The effects of Accretion Luminosity from Population III protostars.

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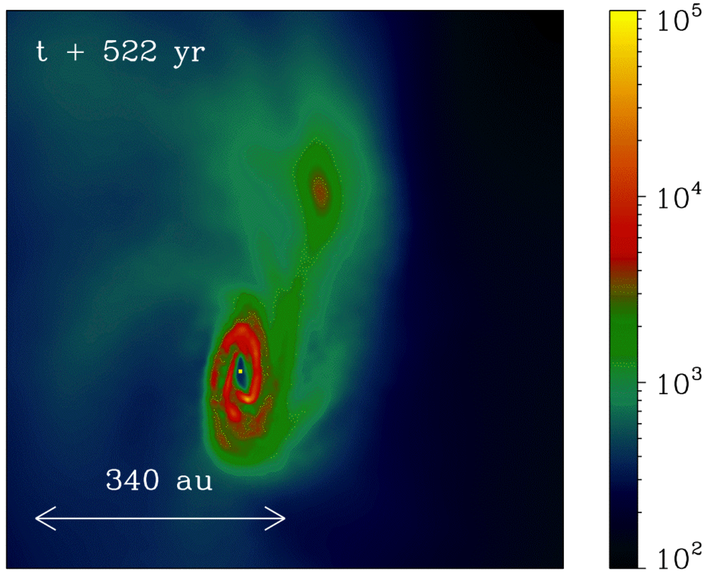


Summary

Accretion Luminosity feedback modifies and delays fragmentation but it cannot prevent it.

Consider two cases:

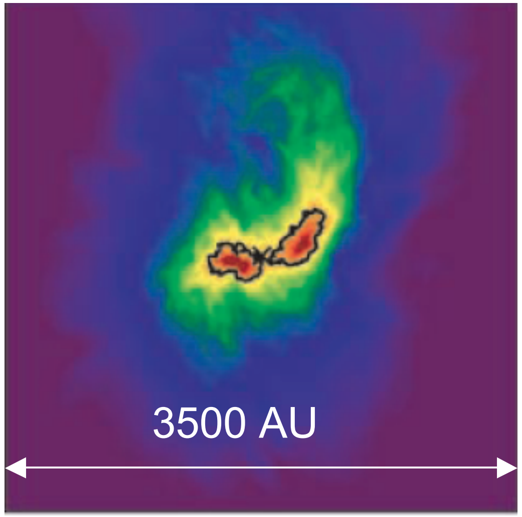
- In a protostellar disk
- In 5 mini-halos

Motivation

1

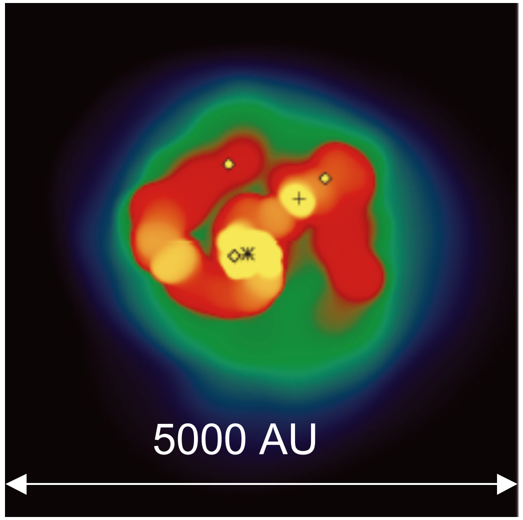
Fragmentation

Recent works have shown evidence of fragmentation and the formation of small N stellar clusters in the primordial universe.



Turk et. al. 2009

AMR forms wide binary 800AU



Stacy et. al. 2010

SPH + *Sinks* small N cluster

Suppressing Fragmentation

Fragmentation is a paradigm shift in our understanding of Pop III star formation. Can we suppress it?

Possible suppression mechanisms:

Ionisation feedback - predicted to be highly effective after protostar reaches Kelvin Helmholtz stage.

Accretion luminosity - effect unclear

Dark Matter annihilation - effect unclear

Modeling Accretion Luminosity

2

Heating Rate

We use a version of GADGET2 which has been heavily modified to include a detailed chemical network:

Accretion luminosity included as a heating term in the chemical and thermodynamic evolution of the gas.

