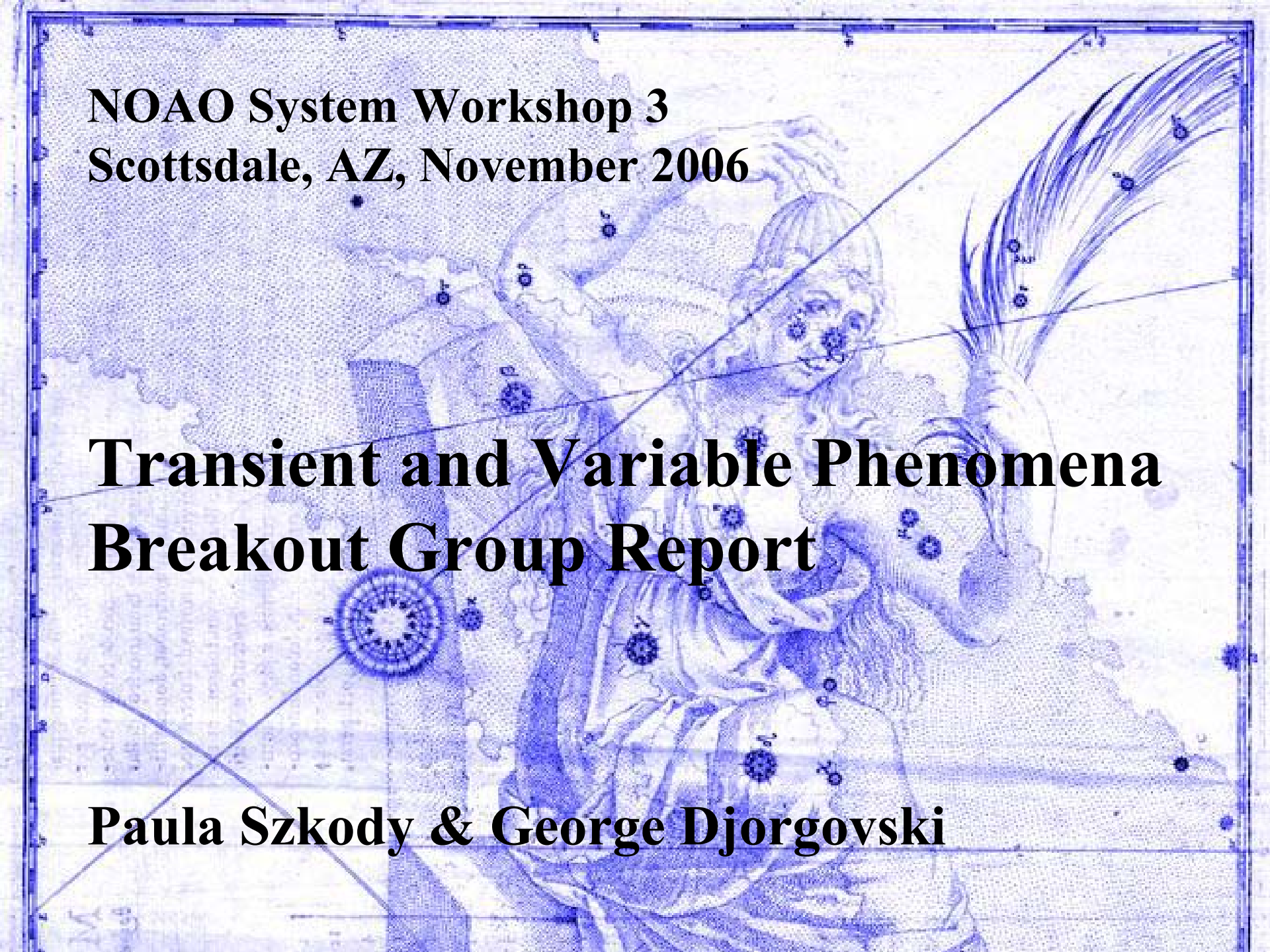


NOAO System Workshop 3
Scottsdale, AZ, November 2006

Transient and Variable Phenomena Breakout Group Report

Paula Szkody & George Djorgovski

Time Domain Astronomy (TDA)

- Scientific motivation and opportunities
  - A very rich variety of astrophysical phenomena
  - Time domain providing unique new insights
- Existing and forthcoming event factories
  - From ~ 10^1 - 10^2 to ~ 10^5 - 10^6 events/night ⇐ **A qualitative change!**
- Observational follow-up needs
  - Rapid photometric/positional monitoring
  - Rapid spectroscopy
- Software and computational needs
  - Virtual Observatory environment / VOEvent concept
  - The necessity of automation
- Recommendations
  - Dedicated facilities and changes in the way we do business

