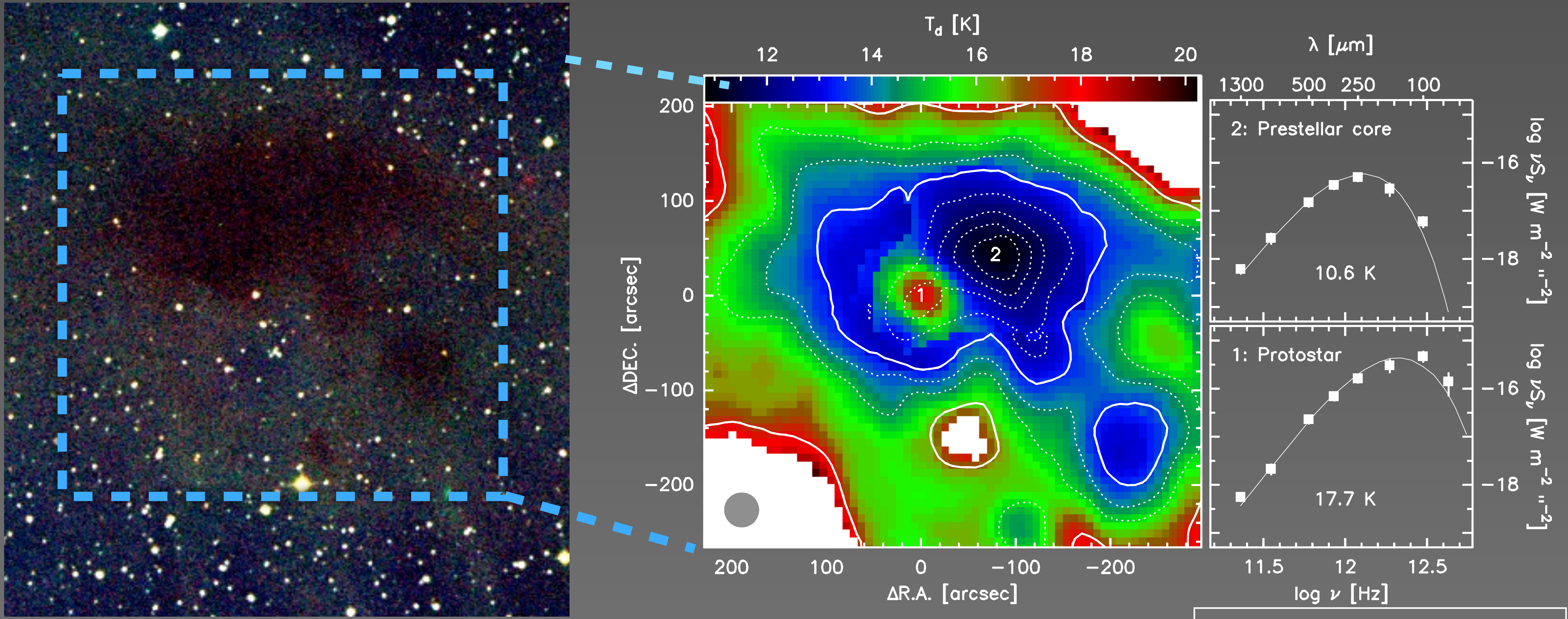
The **E**arliest **P**hases **o**f **S**tar Formation

Physical properties of isolated low-mass cores



Stutz et al. 2010, A&A, 518, L87

R. Launhardt (MPIA) & EPoS team

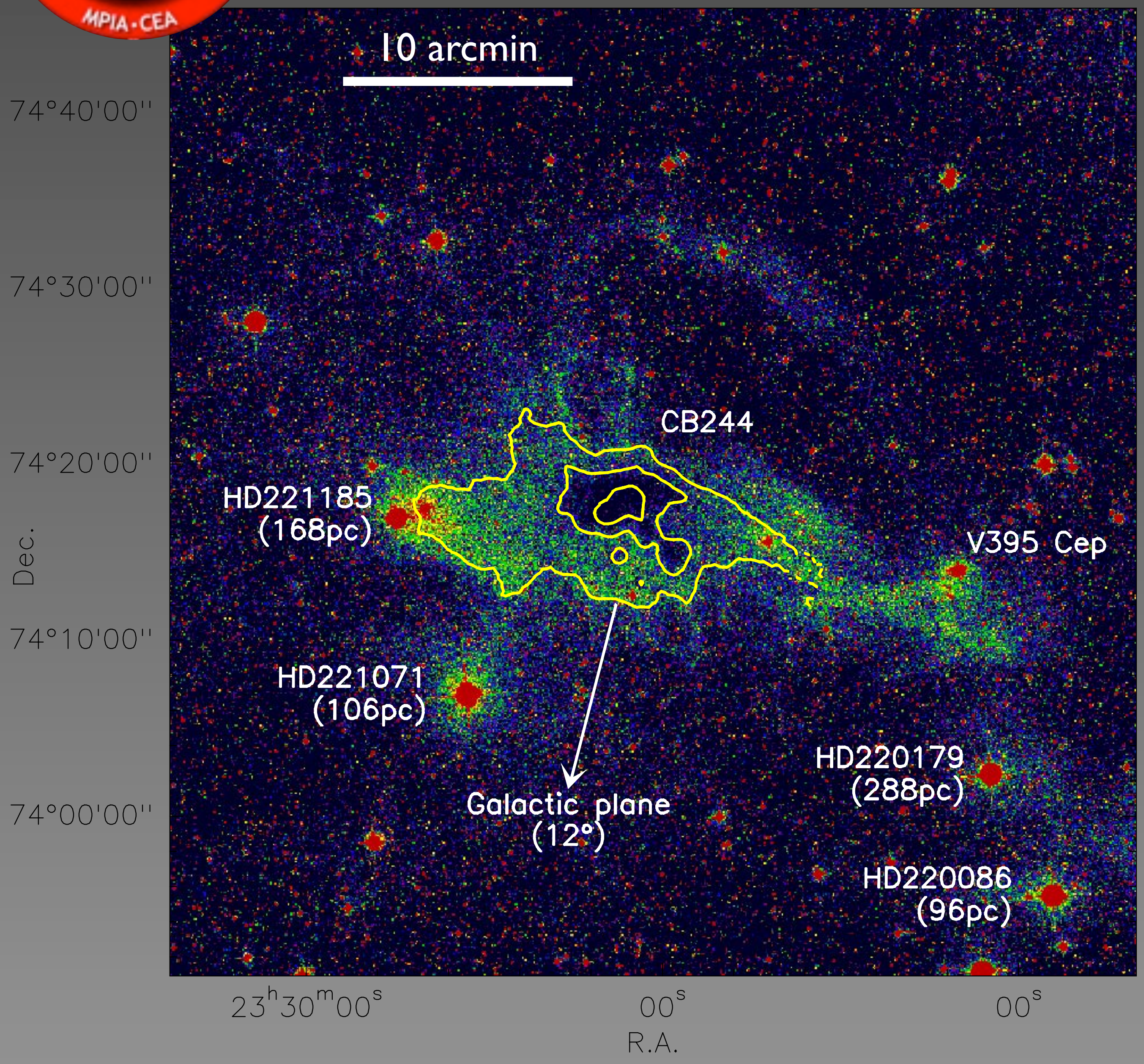
ESA-ESTEC - “The Universe explored by Herschel”, 15-18 October 2013

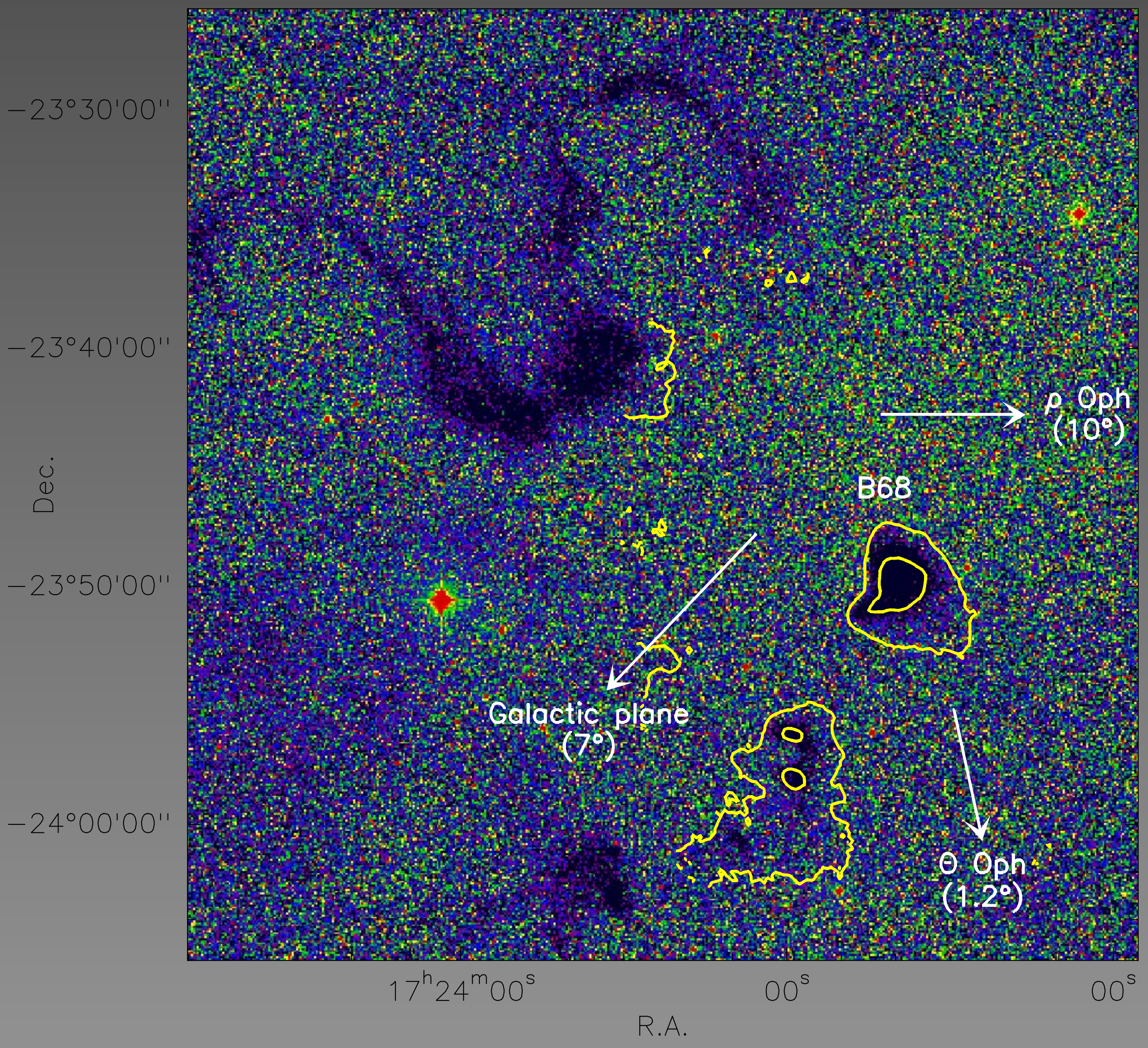
The EPoS team

(incomplete and in alphabetical order)

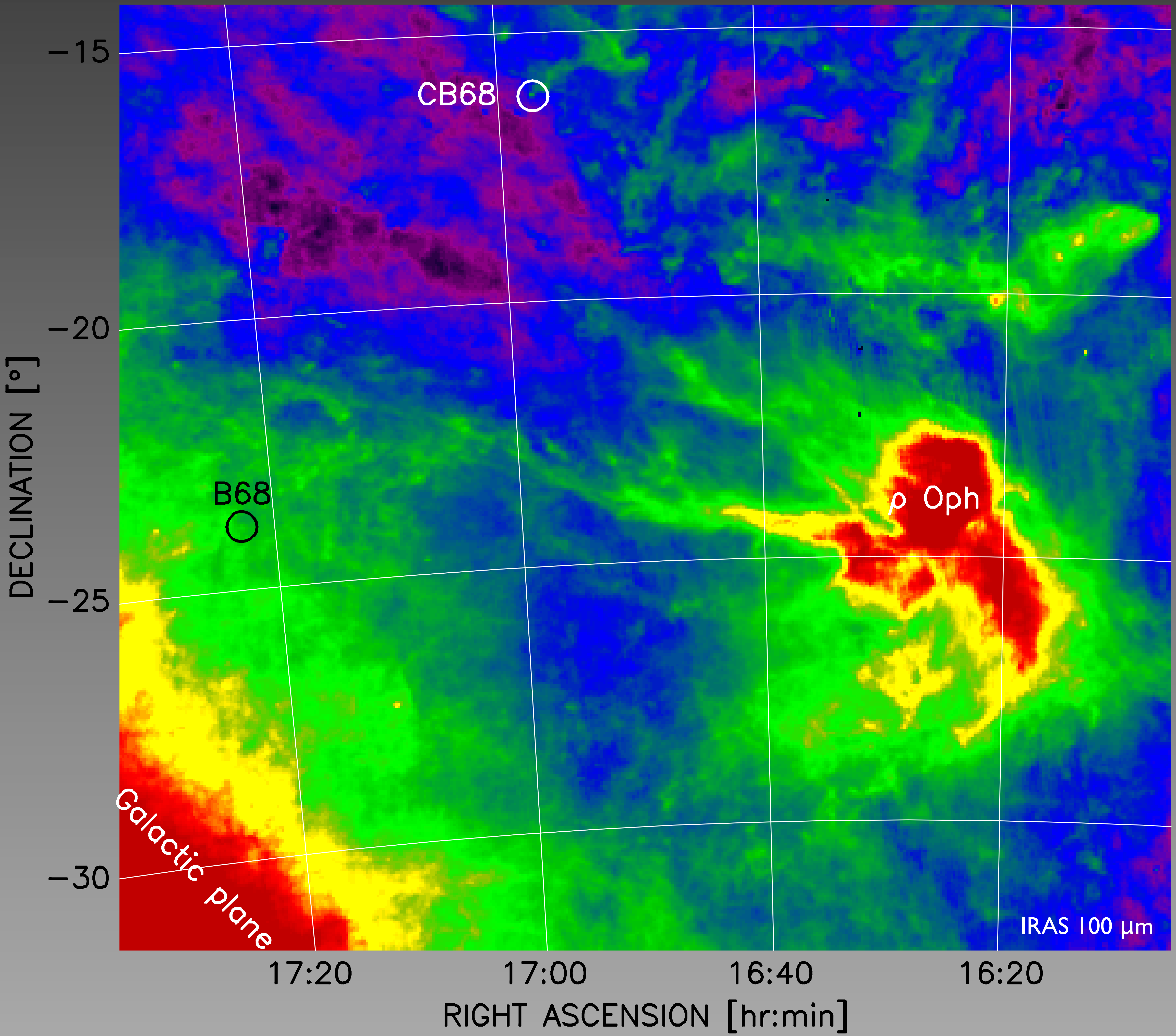
Z. Balog, **J. Bouwman**, *H. Beuther*, *S. Birkmann*, *M. Hennemann*,
Th. Henning, *J. Kaunulainen*, *T. Khanzadyan*, **O. Krause**, **R. Launhardt**,
H. Linz, *N. Lippok*, **M. Nielbock**, *J. Pitann*, **S. Ragan**, **M. Schmalzl**,
A. Schmiedecke, *Y. Shirley*, **A. Stutz**, *J. Steinacker*, *J. Tackenberg*

