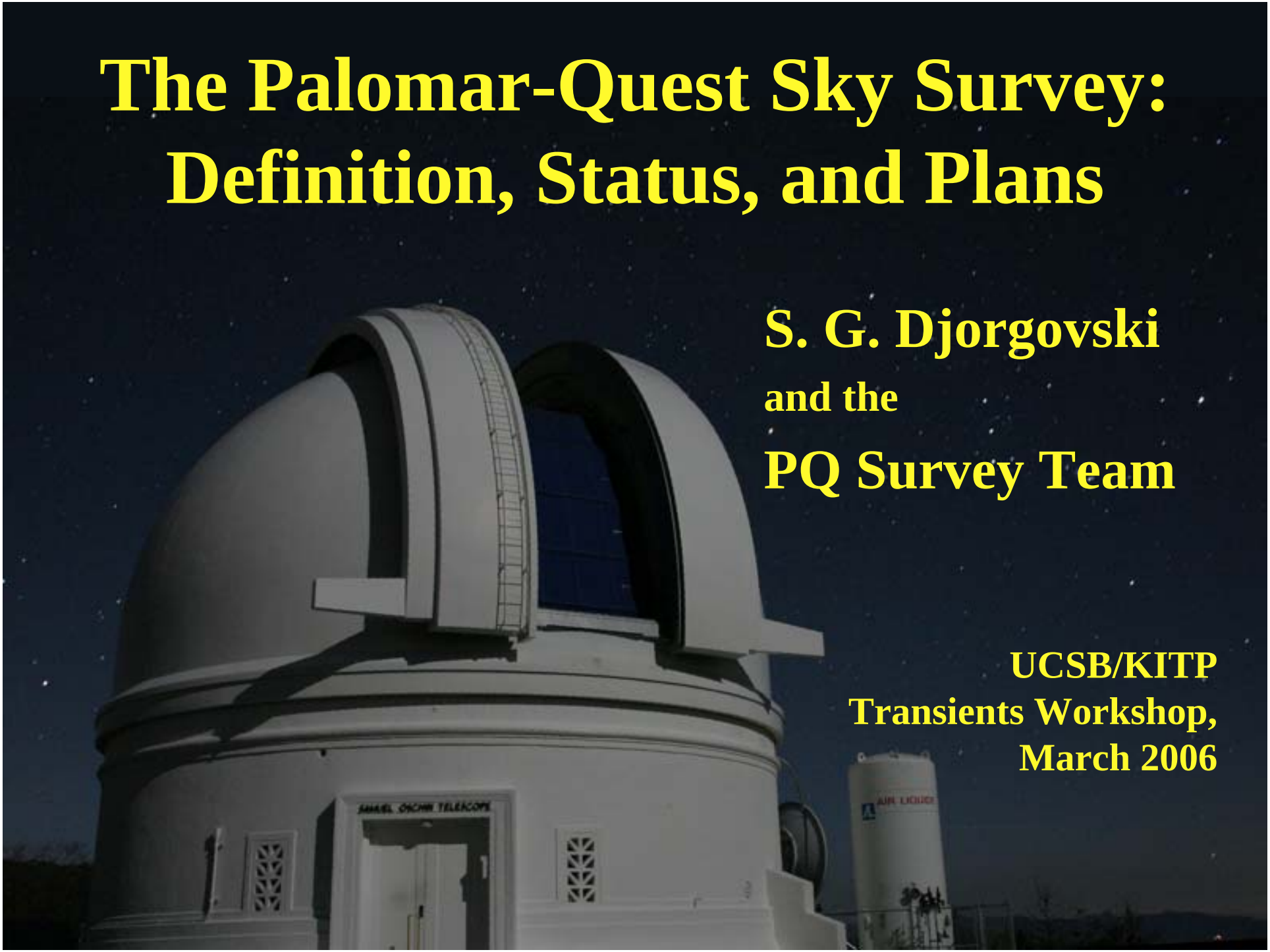
# The Palomar-Quest Sky Survey: Definition, Status, and Plans




**S. G. Djorgovski**
**and the**
**PQ Survey Team**

**UCSB/KITP**
**Transients Workshop,**
**March 2006**

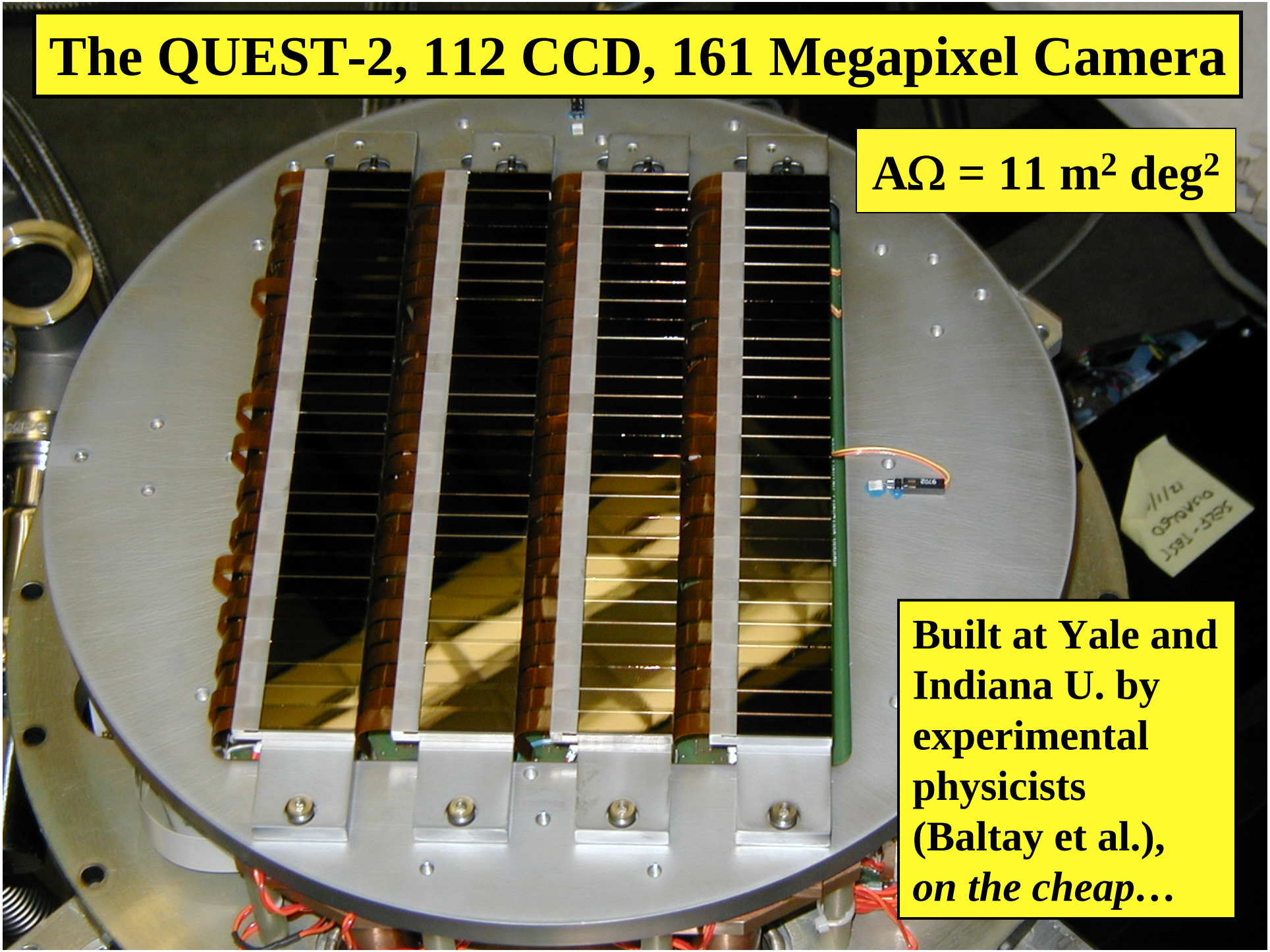
# An Overview

- The Palomar-Quest Survey: definition and goals
- The current status and plans
- Some preliminary results
- VOEventNet project
- Astronomy in the time domain: some general considerations


See also the virtual posters by

- Mahabal et al.
- Drake et al.
- Talk by Aldering et al.

# The QUEST-2, 112 CCD, 161 Megapixel Camera



$A\Omega = 11\ m^2\ deg^2$

**Built at Yale and Indiana U. by experimental physicists (Baltay et al.), *on the cheap*…**

# Survey Modes:

**1. Traditional Point & Shoot (PS)**

Used by M. Brown and NEAT

~ 50% of the time

Repeated short exposures in a single, broad-band *R* filter, 9.2 deg$^2$ per exposure

