Max-Planck-Institut für Astronomie
Comision Nacional de Astronomia
Time Allocation Committee Calar Alto
Königstuhl 17
D-69117 Heidelberg / Germany

| Application No. | |
|---|---|
| Observing period | H 2002 |
| Received | |
| | |

# APPLICATION FOR OBSERVING TIME

from [X] RDS [ ] MPIA [ ] Spain [ ] other

[X] Autumn period beginning of July - end of December, acceptance till March 15.

[ ] Spring period beginning of January - end of June, acceptance till September 15.

1. Telescope: 1.23-m [X] 2.2-m [ ] 3.5-m [ ] **P**

2.1 Applicant


| | |
|---|---|
| Dipl.Phys. Alexander **Scholz** | Thüringer Landessternwarte |
| Name | Institute |
| Sternwarte 5 | 07778 Tautenburg |
| street | ZIP code - city |
| Germany | scholz@tls-tautenburg.de |
| country | e-mail |


2.2 Collaborators

| | |
|---|---|
| Jochen Eislöffel | Thüringer Landessternwarte |
| name(s) | institute(s) |
| | |
| name(s) | institute(s) |

2.3 Observers

| | |
|---|---|
| Alexander Scholz | |
| name | name |

MPIA and CNA point out that by specifying the names under item 2.3 it is obligatory to also send out these observers to Calar Alto. Correspondence on the rating of this application will be sent to the applicant (P.I.) as quoted under 2.1 above.

3. Observing programme and method: Category: E

Title : **Rotation and Activity of Brown Dwarfs and VLM Stars**


Abstract : With a photometric monitoring campaign, we want to study rotation and activity of Brown Dwarfs (BDs) and Very Low Mass (VLM) stars in the Pleiades. Rotation and activity are key parameters for a deeper understanding of stellar physics. Whereas rotation rates and surface activity of solar mass stars were subject of intensive studies in the past, there exist only very few of such investigations for VLM objects. Our proposed observations will allow us first comparisons of the rotation and activity rates of VLM objects in the Pleiades with those of more massive stars in this 'standard' cluster of stellar astrophysics. Together with our previous results from younger clusters, these observations will deliver first insights into the rotational evolution of VLM objects up to the Zero Age Main Sequence.


4. Instrument: CCD Method: imaging

5. Brightness range of objects to be observed: from 14 to 18 I-mag

6. Number of nights:

| applied for | | | already awarded | still needed |
|---|---|---|---|---|
| 21 | | | none | none |
| no restriction | grey | dark | | |

7. Optimum date range for the observations: ................................ 1.10.02 – 21.10.02
Usable range in local sideral time LST: ...................................... 22:13h – 9:22h

## Astrophysical context

Rotation is a key parameter to understand the evolution of stars. The interpretion of the rotation rates of solar mass stars at different ages delivered insights into basic stellar physics (Fig. 1): The rotation rate decreases in the T-Tauri phase because of rotational breaking through magnetic coupling between star and circumstellar disk, increases then as the star contracts on its way to the Zero Age Main Sequence (ZAMS) and afterwards decreases again following a $t^{-1/2}$-law as a consequence of angular momentum loss through stellar winds.

The best method to measure projection-free rotation rates for a large number of objects is photometric monitoring. For stars with asymmetrically distributed spots a periodic variability will be detected. Hence, this method allows a direct measurement of the rotation period.

