Astrometric and photometric standard candidates for the 4-m ILMT survey

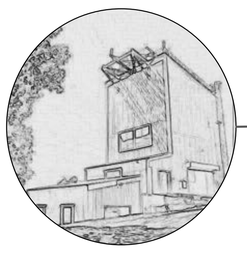
Naveen Dukiya[1,2], Bhavya Ailawadhi[1,3], Talat Akhunov[4, 5], Ermanno Borra[6], Monalisa Dubey[1,2], Jiuyang Fu[7], Baldeep Grewal[7], Paul Hickson[7], Brajesh Kumar[1], Kuntal Misra[1], Vibhore Negi[1,3], Kumar Pranshu[1, 8], Ethen Sun[7], Jean Surdej[9]

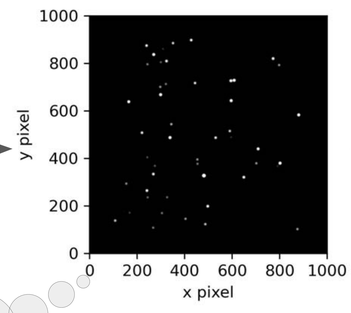
[1]Aryabhatta Research Institute of Observational sciencES, Nainital, India
[2]Mahatma Jyotiba Phule Rohilkhand University, Bareilly, India
[3]Deen Dayal Upadhyay Gorakhpur University, Gorakhpur, India
[4]National University of Uzbekistan, Tashkent, Uzbekistan
[5]Ulugh Beg Astronomical Institute, Tashkent, Uzbekistan
[6]Laval University, Quebec, Canada
[7]University of British Columbia, Vancouver, Canada
[8]University of Calcutta, Kolkata, India
[9]Liège University, Belgium

Abstract

The International Liquid Mirror Telescope (ILMT) is a 4-m class survey telescope that has recently achieved first light and is expected to swing into full operation very soon. It scans the sky in a fixed 22′ wide strip centered at the declination of 29°21′41″ and works in Time Delay Integration (TDI) mode. We present a full catalog of sources in the ILMT strip that can serve as astrometric calibrators. The characteristics of the sources for astrometric calibration are extracted from Gaia EDR3 as it provides an exact measurement of astrometric properties such as RA (α), Dec (δ), parallax (π), and proper motions ($\mu_{\alpha*}$ & μ_δ). We have crossmatched the Gaia EDR3 with SDSS DR17 and PanSTARRS-1 (PS1) and supplemented the catalog with apparent magnitudes of these sources in g, r, and i filters. We also present a catalog of spectroscopically confirmed white dwarfs with Sloan Digital Sky Survey (SDSS) magnitudes that may serve as photometric calibrators. The catalogs generated are stored in an SQLite database for query-based access.

Motivation





x-y positions of all the sources

How do we go from pixel coordinates of stars (and peculiar events) to their celestial coordinates (RA and Dec)?

Perform Astrometry i.e. find a relation between the x-y coordinates and RA-Dec.

Pixel Coordinates ↔ Celestial Coordinates

A catalog of select astronomical sources whose celestial coordinates are knows very precisely.

Generating this catalog of sources is the focus of this work. We would like the sources to have the following properties -

1. The position of these sources should be known very precisely.
2. These sources should be stationary in the sky, i.e. very low parallax and proper motions.
3. These sources should not be spurious and transient events. We use crossmatching between different catalogs to get rid of these spurious sources.
4. These sources should be between the bright and faint limits of ILMT.

Data Used

ESA *Gaia* provides unparalleled astrometric precision. We select sources lying inside the ILMT Field-of-View (FoV) and having low parallax (≤ 10 mas) and low proper-motions (≤ 20 mas/yr).

