High spatial resolution of the compact starburst cluster R136 at 50 to 10 mas

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Why Star clusters?

Understanding the process of star cluster formation is vital for astrophysics since most stars if not all of them form in clustered mode[1].

Clusters form in three stages:

- Collapsing the molecular cold cloud and formation of stars along the filaments
- Formation of massive stars and their destructive influence on the subsequent life of the cluster
- Dynamical evolution of the formed cluster

Why R136?

The goal is to make a high quality reference image of the cluster R136 (30 Dor) in the LMC in the K and H band, and, if possible in the Y and J bands. These challenging observations are necessary to estimate the capabilities of SPHERE of imaging distant clusters. These observations aim first at carefully investigating the binary fraction of the core of the starburst, in which it was claimed that the most massive stars ever weighted have been discovered (~150-300 solar masses)[2].

The reference publications can be divided into two main parts: the work performed using the HST in the visible, and the papers reporting on the HST NiCMOS, but also quite recently the VLT/MAD experiment[3].

The HST observations in the visible have been used to study the initial mass function (IMF), reddening, star-formation history, and stellar content in 30 Dor. Star counts from the optical HST images revealed that the luminosity profile of R136 appears to be best described by two components, with a break at 8-10" (inner 2pc). Meanwhile, near-IR observations with the Hubble Space Telescope (HST) have provided evidence of triggered star-formation, showing the region to be a two-stage starburst[4].

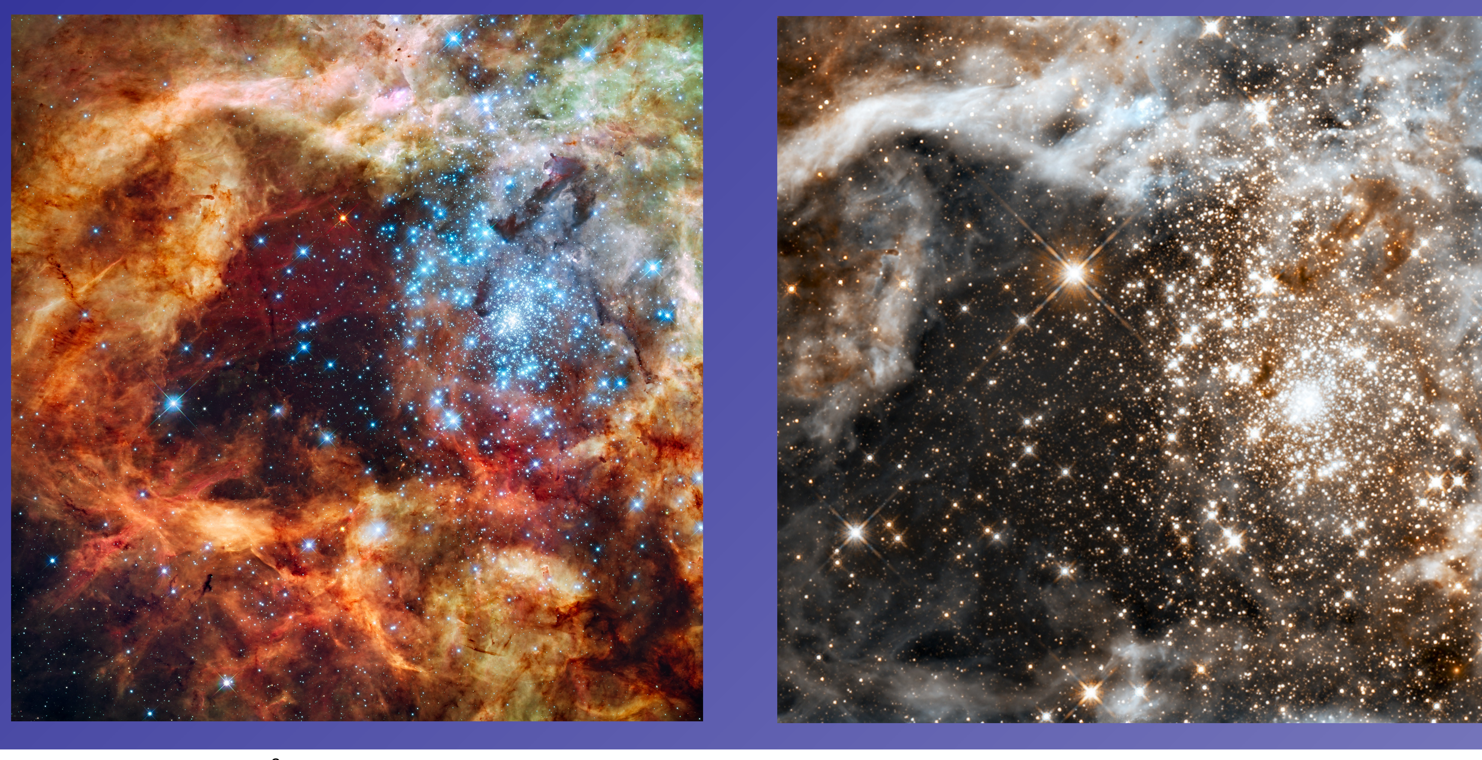
At the centre of 30 Dor is the dense star cluster R136, with stellar ages for the most massive stars in the range of 1-2Myr[5] and a total stellar mass in the range of 0.35-1 10^5 solar masses, depending on the low-mass form of the mass function. However, the core of R136 is too dense for traditional (seeing-limited) ground-based techniques. Moreover, HST could not resolve the core at 2μm and R136a3/a2 remain unresolved to date by any instrument.

