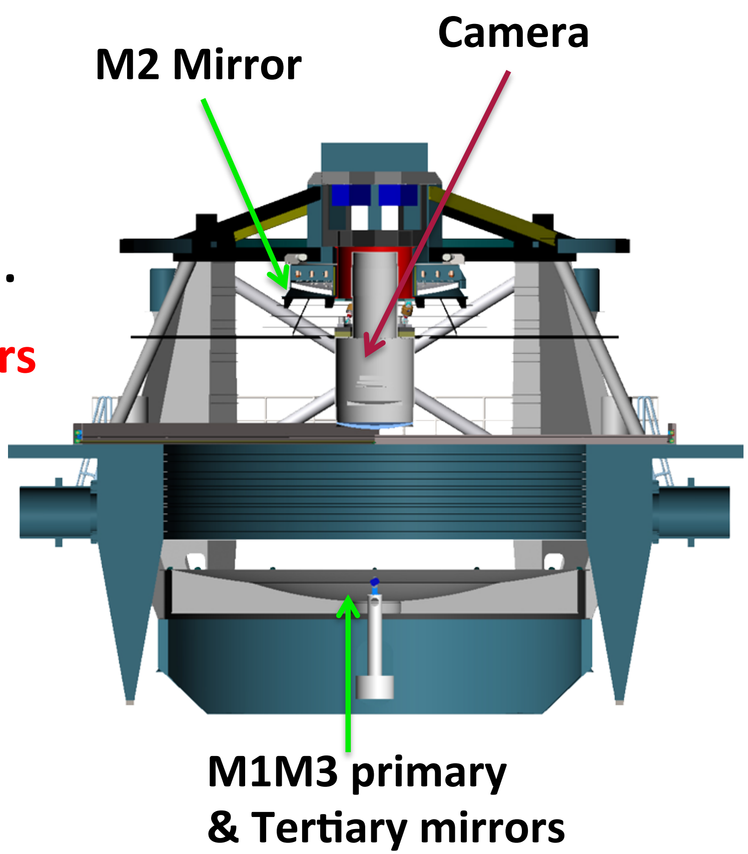

LSST transient
forecast
M. Moniez, LAL-IN2P3, TS2020-II, 4/06/2018

LSST
Large Synoptic Survey Telescope

LSST in a few figures

- Optical telescope **8.4 m diameter**
- Wide-field camera : **3.5°, 3.2 Gpixels**
- 6 wide-band filters **u g r i z y**
- Galaxies: r_{lim}=27.5 after 10 year coadd.
- Final catalogue: 10^{10} galaxies, 10^{10} stars
- Final database 15 PetaBytes
- Weak lensing up to z ~ 3
- 2,500,000 SNIa up to z ~ 1
- BAO: 3.10^{9} galaxies up to z ~ 3
- Transients with alerts (2.10^{6}/night)
- See LSST science-book in http://www.lsst.org



http://www.lsst.org/

The main telescope

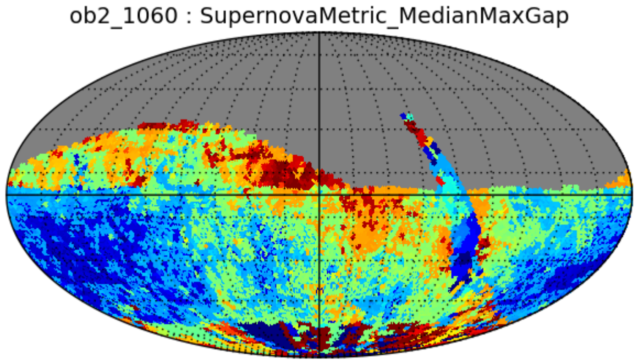
Summary of High Level Science Requirements

Survey Property	Performance
Main Survey Area / duration	18000 sq. deg. / 10 years
Total visits per sky patch	825 (1 visit per ~3-4 nights)
Filter set	6 filters (ugrizy) from 320-1050nm
Single visit	2 x (15 second exposures + 1s shutter + 2s readout)
Single Visit Limiting Magnitude (AB 5σ)	**u = 23.9; g = 25.0; r = 24.7; I = 24.0; z = 23.3; y = 22.1**
10 year coadd. Limiting Magnitude	u = 26.1; g = 27.4; r = 27.5; I = 26.8; z = 26.1; y = 24.9
Photometric calibration	< 5mmag repeatability & colors, <10mmag absolute
Median delivered image quality	~ 0.7 arcsec. FWHM
Transient processing latency	**60 sec after last visit exposure**
Data release	Full reprocessing of survey data annually

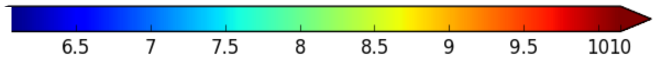
LSST main survey deliverable

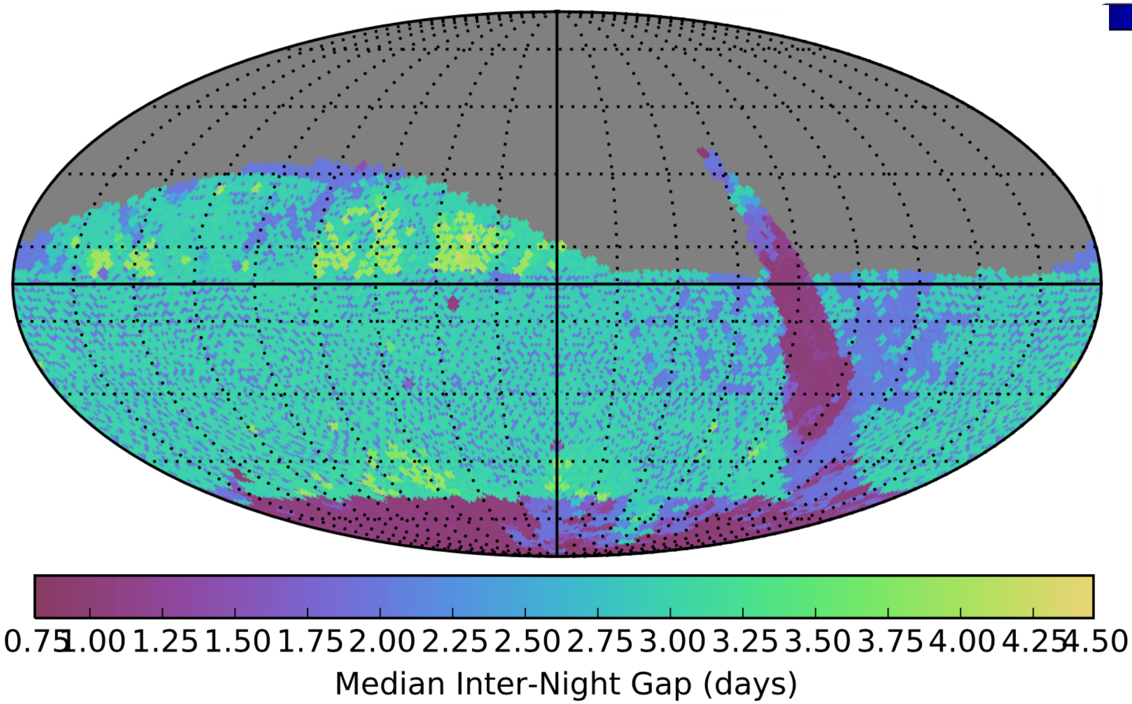
« 4D » object mapping (stars, galaxies...) of 18,000 sq. deg. to an uniform depth

- **(α,δ) positions on the sky**
- **Photometric redshifts z**
- **Time variations**
  - **-> SN, lensing, AGN…**



median maximum gap (in days) in observations near SN light curve peak





Other survey modes

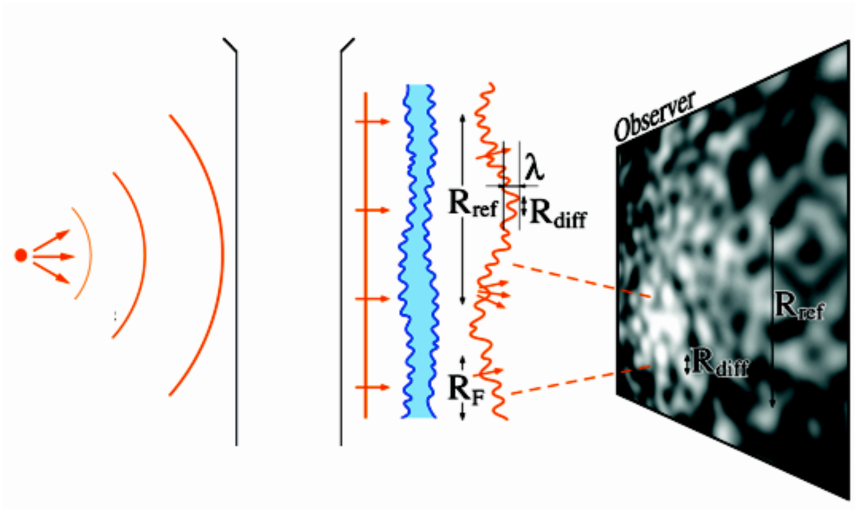
~10% of time ~1h/night

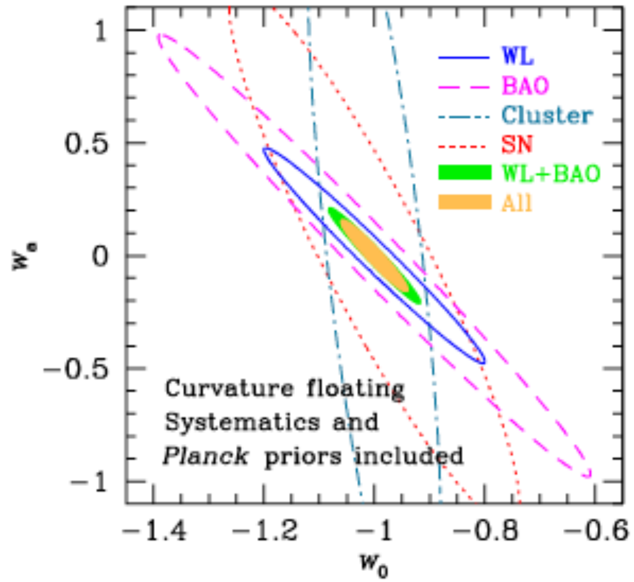
Very Deep + fast time domain + special zones