The EPoS (low-mass clouds) idea

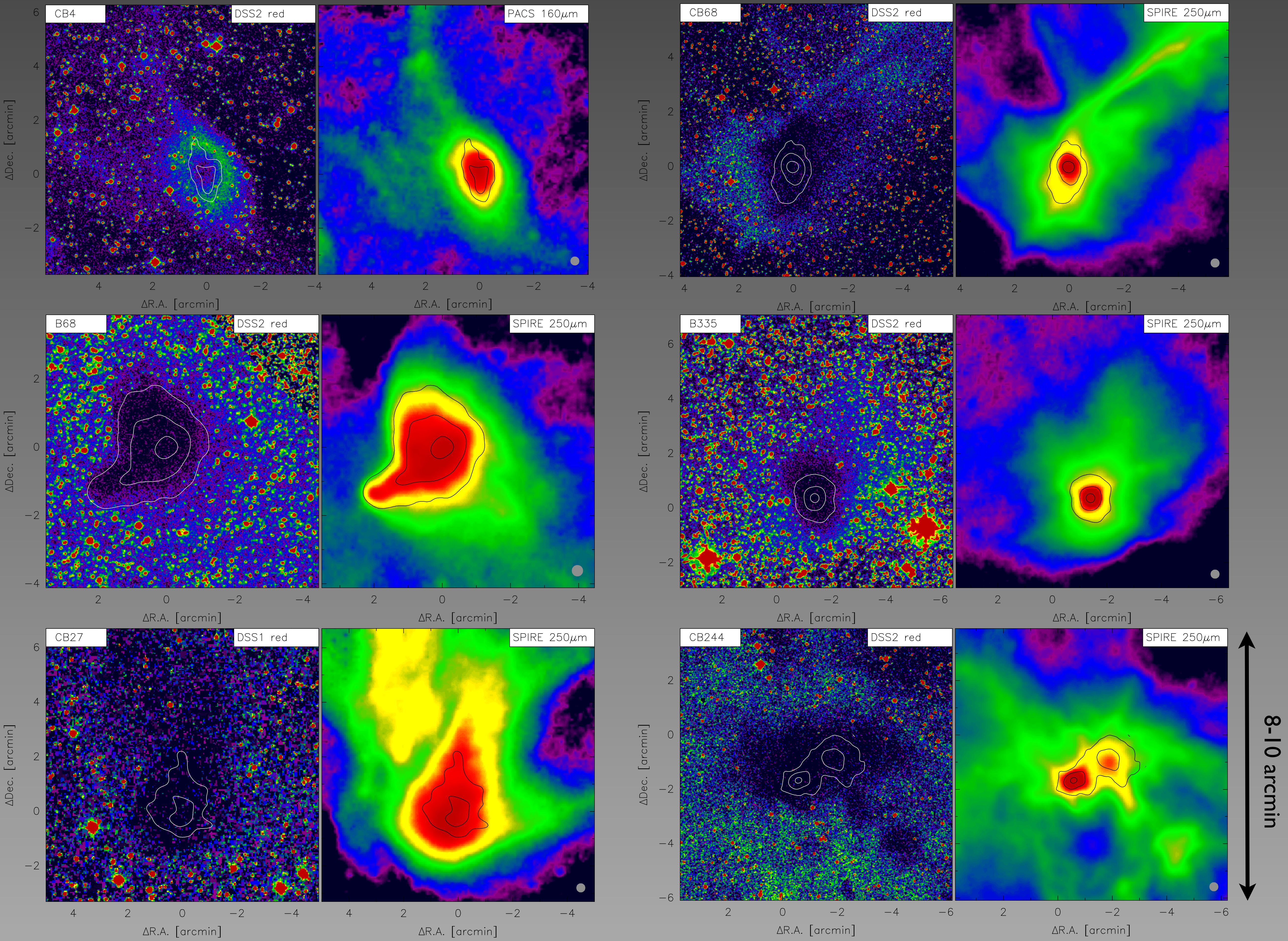




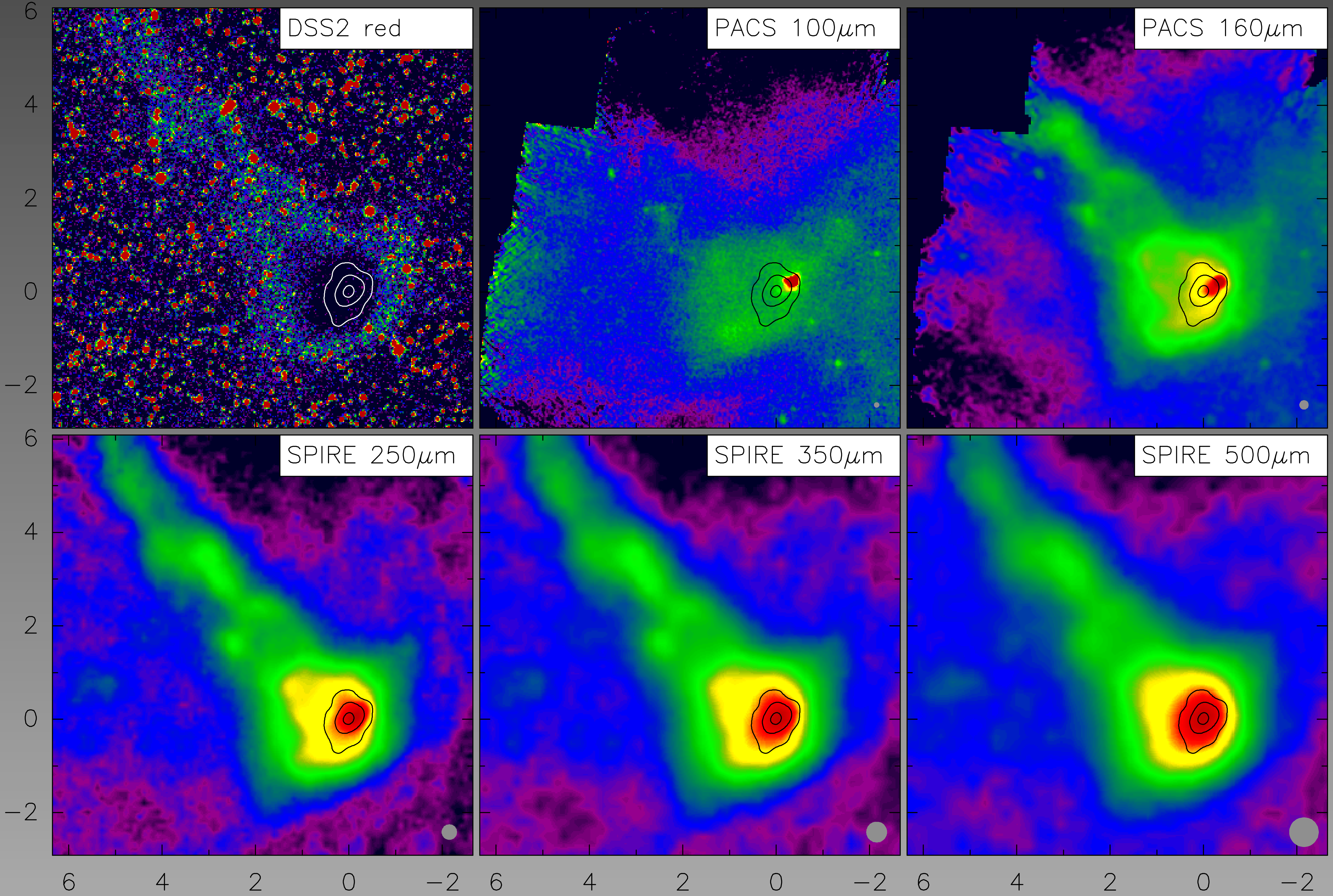
Map the FIR dust emission of small molecular clouds down to ambient background levels to restore the **temperature structure** with high accuracy and derive constraints on **dust properties**


CB68
B68
ρ Oph
Galactic plane
IRAS 100 μm
−15
−20
−25
−30
DECLINATION [°]
17:20
17:00
16:40
16:20
RIGHT ASCENSION [hr:min]

Selected EPoS sources (DSS2 and SPIRE 250μm images)



Herschel images of CB17



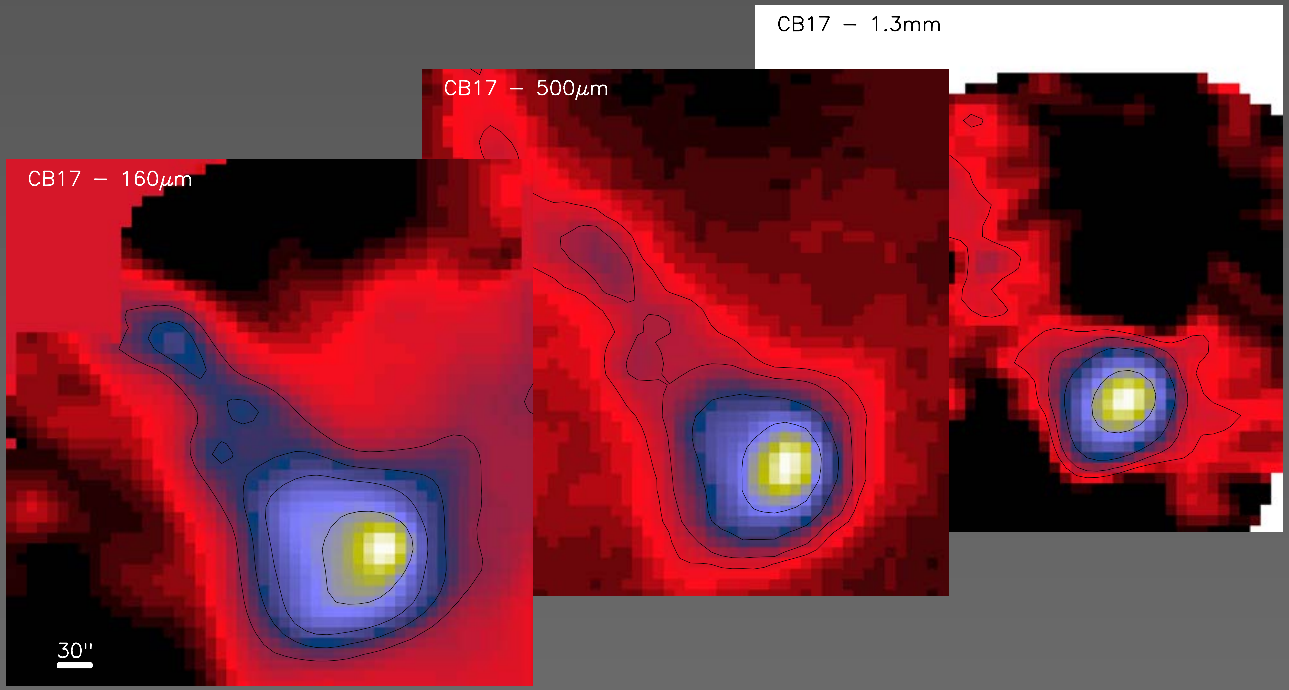
Deriving dust temperature maps:

