Alice Booth

Title

Sublimating ices feeding forming planets

Abstract

New planetary systems are made from dust and gas in the rotating disks around young stars. High-resolution observations of these planet-forming disks with the Atacama Large Millimeter Array (ALMA) can be used to learn about the planet-formation process. In particular, ALMA can trace the composition of the gas available to be accreted by planets. In this talk, I will show recent molecular line observations towards two well-studied warm planet-forming disks: HD100546 and IRS48. These disks show evidence for ongoing planet-formation due to the presence of rings and asymmetries in the millimetre dust disk. The molecular emissions are linked to these dust structures. These data include first detections of the molecules NO, SO2 and CH3OCH3 in protoplanetary disks. This rich observable chemistry is due to ice sublimation and the link between the molecules and the dust structures shows that these dust traps are also ice traps. The array of detected molecules can be used to learn about the physical and chemical conditions in the disk experienced by forming planets. We determine the elemental C/O ratio in the disk using the simple molecules (SO, CS etc), and this provides a direct connection to the observed exoplanet population. On the other hand, the more complex molecules (CH3OH, CH3OCH3, etc.) shed light on the importance of inheritance from earlier stages of the star formation process. The detection of these complex and potentially prebiotic molecules in planet-forming disks provides links to how life originated in our solar system.

Dr. Alice S. Booth

Curriculum Vitae

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Research Interests

I am interested in the formation, composition and detection of planets. I work with interferometric observations of protoplanetary disks and chemical models. I use different molecular species as diagnostic tools to understand both the physical and chemical conditions associated with planet formation. By studying the building blocks of planets we can gain a clearer understanding of the planet formation process. This directly links to understanding the history of the prebiotic molecules in our solar system.

Work/Education

3/2020-Present **Postdoctoral Researcher**, *Molecular Astrophysics Group, Leiden Observatory, Leiden University, Leiden, 5F3M WH*, Supervisor: Prof Ewine van Dishoeck.

9/2016–2/2020 **PhD in Astrophysics**, *School of Physics and Astronomy, University of Leeds, Leeds, LS2 9JT, UK*, Thesis title: "Molecular Line Emission from Planet-Forming Disks", Supervisors: Dr Catherine Walsh, Professor Tom Harquist.

2015 **Summer Internship**, *Department of Astrophysics, University of Oxford, Keble Rd, Oxford OX1 3RH*, Research area: Transit spectroscopy of hot Jupiter exoplanet atmospheres, Supervisors: Dr Hannu Parviainen, Prof. Suzanne Aigrain.

9/2012–6/2016 **BSc in Physics (1st class honours)**, *University of Aberdeen, King's College, Aberdeen AB24 3FX*, Project title: "Using Kepler lightcurves to investigate the rotational properties of exoplanet systems", Supervisor: Dr Ross Macpherson.

Publications

First Author (Total = 7, Citations 97)

[7] **Booth, A. S.** et al. *Molecules with ALMA at Planet-forming Scales (MAPS). XVI. Characterizing the Impact of the Molecular Wind on the Evolution of the HD 163296 System* (The Astrophysical Journal Supplement Series, Volume 257, 1:16, 11/2021)

[6] **Booth, A. S.** et al. *A major asymmetric ice trap in a planet-forming disk: II. prominent SO and SO_2 pointing to C/O<1* (Astronomy & Astrophysics, Volume 651, L6, 7/2021)

[5] **Booth, A. S.** et al. *An inherited complex organic molecule reservoir in a warm planet-hosting disk* (Nature Astronomy, Volume 5, 684-690, 5/2021)

[4] **Booth, A. S.** and Ilee, J. D., *$^{13}C^{17}O$ suggests gravitational instability in HL Tau* (Monthly Notices of the Royal Astronomical Society: Letters, Volume 493, 1, L108-L113, 3/2020)

[3] **Booth, A. S.** et al. The first detection of $^{13}C^{17}O$ in a protoplanetary disk: a robust tracer of disk gas mass (The Astrophysical Journal Letters, Volume 882, Issue 2, L31, 9/2019)

[2] **Booth, A. S.**, Walsh, C. and Ilee J. D. *First detections of $H^{13}CO^+$ and $HC^{15}N$ in the HD 97048 protoplanetary disk* (Astronomy & Astrophysics, Volume 629, A75, 9/2019)

[1] **Booth, A. S.** et al. *Sulphur monoxide exposes a potential molecular disk wind from the planet-hosting disk around HD 100546* (Astronomy & Astrophysics, Volume 611, A16, 3/2018)

