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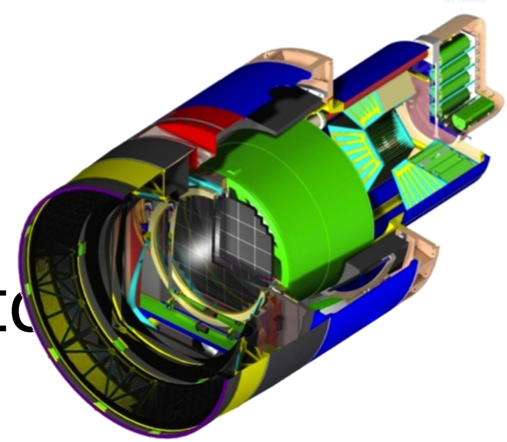
Colloque LSST-France
10 juin 2014

Science autre que cosmologie avec LSST

survol du science-book

LSST : Large Synoptic Survey Telescope

- Optical telescope 8.4 m diameter
- In Chile (Cerro Pachon)
- wide-field camera (3.5°) with 3.2 Gpixels
- 6 filters ugrIzy
- WL up to z ~ 3
- SNIa up to z ~ 1
- BAO: 3.109 galaxies up to z ~ 3



http://www.lsst.org/

Summary of High Level Science Requirements

Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320-1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.9; g = 25.0; r = 24.7; I = 24.0; z = 23.3; y = 22.1
Photometric calibration	< 1% repeatability, absolute, & colors
Median delivered image quality	~ 0.7 arcsec. FWHM
Transient processing latency	< 60 sec after last visit exposure
10-Year Limiting Magnitude	27.7 AB magnitude @ 5σ

LSST science: 4 domains

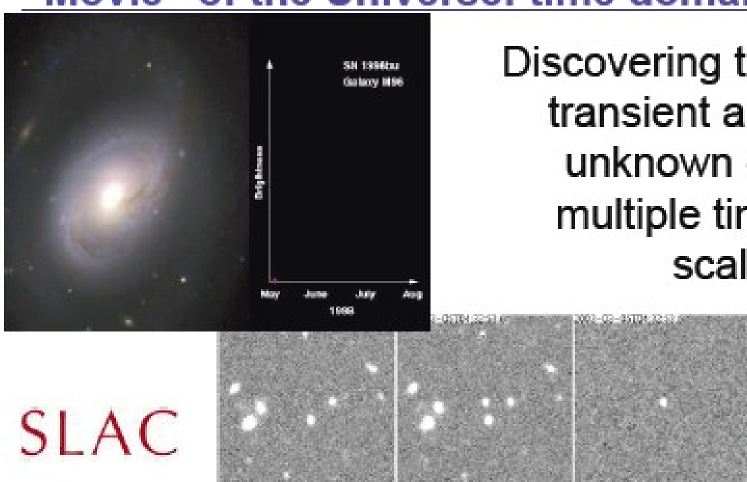
Dark Energy-Dark Matter

LSST enables multiple investigations into our understanding of the universe

Exploring our Solar System

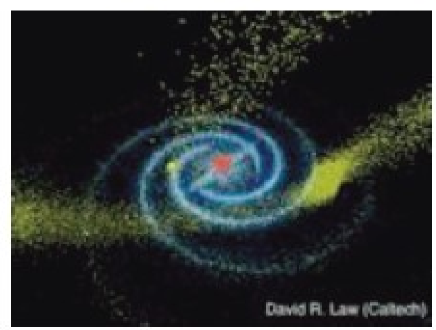
LSST will find 90% of hazardous NEOs down to 140 m in 10 yrs

"Movie" of the Universe: time domain



Discovering the transient and unknown on multiple time scales

Mapping the Milky Way



LSST will map the rich and complex structure of our Galaxy.

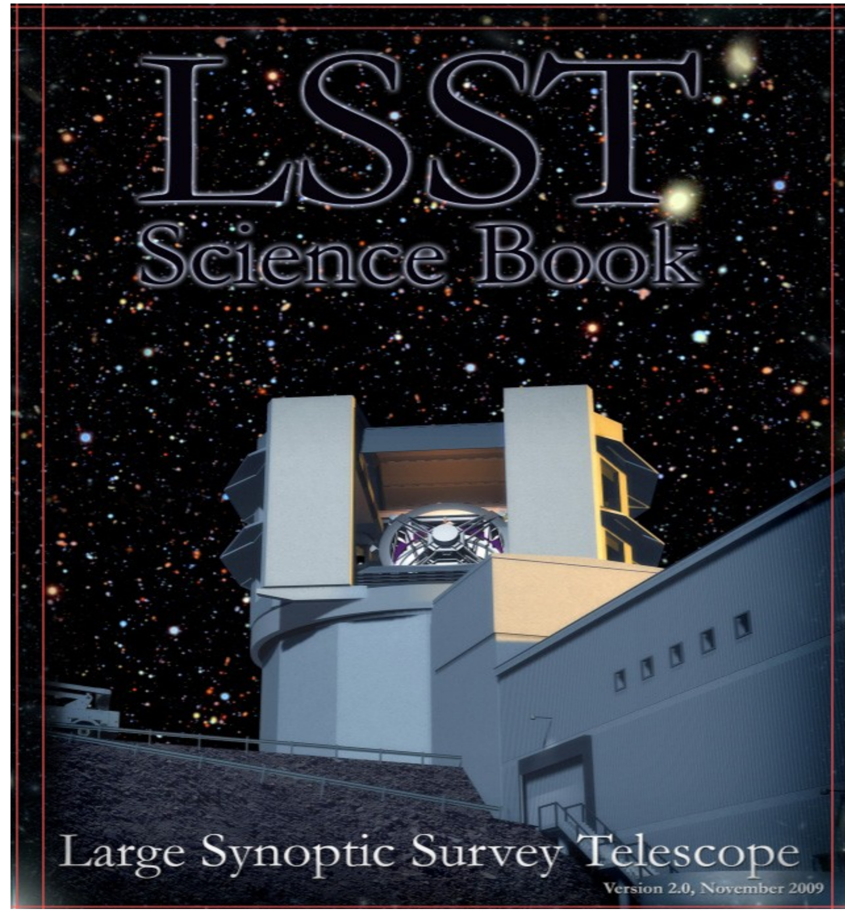
The Science Opportunities are Summarized in the LSST Science Book

http://www.lsst.org

- Contents (596 pages) :
  - Introduction
  - LSST System Design
  - System Performance
  - Education and Public Outreach
  - The Solar System
  - Stellar Populations
  - Milky Way and Local Volume Structure
  - The Transient and Variable Universe
  - Galaxies

Dark Energy

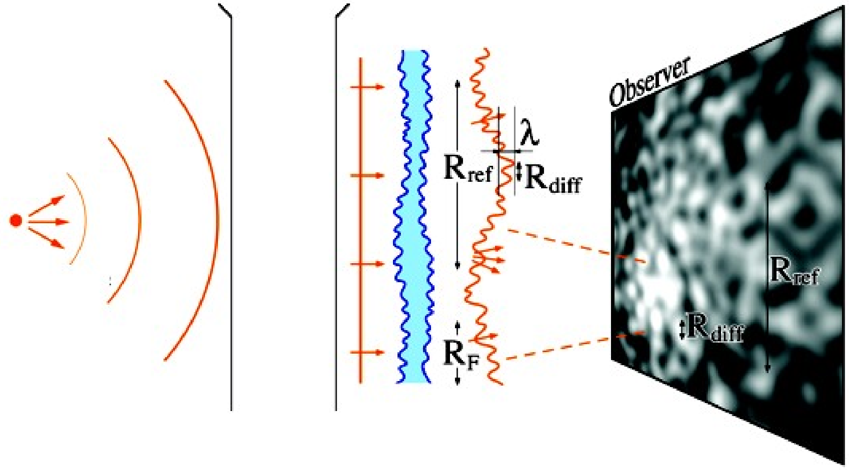
  - Cosmological Physics

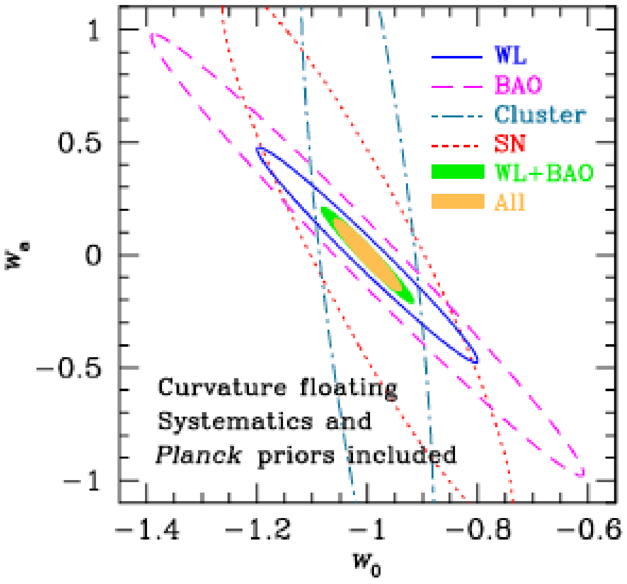


http://arxiv.org/abs/0912.0201

The Science Enabled by LSST

- **Time domain science**
  - Nova, supernova, GRBs
  - Source characterization
  - Gravitational microlensing
  - Interstellar scintillation
- **Finding moving sources**
  - Asteroids and comets
  - Proper motions of stars
- **Mapping the Milky Way**
  - Tidal streams
  - Galactic structure
- **Dark energy and dark matter**
  - Gravitational lensing
  - Supernovae studies
  - Large scale structures (incl. BAO)
  - Slight distortion in shape
  - -> Trace the nature of dark energy





LSST "mission"

Deliverables

- « 4D » object mapping (stars, galaxies...)
  - (α,δ) positions on the sky
  - Redshifts z
  - Time variations (SN, lensing, AGN…)

Science:

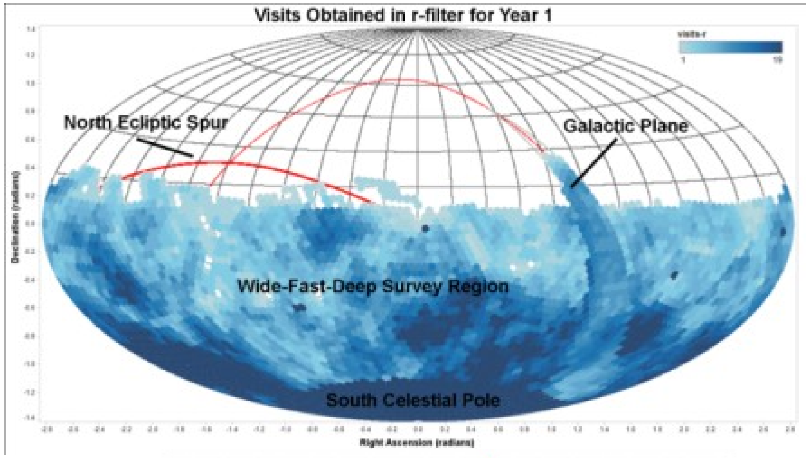
Cosmology

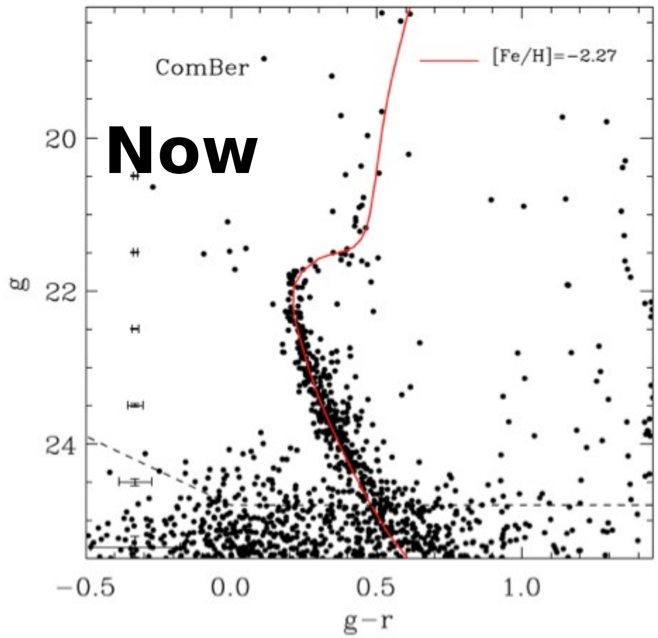
- Archive more than 3x109 galaxies with photometric redshifts up to z=3
- Detection of 250 000 SN Ia per year (with photo-z < 0.8)
- Weak lensing (shape analysis)

Galactic studies

Stellar physics

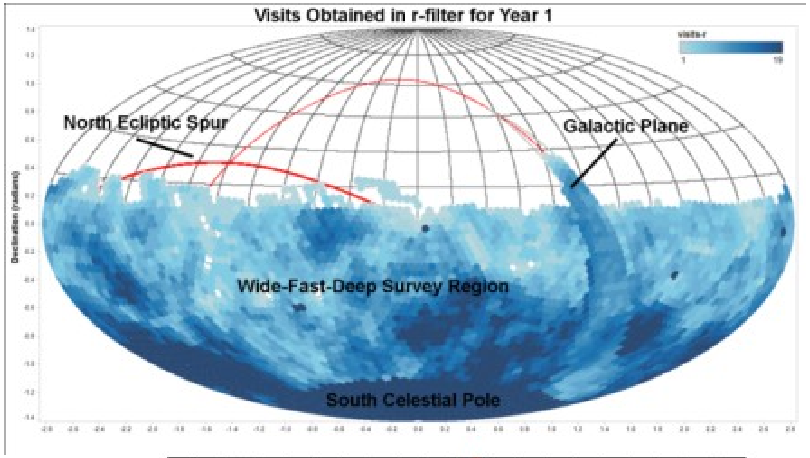
Solar system





LSST “mission”

