Distance determination using the TRGB method

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1 Introduction

The accurate determination of extragalactic distances is fundamental to understanding galaxy formation and cosmology. One of the most reliable standard candle techniques for nearby galaxies is the Tip of the Red Giant Branch (TRGB) method, which exploits the sharp cutoff in the luminosity function of red giant stars at the onset of core helium burning. In this work, we present the photometric analysis pipeline developed to study resolved stellar populations in the Draco dwarf spheroidal galaxy using observations obtained with the GROWTH–India Telescope.

This study focuses on constructing a calibrated color–magnitude diagram (CMD) from multi-band imaging data and preparing the dataset for subsequent TRGB distance determination.

2 Observational Data

The dataset consists of twelve reduced and astrometrically calibrated FITS images of the Draco dwarf galaxy, observed in two photometric filters:

- Six images in the G-band
- Six images in the I-band

Each image is provided with World Coordinate System (WCS) information and standard FITS headers containing instrumental metadata such as exposure time, filter, and pointing coordinates.

3 Photometric Methodology

3.1 Source Detection and Initial Extraction

Source detection was performed on each image using SExtractor bertin1996sextractor. For each image, a source catalog was generated using a custom configuration optimized for point-source detection in crowded stellar fields. Sources were filtered using the following criteria:

- FLAGS = 0 (no extraction warnings)
- Image position cuts to avoid edge artifacts
- Reasonable FWHM range to reject non-stellar objects

This produced a set of clean stellar detections for each frame.

3.2 PSF Modeling and PSF Photometry

To achieve accurate photometry in crowded fields, we employed PSF photometry using PSFEx bertin2011psfex. For each image:

- A spatially varying PSF model was constructed from isolated stars
- PSF-fitting magnitudes (`MAG_POINTSOURCE`) were obtained using SExtractor in PSF mode

This ensured uniform and robust magnitude measurements across the field.

3.3 Astrometric Cross-Matching with External Catalogs

For photometric calibration, stars detected in each image were cross-matched with the Pan-STARRS1 (PS1) catalog chambers2016panstarrs using astrometric coordinates derived from WCS. Only well-measured PS1 stars were retained based on:

- Photometric uncertainty cuts
- Multiple detection requirements

A matching radius of 0.4 arcseconds was adopted to ensure high-confidence associations.

3.4 Photometric Zeropoint Calibration

Photometric zeropoints were derived separately for each image using matched PS1 stars. For each frame, the zeropoint was computed as:

$$ZP = m_{PS1} - m_{inst}$$

where m_{inst} is the PSF instrumental magnitude and m_{PS1} is the catalog magnitude.

Sigma-clipped statistics were used to compute:

- Zeropoint median
- Zeropoint uncertainty

These zeropoints were then applied to calibrate all stellar magnitudes:

$$m_{cal} = m_{inst} + ZP$$

with errors propagated as:

$$\sigma_{cal} = \sqrt{\sigma_{inst}^2 + \sigma_{ZP}^2}$$

3.5 Pooling and De-duplication of Multi-Epoch Detections

Since multiple observations were taken in each filter, detections were pooled across images. To avoid multiple measurements of the same physical star, spatial de-duplication was performed by:

- Grouping stars within 0.5 arcseconds
- Retaining the measurement with the lowest photometric uncertainty

This resulted in two clean catalogs:

- Unique G-band stellar catalog
- Unique I-band stellar catalog

3.6 Cross-Matching Between Filters

The unique G- and I-band catalogs were cross-matched using nearest-neighbor sky matching with a 0.5 arcsecond tolerance, producing a final catalog of stars with both G and I magnitudes.

For each matched star, we computed:

$$(G - I) = m_G - m_I$$

with associated uncertainties propagated accordingly.

4 Construction of the Color–Magnitude Diagram

Using the matched and calibrated stellar catalog, a Color–Magnitude Diagram (CMD) was constructed with:

- Vertical axis: I-band magnitude
- Horizontal axis: $(G - I)$ color

The CMD reveals the expected stellar populations of the Draco dwarf galaxy, including:

- A prominent Red Giant Branch (RGB)
- Sparse foreground and background contamination

This CMD serves as the foundation for subsequent TRGB analysis.

5 Current Status and Future Work

At this stage, the photometric pipeline successfully delivers:

- Calibrated PSF photometry in G and I bands
- A scientifically reliable CMD

Work is ongoing to implement the TRGB detection using luminosity function edge-detection techniques, including:

- Cumulative luminosity function construction
- Savitzky–Golay smoothing
- Second-derivative peak detection

These results will be incorporated in a subsequent version of this report.

6 Conclusion

We have developed and validated a complete photometric reduction and calibration pipeline for resolved stellar photometry in the Draco dwarf galaxy using GROWTH–India Telescope data. The resulting CMD provides a robust basis for TRGB distance determination and further stellar population analysis.

7 References

References

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