Observations of transients in EM spectrum

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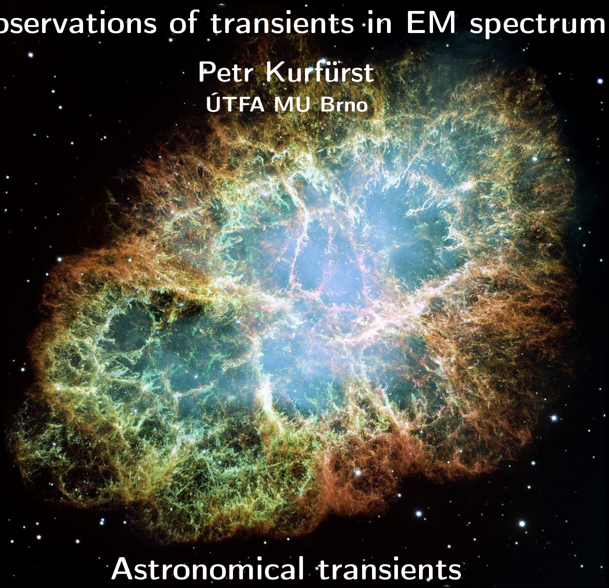


Astronomical transients

Selected chapters from astrophysics, fall semester, 2022

We define transients (within this course) as:

- **Violent events** (mostly deep-sky), such as **novae**, **supernovae** (SNe), **kilonovae** (KNe), **gamma-ray bursts** (GRBs), **tidal disruption events** (TDEs),...

- Sources that do not have a quiescent counterpart, that is, **not "normal" variable stars**, more or less stationary processes connected to **not active galactic nuclei** (AGN), etc.

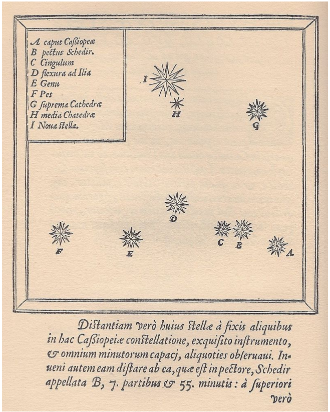
- We also **do not include** the unusual or variable events typical for the local or nearby universe, such as **asteroids**, **high proper motion** stars, **planetary transits**, **comets**, etc.

Current talk outline

- Historical observations
- Modern era
- Systematic surveys:
    - Optical
    - Radio + IR
    - UV, X-ray, γ-ray
- Expected future strategies
- Conclusions

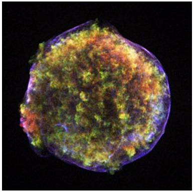
Historical observations

- Tycho 1572 "Nova stella" (Cas B)

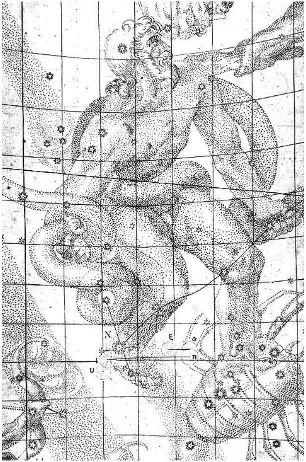


A caput Caſiopeæ
B pectus Schedir.
C Cingulum
D flexura ad Ilia
E Genu
F Pes
G ſuprema Cathedræ
H media Chatedræ
I Noua ſtella.

Diſtantiam verò huius ſtellæ à fixis aliquibus in hac Caſsiopeiæ conſtellatione, exquiſito inſtrumento, & omnium minutorum capacj, aliquoties obſeruaui. Inueni autem eam diſtare ab ea, quæ eſt in pectore, Schedir appellata B, 7. partibus & 55. minutis: à ſuperiori verò



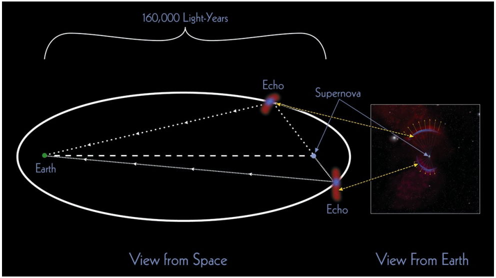
- Kepler 1604 "Nova stella"



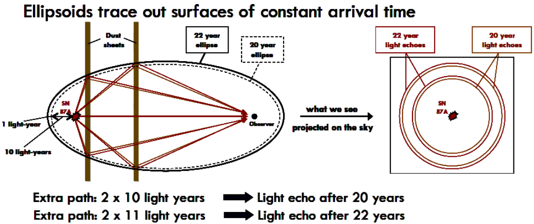
- no optical instrumentation in those times (naked eye observations)
- accurate measurement of relative position by mechanical means
- tracking the "color evolution" (according to known colors of planets)

Connection to ancient transients: (V838 Mon, 1987A, Cas B, Cas A, etc.)

