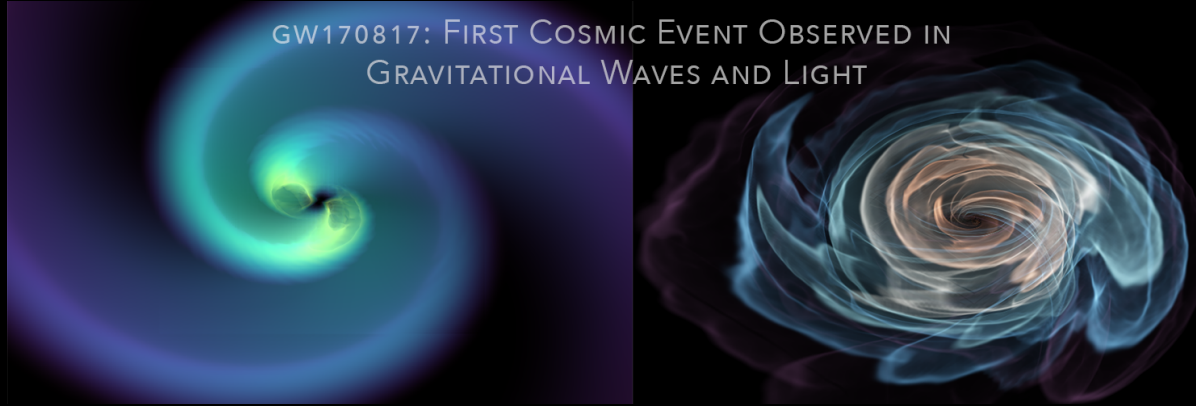


GW170817: FIRST COSMIC EVENT OBSERVED IN
GRAVITATIONAL WAVES AND LIGHT



Mansi M. Kasliwal

ASSISTANT PROFESSOR OF ASTRONOMY
CALIFORNIA INSTITUTE OF TECHNOLOGY



Kasliwal Research Group



Jacob Jencson
(Grad, 5th Year)



Kishalay De
(Grad, 3rd Year)



Samaporn Tinyanont
(Grad w/ Mawet)



Shreya Anand
(Grad w/ Weinstein)



Scott Adams
(Postdoc)



Matt Hankins
(Postdoc)



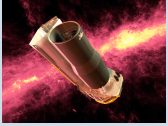
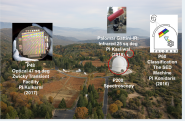
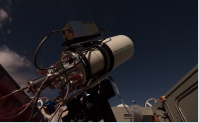
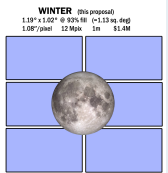
Christoffer Fremling
(Postdoc)



Igor Andreoni
(Postdoc)

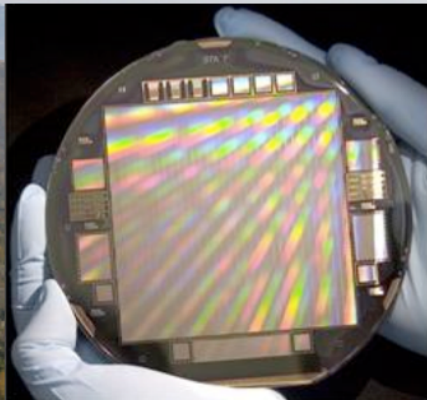
Alumni: Ragnhild Lunnan, Dave Cook, Ryan Lau, Nadia Blagorodnova,
Stephanie Kwan, Lindsey Whitesides, Viraj Karambelkar, Chris Cannella

My Dynamic Infrared Roadmap

	Project	Description	Status
Phase I 	SPIRITS (Jencson PhDT)	Target 200 galaxies with the Spitzer Space Telescope	2014-2019 Ongoing
Phase II 	ZTF	Classify the reddest optical transients	2018-2020 Ongoing
Phase III 	Palomar Gattini-IR (De PhDT)	15,000 sq deg every night in J-band to 16.4 mag	Sep 11, 2018 First Light
Phase IV 	WINTER	1 sq deg yJH camera on a 1 meter telescope	Summer 2020 Just Funded

And then perhaps, go to a Polar Location or Space...

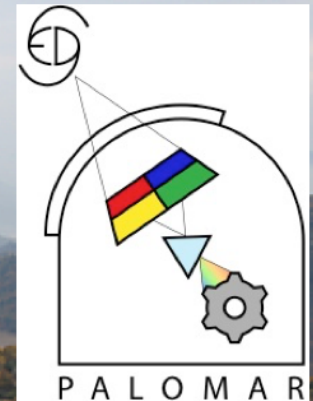
Palomar Observatory



P48
Optical 47 sq deg
Zwicky Transient
Facility
PI Kulkarni
(2017)



Palomar Gattini-IR:
Infrared 25 sq deg
PI Kasliwal
(2018)



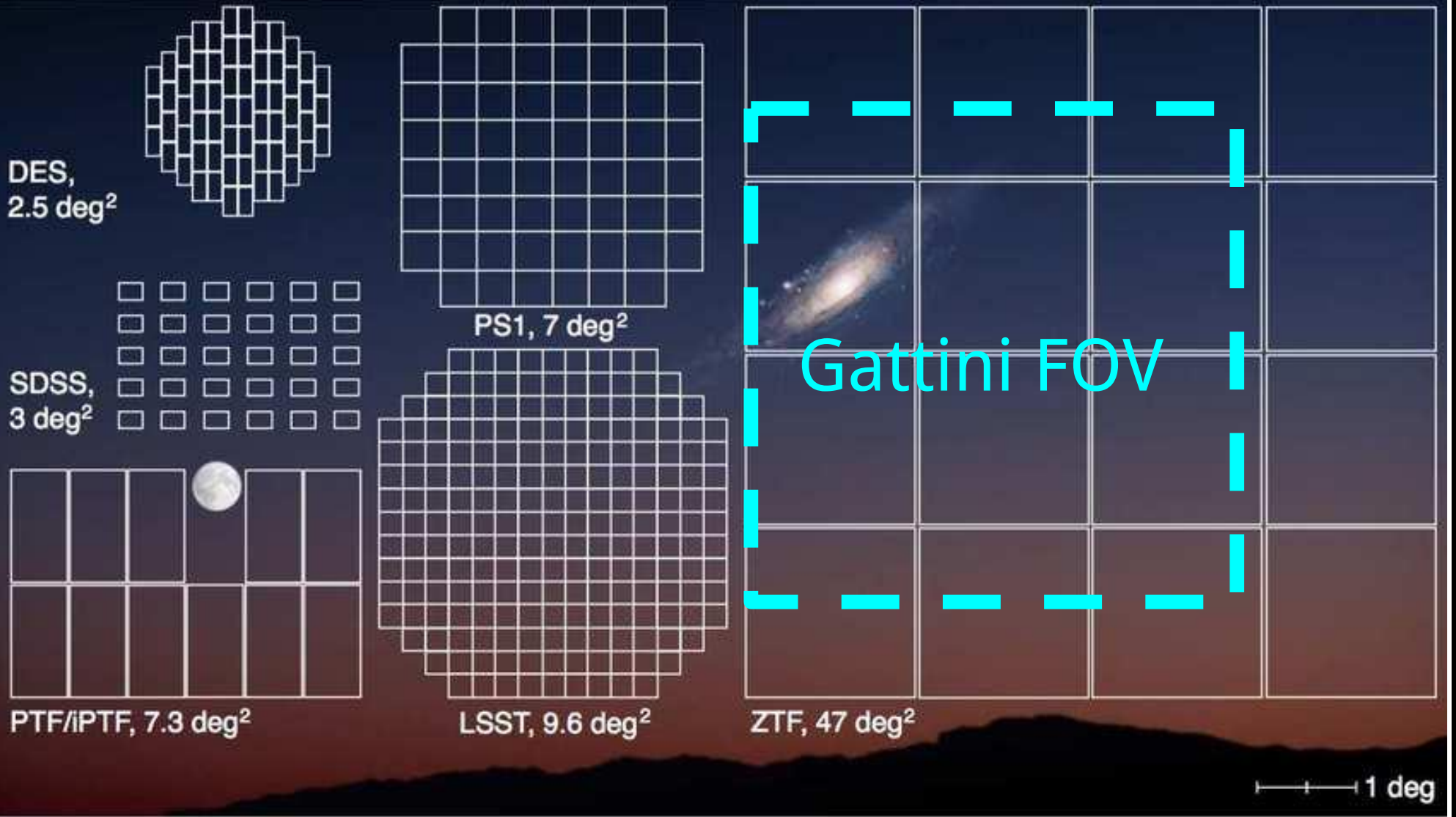
P60
Classification
The SED
Machine
PI Konidaris
(2016)



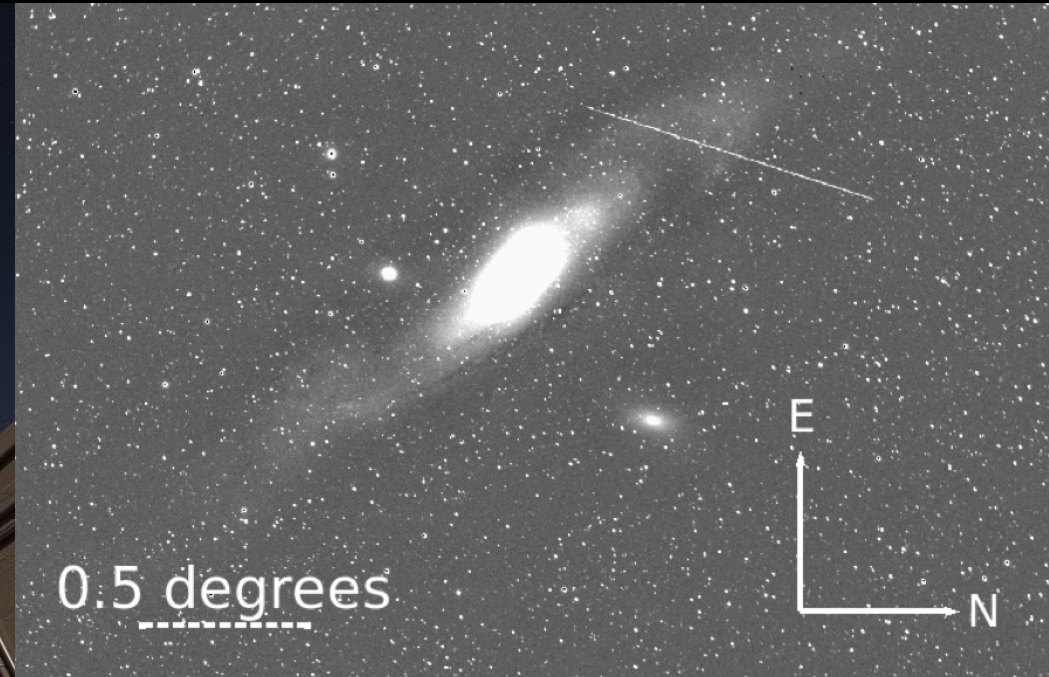
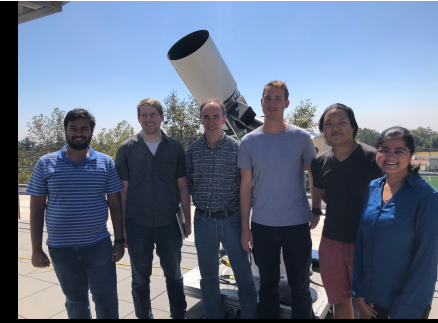
P200:
Spectroscopy

WINTER
1m 1 sq deg
(2020)

Mapping Speed



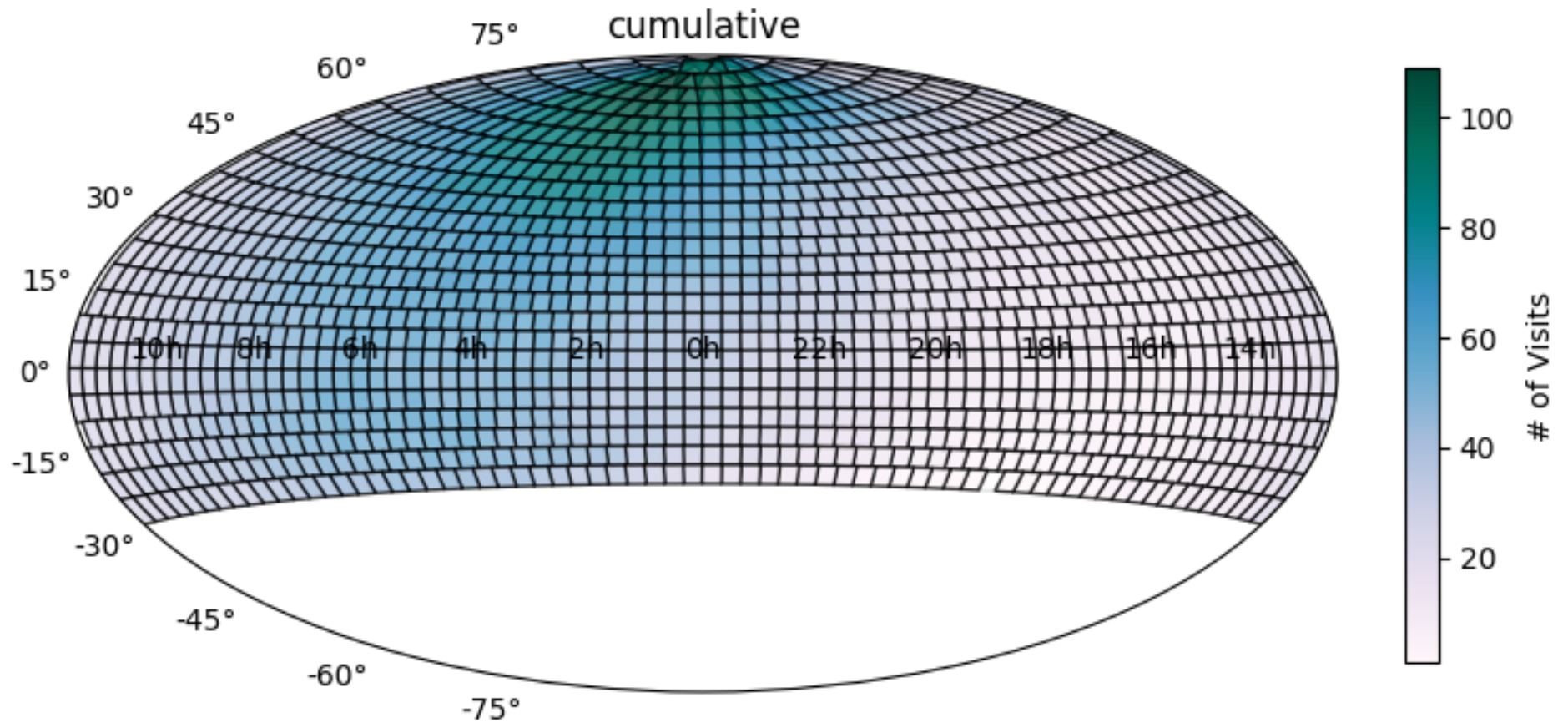
Palomar Gattini-IR: *Opening up the dynamic infrared sky*



