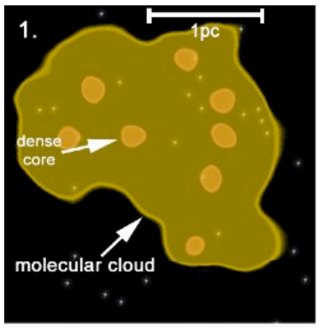
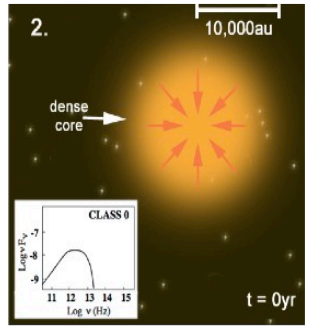
How do you build a star?

The so-called `protostellar disk’ is a key tool in building a star like the Sun, but where does it come from?

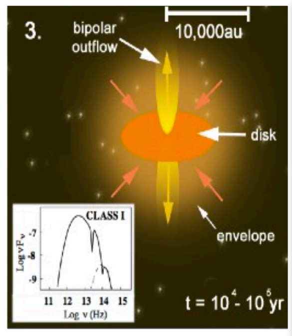
Inset: spectral energy distributions from Isella et al. 2007, showing how the emission of the sources varies.

All stars form in large regions of dust and gas called molecular clouds, whose densest regions collapse into cores.

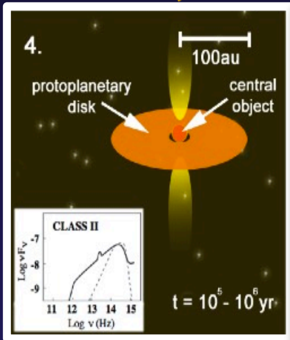




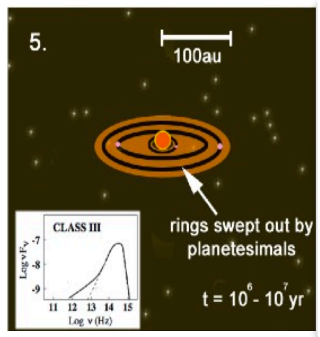
Eventually a core will reach a critical mass and collapse under its own gravity, increasing in opacity and temperature.



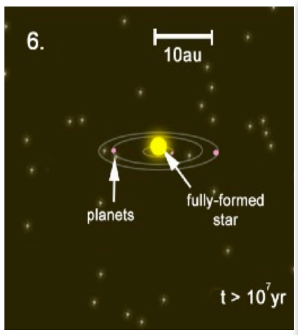
The core spins up to conserve angular momentum, eventually creating a disk. Outflows launch from the central protostar and some natal material (envelope) remains.



Eventually the surrounding envelope dissipates, leaving a protostar with disk and outflows. The disk feeds material to the star via accretion.



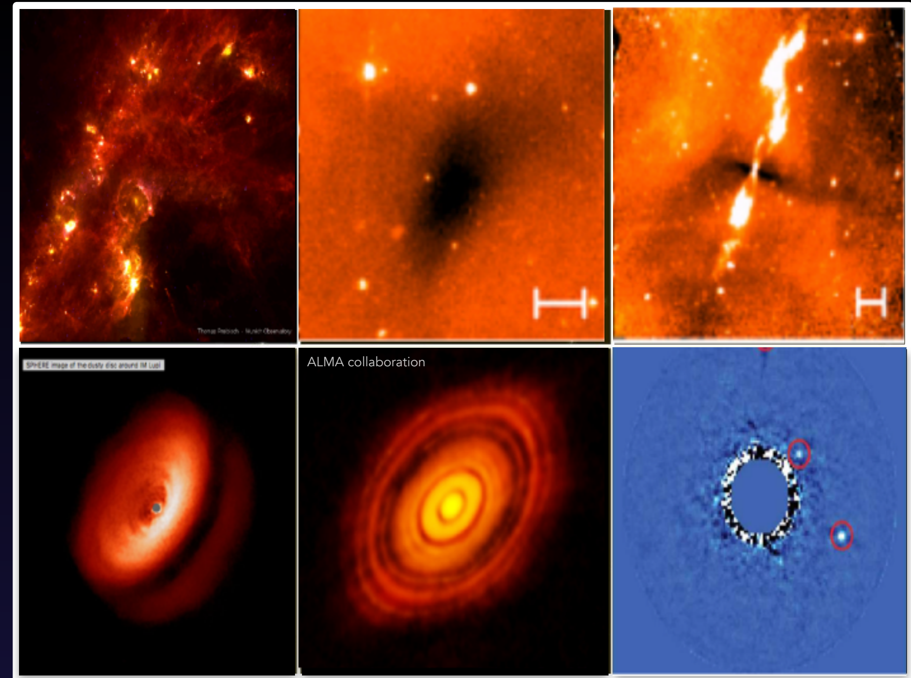
Substructures develop in the disk e.g. rings in the disk due to forming planets(?) after accretion and the outflows subside



