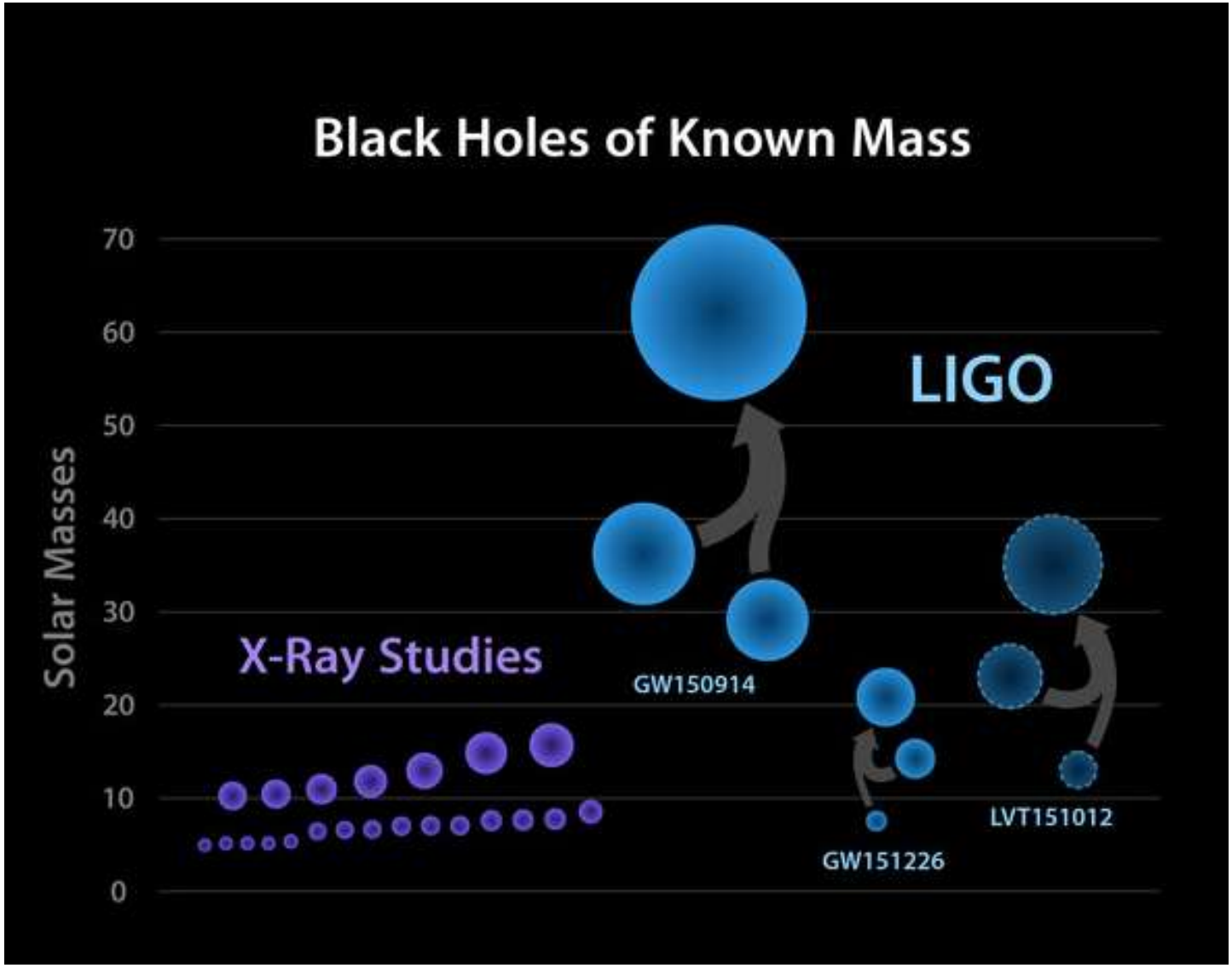
GROWTH
Global Relay of Observatories Watching Transients Happen

Electromagnetic Counterparts to Gravitational Waves

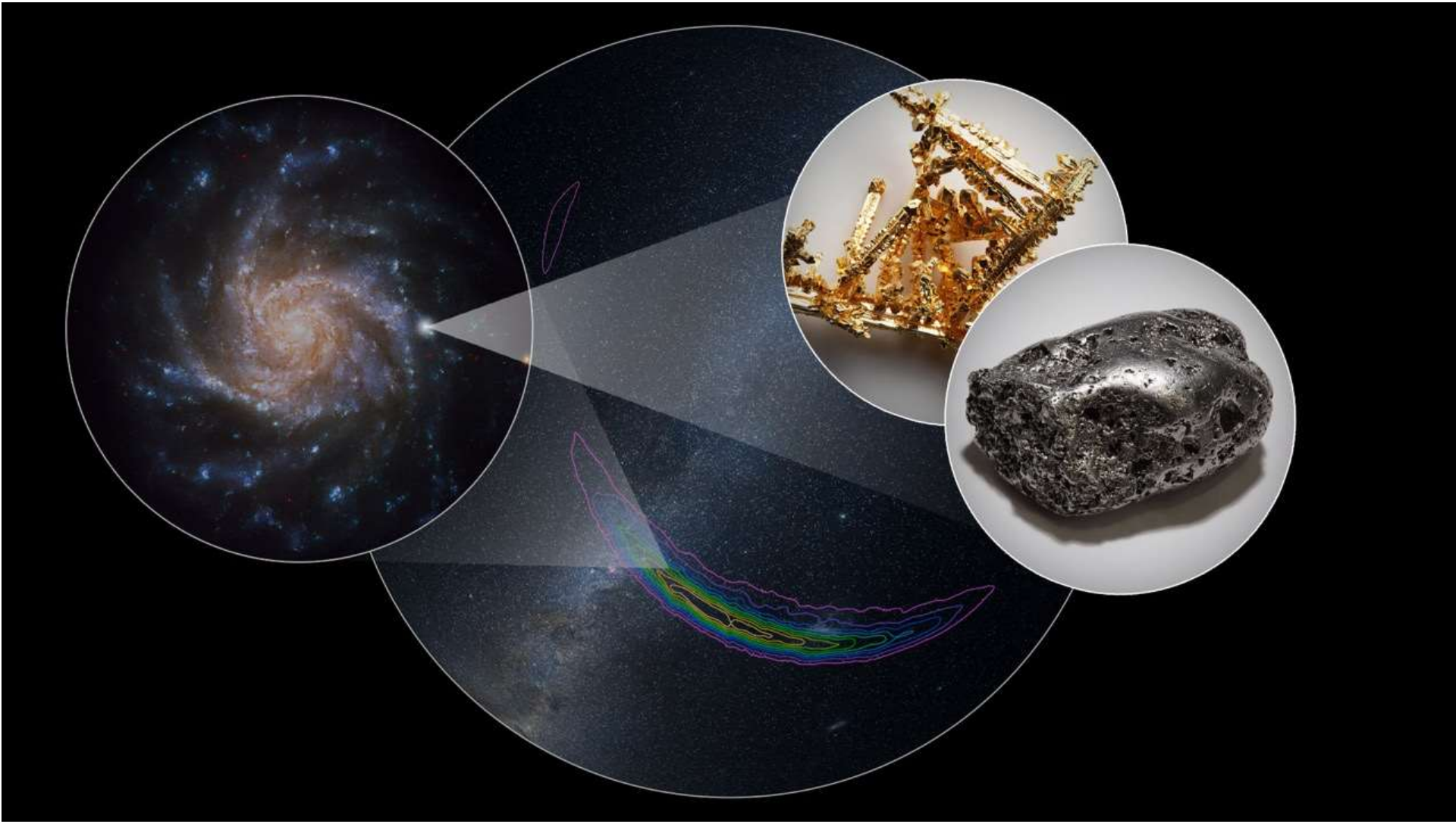
Mansi M. Kasliwal
California Institute of Technology