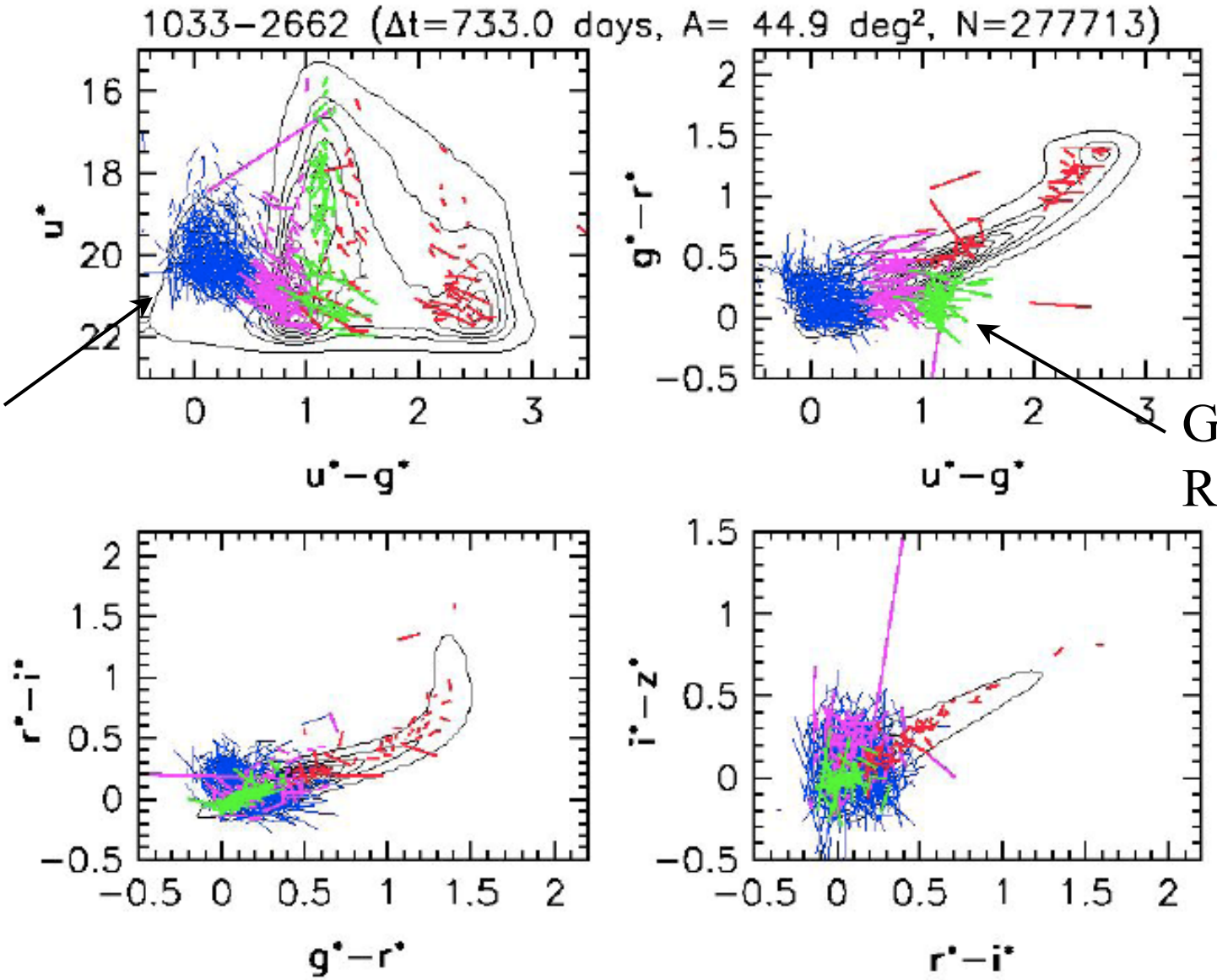
The Rich Variety of Time Domain Science

- **Solar system:** Sun, surface phenomena on moons and planets, KBOs and dwarf planets, Earth-crossing asteroids, …
- **Variable stars:** stellar physics, oscillations, flares, distances, probes of Galactic structure …
- **Stellar explosions:** GRBs and SNe as probes of endpoints of massive star evolution, standard candles, relativistic phenomena
- **AGN:** physics of accretion, SMBH masses, beaming …
- **Lensing and microlensing phenomena:** stellar physics, nature and distribution of dark matter, distances and H_0 …
- **Non-Electromagnetic sources** and their origins: UHECR, UHE neutrinos, GW bursts from merging black holes, …
- **Possible new types of objects and phenomena**

… etc., etc.

