A Method for Identifying M dwarfs with Ultra Cool Companions in 2MASS and WISE

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Background image adapted from WISE "PIA14881: Jabbah and Associates" NASA/JPL-Caltech/UCLA.

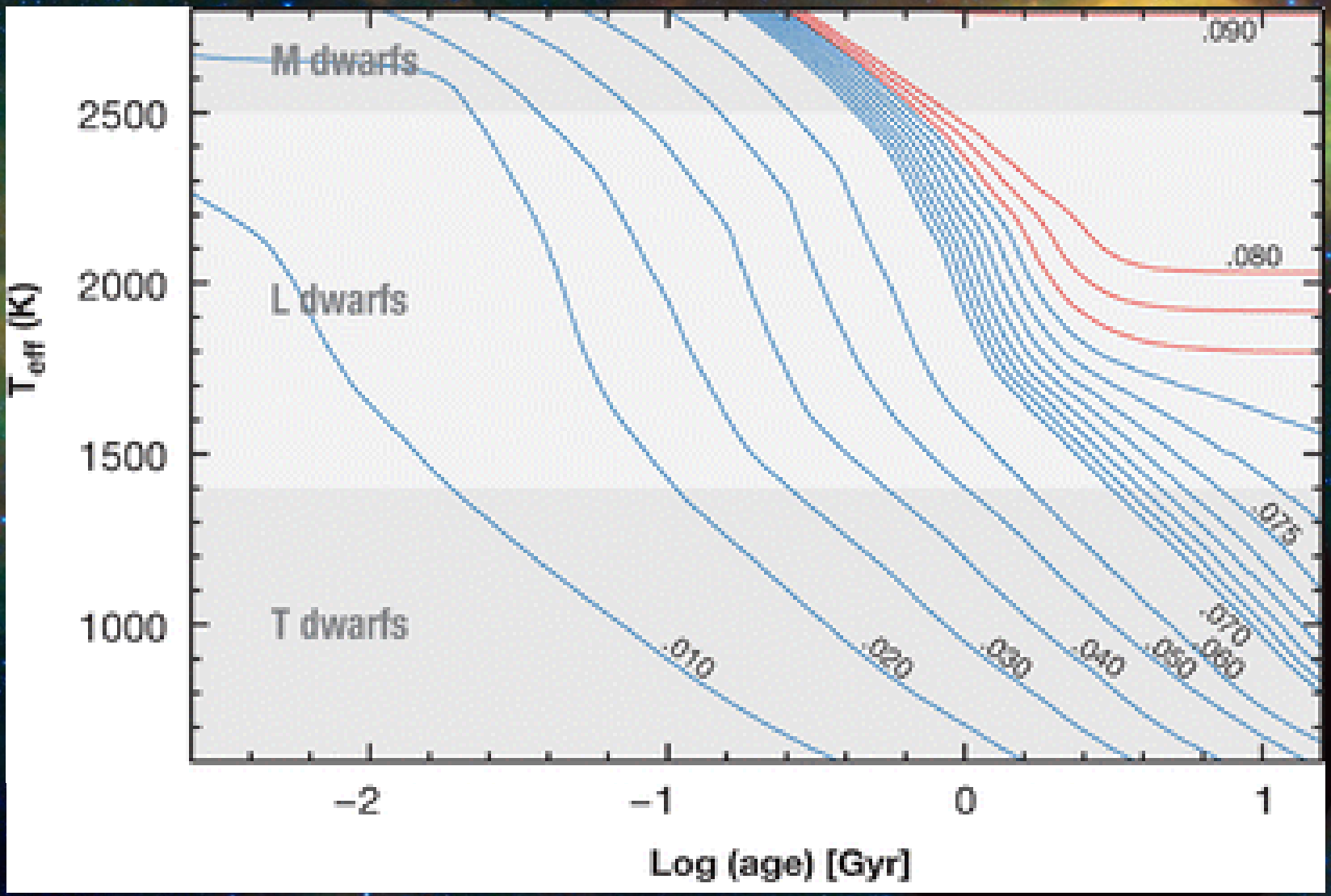
Ultra cool dwarfs (UCDs)

- Ultra cool objects: brown dwarfs and giant planets
- Sub-stellar mass objects
- Upper limit: $\sim 0.07 - 0.09 M_{\odot}$ $(\sim 80\ M_J)$ – H-burning limit (depending on metallicity)
- Brown dwarf/Planet split?: $\sim 0.012 M_{\odot}$ $(\sim 13\ M_J)$ – D-burning limit
- Temperatures: $\sim 300\ K\ - 2000\ K$
- Spectral types: L, T, Y
- Form like stars? Or like planets? Or both?
- Continuum: Cool brown dwarfs → warm giant exoplanets
- Complicated – Thick atmospheres, weather, clouds etc.

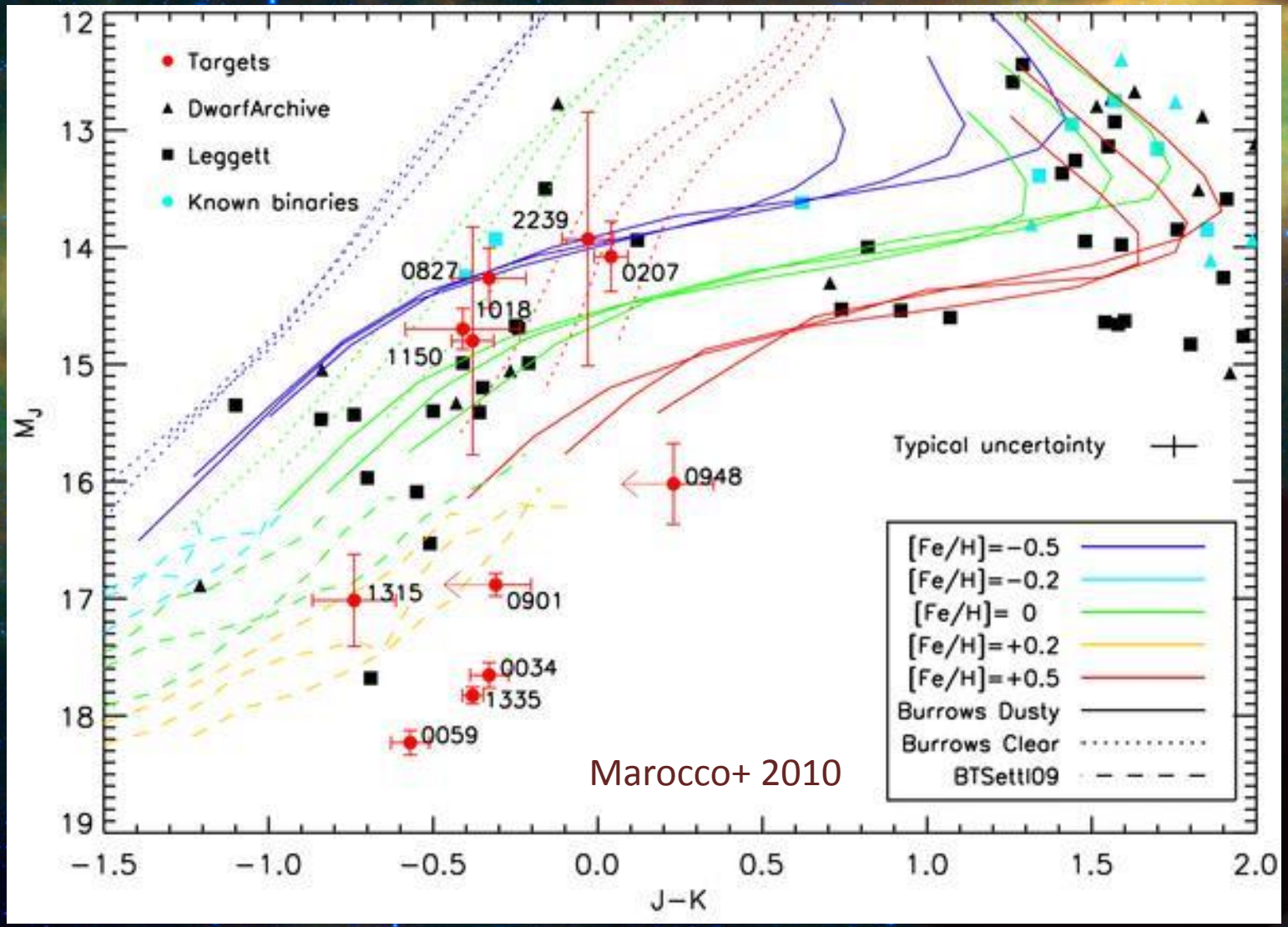
Why?

- Need benchmark binary systems
- With a companion can work out:
  - Dynamical masses (Close companions - radial velocity)
  - Radii (via possible transit)
  - Age (via primary – but challenging)
  - Metallicity (via primary – spectra fitting/M dwarf fitting)
  - Effective temperature, surface gravity etc…
- Constrain evolutionary and formation models
- Test theory - giant planets thought to be uncommon as M dwarf companions

Why? Mass – Age Degeneracy

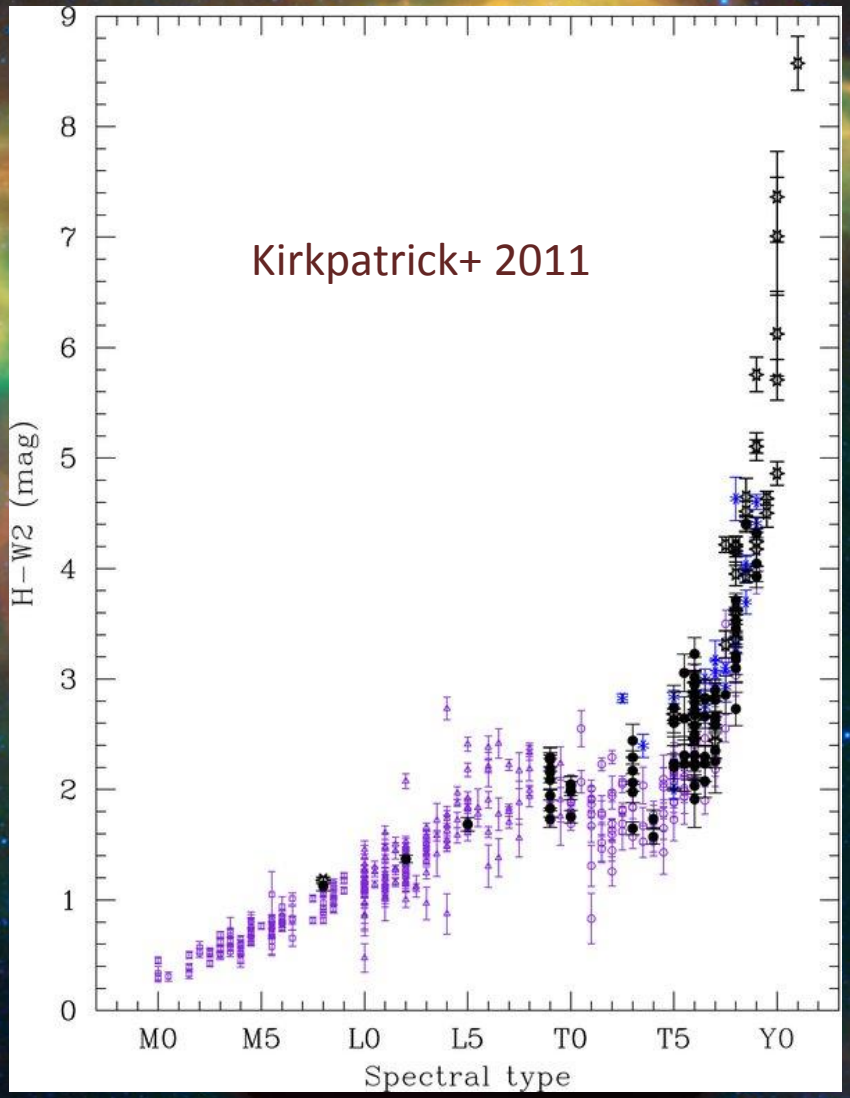


Why? Constraining Models



Finding companions to M dwarfs

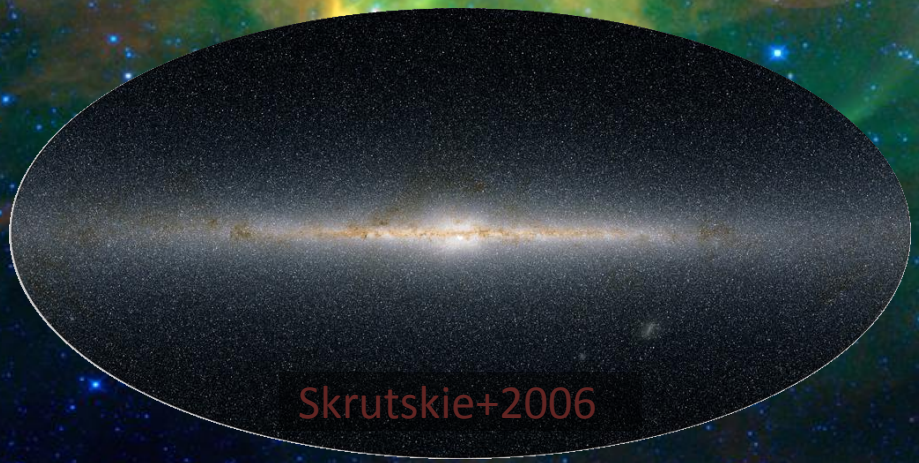
- M dwarfs are faint compared to other stars
- UCDs relatively bright in mid-infrared
- UCDs faint in near-infrared
- Look for colour excess
- BUT – M dwarfs have lots of scatter in colour
- Need to compare M dwarfs that are similar in non-excess colour
- Need big surveys near/mid-infrared surveys
  → WISE and 2MASS