(ecliptic, galactic plane, Magellanic clouds)

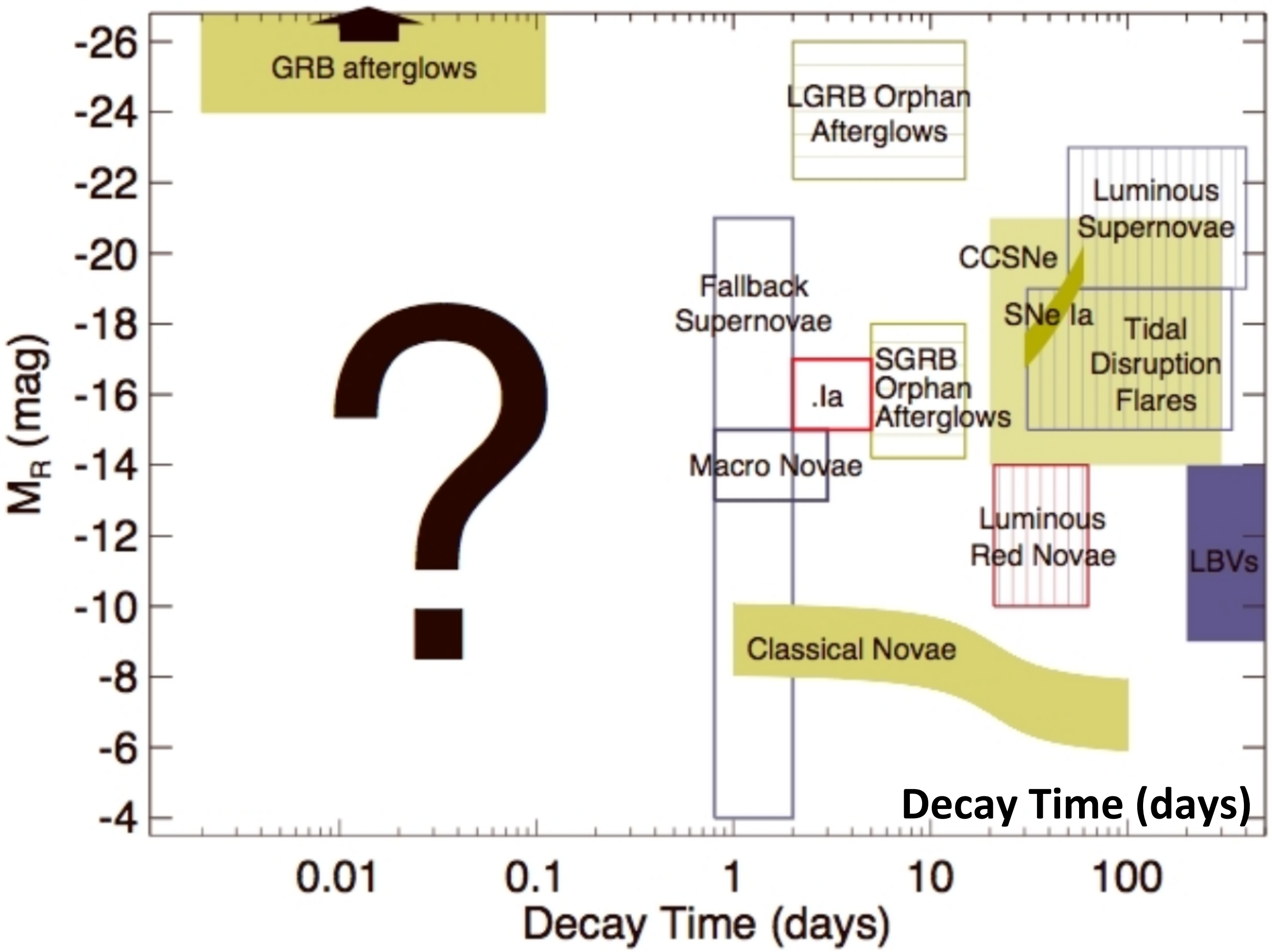
The Science Enabled by LSST
(see science book: arXiv:0912.0201)

- **Time domain science**
  - **Nova, supernova, GRBs, GW**
  - **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