Whereas the rotation of solar mass stars was intensively investigated in the last years (see Fig. 1), we know very little about the rotational evolution of Very Low Mass Stars (VLMS) and Brown Dwarfs (BDs). In the Pleiades, the 'standard' cluster for studies of stellar astrophysics, there are more than 30 solar mass stars with measured rotation periods (e.g., Krishnamurthi et al. 1998), but only 2 with masses $< 0.4\,M_{\odot}$ (Terndrup et al. 1999). Therefore, we started a long-term project to study the rotation of VLM objects in open clusters with ages from 4 to 700 Myr. In the last years, we derived photometric rotation periods for VLM objects in the $\sigma$-Ori cluster (age 4 Myr) and IC4665 (40 Myr). To continue this project, it is crucial to observe a cluster on the ZAMS, where stars show the shortest periods and the widest spread of rotation rates at all. The Pleiades are the best suited cluster to do this, because they have the required age (70 Myr) and are relatively nearby (150 pc). Several groups have identified large numbers of VLM objects in this cluster. E.g., Pinfield et al. (2000) found more than 300 very probable cluster members by combining multifilter photometry with proper motion measurements.

Photometric time series additionally allow us the investigation of surface activity. The amplitude of the periodic variability depends on size and temperature of the starspots and can therefore be used as an activity indicator (see Krishnamurthi et al. 1998). Moreover, flare-like activity phenomena are easily detected in photometric time series as non-periodic variability. Observations of activity in VLM objects is of particular interest because these objects are fully convective. The $\alpha\omega$-dynamo, which produces surface activity on solar mass stars, works in a shell below the convection zone and therefore cannot work in VLM objects. Hence, it was proposed that activity on these objects is generated by a turbulent dynamo (Durney et al. 1993). This would cause less activity than for solar mass stars and no activity-rotation correlation. Observational tests of this scenario are so far inconsistent (Delfosse et al. 1998, Hodgkin et al. 1995).

## Immediate aim

Our aim is to derive rotation periods for VLM members of the Pleiades by photometric monitoring. This will allow for the first time a statistical comparison of periods of VLM objects in the Pleiades with those for solar mass stars in this cluster. Together with our previously found periods in other clusters we are then able to analyse the rotational evolution of VLM objects from the T-Tauri phase to the ZAMS. We will compare these results with those of similar studies for solar mass stars (see Fig. 1).

As a second goal, we will use the lightcurves to obtain information about surface activity. Amplitudes of periodic variabilities and flare rates will be measured and again compared with similar results for solar mass stars. We will search for correlations between activity and rotation to draw conclusions about the interior dynamo processes.

In a companion proposal, we apply for simultaneous near-infrared observations with MAGIC at the 2.2m telescope to derive spot sizes and temperatures for VLM objects in the Pleiades. The I-band time series from the 1.23m telescope will be indispensable input for these measurements.

## Previous work

Within the framework of the PhD-thesis of A. Scholz, we undertook several time series campaigns very similar to the observations requested here. We measured 18 rotation periods for VLM objects in the open cluster IC4665 (age 40 Myr, see Fig. 2 for examples). These results point out that VLM objects rotate faster than solar mass stars of similar age (see Fig. 3). In December 2001 we monitored VLM objects in the $\sigma$Ori-cluster (age 4 Myr) with the CCD at the 1.23m telescope, i.e. with the same setup that we are proposing to use now (see Fig.4).

## Layout of observations

We want to observe four $16' \times 16'$-fields, which cover 50 known VLM cluster members, in a time series in the I-band. The amplitudes of previously measured rotation periods in the Pleiades are typically 0.05 mag. We need 600 sec exposure time to cover the range $14 \ldots 18$ mag with precisions of $0.008 \ldots 0.05$ mag. According to models from Baraffe et al. (1998), this corresponds to a mass range of $0.5 \ldots 0.06\,M_{\odot}$. Our strategy will be to use 17 nights to observe all 4 fields alternately, i.e. we will obtain 8 datapoints per object for these nights. In each of the remaining four nights we will observe only one field to register short periods ($< 8$ hours) with high reliability. This strategy will deliver dense sampling for very short as well as for long periods. After data reduction and differential photometry we will search for periodicities in the lightcurves using various detection methods. The software for all analysis steps is ready and tested from earlier time series campaigns.

