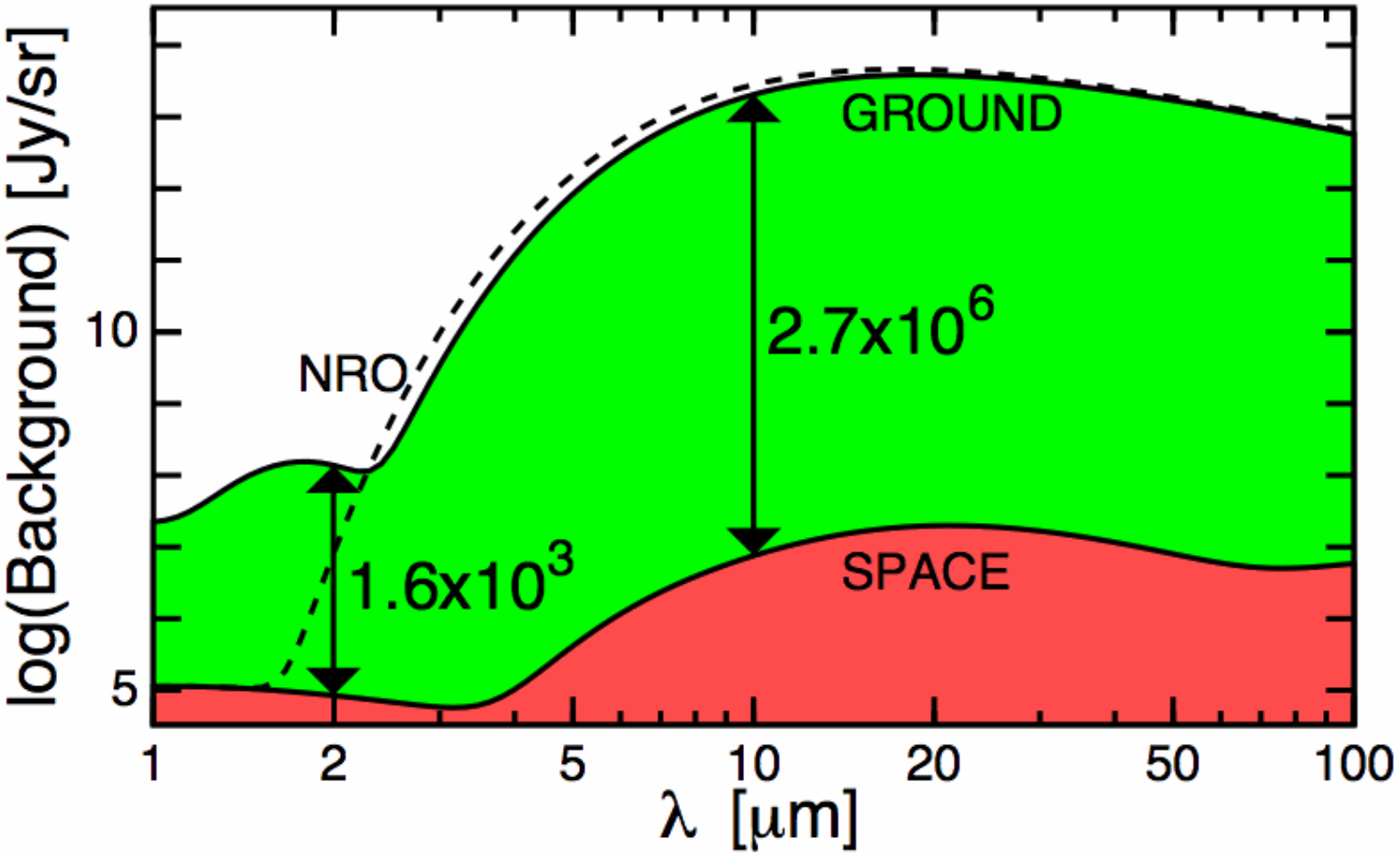
Wide-Field Infrared Surveys: WISE and NEOWISE-R

Ned Wright (UCLA)

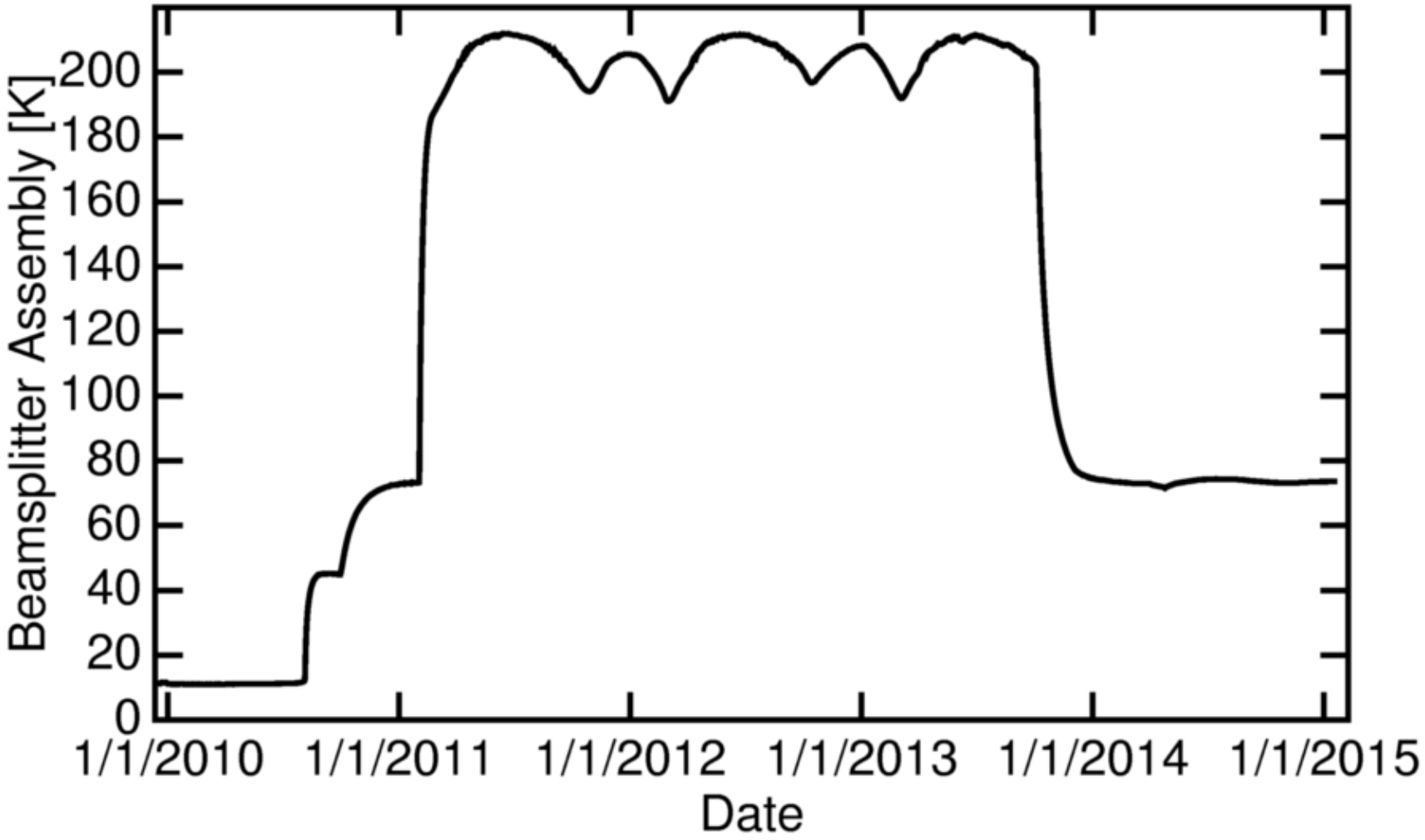
Why Space?

"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!

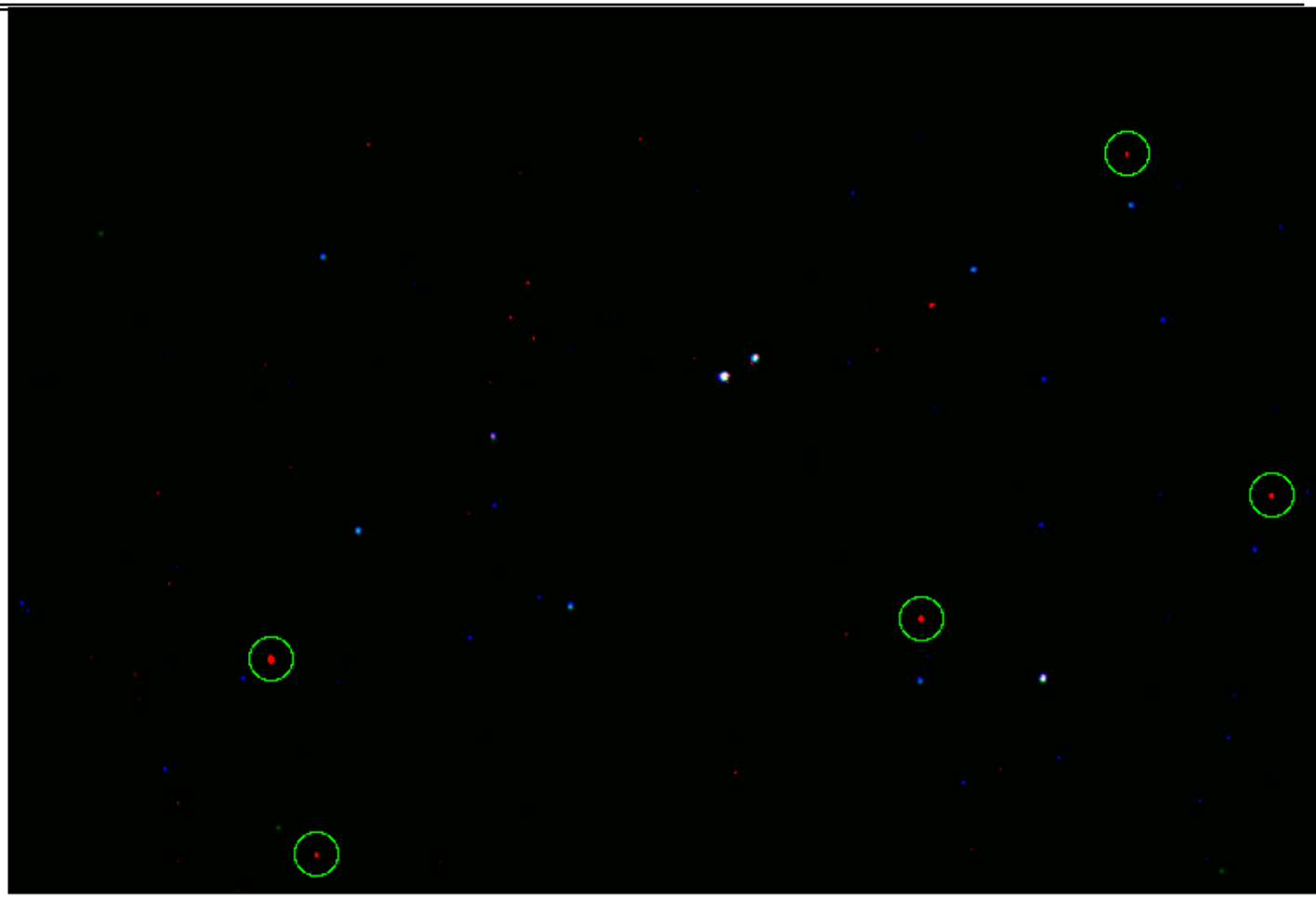
WISE Re-Animated



- Planetary Division of NASA is funding new observations by WISE to search for NEOs. This is NEOWISE-R.

