Complementary Multi-wavelength Surveys: the near-IR+Optical+UV

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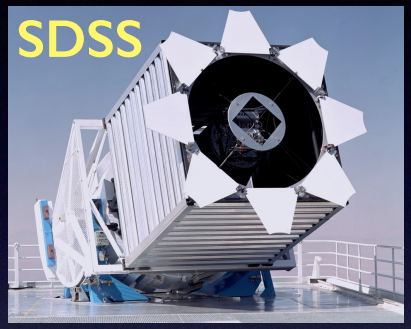
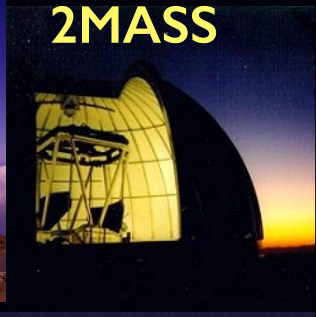
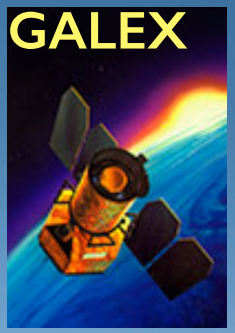
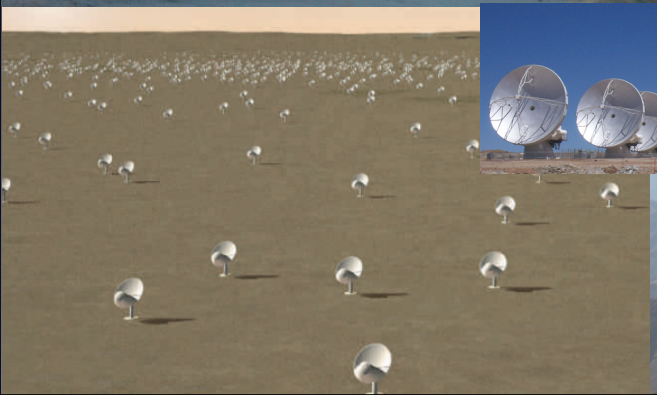




Expanded Very Large Array





Outline

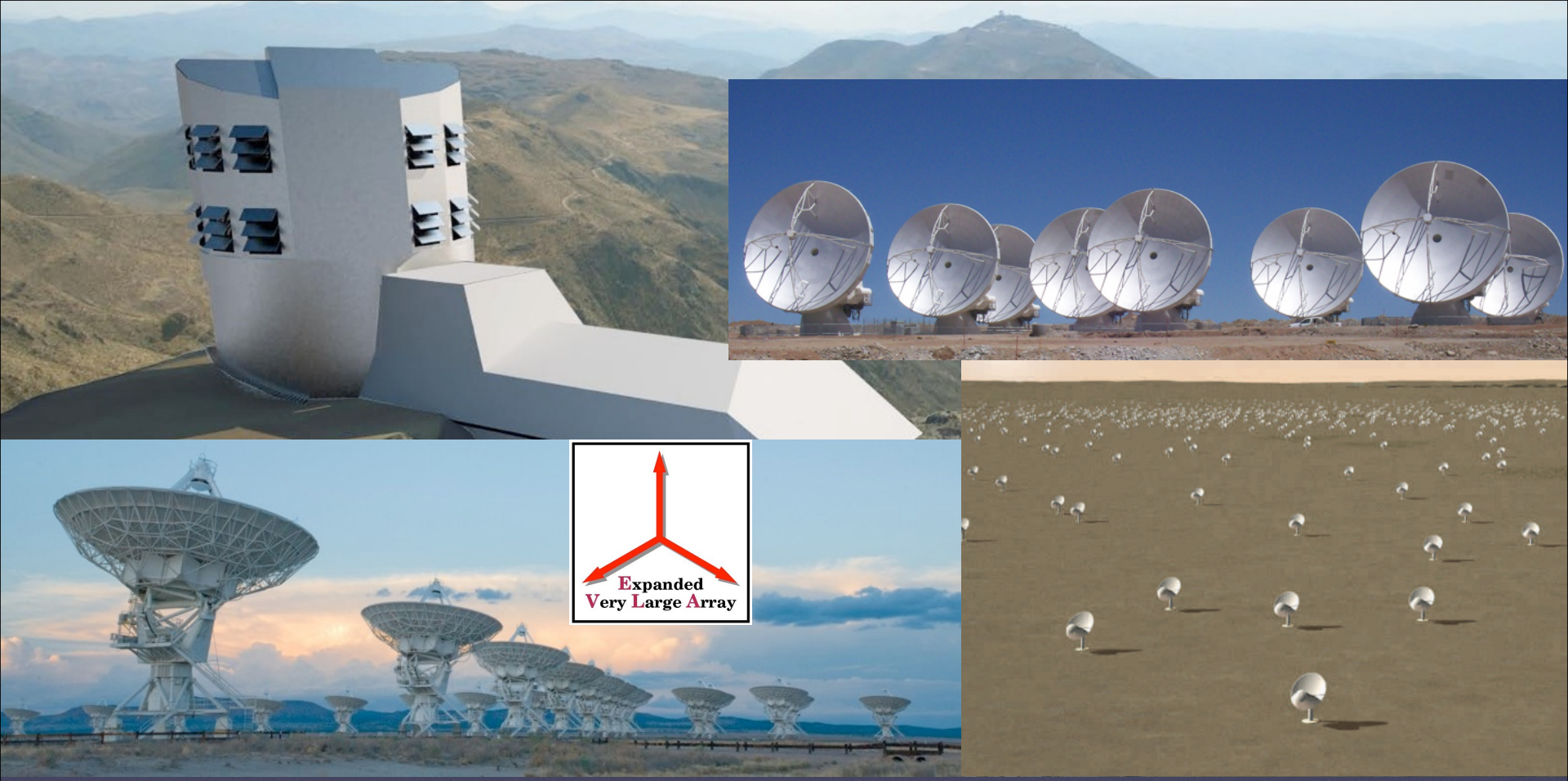
1) Motivation for UV-optical-nearIR surveys complementing radio surveys

