Feedback & Fragmentation: Key processes in high-mass star formation

Takashi Hosokawa (Kyoto U.)

Kuiper & HH (2018) A&A
Chon & TH in prep.

3.Dec.2018 Tokyo Time Machine @IPMU
Two Key Processes
in Pop III star formation

Radiative Feedback

Disk Fragmentation

HII region

TH+16

Greif+13

8.94 yr

How massive stars form with these processes?
How many low-mass stars form together with the high-mass stars?
Any metallicity dependences?
Pop III UV feedback
(TH+16, 11; Stacy+16, 12; Susa+14, 13 etc)

+ The mass accretion onto the star is shut off by the UV feedback at least in some cases.
  → The stellar mass growth is limited, and this effect determines how massive star is finally formed.

※Gas pressure effect (UV radiation enhances the gas pressure)
No HII region forming in these RHD simulations (!)

Actually they have studied a qualitatively different effect, radiation force feedback against the dusty accretion flow.
Interplay?
Rad. force v.s. Photoionization

How is the final mass determined under both of these feedbacks?
First Hydrodynamics Simulations of Radiation Forces and Photoionization Feedback in Massive Star Formation

R. Kuiper\textsuperscript{1} and T. Hosokawa\textsuperscript{2}

at $Z=Z_\odot$, 2D Radiation-Hydro Simulations

(2018) A&A
Accretion Histories

+ UV feedback rather *increase* the final mass (opposite to Pop III case)

Hajime Fukushima explains why (next talk)
Fragmentation does occur, but merger of the fragments also occurs.

What determines the survival rate of the fragments?

⇒ low-mass Pop III stars?
Binary v.s. Merger

What determines such different fates?

Chon + TH in prep.

Simple experiments
Put a fragment (point particle) in a disk by hand, then follow its orbital evolution

Great diversity, depending on the initial positions, and fragment mass
Underlying Physics

Inward migration stalls when the “gap” is opened up in the disk (III)

Angular momentum loss via (I) type-I migration (II) Roche Lobe Overflow

Simple analytic considerations

⇒ predict under which conditions the above processes operate...
\[ q_{\text{env}} \equiv \frac{M_{\text{env}}}{(M_{\text{env}} + M_{\text{core}})} \]

Diagram:

- **(I)** Type-I regime \((R_H < H_d)\)
- **(II)** Roche-lobe overflow \((R_c > R_H)\)
- **(III)** Gap-opening \((R_H > H_d, R_H > R_c)\)

\[ M_{\text{core}} = 0.1M_\odot \]
Putting Numerical Results

Divergent fates are now interpreted well with the diagram.

\[
M_{\text{env}} / (M_{\text{env}} + M_{\text{core}})
\]

large envelope mass

migration stalls

outward migration

accretion + inward migration

tidal disruption + inward migration

Divergent fates are now interpreted well with the diagram.
Summary

Feedback and Fragmentation: key processes in high-mass star formation

**Feedback**: UV (Pop III) v.s. Rad. Force (Pop I)
Pop I UV feedback enhances the mass accretion
⇒ metallicity dependence (Hajime Fukushima’s talk)

**Fragmentation**: binary formation v.s. merger
It looks quite complex, but underlying physics can be derived at least with a simplified setting.