Multimessenger Astronomy with AMPEL

Marek Kowalski, DESY/Humboldt-University

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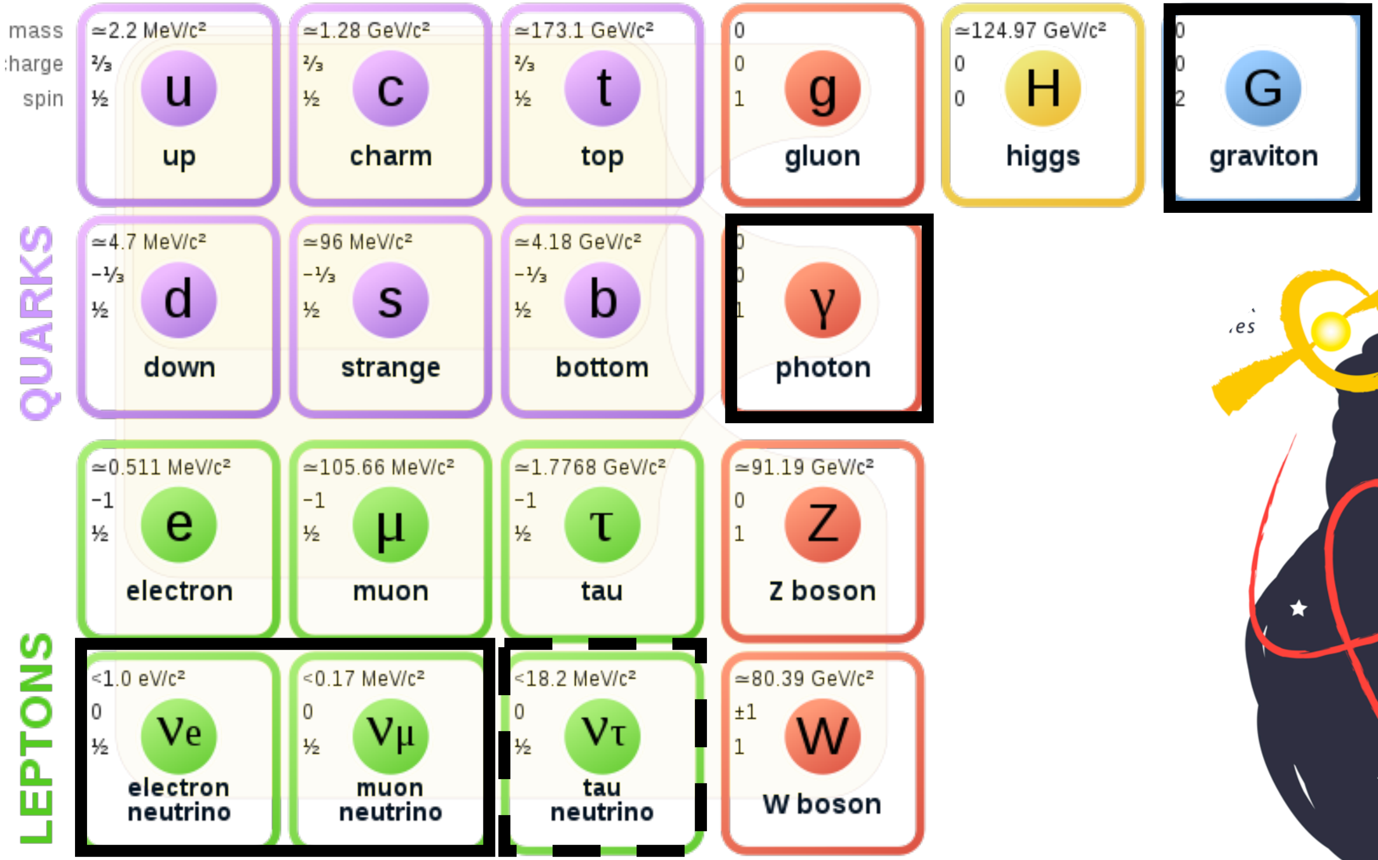
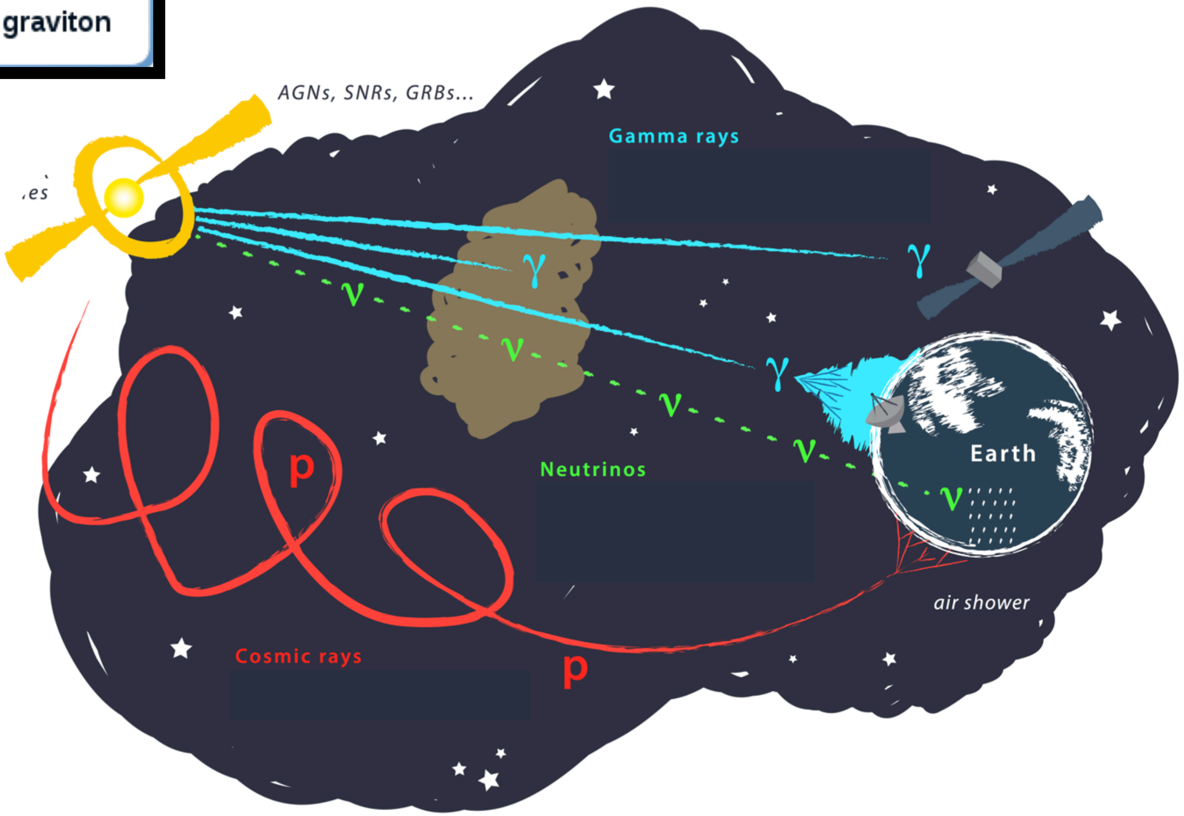
credit: DESY / SciComLab

The dawn of Multimessenger Astronomy

New Windows on the Universe

Multimessenger Astronomy: the exploration of the Universe through combining information from a multitude of cosmic messengers: electromagnetic radiation, gravitational waves, neutrinos and cosmic rays





