Optical Time Domain and Multi-Messenger Astronomy

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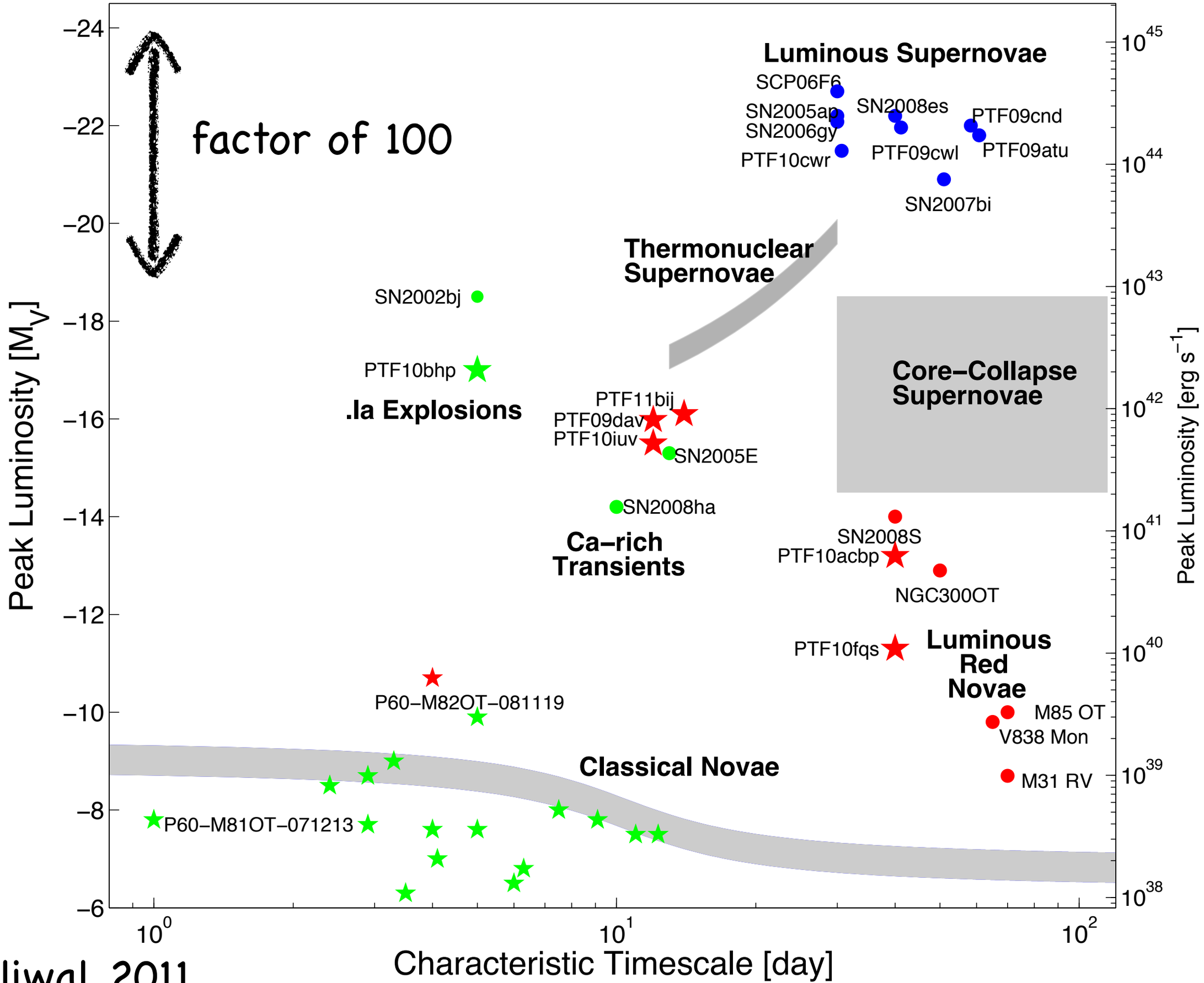
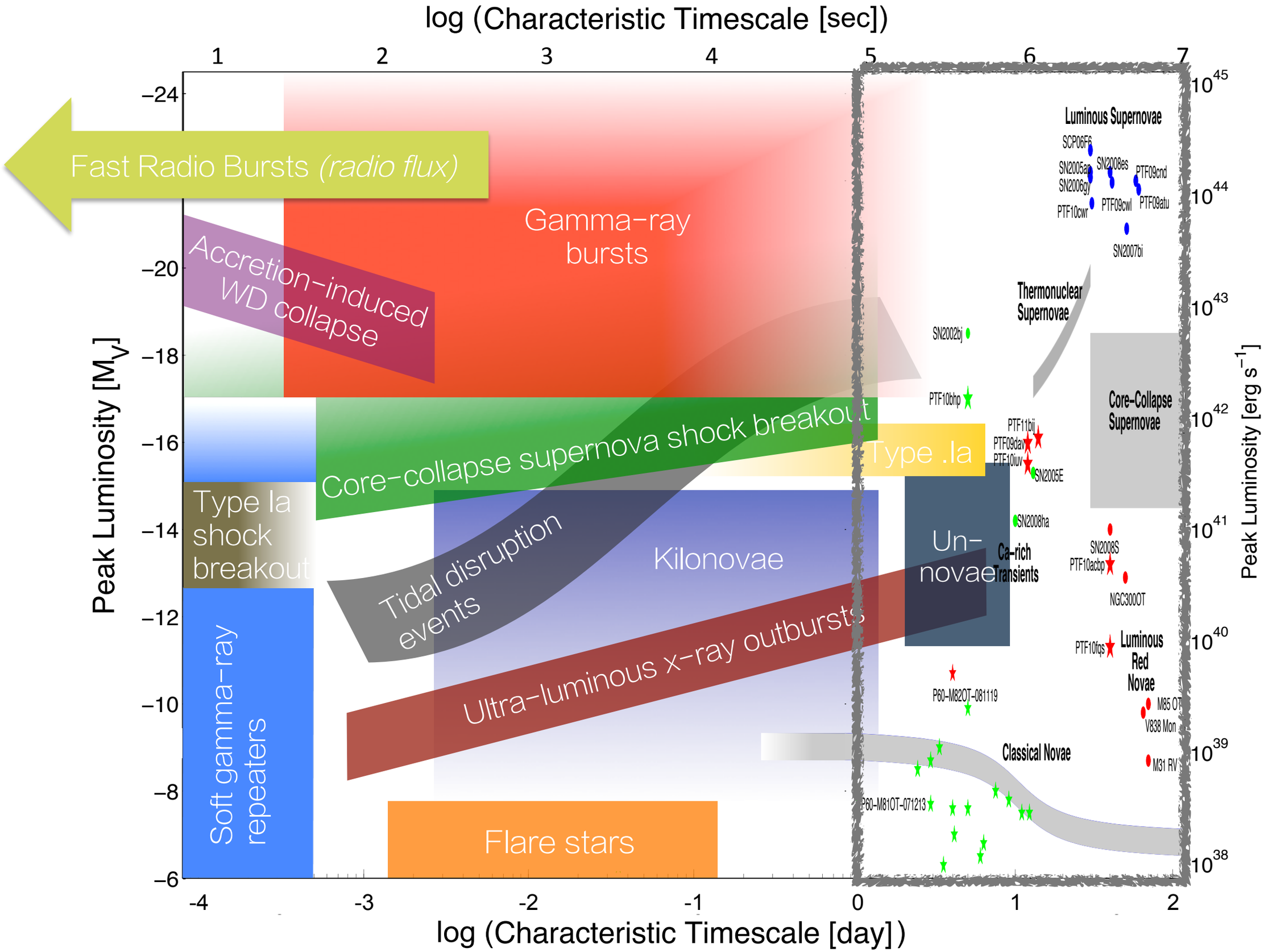
Contents



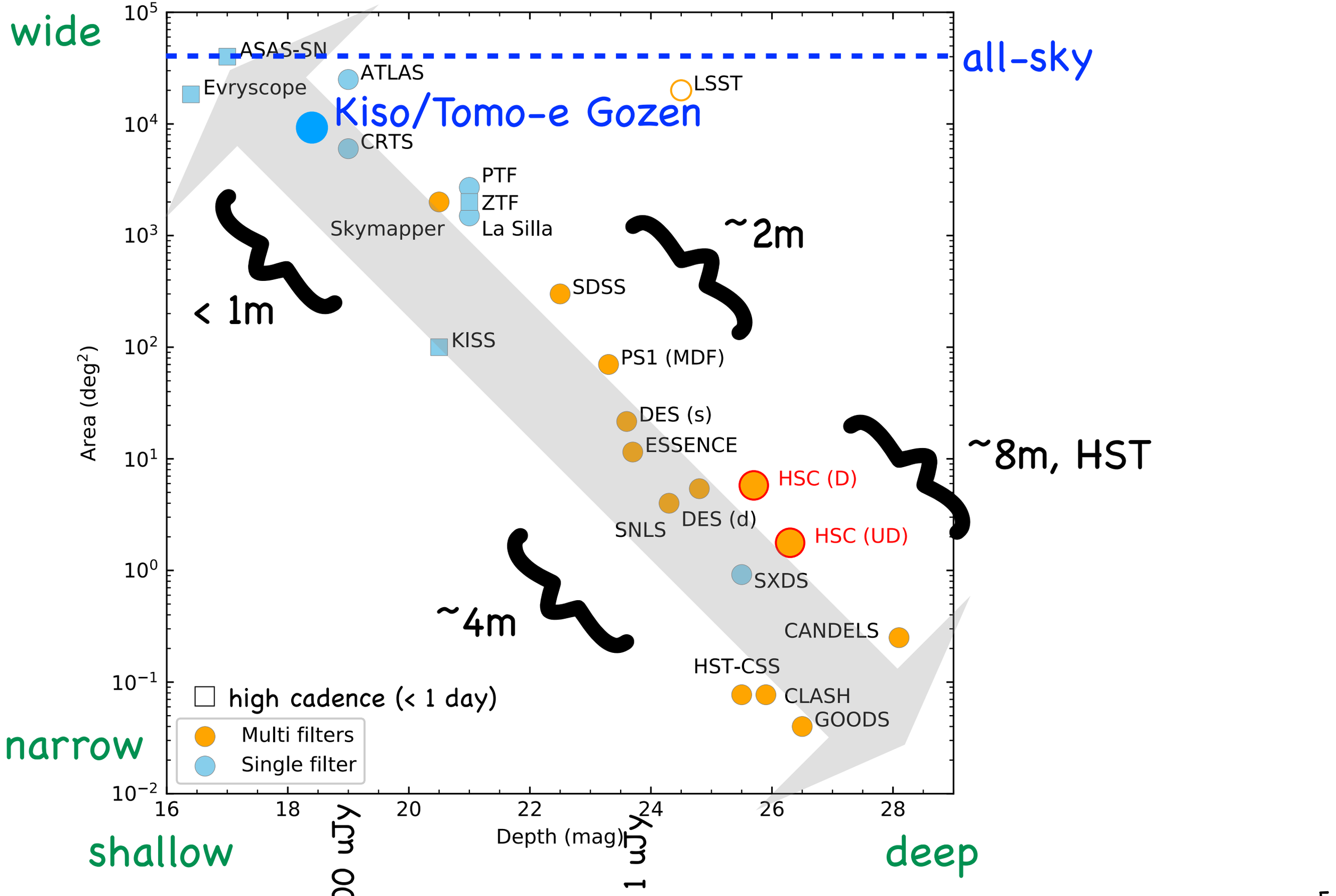
Kasliwal 2011



Kasliwal 2011, Cooke (http://www.astro.caltech.edu/~ycao/B&ETalks/B&E_FRBs_Cooke.pdf)

