The Earliest Phases of Star Formation in IRDCs: Herschel and millimeter studies of G011.11-0.12

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Abstract. Infrared-dark clouds (IRDCs) are believed to be the precursors to massive stars and stellar clusters. The spectral energy distribution (SED) of the cold dust in IRDC filaments peaks in the far-infrared, precisely the wavelength regime probed by Herschel. The Earliest Phases of Star Formation (EPoS) Herschel Key Programme uses PACS and SPIRE imaging to investigate the structure of 45 IRDCs and 14 low-mass molecular cloud cores. In IRDCs, our Herschel observations of unprecedented resolution and sensitivity reveal core populations at a range of evolutionary stages. I present a case study of the IRDC G011.11-0.12. Using the PACS and SPIRE data between 70 and 500 micron, we identify a population of pre-/proto-stellar cores, in particular cores that have not previously been identified in Spitzer 24 micron observations. New SABOCA/APEX follow-up observations highlight the synergies possible between ALMA and Herschel.

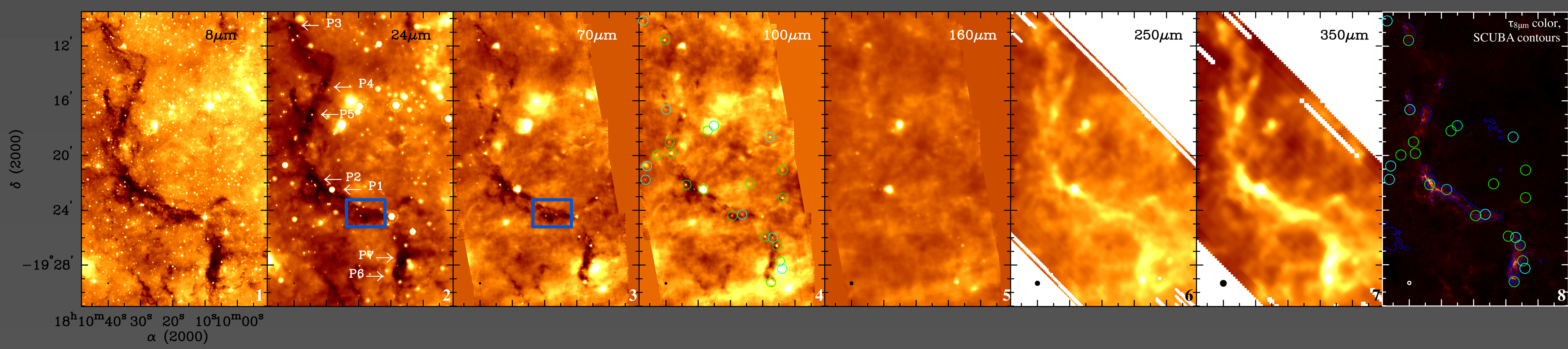

Figure 1: The G011.11-0.12 infrared-dark cloud from 8 to 850μm. The "P" designations (panel 2) are from Johnstone et al. (2003) to identify column density peaks. The circles in panels 4 and 8 are the locations of the cores with detections in all three PACS bands. The green circles are cores with 24μm counterparts, and the cyan circles are those without. The approximate spatial resolution is shown at the lower left corner of each panel. The blue box corresponds to the cut-out region that is shown in Figure 2.

Core population in G011.11-0.12

We fit the PACS 70, 100, and 160μm with a modified Planck blackbody function (see Beuther & Steinacker 2007). The spatial resolution of *Herschel* allows us to probe at "core" scales. The cores have a small range in temperature, however the presence of 24μm counterparts which appear in 16 of the 24 cores and are not included in the SED fit, may indicate the existence of an embedded protostar which heats the core on scales not probed by these observations. Cores without 24μm counterparts may be pre-stellar, or geometry may limit detectability of embedded protostars. Still, the cores have temperatures ~10K higher than that measured in the bulk gas (Pillai et al. 2006), which may be an indication of heating from star formation.

