



A study of 19th-Century Stellar Catalogues for the improvement of modern astrometric data

F. Di Giacomo, S. Zaggia, V. Zanini
INAF - Istituto Nazionale di Astrofisica

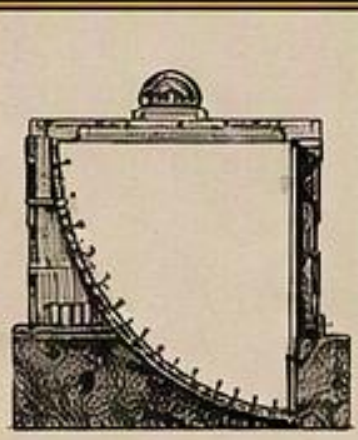
* Hipparchus *
— II century BCE —

**PRECISION
60 ARCMIN**



* Ulugh Beg *
— 1437 —

**PRECISION
30 ARCMIN**



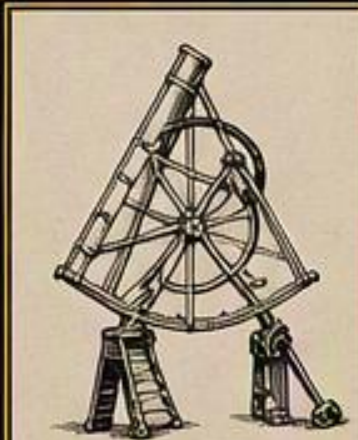
* Tycho Brahe *
— 1598 (1627) —

**PRECISION
1 ARCMIN**



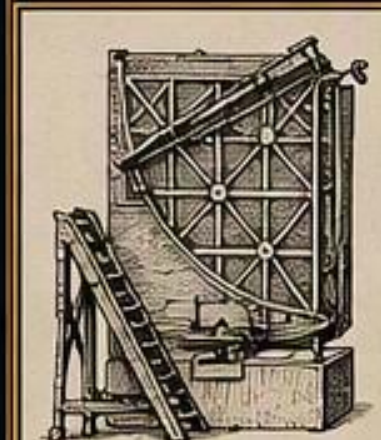
* John Flamsteed *
— 1725 —

**PRECISION
5 ARCSEC**



* Jérôme Lalande *
— 1801 —

**PRECISION
2 ARCSEC**



* Giuseppe Piazzi *
— 1814 —

**PRECISION
? ARCSEC**



INTRODUCTION

- Astrometry measures stellar positions, parallaxes, and proper motions, serving as the primary tool to determine the true scale and dimensions of the Cosmos.
- Missions like Hipparcos and Gaia have revolutionized modern astrometry, but severe detector saturation for bright stars ($G < 5$) strongly limits Gaia's precision for these sources.
- 19th-century catalogues (e.g., Piazzi, Santini) represent a goldmine of data capable of complementing modern datasets by extending the time baseline to over 150 years.

PIAZZI'S CATALOGUE

Between 1792 and 1813, Piazzzi compiled a stellar catalogue of 7,646 stars (second edition) to overcome the astrometric uncertainties of previous works (e.g., Maskelyne 1790).

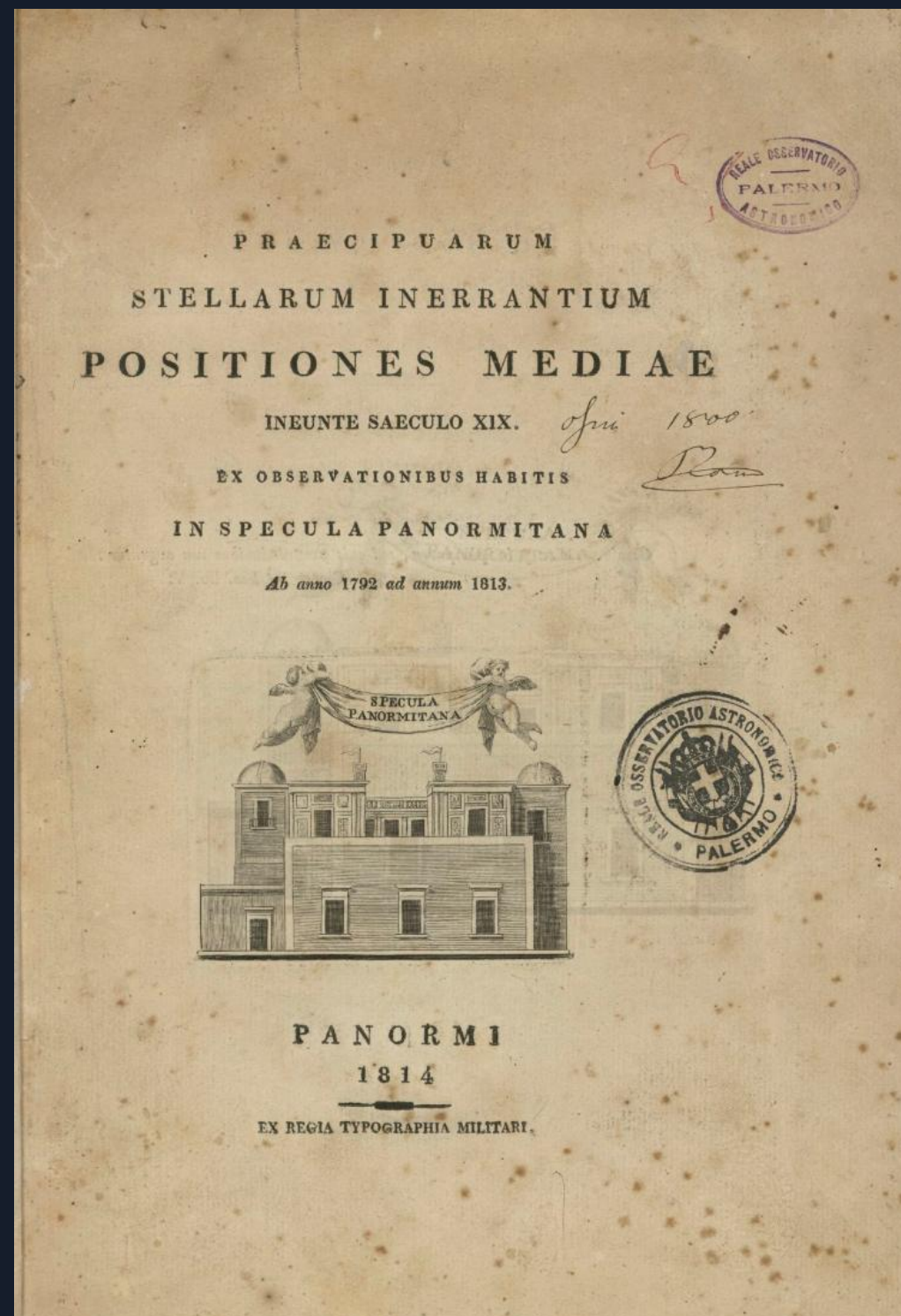
“Therefore, I resolved [...] to confirm all the observations with new ones, and to examine more carefully the other elements upon which the calculations are based: in short, time permitting, to amend, rework, and reform the entire work.”



G. Piazzzi (1814), Praecipuarum stellarum inerrantium positiones mediae ineunte saeculo 19. ex observationibus habitis in specula Panormitana ab anno 1792 ad annum 1813, Panormi

THE PIAZZI STELLAR CATALOGUE

- **Editions:** 1803 containing mean positions of 6,748 stars and 1814 containing 7,646
- **Epoch: 1800.0.**
- **Coverage:** Declination range from -46.3° to 88.7° .
- **Magnitude:** Includes faint stars down to the 12th magnitude.
- **Observations:** Each star observed multiple times, from a minimum of 4 to a maximum of 12 times on different nights to minimize errors.
- Became the standard international reference catalogue for 19th-century astronomers and observatories (used by Gauss, Bessel, and Herschel).



STELLARUM			ASCENSIO RECTA				DECLINATIO				
NUMERUS OBSERVAT.	NOMINA ET MAGNITUDES.	PROXI- ME IN TEMPO- RE.	IN ARCU.	ANNUA PRECES- SIO IN ARCU.	MOTUS PROPRIUS ANNUUS IN ARCU.	NUMERUS OBSERVAT.	ANNUA PRECES- SIO IN ARCU.	MOTUS PROPRIUS ANNUUS.	NUMERUS OBSERVAT.		
		H. M.	G. M. S. 10	S. 100	S. 100		G. M. S. 10	S. 100		S. 100	
271	Pegasi . . . 8.9	22. 50	342.25.32.4	45.37		9	6.17.24.8 B	19.13		9	
272	Aquar. 943 May. 7.8	50	.. 28.11.1	47.10	-0.05.M.	25	9.56.51.8 A	19.14	-0.07.M.	21	
273	Pegasi . . . 8.9	50	.. 30. 9.6	45.37		7	6.18.54.0 B	19.14		7	
274	β Piscium . . . 6	50	.. 35.37.0	46.13		10	0.53. 2.8 A	19.15		10	
275	Piscium . . . 7	51	.. 37.48.6	45.84		6	1.56.49.0 B	19.15		11	
276	Andromedæ . 7.8	51	.. 38.19.5	38.58		4	51.14. 2.3 B	19.15		6	
277	Aquarii . . . 7	51	.. 38.54.0	48.69		2	23.51.34.9 A	19.15		0	
278	81 Aquarii . . 6	51	.. 44.51.9	46.90	+0.04.B.	7	8. 7.49.2 A	19.16	+0.08.B.	7	
279	80 Aquarii . . 7.8	51	.. 47.33.0	46.64		12	5.46.58.0 A	19.17		11	
280	Cephei . . . 7.8	51	342.48.30.0	-7.75		6	83.42.50.8 B	19.17		7	
281	32 Aquarii . . 6	52	343. 2.18.6	46.83		6	7.38.35.6 A	19.19		5	
282	α Piscis Austr. 5.6	52	.. 5.55.5	50.25		5	35.49.35.6 A	19.20		5	
283	Pegasi . . . 6.7	53	.. 10. 9.0	44.47		7	15. 9.37.2 B	19.20		8	
284	1 e Andromedæ 4	53	.. 11. 7.5	40.95	-0.07.B.	8	41.15.14.0 B	19.21	-0.03.B.C.	9	
285	Pegasi . . . 7.8	53	.. 14.52.0	43.70		6	22. 3.33.6 B	19.21		11	
286	2 Andromedæ 5.6	53	.. 21.15.0	40.92	-0.16.B.	6	41.41. 5.9 B	19.22	-0.05.B.P.	6	
287	4 β Piscium . . 5	54	.. 25.26.7	45.76	-0.23.M.B.	6	2.44.49.8 B	19.23	-0.03.M.	6	
288	SCHEAT . . . 2	54	.. 31.25.0	48.14	+0.24.M.C.P.	40	27. 0. 5.2 B	19.24	+0.20.B.C.	11	
289	83 h 1 Aquarii . 6	55	.. 40.52.5	46.91	-0.03.M. (C	8	8.46. 9.2 A	19.26	-0.07.M.C.	11	
290	MARKAB . . . 2	55	.. 42. 5.4	44.62	+0.02.M.M.	162	14. 7.57.1 B	19.26	-0.07.M.M.	55	
291	34 h 2 Aquarii 7.8	55	.. 43.23.1	46.91	-0.05.B.M.	6	8.49.46.5 A	19.26	+0.36.B.(C.P	6	
292	* Andromedæ 7.8	55	.. 47.31.0	41.31		14	40.11.57.4 B	19.27		13	
293	3 Andromedæ . 6	55	.. 48.28.0	30.61		4	48.58. 2.8 B	19.27		6	
294	85 h 3 Aquarii . 7	55	.. 51.58.0	46.92	+0.24.B.	5	9. 0.42.2 A	19.27	-0.16.B.	5	
295	* Drac.36 Rev. 5.6	55	.. 51.33.0	-1.24		19	83.16.81.3 B	19.27		9	
296	9 Gruis . . . 5	56	.. 53.25.5	51.53		10	44.35.45.4 A	19.28		10	
297	Pegasi . . . 7.8	56	.. 53.53.1	44.66		9	13.53. 0.2 B	19.28		9	
298	Gruis 1859 C.A. 9	56	.. 55.51.9	50.69		4	39.58. 9.7 A	19.28		7	
299	86 e 1 Aquarii 5.1	56	343.58.43.0	48.60		9	24.49.11.2 A	19.28		11	
300	Pegasi . . . 7.8	56	344. 5.34.5	44.31		5	17.26.15.0 B	19.29		8	
301	Pegasi . . . 7.8	57	.. 9.14.1	44.17		4	18.50. 0.3 B	19.30		4	
302	87 h 4 Aquarii . 8	57	.. 11.46.5	46.88		15	8.46. 9.4 A	19.31		15	
303	55 l Pegasi . . 5	57	.. 14. 1.0	45.24	+0.06.B.	8	8.19.59.2 B	19.31	+0.07.B.	8	
304	56 Pegasi . . . 4.5	57	.. 20.44.0	43.60		6	24.23.32.4 B	19.32		6	
305	Aquarii 1863 C.A. 6	57	.. 22.28.6	49.15		6	29.54. 2.7 A	19.32		7	
306	Pegasi . . . 7	58	.. 28.48.0	42.72		8	31.44.47.5 B	19.33		10	
307	Aquarii . . . 14	58	.. 30.16.5	46.99		10	10. 5.13.4 A	19.34		12	
308	1 e Cassiopæ . 6	58	.. 32.52.5	37.37		6	58.20.28.0 B	19.34		7	
309	Pegasi . . . 9	58	.. 33.45.6	43.13		6	28.36.49.5 B	19.34		7	
310	5 A Piscium . . 6	58	.. 36.32.1	45.94	-0.11.M.	7	1. 2.33.5 B	19.34	+0.07.M.	10	
311	4 Andromedæ 5.6	59	.. 38. 3.0	40.67		6	45.18.33.5 B	19.35		6	
312	5 Andromedæ 6.7	59	.. 40.39.0	40.11		6	48.12.31.4 B	19.35		8	
313	88 c 2 Aquarii 4.5	59	.. 41.28.5	48.22		11	22.15.14.6 A	19.35		12	
314	* Gr. 1867 C.A. 6.7	59	.. 42. 1.5	51.14		14	43.56.19.4 A	19.35		8	
315	Gruis 1866 C.A. 6	59	.. 44.43.0	50.74		7	41.40.13.6 A	19.36		7	
316	Piscium 982 May. 8	59	.. 47.21.9	45.94	-0.24.M.	5	1. 3.48.0 B	19.36	+0.02.M	5	
317	89 c 3 Aquarii . 5	59	.. 48.12.0	48.33		10	23.32.16.3 A	19.36		7	
318	57 m Pegasi . . 5.6	59	.. 51.32.2	45.34	+0.05.B.	7	7.35.48.3 B	19.37	+0.08.B.	7	
319	Pegasi . . . 7.8	23. 0	.. 59.15.3	43.20		10	28.35.16.5 B	19.38		12	
320	58 n Pegasi . . 6.7	0	344.59.19.8	45.24		5	8.44.28.6 B	19.38		5	

