4ème école de Physique des Astroparticules - Ondes gravitationnelles
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Review of robotic optical telescopes to identify objects associated to the gravitational wave detections

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Summary

Inventory of GW emetors (electromagnetic signatures)
Long GRBs, short GRBs, type II supernovae, kilo novae

Optical detectors
Three kinds of robotic telescopes. What is observable at 200 Mpc ?

Error boxes
Triangulation method. Full covering. Selected areas.

Telescope network
Example of the 2010 run. Next generation of telescopes.

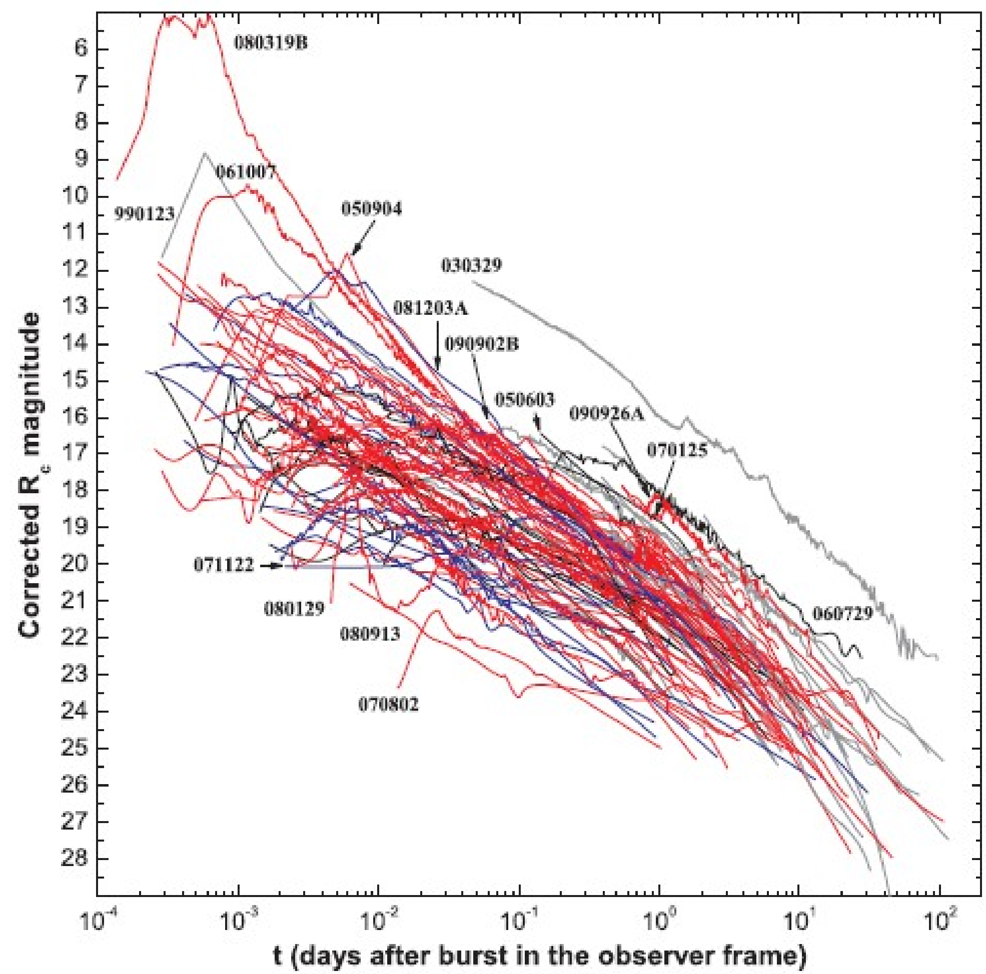
Conclusions

Inventory of GW emetors - Long gamma ray bursts

Collapse of a Wolf Rayet star
GW signature not well defined
Optical signature is the afterglow

- Bright optical decay (Flux ~ t^{-1}) if the jet is seen from the front
- Faint optical bump (Flux ~ t^{-2}) if the jet is seen from the edge (orphan afterglows)

Light curves: Kann et al. (2010) The Astrophysical Journal, 720,1513

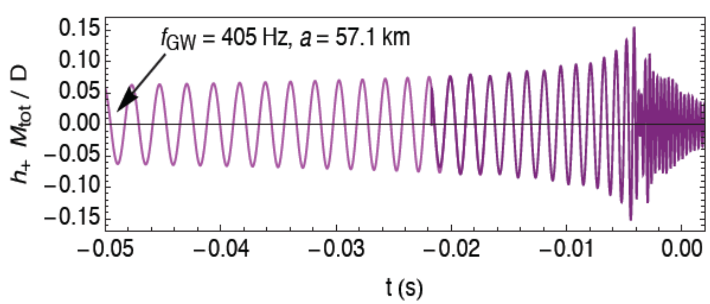


Inventory of GW emetors - Short gamma ray bursts

Merging of two neutron stars
GW signature is well modelized
Optical signature is the afterglow. Fainter than for a LGRB
For a SGRB is the jet is seen from the front

Light curves: Guelbenzu et al. arxiv.org/abs/1206.1806v1

Nicuesa Guelbenzu et al.: short GRBs



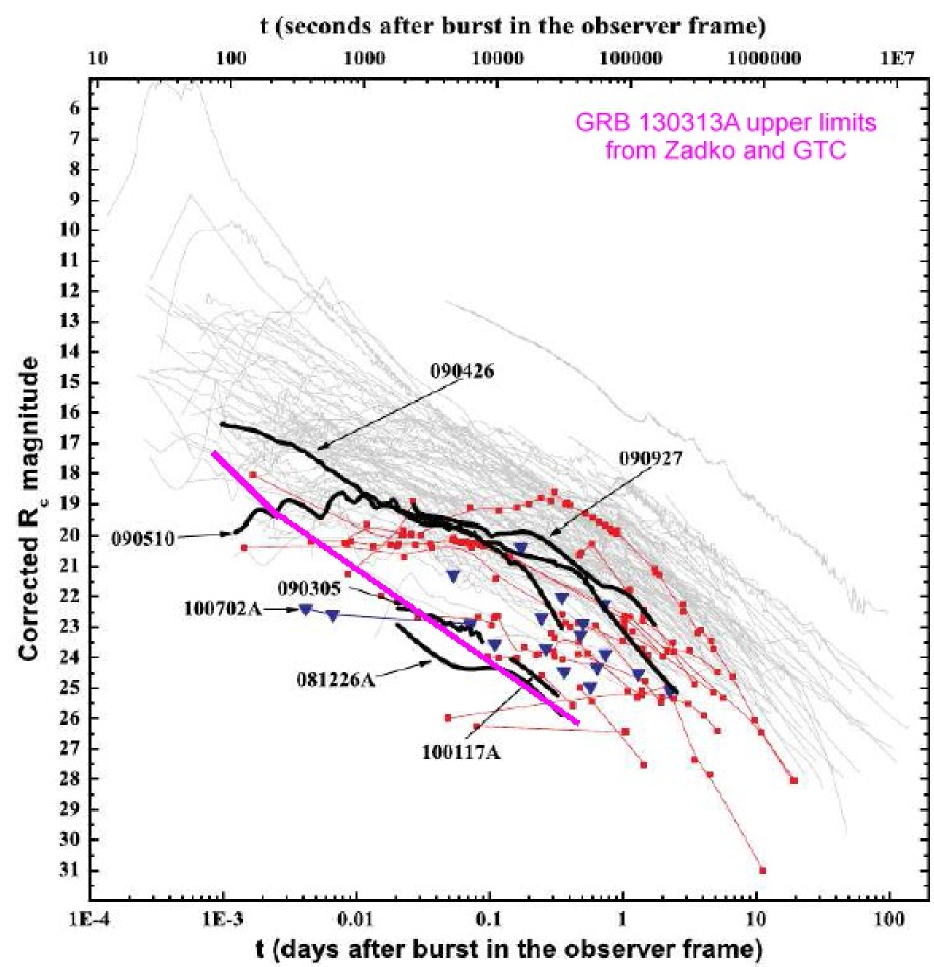
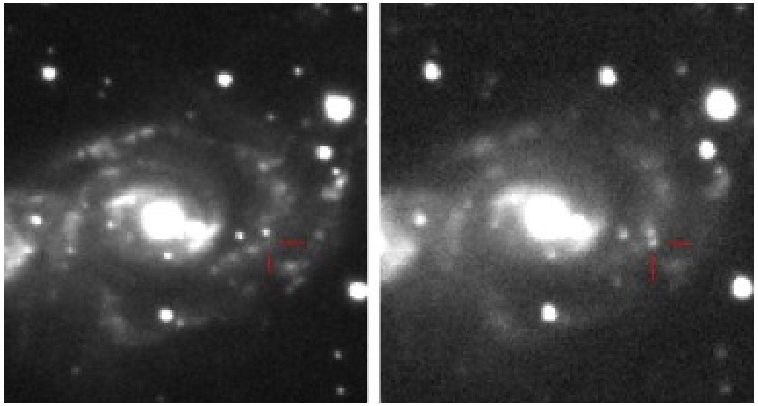


