A Statistical Approach to Distance Calculations for BAaDE Sources

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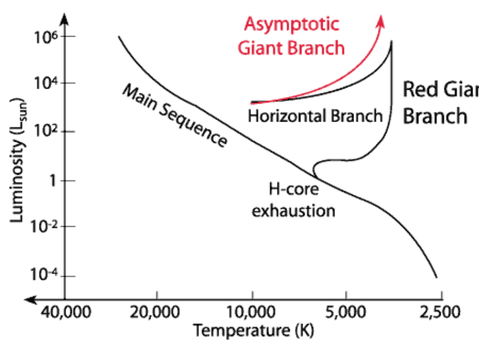
Abstract

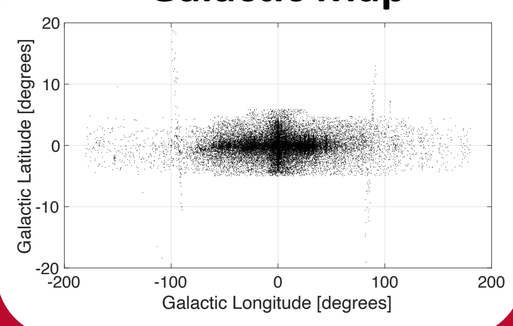
The Bulge Asymmetries and Dynamical Evolution (BAaDE) survey is the largest ever SiO maser survey of 28,062 infrared-selected evolved stars throughout the Galactic plane. We have generated an IR catalogue from 0.79 microns to 70 microns by cross-matching the BAaDE sources with nine different surveys. With this, spectral energy distributions (SEDs) can be formed for our objects. Using this IR catalog and the resulting SEDs, we are attempting to estimate distances to the sources as well as infer properties of the stellar objects and their circumstellar envelopes. The method used to extract these properties is by modeling SEDs of the sources. By generating SED templates, which we can match to sources of known distances, we can subsequently estimate distances to the full set of BAaDE sources. To effectively use this method, an in-depth study of interstellar extinction in the Galactic plane is necessary and we are attempting to map the extinction. Moreover, we will correlate properties of the VLA and ALMA maser data of the BAaDE sources with the IR colors and magnitudes.

Typical Sources

- 28,062 asymptotic giant branch (AGB) stars.
- Sources selected to likely contain SiO masers.
- Variable stars with evolved O-rich circumstellar shells.

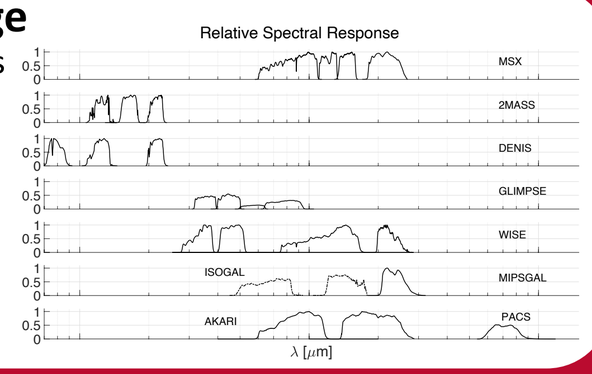


Galactic Map

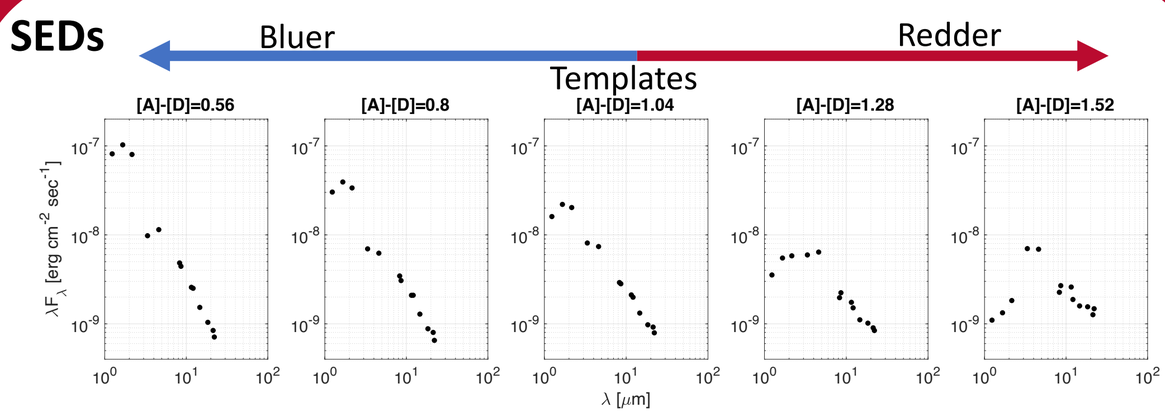


Wavelength Coverage

- BAaDE sources were cross matched with several IR surveys to create a catalogue ranging from 0.79 µm to 70 µm.
- Overlapping bands allow for variability studies.



