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Young Open Clusters with CoRoT

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1. Open Clusters and CoRoT

Open clusters allow to simultaneously study the cluster itself or its member stars in detail. Cluster members were born at the same time and from the same molecular cloud and therefore have the same age, distance and chemical composition. From the investigation of open clusters we can learn about star formation and stellar evolution and test our present stellar models.

With its field of view of ~1.3 square degrees per CCD, CoRoT is a most suitable instrument to observe clusters. In the near future CoRoT will also be the only space telescope with the capability to obtain cluster measurements.

Although the open field of the MOST satellite is of comparable size, the limiting magnitude for MOST is around V = 12mag which constrains the list of observable clusters significantly. The KEPLER field-of-view is located high above the galactic plane where no young clusters can be found. Hence, the KEPLER mission will not be able to observe these objects. Although the field-of-view of the BRITE Constellation cameras would be large enough for clusters, the mission aims at few stars brighter than V = 6mag. Therefore, only the very brightest stars will be observable with BRITE Constellation.

A wealth of scientific aspects can be addressed using CoRoT for observations of open clusters. Depending on the detailed research goals that should be achieved, respective cluster targets for CoRoT can be selected. (In the Appendix we list some statistics on the observability of open clusters in general with CoRoT.)
Here we concentrate on the youngest clusters observable with CoRoT and the science which would be unique using CoRoT for these objects.

1.1. Open clusters younger than 10 million years and CoRoT

Clusters younger than 10 million years are populated by stars recently born from their parental molecular cloud; these stars are still contracting towards the main sequence and have not started hydrogen burning in their cores yet. In such young clusters star formation might still be an ongoing process, which allows the study of the earliest phases of stellar evolution. Hence, the scientific goals that can be addressed with CoRoT observations of clusters younger than 10 million years involve (i) *asteroseismology of pre-main sequence (PMS) stars*, (ii) *investigation of the interaction of young stellar objects* (i.e., T Tauri and Herbig Ae/Be stars) *with their circumstellar matter*, (iii) studies of *rotation and activity properties of cluster members*, (iv) *search for planetary and stellar eclipses around young stars*. For the already taken CoRoT observations of the young open cluster NGC 2264 (in 2008 and 2011), four subteams have been founded following the above-mentioned goals. The teams have been working very successfully in their research fields, where interaction and cooperation among the teams have been very fruitful. The results of the respective investigations of NGC 2264 and its members are absolutely unique due to the high quality observations with CoRoT, which is illustrated in several publications in high-ranked scientific journals. No other satellite presently operating is able to achieve these goals. For potential future CoRoT observations of young clusters the same organizational structure will be maintained as it has been proven successful.

In total, 5 of the clusters in the anticenter direction (i.e., around RA = 6h50m) are younger than 10 million years and are scientifically interesting targets for CoRoT: Dolidze 25, NGC 2264, NGC 2244, Collinder 106 and Collinder 107.
Among those are the two clusters that were already observed highly successfully by CoRoT: Dolidze 25 was observed as additional target during one of the long runs. NGC 2264 had a dedicated short run in 2008 (SRa01) and will be reobserved by CoRoT in December 2011 to January 2012 during a multi-satellite campaign involving also the satellites MOST, *Spitzer* and Chandra. NGC 2244, Collinder 106 and Collinder 107 would be new potential and very unique candidates for CoRoT observations.

In the center direction of CoRoT (i.e., around RA = 18h50m) no cluster is younger than 10 million years.

2. Young open cluster observations in an extended CoRoT mission

If the CoRoT mission is extended for another 3 years beyond 2013, new observations of young stellar clusters will have the potential of significantly advancing the field of PMS stellar variability.

Recent studies of pulsating young stars indicate that their inner structures change significantly between their births from molecular clouds and the onset of hydrogen core burning. With *asteroseismology* as the only tool to probe stellar interiors the relevance of various physical processes to the evolution of young stars can be tested.

Another very important aspect in the context of PMS variability is the study of the *structure and evolution of the inner circumstellar disk*. By comparing the fraction of disk-bearing PMS variables between young clusters of different masses and ages, one can further explore how the environment can affect early disk evolution.

These goals can be addressed in two ways: by observing two new young clusters with ages less than ~10 million years (i.e., NGC 2244 and Collinder 107) and by re-visiting NGC 2264. The high accuracy and long temporal baseline of the photometric time series needed for these studies can only be achieved with space observations provided by CoRoT.

2.1. NGC 2244 and Collinder 107

Within the RA = 6h50m CoRoT observing cone there are two young clusters observable with CoRoT that are highly interesting objects to address all the science goals mentioned above: *NGC 2244* and *Collinder 107* which are located at distances of ~1.4 and ~1.7kpc, respectively.