The dawn of Multimessenger Astronomy

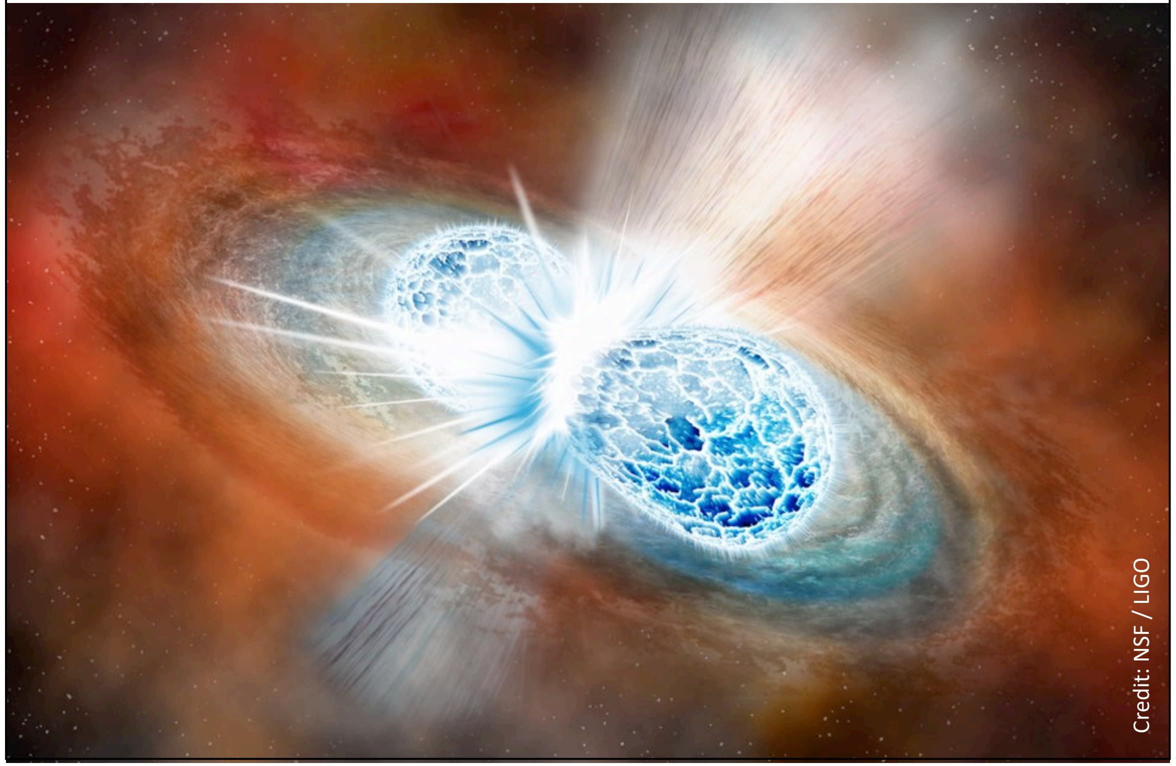
Recent highlights

Highlight #1: First merger of two Neutron-stars

How: Gravitational waves + optical + X-rays

Where: Nature 551 (2017), Science 358 (2017), Astrophys.J. 848 (2017), MNRAS 481 (2018)

Who: ~3000 astronomers / 70 observatories

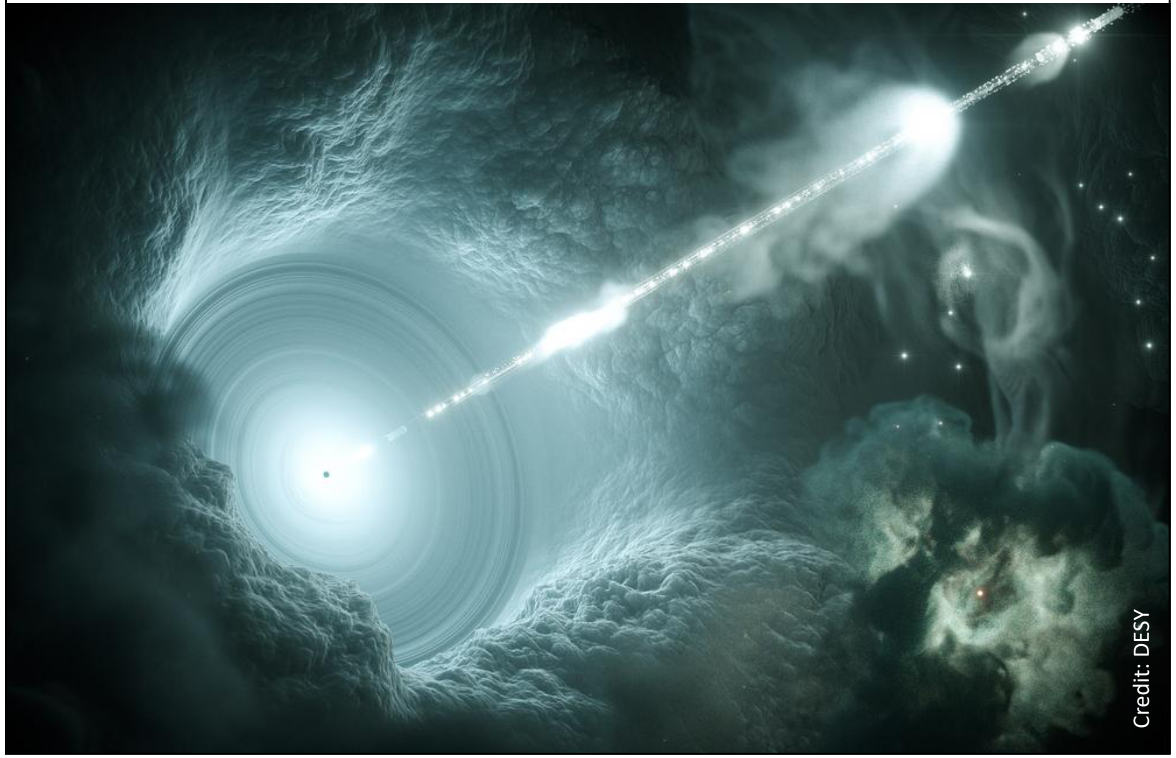


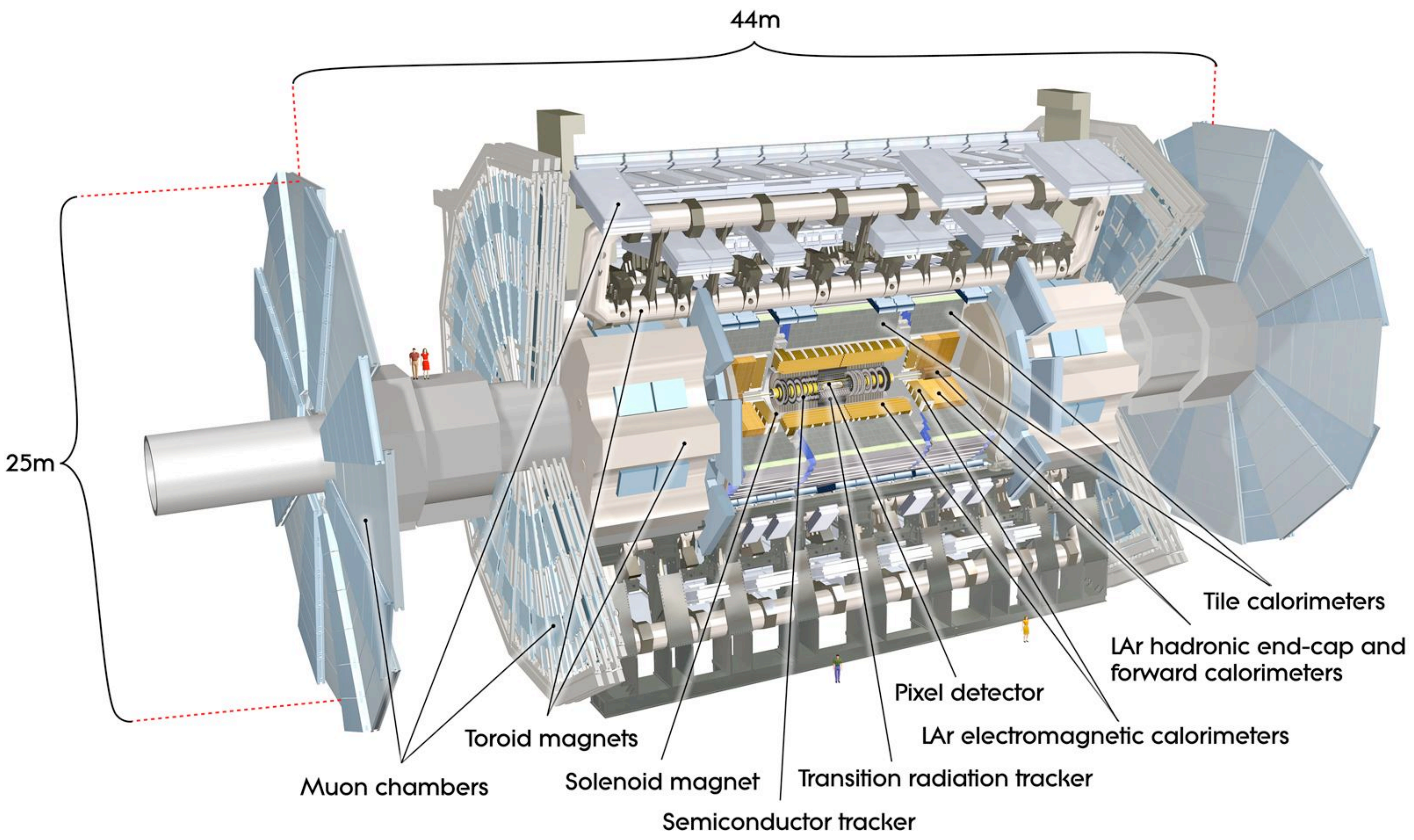
Highlight #2: First source of high energy neutrinos

