Feedback from low-mass protostars

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Some like it hot!

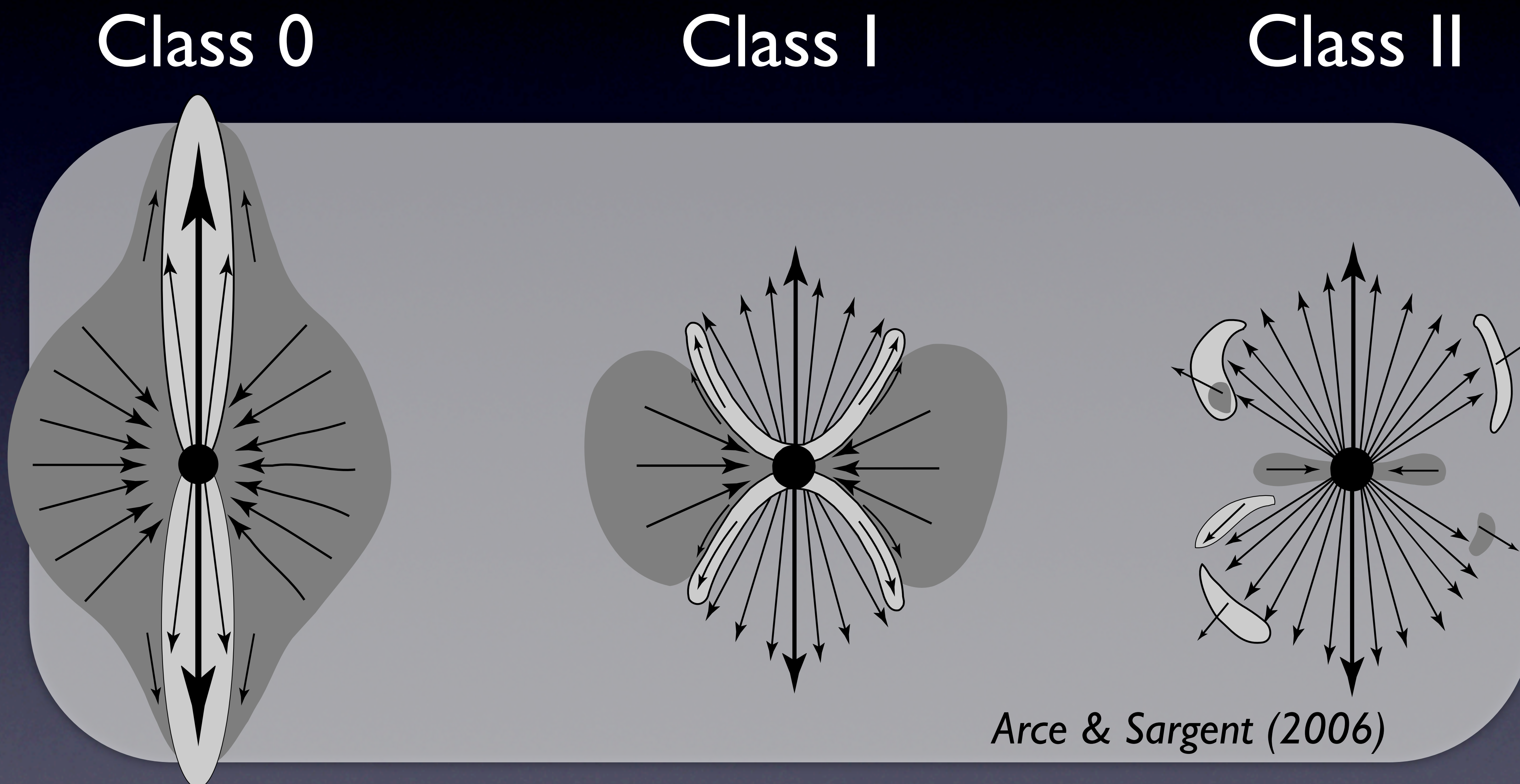
Sterrewacht Leiden

WISH

Lars E. Kristensen

E. van Dishoeck, R. Visser, G. Herczeg, A. Karska, U.A. Yildiz,
S. Bruderer, J. Jørgensen, E. Bergin, S. Doty
The WISH team

Low-mass YSO evolution

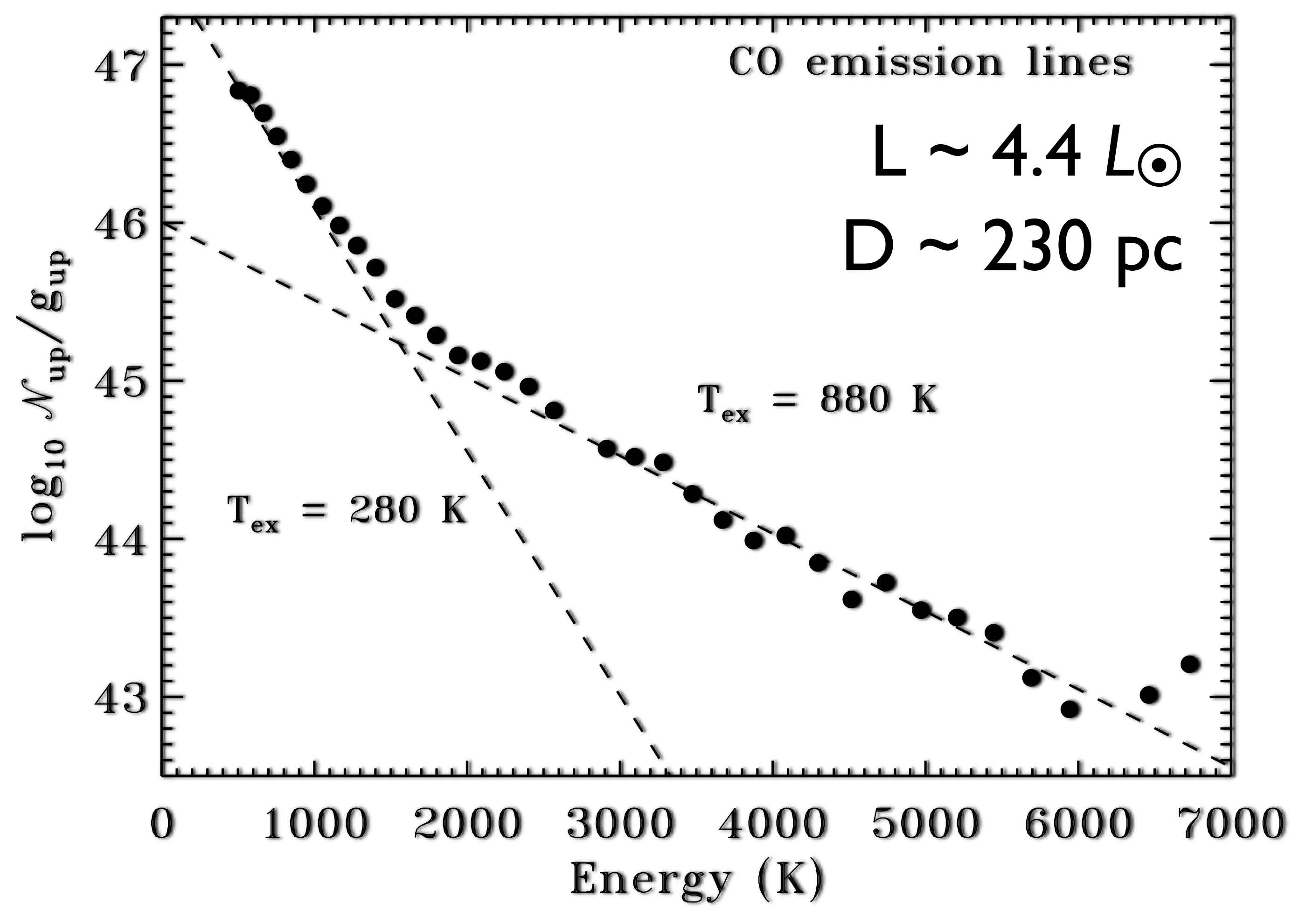


Components: outflow and envelope (maybe disk)

Not very hot gas...

