The CatWISE2020 Catalog

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NASA
POSTDOCTORAL PROGRAM
Administered by USRA

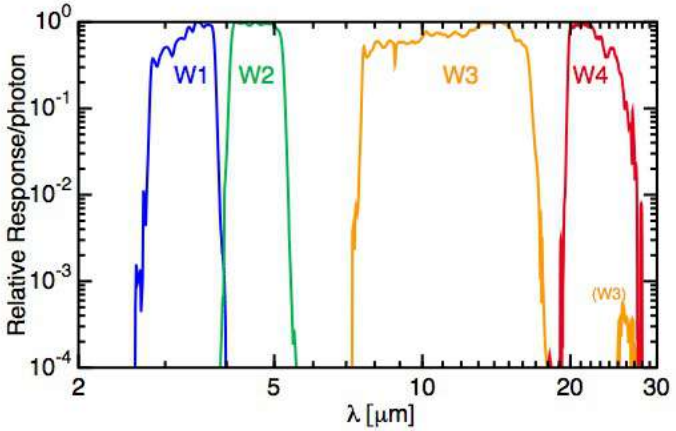
WISE

Image credit: nasa.gov

Wide-field Infrared Survey Explorer (WISE)

40-cm (16-inch) infrared space telescope (PI Edward Wright, UCLA)
Simultaneous 47’ images in 4 bands:

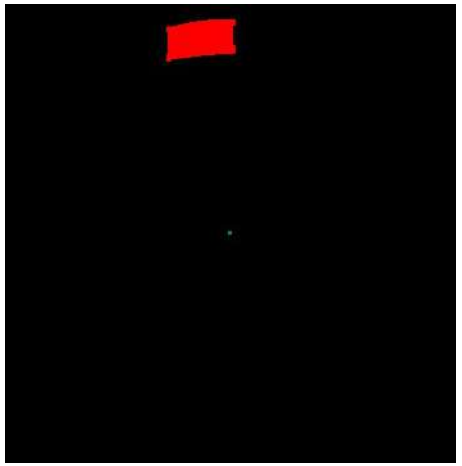
- **W1** (3.4 μm) and **W2** (4.6 μm)
- **W3** (12 μm); operated until Sep. 2010
- **W4** (22 μm); operated until Aug. 2010

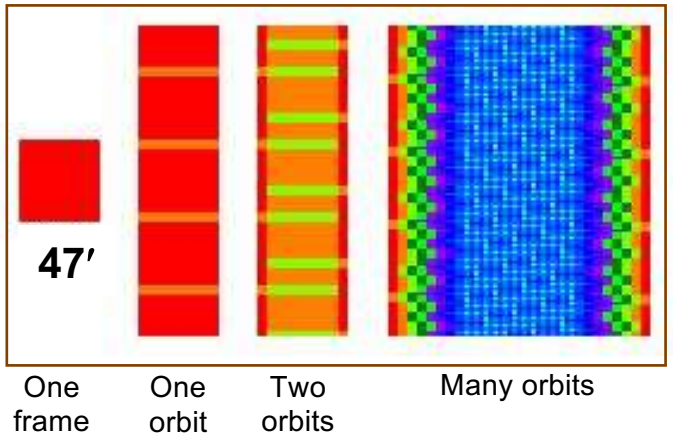


525 km, circular, polar, sun-synchronous, precessing orbit sweeps entire sky every ~6 months

Scan mirror “freezes” orbital motion - enabling efficient mapping:

- 8.8-s exposure/11-s duty cycle
- 10% frame to frame overlap
- 90% orbit to orbit overlap
- 12 exposures/position





Wide-field Infrared Survey Explorer (WISE)

14 December 2009: launch from Vandenberg AFB, California
6 January 2010: first light! Beginning of 4-band cryo

29 September 2010: cryogen depleted, beginning of NEOWISE post-cryo

15 February 2011: completed two full sky surveys, end of planned mission – WISE enters hibernation

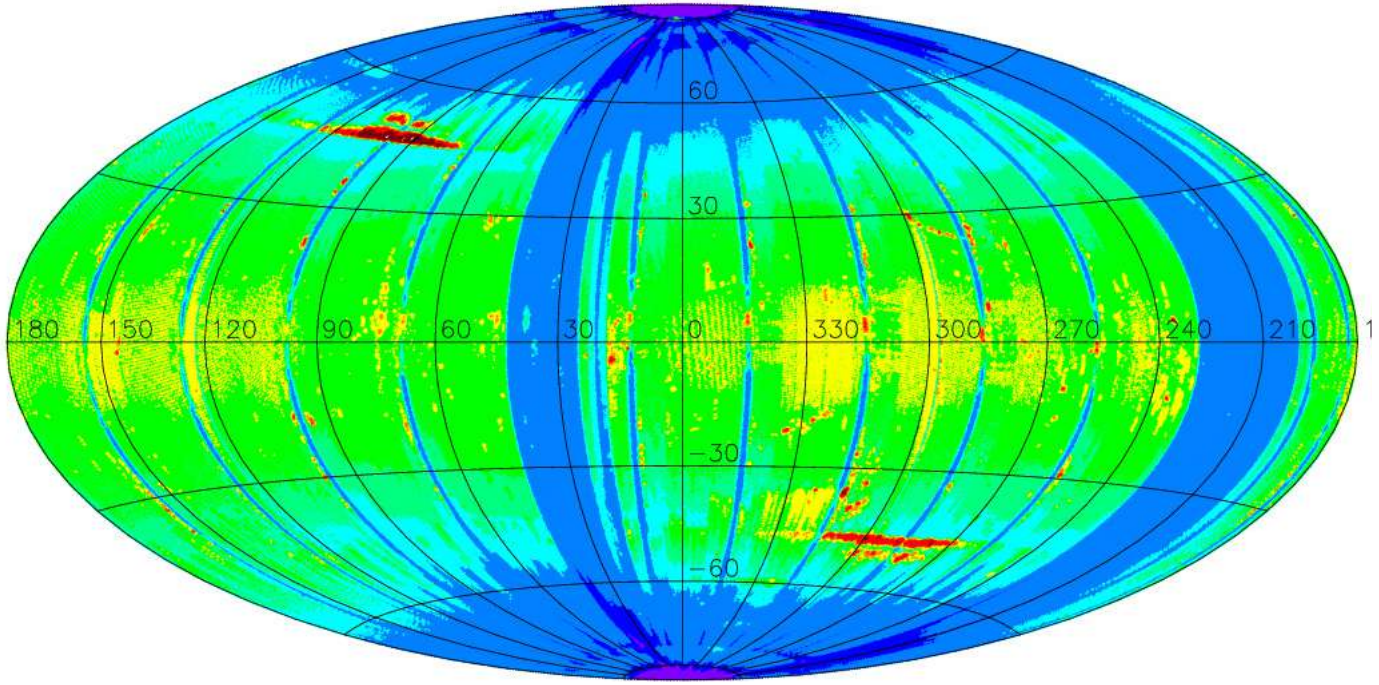
29 August 2013: reactivated as NEOWISE-R to search for Near Earth Objects (PI Amanda Mainzer). Survey restarted in Dec. 2013 – 14 more coverages completed so far (16 total)

Only W1 and W2 bands active after cryogen depleted

WISE All-Sky

Number of exposures

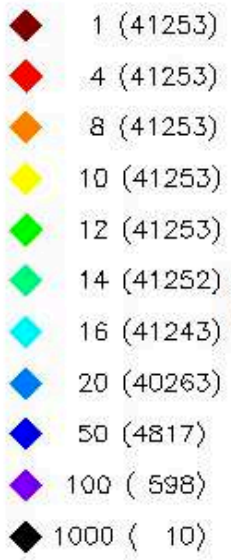
All-Sky Release Coverage



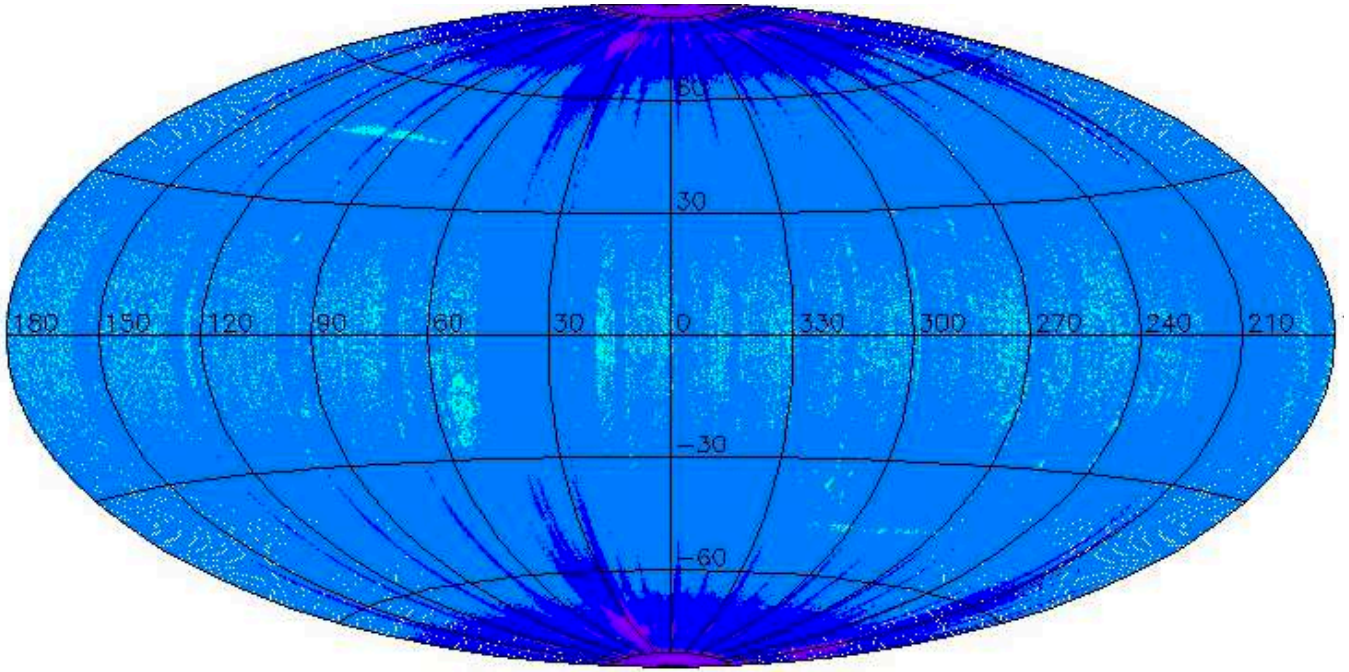
- Based on the first 2010 sky coverage from WISE
- Catalog of **563,921,584 sources** released to community March 2012.

AllWISE

Number of exposures



AllWISE Coverage



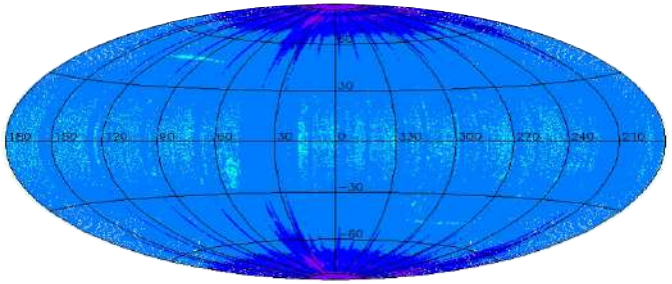
- Combined the two 2010 sky coverages from WISE
- Catalog of **747,634,026 sources** released to community Nov. 2013.
- Detect fainter sources and measured their **motions** over the intervening 6 months

CatWISE

CatWISE (Eisenhardt et al. 2020) is an ADAP-funded project to adapt the AllWISE pipeline to produce all-sky infrared catalogs of brightness, position, and proper motion from WISE and NEOWISE survey data at 3.4 and 4.6 μm.

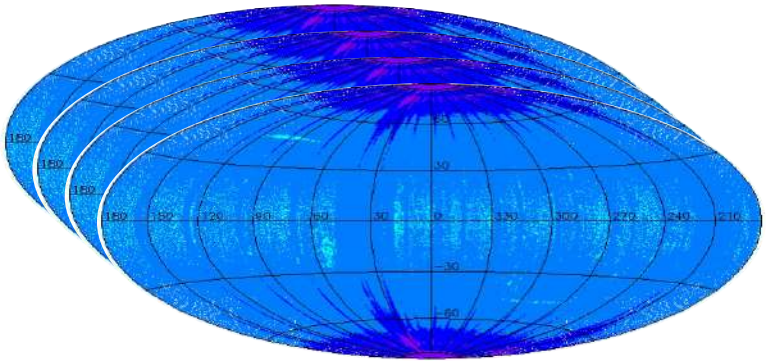
Works with unWISE coadded images (every 6 mo.) rather than individual frames (every 11 sec.)

AllWISE (Nov. 2013)
747,634,026 sources



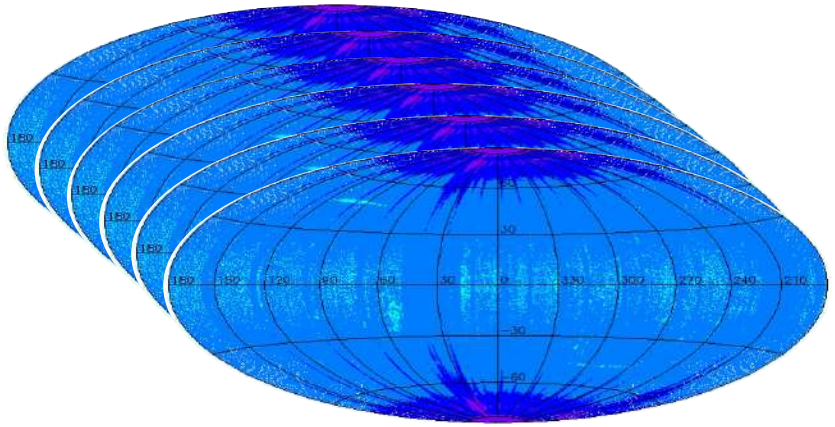
2 sky coverages
6 months baseline
(2010–2011)

CatWISE Preliminary (May 2019)
900,849,014 sources



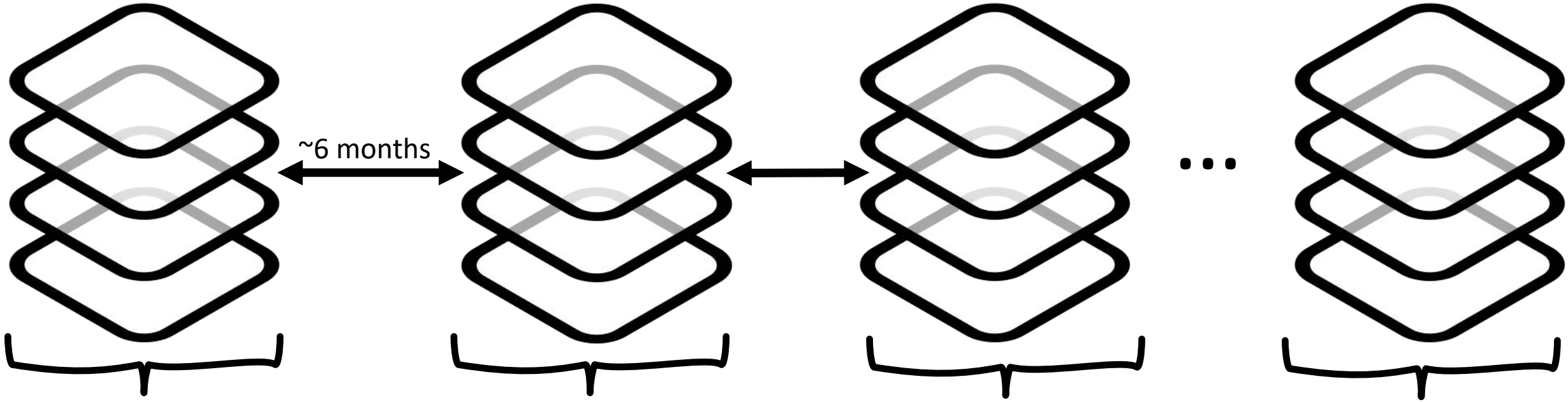
8+ sky coverages
6+ years baseline
(2010–2016)