How: Neutrinos + gamma-rays

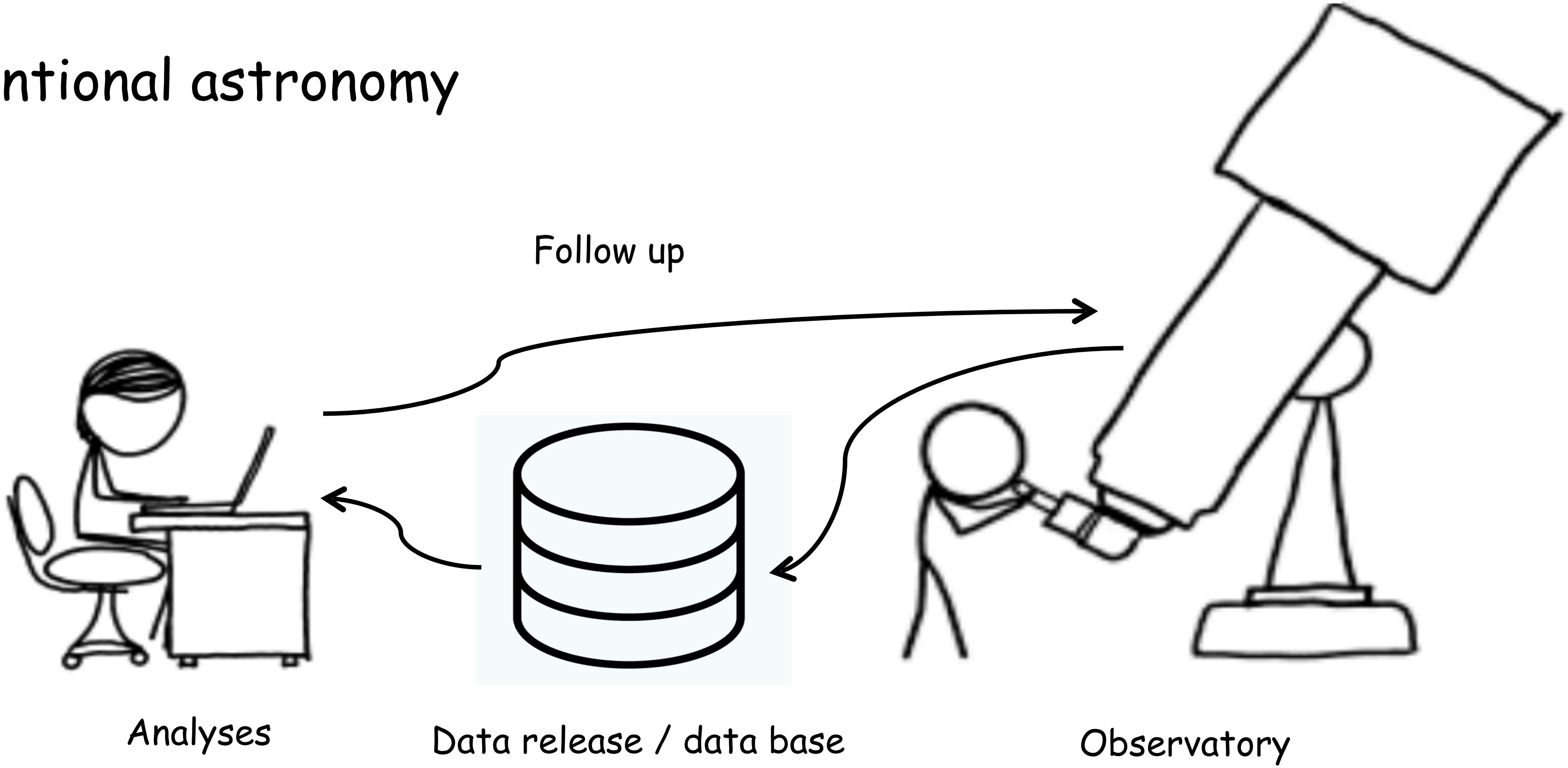
Where: Science 361 (2018), Astrophys.J.Lett. 863 (2018)