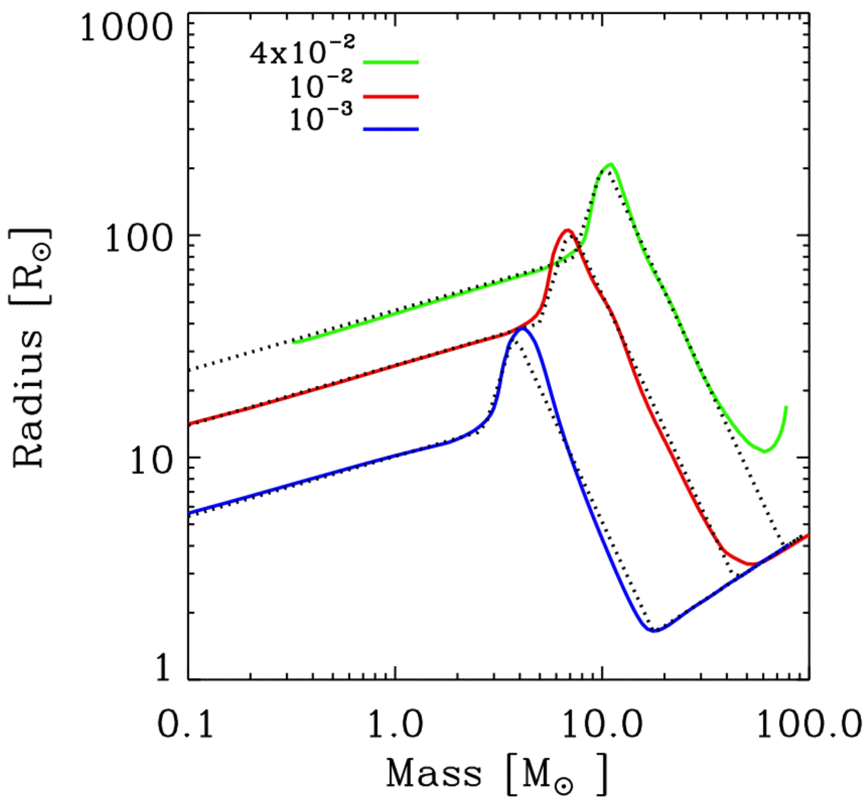
Assuming the gas is optically thin the heating rate for the gas will be

$$\Gamma_{acc} = \rho_g \kappa_P \left(\frac{L_{acc}}{4\pi r^2} \right) \qquad \text{in erg g}^{-1}\text{ s}^{-1}$$

Where κ_P is the Planck mean opacity of the gas from Mayer & Duschl (2005)

$$L_{acc} = GM_* \dot{M} / R_*$$

Stellar Model



Model stellar radius by fitting to models of Omukai et. al. (2003)

$$R_* \propto \begin{cases} 26 M_*^{0.27} (\dot{M}/10^{-3})^{0.41} & M_* \leqslant p_1 \\ A_1 M_*^3 & p_1 \leqslant M_* < p_2 \\ A_2 M_*^{-2} & p_2 \leqslant M_* \ \& \ R < R_{ms} \end{cases}$$

$$p_1 = 5 \dot{M}^{0.27} M_\odot$$

$$p_2 = 7 \dot{M}^{0.27} M_\odot$$

Feedback on Protostellar Disks

3

Primordial Disk Fragmentation

Previously detected fragmentation was at scales of 1000 AU+.