SDSS Variability Studies: *(Ivezic et al.)*

$\Delta t \sim 2$ years. Variability vectors in the color space

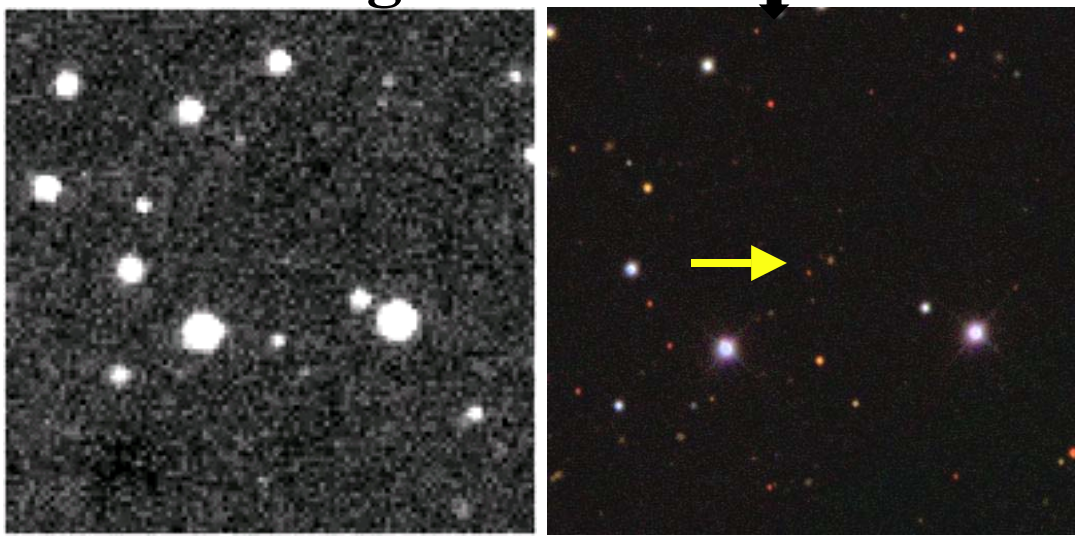


Blue: QSOs

Green: RR Lyrae

From Mundane to Profound …

Flaring M dwarfs

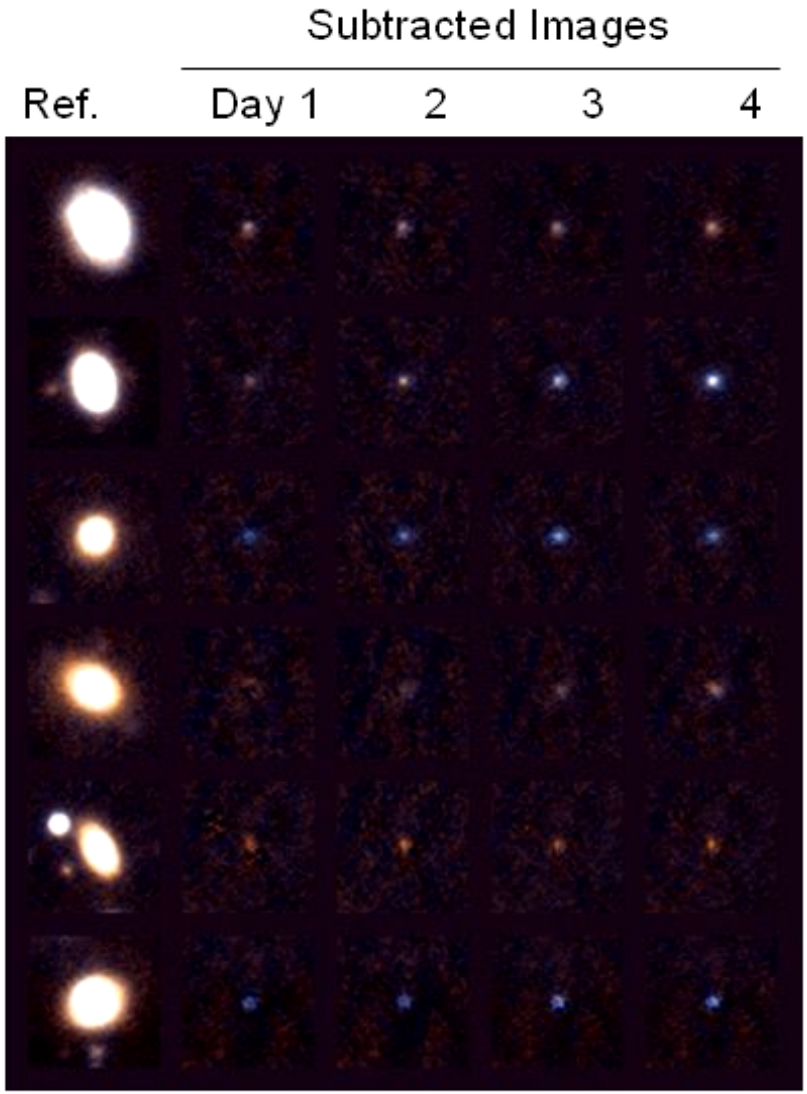


Lynx OT
(Catalina Sky Survey)