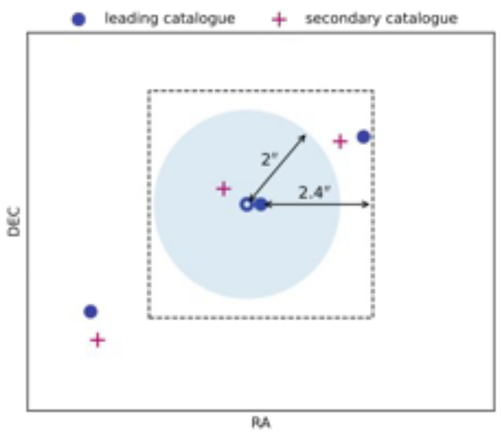
crossmatch — crossmatch

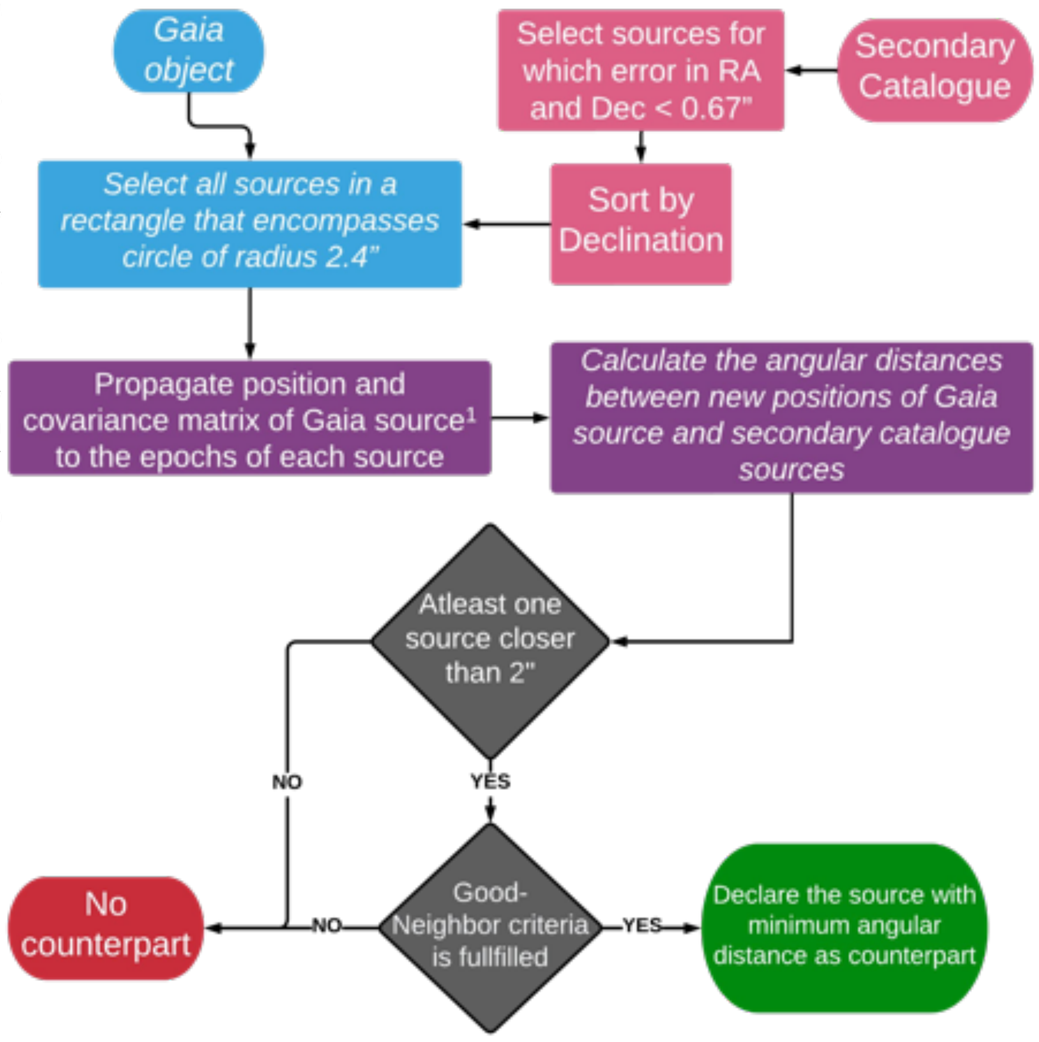
SDSS provides deep u, g, r, i, z photometry and also has spectroscopic observation for many sources.

Panstarrs-1 (PS1) provides g, r, i, z, y photometry of complete sky north of -30 declination.