NSF PIRE

Dawn of Gravitational Wave Astronomy



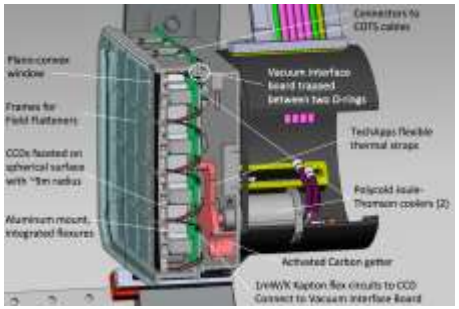
Sites of r-process nucleosynthesis?

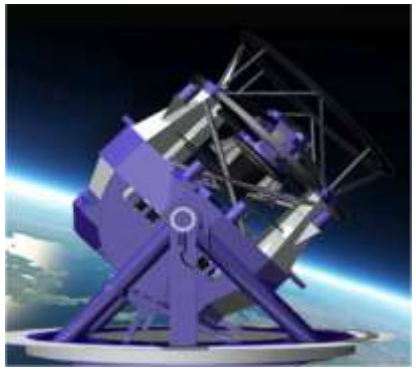


e.g. Li & Paczynski 1998, Kulkarni 2005, Roberts et al. 2011, Nakar & Piran 2011, Barnes et al. 2013, Grossman et al. 2013, Metzger et al. 2014, Kasen et al. 2016

A Resurgence in TDA Discovery Engines

Optical:





Evryscope, ASASSN, HATPI ZTF, CSS-II, PS, BG, ATLAS DECAM, HSC, LSST

Radio:

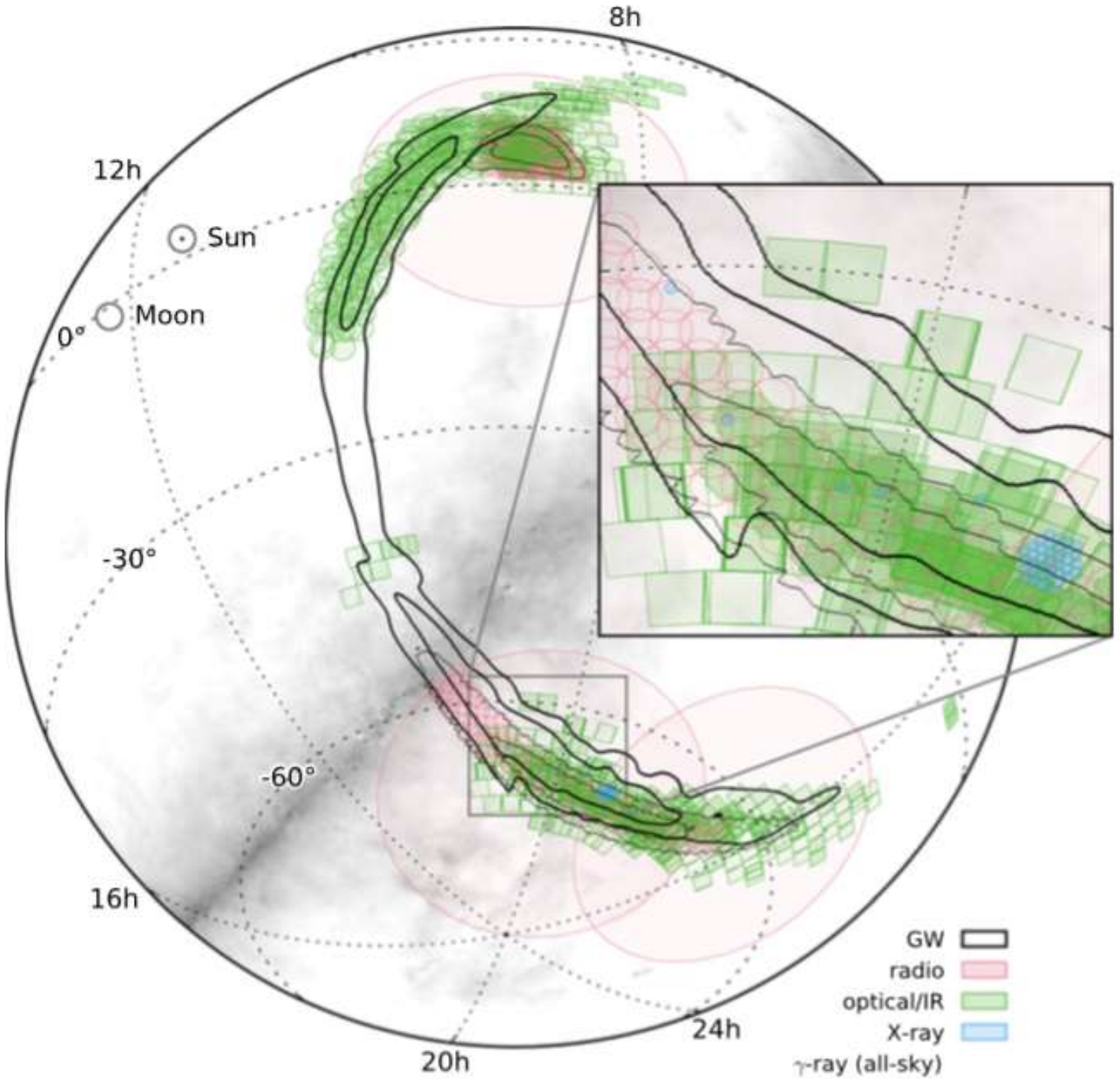
LOFAR, MWA and LWA: meter and decameter-mapping