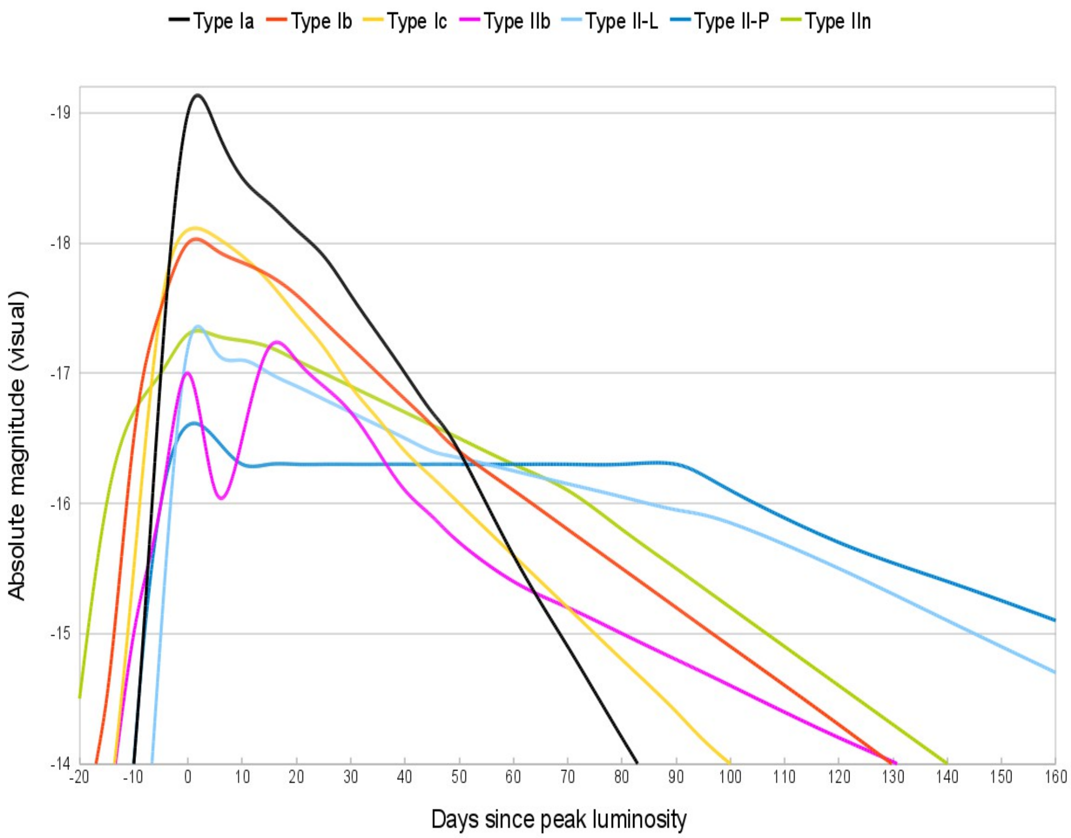
Fig. 14. Light curves of long and short GRB afterglows.

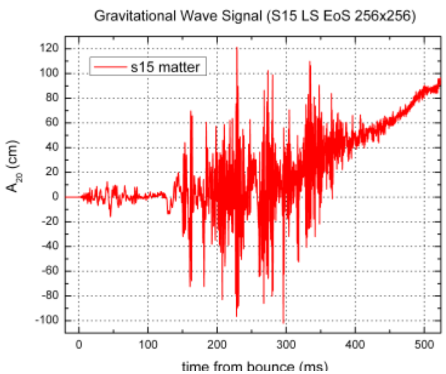
Inventory of GW emetors – Type II supernovae

Collapse of a massive star
GW signature is not well defined
Optical signature is the fireball.

- Maximum of light ~15 days after the explosion. Can be hidden in the host galaxy.
- Shock breakout predicted during the first minutes



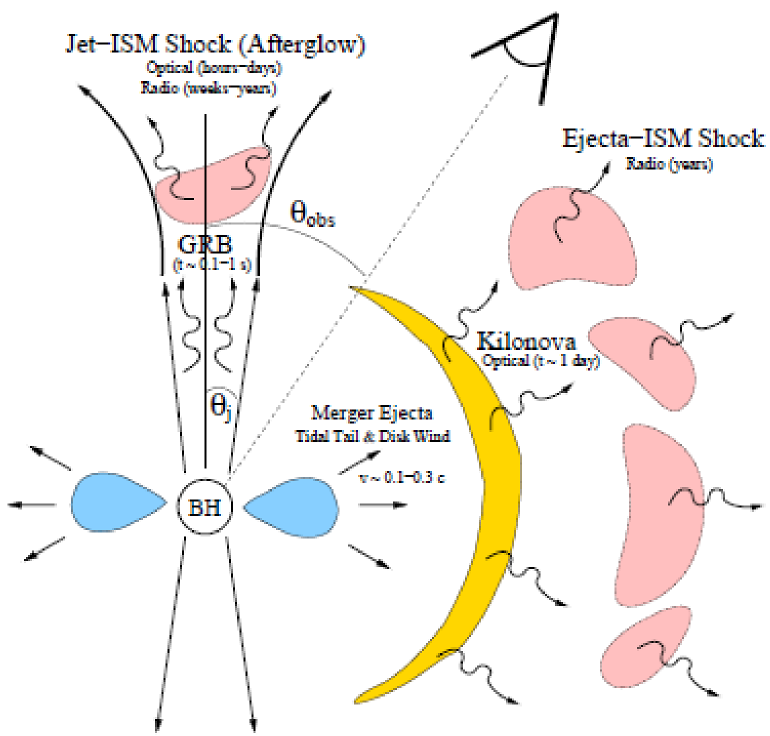


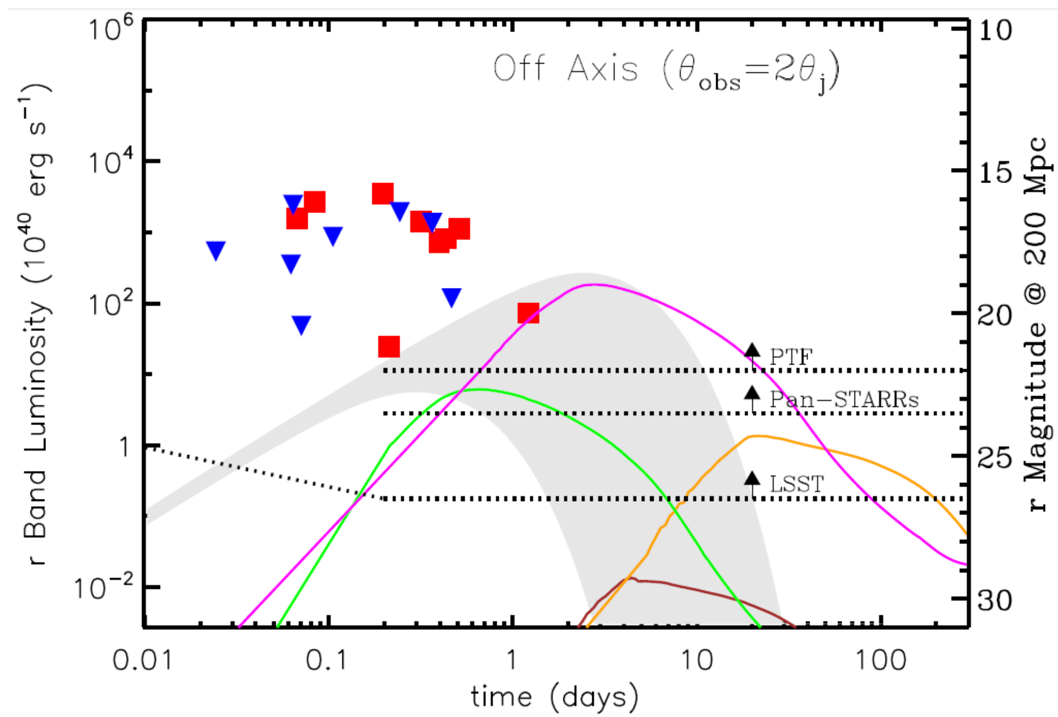


Inventory of GW emetors – Kilo novae

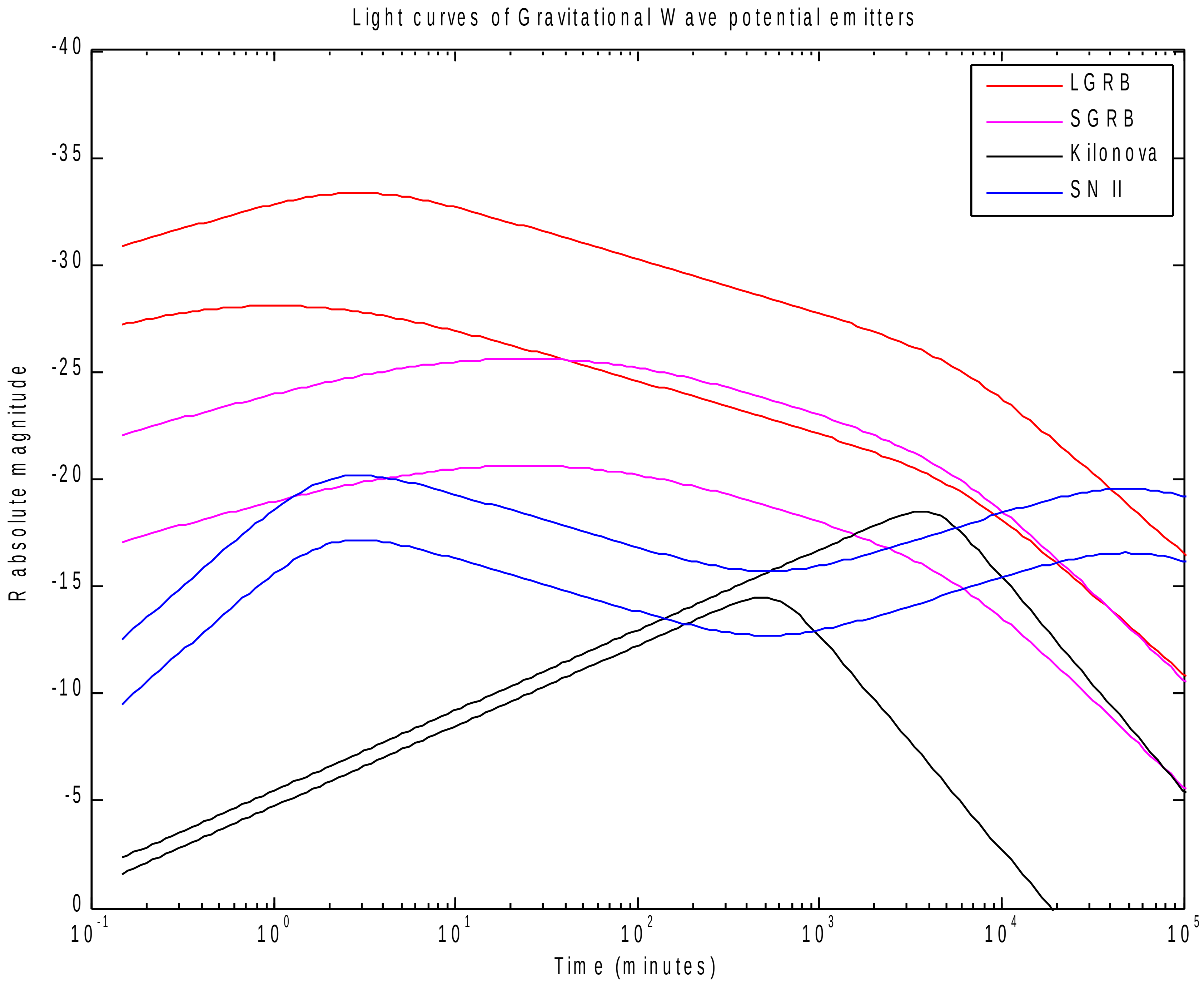
Merging of two neutron stars
GW signature is well modelized (like a SGRB)
Optical signature is a late faint bump with a rapid decay. Only theoretical.