2 u

THE RAMSDEN CIRCLE: CONSTRUCTION & INTEGRATION

- Built by Jesse Ramsden between January 1788 and August 1789 as the centerpiece of the Observatory's first instrument suite.
- Housed in the Circular Hall designed by architect Giuseppe Venanzio Marvuglia. Mounted on a stone pedestal 3.5 feet in diameter and anchored to a pillar that extends to the building's foundations, there is a raised walnut platform for the astronomer. The copper-clad dome rotates on nine metal wheels, designed by Ramsden himself.

[...] the full circle; he [Mr. Ramsden] demonstrated that the quadrant must be abandoned to achieve the highest degree of precision of which observations are capable.

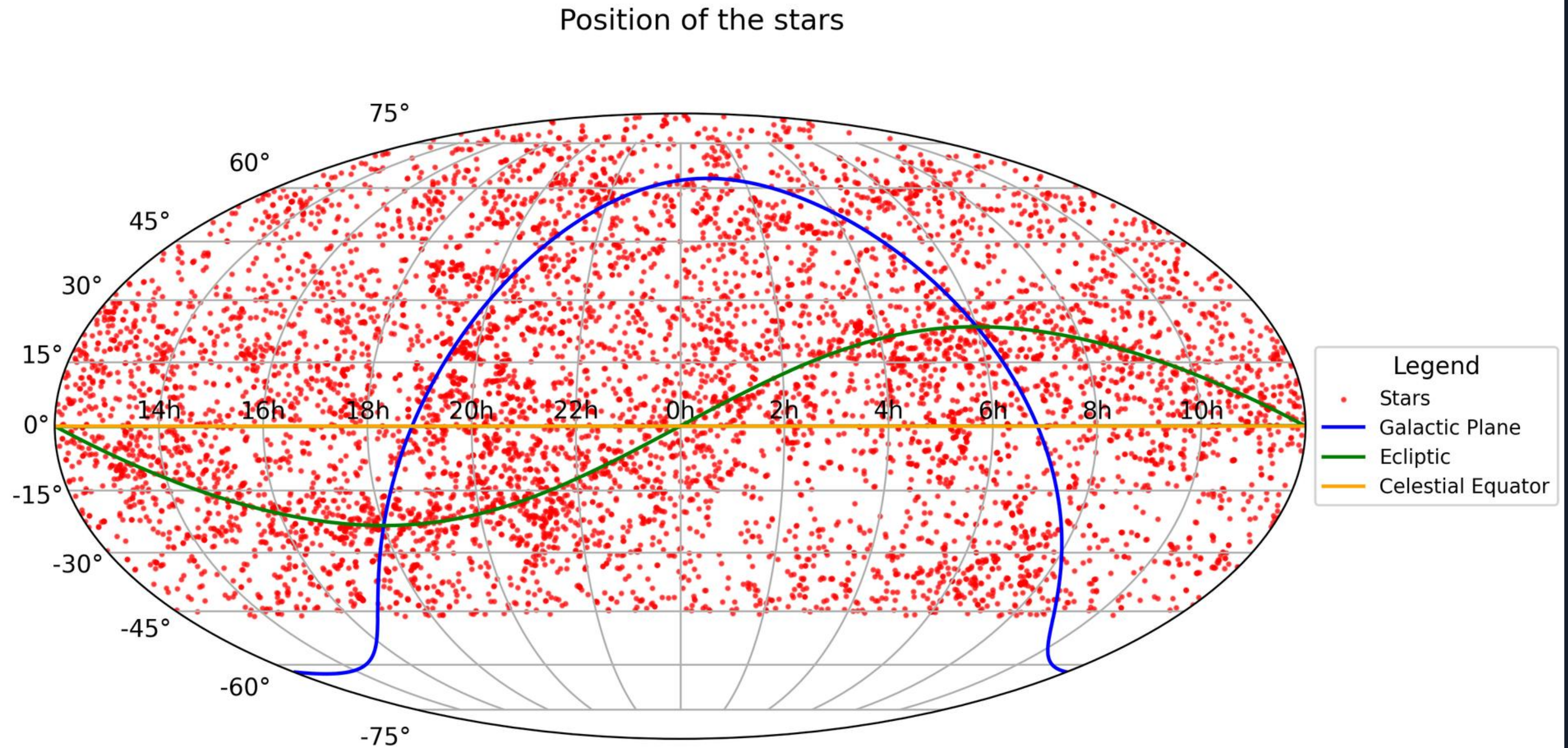


THE RAMSDEN CIRCLE: TECHNICAL DATA

- **Instrument characteristics**
 - Materials: brass, mahogany
 - Height = 280 cm
 - Horizontal circle diameter = 90 cm
 - Vertical circle diameter = 150 cm
- **Optics:**
 - Achromatic telescope with a 7.5 cm aperture and 150 cm focal length.
 - **Resolution:** Direct reading down to 1 arcsecond
- **Error reduction:** 180° rotation of the instrument between sights to mathematically eliminate collimation, zero-point, and eccentricity errors.
- **Calibration & Data Reduction**
 - Direct comparative observations between reference stars (e.g., Altair, Procyon) and the Sun at the equinoxes.
 - Advanced physical corrections: Rigorous modeling of atmospheric refraction, stellar aberration, nutation, and lunisolar precession.