Warm and hot CO

- Surprise from PACS: *highly* excited CO in low-mass protostars
- J_{up}~47 (E_{up}~6000 K)
- Reservoir of hot gas around low-mass YSOs
- Physical origin of hot gas? Location? Trends?



NGC1333-IRAS4B;
(Herczeg et al. in press)

Physical processes

T (K)

10^4 Jet w. internal working surfaces

Wind-induced shell shocks

10^3

UV-heating of cavity walls

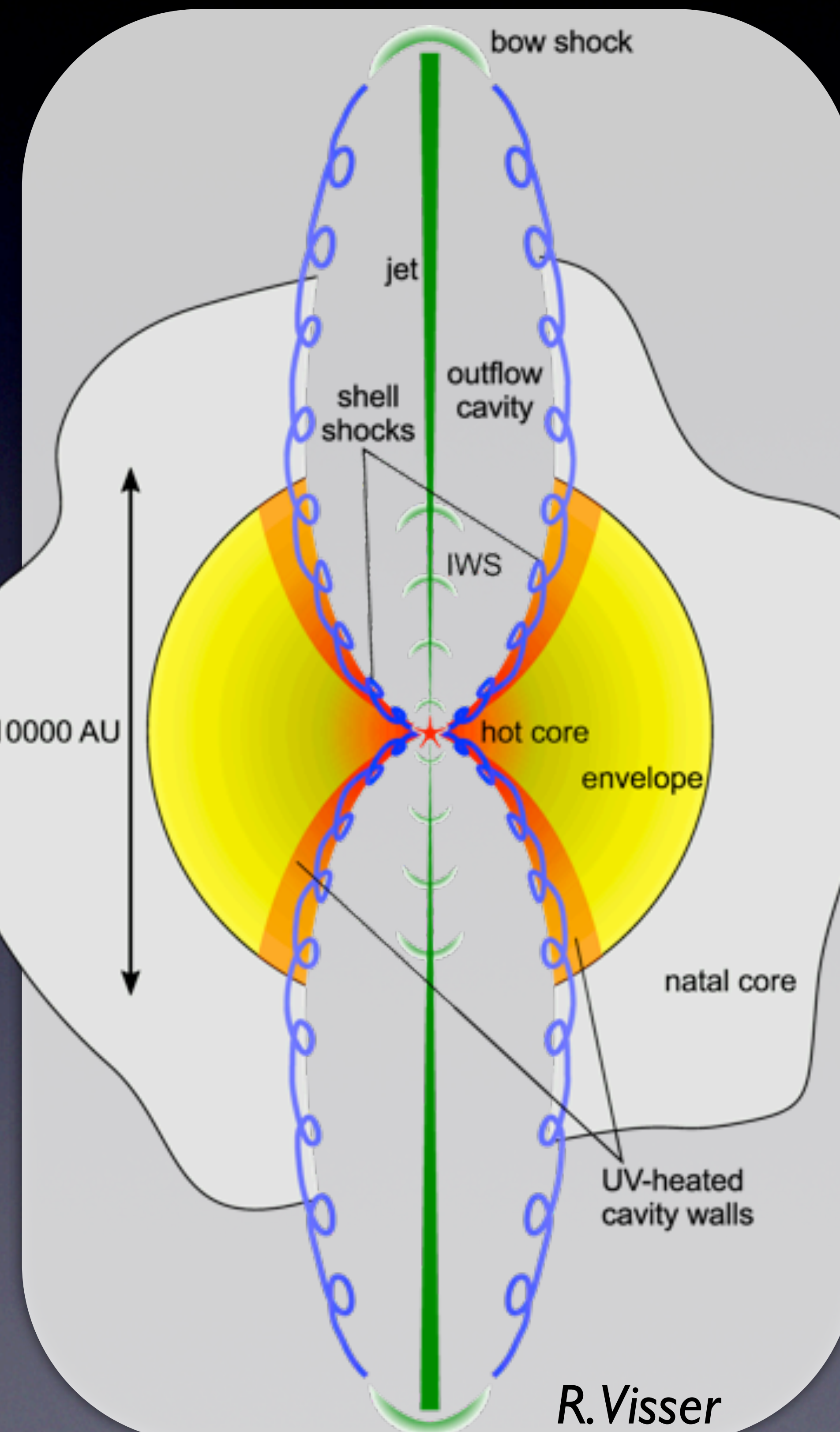
Disk

10^2

Outflow (entrained)