Light curves: Metzger & Berger (2012) The Astrophysical Journal, 746, 48



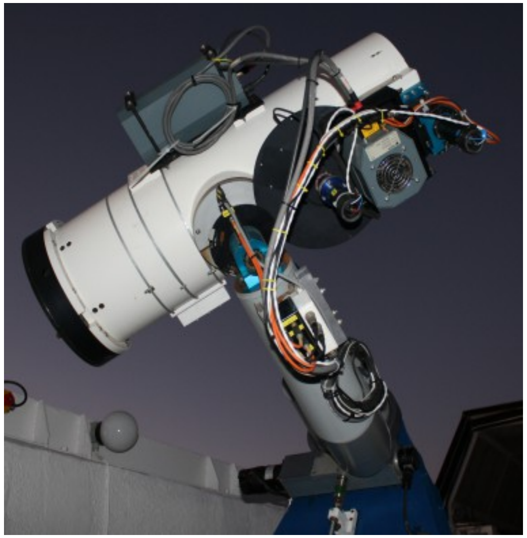


Inventory of GW emetors – Comparison of light curves



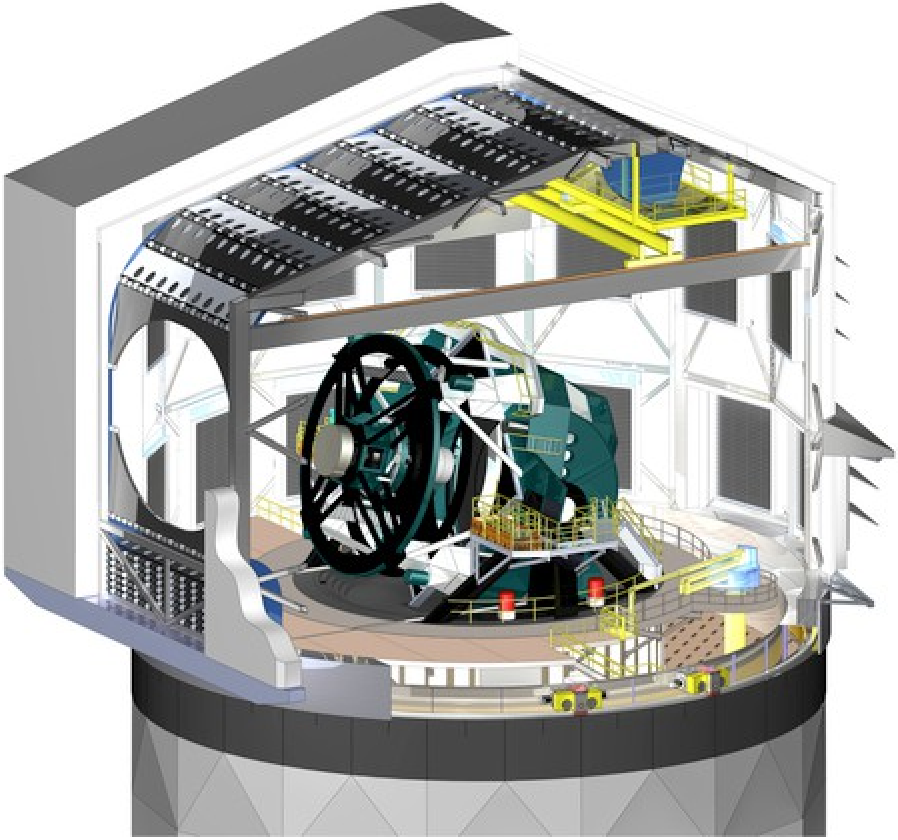
Optical detectors – Three kinds of robotic telescopes

TELESCOPE: Diameter, focal length, slewing time
CAMERA: Exposure time, field of view, readout time



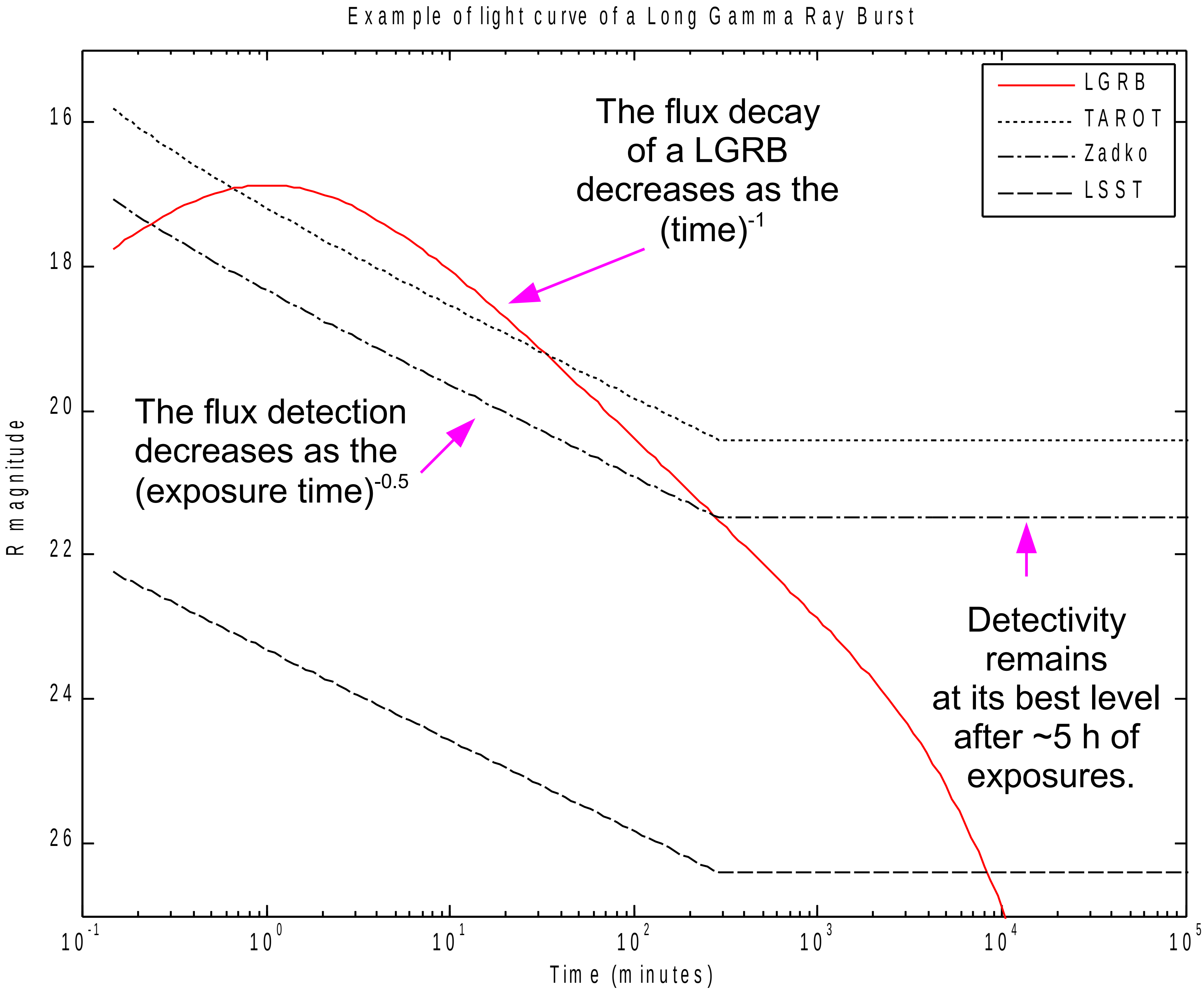
TAROT
D=0.25m
FoV = 2° x 2°
First image in 10 s
Deepest mag = 20.4
Cost = 300 k€

Zadko
D = 1.0 m
FoV = 0.3° x 0.3°
First image in 80 s
Deepest mag = 21.6
Cost = 1 M€