MAD/SPHERE

MAD and SPHERE have the power to penetrate the gas and dust more successfully than in the optical HST images, at comparable angular resolution. The Strehl of MAD in the core reaches 15% in the K band. The Strehl of SPHERE may reach at least 40% in the K-band. The MAD faint magnitude limit in the core is in the range of 18.8, equating to the main sequence mass of >7 solar masses. For SPHERE it will be >2 solar masses.

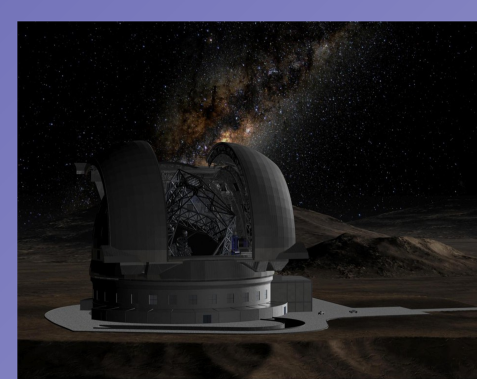
Adaptive Optic System of SPHERE

- The Shack-Hartmann WFS, array of 40x40 sub-apertures
- Single Conjugate Adaptive Optics (SCAO) Controlling System
- Stacked Actuator Mirror (SAM) with a grid of 41x41.



A region of 50x50pc^2 (3.3'x3.3') around the cluster R136 in the 30 Doradus region of the LMC, at the distance of 50 kpc. Left: in the visible; resolution of 47mas. Right: in the Infrared (1.1, 1.6μm); resolution of 140mas. By HST, WFC 3