Apertif, Meerkat and Askap: decimetric mapping

Infrared: SPIRITS, Palomar Gattini-IR, Polar Gattini-IR

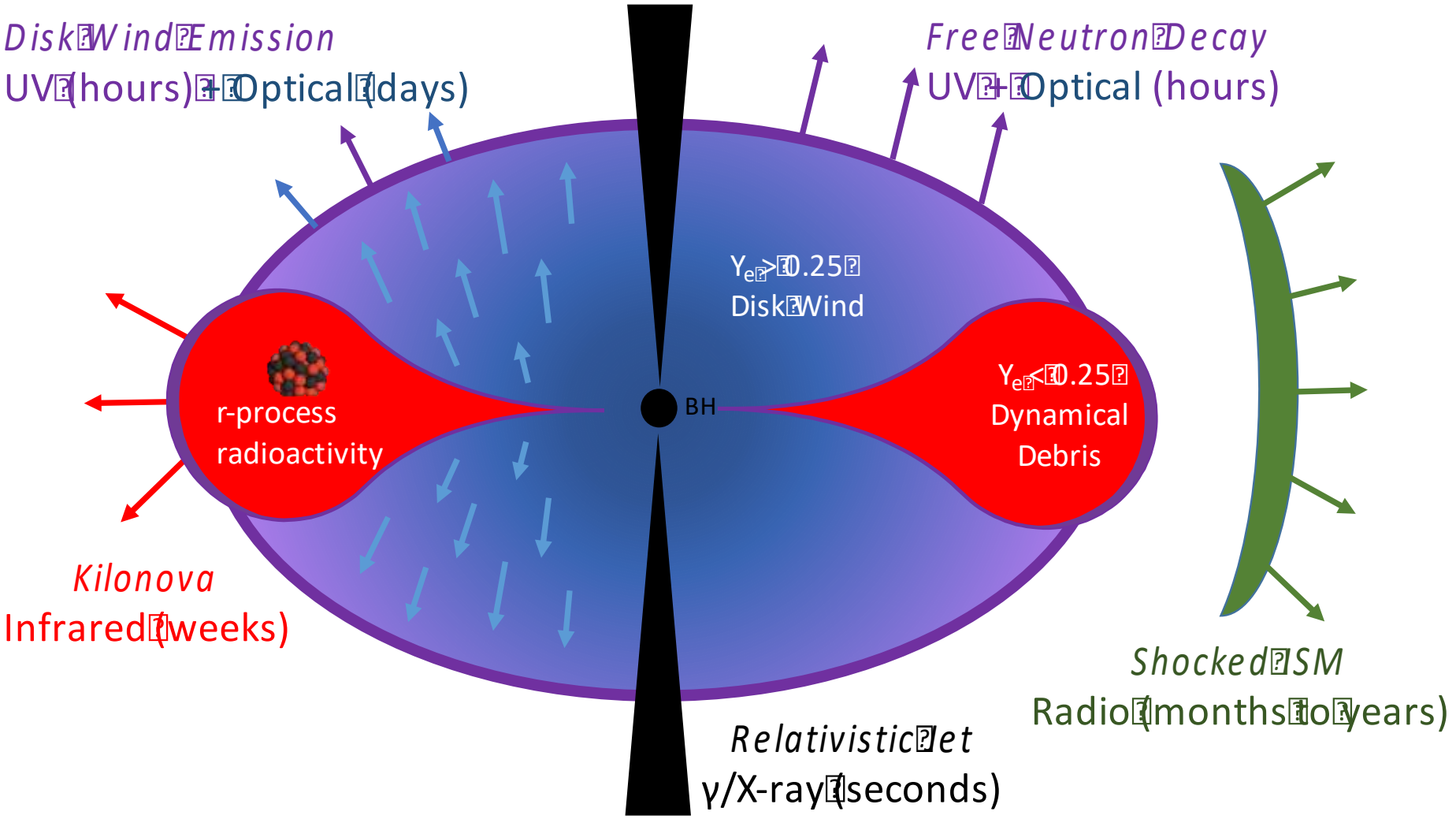
Ultra-Violet: CUTIE & ULTRASAT

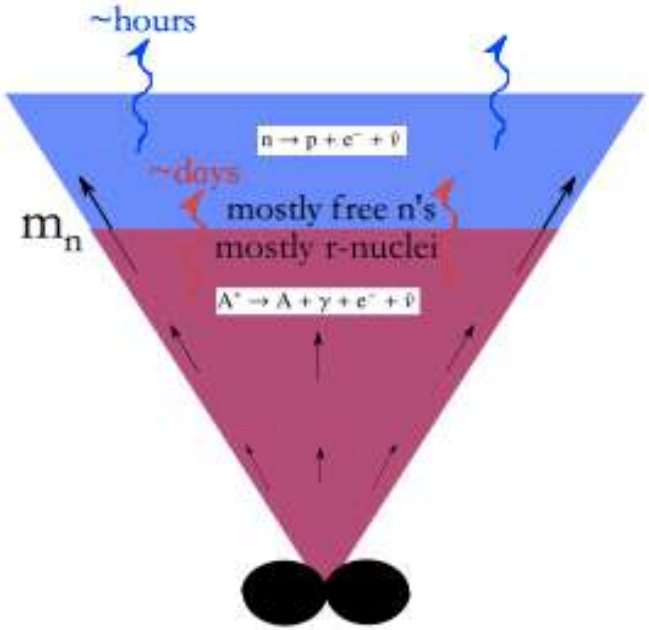
X-rays and Gamma-rays: Swift, Fermi, MIRAX, Lobster-ISS

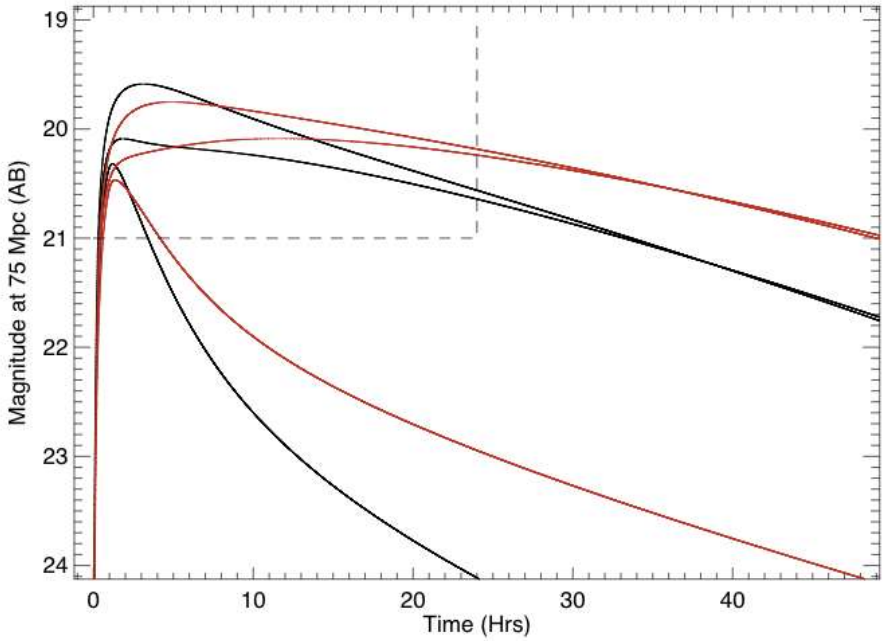


Abbott et al. 2016 – LVC + EM Teams Joint Paper

Models


Disk Wind Emission
UV (hours) + Optical (days)
Free Neutron Decay
UV + Optical (hours)
$Y_e > 0.25$
Disk Wind
$Y_e < 0.25$
Dynamical
Debris
r-process
radioactivity
BH
Kilonova
Infrared (weeks)
Shocked ISM
Radio (months to years)
Relativistic Jet
γ/X-ray (seconds)

