MODELLING HERSCHEL OBSERVATIONS OF HOT GAS EMISSION IN LOW-MASS PROTOSTARS

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Dissecting embedded low-mass YSOs

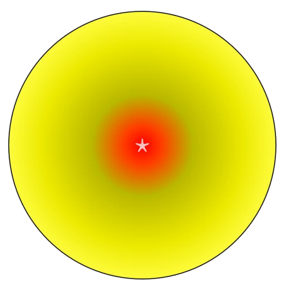
- Rotationally excited CO is an excellent tracer of three key physical components in embedded YSOs: the passively heated envelope, the UV-heated ouflow cavity walls, and the small-scale shocks along the cavity walls
- We developed a three-component model to quantify the emission of CO and other hot gas tracers (e.g. H_2O)
- First test case: the Class 0/I protostar HH46 IRS, using data from Herschel-PACS and APEX-CHAMP+; observations of CO 10–9 with HIFI are planned
- Part of the Key Program "Water in Star-Forming Regions with Herschel" (WISH; PI: E.F. van Dishoeck); CO is used to constrain the models, but the real goal is to study the distribution and properties of H_2O in embedded low-mass YSOs

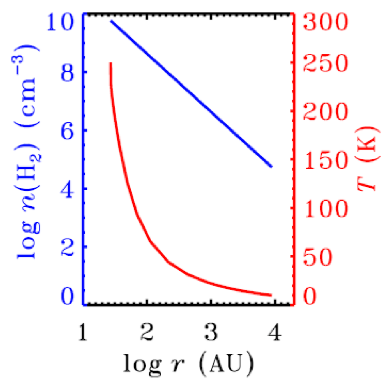
Results & Conclusions

- Rotationally excited CO observed up to 2700 K above ground state
- The full CO ladder:
  - ~1% passively heated envelope
  - ~60% UV-heated cavity walls
  - ~40% shocks along cavity walls
- Quantitative results sensitive to the gas temperature
- Qualitative need for the three components is robust

Passively heated envelope

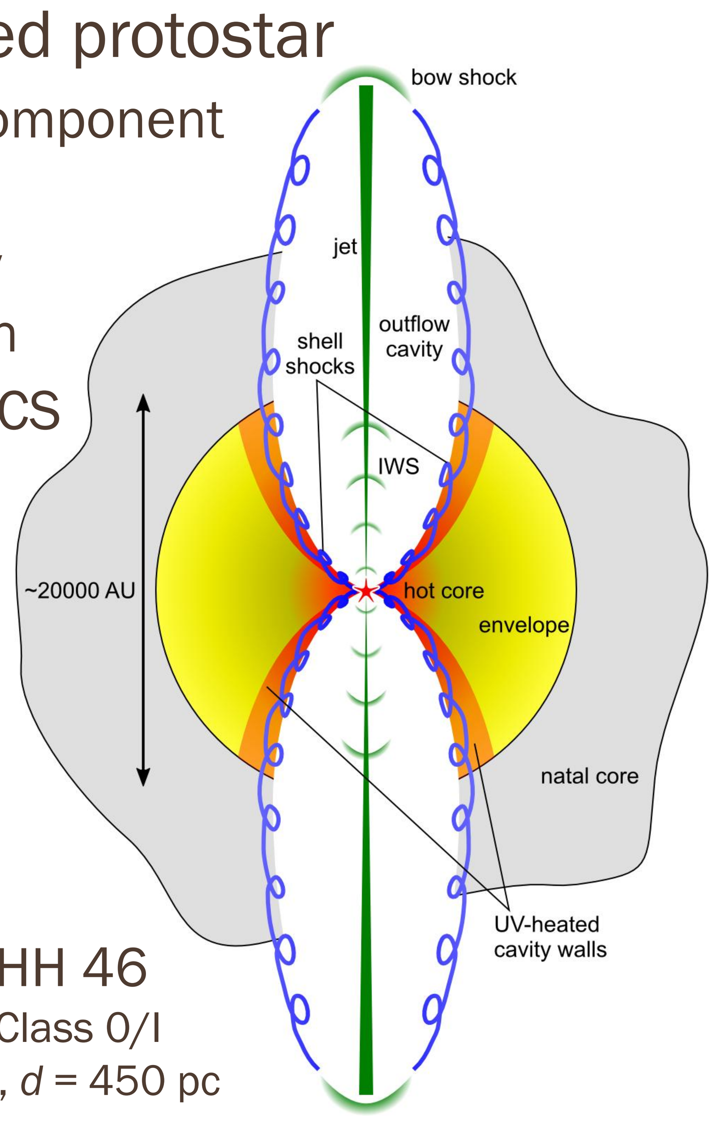
- Spherically symmetric
- Power-law density
- T_{dust} from continuum radiative transfer
- Constrained by SED and sub-mm brightness profiles
- CO abundance from chemical network (UMIST06) including freeze-out and evaporation