NGC 2244 is of approximately the same age as NGC 2264 (~3 Myrs), yet more massive (possessing several O stars that produce more ionizing radiation compared to NGC 2264), and more centrally condensed. Its PMS population is optically visible and suffers practically no extinction. High-precision time series photometry from CoRoT would enable us to conduct similar studies as for NGC 2264. Asteroseismology of pulsating PMS cluster members would help us to investigate the inner structures of young stellar objects, conduct a survey of PMS

pulsators and investigate evolutionary differences between stars that have just emerged from the birth cloud and stars closer to the zero-age main sequence (ZAMS).
CoRoT observations of NGC 2244 would also easily identify stars with irregular, or periodic spot-like and AA Tau-like light curves, which would then be compared to the ones already identified in NGC 2264. Are the fractions of these 3 types of light-curves the same? How do their periods compare?

Collinder 107 (age ~10Myrs), on the other hand, is about 3 to 4 times older than NGC 2244 -- an age at which very few circumstellar disks are observed to remain. CoRoT observations of this older PMS population and subsequent comparison with the two younger regions (NGC 2244 and NGC 2264) would yield further insight into how the fraction of the different types of light curves from young stellar objects vary with time.
Comparative asteroseismic studies of pulsating members of this slightly older cluster to the two younger clusters NGC 2264 and NGC 2244 is also expected the give us new insights in the connection between stellar evolution and the onset of pulsation.

2.2. Reobservations of NGC 2264

The CoRoT light curves of stars in the young cluster NGC 2264 (particularly AA Tau-like light curves) have demonstrated, for example, that we can begin to characterize in greater detail the structure of inner disks of PMS stars.

The region of NGC 2264 will be observed by CoRoT a second time in December 2011 (and January 2012) in a coordinated and synchronized effort with other observatories (MOST, Spitzer, Chandra; VLT, CFHT etc.) so that the different components of variability (i.e., those arising from the PMS star's chromosphere, the inner disk, the accretion column, etc) can be disentangled and more detailed asteroseismic studies can be conducted.

By comparing the 2008 observations with those of this year, we will have a baseline of four years and will thus be able to explore period changes amongst the regular variables. Changes or drifts in periods could be due to e.g., differential rotation, or spin-up or spin-down of the star that is related to the inner disk and magnetic field coupling.
Traditionally differential rotation studies of T Tauri stars have been carried out using very high resolution spectroscopy (e.g., of the Tauri star V410 Tau), which is extremely expensive timewise, and therefore limited to very few objects. However, there are a few differential rotation studies using photometric monitoring: a notable case is that of the T Tauri star HBC 333, located in the young cluster NGC 1333. The star was observed for 5 years and its period shortened by 20% in the span of one year. The proposed explanation for such a significant change is that high-latitude star spots (from which the first longer period was derived) drifted toward low-latitudes (shorter period). The study found that the amplitude and sense of the inferred differential rotation is similar to what is seen on the Sun.
CoRoT is therefore in a unique position to contribute to this particular field, as it can efficiently monitor a large, statistically significant, sample of variable T Tauri stars in NGC 2264 with great precision, over a substantial temporal baseline. By measuring the migration rate of spots (and subsequently determining the differential rotation), the CoRoT data can be used to constrain dynamo models (Küker & Rudiger) and better characterize the magnetic field properties. A better understanding of the magnetic field of a T Tauri star will in turn help constrain the magnetic braking of the disk of the star's spin.
A longer temporal baseline of period monitoring will undoubtedly address these problems with unprecedented accuracy and allow us to further observationally constrain inner disk evolution, and subsequently, planet formation. Furthermore, we would be able to compare the period monitoring of NGC 2264 with the periods in the older cluster mentioned above, Collinder 107, to construct an empirical picture of how angular momentum evolves during the PMS phase.

The relatively fast evolution of young stars from the birthline to the main sequence makes it

possible to measure changes in the pulsation periods already after only a couple of years. For the two PMS pulsators V 588 Mon and V 589 Mon in NGC 2264, the earliest measurements are taken in 1972, followed by several re-observations from ground and from space (using MOST and CoRoT data). These data allowed for the first time to start investigating evolutionary period rate changes. From the comparison of the theoretically expected to the measured period changes in these two stars, stellar evolution in this phase is suggested to be even faster by a factor of ~50 than predicted by theory.
CoRoT has discovered the pulsation periods for other members of the cluster in 2008. These stars will be re-observed in the upcoming CoRoT observations in December 2011, their pulsation periods will be determined and compared to the periods obtained in 2008.
Reobservations of V 588 Mon, V 589 Mon and other pulsating PMS stars in NGC 2264 by CoRoT in an extended mission after 2013 would enable us to reach the high time resolution and accuracy crucial to conduct investigations of evolutionary period rate changes and to confirm our earlier findings.

Appendix: The observability of open clusters in general with CoRoT

A recent search using the WEBDA data base of open clusters (http://www.univie.ac.at/webda) yields over 80 open clusters in the anticenter direction (i.e., around RA = 6h50m) and 35 in the center direction (i.e., around RA = 18h50m). Their ages range from the very youngest (i.e. younger than 10 million years) to the oldest open clusters (i.e. up to 3 billion years). For some of these objects, extensive information from previous studies exist (e.g. for NGC 2264), for other clusters no data are available at all (e.g. for Alessi 14). Some clusters are quite distant (up to 13kpc) and might not be ideal targets for CoRoT, others are located closer to us and might be more interesting to study.

It will be up to other research groups to describe potential older open cluster studies in more detail.