Asteroids Move

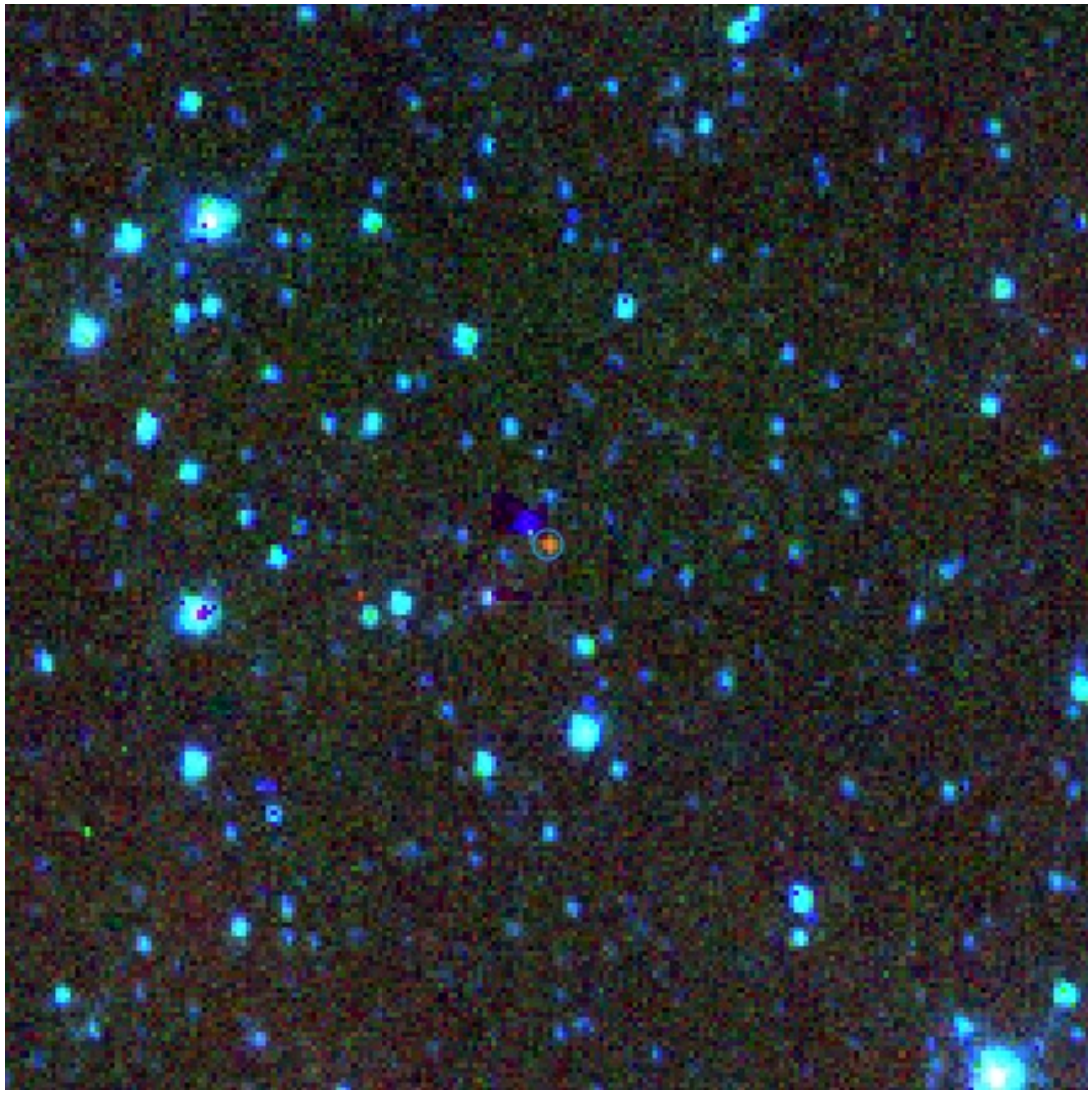
- Four frames of data taken on 2010 Jan. 8 during in-orbit checkout.
- Blue = 3.6um; green = 4.6um; red = 12um
- Circled asteroids are (L to R in the first frame, diameters in km):
  17818 MBA D~12.4
  153204 MBA D~2.8
  22006 MBA D~11.5
  87355 MBA D~4.3
  80590 MBA D~4.1



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

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 = 2.2%, estimated mass 200 megatons
- a = 1.756 AU, e = 0.54, i = 48°
- v_∞ = 29.5 km/sec
- Impact energy in TNT equivalent = Mass*(v_∞^2+11^2)/2.9^2

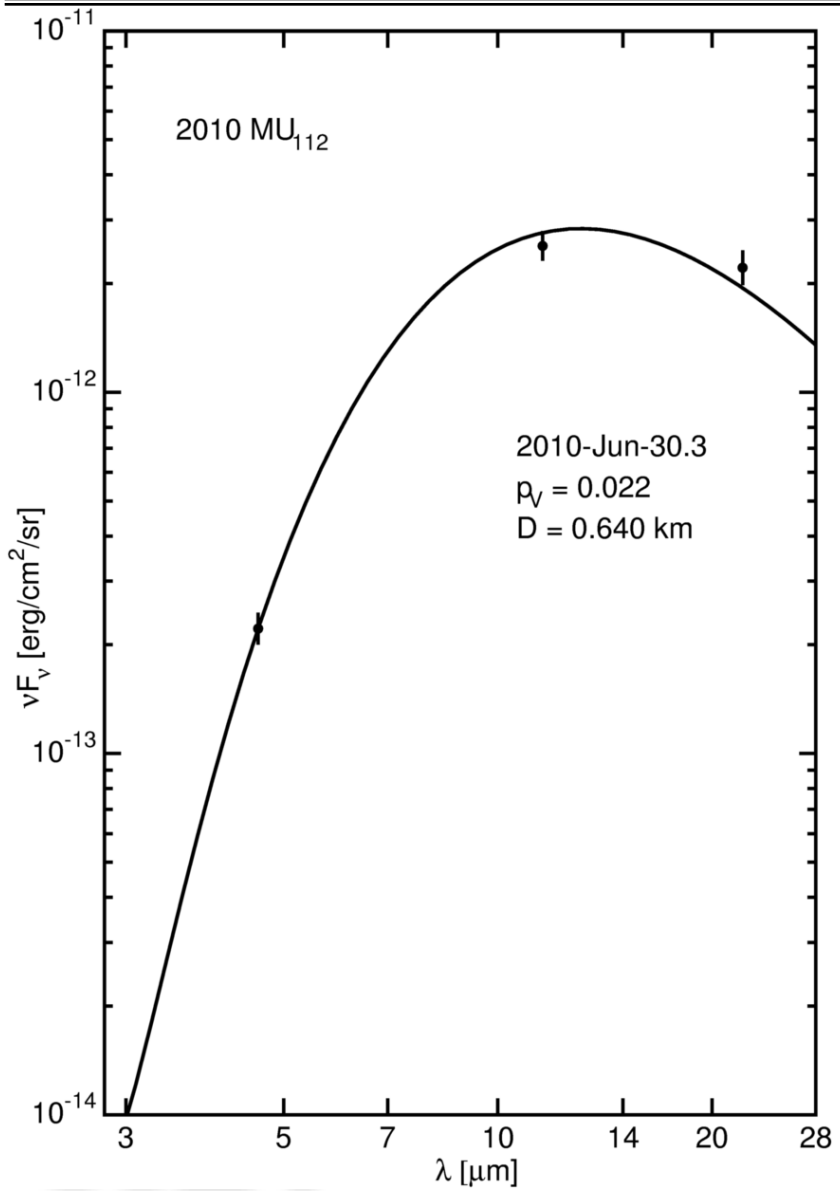


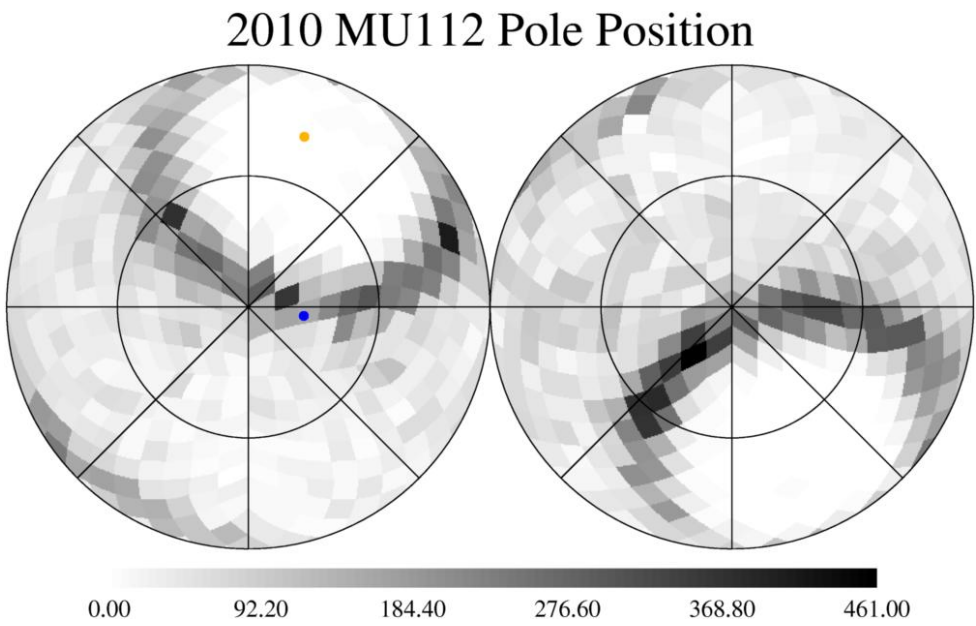
24 billion tons TNT

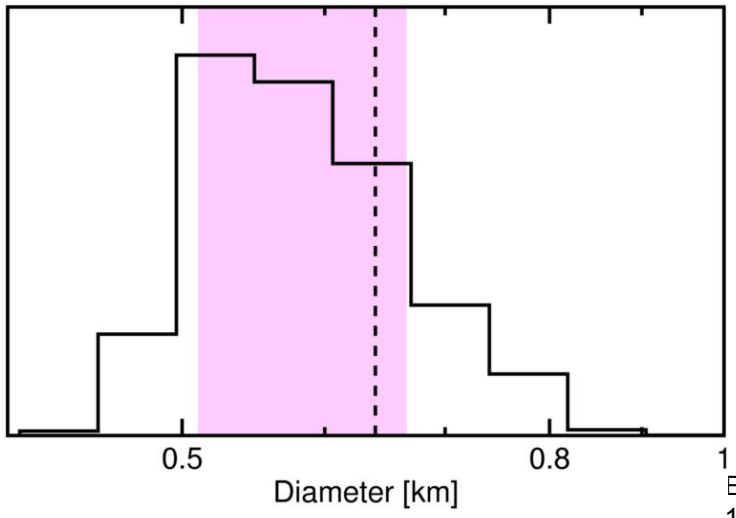
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Wide-field Infrared Survey Explorer (WISE)

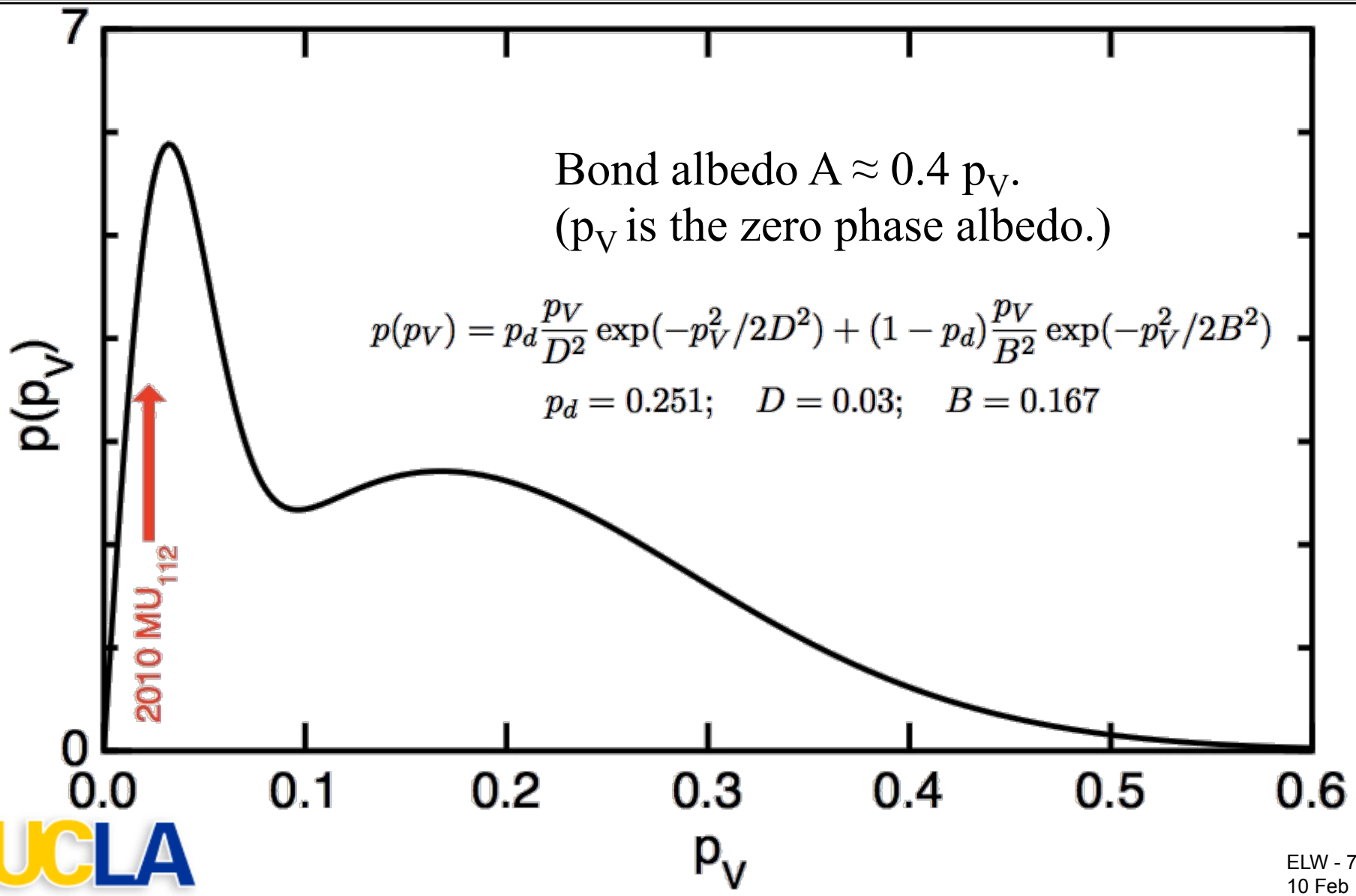
2010 MU_{112}







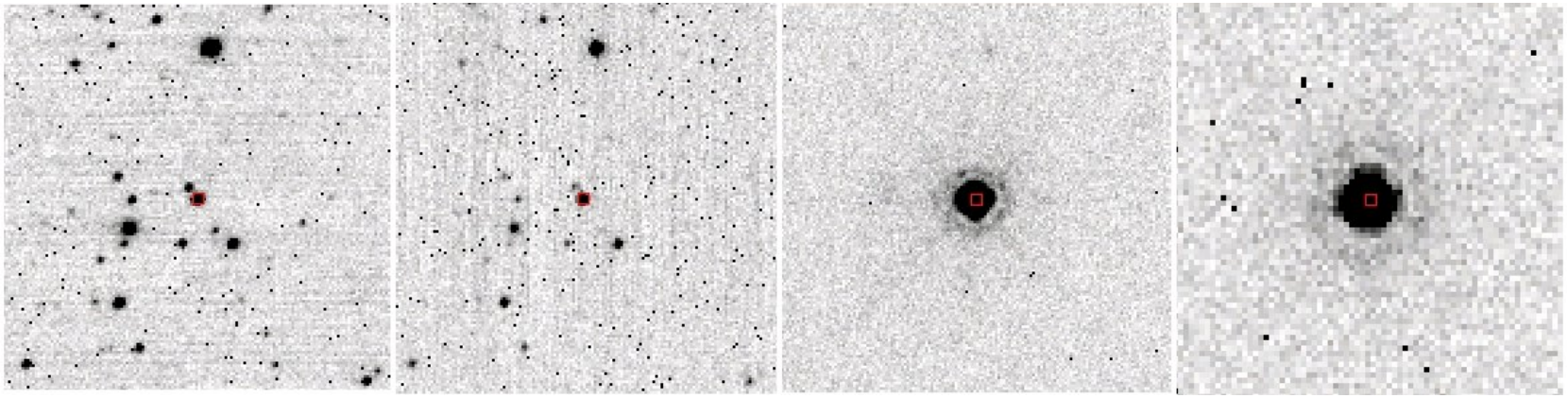
NEO albedo distribution model



Protecting the Planet Again

- Chelyabinsk: about 20 m dia, 450 kT TNT
- 2010 MU_{112}: 600 m dia, 24,000,000 kT TNT