Embedded protostar

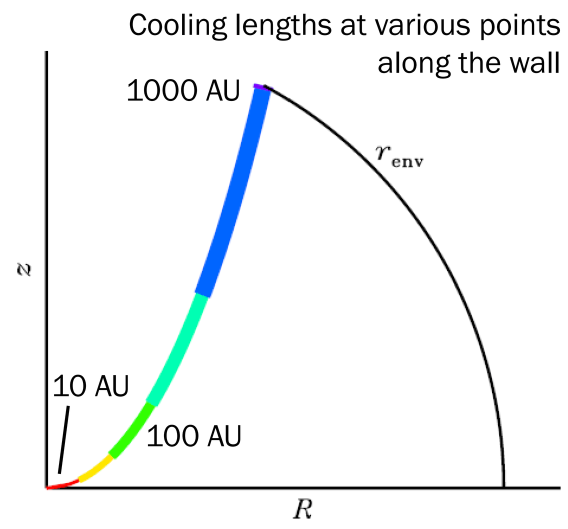
- Three-component model
- Quantify emission
- Fit to PACS data



Test case: HH 46
- Low-mass, Class 0/I
- $L_{bol} = 16\ L_\odot$, $d = 450$ pc

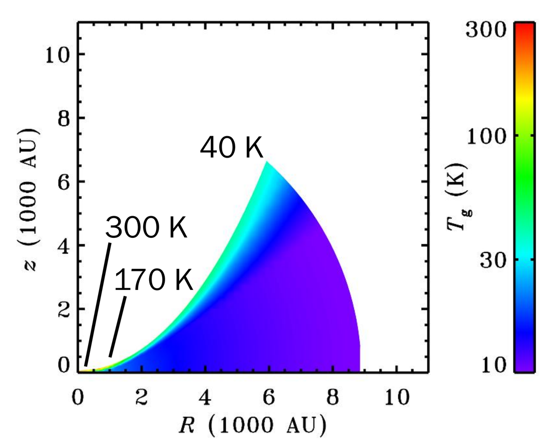
Shocks along cavity walls

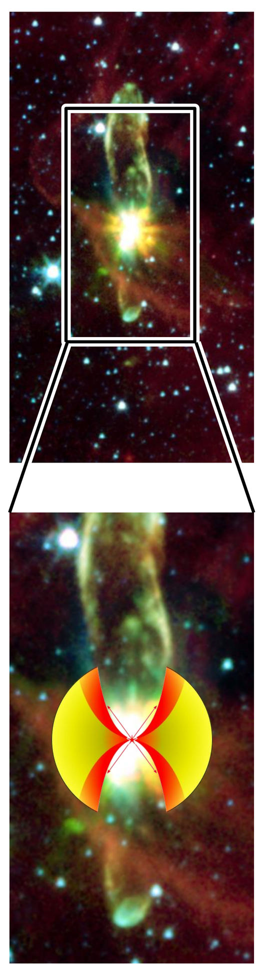
- Series of 1D shock models tiled along the outflow cavity walls
- Cooling length decreases with density (Flower & Pineau des Forêts 2003, Kristensen et al. in prep.)
- Use pre-computed fluxes, scaled with beam filling factors (Kaufman & Neufeld 1996)
- Shock velocity assumed constant along the wall at $v_s = 20$ km/s