Large Synoptic Survey Telescope



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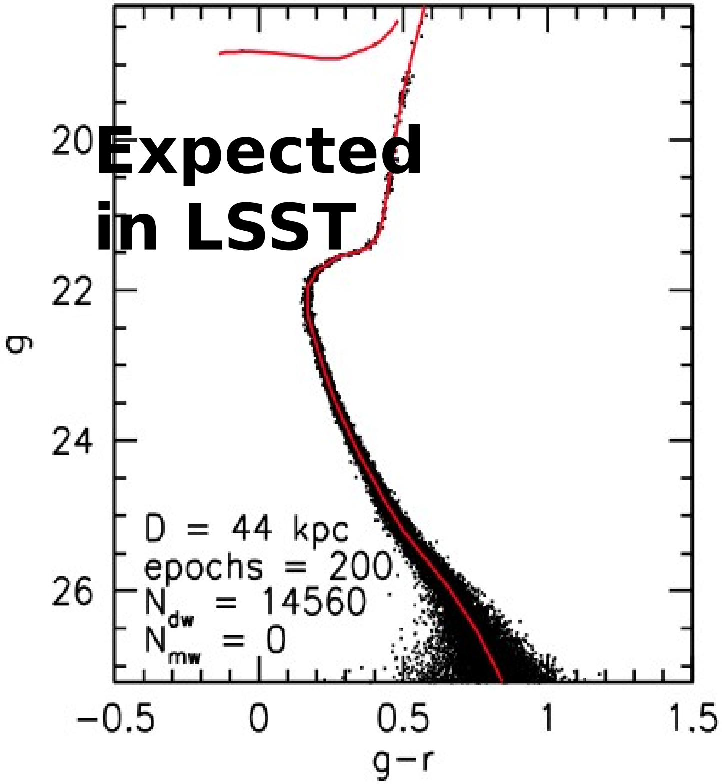
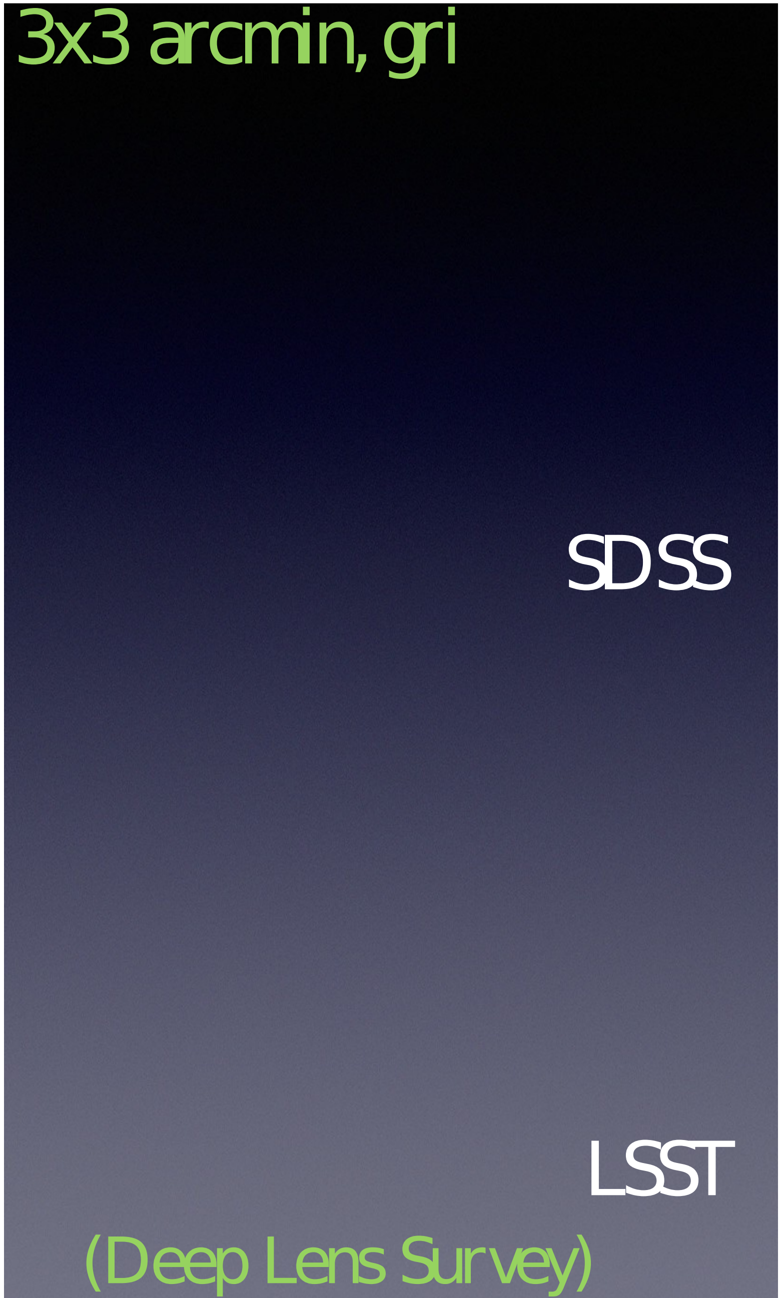
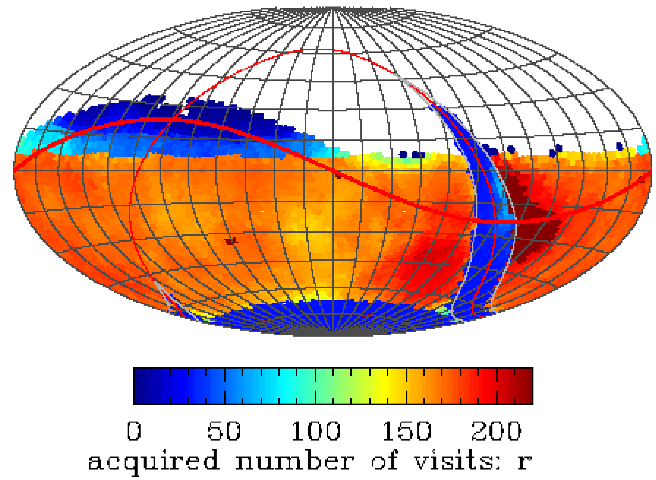




LSST: a uniform sky survey



10% of time for « mini-surveys »

- **deep fields up to r ~ 28**
- **High sampling**

The expected proper motion, parallax and accuracy for a 10-year long baseline survey.

r mag	σ^a_{xy} mas	σ^b_π mas	σ^c_μ mas/yr	σ^d_1 mag	σ^e_C mag
21	11	0.6	0.2	0.01	0.005
22	15	0.8	0.3	0.02	0.005
23	31	1.3	0.5	0.04	0.006
24	74	2.9	1.0	0.10	0.009

[a] Typical astrometric accuracy (rms per coordinate per visit);
[b] Parallax accuracy for 10-year long survey;
[c] Proper motion accuracy for 10-year long survey;
[d] Photometric error for a single visit (two 15-second exposures);
[e] Photometric error for coadded observations (see Table 1).

Solar System

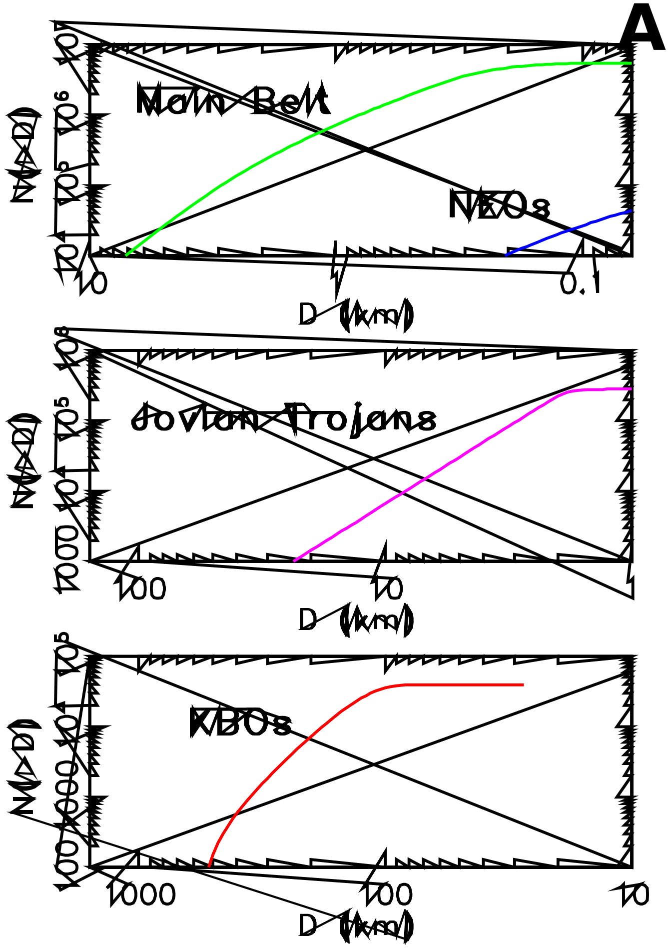
- LSST will detect and determine orbits for millions of small bodies in the Solar System.

- Classes include:
  - Near Earth Asteroids (NEAs), and their subclass, Potentially Hazardous Asteroids (PHAs), whose orbits can potentially impact the Earth.
  - Main Belt Asteroids (MBAs), lying between the orbits of Mars and Jupiter.
  - Trojans, which are asteroids in 1:1 mean motion resonance with a planet.
  - Trans-Neptunian Objects (TNOs), and their subclass, Classical Kuiper Belt Objects (cKBOs). These occupy a large area of stable orbital space.
  - Jupiter-Family Comets (JFCs), whose orbits are strongly perturbed by Jupiter.
  - Long Period Comets (LPCs), which originate in the Oort Cloud at 10,000 AU.
  - Hally Family Comets (HFCs), which also come from the Oort Cloud, but have shorter periods.
  - Damoclids, a group of asteroids with similar dynamical properties to the HFCs.

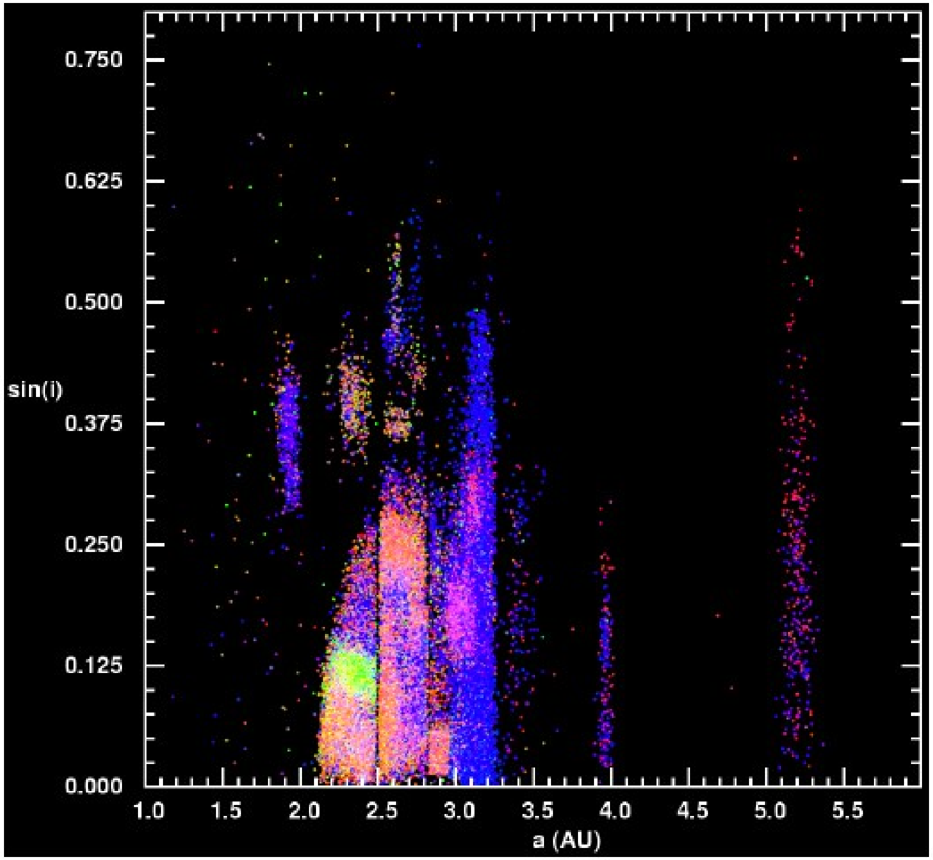
- Understanding the origin and behavior of these various systems is crucial for modelling the formation and evolution of the Solar System.

