# ATLAS

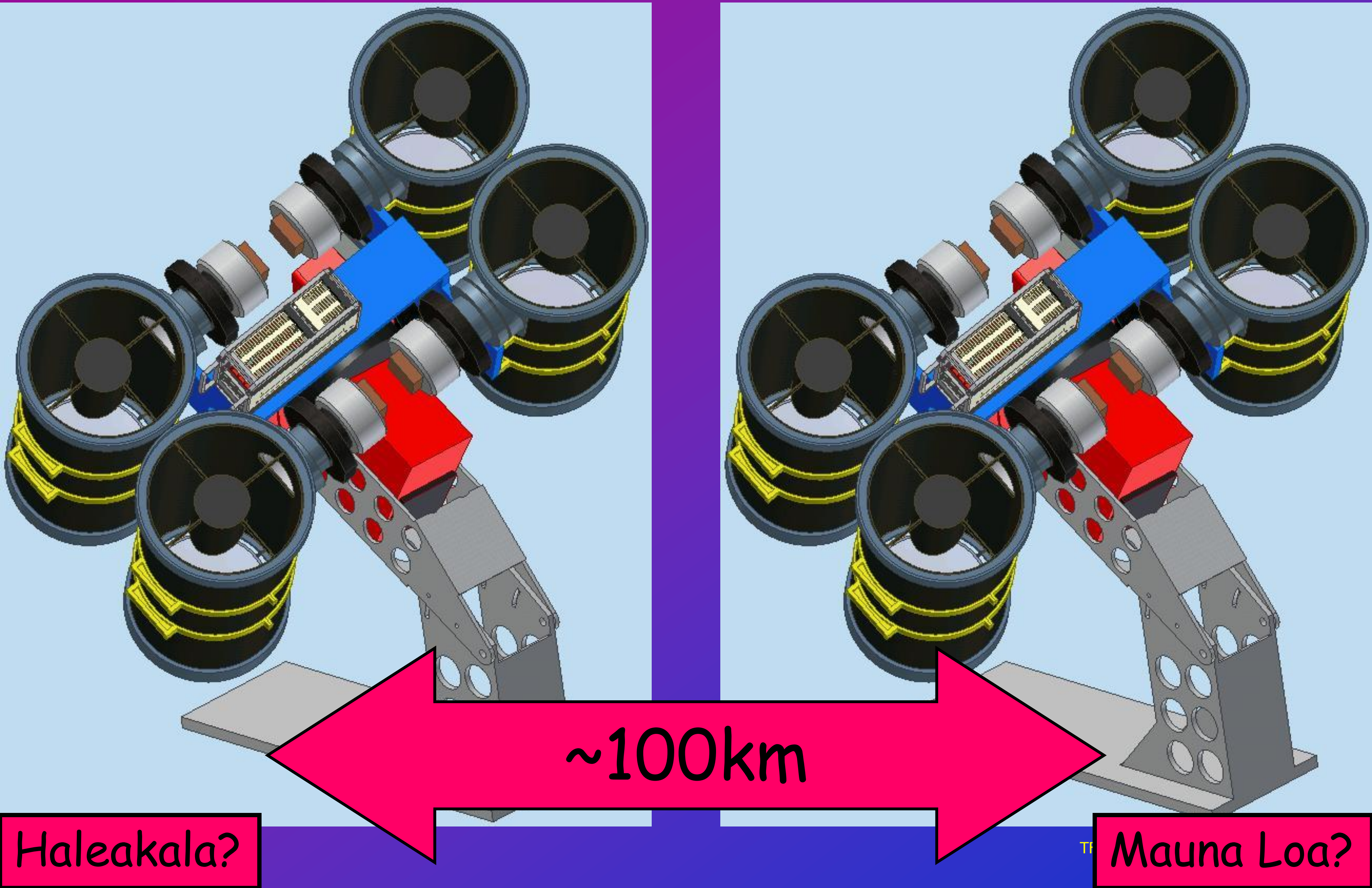
## Asteroid Terrestrial-impact Last Alert System

# Why?

- There's good reasons for remote/robotic observation
  - Lower cost
  - Higher efficiency
  - Education

- But the silicon revolution is also creating fantastic new science opportunities! We can strip-mine the Universe! However, robotic operations are a prerequisite…

# 0.5m aperture, 40 sq deg field of view, 4" PSF

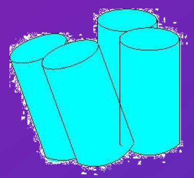


# ATLAS: Early Warning of Impacts

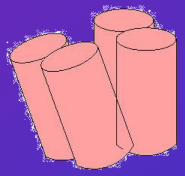
- $3.2M proposal to NASA 2010 ROSES/NEOO
  - $2.1M construction, $550k/yr operations
  - Currently in the dumpster and waiting to see what Congress does…

- Goals
  - Early warning of Earth impactors
  - Not NEO discovery per se, but lots will be found
  - Emphasize practicality over optimization, use COTS as much as possible to get on-sky in 2 years
  - Foster opportunity for replication and extension

# ATLAS in a Nutshell



Blue site



Red site

- Eight telescopes and cameras
  - 0.25m aperture, f/2.8, 5° FOV, 20 sq deg
  - Camera 4x4k pixels at 4.4”/pix, readout 4s, 10e-
- Deployment
  - 2 pairs x 2 pointings x 2 sites separated by 100km
  - One site “blue” (g+r), one site “red” (r+i)
  - Site options include
    - Haleakala – Mauna Loa
    - Mt Hopkins – Mt Lemmon – Kitt Peak
    - Mt Laguna – Palomar