A robotic 30cm telescope with a 25 sq deg FoV camera
Surveys 9,000 sq deg to $J < 16$ mag every night!
In partnership with Anna Moore (ANU)

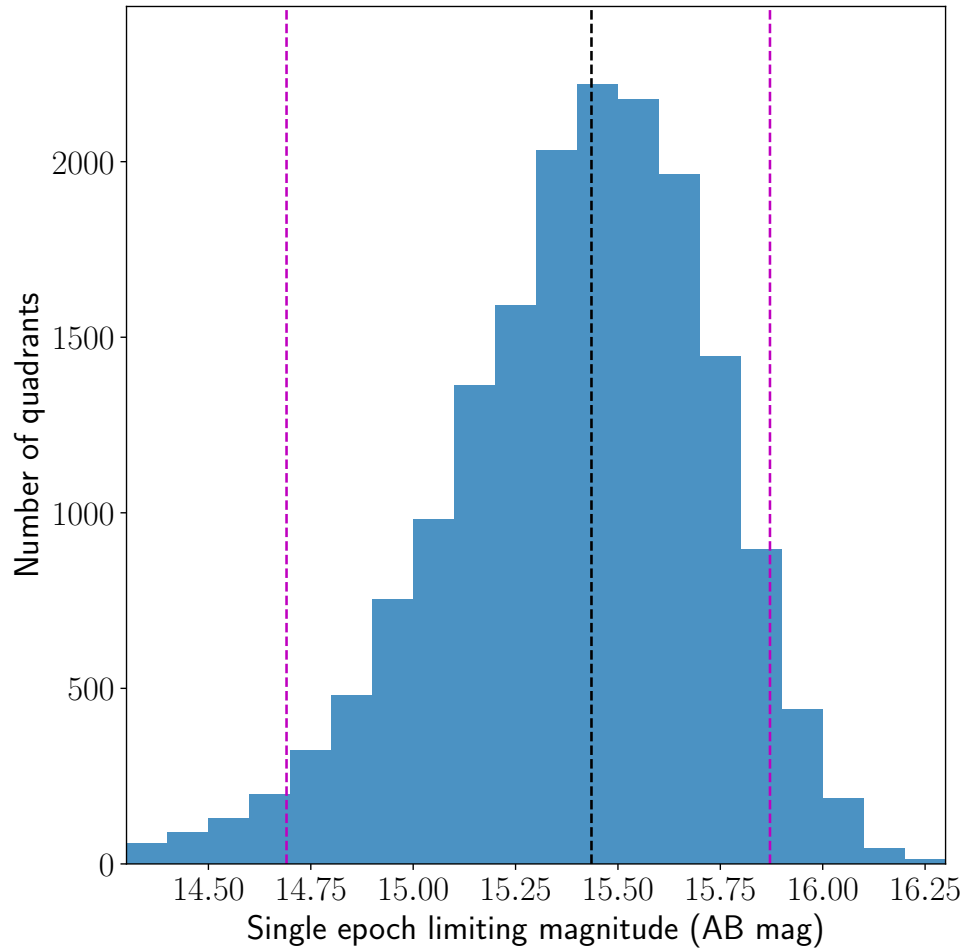
First light: September 11, 2018

Sky Coverage to date

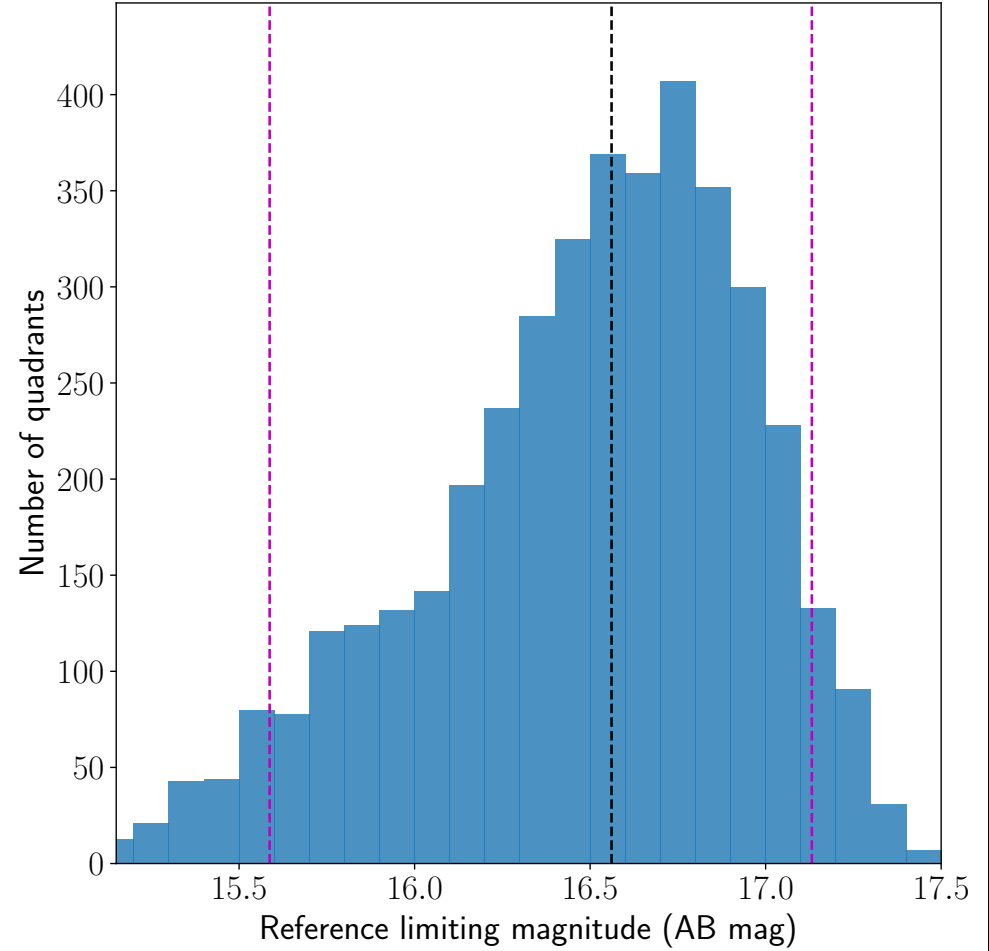


~9000 square degrees mapped every night!

Depth

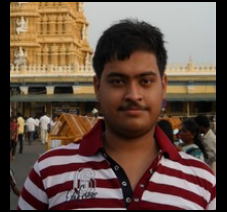
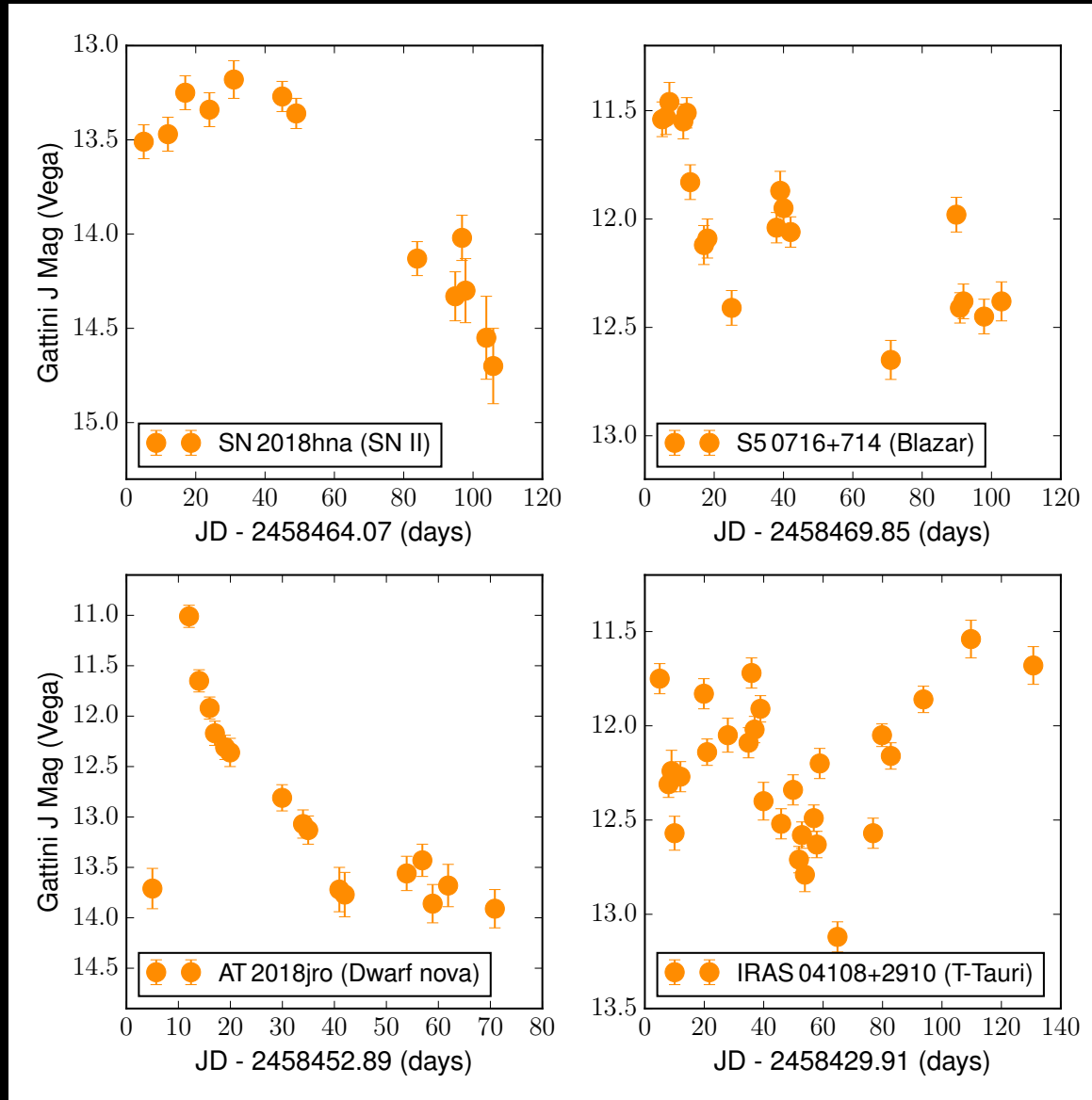


