Main Astronomical Observatory of NAS of Ukraine

The algorithm for automatic identification of asymmetric transits in the TESS database

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Aims

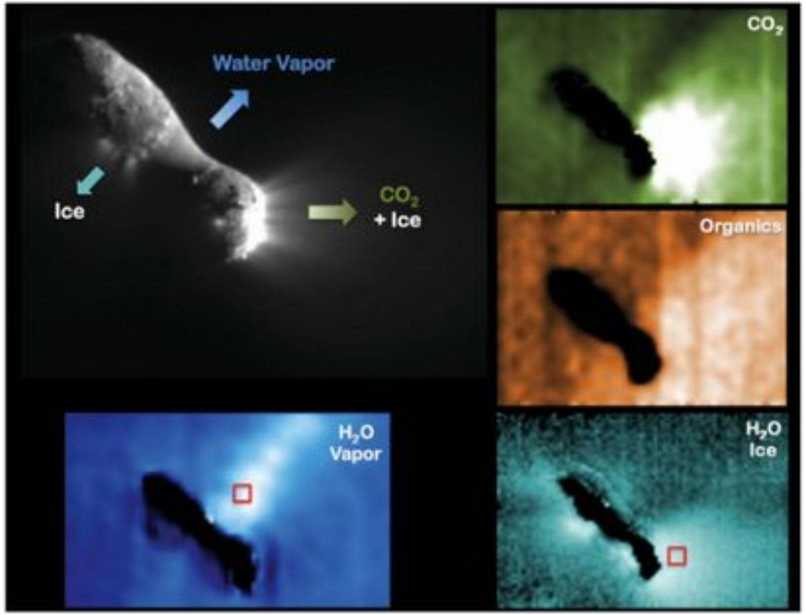
The aim of our work is to analyze the dataset of the TESS mission stored in Mikulski archive for Space Telescopes to search for asymmetric minima in light curves which can be caused by exocomet transits

BECAUSE:

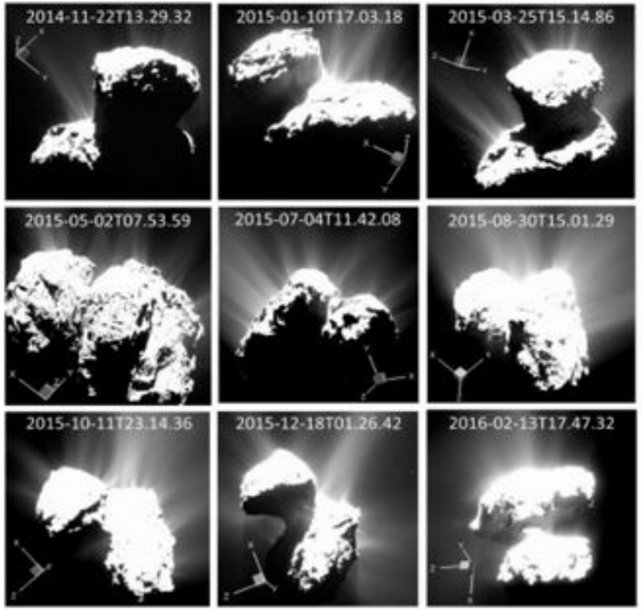
Modern theories of the planetary system formation predict the large population of planetesimals and dust inside the debris disks

AND: planetesimals play important role in both dynamical and physical evolution of the planetary system (Greaves et al., 2004; Ren et al., 2019; Frantseva et al., 2020)

Solar system comets are carriers of key ingredients (complex volatile, organics, amino-acids) leading to life (Altwegg et al., 2016, Schuhmann et al., 2019; Hadraoui et al., 2019)