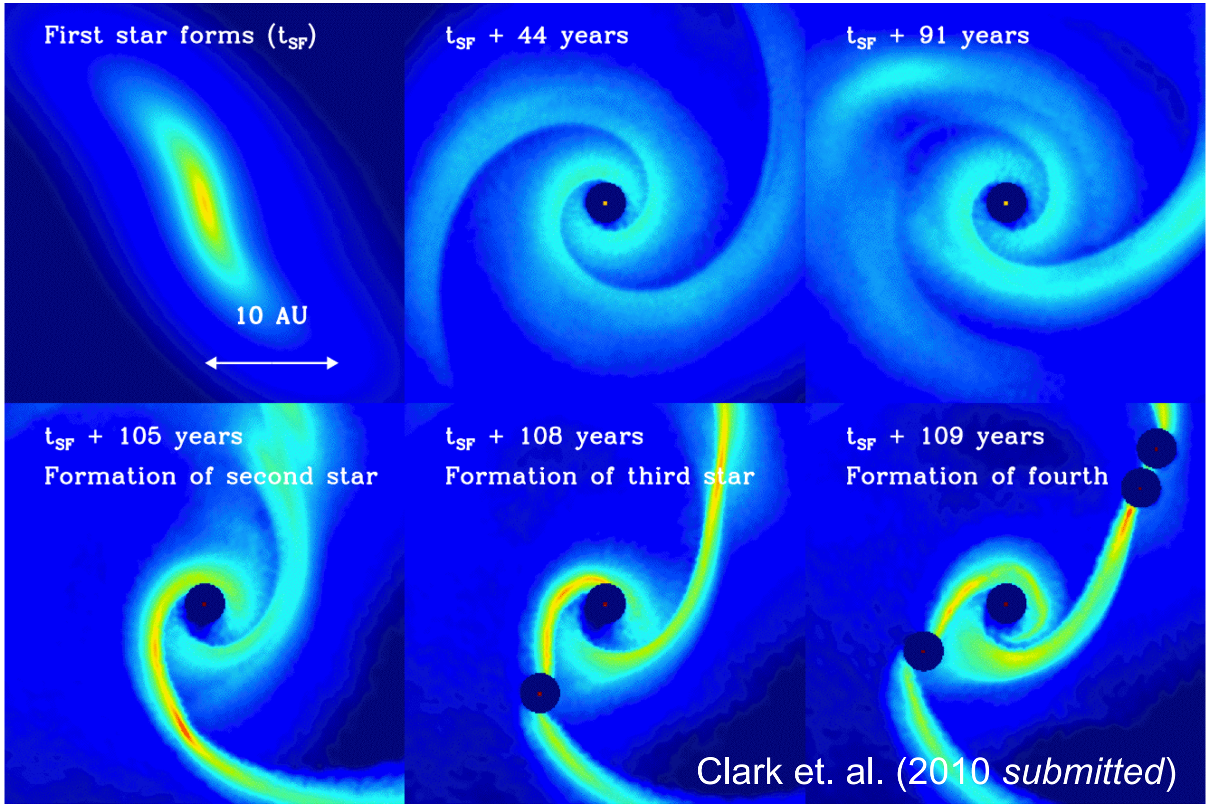
Clark et. al. (2010 *submitted*) resolve the protostellar disk around Pop III protostars starting from cosmological initial conditions using a re-zooming technique.

The disk is unstable to fragmentation.

This leads to the exciting prospect of Pop III close binaries.

If these survive the accretion phase, high red-shift gamma ray bursts and X-ray binaries are potential outcomes.

Effect of Heating



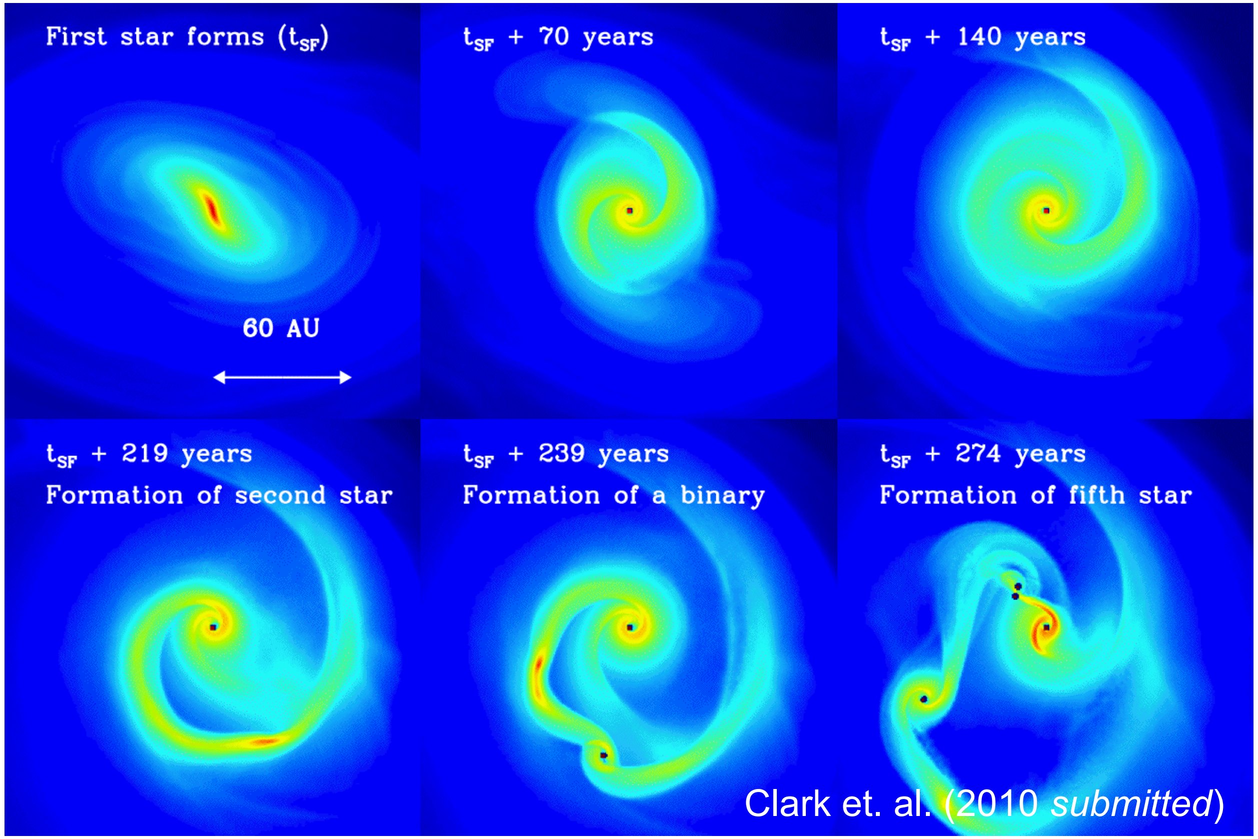
Accretion rate: $10^{-3}\ M_{\odot}$ /yr

