ALL-THE-SKY, ALL-THE-TIME:
EXPLORING THE ANTARCTIC SKY ON TIMESCALES FROM MINUTES TO YEARS

Nicholas M. Law*, Octavi Fors, Philip Wulfken, Jeffrey Ratzloff
Department of Physics and Astronomy, Univ. of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA

The continuously-dark winter Antarctic sky offers an opportunity to build a new type of sky survey: one which continuously images half of the entire sky at minute timescales. Rather than addressing a single scientific question, this comprehensive survey offers the opportunity to engage a very broad section of the astronomical community, by simultaneously producing data for science cases ranging from exoplanets, to variable stars, nearby supernovae, and high-redshift gamma-ray-bursts. We here briefly discuss the science questions addressable with such a survey, along with our design for the Antarctic Evryscope, a survey instrument robust enough to operate unattended in the Antarctic winter.

The Antarctic Evryscope (Law et al. 2014a,b) would be capable of finding the nearest habitable exoplanets around cool stars, while simultaneously finding the first large sample of transiting giant planets around the brightest and most nearby stars, where the planets are much easier to characterize. The system would be the first capable of searching for transiting asteroids around white dwarfs, and would perform comprehensive nearby microlensing and eclipse-timing searches for exoplanets inaccessible to other planet-finding methods. The Antarctic Evryscope would also provide truly comprehensive monitoring of outbursting young stars, white dwarf activity, and stellar activity of all types, along with finding a large sample of very-long-period M-dwarf eclipsing binaries, vital for understanding the stellar mass-radius relation. When relatively rare transients events occur, such as gamma-ray bursts (GRBs), nearby supernovae, or even gravitational wave detections from the Advanced LIGO/Virgo network, the array will return minute-by-minute light curves without needing pointing towards the event as it occurs. By recording all data for later analysis, the Antarctic Evryscope will be able to provide *pre*-event imaging at two-minute cadence for bright transients and variable objects, enabling the first high-cadence searches for optical variability before, during and after transient events.

We are already building a mid-latitude version of the Evryscope (Law et al. 2014b; NSF/ATI funded), but an Antarctic version of the system would offer huge advantages: approximately a factor-of-five increase in sensitivity to habitable exoplanets because of the continuous winter darkness (Law et al. 2013); the ability to reach much smaller exoplanets because of reduced airmass systematics and possibly reduced scintillation; and truly-continuous observations which are the only way to attain a near-certainty of following rare transients before, during and after the events.

The Evryscope concept mounts an array of individual telescopes into a single hemispherical enclosure (the "mushroom"; Figure 1). The array of cameras defines an overlapping grid in the sky that provides continuous coverage of >10,000 square degrees. The camera array is mounted into a single dome which mimics the hemisphere of the sky. Crucially for robust and reliable Antarctic deployment, the Antarctic Evryscope design is a single instrument on a single mount, with *only one moving part.*

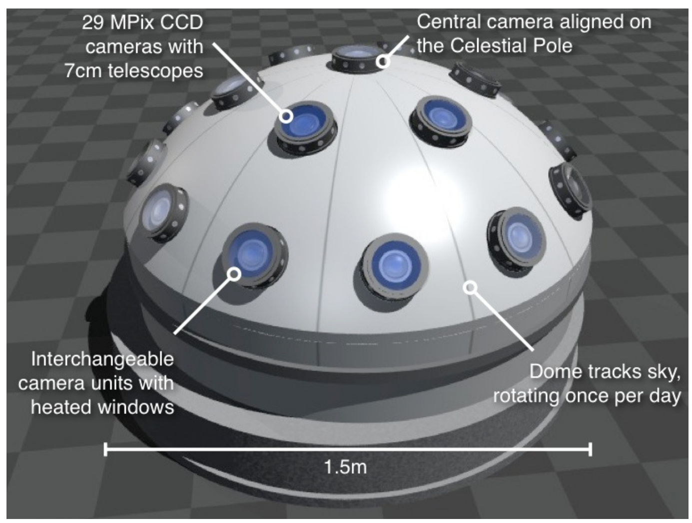


Fig. 1.— The Antarctic Evryscope concept. This example 1.5m-wide dome contains 20 separate 7cm telescopes, delivering a 10,000-square-degree instantaneous field of view with continuous tracking throughout the winter. The concept easily scales to larger apertures and improved sky sampling.

