Estimating distances to AGB stars using IR data

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Motivation

- The BAaDE project has delivered line of sight velocities to more than 10,000 AGB stars in the Milky Way.

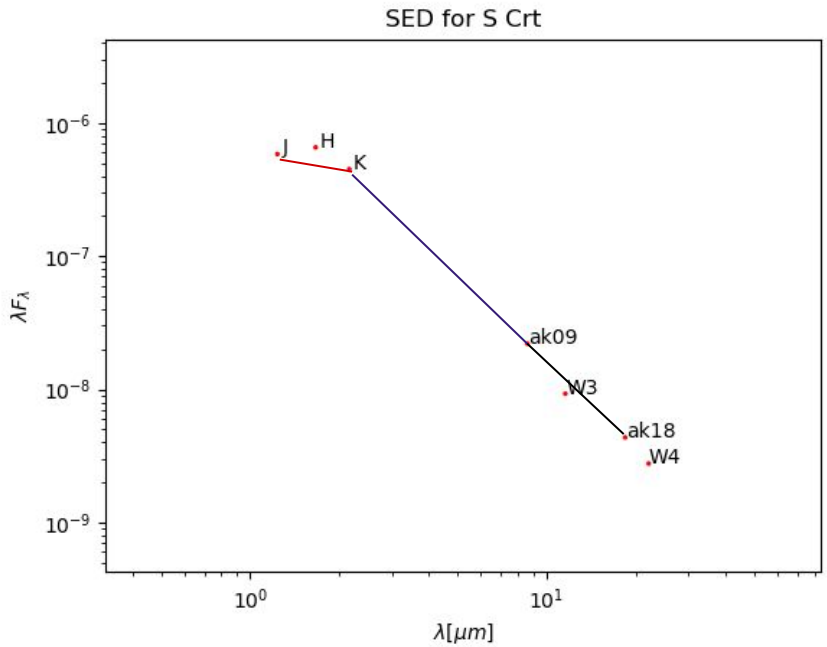
- To incorporate these velocities into dynamical models and to distinguish between different AGB populations, we want to determine the 3D positions and hence distance estimation becomes crucial.

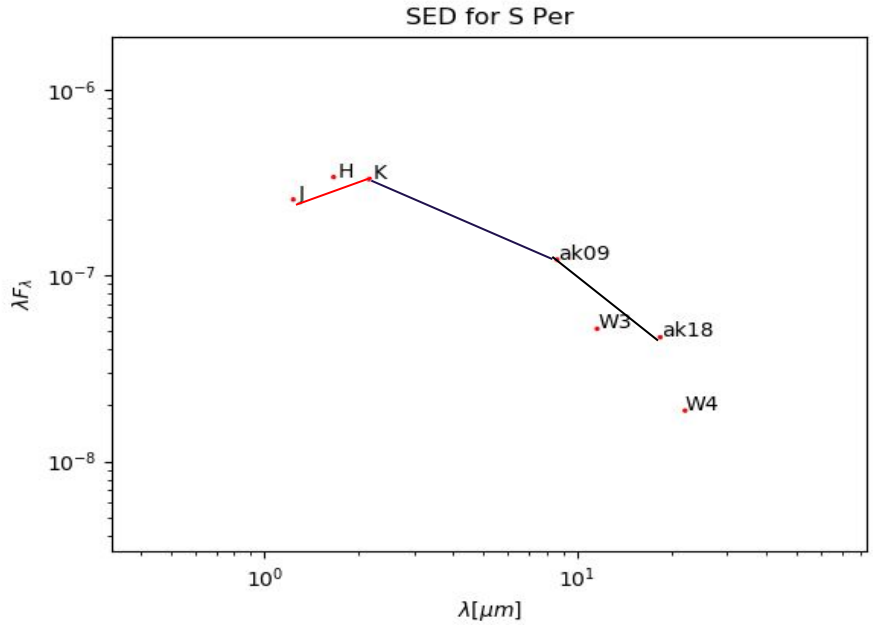
- Distances also enables luminosity and mass-loss rate estimates to be performed.

