6- Water in the outflow shocks

ISO, SWAS and ODIN observations of water in the outflow shocks.

Water formation in molecular shocks: water fountains in the space
THE FORMATION OF OUTFLOWS
The collapse and the conservation of the angular momentum: the formation of outflows and the disks.

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PROBES OF THE OUTFLOWS

The shocks of the outflow are characterized by the emission from plenty of molecules, which are not detected in cold molecular clouds. SiO is one of the first, and most used molecules to probe the outflows. In molecular clouds, Sylicon is almost completely trapped in the dust grains, but shocks can destroy the grain mantles, and if violent enough, also shatter the grain cores. Whent this occurs, Si is released into the gas, where it is readly oxydized to forms SiO. The figure on the left shows again the IRAS16293 region, in theSiO 2-1 line: the regions where SiO emission is bright are not the same where H$_2$CO emission is bright.
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EXAMPLES OF Class 0 OUTFLOWS

Bachiller 1996

SiO

CO (1-0)
SiO (2-1)
CO (2-1)

Reipurth et al 2002

C.Ceccarelli : Water in circumstellar disks and interstellar medium
Astrobiology Winter School, Hawaii 2005
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EXAMPLES OF OUTFLOWS: HH objects
Reipurth et al 2002
THE INTERACTION OF THE OUTFLOWS WITH THE SURROUNDINGS:

When the outflowing gas (travelling at ~100-300km/s) encounters the ambient gas (which is not moving), shocks occur at the interface. Depending on the violence of the shock, there are two types of molecular shocks:

1. when the shock is relatively gentle ($v_s < 50-60$km/s), and there is a magnetic field in the gas, the shock is a Continuum shock, and it is called C-shock;

2. in more violent shocks, all the macroscopic quantities (density and temperature) undergo a Jump, and the shock is called J-shock.
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THEORY OF MOLECULAR SHOCKS : C-SHOCKS

In C-shocks the temperature reaches 3000K at most and molecules are not dissociated. On the contrary, some molecules are even formed in larger quantities, because of the endothermic reactions that take place at those temperatures. WATER is evidently a notable example.
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THEORY OF MOLECULAR SHOCKS: C-SHOCKS

Here are theoretical predictions of C-shocks (Kaufman & Neufeld 1996)

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THEORY OF MOLECULAR SHOCKS : J-SHOCKS

In J-shocks the temperature has a jump, and reaches 10^5K. UV photons and collisions destroy all the molecules which are reformed in the region behind the shock, the so-called post shock region. In the post-shock region the gas cools down from 10^5K to 10K. In the region where the temperature is >250K and shielded by the UV photons, WATER is abundantly formed.

Therefore J-shocks are characterized by strong atomic emission (OI, C^+) and weaker, but still bright molecular emission.
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THEORY OF MOLECULAR SHOCKS: J-SHOCKS

Here are theoretical predictions of J-shocks
(Hollenbach & McKee 1979, 1989)
ISO OBSERVATIONS OF WATER IN SHOCKS

HH54B was the first shock where $H_2O$ emission was detected (Liseau et al. 1996).

Soon after bright water abundance was detected towards Orion (Harwit et al. 1997).

ISO observed water emission in several shock regions. The measured water abundance in ranges from $10^{-5}$ to $10^{-4}$ wrt $H_2$, pretty much in agreement with model predictions.
SWAS OBSERVATIONS OF WATER

SWAS also observed bright water emission at 557GHz. The advantage of the SWAS observations is that they have a very good spectral resolution, and can therefore resolve the lines. The disadvantage is that with one single line it is difficult to estimate the water abundance. However, when done, the estimates are in agreement with the ISO estimates.
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HDO IN SHOCKS: THEORY
Since water in shocks is formed in the warm \((T>250K)\) gas, there is not enhanced deuterium fractionation. Therefore, HDO is expected to be much less abundant of \(H_2O\):

\[
\frac{\text{HDO}}{\text{H}_2\text{O}} \approx 10^{-4}
\]

Observations towards shocks confirm the lack of HDO emission. Actually, the \(\frac{\text{HDO}}{\text{H}_2\text{O}}\) ratio is considered one of the possible ways to discriminate the ice mantle origin.

In fact, in principle, once formed is a shock, water condenses onto the grain mantles after the shock passage and the cooling of the gas/dust. So, in principle, this is also a way to form water ice mantles.
6- Water in the outflow shocks

WATER ICE FORMATION BY SHOCKS

All the water copiously formed in (C-shocks) will freeze out onto grains and form water ices (Bergin et al. 1999).

Confirmation of the process by ISO obs, which detected crystalline water ice in a shocked regions (Molinari et al. 1999)
6- Water in the outflow shocks

Summary

• Molecular shocks were predicted to be powerful source of water

• The predictions were substantially confirmed by ISO and SWAS observations, that detected bright water line emission in shocked regions

• The derived water abundance in the shocks ranges between $10^{-4}$-$10^{-5}$ the $H_2$

• In principle, the water formed in a shock could form ice mantles after the passage of the shock

• The main discriminant for this possibility is the $HDO/H_2O$ ratio, which would be very low.