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México D F. 2009
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Science with the Synoptic All-Sky Infrared Survey Telescope (SASIR)

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Summary

The Synoptic All-Sky IR Survey Telescope project, SASIR, is aimed at obtaining a simultaneous multicolor (Y, J, H, K) synoptic infrared (IR) imaging survey of the entire sky (above declination δ = -30°) with a new, dedicated 6.5-meter telescope at San Pedro Mártir (SPM) Observatory in México. This initiative is being developed as a partnership between the Instituto de Astronomía at UNAM and INAOE, in México, and the University of California and the University of Arizona, in the USA. The 4-year, dedicated survey with a field of view of about one degree, planned to begin in 2017, will reach more than 100 times deeper than 2MASS [31], increasing the effective detection volume by more than one million. The Synoptic All-Sky Infrared Survey will reveal the missing sample of faint red dwarf stars in the local solar neighborhood, and the unprecedented sensitivity over such a wide field will result in the discovery of thousands of z ~7 quasars (and reaching to z > 10), allowing detailed study (in concert with JWST and Giant Segmented Mirror Telescopes) of the timing and the origin(s) of reionization in the early universe. As a time-domain survey, SASIR will reveal the dynamic infrared universe as never seen before, opening new phase space for discovery. Moreover, synoptic observations of over 106 supernovae and variable stars will provide better distance measures than optical studies alone.

SASIR also provides significant synergy with all present and future major facilities, improving the overall scientific return of community investments. Compared to optical-only measurements, IR colors vastly improve photometric redshifts to z ≈ 4, enhancing dark energy and dark matter surveys based on weak lensing and baryon oscillations. The wide field and target of opportunity capabilities will enable a connection of the gravitational wave (e.g., Advanced LIGO and LISA) and neutrino universe – with events otherwise poorly localized on the sky – to transient electromagnetic phenomena. SASIR will enable the distribution of dust to be mapped more precisely and with higher dynamic range than currently possible, removing systematic bias in extragalactic distance and galaxy studies.

Technical Overview: The 6.5 m primary mirror is already funded and casting begins in Summer of 2009. The SASIR telescope and dome structure will be based on the Magellan or MMT design - with demonstrated capability to deliver excellent image quality in an f/5 beam over 1+ degree diameter. This will mitigate risk and speed development. The camera consists of reimaging optics, 3 dichroics and 4 separate focal planes each seeing ~1° diameter of the sky (f/2.5 net focal ratio). In total, there will be 124 2k x 2k arrays, constituting the largest IR imager ever constructed. Thermal emission control and weight/space constraints will present significant engineering challenges, but no new technical development is required. The étendue-couleur is more than 3 orders of magnitude larger than 2MASS and >10x that of VISTA. Still, data rates (~TB per/night) are roughly 100× smaller than those expected from LSST and can be accommodated with ongoing upgrades at SPM. We expect to release survey data in incremental stages throughout the science operations, and to release transients daily.

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1. SASIR Key Science Goals

The following discussion highlights the expected impact of SASIR in just some of the fields of interest in the next decade. Many of these areas are covered in a number of science white papers (WP) that were submitted to The Astronomy and Astrophysics Decadal Survey (Astro2010) generated by the SASIR collaboration. All these WP are already publicly available at http://www8.nationalacademies.org/astro2010/publicview.aspx.

2. Unveiling the Lowest-Temperature Neighbors

Our understanding of stellar populations stems from our sampling of the immediate Solar Neighborhood. This sample is woefully incomplete for brown dwarfs (BDs), objects which are incapable of sustaining core Hydrogen fusion. With masses extending from ~ 0.075MSun to below ~ 0.013MSun (the hydrogen and deuterium-burning minimum masses) BDs probe the low-mass limits of star formation processes and serve as a bridge between stellar astrophysics and planetary science. Lacking nuclear energy generation, they evolve steadily to low luminosities and low effective temperatures and are thus useful chronometers for a variety of Galactic studies (see following Astro2010 Whitepaper [WP]: Burgasser). They ultimately achieve photospheric conditions similar to those of gas giant planets (Teff ≈ 100 - 1000K). Overall, studies of BD populations and their atmospheres support a wide range of scientific endeavors: providing discriminating constraints on star- and planet-formation theories; driving advances in the properties of cool atmospheres; and guiding direct detection strategies for exoplanets. Testing models of BD atmospheres, and identifying true analogues to directly detected exoplanets (e.g., Formalhaut b, Teff ≈ 500K; [16]) will require detailed studies of BDs cooler than those currently known (Teff ≈ 600K).

