

The Effects of Accretion Luminosity on the Environment of the First Stars



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ABSTRACT

We present initial results from the first 3D Population III star-formation simulation to include the effects of accretion luminosity. Accretion luminosity will be a significant heat source for the inner regions of a proto-stellar accretion disk. To test whether accretion luminosity could suppress fragmentation in such a disk, we include this heating in a simulation of a previously unstable proto-stellar disk around a Pop III star. We find that while accretion heating alters the radial position of the fragmentation, it does not prevent it.

METHOD

Original Simulation Properties: The collapse of primordial gas within a dark matter halo to form a PopIII star is followed using the GADGET2 code with nested particle splitting and sink particles. This allows the disk around the first star to be clearly resolved (with a resolution of $10^{-3} M_{\odot}$). The disk is unstable and fragments.

Detailed thermodynamics and chemical modeling have been included in the model to accurately capture fragmentation.

- H₂ cooling using the detailed cooling function of Glover & Abel (2008)
- Optically thick H₂ cooling using the Sobolev approximation as Yoshida et al. (2006)
- Collision induced emission from H₂ 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.

Accretion Luminosity Implementation: The radius of the star the sink particle represents is calculated from the mass-radius relation derived in Stahler, Palla & Salpeter (1986),

$$R_* = 26 M_*^{0.27} (\dot{M}/10^{-3})^{0.41} \quad \text{where all quantities are in solar units.}$$

From this it is simple to calculate the accretion luminosity given our sink particles mass and typical accretion rate of $10^{-3} M_{\odot} \text{yr}^{-1}$,

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

As the disk is optically thin we assume that all the luminosity will reach the gas, and we interpolate the Planck mean opacity of the gas from the table given in Mayer & Duschl (2005). This allows the following heating rate to be calculated,

