Pan-STARRS and the Search for UHECR Sources

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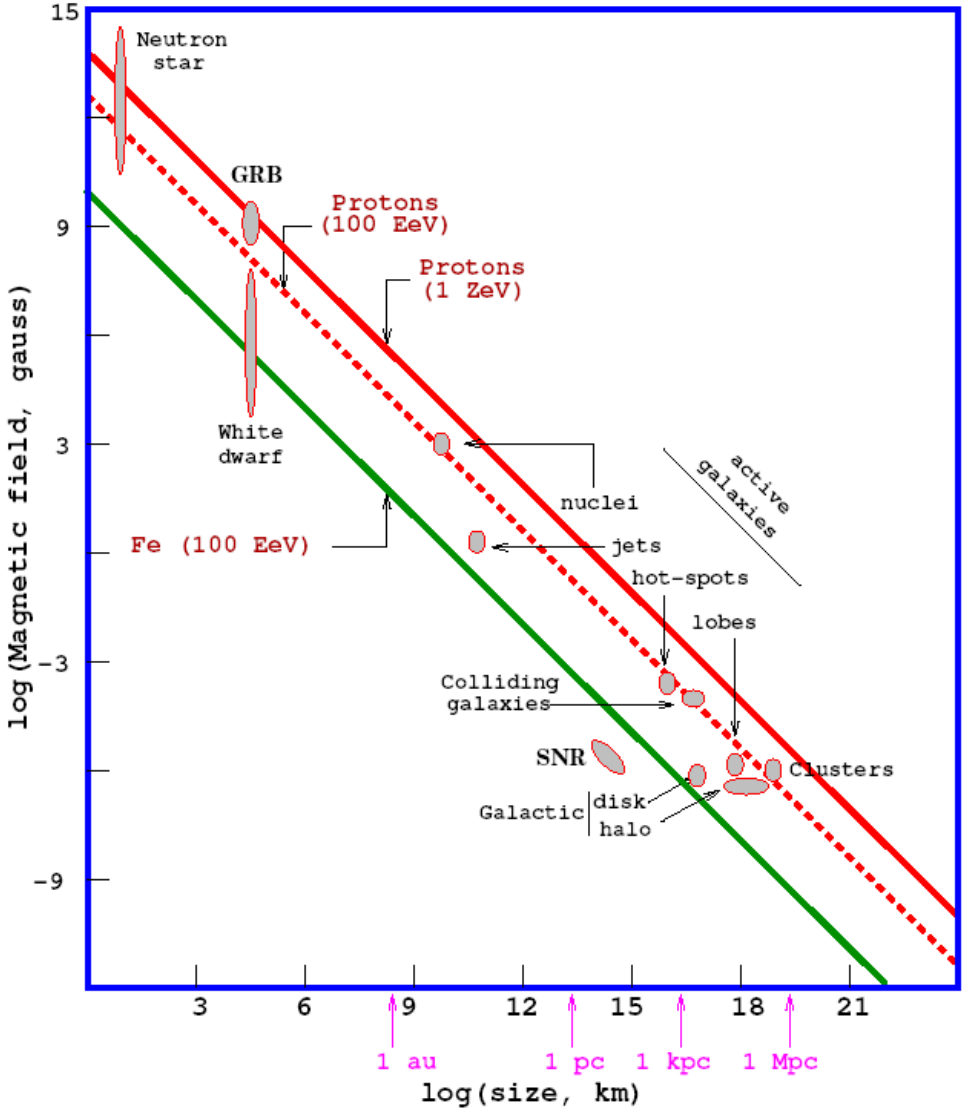
UHECRs: Questions and Challenges

- What are the true energies of the primaries at the highest energies
  - Discrepancies between experiments is narrowing
- What is the true observed flux
  - HiRes seems to have found the clear signature of a GZK falloff
- What is the composition of the primaries
- What is the physical mechanism that generates the primaries
- From where do the primaries originate, e.g., Fermi-type acceleration at shock fronts from
  - SN remnants
  - AGNs/QSOs (including Seyferts, FSRQs, BL Lacs, blazars)
  - Clusters of galaxies

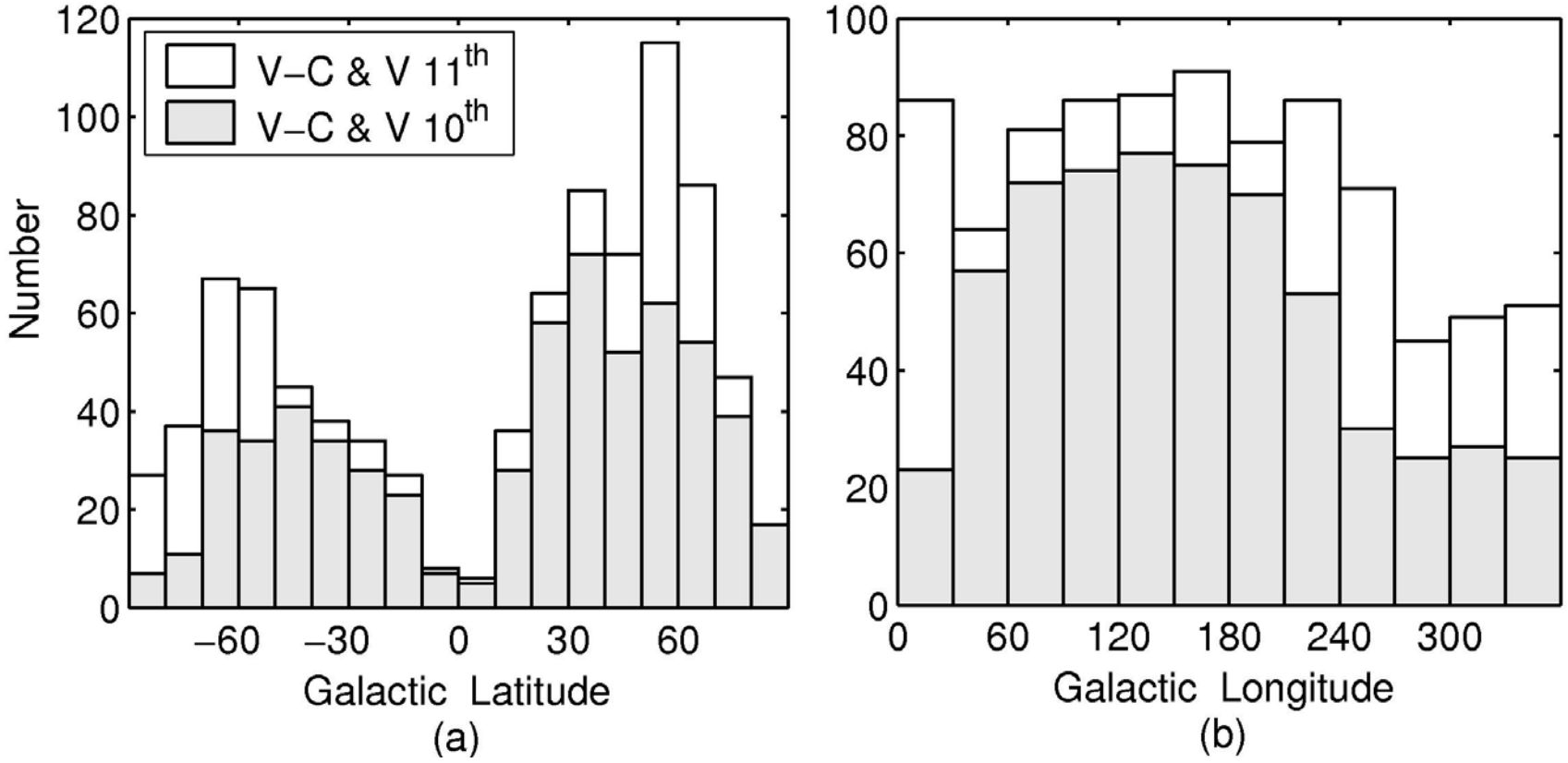
From the Hillas plot, many of the potential source types are objects needing improved/updated catalogs to enable proper analysis; *catalogs that Pan-STARRS will play a major role in advancing*



UHECR Origins: Cross Correlation with Existing Catalogs of Astronomical Objects

- Statistical analysis of possible associations of UHECR arrival directions with candidate objects begins with two critical constraints
  - Angular resolution of UHECR arrival direction
  - Fidelity of catalog of candidate sources
- Propagation of UHECRs much less affected by galactic absorption, so low intrinsic flux/low number of events further hampered by having to cut on gal. lat. when correlating against optical catalogs of candidate sources
- Catalogs of candidate sources are contain features that can significantly limit or bias cross correlation analysis
  - Selection effects such as flux-limited samples, survey boundaries, absorption at low galactic latitudes
  - Catalog completeness and source densities
  - Intrinsic clustering/correlations between the catalog members
- Example: low ang. res. of most UHECR arrival directions (~1°) correlated against an incomplete source catalog $\Rightarrow$ UHECR error circle contains less candidate sources than really exist $\rightarrow$ spurious positive signal

