Potentiel de découverte de transients avec LSST: De la minute à la décennie

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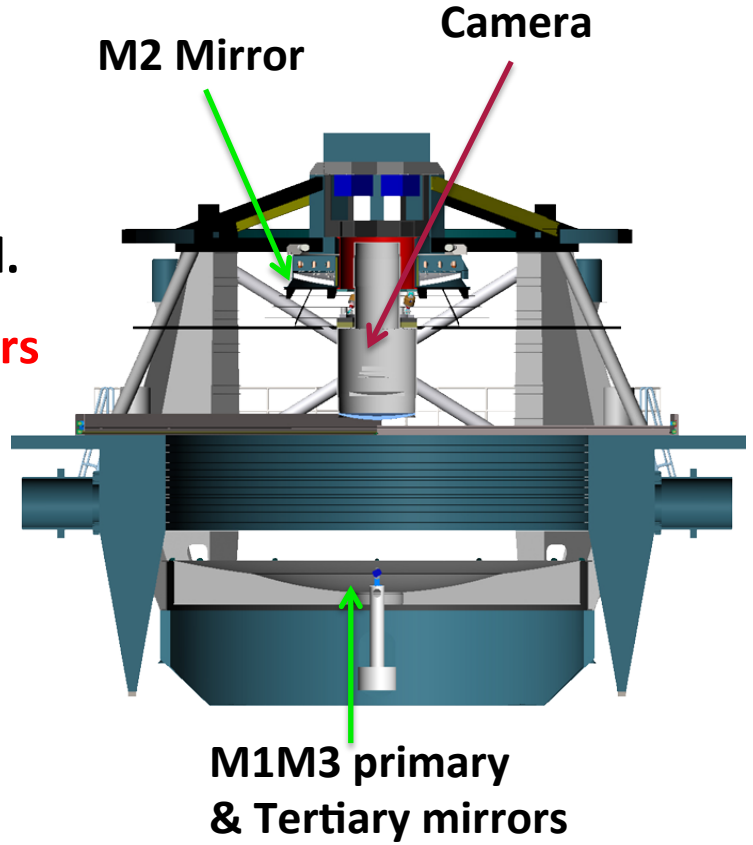
The main telescope

he auxilliary
telescope

LSST in a few figures

- Optical telescope 8.4 m diameter (f/1.23)
- 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



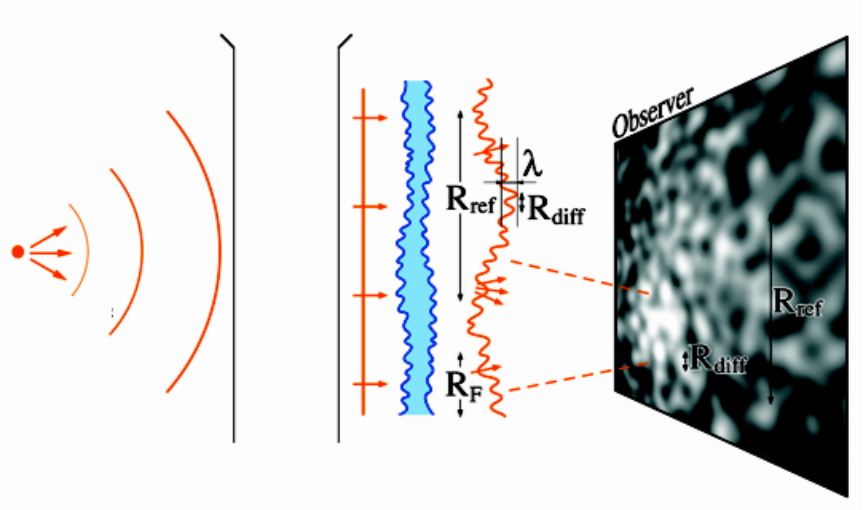
http://www.lsst.org/

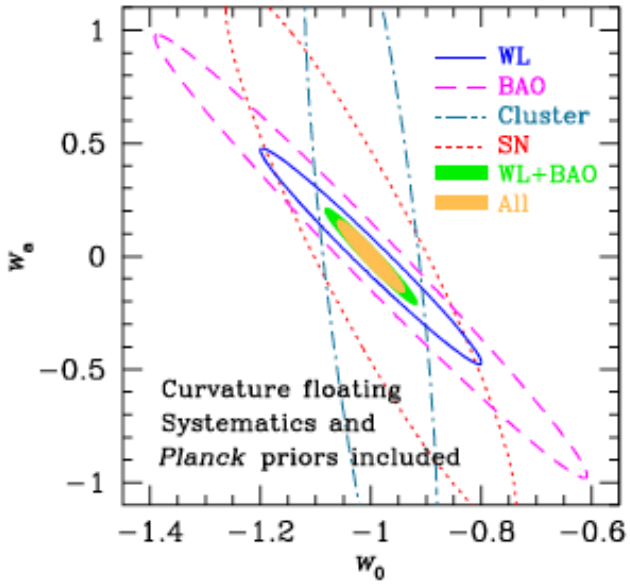
Summary of High Level Science Requirements