Scale: 10^{13} cm^{-3} (dark blue) to 10^{17} cm^{-3} (red)

Fragmentation due to:

-H_2 line cooling keeping the disk cool, T~ 1000K

Effect of Heating



Accretion rate: 10^{-2} $M_{\odot}$ /yr

Scale: 10^{11} cm^{-3} (dark blue) to 10^{16} cm^{-3} (red)

Stronger feedback:

-fragmentation at larger radii.

- fragmentation after a longer time.

-disk is hotter and more diffuse in inner 5 AU.

Feedback on Mini-haloes

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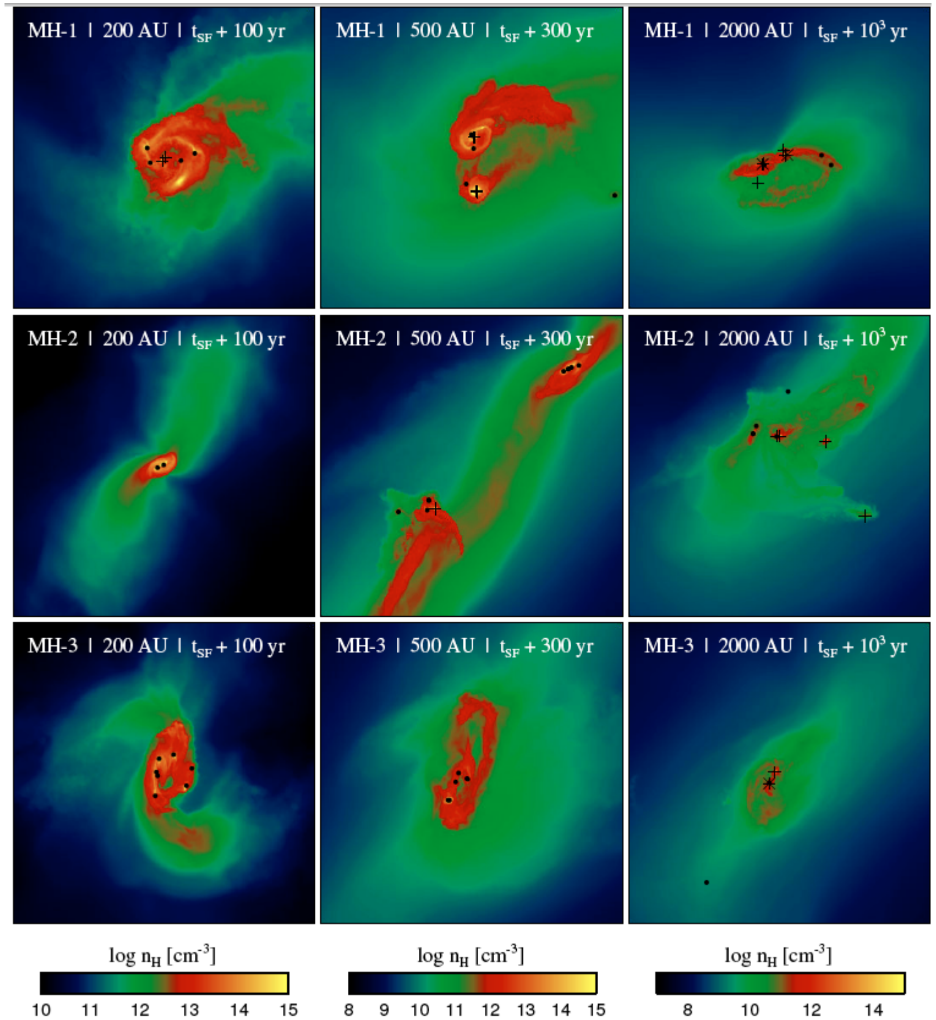
A tale of 5 mini-haloes