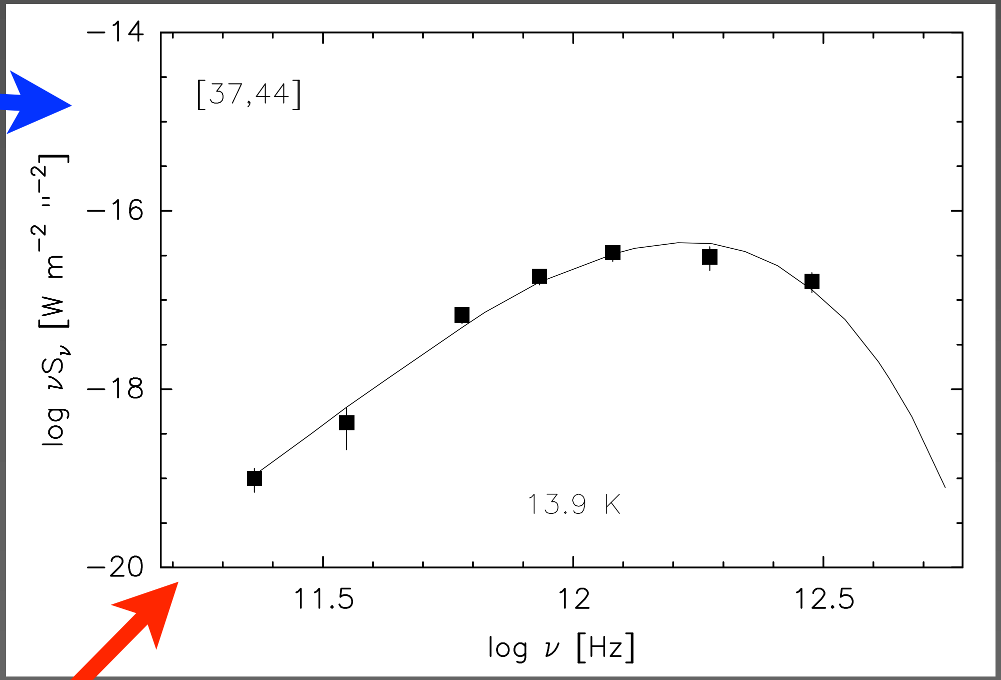
1. Preparing the data:

- Herschel (100-500µm), submm (0.45-2mm), NIR extinction (2.2µm) maps
- Image reconstruction, common flux scale, coordinate system, pointing, resolution
- Derive and subtract background levels
- Estimate true background levels from IRAS and ISO maps, CIB, CMB

2. Extract SED for each pixel:

- Color corrections based on flux ratios



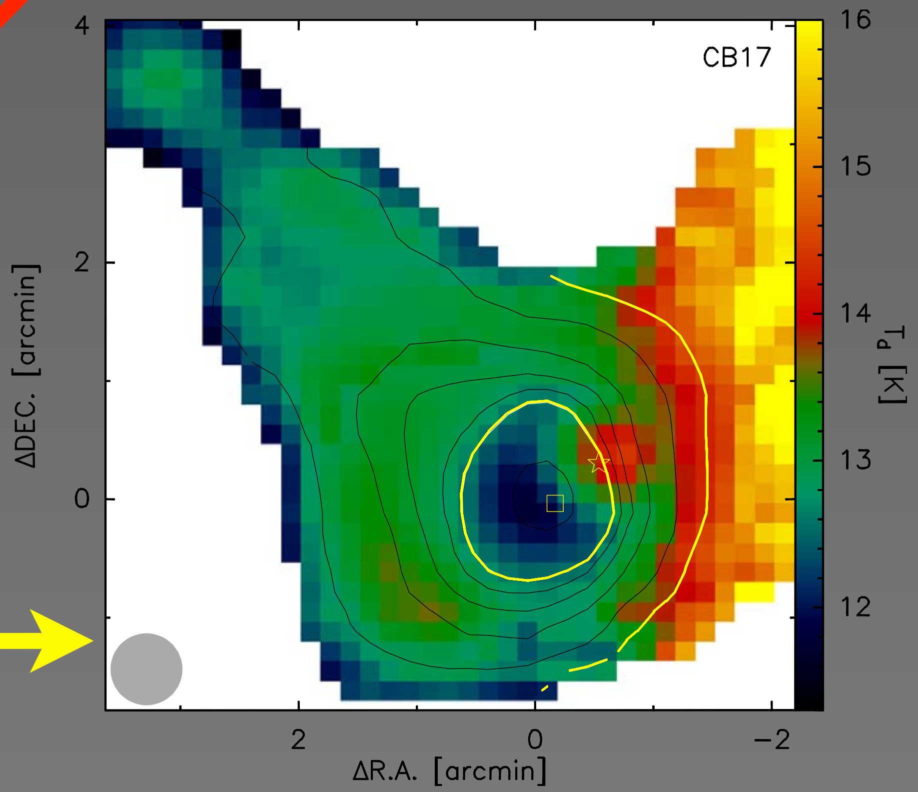


3. χ^2 fit single-T modified BB-SED:

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

$$\tau(\nu)=\boldsymbol{N_H}\; m_H\; M_d/M_H\; \kappa_d(\nu)$$

4. Construct maps of τ-averaged dust temperature and column density:



Deriving dust temperature maps:

5. Reconstruct 3-D T_d and n_H structure (as model-independent as possible):

In plane of sky: $\xleftrightarrow{\text{iterate}}$ **Along line of sight**:

χ^2 fit ΔT & n_0

derive

r_0, η

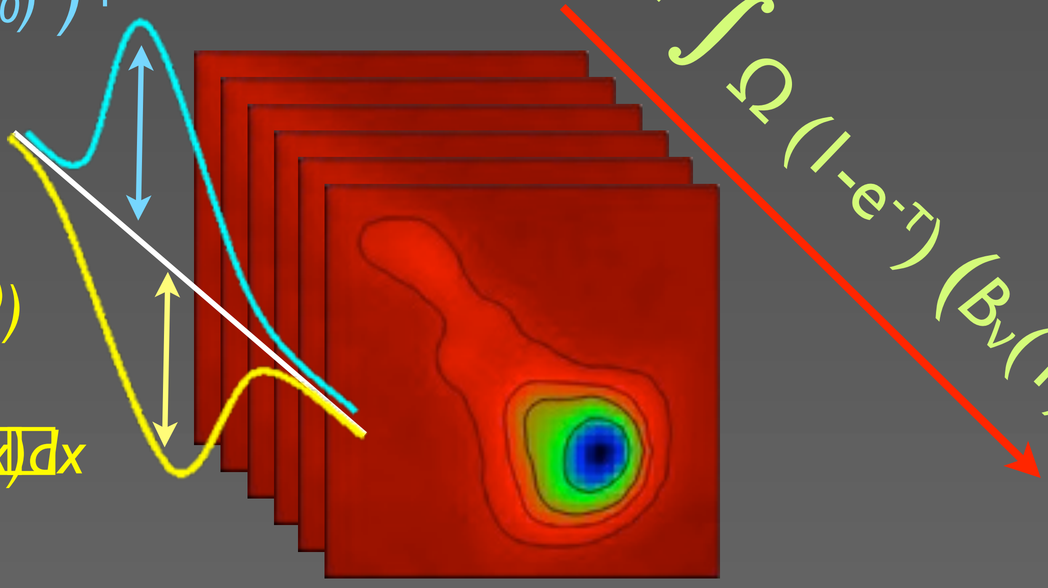
T_{out}, κ_0, r_{out}

from plane-of-sky profiles

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

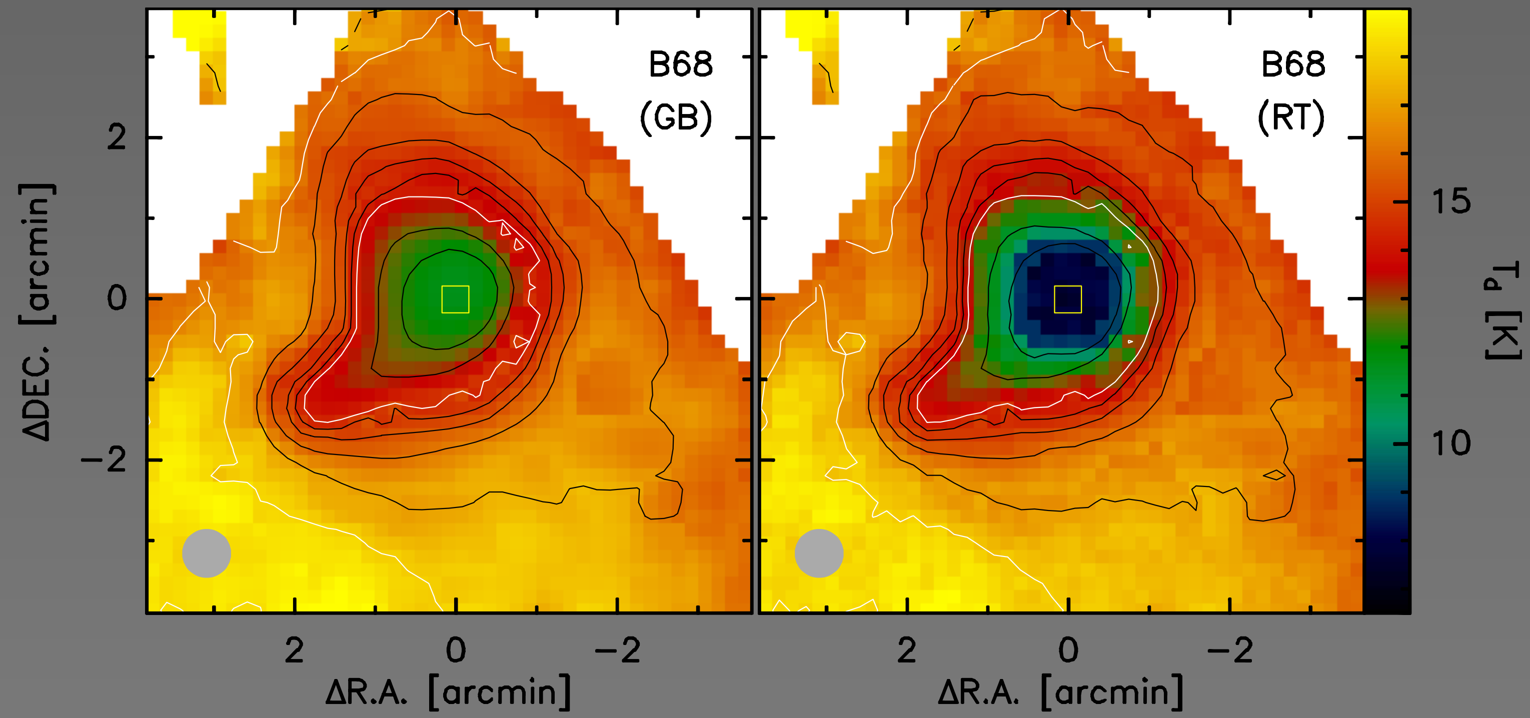
$$T(r) = T_{out} - \Delta T(1-e^{-\tau(r)})$$

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



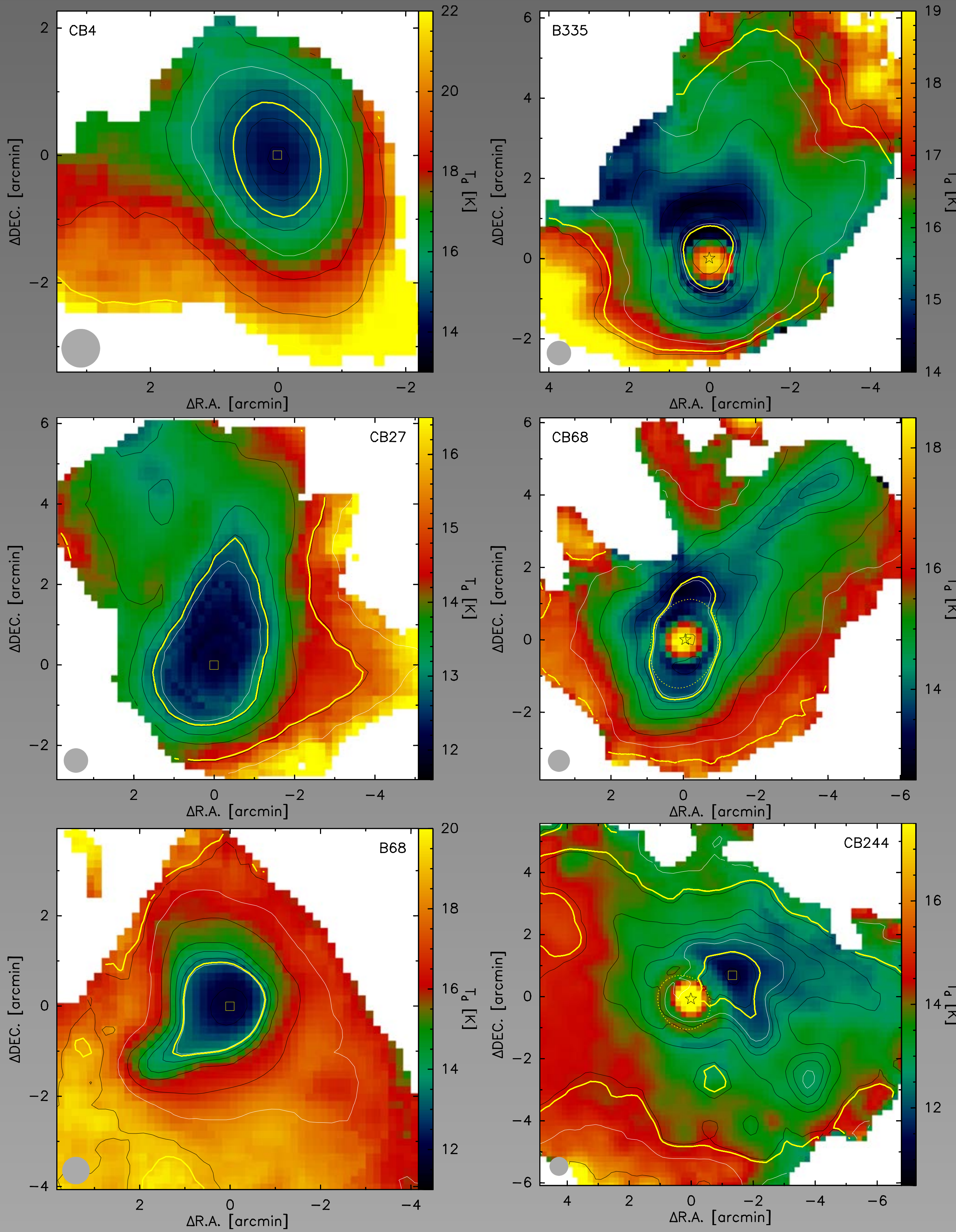
$$S_\nu = \int \Omega\,(1-e^{-\tau})\,(B_\nu(T) - I_{bg})\,dz$$