WISE + 2MASS

Wright+2011

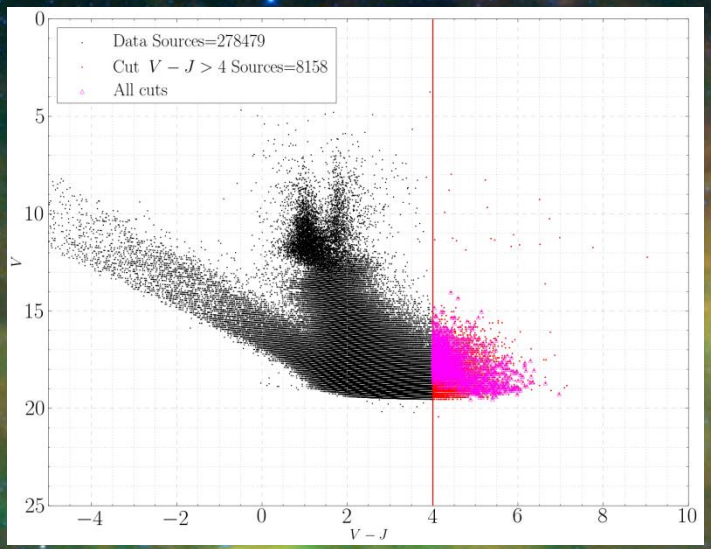
- WISE: Wide-field Infrared Survey Explorer
- All sky full data release March 2012
- Space-based telescope
- Mid Infrared
- W1, W2, W3, W4 (3.4, 4.6, 12, 22 μm)
- W1, W2 designed for brown dwarfs, very red W1 - W2
- 563,921,584 sources

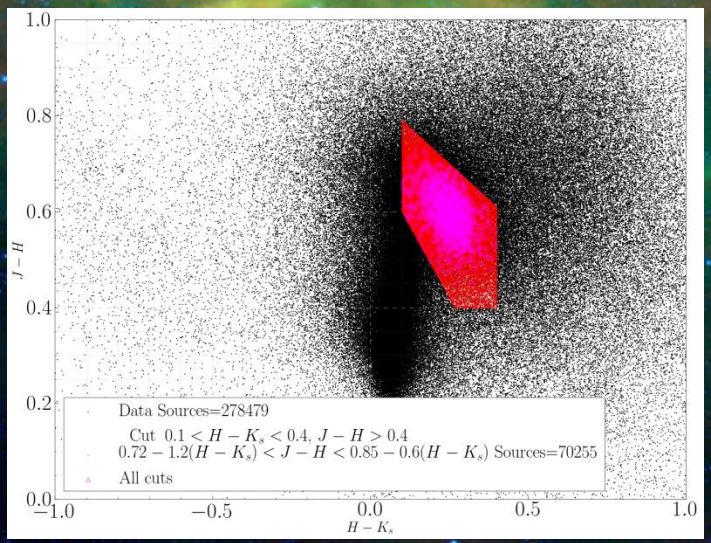


Skrutskie+2006

- 2MASS: Two Micron All Sky Survey
- All sky full data release March 2003
- Ground-based telescope
- Near Infrared
- J, H, K (1.25, 1.65, 2.16 μm)
- 470,992,970 sources

Selecting M dwarfs: Colour cuts



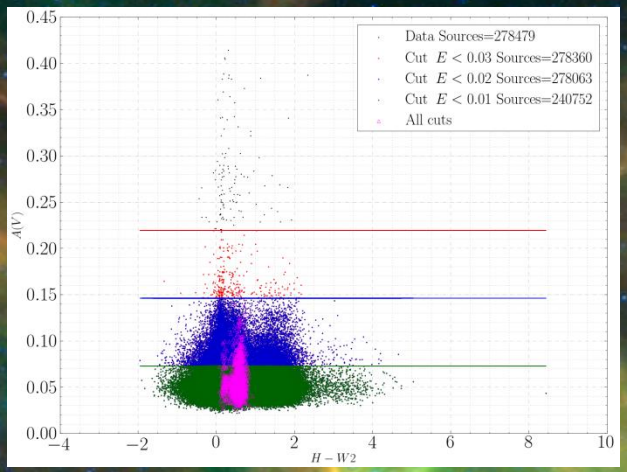


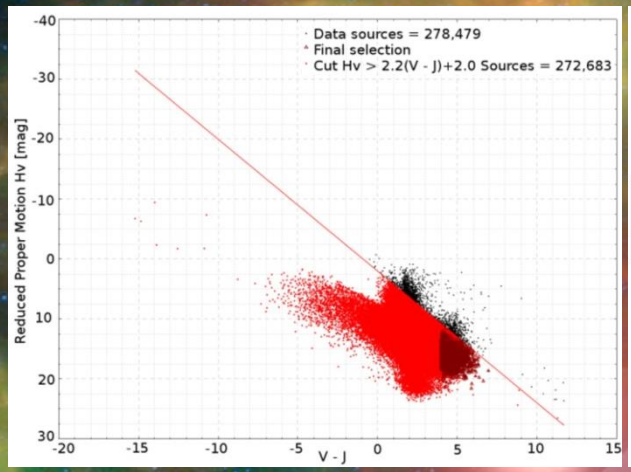
- V – J > 4 → spt > M3
- $J - H > 0.85 - 0.6(H - Ks)$ [1]
- $0.72 - 1.2(H - Ks) < J - H$ [1]
- 0.1 < H – Ks [1]
- $J - H > 0.4$ [1]
- Galactic latitude cut: $\pm$ 15°
- After cuts: 451,581

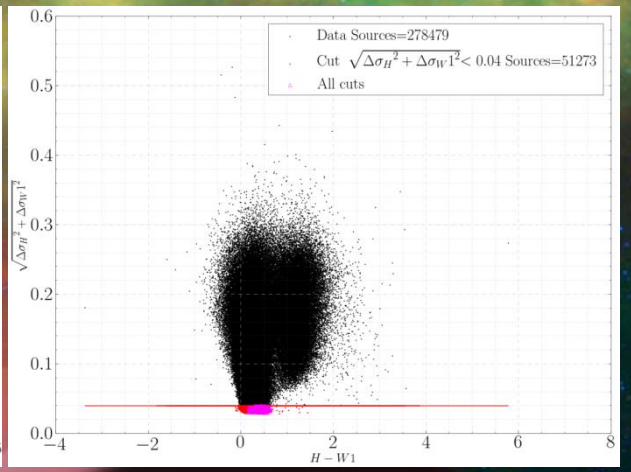
[1] Lepine+2011

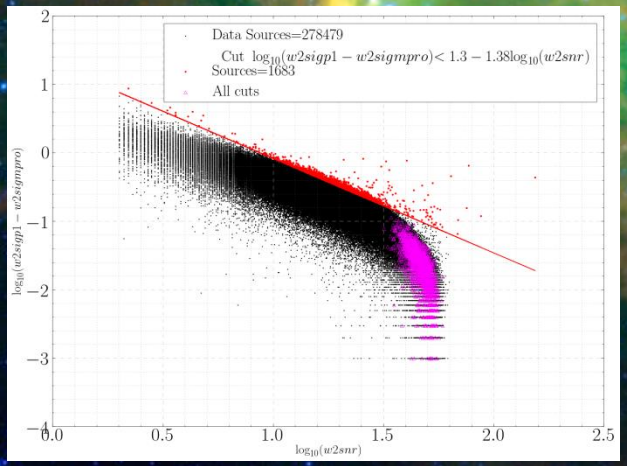
Selecting M dwarfs:

Extinction, Reduced Proper motion, Quality and Variability cuts







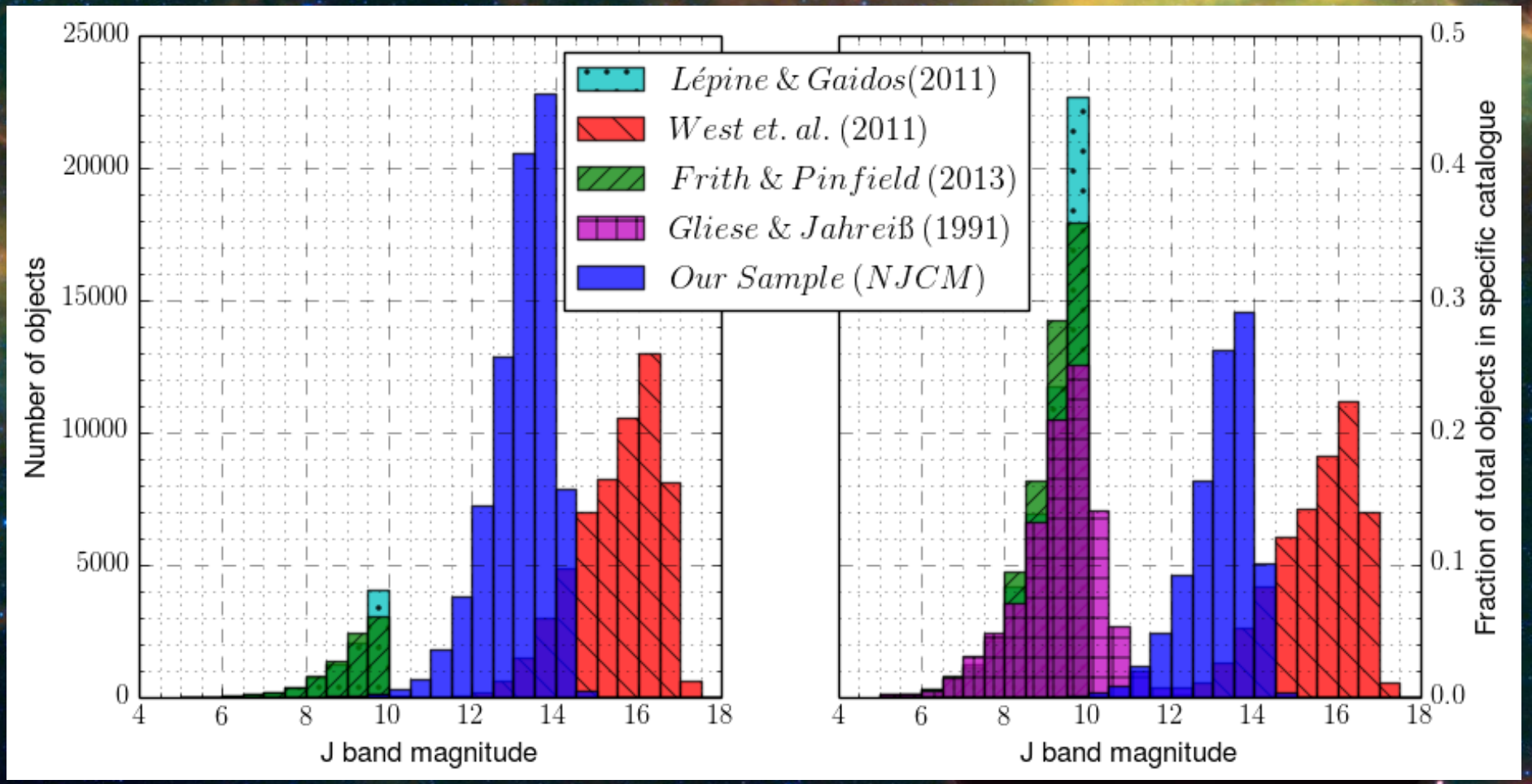


- Extinction: E(H-W2) < 0.03 → A(V) < 0.22
- Reduced Proper motion: (Lepine+11)
  $H_v = V + 5\log_{10}(\mu) + 5 > 2.2(V - J) + 2.0$
- Proper motion quality: $\mu > 4\,\sigma$
- Colour quality: $\sigma_H^2 + \sigma_{W1,W2}^2 < 0.04^2$
- Variability: (Pinfield+2013)
  $\log(\sigma_{pop,W2} - w2) < 1.3 - 1.38\,\log(snr_{W2})$