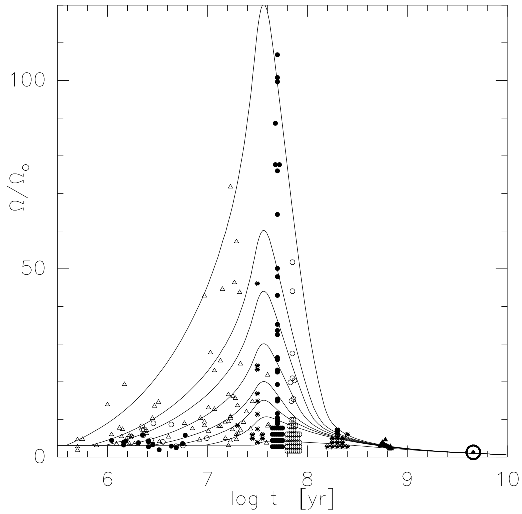


Figure 1: Evolution of angular velocity for solar mass stars (Bouvier et al. 1997). Plotted is the angular velocity in units of the initial angular velocity $\Omega_0 = 3\Omega_\odot$ depending on age. The solid lines are model calculations with various accretion disk lifetimes. Objects in the Pleiades (70 Myr) show the largest angular momentum and the widest spread in their rotation rates. Constructing a similar diagram for VLM objects, it is therefore critical to observe this cluster.

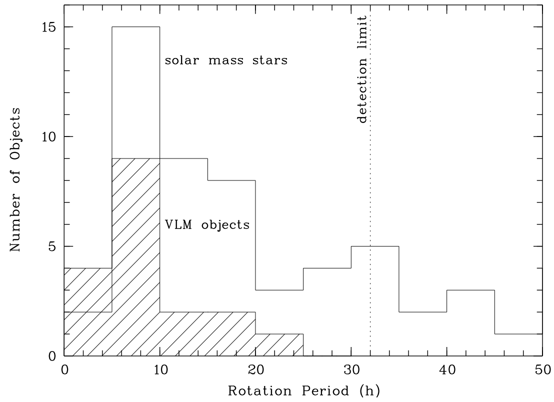


Figure 3: Comparison of the rotation periods for VLM objects with those for solar mass stars. The hatched histogram is the distribution of the rotation periods, which we derived for VLM objects in IC4665. The not hatched histogram shows the same distribution for solar mass stars with comparable ages from the literature. Statistical tests point out, that VLM objects rotate significantly faster than their solar mass siblings.

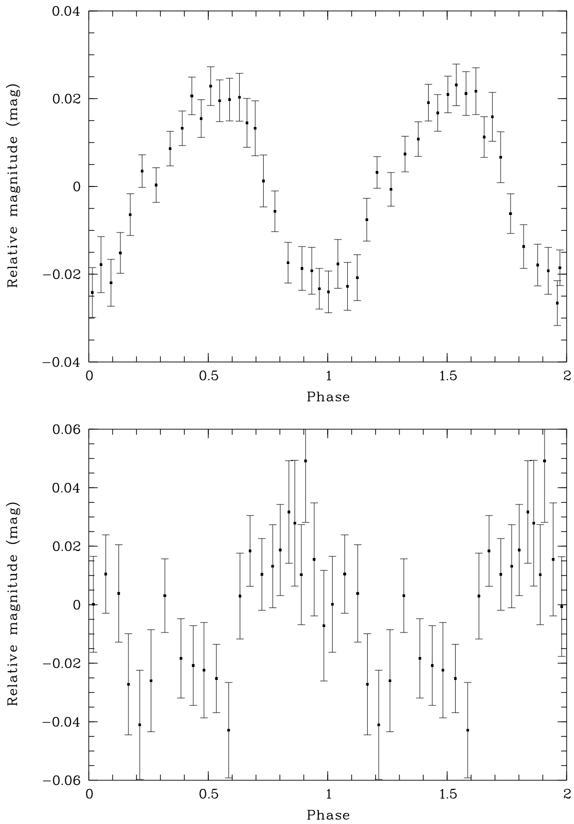


Figure 2: Phased lightcurves of two VLM objects in IC4665. Upper: VLM star ($0.1\,M_\odot$) with a rotation period of 5.4 hours. Lower: Brown Dwarf ($0.045\,M_\odot$) with a rotation period of 4.2 hours.

