Assassinating ASASSN:
Supernovae Identification Using ATLAS Data

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Using current data collection and reduction techniques, we plan to identify supernovae (SNe) faster and fainter than the All-Sky Automated Survey for Supernovae (ASASSN) team is able to. We expect to identify all SNe, with m>17.5 and declinations above $-30°$, before ASASSN is able to.

-30 or -40, JT says -40...choose one and be consistent
17.5 (0.5mag) −OR− 18 (1mag) fainter...which is it?
not emphasis on type Ia supernovae (SNIa)?
Asteroid Terrestrial-impact Last Alert System (ATLAS)

1. INTRODUCTION

WHY DO WE CARE
whats special about SNe
what can they tell us
note we plan to focus on type Ia SNe
Supernova (SN)
Supernovae (SNe)
type Ia supernova (SNIa)
Supernovae (SNe) identification using data collected by ATLAS.

1.1. Importance of SNe

Discuss why we care about finding SNe
    Astronomers use SNe to ...
    SNe are extremely important in cosmology.

2. COLLECTED DATA

2.1. ASASSN Data

The All-Sky Automated Survey for Supernovae (ASASSN) group collects data using eight 14 *cm* telescopes. Each night, these telescopes are able to cover roughly $20,000$ deg^2, reaching down to ~17th magnitude. These eight telescopes are split evenly between two sites. The first telescope array is located on Haleakala and began collecting data in December 2013. In July 2015, the second array became operational at the LCOGT Cerro Tololo station. This allows ASASSN to detect SNe in both hemispheres. **Cite using footnote.–OR–**[1]

Using 400mm f/2.8G Nikon lenses allows for a large field of view. ProLine PL230 CCD cameras are used as detectors. Detection of transients is made possible using image subtraction. With images having 7.8″pixels, ASASSN relies on volunteers collecting confirmation images with larger telescopes. **Cite using footnote.**

2.2. ATLAS

ATLAS is a project funded by NASA to find dangerous asteroids. The motivation and science justification was described **by**[2]. **−OR− Tonry (2011)**. For the duration of this ASASSN project, ATLAS used an f/2, 0.5 m Schmidt telescope on Haleakala and a 110 Mpixel detector to collect 30 deg^2 with each exposure. This telescope was installed in Jun 2015, and achieved more or less continuous operation around Sep 2015.

ATLAS will shortly install a second telescope on Mauna Loa, and a proposal to NASA is being evaluated to build two more units for the southern hemisphere.

The pixel size is 1.86″ and the field of view is 5.4×5.4 deg. The PSF is currently no better than 6.5″ which degrades the limiting sensitivity by one magnitude. The faulty Schmidt corrector will be replaced in March 2017. ATLAS uses two filters "*o*" (essentially $r+i$) and "*c*" (essentially $g+r$), changing according to the phase of the moon.

The basic observation consists of 30 sec of shutter open and about 13 sec of overhead, so that about 900 observations are collected per night. The observation strategy has varied since the telescope was installed, but currently observes one of four Dec bands between -40 and $+60$ Dec, imaging each spot 5 times on a ~15 min cadence. The overlap between observations is about 0.4 deg, and they are dithered by a random amount for a given night, so each objects is seen 5 or more times, depending on whether it falls in an overlap. **wording**

