Ion-Neutral Reactive Scattering Studies for Astrophysics

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Outline

Diffuse clouds
First stars

Dense clouds
Organic chemistry

Prestellar cores
Deuterated chemistry
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Dense clouds
Organic chemistry

Diffuse clouds
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Prestellar cores
Deuterated chemistry
Formation of stars in the early universe

Gravity

As volume decreases temperature increases

Cloud cools by $\text{H}_2$ radiation

$T \rightarrow 200 \text{ K}$

These clouds are galactic is size.
Forming $H_2$ in the early Universe

Associative detachment (AD)

$$H^- + H \rightarrow H_2 + e^-$$
There is nearly an order of magnitude spread. This has significant cosmological implications.
The apparatus the day after first signal
Celebrating our success!

K. A. Miller, DWS, H. Kreckel, X. Urbain, H. Bruhns
Thermal data for $\text{H}^- + \text{H} \rightarrow \text{H}_2 + \text{e}^-$
Adding in our results

Temperature (K) vs. Rate coefficient (10^{-9} \text{ cm}^3 \text{s}^{-1})

Kreckel et al. 2010, Sci 329, 69
Theory and experiment have finally converged.
Outline

Dense clouds

Organic chemistry

Diffuse clouds

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Prestellar cores

Deuterated chemistry
Pathway from atoms in space to life on Earth is full of unknowns.

How far did interstellar chemistry take us on this pathway towards life?
Some gas-phase pathways for forming the chemicals needed for life

Conditions in dense molecular clouds:

\[ n_H \sim 10^4 \text{ cm}^{-3} \quad T_{\text{gas}} \sim 10 \text{ K} \]

Binary Reactions

\[ \left\{ \text{H}_2 \right\} \rightarrow \text{H}_3^+ + \text{C} \rightarrow \text{CH}_n^+ + \text{HCN} \rightarrow \text{carboxyl cyano amino} \]
Published data for $\text{C} + \text{H}_3^+ \rightarrow \text{CH}^+ + \text{H}_2$

QM calc’s beyond current theoretical abilities.
No lab data exist at molecular cloud temperatures.
Over factor of 2 uncertainty in the rate coefficient.
We have built an apparatus to study
\[ C + H_3^+ \rightarrow CH_n^+ + H_{3-n} \]
Ken Miller, X. Urbain, DWS, Jule Stützel, A. O’Connor, Nathalie de Ruette

The Team Members
C + H$_3^+$ summed thermal rate coefficients

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>Rate coefficient (cm$^3$ s$^{-1}$)</th>
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<tbody>
<tr>
<td>10</td>
<td>10$^{-9}$</td>
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<tr>
<td>100</td>
<td></td>
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<tr>
<td>1000</td>
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</tbody>
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Reduced uncertainty from factor of >2 to <20%. 
Outline

- Diffuse clouds
- First stars
- Dense clouds
- Organic chemistry
- Prestellar cores
- Deuterated chemistry
Prestellar core properties can be probed using $H_2D^+$ and $D_2H^+$.
Ionization fraction is inferred using measured $\text{H}_2\text{D}^+$ and $\text{D}_2\text{H}^+$ abundances.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Rate Coefficient (10 K)</th>
<th>Uncertainty</th>
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<td>1.70e-09</td>
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</table>

We are measuring these last three reactions.
Published data for $\text{D} + \text{H}_3^+ \rightarrow \text{H}_2\text{D}^+ + \text{H}$

Langevin and semi-classical results differ by nearly an order of magnitude.

Cross section (Å$^2$) vs. Relative energy (kJ/mol)

- Classical
- Moyano et al. (2004, JCP)
D + H$_3^+$ exoergically forms H + H$_2$D$^+$...

...but with a barrier

Moyano et al. (2004) predict a 1700 K barrier. Reaction should be closed for prestellar cores.
Published data for $\text{D} + \text{H}_3^+ \rightarrow \text{H}_2\text{D}^+ + \text{H}$

Why do Moyano et al. predict a non-zero cross section below the barrier energy?
We have changed the source to study

\[ \text{D} + \text{H}_3^+ \rightarrow \text{H}_2\text{D}^+ + \text{H} \]
The Team Members

DWS, Xavier Urbain, Pierre-Michel Hillenbrand, and Kyle Bowen
Summary

We can study collision energies from 2 meV to 20 eV.
Summary

Associative detachment

H⁺ & H₂⁺ transfer

Isotope exchange

Thanks for your attention. Questions?