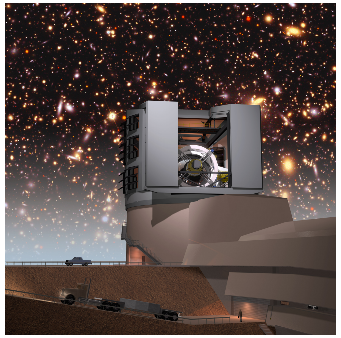
Synergies between SKA and LSST: the transient sky

M. T. BOTTICELLA

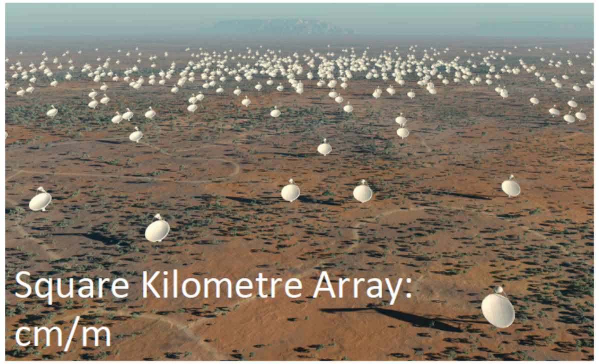
INAF - OSSERVATORIO DI CAPODIMONTE

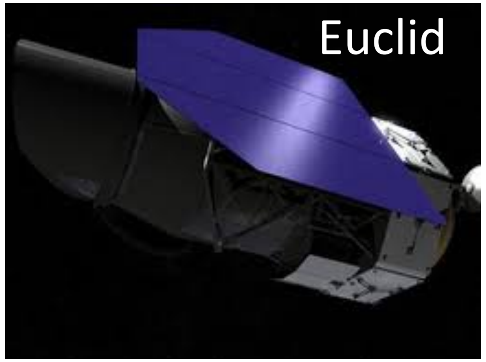


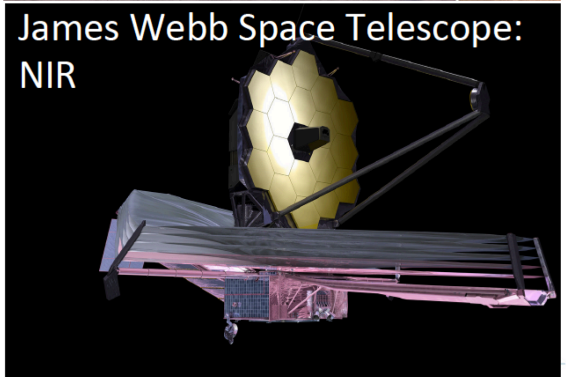
OUTLINES

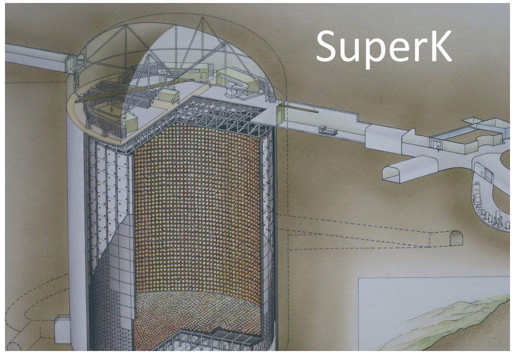
- Transient sky in the optical and radio wavelengths
- LSST overview
- TVS projects
- Science questions in common between SKA and LSST
- Science benefits of combining information from SKA and LSST

