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HAOT: A Python package for hypersonic aero-optics analysis

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Summary

Hypersonic flows present a unique challenges due to the complex interplay of fluid dynamics, chemical reactions, and optical phenomena. As a signal from a Light Detection and Ranging (LiDAR) travels through a hypersonic flow field, the beam would be affected by the flow.

`HAOT` is a Hypersonic Aerodynamics Optics Tools Python package developed to calculate the index of refraction of a hypersonic medium. Its source code is available on GitHub, the documentation is available on Read the Docs and example on the usage of the package is given on the GitHub repo under the example folder.

Statement of Need

Many techniques used to calculate optical properties are scatter in papers but there is not a local repo containing all this calculations, furthermore some of these calculations require the use of spectroscopy constants, which have been properly documented and added to the package.

Algorithms

The `HAOT` package, contains five modules:

```
- Modules:
- Aerodynamics
- Optics
- Quantum Mechanics
- Constants
- Conversions
```

Each module can be imported independed and the documentation explains in detail what each module does. Furthremore, docstrings have been added to the function and the description of each function can be seeing in an interactive python session.

Equation below was introduced by (Smith & Weintraub, n.d.), and it is a good approximation for the change of the index of refraction as a function of altitude.

$$n(h) \approx 1 + \frac{K_1}{T(h)}\left(p(h) + K_2\frac{e(h)}{T(h)}\right)$$

Where: K_1 and K_2 are constants, T is the temperature as a function of altitude, p is pressure as a function of altitude, and $e(h)$ is partial pressure of water vapor.

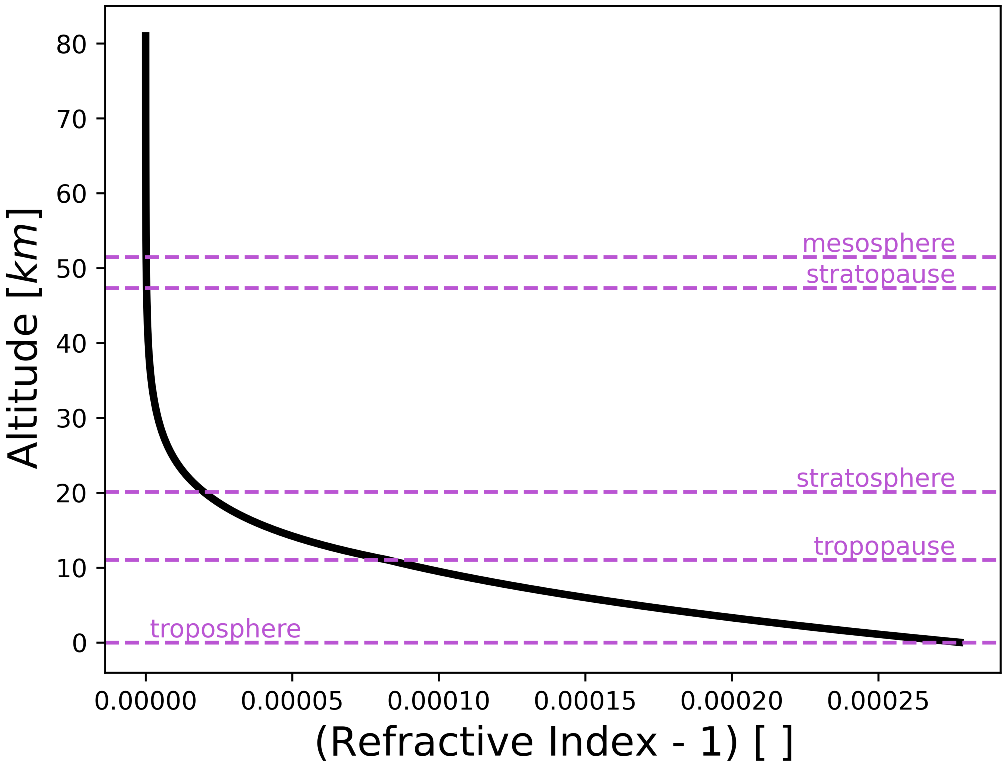

Figure 1: Atmospheric index of refraction for dry air.

Equation below shows the equation used to calculate the dilute index of refraction.

$$n - 1 = \rho \sum_{s=1}^{N} K_s \rho_s$$

Where: ρ_s is the species density, ρ is the flow's density, and K_s is the specie's Gladstone-Dale constant.