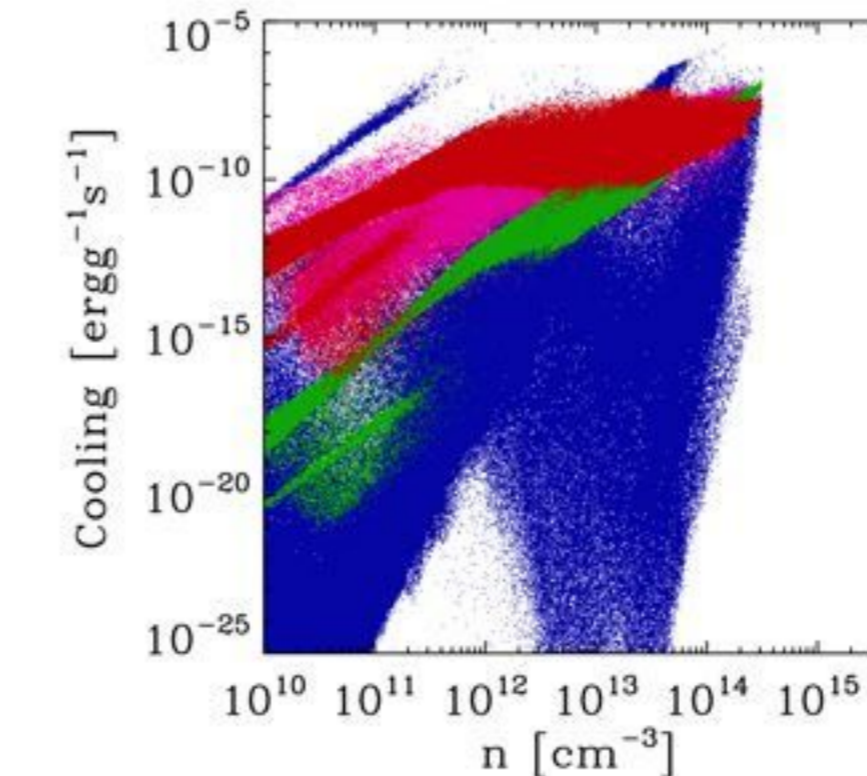
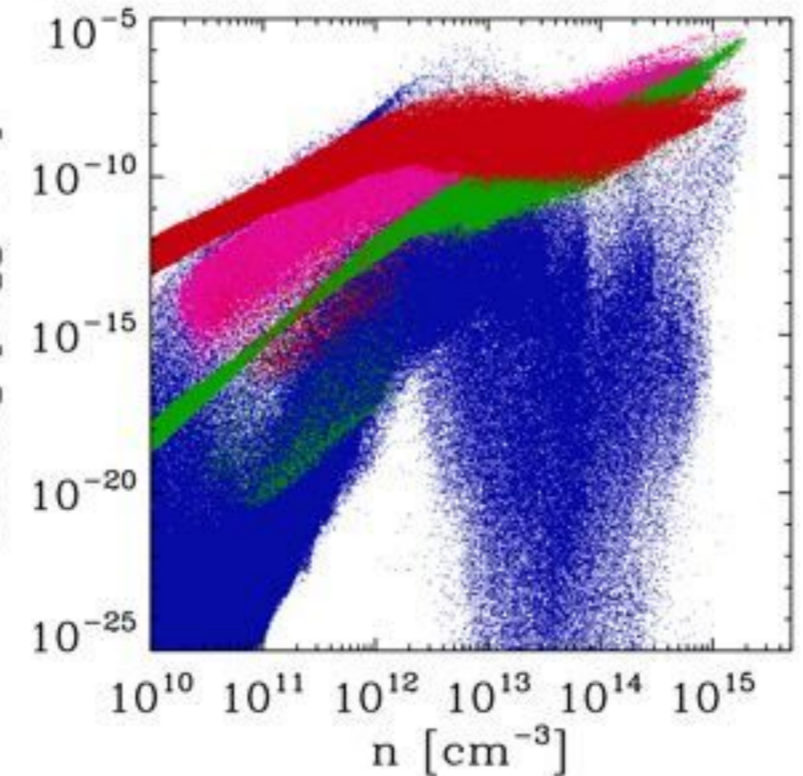
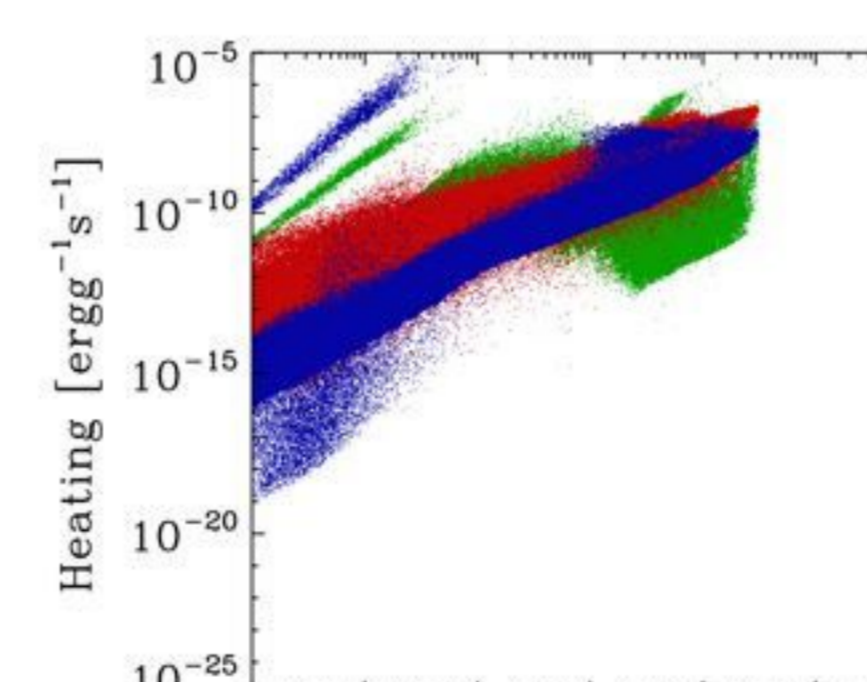
