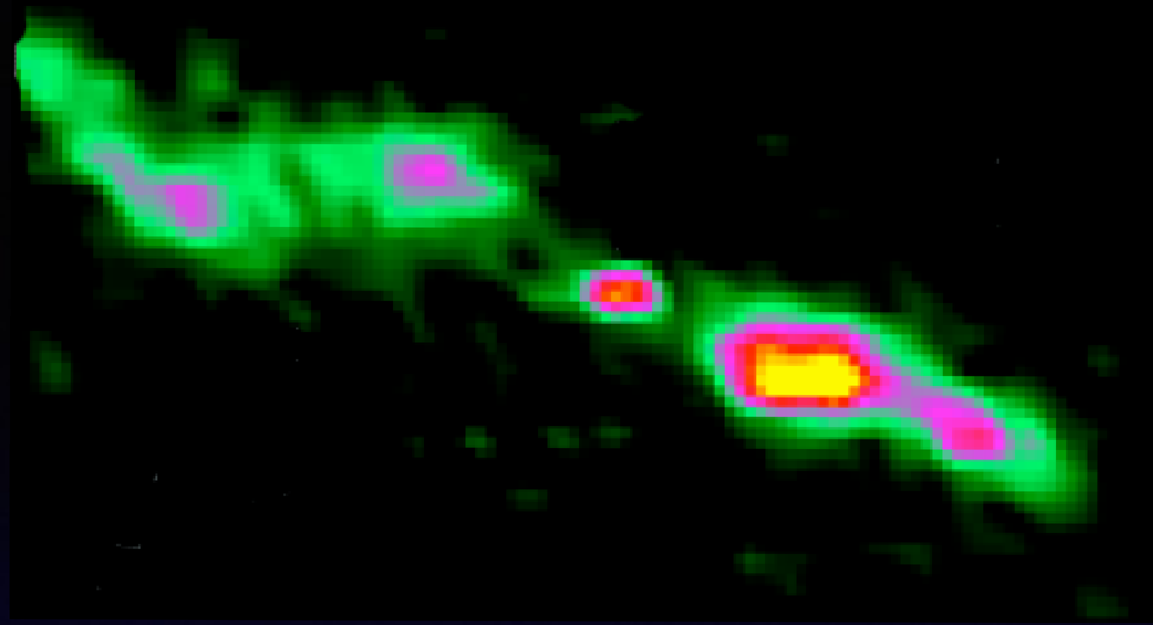

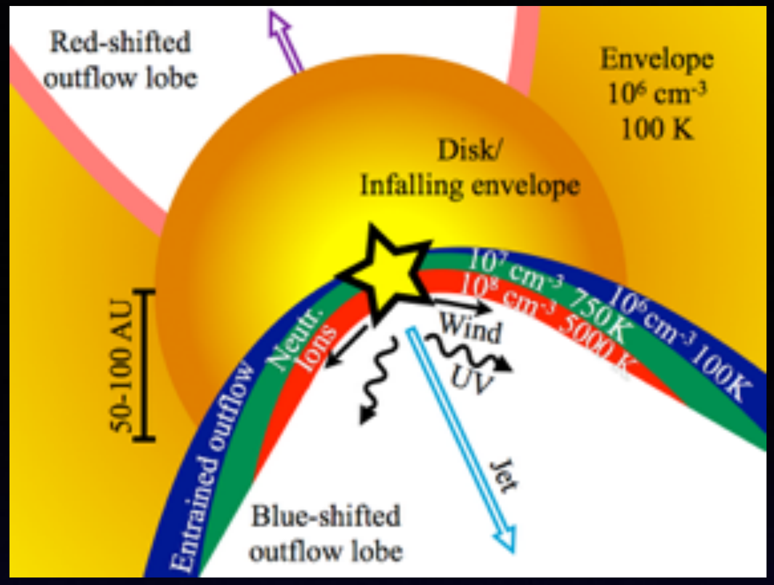

Sunbathing around low-mass protostars: new insights from hydrides

Agata Karska

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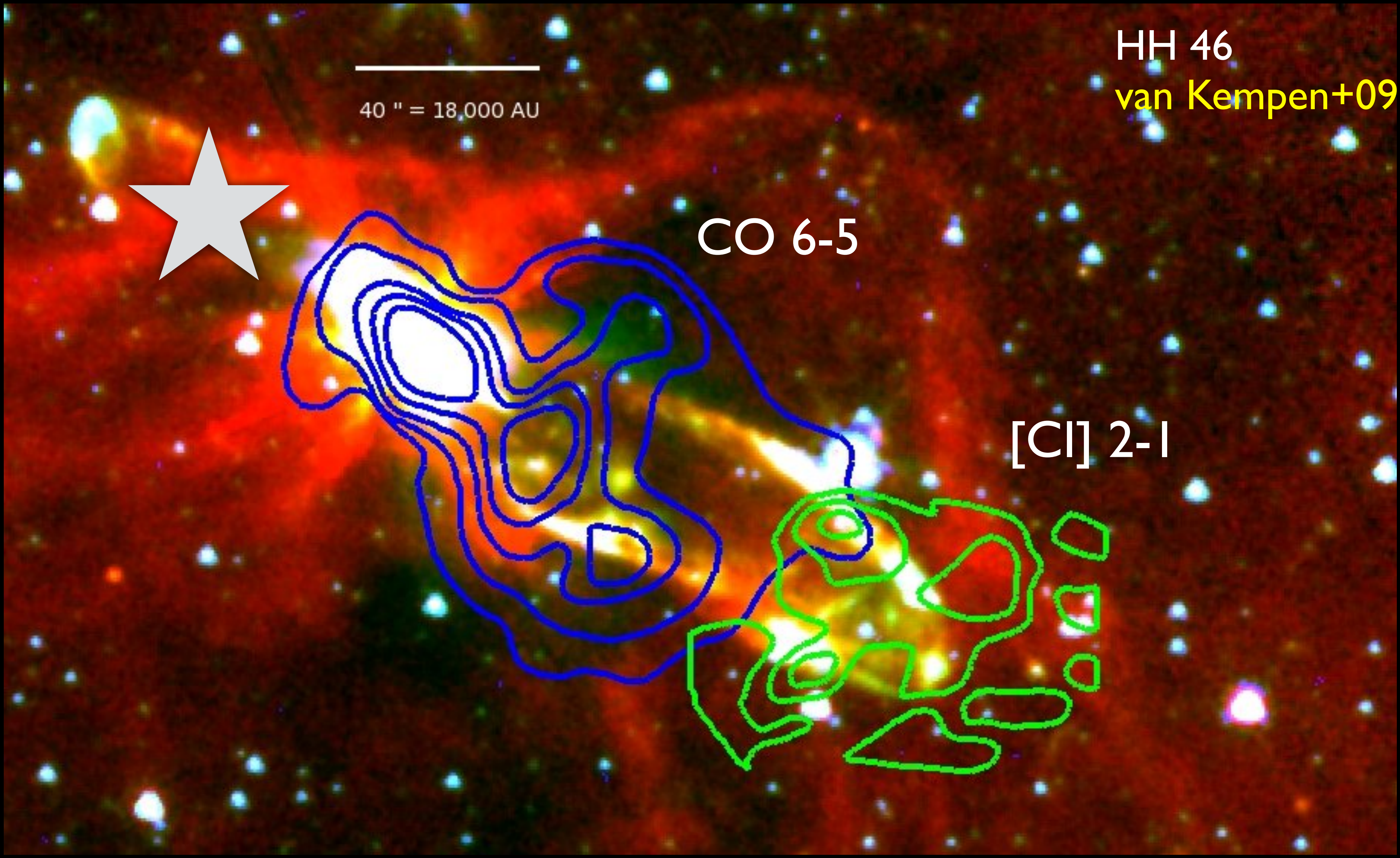
L. Kristensen, M. Kaufman & WISH, DIGIT, WILL teams

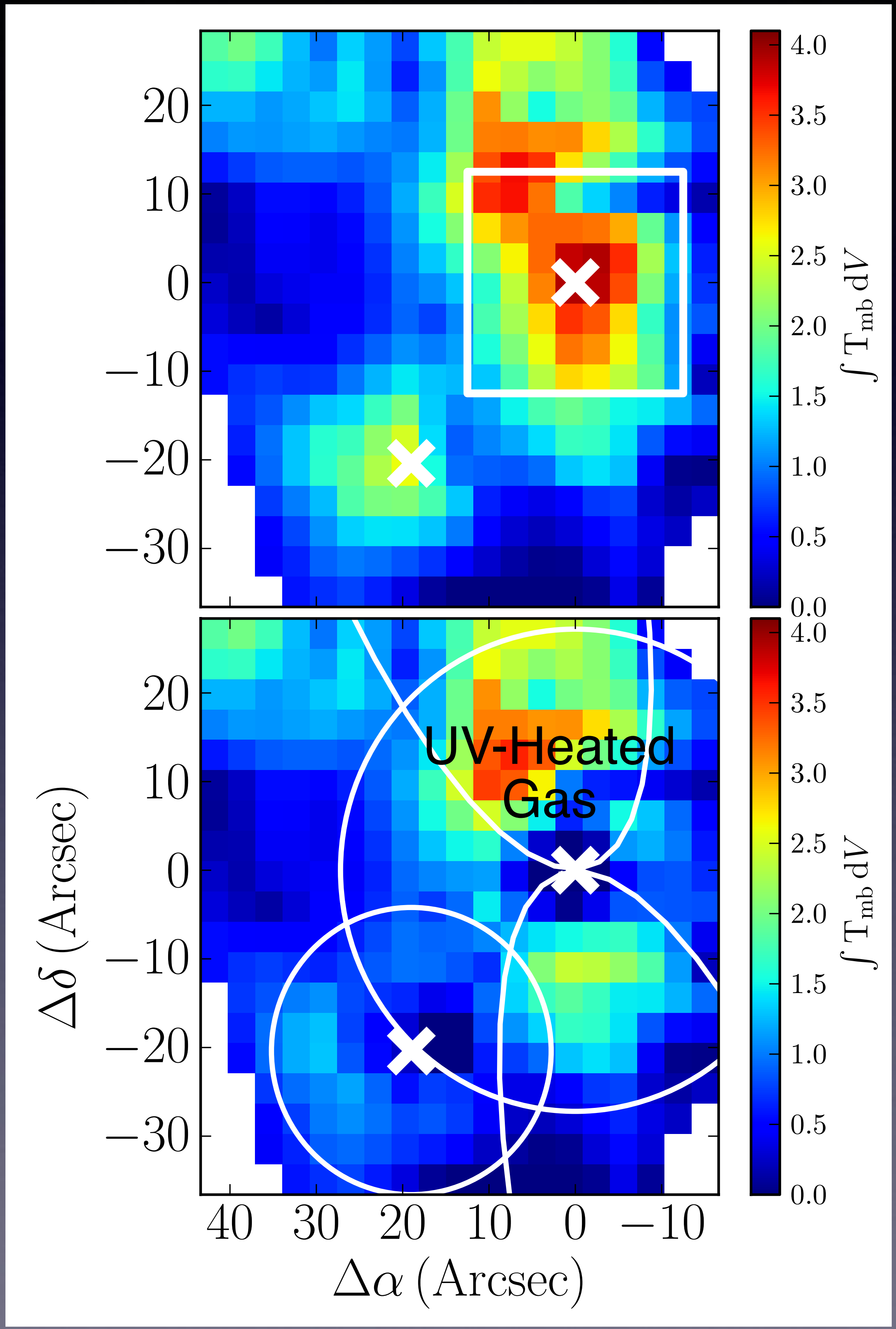
(Univ. of Copenhagen, San Jose St. Univ., USA)

Sunbathing around young stars



- Dissociation of CO at the apex of the jet & narrow CO profiles
- Importance of UV heating along the outflows

