WISE - the Wide-field Infrared Survey Explorer

Ned Wright (UCLA)

Project Overview

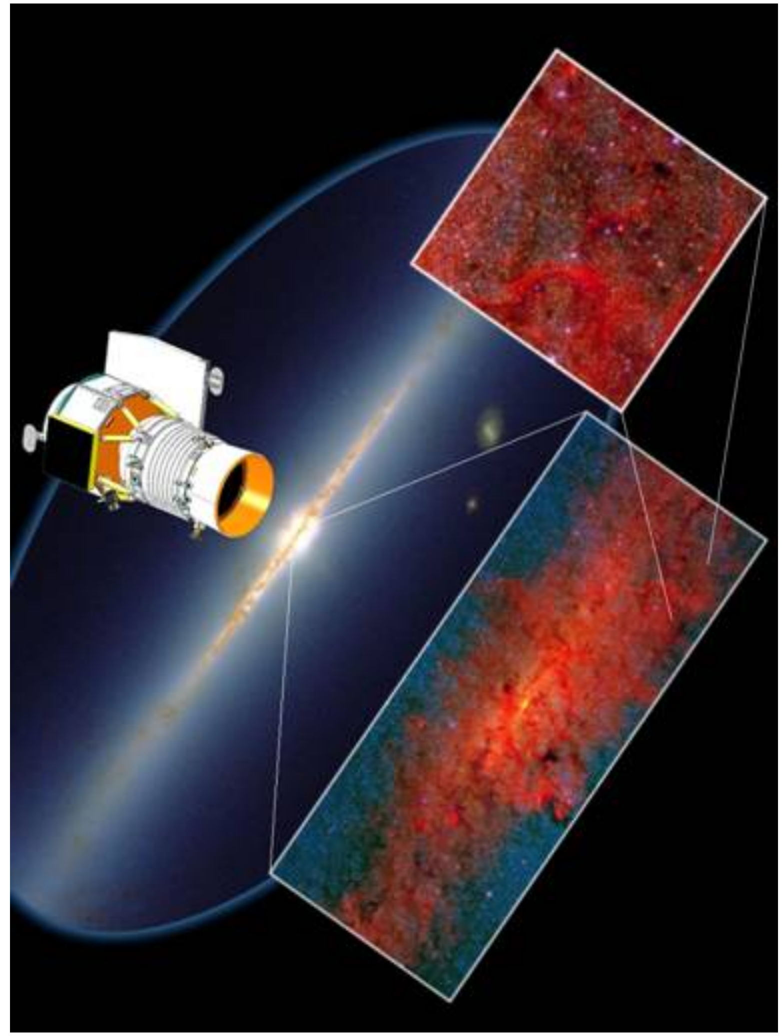
Science

- *Sensitive all sky survey with 8X redundancy*
    - *Find the most luminous galaxies in the universe*
    - *Find the closest stars to the sun*
    - *Provide an important catalog for JWST*
    - *Provide lasting research legacy*

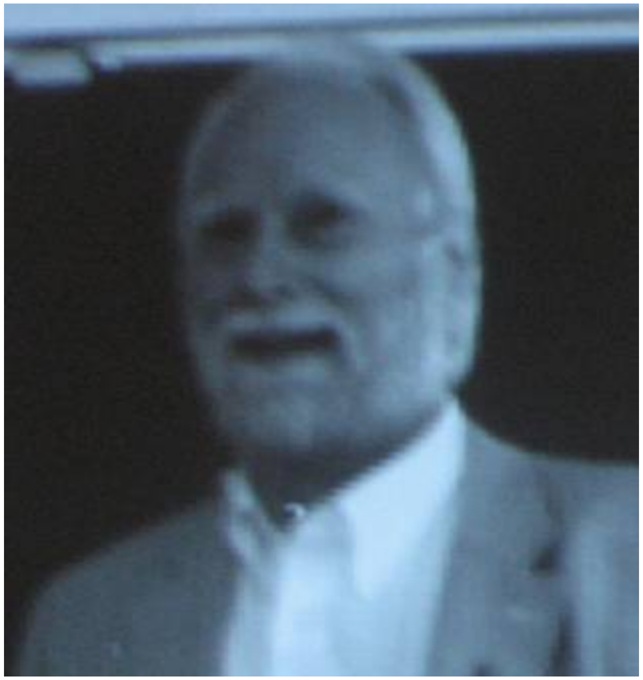
Salient Features

- *4 imaging channels covering 3 - 25 microns wavelength*
- *40 cm telescope operating at <17K*
- *Two stage solid hydrogen cryostat*
- *Delta launch from WTR: 14 Dec 2009*
- *Sun-synchronous 6am 530km orbit*
- *Scan mirror provides efficient mapping*
- *Expected life: 10 months, actual 7.7-9.5*
- *4 TDRSS tracks per day*

Wide Field Infrared Survey Explorer



Infrared



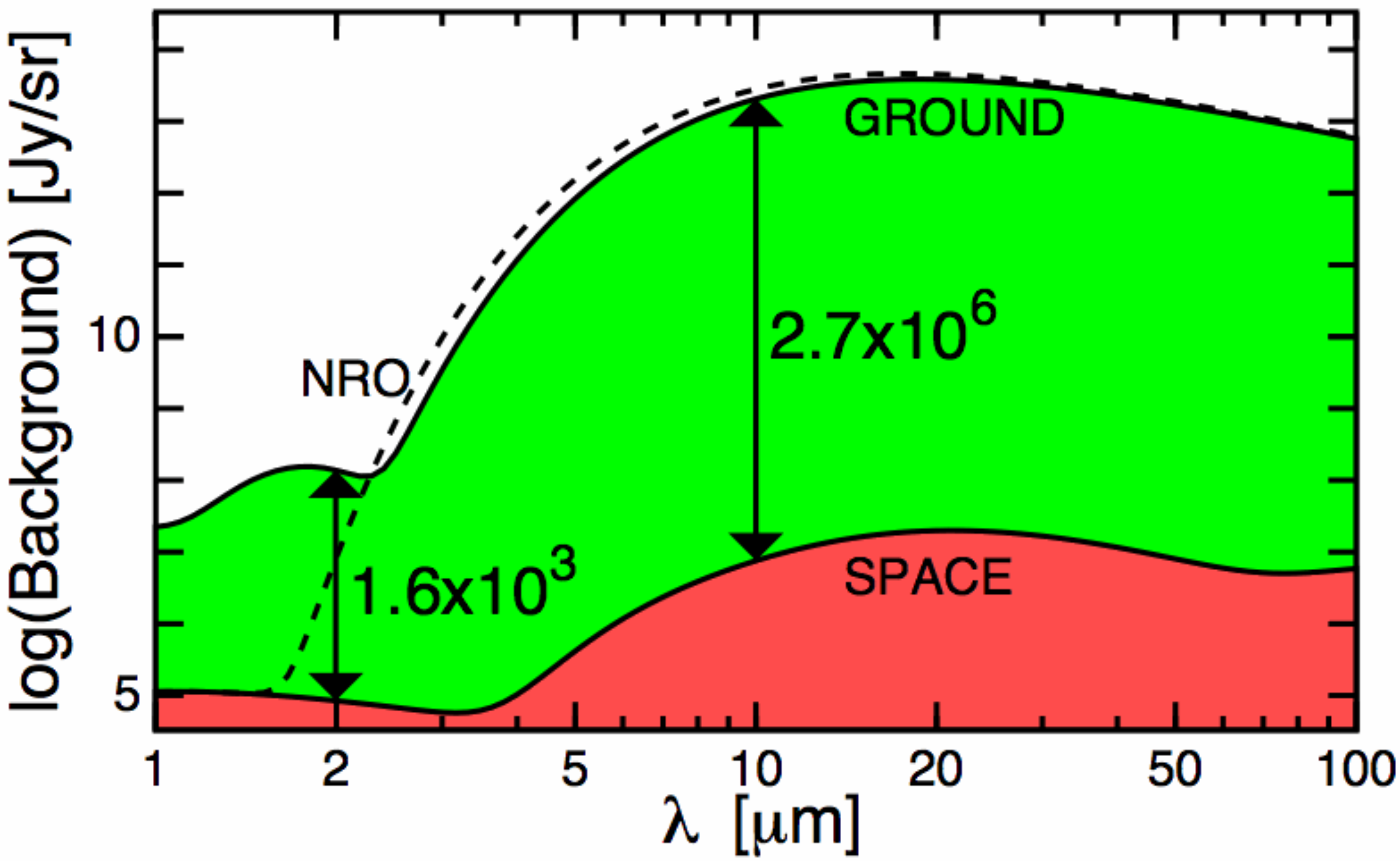
- Optical
- Reflected light

Near-IR
different colors

Thermal-IR
emitted radiation

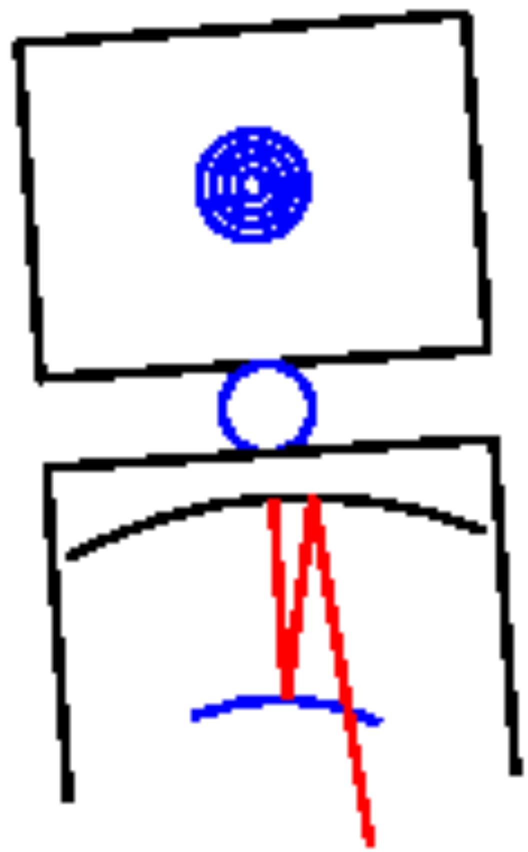
Why Space?

“Ground-based infrared astronomy is like observing stars in broad daylight with a telescope made out of fluorescent lights” — George Rieke.



40 cm WISE telescope in space equals six thousand 8-meter telescopes on the ground!

Animated Scan Mirror Icon



WISE Science Heritage

- NIRAS SMEX proposal in 1988. CJL & ELW as co-I's.
- Review panel suggested ground-based survey which became 2MASS.
- NIRST mission concept study in 1994. PRME & ELW as co-PI's.
- NGSS proposal in 1998.
- NGSS Phase A study in 1999.
- NGSS proposal in 2001.
- NGSS Phase A study in 2002.
- Renamed WISE in 2003

PROPOSAL TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
FOR A
NEAR-INFRARED ASTRONOMY SATELLITE

P1976-9-88

For the period 1 July 1989 through 30 September 1993

Total Estimated Cost: $15,457,092
(not including costs from NASA Centers)

Volume I - Investigation and Technical Plan

Principal Investigator

Dr. Giovanni G. Fazio
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge MA 02138
(617) 495-7458

Associate Director for
Optical and Infrared Astronomy
Dr. David W. Latham

Co-Investigators

Smithsonian Astrophysical Observatory
Dr. John P. Huchra
Dr. David G. Koch
Dr. Gary J. Melnick
Dr. Steven P. Willner

University of California
at Los Angeles
Dr. Edward L. Wright

California Institute of Technology
Infrared Processing and Analysis Center
Dr. Carol Lonsdale, Lead Scientist
Dr. Charles A. Beichman
Dr. Baruch T. Soifer

Space Telescope
Science Institute
Dr. Richard Burg, Lead Scientist
Dr. Brian McLean
Dr. Michael Shara

California Institute of Technology
Dr. Jeremy R. Mould
Dr. I. Neill Reid

Jet Propulsion Laboratory
Dr. Richard Capps

NASA/Ames Research Center
Dr. Craig R. McCreight

Air Force Geophysics Laboratory
Dr. Stephan D. Price

September 1988

Dr. Irwin I. Shapiro
Director

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

NIRAS 1988

- All sky survey.
- Big arrays (58x62).
- Continuous slew.
- Scan mirror to freeze image on array.
- Exposures every 4.5 seconds.

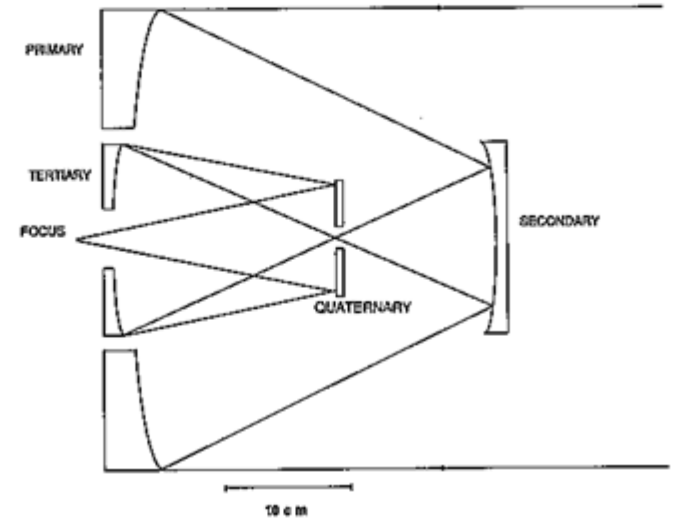


Figure 3-3. Optical Diagram of the Telescope

A scan mirror is used to freeze the sky field-of-view on the detectors for a period of 4.3 seconds as the spacecraft rotates at the orbital rate. The field-of-view is then advanced within 0.2 seconds.

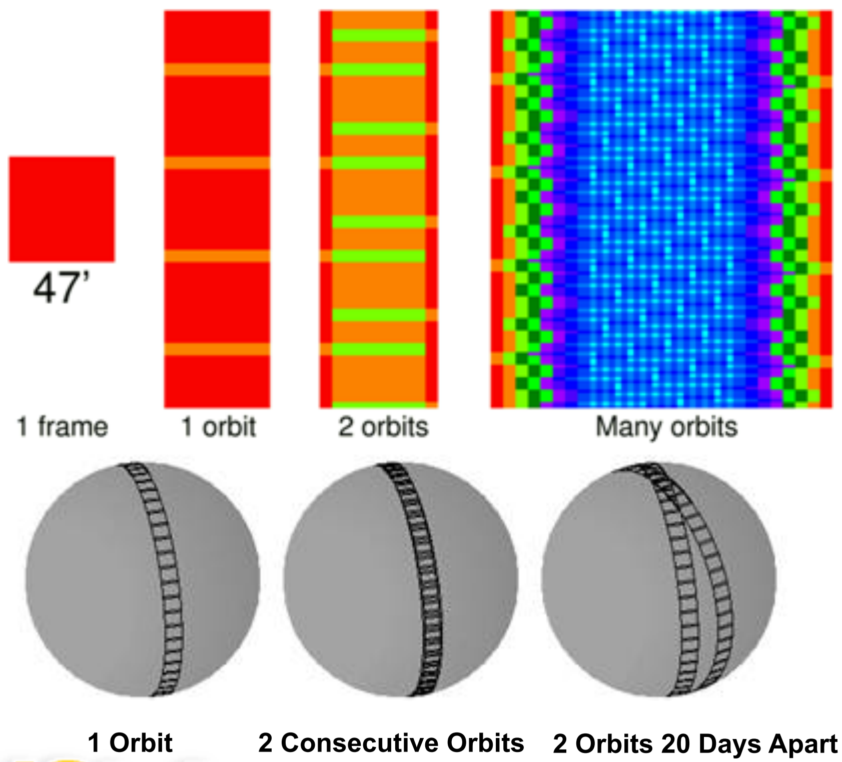
Table 3-1. NIRAS Sensitivity

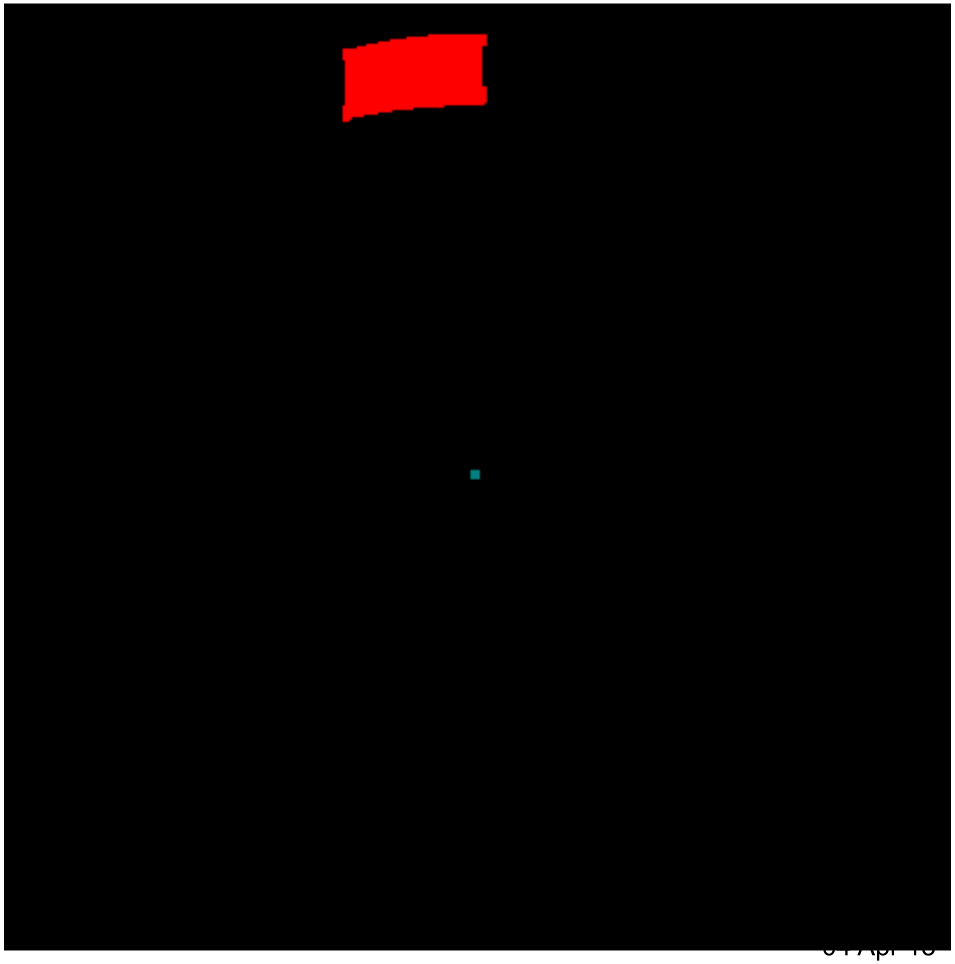
WAVELENGTH (microns)	BANDWIDTH (microns)	S/N	NUMBER OF PASSES	FLUX DENSITY POINT SOURCE (mag)	(mJy)	DIFFUSE (μJy/arcsec^2)
1.87	1.14	1	1	14.6	1.2	1.8
		5	1	12.8	6.0	
		1	4	15.3	0.6	0.9
		5	4	13.6	3.0	
3.52	2.16	1	1	13.4	1.2	1.7
		5	1	11.7	6.0	
		1	4	14.2	0.6	0.9
		5	4	12.4	3.0	

WISE Survey Strategy Provides Minimum of 8 Exposures Per Position

- Scan mirror enables efficient surveying
  - 8.8-s exposure/11-s duty cycle
- 10% frame to frame overlap
- 90% orbit to orbit overlap
- Sky covered in 6 months observing