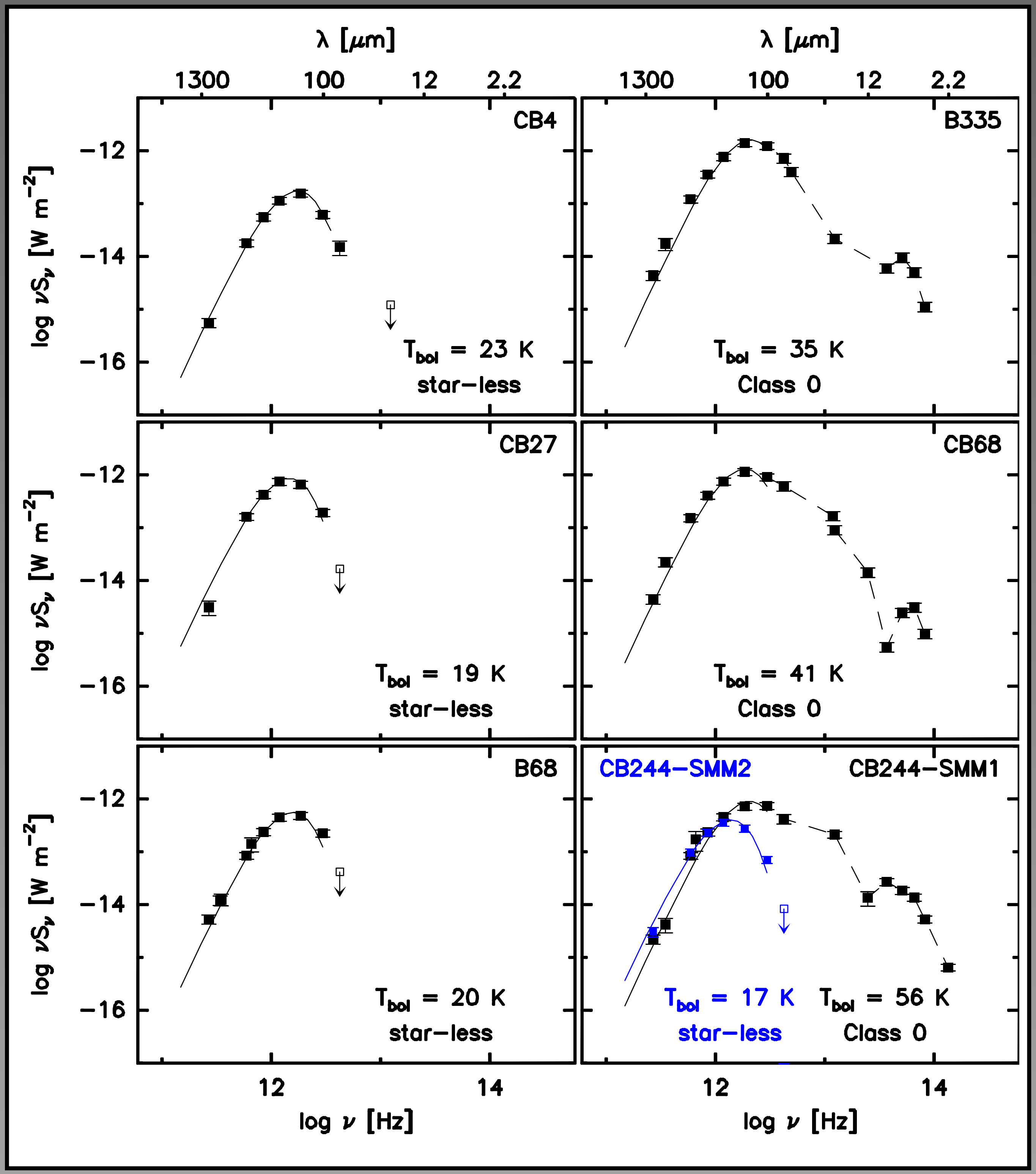
LoS τ-averaged temp. → true local midplane temp.



cf. Posters
P59 (Nielbock)
P67 (Roy)

T_{dust} and N_H maps and SEDs:

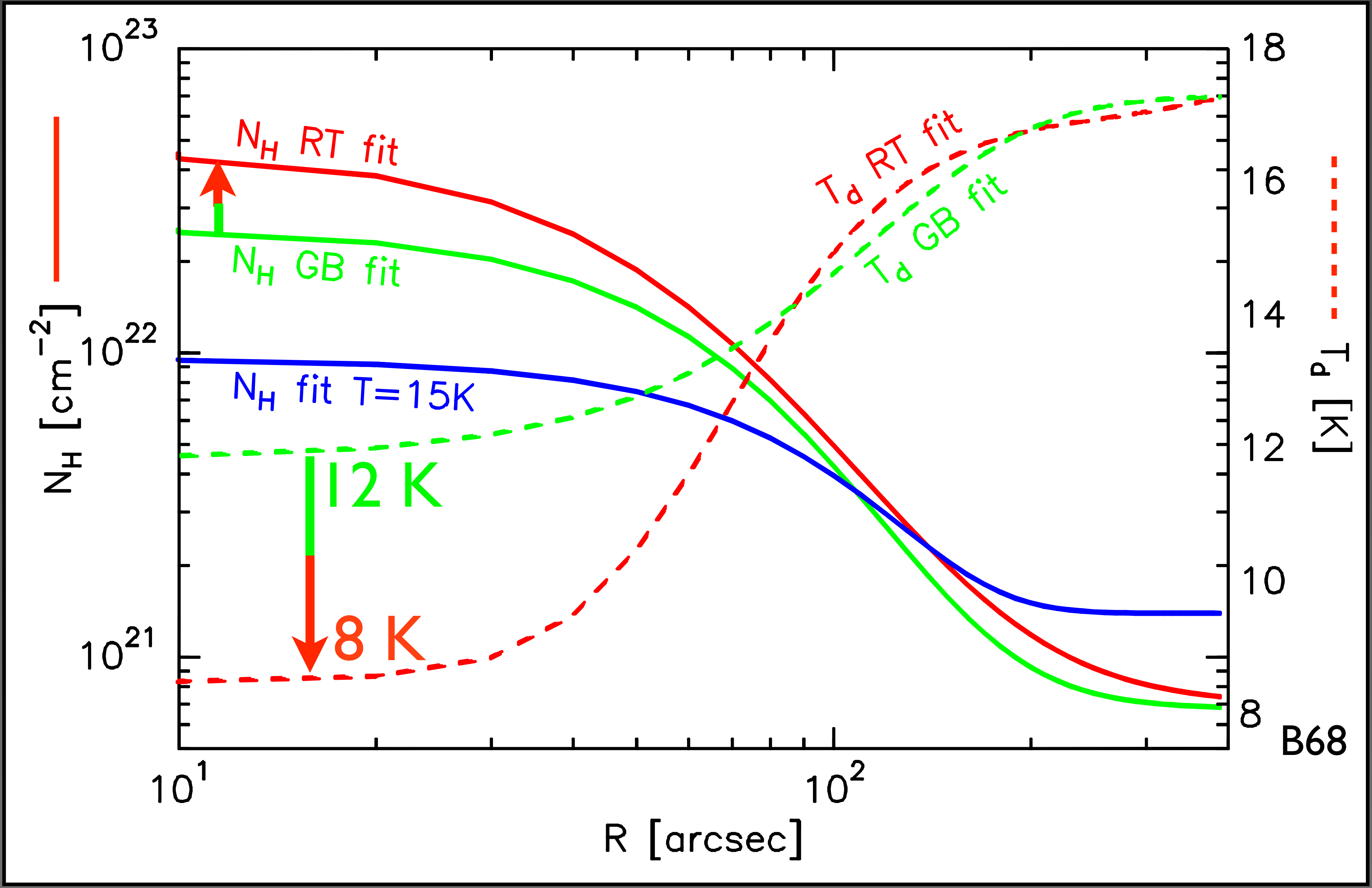




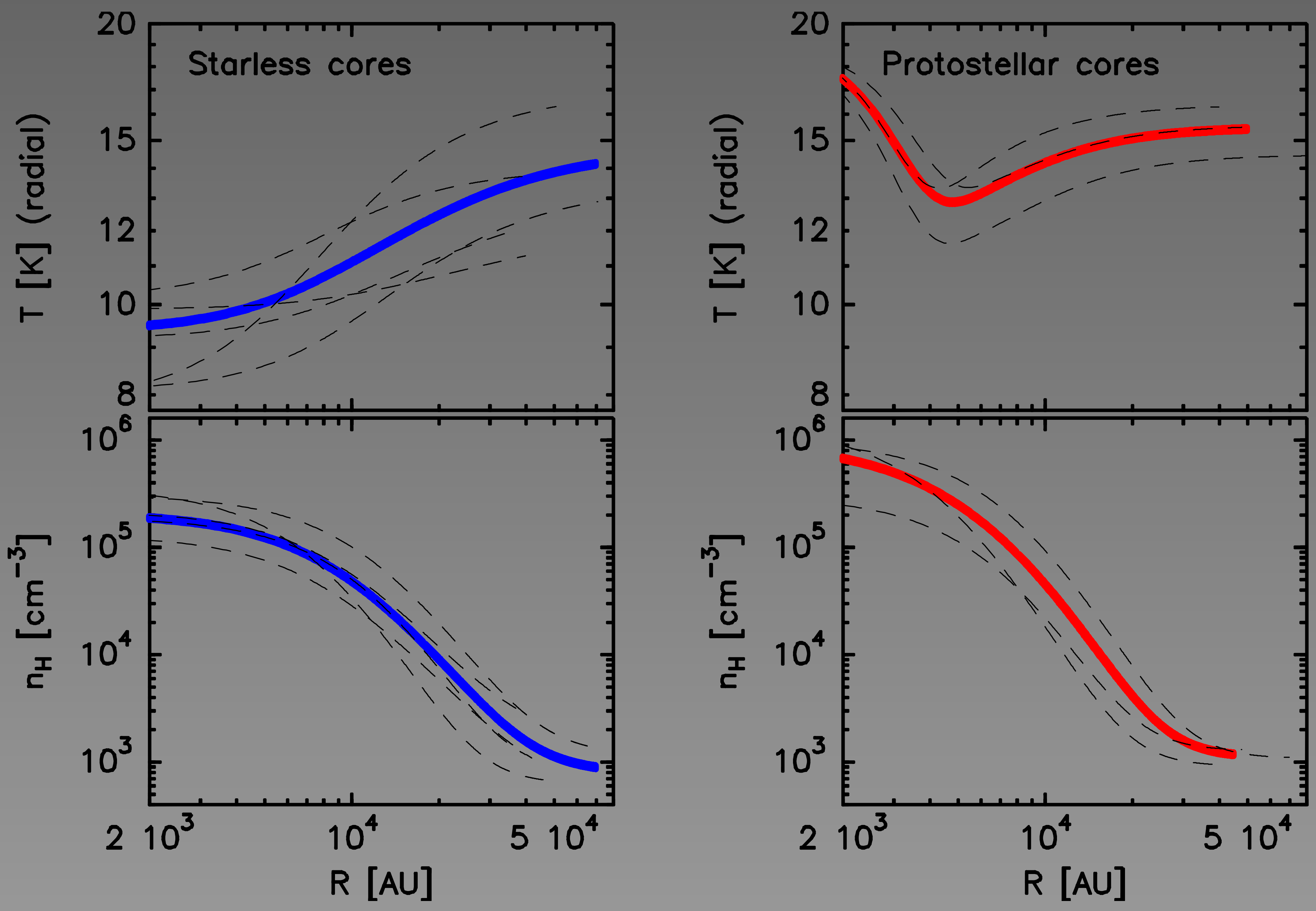
Fluxes are integrated within 1/e x N_H^{peak} contour (D~2-3x10^4AU)