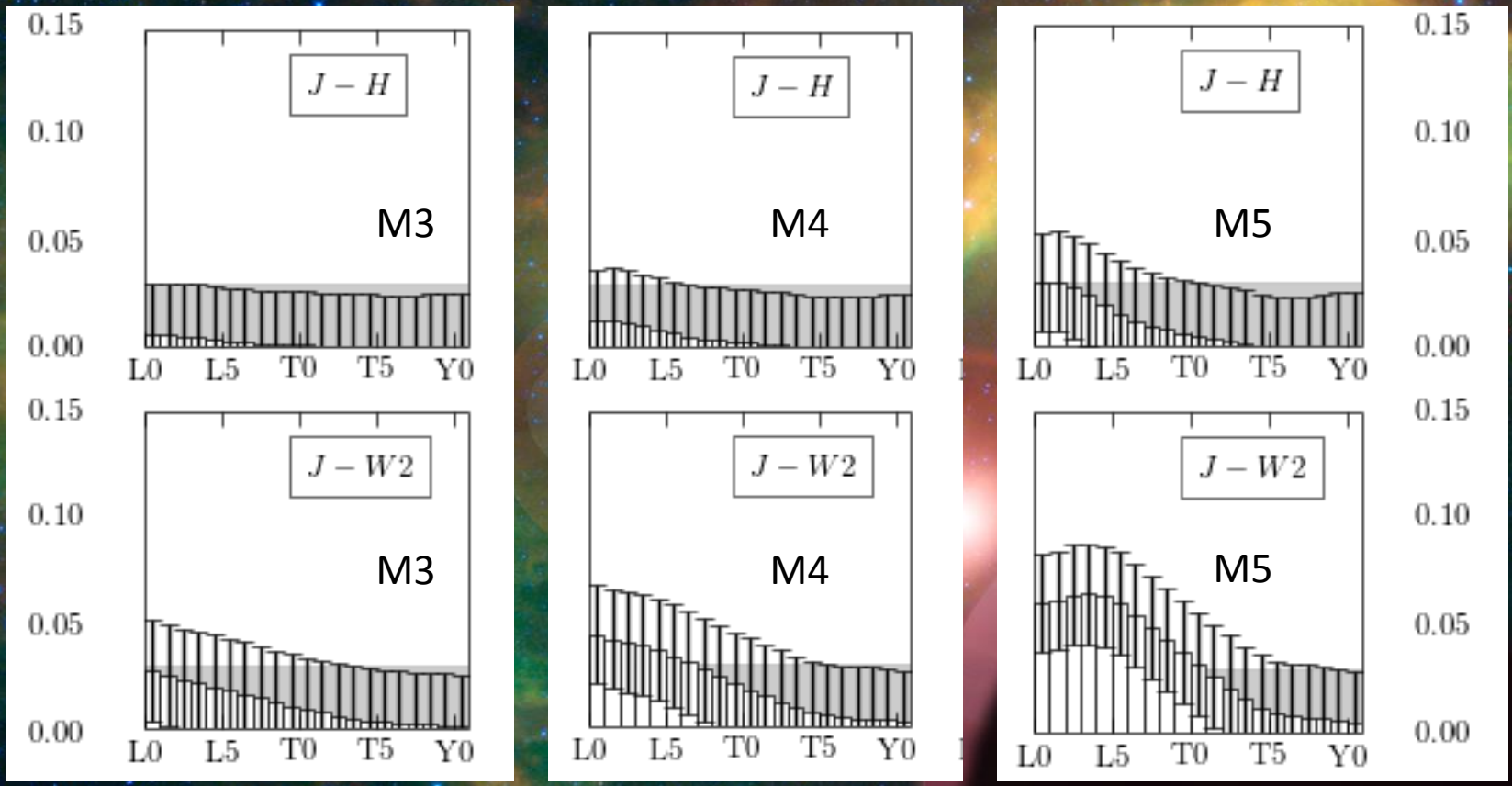
University of Hertfordshire

IPERCOOL: Thursday 25th March 2014

A high quality catalogue of 78,454 M dwarfs

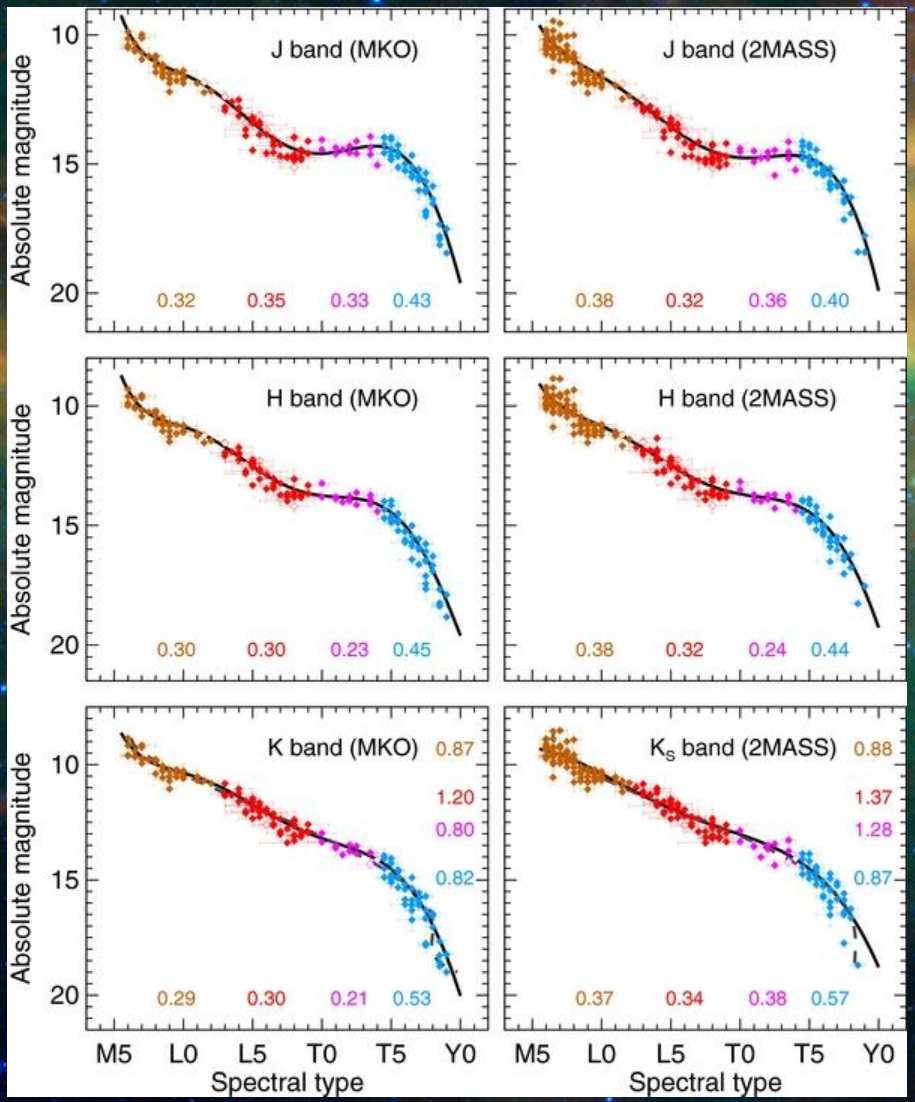


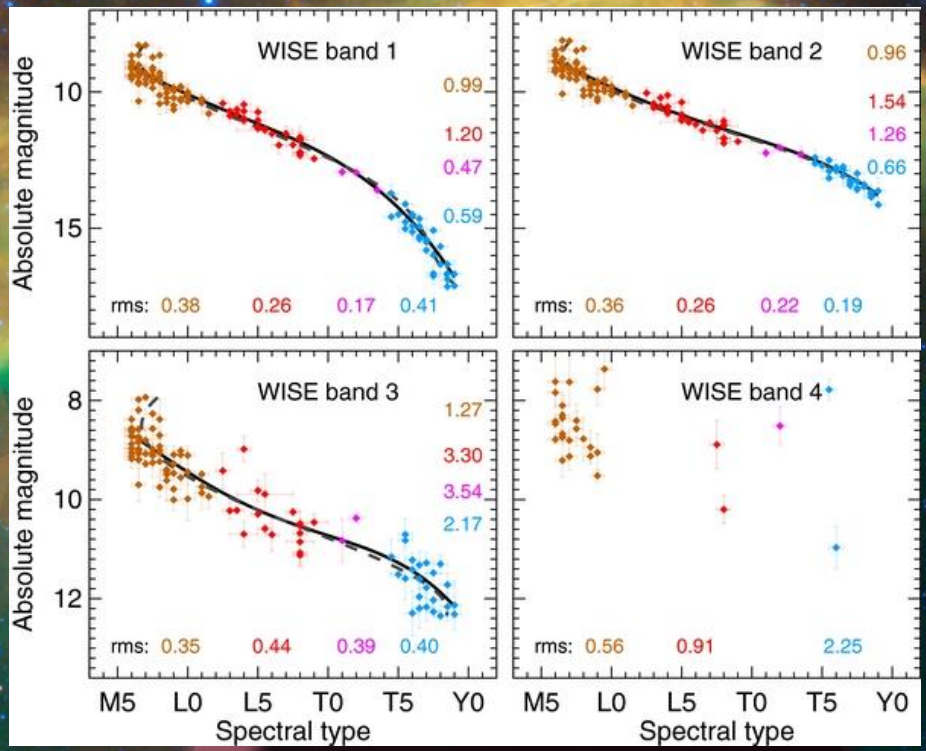
Can we see any excess?



- Simulated M dwarf + UCD systems
- Selected {J, H} – {W1, W2} colours as excess colours
- Selected V-J, J – H and H – K as control colours

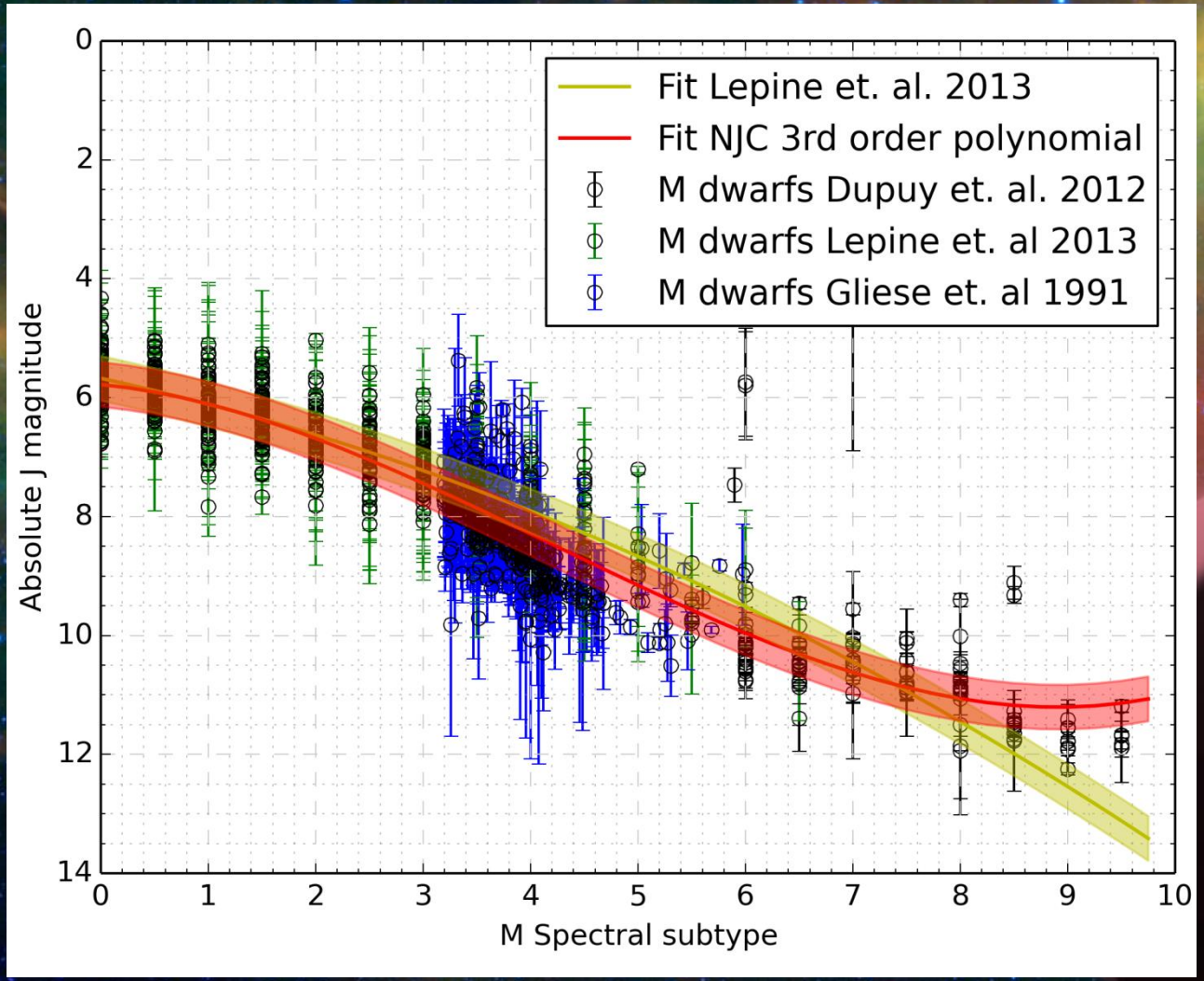
Simulating UCDs





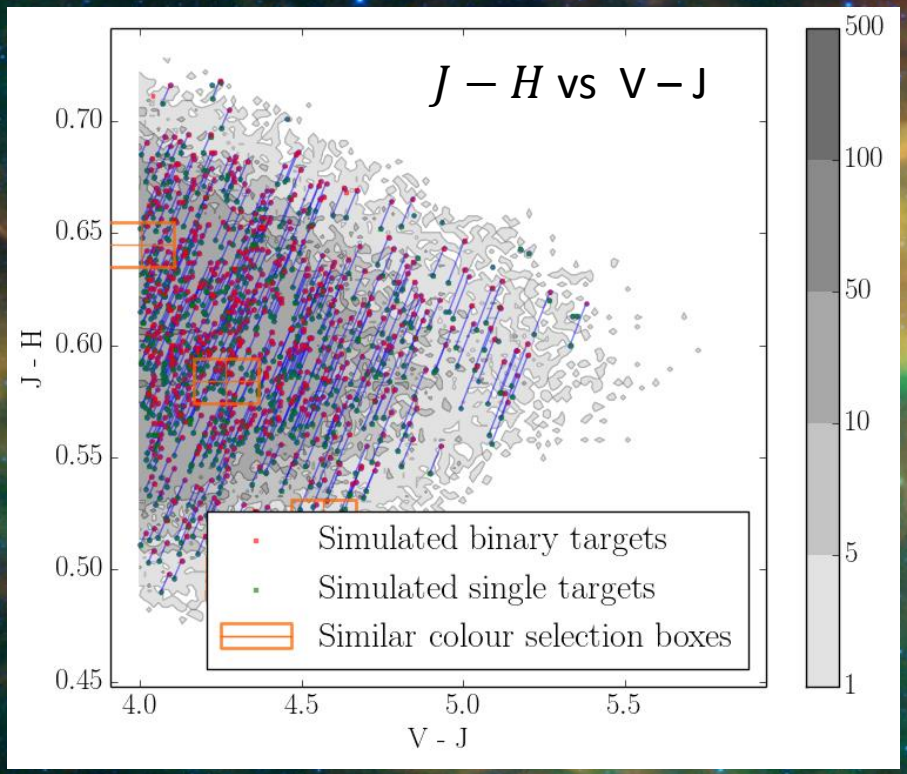
- UCDs simulated using Dupuy+2012
- Dupuy+2012 creates polynomial fitting of absolute magnitude to spectral type

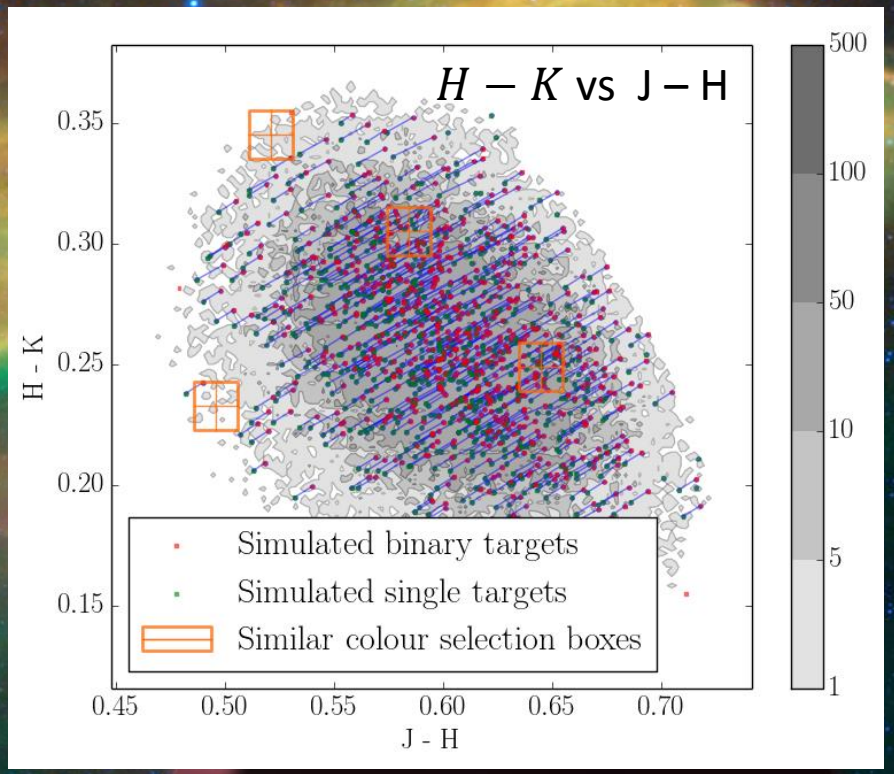
Simulating M dwarfs



- M dwarfs simulated by using
  Lepine+2011
  Gliese+1991,
  Dupuy+2012
- Polynomial fitting using a probabilistic fitting routine
- Add 0.75 mag to account for possible binairty

