Large Synoptic Survey Telescope

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Outline

1. LSST baseline design

   - Monolithic 8.4 m aperture, $\sim$10 deg^2 FOV, 3.2 Gpix camera

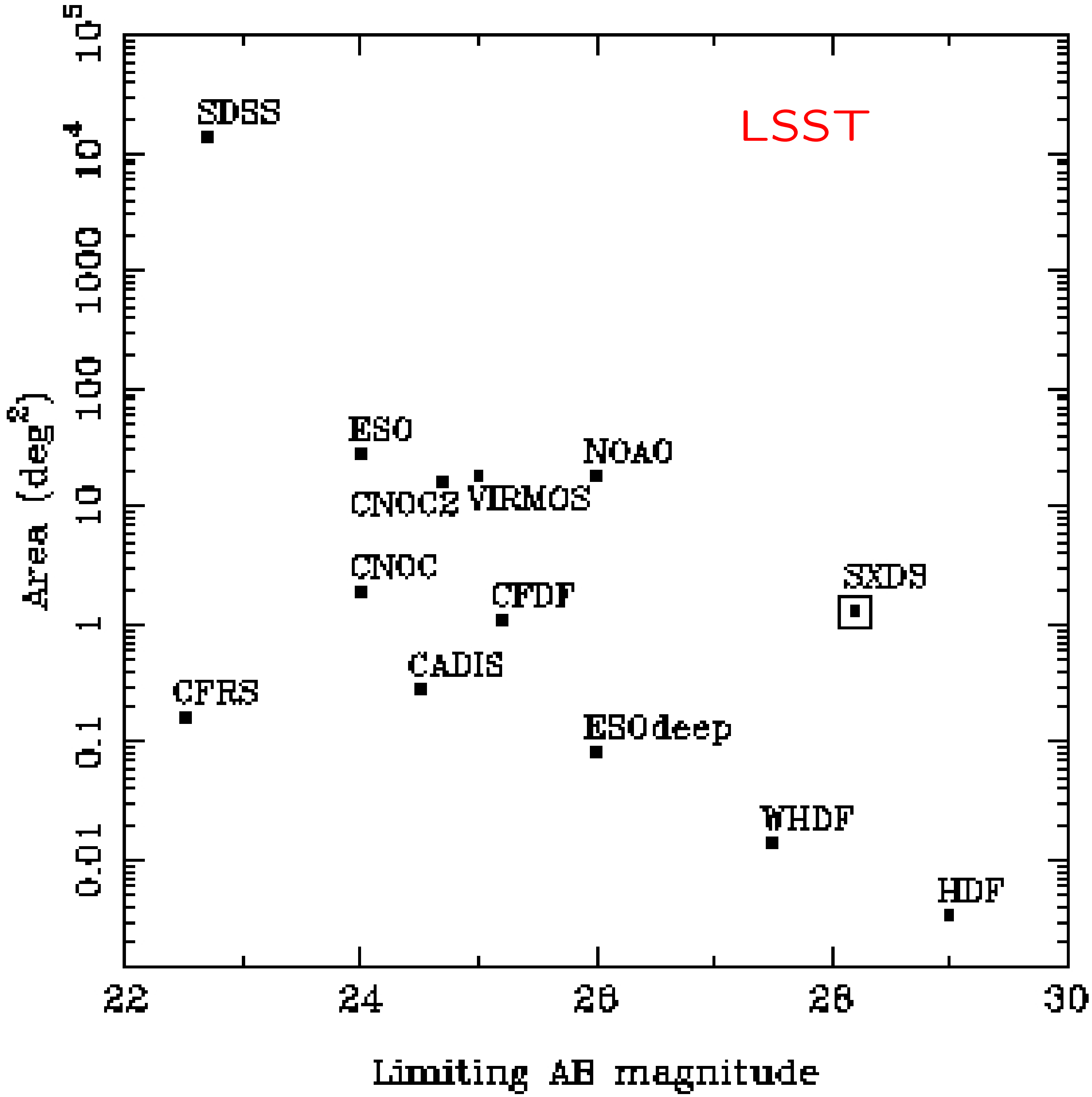
2. LSST science drivers and promises

   - A diverse set of science goals ranging from the characterization of dark matter and energy, to solar system and transient universe: a single data set serves all

3. LSST Expectations Based on Extrapolation of SDSS Results

   - Moving Objects (Solar System and proper motions)
   - Variable Objects (QSOs, RR Lyrae, SNe, Miras, etc.)
   - Transients

LSST: almost as deep as HDF, but twice as large an area as SDSS (in addition to a factor of 2 better photometric and astrometric accuracy, and image quality, and Y band data)



Large Synoptic Survey Telescope

- LSST: ugrizY, r ~24.5 in 30 sec, 0.7 arcsec median delivered seeing, 1% photometry, 10 mas astrometry, data rate 30 TB per night

- Strategy: the whole (observable) sky in two bands every three nights; 1000 visits over 10 years distributed over multiple bands; The same data set serves all the science needs!

- Results after 10 years:
  - Multi-color time domain to V~24.5 with a variety of time scales (10 sec to 10 years);
  - Deep optical color map of half the sky (coadded V>27.5) with a median delivered seeing of 0.7 arcsec
  - <<1% photometry, 0.2 mas/yr proper motions, 1 mas geometric parallaxes
  - 60 PB data set

LSST Science Drivers

Each drives at least one aspect of the system design (e.g. image quality, photometric and astrometric accuracy, bandpass selection, observing strategy):

- Dark Energy and Dark Matter (through weak lensing, SNe Ia, clusters, BAO)
- The Milky Way Map (main sequence to 150 kpc, RR Lyrae and M giants to 400 kpc, geometric parallaxes for all stars within 500 pc)
- The Solar System Map (over a million main-belt asteroids, $\sim$100,000 KBOs, Sedna-like objects to beyond 150 AU, census of killer asteroids larger than $\sim$300 m)
- The Transient Universe (time scales from $\sim$10 sec to 10 years, the whole sky every 3 nights, 1 min latency for reporting transients)

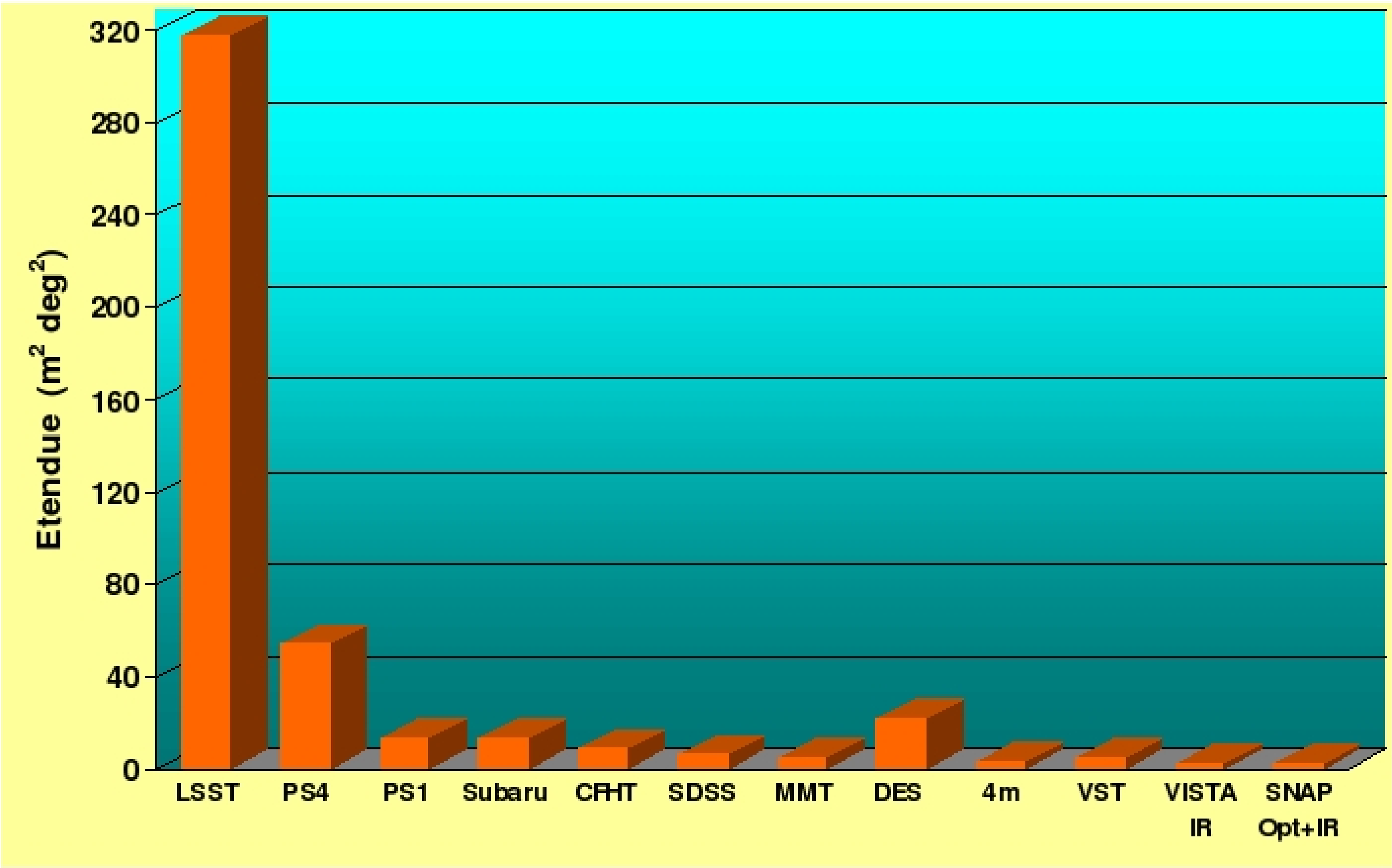
Of course, studies of e.g. galaxy formation and evolution, quasars, star and planet formation, interstellar medium, weird objects, etc. will be enabled, too. For example, the final catalog will include $\sim$3 billion galaxies with photo-z!