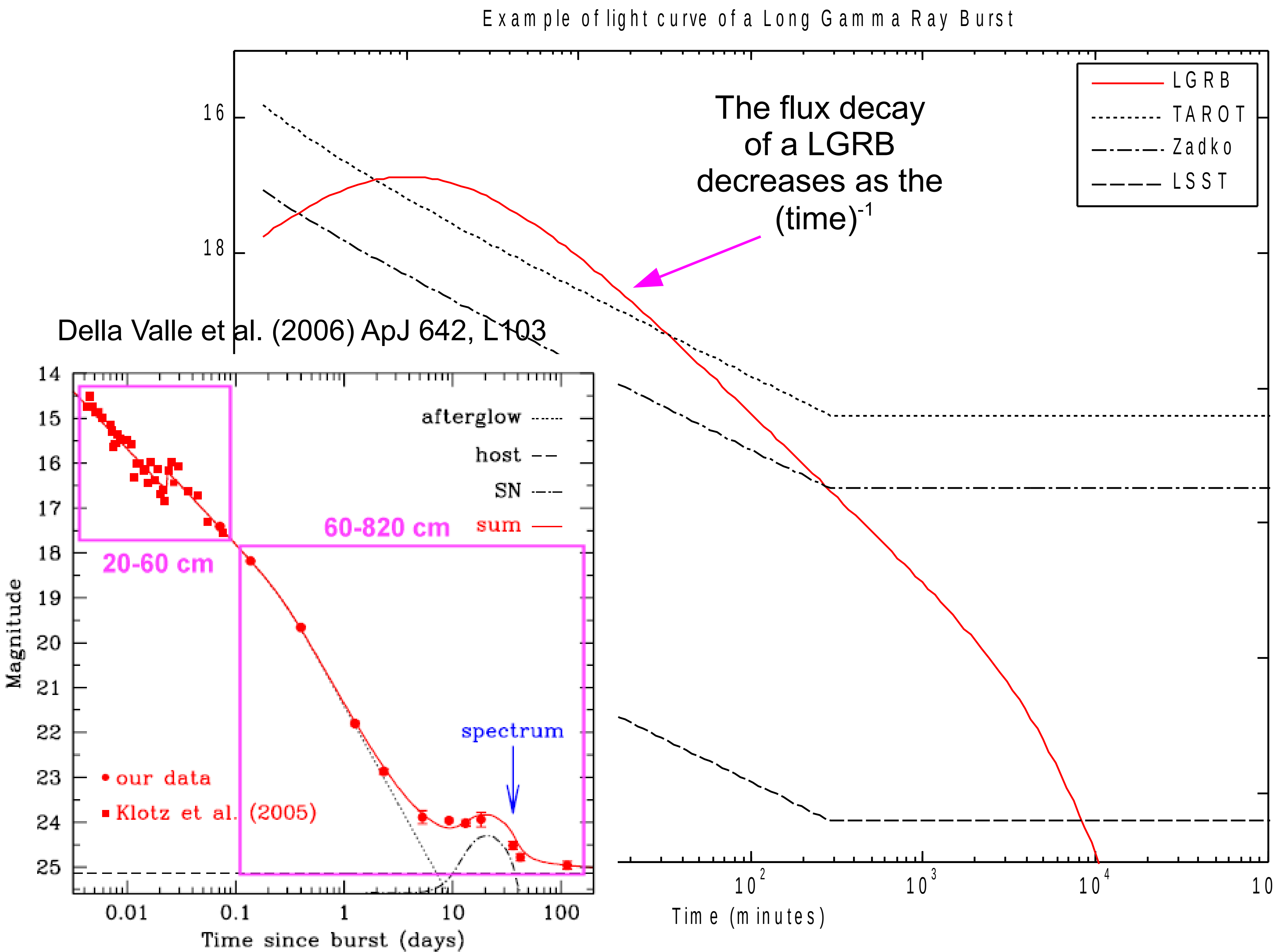


LSST
D = 6.7 m
FoV = 3° x 3°
First image > 10 minutes
Deepest mag = 26.4
Cost = 500 M€

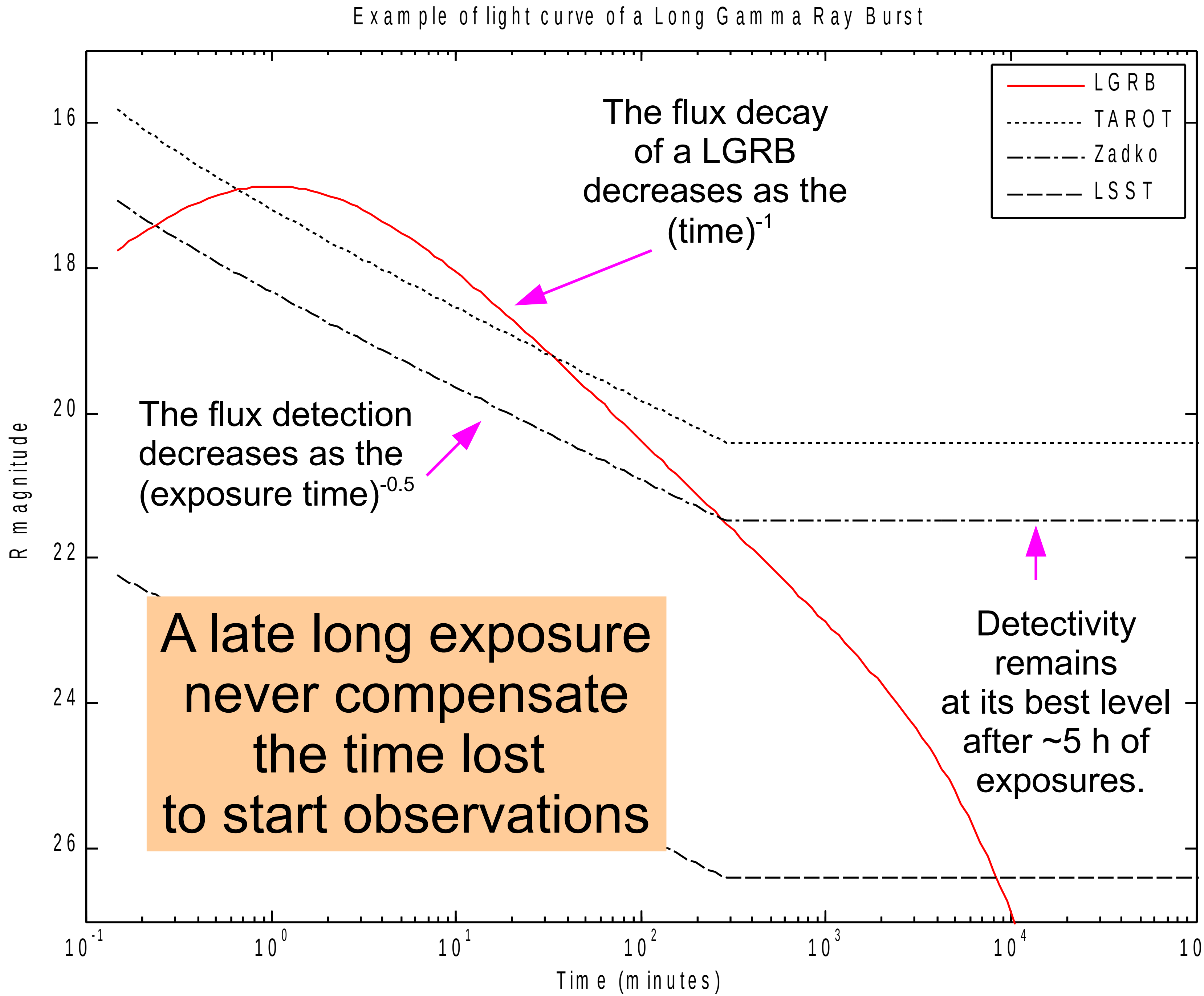
Optical detectors – Basics of the optical detection



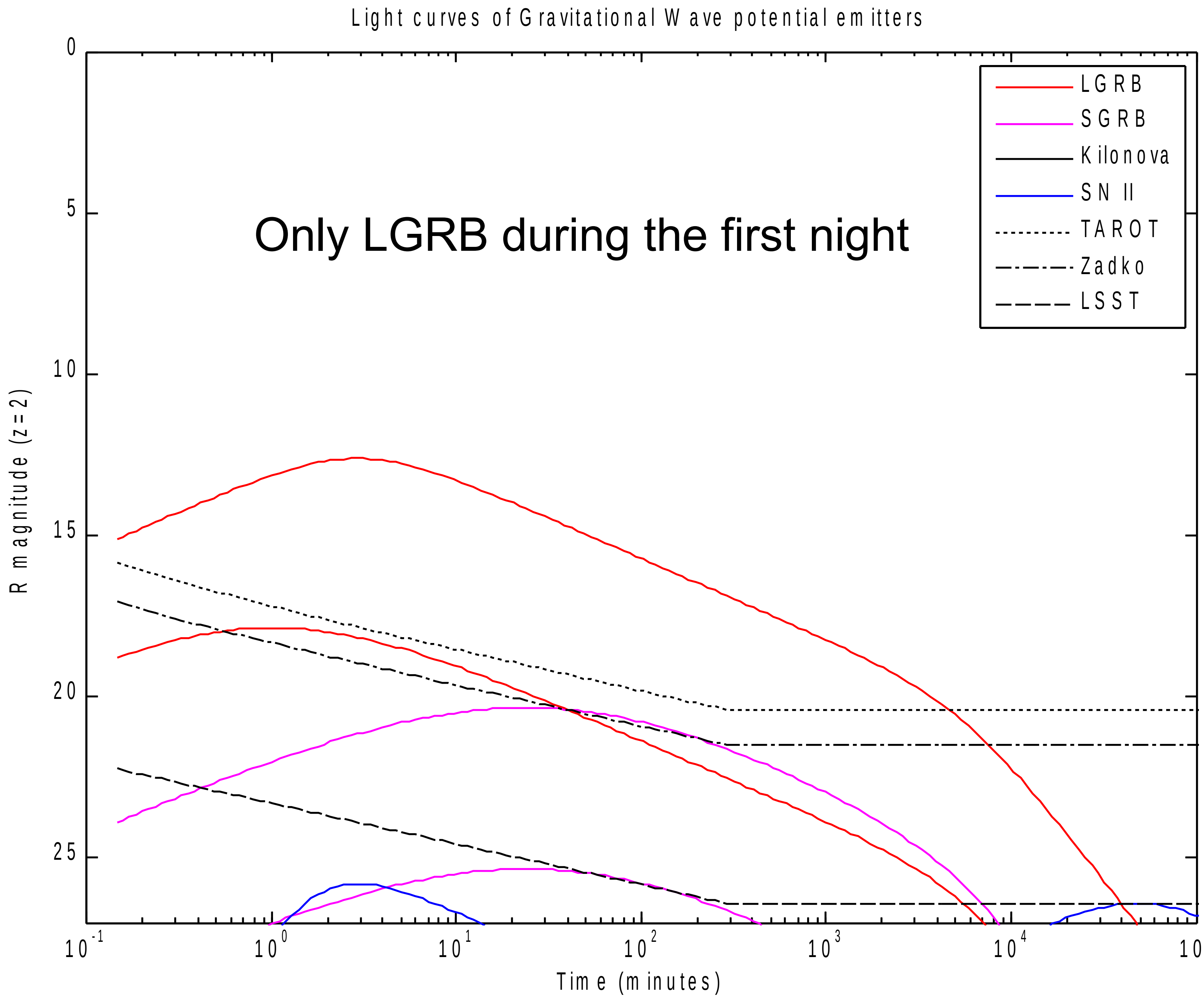
Optical detectors – Basics of the optical detection



