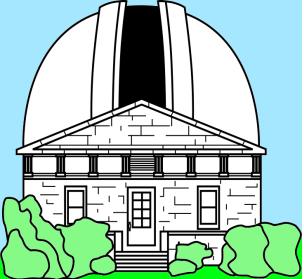


Astrometric Catalogs: radio-optical link

Norbert Zacharias

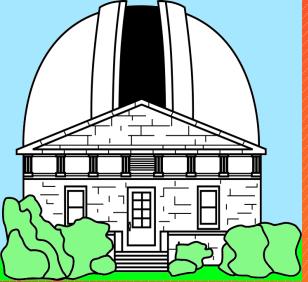
U.S. Naval Observatory
Astrometry Department
Optical Reference Frame Div.

nz@usno.navy.mil

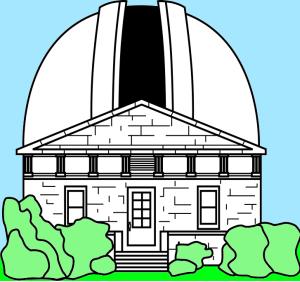


layout

- status radio-optical link issue as of last year
- new data / astrometric catalogs
 - URAT
 - SDSS
 - PanSTARRS
- optical position stability: NOFS 1.55m program
- more sources: WISE mid-IR catalog
- conclusions

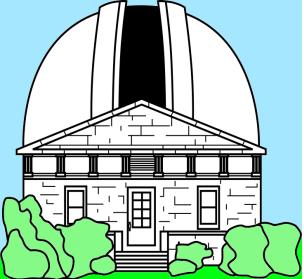


Issue with radio – optical link (review of Dec 2014 talk)

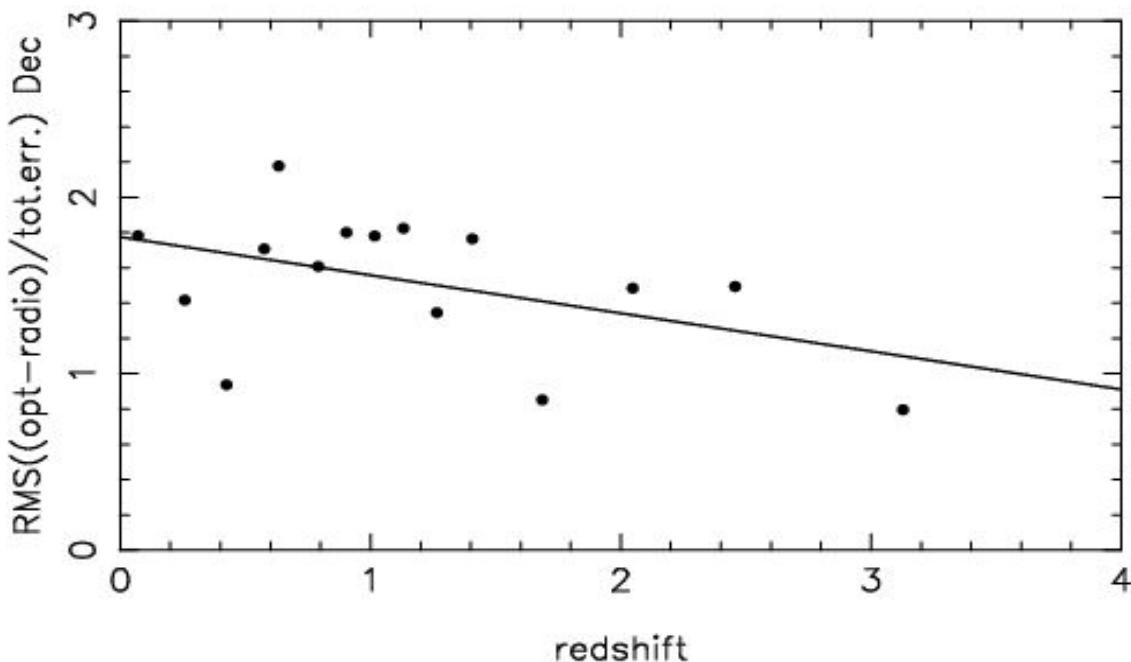
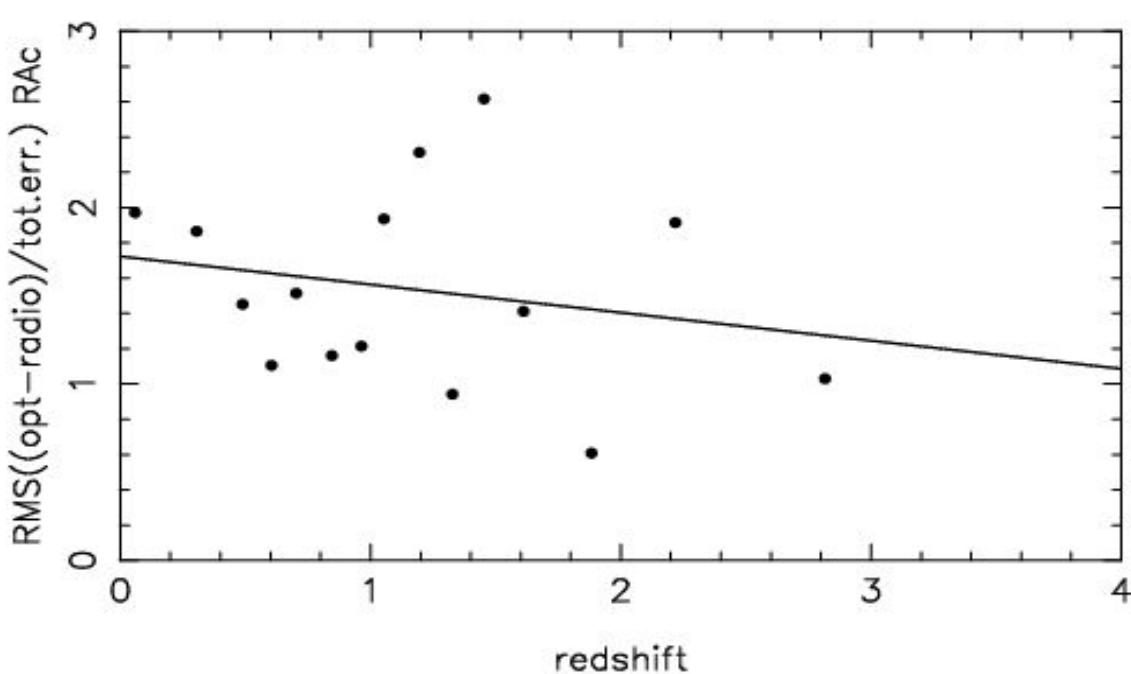


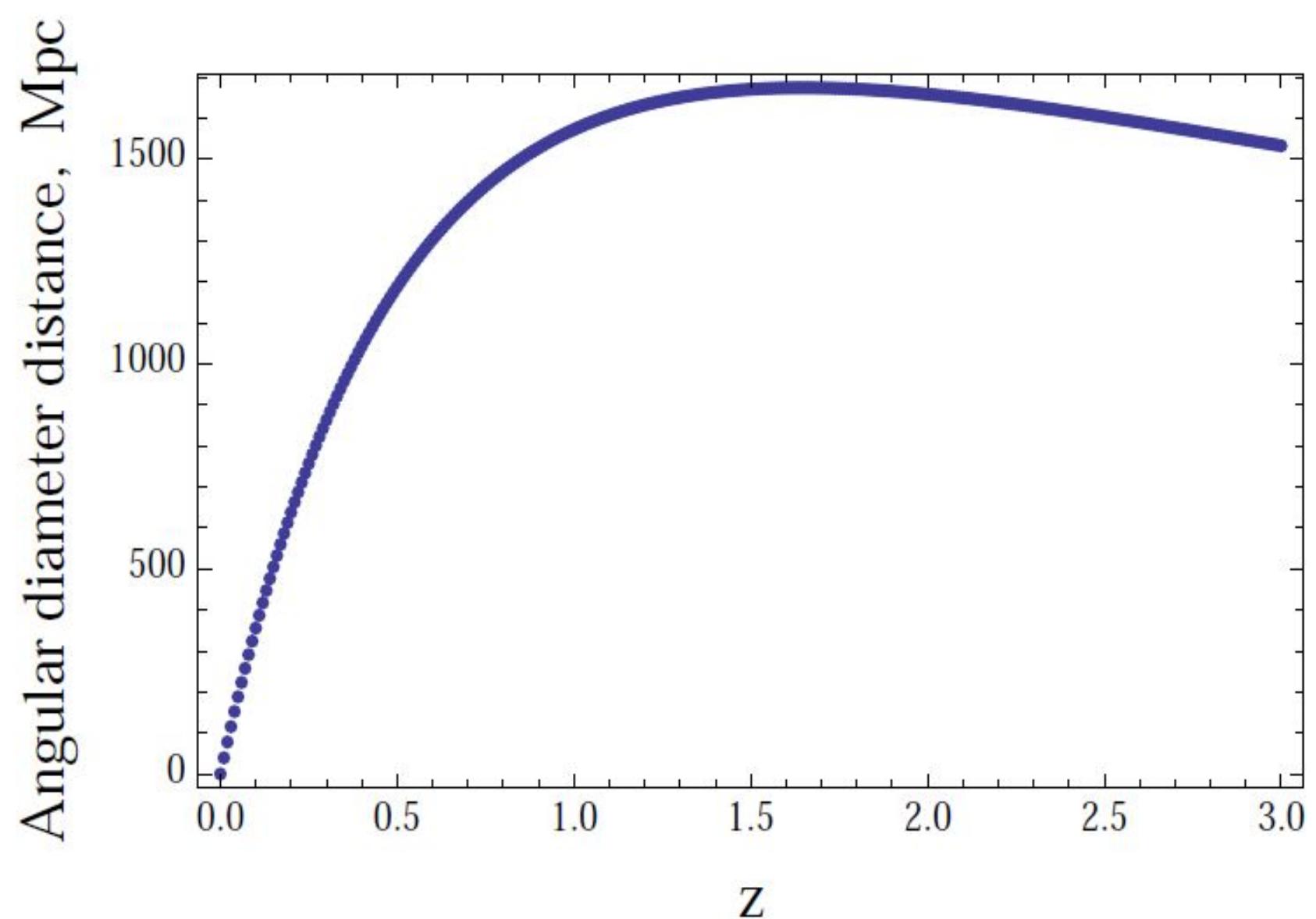
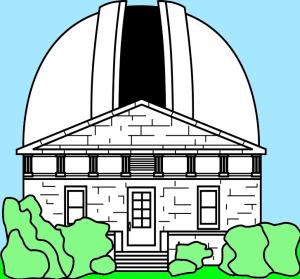
optical / radio center differ

- AJ 147, 95 (2014) paper: radio-optical link observations (CTIO 0.9m telescope vs. ICRF)
- many sources have larger than expected (optical-radio) position differences and f(redshift)
- the more accurate optical observations are, the more “outliers” are seen: extrapolate: at around 10 mas most (all ?) sources are affected
- results indicate non-coincidence of radio and optical centers of emission due to astrophysical reason: optical source structure (host galaxy ?)

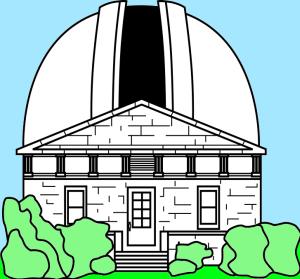


- radio-optical offsets correlate somewhat with redshift (z) !
- seen in earlier studies as well (da Silva Neto et al. 2002)
- not issue of optical reference frame (system.err. CCD data)



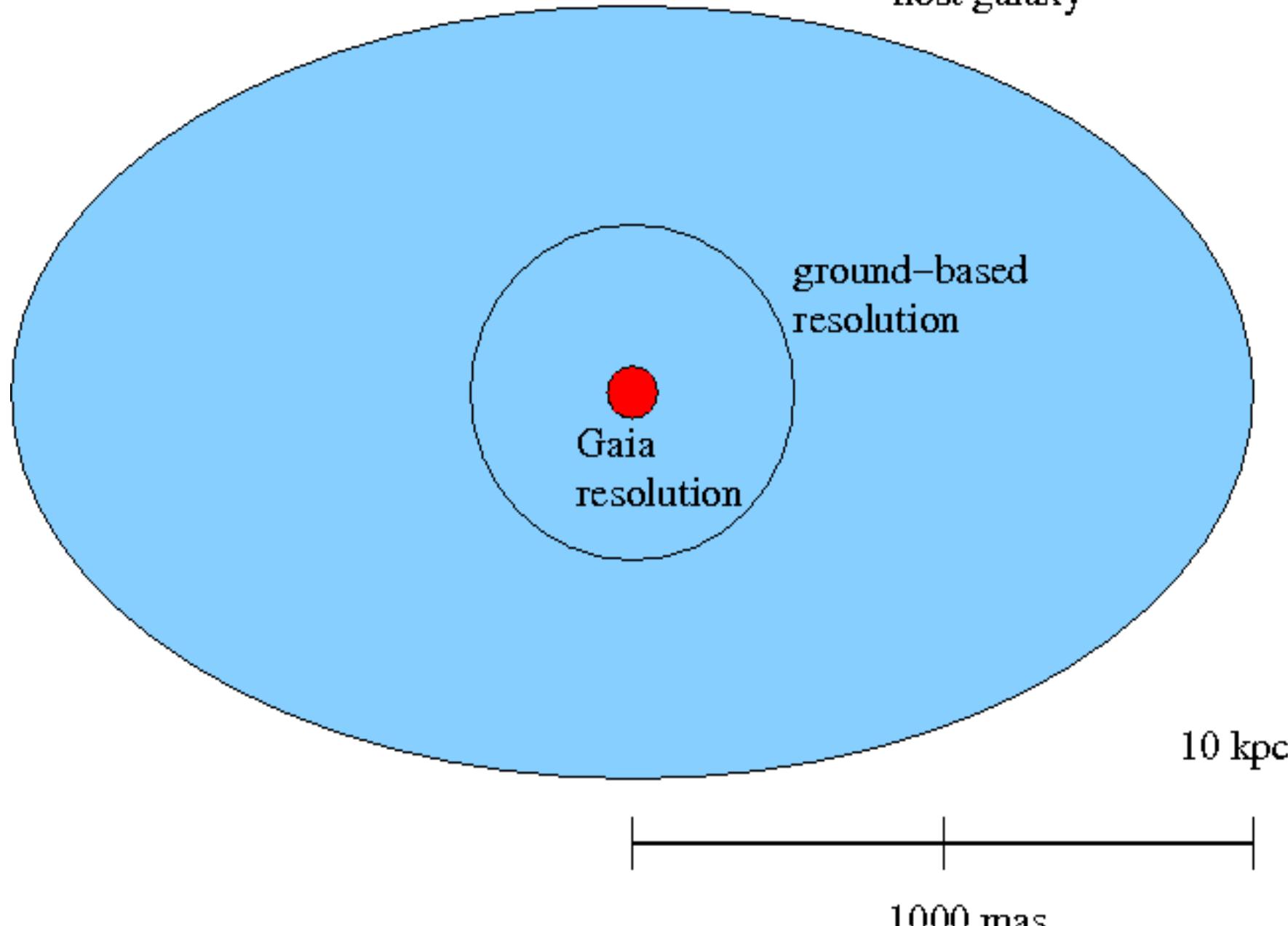


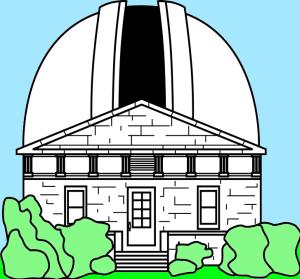
- Valeri Makarov (priv. Comm.)
- most ICRF QSOs: about 1 Gpc angular distance



at 1000 Mpc angular distance: 1 kpc = 200 mas

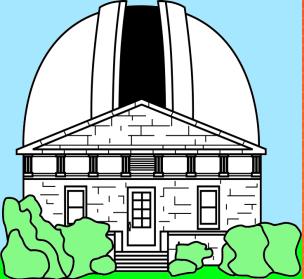
host galaxy



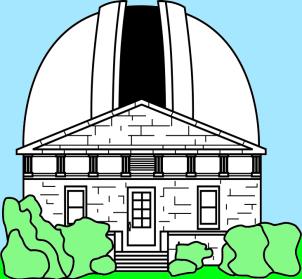


Issue with Gaia-ICRF link?