Small bodies in the solar system

Expected counts vs size



Segregation via orbital paramete
And colors -> find new families

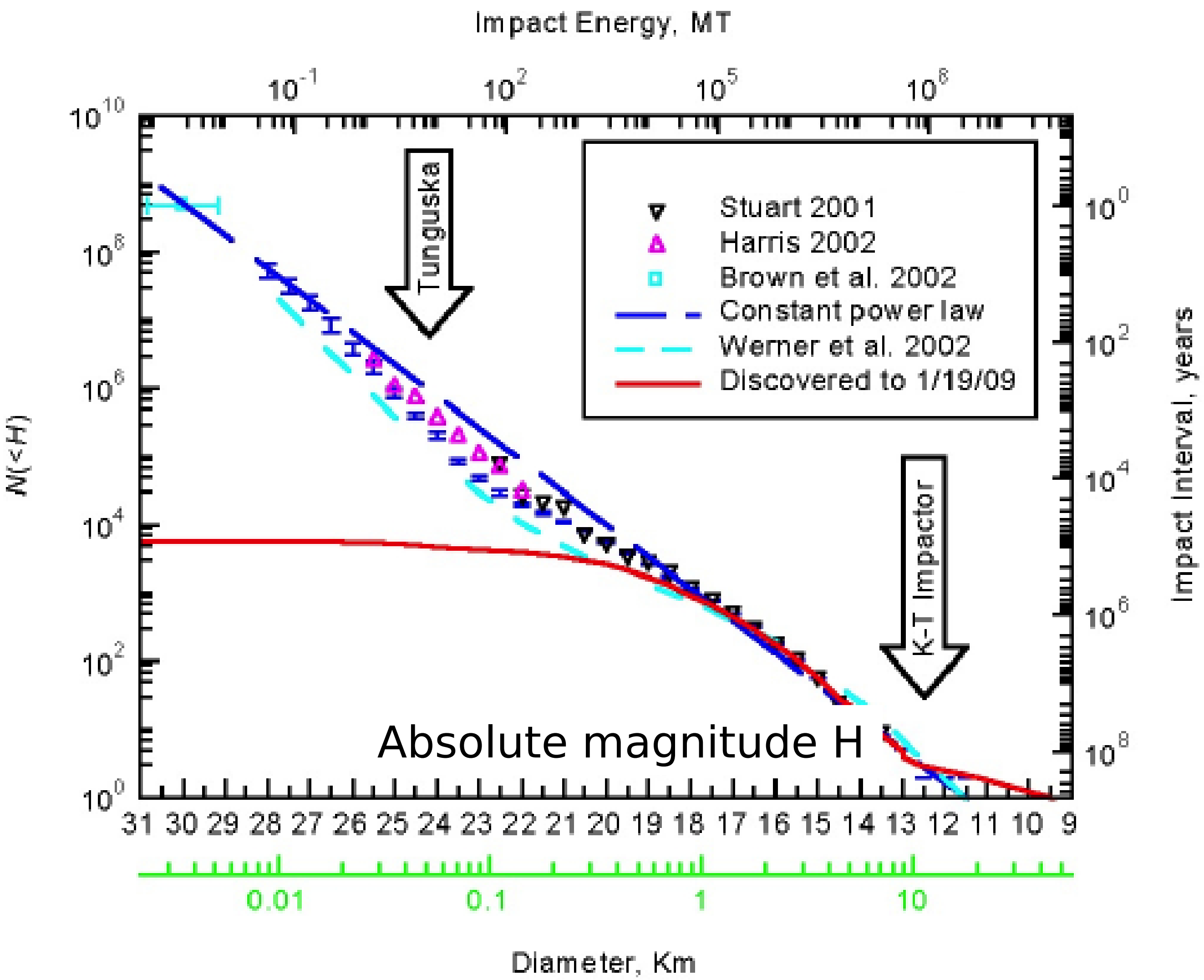


SDSS comets (Solontoi et al. 2010; n~20)

Comets will "last" longer with LSST than with SDSS

! essentially "transient" sources!
but not "true transients"

The “Threat” from “Earth killers”



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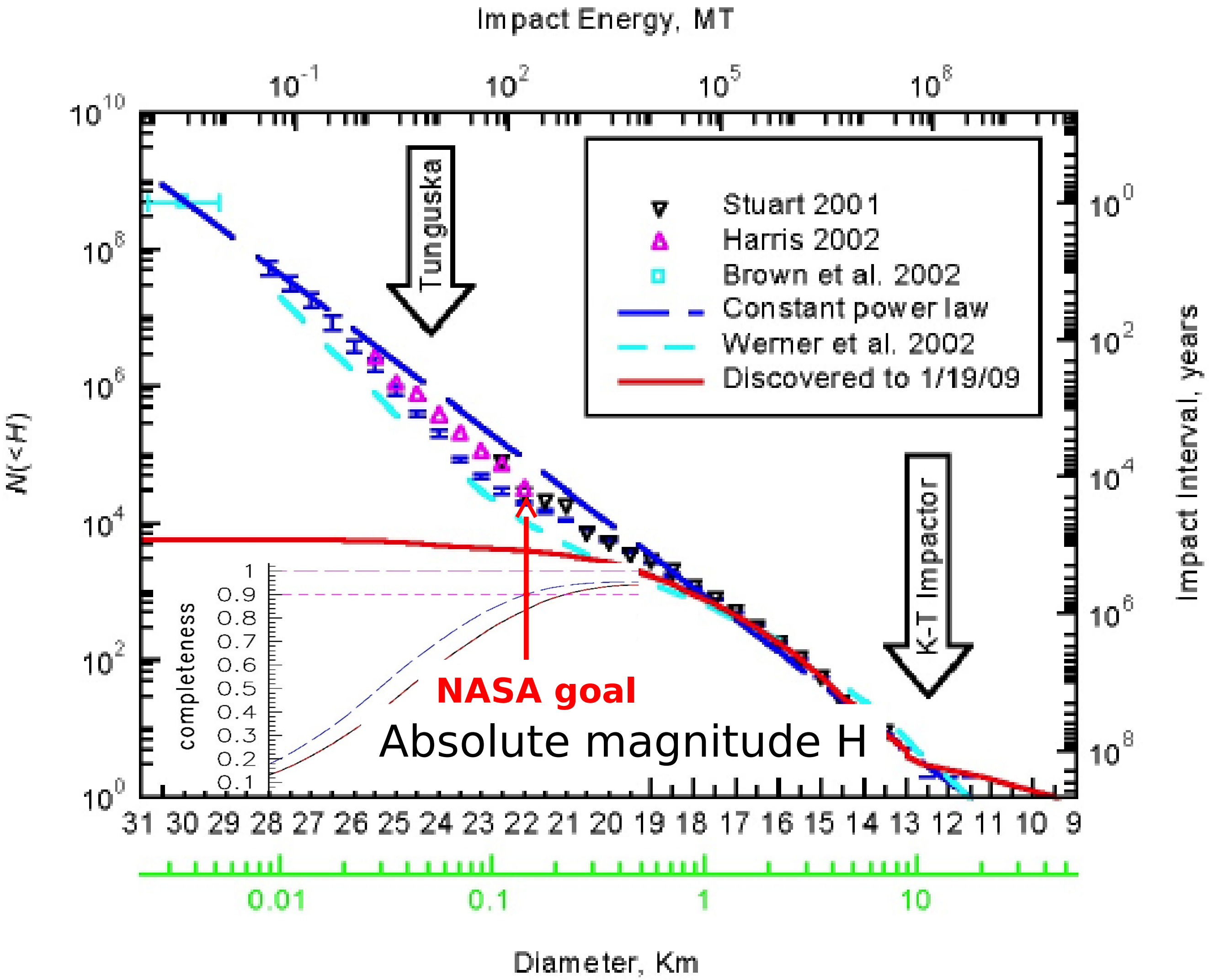


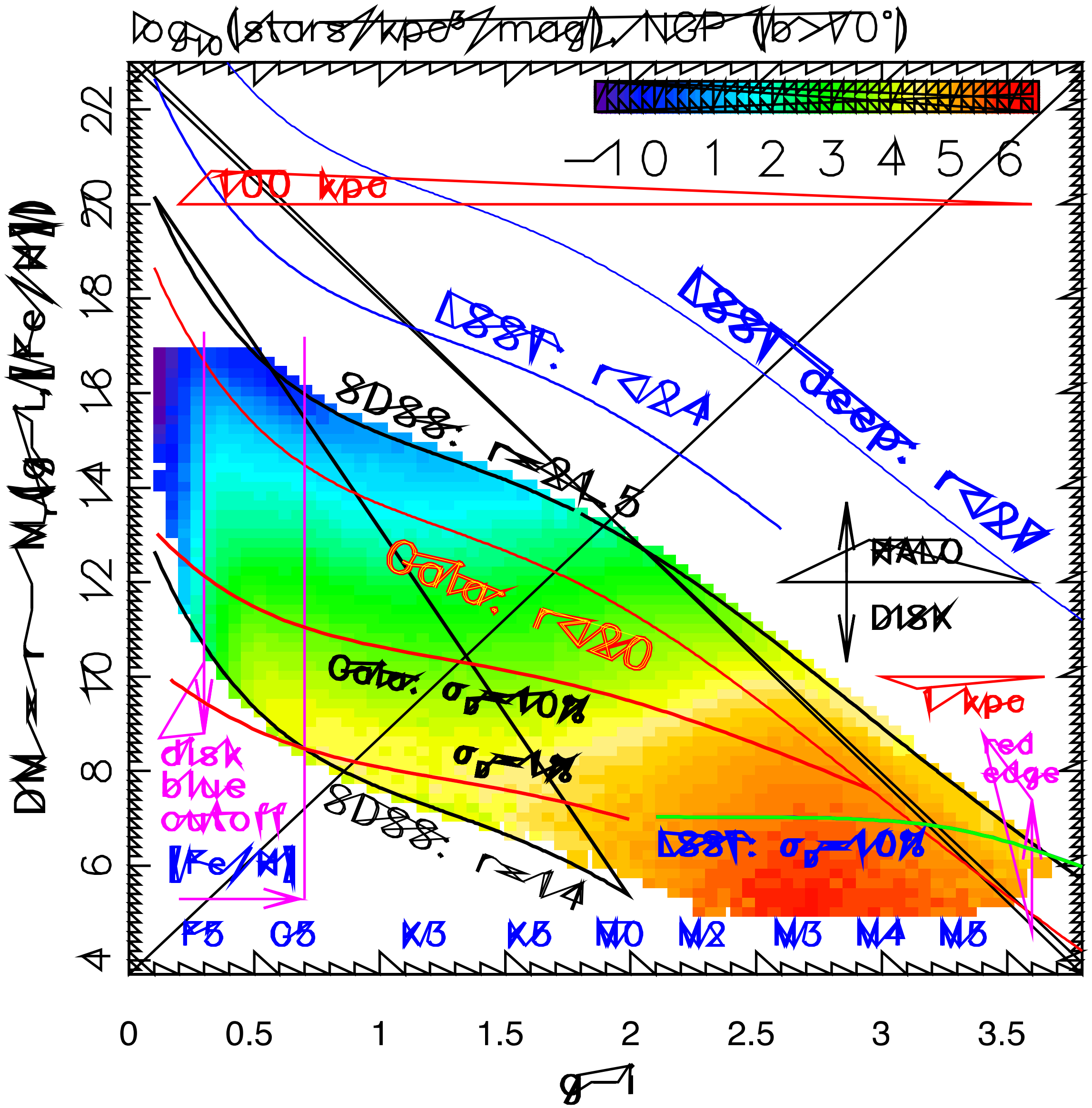
Stellar Populations: Milky way

- LSST will individually resolve and detect billions of stars in the Milky Way and neighboring Local Group galaxies,

- Studies of field stars and stellar associations can address a multitude of astrophysical issues associated with star formation and evolution, the assembly of the MW galaxy, and the origin of the chemical elements.

- Key techniques for these investigations include:
  - Construction of color magnitude diagrams
  - Trigonometric parallaxes to establish absolute distances
  - Stellar proper motions to separate associations from background stars and from one another
  - Using RR Lyrae and other variables as “standard candles”
  - Using eclipsing binaries to measure stellar masses

Volume number density of stars



Number density of ~2.8x106 SDSS stars with 14 < r < 21.5 and b > 70◦ in the ***(distance modulus, g−i)*** diagram

- Mag. limits for Gaia (r < 20)
- Mag. limits for LSST's single epoch data (r < 24, 10 σ)
- Mag. limits for LSST's stacked data (r < 27, 10 σ)
- Dist. limits for obtaining 10% accurate parallaxes with LSST
- limits for obtaining 1% and 10% parallaxes

The Solar Neighborhood

Expected Precision of Proper Motion and Parallax Measurements

THE EXPECTED PROPER MOTION, PARALLAX AND ACCURACY FOR A 10-YEAR LONG BASELINE SURVEY.

r mag	σ_{xy}^{a} mas	σ_{π}^{b} mas	σ_{μ}^{c} mas/yr	σ_{1}^{d} mag	σ_{C}^{e} mag
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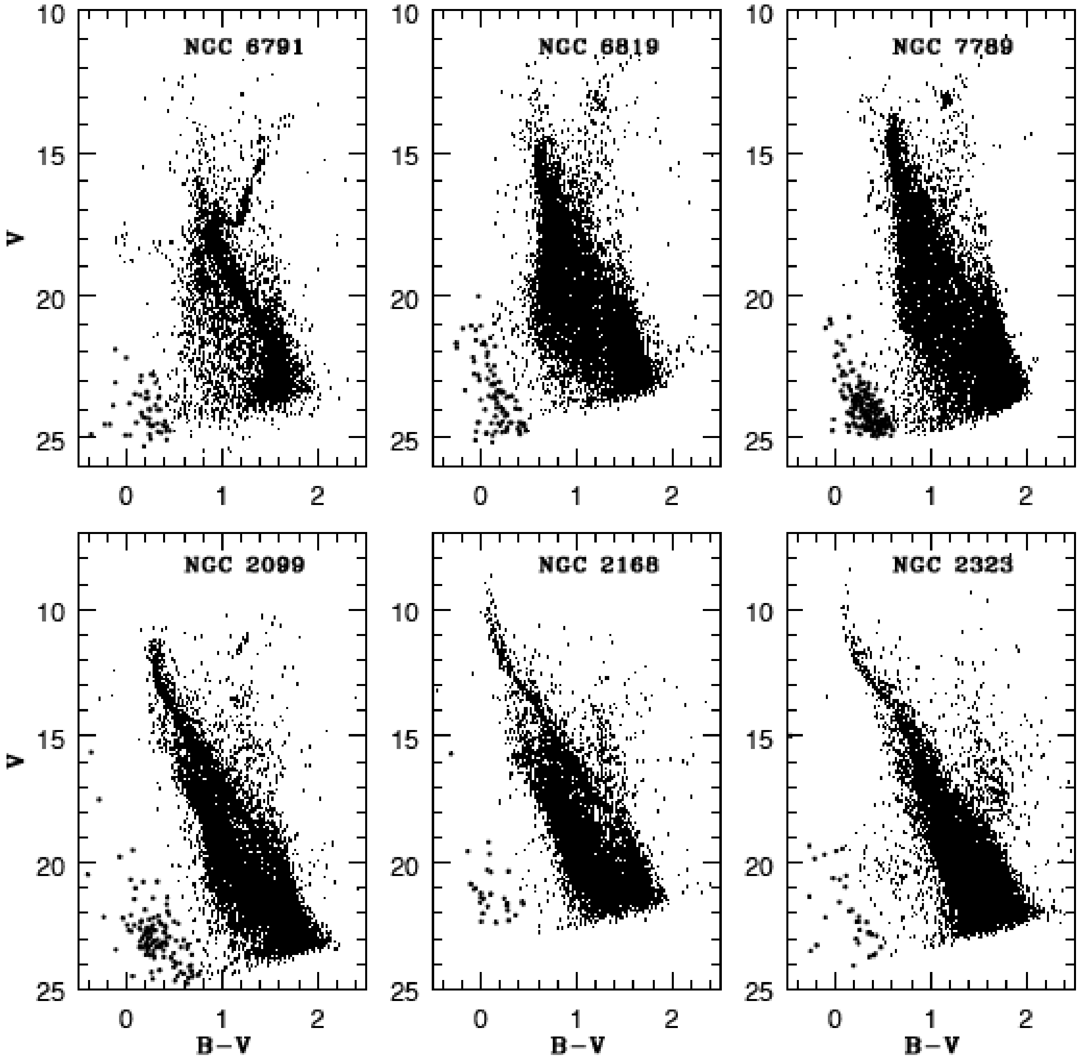
Color Magnitude Diagrams Establish the Ages and Metallicities of Star Clusters



