# Stellar Photometry of Cepheus C using PSF Fitting


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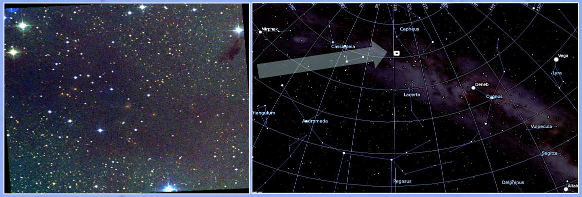
## Abstract

As part of the 2017 NASA/IPAC Teacher Archive Research Program (NITARP), potential young stellar objects (YSOs) were examined in the Cepheus-C star-forming region of the Cepheus OB3 molecular cloud. Aperture photometry was performed on archival Herschel data in order to construct spectral energy distribution diagrams (SEDs). In Evans, et. al (2018), 54 YSO candidates were identified, 11 of which had not been previously identified. As Ceph-C is a crowded field, using aperture photometry is not the best method of determining the flux of close stars. In the current project, PSF-fitting was used to improve the photometry of this crowded region. The Astropy implementations of DAOPhot (Photutils) were used to do PSF-fitted photometry at PACS 70 and PACS 160 wavelengths. This study shows that aperture photometry from the previous years' work was probably sufficient for isolated sources, while PSF-fitted photometry is an improvement for the crowded regions.

**Images A & B: Cepheus C Region**
The target region was ~20 arcminutes on a side, centered on 23h05m51s +62d30m55s. Image (above left): Red: DSS2 IR, Green: DSS2 Optical Red, Blue: DSS2 Optical Blue. Right image from Stellarium.

## Introduction

Continuing a study of the Cepheus C star-forming region begun in prior years,[1] PSF-fitted photometry and aperture photometry were used to improve spectral energy distribution (SED) diagrams. Crowded areas, which included YSO candidates, proved to be the greatest photometric challenge.

Several routines using Python were tried in order to improve upon the previous methods. This lead to an approach incorporating the Photutils package of AstroPy. Comparing the flux values of the YSO candidates using Photutils to the flux values for the same objects from the Herschel Highly Processed Data Products (HPDP) catalog provided a series of reference values so appropriate measures for the standard deviation from the central point under the fitted curve (sigma_PSF) could be determined. Once the best sigma_PSF fit was determined, its value was used in the code resulting in improved photometry across the Ceph-C star field.

## For more about NITARP

*This research is a continuation of research begun through the NASA/IPAC Teacher Archive Research Program (NITARP). Please use the QR code for more general information and how you can become involved with NITARP.*

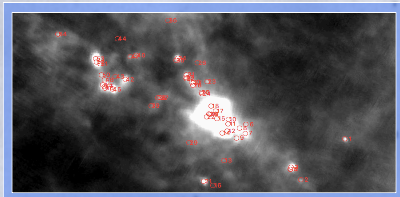
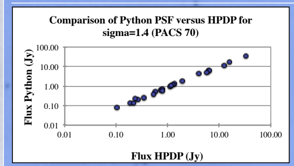
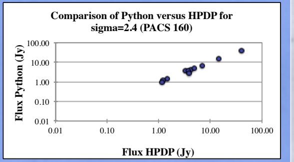


**Image C: Cepheus C (PACS 160) with overlay of sources – note the close proximity of some sources to one another, with others more isolated.**




**Figures D & E: Flux value comparisons of the Python implementation vs the HPDP catalog values of PACS 70 (left) and PACS 160 (right)**

New fluxes measured using PSF-fitting (PACS 70 & PACS 160)

| PACS 70 | | | PACS 160 | | |
|---|---|---|---|---|---|
| Source | Aperture Flux (2018) (Jy) | PSF Flux (Jy) | Source | Aperture Flux (2018) (Jy) | PSF Flux (Jy) |
| 14 | 4.56 | 3.92 | 15 | 33.9 | 27.10 |
| 24 | 0.24 | 0.26 | 18 | 46.8 | 40.54 |
| 31 | 0.69 | 0.37 | 22 | 45.9 | 44.56 |
| 38 | 0.19 | 0.03 | 40 | 1.25 | 1.29 |
| 40 | 0.15 | 0.15 | 41 | 1.72 | 0.88 |
| 52 | 2.55 | 1.21 | 48 | 3.46 | 1.51 |