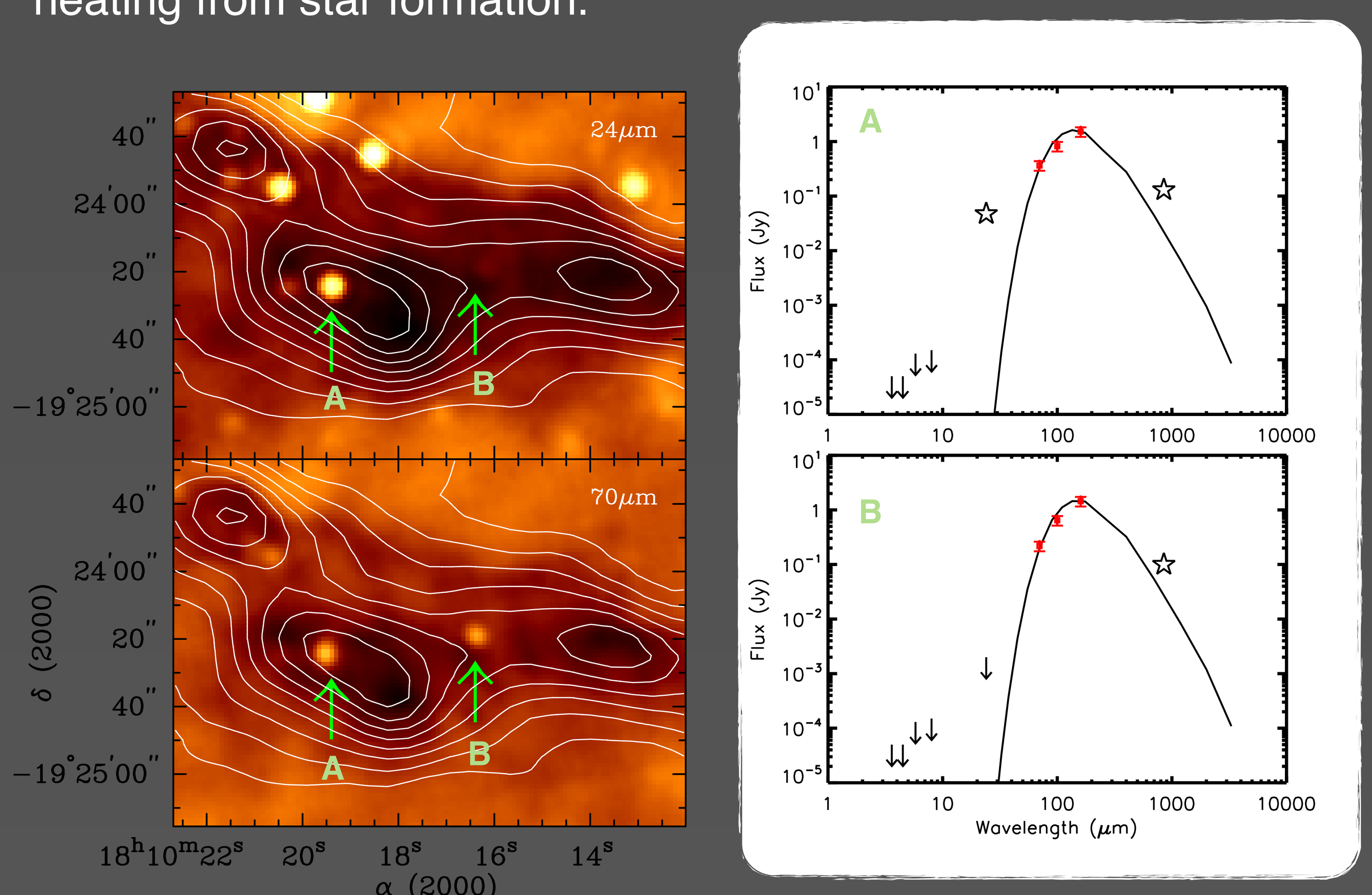

Figure 2: The subregion marked in Figure 1, showing (left) SCUBA 850μm continuum contours over the 24μm and 70μm images. To illustrate the SED-fitting technique, the SEDs of two cores are shown on the right. The red points are the new PACS data to which the modified blackbody was fit. Arrows show upper limits from archival *Spitzer* data, and star symbols indicate detections with *Spitzer* (24μm) and SCUBA (850μm) in excess of the PACS-based SED fits. Core A has a 24μm counterpart, and Core B does not. These two objects have similar properties, but Core A is more likely to have an embedded protostar heating the core internally. Based on the SCUBA data, we estimate the surrounding envelope of gas in this region contains ~700 M⊙.

SABOCA 350μm observations with 7.7'' resolution

The **A**tacama **P**athfinder **Ex**periment is equipped with SABOCA, a 39-channel bolometer array operating at 850 GHz. The 12-meter collecting area of APEX makes it well-suited to observe the cold dust in IRDCs at a superior spatial resolution (7.7'') compared to the SPIRE resolution at the same wavelength (24.9''). With information at similar spatial scales to PACS now at 350μm, we will have a more stringent constraint on the Rayleigh-Jeans tail of the core SEDs. We will also now be sensitive to colder cores, ones that were not detectable even at 70 or 100μm because their SEDs peak at longer wavelengths. These new cores are of particular interest because they represent an earlier evolutionary phase.

