MAD Science Demonstration Proposal

R136: The young massive star cluster at the core of 30 Doradus

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Abstract:
We propose MAD J, H, Ks imaging of R136, the dense star cluster at the centre of the 30 Doradus starburst region. The exquisite spatial resolution provided by MCAO correction in the near-IR on the VLT will be able to probe deep into the cluster core, providing observations of the intermediate-mass population down to stellar masses of $\sim$2 $M_{\odot}$, including the pre–main-sequence phase. When combined with extant *HST* optical imaging and new VLT-FLAMES spectroscopy, this will enable the definitive study of the initial mass function (IMF) in one of the most massive, nearby clusters. With stellar kinematics from the spectroscopy we will also examine the radial dependence of the mass function to investigate the effects of mass segregation. Lastly, the integrated near-IR surface brightness profile will serve as an excellent tracer of the total stellar mass due to the minimised effects of extinction, so we will be able to test the 'excess light' scenario that could plausibly explain the departures from equilibrium seen in the optical profile of R136.

31/08/2007

Scientific Case:

30 Doradus is one of the largest star-forming regions in the Local Group. At its core is the dense star cluster R136, with stellar ages in the range of 2-4 Myr and a total stellar mass of $\sim 5\times10^4\ M_\odot$, putting it on a par with massive clusters found in starburst and interacting galaxies such as M51, M82 and the Antennae. As a proto-typical 'starburst', significant observational effort has been directed toward the region over the past 20 years. 30 Dor provides an excellent laboratory to study star formation, and also offers insight into the nature of distant super-star-clusters and starburst galaxies, for which we only have integrated properties – if we can understand large clusters on our doorstep, we can be more confident of accurate interpretation of those far away.

However, the formation of large clusters remains poorly understood. In a relatively short period of time ($\sim$few Myrs) a complicated mixture of various physical processes take place that transform a giant molecular cloud (GMC) into a star cluster. In the competitive accretion model of star formation [1] massive stars form in the centre of the gravitational well of the GMC. This model successfully explains observations that show massive stars to be more concentrated in young clusters such as in the Orion Nebula [2], yet the situation is complicated by the fact that massive stars will also tend to move toward the cluster centre over their lifetimes due to dynamical interactions, i.e. mass segregation.

To date, ground-based optical imaging and spectroscopy has been used in 30 Dor to study the initial mass function (IMF), reddening, star-formation history, stellar content and kinematics [e.g. 3-7]. But only with near-IR imaging are we able to disentangle multiple objects, and to identify nascent stars that are still partially embedded in their gas clouds. Indeed, *HST*-NICMOS observations of some of the complex nebular structures in 30 Dor have provided evidence of triggered star formation, showing the region to be a two-stage starburst [8,9].

The core of R136 is too dense for traditional (seeing-limited) ground-based techniques. Only with the arrival of *HST* was R136 resolved in optical and UV images [10,11,12], with follow-up spectroscopy revealing a hitherto unprecedented concentration of the earliest O-type stars [13]. The conclusion of these studies was that the high- and intermediate-mass IMF is 'completely normal', i.e. Salpeter-like [13]. This contrasts with results from AO-corrected near-IR images from the ESO 3.6-m that, when combined with the *HST* data, found evidence of mass-segregation via a flattening of the IMF in the core [14]. Unfortunately, by virtue of using such novel technology, the 3.6-m images were limited to a relatively small field-of-view, with the core of R136 in one quadrant of a 12.8$''$ sq. field.

VLT-MAD presents an excellent opportunity to obtain a unique view of R136, allowing us to revisit these conflicting results and settle the debate. The *HST* (BVI) photometry is good to at least $2.8 M_\odot$ [10], corresponding to mid A-type stars on the main sequence. At the distance of the LMC (50 kpc) these stars have near-IR magnitudes of $\sim$20, well-matched to the quoted Ks performance of the MAD camera, CAMCAO. We will probe the intermediate-mass IMF of R136 at unparalleled spatial resolution. Do we see evidence for a flattening of the intermediate-mass IMF with radius? Is there an age spread in stars seen at the pre–main-sequence stage? From direct star counts we will also investigate the finding that the luminosity profile of R136 is best described by two components, with a break at 10$''$ [15]. There is significant extinction at $r \sim 10''$ [e.g. 14], so by penetrating the gas and dust more successfully than in the optical, near-IR observations will provide strong empirical constraints on the outer component of the luminosity profile – the so-called 'excess light' that is predicted to originate from rapid gas removal in the early stages of cluster evolution [16].