- **light echoes** - geometrical schemes

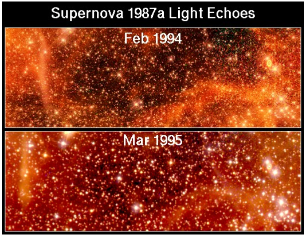


Credit: P. Marenfeld and NOAO/AURA/NSF



Credit: A. Rest - SuperMACHO & EHS collaboration

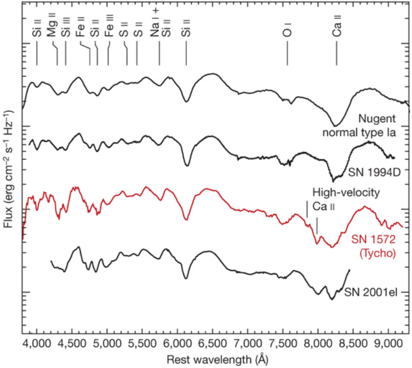
SN 1987A light echoes



Connection to ancient transients: (V838 Mon, 1987A, Cas B, Cas A, etc.)

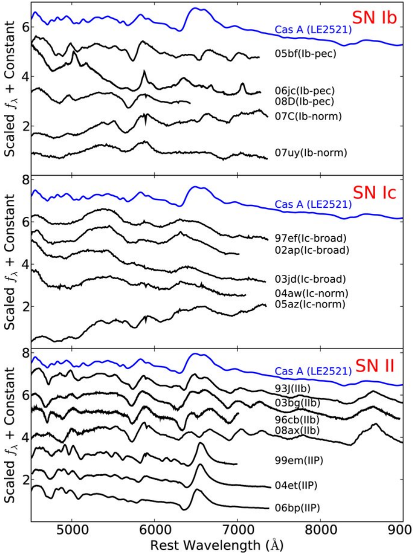
- **light echoes** - spectra

Cas B



Credit: Krause et al. 2008

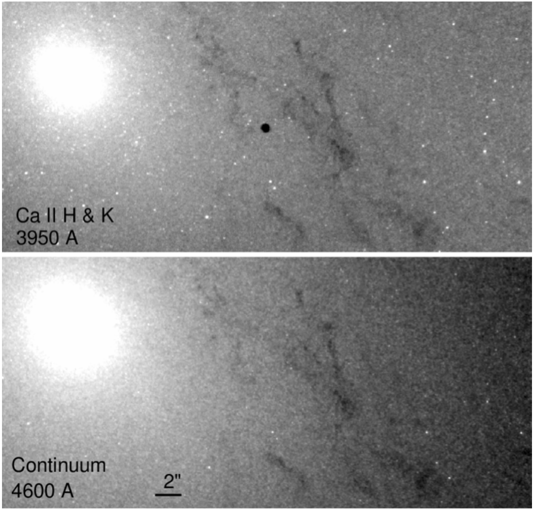
Cas A



Credit: Rest et al. 2011

Beginning of the modern era

- SN 1885A (S Andromeda)

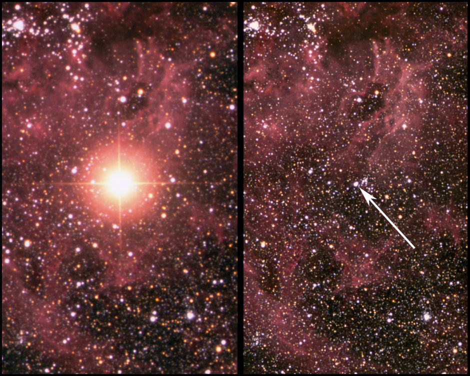


- remnant of SN 1885A (black circle) in CA II absorption (HST)
- remnant is not visible without absorption (in continuum)
- probably type Ia SN (or other type of H-poor SN)

Evolution of techniques

Fritz Zwicky's plate survey - **120 SNe within 50 years**

SN 1987A



- **visual observations, photographic plates**
- **amateur astronomers** - important contributors to science:
- **R. Evans** - 42 SNe by visual observations, **F. Garcia** - SN 1993 in M81, SN 2011dh in M51 (**"twitter supernova"**), and others

Systematic scientific surveys

For finding transients:

- We need to **repeatedly image** the **same area** of the sky
- There is a natural trade-off between **sky coverage** (field area) and observational **cadence**

Small vs. large detectors

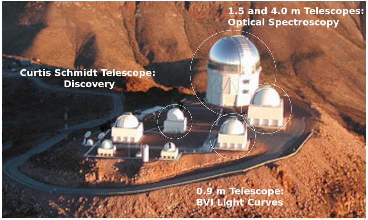
- People prefer using **small detectors** to go deep - cover a **large survey volume at large distance**
- **Wide-field detectors** give the opportunity to cover a **large survey volume at smaller distance**

Targeting surveys

- Surveys targeting **selected galaxies** drawn from catalogs can cover a **larger population** of stars using **smaller detectors** but are **biased against dwarf hosts** (in favor of large/luminous ones)

Systematic scientific surveys (optical)

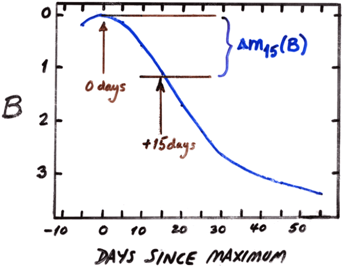
Main driver: cosmology



The Calán/Tololo SN Survey: photographic discovery, CCD follow-up, KAIT (CCD)