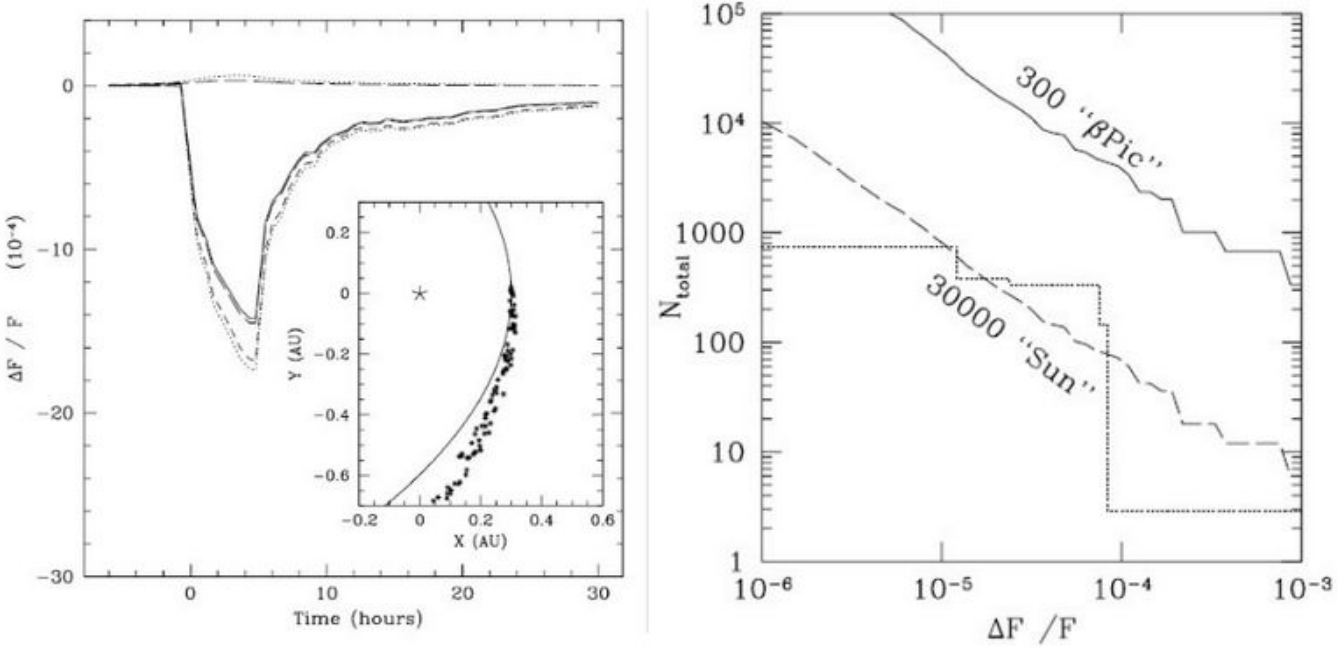
Relative spatial distribution in the coma of comet Hartley 2 (A'Hearn et al., 2011)



Outgassing in comet 67P/Churyumov-Gerasimenko seen by Rosetta (Lai et al., 2018)

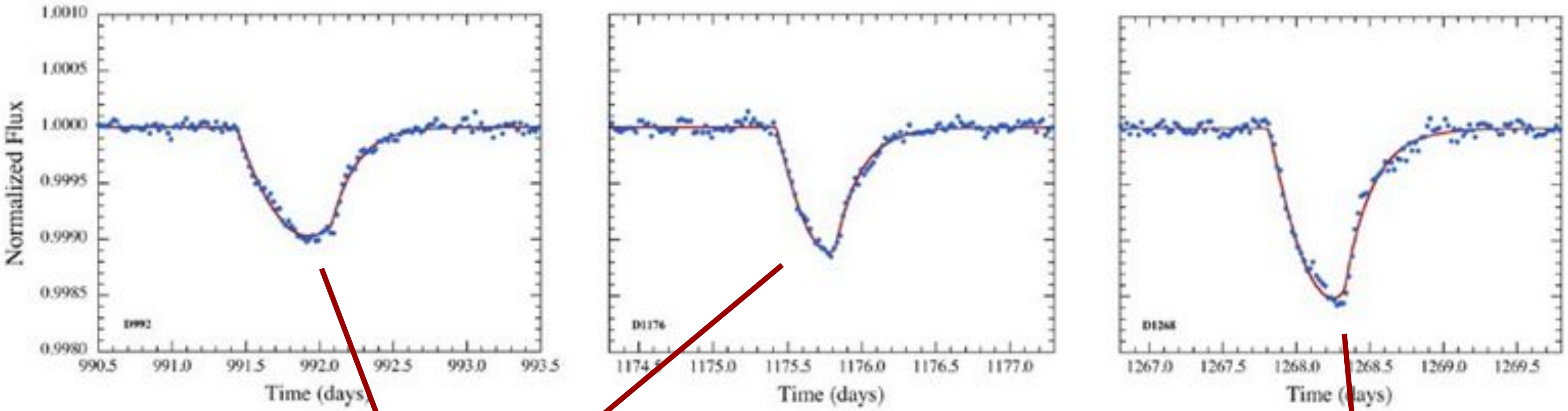
Theoretical prediction and first detections of exocomets

Theoretical prediction of a signature of passing a comet over the disk of a star (exocomet transit) was made in 1999 by Lecavelier des Etangs (Lecavelier des Etangs et al., 1999)



Star brightness variation due to cometary transit (left) and number of possible detections depending on photometric accuracy (right) from Lecavelier des Etangs et al. (1999)

The Kepler and TESS space telescopes provide high-quality photometric light curves for more than 200 000 stars, which enable first detections of asymmetric minima likely caused by comet-like bodies (Rappaport et al., 2018; Kennedy et al., 2019; Zieba et al., 2019) Figure shows the transits found for star KIC 354116 in the Kepler data sets.