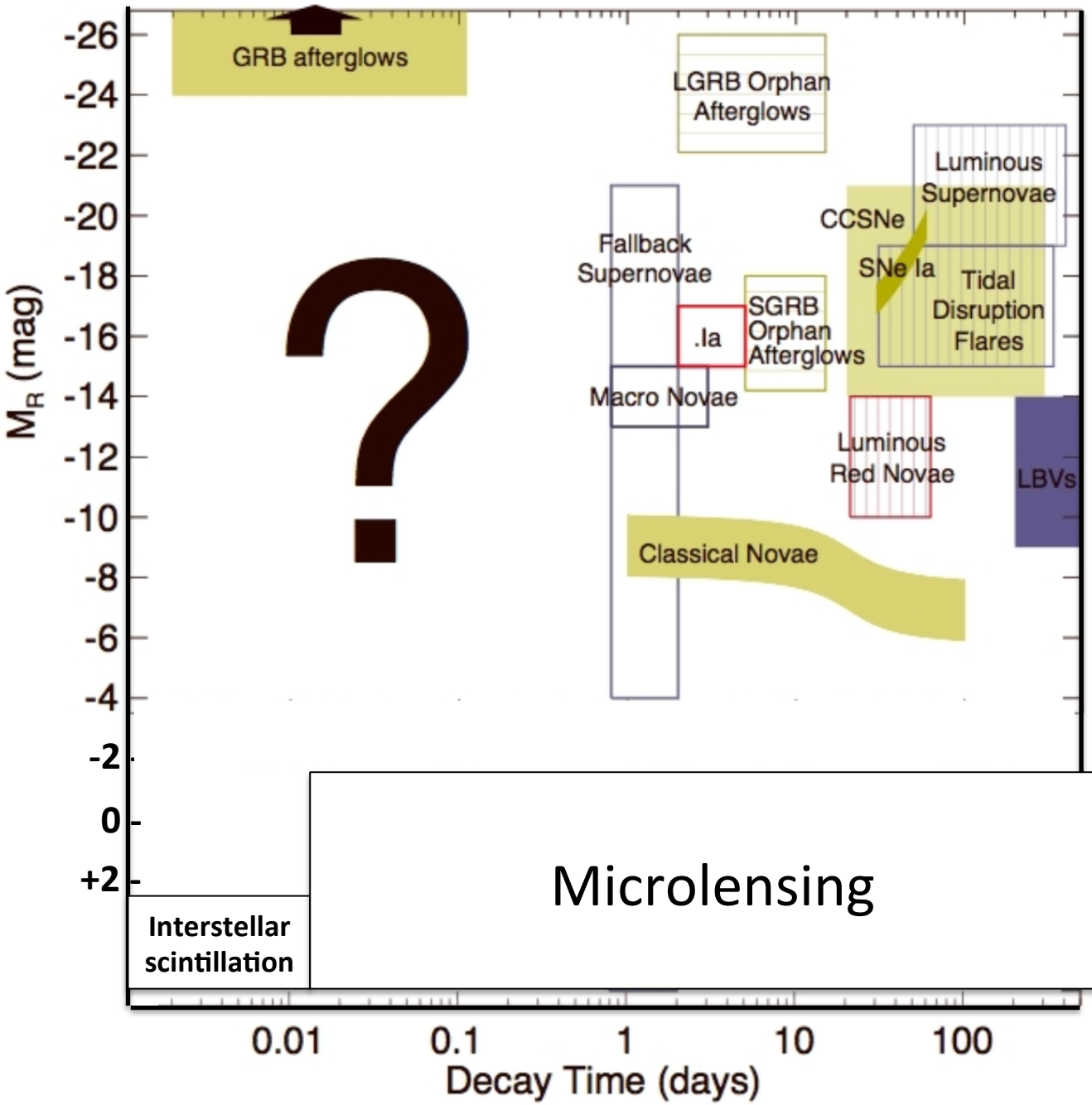
Survey Property	Performance
Main Survey Area / duration	18000 sq. deg. / 10 years
Total visits per sky patch	825 (1 visit per ~3-4 nights)
Filter set	6 filters (ugrizy) from 320-1050nm
Single visit	2 x (15 second exposures + 1s shutter + 2s readout)
Single Visit Limiting Magnitude (AB 5σ)	**u = 23.9; 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

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

Interstellar scintillation	Microlensing	By massive BH

LSST Observing Cadence(*)

- 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 identification
- 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
- **Galactic plane / North Ecliptic / South pole /Mini-surveys**: under discussion

(*) Subject to change

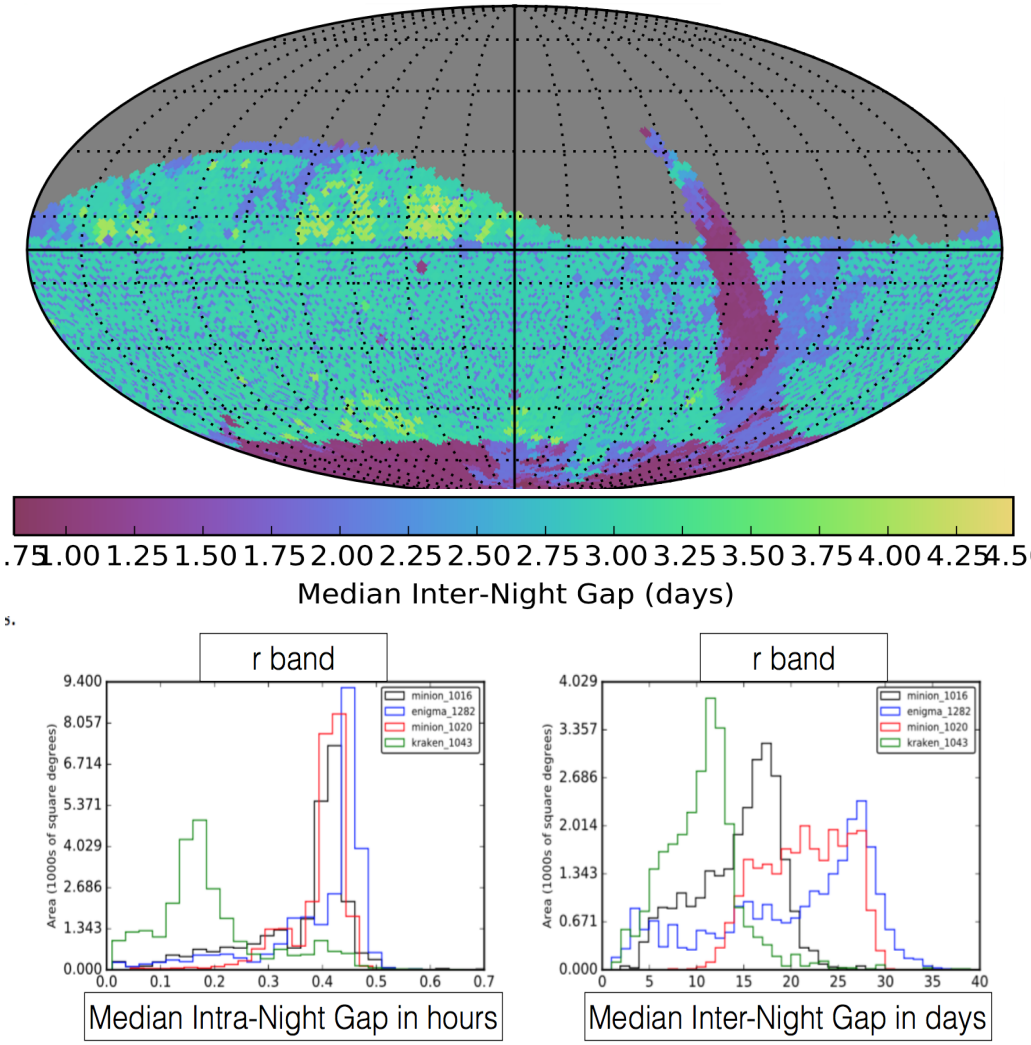


Figure 6.3: Histograms of median *r*-band intra- (left) and inter- (right) night visit gaps for several OpSim runs.