SDSS Counterpart

Possible tidal disruption flares

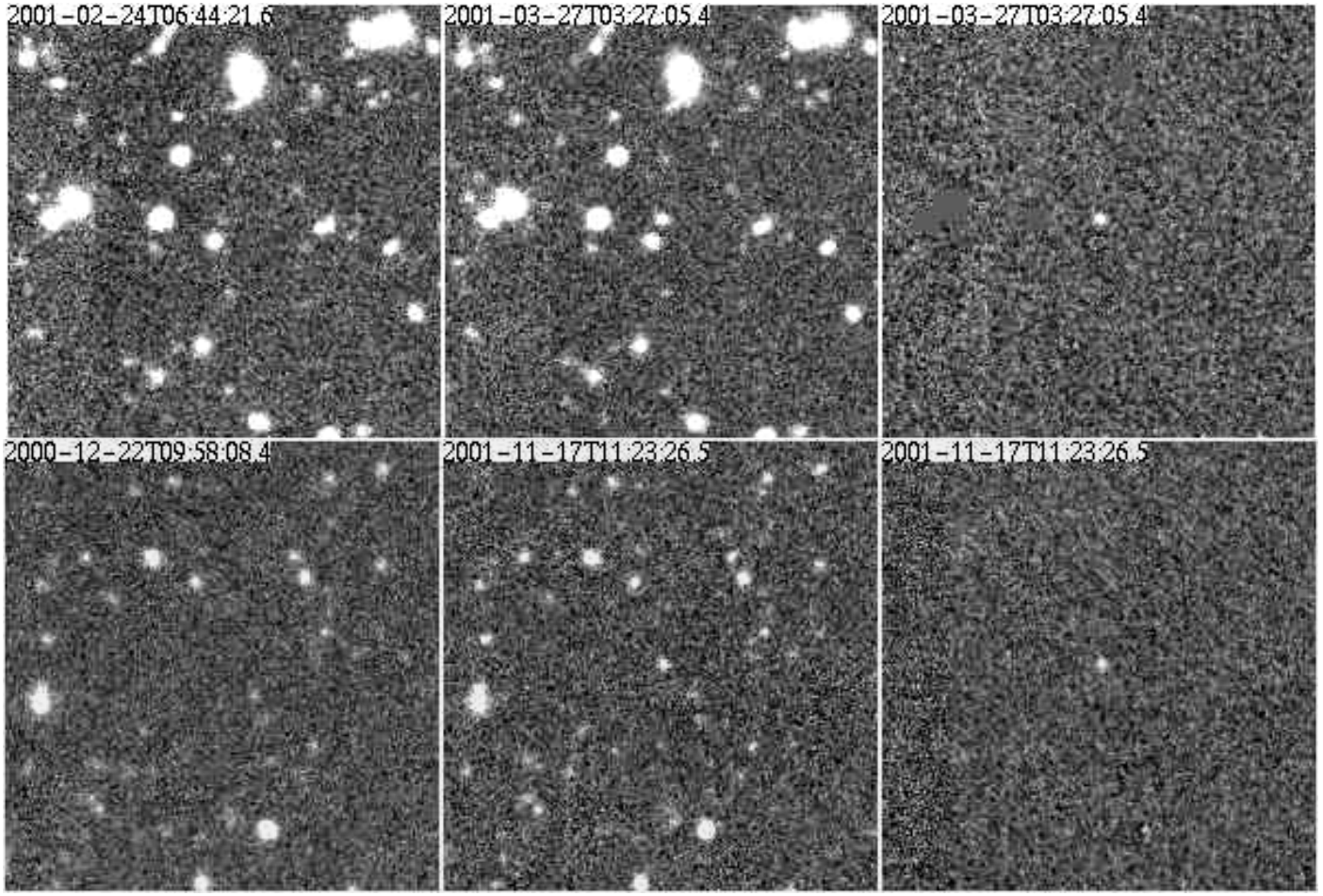
Expected rate ~ 10^{-4} /galaxy/yr, L_{peak} ~ 10^{44} erg/s, E_{tot} ~ 10^{50} erg, probably seen in X-ray, maybe in UV (GALEX)



Totani et al., SUBARU

Faint, Fast Transients From DLS

(Tyson, Becker, et al.)

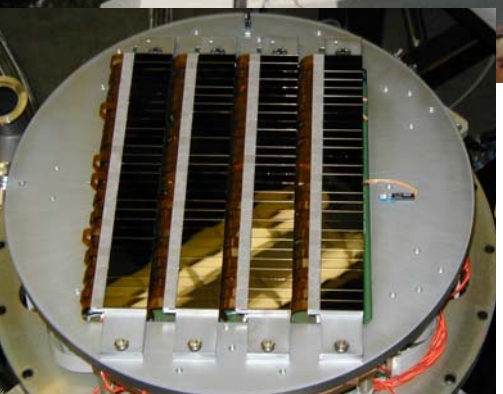


Some are flaring M-stars, some are extragalactic, …

∧ **A heterogeneous population!**

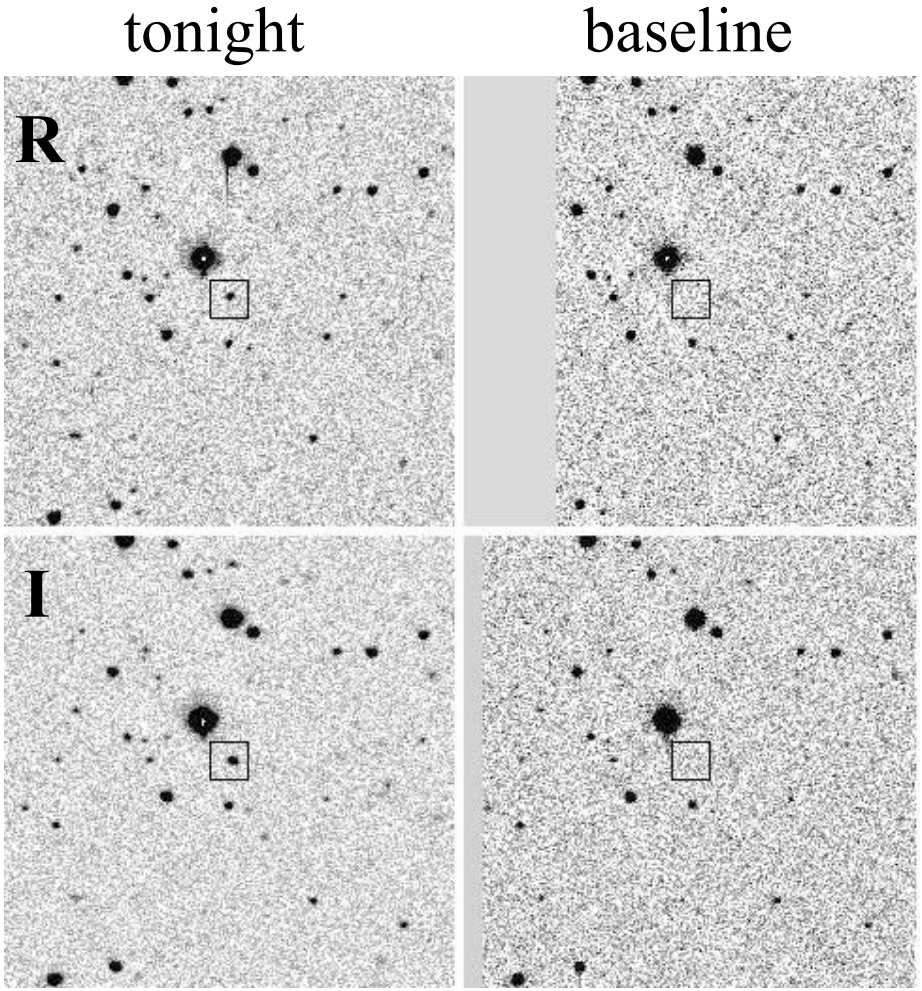
Real-Time Discovery of Transients from the Palomar-Quest survey