Galaxies

- **LSST will probe a Co-Moving Volume ~ 2 Orders of Magnitude Larger than Current or Near-Future Surveys**

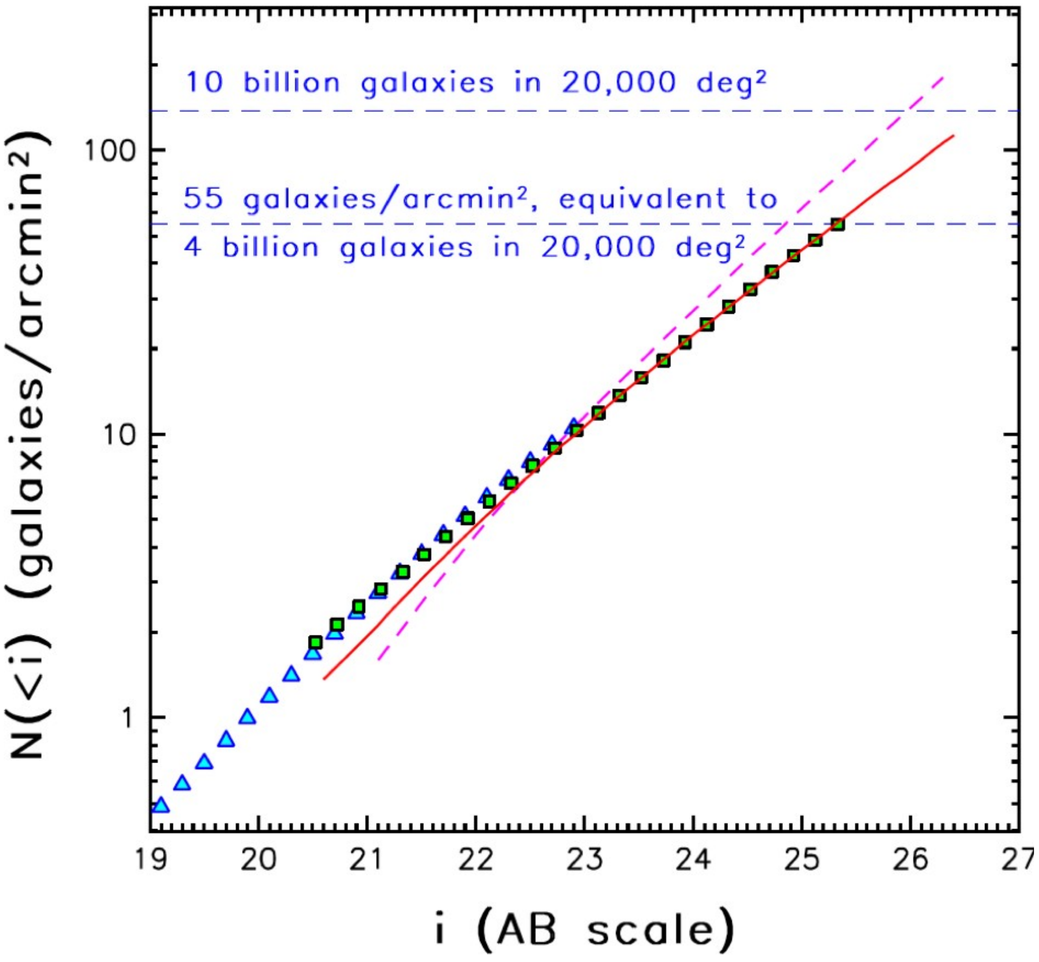
  -> reach 50 galaxies / arcmin2

- The database will include photometry for 1010 galaxies from the Local Group to z > 6.

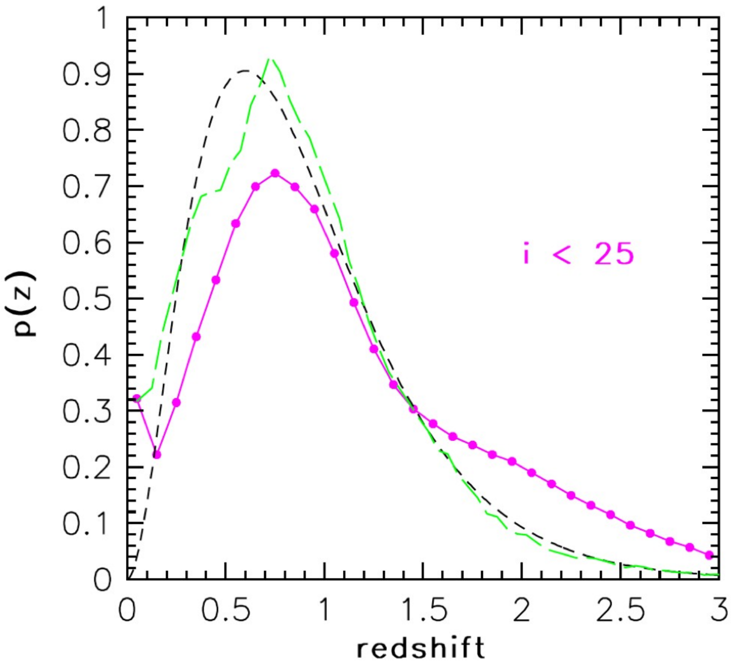
- We will have 6-band photometry for 4 x 109 galaxies.

- Key diagnostic tools will include:
  - Luminosity functions
  - Color-luminosity relations
  - Size-luminosity relations
  - Quantitative morphological classifications
  - Dependence on environment

Galaxy counts (over 20,000 deg2)



- ~4 billion galaxies (55/arcmin2) in "gold" sample defined by i < 25.3 (S/N > 20)
- ~10 billion galaxies on the stacked map (r < 27.5, corresponding to i ~ 26 given the typical colors of galaxies)

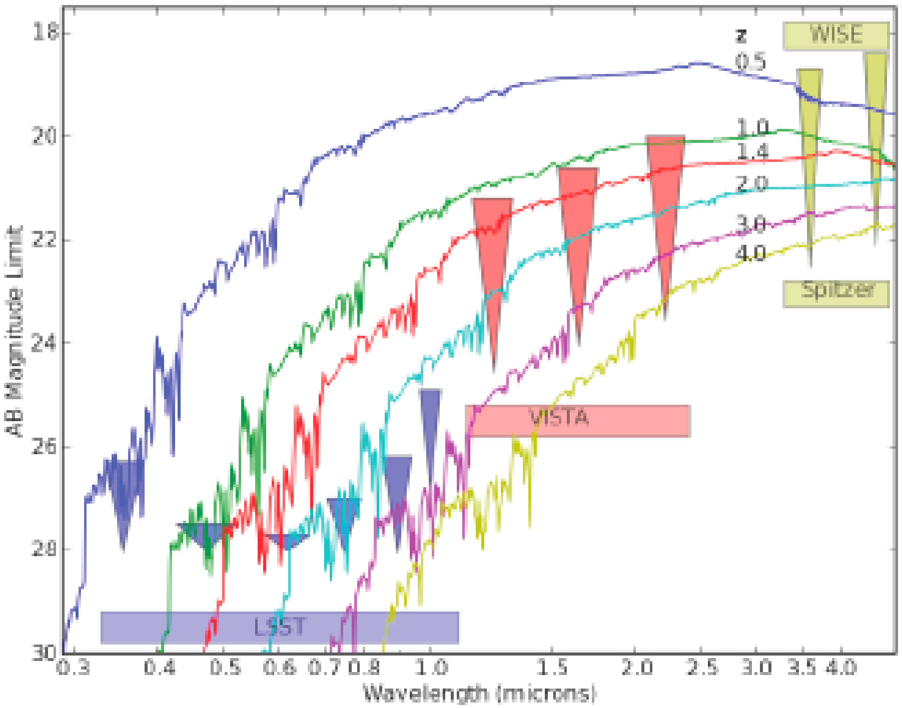


Galaxies

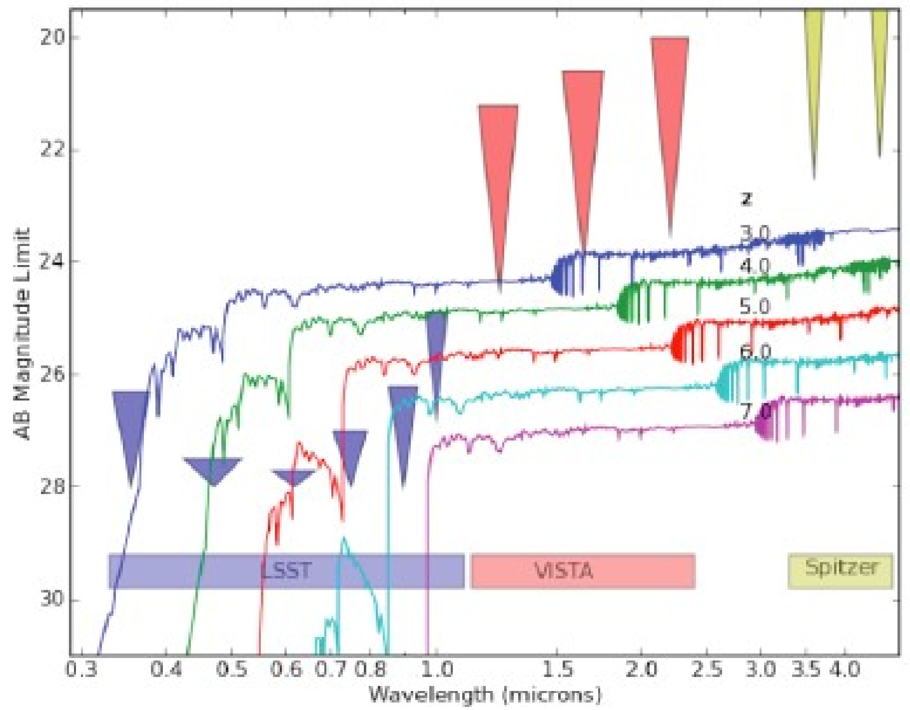
How LSST survey will contribute to Galaxies Studies

- Constrain both the bright and faint end of the Luminosity Function
- With great statistics, over wide redshifts
- Understanding low-mass galaxies
- Destruction mechanisms
- Do gas-poor dwarfs exist in low-density environments?
- Quantifying Galaxy interactions
- Merger rates, tidal destruction
- Detailed mapping of galaxy properties vs. environment

The Expected Sensitivity Leads to Near Complete Samples Out to High Redshifts



Evolving L* Red Sequence Galaxy



Evolving L* Lyman-Break Galaxy

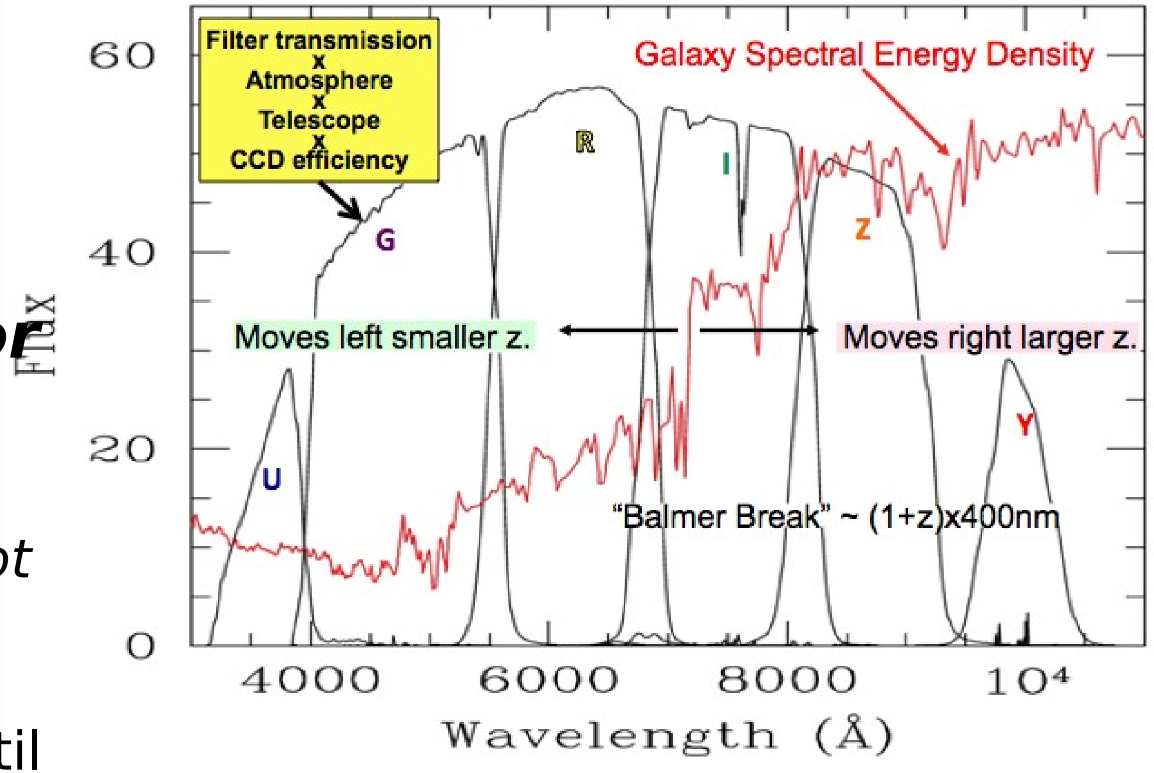
Photometric redshift

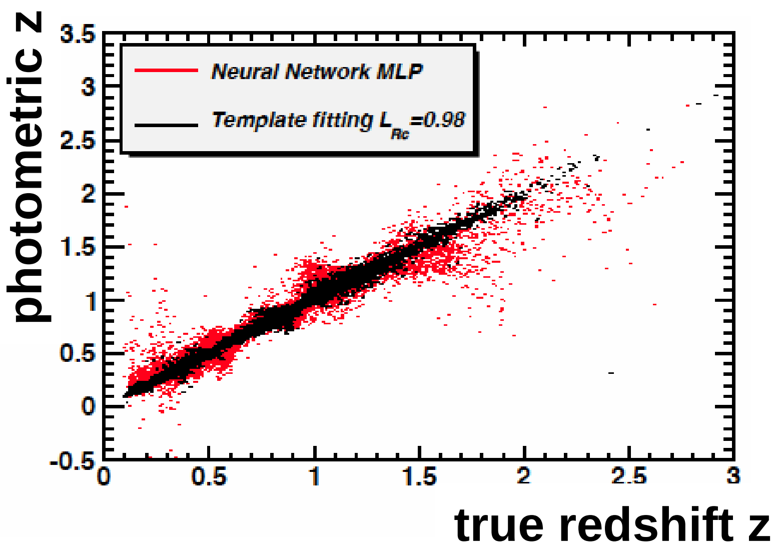
A critical issue for cosmology with LSST