Nightly 5-sigma Depth



Stacked Reference Depth

Collage of Palomar Gattini-IR light curves

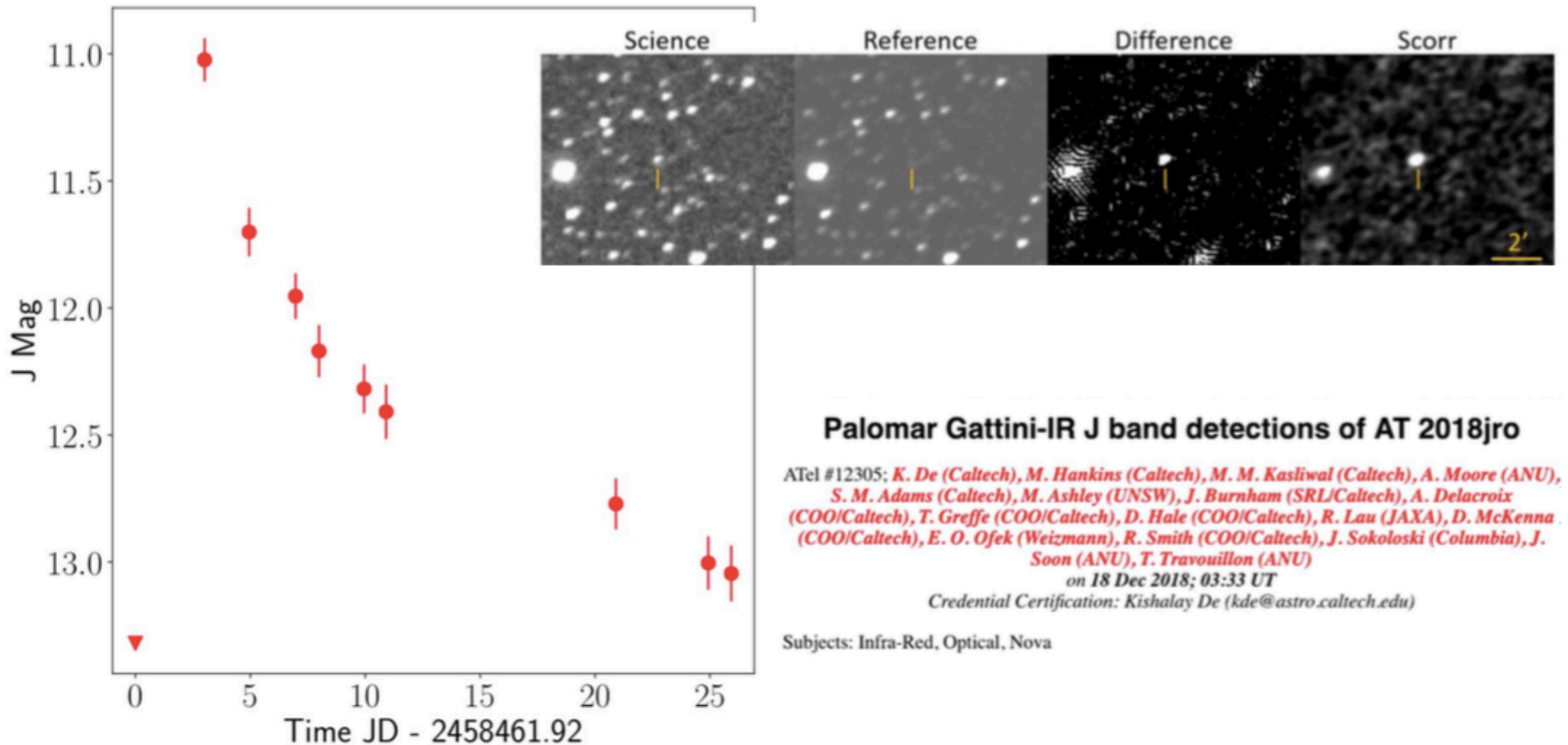


Kishalay De



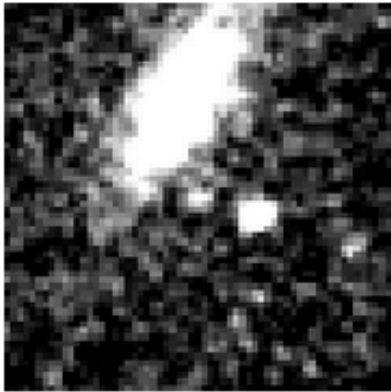
Matt Hankins

Light curve of dwarf nova AT 2018jro

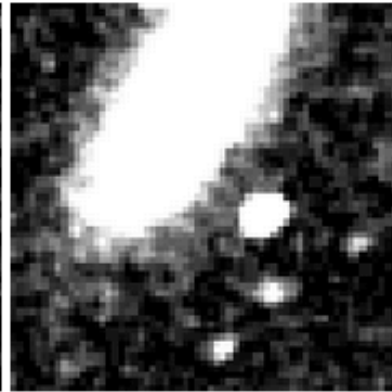


Last Night

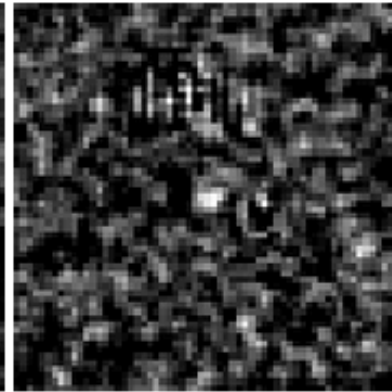
NEW



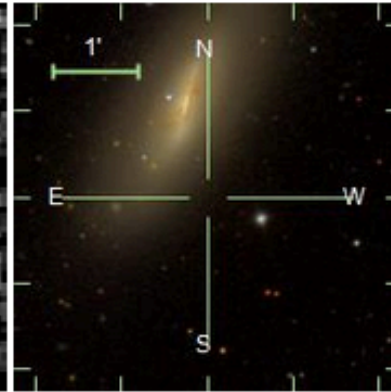
REF



SUB



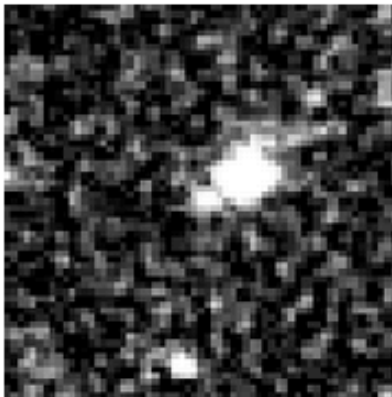
SDSS



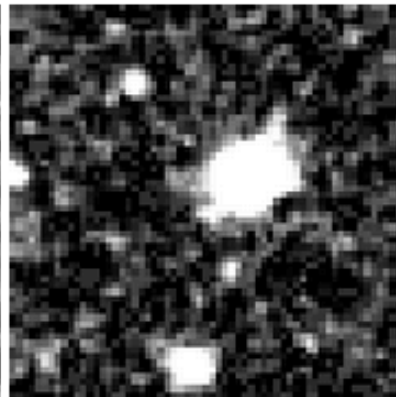
PS1



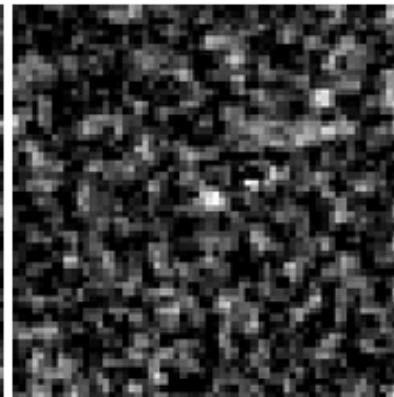
NEW



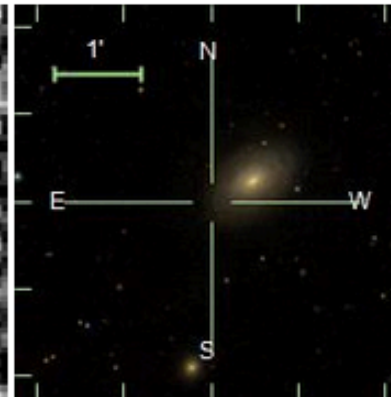
REF



SUB



SDSS



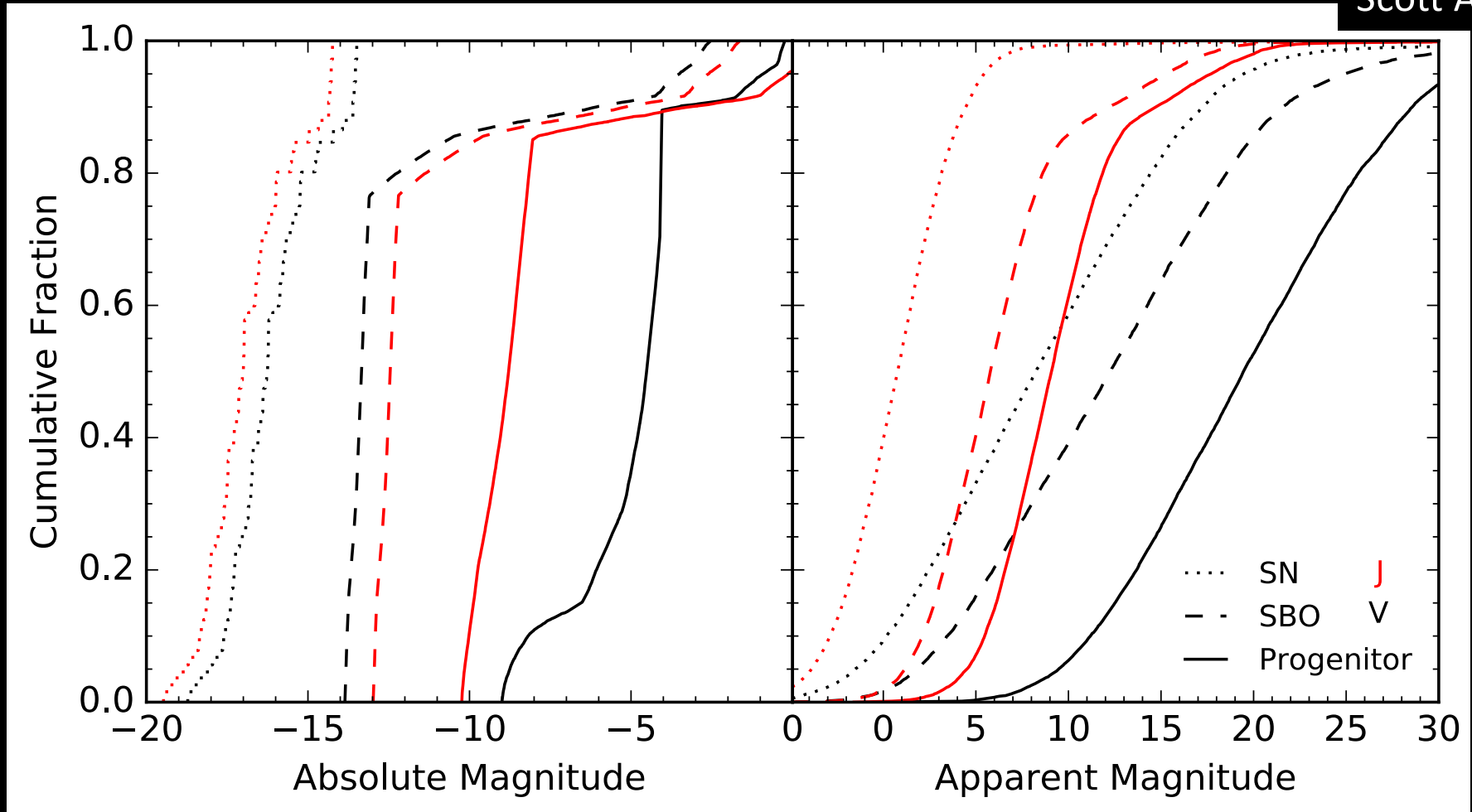
PS1



Supernova in the Milky Way



Scott Adams



Adapted from Adams et al. 2013

SPIRITS is discovering a wide range of IR transient sources.



Jacob Jencson

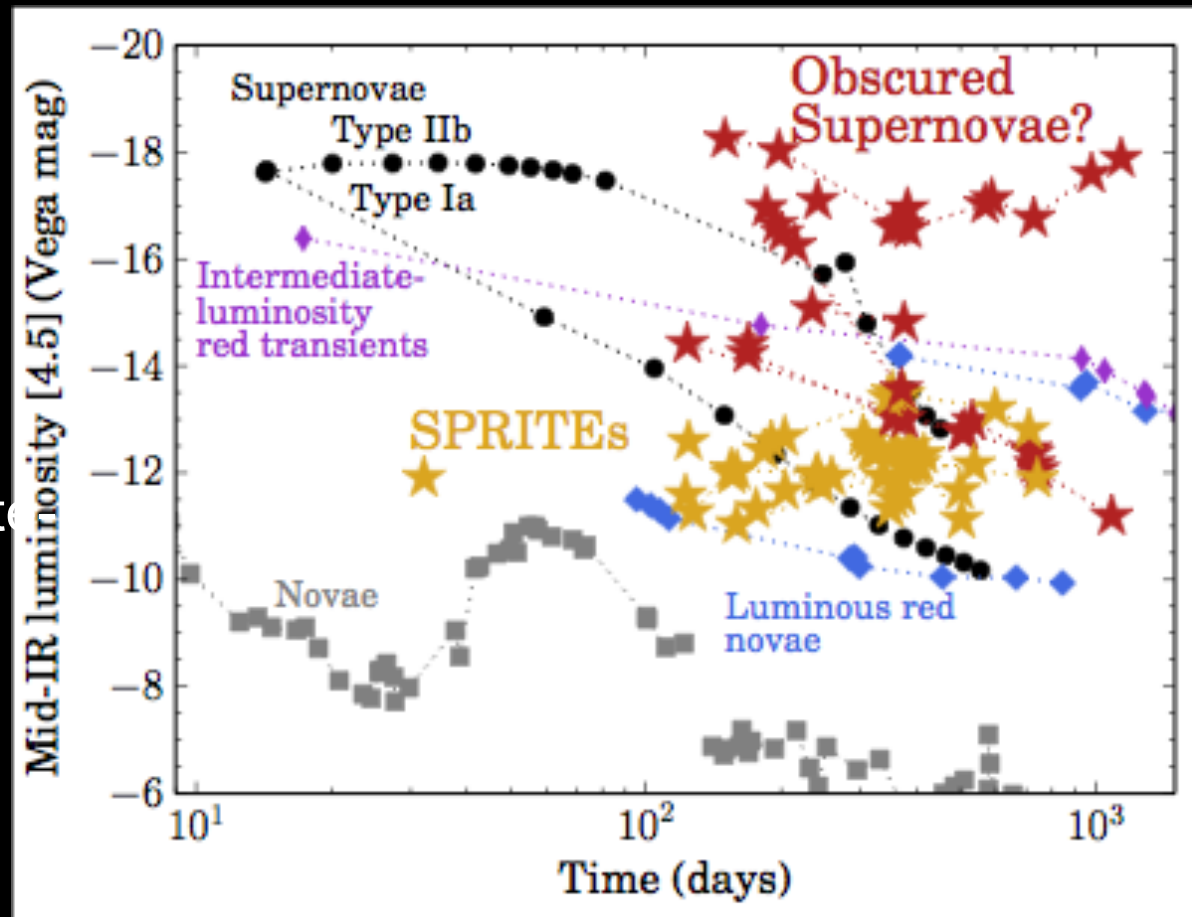
Identified 131+ transients

49 known supernovae

10 candidate obscured supernovae

8 likely classical novae

64 eSPecially Red Intermediate Luminosity Transient Events (SPRITEs)

