WISE - the Wide-field Infrared Survey Explorer

Ned Wright (UCLA)

Project Overview

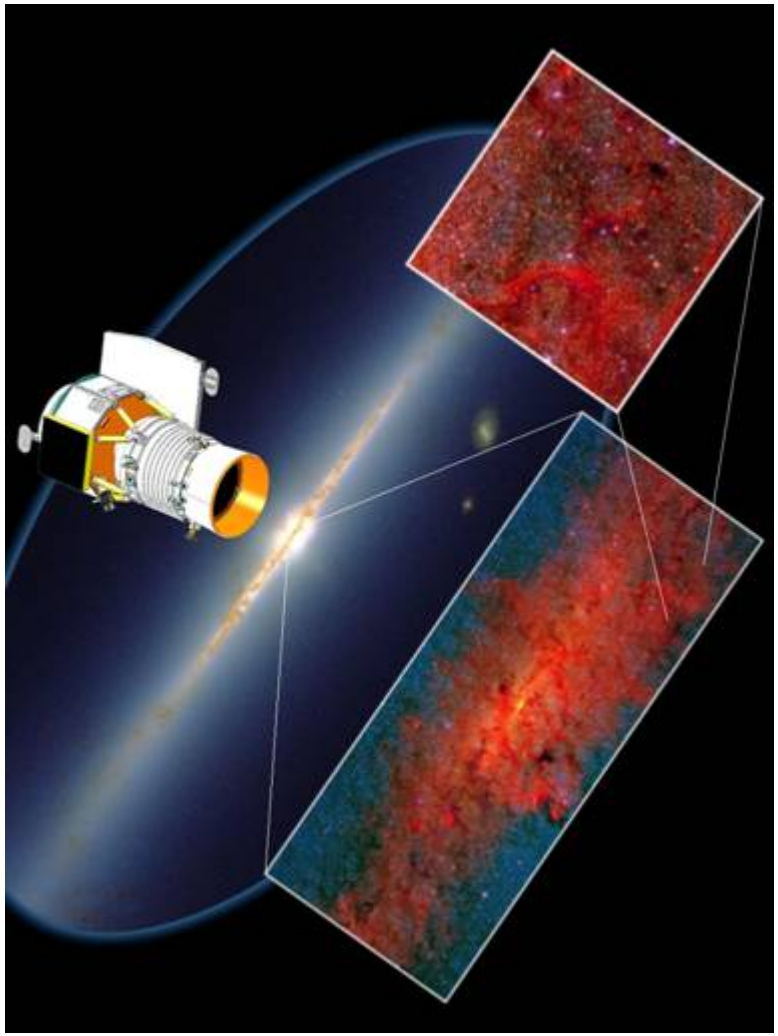
Science

- *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*

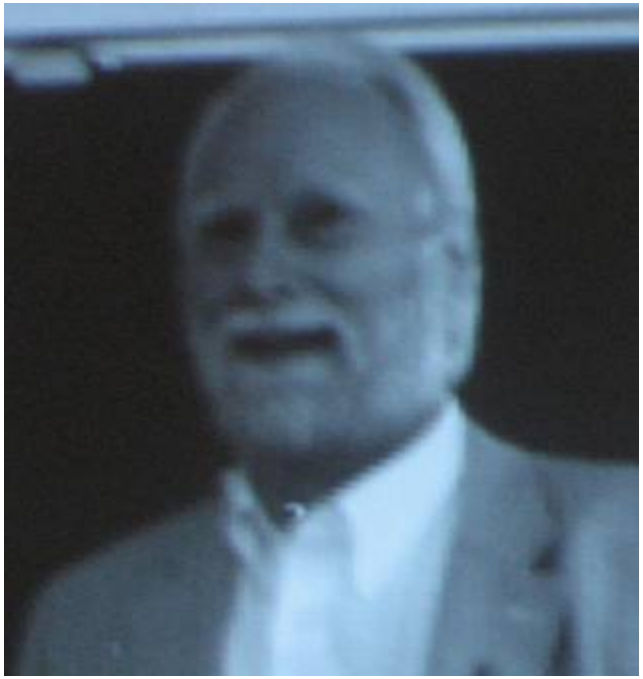
Salient Features

- *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



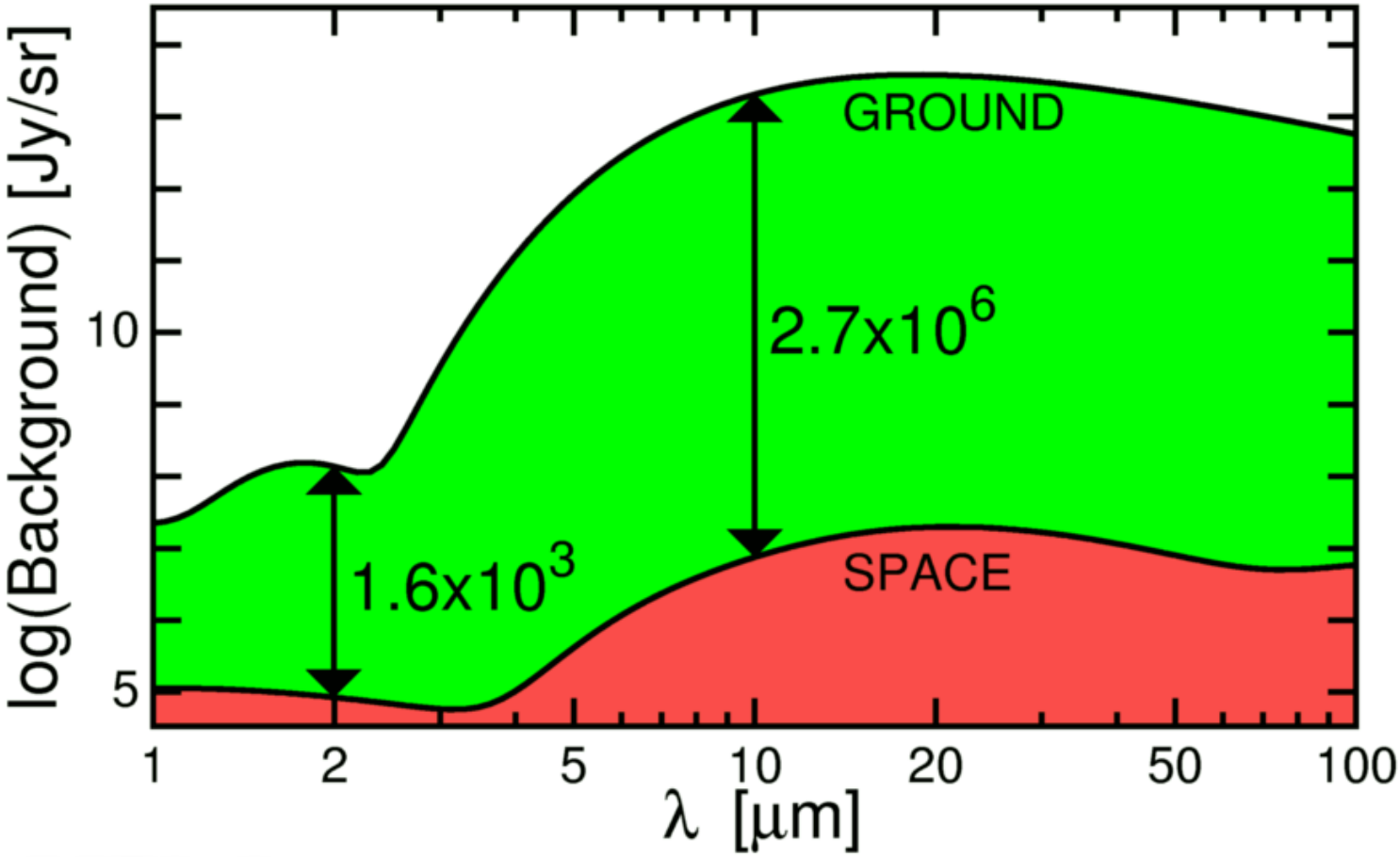
- Optical
- Reflected light

Near-IR
different colors

Thermal-IR
emitted radiation

Why Space?

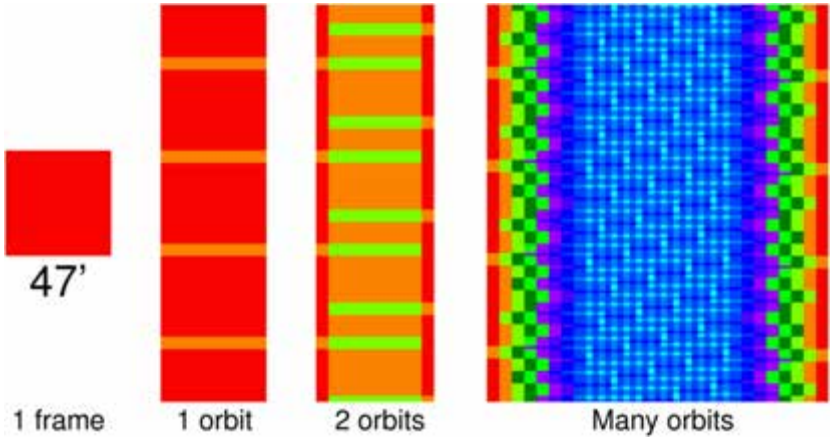
"Ground-based infrared astronomy is like observing stars in broad daylight with a telescope made out of fluorescent lights" — George Rieke.



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

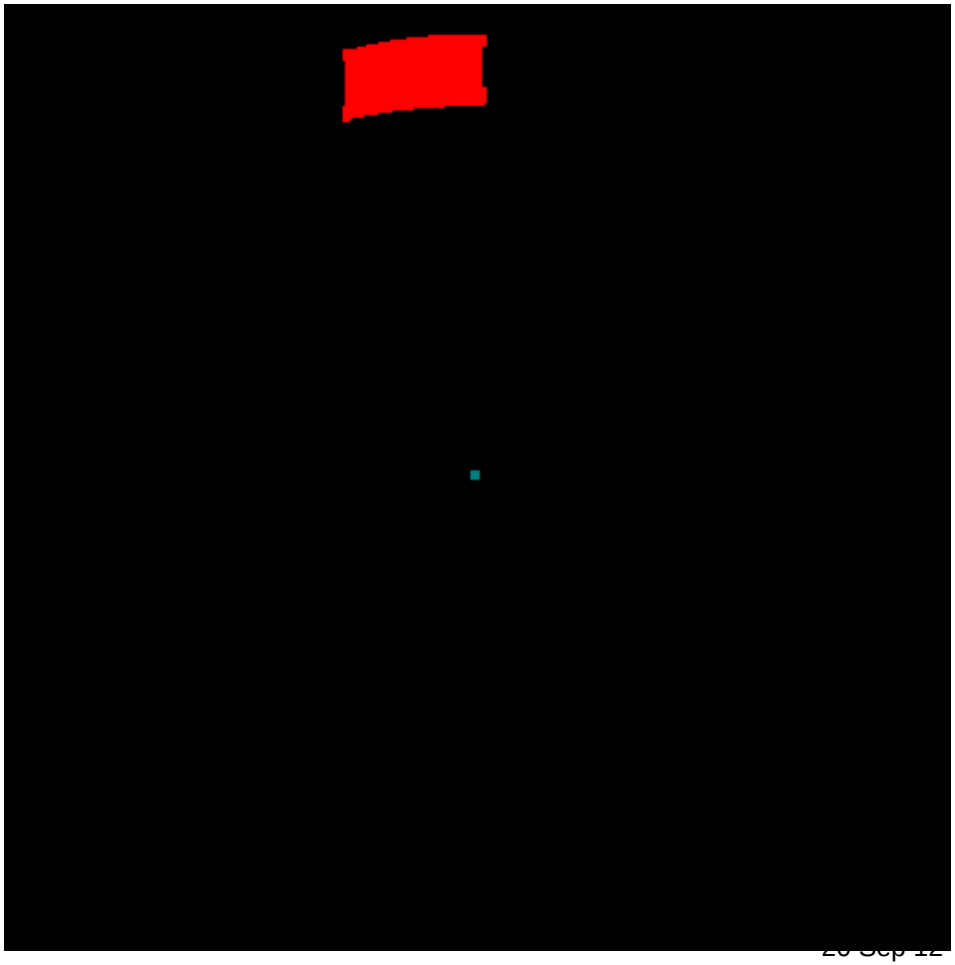
WISE Survey Strategy Provides Minimum of 8 Exposures Per Position

- 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



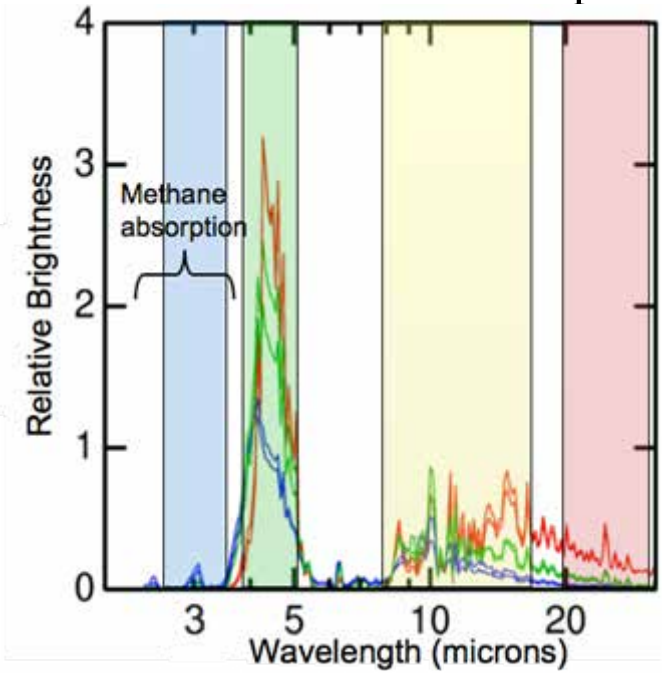
1 Orbit **2 Consecutive Orbits** **2 Orbits 20 Days Apart**

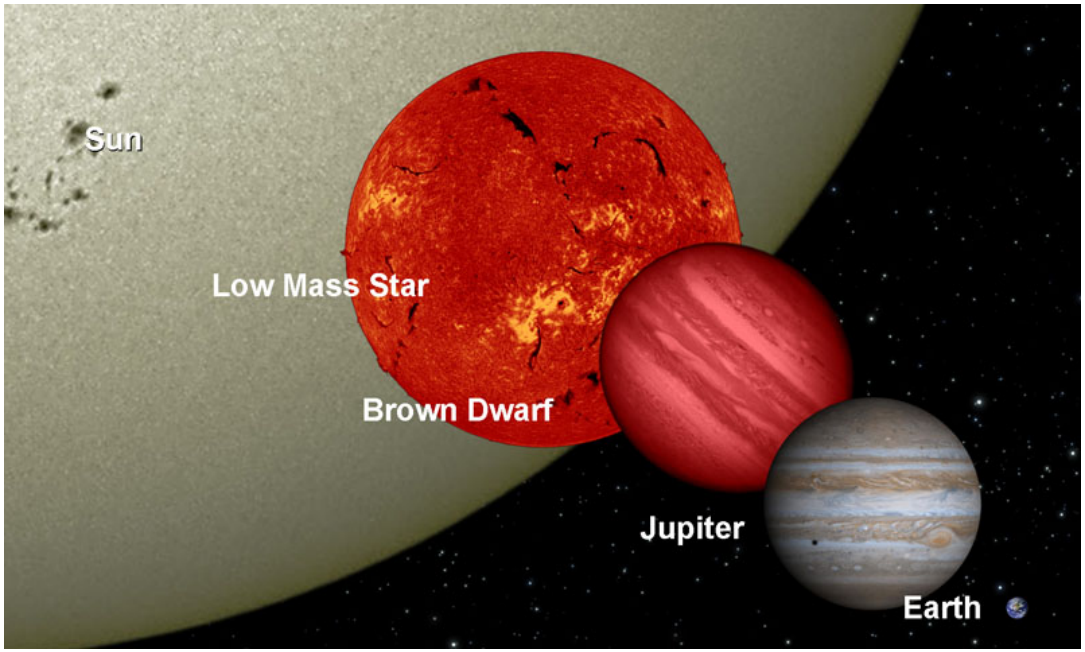
- Single observing mode
- Minimum 8, median 14 exposures/ position after losses to Moon and SAA



WISE and Brown Dwarfs

- Brown Dwarfs are stars with too little mass to fuse Hydrogen into Helium.
- WISE two short wavelength filters are tuned to methane dominated brown dwarf spectra.





- WISE could identify brown dwarfs as cool as 200 Kelvin (-100 Fahrenheit) out to 4 light years, the distance to the nearest known star.

UCLA

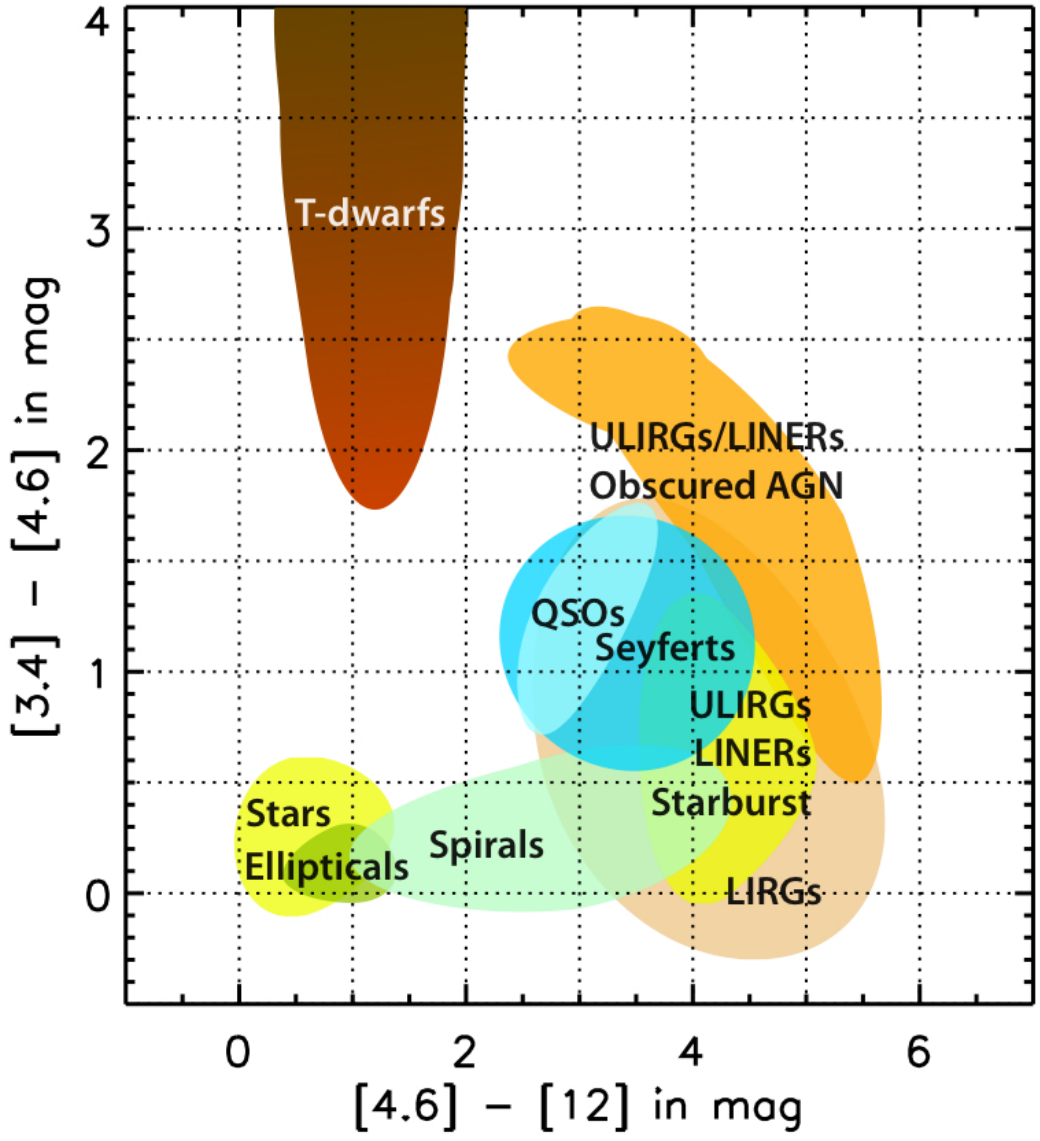
Greenhouse Gases

- Both water and methane are green house gases
- Each requires only one rare “heavy” atom and then makes the rest of the molecule with the most abundant atoms: hydrogen.
  - Carbon dioxide needs three heavy atoms
- Infrared radiation can only escape where H_2O and CH_4 do not absorb: 1.25, 1.6 and 4.6 μm
- Standard abundances ratios are 1 Fe, 1 Mg, 1 Si, 2 Ne, 16 O, 2 N, 8 C, 2100 He and 25000 H

Brown Dwarf Energy Source

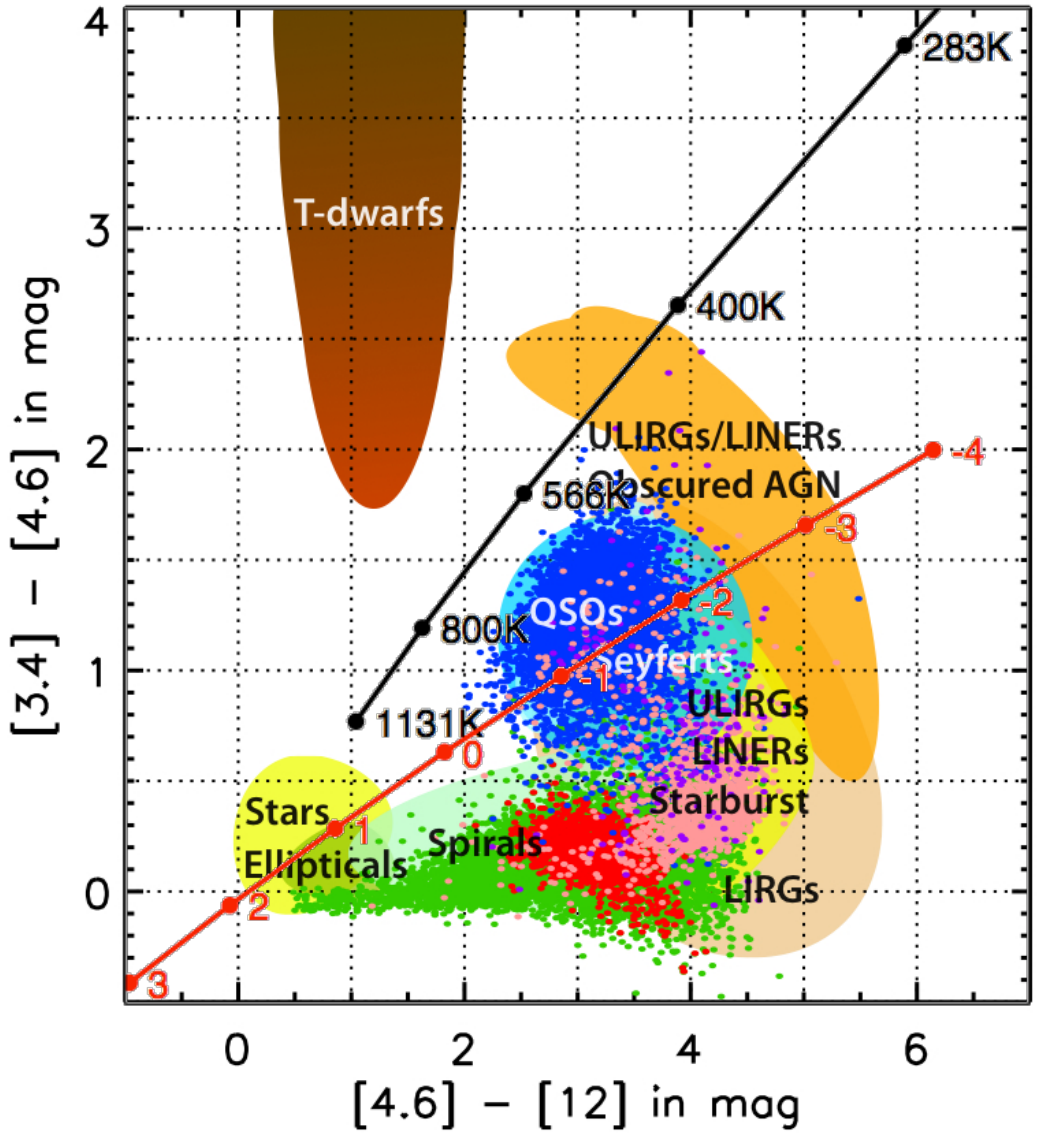
- Not hot enough in the center to run nuclear fusion like stars
- Energy from initial collapse slowly leaks out
- Order of magnitude of the gravitational energy is GM^2/R
  - For a uniform density sphere $(3/5)GM^2/R$, $\rho \approx 1/r^2$ gives $(1)GM^2/R$
- Order of magnitude of luminosity is energy/age or GM^2/Rt
- Fit gives $L = 0.02(GM_J^2/[R_J * 1\text{Gyr}])(M/M_J)^{1.93}([1\text{ Gyr}]/t)^{1.18}$ or about $L/L_\odot = 3 \times 10^{-8}$ for 10 M_J at 10 Gyr
- About 25 times cooler than the Sun or 231 K. Brr!
- Detectable by WISE to a distance of 12 light years

Inhabitants of WISE Color Space



- Astronomers use the magnitude scale: $-2.5\log_{10}(\text{Flux})$
- Colors are magnitude differences OR $-2.5\log_{10}(\text{Flux Ratio})$
- Upper Right Corner contains objects that are RED in both ratios
- Upper Left Corner is RED from 3.4 to 4.6 μm, but not red from 4.6 to 12 μm
- Lower Left Corner contains blue objects: stars and elliptical galaxies

Inhabitants of WISE Color Space

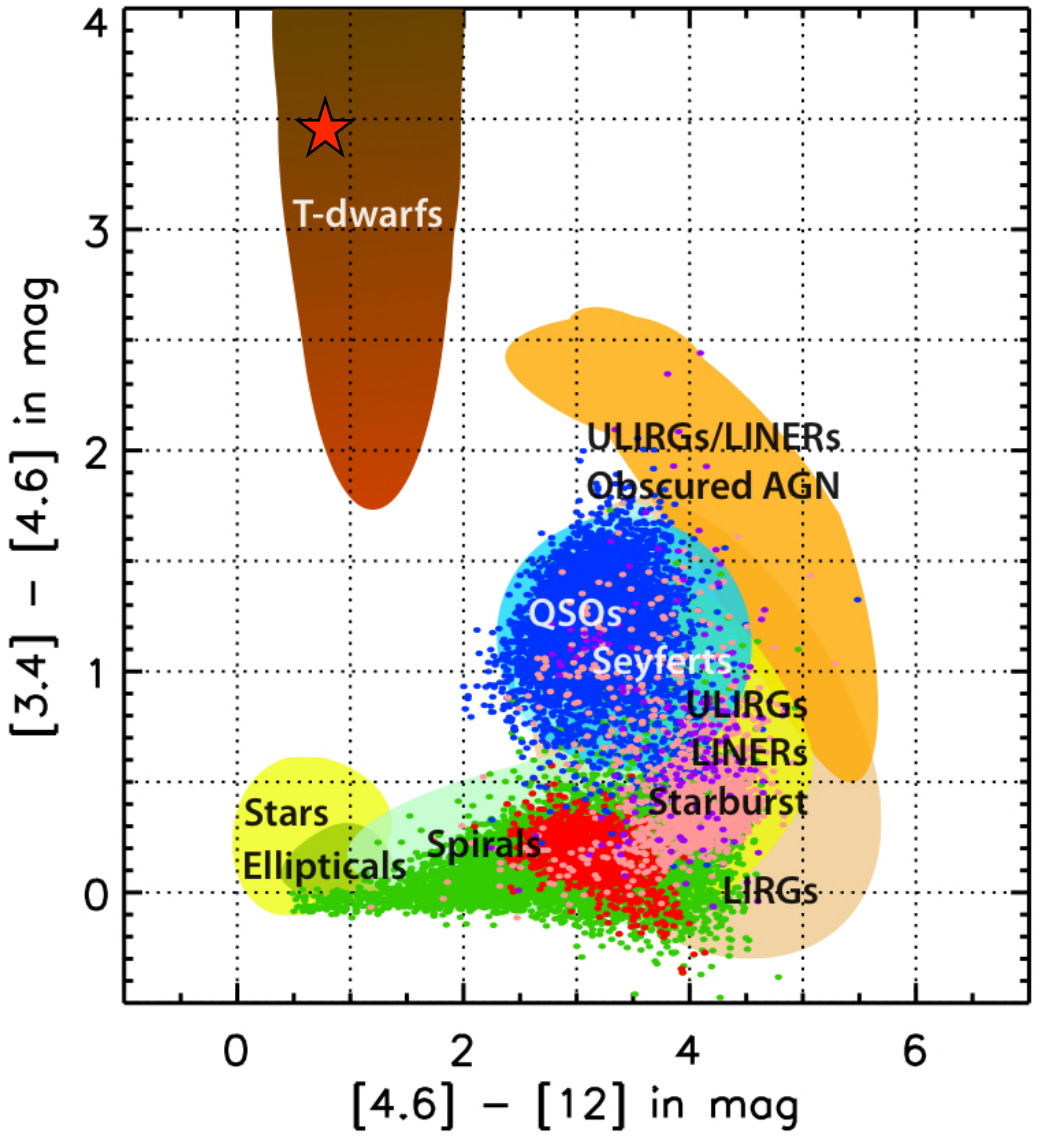


SDSS Classifications:

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

- Blackbodies
- Power Laws

Inhabitants of WISE Color Space



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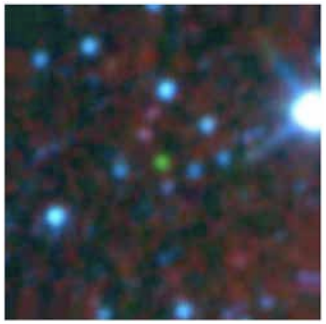
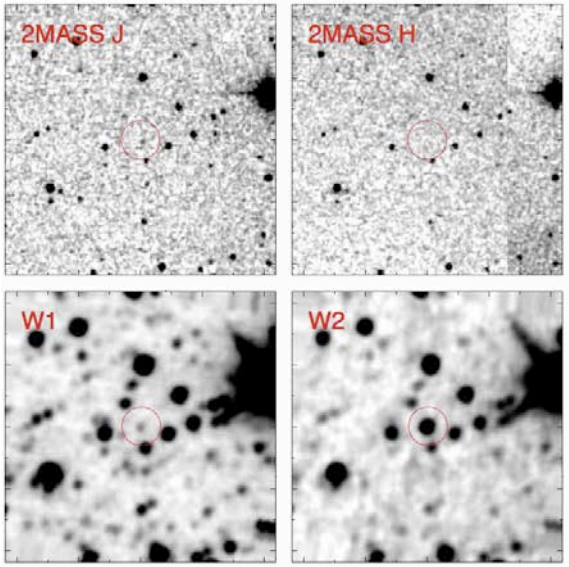
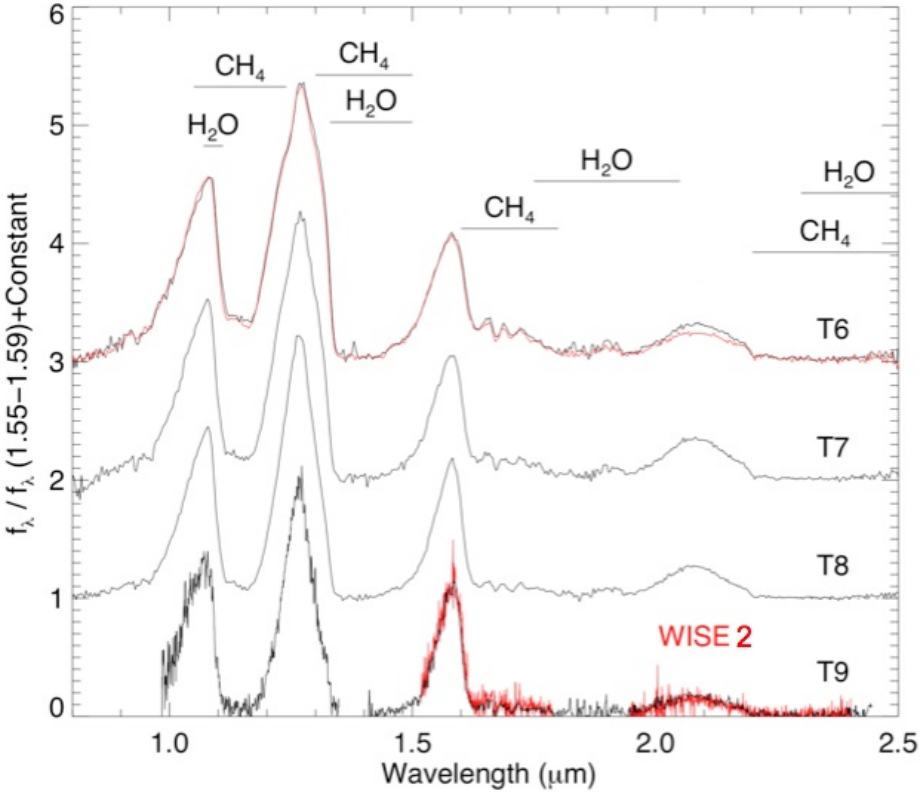
First Spectroscopically Confirmed WISE Brown Dwarf



W0458+64





- WISE 0458+64 spectrum from LUCIFER on LBT.
- At the time, was as cool or cooler than any known BD
- Mainzer et al 2011, ApJ, 726, 30.