- maybe, depending on level of the Detrimental Astrophysical Random Noise (DARN)
 - even a 1 mas DARN would be dominating the error budget in the Gaia / ICRF link
 - is there a sub-class of objects with much lower DARN? (elliptical host galaxies?)
 - how to identify these?
 - how soon can DARN be estimated from Gaia observations?
 - is radio-optical link accuracy on 0.5 mas level good enough?

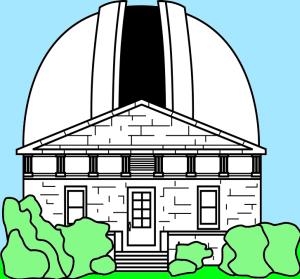


USNO Robotic Astrometric Telescope (URAT)

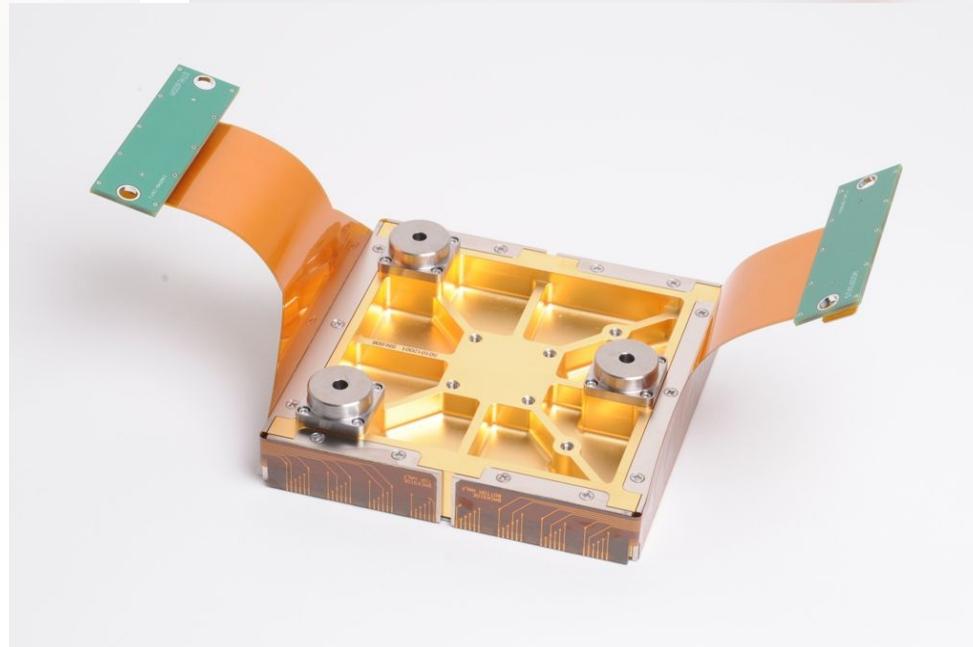
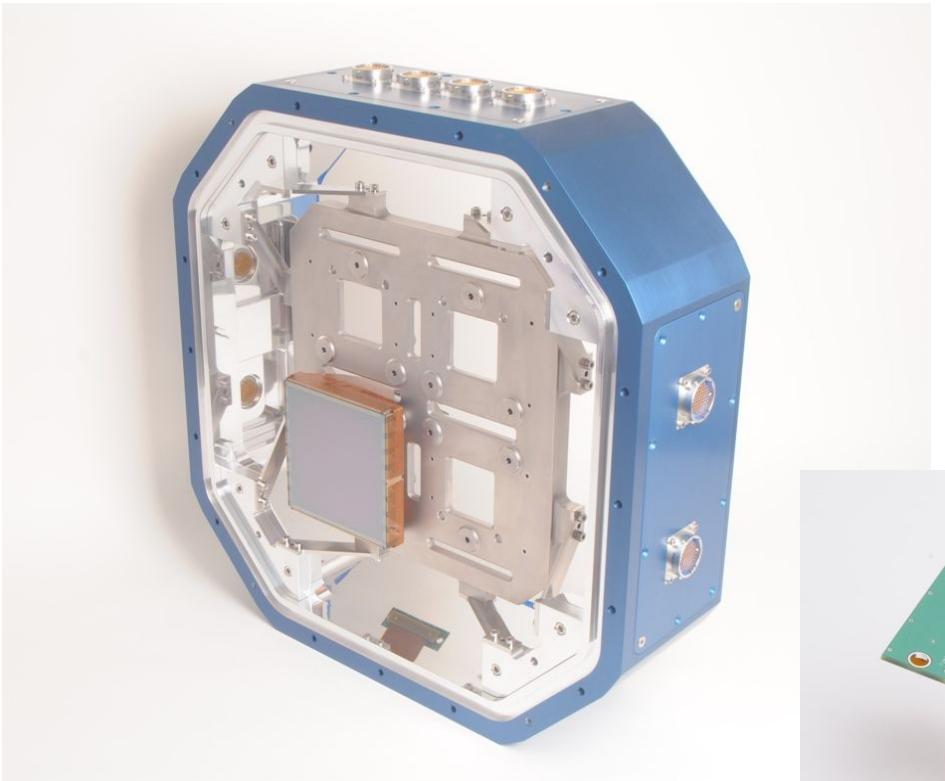


URAT project

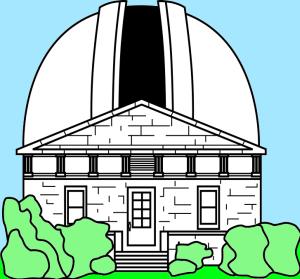
- complete re-make of astrograph 2008-2010
- 28 sq. deg. per exposure! (4 detectors)
- 10 mas per image (well exposed stars)
- multiple sky overlaps / year, 7 - 18 mag
 - clocked anti-blooming: extend dynamic range
 - around full Moon: short expos. grating: 3 – 15 mag
- observe 3 years at NOFS, then CTIO
- solve for positions, motions + parallax



spring 2010, 10k packaging (STA)

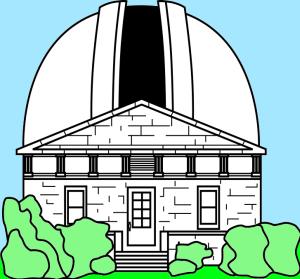






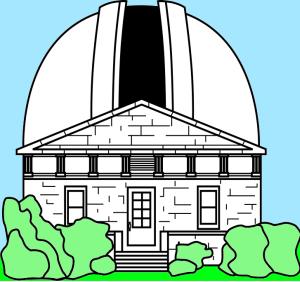
status of URAT project

- use “red lens” with modified astrograph
- detector: STA 10,560 by 10,560 pixels, 9 um
 - “4-shooter” camera funded FY08
- URAT observing program
 - 1st light of URAT in DC: September 2011
 - begin URAT survey at NOFS: April 2012
 - end of Northern Hemisphere observing: June 2015
 - 98,370 exposures taken, each about 1 GB
- URAT1 catalog published 2015 (2 years data)

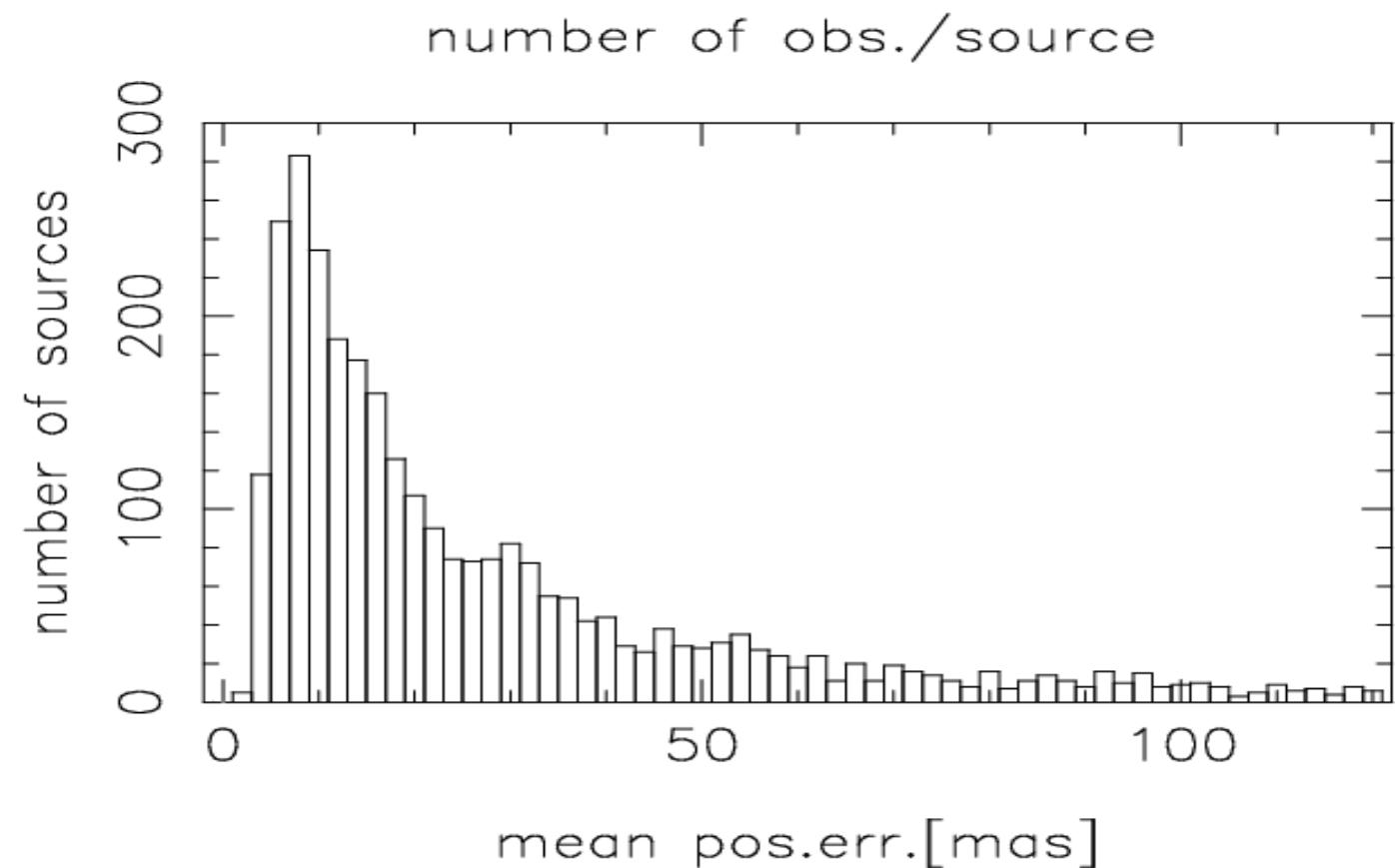
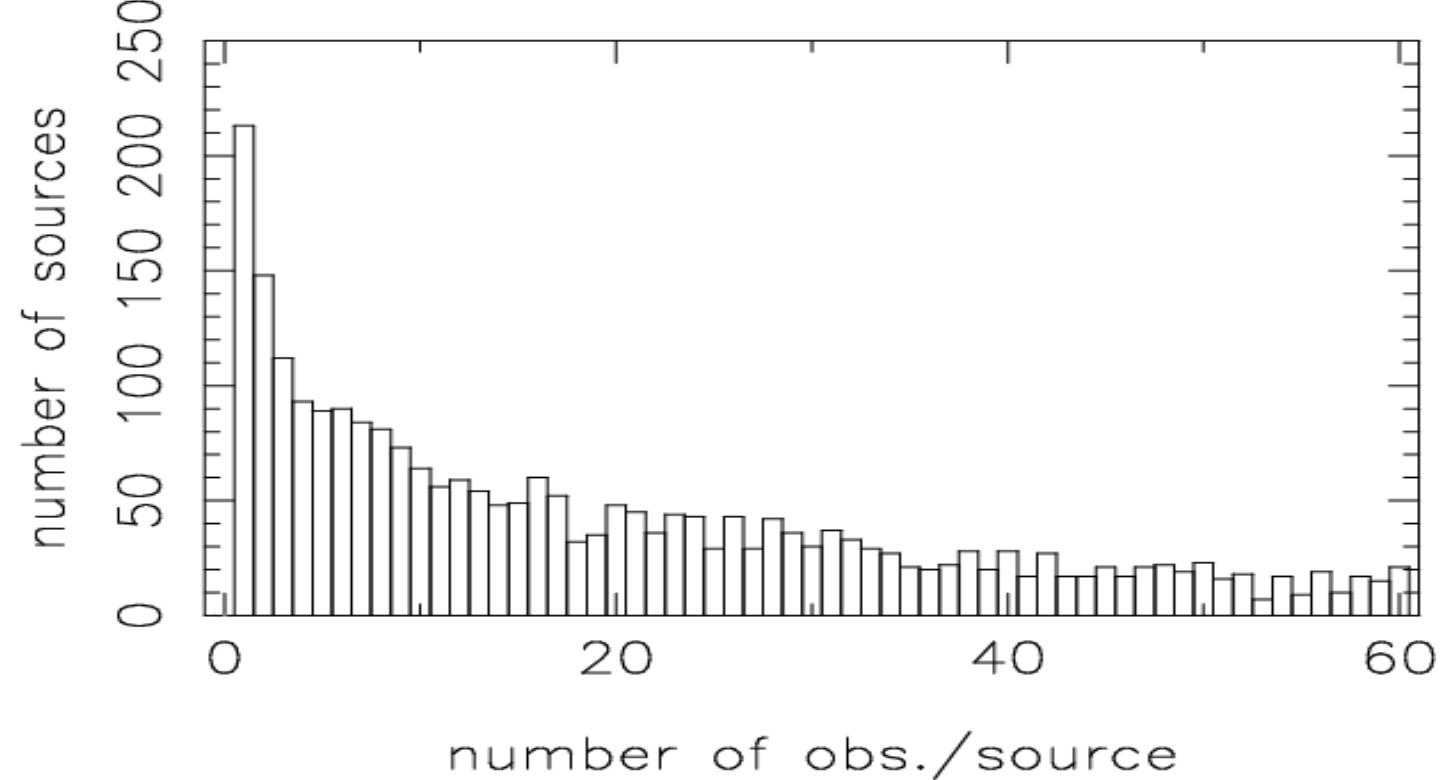