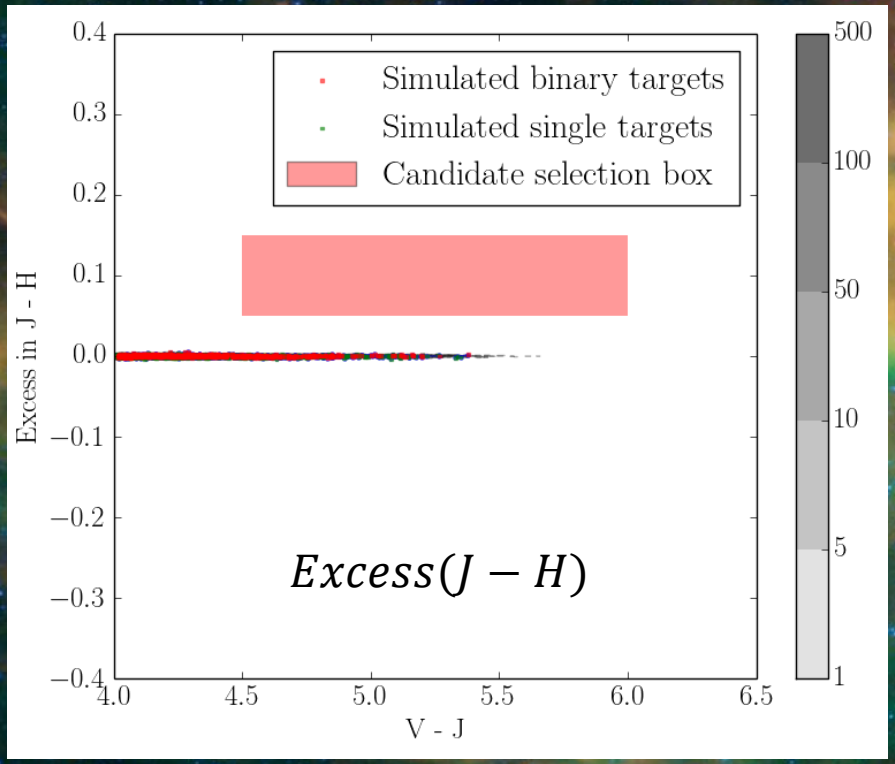
Multi-colour parameter space

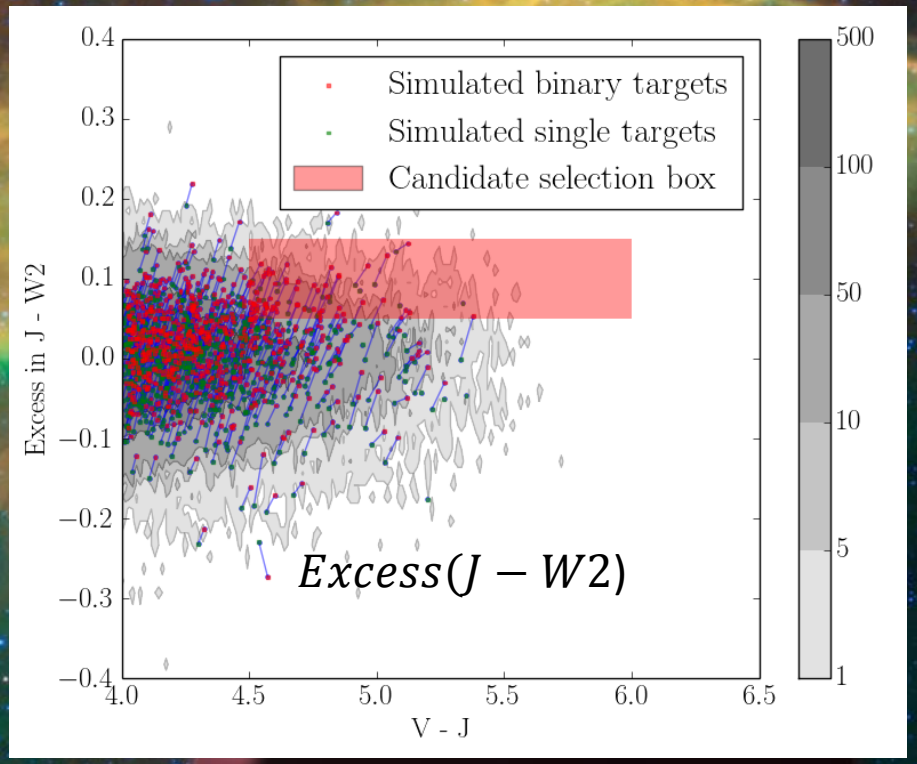




- To obtain excess compare similarly coloured M dwarfs
- Target each M dwarf individually
- Select those M dwarfs similar to target M dwarf in colour-space
- Work out μ and σ for each target colour space volume (orange rectangles)
- Add simulated UCDs to fraction of M dwarfs and repeat process (red & green dots)

Excess distribution obtained

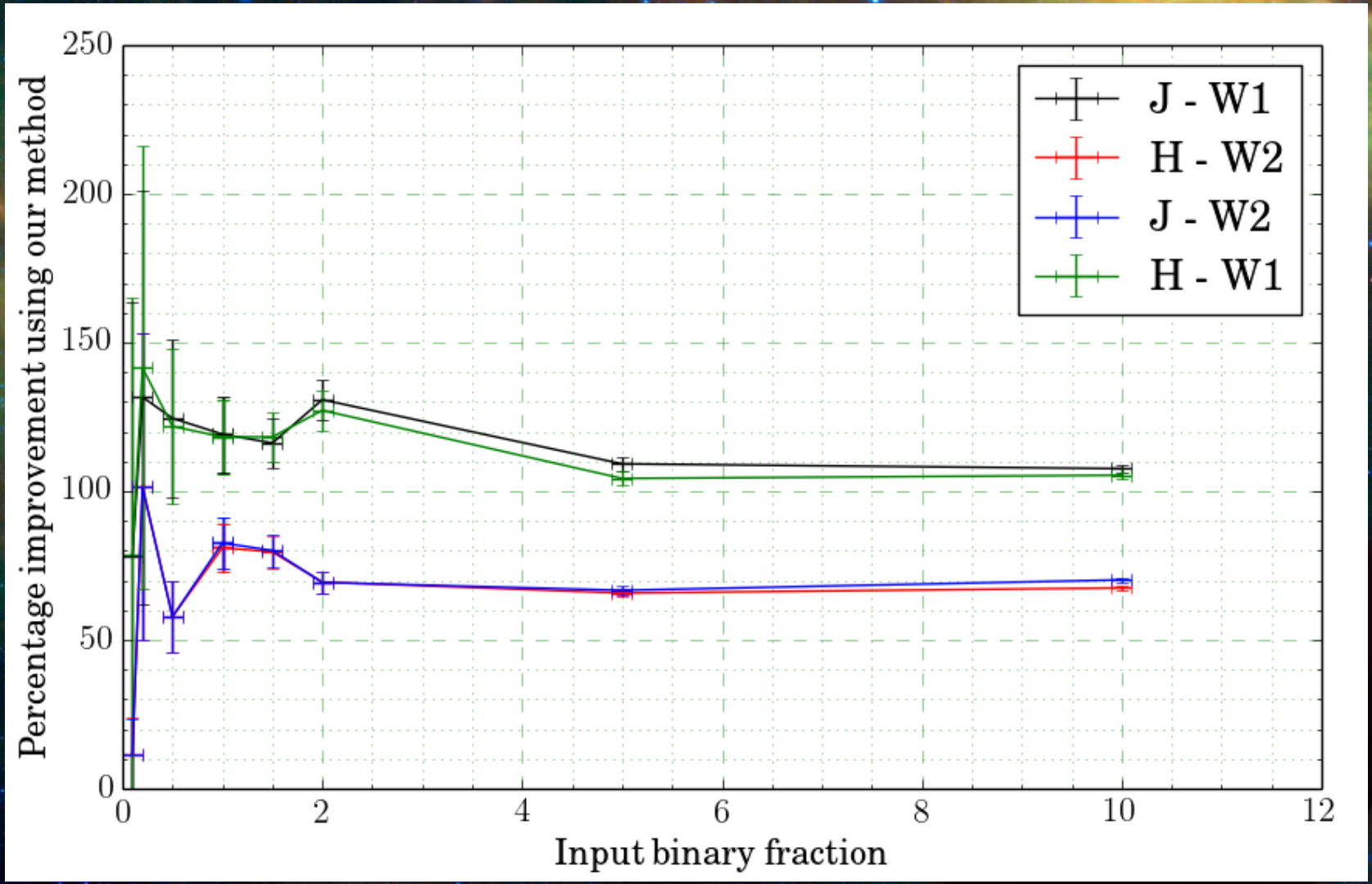




- Work out excess:

  Target colour – mean target volume colour
- Select candidate M dwarfs (red rectangle)
- Compared non-excess colour (left) to excess colour (right)
- Compare number of simulated targets introduced to simulated binary fraction

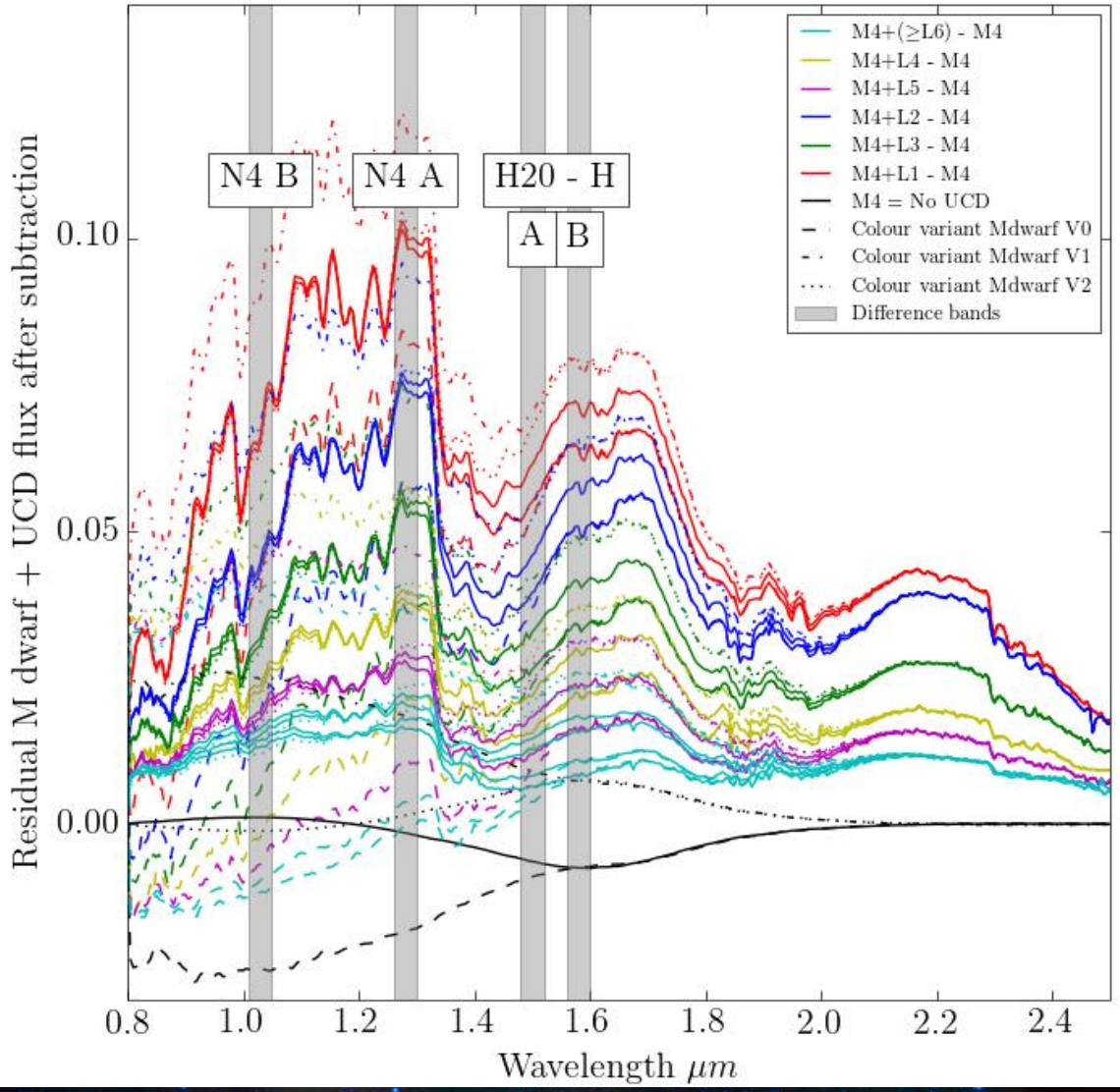
Finding excess → improved detection?