M. Phillips, N. Suntzeff, J. Maza, M. Hamuy

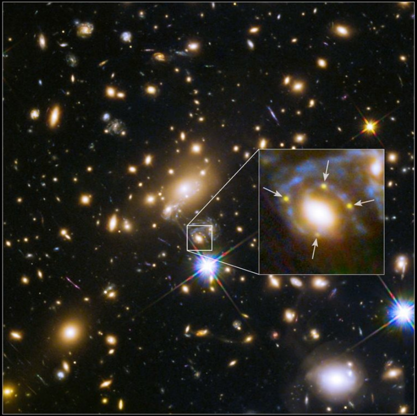
The **Phillips relation** for type Ia SNe (1993, following earlier works by Rust and Pskovskii from the 70's)



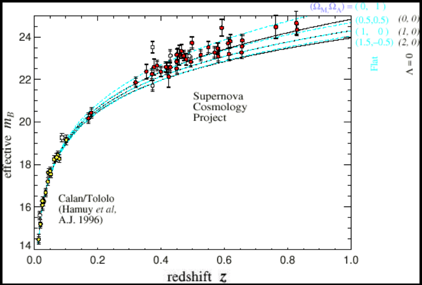
$M_{\max} = -21.726 + 2.698\Delta m_{15}$ (in B band)

Systematic scientific surveys (optical)

- **Clusters vs. Fields**: clusters have **lower rate** per galaxy, **limited gain**
- But: **lensing...**



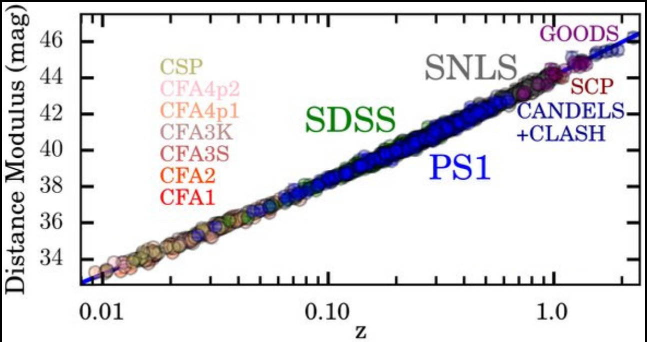
Supernova Refsdal ▪ Galaxy Cluster MACS J1149.5+2223
Hubble Space Telescope ▪ ACS/WFC ▪ WFC3/IR



Cosmology samples:
High-Z team (HZT: Schmidt et al. 1998),
SCP (Perlmutter et al. 1999)

Systematic scientific surveys (optical)

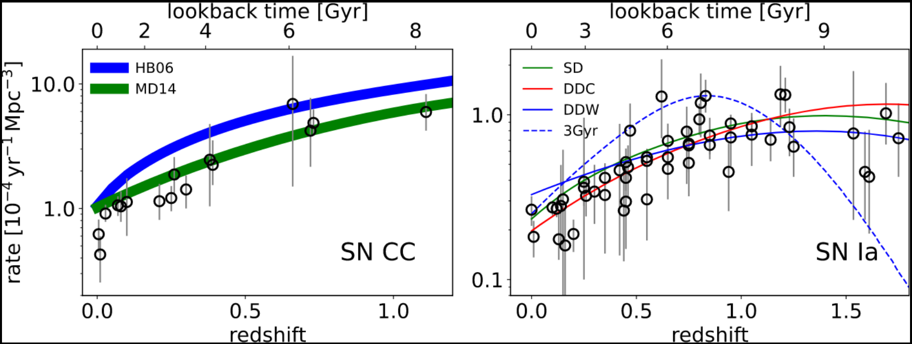
- **Second generation cosmology**: **SNLS, ESSENCE, SDSS, PS1, DES**
- **HST** (Candles & Clash; Gal-Yam, Maoz, Ofek, Sharon; Perlmutter et al.; Riess et al.): almost 1 SN/observation/random field - on average
- **SUBARU** (e.g., Poznański et al.; Graur et al.): 10s per suprime-cam field; 100s per HSC



"Pantheon" sample (Scolnic et al. 2017)

Systematic scientific surveys (optical)

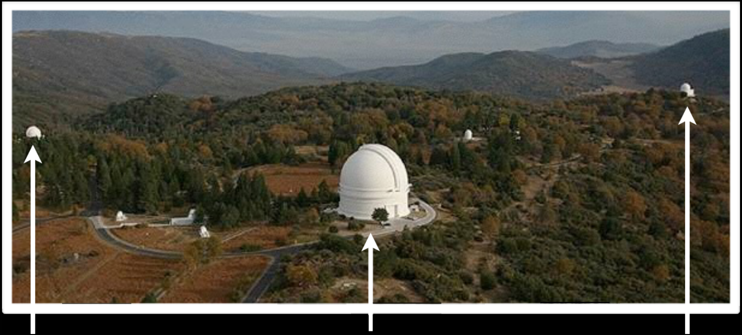
- **SN rates: local rate is** $\sim 10^{-4}$ **events/yr/Mpc^3** (Li et al. 2011, Cappellaro 2015, 2022)
- ratios: **3 : 2.5 : 4.5 - types Ia : Ibc : II**
- **rates increase by order of magnitude** to the peak epoch of SFR



