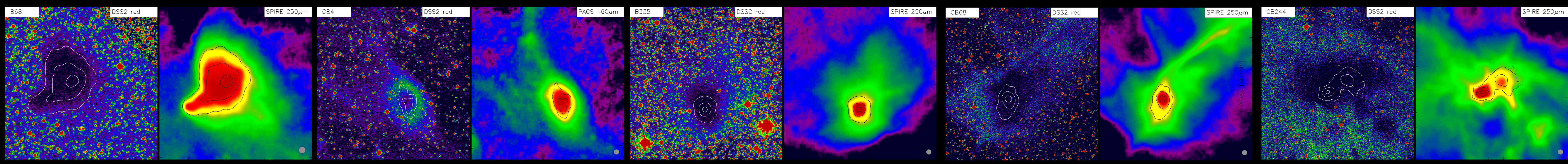
The thermal structure of low-mass cloud cores

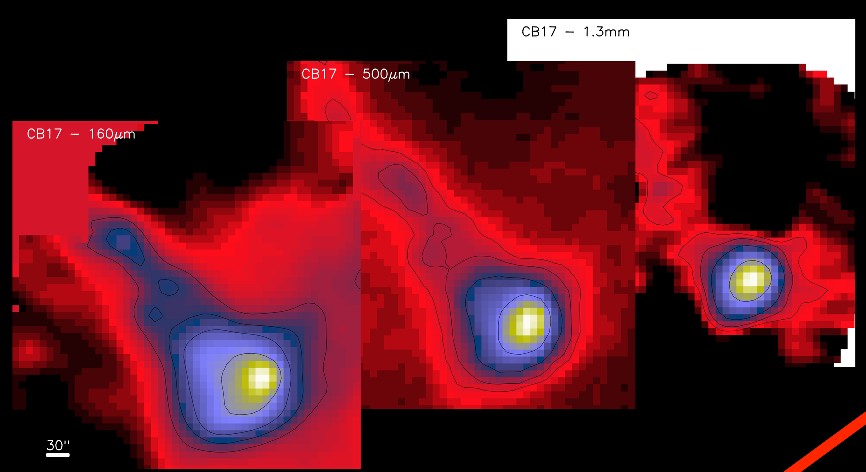
R. Launhardt, A. Stutz, A. Schmiedecke, Th. Henning, O. Krause, Z. Balog, H. Beuther, J. Kainulainen, H. Linz, N. Lippok, M. Nielbock, S. Ragan, M. Schmalzl, Y. Shirley, J. Steinacker

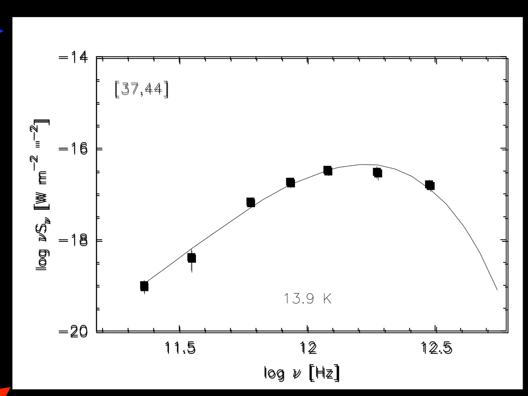


The evolution of the temperature and density structure of star-forming cloud cores is one of the key aspects in protostellar collapse models. Yet this structure, in particular the temperature, is not well-constrained observationally. In the framework of the EPoS Herschel key project, we observed the NIR extinction and FIR through mm dust emission from selected isolated nearby starless and protostellar cloud cores. Based on these data, we reconstruct the full dust temperature and density structure of the cores. We find that the thermal structure of all globules is completely dominated by external heating through the ISRF and moderate shielding by thin extended halos. All globules have warm outer envelopes (14–20 K) and colder dense interiors (7–11 K) with column densities of up to 10^{23} cm^{-2} and central volume densities of a few 10^5 cm^{-3} (starless cores). The protostars embedded in some of the globules raise the local temperature of the dense cores only within radii out to about 5000 AU, but do not significantly affect the overall thermal balance of the globules.

