Refractive Index from a Laser and a Lamp

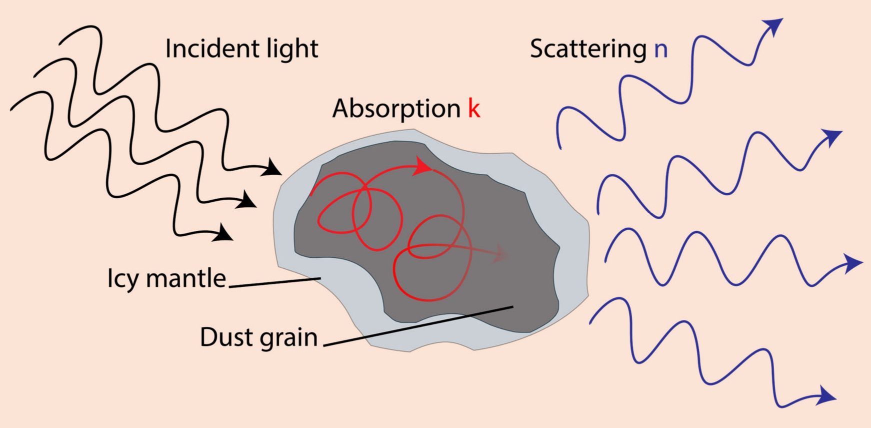
Milan Heinsohn Huala[1,*], Roshini Santhan[2], Ko-Ju Chuang[1]

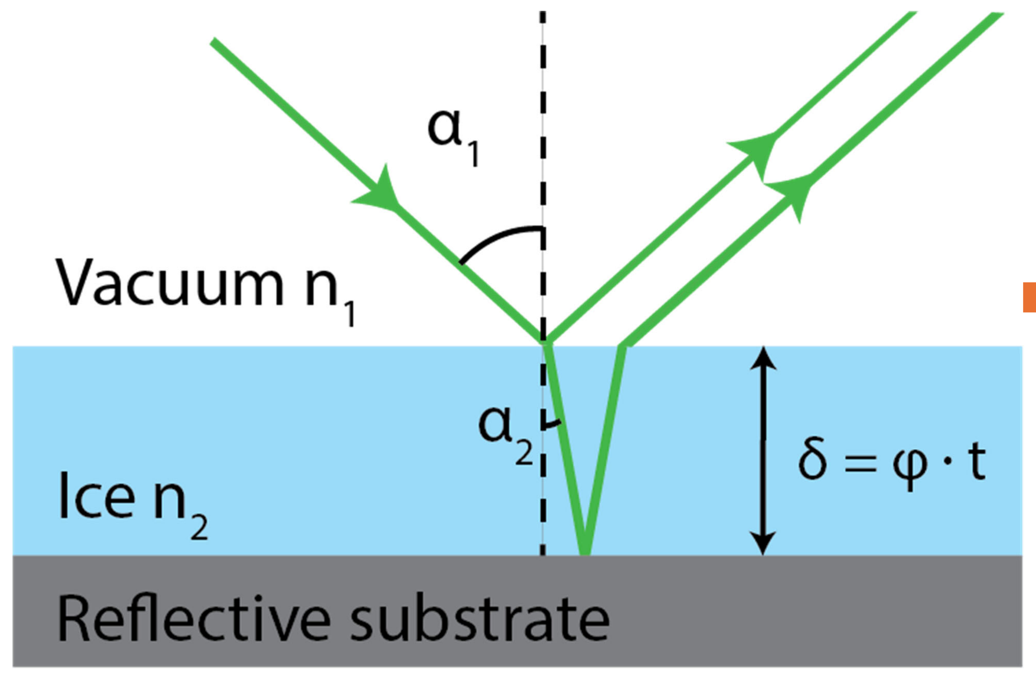
[1]Leiden Lab for Astrophysics, Leiden Observatory; [2]University of Muenster

