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Remote and Interactive Visualisation of Spectral Datacubes

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Abstract

Visualisation tools are essential for astronomical analysis, specially for the study of extended structures. Various instruments, such as radio telescopes or Integral Field Units (IFUs), can produce multidimensional data that require different techniques to those used for 2D images. Because of the extra dimension, 3D datacubes are more complex to view in a computer screen, needing different interactive options to explore them in detail. Additionally, the construction of cutting-edge observatories will present a new challenge for 3D visualisation tools because they will produce datacubes of the order of terabytes. In this work we present `ViSL3D`, a *Python* library to create interactive 3D visualisations of multidimensional spectral line data. This code produces 3D models that can be visualised on a browser interactively. We also showcase how the software can be deployed as part of a scientific archive to create the visualisations remotely in a server, following Virtual Observatory recommendations to apply Open Science practices.

1 Introduction

Scientific visualisation consists of transforming numerical data into representations that can be interpreted visually. It is a fundamental step in most astronomical studies. Different science cases require of different visualisation techniques due to the wide range of data types and analysis requisites [8]. Among these, multidimensional data visualisation is notable for its complexity and computational requirements. Radio telescopes and Integral Field Units (IFUs) can generate 3D data, in particular, spectral datacubes that contain spatial and spectral information. This type of data is valuable to analyse the spectral line emission of galaxies, groups of galaxies, planetary nebulae, young stellar objects, and other extended structure. Traditionally, 3D images have been represented in 2D through techniques such as slicing or position-velocity cuts. However, these methods do not display the data in full detail or are not completely practical, as in the case of slicing with hundreds of spectral channels. To maximise the information extracted from datacubes, 3D visualisation techniques prove highly valuable. Nonetheless, these tend to be computationally more demanding than 2D methods and require of interactive features to be really advantageous. Various tools for 3D visualisation already exist in astronomy, e.g. SlicerAstro [11], VisIVO [15], Yafits [12], iDaVIE-v [1], among others. Even so, additional development is needed to tackle the demands posed by forthcoming astronomical data products [7].

Astronomy has already entered the petascale era [3], with new observatories such as SKAO [13] or ngVLA [10] introducing substantial challenges. One of them is the vast amount of data to be stored and processed, which several telescopes are already producing, for example, the SKAO precursors ASKAP [5] and MeerKAT [6]. Not only the total quantity of data is extensive but the size of individual files as well, with datacubes reaching terabyte scales. Handling such data is unfeasible in standard desktop computers due to insufficient resources. As a result, researchers will have to work in science platforms [14] that offer both data access and specialised services, including visualisation.

In this paper, we present ViSL3D, a new visualisation tool for multidimensional data, designed to allow astronomers to interact with 3D models (see Section 2) and enhance the exploration of data. Additionally, we have tested the implementation of ViSL3D in a service within a scientific archive to produce 3D models remotely in order to deal with the big data challenge. The software details are described in Sec. 2 while the visualisation service deployed in an archive and its efficiency are explained in Sec. 3. Finally, Sec. 4 presents the conclusions of this work.

2 ViSL3D

ViSL3D is a *Python* library that transforms multidimensional data into 3D models by converting structured volume data into triangle meshes representing iso-surfaces, i.e. surfaces created by pixels of the same value. These are equivalent to the contours that are used in 2D. In addition, it builds a web interface to visualise the models. The process is highly user-friendly, allowing the creation of default visualisations with just a few lines of code. For more advanced needs, customised visualisations with additional elements are also supported.

The models are written in Extesible 3D (X3D), an ISO/ICE standard to store, view and print 3D figures. X3D is free and open, and being an international standard ensures long term interoperability across different scientific domains. In addition, it is highly interoperable with HTML5 and other applications and platforms. Apart from the iso-surface representation of the data, which can have different colours and transparencies, it is possible to display additional elements such as grids, coordinates, markers or a 2D image. Queries from astroquery can be used to integrate 2D images and galaxy markers from catalogues directly into the models.