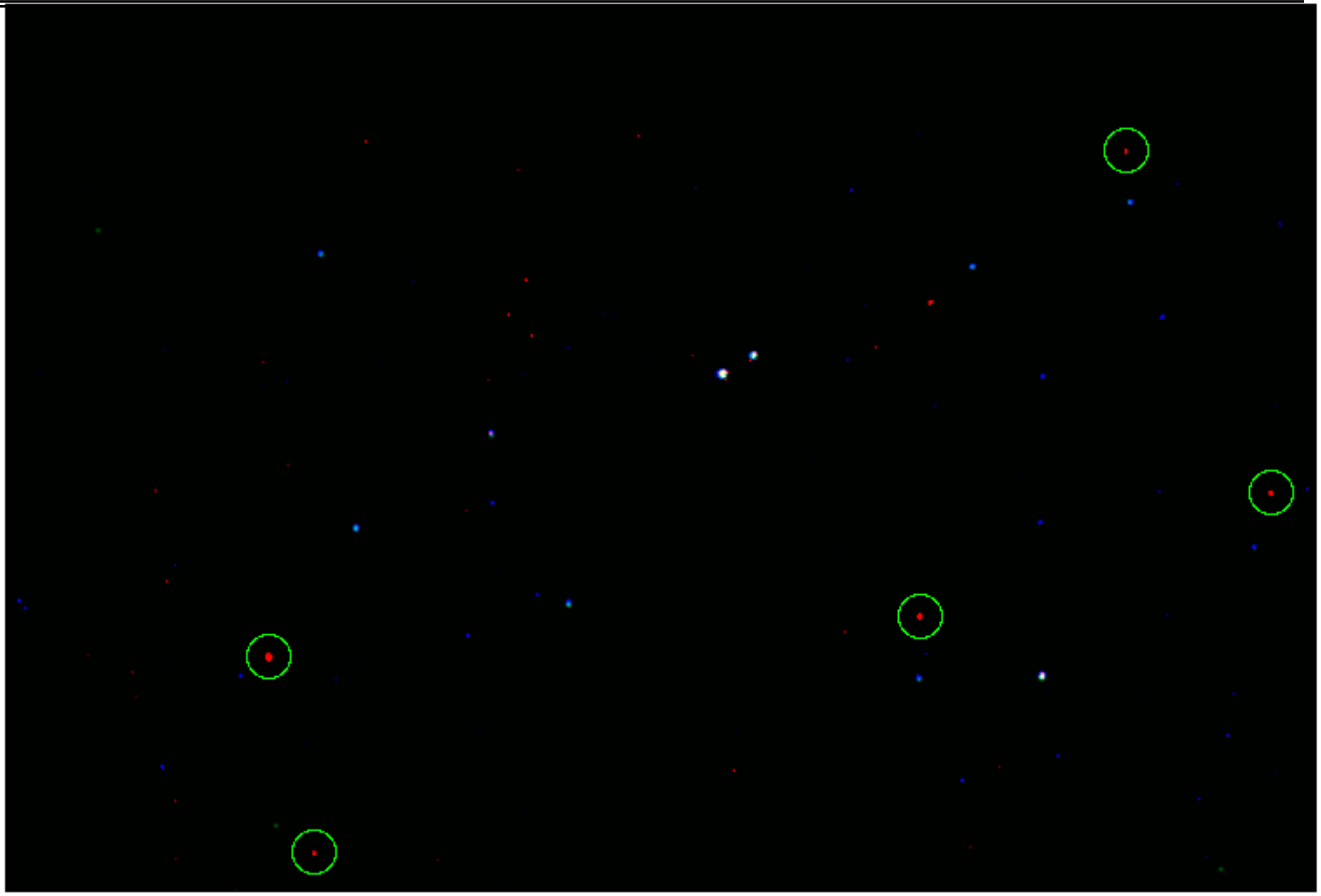
- Single observing mode
- Minimum 8, median 14 exposures/ position after losses to Moon and SAA





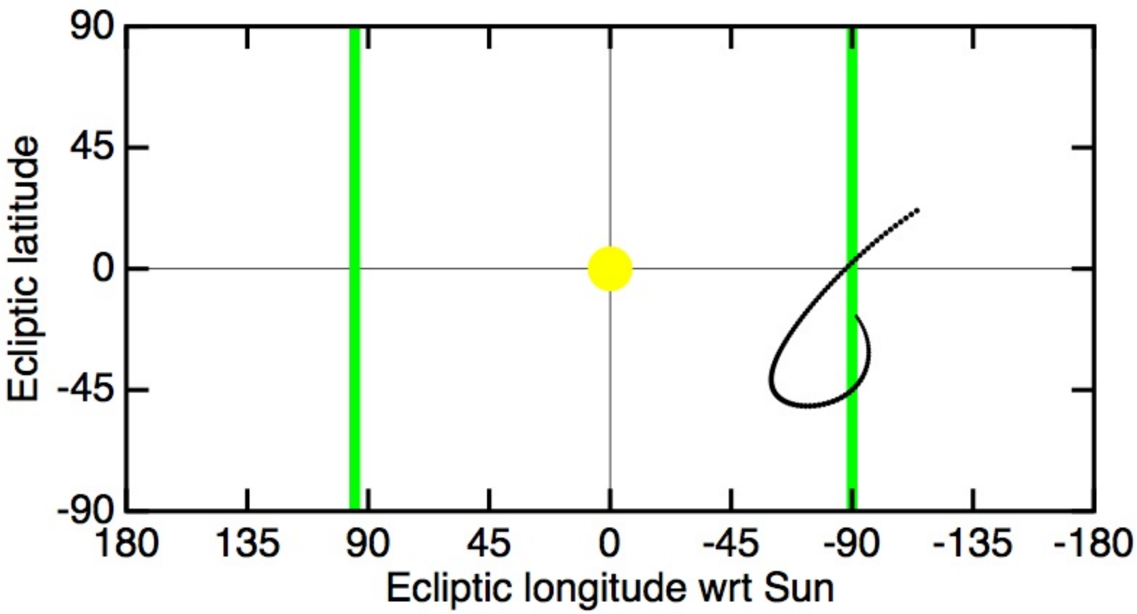
Asteroids Move

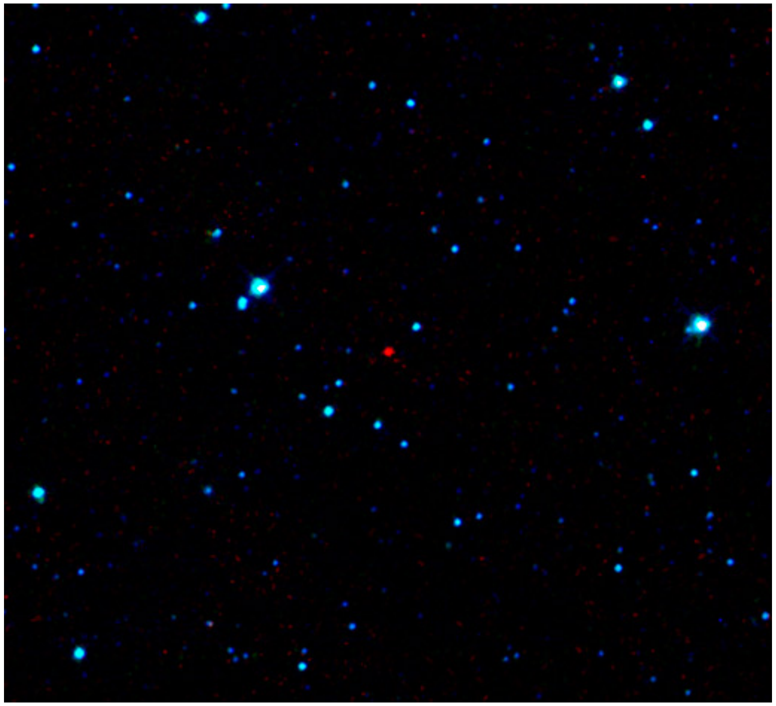
- Four frames of data taken on 2010 Jan. 8 during in-orbit checkout.
- Blue = 3.6um; green = 4.6um; red = 12um
- Circled asteroids are (L to R in the first frame, diameters in km):
  17818 MBA D~12.4
  153204 MBA D~2.8
  22006 MBA D~11.5
  87355 MBA D~4.3
  80590 MBA D~4.1



Field of view = 34 x 25 arcmin (whole WISE FOV is 47 x 47 arcmin)

2010 AB_{78}

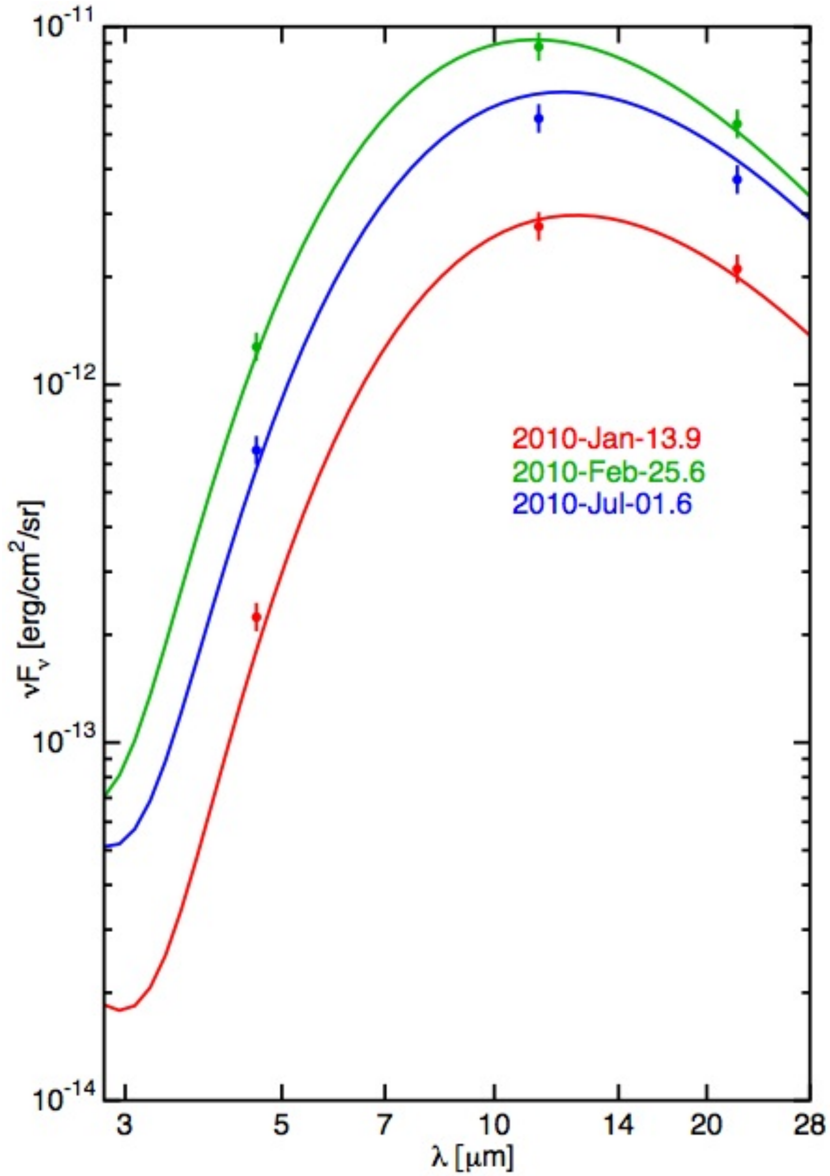




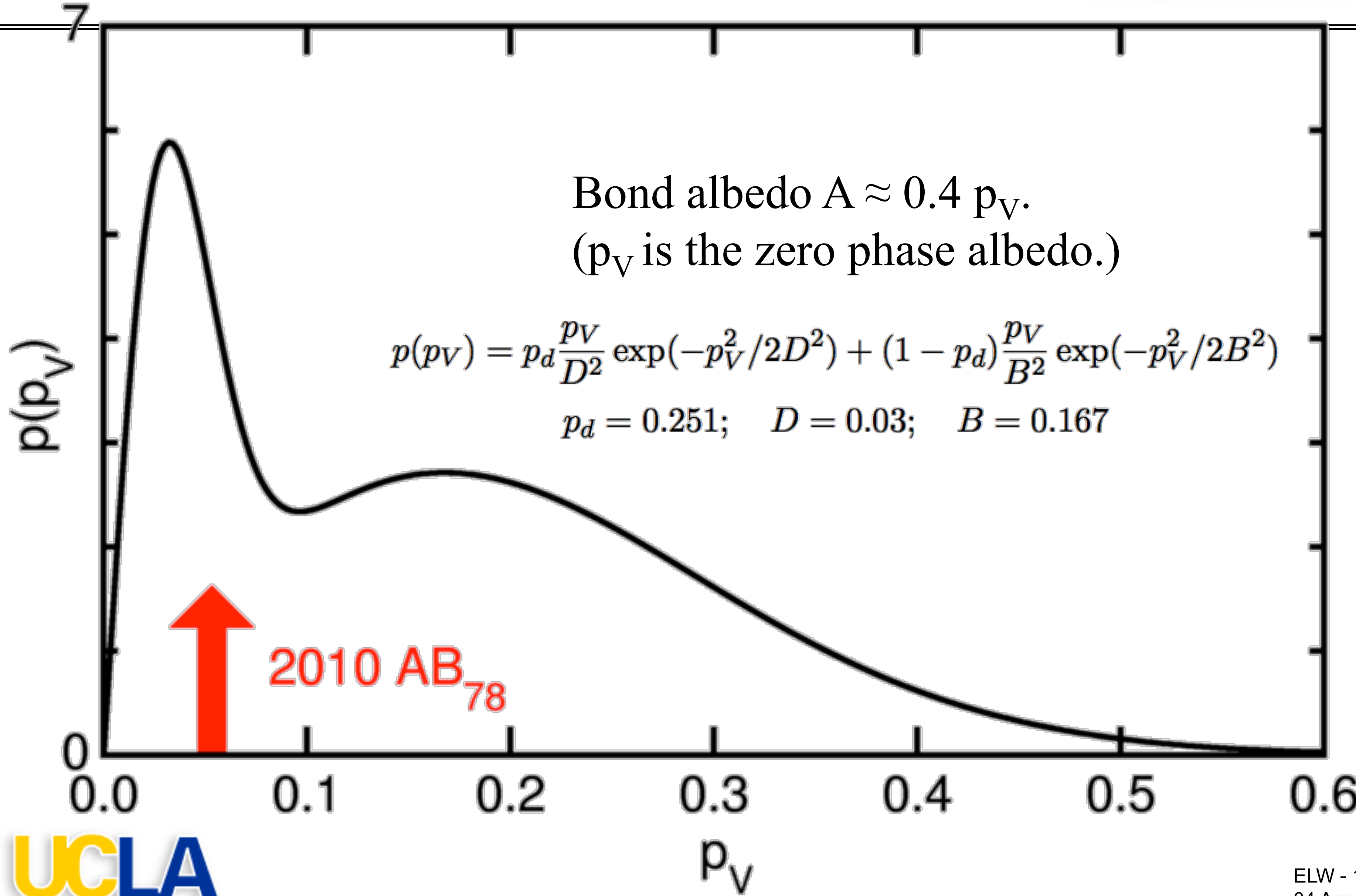
UCLA

Results

- Diameter 1.3 km
- Anomalously faint in July, giving rotation pole at $(\alpha,\delta) = (185\pm26^{o},-35\pm13^{o})$
  - Obliquity of pole is 90 ± 17^{o} with respect to the orbit
- Bond albedo A=0.02, p_V=0.05
- Θ = 0.55 at 1 AU from Sun
- $\sqrt{\kappa\rho C} = 220 \pm 110$ J/K/m²/√s



NEO albedo distribution model



Bond albedo A ≈ 0.4 p_V.
(p_V is the zero phase albedo.)

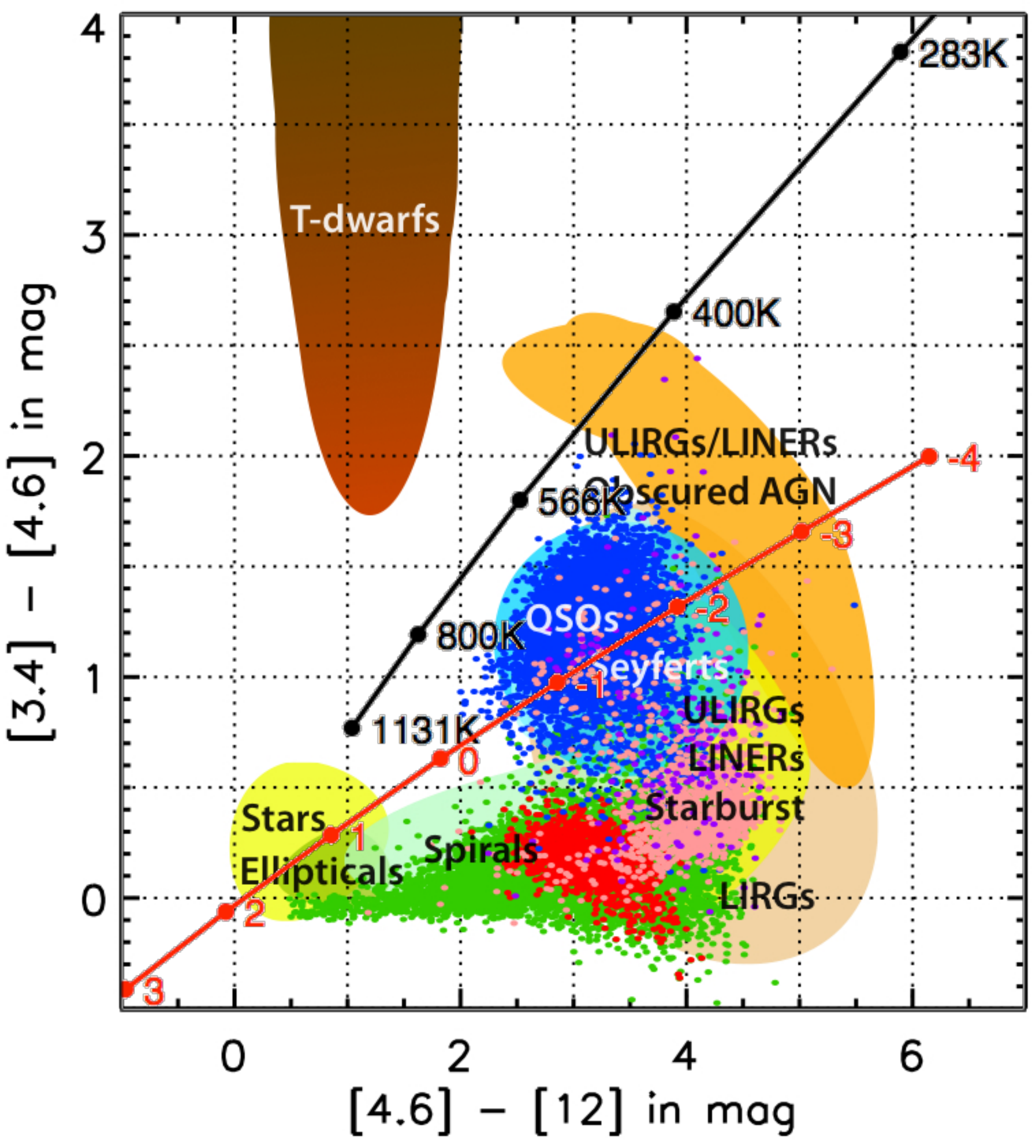
$$p(p_V) = p_d \frac{p_V}{D^2} \exp(-p_V^2/2D^2) + (1 - p_d)\frac{p_V}{B^2} \exp(-p_V^2/2B^2)$$

$$p_d = 0.251; \quad D = 0.03; \quad B = 0.167$$

Most Hazardous WISE Discovery

- 2010 MU_{112} - recovered in Feb 2013 by David Tholen
- Minimum Orbit Intersection Distance = 0.0011 AU
- Closest approach in next hundred years, 12 Dec 2082 at 0.007 AU
- Diameter 600 m, Albedo = 3%, estimated mass 200 megatons
- $a = 1.756$ AU, $e = 0.54$, $i = 48^{o}$
- $v_{\infty} = 29.5$ km/sec
- Impact energy in TNT equivalent = $\text{Mass}*(v_{\infty}^2+11^2)/2.9^2$
  - 24 billion tons of TNT