Veron-Cetty & Veron Catalogs of BL Lacs

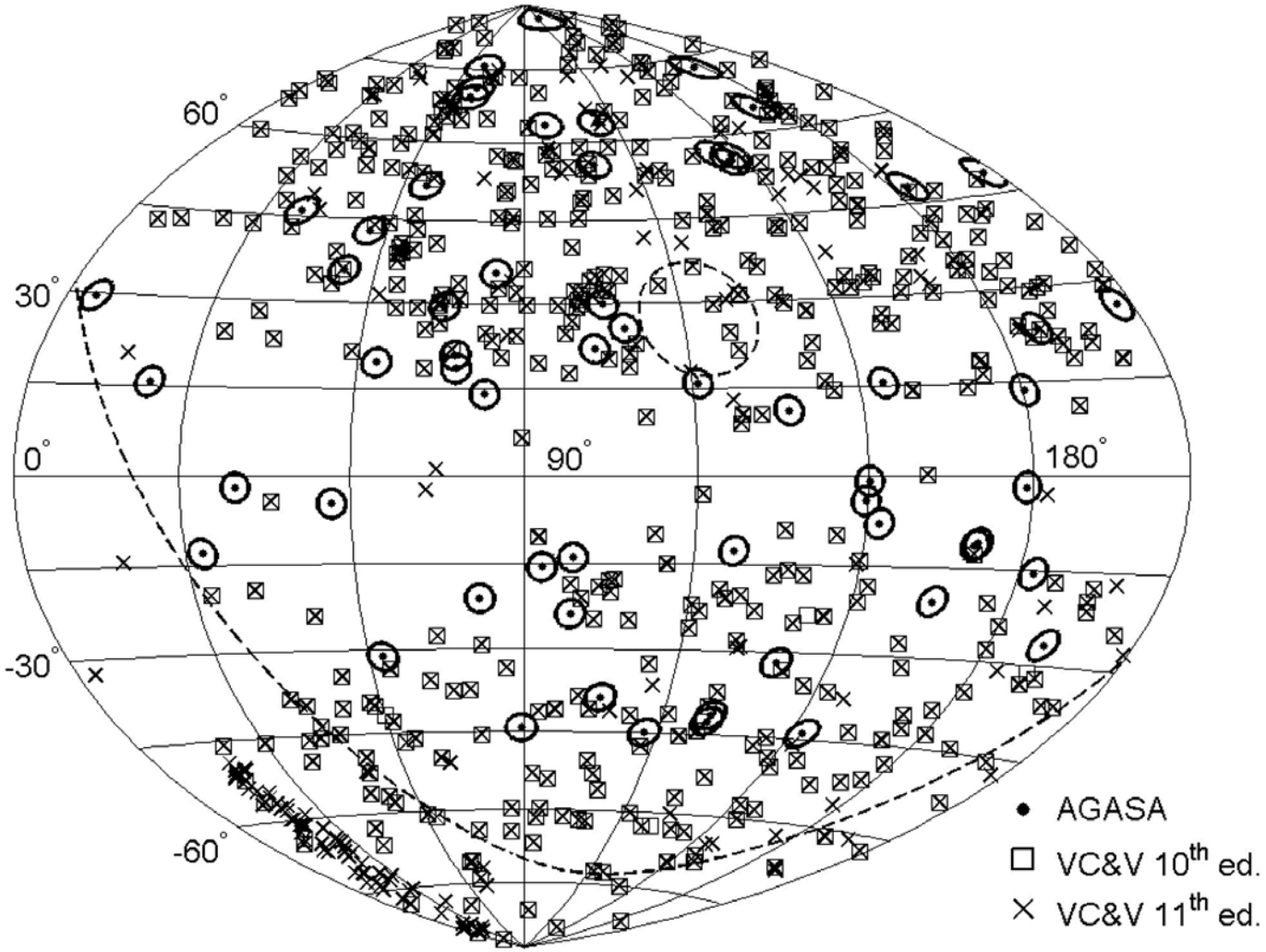


Notes:

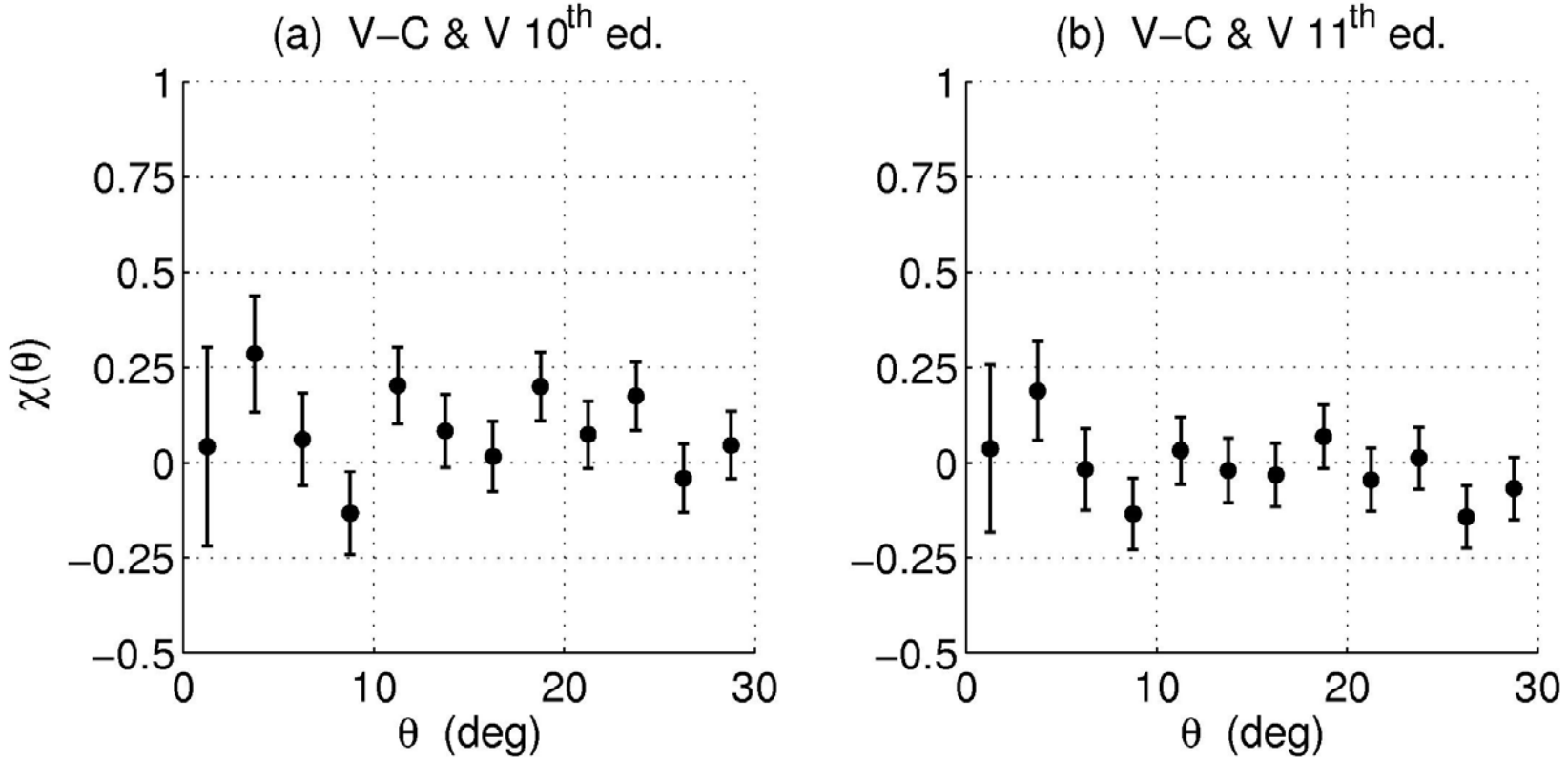
1. Effect of galactic absorption readily apparent in galactic latitude distribution
2. In a complete catalog of BL Lacs, expect the galactic longitude distribution to be uniform, but this is obviously not the case in V-C & V 10th ed.; seems to improve some in 11th ed. (but is an artifact), still obviously incomplete

Searching for Correlation of E > 40 EeV AGASA Events with V-C & V BL Lacs

Note: the main difference between 10th and 11th eds. is the addition of sky *slices* from SDSS and 2dF surveys; SDSS slices not shown here as they lie well outside of AGASA acceptance

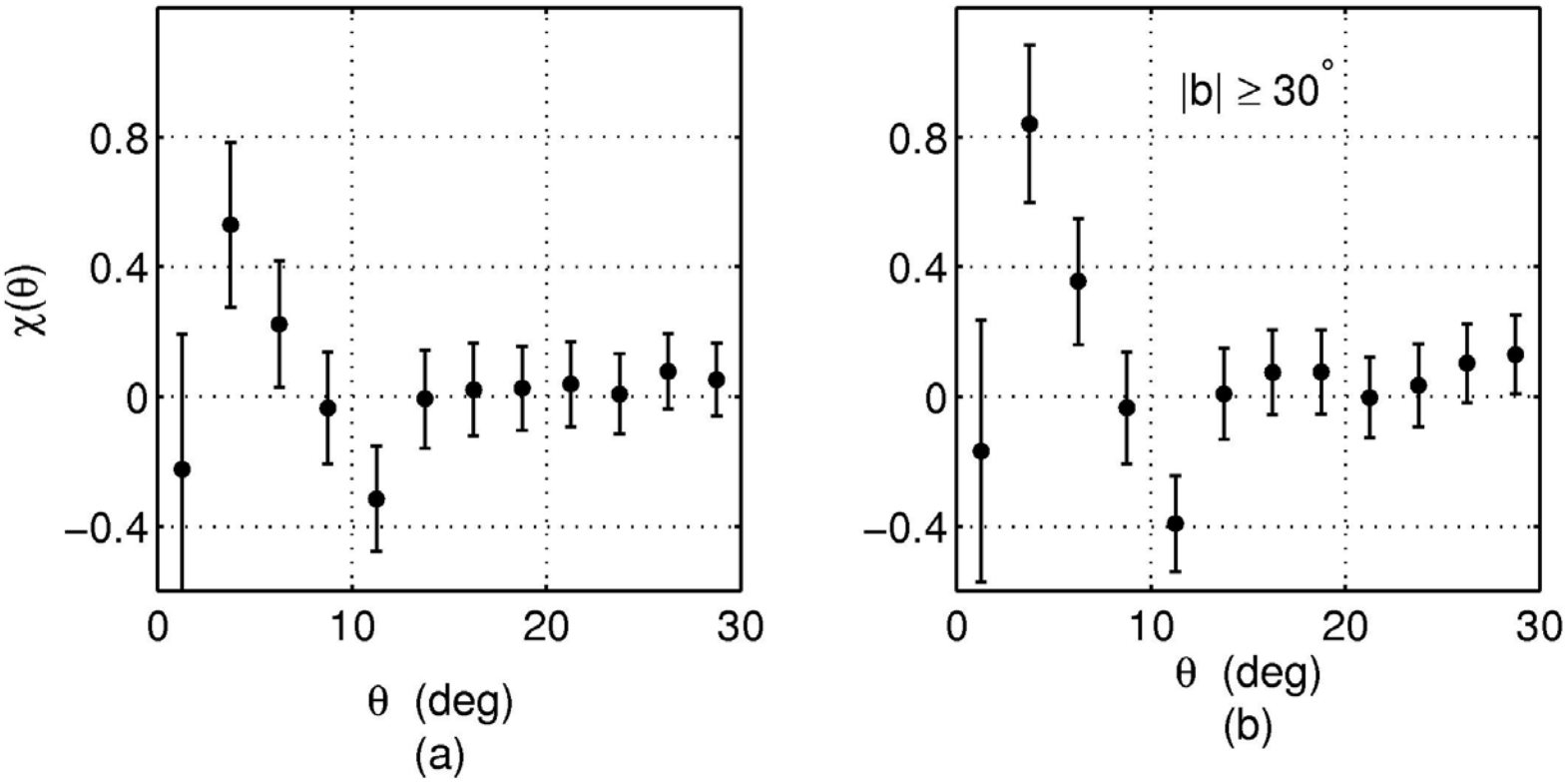


Cross Correlation of E > 40 EeV AGASA Events with V-C & V BL Lacs with $|b| \geq 30°$