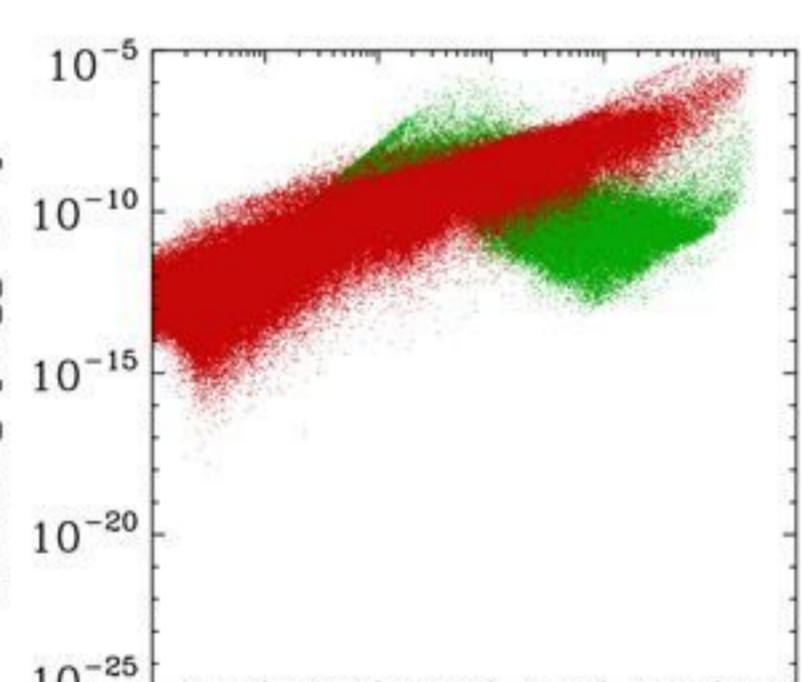
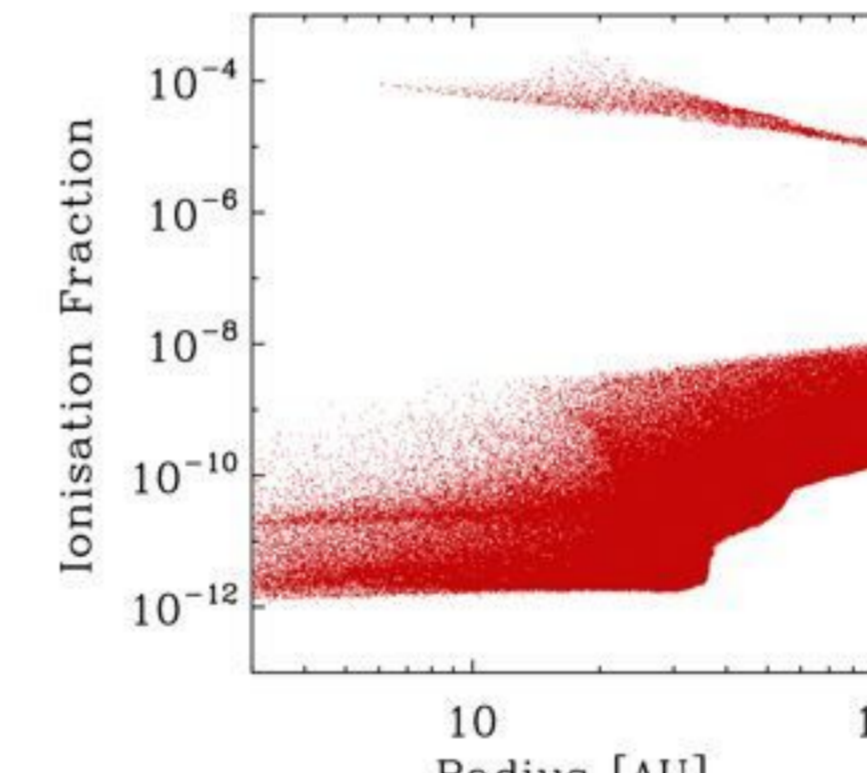