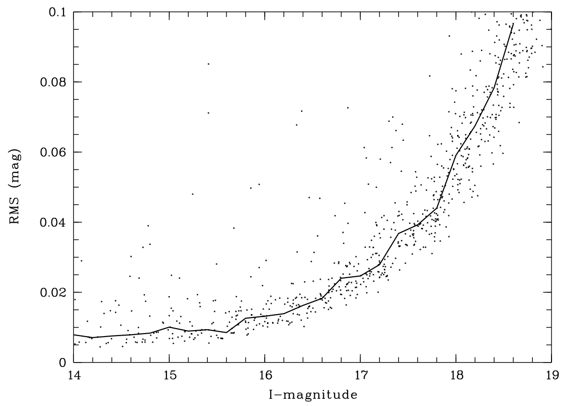


Figure 4: Precision of a 17 nights I-band time series in the $\sigma$Ori-cluster with 600-sec-exposures taken with the CCD camera at the 1.23m telescope in December 2001. Plotted are the root mean squares of all lightcurves depending on the I-magnitude. The solid line is the median RMS. For objects with I=18 we still reach a precision of 0.05 mag.

## 8e. Current logistics of PhD thesis/long term programme

In the PhD thesis of A. Scholz we study rotation and activity of VLM objects by analysing photometric time series. From period searches in the lightcurves we obtain photometric rotation periods. In addition, we search for flares as nonperiodic variability phenomena. The goal of this project is to derive the evolution of rotation rates and activity for VLM objects. Such investigations have been carried out for solar mass stars in the recent past and have delivered many insights into star formation, structure and evolution (see Fig. 1).

In a feasibility study we used an I-band time series from the WFI at the ESO/MPG 2.2m telescope on La Silla to search for periodic and nonperiodic variability in the lightcurves of VLM objects in the open cluster IC4665 (age 40 Myr). We were able to derive rotation periods for twelve VLM stars and - for the first time - for six BDs (see Fig. 2 for examples). These results pointed out that VLM objects rotate very fast compared with more massive stars with similar ages (see Fig. 3).

Analysing activity indicators like the flare rate and the amplitudes of the measured variabilities, we found a second important result: VLM objects at the age of IC4665 are much less active than solar mass stars of similar age. This strongly supports the idea of a turbulent dynamo working in these fully convective objects.

In the last year we observed the young $\sigma$Ori-cluster with the 2m Schmidt telescope at the Thüringer Landessternwarte Tautenburg and determined the first rotation periods for objects in this cluster. In December 2001 we repeated monitoring a field in $\sigma$Ori, this time with the CCD at the 1.23m telescope on Calar Alto. Preliminary results of this campaign demonstrate the excellent suitability of this instrumentation for such projects (see Fig. 4).

We now want to apply our proven observing and analysis strategies to VLM cluster members in the Pleiades. This cluster lies on the ZAMS, where solar mass stars exhibit the shortest rotation periods and the widest spread of periods at all (see Fig. 1), because they have finished their hydrostatical contraction. These characteristics make it indispensable to include the Pleiades in our observing program. To draw first conclusions about the rotational evolution of VLM objects it is crucial to measure rotation periods of objects in this cluster.

9. Objects to be observed

(Objects to be observed with high priority should be marked in last column)

| Designation | $\alpha$ (2000) | $\delta$ (2000) | magnitude in spectral range to be observed | priority |
|---|---|---|---|---|
| Pleiades | $3^{h}\,47^{m}\,30\overset{s}{.}0$ | $24^{\circ}\,29'\,00''$ | I=18 | 1 |

10. Justification of the amount of observing time requested:

Two parameters determine the amount of requested observing time, the time scales of the expected rotation periods and the number of data points needed to sample the periods properly. The known rotation periods of solar mass stars in the Pleiades range from some hours up to 8 days. To make sure that they are no slower rotators among our objects, we require at least 12 nights observing time.
However, according to our experience, we need 150-200 datapoints per object for optimum time series analysis. Observing our four fields alternately with 600 sec exposures, we will get 8 data points on each field per night (overhead of 5 min for CCD readout and field change included). Therefore, in order to obtain the number of datapoints necessary for a reliable period determination with low False Alarm Probabilities, we need data from 21 nights. Therefore, we ask for three weeks observing time.