Large Synoptic Survey Telescope

- Fundamental LSST property enabled by high etendue: Single data set can be nearly optimal for unrelated science programs "One size (data set) fits all"
- This greatly increases surveying efficiency and places requirements on etendue and the survey length, e.g.
  - for SNe over the whole sky every 3 nights in at least two bands: $\sim$300 m^{2}deg^2 (a similar cadence requirement is also imposed by solar system science)
  - for the required number of images for weak lensing: $\sim$300 m^{2}deg^2 **if the survey is not to last longer than $\sim$10 years,** $<$10 years comes from financial considerations and desire to avoid "stale" science; but to obtain competitive proper motion measurements, to study quasar variability, long-period variables, etc: not much shorter than 10 years

Since the total number of detected photons is proportional to (etendue x survey length), these considerations answer the following question: ”Do we want a fast ($\sim$1 year) survey with a huge etendue (say, thousands of m^2deg^2), or a 50 year long survey with an etendue of 60 m^2deg^2?”

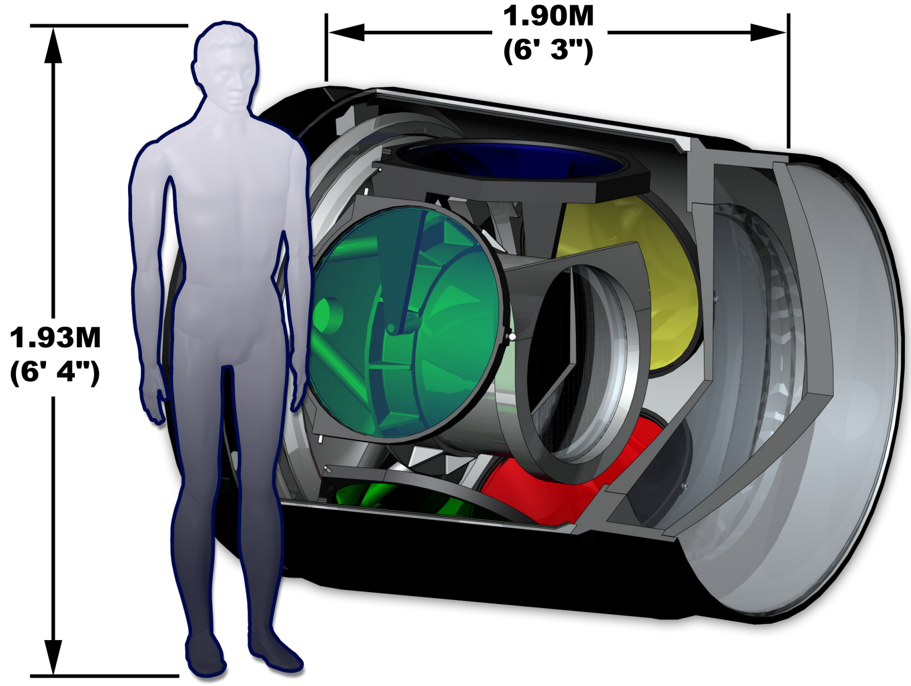
Answer: a 10 year long survey with an etendue of $\sim$300 m^2deg^2 is **simultaneously** optimal for a variety of science programs!

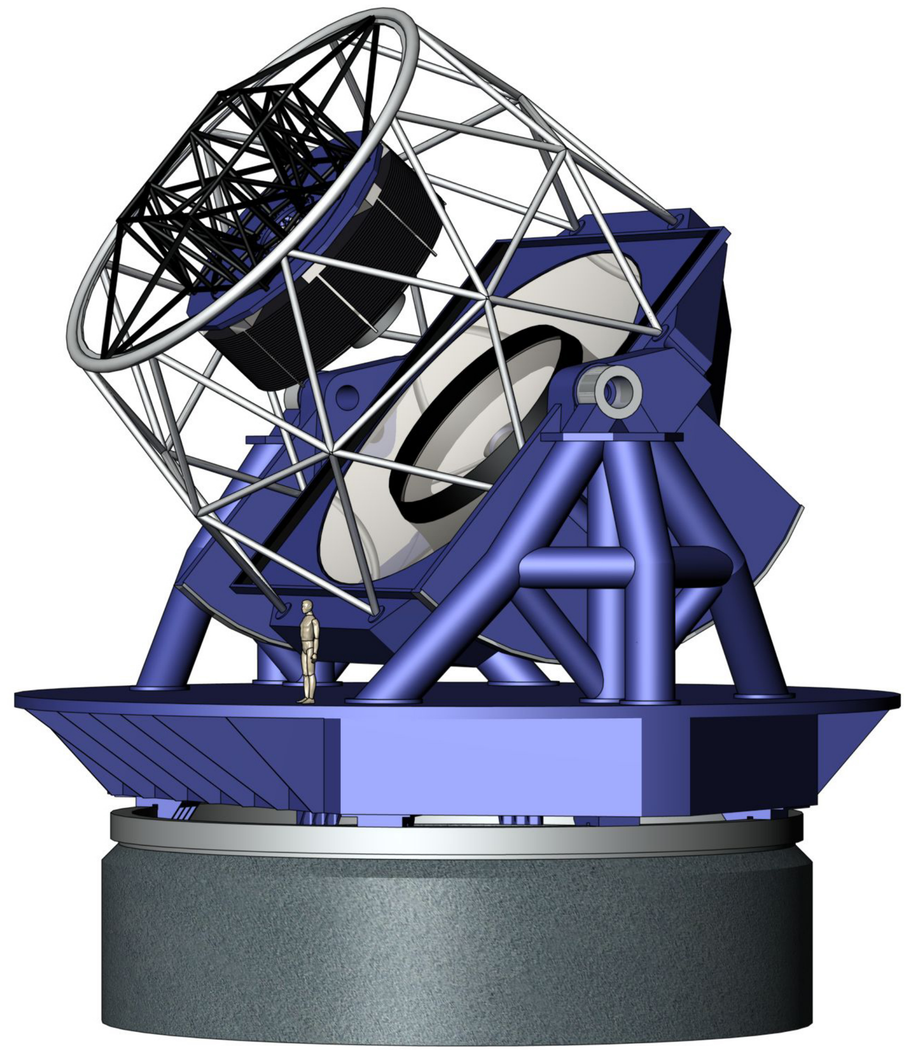


Large Synoptic Survey Telescope

- A collaboration of numerous (∼20) US institutions (NOAO, Research Corporation, UA, UW, ... JHU, Harvard, ... DoE Labs, ... Google, Microsoft, ...)
- A combination of government (NSF and DoE) and private funding (about 270 M$ in 2004 $, without operations costs)
- Already underway with significant private and NSF funding
- The first light around 2012
- Three main system components:
  - **Telescope and Site**
  - **Camera**
  - **Data Management**

Large Synoptic Survey Telescope

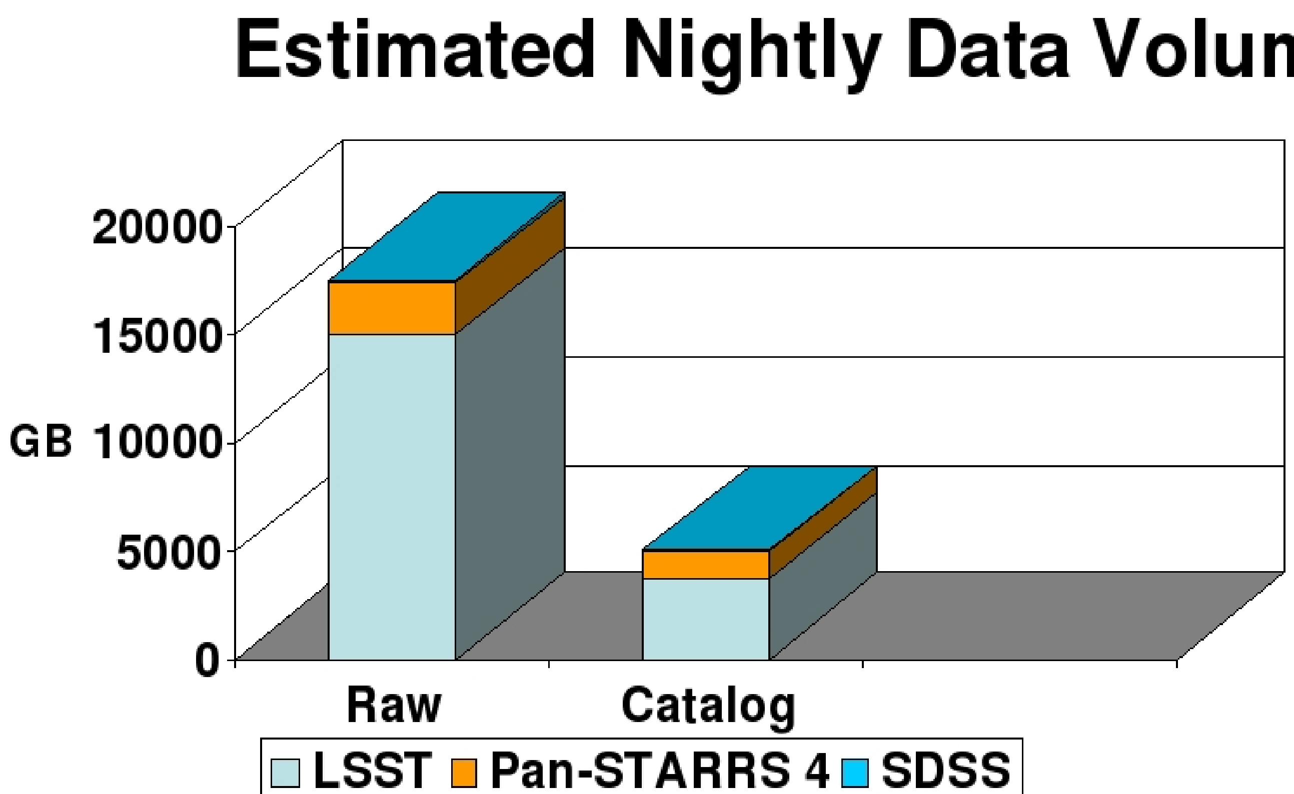




Data Processing and Management

A Community Survey:

- Immediate (30 sec) reporting of likely transients
- Periodic releases (about once a year) of "certified snapshots", including both images and catalogs, and both single visits and (appropriately) coadded data
- Science-ready products for the community: easy access such as database and query system