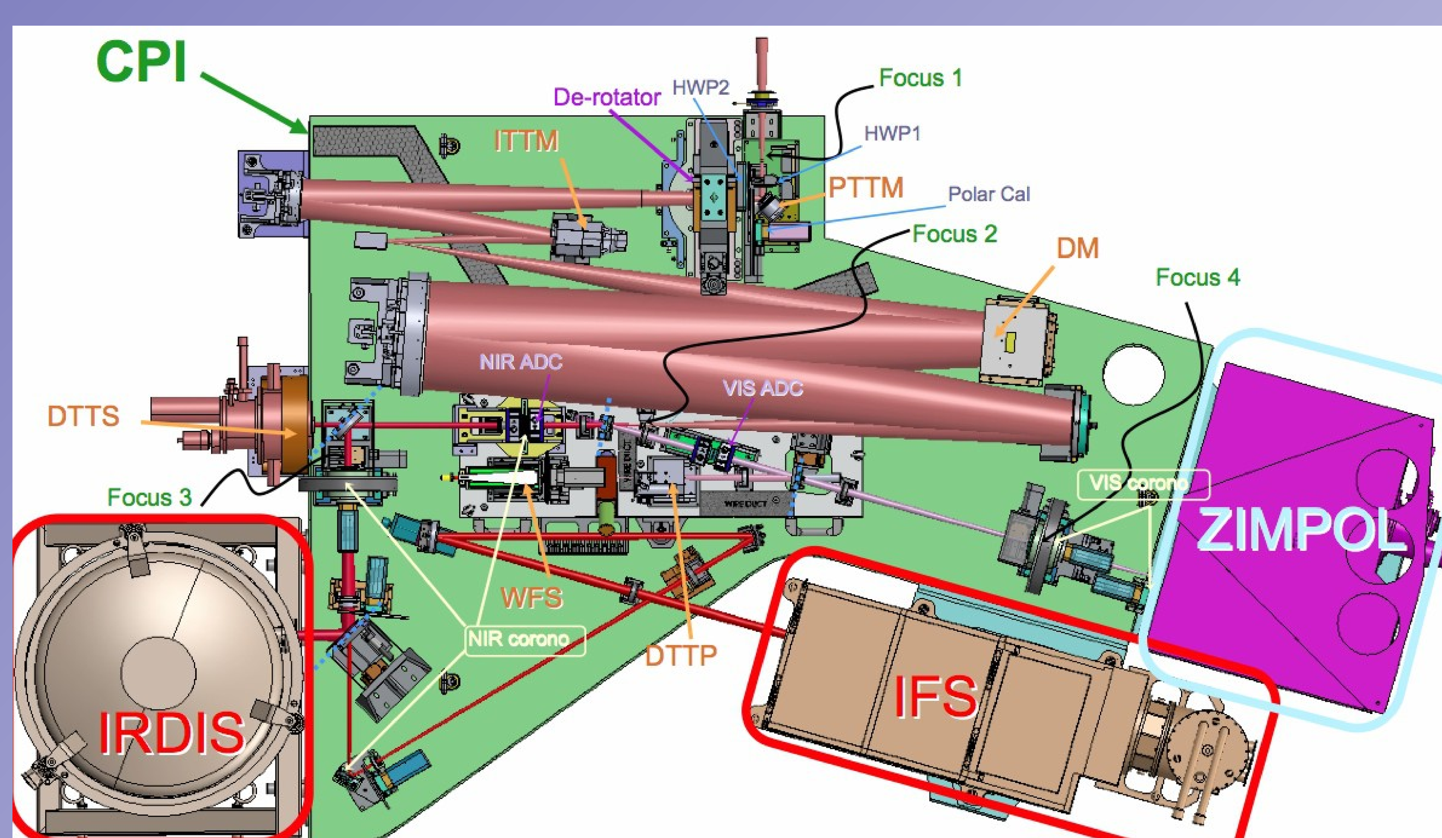
Telescope	type	Diameter (D)	Wavelength (λ)	Resolution (λ/D)
HST	Space	3.5 m	0.5 – 0.8 μm	30 mas – 47 mas
SPHERE/VLT	Ground	8.2 m	1.0 – 2.0 μm	25 mas – 50 mas
MICADO/ELT	Ground	39 m	1.0 – 2.5 μm	5 mas – 13 mas



	SPHERE		MICADO
Main characteristics	IRDIS	ZIMPOL	MICADO
Wavelength range (μm)	0.95 - 2.32	0.6 - 0.9	(0.6) - 0.8 – 2.5
Field of view	6"x 6"	3"x 3"	53"x 53"
Pixel Scale (mas)	12.5	< 7.8	3
FWHM (mas)	31 (J) , 55 (K)		6 (J) , 10 (Ks)
Observing modes	On axis guide star: - Imaging - Dual-band Imaging - Dual-Polarimetric Imaging - Long-slit Spectroscopy	- visible imaging - differential polarimetric imaging	Off axis AO loop

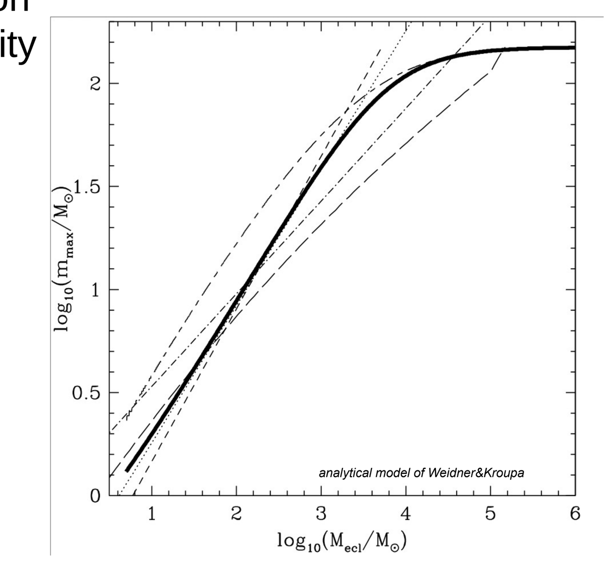
R136 is a very challenging object for SPHERE; the cluster has a bright core (R~9.4) which is partially resolved by the Shack-Hartmann lenses. Given AO sensitivity and source extension the correction will not be optimum.

MICADO/ELT will be perfectly suited for this target in terms of sensitivity and spatial resolution.



