Probing the Origin and Evolution of Interstellar and Protoplanetary Biogenic Molecules: A Comprehensive Survey of Interstellar Ices with SPHEREx

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ABSTRACT

SPHEREx will measure the abundance and distribution of key biogenic ices, such as H$_2$O, CO$_2$, CO, and CH$_3$OH, throughout the Milky Way, increasing the number of lines of sight sampled by more than 100-fold beyond what is currently available. SPHEREx will exploit the ice-rich 2.5 to 5.0 micron region and the tens of millions of already catalogued WISE 3.4 and 4.6 micron point sources (as background continuum sources) to probe the ice content toward molecular clouds, young stellar objects and protoplanetary disks. By obtaining at least 20,000, and possibly more than a million, ice absorption spectra, SPHEREx will resolve long-standing questions about the amount and evolution of these key biogenic molecules through all phases of star and planet formation.

SCIENTIFIC MOTIVATION

Based on currently available, but limited data, it is now known that within molecular clouds:

- Ices are common in dense (n(H$_2$) > 10$^7$ cm$^{-3}$), well-shielded regions
- Ices accumulate in measurable quantities on the surface of dust grains
- Key biogenic molecules, such as water (H$_2$O), carbon dioxide (CO$_2$), carbon monoxide (CO), and methanol (CH$_3$OH) are locked into ice in variable, but large, amounts that far exceed their gas phase abundances (Überg et al. 2011; Boogert et al. 2011, 2013)

Unfortunately, the small sample of Infrared Space Observatory (ISO), Spitzer, and AKARI spectra presently available - fewer than 250 absorption spectra toward Galactic molecular clouds - does not permit us to reliably trace the ice content of clouds through the various stages of collapse to star and planet formation. SPHEREx will increase the number of ice absorption spectra toward molecular clouds by more than a factor of 100.

Within young protoplanetary disks, both models and the limited available data suggest that most biogenic molecules, including water, are primarily locked up in ices toward the disk mid-plane and beyond the snow line. SPHEREx will observe hundreds of protoplanetary disks with inclinations low enough to permit absorption spectroscopy against the central star.

SPHEREx WILL MEASURE ICE COLUMN DENSITIES

The column density of ice, in molecules cm$^{-2}$, can be expressed as:

$$N = \int \frac{1}{\lambda} dN_{\lambda}$$

where $\lambda$ is the bond strength (in cm molecule$^{-1}$) as measured in the laboratory (see Table 1 below). $\lambda$ is the column density in cm$^{-2}$, $\lambda$ is the optical depth, and the absorption depth, is measured in cm$^{-2}$.

$$\tau_{\lambda} = \ln\left(\frac{1}{\lambda}\right)$$

where the unabsorbed source flux at 1 requires a fit to the source SED around 1.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>$\lambda$ (cm$^{-1}$)</th>
<th>$\Delta \lambda$ (cm$^{-1}$)</th>
<th>Vibrational/Modes</th>
<th>(10$^{-17}$ cm$^{-2}$ molecule$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_3$</td>
<td>2.54</td>
<td>0.05</td>
<td>3-2</td>
<td>1.1</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>3.09</td>
<td>0.35</td>
<td>3-2</td>
<td>20</td>
</tr>
<tr>
<td>CH$_3$OH</td>
<td>3.33</td>
<td>0.30</td>
<td>3-2</td>
<td>0.16</td>
</tr>
<tr>
<td>CO</td>
<td>4.73</td>
<td>0.18</td>
<td>3-2</td>
<td>0.21</td>
</tr>
<tr>
<td>$^1$HCO$_3$</td>
<td>4.30</td>
<td>0.25</td>
<td>3-2</td>
<td>7.2</td>
</tr>
<tr>
<td>H$_2$CO</td>
<td>4.50</td>
<td>0.20</td>
<td>3-2</td>
<td>1.3</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>4.67</td>
<td>0.20</td>
<td>3-2</td>
<td>1.1</td>
</tr>
<tr>
<td>$^{13}$CO</td>
<td>4.79</td>
<td>0.20</td>
<td>3-2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

The table below shows the number of 3.4 micron and 4.6 micron point sources cataloged by WISE within $\pm 10^\circ$ of the Galactic plane with an area covering 100 square degrees.

HOW WILL SPHEREx OBTAIN ABSORPTION SPECTRA?

SPHEREx will measure absorption against catalogued WISE 3.4 and 4.6 micron point sources to study dense clouds and YSO envelopes, and the continuum emission from protostars to study low-inclination protoplanetary disks. WISE has catalogued more than 60 million 3.4 and 4.6 micron point sources within $\pm 10^\circ$ of the Galactic plane.

However, not all WISE sources will serve as good background continuum objects for the ice study.

The figure to the right shows the number of 3.4 micron and 4.6 micron point sources cataloged by WISE within $\pm 10^\circ$ of the Galactic plane data set (from a variety of areas) as a function of the source SFD. The dashed vertical lines denote the expected sensitivities of the SPHEREx instrument.

The figure shows the expected number of sources detected by SPHEREx (both 3.4 and 4.6 microns) as a function of the AB magnitude, with the lower curve showing the sensitivity of the instrument.

The figure below shows the estimated number of ice survey targets as a function of the source SFD, with the lower curve showing the sensitivity of the instrument.

SPHEREx will be a game changer for the study of interstellar, circumstellar, and protoplanetary ices.

SPHEREx will generate at least 20,000, and possibly more than a million, high-quality ice absorption spectra towards a wide variety of regions distributed throughout the Galaxy, revealing correlations between ice content and environment not possible with current spectra. With the vastly greater number of spectra generated by SPHEREx, it will be possible to understand, in a statistically significant way, how cloud density, internal temperature, pressure, presence or absence of embedded sources, external UV and X-ray radiation, elemental abundances (e.g. C/O ratio), gas-phase composition, cosmic-ray ionization rate, and cloud evolutionary stage, among other factors, correlate with the ice composition and abundance.