Launhardt et al. 2013, A&A, 551, 68

LoS τ-averaged temp. ↔ Midplane temp. from RT



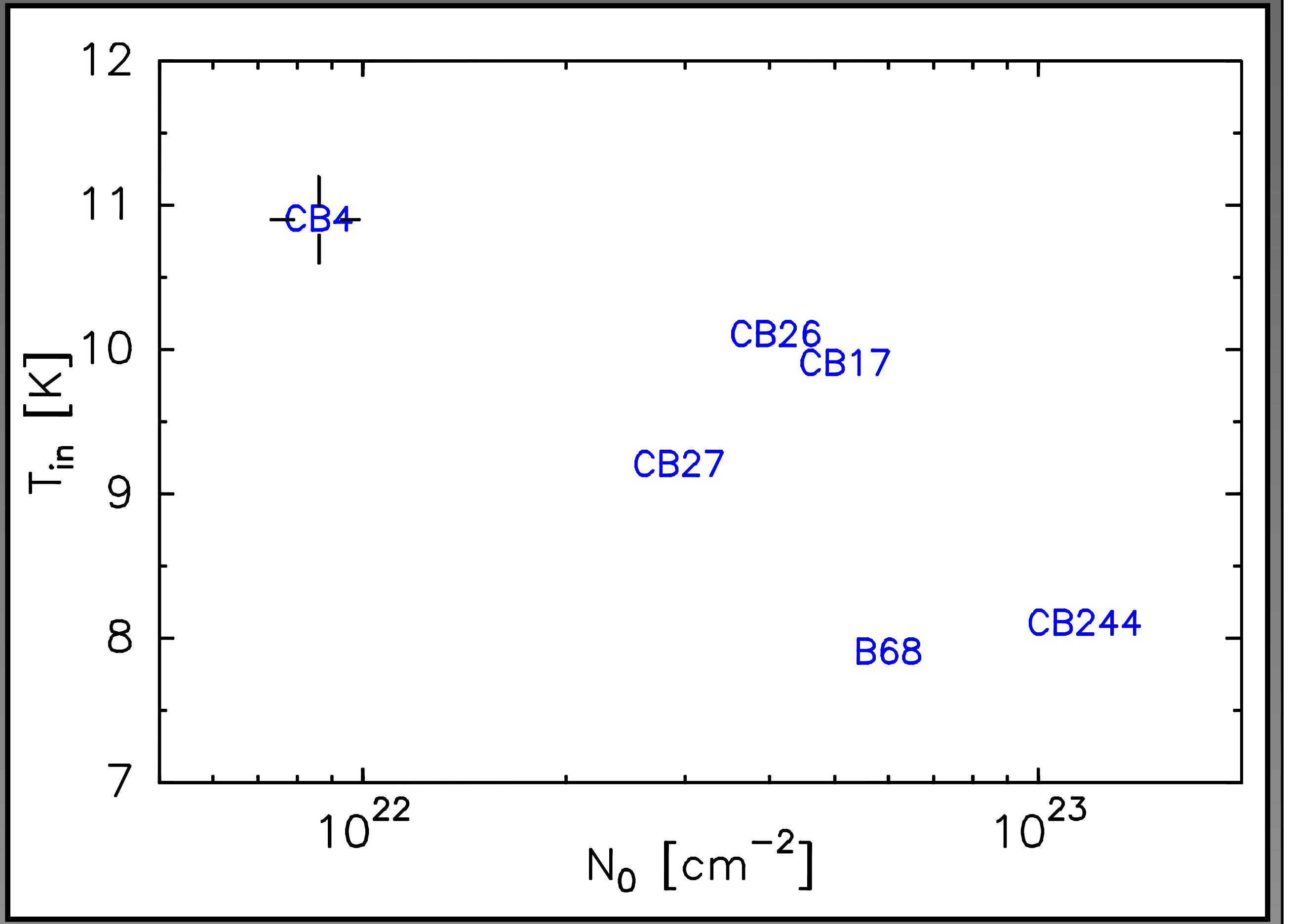
Radial temperature and density profiles:

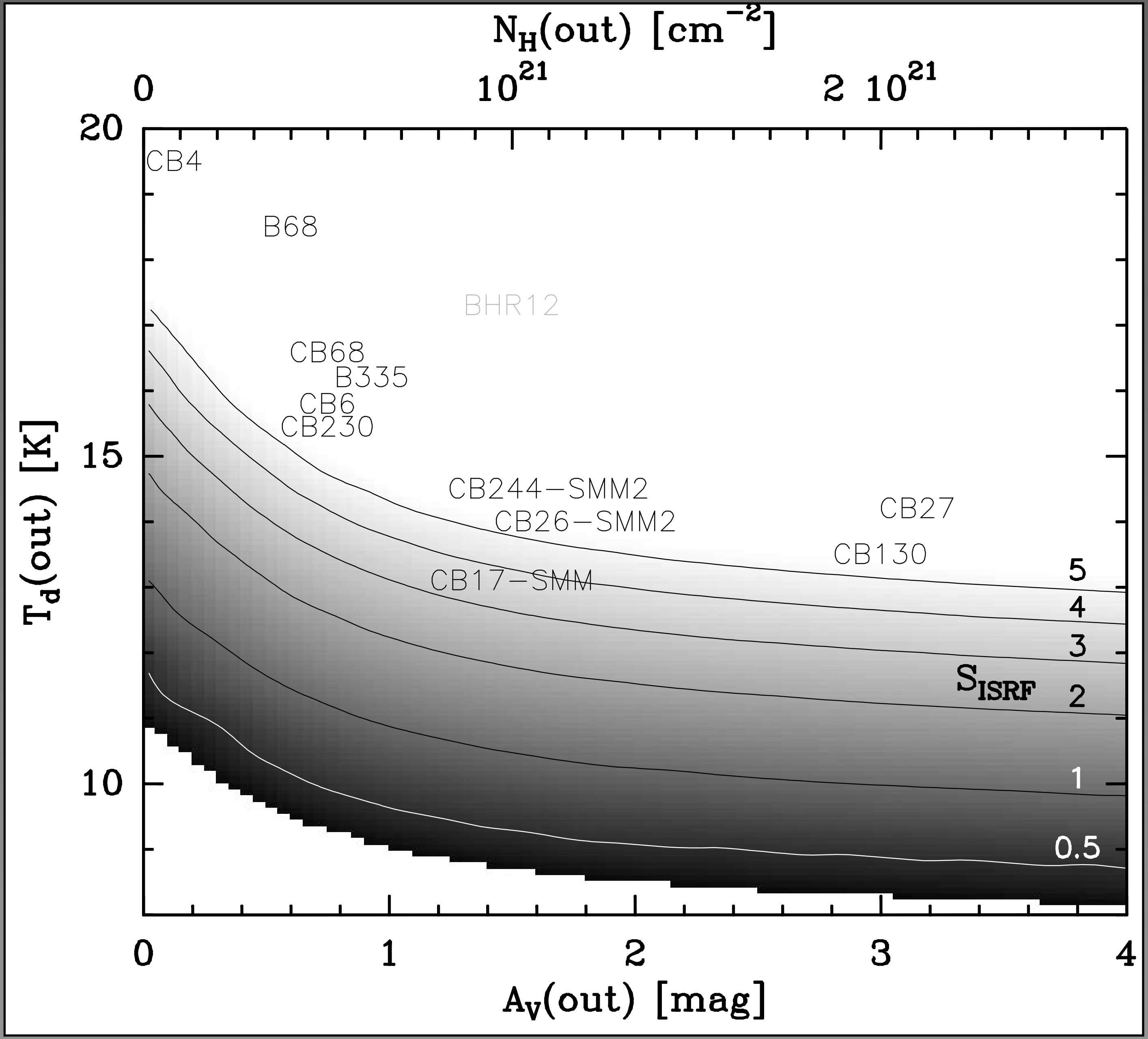


- All sources are dominated by ISRF heating at radii > 5000 AU
- The luminosity is reprocessed ISRF (mostly UV) plus embedded protostars
- The mean outer temperature of all globules is ~15±1 K
- The lowest central temperatures we detect are ~8±1 K
- Specific luminosity = 5.8 ± 1.8 L_{sun} pc^{-2} (=> ISRF)

Stutz et al.	*2010,*	*A&A*	*518, L87*
Nielbock et al.	*2012,*	*A&A*	*547, 11*
Launhardt et al.	*2013,*	*A&A*	*551, 68*
Lippok et al.	*2013,*	*A&A,*	*in press*
Schmalzl et al.	*2013,*	*A&A,*	*subm.*