Inhabitants of WISE Color Space

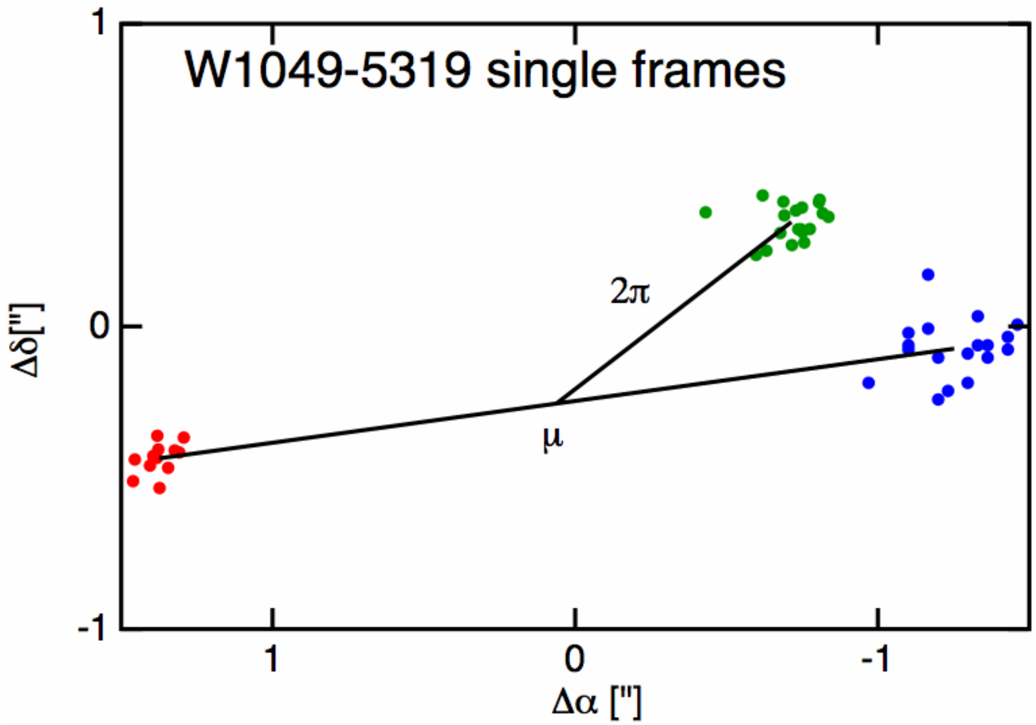


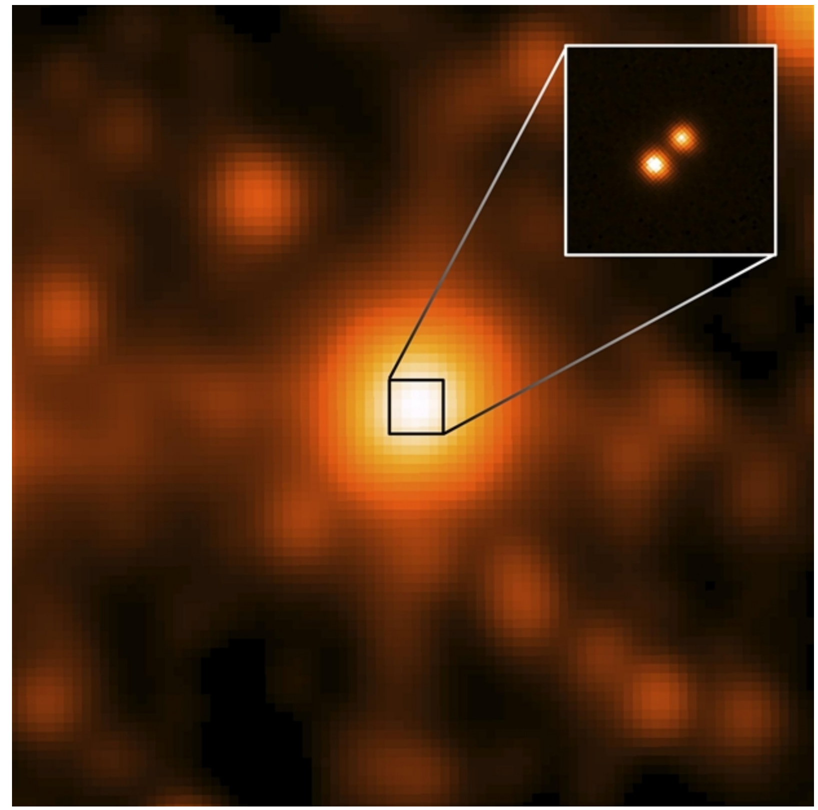
SDSS Classifications:

- Galaxies
- z ~ 0.4 LIRGs
- Local LIRGs
- Local ULIRGs
- QSOs

- Blackbodies
- Power Laws

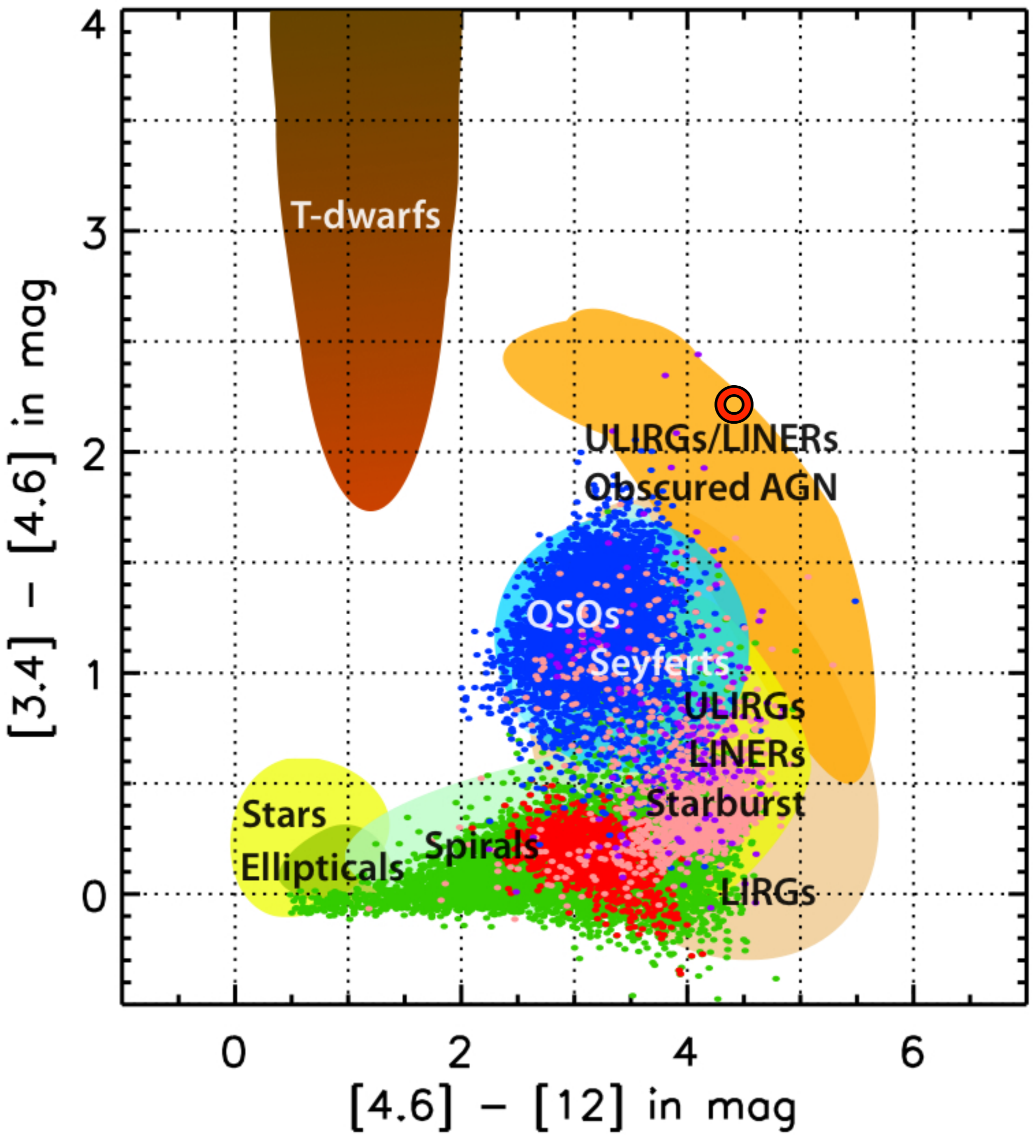
W1049-5319

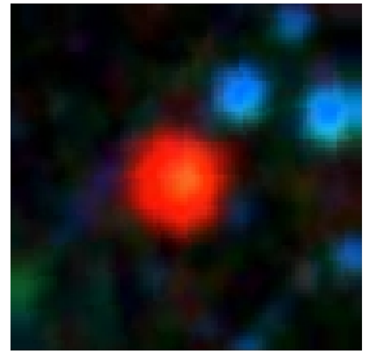




- Distance 2 pc! Proper motion 2.8”/yr
- Luhman (2013) trawled though the WISE single frame detections and found this lurking nearby.

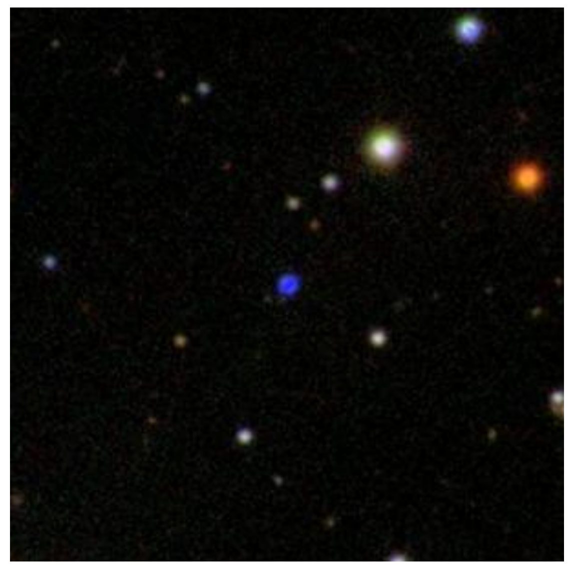
WISE Color Space
A Very Red…Blue Compact Galaxy





- $z=0.0425$
- $Z \sim 1/12\ Z_{\odot}$

WISE image

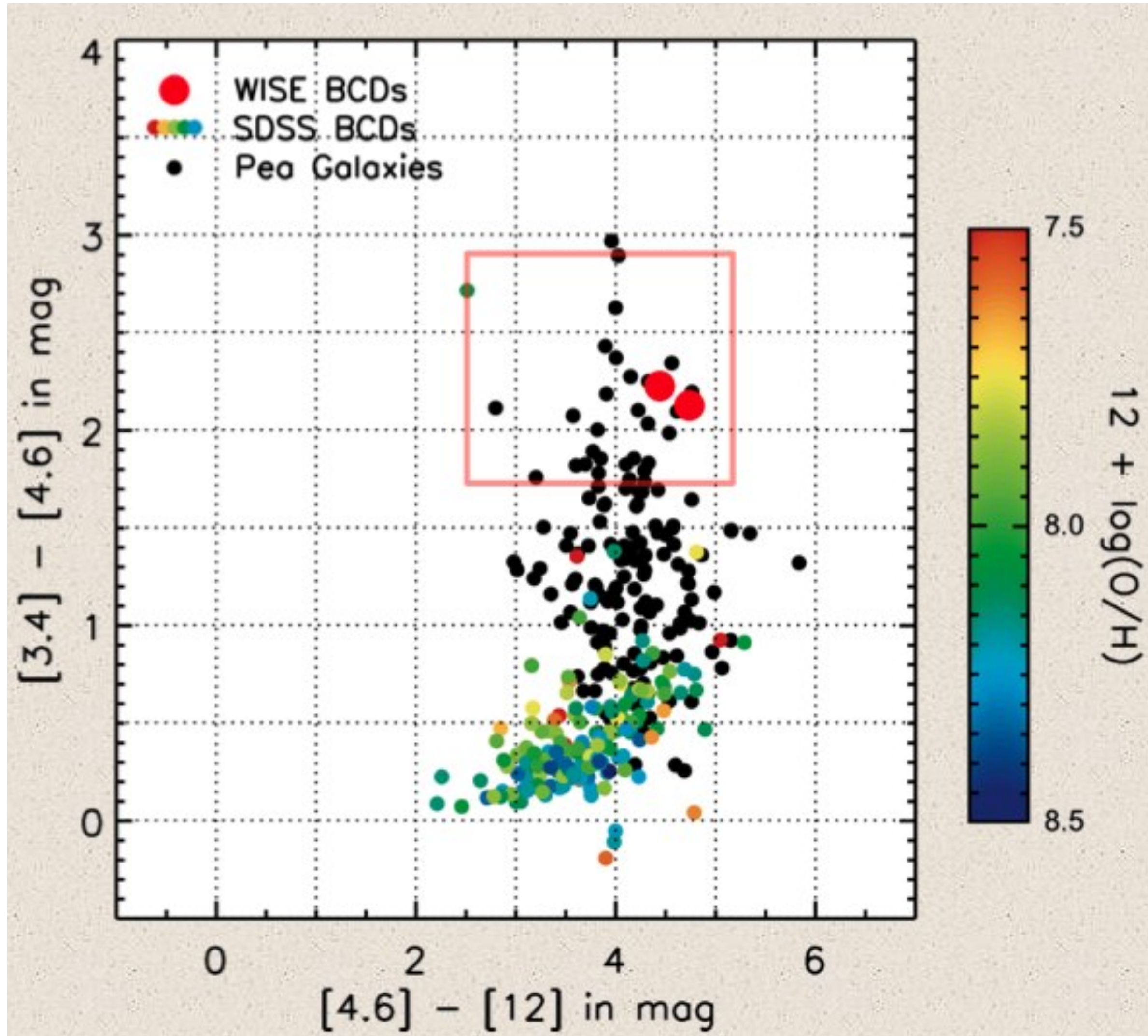


SDSS image

Wide-field Infrared Survey Explorer (WISE)

BCDs & Green Peas

- WISE colors of BCDs and green peas
- From C-W Tsai etal poster 333.11 at the Jan 2011 AAS meeting
- Griffith etal, 2011 ApJL, 736 L22 (arXiv:1106.4844)



A semi-WISE team result

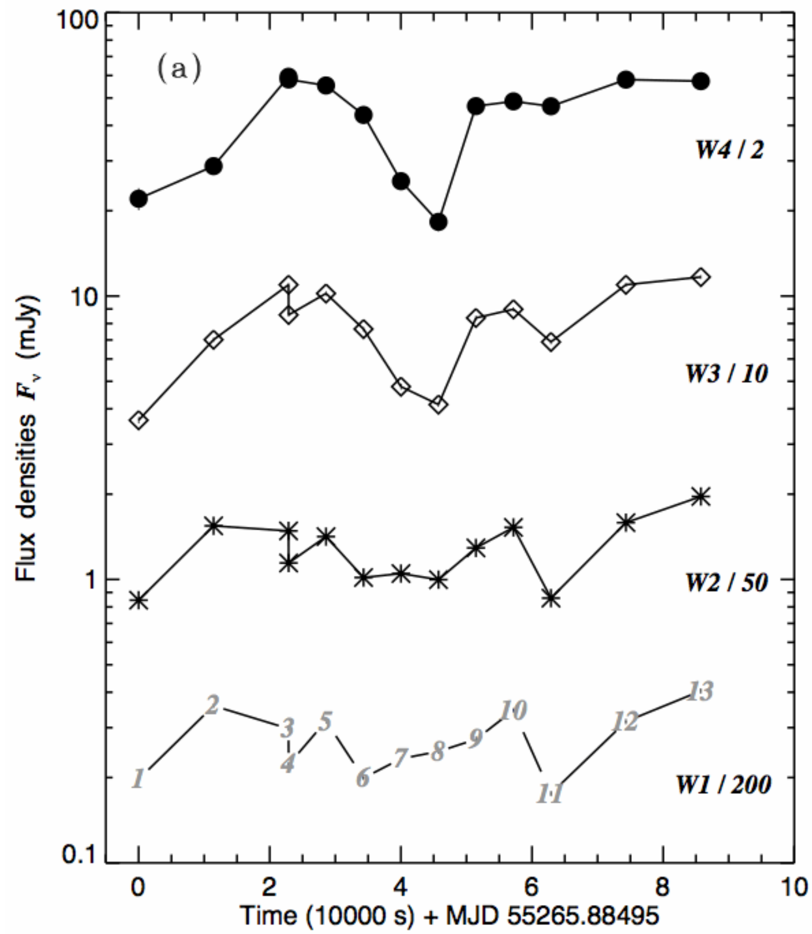
A variable mid-infrared synchrotron break associated with the compact jet in GX 339–4

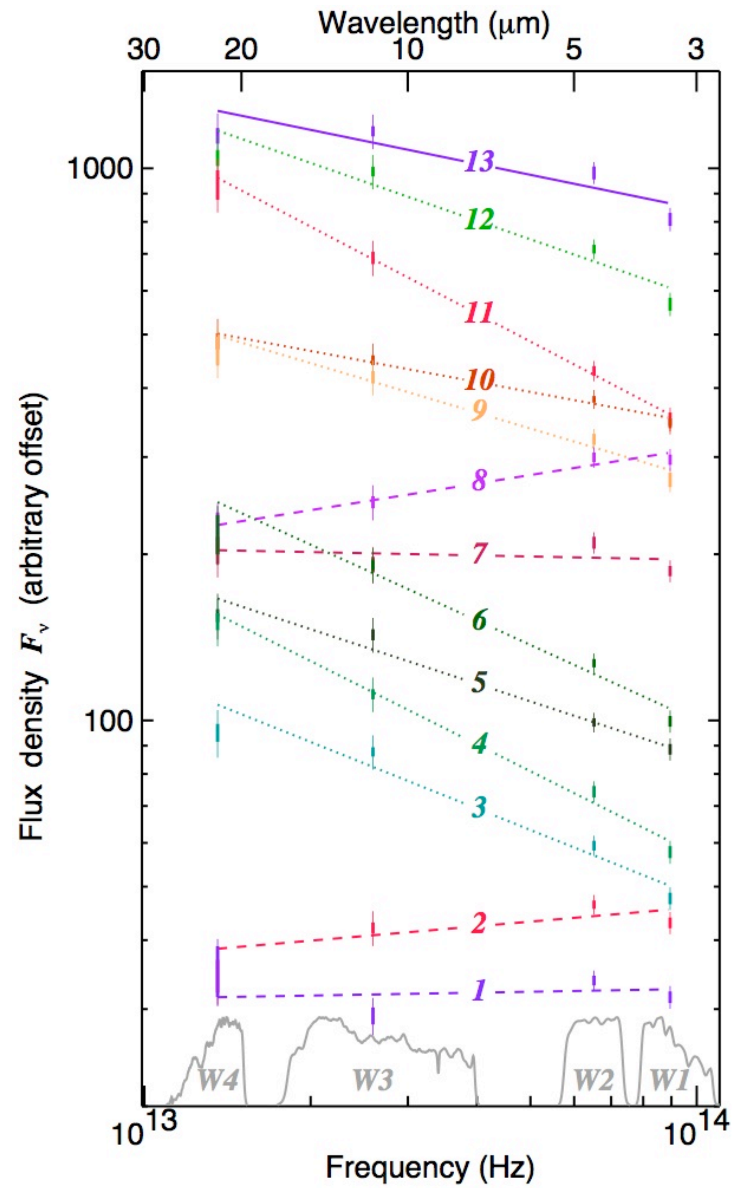
P. Gandhi[1], A.W. Blain[2], D.M. Russell[3], P. Casella[4], J. Malzac[5,6], S. Corbel[7], P. D'Avanzo[8], F.W. Lewis[9], S. Markoff[3], M. Cadolle Bel[10], P. Goldoni[11,12], S. Wachter[13], D. Khangulyan[1] and A. Mainzer[14]

ABSTRACT

Many X-ray binaries remain undetected in the mid-infrared, a regime where emission from their compact jets is likely to dominate. Here, we report the detection of the black hole binary GX 339–4 with the Wide-field Infrared Survey Explorer (WISE) during a very bright, hard accretion state in 2010. Combined with a rich contemporaneous multiwavelength dataset, clear spectral curvature is found in the infrared, associated with the peak flux density expected from