Crossmatching Procedure

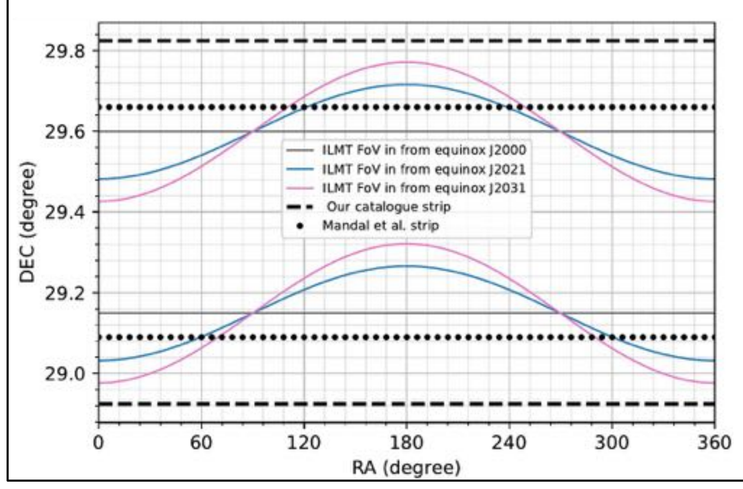
- In the crossmatching procedure, we search for a counterpart of each *Gaia* source inside the secondary catalogs which are photometrically deeper.
- In addition to the positions, we use proper motions provided by *Gaia* to propagate the positions to the epoch when the counterpart was observed and then calculate the angular distances and the Good-neighbour criteria.
- For each Gaia source we consider counterparts only within 2'' .
- We employ the Good-neighbour criteria given by Pineau et al. (2011) which quantifies the likeliness of a crossmatch being genuine based on the angular separation and errors in the positions.
- The diagram below shows a possible scenario that may arise. The dashed rectangular region shows the first cut in the RA-Dec space. The 2" circle is calculated after correcting for proper motions.
- This procedure is performed on ~5.4 million sources to find a counterpart for each of them.





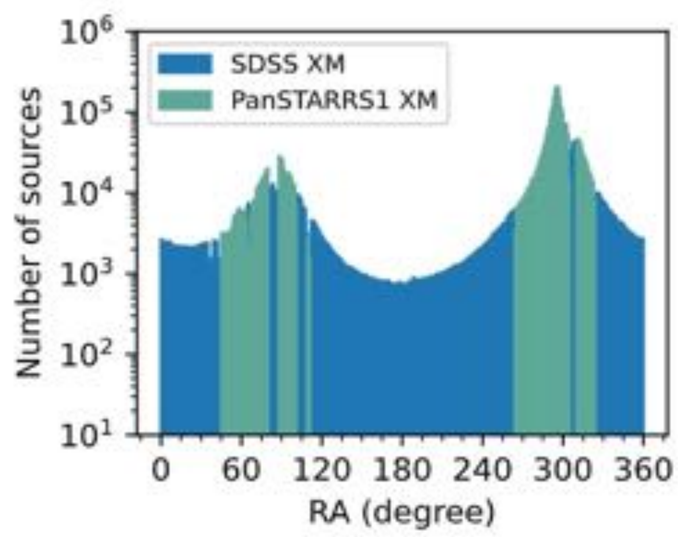
Precession of ILMT Strip

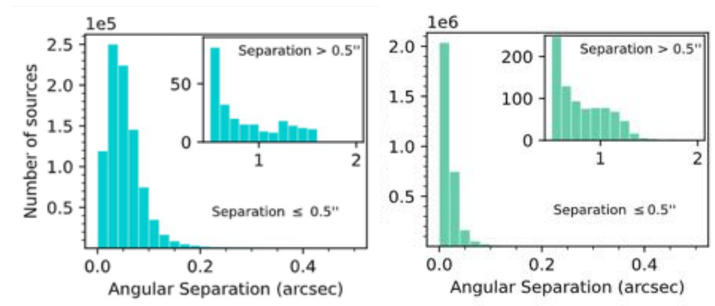
From J2000 to J2031, due to the precession of earth, the area observed by ILMT will change as shown in the figure below. So to make sure we have calibration sources at these later epochs, we have chosen to include all the calibration sources inside a strip of sky 54' wide centered at the ILMT FoV.