Transient science with LSST

<--Time critical-->

LSST alerts -> broker -> trigger follow-up for specific events

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

Search for optical counterparts AND trigger follow-up *[minutes-hours]*

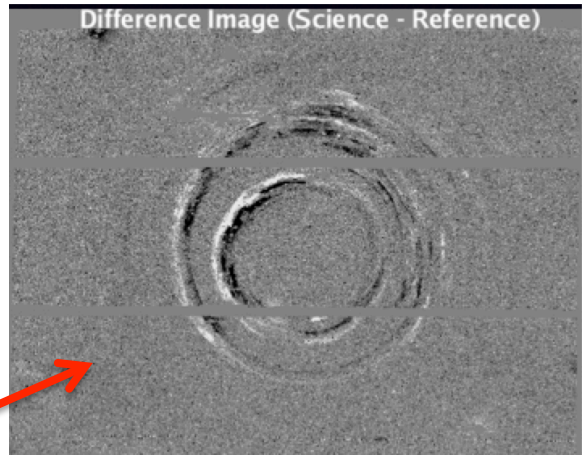
- GW -> ***Hubble constant*** (with spectro-*z*) *[minutes]*
- GRB afterglows
- Neutrino sources
- High Energy cosmic ray sources

<- Offline ->

« Offline » science *[minutes AND years]*

Search for signals through the broker files

- Retroactive targetted search for GW in the interferometer records
  - -> Potential factor 2 for GW searches
  - -> Also GRB afterglows ?
- Microlensing *[months-years]*
- Interstellar scintillation: search for turbulent molecular (hidden) gas in the MW *[minutes]*
- SN echoes… Varying large structures *[years]*



LSST alerts…

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

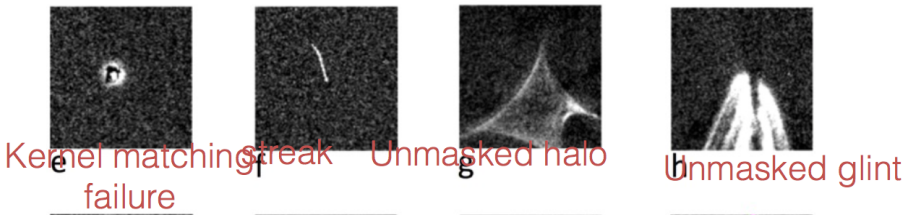
Transients detected (+ or – 5σ) and reported in 60s in difference images =(current – coadded template), called DIASources

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

  → **Julien Peloton talk**

  -> 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** with only **10 new**

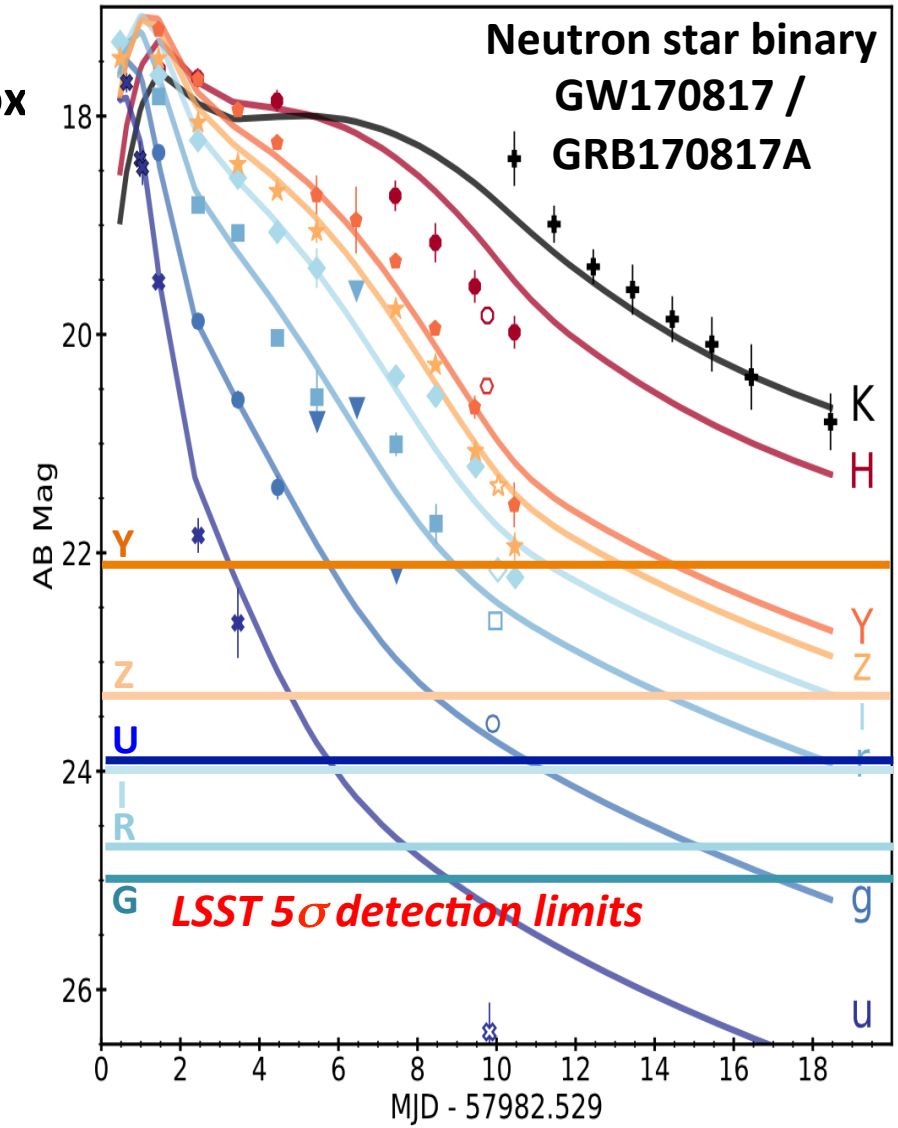
Discovery rate of new transients will drop fast (factor of ~ 100 after 2 years)