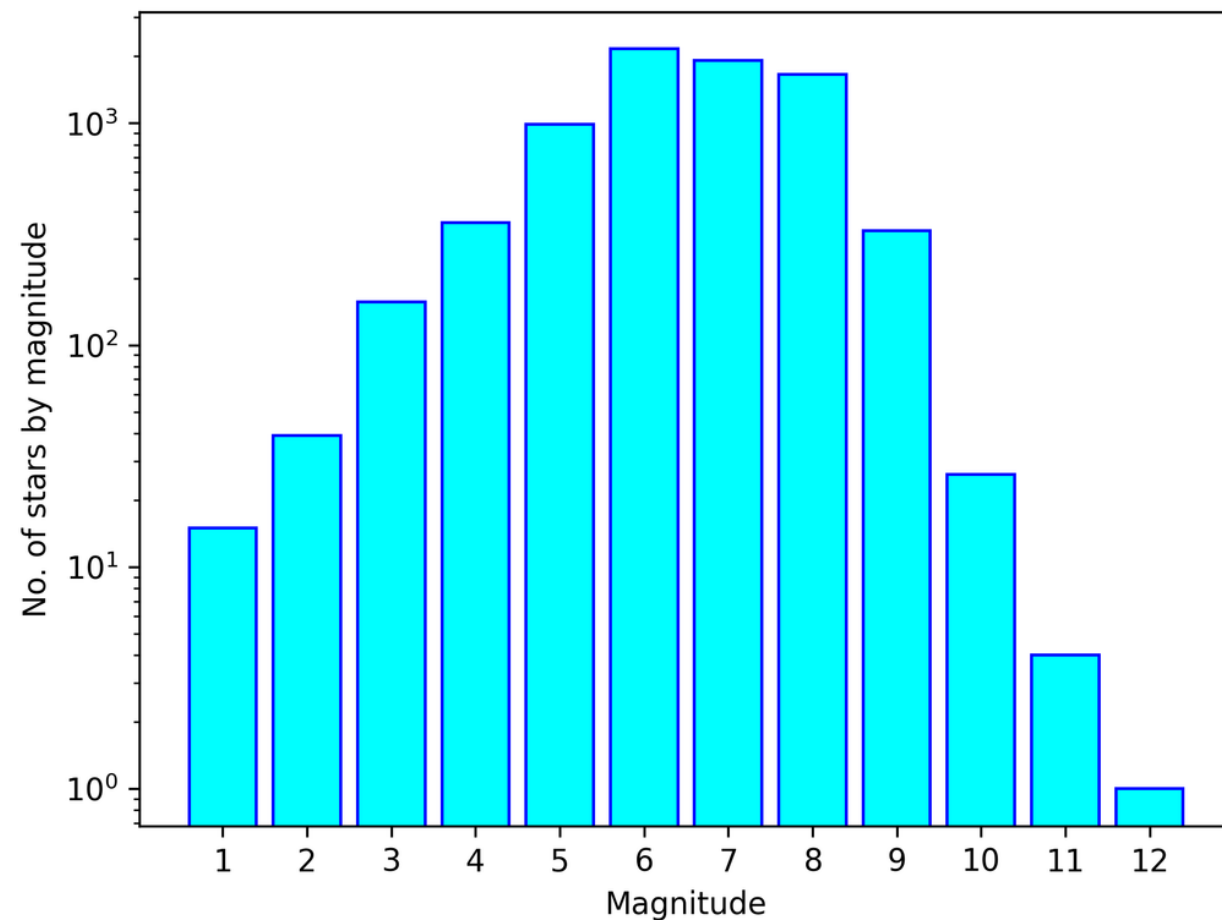


THE PIAZZI STELLAR CATALOGUE: ANALYSIS

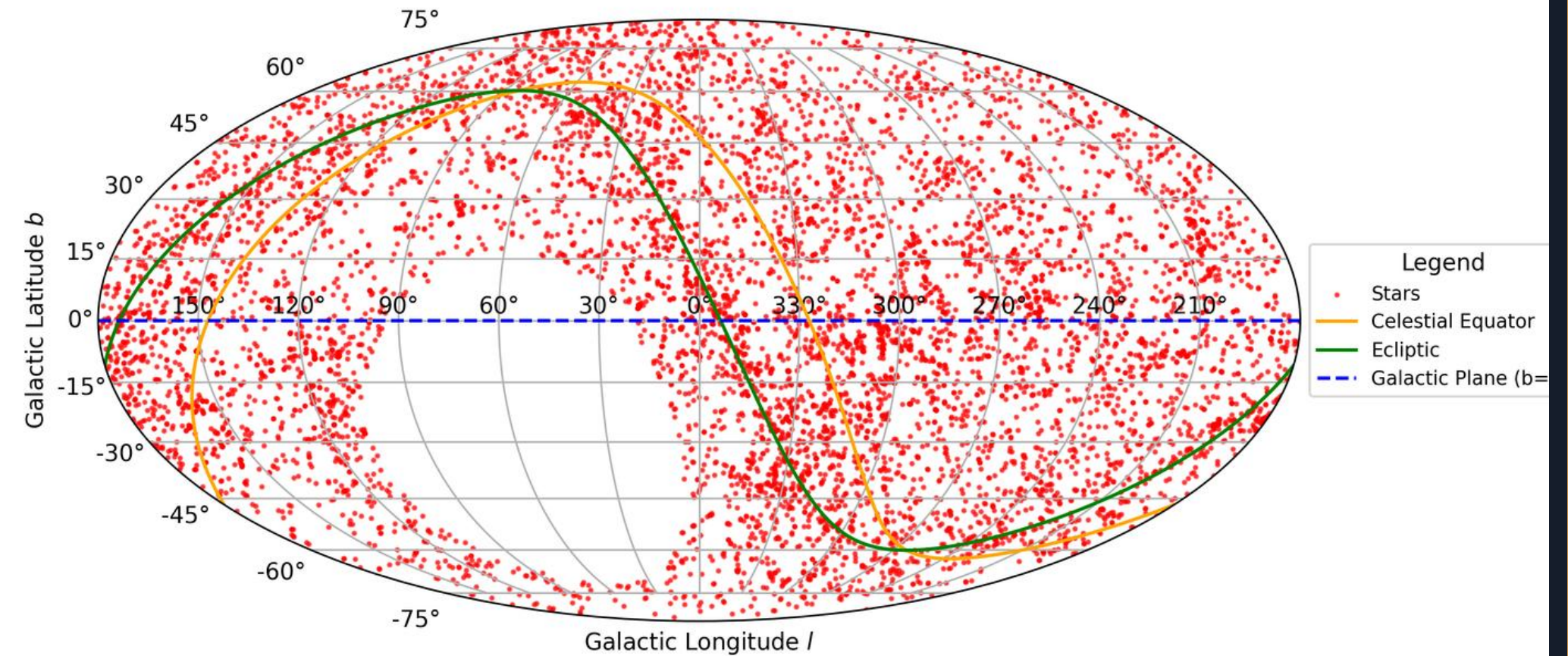


THE PIAZZI STELLAR CATALOGUE: ANALYSIS

Distribution of magnitudes



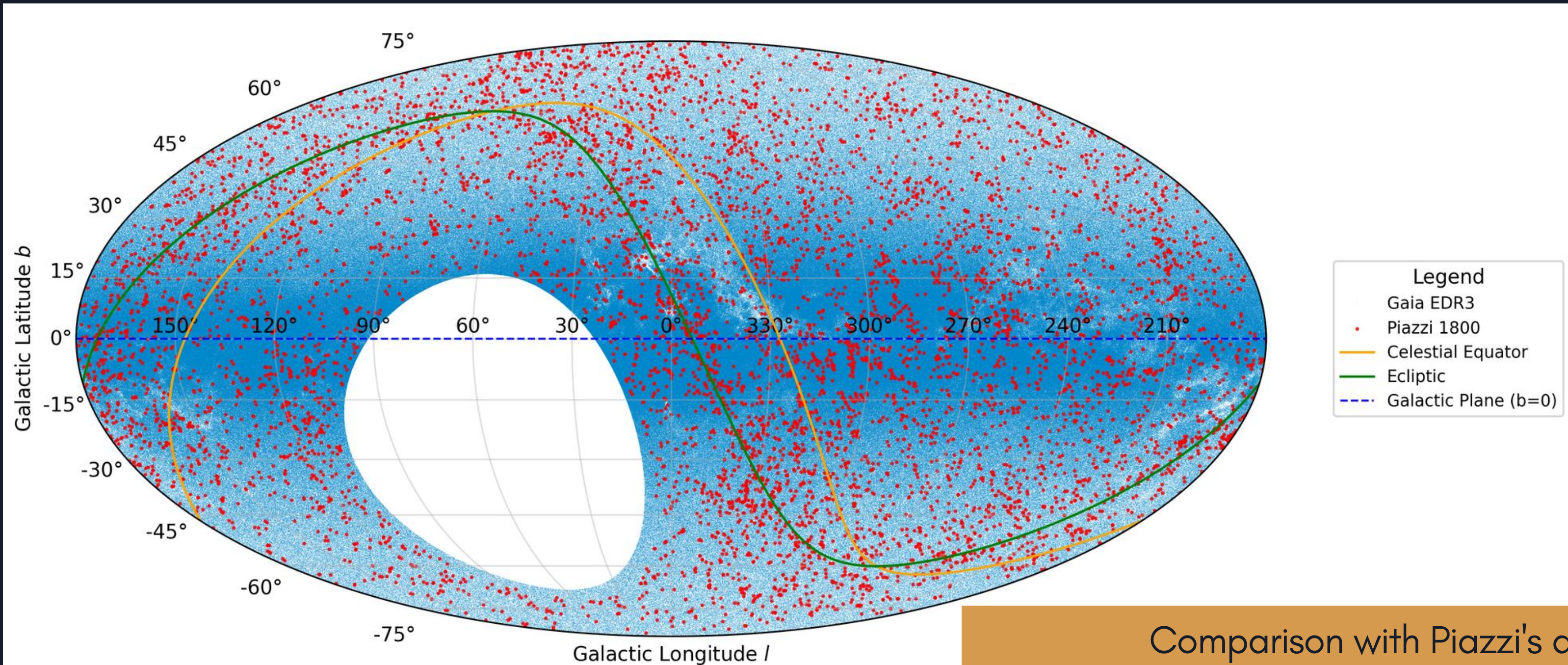
Position of the stars (Galactic Coordinates)



Magnitude Distribution

- Peak between 6th and 8th magnitude (over 2,000 stars each for 6th and 7th mag).
- Decay tail: Gradual dropoff at 9th magnitude
- Marks a generational leap beyond traditional naked-eye catalogues (historical cutoff at 6th mag).

THE DATA ANALYSIS: MATCH WITH GAIA

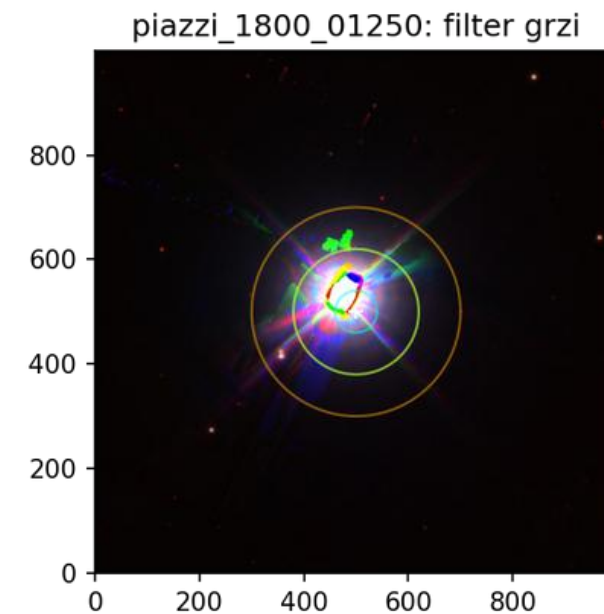
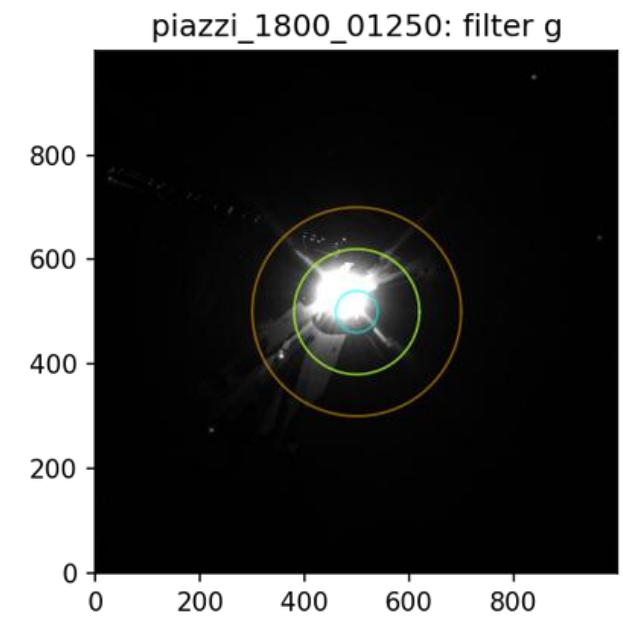
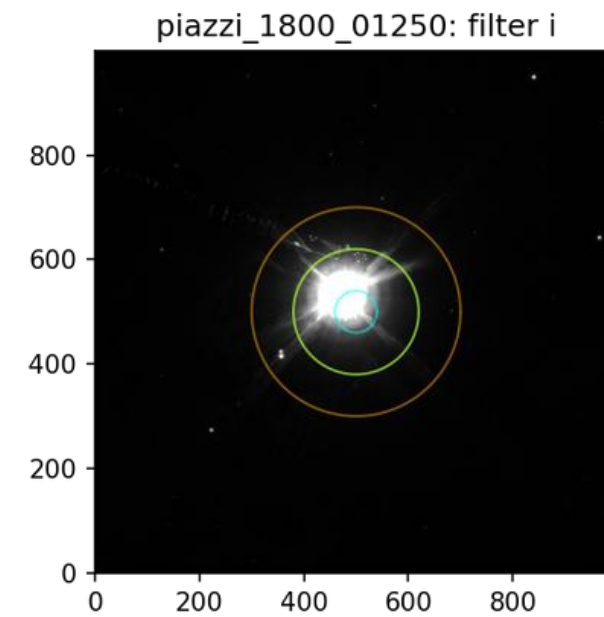


Comparison with Piazzzi's data, with a confidence radius of 10", showed 7304 matches, while 342 stars without association

THE DATA ANALYSIS: COMPARISON TECHNIQUE

Main steps of the comparison technique:

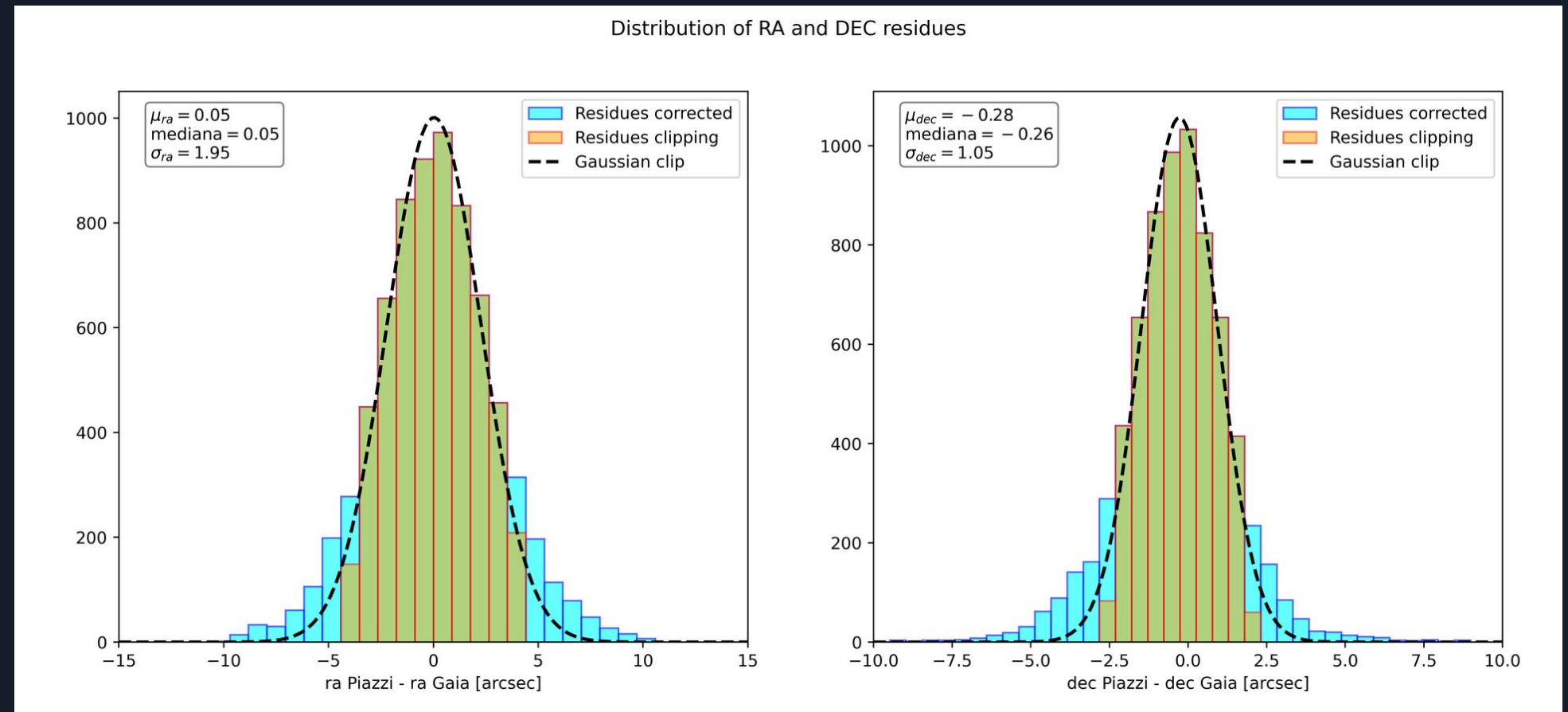
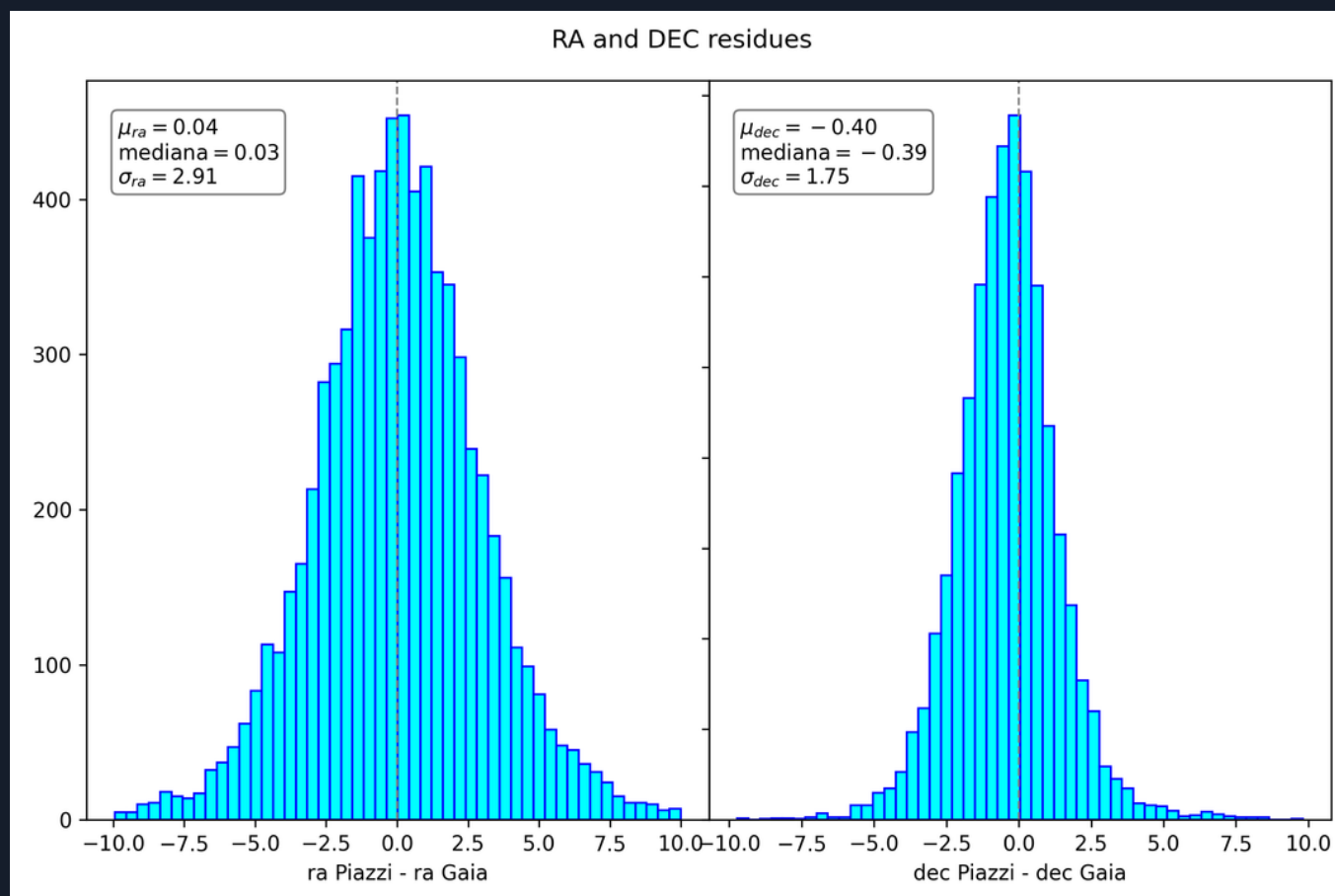
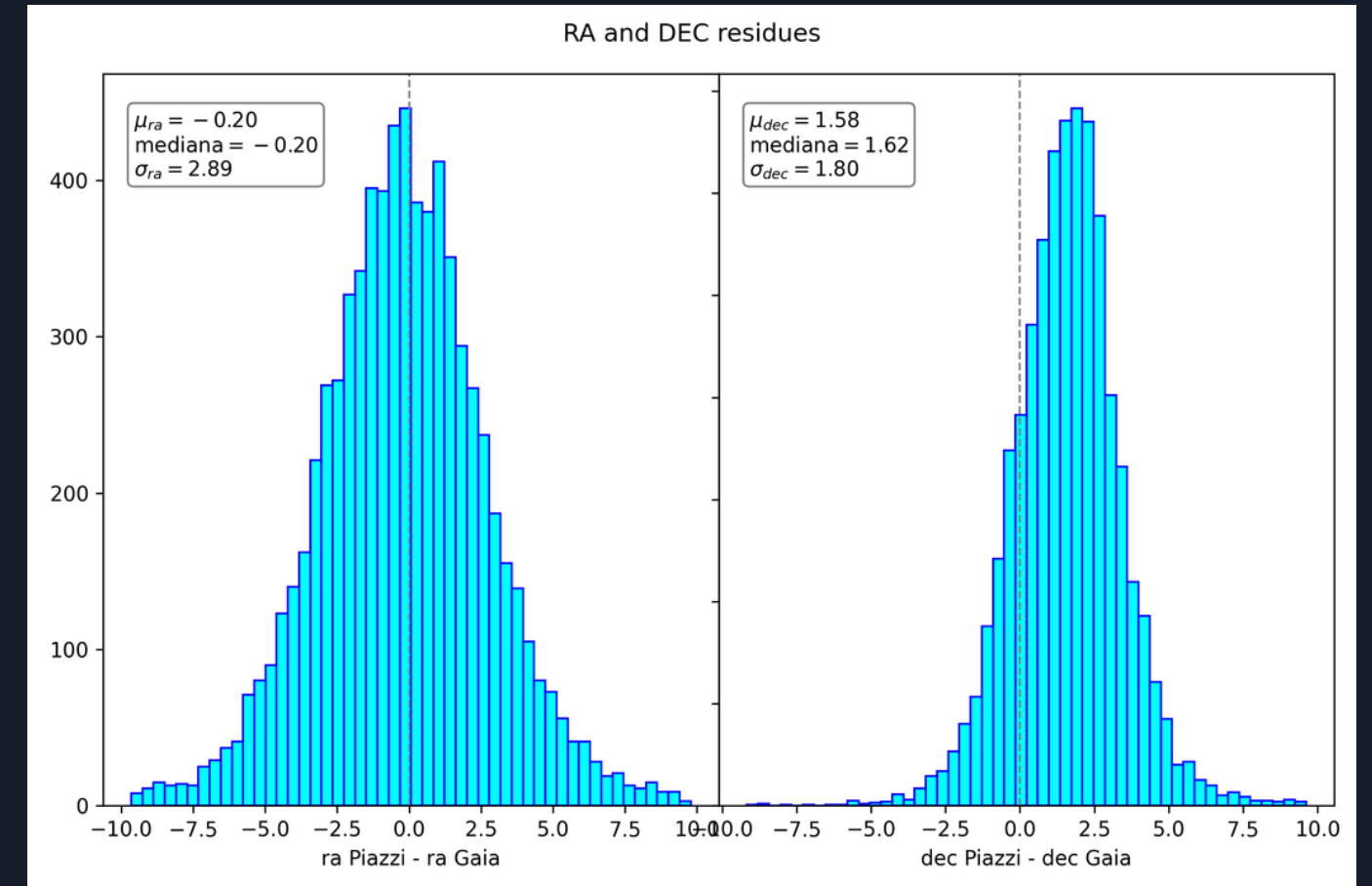
1. **Selection** of the stars from Gaia EDR3 with $-1 < \mathbf{Gmag} < 14$ on the Piazzzi sky footprint
2. **Precession** of the Gaia stars to the **1800.0 epoch** of the Piazzzi Catalogue
3. Application of **proper motion** to all the Gaia stars with the baseline of **-216 years** (Gaia reference epoch 2016.0)
4. For each Piazzzi object **matching the most similar object** in the Gaia Catalogue within a **confidence circle of 10"**