UKIDSS [19] and the pending WISE [8] experiments should detect the first Teff ≈ 500K brown dwarfs within 10 pc (Fig. 1), but deeper optical/NIR surveys are required to extend samples to lower Teff and beyond the local neighborhood. SASIR will provide a 100-fold increase in sensitivity over current NIR surveys, facilitating the detection of 1000K brown dwarfs out to 1 kpc (sampling the Galactic scale height of BDs), 500K brown dwarfs out to 100 pc (a 1000-fold increase in sampled volume over UKIDSS) and 300K "water-cloud" brown dwarfs out to 10 pc. This will help complete the census of stars and BDs down to the lowest masses in the
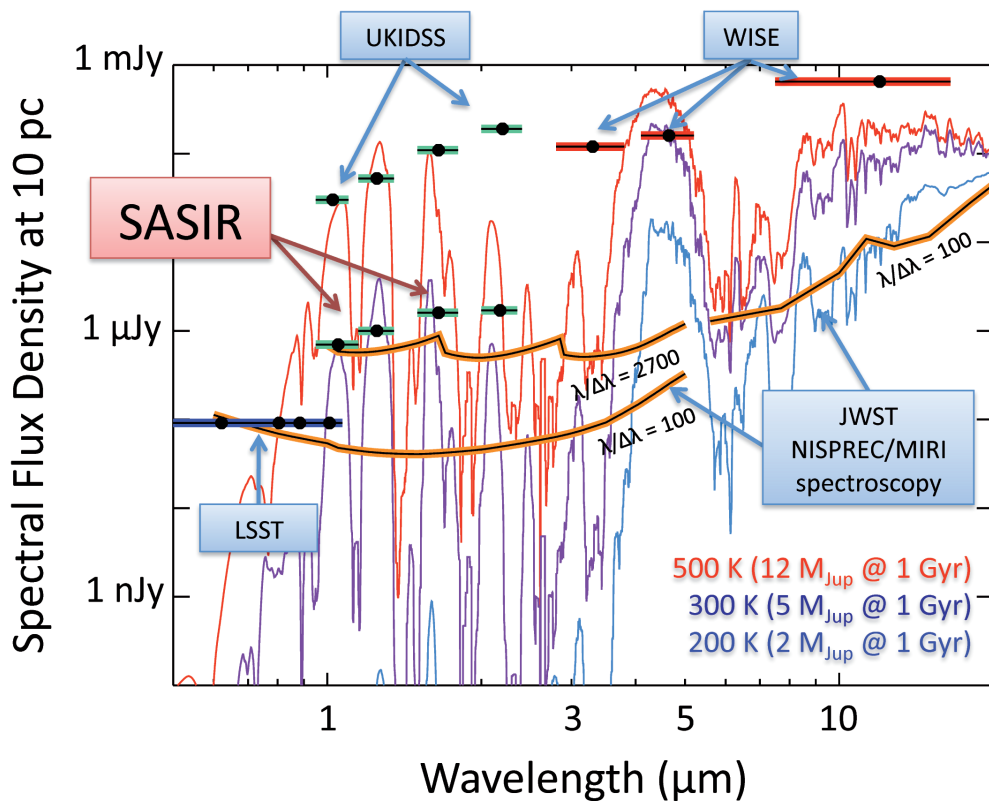
Figure 1. *Model spectra [5] for 500 K, 300 K and 200 K brown dwarfs (top to bottom), scaled to a distance of 10 pc. These models correspond to masses of 12, 5 and 2 Jupiter masses at an age of 1 Gyr, respectively. Sensitivity limits for current and proposed imaging surveys (including SASIR) and spectroscopic facilities (5σ in 1 hour) are indicated.*

immediate Solar Neighborhood, while sampling the density structure of brown dwarfs far from the Galactic plane. The multi-band and multi-epoch detections with SASIR, optimized in cadence for parallax discovery and proper motion studies, in conjunction with single-band detections and upper limits from WISE in the mid-IR and LSST in the optical, will enable robust color- and motion-selection of sources for efficient spectroscopic follow-up with GSMTs and JWST. Expansion of the local census will also enable direct imaging searches for Earth-mass exoplanets and other companions with next-generation high-angular resolution facilities.

3. Probing the Epoch of Reionization with Quasars

With no in situ observations, the objects responsible for the reionization of Hydrogen beyond z ≈ 7 span a wide range of theoretical possibilities [21, 26] (WP: Prochaska, McQuinn, Bouwens, Stiavelli). The consensus is that bright quasars (QSOs) have insufficient number density at z > 5 to drive reionization [e.g., 11], but AGN remain the only extragalactic source known to have high escape fractions of ionizing radiation. Surveys for z > 5 QSOs have observed the brightest sources, leaving the faint end of the luminosity function mostly unconstrained. If the faint end steepens (as for high z galaxies in the UV) or if entirely different classes of AGN [e.g. mini-quasars; 20] exist at early times, these would contribute to the extragalactic ultraviolet background at z > 5. Independent of reionization studies, surveys for z > 6 QSOs are also valuable as tracers of the growth of supermassive black holes (BHs) that populate modern galaxies or as signposts for follow-up studies of early galaxy formation [1, 6]. In the next decade, it will be possible to determine the nature and role of QSOs during reionization with SASIR as a major contributor.

QSO searches in the reionization epoch are challenged by three effects: (i) cosmological dimming; (ii) low number density; and (iii) their extremely red color. Thus, high z QSO surveys require deep near-IR and optical imaging over a large area of sky. While SDSS and 2DF (and the upcoming Pan-STARRS project) provide large areas of optical imaging, no project has achieved comparable depth and area in the near-IR. The nearly completed UKIDSS and the upcoming VISTA surveys (a joint UK/ESO venture) should increase the current samples, but these programs also lack sufficient depth and/or area to meaningfully constrain the QSO population, especially at z > 7 (Fig. 2). A systematic study of AGN during the reionization era requires the survey characteristics of SASIR. At z ~ 6, such surveys would establish the QSO luminosity function (surpassing even LSST for reddened AGN) and are necessary for sampling even the brightest sources at higher z. These measurements would be compared against estimates of the black-hole merger rate at $z \approx z_{reion}$ from gravitational-wave experiments (e.g. LISA).

Our estimations for the number of quasars predicted to be detected by SASIR, UKIDSS, and VISTA hinges on one's assumptions for the quasar luminosity function at each redshift. Following work on surveys for quasars at z < 5, we model the luminosity function as a double power-law:

$\Phi (L) = \Phi (L^*)(L/L^*)^b$, with $\beta = \beta l$ for $L < L^*$ and $\beta = \beta h$ for $L \geq L^*$.

At z ~ 6, Fan and collaborators [9] have estimated the bright-end exponent to be βh = -3.2 ± 0.7 and this group's recent publication reports βh values ranging from -2.6 to -3.3 [17]. These values are consistent with the null results for gravitational lensing of z ≈ 5 quasars (e.g. [27]). We adopted βh = -3.2 as the fiducial value and varied it from βh = -4 to -2.8. Presently, there are no empirical constraints on the shape of the faint-end of the quasar luminosity function at z > 5. We adopted M^*_{1450} = -24.5 and βl = -1.64. These values do not alter the predictions for a (relatively) shallow survey like UKIDSS but would alter the predictions for SASIR at z < 8.