new DIASources will become dominated by cataclysmic variable stars and quasars

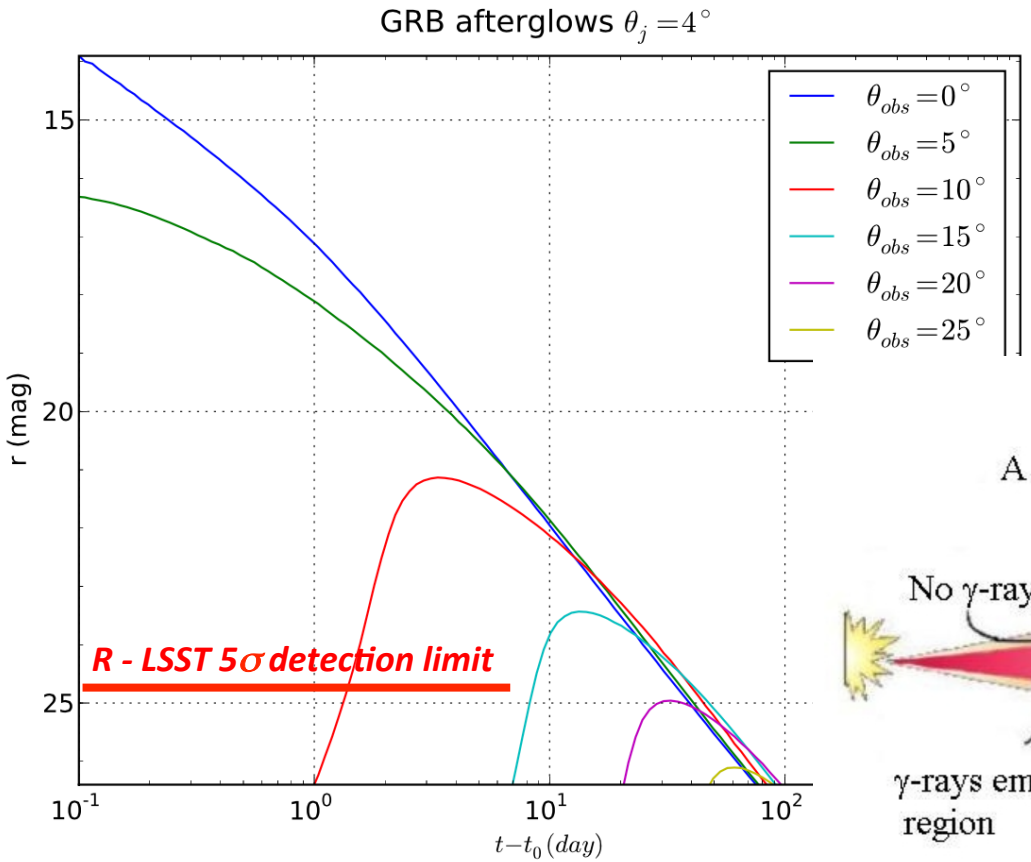
Scenario for a GW search in LSST

Assume GW detected within a **20 deg² box**
-> covered by **3 LSST fields**
-> IF (night) THEN …
data taken and processed **in < 4minutes**
Broker: *Remove already cataloged variable objects: periodic, SNs, asteroids…*
*-> expect **only ~ 3x10** brand new transients @5σ (SNs):*
-> Targeting galaxies not necessary
-> Follow-up these 30.

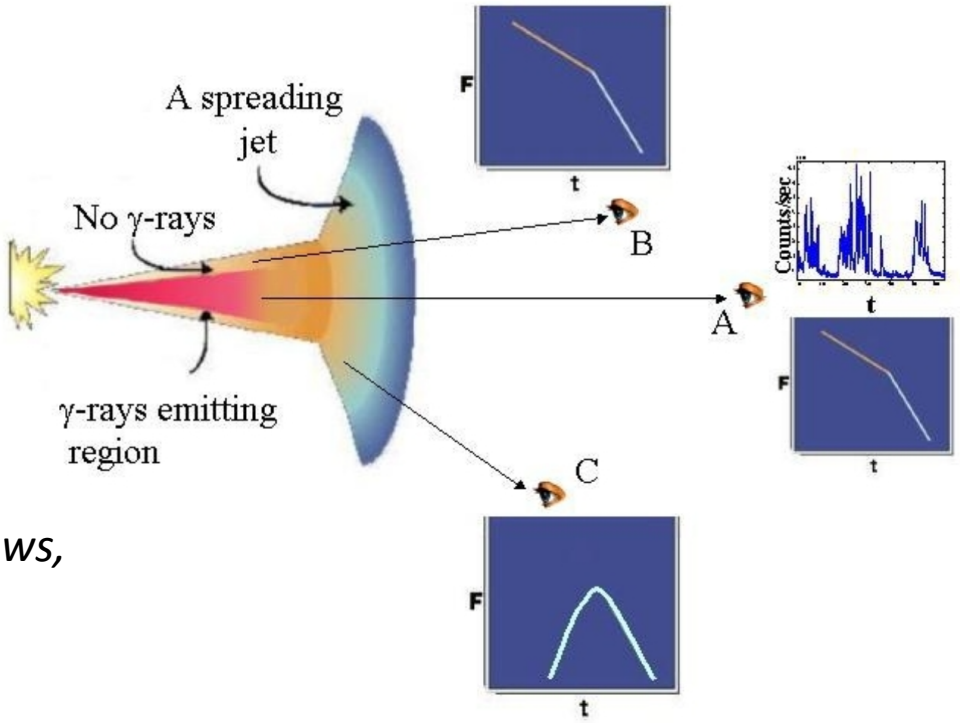
- *Remember* : LSST will only detect the counterpart and NOT monitor it