UV heating of cavity walls



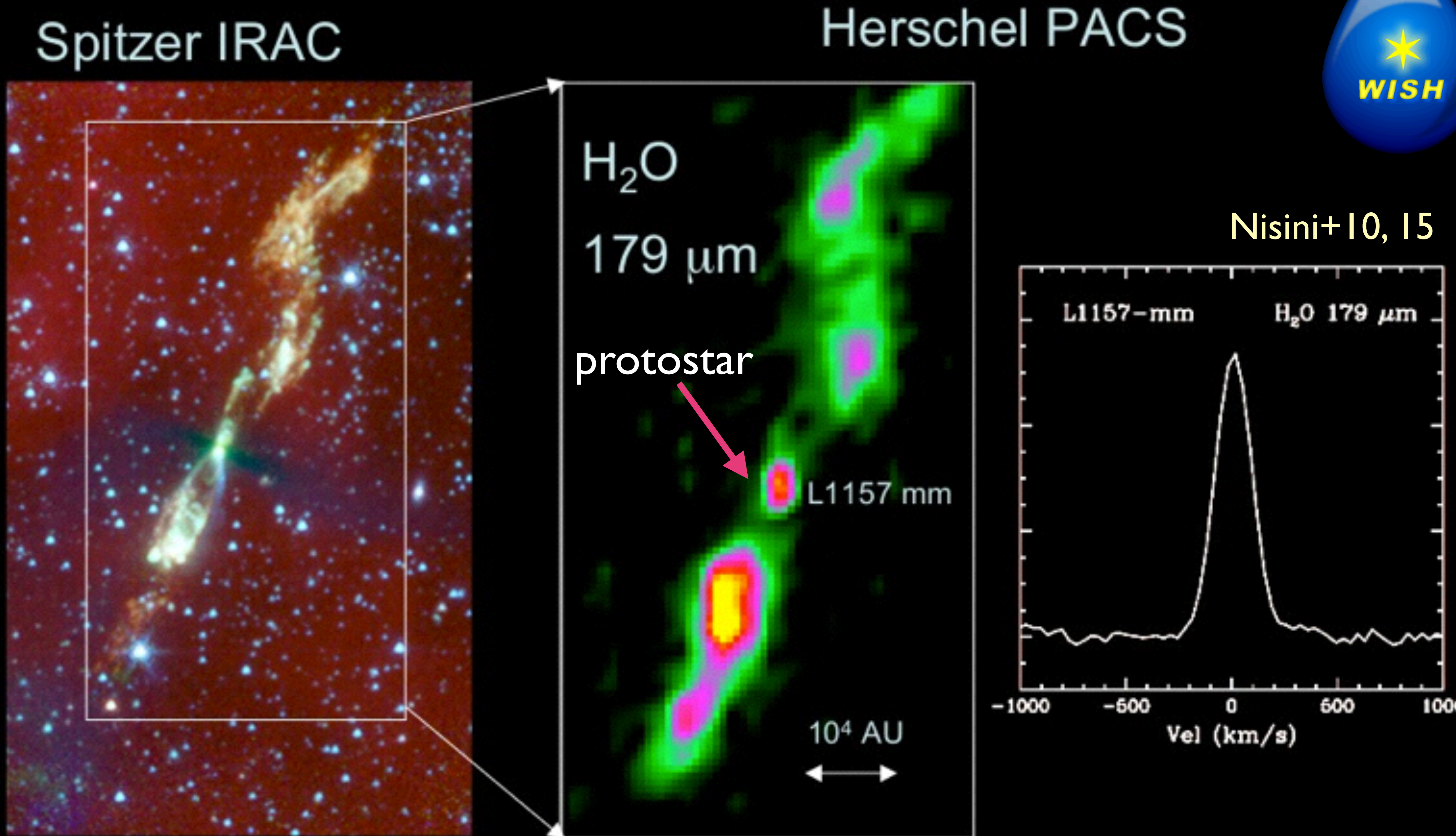
- Spatially extended, narrow ^{13}CO 6-5 profiles attributed to UV heating (Spaans+95)

- Complete mapping survey of ~30 low-mass outflows with APEX

- Similar contribution of UV heating and entrained gas to CO 6-5

Yildiz, Kristensen+15

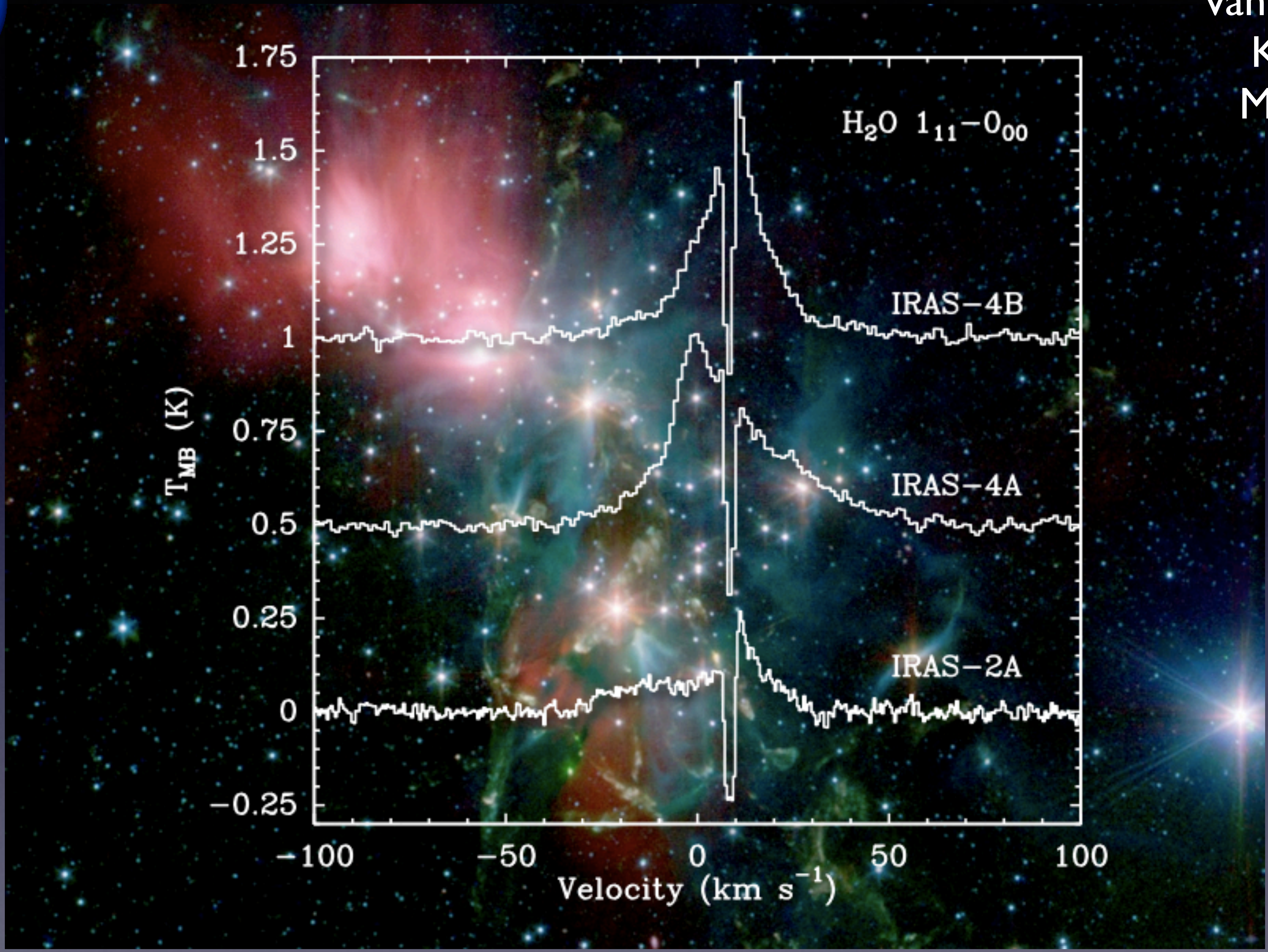
Far-IR: shocks!



