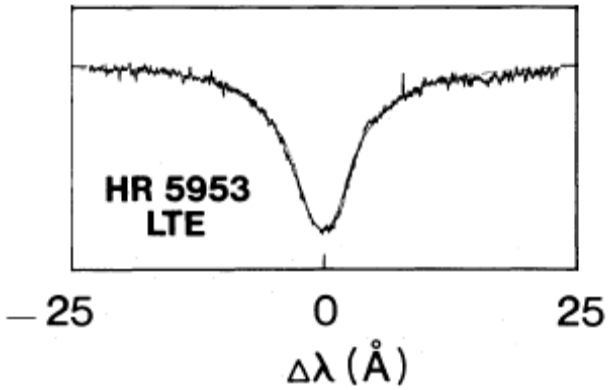
Many thanks for your interest and kind regards,

Dietrich Baade (1), Thomas Rivinius (1), Stan Stefl (1), Anatoly Miroschnichenko (2), Ernst Pollmann (3), Olivier Thizy (4), Jose Ribeiro (4), Christian Buil (4), François Cochard (4), Valérie Desnoux (4)

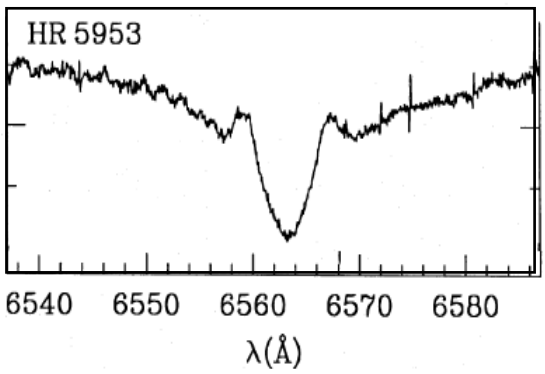
(1)European Organisation for Astronomical Research in the Southern Hemisphere
(2)University of North Carolina Greensboro
(3)ASPA-ArbeitsgemeinschaftAmateur-Astrospektroskopie
(4)ARAS - Astronomical Ring for Access to Spectroscopy on behalf of a much larger worldwide community

GENERAL

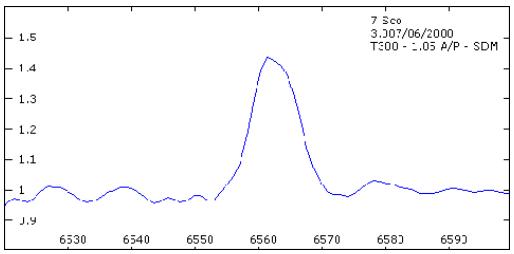
B emission (Be) stars are non supergiant B-type stars that show, or have delta Sco shown, H-alpha emission (see general reviews of Slettebak, 1988 and Porter & Rivinius, 2003). The understanding of their nature and processes to Dschubba create disk around those stars is still unknown and amateur contribution HD 143275 through long-term monitoring is critical. Delta Sco (B0.3IV, HD143275, HR5953, SAO184014) is a great exemple where amateur can contribute HR 5953 through continuous spectroscopical monitoring, specially through the SAO 184014 periastron passage. This bright second-magnitude star was catalogued as a multiple star without certain/confirmed period and was considered as a standard, normal B-type star (Settleback in 1982-1985).
A spectrum by Heasley & Wolff (1983) didn't show any emission. But a spectrum taken in 1990 (published in 1993 by Cote & van Kerkwijk) shows an emission on the flanks of an absorption core and delta Sco was then considered as Be star.



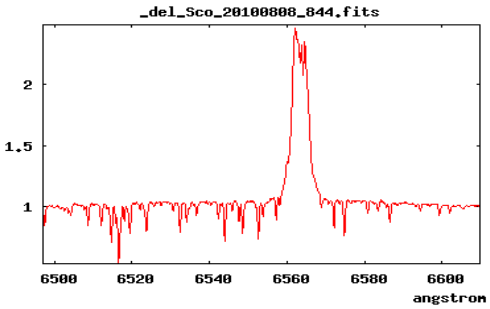
1982 (Heasley, 1983)



29-aug-1990 (Coté, 1993)



3-jun-2000 (S. & D. Morata; Buil atlas)

