The evolution of **dusty fragments** formed via **gravitational instability** using **AREPO**

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Why AREPO?

- Hybrid moving mesh code (Springel, 2010)
- The unstructured, moving voronoi mesh is well suited to non-axisymmetric geometries
- Galilean invariant
- Automatic adaptation of spatial resolution with density, analogous to SPH
- But also the option to define alternative resolution criteria – e.g. merging particles in fragment cores to reduce computation time
- Well-suited for fragmenting discs and other non-axisymmetric disc problems

Using AREPO for dusty fragmenting discs

- Added dust to AREPO in a (soon-to-be) **public** module
- Dust treated as a cold, pressureless fluid that shares a mesh with the gas
- Drag interaction between gas and dust is calculated using a semi-implicit predictor-corrector algorithm
- Chosen scheme exhibits approximately second-order convergence and robust shock-capturing capabilities
- Options for constant-Stokes or Epstein drag regime (*Celeste, Booth, Clarke 2024 - in prep)*
- Also implemented **modified Lombardi cooling** *(Young, Celeste et al. 2024)* – also public

Fragmenting Disc Over Time

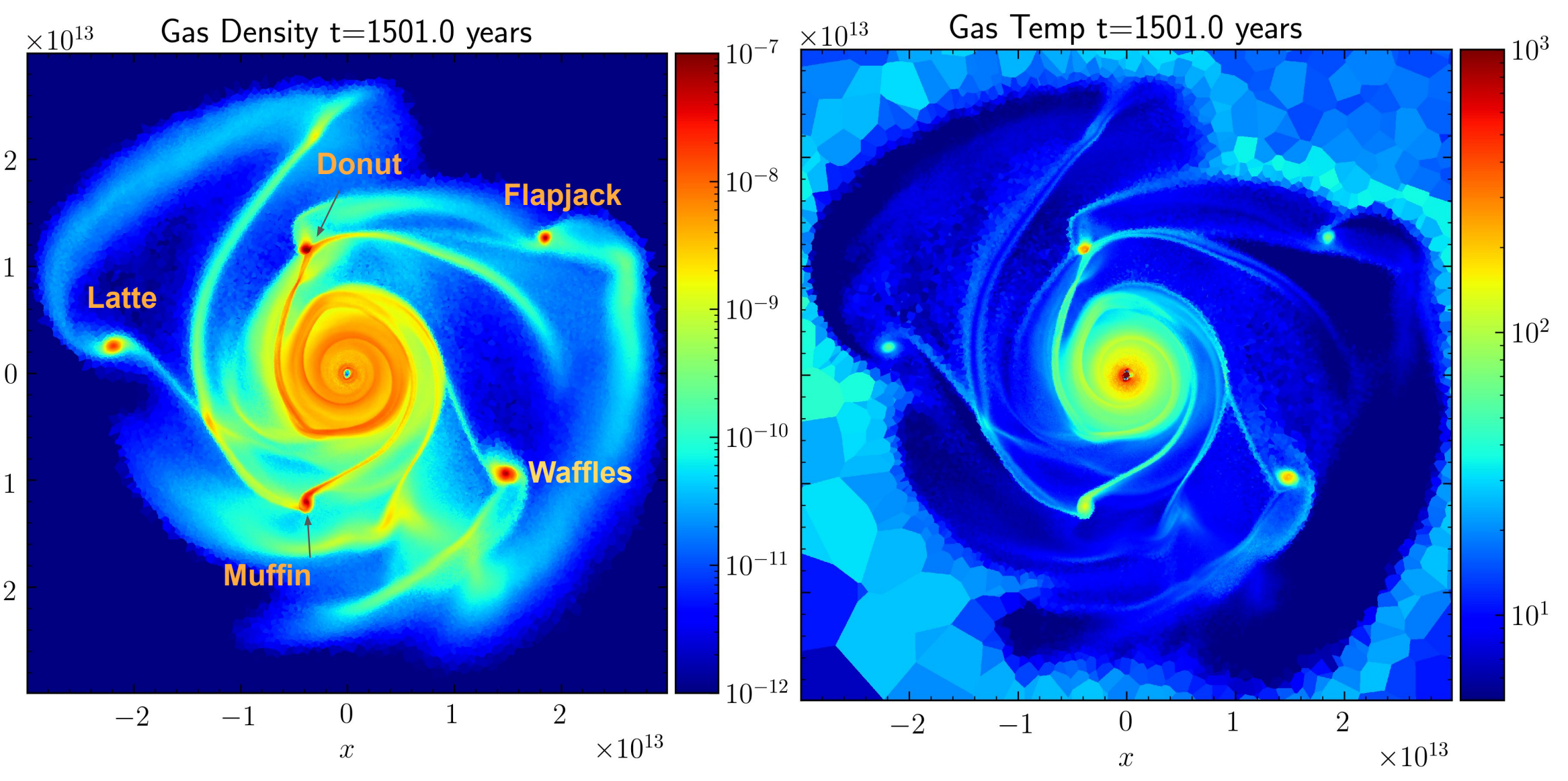

Fig 1. Gas density and temperature for the fragmenting disc at time t=1500 years. A number of fragments have emerged, with masses ranging 1-8 M_{Jup} and initial temperatures 60-200K. We have labelled some fragments here.

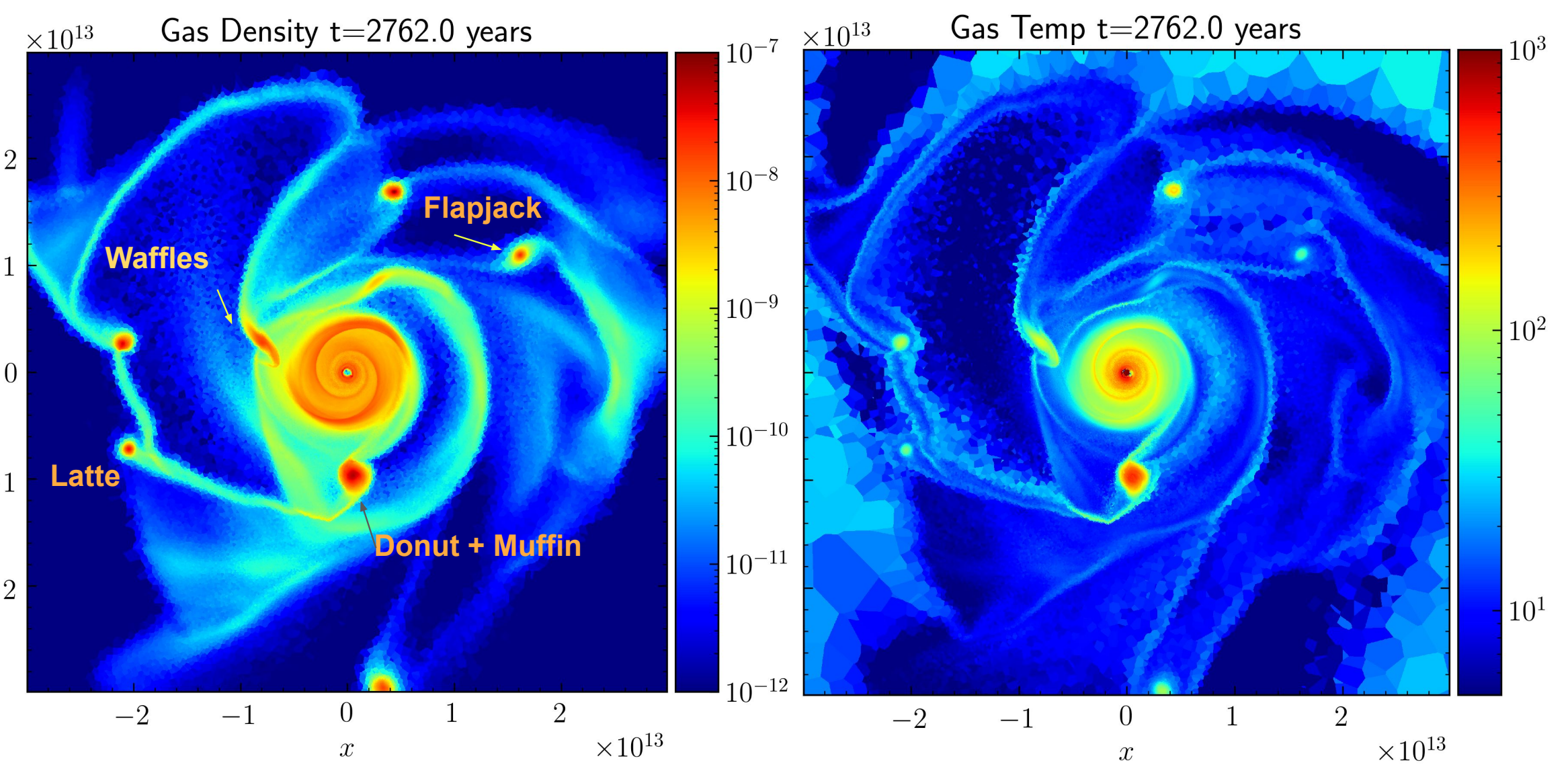

Fig 2. Gas density and temperature at time t=2762 years. Donut and Muffin have merged into a huge 20 M_{Jup} fragment, hereafter "Donuffin". Waffles is in the process of being sheared apart.