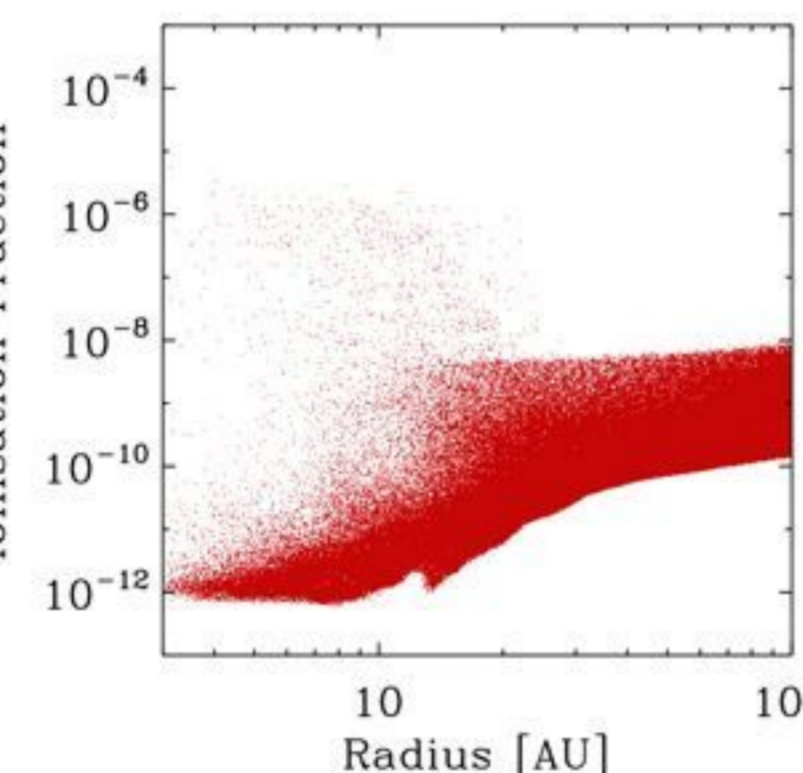
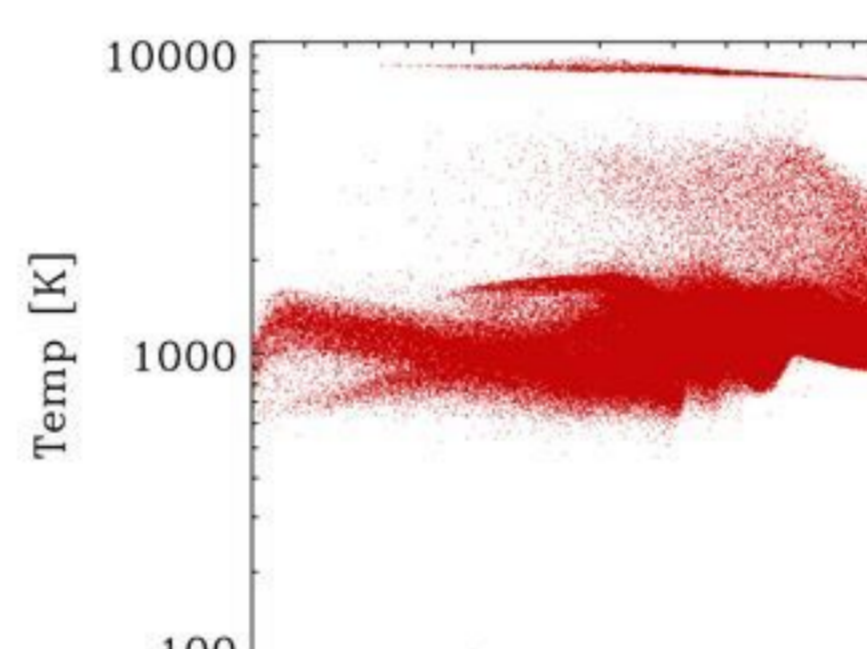
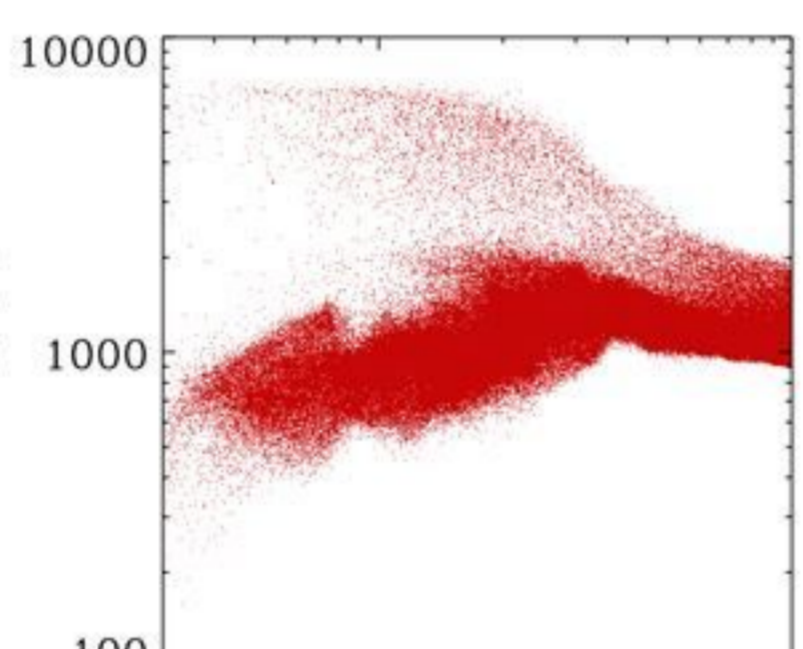
