Planet formation in stellar cluster environments[1]

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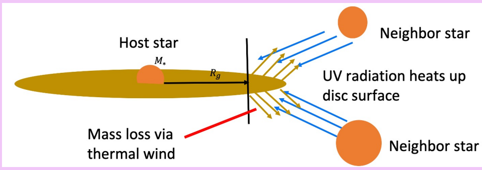
Introduction and Aim

Most planets form in protoplanetary discs around young stars in dense stellar clusters. The FUV radiation from massive stars can heat up the disc surface and drive mass loss via thermal winds. This is called external photoevaporation, which depletes the disc of mass and truncates it, affecting how the disc evolves and forms planets[2].

Orion Nebula Cluster

External photoevaporation of discs

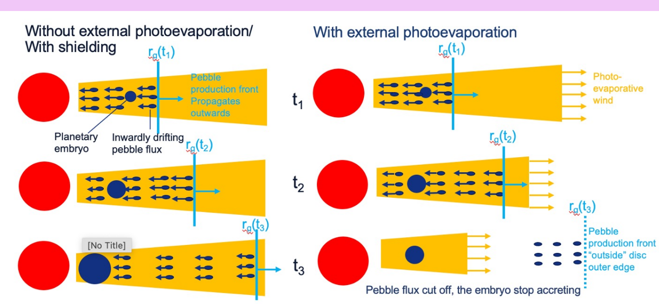


In a dynamically evolving stellar cluster, discs are exposed to time varying FUV radiation. Discs initially embedded in the cloud can be shielded for some time before stellar feedback processes disperse the cloud, exposing discs to strong FUV radiation.[3] Recent studies[4][5] shown shielding can protect discs from high mass loss rates at least for early stage disc evolution, but how this affect planet formation and diversity is still largely unknown.

This paper thus investigated how planet core formation via pebble accretion is affected by external photoevaporation, and how its effects can be mitigated by disc shielding time.

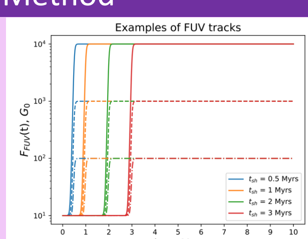
Planet formation via pebble accretion under external photoevaporation

- In pebble accretion, planetary embryos grow via accreting from a flux of inwardly drifting pebbles produced at the pebble production front r_g.
- r_g propagates from inner to outer disc, when r_g reaches disc outer edge, pebble flux is cut off so planet growth stops because.
- **External photoevaporation** truncates the disc radius, reducing time it takes r_g to move to disc edge, thus **reducing the pebble mass reservoir and time-scale over which pebble flux available for accretion in the disc, hindering planet growth.**
- **Cloud shielding time t_{sh} is important in protecting pebble mass reservoir available for accretion.**



Single planet per disc: Method

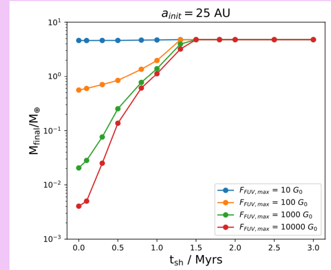
- In Qiao et al. (2023), we coupled a model of planet formation[6] via pebble accretion in a (1D) viscously evolving disc with external photoevaporation induced by a parameterized time-varying FUV field.



- We first included a single planetary embryo per disc, which is subject type I migration and gas accretion, varying 3 parameters:
  (1) Shielding time t_{sh} (0 – 3 Myrs)
  (2) Maximum FUV field strength $F_{FUV,\,max}$ ($10 - 10^4$ G_0)
  (3) Initial semi-major axis a_{init} (10 – 100 AU)

and study how they affect the final mass (M_{final}) and semi-major axis location (a_{final}) of the planets formed.

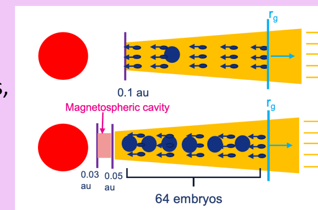
Single planet per disc: Results



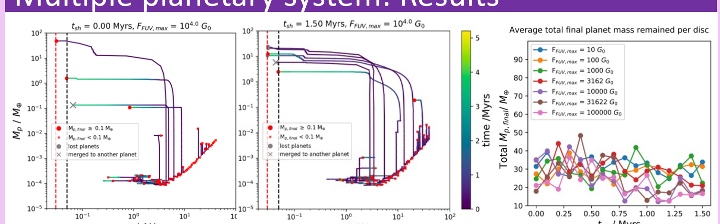
- **Strong external photoevaporation is effective in suppressing planetary core growth** injected at almost all initial semi-major axis (a_{init}) for discs that are not shielded (t_{sh}= 0).
- **Even brief shielding time** (t_{sh} <0.5 Myr) make a difference in delaying rapid truncation, and **drastically affect the planetary mass (M_{final}) and location (a_{final})**
- For medium to strong FUV field ($F_{FUV,\,max}$ = 100 – 10000 G_0) range, **increasing t_{sh} has a nonlinear impact on the resulting planet mass and migration** for planetary embryos originating between 14 – 30 au until a certain value.

Multiple planetary system: Method

- In Qiao et al. (2024) in prep, we included multiple embryos per disc between 1 -40 au , with added effects of planet-planet interactions, gas accretion, and type I and type II migration.
- We allowed non zero e and I, which affects pebble accretion rates
- We Included a magnetospheric cavity that effectively stops inward migration onto the host star
- We varied two parameters: $F_{FUV,\,max}$ ($10 - 10^5$ G_0) and t_{sh} (0 – 1.5 Myrs) and investigated how they affect planet growth and the final planetary architecture.



Multiple planetary system: Results



- The planet growth in multiple planetary system is suppressed by external photoevaporation due to reduced pebble reservoir
- However planets initially formed that were later **lost due to planet-planet interactions eliminates the visible effects of external photoevaporation** in terms of total planet mass remained in the disc.
- Effect of external photoevaporation is visible in wide-orbit planets: Longer t_{sh} results in more wide-orbit planets (> 10 au) of 0.1 – 1 $M_\oplus$

Conclusions

- Planet growth via pebble accretion is sensitive to external photoevaporation of outer disc.
- External photoevaporation limits the inwardly drifting pebble mass budget by depleting the outer disc, conversely, cloud shielding preserve the pebble mass reservoirs, allowing planet growth and migration
- In multiple planetary systems, planets lost due to planet-planet interaction mask the visible effects of external photoevaporation in terms of total mass remained in a system
- But longer t_{sh} still results in more wide-orbit (> 10 au) small terrestrial (0.1 – 1 $M_\oplus$) planets

References

1. Qiao L., Coleman G. A. L., Haworth T. J., 2023, MNRAS, 522, 1939. 2. Ali A. A., 2021, MNRAS, 501, 4136 3. Winter A. J., Haworth T. J., 2022, European Physical Journal Plus, 137, 1132 4. Qiao L., Haworth T. J., Sellek A. D., Ali A. A, 2022, MNRAS. 512, 3788. 5. Wilhelm M. J. C., Portegies Zwart S., Cournoyer-Cloutier C., Lewis S. C., Polak B., Tran A., Mac Low M.-M., 2023b, MNRAS, 520, 5331. 6. Coleman G. A. L., 2021, MNRAS,506,3596