The Porcupine Survey: A Distributed Survey and WISE Followup

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Abstract. Spitzer post-cryogen observations to perform a moderate depth survey distributed around the sky are proposed. Field centers are chosen to be WISE brown dwarf candidates, which will typically be 160 μJy at 4.7 μm and randomly distributed around the sky. The Spitzer observations will give much higher sensitivity, higher angular resolution, and a time baseline to measure both proper motions and possibly parallaxes. The distance and velocity data obtained on the WISE brown dwarf candidates will greatly improve our knowledge of the mass and age distribution of brown dwarfs. The outer parts of the Spitzer fields surrounding the WISE positions will provide a deep survey in many narrow fields of view distributed around the sky, and the volume of this survey will contain many more distant brown dwarfs, and many extragalactic objects.

Keywords: Spitzer Space Telescope, infrared astronomical observations, brown dwarfs, Wide-field Infrared Survey Explorer (WISE)
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1. INTRODUCTION

The Wide-field Infrared Survey Explorer (WISE) will survey the entire sky in 4 mid-infrared bands centered at 3.3, 4.7, 12 and 23 μm, with angular resolution $6''$ ($12''$ at 23 μm), to 5σ sensitivity requirements of 120, 160, 650 and 2600 μJy. WISE will be launched into an IRAS/COBE-like Sun-synchronous nearly polar low Earth orbit in November 2009. The WISE Band 1 and Band 2 filters are optimized for the detection of methane dominated brown dwarfs. The 4.7 μm filter samples the strong peak of brown dwarf emission due to a hole in the methane absorption, and the 3.3 μm filter is in a strong methane band so brown dwarfs are faint, but this band is sensitive to emission from normal stars and can be used to veto normal stars. Very few objects are expected to mimic the extreme [3.3]-[4.7] μm colors of T (and Y) brown dwarfs. WISE will find several hundred brown dwarfs colder than 750 K, which is approximately the lowest currently known temperature. For such cold objects the optical flux is negligible, and the near-IR flux accessible by ground-based telescopes is quite weak. Since the WISE survey covers the whole sky, these objects will include the closest and brightest objects in all spectral classes. As such they will provide the best targets for further study with large telescopes such as the JWST. But it will be very important to collect astrometric

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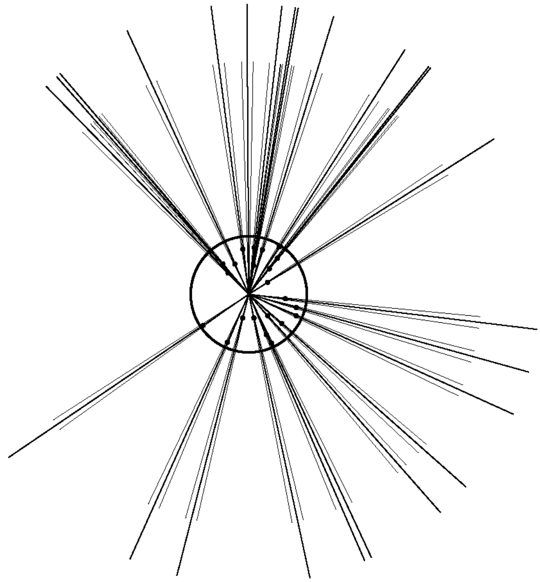

FIGURE 1. Cartoon showing the WISE survey volume (the inner circle), WISE candidates within the circle, and the Spitzer observations as rays extending out to great distance.

information on these sources in order to concentrate JWST time on the nearest and most interesting systems. For objects with small distances from the Solar System, JWST cameras will be able to resolve and separately image self-luminous Jovian planets or detect astrometric wobbles of the central stars, and JWST spectrographs will be able to obtain high SNR data yielding data about the elemental and isotopic abundances in these stars.

TABLE 1. Astrometric accuracies for positions at the mean epoch of the observations θ, the annual proper motion μ, and the annual parallax π.

