Galactic InterStellar Medium: the 3D era with MSE

Adding the third dimension to the Galactic ISM with MSE

Stellar surveys with MSE will be an unprecedented tool to study the Milky Way InterStellar Medium (ISM) properties and its 3D structure on all scales, from subparsec to kiloparsecs. Three-dimensional maps built from massive absorption/extinction data measured along sightlines to stars distributed in distance and direction will illuminate the scene for most of the astrophysical objects and phenomena involving IS matter. High quality 3D maps are also the missing universal tool to realistically model photon and particle propagation in the Milky Way, again at all spatial scales, and to understand their effects on the gas, the dust and the resulting radiative properties. MSE mapping potentialities can be illustrated by the recent three-dimensional ISM large-scale mapping attempts based on reddening or absorption data from stellar photometric/spectro-photometric surveys obtained with a less complete instrumentation (2MASS, SDSS/APOGEE, PanSTARRS, RAVE, LAMOST-GAC, IPHAS, Gaia-ESO...), as well as nearby ISM maps based on combined mono-object measurements.

MSE has the optimal combination of medium/high resolution, wide-field, high-multiplex spectroscopy and a very large telescope: the spectral resolution improves the determination of ISM absorbing columns and/or stellar types used to derive the reddening, and it allows also coupling absorptions with emission spectra by means of velocity identifications; the wide field facilitates the required extended sky coverage; the high multiplex increases the number of targets along a given sightline and the spatial resolution of the maps; finally the high throughput increases the number of weak targets that can be individually studied and the distance coverage. Cross-matching MSE data with all other surveys will also bring precious additional constraints and information on the various ISM diagnostics. Most important, the astrometric ESA mission Gaia will measure the positions of all stars down to the 19-20th magnitude, a fundamental ingredient for all 3D maps that has been crucially missing up to now.

3D maps as a missing universal tool

Paradoxically the Milky Way ISM is still very poorly mapped despite the extremely detailed and sensitive ISM emission surveys at all wavelengths from gamma-, X- rays to IR, mm and the high resolution HI, CO radio spectral cubes. Due to the absence of information on the distance to the IS matter (ISM) generating the emission realistic 3D density and velocity distributions of the galactic ISM are still missing. They would be precious to assess physical and evolutionary models of the multi-phase ISM and add constraints on the dark matter. Other major astrophysical questions would benefit from a detailed 3D distribution of the galactic ISM: (i) the foreground to the CMB and its polarization depends on the 3D dust and gas distribution through the interstellar radiation field that heats the dust. (ii) models of the diffuse galactic gamma-ray emission doubly require the 3D ISM distributions since the emission is generated through the interaction of cosmic rays with ISM nuclei and by upscattering of the interstellar radiation field by cosmic electrons. (iii) obscuration by dust is a major obstacle to the understanding of the stellar populations in the Milky Way and their history and evolution. In particular, the upcoming Gaia mission will not only provide parallaxes to build the maps but also strongly benefit detailed dust maps.

Aprt from those specific objectives potential applications of 3D maps are surprisingly numerous and various, from the identification of foreground or background contaminations in absorption/emission studies of specific objects, to star/ISM interactions, weak objects detectability, environmental conditions of objects in general (see e.g. uses of the existing maps despite their lack of resolution and distance limitation, e.g. Marshall et al 2006, Vergely et al, 2010, Lallement et al, 2014).