- 1010 galaxies *cannot* be spectroscopically measured
- LSST: Calibration until z=3
  -> need 75 000 spectra
  (~50% already exist)

Measure z with only 6 colors ugrizy

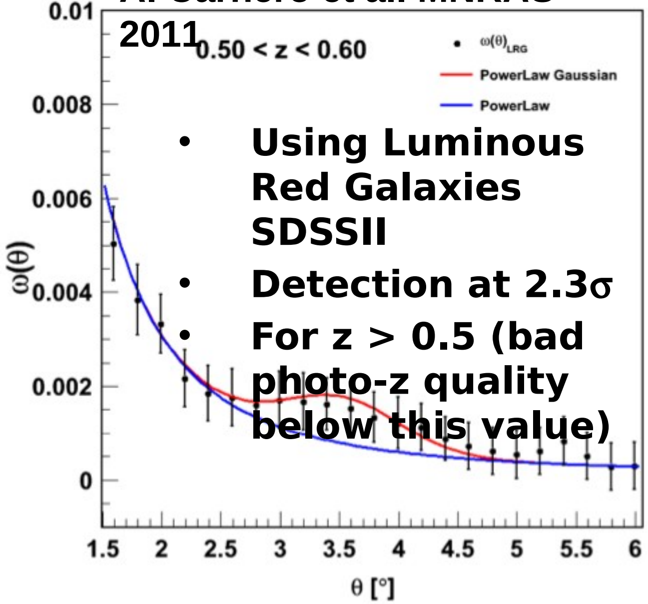
- Simultaneous fit of galaxy type, reddening and z
  – Template fitting and neural network techniques validated with data and tuned with simulation





the golden Photo-z's way

A. Carnero et al. MNRAS 2011



- Using Luminous Red Galaxies SDSSII
- Detection at 2.3σ
- For z > 0.5 (bad photo-z quality below this value)

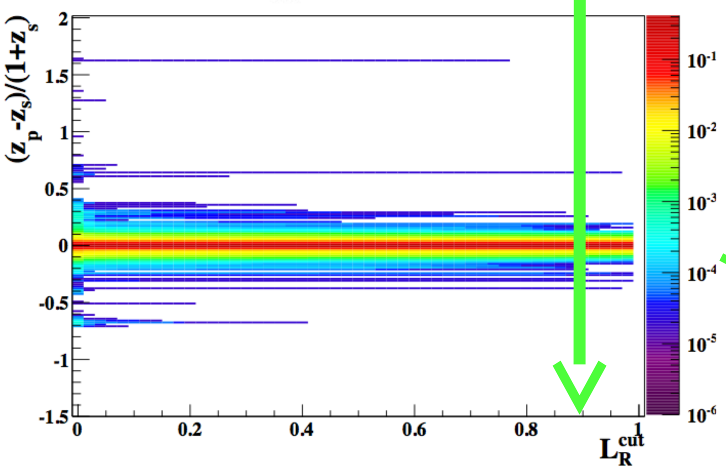
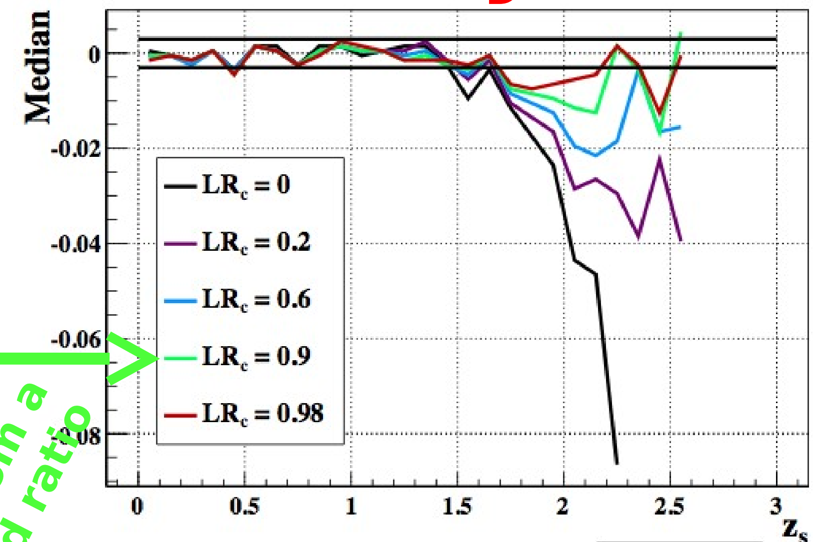
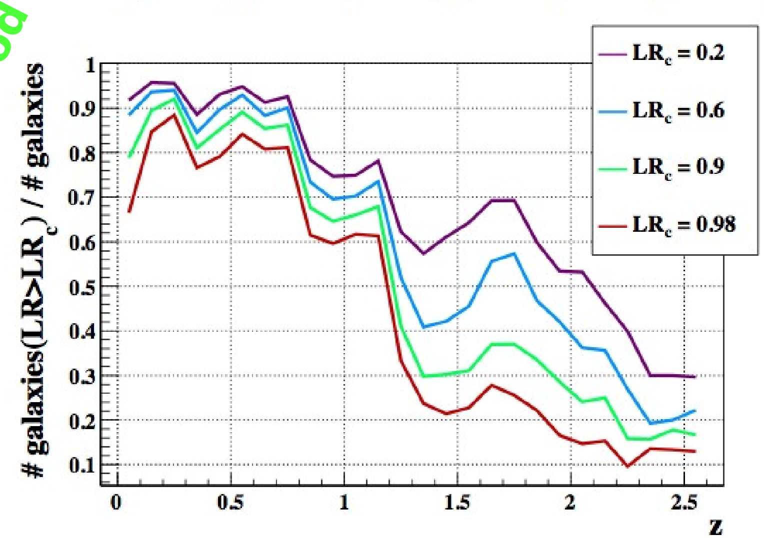


Fig. 14. From the LSST simulation training sample. 2D distribution of $(z_p - z_s)/(1 + z_s)$ as a function of the threshold $L_{R,c}$. In each bin in L_R^c, the distribution of $(z_p - z_s)/(1 + z_s)$ is normalized.

LSST: galaxies selected from a likelihood ratio





Active Galactic Nuclei

- Active Galactic Nuclei involve **massive black holes at the centers of galaxies** that release prodigious amounts of energy through gravitational in-fall.

- In recent years, we have learned that the formation and growth of central black holes plays a crucial role in galaxy evolution through "AGN feedback".

- The enormous dynamic range offered by LSST in luminosity and redshift will revolutionize our understanding of AGN demography and the correlation between AGN properties and their host dark matter haloes.

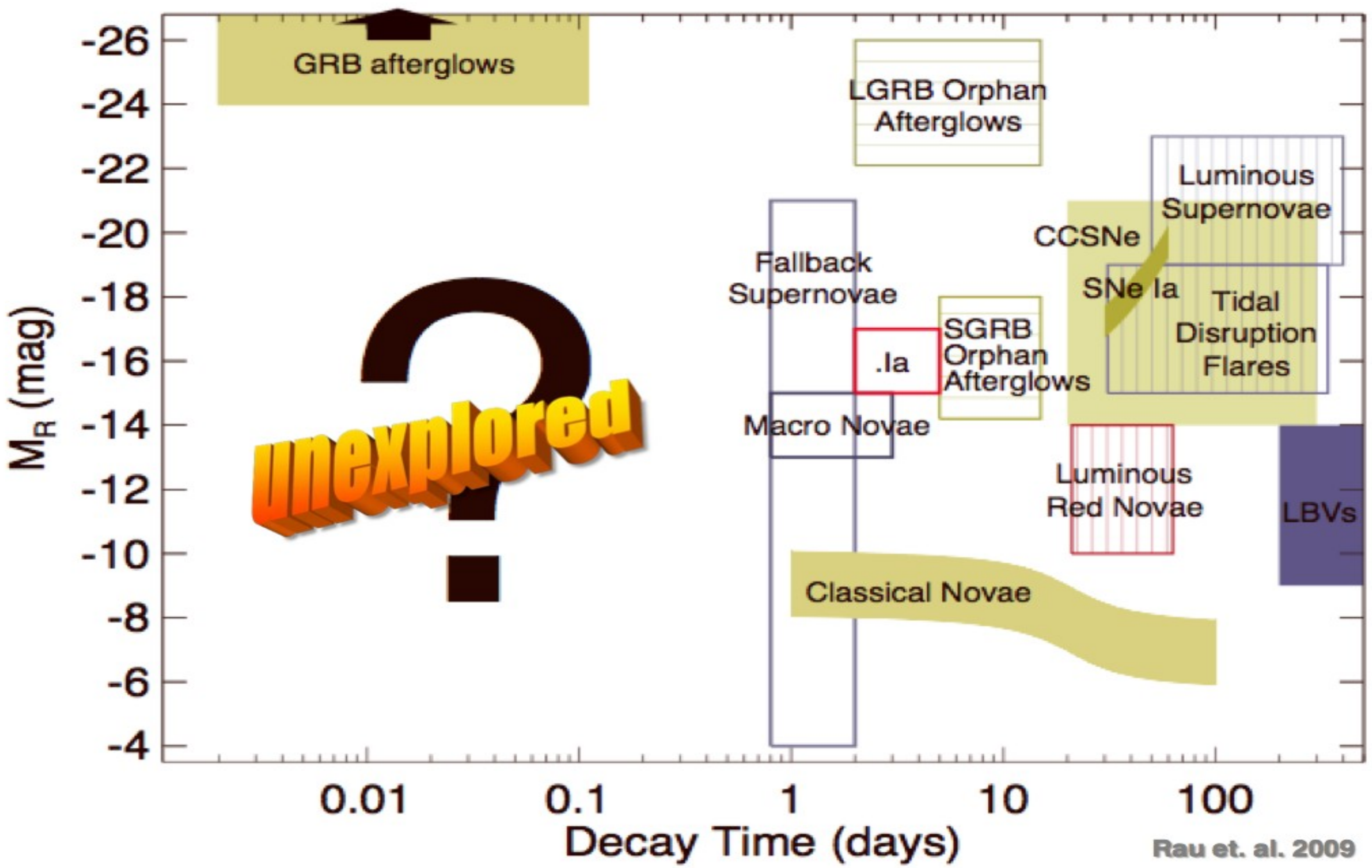
- **LSST will produce a high purity sample of > 107 optically-selected AGNs**. This is at least an order of magnitude larger than current AGN samples using all wavelengths.

