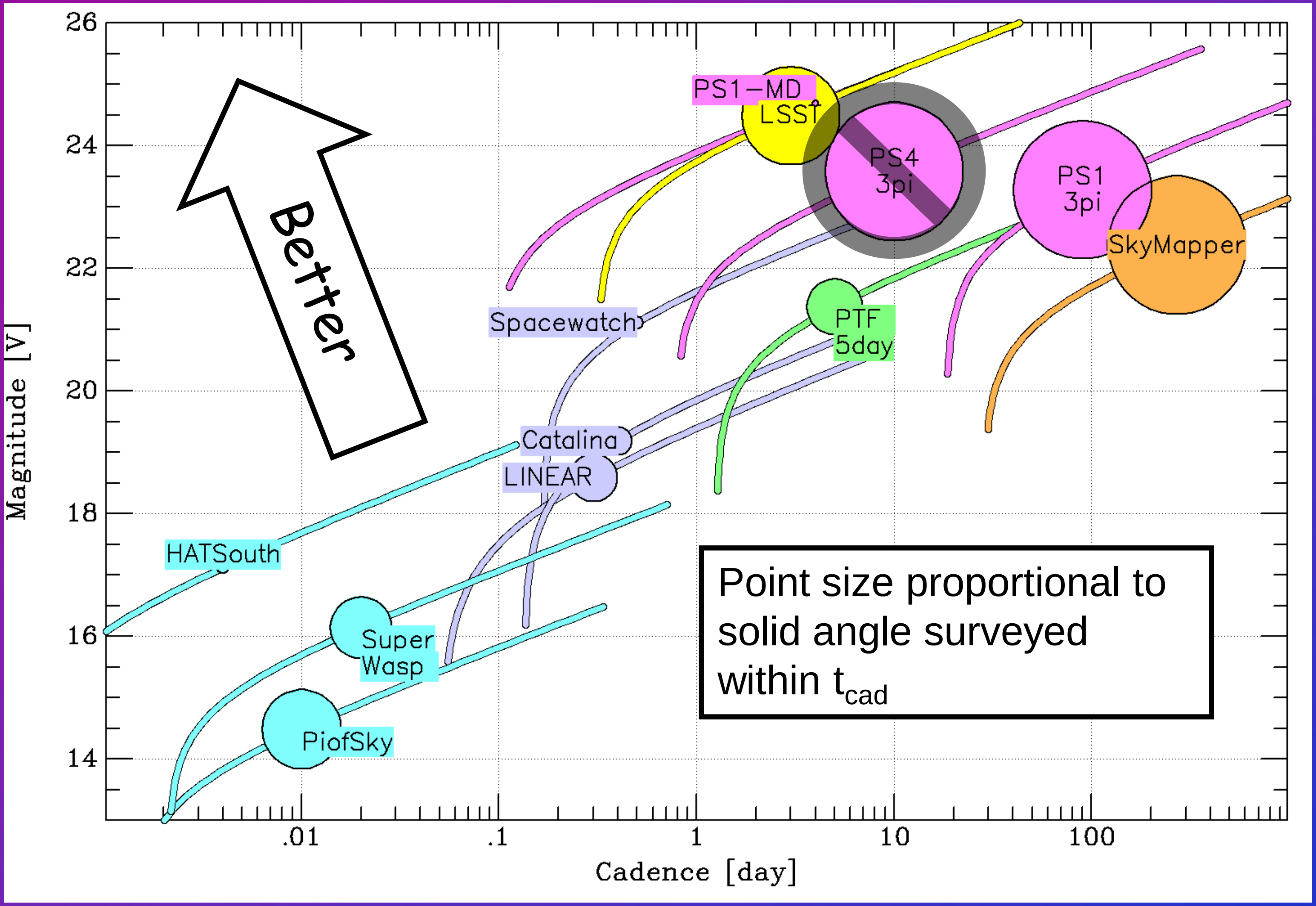
ATLAS

Asteroid Terrestrial-impact Last Alert System

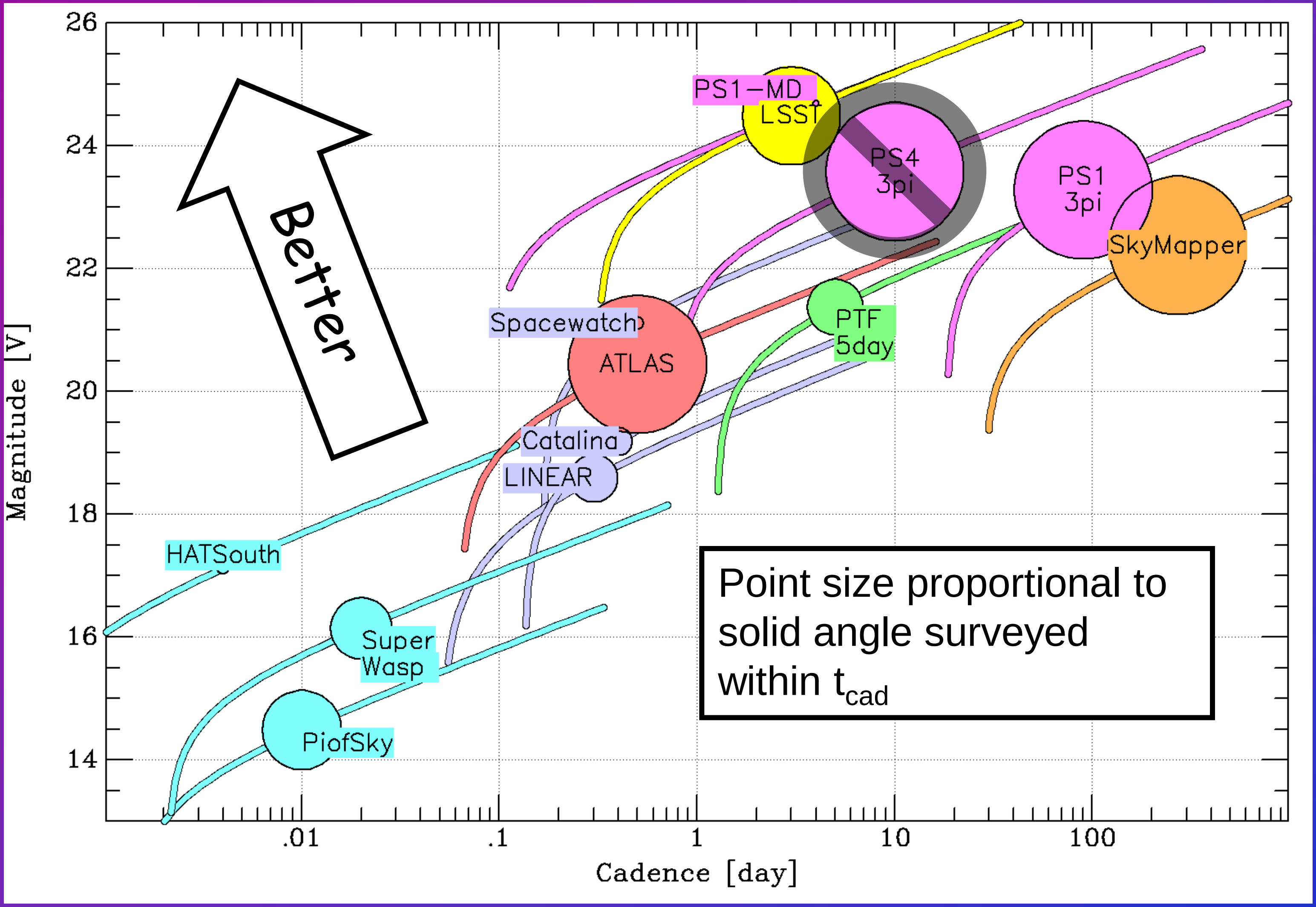
Survey Merit



Tonry 2011, PASP 123, 58

PDC 130415

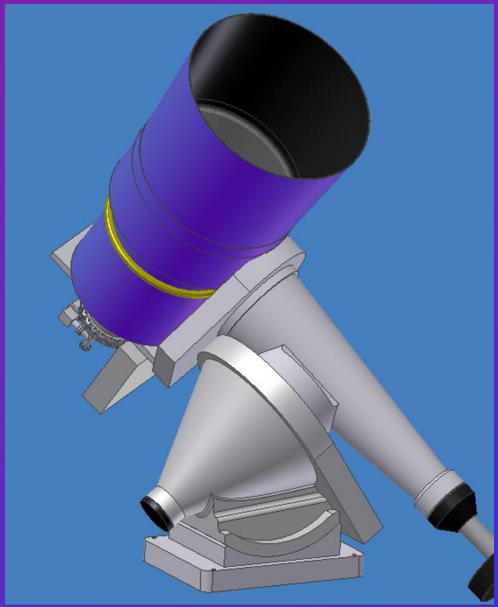
Survey Merit

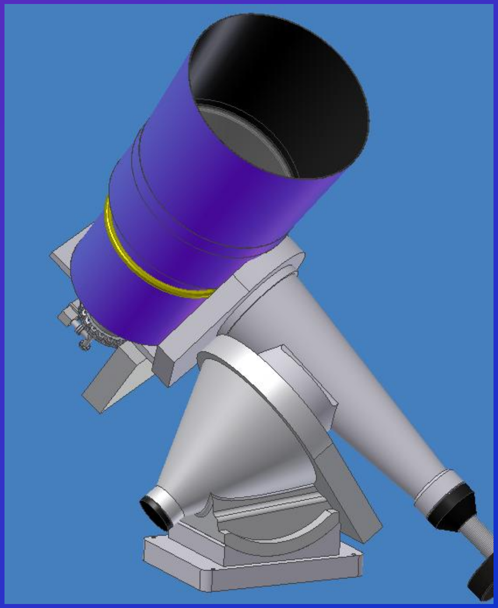


Tonry 2011, PASP 123, 58

ATLAS

- Project funded by NASA to find dangerous asteroids
  - Two or more small (~40–50cm) telescopes covering 60 deg^2 (7–8 deg FOV) producing ~3" images.
  - AΩ similar to Pan-STARRS or SkyMapper but 3" pixels. Less sensitive for motions slower than 1 deg/day.
  - Optimized for high duty cycle!
  - Broad filters (e.g. g+r, r+i, and g+r+i) intended for sensitivity but retaining some color information.
  - Expect to observe 100,000 deg^2 at m~20, i.e. entire visible sky 4–5 times per night.