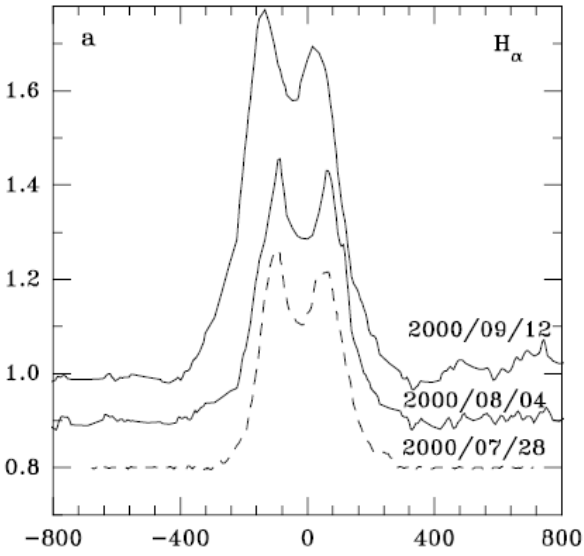


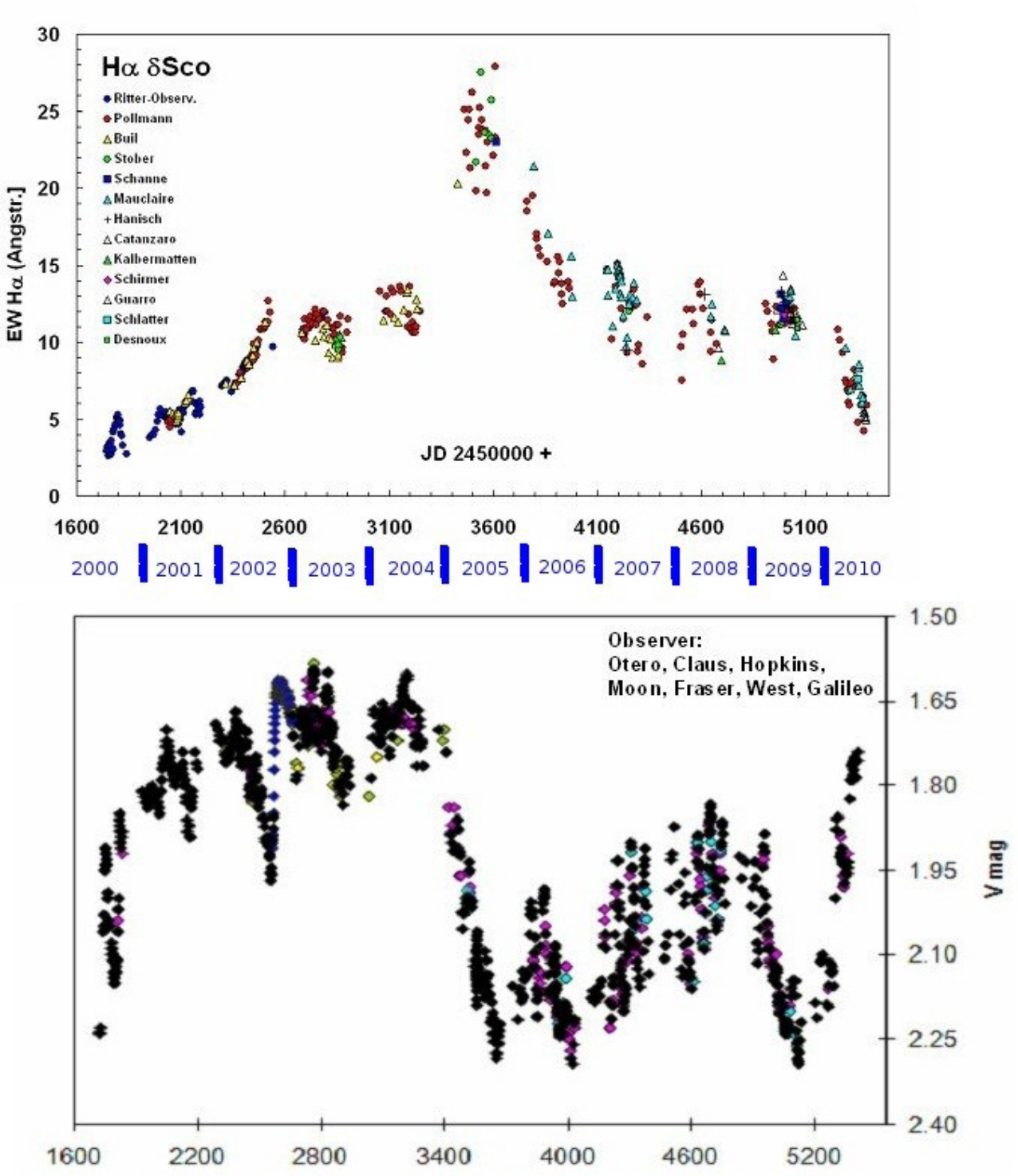
3-aug-2010 (Thierry Garrel; BeSS)

Snapshots of delta Sco spectrum (H-alpha) through the years...