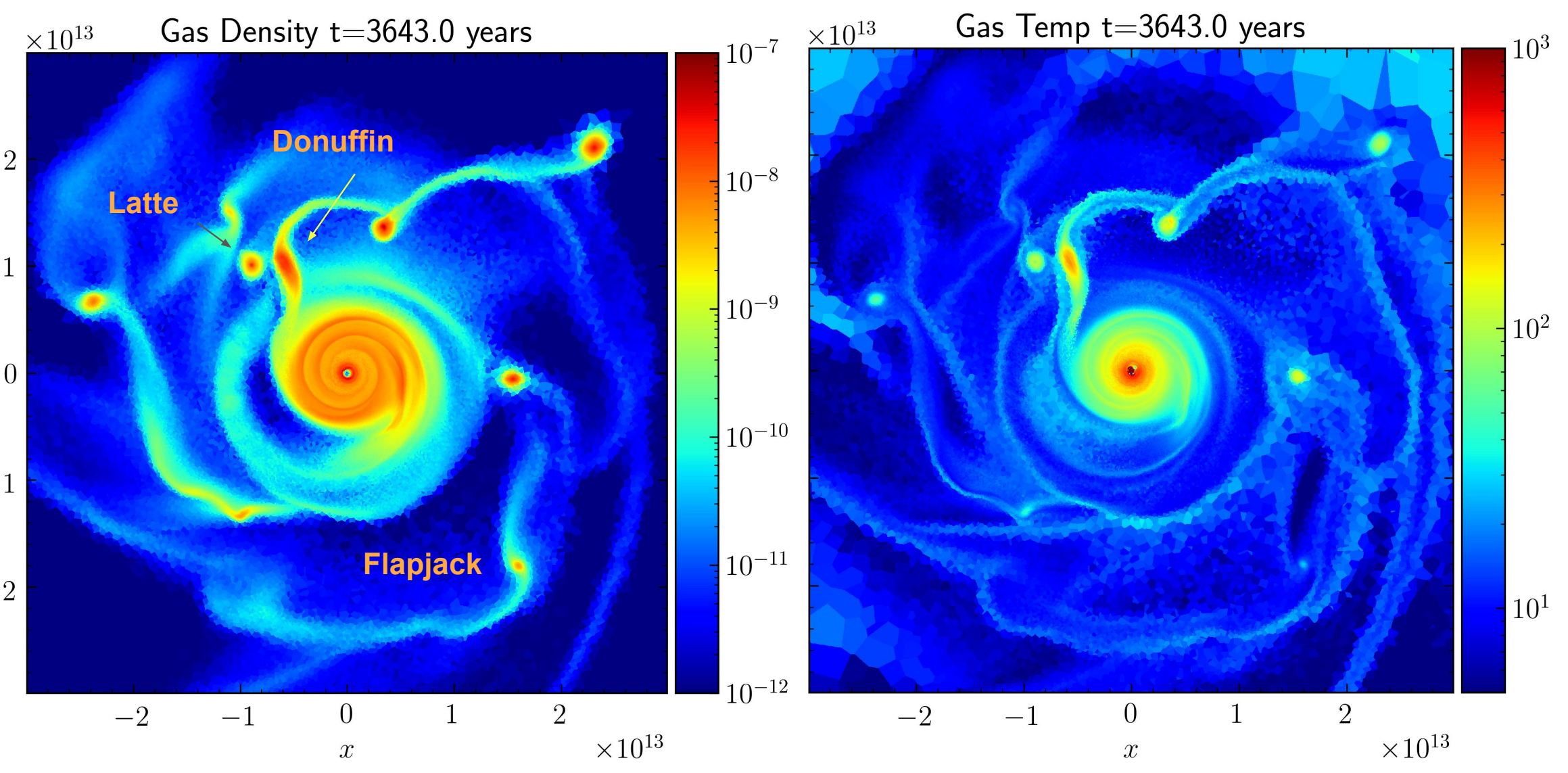

Fig 3. Gas density and temperature at time t=3643 years. Donuffin will soon merge with Latte, forming an even more massive fragment (30 M_{Jup}). New fragments have also formed.