A Caltech-Yale collaboration



112 CCD,
161 Mpix
Camera

Examples of optical transients discovered in the real time in Sept.'06, delay time ~ 15 min



Real-time pipeline now in "beta"

Some Things We Have Learned

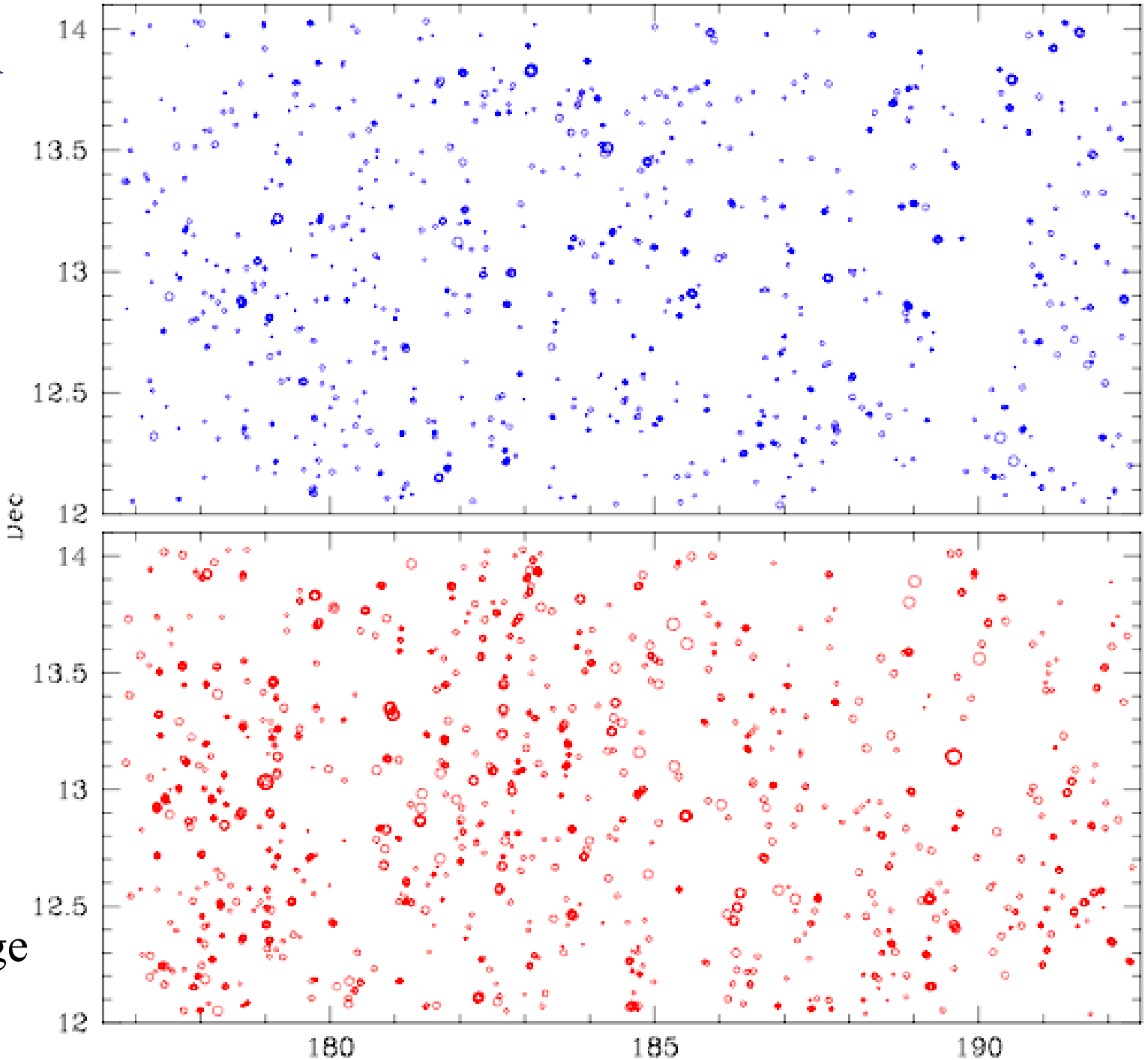
- In a snapshot survey (a single pass), there are ~ 1000 transients/sky down to ~ 20 - 21 mag
- There are ~ 1 - 3 asteroids / deg^2 down to the same depth, depending on the Ecliptic latitude; i.e., ~ 100 asteroids for each transient
  - *A joint asteroid / transient analysis is necessary*
- Most of the transients and variables are known types of objects; stars dominate on short time scales (~ minutes to months), AGN on longer time scales (~ years and beyond)
- Populations of as yet unidentified transients do exist
  - *Real-time follow-up is necessary* in order to understand them
  - Some may be new types of objects or phenomena