CC SNe, Ia SNe rates (Cappellaro et al. 2022)

Systematic scientific surveys (optical)

- **Previous wide-field local surveys:**
- **PTF** (2008-2012), **iPTF** (2012-2017/18)
- Wide-Field Discovery + Automated Multi-Color Follow-Up



P48 = Discovery

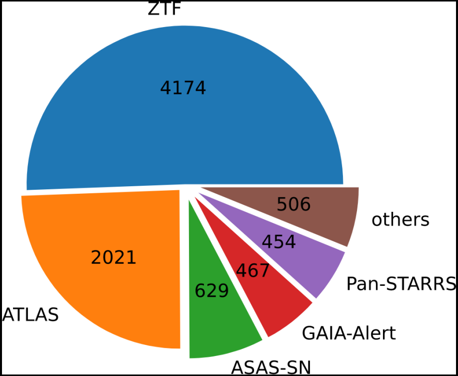
P200+Keck+Lick+Gemini = Spectroscopy

P60+PAIRITEL = Filtered Photometry

- SN search (2-3 day cadence); light curves of approximately 500 million objects had been accumulated

Systematic scientific surveys (optical)

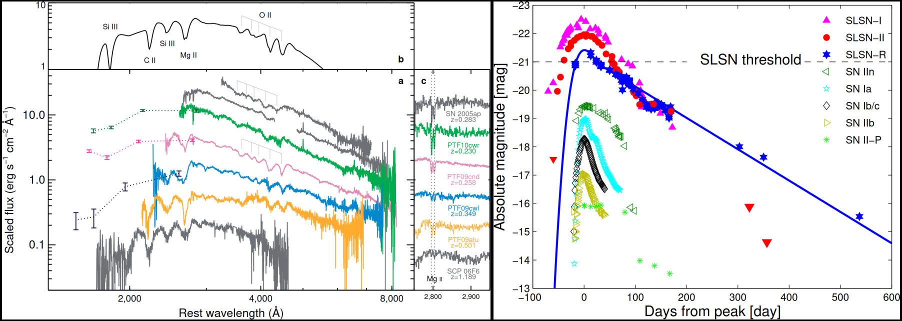
- **Current wide-field local surveys:** extensive, accessible, unbiased
- Almost 95% of all the last 5 years' SNe first announced by five searches: ZTF (follower of PTF, iPTF), ATLAS, ASAS-SN, GAIA-Alert, Pan-STARSS
- ZTF is a 47 deg^2 optical camera on the Samuel Oschin Palomar 48-inch telescope (gri-bands, accessible N Sky, at least every 2 nights, to 20.4 mag)



Credit: Cappellaro et al. 2022

Systematic scientific surveys (optical)

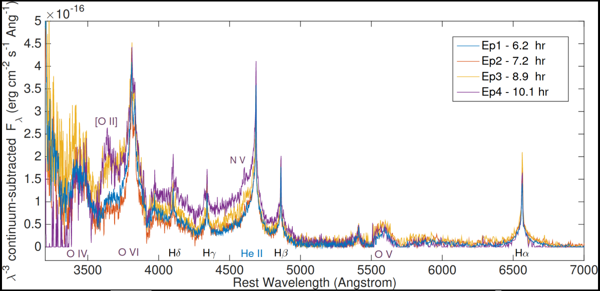
- **Current wide-field local surveys** - some results:
- Almost 95% of all the last 5 years' SNe first announced by five searches: ZTF (follower of PTF, iPTF), ATLAS, ASAS-SN, GAIA-Alert, Pan-STARSS



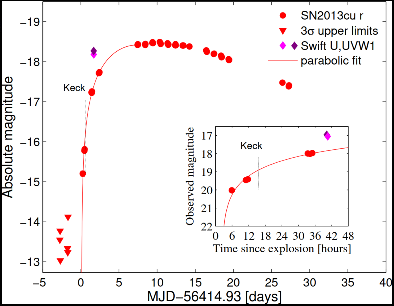
Credit: Quimby et al. 2011, Gal-Yam et al. 2012

Systematic scientific surveys (optical)

- **Current wide-field local surveys** - some results: **Very young SNe**



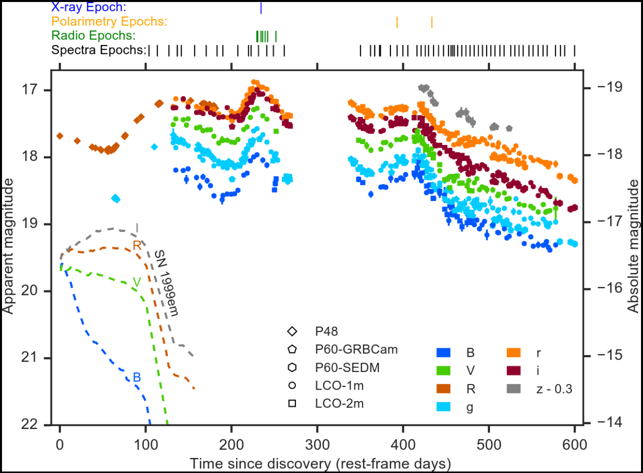
Yaron et al. 2017



Gal-Yam et al. 2014

Systematic scientific surveys (optical)

