Photodissociation of N$_2$ and its impact on nitrogen chemistry in protoplanetary disks

Catherine Walsh
NWO Veni Fellow
Leiden Observatory

Hideko Nomura (Tokyo Institute of Technology)
Ewine van Dishoeck (Leiden Observatory/MPE)
Protoplanetary Disks

Protoplanetary disks are chemically layered

Adapted from Mumma & Charnley, 2011, ARA&A, 49, 471
Protoplanetary Disks

Zooming into the planet forming region (< 10 AU) ...

Sun-like stars show $\text{C}_2\text{H}_2$ emission at 13.7 \(\mu\text{m}\) AND HCN emission at 14.0 \(\mu\text{m}\).

Cool stars show $\text{C}_2\text{H}_2$ emission at 13.7 um AND NO HCN emission at 14.0 um.

Protoplanetary Disks

Zooming into the planet forming region (< 10 AU) ...

In the warm molecular regions of protoplanetary disks, nitrogen is mainly in the form of N$_2$ gas.

Photodissociation of N$_2$ releases N for incorporation into HCN.

N$_2$ is not observable in cold/warm gas so need to use proxies such as N$_2$H$^+$ and CN/HCN.

Many complex organic molecules are N-containing species, e.g., the simplest amino acid, glycine, NH$_2$CH$_2$COOH.

Complex Organic Molecules

Adapted from Hily-Blant et al. 2013, Icarus, 223, 585
Does the radiation field present in the disk influence the nitrogen chemistry through the photodissociation and shielding of $\text{N}_2$?

If so, can this explain the trend seen in the strength of HCN line emission at 14 $\mu$m?
### Protoplanetary Disks

**Spectral type**
- **M Dwarf**
- **T Tauri**
- **Herbig Ae**

<table>
<thead>
<tr>
<th></th>
<th>M Dwarf</th>
<th>T Tauri</th>
<th>Herbig Ae</th>
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</thead>
<tbody>
<tr>
<td><strong>Effective temperature</strong></td>
<td>3000 K</td>
<td>4000 K</td>
<td>10,000 K</td>
</tr>
<tr>
<td><strong>Stellar mass</strong></td>
<td>0.1 M(_\odot)</td>
<td>0.5 M(_\odot)</td>
<td>2.0 M(_\odot)</td>
</tr>
<tr>
<td><strong>Stellar radius</strong></td>
<td>0.7 R(_\odot)</td>
<td>2.0 R(_\odot)</td>
<td>2.0 R(_\odot)</td>
</tr>
<tr>
<td><strong>UV excess(^1)</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>X-ray model(^2)</strong></td>
<td>TW Hya</td>
<td>TW Hya</td>
<td>L(_x) (\sim 10^{29}) erg s(^{-1})</td>
</tr>
</tbody>
</table>

1 Young low-mass stars have a strong UV excess thought to be triggered by accretion

2 Low-mass stars are more X-ray bright than higher-mass stars (TW Hya, L\(_x\) \(\sim 10^{30}\) erg s\(^{-1}\))
Radiation Fields

Radiation fields at R = 1 AU

\[ k_{*,i} = \int_0^\infty F_*(\lambda) \sigma_i(\lambda) \, d\lambda \quad \text{s}^{-1} \]

\[ k_{\text{ph}}^{N_2}(R, Z) = k_{0}^{N_2}(R, Z) \times \theta_{N_2} \left[ N_H^\prime(R, Z), N_{N_2}^\prime(R, Z), T(R, Z) \right] \quad \text{s}^{-1} \]

Adapted from Walsh et al. 2015, in prep

Shielding functions from Li et al. 2013, A&A, 555, A14
Disk Physical Structure

Adapted from Walsh et al. 2015, in prep

- **M Dwarf**
  - Gas Temperature (K)
  - FUV Flux (erg cm\(^{-2}\) s\(^{-1}\))

- **T Tauri**
  - Gas Temperature (K)
  - FUV Flux (erg cm\(^{-2}\) s\(^{-1}\))

- **Herbig Ae**
  - Gas Temperature (K)
  - FUV Flux (erg cm\(^{-2}\) s\(^{-1}\))

Increasing gas temperature

Increasing FUV flux
Disk Molecular Structure

Decrease in molecules in disk atmosphere with increasing spectral type

$C_2H_2$ and HCN relatively abundant in atmosphere of M Dwarf disk

Figures from Walsh et al. 2015, in prep
**Disk Molecular Structure**

Figures from Walsh et al. 2015, in prep

T Tauri C$_2$H$_2$/HCN ratio agrees well with observations
M Dwarf C$_2$H$_2$/HCN ratio too low by one order of magnitude

Are X-rays or shielding playing a role?
Shielding and X-rays

R = 1AU

Figures from Walsh et al. 2015, in prep

Shielding becomes increasingly important towards outer disk where gradients in density and UV are shallower (see e.g., Li et al. 2013)

X-ray chemistry becomes increasingly less important

N$_2$ shielding becomes increasingly more important
Nitrogen Reservoirs

Initial nitrogen reservoir not important in disk atmosphere
Is important in the disk midplane: building blocks of planets

\[ R = 1 \text{AU} \]

Figures from Walsh et al. 2015, in prep
Summary

- Stellar spectral type influences the molecular composition of the disk
- Disks around cooler stars have a higher fractional abundance of molecules in the upper disk atmosphere: weak FUV is amenable to molecule synthesis
- $\text{C}_2\text{H}_2/\text{HCN}$ trend reproduced for T Tauri stars: ratio for M Dwarfs low compared with observations
- $\text{N}_2$ shielding hinders the formation of N-bearing species in a narrow region of the disk molecular layer only: effect is enhanced in disks around hotter stars
- Exclusion of X-rays helps to build more complexity in disk atmosphere around cooler stars
- Initial nitrogen reservoir important in disk midplane only: building blocks for planets
- Observations suggest higher C/O ratio in disks around cooler stars: indicative of mixing in atmosphere?