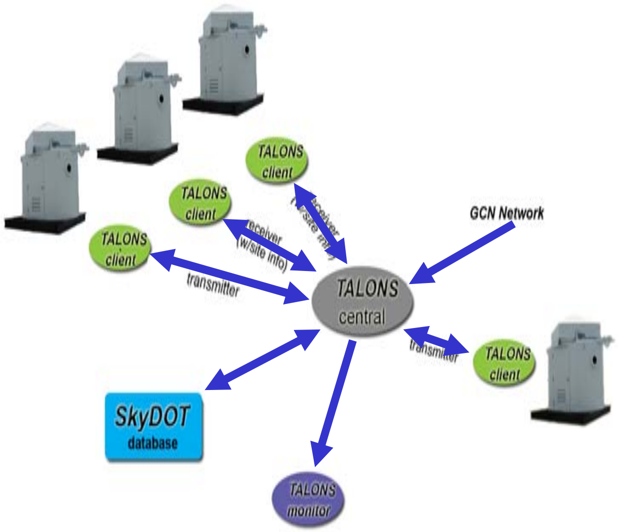
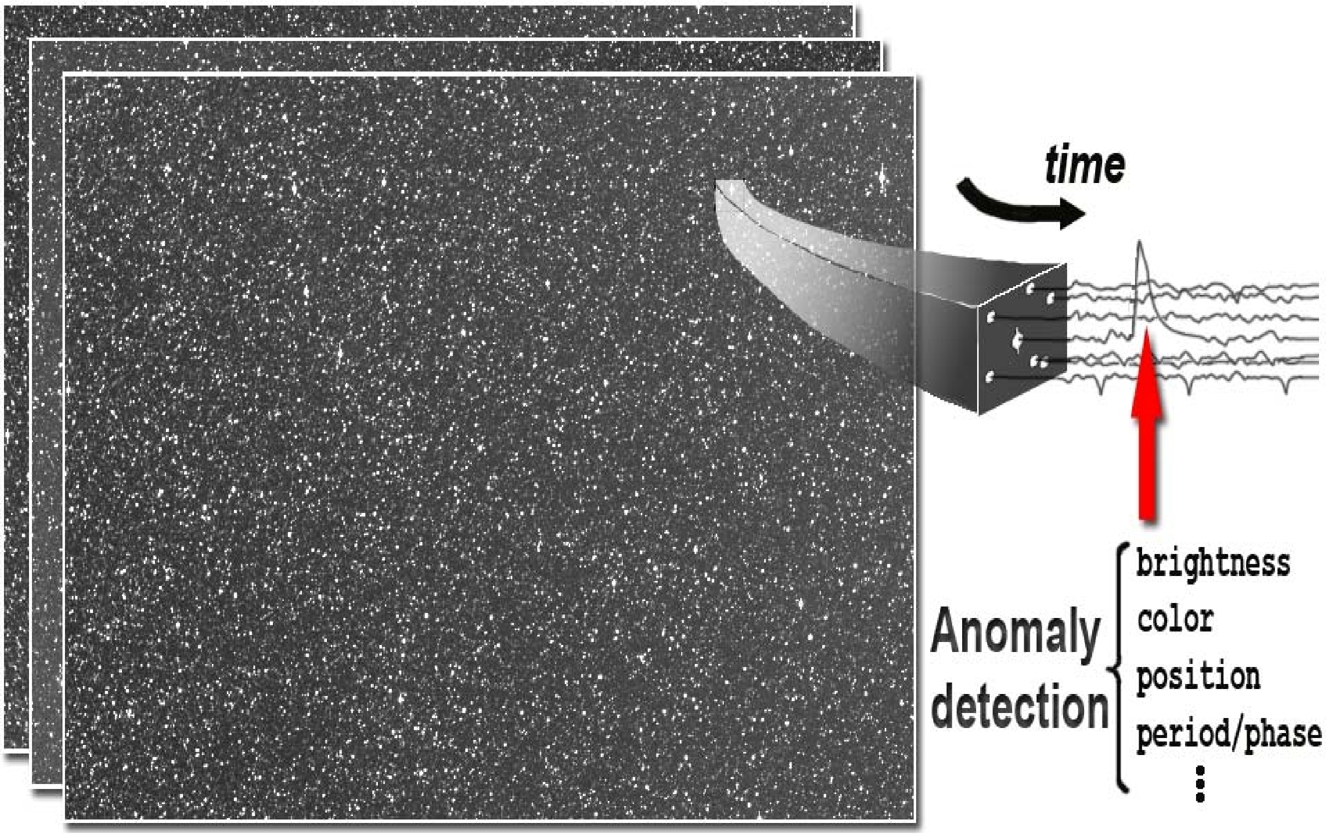
Fast, Bright, Optical Transients

Tom Vestrand and the RAPTOR/”Thinking” Telescopes Team



How do we find orphans as well as important changes in persistent sources and respond in real time?



We have reached the tipping point

- Time Domain Surveys (e.g. LSST) will generate 100 Petabytes of data (~2 Terabyte per hour) that must be mined in real time by the end of the decade.
- More than 10 Billion objects will be monitored for important variations in real time.
- Humans lack attention span, response time, and memory required to monitor the data, recognize important variations, and respond.

Need Integration of Three Components

Robotic Hardware

Wide-Field Sky Monitoring
Rapid Response Telescopes,
Real Time Pipeline

Machine Learning

GENIE,
ML Classifiers,
Anomaly Detection

Context Knowledge

Record of Sky variability (Virtual Observatories),
Massive Distributed Disk Array

Thinking Telescopes

An Engine for Discovery in the Time Domain

System Adaptability: Querying the Sky

Old Approach

- “Hard Wired” to find specific artifacts and phenomena
- not in previous frame, not in sky catalog, ….

New approach

Thinking Telescope—

Monitoring of persistent sources for important changes in real time

- Adaptive processing
- Machine learning
- Anomaly detection and automated classification
- “find more like this”
- “ignore that”

