Proposal:

NORDIC OPTICAL TELESCOPE

APPLICATION FOR OBSERVING TIME

OBSERVING PERIOD 29

April 1, 2004 – September 30, 2004

1. Title of proposal:

Pinpointing Isochrones in Stellar Clusters

2. Abstract:

We propose to obtain the radial velocity curves for two detached eclipsing binaries in the old open clusters NGC 6791 and NGC 188. This will allow us to determine the cluster ages to a much higher precision than has previously been possible since each of the binary systems contain one component which is in its post main–sequence stage of evolution and hence determines the mass at the cluster turnoff point. Both systems are very likely cluster members. For NGC 188, the aim of these observations is also to determine the period of the binary, so we can followup with photometric observations at a later stage. This project is part of a large initiative by our group to study detached binary systems in open and globular clusters in order to improve on our knowledge of cluster ages and distances and test the predictions of stellar evolution theory.

3. Principal Investigator: (**NB:** The P.I. has full responsibility for the content of this proposal!)

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M. Andersen, Potsdam

J.V. Clausen, Copenhagen

H. Robenhagen, Aarhus

H. Bruntt, Aarhus

5. If this is a PhD thesis project at a Nordic institute, please give name of student, supervisor and expected time of completion: Part of this work will go into H. Robenhagen master thesis. Completion, late 2004, early 2005.

6. Observing period(s) requested and preferred scheduling:

Run	Instrument	Time	Month(s)/Date(s)	Moon	Seeing	Sky
A	SOFIN	2n	July-August	N	1.5	C
B	ALFOSC	2n	April-Oct	N	1.2	C
B	STANCAM	2n	April-Oct	N	1.0	T

7. Number of nights already awarded to project: 6

8. Number of nights needed to complete project: 4-6n/semester expected

9. Can your project be done in service/queue mode? Service:Yes, preferred

10. Any other special constraints on the scheduling? Run B and C: We will provide list of possible observing dates

11. Scientific justification for the proposal:

Star clusters continues to play an essential role in developing and constraining our understanding of stellar evolution. With the advent of CCD detectors, it has become fairly easy to obtain deep, high precision color-magnitude diagrams for both open and globular clusters (Stetson, Bruntt & Grundahl, PASP, 115, 413). However, one of the main obstacles in comparing observations of star-clusters to theoretical calculations is the fact that the determination of cluster reddenings and distances remain an outstanding problem – this is, in part, because a conversion between the observed quantities (color, and apparent luminosity) to model quantities (T_{eff}, bolometric luminosity) is needed – this conversion is still very problematic as it requires accurate color-temperature relations (Clem, VandenBerg, Grundahl & Bell, 2003, AJ, Accepted). Furthermore, even in the situation when this is available, the single most important parameter determining the evolution of a star, its initial mass, is usually unknown for the stars in a cluster.
It is well known, that detached double–lined eclipsing binaries provide the possibility to determine the masses and radii of both components if the photometric and radial velocity curves can be determined for the system (Andersen, J. A&AR, 1991, Vol 3, 91). If such systems can be identified in open and globular clusters, we can directly determinine the masses of the two stars, thus "fixing" the mass at one point along the cluster isochrone. Furthermore, if one, or both, of the stars in such a binary is in its post-main-sequence stage of evolution a determination of its mass will give directly the cluster turnoff mass and hence the cluster age. To date, this has only been done for one system in the globular cluster ω Cen, see Kaluzny et al. (astro-ph/111089) and Thompson et al. (2001, AJ, 121, 3089). The error bar on the age determination for the stars in this system (only 0.8Gyr) is a factor 3 better than previous estimates based on other methods.
We have undertaken a comprehensive program to study such systems in open and globular clusters and the present application concerns two objects in the old open clusters NGC 188 and NGC 6791; two of the oldest known open clusters in the galaxy.

V12 in NGC 188: Zhang et al. (2002, AJ, 123,1548) reported the first discovery of this system. The eclipse depth is 0.6mag, but the period is unknown. However, from the published light curve it is clear that this is a detached system with constand luminosity between eclipses. Platais et al. (astro-ph/0309749) has reported a propor–motion membership probability of 97% for this star. The system has $V = 14.8$ and appears to be located slightly brighter than the cluster subgiant branch, indicating that one of its components is likely in a post-MS stage of evolution thus offering the possibility to determine the cluster age directly. We propose to observe this system with SOFIN (or if available, FIES) in order to determine the radial velocity variations – this will allow us to determine the period of the system. In subsequent NOT periods we will then follow-up with photometry such that we can determine the system parameters. This strategy is more 'cost effective', since searching photometrically can be very time consuming for such systems.