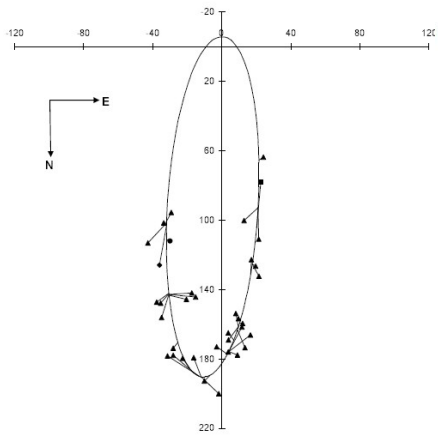
S. Otero from Buenos Aires (Otero et al. 2001; Fabregat 2000) reported a gradual brightening with visual mag estimates: June 30.03, 2.24; July 4.08, 2.23; 16.09, 2.06; 20.02, 2.04. This discovery was soon followed by spectroscopic observations (Miroshnichenko, 2001) revealing a strong double-peak emission line.

The H-alpha and He I 6678 emission line have been continuously monitored (Pollmann 2005, continued through time; Pollmann 2009; Buil Be atlas; BeSS databse). H-alpha Equivalent Width (EW) show an increase until 2005 and a decrease since with a clear anti-correlation to visual magnitude.





H-alpha EW and V-mag anti-correlation (Ernst Pollmann)



The orbital elements for δ Sco

Element	Ref. *a*	Ref. *b*	This Work
Period P (yr)	10.58 ± 0.08	10.58^c	10.74 ± 0.02
Epoch of periastron T	B1971.41 $\pm$ 0.14	J2000.693 $\pm$ 0.008	J2000.69389 $\pm$ 0.00007
Eccentricity e	0.92 ± 0.02	0.94 ± 0.01	0.9401 ± 0.0002
Semimajor axis (mas) a''	107 ± 7	107^c	98.3 ± 1.2
Inclination i	$48\overset{\circ}{.}5 \pm 6\overset{\circ}{.}6$	$38^\circ \pm 5^\circ$	$38^\circ \pm 6^\circ$
Long. periastron ω	$24^\circ \pm 13^\circ$	$-1^\circ \pm 5^\circ$	$1\overset{\circ}{.}9 \pm 0\overset{\circ}{.}1$
Long. of asc. node Ω	$159\overset{\circ}{.}3 \pm 7\overset{\circ}{.}6$	175°	$175\overset{\circ}{.}2 \pm 0\overset{\circ}{.}6$
Systemic RV V_γ (km·s^{-1})		-6 ± 0.5	-6.72 ± 0.05
RV amplitude K_A (km·s^{-1})			23.84 ± 0.05
Semimajor axis of primary a_A (km)			$(7.1 \pm 0.1) \times 10^8$
Mass function $M_B^3/(M_A + M_B)^2$ ($M_\odot$)			0.9 ± 0.4

Ref. *a* Hartkopf et al. (1996)
Ref. *b* Miroshnichenko et al. (2001)
[c] Value assumed from Ref. *a*

Interferometric orbit for delta Sco and orbital elements (Tango et al., 2009)

Recent interferometric observations (Tango et al., 2009) led to new orbital elements and masses estimation: M1 = 15 +/-7 M* and M2 = 8.0 +/-3.6 M* General question: Do we know what are the types of the two stars ?

The latest forecast for the periastron passage in the delta Sco binary is July 4th 2011. However, the uncertainty can be as large as one month while it is important that specific observations aimed at hitting the event must be timed much more accurately. A very conservative estimate should not be more than 10-20 days – this is still ¼ to 1/3 of of the time of the disk perturbation (according to Atsuo's modeling) and so the amateur observations can still improve the periatron passage significantly.