Detection of γ-ray burst afterglows

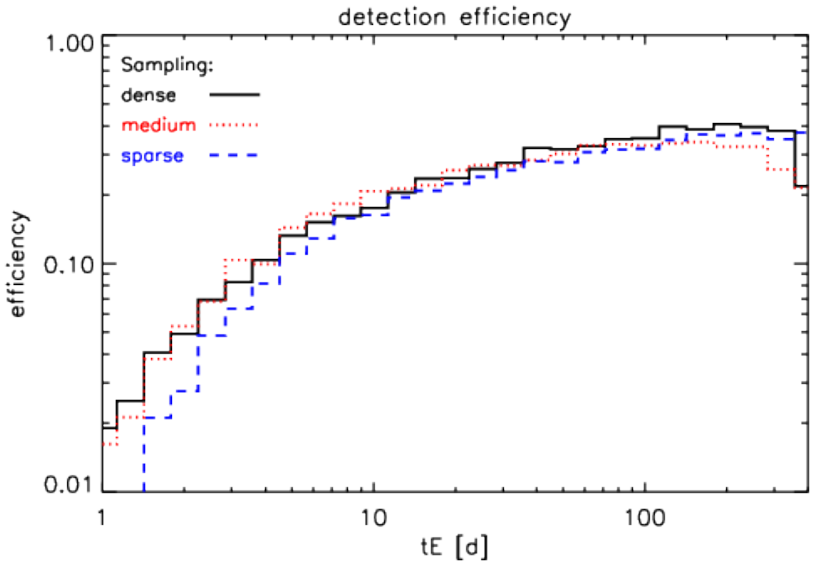


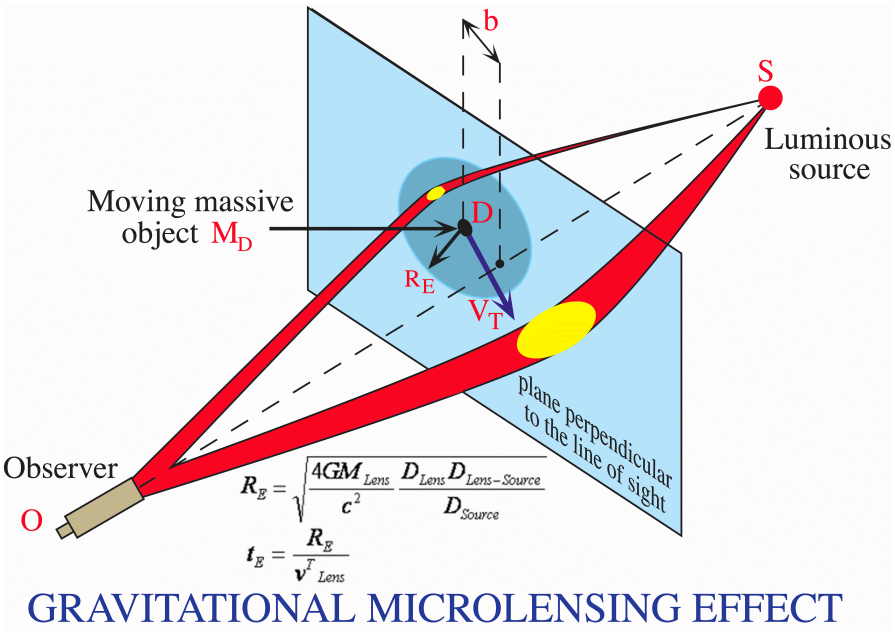
Visibility delayed & fainter
when angle increases



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

Microlensing expectations





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

- **Search for BHs** (Tristan Blaineau Thesis)
- **Search for planets** (floating or not)
- **Study Milky-Way structure** (mass distributions and kinematics)

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

Follow-up after the broker

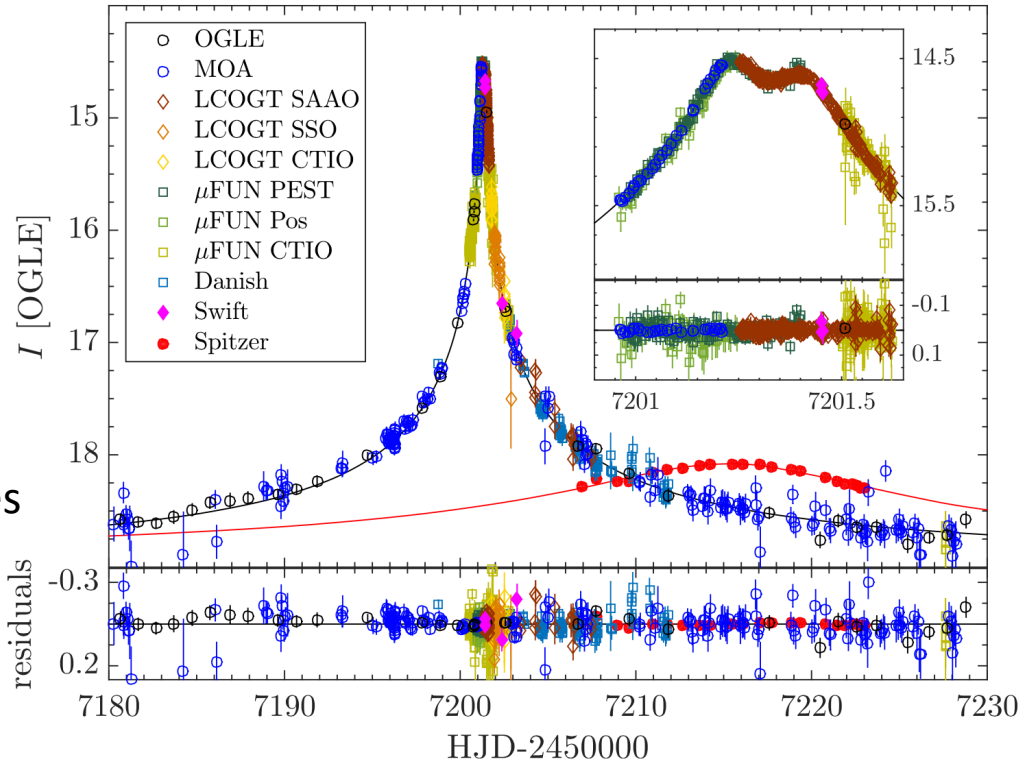
Function of the broker : trigger observations with other instruments

- LSST is not sufficient for the vast majority of transient science
- Need for
  - spectroscopy (SN science…) -> 10m class telescopes
  - More photometry focused on specific candidates :

    GW counterparts, microlensing, scintillation, special variability

    -> 1-4m class telescopes, networks of small telescope, spatial telescopes (Spitzer, Swift, WFIRST, Euclid)
    - To add colours, polarisation…
    - To finely sample the light-curves (search for planets)
  - More astrometry for Earth-killer asteroids (orbitology…)

***Microlensing**: light-curve seen from space differs from light-curve seen from Earth (parallax)*



Precursor: The OGLE Early Warning System

- ~ 300 million stars monitored + emerging objects
- DIA photometric pipeline
- Masking previously detected variable objects
- After 4 successive detections (object magnified or emerging object)

  -> flag

  -> Visual selection

  -> Provide finding charts, light-curves, photometric data, instantaneous microlensing parameters

-> 1800 events/season

Example: microlensing alert file

OGLE-2019-BLG-1450

Field	BLG662.07
Star No	27491
RA (J2000.0)	17:27:49.88
Dec (J2000.0)	-31:03:07.0
Remarks	

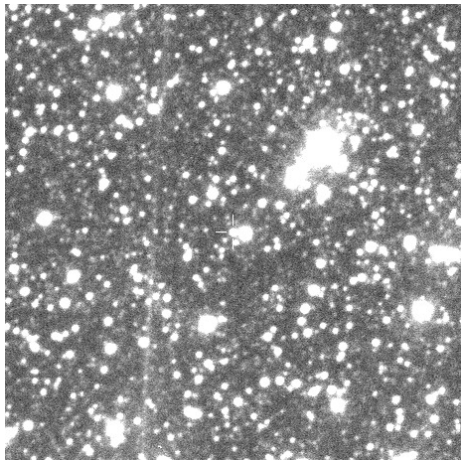
T_{max}	2458765.323 ± 1.146 (2019-10-08.82 UT)
tau	24.018 ± 0.926
u_{min}	0.000 ± 0.261
A_{max}	21581.2 ± -
D_{mag}	10.835 ± 0.000
f_{bl}	1.000 ± 0.000
I_{bl}	17.474 ± 0.001
I_0	17.474 ± 0.001

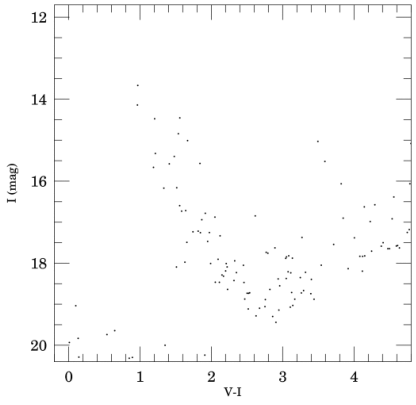
Last Epoch in data: 2458741.60997 (2019-09-15.11 UT)

Click here to download gzipped tar file containing full data set for this event
(including map.dat: O-IV *VI* map (CMD) or *I*-band map of the finding chart field).