Passively heated envelope

10^1

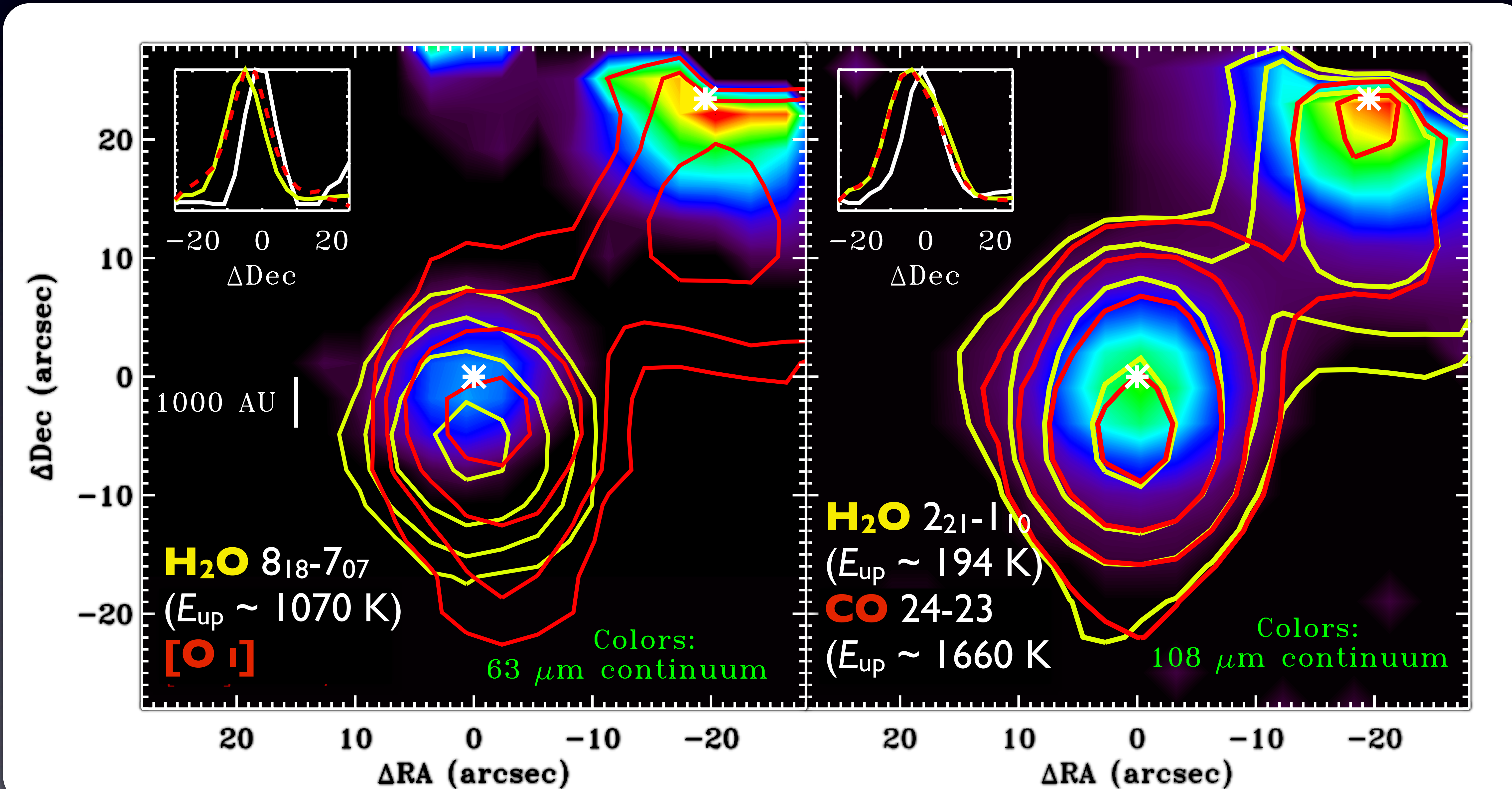


Disentangling the origin challenging

Line vs. continuum

- Highly excited H_2O, CO and [O I] lines spatially offset from continuum: shock origin - not disk!