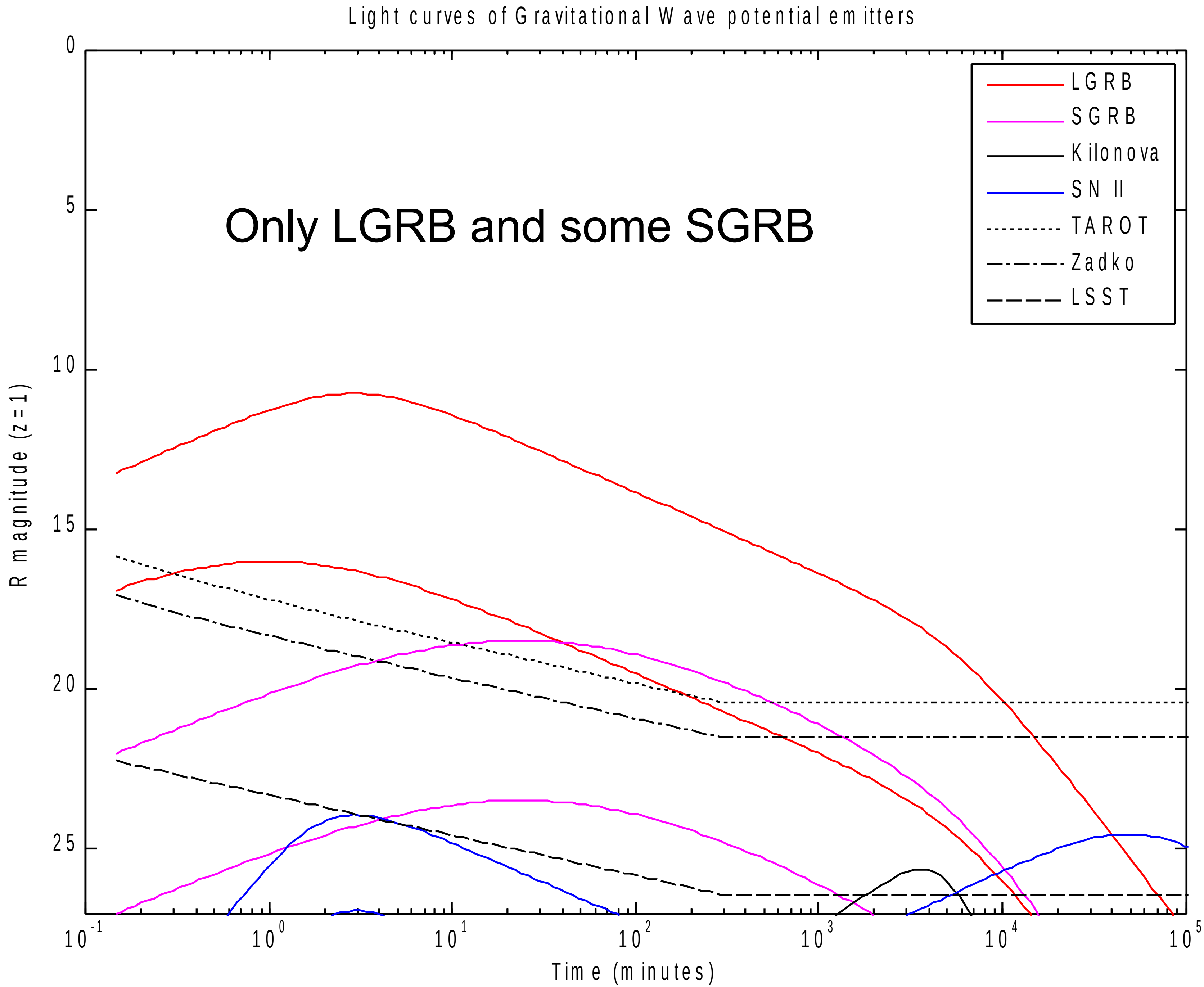
Optical detectors – Basics of the optical detection



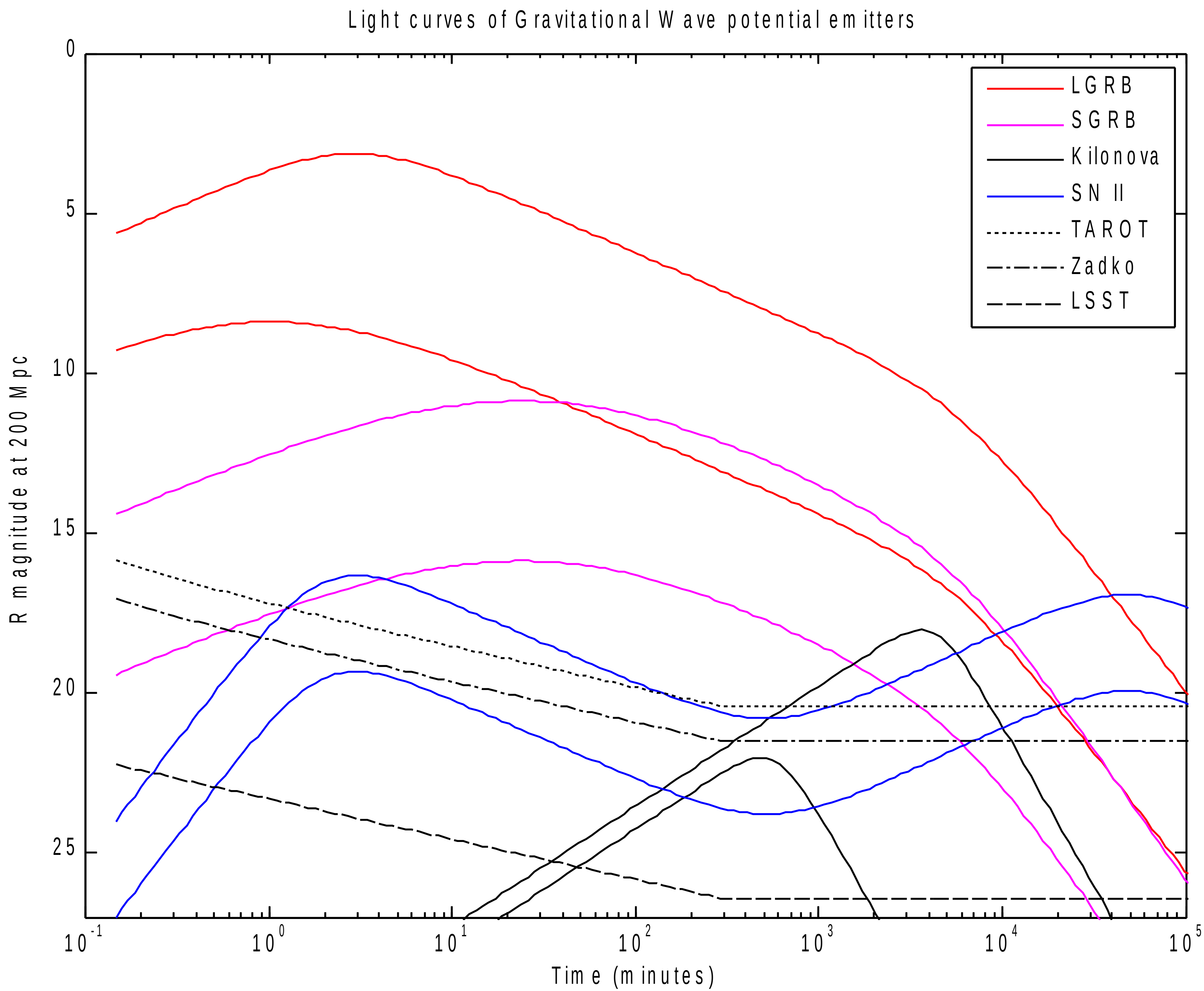
Optical detectors – What is observable at z=2 ?