Deriving dust temperature maps:

1. Preparing the data:
   - Herschel (100-500µm), submm (450-1300µm), NIR extinction (2.2µm) maps
   - Common flux scale, coordinate system, pointing, resolution
   - Derive and subtract background levels
   - Estimate true background levels from IRAS, ISO, CIB, and CMB maps
2. Extract SED for each pixel:
   - Color corrections based on flux ratios

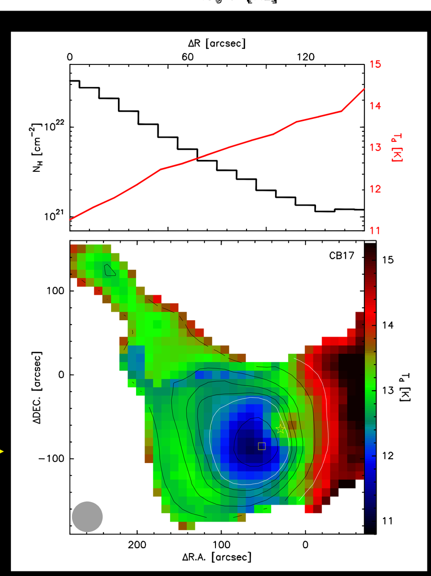




3. χ^2 fit single-T modified BB-SED:

$$S_\nu = \Omega\,(1-e^{-\tau(\nu)})\,(B_\nu(\nu,\boldsymbol{T_d}) - I_{bg}(\nu))$$

$$\tau(\nu) = \boldsymbol{N_H}\, m_H\, M_d/M_H\, \kappa_d(\nu) \quad (\kappa_d \text{ from OH 94})$$



4. Construct maps of τ-averaged dust temperature and column density:
5. Model 3-D T_d and n_H structure:

In plane of sky: ← *iterate* → **Along line of sight**: χ^2 fit ΔT & n_0

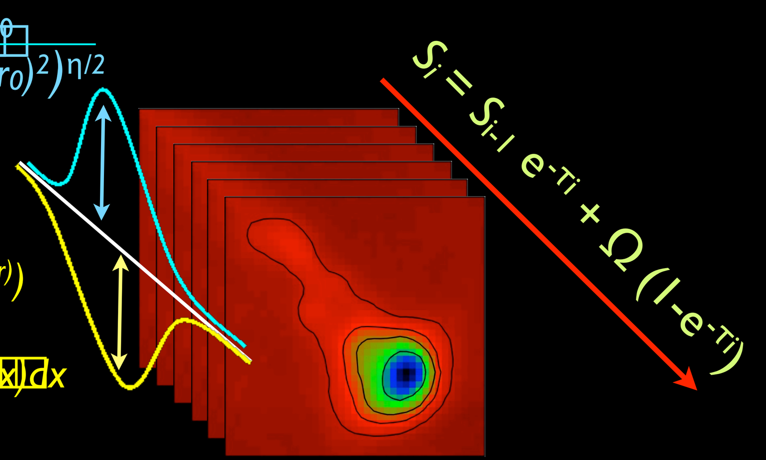
derive r_0, η, T_{out}, T_0, r_{out} from plane-of-sky profiles