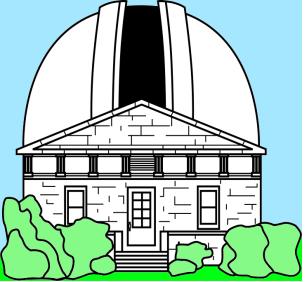
optical (URAT) – radio (VLBI)

- URAT data up to Mar 2015 (Dec = -12 ... +89)
- VLBI: Petrov (2014) RFC: over 9000 sources
- supplement by OCARS photom, redshift data
- 3076 radio sources matched with URAT, of these 2432 have redshifts
- 2429 of 3076 = high quality
($n \geq 4$ obs, $\sigma \leq 50$ mas)
- add 10 mas RMS to URAT random errors to account for possible systematic errors

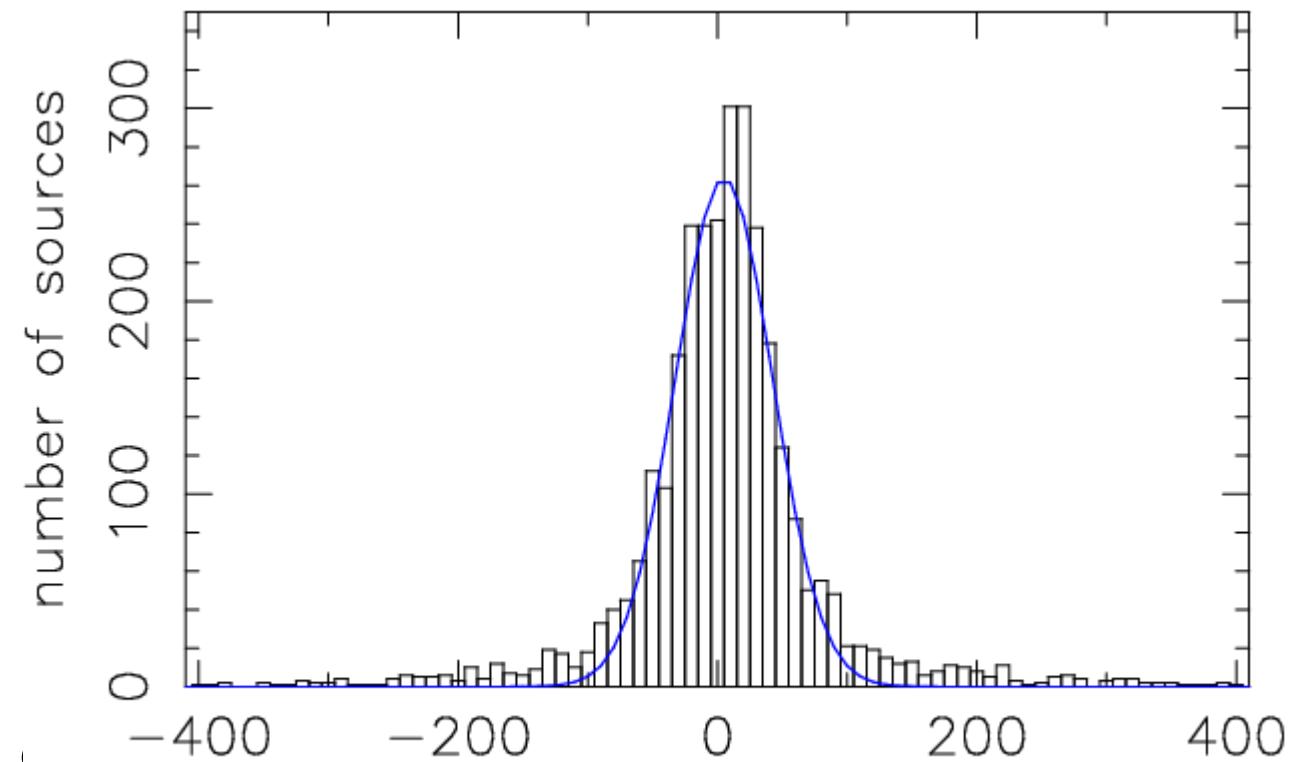
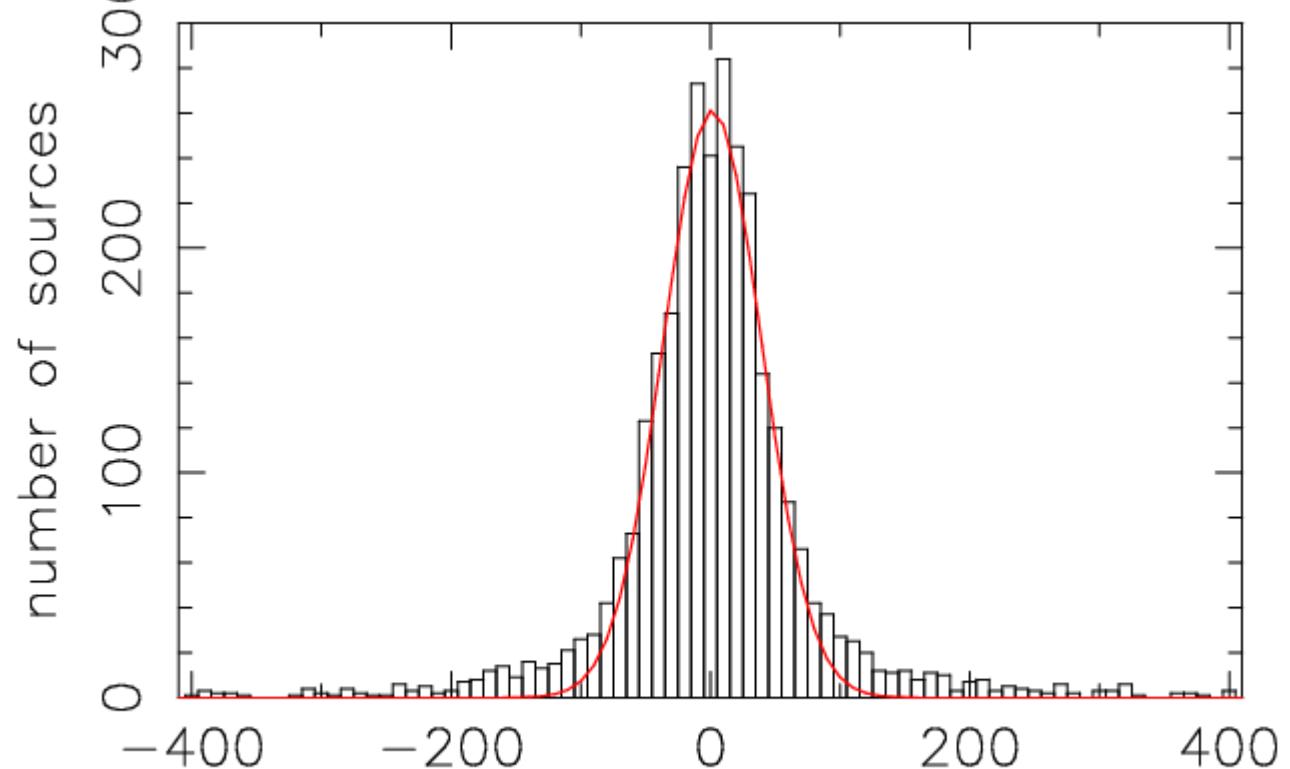


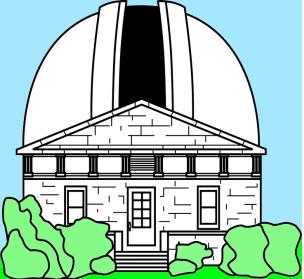
URAT data of radio sources



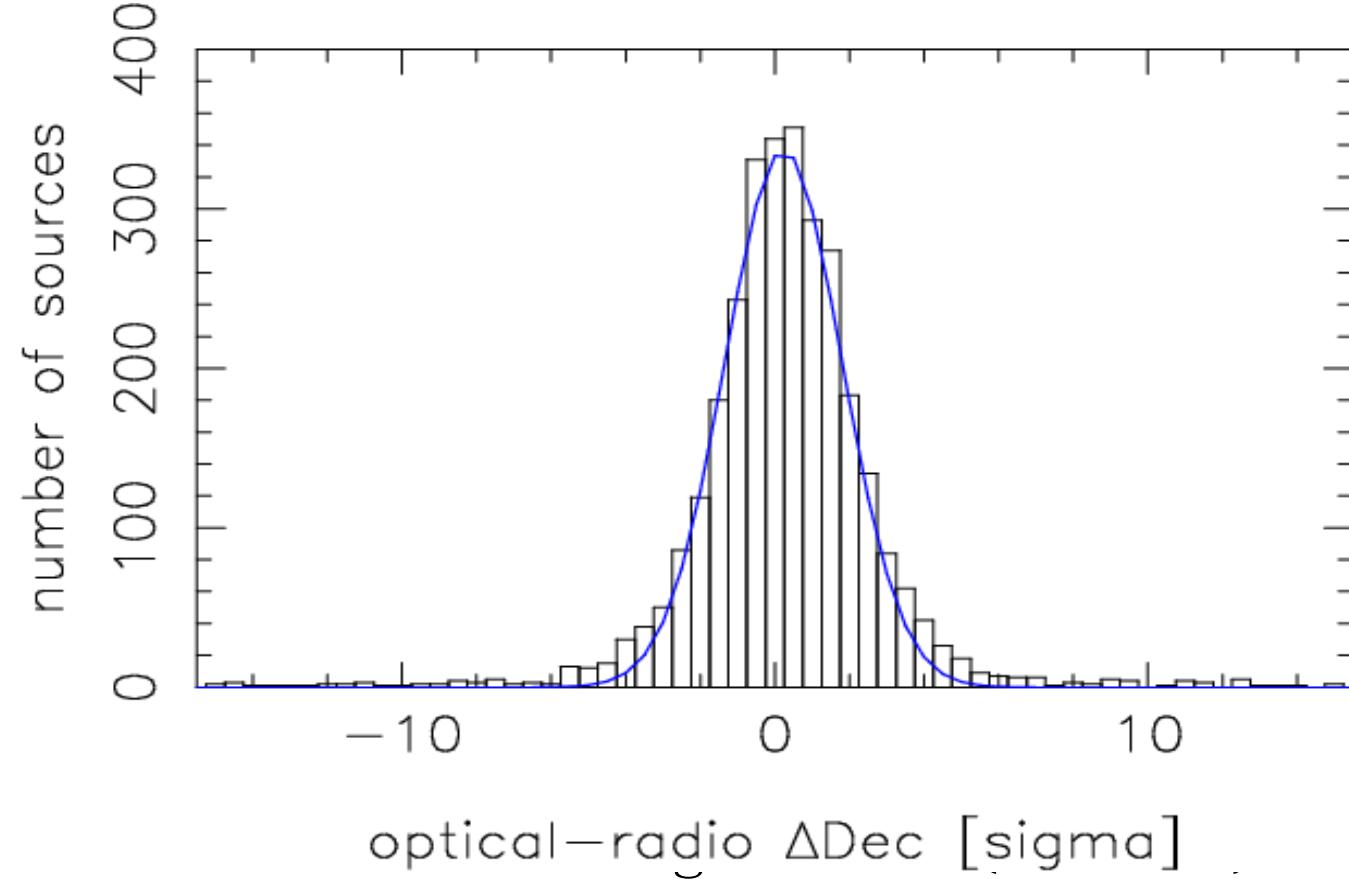
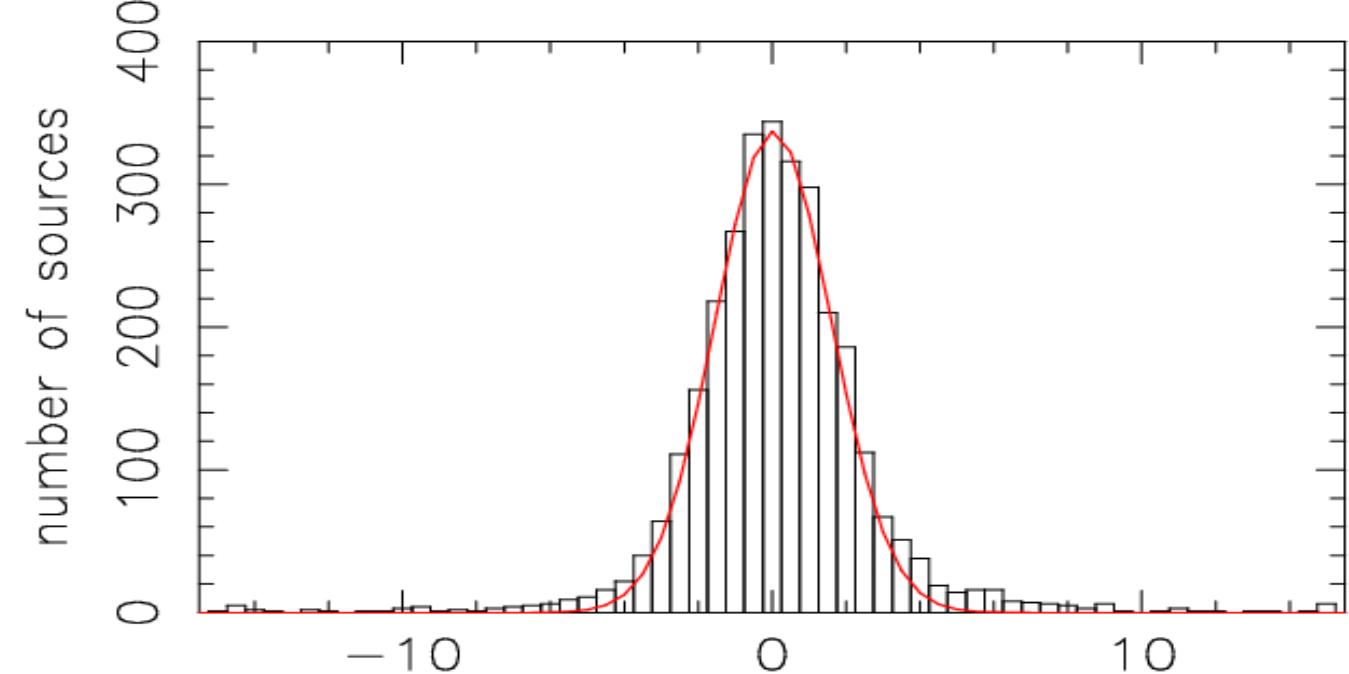