The observations are processed by the ATLAS pipeline which consists of image flattening, star finding, star identification, high precision fits to astrometry (typically RMS of 0.3″ per star and
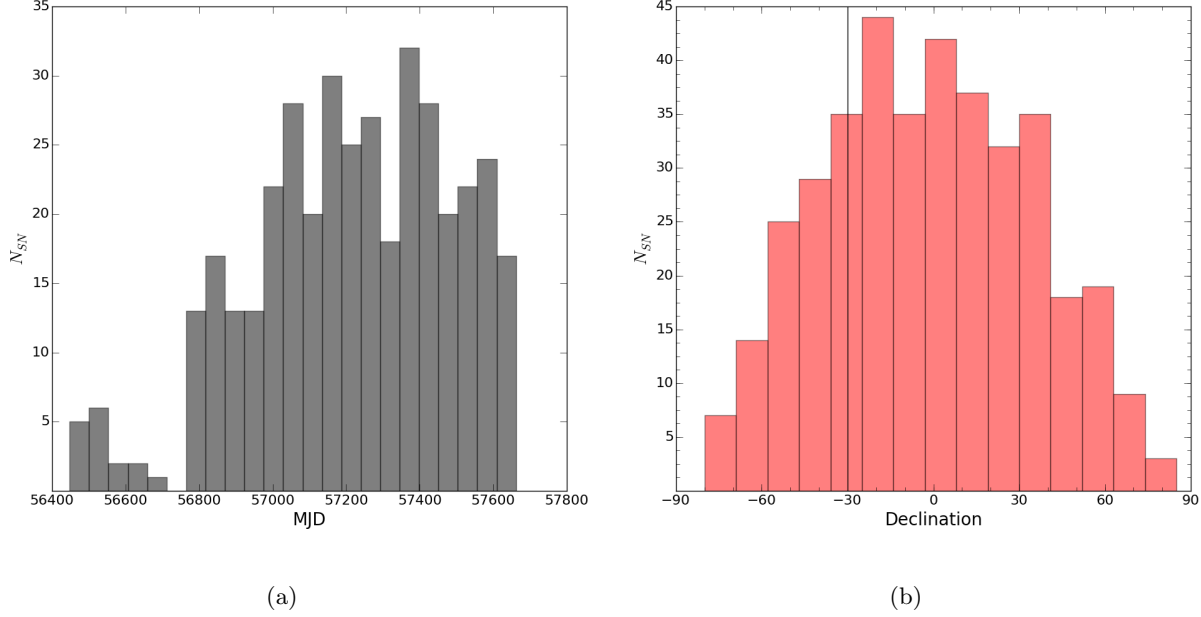
(a)
(b)

Figure 1: *SN discovered by the ASASSN project. Panel '(a)' shows ASASSN SN discovery dates. Panel '(b)' is ASASSN data, binned by Dec. The vertical line at $-30°$ indicates the lower limit on ATLAS observations.*

more than 10,000 stars) and photometry (typically 0.1 mag RMS, limited by **current reference catalog)**, image differencing against a static sky image, and detection of objects that have moved or changed. Difference imaging and the detection of changing objects are discussed in § 2.2.2.

2.2.1. Remove - Is This Double Talk?

Cleanup & reword this section.

- rename section specifically after telescope 02a?
- cite Tonry et al. (2011)[2]
- ATLAS specs[2]
- how data was collected
- is there an offset in observation pattern?
- possible mention upcoming re–reduction of data

ATLAS began collecting data in June 2015. Reduction methods are always being refined and improved. Data reduced before ATLAS became truly operational, in December 2015, is not trusted.

Each night ATLAS covers ∼**xx deg**^{2} five times over. An object is determined to be real if it appears in all good observations overlapping that region of the sky. If an object appears in one of the

images, it is expected to appear in the other four images collected that night that overlap the same region on the sky. This **expectation / requirement** drastically reduces the false alarm rate. Prior to April 2016, ATLAS made four **(duplicate)** observations per night. Increasing the number of observations per night from 4 to 5, while maintaining the same 4 day cadence required an upper limit to be placed at a Dec of $+60°$. This is shown by the dark gray region in the upper right hand corner of Figure 4. With a relatively short average lifetime, detection of SNIa requires frequent coverage of the entire sky. Using current observation patterns, ATLAS surveys the entire sky, between -30 and $+60$ Dec, in just 4 nights. Five observations of the entire sky are recorded by ATLAS every four nights, making detection of all SNIa possible. Once collected, raw observations are reduced using the ATLAS pipeline. **cite what? private communication with John?** For easier extraction of desired data, reduced images are differenced. The process of difference imaging is discussed in § 2.2.2.

An offset in the observation pattern would allow objects that fall on the edge of a detector to be observed over 5 times a night...Does such an offset exist?

2.2.2. Difference Imaging

Difference images are generated by subtracting the wallpaper from reduced images. This is done to isolate objects that are changing. Subtraction of a properly calibrated wallpaper will produced a difference image
containing only objects that are changing in the reduced images.
with no objects that are static in the reduced images.
will remove all static objects from the difference image.