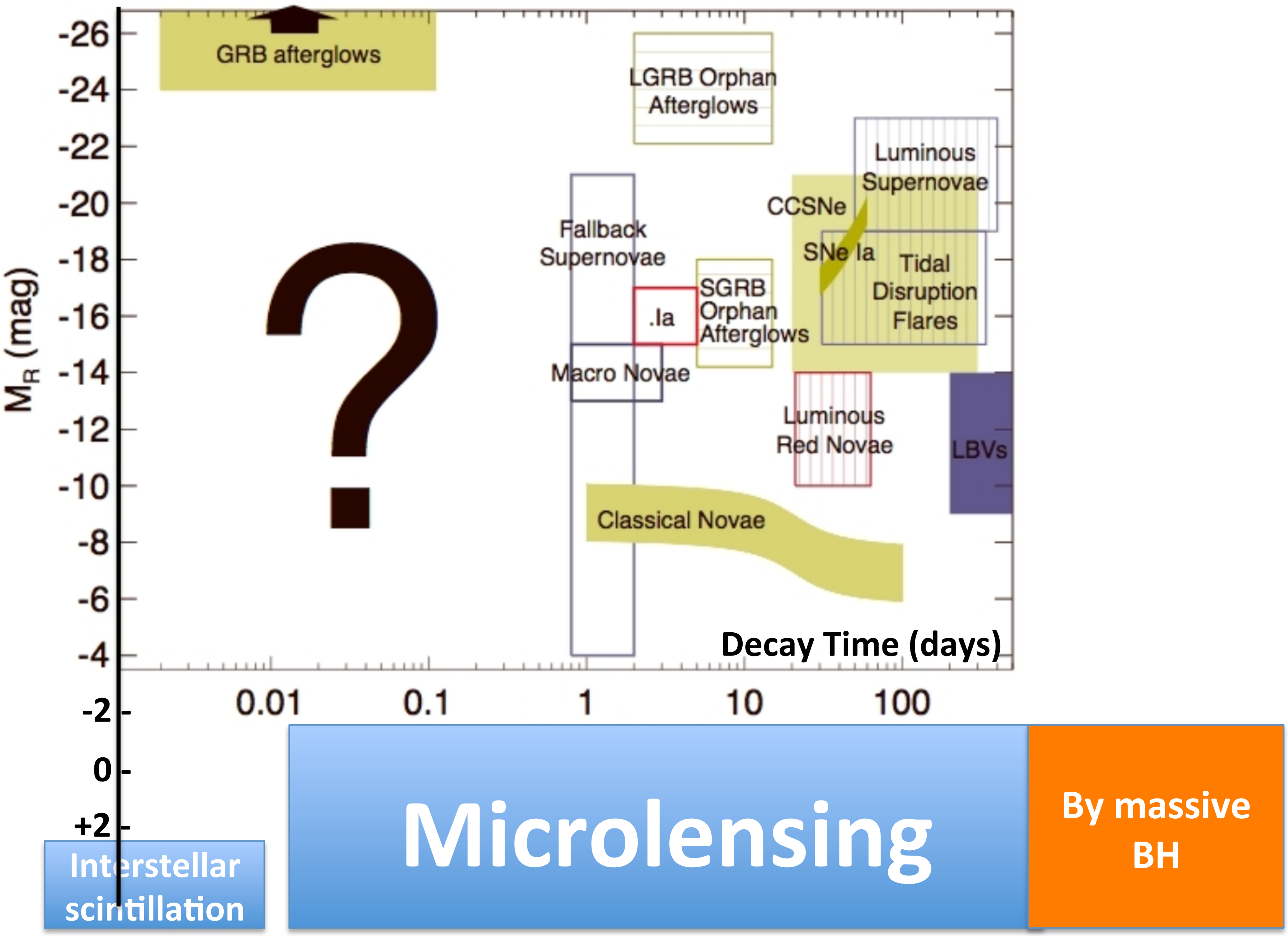


The transient sky

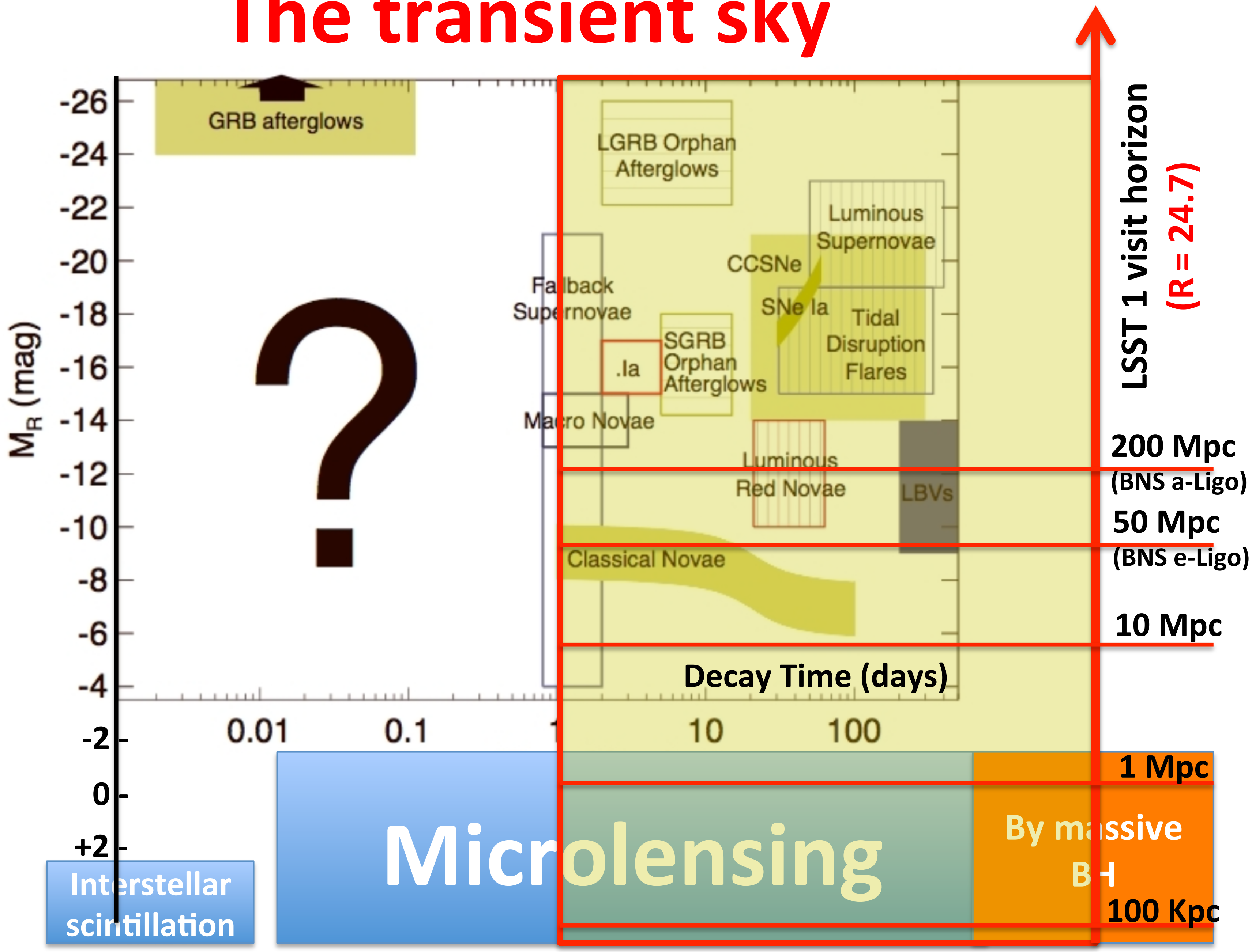


Detection of transients announced within 60s.
Expect ~ 1-10 million per night

The transient sky

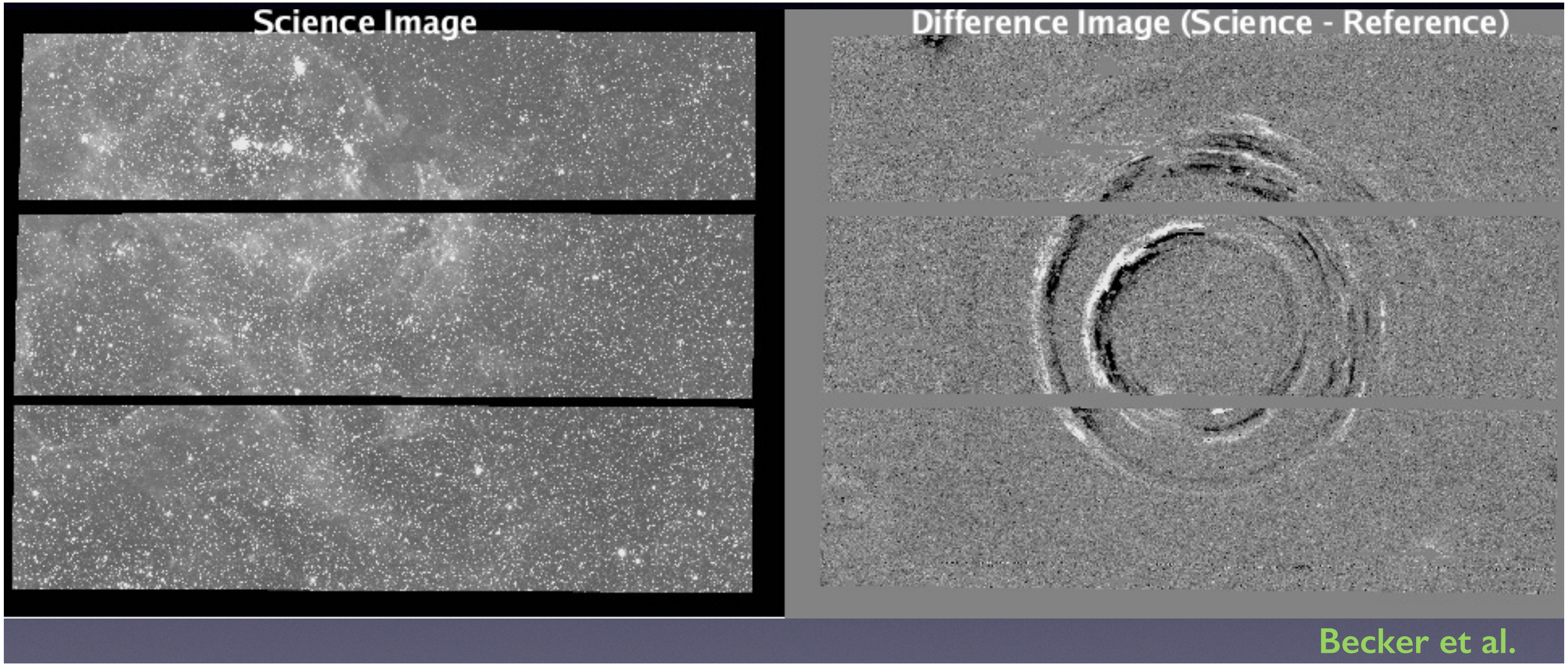


The transient sky



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



LSST Observing Cadence

https://www.youtube.com/watch?v=PKNaI3fAST4

- 2x15s exposures (to 25 mag) per visit to a given field (9.6 deg^2)
  -> cosmic ray rejection
- Visit the field again same night
  -> asteroid rejection
- Number of visits/night: **900** (1 or 2 passbands)
- **main survey (85%) fields:** visited every ~3 days (random color-band) and every ~15 days in *r* band
- **Deep-Drilling (5%, 5 fields)**: 1 hour/night. 50 consecutive 15s exposures x 4 filters

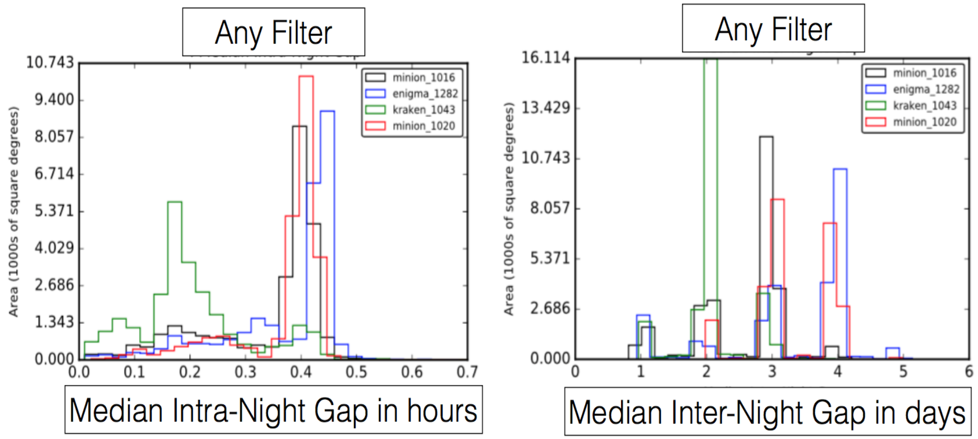


Figure 6.2: Histograms of median intra- (left) and inter- (right) night visit gaps for any band for several OpSim runs.