Constructing the IMF requires accurate masses from multi-wavelength photometry, with spectroscopy needed above $\sim 10 M_\odot$ because of the degenerate colours of massive stars. VLT-MAD will yield near-IR photometry in R136 at a comparable spatial resolution to the *HST* optical images, while also allowing correction of the variable extinction across the cluster. There are existing NICMOS images of R136 [17], but the spatial resolution is lower and the field-of-view is smaller than the imaging capabilities of the MAD system. Finally, we note that a subset of the applicants on this proposal have an approved VLT-FLAMES programme in Period 80 to look for dynamical signatures of gas expulsion and mass segregation in the region of R136 via IFU/multi-fibre spectroscopy (PI: M. Gieles). The MAD images will be relatively impervious to extinction, thereby helping to disentangle the spectroscopic data. For instance, NICMOS images have revealed that some of the 'knots' in the 30 Dor nebula, that were previously classified as O stars, are actually compact multiple systems [18]. Do we detect secondary components of massive stars in/near R136 that have remained obscured until now? What effect does stellar multiplicity and blending have on the upper IMF? How does the IMF compare with results from Galactic clusters?

References:
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(17) Andersen et al., 2007, in press
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Targets and integration time

We request J, H and Ks observations at 3 pointings of the 5-point mosaic template, as shown by the green boxes in Figure 1.

GUIDE STARS: There are four suitable natural guide stars (nos. 499, 548, 952 and 1788), each with $V \sim 12$ (see Figure 1). These can be used to provide a 3-point asterism, with R136 slightly to the west of centre; the central coordinates for the MAD observations are: α = 5:38:47, δ = −69:05:54. We note that there are 3 other stars that could be used as one of the guide stars: nos. 987, 1257 and 1500. The first two have V magnitudes of 11.9 and 12.6 respectively, but are relatively crowded, whereas #1500 is closer than 1788 but fainter (V = 13.1). Two of the co-Is on this proposal (Alves & Ascenso) have MAD observations in-hand of the Galactic cluster NGC 3603 – in advance of the proposed R136 observations (January 2008) more will be learnt about the performance of MAD, and we will be able to make an informed decision of the trade-off between different magnitude NGS and likely performance. In summary, **the NGS requirements can be satisfied**.

BRIGHT TARGETS: In terms of bright stars saturating the detector, we note that the brightest 'red' star in the field is #1445 (see Figure 1), an M-supergiant with V = 13.6, i.e. K is likely to be slightly brighter than $\sim 10^{\mathrm{m}}$. By way of a comparison, we note that with a 5s DIT such a star does not saturate the detector in the NAOS-CONICA ETC.

Target	**RA**	**DEC**	**Filter**	**Magnitudes**	**Total integration time** (sec)	**Field**
R136	05 38 43.3	−69 06 08	J	J <20.0	3×1200	3×57″
R136	05 38 43.3	−69 06 08	H	H <20.5	3×1200	3×57″
R136	05 38 43.3	−69 06 08	Ks	K <20.5	3×2400	3×57″

Time Justification:

We provide exposure times guided by an initial assessment of the observations of NGC 3603 mentioned above. The 5σ limits in these were: $J = 20.5$ (12 min), $H = 21.1$ (12 min), $K = 21.4$ (38 min), taken from the best 50% of images comprising these exposures. To ensure robust K-band magnitudes over the same range as the optical *HST* imaging, we require S/N$\sim$10 at $K_{\mathrm{s}} = 20.5$. This can be achieved via 40 min equivalent exposures at each of the 3 CAMCAO pointings (see green boxes in Figure 1). We also request 20 min exposures in J and H to obtain (internally consistent) colours. Note that the CAMCAO pixel scale potentially undersamples the diffraction limit of the VLT at J and H, but the AO correction in these bands is less effective than at K, and the resulting PSFs are not undersampled, i.e. no microstepping of the images is required.

We also request observations of an offset sky field to flat-field the array and for sky subtraction (notionally at α = 05:38:56.9, δ = −68:52:00, one of the NICMOS control fields from Andersen et al. 2007). For these we request matching observations in each band, with small jitters around the central 57″ pointing (to avoid stars in the master flat-field). These should be taken adjacent in time to the observations of R136 (for each filter), and preferably split either side of the science exposures.

This leads to a total time for science exposures of 4 hours, with 1h20m for the offsets. We note that the LMC is at an airmass < 2 for ∼7 hrs in early January. Depending on the overhead for the offset skies, and allowing 20min for aquisition, the observations proposed here could be undertaken in one night, (although they may benefit from utilising the optimum range of zenith distances over parts of two nights, e.g. K-band one night, J and H the next).

Lastly, we request one standard field pointing, the exact details of which will be decided once the detailed operation plans for Science Demonstration time have been agreed.