Selected Co-Author (Total = 24)

* notes project where I was supervising a student

[7] Brunken*, N., **Booth, A. S.**, et al. *A major asymmetric ice trap in a planet-forming disk: III. first detection of dimethyl-ether* (Astronomy & Astrophysics submitted 12/2021)

[6] Leemker*, M., **Booth, A. S.** et al. *Gas temperature structure across the transition disk cavities* (Astronomy & Astrophysics submitted 12/2021)

[5] Ilee, J. D., Walsh C, **Booth, A. S.** et al. *Molecules with ALMA at Planet-forming Scales (MAPS). IX. Distribution and Properties of the Large Organic Molecules HC_3N, CH_3CN, and c-C_3H_2* (The Astrophysical Journal Supplement Series, Volume 257, 1:9, 11/2021)

[4] Zhang, C., **Booth, A. S.**, et al. *Molecules with ALMA at Planet-forming Scales (MAPS). V. CO Gas Distributions* (The Astrophysical Journal Supplement Series, Volume 257, 1:4, 11/2021)

[3] Czekala, I., Loomis, R A., Teague, R., **Booth, A. S.** et al. *Molecules with ALMA at Planet-forming Scales (MAPS). II. CLEAN Strategies for Synthesizing Images of Molecular Line Emission in Protoplanetary Disks* (The Astrophysical Journal Supplement Series, Volume 257, 1:2, 11/2021)

[2] van der Marel N., **Booth, A. S.**, et al. *A major asymmetric ice trap in a planet-forming disk. I. Formaldehyde and methanol* (Astronomy & Astrophysics, Volume 651, L5, 7/2021)

[1] Notsu, S., Akiyama, E., **Booth, A. S.** et al. *Dust continuum emission and the upper limit fuxes of sub-millimeter water lines of the protoplanetary disk around HD 163296 observed by ALMA* (Astrophysical Journal, Volume 875, 2:96, 3/2019)

Student Supervision

2022-Present Co-supervisor for masters student Liurong Lin - *Searching for signatures of MHD disk winds from Herbig disks*, Leiden Observatory

2021-Present Primary supervisor for masters student Milou Temmink - *Observable chemistry in Herbig transition disks*, Leiden Observatory

2020-2021 Primary supervisor for masters student Nashanty Brunken - *A search for complex organic molecules in IRS 48 disk*, Leiden Observatory

2020-2021 Primary supervisor for masters student Dylan Natoewal - *Chemical signatures of a planet carved gap in the HD 100546 disk*, Leiden Observatory

2020-Present Co-supervisor for PhD Student Lucas Stapper - *Population studies of Herbig Disks*, Leiden Observatory

2020-Present Co-promoter for PhD Student Margot Leemker - *Observations and Models of Molecular Rings in Disks*, Leiden Observatory

Observing Time Awarded

PI

7/2021 Evaporating ices in planet forming disks, ALMA Cycle 8 2021.1.00738.S ranked “B” (30 hours)

11/2020 Toward a complete volume limited sample of Herbig disks disks ranked "B" , NOEMA (Co-P.I. Cridland A., 20 hours)

7/2019 Astrochemical confirmation of a circumplanetary disk, ALMA Cycle 7 2019.1.00193.S ranked “B” (10 hours)

Selected Co-I

11/2021 Orion's hunting grounds: The first unbiased mass census of Herbig Ae/Be disks, NOEMA ranked "B" (P.I. Grant S.)

11/2021 Breaking the degeneracy between carbon abundance and gas mass, NOEMA ranked "B" (P.I. van Diskoeck E.)

11/2021 Chemistry in the UV-exposed disk of the AK Sco Herbig binary, SMA ranked "B" (P.I. Stapper* L.)

7/2021 A snowline origin for the substructures in the Class I disk GY 91?, ALMA cycle 8 2021.1.01588.S rank "B" (P.I. Huang J.)

7/2021 Locating the position of the midplane water snowline in protoplanetary disks around young bursting stars, ALMA cycle 8 2021.1.00115.S rank "C" (P.I. Notsu S.)

3/2021 The Chemistry of Planet Formation: A JWST-ALMA Survey of 4 Planet-Forming Disks, JWST Cycle 1 (P.I. Oberg K.)

6/2020 Tale of two masses: CO and HD, NOEMA ranked "B" (P.I. van Diskoeck E.)

7/2018 The chemistry of planet formation, ALMA Cycle 6 Large Program ranked "A", (Co-P.I.'s: Öberg, K. I., Walsh, C., Guzman, V. V., Bergin, E. A. & Aikawa, Y.)

