Time Allocation Committee for
Centro Astronómico Hispano Alemán (CAHA)
c/o MPI für Astronomie
Königstuhl 17
D-69117 Heidelberg / Germany

Application No.	F05-3.5-054
Observing period	F 2005
Received	15.09.04 16:07

APPLICATION FOR OBSERVING TIME

from ☐ Germany ☒ Spain ☐ other

☐ 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: 2.2-m ☐ 3.5-m ☒

2.1 Applicant

Dr. Mario **Tafalla**	Observatorio Astronómico Nacional
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country	e-mail

2.2 Collaborators

João Alves	ESO
name(s)	institute(s)
Jonathan Foster	Harvard-Smithsonian Center for Astrophysics
name(s)	institute(s)

2.3 Observers

Jonathan Foster	João Alves
name	name

CAHA points 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: C

Title : **Extinction mapping of cores in Perseus**

Abstract : The COMPLETE (COordinated Molecular Probe Line Extinction Thermal Emission) Survey of Star-forming Regions is fully-sampling the density, temperature, and velocity structure of three star-forming complexes. Near-infrared extinction mapping is a direct way to obtain column densities over a wide range of physical conditions. We have already used 2MASS to broadly map extinction in Perseus; the proposed observations will provide higher resolution in the dense regions where 2MASS runs out of stars. Many cores in these dense regions have been mapped in N_2H^+, enabling us to study molecular depletion as a function of density. The broad field of view of OMEGA 2000 will give a high-resolution view of how dense cores form out of the surrounding turbulent cloud, a poorly understood transition.

4. Instrument: OMEGA 2000 Method: Photometry

5. Brightness range of objects to be observed: from 18 to 20.25 K-mag

6. Number of nights:

applied for			already awarded	still needed
4			none	none
no restriction	grey	dark		

7. Optimum date range for the observations: .... 1.01.05 – 1.02.05
Usable range in local sideral time LST: .... 0:30h – 8:30h

Astrophysical context

H_2 dominates the structure of molecular clouds, but its distribution must be inferred by transition lines of tracer gas molecules, dust extinction, or continuum dust emission. These methods rely on different assumptions: depletion of specific molecules at specific densities, a constant dust to gas ratio, or the temperature of dust. The COMPLETE (COordinated Molecular Probe Line Extinction and Thermal Emission) collaboration uses all these techniques on the same regions to probe the assumptions of each method and to derive density, temperature, and velocity structure. Early results show that extinction mapping is the best way to determine the density structure of some molecular clouds, and is thus necessary to compare observed density distributions with simulations and to understand how smooth cores form out of a turbulent cloud.

COMPLETE is two-tiered. Broad, relatively shallow surveys are followed with coordinated, deeper looks at particular sections. This proposal aims to contribute the second phase of extinction measurements for the molecular complex in Perseus (at ≈ 260 pc). The benefits of dust extinction as a tracer of density are its simplicity and dynamic range. We look along a line of sight, measure the reddening of the background stars, convert to extinction, and learn the dust column density. With enough stars, this method works well over a huge range of magnitudes of extinction (A_V = 1-40).

The resolution of an extinction map is proportional to the density of stars used in its construction. To probe dense regions we use near infrared observations, since in the optical no star-light gets through the dust (Figure 1), while at longer wavelengths, stars rapidly become intrinsically dimmer. The near IR (J, H, and K) is ideal since most stars have no intrinsic color in these bands, making it easy to interpret a reddened color without needing a detailed stellar type.

Immediate aim

In phase one of COMPLETE, we used the extinction mapping algorithm NICER (Near Infrared Color Excess method Revisited) and 2MASS photomtery to create a wide map of Perseus. The relatively shallow nature of 2MASS ($K_s \approx 14.3$) means that the critical densest regions are unresolved as 2MASS runs out of stars. We estimate that with these deep observations ($K \approx 20.25$) we will achieve a resolution of $1.5'$, a great improvement over the 2MASS extinction maps, which have a resolution of around $5'$. The 2MASS maps fail to probe regions with extinction higher than 10 A_v; these observations could reach A_v of 40.