**2. Drift Scan (DS)**

~ 50% of the time

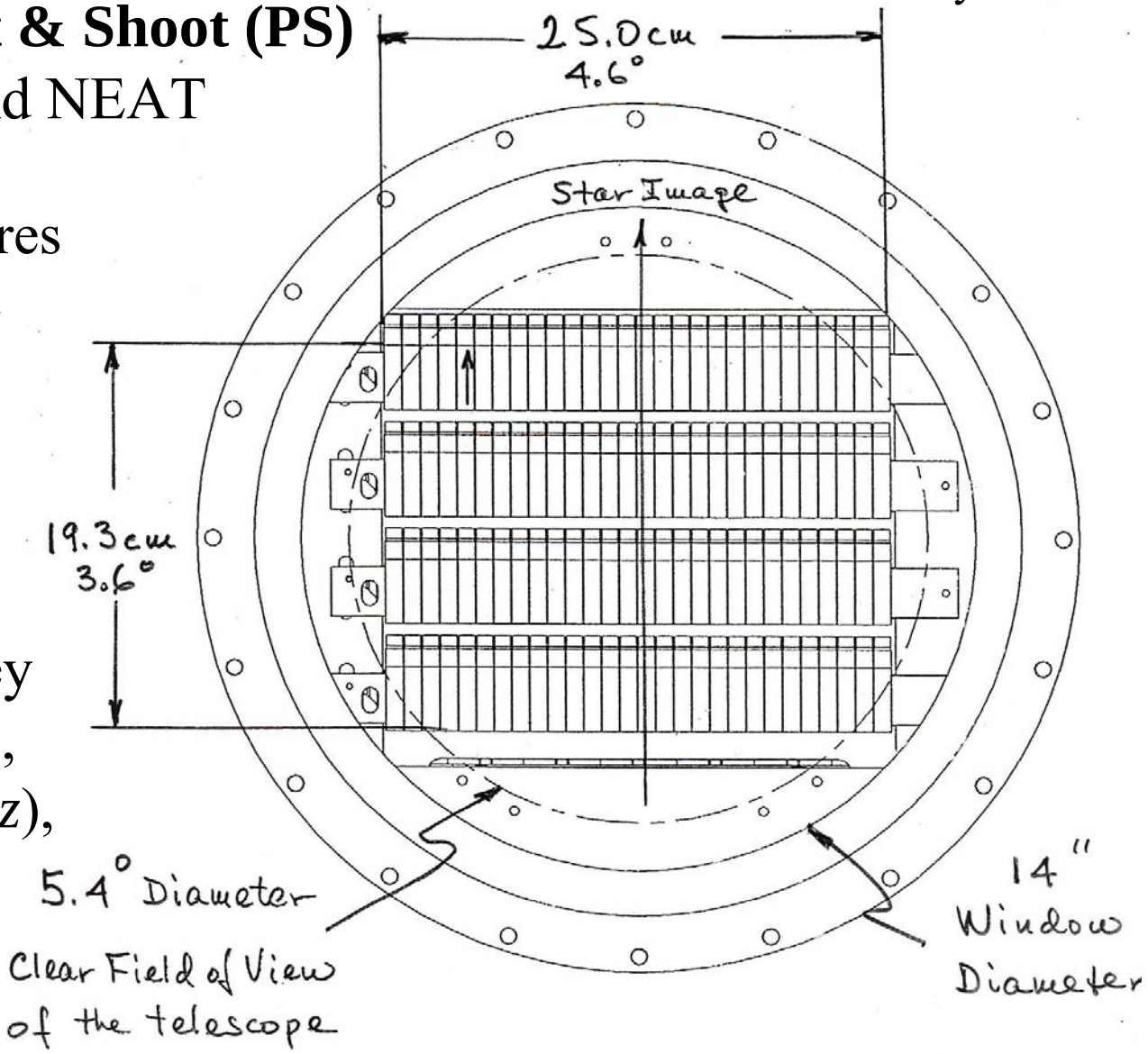
Used by the PQ Survey

Strips 4.6º wide in Dec, in 4 filters (*UBRI* or *rizz*),

~ 500 deg$^2$/night

$t_{exp}$ = 140s */cos* $\delta$

Camera focal plane schematic layout:



# The Palomar-Quest Consortium

40% of the time: Yale & Indiana U. (mostly DS)
40% of the time: JPL (NEAT team) (all PS)
20% of the time: Caltech (~50/50 PS and DS)

# The Palomar-Quest Survey

At Caltech: Djorgovski, Mahabal, Williams, Glikman, Graham, Drake, Donalek, Bogosavljevic, several CACR staff members, several undergraduate students … and hopefully others soon!

At Yale/Indiana: Baltay, Rabinowitz, Silge, Bauer, Jerke, Elman, Lauer, Andrews, several people at Indiana U., several Yale undergrads …

Collaborations with NCSA (Brunner, Rengstorf, et al.), LBL SNF (Aldering, Perlmutter, et al.), INAOE/Mexico (Carrasco, Lopez-Cruz, et al.), EPFL/Switzerland (Meylan et al.)

# The PQ Digital Synoptic Sky Survey

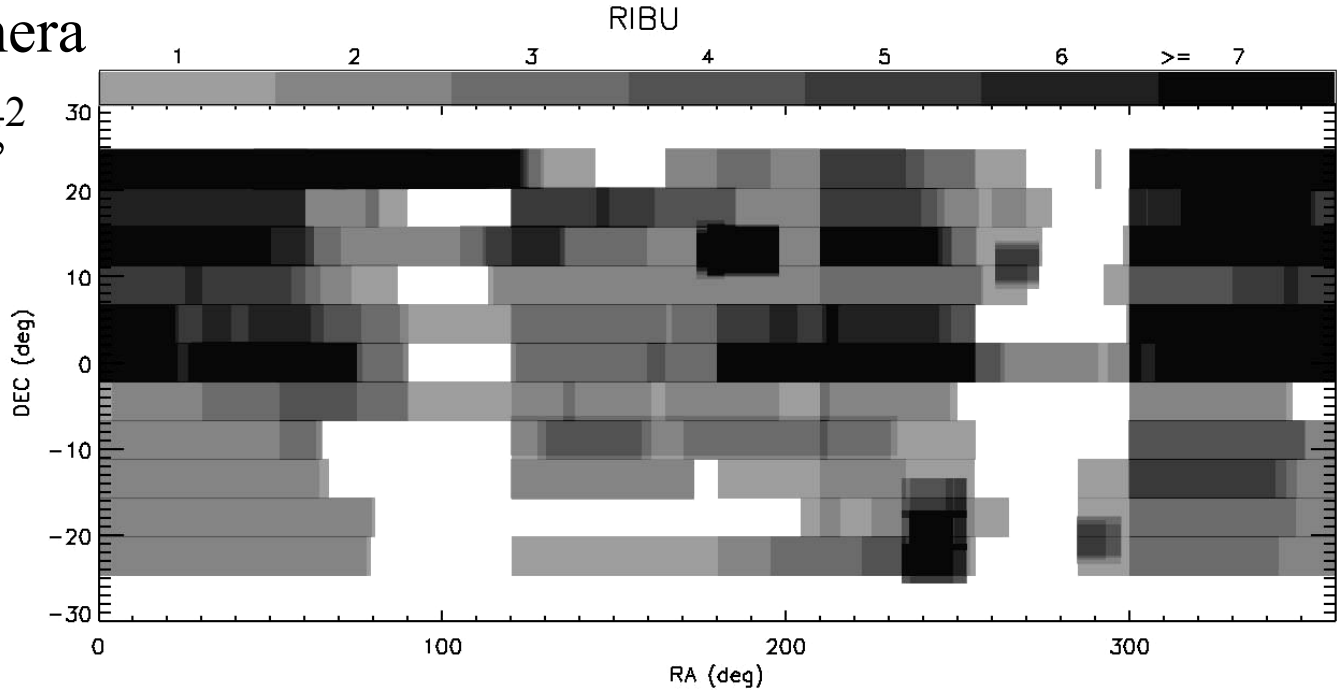
- A collaboration between Caltech, Yale/Indiana U., and on specific topics with other groups (NCSA, INAOE, LBL, EPFL)
- Driftscan mode using Quest-2 camera on the Samuel Oschin 48” Palomar Schmidt telescope
- Data rate ~ 70 GB/night; > 12 TB data already in hand
- Capable of next-day processing ⌫ real-time (mid ‘06?)
- Started in summer of 2003, but many glitches … currently reprocessing all of the data
- NVO connections and standards built in from the start
- Repeated observations, time baselines minutes to years
- **A science and technology precursor / testbed for the LSST and other major synoptic sky surveys in the future**

# PQ Survey Sky Coverage

- Range -25°< δ < +25°, excluding the Galactic plane
- Ultimately cover ~ 15,500 *deg*$^2$ (~ twice the SDSS)
- Rate ~ 500 *deg*$^2$/night in 4 bands
- As of the early Nov.'05, covered ~ 15,500 *deg*$^2$ in either filter set, of which ~ 10,700 *deg*$^2$ at least 5 times; of which ~ 5,200 *deg*$^2$ at least 5 times in *UBRI*, and ~ 2,800 *deg*$^2$ at least 5 times in *rizz*
- Telescope + camera

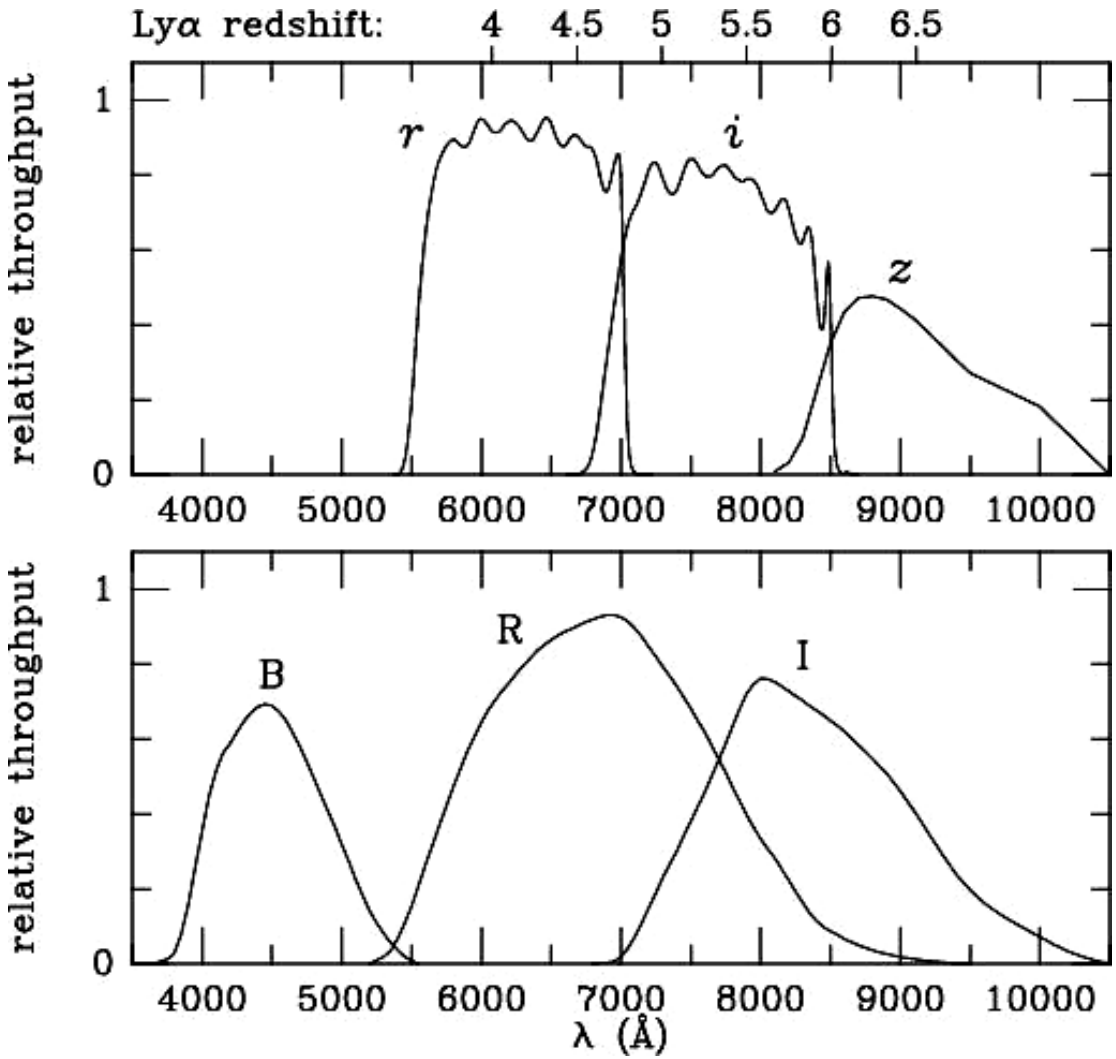
  $A\Omega = 11$ m$^2$ deg$^2$

Sample sky coverage map in UBRI only



# Bandpasses and Depth

Typical limiting magnitudes in a single pass:

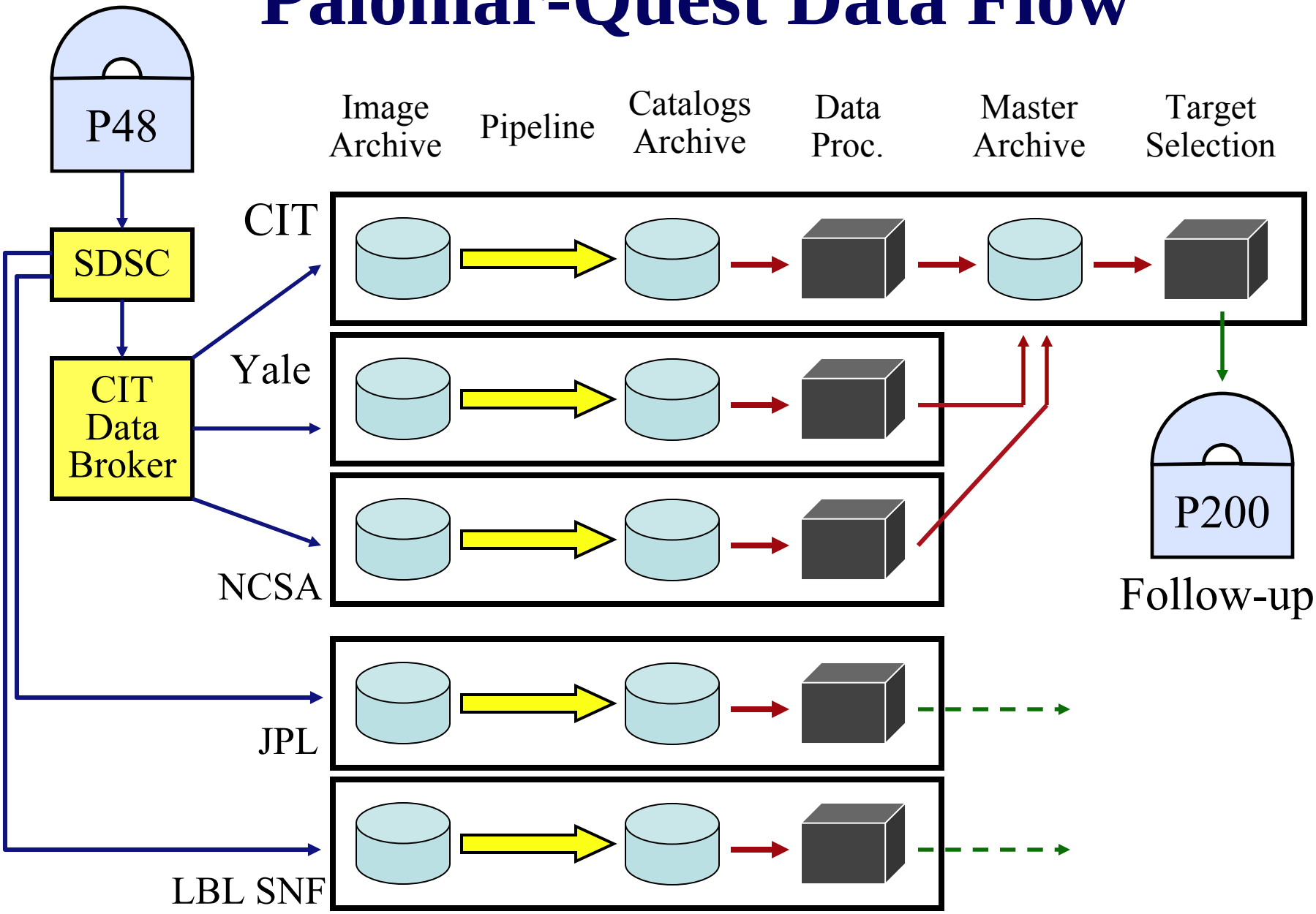



$r_{lim} \approx$ 21.5 mag
$i_{lim} \approx$ 20.5 mag
$z_{lim} \approx$ 19.5 mag
$R_{lim} \approx$ 22 mag
$I_{lim} \approx$ 21 mag

In ~ 6 - 8 passes reach the depth of SDSS in the red:
$r_{lim} \approx$ 23 mag
$i_{lim} \approx$ 22 mag
$z_{lim} \approx$ 21 mag

In 5 years, ~ 0.8 mag deeper …

# Palomar-Quest Data Flow



# **Computing Hardware** - we need lots of it …

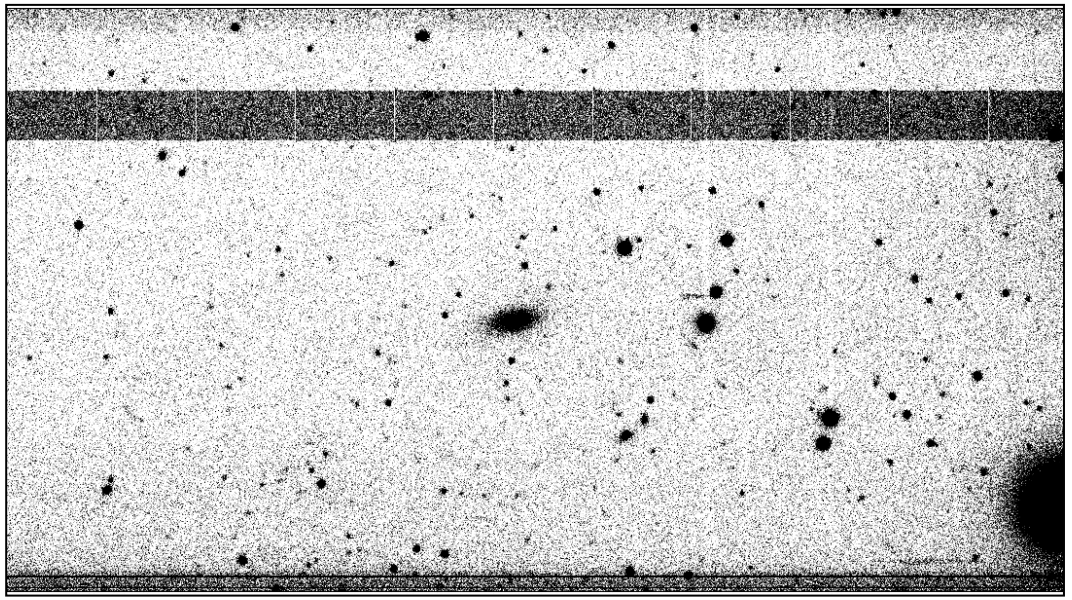
- Much of the heavy lifting done at CACR, some at Astro
- **A Beowulf cluster** with 16 HP/Intel Itanium dual-processor nodes (1.3 GHz each), 6 GB memory with 73 GB scratch disk hanging local off the compute node
- Now a dedicated ~ 50 TB **Datawulf file system** for data storage
- A lot of other Linux/Windows/Mac machines
- Really good, fast networking
- Comparable resources at NCSA plus Yale

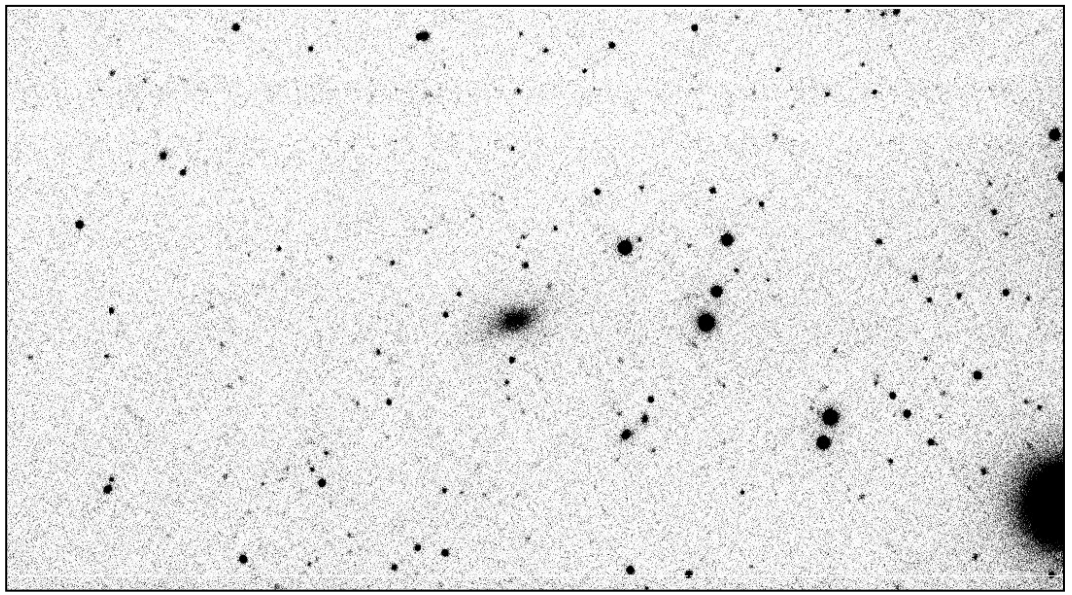
# The PQ Survey Science

- Large QSO and gravitational lens survey
  - Tests of the concordance cosmology
  - Dark matter distribution
  - AGN physics and evolution
- **High-redshift ($z \sim 4$ - 6.5) QSO survey**
  - Probes of reionization and early structure formation
- **Exploring the time domain**
  - Supernovae, GRBs, transients
  - Variable stars, AGN
  - Surprizes and new phenomena?
- Galactic structure and stellar astrophysics
- Multiwavelength (NVO) astronomy
- Solar system: Earth-crossing asteroids, Kuiper Belt

# Cleaning of PQ Data

- The raw data are ***very dirty***: strong and variable dark currents, variable CCD gains, lots of bad columns, intermitent electronics glitches, nonlinearity, …
- Thus the contamination by spurious candidates as outliers in any parameter space is much, *much* worse that what we expected …
- **So we learned to clean the data really well!**