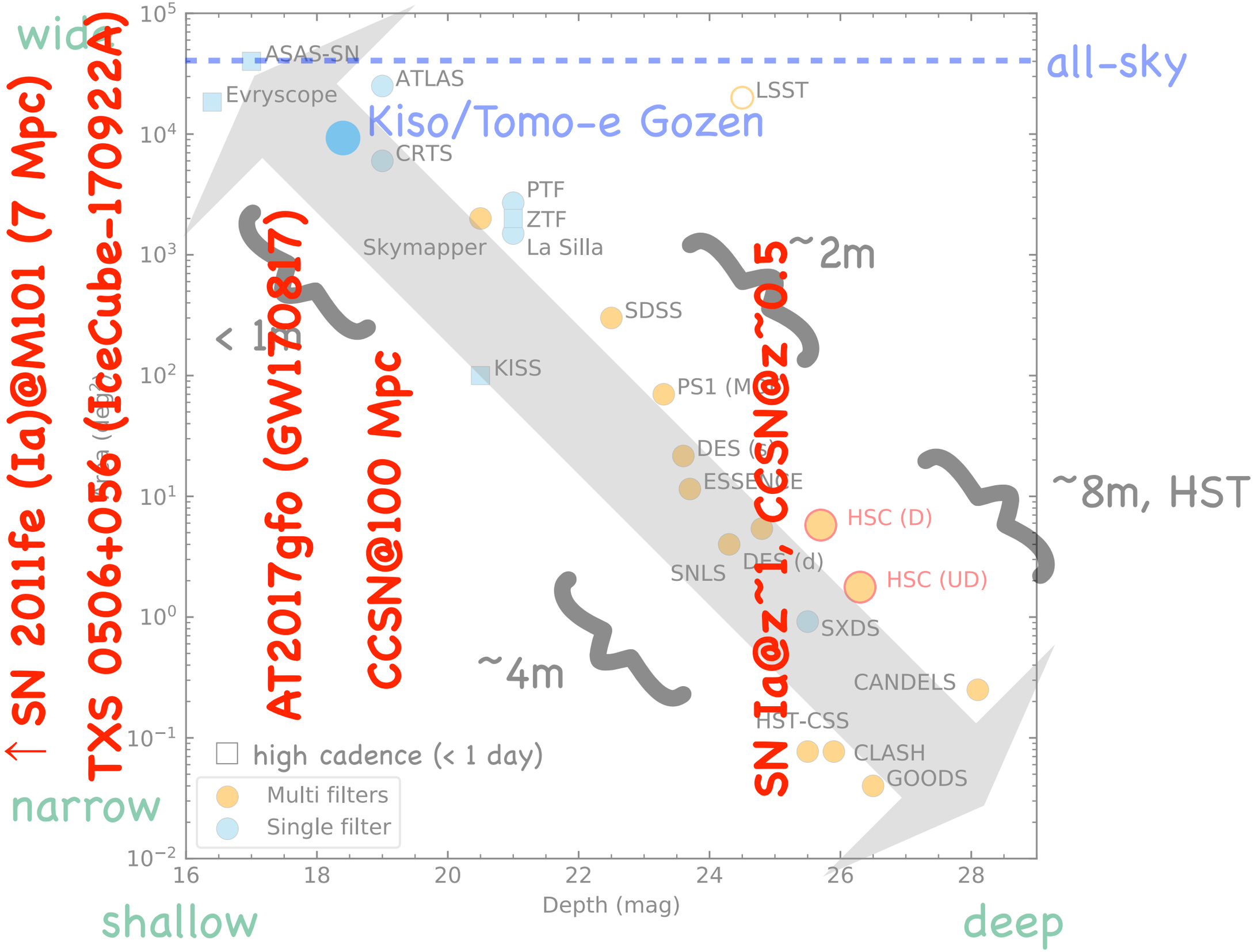
Optical Transient Surveys

Yasuda+2019



Optical Transient Surveys

Yasuda+2019



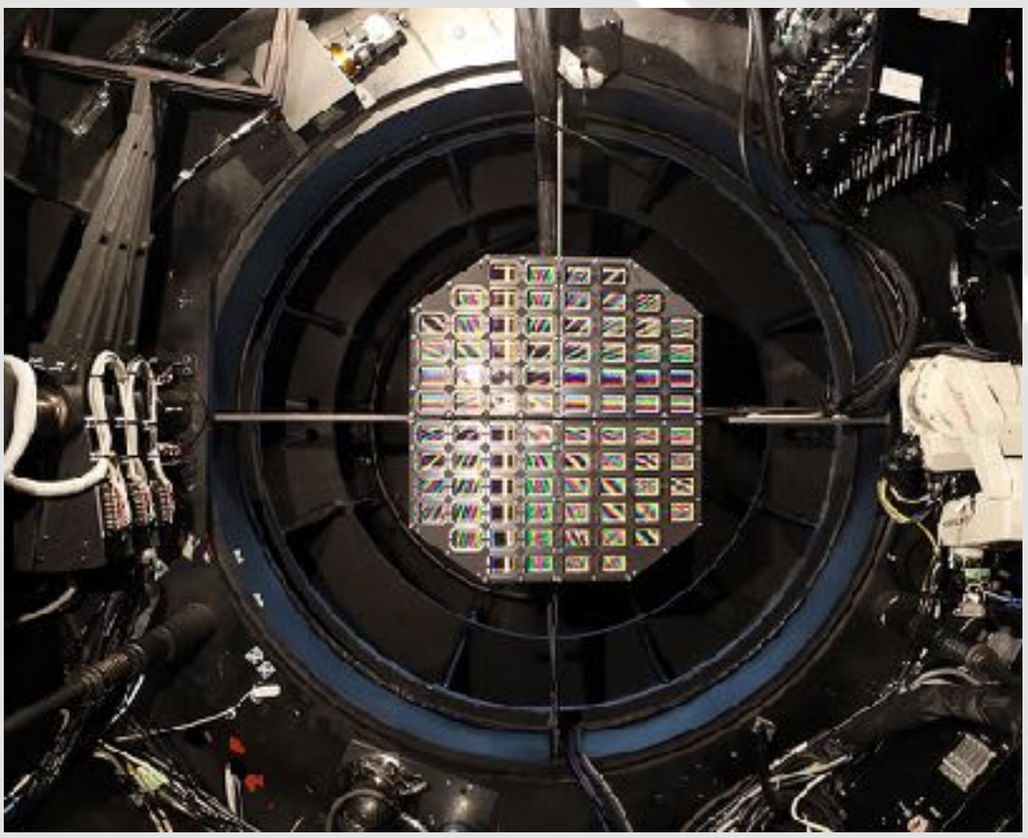
Kiso Schmidt telescope (1.05m)

- KWFC (8 CCDs, 2012-)

  ==> **Tomo-e Gozen** (巴御前; 84 CMOS, Sako+2016)

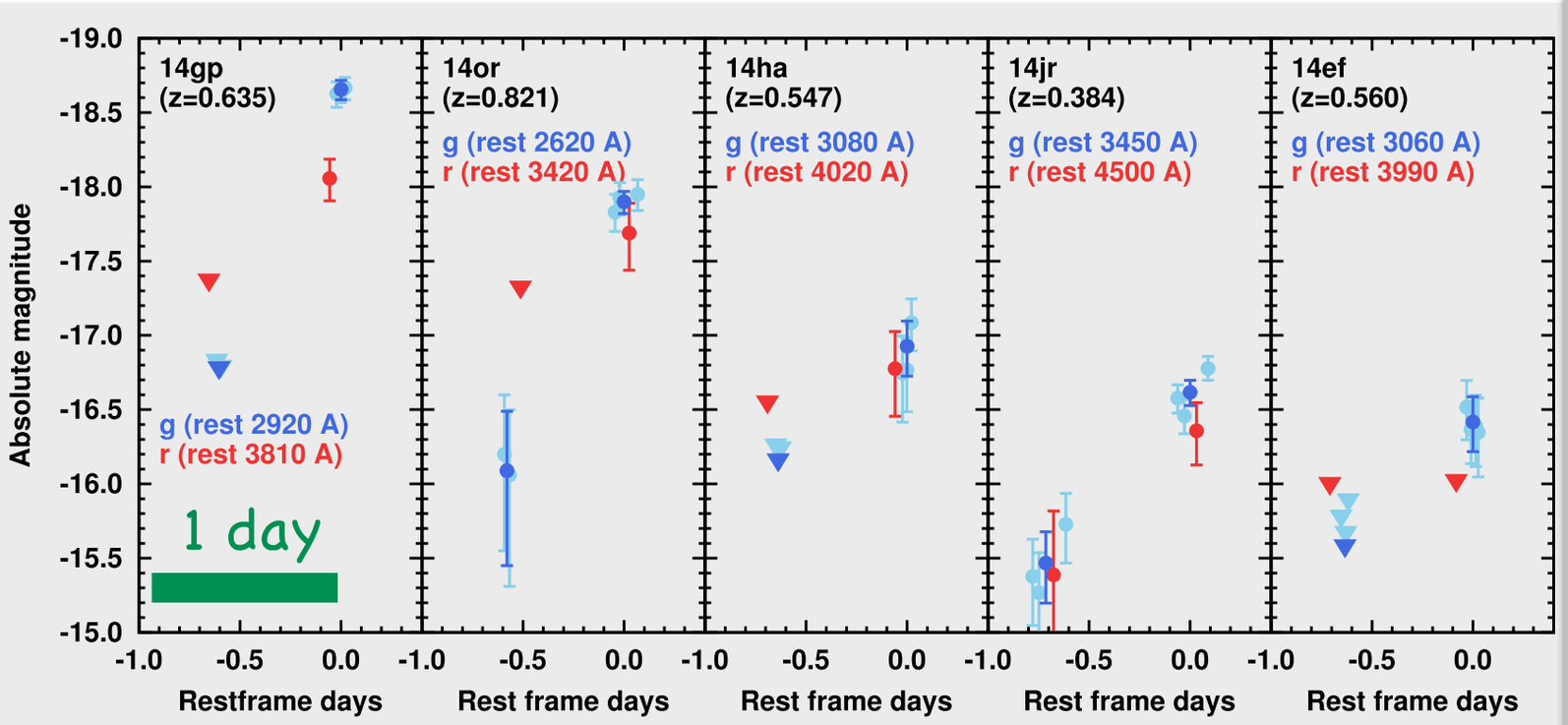
  - completed in April, 2019
  - wide field-of-view (20 deg2), fast readout (>2Hz)
  - high-cadence supernova survey

    ==> "all-sky" (~7,000 deg2) & high-cadence (~2 hrs)
- Start the survey from this October !!!!
- second scale transient search (Richmond, TM, submitted)