No statistically significant correlation, but notice that the slightly higher source density in 11th ed. leads to reduction in cross correlation signal as might be expected

Cross Correlation of E > 40 EeV AGASA Events with DXRBS Blazars



Note: Point in second bin of (b) looks intriguing but probably an artifact (possibly just a binning effect) – but we need more blazars! (new catalog)

Pan-STARRS

The Renaissance of Wide-Field Imaging

- Wide-field imaging (e.g., Palomar, UKST sky surveys) fell into decline with advent of CCDs (high QE, tiny FOV)
- Subsequent decades have seen
  - Exponential growth in area of detectors
  - Matching growth (Moore's law) of computer hardware
  - Major investment in image reduction software
- Current state of the art
  - CFHT/Megacam (3.6m/300Mpix)
  - Subaru/Suprime (8m/100Mpix)
  - Advent of dedicated survey instruments (SDSS, 2MASS …)
- The next step - the NAS Decadal Review LST concept
  - ~ 6m telescope with ~ 7 square deg FOV
  - Scan entire sky to ~24th mag in <~ 1 week
  - Repeated scans -> "time domain astronomy"
  - Stacked images -> "static sky" science

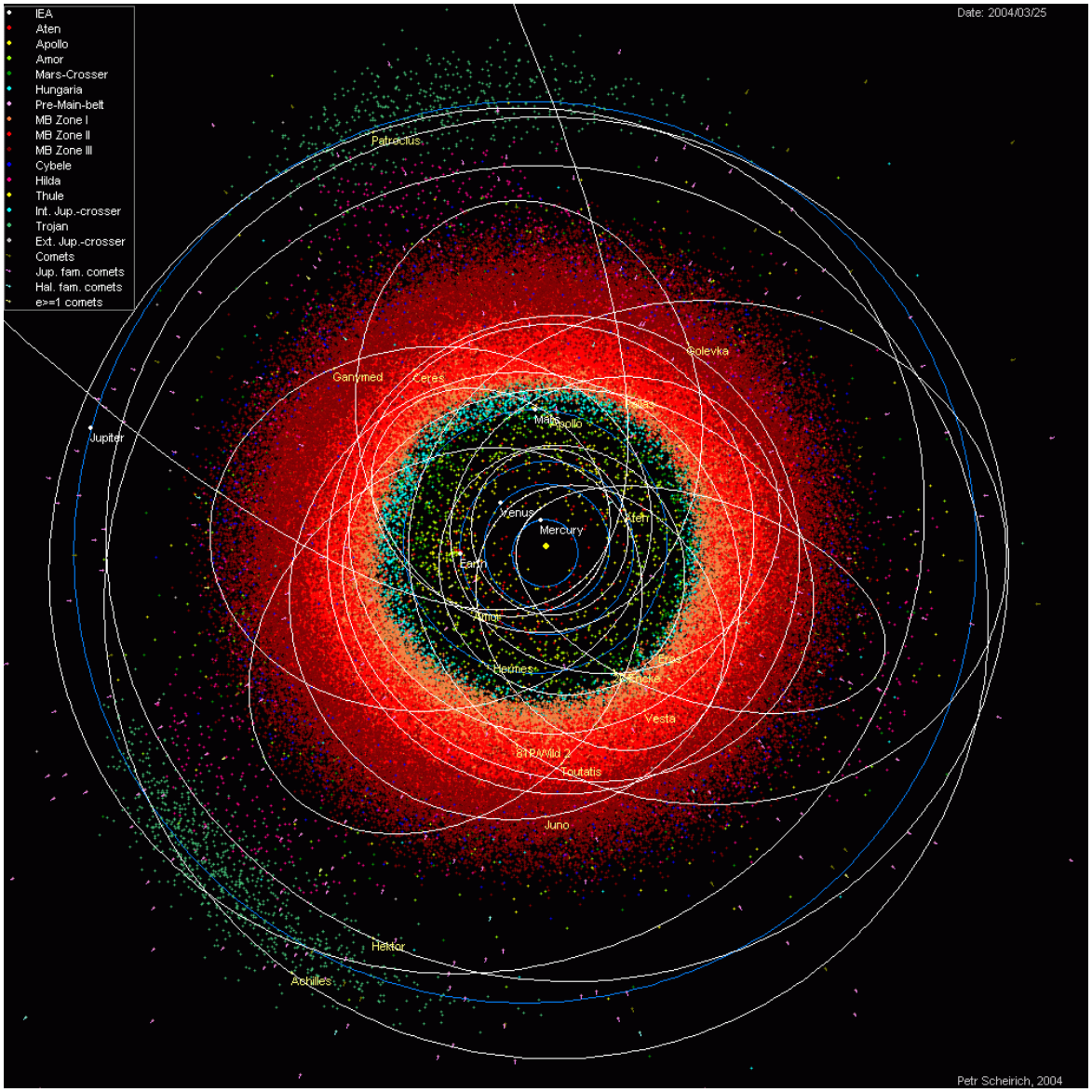
→ ***Pan-STARRS***:

Pan-STARRS Overview

- Pan-STARRS telescope & camera specifications
  - Four 1.8m R-C + corrector ; sited in Hawaii ; A Ω ~ 50 m^2 deg^2
  - 7 square degree FOV; 1.44Gpixel cameras (with 0.26″ per pixel)
  - R ~ 24 in 30 s integration $\Rightarrow$ up to 7000 square deg/night
  - All sky + deep field surveys in *g,r,i,z,y* filters
- Pan-STARRS Science
  - Asteroids (including PHAs)
  - Solar System
  - The Galaxy
  - Cosmology
- Time domain astronomy
  - Transient objects
  - Moving objects
  - Variable objects
- Static sky science
  - Stack repeated scans to form a collection of ultra-deep static sky images

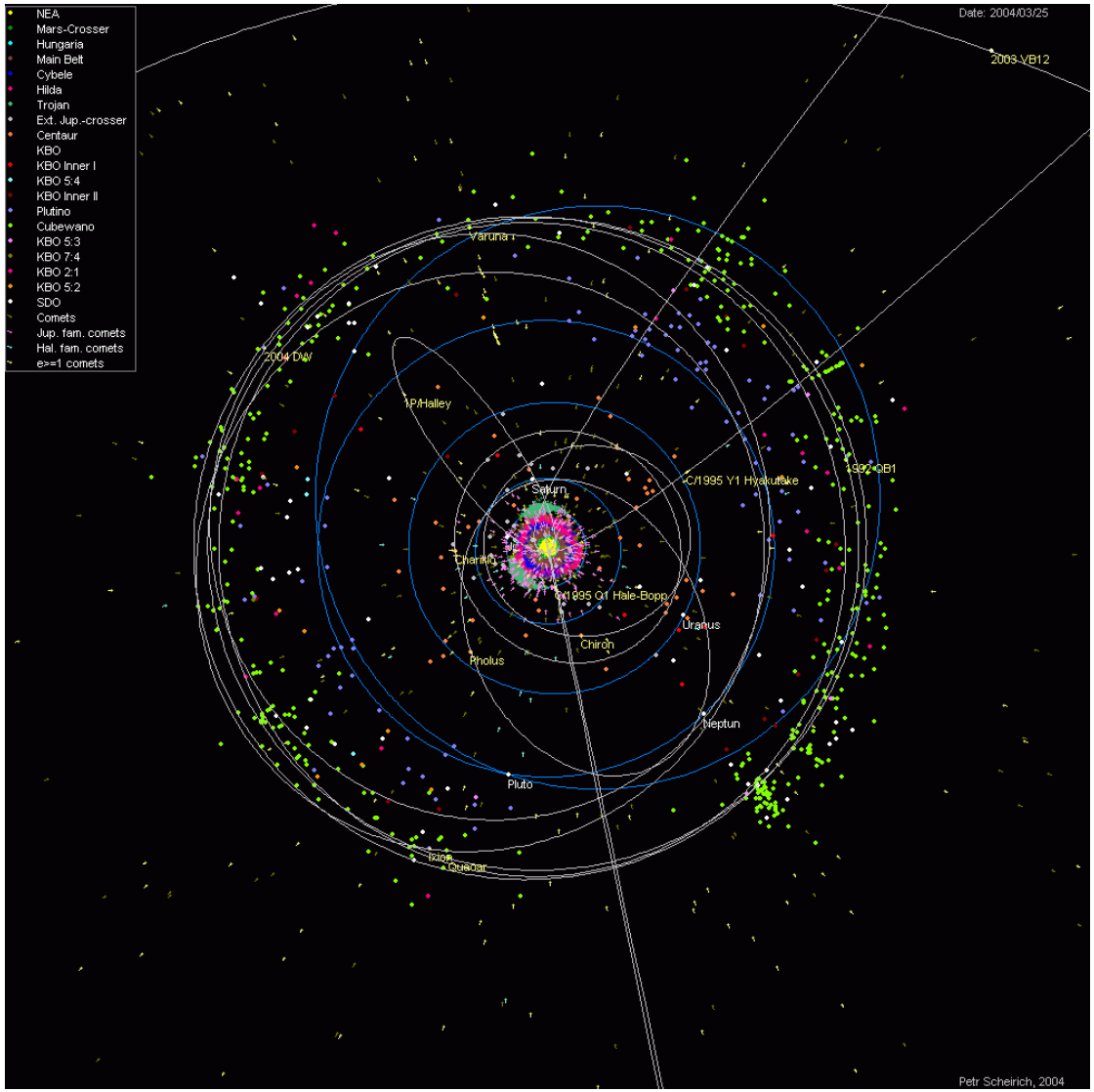
Inner Solar System Science

- ~10^7 asteroids
  - Families
  - Orbit parameter space structure
- ~10^4 near earth objects
  - Phase-space distribution
  - Hazardous asteroids
- Comets