CatWISE2020 (March 2020)
1,890,715,640 sources



12+ sky coverages
8+ years baseline
(2010–2018)

unWISE coadds



unWISE Epoch
~12 images taken
within ~1 day

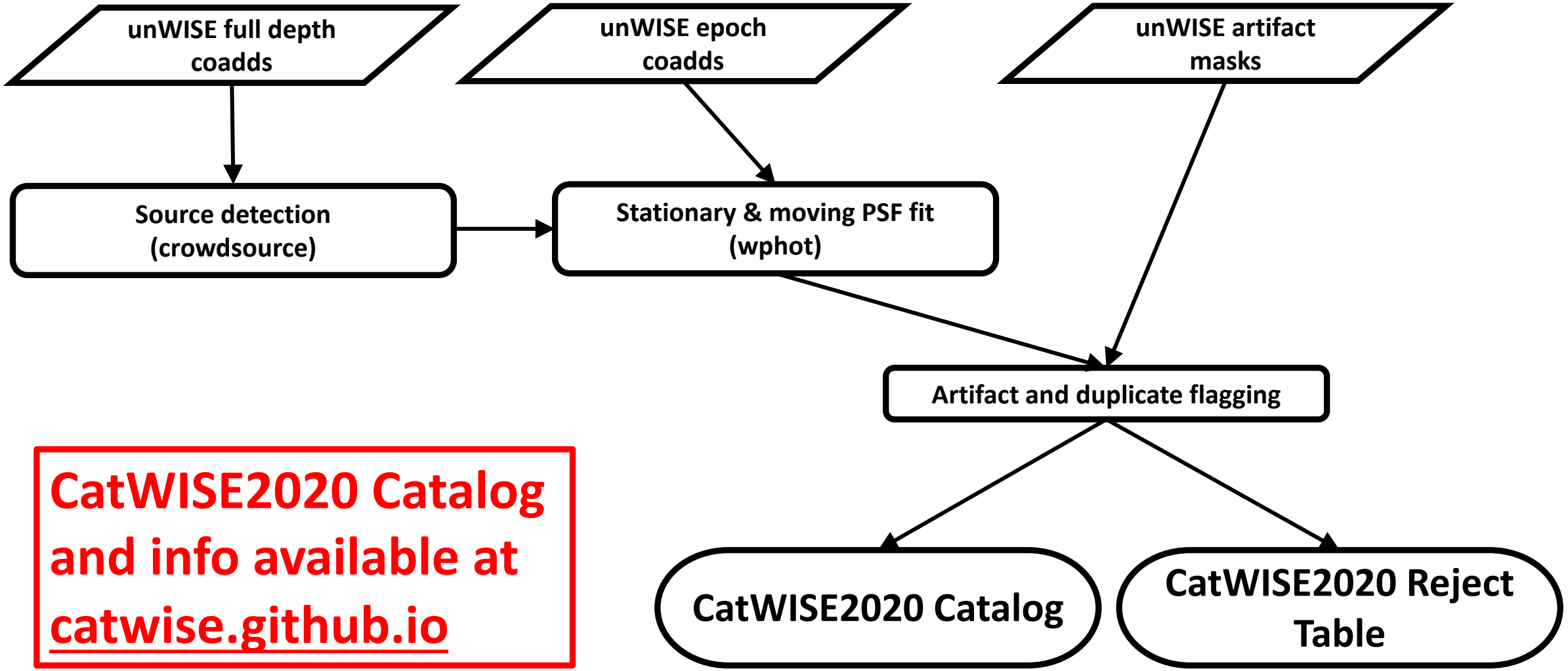
unWISE Epoch
~12 images taken
within ~1 day

unWISE Epoch
~12 images taken
within ~1 day

unWISE Epoch
~12 images taken
within ~1 day

unWISE Full depth
~140 images taken over ~8 years

Further info at unwise.me

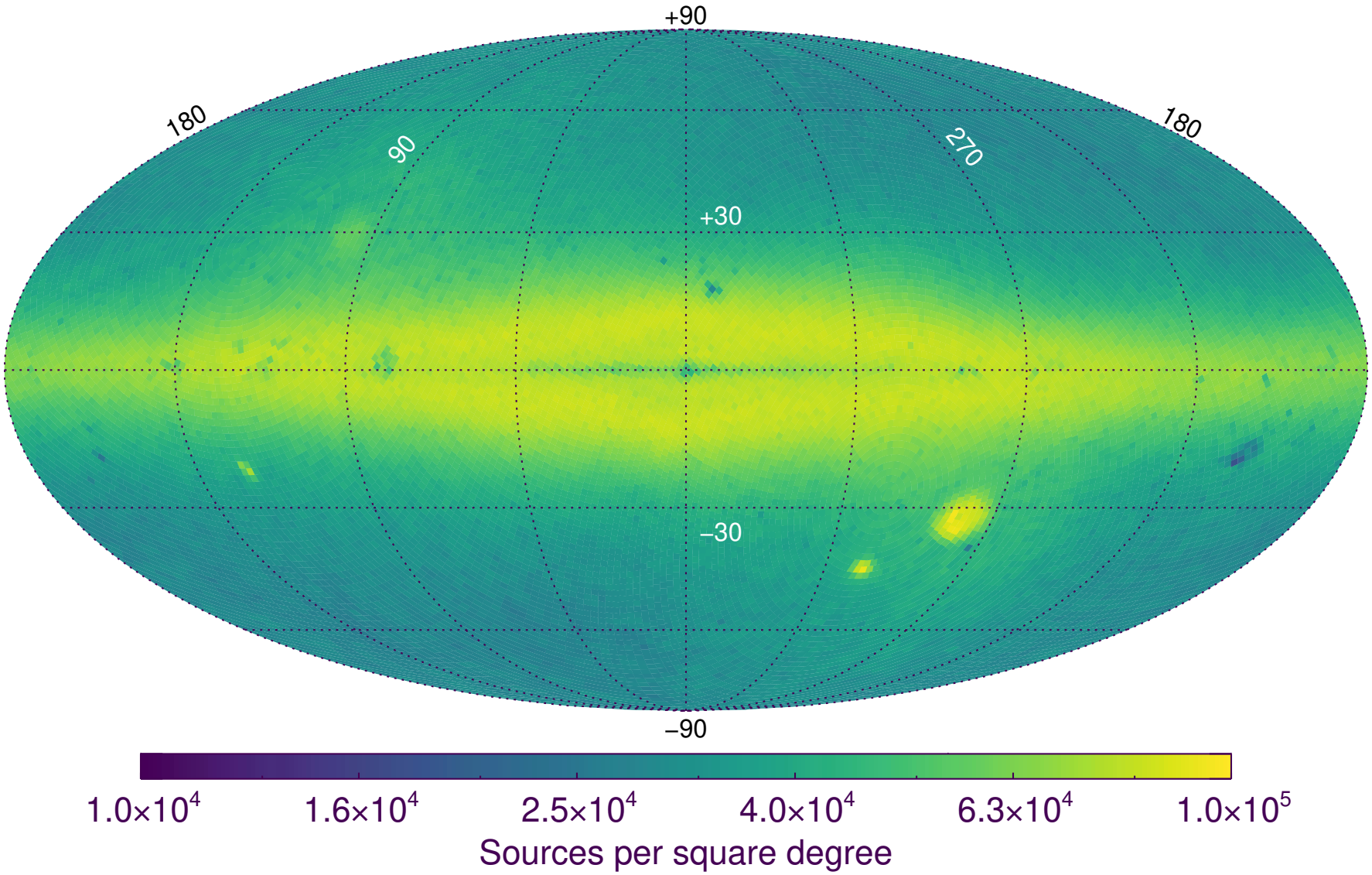


CatWISE2020 Catalog and info available at catwise.github.io

Sources with S/N > 5 and no artifact in at least one band, no duplicates.

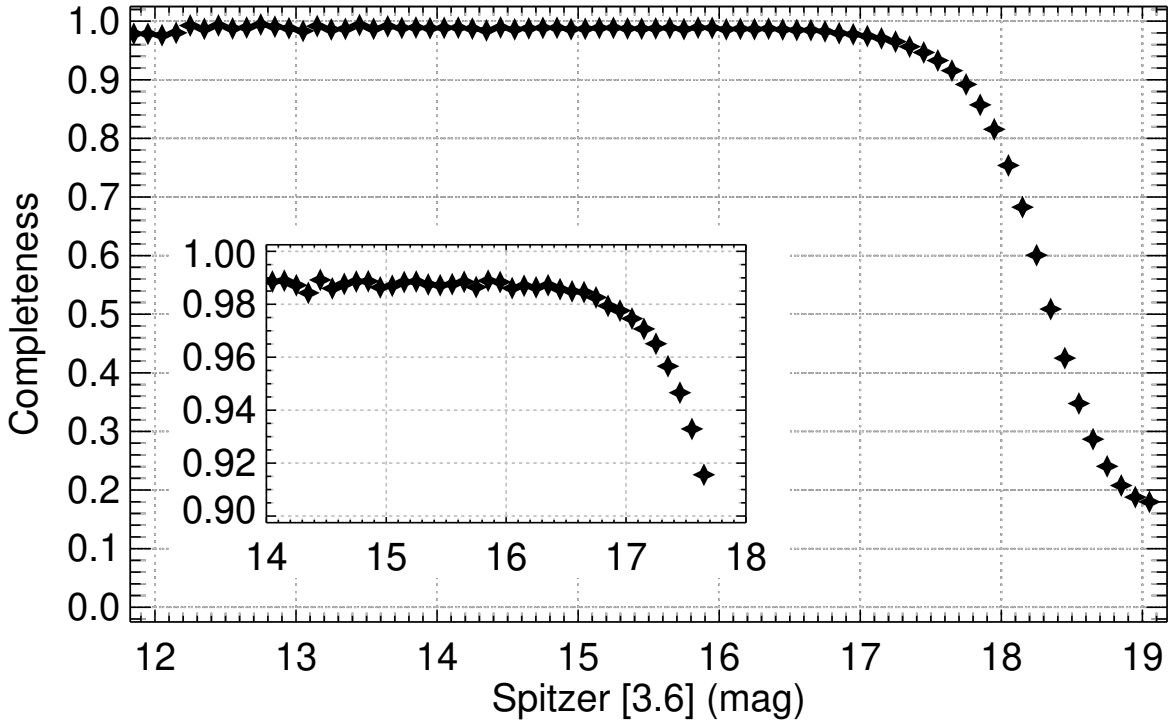
Crowdsource: Schlafly et al. (2019)
Wphot: Cutri et al. (2013)

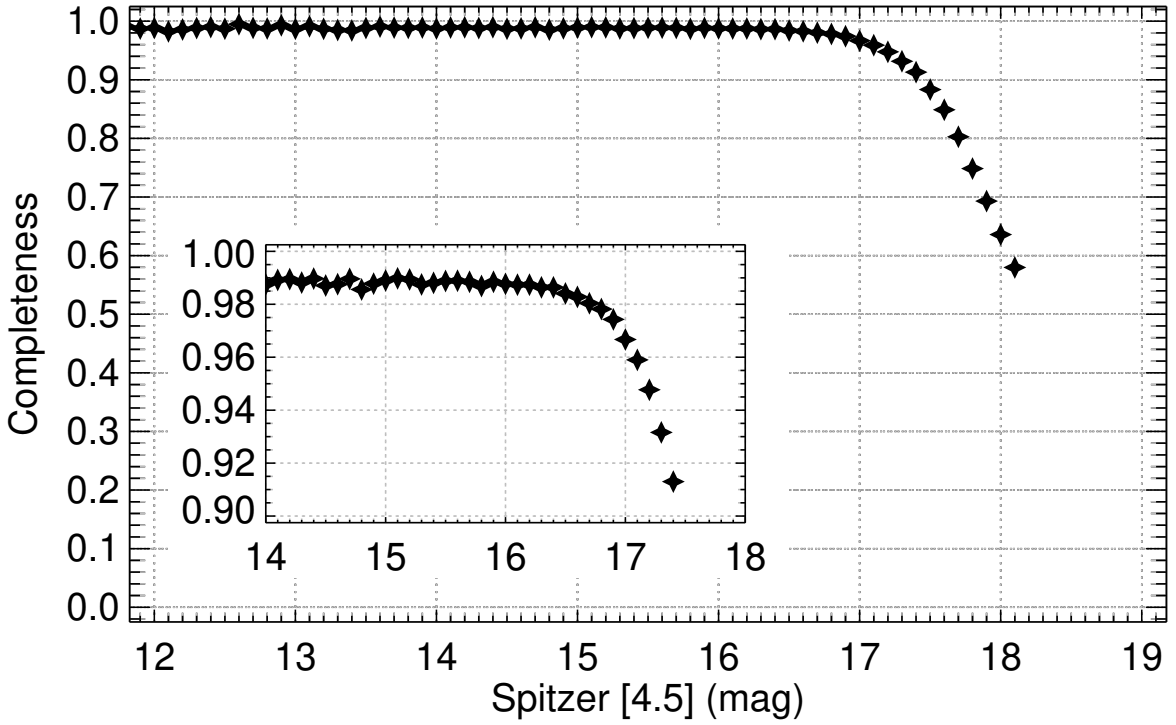
The CatWISE2020 Catalog – source density map



The CatWISE2020 Catalog – completeness and reliability

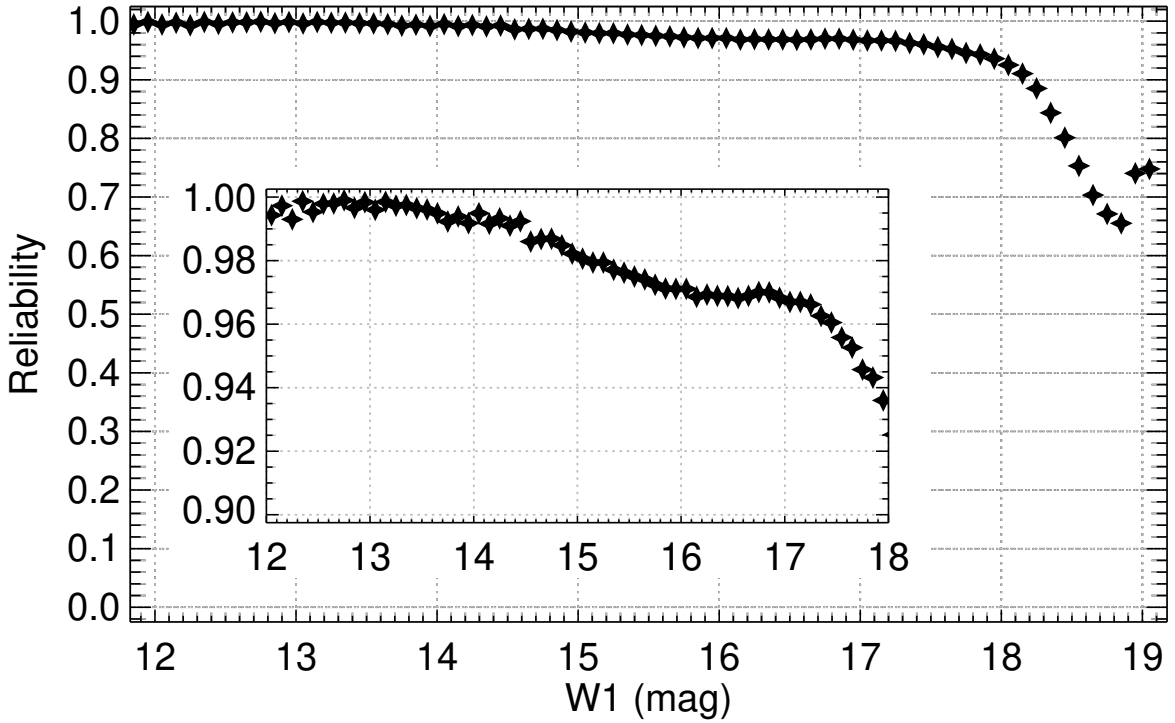
95% completeness at W1=17.4 mag and W2=17.2 mag