I can't be here in person, so please contact me at mcg58@cam.ac.uk if you're interested in using AREPO for dusty disc simulations!

Initial conditions matter for chemical composition!

- Despite forming in the same disc, fragments can have very different conditions at birth; see the temperature plot in Fig 1.
- Whether the majority of dust settles **before** or **after** the fragment is hot enough for sublimation should have an important effect on the relative abundance of dry ice vs volatiles.

Cold Start

- Flapjack is born at a low temperatures and **dust quickly settles to the core** of the fragment
- Thus even if the fragment heats up over time through contraction or mergers, it should be **enriched with volatiles as well as dry dust**
- This phenomenon is proposed in Ilee et al. 2017 as a "cold start"

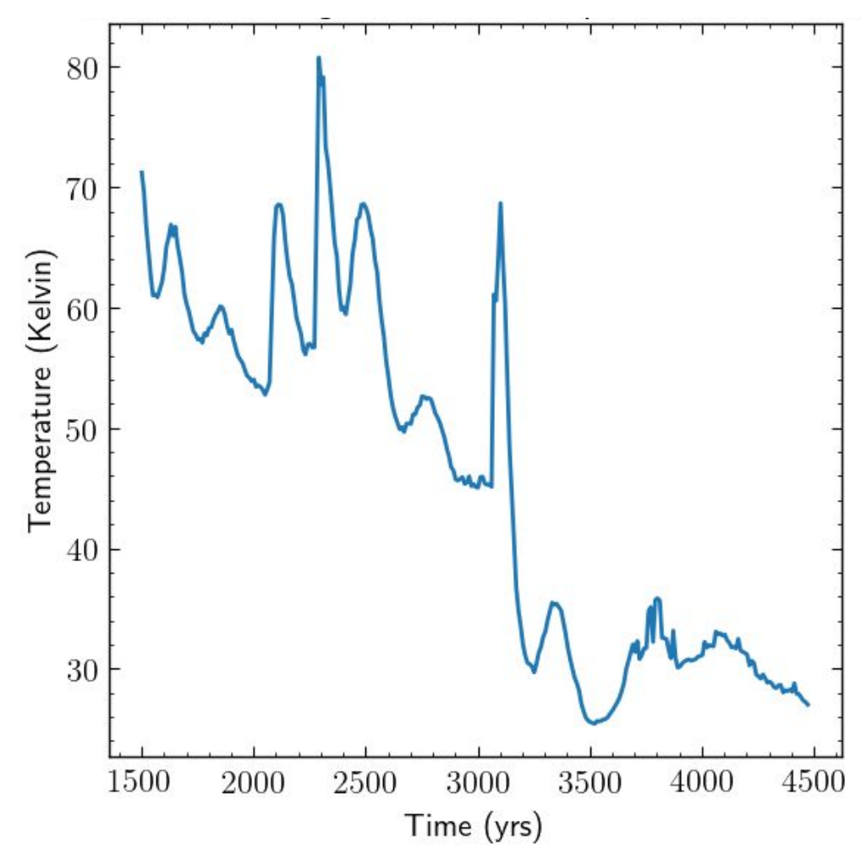

Fig 4. Flapjack's temperature over time.