Examples of the asymmetric minima in the lightcurve of star KIC 3542116 caused likely by exocomets (Rappaport et al., 2018)

shallow!!!!

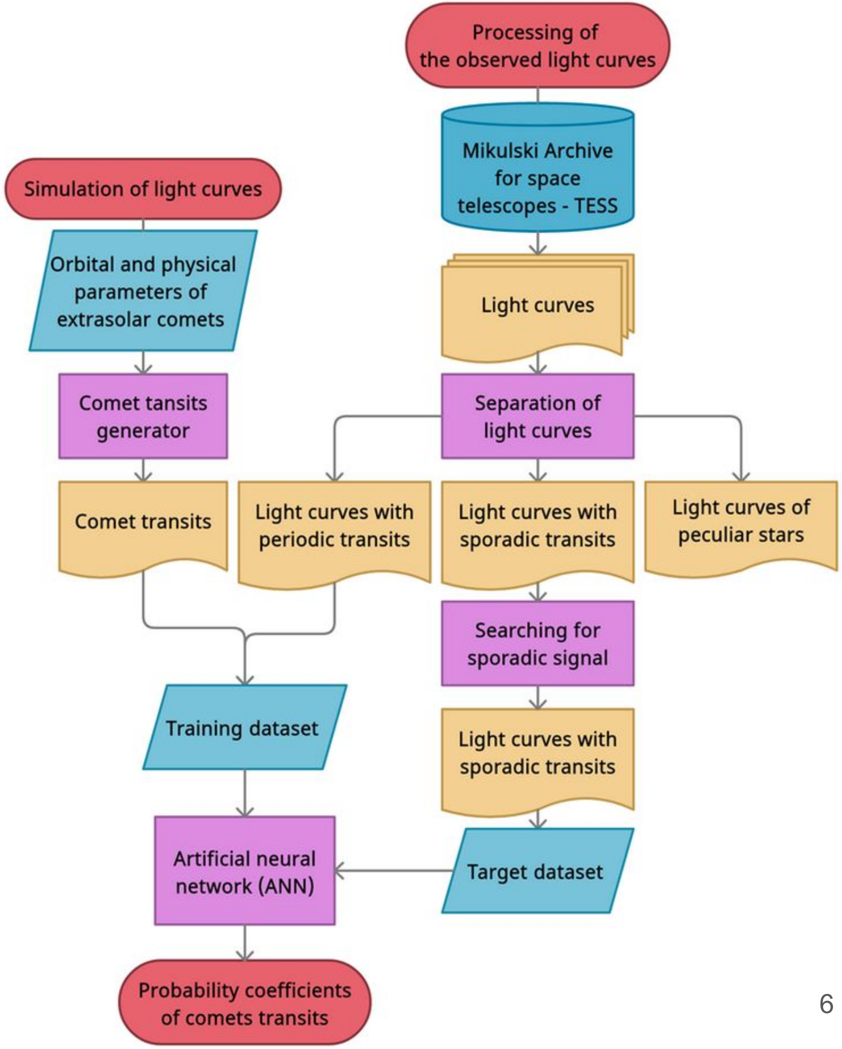
much deeper!!!!

Machine Learning

We report the preliminary results of our work in progress aimed at searching for asymmetric minima in the TESS dataset to classify them applying machine learning methods. This challenging approach allows us to distinguish exocomet transits from those caused by planets.