2) Legacy surveys

3) Ongoing surveys

4) Upcoming surveys

5) Summary



The connections between optical and radio regimes:

1) Science Results (asking similar and often same questions; e.g. stellar and galaxy formation and evolution, dark energy)

2) Tools and Methods (e.g. massive databases)

3) Supplemental data (**identification**, physical processes, HI)

What is needed?

- FIRST faint limit at 21 cm is 1 mJy (mAB=16.4)

- 30% of FIRST sources are detected by SDSS (mAB~22). The matched sources represent about 0.1% of all SDSS sources.

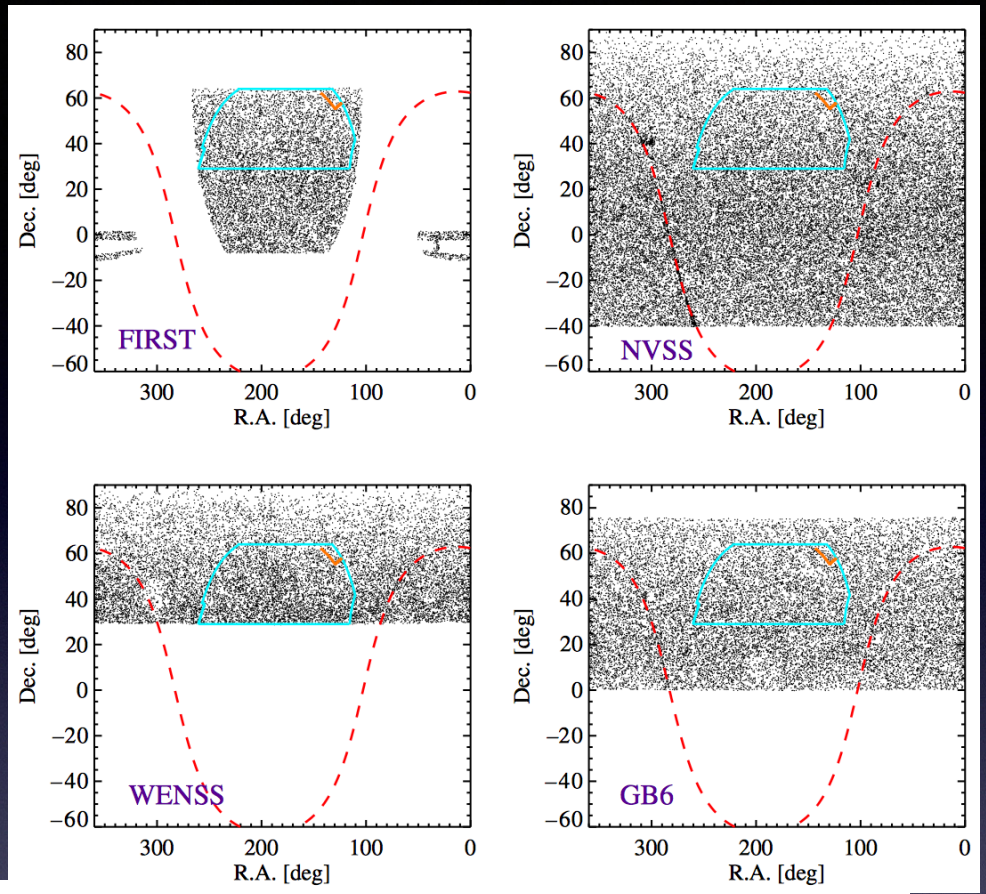
- 90% of radio sources at the FIRST faint limit that are also detected by SDSS are optically resolved