The "wallpaper" (static sky image) is the weighted sum of many, many observations at each point in the sky. ATLAS currently uses the Alard algorithm **(Alard & Lupton, 199x)** for differencing, and the differences are dominated by photon noise and by systematics from saturated stars or flare artifacts from the Schmidt corrector.
include comparison figure?:
red and diff imgs
The ATLAS mission is to find moving objects, but our processing automatically finds all stationary transients and variable stars as well. Once the image is differenced, the program tphot detects all sources at 3-sigma, and cut that back to 5-sigma once each source has been fitted and the detection significance is known. This is augmented by calculated RA, Dec, magnitudes, and other relevant quantities into a "ddt" (difference detection table) file. **wording**
Stationary transients stand out in difference images, increasing their probability of detection.
other advantages of difference imaging
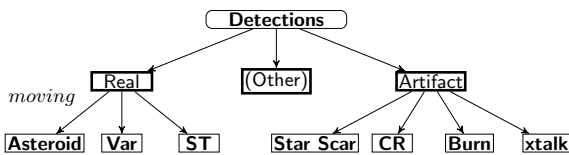**REREAD & REWORD section, when finished**

Figure 2: Probability flowchart. Real - Asteroid are moving objects, ST stands for stationary transient, Var is variable star...discuss artifacts

The most useful classification variable is "starrat" (star ratio), which is defined to be the ratio of flux on the original, un–subtracted image to flux on the difference image. Both fluxes are measured using a circular aperture of 2.0 pixel radius. The star ratio is used in determining if an object is real or just a residuals from subtracted stars. For these, the star ratio will be large (usually greater than 5) because

the star was much brighter before it was subtracted. For asteroids and supernovae, we expect the star ratio to be near 1.0. Since they are not usually in their recorded locations, such objects should not show up in the wallpaper. Any object that isn't in the wallpaper is left unchanged by difference imaging. This means the recorded flux to be the same both before and after image subtraction, resulting in starrat=1.0.
possibly include starrat figure here
in results section get into the range for starrat values
Difficulties include cases where a real transient can produce a high starrat, and cases where a false detection from a star residual can produce a low starrat. The former arise from the fact that supernovae happen in galaxies, which do get subtracted and can raise starrat substantially above 1.0 if they are bright. The latter can occur when we have a star residual detection substantially off-center from the star, so the flux on the un–subtracted image is not as bright as we might expect, and starrat can be lowered to the 2-5 range, or in some odd cases can be negative. So starrat is not foolproof. Nevertheless, a starrat value near 1.0, especially if accompanied by other indications such as consistent astrometry, is a useful piece of evidence pointing toward a real SN, asteroid, or other interesting transient.

3. PROCEDURE

want to make input sections subsections under this section? quantify: how many objects are potentially SNe before class.var. restriction, how many after
$0.9 < starrat < 1.2$
possibly include starrat figure
use DS9 image? if so, then:
remake it
identify exact dates shown by tiles
In order to assassinate ASASSN, it was necessary to show that ATLAS had the potential to find all of ASASSN discovered SNe. To do this, a list of all ASASSN discovered SNe was obtained[1]. **[–OR– cite website using footnote]** By October 11, 2016 ASASSN has reported discovering 385 SNe. Many of these objects were reported before ATLAS was operation. Object cuts are discussed in § 4. Once the data was properly culled, the remaining SNe were found in observations made by ATLAS. One such SN is shown in Figure 3. Finding these SNe in the ATLAS data allowed restrictions to be placed on classification variables, drastically reducing the number of potential SNe candidates. With such a restricted object list, visually examination is able to be used in identifying SNe.
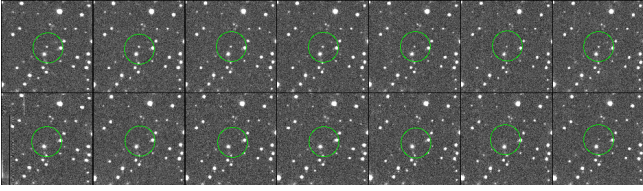
Figure 3: *Each tile shows a different ATLAS observation of the SN "ASASSN-16ke". The SN is enclosed by a green circle, to show its exact location.*

comment on lower panel showing ATLAS obs before SN appeared in fig 3?

4. EXPECTED OBSERVATIONS

Rename section
Necessary to define MJD?

