# MAD Science Demonstration Proposal

## Title: A MAD view of the M 16 elephant trunks


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**Abstract:**

We propose to use MAD for near-infrared imaging of two of the large gas and dust columns (known as "elephant trunks") in the heart of the Eagle Nebula (M 16). These data will reach a spatial resolution directly equivalent to that of the well-known optical images obtained using HST/WFPC-2, and will be a significant improvement over the existing benchmark infrared imaging study made using VLT/ISAAC under exceptional seeing conditions and reaching a spatial resolution of 350 mas. The unprecedented spatial resolution and sensitivity of MAD over a large FOV will enable a much more detailed study of the young stellar and sub-stellar population embedded in these trunks and allows the surface morphology of the photo-ionised trunks to be traced at the same resolution, but in complementary lines, as the optical WFPC-2 images.


**Scientific Case:**

The birth of a star is guided by two key factors: the initial conditions of the gas and dust reservoir in which the star forms, and the influence of the external environment. The presence of nearby OB stars leads to a significant alteration of the environmental conditions during early phases of stellar formation due to their high luminosity, intense ionising radiation, and strong winds. A well-known example is provided by the Eagle Nebula (M 16) where OB stars in the associated stellar cluster NGC 6611 (Hillenbrand et al. 1993, AJ, 106, 1906) are photo-ionising and ablating material in the surrounding nebula, leading to the creation of three parsec-scale elongated gas and dust columns, or "elephant trunks".

These trunks were famously imaged by Hester et al. (1996, AJ, 111, 2349) using WFPC-2 on the HST, and showed a detailed delineation of their surfaces. In particular, a large number of small protrusions were revealed, which Hester et al. postulated might contain young protostars on the verge of being revealed by the encroaching ionisation front. The key question raised was whether these so-called "evaporating gaseous globules" or EGGs were already host to young protostars prior to the nearby OB stars turning on, or that compression and radiative implosion due to the ionisation front had induced the formation of new stars where none were previously present. In either case, it was hypothesised that there would be major implications for the resulting stellar mass function.

The missing piece of the puzzle was direct evidence of protostars embedded in the EGGs which, due to dust obscuration, could not be seen at optical wavelengths. Thus, McCaughrean & Andersen (2002, A&A, 389, 513) used VLT/ISAAC $JHK_s$ imaging to penetrate the dust and examine the contents of the EGGs. Although most of the EGGs appeared to be empty, 15 percent of them did show evidence for associated young low-mass stars or brown dwarfs. In particular, the heads of the two largest trunks contain luminous YSOs, as also noted by Thompson et al. (2002, ApJ, 570, 749) based on their HST NICMOS imaging.

However, given the distance of M 16, a typical EGG with a diameter of $\sim$ 1000 AU covers only 500 mas, and thus the individual EGGs were barely resolved in the ISAAC images, despite the good seeing. Thus it was only possible to make statistical arguments about the fraction of EGGs containing candidate protostars as seen against the significant background field star population, and it was not possible to say anything about multiplicity. In both cases, a new near-infrared study with much improved spatial resolution ($\leq$ 100 mas) will yield important insights into the properties of stars embedded in the EGGs.

When placing these sources in a colour–magnitude diagram to determine their masses, a reliable correction for the highly variable extinction in this region is essential. We thus propose for an additional Br$\gamma$ image that allows a direct extinction mapping of the covered region in combination with the WFPC-2 H$\alpha$ emission-line image, assuming case-B. Such a comparison will also allow to diagnose conditions in the ionisation front as it sweeps over and exposes the trunks.

The proposed MAD imaging study will improve our understanding of the actual importance of the interplay of in-situ conditions and environmental influence on star formation in general. The specific aims are as follow:

- To investigate the detailed nature of the bright sources at the tips of the two main trunks and the morphology of their surroundings;
- To complete the source list of the small cluster of objects at tip the main trunk;
- To identify lower-mass sub-stellar contents of the EGGs beyond the ISAAC detection and confusion limits;
- To provide detailed images of the ionisation front as it sweeps over the trunks, enabling a joint optical/infrared (H$\alpha$/Br$\gamma$) emission line study of the physical conditions in the front.