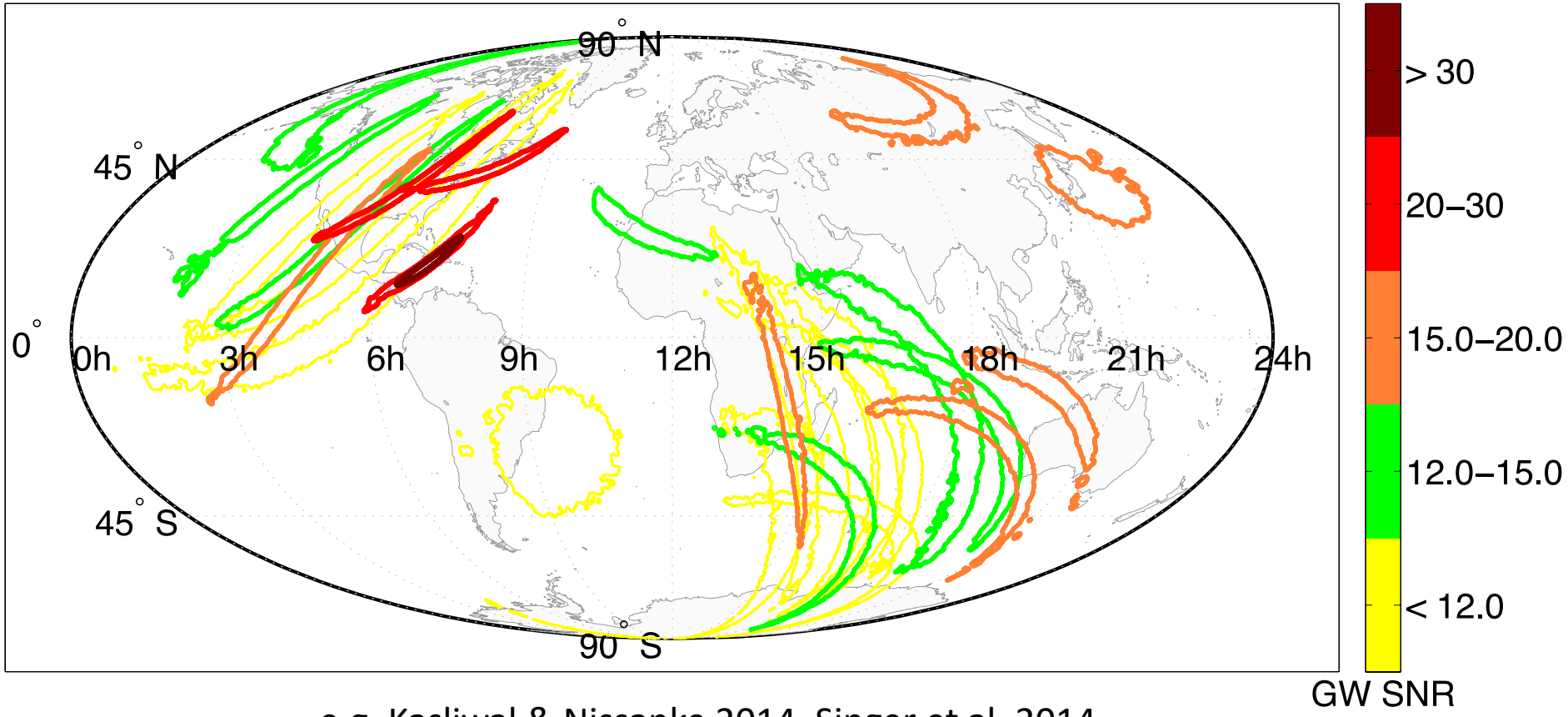




SPEED:

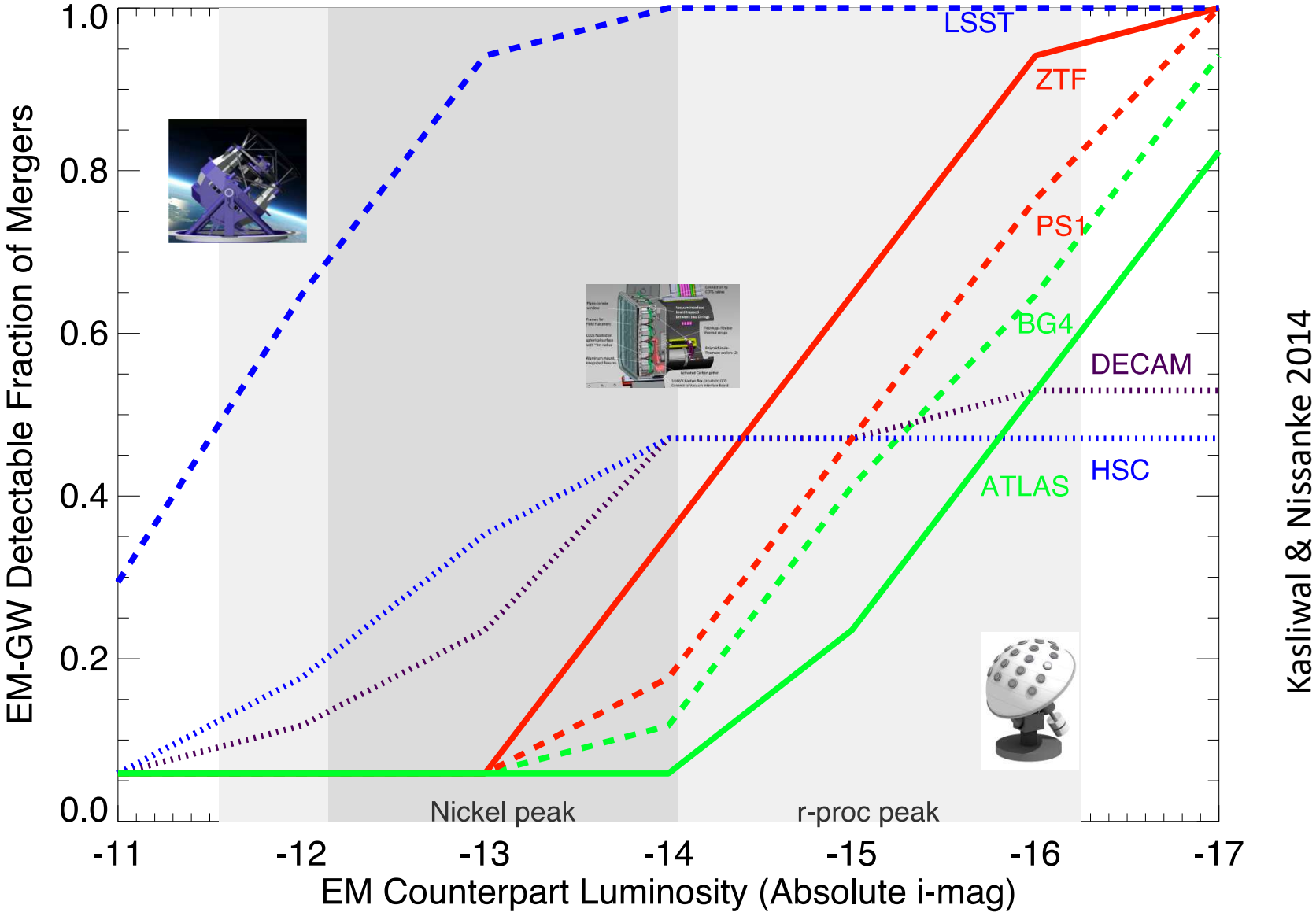
Speed of Response
Speed of Software
Speed of Follow-Up