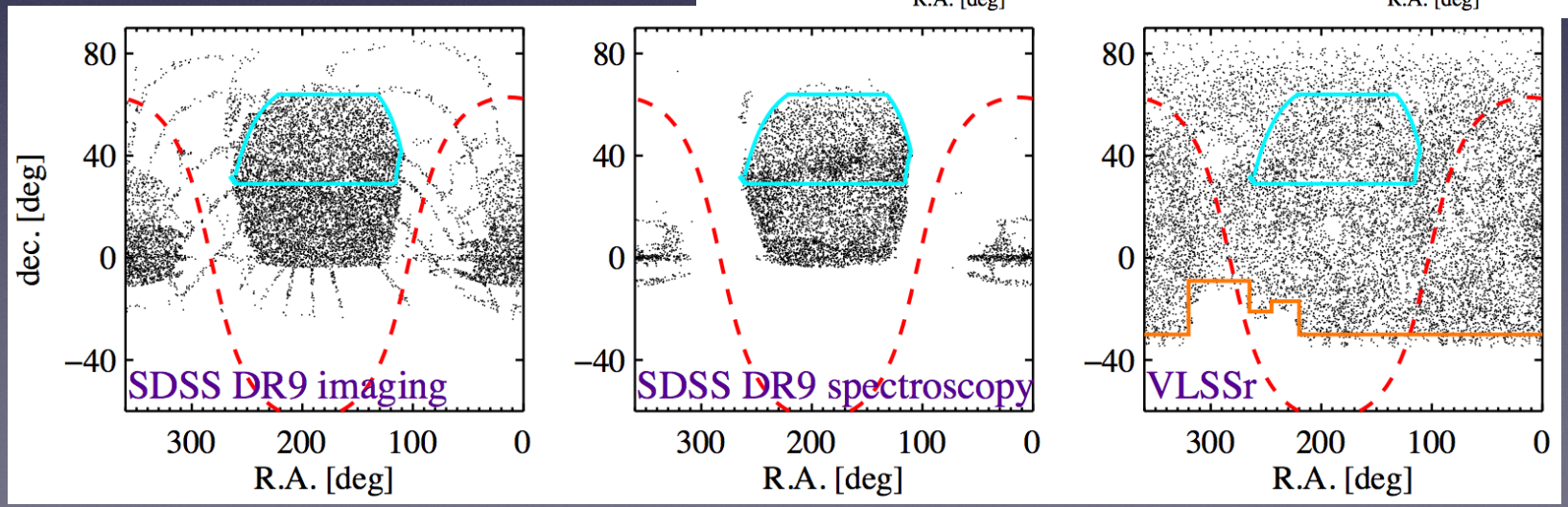
- to reach >95% detection level for FIRST sources, an optical survey to mAB~26 is needed

- of course, it would be scientifically useful to complement such an optical survey with UV and near-IR surveys

What is needed?

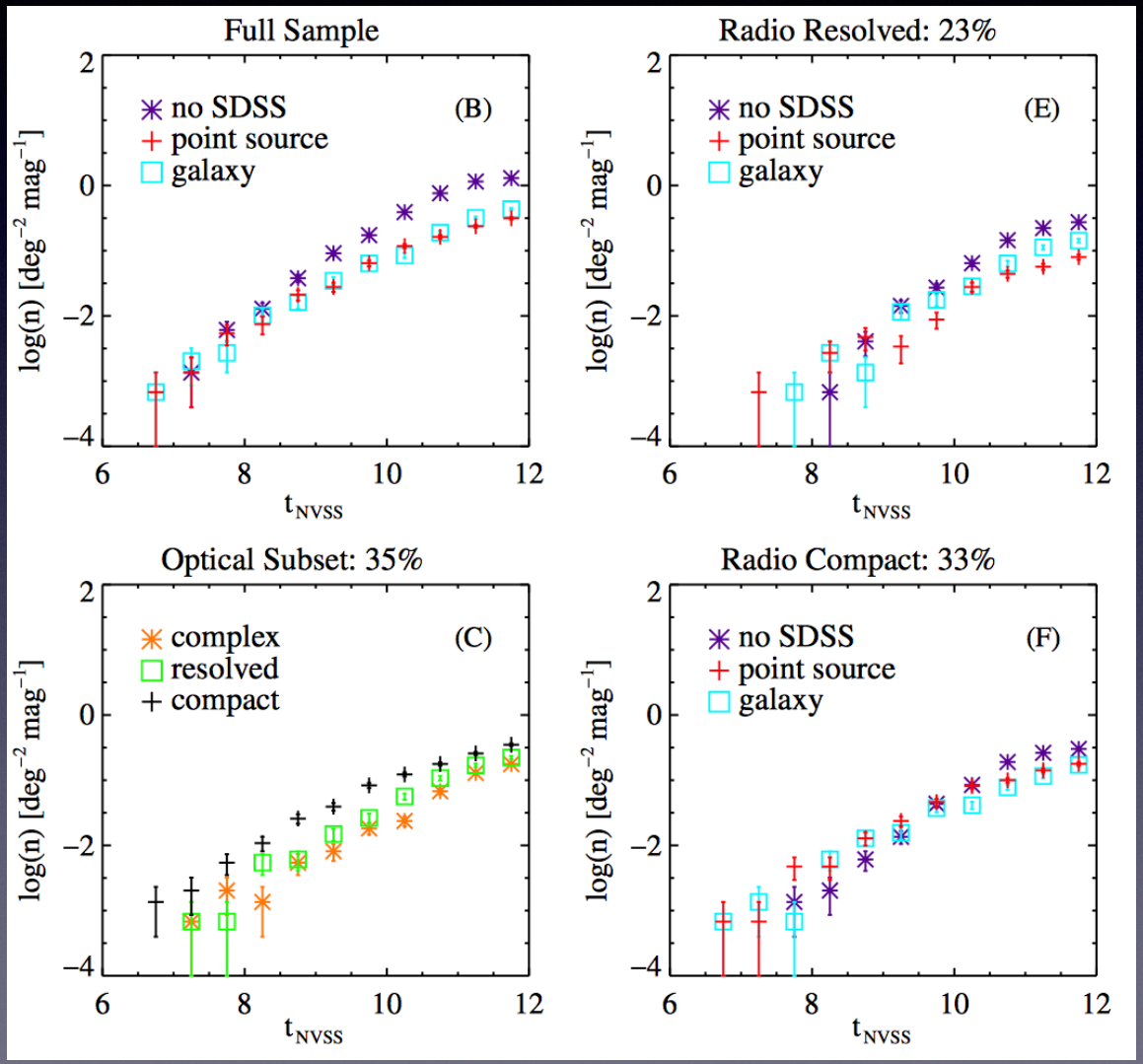
- Depth
- Bandpasses
- Angular Resolution
- Sky coverage
- Time domain?





