

The Formation of Massive Stars with Radiative and Outflow Feedback

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Massive stars play an essential role in the Universe. They are rare, yet the energy and momentum they inject into the interstellar medium with their intense radiation fields dwarfs the contribution by their vastly more numerous low-mass cousins. During their formation, feedback from their intense radiation fields and magnetically launched, collimated protostellar outflows can limit their growth by accretion. In this talk, I will present a series of adaptive mesh refinement 3D radiation-hydrodynamics simulations of the collapse of initially turbulent, massive pre-stellar cores that include radiative feedback from both the direct stellar and dust-reprocessed radiation fields and outflow feedback from the accreting stars. We find that mass is channeled to the stellar system via gravitational and Rayleigh-Taylor (RT) instabilities through nonaxisymmetric disks and filaments that self-shield against radiation pressure while allowing for radiation to escape through optically thin regions. Inclusion of feedback from protostellar outflows punches holes in the ISM along the star's polar directions, thereby increasing the size of optically thin regions where radiation can escape. This effect makes mass accretion via RT instabilities less significant. Furthermore, precession of the outflows due to the star being pushed around by the turbulent accretion flow cause the opening angles of the entrained material to increase with time. This effect, including the enhanced radiative heating by the escape of stellar radiation, further reduces accretion onto the massive star as compared to feedback from radiation alone. Our results suggest that disk accretion is therefore a requirement for the birth of massive stars, especially at late times.

Outflow Disks