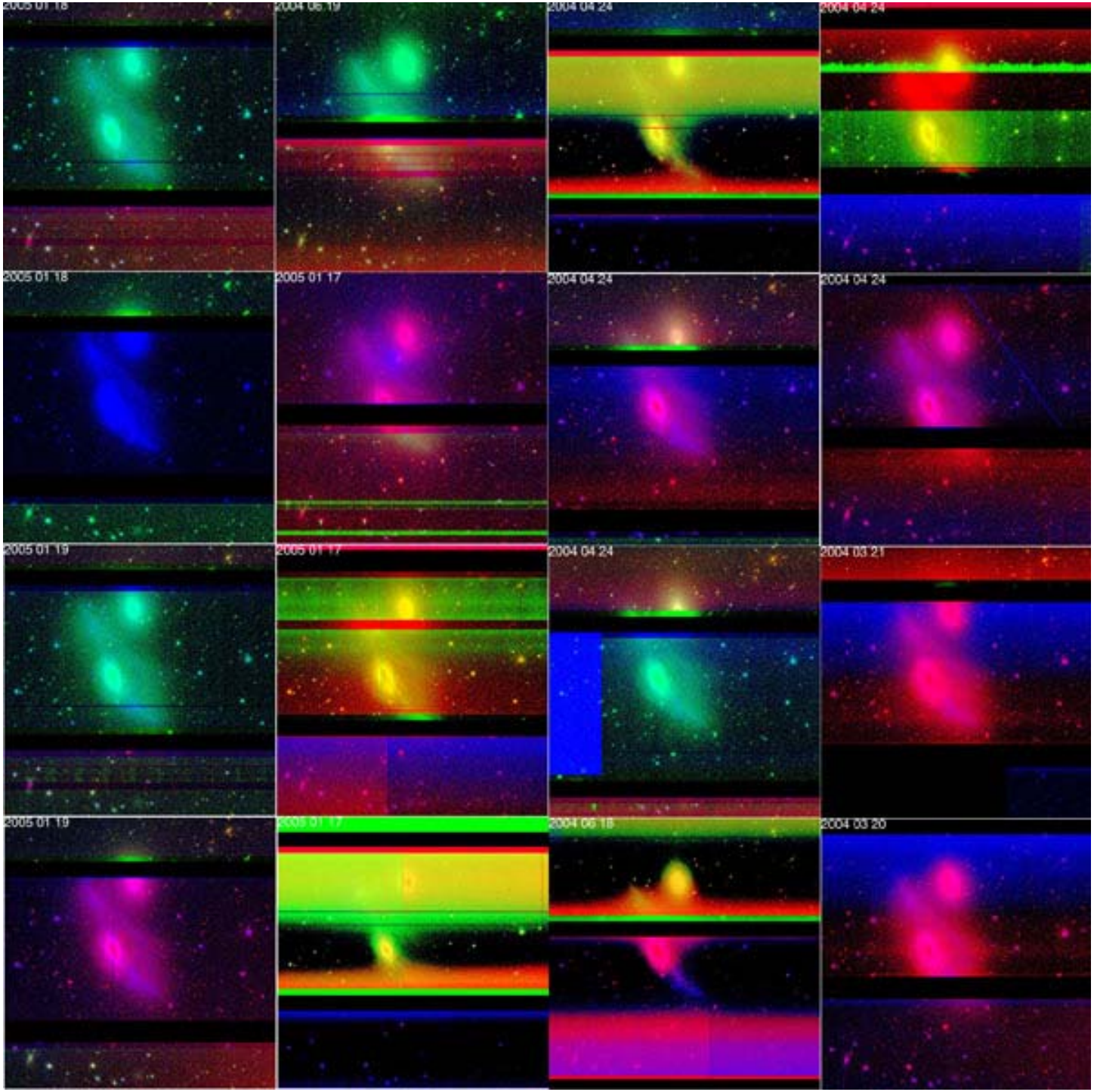




# An Example: 16 passes in raw data

A small section from the Virgo Cluster "Big Picture" mosaic

*IRB* filters
- *RGB* color



# Cleaned, Coadded Images

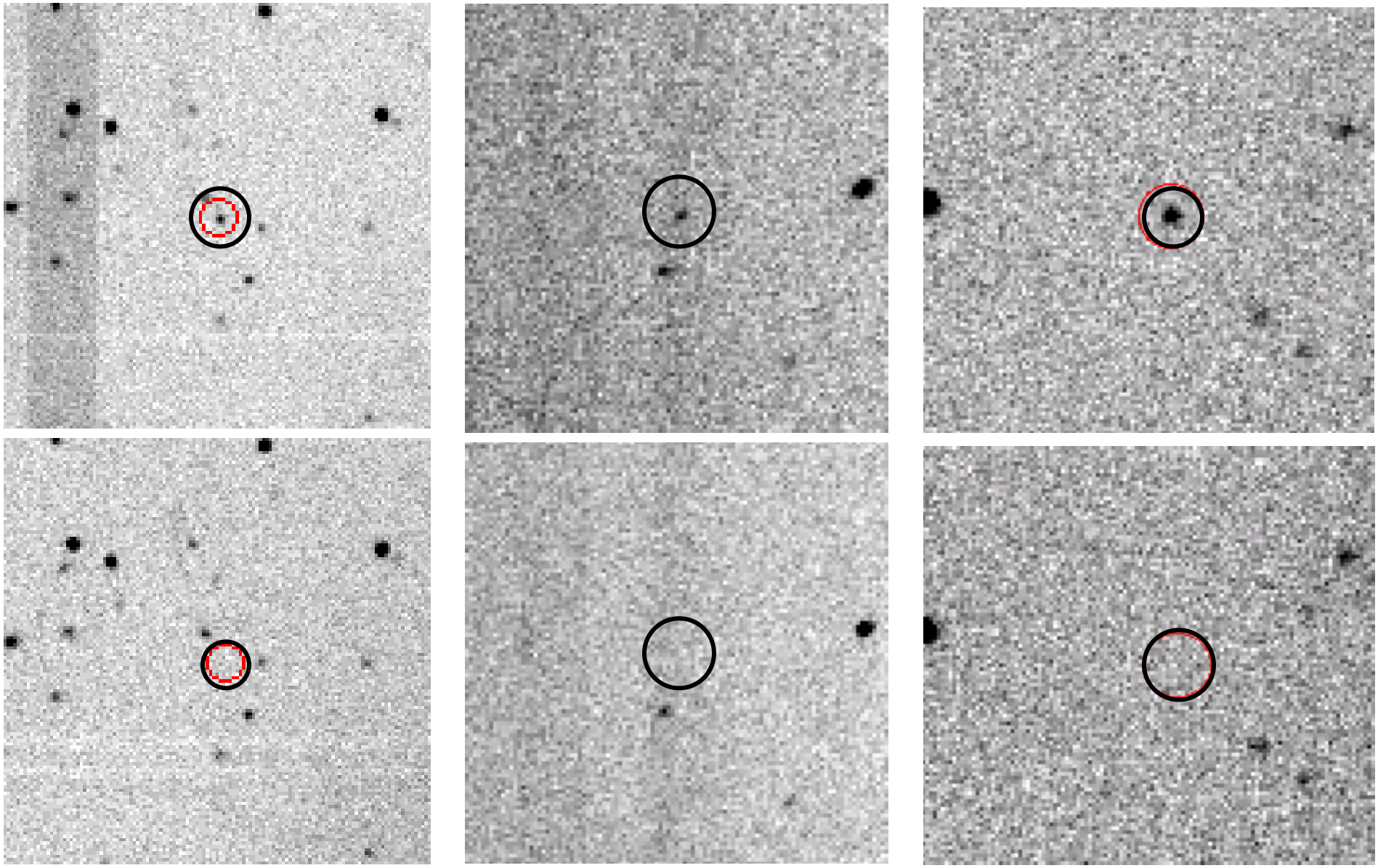
# The PQ Survey Status

- Completely redoing the DRP at Caltech
  - Much (much!) better data cleaning
  - Image remapping to a standard pixel grid, to enable image coaddition and subtraction
    - Using the HyperAtlas technology for this
    - Using some TeraGrid computational resources
  - Yet to come: better object detection, classification
- As of early March'06, > 50% of the data reprocessed
- Next: A real-time DRP for discovery of transents and moving objects
  - Collaborate w. JPL/NEAT, M. Brown
  - VOEventNet project: real-time analysis and follow-up

# The Big Picture

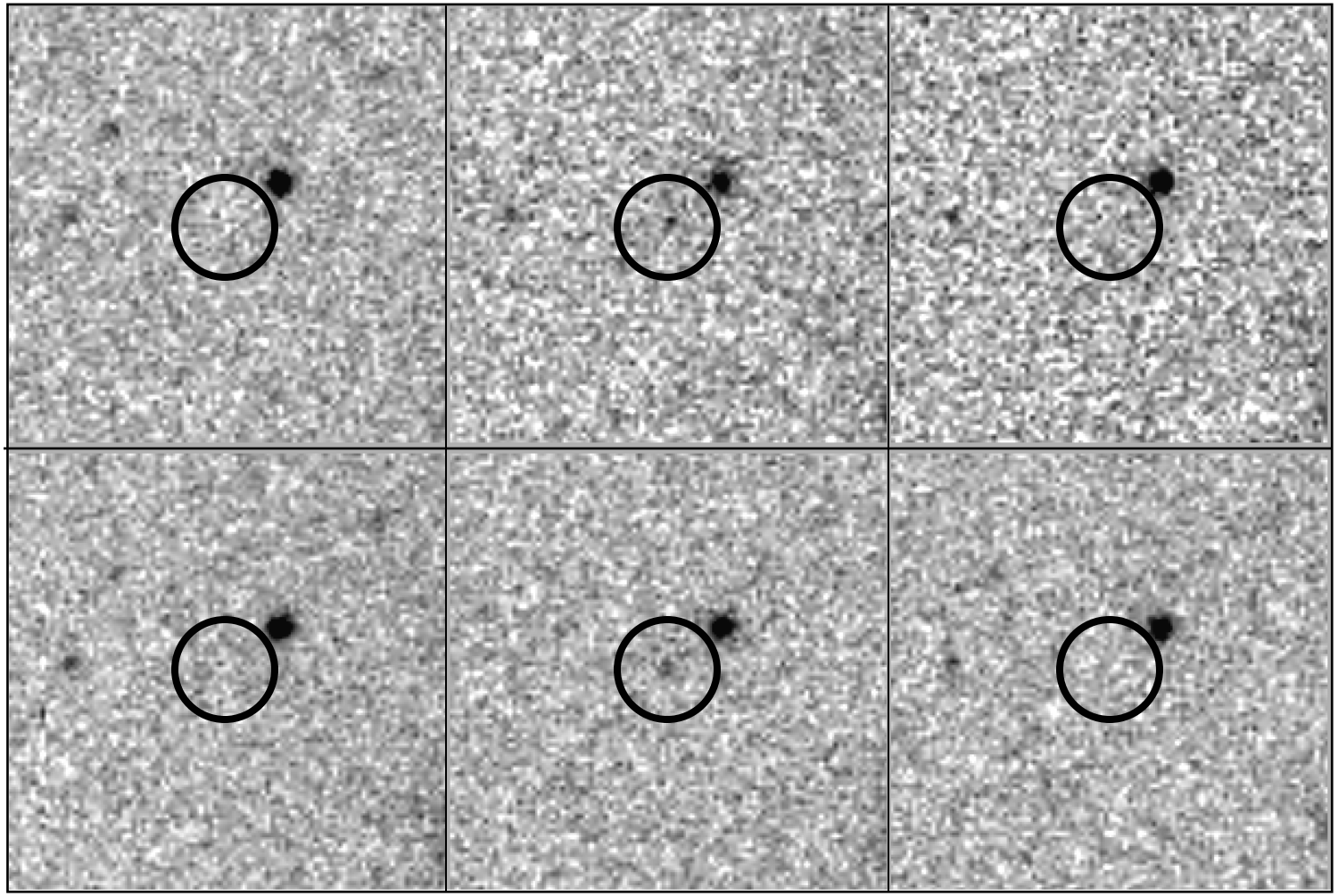
- A 152 ft × 20 ft mural produced for Griffith Observatory from PQ survey BRI images; a 136,800 × 18,000 pixel image, reproduced on steel backed porcellain tiles
- A 15.2° × 2.0° swath through the center of the Virgo cluster
- About 25 passes over ~ 1.5 yrs; each spot covered ~ 10 - 15 times; time baselines from ~ 2 hours to ~ 15 mos.
- ***An excellent test data set for time domain exploration***