5 mini halos from cosmological initial conditions *(Greif et. al. 2010 submitted)*

All of which fragment in the inner 200 AU of a disky region over a 1000 yrs.

Q. What is the effect of accretion luminosity?

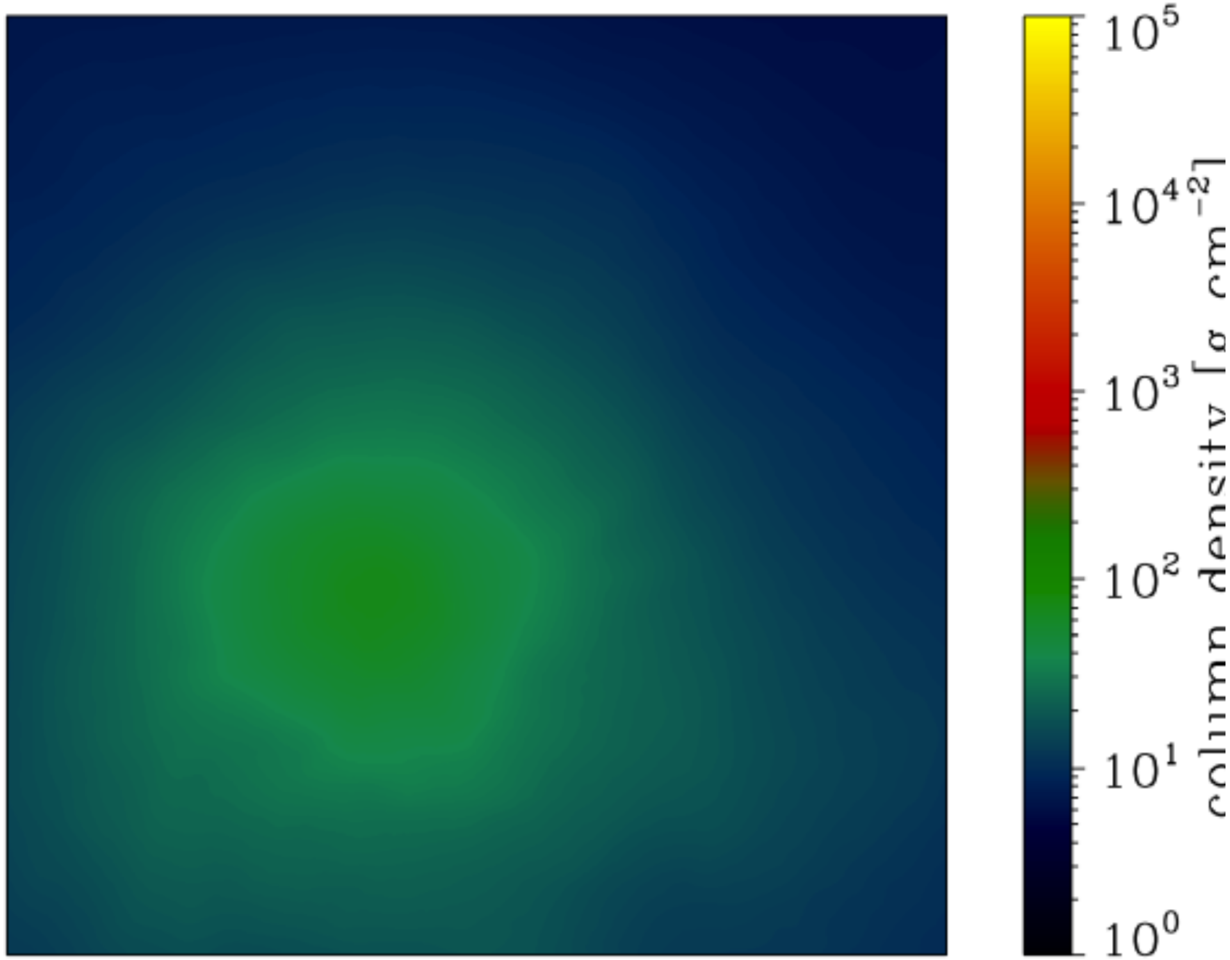
Q. How much fragmentation is there before ionisation becomes significant?