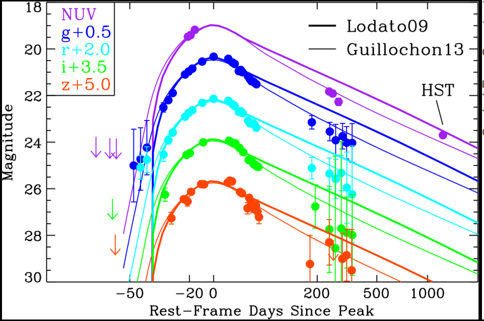
- **Current wide-field local surveys** - some results:
- Rare events: SLSN iPTF14hls ("Holyshit" supernova)

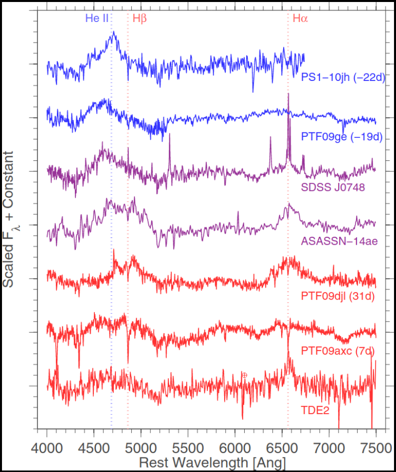


Credit: Arcavi et al. 2017

Systematic scientific surveys (optical)

- **Current wide-field local surveys** - some results:
- Nuclear transients (TDEs) - PS1, PTF, ASASSN





Credit: Gezari et al. 2015, Arcavi et al. 2014

Systematic scientific surveys (range?)

- **1st question:** which wavelength range is this?
- **2nd question:** where is an SN (in the right picture)?

NGC 2207 + SN 2013ai, credit: P. Brown 2013, satellite (?)

Systematic scientific surveys (radio, IR, UV, X, γ)

- **1st question:** which wavelength range is this?
- **2nd question:** where is an SN (in the right picture)?

NGC 2207 + SN 2013ai, credit: P. Brown 2013, satellite Swift (UV)

Systematic scientific surveys (radio, IR, UV, X, γ)

Radio surveys

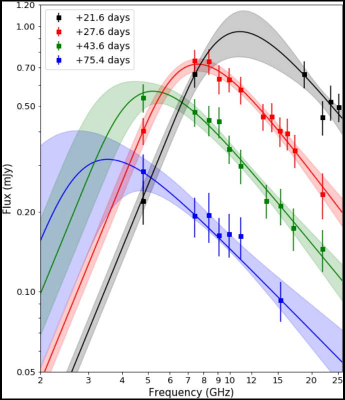
The instruments:

- currently mostly VLA
- LOFAR
- future: SKA (will ALMA?)

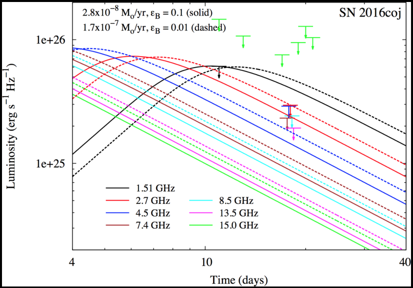
Systematic scientific surveys (radio, IR, UV, X, γ)

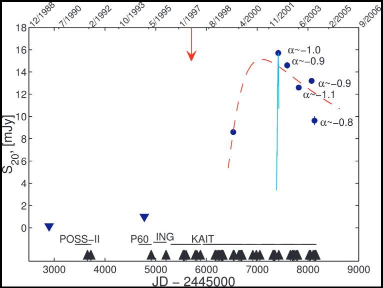
Radio surveys

Radio SNe



credit: Ruiz-Carmona et al. 2022



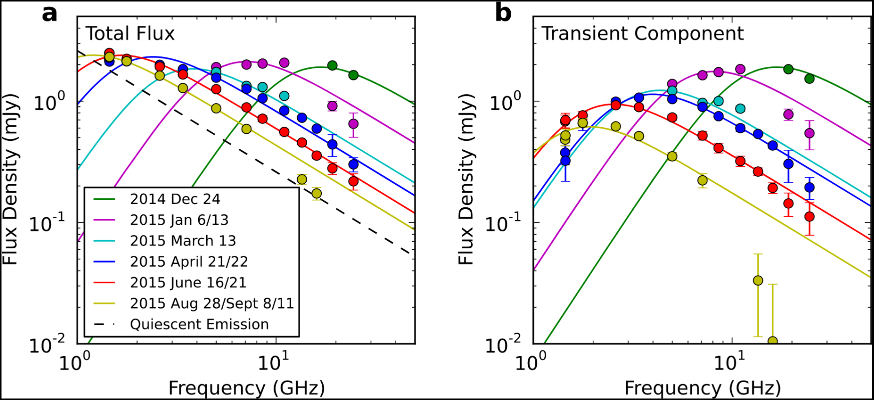


credit: Kundu 2017, Gal-Yam 2006

Systematic scientific surveys (radio, IR, UV, X, γ)

