A PSF-based approach to K2 data
Variables and Exoplanet candidates within K2 cluster fields

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Dwarf Stars and Clusters with K2
Boston, January 17th, 2018
Light curves extraction: the method

- Single Images
- High angular resolution input catalog
- Point Spread Functions (PSFs)
- Local Transformations
- img2lc: FORTRAN 95 parallel code (OPENMP)

Given a target star, the software subtracts all its neighbor sources and measures the target flux:
- Aperture photometry
- PSF-fitting photometry

Asiago Schmidt 67/92 cm Telescope

Nardiello et al. (2015) - Variable stars in two open clusters within the Kepler/K2-Campaign-0 field: M 35 and NGC 2158
Nardiello et al. (2016) - Variable stars in one open cluster within the Kepler/K2-Campaign-5 field: M 67 (NGC 2682)
Light curves extraction: the method

The light curve extractor works for any kind of PSF

FWHM ~ 0.7 arcsec

FWHM ~ 1.7 arcsec

FWHM ~ 2.7 arcsec

Our tool is easily adaptable to imagers on ground-based and space-based telescopes (HST, Kepler, TESS, PLATO, etc)

Nardiello et al., in preparation
From Earth to Space
Dense fields in K2 super-stamps

M35 & NGC2158
(very crowded environment)

Libralato et al. (2016) - A PSF-based approach to Kepler/K2 data - I. Variability within the K2 Campaign 0 star clusters M 35 and NGC 2158
From Earth to Space
Dense fields in K2 super-stamps

M35 & NGC2158
(very crowded environment)

Kepler/K2 Campaign 0
4 arcsec pixel\(^{-1}\)

Asiago Schmidt 67/92 cm telescope
0.86 arcsec pixel\(^{-1}\)

Problem
PSF undersampled!!!

Solution
Library Effective PSF (ePSF)

Best Solution
Time-varying ePSF

Libralato et al. (2016) - A PSF-based approach to Kepler/K2 data - I. Variability within the K2 Campaign 0 star clusters M 35 and NGC 2158
For K2/C0 we used the K2 images to obtain the library ePSF, taking advantage of the drift of the telescope (No calibration data were available)

The ePSF

PSF undersampled!!!

Effective PSF (ePSF)

Library

Time-varying ePSF

Libralato et al. (2016) - A PSF-based approach to Kepler/K2 data - I. Variability within the K2 Campaign 0 star clusters M 35 and NGC 2158
Light curves extraction from K2/C0

Two open clusters in one field: M35 & NGC 2158

- Single K2 Images
- Asiago Input Catalog
- Spatially and temporally varying ePSFs
- Local Transformations

Given a target star, the software subtracts all its neighbor sources (from the input list) and measures the target flux:

- Aperture photometry
  - Different apertures: 1, 3, 5, 10 px
- PSF-fitting photometry

For bright objects, aperture photometry is the best choice.

For Kp>15.5 PSF photometry is better than 3-pixel aperture photometry.

We are able to measure very faint objects (Kp~24)

An extreme (interesting) case: TR1 (Mochejska et al. 2006, candidate exoplanet or EB in NGC2158)

Schmidt 67/92cm Stacked image

K2 single image

K2 w/o neighbors image

Thanks to K2 data, we found TR1 is an EB
We tested our pipeline on a sparse cluster field. 7 candidate exoplanets.
Light curves extraction from K2/C5
An old, dense, open cluster: M67

3 candidate exoplanets

Nardiello et al. (2016) - A PSF-based approach to Kepler/K2 data - III. Search for exoplanets and variable stars within the open cluster M67
Light curves extraction from K2

Works in progress

K2/C2: NGC6093 (M80)

Input catalogue:
- Gaia DR1 (~5000 stars)
- HST (~30000 stars)

Library ePSF obtained thanks to Kepler commissioning data

~110 Kepler px

~120 Kepler px

Nardiello et al. *in prep.*

V28 (Kopacki 2013) - V~19.3

Works in progress:
- NGC6121 (M4) - K2/C2
- Ruprecht 147 - K2/C7
- K2/C11 globular clusters
  - M9, M19, NGC 6293, NGC 6355, and Terzan 5
- ePSF modelling from calibration data
- New detrending algorithm

Our resources
- 3 Postdocs
- 1 PhD student
- 4 Workstations
  - From 32 to 72 threads
  - From 32 to 128 GB RAM
  - >200 TB storage
- From images to raw light curves: ~10 days
From Kepler to TESS

- Launch window: March - June 2018
- 200 000 pre-selected stars
  - Cadence: 2 minutes (60x2s stacked images)
  - 10x10 pixel² postage stamps
- Full-frame images (FFIs)
  - Cadence: 60 minutes (900x2s stacked images)
  - 2048x2048 pixel² images
- Resolution ~ 21 arcsec/px
- 50 % of stellar flux within 1 pixel²
- Calibration and commissioning data during first 60 days (publicly available?)

We are ready for TESS!

- ePSFs: calibration/commissioning data or FFIs
- Input catalogs: Gaia DR2 or ad-hoc high resolution catalogs
- We will focus our attention mainly on FFIs
- Dense environments and faint stars
- TESS-CHEOPS synergy

Credits: NASA/Goddard Space Flight Center
A PSF-based approach to Kepler/K2
K2 and K2@ data analysis reported in the literature is mostly based on aperture photometry. Because of Kepler’s large, undersampled pixels and the presence of nearby sources, aperture photometry is not always the ideal way to obtain high-precision photometry and, because of this, the data set has not been fully exploited so far.

We present a new method (Libralato et al., 2016 MNRAS, 456, 1137) that builds on our experience with undersampled K2@ images. The method involves a point-spread function (PSF) neighbour subtraction and was specifically developed to exploit the huge potential offered by the K2 “super-stamps” covering the core of dense star clusters, but our technique is perfectly suitable to also analyze sparse fields imaged in single, isolated stamps.

By using a high-angular-resolution catalogue and PSFs we are able to pinpoint each star in the adopted input catalogue into each Kepler/K2 exposure and to measure its flux after all detectable close-by neighbours are subtracted from the image. This PSF-based technique allows us to (i) increase the number of analyzable objects in the fields, (ii) estimate an unbiased flux for a given source, (iii) extract the light curve of a star in a crowded environment and (iv) improve the photometric precision reachable for faint stars.

We are currently working on different stellar clusters imaged during K2 Campaigns and Kepler main mission.

Related papers to Kepler/K2 data analysis:
- Paper II: Libralato et al. (2016) MNRAS, 463, 1783. Exoplanet candidates in Praesepe (M 44@).

In the table below, together with all light curves (6th column), we release other useful material such as input catalogs, variable and exoplanet-candidate catalogs, stacked images. All files can be found in each channel folder (7th column).

Due to the large number of files stored, we warn the users that the redirect may take a few moments. "Don’t abandon all hope, ye who enter here!" (semicr.)

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<th>Campaign</th>
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<th>Module</th>
<th>Channel</th>
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(*) Note that for M 67@ the input and the variable/exoplanet catalogs in each Module-14 channel folder are the same. We copied them into each channel folder for sake of completeness.