*heinsohn@strw.leidenuniv.nl

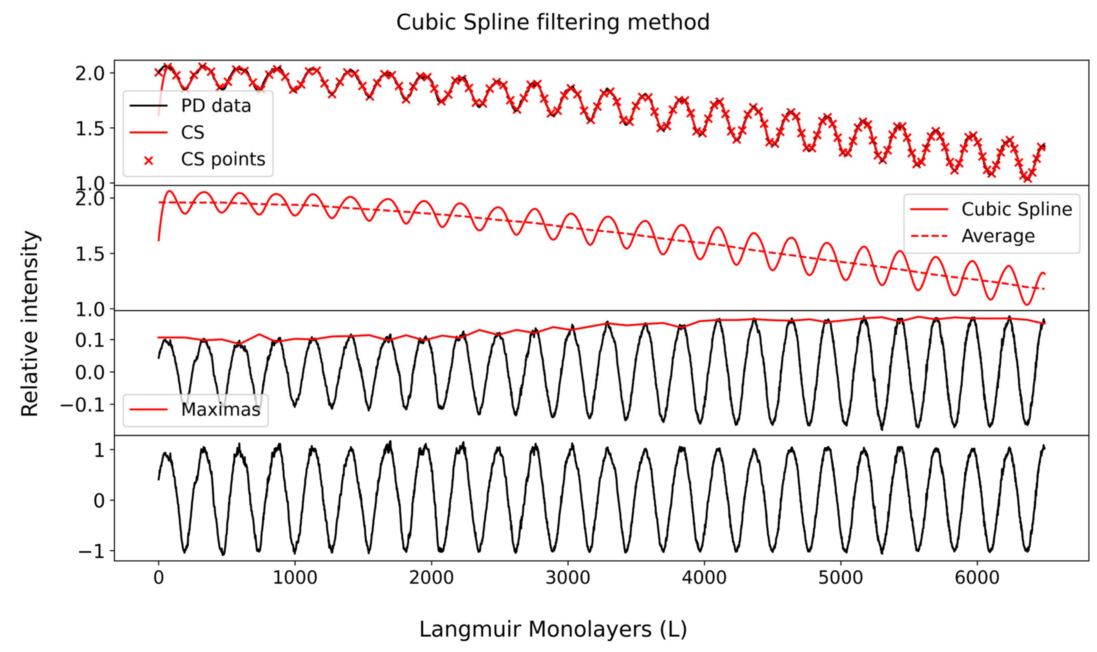
To calculate the **optical constants** of pure or mixed ices, the Kramer-Krönig equations are needed. These require laboratory experiments as input, which we derive from setups in the Leiden Laboratory for Astrophysics. One of these inputs is an accurate **real refractive index** in the optical regime. The Optical Analysis Setup for Interstellar Spectroscopy (*OASIS*) can simulate **interstellar environments** (~10 K, ~1E-8 mbar) and form ices to calculate the real refractive index for 250 nm to 800 nm in a single experiment.

Pictured on the right is the interaction of light with an ice layer on dust. The complex refractive index $m(\lambda) = n + ik$ governs this behaviour and is wavelength dependent. Significant changes to the real refractive index can impact interpretations of **JWST ice spectra** [1].