**Targets and integration time**

| **Target** | **RA** | **DEC** | **Filter** | **Magnitudes** | **Total integration time** (sec) | **Field** (arcmin) |
|---|---|---|---|---|---|---|
| M16-1 | 18 18 50.30 | -13 48 55.0 | $JHK_s$,Br$\gamma$ | $JHK_s$=11.4-20 | 1800,900,600,1800 | 1×1 |
| M16-2 | 18 18 54.00 | -13 49 40.0 | $JHK_s$,Br$\gamma$ | $JHK_s$=8.7 -20 | 1800,900,600,1800 | 1×1 |
| M16-3 | 18 18 49.60 | -13 50 00.0 | $JHK_s$,Br$\gamma$ | $JHK_s$=9.6 -20 | 1800,900,600,1800 | 1×1 |

**Guide stars**

| **Guide star** | **RA** | **DEC** | **Vmag** |
|---|---|---|---|
| S9KJ000836 | 18 18 50.68 | -13 48 12.8 | 11.2 |
| S9KJ000847 | 18 18 52.67 | -13 49 42.6 | 9.4 |
| S9KJ000845 | 18 18 46.01 | -13 49 22.8 | 11.6 |

The asterism is a near-perfect equilateral triangle of foreground stars with magnitudes ranging between 9.4 and 11.6 mag in V, with the stars separated by about 1.6 arcmin. Although Field 3 falls off the triangle and has the widest distance to the next guide star, it will still provide important data for the head of the middle trunk and thus the embedded YSO2 at its tip, even under slightly reduced performance conditions.

**Time Justification:**

We will use three distinct pointings to cover the tips of the two trunks and a region with a considerable number of EGGs at the base of the largest trunk (see Fig. 1). Each pointing will be observed in a small dither pattern with a total integration time of 1800, 900, 600, and 1800 s in $J$, $H$, $K_s$ and Br$\gamma$, respectively, for each pointing. With this integration time we will reach a limiting magnitude of ∼22 mag in $J$ and ∼20 mag in $K_s$. This prediction is based on the experience with previous MAD data in regions of high extinction (e.g. the Trapezium cluster) after scaling the DIT and accounting for the saturation limit. These sensitivity limits will enable the detection of low-mass brown dwarfs in M16 under an average extinction of $A_v \sim 10$.

The DIT value is governed by the saturation limit for the brightest sources in each of the three fields. After a close examination of the VLT/ISAAC images we choose a DIT of 6 s in $J$, 3 s in $H$, and 2 s in $K_s$. We will than distribute the total integration times for the broad band filters among 10 dither positions with an NDIT of 30. For the Br$\gamma$ images we choose a DIT of 30s and a NEXP of 6 for each of 10 dither positions.

For the overheads we account for each of the three fields separately with 20 min pointing and AO acquisition, 1 s per DIT, and 3 s per NEXP for detector overheads, and an additional 90 s dither overhead per filter: 20 min + $3\times(300\times1\,\mathrm{s} + 10\times3\,\mathrm{s} + 90\,\mathrm{s})_{JHK}$ + $(60\times1\,\mathrm{s} + 10\times3\mathrm{s} + 90\,\mathrm{s})_{Br\gamma}$ = 44 min overheads and 85 min integration time per field, hence, a grand total of 6.5 hrs for the whole program.