Who: ~1000 astronomers / 16 observatories



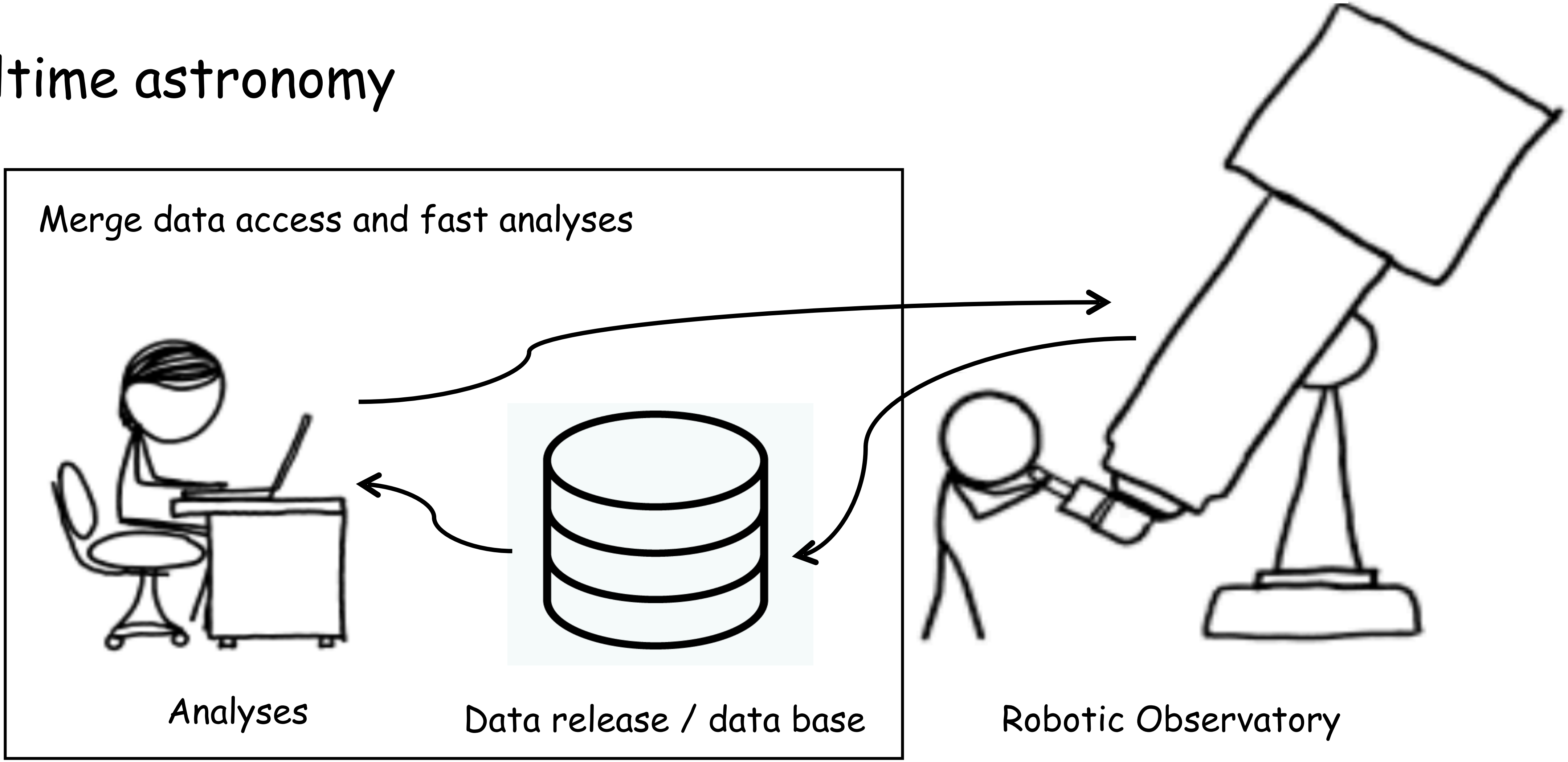

44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Solenoid magnet
Transition radiation tracker
Muon chambers
Semiconductor tracker

Conventional astronomy



Time scale > days; # Supernovae ~100

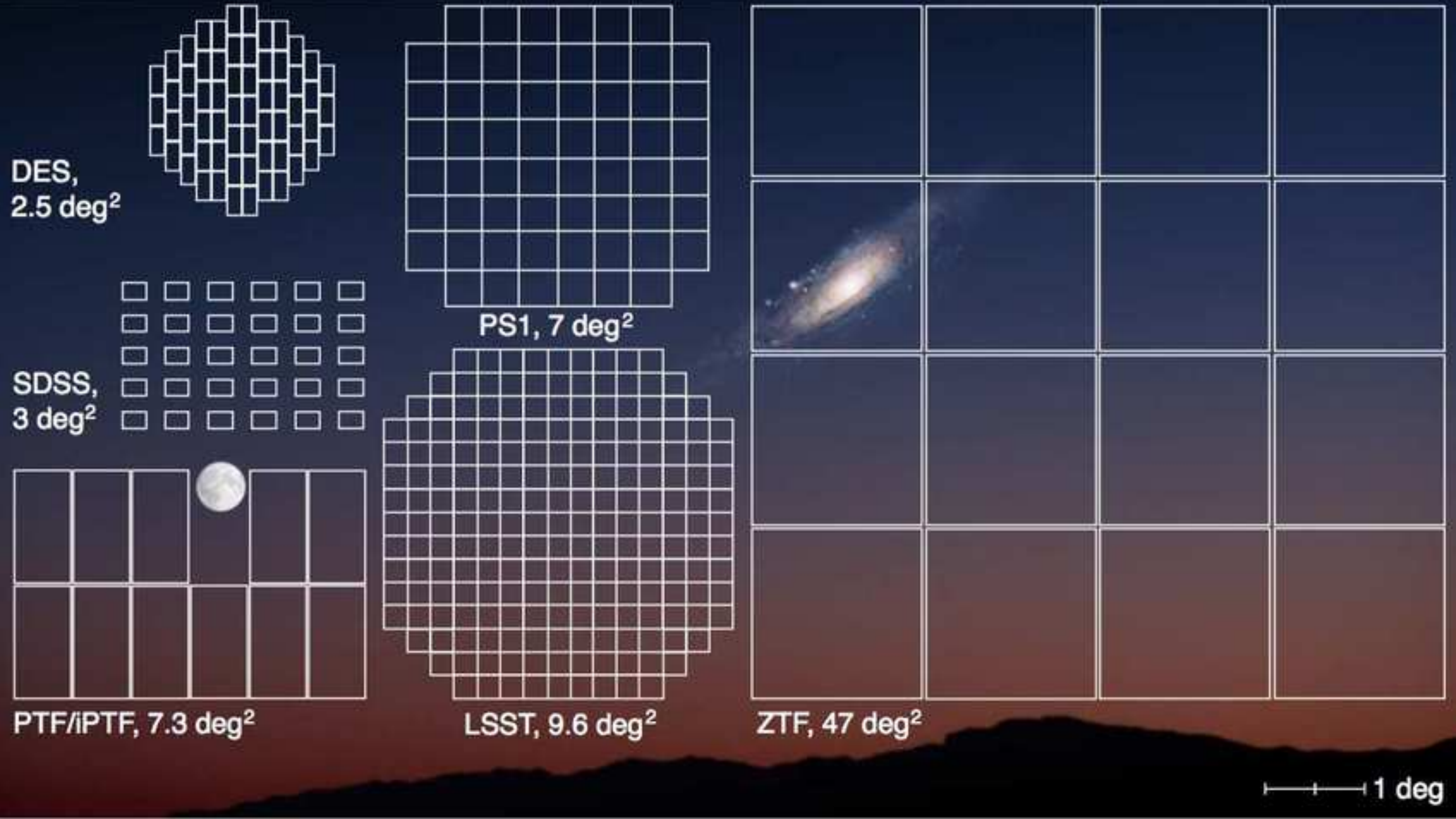
Realtime astronomy



Time scale ~ minutes; # Supernovae >> 1000

The Zwicky Transient Facility Experience…

Combining a public wide-field survey with robotic spectroscopic follow-up


DES,
2.5 deg²
PS1, 7 deg²
SDSS,
3 deg²
PTF/iPTF, 7.3 deg²
LSST, 9.6 deg²
ZTF, 47 deg²
1 deg

Transient detections with ZTF and AMPEL

DiRAC

U. Washington, Seattle

s (16x)

20 detections/s

~2 Mbps

ipac

CalTech, Los Angeles

>80 exposures/h
47 deg² each

~350 Mbps

ZTF (Mt. Palomar, California)