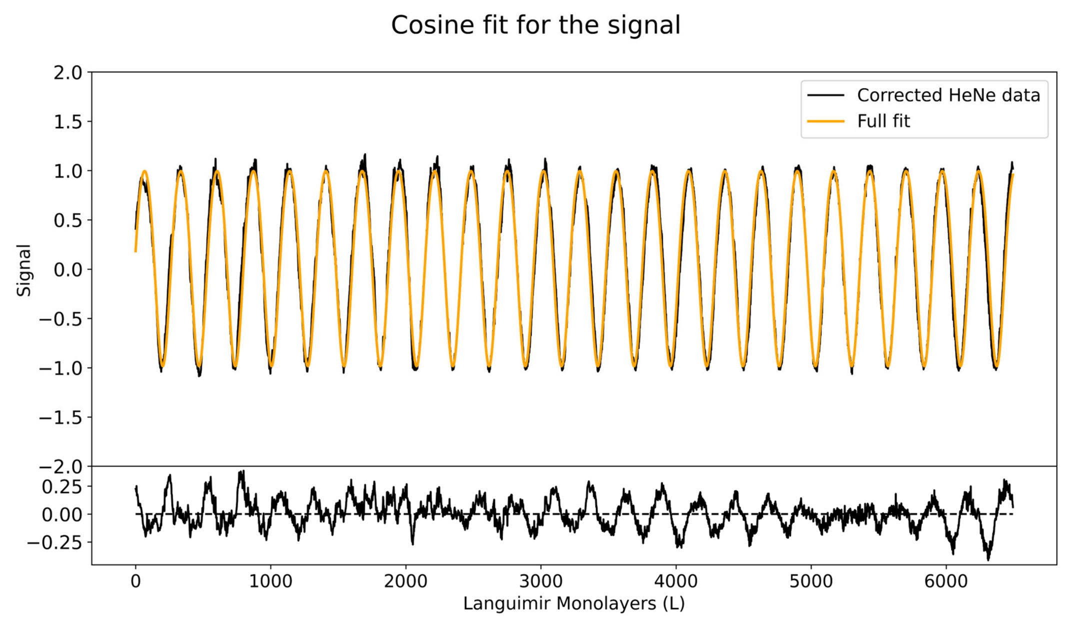




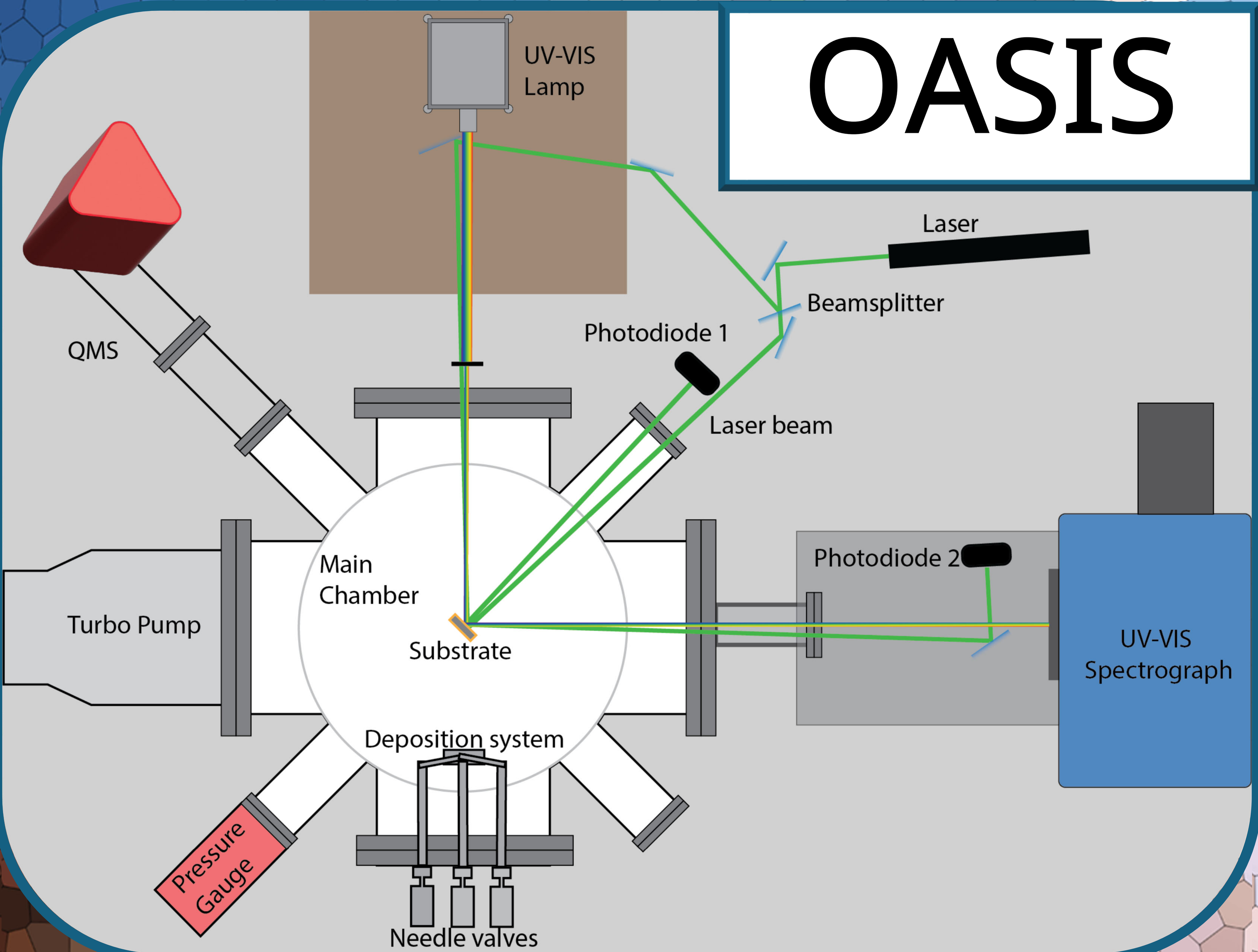
With a thin film of ice, an interference pattern will form due to the difference in pathlength δ. As the ice grows, the interference pattern changes over time.