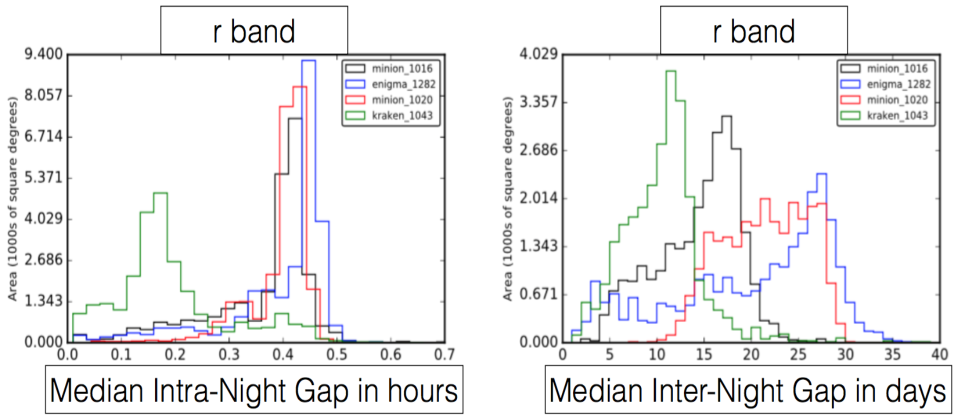


Figure 6.3: Histograms of median r-band intra- (left) and inter- (right) night visit gaps for several OpSim runs.

- Median slew time between visits= 5s
- Average slew time between visits=12s

Science with Trigger <-> LSST

<-------Time critical------->

LSST alerts -> trigger follow-up for specific events

- Microlensing (with caustic crossing) -> ***Dark matter / planets***
- SNs -> ***Cosmology***
- Asteroids -> ***Save the Earth!***
- …

Search for optical counterparts AND trigger follow-up

- GW -> ***Hubble constant*** (with spectro-*z*)
- GRB afterglows
- Neutrino sources
- High Energy cosmic ray sources

LSST Searches triggered by others ?

- For exceptional opportunities only (LSST is a survey): GW counterparts can be found with a few LSST-pointings, follow-up by others

-> needs negligible false positive

<---------------- Time critical, needs careful specific filtering ---------------->

BUT specific LSST alerts can also be used later

- to retroactively search for GW events in the interferometers records

-> Potential factor 2 for GW searches; what about GRB afterglows?

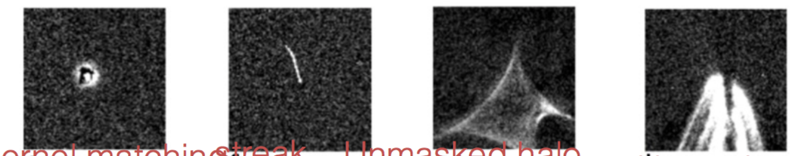
LSST alerts…

Detection of transients announced within 60s.
Expect ~ 2 million per night

Transients detected (+ or –5σ) and reported in 60s in difference images =(current – coadded template), called DIASources

- **Broker**: Filter a stream of ~ 2 million DIAsources/night:
  Variable stars, SNe, asteroids, and « everything else »

  -> Robust filtering
  (remove false detections)



Given a stream of ~ 10,000 DIASources every ~ 40s (per 10 deg^2 field)

- Asteroids will dominate on the Ecliptic, become insignificant >30° 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**

Discovery rate of new transients will drop fast (factor of ~ 100 after 2 years)

new DIASources will become dominated by cataclysmic variable stars and quasars

Alert generation Pipeline

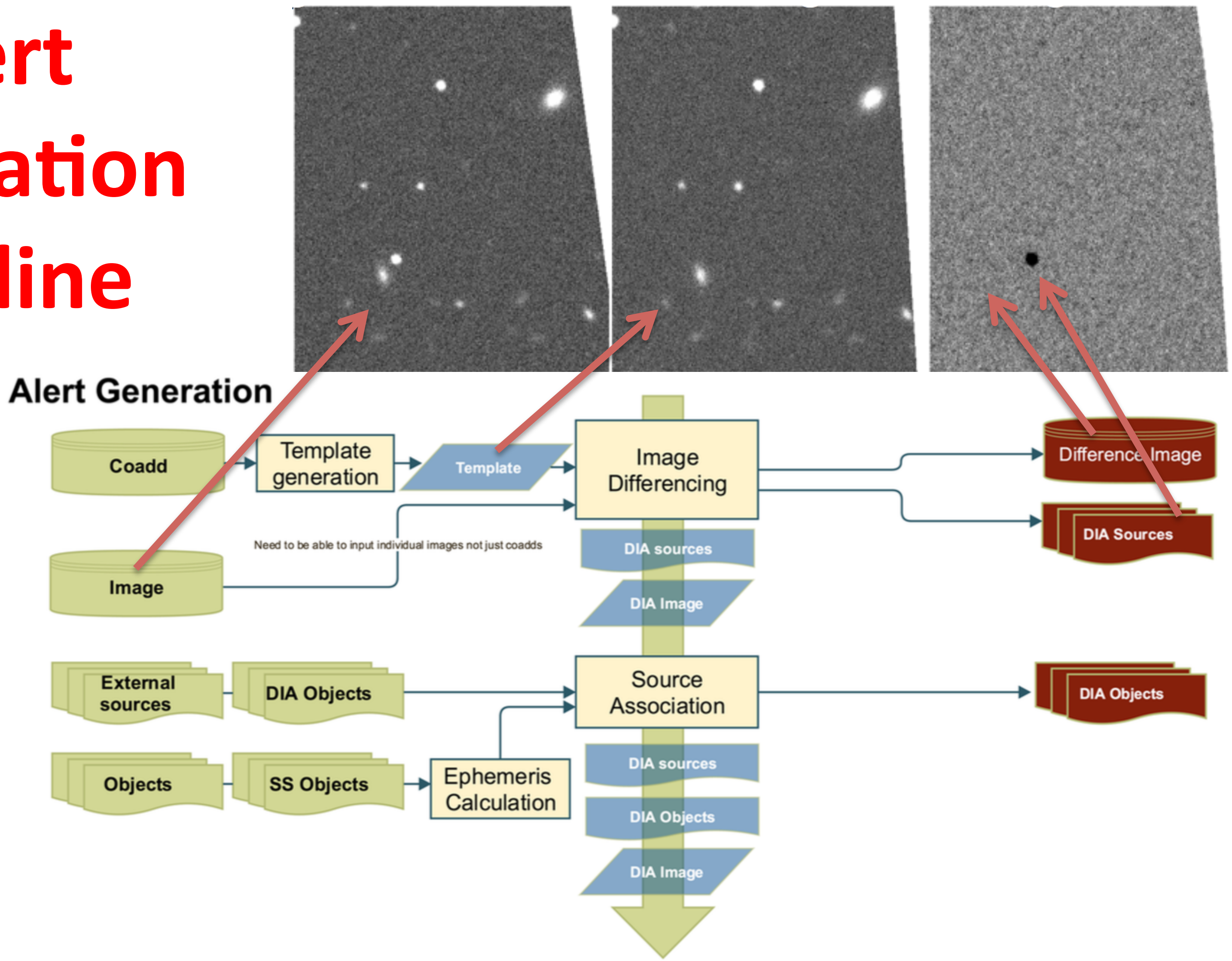


FIGURE 3: Generation of alerts from the nightly data: image differencing and measurement of the properties of the DIASources, identification and filtering of spurious events, association of previously detected DIAObjects and SSObjects with the newly detected DIASources.

Delivery by LSST mini-broker (60s)

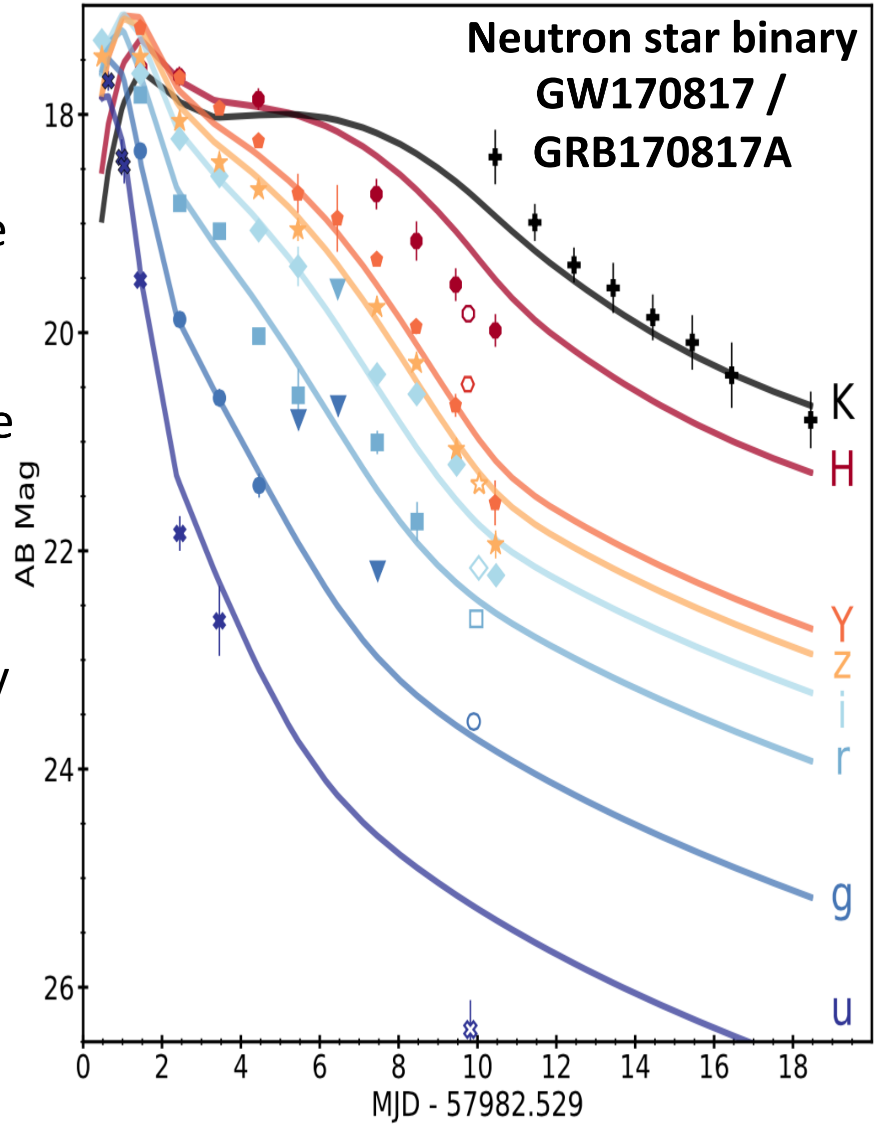
- **Positions** (0.1''), **shapes** (moments), **PSF**, **fluxes** (in the current passband) and **(co)variances**
- Alert confidence level
- **30x30 pixels patch** on difference image and reference image (with mask and variance)
- **6 months of history**: variations associated with the object detected in the difference image
  - Variability characteristics (but no astrophysical interpretation)
  - Environment (neighbouring objects, distances…)
  - See details in document LSST/LDM-151