Moreover, ViSL3D supports three visualisation types. 1) Iso-surfaces are calculated for the entire datacube, applying the same colormap everywhere. Figure 1 represents the HI emission of the Hickson Compact Group [4] (HCG) 16 from radio observations by MeerKAT.

Besides iso-surfaces, the model includes a 2D optical image from DSS2 Blue and markers at positions of galaxies of the group. 2) One cube can be divided into subcubes, each with a unique colormap. Figure 2 shows the planetary nebula A58 observed with the IFU MEGARA/GTC [9]. The datacube contains three spectral lines displayed with different colormaps; the [NII] doublet and Hα. 3) Figure 3 similarly shows A58, but combining two datacubes to overlay [NII], [OIII] and Hα. These can be created with the functions *prep_one()*, *prep_mult()* and *prep_overlay()* respectively or prepared manually. The last two are particularly useful to represent multiple spectral lines or to separate different components within the data.

VISL3D can also create a custom web application to visualise the models. The integration in HTML is made with X3DOM, an open-source framework to include X3D elements in DOM (Document Object Model) interfaces. This is done adding a JavaScript file into the HTML, without plugins, and allows the creation of JavaScript functions to interact with the model. The selection if these technologies facilitates the development of interactive capabilities in the web application, such as: zoom, rotation, pan, hiding and showing iso-surfaces, grids and markers, changing colormaps and the spectral scale and moving the 2D image.

3 Archive service and rendering efficiency

We have deployed a test science archive using the publishing software DaCHS [2] within the Spanish SKA Regional Centre Prototype[1] (espSRC) to gain leverage from its computational resources. We have created a visualisation service connected to the archive using VISL3D and Virtual Observatory (VO) recommendations. The archive enables the discovery of the visualisation service alongside the data through SIAP queries. The service is directly accessed via Datalink, with an independent link for each datacube. Astronomers can input parameters to customise the visualisations, which will be created remotely in the espSRC and then transferred to the client for rendering.

This approach allows the use of the visualisation software with large datasets, even though client resources remain a limiting factor. Specifically, most current web browsers restrict single tab memory usage to around 5 GB, leading to an *Out of Memory* error if rendering an X3D model exceeds this limit. However, those models could still be opened with other third-party visualisation software such as *Blender*, which can use more RAM if available (but not the same capabilities for interaction with the model). For this reason, setting the input parameters of the remote service is relevant to create models that work in the web application. In particular, making cutouts of the large datacube to select specific regions and to avoid areas with only noise, as well as lowering the resolution, can decrease the size of the models in several orders of magnitude and enable their use in web browsers. Both these options are available directly in VISL3D or in the visualisation service implemented in the espSRC test archive.