- Need to establish a method for tens of thousands of AGB stars as the vast majority of these do not have reliable Gaia parallaxes.

Methodology

- Use distance-calibrated infrared (IR) Spectral Energy Distribution (SED) templates to estimate the distances for our sources.
  - Ancillary data accessible from e.g., 2MASS, WISE, AKARI, etc.
- Basic assumption is that stars with intrinsically similar properties produce similar SEDs and are of similar luminosity.
- To compare whether a template and a source has similar properties, we use three different colors: [J]-[K] (2MASS), [A]-[D] (MSX) and [K]-[A].


SED for S Crt
J
H
K
ak09
W3
ak18
W4
10^{-6}
10^{-7}
10^{-8}
10^{-9}
λF_λ
10^0
10^1
$\lambda[\mu m]$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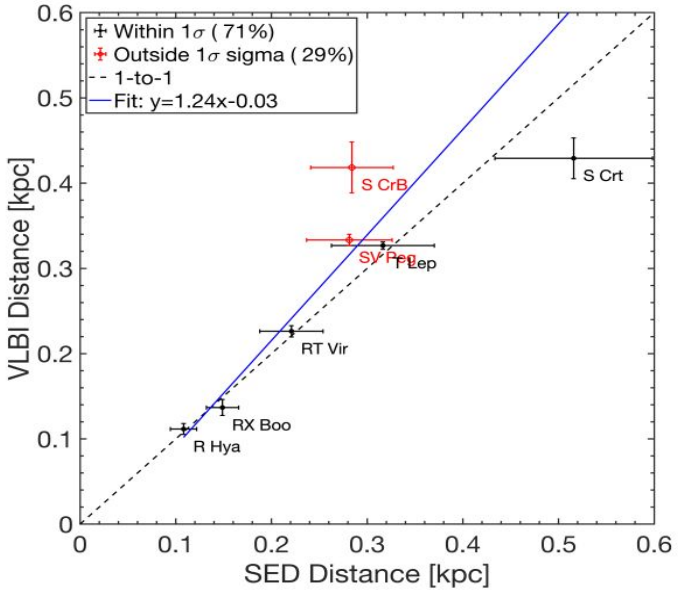
$$d_{\lambda,\mathrm{AGB}} = d_{\mathrm{Template}} \sqrt{\frac{F_{\lambda,\mathrm{Template}}}{a_\lambda \times F_{\lambda,\mathrm{obs,AGB}}} \times 10^{-Z_\lambda A_\mathrm{K}/2.5}}$$

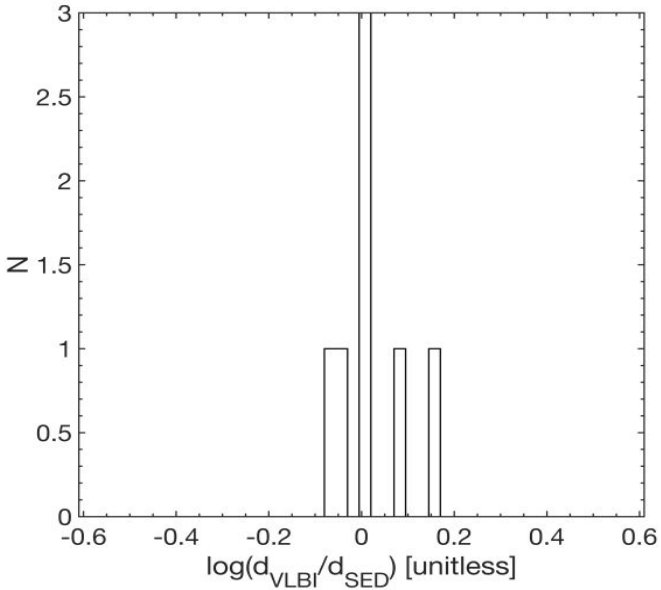
- Simple scaling to template after interstellar extinction correction based on A_K values (Z_λ describes A_K/A_λ)

- Distance estimated at each IR photometry point, and then final estimate is an average of these to reduce variability effects.