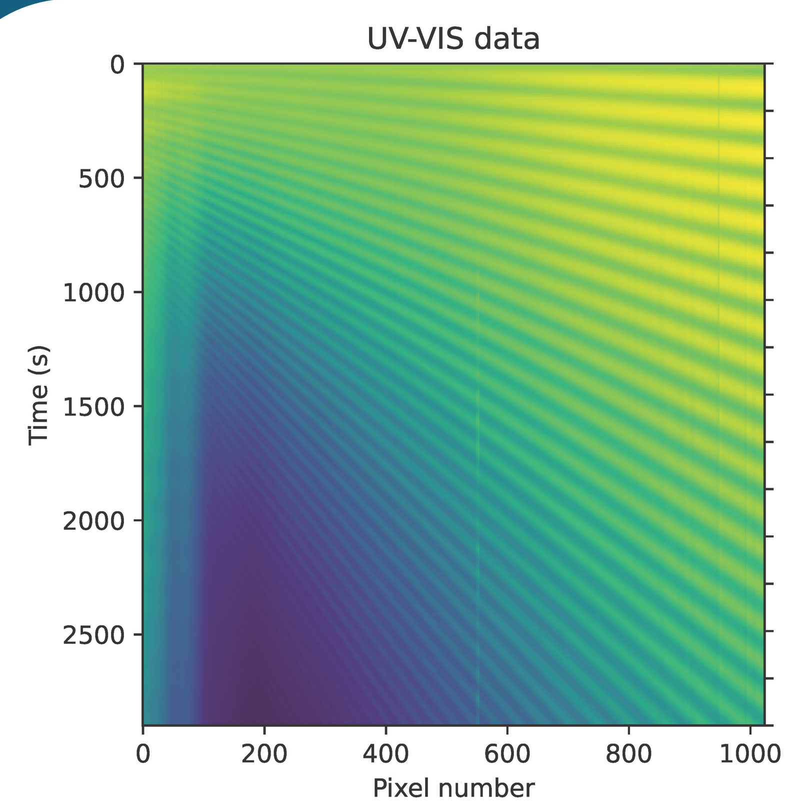


The interference pattern changes with a constant frequency if the deposition rate is constant. This frequency is needed to calculate the refractive index.



The trends in the signal are removed with under-sampling and cubic splines, to trace the signal easily and efficiently.