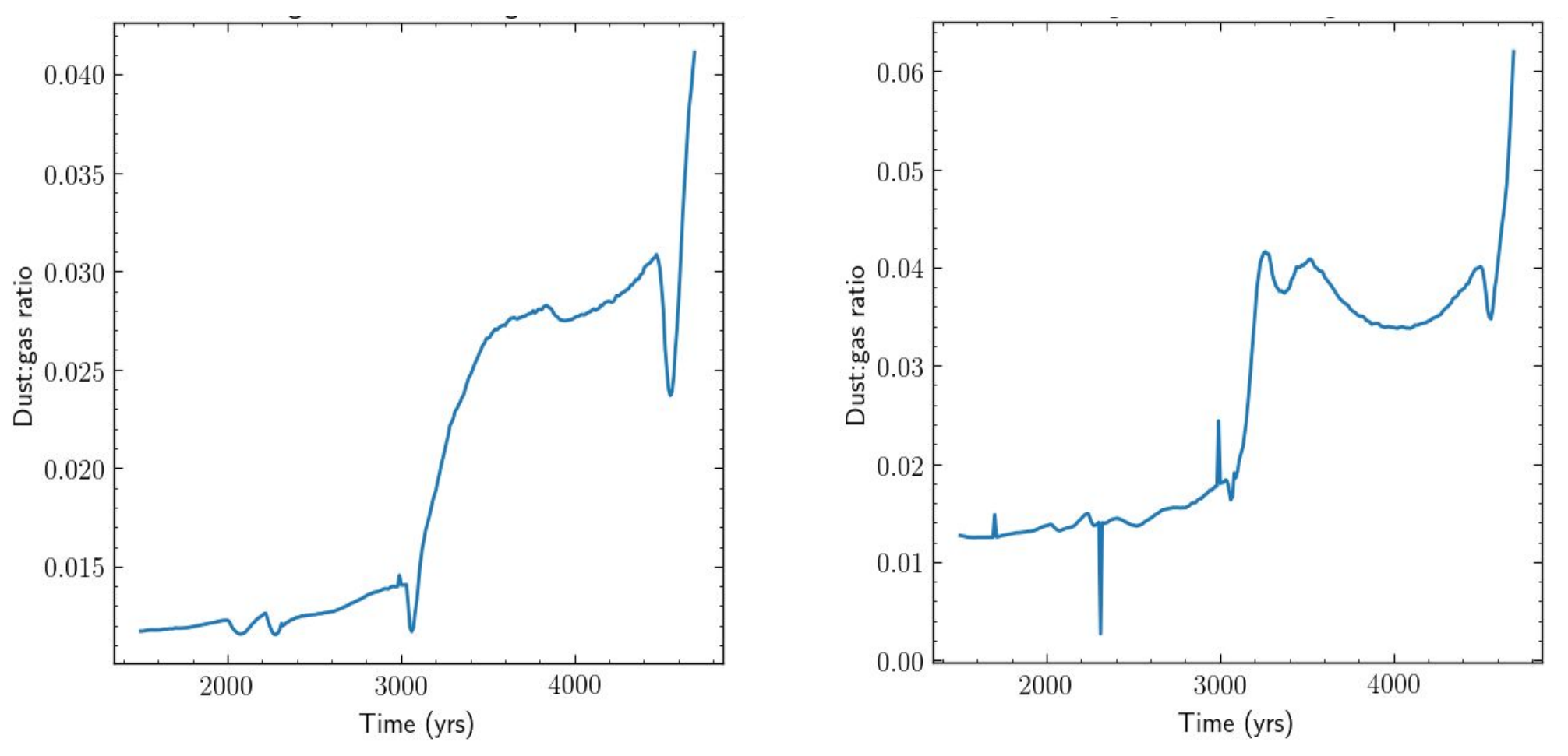

Fig 5. Bulk dust:gas ratio over time for Flapjack.
Left: Within total Hill radius;
Right: Within half the Hill radius

Warm Start

- Waffles is born at a relatively high temperature => **some volatiles sublimate before dust settles**
- Sublimated volatiles may diffuse through the disc, depleting the fragment
- Still **enriched with dry dust**
- Ilee et al. 2017 predict similar hot starts