Simulation of a GW alert (1)

Assume GW detected within a **20 deg² box**

-> covered by **3 LSST fields**

- t=0 (trigger)
- t=40s (average) LSST points towards the GW direction
  -> 3 x double exposures: 3x38s; search for transients starts after 1rst exposure
- t=154s end of data taking
- t=214s **end of transient processing**
  -> expect on average **10K-alerts x 3**
- Delivery to distributors/brokers; primary end-points of LSST alerts stream (http://voevent.org)
- For each transient, LSST provides
  - *Position (<0.1''), flux, shape of source*
  - *½ year history (light-curves in all bands)*
  - *Variability characterization*
  - *Stamp images around the object*

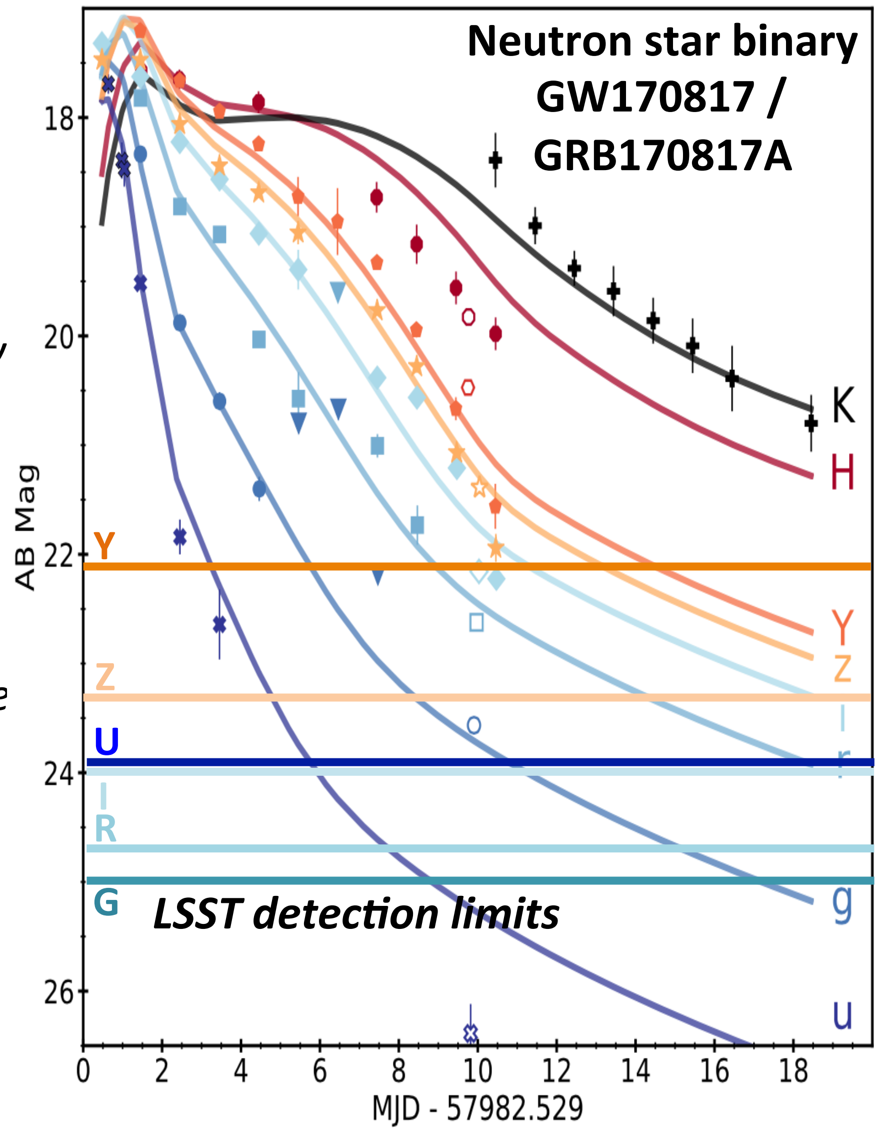


Simulation of a GW alert (2)

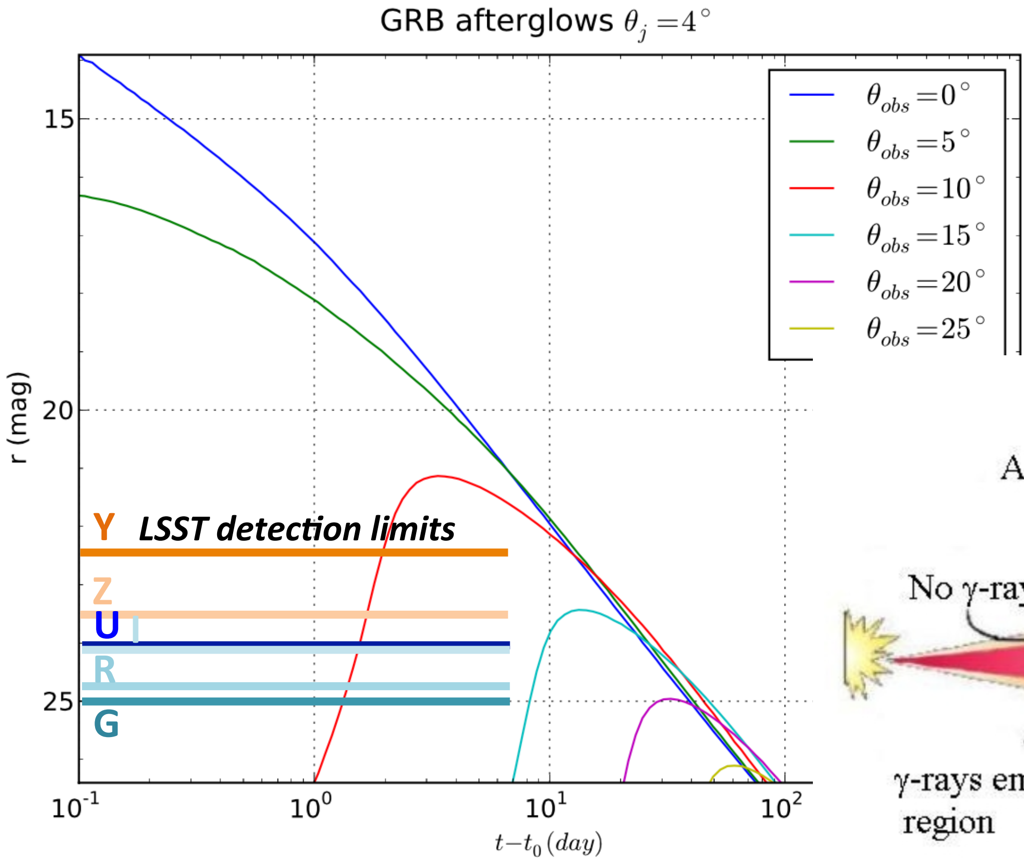
Broker: Filter and classify transients.
LSST will run its own broker for faster interaction with GW and follow-up teams

- *Remove already cataloged variable objects: periodic, SNs, asteroids…*
  -> Residual rate of new transients drastically decreases (÷100) after 2 years of operations
- *~ 100 transients/field, dominated by SNs*
- *But **only ~ 10 of these SNs** are brand new*
  -> Targeting galaxies not necessary
  -> Follow-up these 3x10. The searched counterpart has the best chances to be the brightest (at least at the beginning)

- *Remember 1*: 5σ detection limit in one visit is **[22.1-25]** depending on the filter
- *Remember 2*: LSST will only detect the counterpart and NOT monitor it