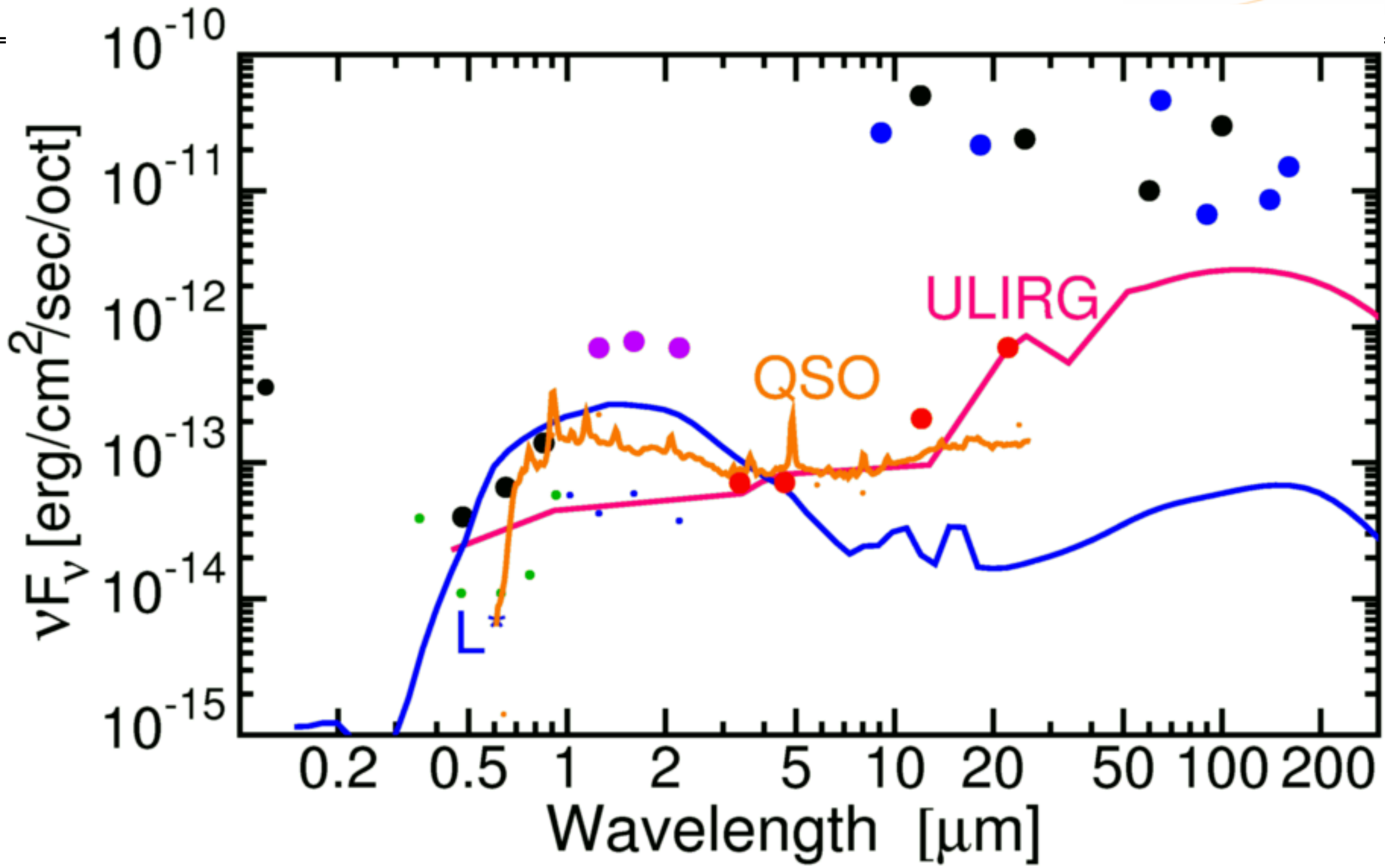
Flaring black hole GX339-4





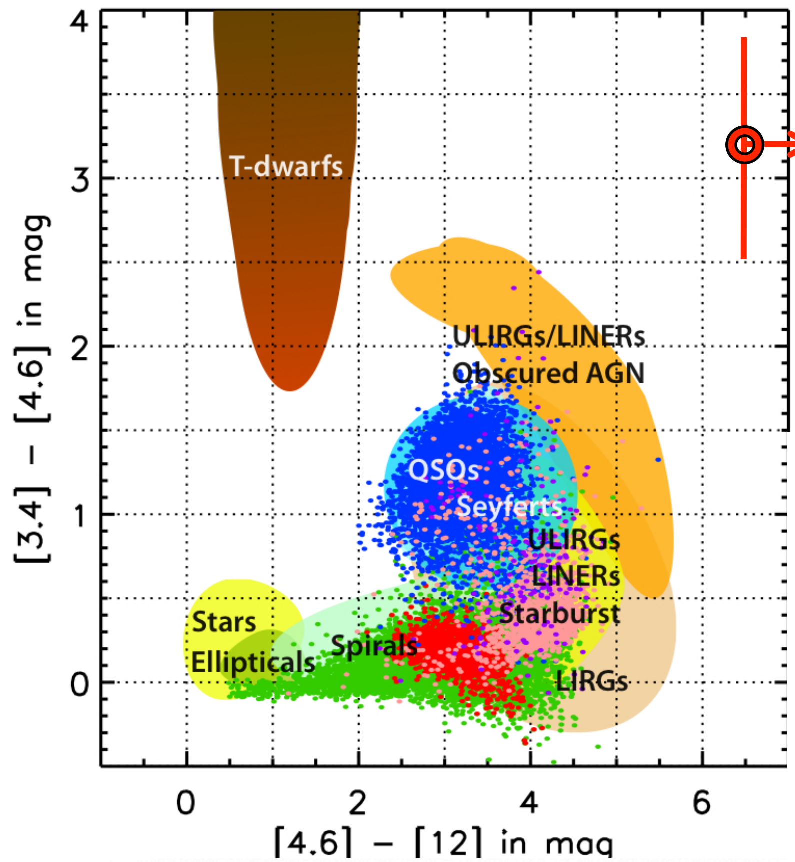
- WISE observations occurred during a very active period

The far-off Universe

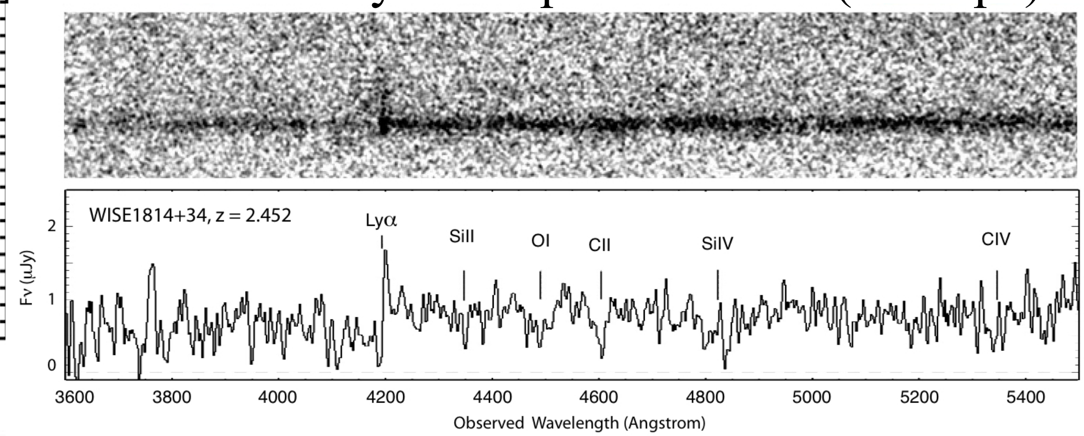


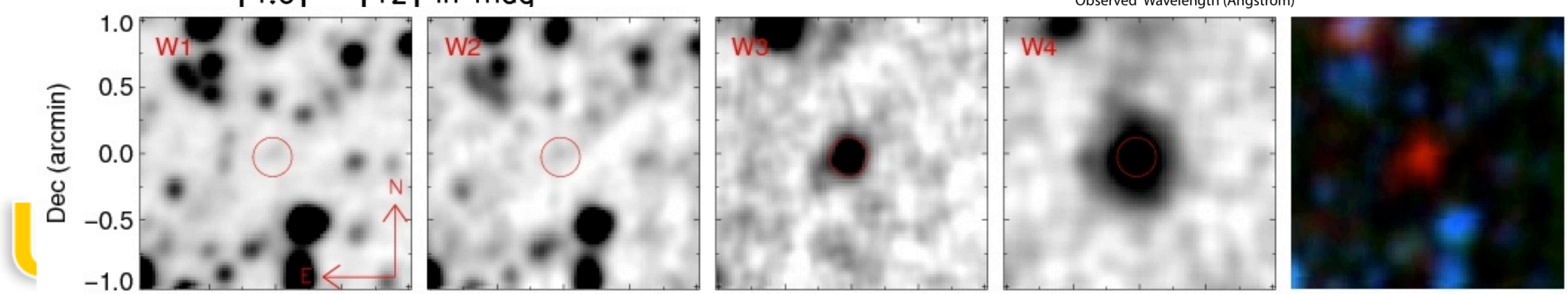
L* at z=0.33, z=6.4 QSO, z=3 ULIRG: FSC15307 x 3

WISE Band 1 and 2 Dropouts



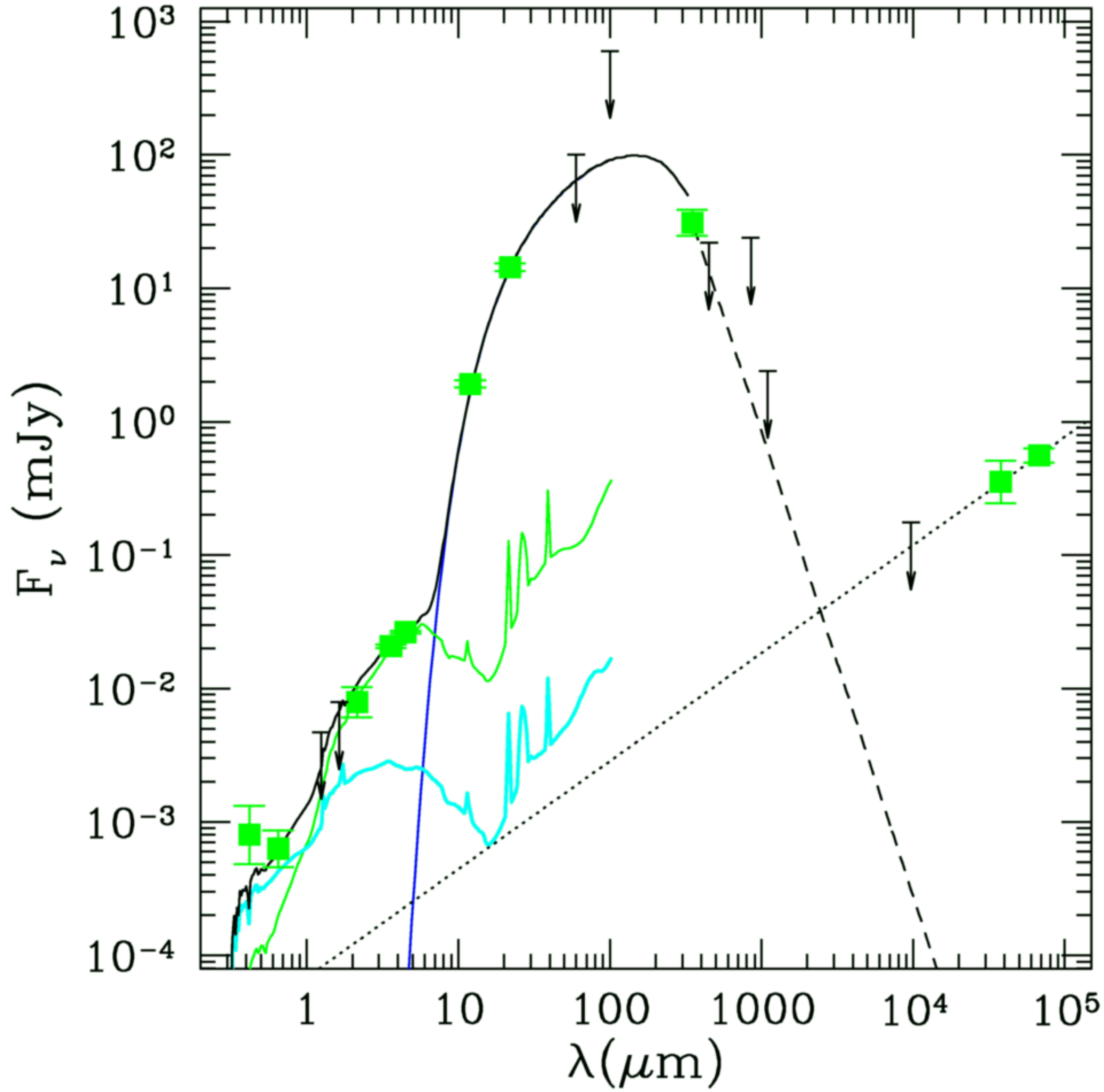
- W1 > 17.4 and W2 > 15.9 and (W3 < 10.6 or W4 < 7.7)
- W1814+34 (Eisenhardt et al 2012, ApJ 755, 173; Bridge et al 2012)
- z=2.452
- Extended Lyman alpha emission (~40 kpc)





SED of W1814+34

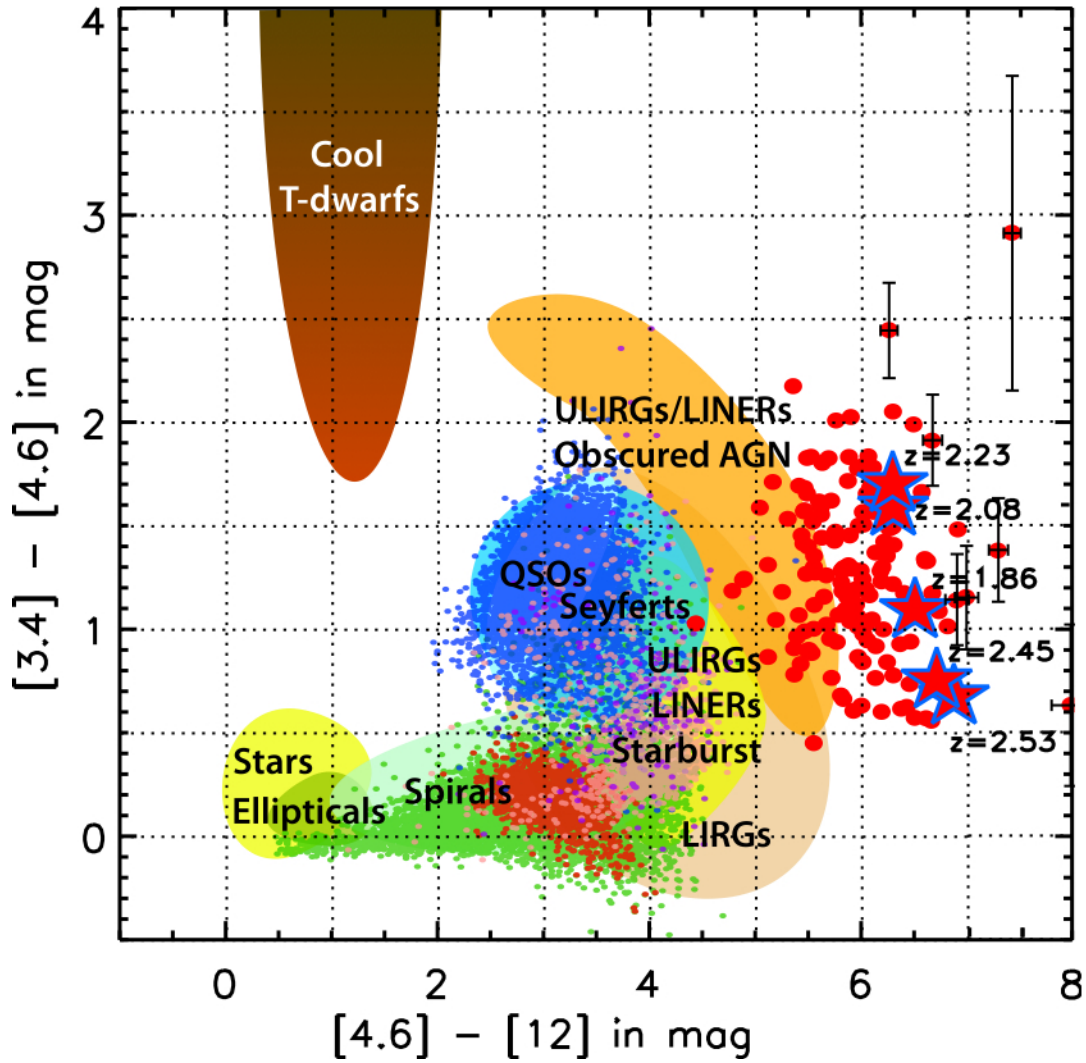
- AGN with $A_V = 50$
- Starburst
- Spiral Galaxy
- Warm Spitzer data to get 3.6 & 4.5 μm since WISE did not detect it at 3.4 & 4.6 μm.
- SHARC II (CSO) at 350 μm
- VLA radio data
- Peak $\nu L_\nu = 10^{13.38}\ L_\odot$



Wide-field Infrared Survey Explorer (WISE)

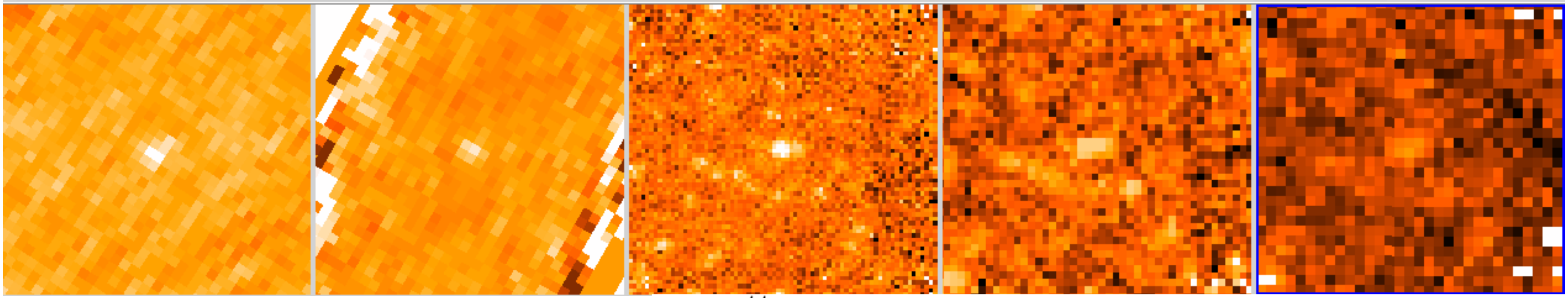
Warm Spitzer Followup

- Objects not detected by WISE at 3.4 & 4.6 µm can be measured using warm Spitzer
  - bigger mirror
  - longer integration times
- Synergy between surveys and great observatories

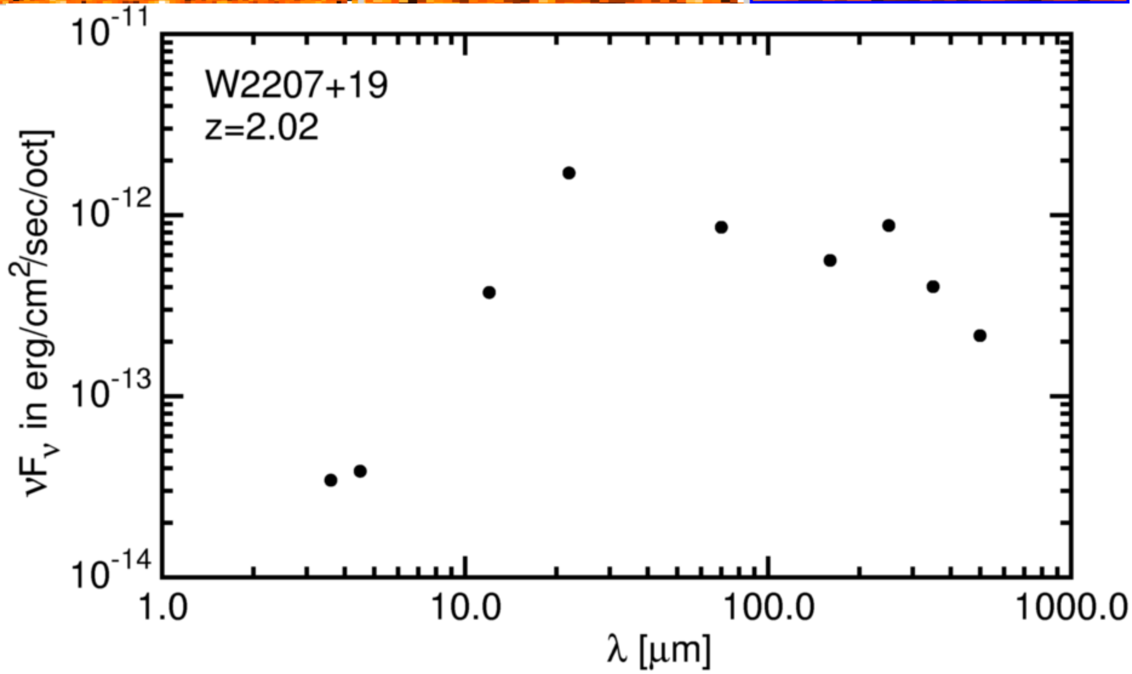


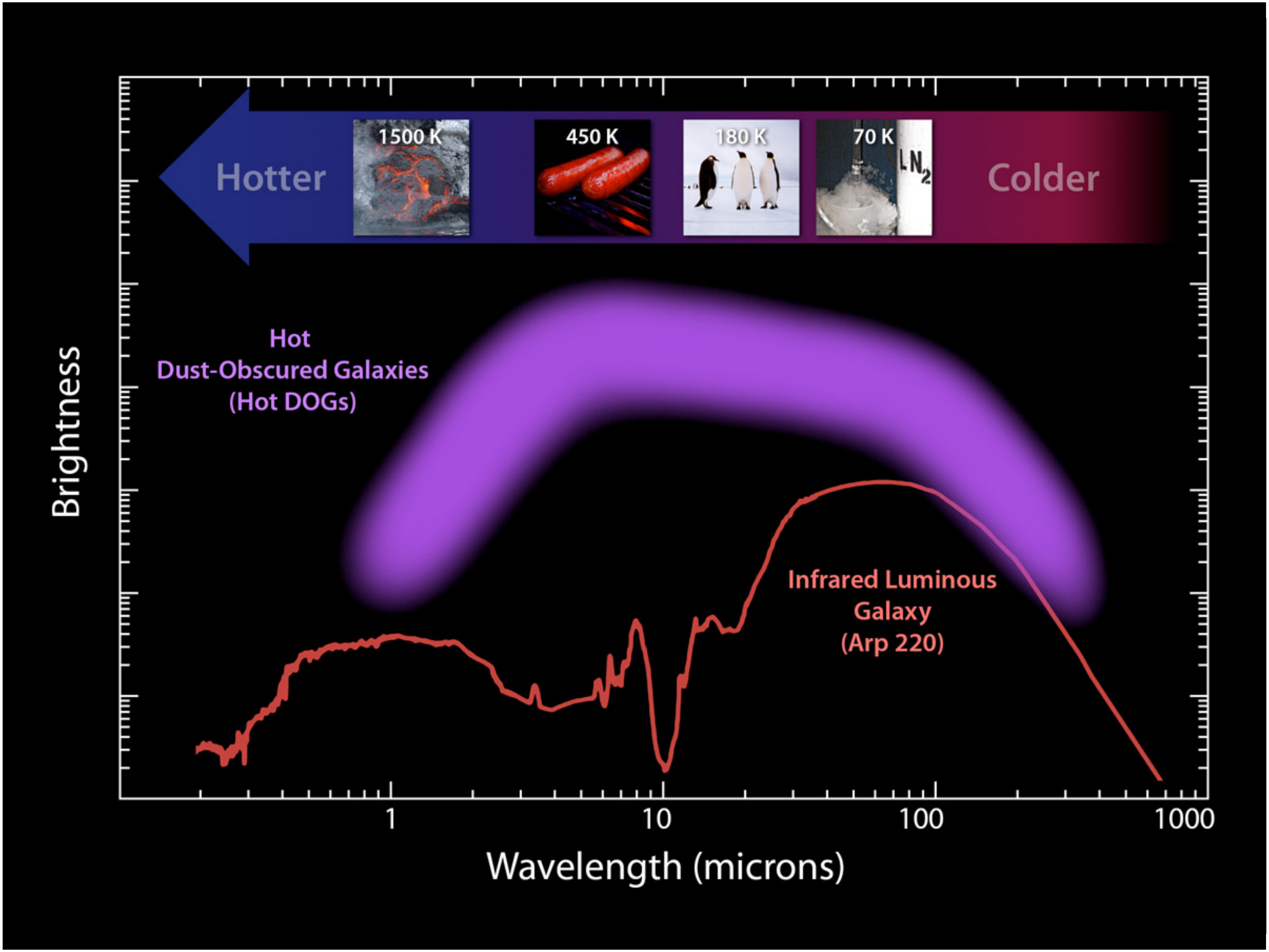
UCLA

Herschel Followup Program



- Example: W2207+19
- Warm Spitzer at 3.6 & 4.5 μm
- WISE at 12 & 22 μm
- Herschel at 70, 160, 250, 350 & 500 μm
- Peak νF_ν at 22 μm
- Peak $\nu L_\nu = 10^{13.13}\ L_\odot$