# ATLAS Details

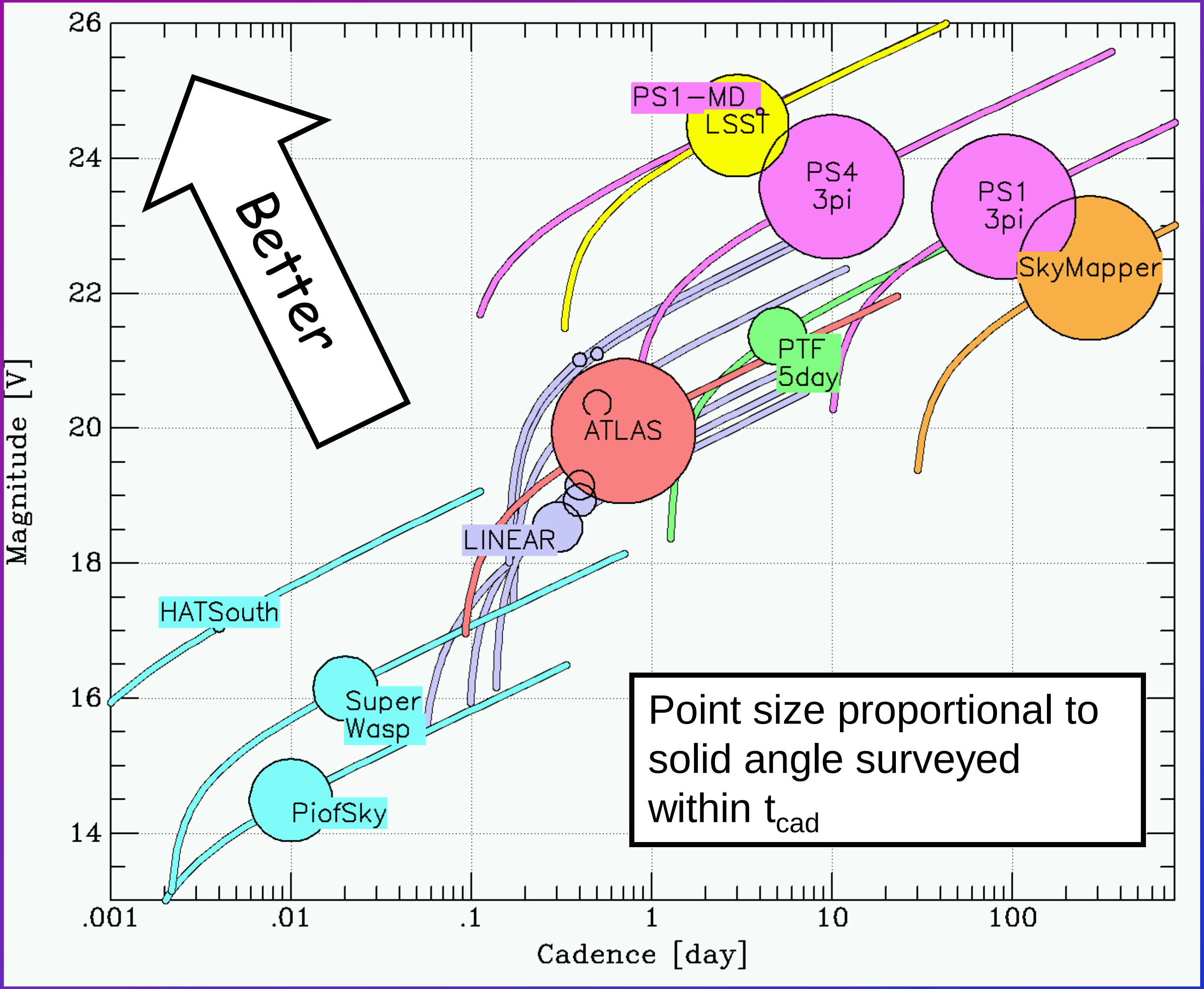
- 30 sec exposure time, 5 sec overhead

- Sensitivity (dark sky) at SNR=5

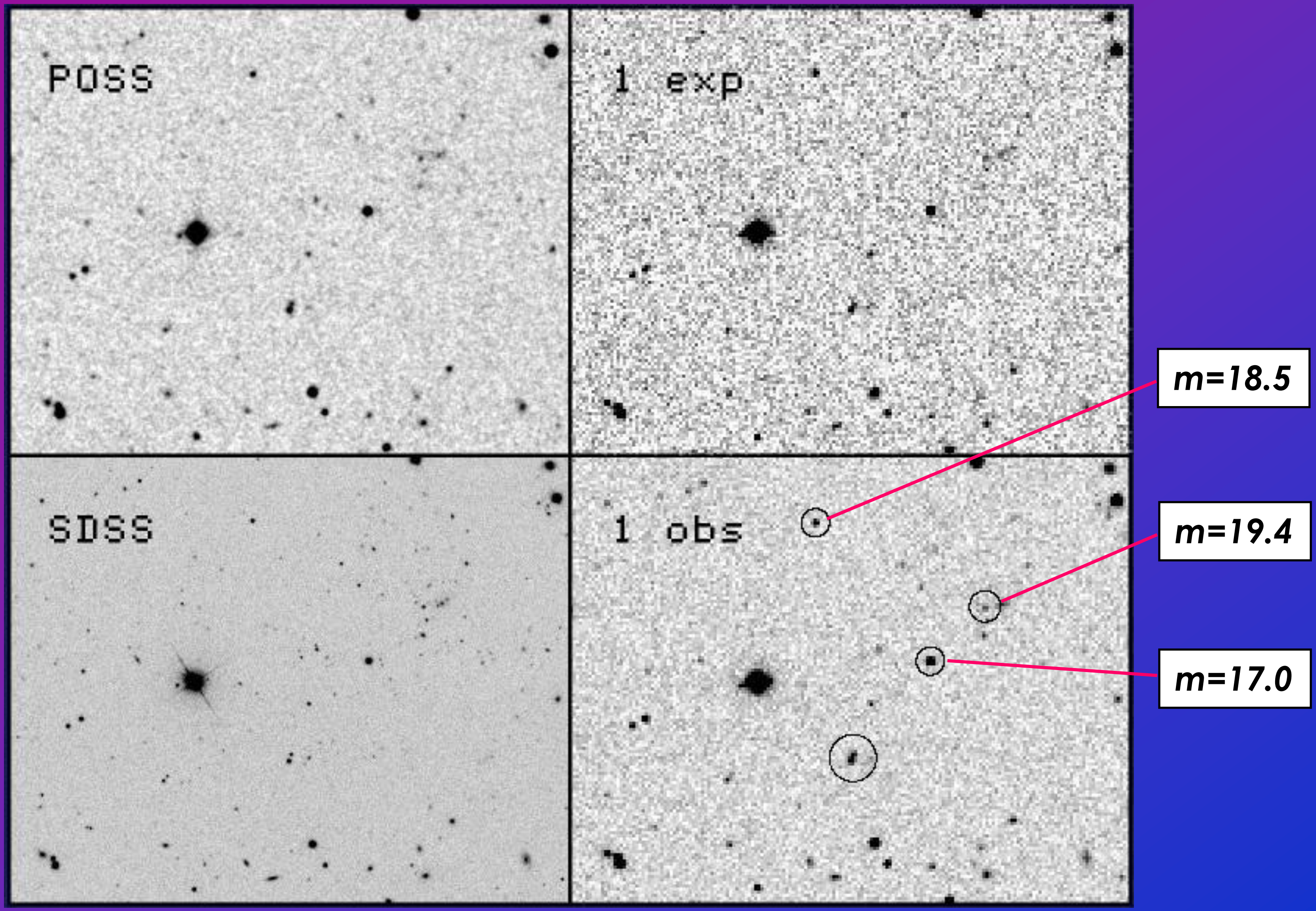
  V=19.1 one telescope, one exposure, red or blue
  V=19.9 all objects each obs
  V=19.9 stationary objects each night, red and blue
  V=20.7 stationary objects, 4 nights, red and blue

- 20,000 sq deg, twice per night
  - Simple observing strategy: just scan up and down in Dec as RA passes the meridian
  - Strive to get pairs of observations ("tracklets") separated by ~1 hour to get vector for moving objects