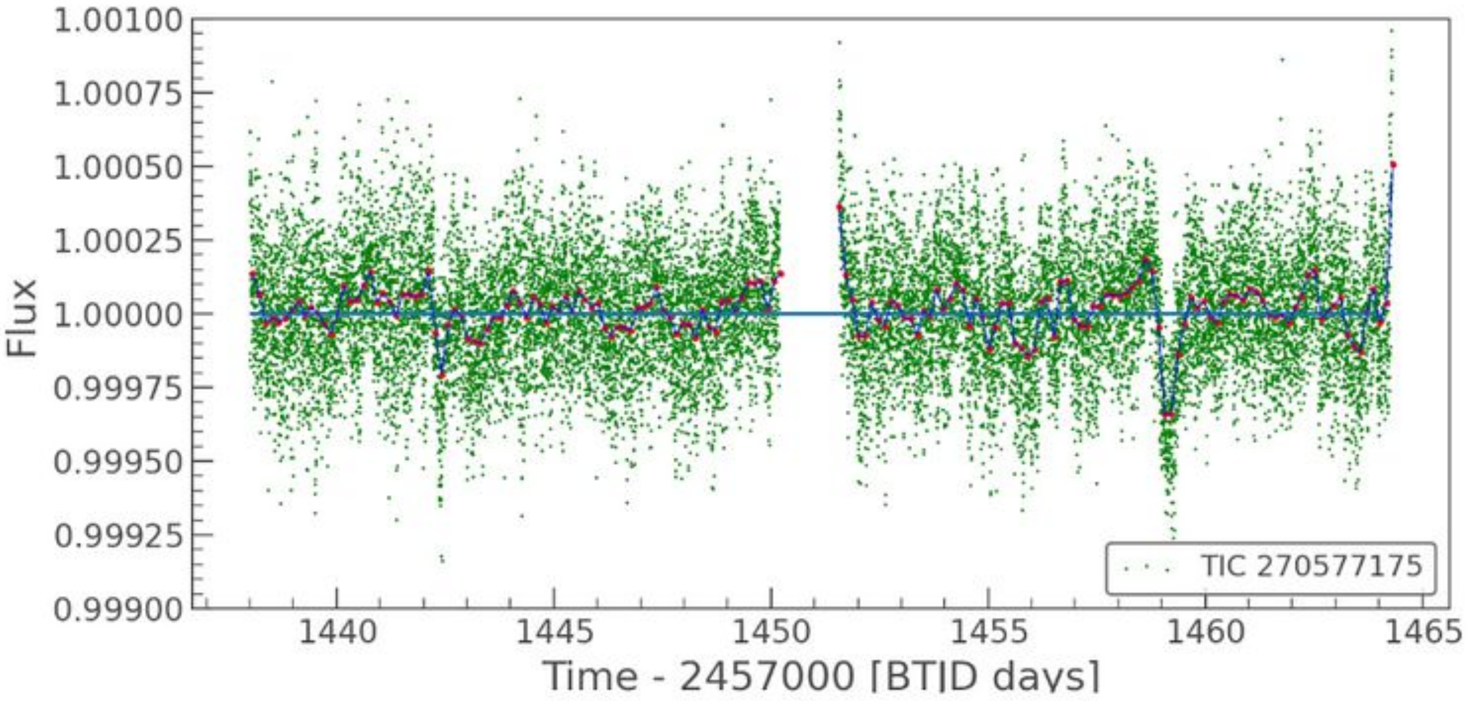
We use short cadence data (PDC_SAP fluxes) of the TESS dataset preprocessed by the Science Processing Operation Center (SPOC) for the analysis. To process the lightcurves we built a code based on the Python package "lightcurve" (Barensten et al., 2019).

In order to train the machine learning model, we use two different samples: the lightcurve profiles caused by the identified exoplanet transits and the simulated brightness profiles due to an exocomet transit. The latter is calculated using the Monte-Carlo approach to form the exocomet dusty tail taking into account orbital characteristics of the transiting body and some physical properties of particles that populated its dusty atmosphere.

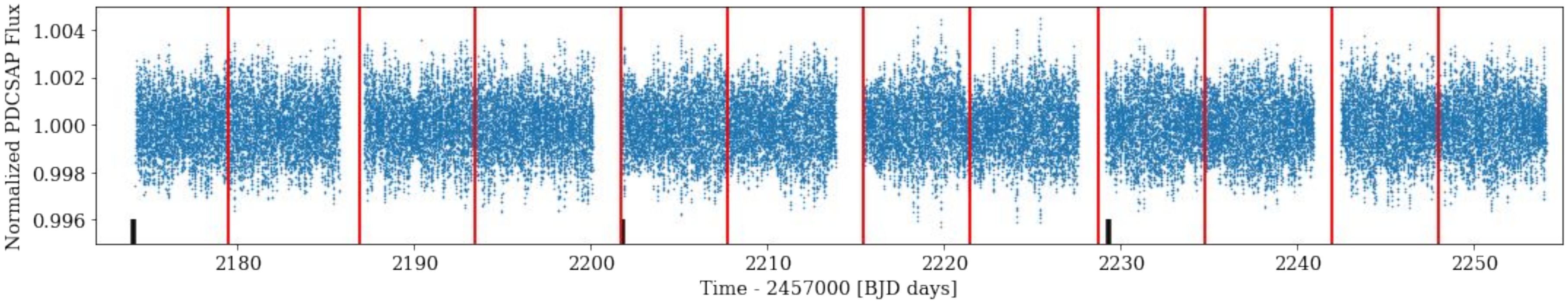


Detection of the asymmetric transits in β Pic system

An example of the automatic processing pipeline presented in our report is the processed light curve of beta Pictoris system observed with TESS (sector=5), where two sporadic minima are likely caused by transiting of a comet like-body.

