
Image Credit: Aaron Geller, Northwestern

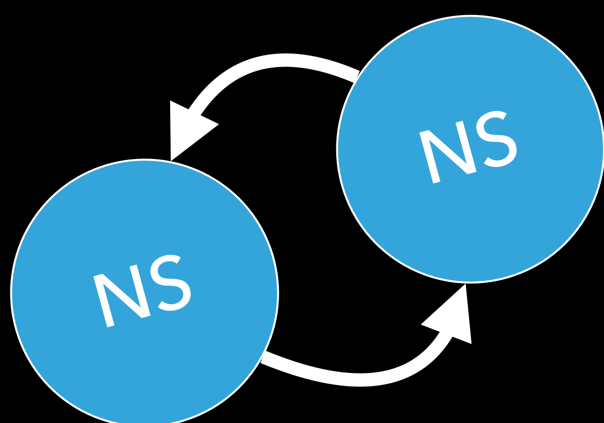
OBSERVING THE DIVERSITY OF NEUTRON STAR MERGER COUNTERPARTS WITH GEMINI

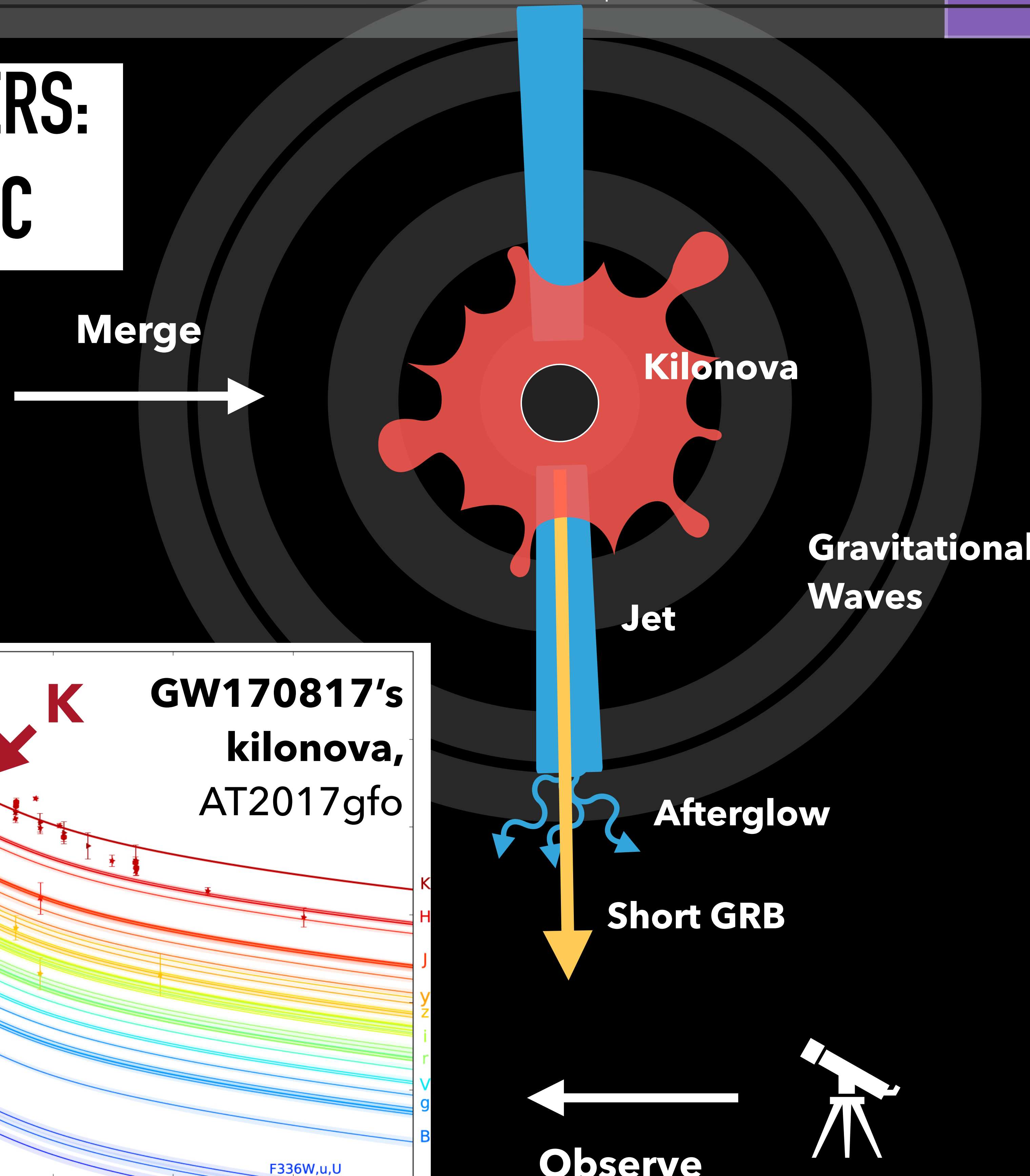
JILLIAN RASTINEJAD

Northwestern

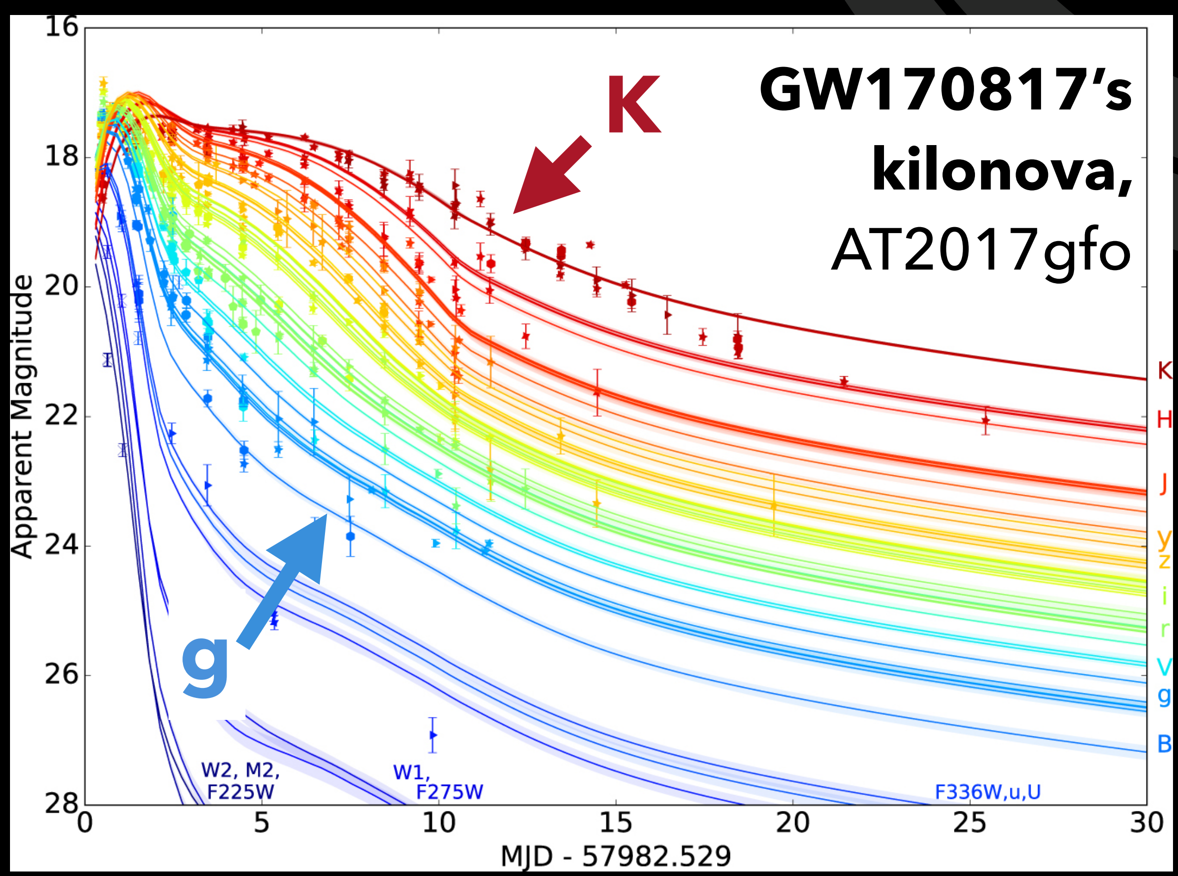
CIERA
CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

