7- Water in the protostellar envelopes

ISO observations of water in protostellar envelopes.
The collapsing protostellar phase and the enhancement of the water abundance
7- Water in the protostellar envelopes

THE COLLAPSING PROTOSTAR PHASE
THE CLASS 0 SOURCES

The Class 0 sources were discovered about 10 years ago as mm continuum sources, with no IR or FIR counterparts. The prototype of the Class 0 sources is IRAS16293-2422 (IRAS16293), in the ρ Oph complex. Because of its vicinity (120pc) and relatively large envelope (~3Mo), it is the best studied Class 0 source.

The figure on the left shows a map of the H$_2$CO emission around IRAS16293. The two stars are the two YSOs of the region, IRAS16293 (on the right) and 16293E (on the left). Note that while IRAS16293 « shines » in H$_2$CO, the other source, colder and likely younger, does not. In addition to the envelope of IRAS16293 there are other peaks of H$_2$CO emission. They are associated with the shocks at the interface of the gas outflowing from IRAS16293 and the parental cloud gas. Highly collimated and fast outflowing gas, giving rise to « bright » shocks, are indeed a distinct propriety of Class 0 sources.
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THE STRUCTURE OF CLASS 0 SOURCES

The structure of the envelopes of Class 0 sources has been the target of many studies in the last few years. The best way to probe it is by looking at different molecular lines (which probe different regions of the envelope). On the right, skematically illustrated the envelope structure, as reconstructed based on several observations. The envelope can be approximated as formed by an outer, cold (<100K) envelope and a inner, warm (>100K) envelope.
Several molecules (H$_2$O, OI, SiO, H$_2$CO, SO, SO$_2$...) have been used to derive the structure of the envelope of the Class 0 protostar IRAS16293-2422. Formaldehyde and methanol are the two molecules which have been used to study a sample of about 10 Class 0 sources. Typically, around 8 lines from the same molecule are observed (Fig. shows an example of 4 H$_2$CO lines), and then interpreted by means of sophisticated models, the « radiative transfer »
The abundance of the observed molecule is approximated by a jump function: in the outer envelope the abundance is $X_{\text{out}}$, in the inner envelope, where $T_{\text{dust}}>100K$, it is $X_{\text{in}}$. The dust temperature and density profiles are derived by continuum observations. The gas and dust density profile is approximated by power laws, constrained by the observations.
In the outer envelope the chemical composition is similar to that of the pre-stellar cores: CO is often found depleted and deuterated molecules are very abundant. This is for example shown in the right Figure, where the formaldehyde and CO abundances are reported for a sample of Class 0 sources (circles; from Maret et al. 2004) and Pre-Stellar Cores (triangles; Bacmann et al. 2003).
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THE CLASS 0 SOURCES : the outer envelope

Observed large $\text{D}_2\text{CO}/\text{H}_2\text{CO}$ ratios.
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THE CLASS 0 SOURCES: the inner envelope

In the inner envelope the dust temperature exceeds the grain mantle evaporation (~100K), the mantles sublimate, injecting into the gas phase the molecules in the mantles: H₂O, H₂CO, CH₃OH, NH₃…. The Fig. shows the X_{in}(H₂CO) example (Maret et al. 2004). In the warm gas, fast chemical reactions involving the « mantle released » molecules take over, and new complex, pre-biotic molecules are found: methil cyanide, acid formic…. 
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\( \text{H}_2\text{O OBSERVATIONS OF CLASS 0 SOURCES} \)

The first, and so far only, multifrequency observations of water vapour in protostars have been obtained with ISO. The problem with these obs is that they had relatively poor spatial and spectral (\( \Delta \nu/\nu \approx 200 \)) resolutions.

NGC1333-IRAS4 (Maret et al. 2002 A&A)
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H₂O OBSERVATIONS OF CLASS 0 SOURCES

Given the poor spatial and spectral resolutions, there is a debate on the origin of the water lines observed by ISO towards low mass protostars.

1. H₂O lines detected on-source and rarely on the outflow peaks

2. H₂O fluxes correlated with the envelope mass (1.3mm)

THE ORIGIN OF THE H₂O LINES OBSERVED BY ISO:

LIKELY IN THE PROTOSTELLAR ENVELOPES
MODELING OF THE OBSERVED H$_2$O EMISSION:

THE THERMAL AND CHEMICAL STRUCTURE OF REAL PROTOSTARS: IRAS16293-2422 & NGC1333-IRAS4

(Ceccarelli et al. 2000 A&A; Maret et al. 2002 A&A)

THE MODEL DOES A VERY GOOD JOB IN REPRODUCING THE OBSERVED LINE FLUXES!

WHICH IMPLIES THAT WE MASTER THE HEATING AND COOLING OF THE GAS!
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THE H$_2$O ABUNDANCE in
IRAS16293-2422 and NGC1333-IRAS4

FROM THE OBS WE DERIVED:
1. DENS AND TEMP PROFILES
2. H$_2$O ABUNDANCE

RESULTS:

1. The derived density and temperature profiles compare very well with previous and later derivations, obtained by different authors with different techniques.
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THE \( H_2O \) ABUNDANCE in
IRAS16293-2422 and NGC1333-IRAS4

FROM THE OBS WE DERIVED:

1. DENS AND TEMP PROFILES
2. \( H_2O \) ABUNDANCE

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<tr>
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<th>I16293</th>
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<tr>
<td>( X_{IN}(H_2O) )</td>
<td>( 3\times10^{-6} )</td>
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</tr>
<tr>
<td>( X_{OUT}(H_2O) )</td>
<td>( 3\times10^{-7} )</td>
<td>( 3\times10^{-7} )</td>
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RESULTS:

1. \( X_{OUT}(H_2O) \) is close to the predicted value
2. \( X_{IN}(H_2O) \) is about a factor 10 lower than predicted
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WHY THE EVAPORATED H₂O IS SO LOW ???

1. The model assumes the sperical symmetry, which very likely breaks downs at small scales, where the ice evaporation takes place

2. The lines used to derive the water abundance are very thick, so a relatively small error in the opacity determination ends up with a large error in the estimated water abundance

3. The water ices do not entirely evaporate at the temperatures reached in low mass protostars.
Summary

• The envelopes of the youngest protostars, the Class 0 sources, are formed by a cold (<100K) and a warm region.

• The outer cold envelope shares many of the chemical properties of the Pre-stellar Cores.

• The chemical composition of the inner warm envelope is dominated by the ice mantle evaporation.

• The observed water abundance in the outer cold envelope is \(~3\times10^{-7}\), consistent with model predictions.

• In the inner warm envelope the water abundance is about 10 times larger, \(~3\times10^{-6}\), about 20 times lower than expected.