These densest regions are vital to our understanding of how stars form, so they are being targeted by other COMPLETE observations. We have already mapped 10 Perseus cores (7 are starless) in N_2H^+ at the IRAM 30-meter. N_2H^+ is very resistant to depletion and thus should trace the structure of cores to very high densities; the dust extinction measurements will allow us to test this hypothesis. The wide field-of-view offered by OMEGA 2000 will give us a high resolution look at the density structure around these cores, allowing us to see how the surrounding turbulent density structure transitions into a smooth, coherent core. This transition to coherence is a crucial unresolved problem in star-formation.

A final aim of these observations is to compare extinction column density maps against maps constructed from integrated intensity maps of Perseus in ^{13}CO obtained by COMPLETE. There are substantial differences in the column-density spectrum inferred from ^{13}CO and extinction, especially at low extinction (see Figure 3). Our hypothesis is that some chemistry/temperature effect is making ^{13}CO a poor tracer of the density structure in this cloud. The proposed deep observations will help us to understand exactly where this discrepancy occurs by providing high-resolution maps at the edges of cores, allowing a detailed comparison with the ^{13}CO map.

Previous work

Prior work has studied the physical conditions present at the birth of stars. Tafalla et al. (2004) have characterized the physical structure and chemical composition of two starless cores. Tafalla & Santiago (2004) have found evidence of the first starless core with essentially no molecular depletion of ^{18}CO at high densities. Possibly this core is too young for molecules to have had time to deplete. This work has relied on 1.2 mm continuum observations to derive the densities of the cores; near-infrared extinction mapping provides a more robust density determination. The NICE algorithm has been applied succesfully to L 977 (Alves et al. 1998), and Barnard 68 (Alves et al., 2001), demonstrating that the basic structure of many dark clouds cores is well characterized by a Bonnor-Ebert sphere. Lombardi & Alves (2001) demonstrated that for 2MASS data the NICER technique agrees with the extinction maps created by the NICE algorithm, but with reduced noise and covering a broader range of extinction.

Layout of observations

Our fields are chosen to coordinate with other observations. IRAM-observed N_2H^+ cores are in L1448, L1451, and B5. The first two regions are small enough to be covered in a single field by OMEGA 2000, while we do B5 in four exposures, covering the entire cloud. We also look at B1, a highly extincted region unaffected by embedded cluster that provides an ideal place to study the transition to coherence. At the edge of each field, we will be able to compare extinction column densities with those inferred from our ^{13}CO map. At each location we will take long exposures in H (1.5 hours) and K (1.25 hours), and a short (15 min) exposure in J. When combining several fields for one cloud we include small overlaps ($\approx 1'$) to allow mosaicing (Figure 2). Four control fields will be taken around the edges of the cloud for calibration.

These observations will be the first systematic extinction maps of many dense molecular clouds at a resolution of 1.5 arcminutes. Coordination with other observations will allow us to answer important quesitons about chemistry, the transition to coherence, and the value of ^{13}CO as a density tracer.

8b. Figures and tables

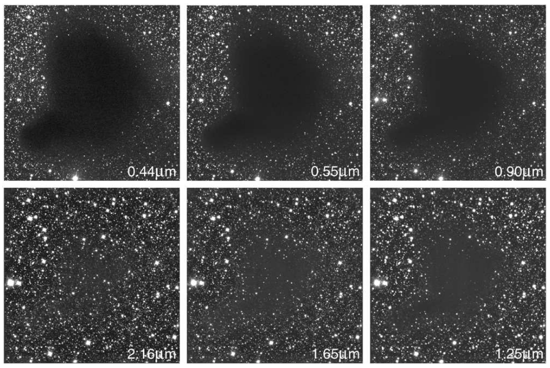

Figure 1: As illustrated above in B68, as we go to longer wavelengths more stars allow us to probe deeper into the molecular cloud and we get a better picture of the structure. From Alves et al. 2001.