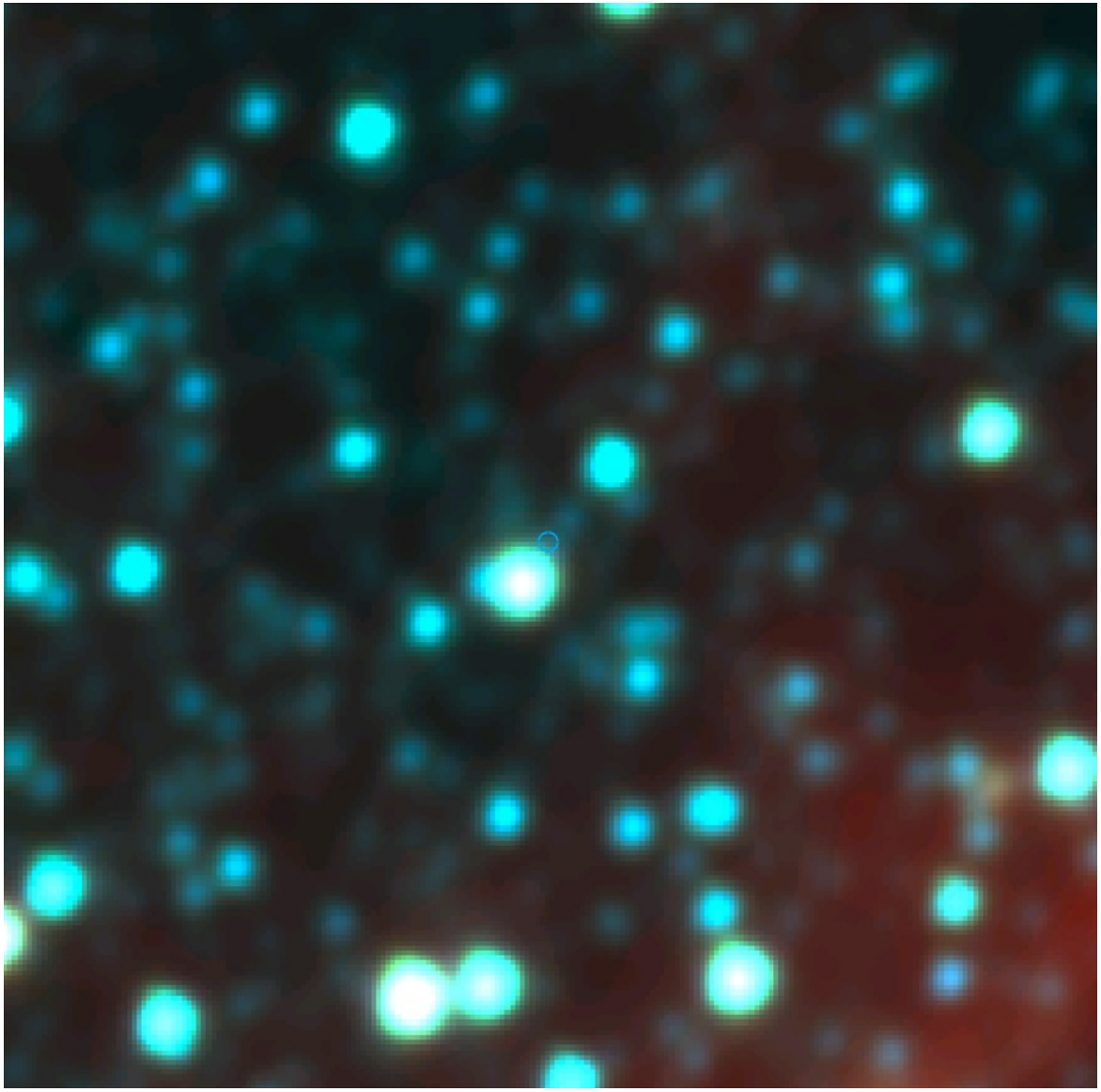
Neptune



- SNR = 563, 346, 6275 & 5849 in W1..4
  - W1..4 = 11.331, 10.878, 3.411, 0.180
  - not horribly saturated
- Neptune is fairly dark 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

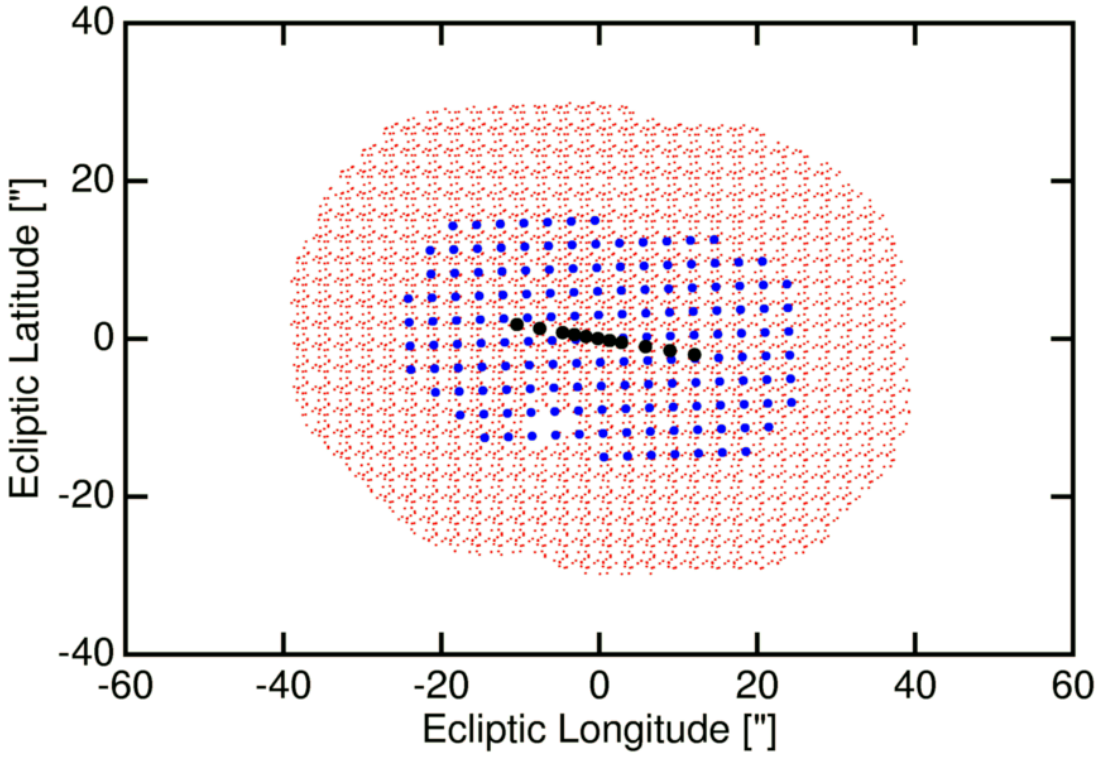
Pluto?

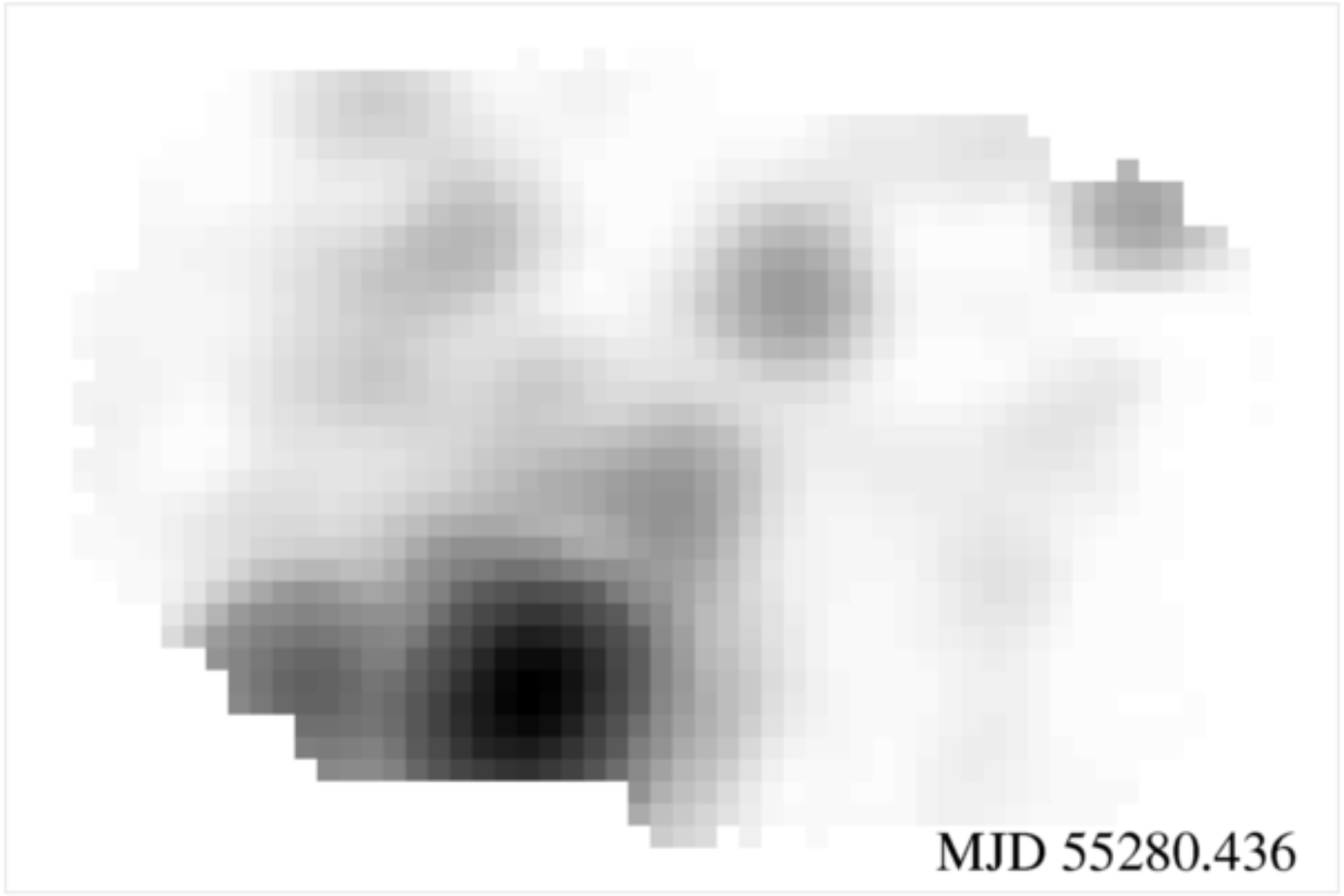
- Buried in Milky Way near the GC in March 2010
- Not at all obvious in the single frames or the coadd
- Never pulled out by the pipeline
- 5’ FoV cutout shown