Regarding Φ^*, [9] reported $6 \pm 2 \times 10^{-10}$ Mpc^{-3} quasars with M1450 < -26.7 at z ~ 6 assuming a cosmology (H0 = 65 km s-1 Mpc-1, Ω = 0.35 and Λ = 0.65). We adopted values as low as 3 x 10-10 and as large a 1 x 10-9 in Figure 2, coupling the lower Φ^* values with the shallower power-law slope. Lastly, we accounted for redshift evolution only in the estimation of Φ^* and adopted the same functional form proposed [9]: $\Phi^*(z)$ αexp(Czz) where Cz = -0.43 is the fiducial value. We also considered Cz = -0.2 and Cz = -1.0, again coupling the faster evolution with the steeper slope (i.e. combining pessimistic assumptions).
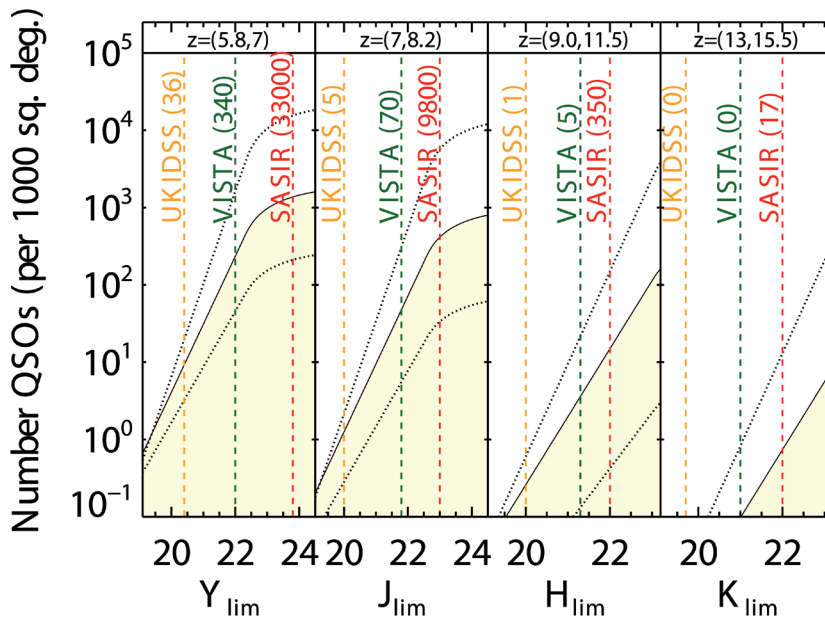

Figure 2. Predicted surface density of quasars (solid black line) per 1000 sq. deg as a function of limiting magnitude assuming a double-power law luminosity function with βl = -1.64, βh = -3.2, with M*1450 = -245 and 6 x 10-10Mpc-3 quasars brighter than M = -26.7 [9]. The solid curves assume a number density evolution α exp(-0.43z). The doted lines indicate more optimistic and pessimistic assumptions on the number density and redshift evolution (see table 1). Vertical lines indicate the magnitude limits of UKIDSS, VISTA and SASIR with the number of detections given the proposed survey area in parenthesis. Only SASIR survey will have the depth and sky coverage to provide a meaningful sample of z > 7 quasars with a realistic chance of detecting sources at z > 10.

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For each redshift interval corresponding to the rough wavelength range of a given filter, we then computed the total volume probed (with the same cosmology as [9]) and therefore the total number of quasars per 1000 sq. deg observed. The numbers listed for the UKIDSS, SASIR, and VISTA surveys correspond to the nominal depths and area for their primary high z quasar survey assuming our fiducial values for the quasar luminosity function. These correspond to the predicted number of quasars that will be detected by the various surveys not the number of sources that will necessarily be discovered.

In Table 1, we present the set of values assumed for the evolving luminosity functions and the predicted number of quasars for each survey. One notes that even for the most pessimistic assumptions (which are inconsistent with the UKIDSS results to date), SASIR is expected to detect hundreds of quasars at z ~ 8 and ≈ 10 at z ~10.

Table 1: Luminosity Function and Surveys

Descr.	M^*_{1450}	β_l	β_h	Φ^* (10⁻¹⁰)	C_z	z = [5.8, 7]			z = [7, 8.2]			z = [9, 11.5]			z = [13, 15.5]		
						U	B	S	U	B	S	U	B	S	U	B	S
Fiducial	- 24.5	-1.64	-3.2	6	-0.43	36	340	33000	5	70	9800	1	5	350	0	0	17
Optimistic	- 24.5	-1.64	-4.0	10	-0.2	79	2500	370000	9	470	140000	2	32	3600	0	1	320
Pessimistic	- 24.5	-1.64	-2.8	3	-1.0	13	69	5100	1	8	800	0	0	10	0	0	0

To actually discover quasars, one must (i) distinguish quasar candidates from other sources and (ii) obtain confirmation spectra. Regarding the former, the principal contaminant is cool, Galactic stars (presuming that one can pre-select point sources from the imaging data). To efficiently discriminate quasars from stars, it is necessary to measure photometry of these sources to higher precision than the simple detection limit of the survey. One then attempts to separate quasars from the stellar locus. For sources at z ~ 6, recent efforts to follow-up UKIDSS candidates have emphasized the value in deep optical imaging (i, z; [13]; [23]). In this regard, SASIR would surely benefit from the ongoing Pan-STARRS survey and (eventually) the proposed LSST project. For higher z candidates, color selection could be made with the near-IR photometry alone. We have not yet folded in all of these considerations for SASIR, in part because our own near-IR magnitude limits are still under consideration. The final step is to acquire near- IR spectra of the sources to classify the target and measure the redshift. For SASIR, the faintest sources detected would require new facilities, e.g. JWST, GSMT. Indeed, this science case is one of the many that highlight the synergy between SASIR and other planned/proposed near-IR projects.

It is important to consider in greater detail whether our assumptions were consistent with the search for high z quasars using the UKIDSS survey. The latest UKIDSS publication on high z quasars reports the discovery of 4 objects with z = 5.72 to 6.13 [23], two of which were previously discovered by SDSS. These four were drawn from 870 sq. deg. of the UKIDSS Large Area Survey (LAS). Our estimation of 36 quasars

assumes the full 4000 sq. deg. planned for the UKIDSS-LAS. Extrapolating their success thus far, one estimates UKIDSS will discover 4 - 40 quasars (95% c.l.) in the full LAS. It is possible, therefore, that our fiducial model is somewhat optimistic but the UKIDSS team has yet to make any rigorous estimates of completeness corrections for their follow-up efforts. In either case, we are confident the range of assumptions listed in Table 1 conservatively brackets the plausible range of quasar luminosity functions.