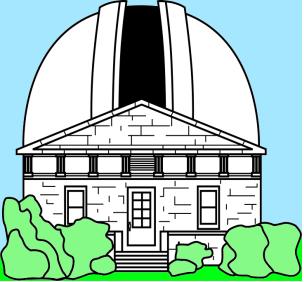
optical
- radio
RA,
Dec
[mas]



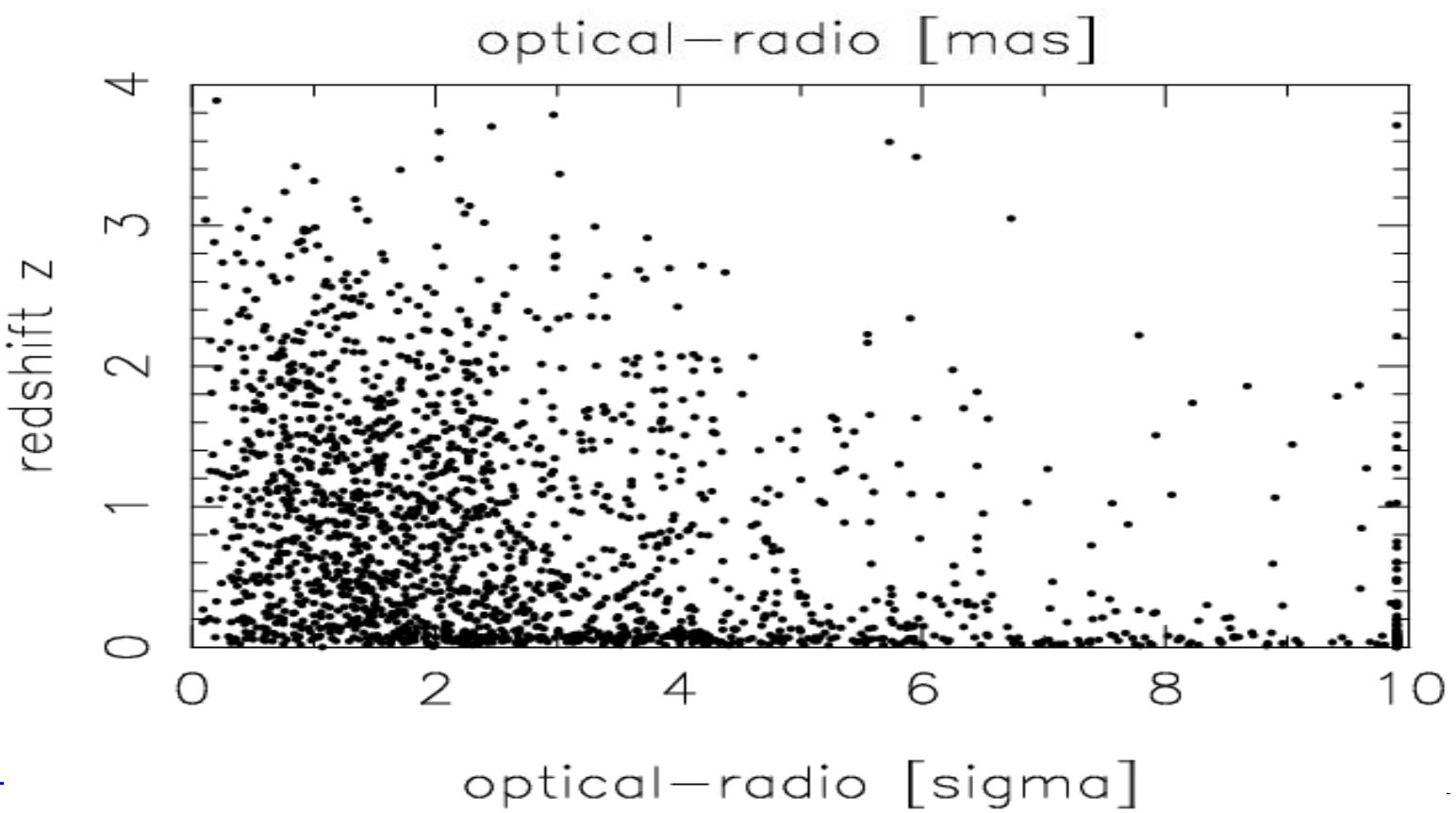
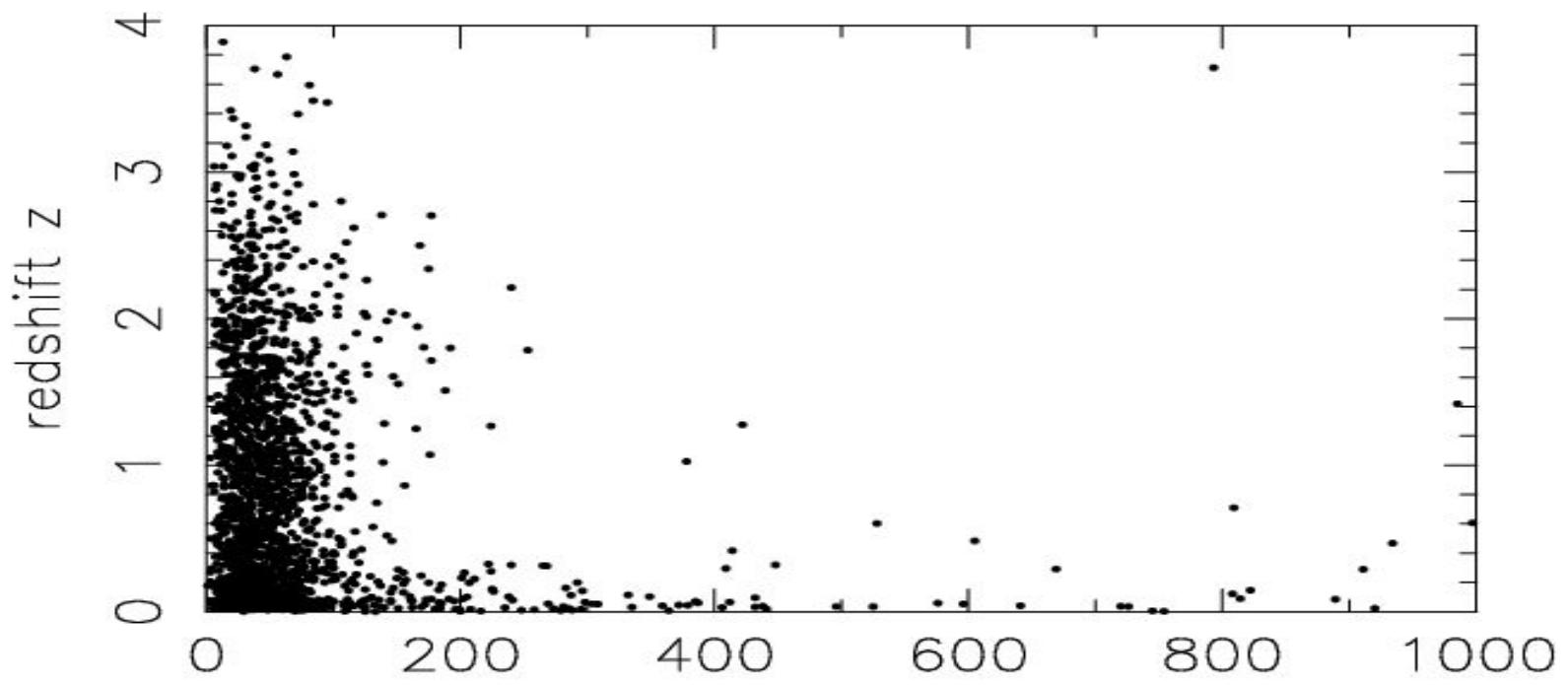


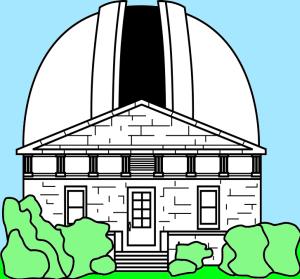
**core is
1.7x
too wide
plus
“fat
wings”**



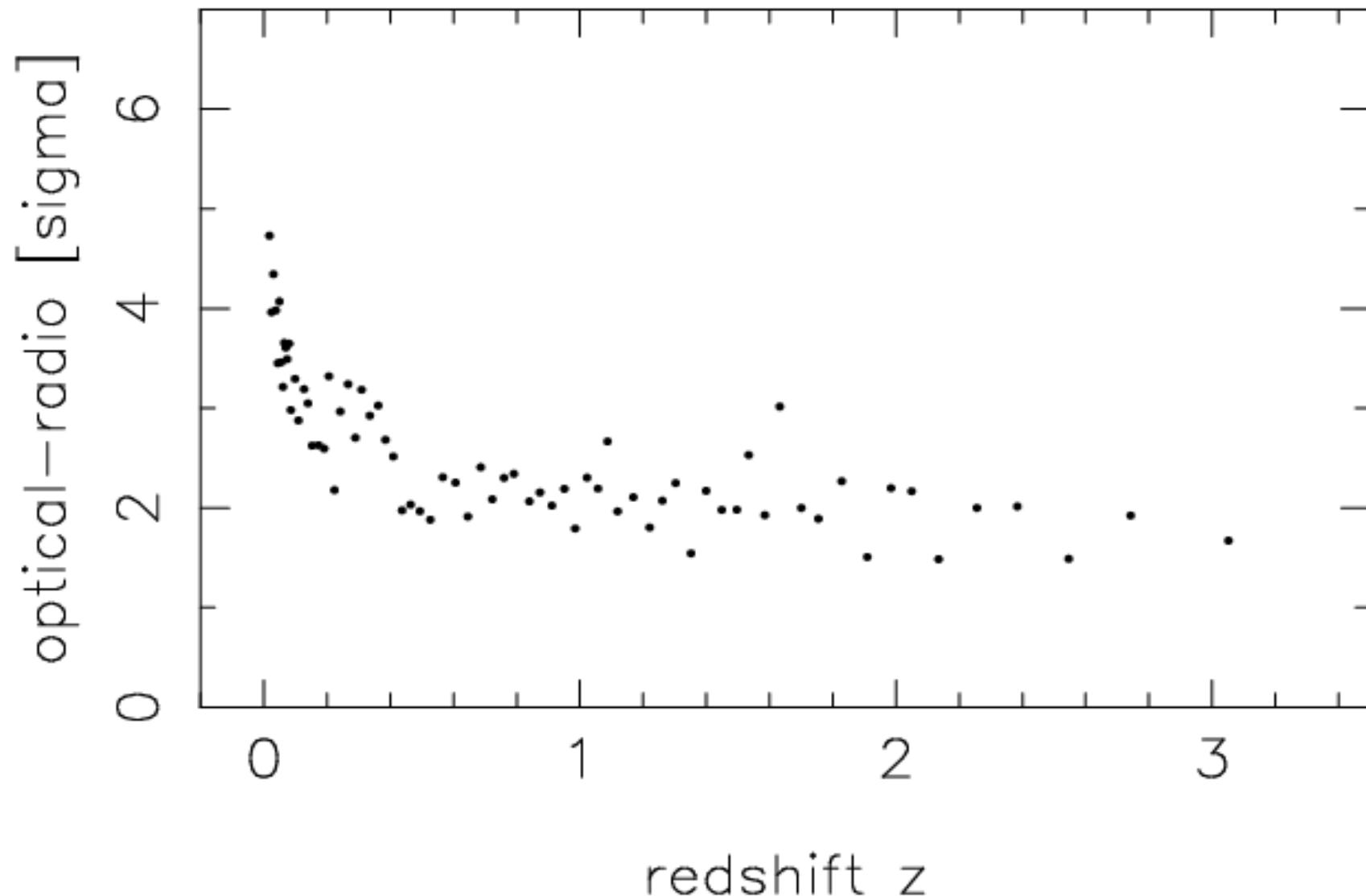


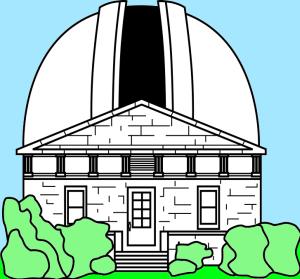
URAT - VLBI vs. z [mas] [sigma]