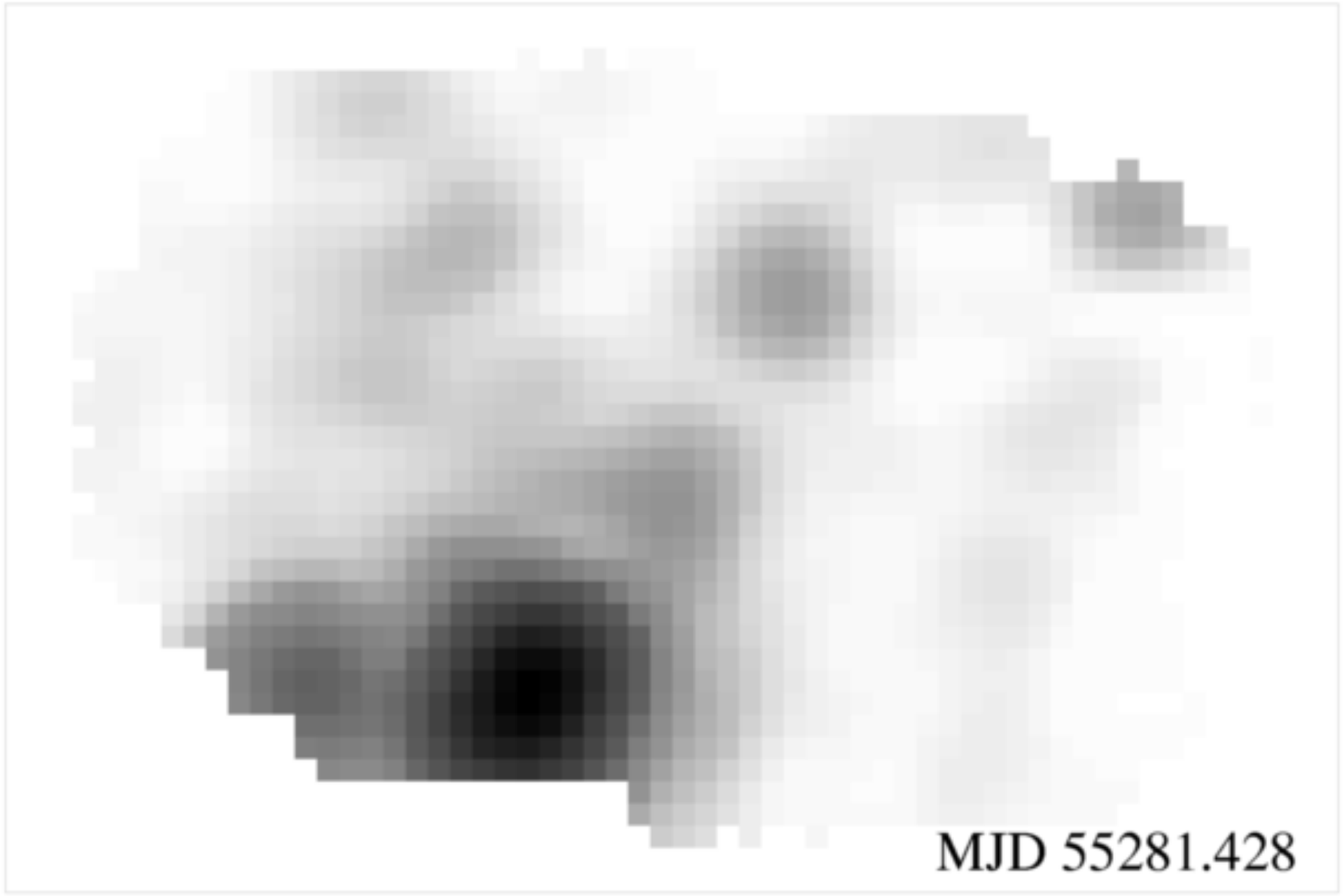


Moving Target Photometry

- We know where Pluto was for each frame
- Fit for a moving source plus a spatially arbitrary but temporally fixed background
- Red dots are all the pixels used
- Blue dots are the fixed background positions
- Black dots show the positions of Pluto




MJD 55280.436


MJD 55281.428

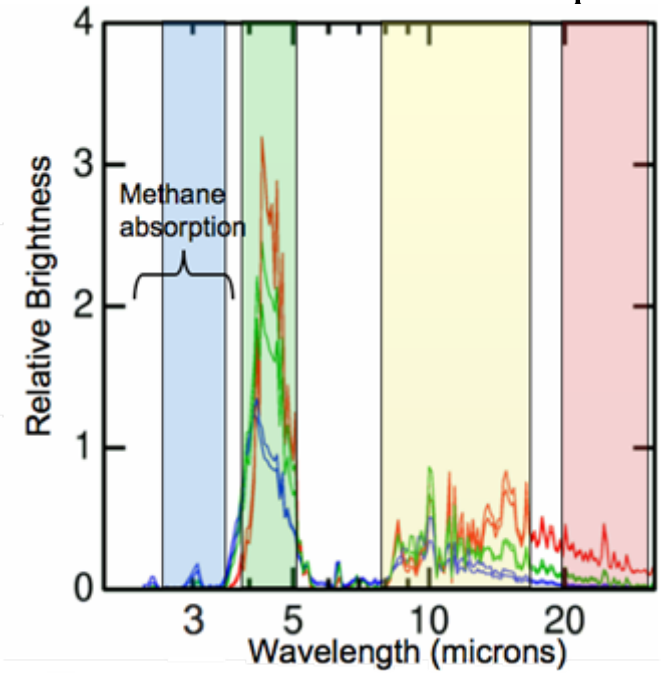
Pluto+Charon Albedo

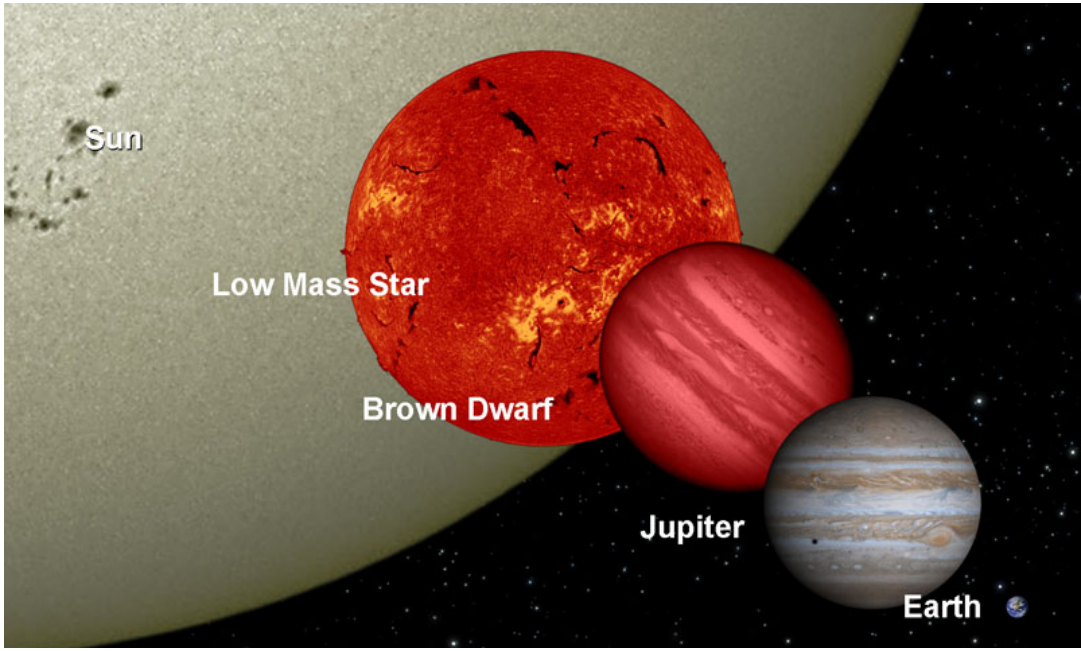
- In March 2010, W1 = 13.78 ± 0.14, photometric albedo p of combined Pluto+Charon = 0.185
- In Sep-Oct 2014, W1 = 14.36 ± 0.11, p=0.121
- In the expected range, even though the model of a moving but constant brightness source is wrong for Pluto which varies with a 6 day period

- Errors by repeated half-sample bootstrap (Mahalanobis 1946) at the frame level

WISE and Brown Dwarfs

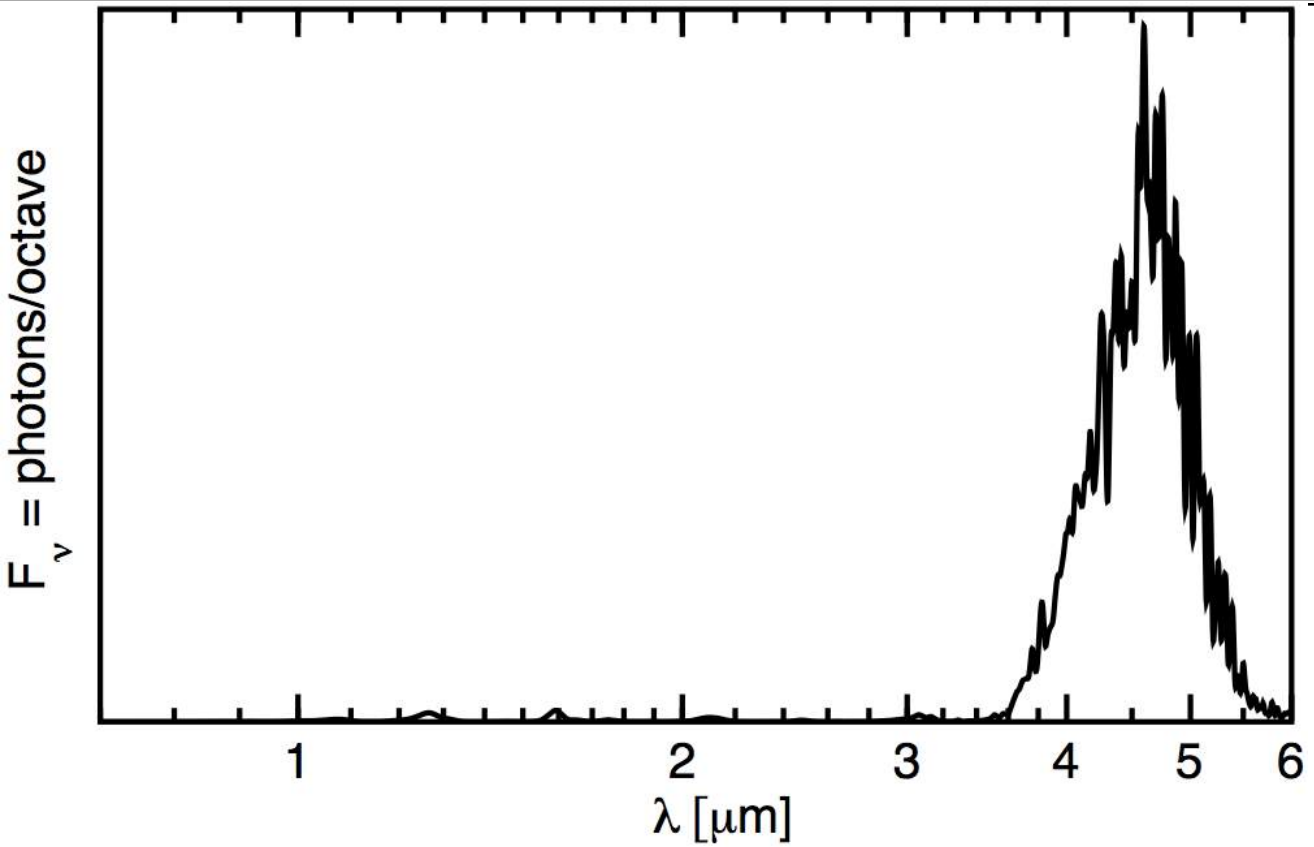
- Brown Dwarfs are stars with too little mass to fuse Hydrogen into Helium.
- WISE two short wavelength filters are tuned to methane dominated brown dwarf spectra.





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

Morley dusty model, T=400 K



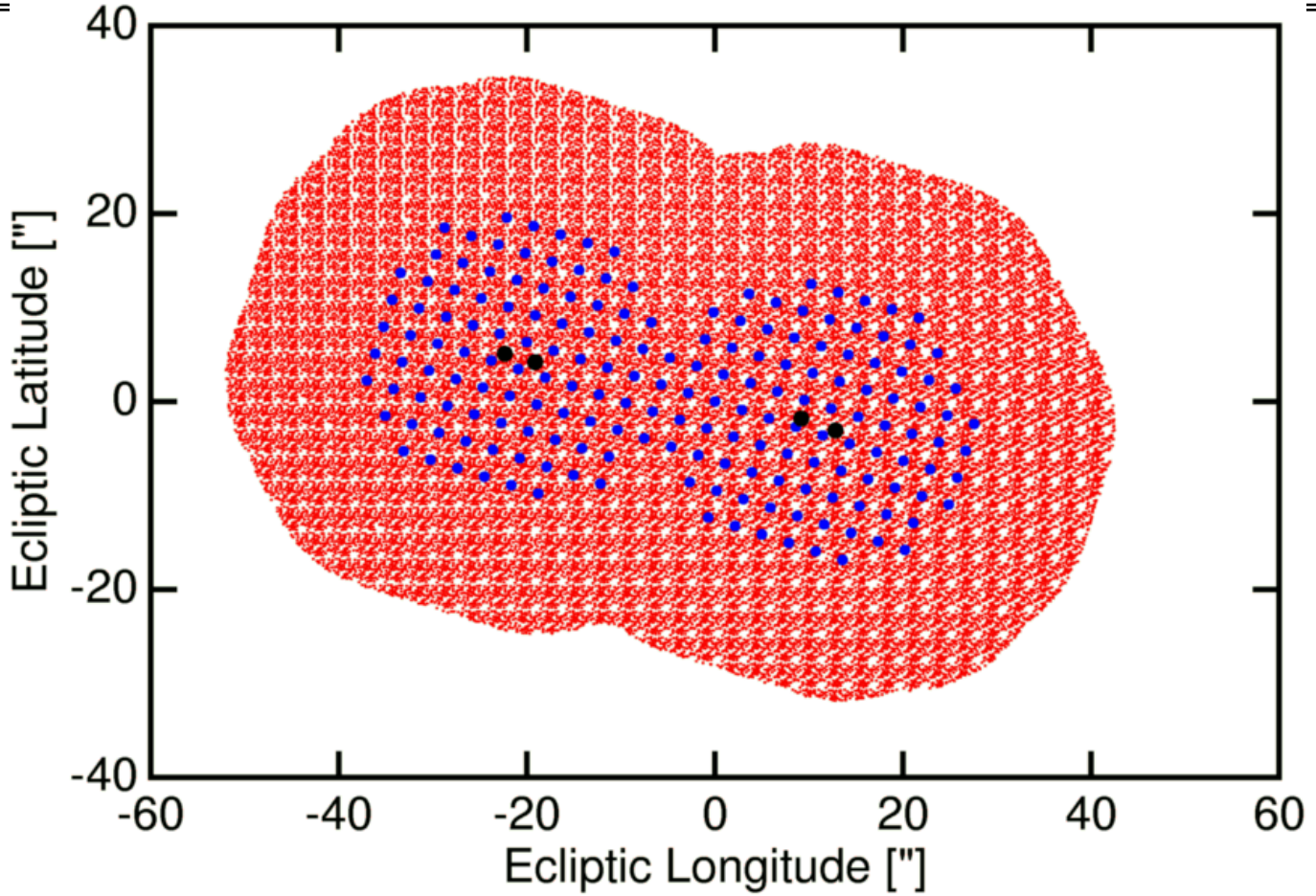
- Model has J-W2=7.35, so reddest WISE objects to date have 30x less flux at 1.27 μm than shown in this figure
- JWST at 4.5 μm is >5000x more sensitive than HST or WFIRST-AFTA for cold brown dwarfs.