Gelino etal: Binarity Search

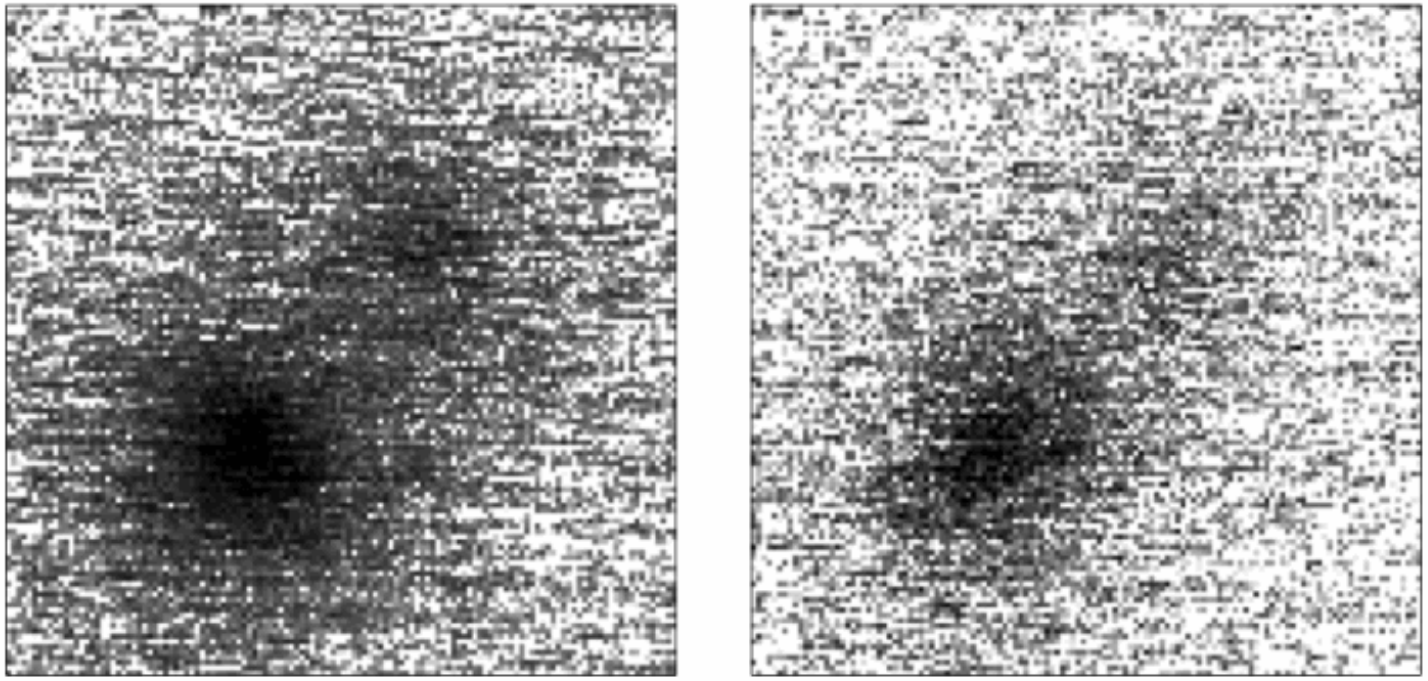


Fig. 5.— J (left) and H (right) LGS-AO images of WISE 0458+6434AB. The images are $\approx$1.25″ on a side with North up and East to the left.

- Cool BD in Mainzer etal: a binary with 0.51” separation
- Very cool binary and much closer to the Sun than CFBDSIR 1458+1013

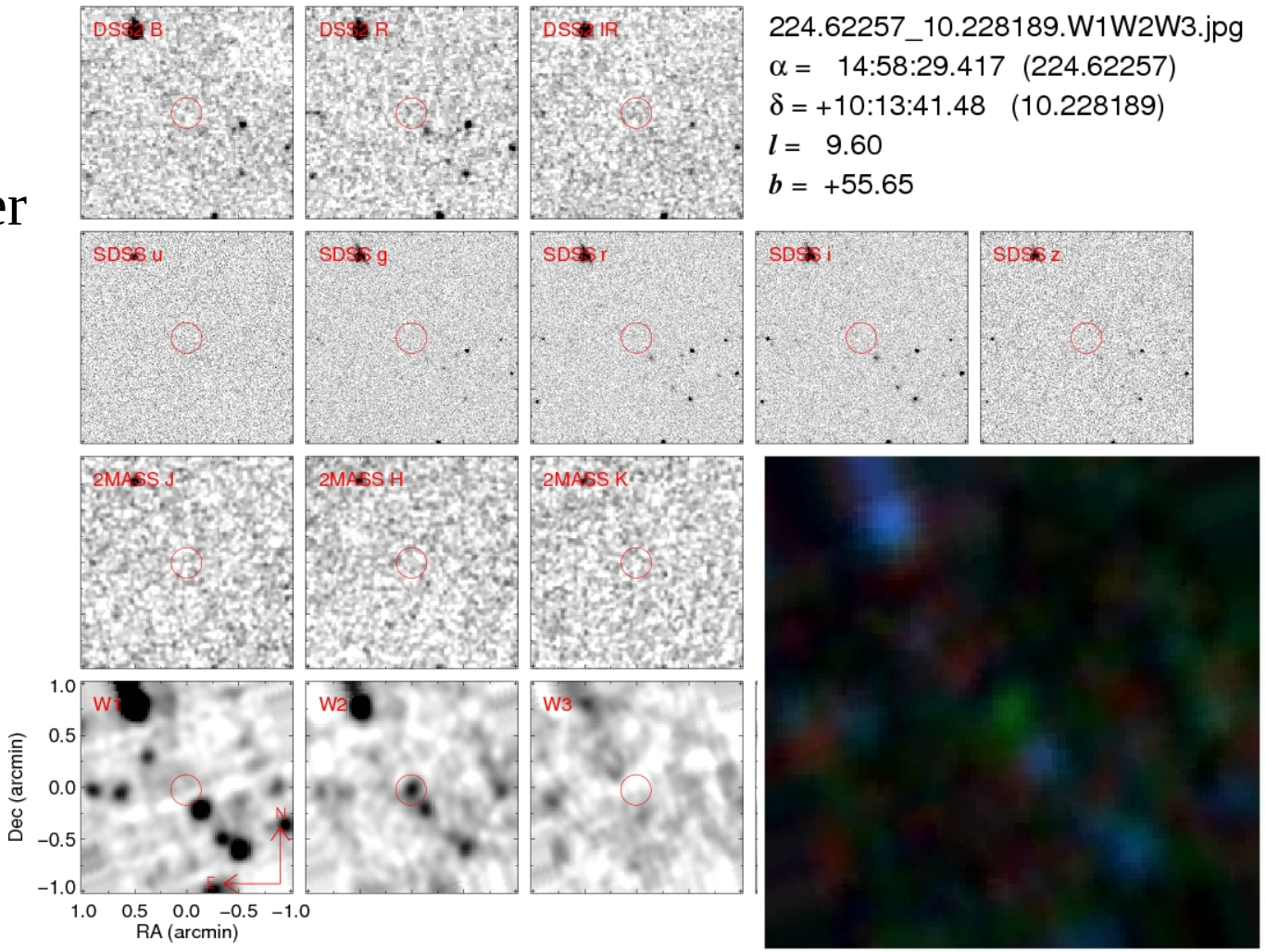
1458+1013

Liu etal 2011: 0.11" binary

Did not have Spitzer data

J_{tot}-W2 = 4.2
H_{tot}-W2 = 4.6

1458+1013B is not as cold or faint as WD 0806-661B which WISE didn't see



- A candidate "coldest brown dwarf"

1841+70AB

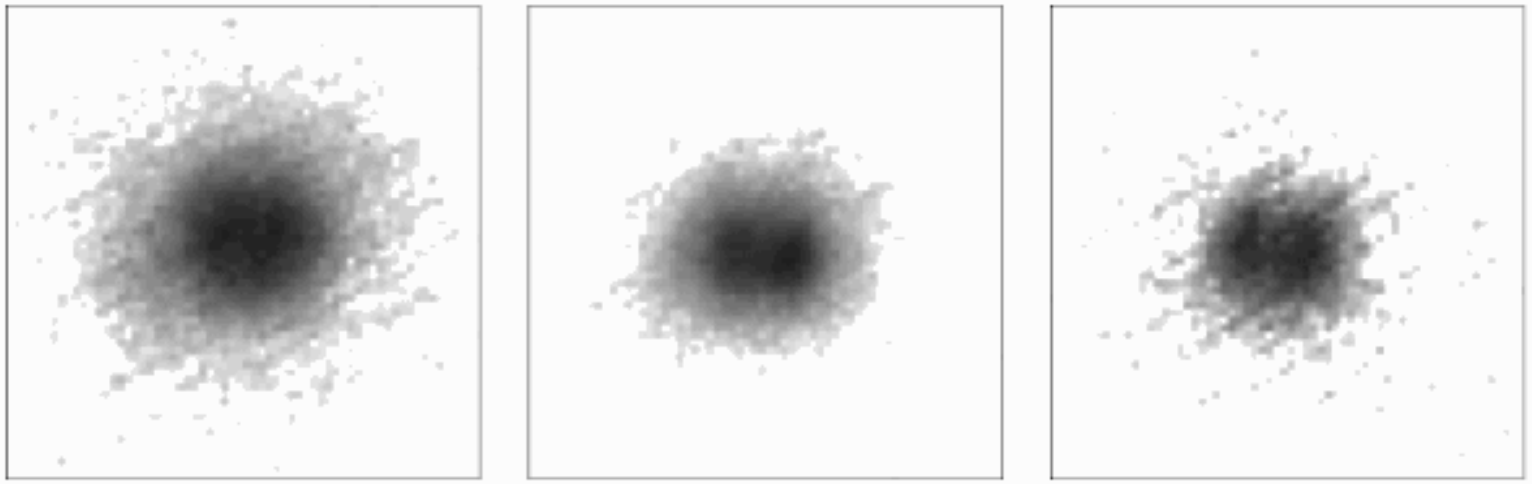


Fig. 4.— JHK_s LGS-AO images (left to right) of WISE 1841+7000AB. Each image is ≈0.″6 on a side with North up and East to the left.

- Very close, could get orbital solution in a decade
- 0.07” separation, but probably at 40 pc distance so 3 AU physical projected distance

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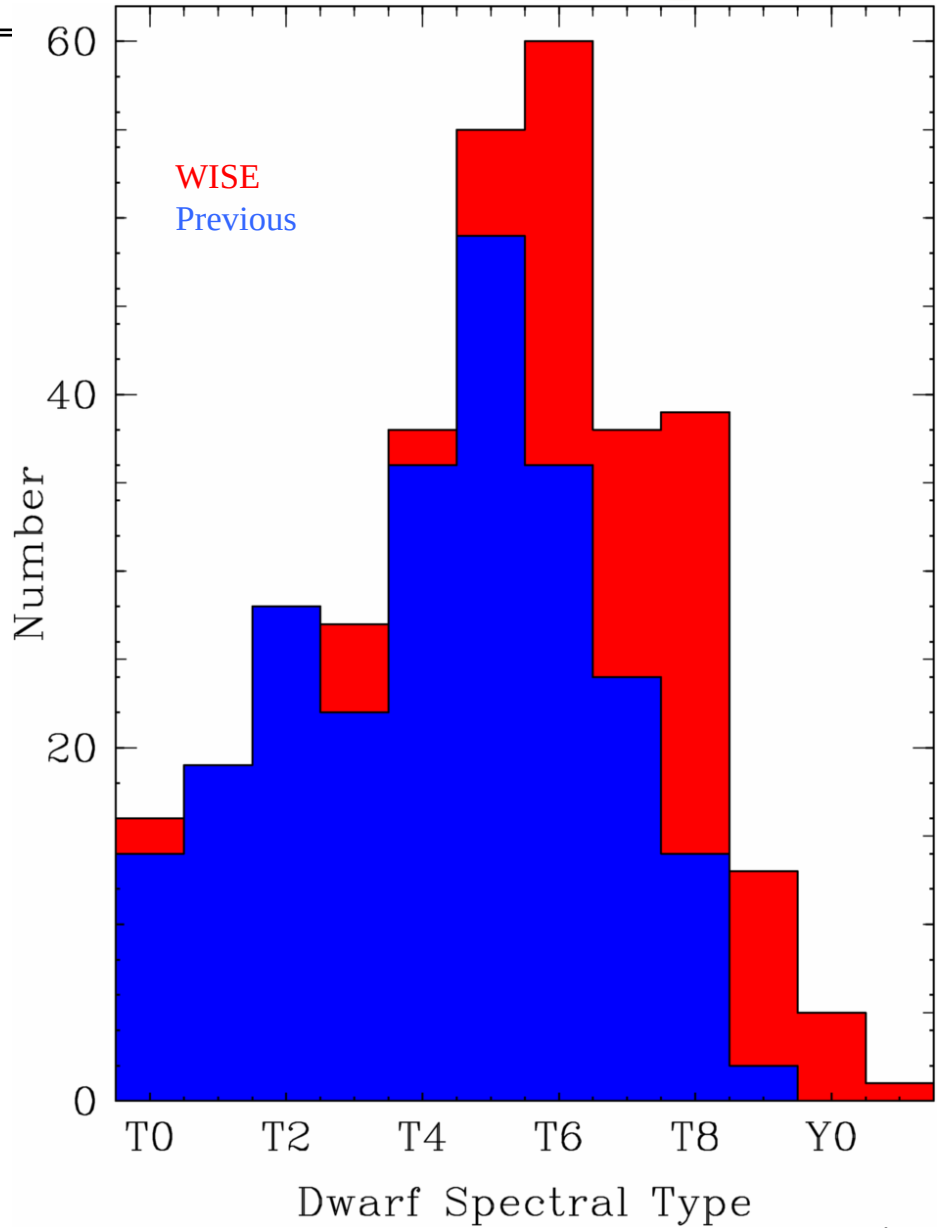
But wait there's more!

- Burgasser et al (2011, ApJ, 735,116, arXiv: 1104.2537): 5 WISE BDs
- Kirkpatrick et al (2011, ApJS 197, 19, arXiv: 1108.4677) has $\approx 10^2$ BDs
- Triples the number of known T8s
- 7× the number of known T9s
- First class Y dwarfs (Cushing etal, 2011, ApJ, 743, 50, arXiv: 1108.4678)



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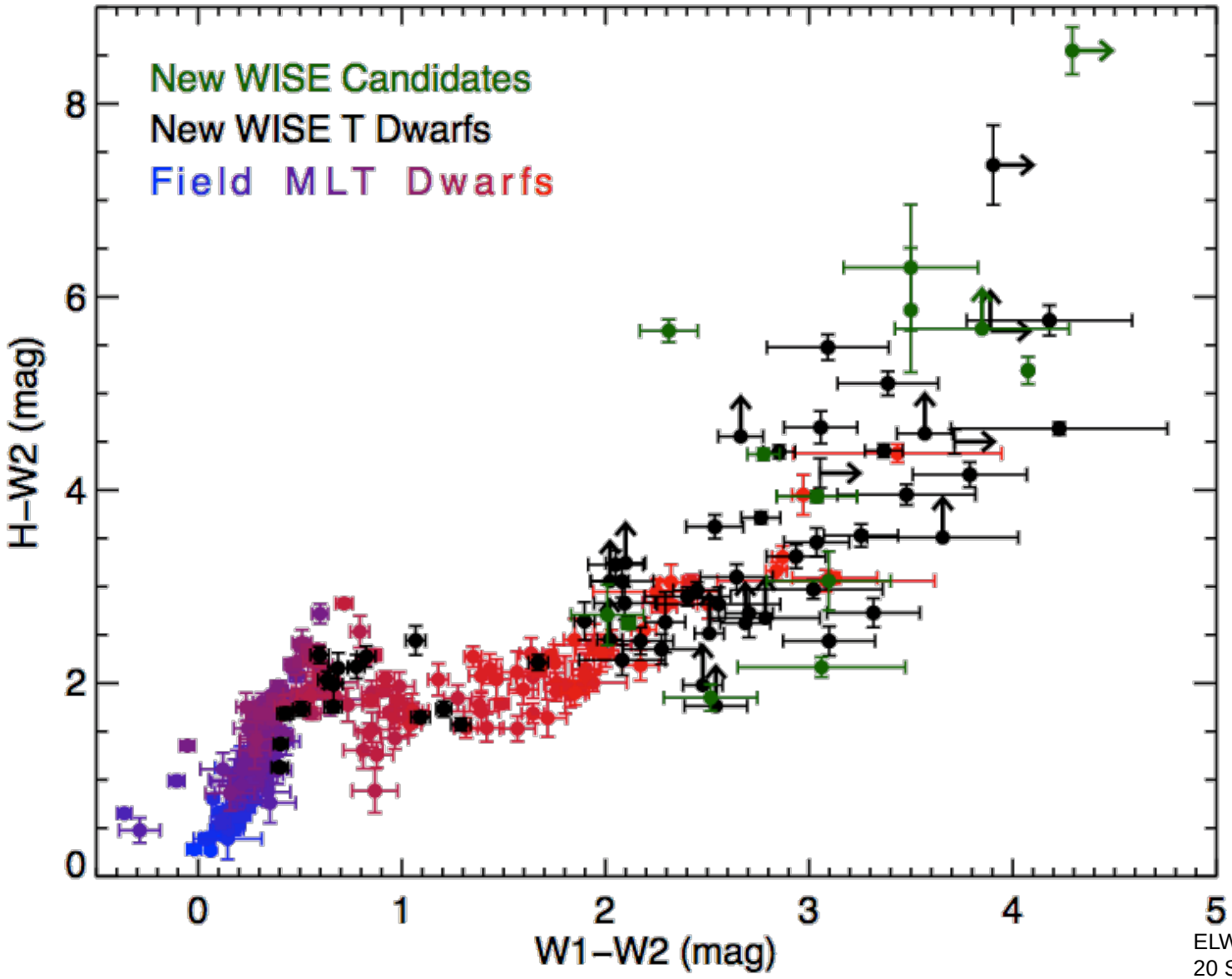
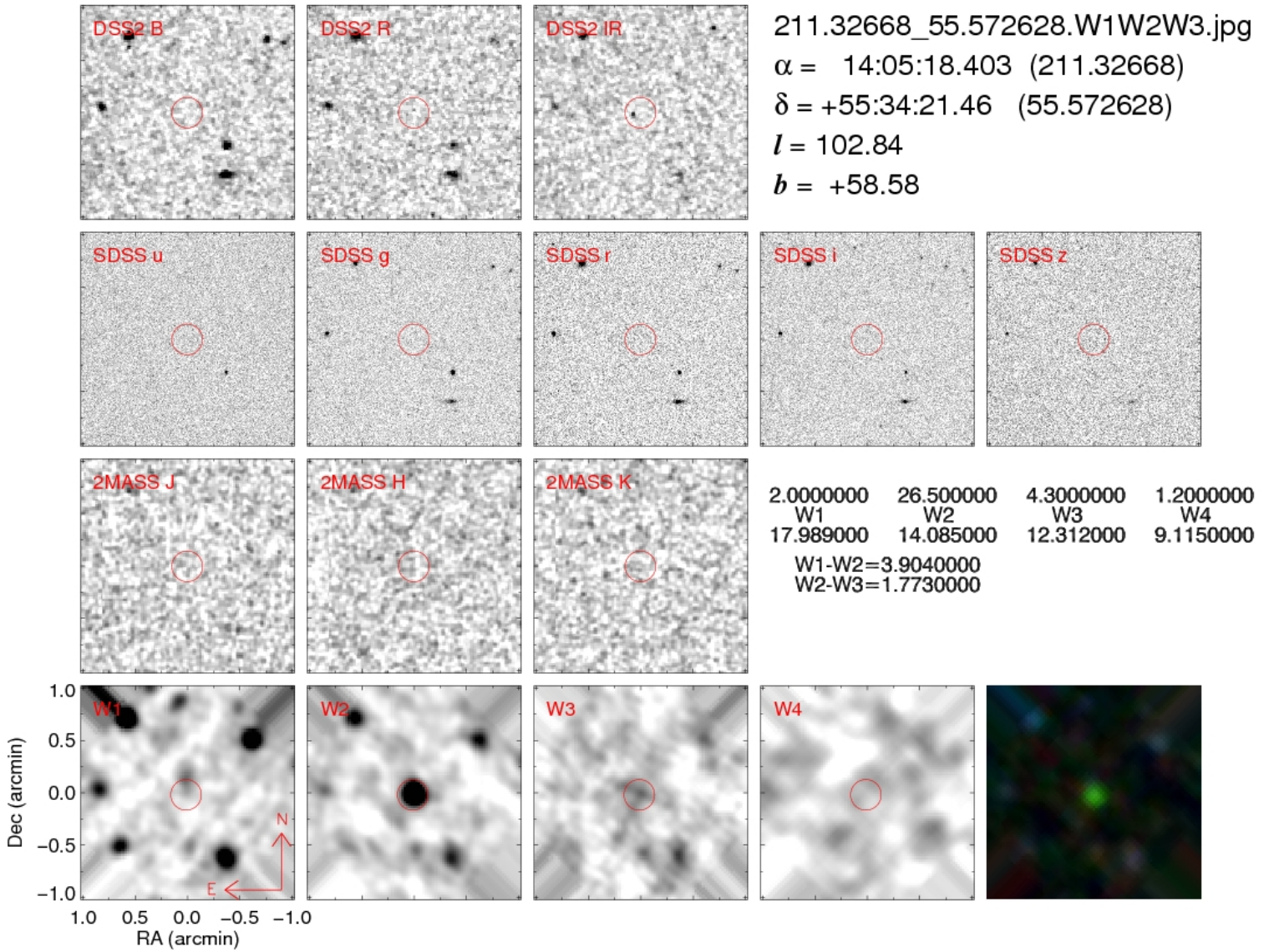
H-W2 vs. W1-W2



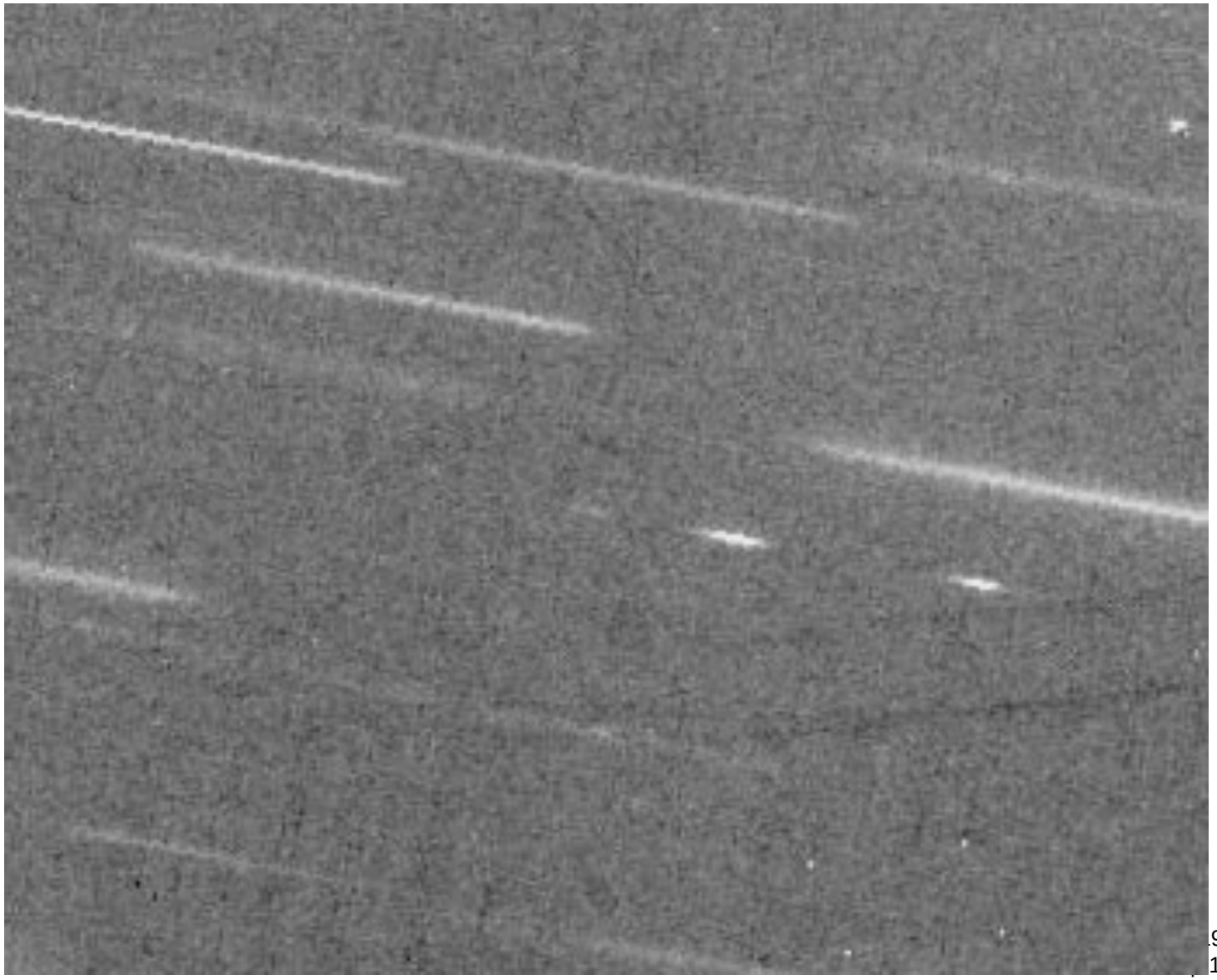
Who's the Coolest of them all?