- Extended pattern of emission and broad line profiles clearly point to shocks

H_2O complex profiles

van Dishoeck+10,
Kristensen+12,
Mottram+14,16

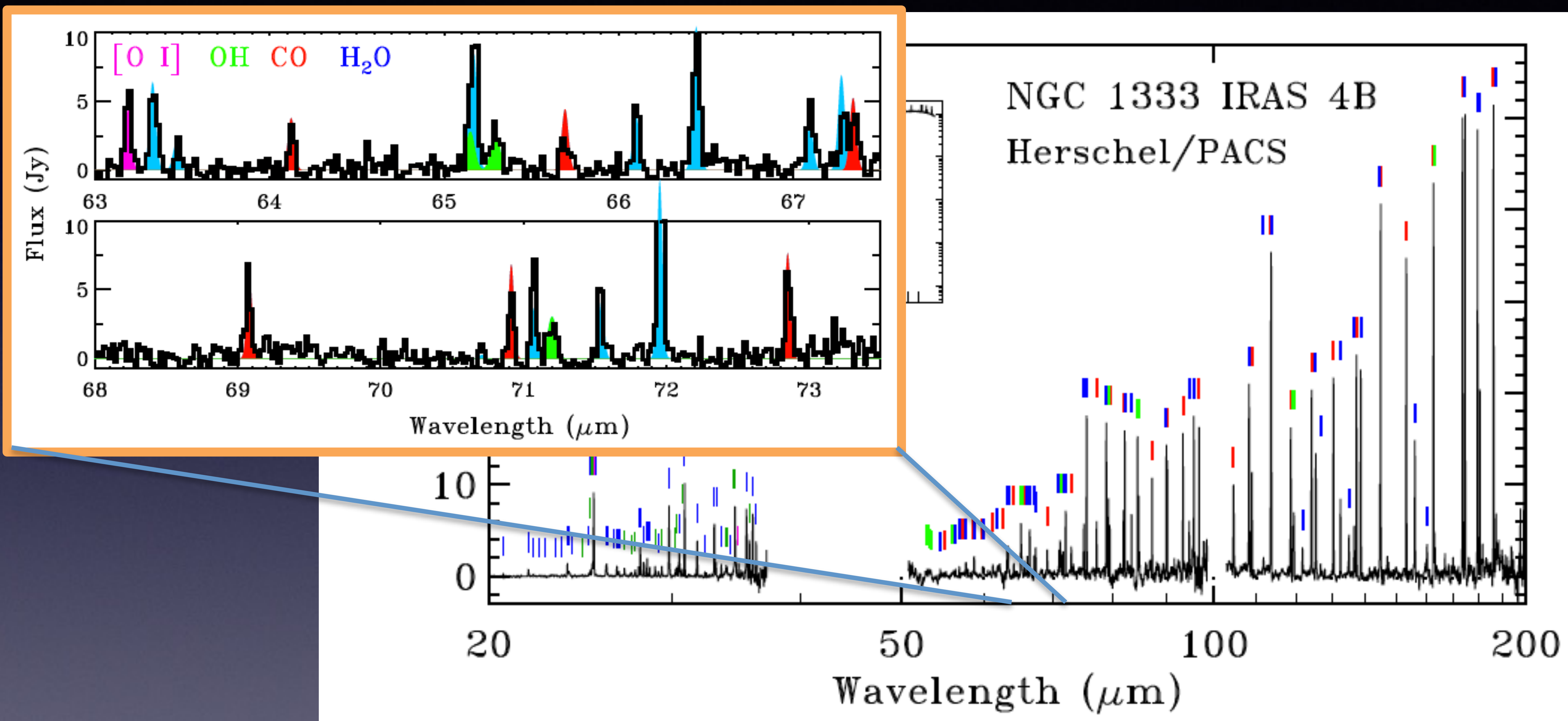


H_2O - a key tracer of dynamics in young stellar objects

Broad line profiles indicate the presence of ~20-50 km s^{-1} gas

Spectra: H_2O, CO, OH

Herczeg, Karska et al. 2012

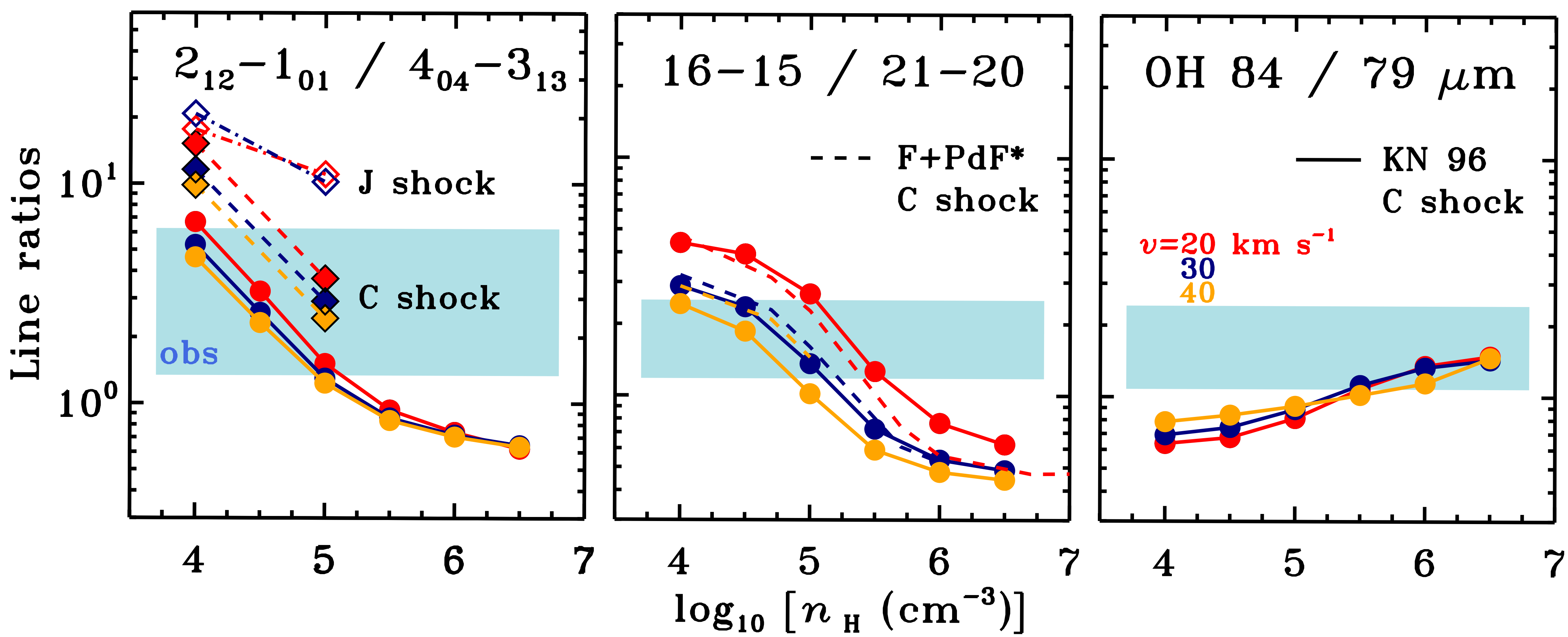


- Detections of CO J_{up}=14-49 and highly excited H_2O
- Broadly consistent with predictions from shock models

Line ratios vs. shock models

- excitation

H_2O / H_2O CO / CO OH / OH



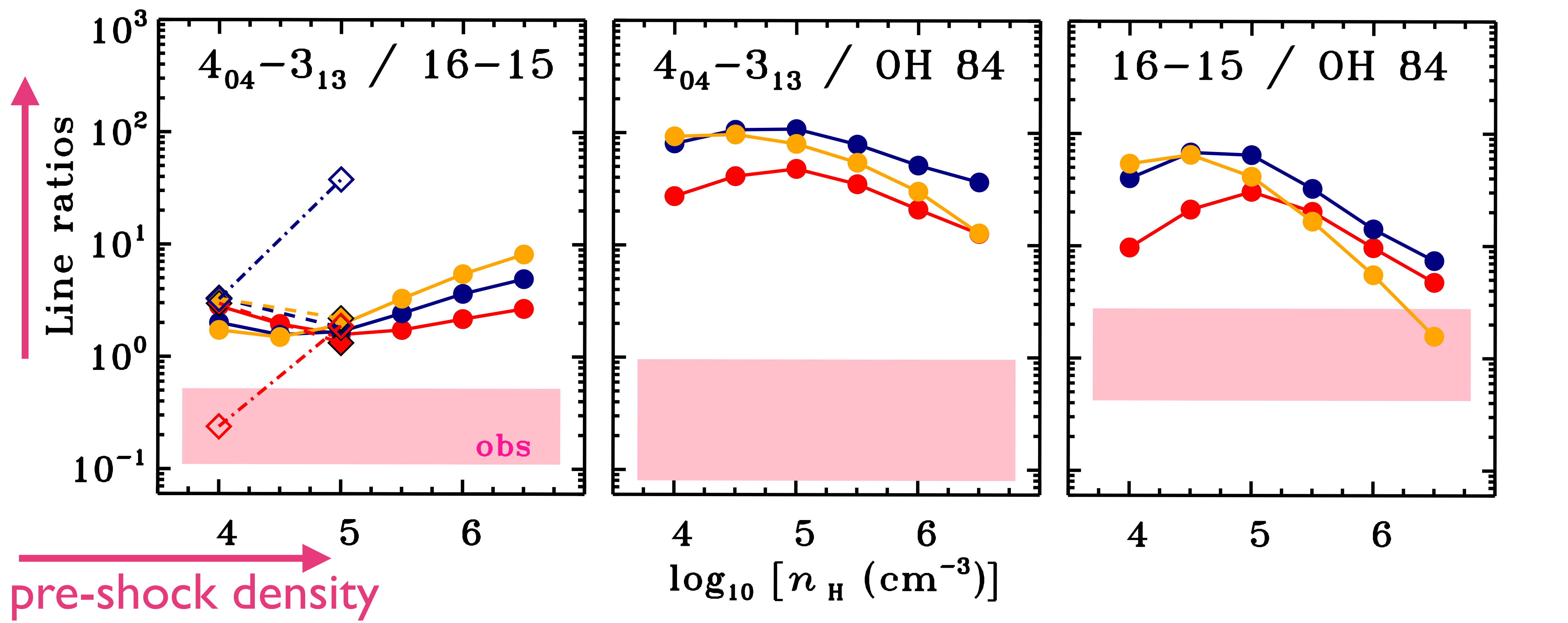
- Line ratios remarkably similar across the sample

- Velocities > 20 km s^{-1}, pre-shock densities of ~10^5 cm^{-3}

Karska et al. 2014b

Line ratios vs. shock models

H_2O / CO H_2O / OH CO / OH



- Observed ratios with H_2O much lower than shock models
- FUV photodissociation likely at play

H_2O complex profiles

van Dishoeck+10,
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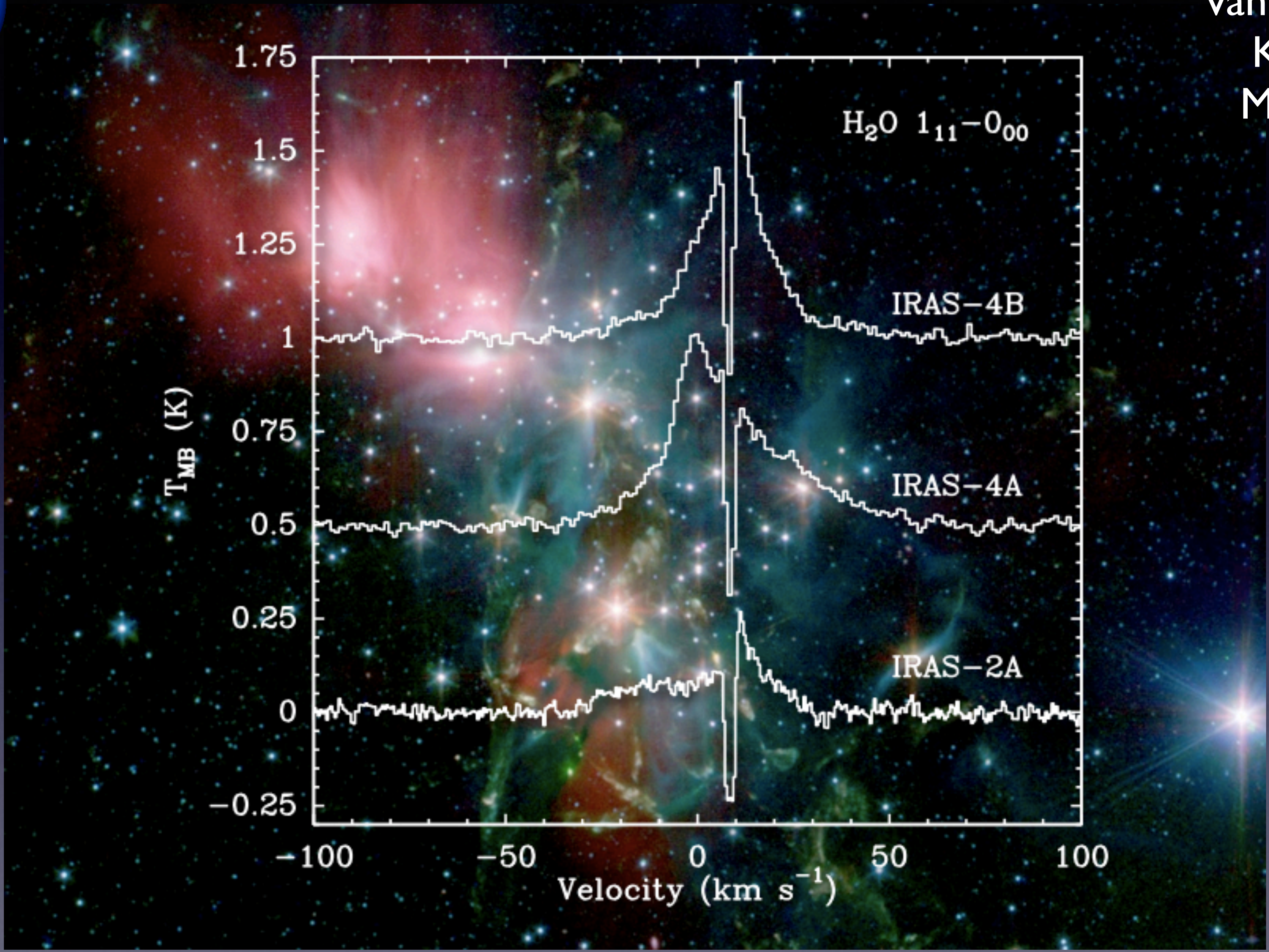
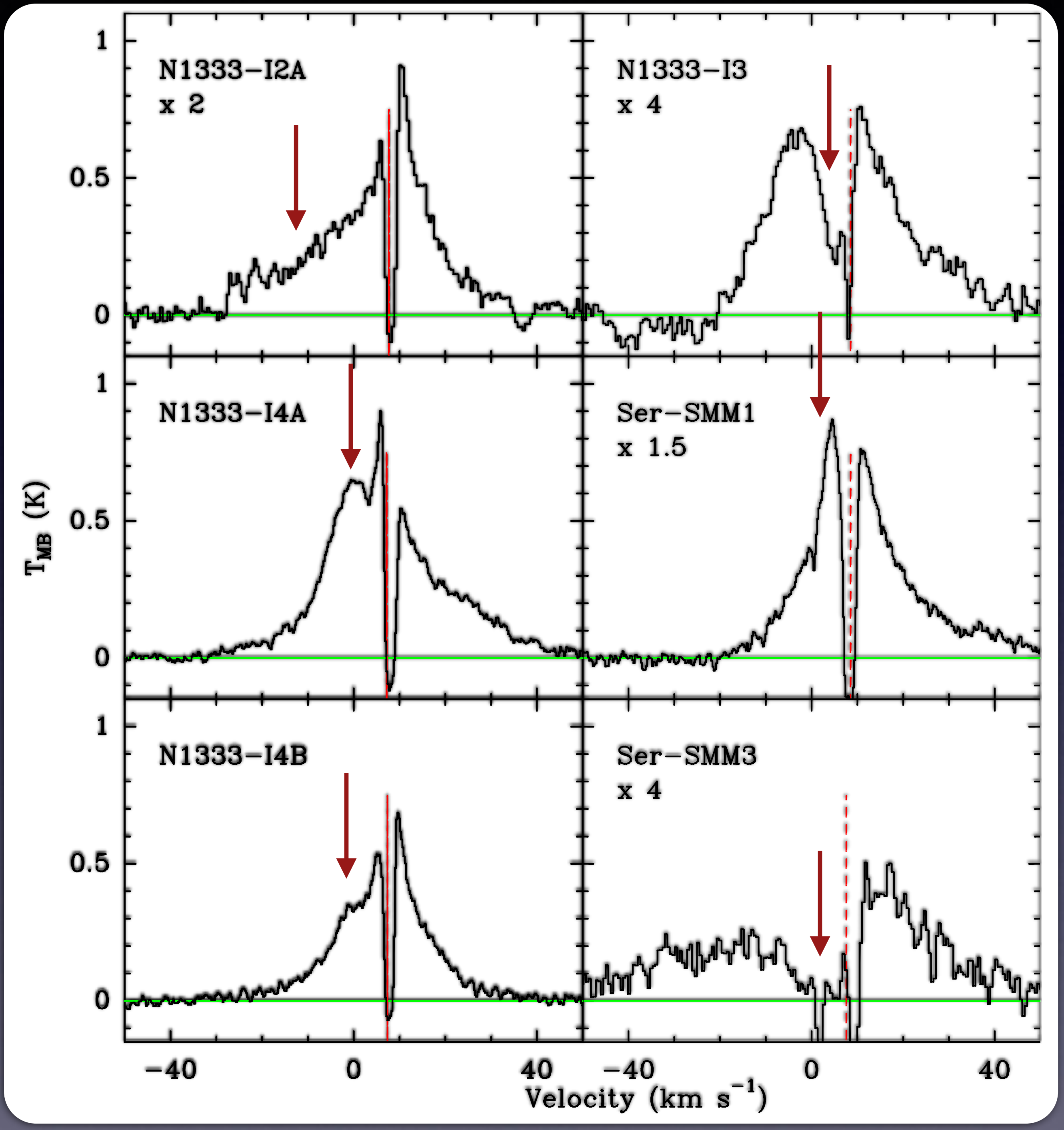


