Fragmentation of protoplanetary discs formed in a collapsing gas cloud

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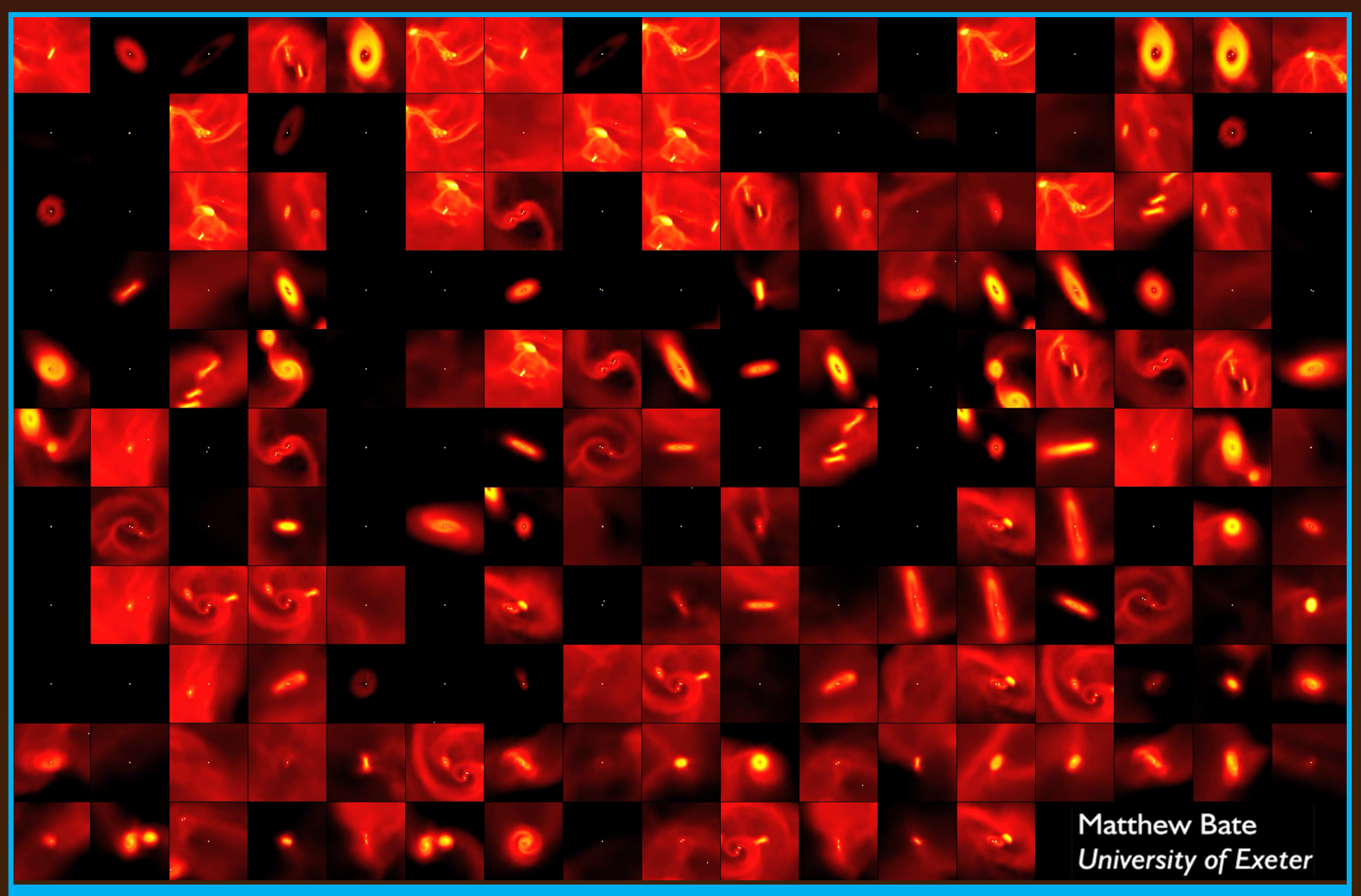
Abstract: Simulations of collapsing giant molecular clouds show protostars forming with discs that may be massive enough to be susceptible to the gravitational instability. This instability may play a key role in both the formation of the star itself, and in the formation of giant planets through disc fragmentation. To model these discs in detail, the individual disc resolutions need to be increased compared to what is possible in simulations of cloud collapse. To this end, we use an iterative particle-splitting scheme that preserves the overall density distribution. This will allow us to run high-resolution simulations of very young protostellar discs with realistic initial conditions to understand the frequency at which they may undergo fragmentation and the properties of the objects that might form in such systems.