URAT-RFC, nbin = 25, excl.>9

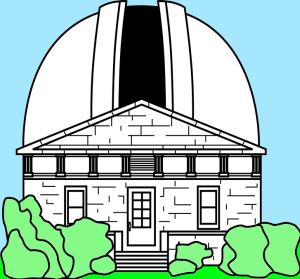




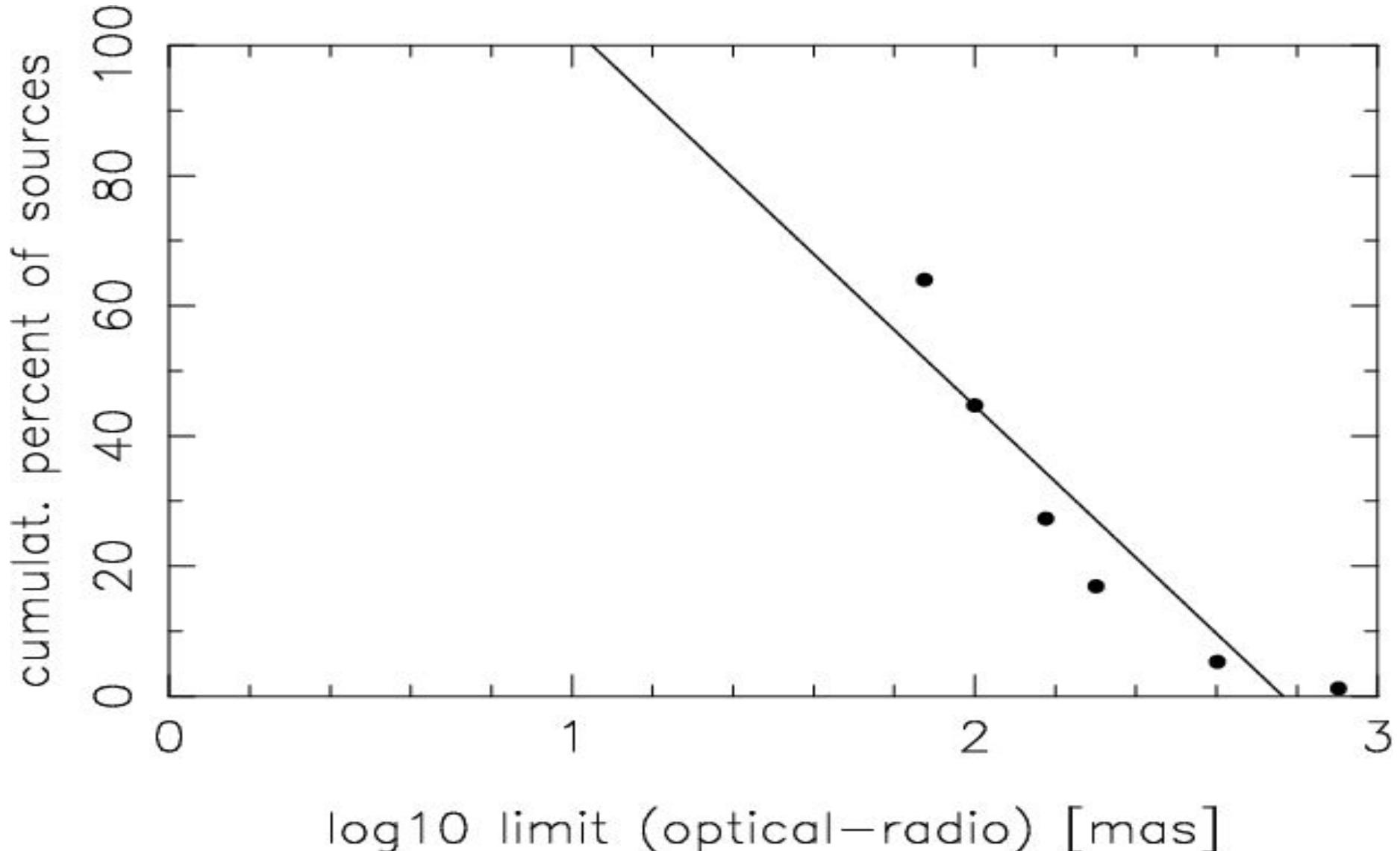
high precision subset

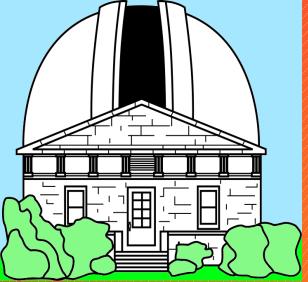
pick only those with $n \geq 4$ URAT observations, and
radial pos.err. ≤ 30 mas (incl. 14 mas err.floor)
= 1540 sources in this set

optical-radio	URAT-VLBI	number	% of 1540	cum. %	mean pos.dif.
[mas]	group	sources			[mas]
<hr/>					
over 800	1	19	1.2	1.2	902.2
800...400	2	63	4.1	5.3	544.9
400...200	3	178	11.6	16.9	271.3
200...150	4	160	10.4	27.3	174.0
150...100	5	268	17.4	44.7	120.6
100... 75	6	297	19.3	64.0	86.4
<hr/>					

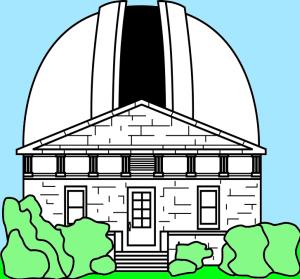


extrapolation of “outliers”



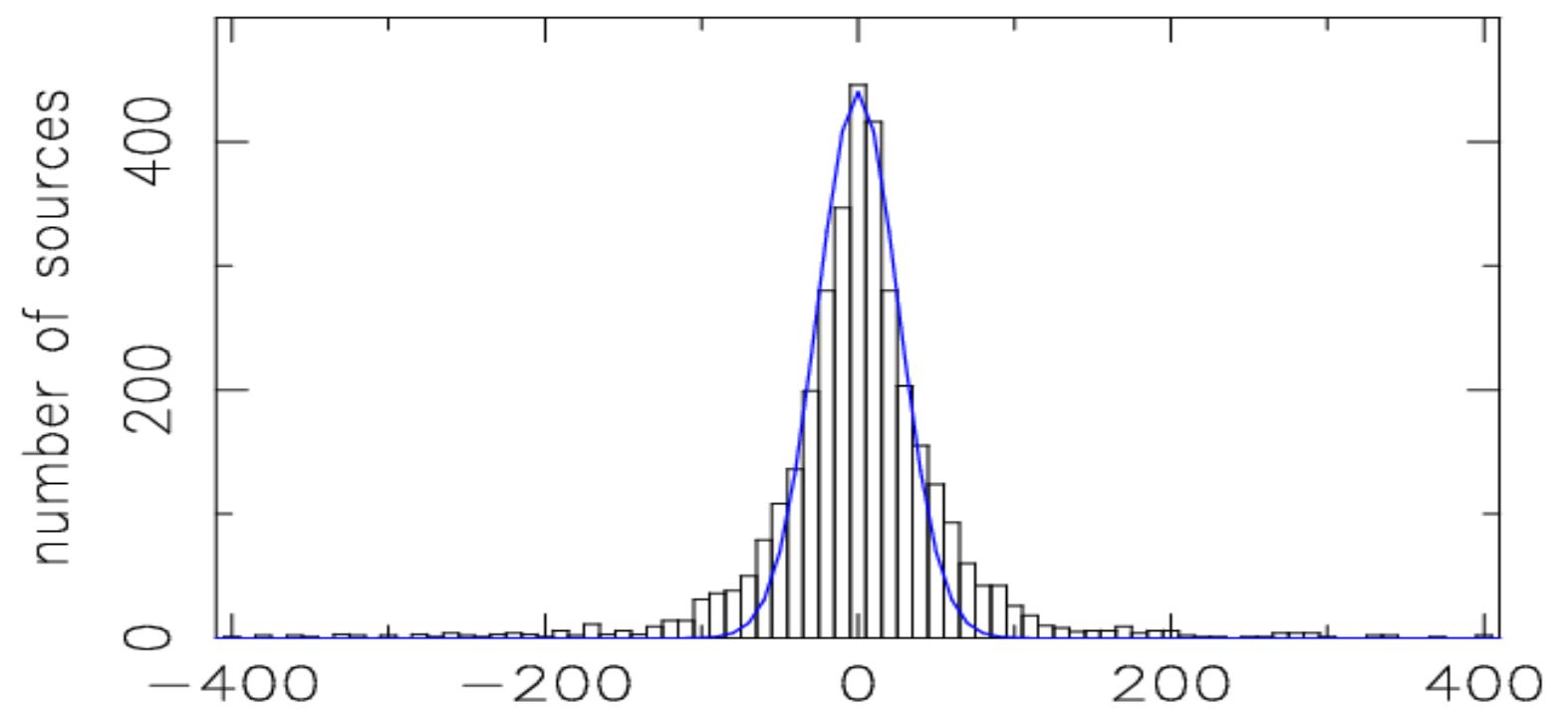
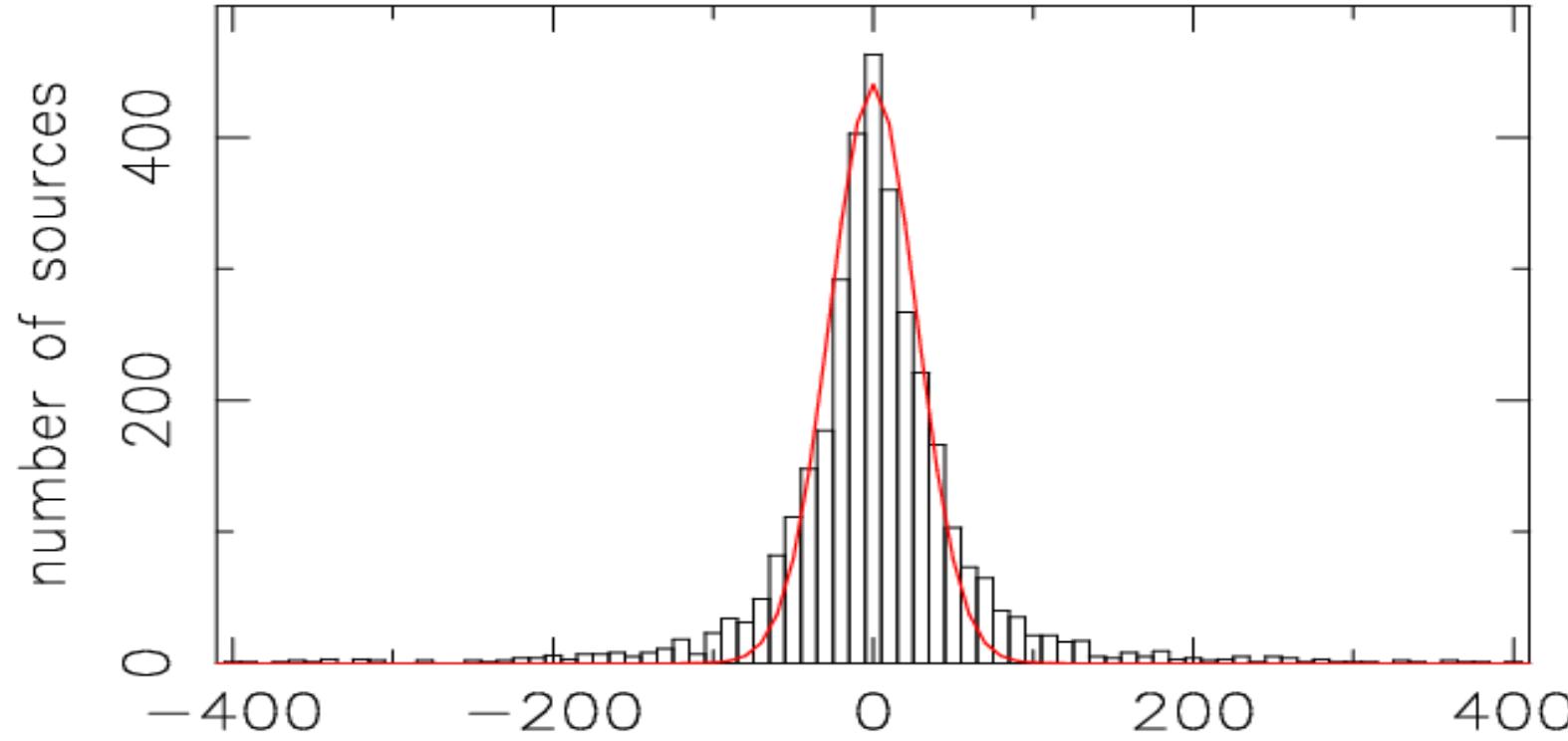
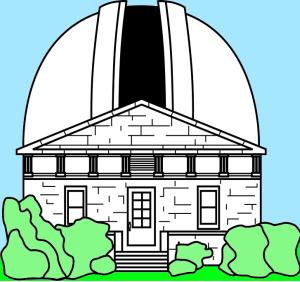