4. The Cosmic Distance Scale, Dark Matter and Dark Energy

An IR View of Periodic Variables in the Local Universe: Pulsating variable stars (WP: Walkow-icz) are preeminent distance indicators in the local universe. When RR Lyrae and Cepheids are used, however, unmodeled dust and metallicity effects manifest directly as uncertainties in cosmological parameters [3, 33]. SASIR would allow for precise calibration of the period–luminosity (P-L) relation of these two classes in the IR, largely skirting the problems with dust (and potentially metallicity [32]) which complicate similar efforts at optical wavebands. Multiple observations at random phases would build an unprecedented calibration of the P-L relations and enable GSMTs to measure precise distances well beyond the Local Group and fix the rungs of the cosmic distance ladder out to ~ 25 Mpc. Mira variables, promising new distance indicators, would also be observable with SASIR to ~ 4 Mpc with what appears to be a metallicity independent P-L relation [12].
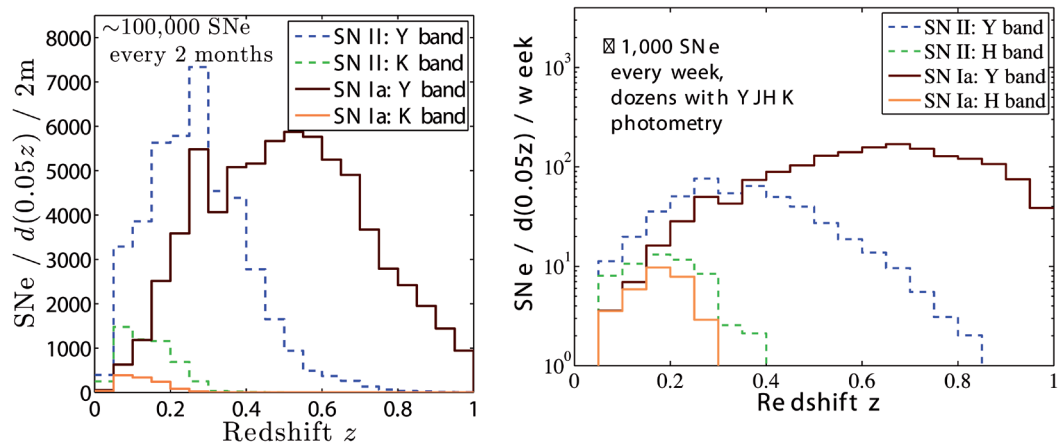

Figure 3. Expected SN counts for two types of surveys with SASIR: a rolling search with weekly cadence (left), and "all-sky" monitoring every two months (right). The number of SNe in the different surveys is inversely proportional to the light-curve information we will have for each SN. The samples are complementary and both have cosmological use.

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Infrared Supernovae: Type Ia supernovae (SNe Ia) (WP: Howell) are better standard candles in the IR than at optical wavebands [36] and minimize systematic effects that plague Ia optical cosmography. Type II-P SNe are an emerging distance indicator (e.g., [28]) recently shown to be almost comparable in precision to SNe Ia ([25]; WP:

Poznanski), and could be even better standard events in the IR. In addition to cosmography, searching for SNe in the IR will improve our understanding of their rates (largely circumventing dust effects) and hence constrain their diverse progenitors. Using optically determined rates alone, SASIR will detect more than 106 SNe during the four-year survey (Fig. 3).

Photometric Redshifts for Weak Lensing and Baryonic Oscillations: Wide-field IR photometry provides a compelling improvement in the photo-z measurements of galaxies, especially beyond z ~ 1.5 (Fig. 4, left). The enhanced accuracy for galaxies across the Northern sky will greatly improve the returns on weak lensing and baryonic oscillation experiments with wide-field optical facilities (WP: Riess, Eisenstein, Heap, Zhan).

Galaxy Evolution and High-redshift Clusters: A frontier endeavor for the next decade will be to determine the progress of nascent galaxies as a function of local environment as the proceed from the the "blue swarm" of small star-forming objects at 2 < z < 3 to the well-defined red sequence of massive galaxies seen in both galaxy clusters and the field at z < 1 (WP: Holden, Labbe, Stanford). The appearance of the red sequence will probably spread from the high- to low-density environments, such as groups, before becoming established in the field. Such a study requires identifying the full range of environments at z > 2, through wide-area imaging, since halos of mass M > 1014 MSun are exceedingly rare at z > 2 (Fig. 4, right).
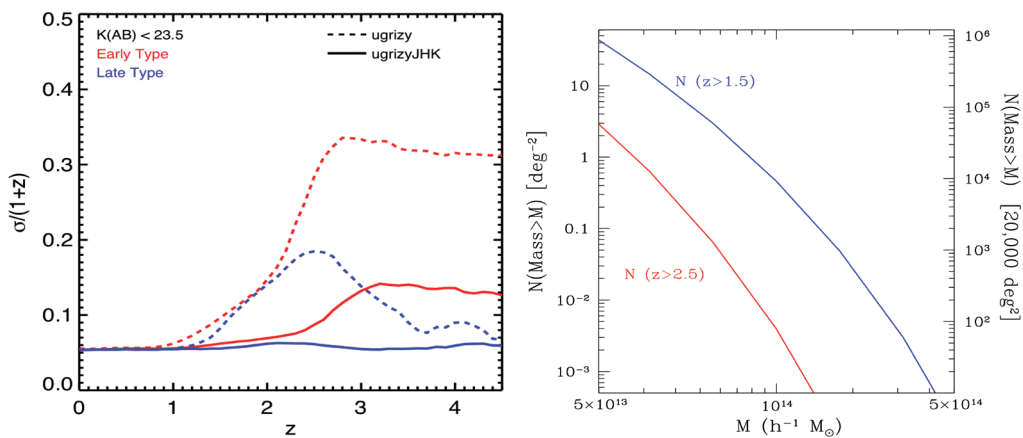

Figure 4. (Left) Simulated photometric redshift accuracy for early (red) and late-type (blue) galaxies. Dashed lines show the expected performance of LSST/Pan-STARRS4 alone. Solid lines include NIR data from SASIR, which vastly improve accuracies at z > 1. Simulations assume a 4% floor to these accuracies [4]. (Right) Expected cluster demographics by mass in two redshift regimes. Finding the rarest massive clusters requires a wide-field near-IR imaging survey so that galaxy populations at z > 2 are selected at rest frame wavelengths.

