ASTERICS Policy Forum
ELT input

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Abstract

The Extremely Large Telescope (ELT) is the new flag facility of the European Southern Observatory (ESO). The ELT is now under construction (first light in 2024) and with its 39-metre primary mirror will be the largest optical/near-IR telescope in the world.

Here we present 3 example science cases to highlight synergies between ELT and other facilities part of the European Strategy Forum on Research and Infrastructure, as well as other future facilities (e.g. JWST, ALMA, LSST, Euclid, ATHENA+). The access to data across these facilities, coordinated observations and availability of efficient tools to combine the multi-messenger information are crucial to our understanding of these key science cases and many more.

First Lights and Epoch of Reionisation

Science Case

Dramatic progress has been made in recent years in charting the assembly history of the earliest galaxies seen at redshifts $z > 6$, less than a billion years after the Big Bang. The study of such primitive systems is driven by our desire to understand how and when the Universe was reionized in the first few 100 million years, as well as to determine those physical processes which shape the mass and luminosity distributions of the emerging generation of star-forming galaxies.

Sometime in the 600Myr between a redshift of $z = 20$ and $z = 7$, the Universe underwent a phase transition whereby the neutral hydrogen created at recombination was reionized. This remarkable event, cosmic reionization, renders the Universe transparent to ultraviolet photons and is as important, in many respects, as the decoupling of matter and radiation revealed by the microwave background. Reionization required a sustained source of ionizing photons and the popularly-assumed explanation is that it results from the onset of the first generation of star-forming galaxies.

These studies represent the final frontier in our quest for a coherent picture of galaxy evolution, and motivate the substantial investments in future facilities such as JWST, the next generation of ground-based near-infrared telescopes (ELT) as well as radio (SKA) and sub-mm (ALMA) facilities, which will be well-equipped to explore this era in outstanding detail.

Making progress

- JWST will be transformational in this field, especially thanks its capabilities at wavelengths $\lambda > 2\mu m$. JWST will pave the way to the discovery of galaxies at $z>10$ via deep imaging and spectroscopic observations to determine Luminosity Function, robust measurement of spectral energy distributions and physical parameters.
- ELT with its huge collecting area and exquisite spatial resolution will perfectly complement JWST. Ultra deep imaging and spectroscopic observations will allow us to detect and spatially resolve the sources of reionization. It will be possible to robustly determine the evolution of Lyman break galaxies (LBG) and Ly-α emitters

(LAE) into the epoch of reionization, measure physical parameters and possibly detect the Ly-α florescence from boundary regions.

- SKA will provide another complementary view by imaging the neutral IGM in HI 21cm emission (and absorption). A unique probe of the process of reionization SKA observations will provide a tomographic view of the HI distribution, and by conducting intensity mapping on the HI 21 cm line it will be possible to identify those shielded, high density HI reservoirs placed at the cores of the ionized regions and hosting the ionizing sources.

All these facilities are needed to have a comprehensive picture of the nature and topology of the reionization. Combining these information it will be also possible to perform cross-correlation between SKA HI maps and LAEs, or use SKA maps to design an informed survey for Lyα sources. The other key element is to understand the nature of the sources responsible for the reionization and the early metal enrichment (i.e. PopIII stars).

- ELT high-resolution spectroscopy will be capable to detect the fingerprint of PopIII stars by measuring the chemical enrichment typical of this population in the Inter-Galactic (IGM) and Inter-Stellar Medium (ISM) in the foreground of Quasars, GRBs and Super-Luminous Supernovae at high redshift. These observations will reveal the 3D distribution and physical properties of the first stars that populated the Universe.
- γ-rays and X-ray surveys (e.g. ATHENA+) are needed to detect distant GRBs and AGNs to be used as beacons, as well as LSST and space missions such as Euclid and WFIRST to detect Super Luminous SNs (SLSN).
- ALMA will provide a complementary view on metal enrichment and obscure star-formation by observing the [CII] 158μm emission line and far-IR continuum.

Observational details

Coordinated observations between JWST, ELT, ALMA and SKA will be extremely powerful to shed light onto the epoch of reionization. Simultaneous observations are not needed, but a good coordination of target selection and availability of well-matched catalogues and photometry for SED builder are essential. A fast response time is crucial for high-resolution spectroscopy observations of distant transients GRBs and SLSN and an efficient Target of Opportunity programme shall be in place.

Neutrino Astronomy

Science Case

The IceCube experiment has detected about one hundred astrophysical neutrinos since 2011. Their origin is still debated and includes both Galactic and extragalactic sources, i.e, a sub-class of BL Lacertae objects (BL Lacs), pulsar wind nebulae, and star-forming galaxies (see Ahlers & Halzen 2015 for a review). Resconi et al. (2016) have presented 3σ evidence that extreme BL Lacs, i.e. strong, very high energy γ-ray sources of the high-energy-peaked type may be the counterparts of some high-energy ($E > 60$ TeV) neutrinos and ultra-high-energy cosmic rays (UHECRs; $E > 52$ EeV). Establishing the provenance of these neutrinos has huge implications for the physics of the emitting sources as it would prove beyond any doubt the presence of hadronic processes (i.e., high-energy protons) in these objects, solving an issue which has been unsolved for many years. One of the main obstacles to the identification of the neutrino sources is the large positional uncertainty, i.e. $\leq 1°$ for track- and $\sim 5 – 10°$ for shower-like IceCube events. Because of this, and of the nature of the signal, this is a textbook example of a multi-messenger case, as detailed below.