# Survey Merit

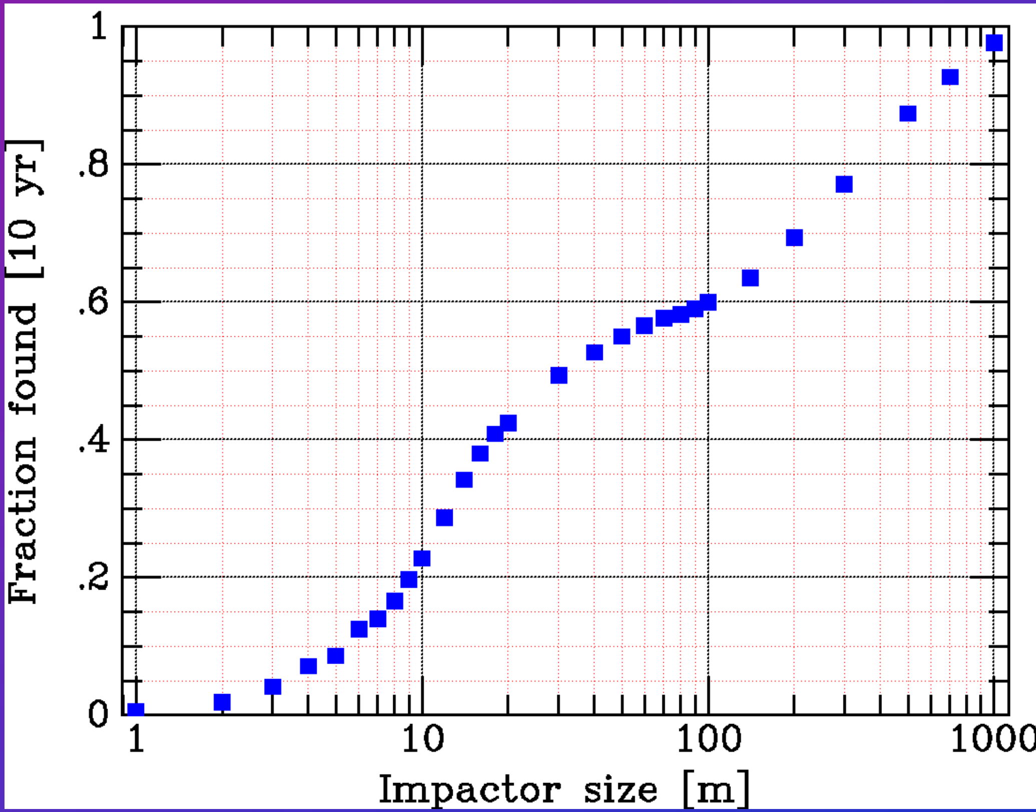


# ATLAS-POSS-SDSS Comparison



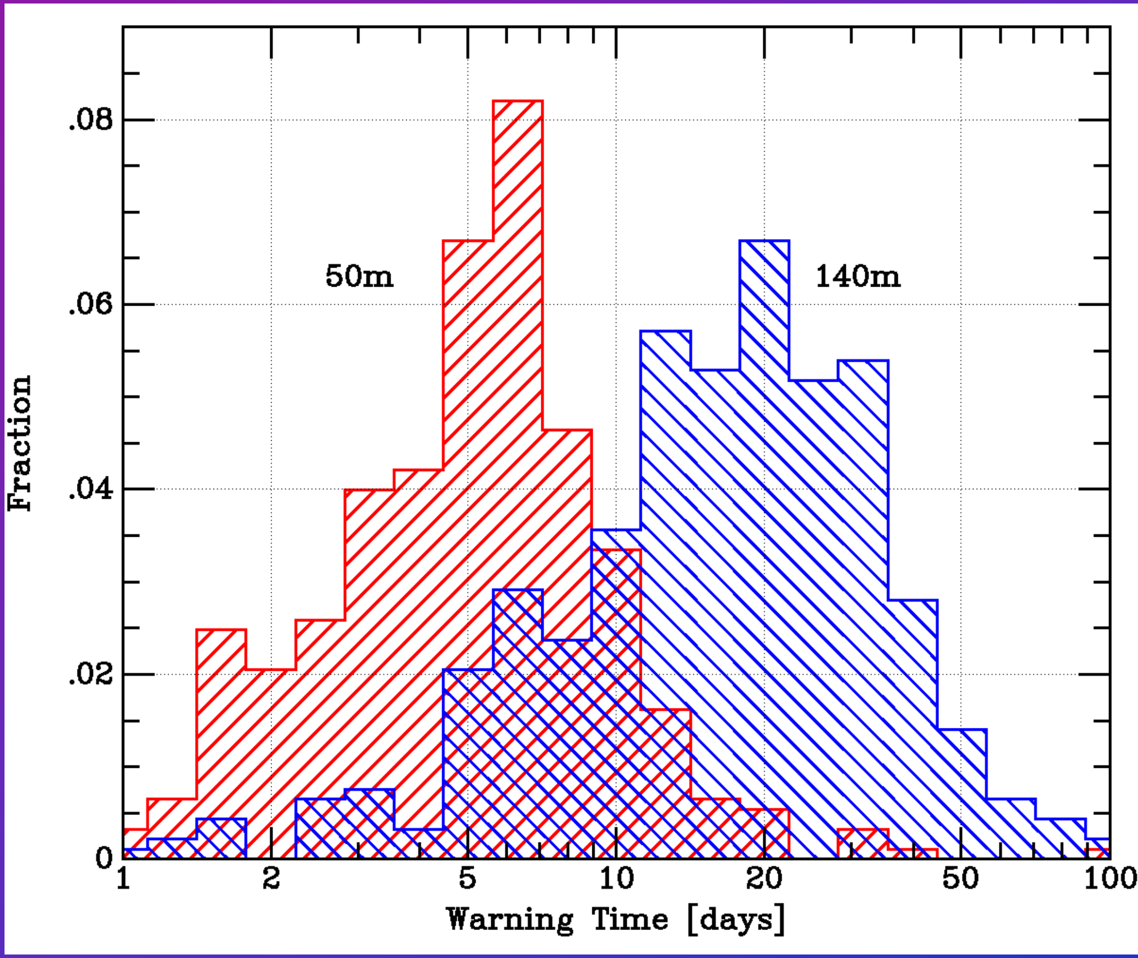
# ATLAS Impactor Discovery Probability

- ATLAS discovery probability depends on size and survey duration
  - Small (<10m) only seen on last day or two.
  - Medium (10-140m) seen for days to weeks before impact.
  - Large (>140m) are often seen on orbits prior to impact.



# ATLAS Warning Time

- Warning time depends on size
  - 140m: ~3 week
  - 50m: ~1 week
- Missed impactors come from the Sun and the south pole.



# Sudan 2008-10-07

- Would ATLAS have found this ~2-3m, ~1-2 kton impactor?
  - Discovered by Catalina 20 hours before impact at V~19
  - ATLAS would have looked at 23h +8 deg around 11pm HST, 2008TC$_3$ would be V~18.7
  - Moon was 0.4 illuminated, 84° from 2008TC$_3$
  - Weather was clear in Hawaii
- Yes, ATLAS would have seen 2008TC$_3$, immediate parallax would trigger MPC and other observers

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FIGURE 2.2 The long-lasting airburst trail over Sudan after the impact of 2008 TC$_3$ on Oct
Courtesy of M. Elhassan, M. H. Shaddad, and P. Jenniskens.

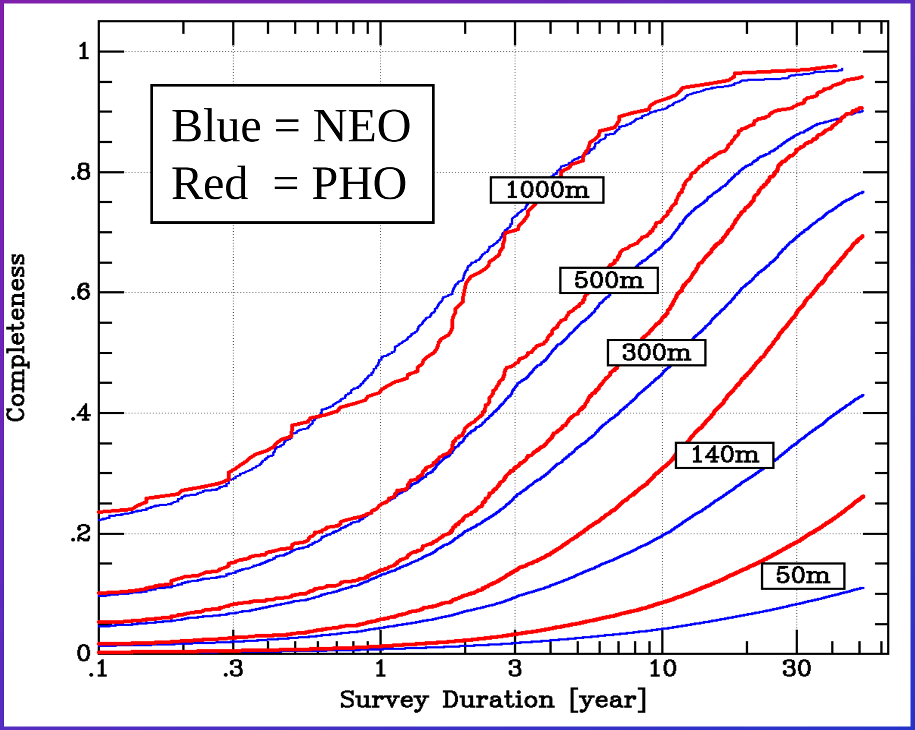
# Indonesia 2009-10-08

- Would ATLAS have found this ~5–10m, ~20–50 kton impactor?
  - Unobserved, but assume same radiant as 2008TC$_3$ and x3.3 larger.
  - ATLAS would have looked at 23h +8 deg around 11pm HST, *Impactor* would be V~16.2
  - Moon was 0.9 illuminated, 63° from *Impactor*, quite bright.
  - Weather was mostly cloudy in Hawaii
  - Previous nights at V~18, ~19, ~19.7.


- No, ATLAS <u>could</u> have seen *Impactor*, even with moon, even on previous night, but weather was bad.

# ATLAS NEO/PHO Discovery Rate

- ATLAS detection of PHOs
  - 1000m 90% in 8 years
  - 500m 75% in 11 years
  - 300m 50% in 7 years
  - 140m 25% in 7 years




- Expect to discover
  - ~400 NEO/yr (>140m)
  - ~150 PHO/yr (>140m)
  - ~1 intra-lunar per week
  - ~1 impact per year

# Asteroid Science

- Light curves
  - With 2 observations at m=18 (25$\sigma$), ATLAS will provide ~400 photometric observations per year on ~$10^4$ asteroids. These can be processed to infer the shape and rotation.
- Asteroid collisions
  - There is 1 collision per day at size 10m, 1 per year at 100m. The dust from the collision will expand an unknown amount before reaching unity optical depth
  - At opposition in the asteroid belt, ATLAS can see a dust cloud of size 1000m, and possibly may capture such an event.

# Novae, Outbursts, Variable Stars

- Luminous blue variables $M_V = -9$ to $-13$:
  - volume reaches Virgo for the brightest.
- Novae at $M_V = -7$ to $-9$:
  - visible from MW, M31, M81, M101, etc, but not Virgo.
- Miras, RCorBor, Cepheids, RR Lyrae, FU Orionis:
  - all variables brighter than $M_V < +3$ are all visible throughout MW to 20kpc. ATLAS has excellent time sampling for their light curves.
- Cataclysmic variables:
  - closer than 1kpc are visible at $M_V < +9$, with enough time sampling for light curves and continuous monitoring for outbursts.

# Gravitational Lensing

- Microlensing
  - Near-field events: lensing star close enough to see lens and source separate (after a while)
    - V=18 expect ~40 mas/yr proper motion
    - Total expected is ~23 events per year at V < 18, 58 events per year at V < 19
  - ATLAS will see ~30/yr total, and ~10/yr at high SNR and time coverage

- Strong lensing
  - Expect ~40 AGN lensed at x3 or more, and ~7 AGN lensed at x10 or more.
  - These are likely to have multiple images and accessible time delays

# Supernovae

- Type Ia supernovae
  - ATLAS monitors half the sky at all times
    - ~5000/yr at $z<0.1$ ($V<19$)
    - ~300/yr at $V<17$ and ~30/yr at $V<15$
  - Science includes
    - Nearby anchor for cosmology: dlum(z)
    - Rates
    - Systematics, environments, clusters, etc.