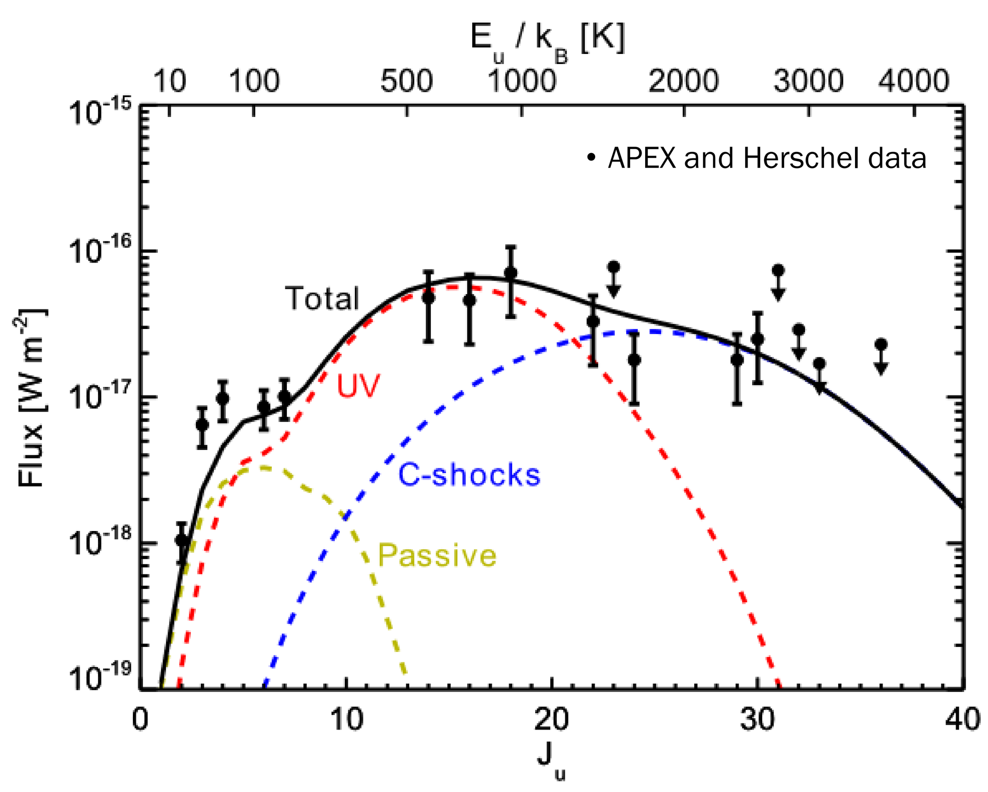
UV-heated outflow cavity walls

- 2D, axisymmetric
- Size and shape from Spitzer image (Velusamy et al. 1999)
- T_{gas} from PDR grid (see box below for details)
- CO abundance corrected for photodissociation