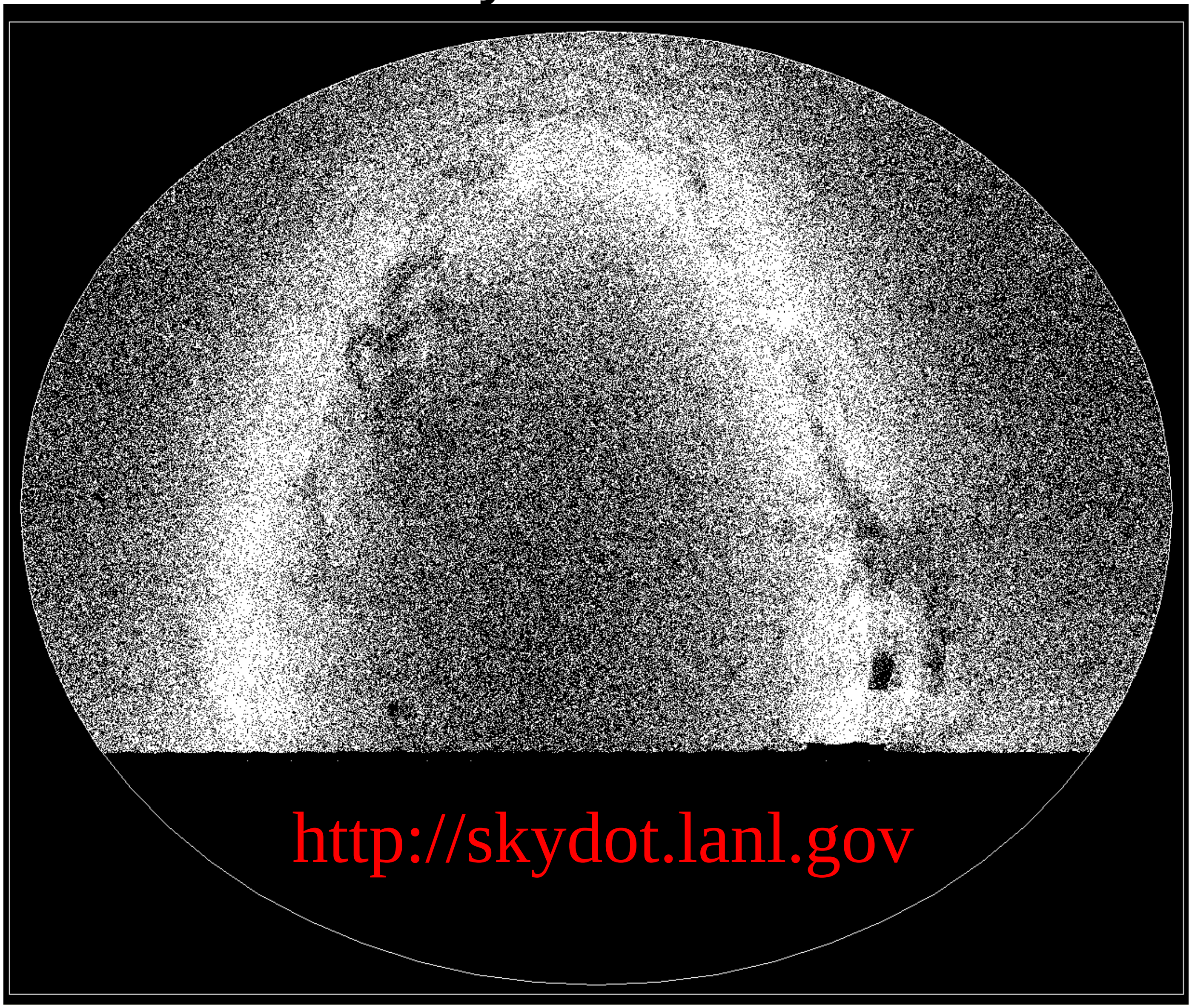
Three Types of Machine Learning

Automated Feature Extraction: Real time identification of artifacts and transients in direct and difference images.

Classifiers: Automated classification of celestial objects based on temporal and spectral properties.

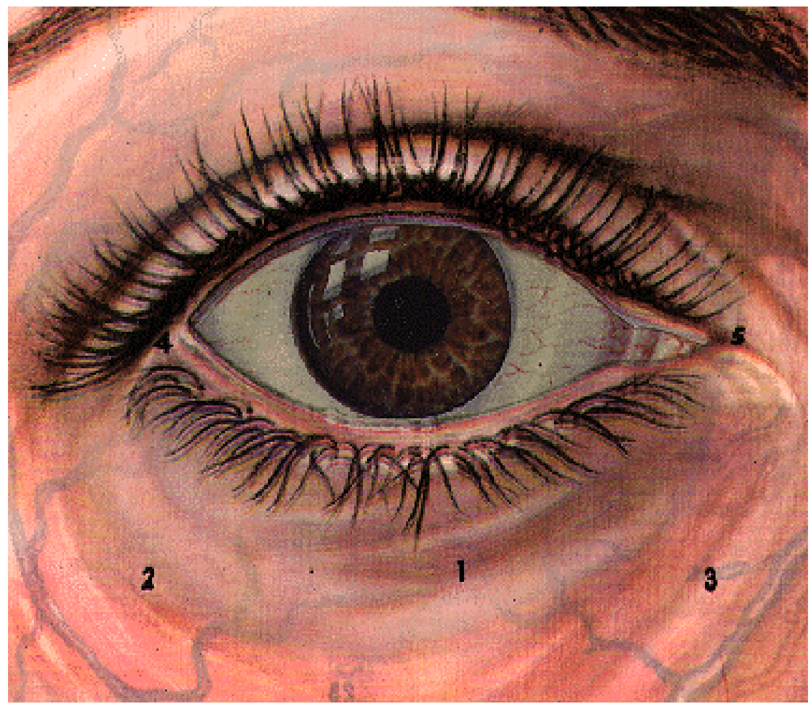
Anomaly Detection: Real time recognition of important deviations from normal behavior for persistent sources.

Memory and Context



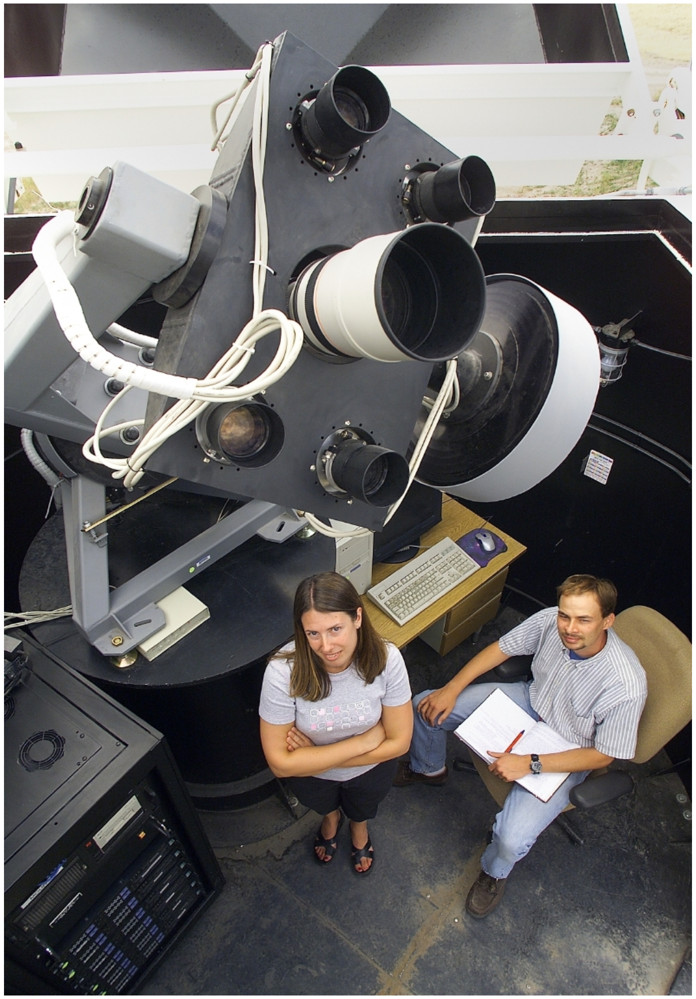
Human Vision:
A “Closed Loop” Real Time System