[1] https://ska-spain.es/

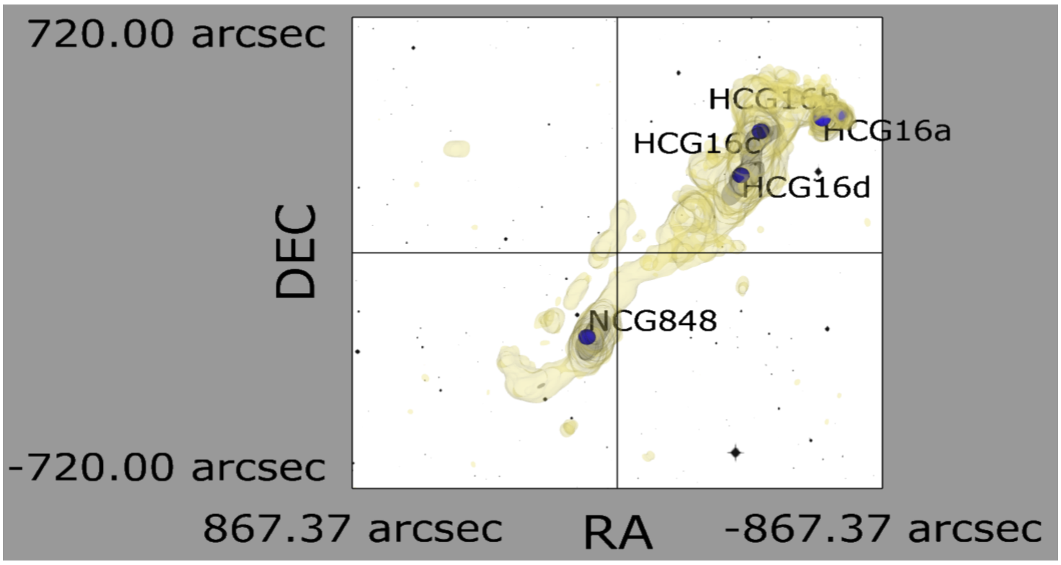

Figure 1: HI emission of HCG 16. Two iso-surfaces at S/N 4 and 20 are shown in yellow and black respectively along a 2D image in greyscale and blue markers at positions of galaxies from the group.

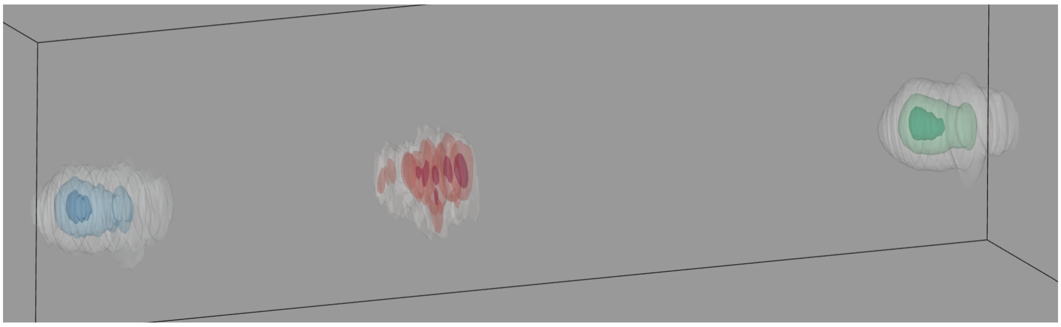

Figure 2: [NII] doublet in blue and green and Hα in red from A58. The iso-surfaces show intensities of 20, 50 and 80%, showed in each colour from light to dark.

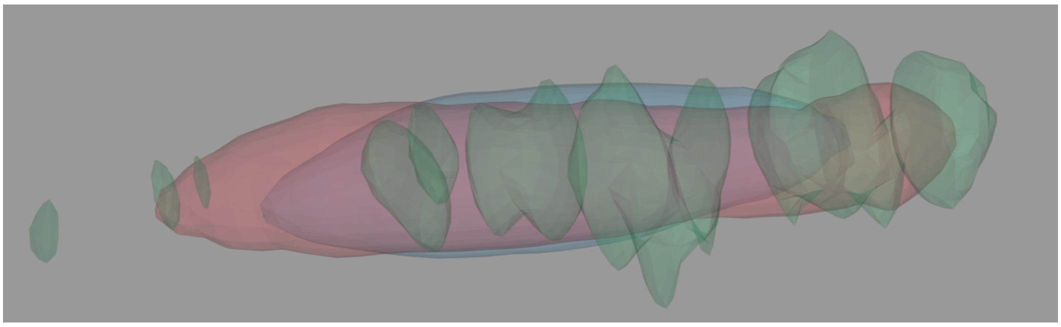

Figure 3: [NII] in blue, [OIII] in red and Hα in green, overlaid. The iso-surfaces represent intensities of 50% in each line.

4 Conclusions

We present VISL3D, a visualisation tool to display spectral line datacubes through iso-surfaces. The iso-surfaces as represented as 3D models written with X3D and can be rendered in a custom web application with X3DOM and JavaScript, making the visualisations interactive. The software is a *Python* library that offers an easy way for users to produce customised 3D visualisations of their data and exploring them interactively. Furthermore, it allows the combination of multi-wavelength data, showing iso-surfaces, including a 2D image in the model, and catalogues to display markers at given positions. Due to RAM usage limitations in web rendering, making cutouts of the data and lowering the resolution is recommended if smaller size models are necessary to be visualised on the web.