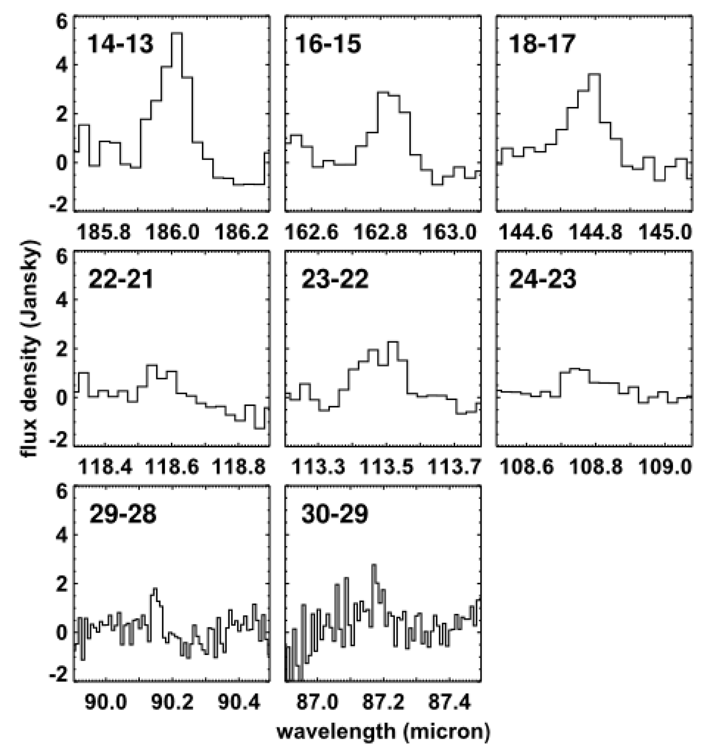




CO ladder: flux vs. excitation

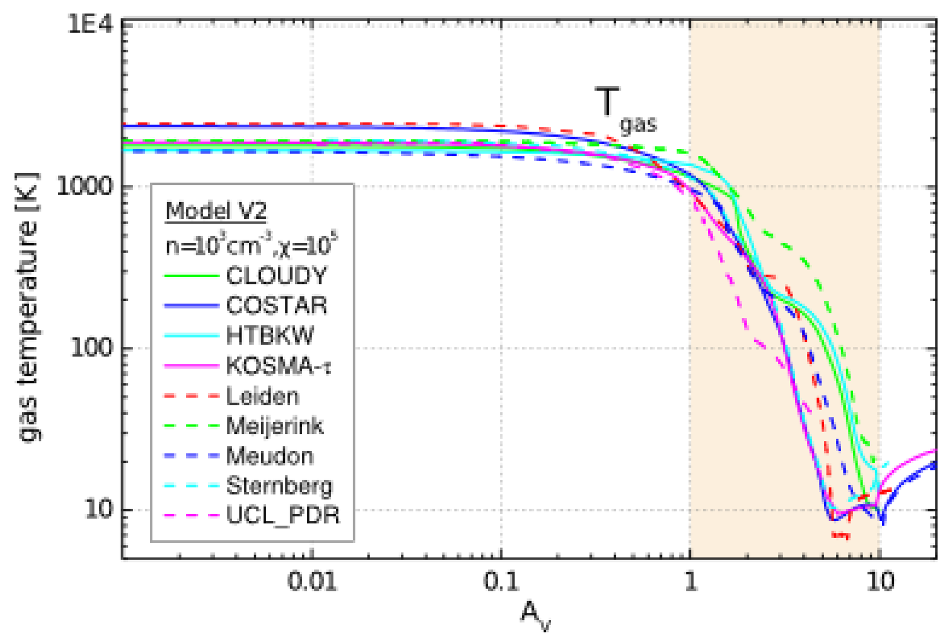


PACS observations of CO



Gas temperature in the cavity walls

- PDR codes give T_{gas} as function of density and incident UV flux
- Problem: T_{gas} differs between codes by up to a factor of ten (Röllig et al. 2007)
- T_{gas} strongly affects shape of CO ladder
- Good news: no PDR grid fits all the data with just passive and UV heating; shocks are always required
- Resolved line profiles are required to better constrain the temperatures



Our approach: put in what we think we know, see what comes out

Fixed parameters

- $r_{env} = 8900$ AU, $M_{env} = 1.6\ M_\odot$
- $a_{cav} = 34000$ AU, $b_{cav} = 10000$ AU
- inclination = 53°

Free parameters

- $L_{UV} = 0.1\ L_\odot$
- $v_{shock} = 20$ km/s

Herschel-PACS data: van Kempen et al. (2010) A&A, 518, L121; model: Visser et al. (in prep.)

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