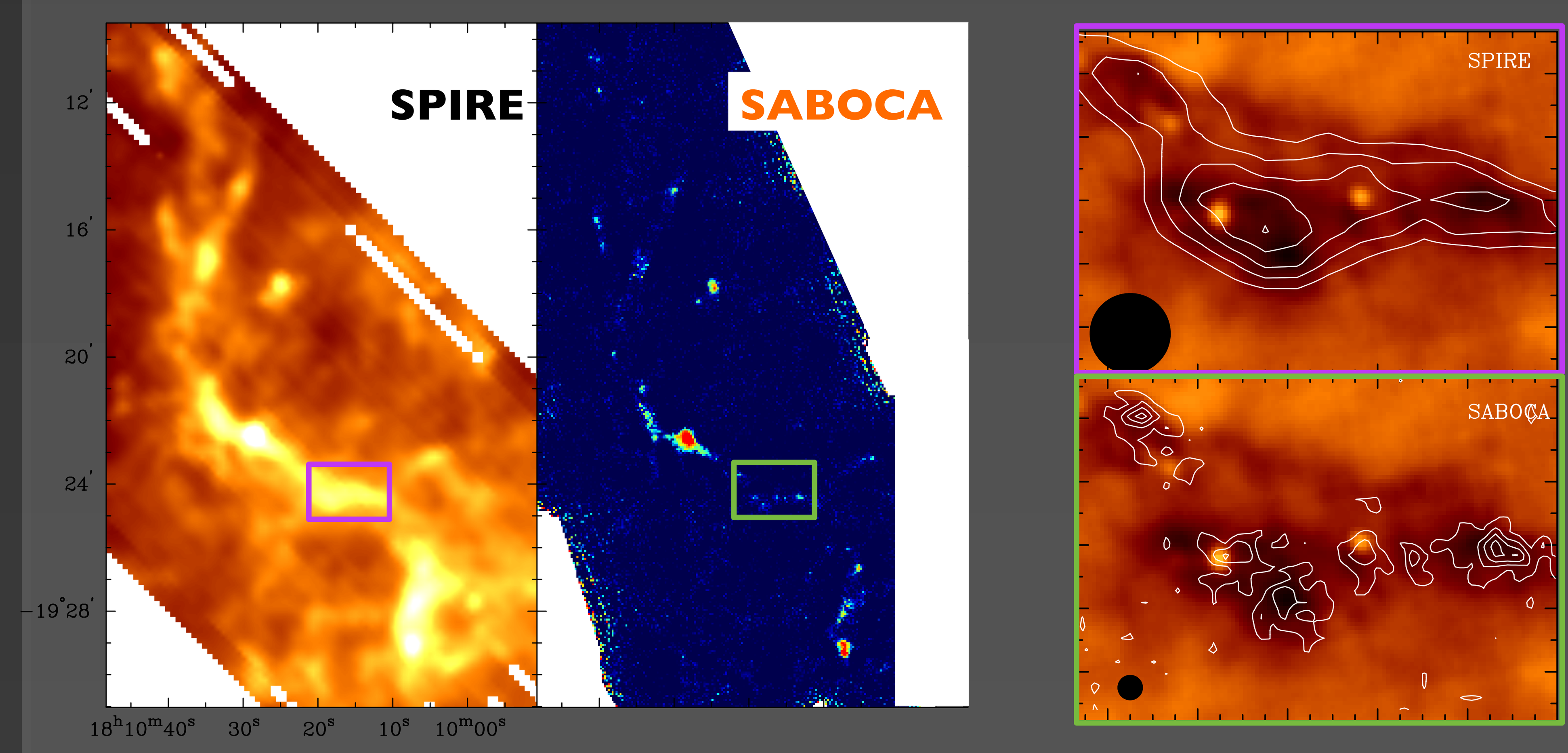

Figure 3: *Left*: The G011.11-0.12 IRDC filament viewed at 350μm with SPIRE (left) and SABOCA (right). Right: SPIRE (top) and SABOCA (bottom) 350μm contours plotted over PACS 70μm image.

Early Results. SABOCA recovers information of the core scales probed by PACS. Not only are many PACS cores from Henning et al. (2010) recovered, new ones which were not detectable at PACS wavelengths have also been revealed. Analysis is underway to determine the full range of core properties in the filament. The median separation between cores is 1 - 2 pc, which is smaller than what Jackson et al. (2010) find for the "Nessie" IRDC (4.5 pc).

Summary and Prospectus. New Herschel observations of the G011.11-0.12 IRDC have been obtained in all PACS and SPIRE bands. We have followed up by obtaining 350μm SABOCA data, recovering the resolution with *Herschel*/PACS, with the objective of constraining the Rayleigh-Jeans tail of the SED of the core population within the filament. G011.11-0.12 is one of 45 IRDCs in the Earliest Phases of Star Formation Key Programme. We aim to extend this investigation of more of the EPoS sample. Such a study is a crucial step in connecting the results we have today from *Herschel* to those we hope to see with ALMA.

References

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