7/2018 Locating the Position of the Midplane Water Snowline in a Protoplantary Disk around a Herbig Ae Star HD163296, ALMA Cycle 6 Regular Program, ranked "C" (P.I. Notsu S.)

Conferences, Talks and Workshops

Talk contributions

7/2021 Netherlands Allegro ALMA science day **Invited Talk** *Online, Leiden, NL*

7/2021 **Invited Seminar** *Online, Tokyo, Japan*

6/2021 Astrochemical Frontiers II Contributed talk *Online*

1/2021 **Invited Seminar** *Online, Uppsala University, Sweden*

1/2021 Netherlands Allegro ALMA science day Contributed talk *Online, Leiden, NL*

7/2020 EAS 2020 Contributed talk *Online, Leiden, NL*

6/2020 Astrochemical Frontiers Contributed talk *Online*

11/2018 **Invited Seminar** *University of Leicester, UK*

8/2018 **Invited Seminar** *Cardiff University, UK*

6/2018 Astrochemistry Workshop - Molecular line emission from planet hosting disks *Tokyo Institute of Technology, Japan*

4/2018 EWASS/NAM S8e - Molecular line emission from planet-hosting protoplanetary disks: sulphur monoxide as a potential tracer of a molecular disk wind? *Liverpool, UK*

3/2018 Internal seminar *University of Leeds, UK*

9/2017 Northern Star Formation Meeting - Sulphur monoxide exposes a potential molecular disk wind from the planet-hosting disk around HD100546 *Liverpool John Moores University, UK*

Poster contributions

12/2020 10 years after HL Tau - Is HL Tau a gravitationally unstable disk? *Online, Chilie*

6/2019 From Stars to Planets II - $^{13}C^{17}O$ a robust tracer of CO gas mass *Chalmers, Gothenberg, Sweden*

4/2019 IAU Symposium on Laboratory Astrophysics - Molecular line emission from herbig hosting disks *Jesus College, Cambridge, UK*

7/2018 Physics and Astronomy Postgraduate Symposium - Finding the footprints of forming planets, **1st Prize** *University of Leeds, UK*

5/2018 Leeds Doctoral Collage Showcase Poster Conference - Finding the footprints of forming planets *University of Leeds, UK*

3/2018 Star and Planet Formation in the Southwest II - Molecular line emission from planet hosting disks *Tuscon, AZ*

Workshops

12/2021 Lorentz Workshop - The Volatile Content of Planets that Form Early *Leiden, NL*

9/2021 Lorentz Workshop - Planet-forming Disks: From Surveys to Answers *Leiden, NL*

9/2018 ICIC Data Analysis Workshop *Imperial Collage London, UK*

8/2017 Monte Carlo Radiative Transfer Summer School *University St Andrews, UK*

7/2017 Lorentz Workshop - Disk Formation Workshop *Leiden University, NL*

2/2017 Chronology of the Formation of the Solar System VI *Les Houches, France*

Prizes and Awards

2018 **First Prize** Physics and Astronomy Postgraduate Symposium (Poster Competition) *University of Leeds*

2016 **Greig Prize in Physics** awarded to the student who has exhibited the greatest proficiency in the study of Physics. *University of Aberdeen*

2013 **Cassie Prize in Physics** awarded to the best first Physics year student *University of Aberdeen*

Outreach

10/2021 Astronomy on Tap Speaker (Evaporating ices feeding forming planets) *Leiden, NL*

2021-Present Skype a Scientist Volunteer *Online*

2021-Present Leiden/ESA Astrophysics Program for Summer Students (LEAPS) Co-coordinator

6/2019 Bradford Science Festival Volunteer *Bradford, UK*

2018–2019 Pint of Science Leeds 2019 Co-ordinator *Leeds, UK*

2018–2019 Popular Astronomy Writer *magazine from the Society for Popular Astronomy*

1/2019 Astronomical Society Talk on Exoplanets *Doncaster, UK*

7/2018 Research Nights Talk (Finding the footprints of forming planets) *Leeds, UK*

2016–2018 Pint of Science Event Co-ordinator Team Atoms to Galaxies *Leeds, UK*

11/2015 Au Talks (Exoplanets) *Aberdeen, UK*

References

1. Prof. Ewine F. van Dishoeck, *Prof., Leiden Observatory*
2. Dr Catherine Walsh, *Associate Professor; UKRI Future Leader Fellow, University of Leeds*