5. A New Phase Space for Transient Discovery

Deep multicolor synoptic monitoring on hundreds to thousands of square degrees on minutes to months timescales would break new ground in the infrared, opening up the potential for totally new classes of objects found by IR variability. There are indications that exploration in this space phase will be fruitful (e.g., WP: Kulkarni Wozniak, York), particularly relevant to "multi-messenger" astrophysics. Indeed the explosive events which dominate the high-energy sky - involving compact objects such as neutron stars (NSs) and BHs (BHs) (of both the stellar and supermassive varieties) - should produce long-wavelength signatures (Figure 5).
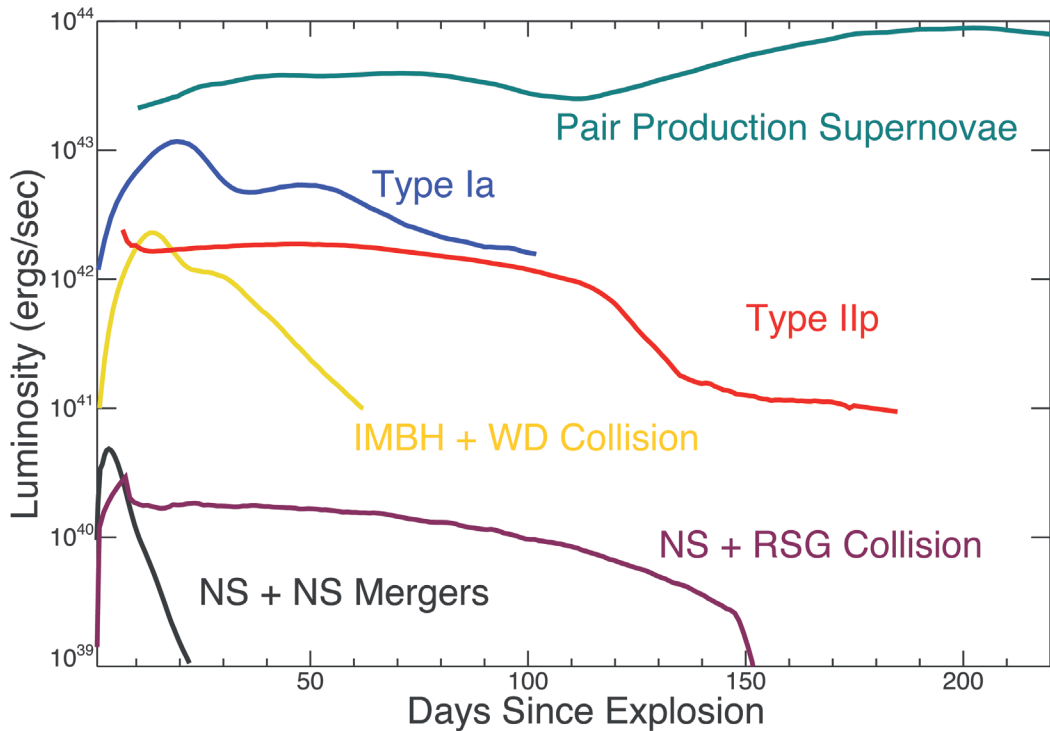

Figure 5. Characterizing the transient universe at IR wavelengths. Aside from the "known" Type Ia (blue) and core-collapse (red) SNe, new types of extragalactic transients are expected to arise from cataclysmic events. Shown are our estimated restframe infrared light curves resulting from the collision between a NS and red supergiant (RSG; purple), the disruption and ignition of a white dwarf by an intermediate mass BH (yellow), and the merging of a NS binary (powered by r-process nucleosynthesis; (black). SASIR will readily see NS-NS mergers to the Advanced LIGO volume (see §2.4). These preliminary model calculations suggest that an assortment of peculiar transients should be uncovered by SASIR, providing a complementary view (less obscured by dust) of the transient universe than that offered by optical synoptic surveys.

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Motivating the need for wide-field monitoring, TeV gamma-ray Čerenkov telescopes and neutrino detectors will localize events only to degree-scale accuracy. Likewise, Advanced LIGO and LISA are expected to localize degenerate object merger events through gravitational waves (GW) with, typically, one-degree scale uncertainties. Much of the science extracted from these new windows on the universe will require the identification of electromagnetic counterparts, which would yield the redshift of the host galaxy and enable their use as standard sirens for cosmography [18, 30] (WP: Bloom). Little is known of these signatures but indications are that the IR is a valuable window [Fig. 5; 16, 29] (WP: Hawley, Phinney, Bloom). As such, SASIR, with its rapid access to deep wide-field imaging is a promising tool.

6. Broad Scientific Reach and Synergies with Other Major Facilities

Beyond the above SASIR highlighted projects, the following lists additional examples of science white books (WP) submitted by us and other groups to Astro2010 (one can reach all papers directly at http://www8.nationalacademies.org/astro2010/publicview.aspx):

- Discover new satellites of the Galaxy minimizing dust biases (WP: Bullock, Johnston),
- Produce large new samples of strong lenses (WP: Coe, Koopmans, Marshall),
- Survey the oldest (i.e. coldest) white dwarfs in the Milky Way (WP: Kalirai),
- Produce a Galactic dust-extinction map of unparalleled spatial resolution (WP: Gordon),
- Probe the bright end of the galactic luminosity function at z > 5 (WP: Bouwens),
- Stellar population analysis of nearby galaxies (WP: Kalirai, Kirby, Lu, Meixner, Worthey, Wyse),
- Discover star cluster systems (WP: Rhode),
- Study stellar morphology (bulge/disk) in nearby galaxies (WP: Clarkson),
- Map the distribution of low-mass stars well beyond the solar neighborhood (WP: Cruz),
- The search for light bosons (WP: Chelouche),
- Finding Type IIn SNe at z > 5 (WP: Cooke),
- Probing quasar variability (WP: Elvis, Murray),
- Long-wavelength signatures of tidal disruption events (WP: Gezari),
- Exploring the nature of X-ray and explosive transients (WP: Soderberg, Wozniak),
- Studies of variable stars from near to far (WP: Walkowicz)

It is worth emphasizing that many of the science WPs submitted to Astro2010 have called for wide-field, near-IR surveys of the sky. While some science goals demand the high spatial-resolution afforded by space missions, most could be done for far less expense by a ground-based observatory like SASIR.