Analysis of MSE stellar spectra and mapping

In each MSE individual star spectrum IS gaseous atomic (NaI, CaII, KI..) and molecular (CH, CH+, CN, C2..) absorption lines and diffuse bands (over 400 bands in the optical) can potentially be extracted according to the wavelength range and the target type, and in parallel the reddening can be determined from the spectral/photometric classification and the distance. Ideally tracers should allow to probe the main IS phases, i.e., dense molecular, diffuse atomic and ionized media. Emission data (mainly HI, CO and Halpha) can be used to help phase disentangling. Angular variations over the sky of the line centres can also be used to constrain the transverse motions too. Tracers should be adapted to the columns of IS matter, sensitive optical lines are appropriate to nearby targets while weak lines and the numerous diffuse interstellar bands (DIBS) that are not suffering saturation should be used for strongly attenuated targets. Extractions of lines and DIBs are now performed for any stellar type, including cool stars. This allows to take benefit of all targets and build maps at the highest possible spatial resolution.

An illustrative example of the MSE potentialities is the multi-component absorption study applied to one of the fields of the Gaia-ESO Spectroscopic Survey (GES) (fig. 1). VLT/FLAMES (R=18,000 48,000) spectra were adjusted by products of a stellar synthetic spectrum, a DIB or line model and a telluric absorption model (left). The velocity structure and the absorption strengths are evolving with distance, tracing the spiral arms and their kinematics (right). MSE survey data, by far superior in angular and magnitude/distance coverage and using Gaia distances will provide the kinematics of the ISM with unprecedented details, along with the 3D distributions.

Existing 3D maps are based on various techniques applied to absorption or extinction data. Fig 3 shows an example of a nearby IS dust map based on reddening measurements (23,000 nearby stars) and a Bayesian inversion method. New methods will have to be developed to adapt to the MSE massive data that will be 4-5 orders of magnitude more numerous to produce extremely detailed and extended maps of gas and dust and thier kinematics.