Selecting the Templates

- To test the method, we selected those sources as templates which had a known VLBI parallax estimate (Xu et. al. 2019). A single VLBI source was used as a template to calculate distances to other VLBI sources. Good agreement is achieved.

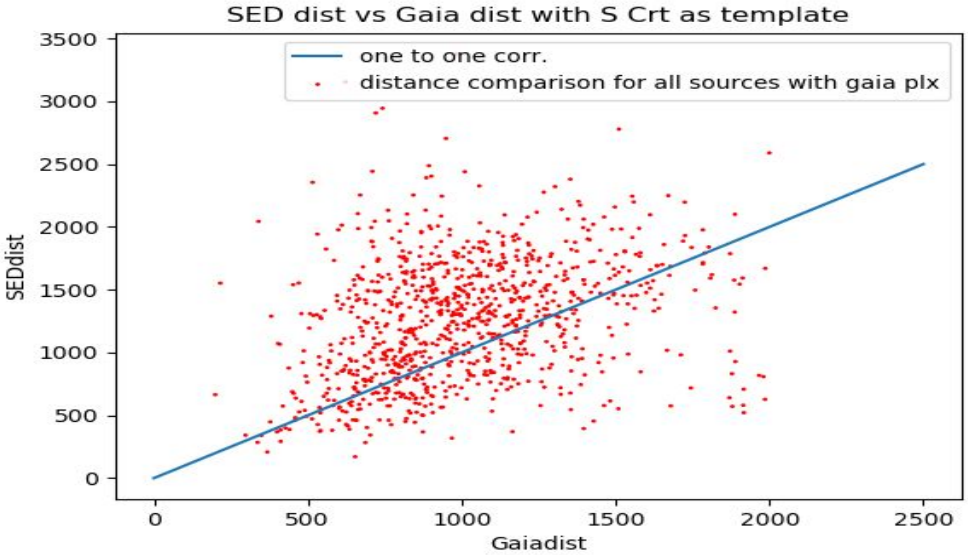




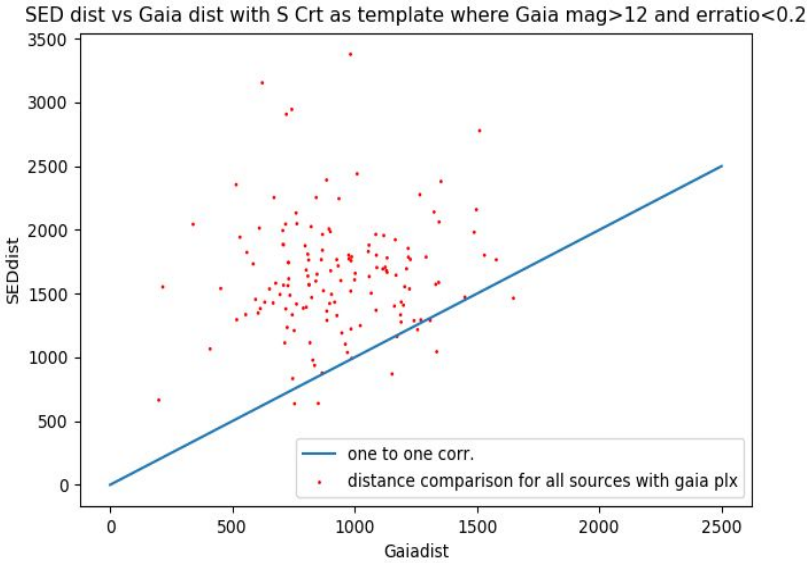
Medina et.al.(2022)

