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

Umut A. Yıldız[1], Kinsuk Acharyya[2], Paul F. Goldsmith[3], Ewine F. van Dishoeck[1,4], and Herschel Oxygen Project (HOP Team)

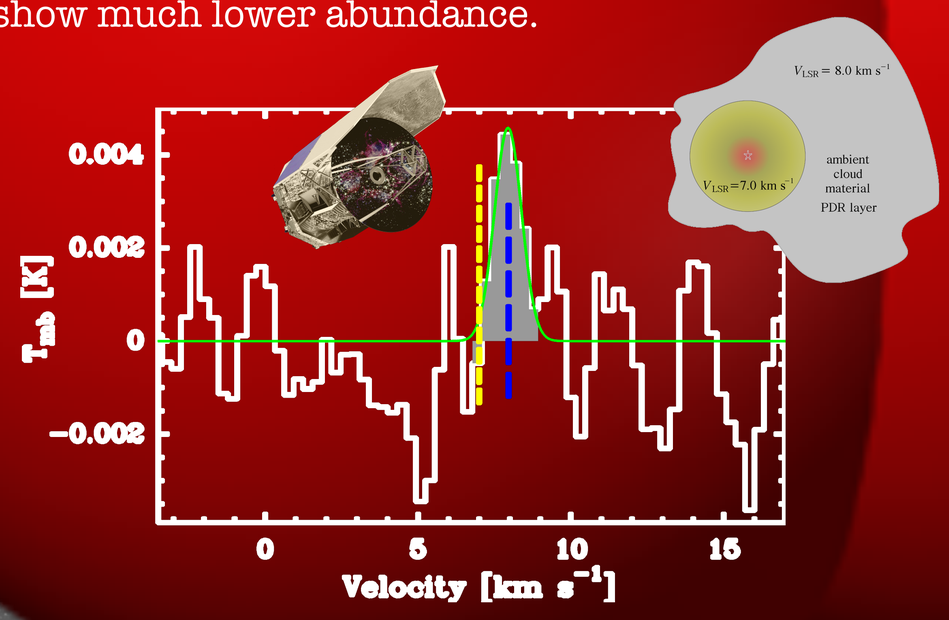
[1]Leiden Observatory, Leiden University, The Netherlands, [2]S.N. Bose National Centre for Basic Sciences, Kolkata, India
[3]Jet Propulsion Laboratory, California Institute of Technology, USA, [4]Max Planck Institut fur Extraterrestrische Physik, Germany

Sterrewacht Leiden

Introduction

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 $X(O_2)\approx 7\times10^{-5}$ relative to H_2, however so far observations show much lower abundance.



Results

7.0 km s^{-1} component

- No O_2 emission is detected from the **protostellar envelope**, down to a **3σ upper limit of X (O_2)<6x10^{-9}**, the lowest O_2 abundance limit toward a protostar to date.
- Full gas-grain model reqiires a long pre-collapse stage (~1x10^6 years) during which atomic oxygen is converted into water ice on grains.

8.0 km s^{-1} component

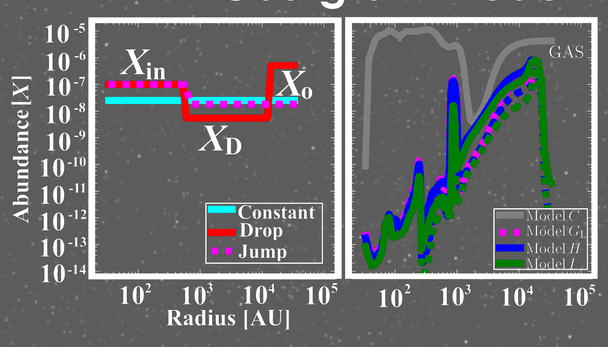
- A 4.5σ tentative O_2 detection is found at V_{LSR} = 8.0 km s^{-1}, which is interpreted as emission originating from the surrounding more extended NGC 1333 cloud.
- Comparison with PDR models with low G_0 agree within a factor of 2 for n<10^4 cm^{-3}.