Examples of analysis

- bin radio sources by optical properties
- bin optical sources by radio properties



Kimball et al. (2008, 2011, 2014)

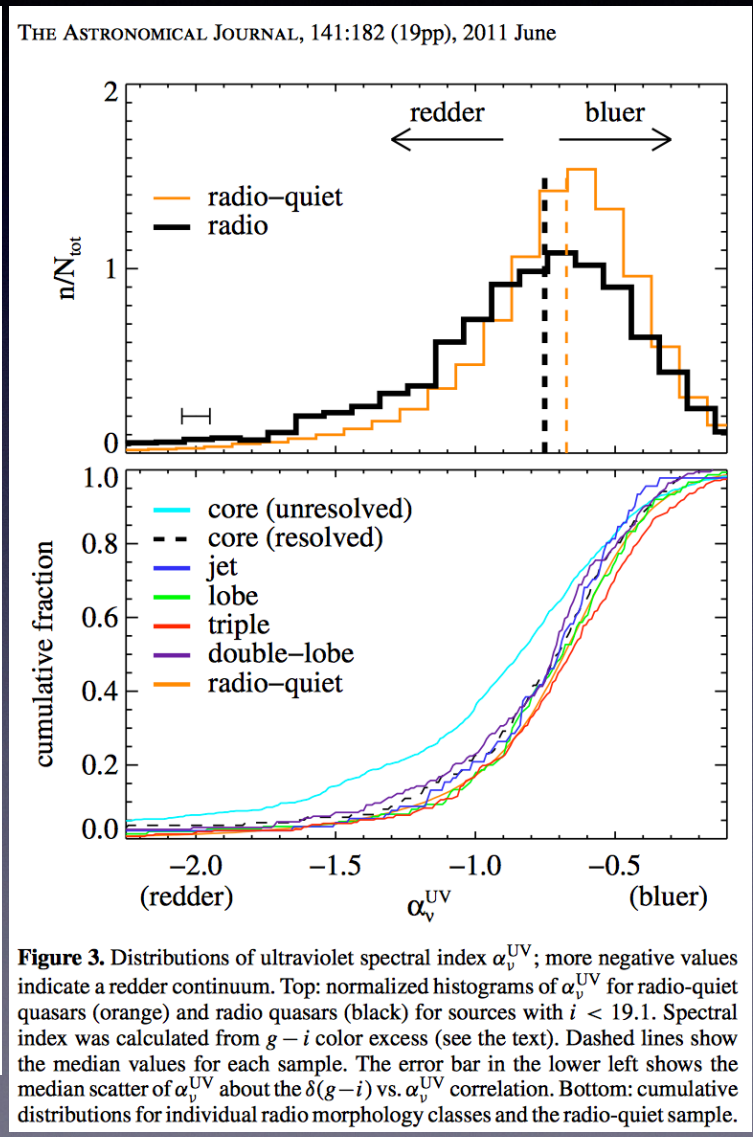


Figure 3. Distributions of ultraviolet spectral index α_ν^{UV}; more negative values indicate a redder continuum. Top: normalized histograms of α_ν^{UV} for radio-quiet quasars (orange) and radio quasars (black) for sources with $i < 19.1$. Spectral index was calculated from $g - i$ color excess (see the text). Dashed lines show the median values for each sample. The error bar in the lower left shows the median scatter of α_ν^{UV} about the $\delta(g-i)$ vs. α_ν^{UV} correlation. Bottom: cumulative distributions for individual radio morphology classes and the radio-quiet sample.