The system forms a 7cm telescope pointed at ∼1/4 of the entire sky simultaneously. This capability will allow us to explore the sky in a new way: snapshot images of every visible part of the sky in one go, repeated on minute timescales and co-added over hours and days. Contrasting the traditional telescope (Greek; far-seeing) to this instrument's emphasis on overwhelmingly wide fields, we have coined a name for this new type of telescope: the *Evryscope*, from the Greek for wide-seeing.

1. SCIENTIFIC CONTRIBUTIONS

The Antarctic Evryscope has the potential to open a new parameter space for optical astronomy by trading instantaneous depth and sky sampling for simultaneous coverage of the entire accessible sky. This large dataset will enable extremely-wide-field transiting exoplanet searches, realtime searches for transient and variable phenomena, and

* nmlaw@physics.unc.edu

it offers the capability to effectively pre-image unexpected events detected by other surveys. Our current designs offer limiting magnitudes that will allow both galactic and extragalactic events to be recorded, and the extremely wide field of view opens the possibility of monitoring large samples of rare objects that up to now have required individual targeting. In the following paragraphs we summarize key initial science areas for the Antarctic Evryscope system.

Exoplanet surveys: Current exoplanet transit surveys are limited to fields of view of 100-1000 square degrees and so cannot effectively search for transits around large samples of stars that occur rarely in the sky. The Antarctic Evryscope would have an order-of-magnitude larger field of view than the next-largest current exoplanet surveys, along with a 5× improved detection sensitivity to long-period exoplanets because of the continuous winter coverage. This would enable four transiting planet key projects:

1. A habitable-zone survey for rocky transiting planets around bright, nearby M-dwarfs: 1-2 Earth-radii transiting planets would be discoverable around every bright Southern M-dwarf; the few-month-period habitable zones accessible from Antarctica, and the large number of rocky planets around stars of that mass (Howard et al. 2012) lead to an excellent probability of detecting habitable worlds around stars bright enough to characterize the planets' atmospheres. Furthermore, the low water vapour content of the Antarctic atmosphere will improve the depth and photometric precision of a red-filtered M-dwarf transit survey compared to mid-latitude sites.

2. Searching for giant exoplanets around nearby, bright solar-type stars whose atmospheres can be easily followed-up for precision spectrophotometric and mapping techniques (e.g. Winn et al. 2011; Majeau et al. 2012).

3. A white-dwarf survey for transiting planets; the Antarctic Evryscope will be the first extremely-wide-field survey with the time resolution and sensitivity to be able to cover a sample of relatively bright, nearby white-dwarfs by searching for deep eclipses (Agol 2011). White dwarfs are small enough that even asteroid-sized bodies would be detectable, and the high incidence of metal-enriched white dwarfs suggest that there are objects to be found.

4. Synergy with TESS and other exoplanet surveys. The Evryscope will provide long-term monitoring of TESS (Ricker et al. 2014) targets, measuring stellar activity and vetting for variable stars. The system will also greatly increase the TESS giant planet yield by recovering multiple transits from objects seen as single eclipses in the relatively short TESS search period.

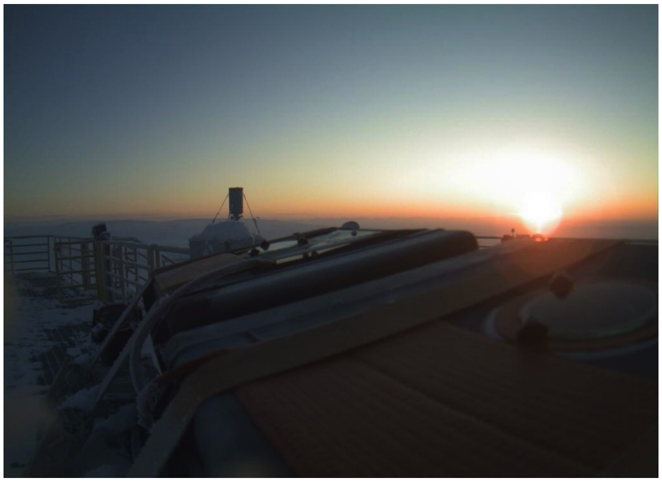
Exoplanet detection from eclipsing and pulsating stars. Transit, eclipse and pulsation timing variations allow us to measure the influence of other bodies in a system on the transiting/eclipsing/pulsating body's orbit. Current surveys must target individually-interesting systems (e.g. Marsh et al. (2013)). The Antarctic Evryscope would monitor tens of thousands of eclipsing binaries and pulsating stars simultaneously, including minute-precision timing of every eclipse and pulse cycle. Performing this search from the Antarctic would allow a push to much longer-period systems, much more comprehensive eclipse monitoring, and thus a much higher probability of planet detection.