# Examples of PQ Transients



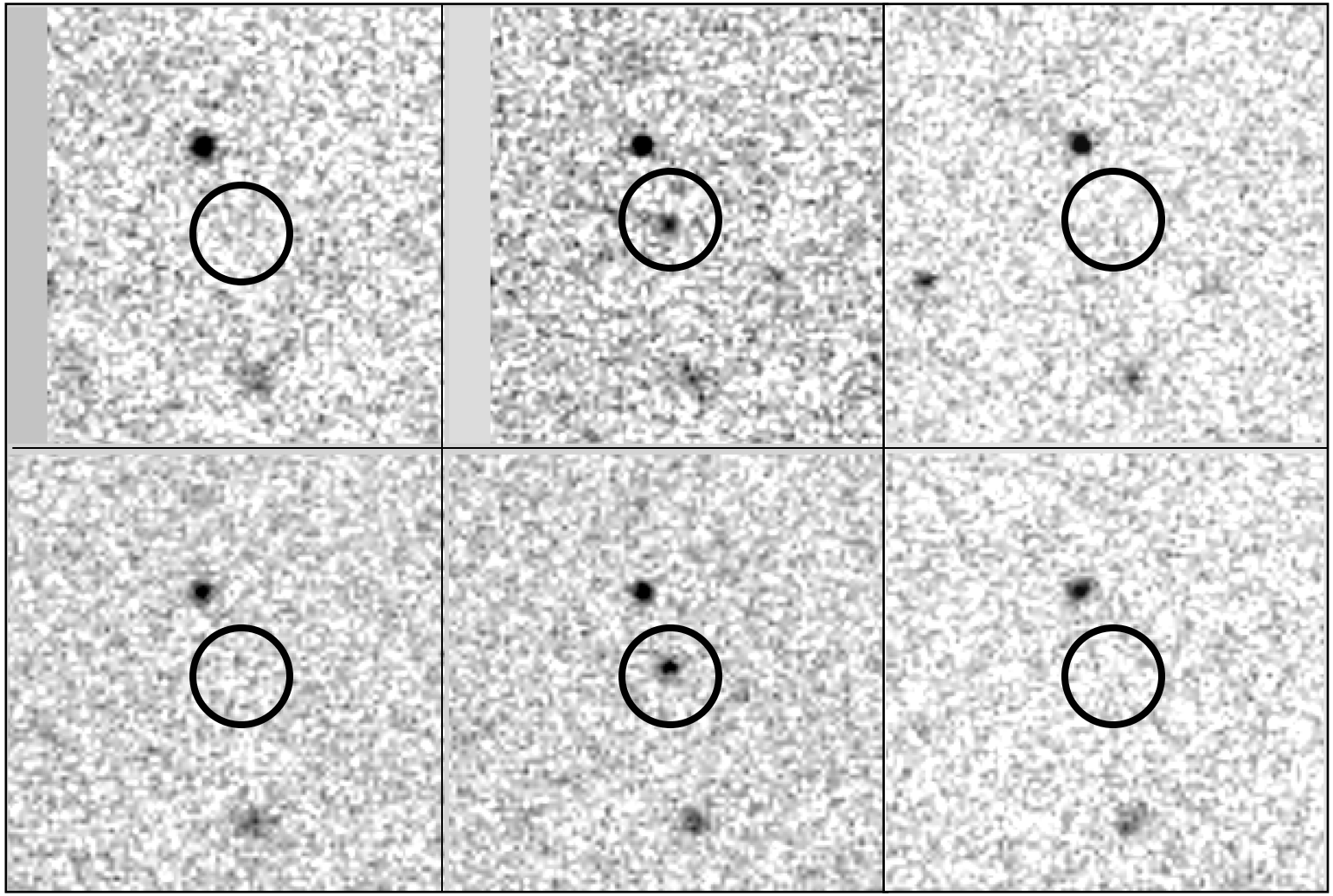
(Mahabal, Kollipara, et al.)

# Transients in the Big Picture




(Drake et al.)

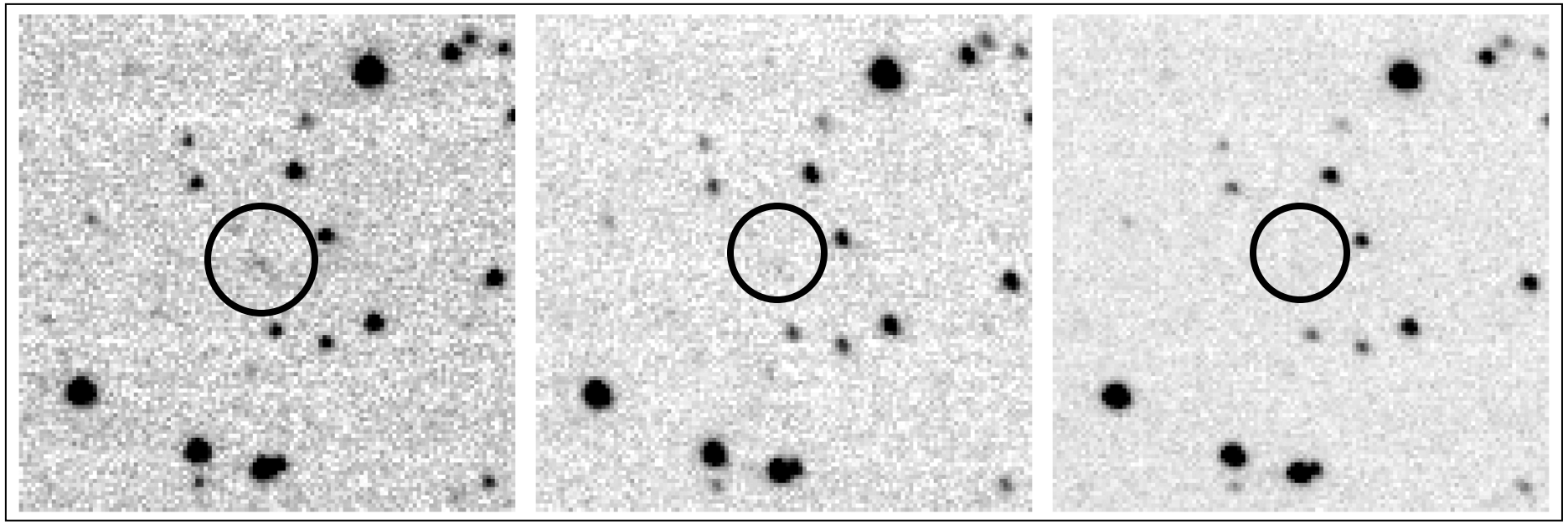
# Transients in the Big Picture




(Drake et al.)

# Transients in the NEAT Data

"Orphan Transients"?