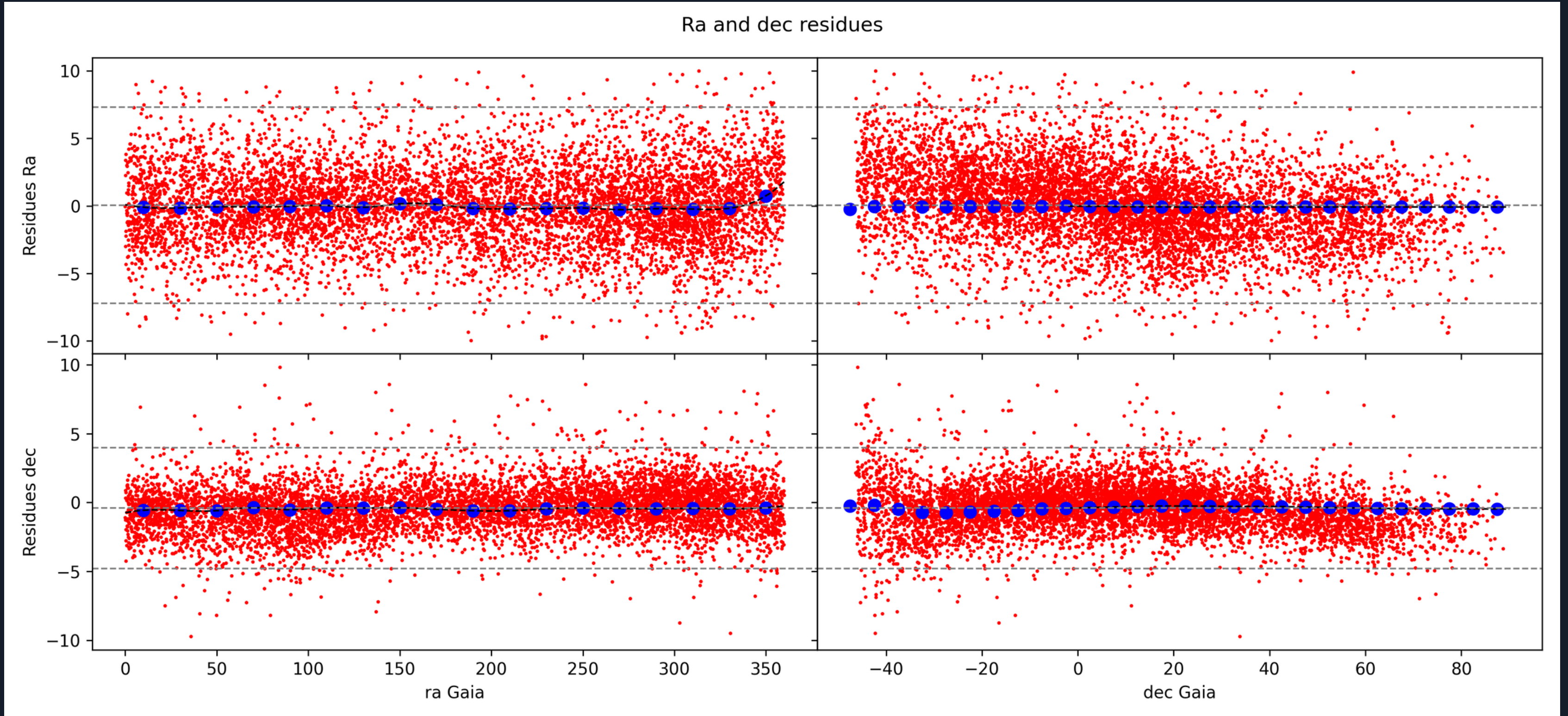
*Comparison of the positions
with the images of Pan-STARRS*

THE DATA ANALYSIS: RESIDUAL & ACCURANCY

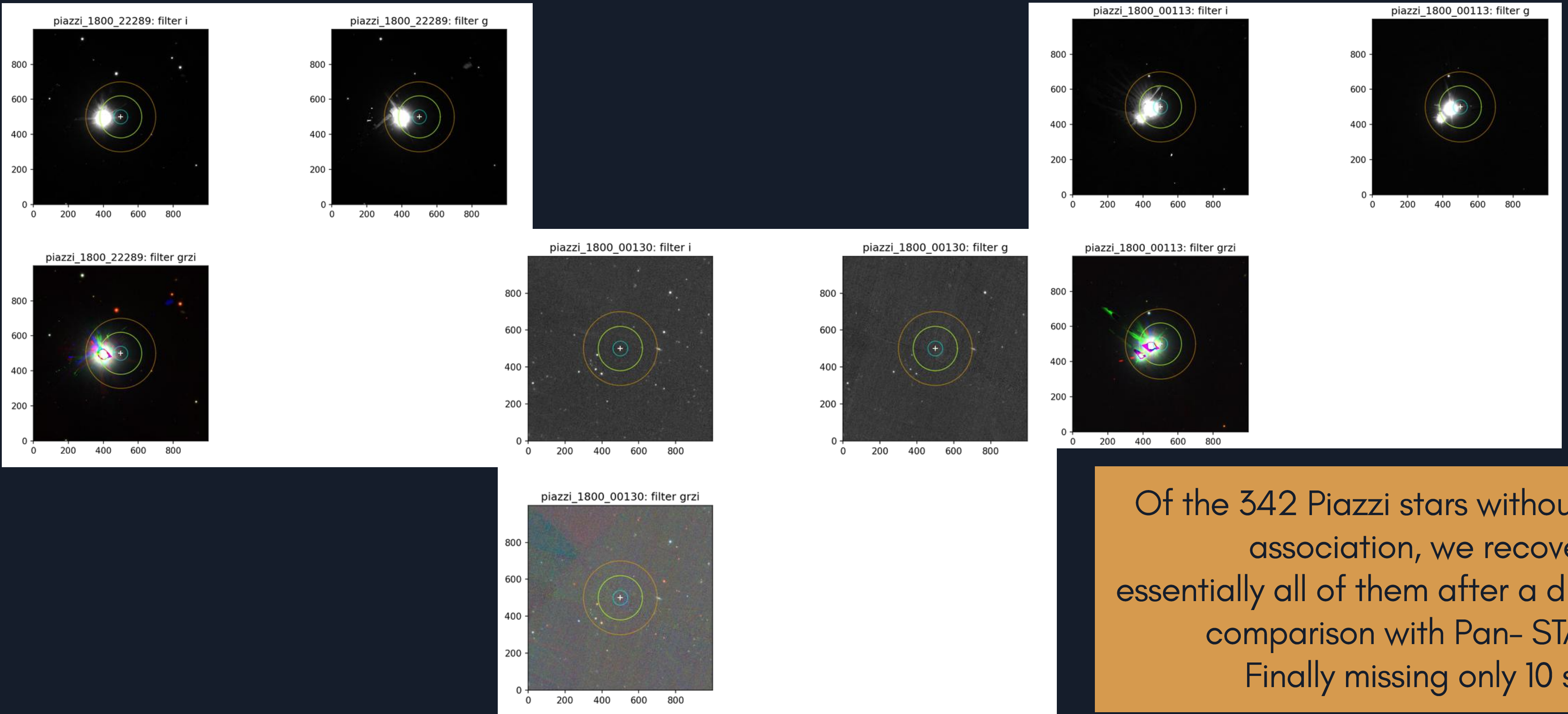
- **Before Systematic Error Correction:**
 - RA: Offset = $-0.20''$; Dispersion = $2.89''$
 - Dec: Offset = $1.50''$; Dispersion = $1.80''$
- **After Systematic Error Correction:**
 - RA: Offset = $-0.04''$; Dispersion = $2.91''$
 - Dec: Offset = $0.40''$; Dispersion = $1.75''$
- **Total accuracy of Piazzi's catalog: $2.21''$**



THE DATA ANALYSIS: RESIDUAL & ACCURACY



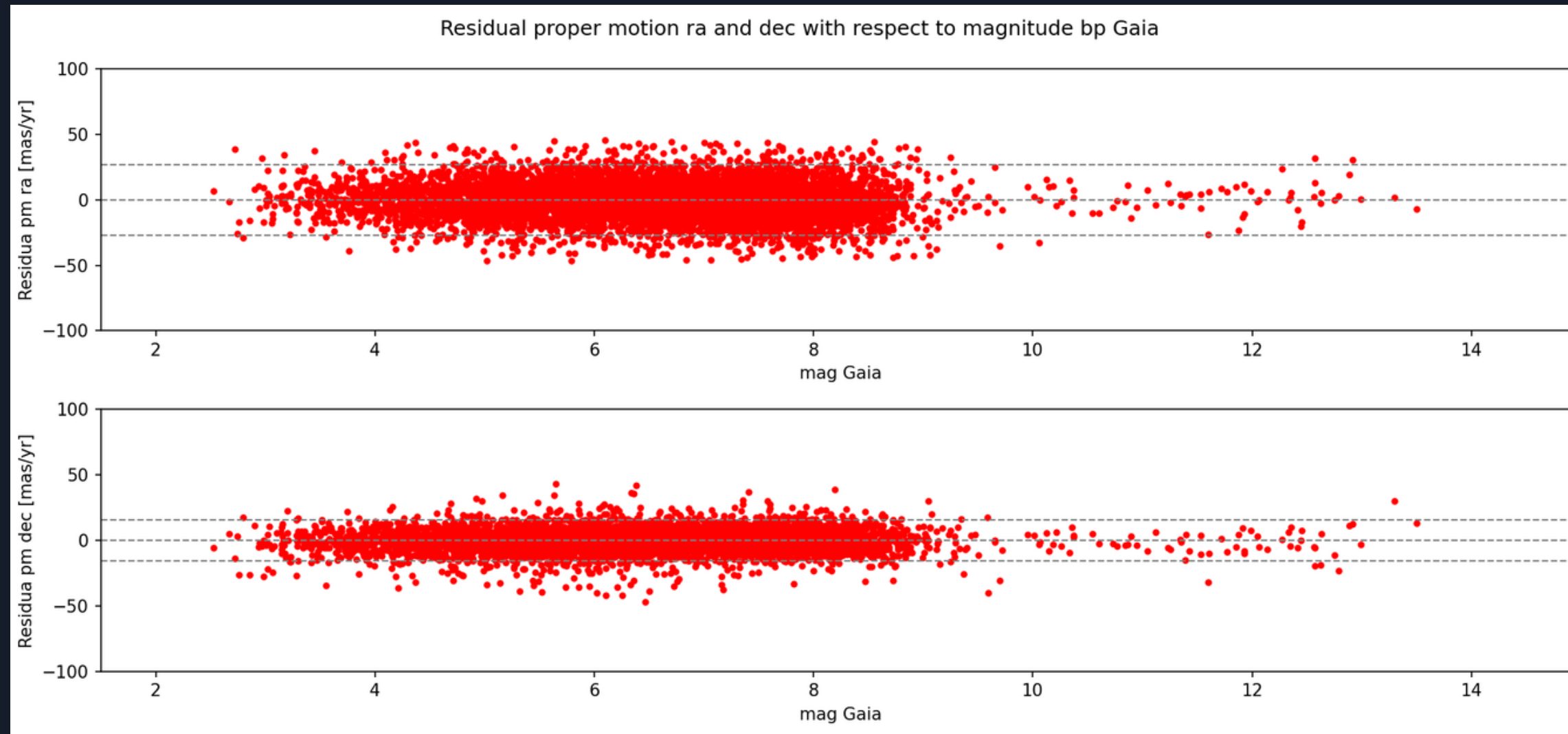
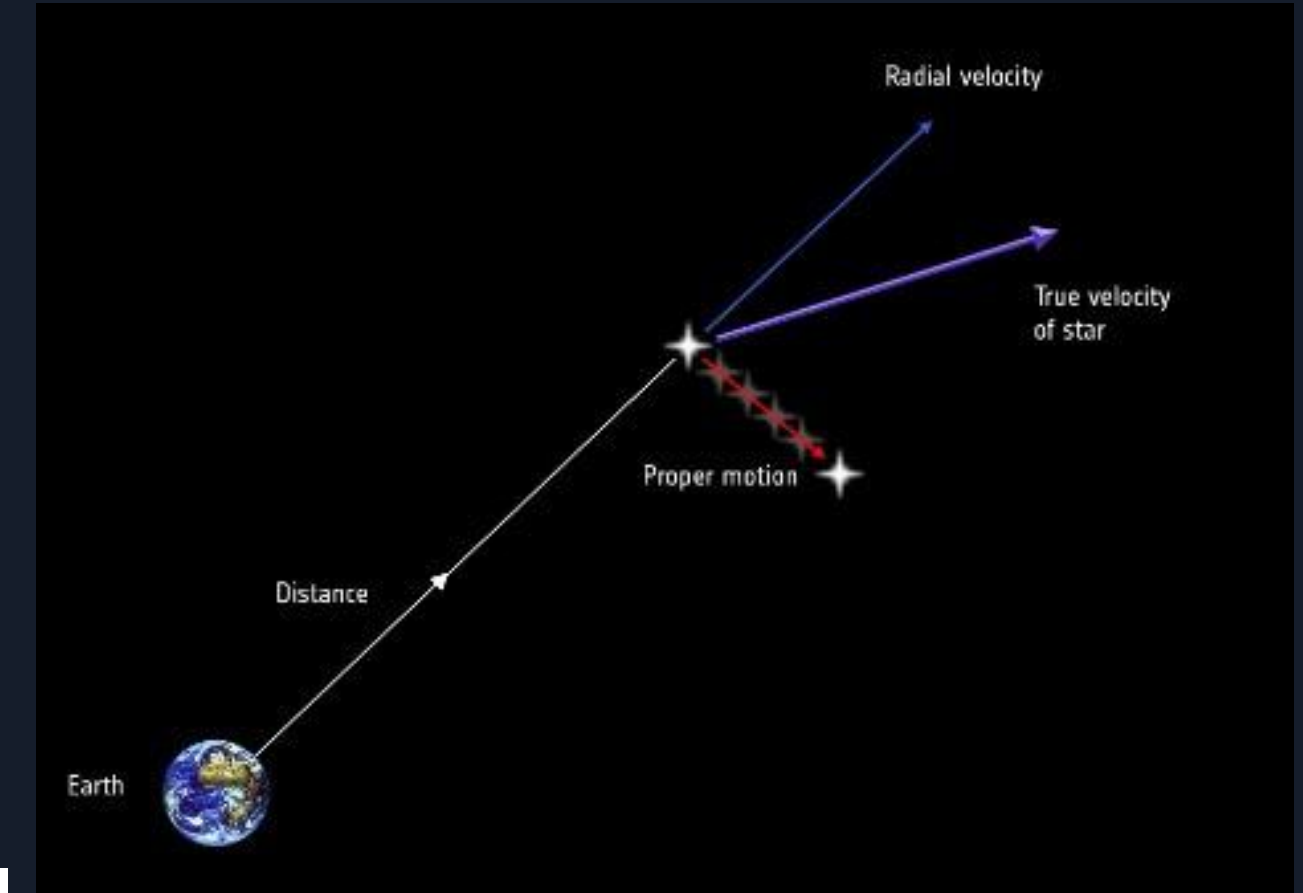
THE DATA ANALYSIS: NO MATCH