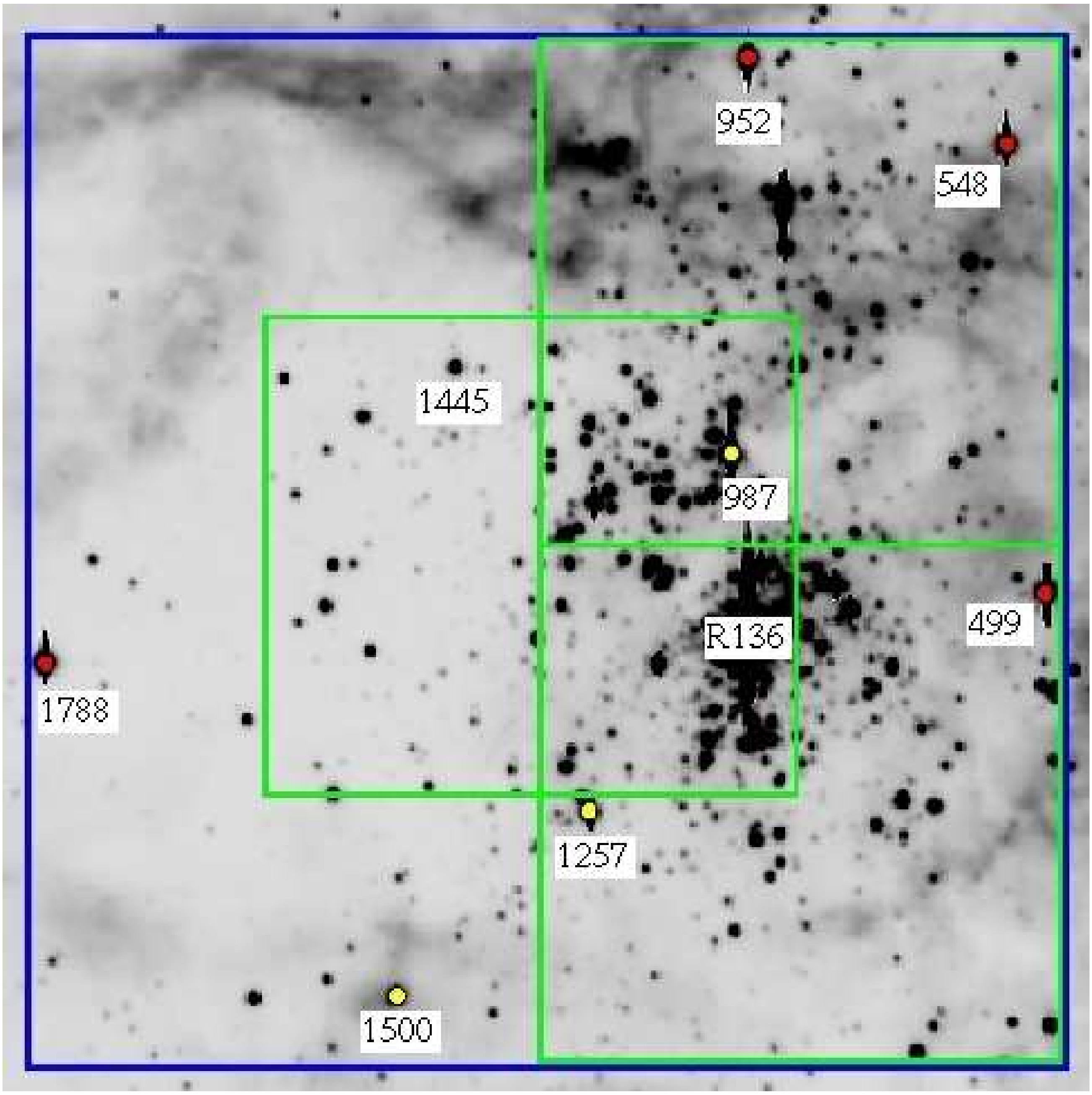

Figure 1: V-band ESO Imaging Survey WFI image of R136. The blue outer box is the MAD field-of-view, the green boxes mark the 3 requested CAMCAO pointings. We have highlighted four uncrowded stars (red dots): nos. 499, 548, 952, and 1788, with V = 11.87, 12.14, 12.03, and 12.04 respectively; these are at the faint limit for the NGS requirements but confirm R136 as a feasible target for MAD observations. The distance from #499 to #1788 is ∼113 arcsec, i.e. these two stars, combined with #952 provide NGS over the required 2 arcmin. Star #1500 is fainter (V = 13.1) but may provide a more useful asterism.