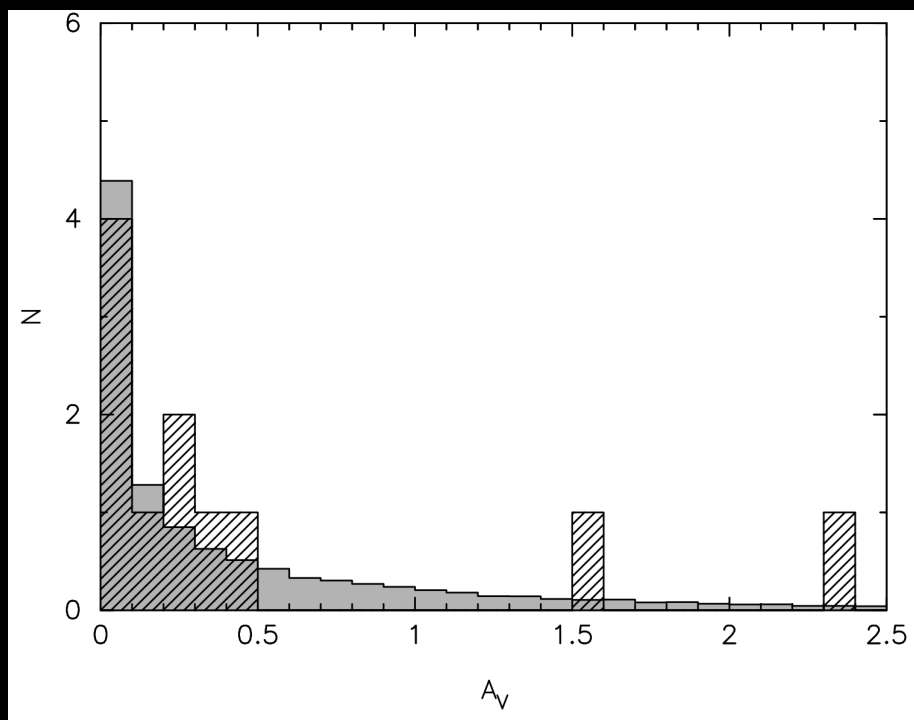


Jencson et al. 2017, 2018, 2019a, 2019b

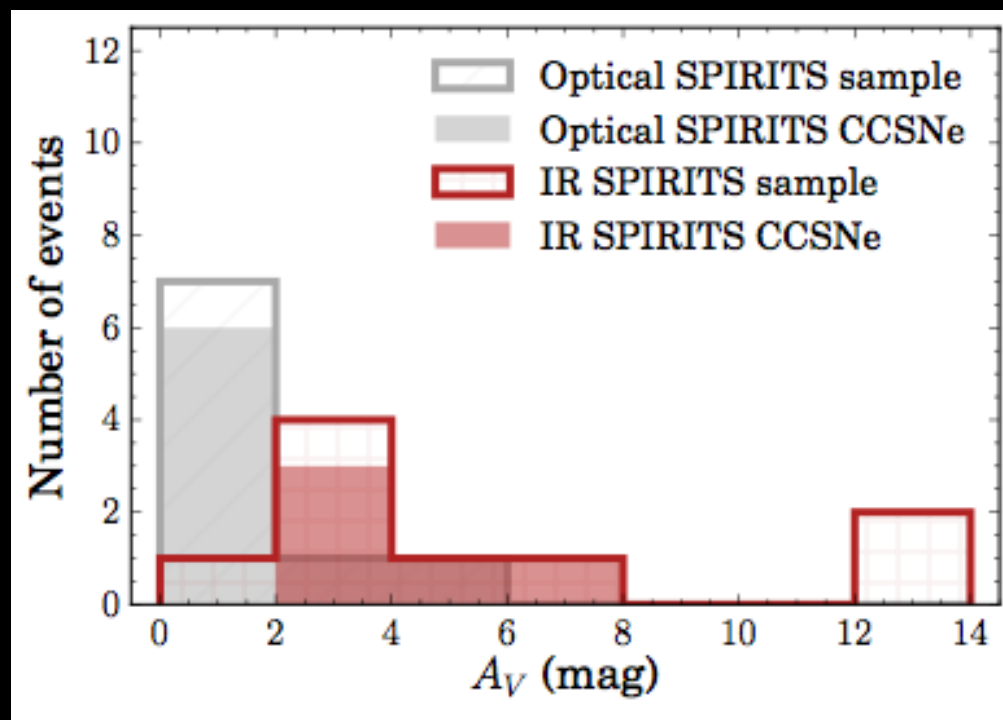
Fraction of optically missed, nearby supernovae as high as 38%.



Jacob Jencson

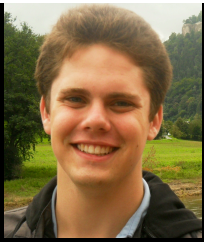


Mattila et al. 2012

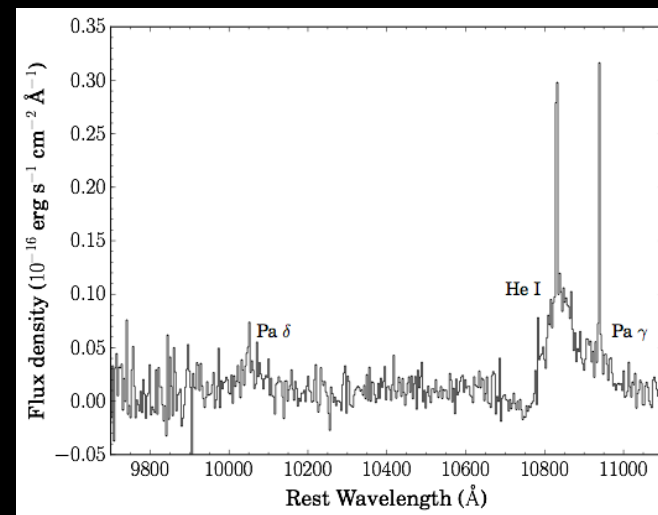
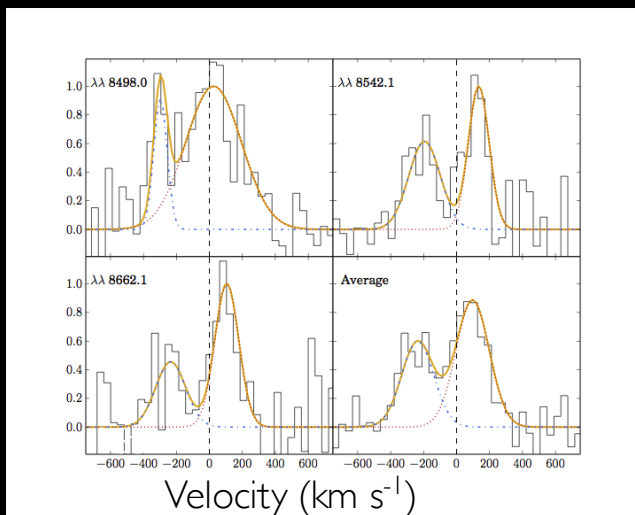
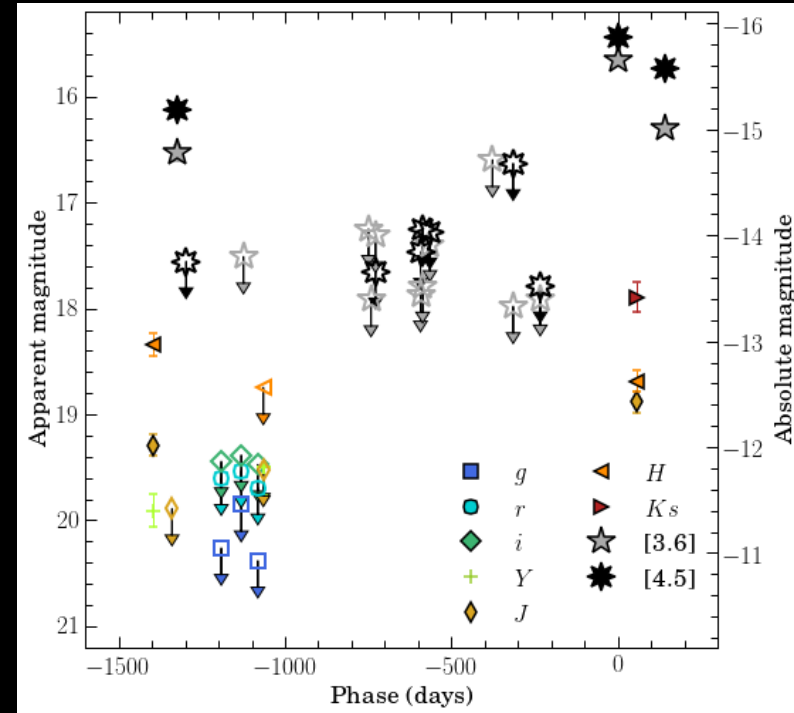
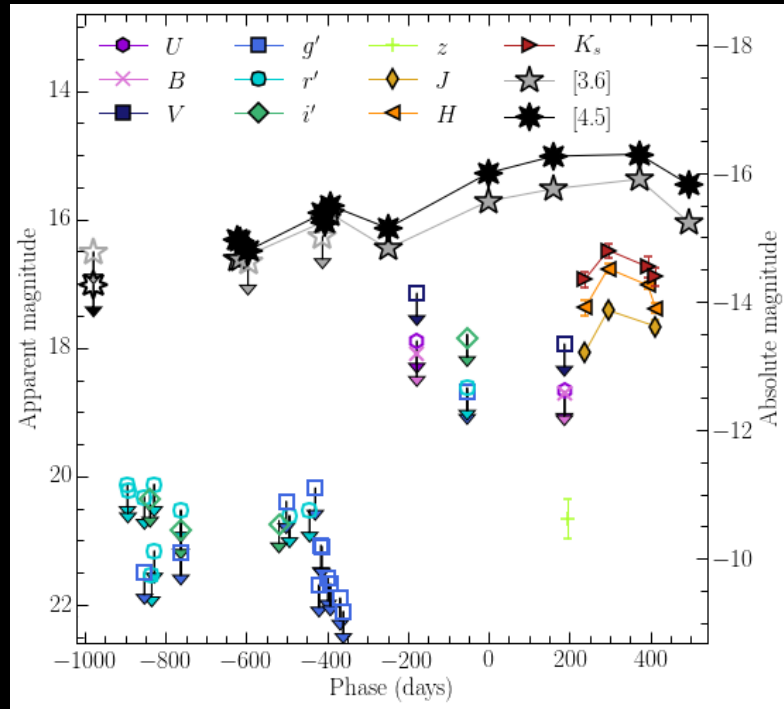


Jencson et al. 2019a

Multiple, luminous IR outbursts before terminal explosion



Jacob Jencson



SPIRITS16tn: an explosion inside a giant molecular cloud?

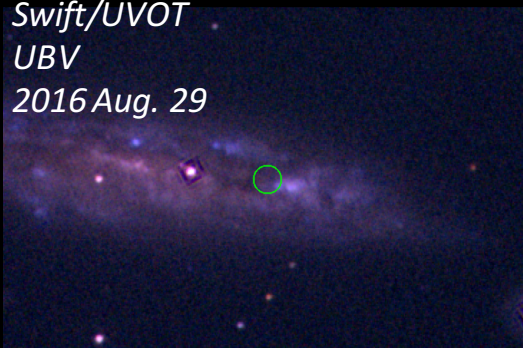


Jacob Jencson

NGC 3556
(M108)

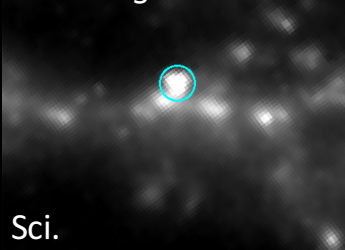


Swift/UVOT
UBV
2016 Aug. 29



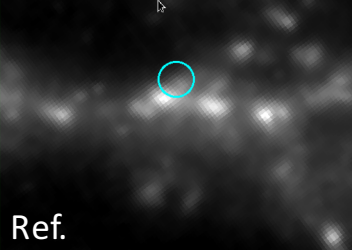
SDSS

Spitzer/IRAC [4.5]
2016 Aug. 15

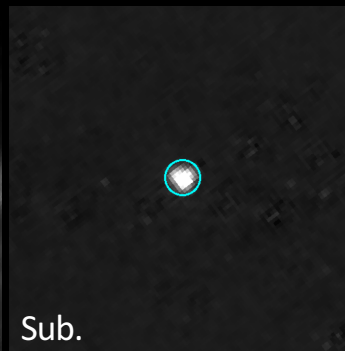


Sci.

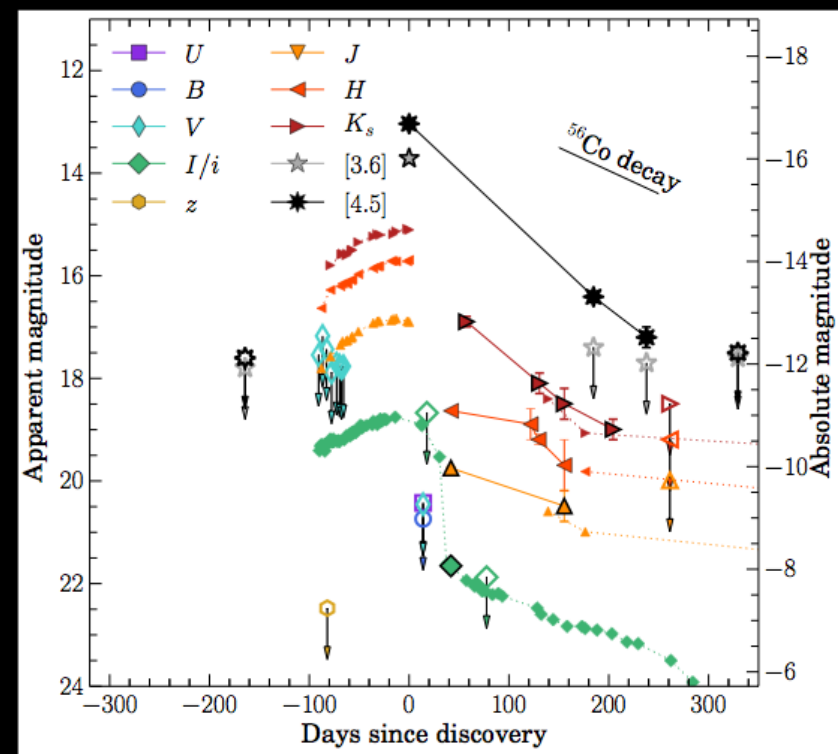
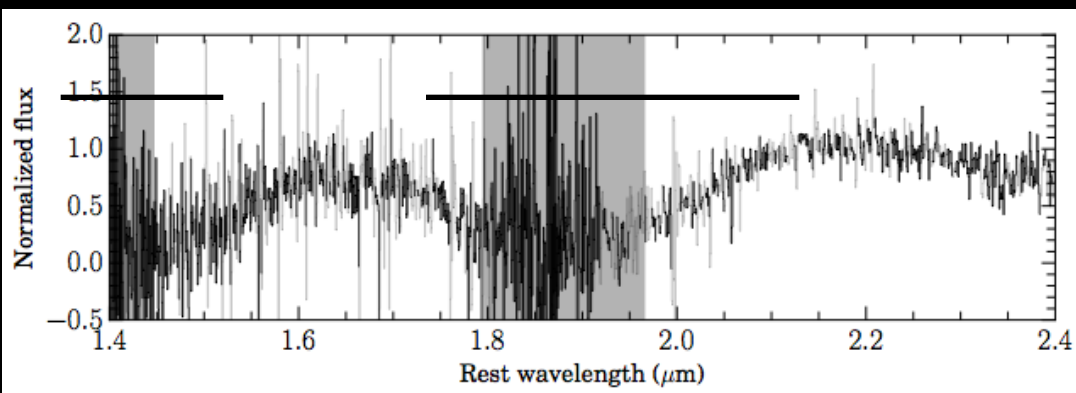
Spitzer/IRAC [4.5]
2011 Feb. 7



Ref.