Multi-messenger Astronomy

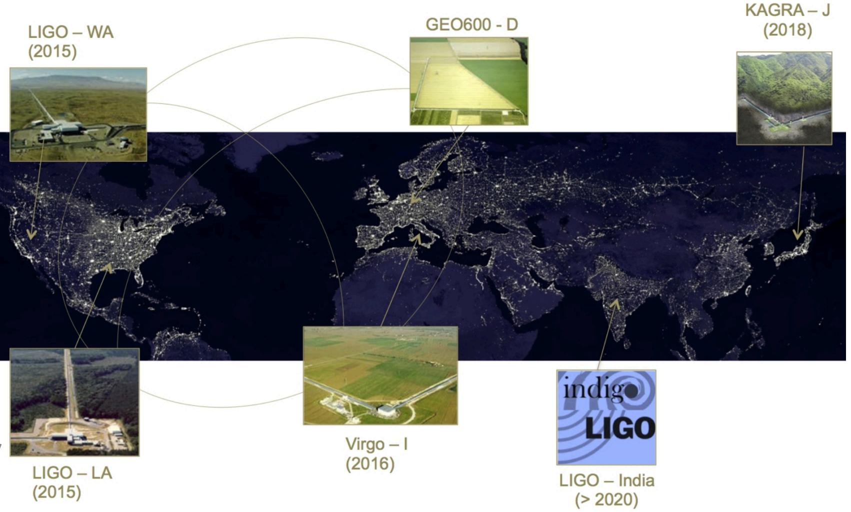




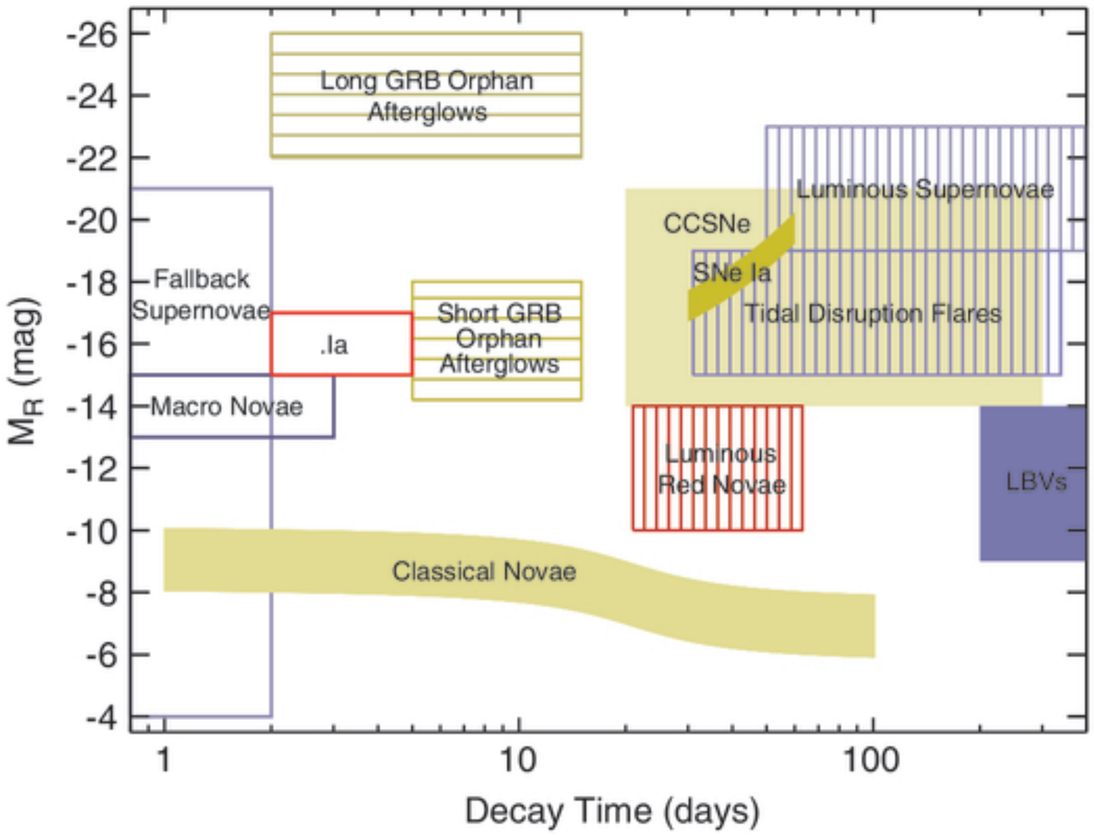


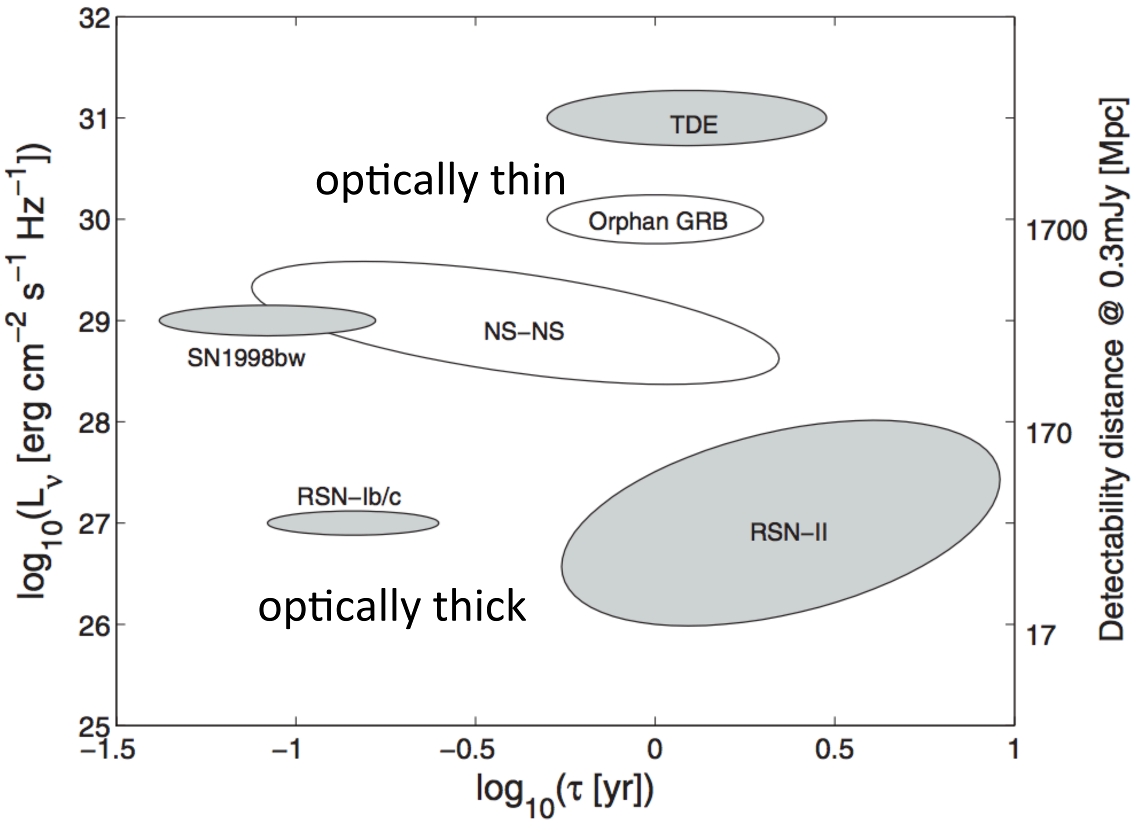


and
the advent of synoptic sky surveys



New regimes in observational parameter space





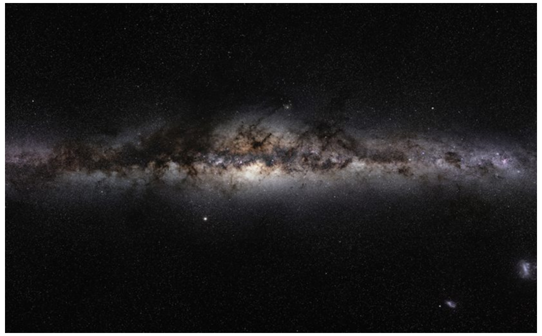
There is still a large range of transient parameter space that has not yet been sampled correlating optical and radio properties

The Large Synoptic Survey Telescope

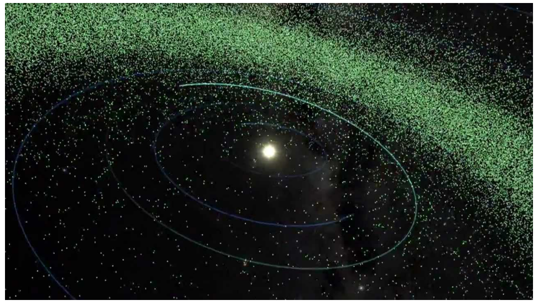
Science Drivers

- probing dark energy and dark matter

- exploring the transient and variable universe



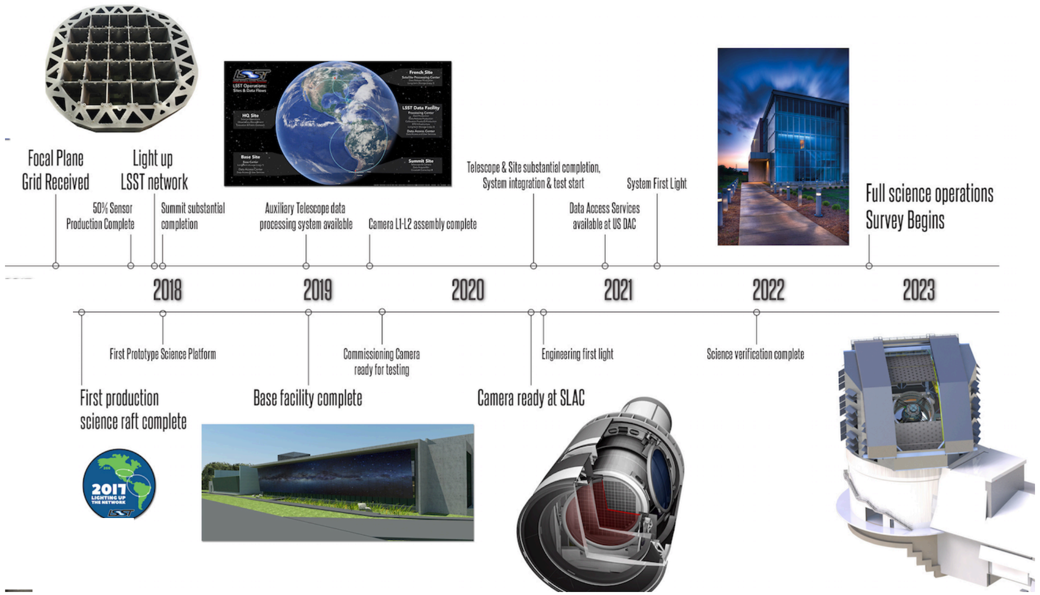
- mapping the Milky Way galaxy



- taking an inventory of the Solar System

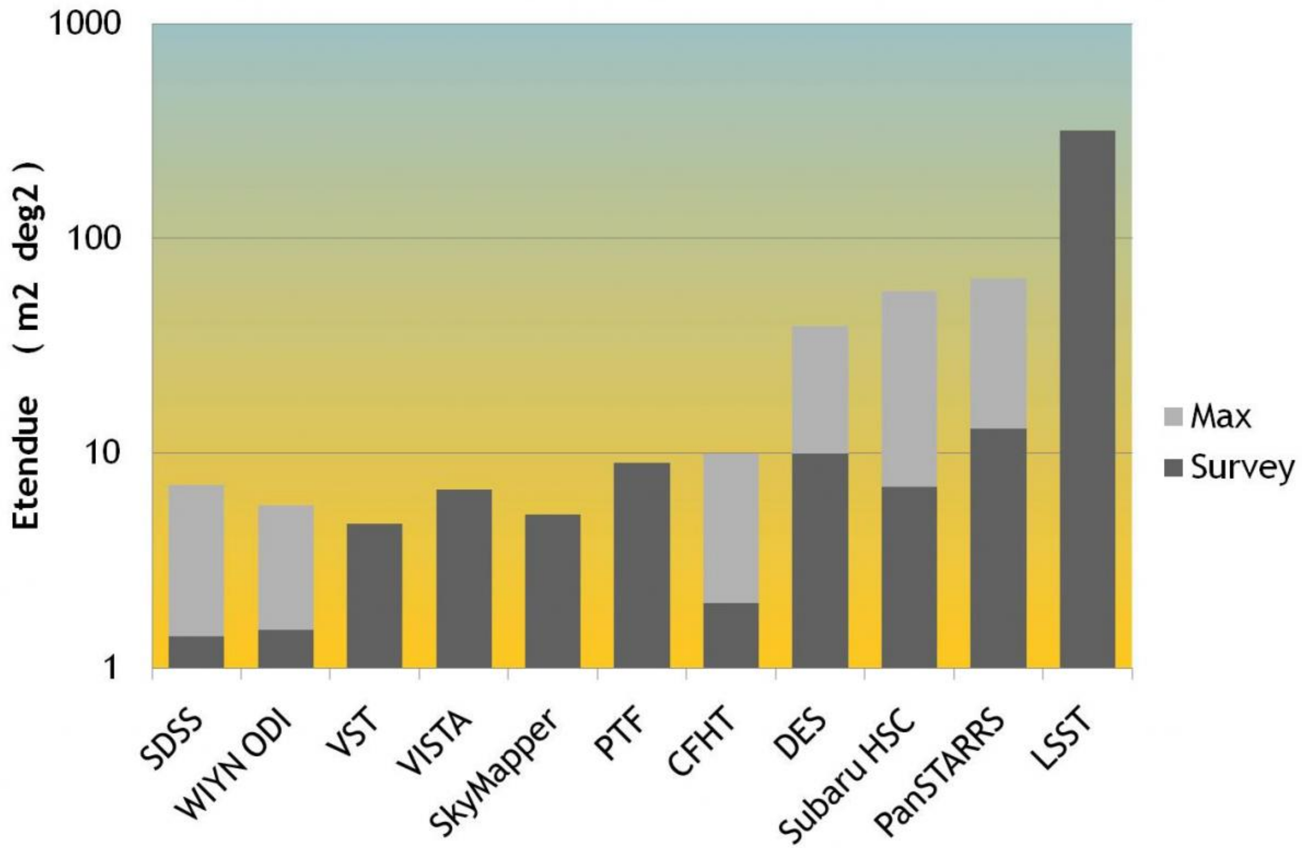
The Large Synoptic Survey Telescope

- High cadence to discover fast transients
- large volume to discover rare transients
- multi-band to measure transient colours
- longer survey duration (2022-2032)