Go to main EWS page where info on other events can be found.

- Finding chart (available also in FITS format (without cross) and Postscript).
  The image size is 2' x 2', North is up and East is to the left.
  If *V*-band database is available also the CMD of the finding chart field is displayed.





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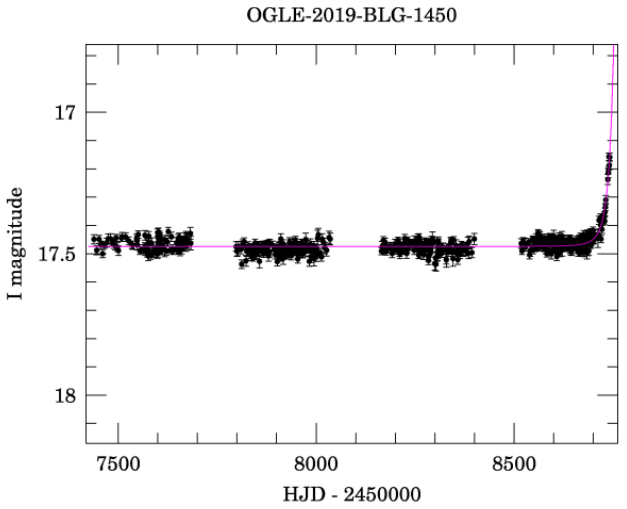
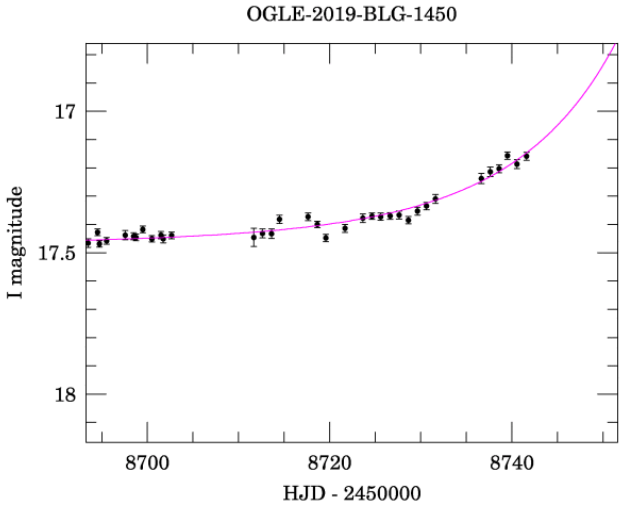
- Full span light curve (available also in Postscript format)



- Event light curve (available also in Postscript format)



- Photometry data file containing 5 columns: Hel.JD, *I* magnitude, magnitude error, seeing estimation (in pixels - 0.