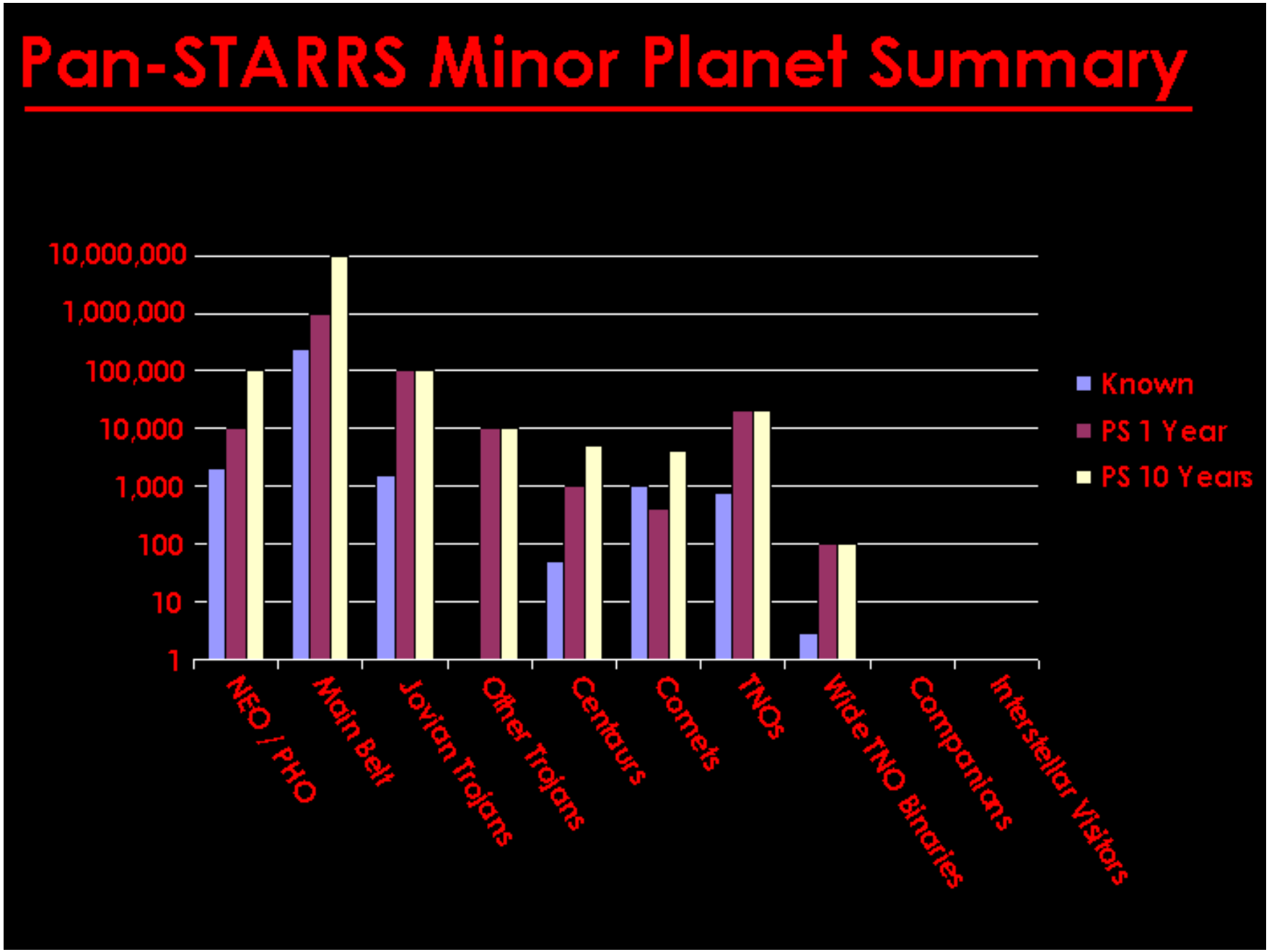


Outer Solar System Science

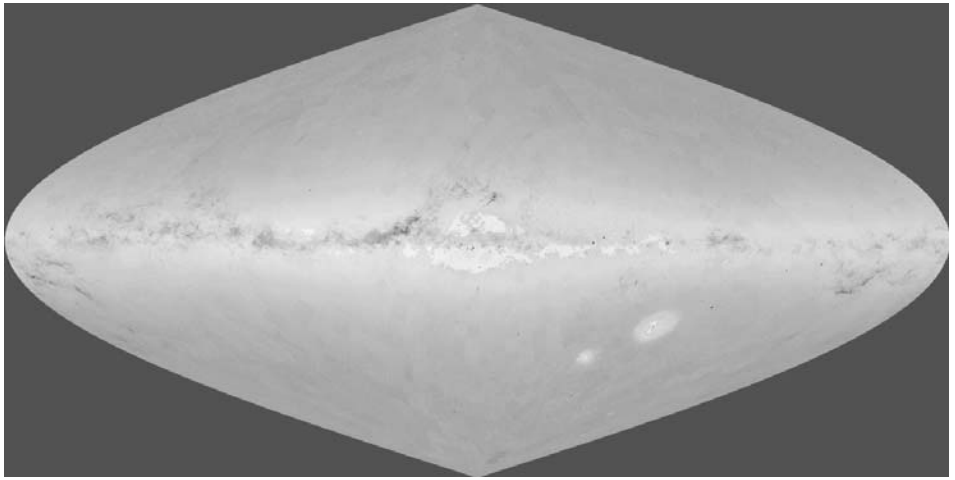
- Trans Neptunian Objects
  - Kuiper Belt formation
  - Orbital distribution
  - Comets
  - Formation and evolution of the solar system
- Interlopers on hyperbolic orbits



Pan-STARRS Minor Planet Summary



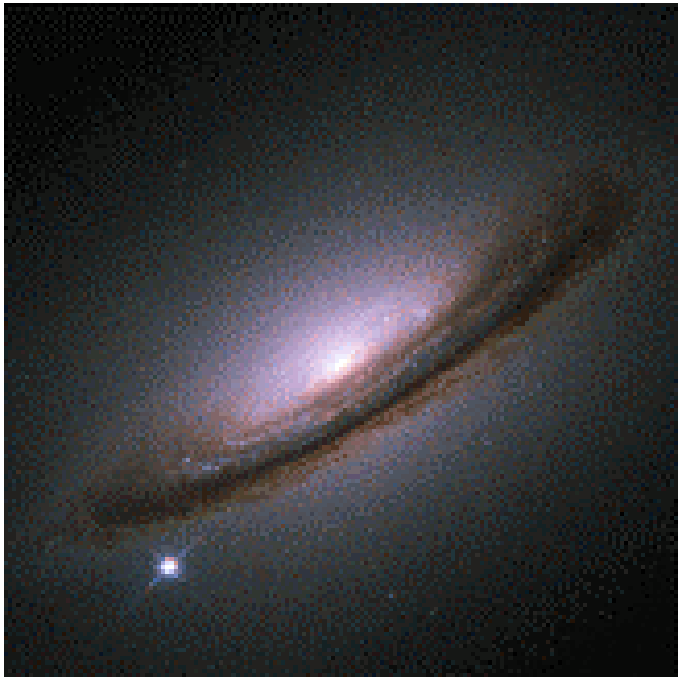
Stars and the Galaxy



- Parallax survey
  - Complete stellar census to 100pc
  - Down to R=24 mag
  - Best substellar IMF available
  - 10-100x more brown dwarfs than SDSS or 2MASS
- Proper motions
  - Proper motions of most stars in the MW : accuracy 2.5 km/s at 1kpc
  - Galaxy formation history, merger tidal tails in halo
- Galactic structure
  - Complete census of RR Lyr and Pop II Cep in halo → density structure, shape and extent of halo/thick disk, dynamical effects of M31 on halo
  - White Dwarfs, K & M dwarfs in thick disk and halo
  - Very faint old disk stars
  - Star counts & colors of inner disk → constrains standard model of Galaxy