SEDs



- Sources can be sorted into different 8.28µm – 14.68µm ([A]-[D]) color categories.
- [A]-[D] color gives insight about CSE properties.
- Average SEDs can be created for color categories by first normalizing each sources SED by the average 8.28µm magnitude.
- The SED shape is affected by both the CSE and interstellar extinction.

Distance Calculations and Errors

- Our large sample size allows for a statistical approach to distance calculations.

<u>Methodology</u>

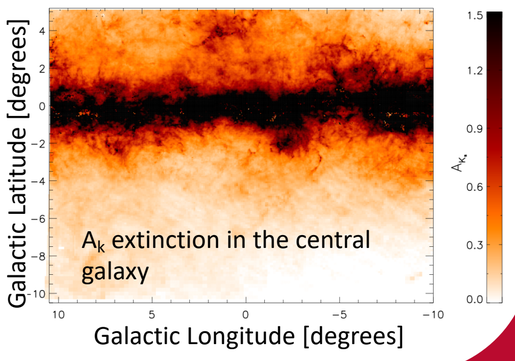
- Create template SEDs for each [A]-[D] color.
- Calibrate the template to a distance by using sources of known distances.
- Use the calibrated SED templates to estimate distances for our sources by scaling individual SEDs.

<u>Templates</u>

- Template SEDs are created using sources above 4 degrees latitude, where the extinction is minimal.
- These templates are plotted in the previous section.

<u>Major Source of Error</u>

- SEDs need to be corrected for interstellar extinction, which is prominent and highly variable in the bulge.



Extinction Corrections

<u>Challenge</u>

- Extinction maps do not exist for the full galactic plane.

<u>Methodology</u>

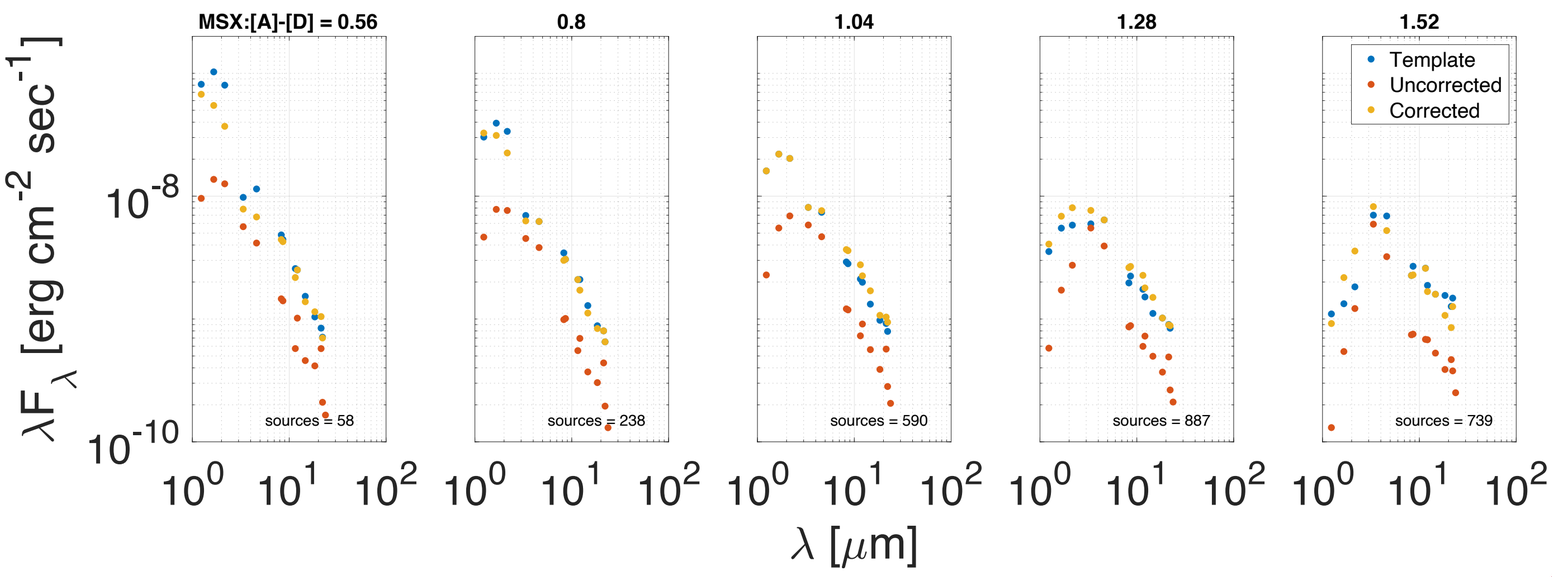
- Calculate average SEDs for a region of interest.
  => λF_λ = SEDs in region of interest
- Compare to extinction-free template SEDs
  => $\lambda F_{\lambda,0}$ = Template SEDs
- Calculate extinction
  => $A_\lambda = -2.5\log(F_\lambda / F_{\lambda,0})$