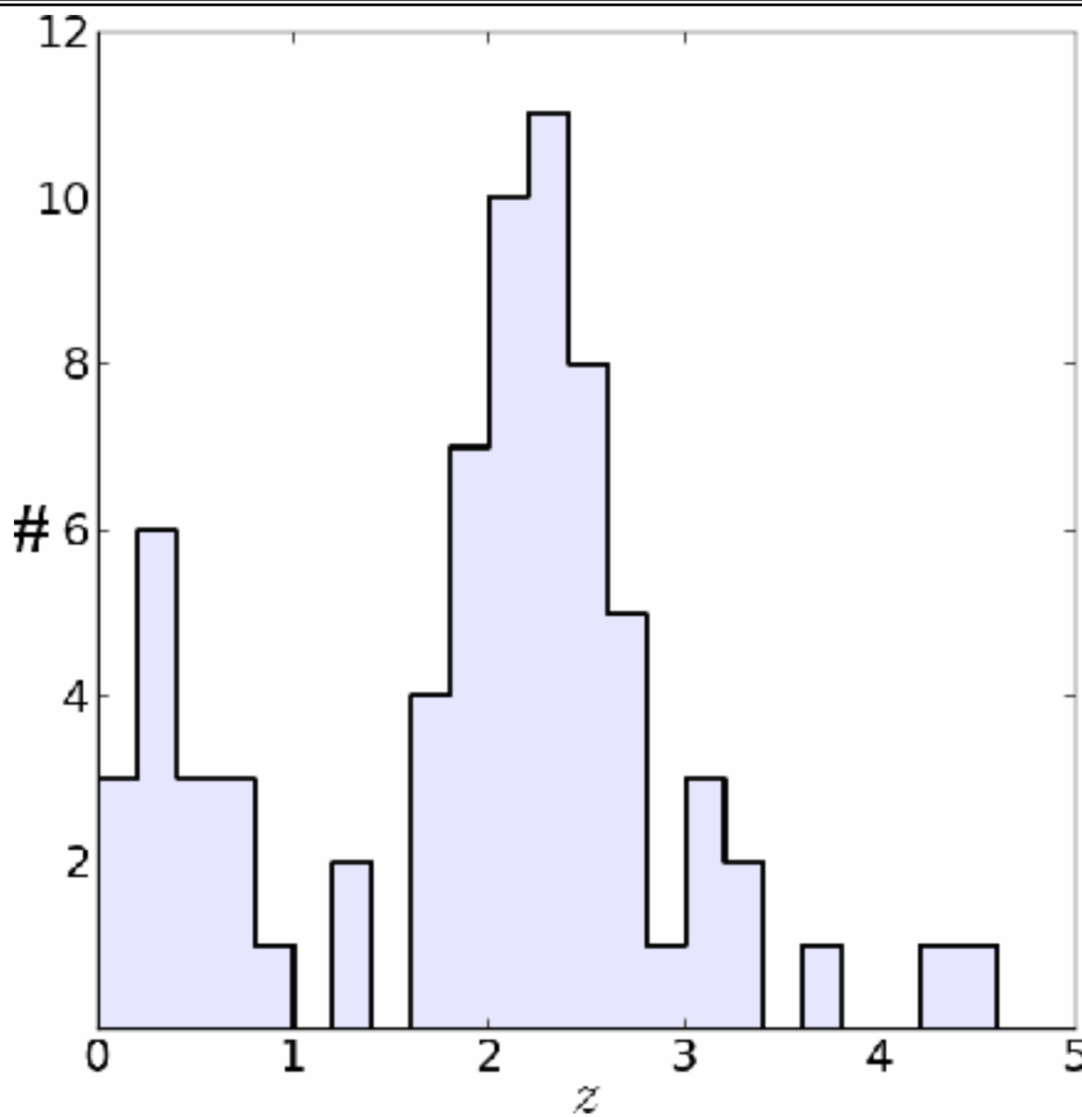




Hotter
1500 K
450 K
180 K
70 K
LN2
Colder
Hot
Dust-Obscured Galaxies
(Hot DOGs)
Brightness
Infrared Luminous
Galaxy
(Arp 220)
1
10
100
1000
Wavelength (microns)

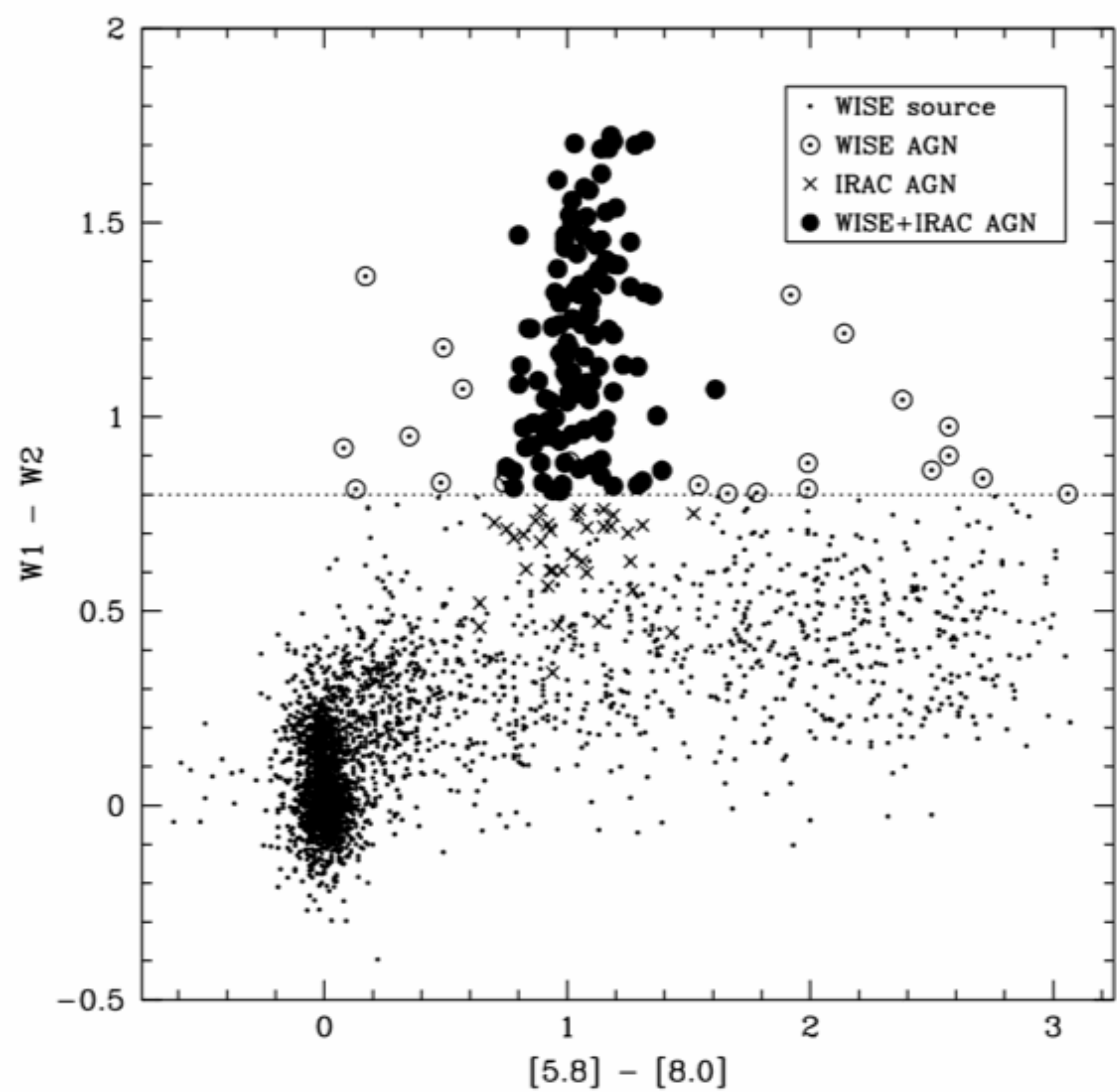
Many W12 drops

- About 1000/sky
- High percentage with high z's: see histogram
- Spitzer followup usually picks up 3.6 and 4.5 μm flux
- Herschel followup usually detects far-IR flux

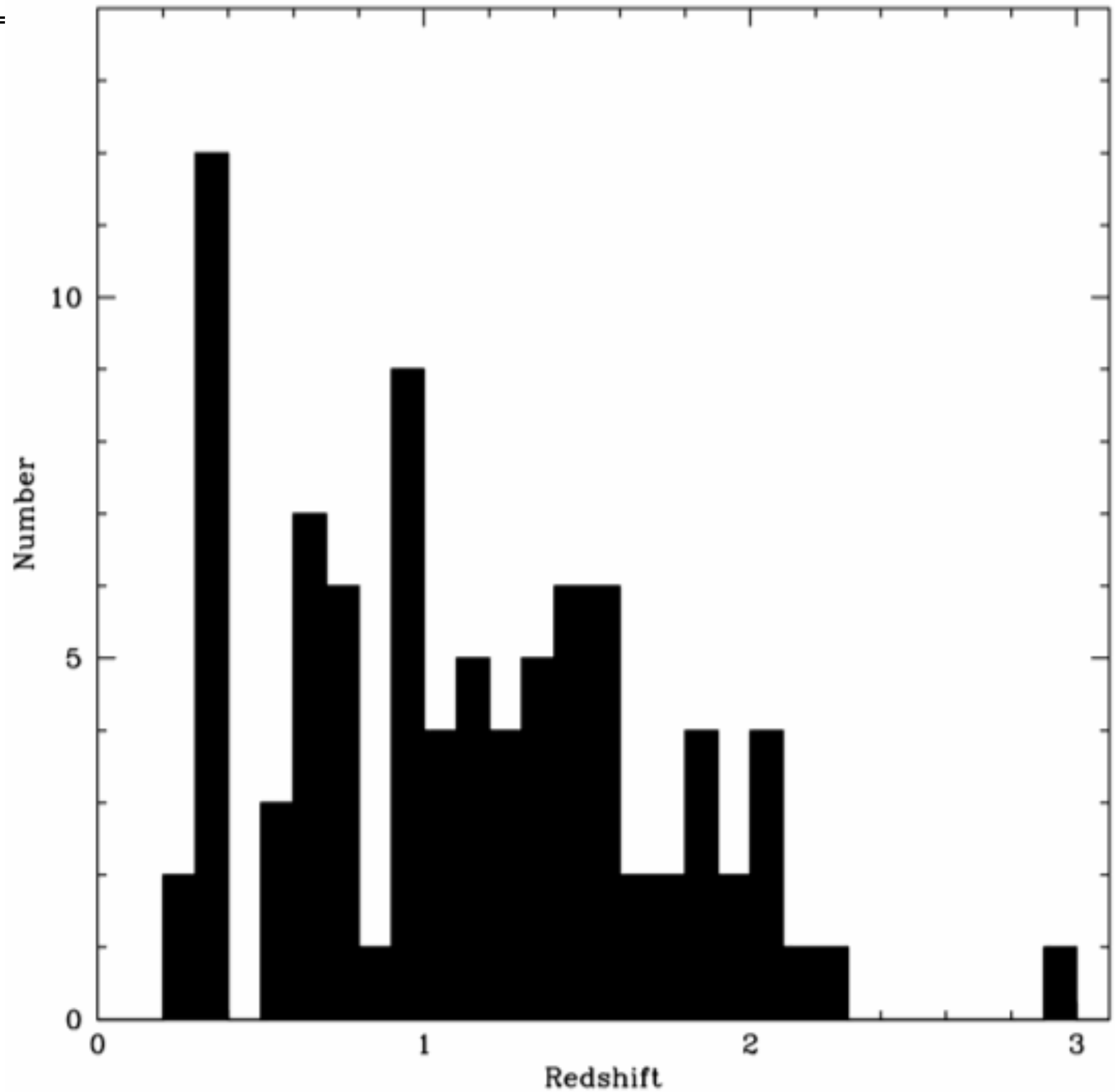


AGN Selection

- Stern et al 2012, ApJ, 753, 30
- Density 70/sq.deg
- 60% have published z's in COSMOS field



Z-distribution

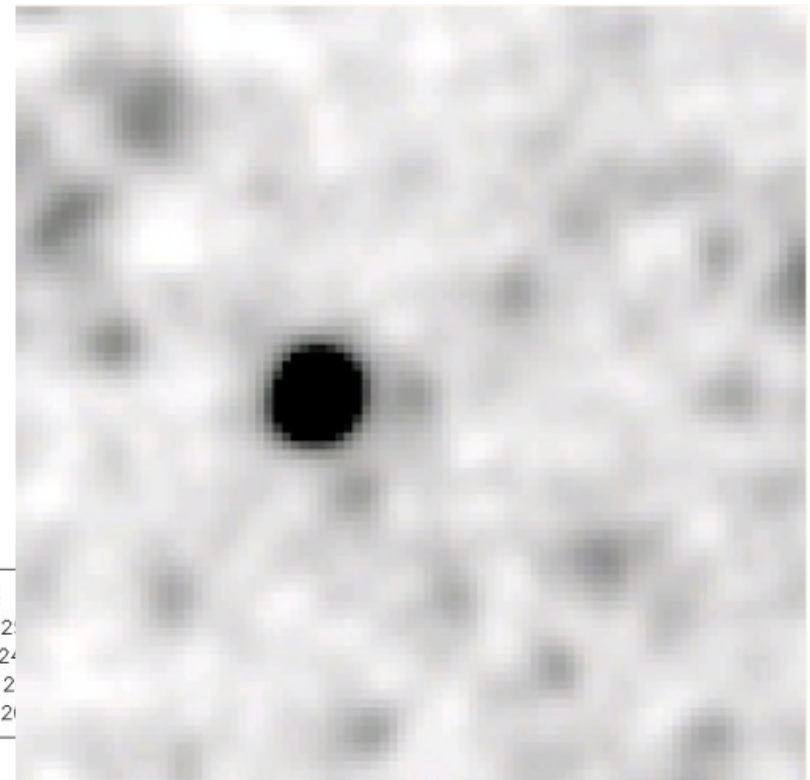


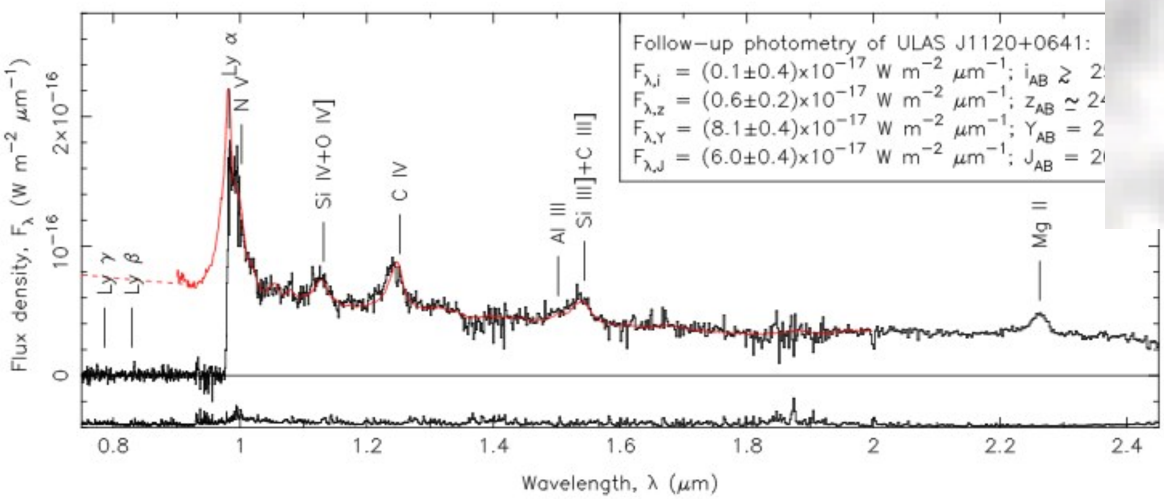
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Wide-field Infrared Survey Explorer (WISE)

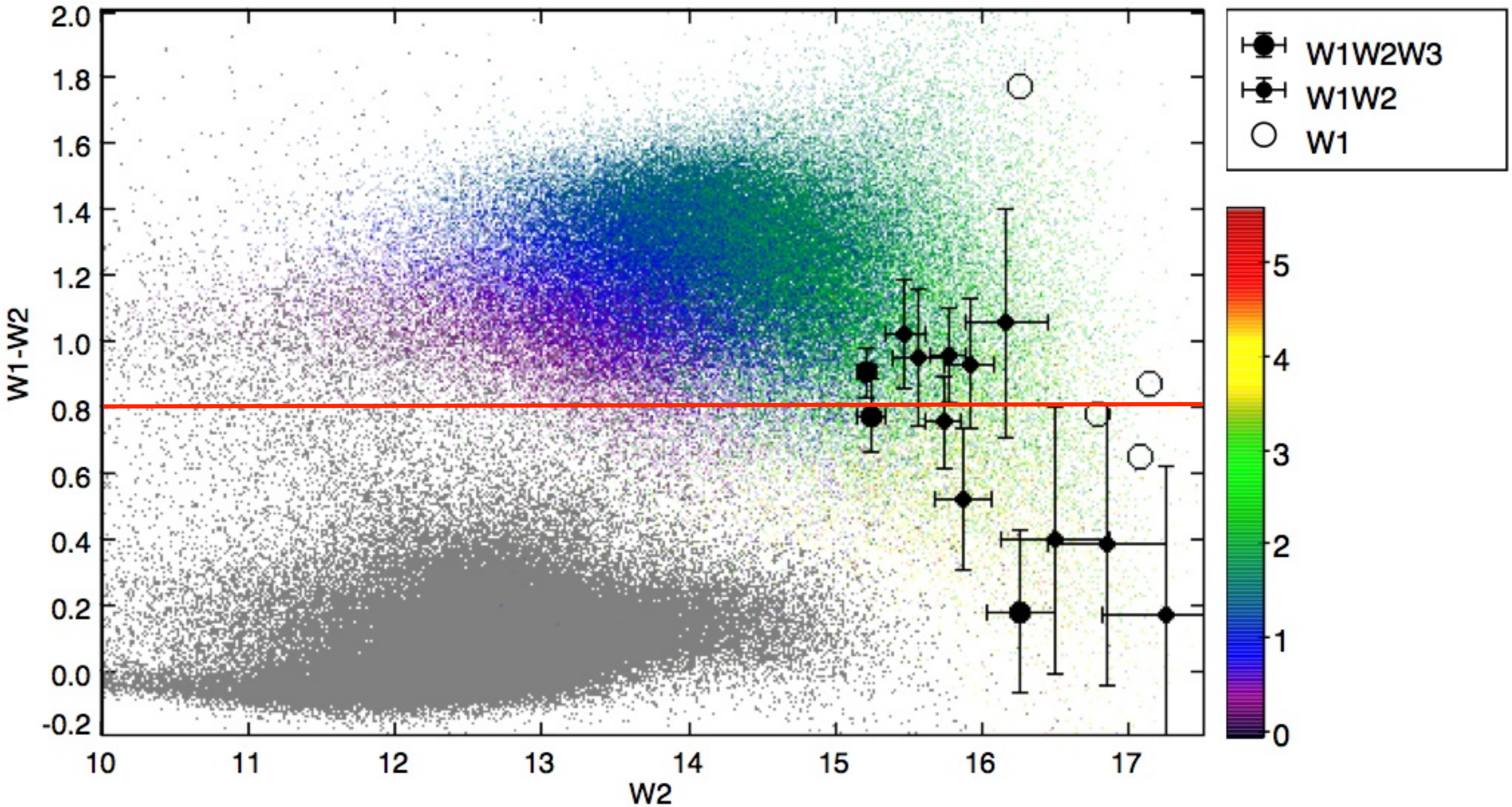
ULAS 1120+0641

- W1-W2 ≈ 1.17±0.31
- ≈43±8 μJy at 3.4 μm
- z = 7.085
- Mortlock etal, 2011, Nature, 474, 616, arXiv:1106.6088



