Mapping dust in the giant molecular cloud Orion A

(Gration, Magorrian 2024)

The giant molecular clouds Orion A and B are the closest regions of active high-mass star formation to Earth. Orion A has a comet-like structure with a dense head, containing the Orion nebula, and a diffuse tail. Orion B is more uniform and contains the Flame nebula. Young stellar objects within these molecular clouds trace the gas where they were created, and past photometric surveys have used these young stellar objects to chart the on-sky distribution of Orion A. Astrometric surveys of these same objects have allowed the mapping of the gross three dimensional distribution of Orion A. In order to map a finer three dimensional distribution, dust is used, since dust is coupled to the gas portion of the ISM, and traces the dense gas of the molecular cloud it is in. Three dimensional dust-mapping relies on inference though, where the dust density of an arbitrary point in Orion A can be inferred by extinctions for stars in the region. To date, dust maps have had limitations such as artificial nonuniformity, and resolution limitations. Since stellar surveys of our galaxy are heavily impacted by dust, it is crucial to properly map this dust, in order to fully utilize the data coming out of those surveys. This paper proposes a new method for creating three dimensional dust maps and uses it to map Orion A. Their method utilizes statistical properties of the ISM, and minimizes assumptions about the dust density distribution to effectively map the dust in Orion A.

For their statistical method, they begin by representing the density of the ISM at any single point, as a random variable. The collection of these variables forms a random field, which represents the density of the ISM as a whole. Similarly, they treat the extinction of light emitted by a source at a single point as another random variable, leading to another random field that represents the extinction undergone by light emitted from any point in space. Although the ISM is complicated, the fluctuations in its density can be approximated as stationary and isotropic. Because of this, the relationship between density fluctuations at any two points is a function of their separation and is calculated by the autocovariance function of the density fluctuations. These approximations also extend to the density itself. They choose their autocovariance functions such that they need only a model of the mean extinction, with one free parameter. They claim that this agnostic approach is both a strength and a weakness, as it does not allow them to encode the fact that density is always non-negative. When using synthetic data, this holds for their results, but when using observational data, they do get negative predicted densities. This can be attributed to mis-specifications in their models, but there are also limitations in the observational data that can cause this as well. The author's choice of autocorrelation function captures the behavior of the ISM's better than others though, and that combined with good data, in this case extinction data inferred from the Rayleigh-Jeans color excess method, leads them to three-dimensional dust maps that are in agreement with other papers. The authors lastly note that maps generated using extinction data via the StarHorse method (bayesian model) fail validation, and cannot even identify the dense head of Orion A. They attribute this to the fact that the StarHorse catalogs are unfiltered, and contain many sources that violate the assumptions in the catalogs methodology, which lead to untrustworthy extinctions that do not get flagged.