Radio surveys

Radio TDEs

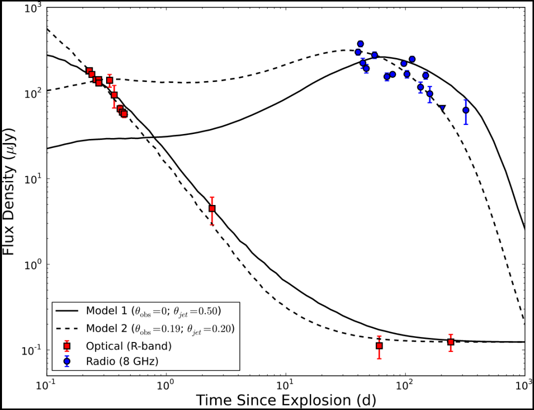


credit: Alexander et al. 2017

Systematic scientific surveys (radio, IR, UV, X, γ)

Radio surveys

- **Relativistic events: GRB 11agg afterglow**
- associated with a year-long, scintillating radio counterpart

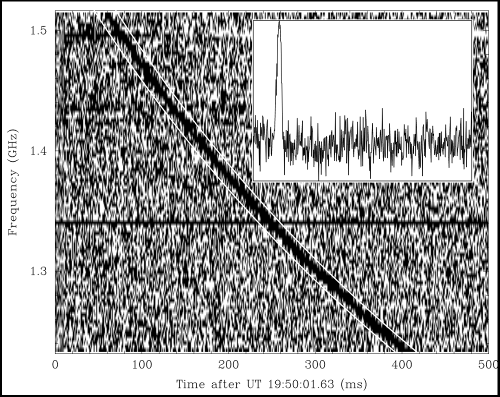


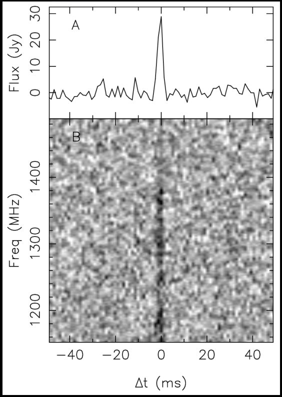
credit: Cenko et al. 2013

Systematic scientific surveys (radio, IR, UV, X, γ)

Radio surveys

- **Fast radio bursts (FRBs)**
- Left: single dish
- Right: interferometry - Zackay & Ofek solved the dedispersion problem





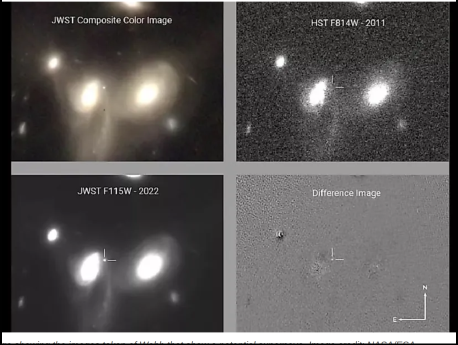
Credit: Lorimer et al. 2007, Bannister et al. 2017

Systematic scientific surveys (radio, IR, UV, X, γ)

IR transients

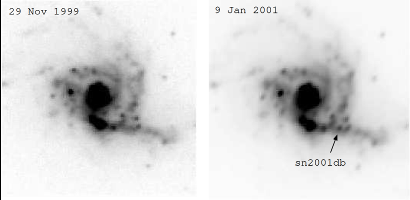
Distant / dust obscured SNe

SN candidate in the galaxy SDSS.J141930.11+5251593 (1 - 1.3 Gpc)



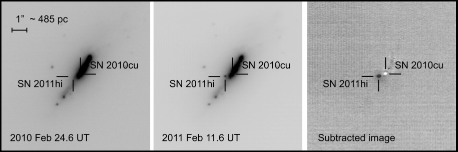
credit: JWST 2022

SN2001db, galaxy NGC3256 ($\sim$30 Mpc)



credit: Maiolino et al. 2002

SNe 2010cu and 2011hi, infrared galaxy (LIRG) IC 883 ($\sim$100 Mpc)



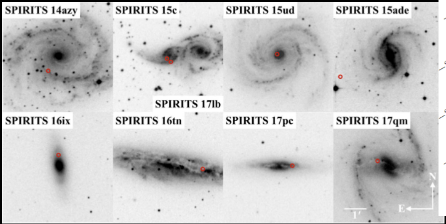
credit: Kankare et al. 2012

Systematic scientific surveys (radio, IR, UV, X, γ)

IR transients

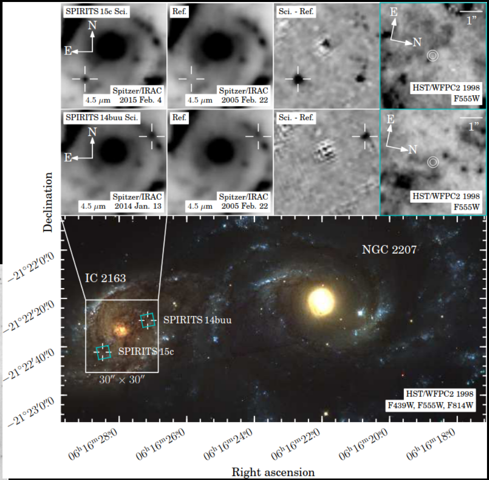
SPitzer **I**nfra**R**ed **I**ntensive **T**ransients **S**urvey (**SPIRITS**) is a six year large program on the warm Spitzer space telescope that repeatedly images 200 nearby galaxies to look for mid-infrared transients at 3.6 - 4.5 μ. It has found **131 transients** and **2536 variables**