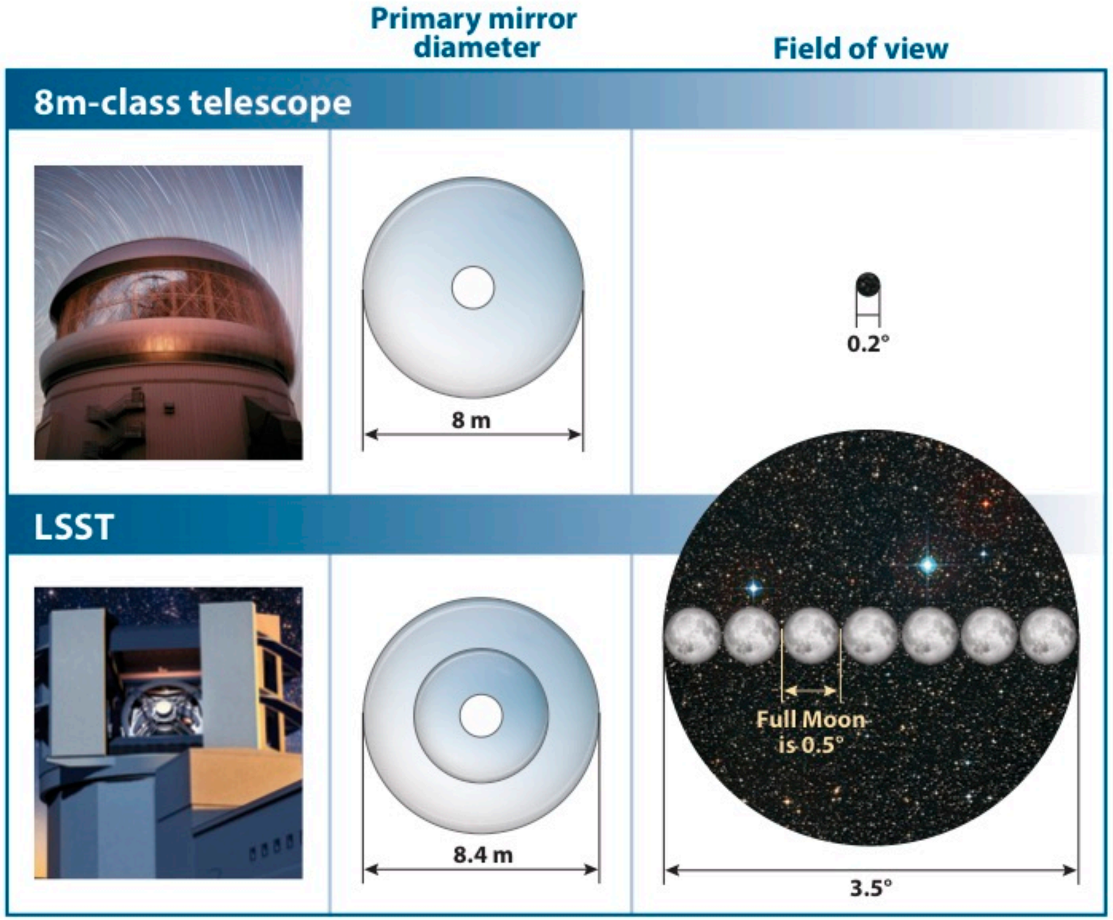
The Large Synoptic Survey Telescope

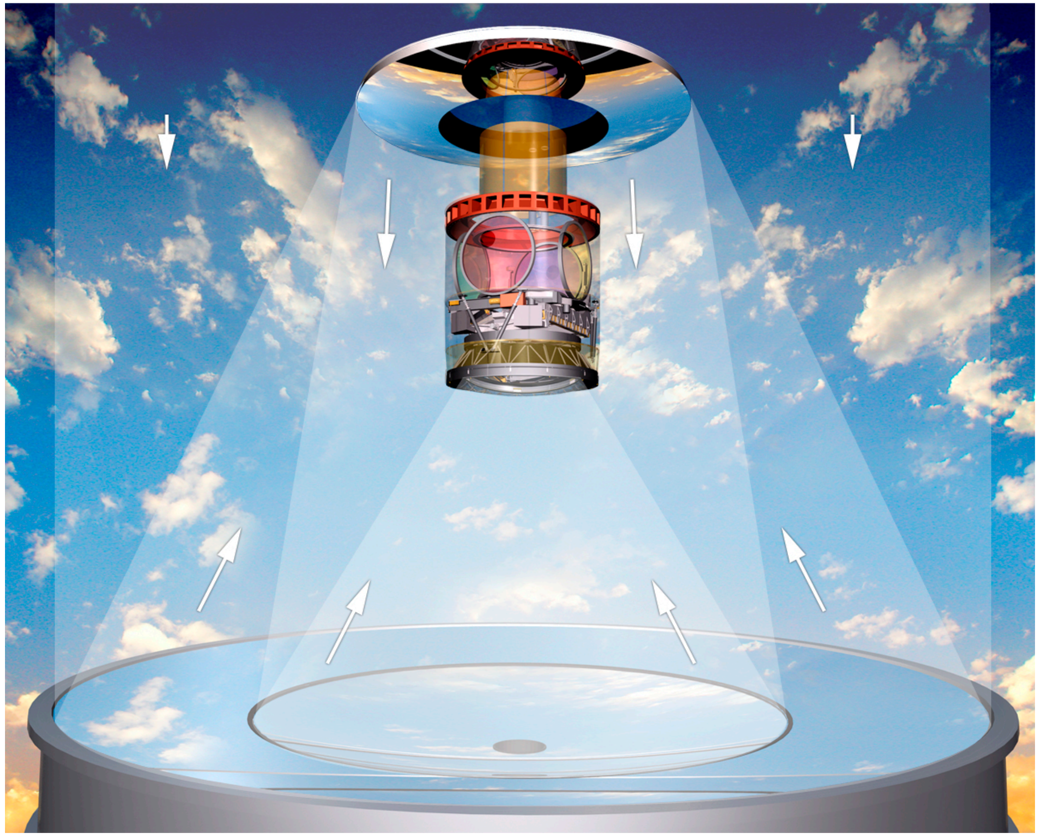
- effective aperture of 6.7 m
- FoV 9.6 deg^2
- Etendue : 319 m^2deg^2