Microlensing Exoplanet Detection. With few-minute cadences over large section of the sky, the Evryscope can also search for rare gravitational microlensing events involving nearby stars Han (2008). Typical galactic microlensing events occur on week-timescales, but exoplanets orbiting the lens star (or even isolated planets) can be detected as much shorter timescale bumps in the light curves. The key to successful microlensing planet detection is continuous monitoring and rapid follow-up. The Antarctic Evryscope's continuous coverage, few-minute temporal resolution, and high photometric precision mean that planetary signatures will be directly visible in the light curves, and all-sky coverage will allow us to search for rare events involving nearby stars rather than distant bulge stars. A survey with the Evryscope's sky coverage is expected to detect several near-field microlensing events each year, potentially finding the first rocky planets in the outer reaches of nearby solar systems (Han 2008; Gaudi et al. 2008).

Variable stars. The Evryscope prototype will monitor the brightness of millions of stars across the sky each night, building up a multi-year, two-minute-cadence database of stellar activity for every star brighter than V=16.5 in the Southern sky. This will enable the detection and characterization of unprecedented numbers of young and active stars, long-period eclipsing binaries which can be used to constrain the mass/radius relation, as well as the detection of a wide variety of other types of stellar variability.

Pre-explosion imaging of gamma-ray-bursts and nearby supernovae. The Evryscope's short-cadence limit of V=16.5 will enable it to measure the lightcurves of the brightest rapid transients such as gamma-ray-bursts. Co-adding will push the depth to up to V=19 on hour timescales, sufficient to monitor nearby supernovae as they occur. Because all data is recorded, the Evryscope will uniquely be able to provide *pre*-explosion imaging for minutes, weeks or even months before each event. This unique capability will potentially enable the detection of outbursts or the monitoring of rise times from the very beginning of transient events. Compared to midlatitude sites, the continuous coverage available in the Antarctic will greatly increase the probability of covering an event while the system is operating (important for intrinsically rare events such as searching for gravitational wave electromagnetic counterparts), as well as allowing the first *uninterrupted* high-cadence light curves for all bright transients.

International collaboration with other surveys. The Evryscope's very rapid cadence, extremely large field of view, and large étendue explores a new region of survey parameter space. As such, it is possible that the survey will reveal new unknown optical transients that would be rejected as cosmic rays or single-detection asteroids in longer-cadence surveys. For example: extremely fast radio transients with currently unknown origins have recently been discovered (e.g. Thornton et al. 2013). Due to their rarity and millisecond-scale speed, there is currently no way to get



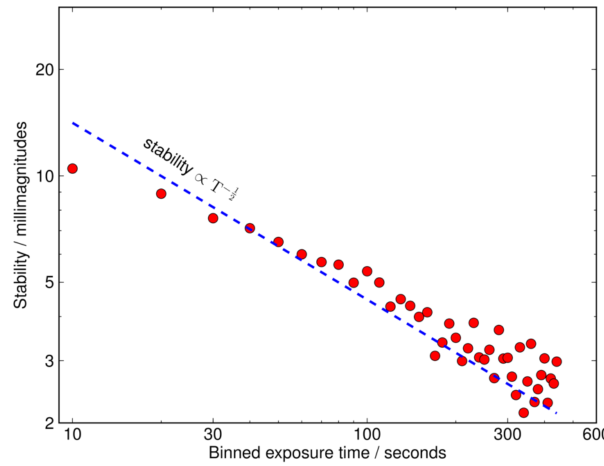


Fig. 2.— *Left:* The AWCam Arctic wide-field exoplanet search telescopes and the first sunrise after a full winter of unattended operation. *Right:* Photometric precision as a function of binning timescale for one of the AWCam telescopes, showing exoplanet-detection levels of photometric stability over periods of months.