11. Constraints for scheduling observations for this application:

The Pleiades are very close to the ecliptic, so that the moon comes very close to our field once every month. Therefore, observations for this proposal should not be scheduled for the days from 24.–29.9., 22.–27.10. and 18.–23.11.. During these days (always around full moon) the moon is less than 30 degree away from the Pleiades and would therefore disturb every measurement.

12. Observational experience of observer(s) named under 2.3:
(at least one observer must have sufficient experience)

Alexander Scholz has observing experience with the CCD camera at the 1.23m telescope.

13. Calar Alto runs (preferably during the last 3 years)
and publications resulting from these

| Telescope | instrument | date | nights | success rate | publications |
|---|---|---|---|---|---|
| | | | | | publications of last 3 years from older campaigns: [100], [101],[102] |
| 1.23 m | MAGIC | Nov 98 | 11 | 70% | [103], [104], [105] |
| 3.5 m | MOSCA | Jun 99 | 4 | 90% | under analysis |
| 3.5 m | OMEGA Prime | Dec 00 | 4 | 80% | [106] |
| 3.5 m | MOSCA | Dec 00 | 3 | 0% | no data |
| 1.23 m | CCD | Jan 01 | 16 | 33% | [107], see also 2) |
| 3.5 m | MOSCA | Nov 01 | 3.5 | 5% | no usable data |
| 1.23 m | CCD | Dec 01 | 14 | 25% | see 1) |
| 2.2 m | MAGIC | Dec 01 | 5 | 25% | under analysis |

1) Data from this run are shown in Fig.4 of this proposal. 2) A. Scholz observed as co-worker in a multi-site campaign for R. Mundt, who is doing the further processing of the data.

14. References for items 8 and 13:


[1] Baraffe I., Chabrier G., Allard F., Hauschildt P.H. (1998): *Evolutionary models for solar metallicity low-mass stars: mass-magnitude relationships and colour-magnitude diagrams*, A&A, **337**, 403

[2] Bouvier J., Forestini M., Allain S. (1997): *The angular momentum evolution of low-mass stars*, A&A, **326**, 1023

[3] Delfosse X., Forveille T., Perrier C., Mayor M. (1998): *Rotation and chromospheric activity in field M dwarfs*, A&A, **331**, 581

[4] Durney B. R., De Young D. S., Roxburgh I. W. (1993): *On the generation of the large-scale and turbulent magnetic fields in solar-type stars*, SoPh, **145**, 207

[5] Hodgkin S.T., Jameson R.F., Steele I.A. (1995): *Chromospheric and coronal activity of low-mass stars in the Pleiades*, MNRAS, **274**, 869

[6] Krishnamurthi A., et al. (1998): *New Rotation Periods in the Pleiades: Interpreting Activity Indicators*, ApJ, **493**, 914

[7] Pinfield D. J., Hodgkin S. T., Jameson R. F., Cossburn M. R., Hambly N. C., Devereux N. (2000): *A six-square-degree survey for Pleiades low-mass stars and brown dwarfs*, MNRAS, **313**, 347

[8] Terndrup D. M., Krishnamurthi A., Pinsonneault M. H., Stauffer J. R. (1999): *A Search for Photometric Rotation Periods in Low-Mass Stars and Brown Dwarfs in the Pleiades*, AJ, **118**, 1814

[100] Terquem C., Eislöffel J., Papaloizou J. C. B., Nelson R. P. (1999): *Precession of collimated outflows from young stellar objects*, ApJ 512, L131