WISE 0855-0714

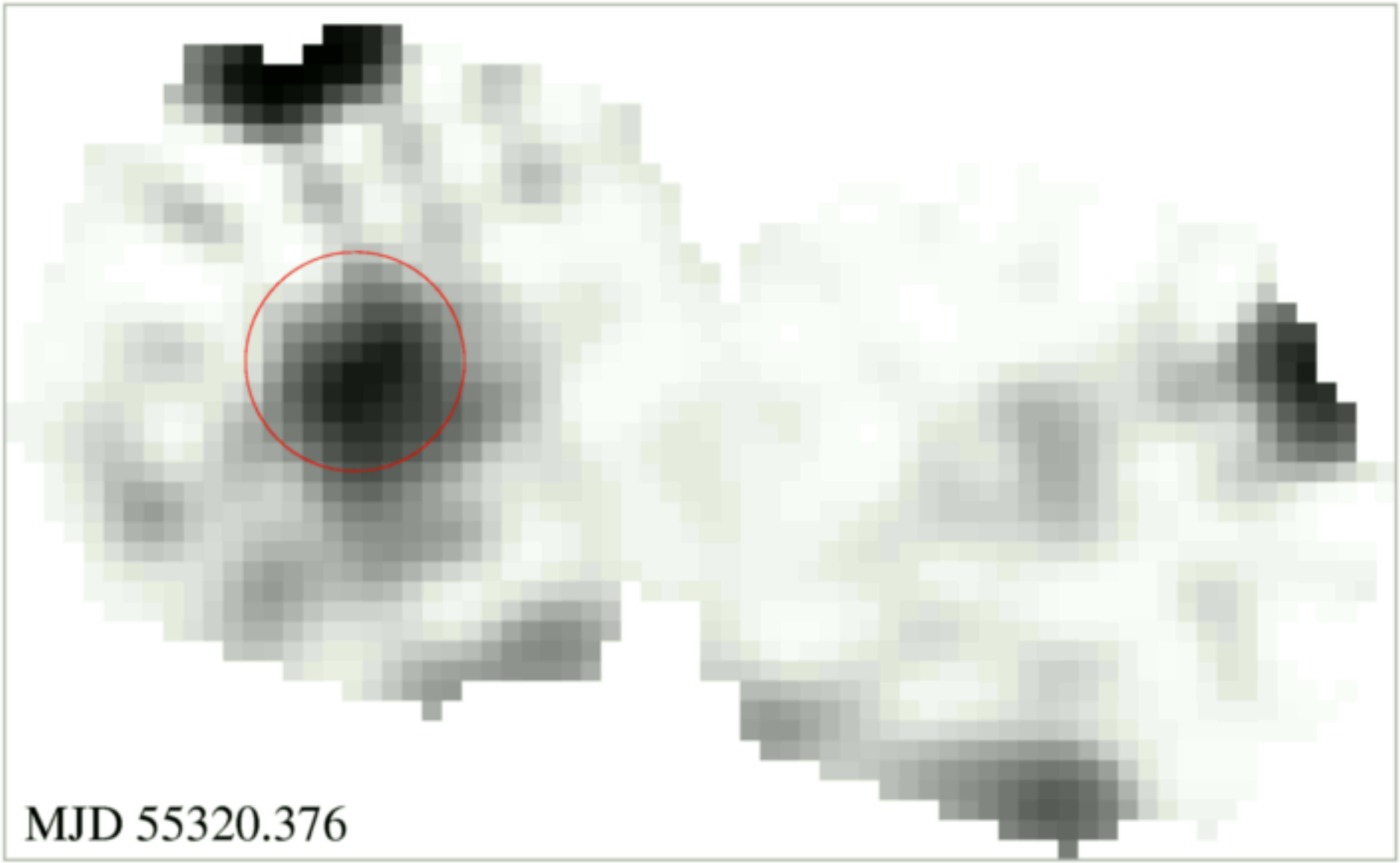
- Flagged by Luhman (2014, ApJ, 781, 4) [1 of 762]; & by Kirkpatrick *et al.* (2014, arxiv: 1402.0661) [1 of 58] as high proper motion without 2MASS counterpart
- Crucial Spitzer followup by Luhman (2014, arxiv:1404.6501) showed W0855 is the reddest and least luminous brown dwarf.
- Or a free floating planet
- 4th closest star system

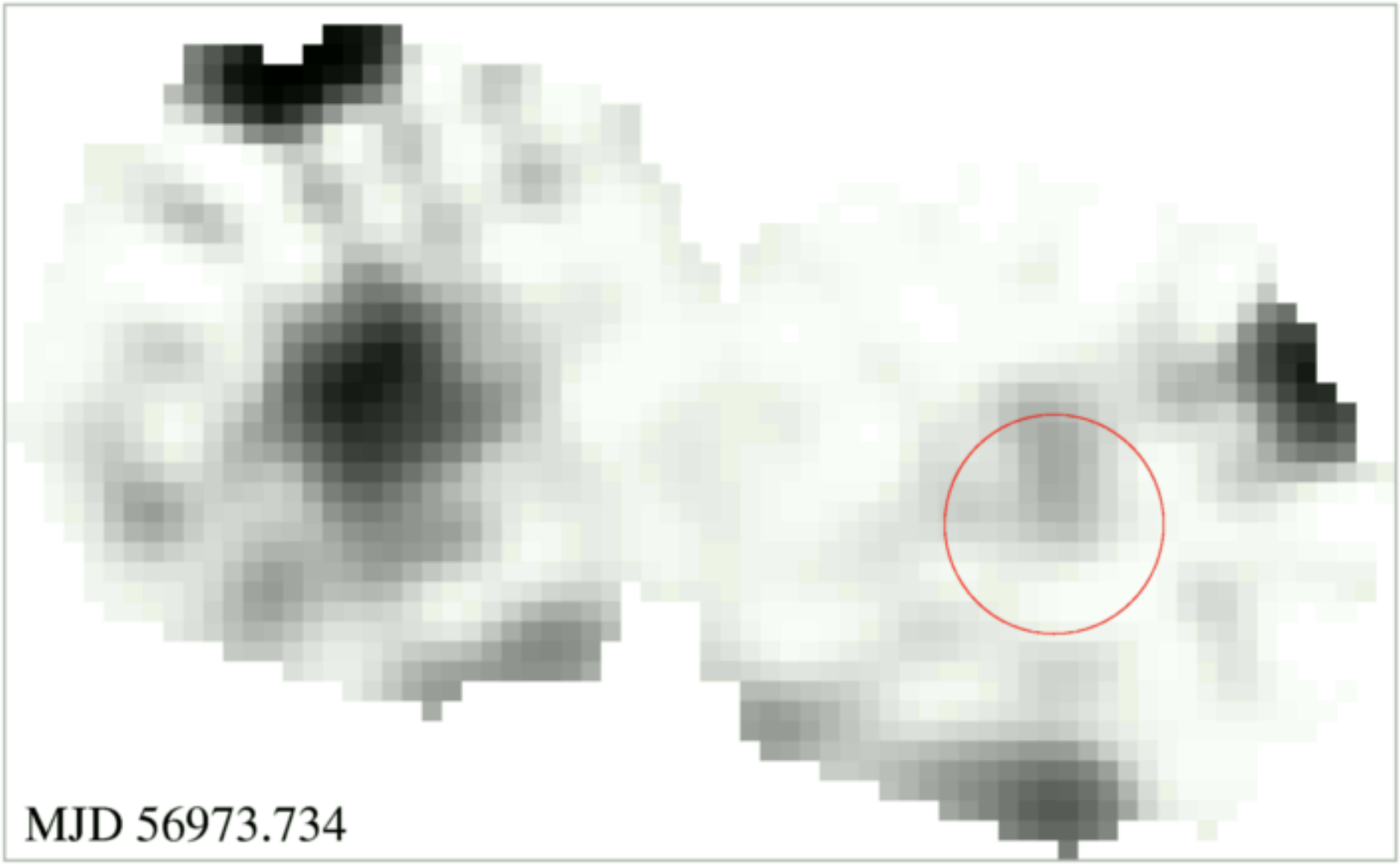
- D = 2.31 ± 0.08 pc (Luhman & Esplin, 2014)
- Proper motion 8.1 “/yr
- $M_{W2} = 17.20 \pm 0.09$
- W1-W2 = $5.0^{+2.2}_{-0.7}$ (Wright *et al.* 2014)
- IRAC [3.6]-[4.5] = 3.55
- J3-W2 = $10.8^{+0.53}_{-0.33}$ (Faherty *et al.* 2014)
- T_{eff} = 250 K, could be 1 Gyr old and 3 M_J, or 10 Gyr old and 10 M_J