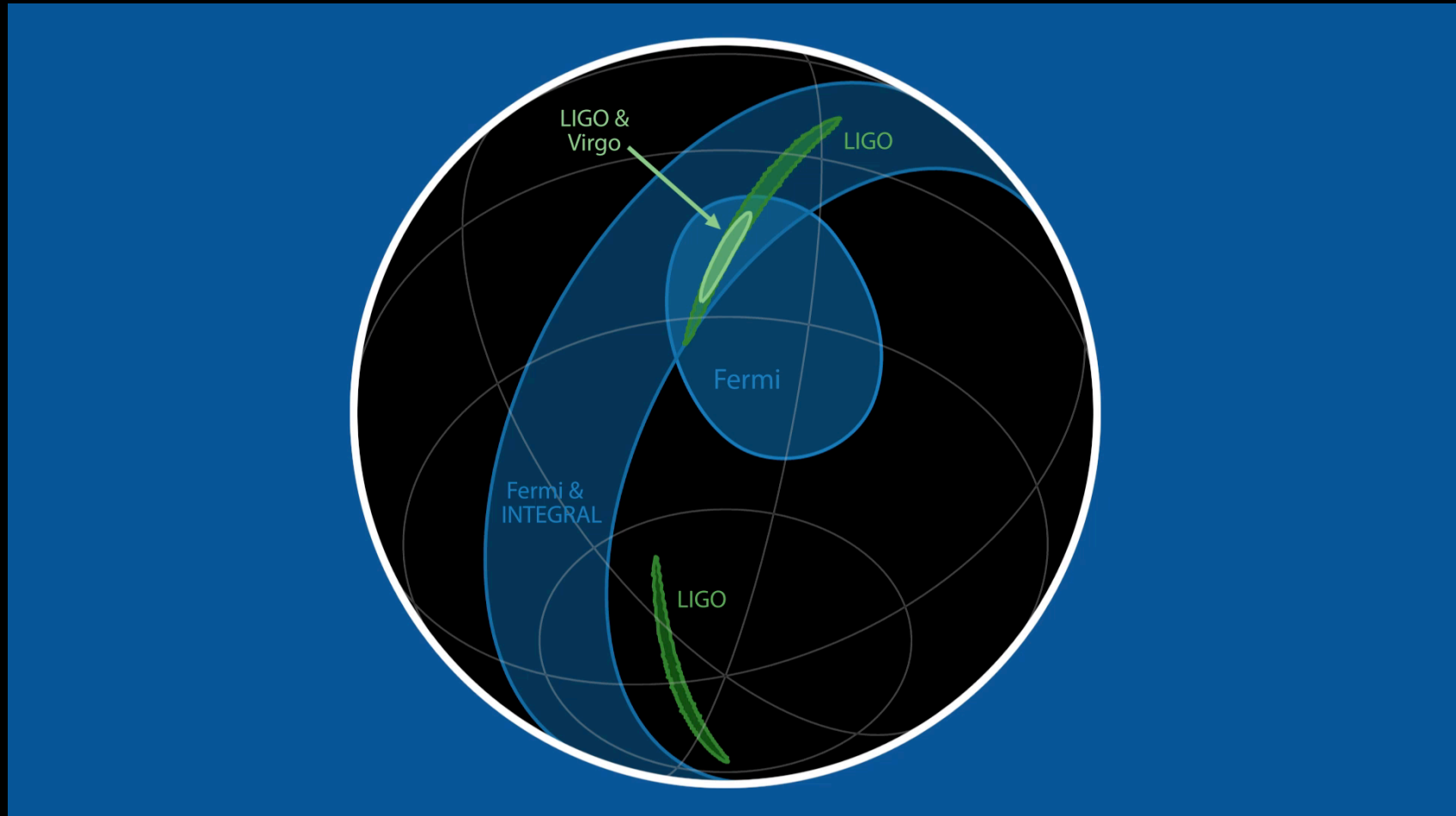
Sub.



Jencson et al. 2018

Gravitational Waves & Electromagnetic Radiation

Localizing GW170817



Movie Credit: R. Hurt

8 Independent Searches in Chile

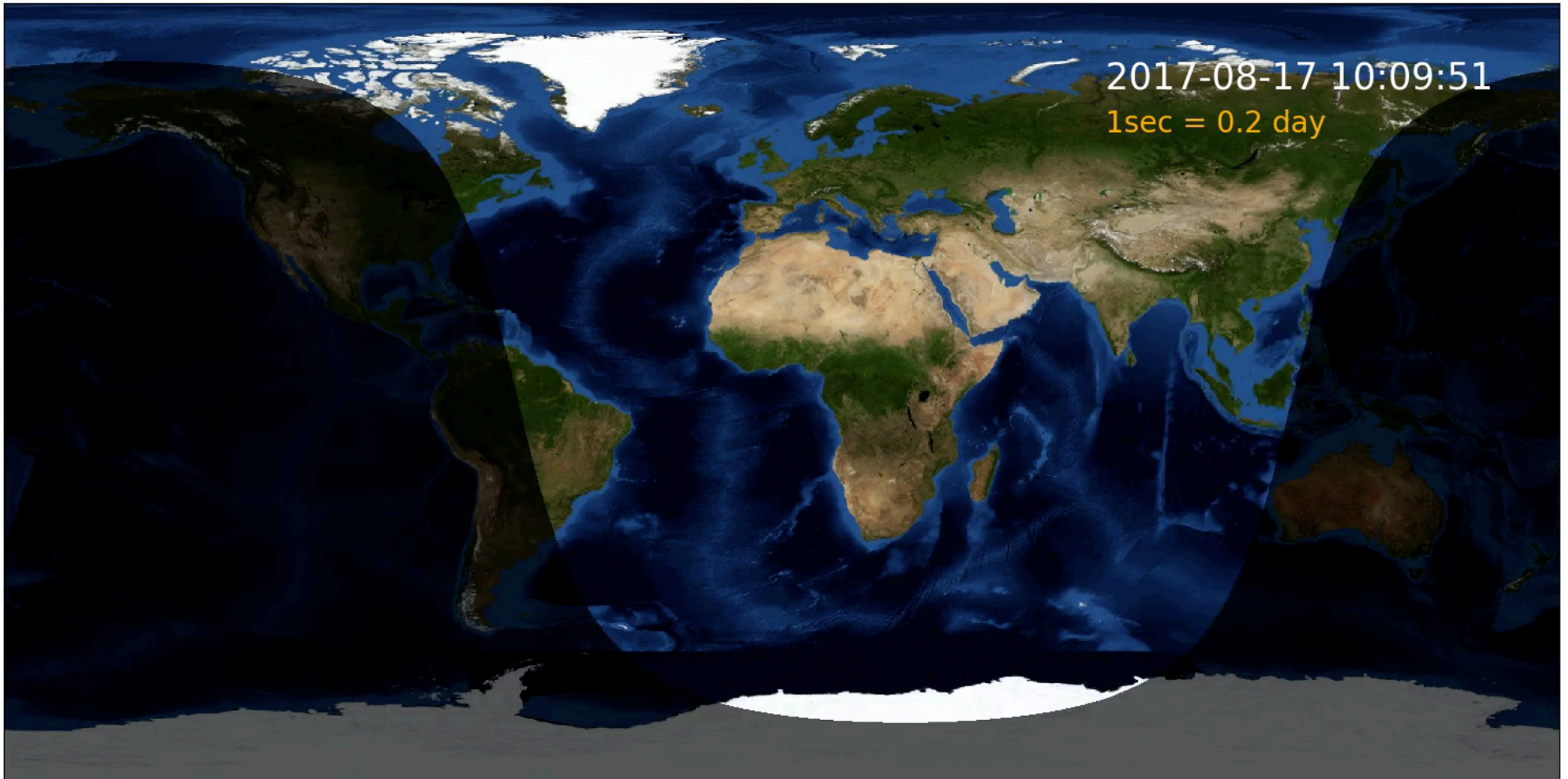
Optical:

1. Swope 40" Las Campanas Telescope (Coulter et al. 2017)
2. MASTER (Lipunov et al. 2017)
3. DLT40 (Valenti et al. 2017)
4. DECam on Blanco Telescope (Soares-Santos et al. 2017)
5. Las Cumbres Observatory (Arcavi et al. 2017)
6. REM (Pian et al. 2017)

Infrared:

1. ESO VISTA (Tanvir et al. 2017)
2. Gemini-South (Kasliwal et al. 2017)

A Global Effort to Unveil Astrophysics



Movie Credit: V. Bhalerao

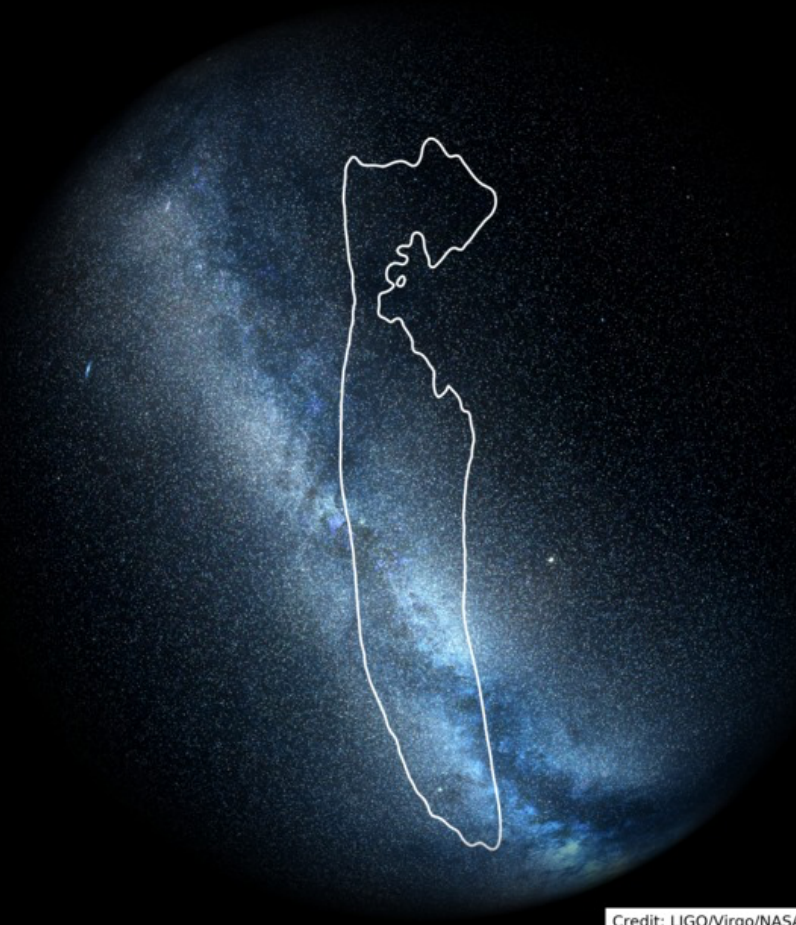
Total 70 ground-based telescopes + 7 space telescopes
(The GROWTH Team: 18 telescopes, 6 continents, 100+ people)