- 1405+55?
- J = 20.2
- J-H = -1.5
- W2 = 14.1
- W1 > 18



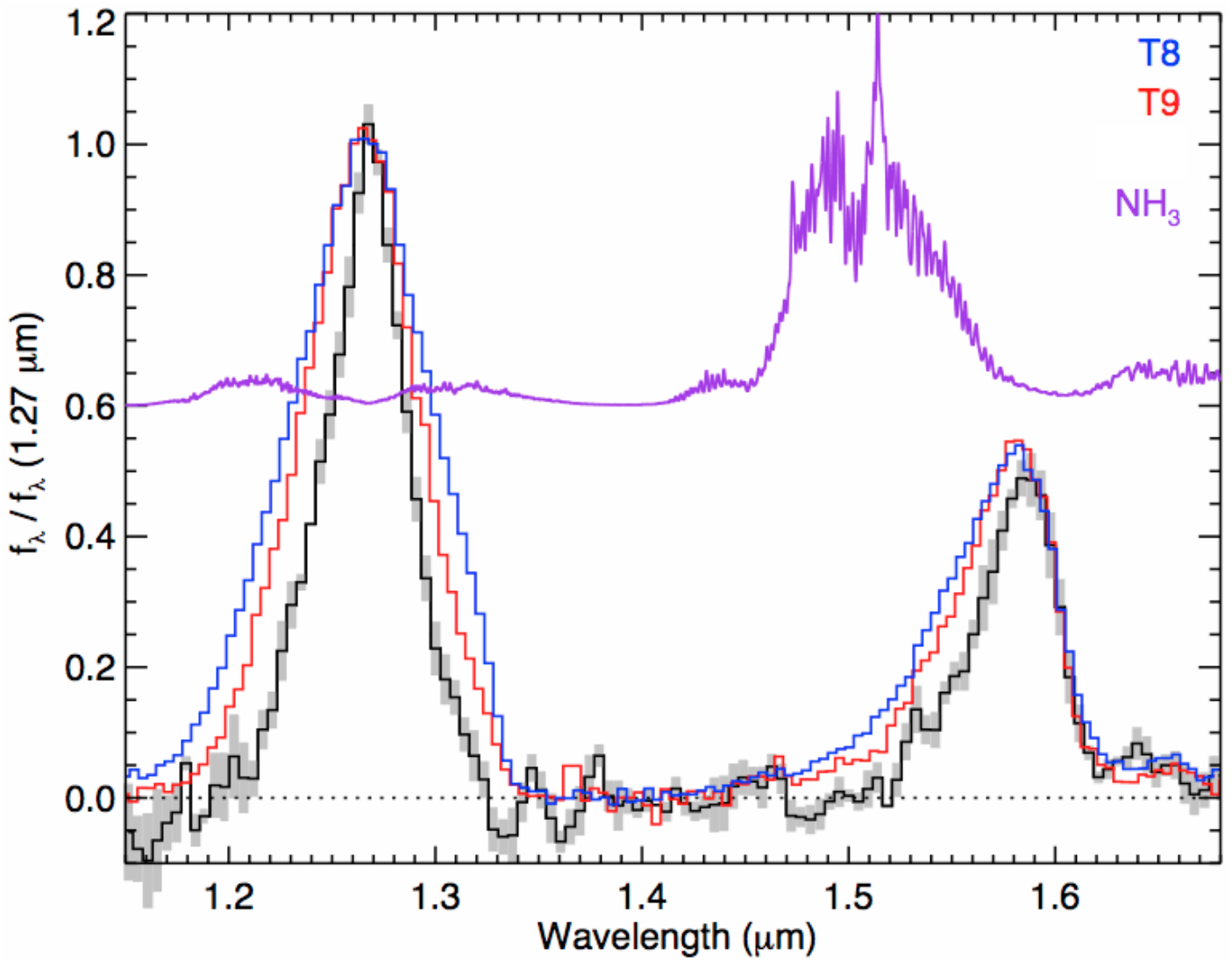
Need HST WF3 IR Grism for spectrum

- Clearly see the 1.27 and 1.59 µm peaks of a CH_4 dominated dwarf



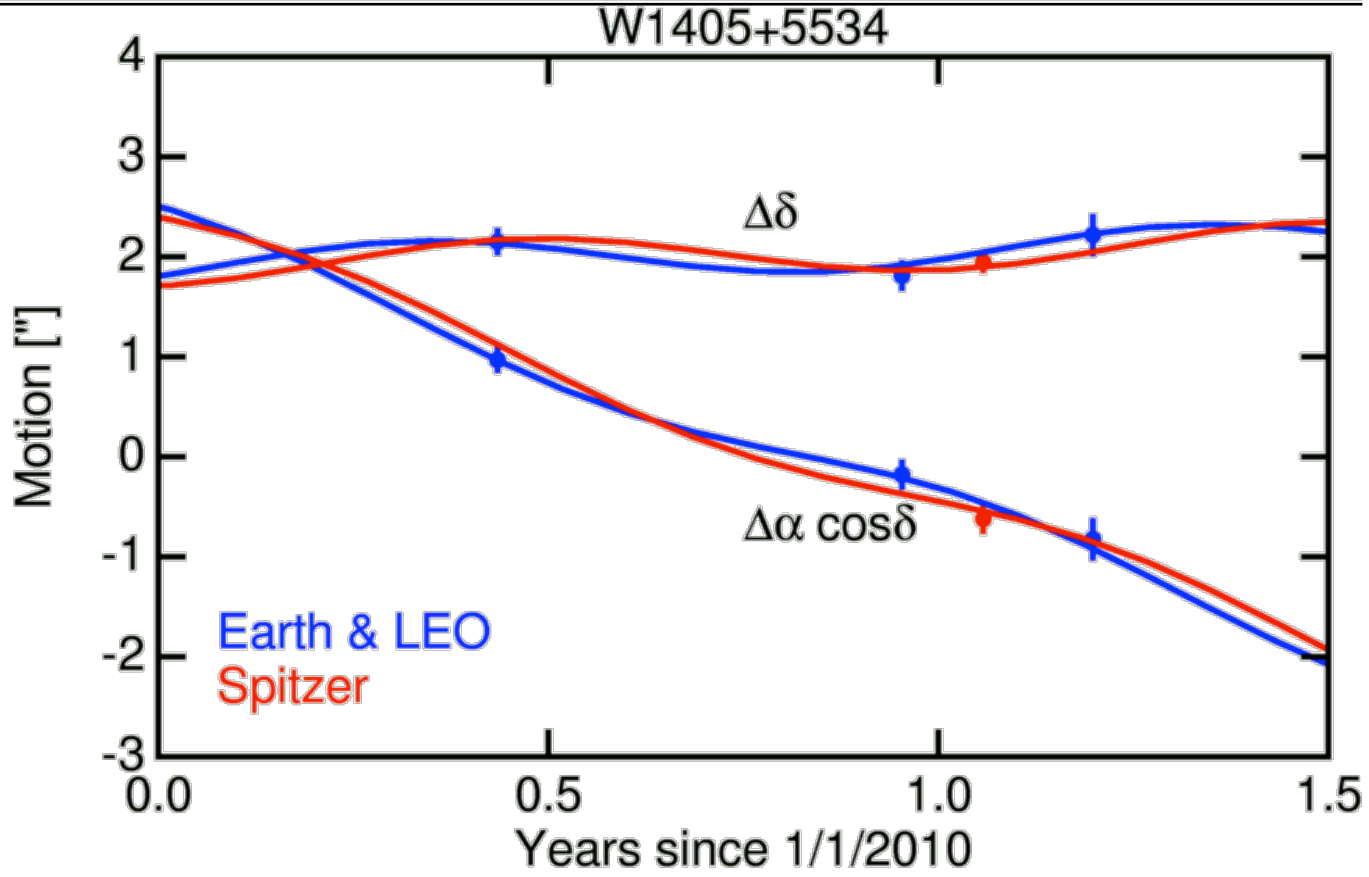
Clear Ammonia Signature

- NH_3 is cutting the short end of the 1.59 µm bump and narrowing the 1.27 µm bump
- 1st Y dwarf!
- Cushing etal 2011, ApJ, 743, 50, arXiv: 1108.4678



Astrometry so far

- 2 WISE positions
- 1 Spitzer position
- 1 HST position
- Proper motion 2.64 ± 0.26 arc-sec/yr
- Parallax 0.21 ± 0.12 arc-sec



WISE data alone give a 6σ detection of motion.

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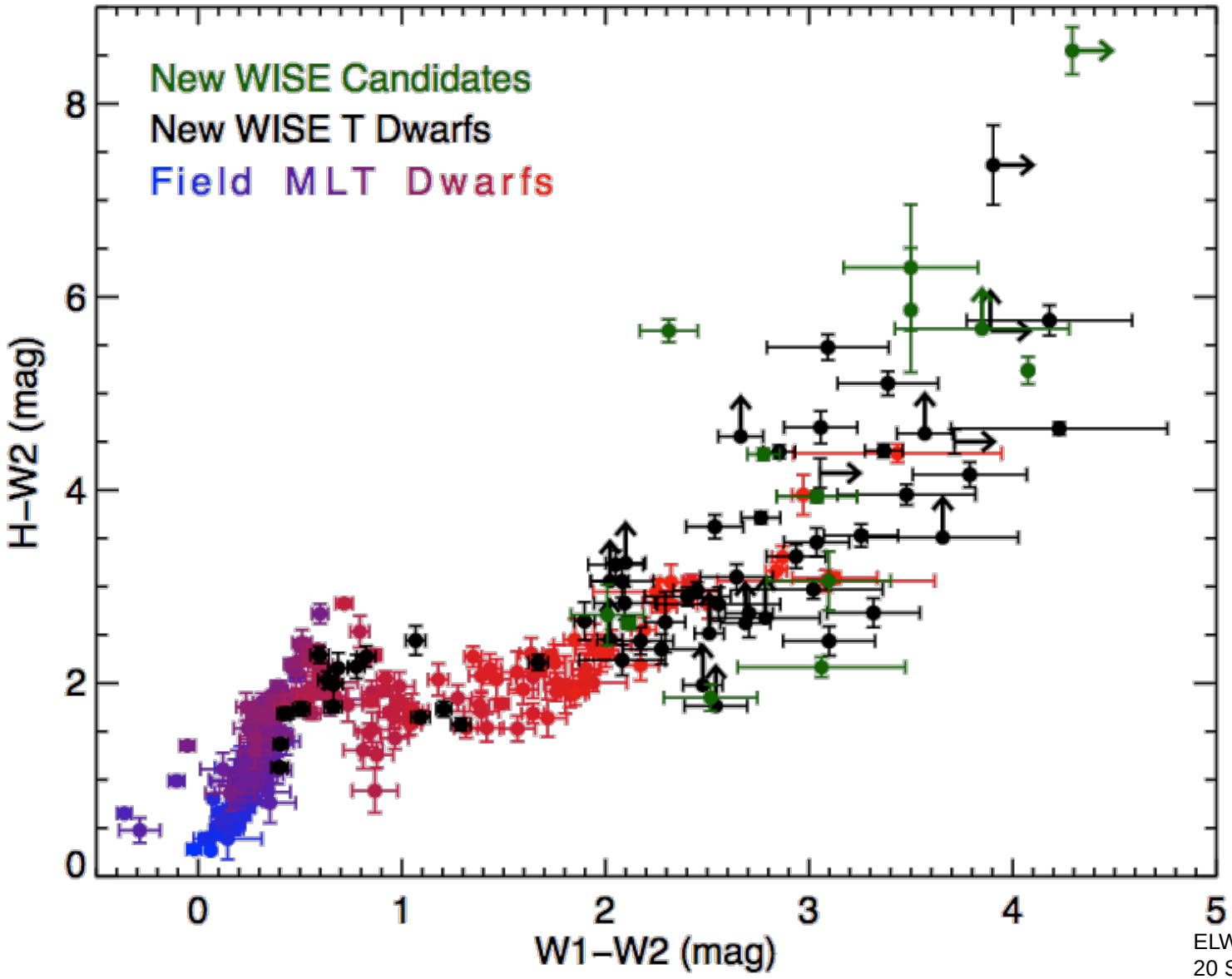
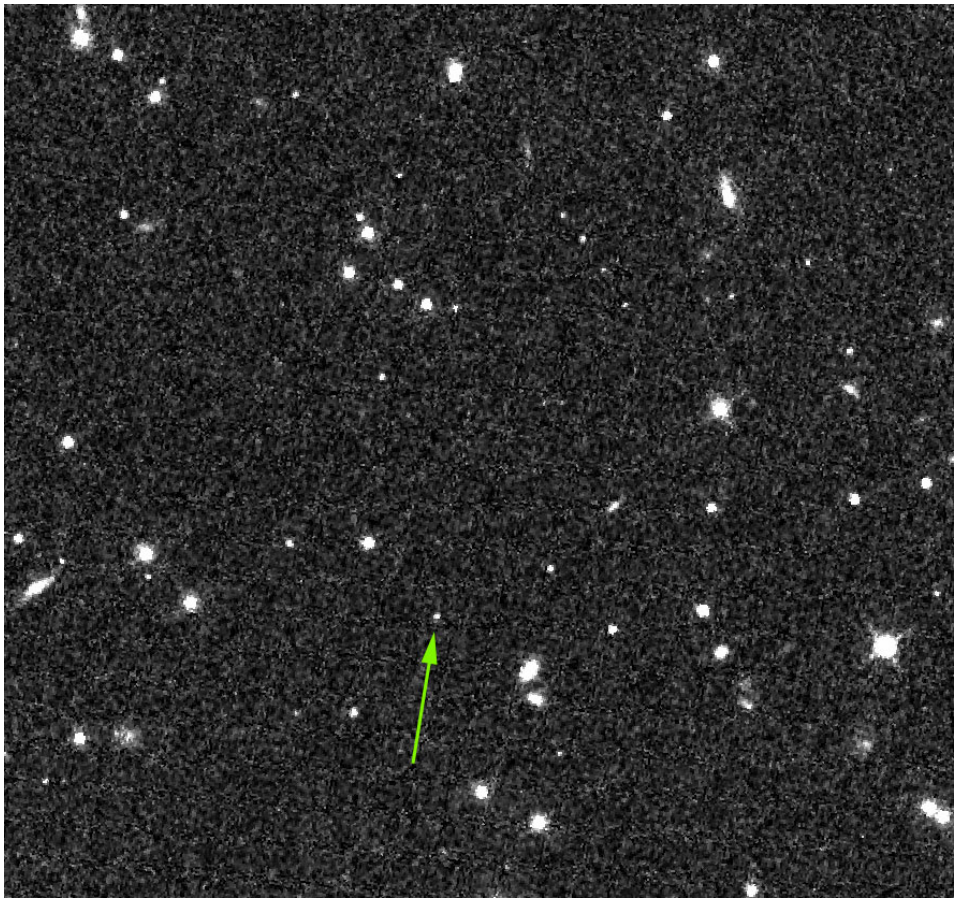
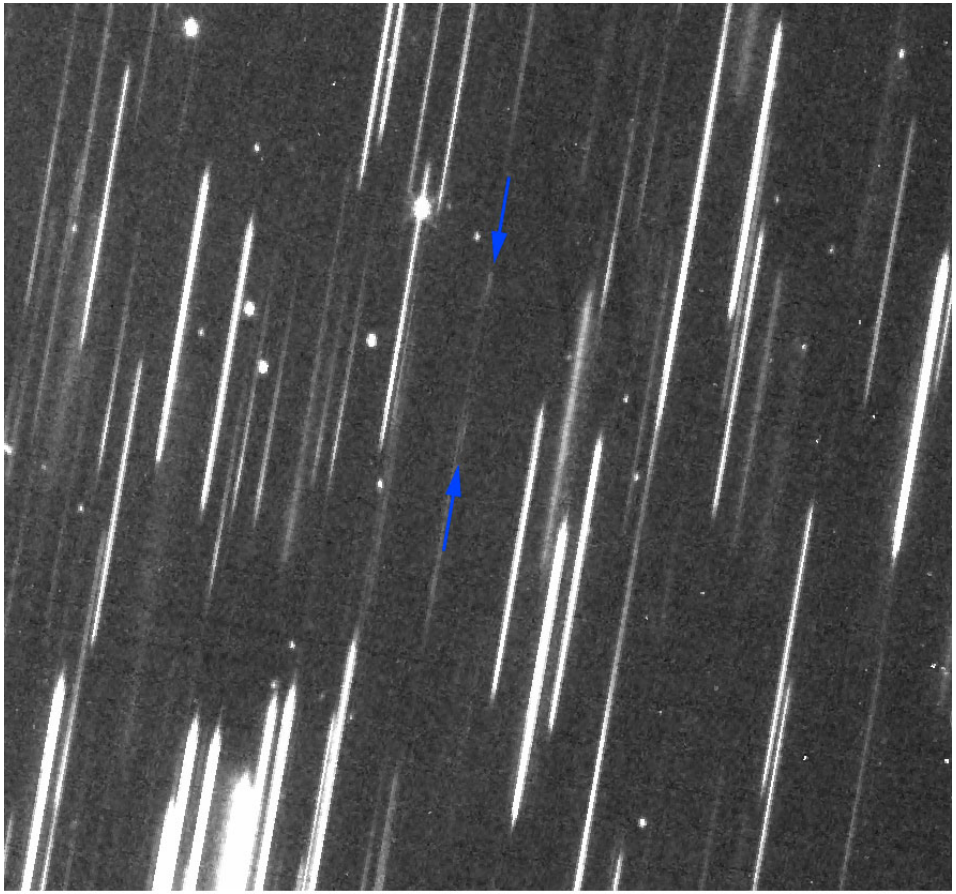
H-W2 vs. W1-W2



W1828+2650





- The reddest source to date as seen by the HST
- W2 = 14.25, W1-W2>4, H-W2=8.5, J-H≈0.72±0.42
- See Cushing etal 2011, ApJ in press, arXiv:1108.4678

See the dying of the J

- Our coldest sources are getting to be impossible to observe in the near-IR.
- Expected behavior by simple physics: $h\nu_J/kT_e=38$ for $T_e=300$ K; and also expected from model atmospheres.

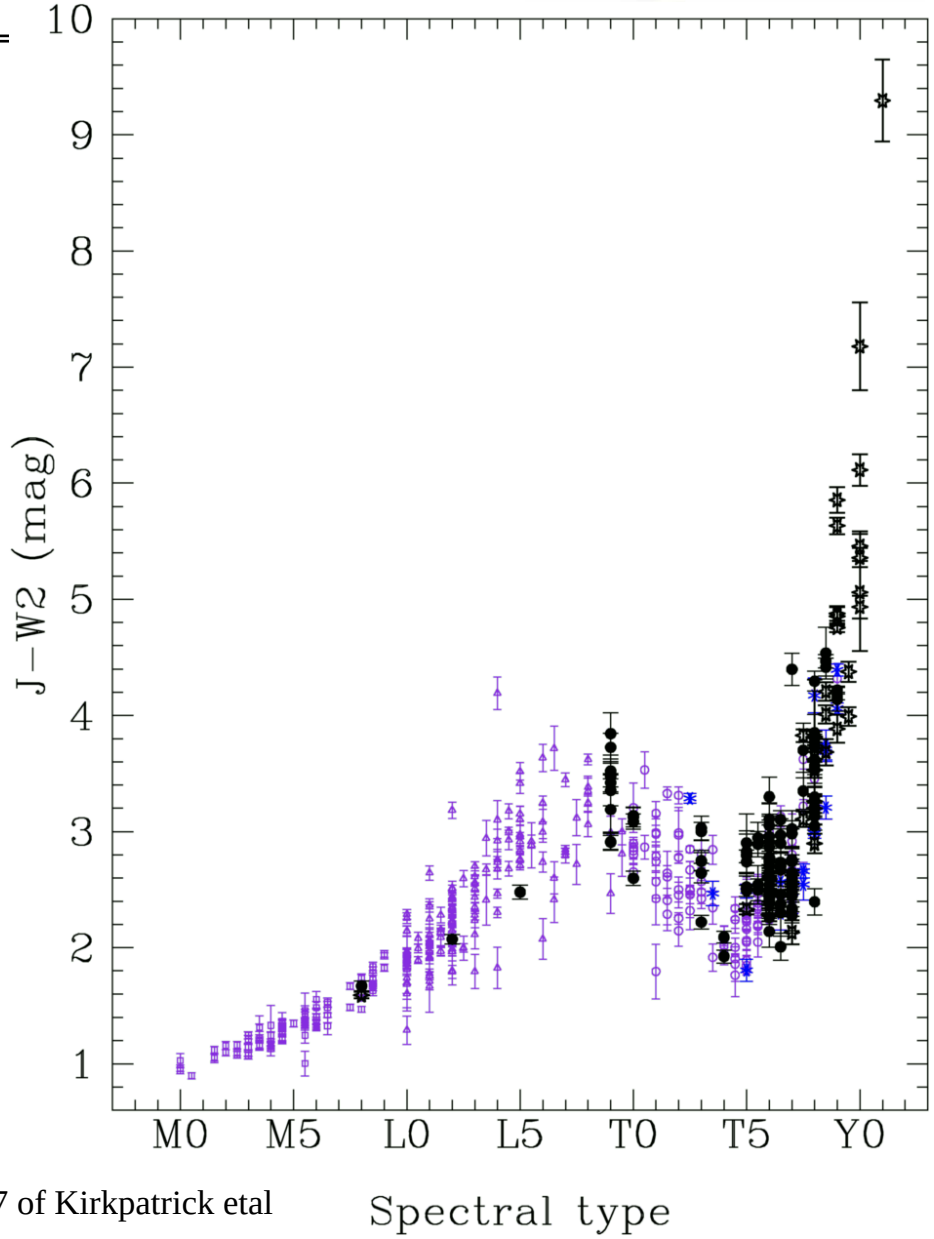
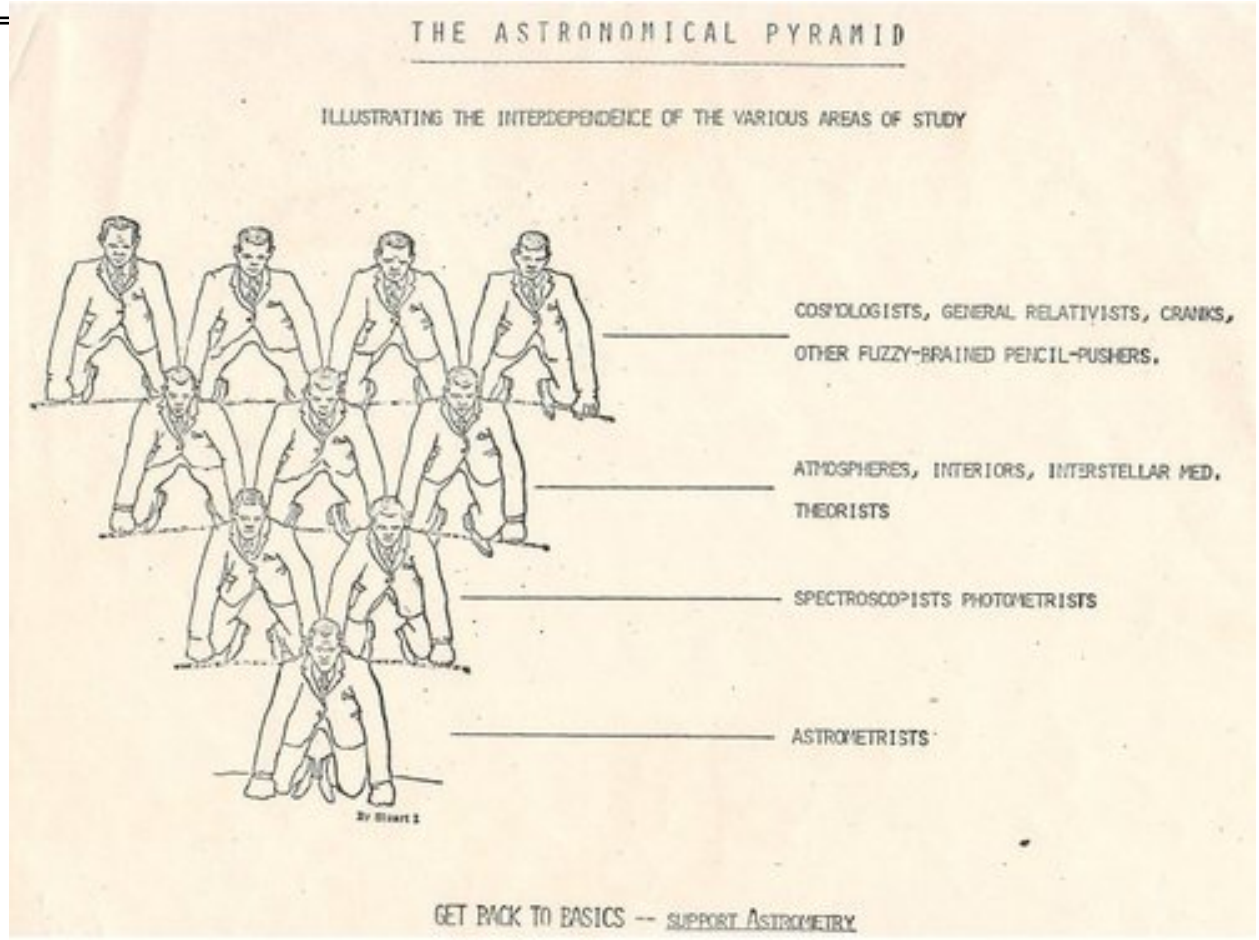


Figure 7 of Kirkpatrick etal

Limit to Spectroscopy

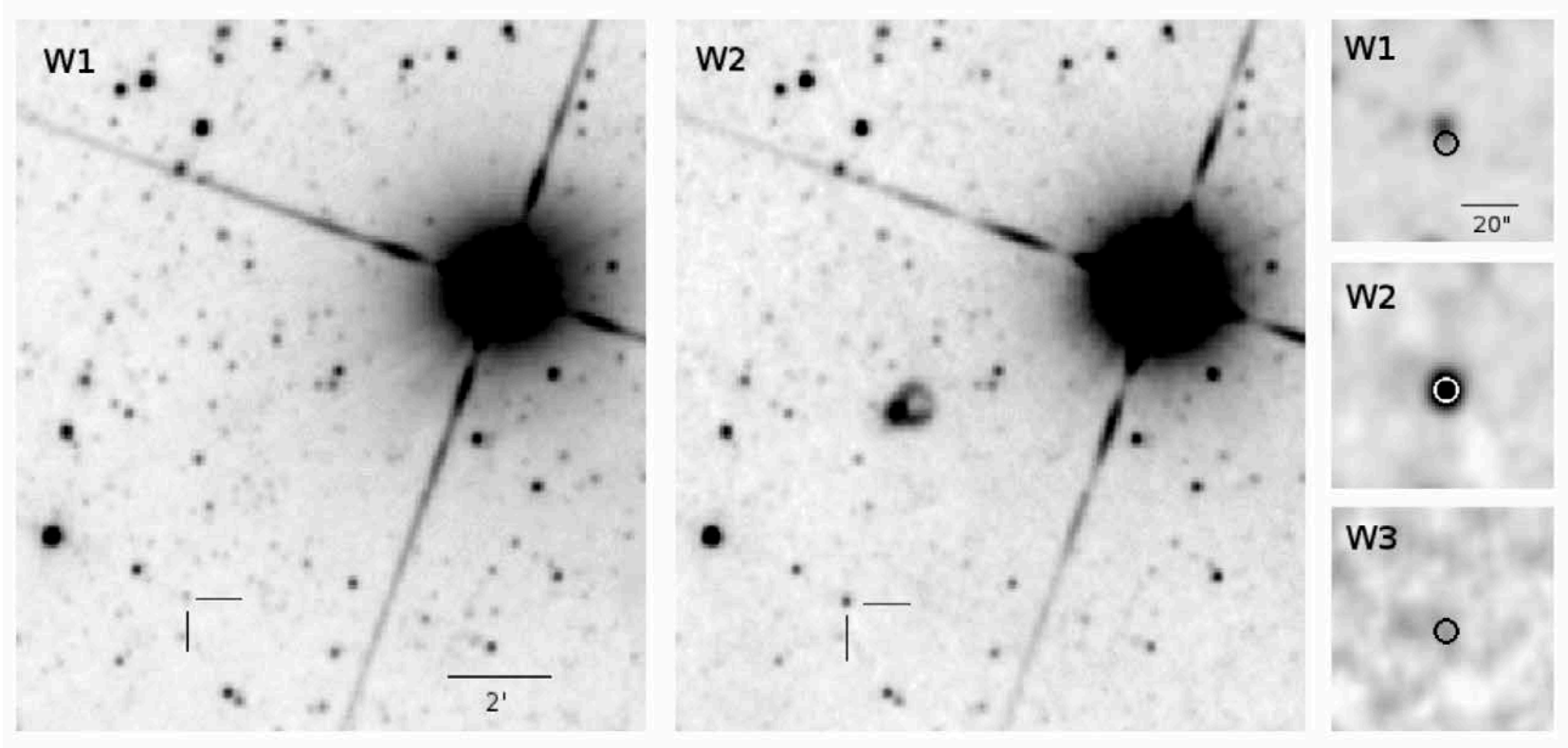
- WISE to W2=15
- J-W2 > 9
- J > 24
- Can't get NIR spectrum even with the HST WF3 IRC grism
- Can't get mid-IR spectra
- Have to wait for JWST?



-Ron Probst

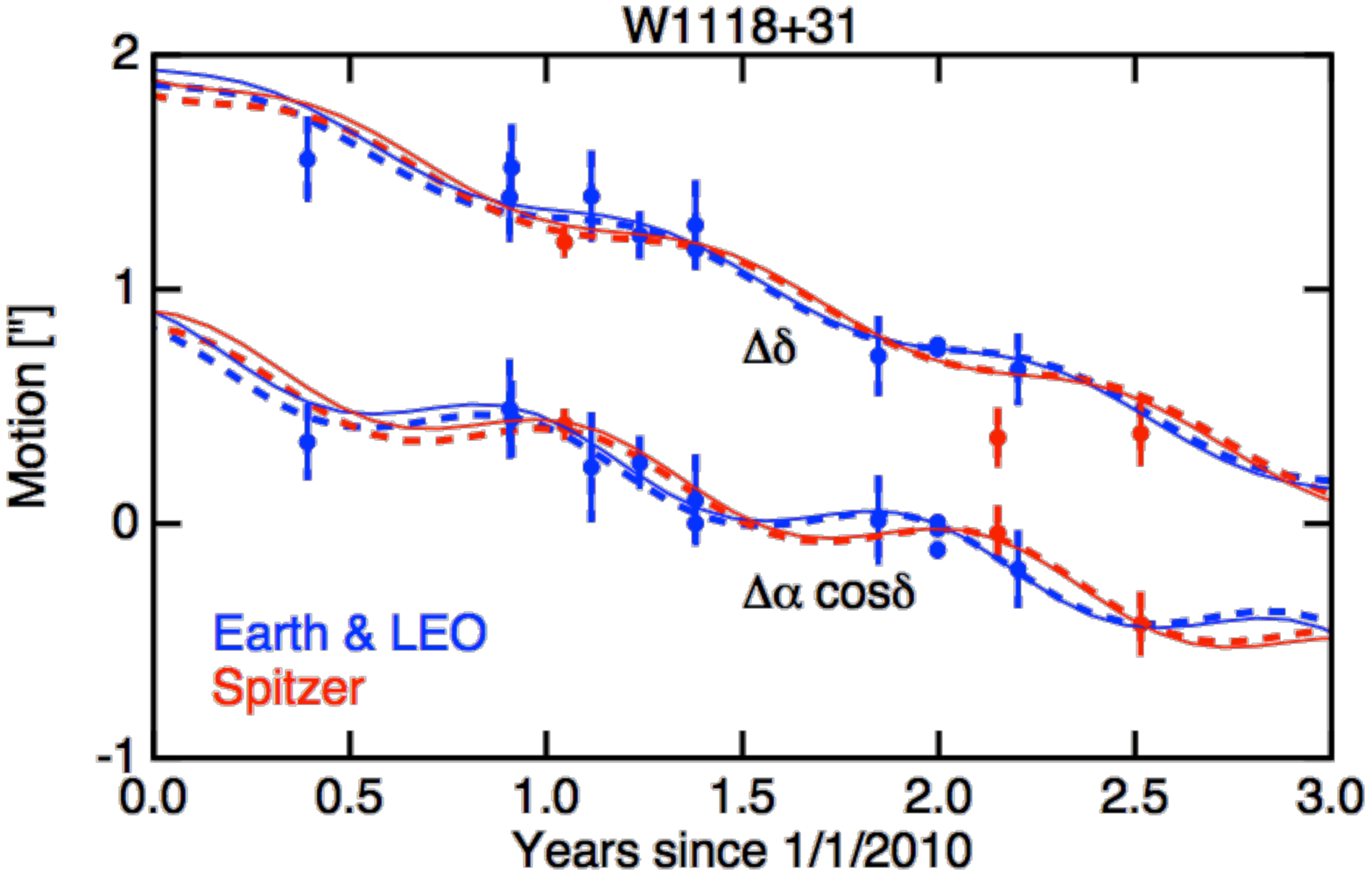
Astrometric Confirmation Needed!

ξ Ursa Majoris



- A T8.5 BD that is a common proper motion member of the ξ UMa system that is visual binary discovered by William Herschel, 8 pc from the Sun, with each component of the visual binary being a spectroscopic binary. QUINTUPLE!