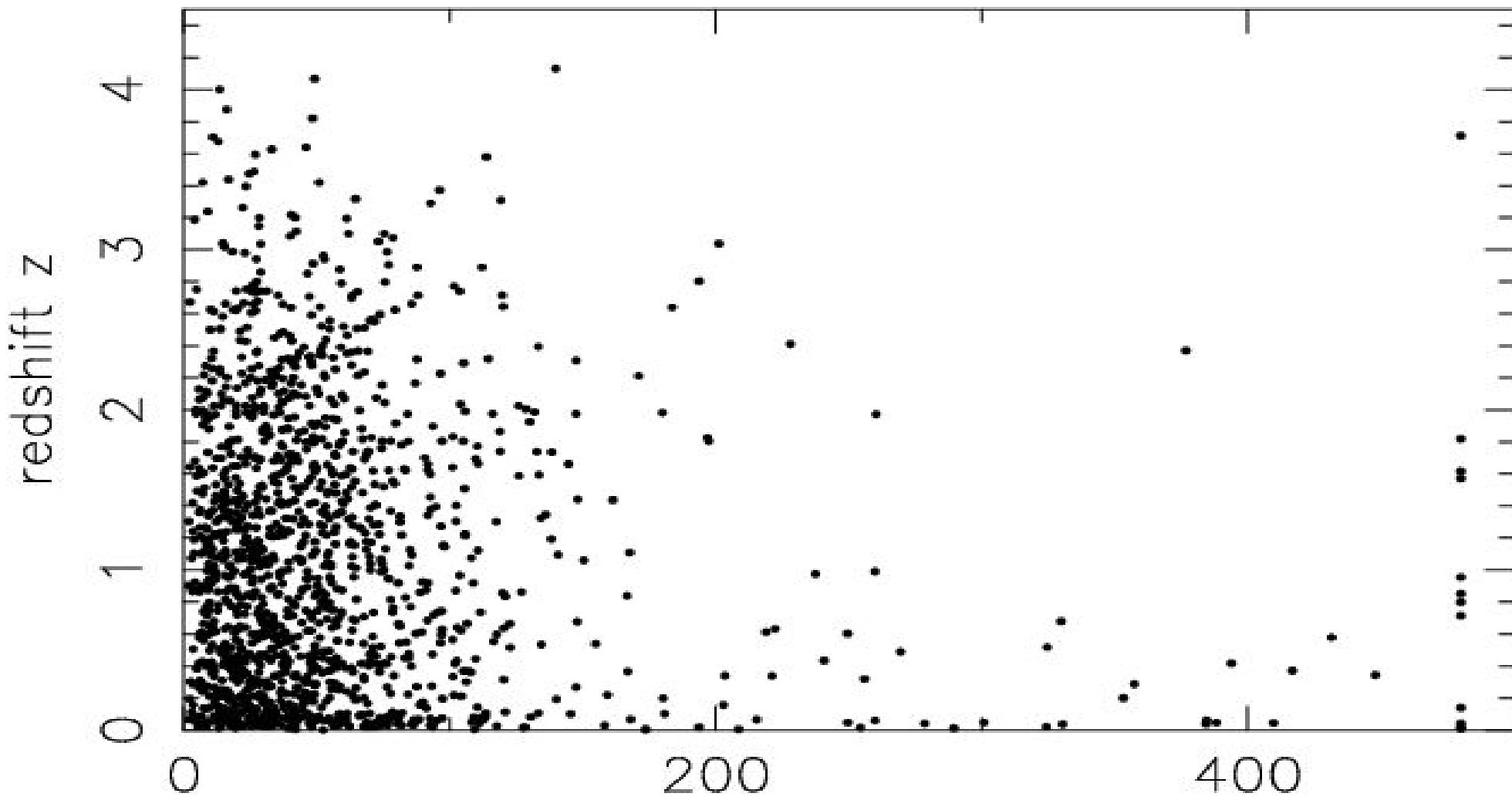
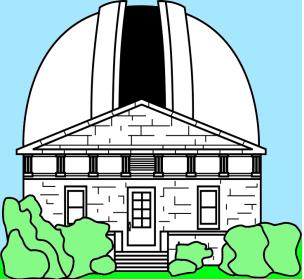
SDSS vs. radio (new comparison)



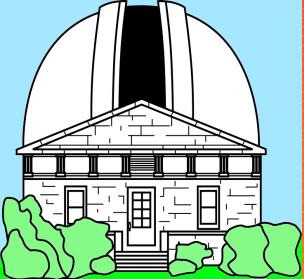
SDSS optical – VLBI radio

- Orosz & Frey (2013): DR9 vs. ICRF2:
 - 1297 sources, 60 mas level, use in Z & Z (2014)
- now compare **DR12** vs. all **RFC** (Petrov)
 - over 9100 VLBI radio sources total
 - **3427 sources match** with SDSS DR12 within 1"
 - 1434 of these have valid redshift from OCARS
 - **core** of (optical-radio) pos.diff. = **27 mas** per coord.
 - again: "**fat wings**", too many > 3-sigma "outliers"

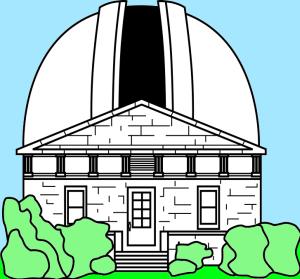




SDSS DR12 – VLBI(RFC) [mas]

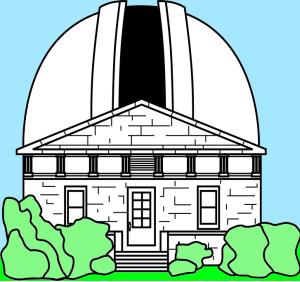


Pan-STARRS vs. radio (see talk by Valeri Makarov)

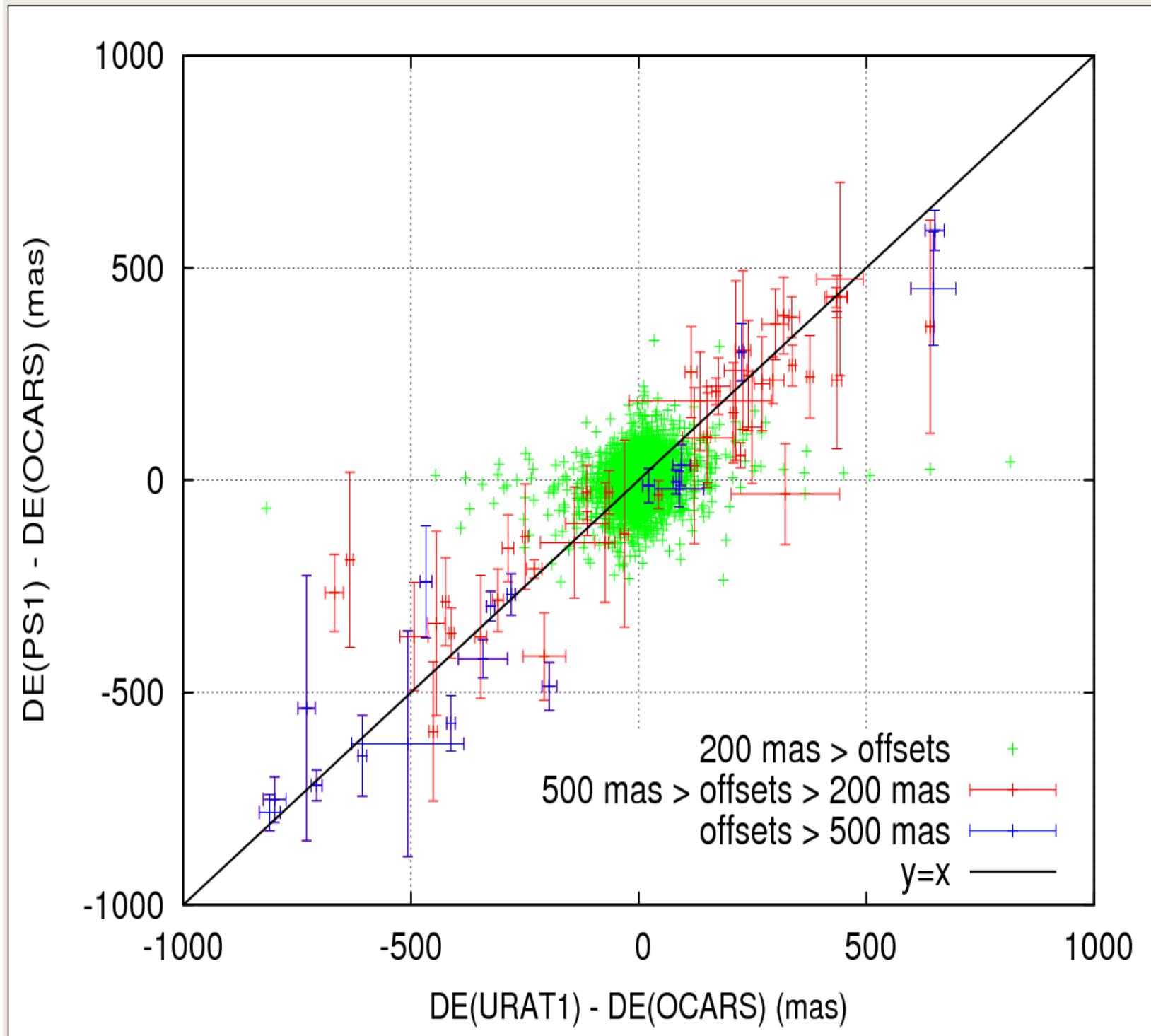


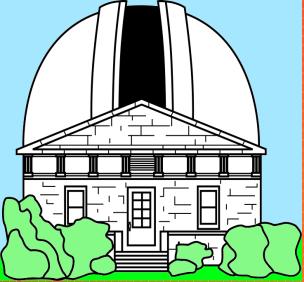
Pan-STARRS data

- PS1 data global solution (Makarov, Berghea)
- compare to URAT1 and ICRF (Frouard)
- proper motion errors in PS1 consistent with simulations
- observed position differences PS1 vs. ICRF larger than expected from simulations:
 - systematic errors in optical data (magnitude equation?)
 - astrophysical radio-optical position offset ?
- see presentation by Valeri Makarov

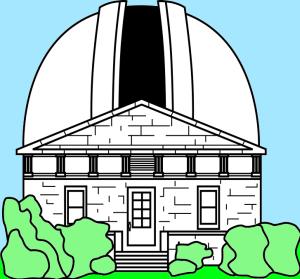


PS1, URAT vs. radio (Dec)



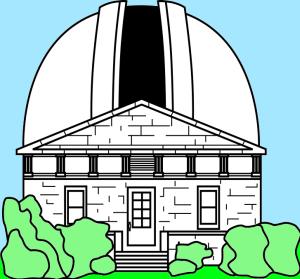


Optical center stability (NOFS 1.55m program)

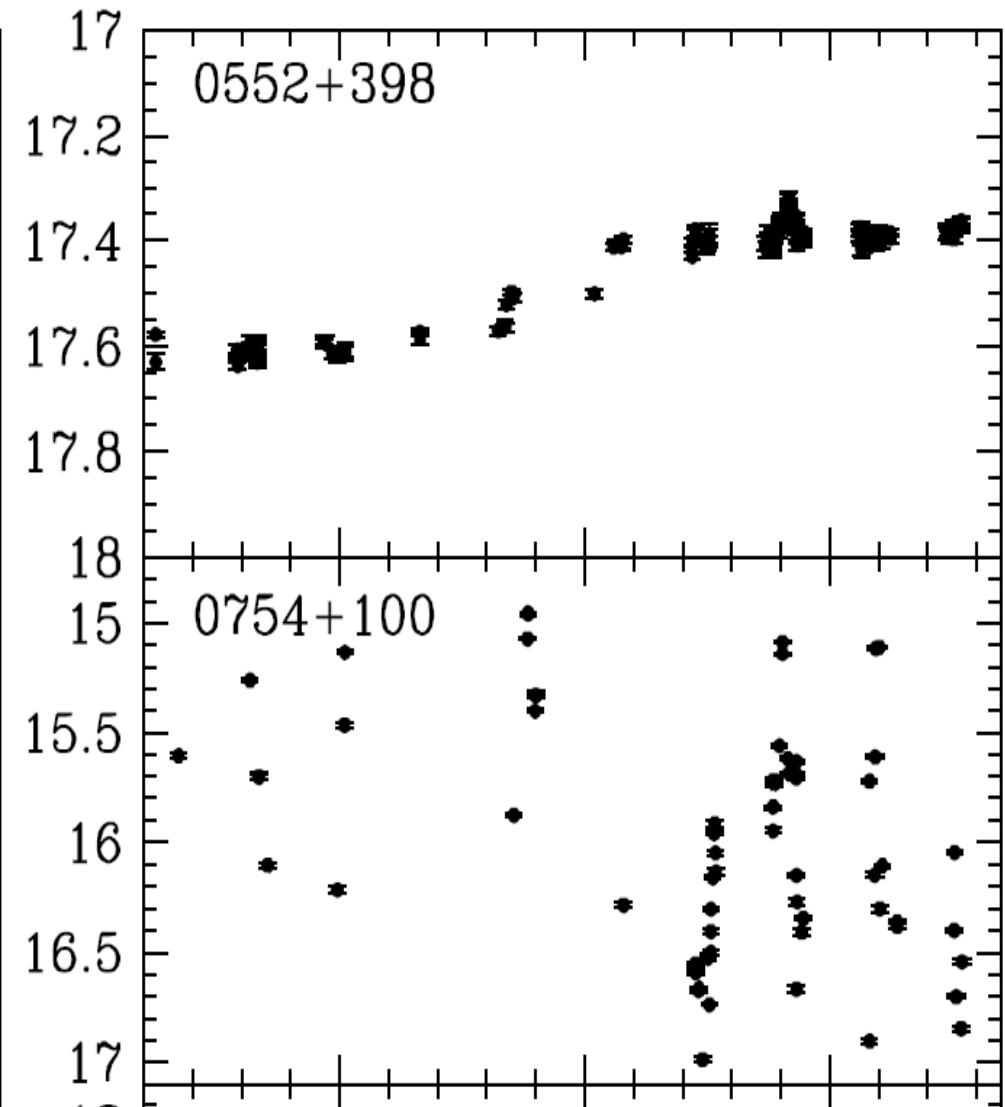
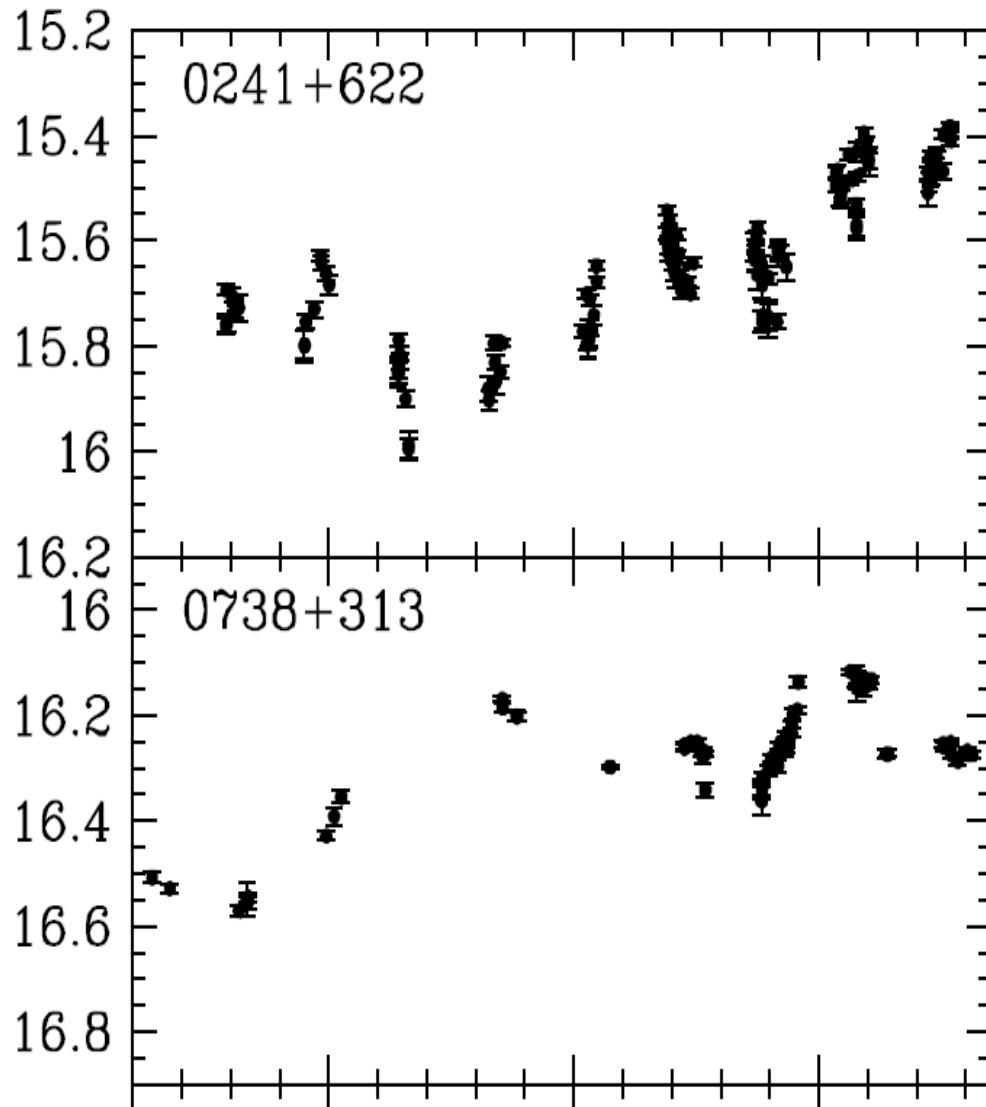