Of the 342 Piazzì stars without an association, we recovered essentially all of them after a direct comparison with Pan-STARR. Finally missing only 10 stars

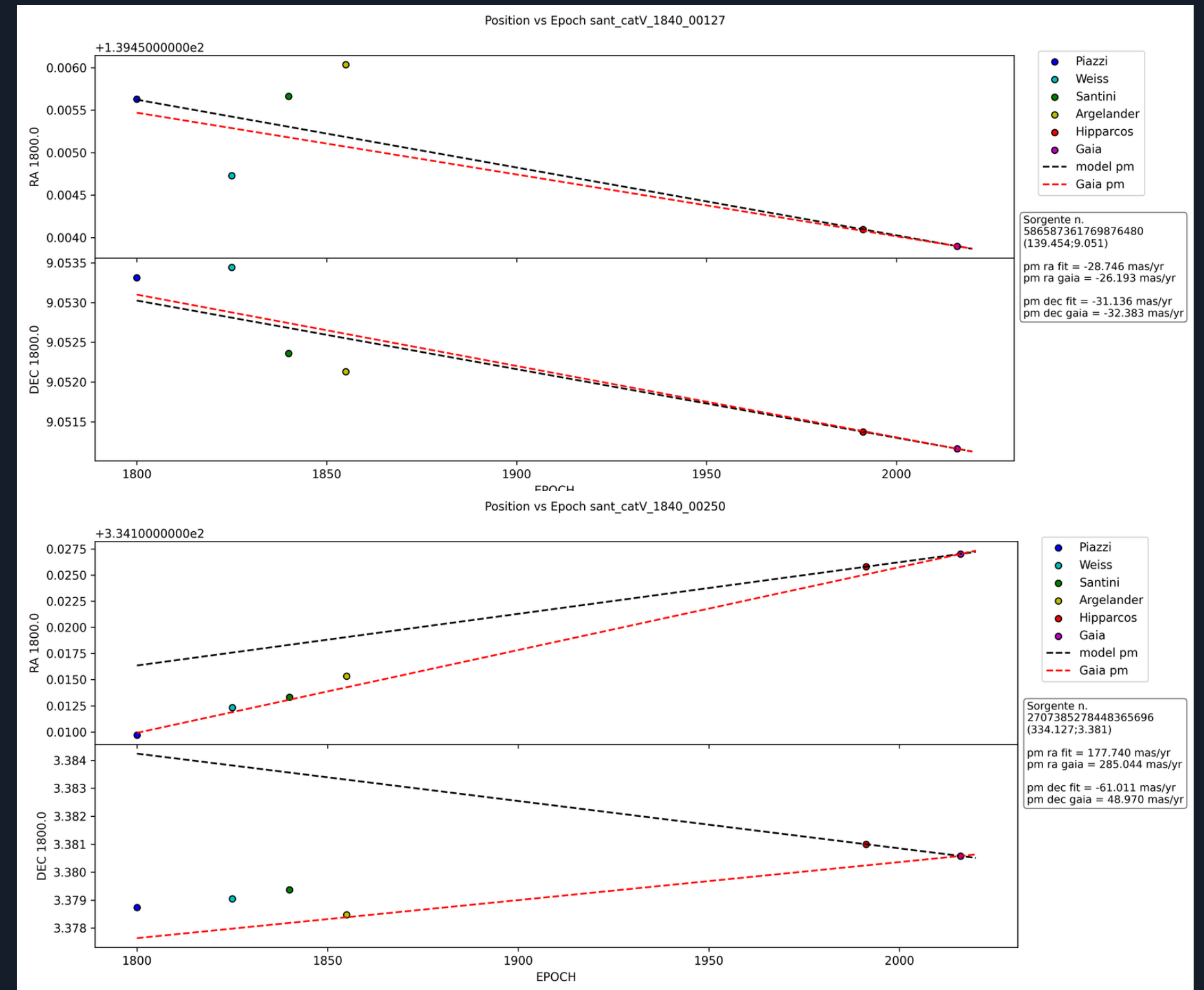
THE DATA ANALYSIS: PROPER MOTION

Using the 216 years baseline we calculated the proper motion of the apparent motion of a stars. Together with other historical catalogues we were able to measure a new proper motion of each stars