$$n(r) = \frac{n_0}{(1+(r/r_0)^2)^{\eta/2}}$$

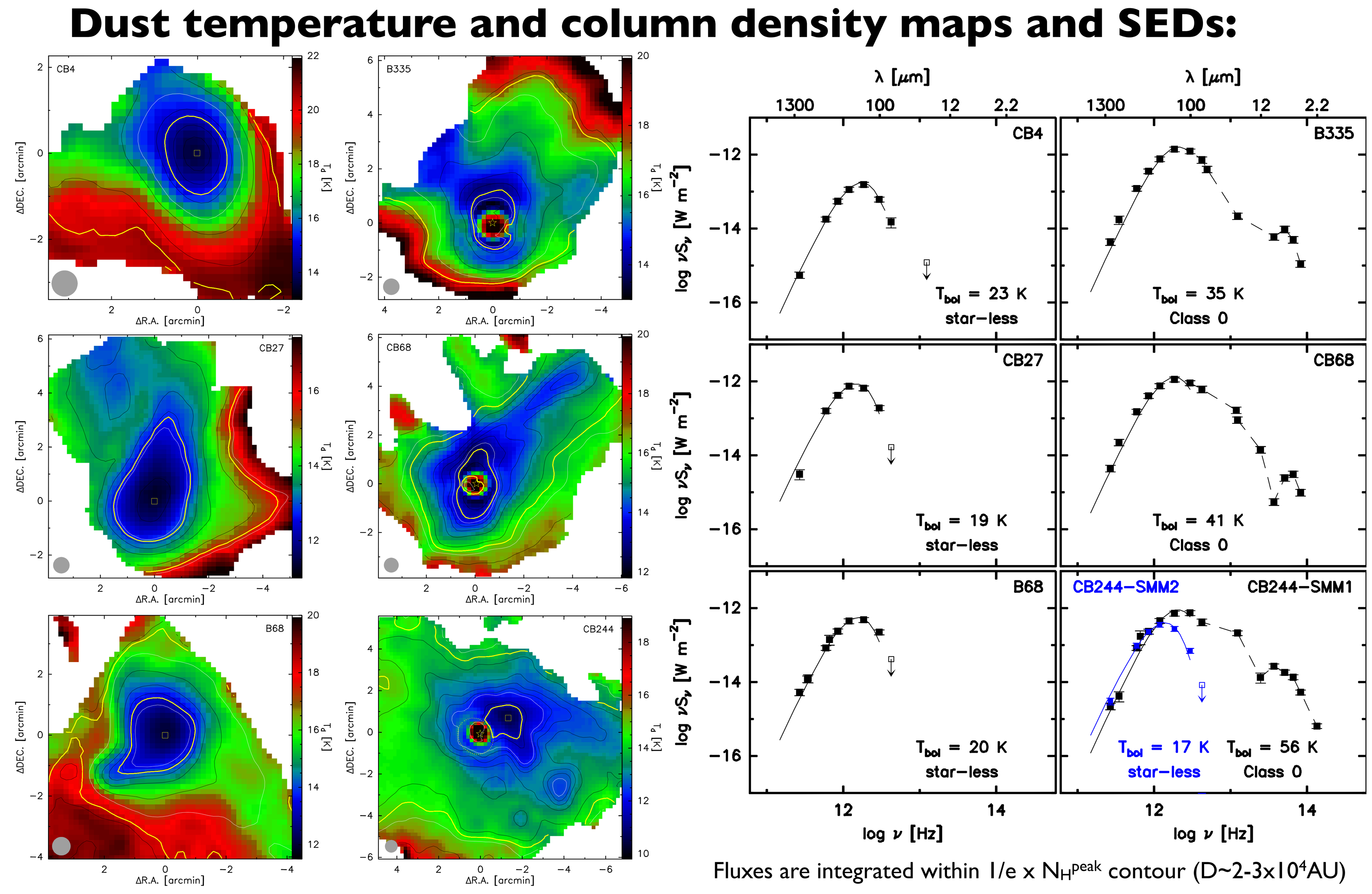
$$T(r) = T_{out} - \Delta T(1-e^{-\tau(r)})$$