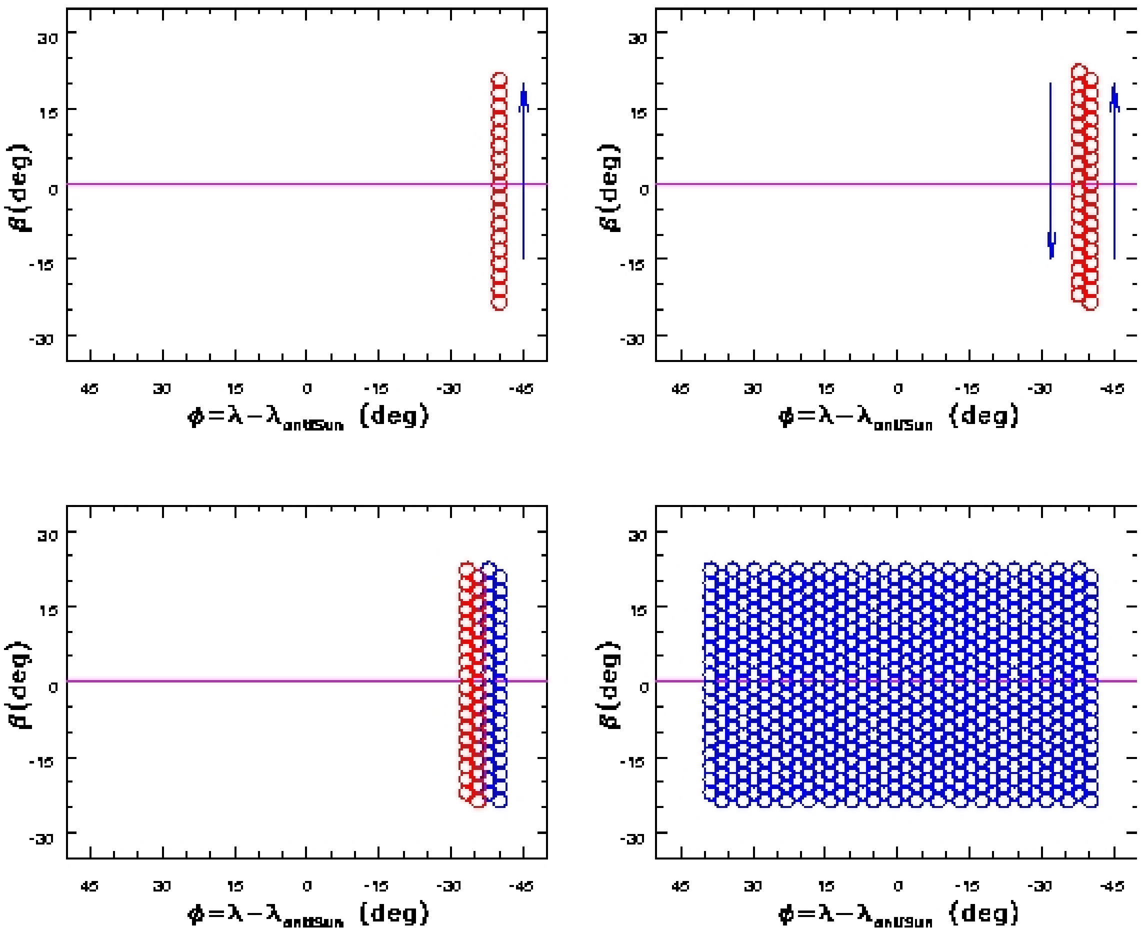
Where is LSST now?

Fast development:

- Since ∼2 years ago, a real project (incorporated, etc.); initially funded by private sources
- Since Sep 2005, NSF D&D funding (14 M$)
- Next major milestone: NSF construction proposal in Dec 2006, DoE proposal in 2007
- If funding stream according to plan, construction begins in 2009, first light in 2012
- Strong project management mandated by numerous institutions and participants
- Still actively looking for partners (both US and international)

LSST and Variable Objects

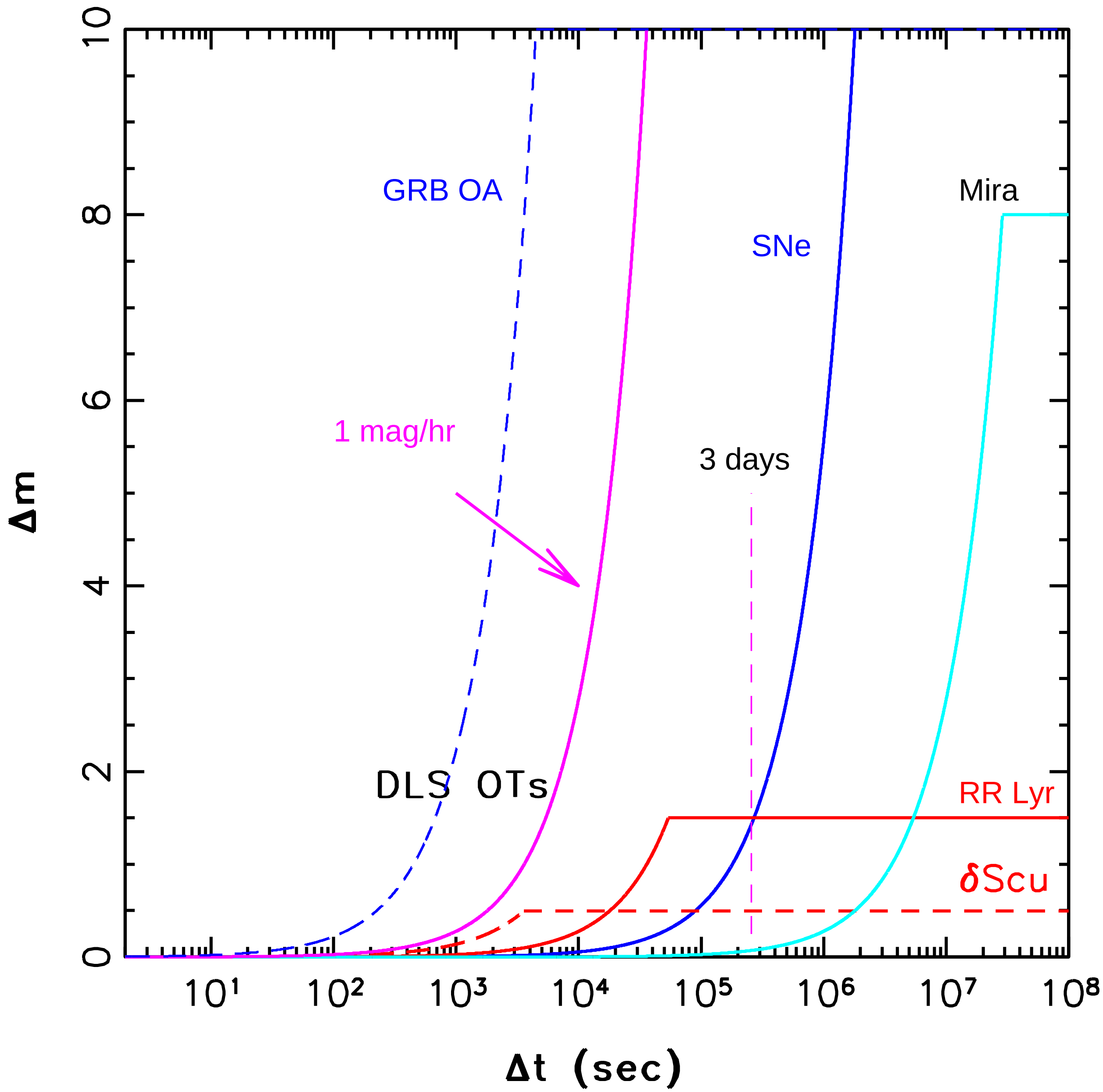
- A “proof of concept” observing strategy
- Extrapolations of SDSS: LSST Potential


β(deg)
30
15
0
-15
-30
45
30
15
0
-15
-30
-45
φ=λ−λantiSun (deg)

LSST and Variable Objects

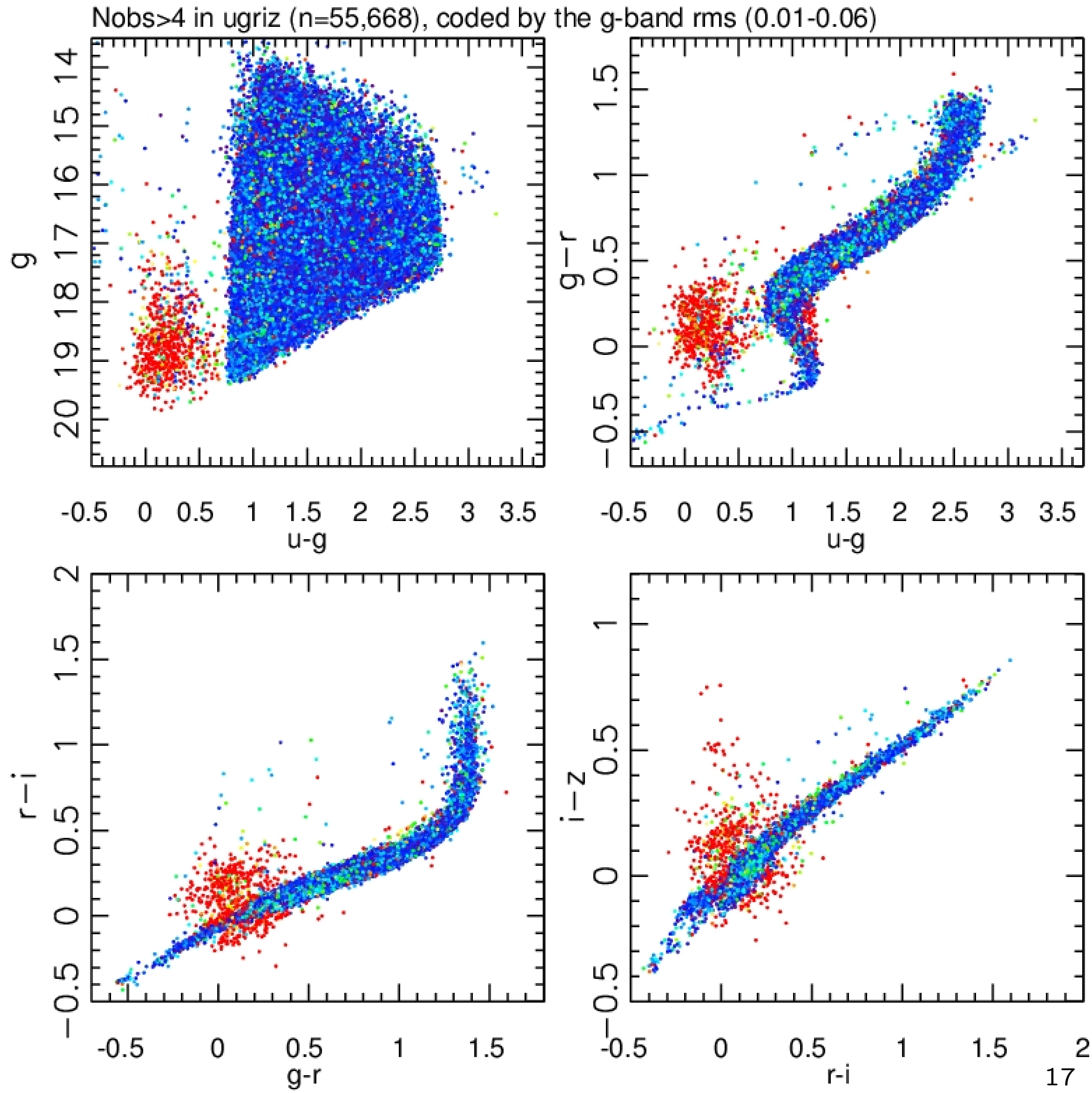
Using this cadence as a benchmark:

- $\sim$30% of the observed area (7000 deg^2/night in 2 bands) will have multiple observations with a variety of time scales (from $\sim$30 sec to 30 min)
- Opening a new parameter space for transient object search: timescales 10^1–10^8 sec, V$\sim$24.5, multi-color, 20,000 deg^2


GRB OA
Mira
SNe
1 mag/hr
3 days
DLS OTs
RR Lyr
δScu
Δm
Δt (sec)
0
2
4
6
8
10
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸

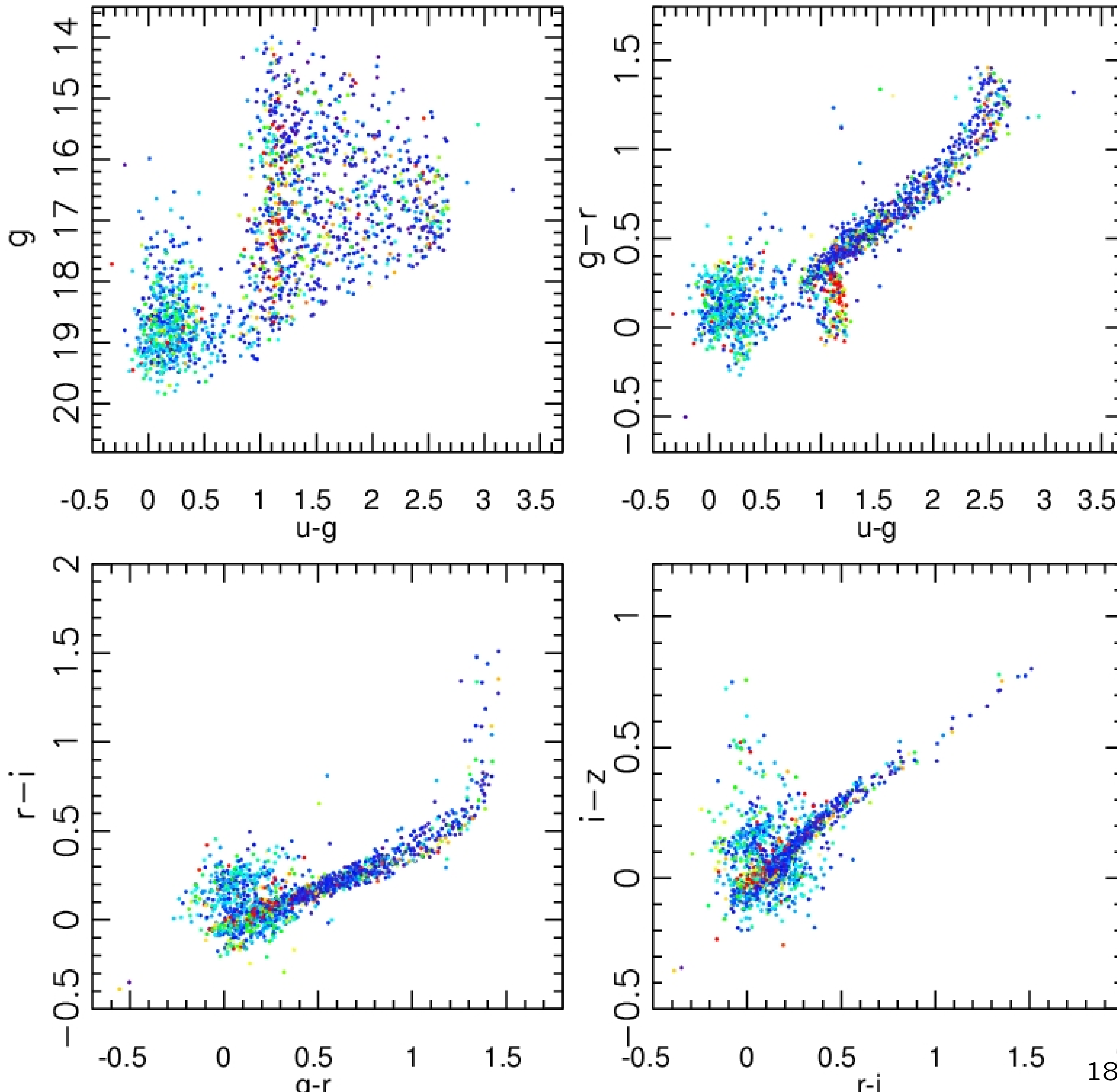
Selected SDSS Results

- Finding (and characterizing) variable objects
- How do QSOs twinkle?
- Variable stars as probes, e.g. RR Lyrae
- Supernovae, Asteroids, etc.



Nobs>4 in ugriz (n=55,668), coded by the g-band rms (0.01-0.06)
g
u-g
g−r
u-g
r−i
g-r
i−z
r-i

Variable (χ^2_{pdf}>3 in gr, n=1,651), g rms: 0.02−0.3

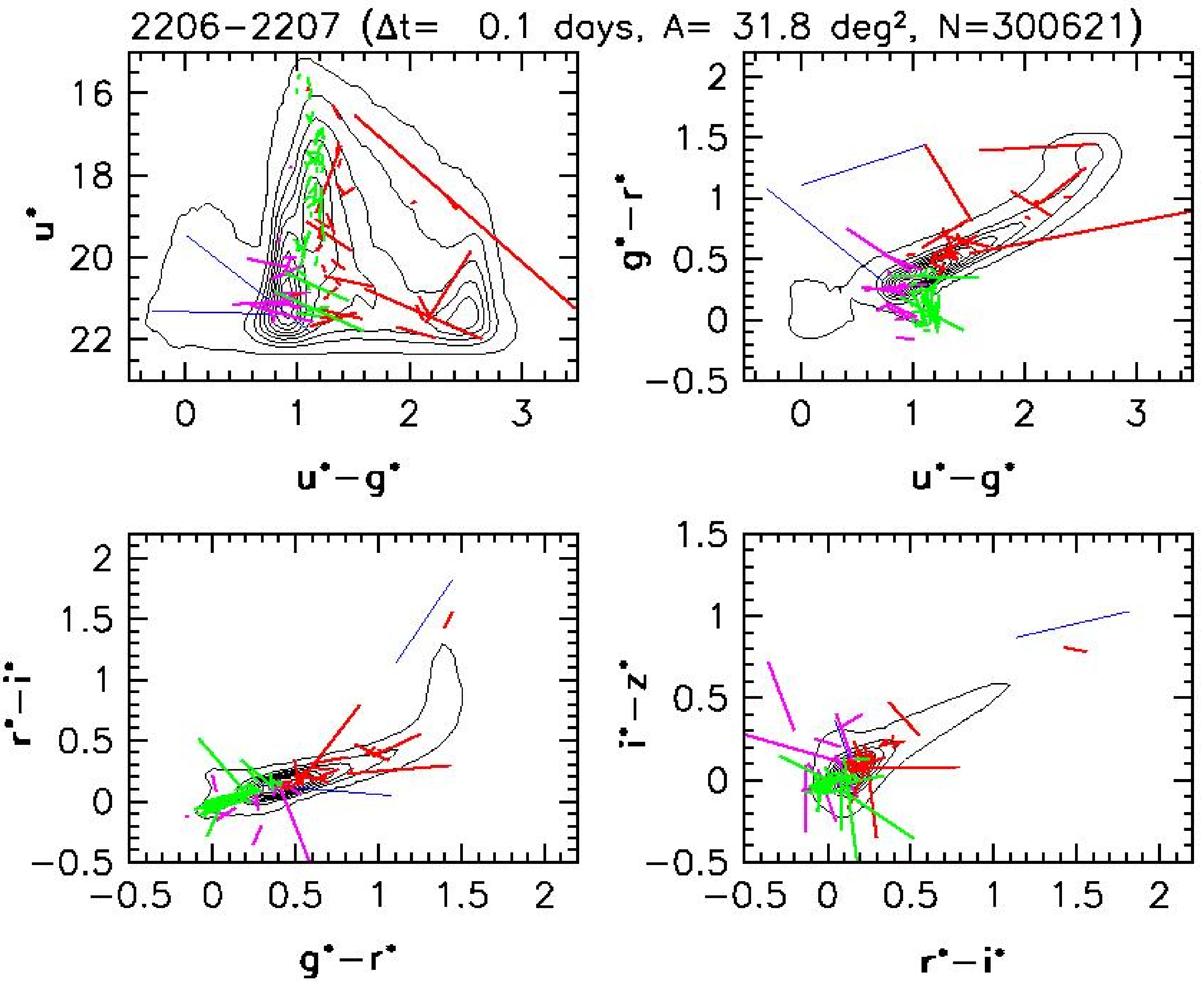


How does Variability Depend on Time Scale?