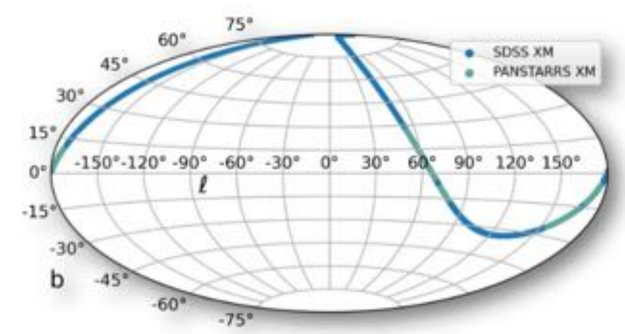


Crossmatching Results

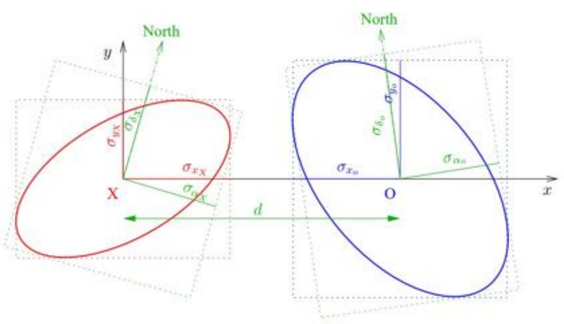
We have found crossmatches 3.93 million *Gaia* sources in SDSS and PS1. 3.56 million of these sources have i magnitude between 16.5 and 22 mag. Plots containing RA distribution of these sources, distribution of angular distances to the counterpart, and distribution of these sources in galactic coordinates are shown below.







Good Neighbour Criteria



The errors in the celestial coordinates can be represented as 2D gaussians. The variance-covariance matrix would be of the form -

$$V_0 = \begin{pmatrix} \sigma_\alpha^2 & \rho_{\alpha\delta}\sigma_\alpha\sigma_\delta \\ \rho_{\alpha\delta}\sigma_\alpha\sigma_\delta & \sigma_\delta^2. \end{pmatrix}$$

But these are aligned towards the north pole (green coordinates). We rotate the variance-covariance matrices of both the sources to lie in the common tangent plane (Red and Blue coordinates).

$$V_t = \begin{pmatrix} \sigma_x^2 & \rho\sigma_x\sigma_y \\ \rho\sigma_x\sigma_y & \sigma_y^2 \end{pmatrix}$$

$$= R(\Omega)^T \begin{pmatrix} \sigma_\alpha^2 & \rho_{\alpha\delta}\sigma_\alpha\sigma_\delta \\ \rho_{\alpha\delta}\sigma_\alpha\sigma_\delta & \sigma_\delta^2 \end{pmatrix} R(\Omega)$$

The convolved matrix of both sources will be a simple addition of individual matrices (assuming the errors on each source are independent).

$$V_c = \begin{pmatrix} \sigma_{x_c}^2 & \rho\sigma_{x_c}\sigma_{y_c} \\ \rho\sigma_{x_c}\sigma_{y_c} & \sigma_{y_c}^2 \end{pmatrix} = V_{t_1} + V_{t_2}$$

Now we can say with probability γ that a catalog 2 object is not a potential counterpart if -

$$\frac{d}{\sigma_{x_c}\sqrt{(1-\rho_c^2)}} > k_\gamma.$$

For γ = 99.7% , k_γ = 3.493. We reject all the counterparts having k_γ higher than that.

Summary

- We have generated a catalogue of objects from *Gaia* that will be used to perform astrometric calibrations of images observed with the ILMT survey.
- This catalogue lists the precise source astrometry from Gaia and photometry in g', r', i' filters from SDSS and PS1. This has been achieved by crossmatching Gaia data with these two catalogues.
- The final catalogue contains ~3.5 million sources with parallax ≤ 10 mas and proper motion ≤ 20 mas/yr.
- The data is stored in SQLite databases for easy query based access.
- This catalogue will be infused in the ILMT data handling pipeline.
- Additionally, we have identified 345 spectroscopically confirmed white dwarfs from this dataset that can serve as photometric calibrators.
- A catalog of non-variable objects from this dataset can be formed during the runtime of ILMT and which can serve as a more complete set of photometric calibrators.
- We have also applied this crossmatching algorithm to crossmatch *Gaia* and Miliquas catalog within our region of interest to identify all the quasars in the ILMT field.

Acknowledgement

The 4m International Liquid Mirror Telescope (ILMT) project results from a collaboration between Aryabhatta Research Institute of Observational Sciences (ARIES, India), the Institute of Astrophysics and Geophysics (University of Liège, Belgium), the Universities of British Columbia, Laval, Montreal, Toronto, Victoria and York University. The authors also thank Hitesh Kumar, Himanshu Rawat and Khushal Singh for their assistance at the 4m ILMT.

References

- Abdurro'uf et al., 2022, ApJS 259, 35
- Gaia Collaboration et al., 2021, A&A 649
- Kumar, B. et al., 2022, JAA 43, 10
- Lindegren et al., 2021, A&A 649, A2
- Marrese, P. M. et al., 2019 A&A 621, A144
- Pineau, F. X., et al., 2011, A&A 527, A126.
- Surdej, J. et al., 2018, Bulletin de la Societe Royale des Sciences de Liege 87, 68