Three generations of UV-optical-near-IR surveys

1) Legacy:

GALEX + SDSS + 2MASS

time domain: ASAS, NSVS, LINEAR, PTF, …

2) Ongoing:

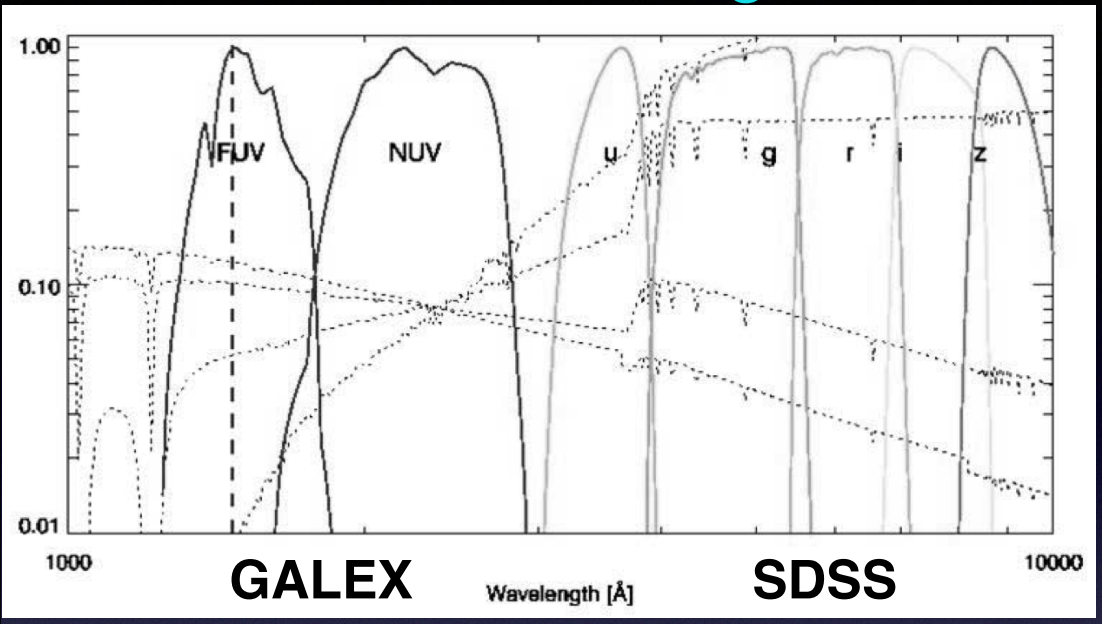
Pan-STARRS, DES, Subaru-HSC, (SkyMapper),

