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The Cosmo.Lab Project: Developing AstroMD, an Object Oriented, Open Source Visualization and Pre-analysis Tool for Astrophysical Data

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Abstract. The Cosmo.Lab project, financed by the European Community, has the object of developing AstroMD, a tool of visualization and analysis of astrophysical data. AstroMD responds to the requirements proposed by several research fields: data coming from cosmological simulations, from observational catalogues and extended objects like radiosources or clusters of galaxies. AstroMD exploits also the most advanced visualization technology, based on virtual reality, in order to build a leading edge instrument for scientific research. However it is a scalable software which can be used also on PCs or workstations. It is open-source and freely downloadable from the web site `http://cosmolab.cineca.it`.

1. Introduction

Today both astrophysical observation and simulations produce many gigabytes of data which have to be efficiently visualized and analyzed. Visualization is the most intuitive approach to data and basic information can be obtained just "at a glance." Then the possibility of moving inside the data allows the scientist to focus on regions of interest and to perform quantitative calculations. Therefore image processing tools are of fundamental importance in astronomy.

AstroMD is a new data visualization and analysis software specifically designed to deal with astrophysical data; it can powerfully handle large datasets allowing both their graphical representation and analysis, corresponding to the requirements proposed by several research fields. This new tool is tested on the dataset of the VIRMOS (observational galaxy catalogue) project, on data coming from observations of extragalactic radio sources and those obtained from cosmological simulations. Although these fields do not cover all the requirements of astronomy, they pose many typical problems that we expect to be solved by AstroMD. The solution to these problems was implemented following the suggestions and the indications of the research groups involved in the project and of a User Interest group.

Astrophysical data have peculiarities that make them different from data coming from any other kind of simulation or experiment, therefore they require a specific treatment. For example, cosmological simulations consider both baryonic matter (described by fluid-dynamics) and dark matter (described by N-body algorithms). Further components, like stars or different chemical species, can be introduced and followed in a specific way. These different species require different types of visualization: dark matter needs particle position or velocity rendering while baryons require mesh based visualization. Furthermore particle associated quantities, like mass density or gravitational potential, require their calculation and visualization on a mesh. Then simulated structures have a fully three-dimensional distribution. Therefore it is necessary to have a clear 3-D representation, efficient and fast tools of navigation, selection, zoom and the possibility of improving the resolution and the accuracy in specific user-selected regions. Moreover evolution can dramatically change the properties of the simulated objects and the information that can be retrieved, therefore it is important to efficiently control sequences of time-frames. AstroMD will satisfy all these requirements.

2. The Software

In order to build a widely used product it was chosen to use a low cost software portable on a number of different platforms, the open source Visualization Toolkit[1] (VTK) by Kitware (Schroeder et al. 1999), available for nearly every Unix-based platform (e.g., Linux or IRIX) and PC's (Windows 2000 and Windows XP). The design and implementation of the library is that visualization and analysis built-in functionalities are controlled by a specific Graphic User Interface (Antonuccio et al. 2002), written in Incr Tcl/Tk[2] that supports the object-oriented programming structure. This allows to extend easily the software. AstroMD objects can represent readers, that allow the user to read data from a file or from a database, filters, that allow the user to manipulate data, and viewers, to visualize the results. VTK supports a wide variety of visualization algorithms and supports stereographic rendering and can be used for virtual reality visualization. Furthermore, being easily extensible, the system allows ad hoc implementation of specific modules.

Efficient manipulation and analysis tools, like smoothing of the particle masses on a mesh or calculation of the power spectrum and correlation functions, are parts of the basic functionalities. AstroMD has also stereographic rendering capabilities, which makes it usable for immersive visualization, presently implemented at the Virtual Theatre of CINECA.[3] The display of data gives the illusion of a surrounding medium into which the user is immersed. The result is that the user has the impression of traveling through a computer-based multidimensional model which could be directly hand-manipulated. In this sense, the virtual reality is a progressive lowering of the barrier which separates users from their data (Earnshaw & Watson 1993).

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[1] `http://public.kitware.com/VTK/`