- Core collapse supernovae
  - ATLAS will detect comparable numbers to SNIa
  - Low metallicity hosts ($[O/H]+12 < 8.2$) where CCSN may become GRBs, ATLAS will find 10/yr at $25\sigma$ and $z<0.04$

# AGN

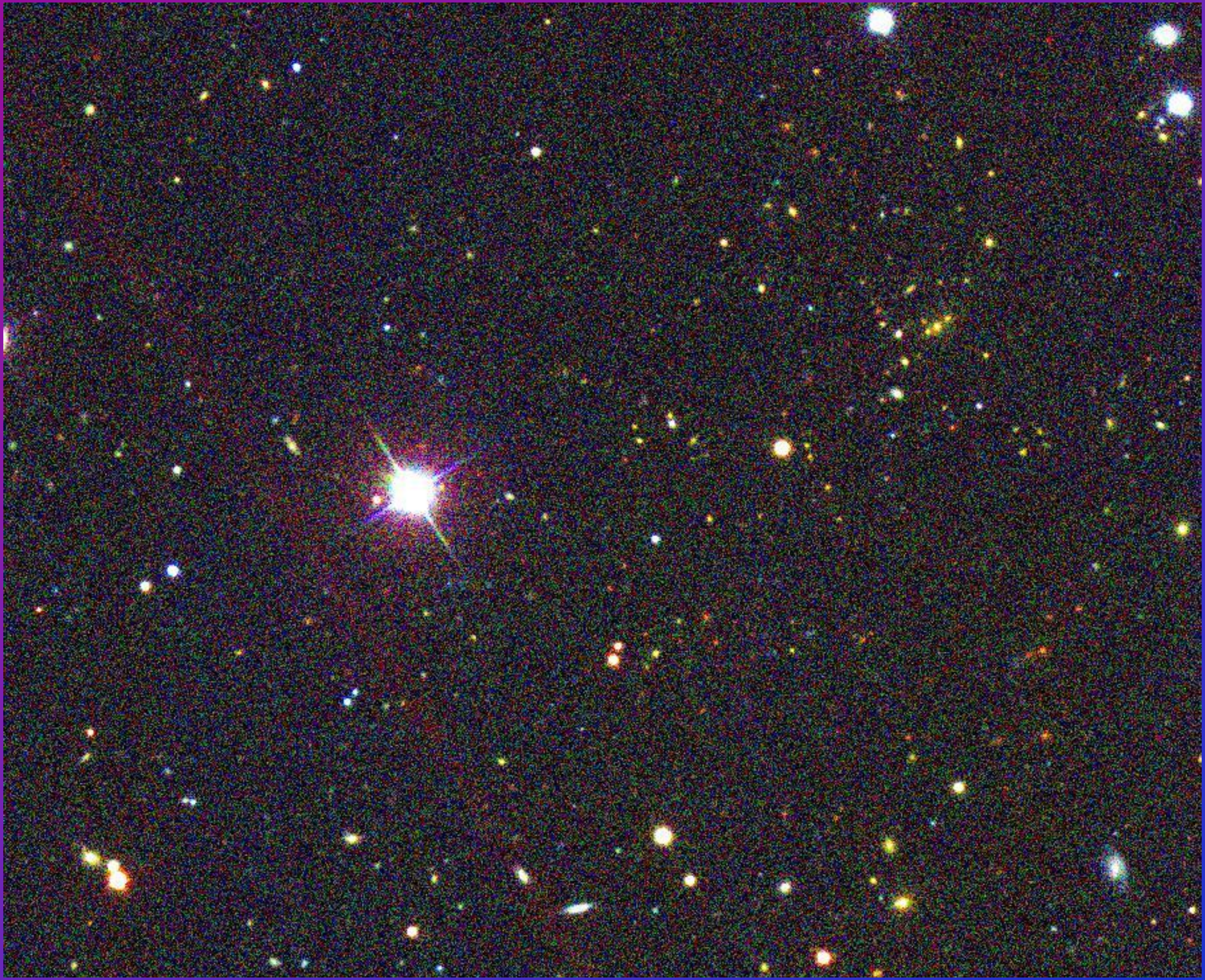
- There are 250,000 AGN brighter than V=19.6. ATLAS will monitor 100,000 of them
  - 10 day cadence 25σ
  - 1 day cadence 10σ
- ATLAS will continuously monitor 40 million galaxies at V=20
- Outbursts comparable to galaxy luminosity will be seen in substantial numbers
  - ~20 BH stellar accretion events (MV ~ −18) per year at 0.1mag photometric accuracy

# Static Sky

- ATLAS observes most of the sky ~350 times per year
  - m~23 sensitivity at 5$\sigma$
    - ~2.5 mag fainter than POSS
    - ~0.5 mag fainter than SDSS
    - ~0.5 mag brighter than PS1 3pi 3 year
- Confused for static sources, although excellent for differencing
- Unconfused for variable sources: ATLAS has a sliding sensitivity into variability structure function:
    - V~20 at 1 day,
    - V~21.3 at 10 day,
    - V~22.5 at 100 day.

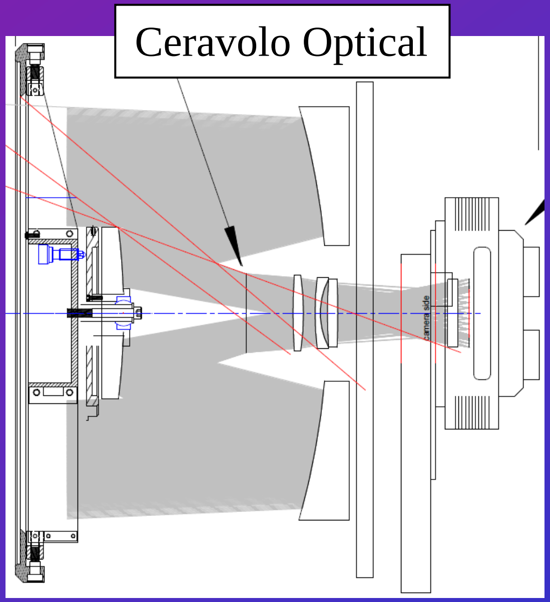
# ATLAS: one year observation

# SDSS



# ATLAS is Extensible

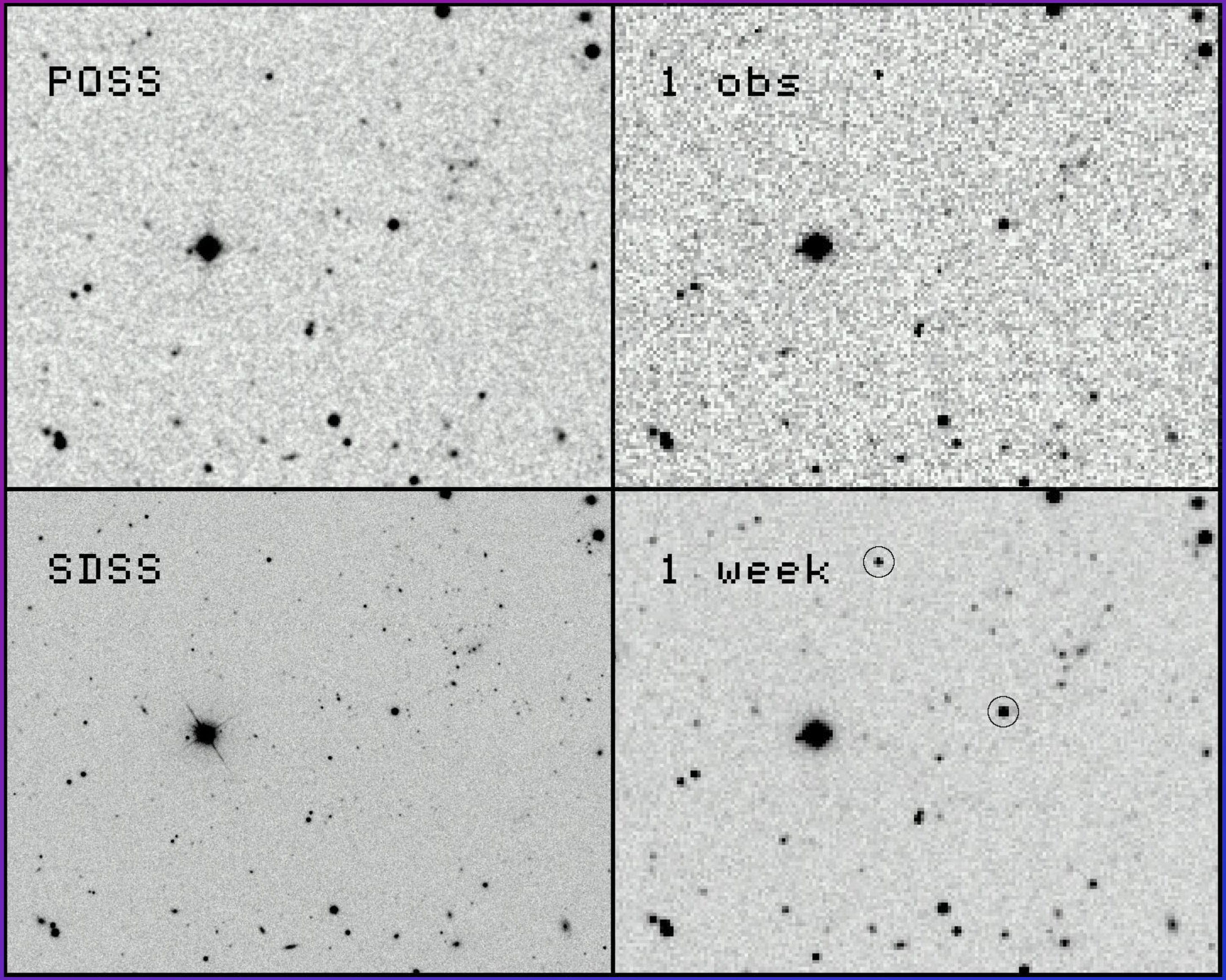
- Worldwide Internet Survey Telescope
- Unit telescope ~0.5m with ~100-400 Mpixel detector
  - Robotic, autonomous local pipeline reductions
  - Cost ~$0.5M?
- Limiting magnitude ~21 for 40,000 sq deg/nt
- Tightly controlled software, scripted operations! ITSS!




