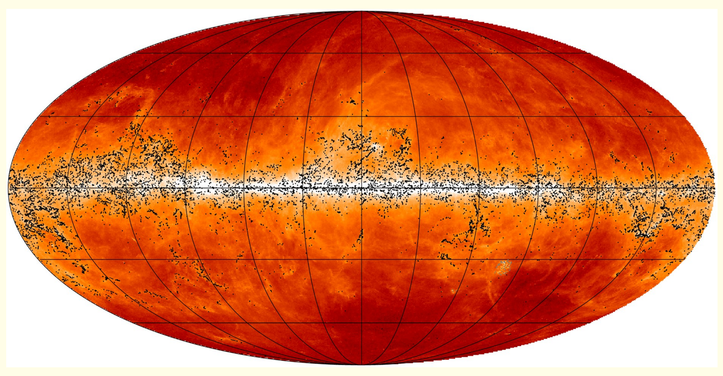
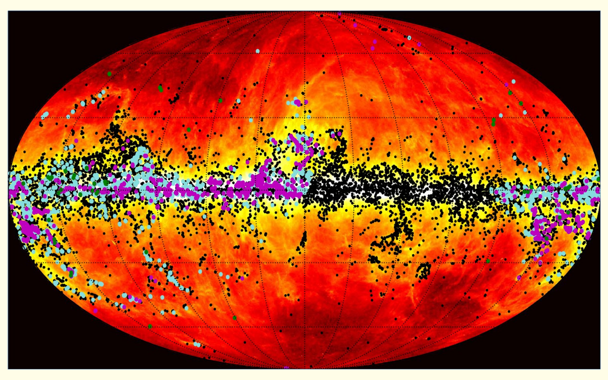


Cold Cores: Studies of early stages of Galactic star formation



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On behalf of the Cold Clumps Planck survey and follow-up projects

The Planck catalogue of galactic cold clumps (PGCC) remains the only “unbiased” all-sky survey of cold dust emission in the Galaxy. PGCC has led to several follow-up surveys, including the Herschel Galactic Cold Cores project, the JCMT/SCUBA-2 continuum survey SCOPE, and the TOP/TRAO line survey. Studies continue on the connections between magnetic fields and cloud filaments, while the latest generation of ALMA follow-up observations are targeting outflows and the chemistry and structure of star-forming cores.

The Planck survey

The PGCC detections were based on the intensity of the cold residual emission, after the subtraction of the warmer emission of the surrounding region (Planck 2016a). Detections were thus based on the *relative* and not absolute temperatures, and thus also some PGCC catalogue values refer to this cold component only. PGCC showed, among other things, that there were no significant, previously unknown high-latitude sites of future star formation. On the other hand, many PGCC clumps are already actively forming stars.

Planck polarisation data remain important for studies of interstellar magnetic fields. Cloud filaments have been observed to become perpendicular to the field lines at high column densities (Planck 2016b, Malinen+ 2016). These studies continue with filaments extracted from Herschel maps with the FilDReaMS method (Carriere+ 2022). Histograms of relative orientation (HROs) are used to quantify the relative orientation of the filaments and the magnetic fields.

The filament study will cover all 116 Herschel fields observed in the Galactic Cold Cores (GCC) project (Oers+, in prep.). Small filaments are again observed to be mainly parallel to the magnetic field, with a transition to the perpendicular geometry typically at 0.8-3 × 10^{21} cm^{-2}. However, in one third of the fields we do not see this trend, with either the parallel geometry dominating at all scales or with a complex morphology that requires more detailed analysis of projection effects, line-of-sight confusion, field strength, etc.