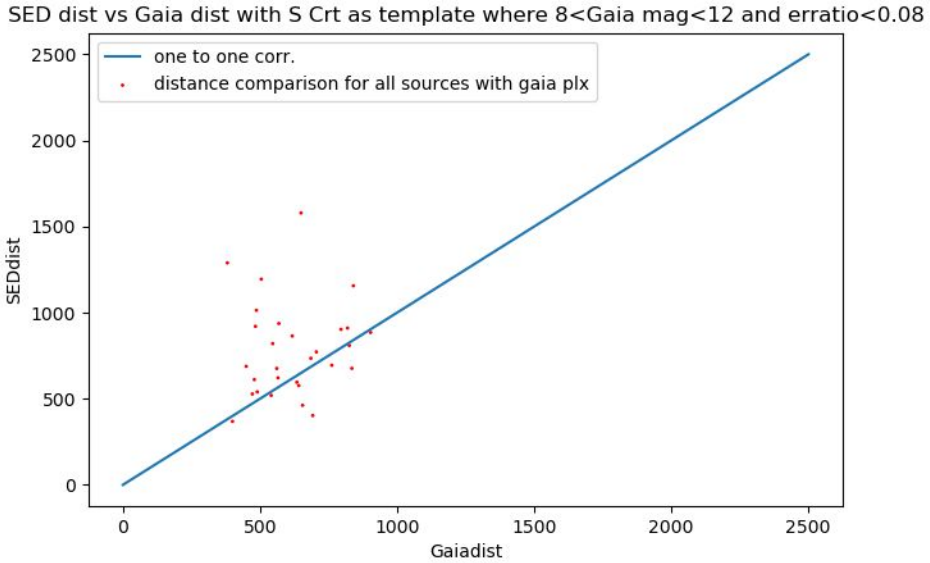
Using templates to estimate distances for BAaDE sources

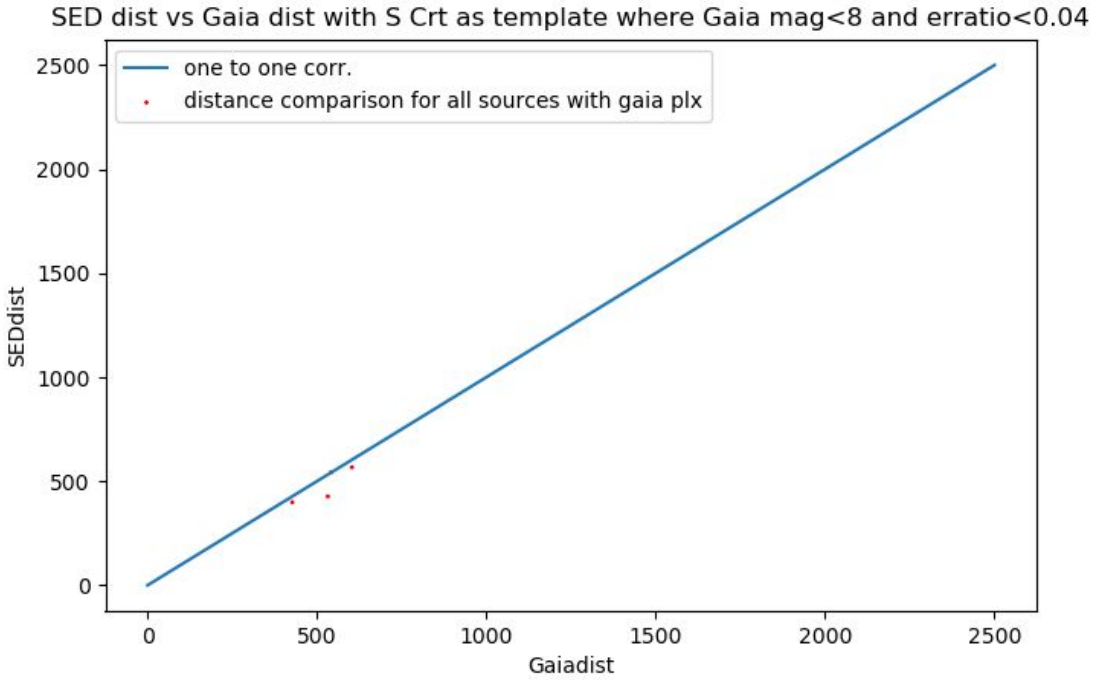
- Results using S Crt template for sources with [J]-[K], [A]-[D] and [K]-[A] color within 0.5 magnitude of template, and comparing to Gaia-based distance estimates



