Accurate Visualization of Galaxy Velocity Fields from Three-Dimensional Integral Field Spectroscopy Data

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Abstract

In recent years, integral field spectroscopy (IFS) has become a major methodology in observational astronomy. Visual analysis of galactic motions is expected to play a crucial role in discovering the physical properties of galaxies. This poster presents a novel method for visualizing galaxy-specific motions using an emerging visual programming environment, Advanced Framework for Learning Astrophysical Knowledge (`aflak`), for visual analysis of three-dimensional IFS data. We demonstrate that the line-of-sight velocity of each region of galaxies can be more accurately visualized by coupling two specific kinds of `aflak` macros for generating position-velocity diagrams and deriving velocity fields.

CCS Concepts

• ***Human-centered computing*** → ***Visual analytics;*** *Scientific visualization; Visualization;*

1. Introduction

In recent years, *integral field spectroscopy* (*IFS*), which is intended to acquire spatial-resolved spectra of astronomical objects with a single exposure, has become a major methodology in observational astronomy. Three-dimensional data obtained by IFS tends to be large; the spatial resolutions are about $2^{10} \times 2^{10}$, while the size in the wavelength direction is about 10 times as large, and thus visual exploration of such anisotropically large-scale volumetric data still remains a challenging task.

In this study, we rely on *Advanced Framework for Learning Astrophysical Knowledge* (`aflak`) [BMT*18, BTU*19, BUT*19b, BUT*19a], which has been developed as a specialized visual programming environment for exploration of such IFS datasets. Astronomy has taken the initiative in computational analytics, and indeed many batch-type multispectral analysis codes have been developed and used by astronomers. In `aflak`, many such past assets are fortunately standardized in the form of composite nodes (referred to as "macros" hereafter), and thus we can judiciously combine those built-in macros to effectively address various complex problems in IFS.

The *velocity field map* reflects one of the most significant celestial motion characteristics. It shows the velocity in the line of sight for each position of the astronomical object (we herein limit it to a galaxy) from the shift of the spectrum caused by the Doppler effect of the object motion. The velocity field map has two-dimensional spatial information but lacks wavelength information. The *p-v* (*position-velocity*) *diagram* is a two-dimensional intensity distribution diagram in which the spectrum on the celestial sphere is arranged along a specific line, as shown in Fig. 1. Its horizontal axis represents the position along the line, while the vertical axis the wavelength or line-of-sight velocity. The p-v diagram maintains wavelength information with decreasing amounts of spatial information. Combining these two representations may lead to new astronomical insights. In this poster, we show that such representations often used by astronomers (e.g. [DCA*08]) on the back of IFS technology can be used to effectively generate velocity field maps with a sharp focus on certain spatial parts of the image.

2. Proposed Method

Data ID = "7443-12703" in the Mapping Nearby Galaxies at APO (MaNGA) project [BBL*15] was selected herein as the target data to be analyzed. This data contains high overall brightness near Hα (emission line of hydrogen seen at $\lambda = 656.3\,\text{nm}$), and when we see the front surface of the volume in the left of Fig. 1, indeed the spatial cross-section sliced at the wavelength near Hα implies that the two galaxies seem to interact with each other. The upper companion galaxy is referred to as Galaxy A (hereinafter G_A), and we herein analyze the velocity of each region of G_A.

Fig. A–1 in the appendix shows a screenshot of the `aflak`'s node editor interface including the full scope of our visual analysis process, which is mainly composed of the two macros: "P-V Diagram" and "Velocity Field," with one of p-v diagram's output being connected to one of Velocity Field's input parameters.

2.1. Datacube Slicer and Probe and P-V Diagram

Fig. 1 illustrates the concept of *datacube slicer and probe,* which generates a multispectral image strip from three-dimensional IFS

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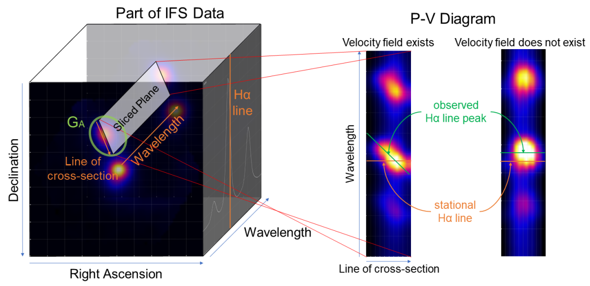
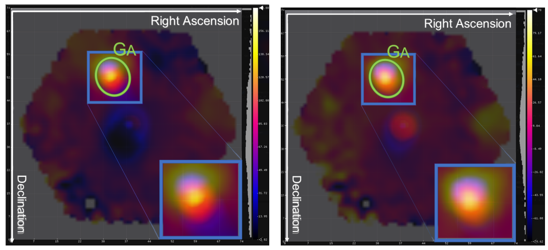