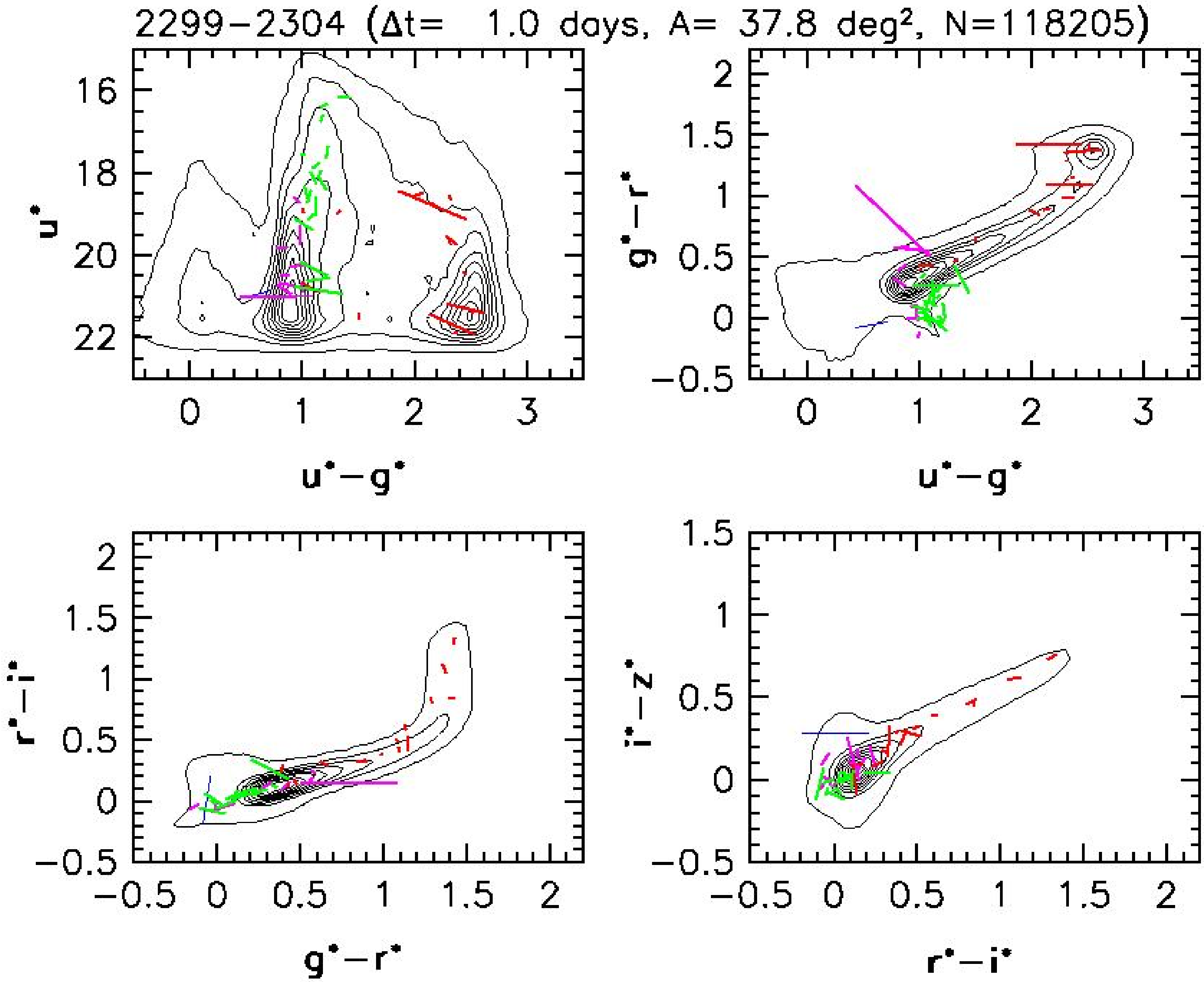
In the following diagrams, the overall source distribution is shown by linearly spaced contours. The observations of variable objects, selected by $\Delta g > 0.075$ && $\Delta r > 0.075$ && 3σ significant, are connected by lines. These lines are (exhaustively and exclusively) color-coded according to the mean source position in $g - r$ vs. $u - g$ diagram:

- blue: low-z QSOs
- green: RR Lyrae
- magenta: “mixed” variables
- red: everything else

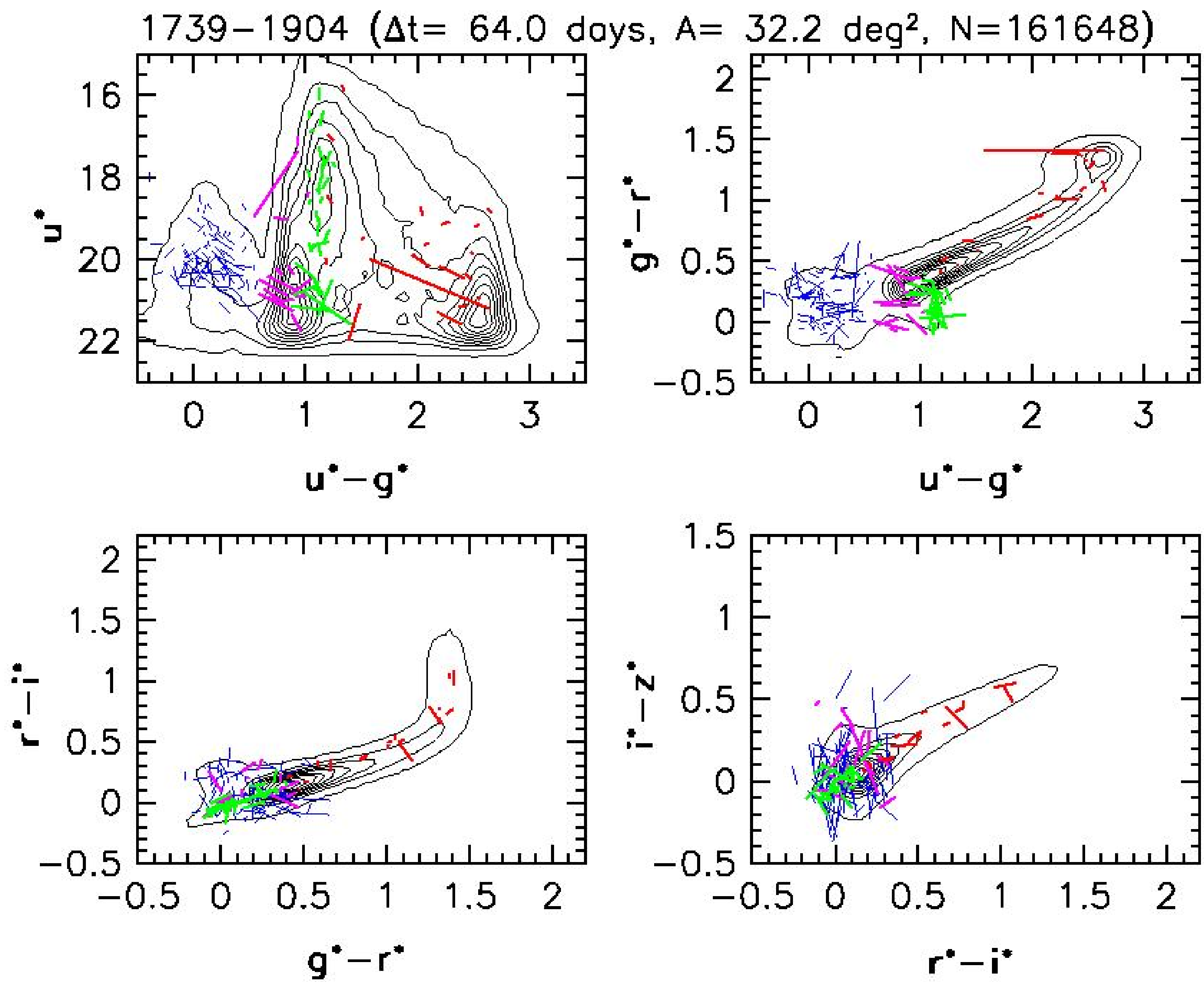
Scans 3 hours apart (note the absence of low-z QSOs):



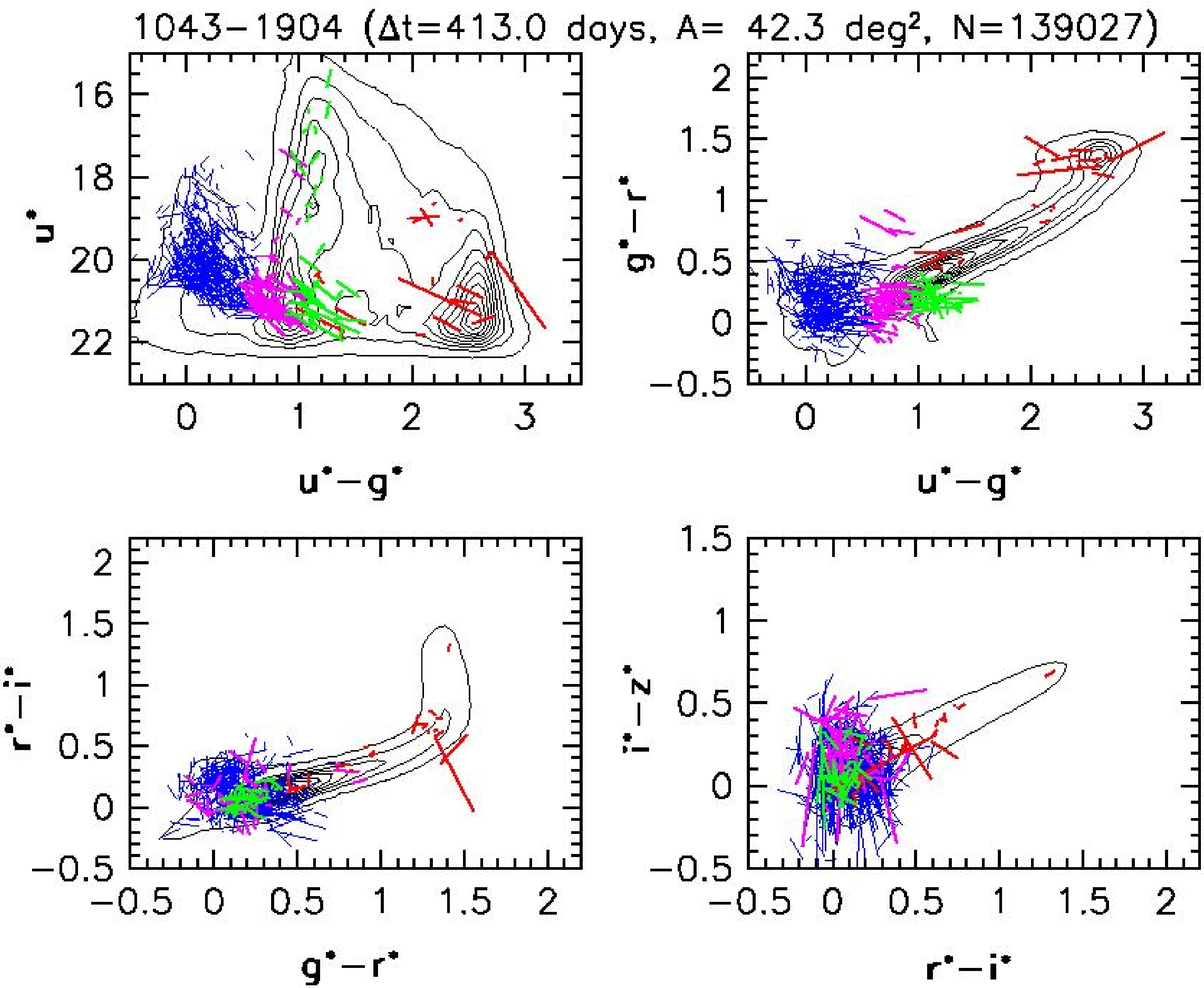
... 1 day apart. Still no QSOs...