ISRF - heating and shielding

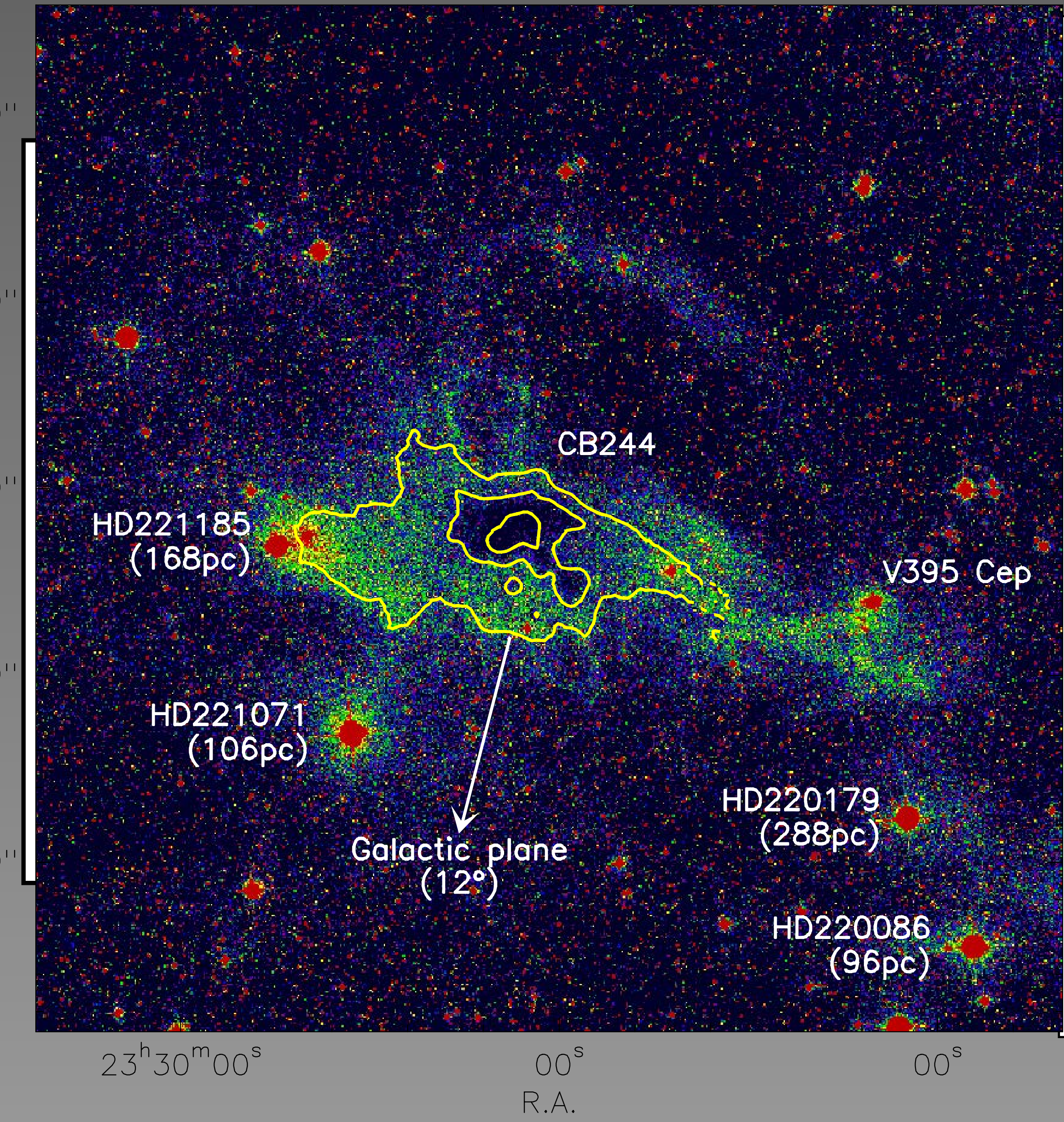


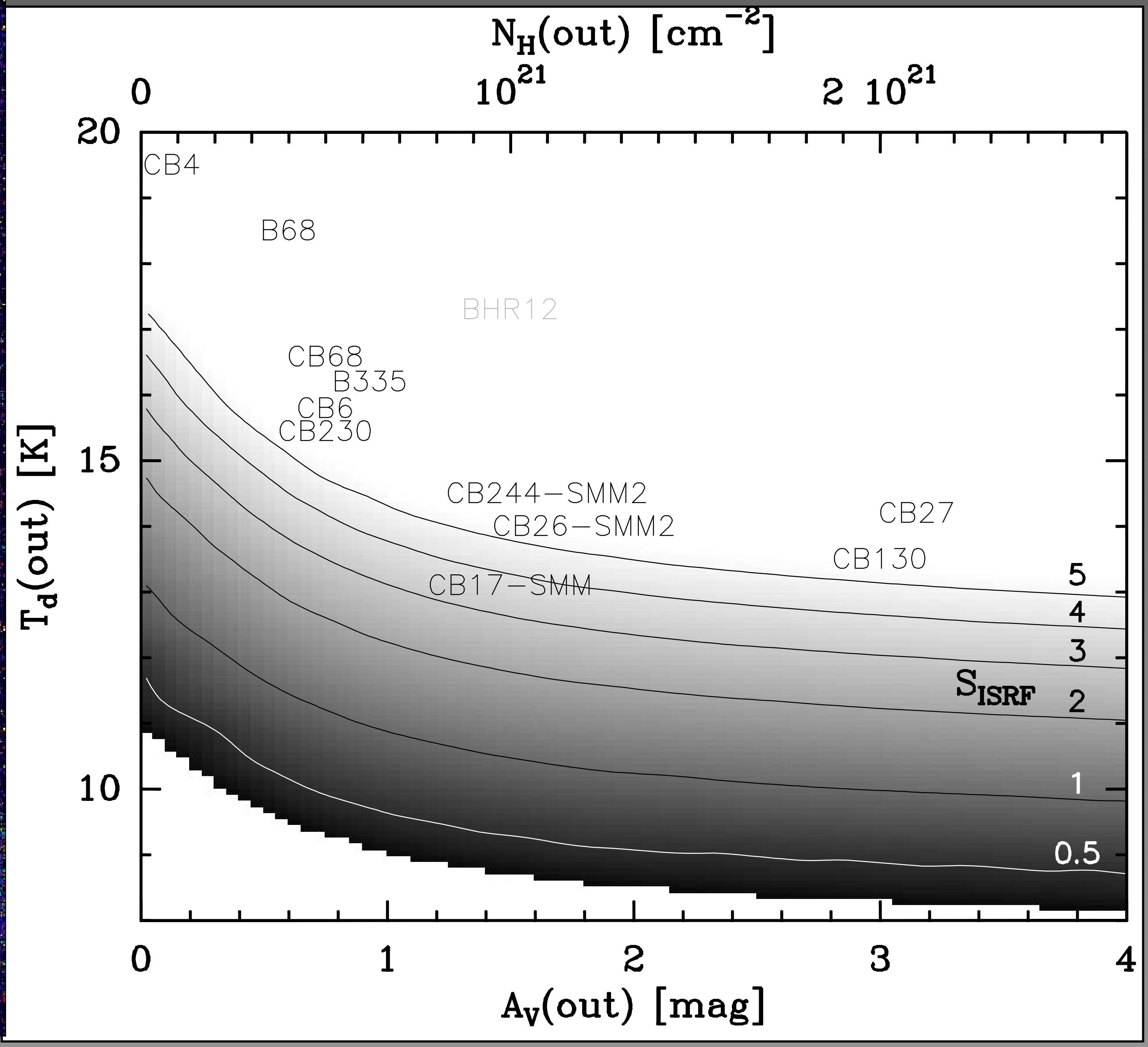


- Central temperature correlates with total column density to outer "boundary"
- Envelope temperature correlates with extinction (N_H) in outer "halo"

Launhardt et al. 2013, A&A, 551, 68

ISRF - heating and shielding





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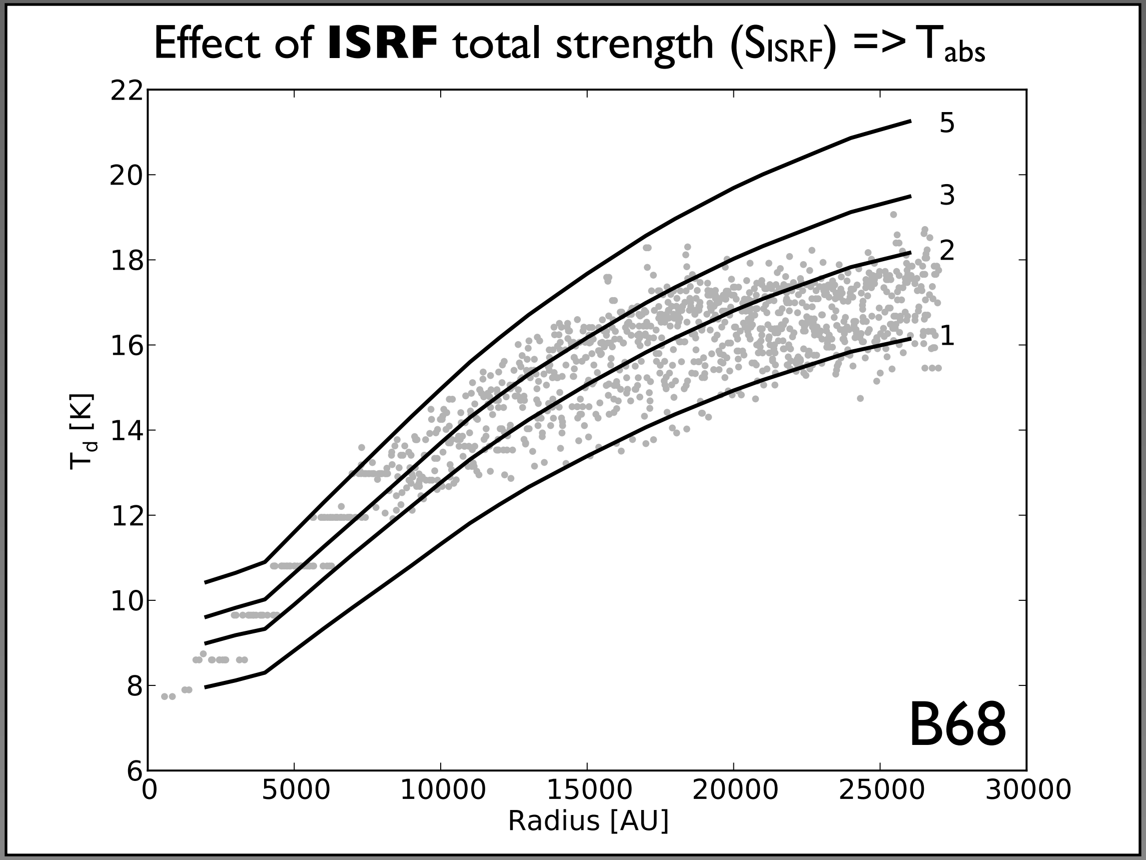
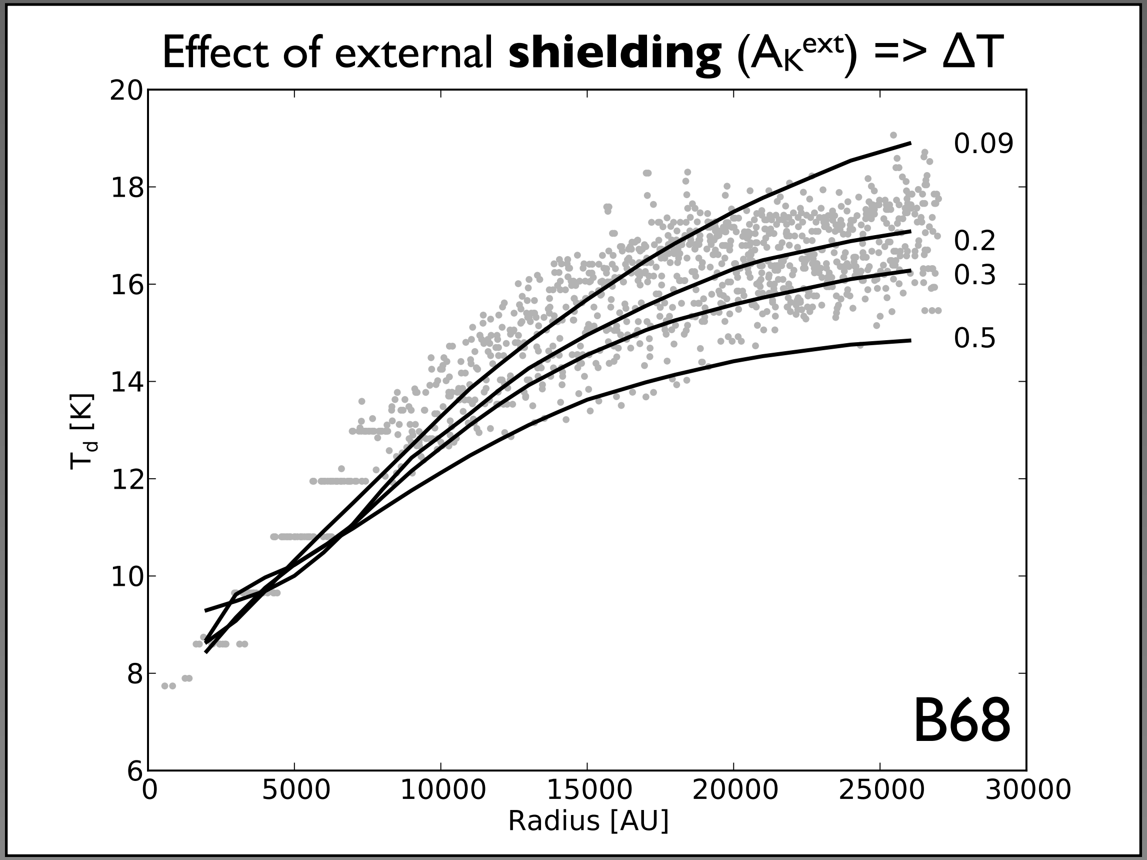
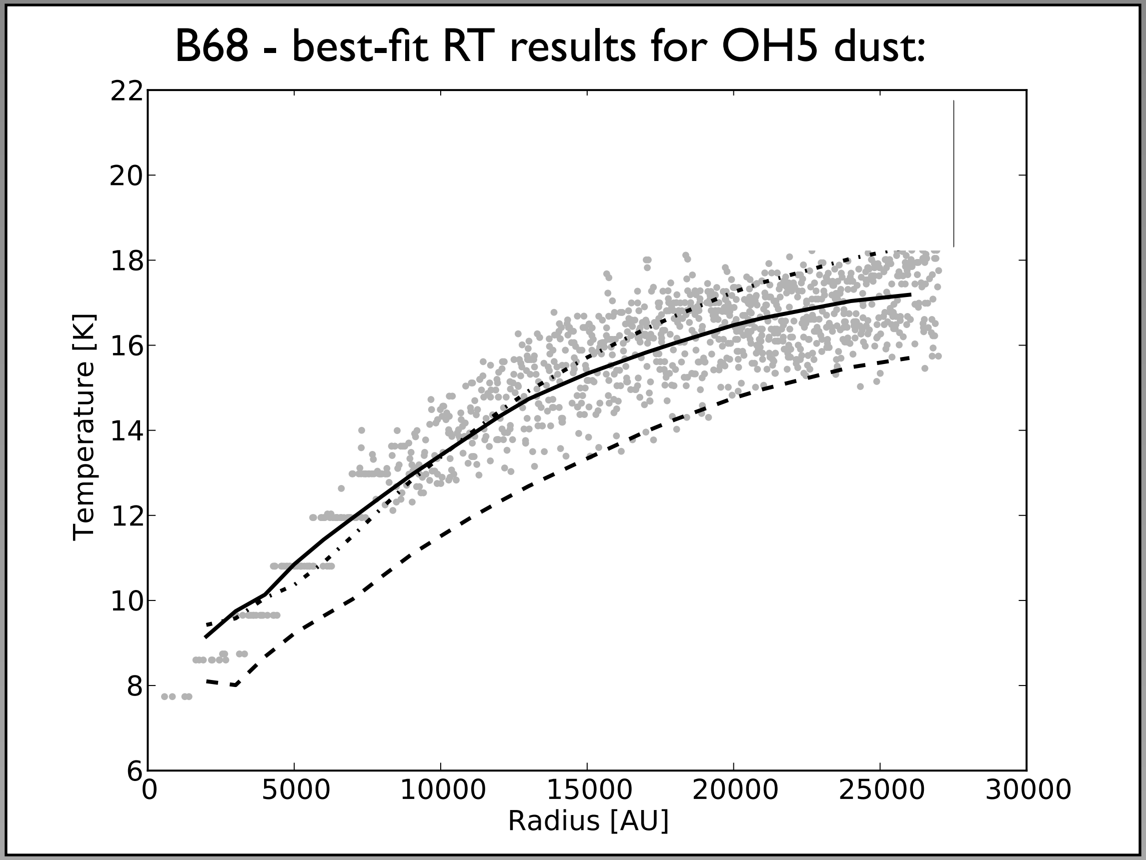
- Envelope temperature correlates with extinction (N_H) in outer "halo"

Launhardt et al. 2013, A&A, 551, 68

Verification with selfconsistent radiative transfer:


