Forming extremely low-mass stars by disc fragmentation

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We suggest that *extremely low-mass stars* (low-mass H-burning stars, brown dwarfs, and planetary-mass objects) are formed by gravitational fragmentation of massive extended discs around Sun-like stars. We argue that such discs should arise frequently, but should be observed infrequently, precisely because they fragment rapidly. By performing an ensemble of radiation-hydrodynamic simulations, we show that such discs typically fragment within a few thousand years to produce mainly brown dwarfs (75%) (including planetary-mass objects, 5%) and low-mass H-burning stars (25%). [The paper can be downloaded at http://arxiv.org/abs/0810.1687 (MNRAS in press)].

DISC INITIAL CONDITIONS AND NUMERICAL METHOD

We start off with an extended disc that has comparable mass with the mass of the host star:

$M_\star = 0.7\,\mathrm{M}_\odot$
$M_{\rm DISC} = 0.7 M_\odot$
$R_{\rm DISC} = 400\,\mathrm{AU}$

$$\Sigma_0(R) = \frac{0.03\,\mathrm{M}_\odot}{\mathrm{AU}^2}\left(\frac{R}{\mathrm{AU}}\right)^{-7/4} \qquad T_0(R) = 250\,\mathrm{K}\left(\frac{R}{\mathrm{AU}}\right)^{-1/2} + 10\,\mathrm{K}$$

Our simulations are performed in two phases:

(i) Until 80% of the disc has been accreted onto the stars (this happens within 20,000 yr) the evolution of the system is followed using SPH, with a new method to capture the thermal and radiative effects when protostellar gas fragments (Stamatellos et al. 2007). *The method also includes irradiation by the central star.*

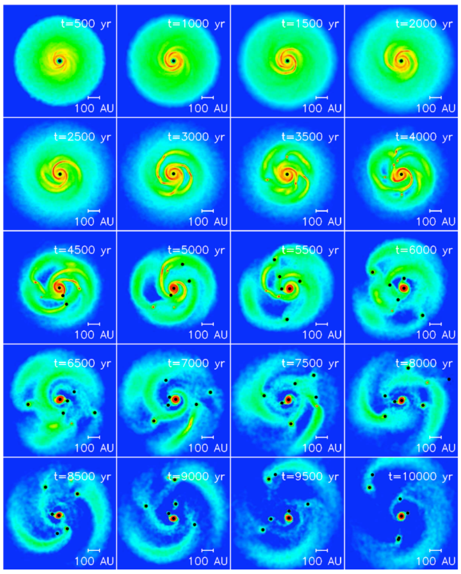
(ii) Afterwards the evolution of the system is followed up to 200,000 yr using an N-BODY code

BINARY PROPERTIES OF EXTREMELY LOW-MASS STARS

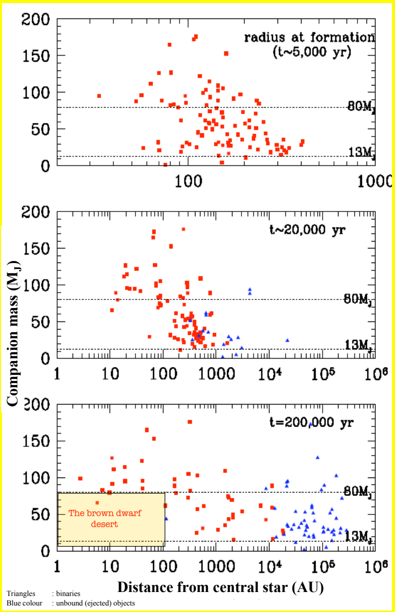
- 13 low-mass binaries are formed in our simulations. 27% of the stars that form are in binaries corresponding to a low-mass binary fraction of 16%. These binaries include star-star (4/13), star-brown dwarf (4/13), brown dwarf -brown dwarf (4/13) and brown dwarf - planetary mass object binaries (1/13).
- 4 of these binaries are ejected in the field, including both close **and wide** binaries.
- Of the binaries remaining bound to the central star, the total mass of the low-mass binary tends to decrease as the distance from the central star increases.
- Most of the low-mass binaries (55%) have components with similar masses (q>0.7).
- Brown dwarfs that are companions to Sun-like stars are more likely to be in binaries (binary frequency 25%) than brown dwarfs in the field (binary frequency 8%).

Radiative hydrodynamic simulation of the evolution of a 0.7-$M_\odot$ disc around a 0.7-$M_\odot$ star

Snapshots of the logarithm of the column density are presented from 500 to 10,000 yr, every 500 yr (as marked on each graph). This particular simulation produces 4 brown dwarfs, and 3 low-mass hydrogen burning stars. After 200,000 years, 4 of these stars have been ejected into the field.



THE ORIGIN OF THE BROWN DWARF DESERT



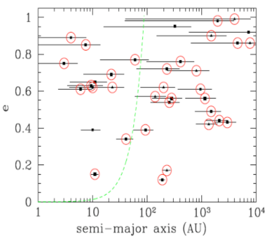
Extremely low-mass stars that form closer to the central star are generally the most massive ones formed in the disc as (i) they form faster and (ii) they form in a region where is more material to accrete. Hence, they become H-burning stars. Brown dwarfs form farther out in the disc. Due to dynamical interactions the low-mass H-burning stars move further in populating the region close to the Sun-like star whereas the brown dwarfs move outwards, creating a brown dwarf desert.

This mechanism provides a natural explanation for the brown dwarf desert.

Brown dwarf companion frequencies predicted by our model

at distances <30 AU → <8%
at distances <400 AU → <16%

SEMI-MAJOR AXES AND ECCENTRICITIES OF LOW-MASS COMPANIONS TO SUN-LIKE STARS

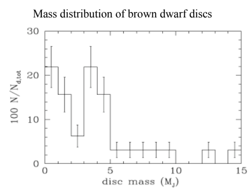


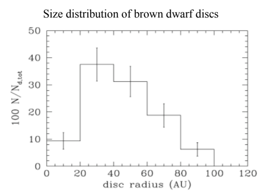
The orbital eccentricities and semi-major axes of extremely low-mass stars which remain bound to the Sun-like primary star. The bars indicate the minimum and maximum extent of the orbit. ***The orbits are generally highly eccentric, as a result of dynamical interactions.*** The circles mark stars with discs, and the triangles correspond to binary systems..

PROPERTIES OF BROWN DWARF DISCS

Most of the brown dwarfs form with discs. These discs have masses of a few M_J and radii of a few tens of AU. Most of the ejected brown dwarfs do not retain their discs.

We predict that brown dwarfs that are companions to Sun-like stars are more likely to have discs than brown dwarfs in the field.





CAVEATS

(i) The simulations presented here correspond only to one set of disc and star parameters (i.e. disc density and temperature profiles, star mass, disc mass and disc radius). Hence, the results need to be updated for a wider set of initial conditions.

(ii) The simulations do not account for the disc formation around the Sun-like star and disc growth due to accretion of material from the infalling envelope (see Attwood et al. for such a study).

CONCLUSIONS

Disc fragmentation is a robust mechanism for the formation of brown dwarfs, as well as planetary-mass objects and low-mass hydrogen-burning stars. It explains successfully properties that are not satisfactorily explained by other formation mechanisms, for example the brown dwarf desert and the observed statistics of low-mass binary systems.

We suggest that even if only a fraction of Sun-like stars host the required massive extended discs needed for the fragmentation scenario to work, this mechanism can produce all the free floating planetary-mass objects, most of the brown dwarfs, and a significant proportion of low-mass hydrogen burning stars.