SF2A 2013
L. Cambrésy, F. Martins, E. Nuss and A. Palacios (eds)

THE ROLE OF SUPER STELLAR CLUSTER IN EXTREME STELLAR FORMATION: WHICH PROGRAMME FOR THE E-ELT ?

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Abstract.
In ULIRGs, the intense star formation (up to 1000 Msol / year) induced by the direct interaction of two galaxies is concretized as extremely compact and bright star clusters with no equivalent in the Galaxy. These super star cluster (SSC) which play a major role in the structural and chemical Evolution of galaxies are rare and distant (d $\approx$ 150 Mpc) with a diameter lower than the resolution achieved with adaptive optics on a 8 -10m telescope. The resolution offered by MICADO on the EELT (10 mas , 8 pc at 150 Mpc) will allow a major leap in three types of programs:

- characterizing the starburst on five times more distant objects
- spatial resolution of the close SSC to address many questions: Schmidt law, filiation with globular clusters, proper spatial structure (IMF, HII region clustering, dust clustering, etc.)
- finding direct links between a starburst and the presence of a central super-massive black hole. Instrumental choices are analyzed against these objectives.

Dans les ULIRGs, l'intense formation d'étoiles (jusqu'à 1000 Msol / an) induite par l'interaction directe de deux galaxies se concrétise sous forme d'amas stellaires extrêmement compacts et lumineux sans équivalent dans la Galaxie. Ces super amas stellaire (SSC) qui jouent un rôle majeur dans l'évolution structurelle et chimique des galaxies, sont rares et lointains (d $\approx$ 150 Mpc) avec un diamètre inférieur à la résolution atteinte avec l'optique adaptative sur un télescope de 8-10m. La résolution que proposera MICADO sur l'EELT (10 mas, soit 8 pc 150 Mpc) permettra d'effectuer un saut qualitatif important sur trois types de programme :

- caractériser la formation par flambées sur des objets 5 fois plus distants
- résoudre les SSC proches pour aborder de nombreuses questions: loi de Schmidt, filiation avec les amas globulaires, structuration spatiale propre(IMF, région HII, clustering de la poussière) etc.
- trouver des liens directs entre la flambée et la présence d'un trou noir ultra-massif central. Les choix instrumentaux sont analysés en regard de ces objectifs.

Keywords: ULIRGs, Super Star Cluster, star formation, HRA, infrared, imaging, ELT

1 Introduction

Star formation triggered by the encounter of two galaxies is especially intense and may lead to star formation rate as high as 1000 times the one measured in the Milky Way (1 Msol /yr). Those extreme galaxies most generally correspond to the class of ultra-luminous galaxies (ULIRGs) which radiate the essential of their energy in the infrared. This is consistent with the fact that the dust cocoon associated to the interaction-driven concentration of gas responsible for the starburst, absorbs most of the stellar power and re-radiates it at longer wavelength. The dust concentration remains opaque during the first phase, so the near to mid infrared domain is the most appropriate to study those objects. Stellar formation occurs essentially under the form of extremely compact and luminous star clusters, some of them can harboring up to the equivalent 10^4 O7 stars !

One archetypical nearby and medium SSC is R136 in the Large Magellanic Cloud. It features the following characteristics: L = $10^8 L_\odot$, 3500 stars, age: 2-5 Myr, size of the core: 4 pc, density: 200 times the one of an OB association, 42 stars O3 (thus the majority of all known O3 star), an IMF which seems to be Salpeter-like.

Those Super Stellar Cluster (SSC) play a major role in the structural and chemical evolution of the galaxies, as illustrated in the scheme below, because of the large conversion of gas in stellar mass, the production of

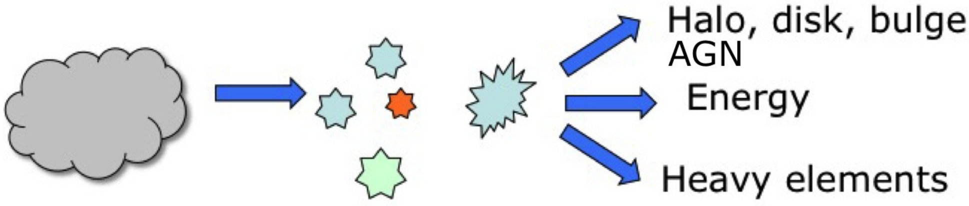

Fig. 1. SSC play a major role in the structural and chemical evolution of the galaxies

heavy elements and their dissemination through SNe, the injection of energy in the whole galactic medium and also because of their presumable role in feeding the super massive black holes at the center of galaxies.