H_2O - a key tracer of dynamics in young stellar objects
Broad line profiles indicate the presence of ~20-50 km s^{-1} gas

Spot shock components

- Typically offset to the blue by 5-10 km s^{-1}
- FWHM of 5-10 km s^{-1}
- New and unseen in, e.g., CO 3-2

(Kristensen et al. 2013)



H_2O 557 GHz $J = 1_{10}$-1_{01}
Observed with Herschel-HIFI

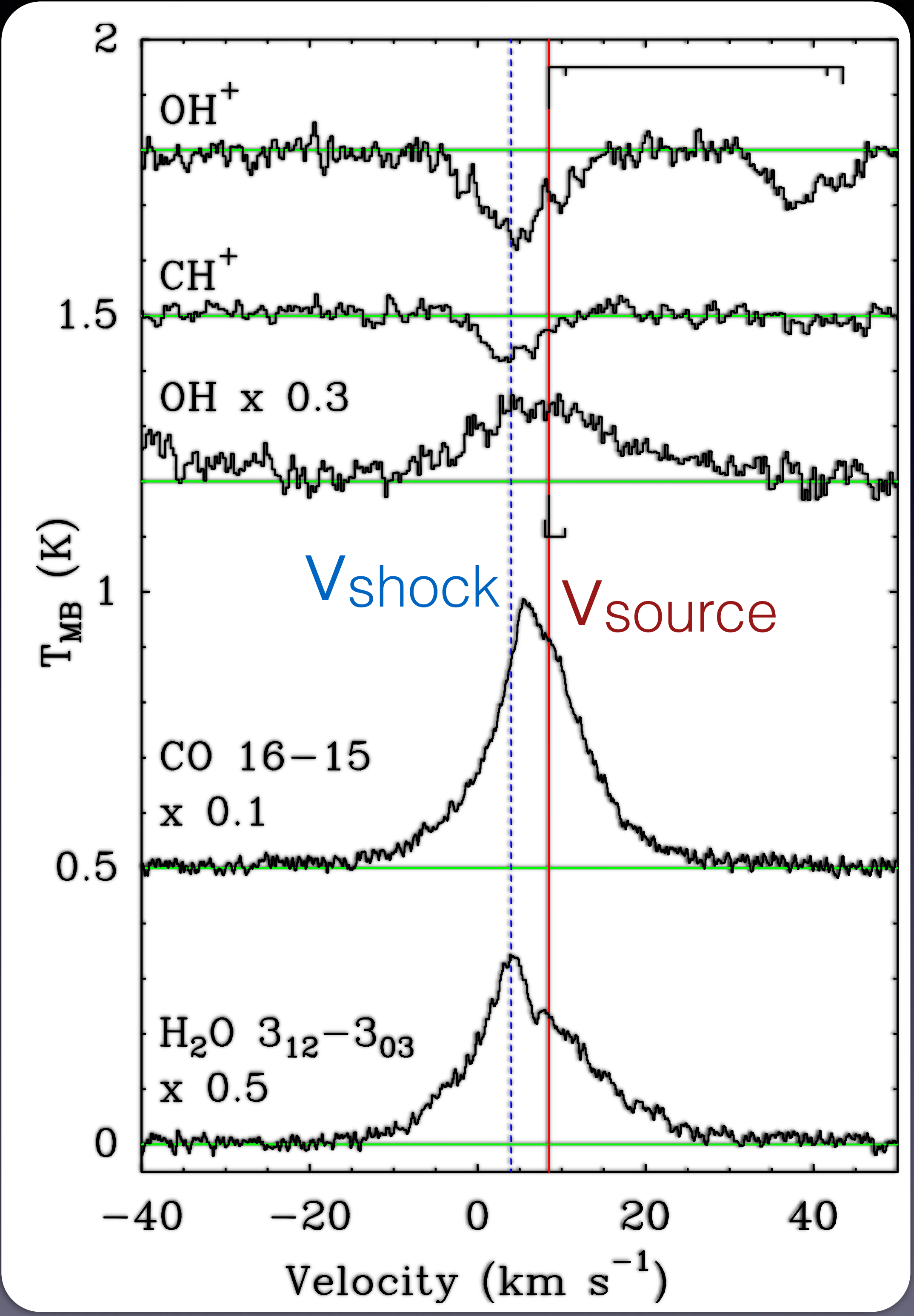
L. Kristensen

Hydrides

- Seen in light ionized hydrides and CO 16-15
- Points to origin close to protostar and hot, dense gas
- *Large columns of ionised hydrides require UV*