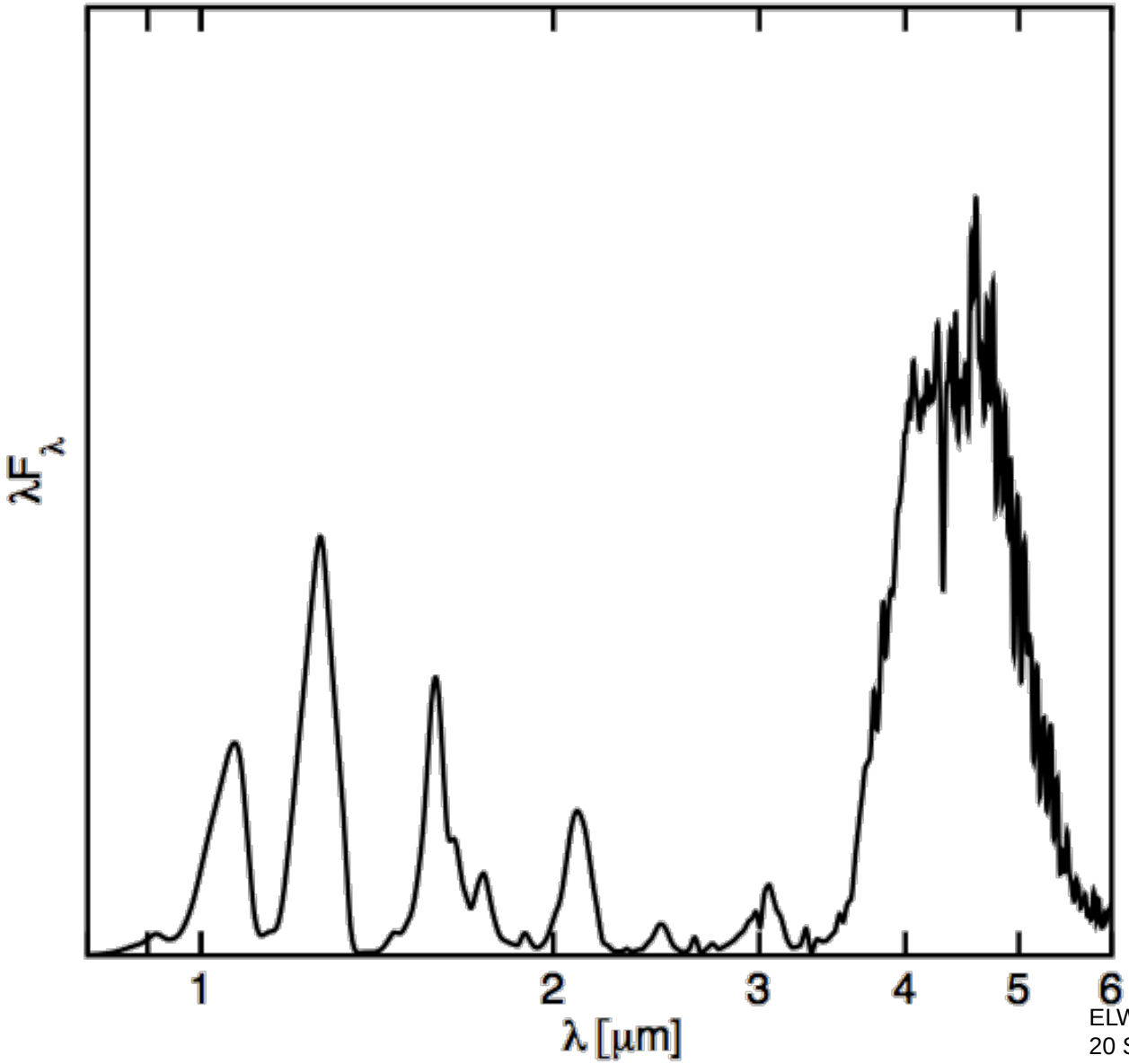
Common Proper Motion



- Astrometry of W1118+31. Bold dashed lines show the best fit, while the light solid curves show the motion of ξ UMa

Pretty Good Model

- Morley etal (2012) sulfide dust
- T_{eff} = 600 K, log(g)=5
- 19.5% clear, 80.5% f_{sed}=4 dusty
- L = $10^{-6.1}$ $L_{\odot}$
- For R=0.91 R_J, T_{eff} = 567±14 K, M=32 M_J , age ≈ 5-8 Gyr



Is the BD color-luminosity law unique?

- Jupiter emission at 5 microns is limited to bands where deep material can be seen
- $L_\nu \approx 4\pi R^2 f_{band} \pi B_\nu(T_{band})$
- Spectra and colors measure T_{band} but not f_{band}
- But $T_{eff} = f_{band}^{¼} T_{band}$

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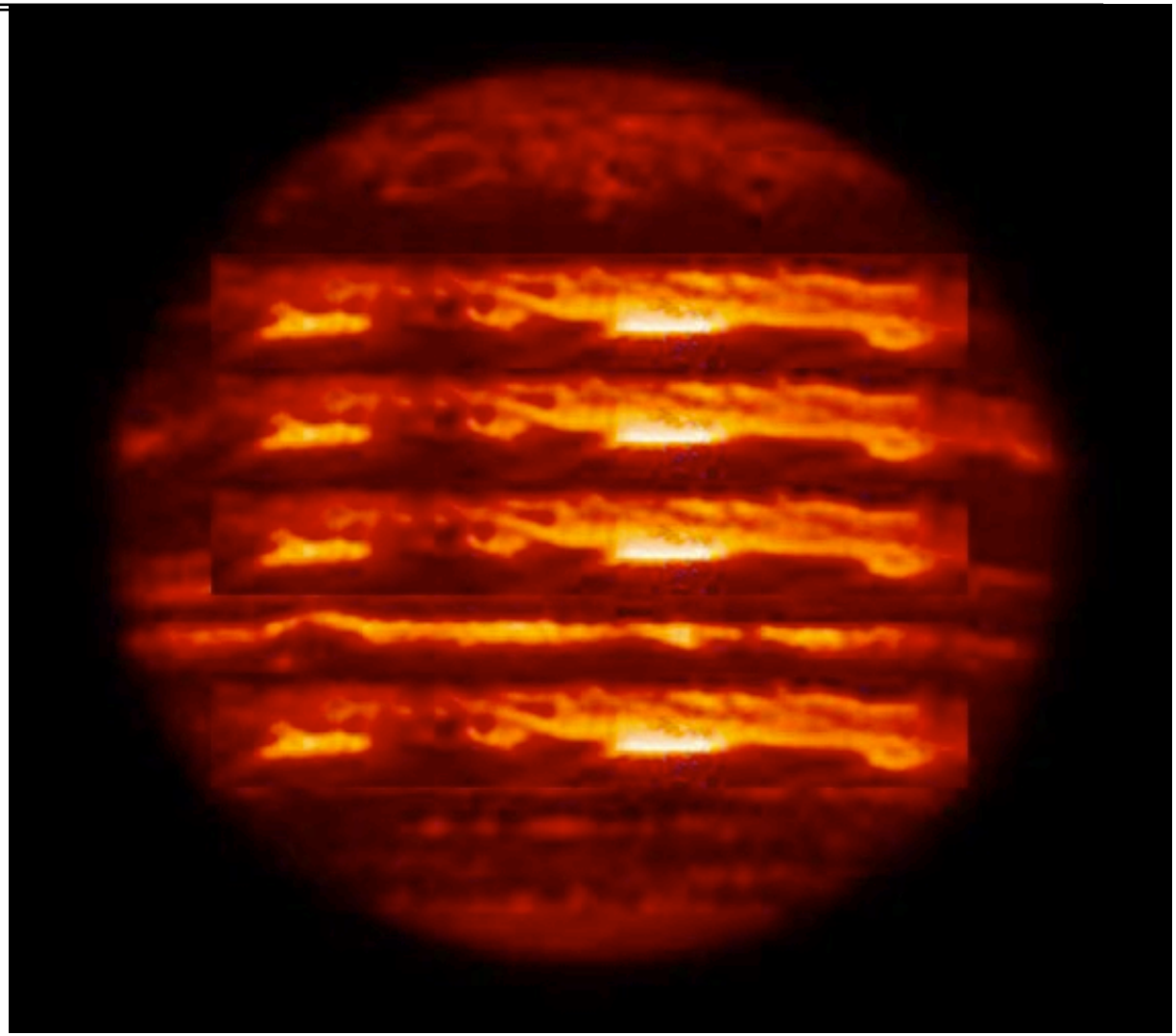
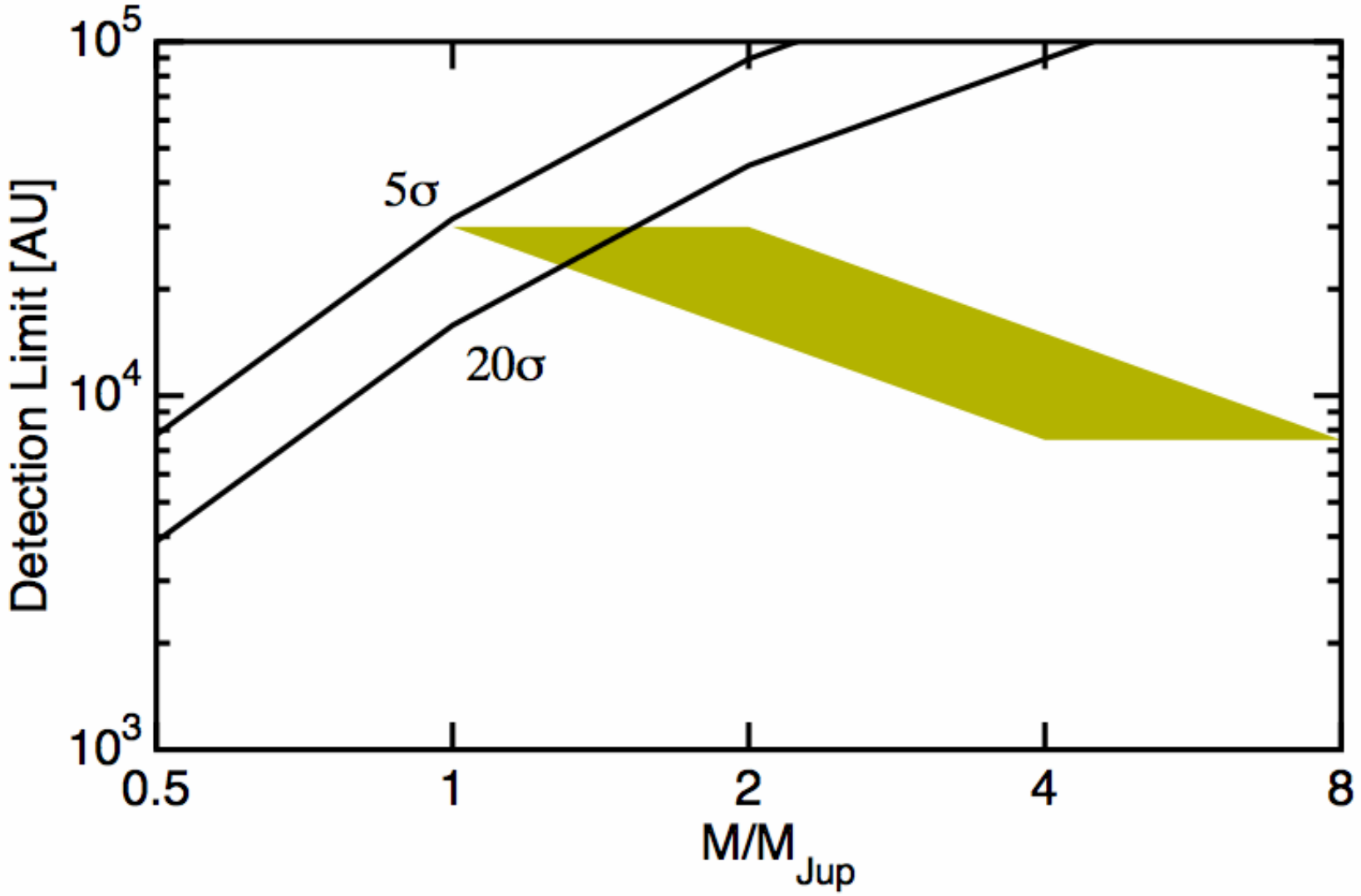
- Spectra and colors measure T_{band} but not f_{band}
- And $T_{eff} = f_{band}^{¼} T_{band}$ so spectral type vs Teff relation can have a large scatter



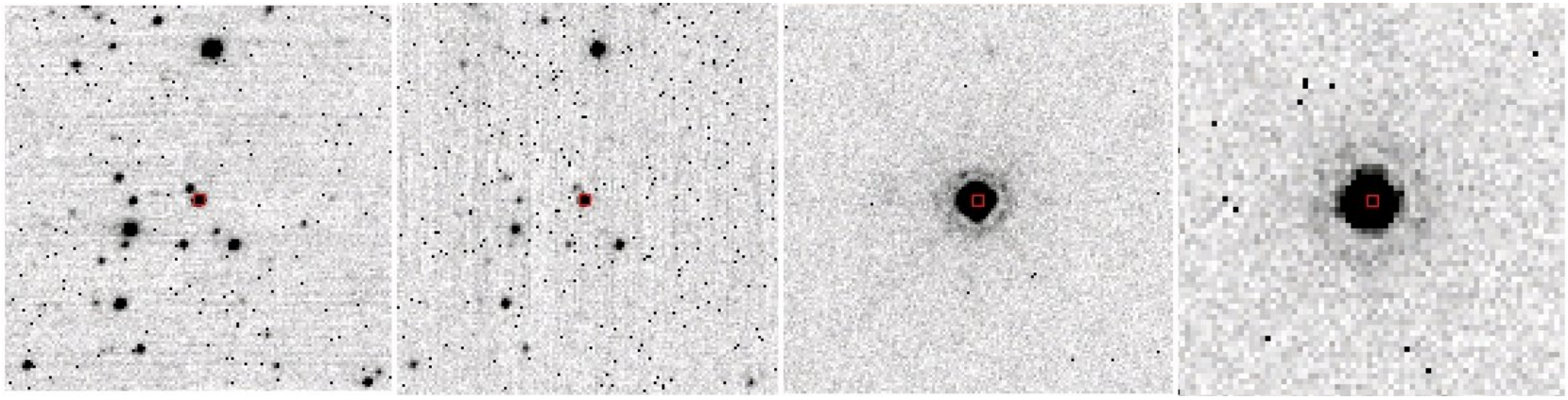
What does a 100 K BD look like?

- DIRBE $\nu F_\nu(4.9\ \mu m)/F_{bol}$ changed from 0.04 to 0.02 between Jupiter and Saturn (after subtracting the rings from F_{bol}).
  - The fitting function in Wright et al (2010) gives a 10× reduction in $\nu F_\nu(4.9\ \mu m)/F_{bol}$ but these T's are outside its useful range.
- Saturn has T_{eff} close to 100 K.
- So a 100 K T_{eff} object with same radius as Jupiter, $10^{-9}\ L_\odot$, would be 4 times fainter in W2 (2× from T_{eff}^4 and 2× from the decreased $\nu F_\nu(4.9\ \mu m)/F_{bol}$) and just barely detectable at 0.5 light-years, or 31600 AU.

M-D Plane Limits



Neptune



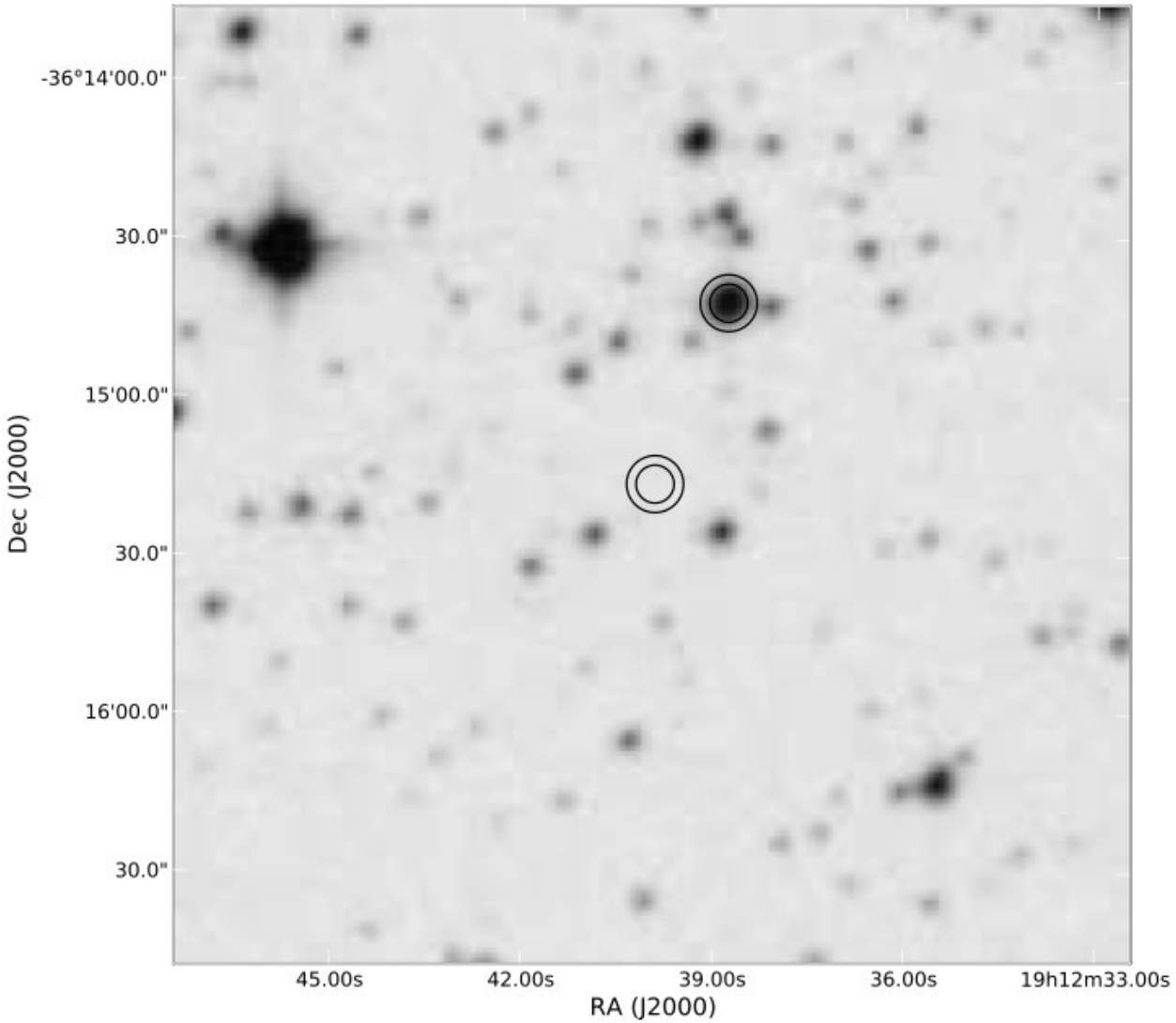
- SNR = 563, 346, 6275 & 5849 in W1..4
  - not horribly saturated
- Neptune is very black at 3.4 µm due to methane
- If moved out, it will be cooler and harder for WISE to see
- Probably a “Neptune” at 700-1000 AU would be visible
- Best SNR would be in W4 which did not cover the sky twice

arXiv:1106.4526

- "A Very High Proper Motion Star and the First L dwarf in the Kepler Field" – Gizis, Troup & Burgasser
- Outside the WISE team, looking through 2MASS non-matches
- WISEP J191239.91-361516.4 has a proper motion of 2.1"/ year
- WISEP J190648.47+401106.8 is an L1 dwarf in the Kepler field: probably the closest star in the field at 17 pc.

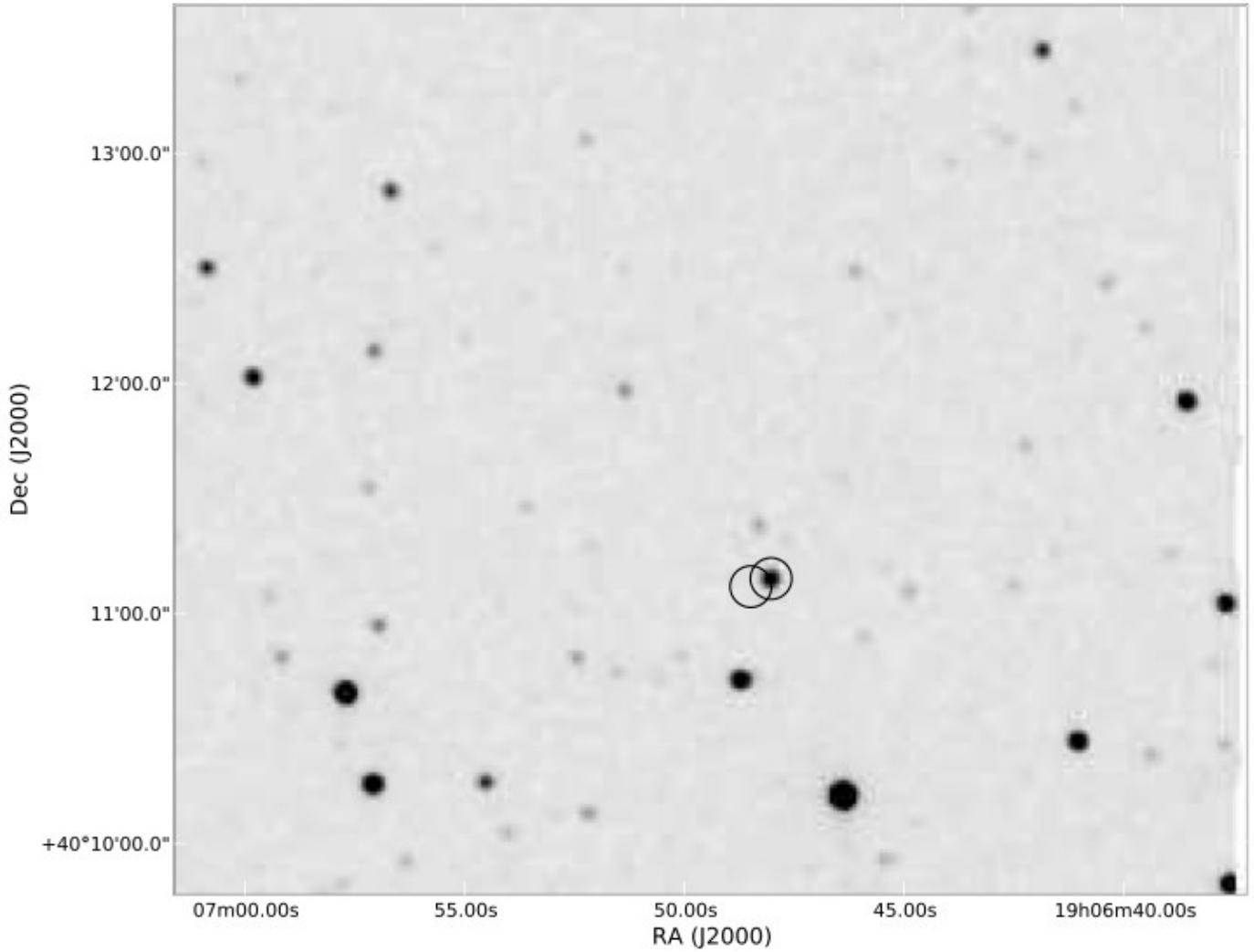
WISE 1912-3615

- W2 = 8.35
- W1-W2 = 0.2
- J-W2=1.17
- μ = 2.1”/yr
- ≈ M4V
- ~13 pc



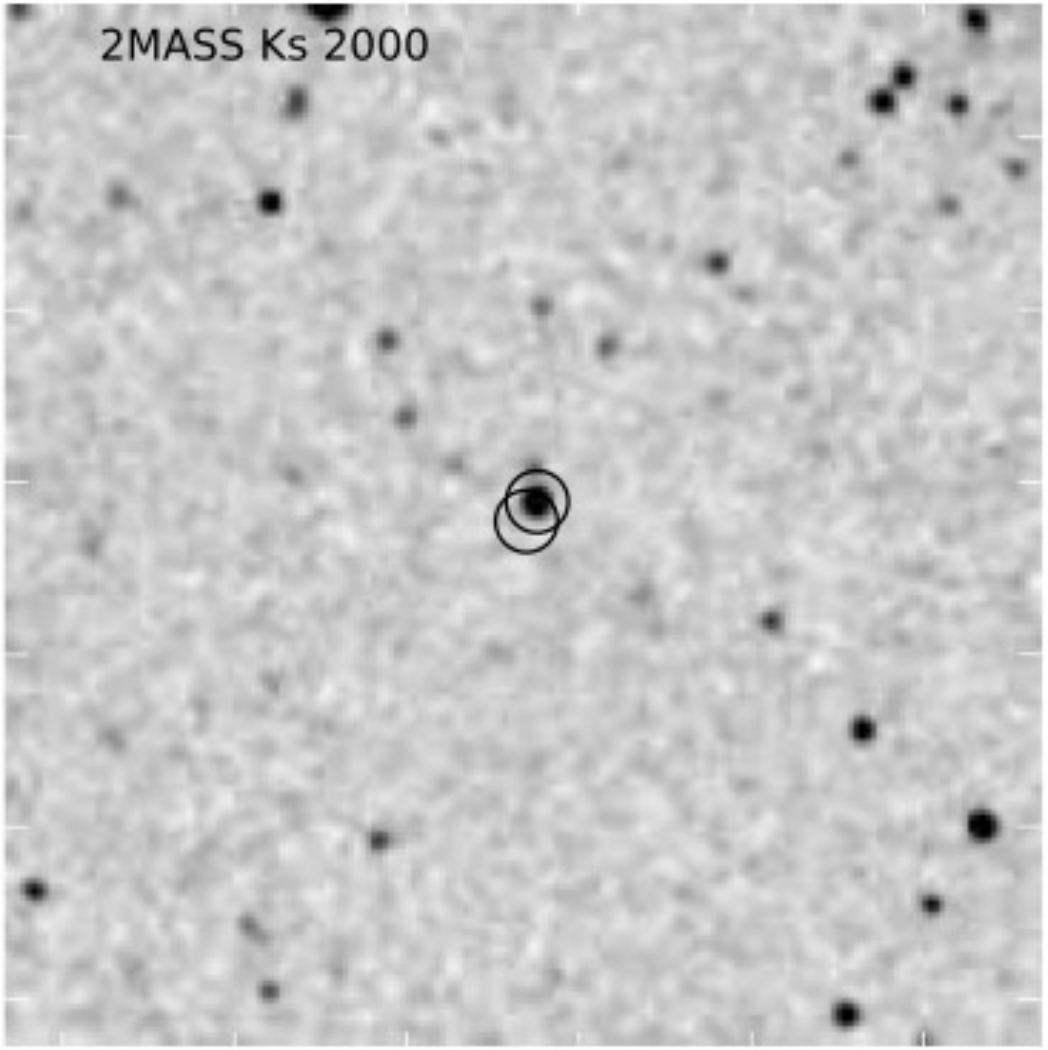
WISE 1906+4011

- W2 = 11.22
- W1-W2 = 0.23
- J-W2 = 1.86
- ≈ L1
- ≈ 17 pc
- In the Kepler field



arXiv:1109.0054

- "WISEP J180026.60+013453.1: A Nearby Late L Dwarf Near the Galactic Plane" – Gizis et al.
- μ = 0.42"/yr
- 8.8 pc
- W2 = 11.03
- J-W2 = 3.27



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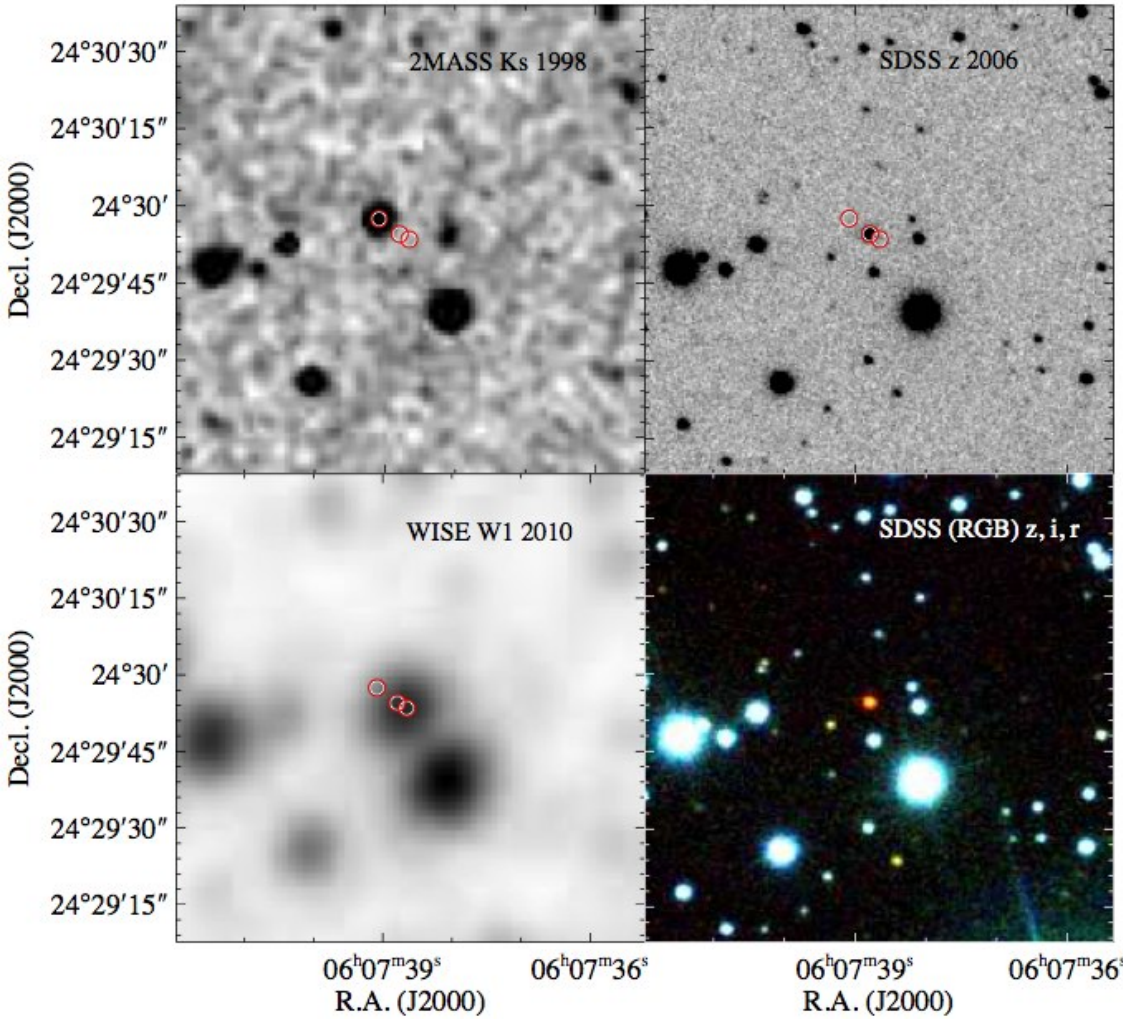
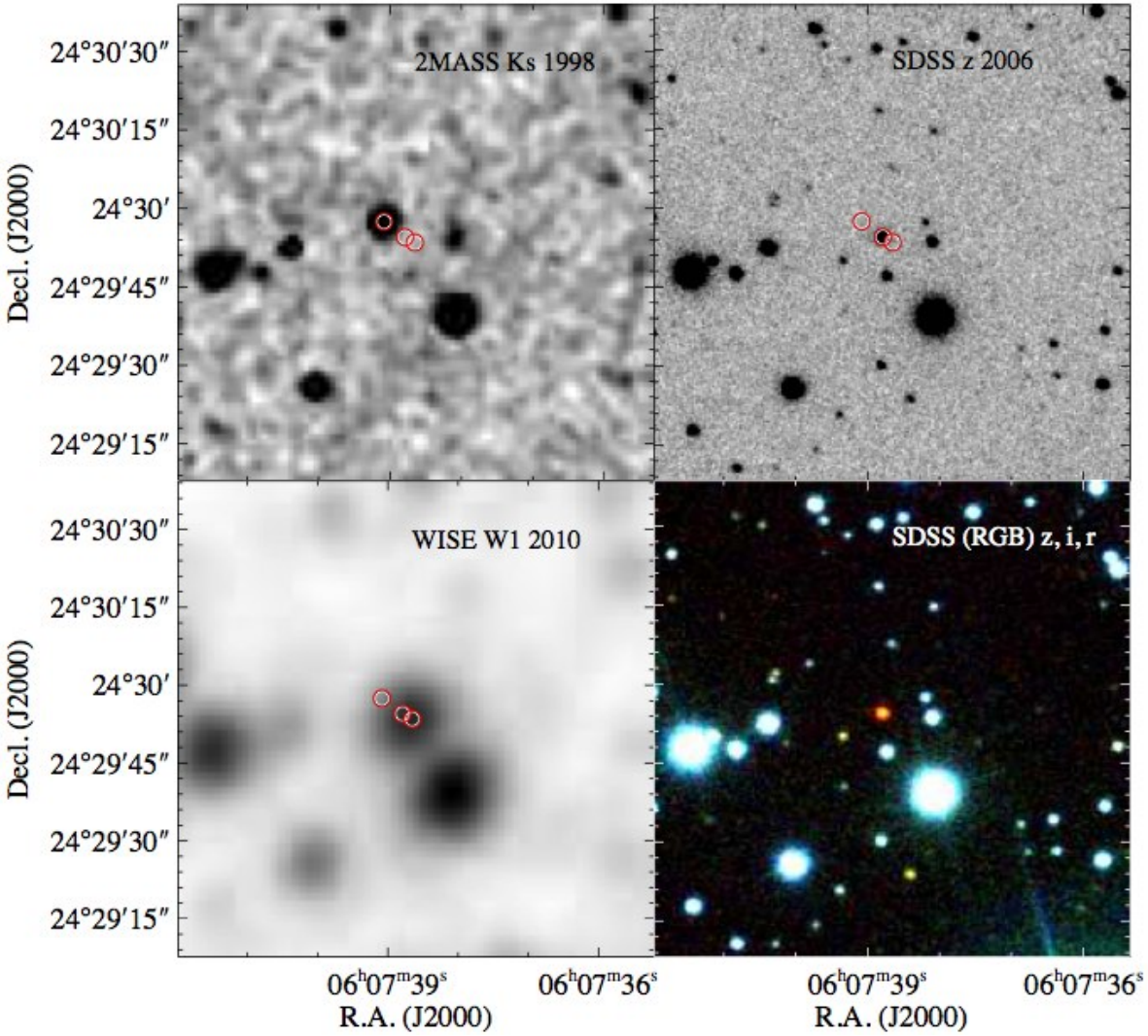
arXiv:1110.4351