Highly contaminated candidates

- Large fraction of candidates will be contaminants
- In the process of improving photometric spectral typing
- Improved selection methods
- Low resolution spectroscopic follow-up
  1. Take colour similar known M dwarfs (control)
  2. Observe spectra of our candidate and control star
  3. Subtract them → Produce ‘residual UCD spectra’ (noisy UCD spectra)
  4. Compare UCD spectral features to identify companions (spectral difference)

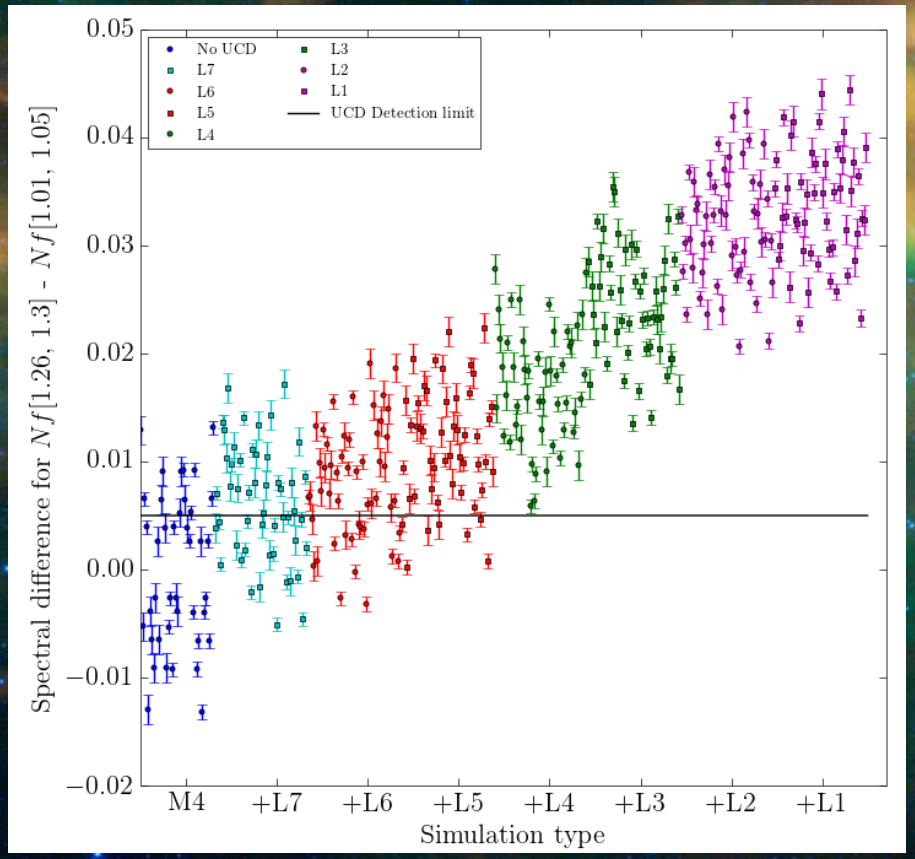
Simulating colour similar spectra

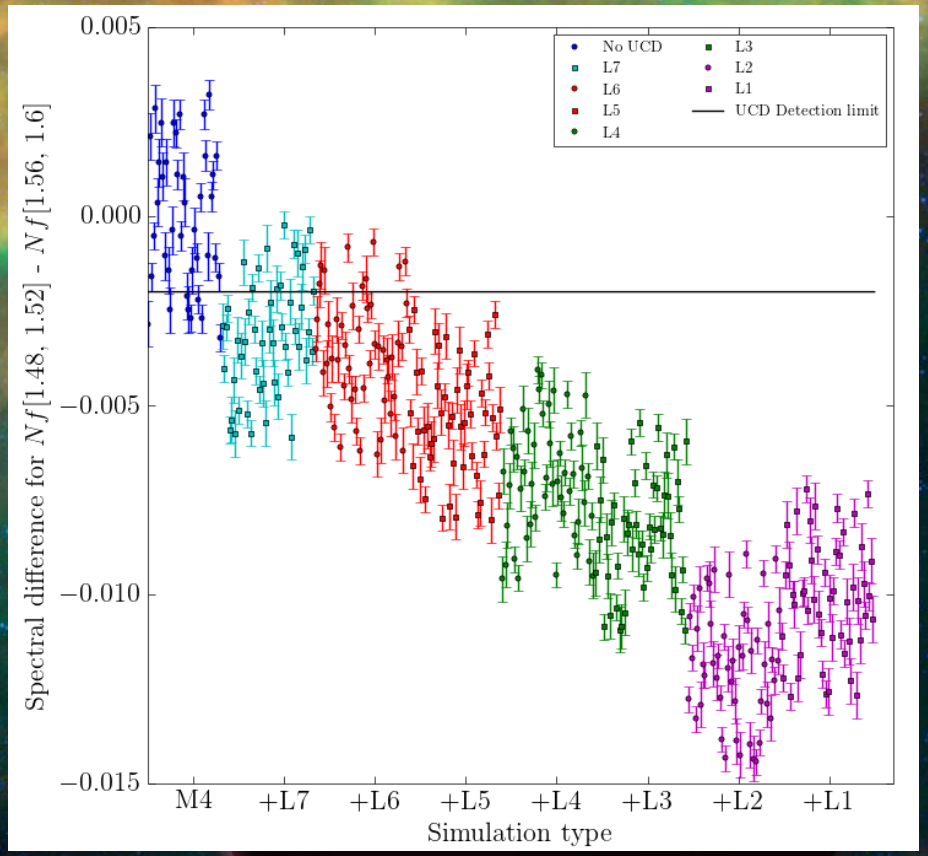


The SpeX Prism Spectral Libraries

www.BrownDwarfs.org

Simulated spectral difference results



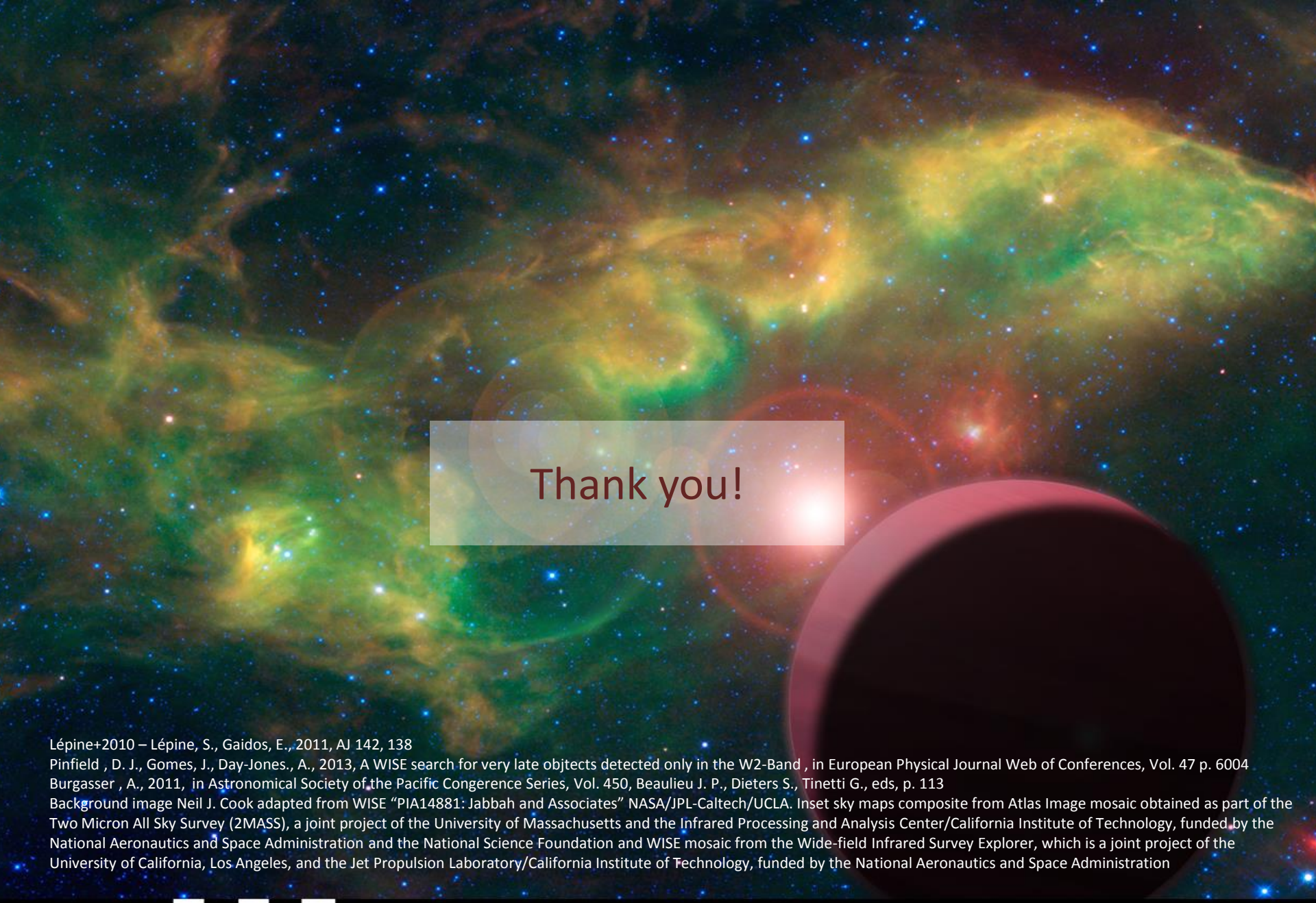


Where next?

- Improve photometric spectral typing using multi-band photometry → reduce contamination (LAMOST and others)
- Follow up these candidates and their respective control stars with low resolution spectra
- Significant detections: further spectra, radial velocities, light curves → confirmation of companion
- M dwarf catalogue:
  - Tycho 2 wide binaries → Metallicities
  - Mid/Late M dwarf Exoplanet search
  - Gaia extension - proof of concept
  - Kepler K2 M dwarf Exoplanet light curves
- Analysis of confirmed candidate

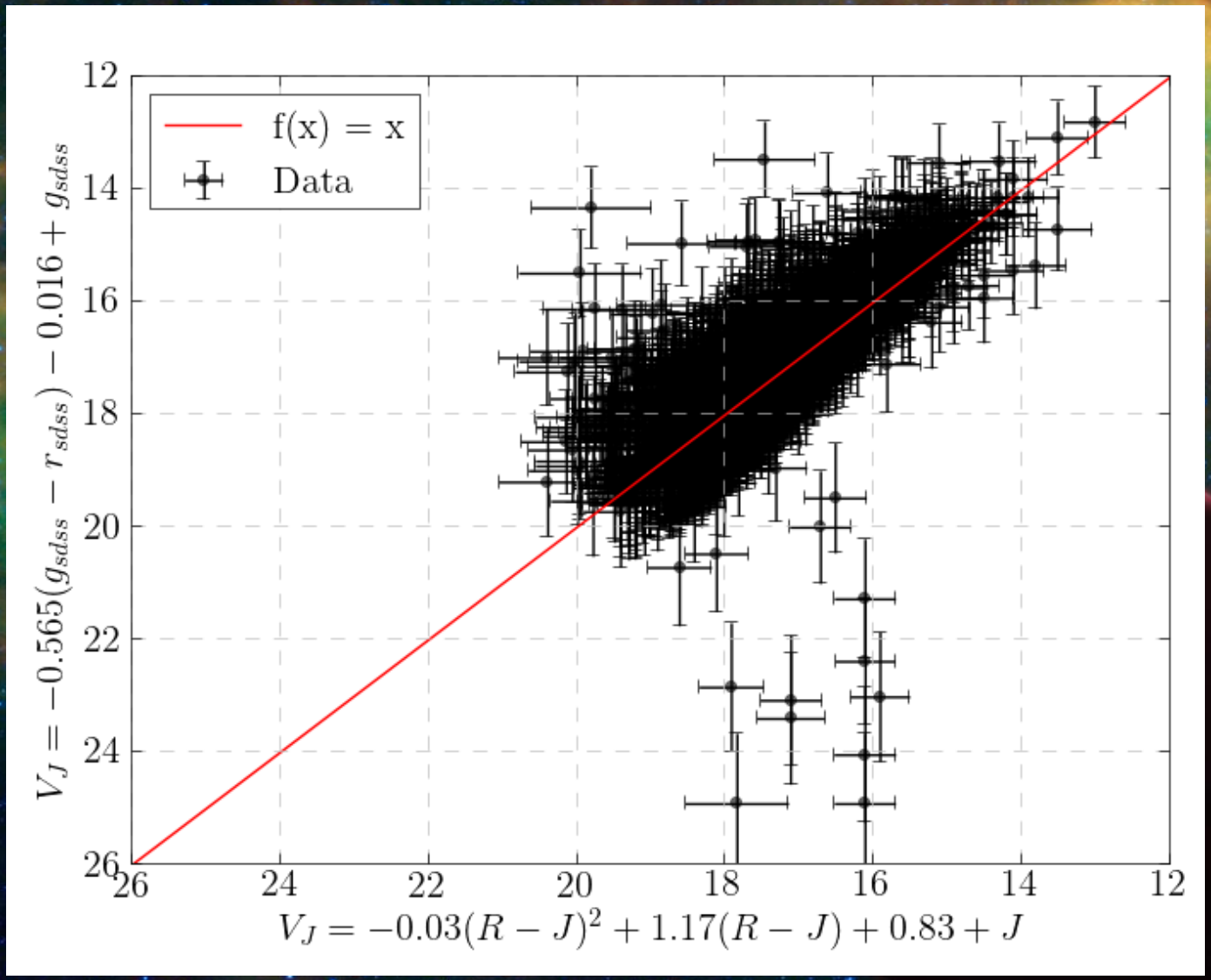
Summary

- Combined WISE + 2MASS using cuts in colour, reduced proper motion and quality
- Produced un-reddened, high quality catalogue of 78,454 M dwarfs
- Found excess by comparing “similar” colour-space sources and using simulations
- Need follow up to reduce contamination and confirm companionship
- Many other uses for our M dwarf catalogue