time domain: CRTS, iPTF, MASTER,

near-IR: UKIDSS, VISTA

3) Future: ZTF, Gaia, LSST, Euclid, WFIRST

FUV NUV u g r i z



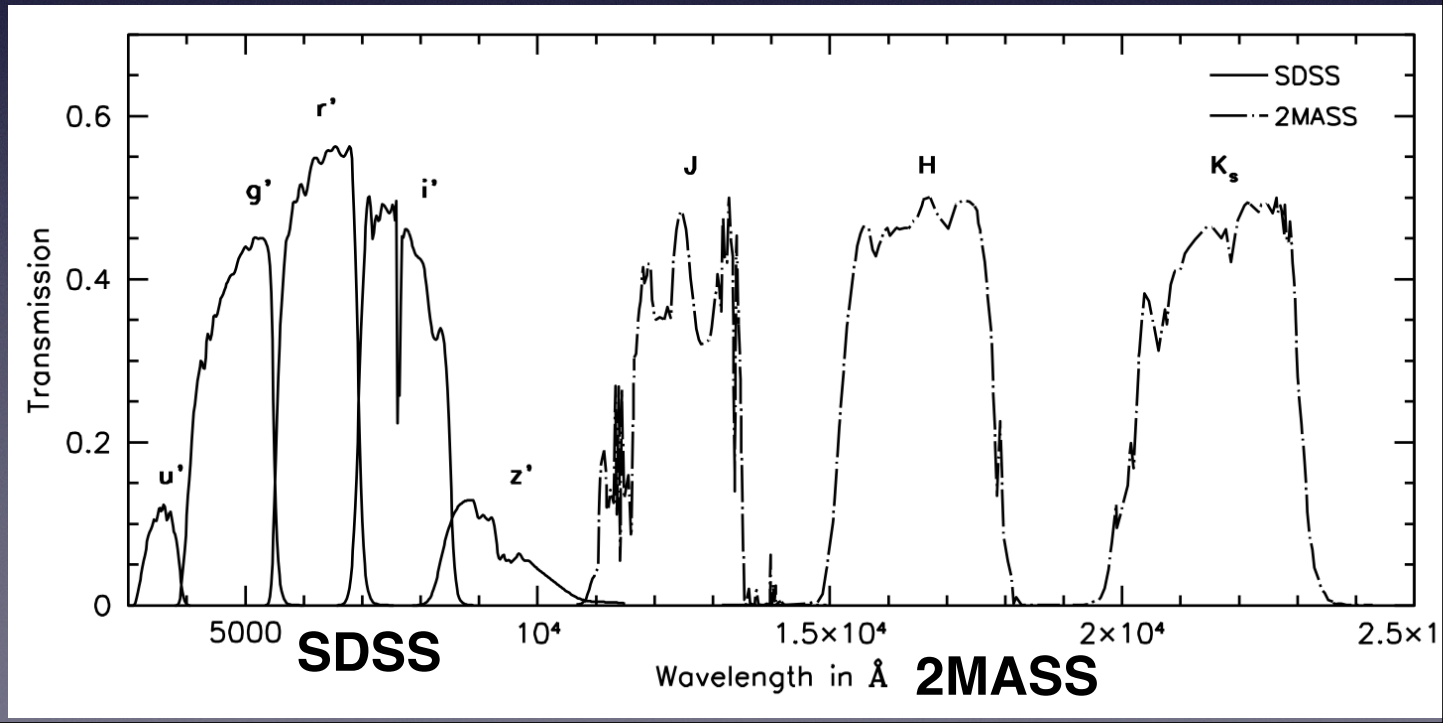
1 mJy: mAB ~ 16.4

6 micJy: mAB ~ 22

60 nJy: mAB ~ 27

J H K

UV-opt-nIR:
0.2 - 2.2 mic



Legacy surveys

GALEX: two UV bands (0.12 and 0.22 mic), mAB ~ 21, all sky

SDSS: five bands (ugriz, 0.3–1.0 mic), mAB ~ 22, ~1/4 sky (north)

2MASS: three IR bands (JHK, 1.2, 1.7, 2.2 mic), mAB ~17, all sky

UKIDSS is a set of five surveys. The areas and 5-sigma depths are as follows:

1.	Large Area Survey (LAS)	4000 sq. degs	K=18.4	extraGalactic
2.	Galactic Plane Survey (GPS)	1800 sq. degs	K=19.0	Galactic
3.	Galactic Clusters Survey (GCS)	1400 sq. degs	K=18.7	Galactic
4.	Deep Extragalactic Survey (DXS)	35 sq. degs	K=21.0	extraGalactic
5.	Ultra Deep Survey (UDS)	0.77 sq. degs	K=23.0	extraGalactic

VISTA:
1/2 sky to
J~21, K~20

UKIDSS:
ZYJHK

Ongoing surveys

A quick comparison of imaging depths for SDSS, DES and LSST:

	SDSS	DES (5 yrs)	LSST (1 epoch)	LSST (10 yrs)
u	22.1	n/a	23.9	26.1
g	22.4	25.2	25.0	27.4
r	22.1	24.7	24.7	27.5
i	21.2	24.0	24.0	26.8
z	20.3	23.4	23.3	26.1
y	n/a	21.7	22.1	24.9

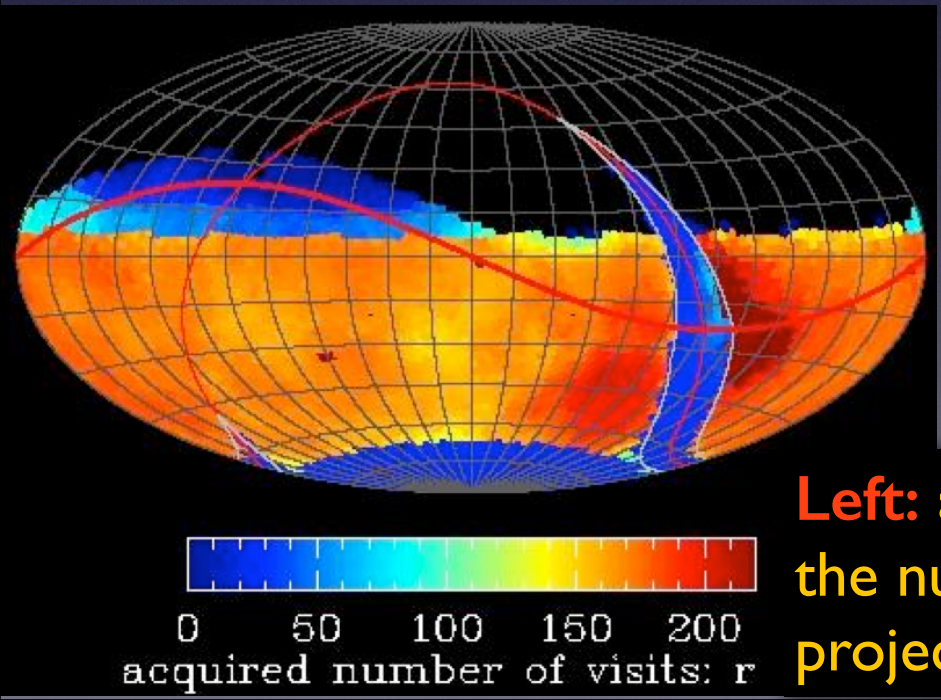
LSST will be 4.0-6.0 mags deeper than SDSS, over 2 times larger area.