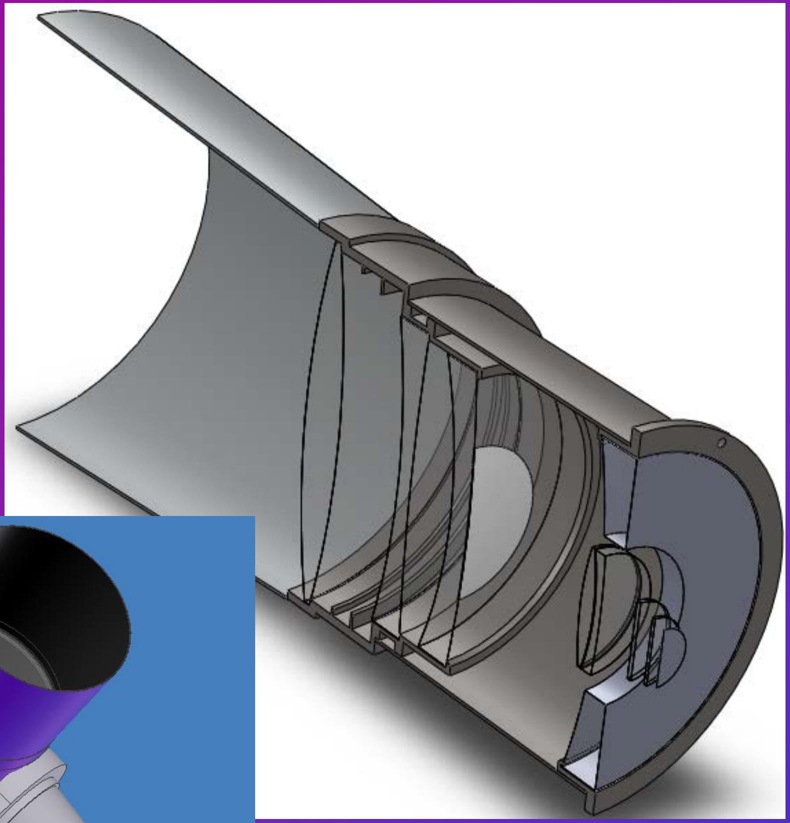


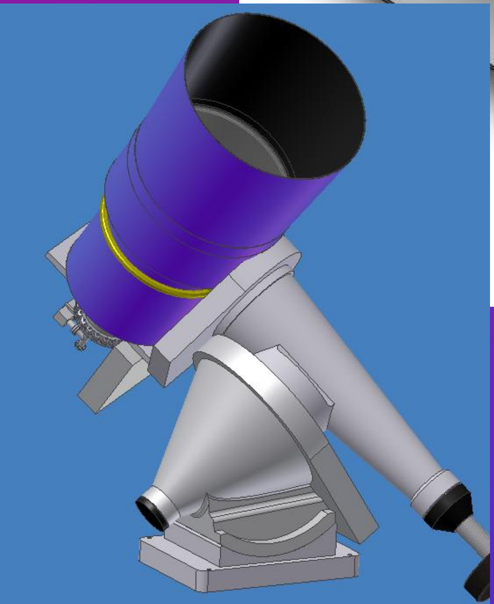
Optimizing Survey Speed

- "Survey speed" at a given sensitivity is the solid angle covered per unit time.
  - Bigger aperture provides more photons
  - Bigger field of view provides more solid angle
  - Sharper images provide better signal to noise
  - Low overhead provides better duty cycle
- Optimal survey speed per unit cost involves tradeoffs. These tradeoffs can be quantified!
  - Detectors are expensive! Pixels can sample sharp images or can cover field of view. Choose wisely.
  - Telescopes are expensive! Field of view trades against image sharpness, cost goes as $D^{2.5}$. Many small telescopes may be better than fewer large ones.
- Survey speed per unit cost optimum appears to be near 0.5m aperture, f/1.8, 7 deg FOV, and 100 Mpixel.

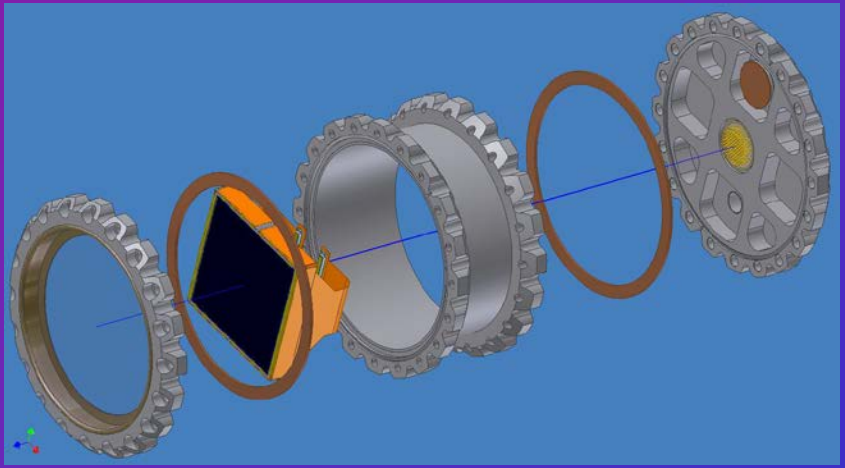
Optimizing Survey Speed

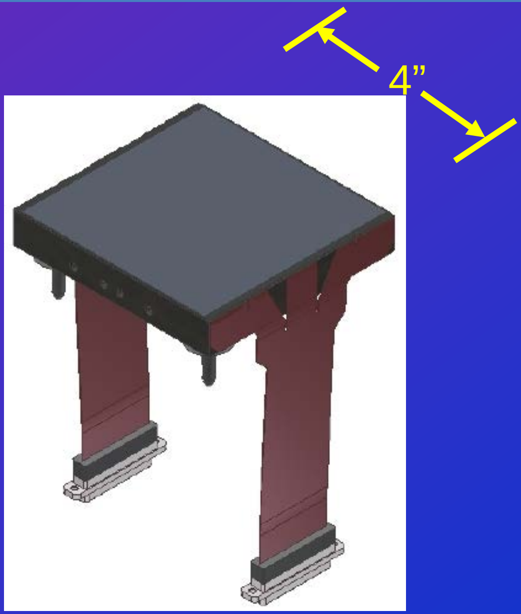
Fast, wide-field optics





100 Mpixel cameras



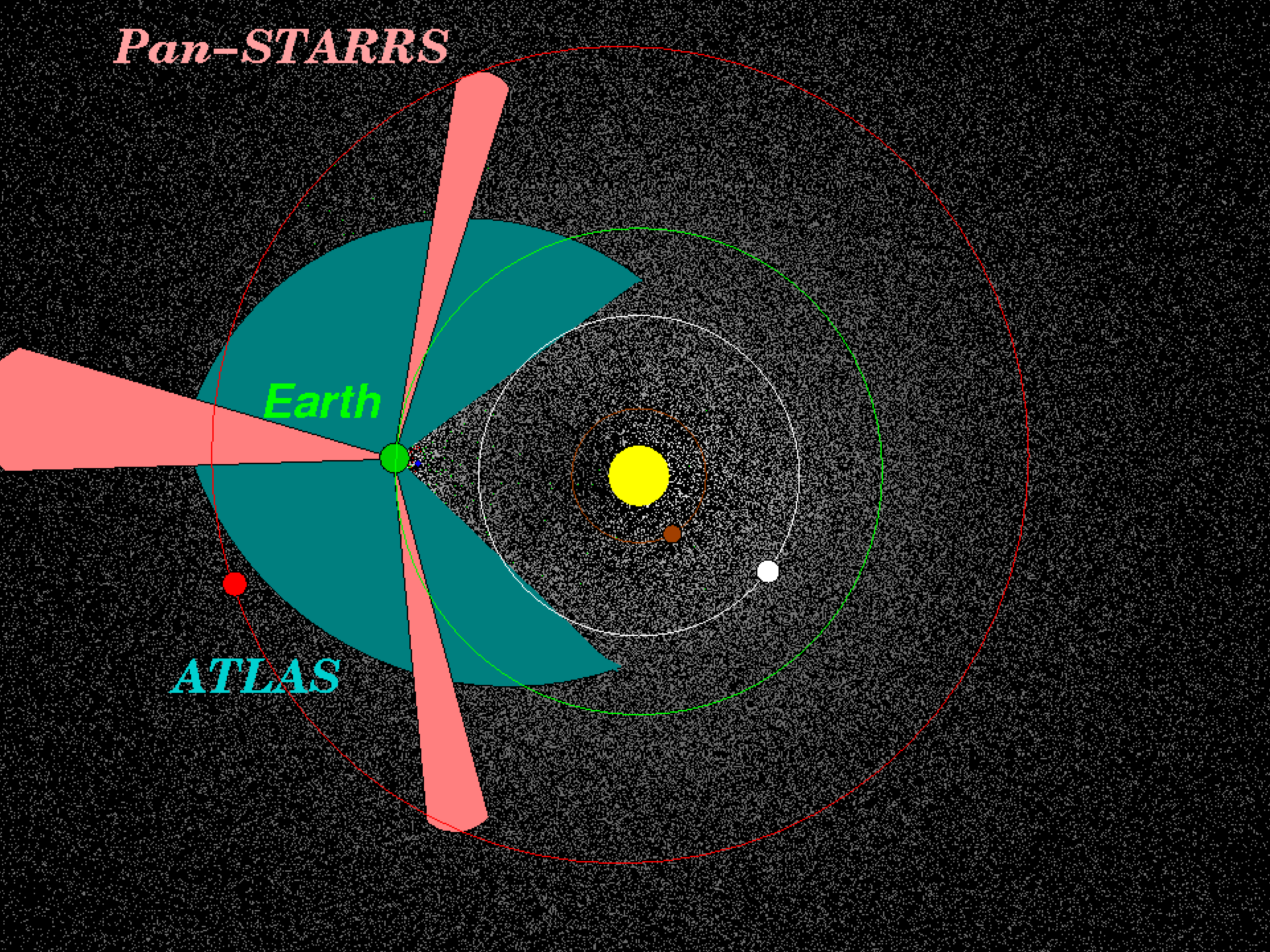


Asteroid Classes and How to Find Them

- 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)
  - Close approach small asteroids with small Δv
  - Impactors
- Impactors have orbits that have a smaller semi-major axis, eccentricity, and inclination than NEOs.

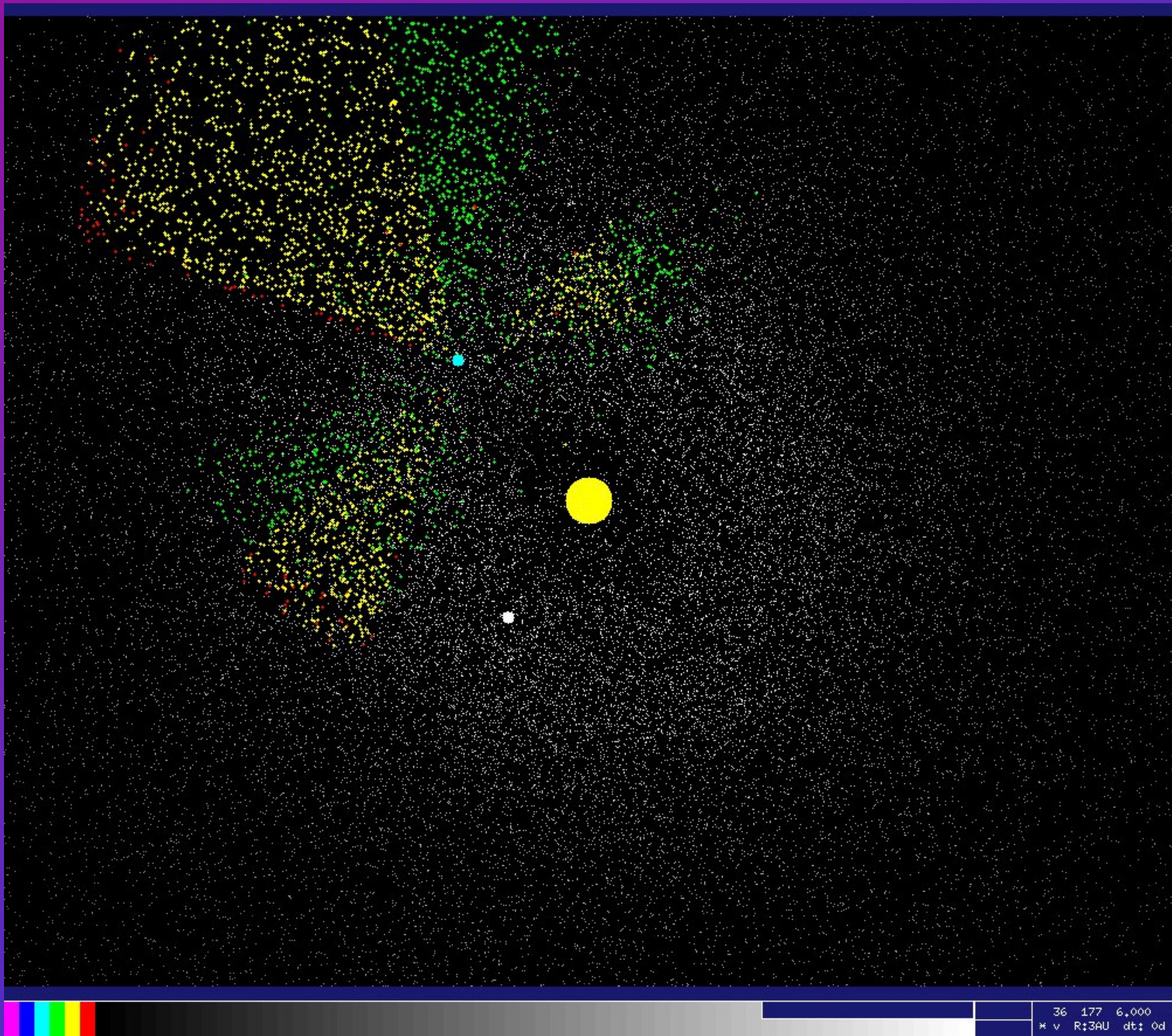
Moving Object Survey Simulator

- We have 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 (including Moon), weather
  - Phase function
  - Trailing losses
  - “Detection” and “Discovery” (identification) criteria
- Any given survey strategy can then be validated and refined using MOPS