Motivation: ①

- Disc fragmentation → wide orbit, massive exoplanets?
- Fragmentation not fully understood
- Rapid process → difficult to observe
- Statistical info could aid observation

Study timeliness:

- **Large dataset of <u>realistic discs</u> available → Bate 2012**
  - *Bate 2018 → find many discs in star-forming env.*
  - *<u>BUT</u> they have low resolution*



Bate 2018 analysis of redsultant discs

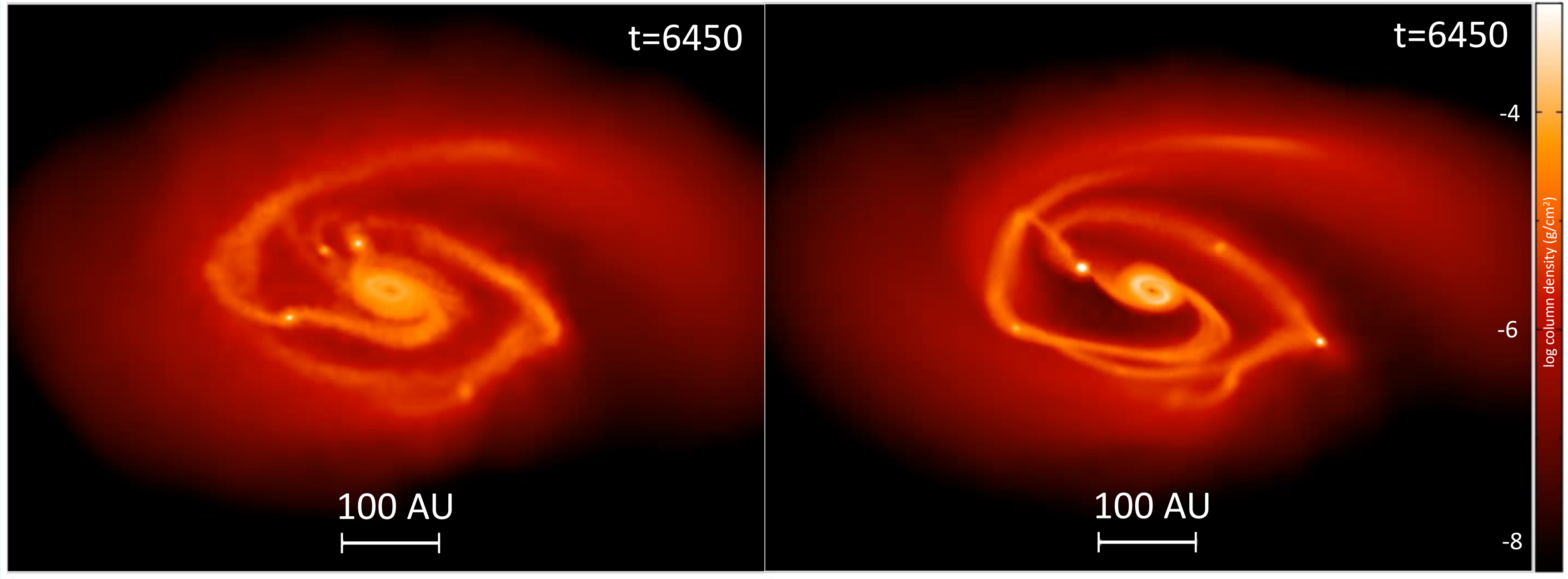
- **Particle <u>splitting code</u> available** → *Bending+ 2020*
- **<u>New cooling method</u> available** → *Young+ 2024*

Questions:

- *How frequently do discs fragment?*
- *How important are dynamical interactions?*

Simulation resolution ②

- Resolution is important in self-gravitating disc simulations
- Different fragments produced at low vs. high res. (see below)
- Requirement: minimum resolvable mass < Jeans mass