With a declination (dec) limit of approximately $-30°$, 100 SN were not expected to be present in the ATLAS data. ASASSN reported the discovery of another 165 SN before ATLAS began collecting data. These two sets do not exist independent of one another. After applying dec and MJD based restrictions and accounting for overlaps between these groups, 161 SN remained from the initial 385 reported by ASASSN. Another 65 SN peaked before ATLAS was truly operational, leaving 96 as potential candidates. All 96 of these objects were found in the ATLAS data, resulting in a 100% completion rate. **CHECK VALIDITY OF THIS**
The 65 SN that peaked before ATLAS was truly operational can be further broken down as follows. Reported peak brightnesses occurring on or before 57364 accounts for 14 SN. During this time the ATLAS reduction process was still being refined, making any reduced data unreliable. Another 50 SN fell in regions that had no overlap with ATLAS observations due to the pattern in which data was collected. The final case was a Type II supernova (SNII). SNII are notoriously short lived; making it likely that ATLAS observed this region of the sky in the time surrounding the explosion, but not during the event.

5. FAILED MATCHES

Remove subsection headings?
We expect to see 96 of the ASASSN SN in ATLAS observations. This presents us with 850 overlap opportunities, using a ±10 *day* window. Of these, 694 observations were recorded and properly reduced. **Why these matches failed can be broken up into four categories – no match, no difference image, no ddt file, or no match within an existing ddt file. These cases are discussed in sections 5.1–5.4.**
§ 5.1–§ 5.4
Why these matches failed can be broken up into four categories, each of which is discussed in the subsections below.

5.1. No match

A total of 25 expected observations lack any matches with ATLAS data. These failed matches do not fall within the ±10 *day* window used.

5.2. No diff file

Missing difference images account for 49 of the expected 850 observations. Matches that were missing difference images can be attributed to an error in the ATLAS pipeline. An error during differencing caused a break in the pipeline and no further images to be generated for that night. Such an error will be corrected once the data is re–reduced.

5.3. No ddt file

For matches that were completely missing a ddt file, ddt files were missing for the entire night. This accounts for 15 failed matches and will be corrected by the next round of differencing.

5.4. No ddt Match

Of the total 850 expected matches, 67 do not show up in existing ddt files. Nature constantly plays a role in collecting astronomical data. When observations are made at the beginning or end of a night, ambient light levels rise and sky background fluctuations. 3 of the 67 missing ddt lines can be attributed to poor observation conditions, brought on by clouds and increased levels of sky background.
Errors during the image differencing process led to the loss of 8 expected overlaps. Older differencing techniques caused entire portions of images to be lost, accounting for 3 failed matches.
There were 6 cases where bright host galaxies caused the SN to become extremely faint in the difference image. Outdated differencing procedures lead to less uniform backgrounds, making it harder to identify faint objects. **reword?** While preforming photometric calculations, the ATLAS pipeline failed to trigger on these 6 faint objects.

There are various reason why the PSF across an image may vary. Here, the major contributers are high levels of sky background and optical issues inherent to the ATLAS system. If not properly corrected for, such issues cause observed objects to become distorted. Distortion can cause sharp edges to become fuzzy, resulting in the ATLAS pipeline failing to trigger on such objects. This accounts for 3 of the missing matches. Objects that were only in reduced images, but not in differenced images account for 26 of the matches missing from the ddt files. Such instances arise when the object is fully subtracted during differencing, due to it existing in the wallpaper. As the wallpaper is an ongoing project, corrected future versions will not cause this issue.

[**WORDING**]

There were 17 cases in which the SN was not detecting in either the reduced or differenced image, indicating poor astrometry. Another possible explanation is bad photometry. If photometry is the issue, the SN explosions must have occurred outside the nominal ± 10 *day* window.