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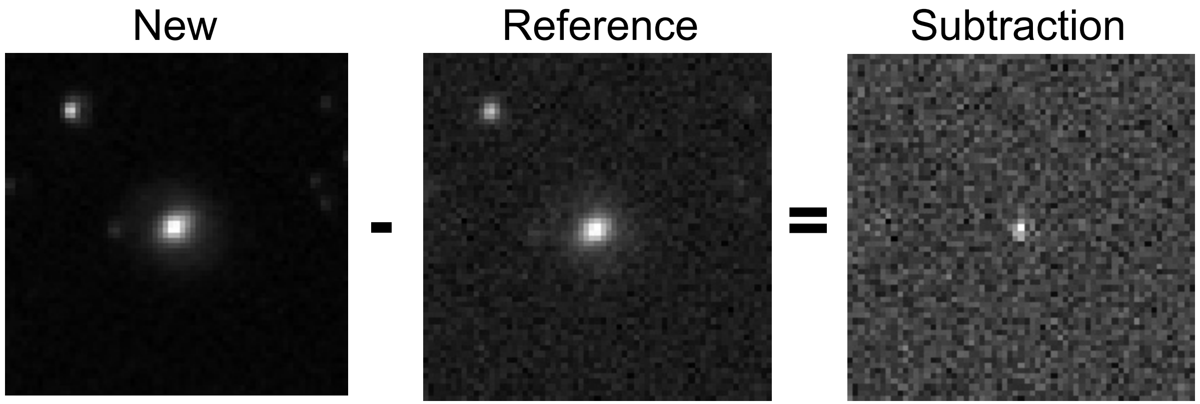
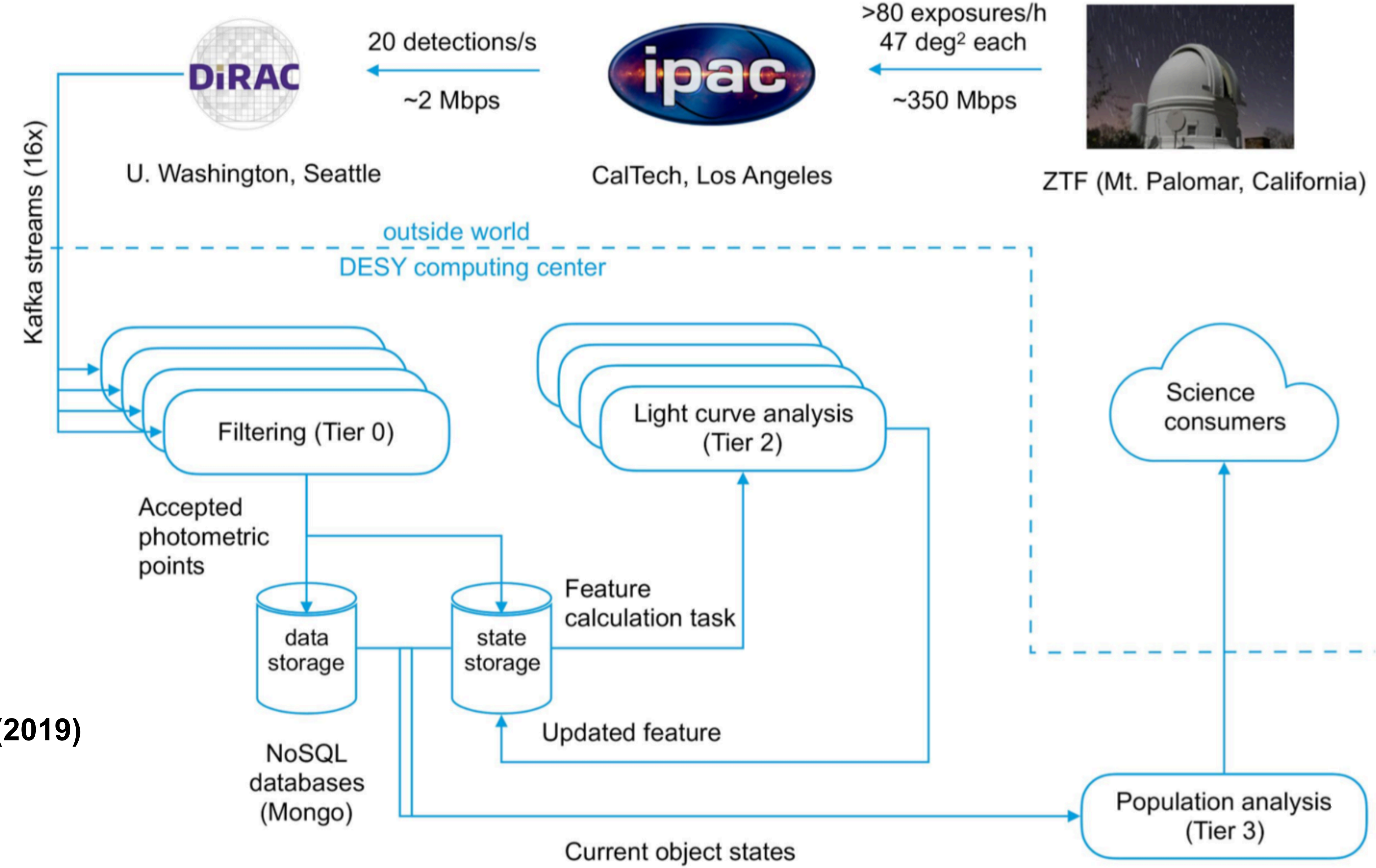


~10^5 events/night; 10% of LSST

Transient detections with ZTF and AMPEL

AMPEL
Real-time analysis framework running 24/7 @ DESY

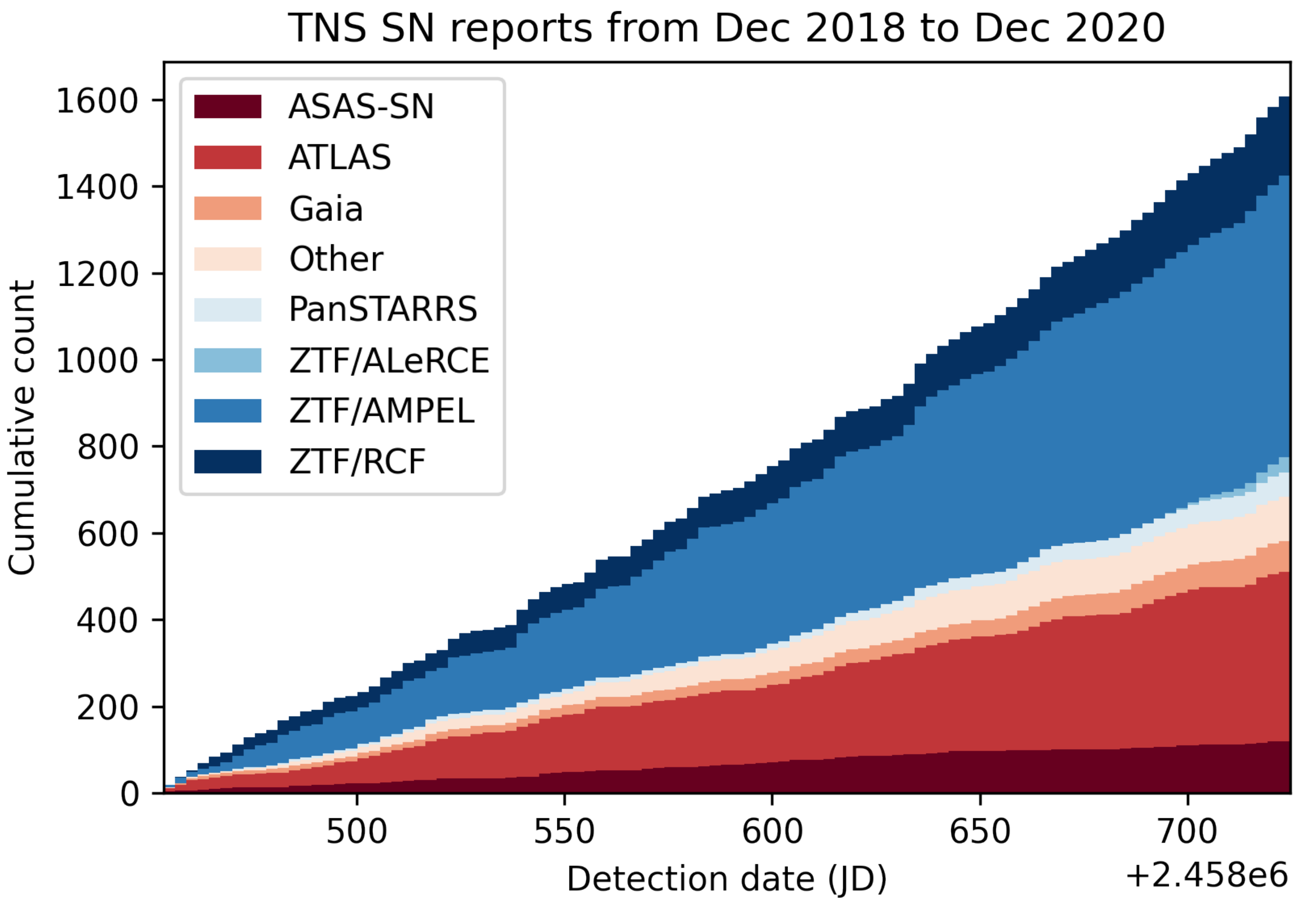
J. Nordin et al. A&A (2019)