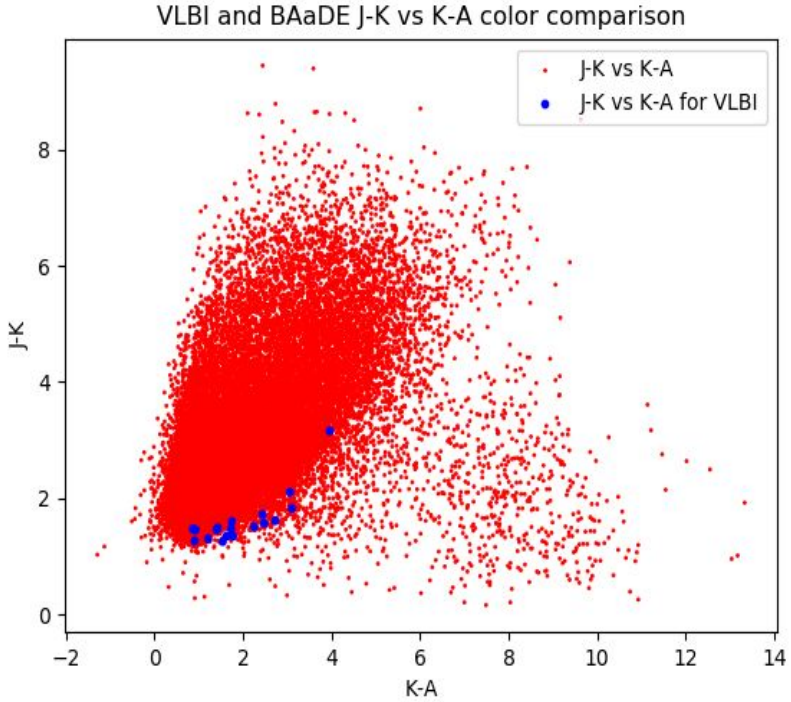
- Andriantsaralaza et al.(2022) points out difficulties for Gaia in providing reliable parallaxes for obscured AGB stars (even if using <20% parallax error).
- Following their work we find a clear distinction between the fainter and brighter sources.

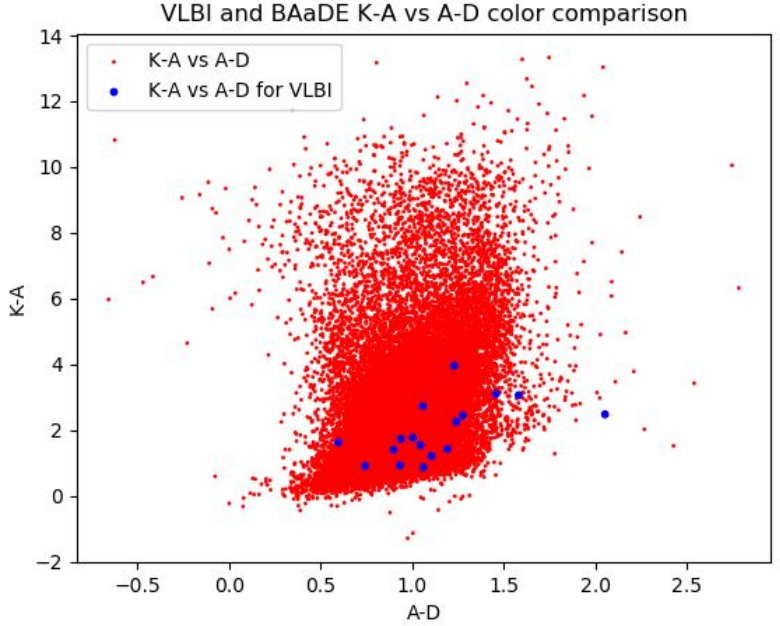





SED dist vs Gaia dist with S Crt as template where Gaia mag<8 and erratio<0.04
one to one corr.
distance comparison for all sources with gaia plx
SEDdist
Gaiadist
0
500
1000
1500
2000
2500

Can we estimate distances to full sample with VLBI templates?