Pan–STARRS
Earth
ATLAS

44,000 NEOs

- PS1 survey
- All 1000m



Grayscale:
apparent brightness

Red:
"Seen" now

Green:
"Found"

Yellow:
"Found & seen"

44,000 NEOs

- ATLAS survey
- All 1000m

Grayscale:
apparent brightness

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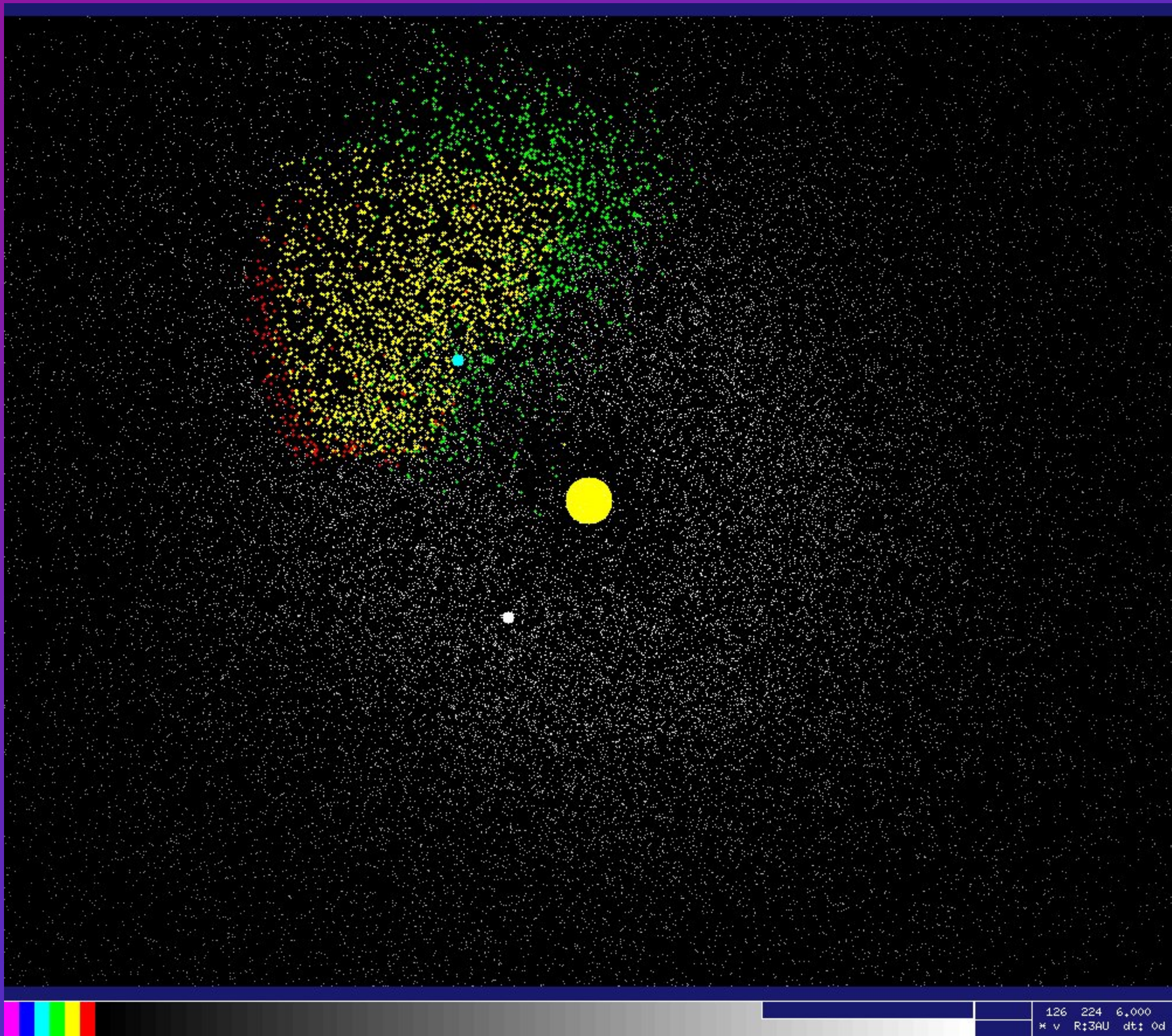
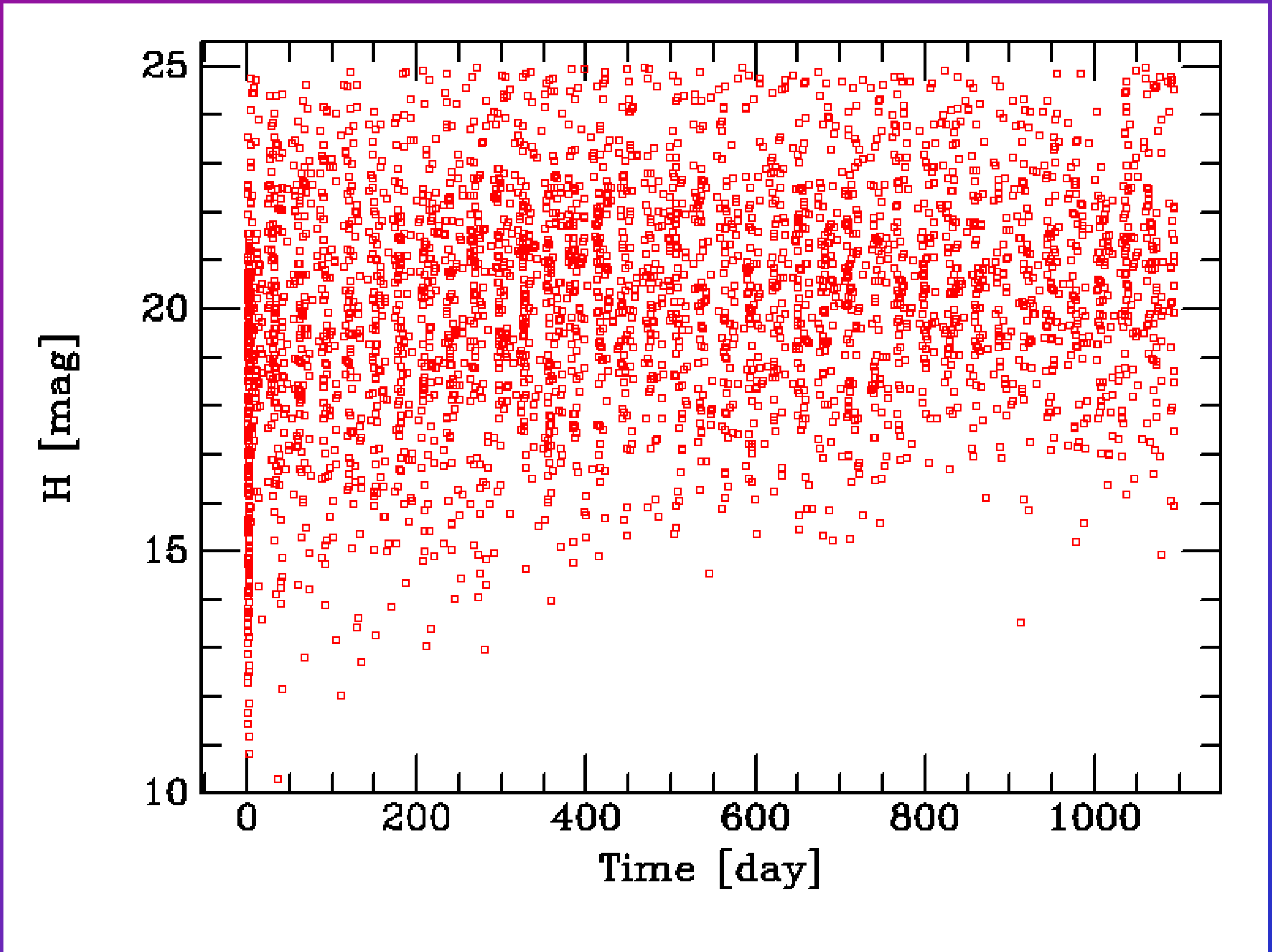
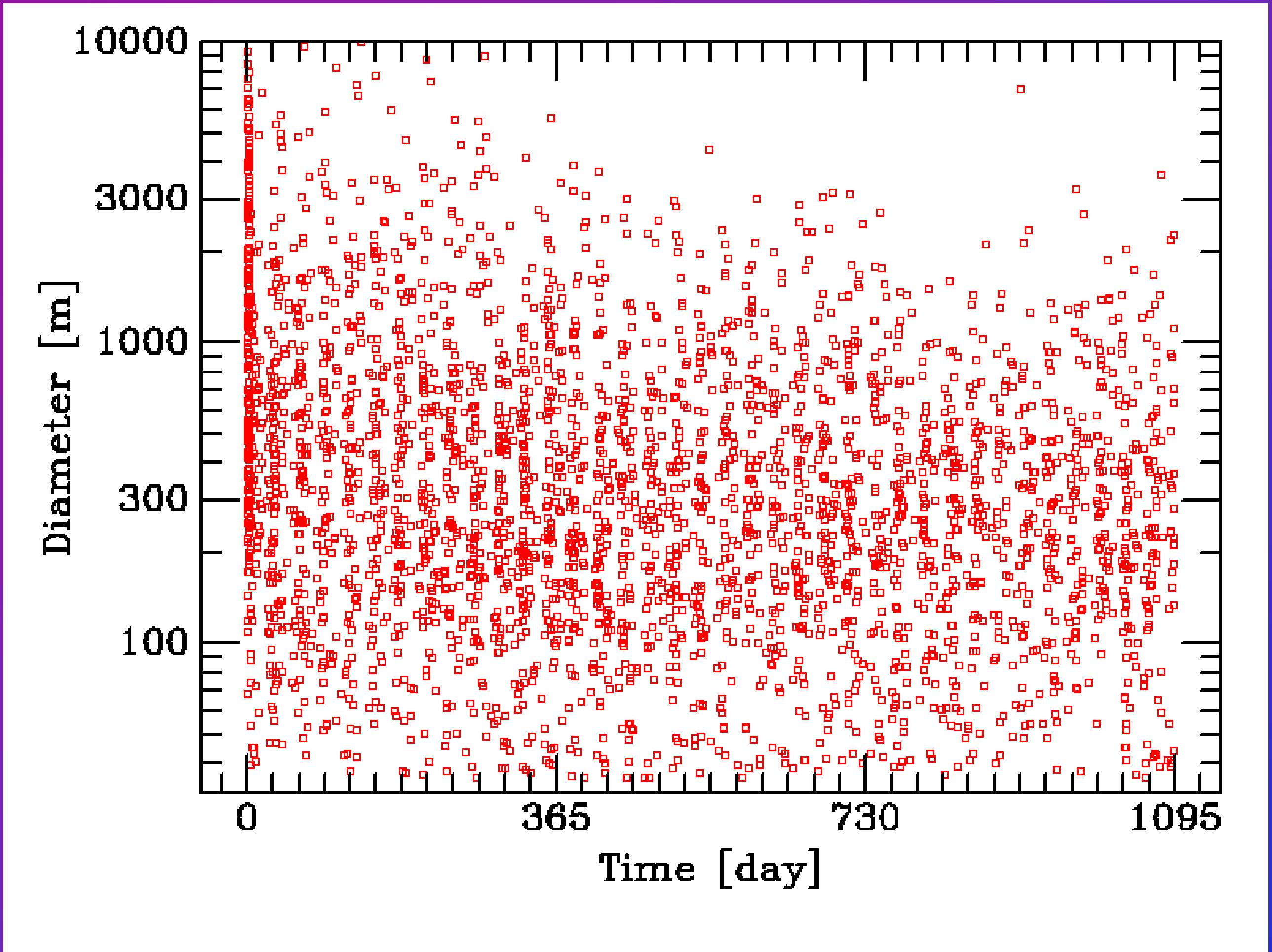