Transients and Variable Stars

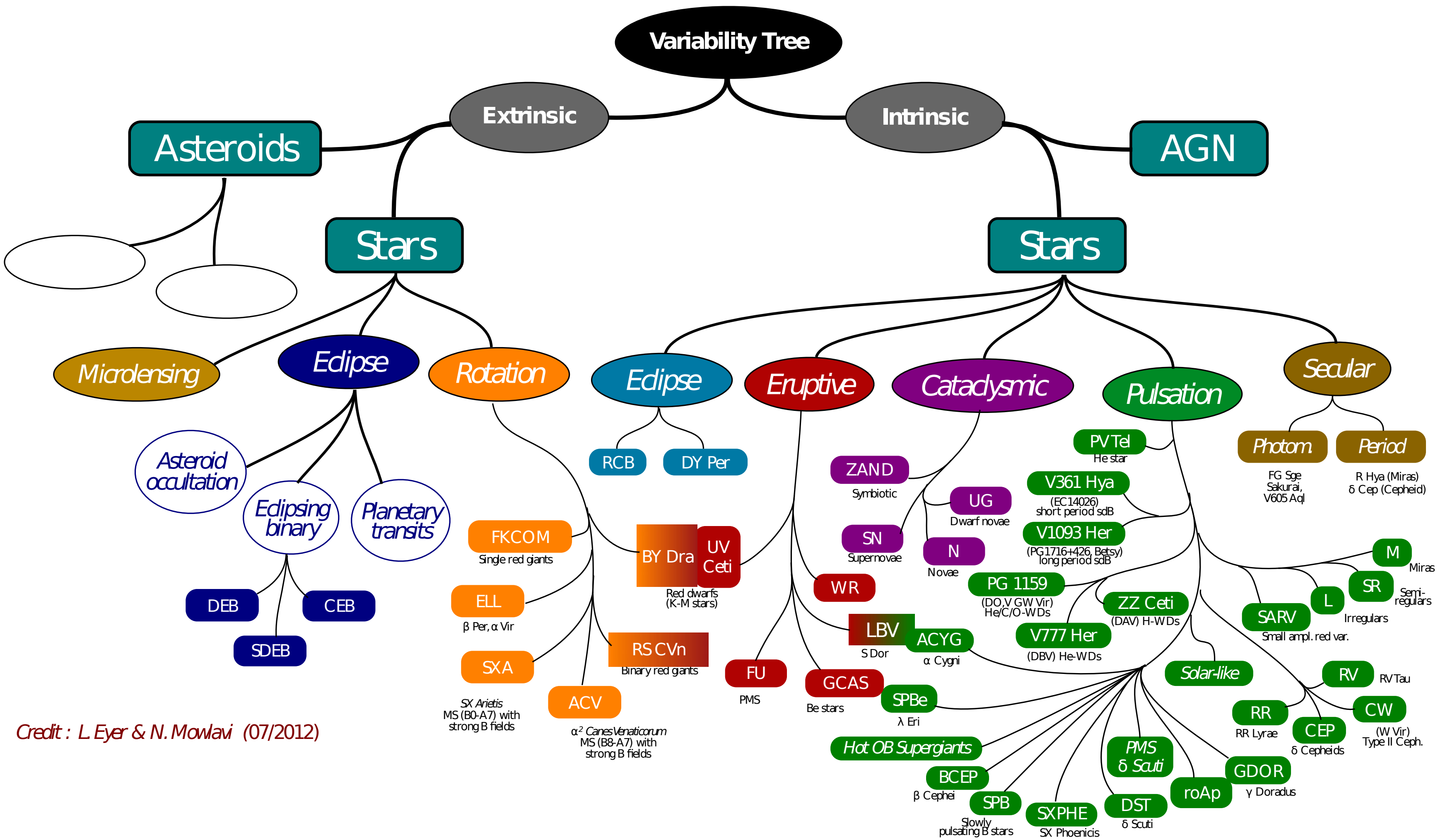
- LSST's unique time sampling allows the detection of stellar variability on timescales **from seconds to years**.

- A wide range of phenomena can be studied with such a rich dataset:
  - Explosive events (supernovae, novae, gamma-ray bursts)
  - Periodic variability associated with binarity
  - Intrinsic stellar variables like Cepheids, RR Lyrae, Miras, which are important for distance measurements
  - Geometrical effects such as gravitational microlensing
  - Dimming of stars as they are occulted by transiting planets

Optical Transients : Mag vs time

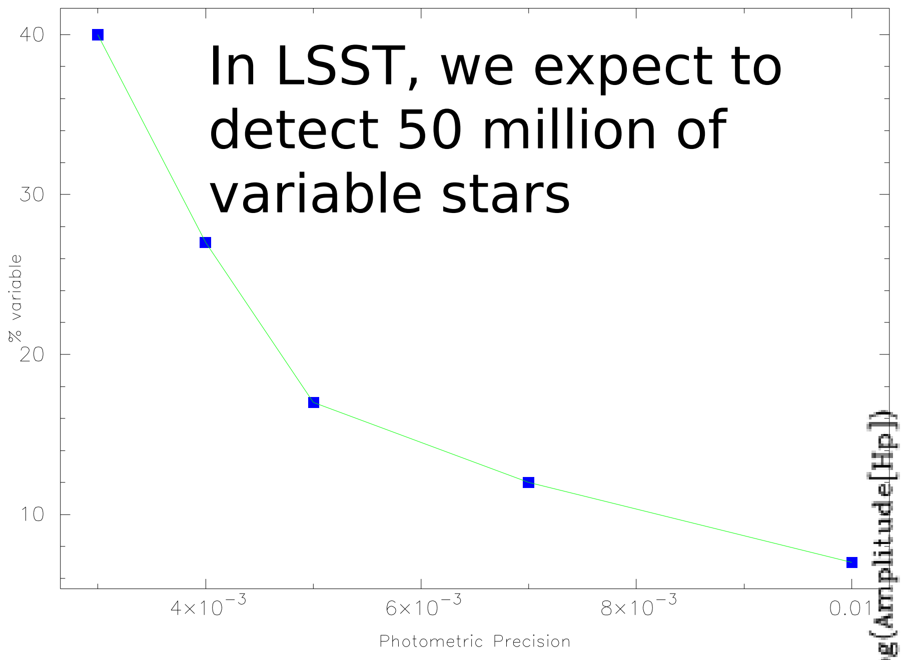


Asteroseismology in the zoo of variable stars

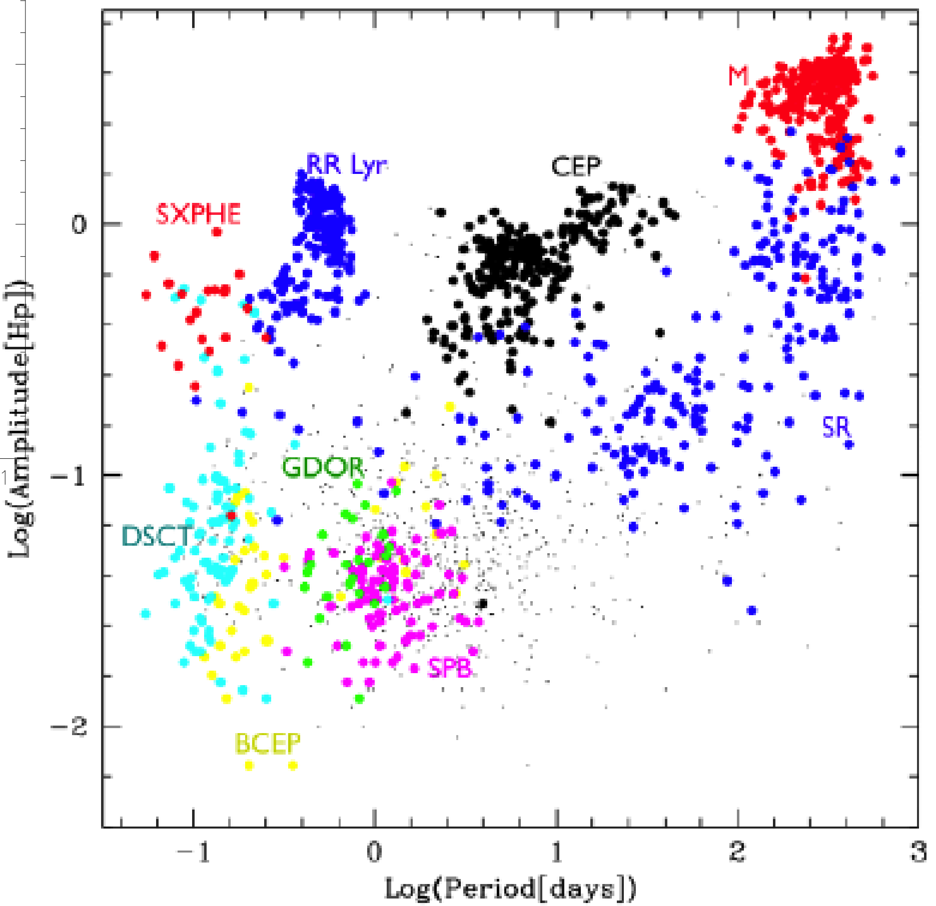


Credit : L. Eyer & N. Mowlavi (07/2012)

Search for variable stars



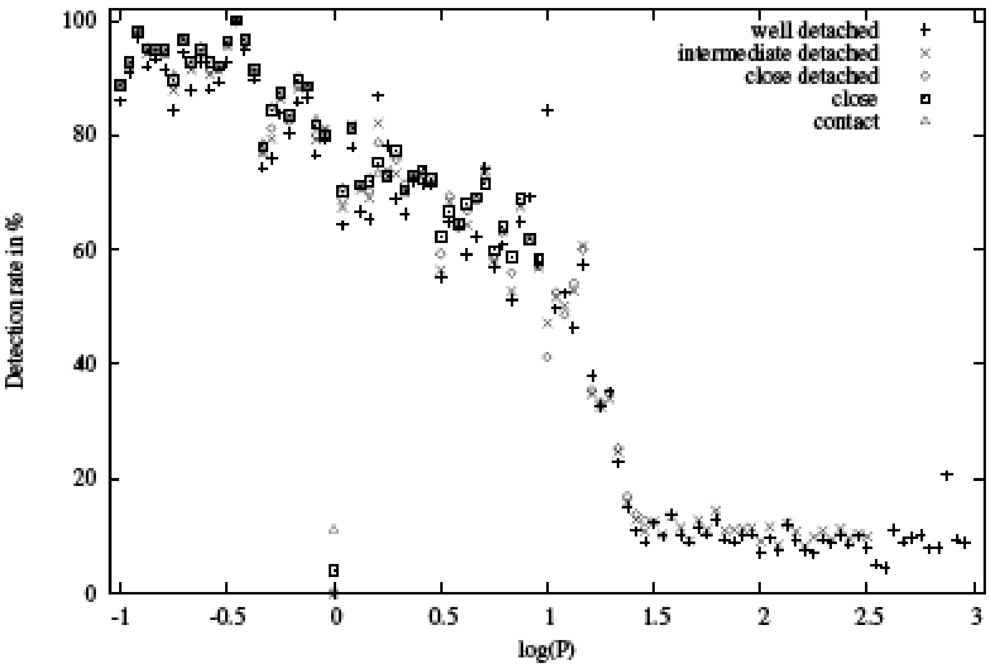
In LSST, we expect to detect 50 million of variable stars



Variable Star Classes Can Be Readil Identified Via Their Periods and Amplitudes

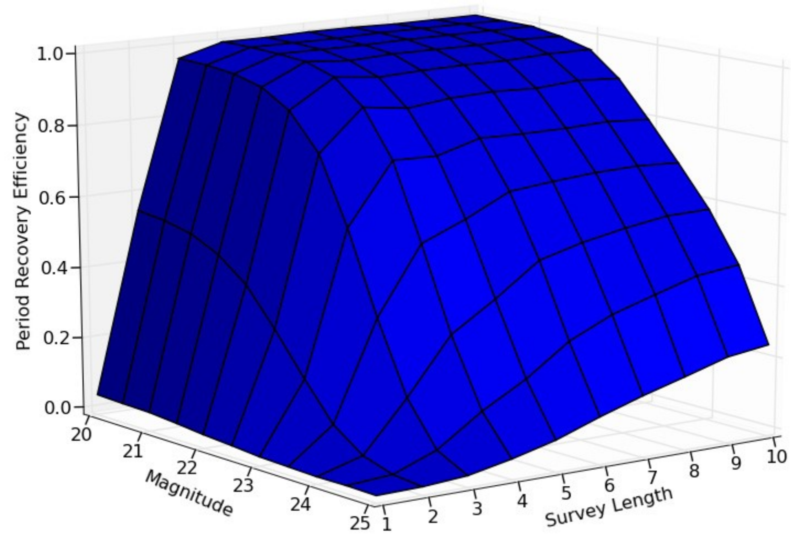
Search for variable stars

Eclipsing Binaries Provide Precision Mass Estimates, Testing Stellar Evolution Models



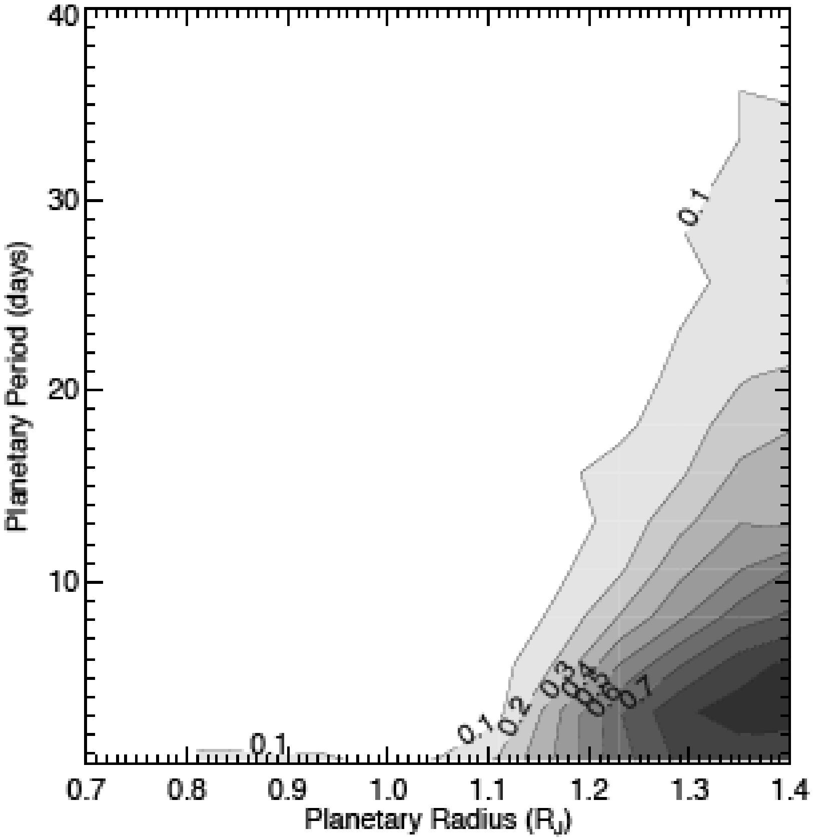
Expected recovery efficiency of eclipsing binaries