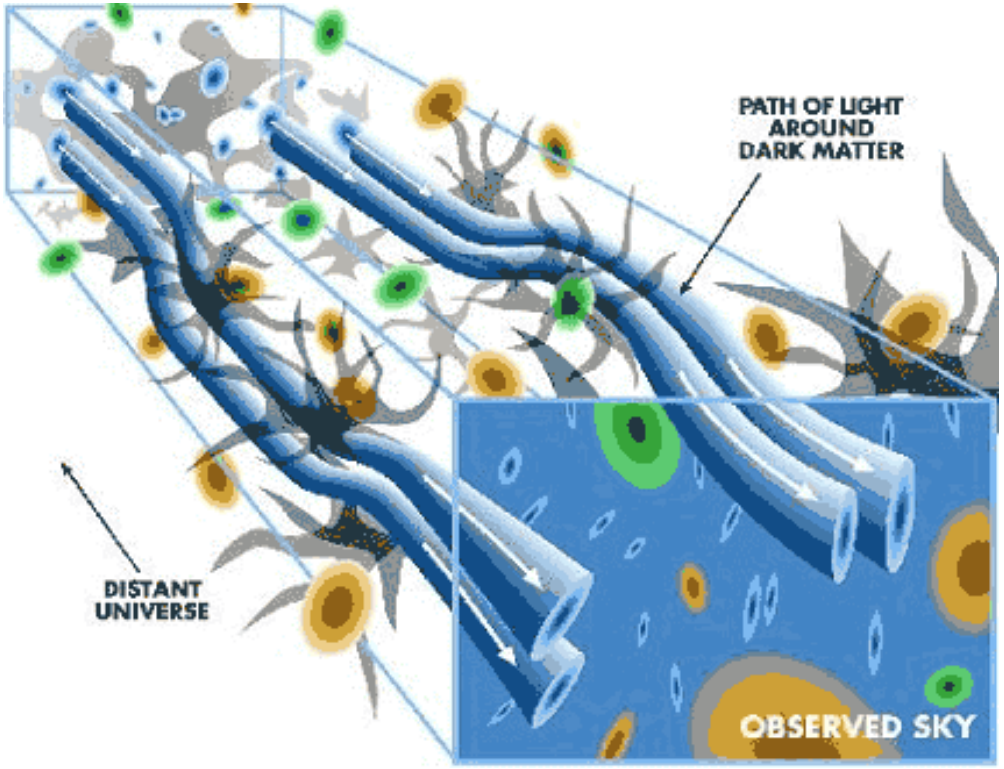
Transient and Variable Objects

- SNE – 10,000's of SNIa to *z*=1
  - Hubble diagram; eqn. of state w(z), measure time (redshift) evolution of dark energy; star formation history and SN physics
- AGN – Dropouts to *z*=7, variability identification
  - Reionization, metals, spheroid formation, nature of radio sources, stellar disruptions, etc.
- GRB – Optical counterparts (~100 per year)
  - Possibly V~8 declining to V~20 in one day
- EXO – Occultations of stars by planets
  - Pan-STARRS is sensitive to Jupiters around sub-solar mass stars or Earths around brown dwarfs.
- VAR – Stellar variability
  - White dwarfs, binaries, Cepheids, Miras, RR Lyrae, microlensing, supergiants, etc, etc.



Static-Sky Cosmology

- Weak Gravitational Lensing
  - Low-k mass power spectrum P(k)
    - Turnover in P(k)
    - Test of inflation theory
  - Evolution of P(k)
    - Probe of w(z)
  - Higher order statistics
    - Gravitational instability theory
  - Cluster mass function
    - Cosmological parameters
  - Geometric tests
    - World model
- Galaxy clustering
  - Galaxy bias
    - Bias vs color, surface brightness, etc.
  - Baryon wiggles
    - Standard ruler -> w(z)



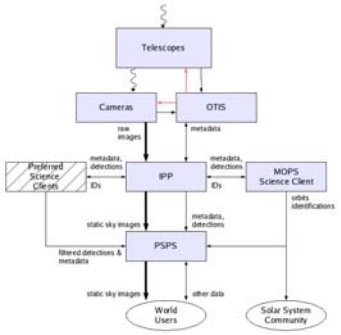
Pan-STARRS PS4/10 yr Science Products

- Sky, the wallpaper:
  - 10 Tpix x 5 colors x N versions
- Sky, the movie:
  - 10 Tpix x 5 colors x 50 epochs
- Sky, the database:
  - 2×10^{10} objects (x 5 colors x 20-60 epochs)
    - Photometry to < 0.01 mag, astrometry to < 5 mas
    - Photometric redshifts of most of these objects
    - Identification and redshifts for *all* galaxy clusters
  - 10^9 proper motions (complete over 3π)
  - 10^8 variable stars and AGN
  - 10^7 asteroids (10^4 NEO/PHA)
  - 10^7 transients (SN, GRB, etc.)
  - 3×10^5 stars within 100 pc (with good parallax)

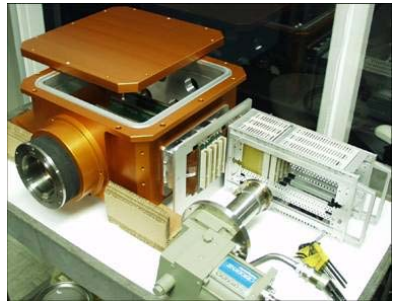
Pan-STARRS Development

Pan-STARRS Development and Evolution

- Development, infrastructure, and testing (2003-2005)

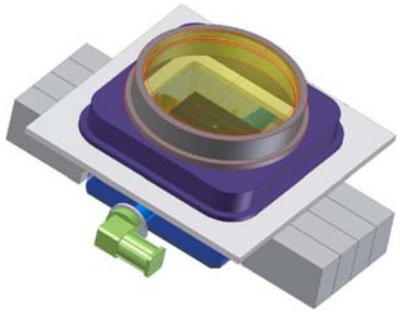


TC 3
360 Mpix

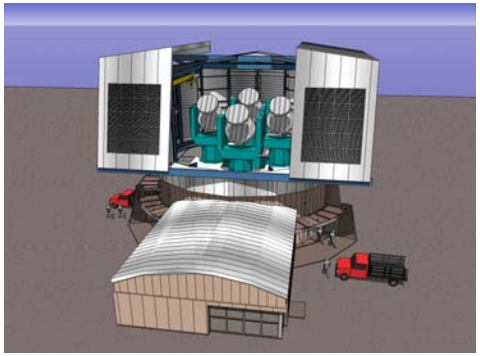


- PS1 Integration and Commissioning 2006
- PS1 Science Mission
  3– 4 yrs (2008-2011)

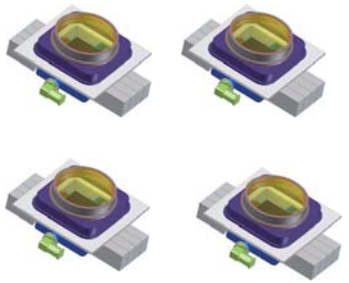
GPC 1
1.4 Gpix



- PS4
  (Development and Construction 2009-2010)