[101] Eislöffel J. (2000): *Parsec-scale molecular $H_2$ outflows from young stars.*, A&A 354, 236

[102] Eislöffel J. (1999): *Jets from Young Stars*, In: E. Guenther, B. Stecklum, und S. Klose (Hrsg.), Optical and Infrared Spectroscopy of Circumstellar Matter, Astron. Soc. Pac. Conf. Ser. 188, 51

[103] Froebrich D., Ziener R., Eislöffel J. (2001): *An Unbiased Search for Molecular Hydrogen Outflows in the Orion B Star Forming Region*, AGM 18, P25

[104] Rengel M., Froebrich D., Eislöffel J., Hodapp K. (2001): *Submillimetre Imaging of Deeply Embedded Outflow Sources and Class 0 Sources*, AGM 18, P66

[105] Rengel, M., Froebrich, D., Hodapp, K., Eislöffel, J. (2001): *Far-Infrared and Submillimetre imaging of deeply embedded outflow sources*, In: 'The Origins of Stars and Planets: The VLT View', Joao Alves (ed.), in press

[106] Scholz A., Eislöffel J. (2001): *Rotation and Atmospheres of Brown Dwarfs and VLM Stars*, AGM 18, P28

[107] Lamm M., Mundt R., Bailer-Jones C.A.L., Herbst W., Scholz A. (2001): *Variability and Rotation of Pre-Main Sequence Stars in NGC 2264*, AGM 18, P20

15. MPIA and CNA do not cover costs of the observing run. It is the responsibility of the applicant(s) to raise the money for the travel to Calar Alto and expenses during the observing run.

    Consumables needed in larger quantities will be charged to the applicant(s).

    Furthermore the applicant(s) should consult our web page with the "Guidelines for Visiting Astronomers":

    http://www.mpia-hd.mpg.de/Public/CAHA/visast.html

16. Members of institutes of the Rat Deutscher Sternwarten (except Max Planck institutes) may apply for travel funding at the DFG with reference to this application and the letter granting observing time. The rating of the proposal by the time allocation committee is accepted by the DFG for its evaluation.

    Should observing time be granted is it planned to apply for DFG funds? yes [X]

    no [ ]

    Should it be necessary to send two observers to Calar Alto, this has to be justified below. Final decision upon its approval lies with the TAC's DFG representative.

17. Justification for 2 observers travelling to Calar Alto, if funds for both will be applied for at DFG:

**Tolerance limits for planned observations:**

| | | |
|---|---|---|
| **maximum seeing:** ″ | **minimum transparency:** % | **maximum airmass:** |
| **photometric conditions:** | **moon: max. phase / ∠ :** /° | **min. / max. lag:** / nights |

- ☐ **3.5m**
  - ☐ Prime focus
    - ☐ LAICA
    - ☐ OMEGA Prime
  - ☐ Cassegrain focus
    - ☐ TWIN spectrograph
      - ☐ beam splitter — blue channel — grating:
      - ☐ mirror — red channel — grating:
    - ☐ OMEGA Cass →
      - ☐ without adaptive optics
      - ☐ with adaptive optics
    - ☐ MOSCA
    - ☐ private instrument → ____
- ☐ **2.2m**
  - Coudé focus temporarily not available
  - ☐ Cassegrain focus
    - ☐ CAFOS
      - ☐ polarizer
      - ☐ Etalon
    - ☐ MAGIC
      - ☐ 1.″6/pixel
      - ☐ 0.″66/pixel → ☐ Grism R270
    - ☐ FOCES
    - ☐ BUSCA
    - ☐ private instrument → ____
- ● **1.23m**
  - ● CCD camera
    - ☐ Savart plate
    - ☐ grating
  - ☐ MAGIC
    - ☐ 1.″2/pixel → ☐ Grism R270
  - ☐ private instrument → ____

Version January 2002

**Scholz** **(rot123)**