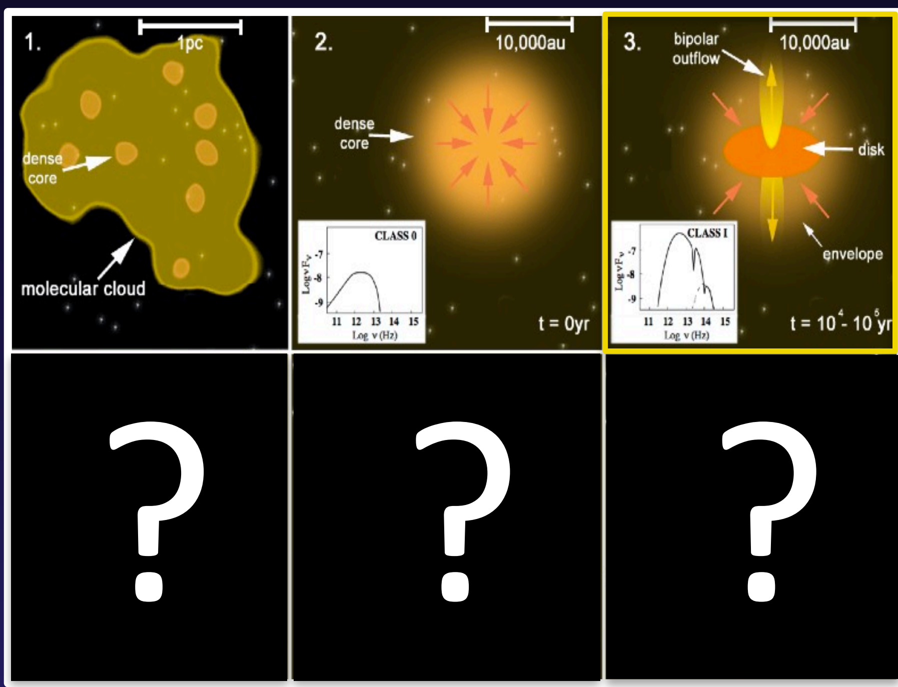
The protostar begins to fuse hydrogen and becomes a main-sequence star. The remaining disk is expelled, leaving behind any planets which have formed.

Unveiling the evolution of disks around massive forming stars - Abigail Frost (KU Leuven)
With René Oudmaijer, Stuart Lumsden (University of Leeds) and Willem-Jan de Wit (ESO)

For low-mass stars similar in size to our own Sun, the different stages of the theoretical formation process described previously have been confirmed observationally.



Massive stars (>8 solar masses) are more deeply embedded and rare than low-mass stars and form in less than 100,000 years, making them difficult to study. Molecular clouds and cold massive cores have been observed and recently embedded systems similar to Class I low-mass sources have been detected around massive young stellar objects (MYSOs). However, how the disks around MYSOs evolve is yet to be constrained.



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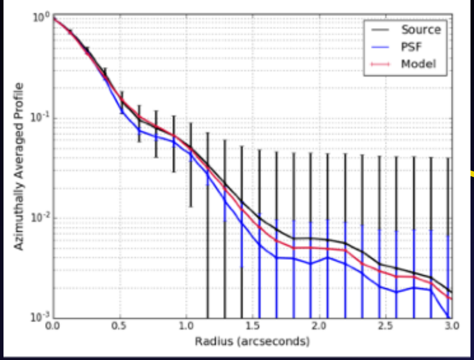
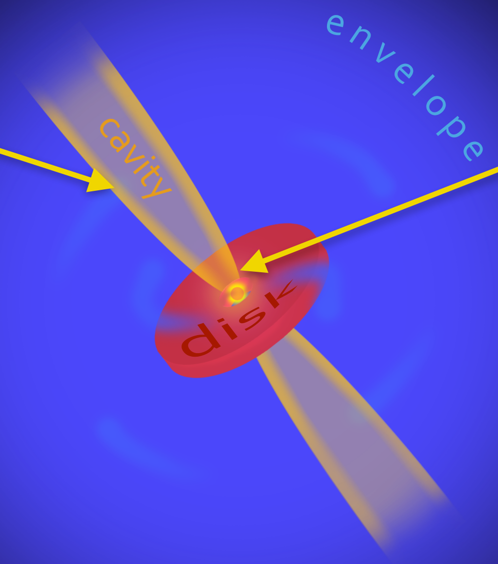
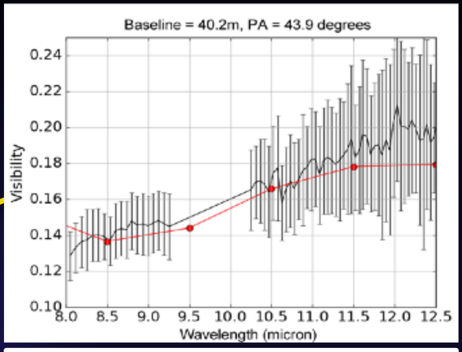
Our work probed a sample of 8 MYSOs at multiple scales, by fitting a 3D radiative transfer model to three different data sets simultaneously (Frost et al. 2019):