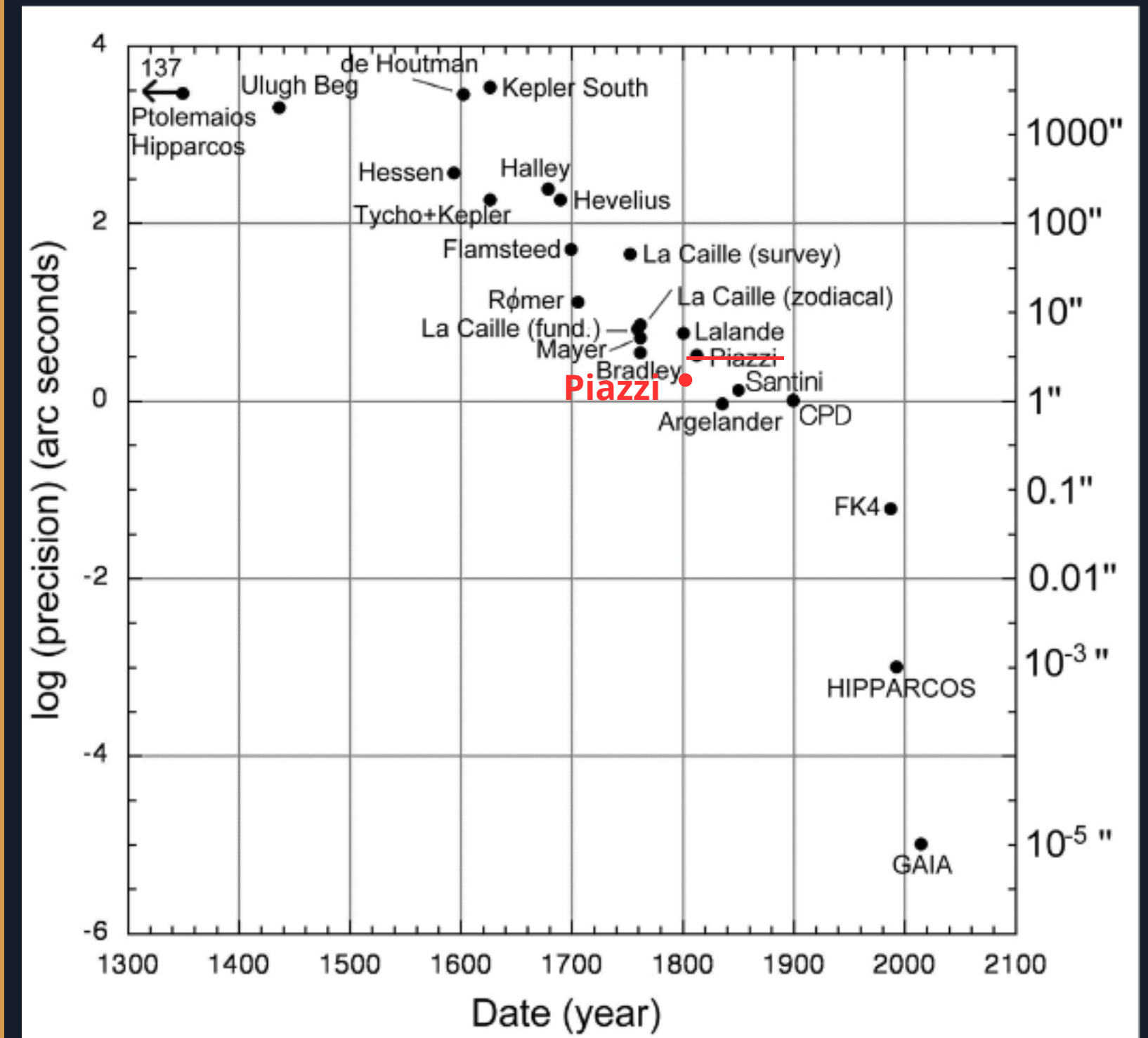
THE DATA ANALYSIS: PROPER MOTION AND OTHER HISTORICAL CATALOGUE

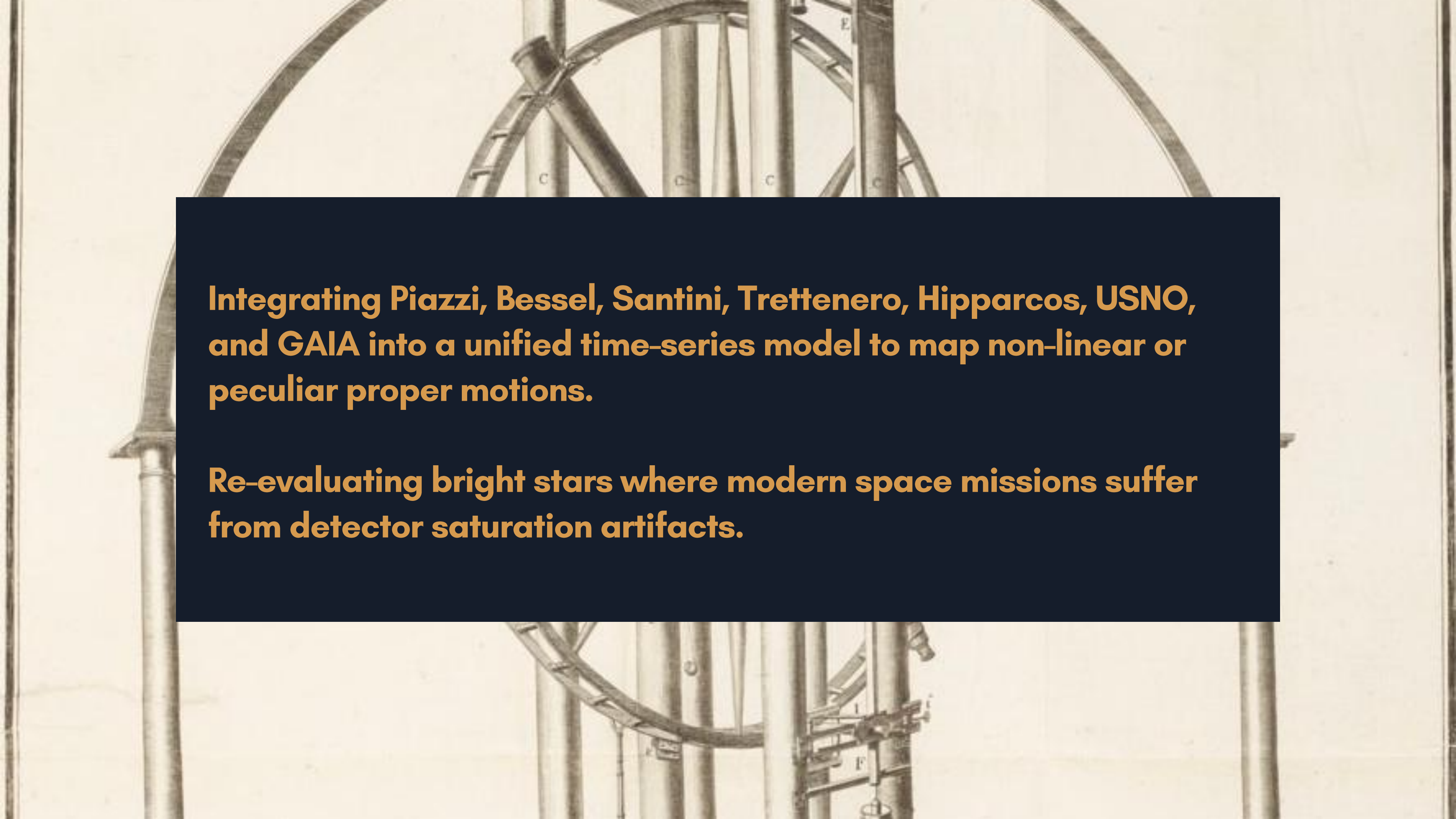
- Multi-Epoch Baseline Strategy:
 - Combines positional measurements across two centuries by linking Piazzi (1800/1814) with intermediate 19th-century catalogues (Santini, Argelander, Weiss) and modern frames (Hipparcos, GAIA).
 - Spanning 150 to 200+ years dramatically increases the accuracy of the PMs
- Uncovers high proper-motion stars and validates long-term kinematic trends directly from historical observational records.
- Demonstrates the lasting scientific utility of early 19th-century observations when embedded in a consistent multi-epoch pipeline.



FINAL ANALYSIS

- **Literature standard (James Lequeux, 2014):**
 - literature places Piazzi's catalogue error at 3.0" – 3.5"
- **Our work:**
 - Modern systematic reduction against GAIA reference frames yields an improved precision of 2.26".
- **Proper motion:**
 - Direct proper motion residual dispersions against GAIA: 7.79mas/yr in DEC and 13.41mas/yr in RA (yielding an average accuracy around 8–10 mas/yr).
- **Instrumental Validation:** Demonstrates that Piazzi's Palermo observations (Ramsden circle) possessed higher intrinsic quality than previously recognized once systematic biases are properly modeled.





Integrating Piazzini, Bessel, Santini, Trettenero, Hipparcos, USNO, and GAIA into a unified time-series model to map non-linear or peculiar proper motions.

Re-evaluating bright stars where modern space missions suffer from detector saturation artifacts.



THANKS FOR YOUR ATTENTION

15-18 September 2026

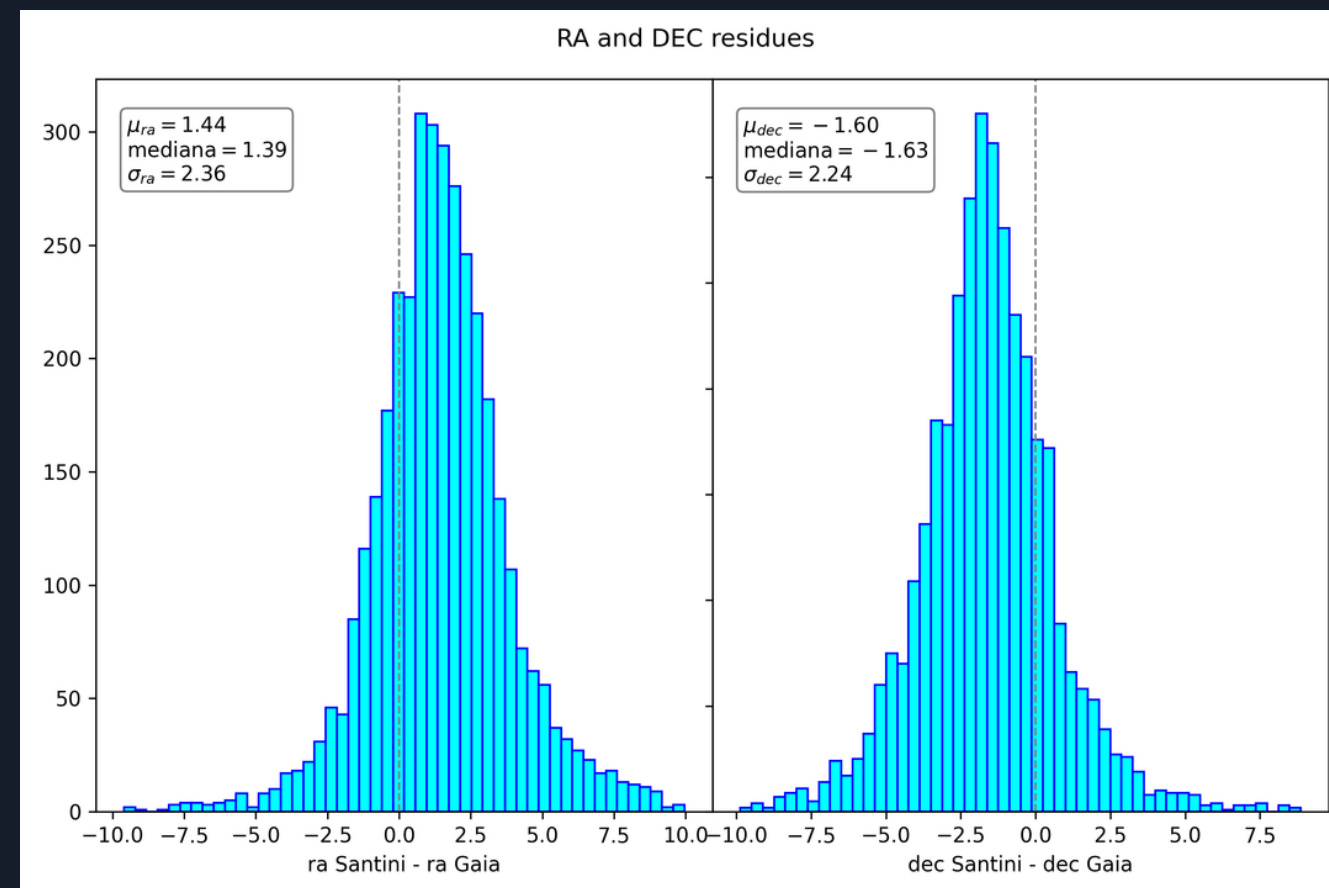
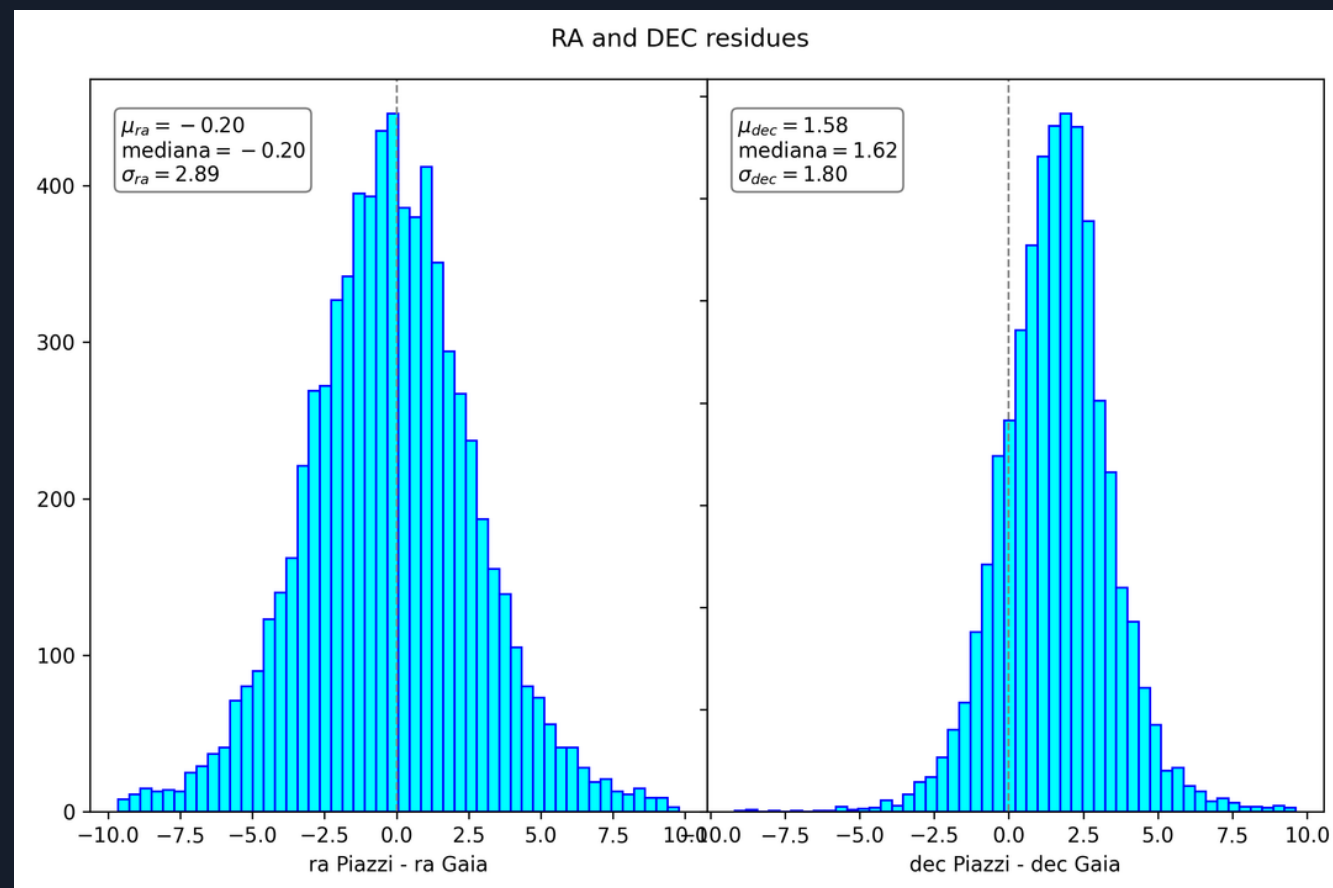
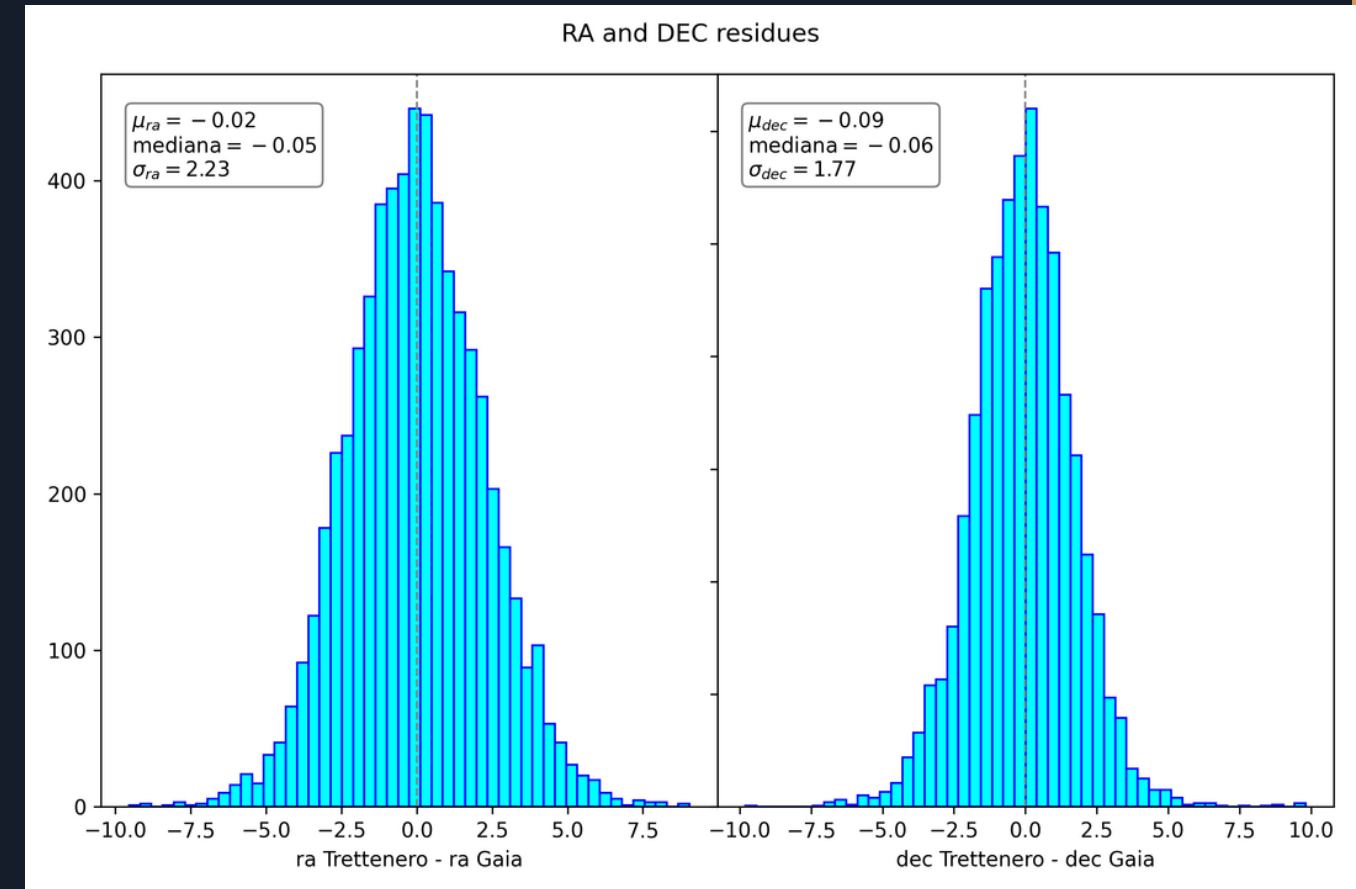
F. Di Giacomo, S. Zaggia, V. Zanini