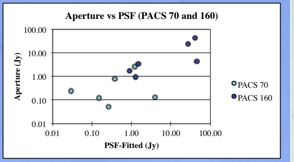
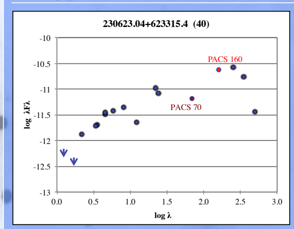
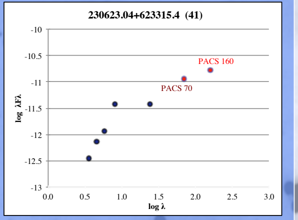
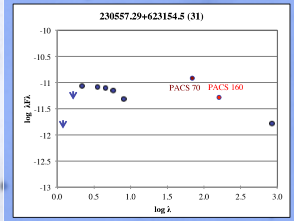
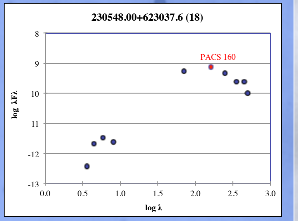



**Table & Figure F: Data of determined values of flux for objects in PACS 70 and PACS 160, also plotted for comparison.**




**Figures G & H (top): Isolated sources #40 (left), and #41 (right).**
**Figures I & J (bottom): Closely spaced sources #31 (left), and #18 (right).**

## Methods

- With various programs available, multiple Python routines were investigated; the best results were achieved using a routine that made use of Astropy Photutils.[2]
- Results were compared to the HPDP[3] photometry (where available); sigma and iteration values were obtained for the region in PACS 70 and PACS 160.
- Computer processing load was reduced by cropping images using *AstroimageJ*.[4]
- Cropped images were fed through a PSF-fitted implementation in a Jupyter[5] notebook to run through the 54 sources.
- Figures D & E to the left show flux plotted from the PSF-fitted values, compared to the values from HPDP data.
- The Table and Figure F to the left show flux plotted from the PSF-fitted values, compared to Aperture values from 2018.

## Data Discussion

PSF-fitted data of both isolated and close objects were examined for agreement with HPDP data. The scatter plots (figures D & E) demonstrate agreement for multiple sources.

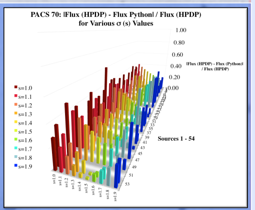



**Figure L: |HPDP − Python| / HPDP showing the "valley" near sigma 1.4.**

- Adjusting the code routine beyond a single iteration did very little to align values to HPDP values.
- The new PACS 70 and PACS 160 points align well with the existing points on the SEDs; improving on the SEDs from the previous year's study.
- Changes in sigma_PSF of ±0.1 produced subtle differences; larger changes resulted in an ever increasing divergence, centered around the chosen values of 1.4 for PACS 70 and 2.4 for PACS 160 (Figure K).
- The new flux values, listed in the Table to the left and plotted in Figure F, produced by this method were added to the SEDs (figures G – J).

## Conclusions

It was expected that the PSF-fitted photometry would improve on previous aperture photometry, especially in crowded regions where aperture photometry was difficult due to closely-packed sources. While it is worth noting that the aperture photometry performed satisfactorily for isolated sources, the PSF-fitting was an improvement in crowded areas.

***Future work should include:***

- Apply PSF routine to additional wavelengths.
- Perform additional work in crowded regions.
- Work to improve Python routines over multiple platforms (Windows, macOS, Linux, etc.).
- Examine PSF-fitting routine further to refine techniques to determine parameters more efficiently.

## References


[1]Evans, et. al., "Identifying Young Stars in Cepheus C," [poster session 231st AAS], 2017
[2]https://photutils.readthedocs.io/en/stable/
[3]https://www.cosmos.esa.int/web/herschel/highly-processed-data-products
[4]https://www.astro.louisville.edu/software/astroimagej/
[5]jupyter.org