

Deep O_2 observations toward a low-mass protostar with *Herschel*-HIFI

Umut A. Yıldız¹, Kinsuk Acharyya², Paul F. Goldsmith³, Ewine F. van Dishoeck^{1,4}, and Herschel Oxygen Project (HOP Team)

¹Leiden Observatory, Leiden University, The Netherlands, ²S.N. Bose National Centre for Basic Sciences, Kolkata, India
³Jet Propulsion Laboratory, California Institute of Technology, USA, ⁴Max Planck Institut für Extraterrestrische Physik, Germany



Introduction

Results

O_2 Oxygen is the third most abundant element in the Universe after Hydrogen and Helium.

- It is difficult to observe O_2 from the ground, therefore space-based observations are necessary.
- First and last! (for long time) observation of O_2 at 487 GHz toward NGC1333 IRAS4A low-mass protostar conducted via *Herschel*-HIFI with 7.7 hours integration time.
- Determining O_2 abundance is important because pure gas-phase chemistry models suggest a steady-state abundance of $X(O_2) \approx 7 \times 10^{-5}$ relative to H_2 , however so far observations show much lower abundance.

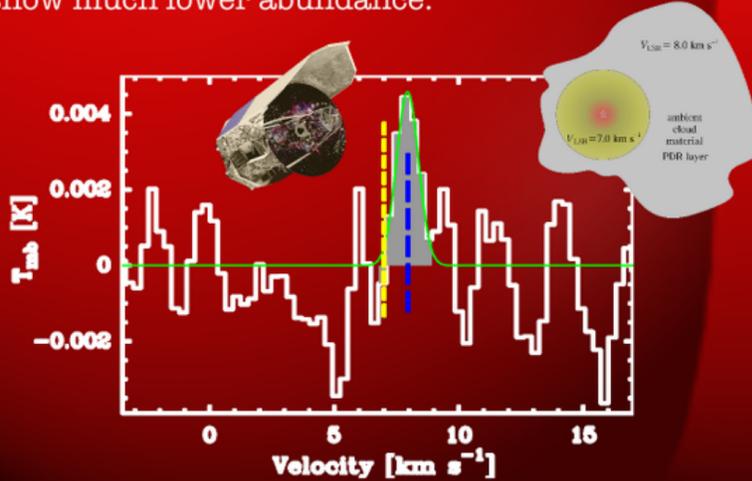
7.0 km s⁻¹ component

- No O_2 emission is detected from the **protostellar envelope**, down to a **3 σ upper limit of $X(O_2) < 6 \times 10^{-9}$** , the lowest O_2 abundance limit toward a protostar to date.

- Full gas-grain model requires a long pre-collapse stage ($\sim 1 \times 10^6$ years) during which atomic oxygen is converted into water ice on grains.

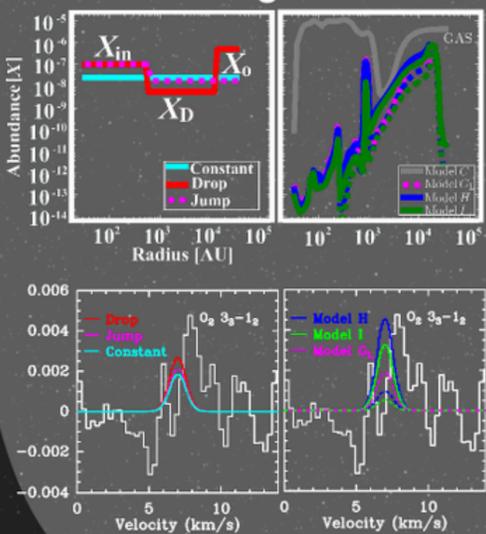
8.0 km s⁻¹ component

- A 4.5 σ tentative O_2 detection is found at $V_{LSR} = 8.0 \text{ km s}^{-1}$, which is interpreted as emission originating from the surrounding more extended NGC 1333 cloud.
- Comparison with PDR models with low G_0 agree within a factor of 2 for $n < 10^4 \text{ cm}^{-3}$.

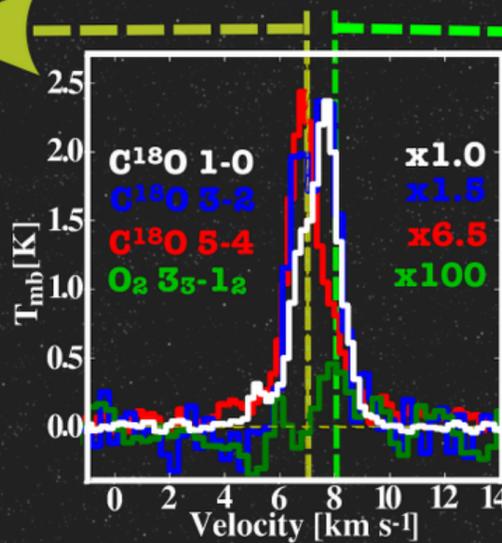


Non-detection

7.0 km s⁻¹ component Emission from the protostar Gas-grain modeling



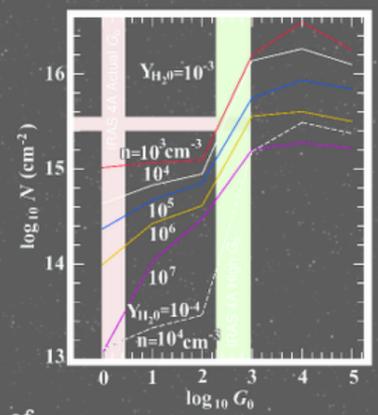
Different abundance profiles; (left) empirical constant and drop (retrieval method); (right) full gas-grain models (forward method).
 Best-fit model spectra produced by abundance profiles shown above.



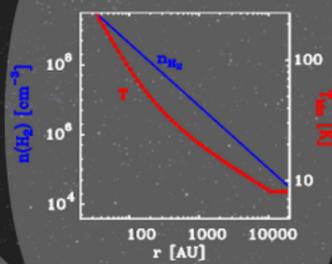
Detection

8.0 km s⁻¹ component Emission from the cloud

Total O_2 column density as function of G_0 and density. The horizontal pink band shows the total O_2 column density range for the observed integrated intensity. The vertical green band presents the range of high- G_0 values required to produce this range of $N(O_2)$ for $n = 10^3 \text{ cm}^{-3} - 10^7 \text{ cm}^{-3}$, whereas vertical pink band presents the actual G_0 estimated at this position.



Envelope structure



References

- Goldsmith et al. 2011, ApJ, 737, 96
- Yıldız et al. 2010, 2012, A&A
- Hollenbach et al. 2009, ApJ, 690, 1497
- Melnick et al. 2012, ApJ, 752, 26
- Van Dishoeck et al. 2011, PASP, 123, 138

L₀ MASS

A public molecular line database of the reduced data for low-mass protostars observed with JCMT, APEX, *Herschel*.
<http://lomass.strw.leidenuniv.nl>

Contact Info: yildiz@strw.leidenuniv.nl

Umut A. Yıldız, Kinsuk Acharyya, Paul F. Goldsmith, Ewine F. van Dishoeck, Gary Melnick, Ronald Snell, René Liseau, Jo-Hsin Chen, Laurent Pagani, Edwin Bergin, Paola Caselli, Eric Herbst, Lars E. Kristensen, Ruud Visser, Dariusz C. Lis, Maryvonne Gerin