(credit: Mansi M. Kasliwal's webpage)



IR transients - credit: Jencson et al. 2019

Two obscured SNe in the nearby star-forming galaxy IC 2163 ($\sim$27 Mpc)



credit: Jencson et al. 2017

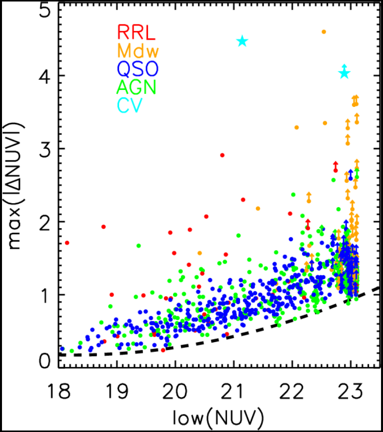
Systematic scientific surveys (radio, IR, UV, X, γ)

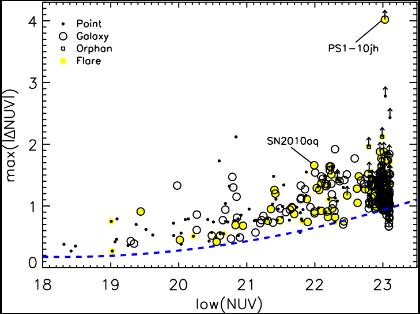
UV transients - young & hot

GALEX TDS (The Galaxy Evolution Explorer Time Domain Survey, 2003 - 2013)

40 deg^2, every 2 days, the mission 3 times extended

Near UV (175-280 nm) and Far UV (135-174 nm) detectors





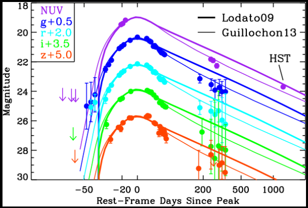
credit: Gezari et al. 2013

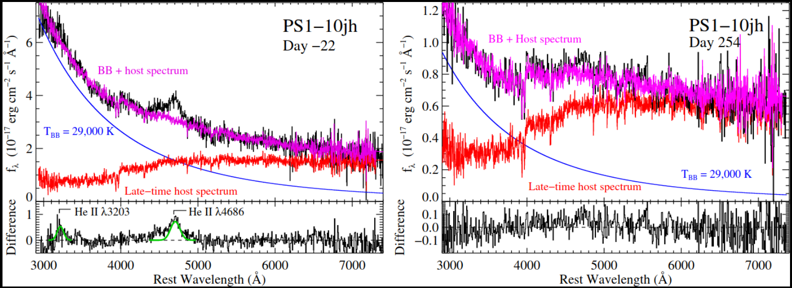
Systematic scientific surveys (radio, IR, UV, X, γ)

UV transients - young & hot

GALEX TDS (The Galaxy Evolution Explorer Time Domain Survey, 2003 - 2013)

The **first TDE**:



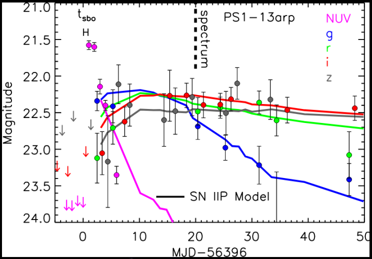


credit: Gezari et al. 2015b

Systematic scientific surveys (radio, IR, UV, X, γ)

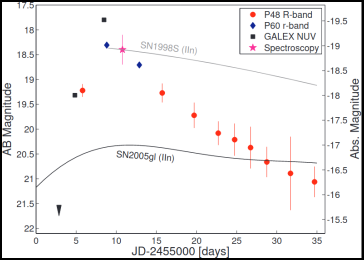
UV transients - young & hot

Early UV from SNe:



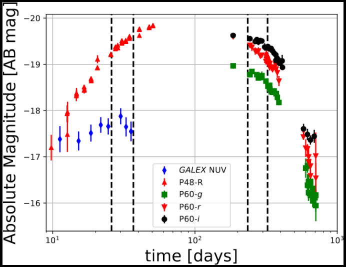
credit: Gezari et al. 2015a, Ofek et al. 2010

PTF follows **GALEX**: SN2009uj



SN12glz and its **rising UV LC paradox** (CSM):

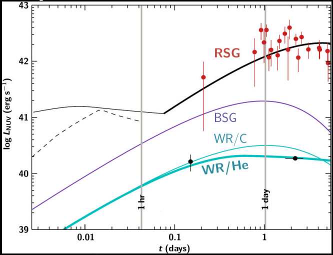
(credit: Soumagnac et al. 2019)