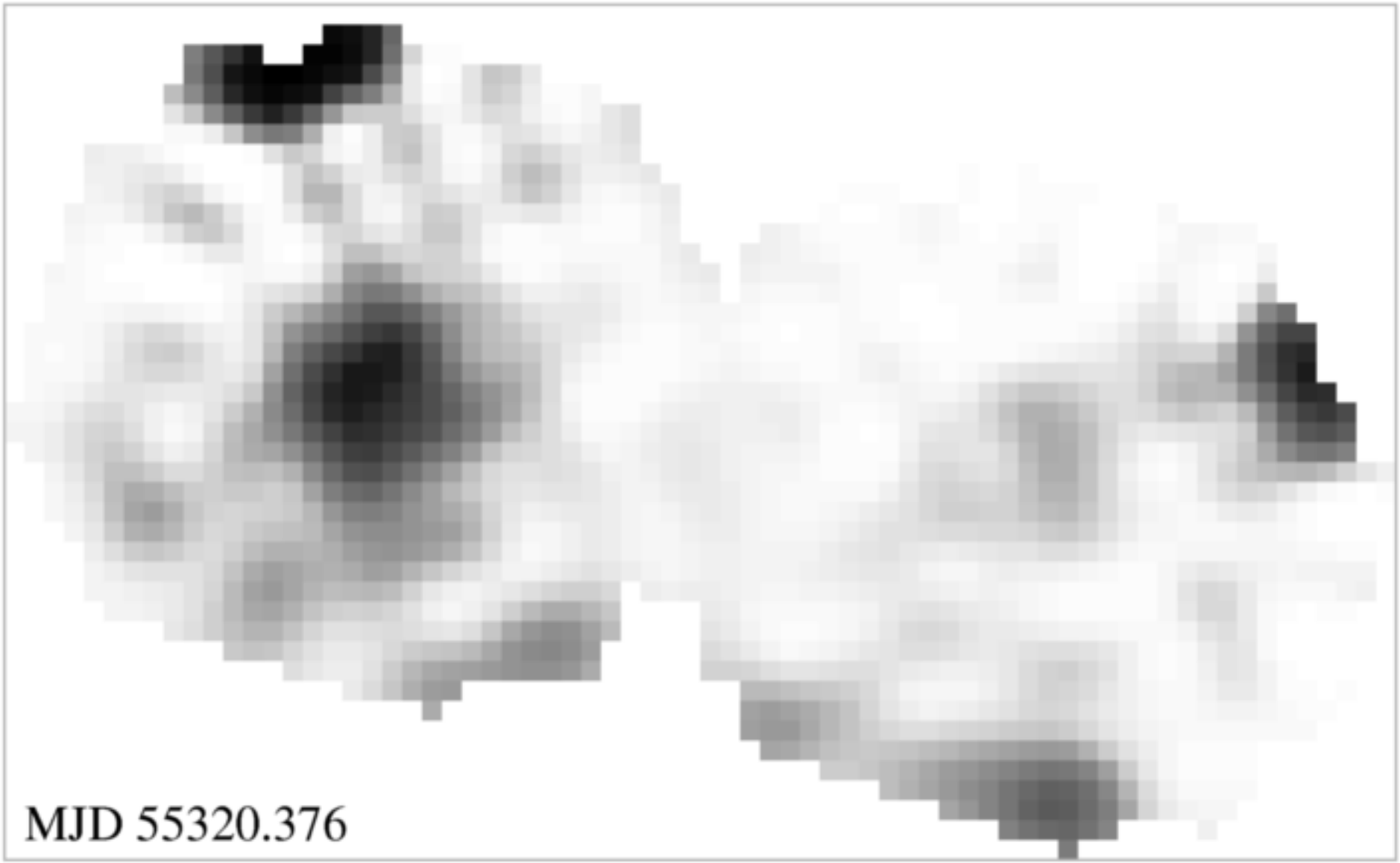
Try Moving Target Photometry

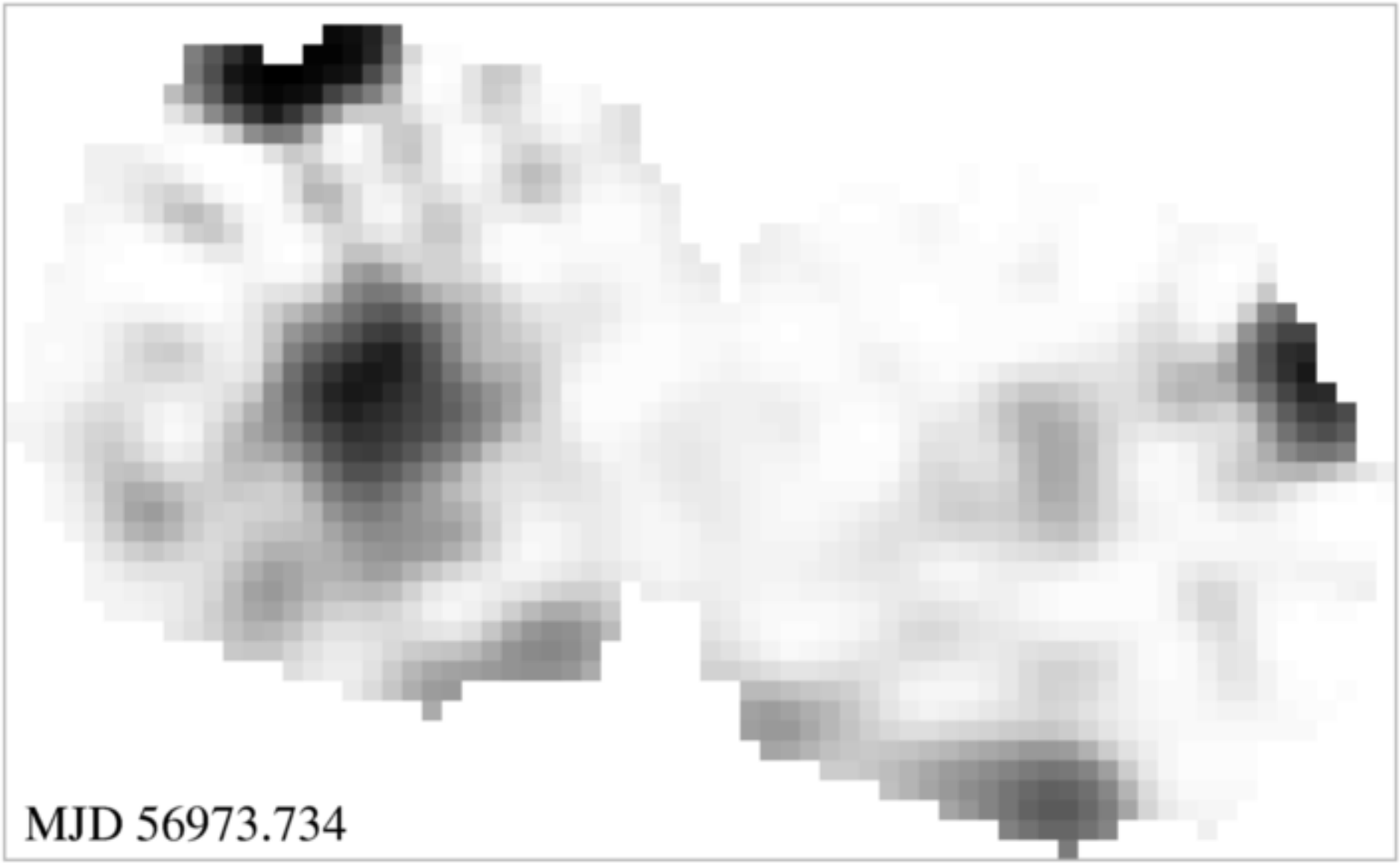


- 4 source positions
- 183 background points
- 81 frames
- 47,758 pixels


MJD 55320.376

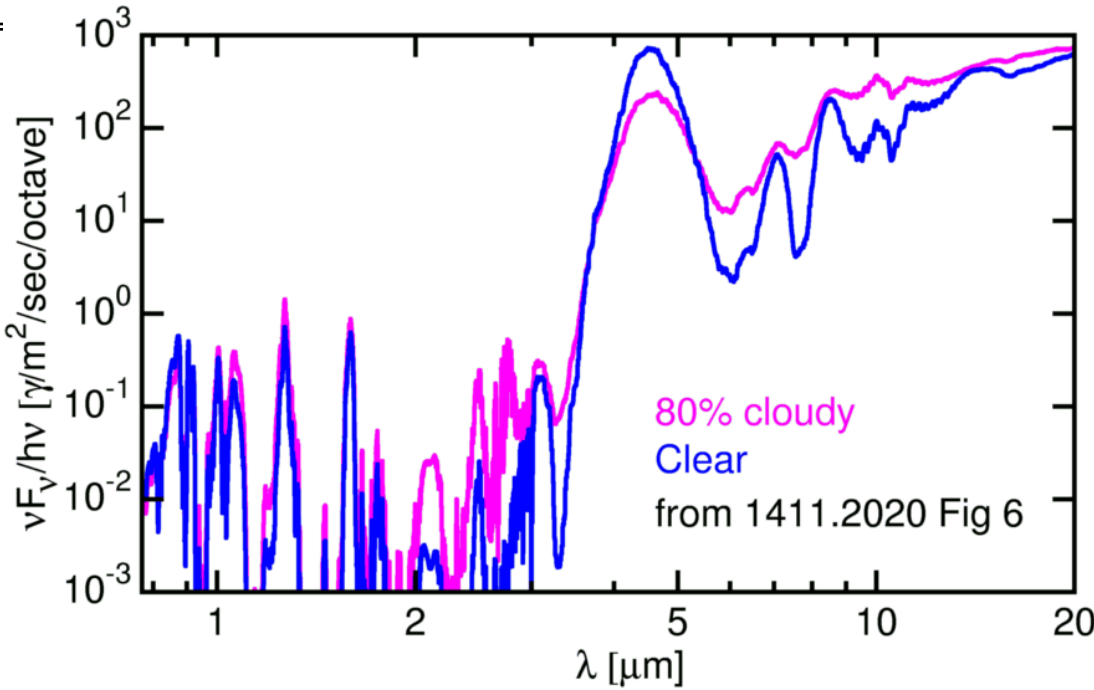

MJD 56973.734


MJD 55320.376


MJD 56973.734

W0855 WISE Color

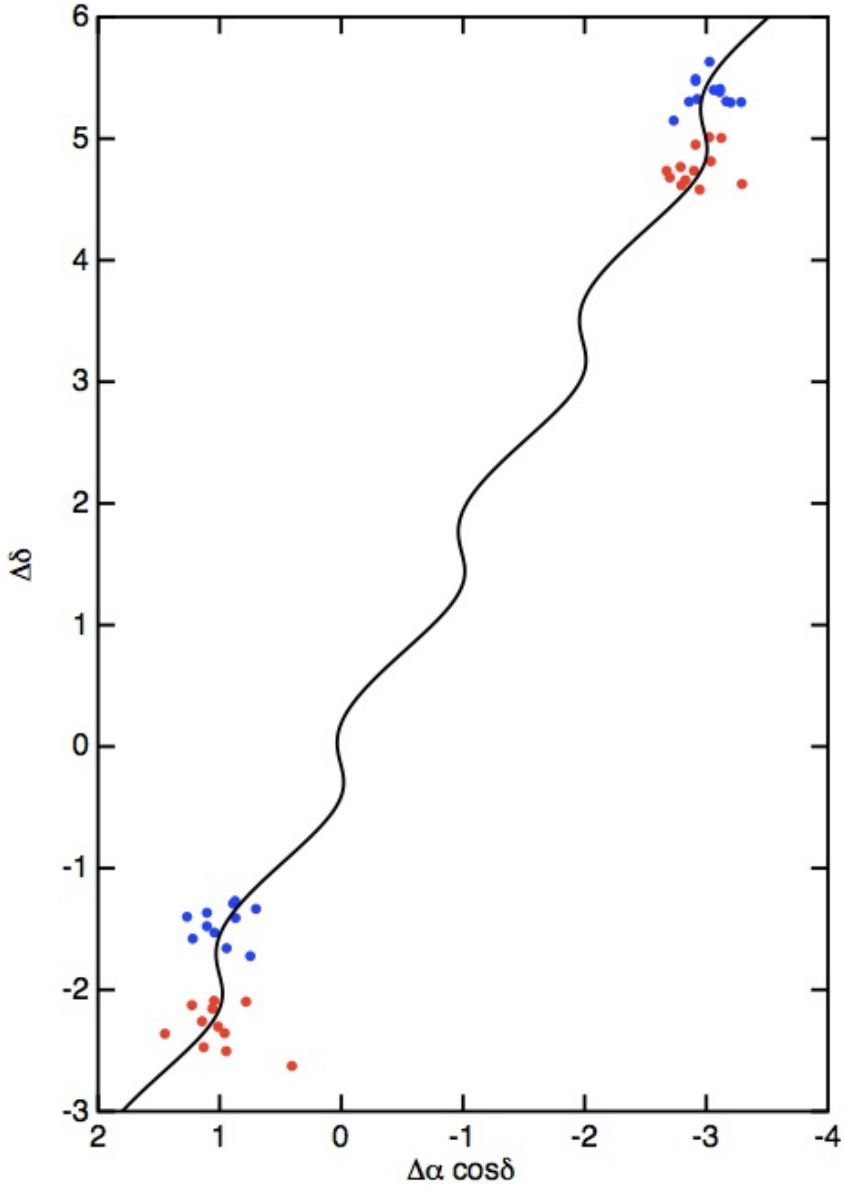
- Flux = 0.95 ± 1.51 DN (zeropoint = 20.5), or
  - 1.8 ± 2.9 μJy
- W1 = $20.56^{+\infty}_{-1.1}$ (1σ)
- W1-W2 ≈ 6.6, > 5.5 at 1σ, > 5 at 2σ
  - Considerably redder than IRAC ch1-ch2
- These limits are based on 81 frames



- Of these two models, the clear case fits better – best fit may be 29% cloudy.

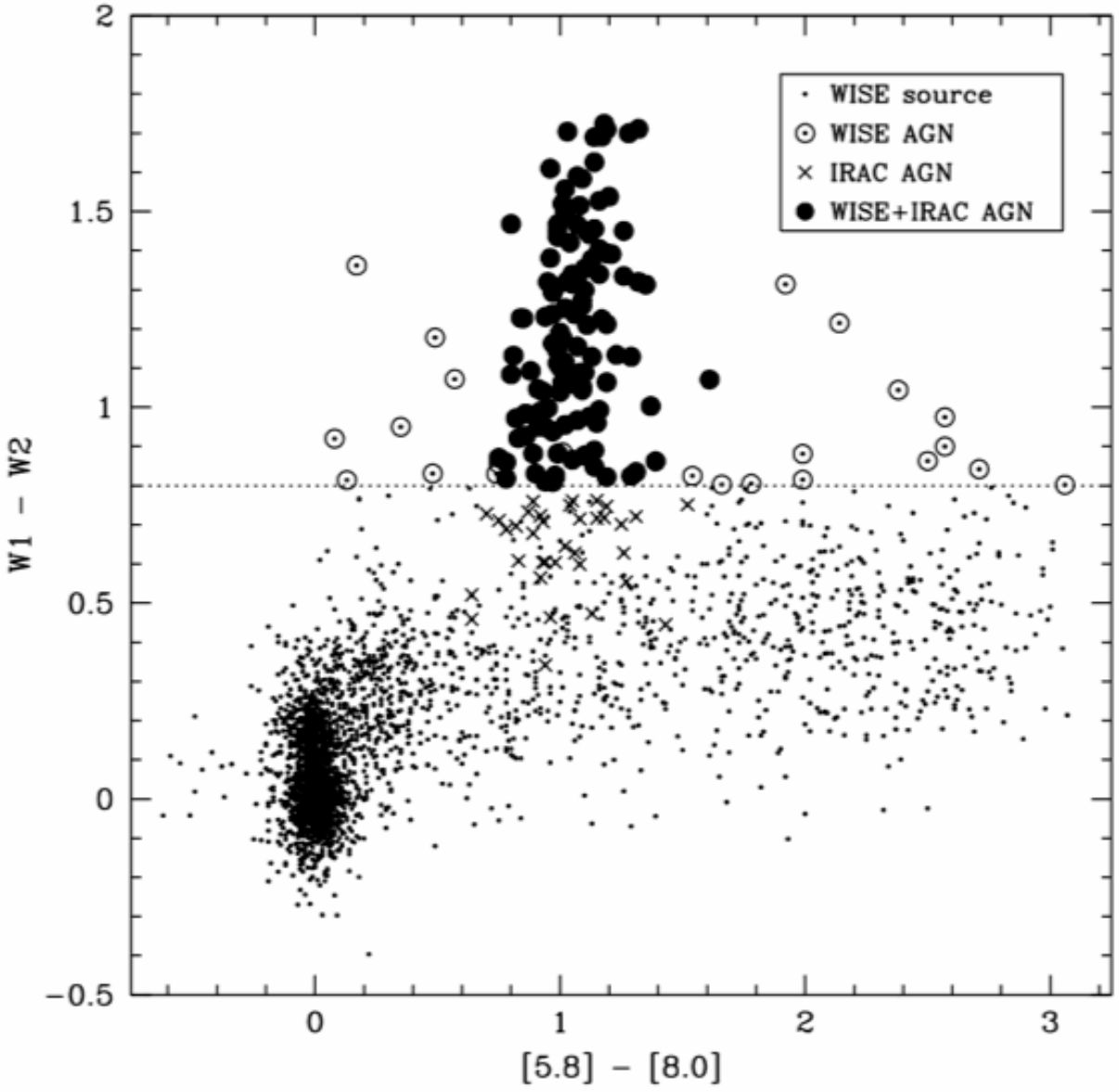
WISE only Parallax Possible

- Gl 570D in 2010 & 2014
- Gl 570A from Hipparcos
  - μ_α = 1037 mas/yr
  - μ_δ = -1726 mas/yr
  - ϖ = 171 mas
- Gl 570D from WISE
  - μ_α = 996 ± 13 mas/yr
  - μ_δ = -1736 ± 14 mas/yr
  - ϖ = 225 ± 23 mas
- Relative orbital motion of ≈30 mas/yr expected