Asteroids in the BigPic area

New ^

Previously known ^

Area = 30.4 deg^2, average ~ 10 passes



The Evolving TDA Landscape

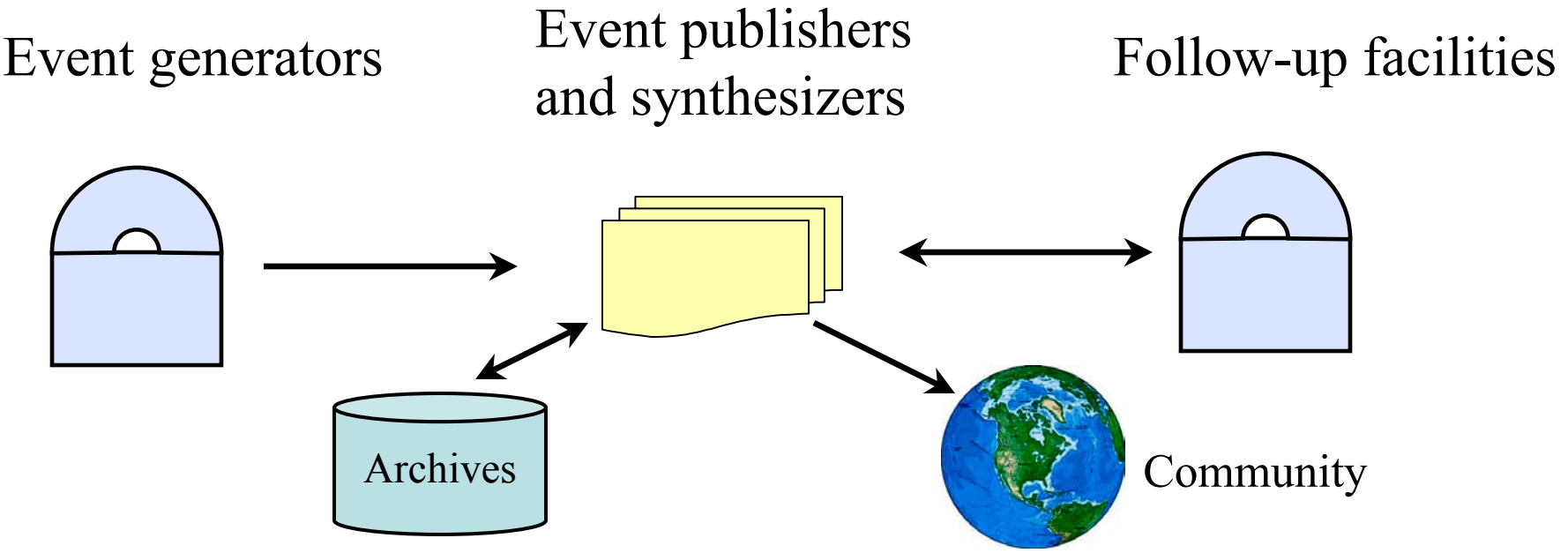
- General surveys vs. dedicated experiments
- Other wavelength regimes also important (radio, high energy, non-EM)
- Now: data streams of ~ 0.1 TB/night, ~ 10^2 transients/nt. (SDSS, PQ, various SN surveys, asteroid surveys)
- Forthcoming on a time scale ~ 1 - 5 years: ~ 1 TB/night, ~10^4 transients/night (PanSTARRS, Skymapper, VISTA, VST)
- Forthcoming on a time scale ~ 5 - 10 years: LSST, ~ 30 TB/night, ~ 10^5 - 10^6 transients/night

∧ **An increasing prominence of TDA**

∧ **The necessity of automated and dedicated follow-up**

The time to start is now!

A Systemic View of TDA



Synoptic, panoramic surveys ∧ event discovery

Rapid follow-up and multi-λ ∧ keys to understanding

The same synoptic survey data streams can (and do) serve multiple scientific goals; and the same infrastructure can serve multiple follow-up needs - but a systemic integration is needed

The General Follow-Up Needs

Follow-up facilities
- Dedicated, synoptic monitoring
- Disruptive TOOs for unique/general obs.

Photometric Π Spectroscopic
(~ 1-2 m class) (~ 4-10 m class)

Issues to consider:

- Rapid response - on what time scales?
- Convert existing telescope, or build new, specialized ones?
  - Consider different operation modes
- Build standardized instruments (e.g., multi-channel imagers)
  - But allow for special purpose, innovative instruments, e.g., fast photometers, polarimeters, etc.