ATLAS NEO Discovery Rate

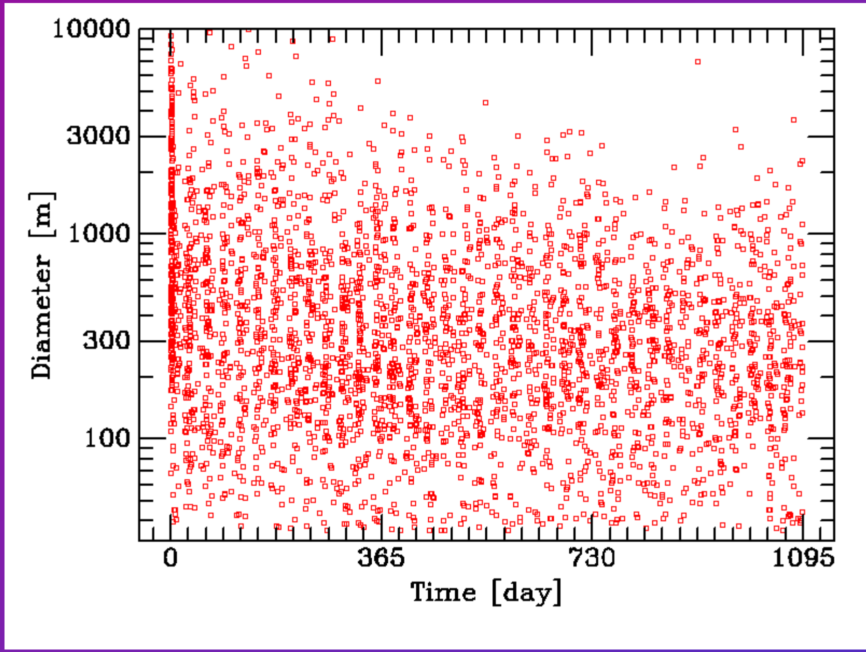


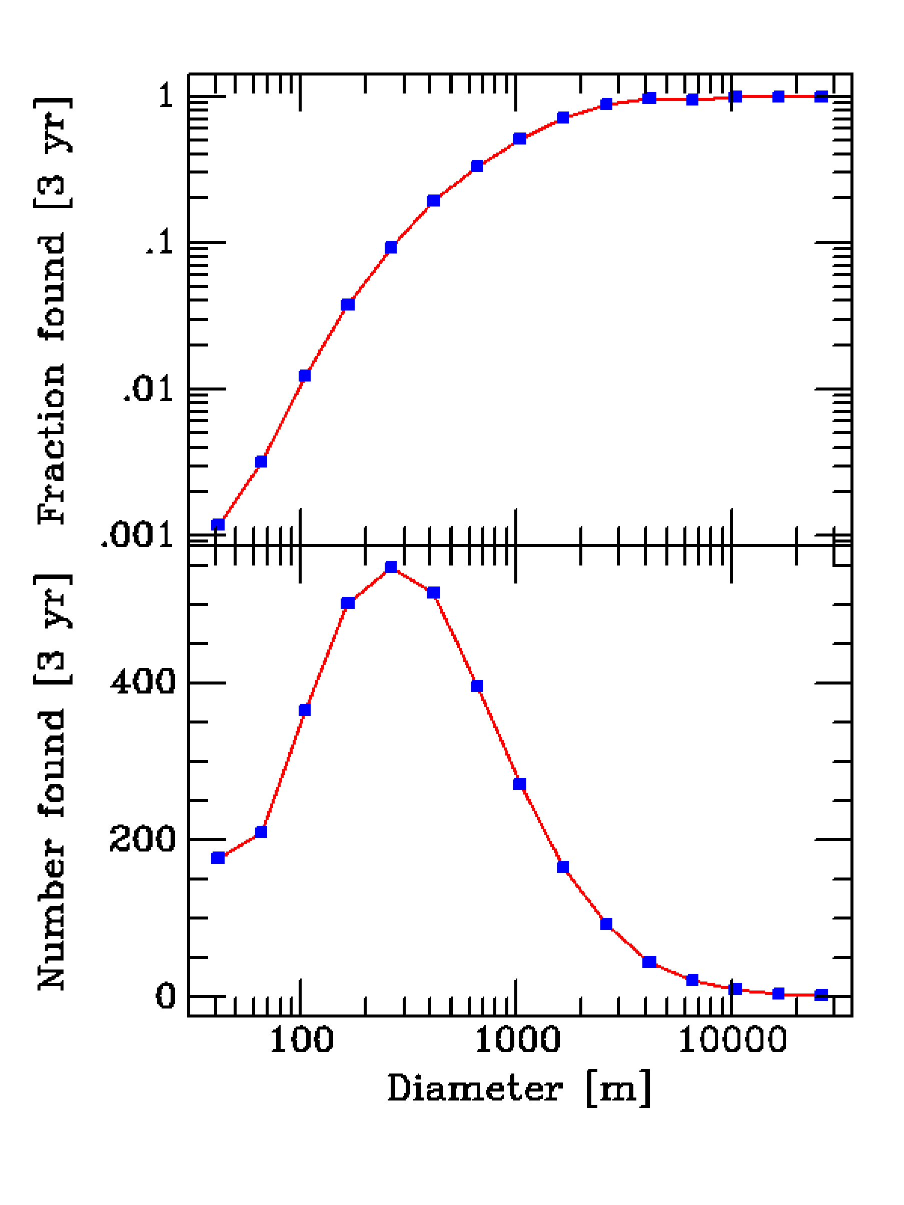
ATLAS NEO Discovery Rate



~1000 / yr from population of 250,000

ATLAS NEO Discovery Rate





10,000 Impactors

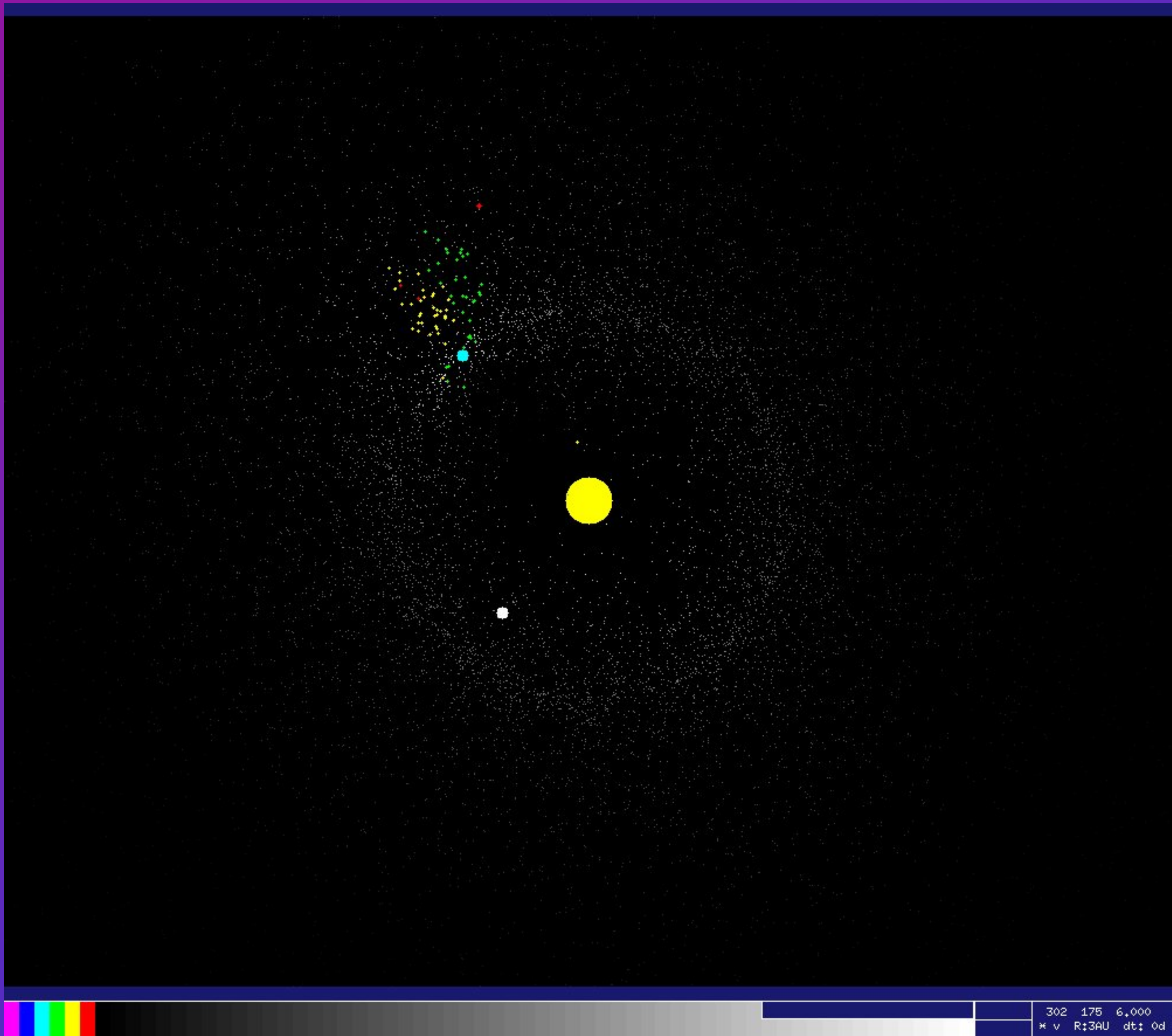
- PS1 survey
- All 140m

Grayscale:
  apparent
  brightness

Red:
  “Seen” now

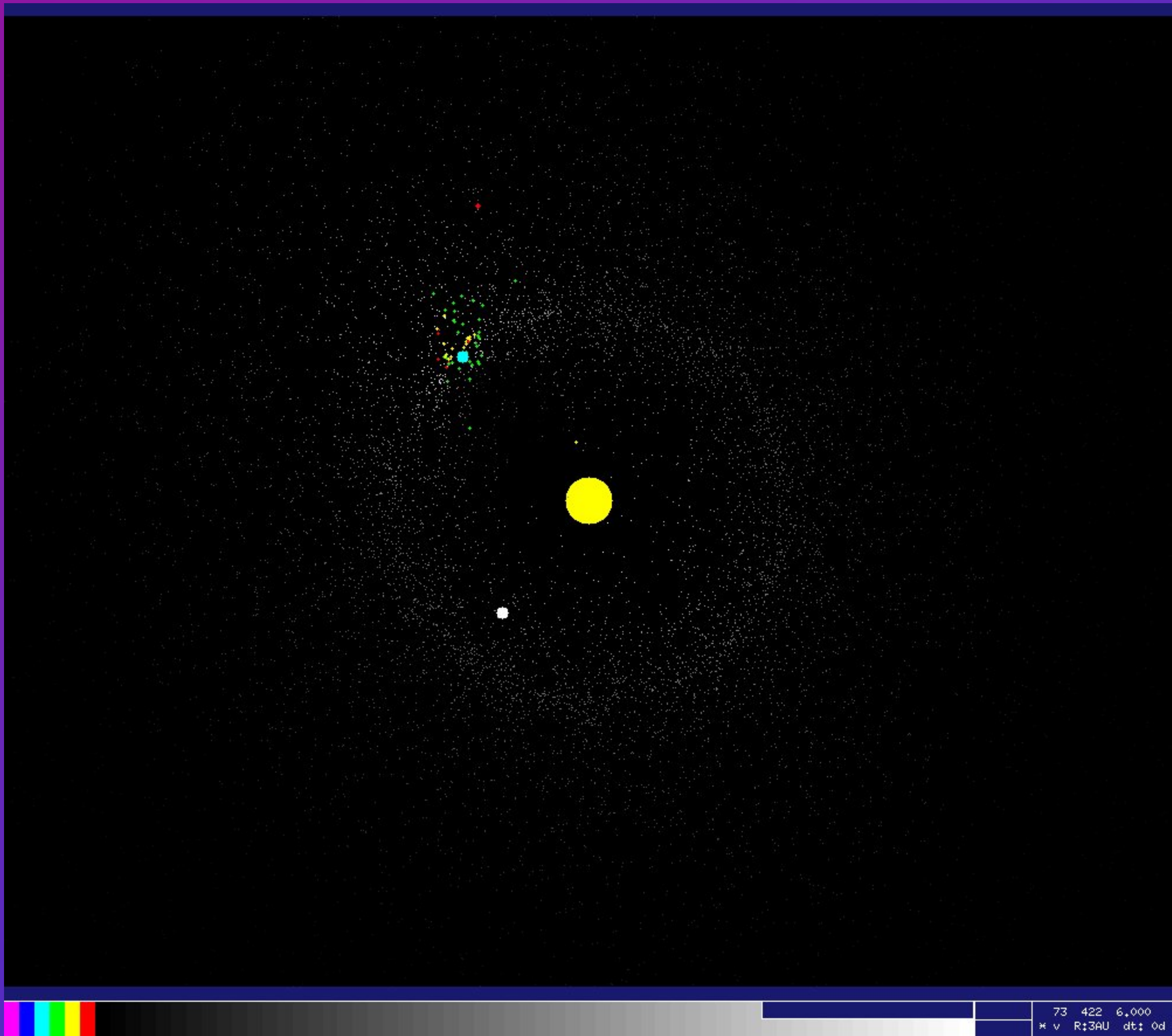
Green:
  “Found”

Yellow:
  “Found & seen”



10,000 Impactors

- ATLAS survey
- All 140m



Grayscale:
apparent brightness

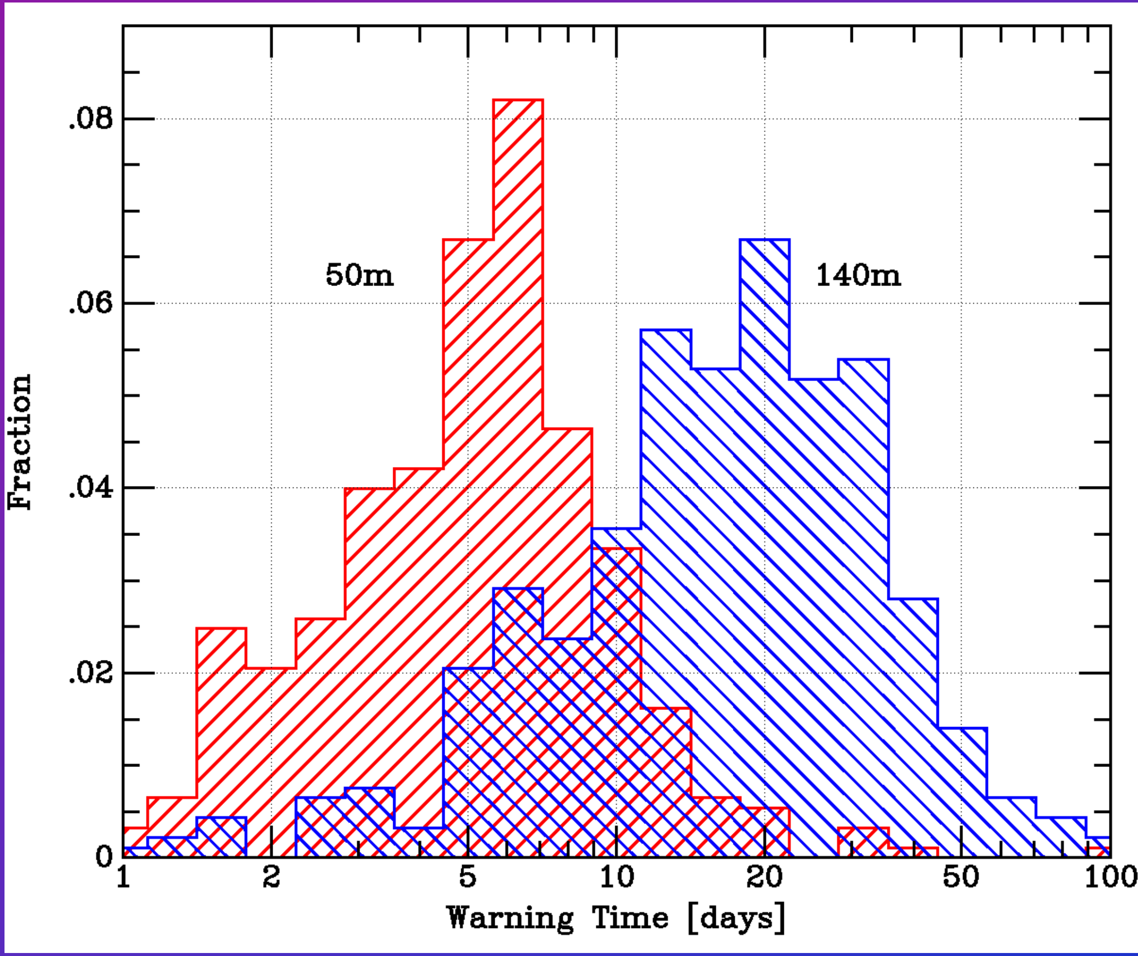
Red:
"Seen" now

Green:
"Found"

Yellow:
"Found & seen"

ATLAS Warning Time

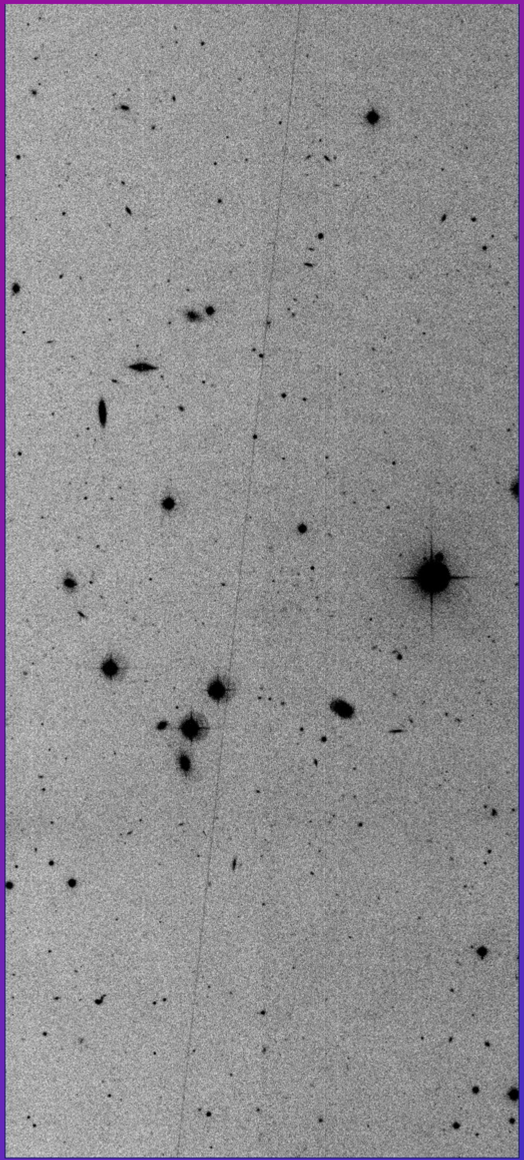
- Warning time depends on size
  - 140m: ~3 week
  - 50m: ~1 week
- Missed impactors come from the Sun and the south pole.