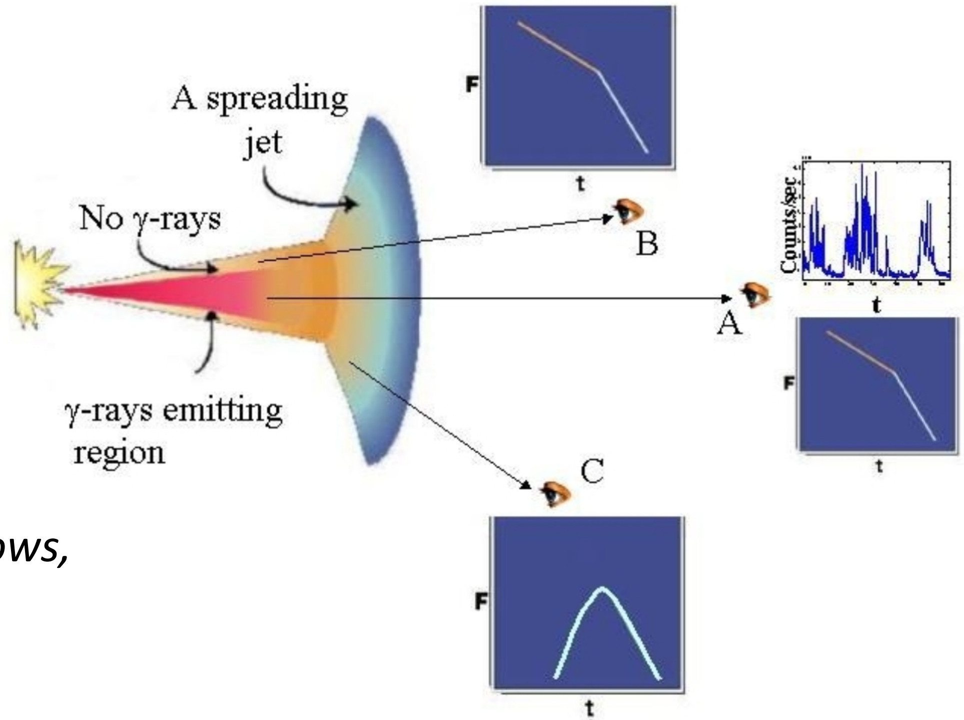


Detection of γ-ray burst afterglows

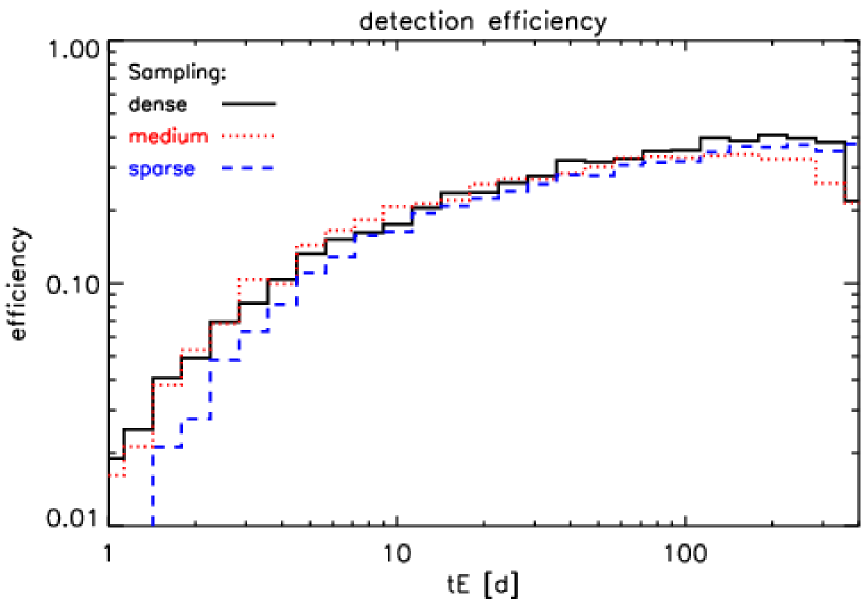


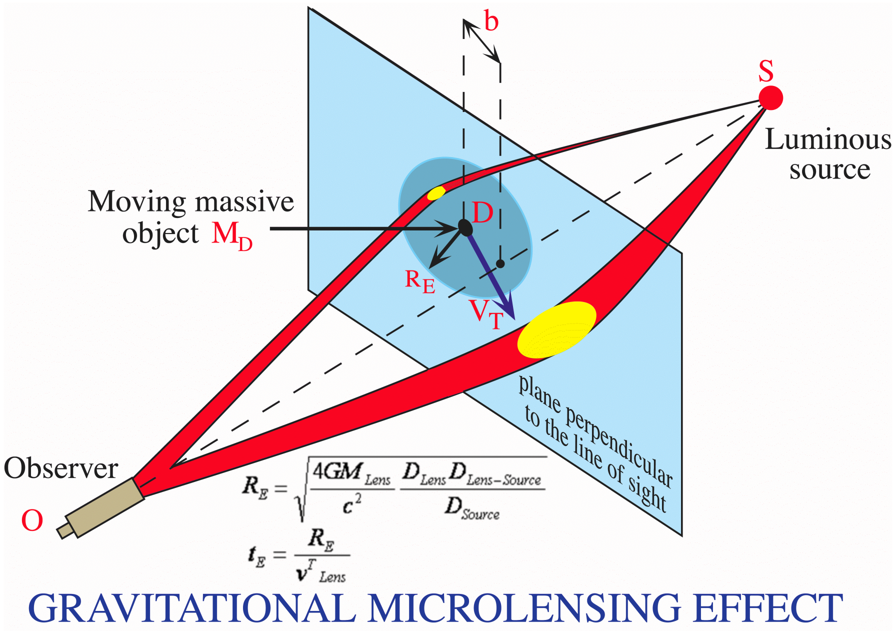
Predicted light curves of GRB afterglows, assuming a source redshift z = 1

Visibility delayed & fainter depending on angle



Microlensing expectations



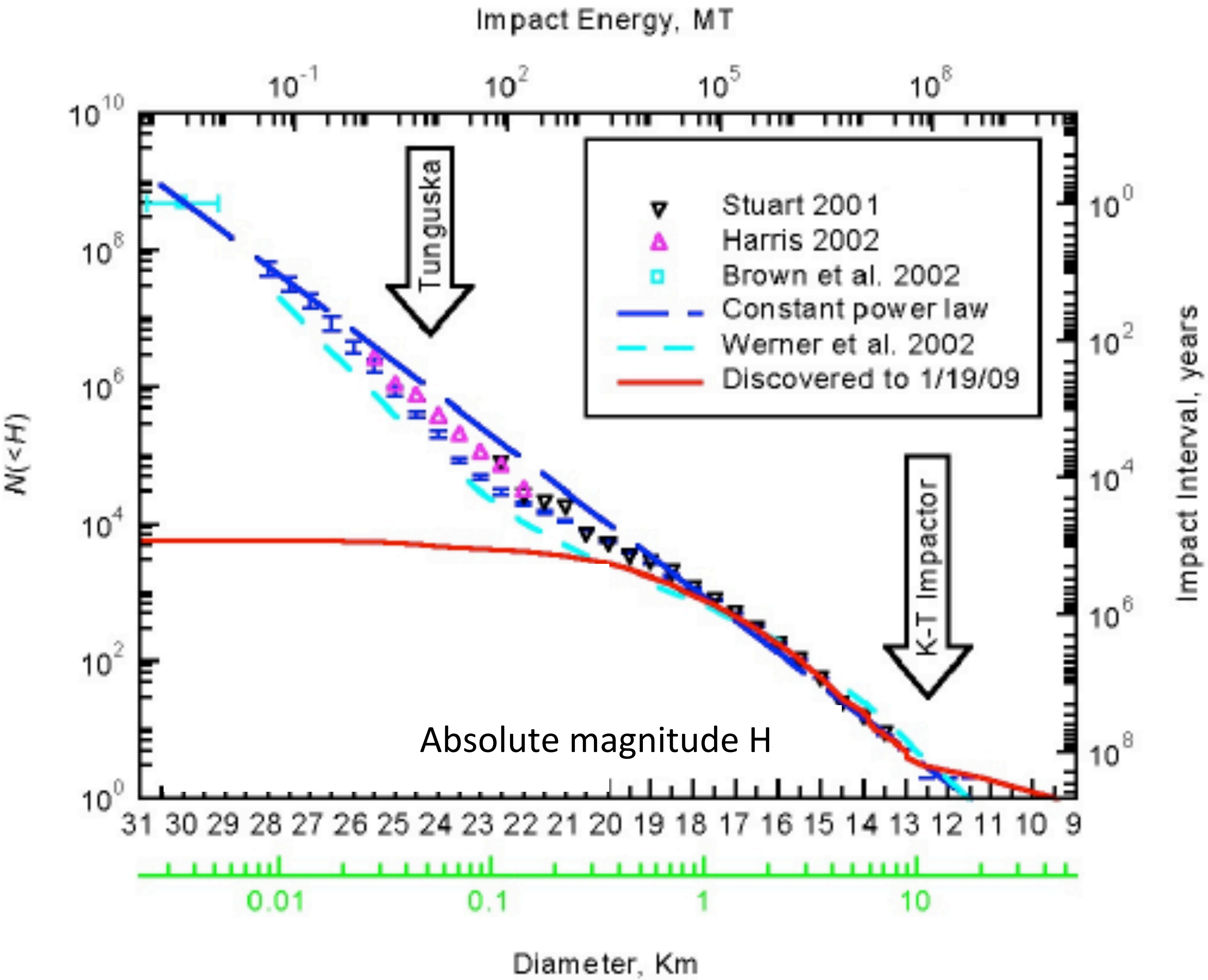


- O(10^8 stars) monitored
- with Δm < 5mmag
- Towards Milky-Way
- Towards LMC/SMC
- On average every 4th night during 10 years