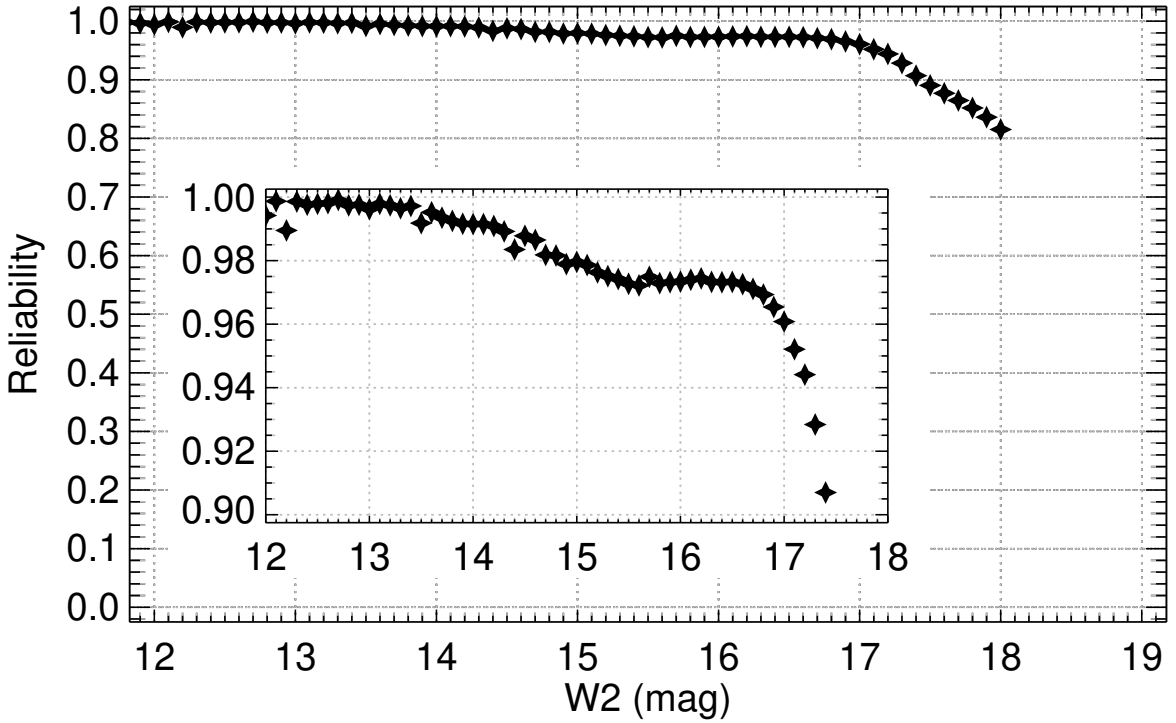




The CatWISE2020 Catalog – completeness and reliability

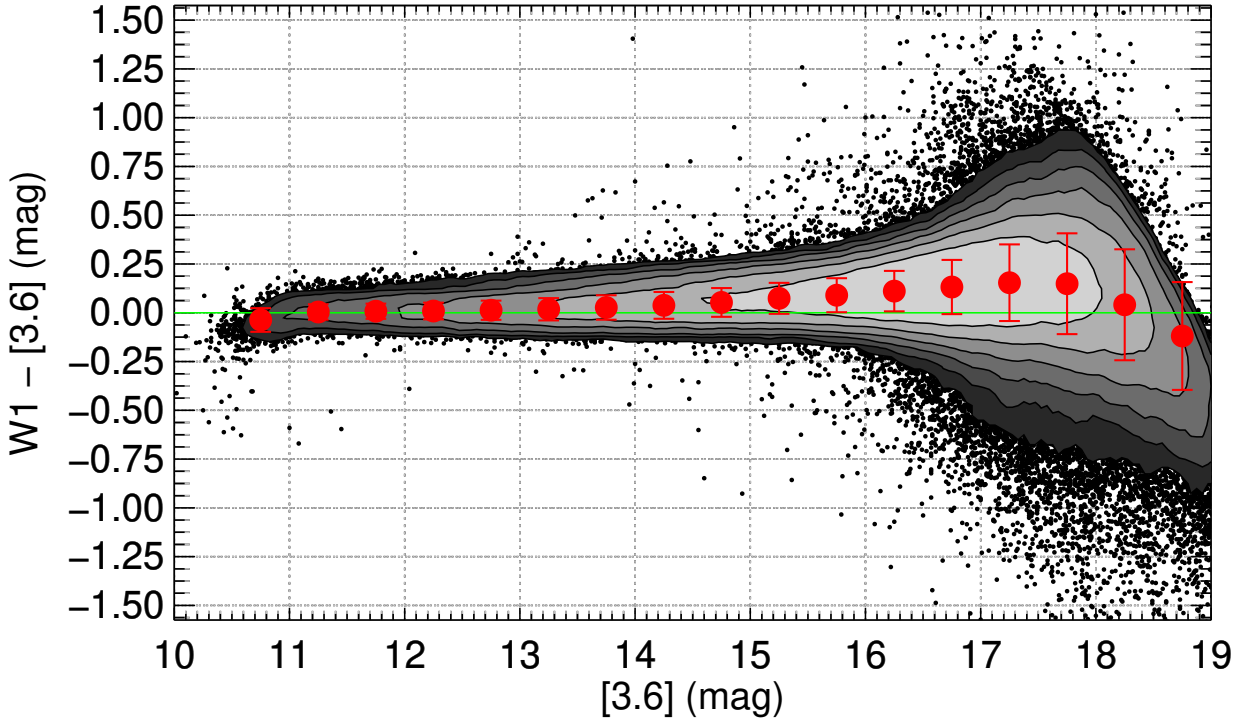
95% reliability at W1=17.7 mag and W2=17.2 mag.

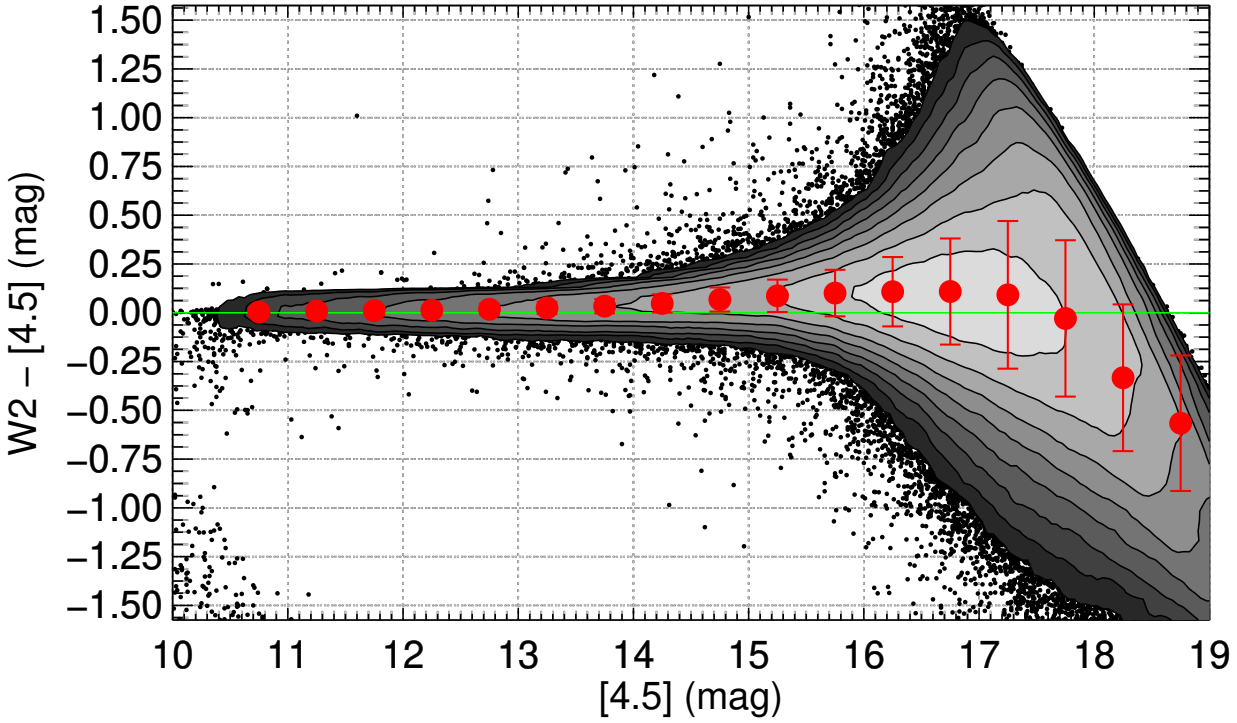




The CatWISE2020 Catalog – photometric performance

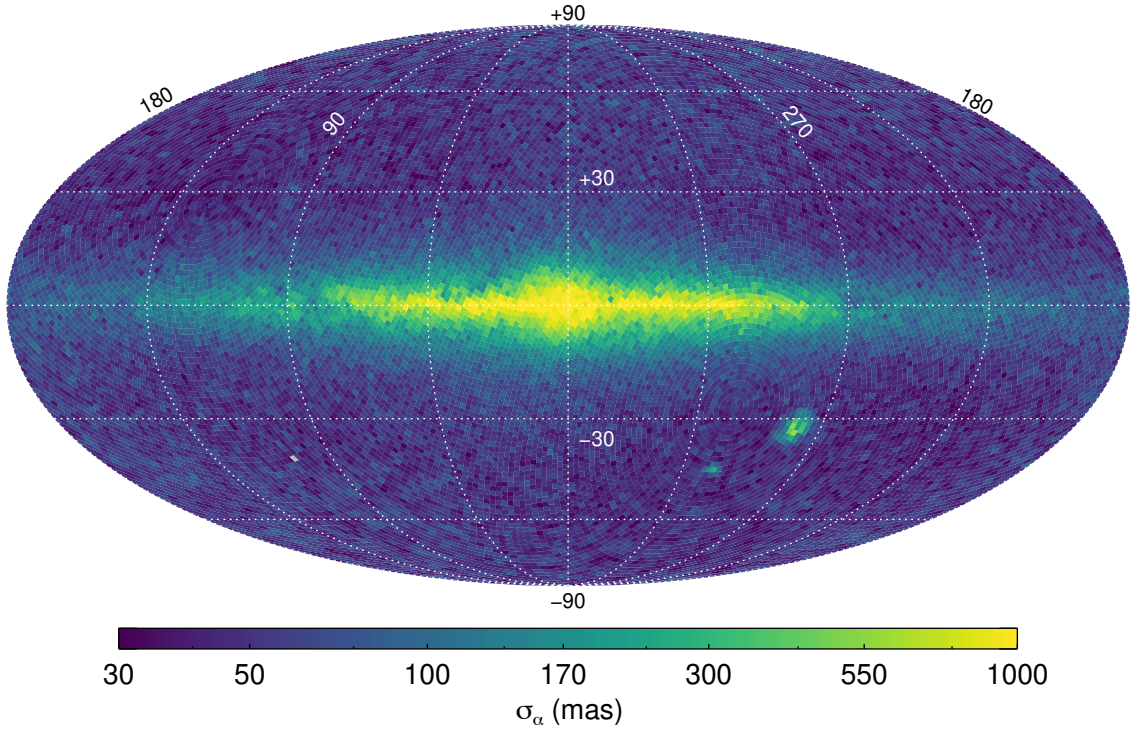
S/N 5 limits are W1= 17.6 mag and W2=16.6 mag (cf. AllWISE W1=17.0 and W2=16.0).
Small systematic bias up to 0.1 mag at W1=17.5 mag and W2=16.5 mag





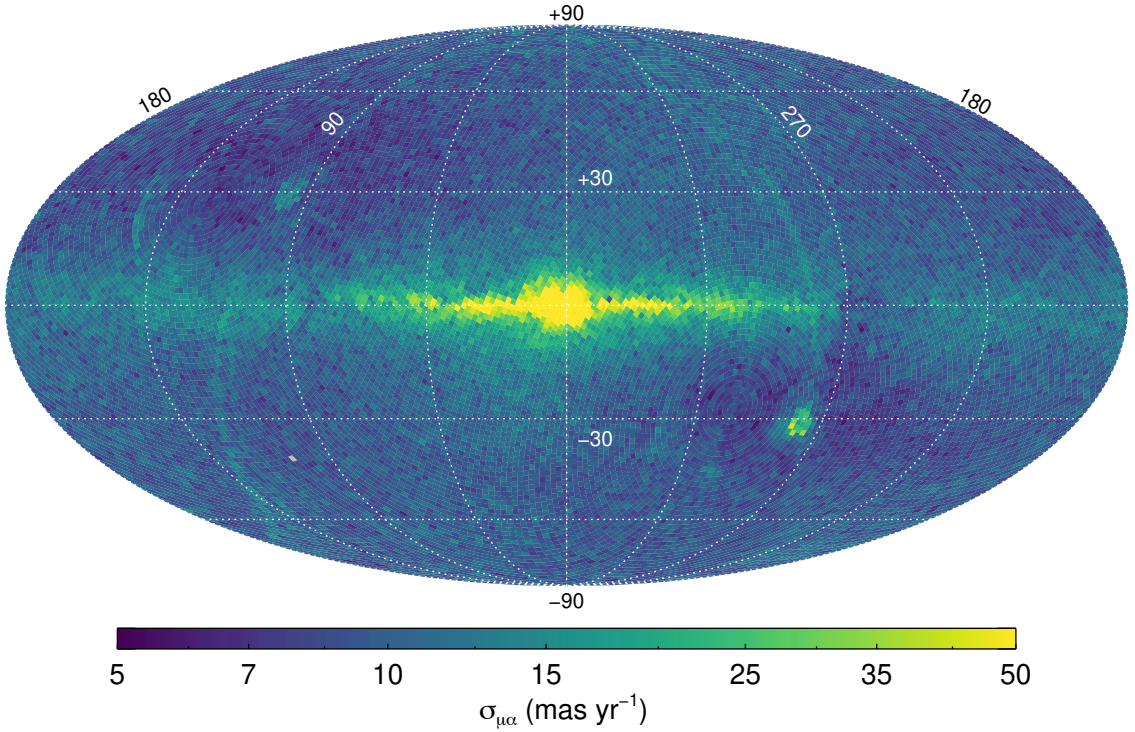
The CatWISE2020 Catalog – astrometric performance

10 < W1 < 17.5 mag



Position

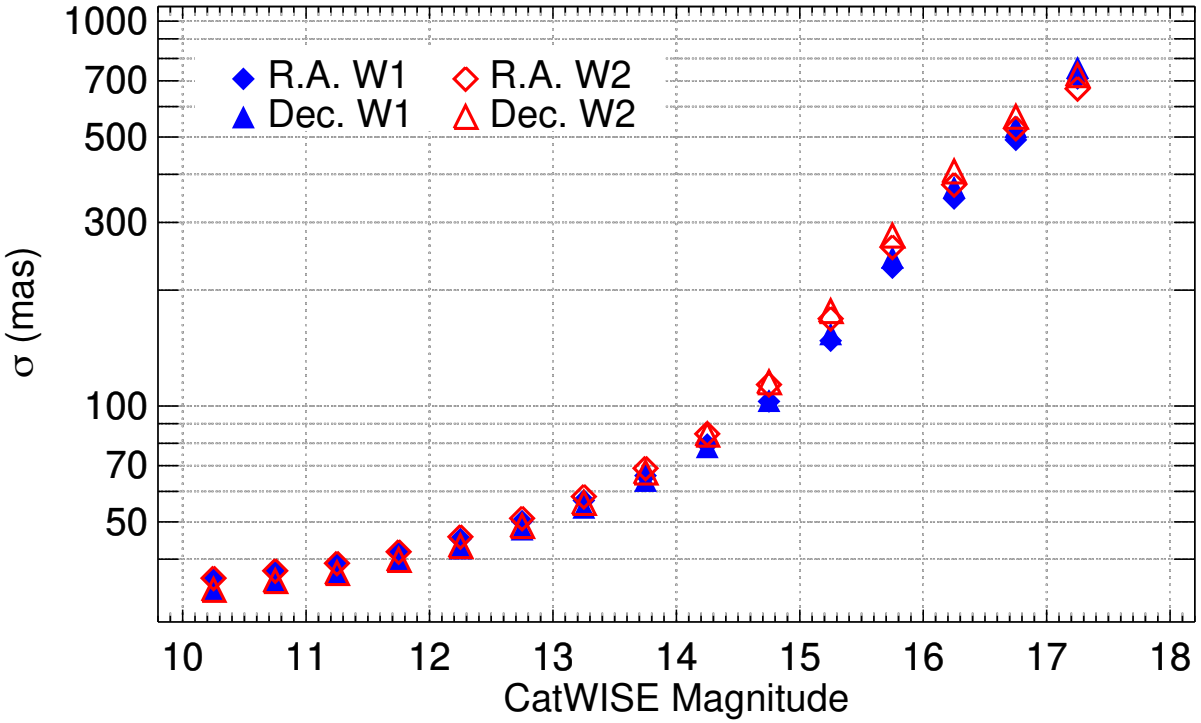
10 < W1 < 17.5 mag



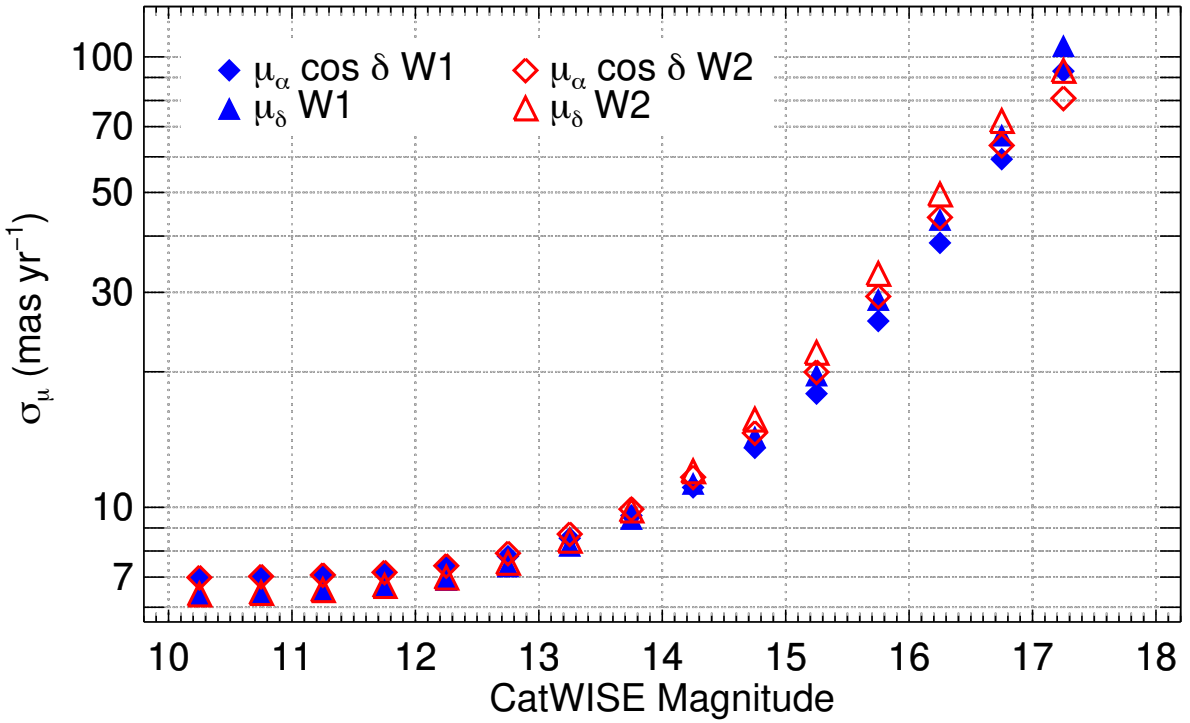
Proper motion

The CatWISE2020 Catalog – astrometric performance

Position accuracy floor ~35 mas and motion accuracy floor ~7 mas/yr;
~600 mas and 80 mas/yr @ W1,W2=17 mag