LSST will be 2.5-3.0 mags deeper than DES, over 4 times larger area.

DES and Pan-STARRS will have a high matching completeness for radio sources (perhaps as high as 90% for FIRST/NVSS sources). Pan-STARRS is north!

LSST: a uniform sky survey

- ~90% of time will be spent on a uniform survey: every 3-4 nights, the whole observable sky will be scanned twice per night
- after 10 years, half of the sky will be imaged about 1000 times (in 6 bandpasses, ugrizy): a digital color movie of the sky
- ~100 PB of data: about 2.5 million 3.2 Gpix images (visits), enabling **measurements for 40 billion objects**

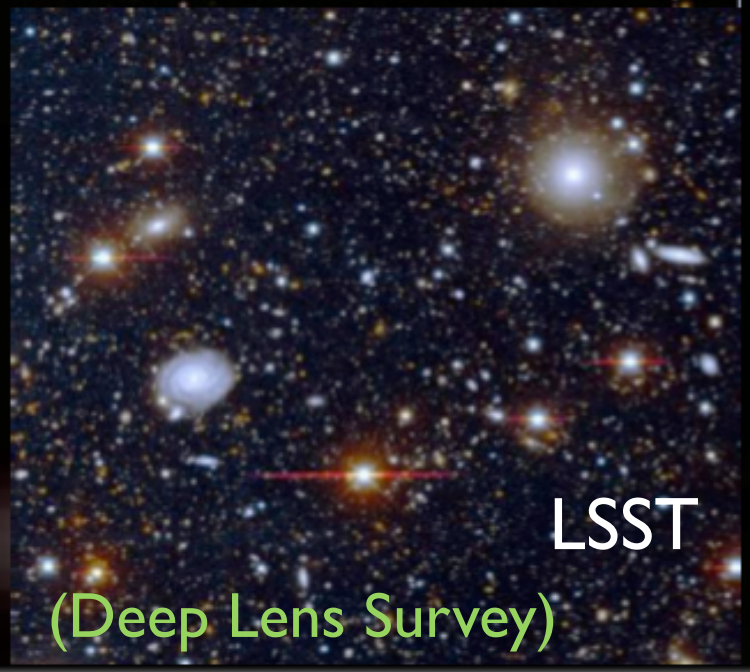


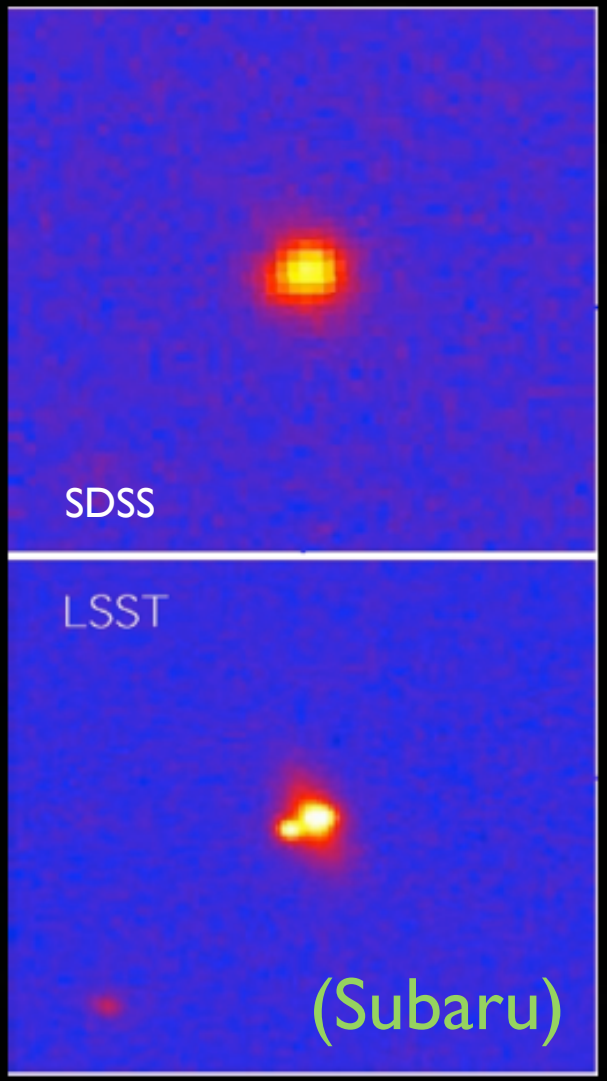
LSST in one sentence:
An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 (36 nJy) based on 1000 visits over a 10-year period: **deep wide fast.**

Left: a 10-year simulation of LSST survey: the number of visits in the r band (Aitoff projection of eq. coordinates)

