Photometry of K2 Bulge data

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K2 – Campaigns 9 and 11

K2C9 – first space-based microlensing survey.

Photometry:

- unstable pointing,
- large pixel: $4'' \times 4''$,
- extended Point Response Function,
- extremely high stellar density.

$7.6' \times 7.6'$ crop
Raw pixel curves
Causal Pixel Model – basics

\[ I_{m,i} = \sum_{m'} a_{m,m'} I_{m',i} + e_{m,i} \]
Goal: K2 photometry for **transits**.

\[ I_{m,i} = \sum_{m'} a_{m,m'} I_{m',i} + e_{m,i} \]

where:

- \( i \) – epoch index,
- \( m \) – target pixel index,
- \( m' \) – some other pixels indexes,
- \( I_{m,i} \) – observed signal,
- \( e_{m,i} \) – residuum: noise and astrophysical signal,
- \( a_{m,m'} \) – CPM coefficients.

\[ \chi^2_m = \sum_i (I_{m,i} - \sum_{m'} a_{m,m'} I_{m',i})^2 + \lambda \sum_{m'} a_{m,m'}^2 \]

\( \lambda \) – L2-type regularization constant.

Goal: K2 photometry for transits.

\[ l_{m,i} = \sum_{m'} a_{m,m'} l_{m',i} + e_{m,i} \]

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\[ \chi^2_m = \sum_i \left( l_{m,i} - \sum_{m'} a_{m,m'} l_{m',i} \right)^2 + \lambda \sum_{m'} a^2_{m,m'} \]

\( \lambda \) – L2-type regularization constant.
CPM – limitations

- Works well if there is no signal most of the time, e.g., for transits.
- Could be run with astrophysical model, but added in a very simple way:

\[ I_{m,i} = \sum_{m'} a_{m,m'} I_{m',i} + c_m F_i + e_{m,i} \]

- Possibility of overfitting.
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Then test new ideas on eclipsing binary OGLE-BLG-ECL-234840 (\( V = 13.8 \) mag, \( P = 370 \) d, \( \Delta V = 0.3 \) mag). . .
MCPM – Modified CPM

Modifications:

• The astrophysical signal in given pixel: $F_i PRF_{m,i}$.

• Calculation of $PRF_{m,i}$ requires:
  • a priori knowledge of event coordinates,
  • astrometry of every epoch separately, and
  • $PRF$ function (Bryson et al. 2010).

• Subtract astrophysical signal in given pixel before running CPM:
  $$I_{m,i} - F_i PRF_{m,i} = \sum_{m'} a_{m,m'} I_{m',i} + e_{m,i}.$$  

• Combination of multiple pixels with the same $F_i$.

• Set $F_i = A(t_i) F_{\text{sat}}$. K2 source flux ($F_{\text{sat}}$) becomes a fitting parameter.
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  - a priori knowledge of event coordinates,
  - astrometry of every epoch separately, and
  - \( PRF \) function (Bryson et al. 2010).
- Subtract astrophysical signal in given pixel **before** running CPM:
  \[
  l_{m,i} - F_i \cdot PRF_{m,i} = \sum_{m'} a_{m,m'} l_{m',i} + e_{m,i}.
  \]
- Combination of multiple pixels with the same \( F_i \).
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Astrometry of subcampaign 91

accuracy of astrometric transformation

cumulative distribution

\( \sigma_{astrometry} \) [pix]

channel:
- 30
- 31
- 32
- 49
- 52
Astrometry of subcampaign 92

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cumulative distribution

$\sigma_{\text{astrometry}}$ [pix]
Example – OGLE-2016-BLG-0940
OGLE-2016-BLG-0940 – Zhu, Huang, Udalski et al. 2017

![Graph of OGLE-2016-BLG-0940 showing magnification vs. HJD-2450000 with data points and a fitted curve.](image-url)
Links:

https://github.com/CPM-project/MCPM
https://github.com/rpoleski/MulensModel

Code useful for general model fitting and developed as part of WFIRST preparations by RP and Jen Yee.

Can be used in microlensing analysis challenges!

Summary:

- Simultaneous model fitting and photometry extraction is required.
- Satellite source flux is a fitting parameter.
- The MCPM method works well in general.