The final group of matches missing from the ddt files comes from an issue with the array dimensionality. Each image is saved as a matrix. The software that determines the correspondence between pixel coordinates and each objects RA, dec assumes the captured image fully extended to the edges of the matrix. In practice, the edges of some collected data are not completely filled. **When these unfilled frames overlap with consecutive images, the objects lie where they are expected.** Not every image fully extends to the intended edges. For this isolated case, the image data ends above the bottom edge of the array. Although the object is expected to be there, it does not exist on this particular image.
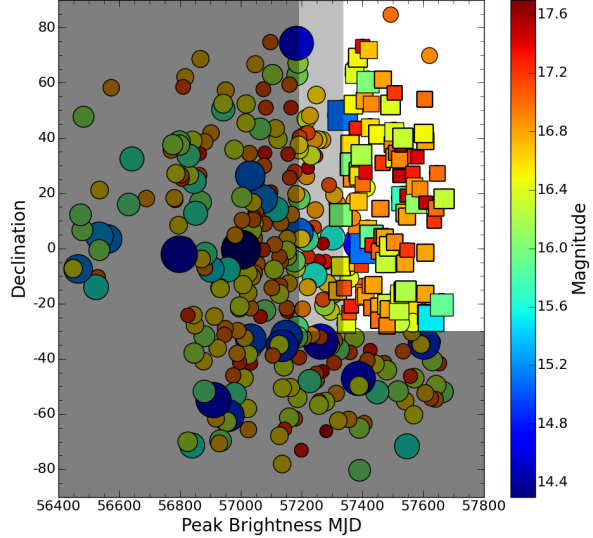

Figure 4: *ASASSN SN that do not have matches in ATLAS data are represented by circles. Squares show SN that were found in ATLAS observations. Regions that have a lower chance of containing SN have been covered in gray. Dark gray regions eliminate objects below the ATLAS observation limit of $-30°$ and those discovered before ATLAS was operational. The light gray region extends from ATLAS first night of collecting data up until 57364, when the reduction method was refined enough to produce usable data. Like the color, point-size represents magnitude.*

6. RESULTS AND DISCUSSION

It has been shown that all ASASSN discovered SNe overlapping ATLAS observations in sky and time are detectable in ATLAS data. Restricting classification variables drastically reduces the false alarm rate, requiring visually inspection of fewer objects. This shows the ability for ATLAS to identify all SNe faster and fainter than ASASSN is able to.

Detection of all SNIa is possible using ATLAS.

As seen in Figure 4, SNe that were not observed ATLAS fall on the edges of observation limits.

Summary of data matched between ASASSN and ATLAS.

reference sections that explain particular cases that matching failed How ASASSN SN help identify those in ATLAS data.

1. what restrictions we intend to place on classification variables like starrat

2. possibly describe what starrat is, how it will help id SN

3. such restrictions cut the number of objects down from xx to $\sim 1000/2000$

ACKNOWLEDGMENTS

7. GENERAL NOTES & THINGS TO ADDRESS

good ref paper http://iopscience.iop.org/article/10.1088/0004-637X/745/1/42/pdf
fix biblio style / numbering
Look at previous JT paper to see if:
numbers inside mathmode: -30°, $-30°$
abbreviations in abstract: ... (ASASSN), or is just ASASSN good
ANS:
numbers nor units in mathmode
figure with smaller cbar? rotated xtick labels?
histogram w/o vertical bar at dec=-30°
remake histogram with peak date not discovery mjd
Check figure width look okay: [width eq 3.35in] –OR– [width eq 1 linewidth]

change out figure of histo with line at dec=-30
add other figures (starrat and the like)