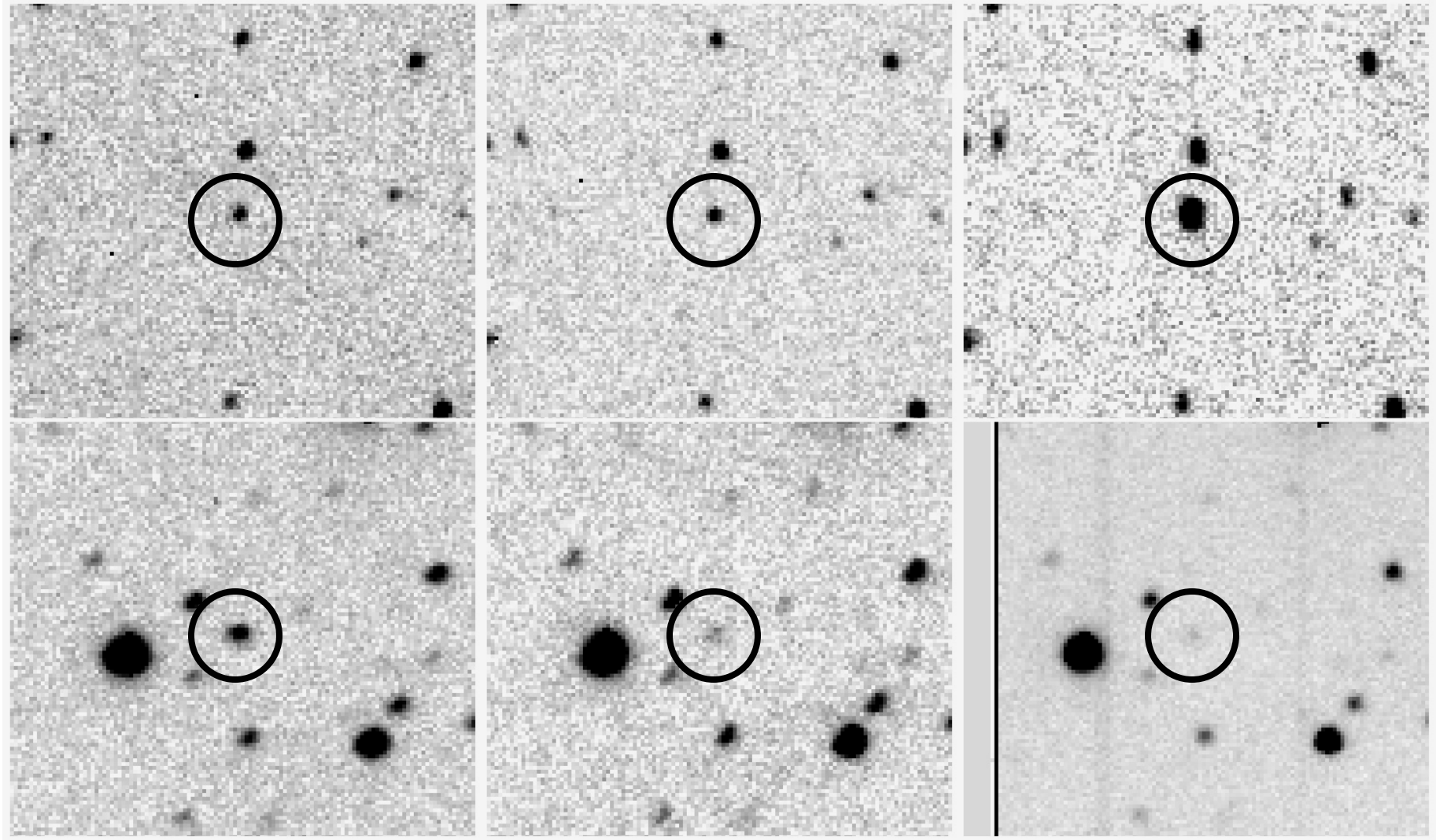


$t_1$ $t_2$ $t_3$

Time baselines ~ 20 min

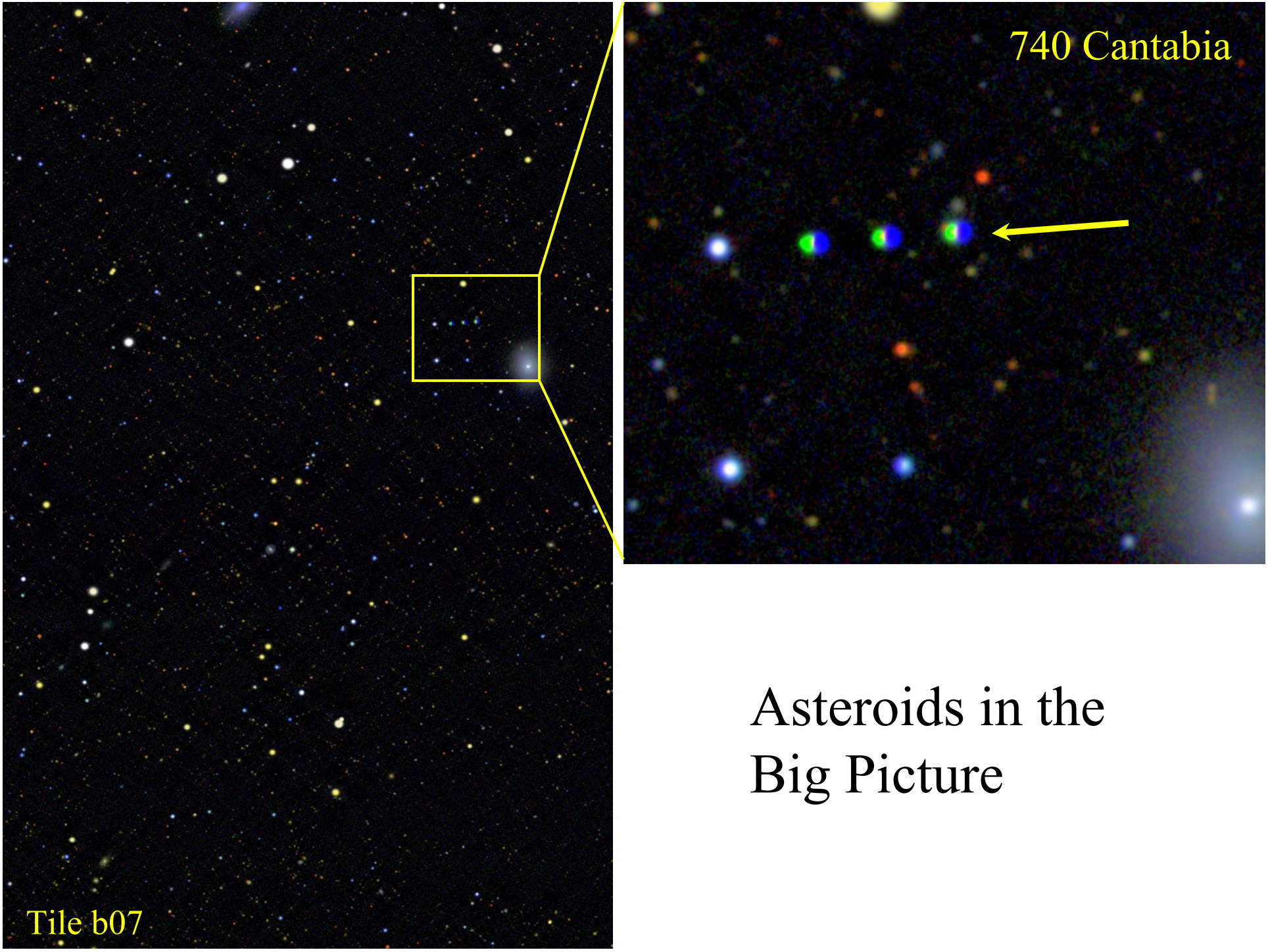
(Mahabal et al.)

# Variables in the NEAT Data



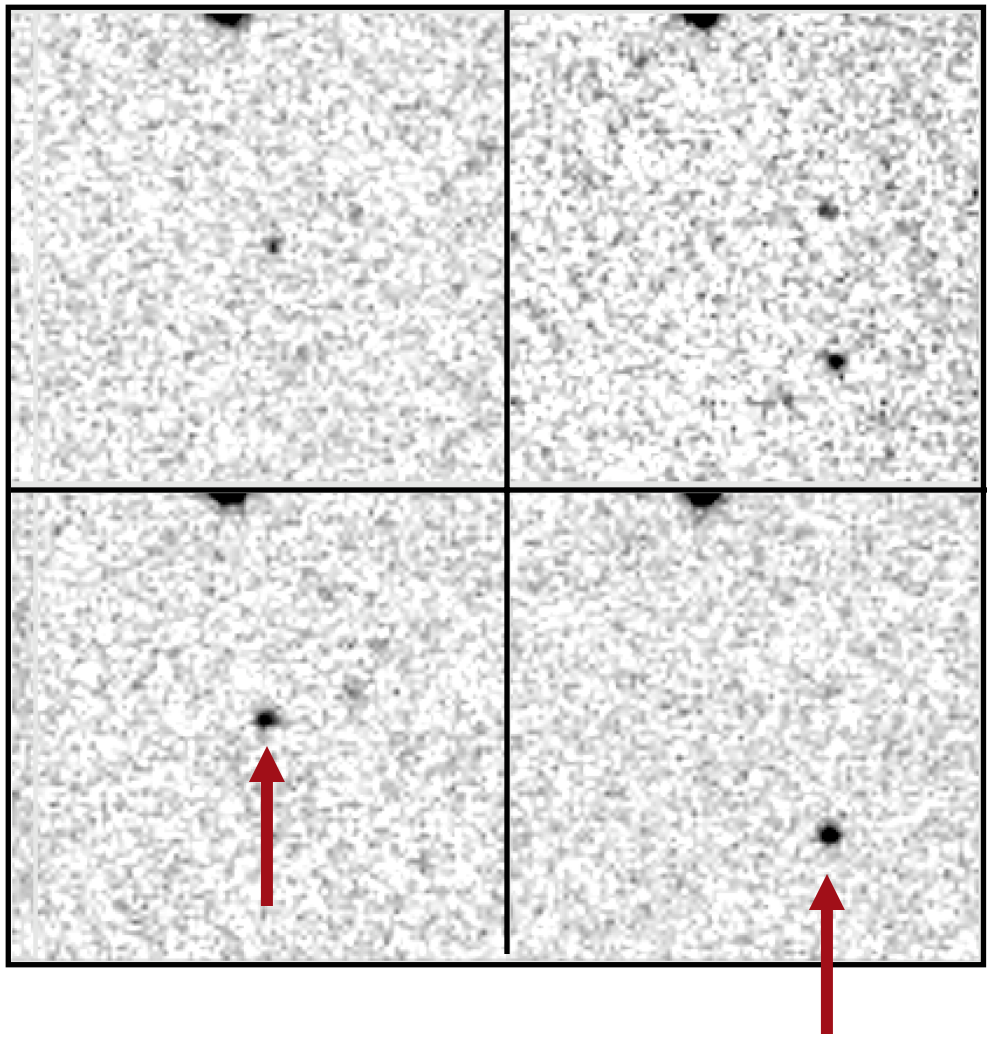
$t_1$ $t_2$ $t_3$

(Mahabal et al.)




# Asteroids in the Big Picture

# Asteroids in the Big Picture

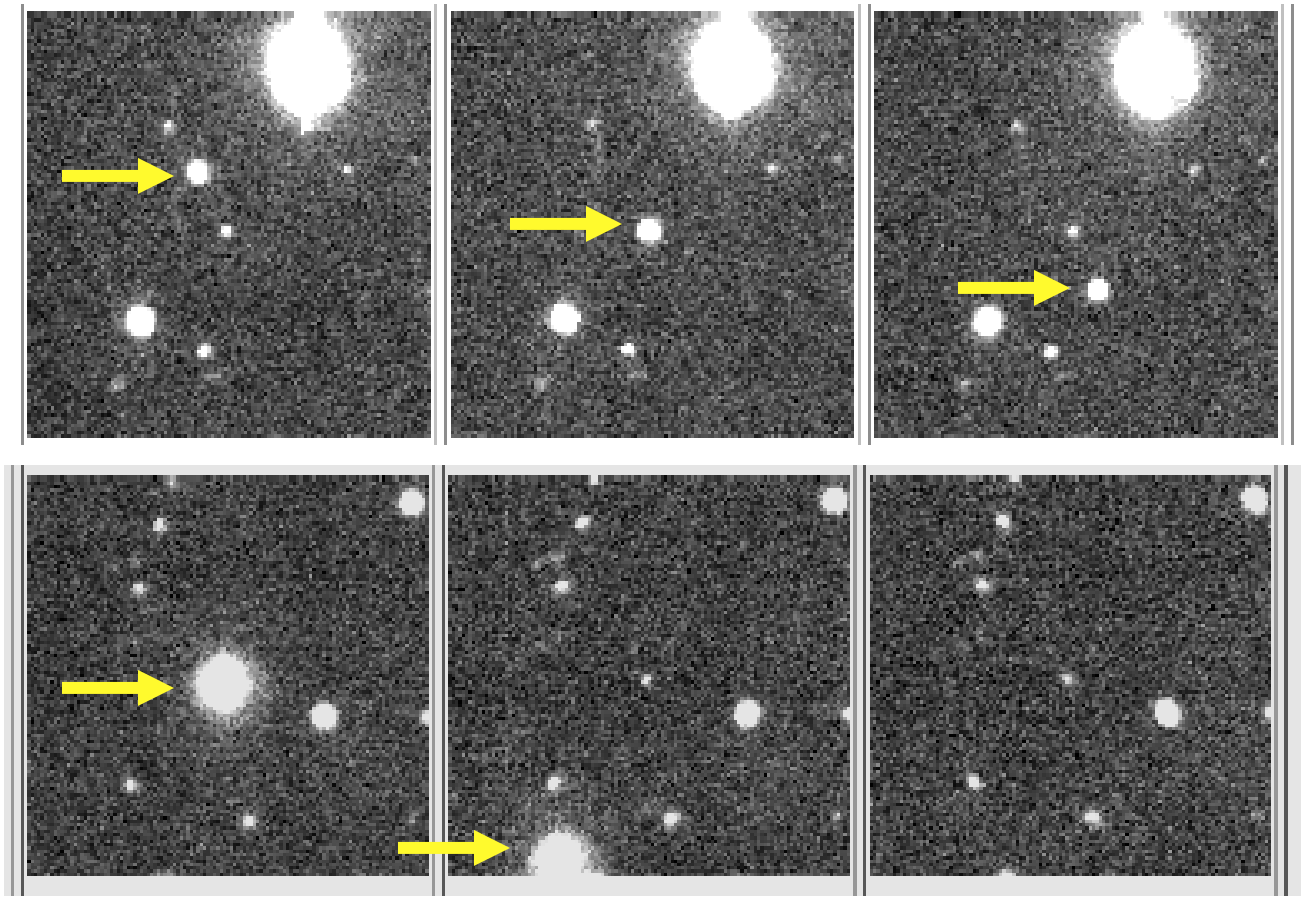



At the high Glactic latitude of Virgo (Ecliptic latitude ~ 40º), we find:
**~ 1 - 2 asteroids / *deg*$^2$**
down to ~ 20 mag in a snapshot survey

(Drake et al.)