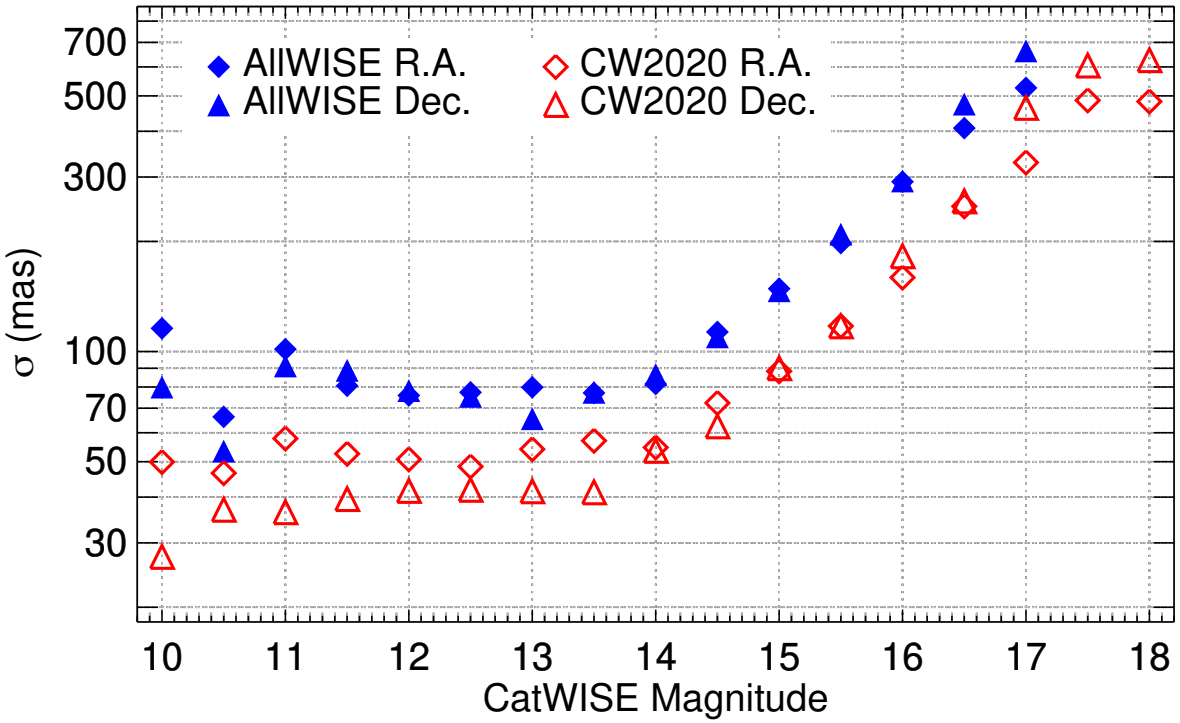
Position



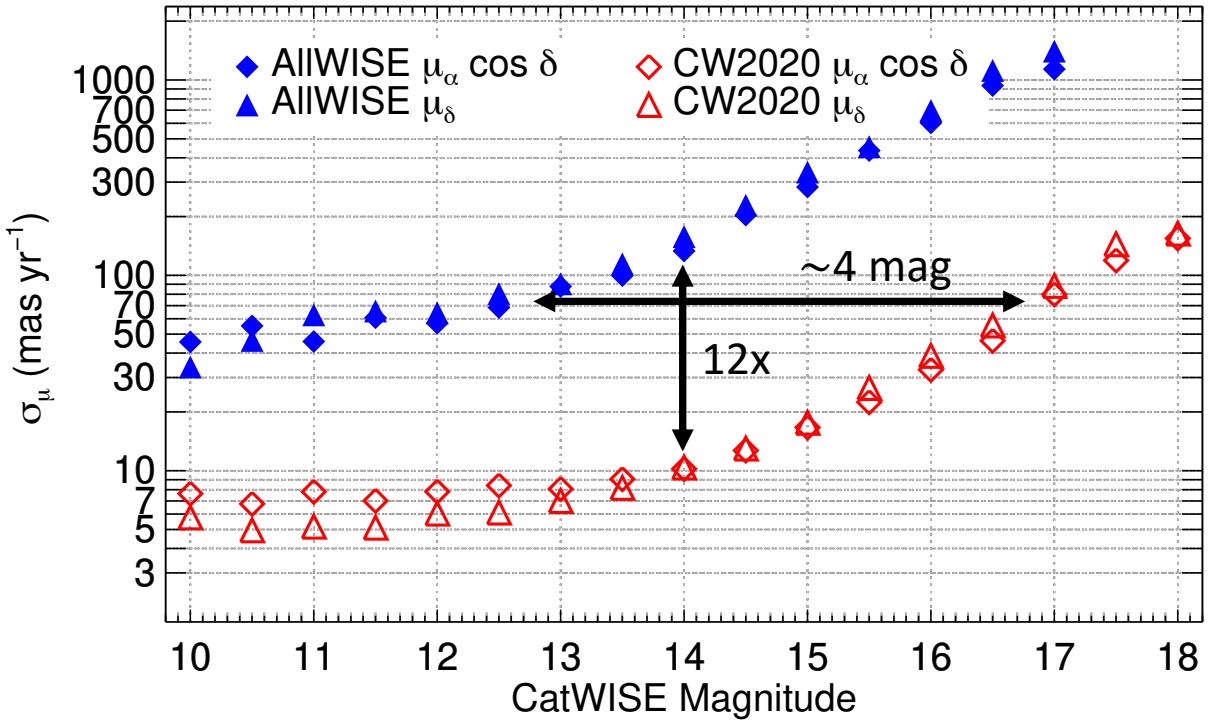
Proper motion

The CatWISE2020 Catalog – astrometric performance

30% improvement in position, 12x improvement in proper motion!

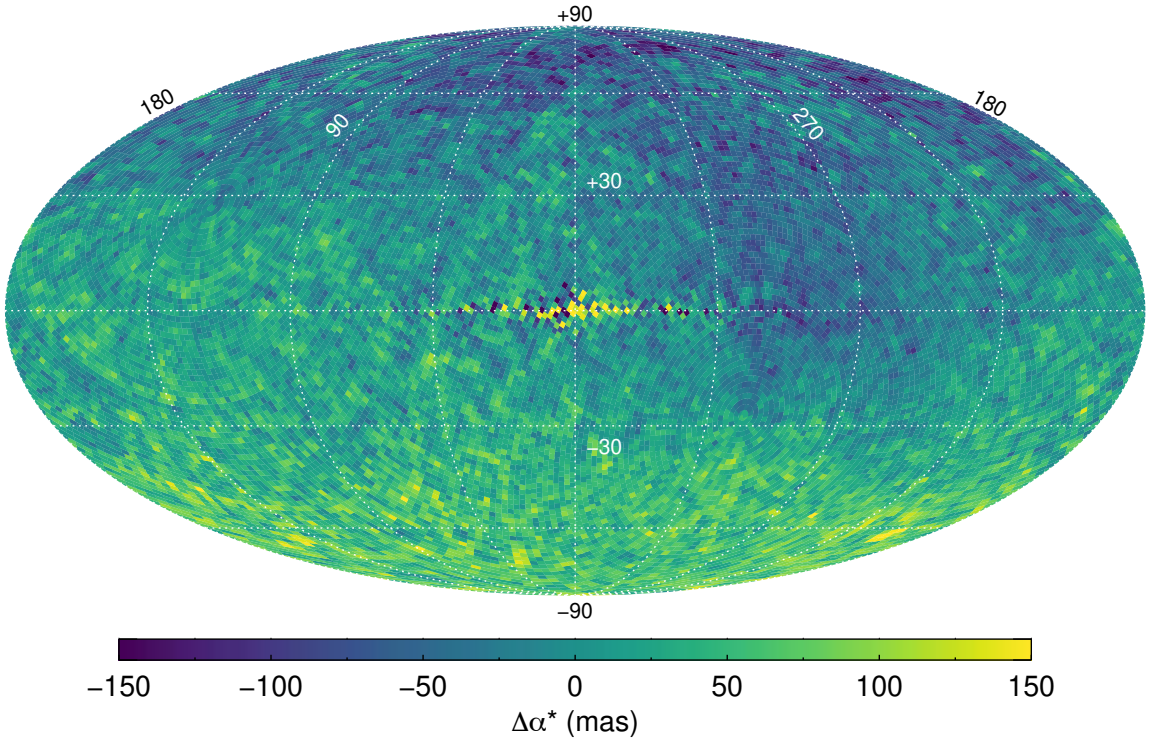


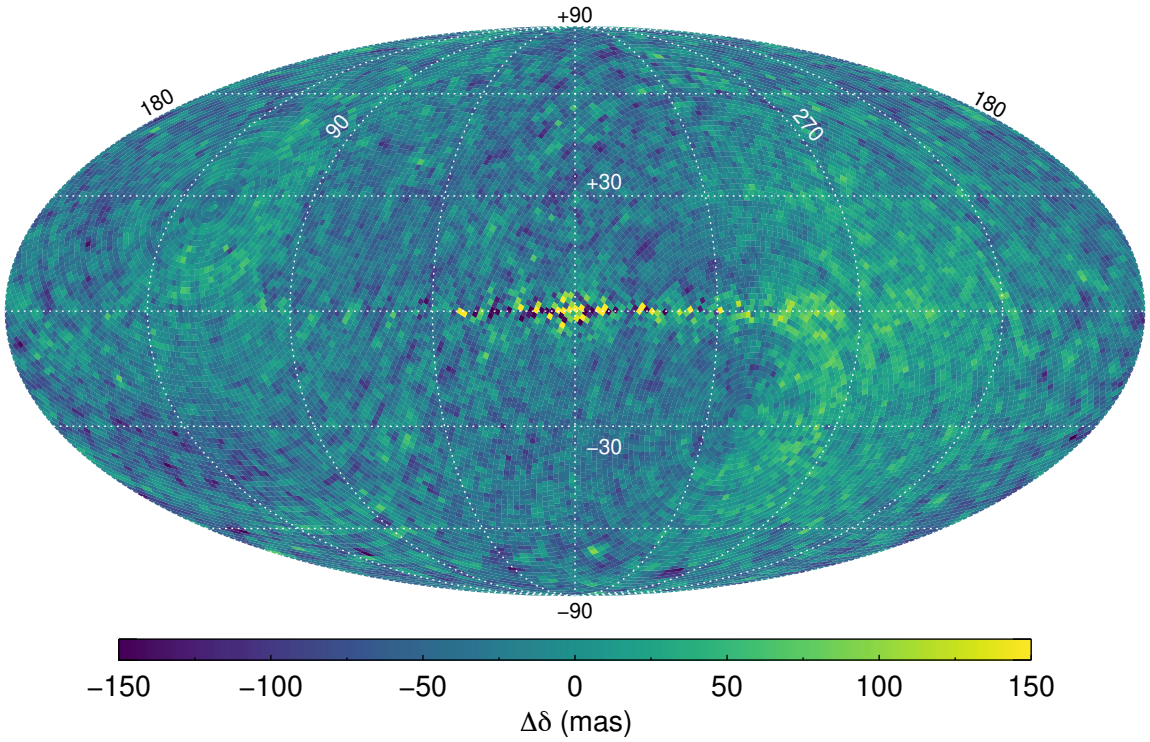
Position



Proper motion

The CatWISE2020 Catalog – astrometric performance

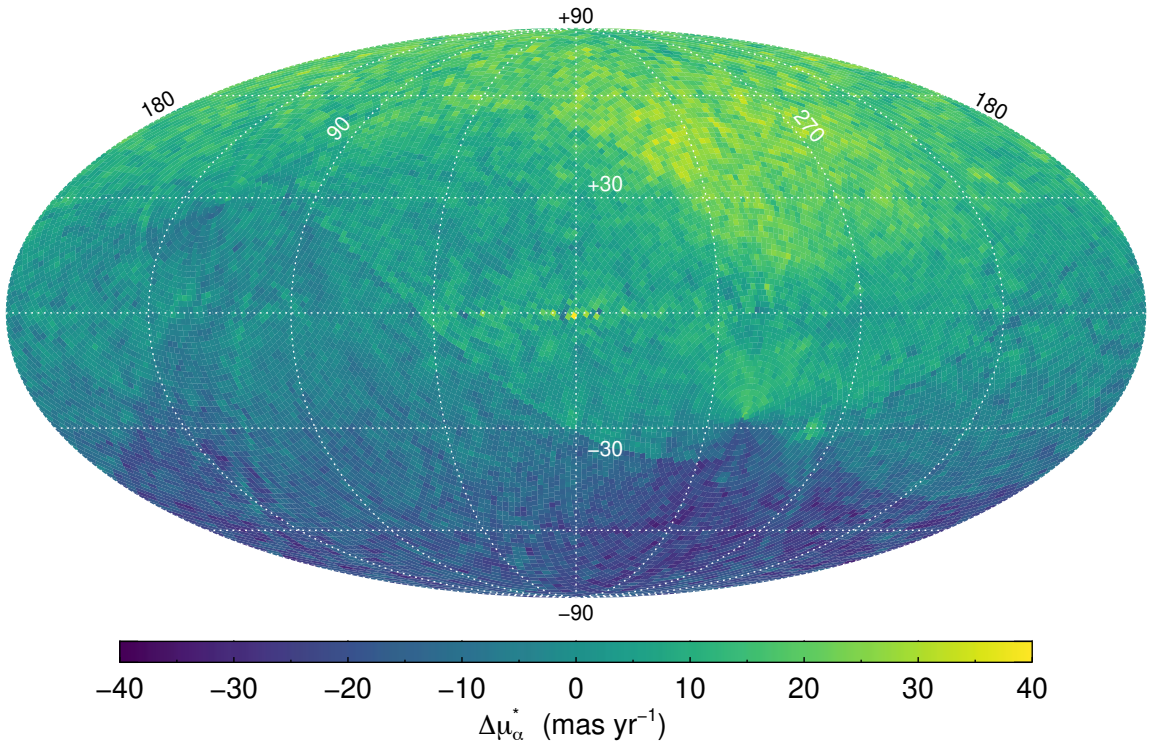


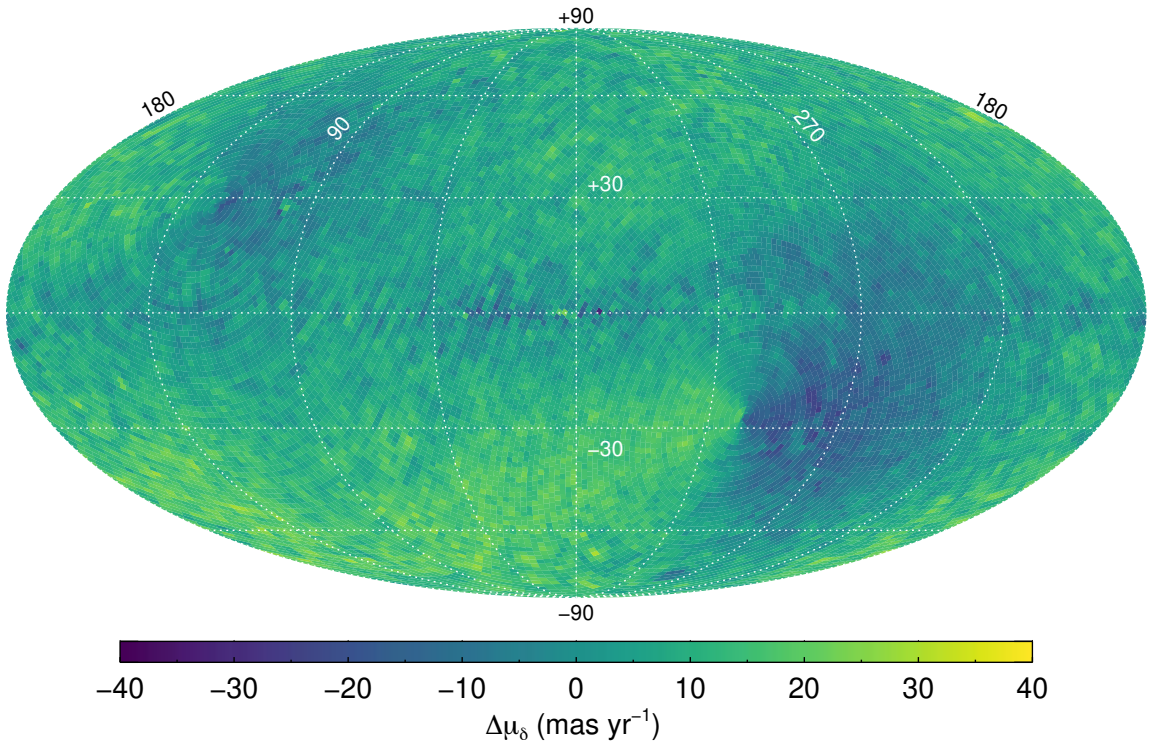


Small systematic offset resulting from uncorrected astrometric offset of early WISE epochs.