Fix citations: ASASSN data[1] or use diff cite method
Shappee et al.[1]
Shappee et al.[1]
...Should be "Shappee et al. (2014)"
make sure the acronym "ATLAS" is defined
check plurality throughout paper: SN or SNe
make sure acronyms are only defined once
Verify Tonry et al. (2011) journal is cited properly: PASP
Check JT's papers for proper capitalization:
Type Ia Supernovae
Type Ia supernovae
type Ia Supernovae
type Ia Supernovae
"ASASSN" –OR– "ASAS–SN"
make sure all paragraphs are broken-up and indented as desired
$1.86''$ looks better than $1.86''$does...change all to have backslash at the end declination (Dec)
NOT: dec m>17.5 –OR– $m > 17.5$
USE: m>17.5
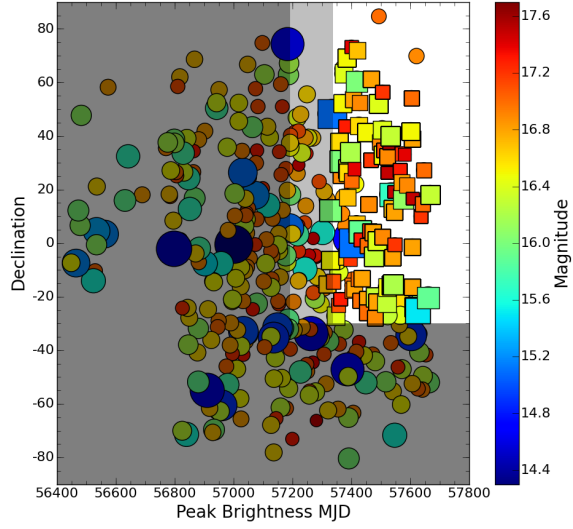change "diff" to difference images, –OR– define it
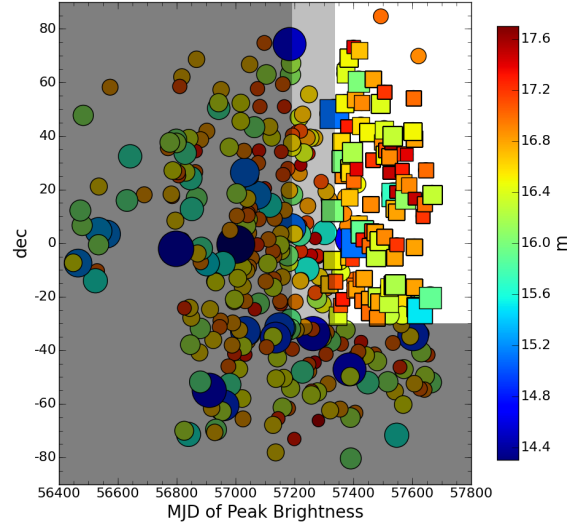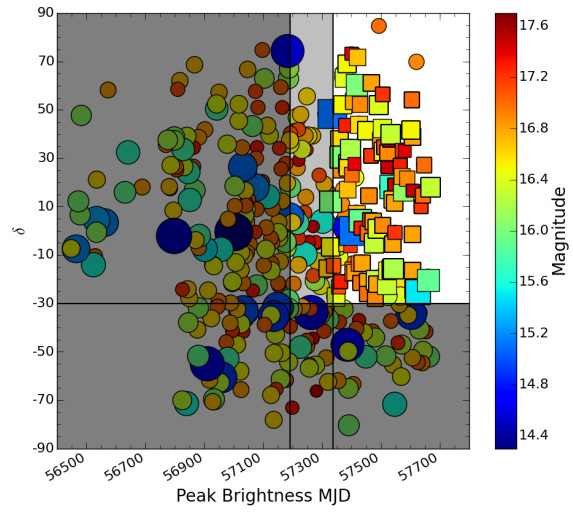
* cmutnik@hawaii.edu
† ASTR 399

[1] B. J. Shappee, J. L. Prieto, D. Grupe, C. S. Kochanek, K. Z. Stanek, G. De Rosa, S. Mathur, Y. Zu, B. M. Peterson, R. W. Pogge, et al., Astrophys. J. **788**, 48 (2014), 1310.2241.
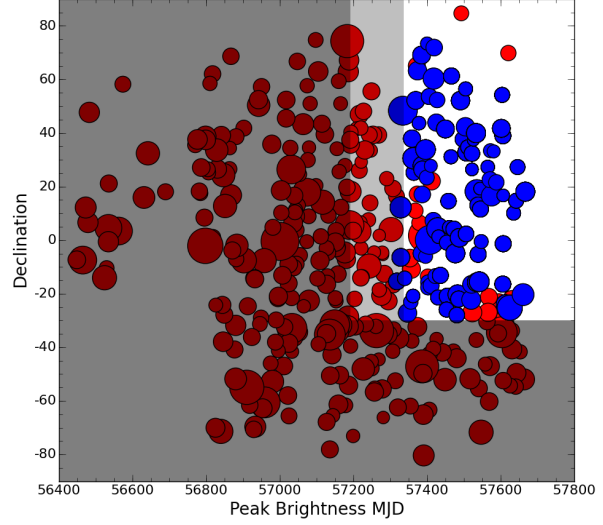[2] J. L. Tonry, PASP **123**, 58 (2011), 1011.1028.