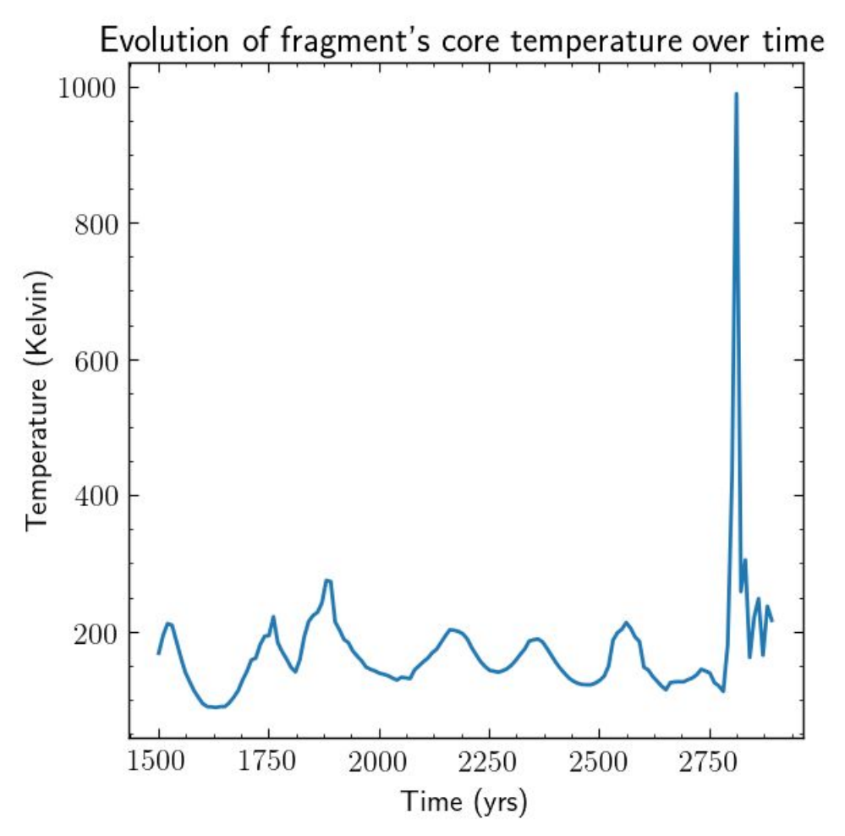

Fig 6. Waffles' temperature over time.

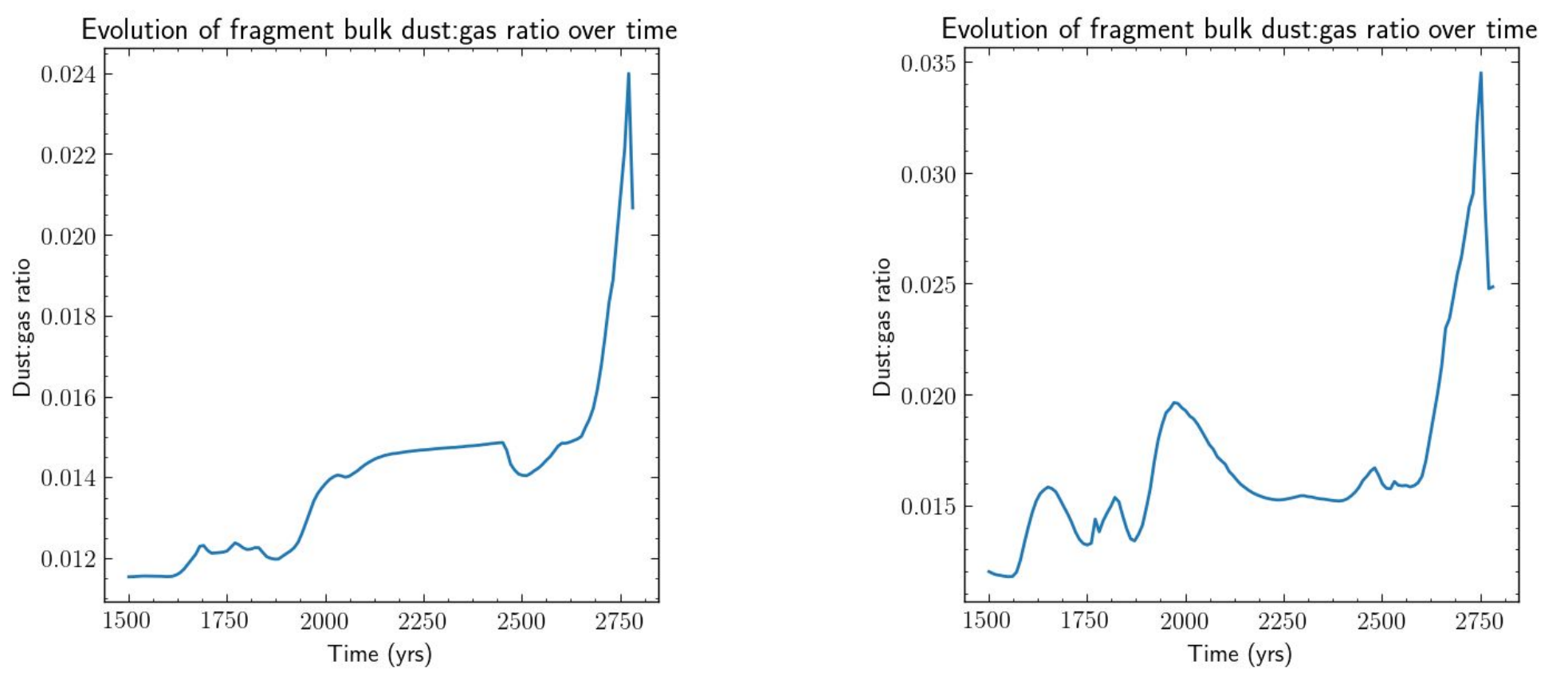

Fig 7. Bulk dust:gas ratio over time for Waffles.
Left: Within total Hill radius
Right: Within half the Hill radius