The best empirical criterion to predict the date of the periastron passage is the radial velocity (RV) of the primary star. Because of the high eccentricity, the RV stays roughly constant for a long time and drops significantly only about one month before the closest encounter. In this case, "significant" means about 10 km/s (about 0.2 Å on H-alpha), which is unambiguously detectable from carefully calibrated spectra.

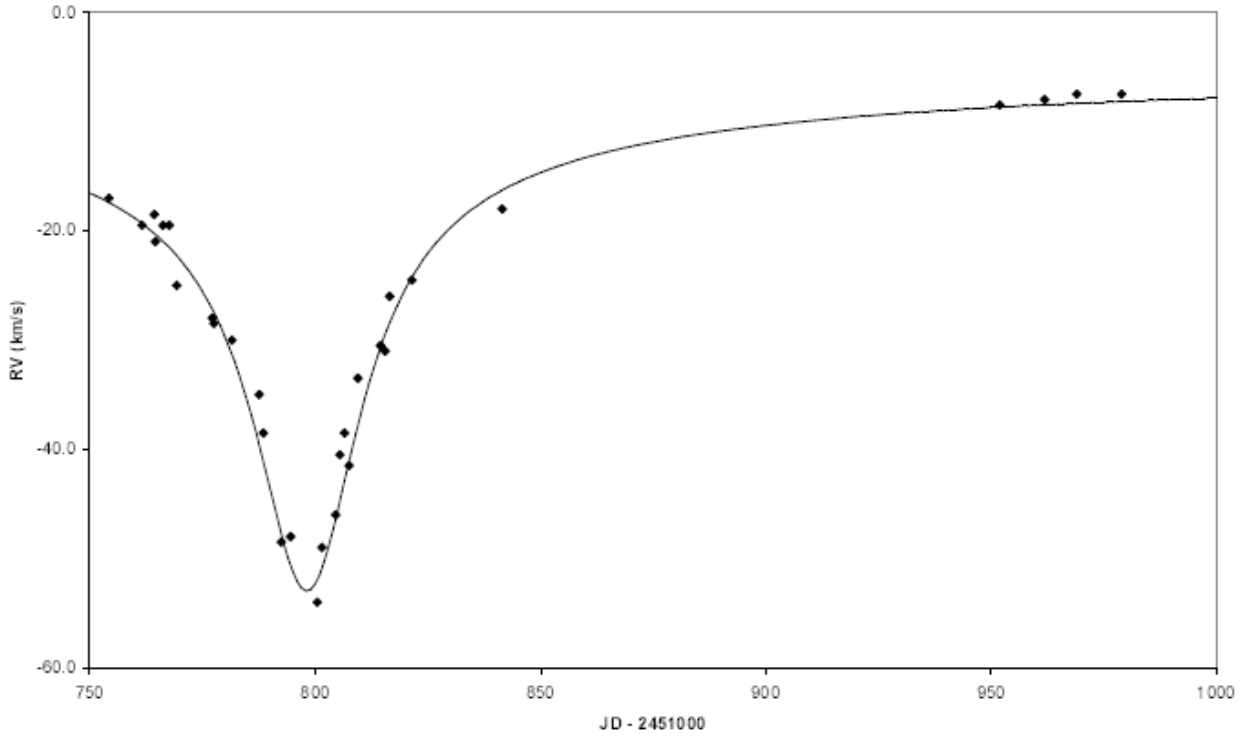
Note that is *not* necessary to achieve high precision in the *absolute* RV. Calibration errors of a spectrograph/telescope and specific spectral lines do not matter as long as they are constant with time so that *variations* can still be inferred with high confidence. Therefore,

- Select spectral lines without too obvious emission components.
- Check your equipment/procedures (incl. data reduction!) around March/April when there should

be no major variability yet of the RV.

Once you are satisfied with the tests, do not change any part of the procedure and follow it rigorously.

For a single observer, it would be necessary to observe delta Sco almost daily, starting around mid-April. But with a large community, it will be enough if everyone observes delta Sco roughly once a week and submits the RV measurements soon after the observations. Once the measured RV has dropped by 30 km/s or more, the observations can be terminated unless they regularly achieve a S/N of 100 or more and have a spectral resolving power, R, greater than 15,000 10 000. In this case, see also the last paragraph.