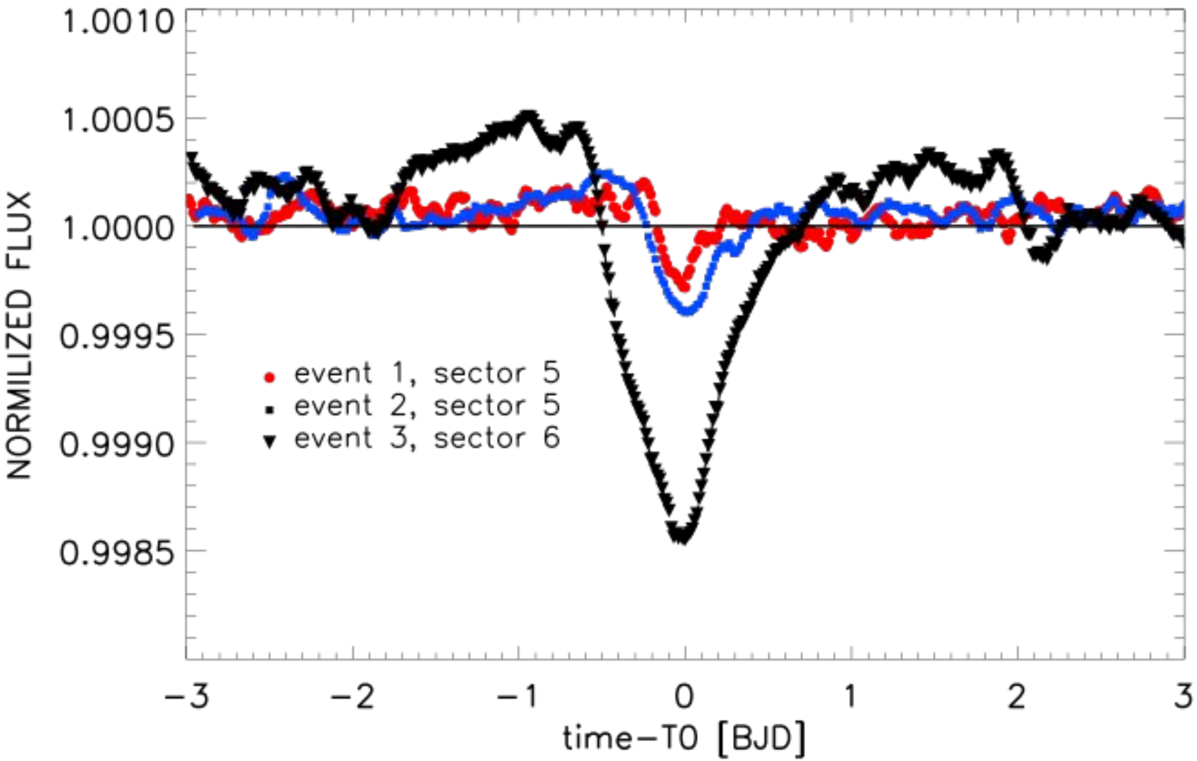


We analyzed new data for beta Pic in sectors 32, 33, 34 in TESS data base. Black lines mark the beginning of the sector, red lines mark the intervals of moment dumps , when spacecraft pointing is unstable (these intervals were removed from the analysis).