The offsets are typically in the ±150 mas range in position, and in the ±40 mas yr^{-1} range in proper motion.

The CatWISE2020 Catalog – astrometric performance





Motion offset maps reflect the solar motion within the LSR.

Corrections are provided on a tile-by-tile basis in Marocco et al. (2021, ApJS, 253, 8) and at IRSA.

The CatWISE2020 Catalog – Summary

CatWISE2020 provides photometry and proper motions for ∼2.2 billion sources from data at 3.4 and 4.6 microns.

CatWISE2020 95% completeness at W1=17.4 (96% reliable) and W2=17.2 (95% reliable).

The (empirical) S/N 5 depth is W1= 17.6 mag and W2=16.6 mag, 0.6 mag deeper than AllWISE.

CatWISE2020 is ∼12x more sensitive to motion than AllWISE, and complements Gaia for low-mass stars and brown dwarfs.

Data access via IRSA, further info at catwise.github.io.

Deep all-sky IR data

+

Great sensitivity to motion

=

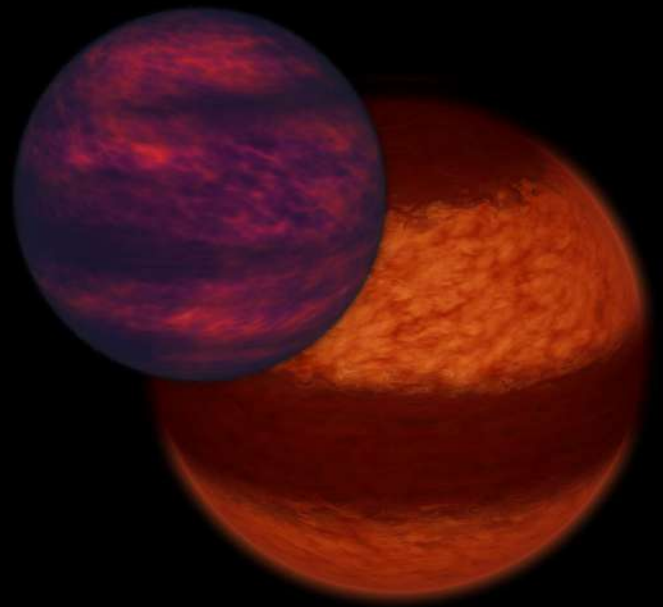
Cold brown dwarfs!

Image: NASA/JPL-Caltech/R. Hurt (IPAC)

Planets & Exoplanets

Up to ~13x Jupiter's mass

Brown Dwarfs



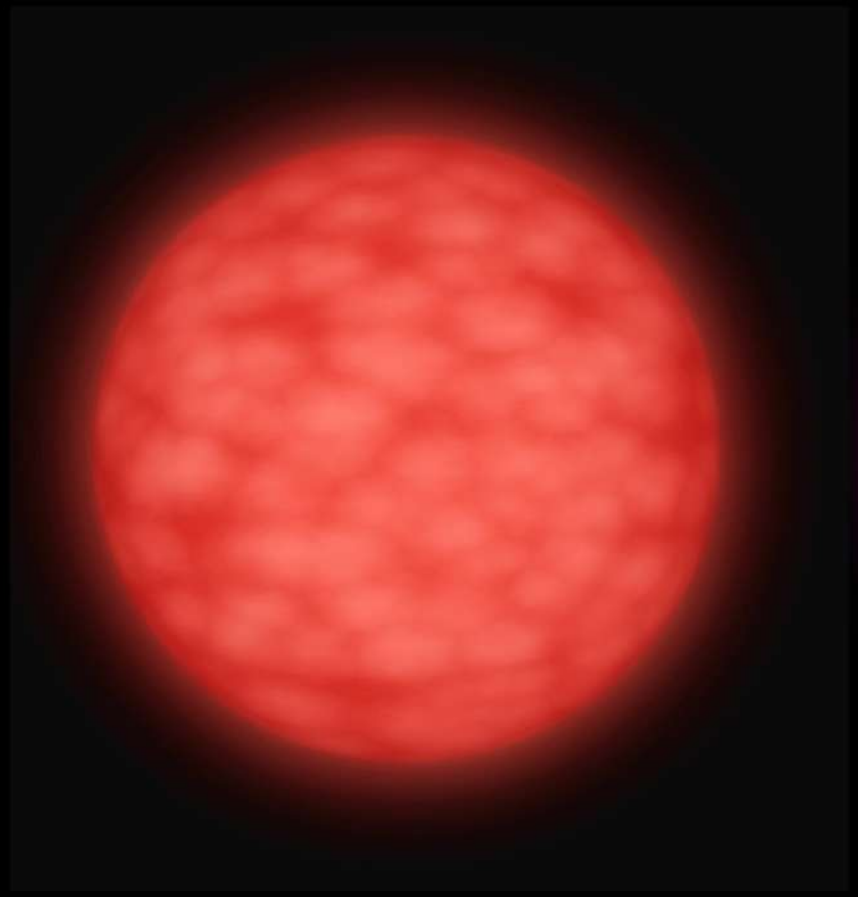
~13x to 80x Jupiter's mass

Stars

(Fueled by Nuclear Fusion)

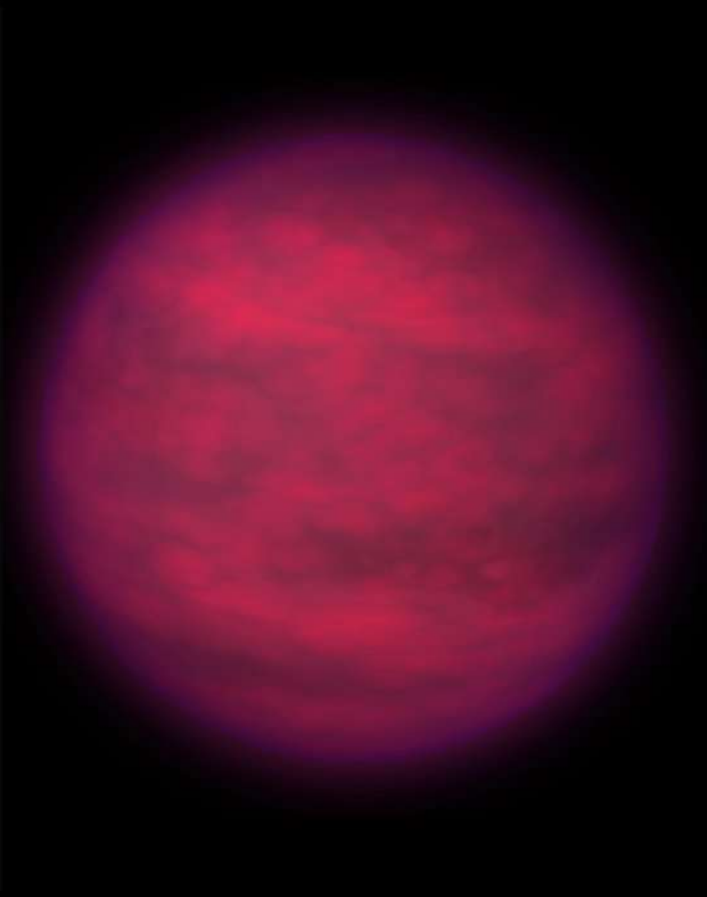
Over ~80x Jupiter's mass

Image: NASA/JPL-Caltech



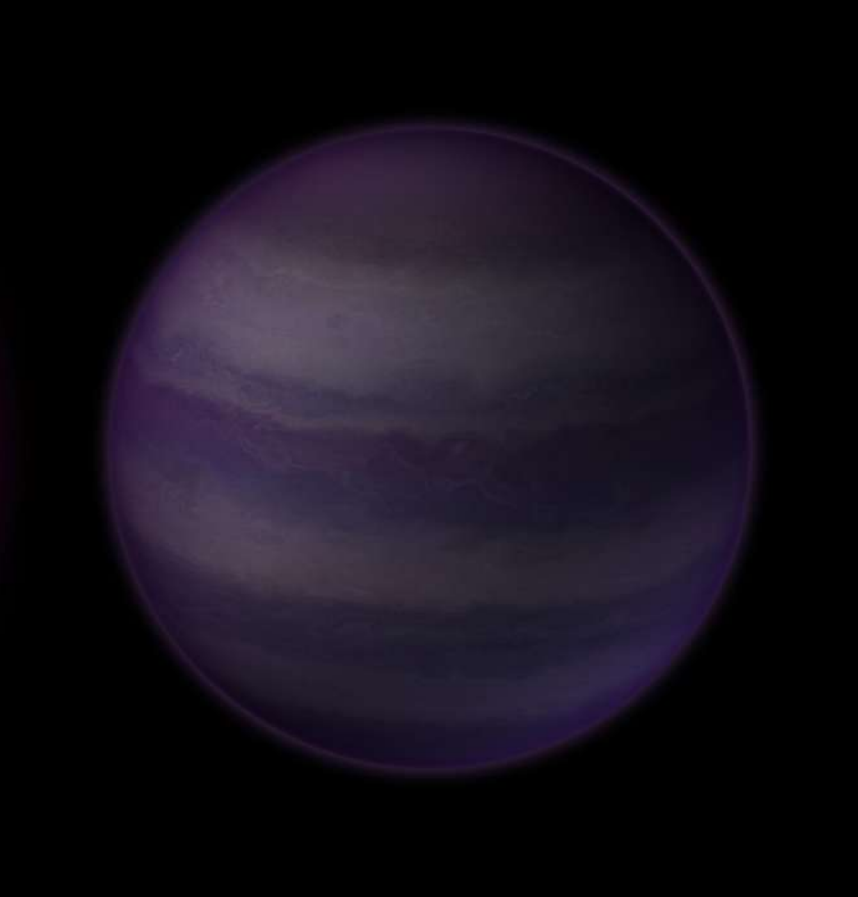
L Dwarf

3000 – 1500 K



T Dwarf

1500 – 500 K

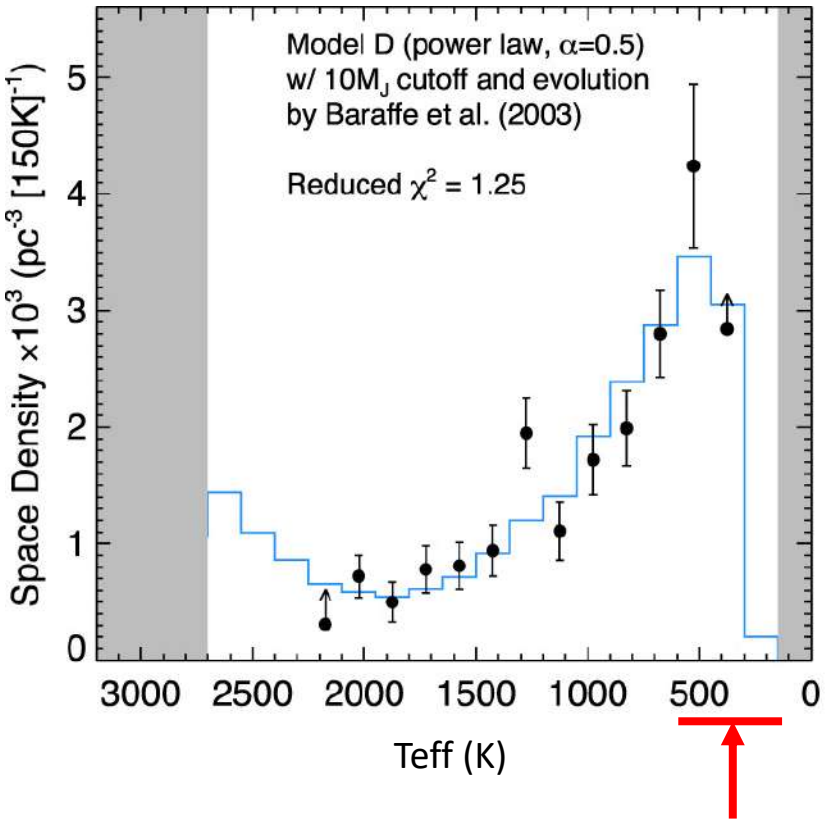


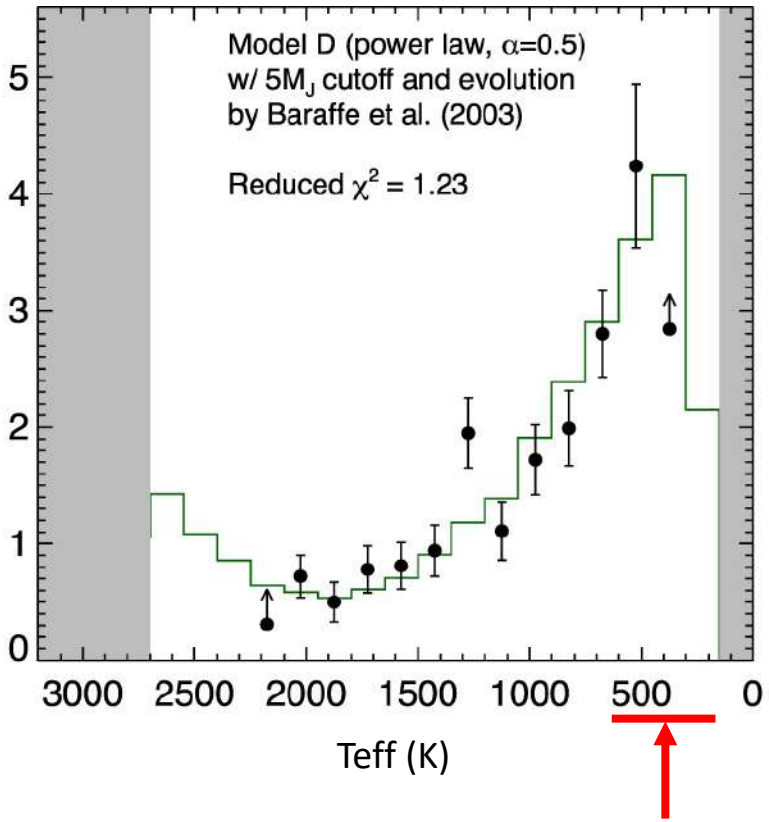
Y Dwarf

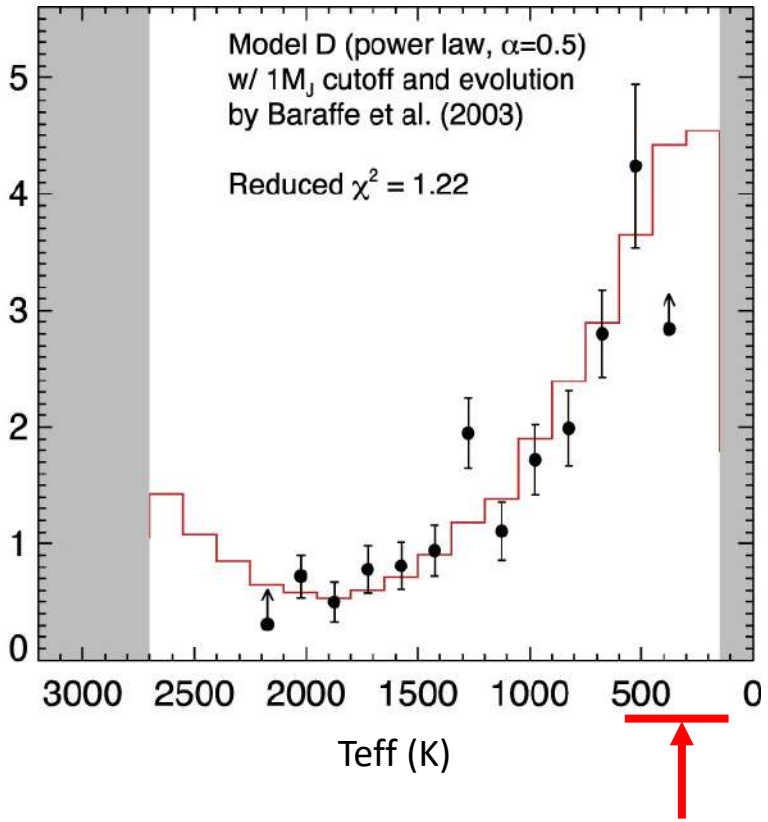
500 – 250(?) K

Is there a low-mass cutoff to star formation?