Provide an adequate data and software environment for event publishing, archiving, and analysis

Computational and Data Challenges Posed by Synoptic Sky Surveys

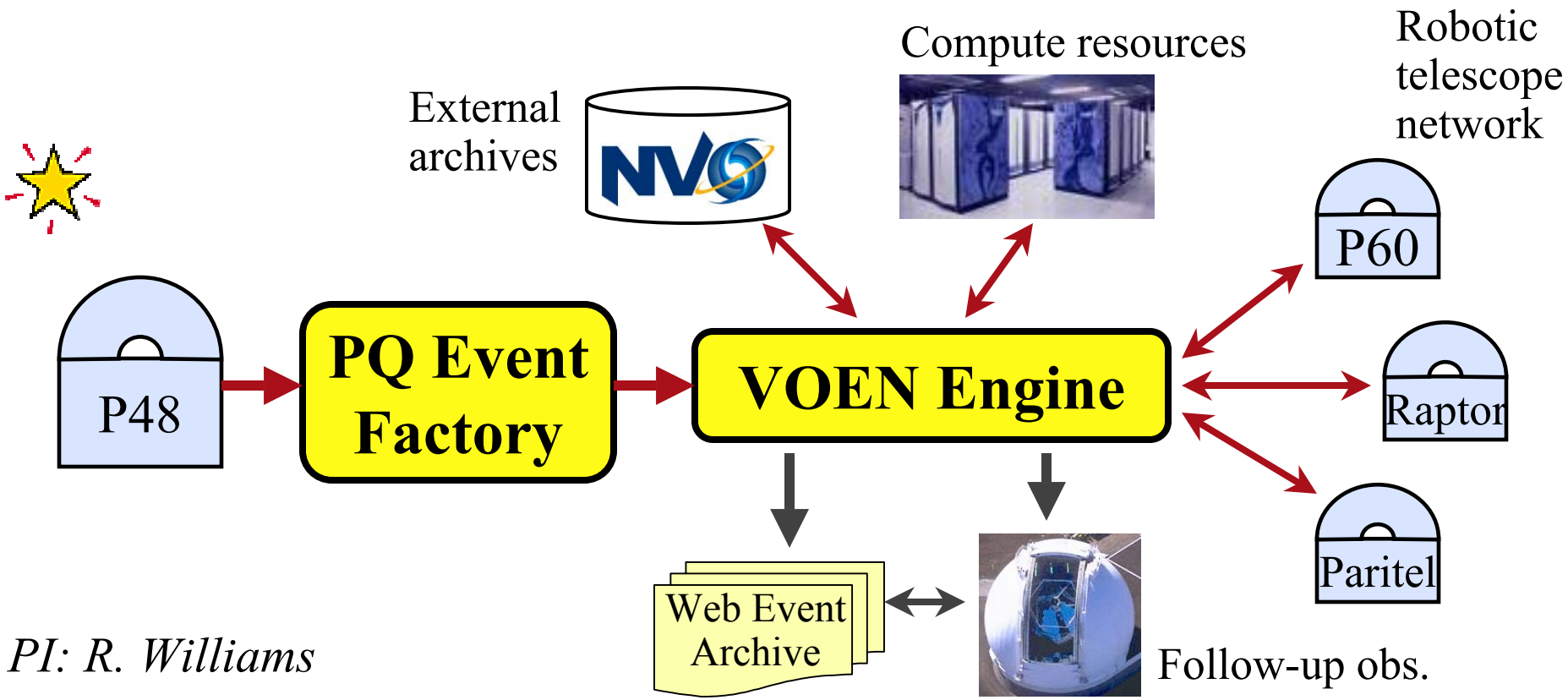
- Data streams: from ~ 0.1 TB/night to ~ 30 TB/night, from ~ 10^2 transients/night to ~ 10^5 transients/night
  - Automated, reliable, adaptive data cleaning
  - High volume data generators $\wedge$ lots of glitches
  - Cutting-edge systems $\wedge$ poor stability
- Rapid, automated response $\wedge$ No humans in the loop
  - Automated, reliable event classification and alert decisions
  - Dynamical data analysis: sparse data from the event originator; folding in heterogeneous external data
  - VOEvent standards for event publishing / follow-up
- High completeness / Low contamination ☯
- Integrate event discovery and multi-λ follow-up

Virtual Observatory Environment for TDA

- The need for a standard event reporting (publishing) and archiving environment; for humans and robots both
  - The VOEvent standard
  - Event generators, publishers, brokers, consumers
  - Easy to plug in, easy to join
- The need for a multi-wavelength data federation/fusion
  - A key to the physical interpretation?
- Access to serious computation resources (astronomy grid)
- Must be scalable for large data and event stream volumes
- Open data environment for TDA; data rights issues
- Is TDA the “killer app” of Virtual Observatory?
- New, distributed software systems, e.g., VOEventNet