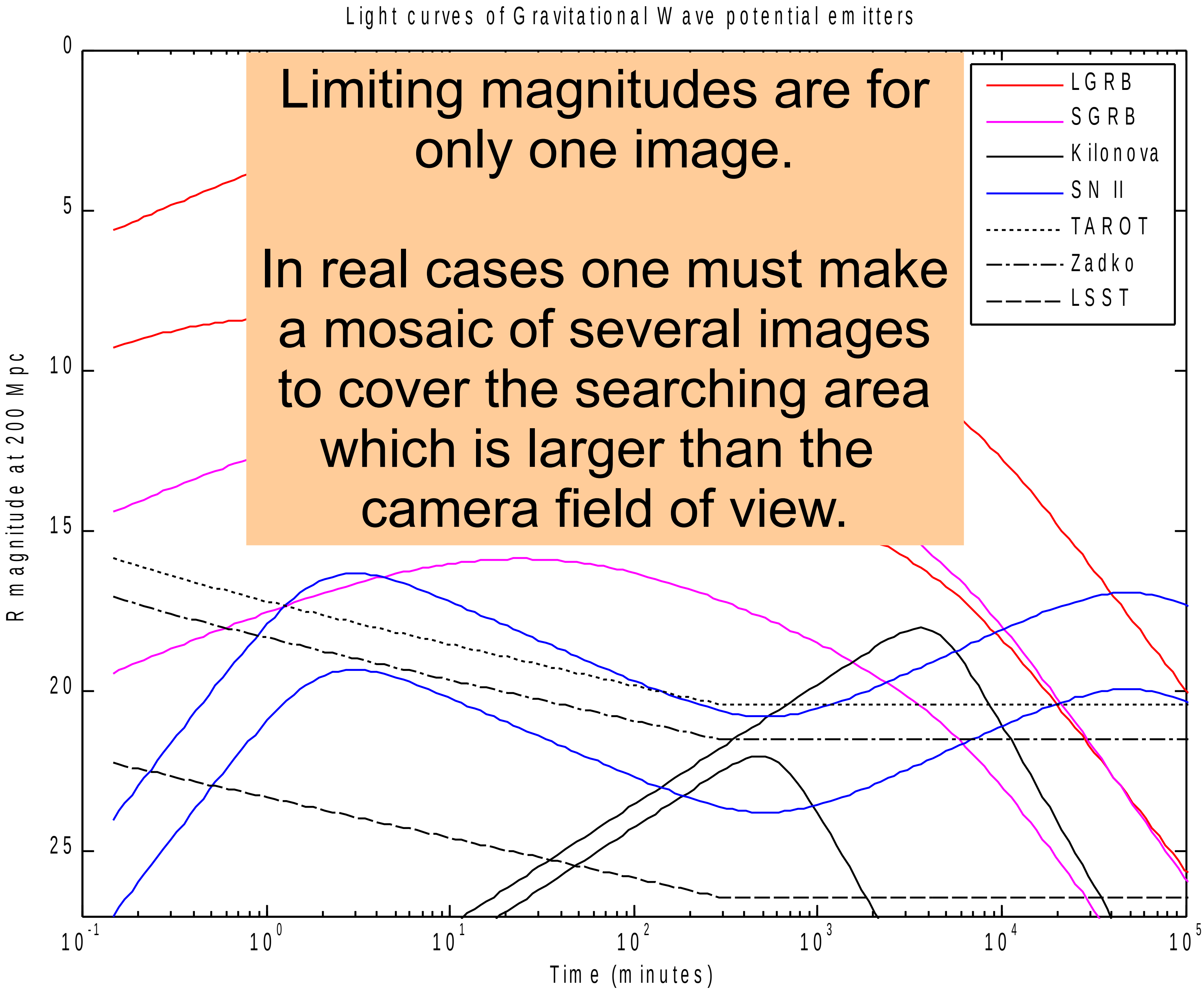
Optical detectors – What is observable at z=1 ?



Optical detectors – What is observable at 200 Mpc ?



Optical detectors – What is observable at 200 Mpc ?



Limiting magnitudes are for only one image.

In real cases one must make a mosaic of several images to cover the searching area which is larger than the camera field of view.

Error boxes – Triangulation method

Chatterji, S. et al. (2006) Phys.Rev. D74 082005, arXiv:0605002
LIGO Scientific Collaboration; Virgo Collaboration (2012) A&A 539, 124

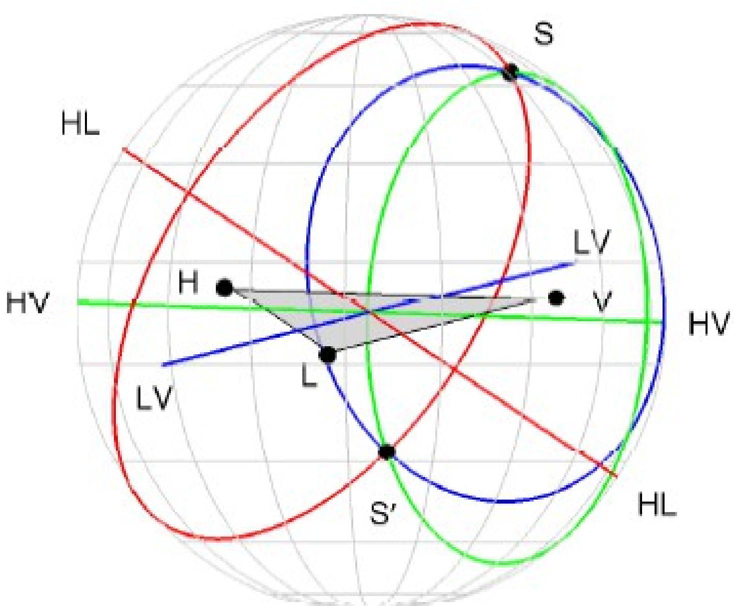
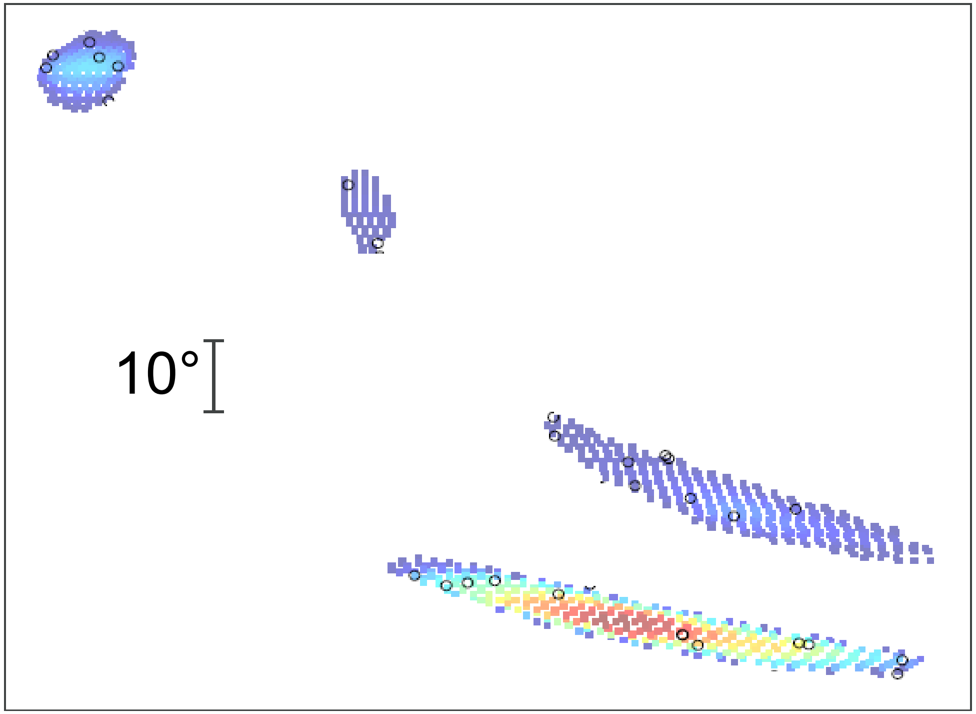


FIG. 1: Geometry of the network and travel times spent by a GWB to propagate across a three-detector network (detectors "H", "L", and "V"). The locus of constant time delay between two detectors form a ring on the sky concentric about the baseline between the two sites. For three detectors, these rings may intersect in two locations. One is the true source direction, S, while the other (S') is its mirror image with respect to the geometrical plane passing through the three sites. This two-fold ambiguity can be resolved by further considering the amplitudes of the responses. For four or more detectors there is a unique intersection point of all of the rings.

<u>One interferometer:</u>
Thickness of one great circle = 8°

<u>Many interferometers:</u>
Common parts of great circles :
- parallel = poor case (8° x 360°)
- perpendicular = best case (8° x 8°)

<u>Complete solution</u>: not only one island:



Error boxes – Full covering the locations

limiting magnitude → one frame exposure time → duration of mosaic

telescope
camera

slewing time
readout time
field of view
error box area

Example with TAROT for an area of 120°^{2}:

magnitude 16 → one frame = 11 seconds → mosaic 660 seconds

TAROT
Andor 486

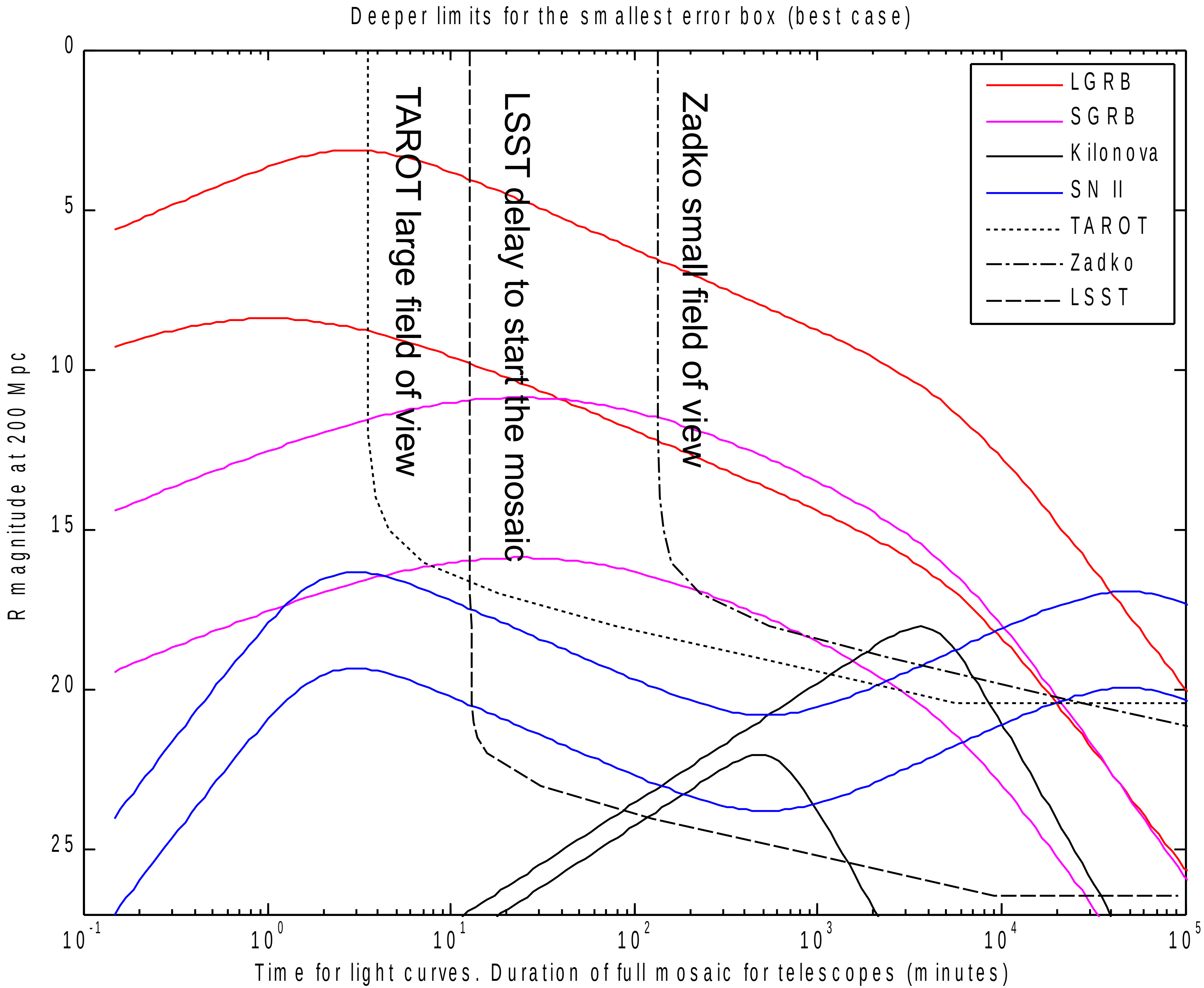
0 second
7 seconds
1.8° x 1.8°
120°^{2}

Must add a delay for the start of the mosaic after the trigger:

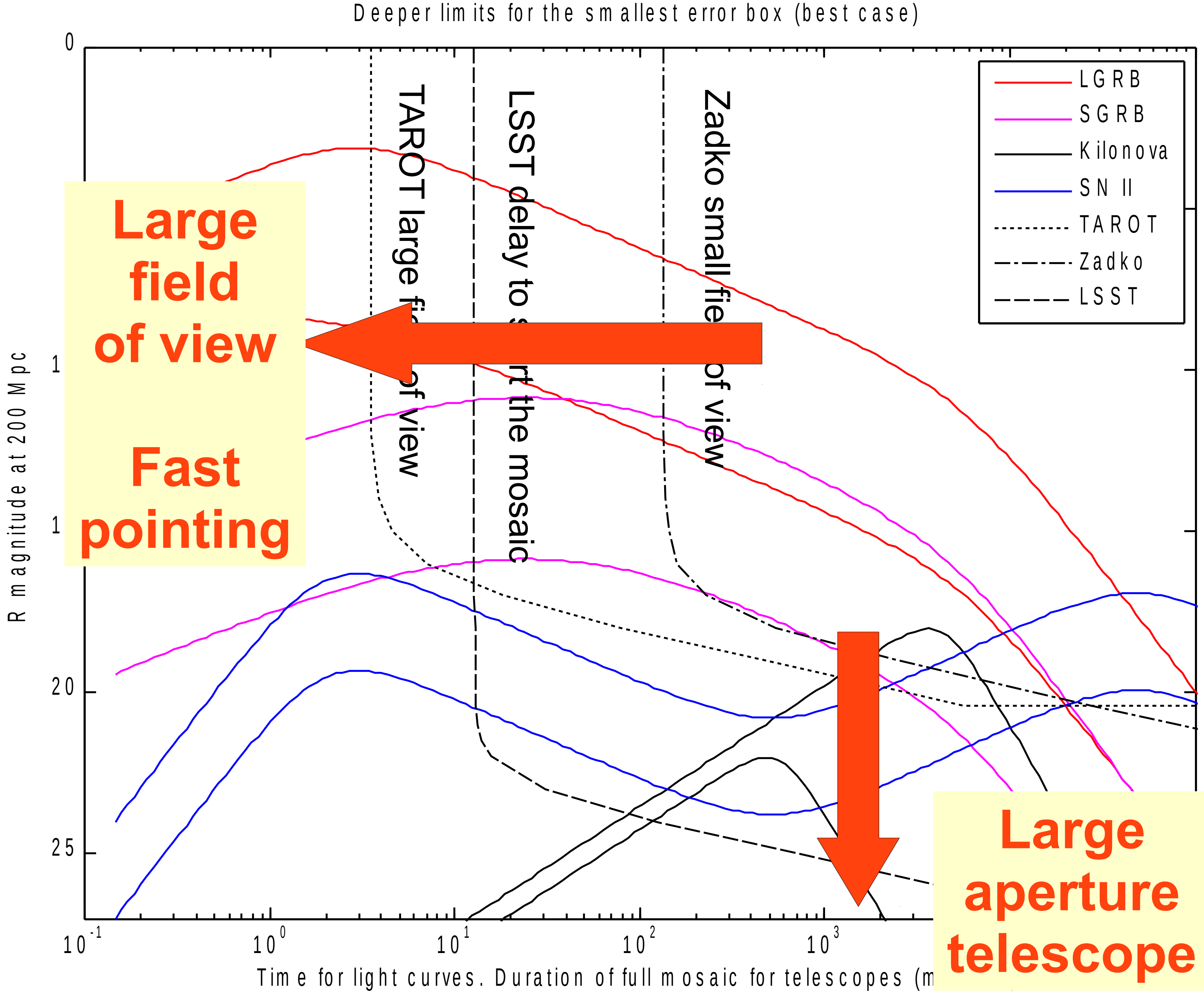
~2 minutes after the trigger for TAROT and Zadko because they are fully robotic.

~10 minutes for LSST to allow a human check for pointing.

Error boxes – Full mosaic covering duration



Error boxes – Full mosaic covering duration

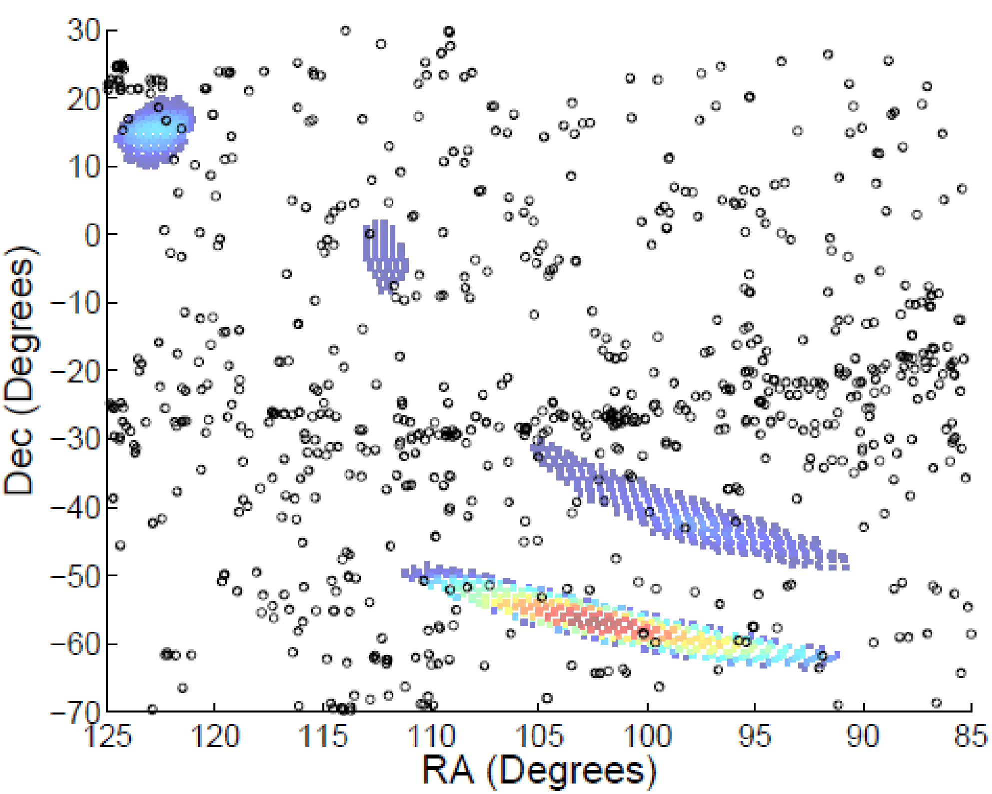


Error boxes – Selected areas

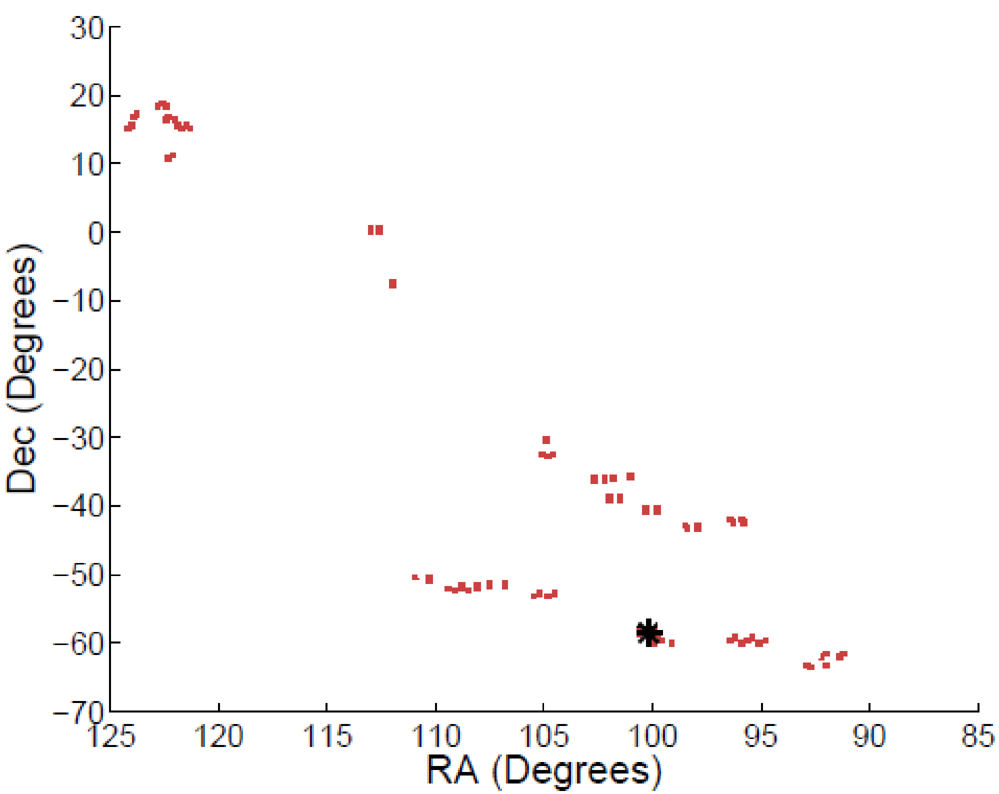
Facts : Although its larger aperture Zadko is less efficient than TAROT for a full coverage.