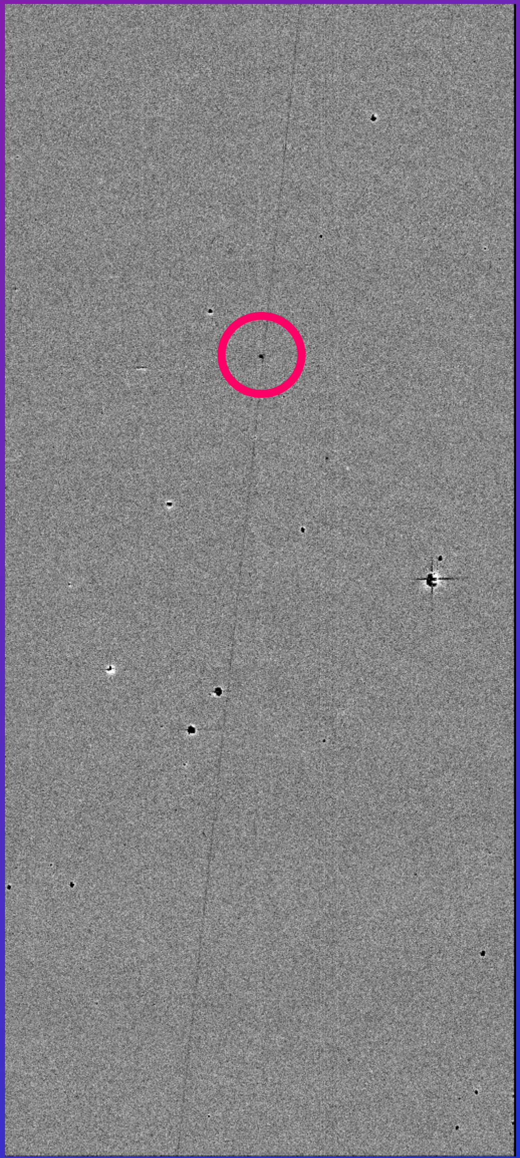


ATLAS is a Software Project

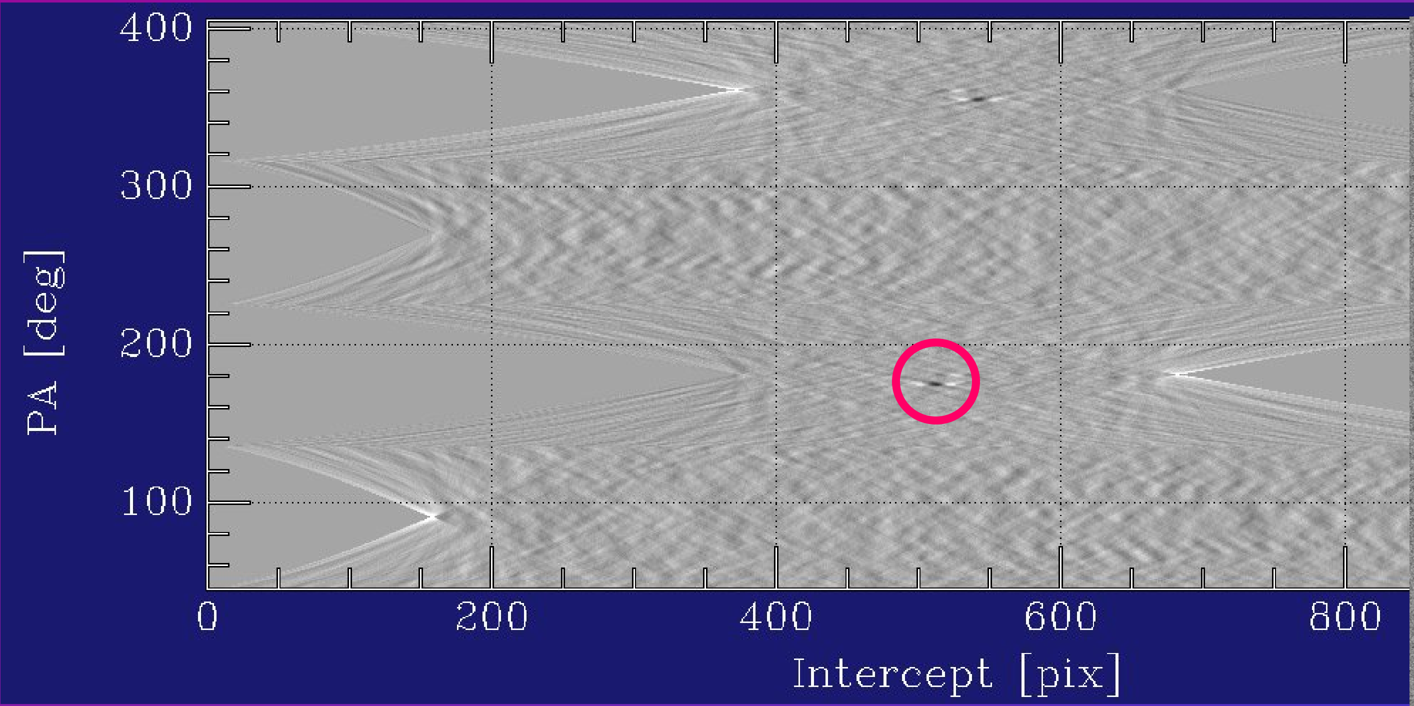
- Survey speed simulator to optimize hardware choices
- Observation strategy simulators
- The usual nuts & bolts to run robotic observatories
- Large data handling (~200 Gpixel per night)
- Image processing and differencing to detect changes efficiently
- Streak detection (Radon transforms?)
- Detection characterization and object linkage
- Databases, GUIs, communications, etc…

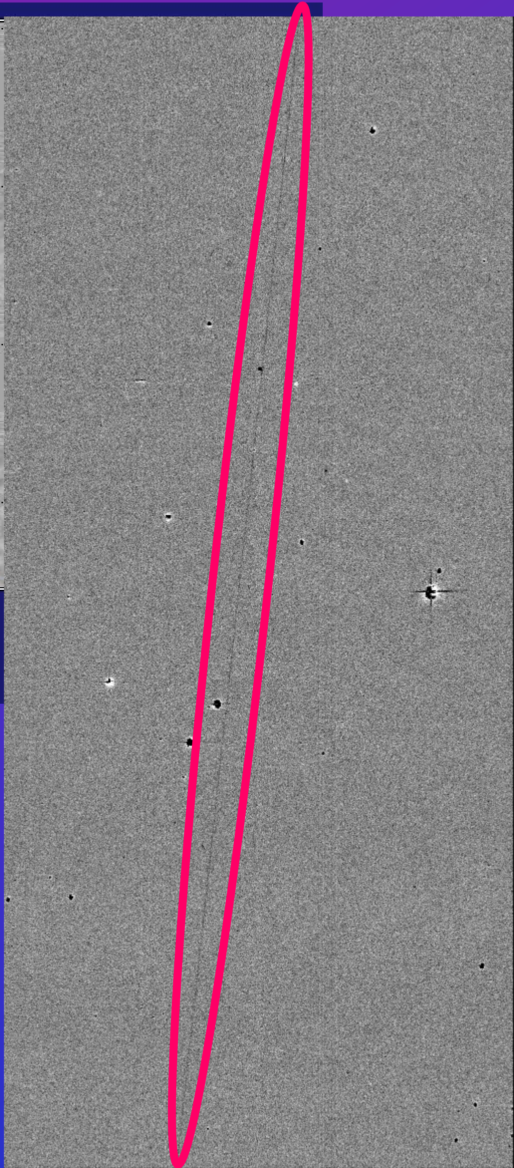
Image Subtraction



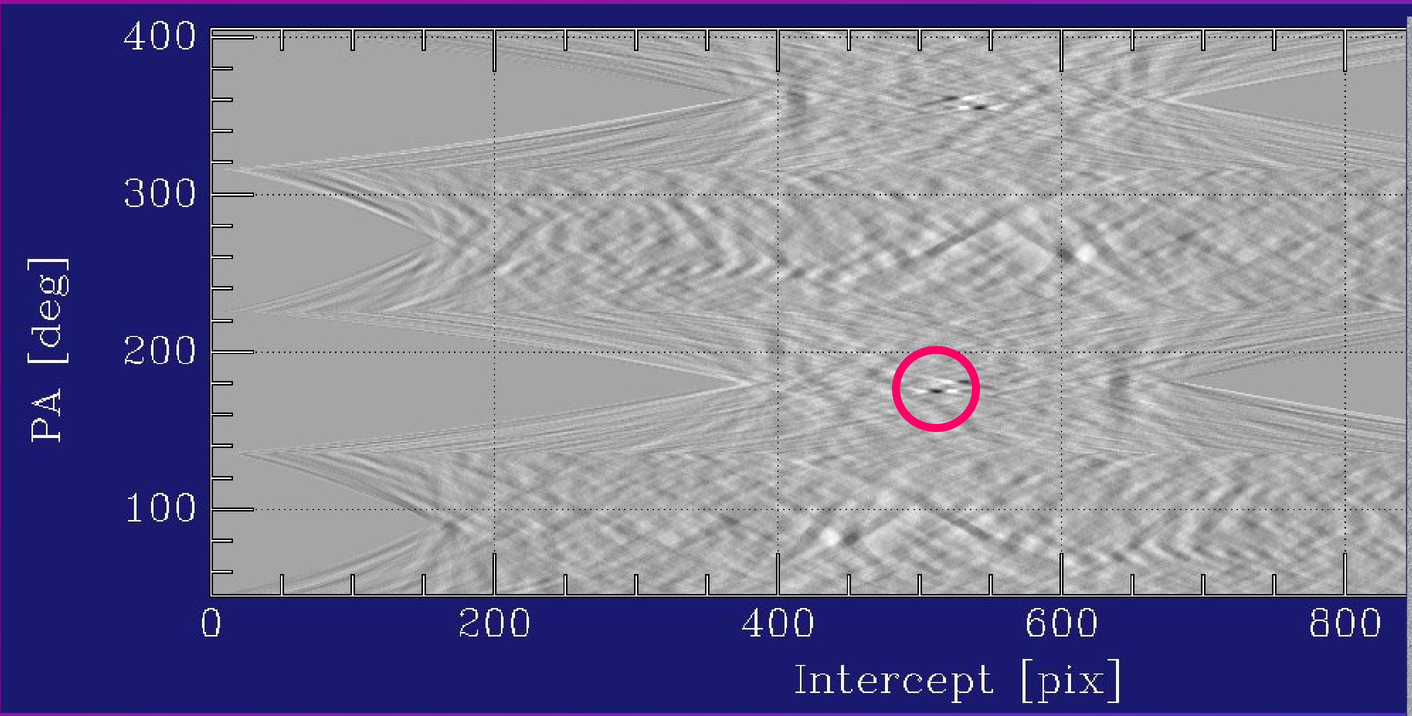


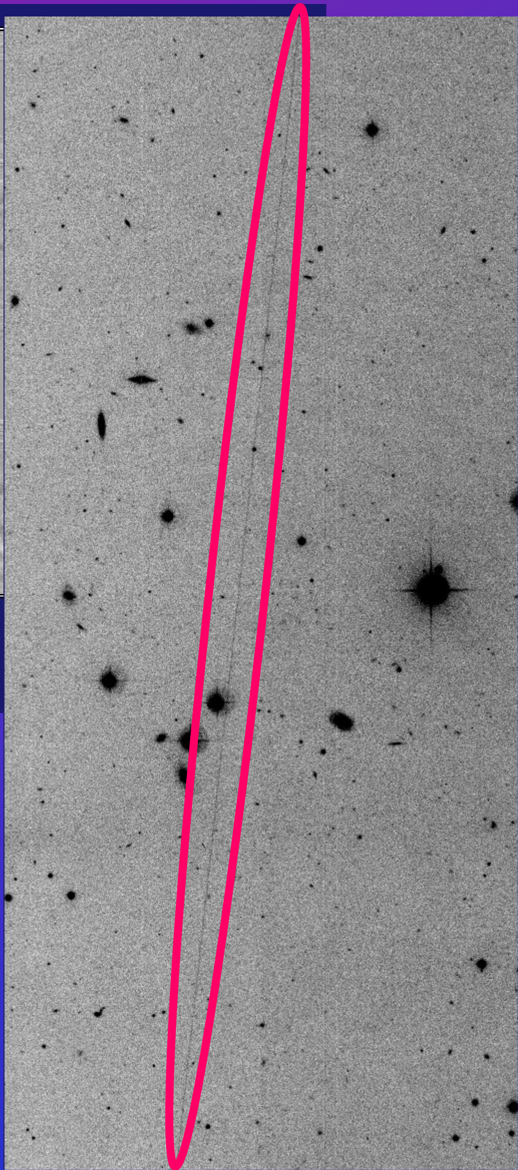
Radon Transform





Radon Transform





ATLAS Status and Schedule

- 2013-01-01:
  - funding start
- 2013-04-15:
  - Senior SW engineer hired, post-doc or JSWE in progress.
  - Request for Proposal out to 12 telescope vendors.
  - Preliminary camera solid models done. Component availability and cost understood (including detectors).
  - First site Mauna Loa Observatory (NOAA)?
- 2013-12-31:
  - Spiral 1 SW full processing of 10^6 PS1 sky probe images
- 2014-08-01:
  - Telescope 1 first light
- 2014-12-31:
  - Spiral 2 SW processing of data stream from Telescope 1
  - Telescope 2 first light
- 2015-12-31:
  - Spiral 3 SW robotic operations of two telescopes

BACKUP SLIDES

ATLAS limiting magnitude

- HATSouth

  mlim = 18.5

  + 1.25 * log(30sec / 240sec)   # Exposure time
  + 1.25 * log(2 / 1)   # Double filt vs single filt
  + 1.25 * log(0.9 / 0.6)   # QE
  + 2.50 * log(40cm / 18cm)   # Telescope aperture
  – 2.50 * log(3.0" / 9.2")   # PSF

  = 20.1

- Pan-STARRS

  mlim = 22.8

  + 1.25 * log(30sec / 80sec)   # Exposure time
  + 1.25 * log(2 / 1)   # Double filt vs single filt
  + 2.50 * log(40cm / 180cm)   # Telescope aperture
  + 1.25 * log(0.70 / 0.62)   # Vignetting
  – 2.50 * log(3.0" / 1.0")   # PSF