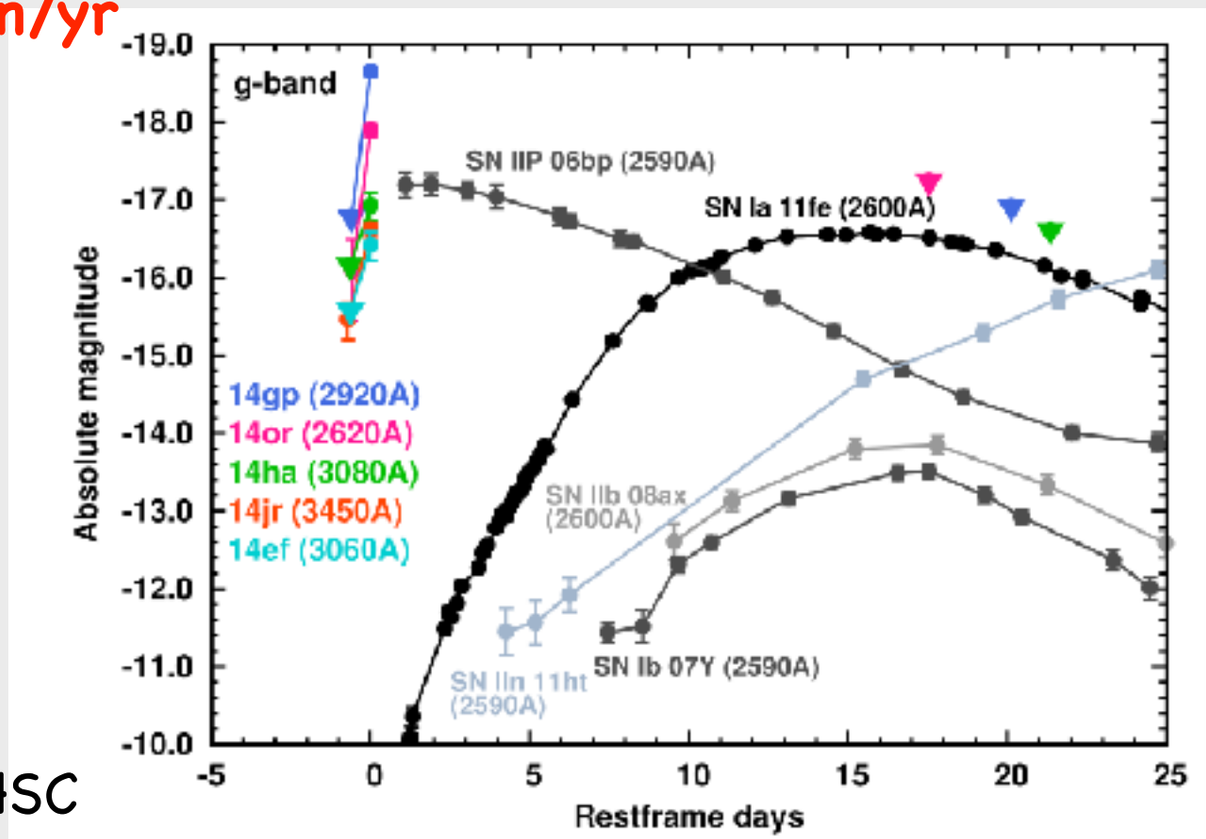
Rapidly Evolving Transients

progenitor stars of core-collapse supernovae

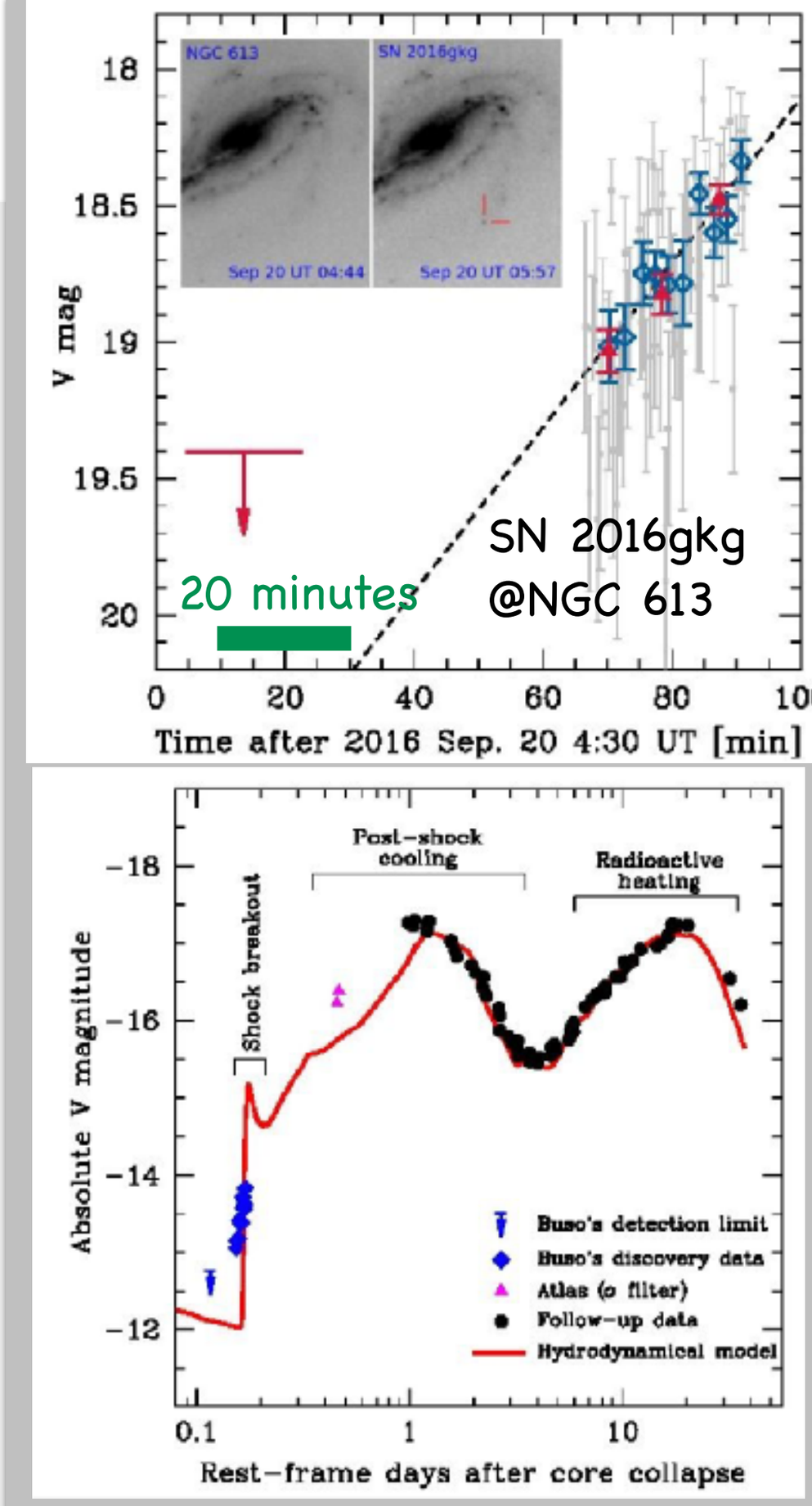


~10^-3 Msun/yr

mass loss



Tanaka, Tominaga, TM+2016 w/ Subaru/HSC

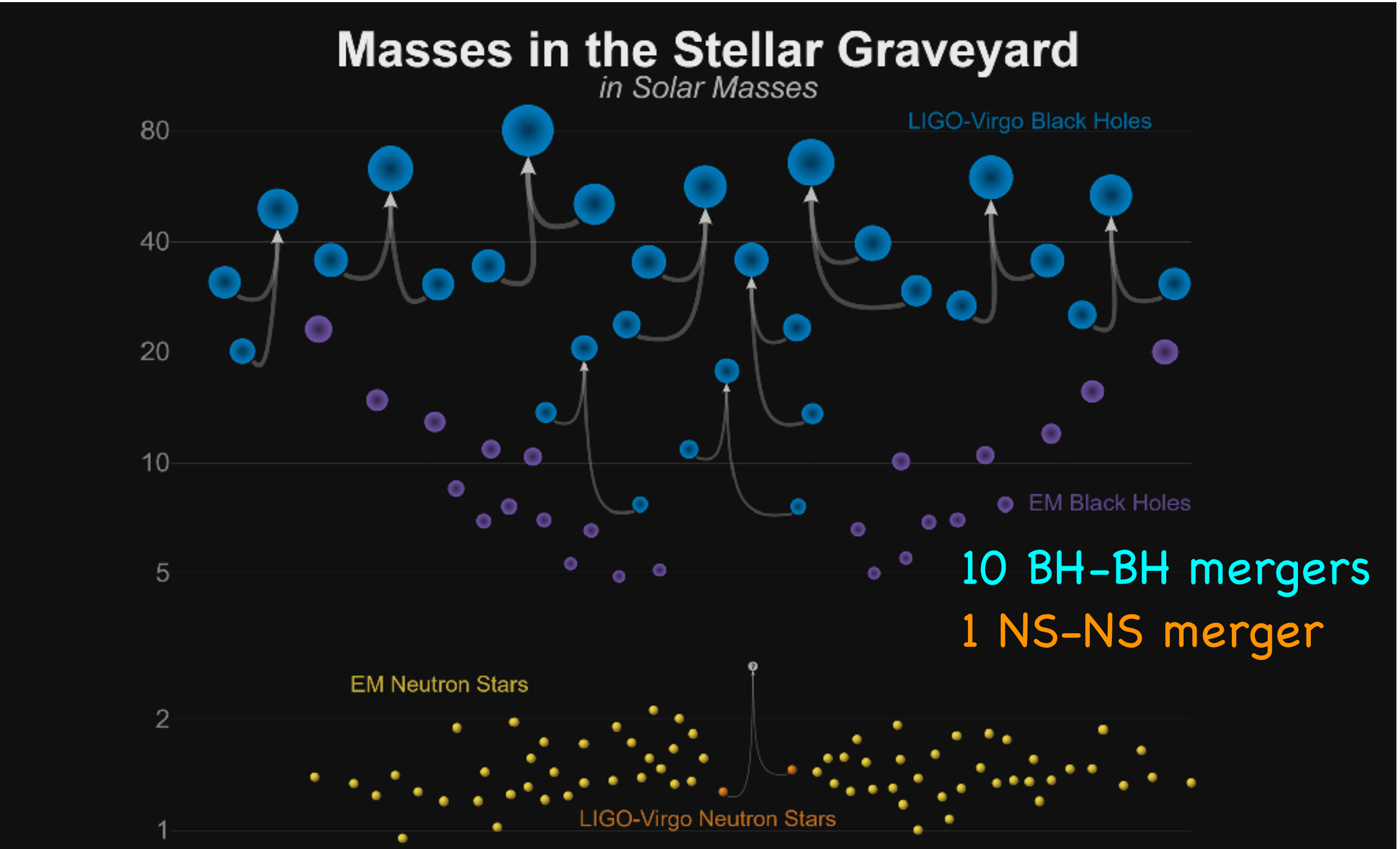


Bersten+2018, Nature

Multi-Messenger Astronomy in Optical

1. Gravitational Wave (LIGOx2, Virgo, KAGRA)
2. High-Energy Neutrino (IceCube)

Gravitational Wave detections w/ LIGOx2, Virgo (O1, O2)



Observing Run 3 (O3)

https://gracedb.ligo.org/superevents/public/O3/

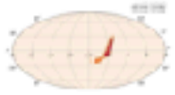
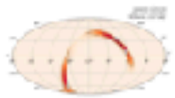
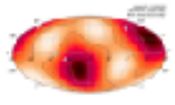
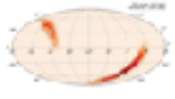
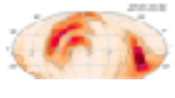
GraceDB — Gravitational-Wave Candidate Event Database

HOME | PUBLIC ALERTS | SEARCH | LATEST | DOCUMENTATION | LOGIN

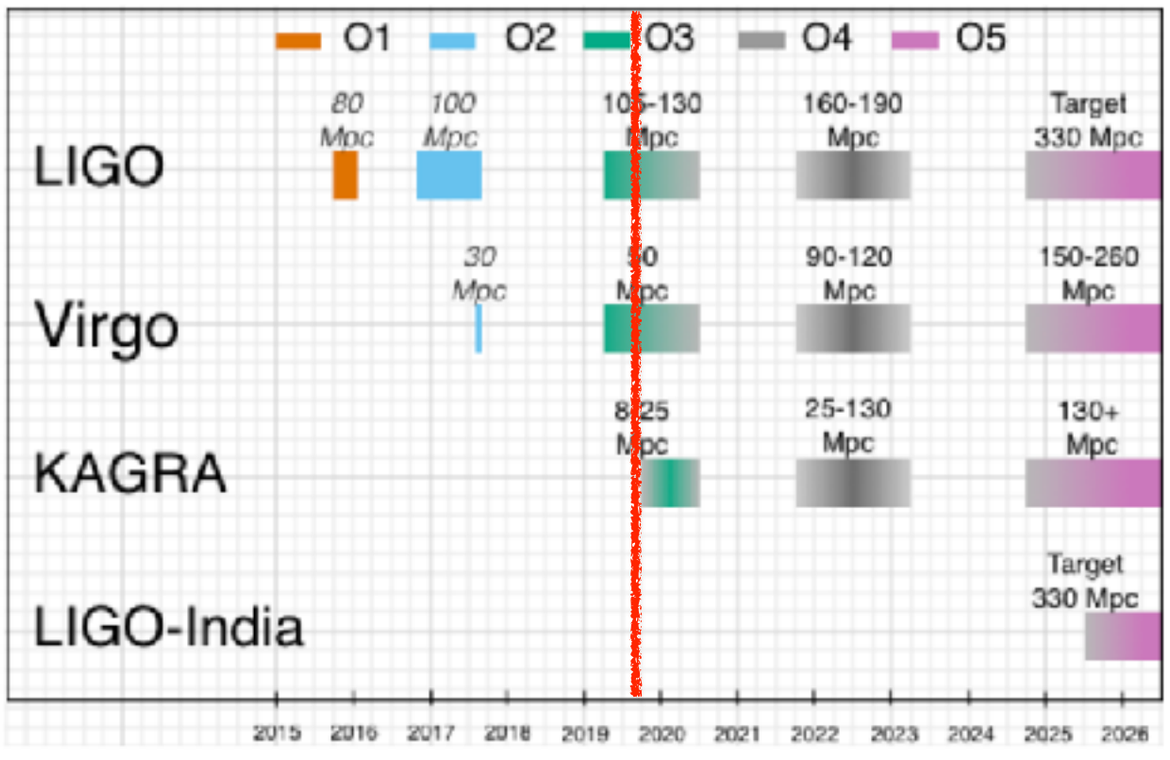
LIGO/Virgo O3 Public Alerts

Detection candidates: 31

SORT: EVENT ID (A-Z)

Event ID	Possible Source (Probability)	UTC	GCN	Location	FAR
S190924h	MassGap (>99%)	Sept. 24, 2019 02:18:46 UTC	GCN Circulars Notices | VOE		1 per 3.5493e+10 years
S190923y	NSBH (68%), Terrestrial (32%)	Sept. 23, 2019 12:55:59 UTC	GCN Circulars Notices | VOE		1.5034 per year
S190915ak	BBH (99%)	Sept. 15, 2019 23:57:02 UTC	GCN Circulars Notices | VOE		1 per 32.55 years
S190910h	BNS (61%), Terrestrial (39%)	Sept. 10, 2019 08:29:58 UTC	GCN Circulars Notices | VOE		1.1312 per year
S190910d	NSBH (98%), Terrestrial (2%)	Sept. 10, 2019 01:26:19 UTC	GCN Circulars Notices | VOE		1 per 8.5248 years
S190901ap	BNS (86%), Terrestrial (14%)	Sept. 1, 2019 23:31:01 UTC	GCN Circulars Notices | VOE		1 per 4.5093 years

31 detection candidates
(some retracted)
no EM counterpart identified



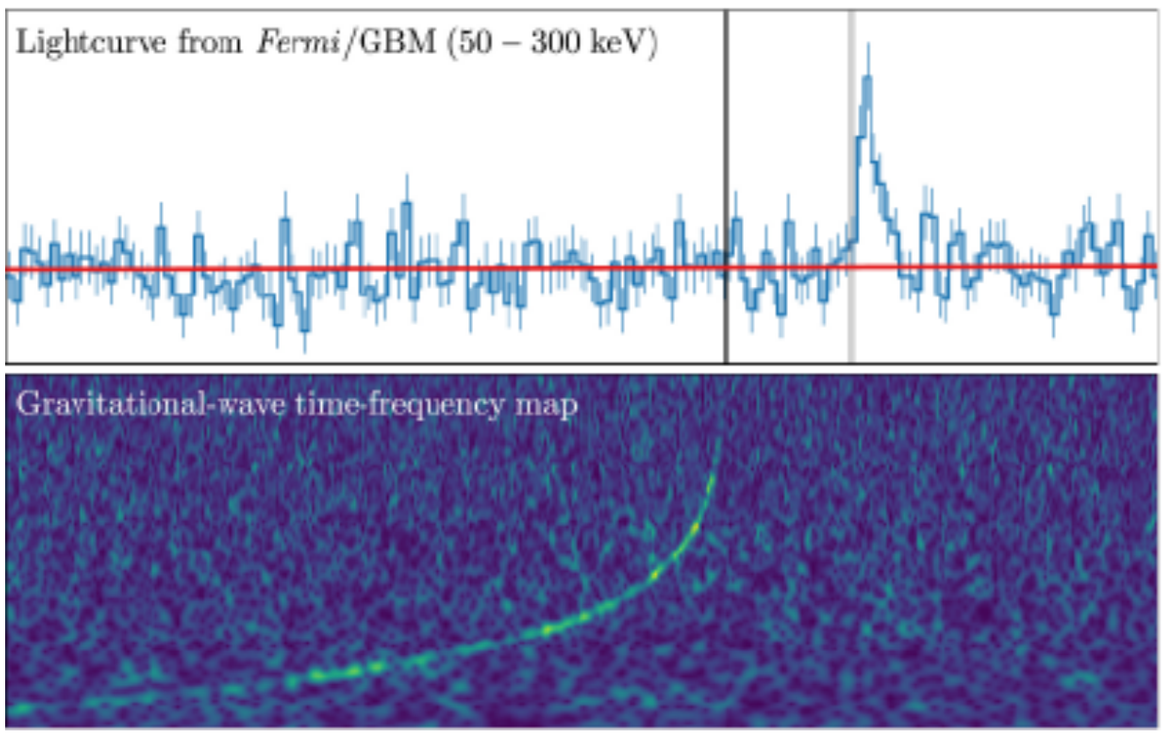
better GW sensitivity ==> larger telescopes