Using Galactic Center sources as template

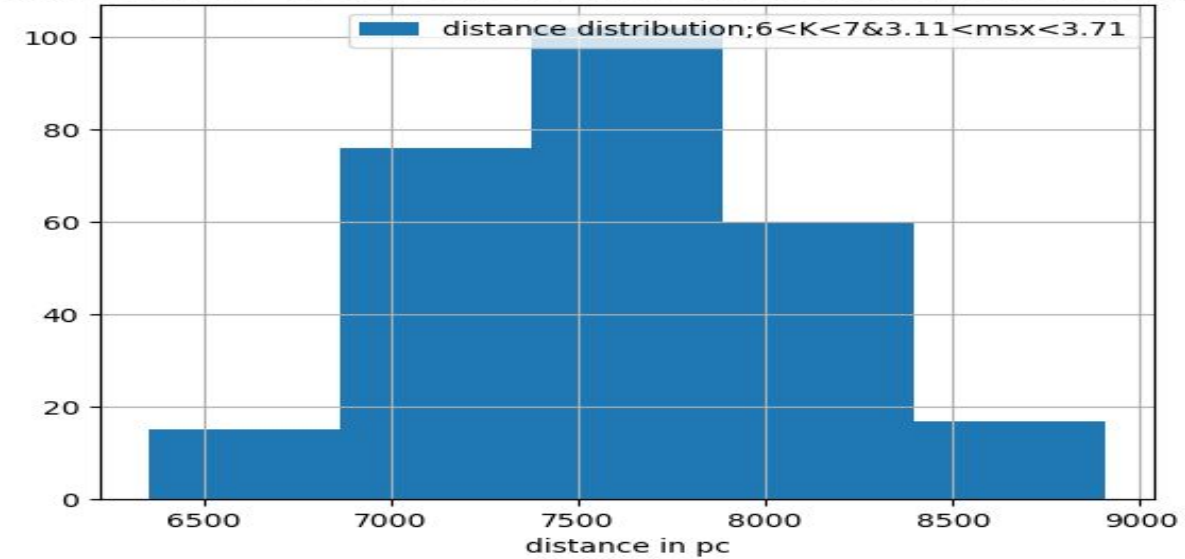
- We defined a set of BAaDE sources likely to be close to the Galactic Center, to expand the template set.

- Selected sources with Galactic latitude and longitude less than 1 degree, and with line-of-sight velocities >100 km/s.

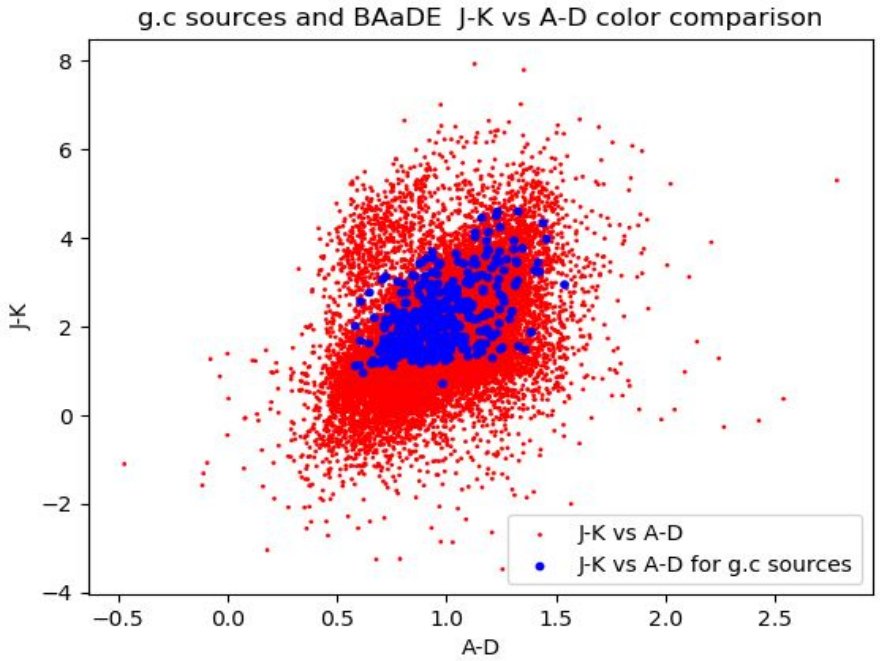
- Assumed these sources are at a distance of 8.178 kpc [GRAVITY collaboration et. al. (2019)].