useful constraints on their optical brightness. The Antarctic Evryscope dataset would allow us to obtain simultaneous optical brightness limits (or even detections) on a minute-by-minute basis without any need for triggering or pointing at these or similar targets. This mode will build synergies with major international time-domain astronomical projects in the Southern hemisphere, most notably the Square Kilometer Array.

2. SYSTEM DESIGN AND PROTOTYPES

Our Antarctic Evryscope design consists of a single mushroom (Figure 1) which contains twenty 7cm telescopes, each with a rectangular 28.8MPix interline CCD imaging a 394 sq. deg. FOV using an 85mm f/1.2 lens. The individual telescopes are fixed into holes in a sealed aluminium-reinforced fibreglass dome and are controlled by low-power computers fixed into the dome itself. The 200W waste heat from the cameras is used to heat the dome and encourage sublimation of snow accumulation. A 5-position filter wheel on each camera allows a selection of filters as well as providing a blocking shutter for dark exposures.

The Antarctic Evryscope is designed to be a completely robotic telescope, suitable for deployment at the South Pole or more remote sites. Unattended operation and the dozens of separate camera systems necessitates designing for high reliability and a minimum of moving parts. Our design uses interline CCDs with an electronic shutter and fixes the filters in place during normal operation. The instrument can thus operate throughout the winter with the R.A. drive as the single moving part.

Data handling. The Antarctic Evryscope will produce a gigapixel image every two minutes, or ~10MB/sec of data on average. The data will be stored on network storage units at the telescope; an off-the-shelf 40TB unit has storage for approximately four months of data assuming 2/3 good weather. We intend to store all data produced by the Evryscope to enable after-the-fact data mining. We do not expect to be able to transfer more than a very small fraction of the data back during the winter, but we will be able to do initial reductions with low-power computers on-site, to search for transient events and return small subimages of interesting regions of the sky.

Arctic prototypes. The Evryscope design is an evolution of exoplanet-search cameras which we have been successfully robotically operating under Arctic conditions for the last three years. The AWCamsLaw et al. (2013) (Arctic Wide-field Cameras) are two small telescopes designed to search for exoplanet transits around bright stars (V=5-10), and are essentially identical to individual Evryscope cameras except they lack the tracking that enables long exposures. The cameras are deployed at the PEARL atmospheric science laboratory at 80°N in the Canadian High Arctic. The cameras and the AWCam project are described in detail in Law et al. (2012, 2013, 2014a).

We have now operated the AWCams for three winters, including a test run in February 2012 and full-winter operations in the 2012/13 and 2013/14 winters. The robustness of our hardware and enclosure design has been validated by perfect operation throughout the entire deployment period, including a total of 10 months of completely unattended robotic operation. Throughout the winter the cameras kept themselves (and crucially their windows) clear of snow and ice, took over 40TB of images, and consistently maintained few-millimagnitude photometric precisions (Figure 2).

3. SUMMARY

The Antarctic Evryscope offers a unique opportunity for Antarctic astronomy: a continuously recorded image of a large fraction of the visible sky, with the ability to follow individual events and objects on minute-by-minute timescales in archival data. We have been operating prototypes of the Evryscope's individual telescopes for the last several years in the High Canadian Arctic, taking advantage of the continuous wintertime darkness to search for long-period exoplanets around bright stars, and we will soon deploy an NSF-funded midlatitude version of the full system. An Antarctic Evryscope would use the Antarctic's continuous winter darkness, very small airmass variations though the night, and dark skies to provide unprecedented sensitivity to transiting exoplanets around bright stars, M-dwarfs and white dwarfs, as well as to provide unprecedented datasets on exotic exoplanet microlensing events, nearby supernovae, and gamma-ray burst afterglows.

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