<u>Example</u>

- $-1 \le$ Lat. [°] ≤ 1
- $-5 \le$ Long. [°] ≤ 5
- N sources = 2,512

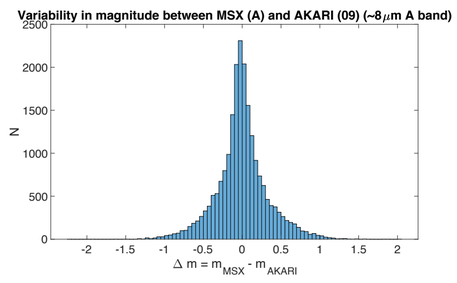
<u>Takeaways</u>

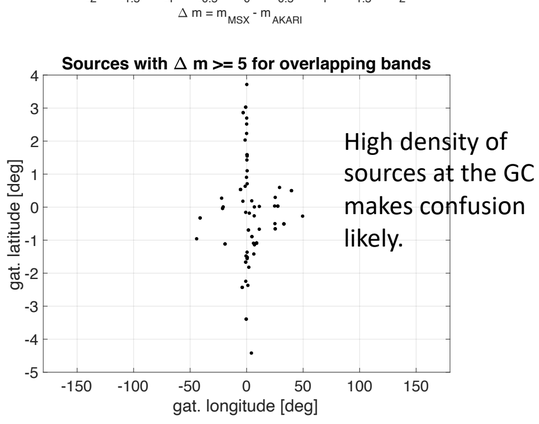
- The uncorrected SEDs have smaller values than the templates due to extinction.
- The corrected SEDs match the templates much better but not perfectly because corrections use average A_λ values found across [A]-[D] colors.



Variability

- Overlapping bands allow typical variability to be estimated.
- We can study the variability dependence on wavelength.
- Variability plots can reveal problematic bands, false cross matches, or sources with possible confusion.
  - We wouldn't expect variability to be larger than 5 magnitudes.

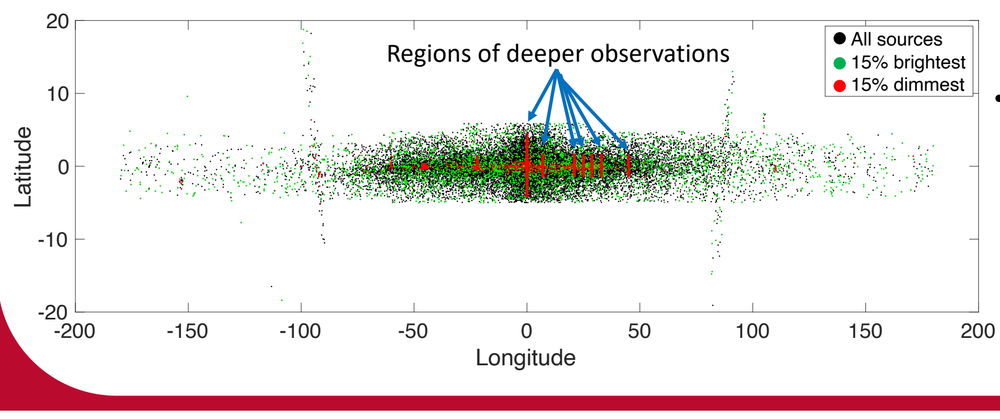




High density of sources at the GC makes confusion likely.

Foreground and Background Sources

- Self-consistency between extinction estimates, distance estimates, source magnitude, and galactic location will be applied.
- For example, a source with very high extinction is most likely in the bulge and is likely to be weaker than an unobscured nearby source.



- The dimmest sources are where extinction is highest and in deeper integration regions.

Future Work

<u>Extinction Calculations</u>

- Create extinction map for the full domain.
- Compare estimated extinction values with previous values, e.g. published extinction maps.
- Correct all sources and get final SEDs.

<u>Distance Calculations</u>

- Gather any known distances to our sources.
- Calibrate SED templates.
- Apply calibrated templates to full source list to estimate distances.

<u>Variability</u>

- Analyze the sources that have unphysical variability to determine if the high variability is due to source confusion, error in cross matched source, or some other error.

<u>DUSTY Modeling</u>

- Ivezic, Nenkova & Elitzur, 1999
- Radiative transfer modeling program to model SEDs
- Extract properties
  Effective source temperature, CSE boundary temperature, CSE thickness, opacity