Radial Velocity during 2000 periastron (Tango 2009)

OBSERVATIONS

One set of observations should consist of the following sequence:

- bias (average median of 10 exposures)
- dark frame (median of 9 exposures)
- flat field (average median of 15 exposures of same exposure/dynamic)
- wavelength comparison spectrum (lamp in your spectrograph; on Lhires III it is recommended to

take one before and one after each stellar spectra serie)

- F-type or RV standard star
- delta Sco
- F-type or RV standard star
- wavelength comparison spectrum
- A or B type reference star for instrumental response of your equipment (ex: gam Peg, Altair...) ?

If your time permits, take two such sets of observations in fairly direct succession. If the RVs of delta Sco derived from these observations differ by more than 5 km/s (about 0.1 Å on H-alpha), *neither of them* should be reported because the uncertainties are too large. If time doesn't permit, you may want to take delta Sco spectrum before the F-type reference star. If you can, adjust exposure times such that the exposure levels are between 30% and 60% of the saturation limit of the detector. If in doubt, stay closer to the lower limit. For the wavelength comparison spectra, saturation of some strong lines may not be avoidable. In that case, set the exposure time such that you have 10-20 unsaturated lines with known wavelengths (i.e., no blends of two or more lines) distributed over the wavelength range of interest.

For the F-type and RV standard star, use the following selection criteria:

- they should be bright.
- they should have a similar declination as delta Sco has.
- they should be observed at a similar hour angle as delta Sco. Since delta Sco and these stars should

be observed close in time, this means that the right ascensions should be similar. You do not need to select an F-type stars and an RV standard star. One star can serve both purposes. Proposed F-type references stars:

40 Oph (mag 4.5, type F1III/F5IV ?)

Alternative: 45 Oph (mag 4.3, type F5IV) HD 156897, HR 6445

Note: need for another F-type reference star with lower RA position to be able to record it before delta Sco is rising up in the morning early in the year...
The times of the observations of delta Sco must be given in UT and accurate to 5 minutes. They should refer to the mid-exposure, and the exposure time (end time of last exposure minus begin time of first exposure; exposure time include time between individual frame even if CCD is in readout mode) should also be provided.

DATA REDUCTION

For Lhires III users, process your spectra with provided software with your equipment (RLhires or SpcAudace). For eShel users, use AudeLA/eShel spectra reduction.

Otherwise, manually, follow the following steps:

Substract the dark frame. If your camera is not temperature regulated, use an optimized substraction using the bias frame (a single number can be used for bias unless there is significant large-scale structure in the bias observation)

- Divide the biasdark-corrected stellar spectra by the biasdark-corrected flat field on a 2-D basis.
- Substract sky background to ensure it is at zero below and above the 2-D spectrum
- Extract the 1-D spectra only after those 2-D operation. Use an optimized extraction algorythm if

possible (see Horne 1986), an addition per column otherwise.

For the subsequent wavelength calibration, make sure that your algorithm always finds and utilizes the same comparison lines. If you have enough lines to choose from, select the narrowest lines. If a second-order polynomial gives a good fit (better than 0.05 of a pixel), use it. Do not go

to polynomial orders larger than 3 even if the error apparently decreases (in most cases, this is really

just apparent).

- Check your calibrated spectrum with telluric lines if present to verify your calibration quality. But do not remove telluric lines from your spectrum.
- Resample the spectra to a step size about half as wide (in wavelength) as a detector pixel.

==>??? why whould we resample ???

- Check whether dividing the reference-star spectrum (your F-type or radial-velocity standard star) by a second or at most third-order polynomial fitted to the continuum yields a clearly improved rectification of the continuum. If it does, divide the spectrum of delta Sco by the same

polynomial function (i.e. do not fit the continuum of delta Sco) *unless* this division make the continuum of delta Sco more strongly bent than before.

==>This is to correct from instrumental response. We usually recommend amateurs to perform this on a reference hot star to have less absorption lines in the spectrum. Our recommended reference stars for instrumental response are Altair or gamma Peg for exemple... Wouldn't it be more efficient than using a F-type star for this particular processing step?

- Measure the RV in the so processed spectrum of delta Sco.

Note: the best seems to measure RV on He II 4200 or 4540 line. Otherwise, measure H-alpha.
==>Which algorythm do you recommend (gaussian fit)?
==>How do we handle H-alpha shape impact on RV?
==>How do you calculate your RV accuracy?
Measure the RV of the F-type reference star in the same way. If the two measurements differ by more than 5 km/s, do not submit the measurements of delta Sco - they would be too uncertain.