*Two simulations of Sink 4 $(M_* = 0.38 M_\odot, M_{disc} = 0.54 M_\odot)$ extracted from Bate 2012 simulation. **Left:** Low resolution. **Right:** High resolution. Credit: Alison Young*

References:

1. Bate, 2012, MNRAS, 419, 3315
2. Bate, 2018, MNRAS, 475, 5618
3. Bending, Dobbs, Bate, 2020, MNRAS, 495, 1672
4. Young, Celeste, Booth, Rice, Koval, Stamatellos, Carter, 2024, 531, 1746
5. Tobin, Sheehan, Megeath, Díaz-Rodriguez, Offner, ApJ, 890, 130

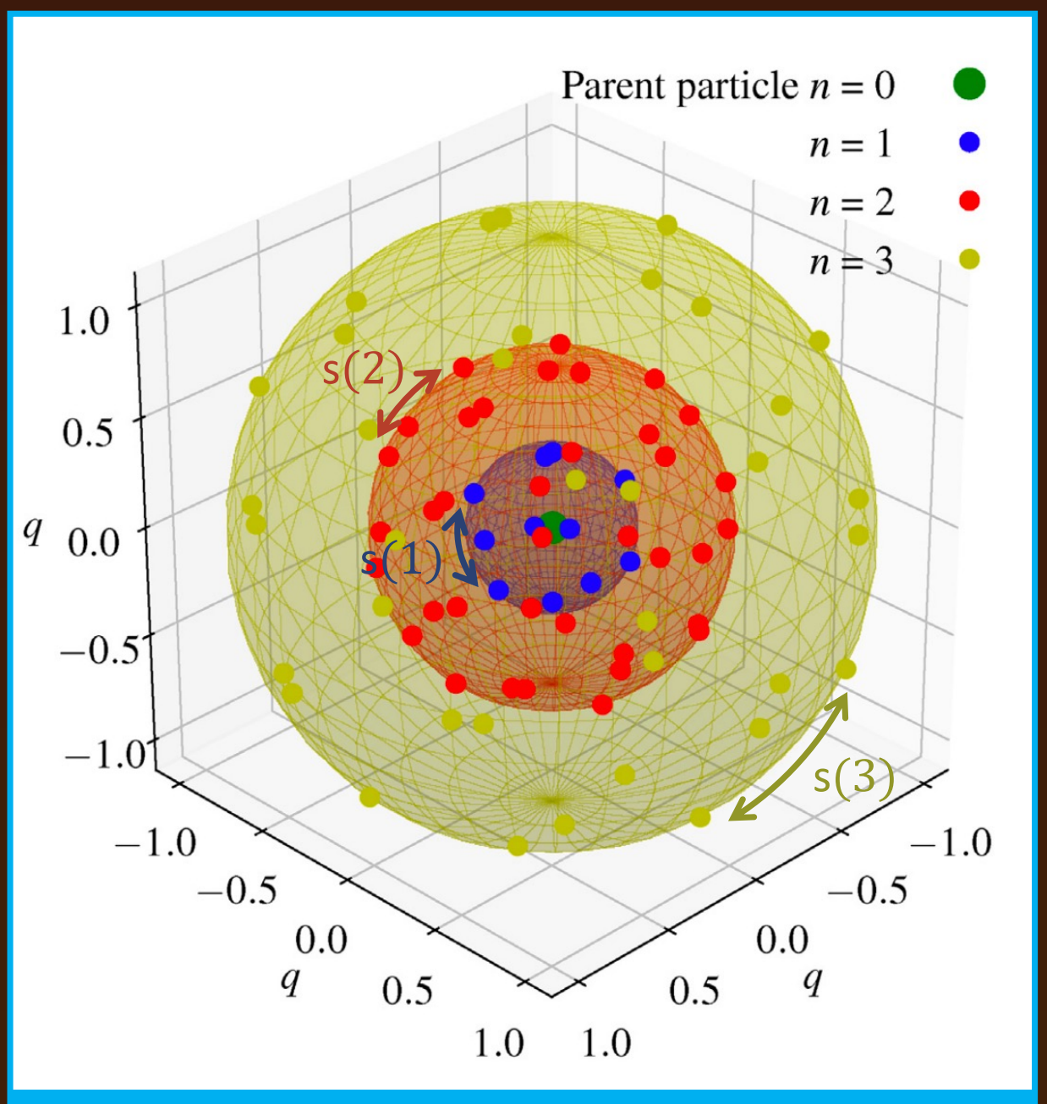
Splitting scheme: ③

- Iterative splitting scheme as used by Bending+ 2020 allows us to increase resolution of Bate 2018 discs
- Daughter particles are placed around the parent particle on shells
- A *nearly* arbitrary number of daughter particles is possible
- Spacing of particles on shell with radius q given by:

$$s(q) = s_0 \left(\frac{w(q)}{w(0)}\right)^{-\frac{1}{3}}$$

- Radius of shell *n* given by:

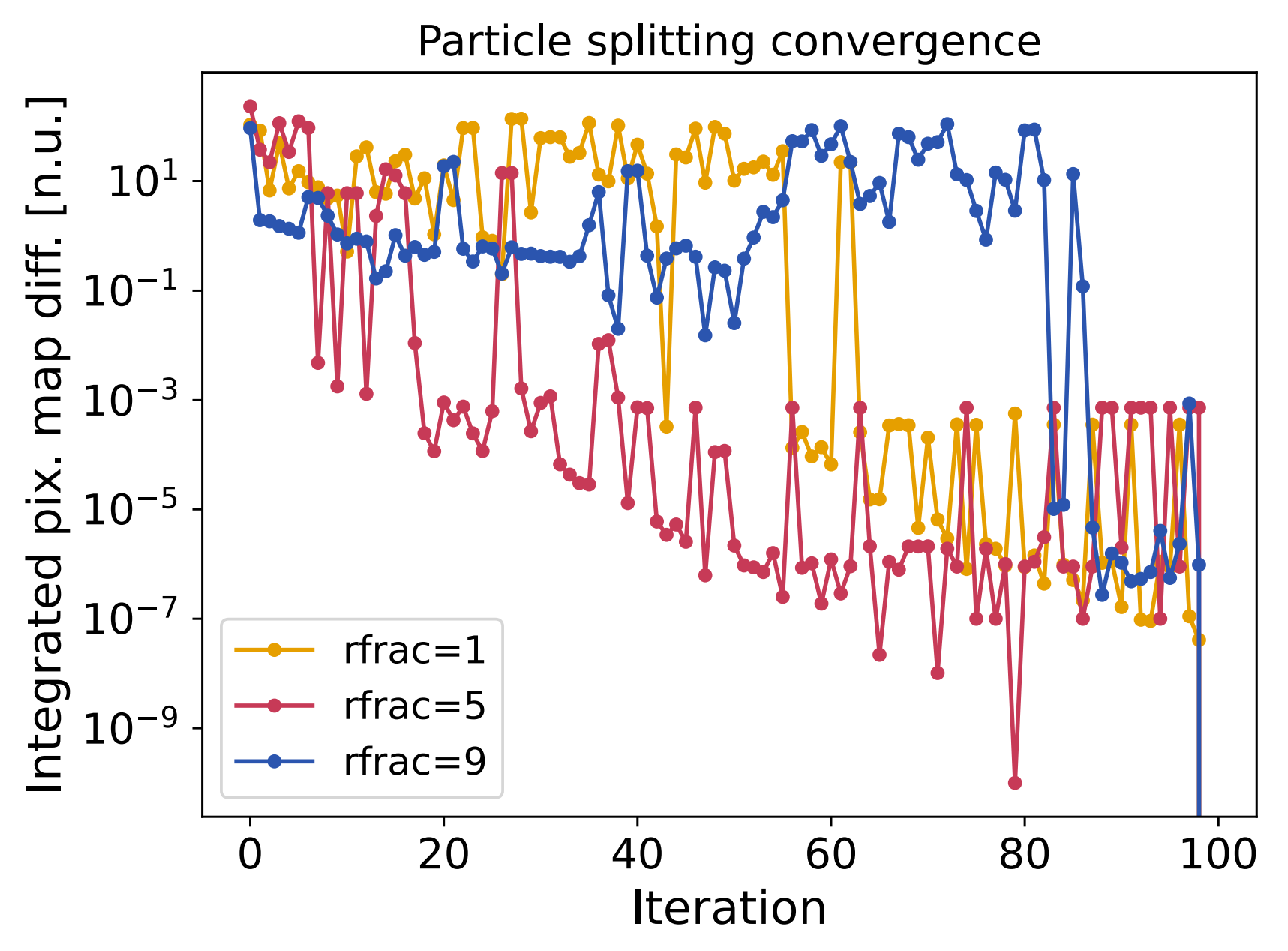
$$q_n - q_{n-1} = \frac{1}{q_n - q_{n-1}} \int_{q_{n-1}}^{q_n} s(q)\mathrm{d}q$$