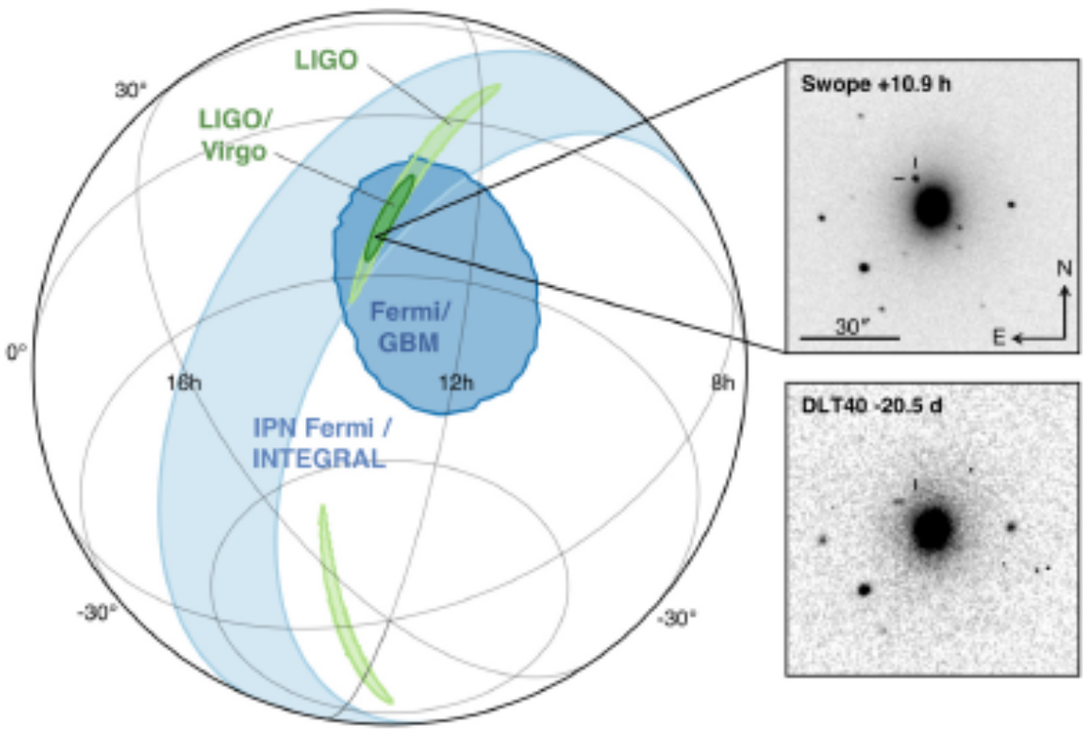
now

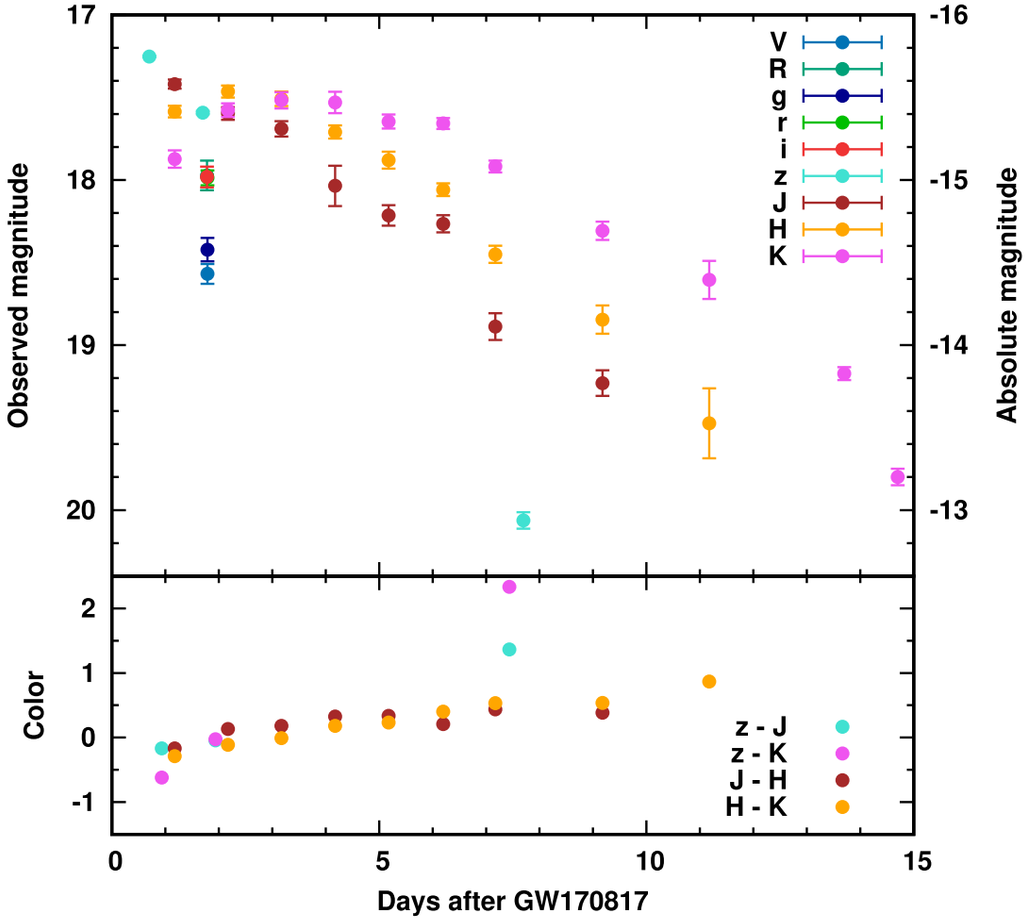
First Kilonova: Gravitational Wave Source incl. NSs

Fermi (gamma)

GW





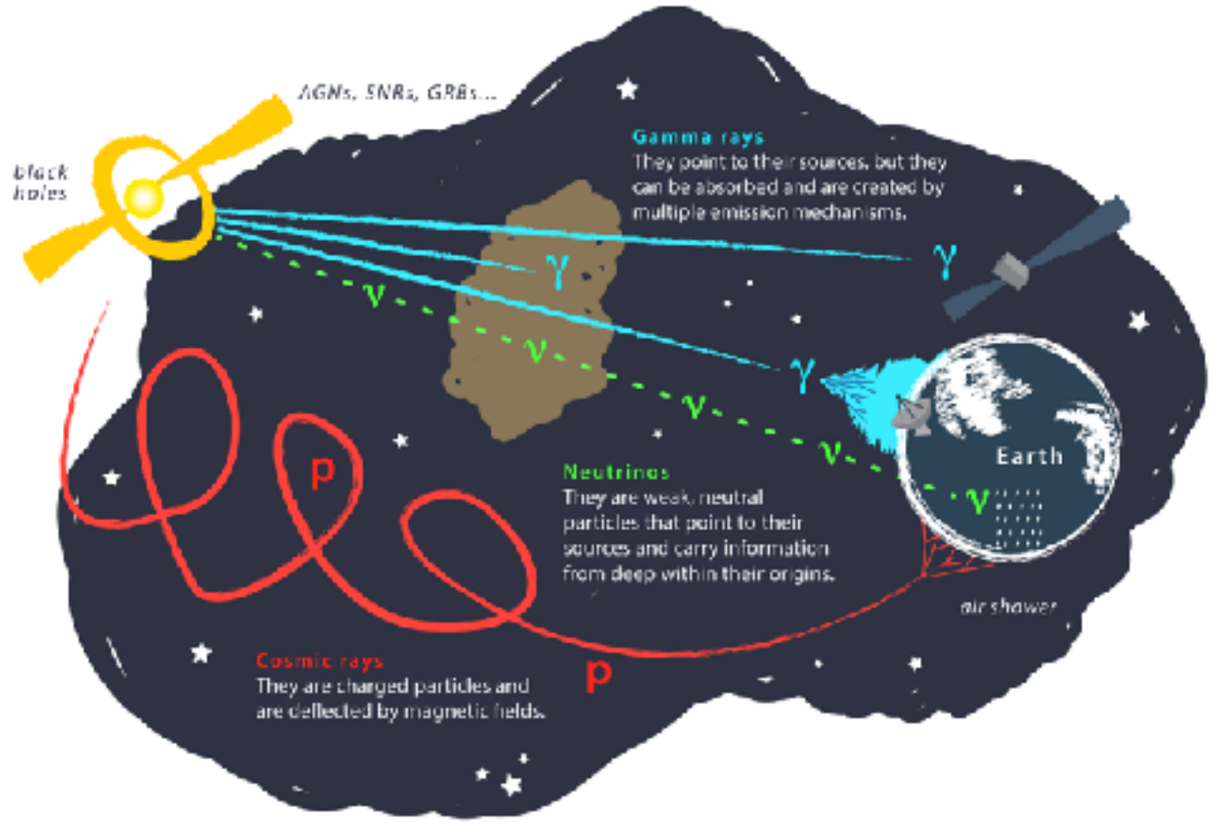


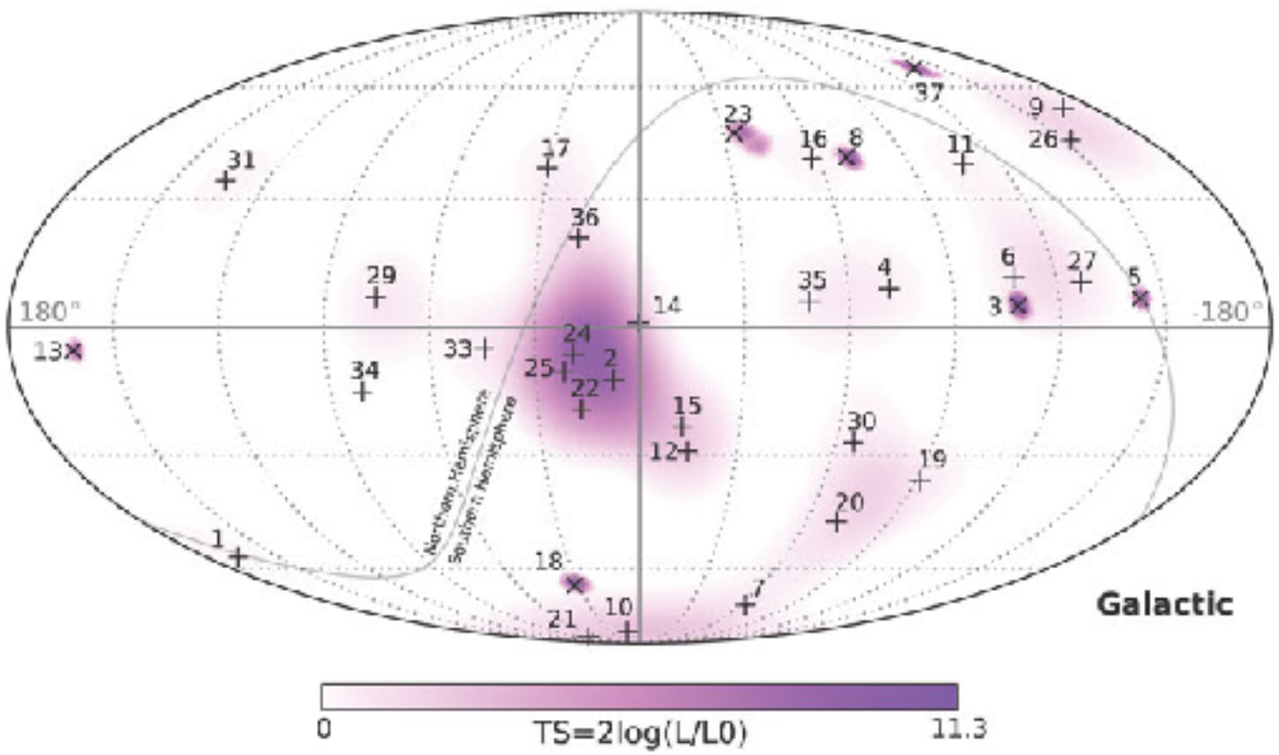
- red color/spectrum due to broad absorption.
  - very different from supernova spectra
  - lanthanoid elements
  - high-speed ejecta (~0.1-0.3c)
- different from expectations....
  - bluer in early phase.
  - brighter
- need more samples
  - different viewing angles, rate, yield, etc.

