

# Preface

In this thesis, we identify and characterise the properties of starless cores in the nearby Ophiuchus, Taurus and Cepheus molecular clouds. Starless cores are over-densities within larger molecular clouds from which, if gravitationally bound, an individual stellar system will form. The gravitationally bound and collapsing subset of starless cores are known as prestellar cores. The prestellar core phase is the earliest stage in the star formation process at which it can be stated that, barring external disruption, at least one star will form. Hence, a detailed understanding of the properties of prestellar cores is necessary in order to understand the properties of the stars which will form from them. Particularly, the mass distribution of prestellar cores is linked to the initial mass function (IMF), and a statistical understanding of prestellar core properties and the conditions under which they vary is necessary for an understanding of the origin, and possible universality, of the IMF.

In this thesis, we use observations taken by the James Clerk Maxwell Telescope (JCMT) Gould Belt Survey in synthesis with data taken by the Herschel Space Observatory Gould Belt Survey, IRAM 30 m telescope data, and other previously published measurements in order to characterise the properties of a large sample of starless cores in a variety of environments in nearby molecular clouds: in the Ophiuchus molecular cloud, a site of clustered low-to-intermediate-mass star formation; in the Taurus molecular cloud, a site of relatively isolated low-mass star formation; and in the Cepheus Flare molecular clouds, in which star formation is proceeding in a variety of environments, and in some areas is thought to have been enhanced by the recent passage of an expanding supernova-driven shell through the cloud. In this thesis, we discuss the distributions of temperatures, masses, sizes densities of cores in each of these regions and environments. We also perform a detailed virial analysis of the cores in each region, including the effect of external gas pressure on the cores' energy balances. We find that many virially bound starless cores are confined by external gas pressure rather than by self-gravity, and hence, that external gas pressure cannot be neglected in stability analyses.

We identify sources in SCUBA-2 850- $\mu\text{m}$  emission and determine temperatures by fitting a modified blackbody model to their spectral energy distributions,

measured using SCUBA-2, PACS and SPIRE data. We construct empirically determined convolution kernels based on telescope beam maps to accurately bring SCUBA-2 and Herschel data to a common resolution. Masses are calculated using best-fit temperatures and measured 850- $\mu\text{m}$  flux densities.

In Ophiuchus, the mass distribution of starless cores is consistent with the expected shape of the core mass function (CMF). We determine core masses from  $\text{C}^{18}\text{O}$  and  $\text{N}_2\text{H}^+$  measurements and find some evidence for high-density  $\text{N}_2\text{H}^+$  freezeout. Virial analysis, including external pressure, shows that most cores are either bound or virialised. Gravitational potential and external pressure energies are found to be typically of a similar order of magnitude, with some variation between regions. Non-thermal linewidths decrease between  $\text{C}^{18}\text{O}$ -traced and  $\text{N}_2\text{H}^+$ -traced materials, indicating dissipation of turbulence. Core properties vary with region, and hence, we infer a south-west to north-east evolutionary gradient.

In Taurus, we identify starless cores in SCUBA-2 850- $\mu\text{m}$  emission Herschel 250- $\mu\text{m}$  emission, and Herschel 250- $\mu\text{m}$  emission filtered to remove large-scale structure. Cores detected and characterised using unfiltered Herschel 250- $\mu\text{m}$  data have higher densities and temperatures than their equivalents in SCUBA-2 emission. SCUBA-2 detects only the densest starless cores relative to the filtered Herschel data, due to a surface-brightness sensitivity limit, as both populations have similar ranges in temperature. Virial analysis shows that the SCUBA-2 cores are pressure-confined and that almost all are virially bound in the absence of an internal magnetic field. The magnetic field strengths required to bring our cores into virial equilibrium are consistent with those measured in dense gas in Taurus.

In Cepheus, we compare starless cores in the regions L1147/58, L1172/74, L1251 and L1228. Region CMFs generally show sub-Salpeter power-law indices. L1147/58 and L1228 have a high ratio of cores to protostars; L1251 and L1174 have a low ratio, suggesting that the latter are active sites of star formation, while in the former, star formation proceeds quiescently. Core external pressures are estimated; all but one of our cores are pressure-confined. We find a power-law relation between gravitational potential and external pressure energies. Cores which obey this relation are strongly pressure-dominated; those which do not are candidates for gravitational collapse.

