Making Water in C-Rich Winds

**Context**

Decin et al. (2010, Nature): Detection of warm water vapor in CW Leo

**Mechanism I:**
Deep-envelope penetration of interstellar UV

**Mechanism II:**
Shock-induced non-equilibrium chemistry

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Decin et al. 2010
Agúndez et al. 2010

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Cherchneff 2011
**Aims & Methods**

Constrain H$_2$O formation with Herschel data.

<table>
<thead>
<tr>
<th></th>
<th>MESS GTKP (PI: Groenewegen M.)</th>
<th>OT2 (PI: Decin L.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Miras</td>
<td>7 Miras + LL Peg</td>
<td></td>
</tr>
<tr>
<td>2 SRa variables</td>
<td>1 SRa variable (?)</td>
<td></td>
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<tr>
<td>0 SRb variables</td>
<td>4 SRb variables</td>
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Total: 18 sources

**Approach:**
1. Trend analysis of distance-independent line-strength ratios
2. Theoretical model grid for qualitative comparison
MAKING WATER IN C-RICH WINDS

MESS: V Hya

Spectra Samples

OT2: V384 Per
Results: Line Ratios

All 18 sources show H$_2$O emission!

Assumption: H$_2$O abundance ~ $I_{H_2O} / I_{CO}$ ~ $(I_{H_2O} / I_{H_2}) \times (I_{H_2} / I_{CO})$ if $\dot{M} \sim I_{CO}$

\[
\log \left[ \frac{I_{0H_2O(J=2,1-1,0,1)}}{I_{CO(J=15-14)}} \right]
\]

\[
\log \left[ \dot{M}_g (M_\odot/yr) \right]
\]
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Results: Line Ratios

All 18 sources show H$_2$O emission!

Assumption: H$_2$O abundance $\sim$ $I_{H_2O}$ / $I_{CO}$ $\sim$ ($I_{H_2O}$ / $I_{H_2}$) x ($I_{H_2}$ / $I_{CO}$) if $\dot{M}$ $\sim$ $I_{CO}$
Result: 6.3-Micron Flux

1. Stellar spectrum
2. Dust content
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Results: 6.3-Micron Flux

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**Results: 6.3-Micron Flux**

1. Stellar spectrum
2. Dust content

Decrease dust-to-gas ratio

\(0.005 \rightarrow 0.001\)
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Results: Model Comparison

\[
\log I_{\text{H}_2\text{O}(J=15-14)} / I_{\text{CO}(J=15-14)}
\]

\[\bar{m} = \dot{M} R / (4\pi v_\infty R^2)\]

\[\bar{m} = \dot{M} R / (4\pi v_\infty R^2)\]
Results: Water Line Ratios

Decin et al. 2010, Agúndez et al 2010:
Abundance with radial gradient

Cherchneff 2011:
Constant(-ish) abundance
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Results: Water Line Ratios

Constant Abundance works best
## Conclusions

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Room for improvement/future prospects/ideas:

1. **SHOCKS** Expand parameter space of chemical models
2. **SHOCKS** Higher accuracy reaction rates (laboratory measurements)
3. **IS-UV** Resolve the clumpy winds with ALMA!
4. **IS-UV** 3D radiative transfer vs 1D simplifications to model material clumping
5. **ALL** In-depth radiative-transfer modeling of individual C-rich sources (energy balance?)
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Cheers!
**Results: Water line ratios**

Decin et al. 2010, Agüindez et al. 2010: Abundance gradient

Cherchneff 2011: Constant Abundance