Coarse Gravitational Wave Localizations



e.g. Kasliwal & Nissanke 2014, Singer et al. 2014

Optical Hardware



Software Speed

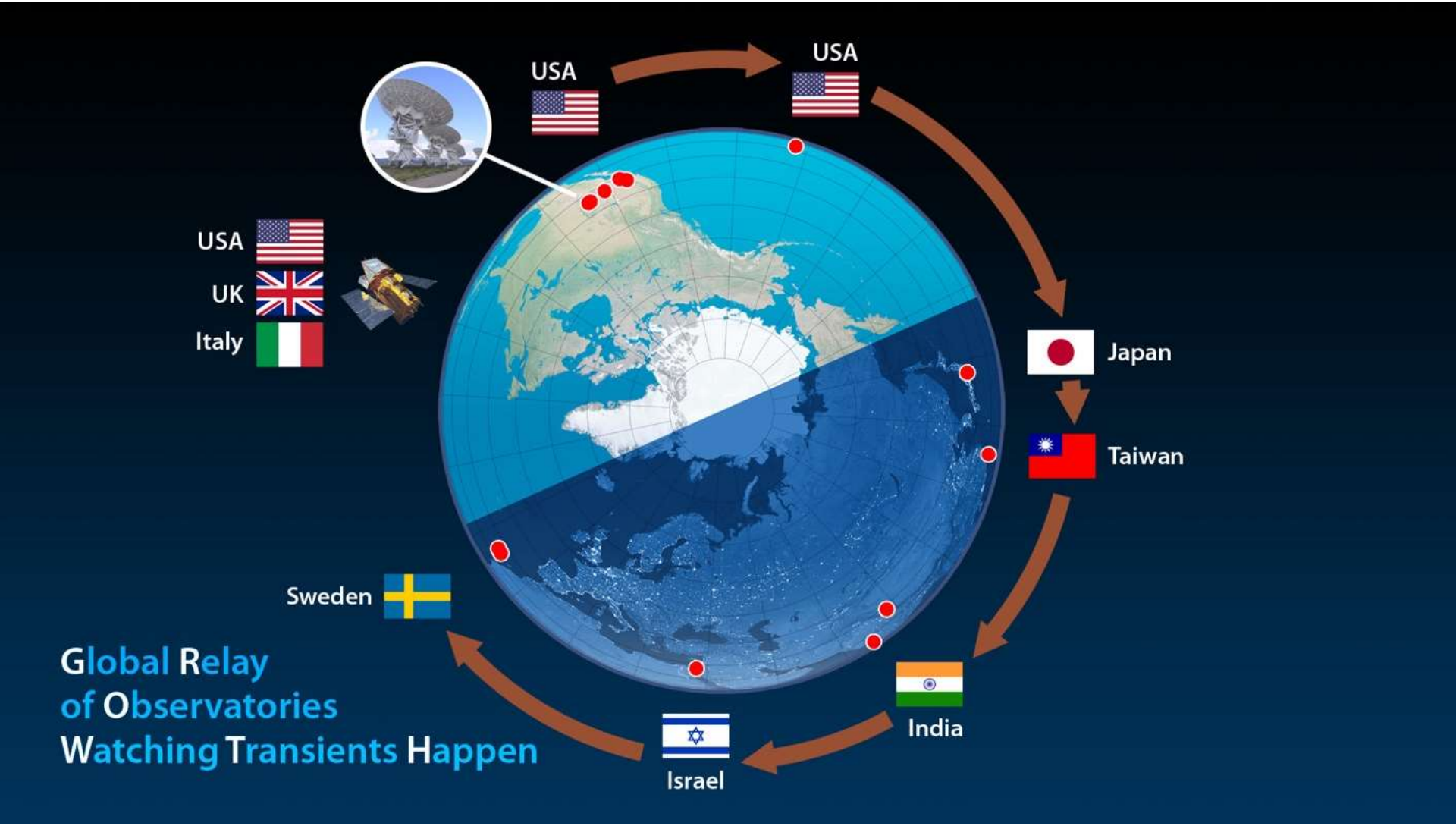
Palomar *(Zwicky)* Transient Factory

Oschin 48" Telescope

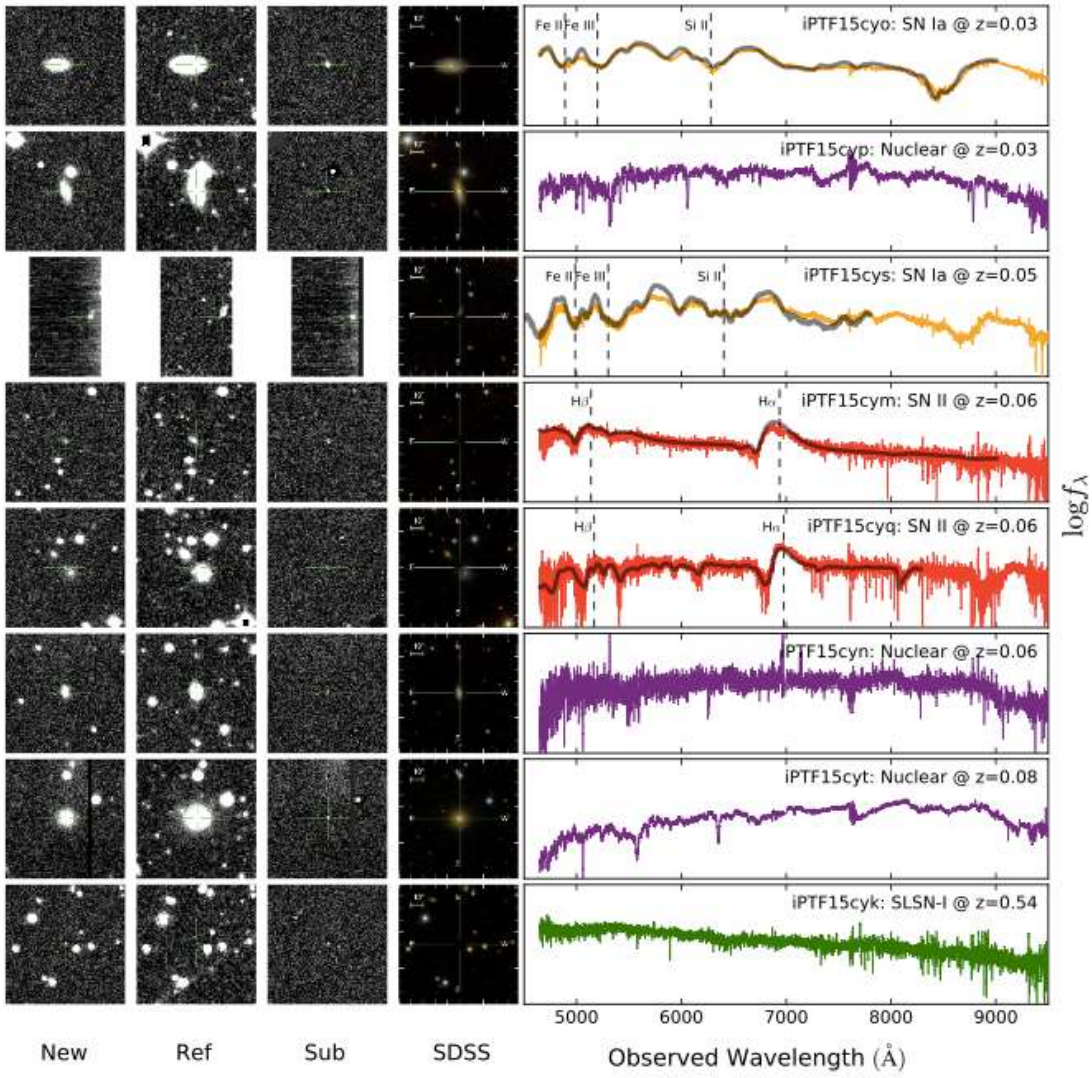
Mayer 60" Telescope

Hale 200" Telescope

Follow-Up is Key



GW150914: All candidates classified in 2 hours!



Kasliwal et al. 2016

Needle in haystack

127676 candidates in subtraction images

78951 do NOT have a quiescent stellar source

15624 are detected twice and NOT asteroids