- Wide-field, low resolution imaging by rods cells of retina
- Narrower field, higher spatial resolution imaging by cone cells of fovea---yields color information
- Binocular vision---for distance information and correction of image defects
- Processor running complex real time software---the brain
- Eyes are rapidly slewing to quickly point the fovea for follow-up observations
- Brain has an adaptive catalog---our memory

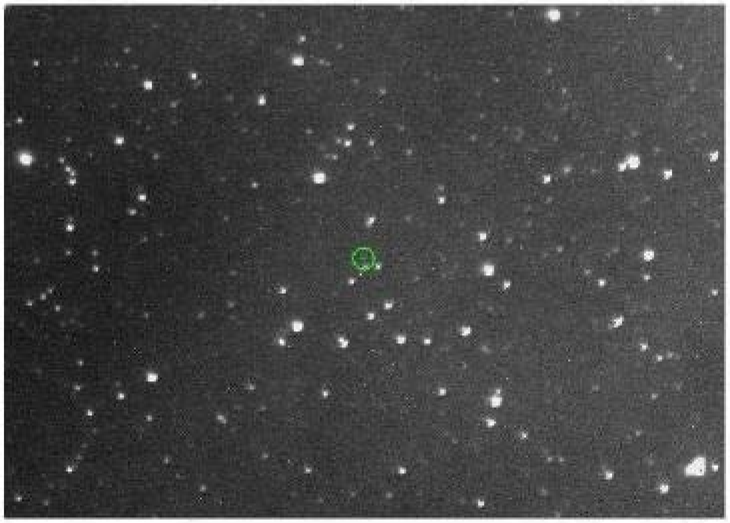


Raptor: Sky Monitoring with Both Eyes Open

- Wide-field imaging system monitors ~1300 square-deg with resolution ~35 arcsec and limiting magnitude of R~13th in 60 seconds. (like the rod cells of the retina)
- Each array has a "fovea" telescope with limiting magnitude of R~16.5 (60 sec), resolution of ~7 arcsec and Gunn g (or r) filter. Provides color, better resolution, and faster cadence light curves (cone cells of fovea)
- Rapidly slewing mount places the "fovea" anywhere in the field in <3 seconds. (rapid eye movement).
- Two identical arrays are separated by ~38 km. (stereoscopic vision)