SN detections with ZTF and AMPEL

Our “Lumi”

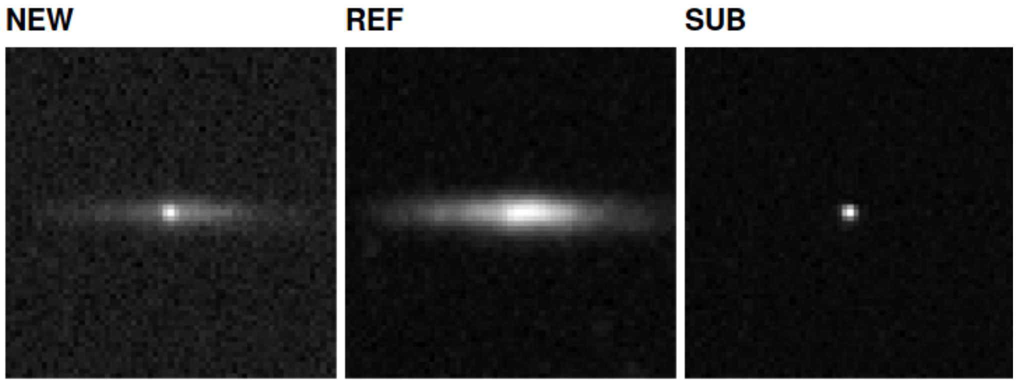
Automatic identification of supernova candidates and insertion to transient name server (TNS)

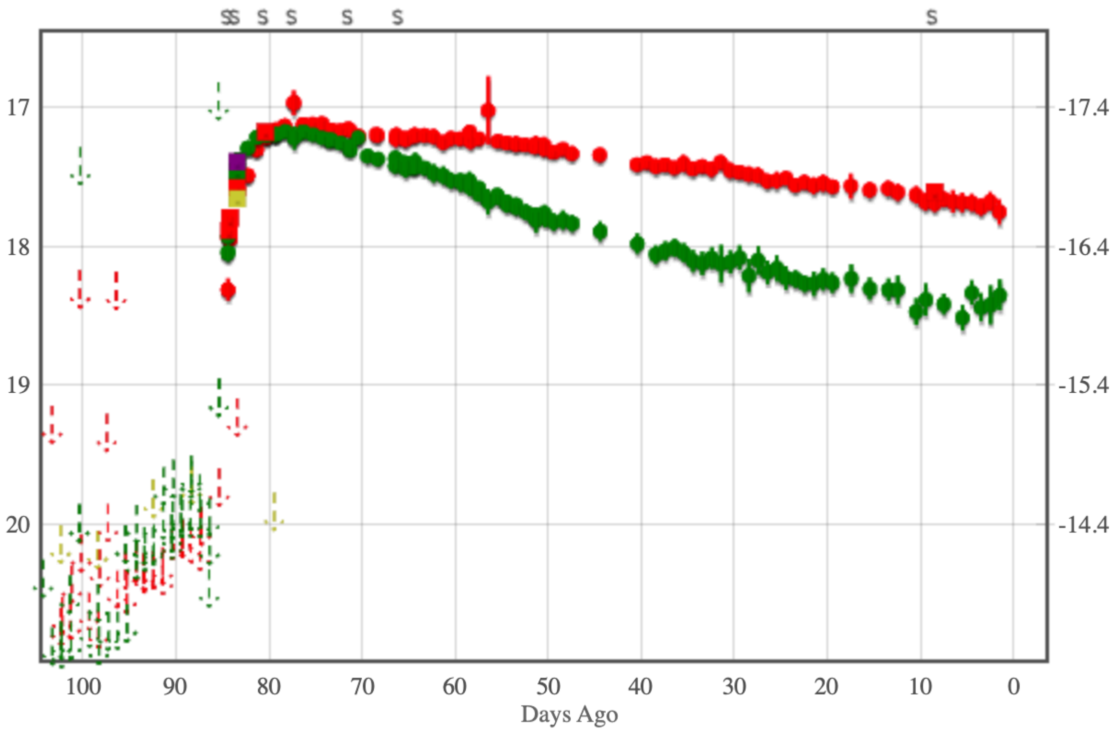


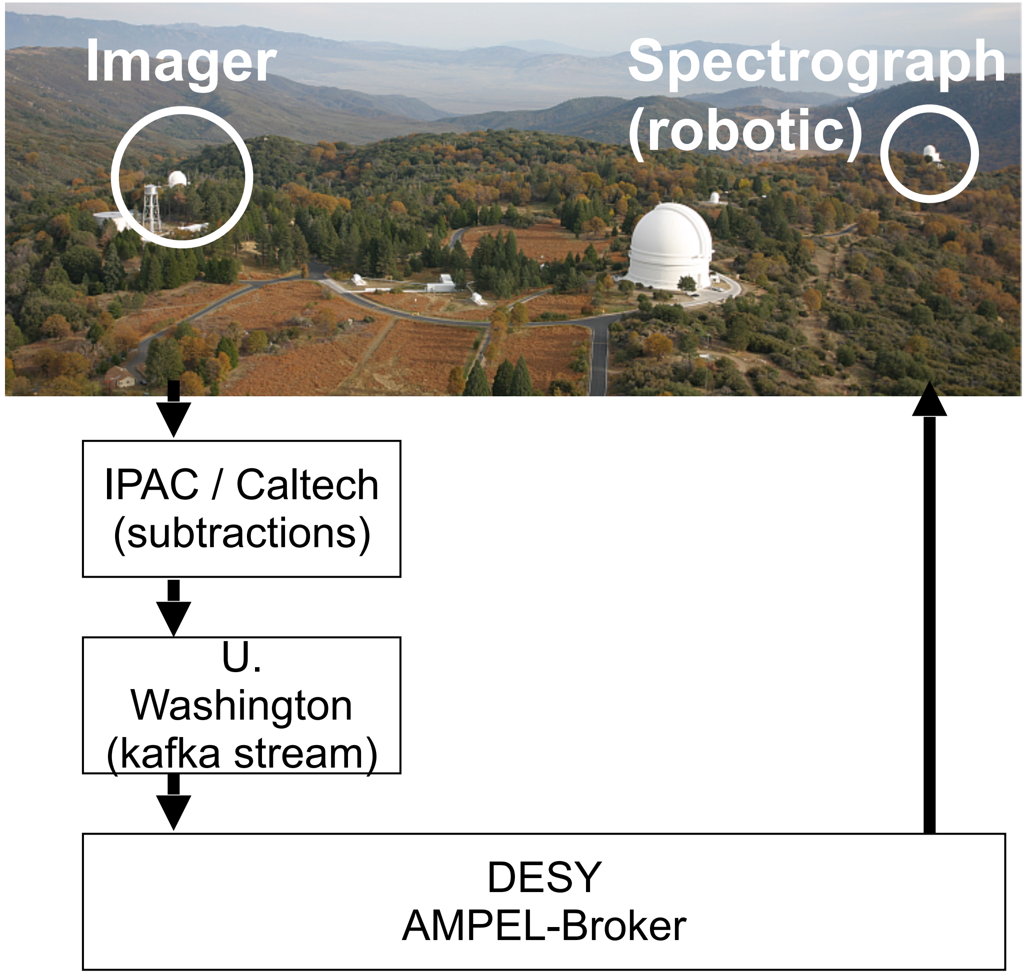
~40 % of all Supernova detected by AMPEL/ZTF