Before GW170817, very limited observational constraints on kilonova properties (short GRB afterglow)

wide-field surveys for IceCube EM counterparts

http://icecube.wisc.edu

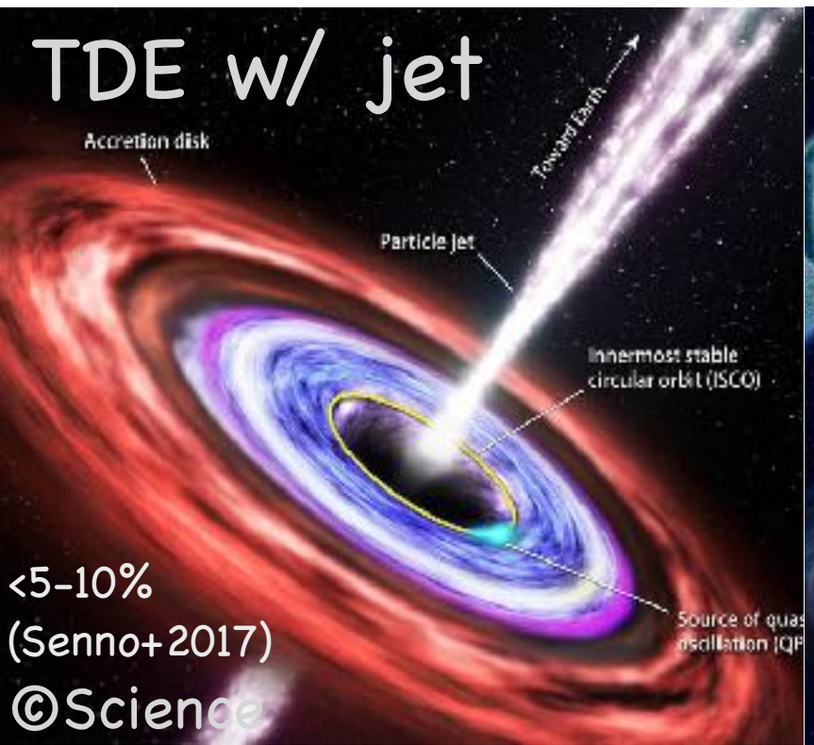


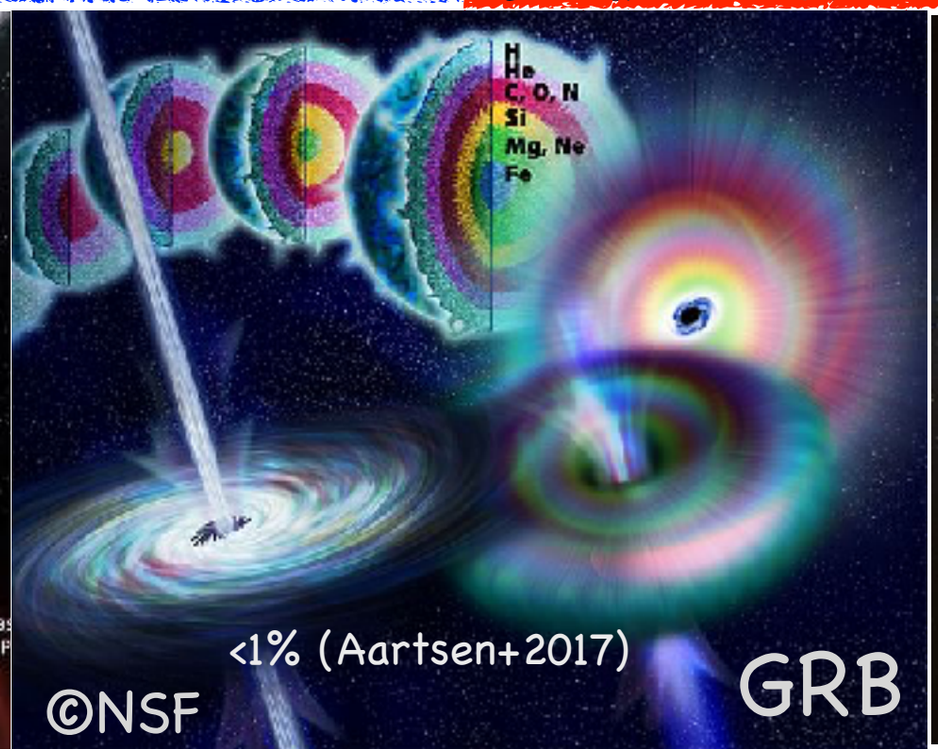


- High Energy neutrino detector
- isotropic ==> extragalactic?
- ~1 deg localization
- no correlation
  w/ TeV gamma sources or GRBs
- 54 events (1347 days, 2010-2014)
- automatic alert since 2016/04
  ==> electromagnetic follow-up
  - New alert system: GOLD & BRONZE (2019/07-)

Origin of high-energy (TeV-PeV) neutrinos (cosmic ray)

transient (variable)

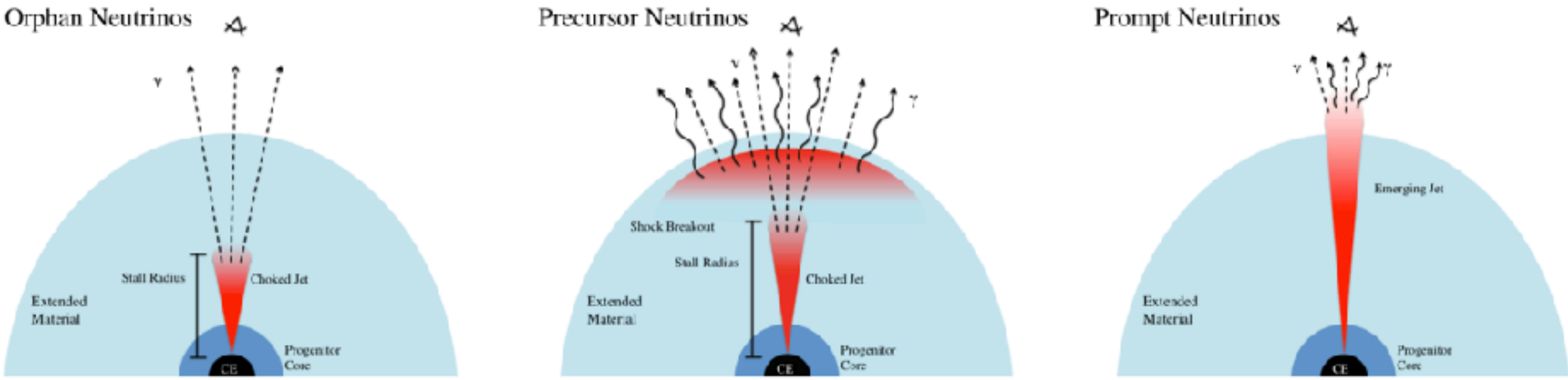




Neutrino from Choked-Jet Supernova

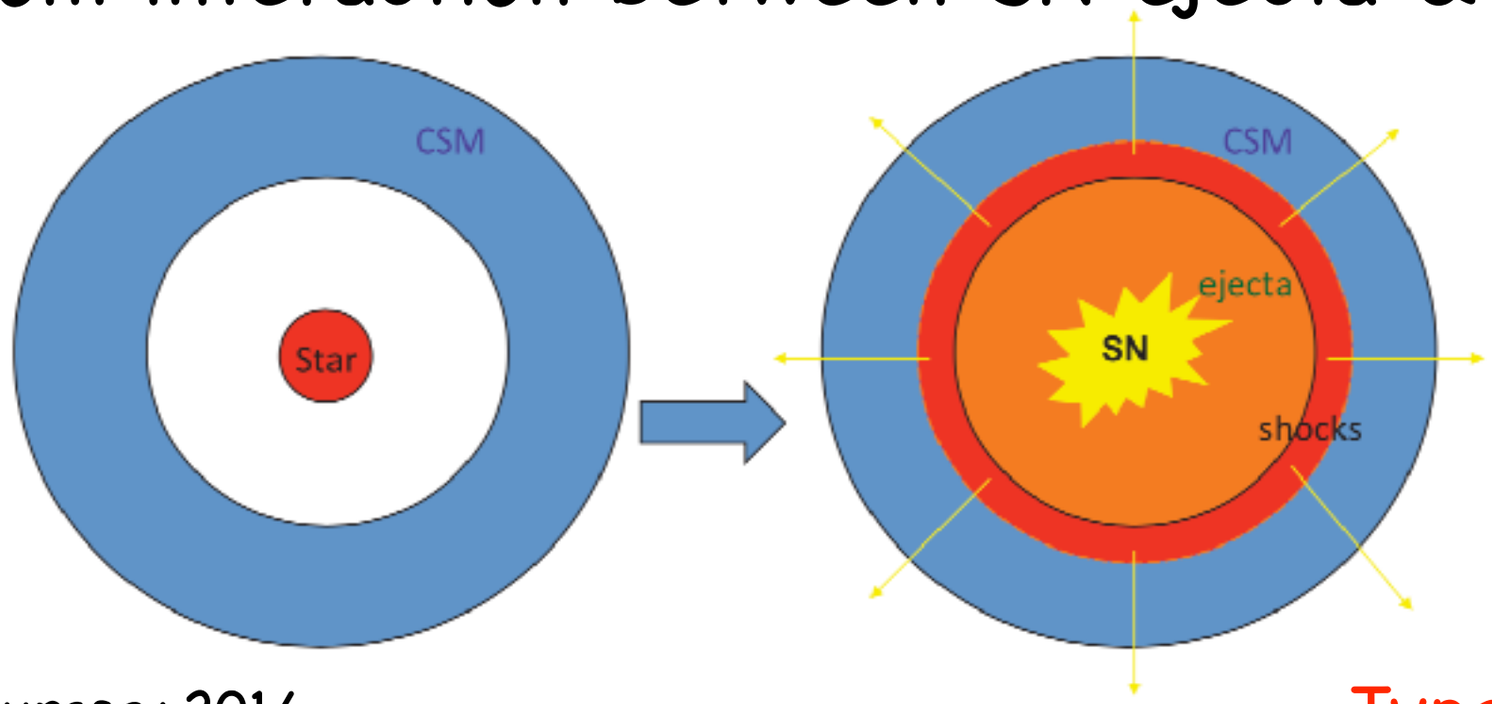
Type Ic broad-line supernova

(GRB, Type Ic broad-line)



Senno+2017

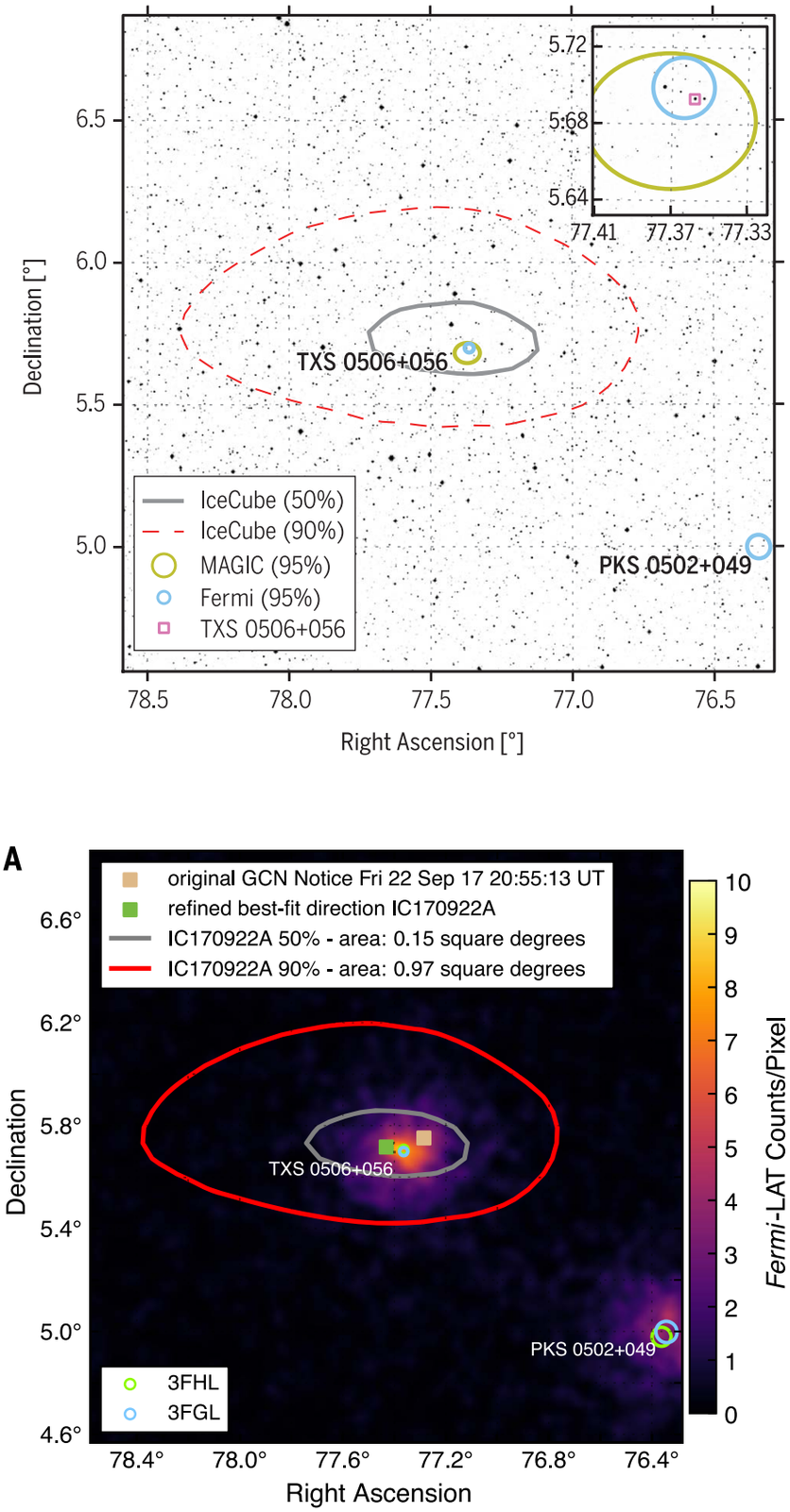
Neutrino from interaction between SN ejecta & CSM