Table 8.4: **Nearby Microlens Event Rates**

Lens type	**Past** per decade per deg^2	**Present** per decade per deg^2	**LSST** per decade per deg^2	**LSST** 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

The "Threat" from "Earth killers"



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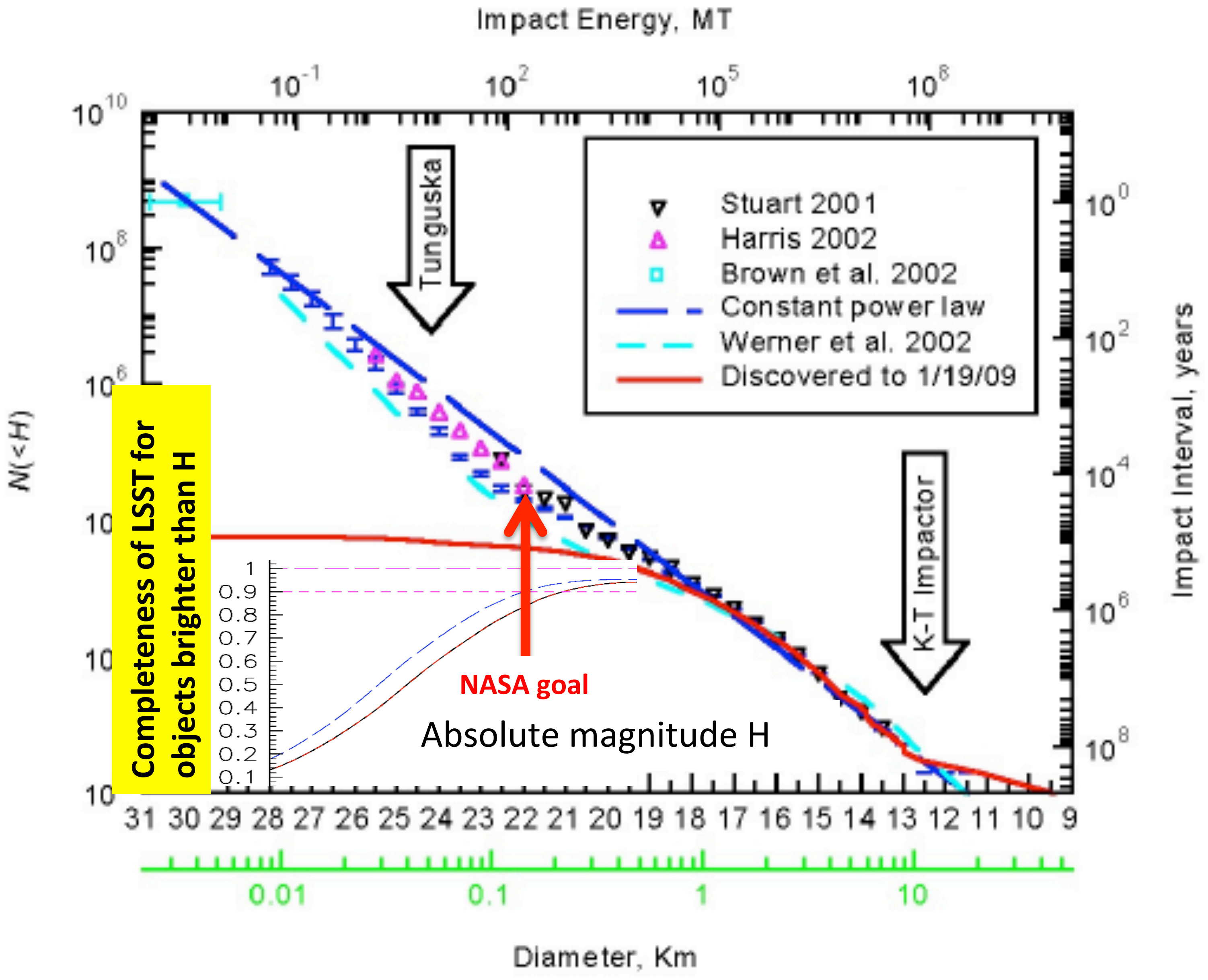


LSST transient : things to know

- **LSST is a survey and NOT an observatory/facility**
  - The consortium will not offer open time or ToO (GW only can motivate dedicated pointings)

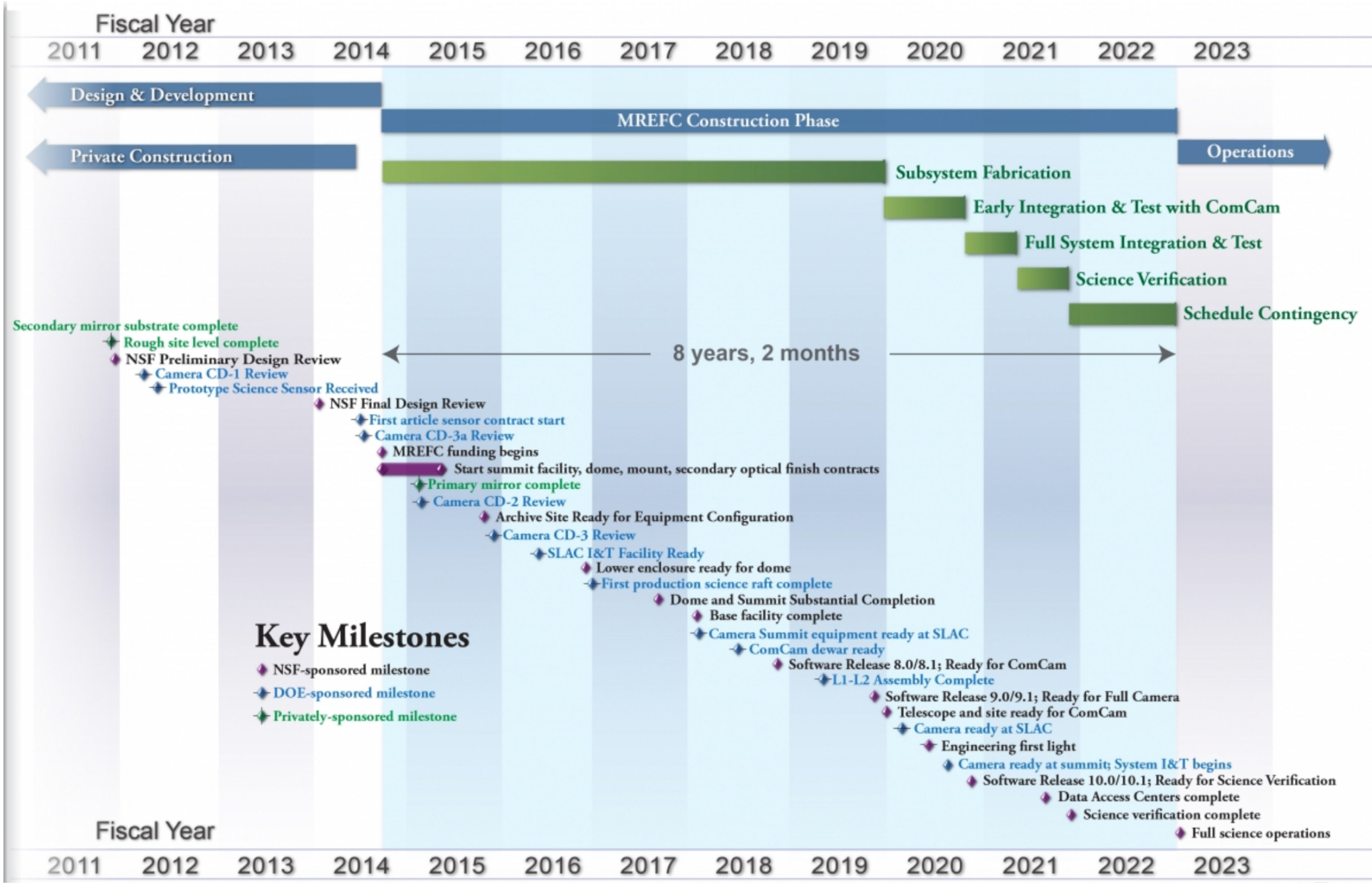
    don't dream on requests like: Ask for one month to survey this or that
  - ~ half of the sky visited every 3-4 nights (but with variable filters)
  - 1000 deg^2 In the Galactic Center observed only 180 times (confusion limits interest for *ad libitum* coaddition…) -> almost useless for μlensing in GC
- **But there is some flexibility: cadencing is not set in stone**
  - As long as the uniformity of the **main** survey is guaranteed over the 10 yrs
  - As long as there is no conflict with the cosmological goals
  - Taking into account the filter changes (6 filters)
  - If it is discussed with enough anticipation with the science group « transient searches »
  - If the community (GW, neutrino, HECR…) proposes a convincing plan
- **Also think on the commissioning (2021-22) and mini-surveys (1-10% time)**

Complements

Ref. documents :