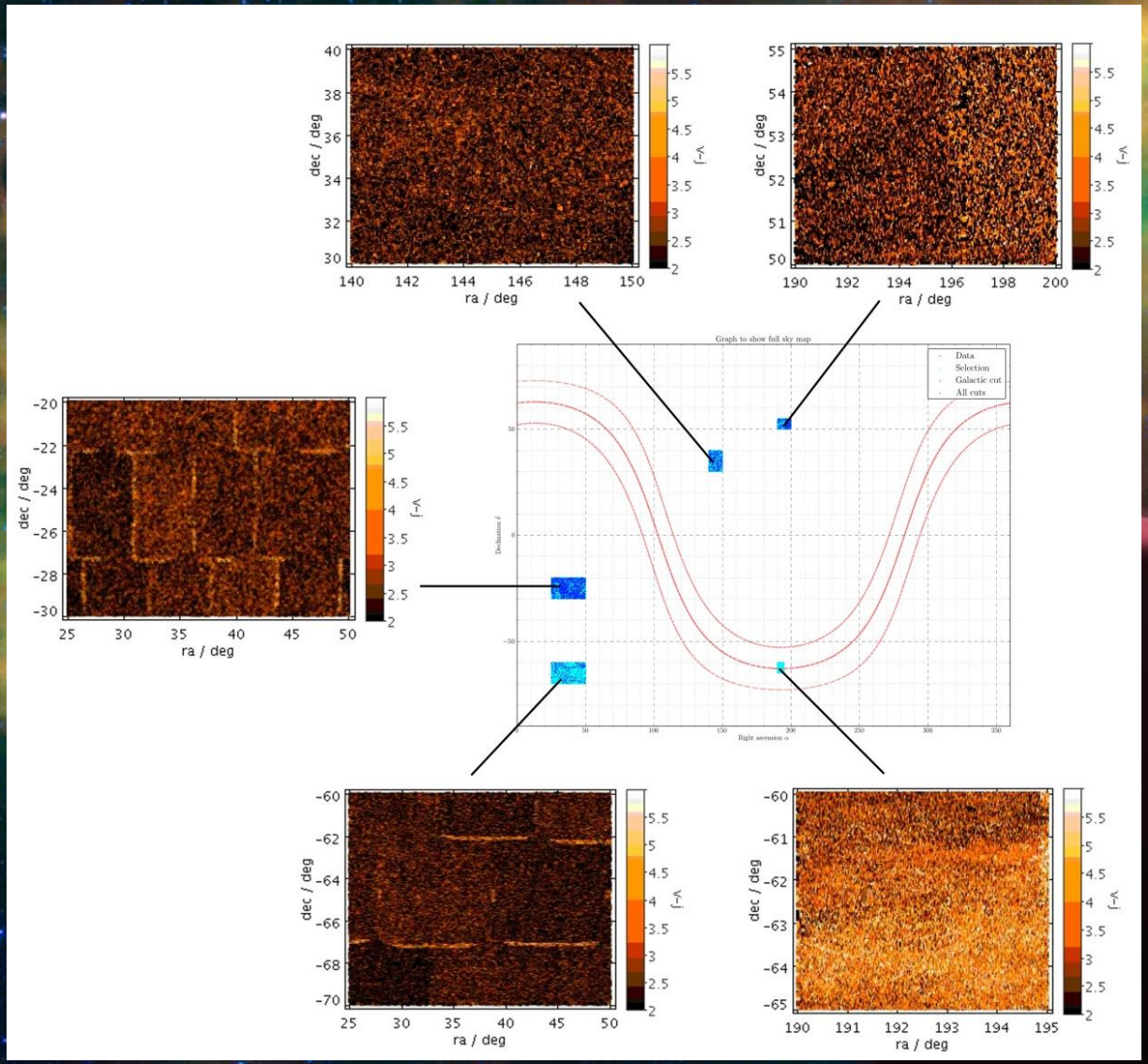


Lépine+2010 – Lépine, S., Gaidos, E., 2011, AJ 142, 138
Pinfield , D. J., Gomes, J., Day-Jones., A., 2013, A WISE search for very late objtects detected only in the W2-Band , in European Physical Journal Web of Conferences, Vol. 47 p. 6004
Burgasser , A., 2011, in Astronomical Society of the Pacific Congerence Series, Vol. 450, Beaulieu J. P., Dieters S., Tinetti G., eds, p. 113
Background image Neil J. Cook adapted from WISE "PIA14881: Jabbah and Associates" NASA/JPL-Caltech/UCLA. Inset sky maps composite from Atlas Image mosaic obtained as part of the Two Micron All Sky Survey (2MASS), a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation and WISE mosaic from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration

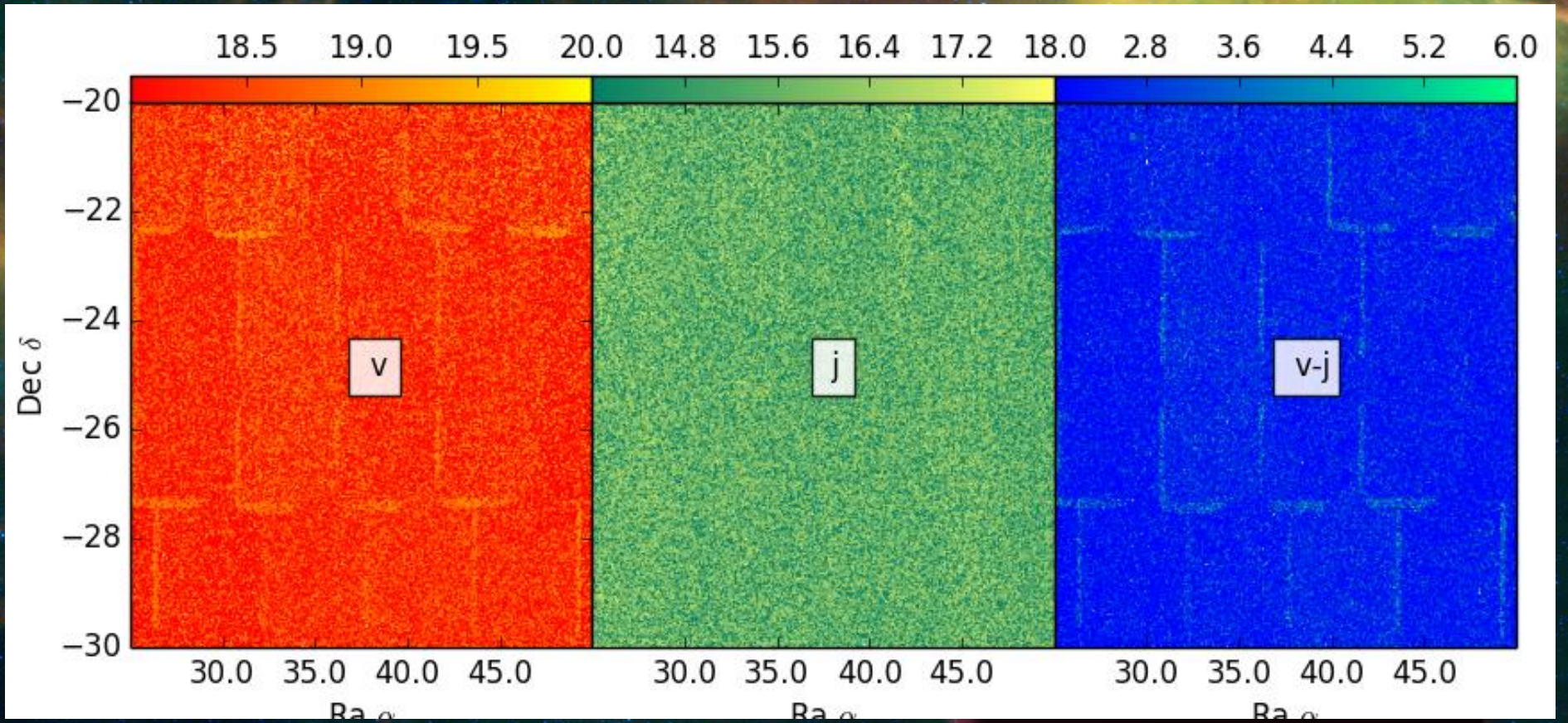
V consistent with SDSS



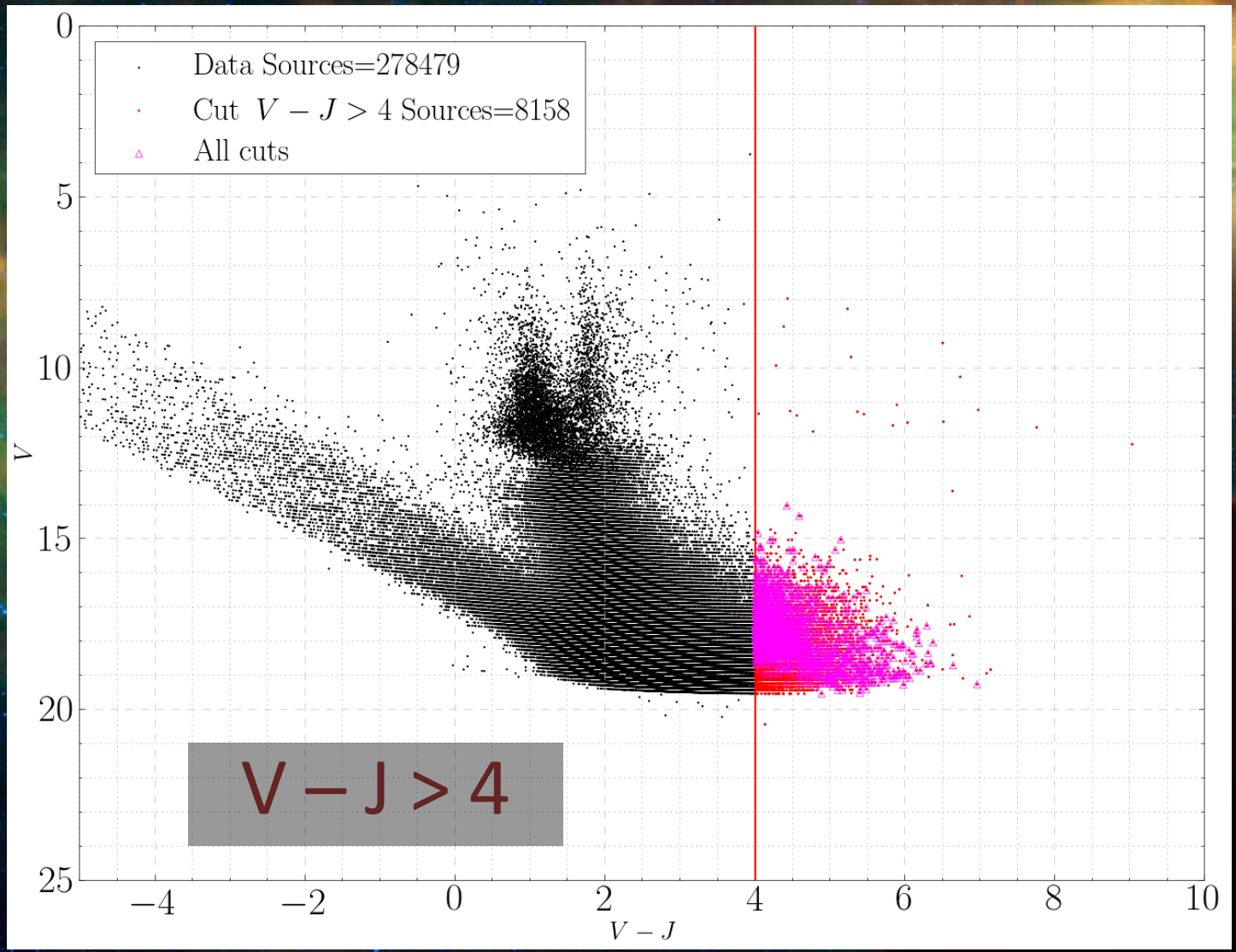
V Band plate overlap 1



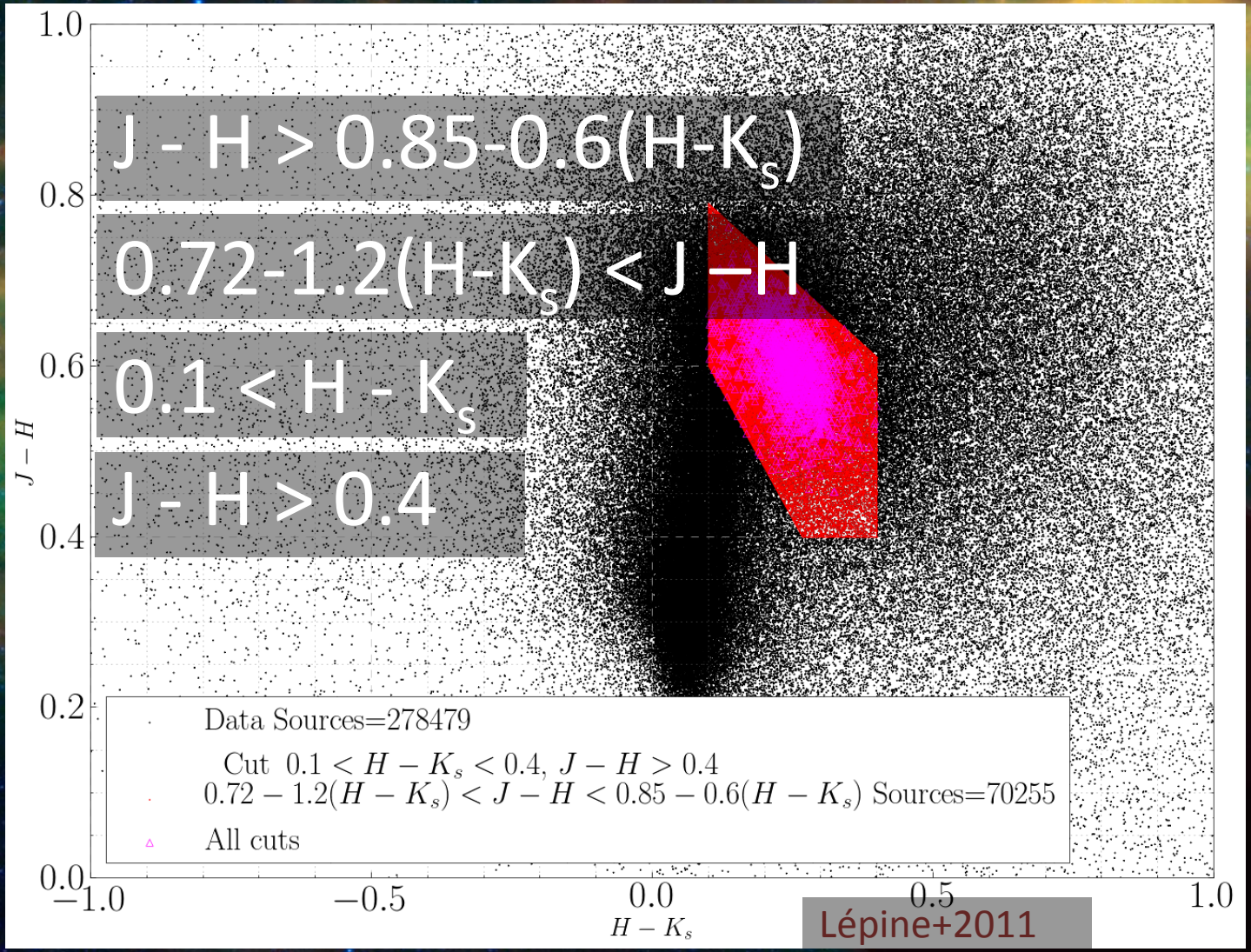
V Band plate overlap 2



Colour cut: V - J

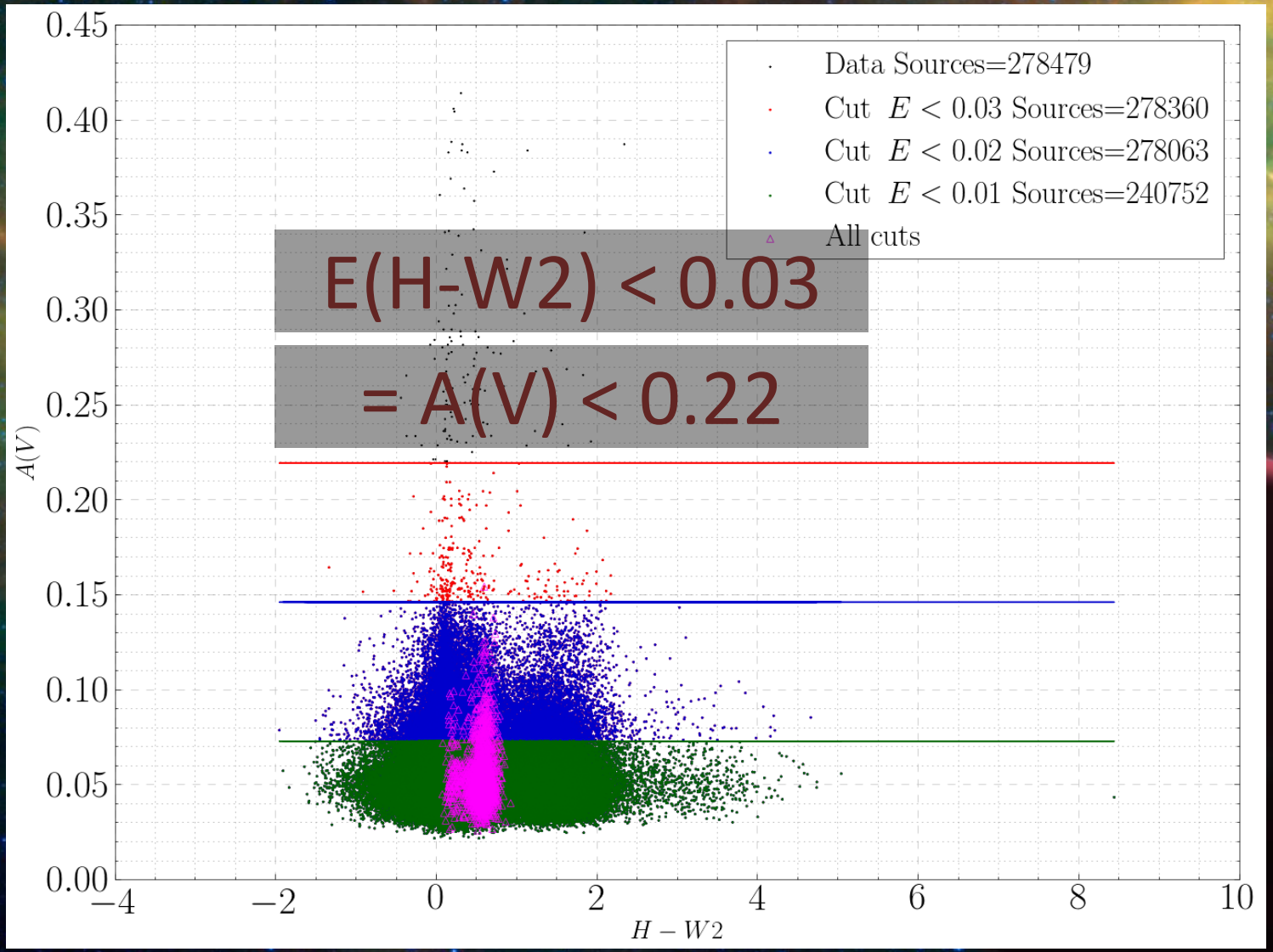


Colour cut: J-H, H-K_s

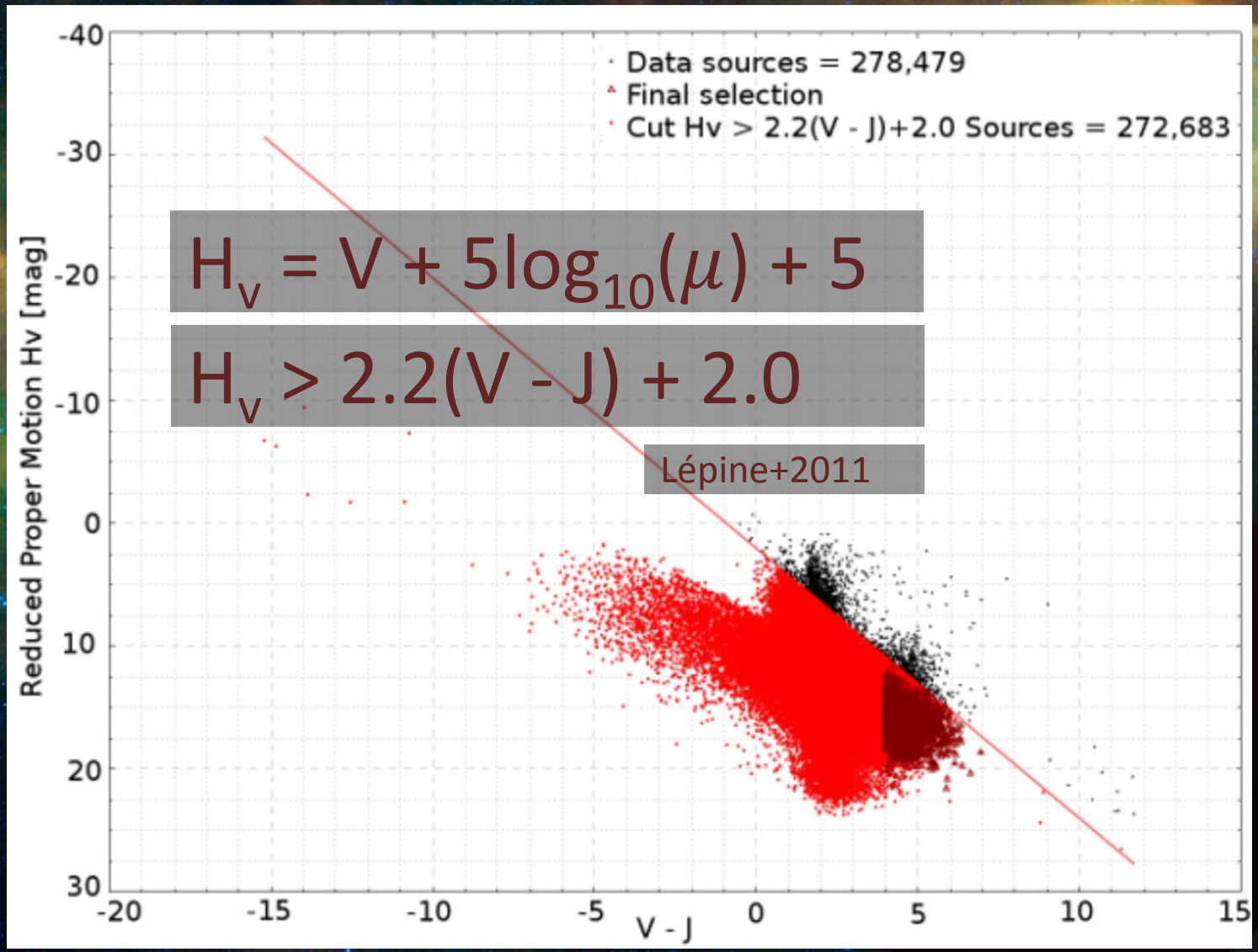


Lépine+2011

Extinction cut



Reduced Proper Motion Cut

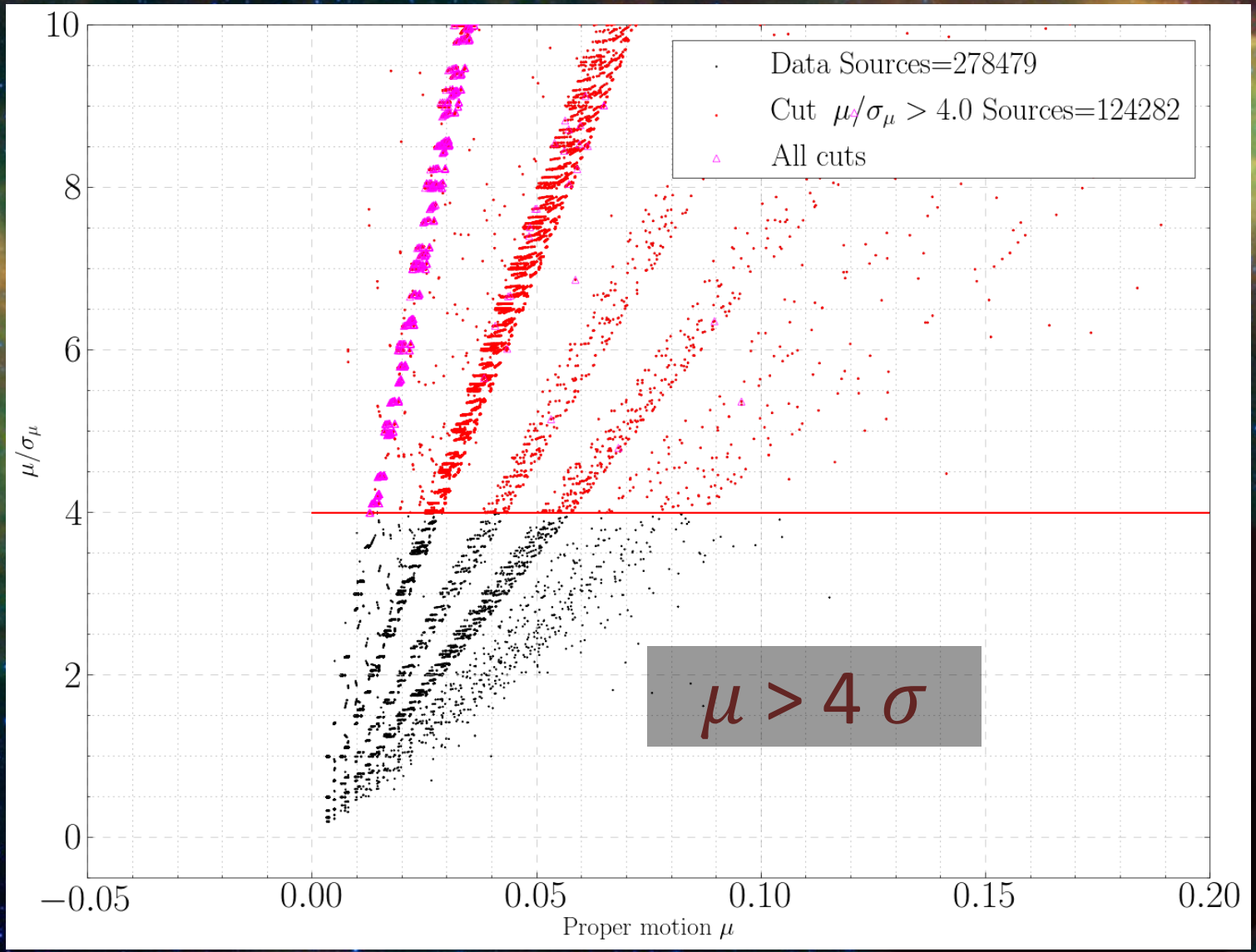


$H_v = V + 5\log_{10}(\mu) + 5$

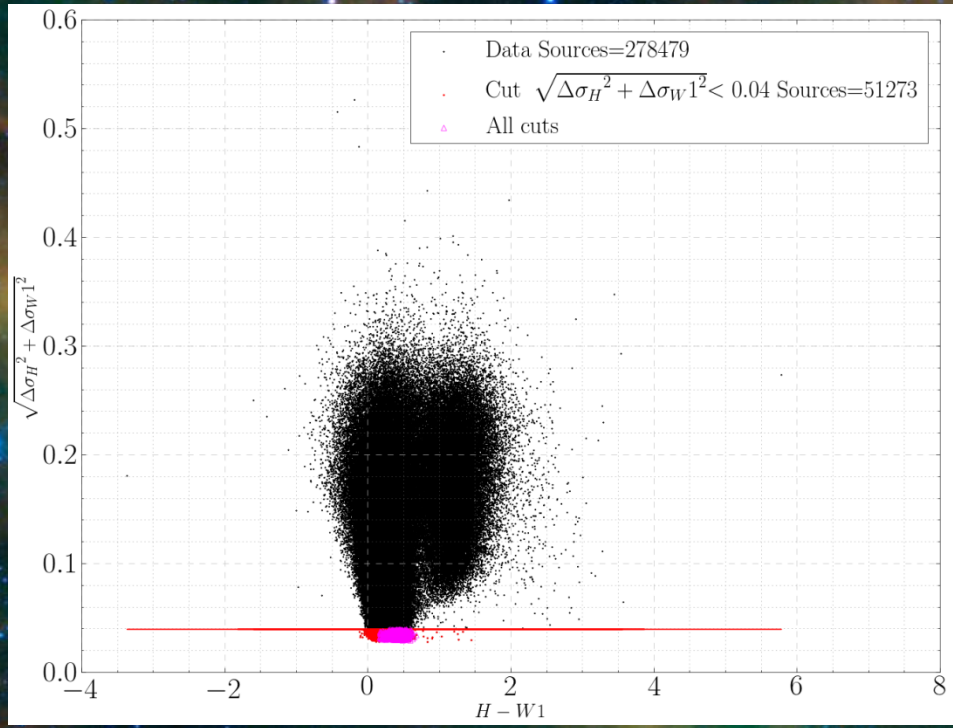