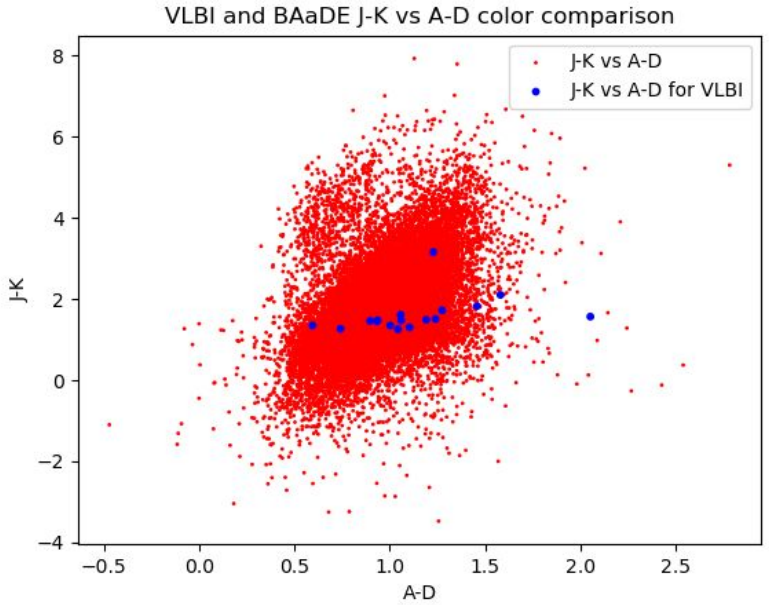
Introducing a magnitude cut

- To get rid of outliers which were either too bright or too faint we introduced a magnitude cut in 2MASS K and MSX A band, resulting in a SED distance distribution for 270 GC sources:



Requirement for more templates of different SED shapes





Conclusions

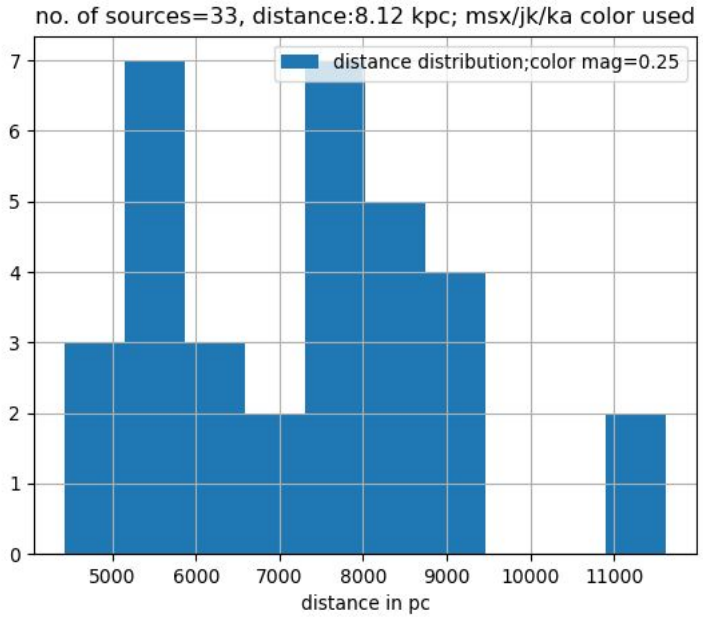
- We used VLBI templates to estimate distances to a subset of BAaDE AGB sources. This worked well when the stars were brighter as indicated by their Gaia magnitude.

