Sunbathing around low-mass protostars: new insights from hydrides

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Sunbathing around young stars

- Dissociation of CO at the apex of the jet & narrow CO profiles
- Importance of UV heating along the outflows
- 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
Protostars interact violently with their surroundings. HH46, Arce+13

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

- Far-IR: shocks!

- Nisini+10, 15

Spitzer IRAC

Herschel PACS

H$_2$O
179 µm

protostar

L1157 mm
10^4 AU

Vel (km/s)

- Extended pattern of emission and broad line profiles clearly point to shocks
H$_2$O complex profiles

H$_2$O - a key tracer of dynamics in young stellar objects
Broad line profiles indicate the presence of $\sim$20-50 km s$^{-1}$ gas
- Detections of CO $J_{\text{up}}=14-49$ and highly excited H$_2$O
- Broadly consistent with predictions from shock models
- Line ratios remarkably similar across the sample
- Velocities $> 20 \text{ km s}^{-1}$, pre-shock densities of $\sim 10^5 \text{ cm}^{-3}$
- Observed ratios with H$_2$O much lower than shock models
- FUV photodissociation likely at play
H$_2$O complex profiles

H$_2$O - a key tracer of dynamics in young stellar objects

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

van Dishoeck+10, Kristensen+12, Mottram+14,16
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\(_2\)O 557 GHz \(J = 1_{10}-1_{01}\)
Observed with Herschel-HIFI
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)
FUV irradiated C shock models

- UV affects the thermal structure of the shock
- UV increases pre-shock oxygen abundances
- UV dissociates post-shock $\text{H}_2\text{O}$

→ talk by M. Kaufman

Melnick & Kaufman 2015, Kaufman et al. in prep.
Line ratios vs. shock models

\[ \frac{H_2O}{CO} \quad \frac{H_2O}{OH} \quad \frac{CO}{OH} \]

- Observed ratios with \( H_2O \) much lower than shock models
- FUV photodissociation likely at play
Line ratios vs. shock models

- C-shock models with UV and pre-shock densities of $10^5$ cm$^{-3}$ reproduce the observations well
Profiles: warm vs. hot

Kristensen et al. subm.

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

Distinct profile components can be linked to the components on CO ladders
Two-component CO ladders

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

- Warm and hot components contribute \( \sim 80\% \) and \( \sim 20\% \) to the total CO 16-15 flux

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

Karska+13, Manoj+13, Green+13
Take-home messages

- Distinct blue-shifted velocity-component seen in H$_2$O and CO 16-15 lines can be linked to UV via profiles of light ionised hydrides

- Presence of UV photons explains low H$_2$O 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⊙
D ~ 230 pc

\[ n = 10^5 \text{ cm}^{-3} \]
\[ v = 80 \text{ km s}^{-1} \]
Link to velocity resolved line profiles

- 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

Models with UV reproduce highly-excited CO lines

Karska, Kaufman, subm.
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Excitation & chemistry

- Water/HCO\(^+\) require dense medium, CO requires hot medium: 
  \(n(\text{H}_2) \sim 10^7 \text{ cm}^{-3}\), \(T \sim 700 \text{ K}\)

- Chemical key: \text{H}_2\text{ dissociation} + \text{reformation}

- UV radiation required for pre-dissociation

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Neufeld & Dalgarno 1989