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Massive star formation by accretion: how to circumvent the angular momentum barrier?

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We present pre-main sequence models for massive star formation computed with the GENEVA code self-consistently including accretion and rotation. The models show that a braking mechanism is needed in order to circumvent the angular momentum barrier. This mechanism has to be efficient enough to remove more than 2/3 of the angular momentum from the inner accretion disc.

Stellar evolution code: GENEVA (1D hydrostatic code)

Disc accretion: The thermal properties of the accreted material match that of the stellar surface.

Accretion of mass: (1) constant $dM/dt = 10^{-5} - 10^{-3}\ M_{sun}\ yr^{-1}$
(2) Churchwell-Henning (dM/dt increasing with time, best fit of observed Herbig Ae/Be stars on the HR diagram)

Accretion of angular momentum:

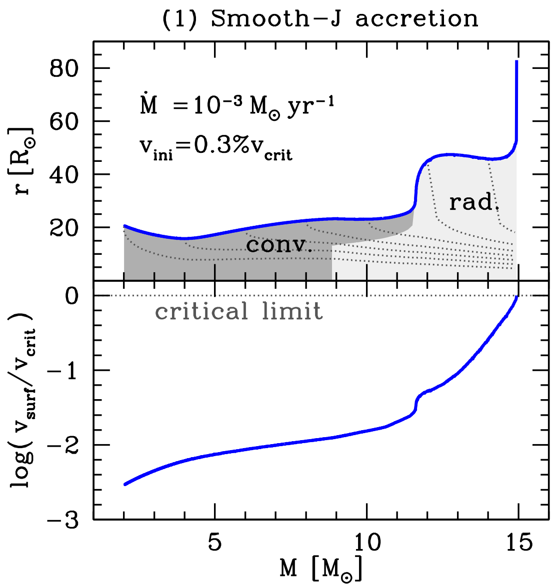
(1) smooth-J accretion: The angular velocity of the accreted material equals that of the stellar surface.

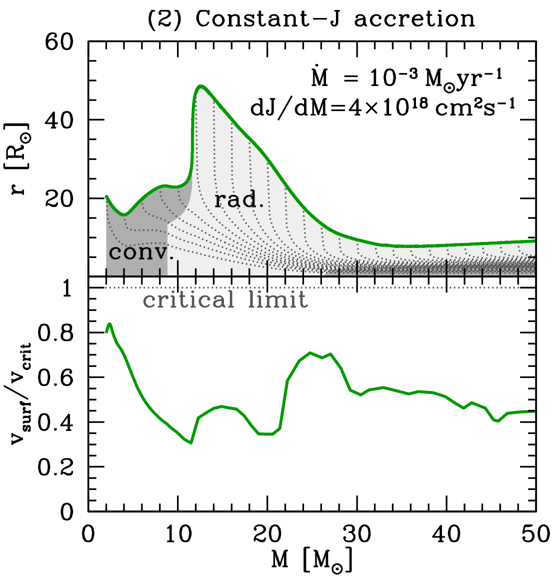
(2) constant-J accretion: The specific angular momentum of the accreted material is constant.

(3) Keplerian-J accretion: The specific angular momentum of the accreted material is a constant fraction of the Keplerian value at the stellar surface.

Internal transport of angular momentum:
convection + meridional circulation + shear diffusion

Critical limit: Centrifugal force cancels gravity. Upper limit of rotation velocity for hydrostatic equilibrium. Above this limit, accretion stops and the star loses mass.





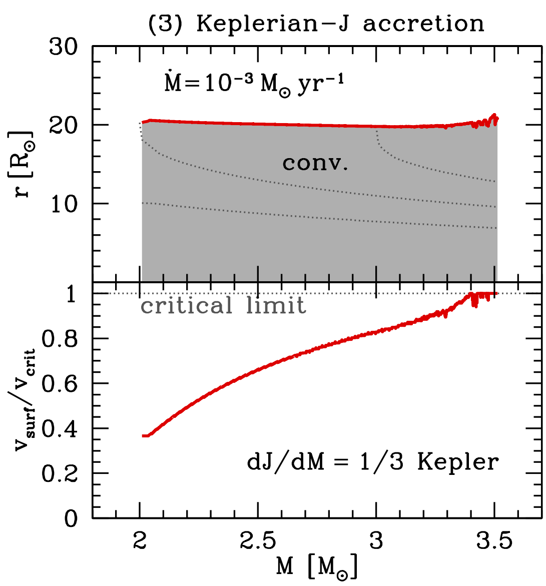
RESULTS:

The transport of angular momentum by shears and meridional currents is negligible.

(1) smooth-J accretion: The star reaches the critical limit during the post-swelling contraction, at masses 10-15 M_{sun}, independently of the initial rotation velocity and the accretion rate. Only a change in the J-accretion history allows to circumvent this angular momentum barrier.

(2) constant-J accretion: Since the angular momentum transport is negligible in radiative regions, choosing a low enough value of dJ/dM ($\approx 4\times10^{18}\ cm^2\ s^{-1}$) allows to circumvent the angular momentum barrier, and to reach any mass without facing the critical limit.

(3) Keplerian-J accretion: If dJ/dM exceeds 1/3 of the Keplerian value, the star reaches the critical limit at 3-4 M_{sun}, due to the internal angular momentum transport by convection.



CONCLUSIONS:

- **Smooth-J accretion leads to an angular momentum barrier that prevents from forming massive stars by accretion.**
- **A braking mechanism that removes more than 2/3 of the angular momentum from the inner accretion disc is needed in order to circumvent the angular moment barrier.**
- **Due to the weak efficiency of angular momentum transport by shears and meridional currents, the internal rotation profile during the accretion phase reflects essentially the accretion history.**
- **Careful choice of the J-accretion history allows production of stars of any mass and rotation velocity compatible with structure equations.**