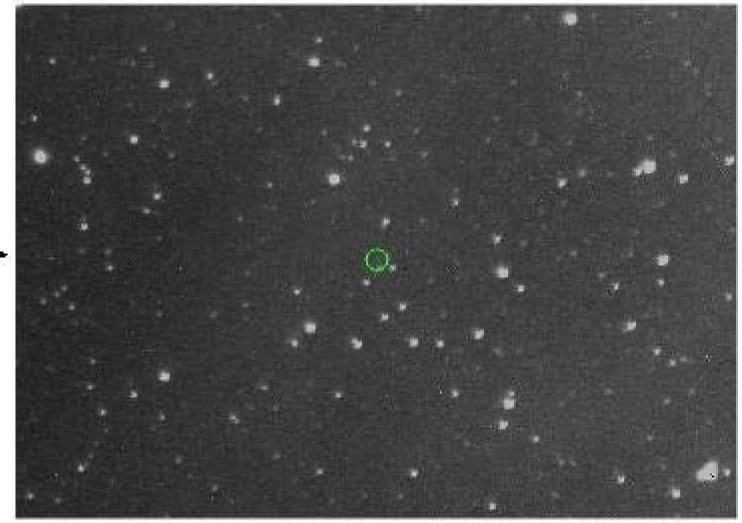


RAPTOR Trigger and Follow-Up: Asteroid 7 Isis

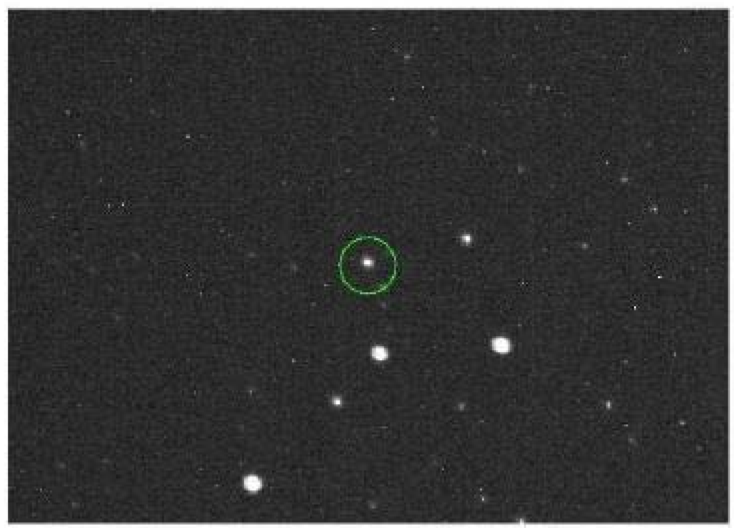


Raptor-A Wide Field Image

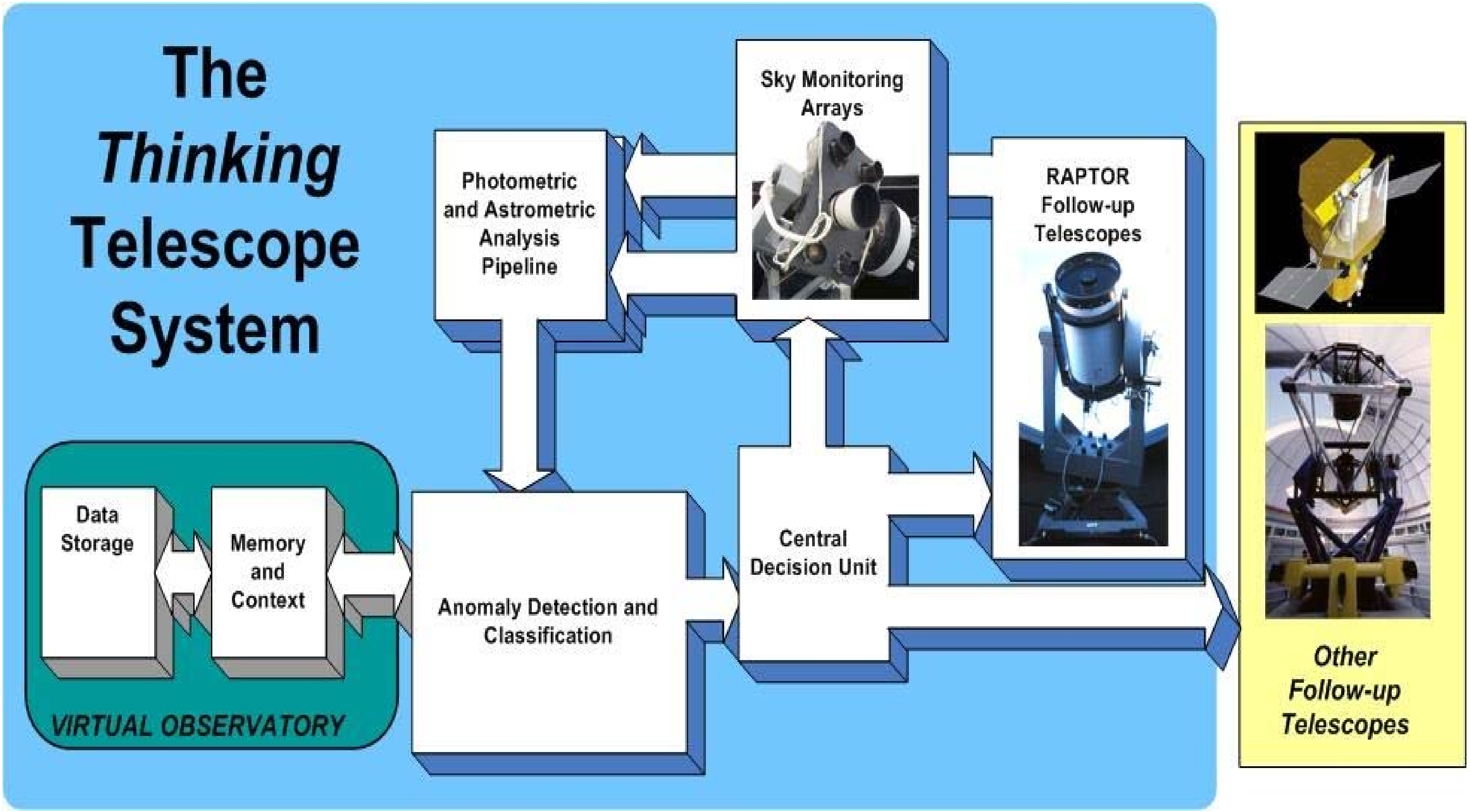
38 km



Raptor-B Wide Field Image

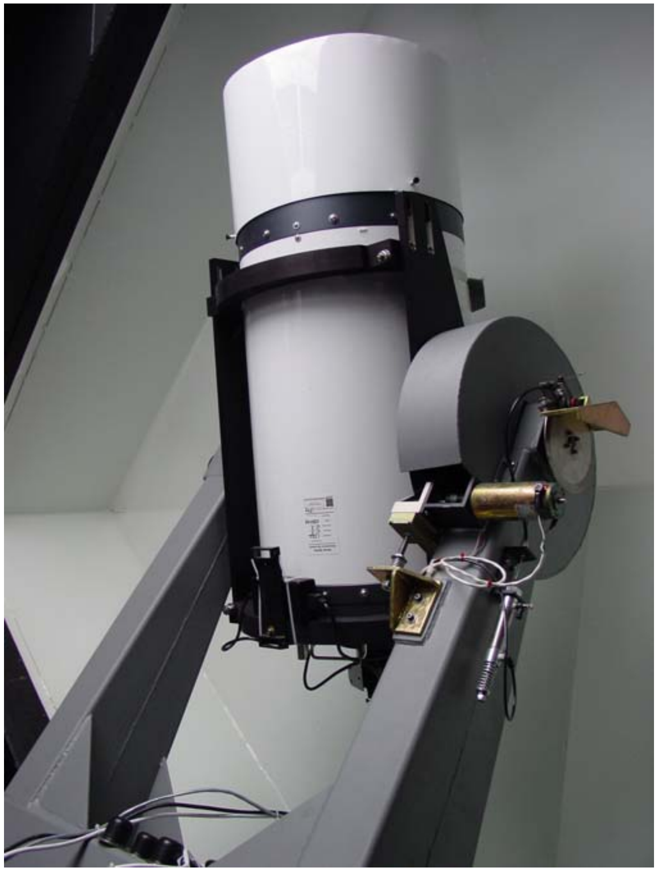


Raptor-A Fovea Follow-Up Image: 3 second response time



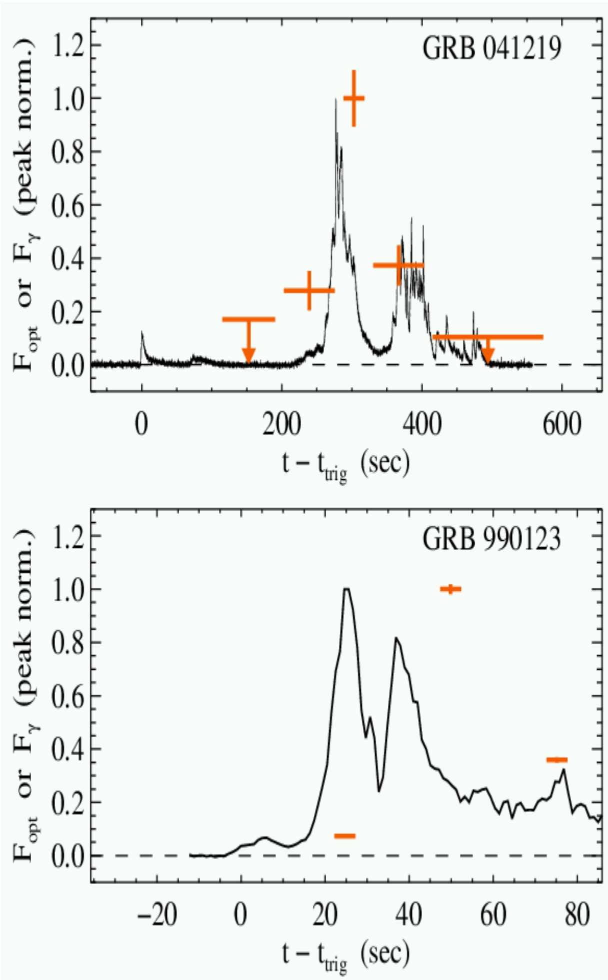
Los Alamos NATIONAL LABORATORY

A more powerful fovea telescope….