  = 19.9

Impactor Distributions

NRC Report 2010

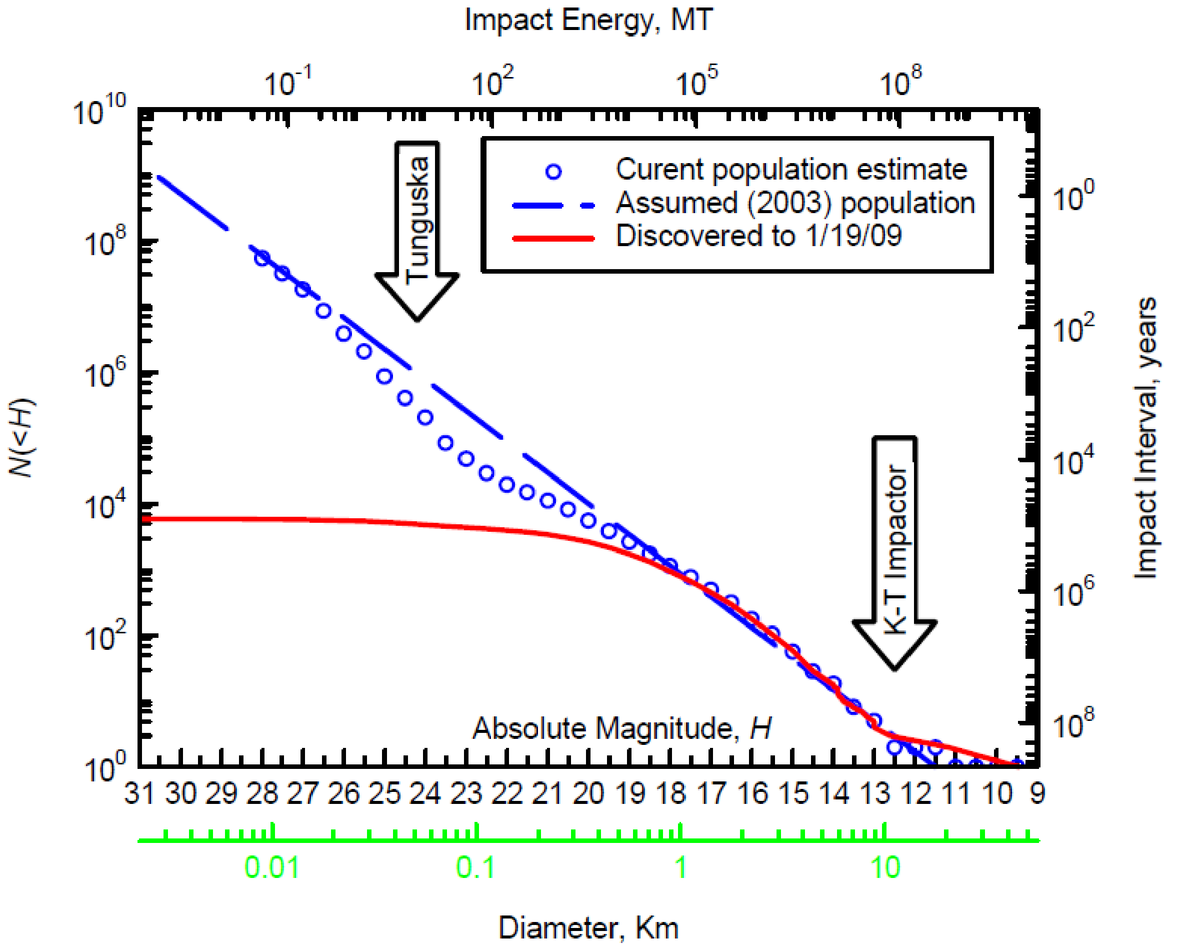
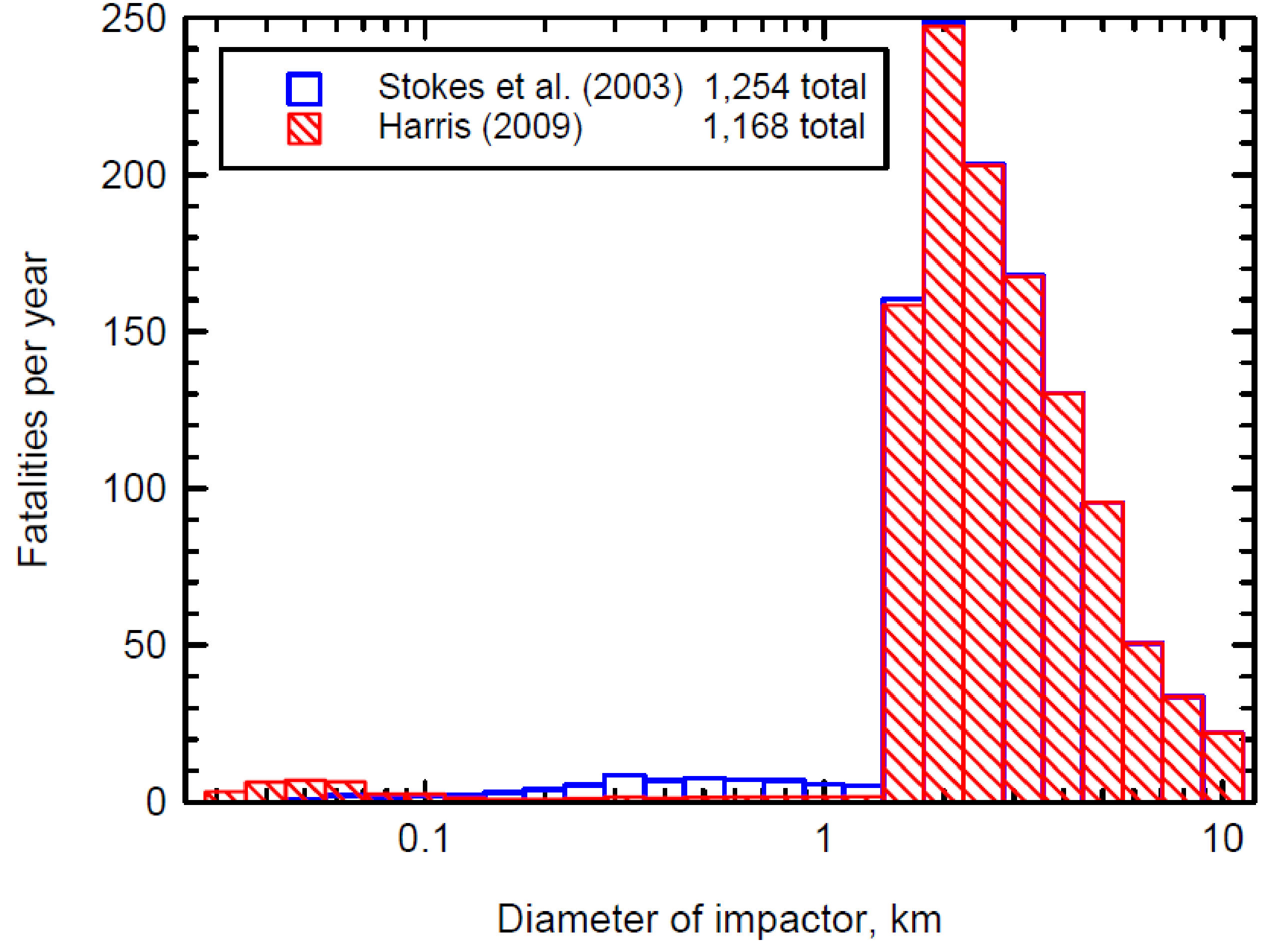


FIGURE 2.4 Numbers, N, of objects brighter than absolute magnitude *H* (see Appendix E) as a function of *H*. Ancillary scales give the average impact interval (right), impact energy in megatons of TNT for an assumed velocity of 20 km/s (top), and NEO diameter determined from the absolute magnitude using 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.

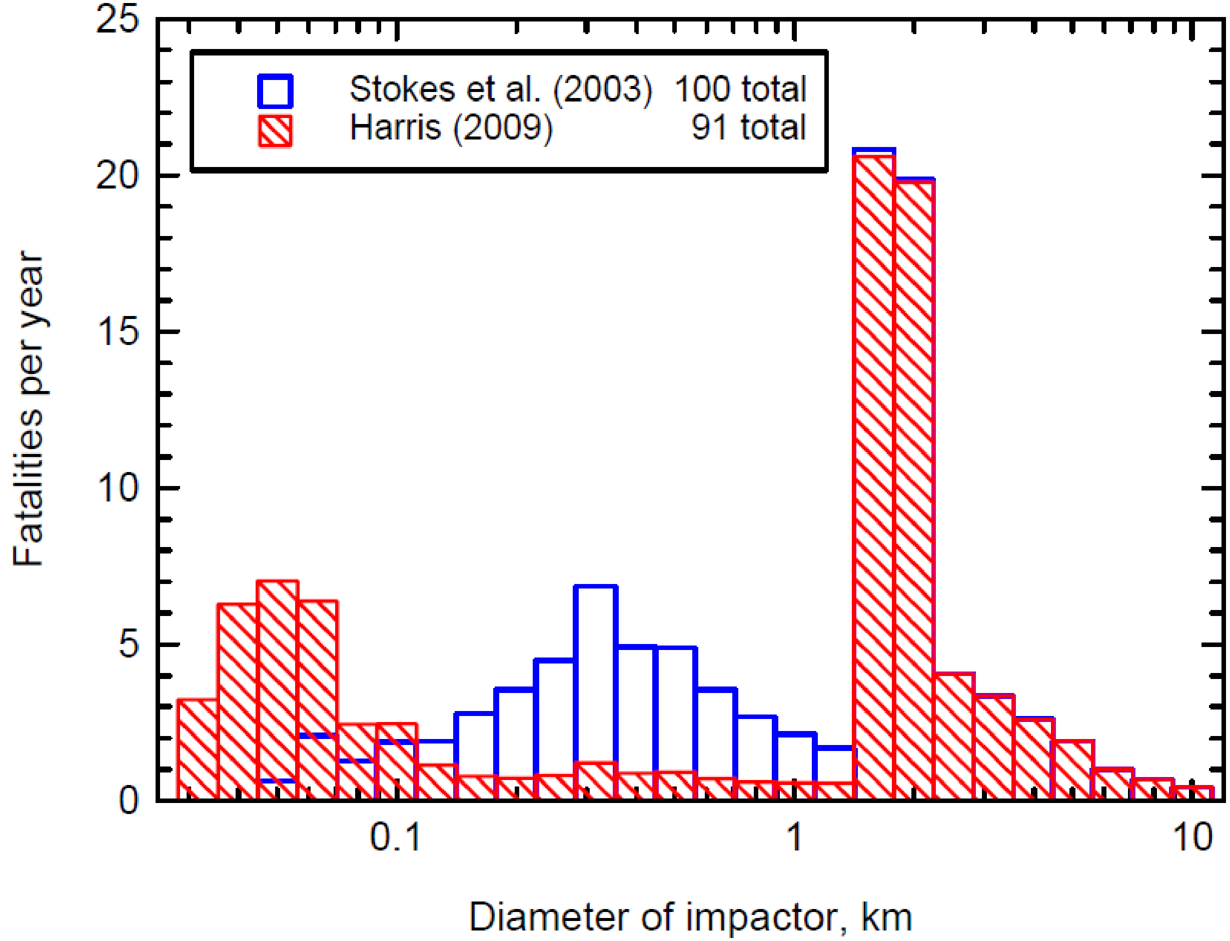
Fatality Rate (pre-Spaceguard)



NRC Report 2010

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.

Fatality Rate (2009)



NRC Report 2010

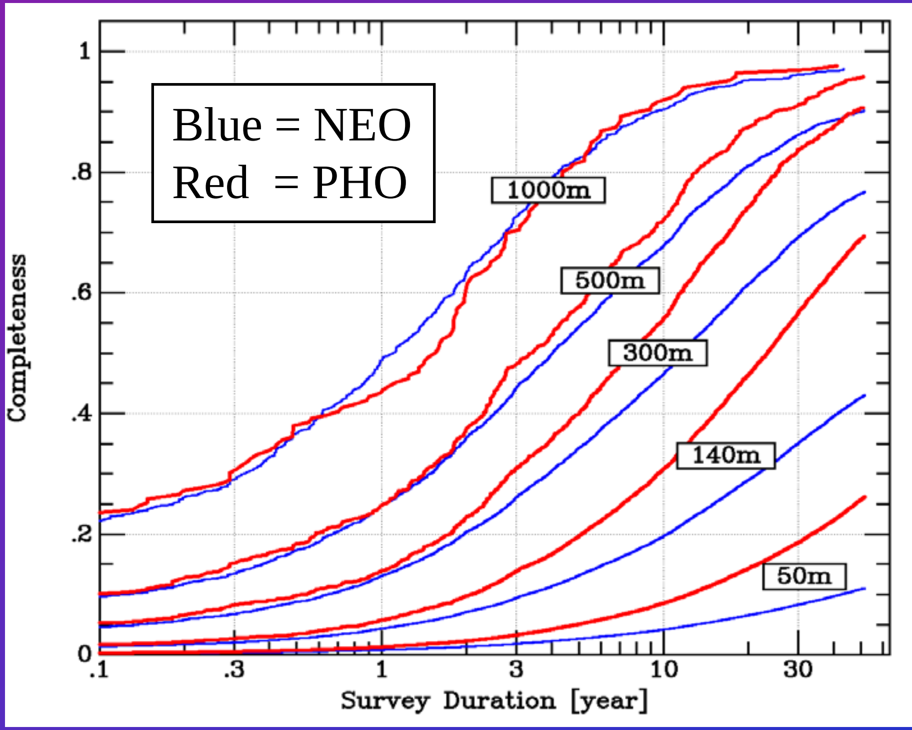
FIGURE 2.7 Estimated average fatalities per year for impacts by asteroids of various sizes calculated for the circumstances after 85 percent completion of the Spaceguard Survey. One curve references the data used in the Stokes et al. (2003) study. The new revised data includes corrections resulting from 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.

