Challenge Accepted: Linking Planet Formation with Present-Day Atmospheres

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ExoPAG 33
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Logistics

Dates: 08-12 July 2024

Location: Max-Plack Institut für Astronomie

Scientific Organizing Committee: Bertram Bitsch, Ian Crossfield*, Adina Feinstein, Sasha Hinkley, Laura Kreidberg*, Paul Mollière, Christoph Mordasini, Anjali Piette, Niall Whiteford

Conference Website: https://the-great-link.github.io/

White Paper: https://arxiv.org/abs/2506.00669

Conference Goals

A major goal for exoplanet atmosphere characterization is to infer the formation history of gaseous exoplanets from their present-day atmospheric composition. With the first JWST observations of disks and atmospheric spectra in hand, it is a good time to revisit the link between formation and modern chemistry. The connection is nontrivial and requires a detailed understanding of everything from the protoplanetary disk properties to the planet formation mechanism to current atmospheric physics.

The aim of this workshop is to bring together experts across these topics to build a new understanding of planet formation in the JWST era.

Schedule

	Day 1	Day 2	Day 3	Day 4	Day 5
Topic	The challenge: Disc, planetary formation theory (GI, core accretion, ice lines, models)	The challenge: Atmosphere theory (models, C/O ratios, clouds, inference issues, interiors)	The link: Planet Formation to Present-Day Atmospheres	The link: Archival observations, looking to JWST and ELTs (and model development)	Challenge accepted: outlook to collaborative projects and proposals
Activity			Small group discussions	Speed Proposals	Large group discussions

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Breakout Discussion Topics

1. Moving on from C/O
2. Interior-atmosphere connections for sub-Neptunes
3. V1298 Tau (23 Myr solar analog with 4 transiting exoplanets) / stellar activity
4. Towards better C & O inventories of inner disks

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Speed Proposal Sessions

What happens if we "force" the different fields to interact and come up with a proposal idea?

20-minute brainstorming session with a randomly assigned team
Deliverable: Title & pitch, which was later shared with the group

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Final Entire Group Discussion

1. Can we build formation models with fewer free parameters?
2. What are the challenges and caveats of using S-bearing species to trace formation?
3. Why do observers not report systematic errors?
4. What are the least ambiguous testable predictions of planet formation models?
5. Is there any point in speculating a planet's formation history?

One of the biggest challenges faced by this workshop was the language barrier.

The communities speak different languages and sometimes have different meanings for the same words. There was a big effort by members of the workshop to be in alignment with the technical details of each subfield. This took more time than anticipated.

In an effort to combat this for future workshops, we wrote a white paper/ overview paper of the current fields that were represented.