SN detections with ZTF and AMPEL

Fully automated rapid reaction spectroscopic follow-up and classification



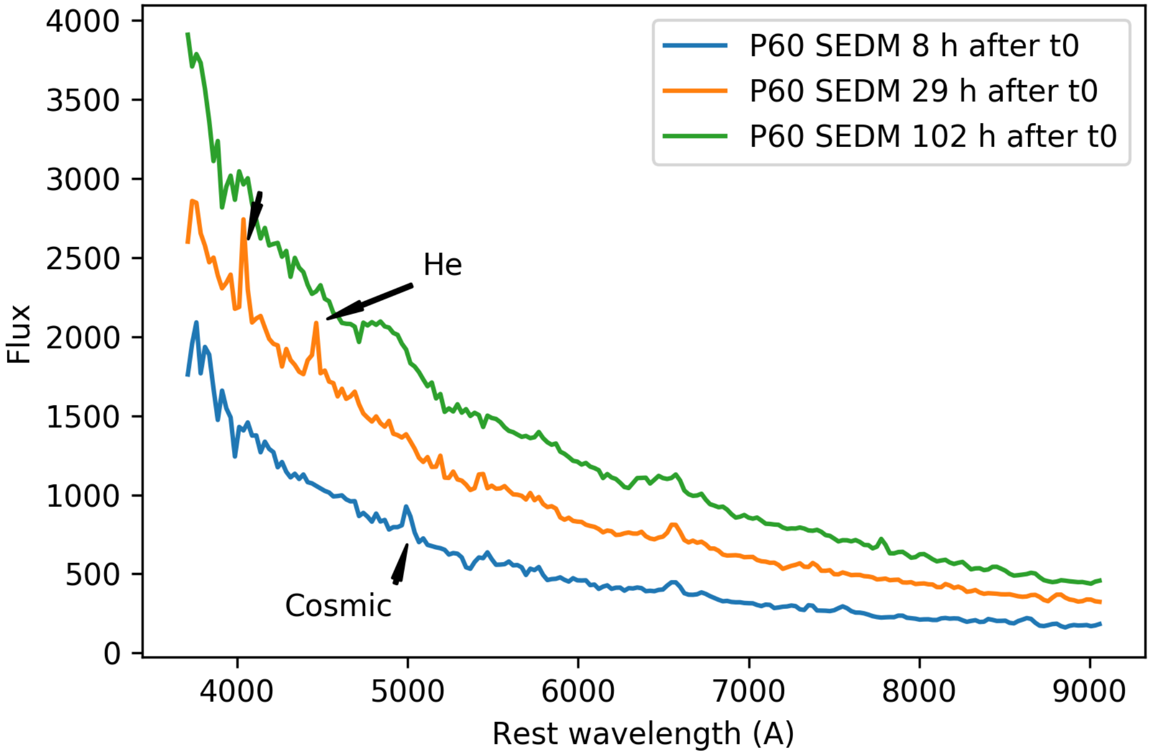


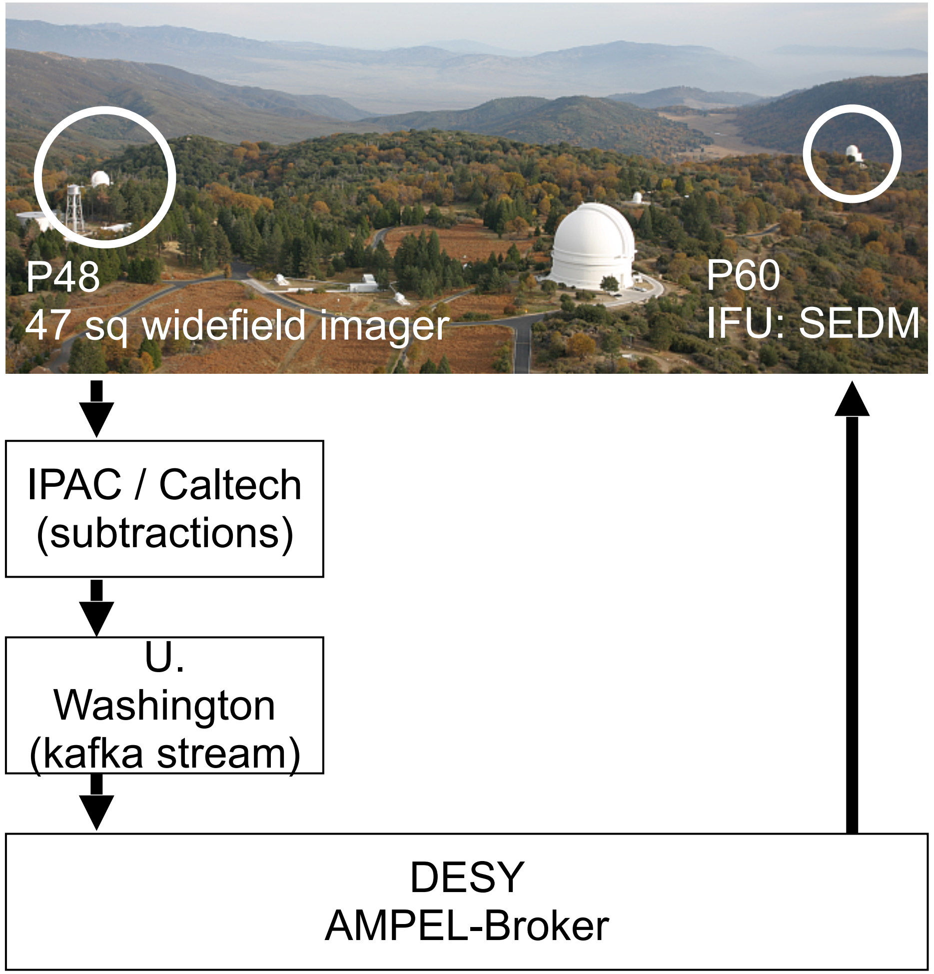


SN detections with ZTF and AMPEL

Fully automated rapid reaction spectroscopic follow-up and classification

Autonomously discovered 5h after explosion followed by first ever automatically triggered, observed and reduced spectrum.



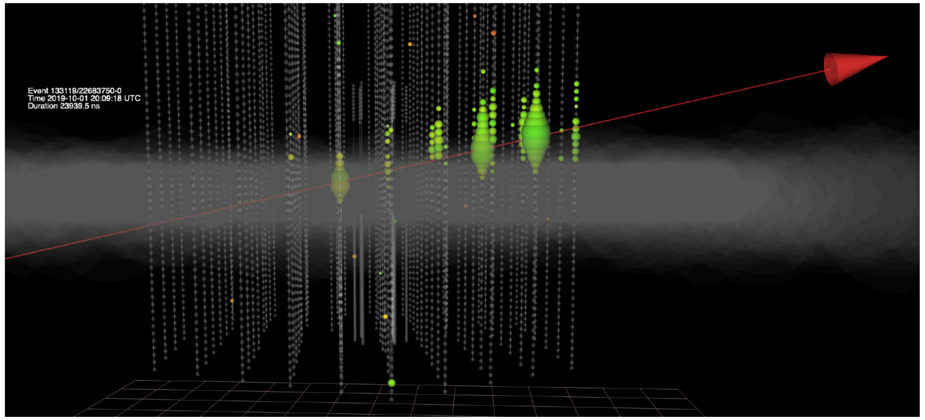


Robert Stein
PhD student @ DESY

Neutrino-Optical coincidences

ZTF follow-up of IceCube neutrinos

IceCube-191001A: 217 TeV

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TITLE:   GCN CIRCULAR
NUMBER:  25913
SUBJECT: IceCube-191001A - IceCube observation of a high-energy neutrino
candidate event
DATE:    19/10/01 23:16:38 GMT
FROM:    Robert Stein at DESY  <robert.stein@desy.de>