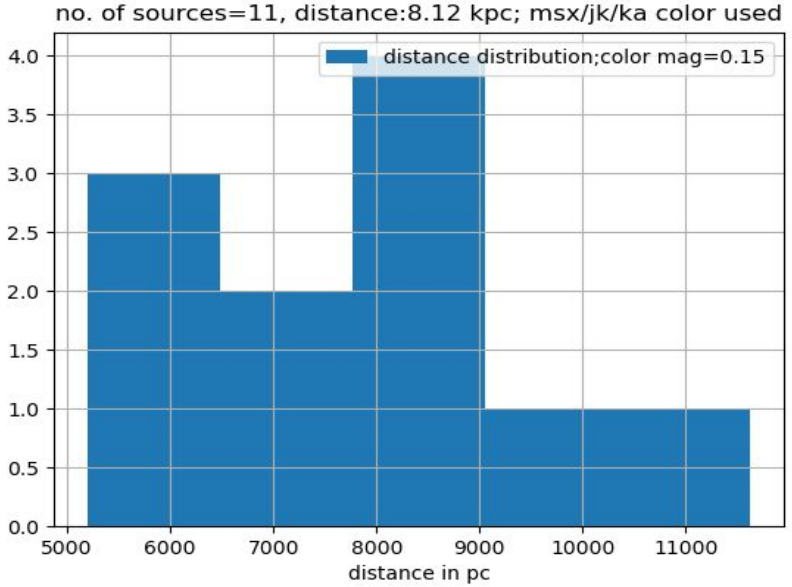
- We estimate distances to a number of sources also without Gaia parallaxes (hence not included in the plots shown).

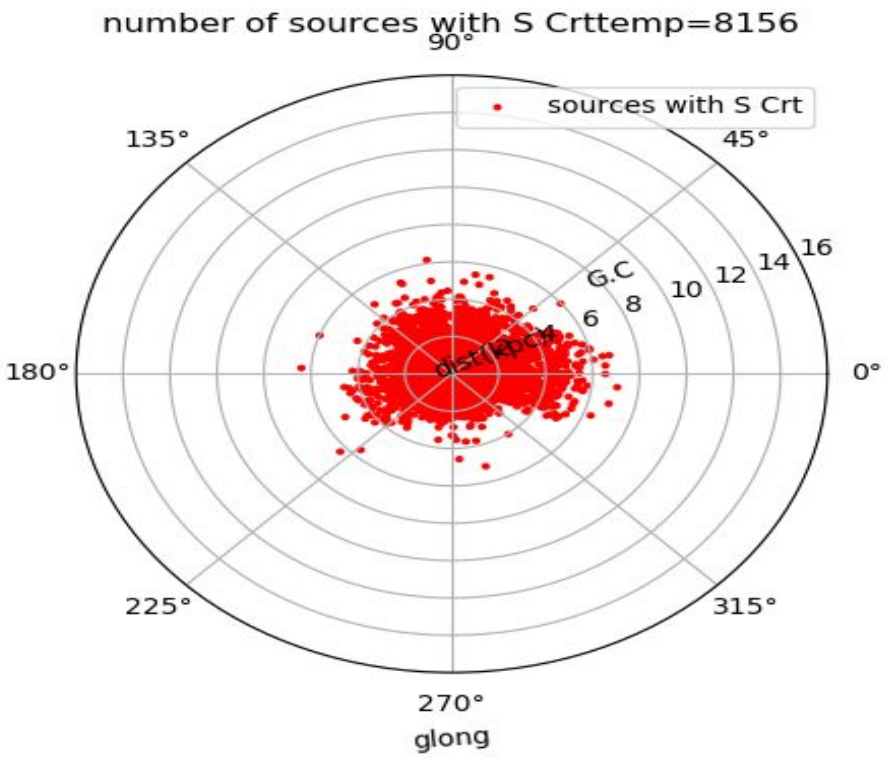
- The GC source templates work well and can cover a significant amount of sources, although not the whole sample.

- We would be needing more templates with different SED shape comparable to our sources, to have distance estimates for the full sample.

While working with galactic center sources we initially followed similar constraints as with VLBI templates. To start with we selected the GC source having median color distribution and applied it on the other GC sources with the following color constraints.






number of sources with S Crttemp=8156
90°
135°
45°
180°
0°
225°
315°
270°
glong
sources with S Crt
G.C
dist(kpc)
6
8
10
12
14
16