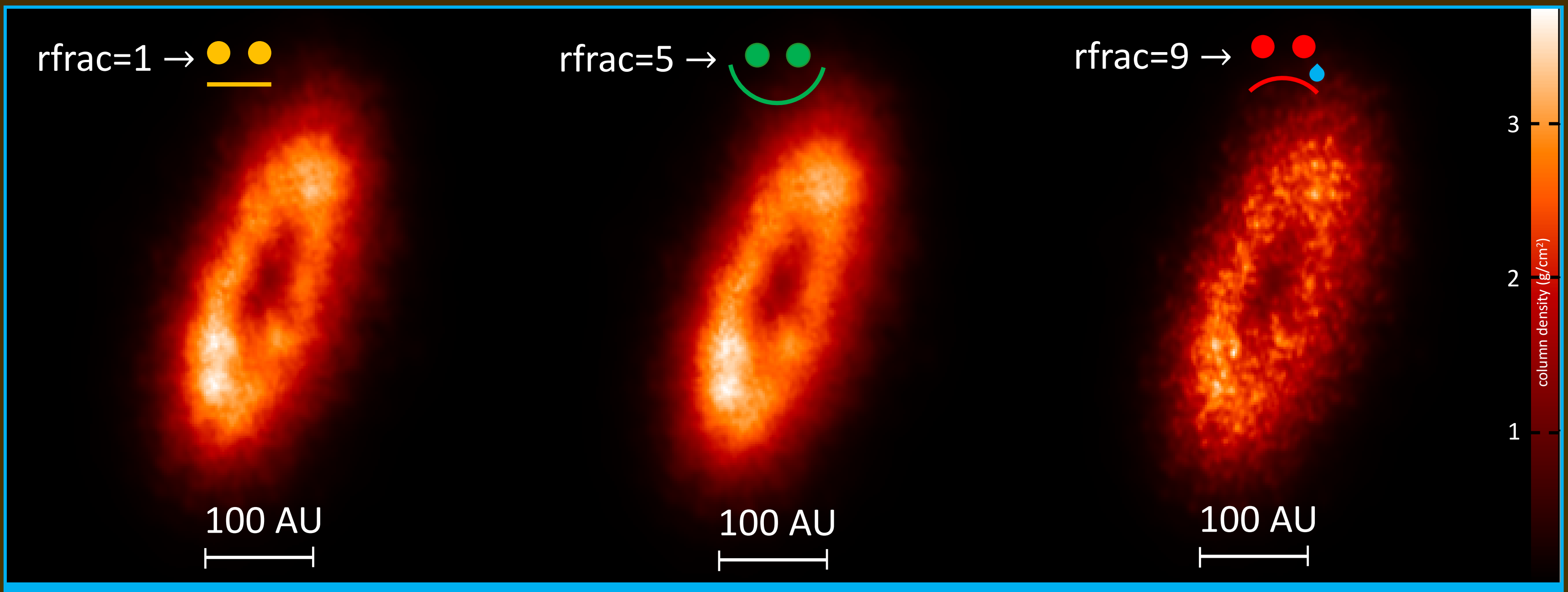
Bending+ 2020 particle splitting scheme

Tuning splitting parameters

- Density matching is sensitive to input parameters
- A key parameter, *rfrac,* controls distance particles can **move from starting position** during density matching



Convergence of splitting routine at different rfrac values



Sensitivity of density matching to the rfrac parameter value

Future work: ④

- Tobin+ 2020: non-binary low-mass discs overrepresented in simulations
- Stellar fly-bys, unbound encounters

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