with $\tau(r) \sim \kappa_0 \int_r^{r_{out}} n_H(x)\,dx$

$$S_i = S_{i-1}\, e^{-\tau_i} + \Omega\,(1-e^{-\tau_i})$$

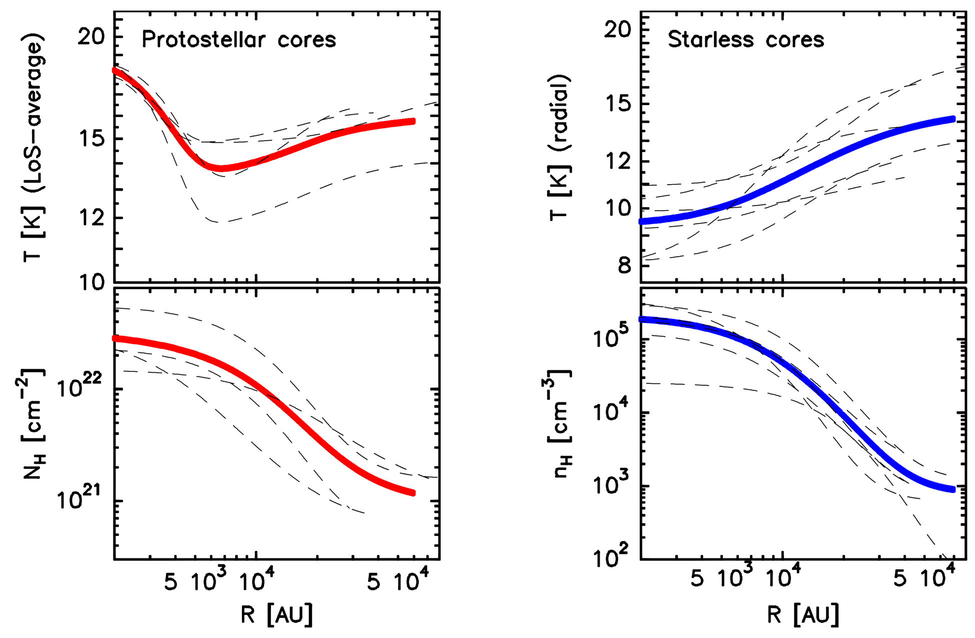


Dust temperature and column density maps and SEDs:



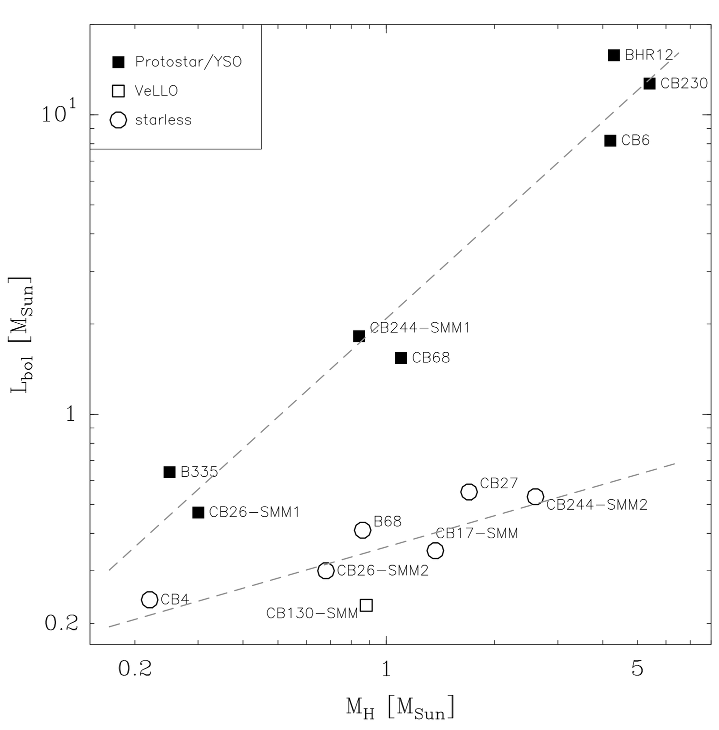
Fluxes are integrated within 1/e x N_H^{peak} contour (D~2-3x10^4AU)

Temperature and column / volume density profiles:



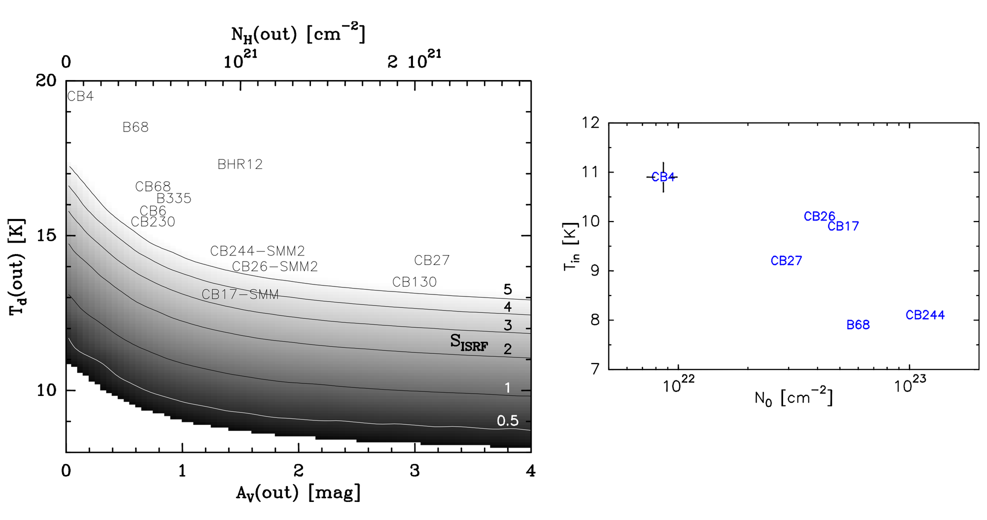
- Note that the profiles shown are LoS-averages from GB fitting for protostars and true radial profiles from RT models for starless cores
- All sources are dominated by ISRF heating at radii > 5000 AU
- The bulk of the luminosity is therefore driven by the ISRF
- The mean outer temperature of all globules is ~15 K
- The lowest central temperatures we detect are ~7 to 8 K