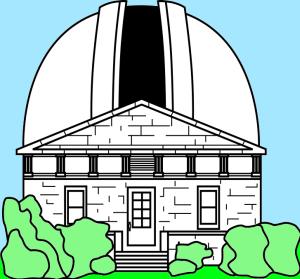
observe sample of ICRF

- Naval Observatory Flagstaff Station (Harris, Dahn)
- 1.55 m aperture f/10 reflector, 13.5 arcsec/mm
- decades long parallax program (**sub-mas**)
- 12 ICRF sources (range of z, mag, type)
- 2002 to 2011, initially for SIM prep.science project
- handle as “parallax star”: fit proper motion, par.
- look at position residuals and photometry
- H. Harris et al. (2015) in prep.

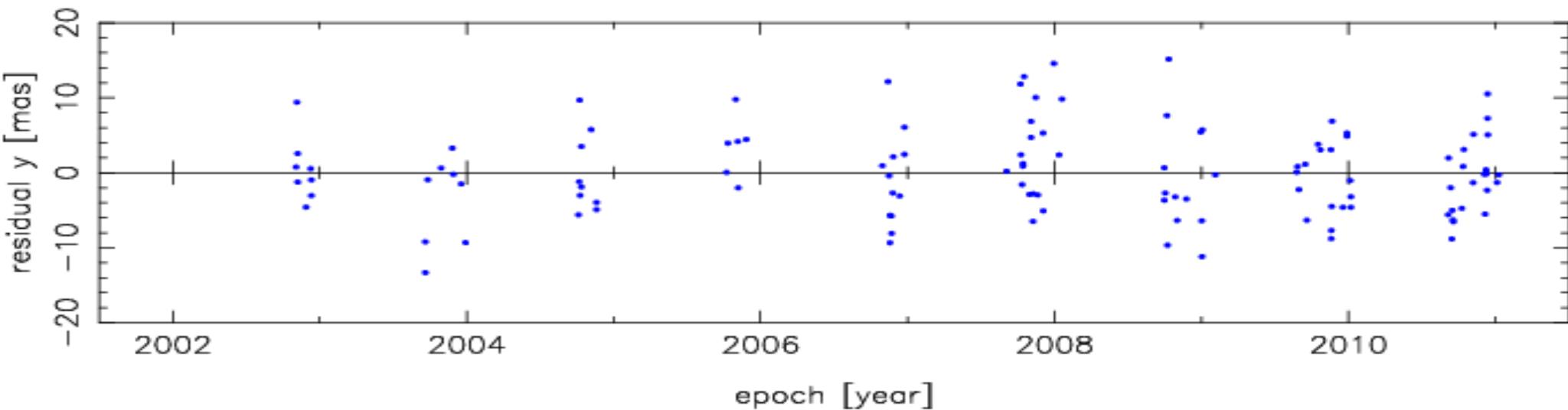
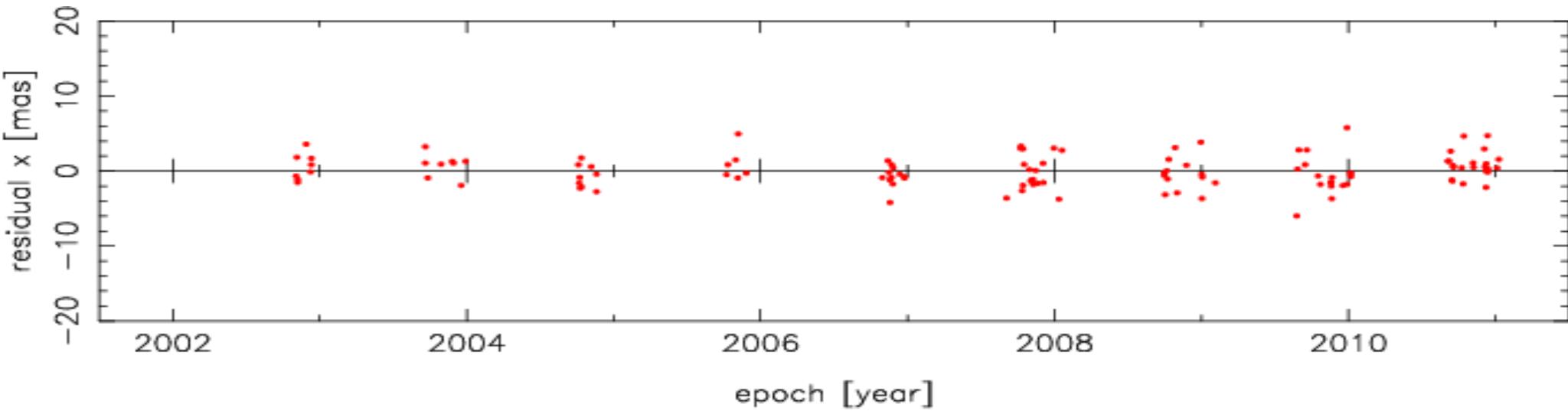


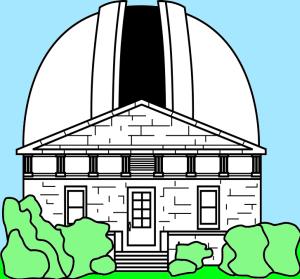
NOFS 1.55m photometry



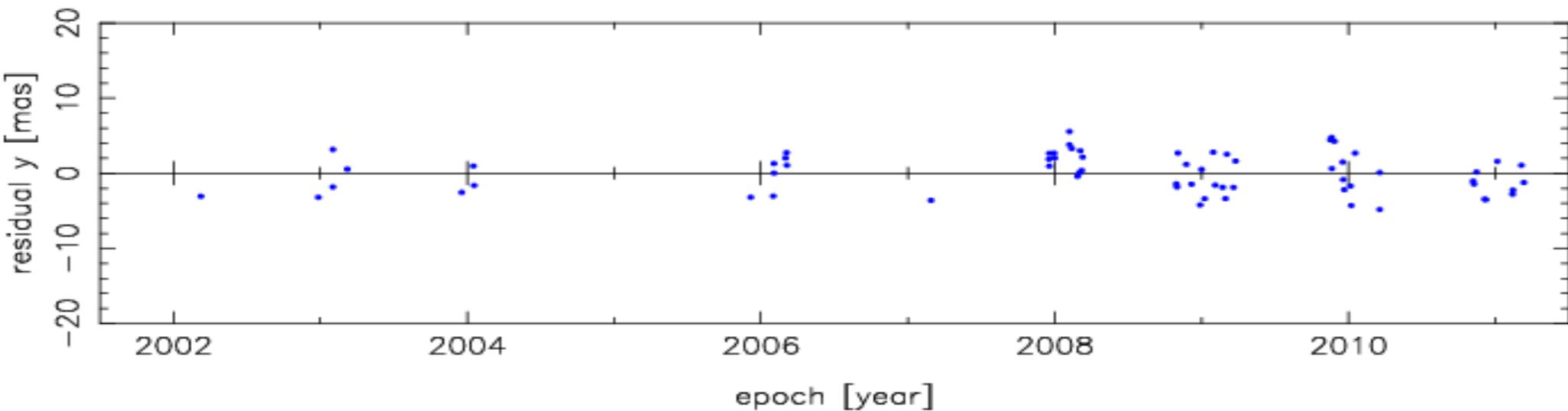
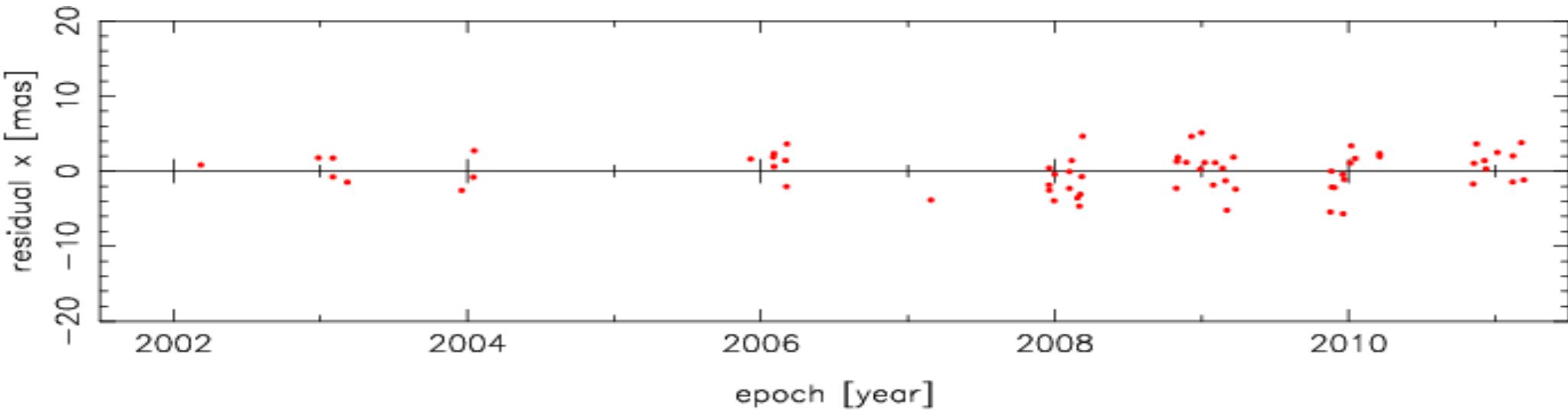


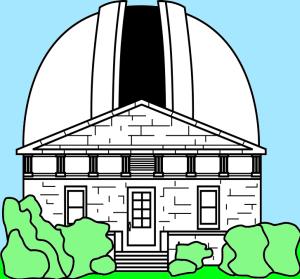
pos.resid. 0241+662 z=0.04



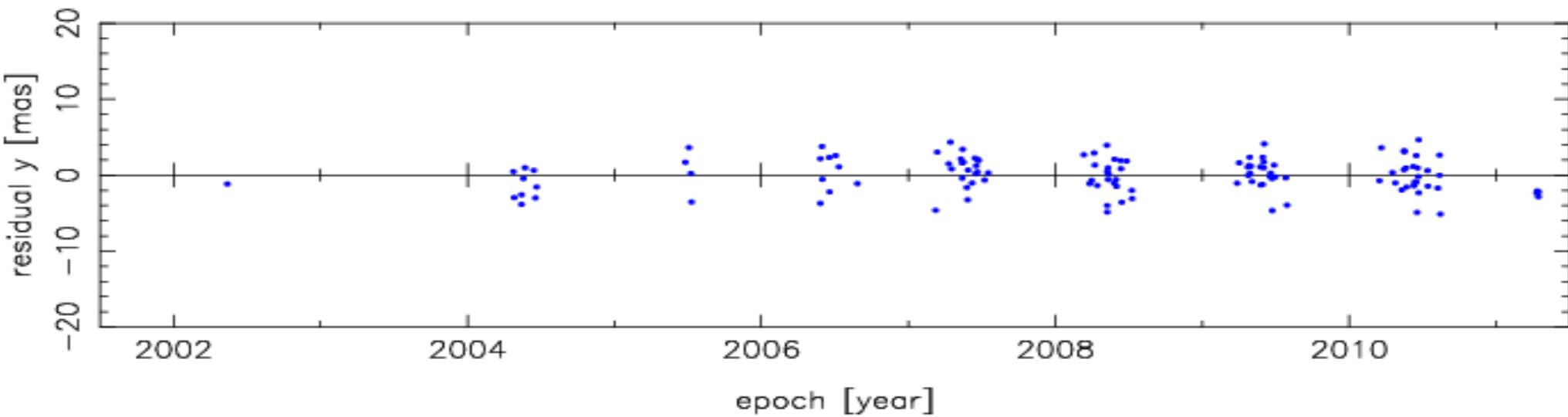
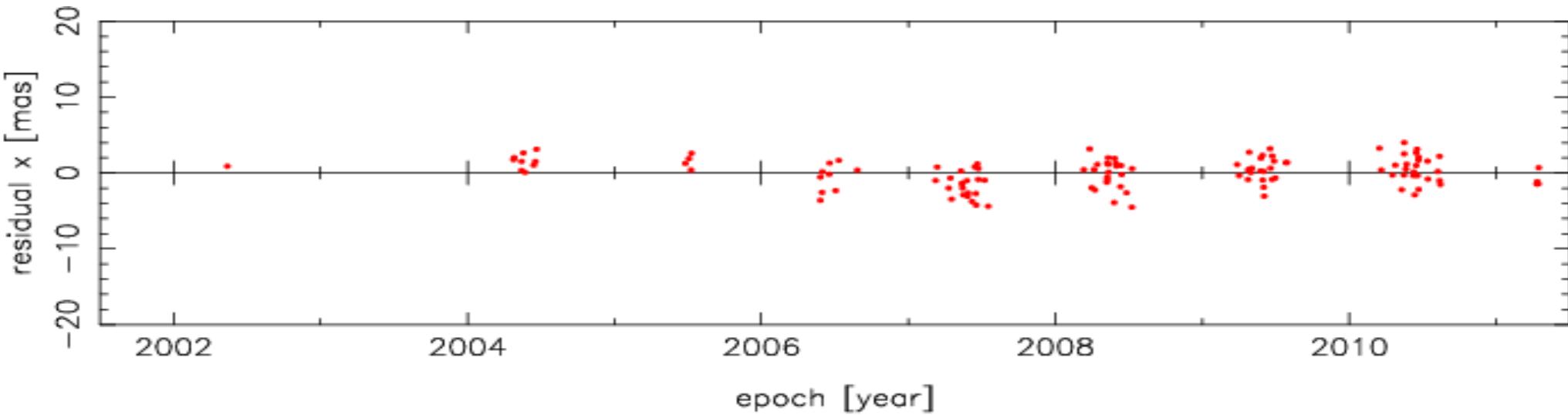