ATLAS
www.fallingstar.com
arXiv:1011.1028
2011PASP..123...58

# BACKUP Slides

# ATLAS, POSS, SDSS



# Fast Transients

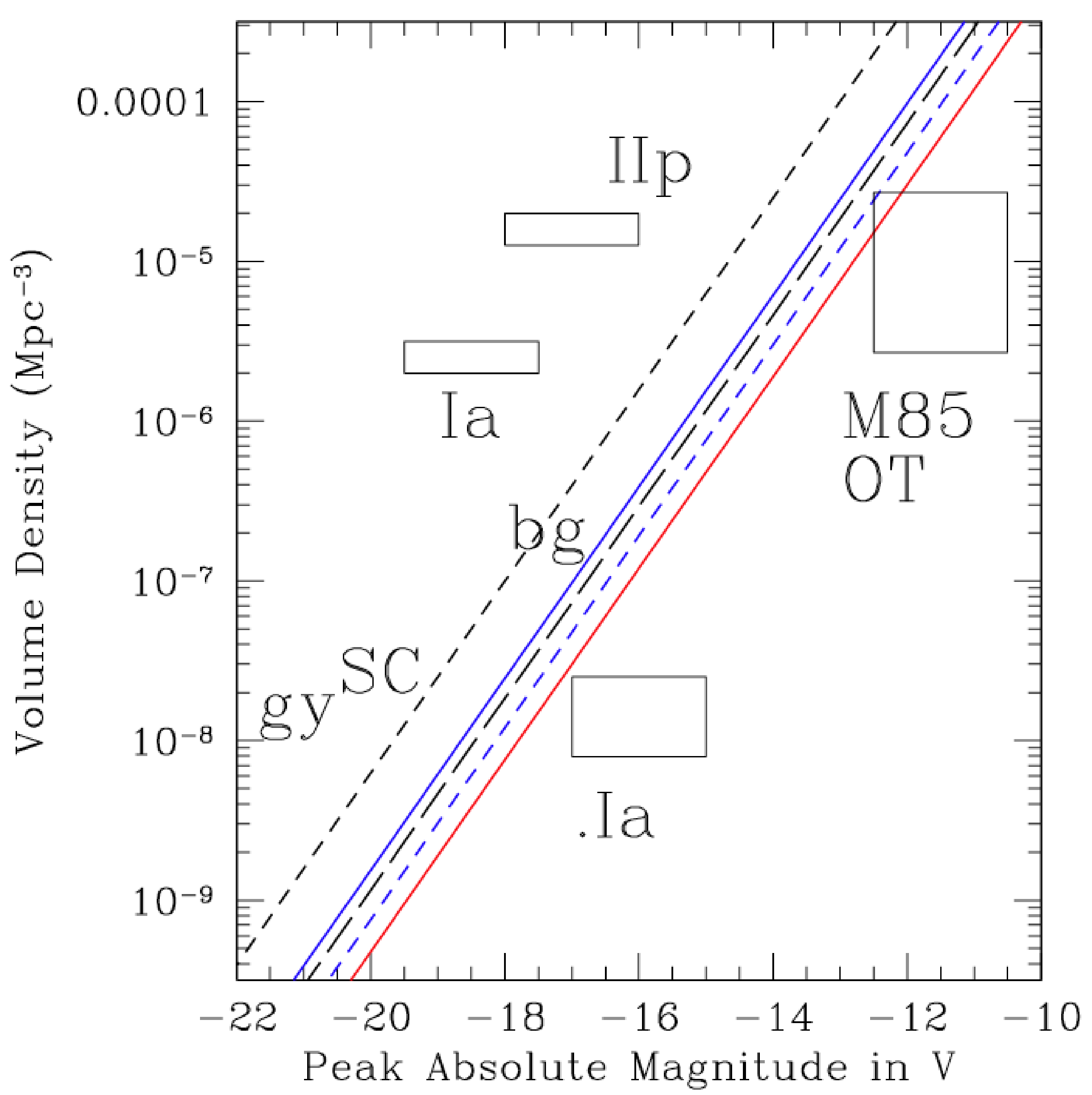
- The probability of capturing a fast transient is
  $(\Omega/4\pi)\ (\Delta t/t_{cad})$
- where $\Delta t$ is the transient's duration above the survey's sensitivity limit, $(\Omega/t_{cad})$ is the survey's solid angle and time to survey it.
- ATLAS is the fastest survey with $m_{lim} > 17$
  - ATLAS = 20,000 $deg^2\ day^{-1}$ $m < 20$
  - PTF = 1,200 $deg^2\ day^{-1}$ $m < 20.5$
  - PS1-3pi = 1,500 $deg^2\ day^{-1}$ $m < 22.7$
  - PS4 = 6,000 $deg^2\ day^{-1}$ $m < 23$
  - LSST = 7,000 $deg^2\ day^{-1}$ $m < 24$
- Relative ability to detect transients depends on the brightness and decline rate of the transient.

# Rough Survey Parameters

- Lars Bildsten's estimates of stellar explosions

| Survey | SNLS | SDSS | TSS | SKY | PTF | PS1 | DES | ATLAS | LSST |
|---|---|---|---|---|---|---|---|---|---|
| Depth | 24.3 | 22.5 | 18 | 19 | 20.6R | 24 | 25R | 20 | 24 |
| Omega | 4 | 260 | 200 | 1000 | 2700 | 50 | 15 | 20000 | 30000 |
| Cad (d) | 3 | 2 | 1 | 3-4 | 5 | 4 | 5 | 1 | 3-4 |
| Year | 03-08 | 05-08 | now | 09-? | now | 09-? | 11- | ? | ? |
| z at -18 | 0.7 | 0.3 | 0.04 | 0.06 | 0.15 | 0.6 | 0.6 | 0.1 | 0.6 |

# Unbiased Survey Volumes




The boxes plot the volume rate * duration for

- Type Ia (30 d),
- Type IIp (100 d),
- .Ia (5 d), and
- M85-OT (60 d),

All LOCAL!!

Lines show the 1 event per "exposure" line for

- SNLS (dash)
- SDSS (long-dash)
- PS1 (blue-dash)
- PTF (blue-solid)
- ATLAS (red)

# Space Junk

- Excellent parallaxes permit discrimination of Earth-orbiting things from brief transients and asteroids

- LEO objects
  - m = 11.8 (15cm piece of junk at 0.1 albedo)
  - 10,000 such objects?
- GEO objects
  - m = 16.8 (1m piece of junk at 0.1 albedo)