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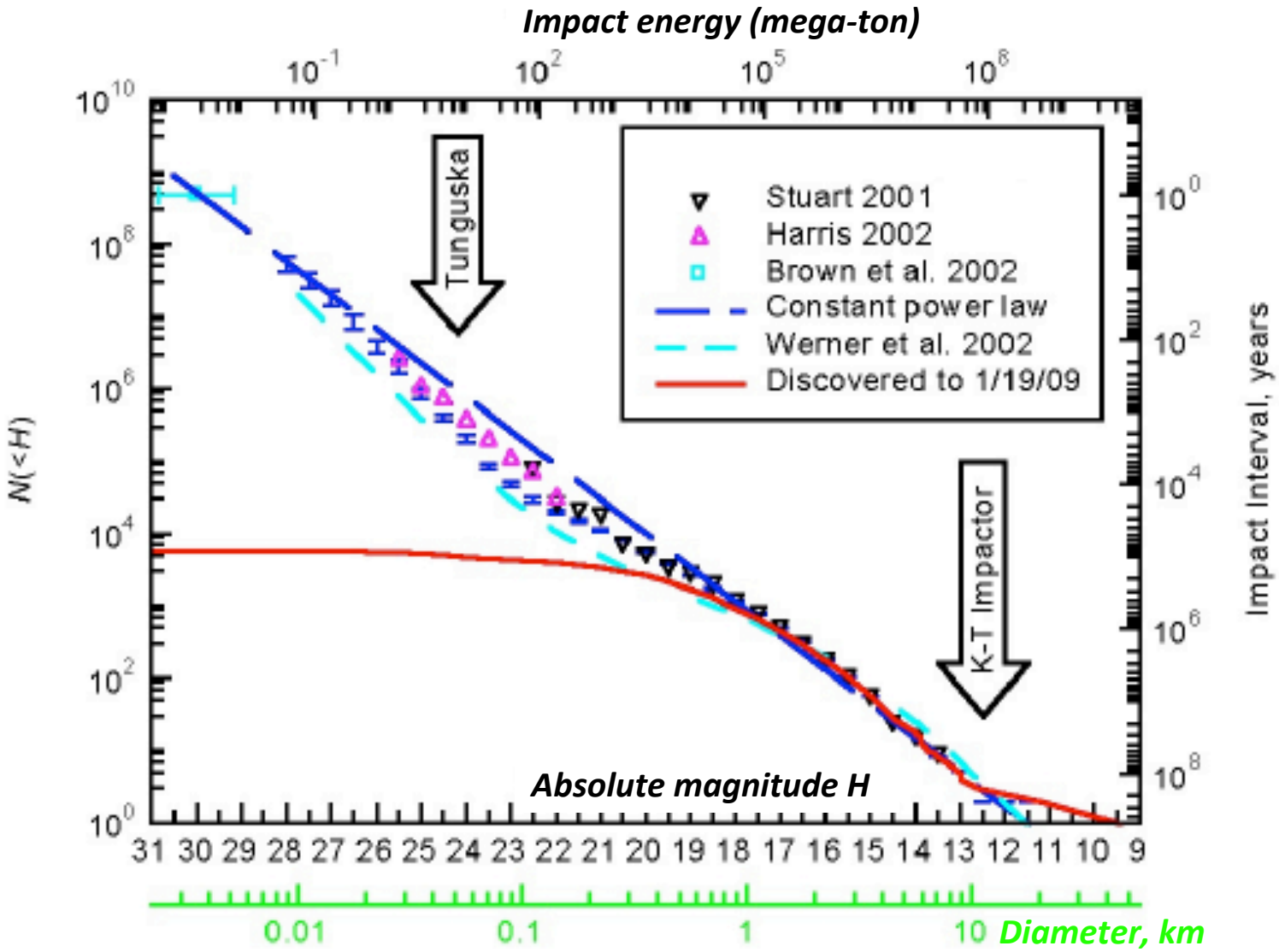
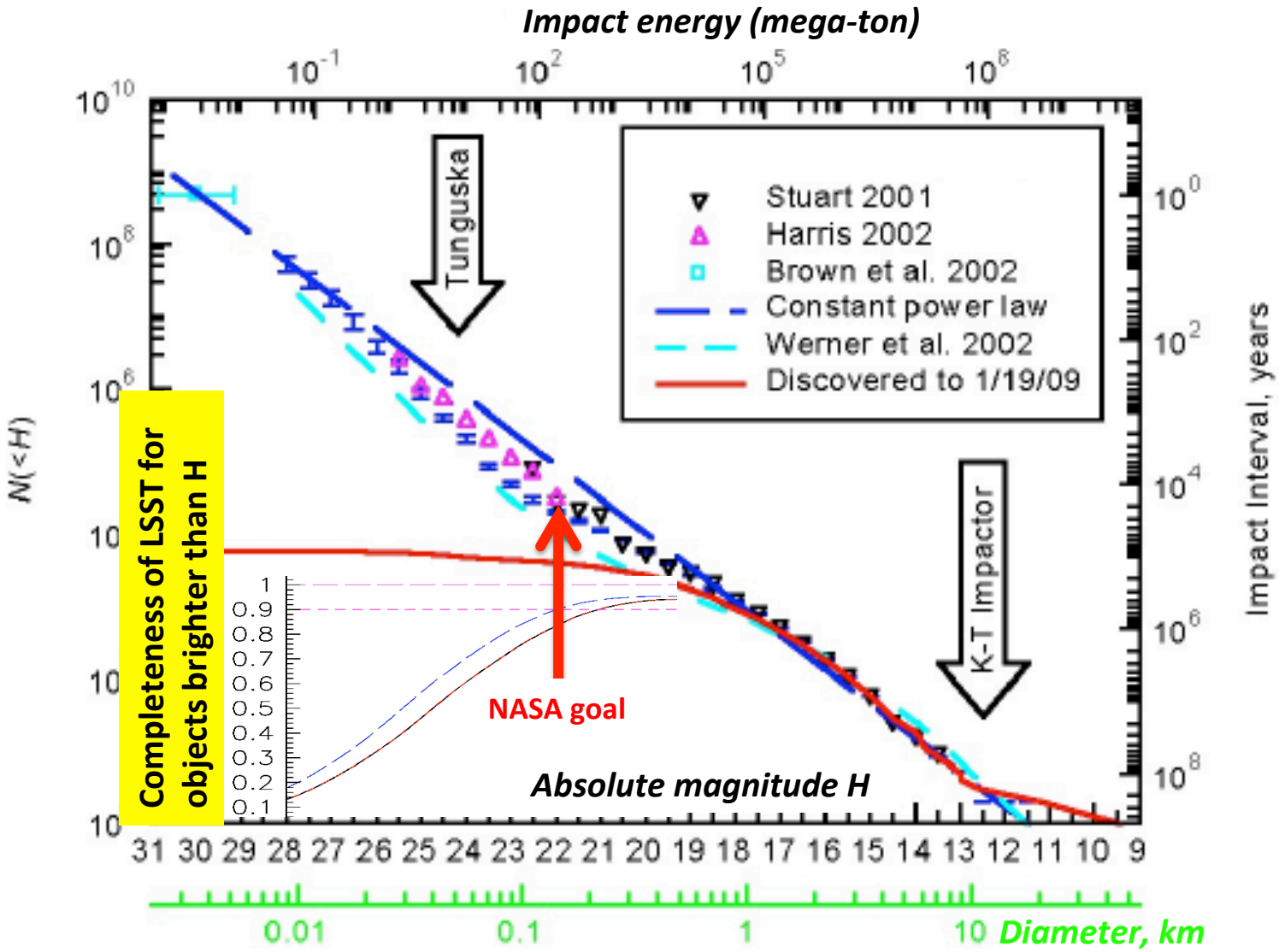
The "Threat" from "Earth killers"



The "Threat" from "Earth killers"



Interaction with LSST-transient

- **Remember: LSST is NOT an observatory/facility**
  - The consortium will not offer open time or ToO
    - **Exception**: GW only can motivate dedicated pointings
  - ~ half of the sky visited every 3-4 nights (but with different filters)
  - 1000 deg^2 In the Galactic Center observed only 180 times (confusion limits interest for *ad libitum* coaddition…) -> only long time-scale μlensing
- **But there is some flexibility: cadencing is not (yet) 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)
- **Also think on the commissioning (2021-22) and mini-surveys (1-10% time)**
  ex. mini-survey 1/2 nights movie towards LMC is necessary for scintillation
- **The broker will deliver public alerts:** but with some restrictions
- **Bringing follow-up facilities to LSST** is probably a good value…
- **Collaborate with a member of LSST** to benefit from privileges
- **discuss** with enough anticipation with the TVS science group -> establish contact with the french community already involved in LSST.