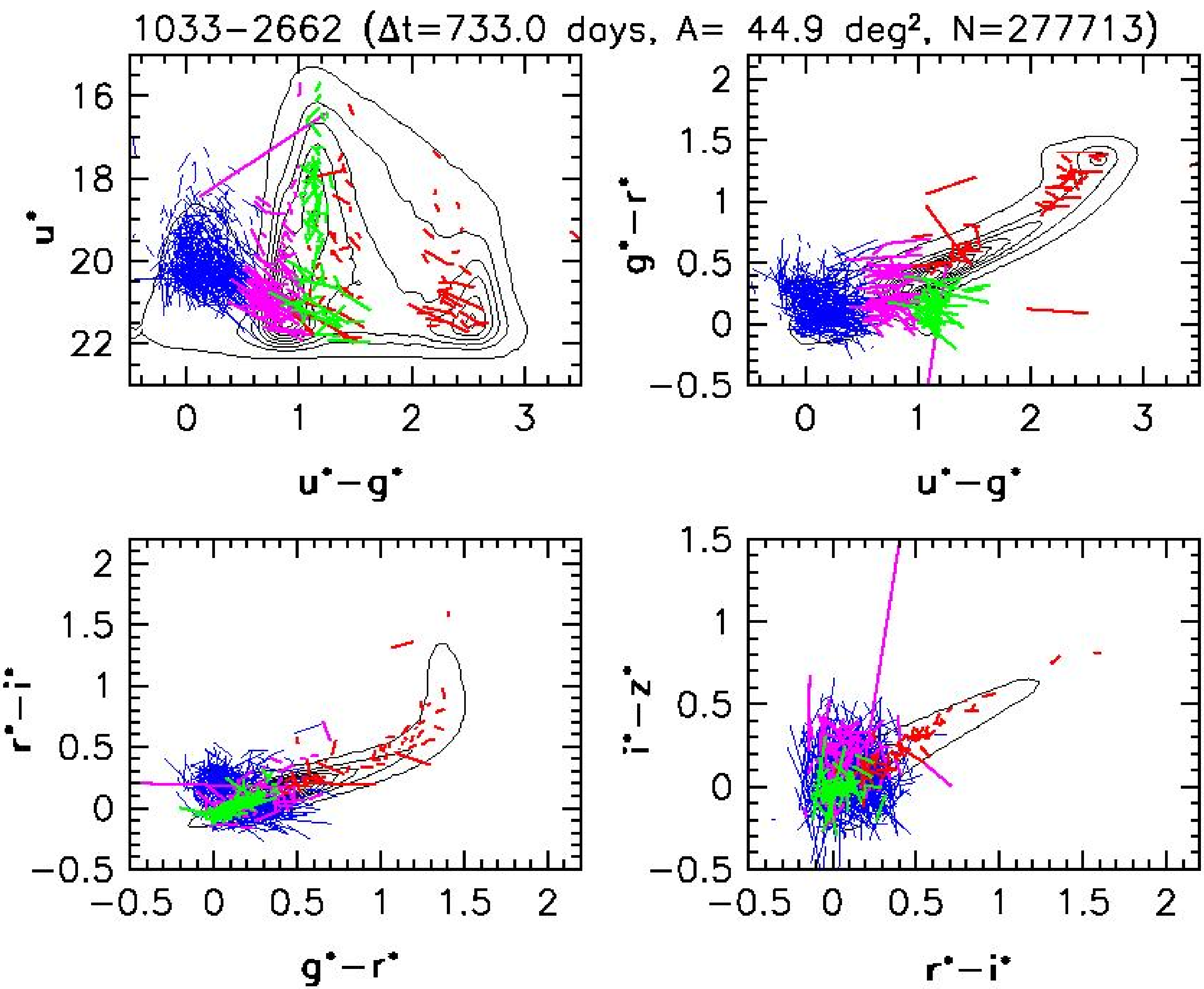
$\Delta t \sim 2$ months, QSO variability becomes detectable!



$\Delta t \sim 1$ year



$\Delta t \sim 2$ years. QSOs dominate the variable sample!



QSO Variability:

- The distribution of Δm follows an exponential distribution,

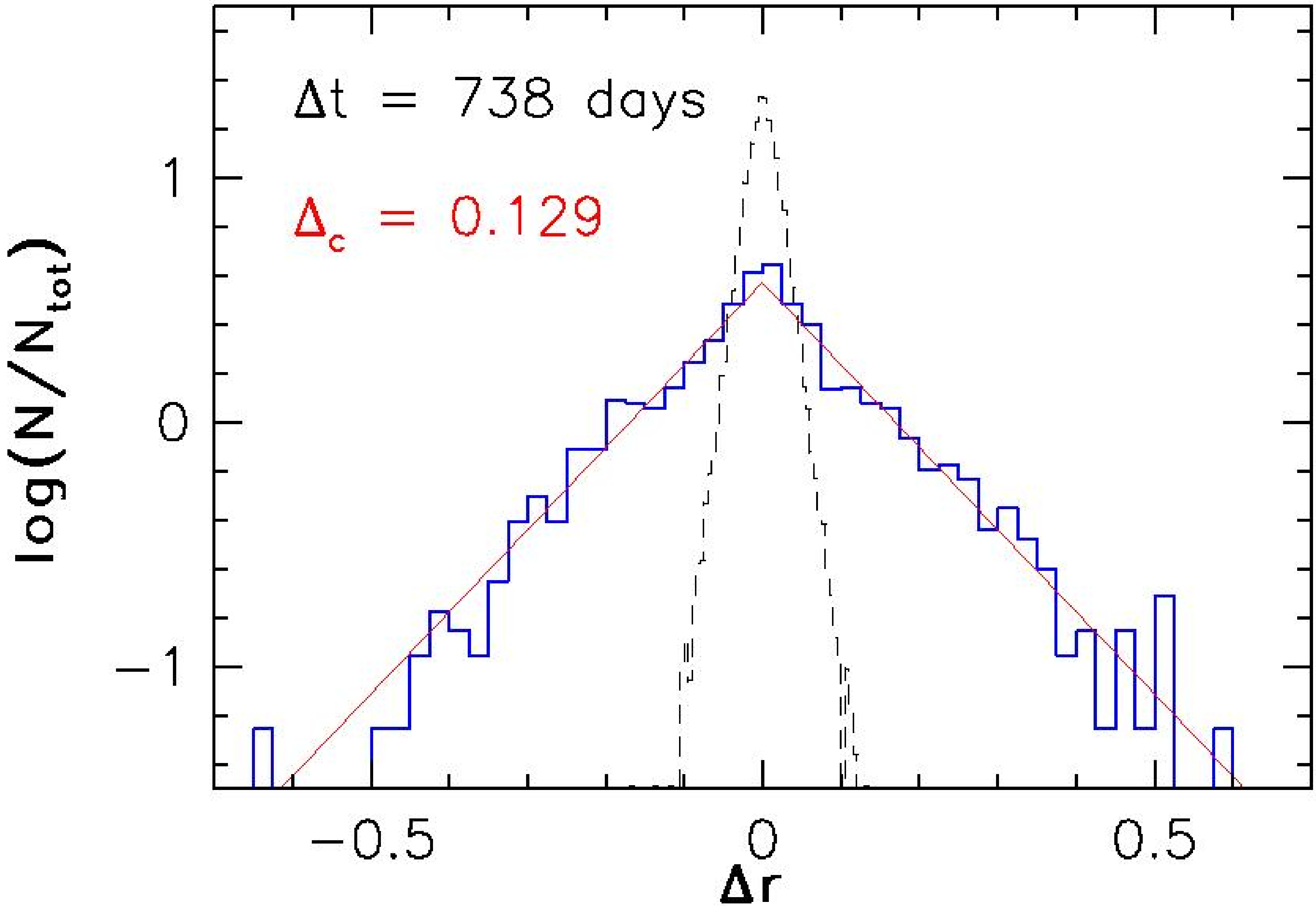
$$f(\Delta m) \propto \exp(-\Delta m/\Delta_c)$$

with the characteristic amplitude, Δ_c, increasing with time and frequency.