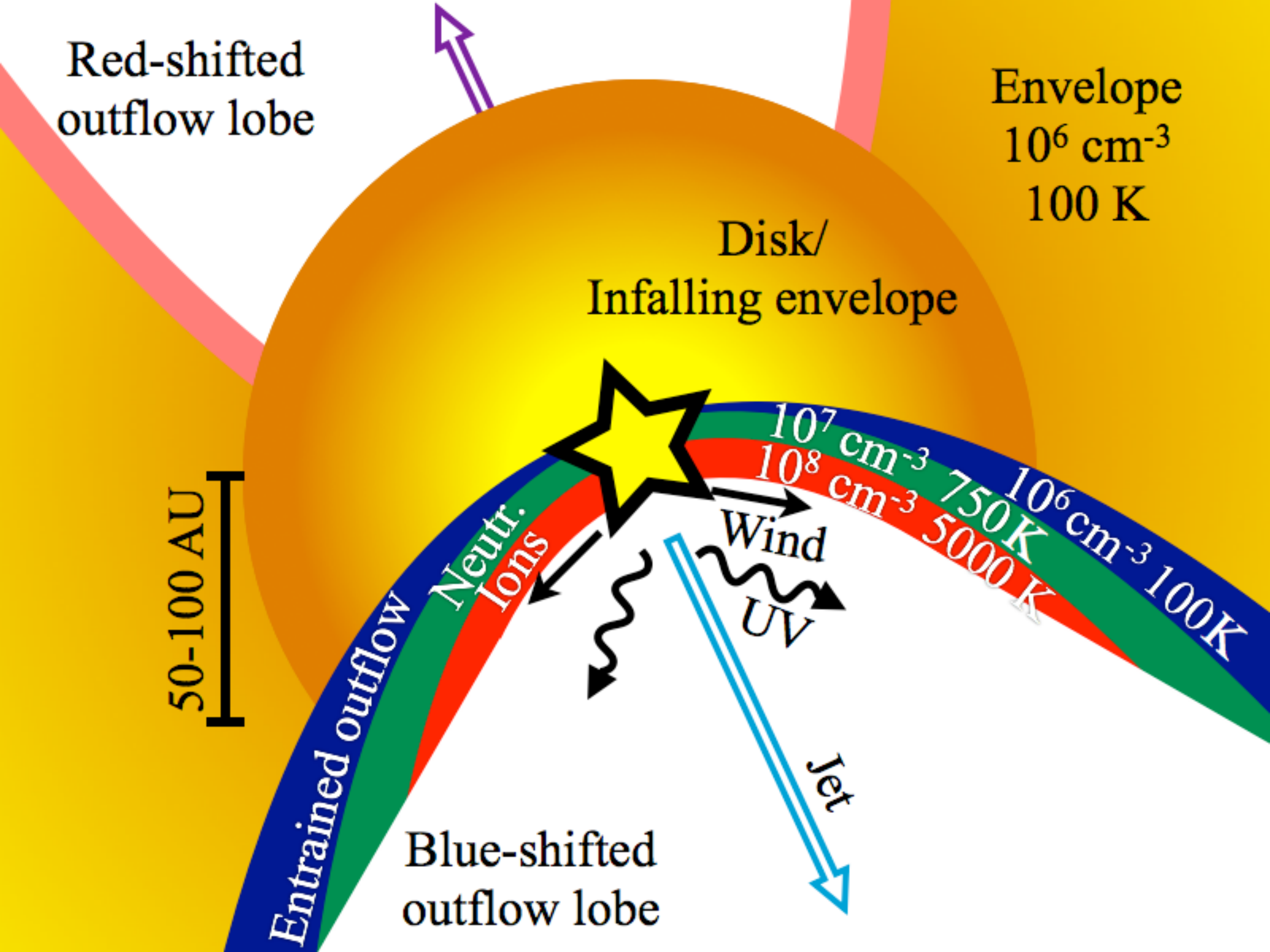
→ talk by A. Benz

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



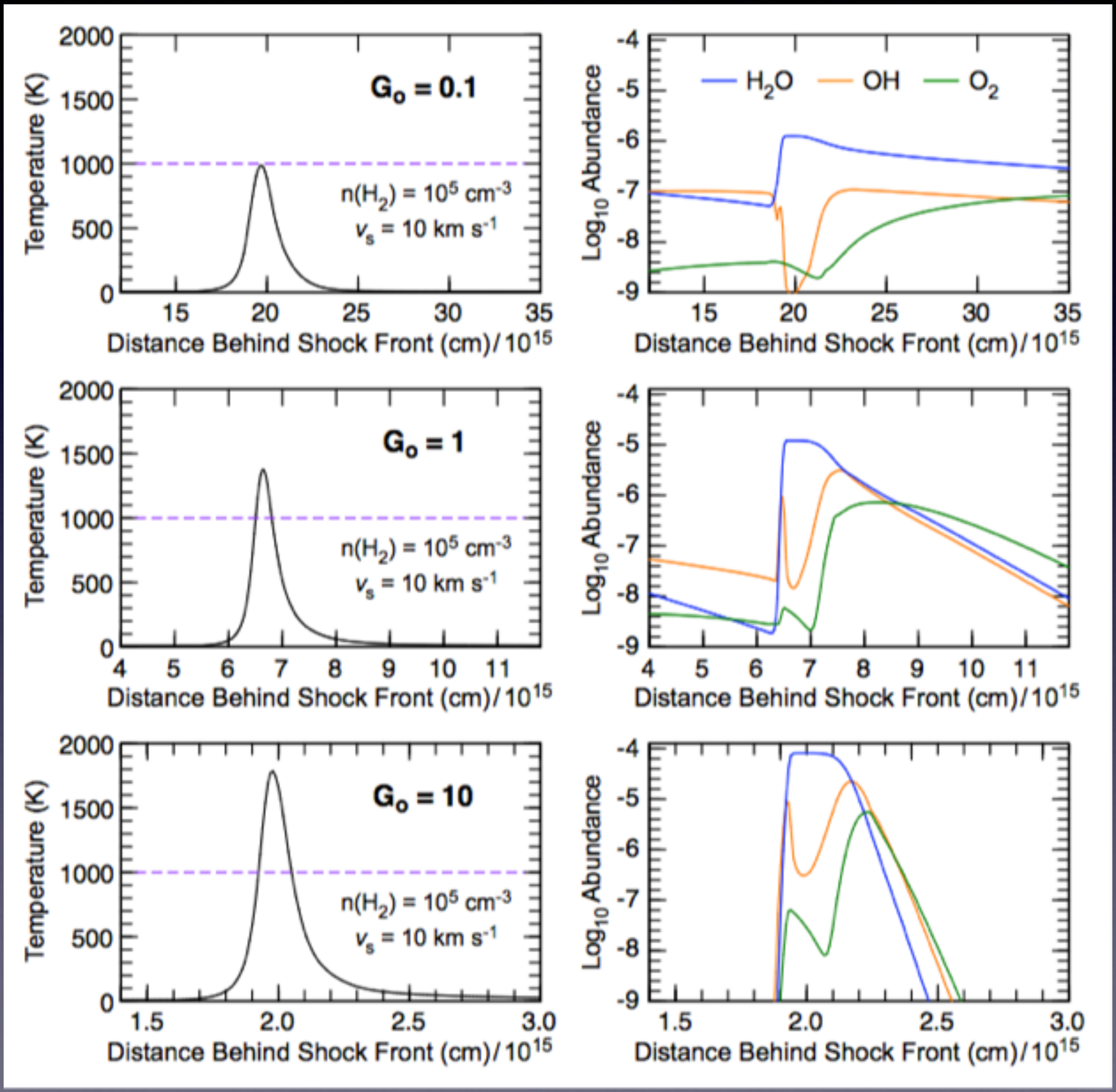
Kristensen et al. (2013)
Benz et al. (2015)

L. Kristensen



Red-shifted
outflow lobe
Envelope
10^6 cm^{-3}
100 K
Disk/
Infalling envelope
10^7 cm^{-3}
10^8 cm^{-3}
750K
5000 K
10^6 cm^{-3} 100K
Wind
UV
Neutr.
Ions
Entrained outflow
50-100 AU
Jet
Blue-shifted
outflow lobe

FUV irradiated C shock models



- UV affects the thermal structure of the shock

- UV increases pre-shock oxygen abundances

- UV dissociates post-shock H_2O

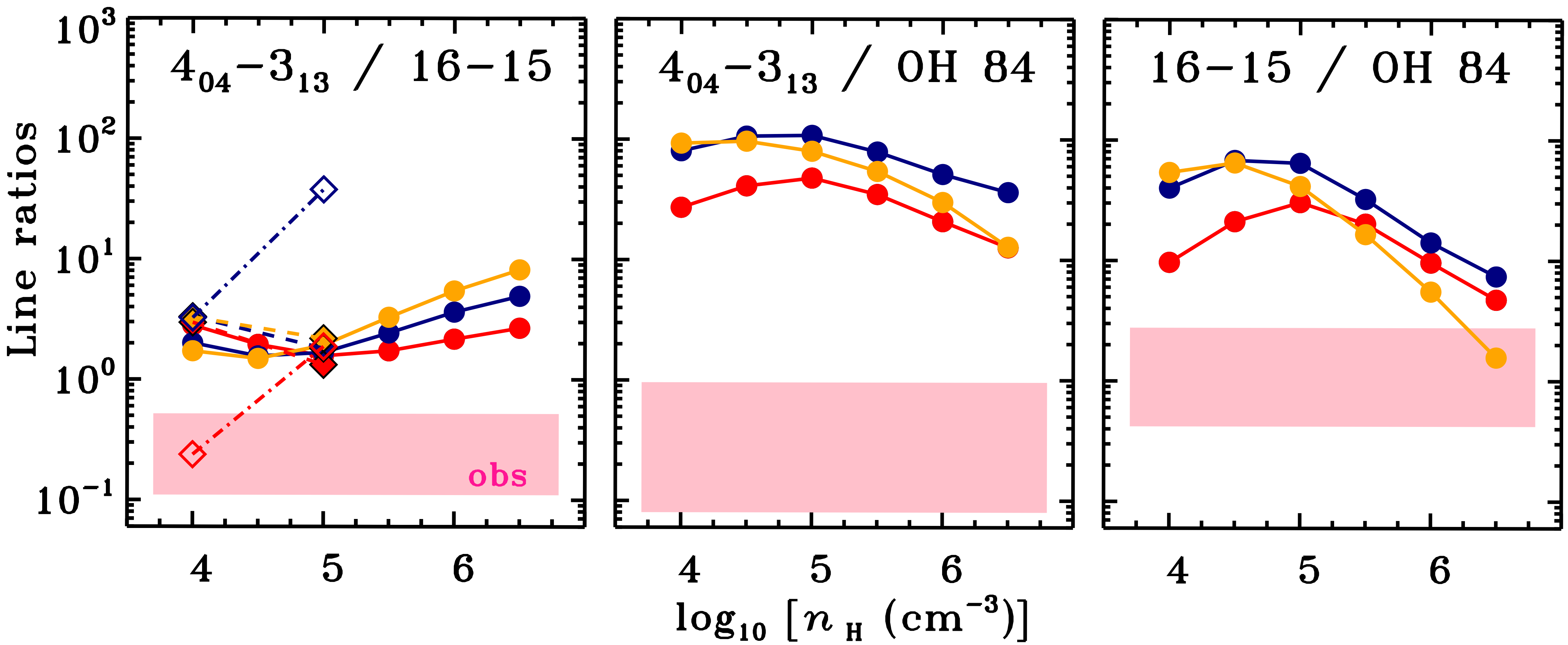
→ talk by M. Kaufman

Melnick & Kaufman 2015, Kaufman et al. in prep.

Karska et al. 2014b

Line ratios vs. shock models

H_2O / CO H_2O / OH CO / OH

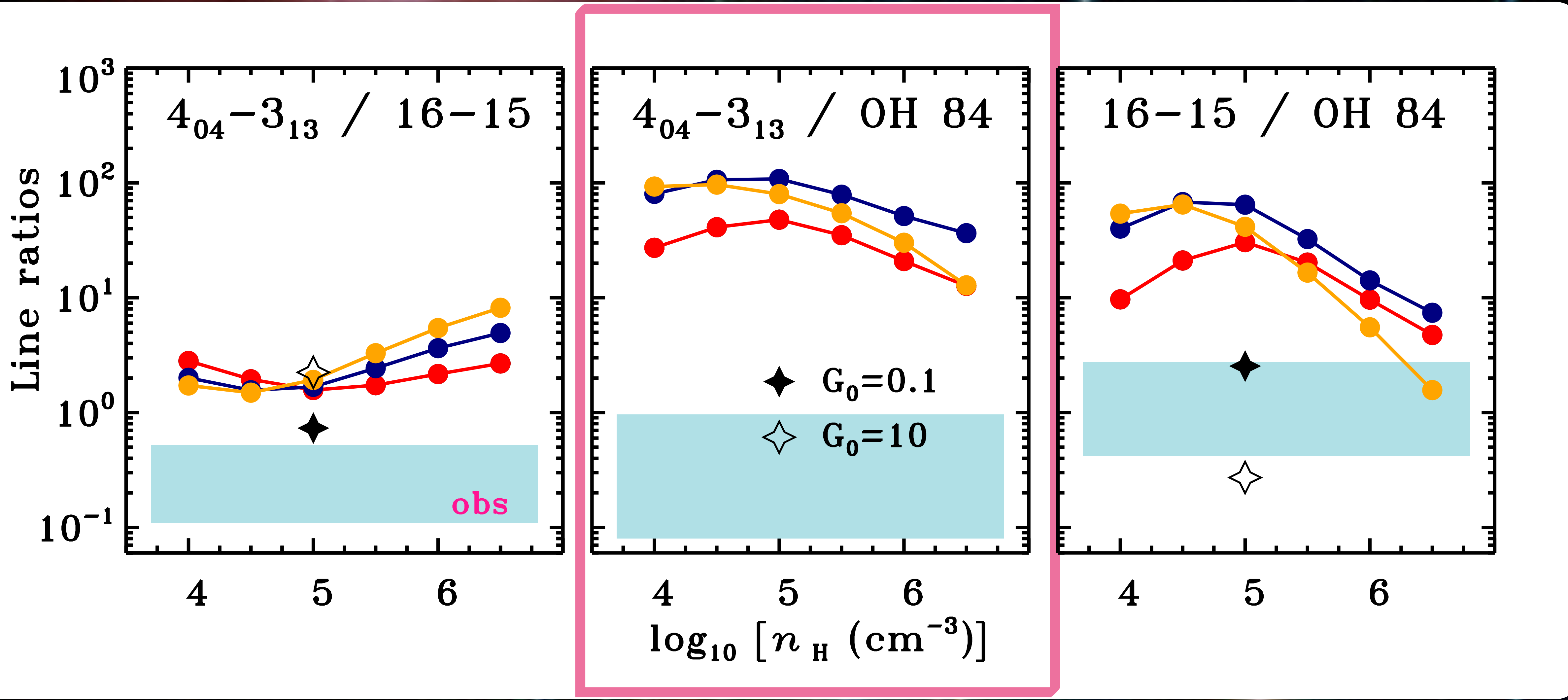


- Observed ratios with H_2O much lower than shock models
- FUV photodissociation likely at play

Karska, Kaufman, et al. subm.