A tale of 5 mini-haloes

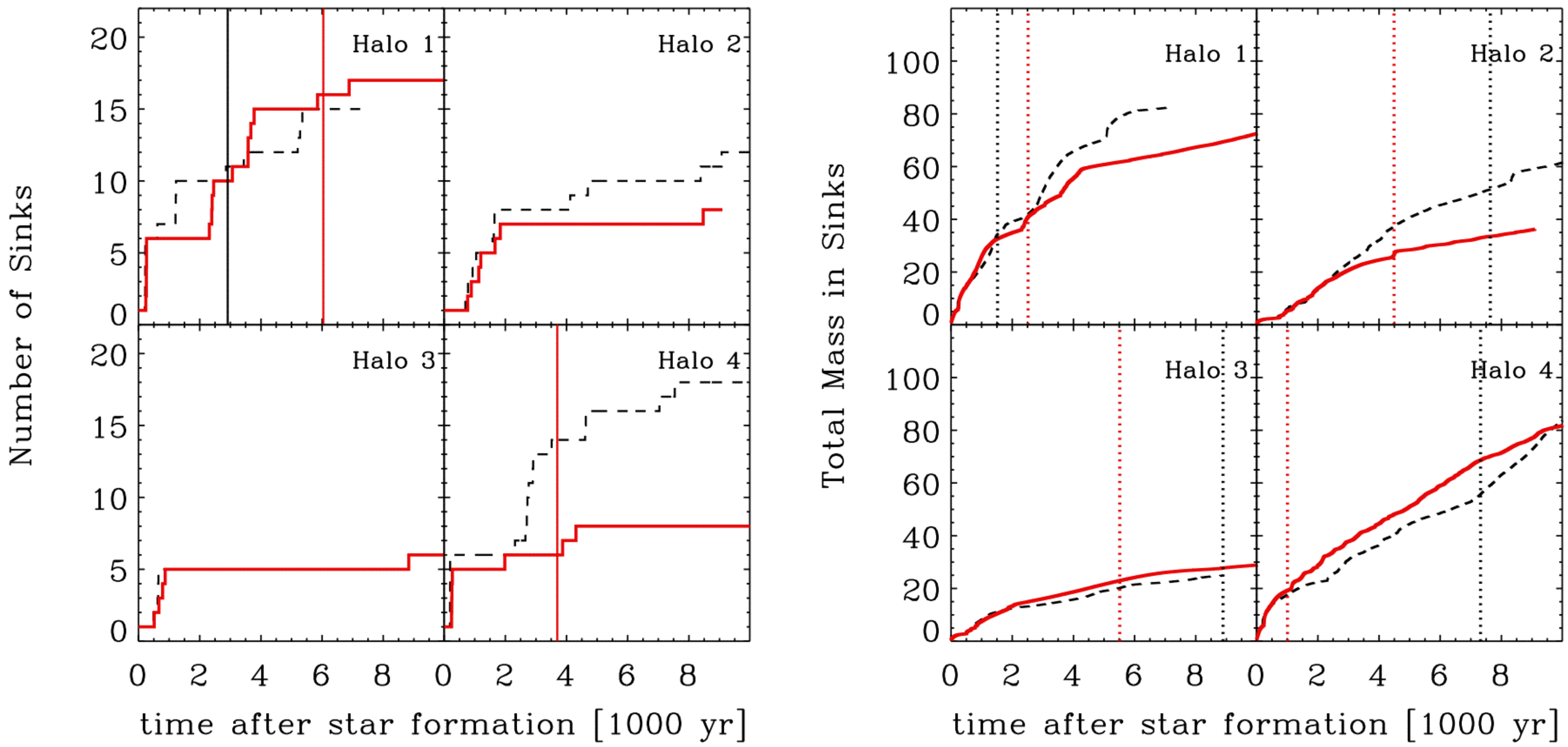
Re-simulate inner 2 pc.

mass resolution 10^{-2} $M_{\odot}$, sink radius 20 AU, follow over 10,000 yrs

Fragmentation still occurs in all cases



Effect of Heating



Accretion luminosity delays fragmentation.