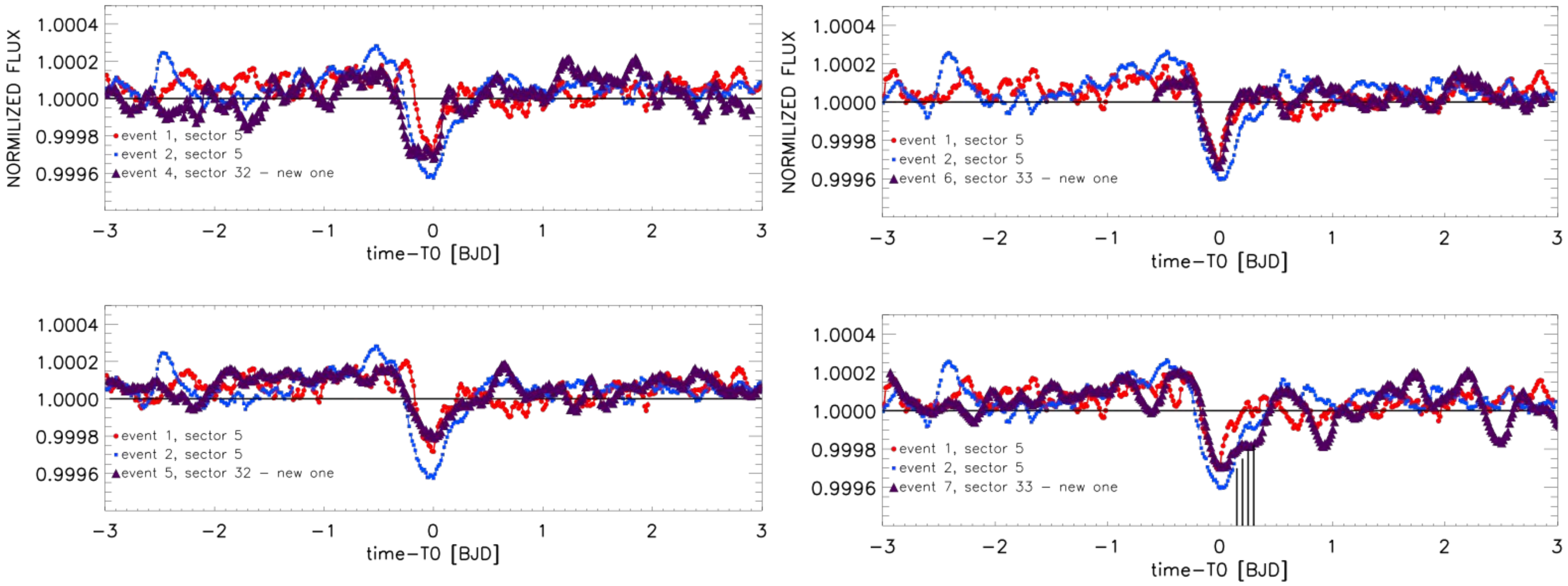


Detection of the asymmetric transits in β Pic system (TESS, 5, 6 sectors).

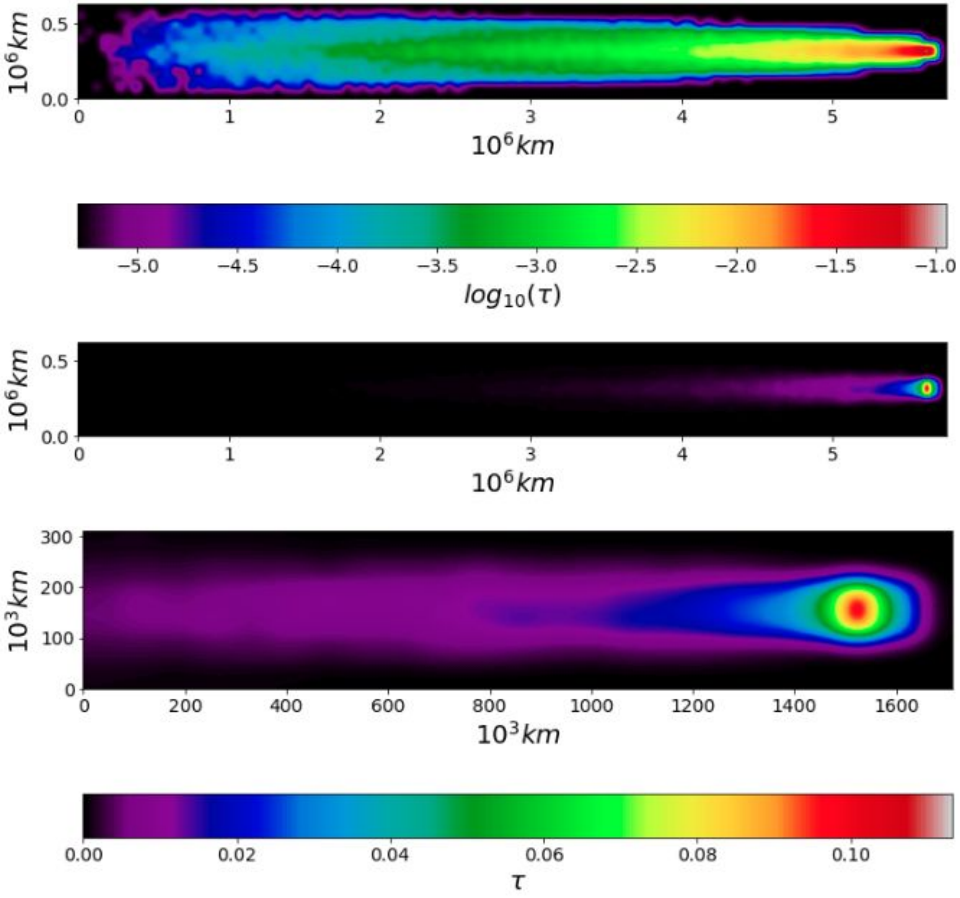
Three transit events (previously identified) in the same plot. Two of them are shallow, less then 0.03% of flux drop (Zieba, 2019).