Kirkpatrick et al. 2021, ApJS, 253, 7K







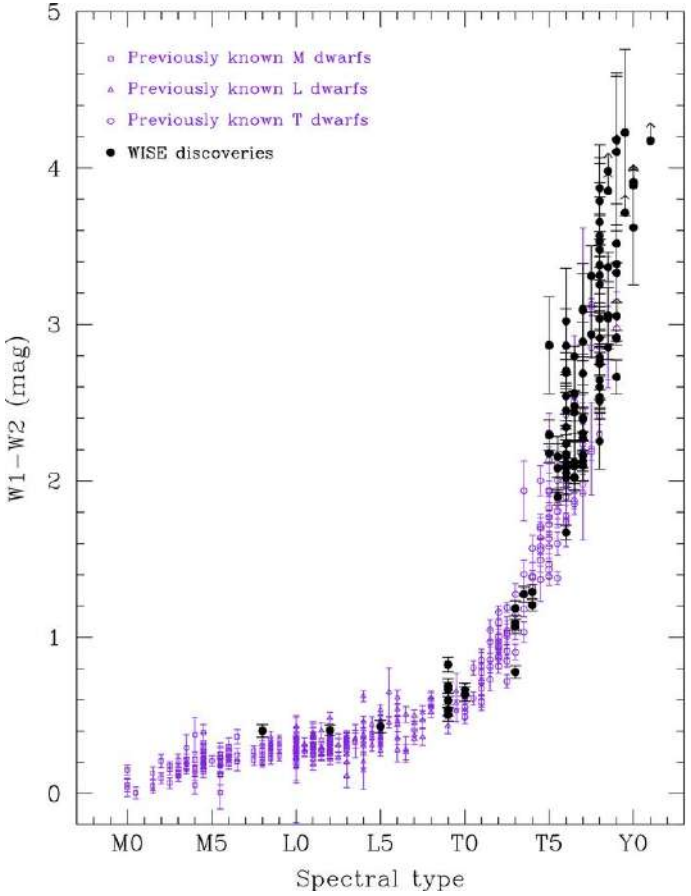
Identifying sources in the coldest bins is crucial!

CatWISE

Searches with “classical” + machine learning approach.

“Classical” approach: color + proper motion selection. Visual inspection of candidates.

Machine learning: classifier trained on known cold BDs. Visual inspection of objects above chosen threshold, retraining, reclassification.

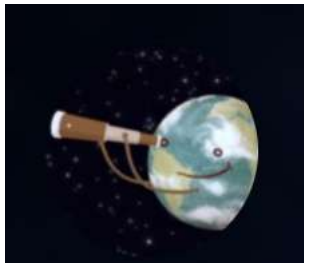


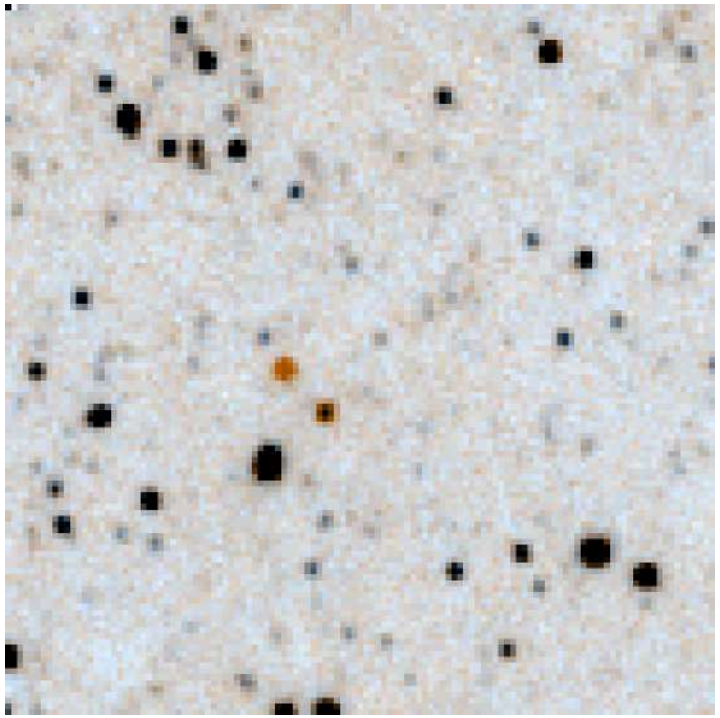
Kirkpatrick et al. (2012)

Backyard Worlds: Planet Nine

Citizen science project (Kuchner et al 2017). Volunteers visually inspect “flipbooks” of WISE/NEOWISE images to search for moving sources.

Available through Zooniverse.





CatWISE + Backyard Worlds = 100s of new discoveries!

Expanding the Y Dwarf Census with *Spitzer* Follow-up of the Coldest CatWI

Aaron M. Meisner[1], Christophe Jacqueline

CW Dwa WISEA J mass Ob

Spitzer Follow-up of Extremely Cold Brown Dwarfs Discovered by the Backyard Worlds: Planet 9 Citizen Science Project

The Field Substellar Mass Function Based on the Full-sky 20 pc Census of 525 L, T, and Y Dwarfs

J. Davy Kirkpatrick[1], Christopher R. Gelino[1], Jacqueline K. Faherty[2], Aaron M. Meisner[3], Dan Caselden[4], Adam C. Schneider[5,6], Federico Marocco[1], Alfred J. Cayago[7], R. L. Smart[8], Peter R. Eisenhardt[9] + Show full author list

Daniella C. Bardalez Gagliuffi[1], Jacqueline K. Faherty[1], Adam C. Schneider[2], Aaron Meisner[3], Dan Caselden[4], Guillaume Colin[4], Sam Goodman[4], J. Davy Kirkpatrick[5], Marc Kuchner[6], Jonathan Gagné[7] + Show full author list

J. Davy Kirkpatrick[1], Federico Marocco[1], Dan Caselden[2], Aaron M. Meisner[3], Jacqueline K. Faherty[4], Adam C. Schneider[5,6], Marc J. Kuchner[7], S. L. Casewell[8], Christopher R. Gelino[1], Michael C. Cushing[9] + Show full author list

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Aaron M. Meisner[1], Christophe

The Field Substellar Mass Function Based on the Full-sky 20

Jacqueli

CW

WISEA

mass Ob

Finding them is only the first step…

Dan Caselden[4], Adam C. Schneider[5,6], Federico Marocco[1], Alfred J. Cayago[7], R. L. Smart[8], Peter R. Eisenhardt[9] + Show full author list

Daniella C. Bardalez Gagliuffi[1], Jacqueline K. Faherty[1], Adam C. Schneider[2], Aaron Meisner[3], Dan Caselden[4], Guillaume Colin[4], Sam Goodman[4], J. Davy Kirkpatrick[5], Marc Kuchner[6], Jonathan Gagné[7] + Show full author list

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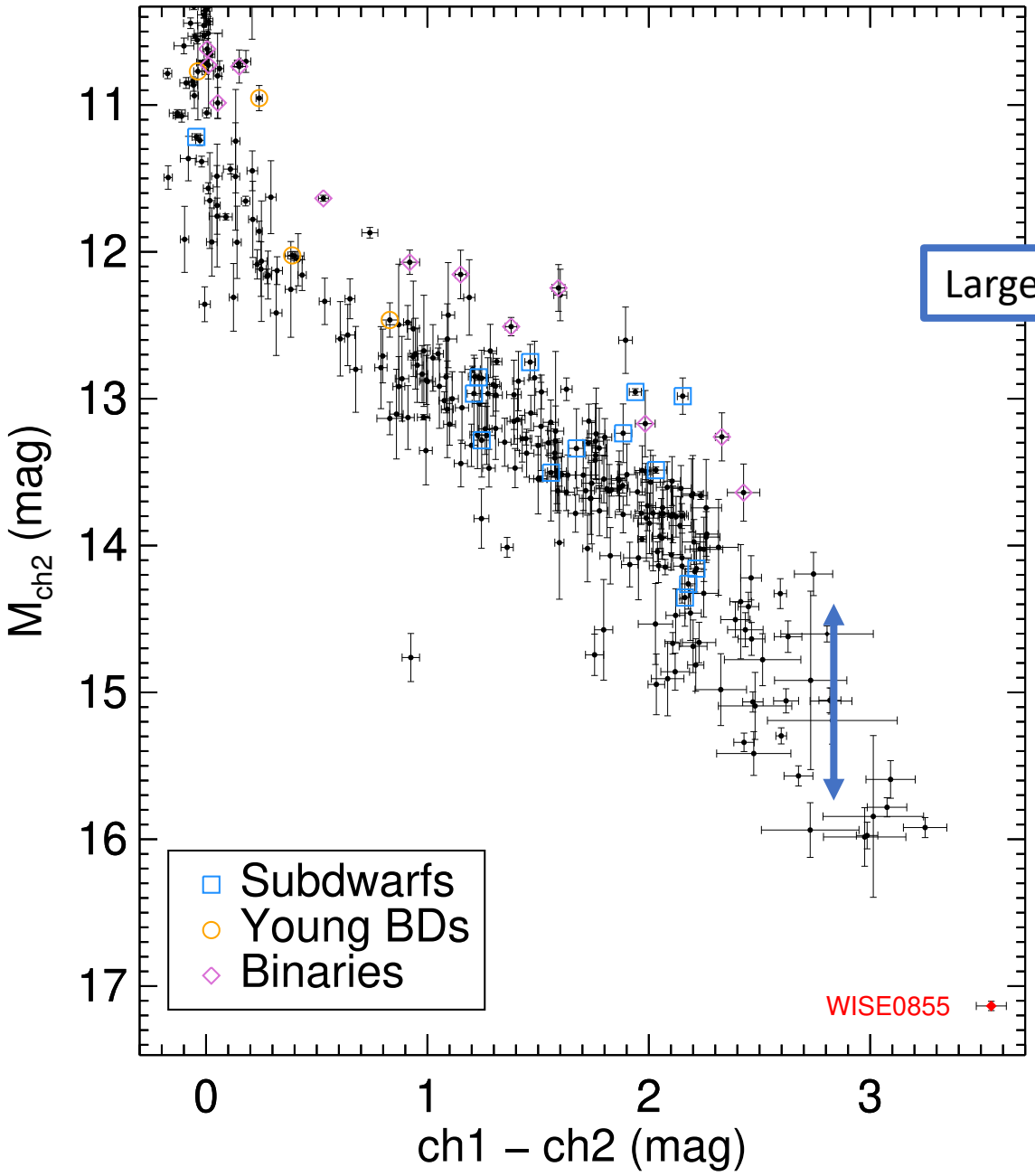
Ongoing follow-up campaign!

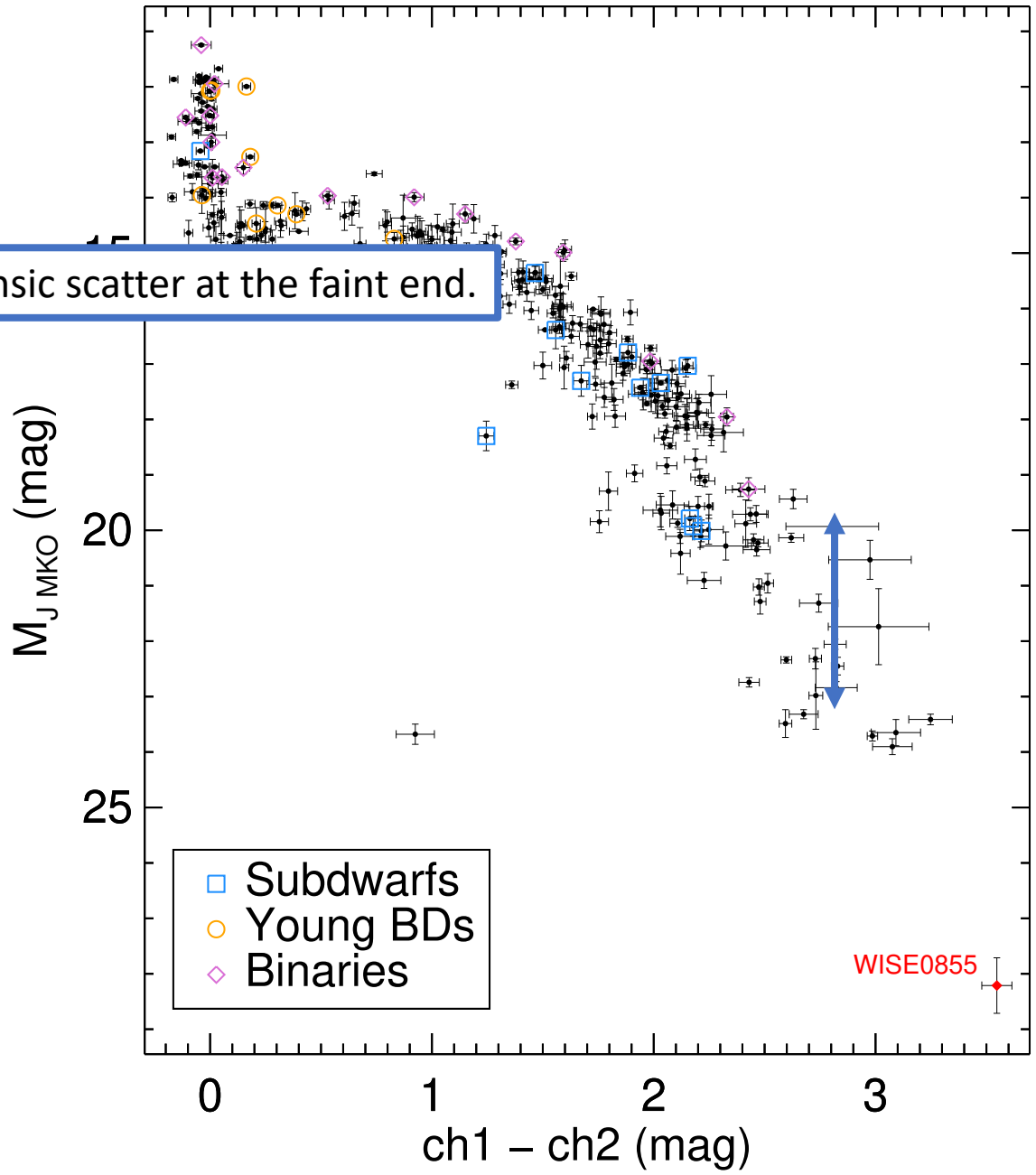
Spitzer/IRAC + HST/WFC3 + Palomar/WIRC + GTC/EMIR + VLT/HAWKI + UKIRT/WFCAM –> Parallaxes for ∼300 BDs!

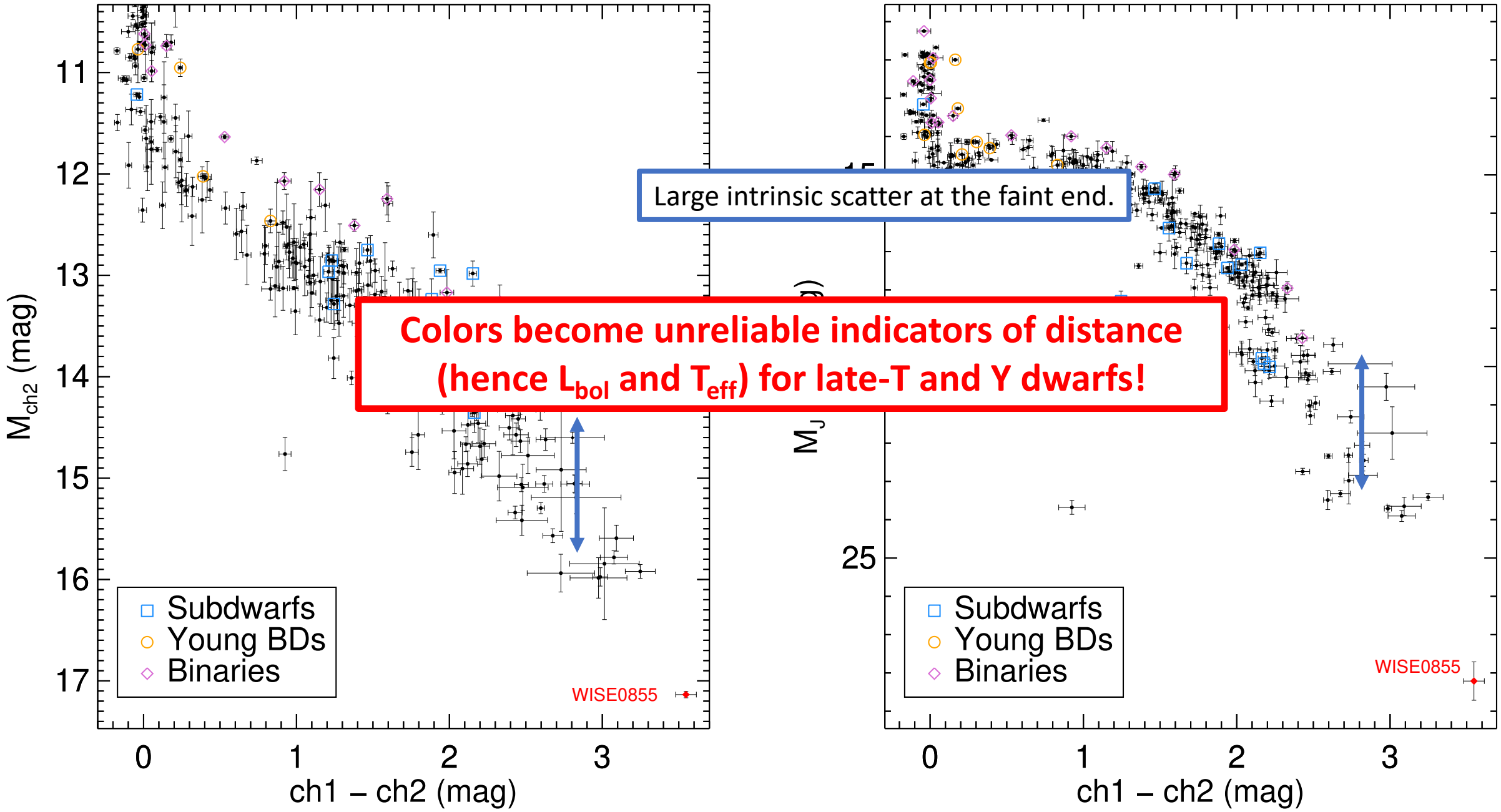
Palomar/WIRC + Keck/MOSFIRE + HST/WFC3 – multi-band photometry –> spectral typing