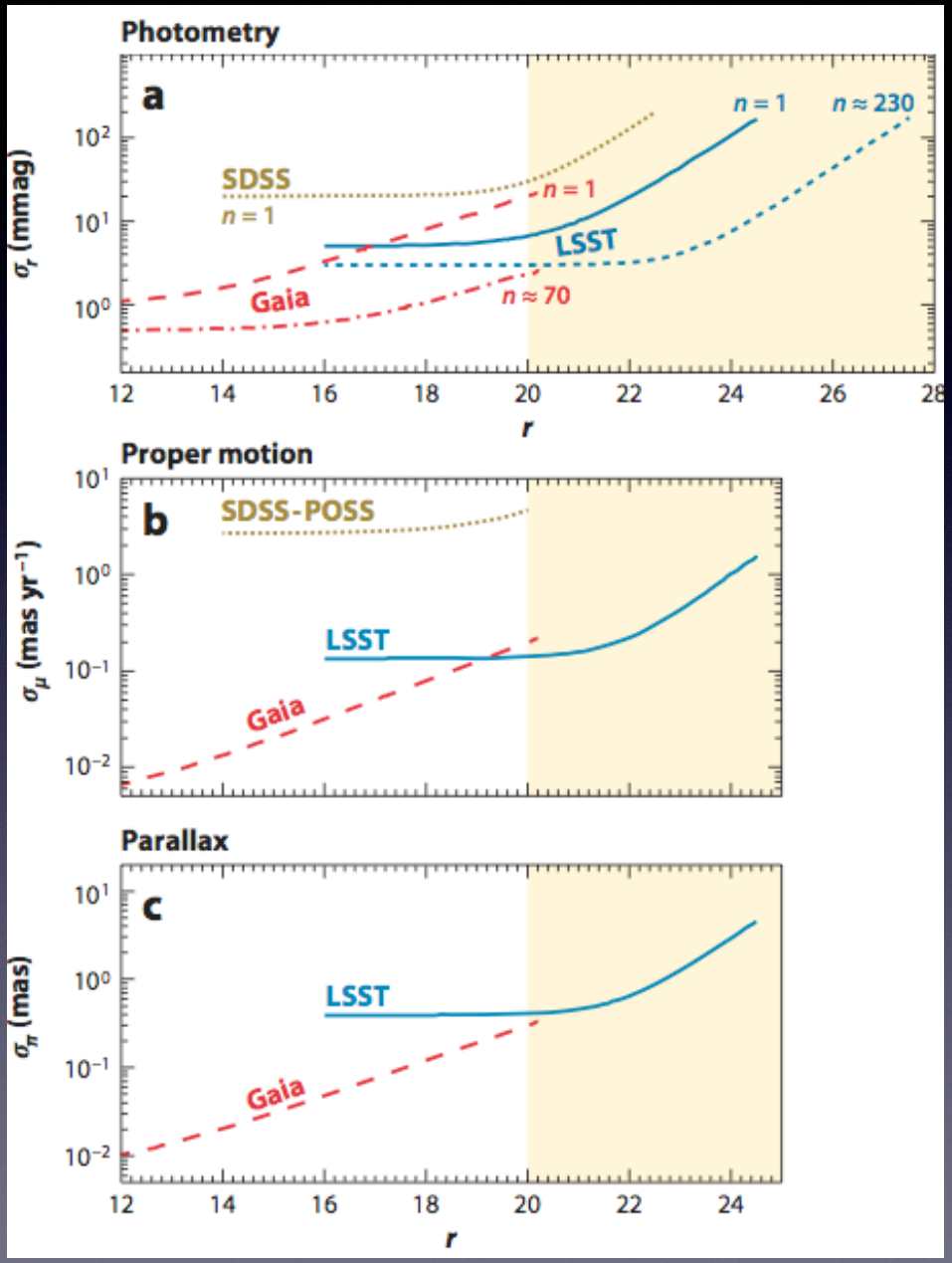
SDSS-LSST comparison: LSST=d(SDSS)/dt, LSST=SuperSDSS

3x3 arcmin, gri





Gaia vs. LSST comparison



Ivezić, Beers, Jurić 2012, ARA&A, 50, 251

- **Gaia:** excellent astrometry (and photometry), but only to r < 20
- **LSST:** photometry to r < 27.5 and time resolved measurements to r < 24.5
- Complementarity of the two surveys: photometric, proper motion and trigonometric parallax errors are similar around r=20

The Milky Way disk "belongs" to Gaia, and the halo to LSST (plus very faint and/or very red sources, such as white dwarfs and LT(Y) dwarfs).

Summary

1) Existing UV-opt-IR surveys are not deep enough for the full identification of ~1 mJy radio sources

2) Ongoing surveys will greatly improve areal coverage and depth (north: Pan-STARRS, south: DES)

3) Time domain is a different game (esp. if coeval)

4) Gaia will give all-sky coverage and excellent astrometry and photometry but only to V~20 (21?)

5) LSST will eventually provide the deepest coverage over 1/2 sky (south: Dec < +5 deg)

6) Many interestingly deep optical and near-IR surveys cover only a fraction of sky: it is important to optimize the sky coverage of any new major radio surveys with this in mind!