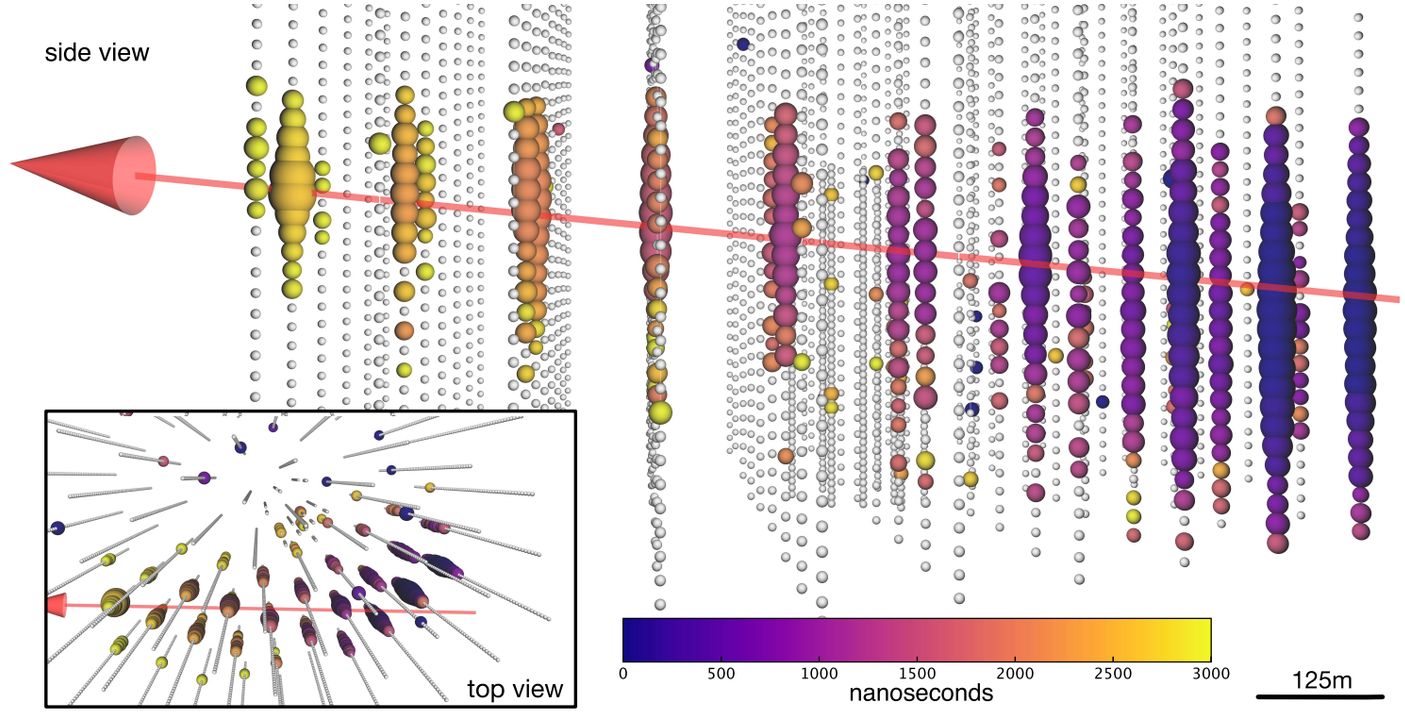


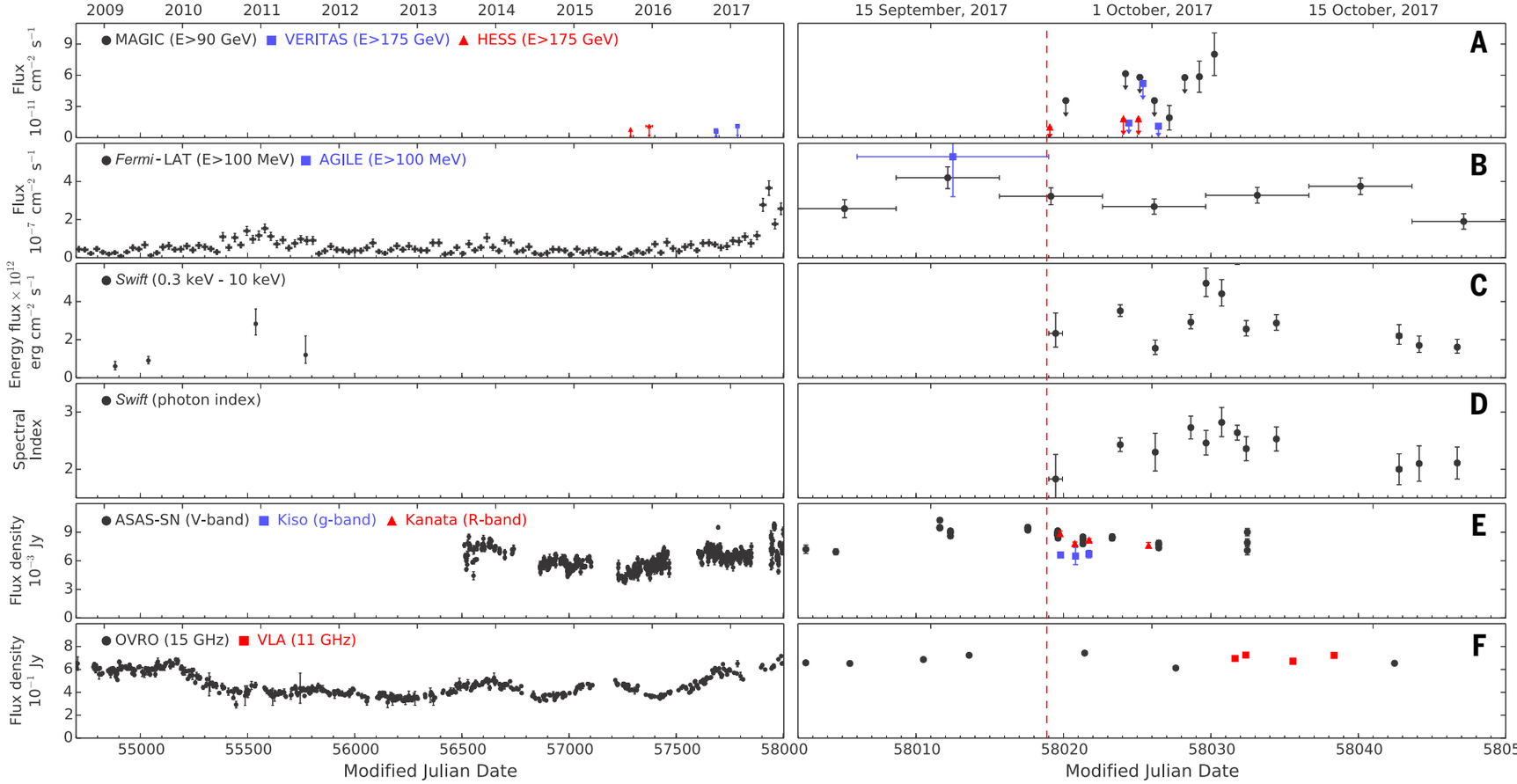
Murase+2014

Type IIn supernova

EM Counterpart Discovery of **IceCube-170922A**



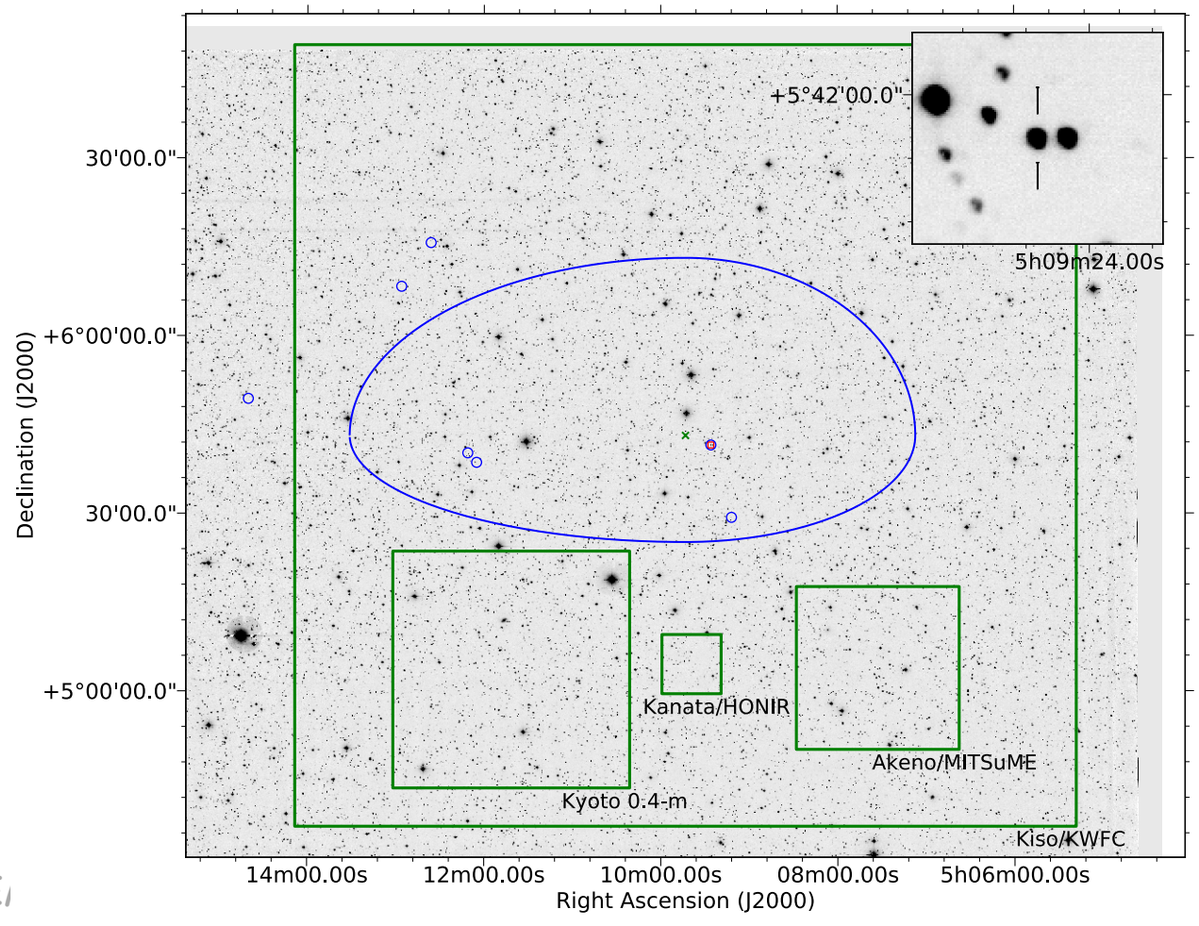


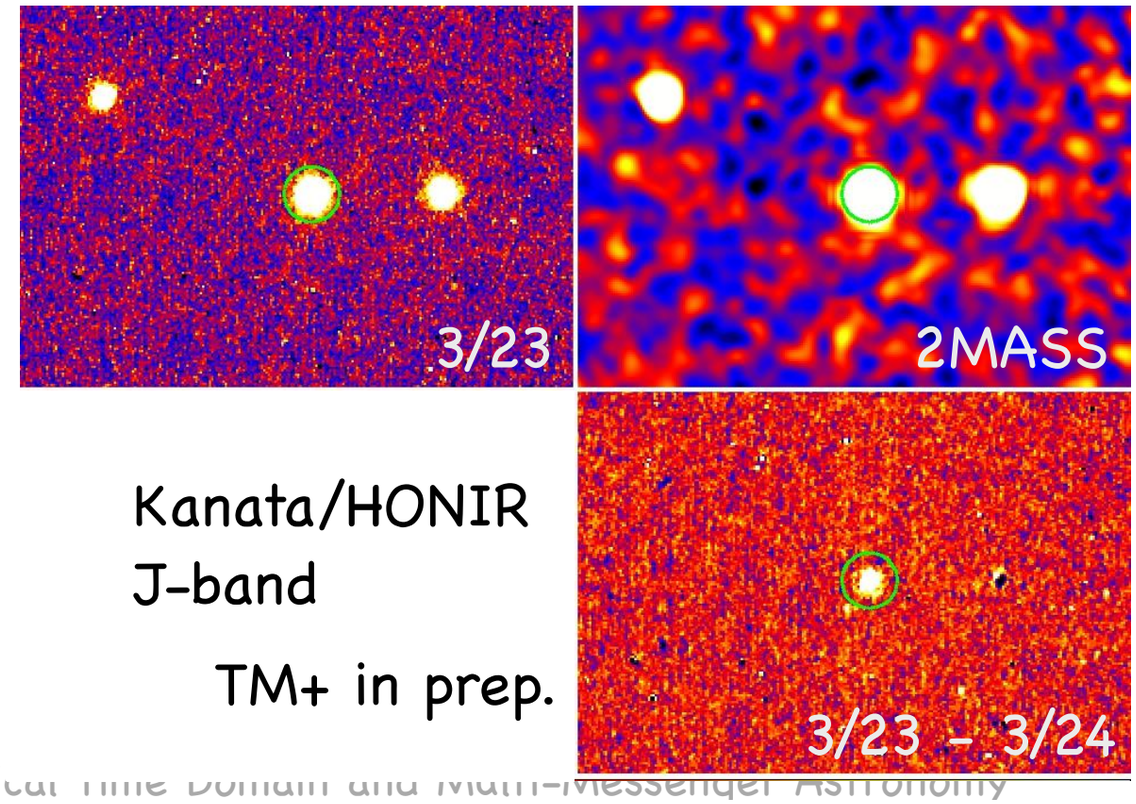


IceCube Collaboration+ 2018

EM Counterpart Discovery of **IceCube-170922A**

- IceCube alert (GCN 21916): 2017/09/22, 20:54:30 (UT)
- 7 BROS (**blazar** candidates, Itoh+ in prep.) sources within error region
  - **TXS 0506+056** variability detected with Kanata/HONIR
    ==> Fermi/LAT variabilities (gamma, ATel #10791, Tanaka+)
    ==> multi-wavelength follow-up (IceCube Collaboration+2018)
    optical/NIR imaging, spectroscopy, polarization: incl. MITSuME, Kiso, Nayuta, Kanata, IRSF (OISTER) + Subaru (TM+ in prep.)
- z=0.336 (Paiano+2018, GTC/OSIRIS)





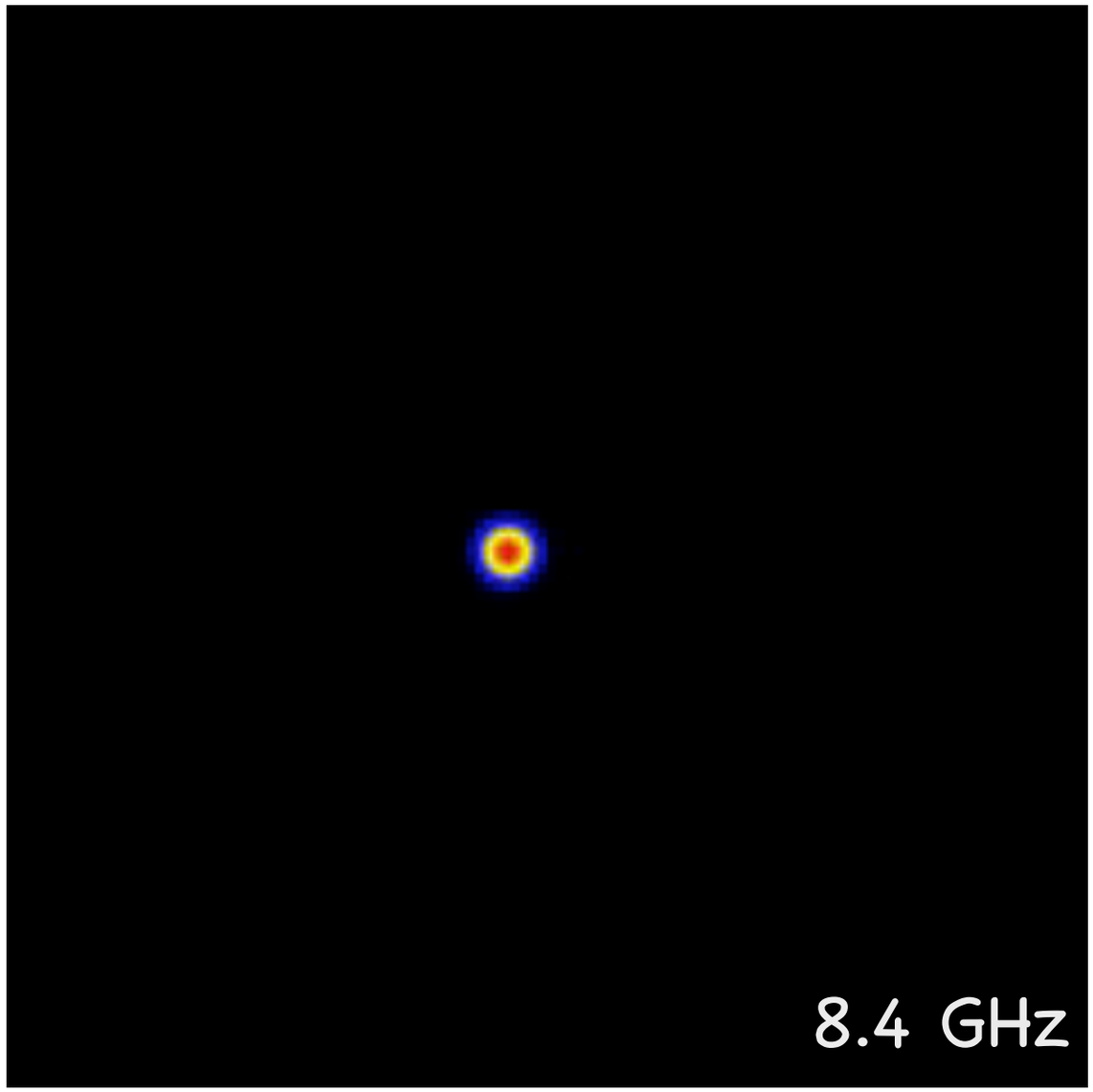
Optical Time Domain/transient + VLBI?

- supernova ejecta interaction w/ CSM
  - mass loss history just before explosion
    = end of life of massive stars