Herczeg et al. 2012; Watson et al. 2007

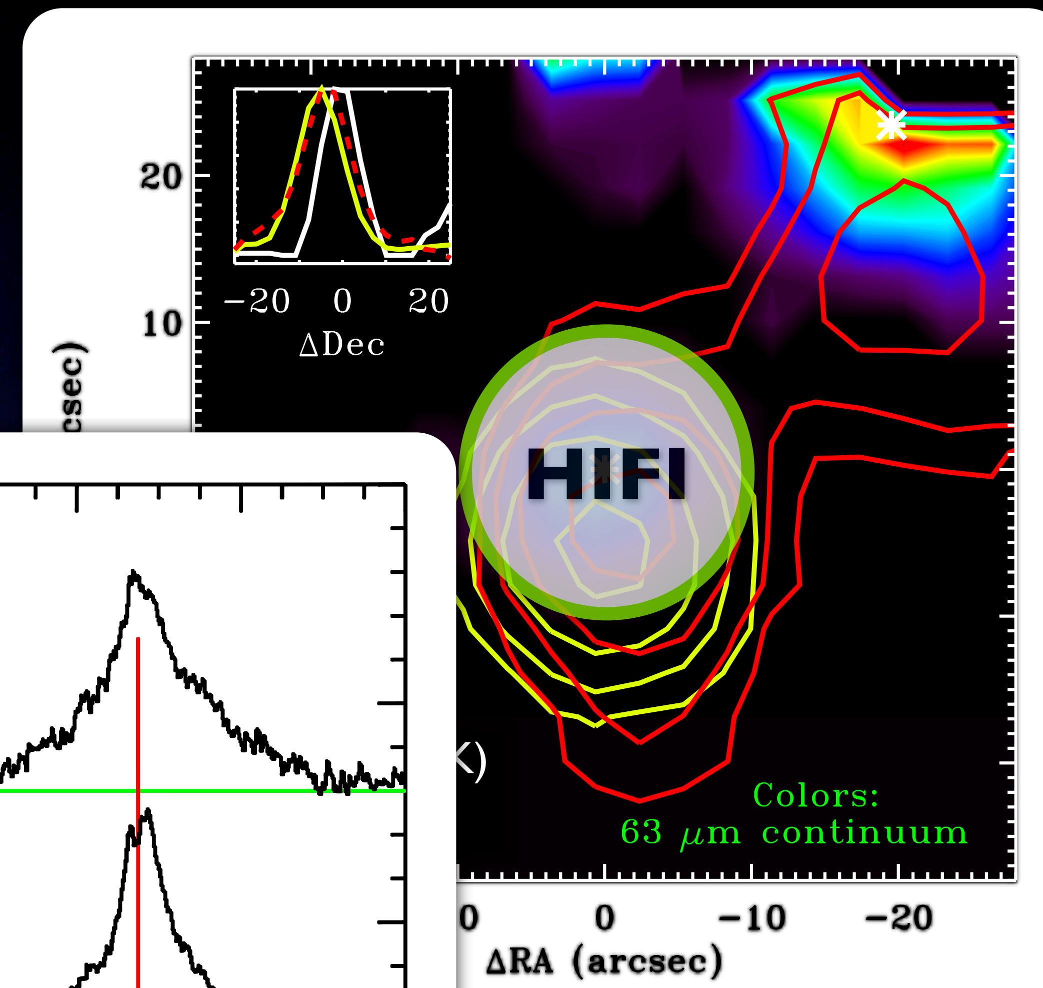


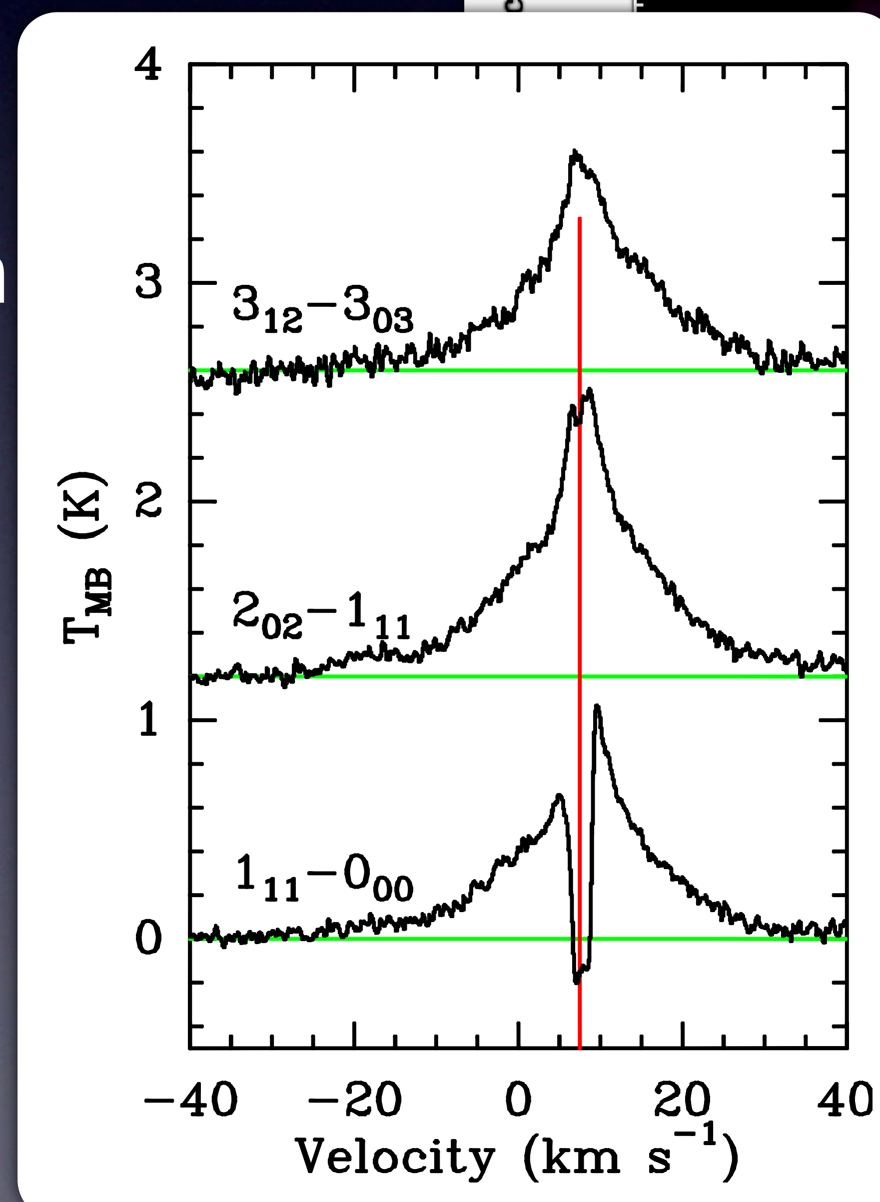
Posters by Karska et al., Puravankara et al.

Fully sampled PACS map: resolution is 5" at 63 μm

H_2O HIFI observations

- H_2O profiles remain constant with excitation
- H_2O traces *currently* shocked gas





N1333-I4B
L ~ 4.4 $L_\odot$
D ~ 235 pc

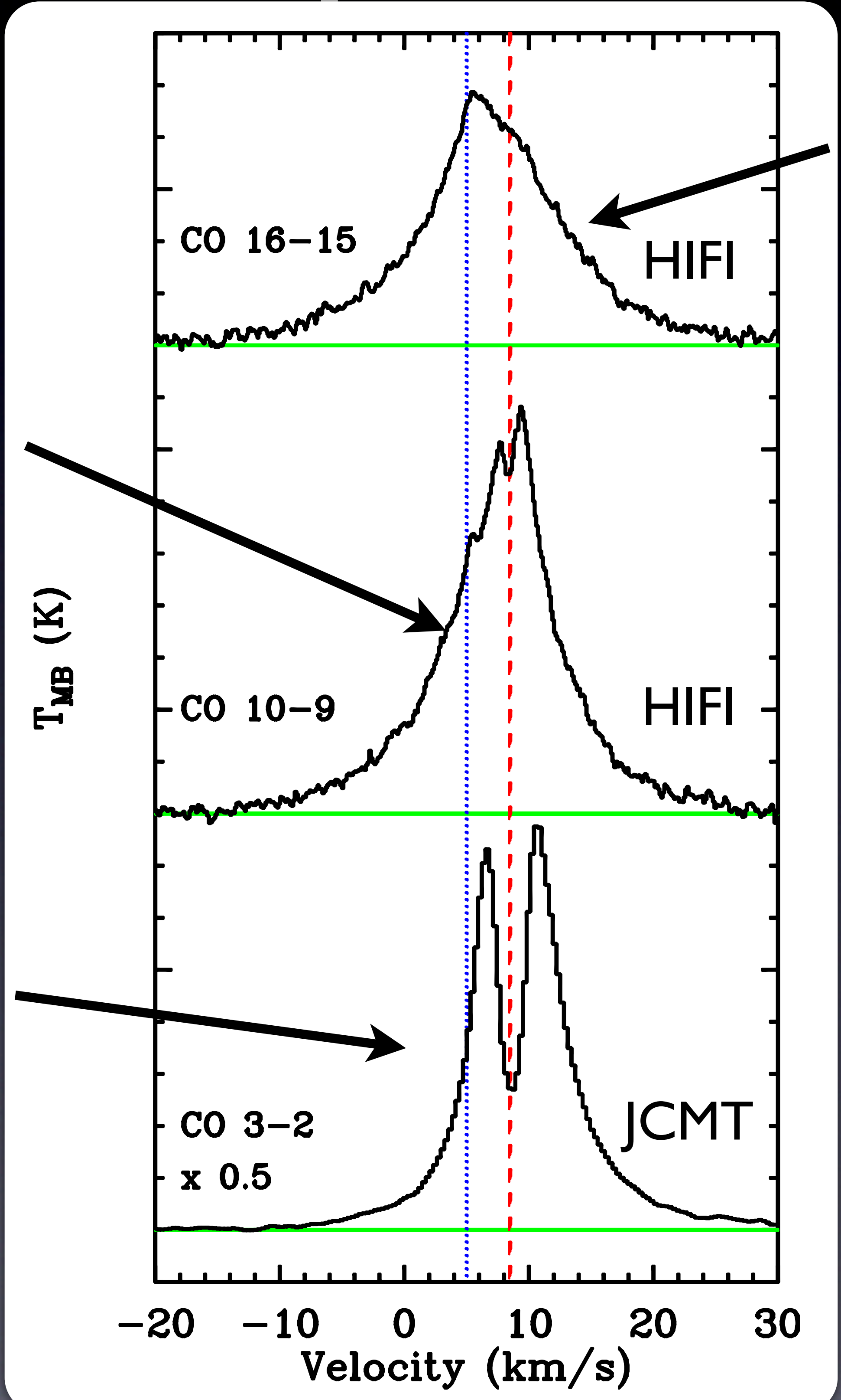
Kristensen et al. (2010)
Bjerkeli et al. (2011)
Santangelo et al. (2012)
Vasta et al. (2012)

(See also poster by Santangelo et al.)