5803 pass our machine learning threshold

1007 are coincident with a nearby galaxy

13 were vetted by human scanners

8 were scheduled for follow-up spectroscopic observations

0 were associated with the gravitational wave

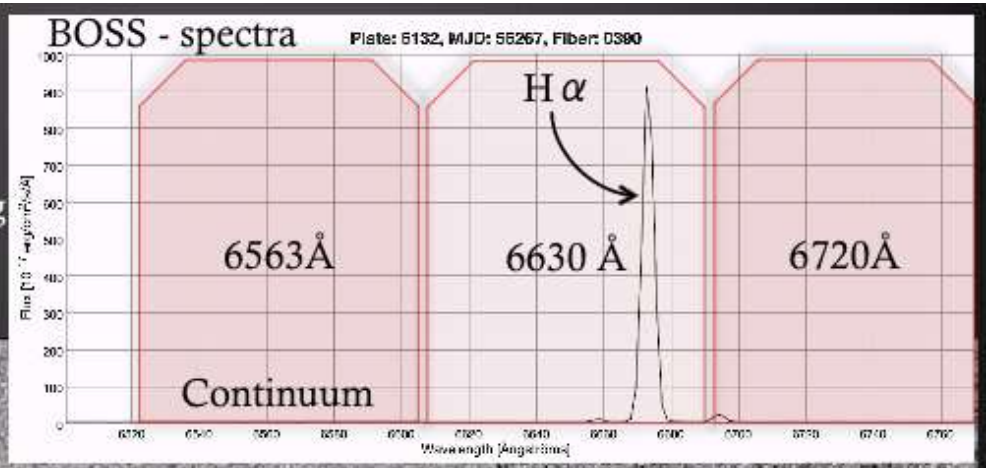
Kasliwal et al. 2016

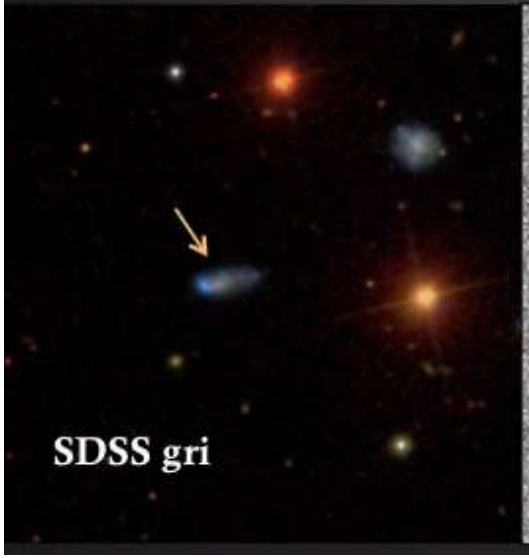
Census of the Local Universe (CLU Galaxy Catalog)

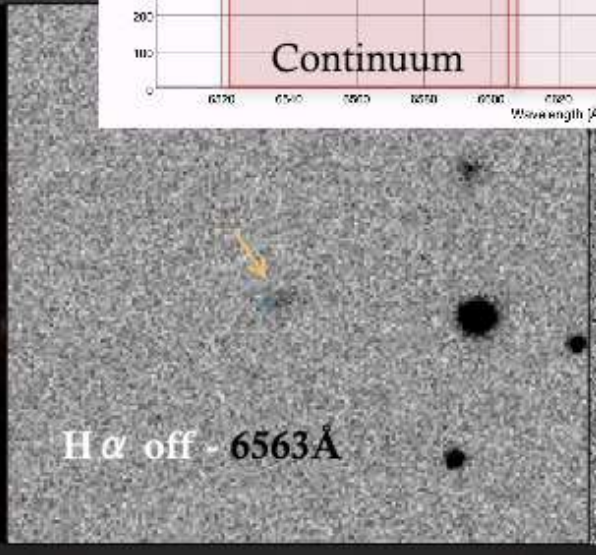
Dave Cook
237.08

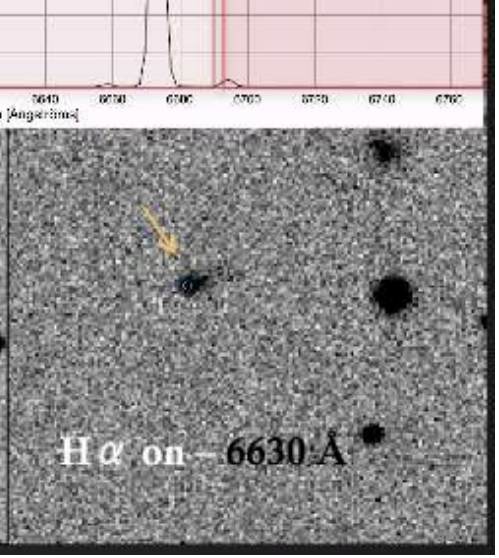
Narrowband Strategy

- New Galaxy
- Hα color (On − Off) = 1.5 mag
- at z ~ 0.017 (~75 Mpc)
- Hα EW = 675 Å