  - progenitor stars of Type Ia supernovae
- relativistic jets for Type Ic supernovae/GRBs
  - jet in kilnovae (GW170817)/sGRBs
  - high-energy neutrino sources?
- relativistic jets in AGN
  - blazars
    - high-energy neutrino sources?
  - radio-loud NLS1s

VLBI observations for nearby SNe

- detection: all Type II or Ib/c
  - massive star origin
- ejecta-CSM interaction
  - CSM density, ejecta density, magnetic field
- ~> 1 mJy / beam @ 8.4 GHz (~0.5-1 mas)
- distance ~< 10 Mpc
  - rate: ~1 SN / yr
- "movie"
  - SN 1993J (~3 Mpc): Type IIb

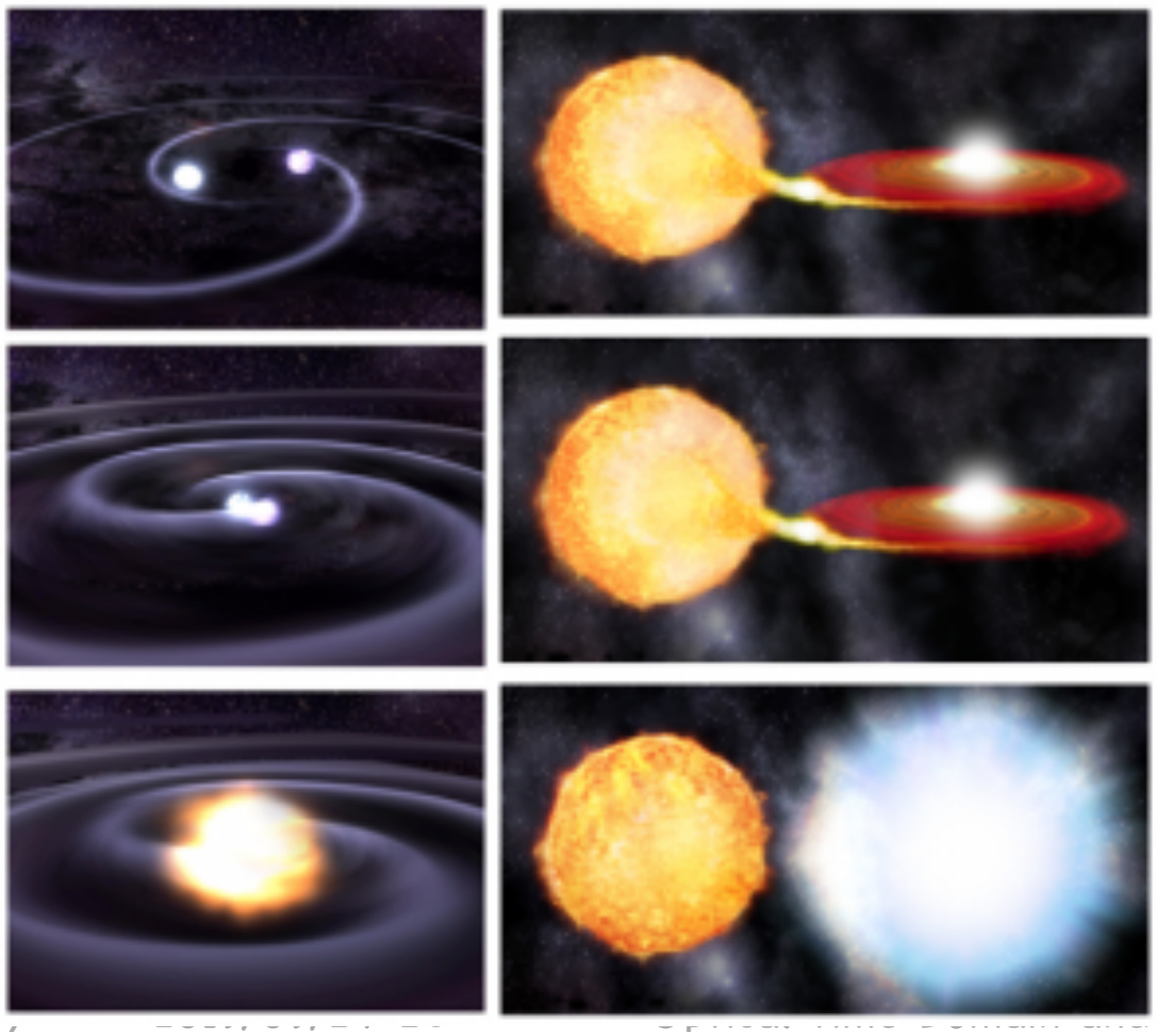
Bietenholz+2003



Type Ia supernova progenitors: single/double degenerate?

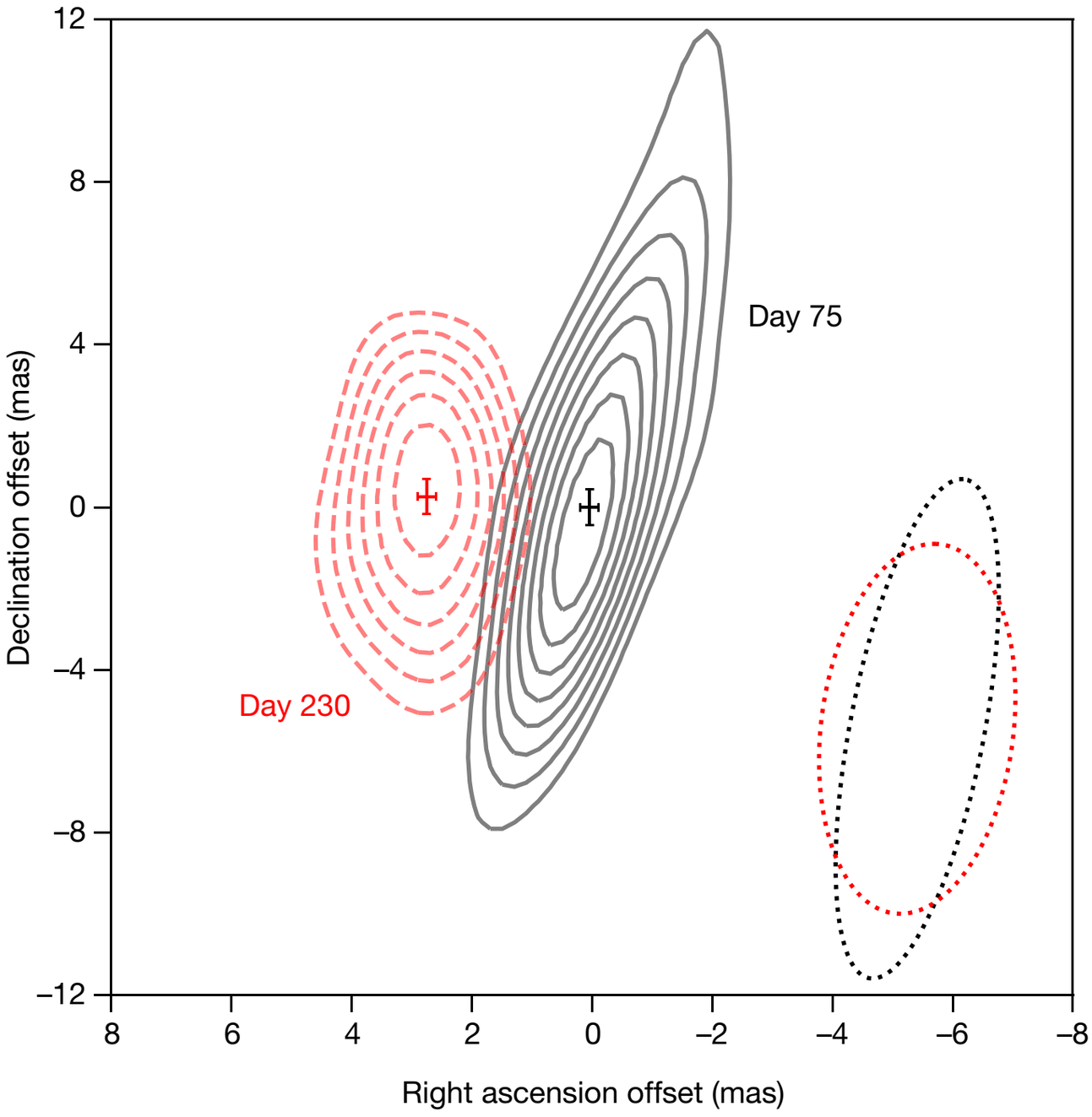
- recent mass loss expected for single degenerate
- no detection even for nearest cases
  - SN 2011fe@M101 (Chomiuk+2012, <19 uJy@5 GHz?)
  - SN 2014J@M82 (Perez-Torres+2014, <12-41 uJy@1.5-22 GHz)
- tight constraint on mass loss rate: several x 10^-10 Msun/yr
  ==> likely double degenerate (at least for these two)