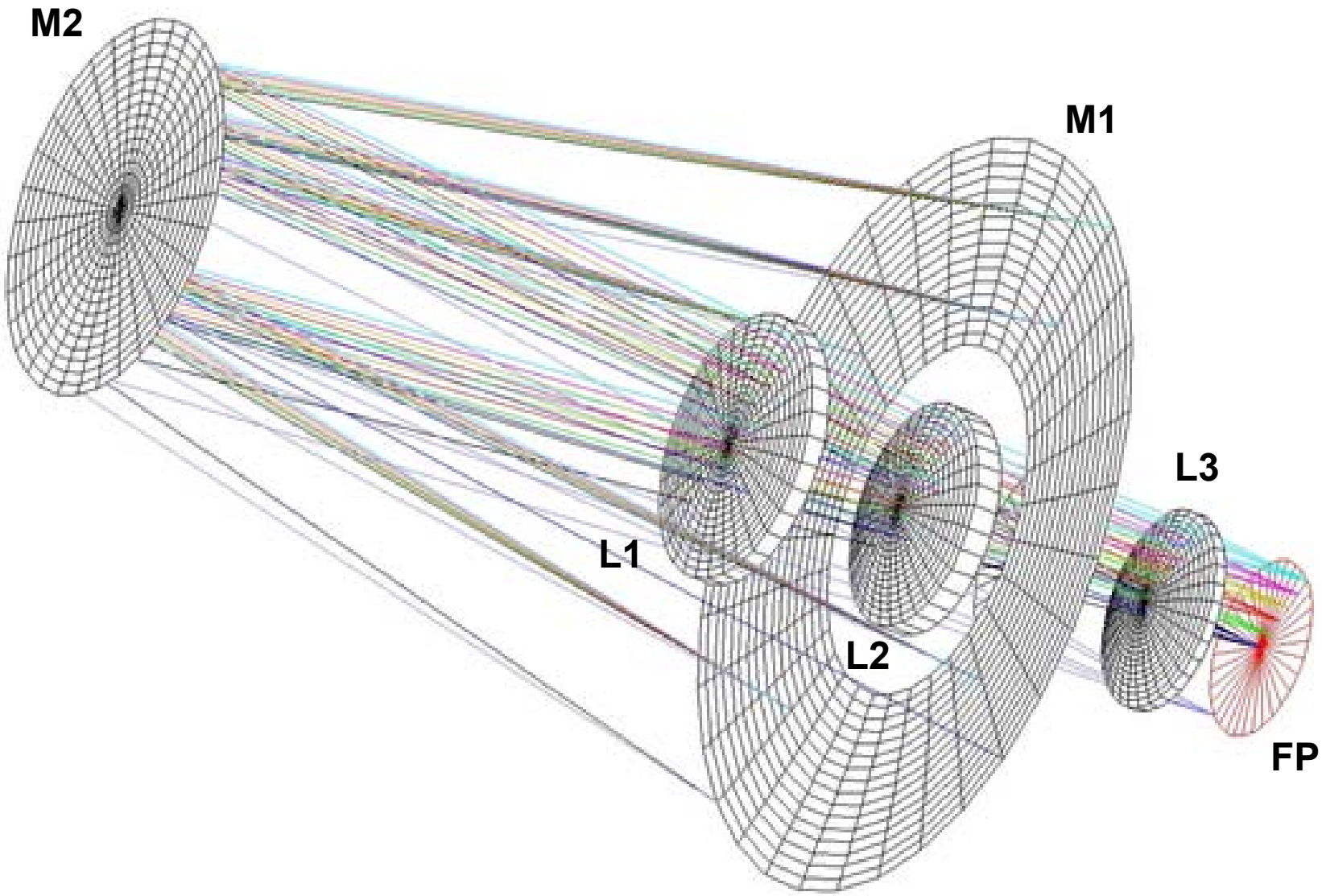


GPC 1, 2, 3, 4
5.6 Gpix

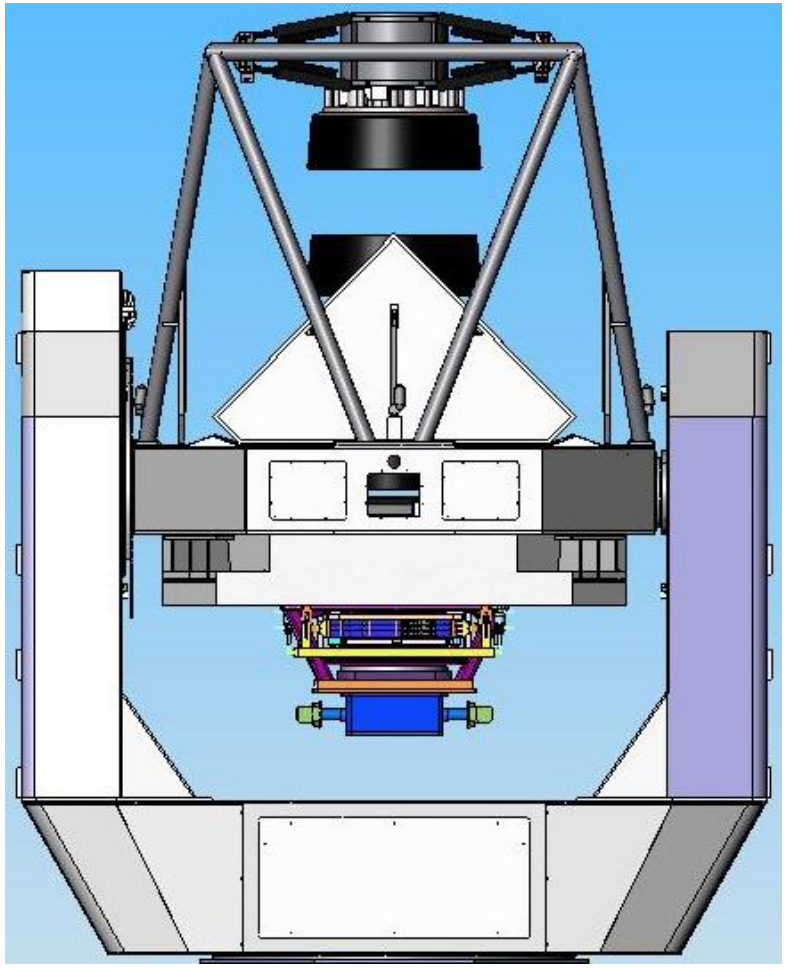


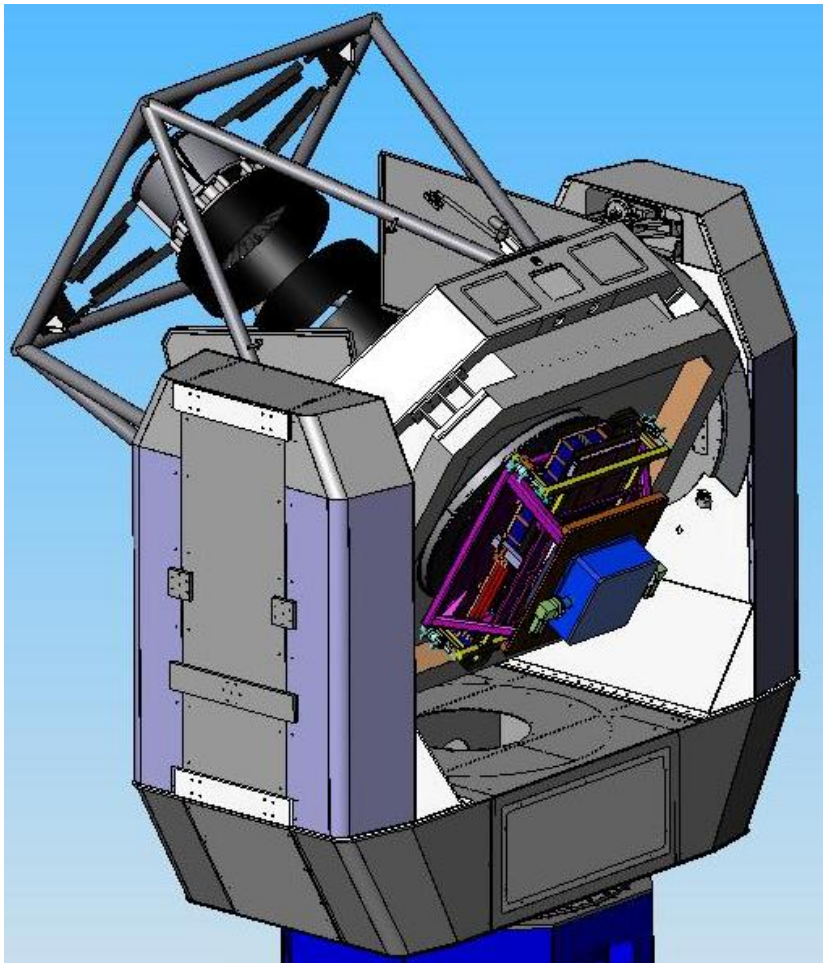
- PS4 10 yr Mission
  (2010 – 2020)