Cepheids and RRLyr. Provide distances

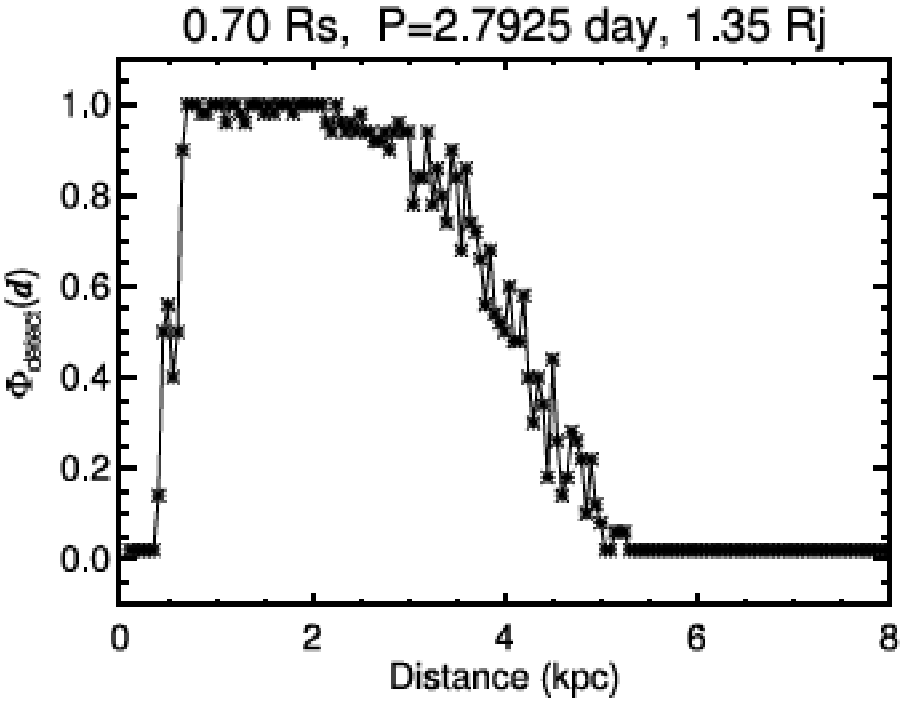


Expected recovery efficiency of RRLy

LSST Is Likely to Find a Large Sample of “Hot Jupiters”



Planetary detection probabilities for a 0.7Rsol star@1kpc



Planetary detection probabilities as a functionof the distance of the star

Alerts…

Sources detected in difference images (images with respect to coadded templates, called DIASources) reported in 60s

- Filter a stream of ~10 million DIAsources / night variable stars, SNe, asteroids, and “everything else »

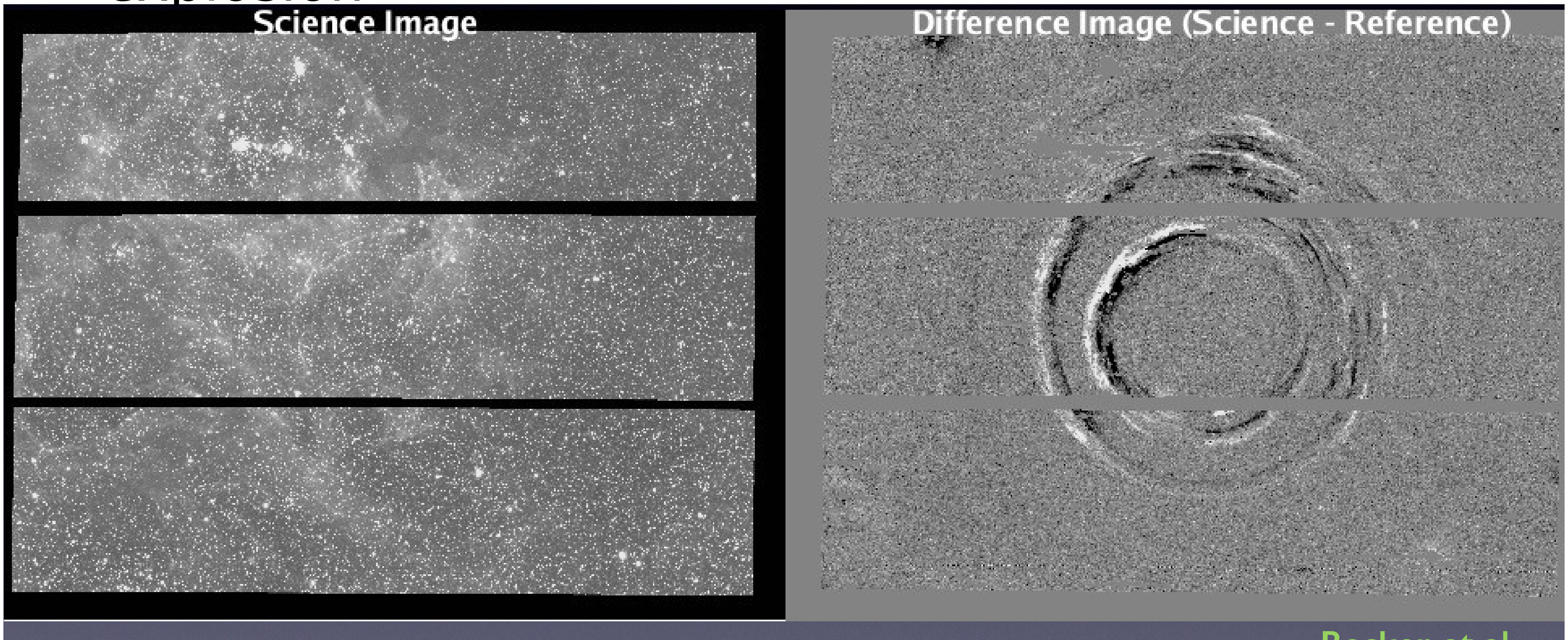
  -> Robust filtering + rapid followup

Given a stream of ~10,000 DIASources every ~40s (per 10 sq. deg. Field)

- Asteroids will dominate on the Ecliptic, become insignificant >30 deg. from it.
- Variable stars (~1 % of all stars) will dominate in the Galactic plane, always significant (~400/field @ Galactic pole)
- Quasars will contribute up to 500/field (but likely several times lower)
- SNe will contribute up to about 100/field

Not only point-sources

- LSST will extend time-volume space a thousand times over current surveys (new classes of object?)!
- Not only point sources - echo of a supernova explosion



Microlensing expectations

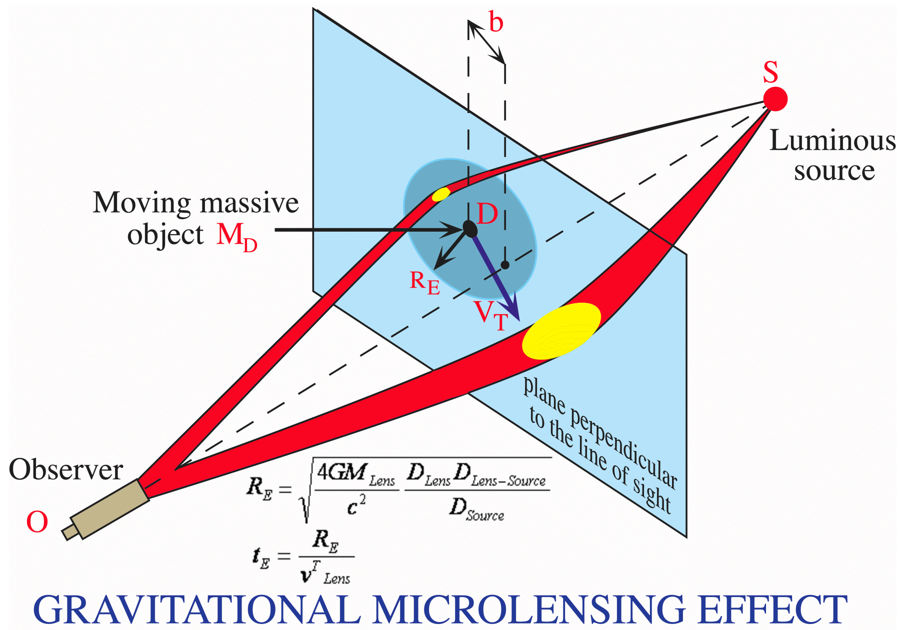
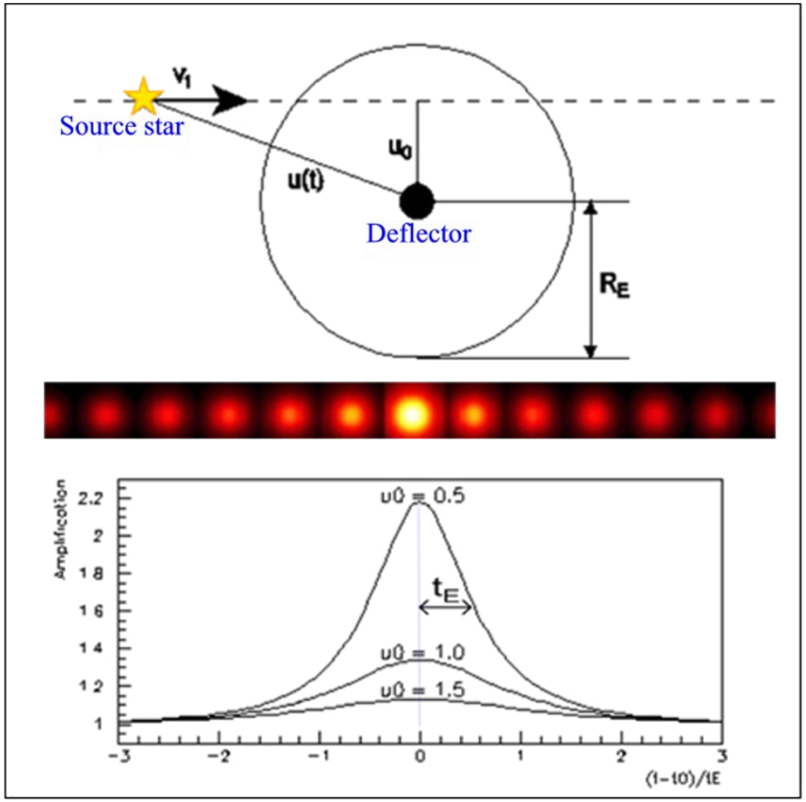


Table 8.4: **Nearby Microlens Event Rates**

Lens type	**Past** per decade per deg^2	**Present** per decade per deg^2	**Future** per decade per deg^2	**Future** per decade **over 150** deg^2
M dwarfs	2.2	46	920	1.4×10^5
L dwarfs	0.051	1.1	22	3200
T dwarfs	0.36	7.6	150	2.3×10^4
WDs	0.4	8.6	170	2.6×10^4
NSs	0.3	6.1	122	1.8×10^4
BHs	0.018	0.38	7.7	1200

Description of a microlensing event



Light curve characteristic:

- Symmetric
- Achromatic
- Unique (~1 evt / 106)

The optical depth τ :

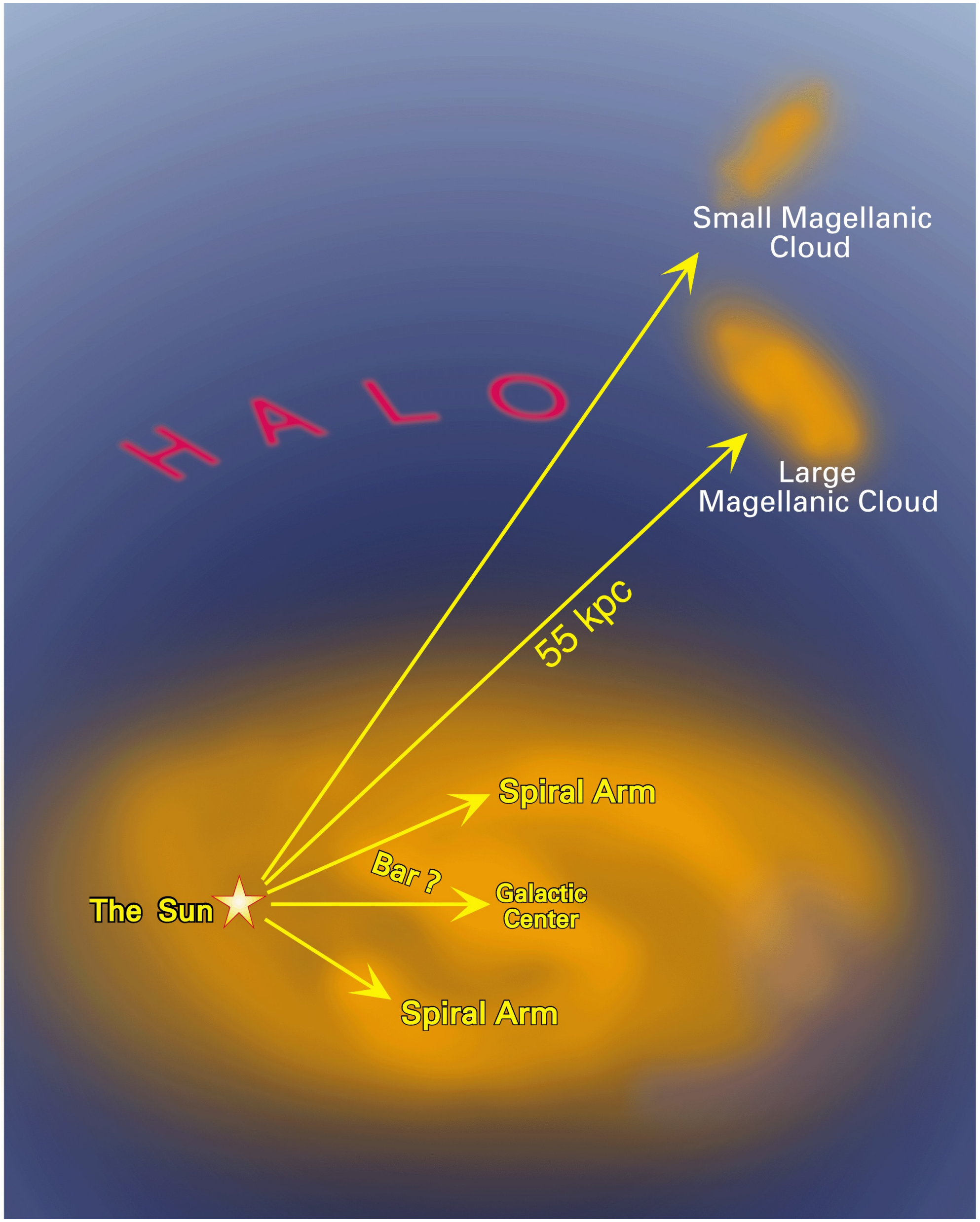
probability for a star to be behind an Einstein disk