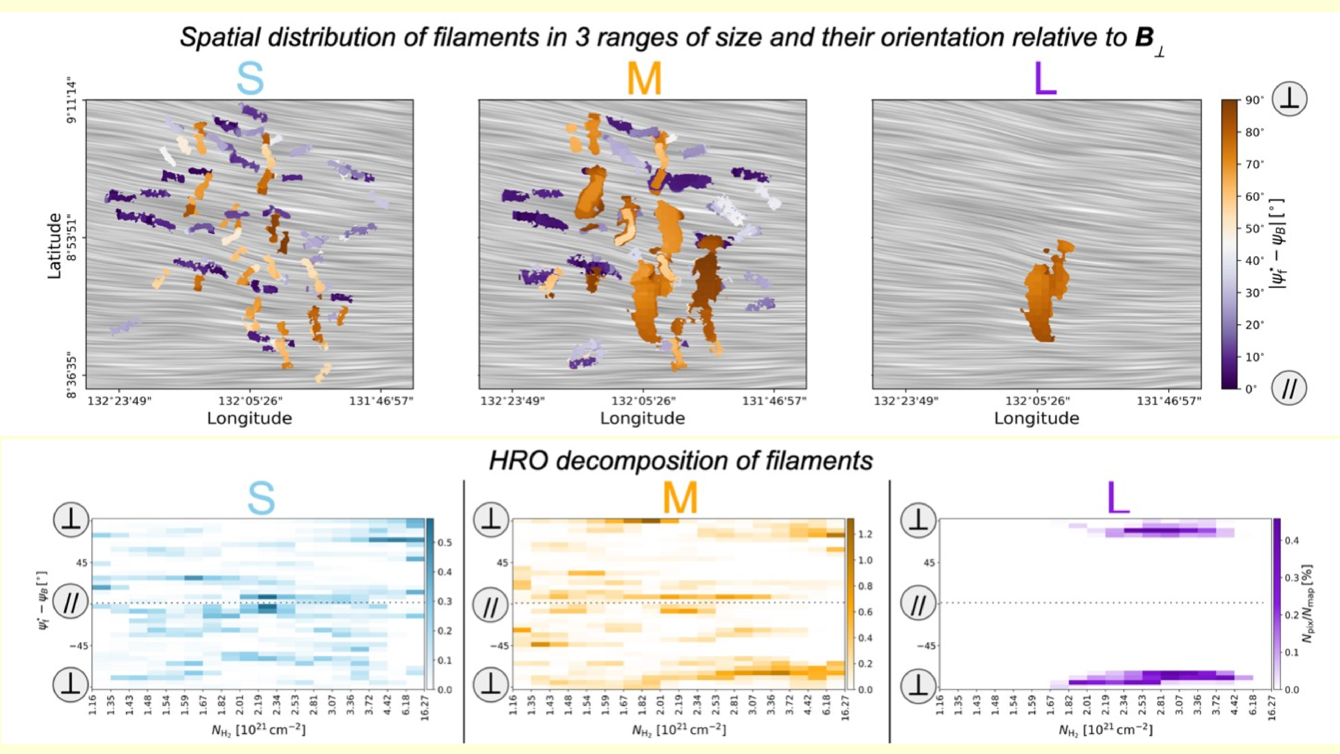