Follow-up of gravitational waves



Credit: LIGO/Virgo/NASA/Leo Singer

GW190425z



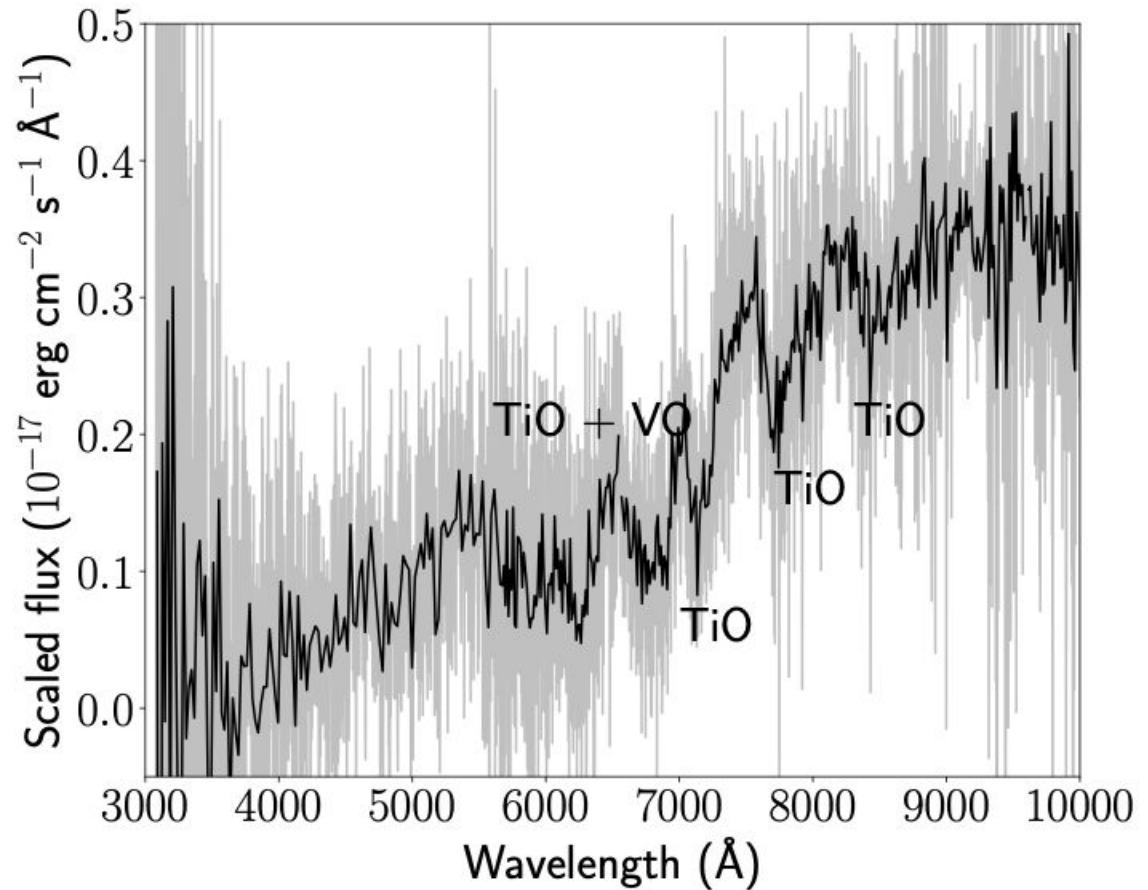
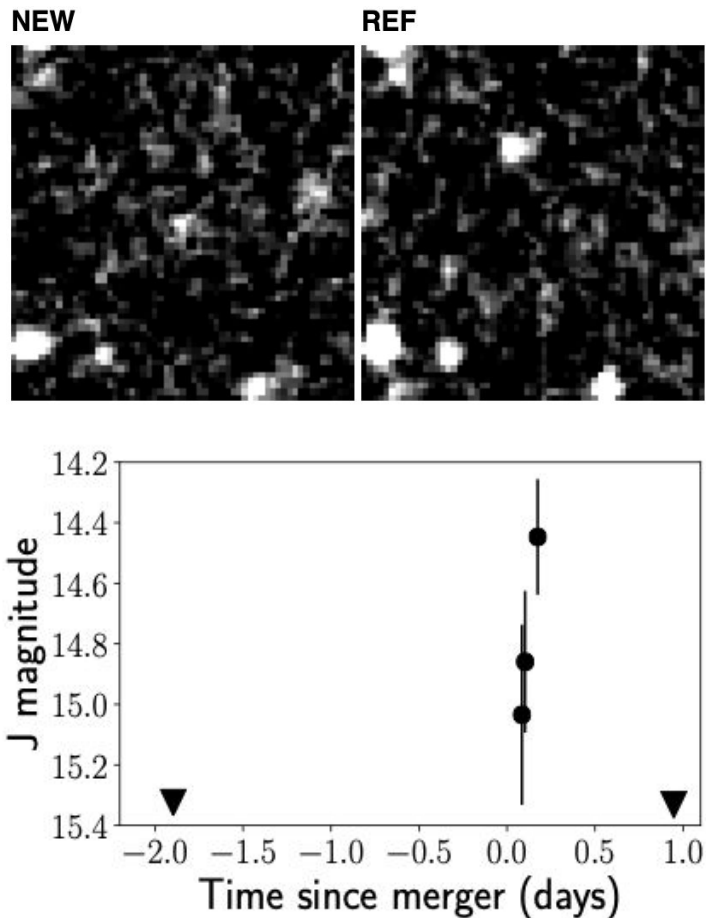
Credit: LIGO/Virgo/NASA/Leo Singer

GW190426c

An Infrared Transient from Palomar Gattini-IR



Kishalay De Matt Hankins

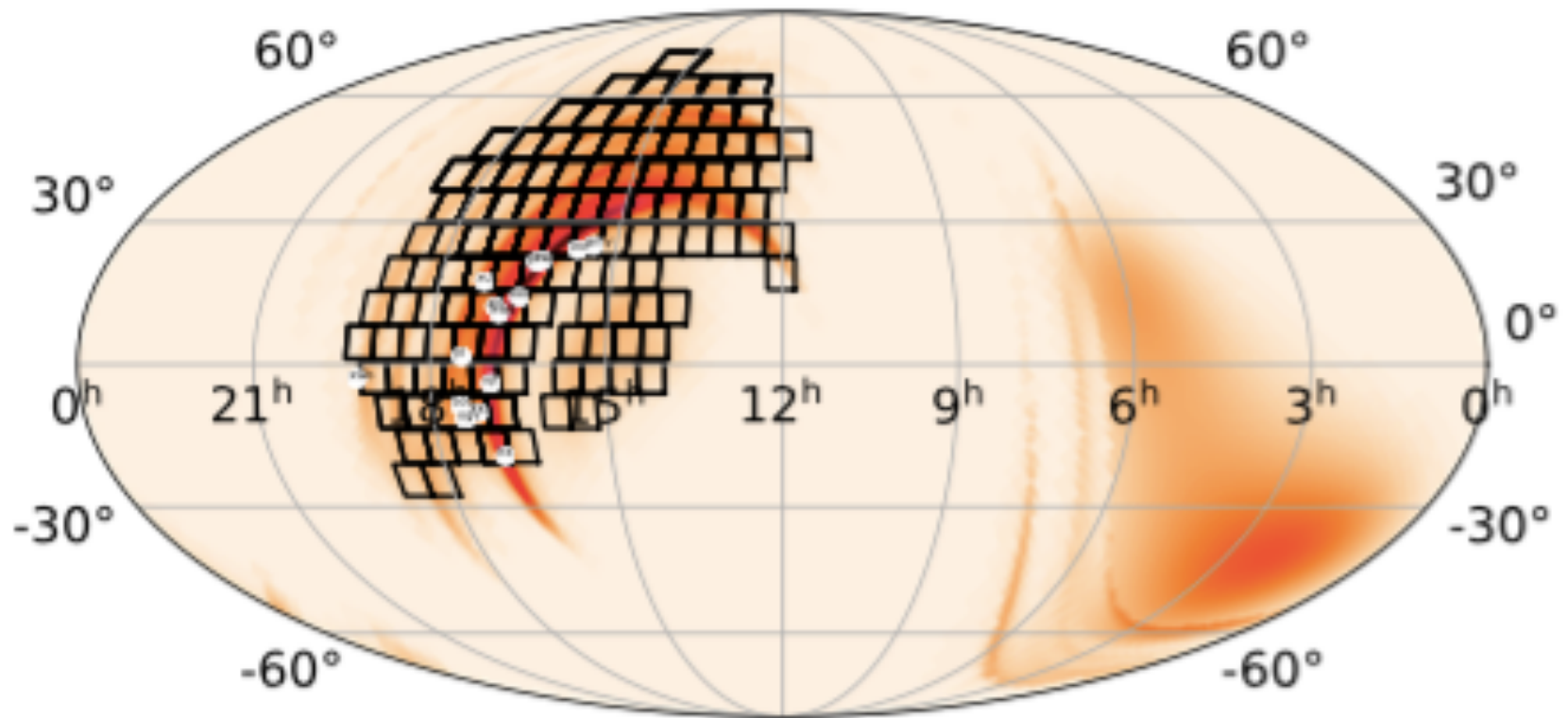


Coughlin et al. 2019c

S190425z: Second NS-NS merger (from 1 GW interferometer)



Michael Coughlin



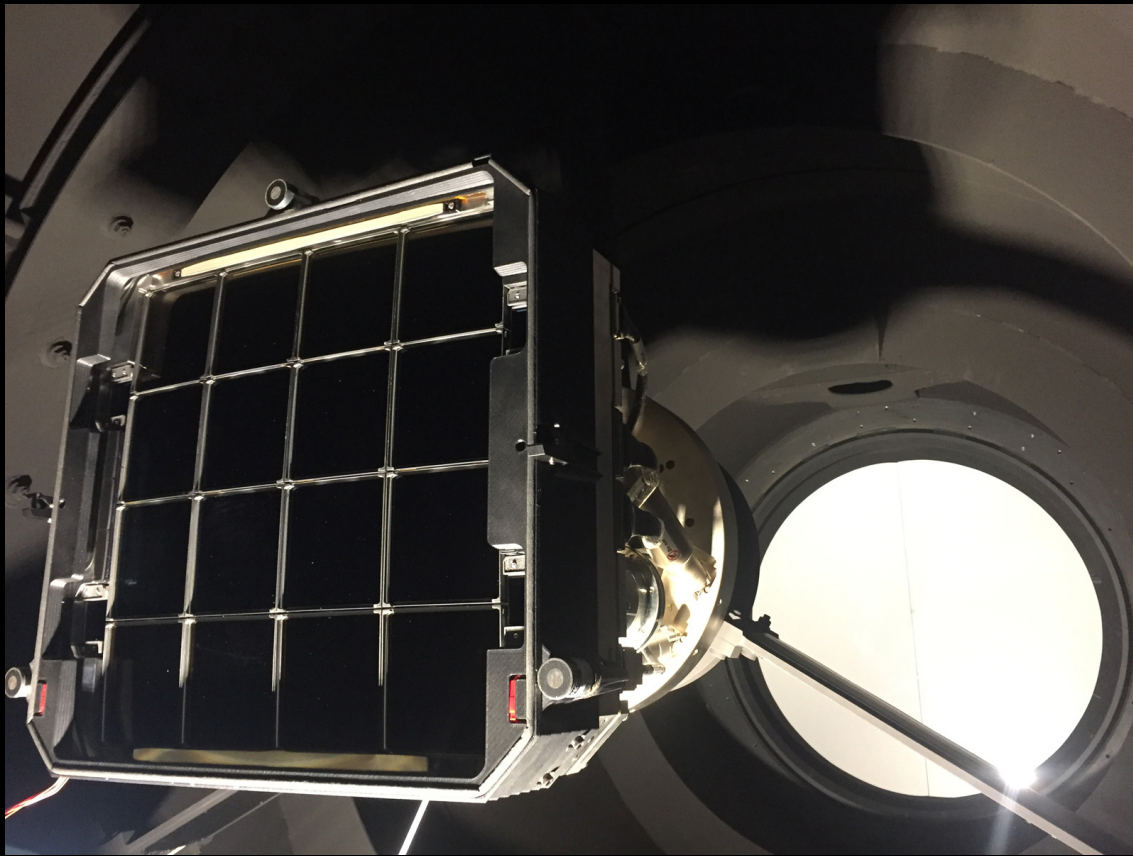
Coughlin et al. 2019c

90% localization was 10,000 sq deg (updated to 6000 sq deg)!

15 young ZTF candidates, 2 consistent with kilonovae photometrically,

Case closed in 30 hours.

The Zwicky Transient Facility (ZTF)



Samuel Oschin 48-inch Schmidt telescope, Palomar Observaotry

576 megapixel

Field of view: 47 deg²

Limiting magnitude: 20.5 mag

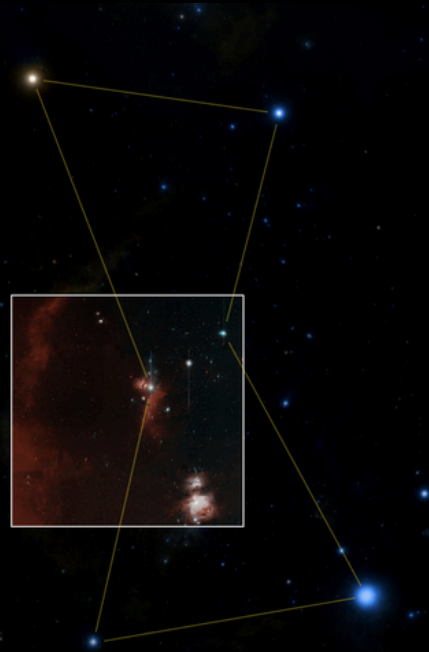
3760 deg²/hour

ZTF g, r, i filters

Bellm et al. (2019a, b), Dekany et al. (2019), Bellm et al. (2019b), Graham et al. (2019), Masci et al. (2019), Patterson et al. (2019), Mahabal et al. (2019), Tachibana & Miller (2019), Kasliwal et al. (2019)

Two Public Surveys

- All-sky gR at 3-day cadence
- Galactic plane gR at 1-day cadence
- Real-time public alert stream in LSST format since June 2018! Delay of ~ 7 minutes between observation and alert packet dissemination.
- Event Brokers: ANTARES, LASAIR, ALERCE, MARS



Needle in Haystack

Filtering criteria	# of Alerts on April-25	# of Alerts on April-26
ToO alerts	50,802	287,844
Positive subtraction	33,139	182,095
Real	19,990	118,446
Not stellar	10,546	61,583
Far from a bright source	10,045	58,881
Not moving	990	5,815
No previous history	28	234