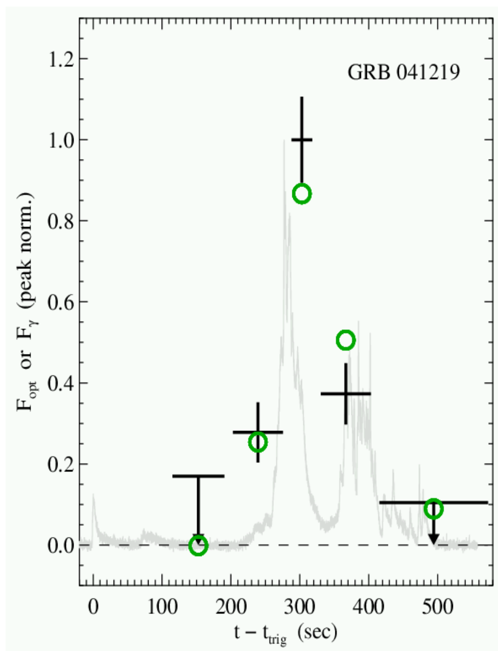


- Deployed RAPTOR-S in October/November 2004 telescope for studying the optical emission from gamma ray bursts during the critical first few minutes after a GRB----slew speed >100 deg/second, acceleration >100 deg/sec^2, can go anywhere in the sky and begin imaging in <10 seconds (single-tube prototype for RAPTOR-T)

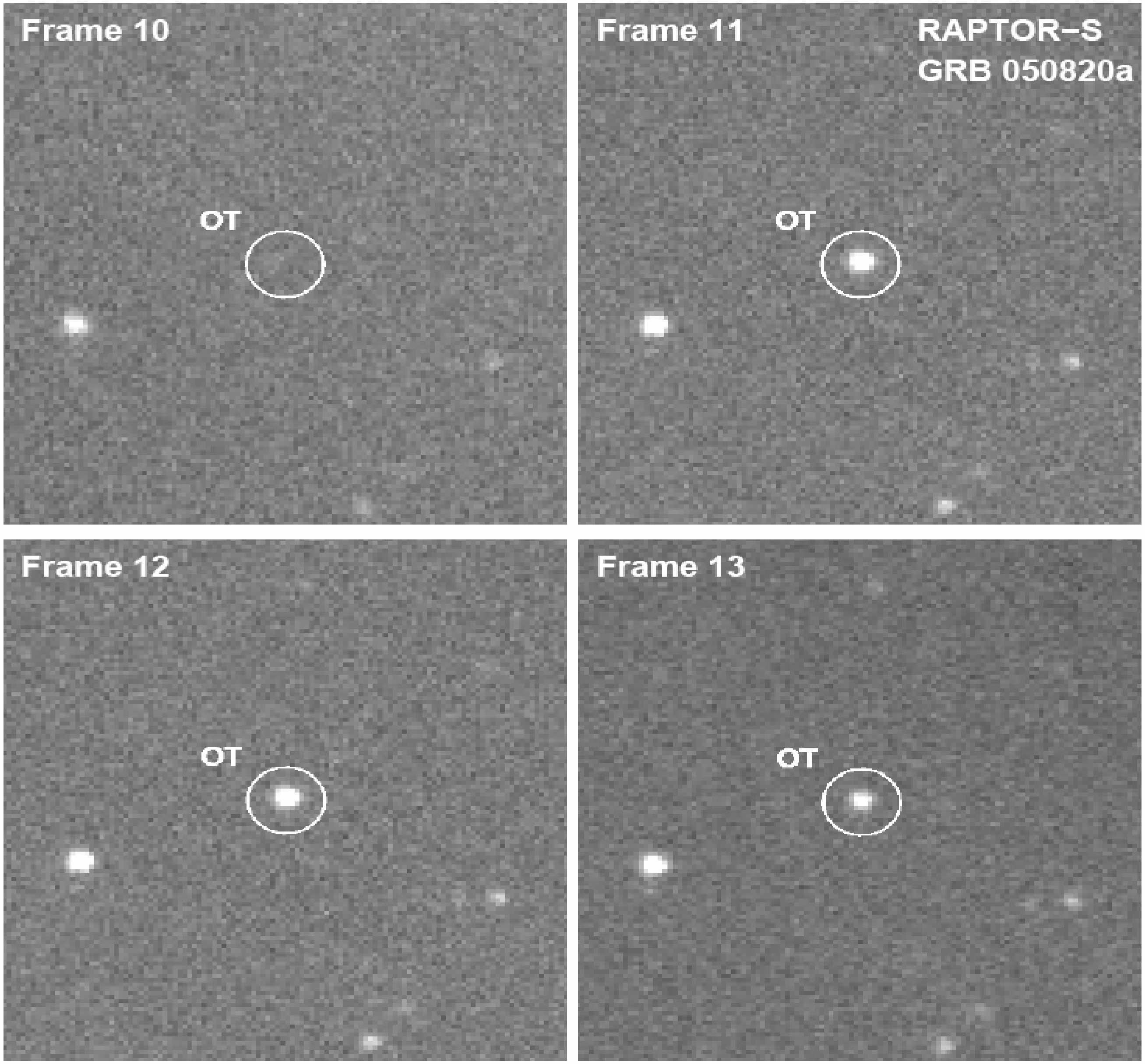
Prompt Optical Emission from GRBs



A new taxonomy for optical emission from GRBs (Vestrand et al., Nature, 435,178, 2005).



1) Prompt Optical Emission varying simultaneously with prompt gamma-rays.
2) Early Afterglow Emission that may start during prompt gamma-rays, but persists after gamma-rays fade.
3) Late Afterglow Emission that can last for hours to days.



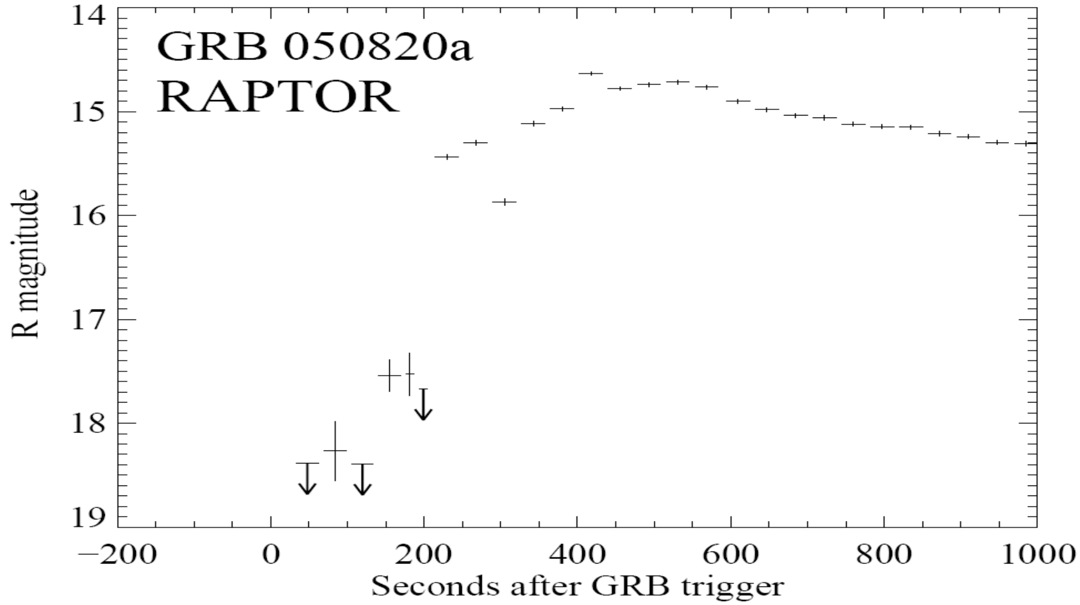
Frame 10
OT
Frame 11
RAPTOR-S
GRB 050820a
OT
Frame 12
OT
Frame 13
OT