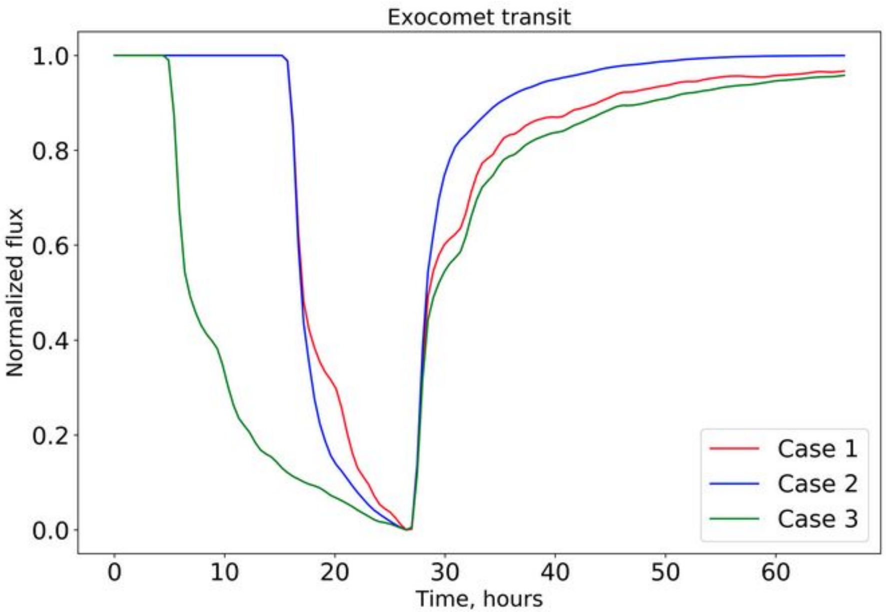
We identified 4 new events (in sectors 32 and 33), all of them are aperiodic, asymmetric and very shallow, similar to those two found previously in sector 5



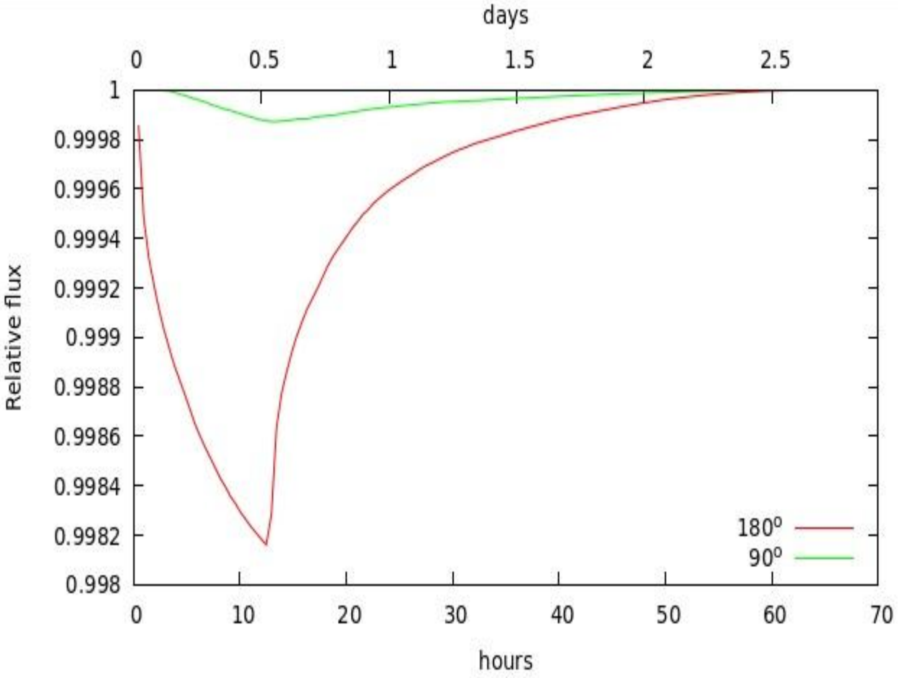
Our modeling of the dust tail of comet Hale - Bopp