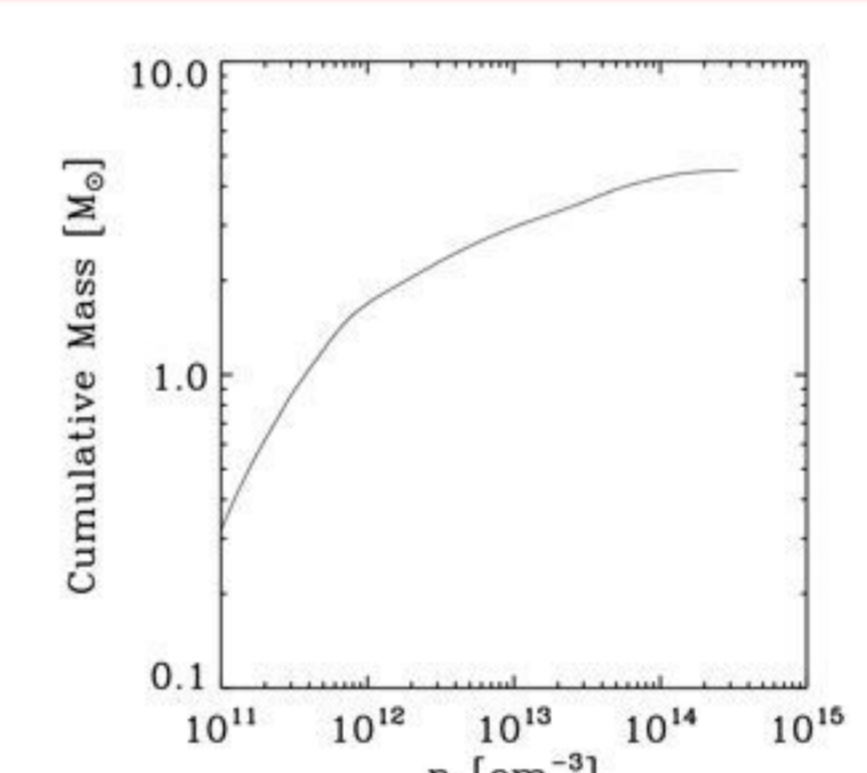
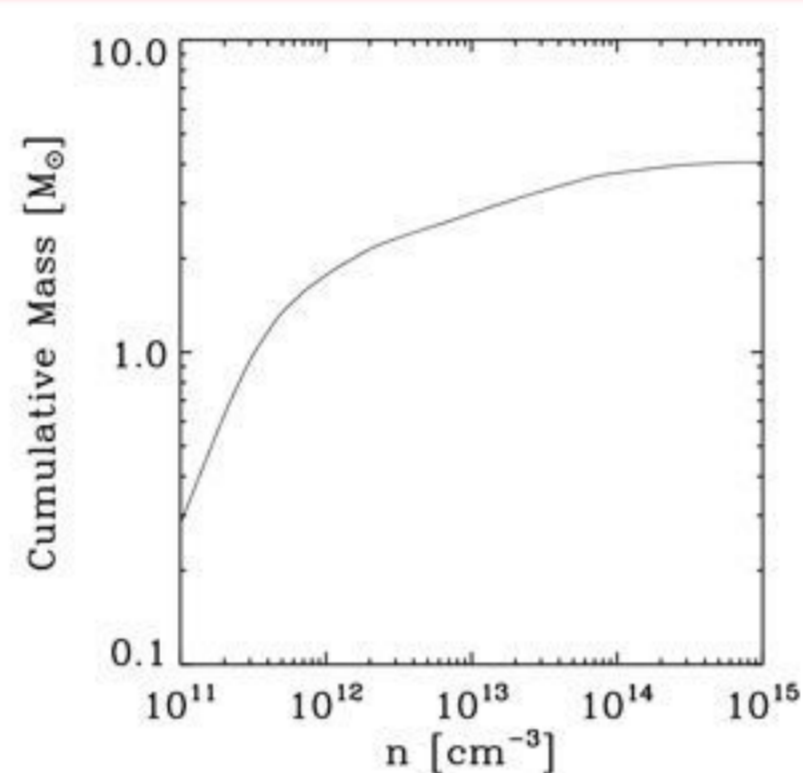
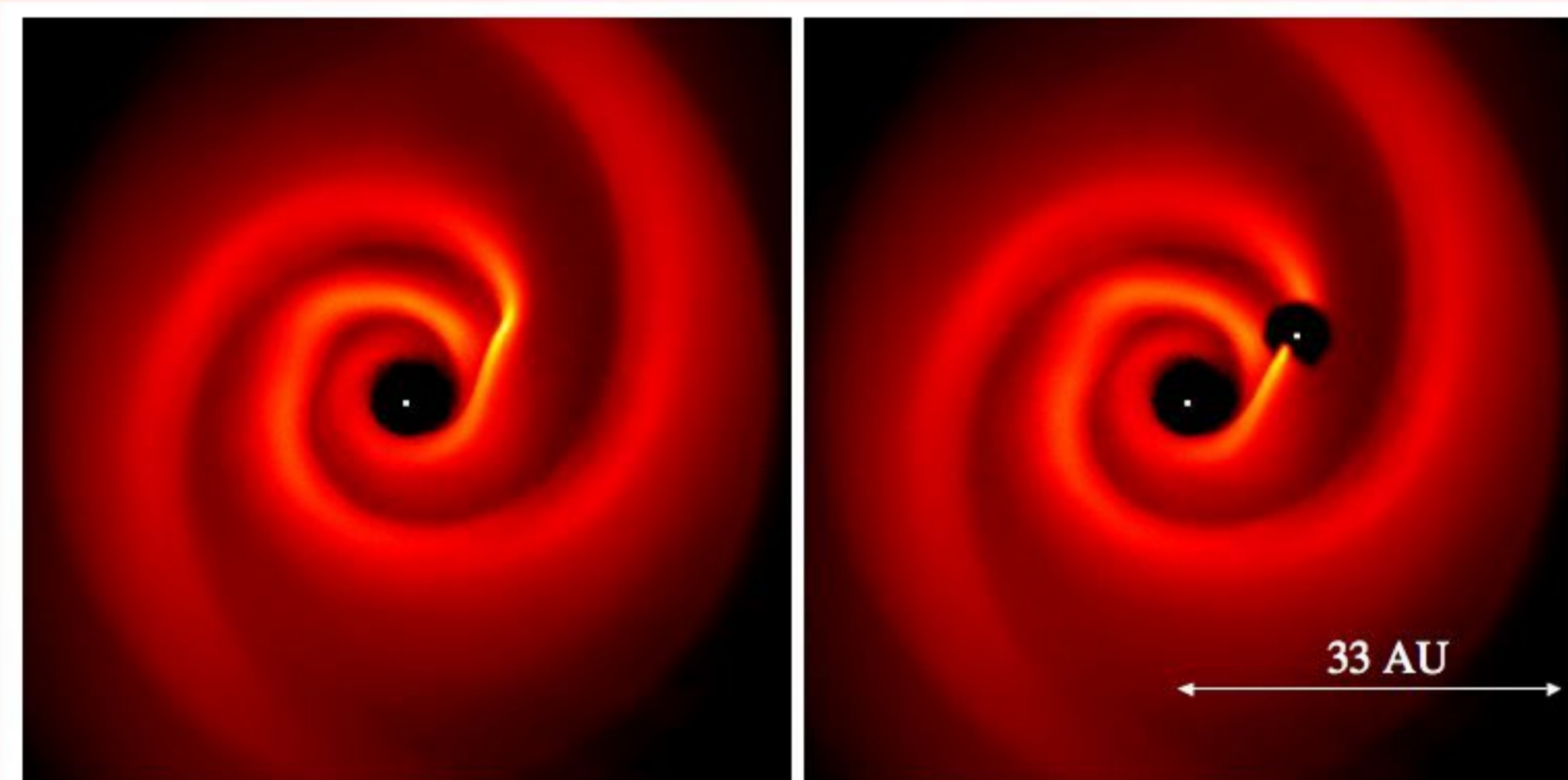
$$\Gamma_{acc} = \rho_g K_p \left(\frac{L_{acc}}{4\pi r^2} \right) \quad \text{in erg g}^{-1} \text{ s}^{-1}$$

