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Tracing micron-sized grains in molecular clouds with coreshine

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Recently discovered scattered light at 3-5 μm from low-mass cores (so-called "coreshine") reveals the presence of grains around 1 μm. But only a fraction of the cores investigated so far show the effect. We derive a simple limit for detecting scattered light from a low-mass core can be derived. The extinction by the core prohibits detection in bright parts of the Galactic plane, the phase function favors the off-plane detection near the Galactic center and to some extent near the Galactic anti-center. Our 3D radiative transfer calculations for the core L260 show that also the K band is capable of probing coreshine, and that the shape of the Ks band surface brightness profile limits the largest grains to sizes of to 1-1.5 μm. For the core L1506C showing coreshine and strong depletion, but low density and turbulence our grain growth calculations and radiative transfer modeling show detectable coreshine at 3.6 μm only when we increase the core density and the turbulence above what is currently observed. The grains could be part of primitive omnipresent large grain population becoming visible in the densest part of the ISM, could have been grown under the turbulent dense conditions of former cores, or in L1506C itself. In the later case, L1506C must have passed through a period of larger density and/or stronger turbulence. This would be consistent with the surprisingly strong depletion usually attributed to high column densities, and with the large-scale outward motion of the core envelope observed today.

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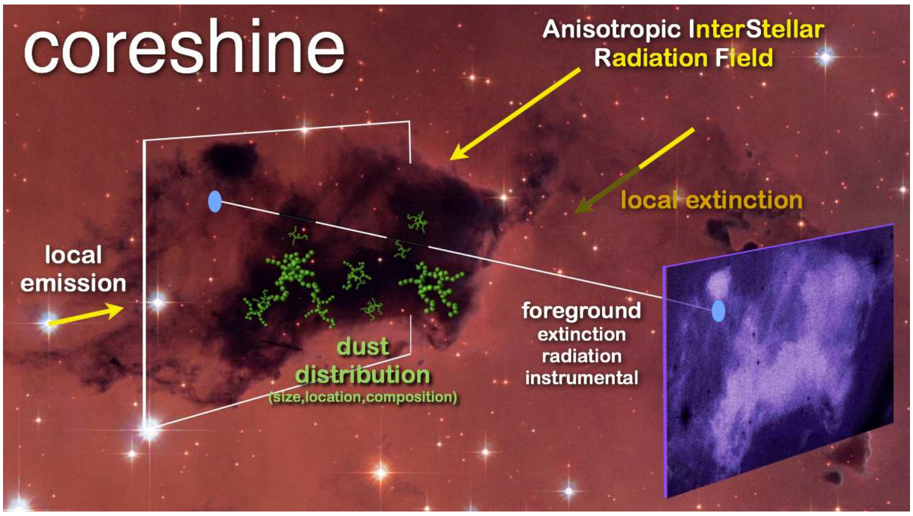

Figure 1: Illustration of the basic physical ingredients of coreshine. The strongly anisotropical ISRF is scattered by the grains in the core towards the observer. Additionally, the core is seen in extinction against the background radiation. Local extinction and sources can modify the received coreshine.

1. Introduction

Dense regions in molecular clouds have been identified as the site where star formation starts. As the initial conditions impact the formation process, much effort has been devoted to analyze the change in conditions from the diffuse interstellar medium (ISM) to these dense cold cores. Through absorption, scattering and emission, cosmic dust grains embedded in the core gas enshroud the view on the star formation process at optical wavelengths, but also provide information on the physical conditions at longer wavelengths. A key quantity of the grains is their size distribution. For the diffuse ISM, [1] were the first to suggest a power-law distribution with a size limit of 0.25 μm for non-graphite grains (abbreviated MRN). For the denser phases of the ISM, however, the modeling of thermal emission and extinction of grains provided indirect evidence for the existence of a population of grains beyond this size (for a list of references and also for a description of the discovery see the talk by Pagani in this volume).

Fig. 1 illustrates the main ingredients to observe scattered light from a core. The core is seen in extinction against the background radiation field. This surface brightness depression at the location of the core is filled with light scattered from the incident anisotropic interstellar radiation field (ISRF) towards the observed. Local extinction and nearby sources will further modify the observed coreshine. Up to now, only the core L183 has been modelled with a detailed 3D structure and dust model to explain the coreshine in the Spitzer images by [2]. Studying cold Spitzer archival data, [3] found the coreshine effect to be a common feature among nearby low-mass cores. This finding and the potential of the effect to study the central parts of the cores, to probe possible grain growth in cores and in this way the history of the cores has led to two warm Spitzer observing programs described in [4] and [5], the first one being the largest Galactic Spitzer program in cycle 8. In this contribution, we describe new work on exploring the coreshine effect in general and the modeling of two interesting cores with prominent coreshine.