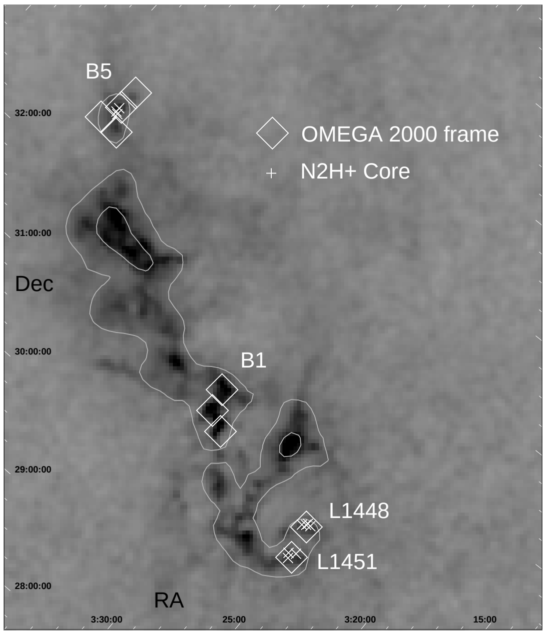

Figure 2: The extinction observations requested here (white boxes) complement other observation which have been obtained by the COMPLETE team and the P.I. In particular, the 2MASS-based extinction map shown above (with contours at $A_V = 3$, 6, and 9 magnitudes) is based on insufficiently deep observations to probe the densest regions at high resolution. For specific cores which the P.I. has observed in N_2H^+ (white crosses), these new observations will allow us to do a detailed study of chemical depletion in a large number of cores with critical information about the density structure surrounding these cores.

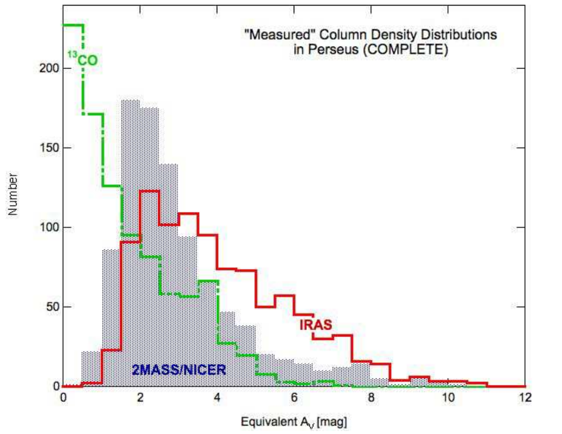

Figure 3: This is a preliminary figure showing the measured or inferred column density-distribution function for Perseus from three different methods. All three methods should give the same answer, and all three are used to study the density structure of clouds, so it is vital to find out which ones are wrong, and why.

9. Objects to be observed

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

Designation	α (2000)	δ (2000)	Rough A_V (mag)	priority
B5-01	$03^h\,48^m\,06\overset{s}{.}2$	$+32^\circ\,42'\,07''$	3	1
B5-02	$03^h\,47^m\,35\overset{s}{.}9$	$+33^\circ\,09'\,51''$	3	1
B5-03 [a]	$03^h\,47^m\,38\overset{s}{.}8$	$+32^\circ\,56'\,08''$	6	1
B5-04	$03^h\,46^m\,56\overset{s}{.}5$	$+32^\circ\,41'\,24''$	4	1
L1448 [b]	$03^h\,25^m\,34\overset{s}{.}0$	$+30^\circ\,43'\,01''$	5	1
L1451 [c]	$3^h\,25^m\,08\overset{s}{.}7$	$+30^\circ\,20'\,49''$	6	1
B1-01	$03^h\,33^m\,36\overset{s}{.}2$	$+31^\circ\,17'\,35''$	8	2
B1-02	$03^h\,33^m\,16\overset{s}{.}2$	$+31^\circ\,02'\,41''$	8	2
B1-03	$03^h\,32^m\,13\overset{s}{.}9$	$+30^\circ\,55'\,21''$	8	2

[a]Covers a region of N_2H^+ cores
[b]Covers a region of N_2H^+ cores
[c]Covers a region of N_2H^+ cores

10. **Justification of the amount of observing time requested:**

OMEGA 2000 on the Calar Alto telescope provides an ideal site for infrared-extinction surveys. The camera's extremely large field of view, combined with a fair size telescope provides both the spatial coverage and depth necessary to study the density structure of cores as they collapse out of their surroundings.