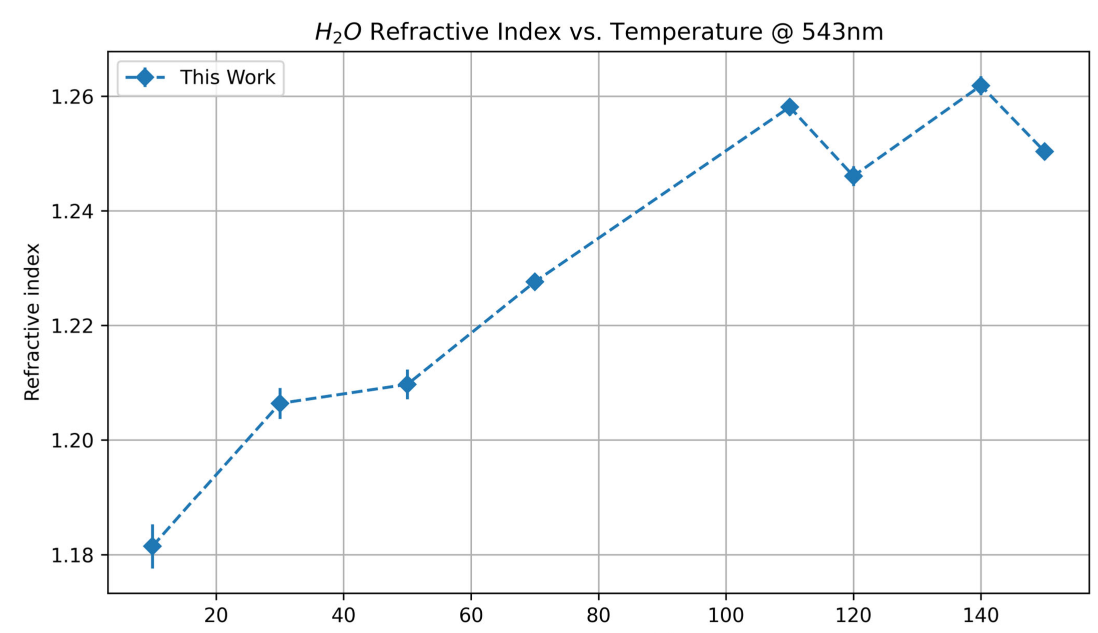




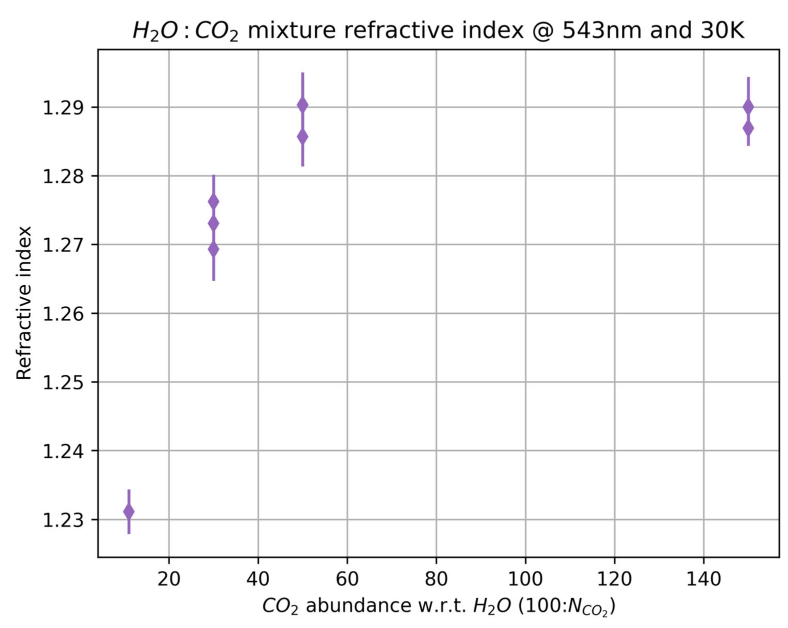
The raw data from the UV-VIS spectrograph is processed similarly to the laser data. These results can be used to calculate the refractive index curves over the optical regime. The formula uses the refractive index from the laser calculation, which dominates the accuracy of this step.

$$n_l = \sqrt{\frac{\omega_\alpha^2 \sin^2(\beta_1) - \omega_\beta^2 \sin^2(\alpha_1)}{\omega_\alpha^2 - \omega_\beta^2}}$$

The refractive index is calculated from two different angles, which allows for independent measurements of *n*, without using other constants.