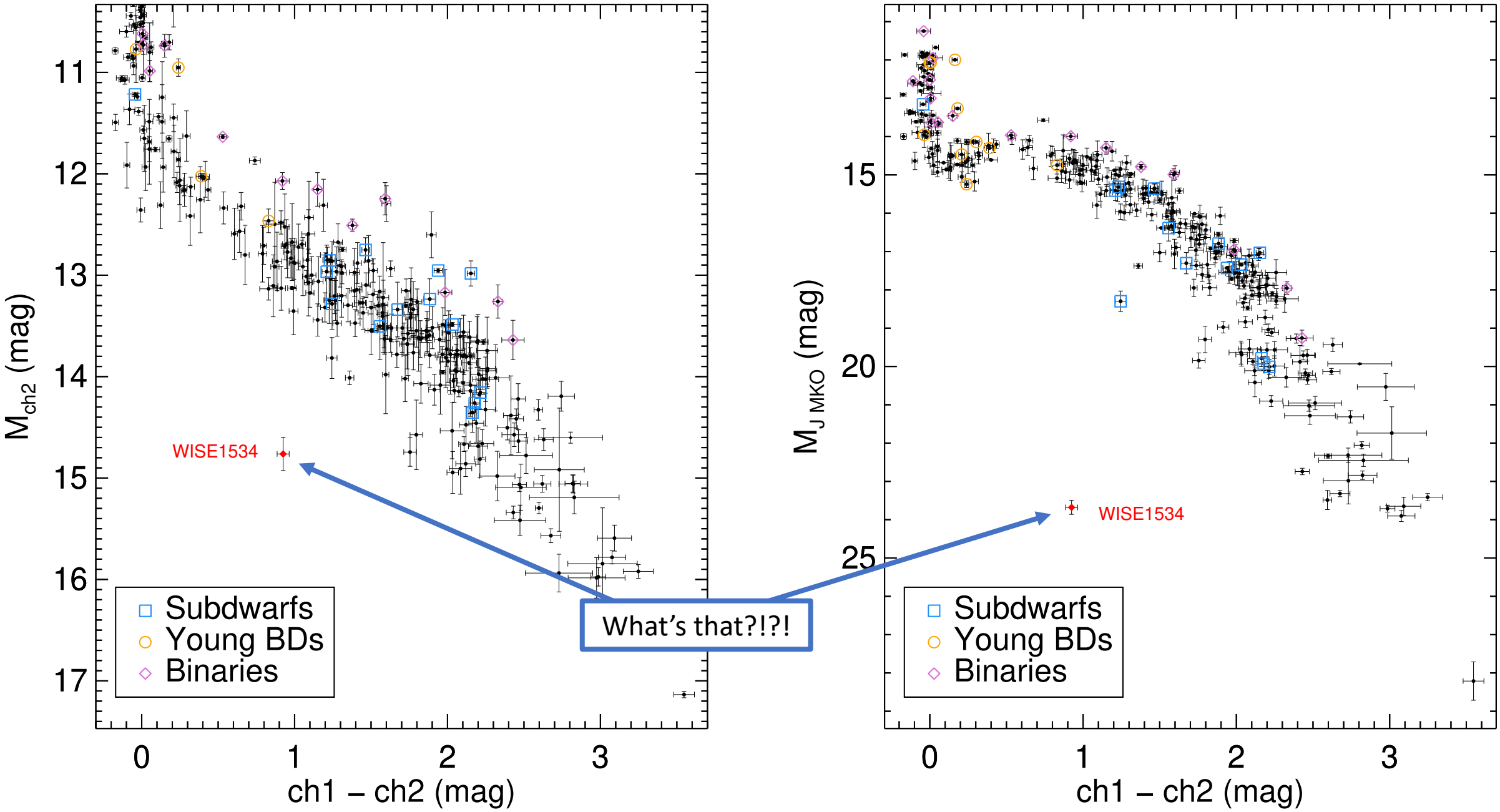
JWST/NIRSpec+MIRI – spectroscopic+photometric follow-up of color outliers –> how does the photometric diversity maps into spectral features?



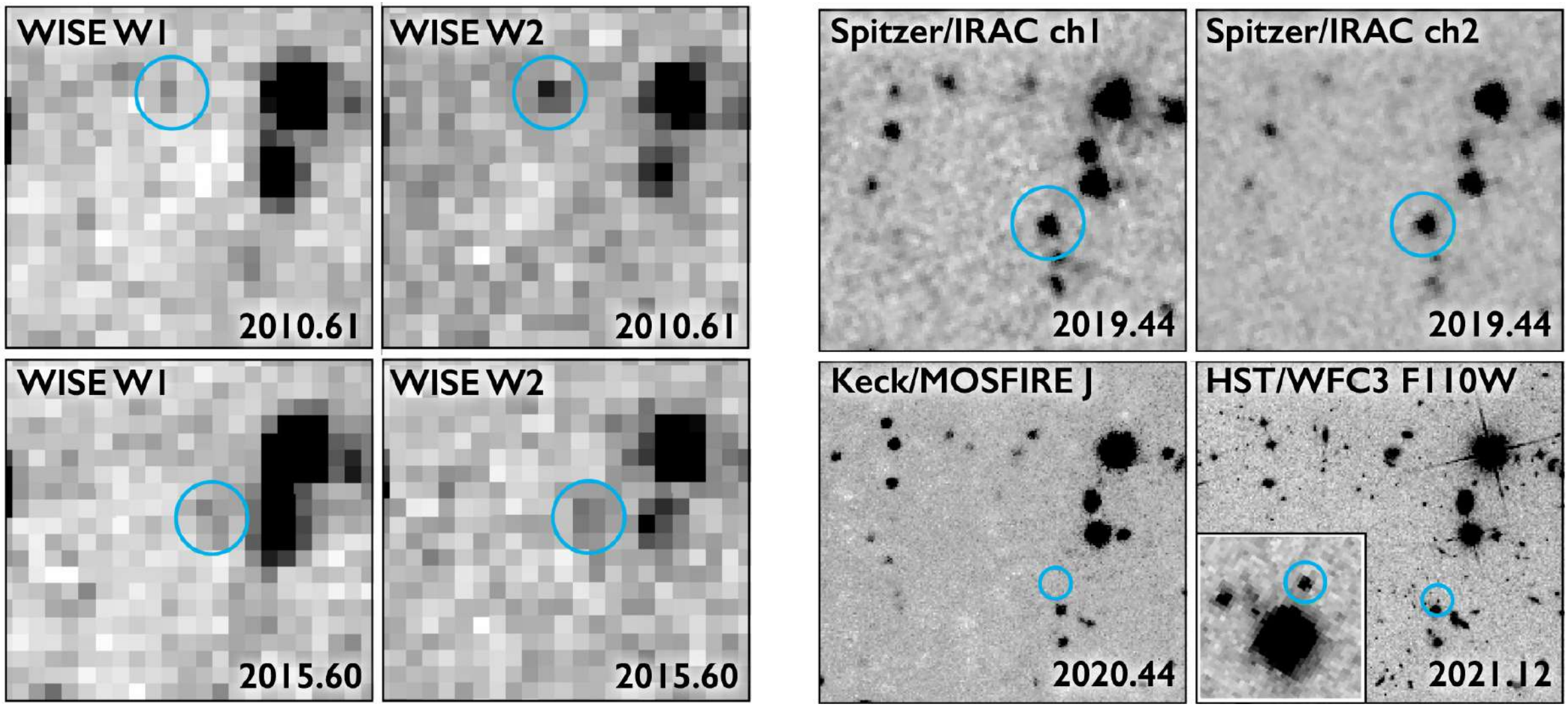
Large intrinsic scatter at the faint end.




Large intrinsic scatter at the faint end.
Colors become unreliable indicators of distance (hence L_{bol} and T_{eff}) for late-T and Y dwarfs!
M_{ch2} (mag)
ch1 – ch2 (mag)
M_J
Subdwarfs
Young BDs
Binaries
WISE0855

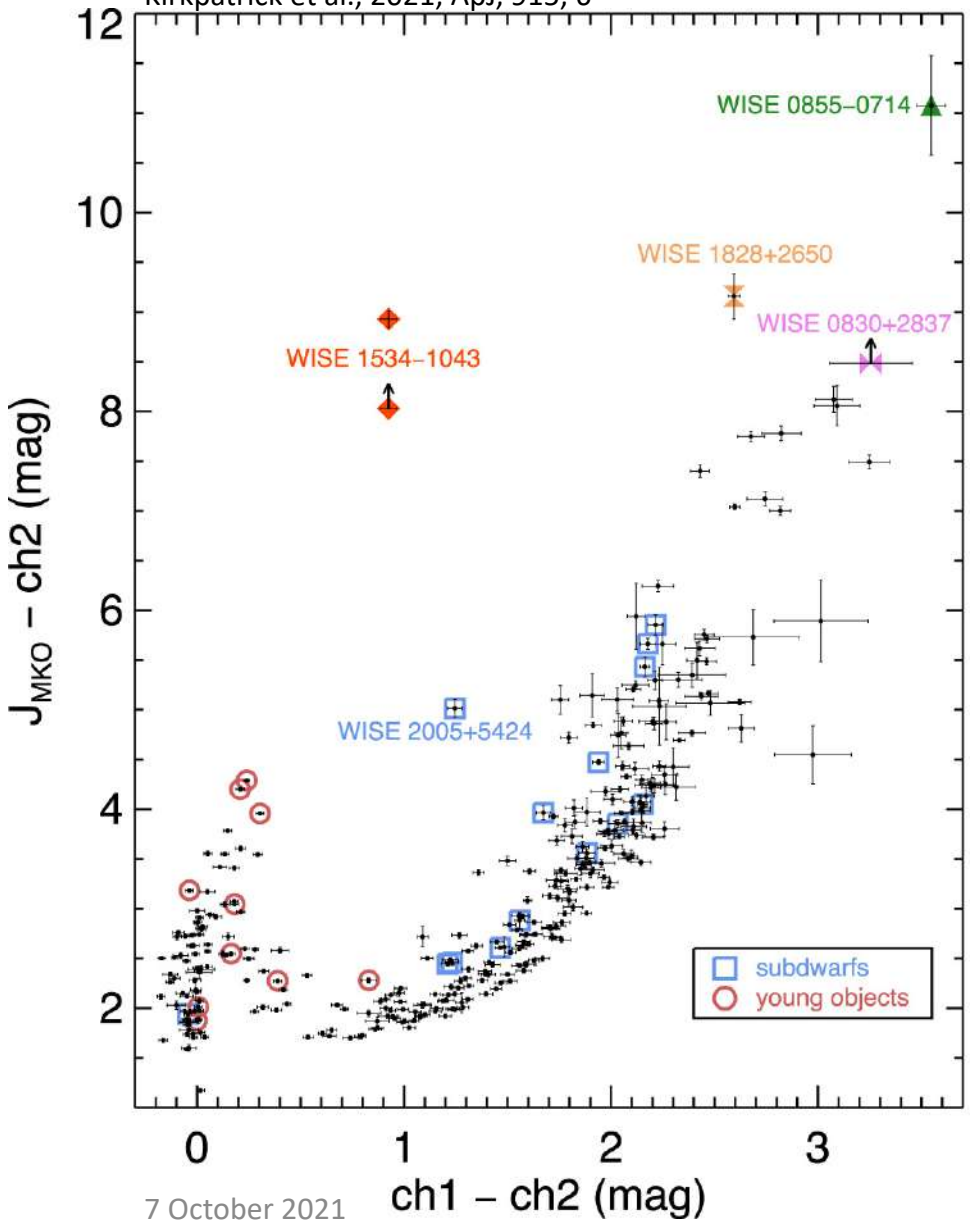

11
12
13
14
15
16
17
M_{ch2} (mag)
WISE1534
Subdwarfs
Young BDs
Binaries
0
1
2
3
ch1 – ch2 (mag)
What's that?!?!
15
20
25
$M_{J\ MKO}$ (mag)
WISE1534
Subdwarfs
Young BDs
Binaries
0
1
2
3
ch1 – ch2 (mag)

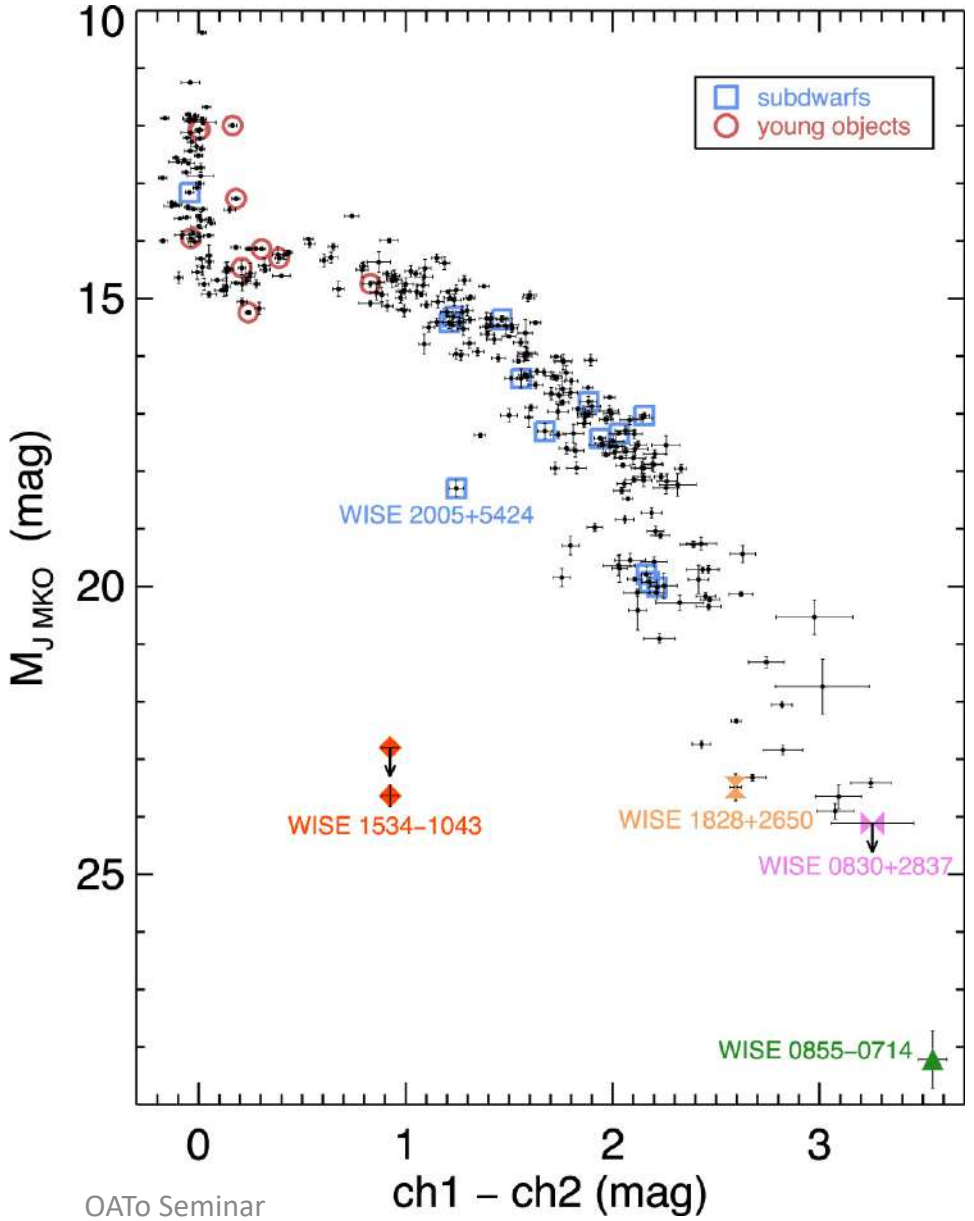
“We don’t make mistakes, we have happy accidents” (Bob Ross)



The first Y subdwarf?