CO profiles

CO 10-9 reminiscent of entrained-gas profile

Low-*J* CO traces entrained outflow gas



CO 16-15 profile *different* from other two

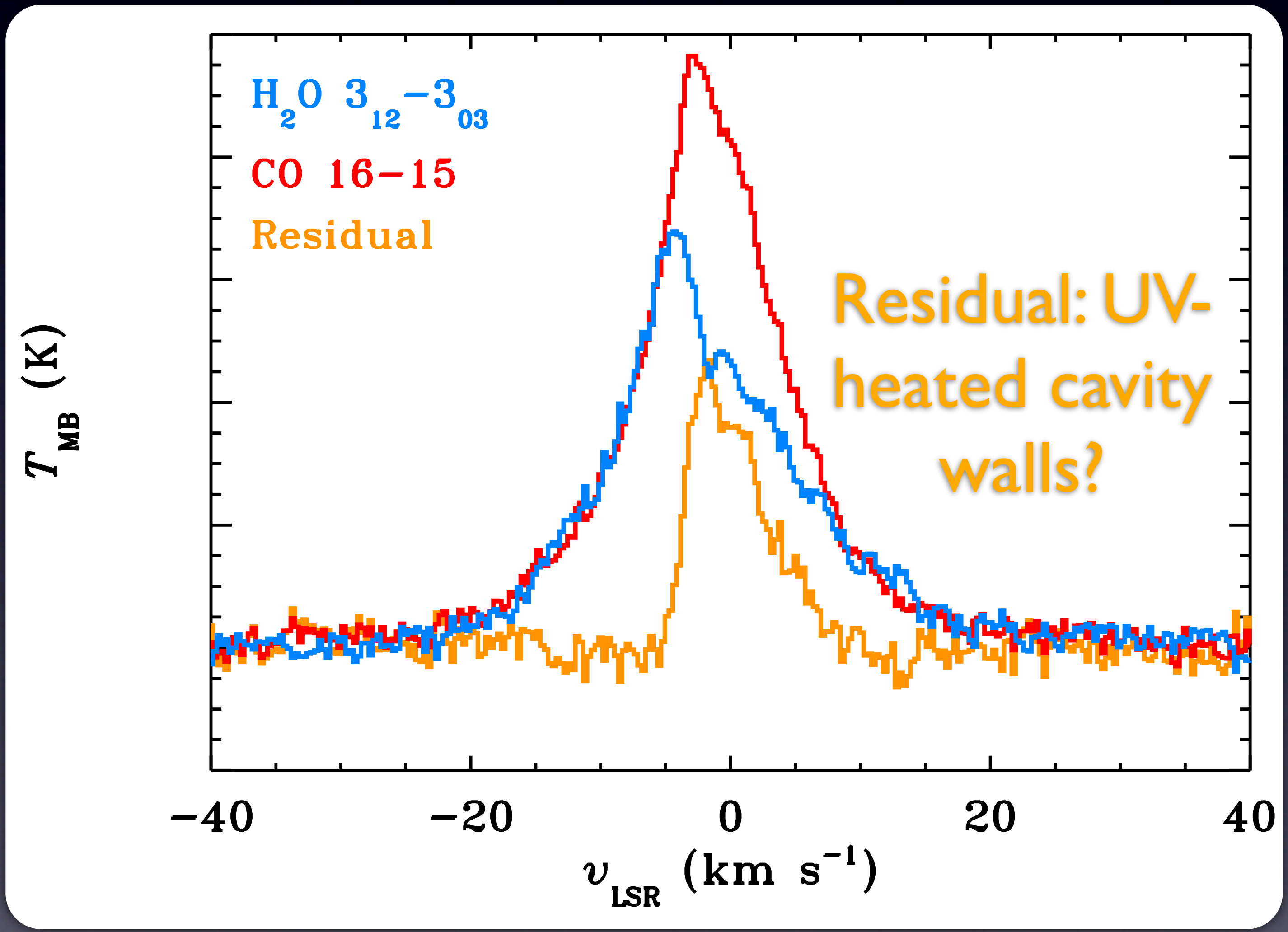
What does **CO 16-15** trace?

Ser SMM1
L ~ 30 $L_\odot$
D ~ 230 pc

Kristensen et al. in prep.

H_2O and CO comparison

- H_2O and CO 16-15 profiles remarkably similar
- Disentangling physical origin through line profiles
- CO 16-15 emission primarily originating in *currently* shocked gas



(Kristensen et al. in prep.)
For more on UV-heated cavity walls: see poster by Yildiz et al. + Yildiz et al. 2012 (in press)

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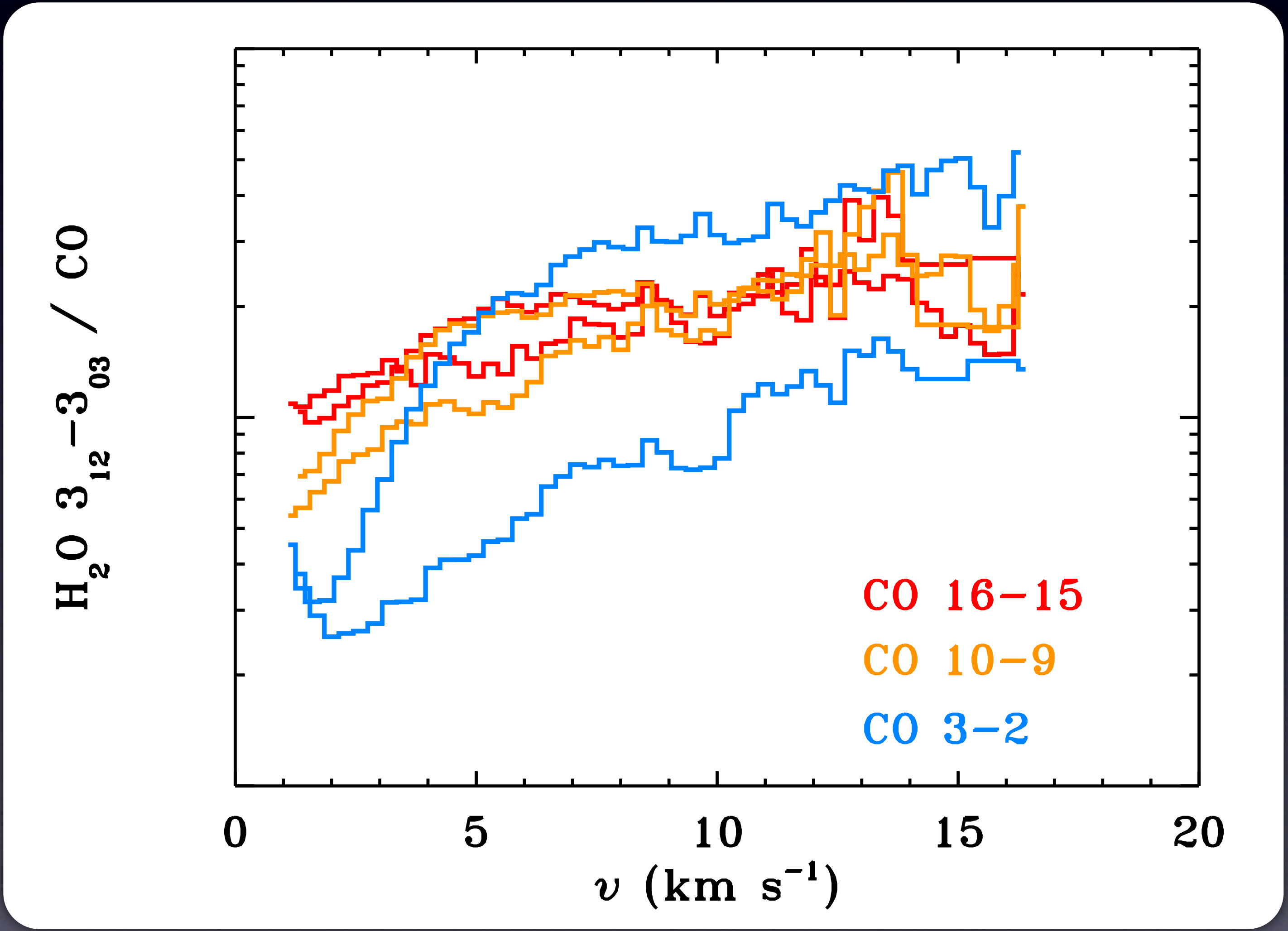