- "Discovery of a Late L Dwarf: WISEP J060738.65+242953.4" – Castro & Gizis
- Proper motion 0.57"/yr
- 7.8 pc distance
- W2 = 10.92
- J-W2 = 3.27



arXiv:1107:1812

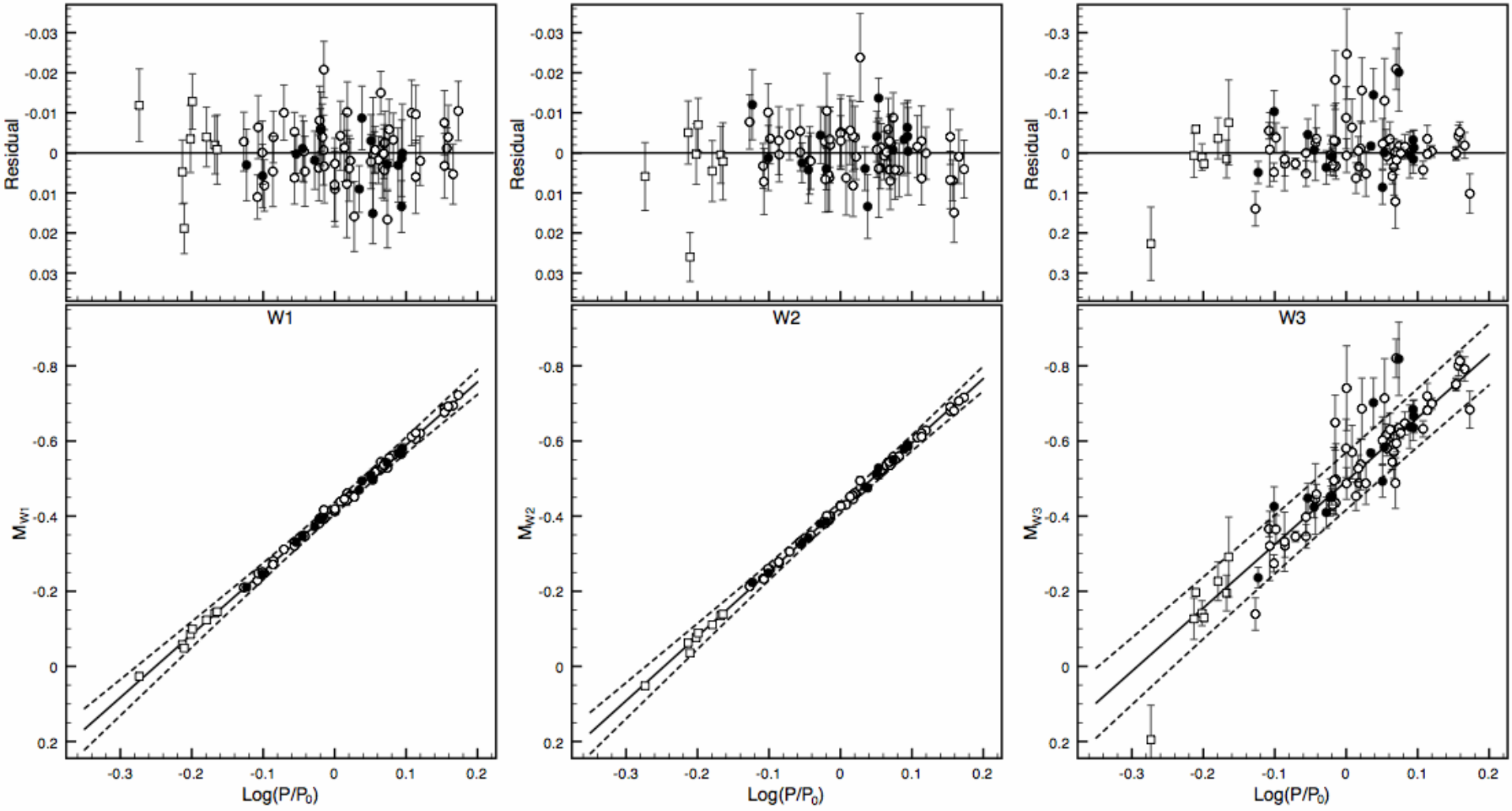
- "Discovery of a Companion at the L/T transition with WISE" - Loutrel et al.
- Proper motion = 0.6"/yr, common with HD 46588
- W2 = 12.93
- W1-W2 = 0.65
- J-W2 = 3.33
- 17.9 pc



RR Lyra PL Relation

- Klein etal arXiv:1105.0055
- Outside the team, based on Preliminary Release Data
- P-L law fits with less than 1% error in the distance
- Evidently the WISE relative photometry is pretty good!

RR Lyras



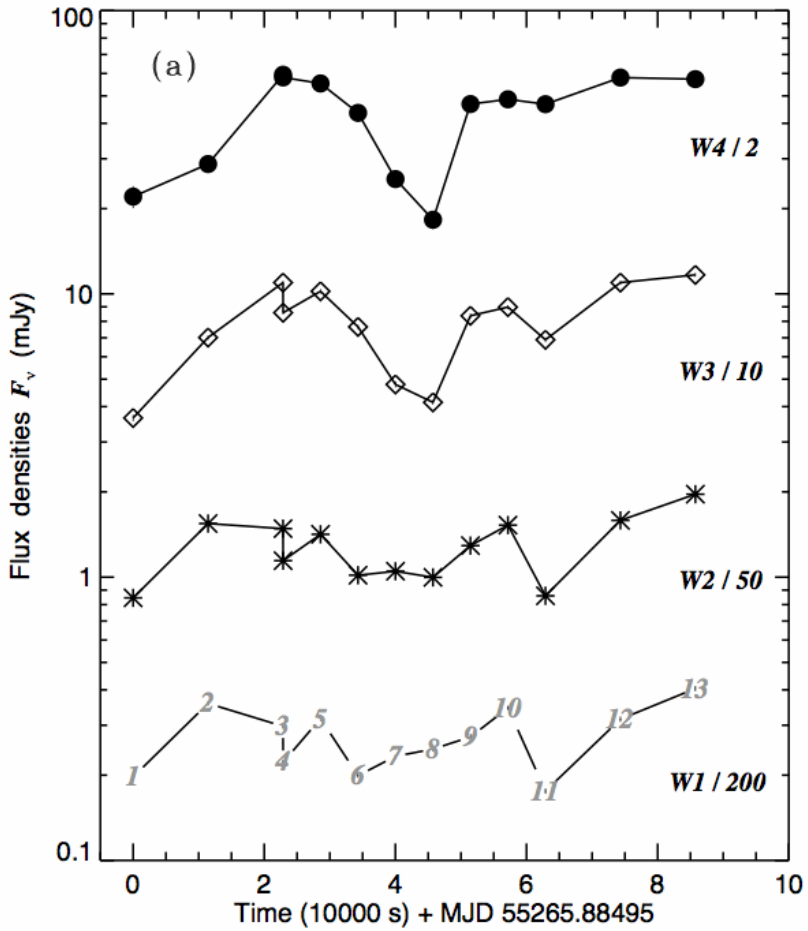
A variable mid-infrared synchrotron break associated with the compact jet in GX 339–4

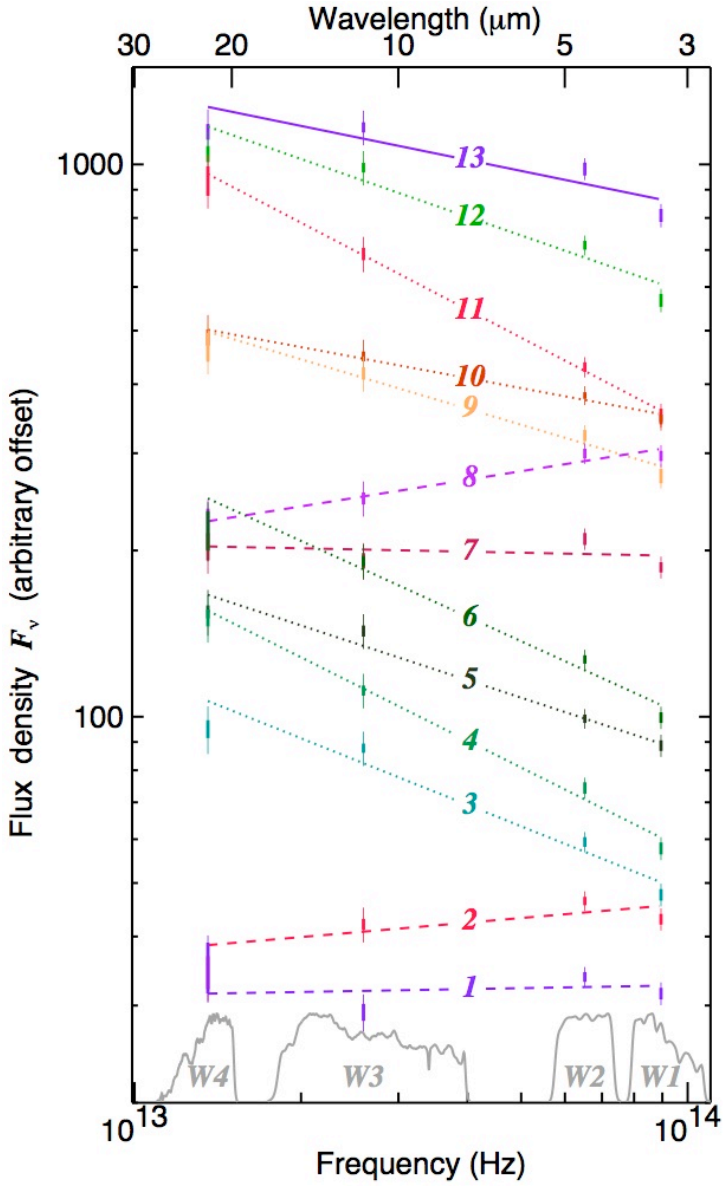
P. Gandhi[1], A.W. Blain[2], D.M. Russell[3], P. Casella[4], J. Malzac[5,6], S. Corbel[7], P. D'Avanzo[8], F.W. Lewis[9], S. Markoff[3], M. Cadolle Bel[10], P. Goldoni[11,12], S. Wachter[13], D. Khangulyan[1] and A. Mainzer[14]

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

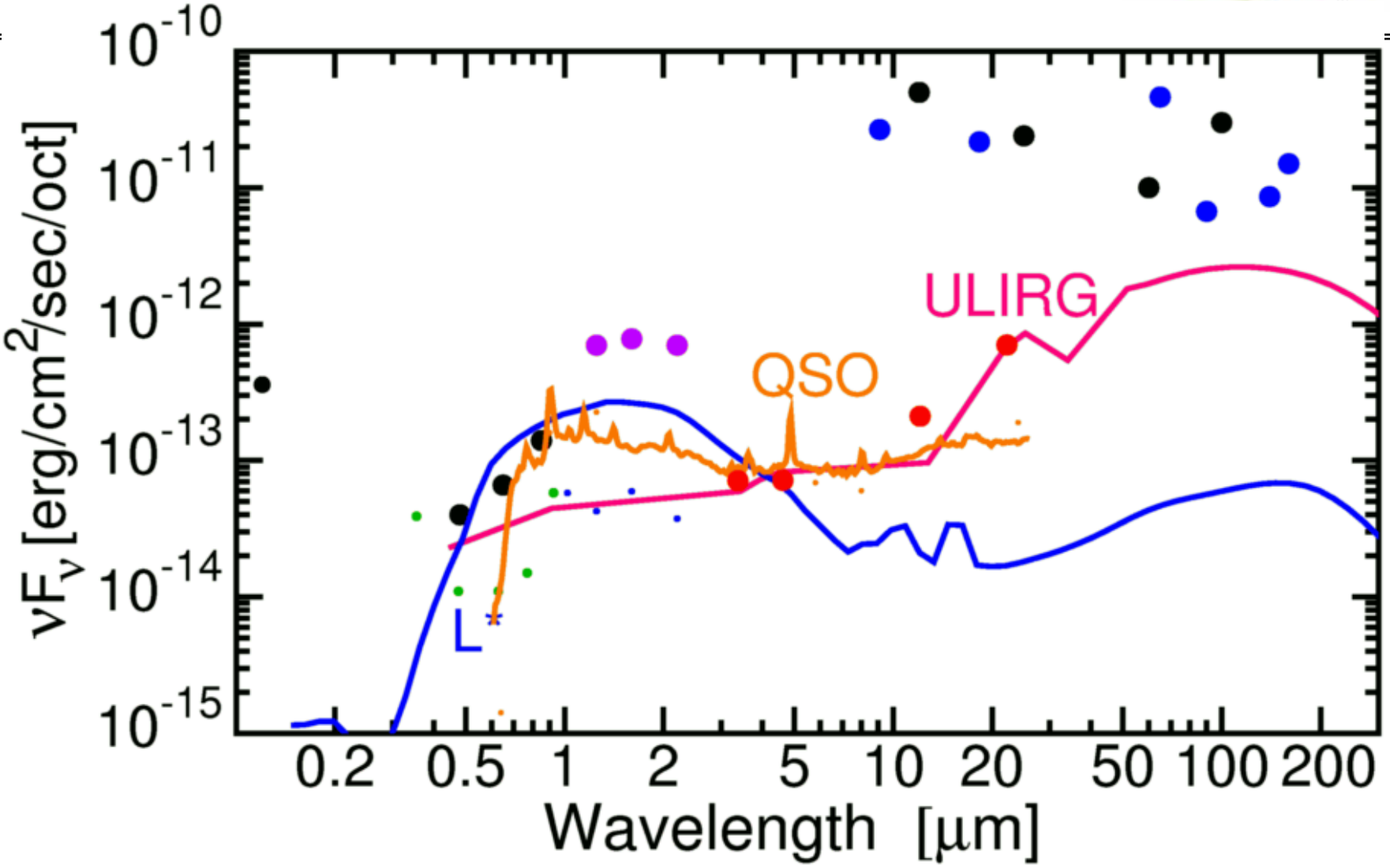
Flaring black hole GX339-4





- WISE observations occurred during a very active period

The far-off Universe

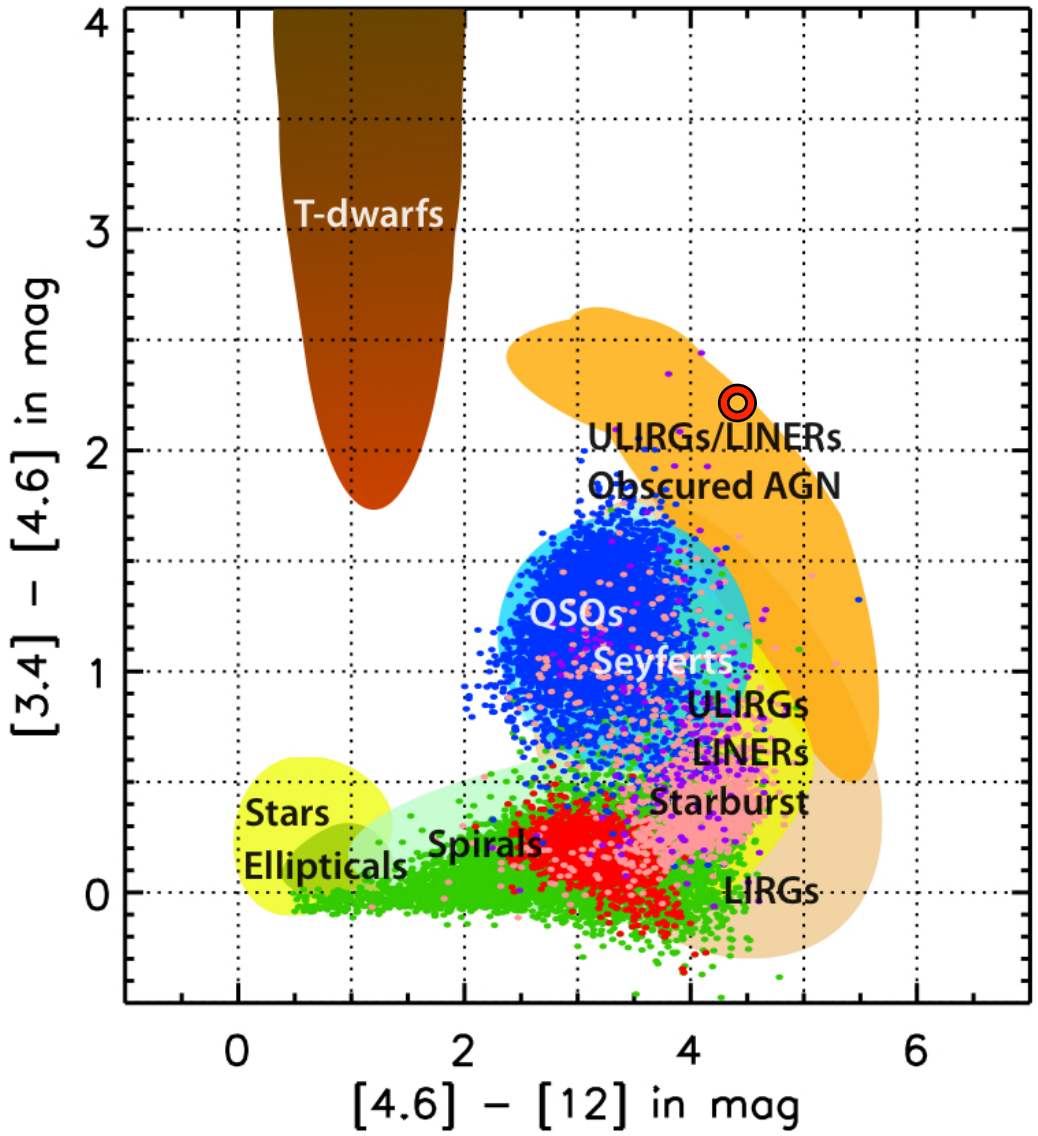


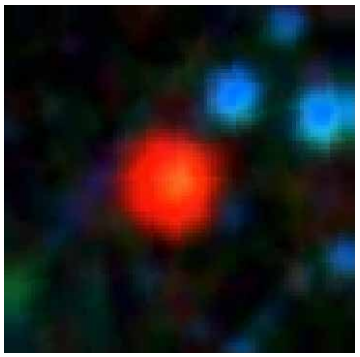
L* at z=0.33, z=6.4 QSO, z=3 ULIRG: FSC15307 x 3

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

Wide-field Infrared Survey Explorer (WISE)

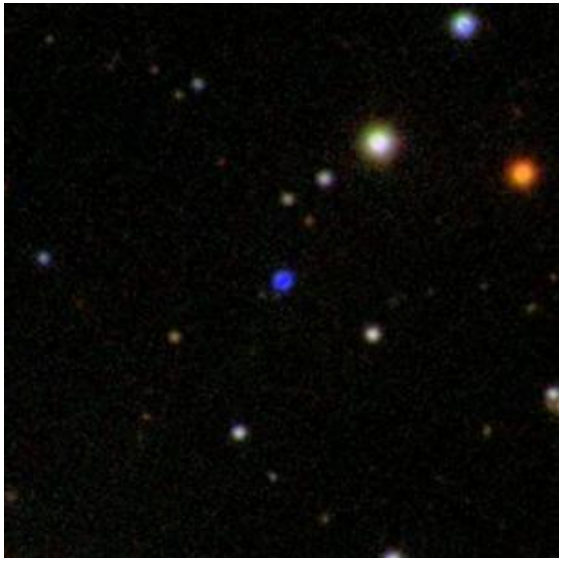
WISE Color Space
A Very Red…Blue Compact Galaxy





WISE image

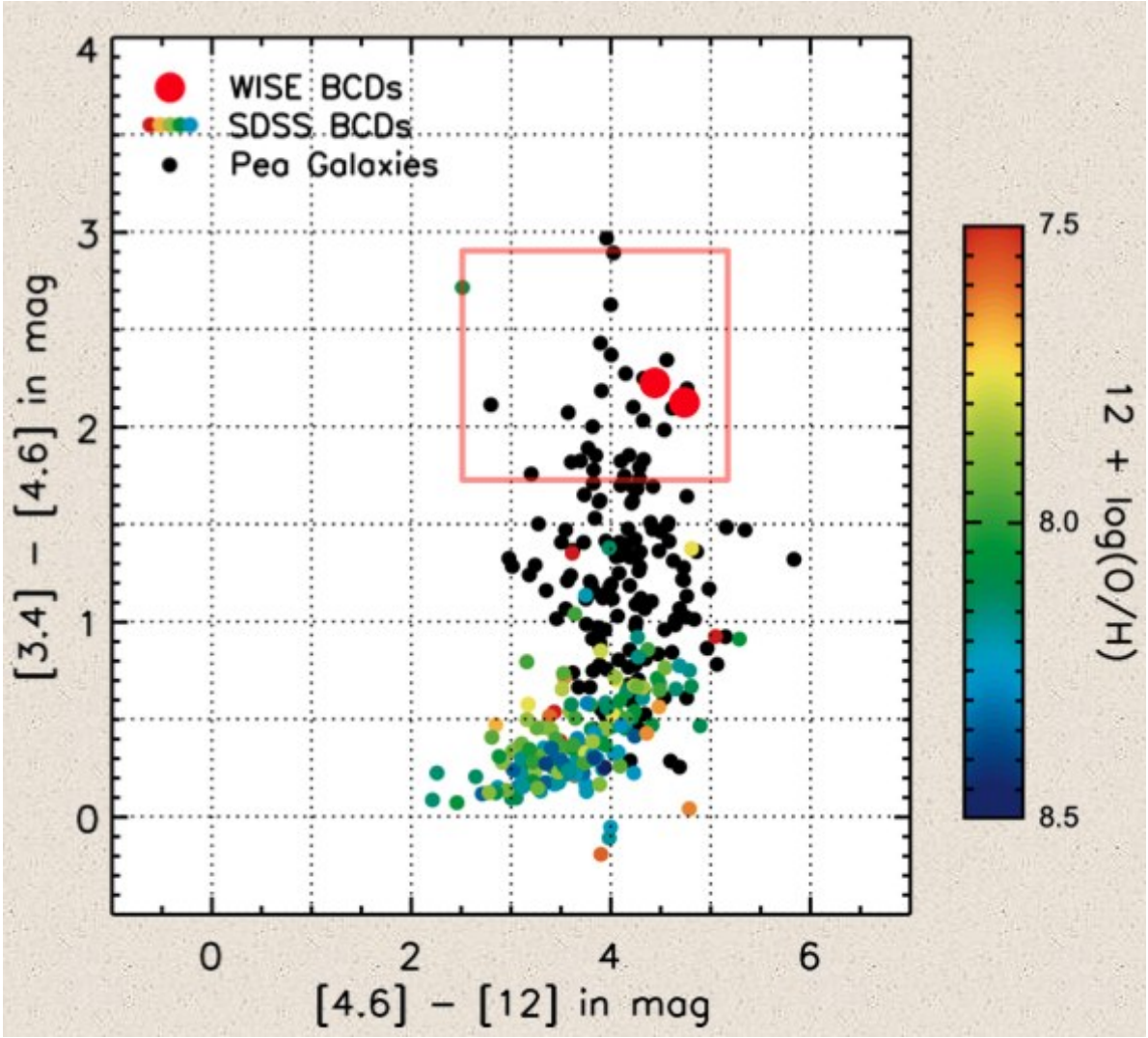
- z=0.0425
- Z ~ 1/12 $Z_{\odot}$



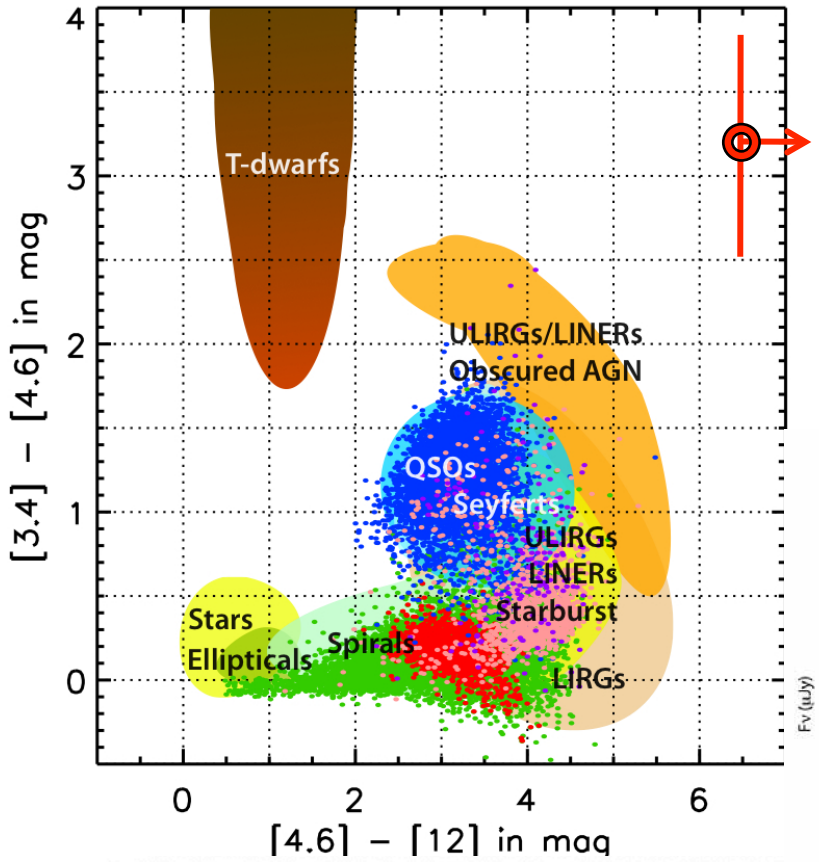
SDSS image

BCDs & Green Peas

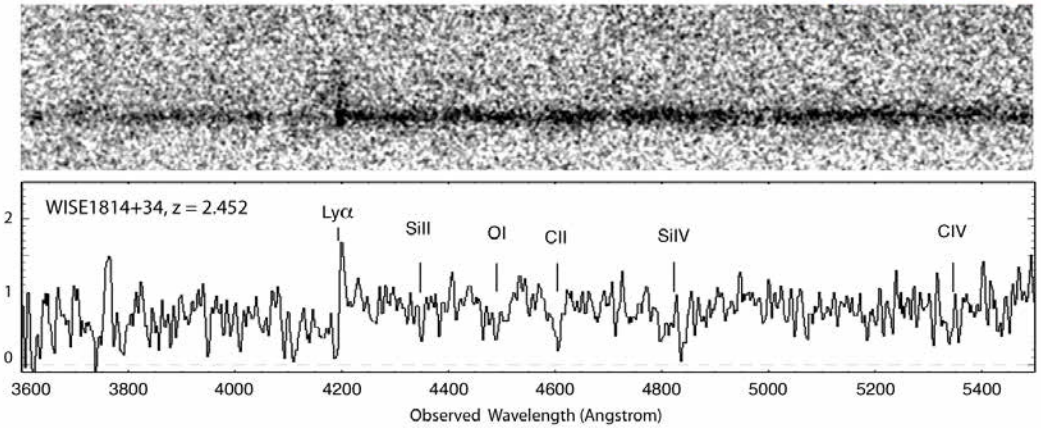
- WISE colors of BCDs and green peas
- From C-W Tsai etal poster 333.11 at the Jan 2011 AAS meeting
- Griffith etal, 2011 ApJL, 736 L22 (arXiv:1106.4844)