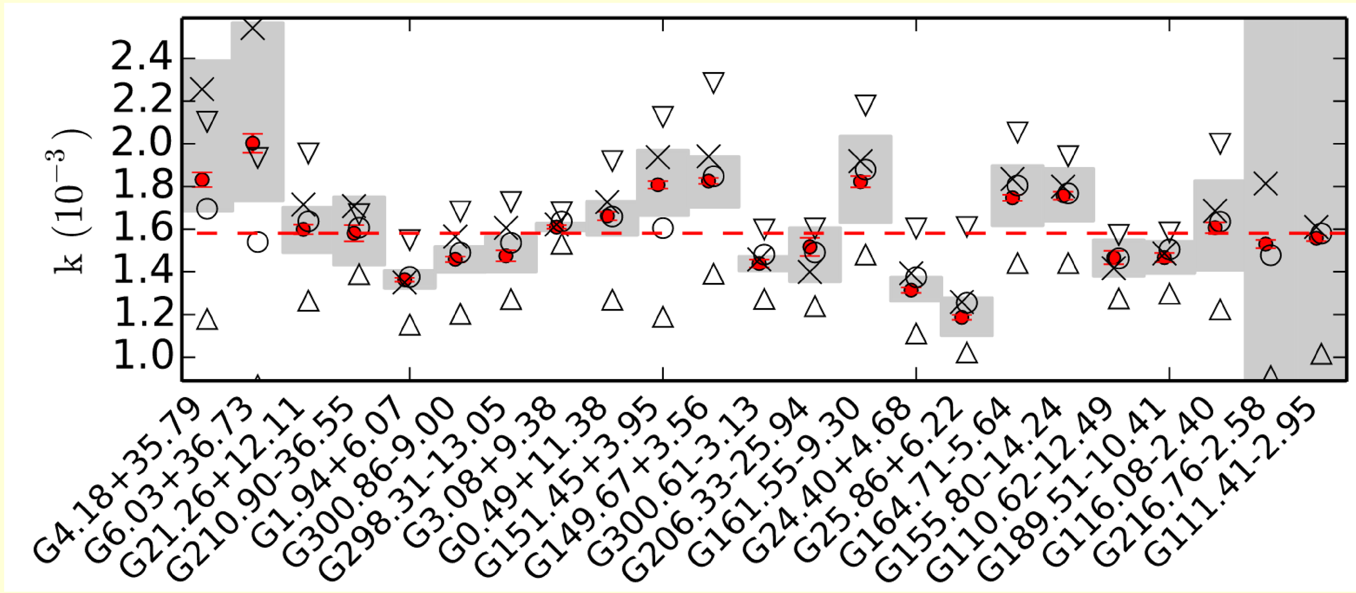