We have many genuine transient detections, but they are mostly asteroids!

Synoptic sky surveys will have to address simultaneously the Solar System objects, and transients, in a joint analysis



# A PQ Prototype Service to Match Detected Transients to Other Databases (Asteroids, Variables, etc.)

| | |
|---|---|
| **ID:** | 87 |
| **EPOCH:** | 2005-12-04 |
| **POS (RA deg, Dec deg):** | 185,-1 |
| **SR/SIZE (RA deg, Dec deg):** | 0.2 |

**String**

**DateTime**

**SIAP like**

| Catalog | Include? | Symbol | Color | Size | Comment |
|---|---|---|---|---|---|
| Asteroids | ☑ | circle | red | 21 | IMCCE http://www.imcce.fr |
| Variables | ☑ | circle | green | 21 | GCVS http://www.sai.msu.su |
| Radio | ☑ | circle | blue | 21 | NVSS http://www.nrao.edu |
| GRBs | ☐ | circle | black | 21 | To be implemented |
| GCNs | ☐ | circle | yellow | 21 | To be implemented |
| XRay | ☐ | circle | cyan | 21 | To be implemented |

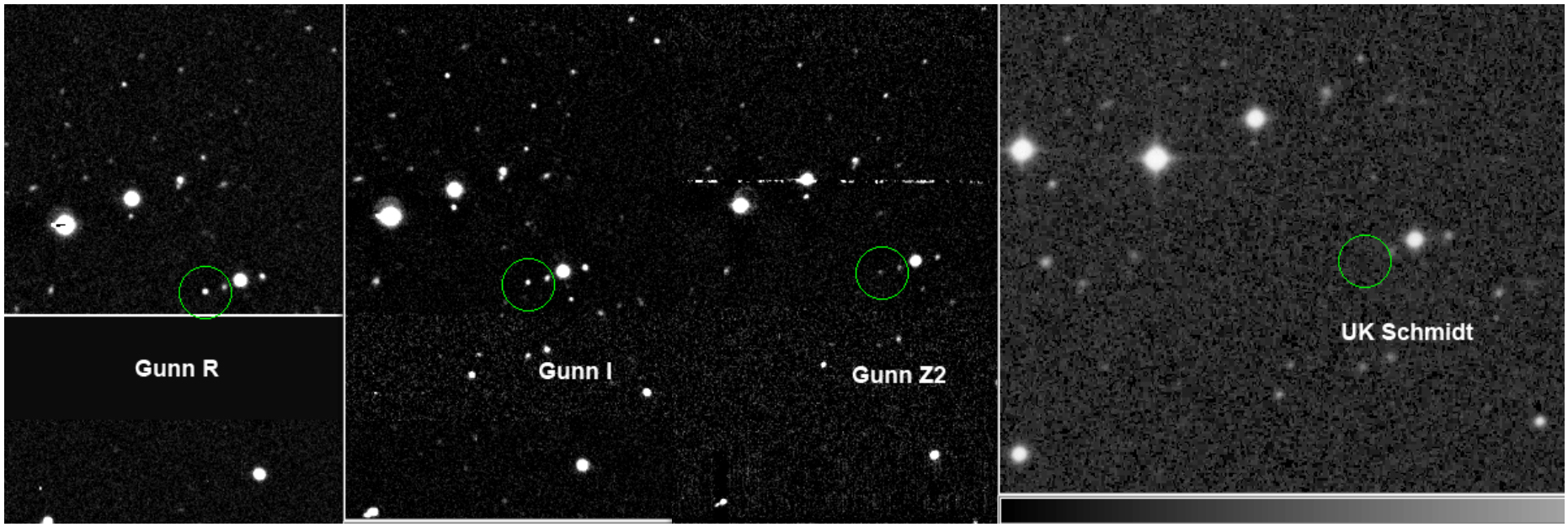
submit

Mahabal et al.

# New Planets and Planetoids?

Pre-discovery PQ images of Planet X

Archival comparison




| | | | | |
|---|---|---|---|---|
| 20030908 | 1:37:42.1 | -5:58:14 | (PQ RIZZ not yet processed) | } Pre-discovery |
| 20031004 | 1:36:51.7 | -6:04:03 | (PQ RIZZ processed) | |
| 20031005 | 1:36:49.6 | -6:04:15 | (PQ RIZZ processed) | |
| 20031021 | 1:36:14.2 | -6:07:16 | (M. Brown discovery night) | ⬅ Real discovery |
| 20050119 | 1:34:44.0 | -5:49:45 | (PQ UBIR not processed) | |

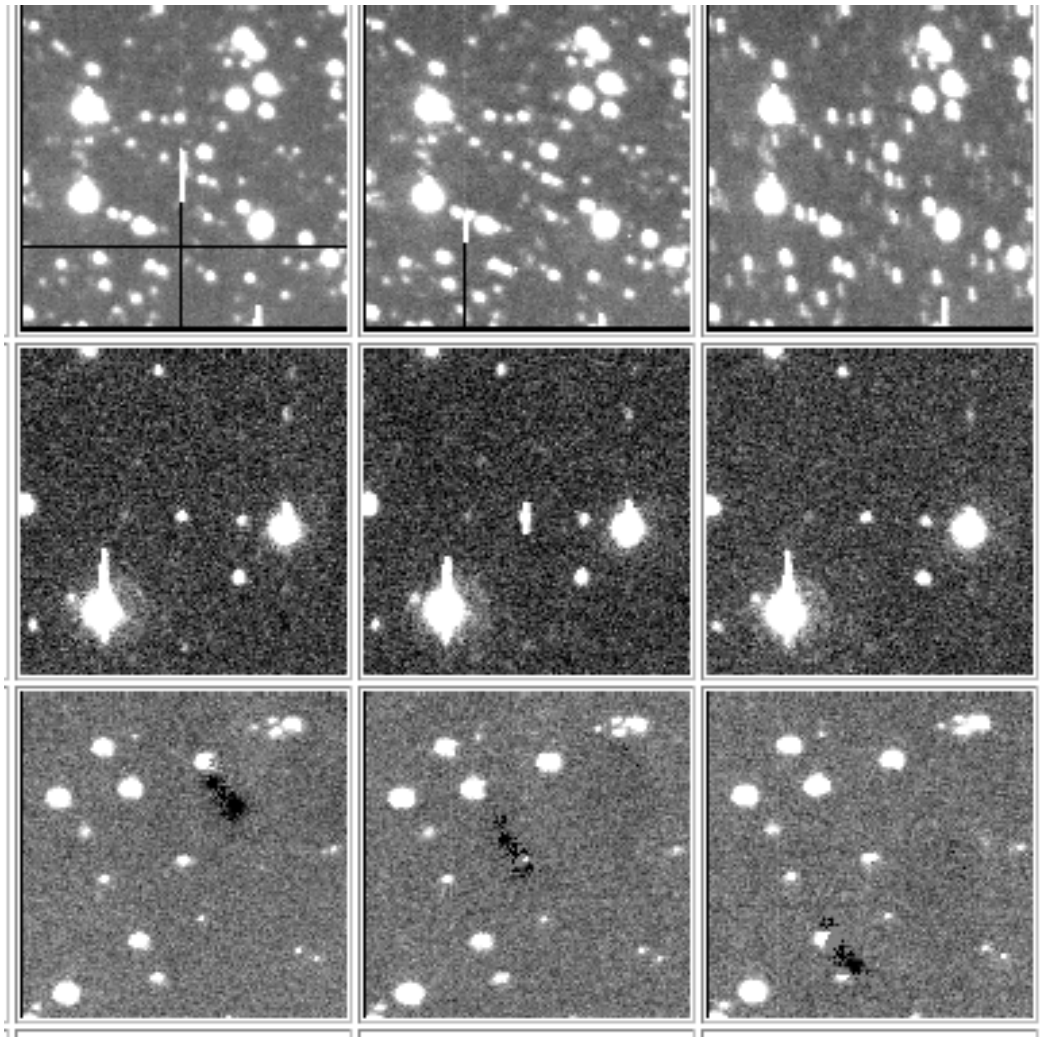
➔ A potential for planet discovery in single-pass PQ scans

# Examples of Artifacts

Good data cleaning is essential in order to maintain a high completeness and a low contamination in the time domain

Types of Artifacts:

- CCD defects
- Reflections
- Grazing CRs
- Partially uncorrected bad columns
- Unknowns