If extensive and more and more complete surveys of ULIRGs do exist (e.g. the recent GOALS sample project: Stierwalt et al. (2013)), the population of SSC themselves remains however badly known because of the large distance of ULIRGs. Especially, their true distribution in mass, size, luminosity, stellar content, dust content, gas content, super-novae rate, etc. remain to be established on a significant sample in order to understand why SSC are so extreme compared to star forming regions in normal galaxies, and how those quantities relate with the intensity of the burst and their location in the system of interacting galaxies.

2 The questions E-ELT should help to anwer

SSC present a clear interest for the study stellar evolution because they show places of ideally synchronous stellar evolution and they allow to study different ages in the same galaxy with a fine temporal evolution. They also present a large coverage in mass and luminosity. General laws, such as the mass function or the related Kennicutt-Schmidt law can be studied in those extreme cases. Finally the question if wether SSC are progenitors of globular cluster and what is their stability (do 10 % of them survive after 40 Myr ?) are important questions.

The typical burst duration being of the order of 10 Myr, ULIRGs are rather rare so that any sample is far enough on the average (typically d = 150 Mpc) for high angular resolution (HAR) to be mandatory. For instance if we consider an ULIRG at 140 Mpc (the median distance in the catalog of Haan et al., 2011) and a typical diameter of a SSC of 20 pc the angular size would be 30 mas. This figure corresponds to half the actual resolution one can achieve in the near-IR on 8m class telescopes equipped with adaptive optics or on the HST in the visible: today, we can barely separate SSC but we cannot make a detailed study of their strucure. On the other hand, HAR will allow to separate SSC in regions where they are concentrated, thus avoiding confusion that would lead to bias the properties of individual SSC towards high values (see Randriamanakoto, 2013). Several programs to study active star formation in ULIRGs have already been conducted using the HST. The survey by Haan et al (2011) is especially noteworthy because it corresponds to a large sample (88 galaxies) and is made in the visible and H bands. There are also several works based on near-IR observations with 8m class telescopes, using spectroscopy or imaging and which are extremely valuable: for instance the recent study of Piqueras-Lopez et al. (2012) presenting an atlas of Integral Field Spectroscopy of 10 LIRGs and 7 ULIRGs and the spectroscopic survey by Davies et al. (2003) of 7 ULIRGs, however both surveys were done under good seeing conditions but not using AO.

The goal that E-ELt should allow to reach is a significant step in angular resolution to study individuals in the population of SSC in several of those distant objects. The study will allow to look for indications on burst propagation and history, as well as relations to a possible AGN, to carry out a statistical analysis of a large set of SSC in various ULIRGs to derive individually, i.e. without confusion, some fundamental properties: extinction-corrected luminosity, precise stellar content (CO bands and H lines), age of the burst or even sequence of ages between SSC (e.g. see Garca-Marin et al. 2006), dust content (IR excess), molecular content (H2 lines); we then will be able to establish overall distributions, especially luminosity and mass function. Correlations and trends between those quantities will also be possible in order to look if they still follow or deviate from known relations found in the nearby Universe, such as the one between the luminosity of the brightest cluster vs the SFR (Bastian, 2008).

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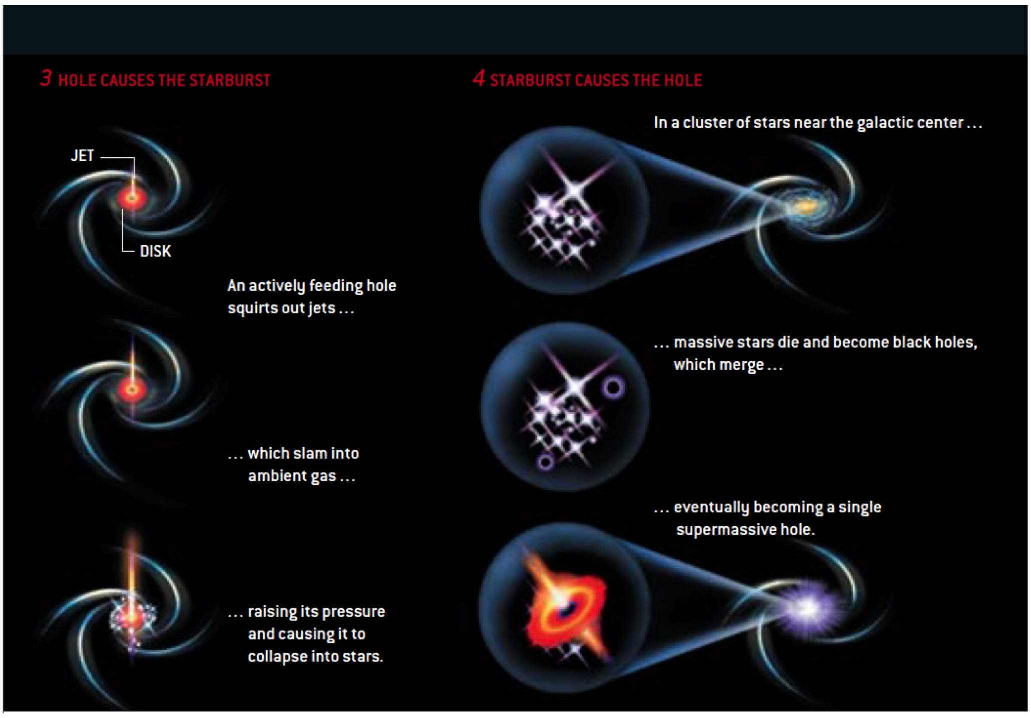

