WISE - the Wide-field Infrared Survey Explorer

Ned Wright (UCLA)
Wide-field Infrared Survey Explorer (WISE)

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 (WISE)

Infrared

- Optical
- Reflected light
- Near-IR different colors
- Thermal-IR emitted radiation
“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

- Single observing mode
- Minimum 8, median 14 exposures/position after losses to Moon and SAA
• 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.
Both water and methane are greenhouse 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 H₂O and CH₄ 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 $10 \text{ Gyr}$
• About 25 times cooler than the Sun or $231 \text{ K}$. 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
- \( z \sim 0.4 \) LIRGs
- Local LIRGs
- Local ULIRGs
- QSOs
- Blackbodies
- Power Laws
Inhabitants of WISE Color Space
First Spectroscopically Confirmed WISE Brown Dwarf

- WISE 0458+64 spectrum from LUCIFER on LBT.
- At the time, was as cool or cooler than any known BD
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 et al: a binary with 0.51'' separation
- Very cool binary and much closer to the Sun than CFBDSIR 1458+1013
Liu et al. 2011: 0.11” binary

Did not have Spitzer data

\[ J_{\text{tot}} - W2 = 4.2 \]
\[ H_{\text{tot}} - W2 = 4.6 \]

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

- A candidate “coldest brown dwarf”
Fig. 4.— $JHK_s$ LGS-AO images (left to right) of WISE 1841+7000AB. Each image is $\approx 0.6'$ 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
But wait there’s more!

- Triples the number of known T8s
- 7× the number of known T9s
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H-W2 vs. W1-W2

New WISE Candidates
New WISE T Dwarfs
Field MLT Dwarfs
Who’s the Coolest of them all?

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

α = 14:05:18.403  (211.32668)
δ = +55:34:21.46   (55.572628)
l = 102.84
b = +58.58

\[ W1-W2=3.9040000 \]
\[ W2-W3=1.7730000 \]
Need HST WF3 IR Grism for spectrum

- Clearly see the 1.27 and 1.59 μm peaks of a CH₄ 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
- 1$^{st}$ Y dwarf!
Astrometry so far

- 2 WISE positions
- 1 Spitzer position
- 1 HST position
- Proper motion \(2.64 \pm 0.26\) arc-sec/yr
- Parallax \(0.21 \pm 0.12\) arc-sec

WISE data alone give a \(6\sigma\) detection of motion.
Wide-field Infrared Survey Explorer (WISE)

H-W2 vs. W1-W2

New WISE Candidates
New WISE T Dwarfs
Field MLT Dwarfs
W1828+2650

- The reddest source to date as seen by the HST
- $W2 = 14.25$, $W1-W2>4$, $H-W2=8.5$, $J-H\approx 0.72\pm 0.42$
- 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.
Wide-field Infrared Survey Explorer (WISE)

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?

Astrometric Confirmation Needed!

-Ron Probst
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 et al. (2012) sulfide dust
- $T_{\text{eff}} = 600$ K, \(\log(g)=5\)
- 19.5% clear, 80.5% $f_{\text{sed}}=4$ dusty
- $L = 10^{-6.1}$ L$_\odot$
- For $R=0.91$ R$_J$, $T_{\text{eff}} = 567\pm14$ K, $M=32$ M$_J$, age $\approx 5$-8 Gyr
Is the BD color-luminosity law unique?

- Jupiter emission at 5 microns is limited to bands where deep material can be seen
- \( L_\nu \approx 4\pi R^2 f_{\text{band}} \pi B_\nu(T_{\text{band}}) \)
- Spectra and colors measure \( T_{\text{band}} \) but not \( f_{\text{band}} \)
- But \( T_{\text{eff}} = f_{\text{band}}^{1/4} T_{\text{band}} \)
Is the BD color-luminosity law unique?