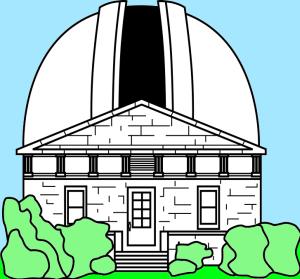
pos.resid. 0754+100 BL-Lac





pos.resid. 1656+053 z=0.89

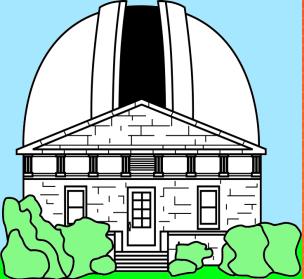




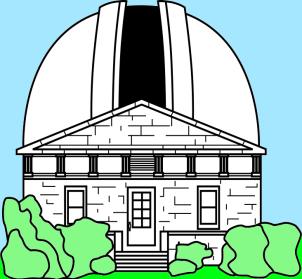
NOFS 1.55m ICRF sample

object name	source type	z	nn	Rmax observed	Rmin photom.	dmag	dxy mas

0241+622	QSO	0.04	102	16.0	15.4	0.6	10
0552+398	QSO	2.37	132	17.6	17.4	0.2	2
0738+313	QSO	0.63	61	16.6	16.1	0.5	--
0754+100	BL	0.66	61	17.0	15.0	2.0	2
0839+187	QSO	1.27	71	16.5	16.0	0.5	2
0851+202	BL	0.31	64	15.0	13.1	1.9	2
0912+197	BL	1.52	78	16.0	15.1	0.9	2
1656+053	QSO	0.89	109	16.6	16.5	0.1	2
1830+285	QSO	0.59	146	17.8	17.1	0.7	--
1937-101	QSO	3.79	151	16.8	16.7	0.1	2
2059+034	QSO	1.01	79	17.8	17.5	0.3	--
2201+315	QSO	0.30	134	15.5	15.2	0.3	2

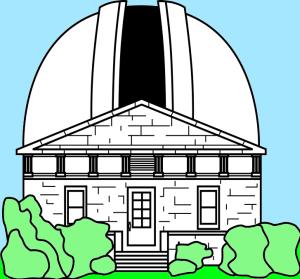


WISE mid-IR data (identify more AGN sources)

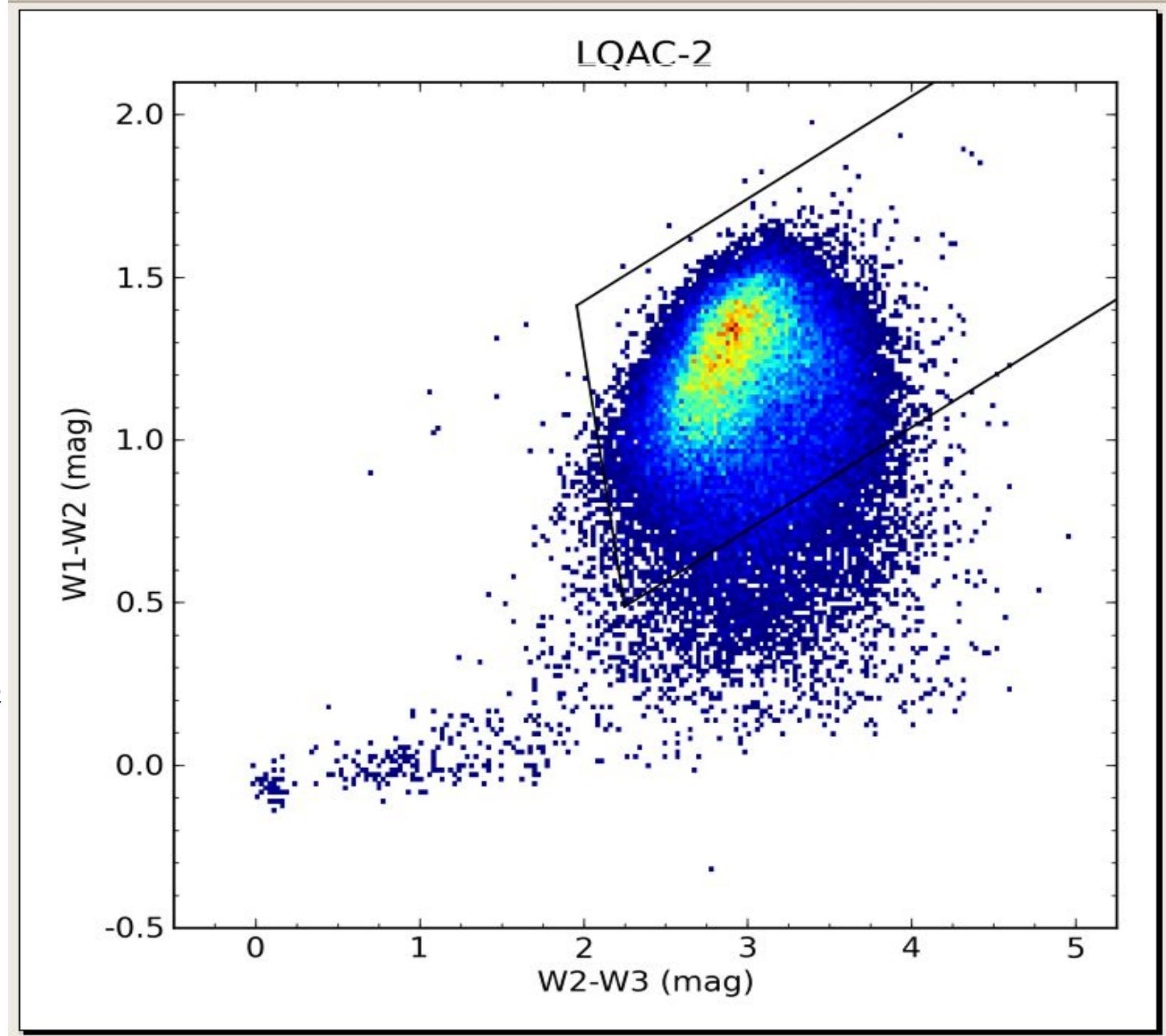


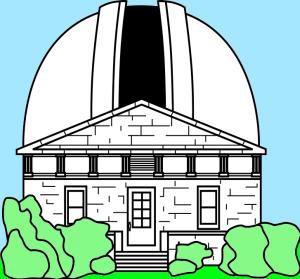
WISE data

- Wide-field Infrared Survey Explorer space mission
- 2010 Jan-Aug: 3.4, 4.6, 12, 22 um bands
- 40cm optics, 6" resolution, 2.75"/pixel, ≥ 8 obs.
- AllWise catalog (NASA/IPAC): 728 mill. Obj.
- 2MASS + UCAC4 PM as reference frame
- 1900 ICRF sources in common: sigma = 91 mas
- Secrest+ (submitted): identify 1.4 mill. AGNs
- Comparison to URAT, RFC in progress

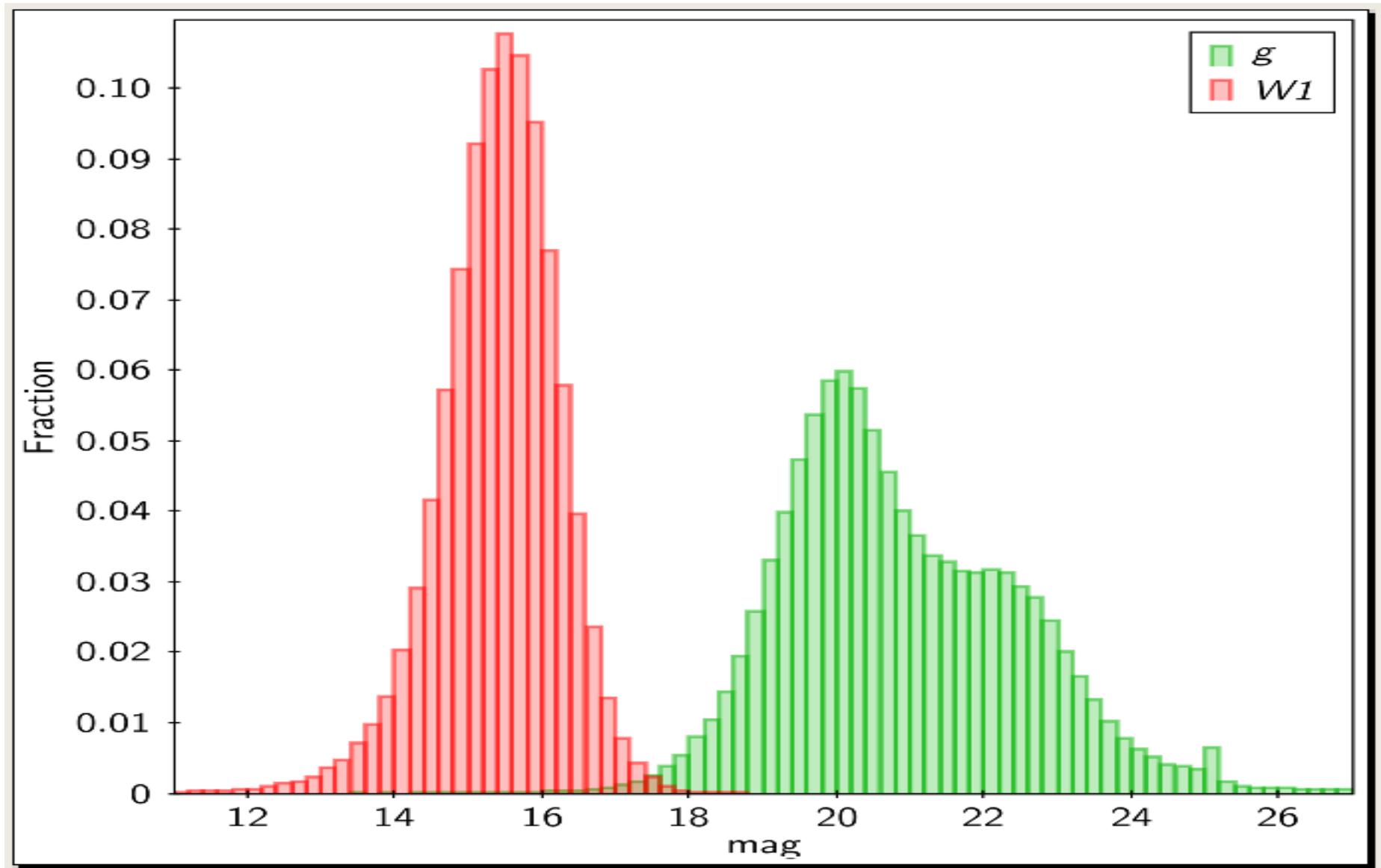


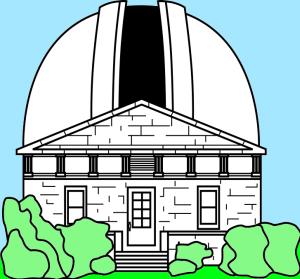
WISE color space





WISE by magnitude



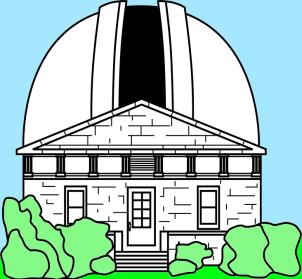


WISE benefits, limits, beyond

- identify **more** possible optical-radio **link** targets
- Mid-IR “see” through dust, AGN core dominant
- unlikely to solve optical-radio position offset issue due to only moderate astrometric precision of data

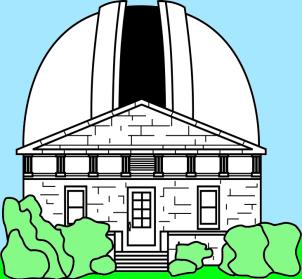
NEXT STEP:

- VLBA approved proposal (Makarov & Petrov):
get radio positions of about 5000 more sources



Summary (1)

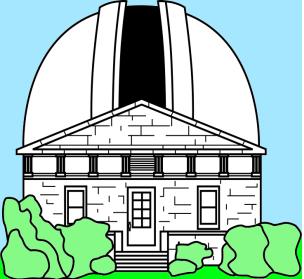
- Gaia: good on its own for **absolute PM**, parallax
- potential issue with **position link** Gaia / ICRF
 - more evidence for what we **see** in the **optical** (0.1 to 1 arcsec resolution) is **not** the **QSO radio core alone**
 - most sources could be randomly offset by likely between 1 and 10 mas (even “good” sources)
 - except very nearby sources: optical position seems to be stable, i.e. not correlated with photom. variability (at least on 2 mas level, for small sample investigated so far)



Summary (2)

continue potential issue with position link:

- Case A: DARN << 1 mas : we are good, pick “best”
- Case B: DARN = 1 (or few) mas:
 - vastly increase number of QSO targets in common
- Case C: DARN is order 10 mas
 - use different type of link objects, or
 - do nothing, accept Gaia / ICRF link at 0.5 mas ?
- need to learn how large this effect really is, any results from Gaia yet ?
- Science based on assuming optical = radio center (give or take sub-mas effects) is likely “not to work”



continue discussions
at IAU GA

Commission 8 “Astrometry”

Wed. Aug. 5, 1400-1800

request presentations, your presence