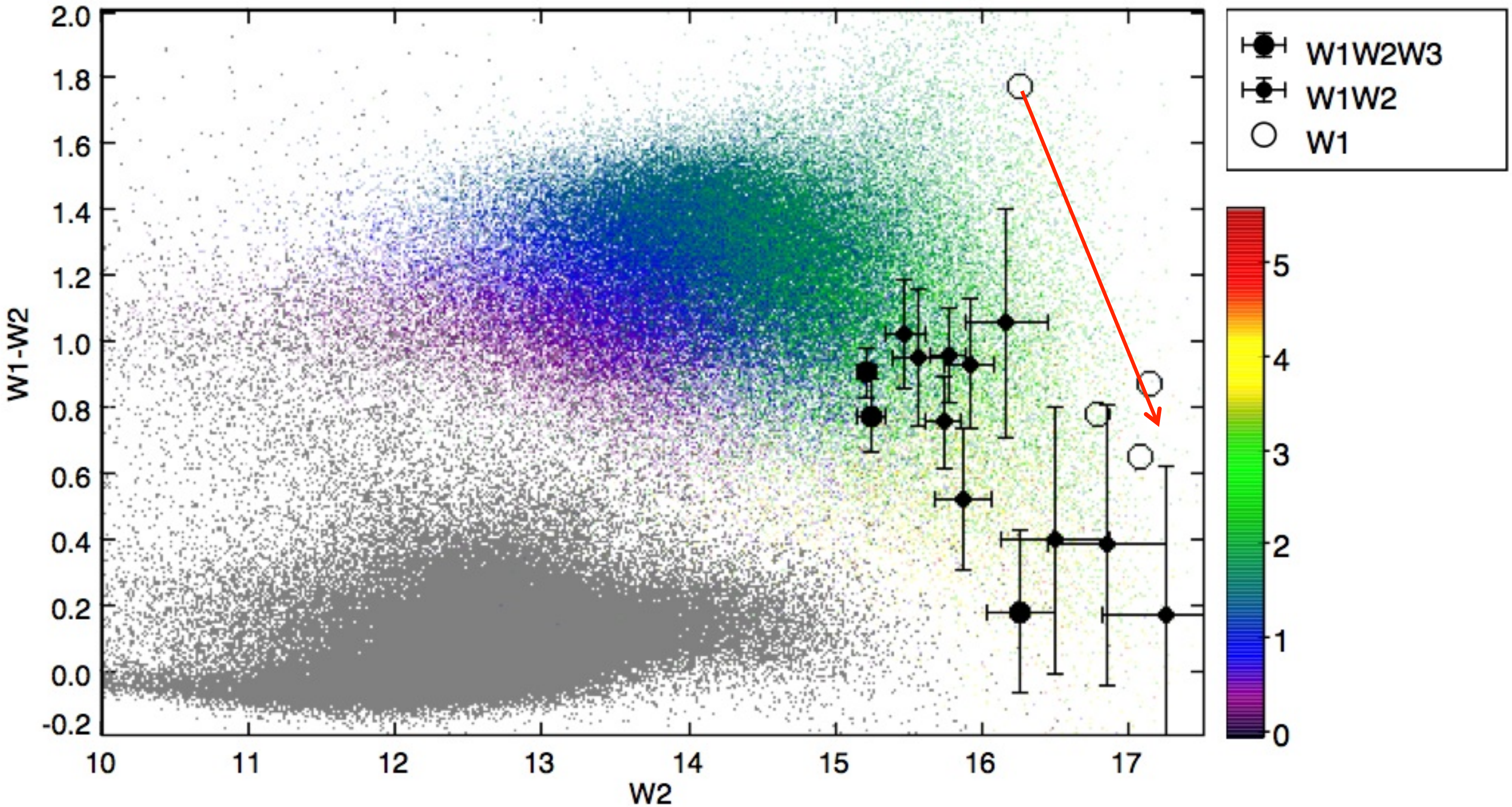


Blain etal 2013



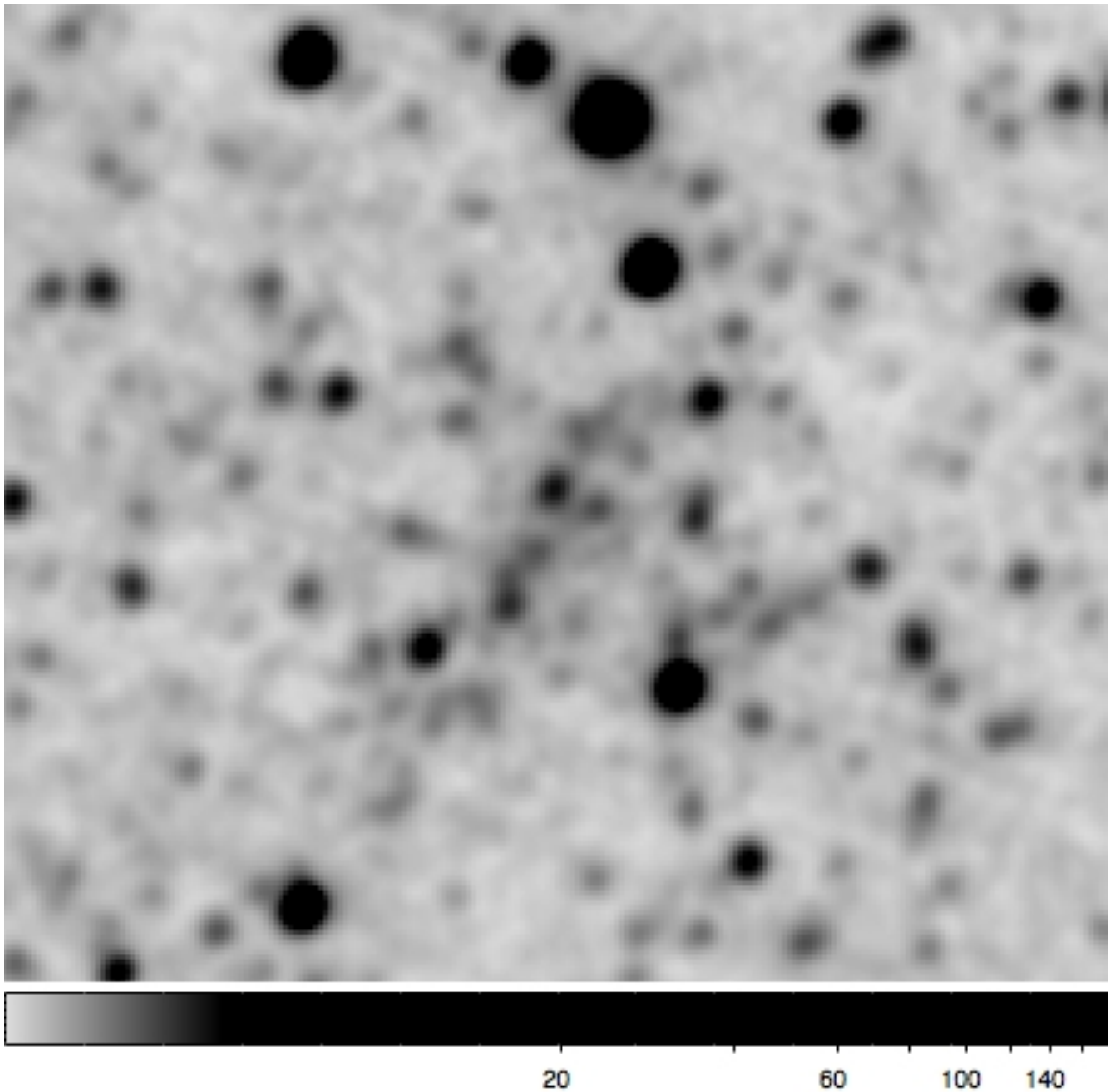
- WISE data on z > 6 QSOs, 55% detected

Blain etal 2013

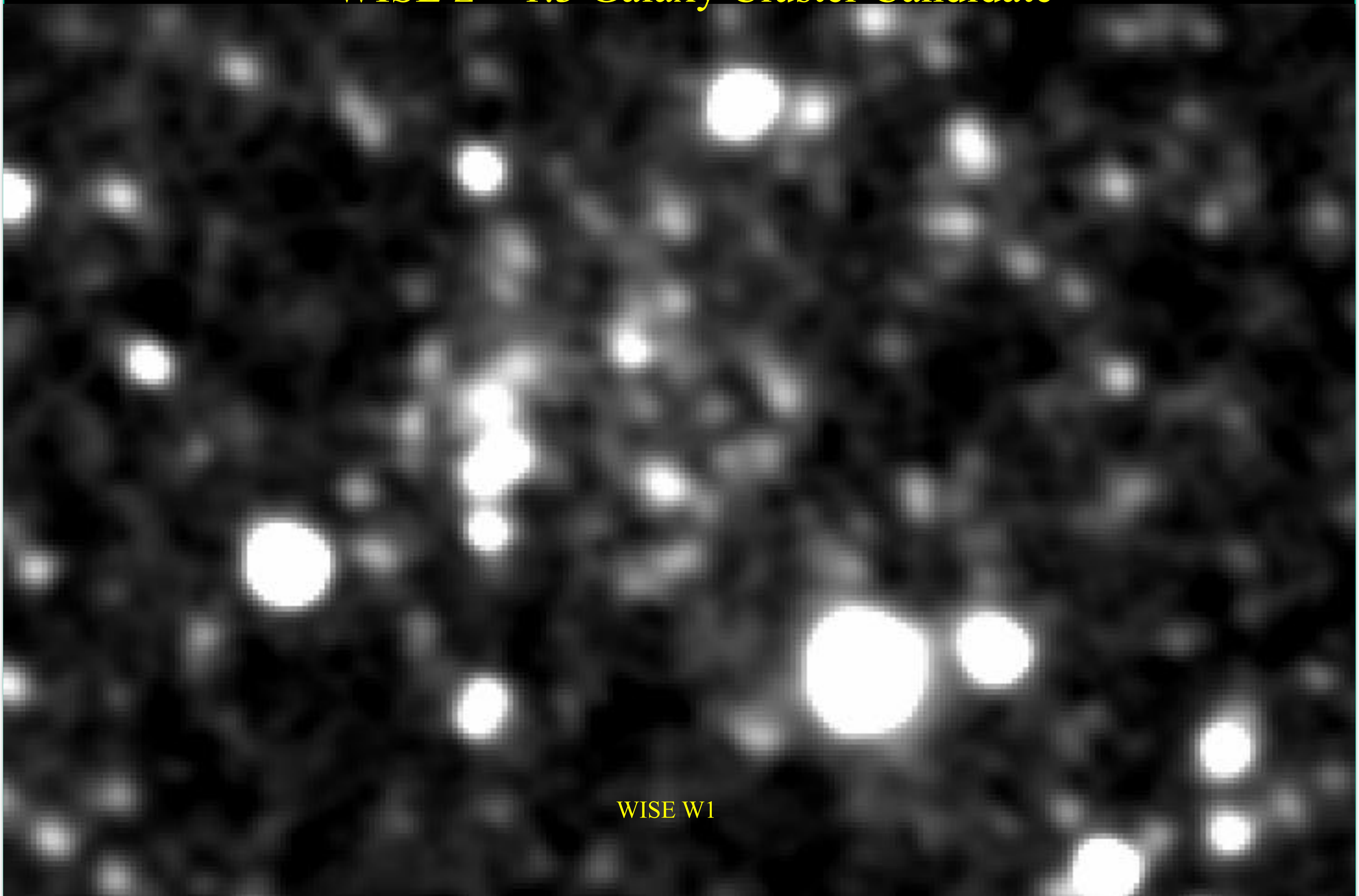


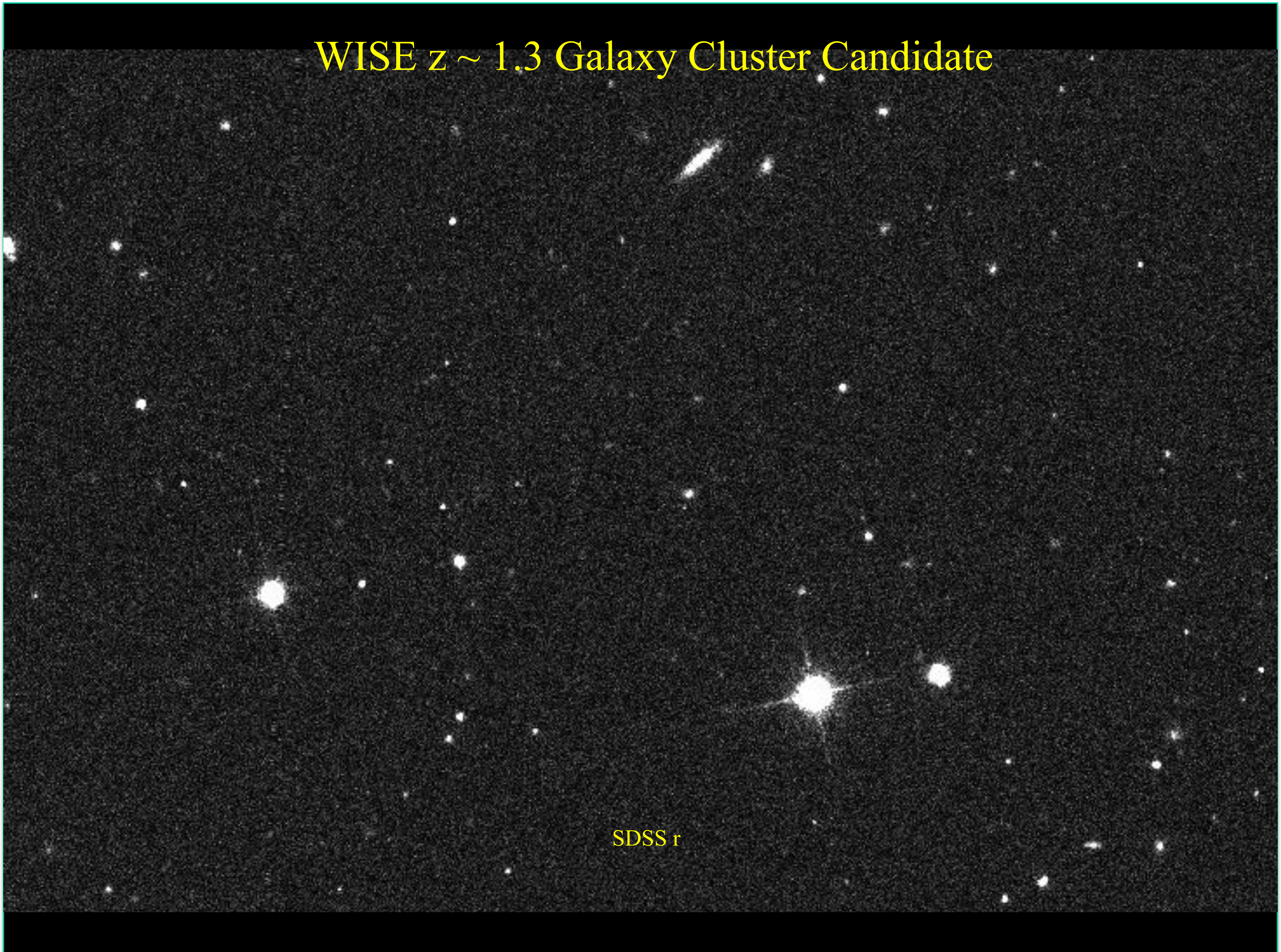
- WISE data on z > 6 QSOs

W1 image of SPT z=1.13 cluster

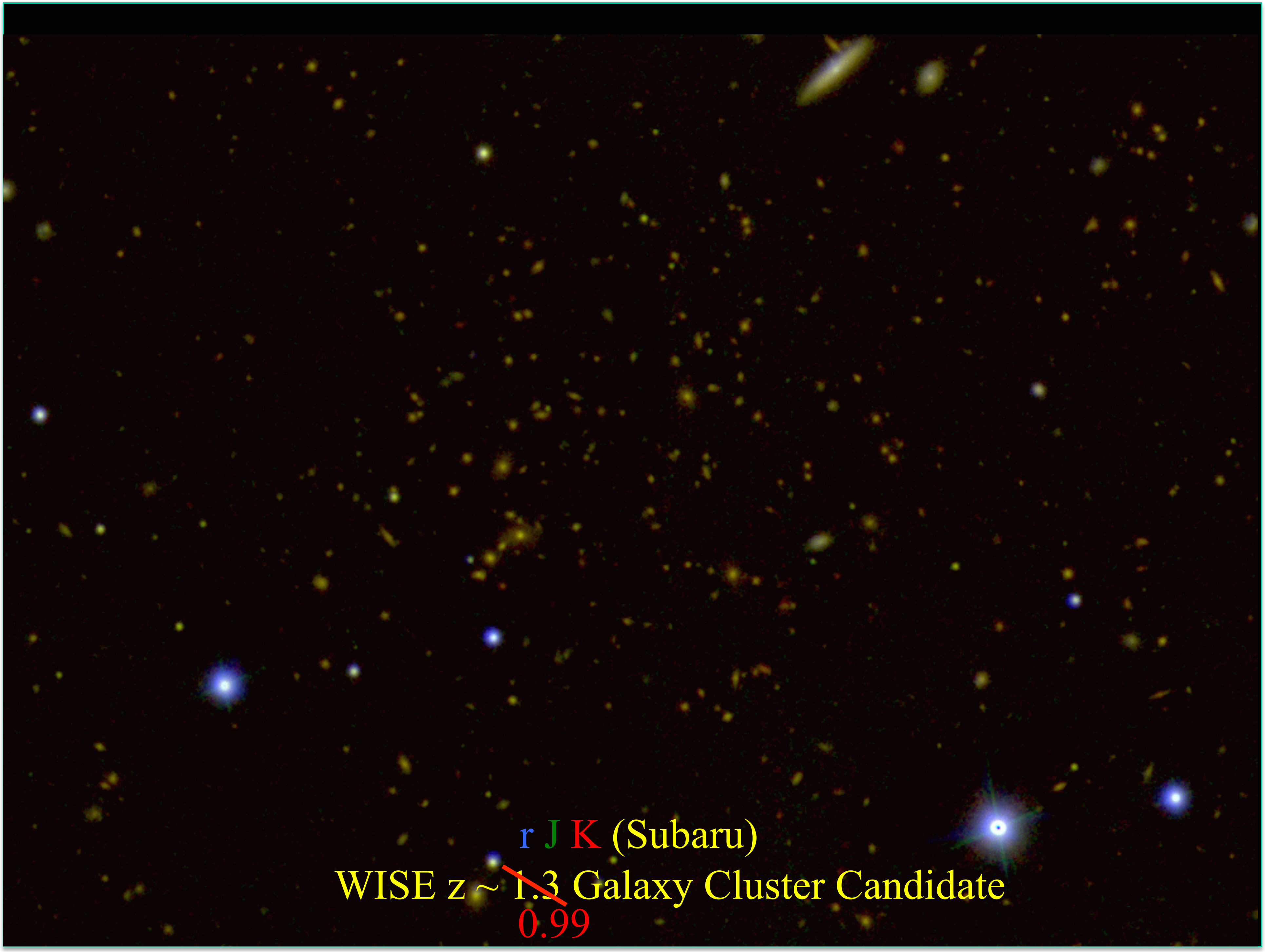


WISE z ~ 1.3 Galaxy Cluster Candidate




WISE z ~ 1.3 Galaxy Cluster Candidate
SDSS r

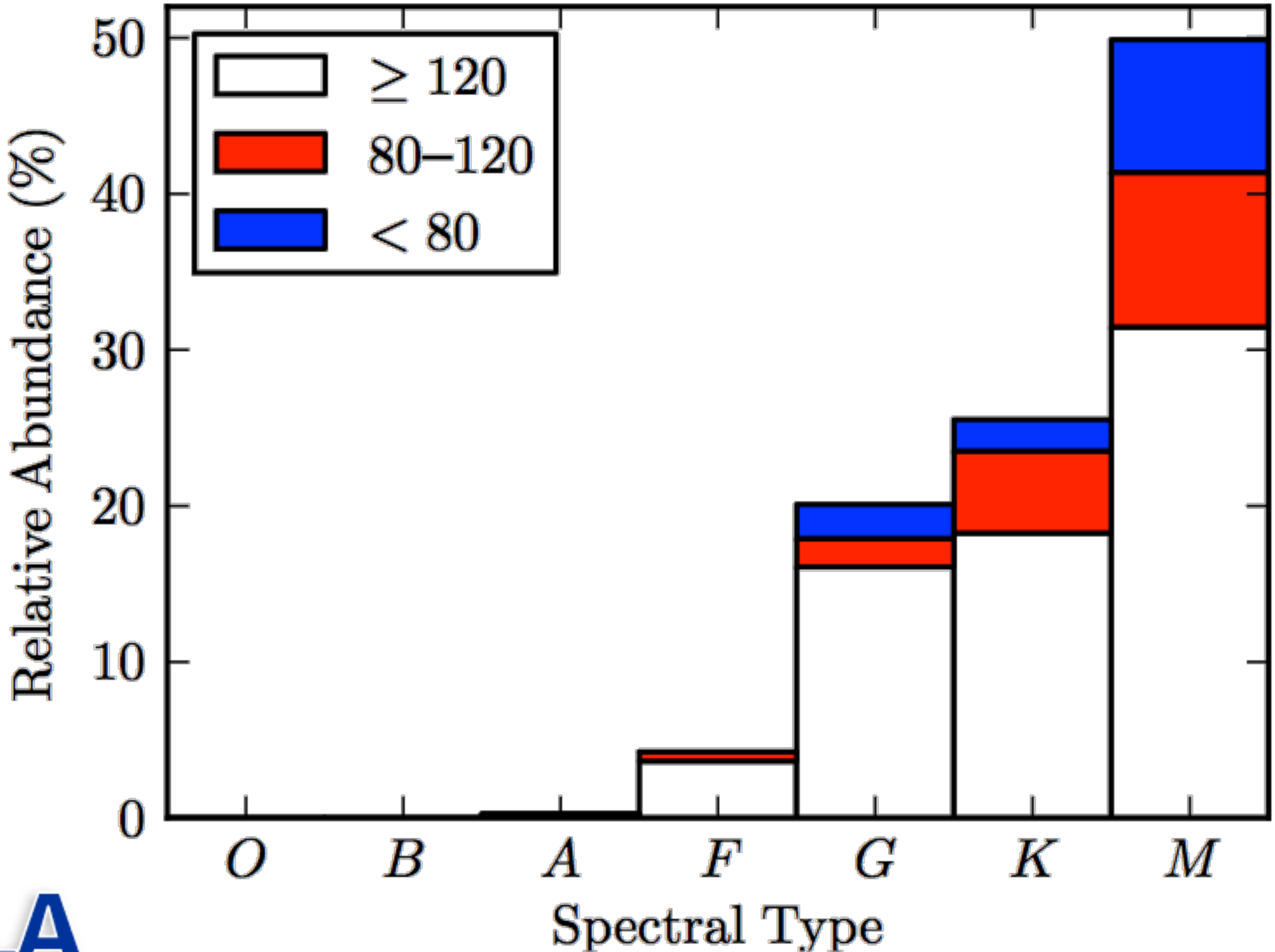

r J K (Subaru)
WISE z ~ 1.3 Galaxy Cluster Candidate


r J K (Subaru)
WISE z ~ ~~1.3~~ Galaxy Cluster Candidate
0.99

Blind Survey of WISE Sources