V20 in NGC 6791: In the summer of 2003 we observed this detached system (P=14.4699d) over six nights with NOT (service observing, 4.5 nights of useful data) to obtain the light curve during eclipses. Figure 1 shows the main results of the observations: the system consists of a star located exactly at the cluster turnoff and a 2.5mag (V) fainter main–sequence star. This shows that the system is very likely a member of the cluster. In addition we discovered three new eclipsing systems, of which two are likely members of the clustter. With the observations applied for here, two nights of spectroscopy and two nights of imaging, we wish to obtain the radial velocity for the primary component (the secondary is so faint, that it is unlikely that we can detect it in the spectrum) and complete the photometry of the light curve. We cannot use SOFIN for this purpose as the system is too faint to be seen with the slit viewing system.
With only the velocities for the primary, we will not be able to determine individual masses and radii from these observations, but combining the photometric observations with radial velocity curve for the primary allows to determine to orbit inclination and the relative radii and total mass of the system. If this is coupled with the mass-luminosity relation (which is well known for these masses and metallicities) we can determine the masses in this way. This will give a

12. Scientific justification *–continued–*

very valuable constraint on the age of this system – a problematic issue, as discussed in Stetson, Bruntt and Grundahl (2003, paper 2) due to the problems mentioned above with color-temperature relations.

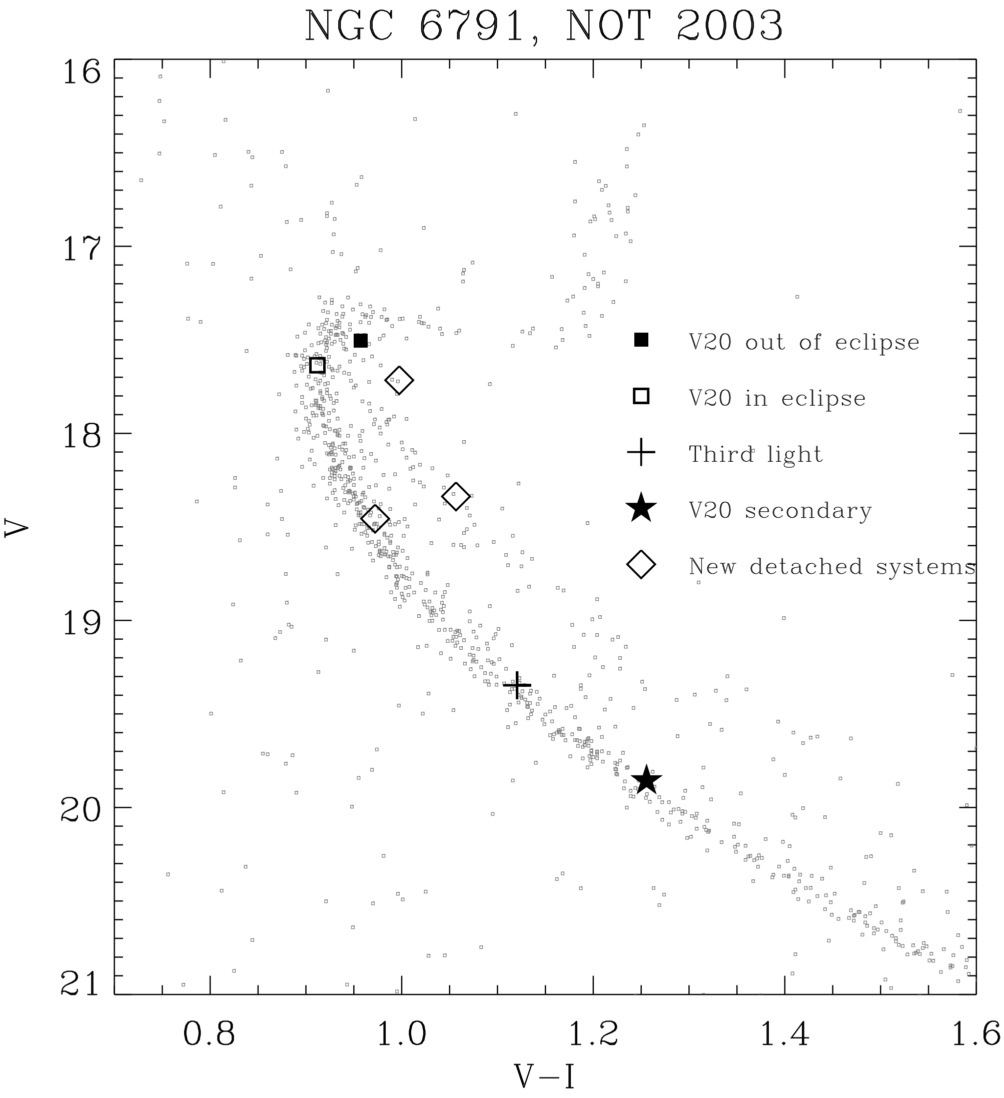

Fig. 1. Color-magnitude diagram for NGC 6791 based on our earlier NOT observations. The location of V20 in and out of eclipse is marked with the filled and open squares, and the star symbol denotes the location of the secondary. Note, that due to the excellent seeing in some of the new NOT data (0.45 arcsec) we discovered that there is a third light component of the system, only 0.5 arcsec away. The excellent quality of the STANCAM data has allowed us to determine its position, indicated by the plus sign. This star is also likely to be a cluster member. Due to the presence of this third light and the faintness of the secondary we will likely not be able to see the signature of the secondary in the spectra. Note the well defined main-sequence and turnoff region.