Datasets	$\sigma(\theta)$	$\sigma(\mu)$	$\sigma(\pi)$
WISE baseline	0.50″	…	…
WISE extended	0.35″	1.40″/yr	…
Spitzer + WISE baseline	0.07″	0.20″/yr	0.08″
Spitzer + WISE extended	0.07″	0.14″/yr	0.07″

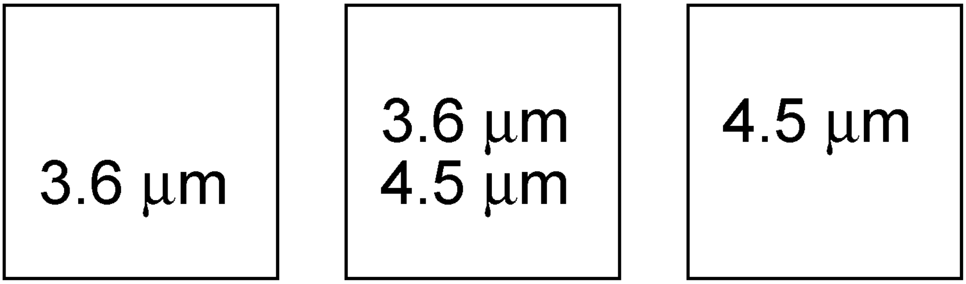

FIGURE 2. First epoch with Spitzer.

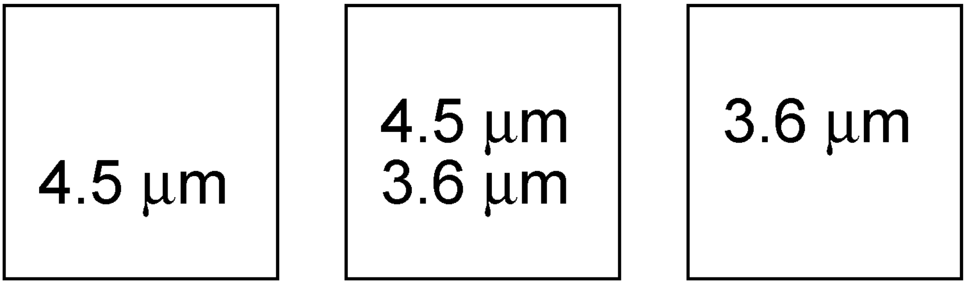

FIGURE 3. Second Spitzer epoch, 6 months later.

2. WISE CANDIDATE BROWN DWARFS

The WISE catalog will have $\mathcal{O}(10^8)$ sources at 4.7 μm, and the reliability requirement is > 0.999. The methane dominated brown dwarfs found by WISE will be brightest at 4.7 μm, and many of them will only be detectable at 4.7 μm. This means that there might be as many as $\mathcal{O}(10^5)$ false 4.7 μm only sources that could be confused with brown dwarfs.

The WISE team will make a special effort to reduce the false positive rate, both by visual inspection of the 8 or more frames covering each object, and by leveraging the photometric and astrometric information gained by cross identification of the WISE sources with other very large area surveys. Thus there might be $\mathcal{O}(10^4)$ candidates. We propose to take Spitzer 3.6 and 4.5 μm images of these fields, which will generate a fairly large area survey spread into many pencil beams or quills, as shown in Figure 1.

3. WISE SCHEDULE

WISE observations are planned to occur during calendar year 2010. In the baseline WISE mission, the sky is surveyed once in a six month interval, but all of the eight or more images of a given object are taken in a one or two day period, so there is only one epoch for each source. The WISE cryostat is currently estimated to have a lifetime greater than a year, which would allow a second pass over the sky. If this

WISE extended mission occurs, there will be two epochs separated by 6 months on every object. Astrometry from WISE is required to be better than 0.5 arc-sec relative to 2MASS, so if the extended mission occurs WISE alone will be able to estimate proper motions to an accuracy better than 1.4 arc-sec/yr if the parallax does not confuse the proper motion determination. In any case, candidates that show significant motion on a 6 month baselines deserve followup with Spitzer. The baseline WISE mission will only give a position at a single epoch and no proper motion information.

But no proper motion information does not mean there will be no proper motion. For a typical transverse velocity of 30 km/sec, the proper motion will be $(6/D)$ arc-sec/yr, where D is the distance in parsecs. This can easily confuse the cross-identification of WISE brown dwarfs with other surveys such as 2MASS, SDSS, the UKIDSS Hemisphere Survey, VISTA, and the POSS. WISE candidates that show up in these other surveys, with no position displacement and colors inconsistent with a cool brown dwarf, can be vetoed. But positive confirmation of nearby brown dwarfs using non-simultaneous data will be difficult without good proper motions.

The preliminary WISE data release will occur in early to mid 2011, with a final data release coming one year later. Thus the followup observations with Spitzer could occur in the 2012 to 2014 time frame. The observations proposed here would give two Spitzer observations with a 6 month separation, and the time base between the WISE and Spitzer observations would be 2 to 3 years. Spitzer positions should be accurate to 0.1 arc-sec, since the WISE candidate brown dwarfs will be quite high SNR in the Spitzer data.