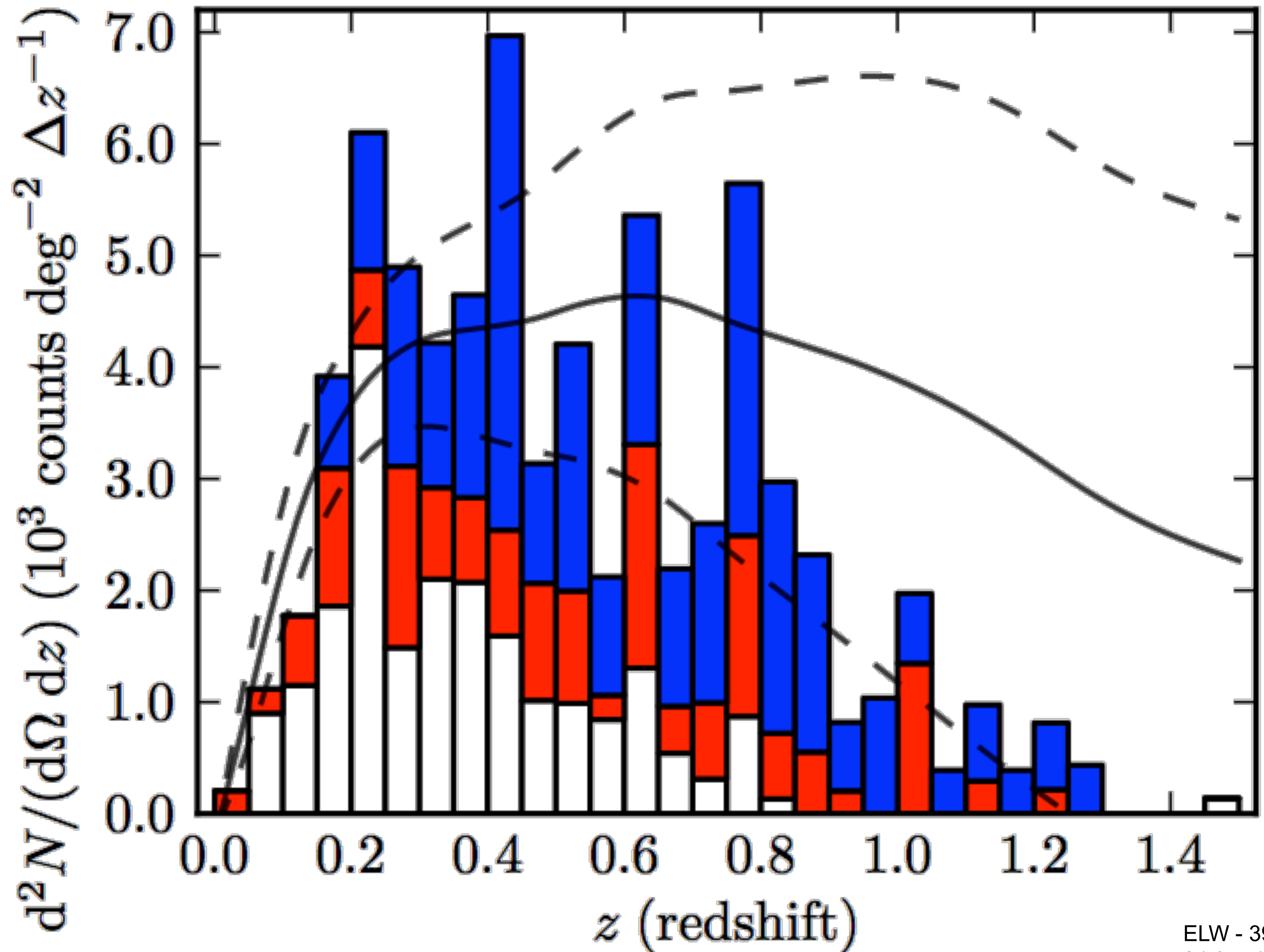
- Lake etal, arXiv:1111.0341
- 762 DEIMOS (on Keck) spectra of "all" WISE sources in FoV's centered on 10 ULIRG candidates
- Three different levels of W1flux limits
  - W1 > 120 μJy, the required sensitivity
  - W1 > 80 μJy, the all-sky achieved sensitivity
  - No limit on W1, with many sources pulled in by the other bands
- For W1 > 120 μJy, 60% of all high-latitude sources are galaxies with median redshift 0.3
- Stars at high |b| are mainly M dwarfs

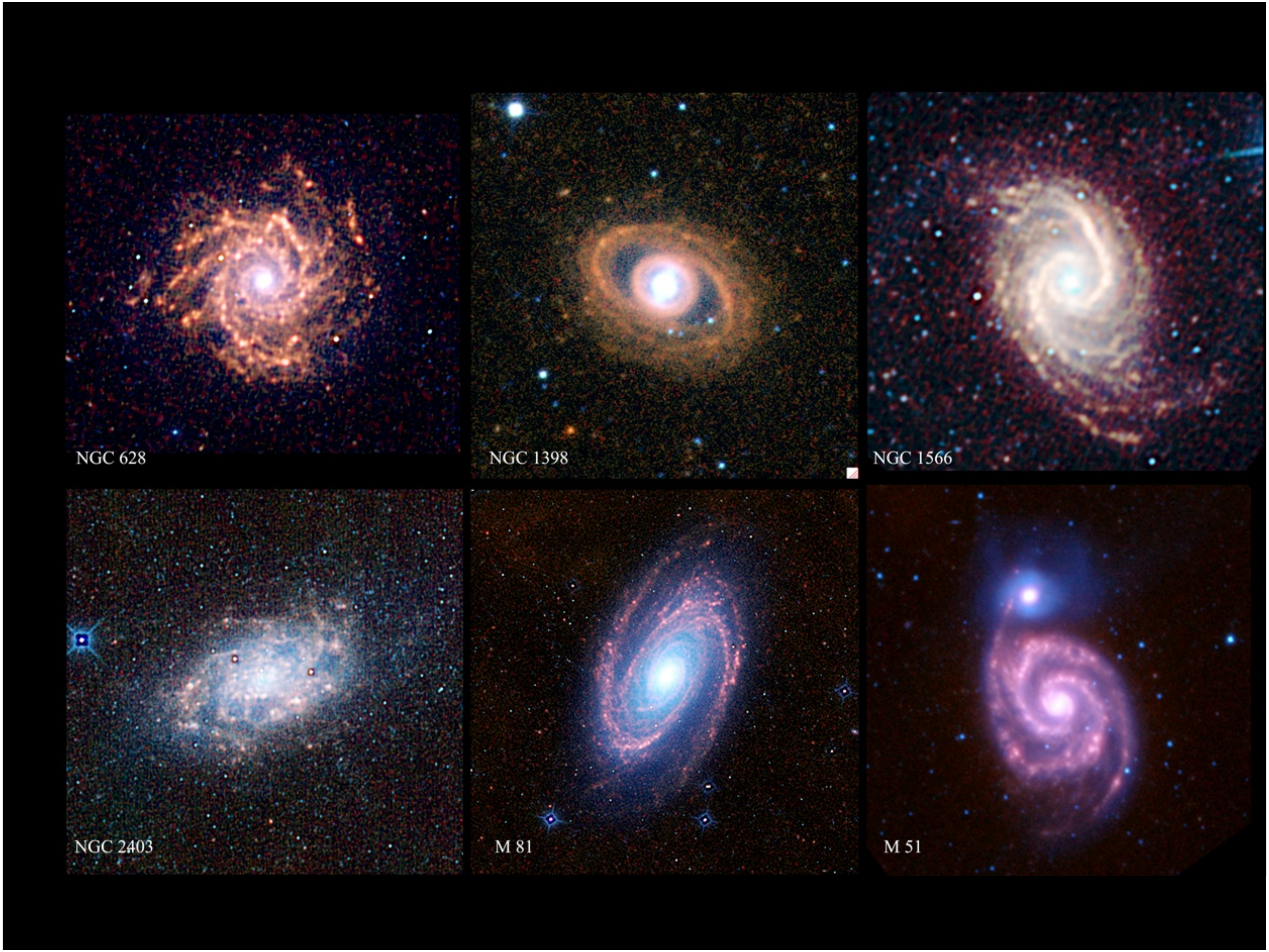
Stellar Type Histogram

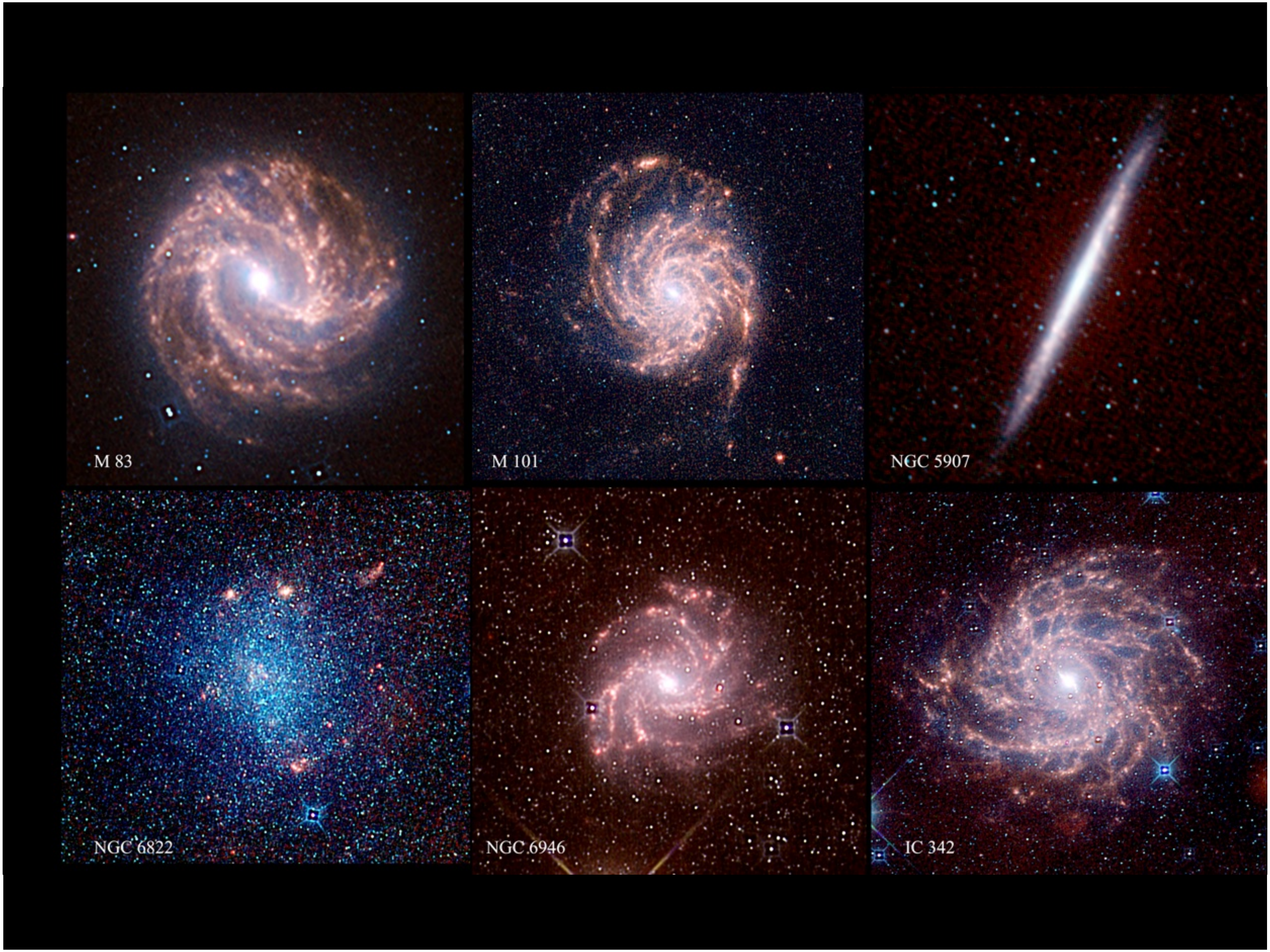


Wide-field Infrared Survey Explorer (WISE)