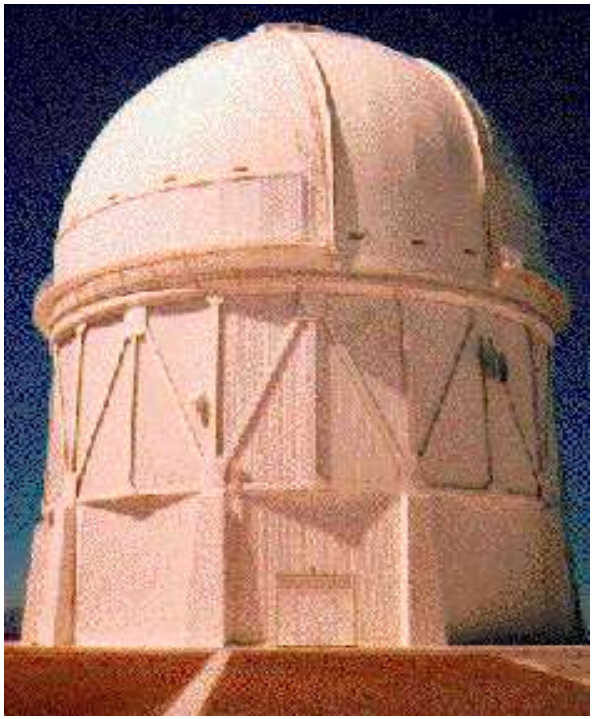
BUT…

What if even 2% of the neutrons fail to escape?

What if the ejecta mass is small and dominated by lanthanides?

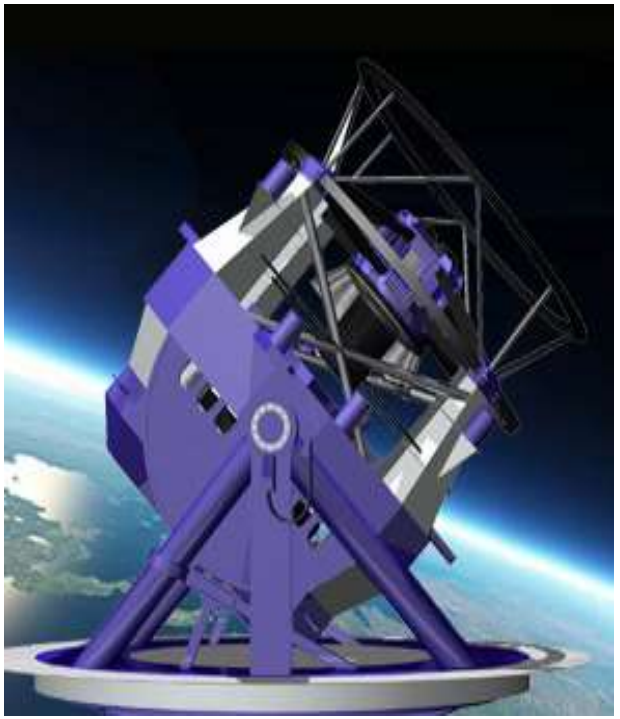
What if the lifetime of the hypermassive neutron star is too short?

Deep I & z-band Searches



CTIO-DECAM
4m, 3 deg^2

Subaru HSC
8.2m, 1.8 deg^2

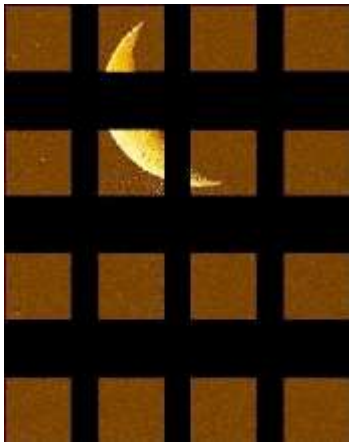


LSST
6.7m, 9.6 deg^2

BUT…

What if opacities push the emission entirely in the infrared beyond 1 micron?

Infrared



VIRCAM on VISTA
0.6 deg^2 on 4.1m

WFCAM on UKIRT
0.16 deg^2 on 3.8m

ETA (proposed)

Space

Stay Tuned: 25 deg^2 J-band imager at Palomar this summer!