7. Technical Overview

The enormous scientific promise of SASIR is based on a dedicated wide-field (1 degree diameter) large aperture telescope (6.5 m in diameter), located in a dark site with a large fraction of clear nights (~75%), enabling deep and synoptic imaging of the whole Northern sky simultaneously in NIR bands (Y , J , H and K) with four independent focal planes.

This uniquely powerful survey and facility does not require new technology exploration or a totally new kind of telescope. Indeed, as described in §3.1, the SASIR telescope design will use already proven and operational concepts (such as from the Magellan and MMT telescopes) as the point of departure. Nevertheless, given the confluence of a moderately wide field with multiple and large focal planes, its actual design and technical feasibility, with present day technology and IR materials, needs to be carefully studied in the preliminary design phase
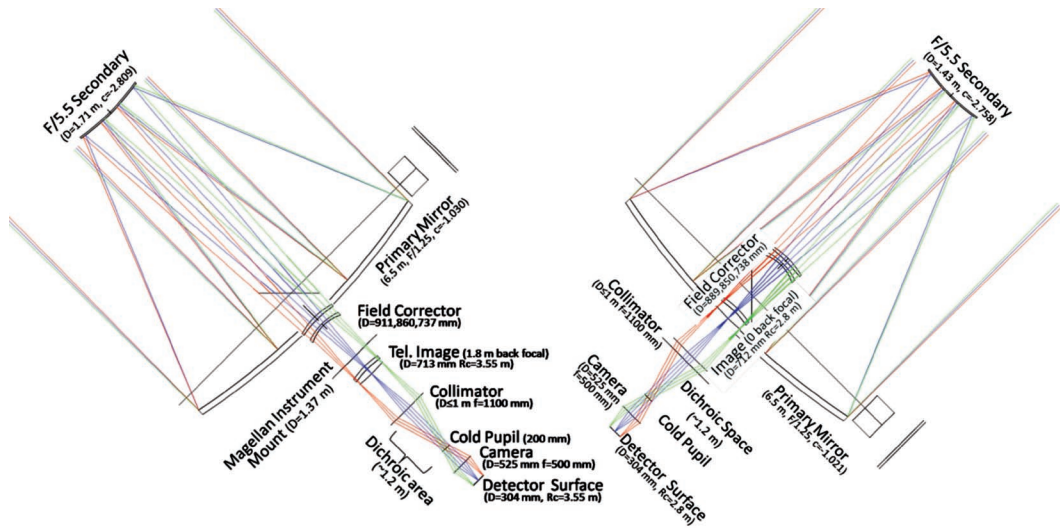

Figure 6. SASIR telescope designs (Magellan nominal back focus at right, null back focal at left). A single arm is shown with indicative camera and collimator parameters (dichroics not drawn). The telescope and corrector deliver and effective f/5.5 focal, the whole system is ~f/2.5. Relevant characteristics of the main components are shown. These two baselines are to be studied (optics, mechanics, costing) in more detail.

8. The 6.5 meter SASIR Telescope

The telescope structure and primary mirror are to be based on the highly successful and efficient Magellan Telescopes in operation at Las Campanas Observatory in Chile and the MMT telescope at Mt. Hopkins. The Magellan and MMT optics and structures are each well suited to wide-field imaging. In particular, a successful one-degree f/5 corrector has been in operation at the MMT [10] while a second system is being commissioned at Las Campanas. Furthermore, we have demonstrated [14]

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that this design is quite capable of delivering fields of view beyond 1.5° in diameter. The three main challenges facing the design of the SASIR telescope are therefore of a different nature:

- Simultaneous feeding of up to four focal planes, with collimator/camera NIR optics of reasonable size;

- Controlling spurious thermal emission in the H and K bands (under a proper baffling system, coupled with space for a cold pupil);

- Maintaining the instrument within the weight and envelope limits of the Magellan or MMT structure.

The first challenge not only drives the survey speed but makes SASIR different and quite powerful with respect to its closest relatives, the 4 m-class VISTA and UKIDSS systems and the 8 m LSST. The SASIR collaboration will be developing its telescope concept by fully investigating and resolving among potential telescope solutions that optimize the science returns and minimize the risks of the camera design: a conventional telescope plus image reducer(s), as here presented, a 3-mirror telescope with an intermediate collimated beam, or a conventional telescope with dichroic(s) in non-parallel beams.

A range of variants on the base Magellan design are currently under consideration for a solution that will permit up to four individual-band cameras, each with about 1° field of view (FoV), with NIR refractive optics under about 500 mm in diameter. The current reference concept consists of a f/5.5 Ritchey-Chretien design with a 3-lens field corrector (all spherical, Silica-like glass). In order to allow for a cold pupil as well as the placement of dichroics, the telescope is coupled to a focal reducer, with a collimated beam of 200 mm and a camera with focal length of 500 mm. Figure 6 shows two examples of the telescope concept, the first one maintaining the back focal distance of Magellan, while the second telescope focuses at the primary vertex, exploring the range in which the diameter of the secondary and the height of the pupil can be controlled.

 The present studies include cases for telescope f-ratios from f/3.5 up to f/11, at both Cassegrain and Nasmyth stations, and a range of pupil diameters. The designs shown deliver an image quality close to the diffraction limit across the whole FoV, between 0.03" and 0.1" FWHM. These idealized (pre-construction) telescope performances indicate that most of the optical error budget can be left for the more difficult collimator and camera designs, as well as for the construction and operation of the entire system. These telescope concepts let us explore the main parameter space and general dimensions for the SASIR collimator and camera systems. A full range of parameter exploration is expected for the conceptual and preliminary design phases of the project.