Lessons From MOSS

- Finding impactors is different than NEOs
  - On average impactors can be found closer
  - Impactors tend to have higher angular velocities
  - Impactors eventually hit us!
- On final approach impactors
  - Fairly isotropic, but tendency to get hit from behind
  - *Every* impactor is eventually pretty bright!
  - Probability of impactor detection is proportional to how fast solid angle gets covered
  - Warning time increases with sensitivity, $\Delta t \sim 10^{0.2m}$, so 1 magnitude improvement in sensitivity is 60% more warning time
  - Parallax can be useful out to ~30 days before impact: reduces false alarms but fewer tracklets…

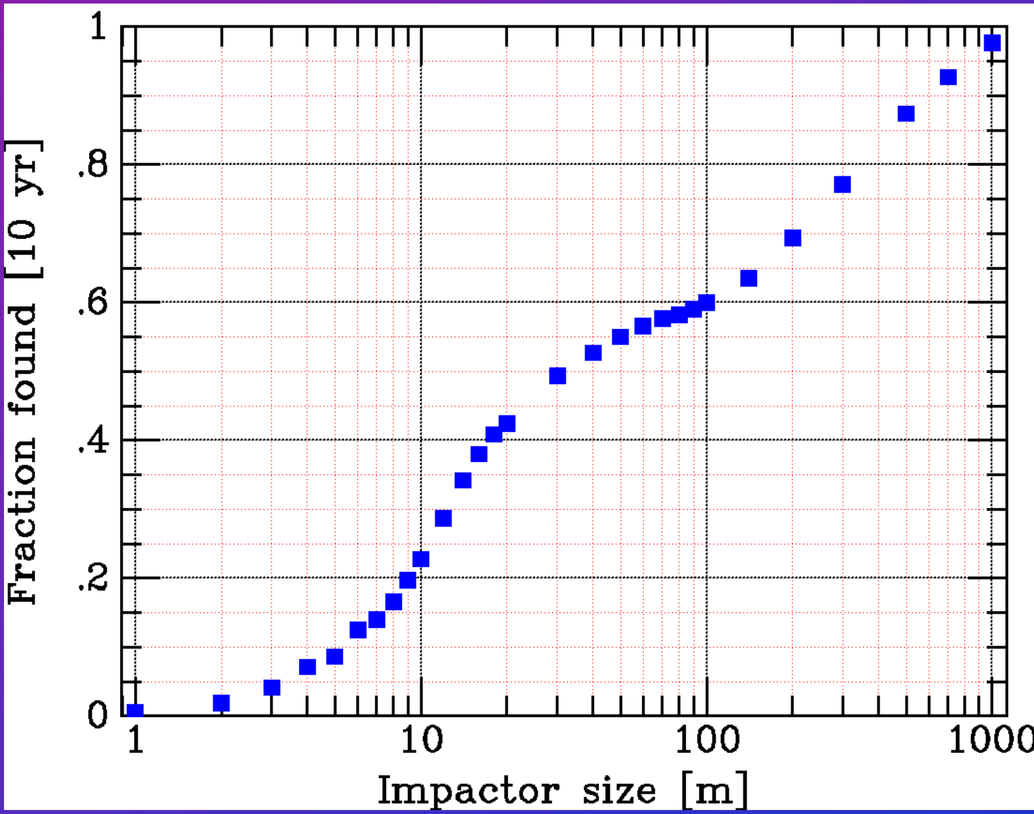
ATLAS NEO/PHO Discovery Rate

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



ATLAS Impactor Discovery Probability

- ATLAS discovery probability depends on size and survey duration
  - Small (~20m) only seen on last day or two.
  - Medium (20-140m) seen for days to weeks before impact.
  - Large (>140m) are often seen on orbits prior to impact.



Asteroid Science

- Light curves
  - With 2 observations at m=18 (25σ), 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.

ATLAS Science

- Solar system
  - ~10^3 NEO/yr, ~10^4 asteroid rotation, etc.
- Stars
  - ~hr resolution light curve of all stars to $m < 19$
- Planets: habitable planets
  - search WD for planetary transits, $\eta_{Earth} < 0.01$
- Gravitational lensing: dark matter, H_0
  - near field microlensing; AGN time delays
- Supernovae: SN properties and large scale flows
  - ~10^4 SNIa/yr, many CCSN, ~10 bright ultraSN/yr
- AGN and black holes: AGN properties and evolution
  - ~hr resolution of ~10^5 AGN to $m<19$
- Gravity waves: because it's there (*surely!*)
  - E&M counterparts to events creating gravity waves

Variable Stars

- Eclipses from planets around white dwarfs
- 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

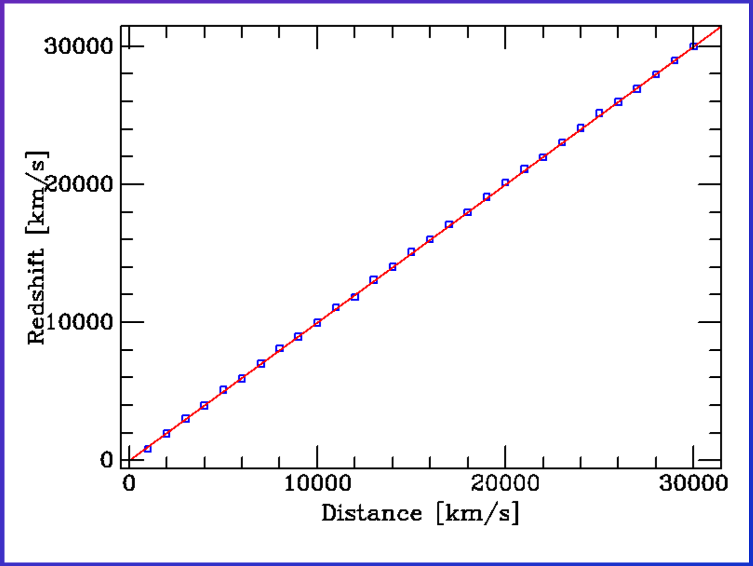
- Type Ia supernovae
  - ATLAS monitors half the sky at all times
    - ~5000/yr at z<0.1 (V<19)
    - ~300/yr at V<17 and ~30/yr at V<15
  - Science includes
    - Peculiar velocities to probe dark matter
    - Nearby anchor for cosmology: dlum(z)
    - Rates
    - Systematics, environments, clusters,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

SNIa per year		
<z	<m	#/yr
0.1	19	5000
0.04	17	300
0.016	15	~30

- 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 25σ and z<0.04

Large Scale Flows

- Use SNIa as standardizable candles:
  - ~10% distance accuracy per SNIa
  - ~1 SNIa each year per $(30\mathrm{Mpc})^3$.
  - Therefore measure the distance of a shell of thickness 1,000 km/s with an accuracy of 100 km/s per year *independent of distance*, limited when systematics dominate (~30,000 km/s?)



  - Independent measure of
    - Monopole (Hubble bubble)
    - Multipole (large scale flows)
  - Need ~20 spectra/night…

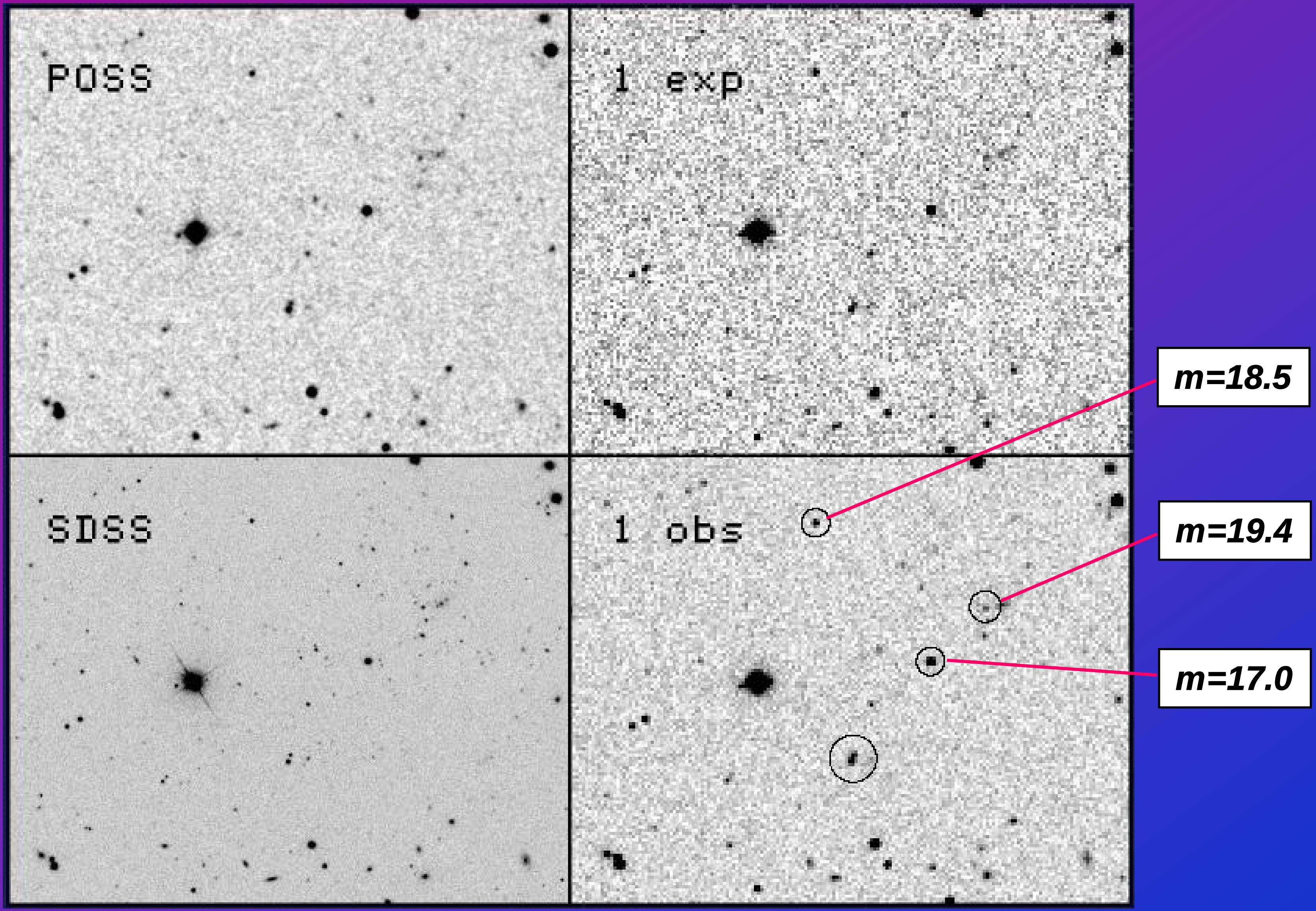
AGN

- 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 5σ
    - ~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-POSS-SDSS Comparison



ATLAS: one year observation

SDSS