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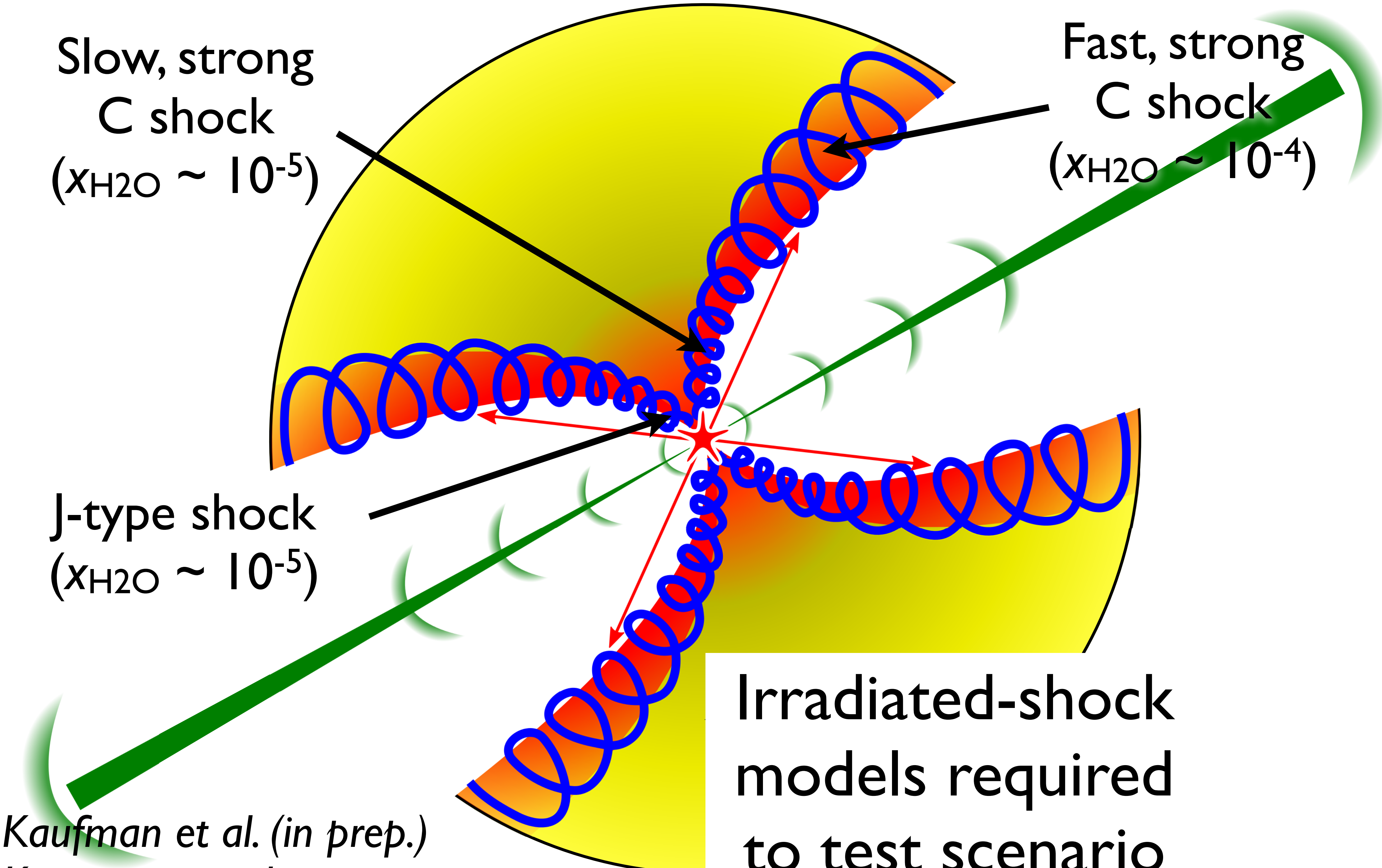
Where are the shocks (and the H_2O)?