Core temperatures and masses in each cloud are similar. Cores in Ophiuchus are significantly smaller and denser than in other regions. Ophiuchus shows strong evidence for clustering: a non-uniform surface density of sources, and small nearest-neighbour distances between sources. Taurus is a dispersed region, while Cepheus is intermediate. Ophiuchus shows the most variation of core properties with location. Cores in Taurus are extremely homogeneous; cores in Cepheus show a wide range of properties, but little correlation of properties with location.

We present a new analytical model for the evolution of starless cores. We find that not all pressure-confined and virially bound cores will become gravitationally bound, with many instead collapsing to virial equilibrium. Hence, we state that only gravitationally bound starless cores can be definitively considered to be prestellar.

## Thesis Outline

The outline of this thesis is as follows:

Chapter 1 introduces starless and prestellar cores and discusses the current paradigm of low-to-intermediate-mass star formation in molecular clouds. The initial mass function and core mass function are introduced, and the possible causal link between the two is considered. Several means of assessing the stability of starless cores against collapse are discussed. The low-mass protostellar evolutionary sequence is also discussed. We describe the Gould Belt of star-forming regions, and recent wide-area surveys intended to map a large fraction of its area.

Chapter 2 discusses the telescopes used to take the observations presented and used in this work. The data reduction processes for SCUBA-2 data and Herschel observations are described, as are the methods used to make data from SCUBA-2 and Herschel comparable. Parts of the discussions of masking and of convolution kernels were published by Pattle et al. (2015), *Monthly Notices of the Royal Astronomical Society*, vol. 450, p. 1094.

Chapter 3 discusses the Ophiuchus molecular cloud. The SCUBA-2 Gould Belt Survey data of the region are presented. Sources are extracted from the SCUBA-2 850- $\mu\text{m}$  data and characterised using SCUBA-2 and Herschel data. The core masses derived from continuum measurements are compared to those derived from HARP C<sup>18</sup>O and IRAM N<sub>2</sub>H<sup>+</sup> observations. A virial stability analysis is performed on those cores for which data are available. The virial stability of the cores is compared to their predicted stability according to the Bonnor–Ebert criterion. The variation of core properties and the effectiveness of dissipation of turbulence with region across Ophiuchus is discussed. This chapter was published by Pattle et al. (2015), *Monthly Notices of the Royal Astronomical Society*, vol. 450, p. 1094.

Chapter 4 discusses the Taurus molecular cloud. Sources are extracted from the SCUBA-2 850- $\mu\text{m}$  data, Herschel 250- $\mu\text{m}$  data, and Herschel 250- $\mu\text{m}$  data filtered to match the spatial scales detectable with SCUBA-2. The sources are characterised using SCUBA-2 and Herschel data. The three sets of sources are compared, and the criteria distinguishing a core seen in Herschel data which is detectable with SCUBA-2 from those which are not are discussed. A virial analysis is performed on those SCUBA-2 cores for which data are available, and the energy balance in starless cores in Taurus is discussed. A modified version of the first half of this chapter has been published by Ward-Thompson, Pattle et al. (2016), *Monthly Notices of the Royal Astronomical Society*, vol. 463, p. 1008.

Chapter 5 discusses the Cepheus Flare molecular clouds. Sources are extracted from the SCUBA-2 850- $\mu\text{m}$  data and characterised using flux densities measured from the 850- $\mu\text{m}$  data and temperatures provided by the Herschel Gould Belt Survey. The number statistics of starless, embedded and Class II sources are discussed. The Bonnor–Ebert critically stable masses and external pressures are estimated for each core. External pressures and the energy balance between gravity and external pressure are estimated using archive <sup>13</sup>CO data. An upper limit on the degree to which the cores in Cepheus are virially bound is determined. A modified

version of this chapter has been published by Pattle et al. (2017), *Monthly Notices of the Royal Astronomical Society*, vol. 464, p. 4255.

Chapter 6 compares the Ophiuchus, Taurus and Cepheus Flare regions. An evolutionary model for initially pressure-confined starless cores is proposed and discussed. A modified and expanded version of the second half of this chapter has been published by Pattle (2016), *Monthly Notices of the Royal Astronomical Society*, vol. 459, p. 4255. Chapter 7 summarises our conclusions.

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Submillimetre Studies of Prestellar and Starless Cores  
in the Ophiuchus, Taurus and Cepheus Molecular  
Clouds

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2017, XVI, 254 p. 113 illus., 82 illus. in color., Hardcover

ISBN: 978-3-319-56519-4