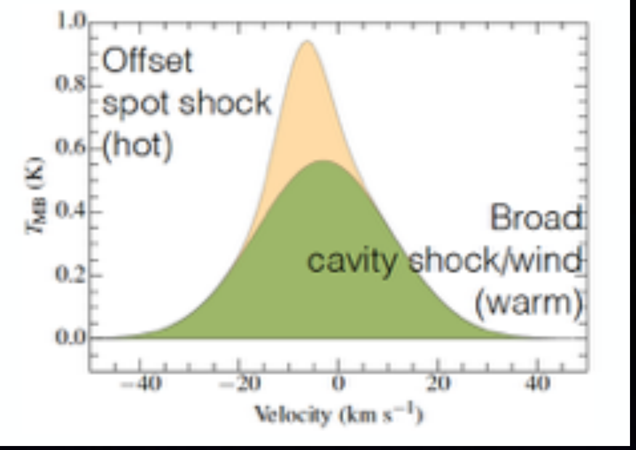
Line ratios vs. shock models

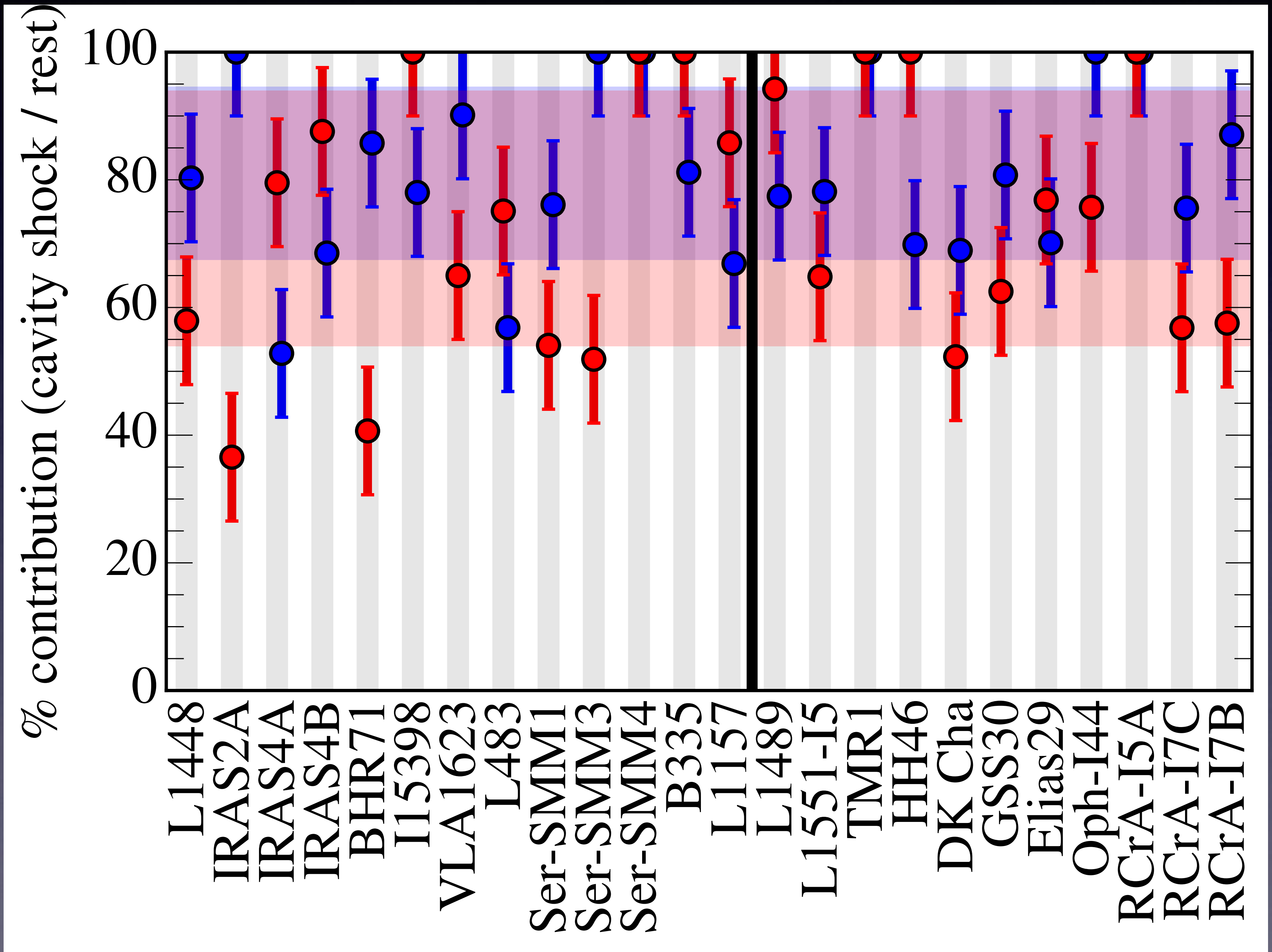
H_2O / CO H_2O / OH CO / OH



- C-shock models with UV and pre-shock densities of 10^5 cm^{-3} reproduce the observations well

Profiles: warm vs. hot



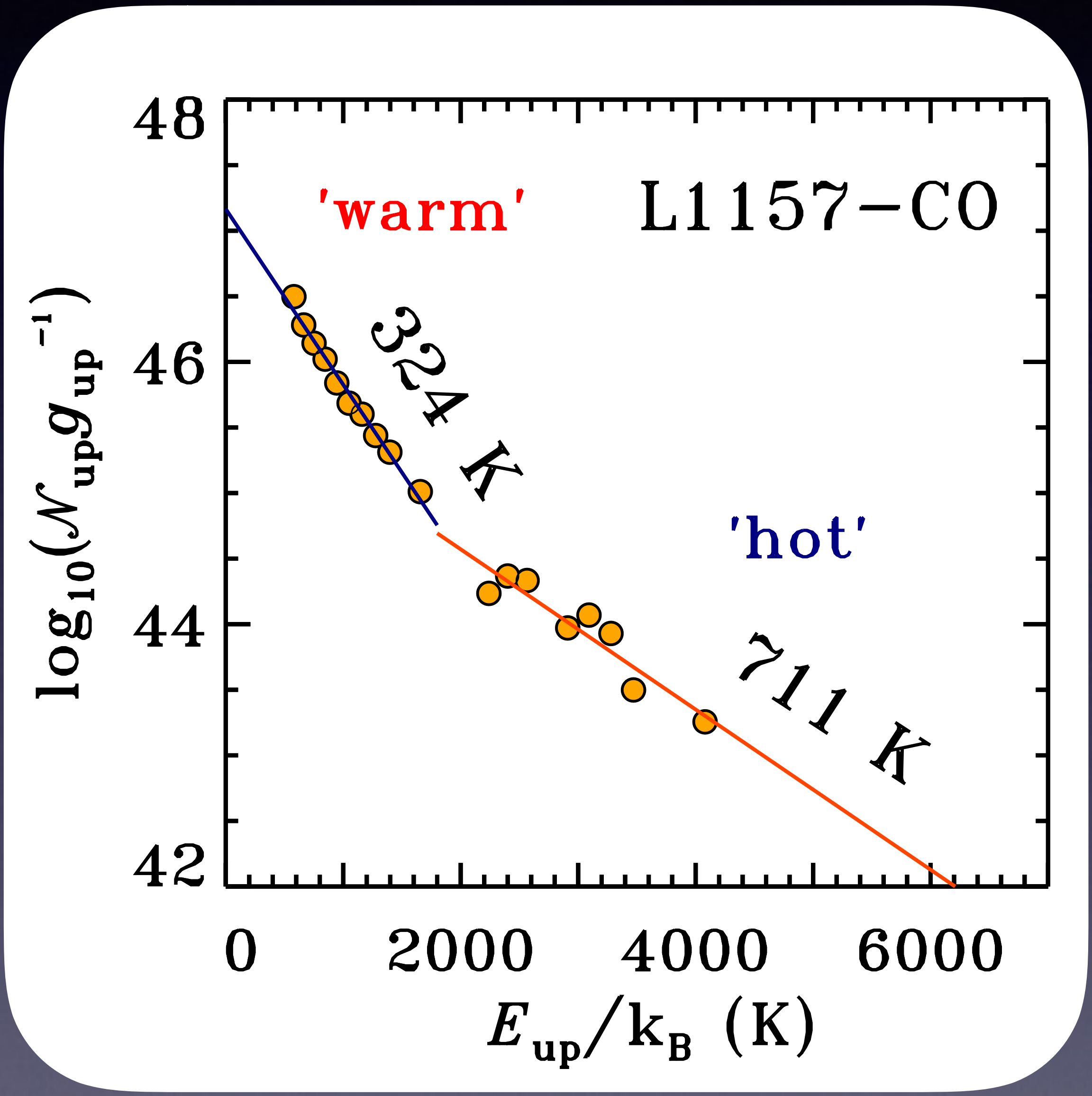


Broad, cavity shock component contributes ~75% to total CO 16-15

Distinct profile components can be linked to the components on CO ladders

Kristensen et al. subm.

Two-component CO ladders



Karska+13, Manoj+13, Green+13

- Ubiquitous 300 K 'warm' component and less frequent 'hot' component of 600-1100 K

- Warm and hot components contribute ~80% and ~20% to the total CO 16-15 flux

- Good agreement with fractions of the flux in cavity and offset components in line profiles

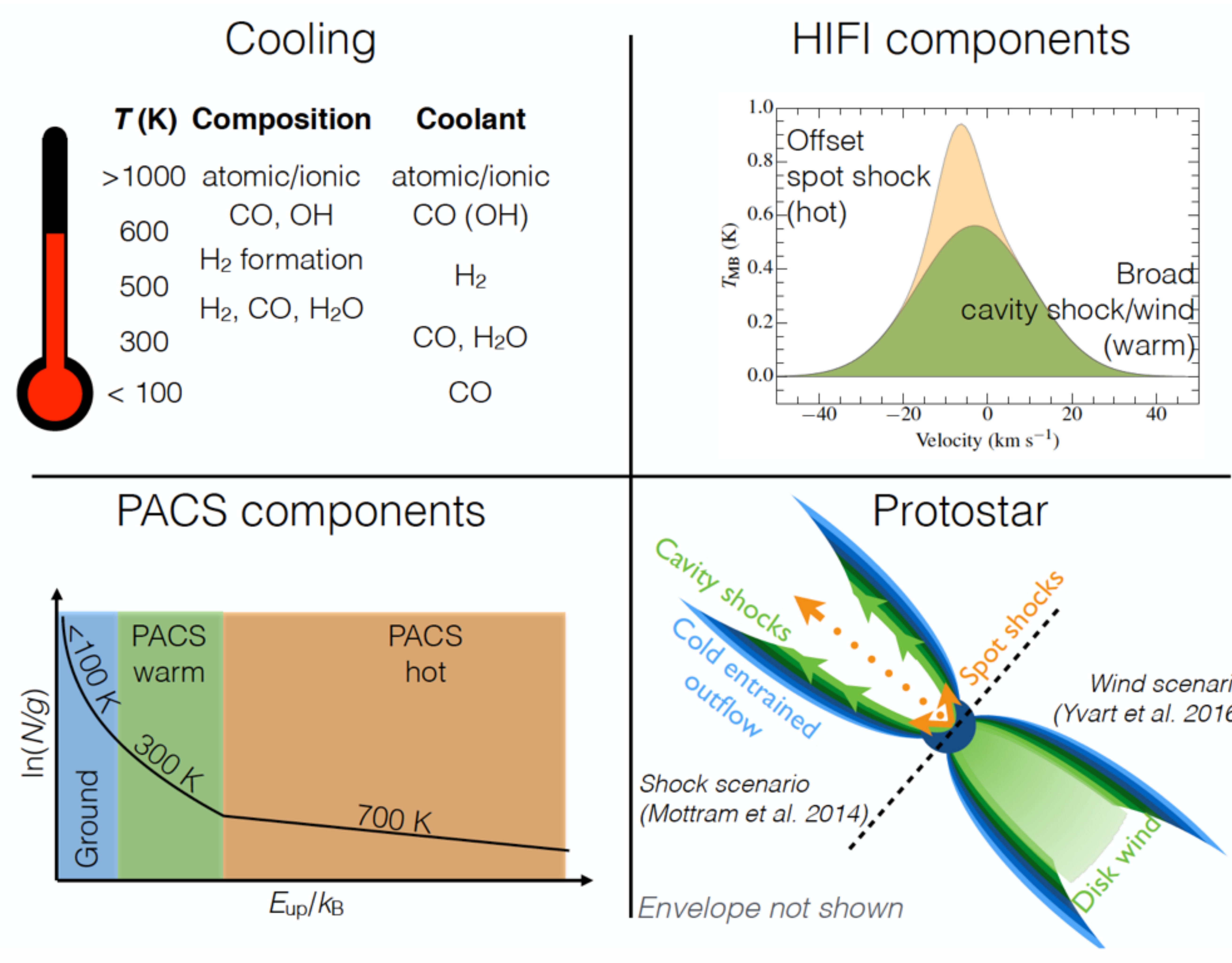


Fig. Lars E. Kristensen

Take-home messages

- Distinct blue-shifted velocity-component seen in H_2O and CO 16-15 lines can be linked to UV via profiles of light ionised hydrides