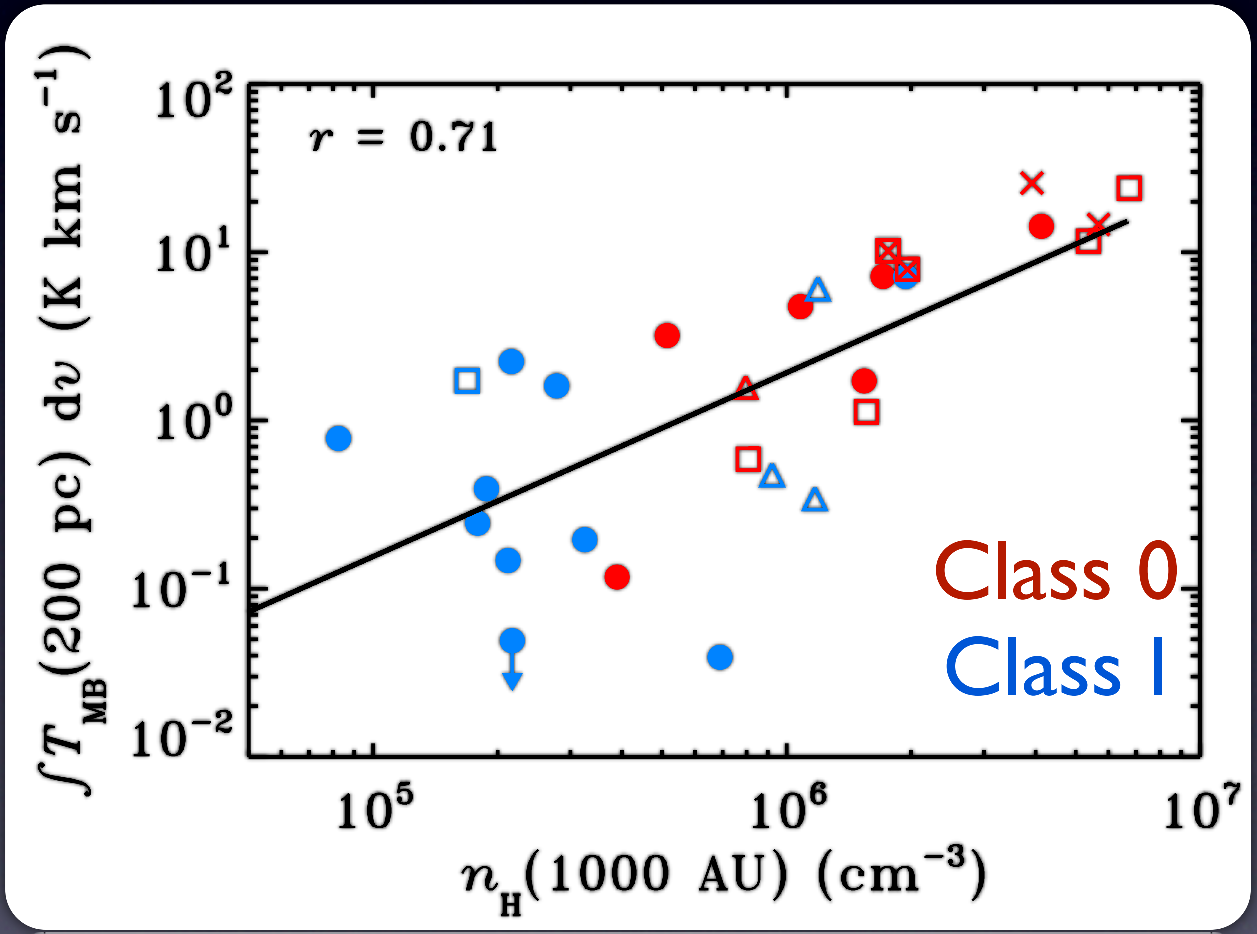


Irradiated-shock models required to test scenario

Kaufman et al. (in prep.)
Kristensen et al. in press; in prep.

H_2O excitation

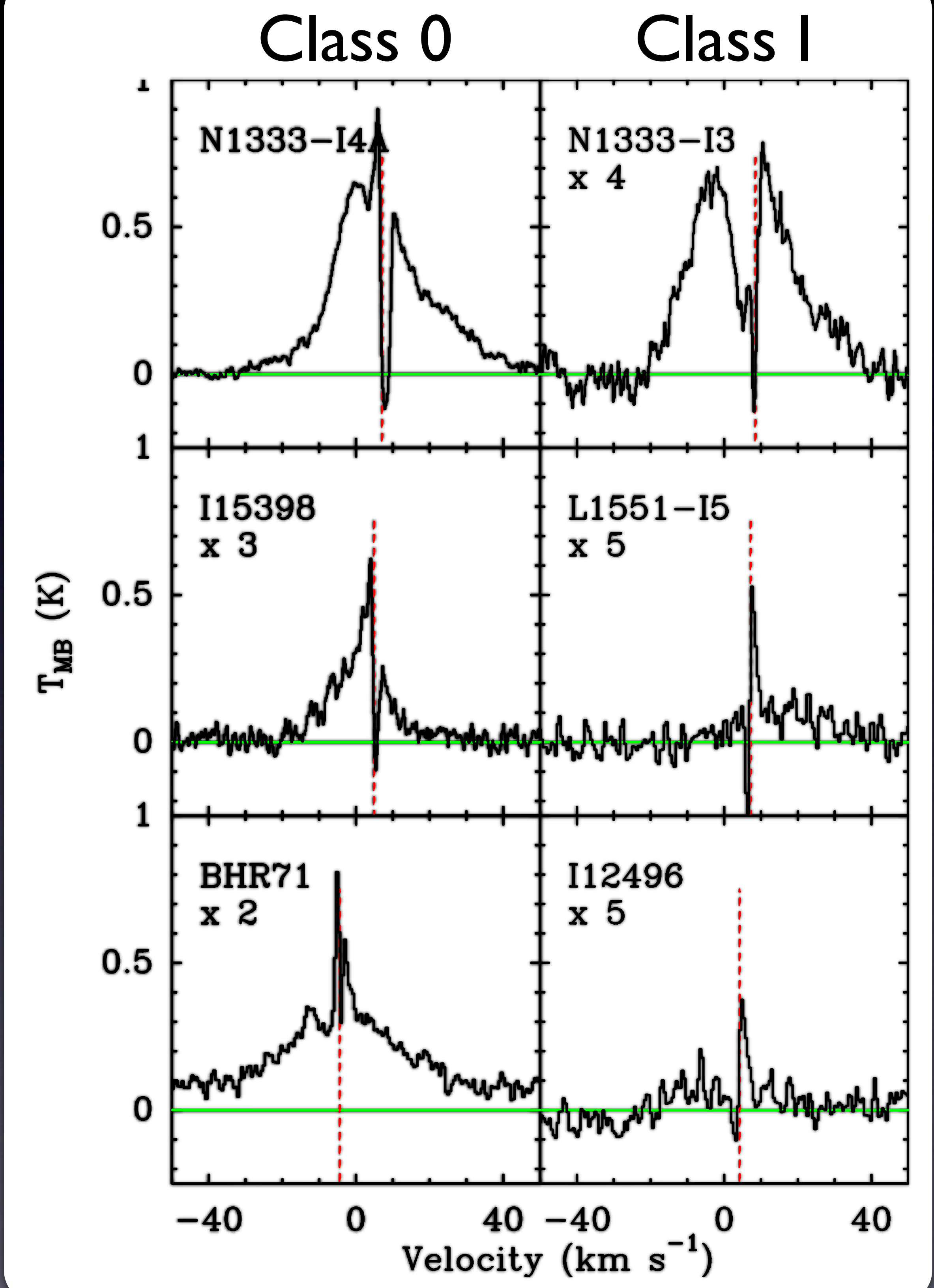
- Evolution explains why H_2O was not detected in Class I sources with *Odin*, SWAS *(Ashby et al. 2000)*
- H_2O sub-thermally excited (n_{crit} ~ 10^8 cm^{-3}; *Dubernet et al. 2006*)
- Emission ~ $n(H_2) \times N(H_2O)$
- H_2O excitation follows envelope density



(Kristensen et al. in press)

H_2O profile evolution

- *Class 0:* EHV gas (jet shocks), very broad, inverse P-Cygni profiles
- *Class I:* regular P-Cygni profile (expansion), narrower outflow profile
- **Quantitative** differences between profiles