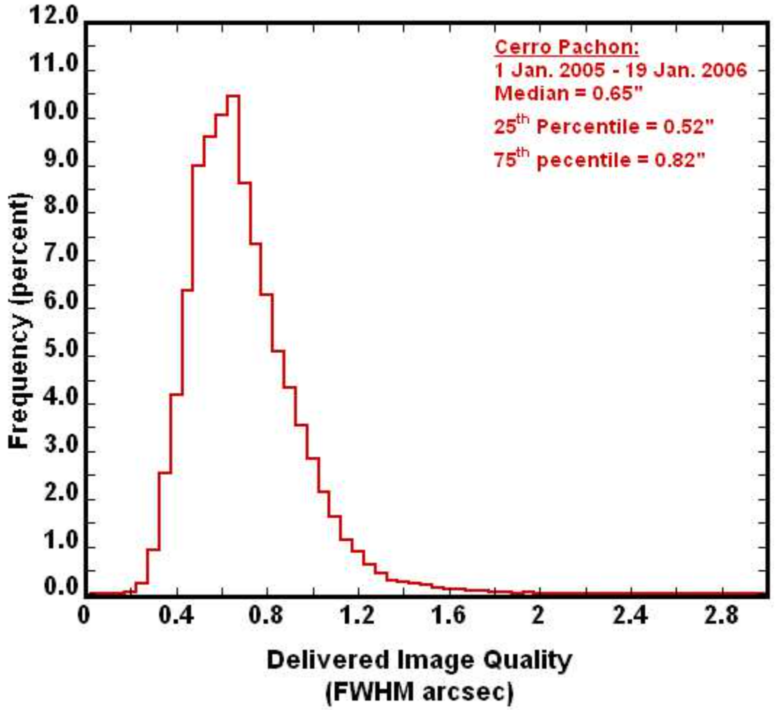
- LDM151
- LSE-163_DataProductsDefinitionDocumentDPDD

LSST Project Schedule



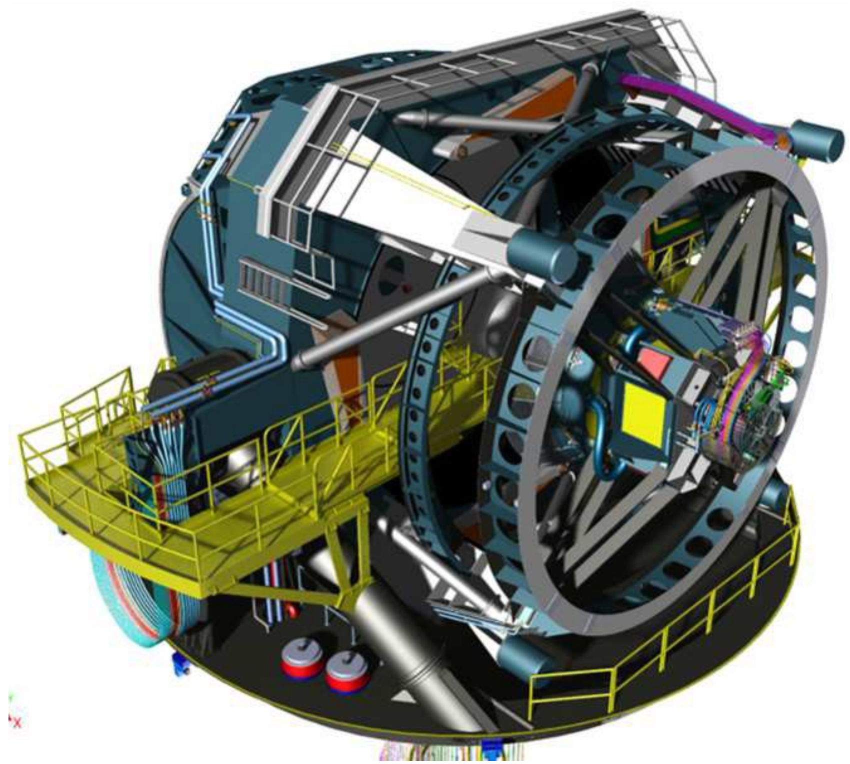
Site quality

- 1 year study
- Median seeing @500nm : 0.65 ”



Telescope Mount Enables Fast Slew and Settle

- Points to new positions in the sky every 39 seconds (average)
- Tracks during exposures and slews 3.5° to adjacent fields in ~ 4 s



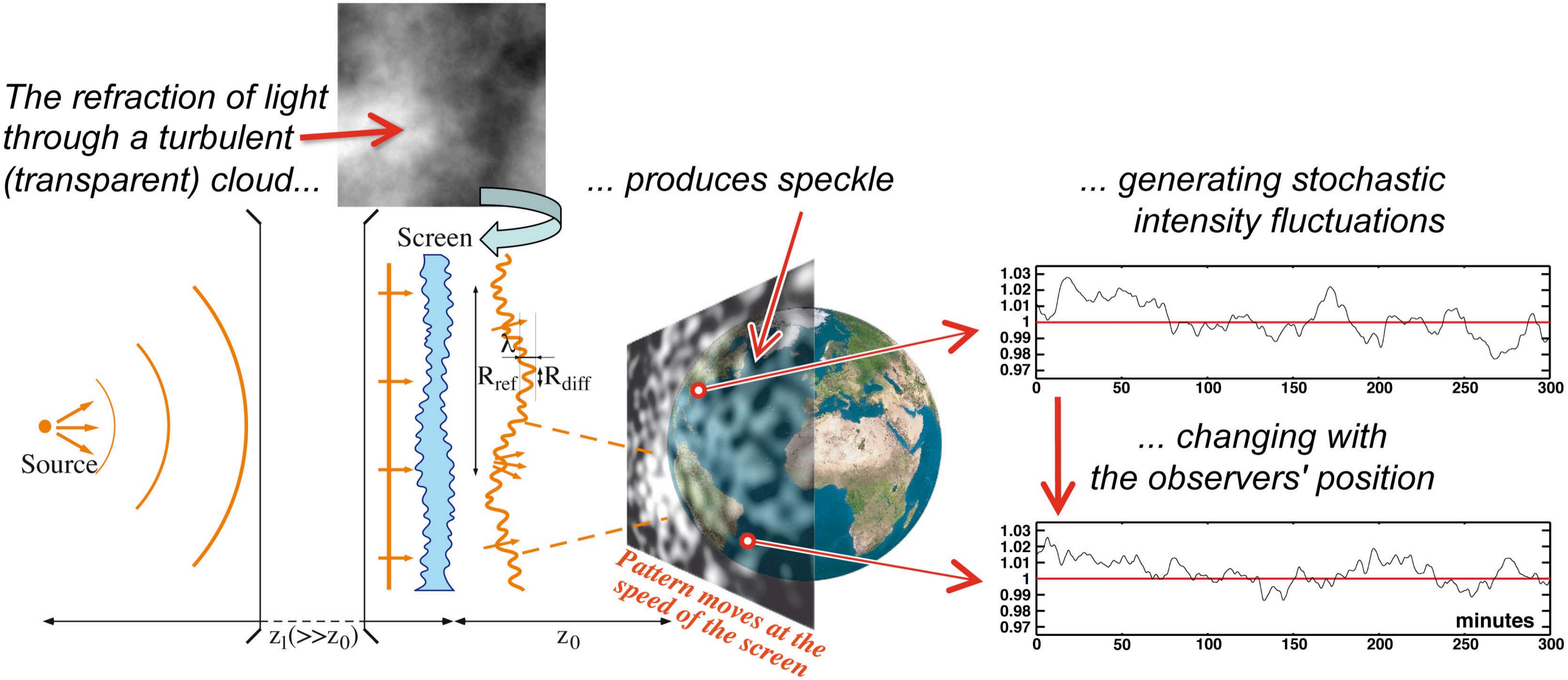
LSST visits

the total number of visits is 2.45 million, with

- 85.1% spent on the Universal proposal (the main deep-wide-fast survey)
- 6.5% on the North Ecliptic proposal
- 1.7% on the Galactic plane proposal
- 2.2% on the South Celestial pole proposal
- 4.5% on the Deep Drilling proposal (5 fields)

Search for missing H_2 turbulent galactic gas

through scintillation detection (the OSER project)



Light received by telescope varies with

- ***timescale ~10 min*** *(due to the relative velocity of the gas)*
- ***modulation of a few %*** *(depending on distances / turbulence parameters / source extension)*

Illumination pattern from a scintillating star

Alerts will be available through a hierarchy of services

- **External value-adding systems ("brokers": e.g., ANTARES)**
  - Validated and tested systems that ingest the full LSST data stream and provide additional information about events (e.g., astrophysical classifications, matches to external datasets)
  - Systems that rebroadcast the LSST data stream (a cascade effect increasing the number of access points without needing bandwidth)
- **A limited LSST filtering service ("mini-broker")**
  - Configurable agents that return subsets of the attributes of events (e.g. summaries of the light curve, exclusion on cutout images)
  - Access to these agents will be through standard VOEvent clients and will require authentication
- **Access to historical alerts through the L1 and alert databases**
  - L1 DB: query for DIAObjects/DIASources/SSObjects by properties
  - Alert DB: enables training of brokers/classification algorithms by replaying previous alert stream

Microlensing challenges

- **Selection criteria**
  - On-line trigger to initiate follow-up
  - Off-line to search for any exotic events
  - Estimate **efficiency $\varepsilon(t_E)$**
  - Exploit the excellent photometric repeatability (<1% for g<21) to search for large impact parameter events and non-standard events
- **Use astrometric information**
  - Decrease microlensing degeneracy (D_{os})
- **Synergies**
  - EUCLID (ground-space parallax, NIR)
  - On Earth follow-up telescopes

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
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).