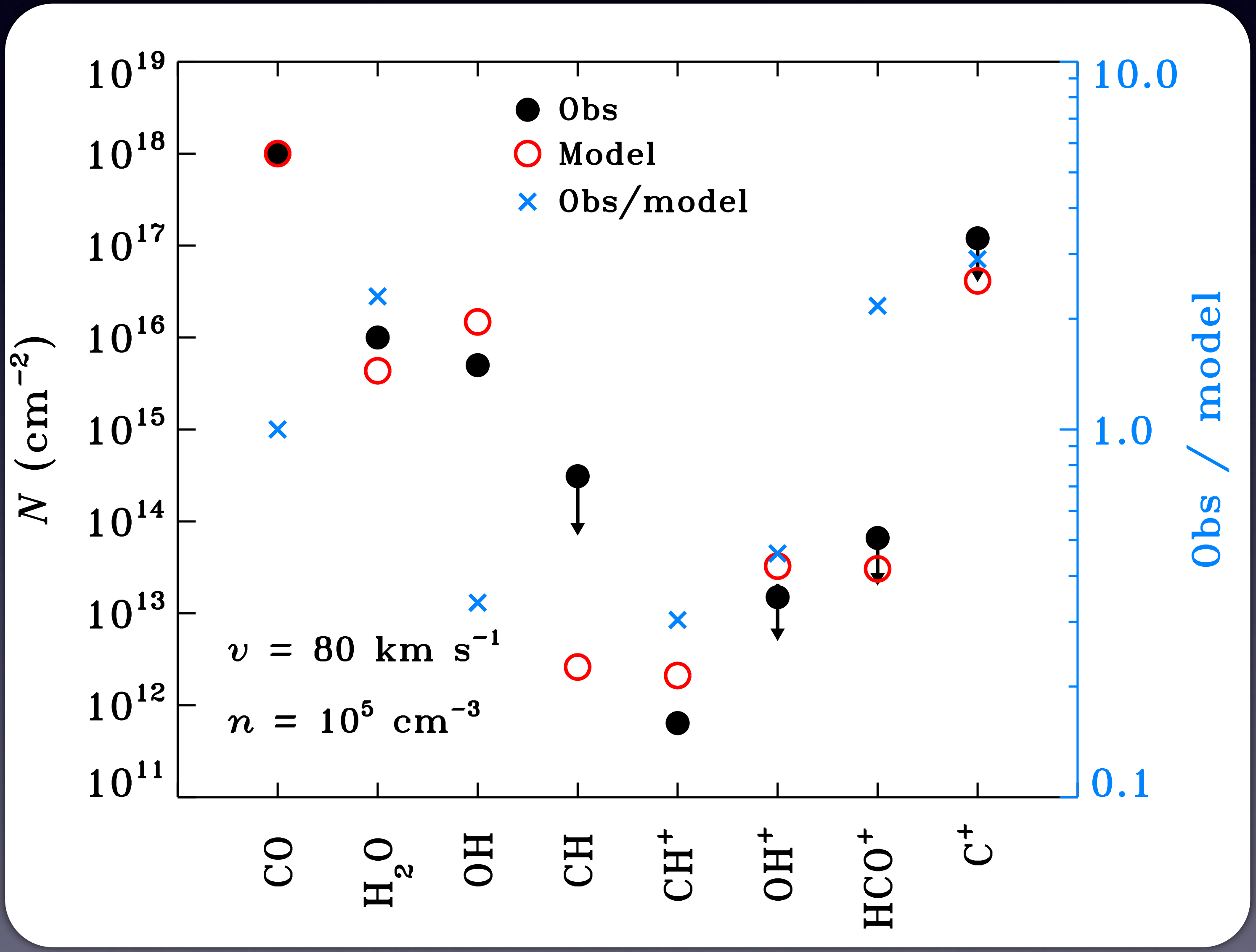
- Presence of UV photons explains low H_2O abundances, far-IR line ratios and likely CO ladders of low-mass protostars

- High spectral resolution spectra in the 50-200 μm are extremely useful for the interpretation (HIRMES!)

Model comparison

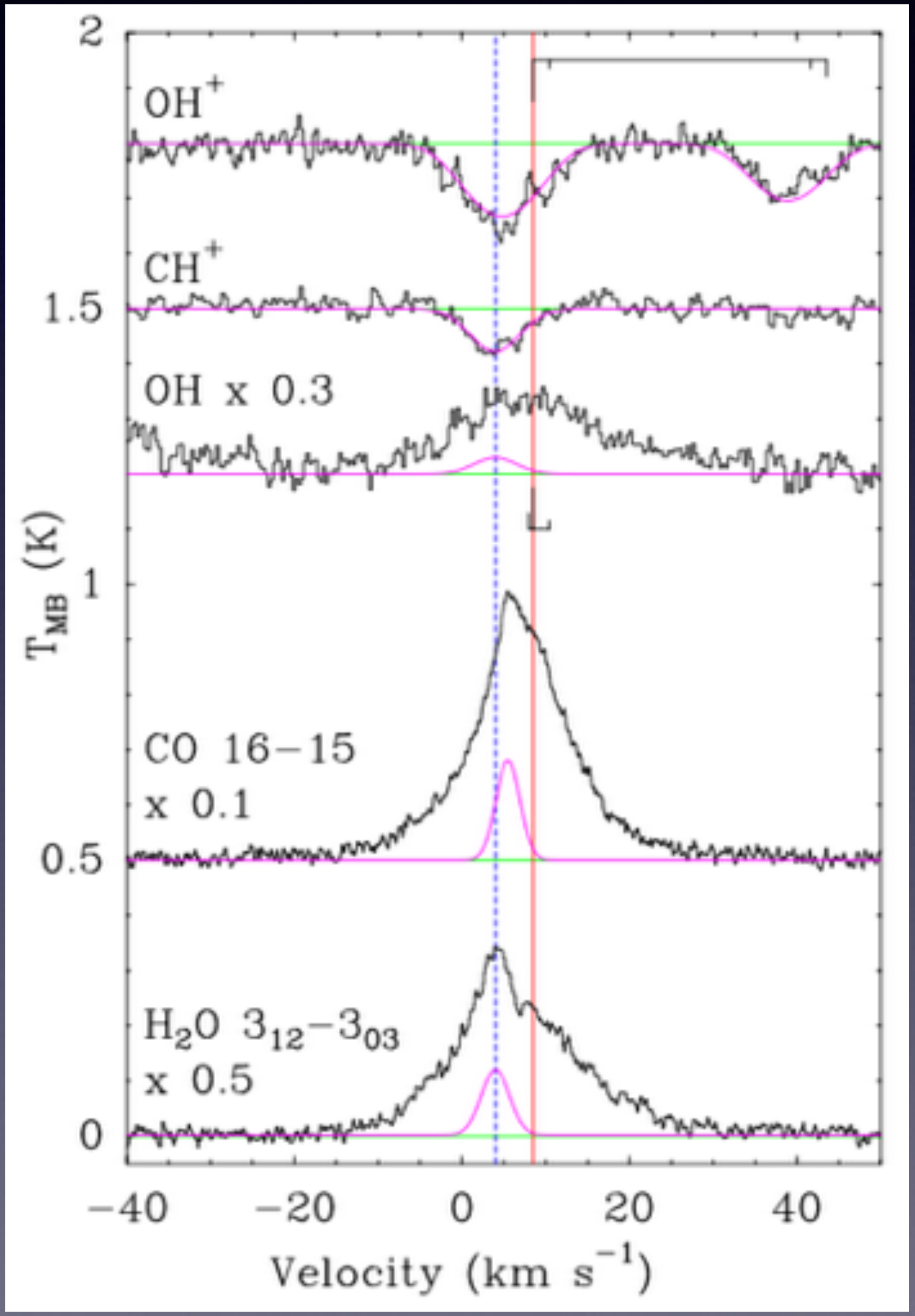
- Dissociative wind shocks
  (Neufeld & Dalgarno 1989)
- Column densities match within factor of 3

NGC1333-I4A
L ~ 5 $L_\odot$
D ~ 230 pc



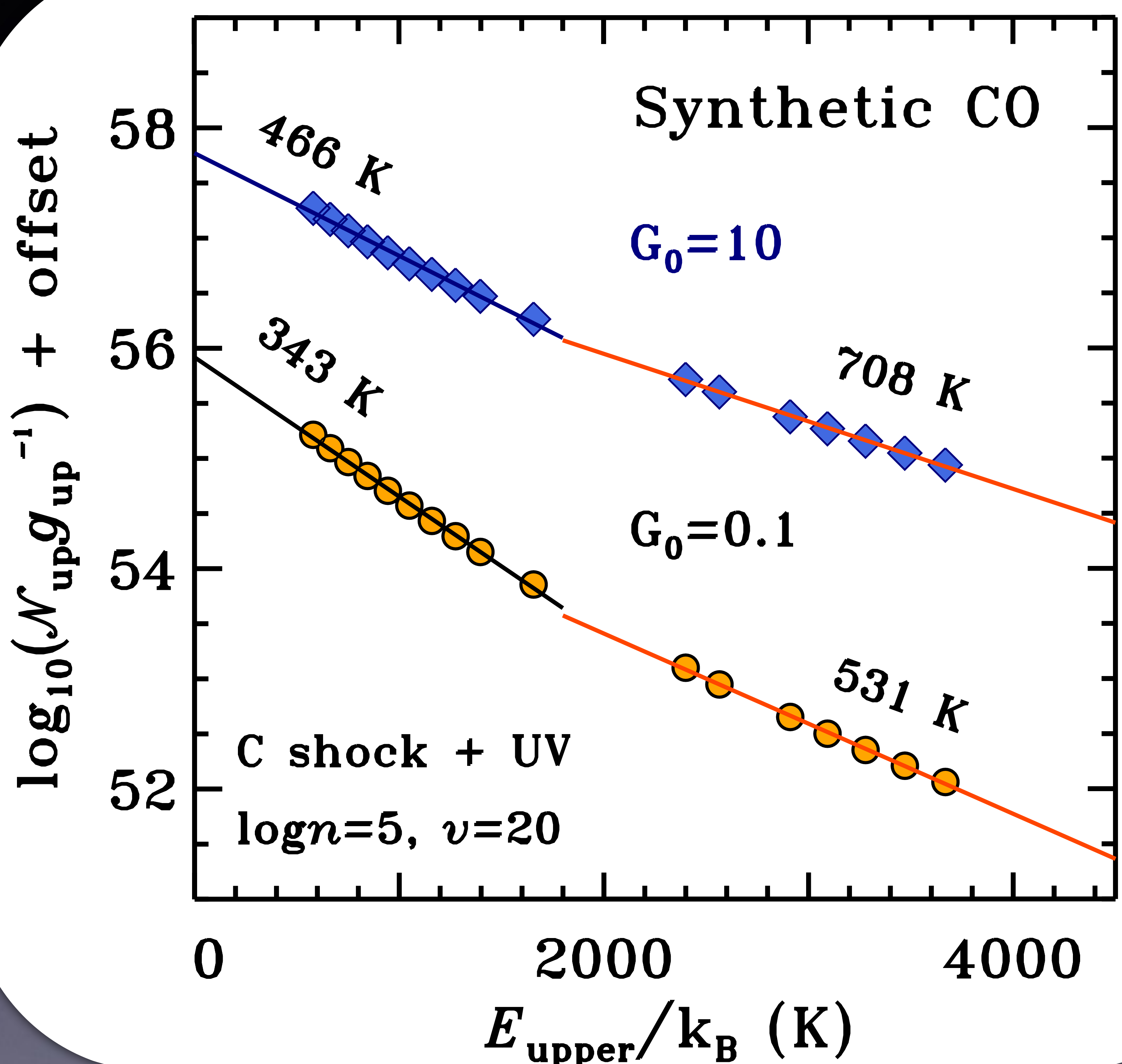
Link to velocity resolved line profiles

Kristensen+13,16, Mottram+14



- Respective kinematic component of the 'hot' PACS component seen in the HIFI line profiles
- Same velocities as hydrides, confirming the connection to the UV irradiation