Optics Design – Ray Trace Diagram



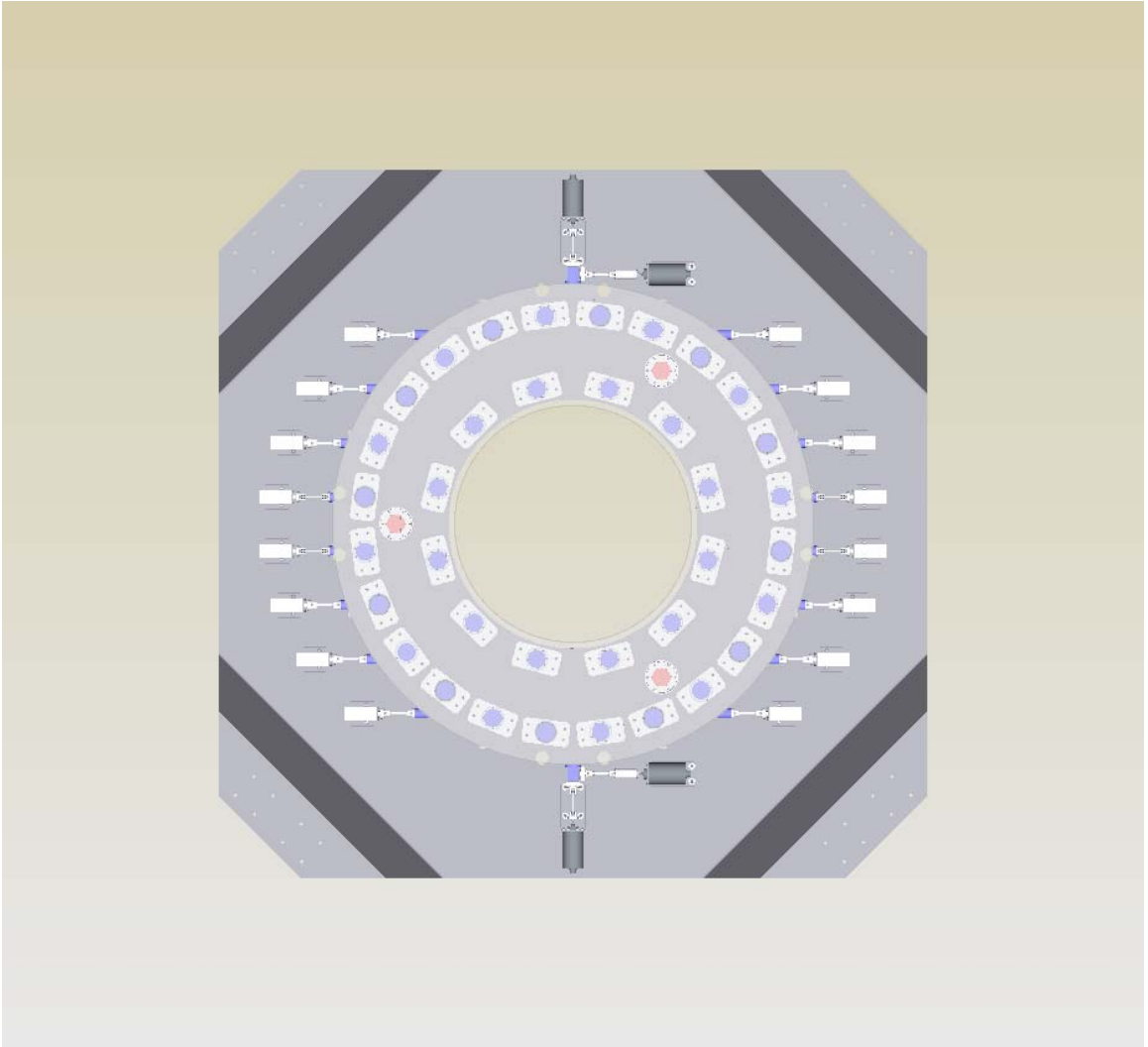
PS1 Telescope Views





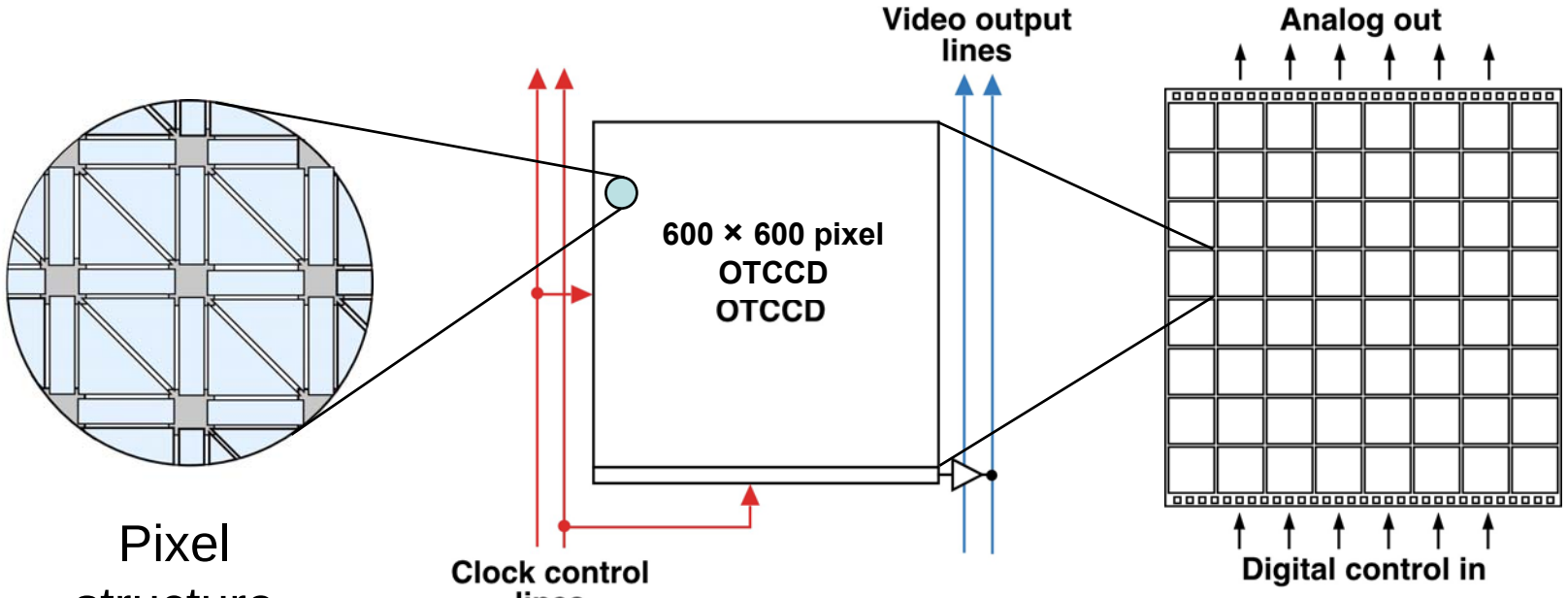
Active Optics Capability

- Secondary has
  x,y,z, tip, tilt
- Primary has
  x,y,z,tip,tilt
  and 36 actuators
  along optical axis
  to correct for gravity
  and astigmatism
- Need to correct
  often to maintain
  image quality over
  large field of view



Detectors: The Orthogonal Transfer Array

- A new paradigm in large imagers.
- Partition a conventional large-area CCD imager into an array of independently addressable CCDs (cells).
- A new pixel design to noiselessly remove image motion at high speed (~10 μsec)

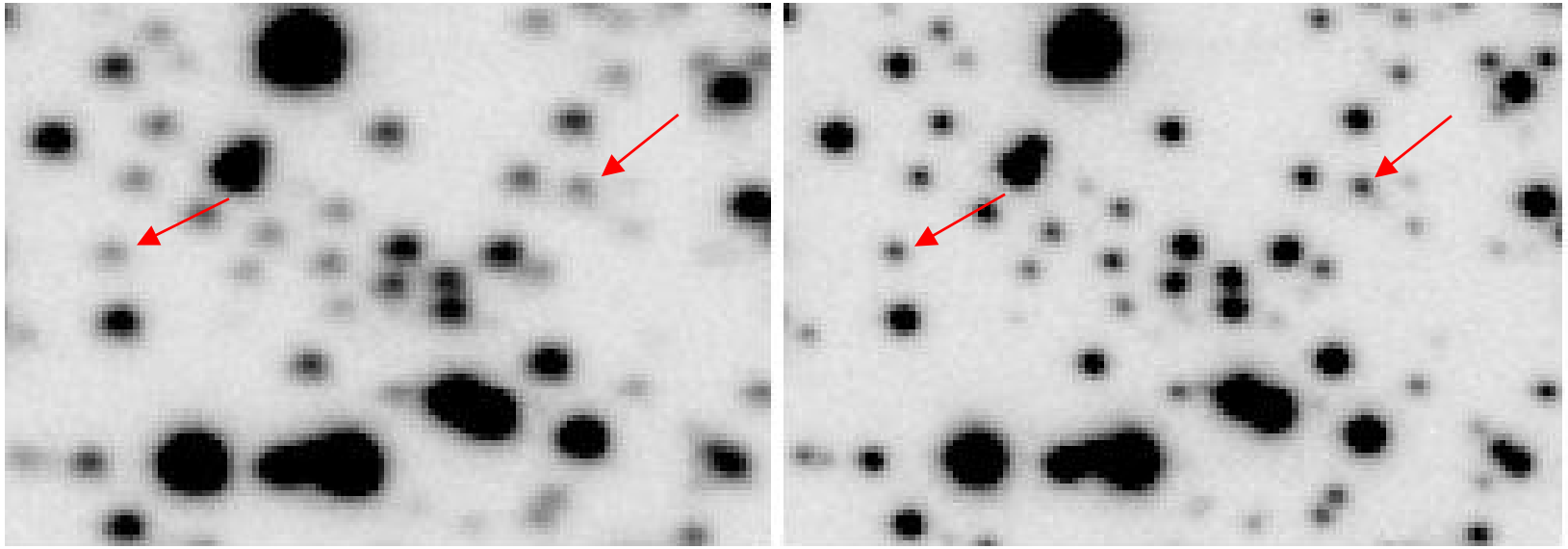


Pixel structure

Independently Addressable Cell

OTA: 8x8 Array of Cells

Orthogonal Transfer Arrays



Notice the increase in source intensity at these two (and many other) points

STARGRASP Controller:
State of the Art Electronics Technology

- SDSU controller
  - 8 channels = 1 OTA
  - 500 kpix/sec
  - 100W power

- STARGRASP controller
  - 16 channels = 2 OTA
  - 1000 kpix/sec
  - 25W power

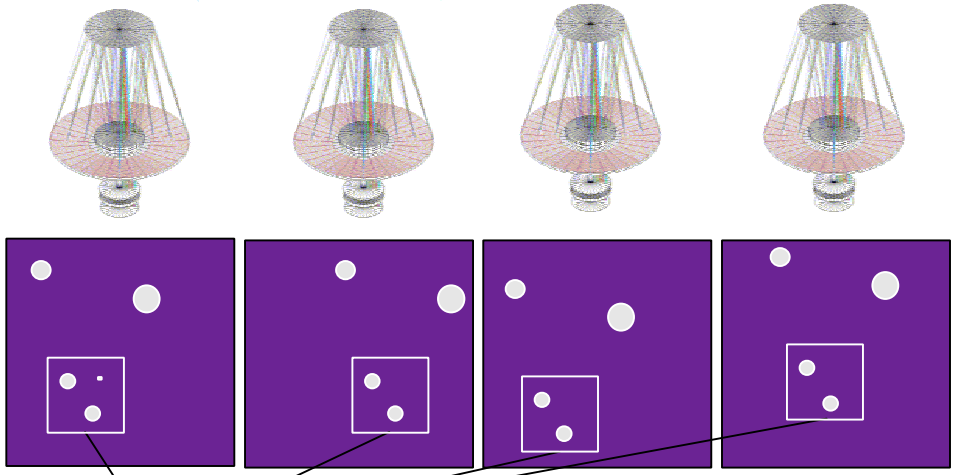
Control/Reduction of Systematics

- Photometric Calibration
  - Absolute calibration of detectors in the lab
  - Daily total system throughput via calibration screen
  - Imaging Sky Probe (grizy)
    - Monitor extinction/transparency Tycho stars
    - Night sky emission
  - Spectroscopic Sky Probe
  - Atmospheric Dispersion Compensator (crowded field photometry)
  - Photometric and astrometric standards catalog

- Point Spread Function/Shape Measurement
  - Real-time wave-front curvature sensing for control of optical surfaces
    - 5DF secondary + 12 actuators for M1 deformation
  - Orthogonal transfer fast guiding
  - Image multiplicity
  - Atmospheric Dispersion Compensator (eventually)

Real-Time Image Analysis

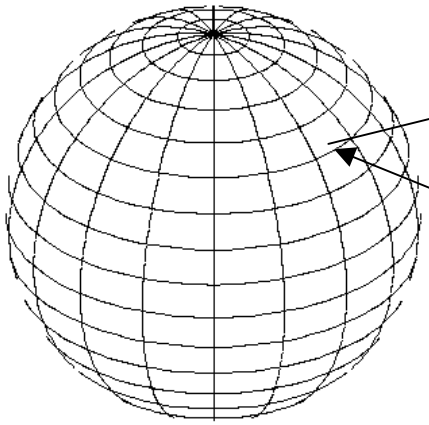
PS1 : N sequentially
PS4 : 4 simultaneous



raw
stacked
image

-

The Static Sky



static
sky
image

+

Image Combine
&
Image Difference

difference
image

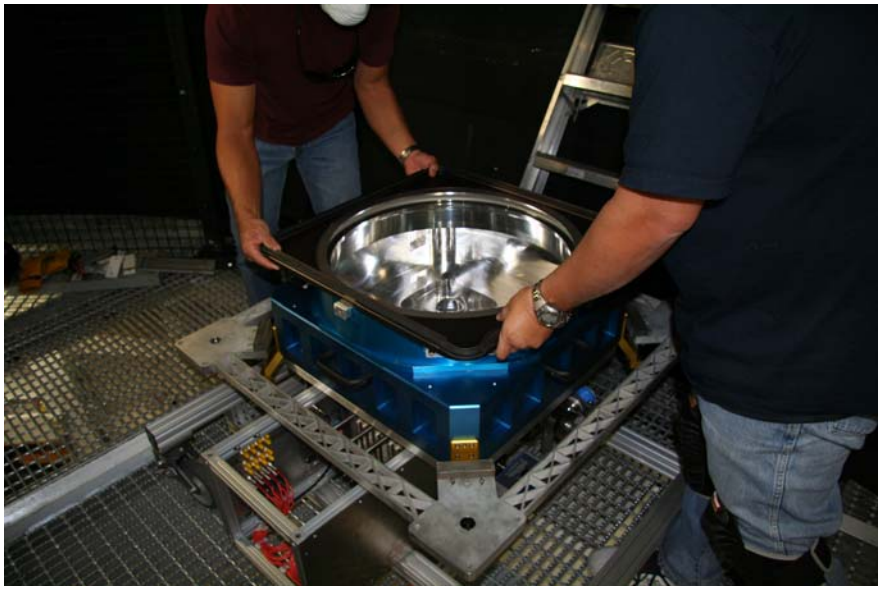
Cleaned stacked image

PS1

Haleakala High Altitude Observatory Site
(before PS1)

