The theory of multiple formation

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Many - maybe most - stars form in *multiples*: binaries, triples, quadruples… sextuples +?

Impact on star, planet, galaxy formation & evolution

Chen+ 2013
Theory pre-2000

To make multiples:
  Angular momentum & perturbations.
  Opacity limit for fragmentation.

Burkert & Bodenheimer 1993
Reviews: Bodenheimer+ 2000; Goodwin+ 2007
Theory post-2000

Turbulence!
Source of am, perturbations, discs and disc fragmentation.

Bate 1997,2002+; Burkert & Bodenheimer 2000; Goodwin+ 2004, 2006; Delgado Donate+ 2004; Attwood+; Krumholz+; Walch+; Lomax+; Matzner+…
Reviews: Goodwin+ 2007; Reipurth+ 2014
The basic picture

Turbulence provides angular momentum and large- and small-scale perturbations.

Fragmentation at opacity limit (~0.01 Msun).

Fragments form in filaments, form discs which are loaded and fragment.

Makes lots of fragments…

Problem solved?
Problems: physics

Lots of nasty physics: thermodynamics/radiation/chemistry, details of turbulence, magnetic fields…

Big problem with massive stars…

Offner+ 2010; Joos+ 2013; Commercon+ 2011; Masson+ 2016; Lomax+ 2015; Krumholz+ 2007; Dale+ var.; Stamatellos+ var.; Bate var.
Problems: numerics

Lots of nasty numerics
(esp discs):

Resolution
Sink particles
Numerical viscosity
Numerical instabilities
AMR vs. SPH

Non-ideal MHD+RT…

Meru&Bate 2012; Young&Clarke 2015,2016; Rice+
2014; Forgan&Rice 2012; Hubber+ var.;
Problems

But maybe these problems don’t matter too much?

Additional physics seems to change the details, but not the general prediction that fragmentation is easy, and multiples are a generic outcome of star formation…

Have we got it ‘right’?
Complication: stochasticity

Complex non-linear effects: stochastic and chaotic.

Plus characterising high-order multiples is a sod…

Goodwin+2004; Lomax+ 2015; many others…
Complication: dynamics (1)

High-order multiple systems decay:

Produces (low-mass) singles.

Can alter observational classes.

Hardens remaining system.

Aarseth+ 70s; Anosova 1987; Sterzik+ 1995,1998; Reipurth & Clarke 2000; Goodwin & Kroupa 2005; Umbriet+ 2005; Reipurth & Mikkola 2012; Chen+ 2013; Stamatellos & Whitworth var.
Encounters can change/destroy multiples. Stochastic and environment-dependent (cluster/association!?!?)


Kroupa 1995; Parker+ var. (Parker&Goodwin 2012);
King+ 2012
Complications

What we see isn’t what formed…

Is formation environment-dependent? (If yes: how? If not: why?). Where does the field come from?


King+ 2012; Marks & Kroupa var.; Parker & Goodwin+ var.
Observations suggest multiples are a/the major mode of star formation.

Theory seems able to produce these:

Multiples form from a stochastic/chaotic physics-rich turbulent/discy mess and then undergo complex internal and external dynamical evolution.
Conclusions

We have very little idea how ‘right’ we are getting it.

*Future is bright*: theory getting better, plus better observations to compare with.

Great time to work in this area: the perfect balance of ‘important’, and ‘not really understanding it.’