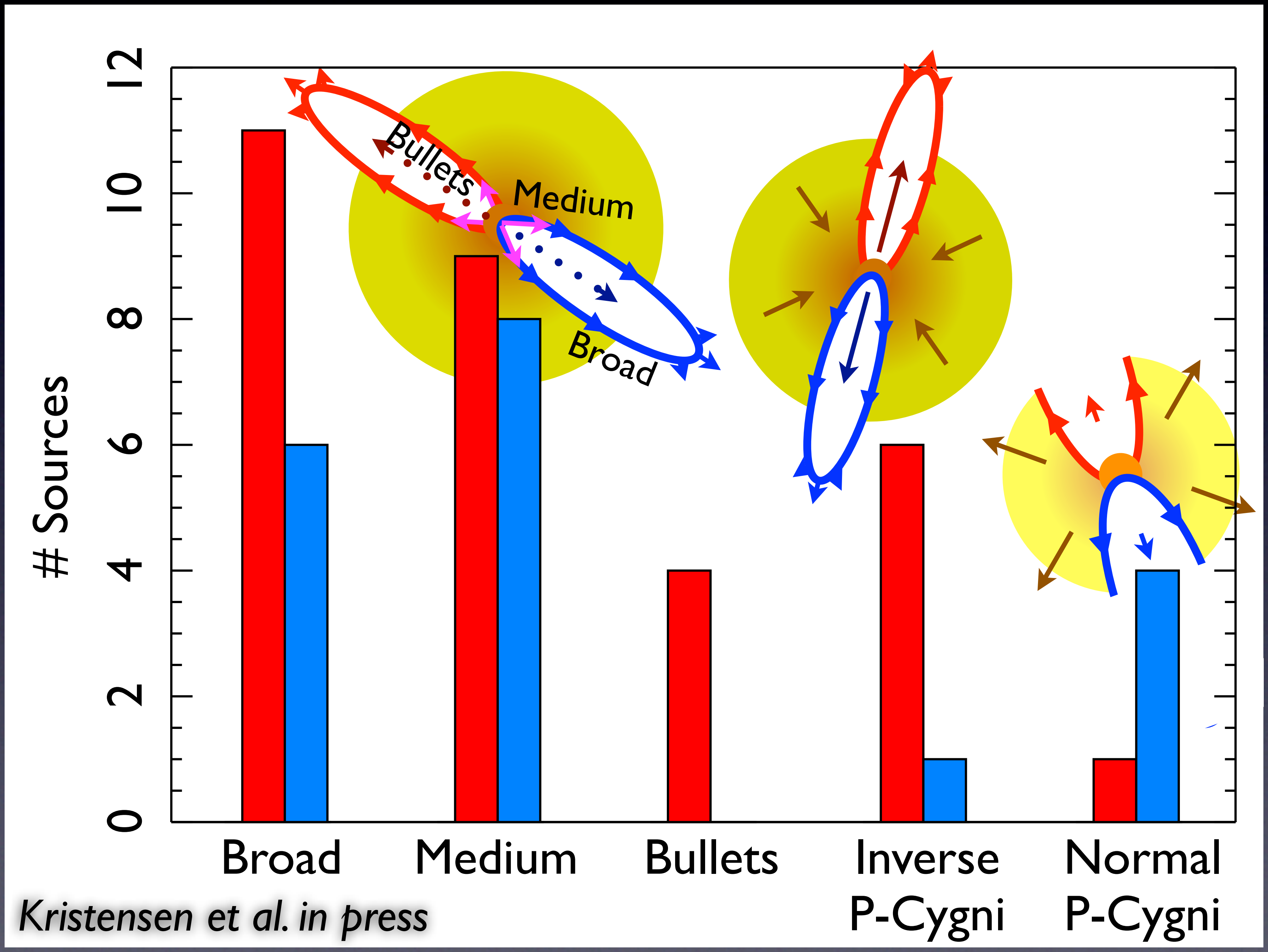


Kristensen et al. in press

(Dynamics: poster by Mottram et al.)

(Possible scenario: poster by Yvart et al.)

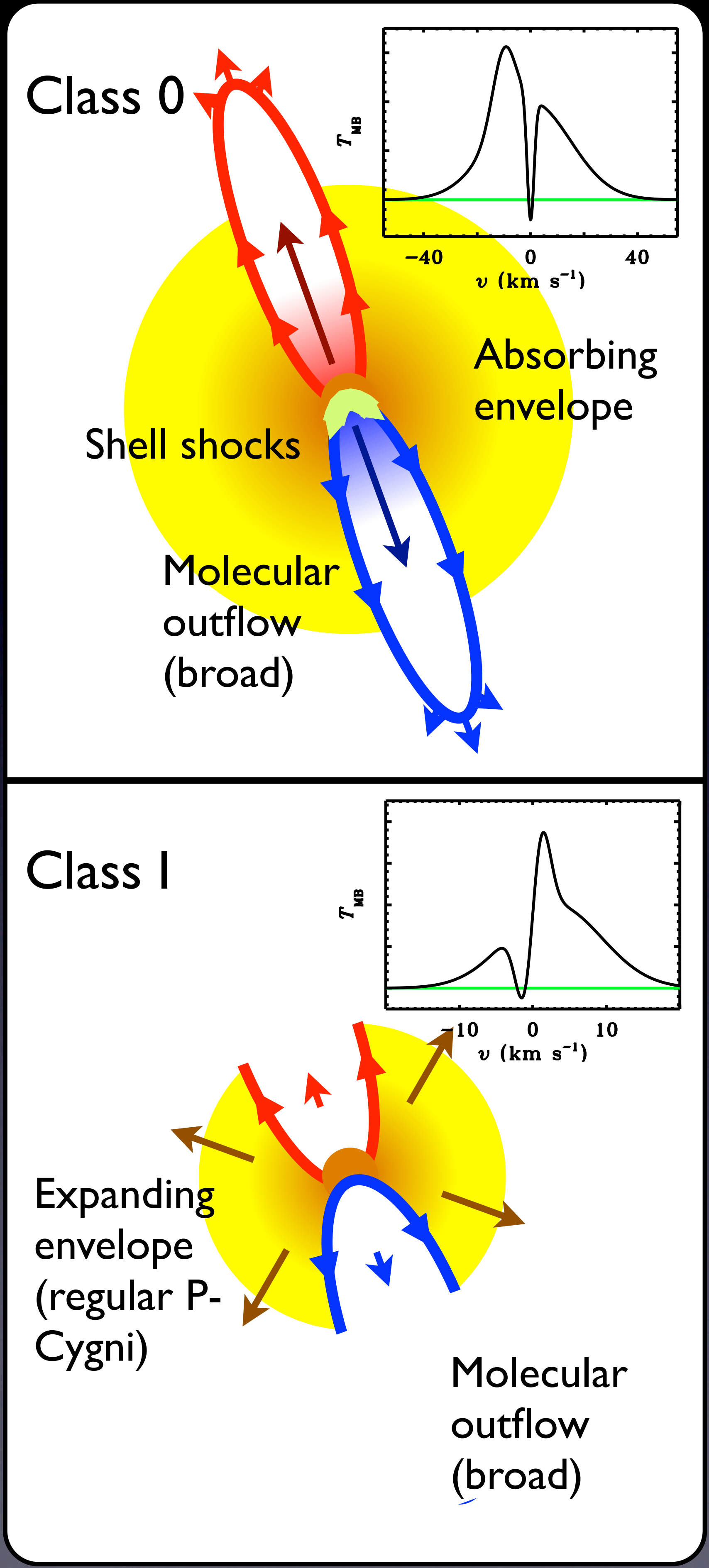
H_2O as evolutionary tracer



Clear trend in components in spite of small number of sources

Evolutionary scheme

- *Class 0*: H_2O tightly linked to outflow, infall, molecular jet, **shocks dominate H_2O and CO excitation**
- *Class I*: envelope opens, outflow force decreases, expansion, **shocks dominate H_2O excitation, UV dominates CO**



(Visser et al. 2012, Kristensen et al. in press, Mottram et al. in prep.)
(Poster by Mottram et al.)

Summary & conclusions

- High-J (J > 10) CO emission primarily traces *currently* shocked gas in protostars
- Water excitation is dominated by shocks in dense gas, both in Class 0 and I sources
- Water traces turnover from infalling to expanding envelopes ==> evolutionary tracer