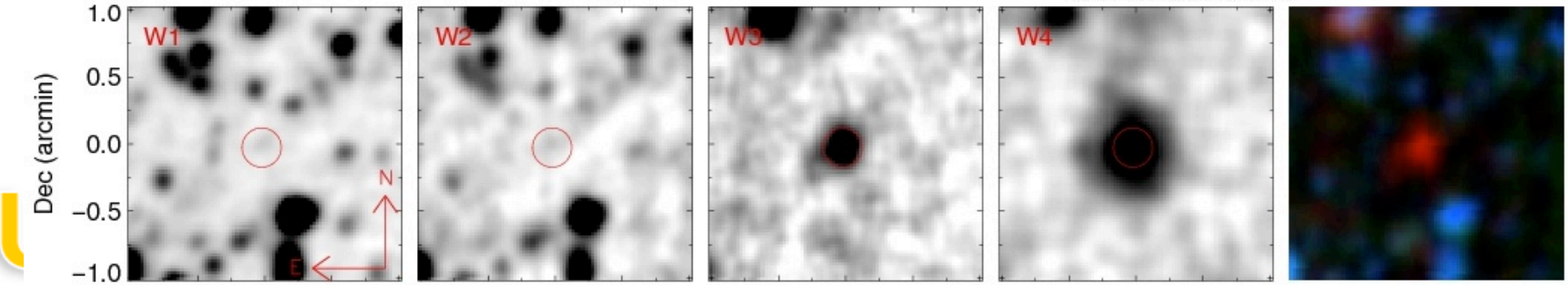


WISE Band 1 and 2 Dropouts



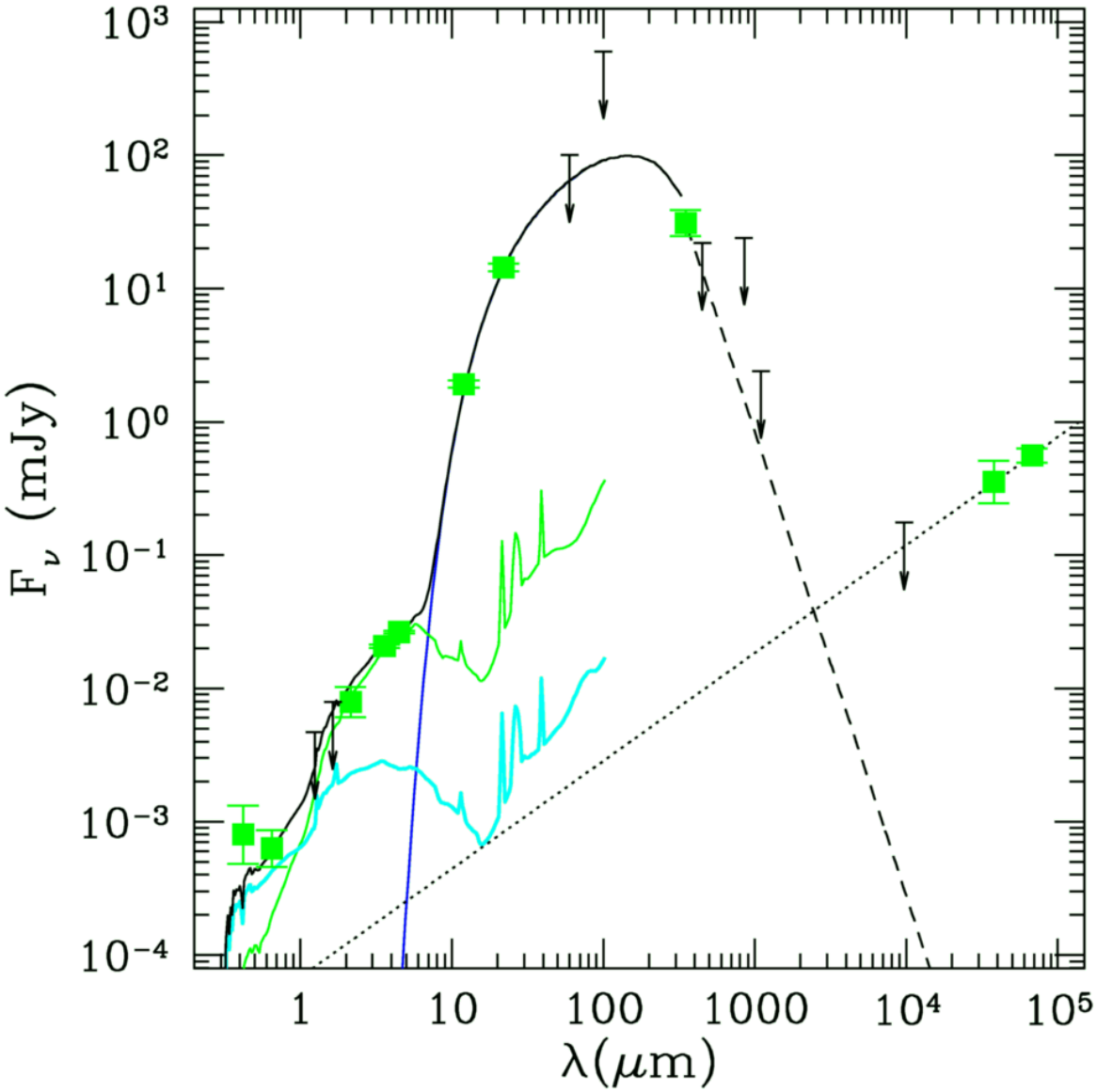
- W1 > 17.4 and W2 > 15.9 and (W3 < 10.6 or W4 < 7.7)
- W1814+34 (Eisenhardt et al 2012, ApJ 755, 173; Bridge et al 2012)
- z=2.452
- Extended Lyman alpha emission (~40 kpc)





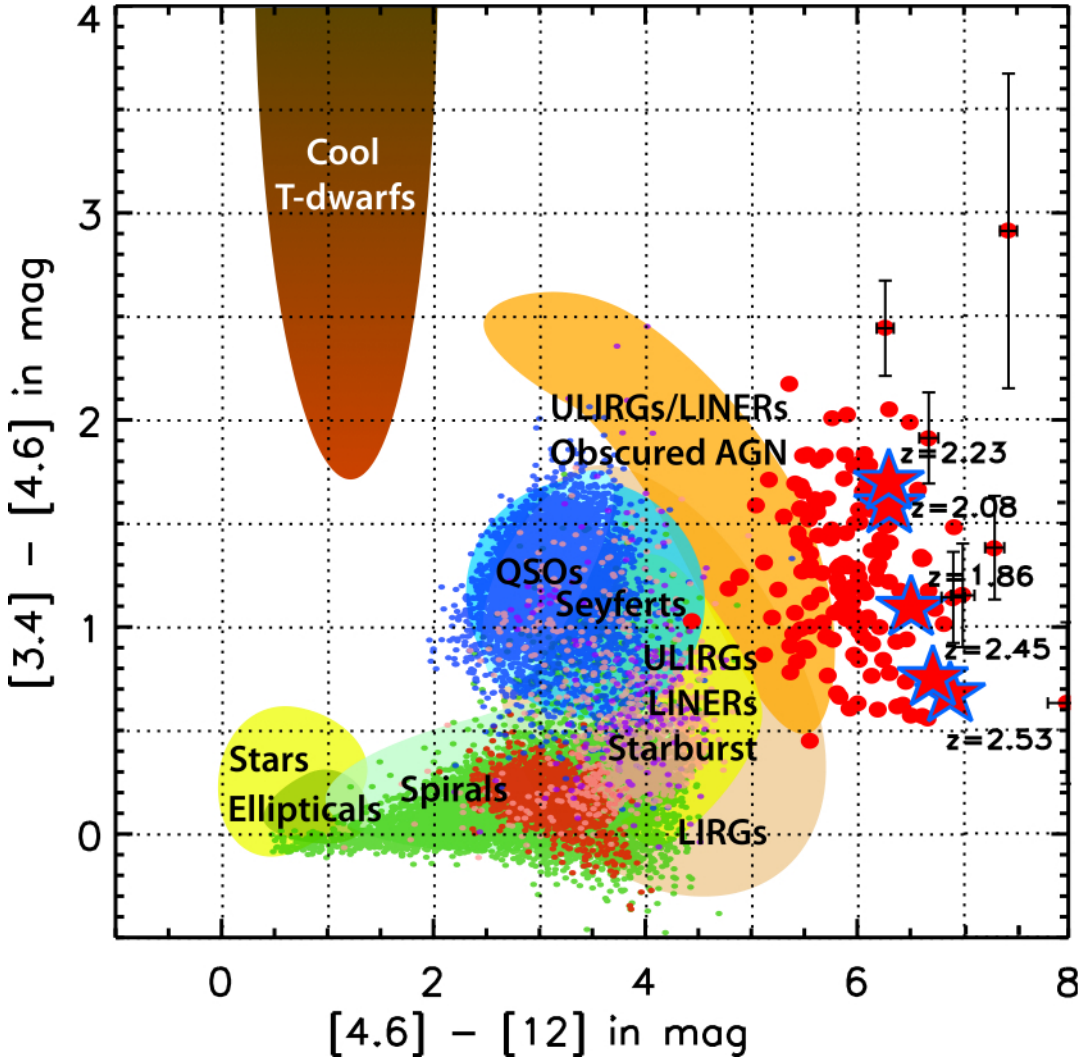
SED of W1814+34

- 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 $\nu L_\nu = 10^{13.38}\ L_\odot$



Warm Spitzer Followup

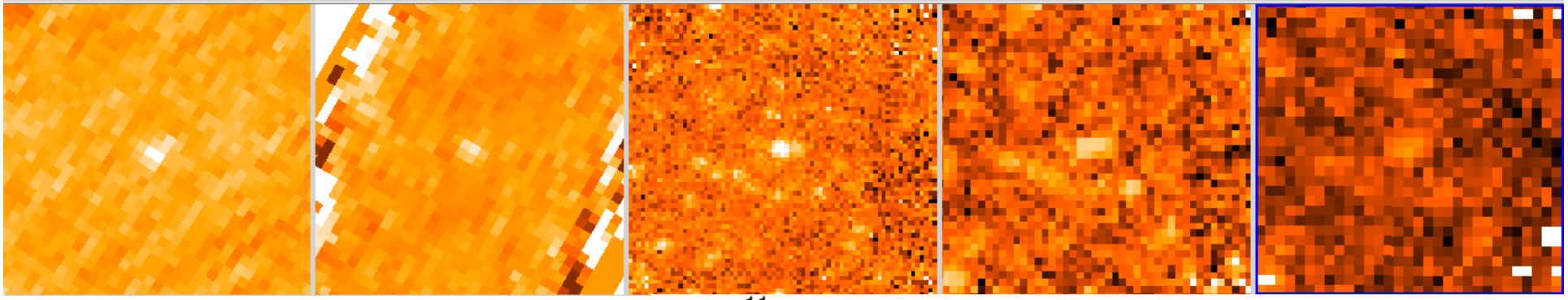
- Objects not detected by WISE at 3.4 & 4.6 µm can be measured using warm Spitzer
  - bigger mirror
  - longer integration times
- Synergy between surveys and great observatories



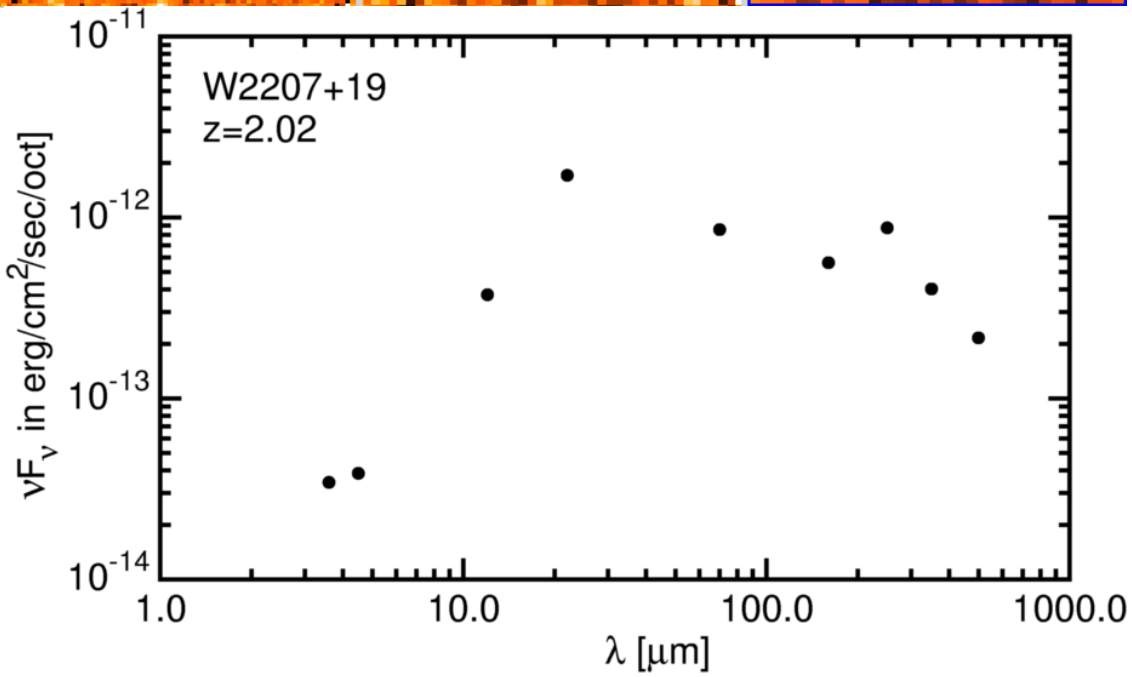
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Wide-field **I**nfrared **S**urvey **E**xplorer (WISE)

Herschel Followup Program



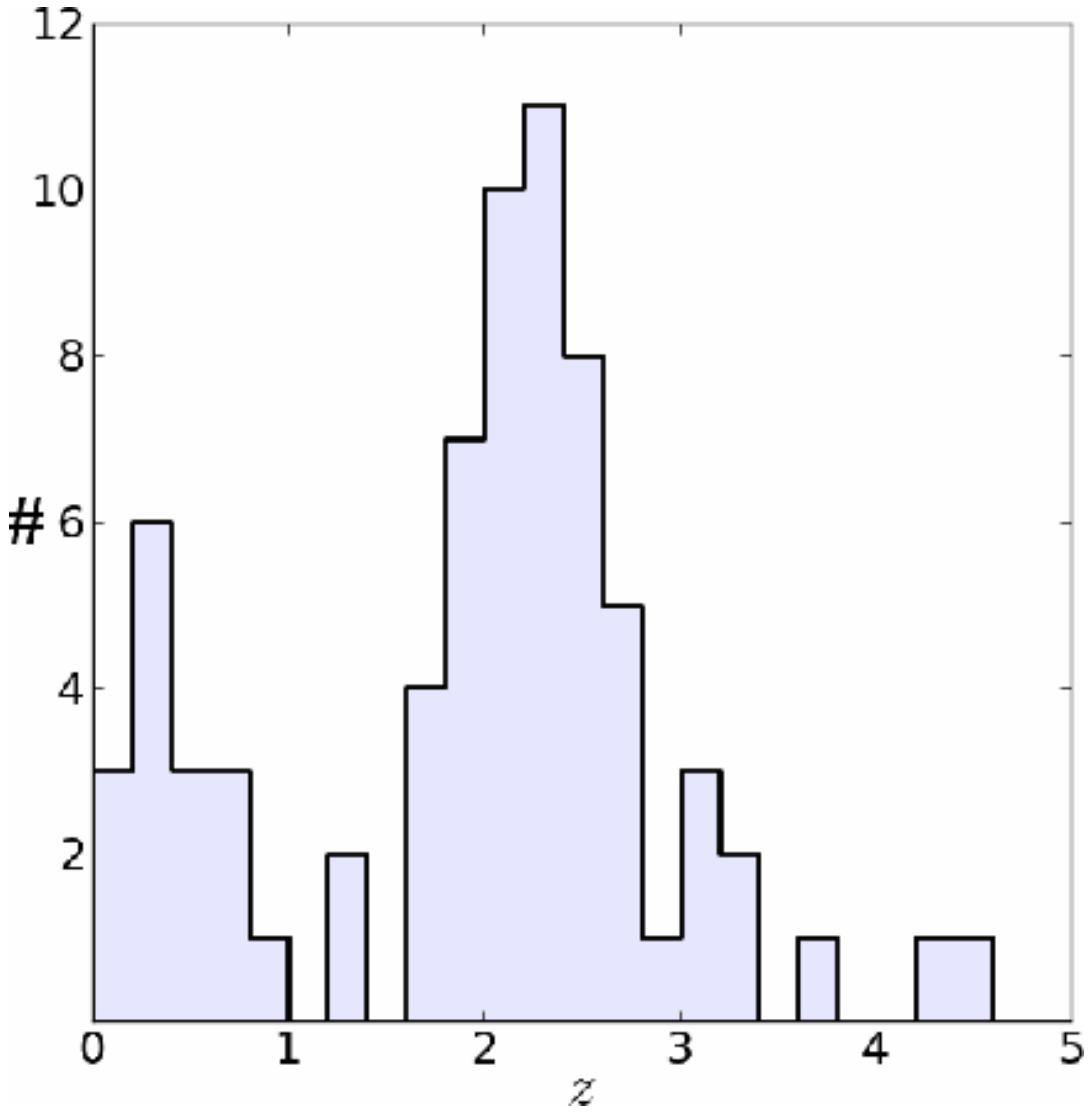
- Example: W2207+19
- Warm Spitzer at 3.6 & 4.5 µm
- WISE at 12 & 22 µm
- Herschel at 70, 160, 250, 350 & 500 µm
- Peak νF_ν at 22 µm
- Peak $\nu L_\nu = 10^{13.13}\ L_\odot$