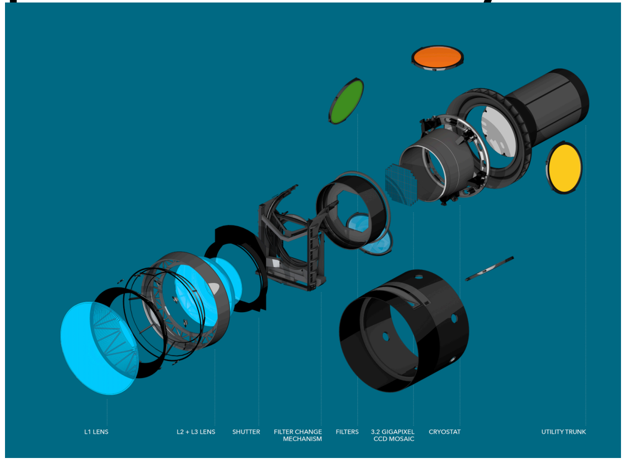
The Large Synoptic Survey Telescope

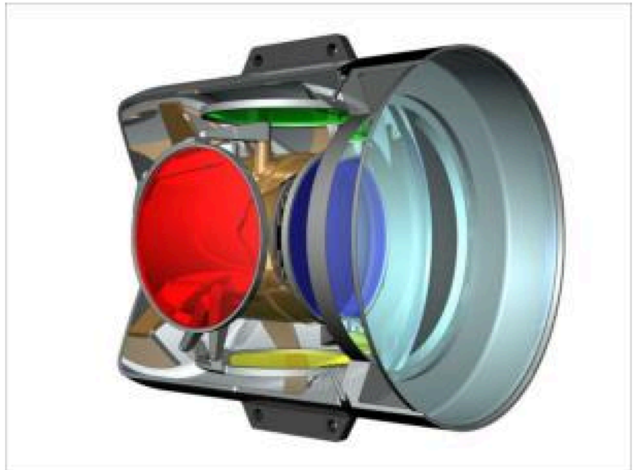
Innovative Optical Design





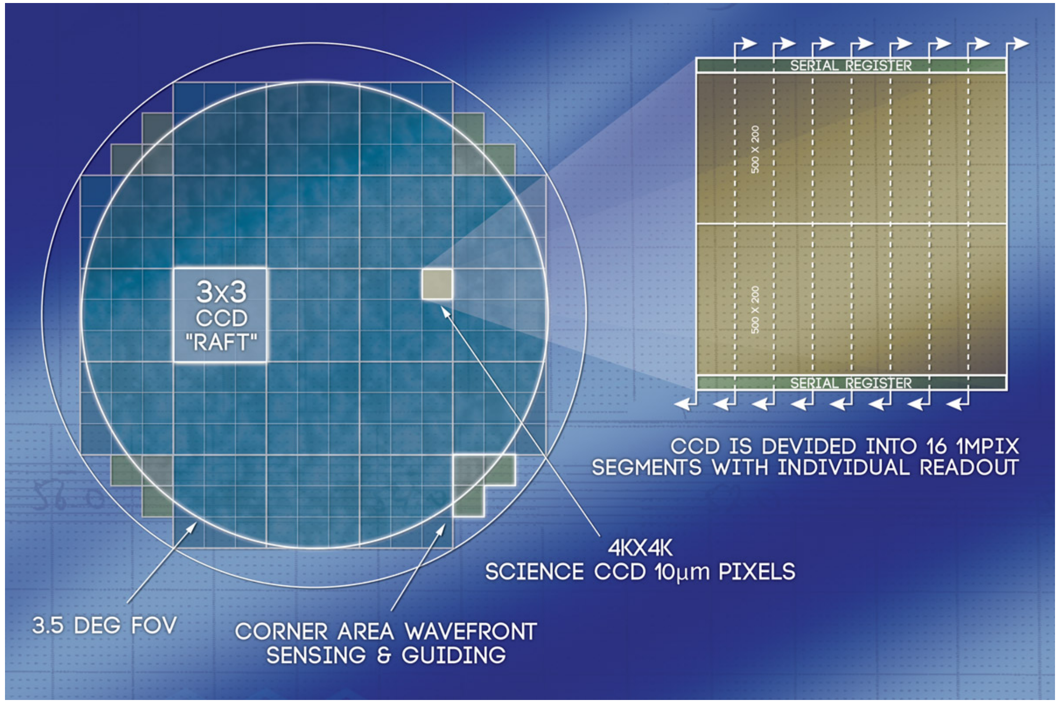
The Large Synoptic Survey Telescope

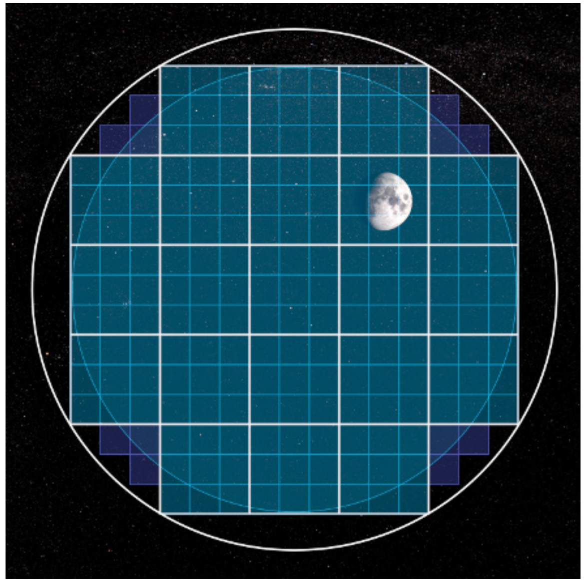




3.2 billion-pixel camera
189 16-megapixel silicon detectors arranged on 21 "rafts"

The camera includes a filter-changing mechanism
It is positioned in the middle of the telescope





9.6 deg^2
0.2x0.2 $arcsec^2$ pix

40 times the size of the full moon

The Large Synoptic Survey Telescope

Wide-Deep-Fast   80-90% total time

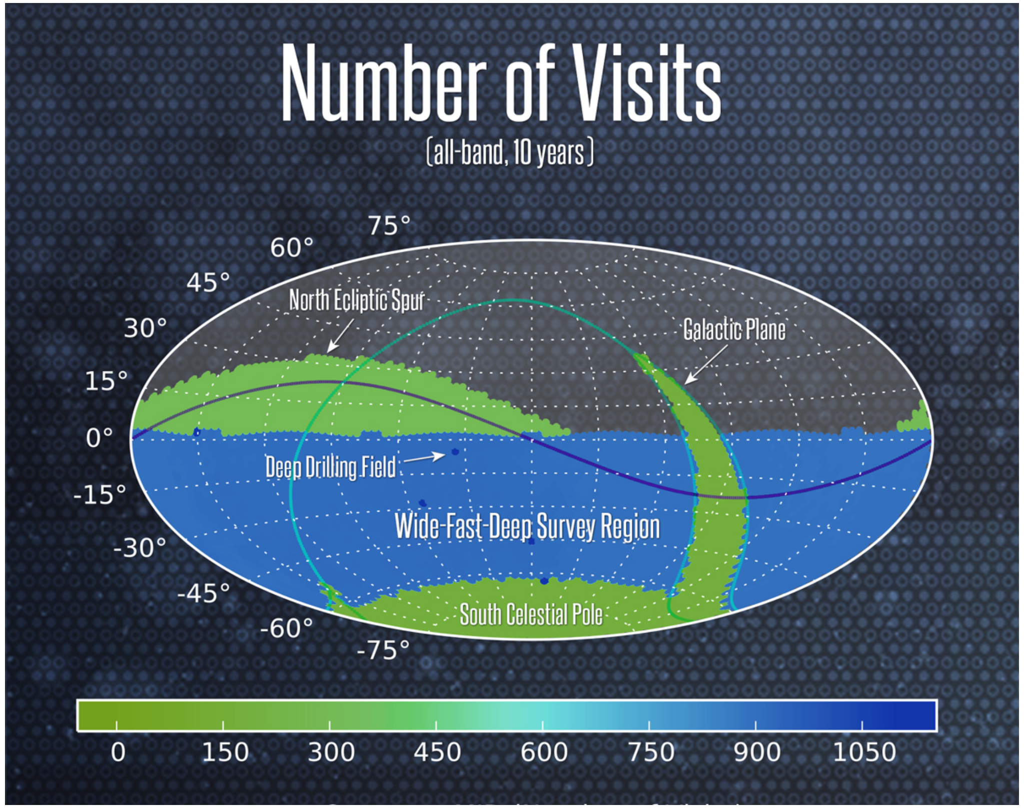
cover **large** swaths of sky to **faint magnitudes** repeatedly at **short intervals**

Baseline 2018a

18,000 deg^2 of sky
30-second visits (pairs of 15-second exposures)
repeated every three to four nights
about 825 visits in 10 years spread over the filters ugrizy

2000 deg^2 rapid revisits (40 seconds to 30 minutes)
for very fast transient discovery

Deep Drilling Fields (4.5%)



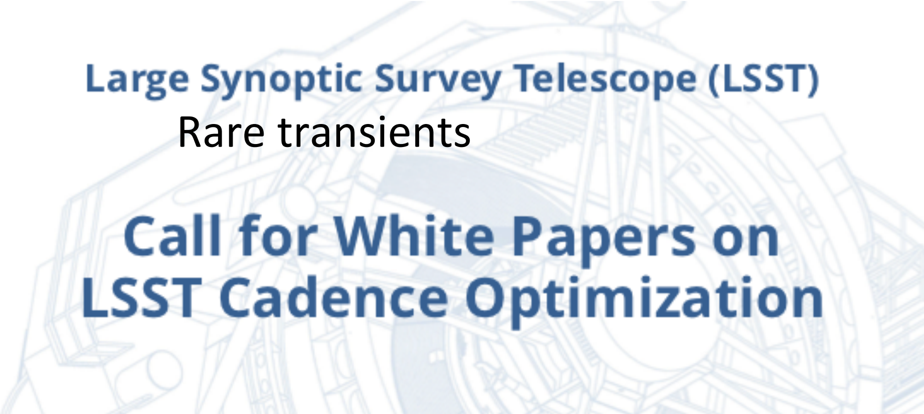
The Large Synoptic Survey Telescope

The LSST community is invited to play a key role in the definition of LSST's Observing Strategy by submitting white papers to help refine the 'main survey' and fully define the use of 10-20% of time expected to be devoted to various 'mini surveys' (including the 'Deep Drilling mini surveys' and 'Target of Opportunity' programs).

Young Stars and their Variability with LSST

TDEs with LSST

Target of Opportunity Observations of Gravitational Wave Events with LSST



Rare transients

A Smart and Colorful Cadence for the Wide-Fast Deep Survey

Continuous Cadence Acquisition of the LSST Deep Drilling Fields

Unveiling the Rich and Diverse Universe of Subsecond Astrophysics through LSST Star Trails

Presto-Color: An LSST Cadence for Explosive Physics & Fast Transients

Higher cadence observations and sufficient multi-band coverage
SNe , AGNs, TDEs

Faster imaging for FRBs, GRBs, X ray binaries

The Large Synoptic Survey Telescope

Data products

10 million time-domain events per night
a catalogue of 37 billion source (20 billion galaxies 7 billion stars)

Prompt data products are generated continuously every observing night, including both alerts to objects that have changed brightness or position, which are released with 60-second latency, source catalogs derived from difference images and image data products that are released with 24-hour latency

Data Release data products: will be made available annually as the result of coherent processing of the entire science data set to date. These will include calibrated images, measurements of positions, fluxes, and shapes, variability information, and an appropriate compact description of light curves. The Data Release data products will include a uniform reprocessing of the difference-imaging-based Prompt data products.

