EXTRAGALACTIC OPTICAL-RADIO LINK RESEARCH AT USNO

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ABSTRACT. Over 500 counterparts of ICRF sources were observed during 24 deep CCD observing runs as part of the USNO CCD Astrograph Catalog (UCAC) project, providing a direct link to Tycho-2 stars. For some sources a positional accuracy of 10 mas is achieved. A sample of 12 extragalactic ICRF sources are being observed at the Naval Observatory Flagstaff Station (NOFS) 1.55-meter telescope over several years to monitor optical position stability. First high resolution imaging of selected sources are obtained at the Lick 3-meter AO system to correlate source structure with optical-radio centroid offsets. As part of the Space Interferometry Mission (SIM) preparatory science about 240 bright QSO's are monitored for photometric variability in B,V,R and I. The USNO Robotic Astrometric Telescope (URAT) will be able to combine deep CCD imaging of all ICRF2 target areas and millions of compact galaxies with a stellar, astrometric, all-sky survey of multiple epochs.

1. OPTICAL COUNTERPARTS OF ICRF SOURCES

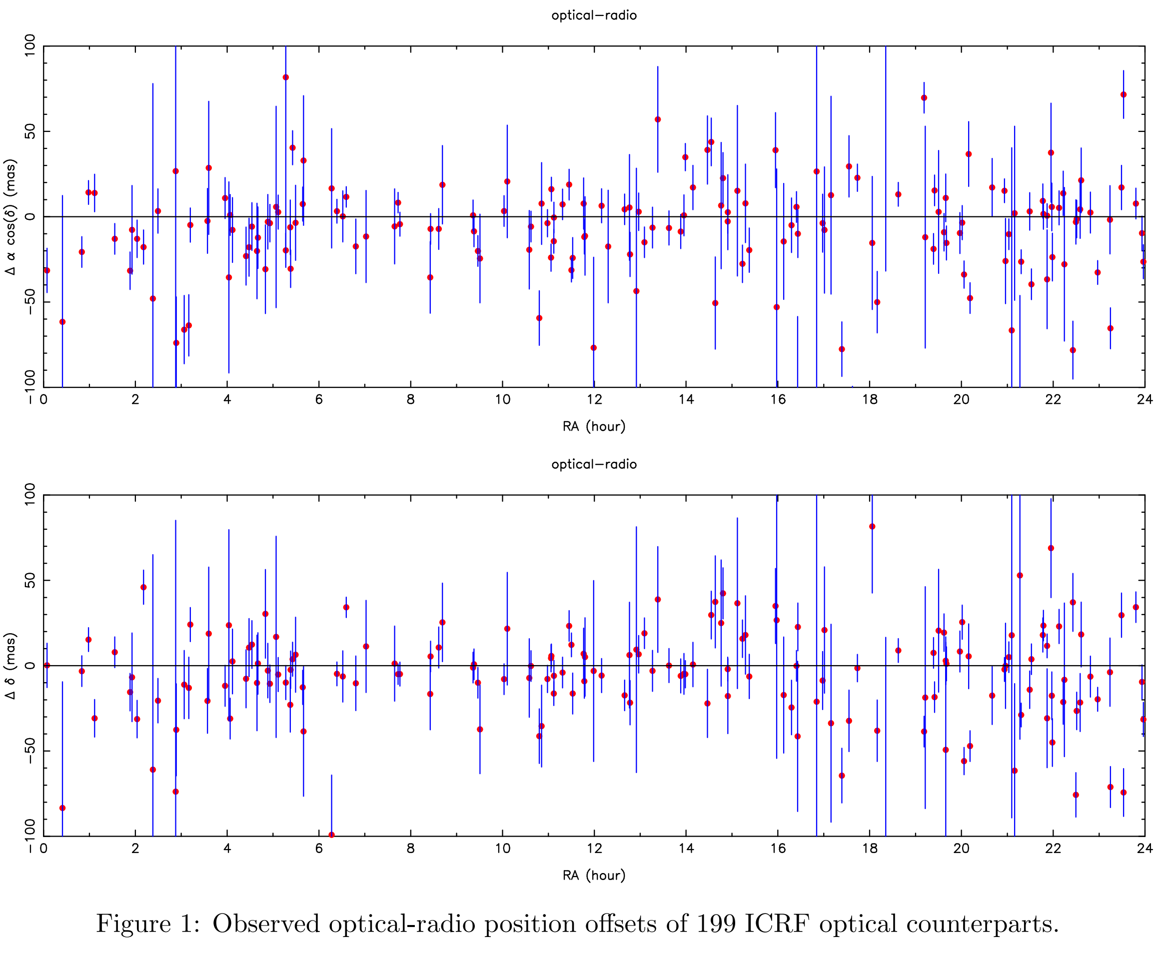

Figure 1: Observed optical-radio position offsets of 199 ICRF optical counterparts.