Solution: Use the small field of view telescopes to check specific areas:
Selection of potential host galaxy candidates (catalogue GWGC)

black circles = all known galaxies



Red squares = selected galaxies



Small field of view large aperture telescopes = Complementary data

Telescope network – Example of the 2010 run

LIGO and VIRGO in the same time

described in LIGO Scientific Collaboration; Virgo Collaboration (2012) A&A 539, 124

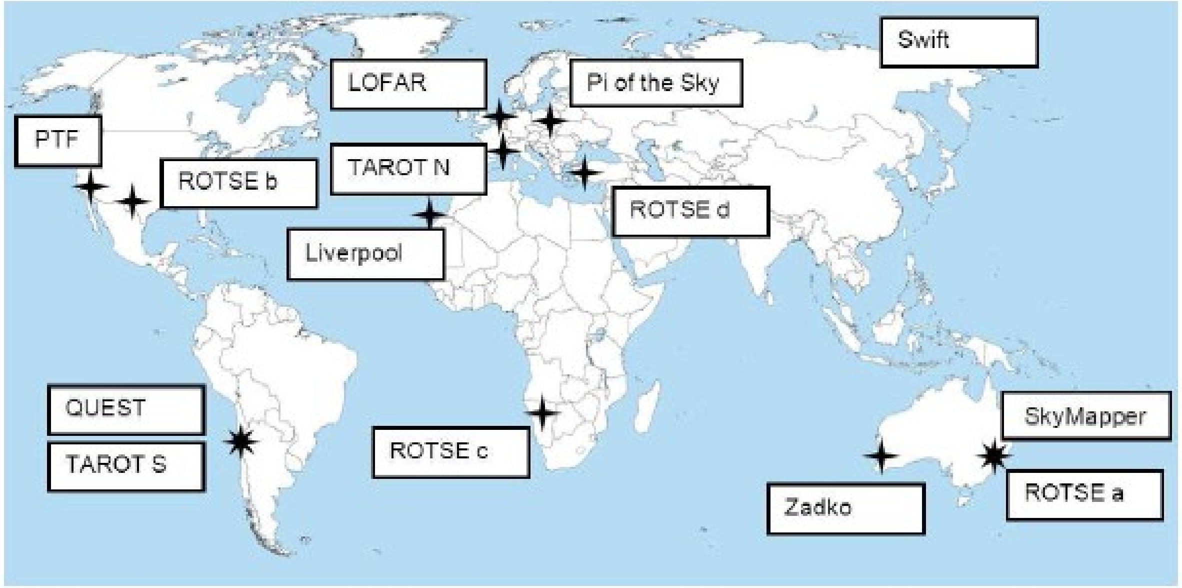


Fig. 1. A map showing the approximate positions of telescopes that participated in the project. The Swift satellite observatory is noted at an arbitrary location.

Large field of view:

7 Submeter class telescopes:
Pi of the Sky, ROTSE, TAROT

3 Meter class telescopes:
PTF, QUEST, Skymaper

Small field of view

2 Meter class telescopes:
Liverpool, Zadko

Name	Run	Tiles per Trigger	Target Alerts Per Week	Triggers Imaged
Palomar Transient Factory	Autumn	10	1/3	1
Pi of the Sky	Autumn	1	1	1
QUEST	Both	3	1	5
ROTSE III	Autumn	1	1	5
SkyMapper	Autumn	~9	1	3
TAROT	Both	1	1	3
Zadko Telescope	Autumn	5	1	2
Liverpool Telescope	Autumn	1	1	1
LOFAR	Autumn	1	1	2
Swift	Both	5	1/4	2

Telescope network – Next generation of telescopes

Dedicaded telescopes to have no delay for the first slewing.

Next generation of submeter class diameters

TAROT → RAPIDO : Larger field of view,. Low cost (~50 k€)

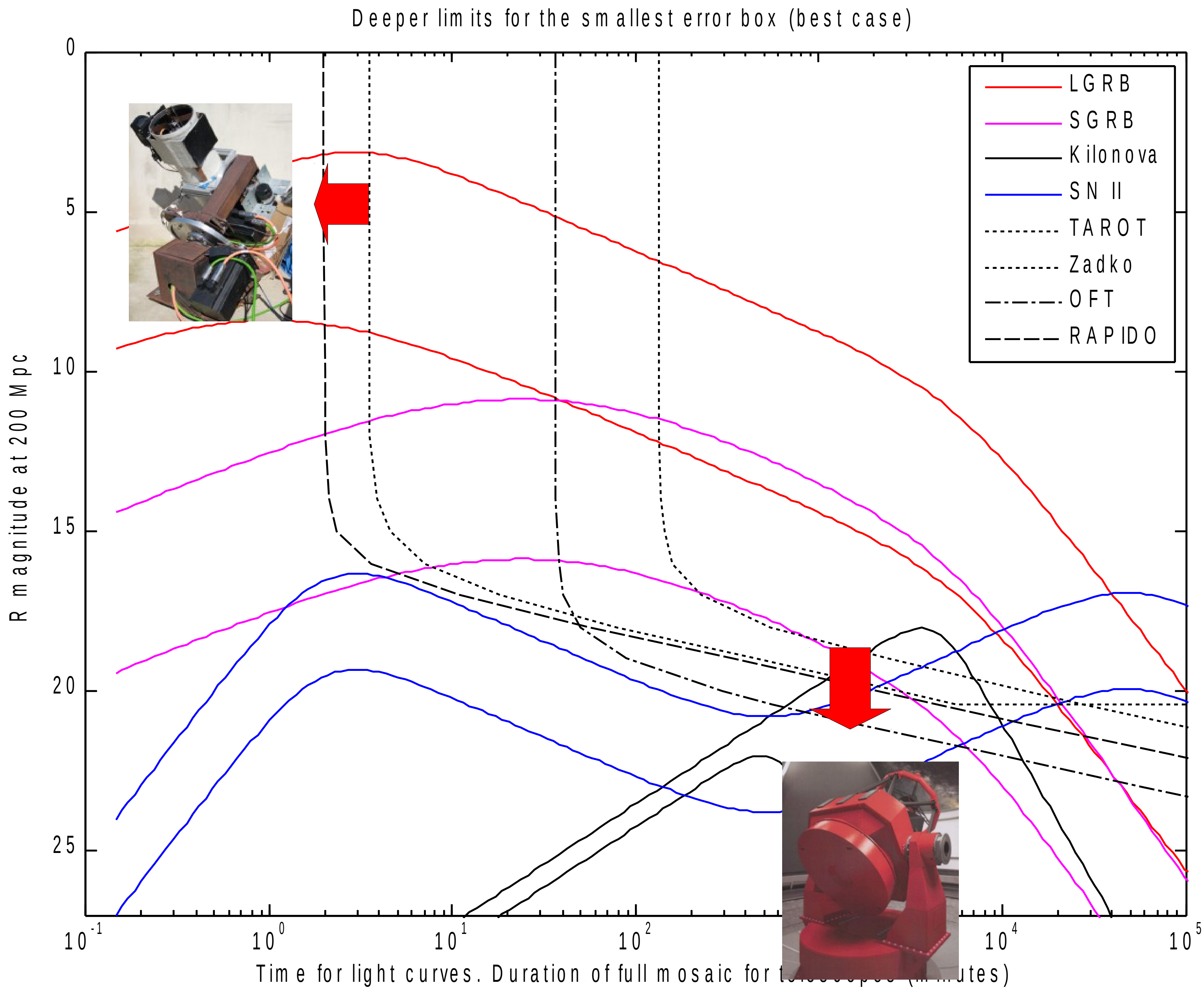
RAPIDO is a prototype. Will be installed in Chile in 2015.
It can be duplicated.

Next generation of meter class diameters

Zadko → OFT : Larger field of view, fast slewing, infrared

OFT is a unique telescope. Will be installed in Mexico in 2016.

Telescope network – Next generation of telescopes



Telescope network – Existing GRB networks

NETWORK : ROTSE
TELESCOPES : ROTSE IIIa, ROTSE IIIb, ROTSE IIIc, ROTSE IIId

NETWORK : RTS2
TELESCOPES : BART, BOOTES 1-2-3..., FRAM, WATCHER-1

NETWORK : CADOR
TELESCOPES : TAROT Calern, TAROT Chile, Zakdo

NETWORK : Thinking Telescope systems
TELESCOPES : RAPTORs A, S, T, Z, Qa and P

NETWORK : Robonet
TELESCOPES : Liverpool, FTN, FTS

NETWORK : Skynet (Follow-Up Network for Gamma-Ray Bursts - FUN GRB)
TELESCOPES : 4.1-m SOAR, 3.5-m ARC, 1.5-m Kuiper, 0.9-m SARA, GORT, TTT, PROMPT

NETWORK : EAFON (East Asian GRB Follow up Observation Network)
TELESCOPES : TNT, EST, LOT, Kiso

NETWORK : MASTER-Net
TELESCOPES : Vostryakovo, Kislovodsk, Ekaterinburg, Irkutsk, San Juan
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CONCLUSIONS for ground based optical telescopes

Observing optical counterparts of GW triggers

Small aperture telescopes with large field of view

Rapid exhaustive scan of larges areas.
Low cost allows to build a network of observatories that increases the reliabilty.
    They are limited in detectivity.

Large aperture telescopes with small field of view

Examination of some selected fields in large areas.
Complementary to exhaustive scans.
    Their number is limited due to their cost

Very large aperture telescopes with large field of view

Only LSST and Pan STARRS.
    They are not operational before 2021
    They are not able to respond promptly to the alerts.

THE END