Disk surface α RE2 α Mlens

⇒ τ α Σ **Mlens**

α **total mass of the probed structure**

The targets

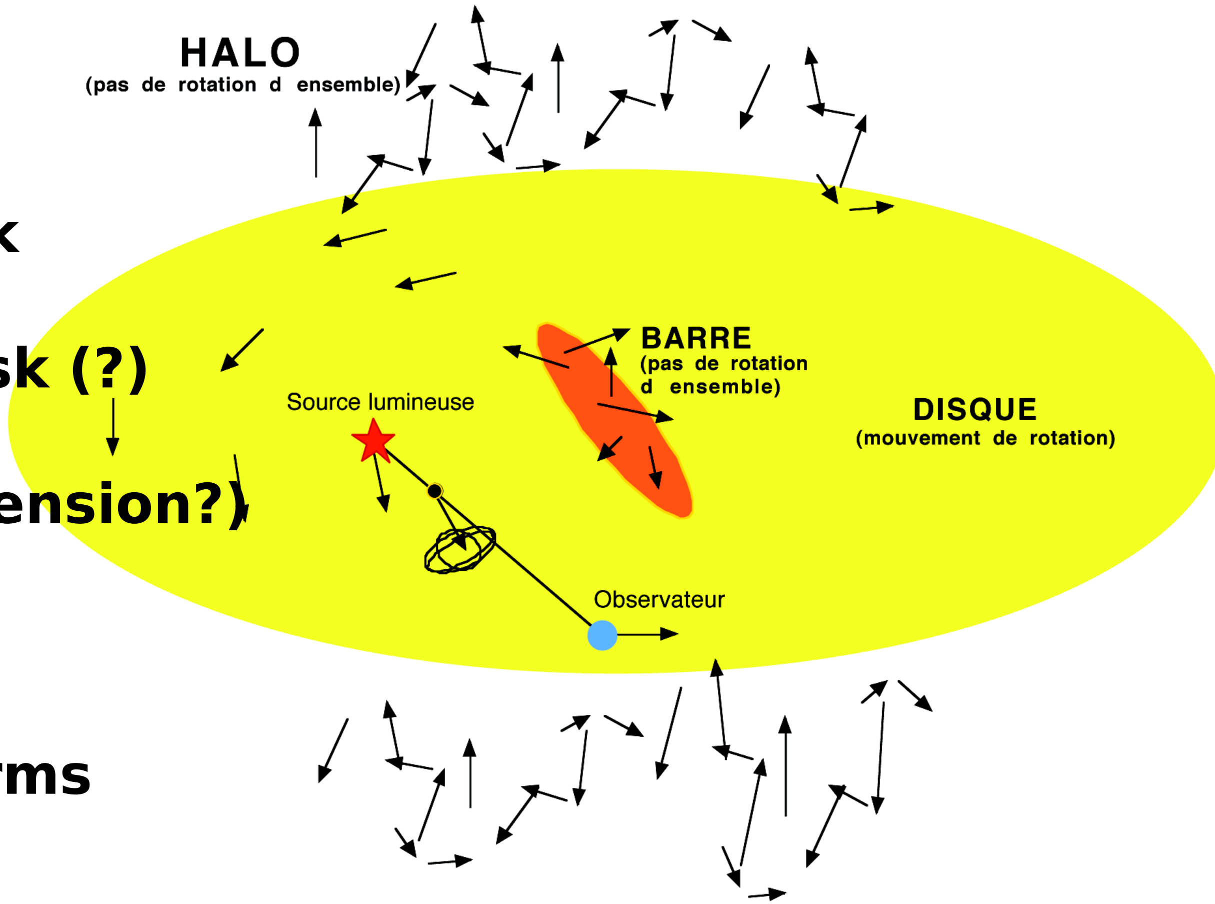


- **Magellanic Clouds** => probe hidden matter in **halo** **(τ ~ 5.10-7)**
- **Galactic center** => probe ordinary stars as lenses in **disk/bulge (τ ~ 2.10-6)**
- **Spiral arms** => probe ordinary stars in **disk, bar** + hidden matter in **thick disc (τ ~ 5.10-7)**
- Non-microlensing (**SN, proper motion**)

Lenses along the line of sight belong to several structures

Different Distances/Masses/Velocities

- **Bulge**
- **Thin disk**
- **Thick disk (?)**
- **Bar (extension?)**
- **Halo**
- **Spiral arms**

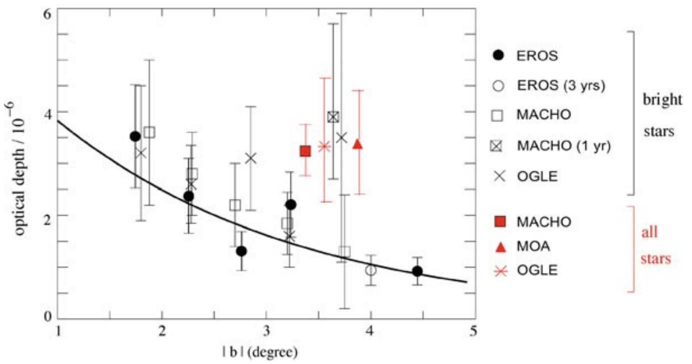


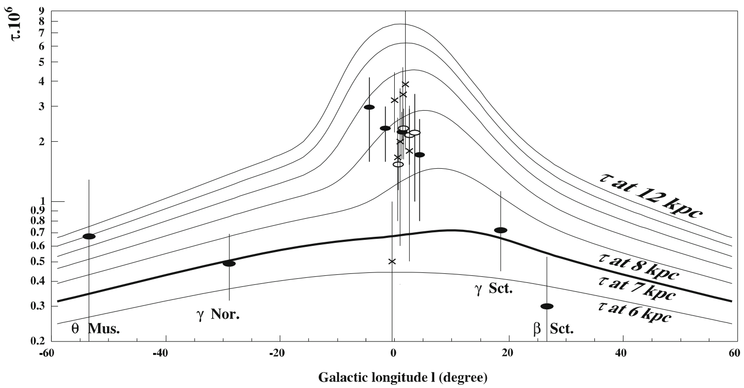
Microlensing: optical depth, durations

- Milky-way structure
  - Optical depth τ
  - Thick disk
  - Bar (size, mass)
  - Duration tE ~ Mlens1/2/VT
  - Non-local IMF (of lenses)
  - Dynamics
- + measure contribution of MACHOs to dark halo; now:

  <10% [3x10-7-3]Msol

  <20% [10-7-10]Msol

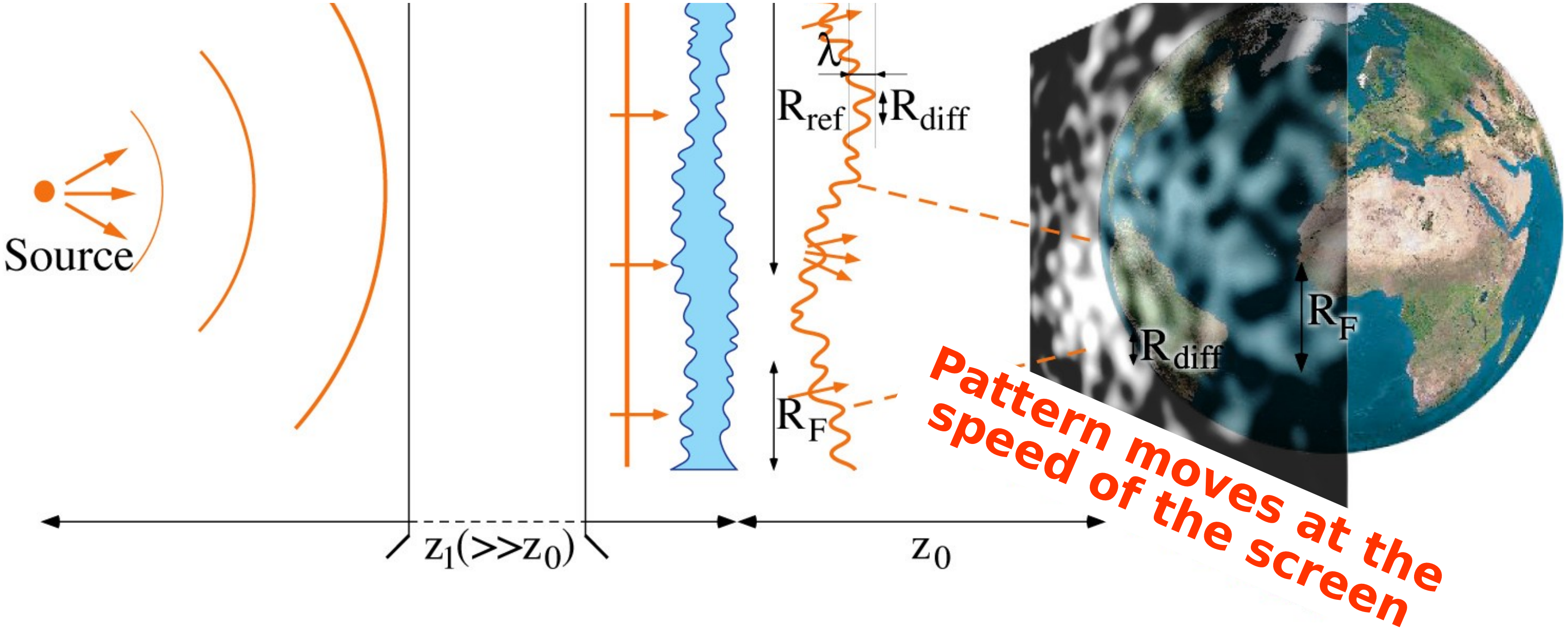




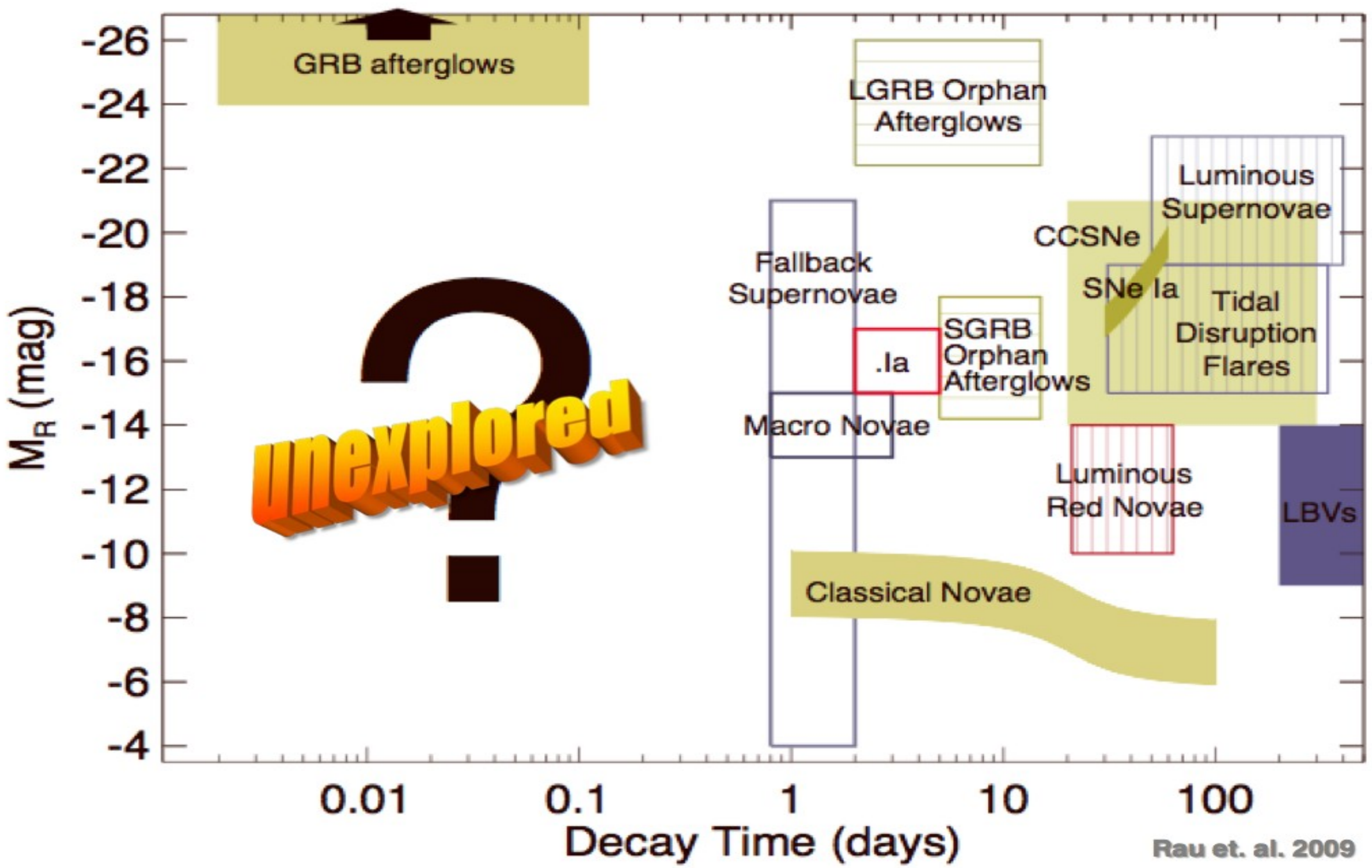
Based on 1184 events
From OGLE III

Search for hidden turbulent galactic gas

through scintillation detection (the OSER project)



Optical Transients : Mag vs time



Reference documents

- LSST science book (596 pages)
  sur **http://www.lsst.org**
- White paper of the Dark Energy Survey Collaboration (**arXiv:1211.0310**): organisation and forthcoming activities (3 years) of DESC.

Conclusion

- **Incomplete list (quasars, AGNs…)**
- **To be added to the cosmological subjects**
- **Every astrophysical subject should benefit from LSST**
- **Don't forget the unknowns…**