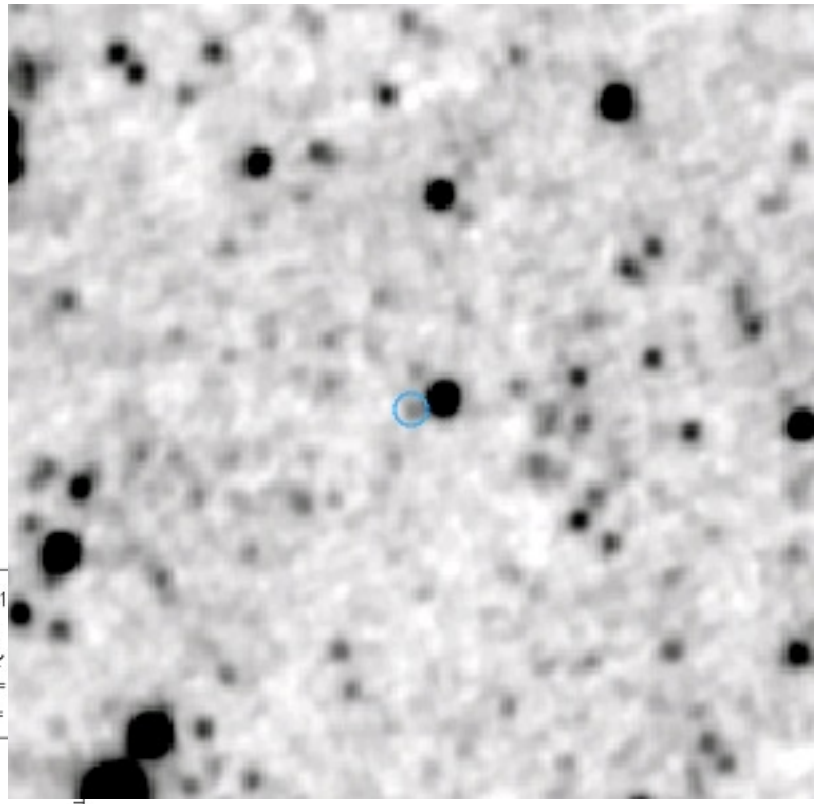
AGN Selection

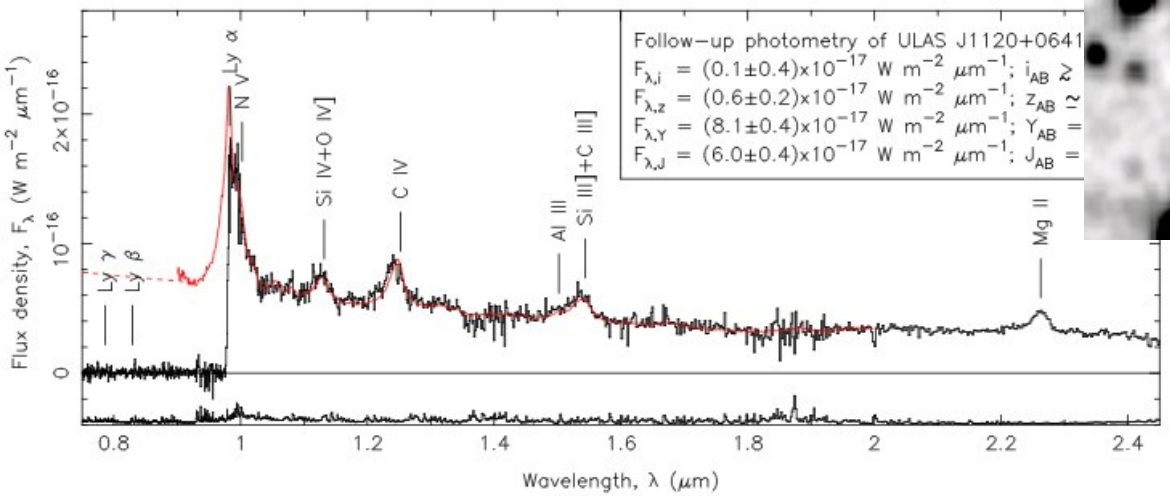
- Stern et al 2012, ApJ, 753, 30
- Density 70/sq.deg
- 60% have published z's in COSMOS field



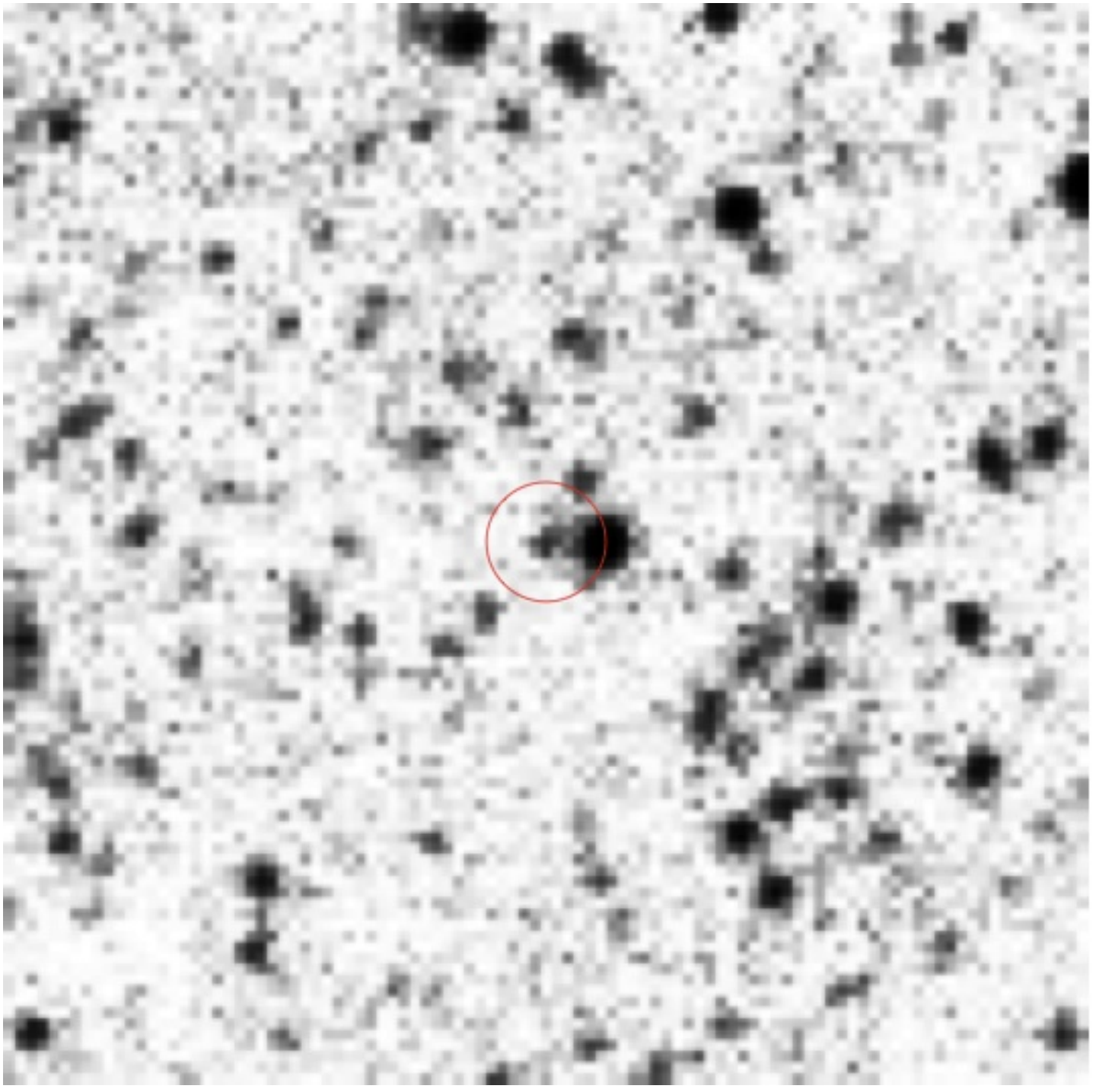
ULAS 1120+0641

- 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



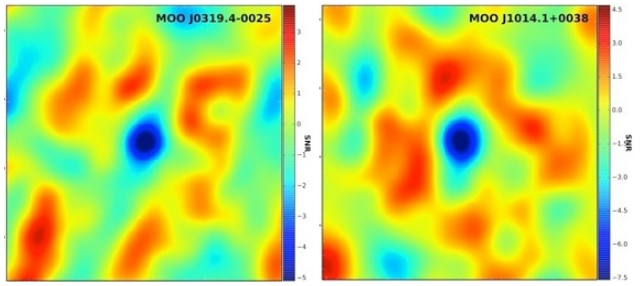


- Need zYJH to find high redshift dropouts
- Width more important than depth

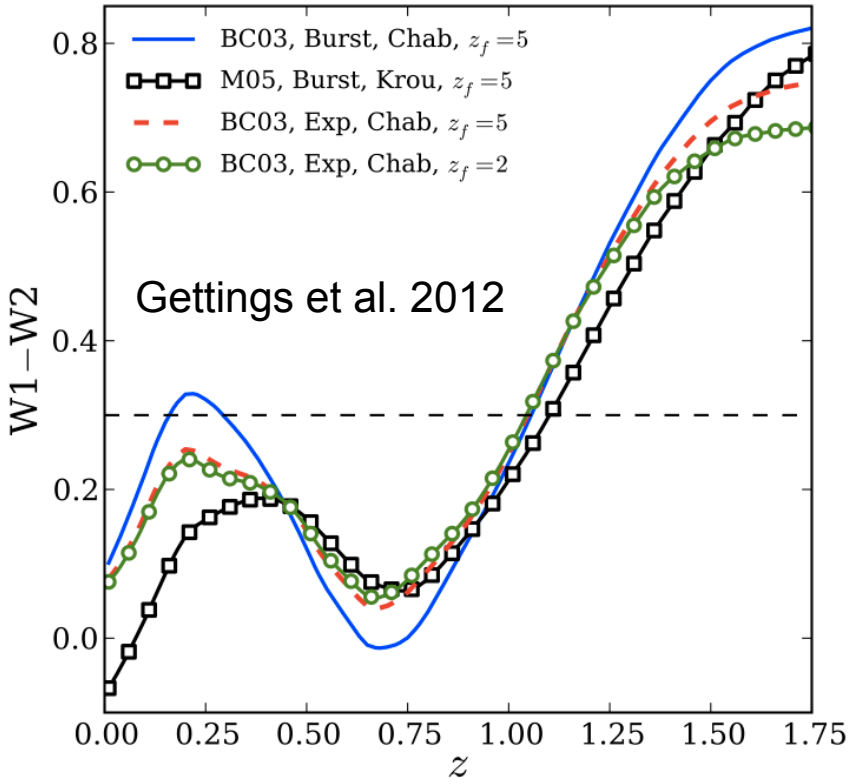


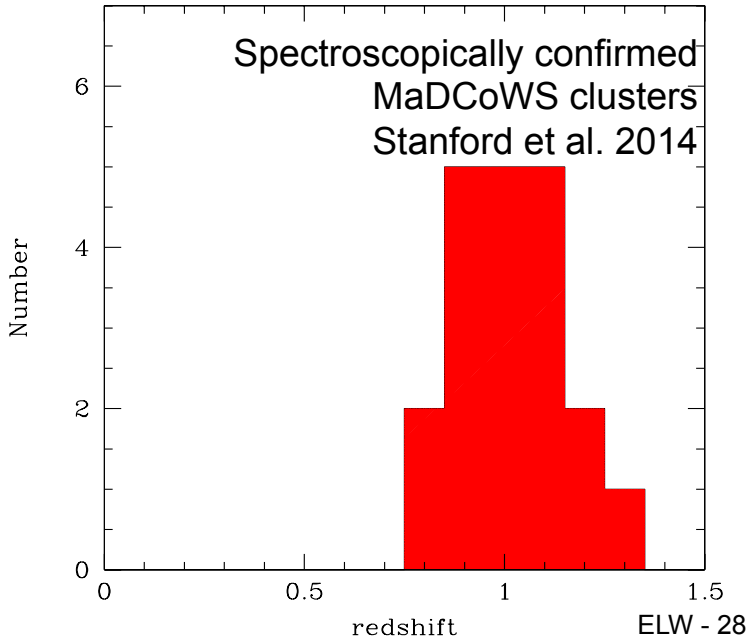
Massive Distant Clusters of WISE Survey (MaDCoWS)

- 20 MaDCoWS clusters at z ~ 1 (Stanford et al. 2014)
- CARMA S-Z signatures for 7 (Brodwin et al. 2014)
  - Time for 20 more allocated
- Current MaDCoWS sample W1 selected
- With MaxWISE, can select on W2 and probe massive structure growth in first half of Universe



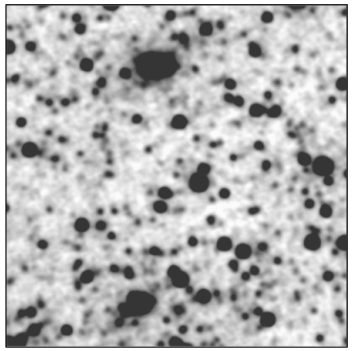
M~5×10^{14} M$_\odot$ from CARMA S-Z
Brodwin et al. 2014