9. The SASIR Camera

Foreoptics: SASIR plans a split-beam design for the camera optics, like 2MASS, to simultaneously image in 4 filters. The full optical design of SASIR will be driven by the following guide-lines and constraints: the aperture and curvature of the primary mirror (f/1.25), a FOV of 1.06°, a plate scale of 0.228'' per 18 µm pixel (f/2.5 net system), an after-construction-under-operation image quality that does not deteriorate by more than a few percent the median NIR seeing, a high-throughput design (e.g. efficiency > 30%) at least within the λ = 0.8–2.4 µm range, and a system with low thermal emission from its optical components that also permits the proper buffering of scattered thermal emission. The conceptual designs of the collimator and camera, based essentially on a scaled version of already known systems (e.g. FourStar NIR Camera for the Magellan Telescope; [24]), will be developed in parallel and share optimization constraints with the telescope concept.

Detectors: Given the expense for science-grade IR detectors, our design is driven by a desire to cover a large field of view with the fewest pixels while still adequately sampling the good seeing at SPM. The nominal detectors are 2048 x 2048 arrays with 18 or 20 µm pixels, now commercially available.1 This translates to 0.228 - 0.25 "/pixel. We are baselining 124 science-grade arrays (Figure 7). SASIR will not be sensitive to the read-noise of the detectors, as even short exposures are expected to be background limited. We will thus allow for as flexible and dynamic imaging as the science requires.

A Pathfinder Instrumentation Project: Our collaboration has begun construction of a new camera, the Reionization & Transients Infrared (RATIR) Camera, to be housed on the 1.5 m telescope at SPM. The 2-year experiment has its own transients science
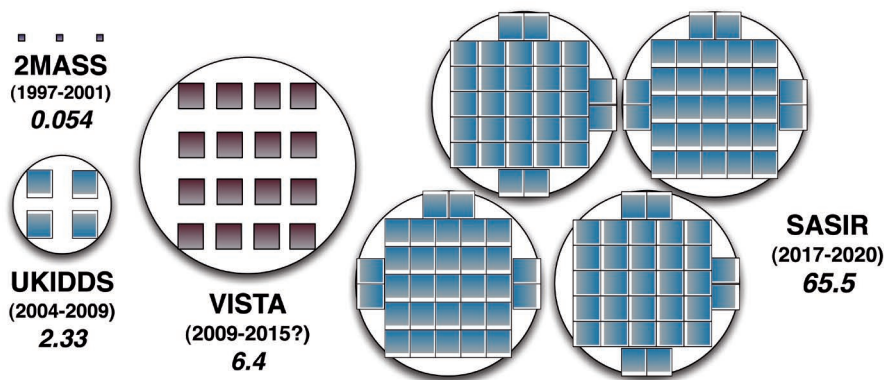
Figure 7. To scale physical comparison of the focal planes of 2MASS, UKIDDS, VISTA and SASIR. The éntendue-couleur (m2 deg2 x number of simultaneous bands), the instantaneous light grasp, is shown for each facility.

drivers, but will serve as an important pathfinder for SASIR development: RATIR will be used for collaboration building, to engage 3rd party vendors and to help the collaboration gain first hand experience with the detector operations in advance of SASIR. RATIR will obtain nightly transmission and sky brightness statistics in Y, J, H for the duration of that experiment; this will directly feed into the SASIR survey simulations. As of now, we have only limited information about the SPM IR sky background as a function of lunar phase and almost no information about the Y-band site metrics.

10. Survey Strategy and Cadence Optimization

The Survey optimization will be revised in detail during the preliminary design, accounting for articulated priorities of the diverse science cases. The baseline plan calls for 20 second double-correlated exposures – this optimizes on-sky exposures without saturating fainter 2MASS stars (which will be crucial for establishing the photometric baseline). For a total on-source dwell of 80 seconds (2 visits per night consisting of 2 integrations each) and nominal slew time to next field of 6 seconds, we expect to cover about 140 sq. deg per 8-hour night, implying that the entire visible sky from a single site could be imaged every 2-3 months. Table 2 shows the expected point source and extended source sensitivities (see also Figure 8).

The simplest survey strategy would be to cover the sky repeatedly with roughly equal time between visits. Over a 4-year survey each position could be observed ~ 6 times. To determine the parallax and proper motions of objects in the solar neighborhood (§2.1), we require at least three visits per field. In practice, there will be several different cadence strategies, with both competing and complementary goals. For instance, a fast transients search would yield very deep imaging in several hundreds of degrees squared. The SN search (§2.3) would benefit from repeated scans of the same part of the sky every few nights, while a search for high proper motion objects would only require repeat observations on a months to years timescale.

Figure 8. Comparison of the nominal SASIR survey with other significant surveys already completed (x symbol) or planned (circle or square open symbols). Left: The point source sensitivity versus wavelength for wide- area surveys where we have assumed 6 total visits (480 s) for SASIR. Right: The point source K -band sensitivity versus sky coverage. The other survey data for these figures were compiled by D. Stern (JPL).