Dependence of the light curve on the transit parameters

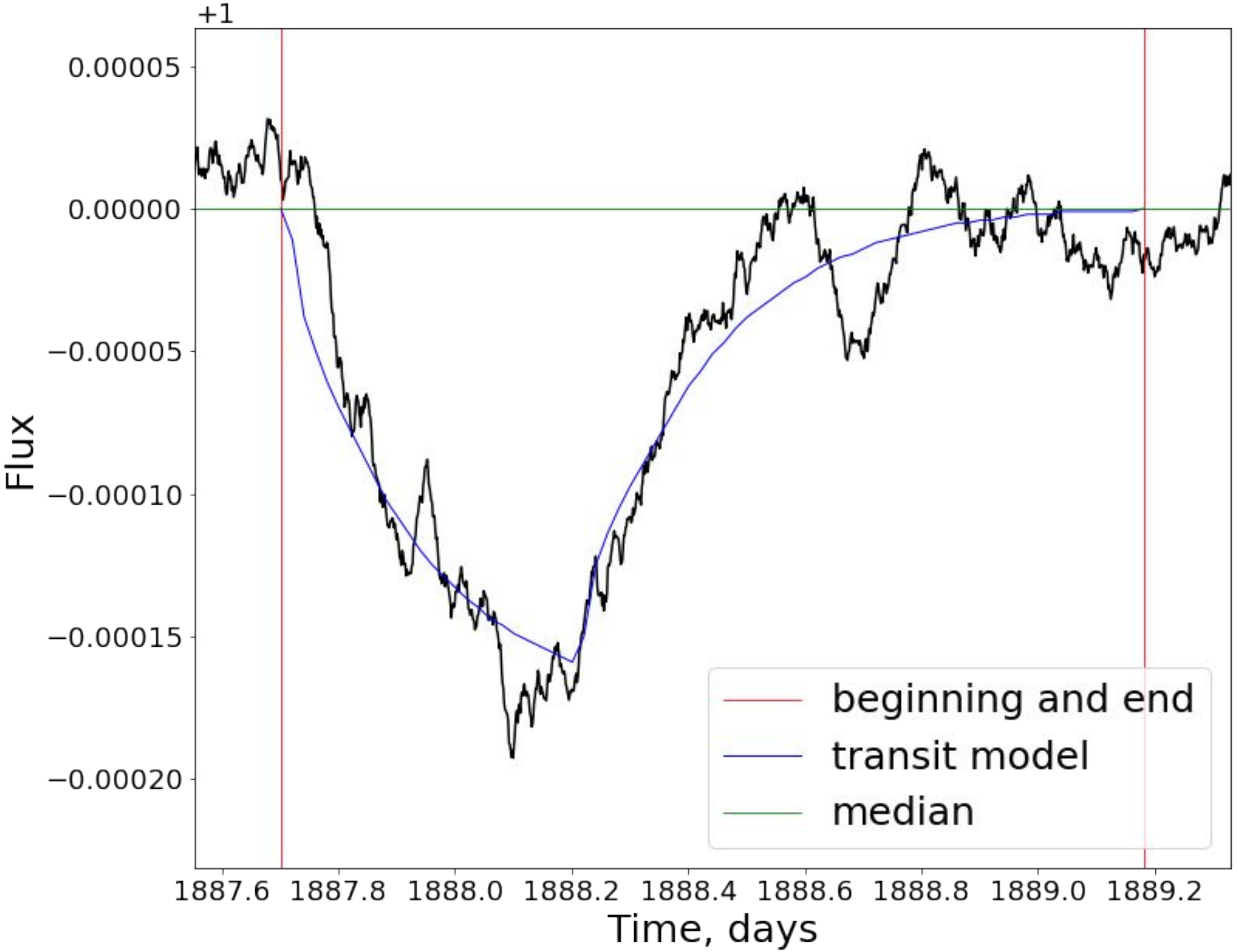


Shapes of exocomet transits as a result of modulation.
Case1: Transit for comet C / 2006 S3 and Sun,
Case2: Reduced time of tail formation compared to Case1,
Case3: Radius twice the size of the Sun compared to Case1.



Dependence of the light curve on the transit parameters
Green: the passage of the comet along the chord,
Red: the central passage (the angle of the central inscribed angle at which the chord is visible from the center)

Encapsulation of synthetic exocomet transits in the light curve.



Green line: median flow value.
Blue line: model of exocomet transit.
Red lines: Beginning and end of transit.
Red line: The resulting flow value

Conclusions

- We developed the code based on the python package “lightkurve v2.0” for processing the light curves.
- We developed the code to simulate a cometary transit based on the modelled dusty tails of comets with different orbital and physical parameters.
- We are creating the samples of comet-like and planet transits for machine learning.
- We found 4 dips in the beta Pictoris light curve analysing new observations of the TESS mission in sectors 32, 33, 34. These transits are shallow, asymmetric, with depths at the level of 0.03% of flux, and duration less than 1 day. New dips are very similar to the transit events recently found in sector 5 and for other two stars KIC3542116 and KIC 11084727 of the Kepler mission.
- This finding gives evidence that such shallow dips are likely not rare phenomenon at least in the beta Pic system.