# Impactor Distributions

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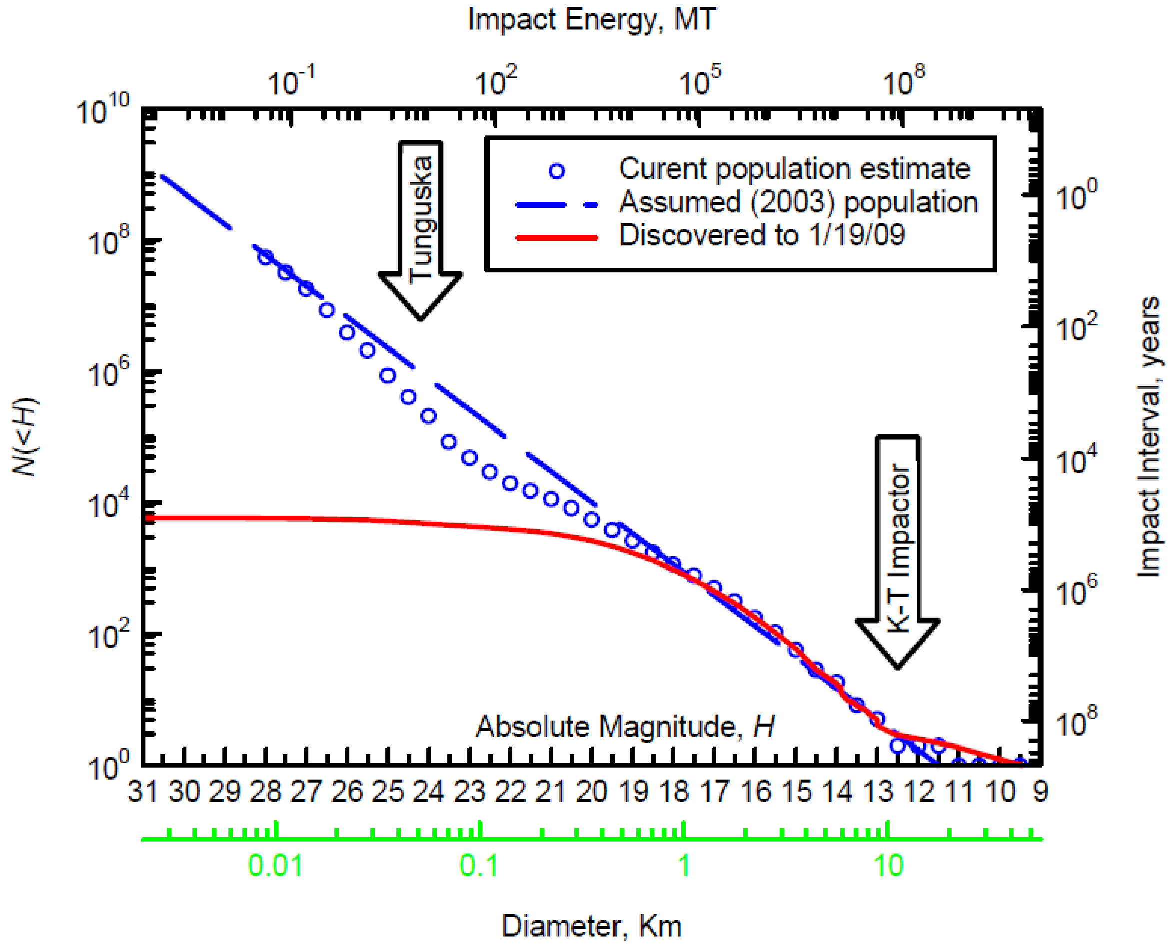


FIGURE 2.4 Numbers, N, of objects brighter than absolute magnitude *H* (see Appendix E) as a function of *H*. Ancillary scales give the average impact interval (right), impact energy in megatons of TNT for an assumed velocity of 20 km/s (top), and NEO diameter determined from the absolute magnitude using an average value for the NEO albedo. Variance in impactor velocity and albedo will result in uncertainties in the calculation of impact energy and NEO diameter. Note: "K-T" refers to the boundary between geological eras set 65 million years ago. SOURCE: Courtesy of Alan W. Harris, Space Science Institute.

# Fatalities per Impact

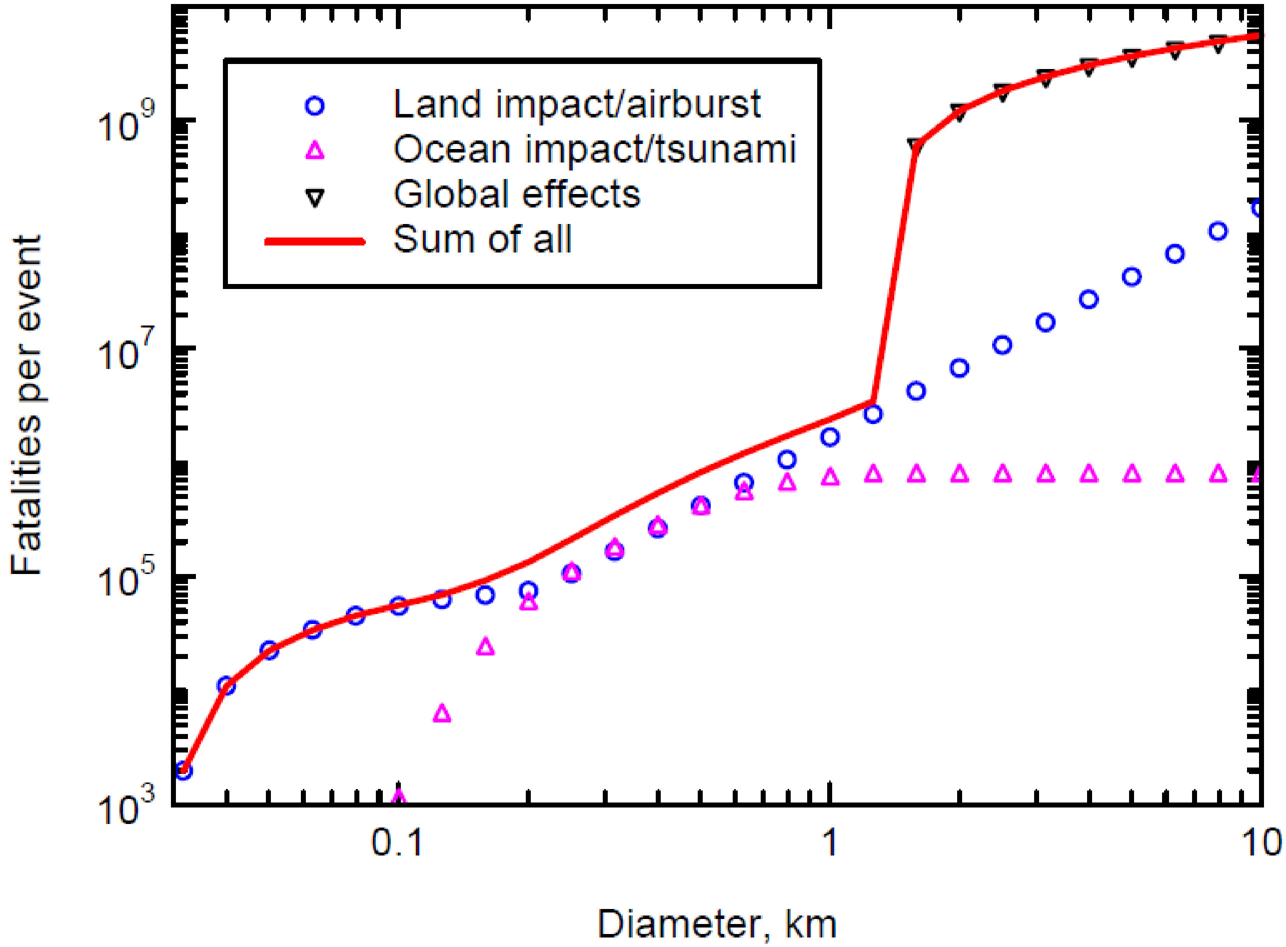


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FIGURE 2.5 Model of fatalities per event for impacts of various size NEOs. The solid curve represents the total fatalities associated with both ocean and land impacts, including those with global effects. The sharp increase in the solid (red) curve reflects the assumption of a large increase in fatalities for an impact that crosses the global-effect threshold. SOURCE: Courtesy of Alan W. Harris, Space Science Institute.