- Reduce one stellar spectrum with both observations of the wavelength calibration lamp. If the two results differ by more than 5 km/s (about 0.1 Å on H-alpha), do not submit the measurements of delta Sco. They would be too uncertain.

Otherwis: If RV measurements are within 5km/s accuracy (about 0.1 Å on H-alpha), submit the raw RV; do not correct for the Earth's rotation or orbital motion.

USAGE OF THE RV DATA

The RV data will be used to establish a more precise forecast of the periastron date. It is not intended to derive a new orbital solution but everyone will, of course, be free to do so anyway.

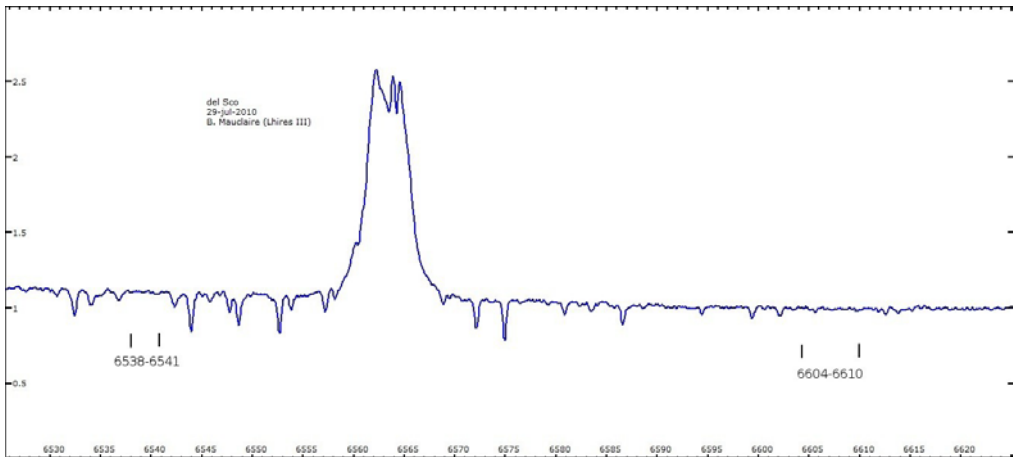
ADDENDUM FOR OBSERVATIONS WITH S/N>100 AND R>10 000 R>15,000

Note: eShel spectrograph is R>10000. Are those spectra still interesting to collect during this phase? From such observations, a so-called dynamical spectrum could be constructed: Plot all spectra in one frame. Use vertical offsets between them, which correspond to the time elapsed between the observations. If the wavelength coverage of the spectra is large, the wavelength (horizontal axis) should be broken up into several regions, each plotted separately so that the line profiles and possible variations are well visible.

Such observations can usefully be obtained throughout the full 2011 observing season for delta Sco. However, in order to be of practical value, at least 10 observations within 3 consecutive nights need to be obtained. There is no upper limit unless there are no trustworthy variations. Initially, it will be sufficient to submit dynamical spectra in .jpg format. FITS spectra would be desirable, especially in the case of major variations.

ANNEXE: S/N CALCULATIONS

We recommend to use around H-alpha [6536-6541] and [6604-6610] spectral regions for continuum level determination and [6604-6610] to measure S/N ratio.



delta Sco recent spectrum (B. Mauclaire, BeSS database)
with recommended continuum region

SUBMISSION OF DATA

Export your delta Sco spectra into FITS/BeSS format (include geographical location, exposure time, observing time, equipment description...). Send all delta Sco processed spectra and RV measurements (HeII 4540 or Halpha, precise which line is used for RV measurement) to Olivier Thizy (olivier.thizy@shelyak.com) and to Spectro-L discussion group. The earlier the submission, the better. Then submit the processed spectra in BeSS database whenever possible for archiving purposes or further study. A web page is on-line and will contain live RV graphs: http://arasbeam.free.fr/... Question: Are the Radial Velocities of He II 4540 and Halpha the same or not ? How do they compare ? Can we "mix" RV measurement from both lines in the same RV graph or not ?

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General

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Spectro-L discussion group: http://groups.yahoo.com/group/spectro-l/

Be-Star Mailinglist: https://www.jiscmail.ac.uk/cgi-bin/webadmin?A0=be-stars

BeSS file format specs and database: http://basebe.obspm.fr/basebe/

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