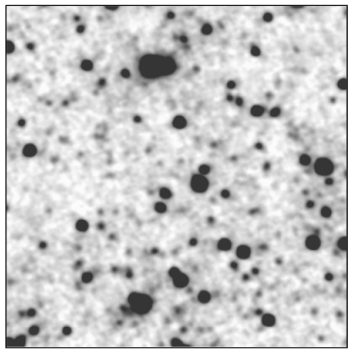


Distant Galaxies and MaxWISE

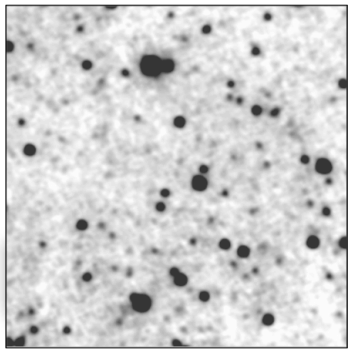
Increasing Exposures on North Ecliptic Pole



MaxWISE Depth

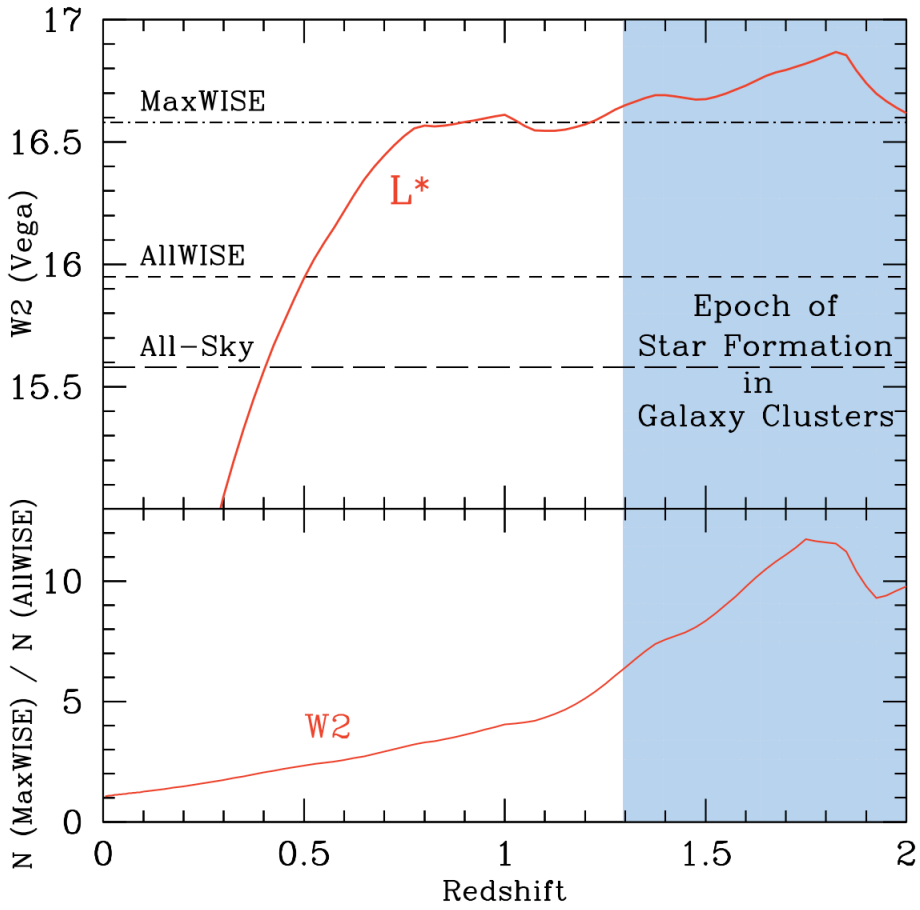


AllWISE Depth

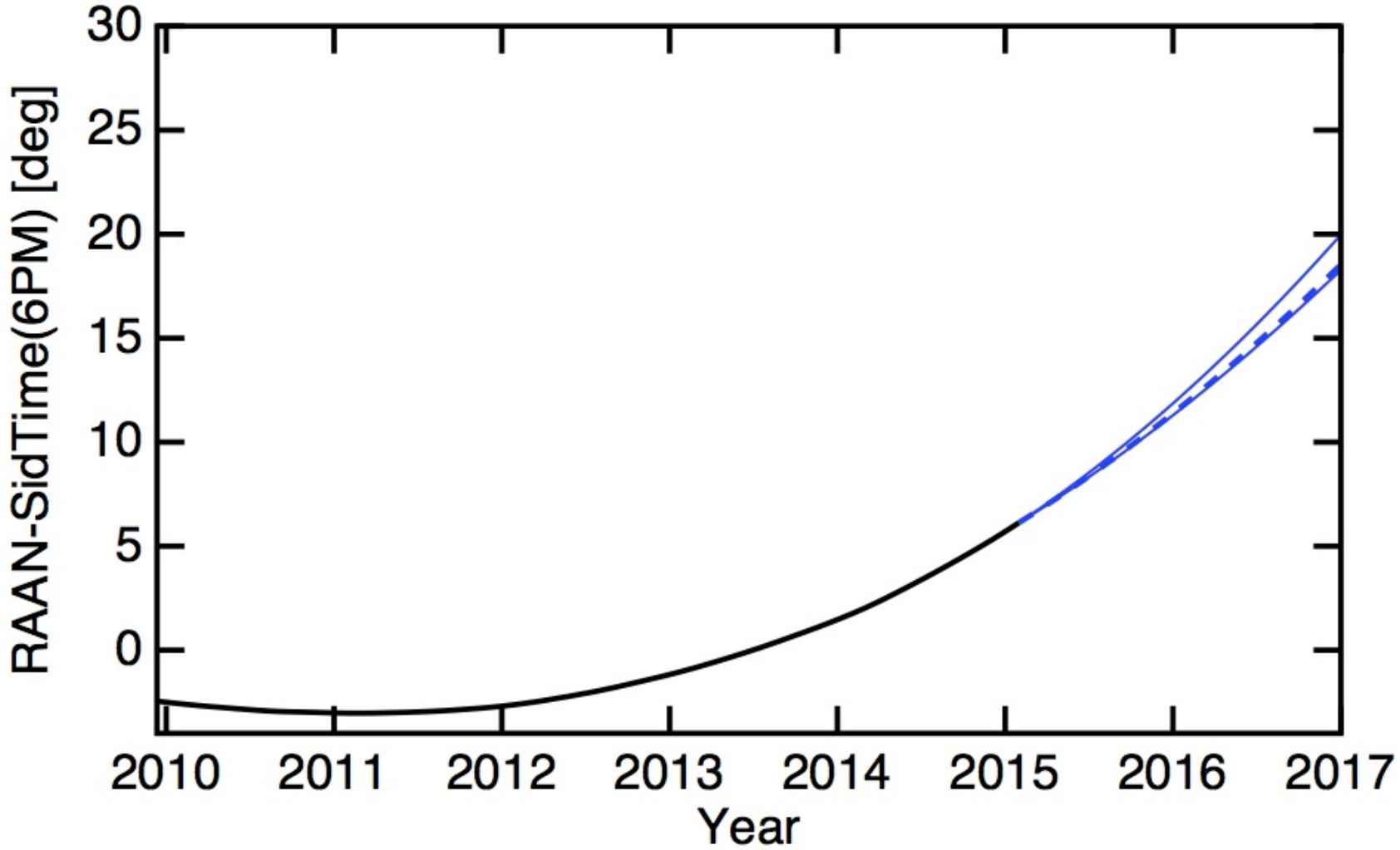


WISE Depth

With four times as many exposures as AllWISE, MaxWISE sensitivity reaches a plateau for typical (L*) cluster galaxies that extends vastly further into the distant Universe



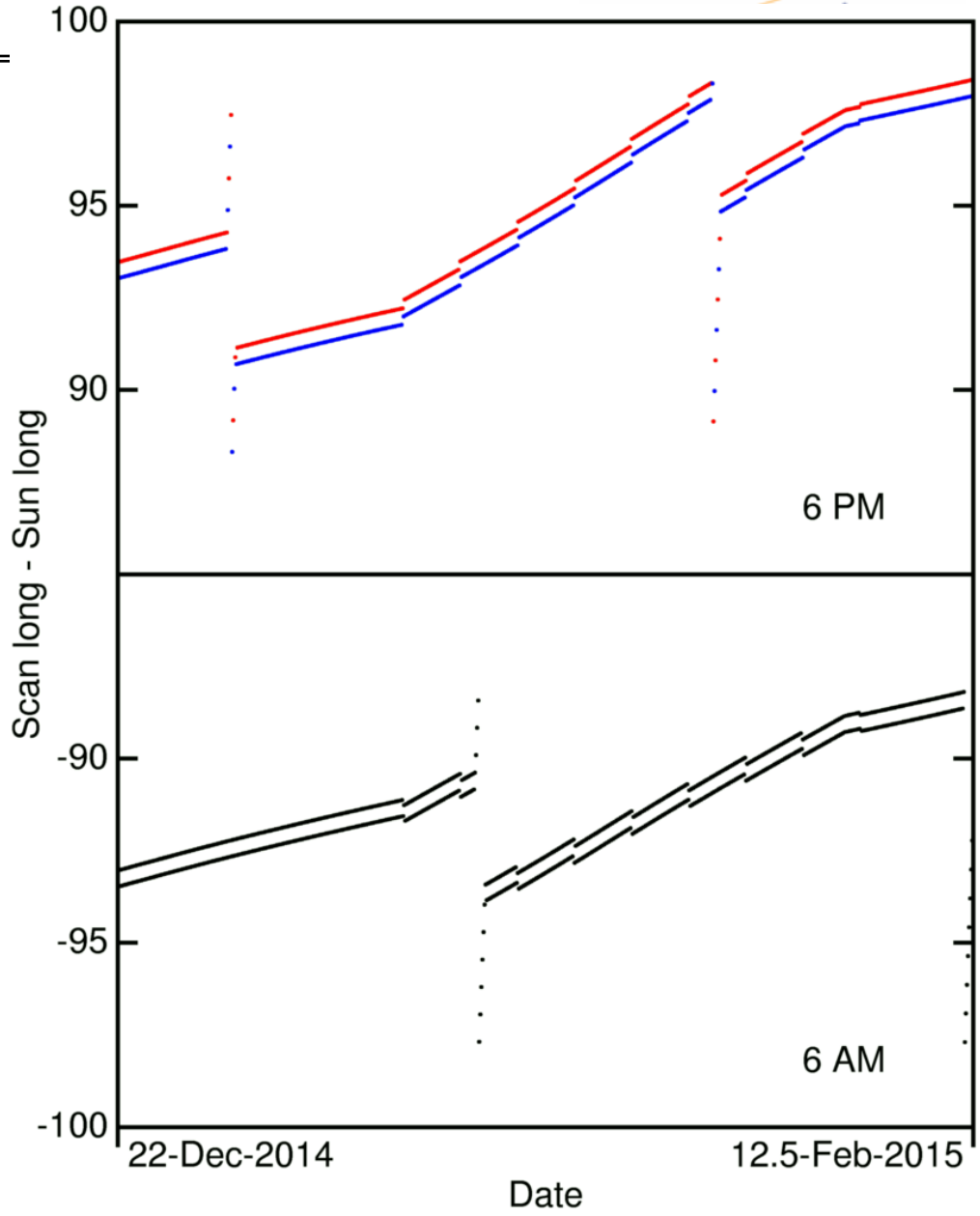
Future: Orbit is Drifting



- quadratic extrapolations fit to last two years.
- WISE can probably survive through 2016.

Planning for 8.3° Orbit in 2015

- In 2014 NEOWISE scanned 92.5±1.6° from Sun on both sides.
- In 2015 NEOWISE will scan 90±1.6° from the Sun on the AM side and 98.3±1.6° on the PM side.
- Transition now completed.



Astrophysics with NEOWISE

- Planetary Division only funds analysis up to single frame images and detection lists.
- A grand co-add of all the old WISE and new NEOWISE-R data will be very valuable for astrophysics:
  - Proper motions get an order of magnitude better, parallax gets separated
  - Better 3.4 & 4.6 μm sensitivity yields many more z > 1 clusters of galaxies and millions of new QSOs & AGN
  - IR variability over hourly, semi-annual and longer time scales for stars and AGN, RR Lyr, Cepheids, LPVs
- Transient alerts using image subtraction
- Proposal submitted to NASA Astrophysics, 1st to the Explorer MoO call that was defunded, 2nd an unsolicited proposal at their request, then 3rd to the senior review since Astrophysics was broke as usual. Unfunded again…

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

NEOWISE Single Frames Are Coming

- Single frame detections
- Single frame images
- Lots of faint sources to vet: 1/3 million W2 only AllWISE detections with W2 > 15. Too faint for single frame detections. You must coadd
- Lots more discovery space in the faint end of the catalog
- It would be efficient for NASA to fund a coadd of all the frames and catalog the billion sources looking for propoer motion and parallax, but so far this has not happened
- So let's make ADAP all WISE, all the time

Big Thanks Are Due

- Ball and SDL worked very well together and built an incredible observatory that is still going strong!
- Delivered **on time to the day** in our confirmation review schedule
- Data products from IPAC really maximize the utility of WISE data
- Without JPLers Bill Irace, Valerie Duval, Peter Eisenhardt, Amy Mainzer, Fengchuan Liu, Beth Fabinsky et al none of this could have worked.