Caution is the better part of valor

It could be fast

It could be red

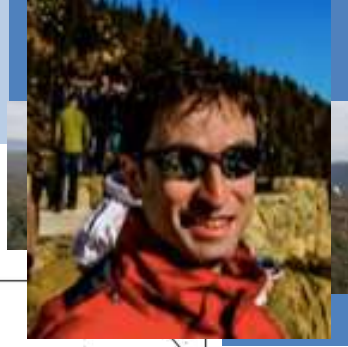
It could be temporally coincident

It could be next to a nearby galaxy

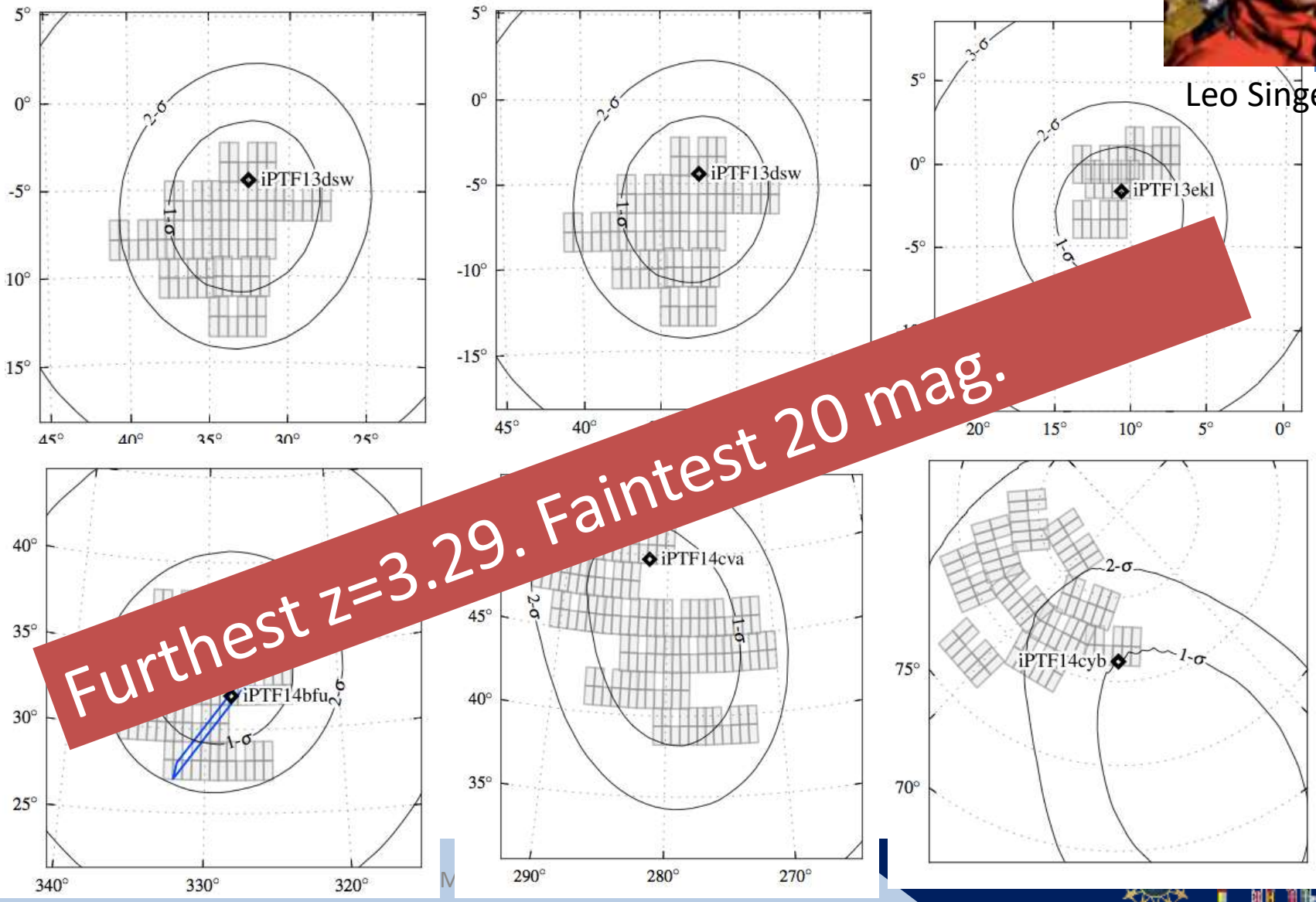
BUT unrelated!

"Spectrum is Truth"

Thank you



Leo Singer



Furthest z=3.29. Faintest 20 mag.

Singer et al. 2013, 2015 (PhDT)

TDA in the LSST era

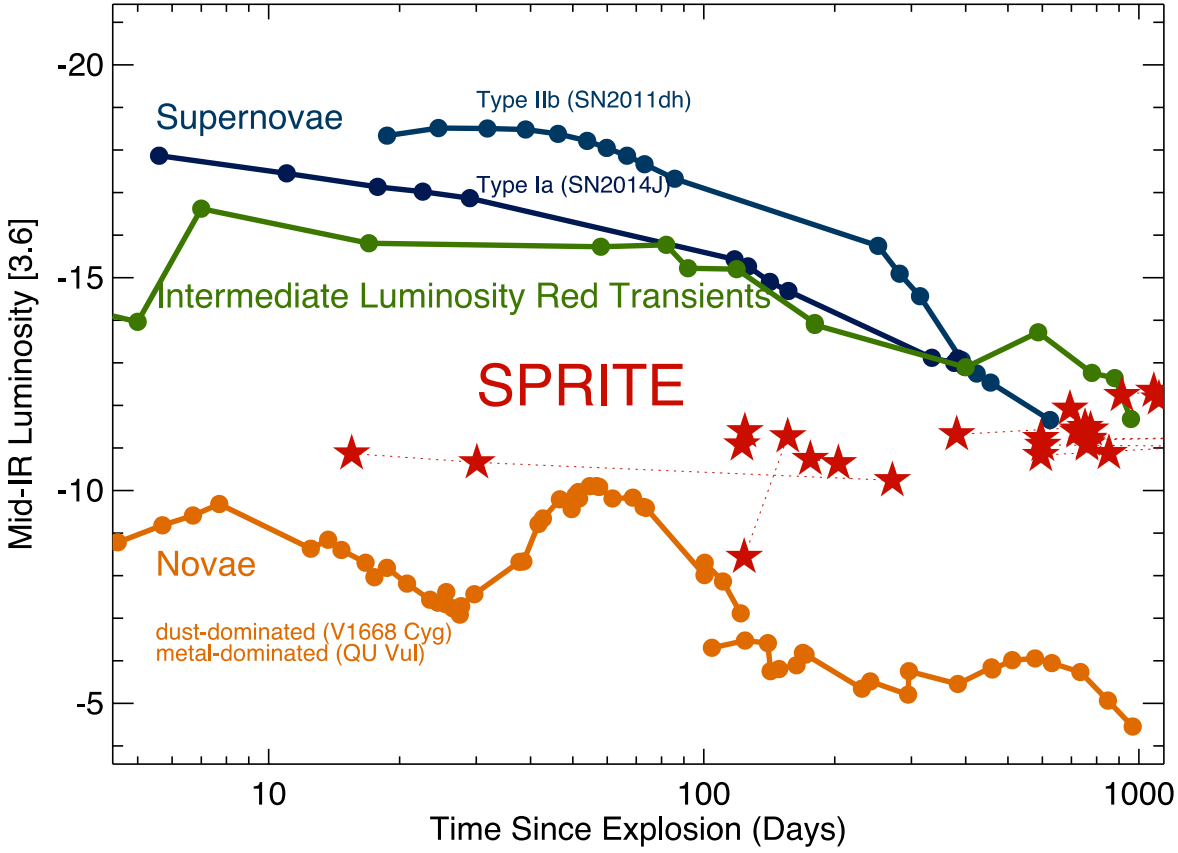
PTF: 4×10^4 events/night
ZTF: 3×10^5 events/night
LSST: 2×10^6 events/night

Technical	develop algorithms & software for detection & classification
Scientific	discover new transient & variable phenomena
Organizational	organize collaborations and followup strategies with real data

GROWTH builds a global community ready to contribute LSST time-domain science!

SPIRITS:

SPitzer InfraRed Intensive Transients Survey



Kasliwal et al. 2016b, ApJ, submitted

Cycles 10-13
1410 hours of Spitzer mid-IR
190 Galaxies x 14 epochs
(PI Kasliwal)

Every Year:
110 nights of near-IR imaging
66 nights of optical imaging
33 nights of spectroscopy

147 transients (35 SPRITEs)
1948 strong variables

A New Infrared Discovery Engine?