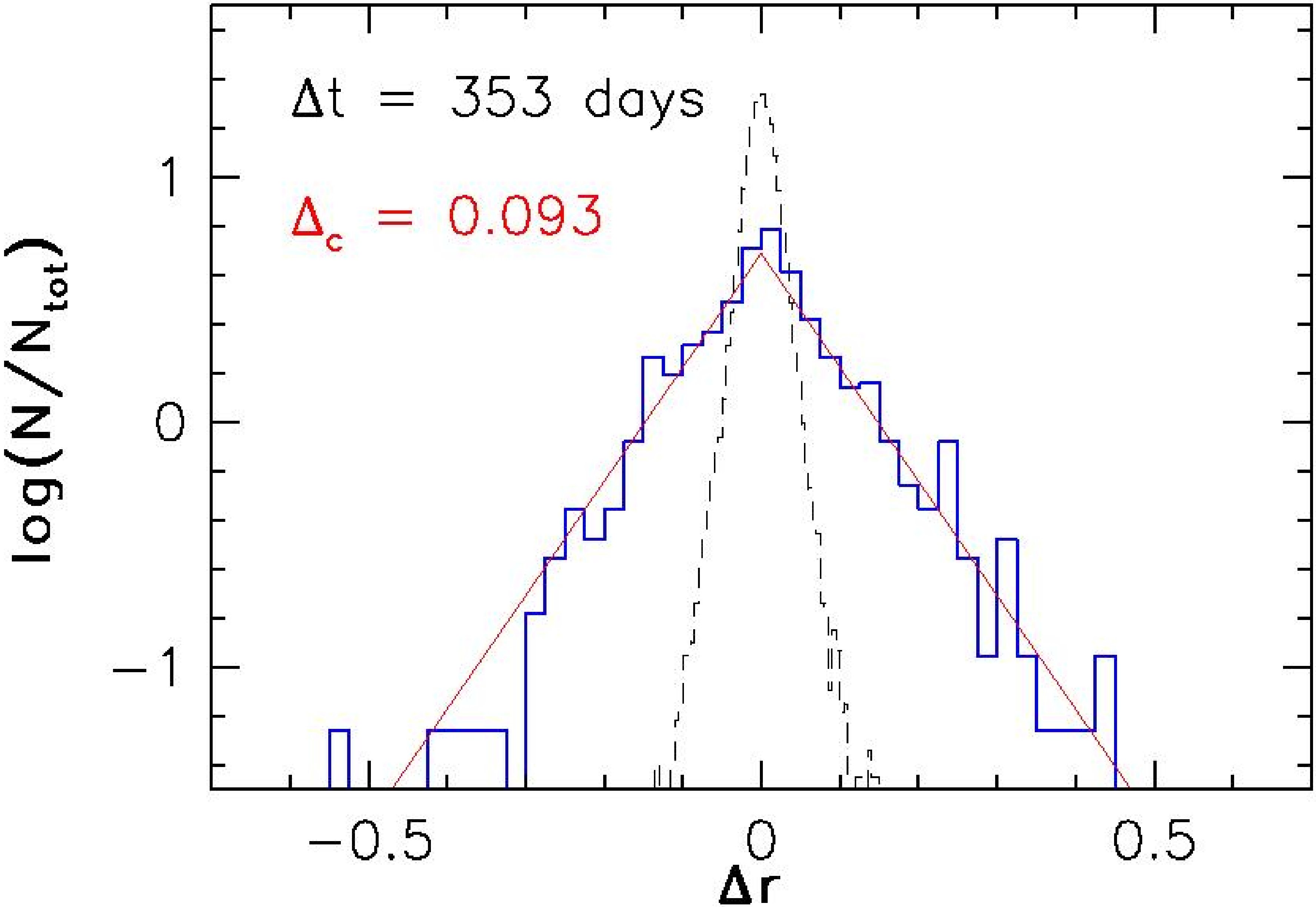
While similar and consistent with the structure function analysis ($rms \propto \Delta_c$), note that the whole distribution is determined here, not only its second moment.

$f(\Delta m)$ **is not a Gaussian!**

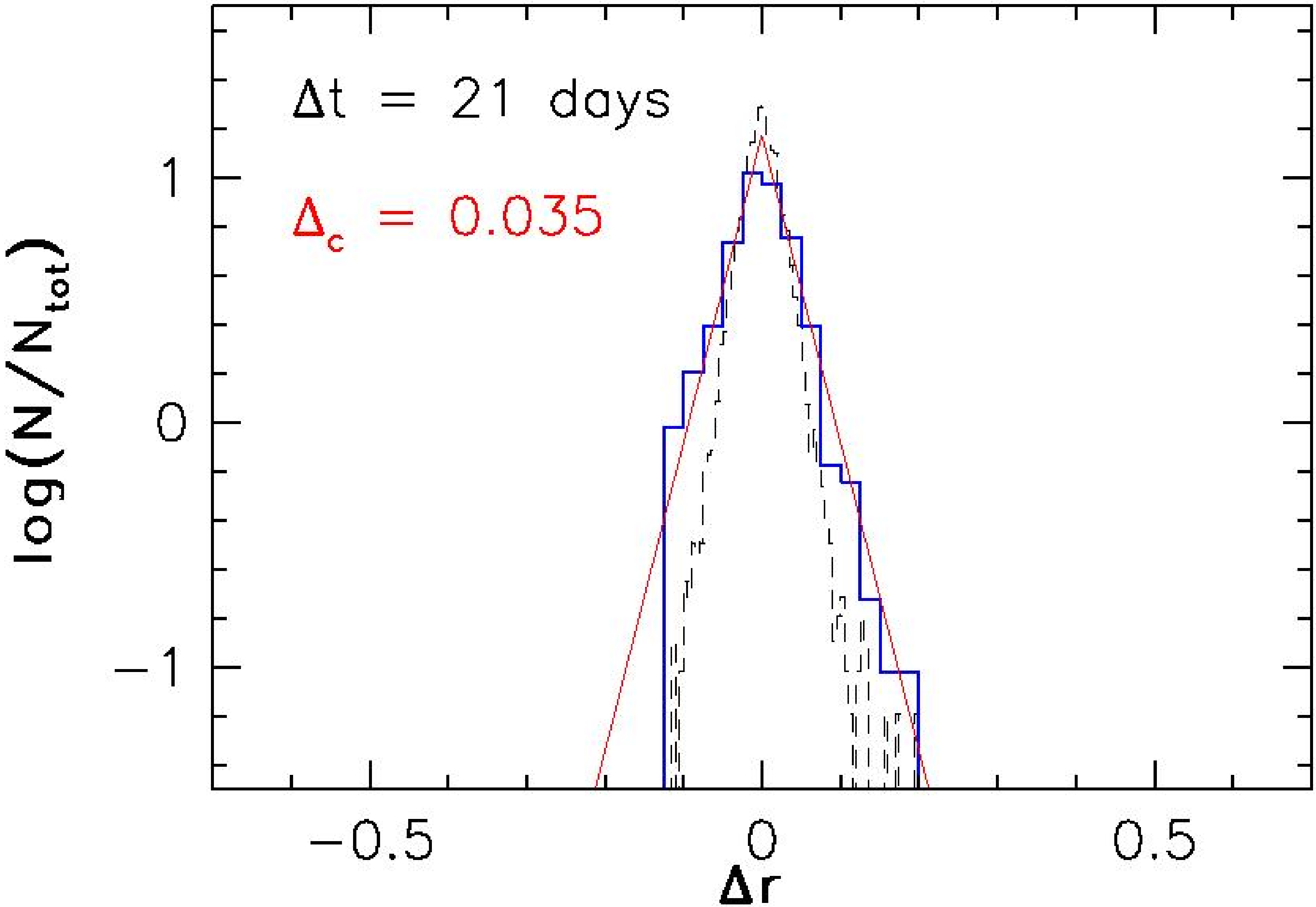
$f(\Delta m) \propto \exp(-\Delta m/\Delta_c)$!



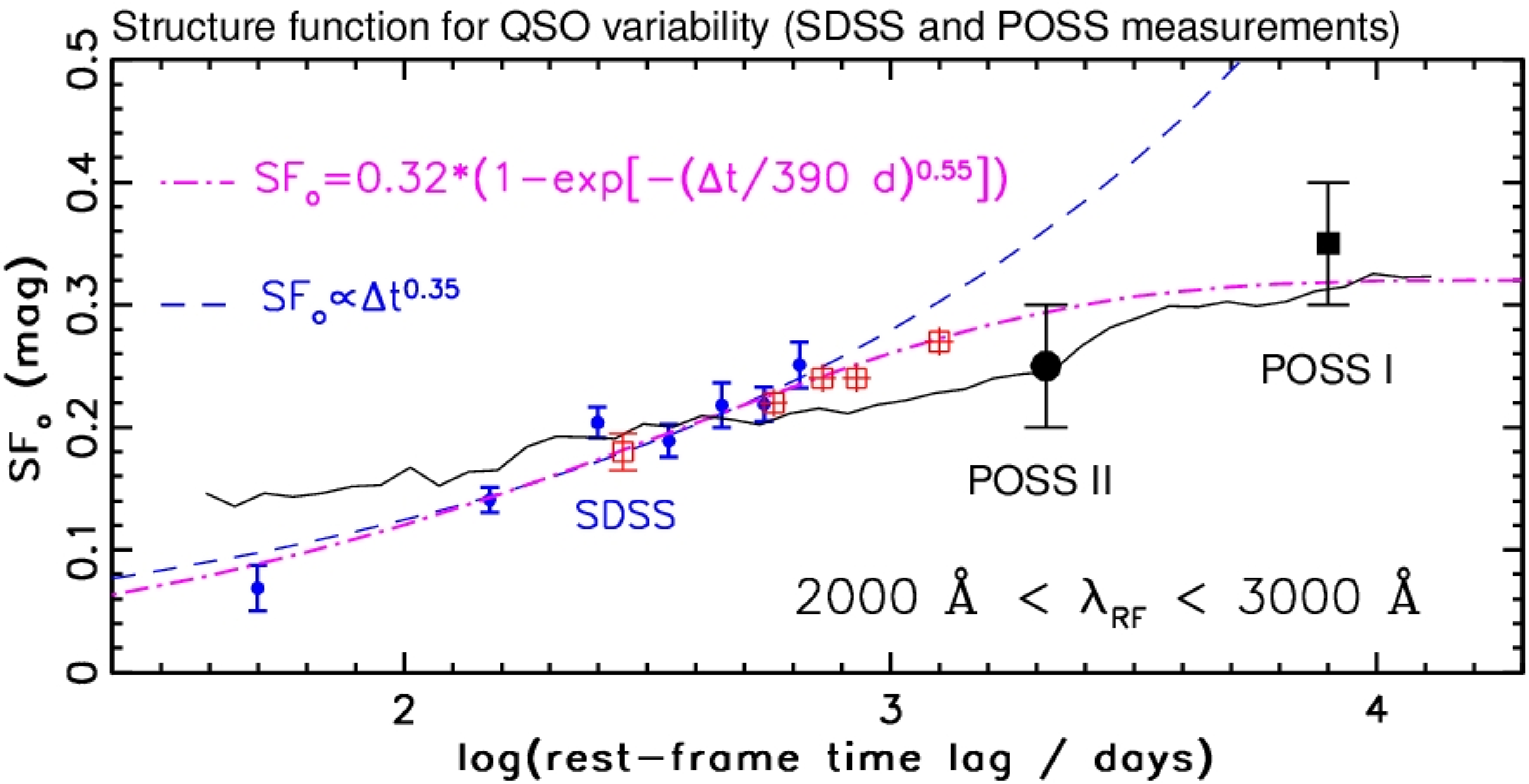
Δ_c decreases as Δt decreases,



and Δ_c continues to decrease...