INAF – Astronomical Observatory of Padua

PIAZZI 200: new frontiers in astrometry, small bodies and technologies – Palermo, 30 September – 2 October 2026

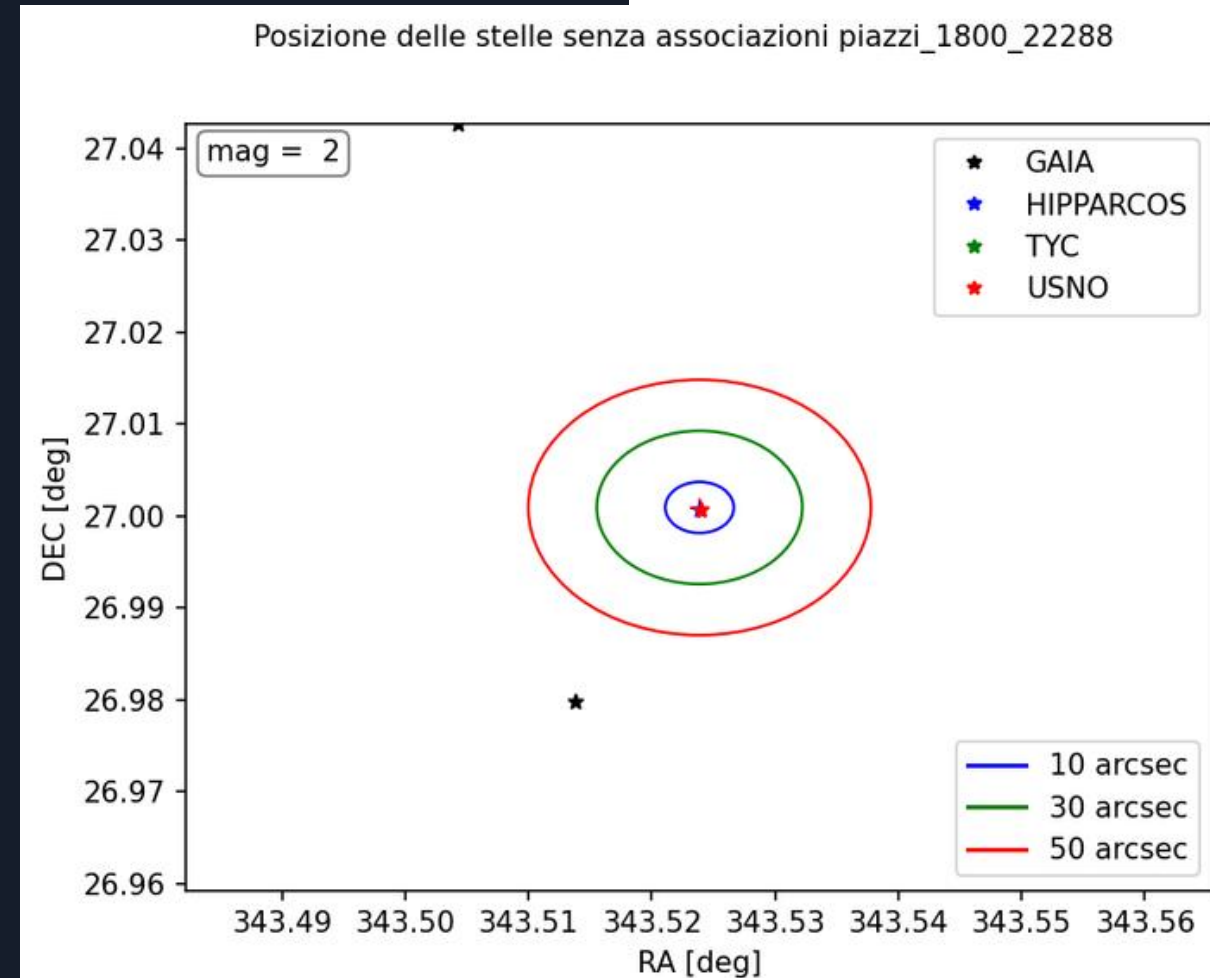
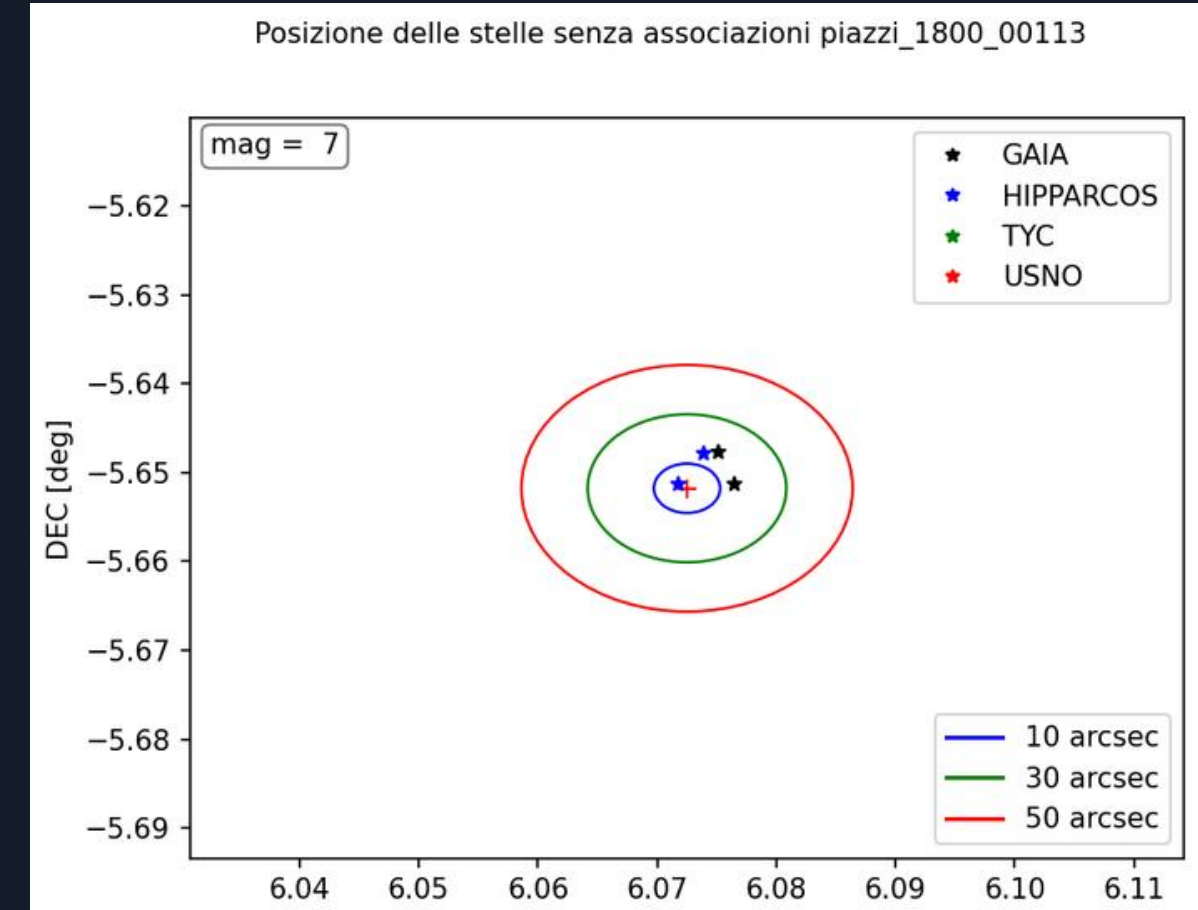
THE DATA ANALYSIS: PIAZZI VS OTHER CATALOGUES

- Piazzi (1814):
Lower systematic offsets than Santini's subsequent catalogs.
- Santini (Padova, 1840-1847):
Higher dispersion in RA.
- Trettenero (Padova, 1857-1862-1870):
High precision both in RA and DEC



THE DATA ANALYSIS: NO MATCH

- Methodological Approach for Unmatched Targets:
 - Spatial mapping centered on Piazzì's coordinates with confidence radii (10", 30", 50").
 - Extended cross-match performed across all unmatched candidates using Hipparcos and USNO catalogs.
- In specific cases, GAIA sources lie outside the search radius or are completely missing near very bright stars due to severe optical saturation or deblending masks.
- Hipparcos and USNO entries fall precisely within the 10" inner confidence radius where GAIA fails to register clean



THE DATA ANALYSIS: MAGNITUDE & COLOR

- Peak agreement in BP: smallest offset (0.36) and minimal color trend in scatter plots.
- Matches the physiological response of the human eye (scotopic/mesopic vision) during night visual observations with the Ramsden telescope.

