

NGTS Clusters Survey VI. Stellar rotation in seven young open clusters within the PLATO LOPS2 field

MOTIVATION

PLATO's long stare field (LOPS2) hosts a multitude of open star clusters spanning ages $< 1\text{Gyr}$, a critical period where pre-main sequence (PMS) stars transition from a 'spin-up' regime during contraction to 'spin-down' after reaching the main sequence.

This transition at the Zero-age main sequence (ZAMS) is marked by rapid evolution in both rotation rates and dispersions at a given stellar mass and is thus vital for refining gyrochronal models.

With solar mass stars arriving on the ZAMS at $\sim 40\text{Myr}$ and empirical models restricted to ages $\geq 80\text{Myr}$, study of younger open clusters is important to understand the evolution of solar mass stars.

LOPS2 FIELD & CLUSTER MEMBERSHIP

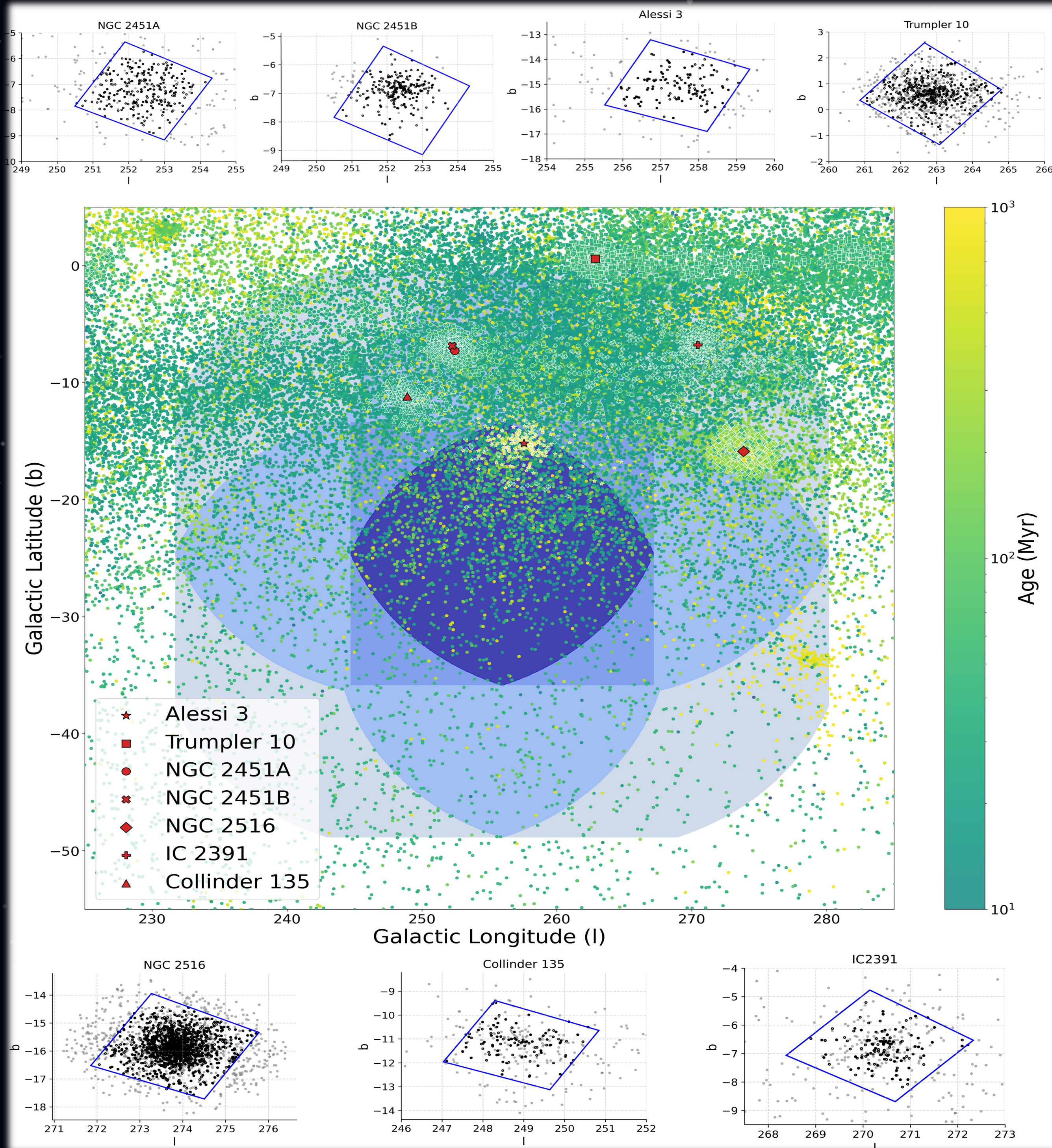


Fig. 1 — Positions of young stars ($< 1\text{Gyr}$) with $G_{\text{mag}} < 17$ and distance $< 500\text{ pc}$, colour coded by age (Myr) and overplotted onto the PLATO LOPS2 field with its relative camera assembly overlaps (running from light to dark with increasing camera exposure, from 6-24). Inset figures show the spatial distribution for each of the seven clusters observed, with their relative positions highlighted in the central plot.

Methodology

- Star spots are carried across the observational line of sight as the star rotates, resulting in photometric modulation in line with the rotation period.
- Using the Lomb-Scargle (LS) periodogram to model the photometric modulation of a lightcurve allows constraint of the stellar rotation period.
- Period estimates were vetted by phase folding the data on the three highest power LS peaks, whilst also fitting a best fit model for each period estimate and visually inspecting the results for each estimate.
- Where possible, the adopted period by NGTS was also compared to TESS data (opting where possible to use CDIPS [3]).
- Higher order systems were identified via two complimentary approaches;
 - Photometric binaries were identified by creating a Colour Magnitude Diagram (CMD) in Gaia G_{mag} vs $(B_p - R_p)_0$ to look for outliers from the single star sequence. To identify the single star sequence, the CMD was modelled using a Gaussian Process, iteratively rejecting outliers until convergence.
 - Astrometric binaries were identified using a Gaia RUWE threshold of $\text{RUWE} < 1.4$.