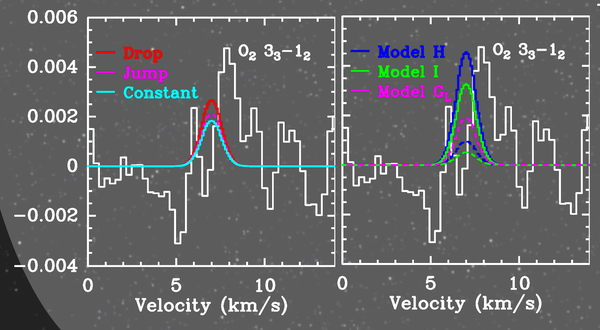
✗ Non-detection

7.0 km s^{-1} component

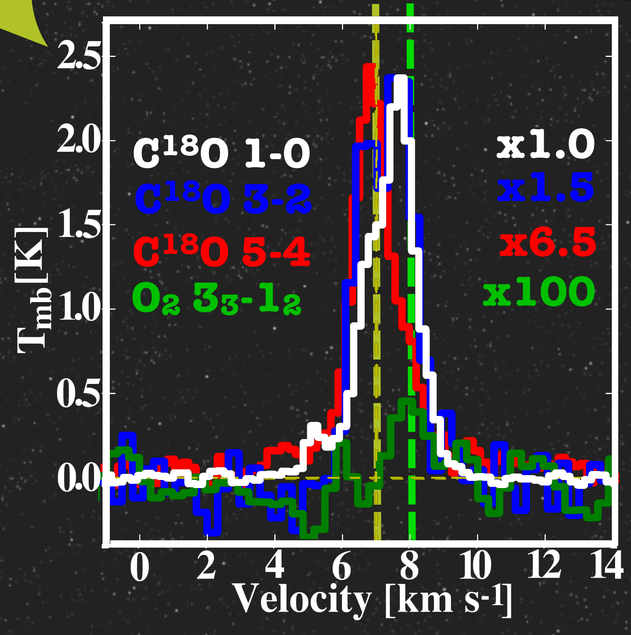
Emission from the protostar

Gas-grain modeling

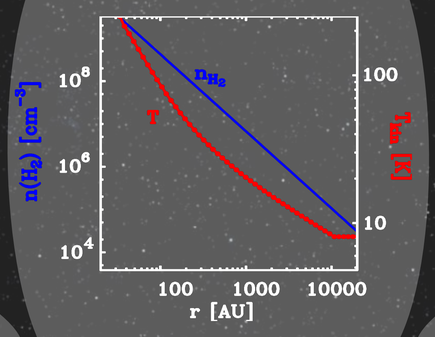




- Different abundance profiles; (left) empirical constant and drop (retrieval method); (right) full gas-grain models (forward method).
- Best-fit model spectra produced by abundace profiles shown above.



Envelope structure

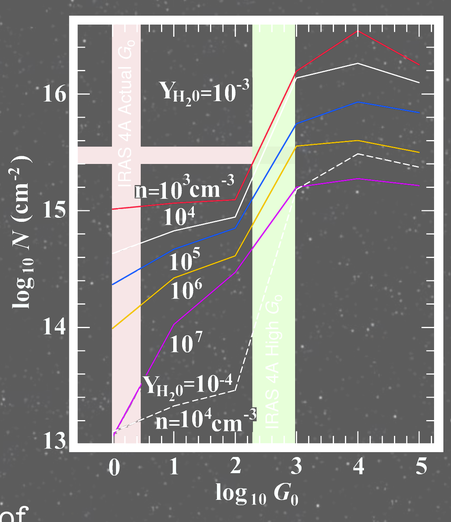


✓ Detection

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 cm^{-3} -10^7 cm^{-3}, whereas vertical pink band presents the actual G_0 estimated at this position.



References

(1) Goldsmith et al. 2011, ApJ, 737, 96
(2) Yildiz et al. 2010, 2012, A&A
(3) Hollenbach et al. 2009, ApJ, 690, 1497
(4) Melnick et al. 2012, ApJ, 752, 26
(5) Van Dishoeck et al, 2011, PASP, 123, 138

LOMASS

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