3D Reconstruction of Planetary Nebulae using Hybrid Models

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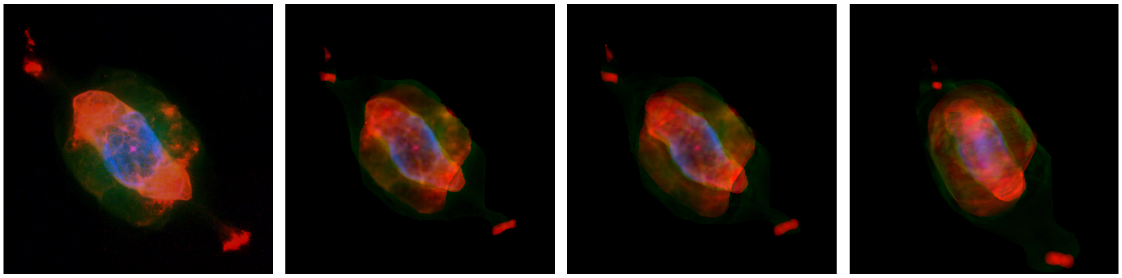

(a) (b) (c) (d)

Figure 1: *An observational image of the Saturn nebula (a), obtained by the Hubble Space Telescope, is used to reconstruct a three-dimensional model with volumetric and surface effects: (b) orthographic rendering from the original viewpoint, (c) perspective rendering from the same viewpoint, (d) perspective rendering from a different position.*

1 Introduction

Distant astrophysical objects like planetary nebulae can normally only be observed from a single point of view, which makes deducing plausible 3D models a hard task that usually involves a lot of manual work [Nadeau et al. 2001]. However, additional physical assumptions can be used in order to estimate the missing depth information. In previous work [Wenger et al. 2009], a certain axial symmetry was assumed which is present in many planetary nebulae, so that tomographic methods could be used for the reconstruction. However, this assumption obviously fails for many of the most complex and interesting objects in question, and it only leads to unambiguous results as long as no absorption occurs within the nebula.

Our new approach models the underlying physics of planetary nebulae more closely by making use of the fact that they often consist of nested gaseous clouds or *shells* which contain the remains of subsequent eruptions of a dying star. Within such a cloud, the volume is likely to homogeneously emit light due to recombination processes in the ionized gas, while the surfaces of each cloud may contain dust or debris that can either absorb radiation that was emitted elsewhere or be excited to emit additional radiation by themselves. While off-line renderings of such phenomena have been feasible in the past [Baranoski and Rokne 2006], our work deals with the problem of creating suitable models using a minimum amount of user interaction, and of visualizing the results interactively.

2 Our Approach

As a first step, the geometry of the different shells has to be specified. Since the identification of a shell in a planetary nebula usually involves a lot of physical reasoning, this task cannot be entirely automatized. However, software can assist the user in various ways in this initial step, depending on the amount of control the user wants to exercise. Either an entire mesh can be created using suitable modeling software, or only the outlines of distinct objects are traced by the user, while our program automatically generates a smooth closed mesh satisfying the given border conditions, similar to some 3D drawing tools, e.g. [Igarashi et al. 1999].

As soon as the geometry of the model is determined, the volume emission density of each mesh can be estimated so that the average squared difference between the volume-rendered model and the observed image is minimized. Then, the surface emission and absorption layers have to be determined. Since this problem is inherently ambiguous, it is further constrained by demanding that each surface layer is self-consistent, that is, it has a unique texture that does not change throughout the layer. We achieve this by taking a sample of each surface layer in a region where no other layers are present and by extrapolating this sample into the rest of the layer using a texture synthesis method. The residual intensity can finally be distributed among the layers without disturbing the visual continuity.

The resulting models are rendered at interactive frame rates using a depth peeling algorithm for depth-sorting of surface layers and volume rendering techniques for the volumetric and surface effects (Figure 1).

References

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