Figure 1: *The concept of datacube slicer and probe. One can specify a line segment in the spatial cross-section image, then cut the three-dimensional data out in the wavelengths direction. The resulting cross-section defines a p-v diagram. When a velocity field is available, the observed peak of the Hα line appears oblique in the p-v diagram. Otherwise, the peak of the line would remain horizontal on the p-v diagram.*



(a) With p-v diagram (b) Without p-v diagram

Figure 2: *Comparison with and without the p-v diagram. The sliced image underlies both velocity field maps; the unit of its pixels is* km/s. *(a) Using the result shown in Fig. A–2, only the upper left of* G_A *is bright, and it can be seen that the velocity of this part that moves away is high. (b) The bright area spreads over the entire* G_A*, and motion characteristic is invisible.*

data, where the line of intersection can be arbitrarily specified by the astronomer on the corresponding spatial cross-sectional image and the image strip is prolonged in the direction of the wavelength axis. Technically, the pixels on a line drawn by the user are found using Bresenham's algorithm and the data is retrieved in the direction of the wavelength. This concept lets astronomers probe into IFS data closely.

Utilizing the datacube slicer and probe concept, we generate a p-v diagram along a cross-sectional line passing through the core of G_A. As shown in the left of Fig. 1, the direction of the cross-sectional line is defined from top to bottom and the wavelength range is selected within a window centered at Hα. Note that the spatial cross-sectional line has to be determined manually by the user, and, in this case, it has been done in advance.

The appendix also includes Fig. A–2, which gives the detailed structure of the macro and the result of the p-v diagram generation. The `range_specification` node takes a window of wavelength to output a part of the input three-dimensional data. The `extrude` node takes the spatial range to output a sliced image.

Taking a close look at the p-v diagram shown in the center of Fig. 1 or Output #3 of Fig. A–2, especially at the bright part in the middle, there can be found a difference in the line-of-sight velocity according to the location in G_A. It can be estimated that shifting due to Doppler effect generates this part of diagonal distribution from the upper left to the lower right, despite the same Hα line. In fact, two astronomers have found that the peak of the emission line is oblique in the p-v diagram, so that there is a difference in velocity among locations. In the absence of a velocity field, the peak of the line would be horizontal on the p-v diagram, as shown in the right of Fig. 1.

2.2. Velocity Field Map

Fig. A–2 also gives the detailed structure of the macro "Velocity Field" and the resulting map. The velocity field can be approximated as $v = c(\lambda_o - \lambda_s)/\lambda_s$, where λ_o denotes the observed wavelength of a given spectrum, λ_s the stationary wavelength, and c the speed of light, and it is important to determine the range for computing the centroid, λ_o, for the spectrum of each pixel. In Fig. A–2, thanks to the *bi-directional binding* function in `aflak` [BUT*19a], the horizontal lines in the center p-v diagram (Output #3) and the vertical lines (index values) of the upper-left spectrum profile (Output #4) are dynamically linked to each other. As a result, it may be possible to estimate the Hα emission distribution of G_A and thereby determine a better position of the λ_o. The `extract_centrobaric_wavelength` node locates λ_o while the `create_velocity_field_map` node computes v.

2.3. Comparison with and without P-V Diagram

When the velocity field map with the p-v diagram is superimposed on the sliced plane (Fig. 2(a)), it can be seen that the upper-left side of G_A moves away at a faster speed and that the motion of rotation can be observed. On the other hand, without the coupling of the p-v diagram (Fig. 2(b)), the position of the λ_o is determined from the entire spectrum. This leads to a lack of motion characteristics because the velocity field has a similar value in the entire area of G_A. Thus, it turns out that the accuracy of the visualization results depends highly on the upstream sophistication of macro combination.

3. Concluding Notes

In this poster, we presented a method for accurately visualizing the galaxy motion structure. Using a visual programming environment for visual analysis of three-dimensional IFS data, the accurate galaxy velocity in the line of sight can be visualized by combining two kinds of data analysis macros. In the present case, however, it was possible to determine the wavelength distribution with a predetermined spatial cross-sectional line to some extent, but it is conceivable that the computation of λ_o needs to be modified, such as when fitting with the Gaussian functions.

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