$H_v > 2.2(V - J) + 2.0$

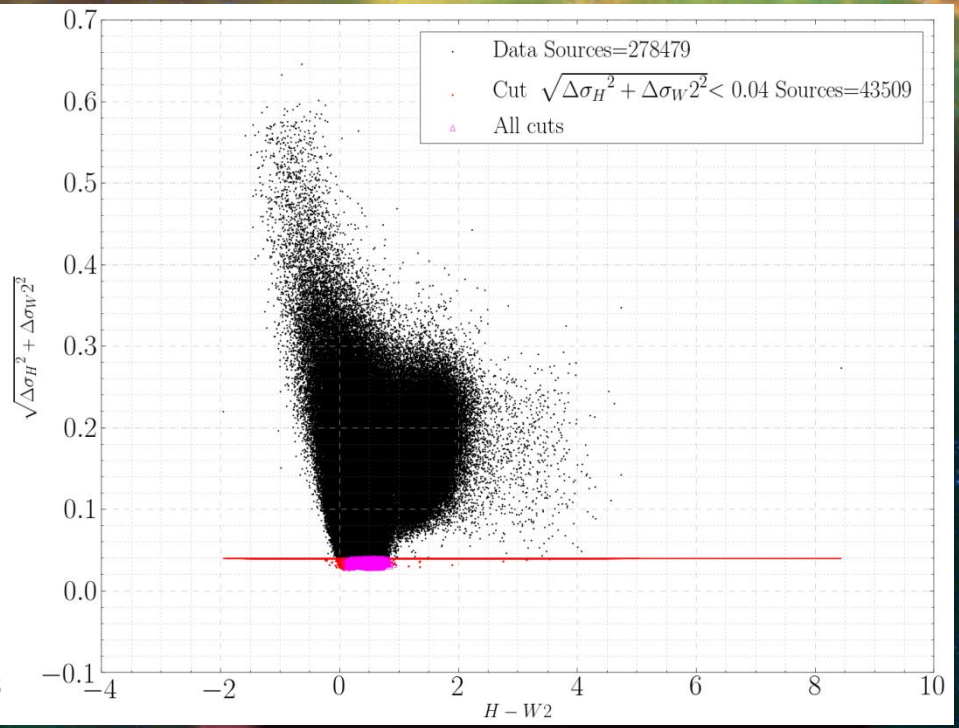
Lépine+2011

Proper Motion Quality



Photometric Quality

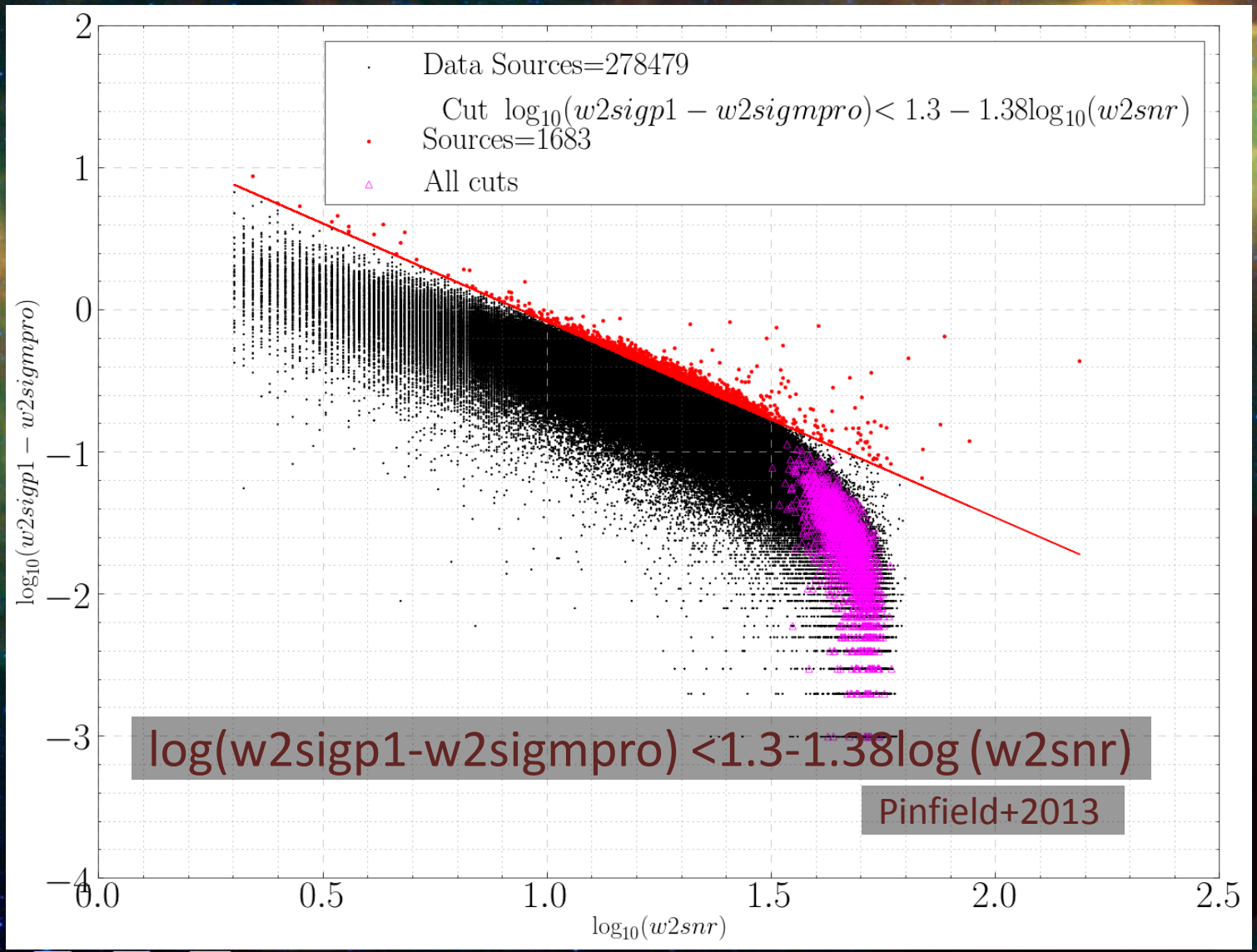




$$\sqrt{\sigma_H^2 + \sigma_{W1}^2} < 0.04$$

$$\sqrt{\sigma_H^2 + \sigma_{W2}^2} < 0.04$$

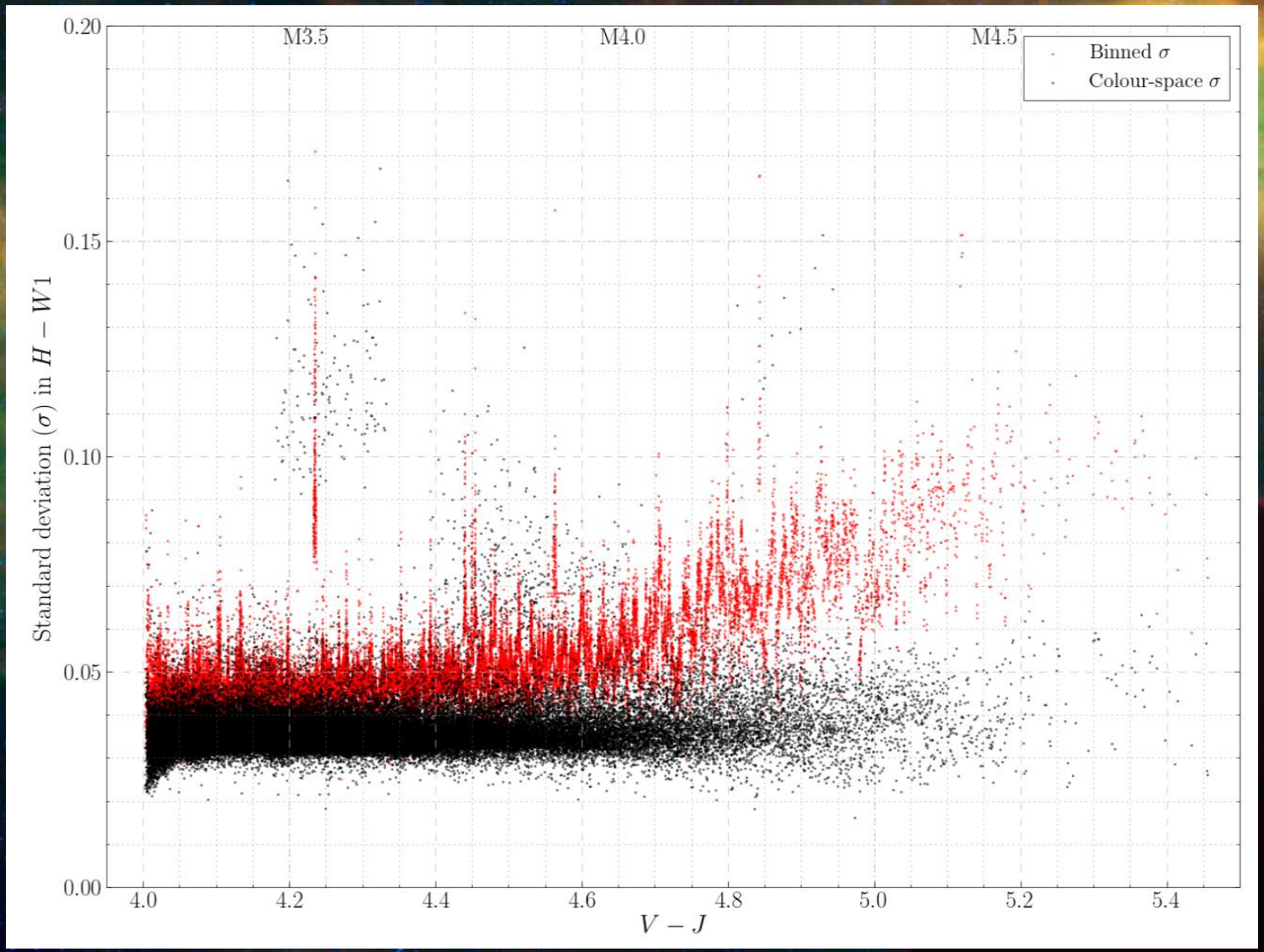
Variability



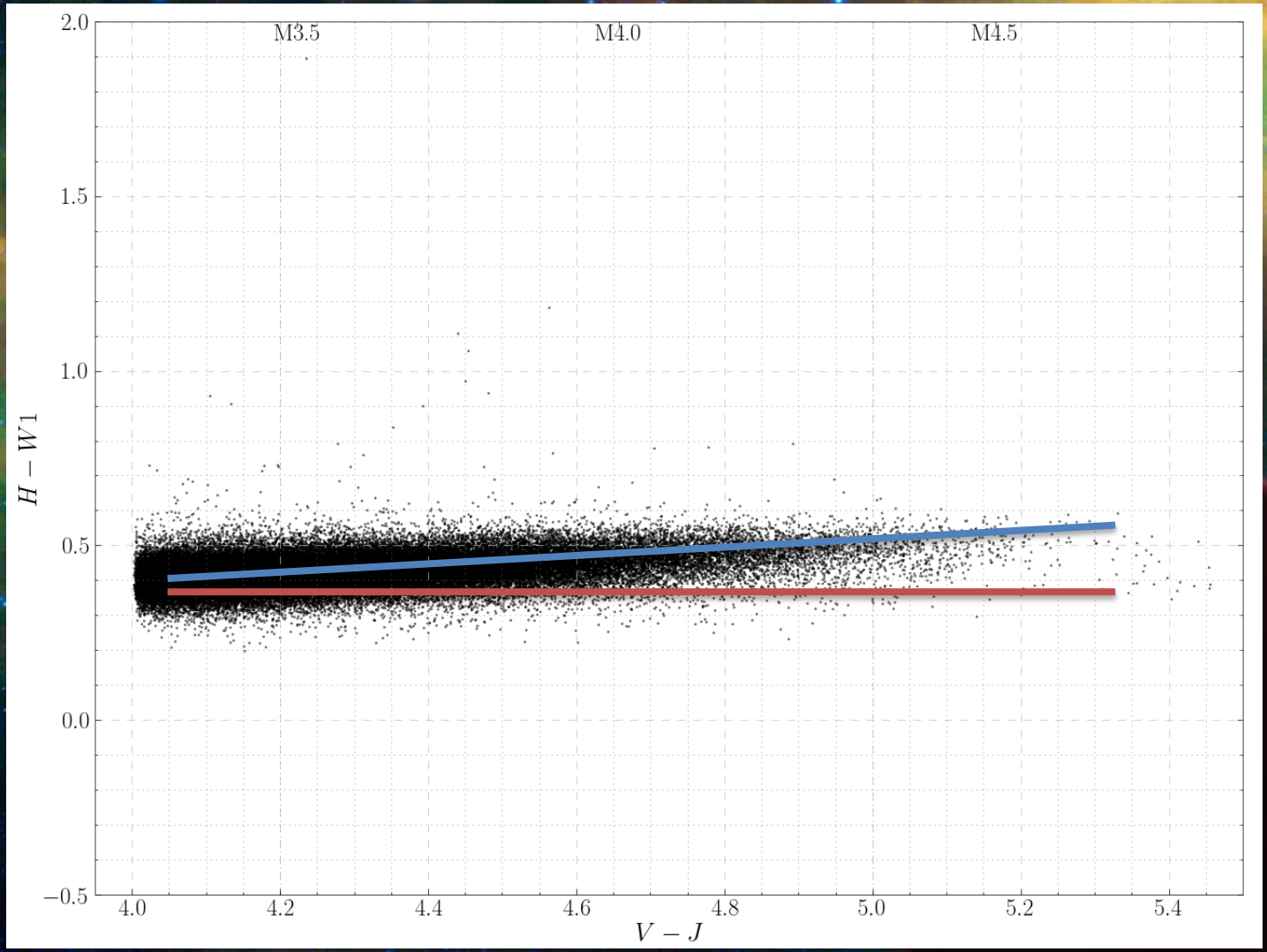
log(w2sigp1-w2sigmpro) <1.3-1.38log (w2snr)

Pinfield+2013

Improvements in Excess using colour space



H-W1 vs V-J plot



Binary fraction?