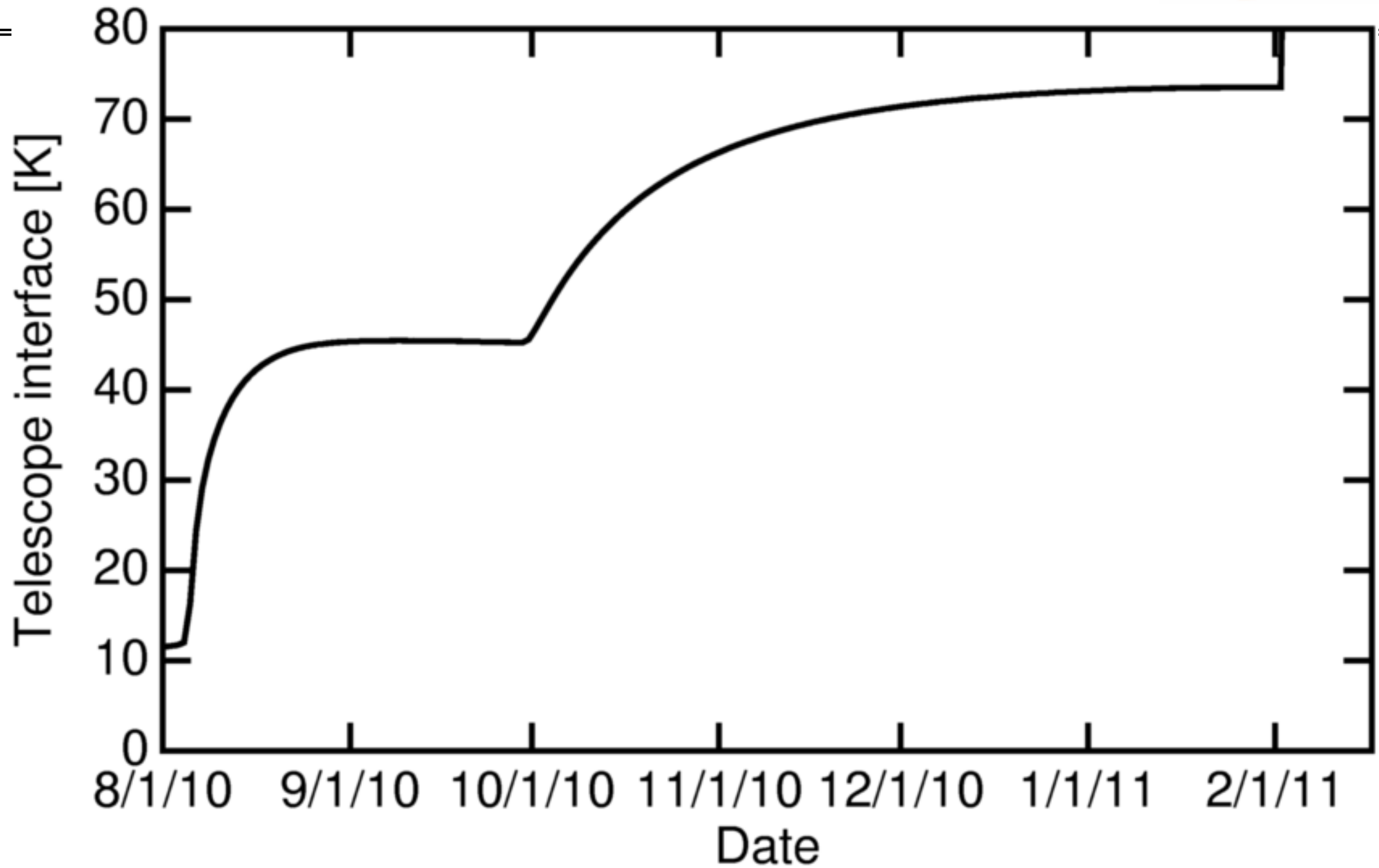
Redshift Histogram




NGC 628
NGC 1398
NGC 1566
NGC 2403
M 81
M 51

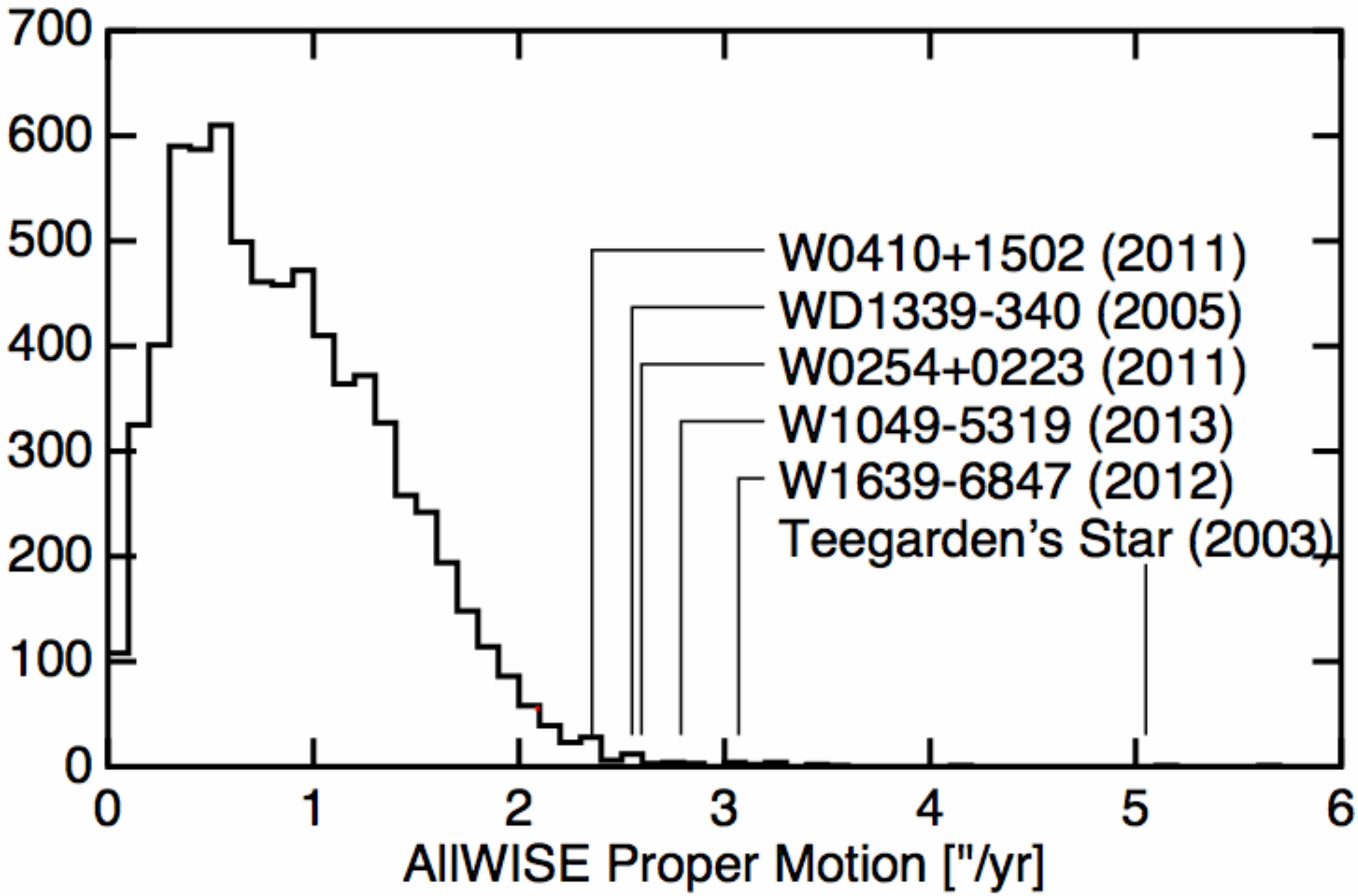

M 83
M 101
NGC 5907
NGC 6822
NGC 6946
IC 342

Warming Telescope



- Data from 8/7/10 to 9/30/10 released in June 2012.
- AllWISE coaddition of data from 10/1/10 to 2/1/11 will give proper motions and deeper 3.4 & 4.6 μm catalogs.

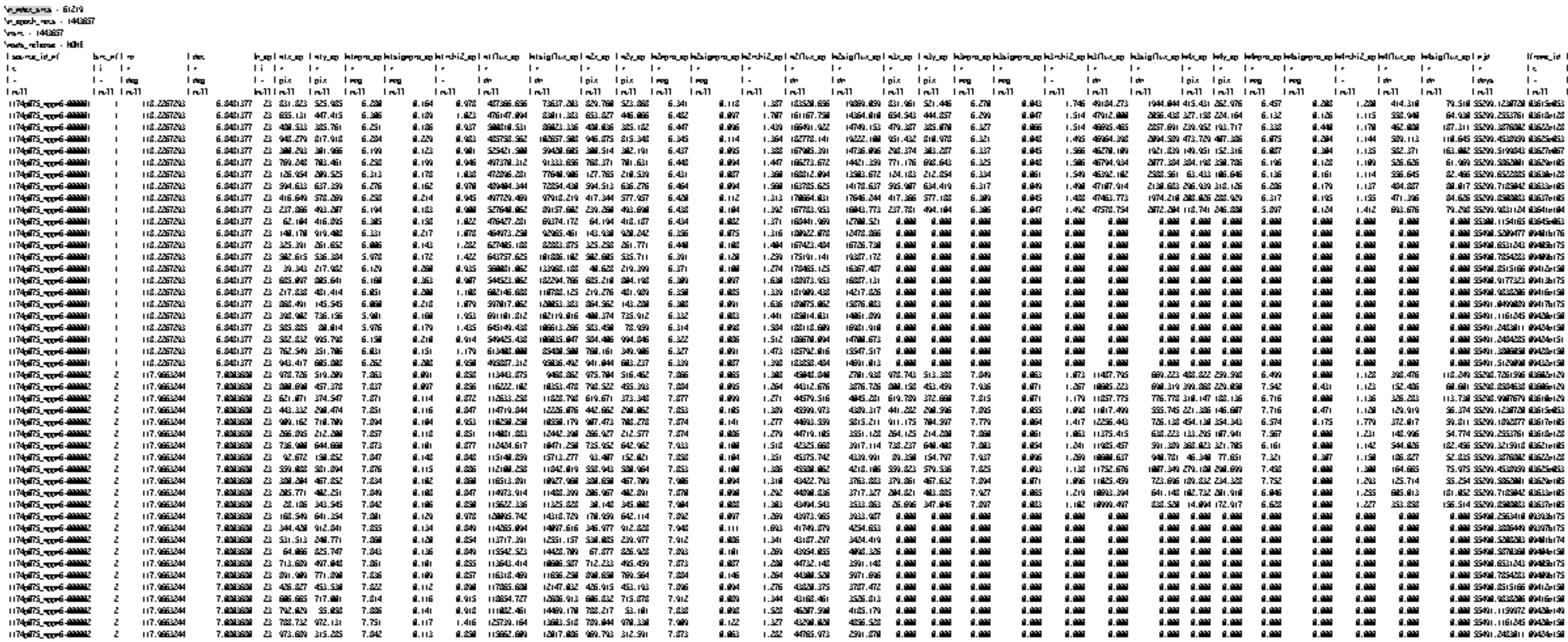
Proper Motion Sensitivity



- 2.5 "/yr at >99.5%-tile

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Multi-Epoch Database

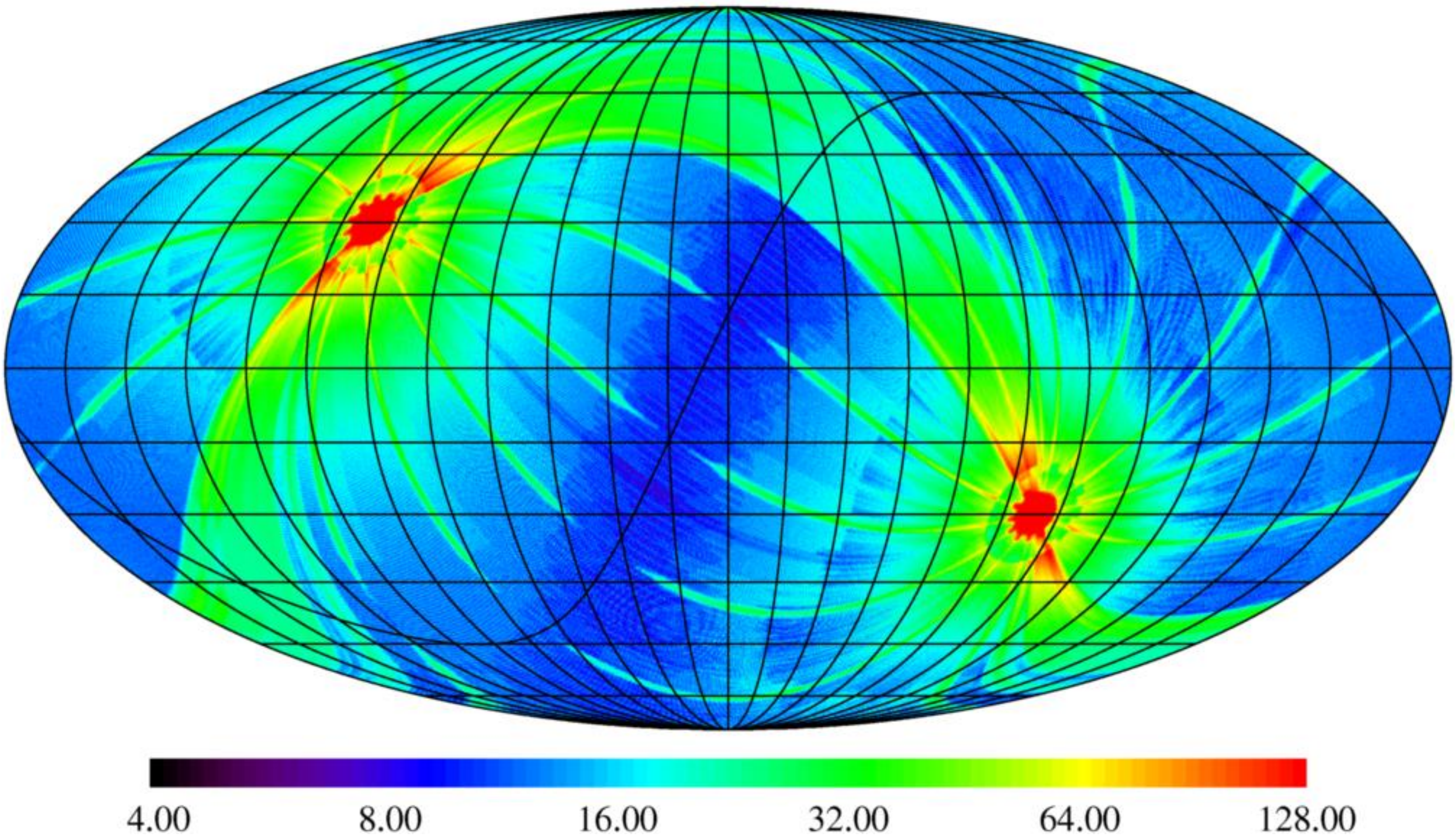


- Pardon the eye chart! This only covers two sources.
- Expect about 30 billion rows in this table.
- Columns for Src_ID, α&δ, (x,y,mpro,sigmpro,rchi^2,flux, sigflux)x4 bands ,MJD, frm_ID

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

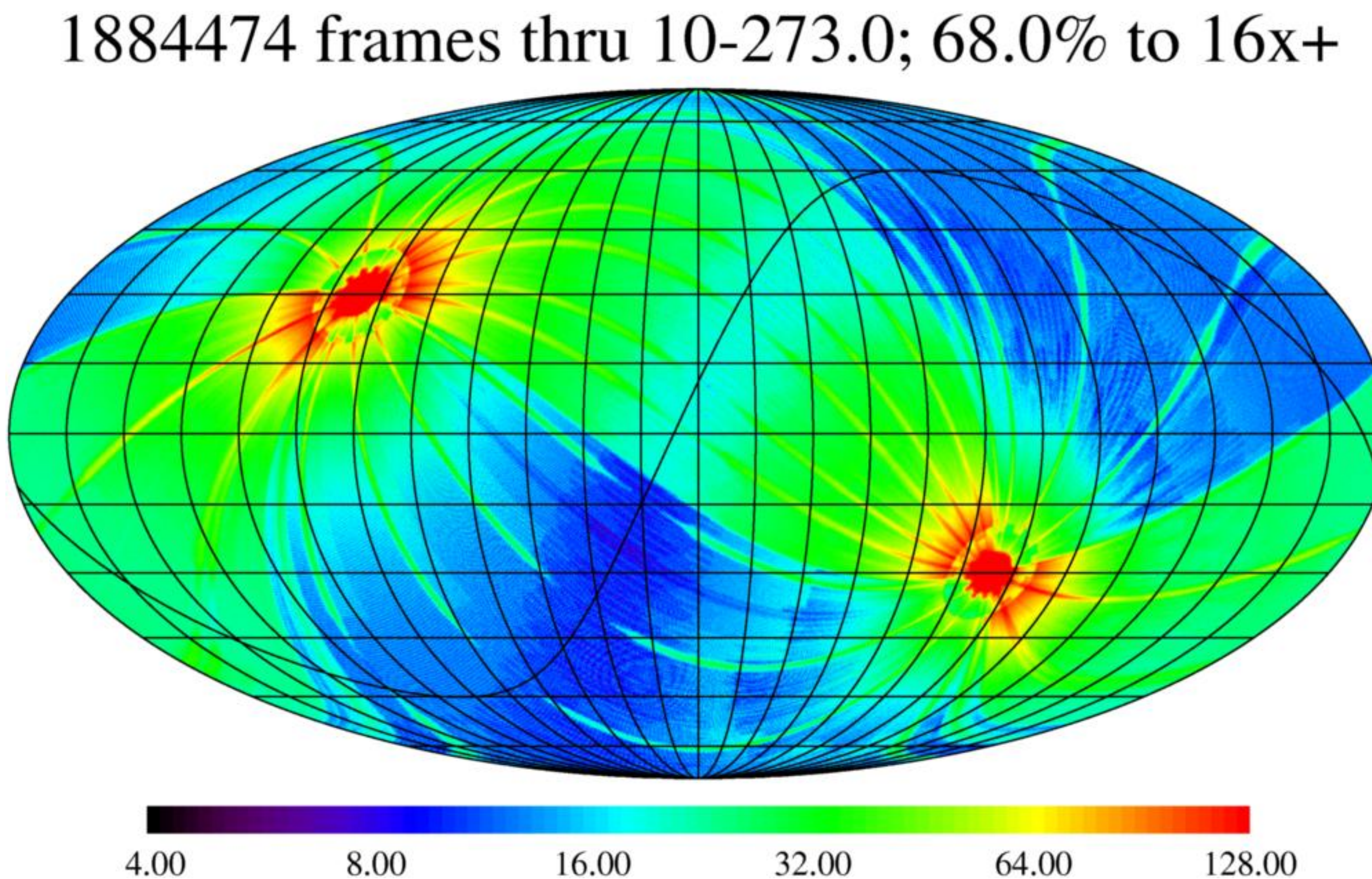
Coverage Released 14 Mar 2012

Actual Coverage Achieved for W4



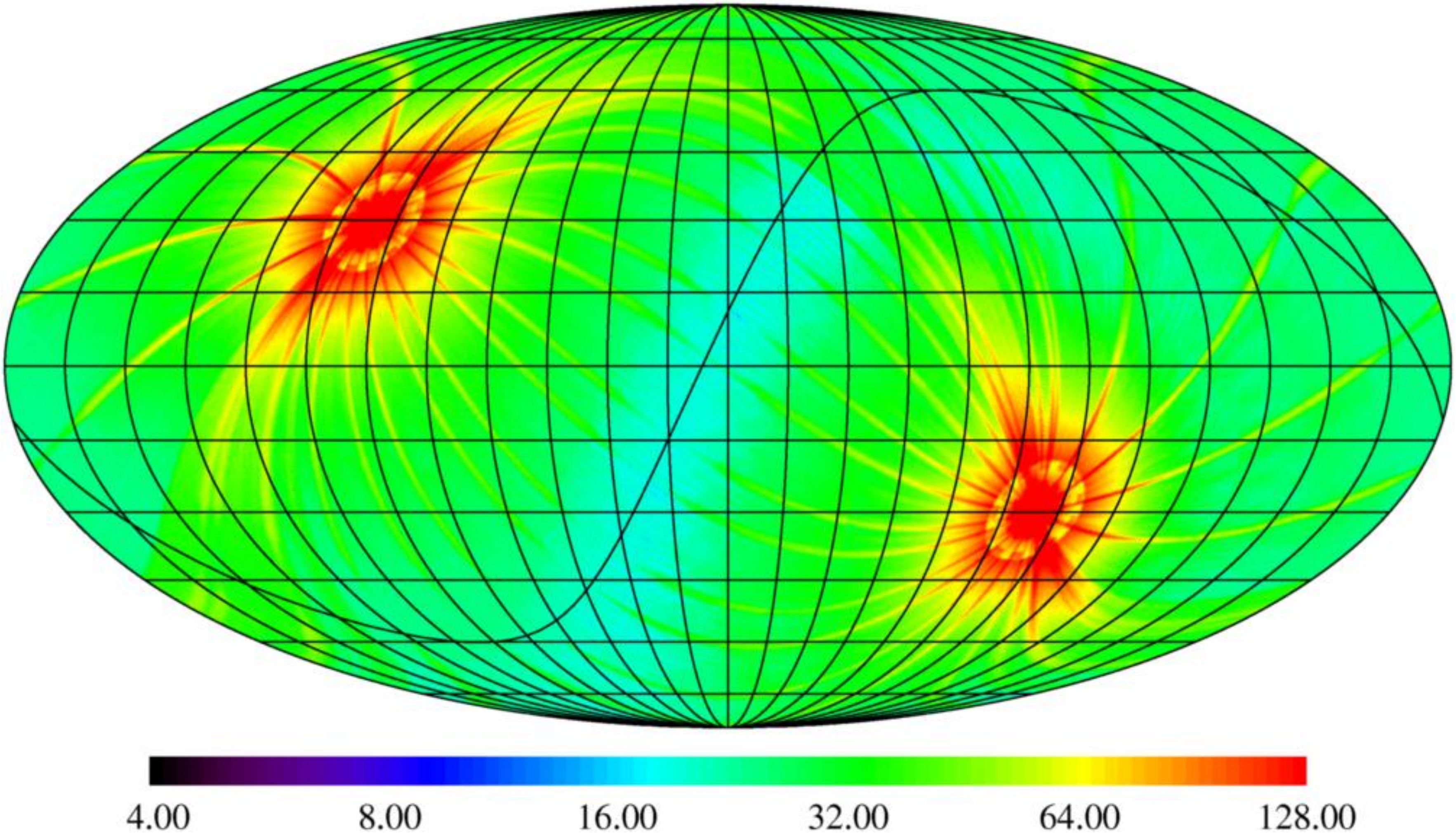
UCLA

More Coverage upto 9/30/10



Final 2 band coverage

2784184 frames thru end of mission



Ten trillion pixels observed!

Thus WISE has

- Discovered many new NEOs and potentially hazardous asteroids and gave radiometric diameters for nearly 160,000 objects.
- Searched for the ½ to ⅔ of the stars in the solar neighborhood that have not yet been seen, including the closest stars to the Sun.
- Surveyed star formation in the Milky Way and in massive Ultra-Luminous Infrared Galaxies.

- Or at least we have the data now: 10 trillion pixels worth. We have lots of work left analyzing this treasure trove of information.

WISE Summary

- Launched 14 Dec 2009
- Band centers 3.4, 4.6, 12 & 22 microns
- Sensitivity better than 0.08, 0.11, 1 & 6 mJy
- Saturation at 0.3, 0.5, 0.7 & 10 Jy point sources
- Angular Resolution 6, 6, 6 & 12 arc-seconds
- Position accuracy about 0.15 arc-seconds 1σ 1-axis for high SNR
- Completed all-sky survey 17 July, big tank ran out hydrogen 5 Aug, little tank empty on 29 Sep, two-band survey for asteroids continued until 1 Feb 2011.
- Data releases:
  - Preliminary release of 57% of the sky on 14 April 2011
  - All-sky Release 14 March 2012
  - Three band data release 27 June 2012
  - Two band single image release 31 July 2012
- Data products include image atlas and source catalog

UCLA

http://wise.astro.ucla.edu

Two Proposals Under Review

- WITS (Wide-field Infrared Time-Domain Survey) submitted to NASA Astrophysics Explorer MoO call
  - TURN WISE back ON
  - Scan wider range of solar elongations to get observations over two week period every six months for two years
  - Measure variability of MW Cepheids, Miras, QSOs
  - Better SNR on z=1 galaxies
- Re-Animation of NEOWISE – submitted to the Human Exploration & Operations Mission Directorate (HEOMD)
  - TURN WISE back ON
  - Resume WISE scan pattern to find more NEOs
  - Obviously also gets variability of Miras, QSOs and better SNR on z=1 galaxies

JWST is coming

- JWST covers the WISE bands.
- Mining the WISE data to find targets for JWST will pay off dramatically in 5 years.