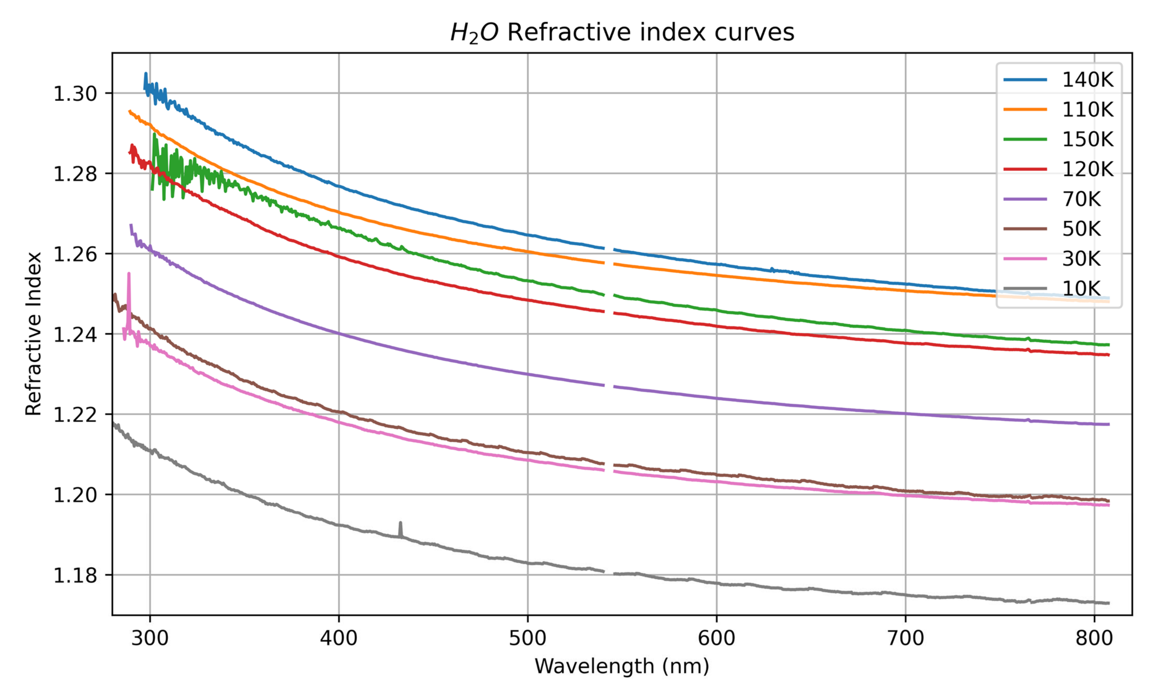
Experiments on *OASIS* can be of pure, binary or even trinary ices, due to the three independent leak valves installed on the deposition system. Currently, binary ice experiments are being conducted of different mixtures of **water and carbon dioxide.** Some of the results are shown here. The refractive index follows a decreasing trend for higher carbon dioxide mixing ratios in the ice. This is consistent with the results found in other literature [2].



$$n_2(\lambda) = n_{2,l} \frac{\omega(\lambda)\lambda}{\omega_l \lambda_l} \sqrt{\frac{1}{\sin^2(\alpha)} - \left(\frac{\omega(\lambda)\lambda}{\omega_l \lambda_l}\right)^2 \frac{1}{n_{n,l}^2} + 1}$$

Take-home message

OASIS with its current setup and methodology is capable of **accurate real refractive index** of inter- or circumstellar relevant ice measurements. The ices measured are formed in **simulated interstellar conditions**. The two laser-beams at different angles allow for accurate single-wavelength *n* values, whilst the broad-spectrum optical regime lamp allows for the calculation of the **real refractive index curves** in a **single experiment**. These refractive indices are useful for calculating the optical constants, which are a necessity for **radiative transfer modelling**.



Universiteit Leiden, Leiden Observatory · Sterrewacht Leiden · NOVA · INTERCAT Center for Interstellar Catalysis · Leiden Laboratory for Astrophysics

[1] Rocha, W. R. M. *et al.* Water ice: Temperature-dependent refractive indexes and their astrophysical implications. **681**, A9 (2024).
[2] Maté, B. *et al.* Infrared optical constants and band strengths of interstellar ice analogues: $H_2O:CO_2$ and $H_2O:CO_2:CO$ mixtures at 10 K. *A&A* **704**, A56 (2025).