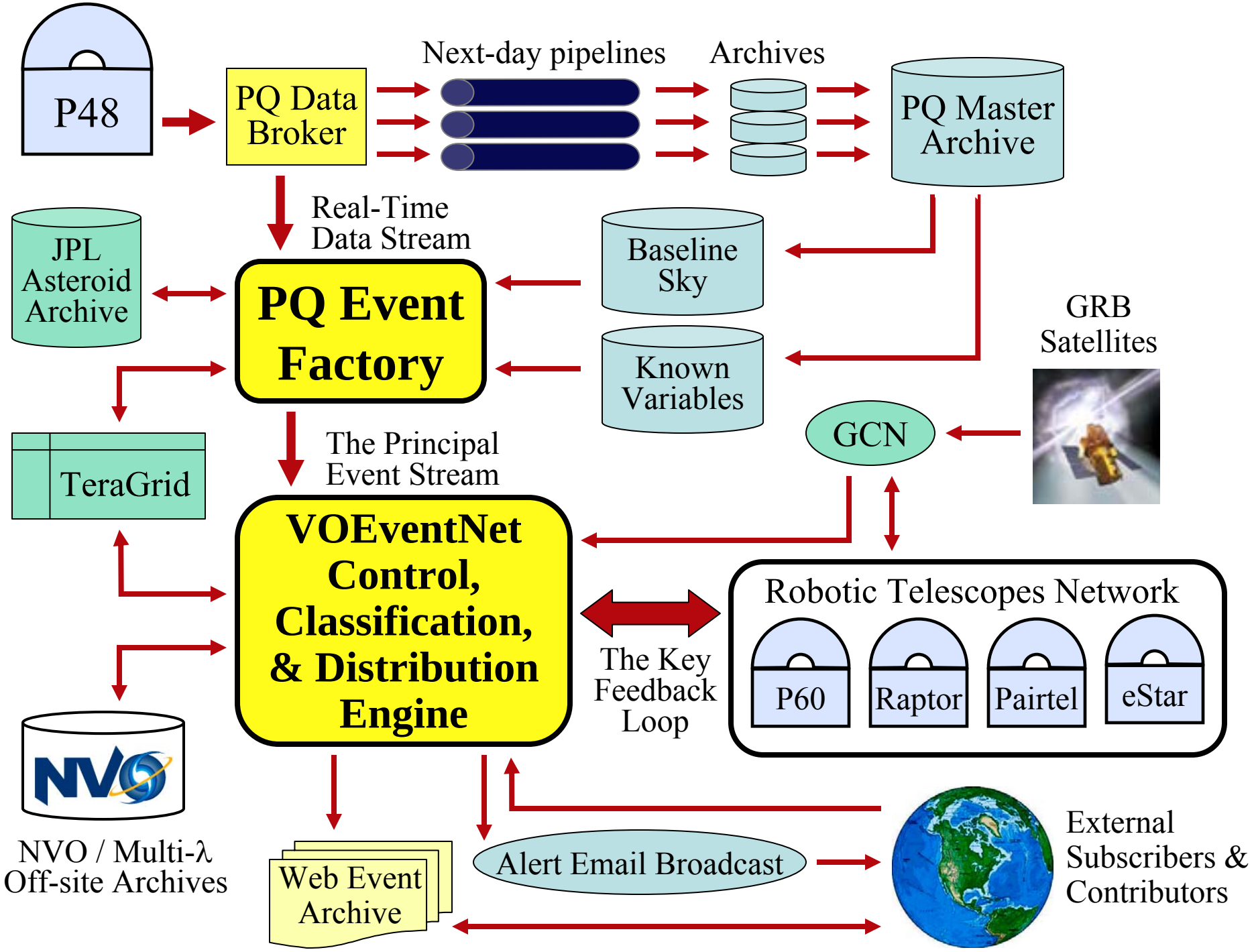


# Where Are We Going Next?

- Final touches on the new data cleaning pipeline
- Reprocess the rest of the accumulated data
- Coadd images using Hyperatlas technology
- Derive catalogs from coadded images, use for a variety of projects including high-z QSO search
- These images and catalogs form the ***fiducial sky for the time domain studies***
- We will federate PQ data with SDSS, DPOSS, 2MASS, FIRST, etc., for VO-type studies
- Real-time data processing ~ summer ‘06?
- VOEventNet project: real-time astronomy in the Virtual Observatory environment

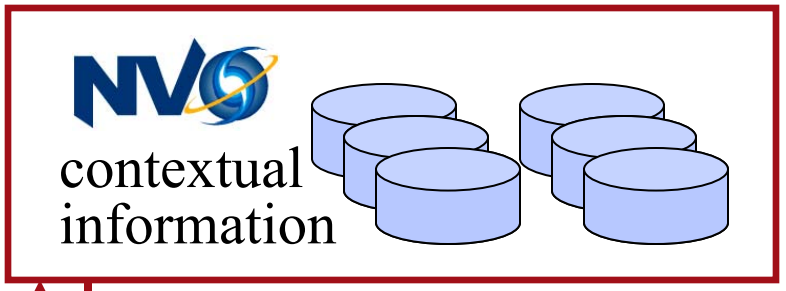
# The VOEventNet Project

- A prototype implementation of a real-time astronomy system in the Virtual Observatory framework (VOEvent)
- PI = Roy Williams
- A partnership between Caltech (CACR, PQ, P60), UCB (Pairitel), and LANL (Raptor), possibly also UK (e-Star)
- PQ is the principal event factory
- Some tests this year, real operations in 2007?
- The goal is to ingest, classify transient events, “publish” them electronically, enable automated follow-up and feedback, and grow event portfolios, all following the emergent VO standards


P48
PQ Data Broker
Next-day pipelines
Archives
PQ Master Archive
Real-Time Data Stream
JPL Asteroid Archive
Baseline Sky
PQ Event Factory
Known Variables
GRB Satellites
GCN
TeraGrid
The Principal Event Stream
VOEventNet Control, Classification, & Distribution Engine
Robotic Telescopes Network
P60
Raptor
Pairtel
eStar
The Key Feedback Loop
NVO
NVO / Multi-λ Off-site Archives
Web Event Archive
Alert Email Broadcast
External Subscribers & Contributors

# Towards Automated Event Classification

A **necessity** for large synoptic surveys

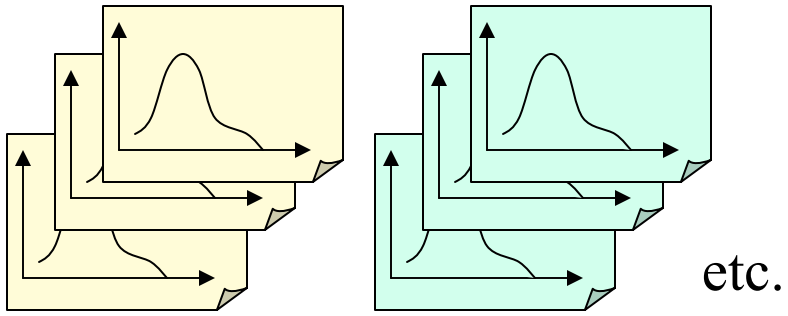



**Event parameters:**
$m_1(t)$, $m_2(t)$,…
$\alpha$, $\delta$, $\mu$, …
image shape…

**Event Classification Engine**

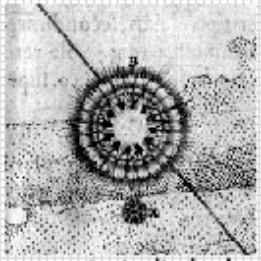
P(SN Ia) = …
P(SN II) = …
P(AGN) = …
P(CV) = …
P(dM) = …
….

Expert and ML generated priors




First star-galaxy classification, now event classification

# VOEventNet Webpage: GCNs



voeventnet.caltech.edu

- Home
- Project Description
- Personnel
- GCN VOEvent Information
- Transients in the Griffith Park "Big Picture"
- IVOA VOEvent pages
- Search the Nexus

VOEventNet is sponsored by NSF Grant No. CNS-0540369 and includes collaborators at California Institute of Technology, University of California Berkeley, and Los Alamos National Laboratory

## VOEventNet: Real-Time Astronomy with a Rapid-Response Telescope Grid

### GCN VOEvent Information

- This page is generated automatically as incoming GCN events are received and was last updated at UTC **2006-03-13T19:05:05.**
- A list of GCN notice types that are available in VOEvent format is **here** .
- Information on subscribing to receive xml GCN notices with jabber in **real time** is here:
- A near real time feed is available here: XML RSS
- This table contains information about Gamma Ray Bursts obtained from GCN notices (Table Help).

### GCN GRB Triggers

| GRB/Trigger | | | Observation | | | | | |
|---|---|---|---|---|---|---|---|---|
| Trig-SubNums | Date/Time | Instrument alert type | RA (deg) | Dec (deg) | Error | Inten | Comments | DataScope |
| ▶201487 | 2006-03-13T19:04:54 | SWIFT_FOM_Observe | 66.5993 | -10.8652 | n/a | n/a | Not a new GRB. | View data |
| 146-1 | 2006-03-13T08:33:03 | MILAGRO_Source | 205.0453 | 66.7687 | 0.5400 | 78 | Possible GRB | View data |
| 4032-1 | 2006-03-13T08:30:35 | HETE_SC_Alert_Source | n/a | n/a | n/a | n/a | Probable GRB. | |
| 145-1 | 2006-03-12T21:13:35 | MILAGRO_Source | 350.7781 | 12.0340 | 0.5400 | 34 | Possible GRB | View data |
| ▶201391 | 2006-03-12T16:18:55 | SWIFT_UVOT_Darkburst | 45.7758 | 12.8345 | 0.0500 | n/a | Possible GRB | View data |
| 143-1 | 2006-03-11T17:25:13 | MILAGRO_Source | 342.9764 | 15.8329 | 0.5400 | 21 | Possible GRB | View data |
| 140-1 | 2006-03-11T00:47:32 | MILAGRO_Source | 67.7522 | 66.4130 | 0.5400 | 29 | Possible GRB | View data |
| 4031-1 | 2006-03-11T00:28:22 | HETE_SC_Alert_Source | n/a | n/a | n/a | n/a | Probable GRB. | |
| ▶3218 | 2006-03-10T23:51:03 | INTEGRAL_Offline | 245.0154 | -15.7964 | -0.0542 | 8.33 | Possible GRB | View data |
| | | | | | | | Probable GRB. | |

**http://voeventnet.caltech.edu/GCN.html**

# These Software Systems Are Hard!

- Automated, reliable, adaptive data cleaning
  - High volume data generators ⇗ lots of glitches
  - Cutting-edge systems ⇗ poor stability
- Need high completeness *and* low contamination
- Time criticality: time scales of minutes or less require fully robotic systems, with no humans in the loop
- Automated, reliable, objective event classification and alert decisions
  - ***Necessary*** for high-throughput systems, and especially for automated follow-up
  - Sparse data from the event originator; folding in of the heterogeneous external data; VO connections; etc.
  - Need to incorporate and update expert knowledge, machine learning methods

# What Have We Learned So Far?

- Faint, variable sky has ***a very rich phenomenology***
  - The same survey data streams can feed many different, specific experiments
  - Systematic exploration vs. targeted surveys: optimal strategies require some careful thinking
- From the DPOSS plate overlap survey (and consistent with the early PQ results), ***in a snapshot survey, there are ~ $10^3$ transients / sky*** down to ~ 20 mag
  - Many of them are probably AGN, CVs, flaring stars, and distant SNe; some may be GRB orphan afterglows; and *some may be new types of phenomena*
- Asteroids will be a significant contaminant in a search for transients, > 1 $deg^{-2}$ down to ~ 21 mag. ***A joint moving/variable object analysis is necessary***

# Some Thoughts …

- Event discovery is just a start; 99% of the astrophysics is in the follow-up, and mostly in optical spectroscopy
  - **Spectroscopic follow-up will be a key bottleneck for any synoptic sky survey!**
- Multi-wavelength synthesis is also essential, both for follow-up / interpretation, and for archival matching for initial object classification
  - Virtual Observatory environment is good for this
    … and also for the dissemiantion of events and follow-up
- Most major astronomical projects now, especially surveys, are primarily ***software projects***, with software accounting for ~ 30 - 80% of the total cost; synoptic surveys can be only more so
  - We cannot afford a wasteful duplication of efforts, resources