4. UTILITY OF WARM SPITZER DATA

Both the WISE and Spitzer observations will be taken very close to 90° elongation from the Sun which means that the baseline for the parallax measurement will be the full 2 AU diameter of the Earth's orbit. Thus the Spitzer data will provide parallax accuracies very close to $\sigma(\theta)/\sqrt{2}$ as shown in Table 1.

The proposed Spitzer observations involve two epochs taken 6 months apart. At each epoch the WISE candidate is observed with both fields of the IRAC. We propose a 5 point Gaussian dither pattern with small steps in each field of view, with 30 second frame times, leading to 150 seconds of integration time in each band per epoch. A single epoch thus provides both 3.6 and 4.5 μm data on the central position, plus two flanking fields covered in only one of the bands, as shown in Figure 2. The second epoch taken 6 months later will have the orientation of the IRAC fields reversed as seen in Figure 3, so that each of the flanking fields gets covered in both bands, while the central field is covered in both bands during each epoch. Since the IRAC fields are quite close together, there is only a weak requirement on the orientation of the second epoch. We hope that 7 to 9 candidate positions can be done per hour at each epoch. Then 2500 total hours can provide followup data in two epochs for about 10,000 WISE candidate positions.

The data taken in this survey will provide a large sample of serendipitous objects. The 5σ limits in the flanking fields will be 3 μJy and 6 μJy in IRAC bands 1 and 2, if the post-cryogen performance matches the cryogenic performance. The central field will be covered twice, giving 2 and 4 μJy limits. For serendipitous brown dwarfs, each WISE candidate leads to surveying a solid angle of $2 \times 5' \times 5'$ to a distance 5 times greater than the WISE depth, and the central $5' \times 5'$ to a distance 6 times greater than WISE. Therefore the volume surveyed by Spitzer at each WISE candidate position corresponds to a volume of 3.7 sq deg surveyed to the WISE depth. Thus 2500 hours, covering 10,000 WISE candidates, would also survey a volume corresponding to 37,000 square degrees of WISE data. Thus there will be a comparable number of cool brown dwarfs discovered serendipitously in these data.

5. REQUIRED TIME

The survey plan depends on how much overhead there is for each observation. If the overhead is T and the integration time is t, the survey depth goes like $t^{-1/2}$, and the number of serendipitous sources discovered per hour goes like $t^{3/4}/(t+T)$. This discovery rate is a maximum when $0.75/t - 1/(t+T) = 0$ or $(1+T/t) = 4/3$. Thus the integration time should be 3 times larger than the overhead, as noted by Eisenhardt *et al.* (2004, ApJS, 154, 48). The actual time per AOR computed by Spot is 629 seconds, but the density of WISE candidates on the sky will be high so the slews between candidates will be a few degrees or less, and the slew penalty in Spot may be too high. Thus an overhead of 100 to 150 seconds per candidate may be reasonable. An overhead of 150 seconds gives 2500 hours of total time to do 10,000 candidates in two epochs, while the Spot time per AOR gives 3500 total hours.

6. OTHER USES

The value of the serendipitous extragalactic data will be substantial. For 2500 hours a solid angle of 208 square degrees is covered. This is 50 times the solid angle of the Spitzer Shallow Survey, covered to a greater depth. Since the WISE brown dwarf candidates will be randomly distributed over the high galactic latitude sky, the effect of cosmic variance on the statistics of extragalactic sources will be minimized. Each $5' \times 5'$ spans 2.5 Mpc for redshifts in the range 1-2 where the angular size distance is a maximum in the concordance model, and this is a large enough patch to study clustering.

A Spitzer post-cryo survey of WISE ULIRGs may also be worthwhile. ULIRGs with a $F_\nu \propto \nu^{-2}$ will be detected by WISE in its 12 and 23 μm bands but may not be seen at 3.3 and 4.7 μm. Spitzer data will extend the spectral energy distribution to shorter wavelengths and give improved positions. For ULIRGs, a survey deep enough to detect neighboring galaxies down to L_* would be useful since it would allow one to measure the clustering properties of the population. Since the ULIRGs could be at $z \approx 3$, this would require longer exposures on each field to reach L_*.

7. CONCLUSION

The Porcupine Survey proposed here will greatly enhance the value of the WISE survey, and will positively identify very nearby star systems that will be prime targets for follow-up with the JWST. The combination of WISE, Spitzer post-cryo and JWST observations could very well lead to the discovery and verification of the closest star systems to the Sun and the closest extrasolar planets.

8. FURTHER READING

See the WISE web site for astronomers at `http://www.astro.ucla.edu/~wright/WISE` or the WISE public Web site at `http://wise.astro.ucla.edu`.

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