Between 1997 and 2004 the CTIO 0.9m, KPNO 0.9m and 2.1m telescopes were utilized in 24 observing runs to image over 500 optical counterparts of ICRF sources. Contemporaneous to these deep CCD imaging the USNO astrograph observed the same fields as part of the UCAC project (Zacharias et al. 2004) in order to provide a direct tie to the Tycho-2 and thus the Hipparcos reference frame. Reductions have been performed for 236 fields (mainly in the southern hemisphere) of which 199 gave optical counterpart position results (Figure 1), see also Zacharias & Zacharias (2005).

The total estimated positional error per coordinate for many sources is in the 10 to 20 mas range. However, a higher than expected fraction of sources show an optical-radio position offset larger than 3-sigma of the total error. Whether this is the result of underestimated systematic errors or caused by physics (optical source structure) is yet unknown.

2. OPTICAL ASTROMETRIC STABILITY ON MAS LEVEL

Between 2002 and Oct. 2007 484 CCD images were obtained with the Naval Observatory Flagstaff Station (NOFS) 1.55m Strand Reflector of a selection of 12 ICRF optical counterparts (see Table 1). The goal of this differential astrometry investigation is to assess the positional stability over time at optical wavelengths with single exposure standard errors of about 3 mas per coordinate and 14 to 77 observations per source. The targets were selected to cover a wide range in parameters (ICRF defining, contributing or other sources, quasar or BL-Lac object type, redshift, radio quality, radio structure index). For radio characterization see Fey & Charlot (1999).

source	I	t	mag	z	Q	SIX
0241+622	C	Q	12.2	0.04	18	2
0552+398	C	Q	18.0	2.37	96	2
0738+313	D	Q	16.1	0.63	61	4
0754+100	D	L	15.0	0.66	68	2
0839+187	D	Q	16.4	1.27	46	4
0851+202	C	L	15.4	0.31	83	2
0912+297	D	L	16.4	?	–	1
1656+053	C	Q	16.5	0.89	57	3
1830+285	D	Q	17.2	0.59	58	3
1937−101	C	Q	17.0	3.79	52	3
2059+034	D	Q	17.8	1.01	66	2
2201+315	O	Q	15.6	0.30	74	3

Table 1: Sources on the optical stability monitoring program at the NOFS 1.55m telescope. I = ICRF object type (D = defining, C = contributing, O = other), t = optical type (Q = QSO, L = BL-Lac), mag = approximate V magnitude, z = redshift, Q = radio quality, stability over time (0 = poor, 100 = excellent), and SIX = radio structure index (1 = very good, 4 = poor).

3. HIGH RESOLUTION OPTICAL IMAGING

In September 2007, following an unsuccessful attempt in 2006 (poor seeing), high-resolution (0.3 arcsec) images of 3 extragalactic, compact sources were obtained using the Lick 3-meter adaptive optics (AO) system. The source IRAS 0147+3554 clearly shows an asymmetric image profile due to structure of the underlying spiral galaxy. This is a program in collaboration with E. Gates, Lick Observatories.

USNO has also pursued observing opportunities using HST and the LuckyCam at ESO, however, no observing time was been granted yet. It will be very challenging to obtain sufficient observing time to even image once all optical counterparts of the current ICRF1 with high resolution at optical wavelengths, something which is being achieved regularly at radio frequencies.

4. BRIGHT QUASAR PHOTOMETRY

A total of 242 optically bright quasars, evenly distributed over all sky, are on a photometric monitoring program. The sources have been selected, regardless of radio flux, starting with the Veron catalog (Veron et al. 2000), as the optically brightest targets giving a good all-sky distribution and displaying symmetric, compact appearance on digitized Schmidt survey images. Most targets are in the 15 to 17 mag range with some as faint as 20th mag to fill gaps near the galactic plane. The optically very brightest quasars and BL-Lac objects were excluded due to asymmetric structure already visible on the arcsec level.