Fig. 1: Example of the HRO analysis in a Herschel field. Upper frames show the filamentary structures extracted with the FilDReaMS method at three different size scales. The lower frames show the HROs, in this case the perpendicular geometry being clearly dominant for large structures and $N(H_2)$> $2{\times}10^{21}$ cm^{-2}.

Follow-up surveys

The Herschel dust observations of nearby PGCC clumps showed FIR spectral indices β~1.8 and high FIR emissivity with k=τ(250μm)/τ(J)~1.6×10^{-3} (Juvela 2015; figure below).



Building on ground-based continuum and line follow-ups (TOP-SCOPE, Liu+ 2018), observations have continued at higher resolution. As an example, the ALMA Survey of Orion Planck Galactic Cold Clumps (ALMASOP, PI: T. Liu) has examined PGCC targets in Orion, down to sub-1000 au scales, studying extremely dense core substructures (Fig. 2), the formation of binary and multiple systems (Luo+ 2022), the chemistry of hot corinos (Hsu+ 2023), and the episodic protostellar outflows (Jhan+ 2022; Dutta+ 2023).

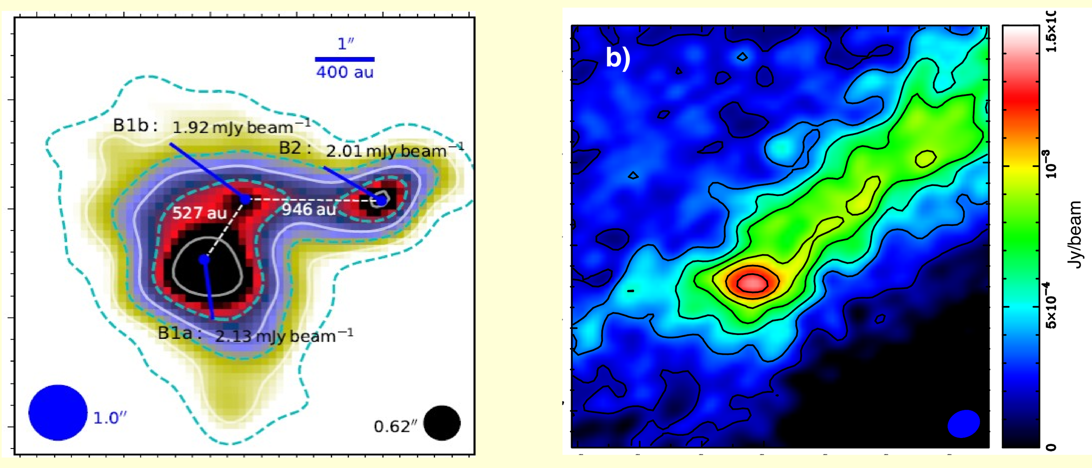


Fig. 2: Small-scale fragmentation in an Orion low-mass prestellar core G205-M3 (Sahu+2021; left), and an extremely dense object embedded in the prestellar core G208.68-N2 (Hirano+ 2024; right).

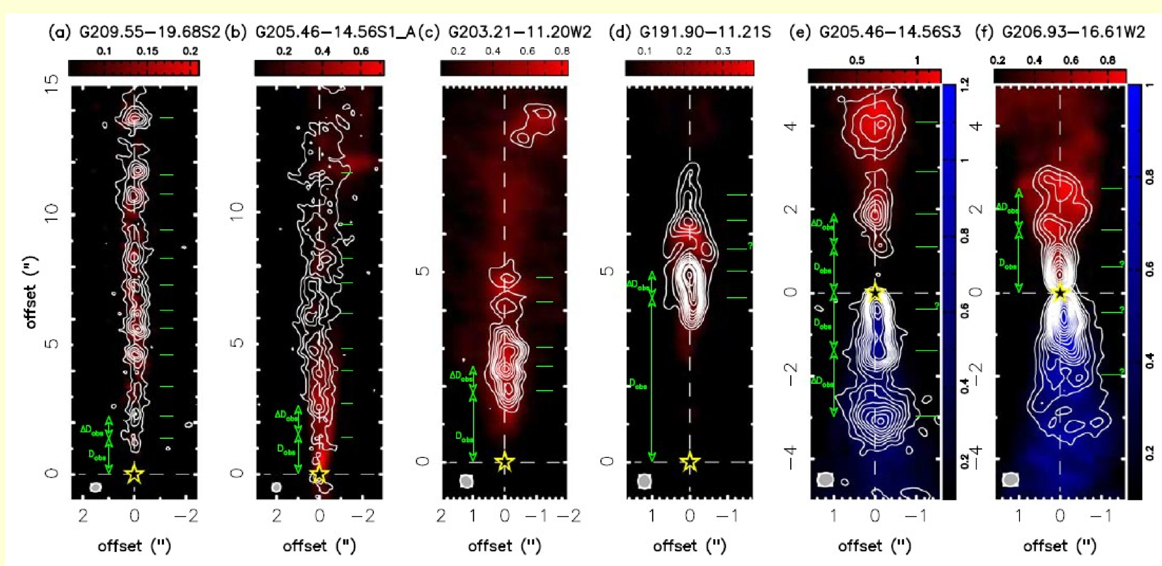


Fig. 3: Protostellar outflows and jets in Orion protostars, observed in CO (colour) and SiO (contours) emission (Jhan+ 2022).

References: Carriere+ 2022, A&A 668, A41; Dutta+ 2023, AJ 167, 72; Hirano+ 2024, ApJ 961, 23; Hsu+ 2023, ApJ 956, 120; Jhan+ 2022, ApJ 931, 5; Juvela+ 2015; A&A 584, A93; Liu+ 2018, ApJS 234, 28; Luo+ 2022 ApJ 931, 158; Malinen+ 2016, MNRAS 460, 1934; Planck 2016a, A&A 594, A28; Planck 2016b, A&A 586, A138; Sahu+ 2021, ApJ 907, L15