# Fatality Rate (pre-Spaceguard)

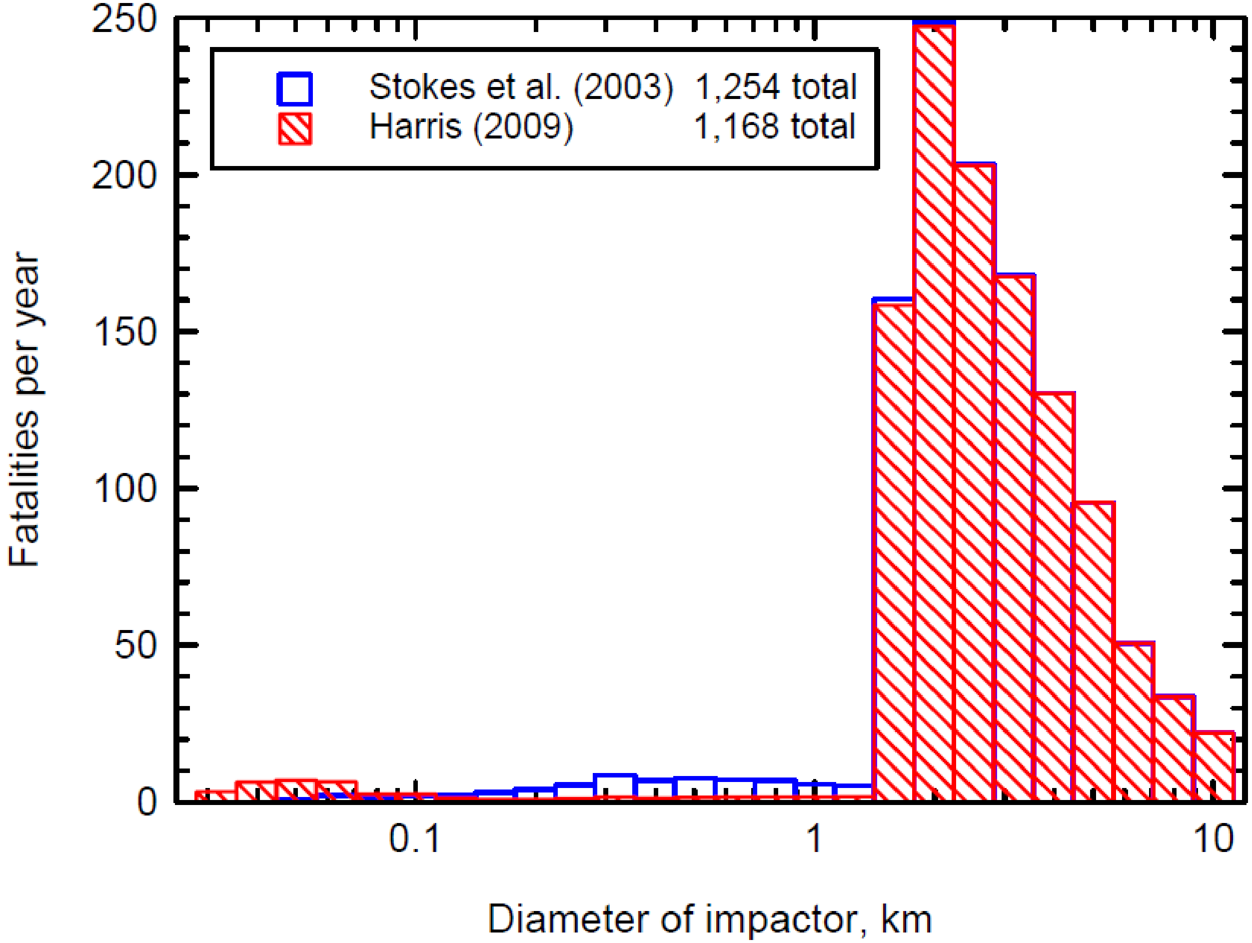


FIGURE 2.6 Estimated average fatalities per year for impacts by asteroids of various sizes calculated for the circumstances prior to the Spaceguard Survey. One curve references the data used in the Stokes et al. (2003) study. The new revised data includes corrections resulting from understanding of the threat due to tsunamis and airbursts, and recent revisions to the size distribution of NEOs (see Figure 2.4). SOURCE: Courtesy of Alan W. Harris, Space Science Institute.

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# Fatality Rate (2009)

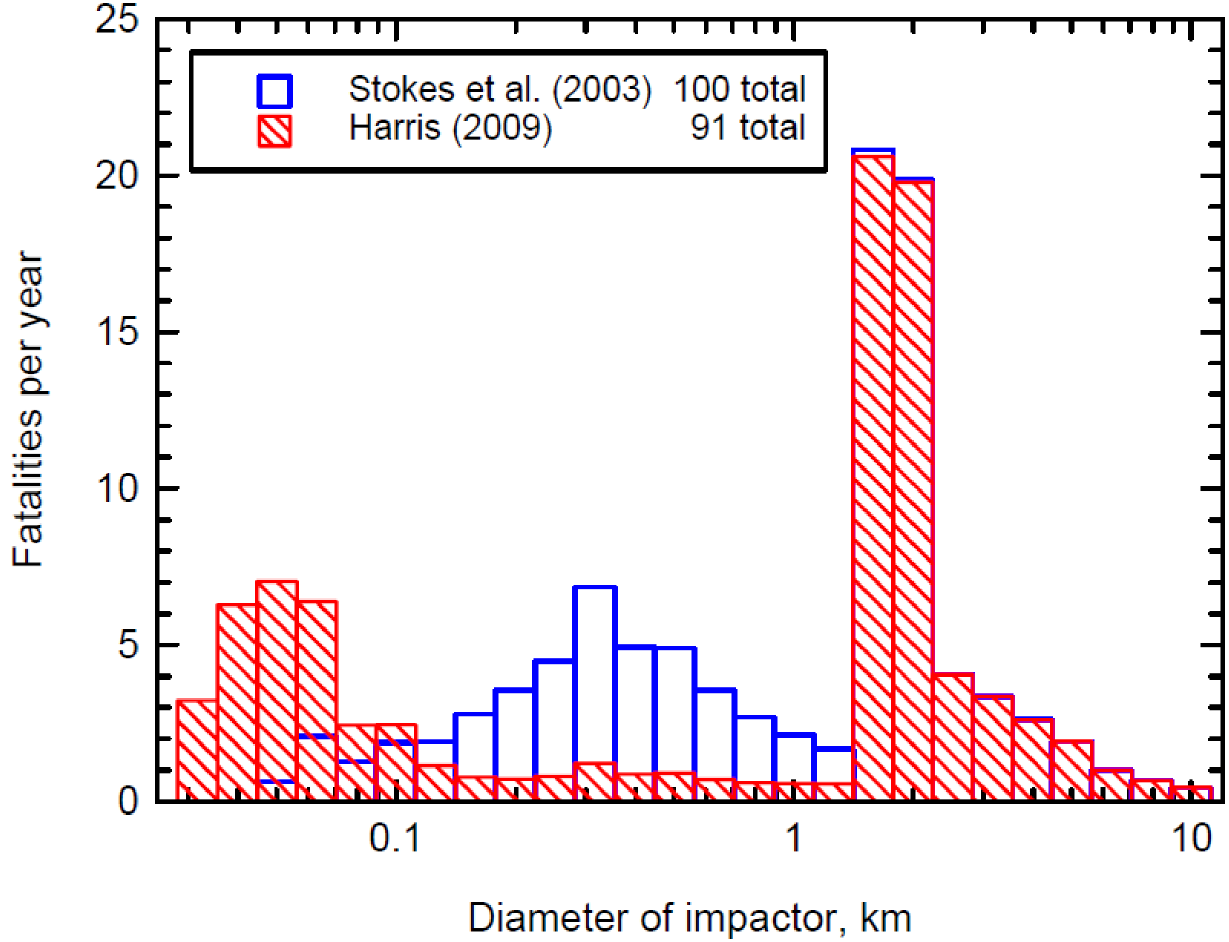


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FIGURE 2.7 Estimated average fatalities per year for impacts by asteroids of various sizes calculated for the circumstances after 85 percent completion of the Spaceguard Survey. One curve references the data used in the Stokes et al. (2003) study. The new revised data includes corrections resulting from improved understanding of the threat due to tsunamis and airbursts, and recent revisions to the size distribution of NEOs (Figure 2.4). SOURCE: Courtesy of Alan W. Harris, Space Science Institute.

# Asteroid Classes and How to Find Them

- Different subclasses of asteroids have different distributions and therefore optimal search strategies are different.
  - All asteroids, including outer solar system
  - Inner solar system, including main belt
  - Near Earth Objects (perihelion < 1.3 AU)
  - Potentially Hazardous Objects (MOID < 0.05 AU)
  - Impactors
- Impactors have orbits that have a smaller semi-major axis, eccentricity, and inclination than NEOs.

# Moving Object Survey Simulator

- We developed a fast orbit integrator for testing survey capabilities and search strategies against different catalogs of asteroids.
- Important factors include
  - Sensitivity, solid angle, cadence
  - Extinction, sky brightness, weather
  - Phase function
  - Trailing losses
  - "Detection" and "Discovery" (identification) criteria
- Orbit lists from Veres et al (2009) based on Bottke et al (2002)
  - 270,000 NEOs to H=25 (35m)
  - 10,000 impactor subset that strike over 100 years