Open questions

- Most information, theories and models are limited to the clusters in our Galaxy and we are not sure if they work for the clusters in other galaxies or not, such as:
  - Mass segregation
  - Universal shape of the IMF
    Detailed knowledge of IMF and how it varies through time and space is important to understand and predict the evolution of stellar systems[1].
  - Relation between the total mass of the cluster and its massive member's mass[10]
  - Binary fraction
  - Infant mortality



- We want to overcome the existing limitations of high spatial resolution imagery of clusters in other galaxies.

Scientific Goals

- Detect the faint population in the inner core of the cluster: improving IMF
- Check for the most massive stars weighted in the core of the cluster are not groups of stars[2].
- Make a high quality reference image for astrometry monitoring

SPHERE will provide spatial resolution of 60 mas in the K-band better than twice HST resolutions at the same wavelength (140 mas). With a good Strehl ratio in the K-band, SPHERE may probably resolve R136's core and, if present, discover faint later type sources in the vicinity of the brightest sources.

Problems

R136 is a faint and resolved object for the extreme OA (R~9.4 within the 2" core)[6],[7]. The sub-pupils see a partially resolved source (sub-pupil resolution ~0.8") and the frequency of the correction has to be decreased compared to the range of nominal performances. Observations with good to excellent Paranal conditions (0.6"-0.8") are required for these observations.

Aim

- use CAOS; a Code for Adaptive Optics Systems[8] Software package SPHERE[9]; an end-to-end numerical tool designed for detailed simulations of the instrument to define and simulate as realistically as possible the behavior of an AO system; from the atmospheric propagation of light to the sensing of the wave front aberrations and the correction through a deformable mirror.
- I will add some artificial stars into the scene and simulate the possibility of SPHERE to detect them.
- If everything goes well, how we should improve the key theories about Star Cluster Formation and evolution.

Raw image of R136 by HST in 0.8μm (wfpc2_f814w); resolution: 47mas

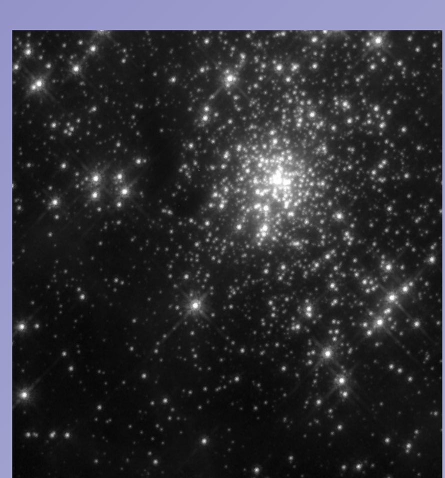
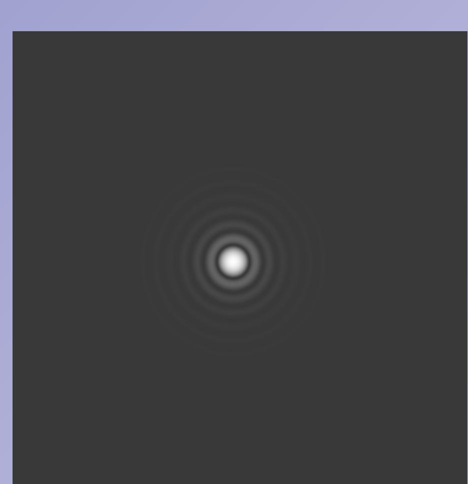
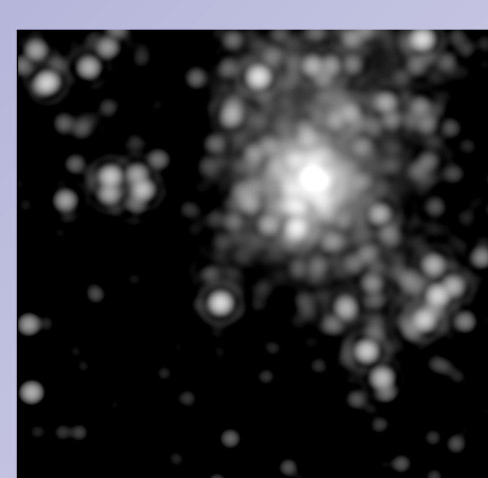


image of R136 after some photometry corrections



PSF from the sub-aperture of the SPHERE/VLT WFS (Airy pattern) with FWHM=0.8"



The image of R136 which can be seen by each Shack-Hartmann sub-aperture

Bibiography

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[10]Weidner, C., et al. 2010, MNRAS, 401, 1, 275