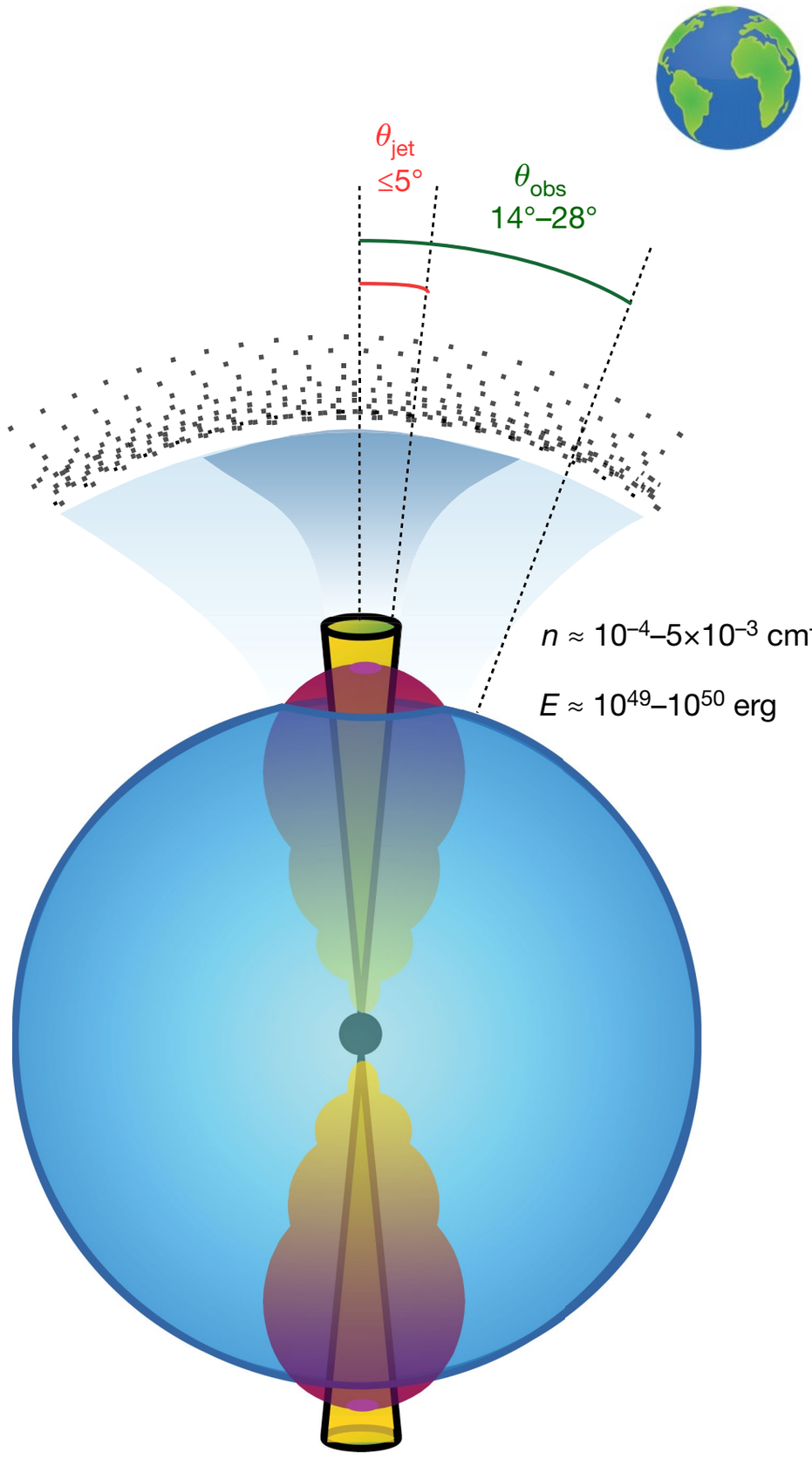
double degenerate (DD)　single degenerate (SD)



©AAVSO

GW170817 kilonova w/ VLBI

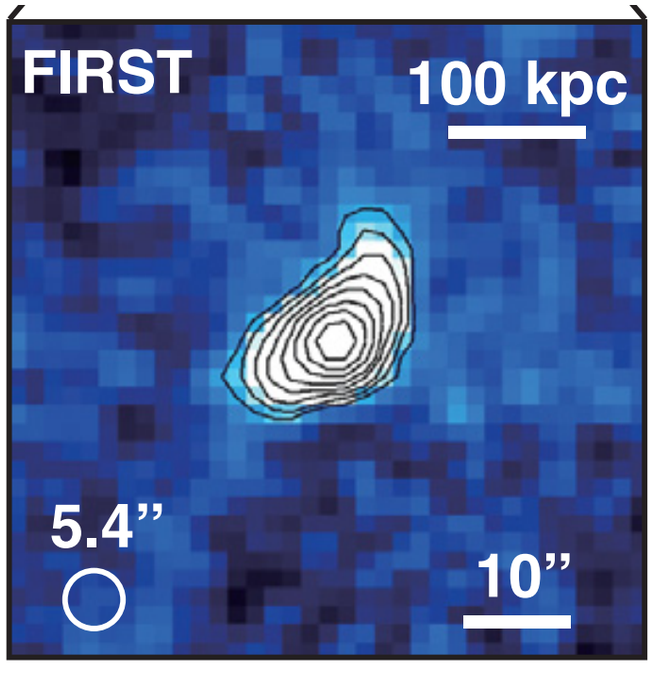


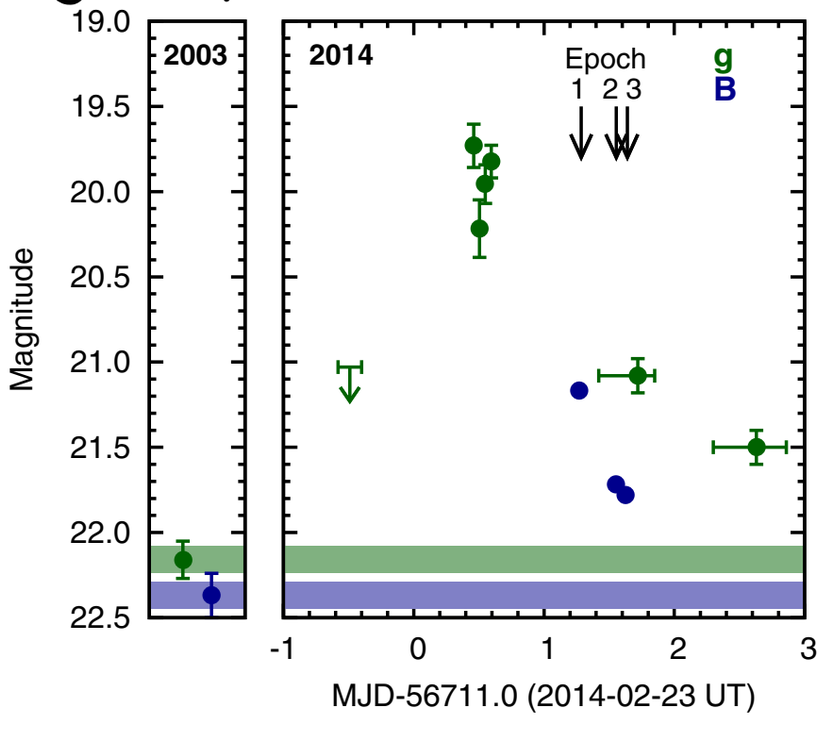


Mooley+2018

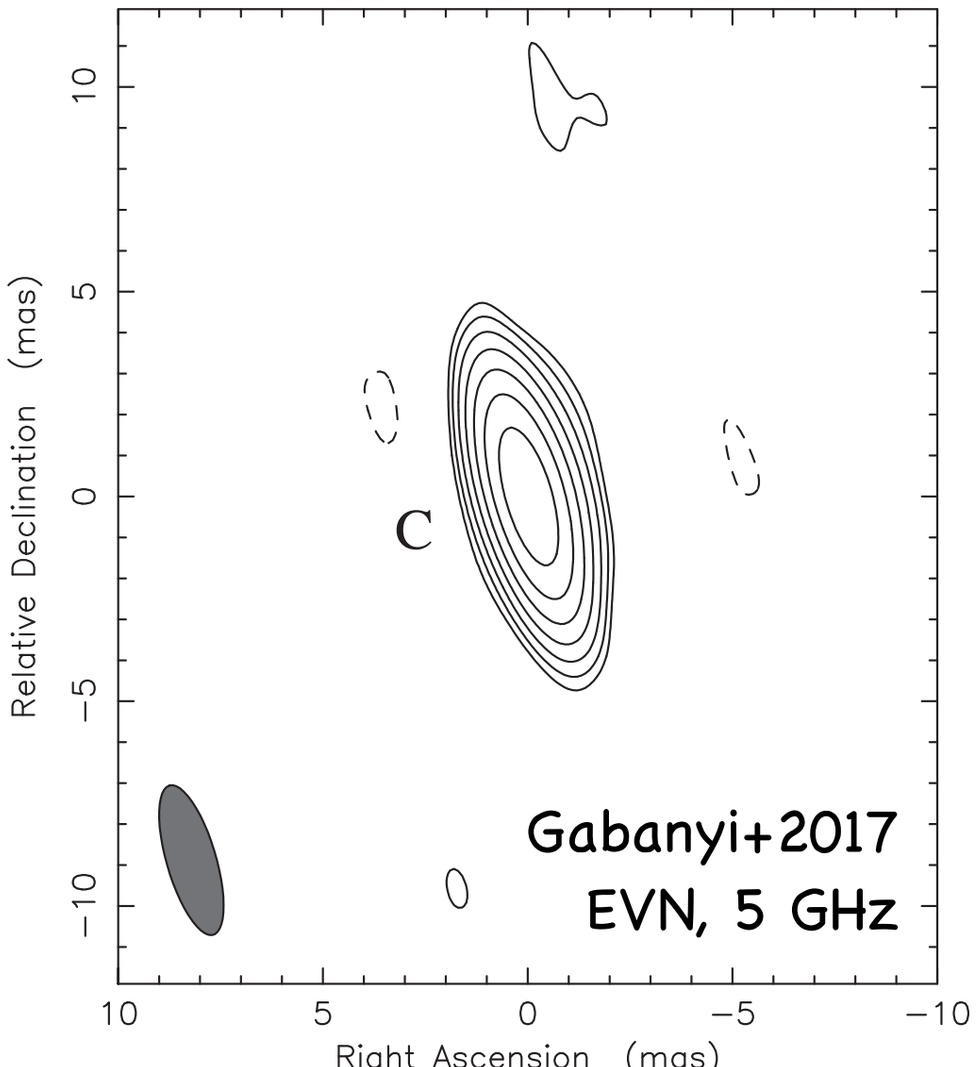
AGN w/ relativistic jets

- so many blazar studies
  - identification of Fermi/LAT unID sources w/ VLBI and optical variability
- IceCube neutrino-related studies
- serendipitous discovery of a radio-loud narrow line Seyfert 1
  - rapid brightening (<1 day) in Kiso Supernova Survey (TM+2014)
  - 10^7 Msun black hole (Tanaka, TM+2014)
  - radio follow-up: JVN, EVN (Gabanyi, TM+2017) , VERA
  - optical/NIR monitoring (TM+2017)
    - constant power-law index
    - no companion galaxy
      ==> not a merger system?





Tanaka, TM+2014



Summary

- Time Domain Astronomy in optical is now rapidly evolving.
- High-Cadence surveys (multiple visits per night) even for extragalactic objects are now one of the frontier fields.
- Multi-Messenger Astronomy is now one of the hot topics;
  - EM counterparts of gravitational wave sources: kilonovae
  - EM counterparts of IceCube high-energy neutrinos:
    - blazar? peculiar supernovae?
- Optical-Time-Domain & VLBI collaborative observations
  - nearby SNe w/ CSM interaction
  - jets in kilonovae
  - AGN w/ relativistic jets