This is then included in the calculation of the equation of state of the gas alongside the other heating and cooling terms.

Without Accretion Luminosity

THE EFFECT OF ACCRETION FEEDBACK

With Accretion Luminosity



Above: Column density [10^3 g cm^{-2} to 10^6 g cm^{-2}] of disk when the fragment forms 77.5 years after the formation of the central sink.
Right: The temperature, ionisation and heating /cooling rates of the gas.

Fragmentation radius: 10.4 AU

Interval between formation of fragments: 77.5 yr

• Density

The disk reaches densities as high as $n = 10^{15} \text{ cm}^{-3}$, and has strong spiral structure. The fragment forms at a radius of 10AU in one of the spiral arms.

• Temperature

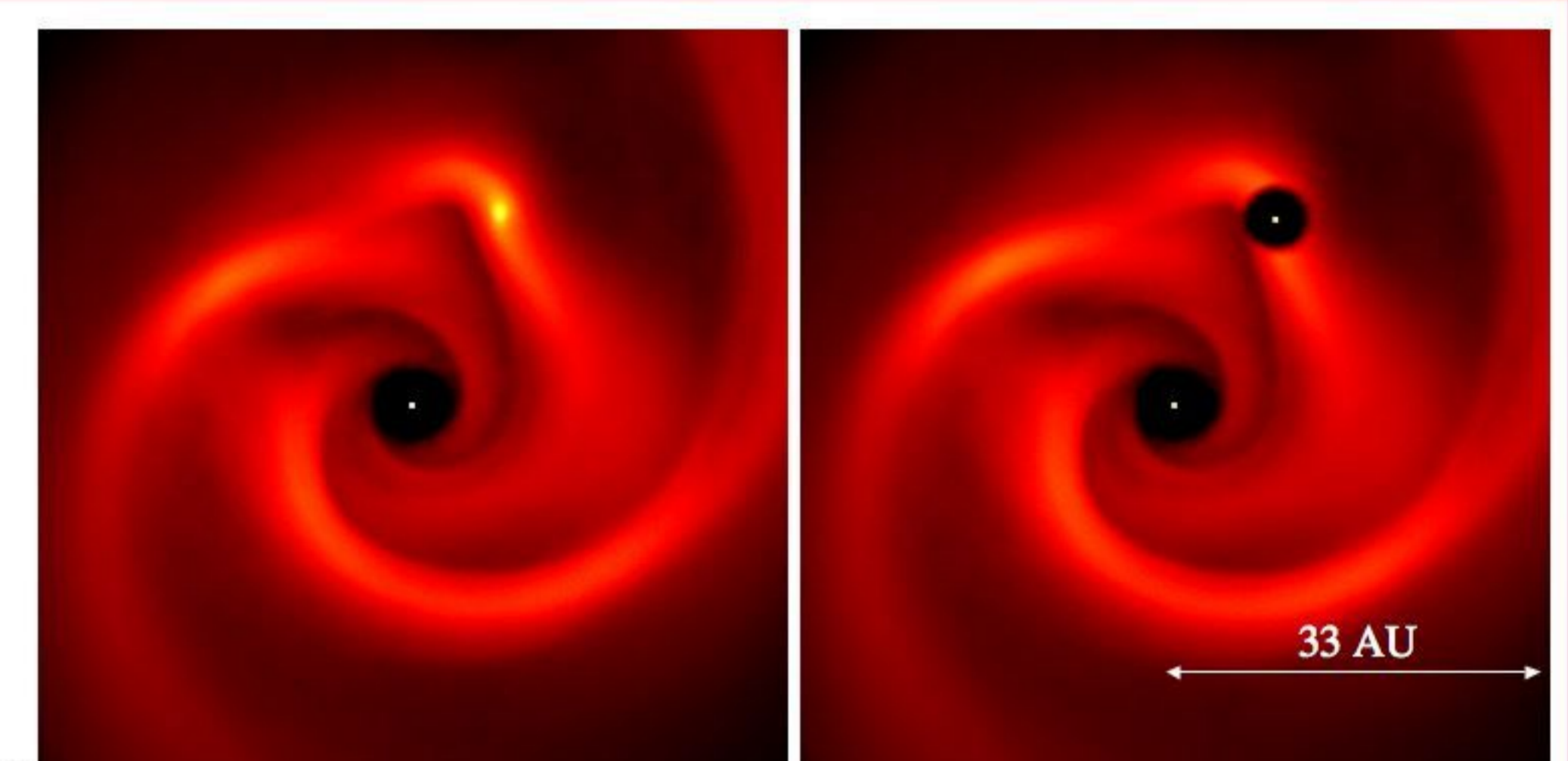
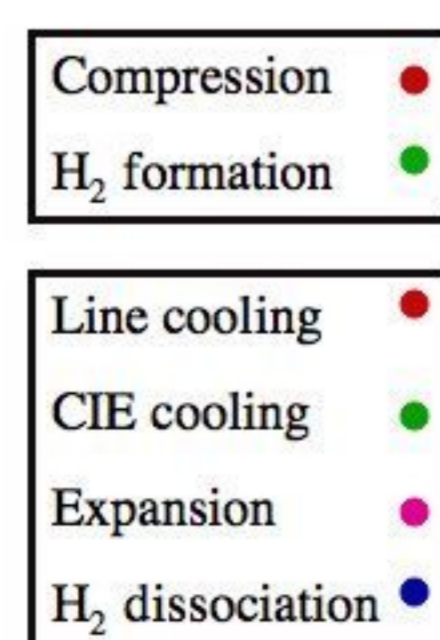
The temperature profile around the sink is mainly flat with an average temperature of 1164 K. However, some lower density dissociated material above the disk can reach higher temperatures. Close to the sink where the density is high the gas can cool to lower temperatures.