User Generated data products: will originate from the community, including project teams. These will be created and stored using suitable Application Programming Interfaces that will be provided by the LSST Data Management System

The Large Synoptic Survey Telescope

LSST Project
LSST Corporation
LSST Science Collaborations :

Galaxies
Michael Cooper (UC Irvine)
Brant Robertson (University of California, Santa Cruz)

Stars, Milky Way, and Local Volume
John Bochanski (Rider University)
John Gizis (University of Delaware)
Nitya Jacob Kallivayalil(University of Virginia)

Solar System
Megan Schwamb (Gemini Observatory, Northern Operations Center)
David Trilling (Northern Arizona University)

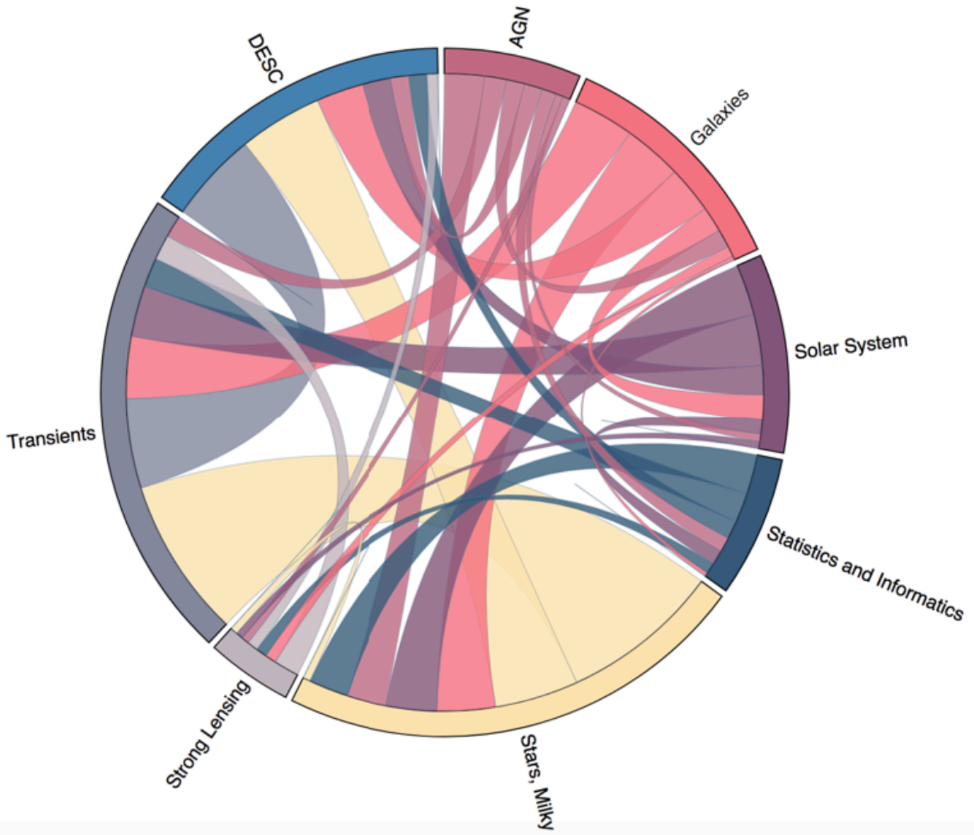
Dark Energy
Eric Gawiser (Rutgers The State University of New Jersey)
Phil Marshall (KIPAC)

Active Galactic Nuclei
Niel Brandt (Pennsylvania State University)

Transients and variable stars
Federica Bianco (New York University)
Rachel Street (LCO)

Strong Lensing
Charles Keeton (Rutgers-The State University of New Jersey)
Aprajita Verma (Oxford University)

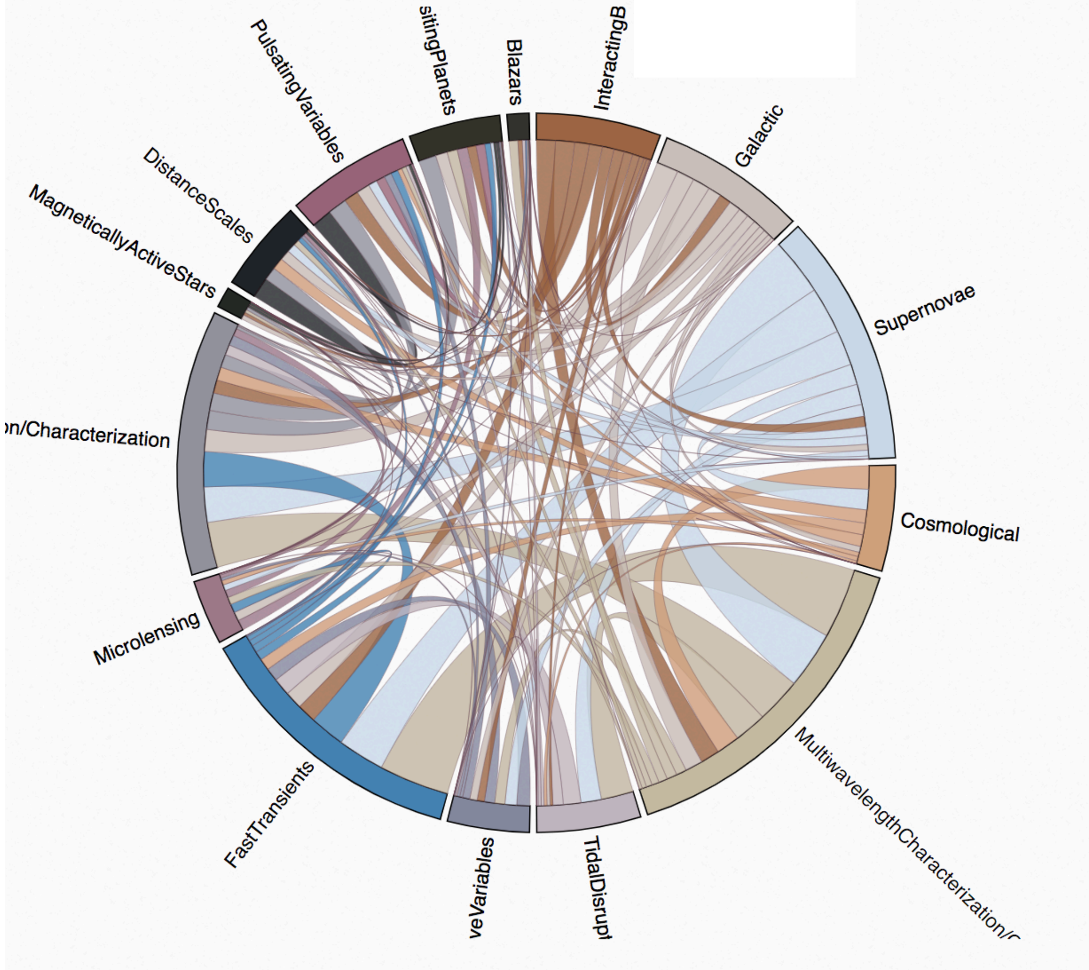
Informatics and Statistics
Tom Loredo (Cornell University)
Chad Schafer (Carnegie Mellon University)



LSST data rights can join one or more LSST Science Collaborations

Transients and Variable Stars Science Collaboration

- Fast Transients
- Interacting Binaries
- Magnetically Active Stars
- Microlensing Subgroup
- Multiwavelength Characterization/Counterparts
- Non-degenerate Eruptive Variables
- Pulsating Variables
- Supernovae
- Tidal Disruption Events
- Transiting Planets



LSST ITALIA

Galaxies 3 PIs
A. Moretti *The high-z AGN and galaxies into the Reionization epoch with LSST*
A. Bivano *Clusters of galaxies as probes of cosmology, dark matter, and the evolution of cosmic structures*
N. Napolitano *Stellar and Dark Matter in galaxies*

Stars 7 PIs
L. Girardi *Galactic and Local Group. archaeology with LSST*
F. Damiani *Star formation and episodic accretion*
P. Ventura *Multiperiodic phenomena in variable stars*
L. Magrini *Photometric metallicities with LSST data*
G. Clementini *The Gaia-LSST synergy: from pulsating stars and star formation history to WD Planets*
I. Musella *RR Lyrae, Cepheids and LBVs to constrain theory using LSST*
G. Bono *Stellar Variability: The 3D Structure of the Galactic Spheroid*

Time Domain Astronomy 5 PIs
E. Brocato ***The astrophysical sources of gravitational waves***
S. Campana ***Gamma Ray Bursts and Tidal Disruption Events***
A. Pastorello ***Studying peculiar supernovae, supernova impostors and stellar mergers with LSS****T*
M. T. Botticella ***Supernovae Demography and Rates. based on Machine Learning Classification***
C. Raiteri ***Active Galactic Nuclei, Fast Radio Bursts and Blazars with LSST***