UCLA

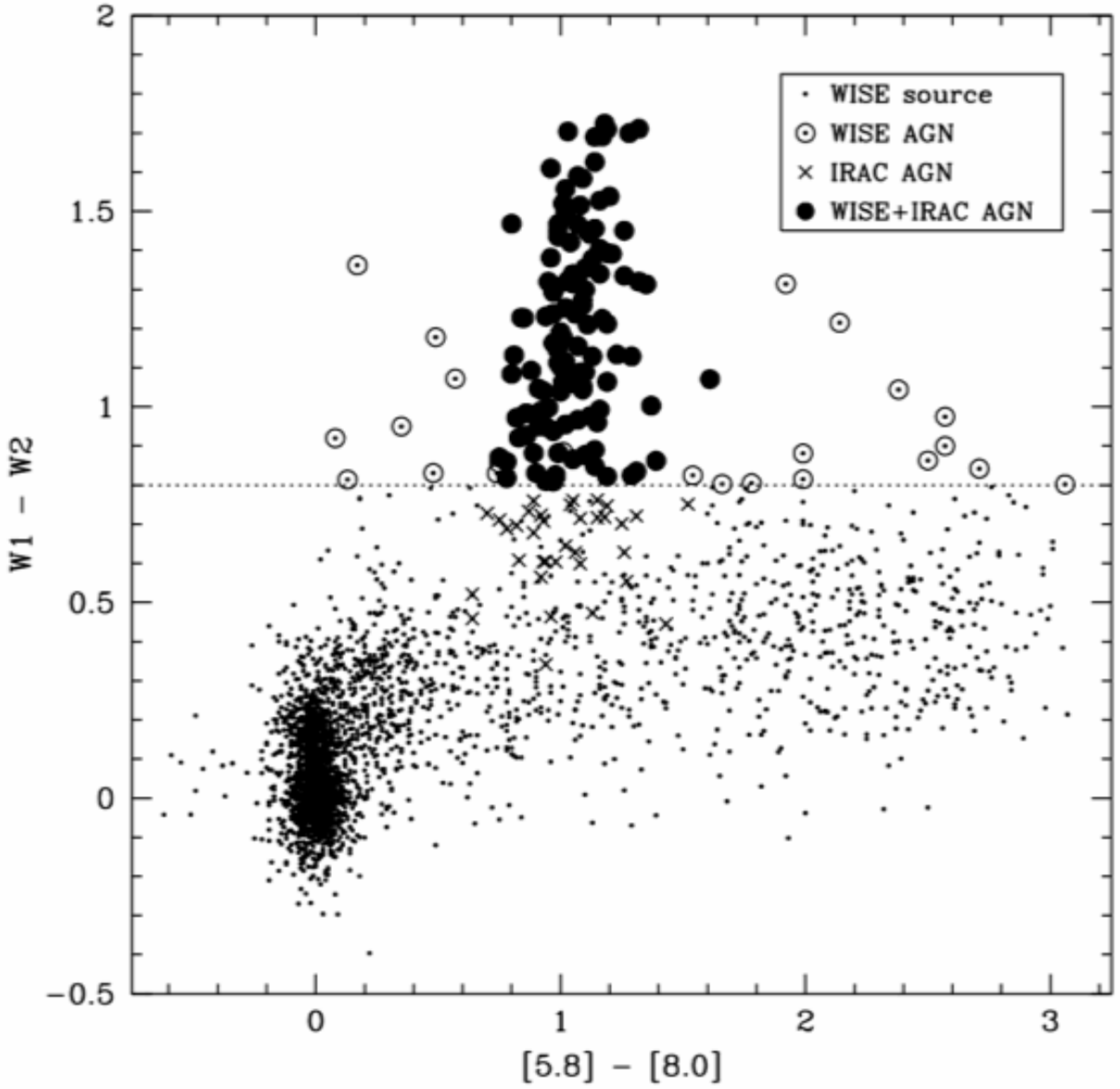
Many W12 drops

- 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

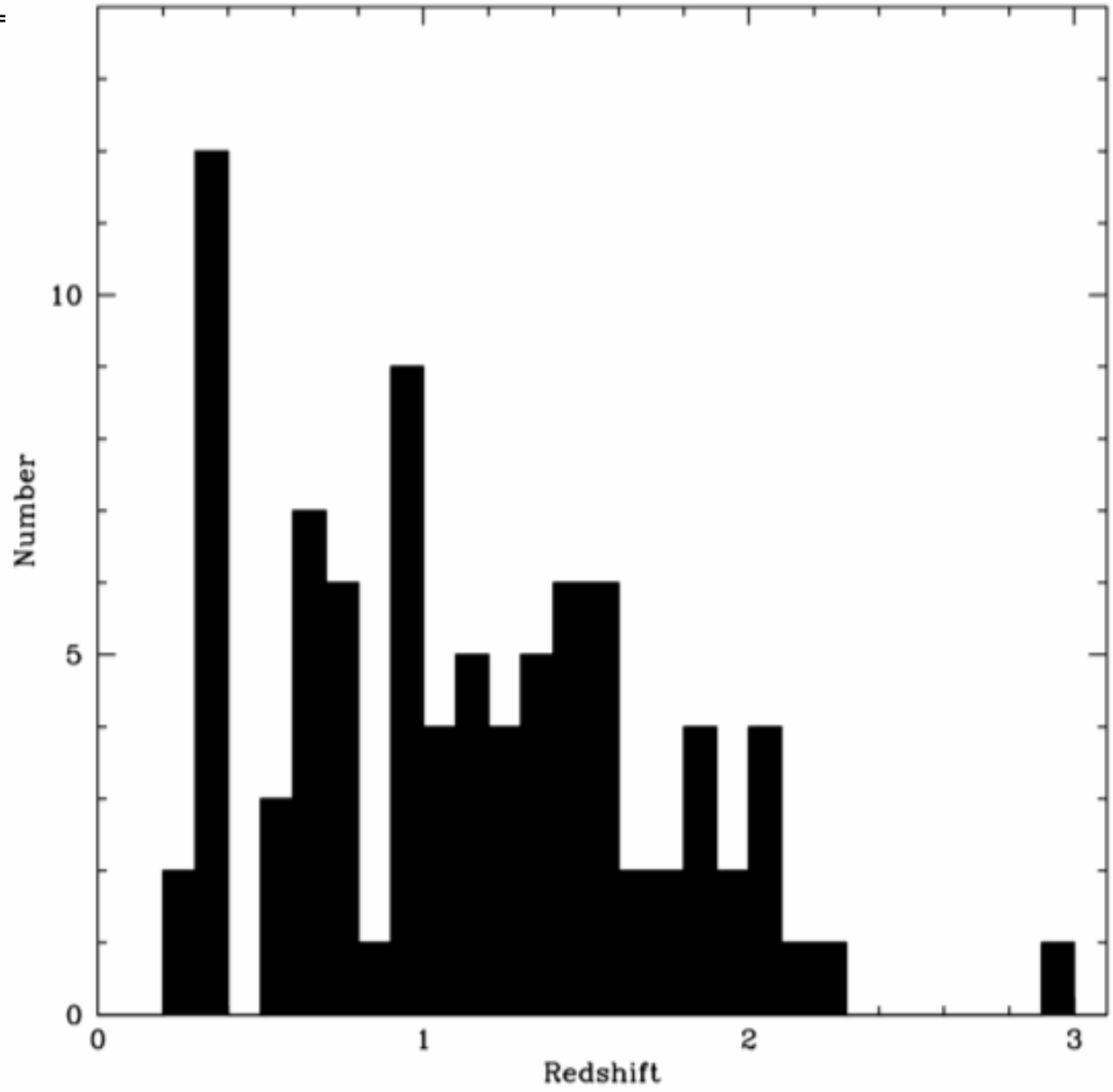


AGN Selection

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

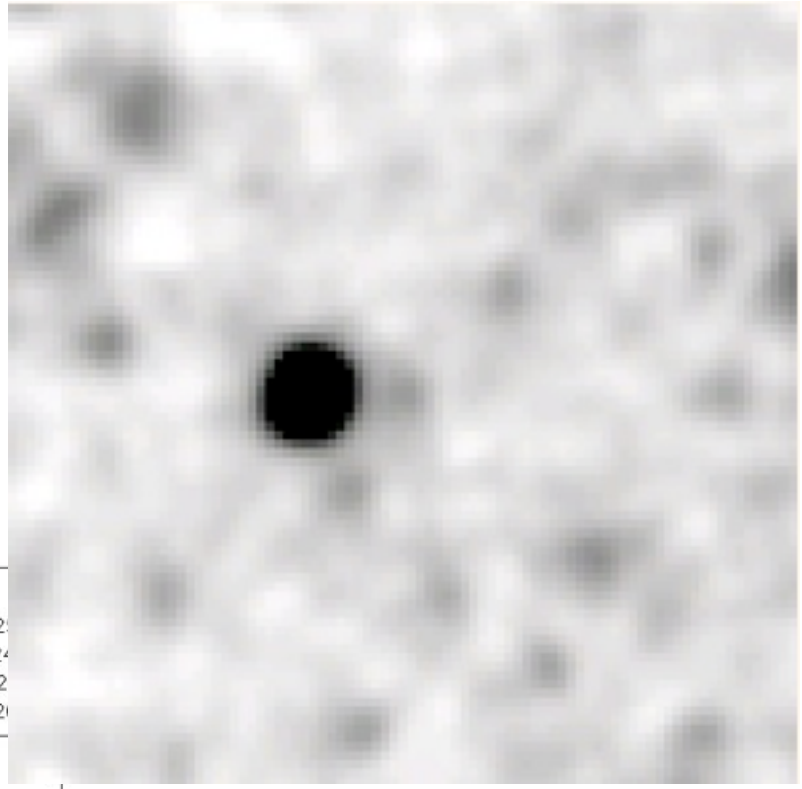


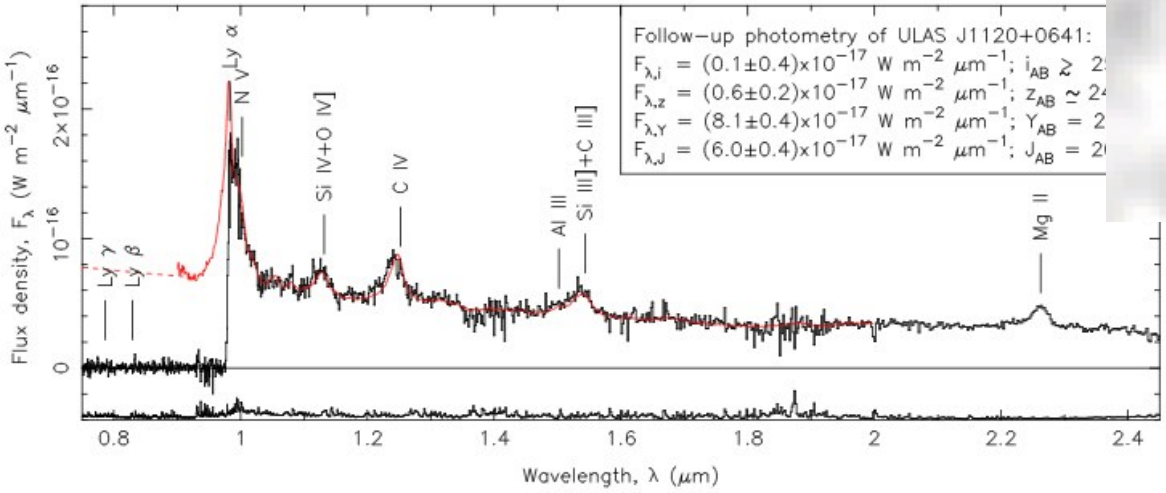
Z-distribution



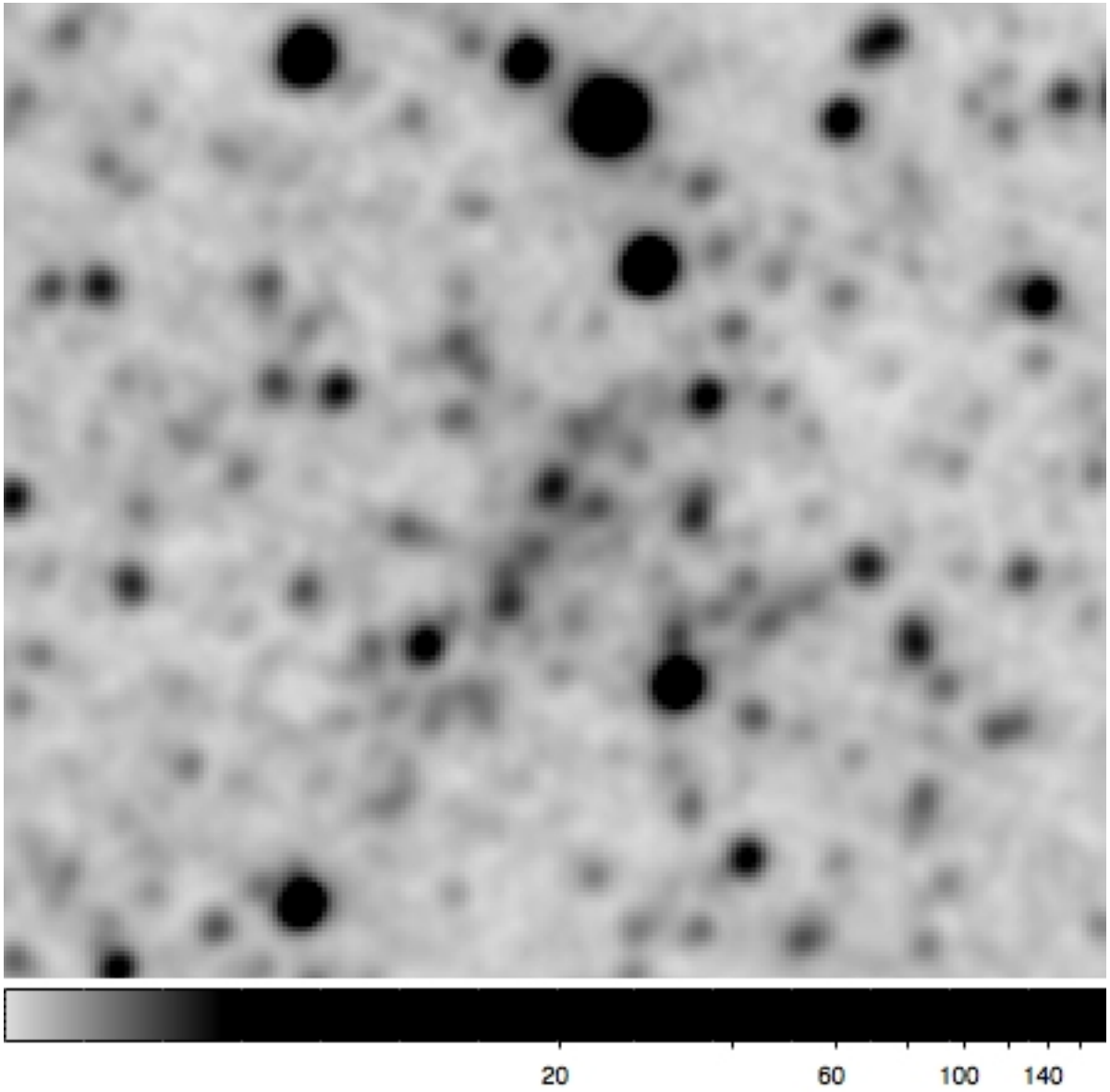
ULAS 1120+0641

- 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

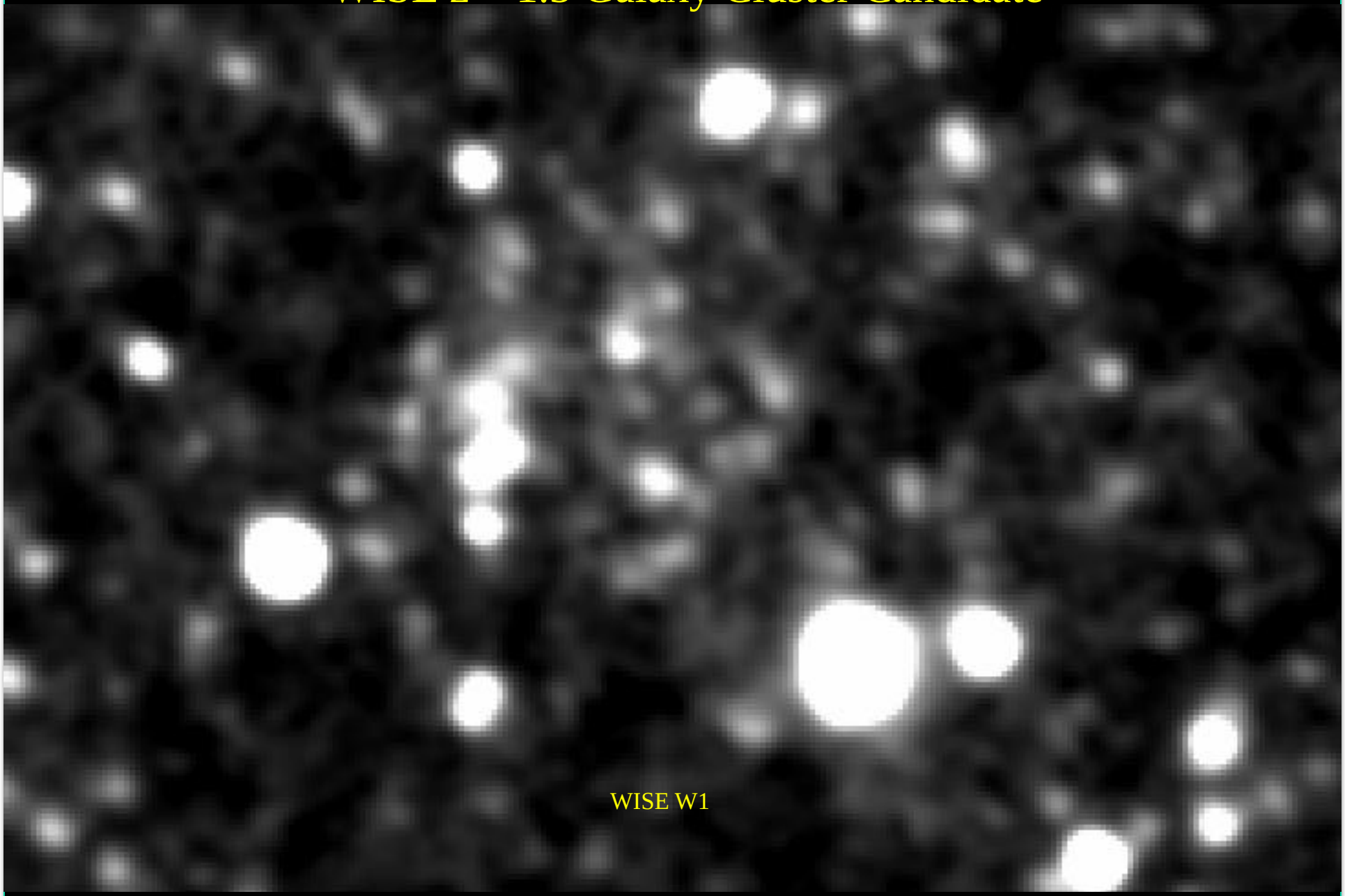




W1 image of SPT z=1.13 cluster



WISE z ~ 1.3 Galaxy Cluster Candidate



WISE W1

WISE z ~ 1.3 Galaxy Cluster Candidate

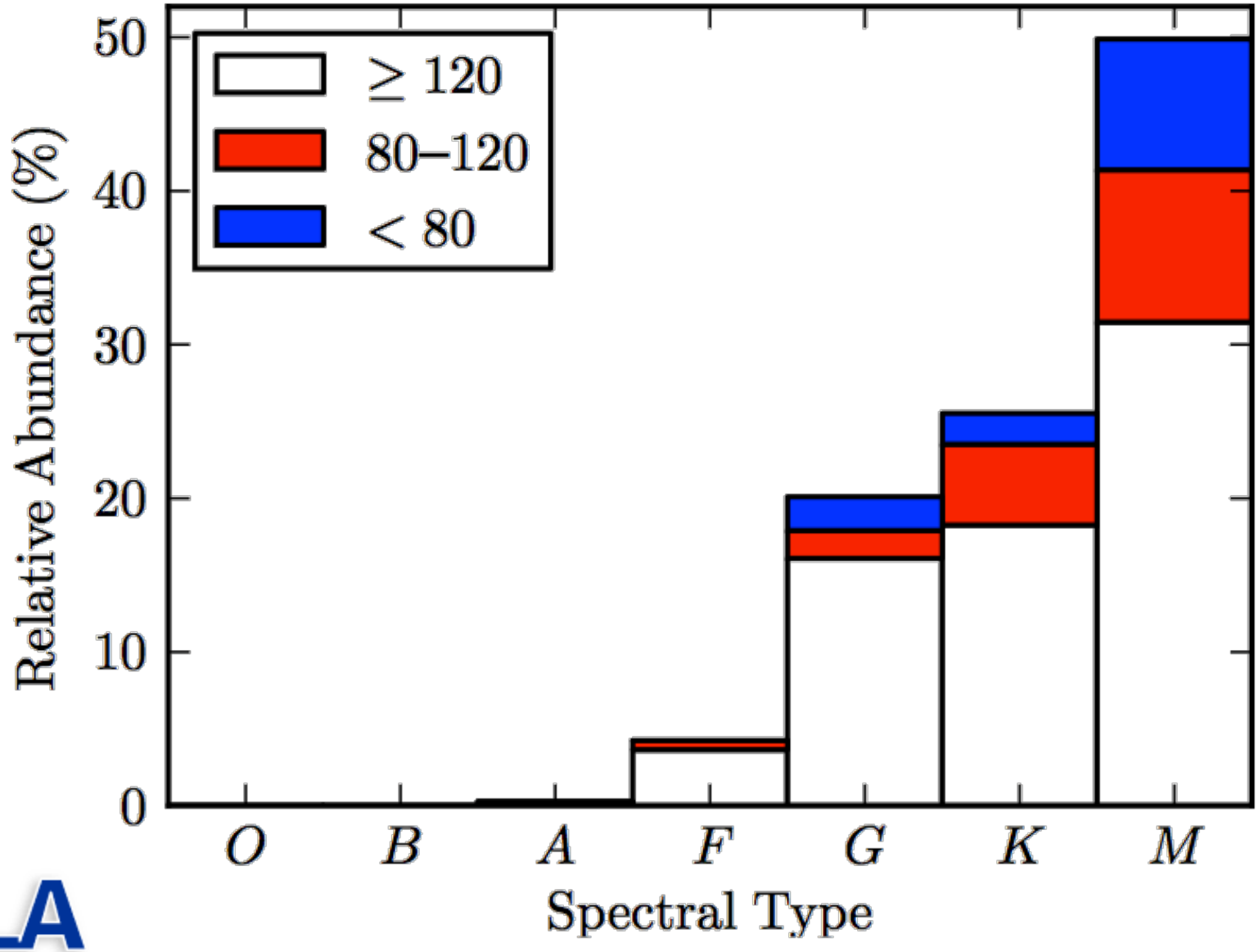

r J K (Subaru)
WISE z ~ 1.3 Galaxy Cluster Candidate


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

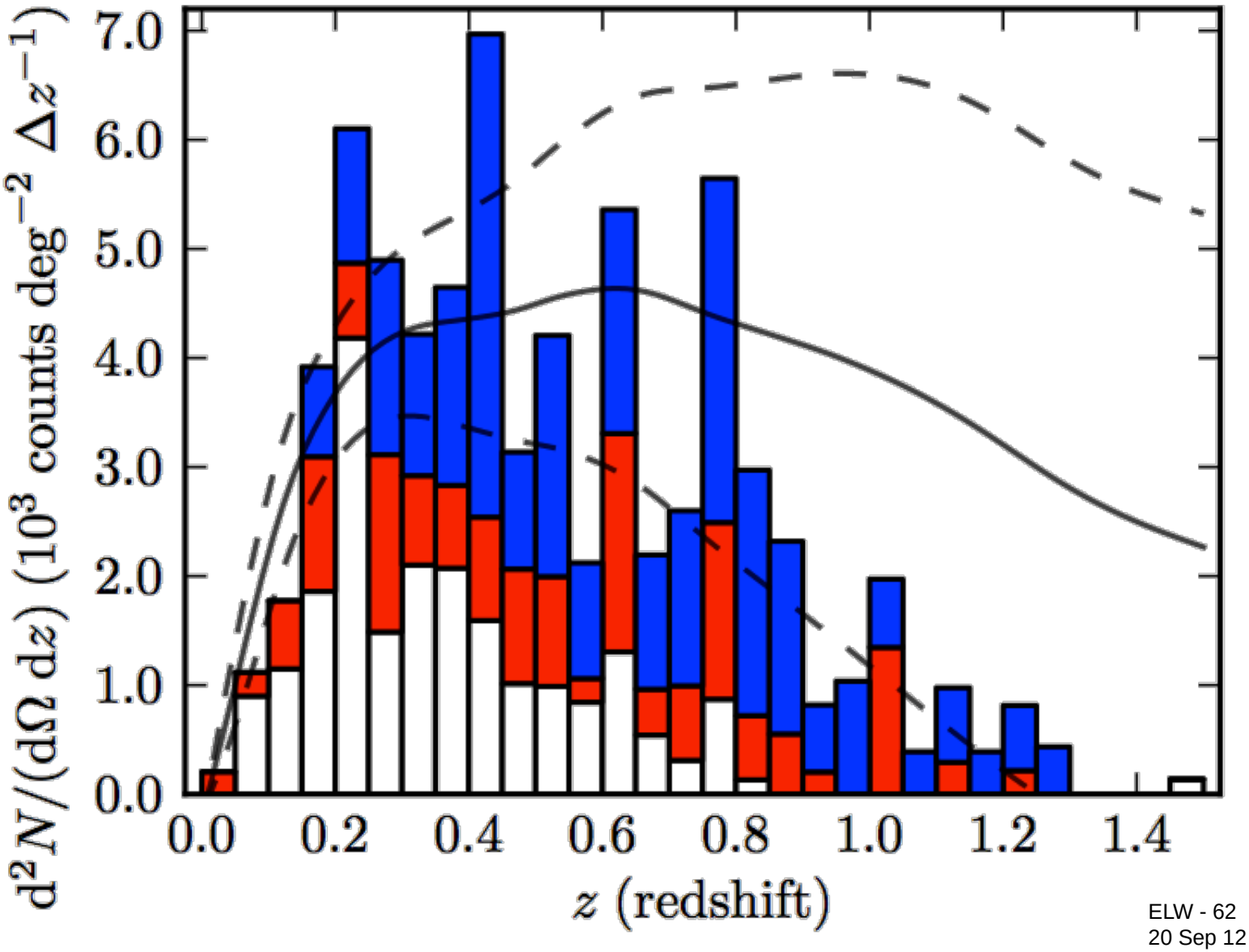
Blind Survey of WISE Sources

- 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

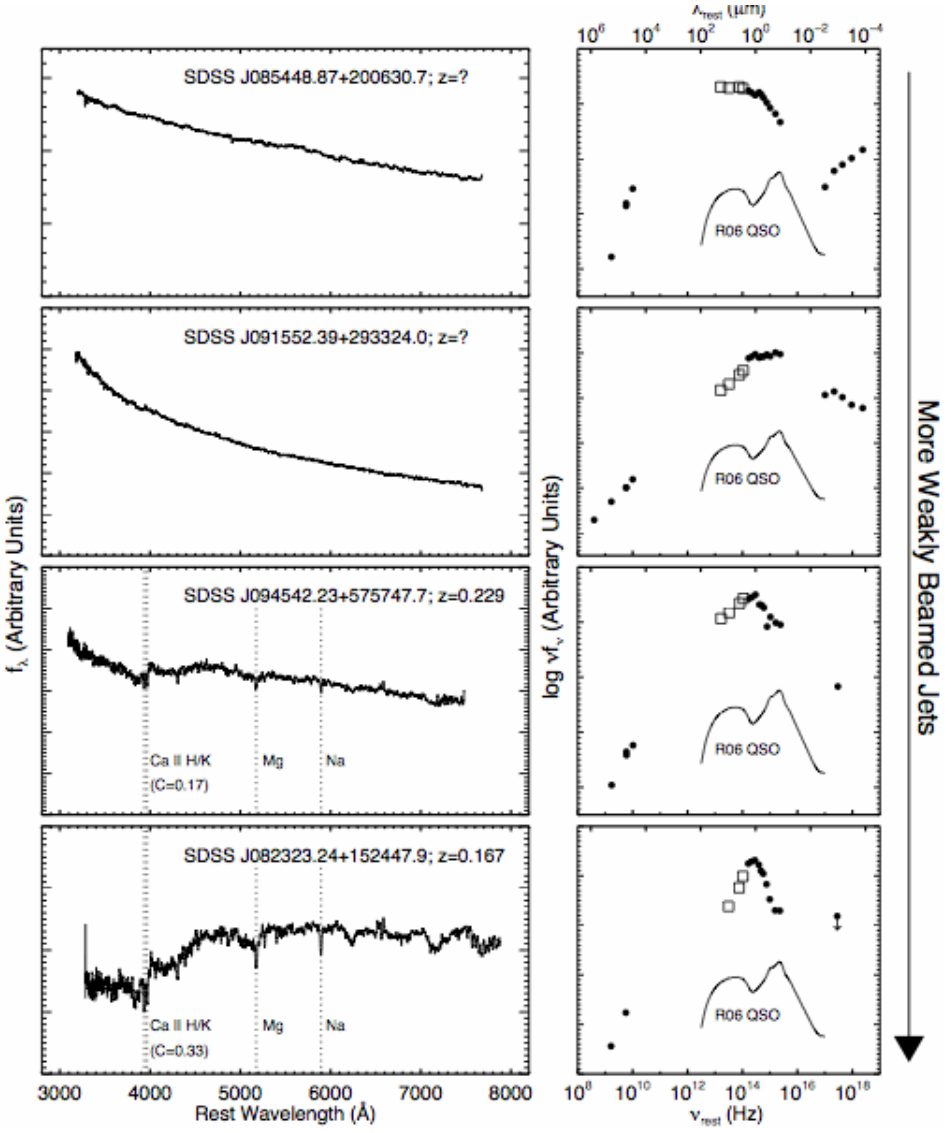


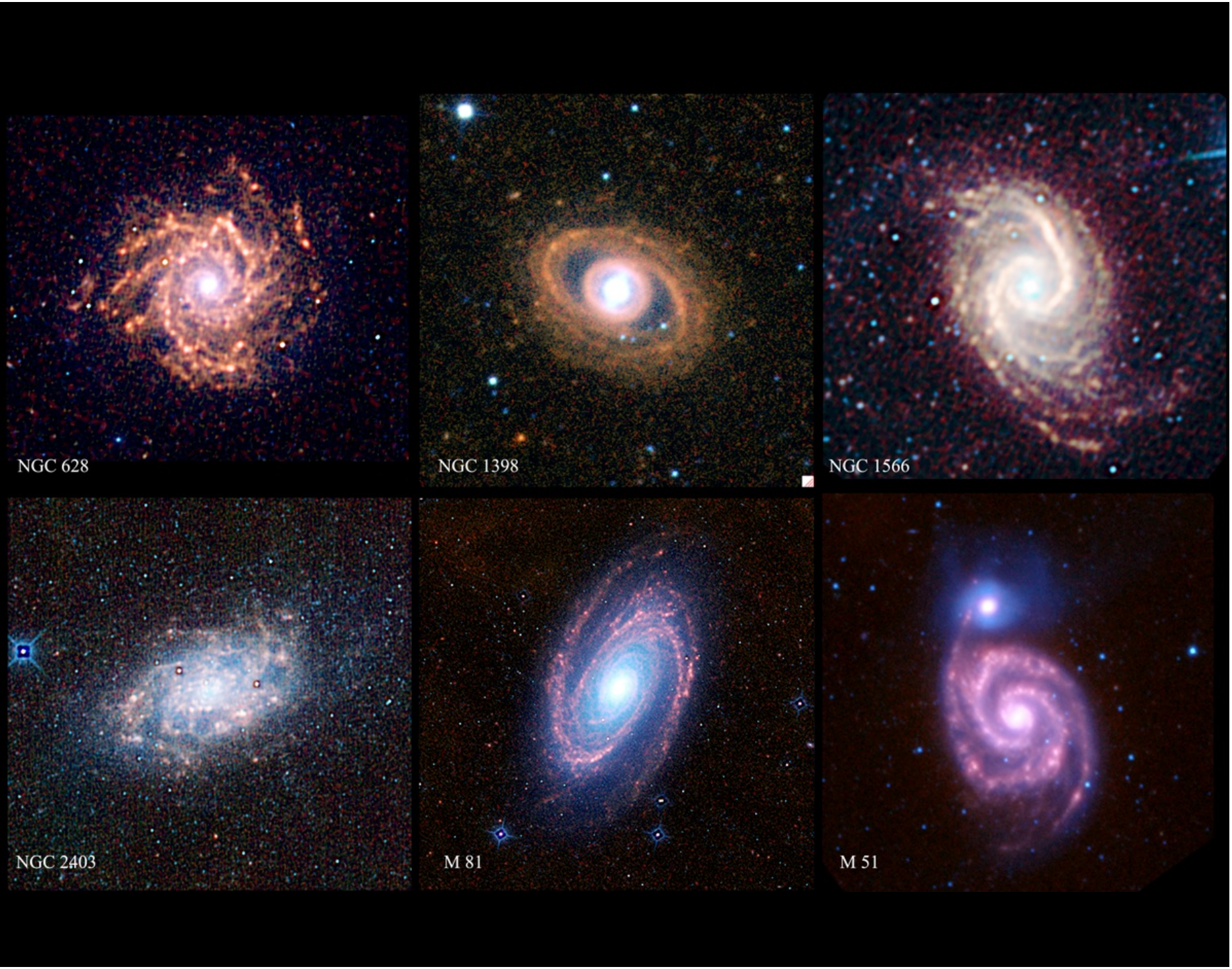
Redshift Histogram

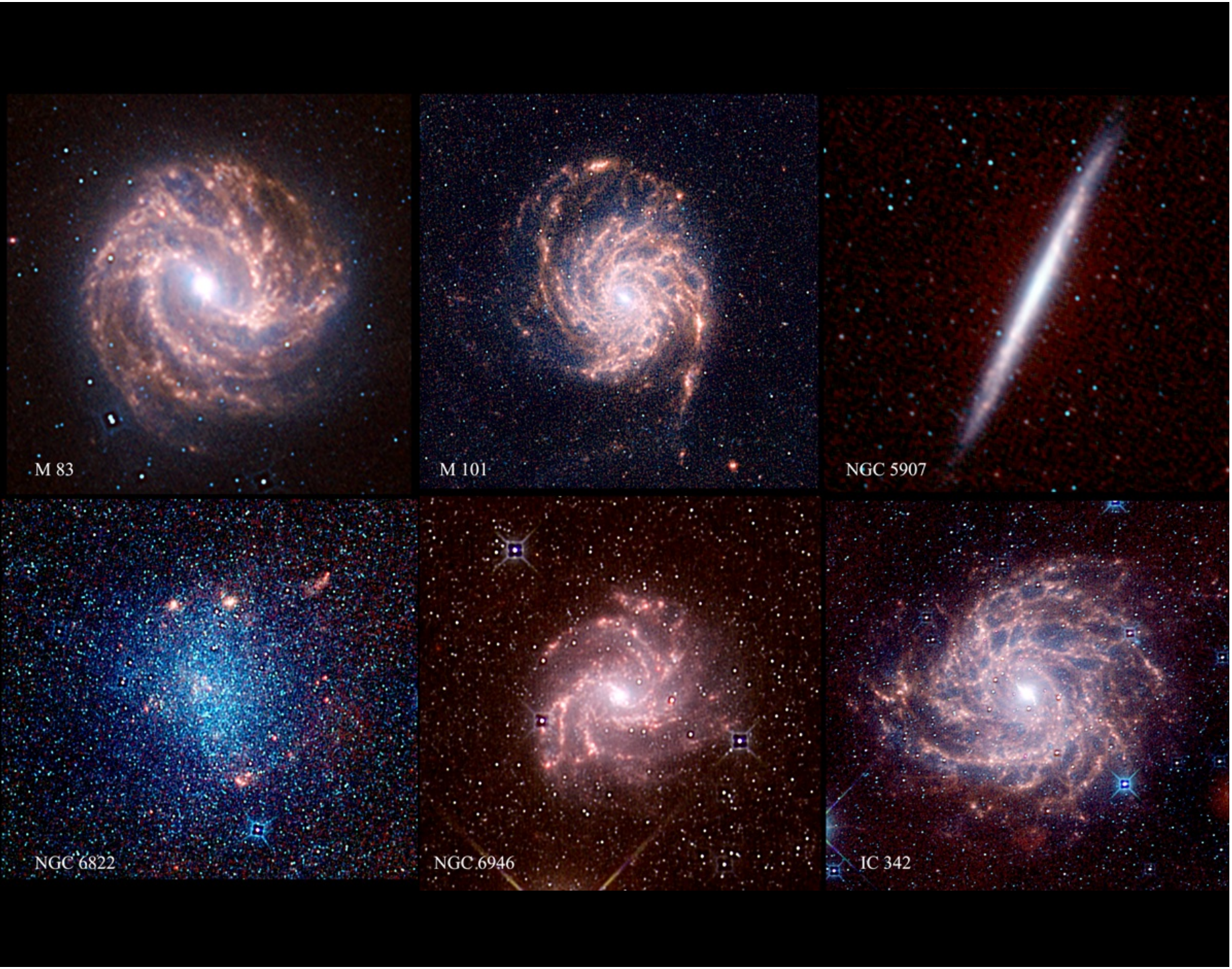


arXiv:1112.5162

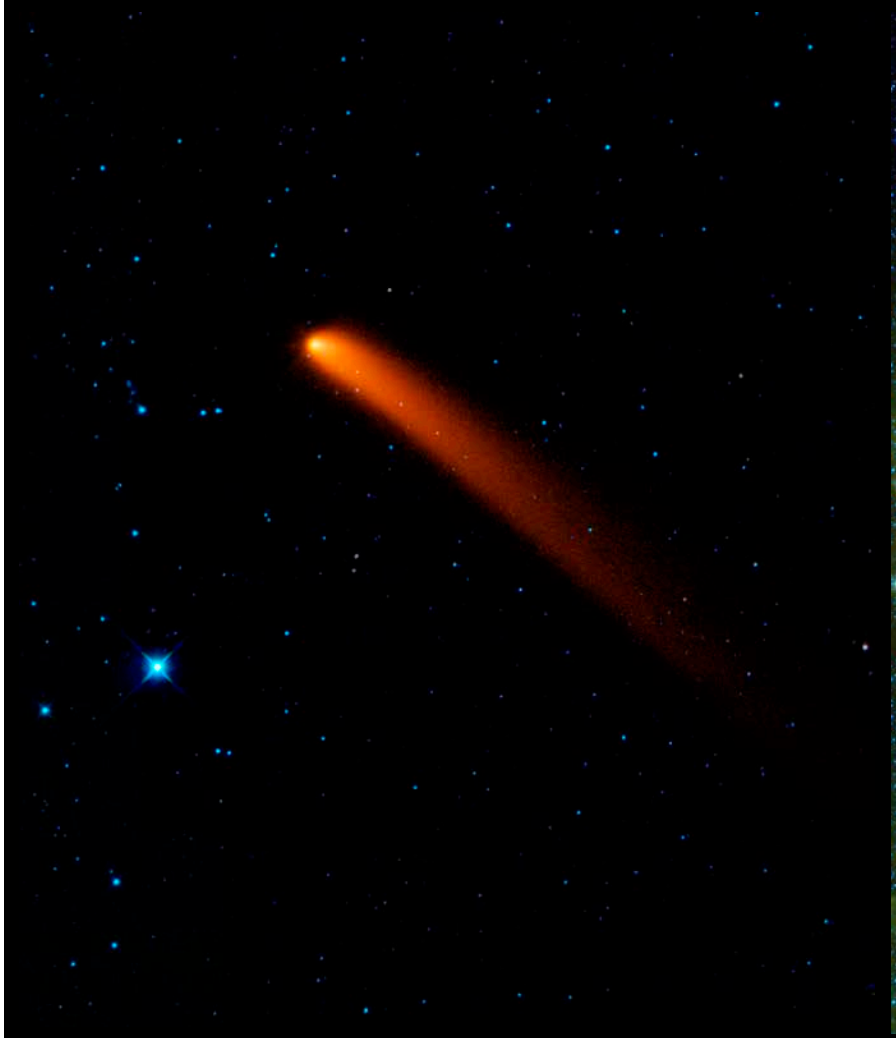
- Plotkin etal
- "The Lack of Torus Emission from BL Lacertae Objects: An Infrared View of Unification with WISE"




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


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

Early Release Observations

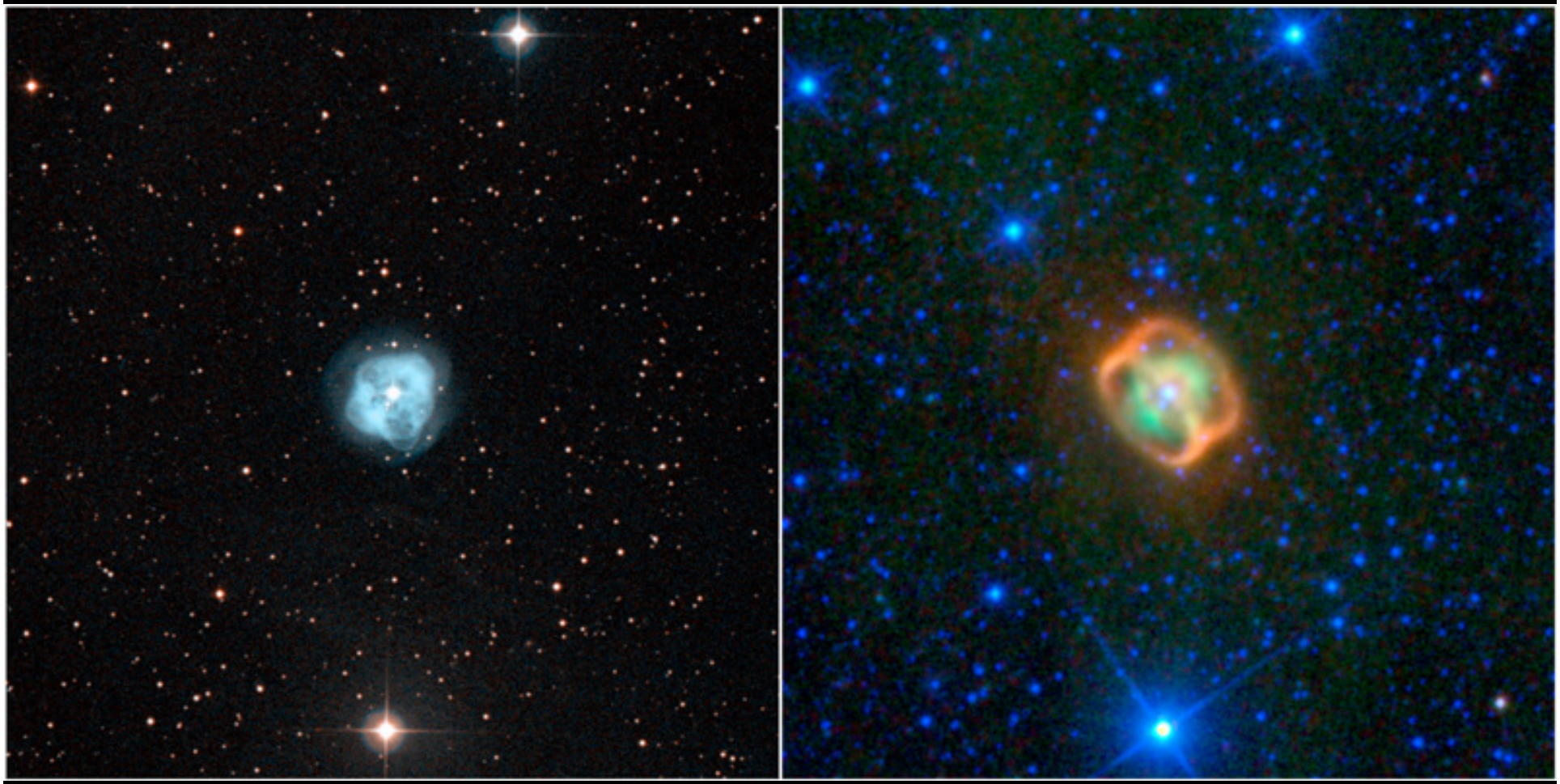


- Released Wednesday 16 Feb 2010

Early Release Observations

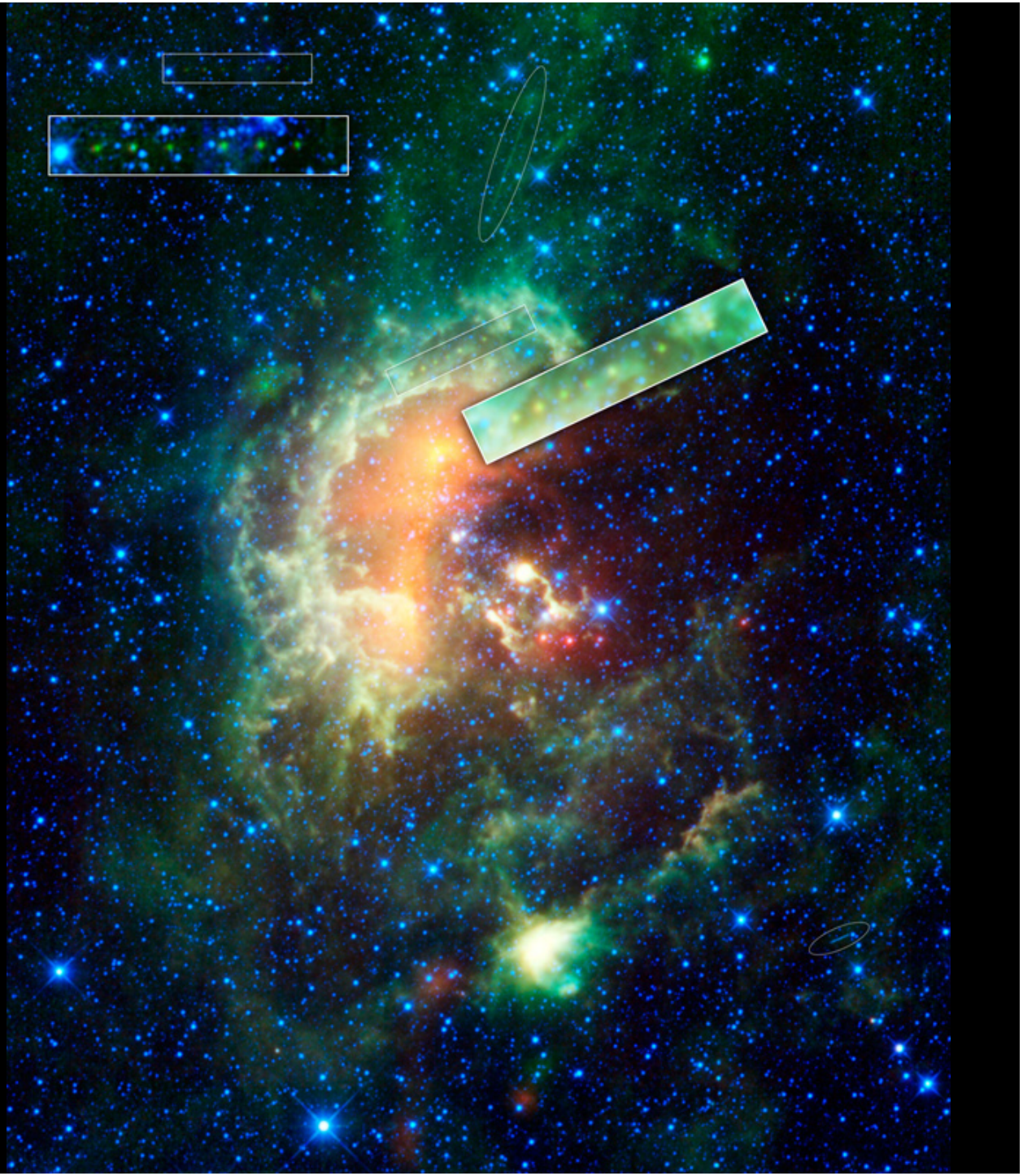
- Released Wednesday 16 Feb 2010

NGC 1514



- Ressler et al (2010)