Effect of **ISRF** total strength (S_{ISRF}) => T_{abs}

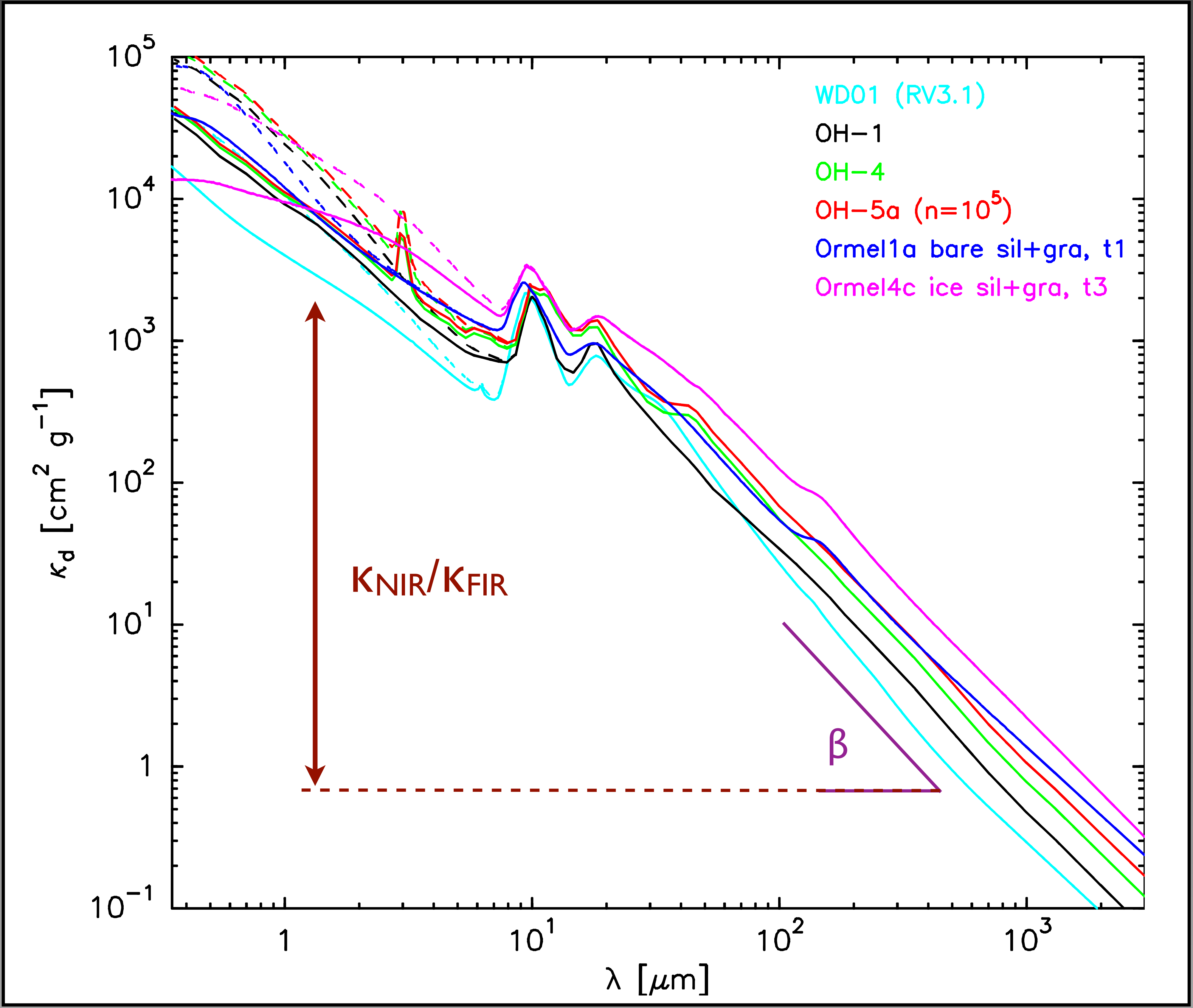

Effect of external **shielding** (A_K^{ext}) => ΔT


B68 - best-fit RT results for OH5 dust:

- T_{out} can be well reproduced for all cores with $S_{ISRF} = 1$ and observed A_K^{ext}
- T_{in} well reproduced for 3 sources, but significantly lower than observed for 3 others
- Results are (nearly) independent of dust model used
- Work in progress

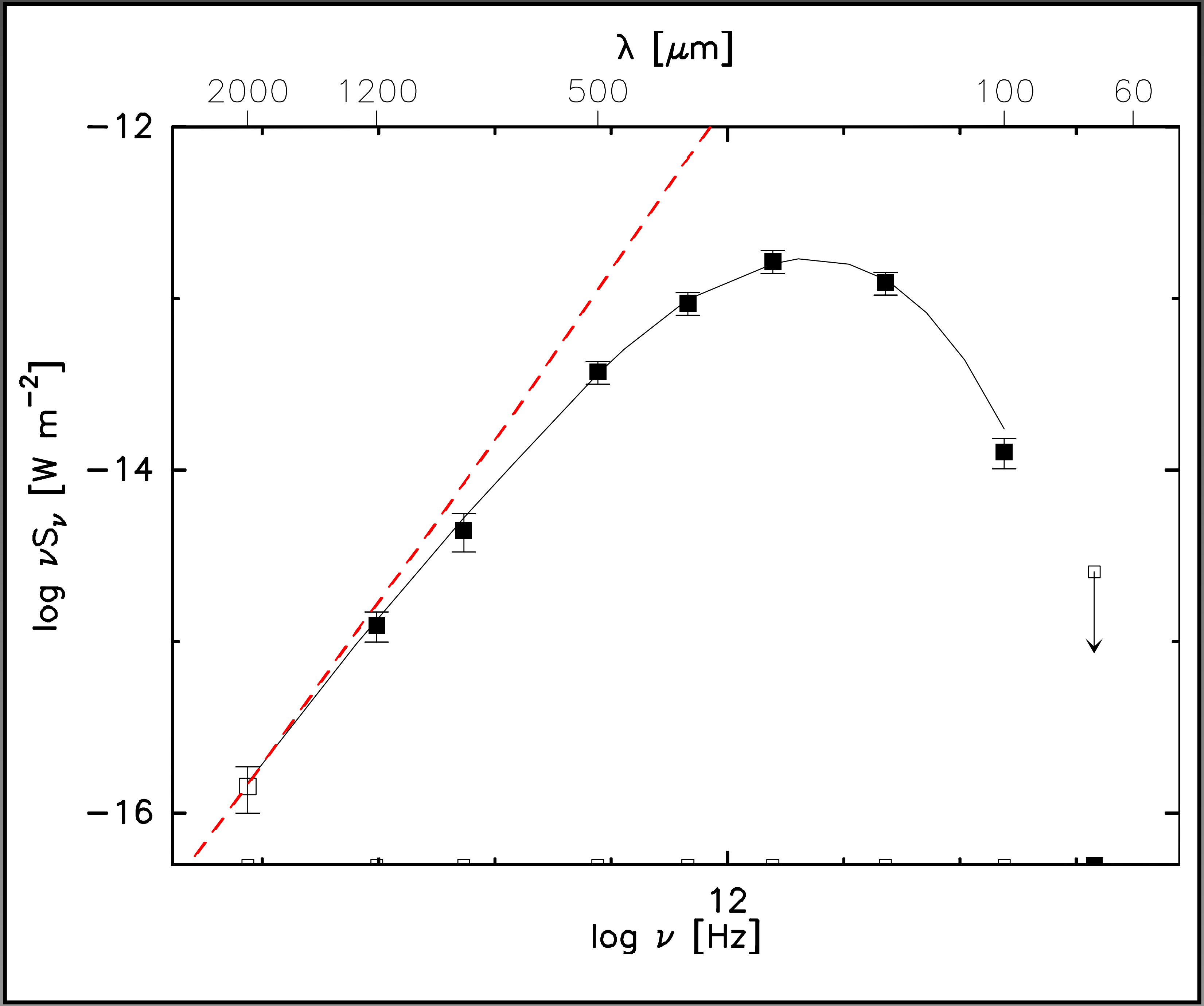
Nils Lippok, thesis and paper in prep.

Constraining the dust opacity law



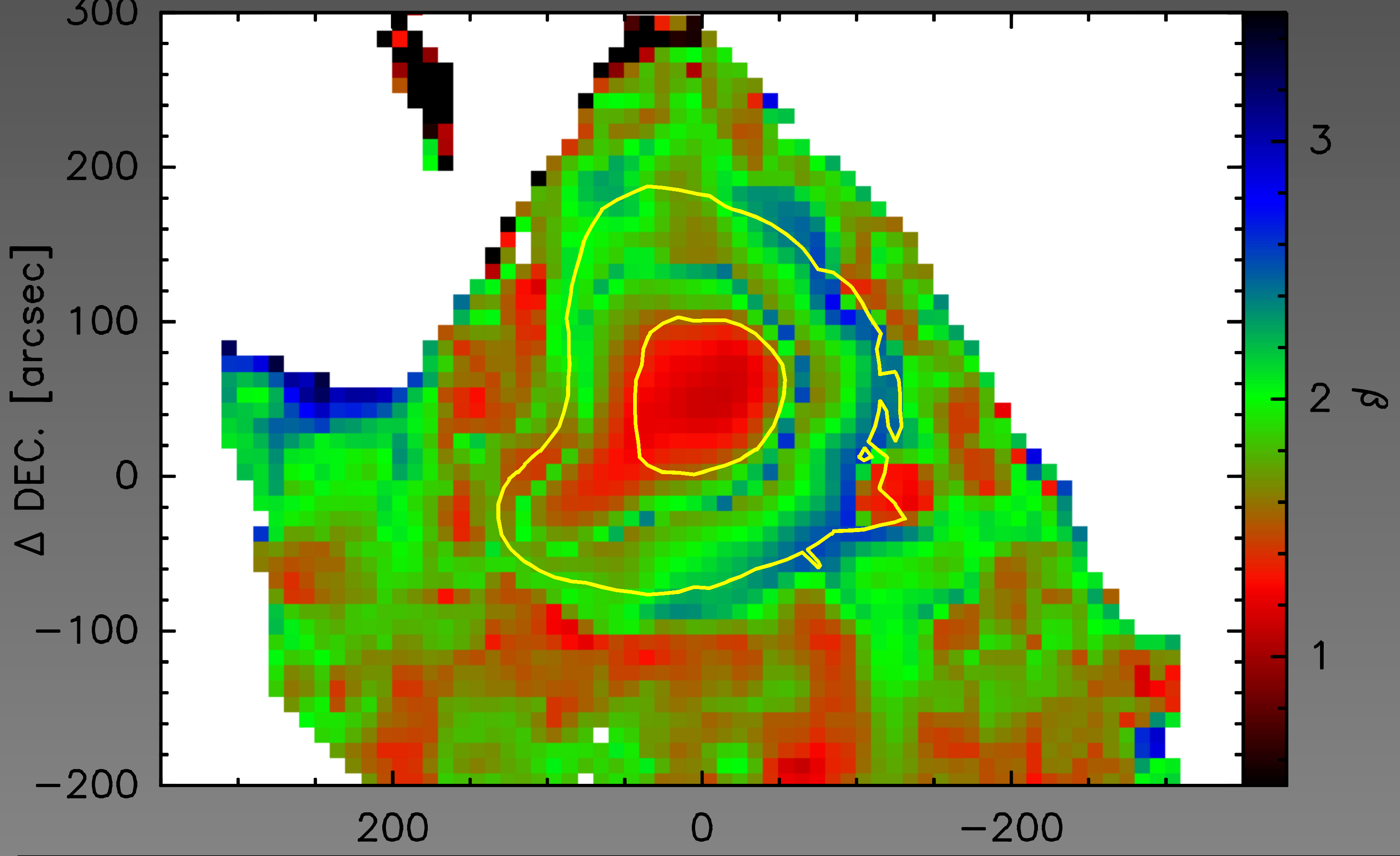
OH:	*Ossenkopf & Henning 1994*
WD01:	*Weingartner & Draine 2001*
Ormel:	*Ormel etal 2011*