With a FOV= $15.4' \times 15.4'$ we plan a total of 9 science pointings (see Figure 2) and 4 control fields. The method that will be used to derive infrared extinction relies strongly on the observation of these control fields, from which we derive the normal stellar background and any extinction that is foreground to the entire complex. Since the Perseus complex stretches over a fairly broad region, we will obtain control fields at four locations around the edge of the complex where we expect there is no gas and dust, as evidenced by a lack of CO emission and zero extinction in the 2MASS extinction map. One control field each night will provide for accurate calibration.

Martin Cohen provided us with estimated cumulative star counts for the center of Perseus in H and K using his SKY4 model (Cohen 1994). The number of stars observed limits the resolution of the map. From our experience with the 2MASS extinction map we discovered that to make a map with no holes after we spatially smooth required an average of ≈ 12 (stars)/(pixel), a criteria we adopt here.

The limiting factor in dense cores at this galactic latitude is seeing enough stars in H (which is, at an A_V of 10, 0.6 magnitudes dimmer than K). We aim for $1.5'$ resolution which corresponds to ≈ 0.10 pc at the distance of Perseus. To achieve the necessary stellar density, the SKY4 model predicts we will have to reach a magnitude of H ≈ 21 (20.4 mag with an A_V of 10 in the densest regions). Based on the OMEGA2000 manual's Figure 45, in which they reach 5σ photometry to an H magnitude of 20.8 in 25 minutes of integration, we expect to reach 5σ photometry to our limiting magnitude in H in 45 minutes of integration time. Since the efficiency of correlated double sampling with fast reset is given as 50% in the manual, this corresponds to a total time of 1.5 hours.

A similar stellar density in K is reached a 20.25 mag, which can be reached in 37 minutes of integration, or 1.25 hours of observing. At regions of high extinction we will see few stars at J, so this frame is used mainly to obtain color-color diagrams of the region for calibration purposes. We plan to reach a J of 20.5 mag in 6 minutes of integration time, or 12 minutes of observing. In total then, a science frame will require 3 hours of observing (accounting for overhead).

Our source is observable (above an airmass of 2) for about 8 hours during the optimum time requested in this proposal. We propose to do 2.5 science frames and one calibration region each night. Our 9 frames will thus require 4 nights.

11. **Constraints for scheduling observations for this application:**

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

João Alves has extensive observational experience in obtaining infrared photometry for extinction maps. Having worked with this method for the last 6 years, he has obtained data for a number of cores (e.g. B68, IC5146, L977) at a variety of sites with a wide range of instruments.

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

Telescope	instrument	date	nights	success rate	publications

14. References for items 8 and 13:

Alves, J., Lada, C. J., & Lada, E. A. (2001), *Internal structure of a cold dark molecular cloud inferred from the extinction of background starlight*, Nature, 409, 159.

Alves, J., Lada, C.J., Lada, E.A., Kenyon, S.J. & Phelps, R. (1998), *Dust Extinction and Molecular Cloud Structure: L977*, ApJ, 506, 292.

Cohen, M. (1994), *Powerful model for the point source sky: Far-ultraviolet and enhanced midinfrared performance*, AJ, 107, 582.

Lombardi, M. & Alves, J. (2001), *Mapping the interstellar dust with near-infrared observations: An optimized multi-band technique*, A&A 377, 1023.

Tafalla, M., Santiago, J. (2004), *L521E: The first starless core with no molecular depletion*, A&A, 414, L53-56.

Tafalla, M., Myers, P.C., Caselli, P., Walmsley, C.M. (2004), *On the internal structure of starless cores I. Physical conditions and the distribution of CO, CS, N_2H^+, and NH_3 in L1498 and L1517B*, A&A, 416, 191-212.

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15. CAHA does 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.

    Should observing time be granted is it planned to apply for DFG funds? yes [ ]
    no [X]

Tolerance limits for planned observations:

maximum seeing:	2″	**minimum transparency:**	50%	**maximum airmass:**	2
photometric conditions:	yes	**moon: max. phase / ∠ :**	1/20°	**min. / max. lag:**	/ nights

- ● **3.5m**
  - ● Prime focus
    - LAICA
    - ● OMEGA 2000
  - Cassegrain focus
    - TWIN spectrograph
      - beam splitter / mirror
      - blue channel grating: / red channel grating:
    - OMEGA Cass → without adaptive optics / with adaptive optics
    - MOSCA
    - PMAS → PPAK / LensArray
    - 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 →