Mass in fragments remains the same.

Variability

Number of fragments depends on time:

(tidy this to final version)

Halo	No feedback 10 $M_\odot$	15 $M_\odot$	Feedback 10 $M_\odot$	15 $M_\odot$
1	10 at 1520 yr	11 at 2914 yr	10 at 2518 yr	16 at 6040 yr
2	10 at 7637 yr	12+ at 14093+yr	7 at 4491yr	8+ at 9502 yr
3	5+ at 9,153+yr	5+ at 9,153+yr	5 at 5140 yr	6+ at 11,256+ yr
4	17 at 7,318 yr	19+ at 17,077 yr	5 at 1006 yr	6 at 3697 yr
5	7 at 604 yr	17 at 1060 yr	18 at 1441 yr	23 at 3901 yr

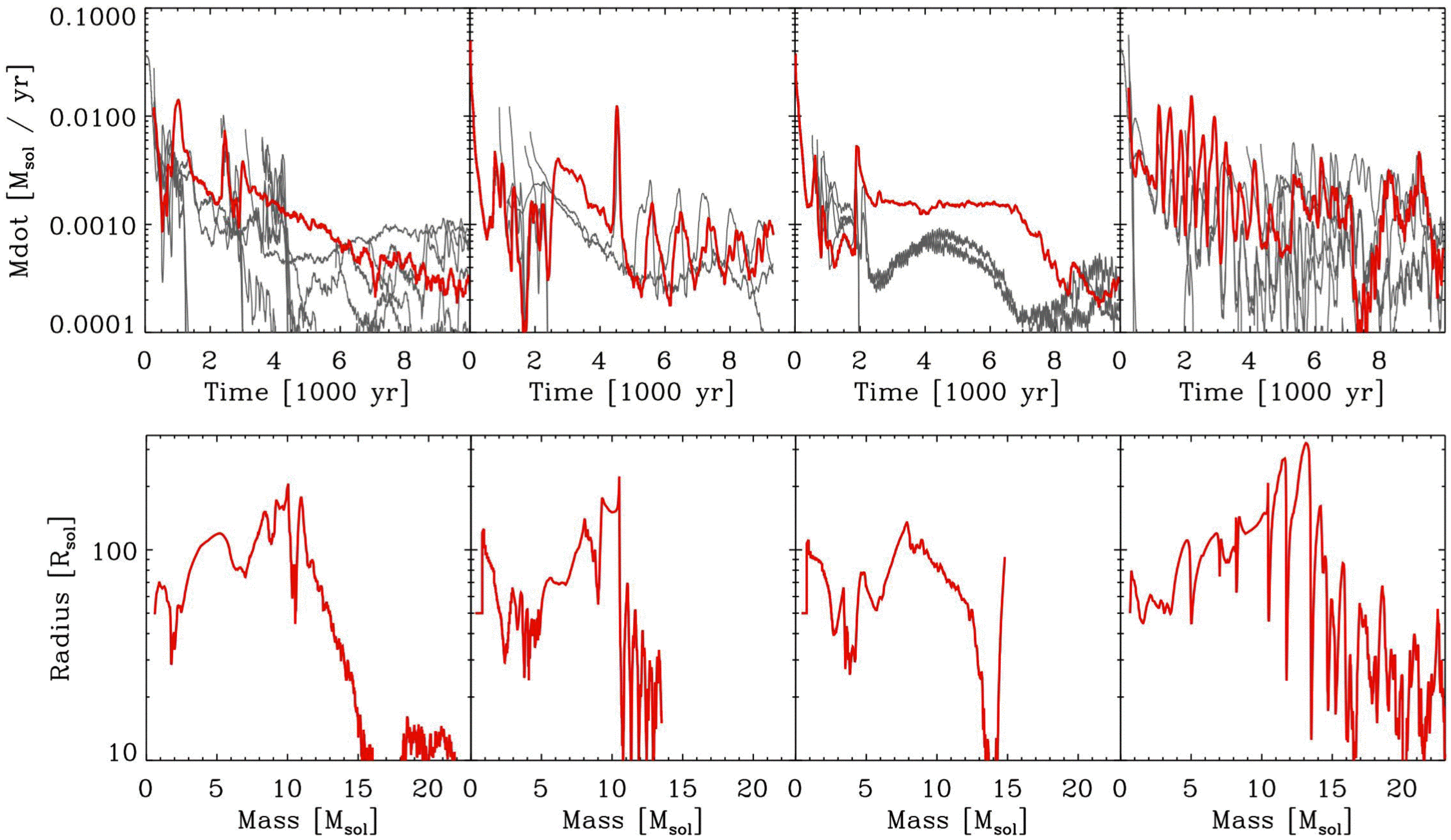
Rough order of importance:

1) Inter halo variability.
2) Accretion feedback.

If many fragments form in a short time then dynamical interactions dominate the evolution.

Stellar Modeling

What is the correct stellar model for a variable accretion rate?



Future Work

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Future Work

Future work:

- Ionisation feedback, *with Thomas Peters.*
- Dark stars, *with Dominic Schleicher and Fabio Iocco*
- Initial conditions for stellar modelling

Outstanding issues:

- The dynamics of close interactions in the primordial universe

Conclusions

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Conclusions

Accretion Luminosity feedback modifies and delays fragmentation but it cannot prevent it.

1. Protostellar disks will fragment into multiple objects.
2. Feedback increases the time for the disk to become unstable and the radius of fragmentation.
3. Inter-halo variability has a larger effect on fragmentation than accretion feedback.
4. Feedback can suppress the total number of fragments in a mini-halo... *sometimes.*
5. The dynamical nature of these halos is a challenge to current stellar evolution models.

Extra

Overview

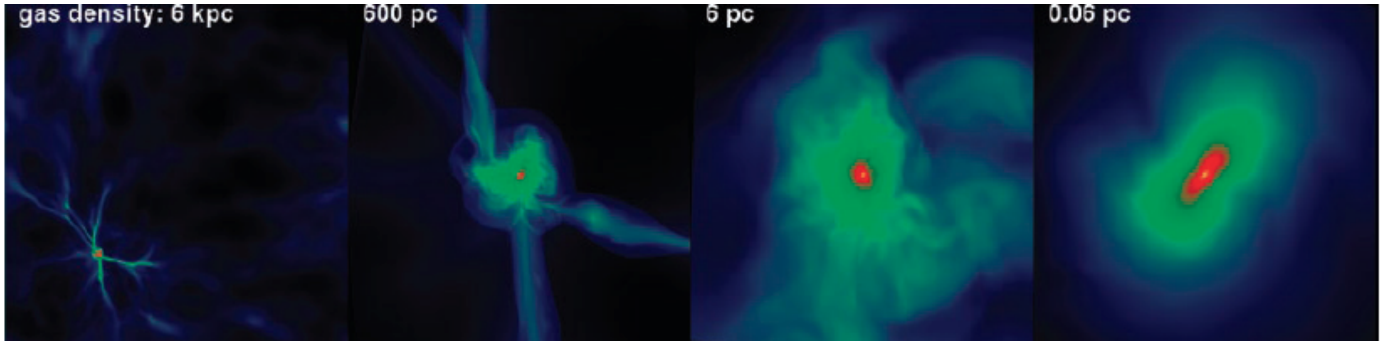
1. Motivation
2. Modeling Accretion Luminosity
3. Feedback on Protostellar Disks
4. Feedback on Mini Haloes
5. Conclusions

How Massive are Pop III stars?

Early simulations found massive single stars were formed in primordial mini-haloes.

-*Abel et. al. (2000, 2002), Yoshida (2008)*

but these works had to stop after the first star...



Abel et. al. 2002

The Code

We use a version of GADGET2 which has been heavily modified to include a detailed chemical network:

- **H_2 cooling** using the detailed cooling function of Glover & Abel (2008)
- Optically thick H_2 cooling using the **Sobolev approximation** as Yoshida et al. (2006)
- **Collision induced emission** from H_2 at high densities (Ripamonti & Abel 2004)
- **Ionisation and recombination** as described in Glover & Jappsen (2007)
- Heating and cooling from changes in the **chemical makeup** of the gas.
- Heating and cooling from **shocks, compression and expansion** of the gas.

-In the disk:

-At very high densities, H_2 dissociation and CIE cooling take over.

-Compressional and viscous heating are more important than luminosity