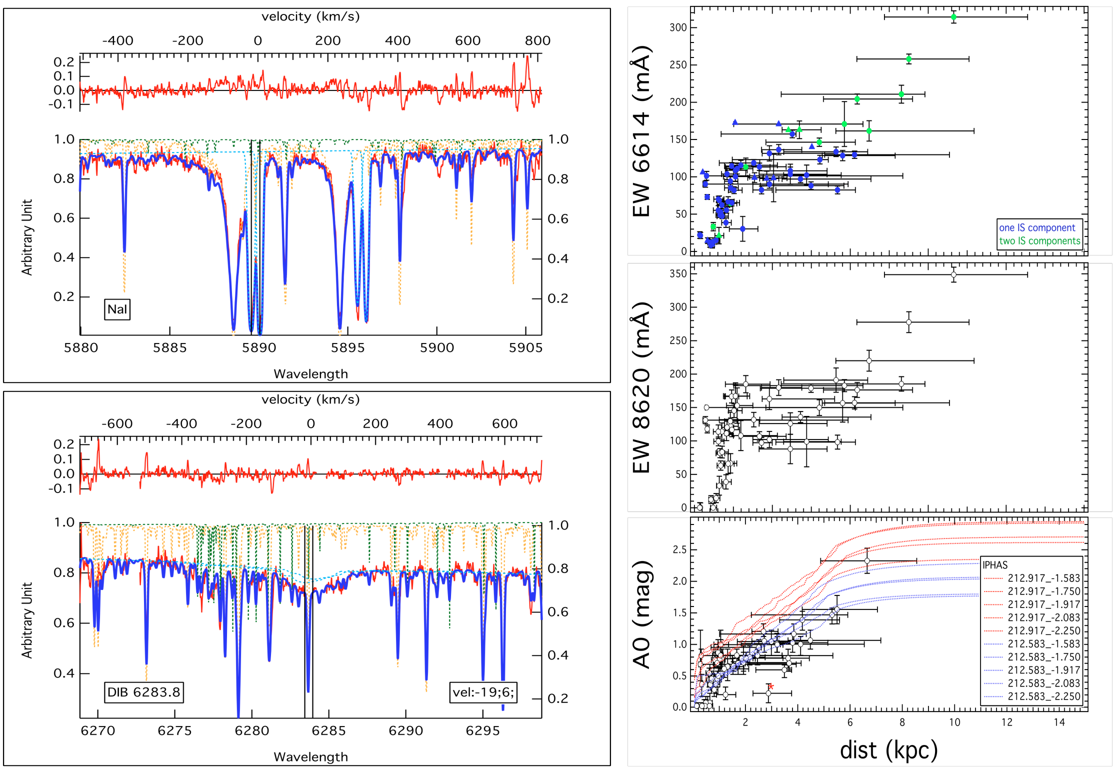

Fig 1: Left: IS NaI doublet (top) and DIB 6284A (bottom) extracted from a typical Gaia-ESO Survey spectrum (here a V=14.7 target star at D=2.8 kpc). The R=48,000 VLT/UVES spectrum is modeled with the product of a synthetic stellar spectrum, an interstellar line and DIB model with two velocity components and a synthetic telluric absorption. The radial velocities of the NaI lines and DIBS are kept linked during the adjustment (figure from Puspitarini et al, 2014).

Right: Radial evolution of the exinction A0 and of the strengths of two DIBs (6284A and 8620A) for one of the field of the Gaia-ESO Survey. Distances are photometric and derived from the spectroscopic stellar parameters and photometric data (figure from Puspitarini et al, 2014). DIBs and exticntion vary in a similar way and trace the local Arm and Perseus. A comparison is done with extinctions from the photometric IPHAS survey (Sale et al, 2014). Most targets are observed with GIRAFFE at R=18,000. With MSE such curves will be obtained in all directions. They will be much more precised thanks to Gaia parallax distances on one hand, and MSE better superior sensitivity/multiplicity on the other hand.

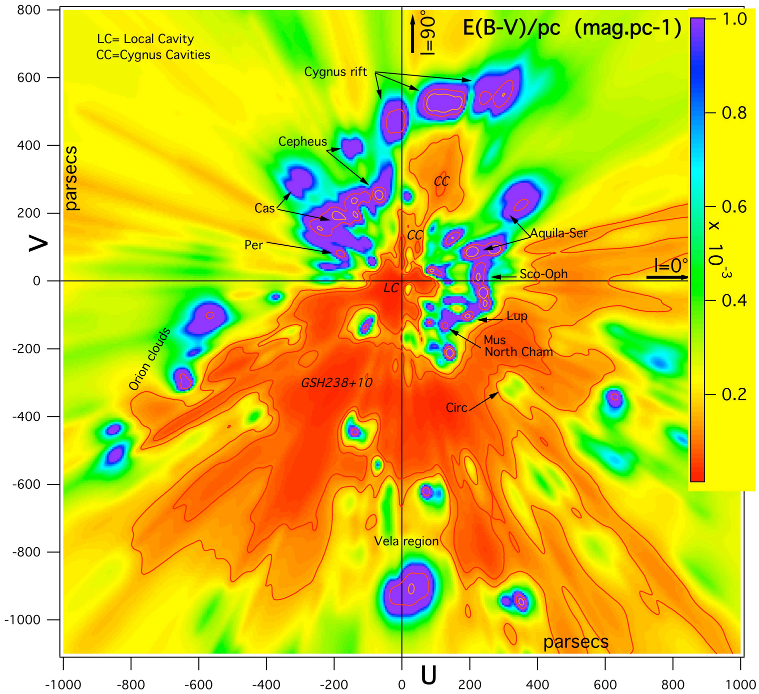

Fig 2 : Planar cut in the 3D opacity distribution inverted from reddening measurements (Lallement et al, 2013). The Sun is at 0,0 coordinates. Units are parsecs, violet is very low density and red indicates dense areas. External areas with a homogenous color correspond to the absence of constraining (distance- and longitude-distributed) target stars. The local cavity at the center is surrounded by well-known cloud complexes and other cavities, including a huge region devoid of dust in the third quadrant. This map based on only 23,000 stars allows to figure out what could be achieved based on hundred million targets or more from MSE large surveys!

References:

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