TVS
and SKA-CTA PRIN
PI Giroletti

LSST and SKA

Several science question in common between the two projects

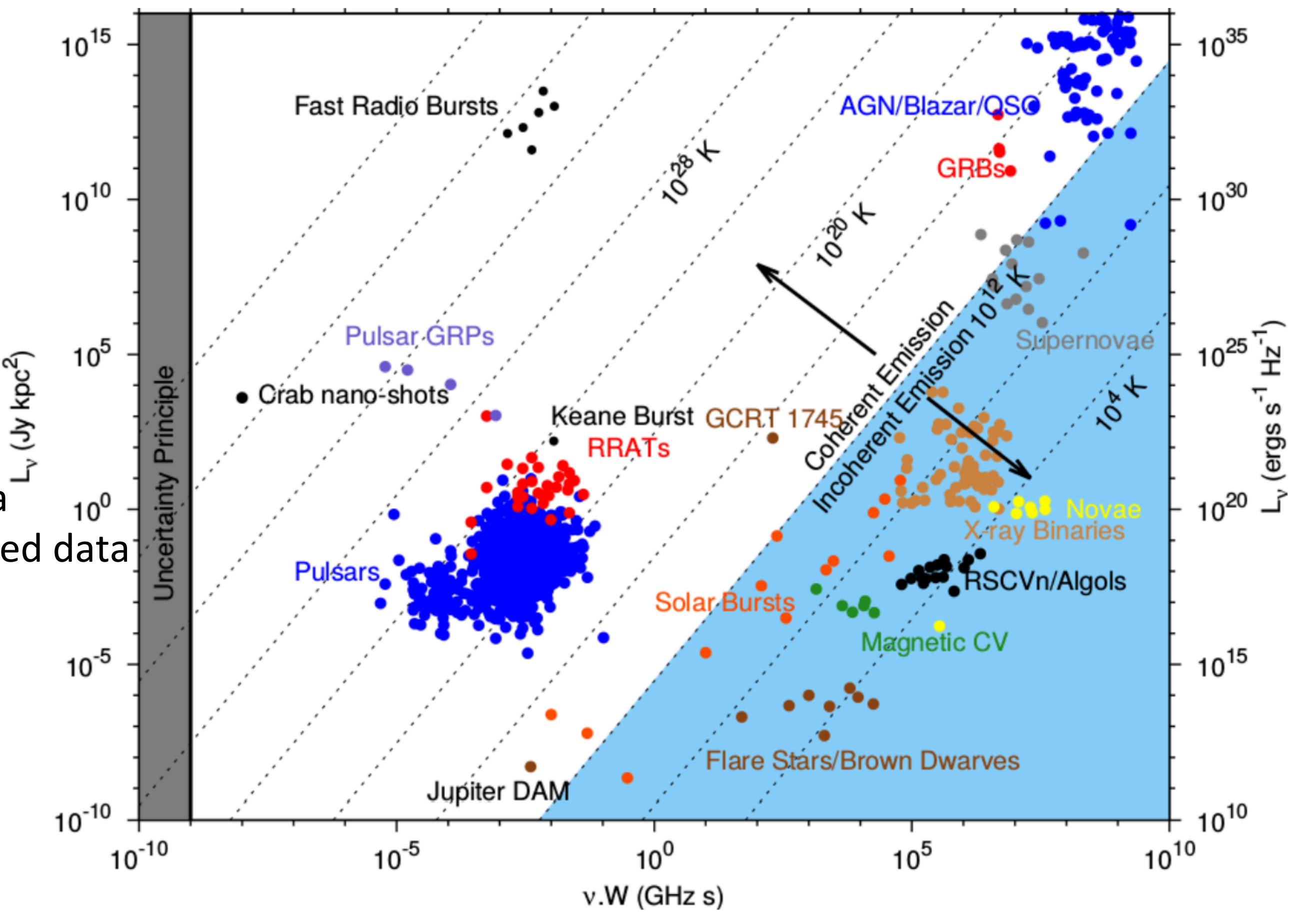
- cosmology
- galaxy evolution
- time-domain astrophysics

- monitoring a large sky area
- on the sky over much of the same time-period
- Match between the temporal cadence in the optical bands and time resolution in the radio bands

Radio Transients

Coherent emission

Relatively fast variability
High brightness temperature
Often highly polarised
Sometimes very steep spectra
found primarily in beam formed data



Incoherent synchrotron emission

Relatively slow variability
Brightness temperature limited
Associated with all explosive events
found mainly in image stacks

Pietka et al 2015

radio follow-up of optical transients
search for optical counterpart of radio sources

understanding the physics of known transients

radio follow-up of discoveries in the optical bands

The radio emission from CC SNe is essentially

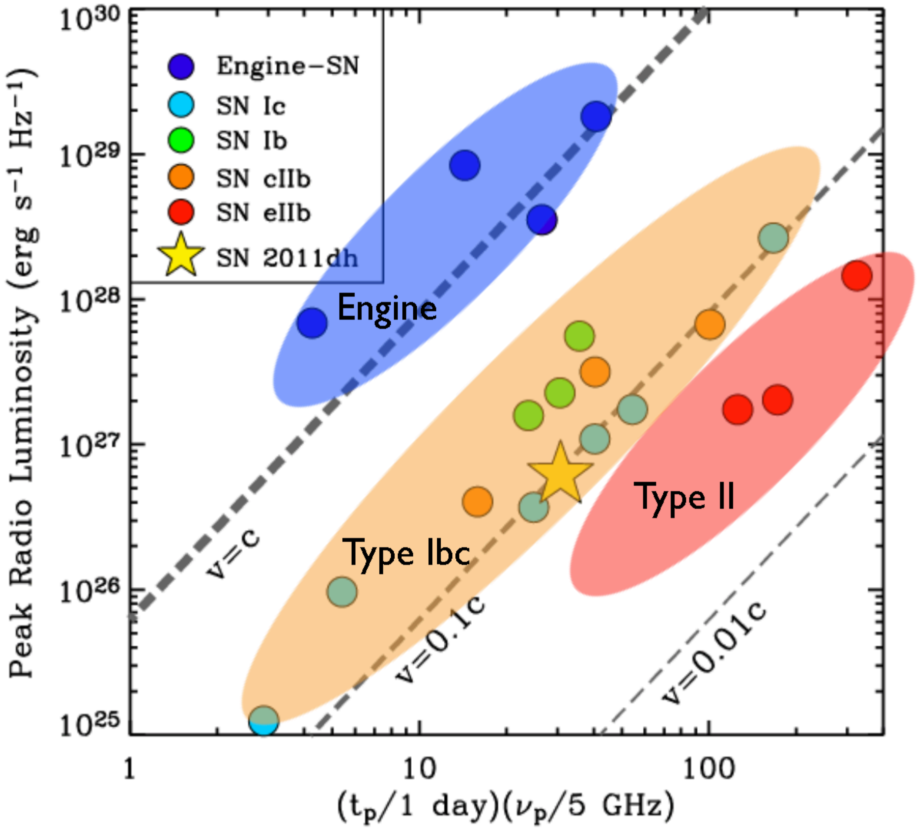
non thermal synchrotron emission from relativistic electrons a

CC SNe span more than five orders of magnitude in L_{peak}

L_{peak} is proportional to t_{peak}

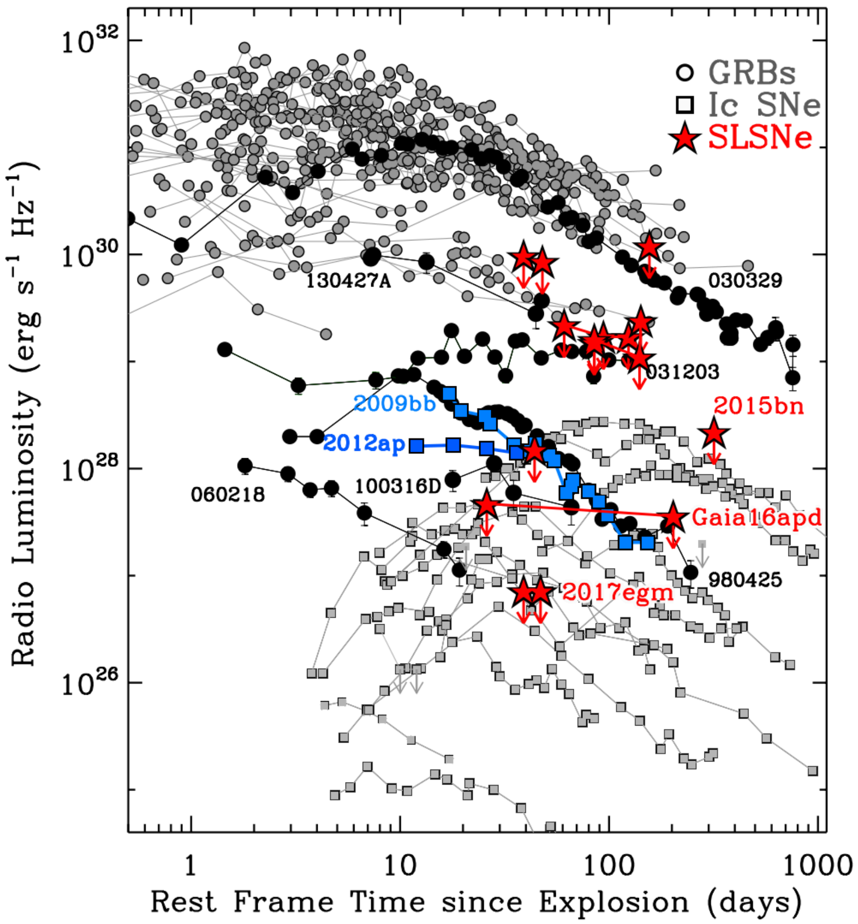
Each SN subtype is located in specific regions