The IceCu

On 19/10/
high prob
by the IC
neutrino
alarm rat
IceCube d

After the
(https://
<https://
sophistic
direction

Date: 19/
Time: 20:
RA: 314.0
Dec: 12.9
```

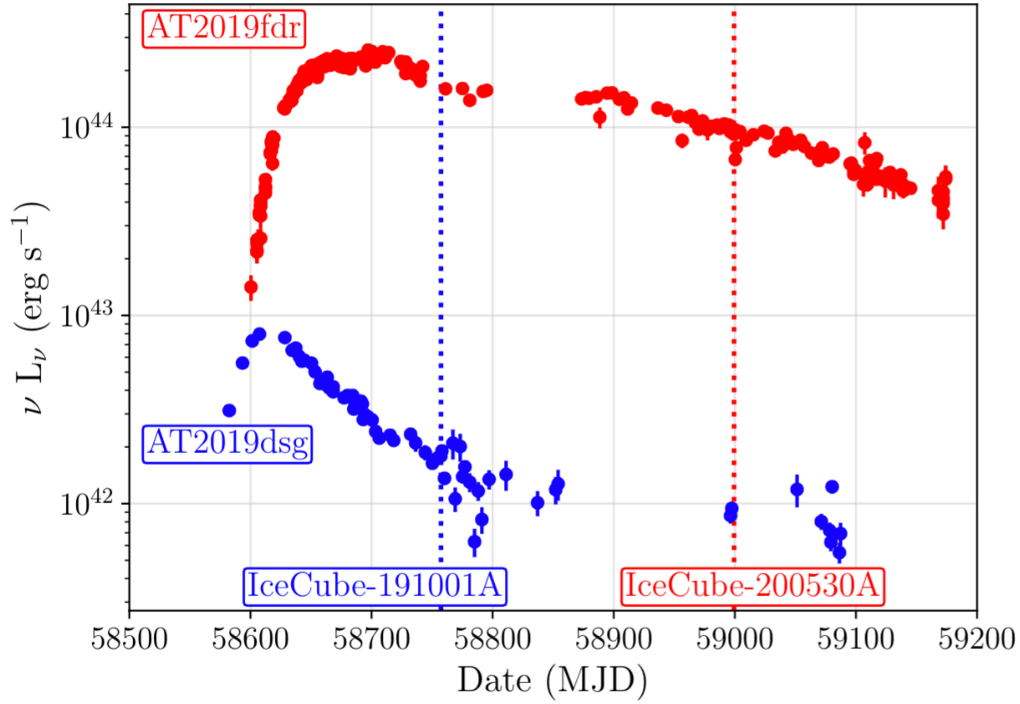
Candidate Counterparts to IceCube-191001A with ZTF

ATel #13160; ***Robert Stein (DESY), Anna Franckowiak (DESY), Jannis Necker (DESY), Suvi Gezari (UMd), Sjoert van Velzen (UMd/NYU)***
on 2 Oct 2019; 22:00 UT
Distributed as an Instant Email Notice Transients
Credential Certification: Anna Franckowiak (anna.franckowiak@desy.de)

Subjects: Radio, Optical, X-ray, Neutrinos, Supernovae, Transient, Tidal Disruption Event

Tweet

On behalf of the Zwicky Transient Facility (ZTF) and Global Relay of Observatories Watching Transients Happen (GROWTH) collaborations: We observed the localization region of the neutrino event IceCube-191001A (Stein et al., GCN 25913) with the Palomar 48 inch telescope



Tidal Disruption Events in coincidence with IceCube neutrinos @ 3.5 sigma

Stein et al., *Nature Astro.* 2021, S. Reusch et al, *PRL* 2022

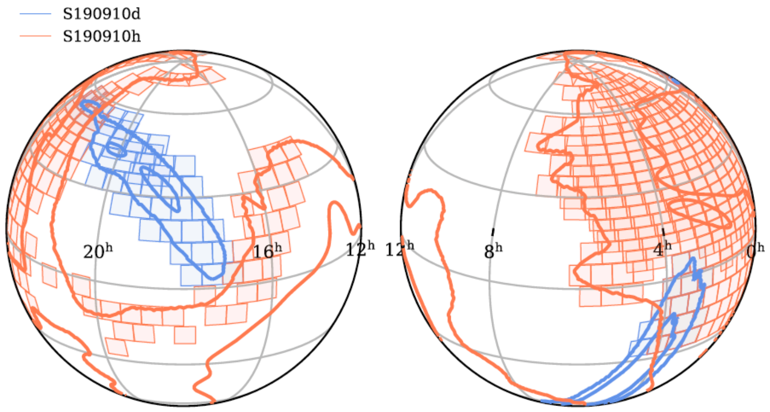
GW follow-up

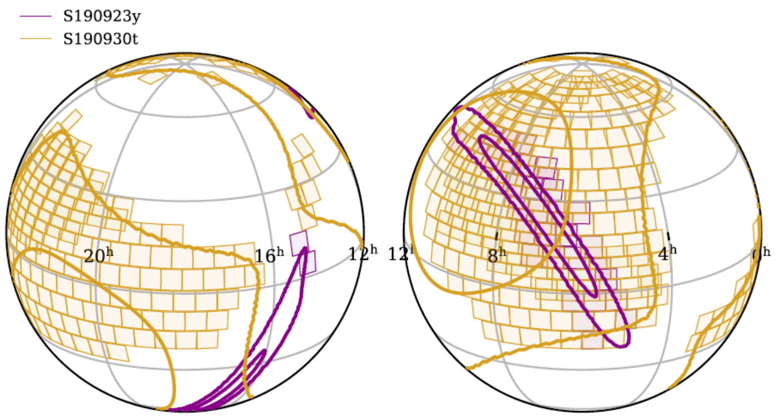
Serendipitous search instead of triggered for large areas

	FAR	Localization	Distance	Classification
GW190425z	1 per 69000 yrs	7461 sq deg	156 +/- 41 Mpc	BNS
GW190426c	1 per 1.6 yrs	1131 sq deg	377 +/- 100 Mpc	NSBH
GW190510g	1 per 3.6 yrs	1166 sq deg	227 +/- 92 Mpc	BNS
GW190814bv	1 per 10^25 yrs	23 sq deg	267 +/- 52 Mpc	NSBH
GW190901ap	1 per 4.5 yrs	14753 sq deg	241 +/- 79 Mpc	BNS
GW190910d	1 per 8.5 yrs	2482 sq deg	632 +/- 186 Mpc	NSBH
GW190910h	1 per 0.9 yrs	24264 sq deg	230 +/- 88 Mpc	BNS
GW190923y	1 per 0.67 yrs	2107 sq deg	438 +/- 133 Mpc	NSBH
GW190930t	1 per 2.0 yrs	24220 sq deg	108 +/- 38 Mpc	NSBH
GW191205ah	1 per 2.5 yrs	6378 sq deg	385 +/- 164 Mpc	NSBH
GW191213g	1 per 0.89 yrs	4480 sq deg	201 +/- 81 Mpc	BNS
GW200105ae	NA	7373 sq deg	283 +/- 74 Mpc	NSBH
GW200115j	1 per 1513 yrs	677 sq deg	332 +/- 78 Mpc	NSBH
GW200213t	1 per 1.8 yrs	2326 sq deg	201 +/- 80 Mpc	BNS

Effective, prompt and comprehensive searches are now being done even for 1000s of square degree localizations. Software (AMPEL!) is key.

~20 GCNs posted on follow-up of ZTF candidates.
Coughlin et. al. Astrophys.J.Lett. 885 (2019) 1, L19, https://arxiv.org/abs/1907.12645
Kasliwal, Astrophys.J. 905 (2020) 2, 145, https://arxiv.org/abs/2006.11306





Conclusion

- Multimessenger astronomy has recently delivered spectacular breakthroughs, e.g. the first detection of counterparts of GWs and (likely) cosmic neutrinos
- We are implementing new ways of automatization and connections between observatories, enabling optimal exploitation of resources
- Upcoming observatories, such as LSST and IceCube-Gen2, will increase the data rates further by an order of magnitude
- The French (FINK) and German (AMPEL) broker teams are working together to harness the data streams.