A summary of this behavior: structure function



QSO Variability:

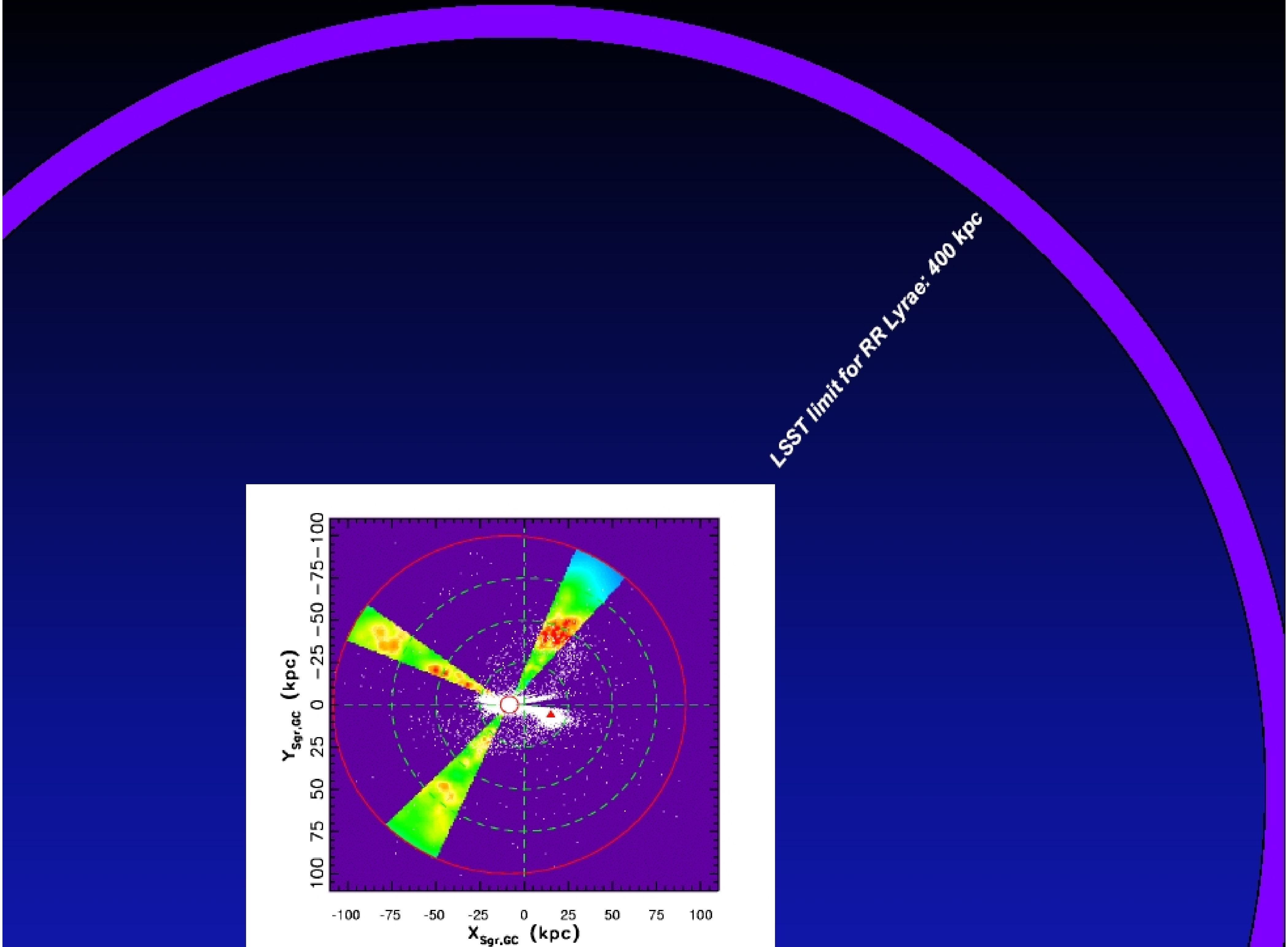
- The distribution of Δm follows an exponential distribution,

$$f(\Delta m) \propto \exp(-\Delta m/\Delta_c)$$

A much higher occurence of large variations than for Gaussian distribution:

Assuming Δ=0.3 mag;

dm	fraction (1 in N)	Gauss N
1	25	1000
1.5	100	10^6
2	1000	---
3	20000	---
4	10^6	---


LSST limit for RR Lyrae: 400 kpc
-100 -75 -50 -25 0 25 50 75 100
X Sgr,GC (kpc)
-100 -75 -50 -25 0 25 50 75 100
Y Sgr,GC (kpc)

How will LSST improve these results?

- Several hundred million variable stars!

- Instead of $<$100,000 QSO with several observations, several million QSOs with 1000 observations per object

- Sensitivity for RR Lyrae to 400 kpc

- 2.5 million supernovae over 10 years ($z < 1$)

- In general, LSST will open a new parameter space for transient object search: timescales 10^1–10^8 sec, V$\sim$24.5, multi-color, 20,000 deg^2

Astronomical Image Processing Workshop

Dubrovnik, Croatia, Sep 4-9, 2006

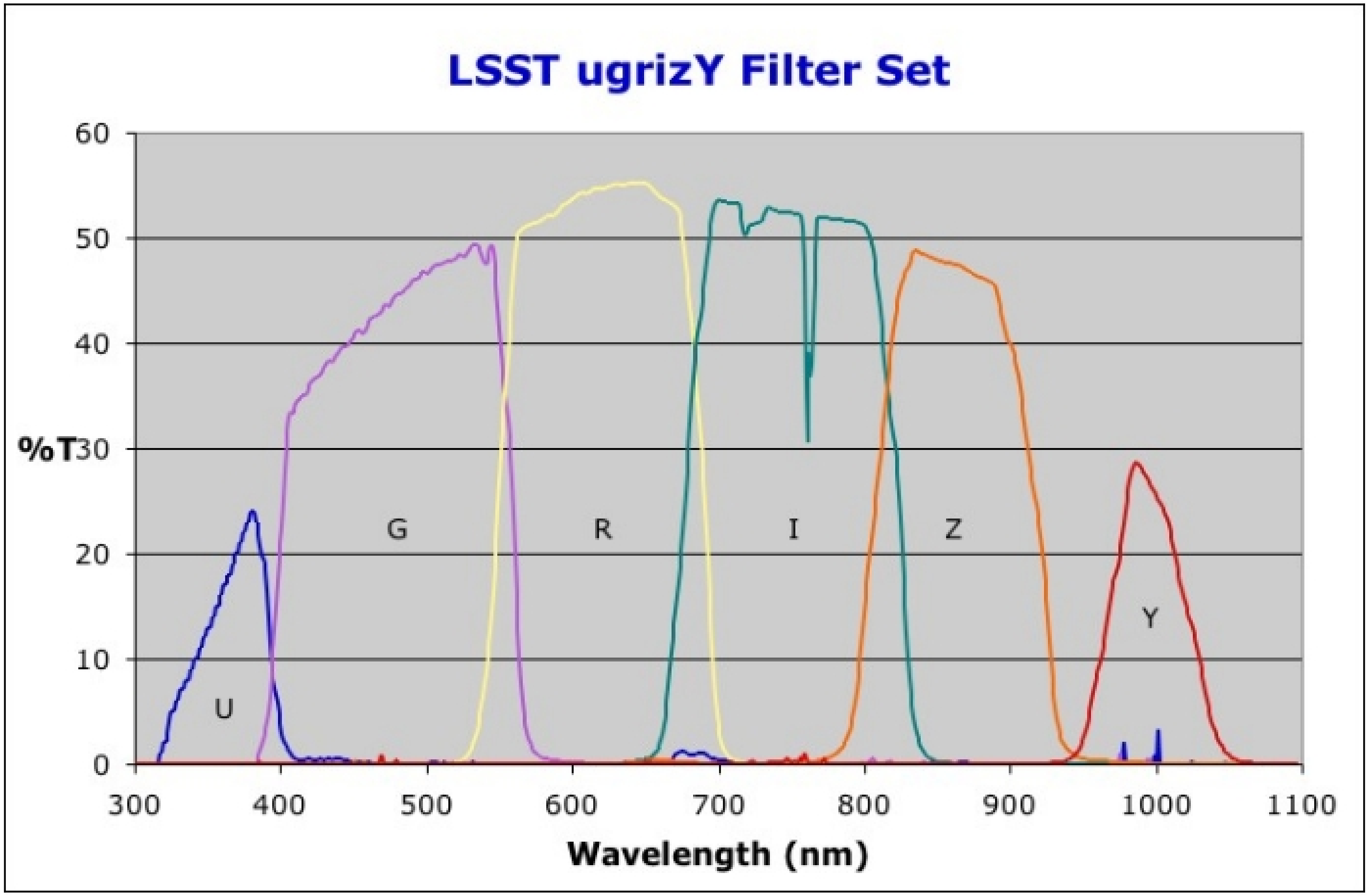
Registration (deadline Mar 31):

http://www.astro.washington.edu/aipw

This workshop will provide participants with the skills needed to understand modern image processing, to understand the outputs of the current and next generation of surveys, and to be in a position to contribute to the algorithm development needed to make projects such as Pan-STARRS and LSST a reality.

SOC: James Gunn, Ralf Bender, Emmanuel Bertin, Željko Ivezić, Robert Lupton, Eugene Magnier, Peter Stetson

LSST filter set



System optical throughput analysis

- Meets filter complement, performance requirements
- Meets image depth, image quality requirements