Type Ib/c and IIb SNe seem to have higher blastwave speeds



understanding the physics of known transients

radio follow-up of discoveries in the optical bands



Bridging the gap between Type Ibc SL SNe and long GRB

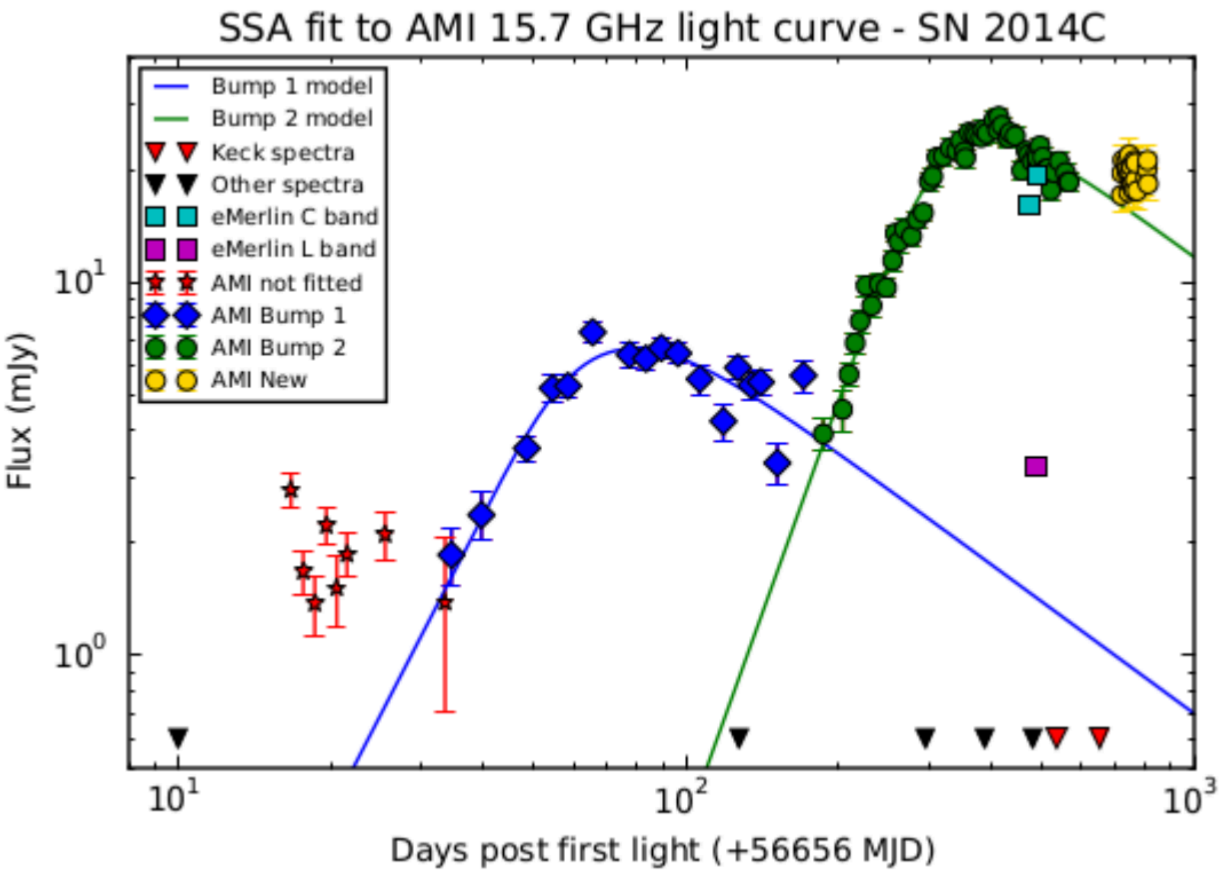
Radio observations are a powerful tool to constrain the central engine properties and sub-parsec environments of the H-stripped stellar explosions.

a combination of both early time and late time coverage is needed

Margalit et al 2018

understanding the physics of known transients

radio follow-up of discoveries in the optical bands



SN 2014C

understanding the physics of known transients

Radio observations can discriminate between the progenitor models of SNe Ia

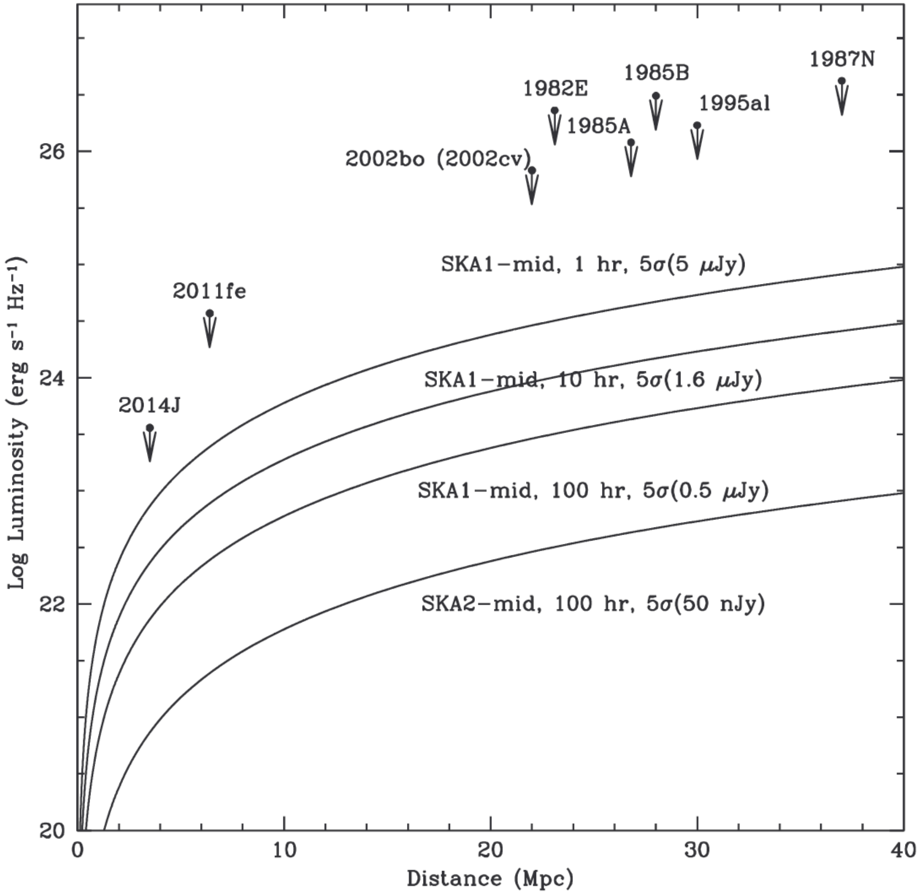
No SN Ia has been detected so far in the radio implying a very low density for CSM

$\dot{M} < 10^{-10}\ M_\odot\ yr^{-1}$ SD system
$\dot{M} < 10^{-11}\ M_\odot\ yr^{-1}$ DD system

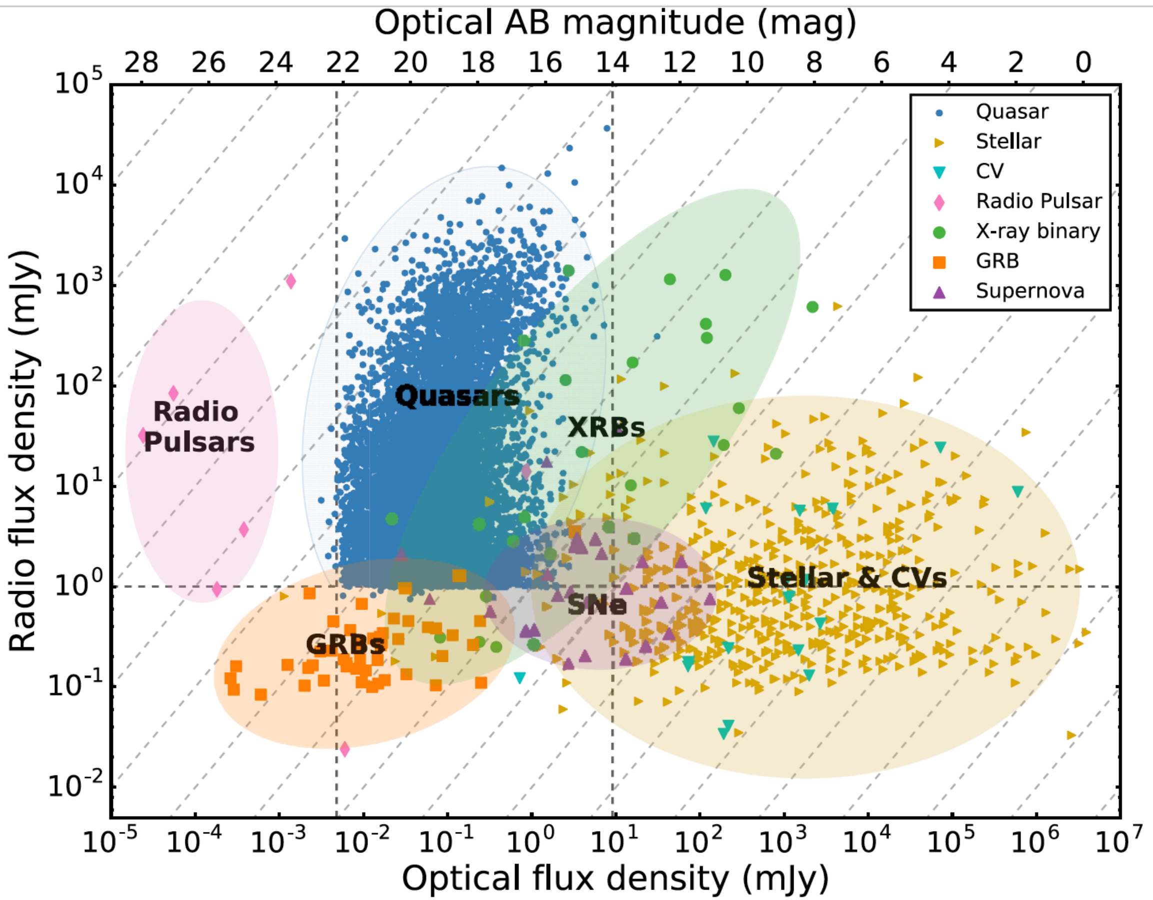
SN 2014J $M < 7.0 \times 10^{-10}\ M_\odot\ yr^{-1}$
SN2018pv $M < 1.7 \times 10^{-8}\ M_\odot\ yr^{-1}$
SN2016coj $M < 2.3 \times 10^{-8}\ M_\odot\ yr^{-1}$
SN2018gv $M < 1.9 \times 10^{-8}\ M_\odot\ yr^{-1}$