GRB 050820a

RAPTOR

Optical

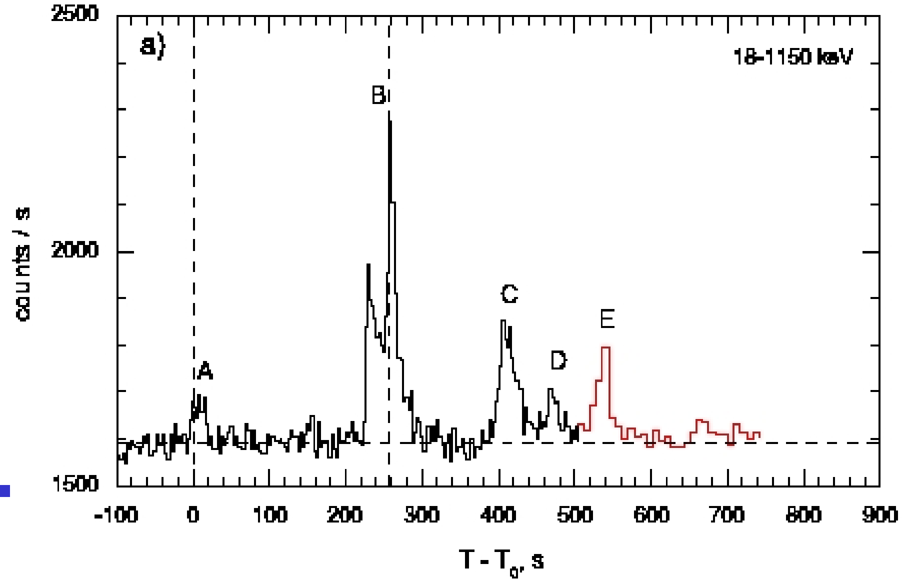
Lightcurve



KONUS

Gamma-Ray

Lightcurve



vestrand

Simple Conjecture

Prompt Optical:

$$F_p(t) = C_p F_\gamma(t) \qquad (1a)$$

Optical Afterglow:

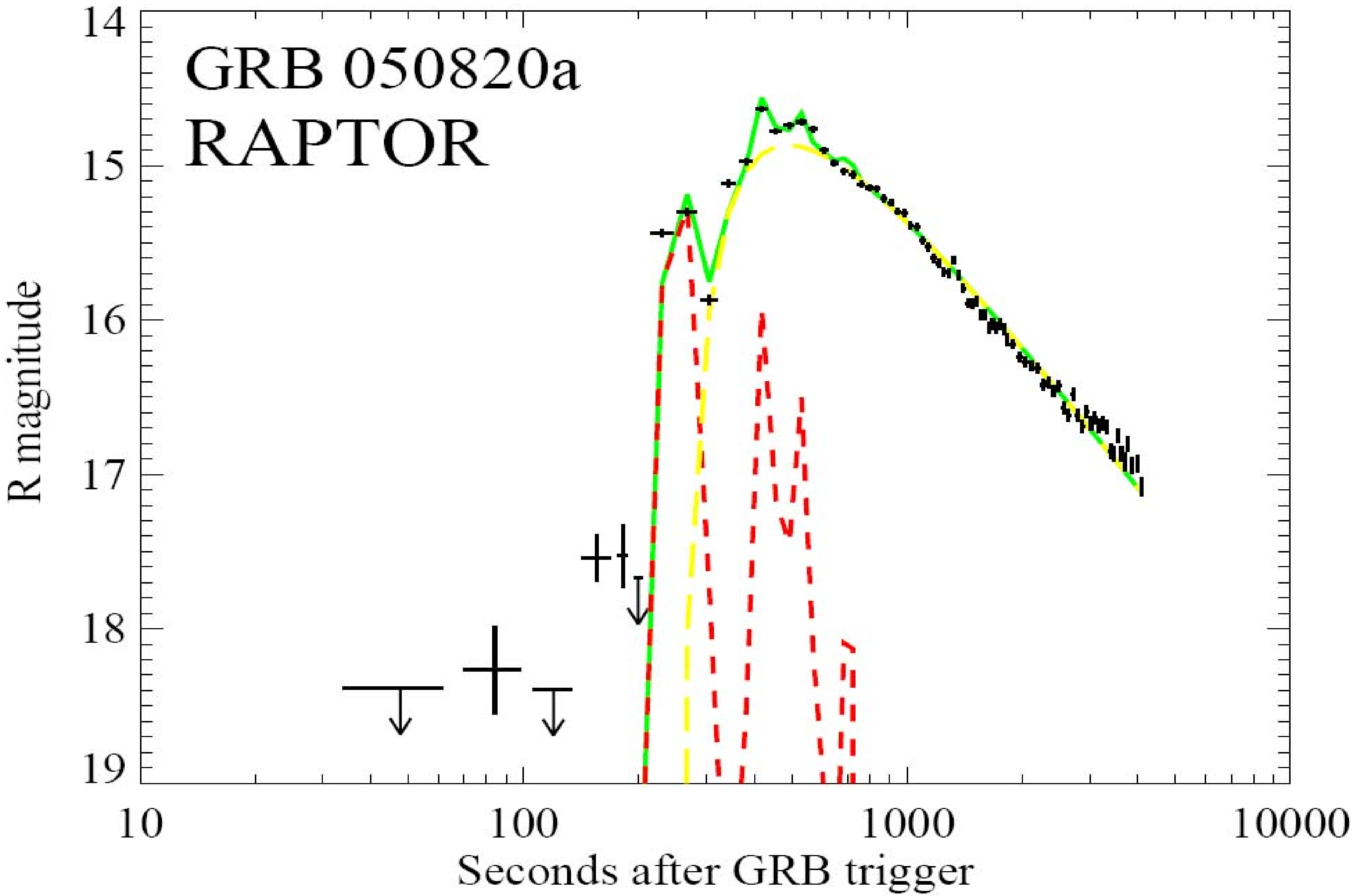
$$F_a(t) = C_a \left(\frac{t - t_0}{t_0}\right)^{-s} \exp\left(\frac{-\tau}{t - t_0}\right) \qquad (1b)$$