13. Technical description of the observations.

Run A: I. Ilyin, has kindly estimated (at our request) that SOFIN can give S/N$\sim$15 in a 10-15min exp for a V=15 star at the lowest resolution ($\sim$27000). Our star in NGC 188 has V = 14.8 and is just visible for the slitviewer. Given the high spectral resolution, we can likely detect the spectra of both components, if the S/N is sufficiently high, therefore we will expose 2 times 15min at each epoch. We estimate the overhead (readout, ThAr exp + preset) to be 15min, thus each epoch requires 45min. 20 epochs thus requires 15hours of observing time. We request 20 epochs spread out over a typical SOFIN run of 2 weeks, to determine the unknown period of this detached system. As the orbital period is unknown, we wish to obtain 2-3 exposures per night in order to sample the period randomly.

Run B: M. Andersen, has estimated that with a seeing of 1 arcsec, slit width of 0.5 arcsec, and V = 17.5 we obtain a S/N ratio of 15 in 1 hour using ALFOSC. The resolution will be approximately 4000, and we will cover a wavelength range of 3000Å this ensures that sufficiently strong lines (eg. Hα) are available to determine the radial velocity of the primary component of this system. Although a higher resolution is desirable in order to increase the chances of detecting the spectrum of the secondary, we cannot use SOFIN for this observation as such a faint star cannot be placed on the slit with high precision. With exposure times of one hour, the 2 requested nights allows 16 RV epochs to be obtained.

Run C: Our previously allocated nights, show, that we will be able to obtain the required presicion with the length of the exposures we have used this far ($V : 180s, I : 120s$) The requested time is mainly dictated by the need to cover two eclipses – the total duration of an eclipse is one night.

For both run A and B, we will obtain ThAr spectra immediately before and after each exposure. Night sky-lines will also be included in the wavelength solution. We estimate that in both cases, it should be possible to reach a velocity precision of better than 5km/s.; sufficient for our needs.

14. Requested instrument setup(s):

Run	Instrument	Mode	Setup
B	ALFOSC	Spectro-Echelle	Grism#9-0.7arcsec-slit
C	StanCam	Standard imaging-filters	UBVRI
A	SOFIN	Spectroscopy	Low-res camera

Remarks: Run B: the 0.5 arcsec mode for ALFOSC is not listed in this application form, but is on the WWW pages, we need the 0.5arcsec setup to have the highest possible resolution.

15. Target list with coordinates, or intervals in R.A. and Decl. of (sample of) objects:

Run	Name	α_{2000}	δ_{2000}	Magnitude	Diam($'$)	Additional Info.
A	NGC188-V12	00:52:37.74	+85:10:35.2	V=14.8		EA
B	NGC6791-V20	19:20:54	+37:45:35	V=17.5		EA
C	NGC6791-V20	19:20:54	+37:45:35	V=17.5		EA

Remarks:

16. Backup programme (or justification why none is needed).

17. List of observing periods, and publications from NOT observations, within the last three years.

- **July 9–17, 2001, Data completely reduced. Papers 1) and 2)**

- **P27, 6 service nights, : Grundahl et al: A New Age for an Old Cluster:**
Data completely reduced (4.5 useful nights) , see figures and discussion in Sci. Just. of the results from this run.

- **July 31-Aug. 1, 2003: Grundahl et al. Helium Variations in Globular clusters:**
Data flat-fielded, some difficulties encountered due to missing overscan region in images – but otherwise good data quality, good seeing. The quality of the preliminary CMDs look consistent with expectations.

- **Publications:**

1) Bruntt, Grundahl, Tingley et al. (2003), A&A, 410, 323
2) Stetson, Bruntt & Grundahl (2003), PASP, 115, 413
3) Moehler, Landsman, Sweigart & Grundahl, A&A, 405, 135
4) Grundahl, Stetson, & Andersen (2002), A&A, 395, 481
5) Grundahl, VandenBerg, Bell, Andersen (2000), & Stetson, AJ, 120, 1884
6) Clem, VandenBerg, Grundahl & Bell, (2003), AJ, accepted.

18. Additional remarks not covered by the items above, if any:

The observations applied for here are part of a larger effort using both NOT and ESO telescopes to investigate detached eclipsing binaries in open and globular clusters. We have been allocated VLT time (12h) to study one system in the old open cluster NGC 2243 (these observations are scheduled for the current ESO observing period).