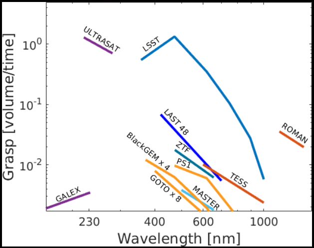


Systematic scientific surveys (radio, IR, UV, X, γ)

UV transients - young & hot

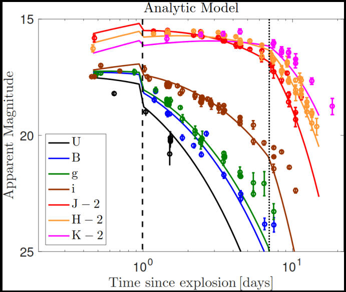
ULTRASAT mission (200 deg^2, 23.5 AB limiting mag, NUV 220-280 nm):
early SN explorer, search for **UV emission from GW sources** (planned 2025)





credit: Ganot et al. 2016, web ULTRASAT
(hopefully **QUVIK** will follow as well)

GW kilonova:
(credit: Waxman et al. 2018)



Systematic scientific surveys (radio, IR, UV, X, γ)

X-ray transients

Past X-ray observatory satellites (not all):

- BeppoSAX (1996-2002) - a crucial role in resolving the origin of GRBs
- ROSAT (1990-1999)

Current X-ray observatory satellites:

- XMM/Chandra (ESA/NASA)
- Swift (NASA) - multi-λ, rapid followup of transients, $\sim$70 targets/day
- MAXI (JAXA - Japan) - on ISS, a wide field sky survey, measures the brightness of X-ray sources every 96 minutes
- eRosita (MPI) - stopped collecting data on Feb 26, 2022

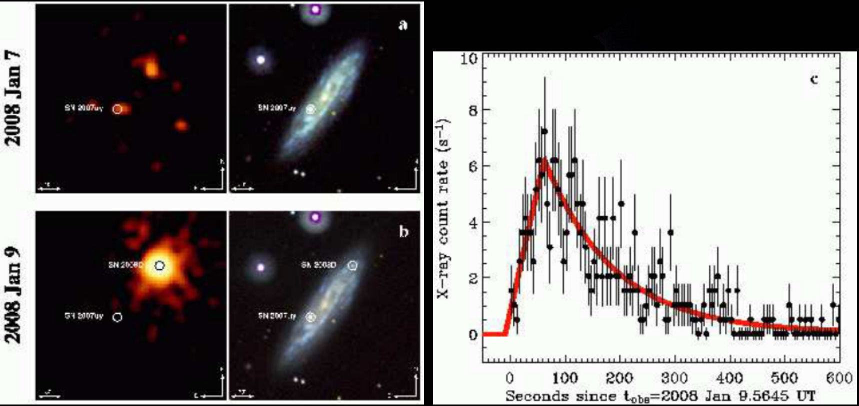
Proposed (future) X-ray observatory satellites:

- Astro-H2 (also XRISM - JAXA/NASA) - planned to launch in 2023
- ATHENA (ESA) - $\sim$100 times more sensitive than the best of existing X-ray telescopes

Systematic scientific surveys (radio, IR, UV, X, γ)

X-ray transients

Shock breakouts: SN2008D

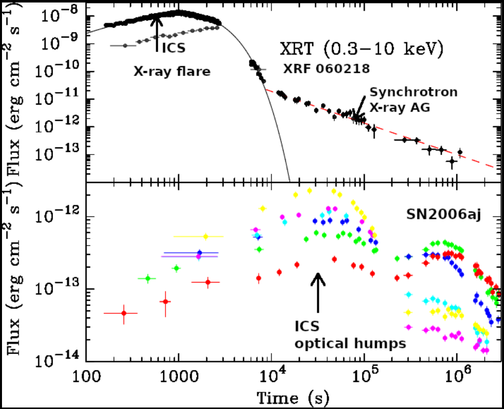


credit: Soderberg et al. 2008

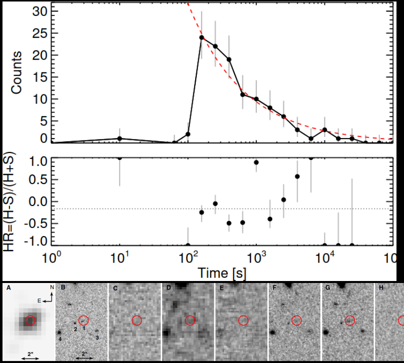
Systematic scientific surveys (radio, IR, UV, X, γ)

X-ray transients

Relativistic: XRR, XRF



credit: Campana et al. 2006



credit: Bauer et al. 2017

Systematic scientific surveys (radio, IR, UV, X, γ)

γ-ray transients

- Long history (Fermi, Swift)... poor localization
- GRBs - KNe, SNe, TDEs (see the ongoing GRB lecture)

Neutrino transients

- Low energy (SNe) - detected only within the local group (super-K, IceCube)
- Neutrinos from SN1987A do not require a NS remnant!
- High energy (IceCube) - there are astrophysical neutrinos, but sources not clear - are these transients? (e.g., Aartsen et al. 2021)

GW transients

- short history - a few recent years
- LIGO, VIRGO, KAGRA, future LISA... (see the ongoing GW lecture)