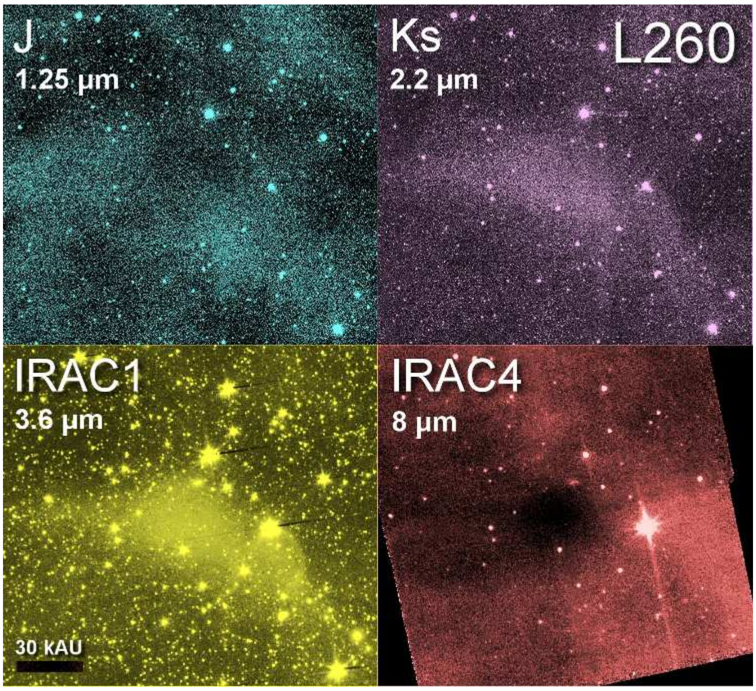

Figure 2: Images of the core L260 in J, Ks, IRAC1, and IRAC4. In the J band, only scattered light from the outer core part is seen while at Ks and IRAC1 coreshine is visible from all parts of the core. The IRAC4 band shows the core in extinction.

2. Detecting scattered light from low-mass molecular cores

In [6] we analyze the conditions for the detection of scattered light at 3.6 μm from low-mass molecular cloud cores. We find it to be both influenced by local effects like the radiation field in the vicinity of the core and global effects like the interplay of core position with respect to the Galactic center and the directional characteristics of the scattering. For optically thin radiation and a constant grain size distribution throughout the core, we derive from the radiative transfer equation a simple limit for detecting coreshine that holds for grains with sizes smaller than 0.5 μm. Details of the calculation concerning the integral over the size distribution can also be found in [7].

The extinction of background radiation by the core prohibits detection in large parts of the Galactic plane and especially near the LoS towards the GC. For grain distributions extending to 1 μm, the forwardly-peaked directional characteristics of the scattering favors the detection of coreshine near the GC. The derived scheme can be used to identify cores which deviate from the expected flux and might be of interest in terms of nearby radiation sources, PAH contamination, or grain properties. Combining the global constraints on coreshine detection, cores above or below the GC are best detectable. The moderate amplification by backward scattering of GC radiation along with the lower background supports detection of coreshine near the anti-center.

3. Including K band coreshine to model the core L260

The core L260 is one of the few cores which has also been observed in the near-infrared. Fig. 2 shows the images in the Ks, IRAC1, and IRAC4 filters. While for this core, the optical depth is too high in the J band to receive scattered light from the core center, Ks and IRAC1 reveal coreshine from all locations in the core.

In [8], we compared the surface brightness model along a cut through the image containing the core center with radiative transfer models of a simple 1D core with a flat+powerlaw radial profile with the overall properties of L260, and an MRN size distribution with varying maximal grain size limit but which is constant across the core. The Ks and IRAC band 1 and 4 could be fitted with the same density and dust properties. The maximal grain size was found to be 1-1.5 μm.

4. L1506C: a core with a turbulent history or revealing a pristine dust component

Both explanations were also investigated to explain the scattered light observed from the central part of L1506C in IRAC1. In [9], we use again a simple core density structure, an ISRF based on the DIRBE map, and standard dust opacities, and a constant MRN dust size distribution with a size limit of 0.25 μm and do not arrive at sufficient scattered light to explain the observed surface brightness of cores with coreshine. Only when increasing the maximal size to 0.65 μm now containing what could be a primitive component from earlier star formation cycles before the Taurus filaments came to being, we are able to reproduce the coreshine level with our radiative transfer calculations. An implication of the existence of a global primitive large-grain component would be that most low-mass cores comparable to L1506C should show coreshine as far as the background level allows its detection, shielding effects do not block the radiation either during illumination or on its way to the observer, or large-scale processes like supernovae have modified the size distribution as suggested in [10].

Another possibility is that the large grains responsible for the scattering have been formed in the core. We applied a grain growth model based on the detailed grain growth calculation presented in [11] which has turbulence, core size and density as input parameter. Using the size distributions obtained after 1 Myr, the density structure and turbulence as it is observed today for L1506C, and a model core with properties similar to that of L1506C, the resulting coreshine was too low to explain the currently observed coreshine level. Increasing the density beyond the currently observed values, we also failed to reproduce the observed coreshine within the limits of our simple model. However, our results indicate that grain growth in a core that is denser and/or more turbulent could lead to the observed coreshine surface brightness. Within the gravo-turbulent scenario of star formation, the same large-scale motions that would have created the density maximum in the filament at the location of L1506C could have torn the core partially apart leaving just the gravitationally bound part.

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