[2] `http://incrtcl.sourceforge.net/itcl/`

[3] `http://cosmolab.cineca.it`

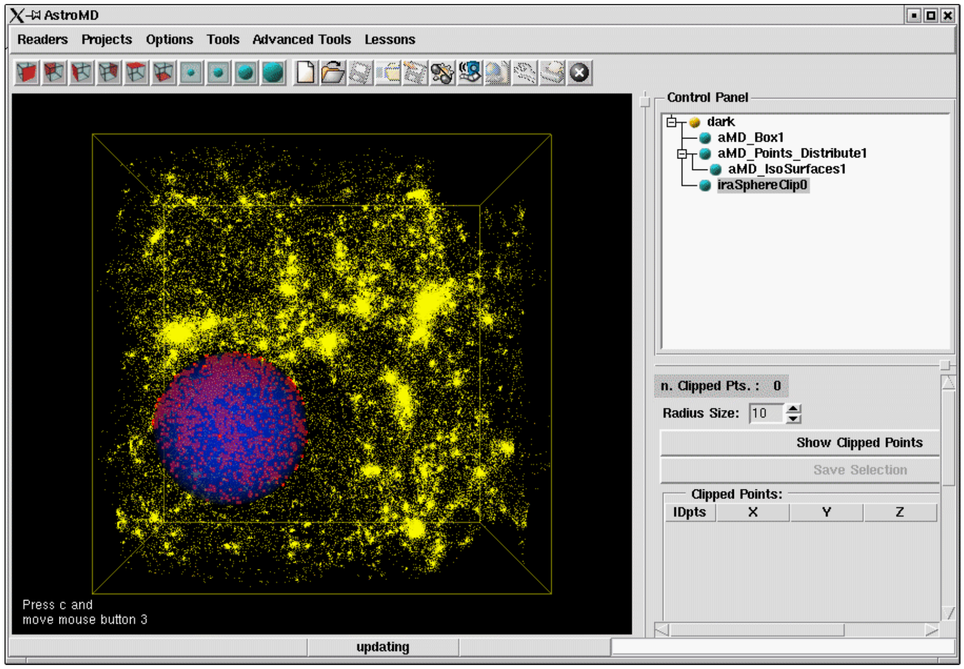

Figure 1. The main GUI of AstroMD.

3. AstroMD Functionalities

AstroMD allows the user to treat both particles (unstructured data) and continuous fields discretely represented over a computational mesh (structured data). The input data formats presently accepted by AstroMD are the common unformatted C standard (raw format), the TIPSY[4] and the FITS[5] formats. ASCII files can be also read.

Data are visualized with respect to a box which describes the analyzed region. A cubic or spherical sub-region can be selected interactively inside the parent box with a different spatial resolution, in order to focus on the most interesting regions. Data inside the sampler can be analyzed with the embedded tools or can be saved in specific files for an off-line analysis. Boxes can be translated, rotated, zoomed in and out with respect to selected positions. Colours and luminosities can be chosen by the user. Images of different evolutionary stages can be combined in order to obtain a dynamic view of the behaviour of the system. The opacity of the particles can be increased, so that low density regions are more easily detectable, or decreased, so that the details of the high density regions substructures are shown. Different particles species (e.g., dark matter and baryons) can be visualized at the same time using different colours. Other particles related to continuous quantities, like density fields, can be calculated as typical grid based fields and visualized as isosurfaces or volumes.

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[4] `http://www-hpcc.astro.washington.edu-/tools/tipsy/tipsy.html`

[5] `http://heasarc.gsfc.nasa.gov/docs/heasarc/fits.html`

Scalar fields can be visualized by isosurfaces or by volume rendering. The value of the isosurface can be selected on the user interface (Antonuccio et al. 2002). The volume rendering can be calculated using both the texture mapping and the ray tracing technique.

Different time frames can be shown in a sequence. A single image or sequences of images can be saved in bitmap or jpeg format to prepare an animation of the evolution. AstroMD includes also a randomizer tool that allows the user to select a random subset of data, with no systematic errors in the selection procedure.

Data can be analyzed by various tools. First of all, the Power Spectrum, which expresses the weight of each of the Fourier components of the mass distribution. The Power Spectrum is a powerful measure of the statistical properties of the distribution (Antonuccio et al. 2002). Then the Correlation Function, that indicates the probability to find a particle at a distance r from any other particle, and is usually used to analyze the clustering properties of a sample of discrete objects (particle, galaxies, galaxy clusters, etc). It has been implemented using the Peebles and Hauser estimator (Pons-Borderia & Martinez 1999), that is preferable at large scale, for samples with non uniform density. The Minkowski Functionals, which provide a tool to characterize the large-scale distribution in the Universe (Schmalzing et al. 1996). They describe the geometry, the curvature and the topology of a point set. Finally, a group finder algorithm, known as Friends-of-Friends,[6] which allows to identify clusters in a particle distribution. A particle belongs to a FoF group if it is within some linking length of any other particle in the group.

New functionalities are being developed to allow AstroMD to handle observational data and to interact with databases allowing the user to submit query to extract and/or insert data in database tables.

Finally special attention is devoted to the implementation of didactic tools (like html pages related to data and catalogues and objects therein), to make AstroMD also a valuable instrument for teaching and disseminating astronomy.

References

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[6] `http://www-hpcc.astro.washington.edu/tools/fof.html`