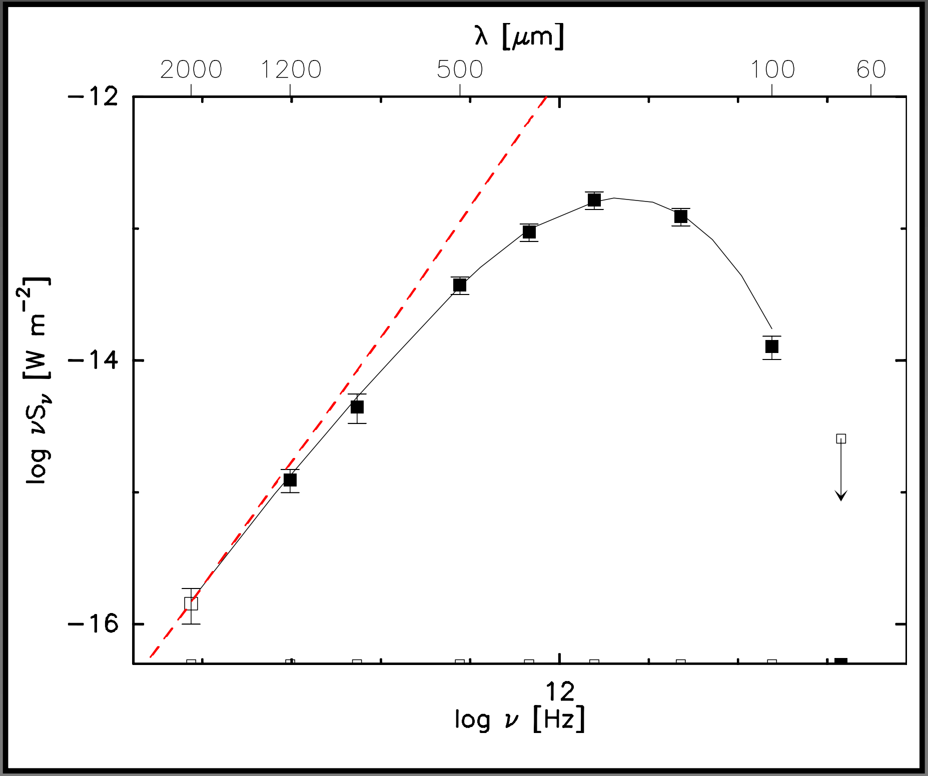
Constraining the dust opacity law - β

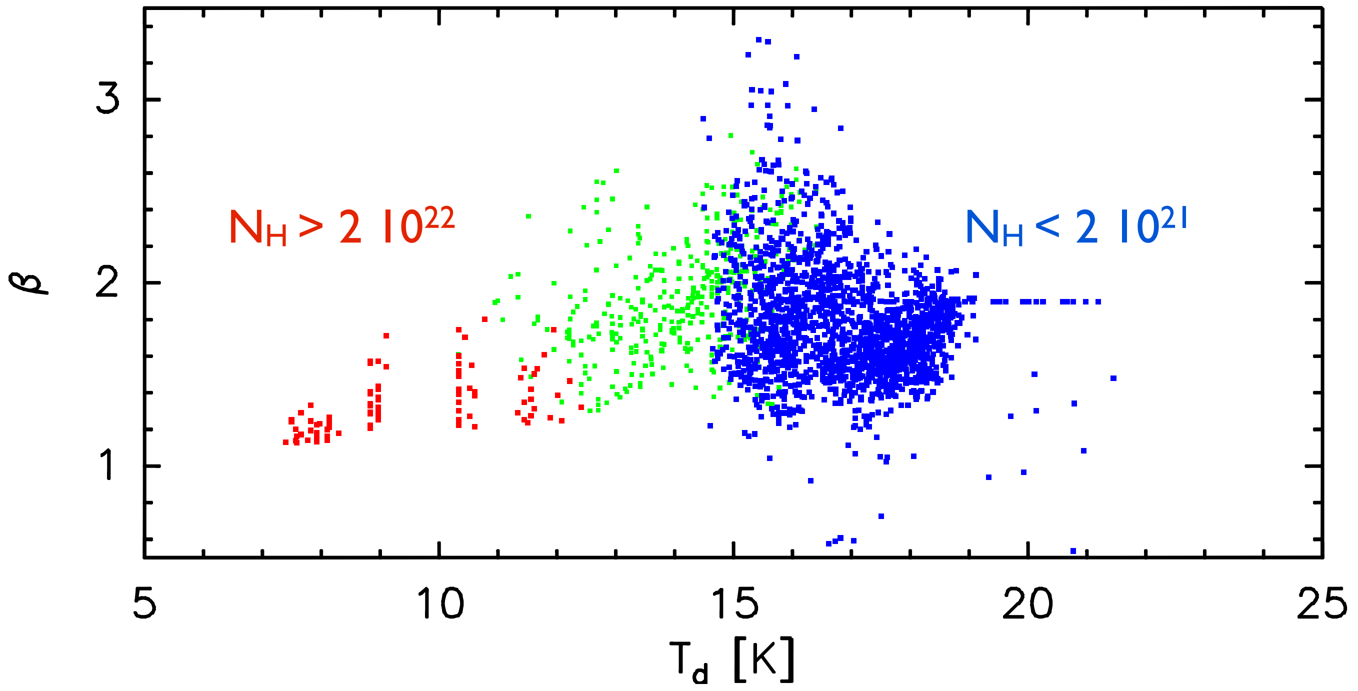


Constraining the dust opacity law - β

Method: Modified BB-fit (χ^2)solving simultaneously for T, N_H, and ß



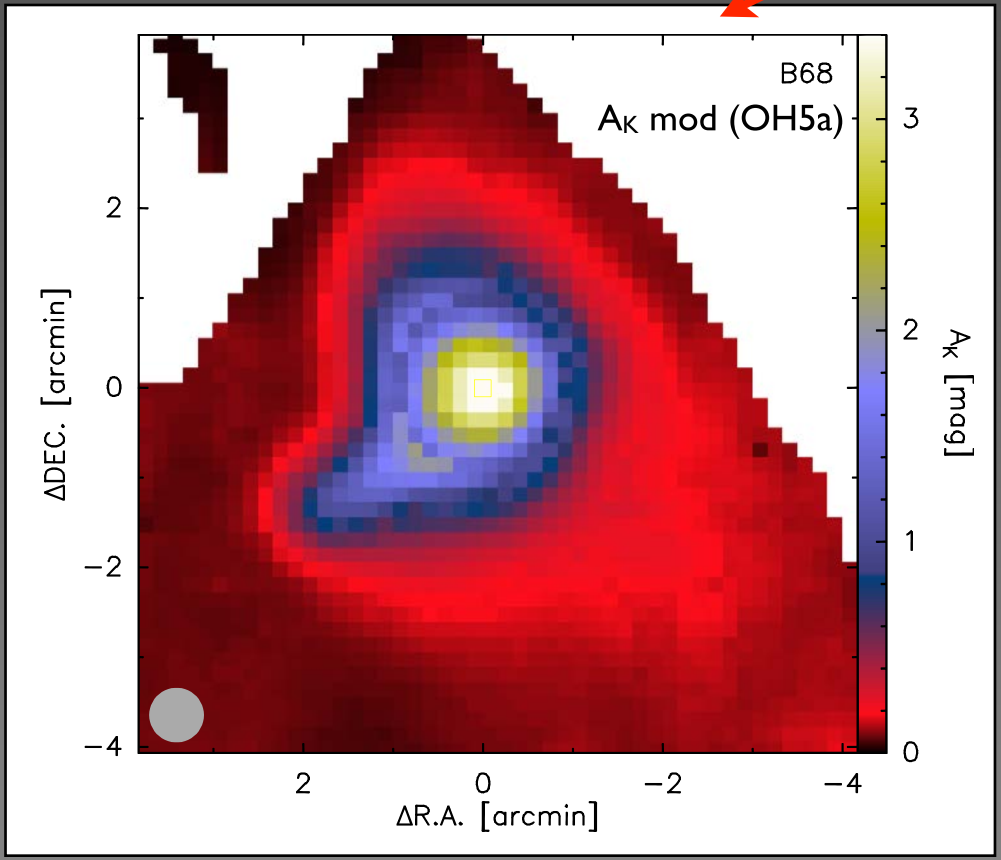


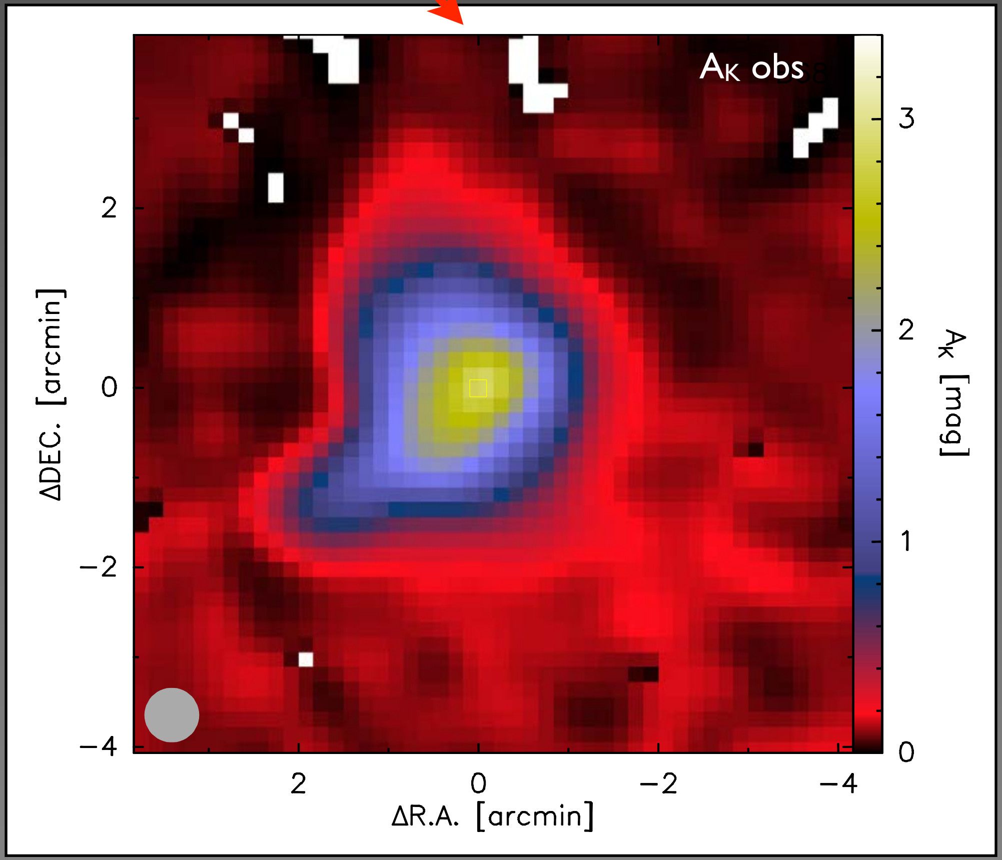


$\beta = 1.85 \pm 0.3$

Constraining the dust opacity law - $\kappa_{NIR}/\kappa_{FIR}$

Method: Compare A_K map **predicted** by RT fit to emission data to **observed** A_K map

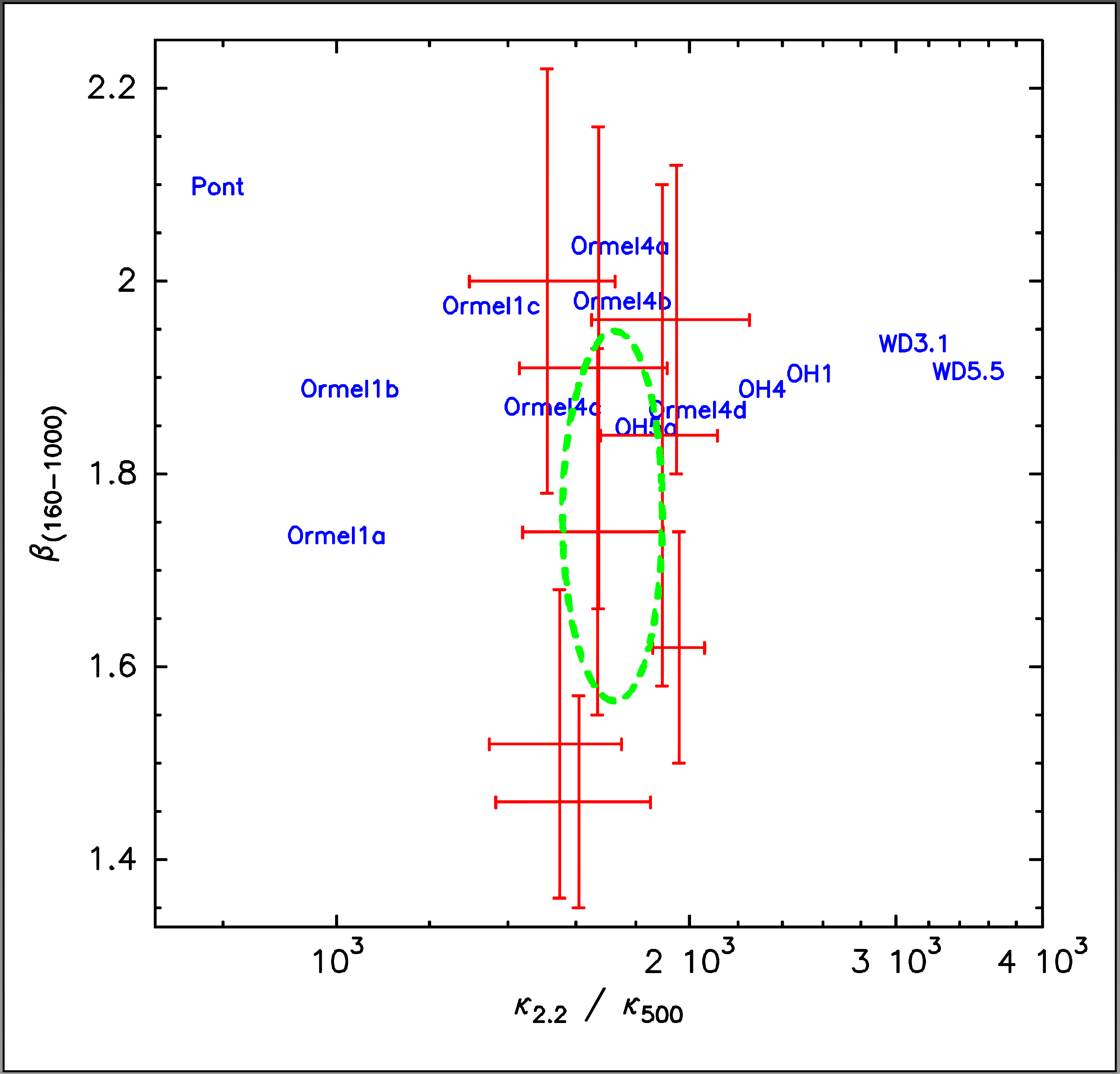




Assume $N_H \propto \kappa_{500\mu m}$ => $\kappa_{2.2\mu m}/\kappa_{500\mu m} = 1900 \pm 200$

More correct alternative: use density-weithgted Planck function (Shirley ea. 2011), but results agree within 10%

Constraining the dust opacity law



- $\kappa_{2.2}/\kappa_{500}$ = 1730 ± 170
- Range of applicable dust models narrowed
- $\beta_{\text{FIR-submm}}$ = 1.75 ± 0.2
- No constraining power (yet)
- => Include more data (SCUBA2, 2mm), improve analysis methods (e.g., Kelly ea. 2012), avoid isothermal approximation, include T-dependance and non-constant β, etc.
- Constraining absolute mass absorption coefficients requires better gas analysis, but there are indications that e.g. OH5 tends to underestimate column densities by factor 2-3

Summary

1. The thermal structure (isolated) molecular cloud cores is dominated by **external heating** from the ISRF.

2. Embedded protostars contribute ~10-50% to L_{bol} and affect/heat only inner dense core (<5000AU)

3. **Envelope T_d** (at N_H~10^{21}cm^{-2}) of isolated globules is **15±1K**
   => consistent with ISRF heating

4. **Internal T_d** of starless cores is **10±2K**
   => consistent with RT models for 3 sources, higher than predicted for 3 others

5. $\kappa_{2.2}/\kappa_{500}$ ratio for dust opacity models well-constrained (1700±200), β_{FIR} remains uncertain (1.75±0.2) and needs more work and data

6. Thanks to Herschel we can now quantitatively constrain models