Making progress

There are various levels of additional value, which can be expected thanks to the 4 ESFRI RIs and other facilities. Namely, in order of decreasing energy:

- KM3NET will provide better angular resolution ($\sim 0.2°$ for tracks, $\sim 2°$ at ~ 100 TeV for showers), which will greatly facilitate the identification task;
- CTA will increase the number of known very high-energy sources (by about one order of magnitude in the case of BL Lacs) and, by reaching higher energies than currently available, will also give a handle on the presence of hadronic processes;
- 8 – 10m telescopes will provide optical/near-infrared (NIR) imaging and spectra of the targets within the relevant error circle. The photometric data will be used to build

spectral energy distributions (SEDs) of likely counterparts, while the spectra will be used to derive a redshift and characterize the source.

- The ELT will be vital for the spectroscopy of very faint (i.e., R > 26) sources.
- SKA will secure radio data at levels not reached by current facilities (< 1 μJy at a few GHz), which are fundamental as most (all?) classes of neutrino counterparts considered so far are radio sources, given their non-thermal nature. Moreover, given the still limited sensitivity of γ-ray detectors, there could be sources where the γ-ray counterpart cannot be identified, in which case the radio band will be vital.

Only by using γ-ray, optical/NIR, and radio data (plus other multi-wavelength data, e.g., X-ray data from *Chandra* and *XMM*) can we solve the problem of the astrophysical counterparts of neutrino events.

Observational details

The ideal sequence would start with the KM3NET detection, followed by CTA, optical/NIR, and SKA observing in the relevant field of view. Simultaneity is not essential, although it would be desirable, as it would provide an extra parameter for identification. Archival data could also obviously be used if available. VO tools would include, at a minimum, Aladin, TOPCAT, and an SED builder. The most efficient time application would be a Target of Opportunity programme.

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Dark Matter: stellar perspectives

Science Case

One of the most relevant contributions of modern astrophysics to fundamental physics was the discovery of Dark Matter. After half century we still lack a clear understanding of its nature (baryonic versus non-baryonic) and in particular, whether we are facing a limitation in the physics laws (gravitation, standard model) we are using or possible observational biases in estimating the Mass-to-Light (M/L) ratios. Moreover, the current empirical evidence indicates that early-type dwarf galaxies (~10^[8-9] M/Mo) are characterized by M/L ratios that are one/two order of magnitude larger (Fabrizio et al. 2017) than regular galaxies (~10^[10-11] M/Mo). We still lack plain physical arguments to explain why dwarf galaxies are strongly dominated by DM, while globulars (~10^6 M/Mo) show no evidence (M/L~1). There is no doubt that dwarf galaxies in the Local Group (LG) and in the Local Volume (LV) are a perfect laboratory to attack this longstanding astrophysical problem. They are also the natural playground for future ground-based observing facilities, since the detection of DM ranges from gamma-rays (WIMPS) to NIR.

Setting the scene

Resolved stellar populations are going to experience a quantum jump on a time scale of a few years. The reason is twofold:

- Gaia is going to provide very accurate measurements of the proper motion for several nearby dwarf galaxies, together with very accurate distances. This means the unique opportunity to constrain the orbit of satellite dwarf galaxies, and in turn, their interaction with the Milky Way.
- 8 – 10m telescopes equipped with multi-fiber and integral field spectrographs will provide medium and high resolution spectra to measure the kinematics and the chemical enrichment of multiple stellar populations present in nearby dwarfs. This means the unique opportunity to investigate the role played by the environment in

their evolution. Moreover, LSST is going to provide accurate and deep multi-band (u,g,r,i,z,y) photometry for the entire southern sky and will move the proper motion measurements by Gaia from G~20-21 mag down to g~26-27 mag. This means the complete census of LG dwarfs and the bright component in LV dwarfs.

Near Future developments

- The ELT is going to play a crucial role, since HARMONI and MOSAIC are going to provide the spectroscopic follow up down to the main sequence of nearby dwarfs, and in turn, the opportunity to investigate their "ab initio" chemical distributions and the role played by (supernovae, AGB, neutron stars) in their chemical enrichment. This also means the opportunity to provide solid constraints on the so-called J-factor to provide firm predictions on the total mass of the DM halos.
- CTA its array dimensions will guarantee a good sensitivity up to at least 200 TeV. This means a significant step forward when compared with the latest generation of telescopes (HESS, MAGIC, VERITAS) operating at TeV energies. In spite of the paramount observational effort the current facilities have only provided upper limits on the detection of WIMPS. CTA will play a crucial role for the indirect search of dark matter with Cherenkov telescopes.
- SKA will provide new firm constraints on the neutral hydrogen present in early-type dwarf galaxies. The current measurements are only providing upper limits. However, there are reasons to believe that they are exhausted dwarf irregulars, but we still lack firm estimates on the gas mass present in these systems.

These circumstantial evidence indicates that firm constraints on the nature of DM requires new data ranging from gamma-ray to optical and NIR.

Observational details

The observing strategy is quite well established. Deep and accurate optical/NIR photometry from 8-10m class telescopes is going to open the path. The discovery of hundreds of new low-surface brightness galaxies will provide a new spin in the selection of the best candidates for the detection of DM. ELT is the natural second step, since the kinematics of these new systems will provide new firm estimates of the ML ratios and their kinematics (rotation). Finally, CTA is going to provide solid constraints on the nature of the non-baryonic component of DM.