Masses and luminosities:



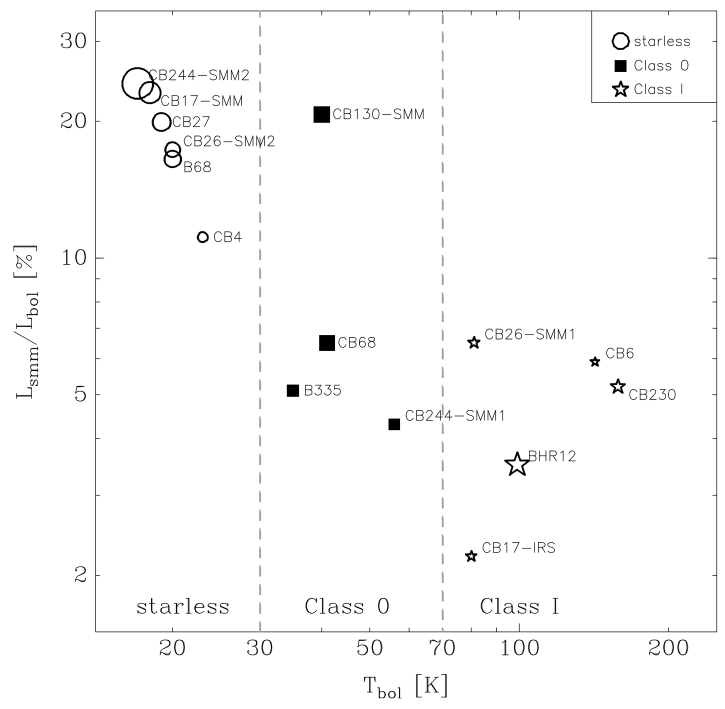
- Dense cores (D~2-3x10^4AU) with M~0.5-2 M_{sun} receive ~0.3-0.6 L_{sun} from ISRF and irradiate at FIR-submm
- VeLLos (CB130) do not contribute to core energy balance
- Protostars, even low-mass (B335), contribute significantly only to core energy balance

Shielding and the ISRF:



- The outer envelope temperatures correlate with the column density / A_V of the extended halos
- The central temperatures (of starless cores) correlates with the total column density
- Our analysis confirms that globules are predominantly externally heated by the ISRF and shielded by thin extended halos
- These results suggest that previous models have underestimated the levels of heating by the ISRF as well as the shielding by extended halos that are hard to detect observationally

Evolutionary stages:



- With Herschel data we can now also measure starless cores
- All starless cores have L_{bol} < 25K and L_{submm}/L_{bol} >10%
- Class 0/1 sources have L_{submm}/L_{bol} ~ 3-7%
- L_{submm}/L_{bol} ratio is good indicator of starless cores
- T_{bol} is better indicator for Class 0 and later

Conclusions:

- The thermal structure of globules is dominated by external heating through the ISRF, with warm envelopes (15±2 K) and cold interiors (10±2 K).
- The outer dust temperature is determined by shielding against the ISRF by thin extended halos.
- The central temperatures in starless cores anti-correlate with the total column density that provides shielding against the ISRF
- Embedded (low-mass) protostars raise the local temperature only within r < 5000 AU, but do not affect the overall thermal balance of the globules.
- There is accumulating evidence that dust opacity models for un-coagulated grains fit the bulk of the emission better than, e.g., the OH5 model and that nearly all published dust models over-predict the NIR extinction per dust column.

References:

- *Stutz et al. 2010, A&A, 518, L87 (CB244 - SDT)*
- *Beuther et al. 2010, A&A, 518, L78 (High-mass)*
- *Henning et al. 2010, A&A, 518, L95 (High-mass)*
- *Nielbock et al. 2012, A&A, 547, 11 (B68)*
- *Ragan et al. 2012, A&A, 547, 49 (high-mass overview)*
- *Launhardt et al. 2013, A&A, 551, 98 (low-mass Overview)*
- *Lippok et al. 2013, A&A, submitted*
- *Schmalzl et al. 2013, A&A, submitted (CB17)*