• Heating

The main heating source in the disk is compression.

• Cooling

Line cooling and CIE cooling are both significant cooling terms. Additionally there is some cooling from gas which has been compressed when it entered the spiral arm re-expanding.



Above: Column density [10^3 g cm^{-2} to 10^6 g cm^{-2}] of disk when the fragment forms 119.2 years after the formation of the central sink.
Left: The temperature, ionisation and heating /cooling rates of the gas.

Fragmentation radius: 18.9 AU

Interval between formation of fragments: 119.2 yr

• Density

The disk now has slightly lower densities, $n = \text{few } 10^{14} \text{ cm}^{-3}$. There is still strong spiral structure, but it is now more extended and the fragment forms later and at a greater separation from the central sink.

• Temperature

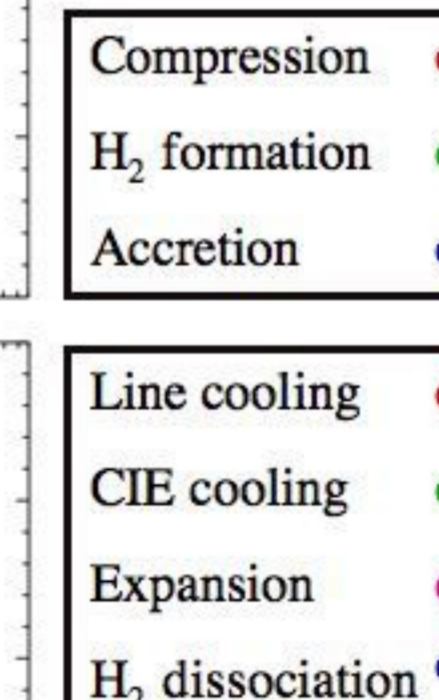
As before the temperature profile is largely flat with an average temperature of 1166 K. Additionally, there is now hot gas with a high ionisation fraction above the disk. However, this is a small contribution to the total mass (1%). The gas close to the sink can no longer cool, but is instead heated by the accretion luminosity.

• Heating

The accretion luminosity heating is comparable to the heating rate from compression in the inner disk.

• Cooling

The line cooling and CIE cooling are comparable to before, but since the disk is now less dense, they have a lower maximum value. Additionally, the extra heating has altered the chemical composition of the disk, and now there is a greater contribution from H₂ dissociation.



THE BOTTOM LINE

The inclusion of heating from accretion luminosity into a simulation of a previously unstable disk around a Population III star, did not prevent the disk from fragmenting. Instead fragmentation occurred further from the star and at a later time. However, the structure of the disk was slightly altered due to the extra heating. The disk was more extended and less dense, and the temperature of the inner disk was higher, making it harder for gas to fragment at small radii.

References:

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