(a)

(b) **Same as (a) with cbar=0.9**

(c) **cbar the same size as (a) but xtick labels are formatted differently. Differentiation between Grey regions has been made easier.**

(d) **Here color is used to distinguish between SN that matched and those that didn't. Magnitude is still represented by point–size, with lower values having larger areas.**
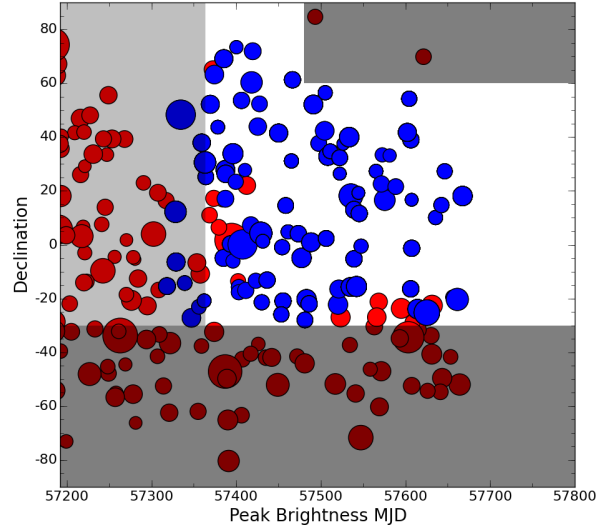
Figure 5: **Panels (a), (b), (c), and (d) are all variations of the same plot. Slight variations in way labels; doesn't change content.**
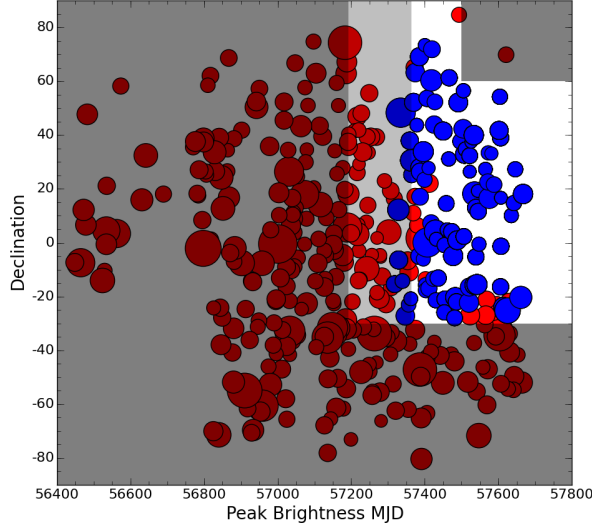
(a) **Here, a gray region starting at 57500, has been added for when ATLAS went from 4 to 5 observations a night, giving and effective limit at dec=+60°.**
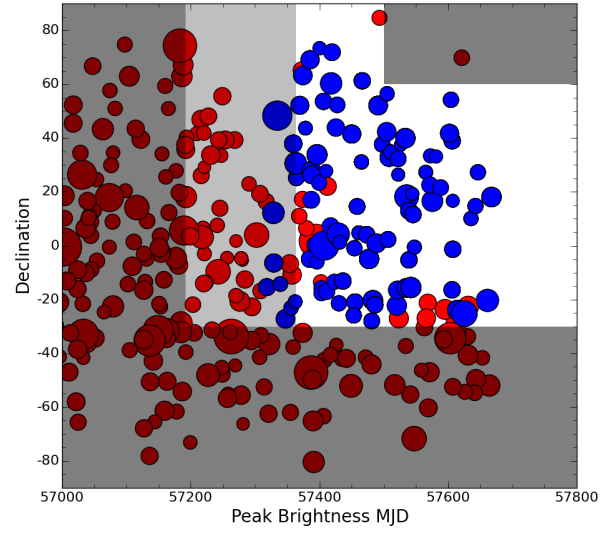
(b) **Here, the figure is restricted, to better show where ATLAS was truly operational.**

(c) **Here, the figure is restricted further, to better show where ATLAS was truly operational. 57480 was used as the time when ATLAS went form 4 to 5 obs, lowering dec limit.**

Figure 6: **Panels (a), (b), and (c) are all variations of the same plot shown in Figure 5. Slight variations in way labels; doesn't change content.**