$C_p, C_a \equiv$ Component amplitudes

$t_0 \equiv$ Onset of energy release

$\tau \equiv$ Flux rise timescale

$s \equiv$ Power − law decay index


GRB 050820a
RAPTOR
R magnitude
14
15
16
17
18
19
10
100
1000
10000
Seconds after GRB trigger

Timescales* for GRB 050820a

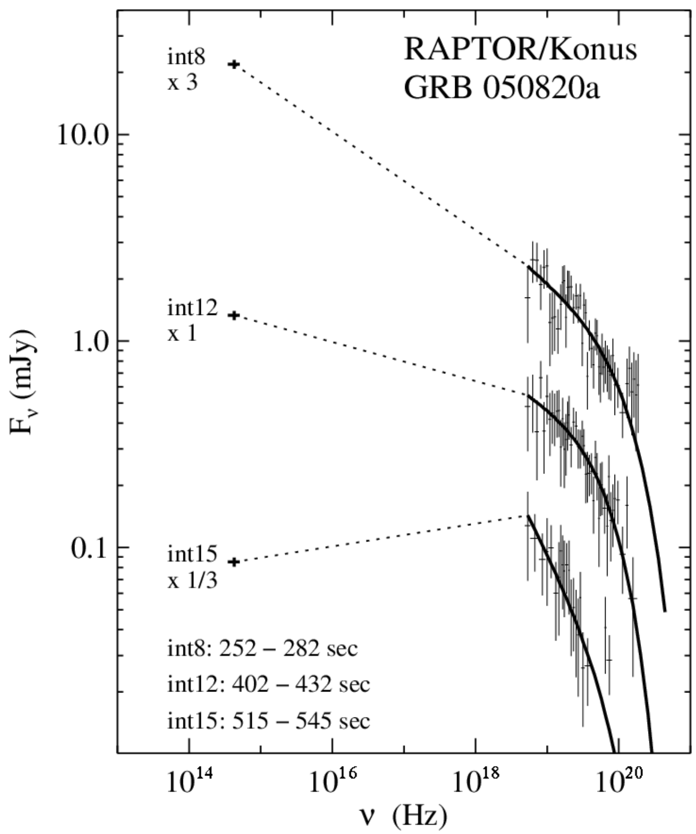
- Early afterglow component has a rise timescale of ~280 seconds after the onset of the prompt gamma-ray, afterglow decays with a power law index of ~1.1
- Prompt optical variability shows no evidence for delays
- t_o time should be measured from the dominant impulse energy release as measured by prompt gamma-rays
- **Evidence for reverberation**

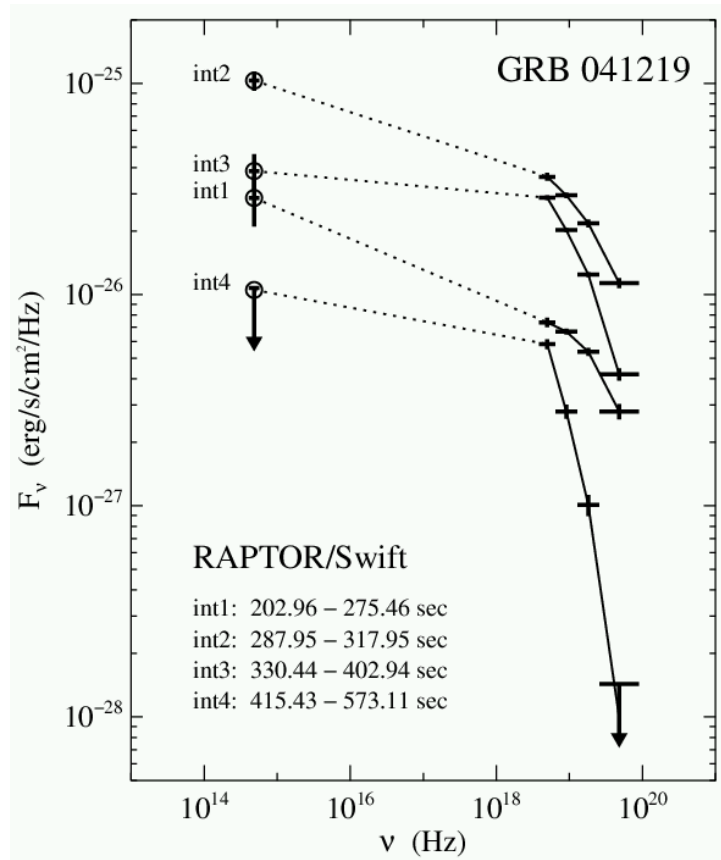
*without correction for the redshift (z=2.6)

In the Standard Theoretical Framework it makes physical sense to attribute the components to

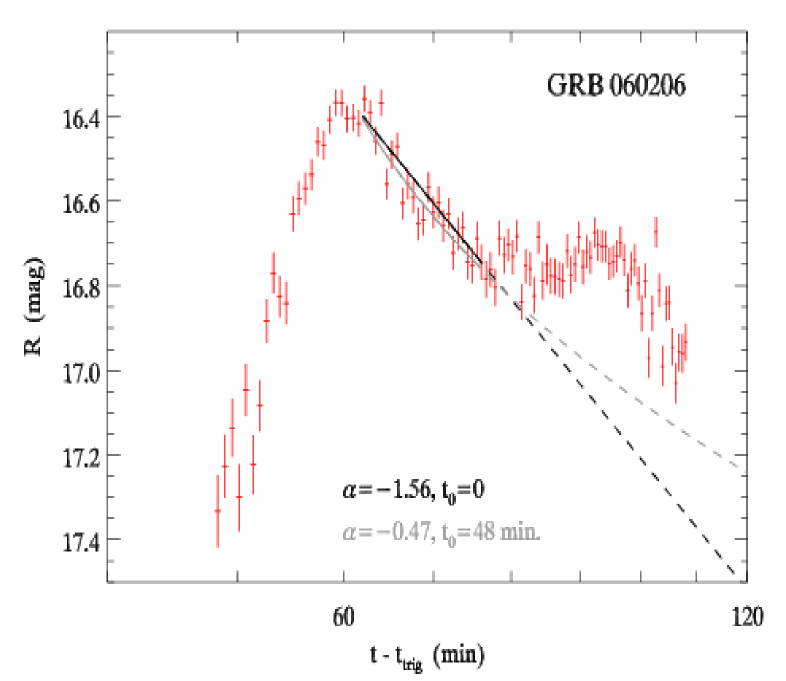
- Prompt optical emission is generated by internal shocks in ejecta---driven by engine.
- Early afterglow is generated by interaction with surroundings.
- Measuring the rise timescale of the early afterglow is a measure of the amount of "stuff" in the explosion environment.

