Mem. S.A.It. Vol. 88, 836
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The initial conditions of star formation from spatio-kinematics

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Abstract. In this contribution I describe recent efforts to determine the initial density of star forming regions by comparing the observed spatial and kinematic distributions to simulations.

1. Introduction

One of the outstanding problems in star formation is constraining the initial, or maximum stellar density that an individual star experiences before it becomes a member of the Galactic field, like our Sun. If all stars experience a dense (>100 stars pc^{-3}) birth environment, then planet formation may be hindered/disrupted (Adams et al. 2004), or planets may be scattered out of stable orbits around their parent star (Parker & Quanz 2012). However, observations of other galaxies suggest that the star formation rate is lower than one would naïvely expect, with the most likely culprit being feedback from the most massive stars (Kereš et al 2009). However, for feedback to be most effective, high stellar densities are required. There is therefore a tension between the low densities required for stable planet formation, and the high densities required for understanding extragalactic star formation.

Determining the initial stellar density is problematic because star-forming regions dynamically evolve at different rates, depending on the inital density. A dense region will try to relax through violent and/or two-body relaxation and expand quickly, whereas a low-density region does not expand as quickly. The upshot is that two regions with very different *initial* densities may have very similar observed densities at ages 1 – 10 Myr (Parker 2014).

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2. Recent results

2.1. Spatial distributions

We have combined information on the spatial distributions of the most massive stars in a star-forming region relative to the distribution of lower-mass stars, with a measure of the overall spatial distribution of the star-forming region to infer the amount of dynamical evolution that has taken place at a given age. We do this by comparing the observed values to those from tailored *N*-body simulations.

This spatial analysis requires the assumption that the most massive stars do not always form with a different spatial distribution to low mass stars, and that star formation in general produces a spatially and kinematically substructured distribution. Observations of pre/protostellar cores appear to verify these assumptions, although further observations and hydrodynamical simulations of star formation would help address this issue.

So far, we have analysed the ONC, Cyg OB2, IC 348, NGC 1333, Chamaeleon I, ρ Oph and Taurus (Parker et al 2014, Wright et al 2014, Parker & Alves de Oliveira 2017). Of these regions, only the ONC is consistent with having had a significantly high initial stellar density that would affect planet formation and evolution ($\sim$1000 stars pc^{-3}). Interestingly, Cyg OB2 appears to have never been more dense in the past, making it a viable site for massive star formation in low-density regions. This result also rules out the popping cluster scenario, which postulates that OB associations are the expanded remnants of dense star clusters. If this were the case, we would would expect the massive stars to be in areas of higher than average surface density due to the effects of previous dynamical relaxation.

Several of the remaining regions (e.g. IC 348, NGC 1333) straddle the boundary between low and high density initial conditions and further information is required to assess the impact of these star-forming environments on planet formation.

2.2. Radial velocities

Recent high precision radial velocity surveys have enabled the one-dimensional velocity dispersions to be measured in many star-forming regions. The velocity dispersion can then be compared to the expected velocity dispersion if the star-forming region were in virial equilibrium. Unfortunately, two issues exist with this method.

First, the orbital motion of binary stars inflates the velocity dispersion, making the region appear supervirial when it may be in virial equilibrium (or even subvirial). The effects of this orbital motion must first be subtracted from the velocity dispersion, and this requires assumptions about the fraction of binary stars, and their orbital distributions (both of which are highly uncertain).

Secondly, a region undergoing violent relaxation will often attain a high (supervirial) velocity dispersion during its collapse, which is frozen in for the remainder of the region's evolution. However, the cluster has relaxed to virial equilibrium and the velocity dispersion measurement is therefore an erroneous indication of the cluster's dynamical state (Parker & Wright 2016).

Given the effort required to accurately determine the velocity dispersion, and the uncertainty surrounding the treatment of binary stars, it would seem more useful to use other measures of the dynamical state of a star-forming region, such as proper motion velocities. Whilst these will be available from *Gaia*, a near infrared equivalent would probably be required to probe the most obscured star-forming regions.

Acknowledgements. I had the pleasure of meeting Francesco Palla only once, when I gave a colloquium at Arcetri in March 2015. Francesco introduced himself to me just after my arrival at the observatory (of course, I already knew exactly who he was!), and he offered to show me around Galileo's house at lunchtime. I don't really remember what I was trying to convince people of during my colloquium, but my abiding memory of the visit was discussing science, art and literature with Francesco in the Spring sunshine.

I acknowledge support from the Royal Society in the form of a Dorothy Hodgkin Fellowship.

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