Fig. 2. Does the starburst causes the AGN or the inverse ?

One of the most important point will be the capability to resolve a large number of the SSC in diameter: this will immediately set the star density within the cluster, a fundamental parameter as regards its disruption and its age and allow to tackle some basic questions such as : *i)* the law of radial distribution of stars and its link to the initial collapse; *ii)* the structuration of the SSC as a set of separate HII regions or a unique giant one; *iii)* the propagation of the starburst within the cluster; *iv)* the IMF (Salpeter, top-heavy ?); *v)* the possible formation of a super-wind; *vi)* the link with the fine molecular gas distribution (Alma); *vii)* the clustering of the dust which impacts directly on the UV escape fraction; *vii)* the intra- and inter-cluster dynamics.

The question of the likely link between the starburst and an AGN will be more directly approached when reaching the pc scale, so that the old question of the egg and the chicken (which started first ?), summarized by Fig. 3 will receive new and hopefully conclusive elements.

Finally, another exciting question which is the history of star formation in the Universe will be approached in a more acute way since the distance at which a detailed mapping of SSC in starburst galaxies is still possible would be 5 times larger. This means in particular that studying the characteristics of resolved SSC in galaxies with z=2 will become possible.

3 Which instruments ?

Fig. 3 illustrates the huge gain in resolution brought by the E-ELT in the case of MICADO, the very likely first light imager of the future telescope: a star-forming galaxy at z=2 will be clearly resolved in its main SSC.

For the early science programme, MICADO will likely be the first choice since it will offer most of the features one wishes : broad-band filters to study continuum emission from stars, dust and the ionized gas, hopefully a set of narrow-filter sampling a range of redshift to study the stellar content (CO lines), the ionized gas (H+ lines), the molecular gas (H2 lines) and SNe (FeII lines). Single slit spectroscopy will also be available for detailed line profiles and kinematics studies.

In a second time, METIS the thermal infrared imager will give access to the thermal infrared range and thus to dust contents and heating, as well as to the most extinct regions, likely the youngest ones.

The sensitivity offered should allow to reach the 19-22 magnitudes of a SSC at 400 pc within a rather short time. For more distant objects such as the case illustrated on Fig 3 (z=2) four hours will typically be required to reach a sufficient S/N ratio.

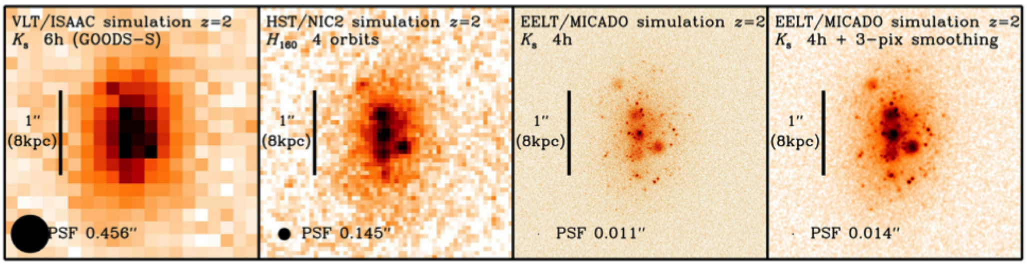

Fig. 3. Simulation of imaging in Ks-band of a distant galaxy at z=2 with MICADO

Finally when multi-objects spectrographs fed by MOAO will become available, another step will be possible, especially to study kinematics and providing a fine spectroscopic diagnostics.

4 Conclusion

The E-ELT with its infrared imagers MICADO and METIS will have an essential asset in the study of extreme star formation in remote galaxies, since it will allow not only to separate SSC and thus study distribution functions, especially mass and luminosity functions, but more fundamentally, it will allow to resolve the SSC themselves opening a completely new field. We will obtain keys elements on the starburst propagation, a possible IMF segregation, dust clustering and UV escape, HII region structure, intra-cluster dynamics, direct link of the nuclear starburst with the AGN etc.

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