- Jupiter emission at 5 microns is limited to bands where deep material can be seen
- \( L_v \approx 4\pi R^2 f_{\text{band}} \pi B_v(T_{\text{band}}) \)
- Spectra and colors measure \( T_{\text{band}} \) but not \( f_{\text{band}} \)
- And \( T_{\text{eff}} = f_{\text{band}}^{1/4} T_{\text{band}} \) so spectral type vs \( T_{\text{eff}} \) 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 $10 \times$ 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 ($2 \times$ from $T_{eff}^4$ and $2 \times$ 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

\[ \text{Detection Limit [AU]} \]

\[ 10^3 \quad 10^4 \quad 10^5 \]

\[ 0.5 \quad 1 \quad 2 \quad 4 \quad 8 \]

\( \frac{M}{M_{\text{Jup}}} \)

\( 5\sigma \)

\( 20\sigma \)
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
• “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

- $W2 = 8.35$
- $W1 - W2 = 0.2$
- $J - W2 = 1.17$
- $\mu = 2.1''/yr$
- $\approx$ M4V
- $\sim 13$ pc
- W2 = 11.22
- W1-W2 = 0.23
- J-W2 = 1.86
- ≈ L1
- ≈ 17 pc
- In the Kepler field
“WISEP J180026.60+013453.1: A Nearby Late L Dwarf Near the Galactic Plane” – Gizis et al.

- $\mu = 0.42''$/yr
- 8.8 pc
- $W2 = 11.03$
- $J-W2 = 3.27$
• “Discovery of a Late L Dwarf: WISEP J060738.65+242953.4” – Castro & Gizis
• Proper motion 0.57”/yr
• 7.8 pc distance
• $W2 = 10.92$
• $J-W2 = 3.27$
• “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 et al 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!
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RR Lyras

Graphs showing the relationship between residual and logarithm of period over period of the primary, for W1, W2, and W3 bands.

UCLA

ELW - 41
20 Sep 12
A variable mid-infrared synchrotron break associated with the compact jet in GX 339–4

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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
L* at z=0.33, z=6.4 QSO, z=3 ULIRG: FSC15307 x 3
WISE Color Space
A Very Red...Blue Compact Galaxy

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

WISE image
SDSS image
BCDs & Green Peas

- WISE colors of BCDs and green peas
- From C-W Tsai et al., poster 333.11 at the Jan 2011 AAS meeting
WISE Band 1 and 2 Dropouts

- W1 > 17.4 and W2 > 15.9 and (W3 < 10.6 or W4 < 7.7)
- z=2.452
- Extended Lyman alpha emission (~40 kpc)
- 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
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 $\nu F_\nu$ at 22 µm
- Peak $\nu L_\nu = 10^{13.13} L_\odot$
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

- Density 70/sq.deg
- 60% have published z’s in COSMOS field
Z-distribution
ULAS 1120+0641

- $W1-W2 \approx 1.17 \pm 0.31$
- $\approx 43 \pm 8 \mu$Jy at 3.4 $\mu$m
- $z = 7.085$
Wide-field Infrared Survey Explorer (WISE)

W1 image of SPT z=1.13 cluster
WISE z ~ 1.3 Galaxy Cluster Candidate
WISE $z \sim 1.3$ Galaxy Cluster Candidate
r J K (Subaru)
WISE $z \sim 1.3$ 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 W1 flux 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

- Relative Abundance (%)
- Spectral Type
- O, B, A, F, G, K, M
- ≥ 120
- 80–120
- < 80

Wide-field Infrared Survey Explorer (WISE)
Redshift Histogram

\[
d^2N/(d\Omega dz) (10^3 \text{ counts deg}^{-2})
\]

vs.

\[
z \text{ (redshift)}
\]
• Plotkin et al
• “The Lack of Torus Emission from BL Lacertae Objects: An Infrared View of Unification with WISE”
Early Release Observations

- Released Wednesday 16 Feb 2010
Early Release Observations

- Released Wednesday 16 Feb 2010
NGC 1514

• IC 410
• Asteroids
  – 1719 Jens
  – 1992 UZ5
• Satellites in high orbit
• Tycho SNR
Thor’s Helmet

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
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
Wide-field Infrared Survey Explorer (WISE)

Coverage Released 14 Mar 2012

Actual Coverage Achieved for W4
Wide-field Infrared Survey Explorer (WISE)

More Coverage upto 9/30/10

1884474 frames thru 10-273.0; 68.0% to 16x+
Wide-field Infrared Survey Explorer (WISE)

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 $\frac{1}{2}$ to $\frac{2}{3}$ 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