for an assumed wind speed of 100 km/s.

Perez Torres et al 2018



Radio transient classification



the relation between the radio and optical flux densities can be used to classify radio transients

Stewart et al 2018

Systematic radio search

Unveiling the optically obscured CC SNe

Comparison between radio and optical CC SN rate in the local Universe

Comparison between SFR and CC SN rates in extreme environments

direct detection of KN, GRBs ....

- ➢ sky coverage of surveys with adequate sensitivity and time resolution
- ➢ strategy that revisits that same sky on multiple occasions
- ➢ real-time response and localisation

Good angular resolution ($\lesssim$ 1 arc sec)
Large field of views ($\gtrsim$10 deg^2)
Frequencies around or above 2 GHz
Sensitivity close to the μJy/b level
3-5 visits/yr
$\Delta t_{cadence}$ ~ 90 d

three visits over a year are enough
to reliably detect any new KN in the radio

SKA survey	Area (deg^2)	rms (μJy beam^{-1})	Sampled Volume Gpc^3 yr^{-1}	N_{det} (Gpc^{-3} yr^{-1})
SKA1-Mid-A	31 000	5.0	17×10^{-4}	$0.61^{+1.39}_{-0.36}$
SKA1-Mid-B	500	0.9	3.6×10^{-4}	$0.13^{+0.29}_{-0.08}$
SKA1-Mid-C	20	0.24	1.1×10^{-4}	$0.04^{+0.08}_{-0.02}$

Della Valle et al 2018

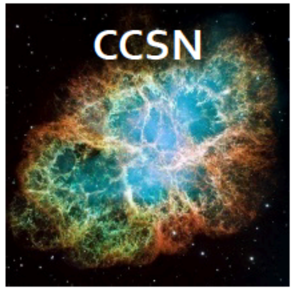
Optical Rates

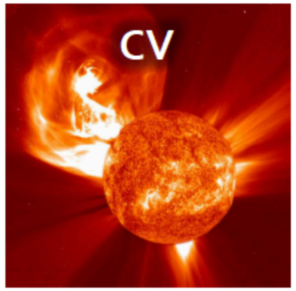
SNe

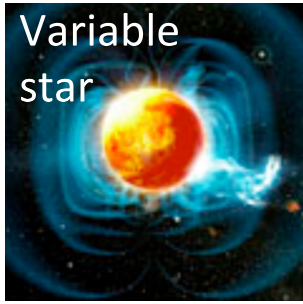
Class	M_v [mag]	τ^b [days]	Universal Rate (UR)	PTF Rate [yr^{-1}]	LSST Rate [yr^{-1}]
Luminous red novae	$-9..-13$	20..60	$(1..10) \times 10^{-13}\,yr^{-1}\,L_{\odot K}^{-1}$	0.5..8	80..3400
SNe .Ia	$-15..-17$	2..5	$(0.6..2) \times 10^{-6}\,Mpc^{-3}\,yr^{-1}$	4..25	1400..8000
SNe Ia	$-17..-19.5$	30..70	$^{c}\ 3 \times 10^{-5}\,Mpc^{-3}\,yr^{-1}$	700	200000^{d}
SNe II	$-15..-20$	20..300	$(3..8) \times 10^{-5}\,Mpc^{-3}\,yr^{-1}$	300	100000^{d}

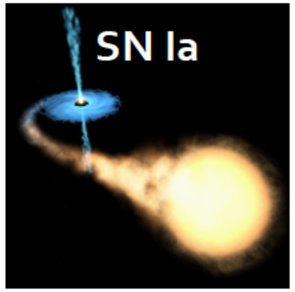
Transients

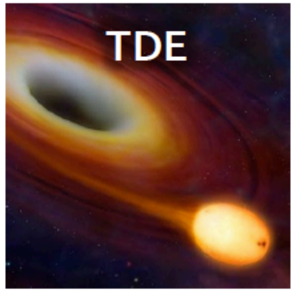
Variables











Transient	Before LSST	After LSST
Superluminous SNe	~20	~10^5
Tidal Disruption Events	~20	~10^4
Orphan LGRBs/Dirty Fireball	1	≲10^3
Orphan SGRBs/Kilonovae	1	≲10^2

All these transients will be discovered in an unbiased way

Radio Rates

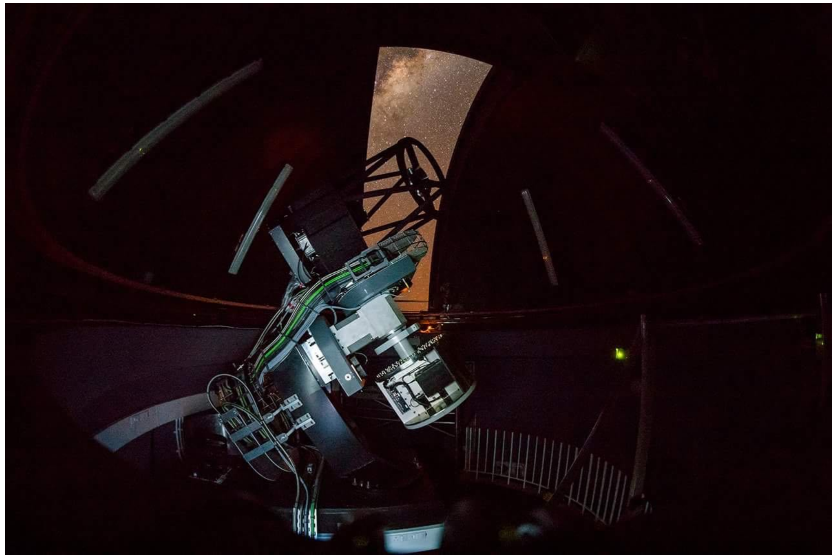
	LGRB On-Axis	LGRB θ=0.4	LGRB θ=0.8	LGRB θ=1.57	LLGRB (SN 1998bw)	SGRB On-Axis	SGRB θ=0.4	SGRB θ=0.8	SGRB θ=1.57	NSM Prompt BH	NSM Magnetar/AIC	TDE On-Axis	TDE Off-Axis	SN Ib/c	
SKA-Expanded	2060	1300	1900	860	64	420	170	20	1	12	5200	8	240	2	1.3 GHz
SKA	140	150	270	160	7	66	30	4	0.2	2	1090	3	72	0.8	1.3 GHz
SKA-Low	5	12	45	320	18	22	28	28	7	48	6200	2	280	2	150 MHz

Metzger et al 2015

Class	Rate (deg^{-2})	References
AGN	2.3	Thyagarajan et al. (2011)
TDE	0.52	Frail et al. (2012)
GRB afterglow	0.052	Frail et al. (2012)
SN	0.21	Frail et al. (2012)
SGR	10^{-8}	Olausen & Kaspi (2014), Ofek (2007)
XRB	2.4×10^{-4}	Gallo, Fender, & Pooley (2003)
Dwarf Nova	0.0013	Pretorius & Knigge (2012), Servillat et al. (2011)
Classical nova	0.0023	Roy et al. (2012)
RSCVn	0.011	Williams et al. (2013), Favata, Micela, & Sciortino (1995), Ottmann & Schmitt (1992)
Algol	0.062	Duerbeck (1984)
Flare star	0.0064	Reid, Cruz, & Allen (2007), Osten (2008)
Magnetic CVs:		
Polars	0.038	Ramsay et al. (2004), Pretorius, Knigge, & Schwope (2013)
IPs	0.0008	Pretorius & Mukai (2014), Pretorius, Knigge, & Schwope (2013)
Polars + IPs	0.039	–

Precursor project

Together MeerLICHT (optical telescope) and MeerKAT (precursor to SKA) will simultaneously be scanning the Southern Sky



The project involves data fusion of multiple catalogues,
source association
radio - optical flux correlation of objects which will provide an input to automated source classification.