GYROCHRONOLOGY – A NEW LOWER AGE ANCHOR

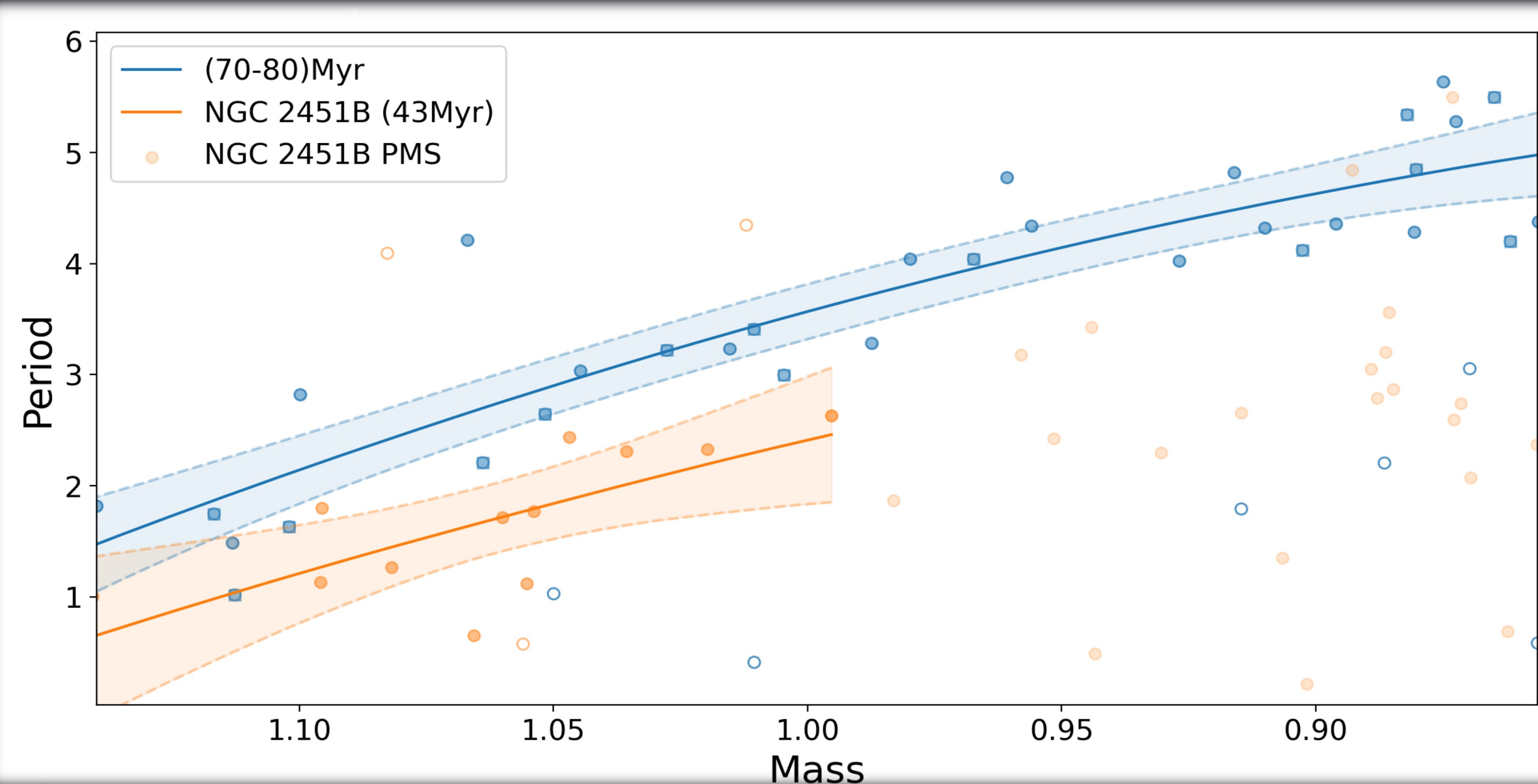


Fig. 3 — Best fit slow sequence models and their corresponding 95% confidence intervals. Blue represents the canonically-accepted lower age anchor of $\sim 70\text{-}80\text{ Myr}$. Orange represents, NGC 2451 B at $\sim 40\text{Myr}$. Low opacity orange markers represent stars from NGC 251 B still on the PMS, and hollow markers represent outliers identified during fitting.

NGTS Clusters survey (NCS)

The NCS is monitoring nearby young open clusters in order to;

- Characterise early evolution of stellar rotation, active region lifetimes and flares.
- Detect and characterize young transiting exoplanets and eclipsing binaries (EBs).

To date 23 young open clusters, with ages spanning 1Myr to 3Gyr, have been observed. The first five NCS papers present new insights into the early evolution of stellar rotation, flare frequency and star-disk interaction, as well as precise constraints on fundamental stellar parameters from new young EBs.



CLUSTERS & MEMBERSHIP

Alessi 3 Collinder 135 IC 2391 NGC 2451A NGC 2451B NGC 2516 Trumpler 10

- LOPS2 is centered at $l = 255.9375^\circ$ & $b = -24.62432^\circ$ with a field of view $\sim 49^\circ \times 49^\circ$, covering roughly 5% of the sky.
- NCS has observed seven young open clusters within LOPS2, with long baseline photometric observations on each cluster typically spanning 6-8 months.
- Ages for the clusters range from $\sim 40\text{-}700\text{Myr}$, spanning almost the entire range of stellar youth.
- Our independent cluster membership characterisation identifies 8581 stars across the seven clusters.
- NCS extracted photometry on 3031 FGKM stellar type cluster members from the cluster cores.

PERIOD-MASS DISTRIBUTIONS (ALL 7 CLUSTERS)

