A CATALOG OF 29 OPEN CLUSTERS AND ASSOCIATIONS OBSERVED BY THE KEPLER AND K2 MISSIONS

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KEPLER’S CLUSTER OBSERVATIONS

Since its launch in 2009, the Kepler Space Telescope (Borucki et al. 2010) has photometrically monitored ~500,000 stars comprising a large range of ages. Its 4-year “prime” mission observed a single ~ 10° × 10° field in Cygnus, while the K2 Mission (initiated in 2014; Howell et al. 2014) has focused for 70–80 days at a time on objects in the ecliptic plane. A highlight of Kepler’s observations has been the inclusion of galactic open and globular clusters in its target list. These groups of stars are considered to be coeval, and thus provide ideal laboratories for testing stellar astrophysics and planet occurrence versus age.

The Kepler and K2 Missions publicly release all collected imaging data, as well as light curves for the majority of targets. Cluster observations are collected in one of two formats: 1.) small “target pixel files” (TPFs) centered on isolated single targets, or 2.) “superstamps”—larger regions consisting of both the cluster of interest and foreground/background stars (see Cody et al. 2018). The missions have produced and released light curves for targets in TPFs, but have left it up to the community to extract them from superstamps. Stars in crowded cluster environments require more careful tuning of photometric analysis methods to produce precision time series. As a result, some Kepler/K2 clusters have received more attention than others to date. In this note, we present the compilation of all clusters and associations observed by Kepler from 2009–2018, and highlight key cluster science results as well as potential avenues for future research.

CLUSTER SCIENCE AND FUTURE POTENTIAL

In all, Kepler has observed two star forming associations (age < 10 Myr), 18 open clusters (1 Myr to 8 Gyr), and nine globular clusters (> 11 Gyr). The compilation of clusters is provided in Table 1, along with the observing campaign and an assessment of the degree of attention received by each cluster’s Kepler/K2 data in the literature.

Investigations into Kepler/K2 clusters have comprised a number of areas, from stellar to planetary science. Asteroseismology, particularly focusing on red giants, has been carried out in the open clusters observed during the Kepler prime mission (Hekker et al. 2011, Corsaro et al. 2012, and references therein), and more recently, the first solar type oscillations have been detected in a K2 cluster (the Hyades; Lund et al. 2016). Asteroseismology has also been conducted in M67 (Stello et al. 2016) and M4, one of the globular clusters targeted by K2 (Miglio et al. 2016).

Many cluster members have starspots, making gyrochronology and rotation studies popular endeavors. Stellar spin-down has been probed in the main sequence stars of M67 (Barnes et al. 2016 and references therein) as well as the 2.5 billion-year-old cluster NGC 6819 (Meibom et al. 2015). Stellar angular momentum evolution from the pre-main sequence to intermediate ages has also received attention, with analyses by Rebull et al. (2016, 2018) among others.

Among the clusters, numerous eclipsing binary systems have been uncovered and used to probe stellar structure as a function of age (e.g., Gillen et al. 2017 and references therein). The Kepler mission also enabled the first discovery of planets in an open cluster (Meibom et al. 2013), leading to a handful of other finds from K2 (Livingston et al. 2018, Vanderburg et al. 2018 and references therein). In the youngest clusters and associations, precision time series photometry has also enabled detailed analyses of pre-main sequence accretion phenomena and obscuration by circumstellar material (Cody & Hillenbrand 2018 and references therein).

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Table 1. Clusters and associations observed during the Kepler and K2 Missions

| Region        | Campaign (Program) | Stamp? | Region | Age Range | Extensively studied? |
|---------------|--------------------|--------|--------|-----------|---------------------|
| NGC 6819      | Kepler prime       | Y      | open cluster | 1–2       | Y                   |
| NGC 6791      | Kepler prime       | Y      | open cluster | ∼8        | Y                   |
| NGC 6811      | Kepler prime       | N      | open cluster | 1–2       | N                   |
| NGC 6866      | Kepler prime       | N      | open cluster | 0.4–0.8   | N                   |
| M35           | K2 C0              | Y      | open cluster | 0.1–0.2   | N                   |
| NGC 2158      | K2 C0              | Y      | open cluster | 1–2       | N                   |
| M4            | K2 C2              | Y      | globular cluster | ≥11   | N                   |
| M80           | K2 C2              | Y      | globular cluster | ≥11     | N                   |
| Upper Scorpius| K2 C2, C15         | N      | association | ≤0.01     | Y                   |
| ρ Ophiuchi    | K2 C2              | N      | open cluster | <0.01     | N                   |
| Pleiades      | K2 C4              | N      | open cluster | 0.1–0.2   | Y                   |
| Hyades        | K2 C4, C13         | N      | open cluster | 0.4–0.8   | Y                   |
| M67           | K2 C5, C16, C18    | Y      | open cluster | 3–4       | Y                   |
| Praesepe      | K2 C5, C16, C18    | N      | open cluster | 0.4–0.8   | Y                   |
| Ruprecht 147  | K2 C7              | Y      | open cluster | 3–4       | N                   |
| NGC 6717      | K2 C7              | N      | globular cluster | ≥11     | N                   |
| NGC 6530      | K2 C9              | Y      | open cluster | <0.01     | N                   |
| M9            | K2 C11             | Y      | globular cluster | ≥11     | N                   |
| M19           | K2 C11             | Y      | globular cluster | ≥11     | N                   |
| NGC 6293      | K2 C11             | Y      | globular cluster | ≥11     | N                   |
| NGC 6355      | K2 C11             | Y      | globular cluster | ≥11     | N                   |
| Terzan 5      | K2 C11             | Y      | globular cluster | ≥11     | N                   |
| NGC 1647      | K2 C13             | N      | open cluster | 0.1–0.2   | N                   |
| NGC 1746      | K2 C13             | N      | open cluster | -         | N                   |
| NGC 1817      | K2 C13             | N      | open cluster | 1–2       | N                   |
| Taurus        | K2 C13             | N      | association | <0.01     | N                   |
| NGC 1750      | K2 C13             | N      | open cluster | 0.1–0.2   | N                   |
| NGC 1758      | K2 C13             | N      | open cluster | 0.4–0.8   | N                   |
| NGC 5897      | K2 C15             | Y      | globular cluster | ≥11     | N                   |

Note—Basic data on the clusters and associations photometrically monitored as part of the Kepler and K2 missions. Column six provides a measure of how well studied the cluster is by noting whether there are more than five papers analyzing its Kepler or K2 data. We note that the cluster status of NGC 1746 is debated; it may be an asterism of unrelated stars.

While the science return thus far from the clusters of Kepler and K2 has been excellent, only a fraction of its potential has been mined. According to our criteria of assessment (>5 refereed papers), only a third of observed clusters have been extensively studied thus far. We hope that by providing the complete list observed by Kepler, the astronomical community will be motivated to further probe the astrophysics of member stars and their companions. The more crowded regions will benefit from new photometry techniques under development, such as psf modeling and fitting. This is especially the case for the globular clusters, which provide an opportunity to study some of the oldest stars in the universe.
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