<u>Near diffraction-limited imaging at ~20um</u>

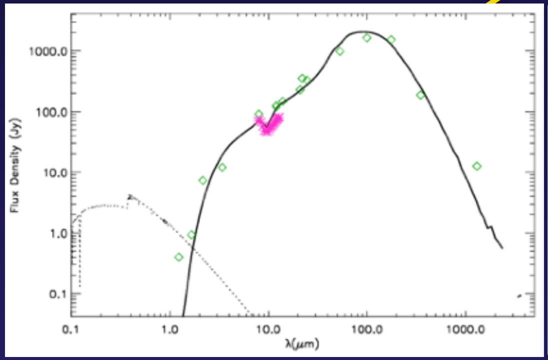
- ~0.1″ resolution
- Most sensitive to the emission of outflow cavity walls and envelope infall rate





<u>N-band interferometry</u>

- Traces the inner geometry of the disk and innermost cavity
- Additional cavity geometry constraints from imaging data allowed disk and cavity emission to be separated



<u>Spectral energy distributions</u>

- Near-infrared to millimetre fluxes
- Provide information on the entire environment

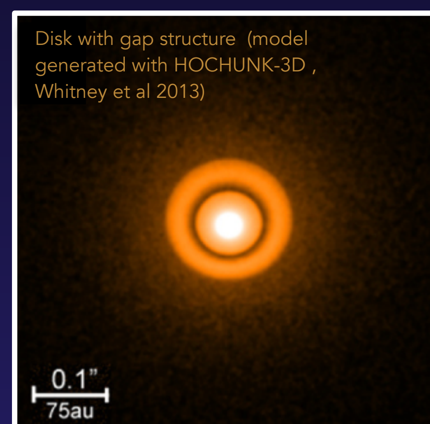
- The final models for each of the sources all had disk+envelope+outflow geometries
- 75% of the disks showed substructure
    - Most had inner holes (the minimum dust radius was larger than the dust sublimation radius)
    - One case shows a gap-like structure

Unveiling the evolution of disks around massive forming stars

- Cooper (2013) investigated the near infrared spectra of MYSOs and found that the bluer, more evolved MYSOs showed different spectral features to the redder, younger sources.
- Using spectra from the literature we classified the sources we analysed with our multi-scale method
    - All Type III sources have substructure in their disk, 50% of Type II and no Type Is
- Strong correlation between luminosity and the size of the inner holes (0.92) implies photoevaporation could be the cause
- Conclusions:
    - Disk evolution is occurring in MYSOs
    - Disk substructure in MYSOs implies that disk evolution can occur quicker than previously thought
    - Disks evolution appears to be occurring around MYSOs as it does for low-mass stars
- Future work:
    - Understanding the processes causing these substructures
    - Exploring even larger scales

Frost et al. 2020a+b (in prep.)

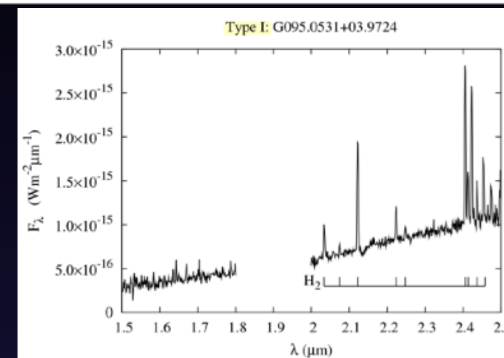
Illuminated inner disk rim with inner hole (model generated with HOCHUNK-3D , Whitney et al 2013)

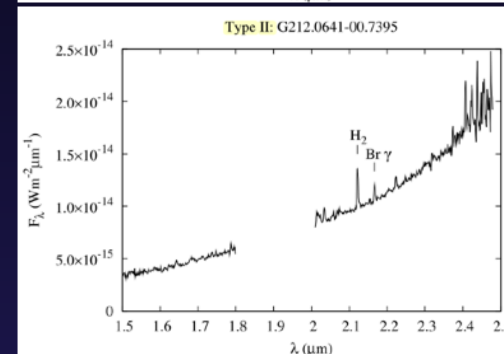


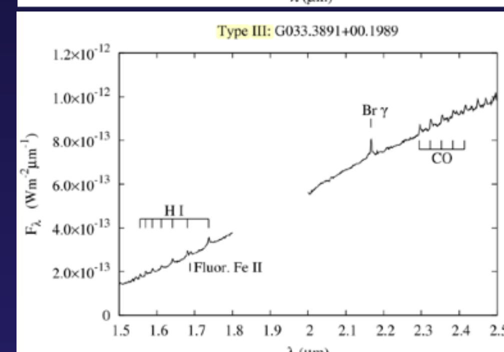
Disk with gap structure (model generated with HOCHUNK-3D , Whitney et al 2013)

Table 4.1: Classification criteria for the YSO subtypes.

	H_2	Br γ	Br 10	Fluor. Fe II
Type I	Strong	Absent	Absent	Absent
Type II	Present	Present	Weak or Absent	Absent
Type III	Weak or Absent	Strong	Present	Present







Example spectra and classification from Cooper 2013