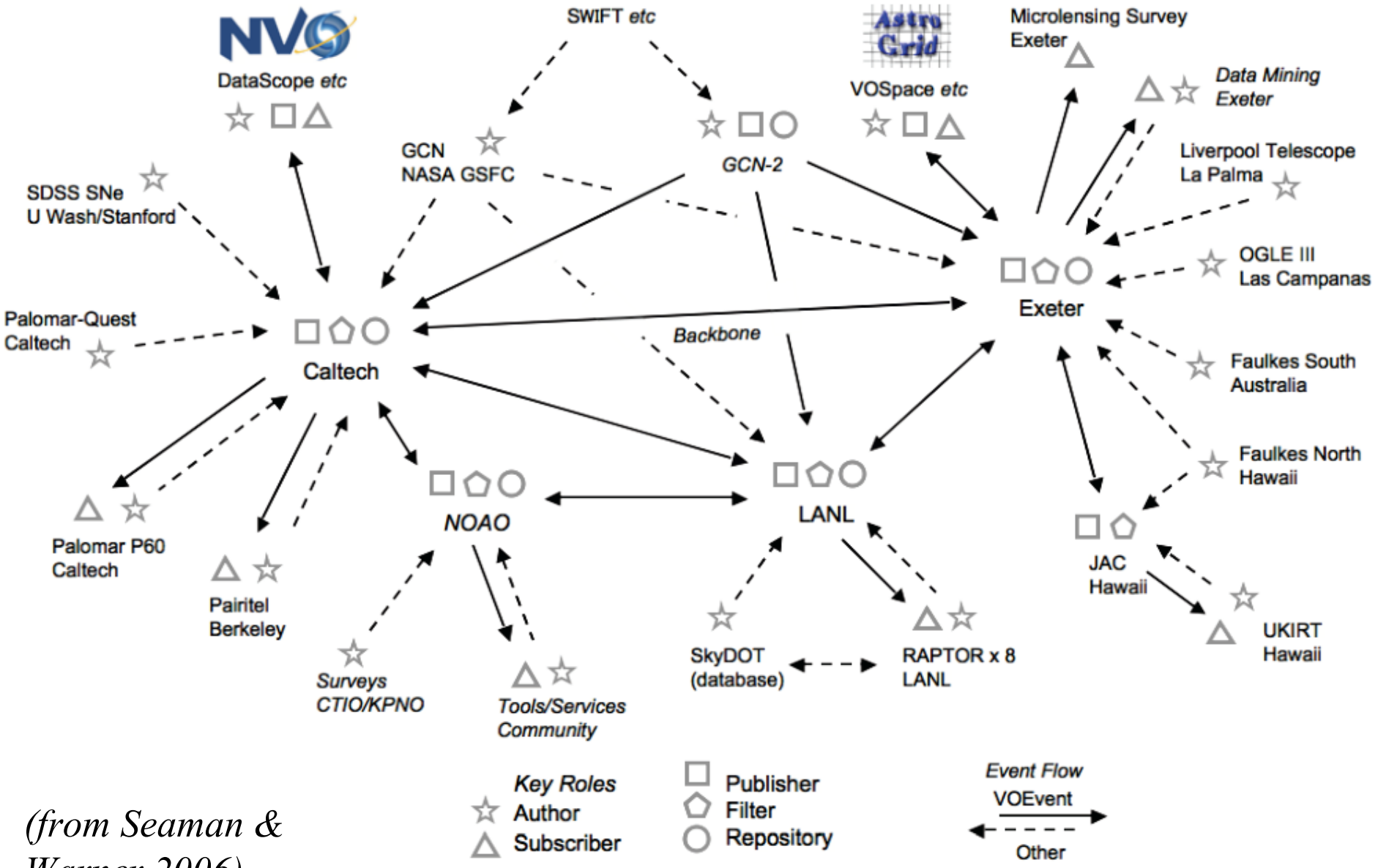
The VOEventNet Pilot Project

- A telescope sensor network with a feedback
- Scientific measurements spawning other measurements and data analysis in the real time
- Please see **http://voeventnet.org**



PI: R. Williams

The Emerging Global VOEvent Network



(from Seaman & Warner 2006)

Recommendations: Follow-Up Facilities

- There is a growing need for dedicated TDA follow-up facilities, both imaging and spectroscopic; this will become critical as we approach the LSST era
- Evaluate the relative merits of conversion of existing telescopes and instruments, vs. building of new, specialized/optimized ones; what is the optimal mix?
- Use the TSIP program to enhance the TDA capabilities:
  - Make it science-based rather than aperture-based
  - Large telescopes: some are more TOO-capable, use TSIP to buy compensating (non-TOO) access on others
  - Small telescopes: dedicate some to synoptic follow-up only, compensate non-TDA users with TSIP time elsewhere
- Enable a broader instrum. development, e.g., polarimetry

Recommendations: Software Environment

- The relative importance and cost of software is growing, and should be addressed carefully in any TDA planning
  - Funding sources outside the NSF AST should be explored
- Establishment of standards is essential for an optimal, system-wide approach to TDA
  - Expand on the VOEvent work
- Rapid access to data is needed to assure maximum scientific returns
- VO environment provides a natural and effective framework to address these needs
- Establishment of such practices and infrastructure now is critical for an efficient use of the LSST and other major forthcoming synoptic surveys

Recommendations: Plans and Policies

- Need to explore the following issues:
  - Encouragement of an "open data" policy
  - Data access rights vs. observing time ownership
  - Prioritization for automated observing modes
  - The evolving role of TOO in the data glut regime
- Enhance the dialog with the "asteroid" community for joint data generation and analysis, system-wide
- Start the planning process now
  - Near term: start a (partial?) conversion of some of the existing facilities into a coordinated system of dedicated follow-up TDA facilities; use TSIP to facilitate this
  - Long term: develop and build new follow-up facilities
- Form a task force to address these issues in more detail