PS1 Facility as of June 2006

¼ Scale Test Camera 3 Installation, Feb. 2007



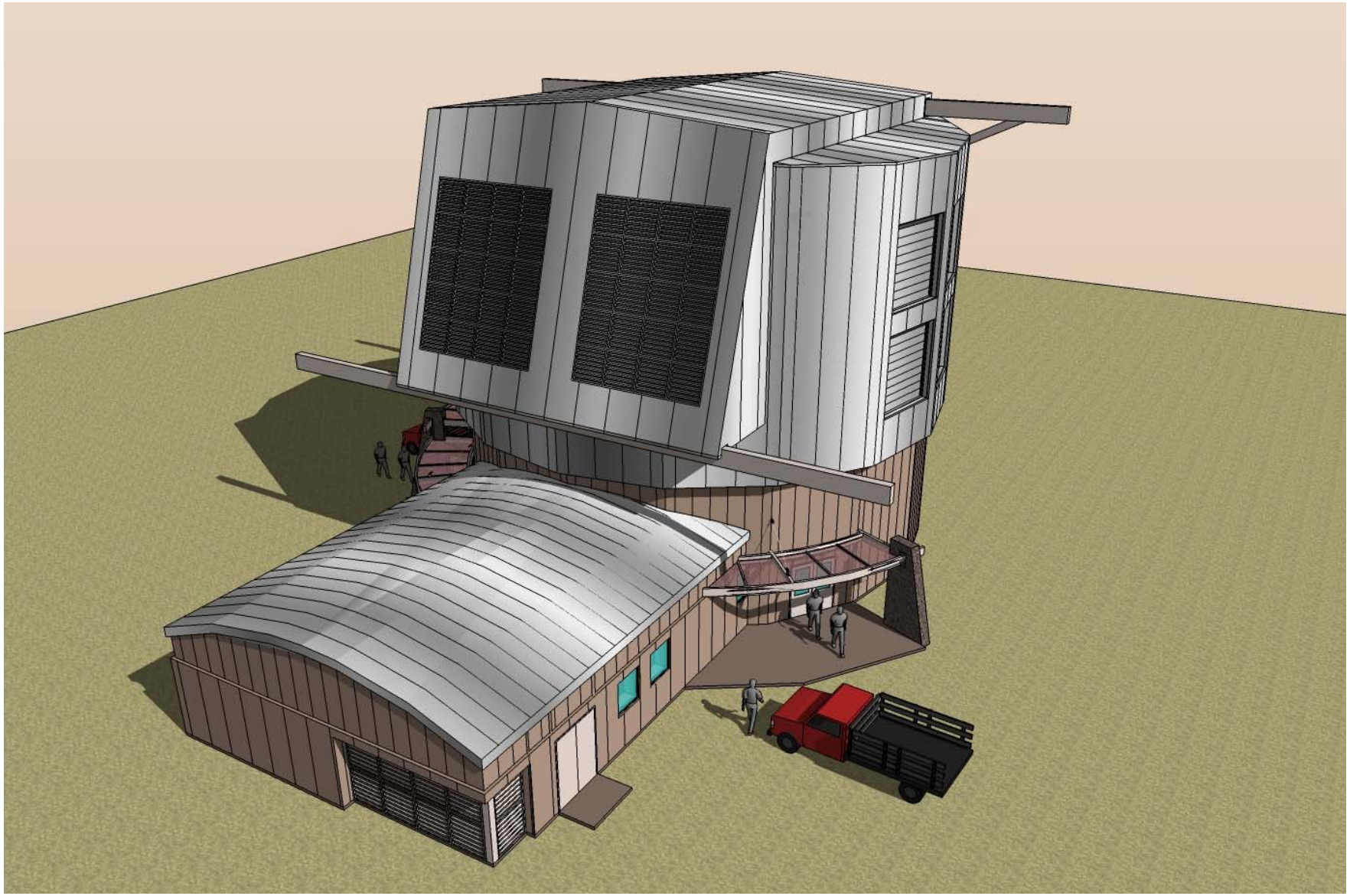
Current PS1 Commissioning Schedule

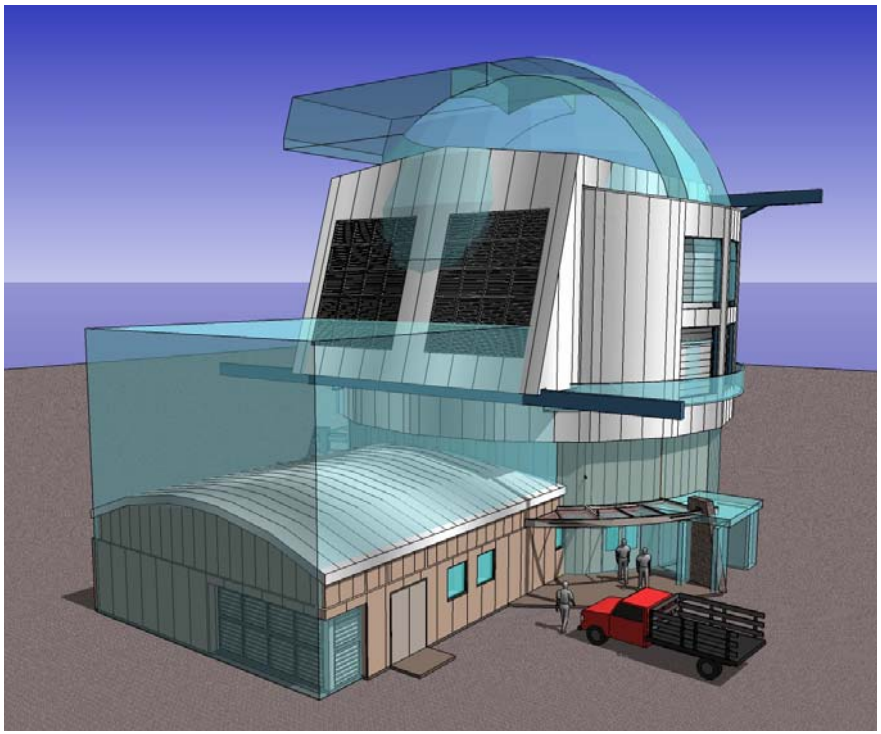
- Feb 07: quarter-scale focal plane (16 OTA TC3) on sky, TC3 Run 1
- Apr 07: complete telescope integration of M2a, L1, L2, L3, FM, shutter, TC3 Run 2
- Apr 07 thru May 07, checkout of optics/filter/shutter, testing including continued refinement of tracking & pointing models, guiding, OT shifting, controller readout
- Jun 07: PS1 summit system completes integration including 64 OTA GPC1 on sky
- Aug 07?: IPP connection completed from summit to MHPCC; calibration system installed at summit
- Jun 07 thru Oct 07:
  - Subsystem engineering commissioning completes for Tel, Cam, IPP, OTIS
  - System level commissioning ("Pre-operations") begins; checkout of scheduling & queueing tools; test network and communications, complete IPP testing, establish cadences and conduct test survey strategies, test Moving Object Processing SW,collect calibration and initial science data, image quality and data validation analysis; (hopefully) finalize control room setup & training/participation of ops staff
- 15 Nov 07: ORR

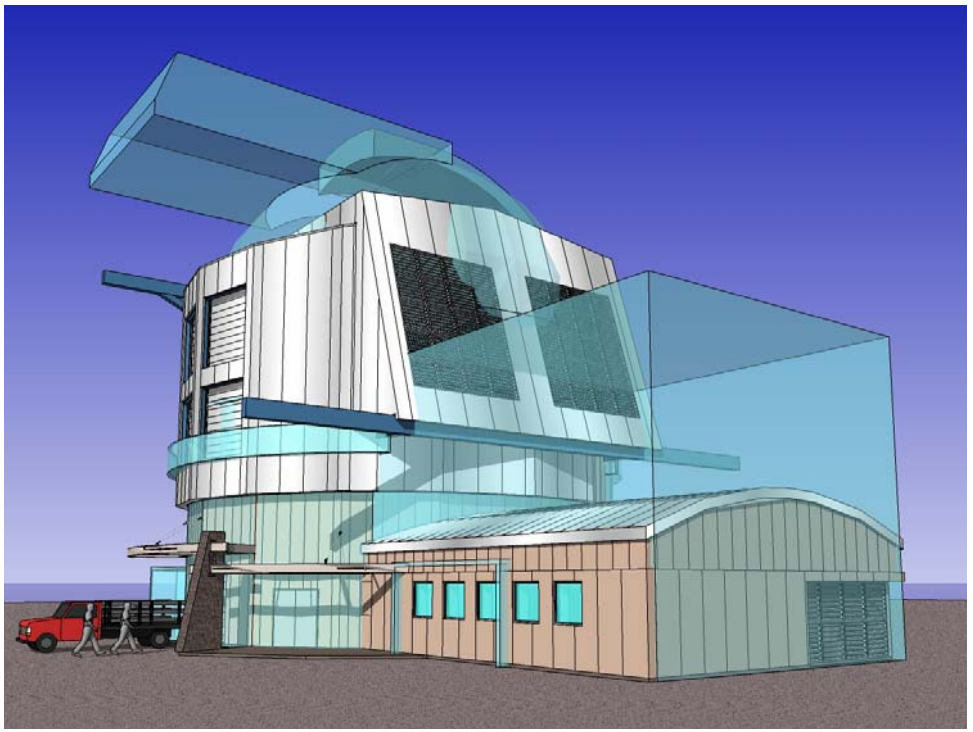
PS4

Potential Mauna Kea Site for PS4 (4 Pan-STARRS telescopes)

PS4 Enclosure Design Concept







Pan-STARRS and UHECR Candidate Sources – Recap

- 1000's of SNe and GRBs from PS1 and PS4, correlate in time with neutrino, gamma, and cosmic ray detectors

- AGNs/QSOs will be identified by Pan-STARRS that with dedicated follow-up will significantly increase catalog completeness and enable a new level of precision cross correlation (in tandem with continuing increases of particle detector resolution of arrival directions

- Galaxies and Clusters of Galaxies over 3π of the celestial sky, to depth several hundred Mpc (many, many times radius of GZK sphere) ***and*** to much lower galactic latitudes (should be reasonably complete down to $|b| \geq 10\text{-}15°$ (compare to Abell catalog which drops very sharply at $|b| < 30°$

Thank You!