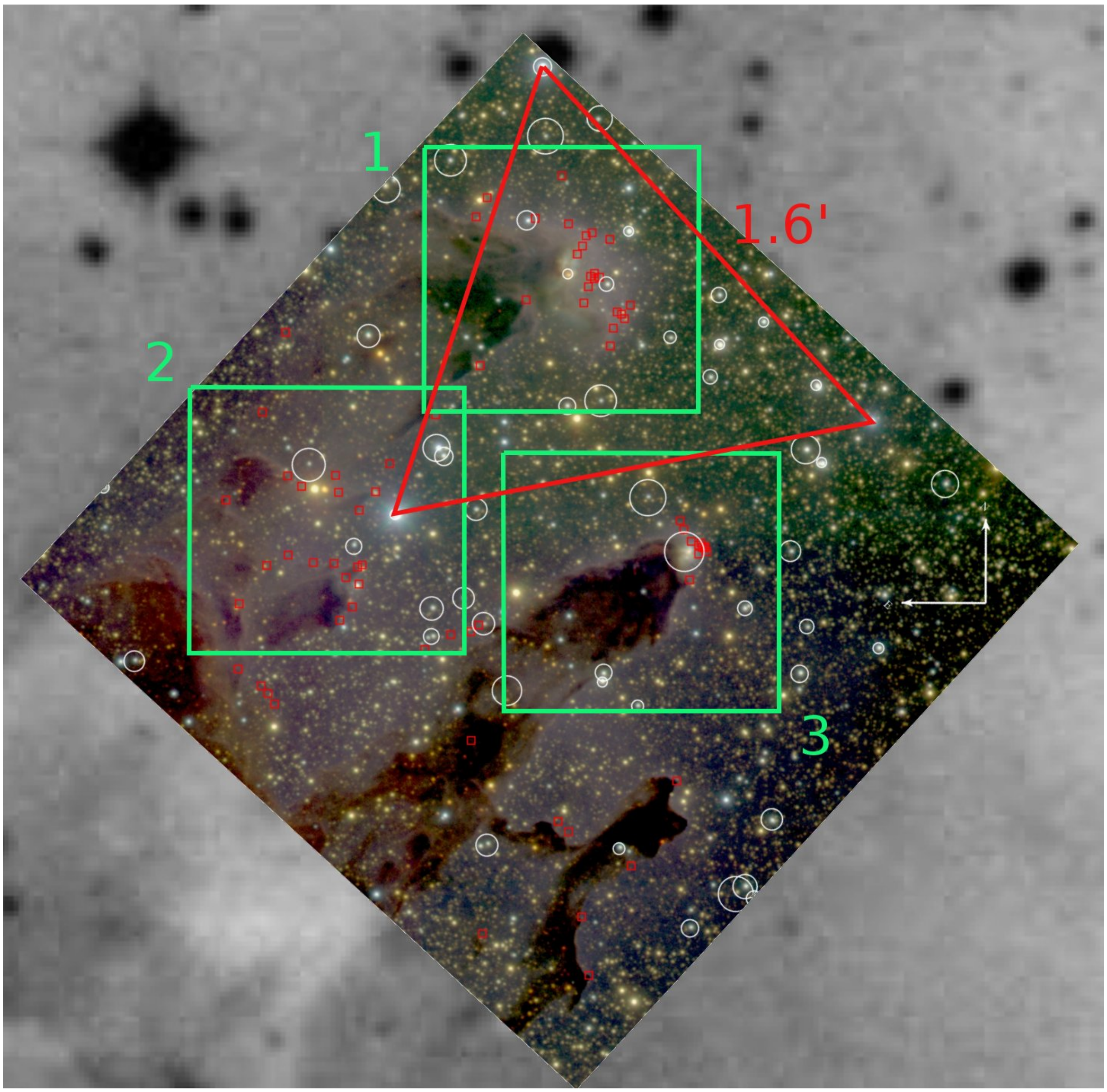


Fig. 1: Field positions for the three proposed MAD pointings (green) and the asterism of the three guide stars (red). North is up and east is left. The colour inset is a VLT/ISAAC $JHK_s$ mosaic by McCaughrean & Anderson (taken from Linsky et al. 2007, ApJ, 654, 347) superimposed on an AAO short-r image. The small red boxes mark the positions of the EGGs, the white circles are *Chandra* X-ray sources.