- IC 410
- Asteroids
  - 1719 Jens
  - 1992 UZ5
- Satellites in high orbit



- Tycho SNR

Thor's Helmet

- See Schneps & Wright 1980, Sky & Telescope, 59, 195: "A bubble in space - The shell of NGC 2359"

Balloon-borne far-IR astronomy

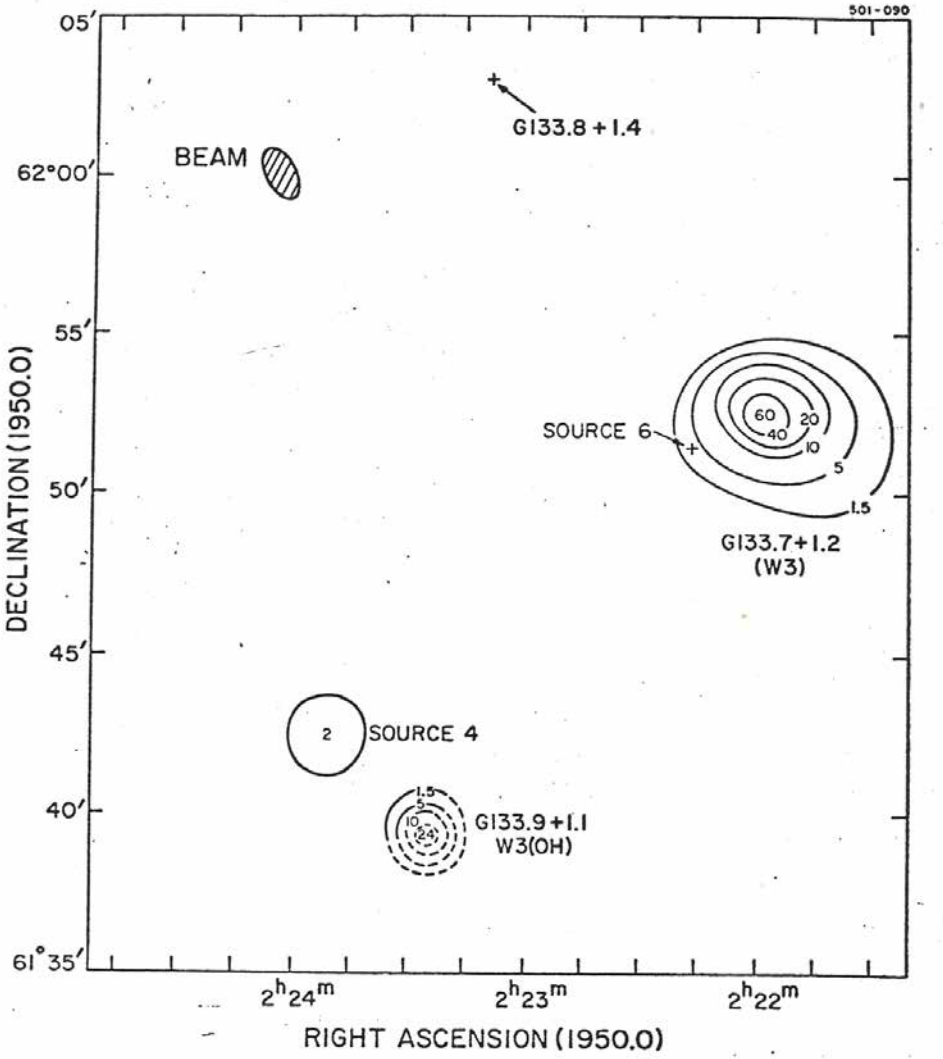
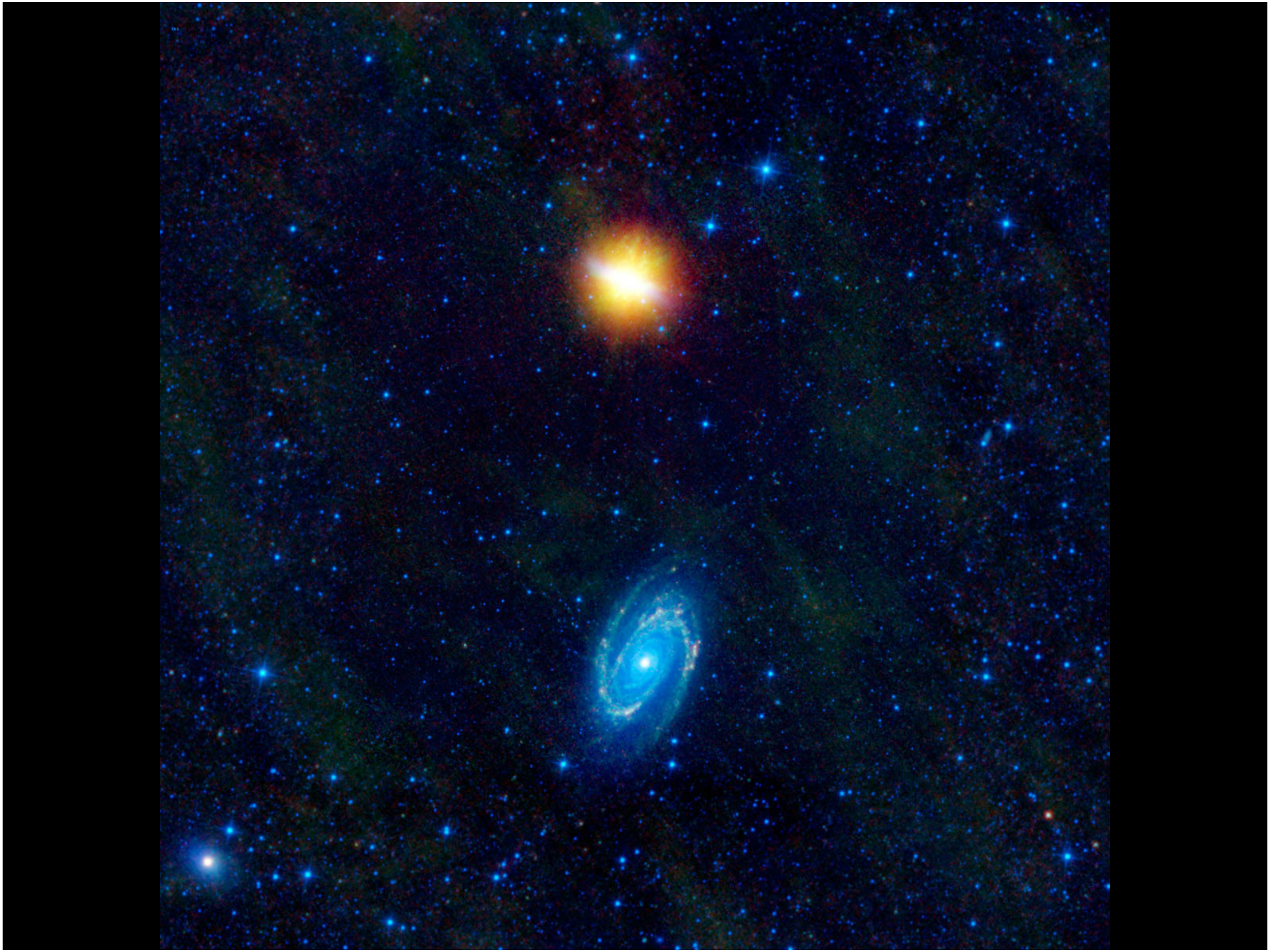


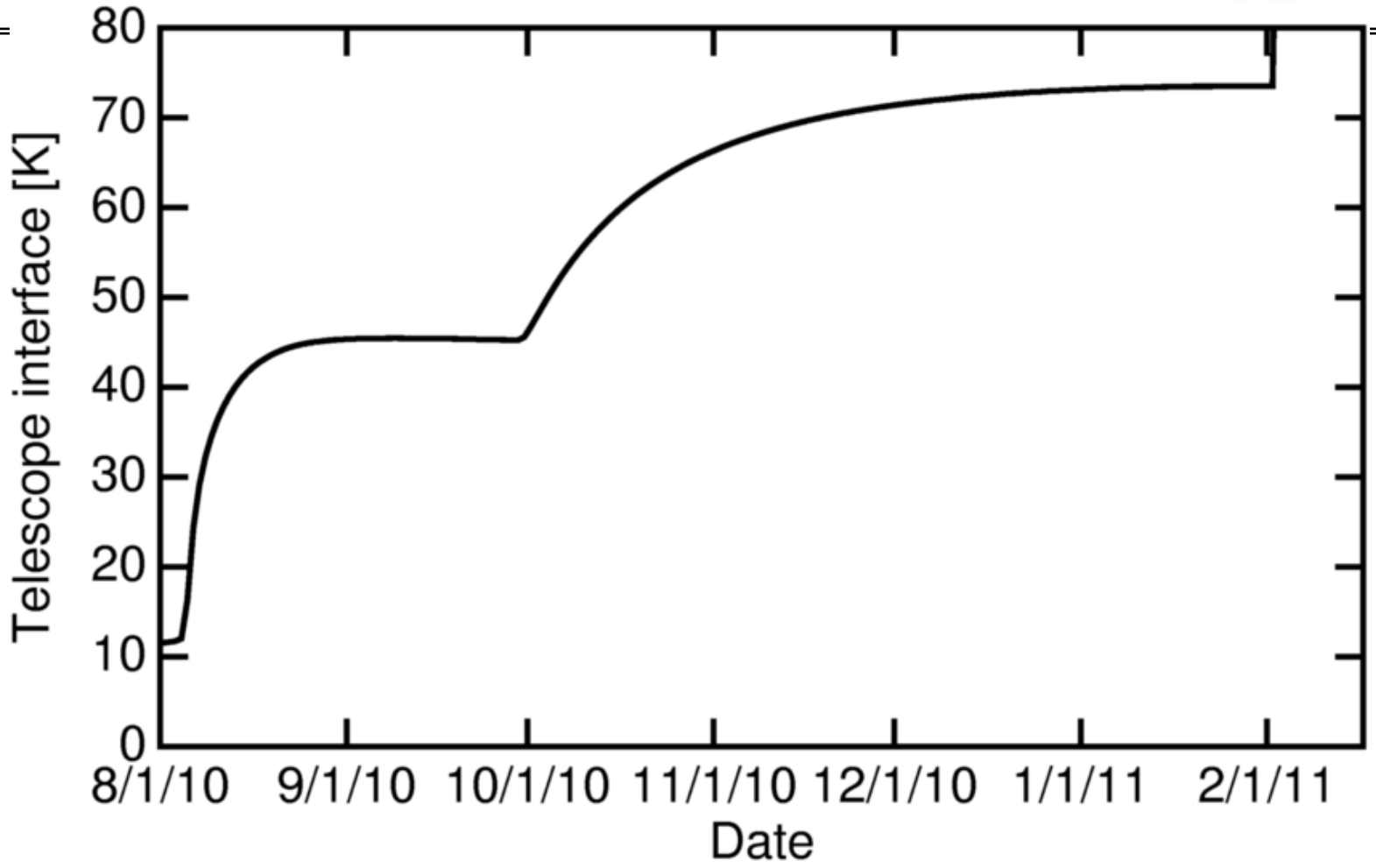
Figure 6.5 Map of W3 region at an effective wavelength of 69μ. Contours are in units of 600 Jy in the beam.

- Figure 6.5 of Wright (1976 PhD thesis) overlaid on Heart & Soul



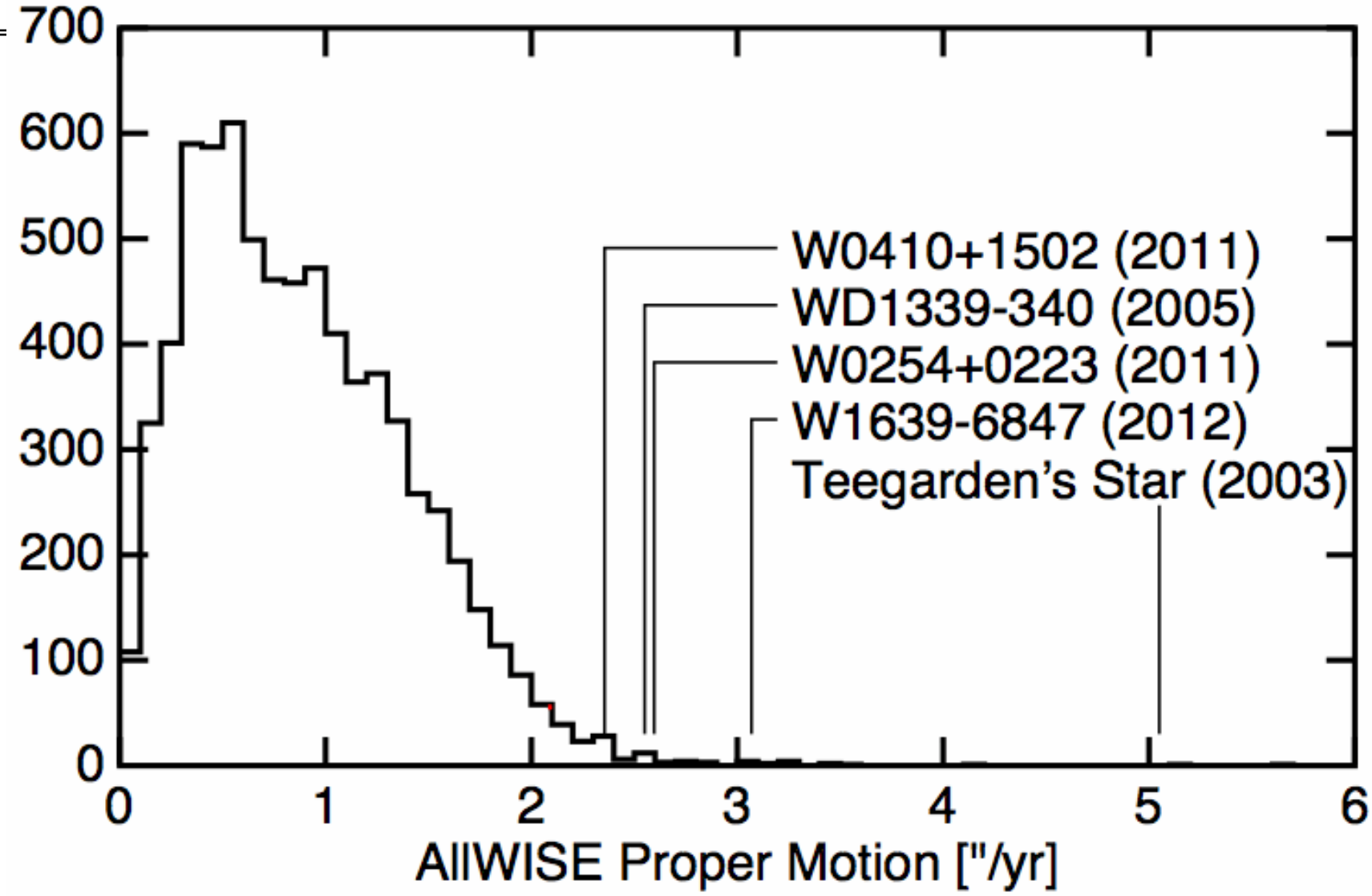
Zeta Oph Bow shock – Astronomy Picture of the Day for 4 Feb 2011

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.

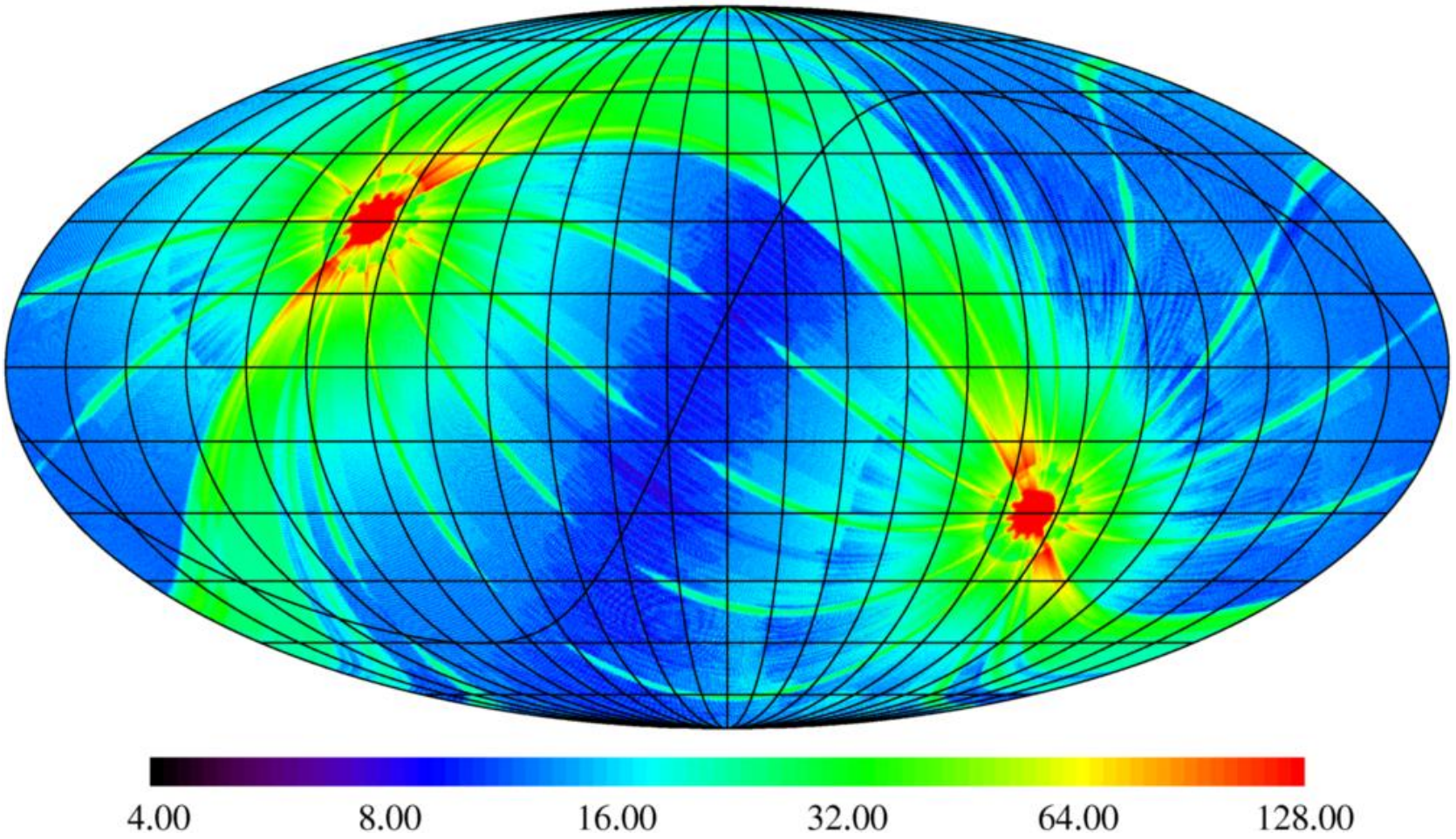
Proper Motion Sensitivity



- 2.5 "/yr at >99.5%-tile

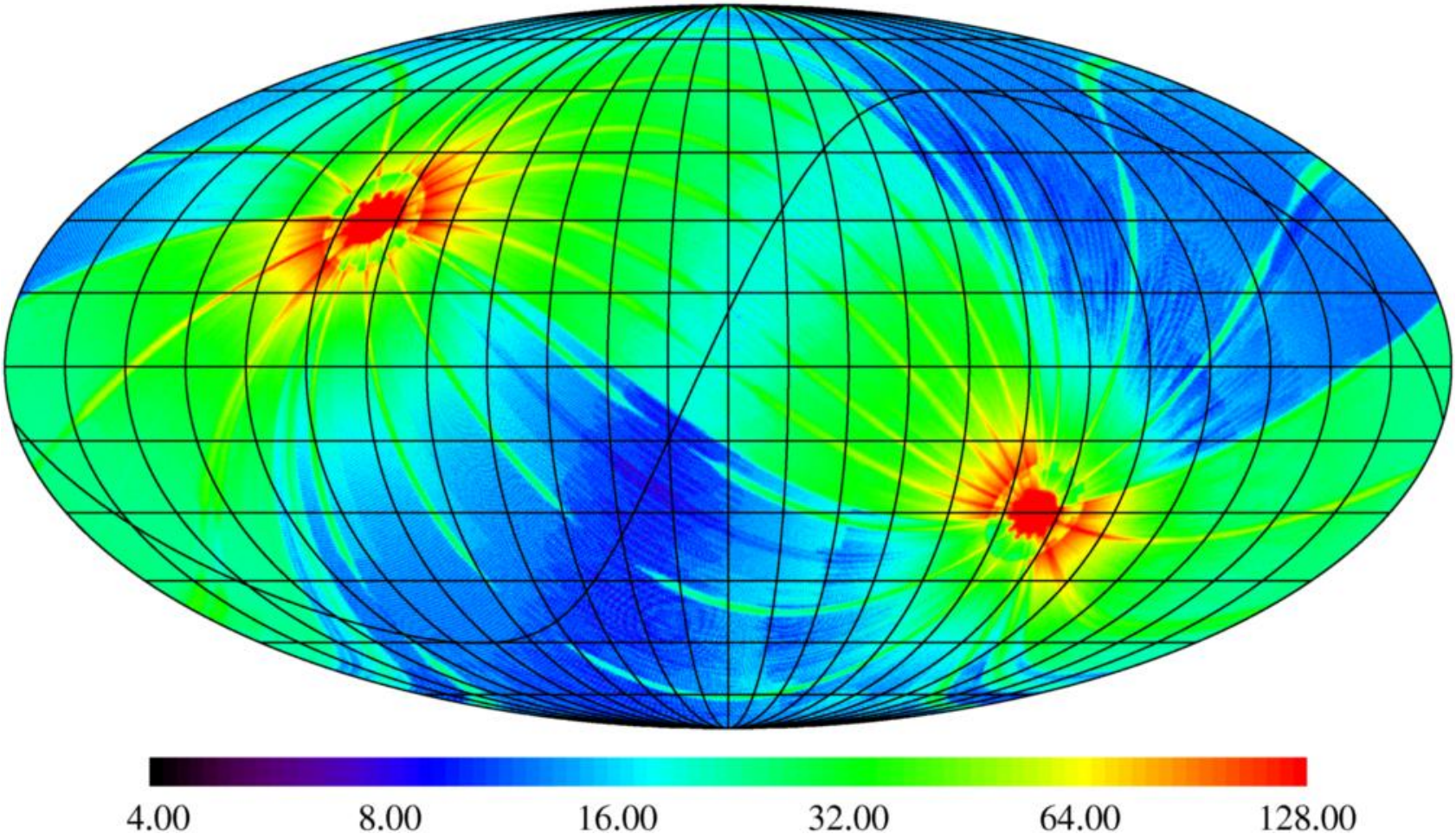
Coverage Released 14 Mar 2012

Actual Coverage Achieved for W4



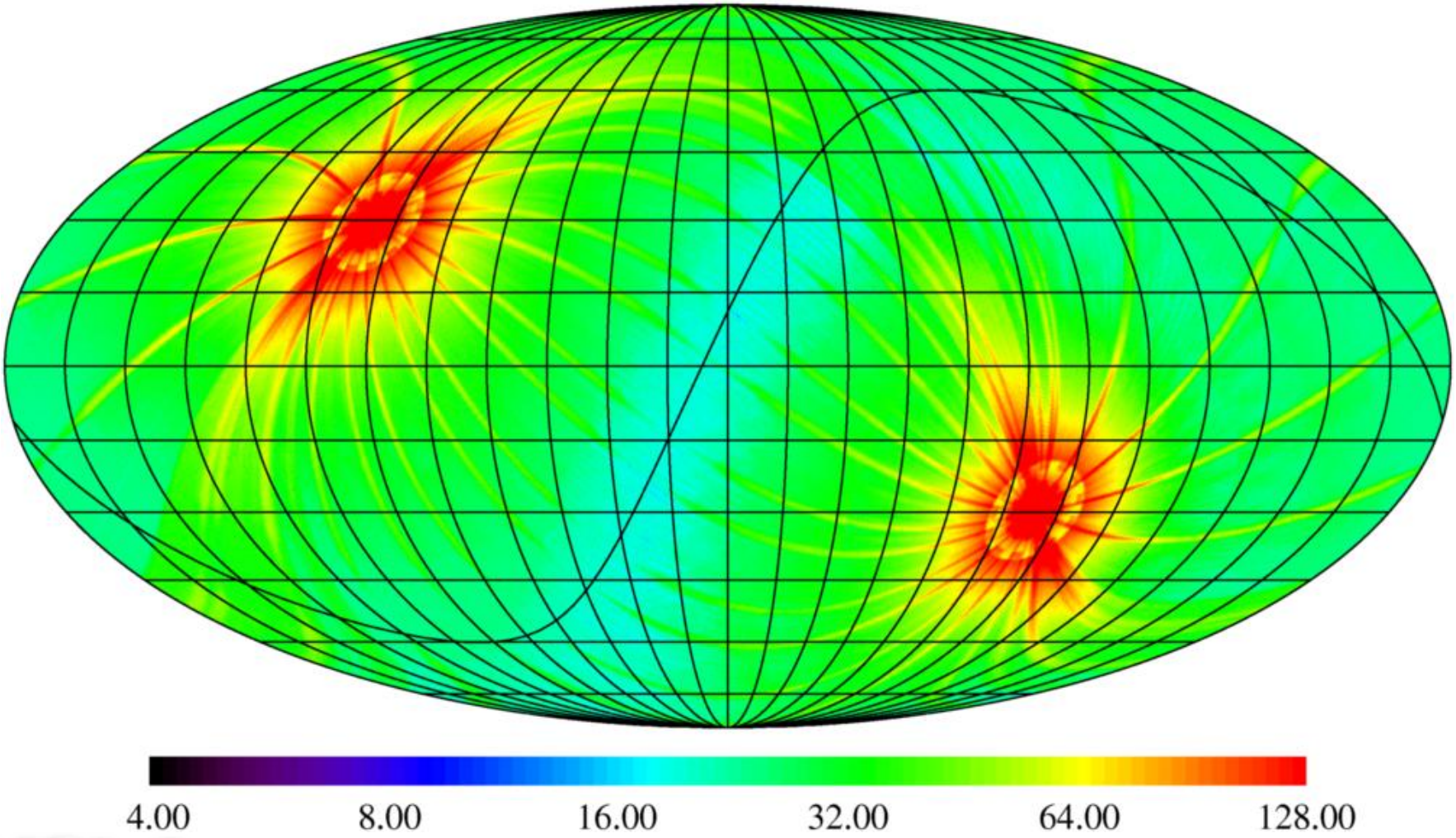
More Coverage upto 9/30/10

1884474 frames thru 10-273.0; 68.0% to 16x+



Final 2 band coverage

2784184 frames thru end of mission

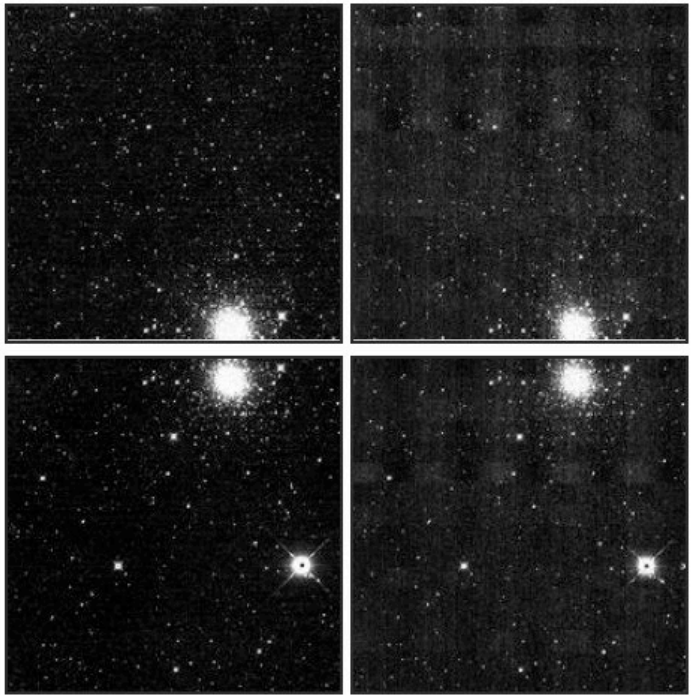


Ten trillion pixels observed!

M3 again

with Comet Garradd in January 2010

as seen 3 Jan 2011



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

http://wise.astro.ucla.edu