Coughlin et al. 2019c



USA



USA



ATCA, ASKAP, VLA, GMRT

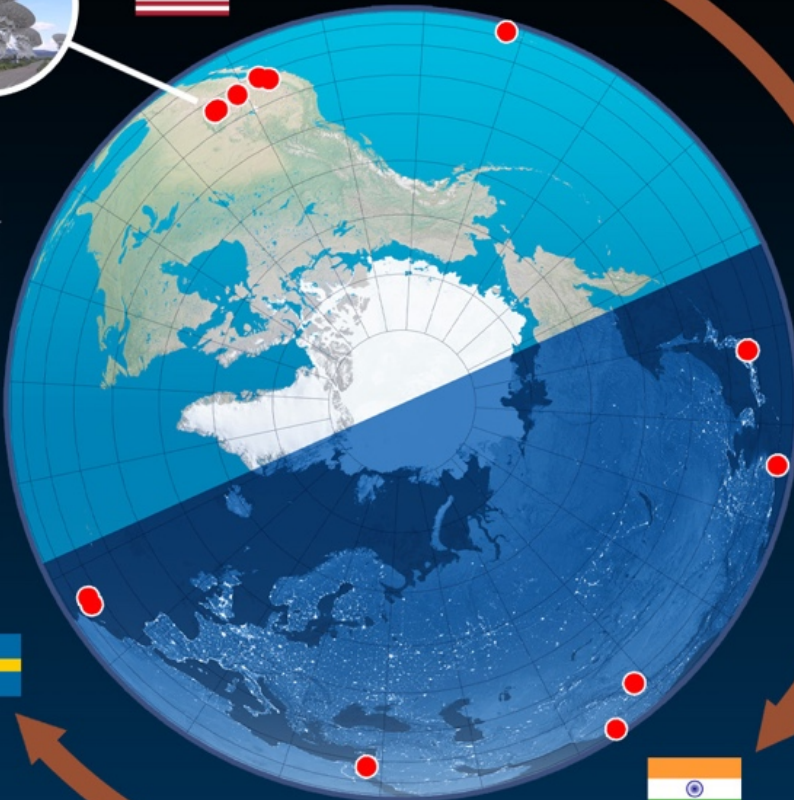
USA



UK



Italy



GROWTH-India



Japan



Taiwan

Sweden



Global Relay
of Observatories
Watching Transients Happen



Israel



India



GROWTH

Global Relay of Observatories Watching Transients Happen



Team Never Sleeps



GROWTH

Global Relay of Observatories Watching Transients Happen

A Dynamic Collaborative Platform

Total Number of SNe: 430 | Ia: 296 | II: 89 | Ib: 12 | Ic: 8 | Ib/c: 0 | Ic-BL: 2 | SLSNe: 11

GROWTH Followup Marshal

- view source
- query database
- view report
- at an observing run
- scan for candidates
- add source
- transfer source
- ToO Marshal
- schedules

Welcome, Mansi

Currently Displaying For
All Your Science Programs

newsfeed

Transient Advocate: n/a

Paula Szkody commented on [ZTF18aaznfpk](#): "known DN MN Lac"
4 hours ago

Anna Ho uploaded a P60 (SEDM) spectrum to [ATLAS18slid](#) from 2018-08-06
12 hours ago

Anna Ho commented on [ATLAS18slid](#): "I put in ATLAS photometric points from ATels"
12 hours ago

Anna Ho uploaded ATLAS photometry to [ATLAS18slid](#)
12 hours ago

Sjoert van Velzen commented on [ZTF18aajupnt](#): "BH mass from M-sigma ~1e7 Msun"
13 hours ago

Anna Ho set the redshift of [ZTF18ablqzpz](#) to 0.0414
16 hours ago

Suvi Gezari commented on [ZTF18aajupnt](#): "Nucleus brightened in NUV from 19.0 mag (GALEX) to 17.9 mag (Swift)"
18 hours ago

Suvi Gezari classified [ZTF18aajupnt](#) as "TDE"
18 hours ago

Suvi Gezari commented on [ZTF18aajupnt](#): "Tyrion Lannister ZTFbh SWG name"
18 hours ago

customize

[My Account](#)
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[My Subscriptions](#)

next runs

2018-08-07 Keck1+LRIS
2018-08-12 P200+DBSP

P60 schedule

most viewed this week

	ZTF18ablqzpz 297 views
	ZTF18abkhqhk 111 views
	ZTF18abcfdzu (SN IIP) 99 views
	ZTF18abkmbpy 83 views

kde: 0.128
kde: Narrow H alpha has a ~1000 km/s broad component. SN IIn?

GROWTH Marshal:

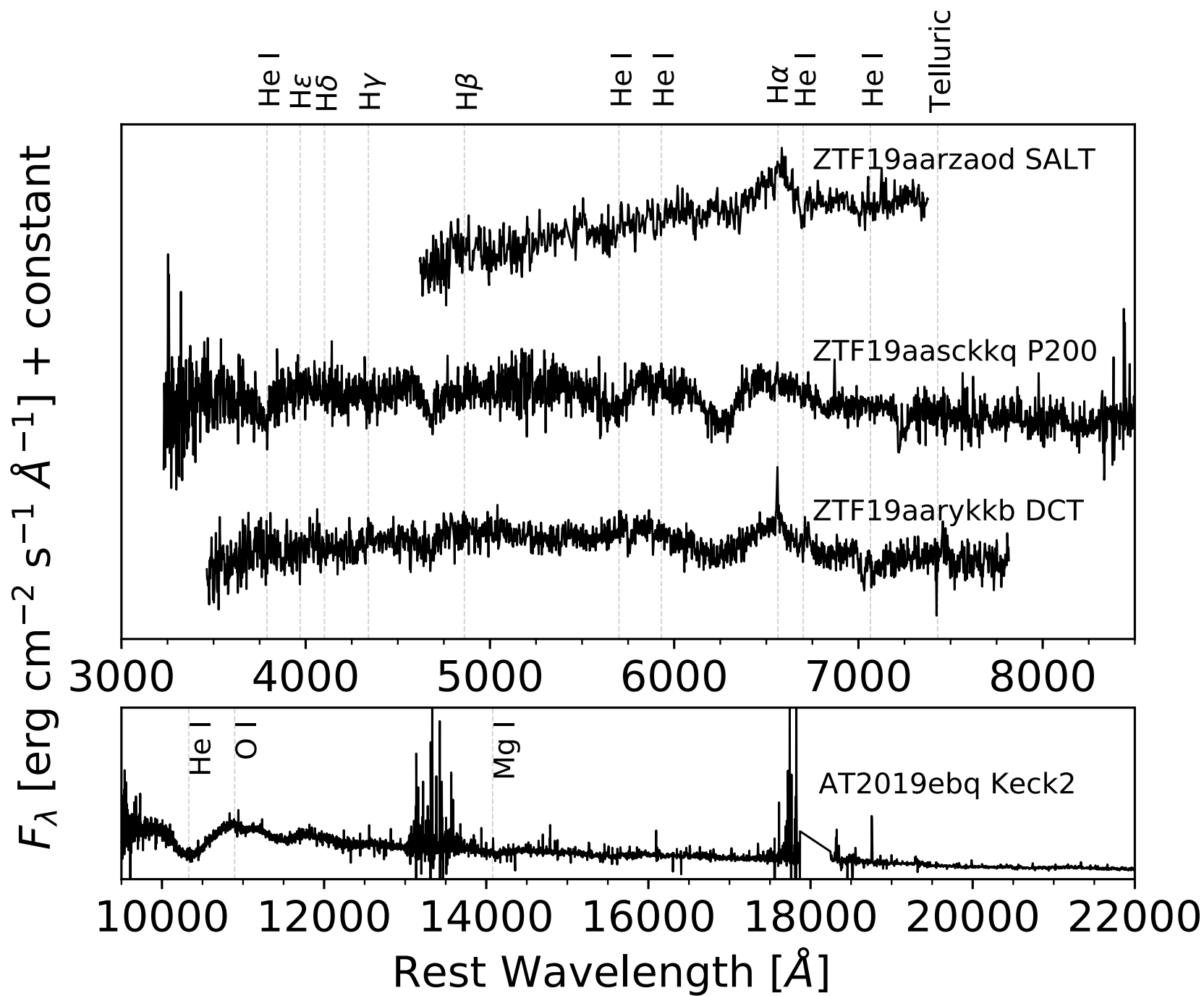
137 Scientists

38 Science Programs that filter

100,000 events/night

1655 Supernovae per year

37 Telescopes



Photometric Follow-up

Candidate	Coordinates (RA, Dec)	Discovery Mag.	Classification	Spectroscopic facilities	Photometric evolution
PGIR 19bn	15:29:37.43 +33:57:37.0	J = 15.0	M-Dwarf	KECK LRIS	
ZTF19aarykkb	17:13:21.95 -09:57:52.1	r = 18.63	SNII	HCT, LT, DCT	
ZTF19aarzaod	17:31:09.96 -08:27:02.6	r = 20.11	SNIIIn	SALT	
ZTF19aasckwd	16:52:39.45 +10:36:08.3	r = 20.15	SN Ia	SOAR	
ZTF19aasckkq	16:33:39.14 +13:54:36.7	g = 20.86	SN I Ib	P200, SOAR	
ZTF19aasbphu	16:22:19.95 +21:24:29.5	r = 19.71	Nuclear*	–	$\Delta m / \Delta t = 0.11$
ZTF19aaryxjf	16:58:22.87 -03:59:05.1	g = 19.95	SN*	–	$\Delta m / \Delta t = -0.014$
ZTF19aarxxwb	19:14:46.40 -03:00:27.0	g = 18.89	SN*	–	$\Delta m / \Delta t = 0.12$
ZTF19aasda jo	16:57:25.21 +11:59:46.0	g = 20.7	SN*	–	$\Delta m / \Delta t = 0.045$
ZTF19aasbamy	15:25:03.76 +24:55:39.3	g = 20.66	SN*	–	$\Delta m / \Delta t = 0.01$
ZTF19aarycuy	16:16:19.97 +21:44:27.4	r = 20.07	SN*	–	$\Delta m / \Delta t = 0.02$
ZTF19aasbau i	15:40:59.91 +24:04:53.8	g = 20.49	SN*	–	$\Delta m / \Delta t = 0.01$
ZTF19aasejil	17:27:46.99 +01:39:13.4	g = 20.53	SN*	–	$\Delta m / \Delta t = 0.01$
ZTF19aascxux	17:13:10.39 +17:17:37.9	g = 20.56	SN*	–	$\Delta m / \Delta t = 0.06$
ZTF19aashlts	16:52:45.01 -19:05:38.9	r = 19.95	SN*	–	$\Delta m / \Delta t = 0.03$
ZTF19aasfogv	17:27:22.32 -11:20:01.9	g = 20.53	SN*	–	$\Delta m / \Delta t = 0.01$

Coughlin et al. 2019c

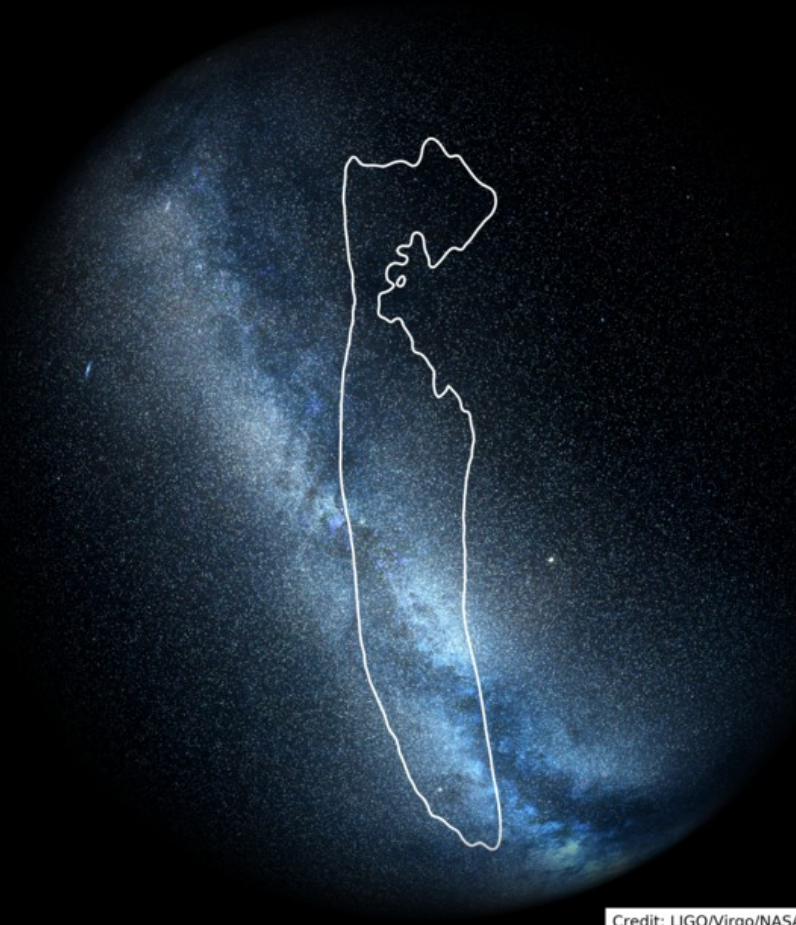
Too slow to be the electromagnetic counterpart!