Kirkpatrick et al., 2021, ApJ, 915, 6





ch1−ch2~0.9 mag
J−ch2 > 8 mag
F110W−ch2~9 mag

$PM_{tot} \sim 2.7$ arcsec yr^{-1}

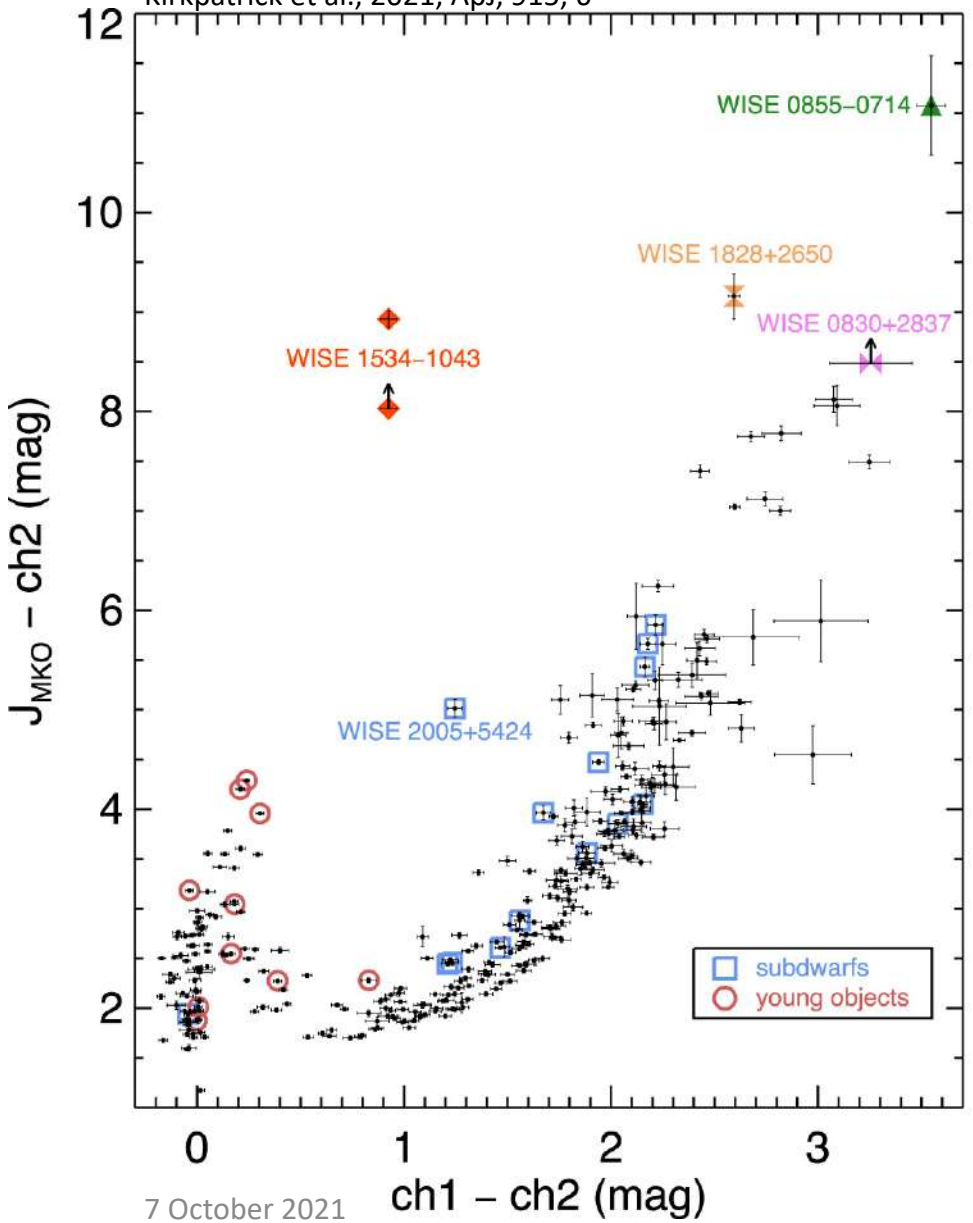
$D = 16.3^{+1.4}_{-1.2}$ pc

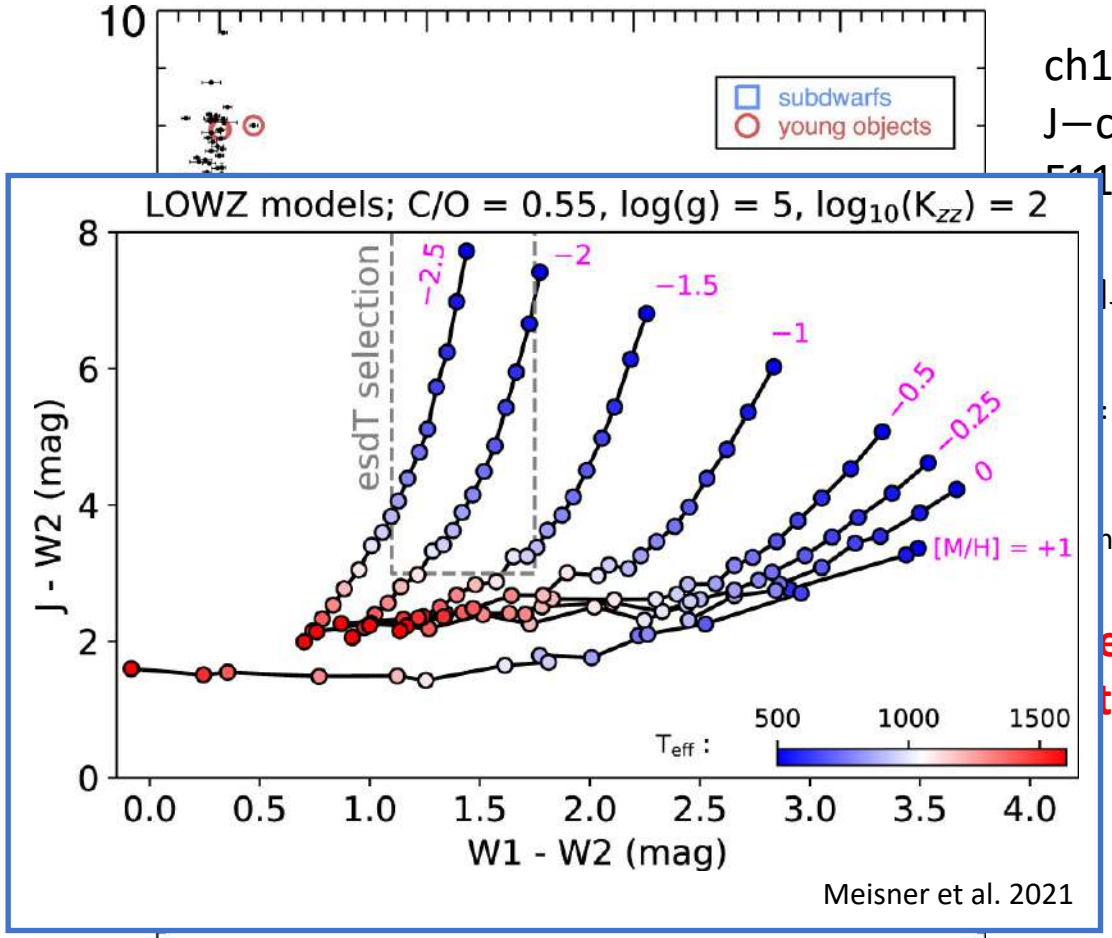
$V_{tan} \sim 210$ km s^{-1}

Likely a member of the halo!

The first Y subdwarf?

Kirkpatrick et al., 2021, ApJ, 915, 6





Meisner et al. 2021

ch1−ch2~0.9 mag

J−ch2 > 8 mag

5110W−ch2~9 mag

μ_{tot} ~ 2.7 arcsec yr^{-1}

$16.3^{+1.4}_{-1.2}$ pc

v_{tan} ~ 210 km s^{-1}

ely a member the halo!

The CatWISE2020 Catalog – Summary

CatWISE2020 provides photometry and proper motions for ∼1.9 billion sources from data at 3.4 and 4.6 microns.

CatWISE2020 95% completeness at W1=17.4 (96% reliable) and W2=17.2 (95% reliable).

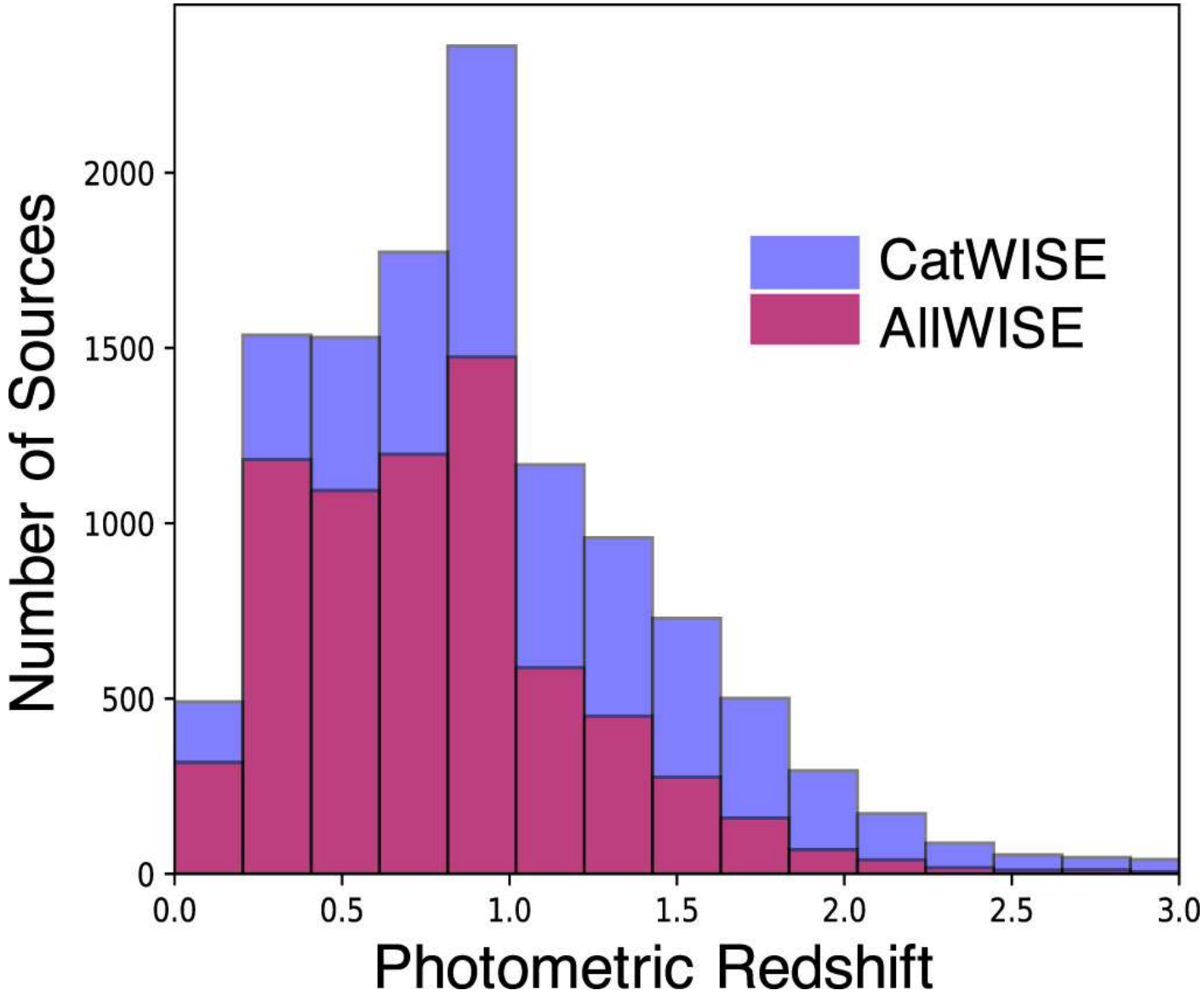
The (empirical) S/N 5 depth is W1= 17.6 mag and W2=16.6 mag, 0.6 mag deeper than AllWISE.

CatWISE2020 is ∼12x more sensitive to motion than AllWISE, and complements Gaia for low-mass stars and brown dwarfs.

Data access via IRSA, further info at catwise.github.io.

CatWISE2020 is an excellent resource to identify cold brown dwarfs in the solar neighborhood.

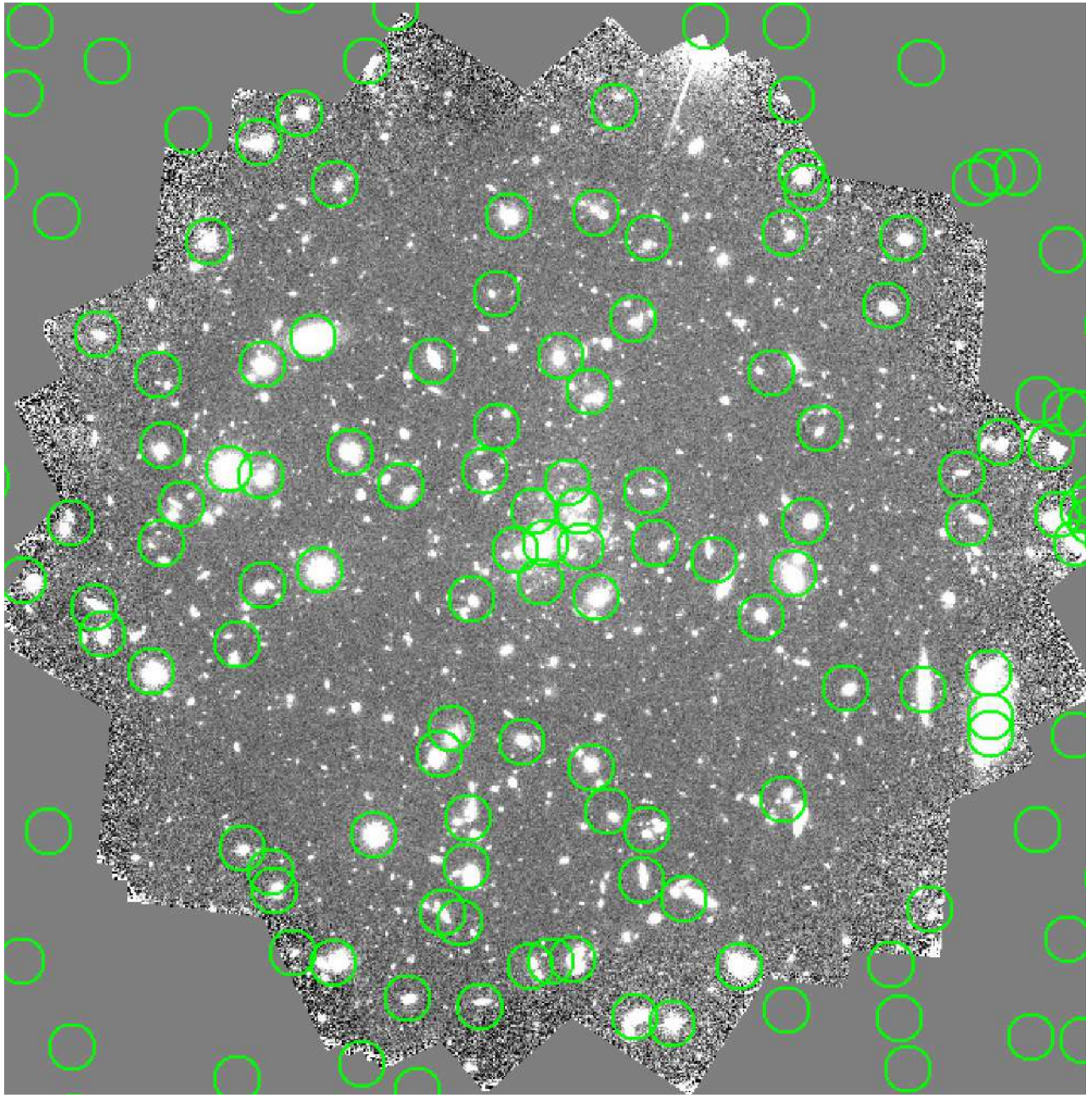
High-z galaxies



Eisenhardt et al. 2020
Laigle et al. 2016

CatWISE2020 and a Galaxy Cluster at z = 1.75

Green Circles: CatWISE2020 sources
Background: HST F160W image of IDCS 1426.5+3508 (Stanford et al. 2012)



The CatWISE2020 Catalog – Summary

CatWISE2020 provides photometry and proper motions for ∼2.2 billion sources from data at 3.4 and 4.6 microns.

CatWISE2020 95% completeness at W1=17.4 (96% reliable) and W2=17.2 (95% reliable).

The (empirical) S/N 5 depth is W1= 17.6 mag and W2=16.6 mag, 0.6 mag deeper than AllWISE.

CatWISE2020 is ∼12x more sensitive to motion than AllWISE, and complements Gaia for low-mass stars and brown dwarfs.

Data access via IRSA, further info at catwise.github.io.

CatWISE2020 is an excellent resource to identify cold brown dwarfs in the solar neighborhood **and much more!**

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Thank you!

For further info:
Our webpage: catwise.github.io
Data release papers: Eisenhardt et al. (2020), ApJS, 247, 69
Marocco et al. (2021), ApJS, 253, 8
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