Note. - Based on a preliminary simulation of a four band survey (Y and 2MASS filters J, H, KS) with 75% clear weather fraction and average seeing of 0.6 arcsec
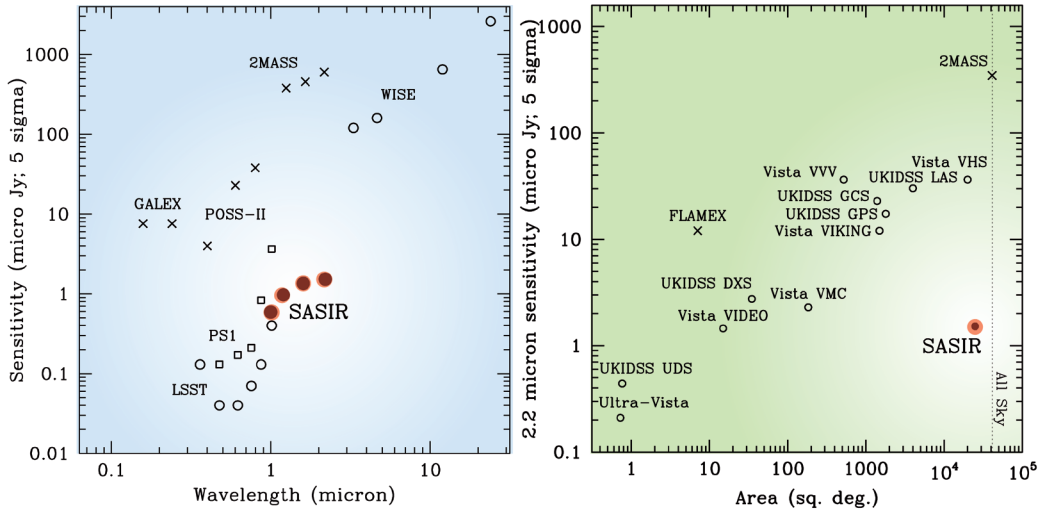
and 18 μm pixels. Each epoch assumes 80 sec total integration with 6 epochs per field over the entire survey (24,000 sq. deg.). As a consistency check to the simulation, note that the 5σ limiting magnitude of 2MASS (1.3m diameter, 7.8 s integration, seeing ~ 2.5") was 17.55 AB (346 μJy). For sky-limiting imaging, the limiting magnitude increases as 2.5 Log10 (diameter time 0.5/seeing), with diameter, time, and seeing expressed as ratios. For the nominal six visit all-sky survey, this

Table 2. Nominal Sensitivities from SASIR Concept Design

| Filter | Point Source Sensitivity | | | | Extended Source Sensitivity | |
| | Single Epoch (5-σ) | | Survey (5-σ) | | Survey (5-σ per pixel) | |
	[AB mag]	[μJy]	[AB mag]	[μJy]	[AB arcsec^{-2}]	[μJy arcsec^{-2}]
Y	23.49	1.45	24.47	0.59	23.32	1.71
J	22.95	2.40	23.93	0.97	22.78	2.82
H	22.60	3.30	23.57	1.35	22.42	3.89
K$_S$	22.47	3.74	23.44	1.52	22.29	4.40

implies a nominal depth of 5.4 mag fainter than 2MASS.

11. Data Taking and Data Management Strategies

SASIR Data Management will benefit from direct experience with the Peters Automated Infrared Imaging Telescope (PAIRITEL) Project [2], the largest time-domain robotic telescope operating at infrared wavelengths. In particular its low-level telescope and camera interfaces, pipeline and archive system, and autonomous scheduling system are a reference for determining a baseline data taking strategy commensurate with instrument limitation and SASIR science goals. We envision that

the Data Management architecture developed fully in the conceptual design phase will most resemble that of Pan-STARRS, UKIDSS and VISTA.

12. Project Site and Infrastructure

The site, located in the northern part of Mexico in the Sierra San Pedro Mártir in the state of Baja California at an altitude of 2890 m, has been developed over the last forty years and has three telescopes with main optics diameters of 2.1-, 1.5-, and 0.84 m, with a number of photometric, spectroscopic and imaging capabilities in the optical, near-, and mid-infrared regimes. SPM excels in the transparency and darkness of the night sky as well as in the seeing quality and stability [7, 34, 35]. Comparison with other sites suggests that SPM has the largest percentage of clear nights of any site in the Northern Hemisphere. The median seeing reported by Michel et al. 20 is 0.6" in the in the V band. It is yet to host competitive next-generation telescope facilities that fully exploit its unique virtues. The site had been considered by the LSST consortium prior to the decision to locate it in Cerro Pachón (Chile), as well as by next-generation extremely large telescope projects, such as the Thirty Meter Telescope (TMT).

The road that climbs the Sierra is paved up to the entrance to the National Park, while the last 16 km (within the park) is being completed now. Ample lodge and workshops at the Observatory are located 2 km from the telescopes and the selected SASIR site. The Observatorio Astronómico Nacional (OAN) has five electric generators with capacities of 280, 230, 200, 150, and 90 kW, respectively, but plans to soon connect SPM to the public electric network. This new line will also carry a fiber-optic network for a very high speed network, upgrading the current microwave link. IA-UNAM has a research branch in nearby Ensenada with a staff of 25 astronomers and a similar number of technical staff and students. IA-UNAM headquarters at Ensenada also serves as the logistic and administrative station for the observatory at SPM.

13. Design Considerations for the 2nd-Phase Operations

The SASIR Telescope is expected to be operational for 30+ years, well after the SASIR Survey is completed. The consortium envisions the telescope to continue mostly as a dedicated surveying facility. The current plan is to perform a wide-field optical/NIR spectroscopic survey, making use of the large detector investment. The SASIR telescope will be designed so as not to preclude or undermine the feasibility of such a multiobject spectroscopic survey.

14. Project History, Partnerships, and Current Status

The SASIR initiative started in 2007 and the design is still at a preliminary conceptual level. The preliminary conceptual design was created in tandem with the devel-

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opment of the SASIR science case over 2008, culminating in the production of a preliminary whitepaper. Two principals meetings were conducted in the first half of 2008 (in Santa Cruz and in México City). A two-week collaboration workshop, with >40 people in attendance, was held in Puebla, México in August 2008. The most significant engagement (face-to-face meetings, regular telecons) with third party vendors to-date has been with detector manufacturers (Raytheon and Teledyne).

SASIR is an international partnership between the Instituto de Astronomía at Universidad Nacional Autónoma de México (IA-UNAM), the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), the University of California, and the University of Arizona. The SPM site (OAN) is operated by UNAM. The University of Arizona is in charge of the casting and figuring of the primary mirror. Extending partnerships, particularly universities and national laboratories, is a priority for the collaboration.

The SASIR telescope and camera are to be developed over an eight year span, starting in 2009. The facility will be operated to carry out and complete the SASIR Survey in four to five years, starting in 2017. The SASIR collaboration expects to release SASIR survey data to the astronomy community incrementally during the science operations (following the models of 2MASS, SDSS, UKIDSS), with no more than a 18-20 month delay. Following the LSST model, transients will be released to the community at least as quickly as everyday, and possibly in near real-time.

15. Acknowledgements

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