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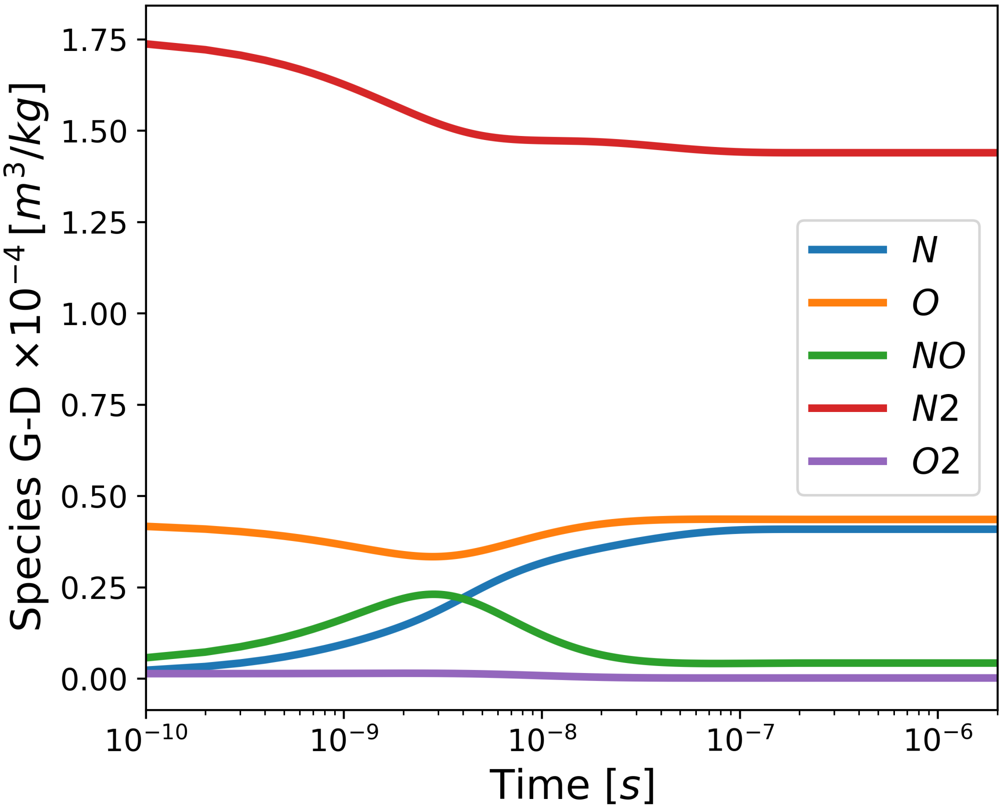

Figure 2: Species Gladstone-Dale constants for a 5 species gas.

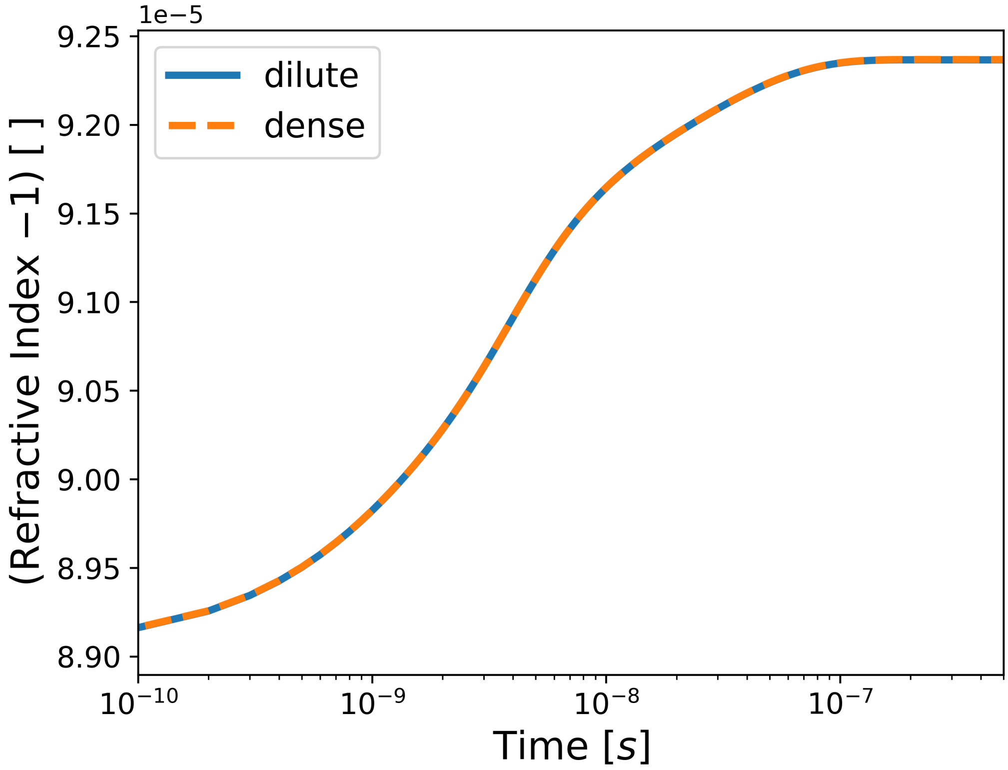

Figure 3: Index of Refraction for a 5 species gas.

A more extensive work showing the results of this pacakge was done by (Liza et al., 2023).

Acknowledgements

References

Liza, M., Tumuklu, O., & Hanquist, K. M. (2023, June). Nonequilibrium effects on aero-optics in hypersonic flows. *AIAA AVIATION 2023 Forum*. https://doi.org/10.2514/6.2023-3736

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