Follow-up of gravitational waves



Credit: LIGO/Virgo/NASA/Leo Singer

GW190425z



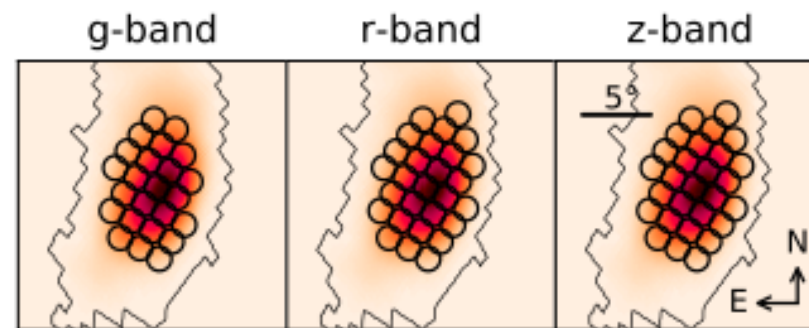
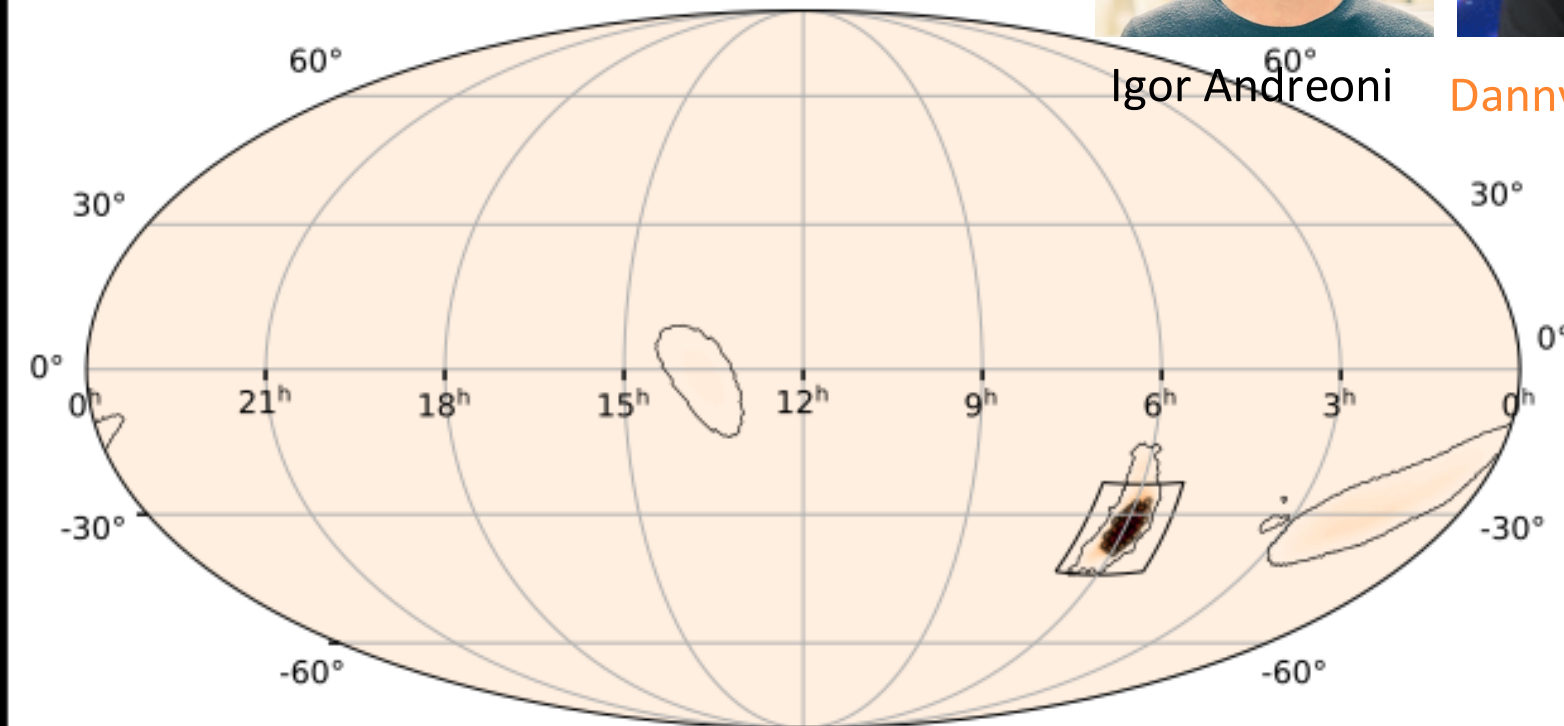
Credit: LIGO/Virgo/NASA/Leo Singer

GW190426c

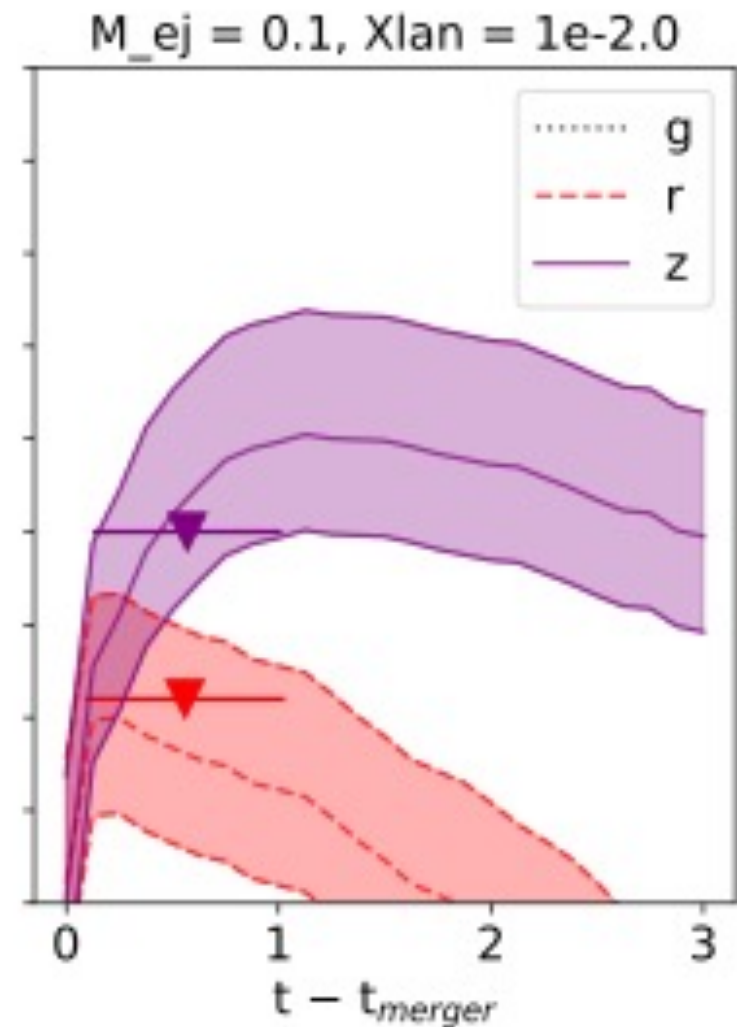
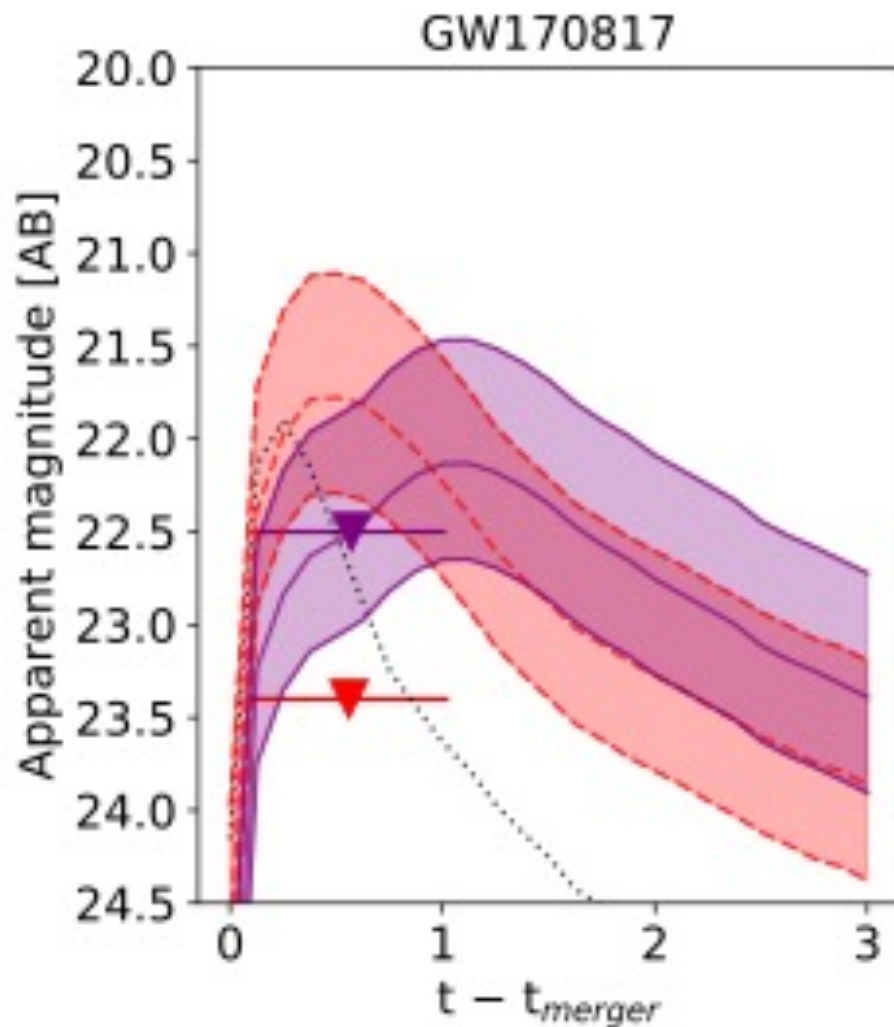


Igor Andreoni

Danny Goldstein

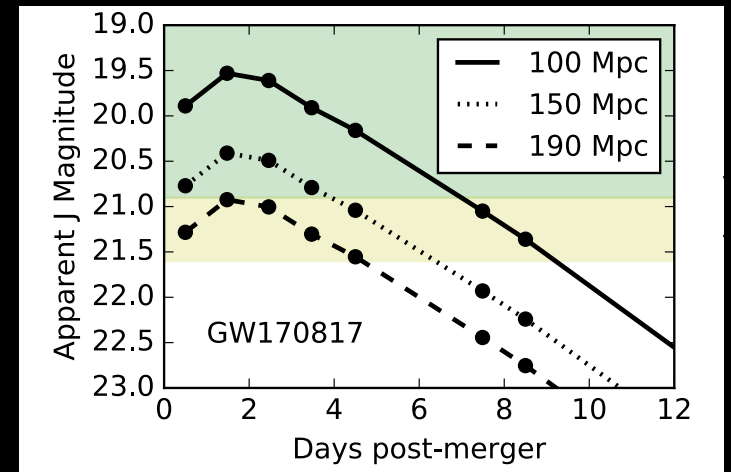
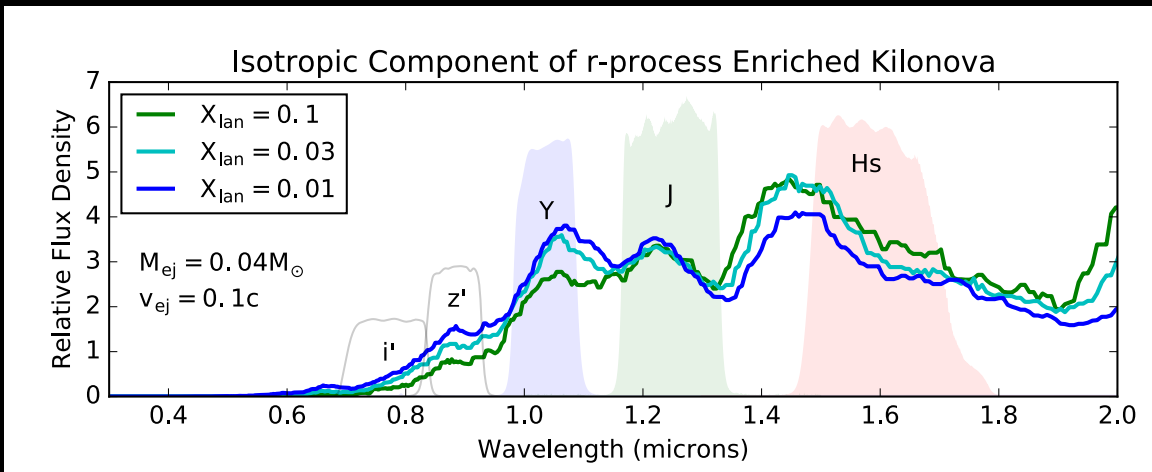
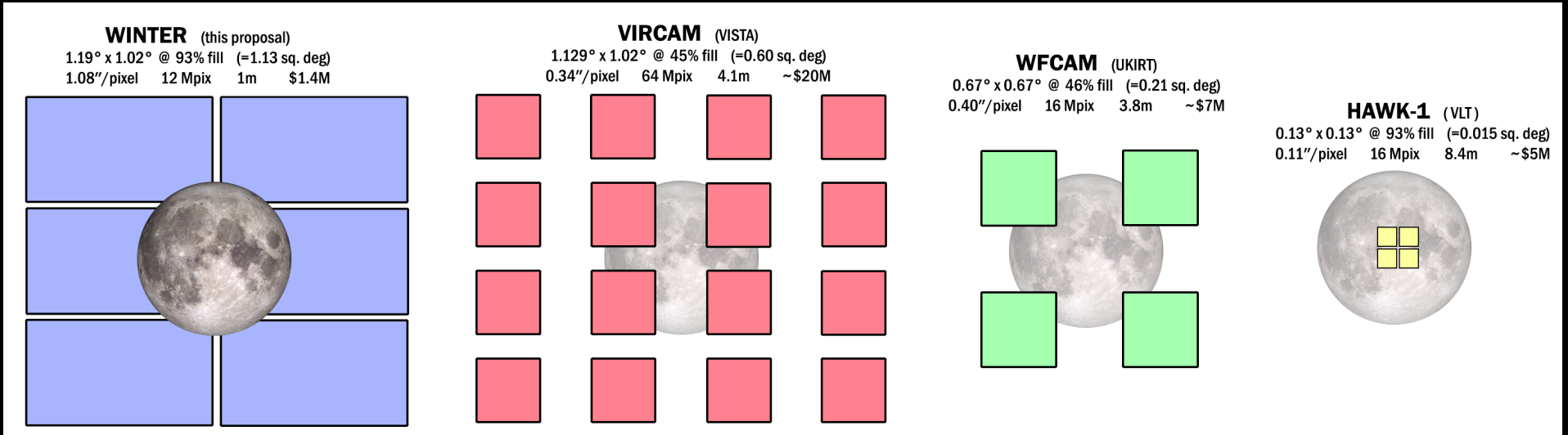


Dark Energy Camera Search Limits



WINTER @ Palomar

Alternative Semiconductor Technology



In Partnership with Rob Simcoe (MIT)
 Now funded by NSF MRI + Packard; First light: Summer 2020



Thank you