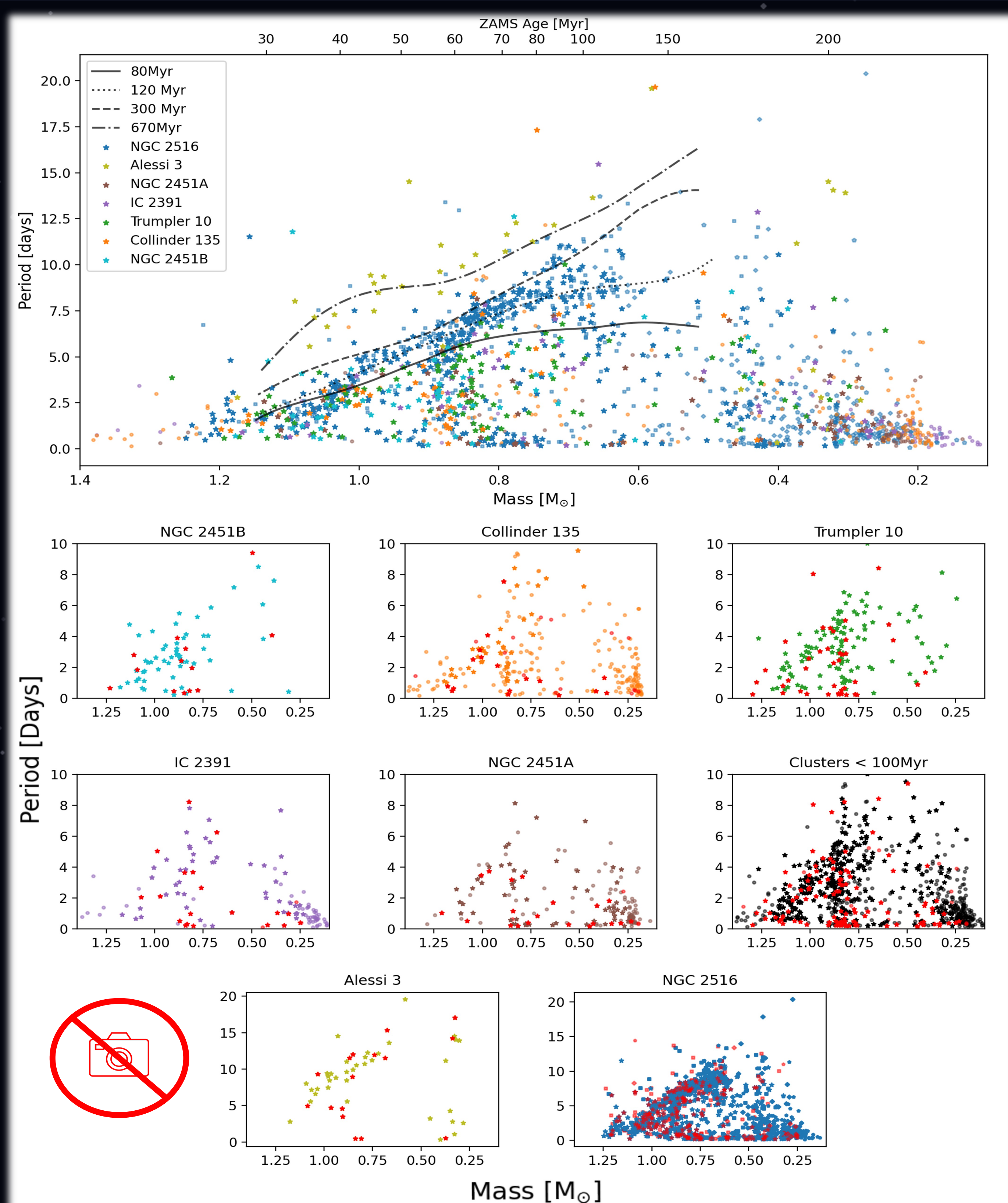


Fig. 2 — Period-mass diagram combining the single star rotation sequences for all seven clusters (top panel), with gyrochrones from [2] plotted to provide wider context on stellar evolution. Individual cluster subplots (below) isolate each distribution; with red stars representing binary stars identified during our analysis.

KEY RESULTS

- We report 1063 rotation periods across all seven clusters, identifying 265 of these systems as binary or higher order systems.
- The distributions for three clusters; Alessi 3, Trumpler 10 & NGC 2451 B are the first known dedicated rotation period distributions to date.
- We note that at $\sim 40\text{Myr}$, the slow sequence of stars that have reached the ZAMS is distinguishable from the current lower gyrochronology age anchor of $\sim 70\text{-}80\text{Myr}$ (See Fig. 3). This halves the age to which we can age date young open clusters.
- We observe stalled spin down at $\geq 1M_{\odot}$ from the age of 70Myr to at least 150Myr, earlier than previous epochs of observed stalled spin down at $\sim 0.7\text{-}1\text{Gyr}$ in stars $\leq 0.7M_{\odot}$.
- This observation supports the prediction made by Spada & Lanzafame [4] who suggest angular momentum redistribution offsetting magnetic braking is responsible for stalled spin down and should be observed at a range of masses and ages.
- We use our period distribution for Alessi 3 to provide a differential gyrochronology age estimate of $687 \pm 106\text{Myr}$.
- This work has recently been submitted to MNRAS and is under review.