Spectra of Prompt GRB Emission





A Gamma-Ray Faint/ Optically Bright, High Redshift (z=4.045) Transient (GRB 060306)



- Swift (15-350 keV) fluence for trigger pulse $8x10^{-7}$ erg cm^{-2}
- Dramatic optical re-brightening starting about 48 minutes after GRB trigger
- The RAPTOR optical emission corresponds to an E_{iso}~$0.7x10^{50}$ ergs in a narrow UV band (130± 22nm) in rest frame of burst
- Structured or patchy jet?
- "Dirty" fireball?

See Wozniak et al. 2006

RAPTOR Version 2.0 (upgrade this summer)

RAPTOR-T

Four co-aligned 0.4-m telescopes capable of slewing anywhere in the sky in less than ten seconds, simultaneously observing through different broad-band filters.

Science Goals

- **Find fast optical transients without high energy triggers and respond**
- Identify the most distant GRBs to use as cosmological probes
- Make first measurements of spectral evolution of prompt and early afterglow spectra
- Probe circumburst environment

RAPTOR-K

16 telescope array that simultaneously images 10^3 square-degrees of sky to a depth of R~16^{th} in 30 seconds. Full sky on a ten minute circuit.

Summary

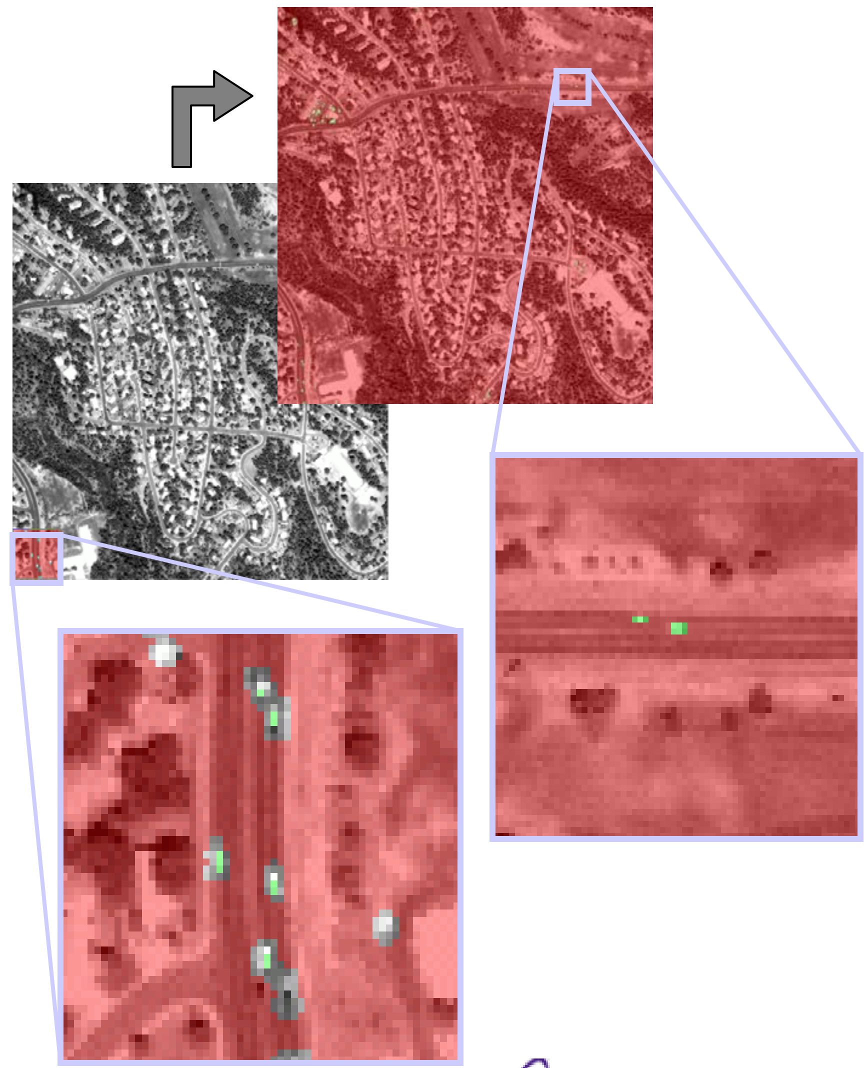
Fast, bright, optical transients exist and some will allow us to probe the high redshift universe in new ways…

But, to effectively study fast optical transients we will need to build full “thinking” systems that monitor the huge volume of data, recognize important variations, and respond in real time without humans in the loop.


http://go.funpic.hu

Supervised Machine Learning

- **Easier to show a machine what to find…**
  - Machine Learning derives classification algorithms directly from examples of data
- **...than to tell a machine how to find it**
  - Requires domain expertise
  - Involves software development
  - Demands careful attention to statistical characterization
  - Entails substantial amount of *trial and error*



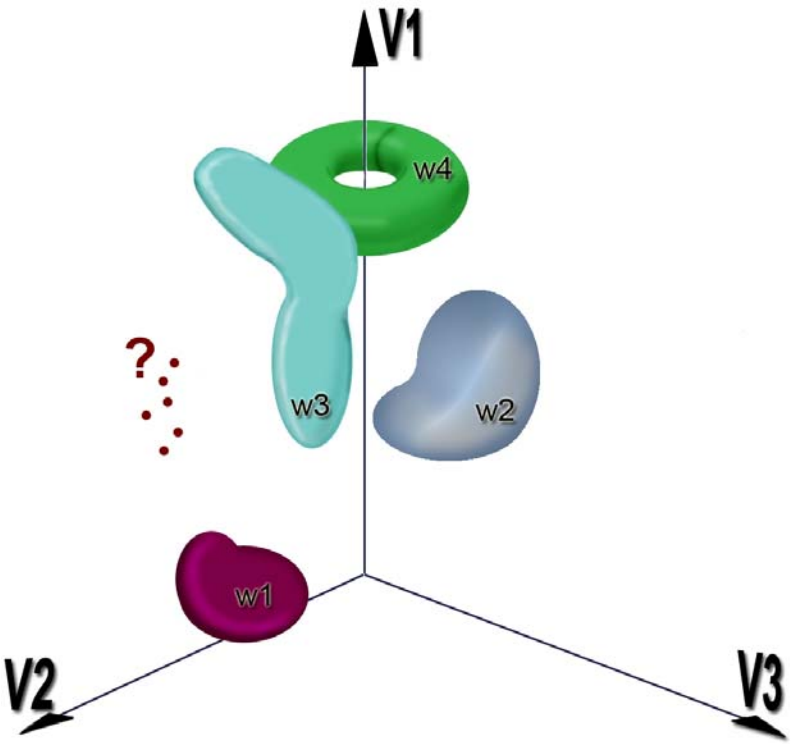
What is an Anomaly?

Dictionary Gives two Definitions—

1) Deviation or departure from the normal or common order, form, or rule

2) One that is peculiar, irregular, abnormal, or difficult to classify.

Anomaly Detection



- Unsupervised machine learning
- Finds things that don't fit in.
- Anomalies do not permit positive definition---***If I knew what they were, we wouldn't call them anomalies.***