Quasars are being observed with the CTIO and NOFS 1.0-meter telescopes in B, V, R, and I bands. This program is part of the Space Interferometer Mission (SIM Planet-quest, see also Unwin et al. 2007) preparatory science within the "Astrophysics of Reference Frame Sources" SIM key science project (PI: K. Johnston). With the lack of high resolution optical images (see above) optical variability information can be used as the next best indicator for "stable" sources to select most appropriate candidates for a future SIM celestial reference frame, which needs about 50 pre-selected sources. Results from this program will also be used in the work leading to the construction of the future ICRF2 (Ma et al. 2007).

Photometric observations have been obtained for all sources, many with more than 1 epoch. Significant differences in observed magnitudes w.r.t. the Veron catalog are found. A paper is in presentation for AJ (Zacharias et al. 2008).

5. THE URAT PROJECT

The USNO Robotic Astrometric Telescope (URAT) project aims at an all-sky survey to extend the UCAC data to fainter limiting magnitudes and higher positional accuracies. URAT comes in 2 phases. The first will use the URAT focal plane at the existing USNO Astrograph "redlens", which also was used for the UCAC program. Phase 2 requires the construction of a new, dedicated, astrometric telescope of which the primary mirror has been manufactured while currently no funding is identified to complete that telescope. Table 2 gives an overview about the properties of the 2 phases of the URAT program.

parameter	URAT phase 1	URAT phase 2
telescope	redlens astrograph	new design
focal length	2.00 m	3.60 m
aperture	0.20 m	0.85 m
field of view	9.00 deg	4.50 deg
field diameter	324 mm	283 mm
pixel scale	0.905 ″/pix	0.515 ″/pix
sky cov./exposure	27 sq.deg	9.1 sq.deg
bandpass	670–760 nm	
brightness range	10–18 mag	13–21 mag
catalog accuracy	10 mas	5 mas
solve for	position, proper motion, parallax	
begin of survey	2009	not determined

Table 2: The above values for pixel scale and sky coverage assume the use of the "4-shooter" camera which is based on 4 CCD chips of 111 million pixel each (STA1600 chip). The catalog accuracy is for well exposed stars; at the limiting magnitude the errors will be about a factor of 3 larger.

Details of the optical design of URAT are given by Laux & Zacharias (2005), and Zacharias et al. (2006), while the project itself is described in Zacharias (2005, 2007). Latest progress with the detector development is presented in Zacharias et al. (2007). The 10k camera with a single CCD chip of the kind (95 mm by 95 mm, full-wafer device) saw first light in October 2007 and astrometric characterization of this back-illuminated detector is in progress at the USNO astrograph telescope. The "4-shooter" URAT focal plane assembly will be built in 2008.

The large sky coverage with a single exposure will allow multiple sky overlaps per year. With at least 2 years of operation on each site (northern and southern hemisphere) not only mean positions but also proper motions and parallaxes can be derived for all stars from the URAT observing program itself. The limiting magnitude will be deep enough to be able to access optical counterparts of ICRF sources directly.

The URAT program can provide highly accurate reference stars for the PanSTARRS and LSST projects.

6. CONCLUSIONS

The analysis of ICRF-2 sources at radio frequencies is in "good shape" (e.g. Ojha et al. 2005, Ma 2006) while the optical effort is lagging behind in characterization of optical counterparts (high resolution imaging, variability and geometric stability analysis), and positional accuracy. The Hipparcos Celestial Reference Frame is, 10 years after it became available, still the primary standard of the optical reference frame, with no significant deviations from the ICRF detected.

Current optical reference frame research is active in 3 areas: a) building on the Hipparcos and Tycho data and going to fainter stars for a densification of the existing optical reference frame (e.g. UCAC and URAT), b) maintaining the link between the currently bright optical reference frame (Hipparcos) and the radio-defined ICRF by observing the optically faint counterparts, and c) preparatory work for a future high accuracy optical reference frame (e.g. SIM and Gaia) which is likely to supersede the VLBI based radio reference frame. In all areas USNO is heavily involved.

7. REFERENCES

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