Besides these techniques to reduce the size of the models, analysis and visualisation services will have to be provided by remote platforms due to large-scale datasets that surpass the storage and processing capacities of desktop computers, such as those from next-generation telescopes like SKAO. We have developed a prototype scientific archive with DaCHS, deployed in the espSRC, to yield a visualisation service using VISL3D. The service can be used to create 3D models remotely in the server-side. The archive exploits VO standards to facilitate the discovery of the service by connecting it to each dataset, enabling visualisation without the need of downloading the datacube. Only the model, which generally is lighter than the data, is transferred to the client.

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References

[1] Comrie A., Sivitilli A., Vitello F., Jarrett T., Marchetti L., 2021, Zenodo. https://doi.org/10.5281/zenodo.4614116

[2] Demleitner M., 2018, ascl.soft. ascl:1804.005

[3] Hassan A., Fluke C. J., 2011, Publications of the Astronomical Society of Australia, 28, 150. doi:10.1071/AS10031

[4] Hickson, P., 1982. Astrophysical Journal 255, 382–391. doi:10.1086/159838.

[5] Johnston S., Taylor R., Bailes M., Bartel N., Baugh C., Bietenholz M., Blake C., et al., 2008, Experimental Astronomy, 22, 151. doi:10.1007/s10686-008-9124-7

[6] Jonas J., MeerKAT Team, 2016, Proceedings of MeerKAT Science: On the Pathway to the SKA, 1. doi:10.22323/1.277.0001

[7] Labadie-García I., Garrido J., Verdes-Montenegro L., Mendoza M.Á.,Parra-Royón M., Sánchez-Exposito S., Ianjamasimanana R., 2024, submitted, SSRN: https://ssrn.com/abstract=4983284, http://dx.doi.org/10.2139/ssrn.4983284

[8] Lan F., Young M., Anderson L., Ynnerman A., Bock A., Borkin M. A., Forbes A. G., et al., 2021, arXiv, arXiv:2106.00152. doi:10.48550/arXiv.2106.00152

[9] Montoro-Molina B., Tafoya D., Guerrero M. A., Toalá J. A., Santamaría E., 2024, Astronomy & Astrophysics, 684, A107. doi:10.1051/0004-6361/202348528

[10] Murphy E. J., Bolatto A., Chatterjee S., Casey C. M., Chomiuk L., Dale D., de Pater I., et al., 2018, Astronomical Society of the Pacific Conference Series, 517, 3. doi:10.48550/arXiv.1810.07524

[11] Punzo, D., van der Hulst, J., Roerdink, J., Fillion-Robin, J., Yu, L., 2017. Astronomy and Computing 19, 45–59. URL: https://www.sciencedirect.com/science/article/pii/S2213133717300173, doi:https://doi.org/10.1016/j.ascom.2017.03.004.

[12] Salome P., Moreau N., Ba Y. A., Caillat M., 2024, Astronomical Society of the Pacific Conference Series, 535, 203, URL: https://ui.adsabs.harvard.edu/abs/2024ASPC..535..203S

[13] SKA Observatory, 2021, https://skao.canto.global/s/M8159?viewIndex=0

[14] Swinbank, J.D., Bartocco, S., Russo, S.A., S'anchez-Exp'osito, S., 2022. URL: https://doi.org/10.5281/zenodo.6044637, doi:10.5281/zenodo.6044637.

[15] Vitello, F., Sciacca, E., Becciani, U., Costa, A., Bandieramonte, M., Benedettini, M., Brescia, M., Butora, R., Cavuoti, S., Giorgio, A.M.D., Elia, D., Liu, S.J., Molinari, S., Molinaro, M., Riccio, G., Schisano, E., Smareglia, R., 2018. Publications of the Astronomical Society of the Pacific 130, 084503. URL: https://dx.doi.org/10.1088/1538-3873/aac5d2, doi:10.1088/1538-3873/aac5d2.