Planet Formation Models

- Core accretion
- Gravitational instability
- Testable predictions

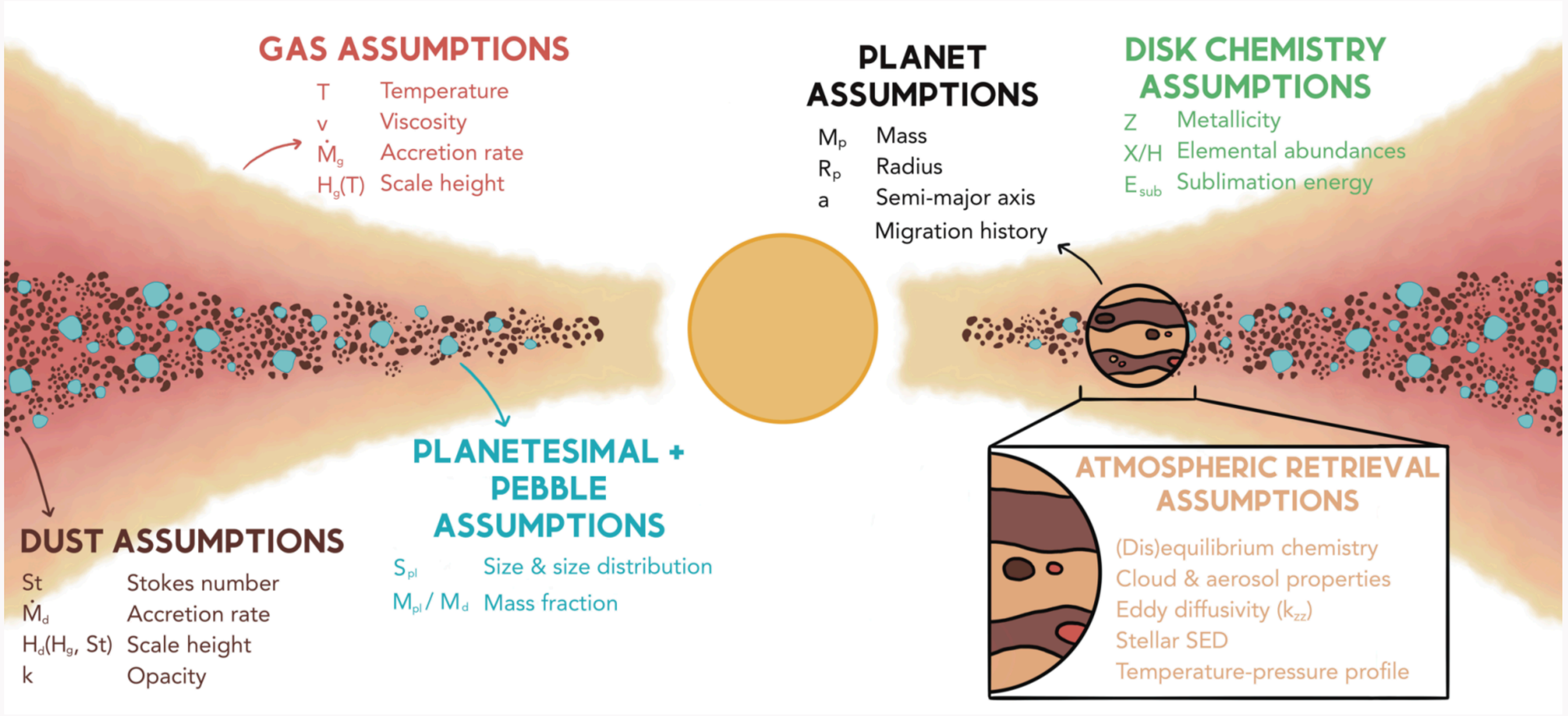
Protoplanetary Disks

- Disk dust properties
- Disk volatiles

Giant Exoplanet Atmospheres

- Atmospheric modeling & inferences
- Transiting exoplanets
- Directly imaged exoplanets

There was significant discussion on understanding the assumptions made at every stage of linking exoplanet atmospheres to formation scenarios.



Feinstein, Booth, Bergner, et al. (under review)

From these assumptions, meeting participants brainstormed some potential paths forward for each field.

Ways Forward - Breaking beyond *only* using C/O

Planet Formation

- Understanding heavy element distribution
- Understanding biases in atmospheric abundances/ elemental ratios

Disk Chemistry

- Measuring elemental abundances beyond C & O
- Measuring isotopic ratios
- Constraining disk refractory compositions

Planetary Atmospheres

- Measuring elemental abundances beyond C & O
- Measuring stellar abundances and elemental ratios
- Understanding how elemental ratios evolve

Feinstein, Booth, Bergner, et al. (under review)

Ways Forward - Incorporating dynamics

Planet Formation

- Understanding how formation processes modify the abundances of gases and solids
- Understanding how N-body interactions influence the composition of growing planets
- Understanding the life cycle of solids during the disk lifetime

Disk Chemistry

- Connecting volatile transport and disk structure

Planetary Atmospheres

- Exploring conditional properties of gas giant planets (e.g., different system configurations)

Feinstein, Booth, Bergner, et al. (under review)

Ways Forward - Leveraging larger surveys

Planet Formation

- Population-level statistics of exoplanet compositions, as single-system solutions will be degenerate

Disk Chemistry

- Measuring properties of larger and more representative disk samples
- Understanding the environmental context of planet formation

Planetary Atmospheres

- Defining a ground "truth" for atmospheric abundances
- Building homogeneous data sets of atmospheric observations

Feinstein, Booth, Bergner, et al. (under review)

Ways Forward - Limitations in modeling

Planet Formation

Disk Chemistry

Planetary Atmospheres

- Understanding the uncertainty in atmospheric modeling
- Combining interior structure modeling with atmospheric characterization
- Obtaining more accurate opacities & equations of state

Feinstein, Booth, Bergner, et al. (under review)

Ways Forward - Connecting observations between fields

Planet Formation

Disk Chemistry

- Expanding the wavelength coverage to the far-IR to better quantify disk masses and the water budget

Planetary Atmospheres

- Detecting and characterizing young planets *in* protoplanetary disks (e.g., IRAS 04125+2902 b; Barber et al. 2024)

Feinstein, Booth, Bergner, et al. (under review)

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Let's keep talking! There was overall excitement about continuing to host these ~small interdisciplinary meetings. We found the meeting to be more productive due to the small size, however future meetings should consider their own white papers to not gatekeep information.

White Paper: https://arxiv.org/abs/2506.00669