Irradiated shocks: CO ladders



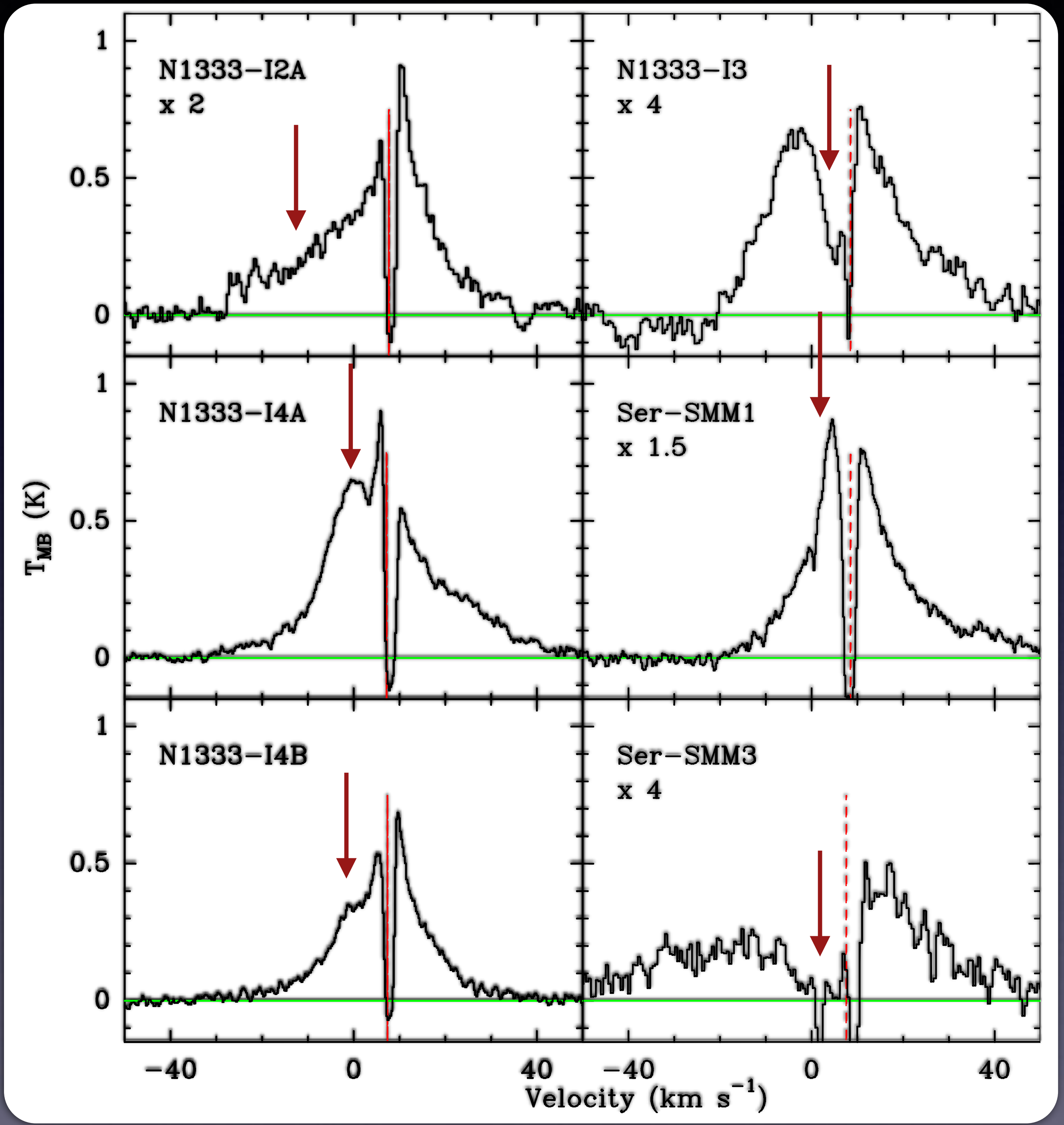
Karska, Kaufman, subm.

Models with UV reproduce highly-excited CO lines

Spot shock components

- Typically offset to the blue by 5-10 km s^{-1}
- FWHM of 5-10 km s^{-1}
- New and unseen in, e.g., CO 3-2

(Kristensen et al. 2013)



H_2O 557 GHz $J = 1_{10}$-1_{01}
Observed with Herschel-HIFI

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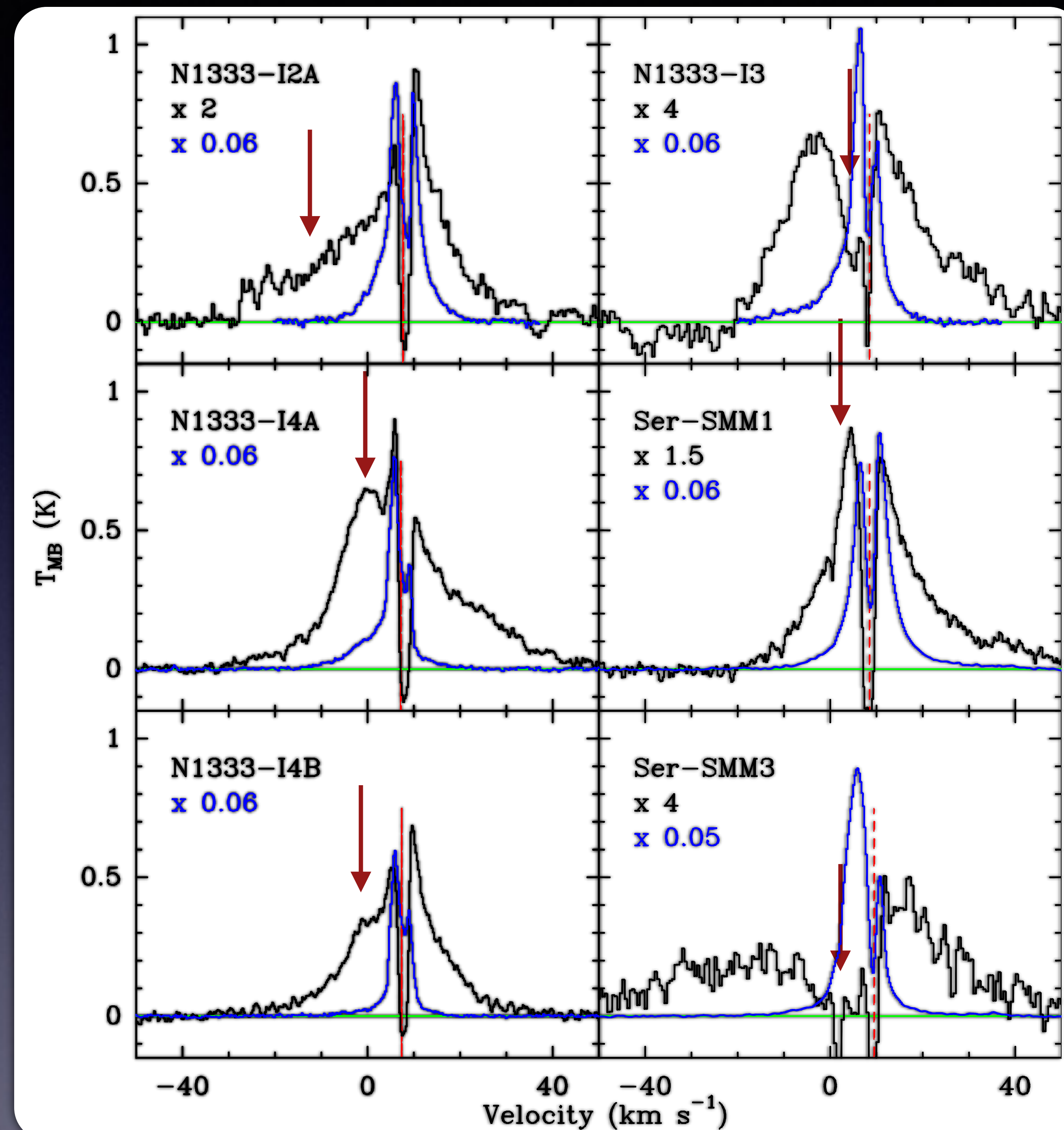
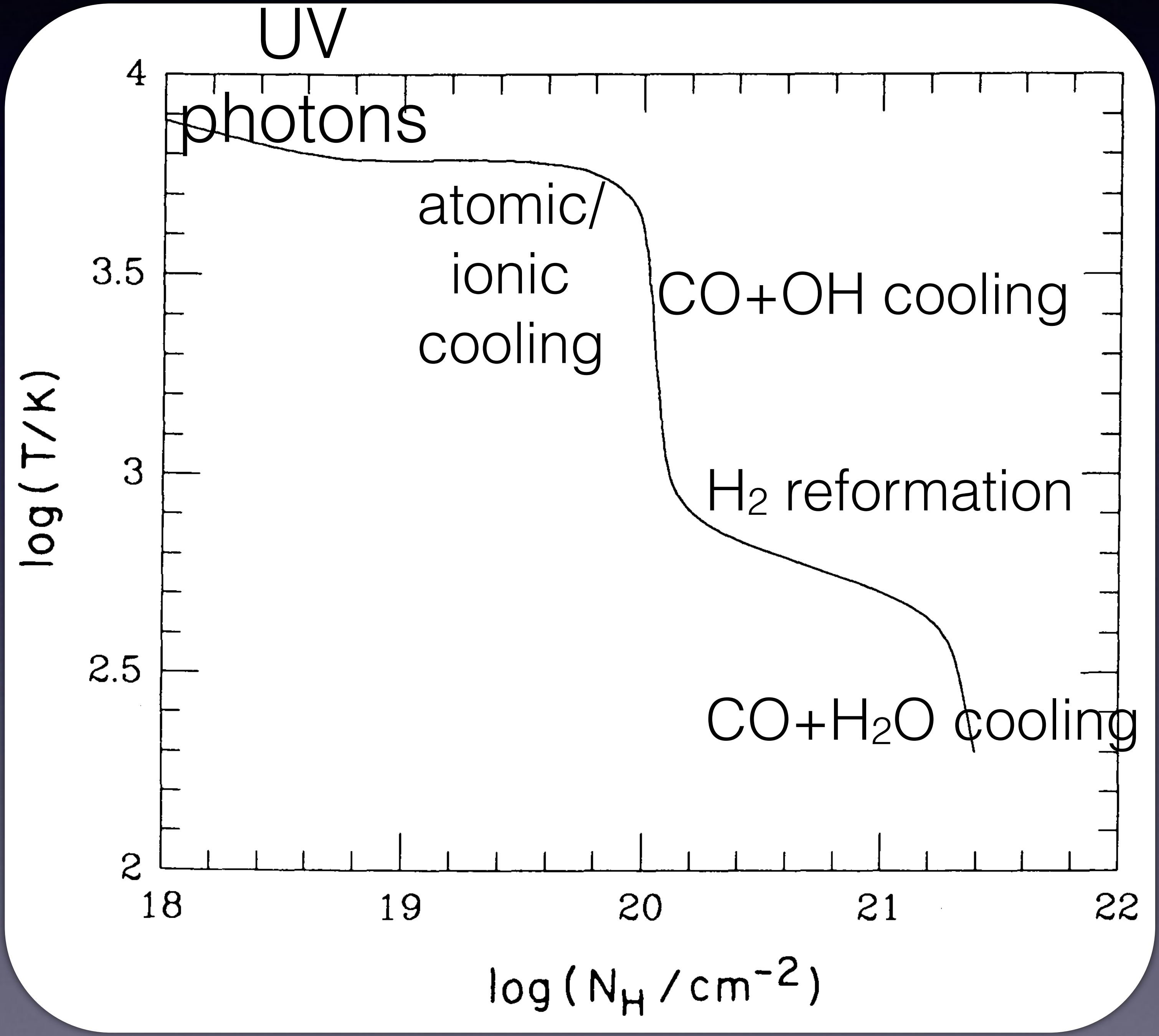


H_2O 557 GHz $J = 1_{10}\text{-}1_{01}$
Observed with Herschel-HIFI

Excitation & chemistry

- Water/HCO^+ require dense medium, CO requires hot medium: $n(H_2) \sim 10^7$ cm^{-3}, $T \sim 700$ K
- Chemical key: H_2 dissociation + reformation
- UV radiation required for pre-dissociation



Neufeld & Dalgarno 1989