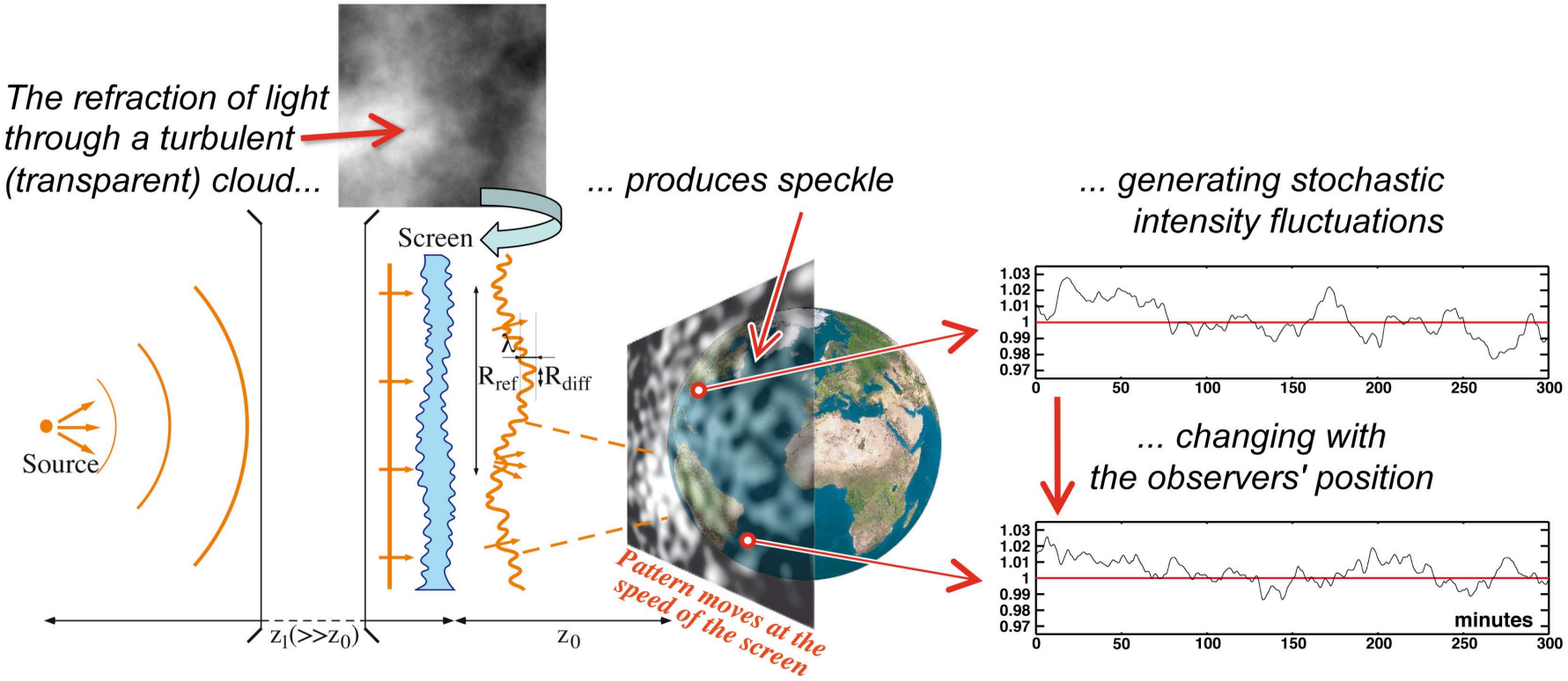
Complements

Ref. documents :

- LDM151
- LSE-163_DataProductsDefinitionDocumentDPDD

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)*

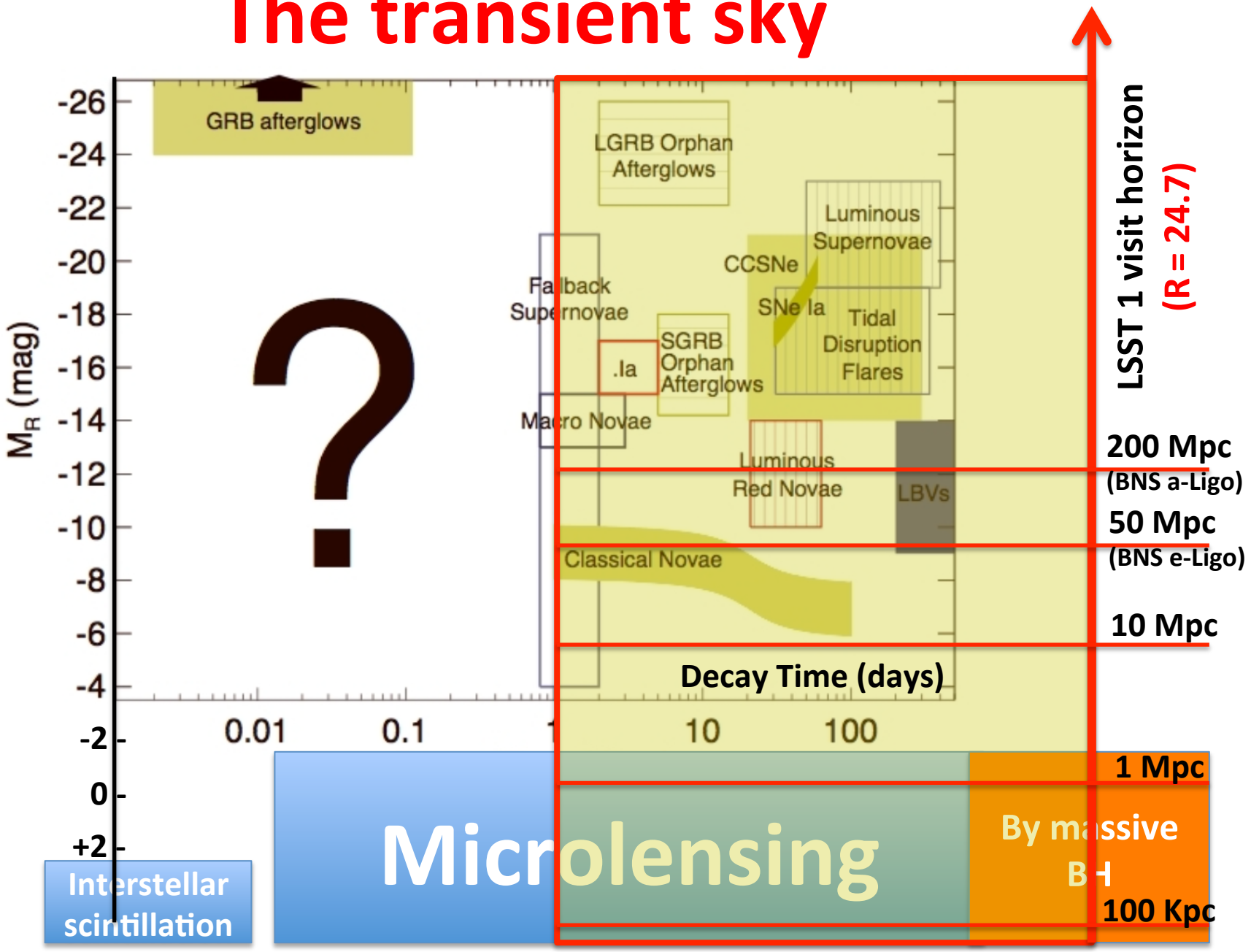
Illumination pattern from a scintillating star

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)**

The transient sky



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

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…**

Other survey modes

~10% of time ~1h/night

Deep fields + fast time domain + special zones (ecliptic, galactic plane, Magellanic clouds)