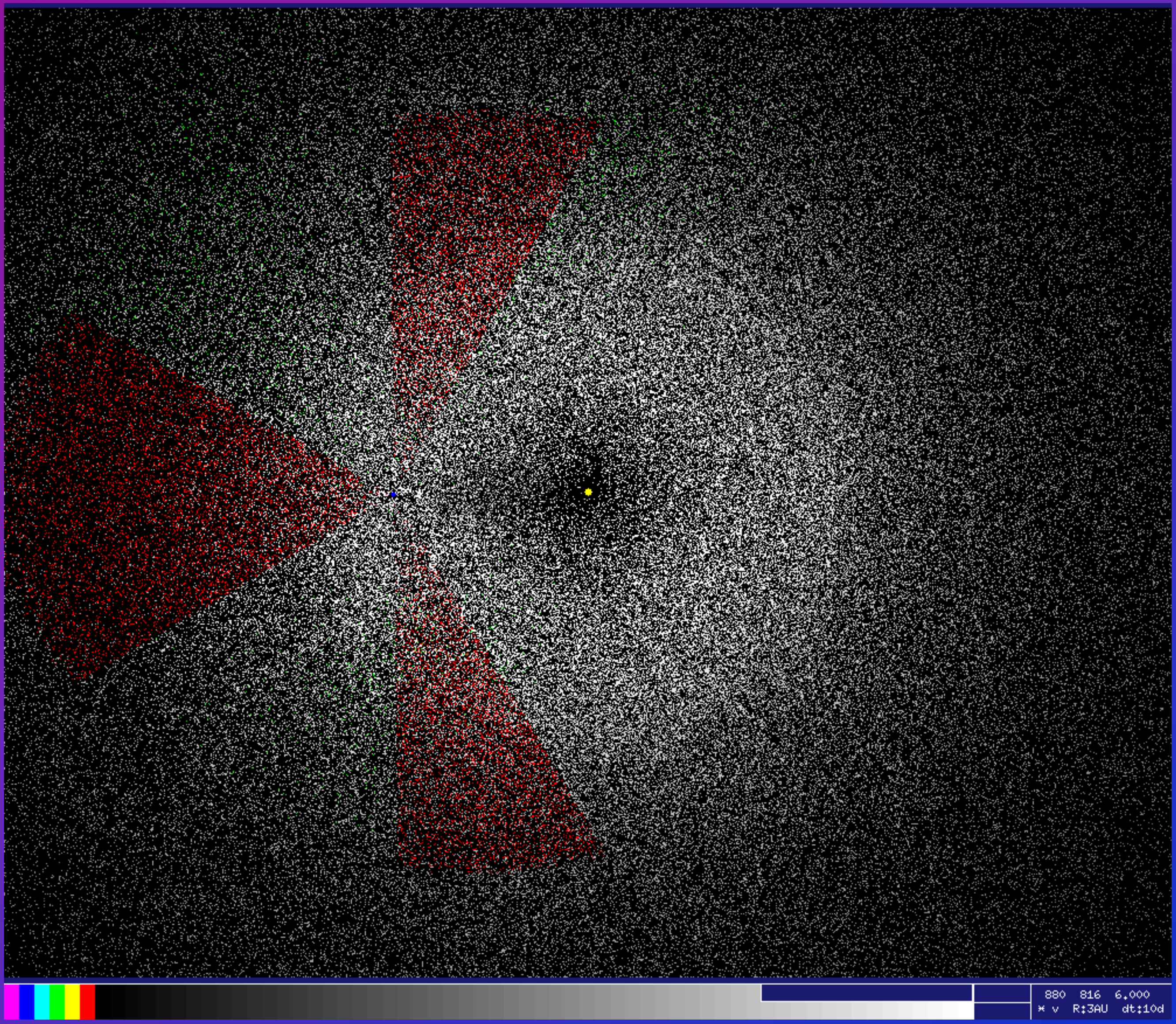
# 270,000 NEOs

- PS1 survey
- All 1000m

Grayscale:
apparent brightness

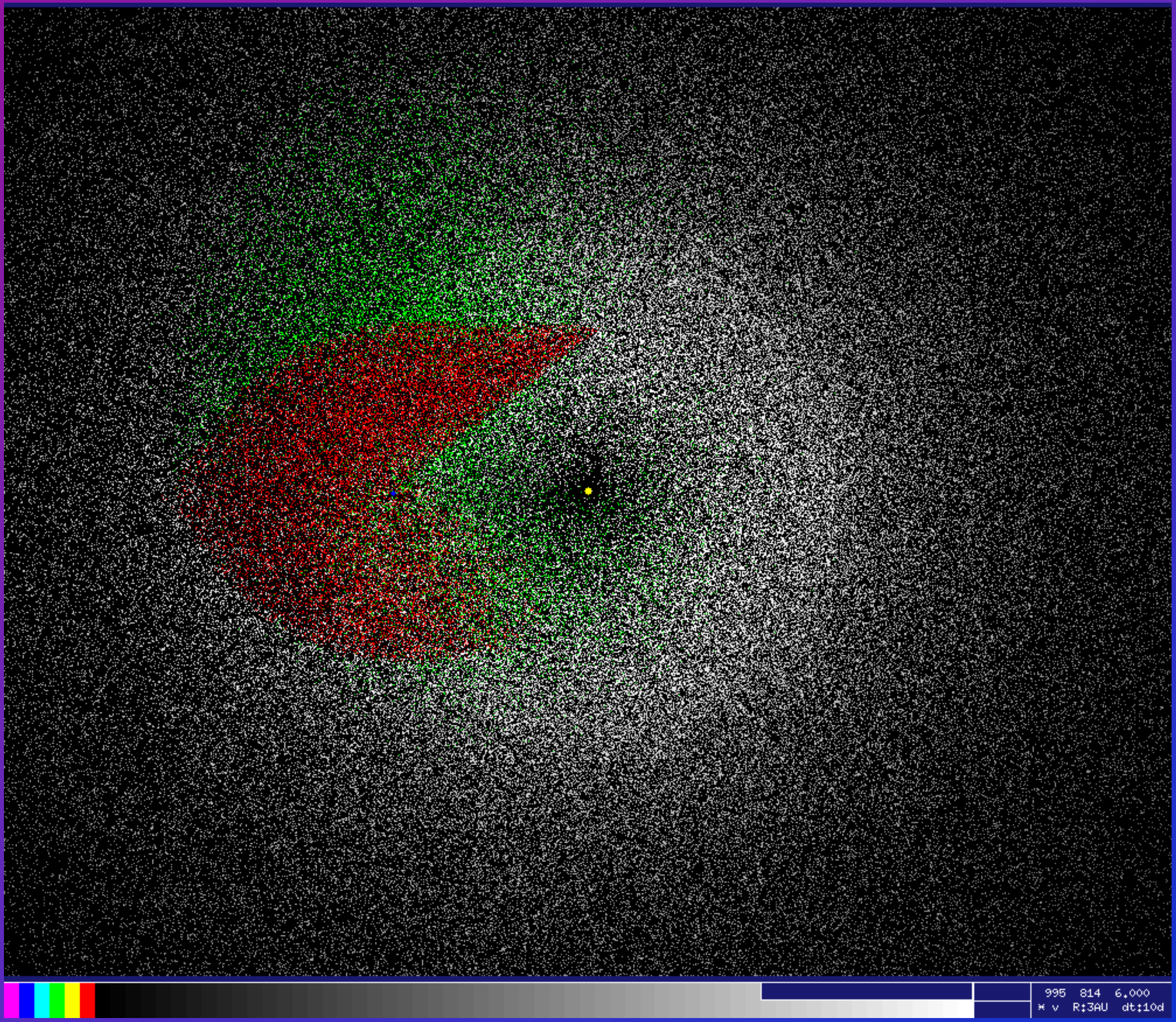
Red:
"Detected" now

Green:
"Discovered"



# 270,000 NEOs

- ATLAS survey
- All 1000m




Grayscale:
  apparent brightness

Red:
  "Detected" now

Green:
  "Discovered"

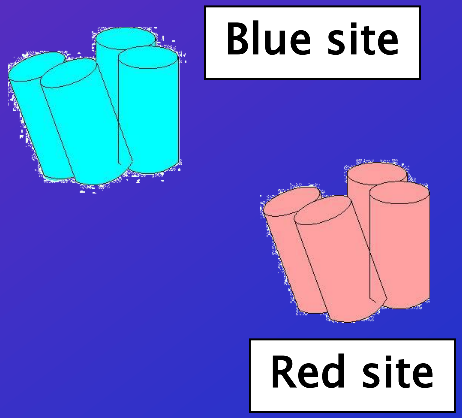
# ATLAS Details

- Optics and mount (8)
  - Takahashi Eps-250 or equivalent 0.25m aperture
    - 5° field of view
    - 0.7m focal length for 4.4" pixels
  - Finger Lakes PDF focusser
  - Filter slide with "blue" (g+r) or "red" (r+i) filter
  - Uniblitz shutter
  - AstroPhysics 3600-GTO (or Software Bisque ME)
- Camera and controller (8)
  - 4x4k CCD with 15um pixels (pair of MITLL CCID20)
  - "Microcam" cryostat, TE cooled, ion pump, chiller
  - IFA StarGrasp controller

# Microcam, Epsilon-180, and CCID20's

# ATLAS Details

- Enclosure and sites (2)
  - Completely robotic operations
  - Ironwood Observatory mobile observatory trailer (or equivalent from Pier-Tech)
  - Two sites separated by ~100km for parallax ($3\sigma$ parallax at 0.1AU ~ 15 days prior to impact), one site has “blue” filters, the other has the “red” filters, exposures simultaneous
  - Possible sites include
    - Haleakala – Mauna Loa
    - Kitt Peak – Mt. Hopkins – Mt. Lemmon
    - Palomar – Mt. Laguna




- Usage of 8 telescopes
  - Telescopes co-aligned in pairs
  - Pairs have adjacent pointing for 40 sq deg per exposure

# Ironwood Observatory

Basic Concepts:

- A strong foundation/platform
- A 8x6 roll-off roof design
- Weather-aware system
- Redundant systems
- Battery backup
- Roof control system
- Control cabin with storage

# ATLAS Details

- Computers
  - Rack of 6 slices at each observatory
  - Rack of 12 at home base
  - Display workstations
- Software
  - Hardware and network management new
  - Observation code derived from Pan-STARRS
  - Reduction pipeline derived from SNIa heritage
  - Detection analysis and reporting by MOPS
  - Operations by 2 post-docs and a "data-aid"