NEUTRON STAR MERGERS: GW170817 AT 40 MPC



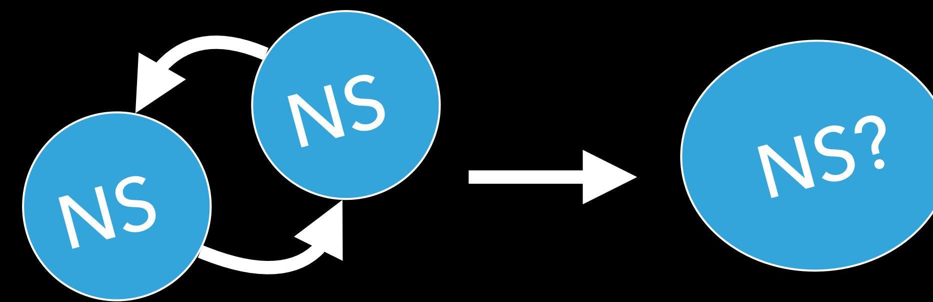


Villar+17
with data compiled from
Andreoni+17;
Arcavi+17; Coulter+17;
Cowperthwaite+17;
Diaz+17; Drout+17;
Evans+17; Hu+17;
Kasliwal+17;
Lipunov+17; Pian+17;
Pozanenko+17;
Shappee+17;
Smartt+17; Tanvir+17;
Troja+17; Utsumi+17;
Valenti+17



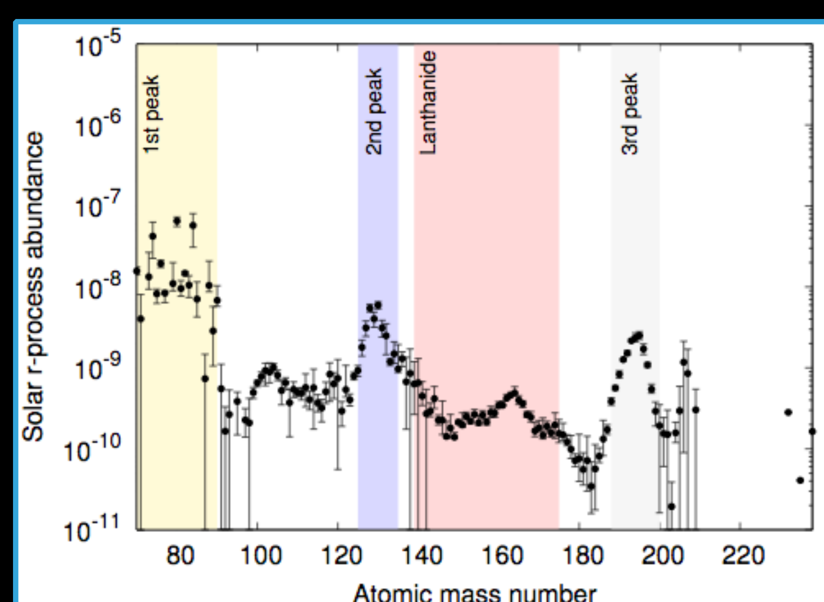
What can we learn from kilonovae?

Equation of State (maximum mass of NS)

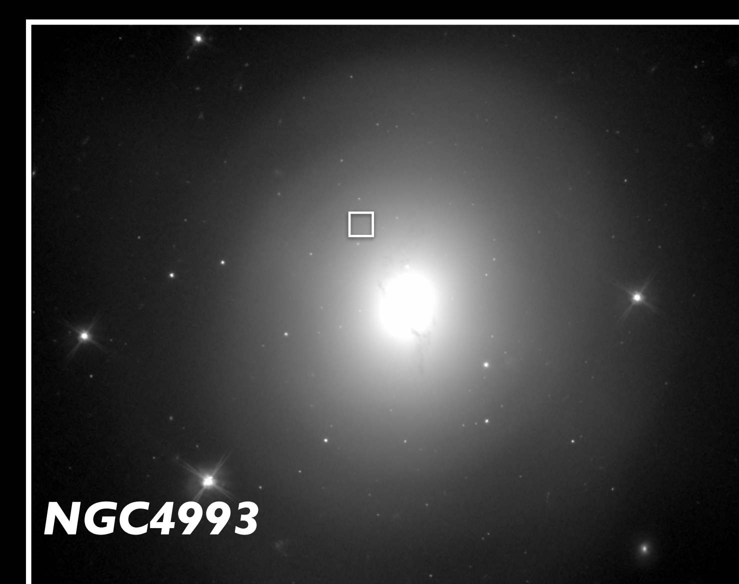


Impact on environment & chemical evolution

The origin of heavy (r-process) elements



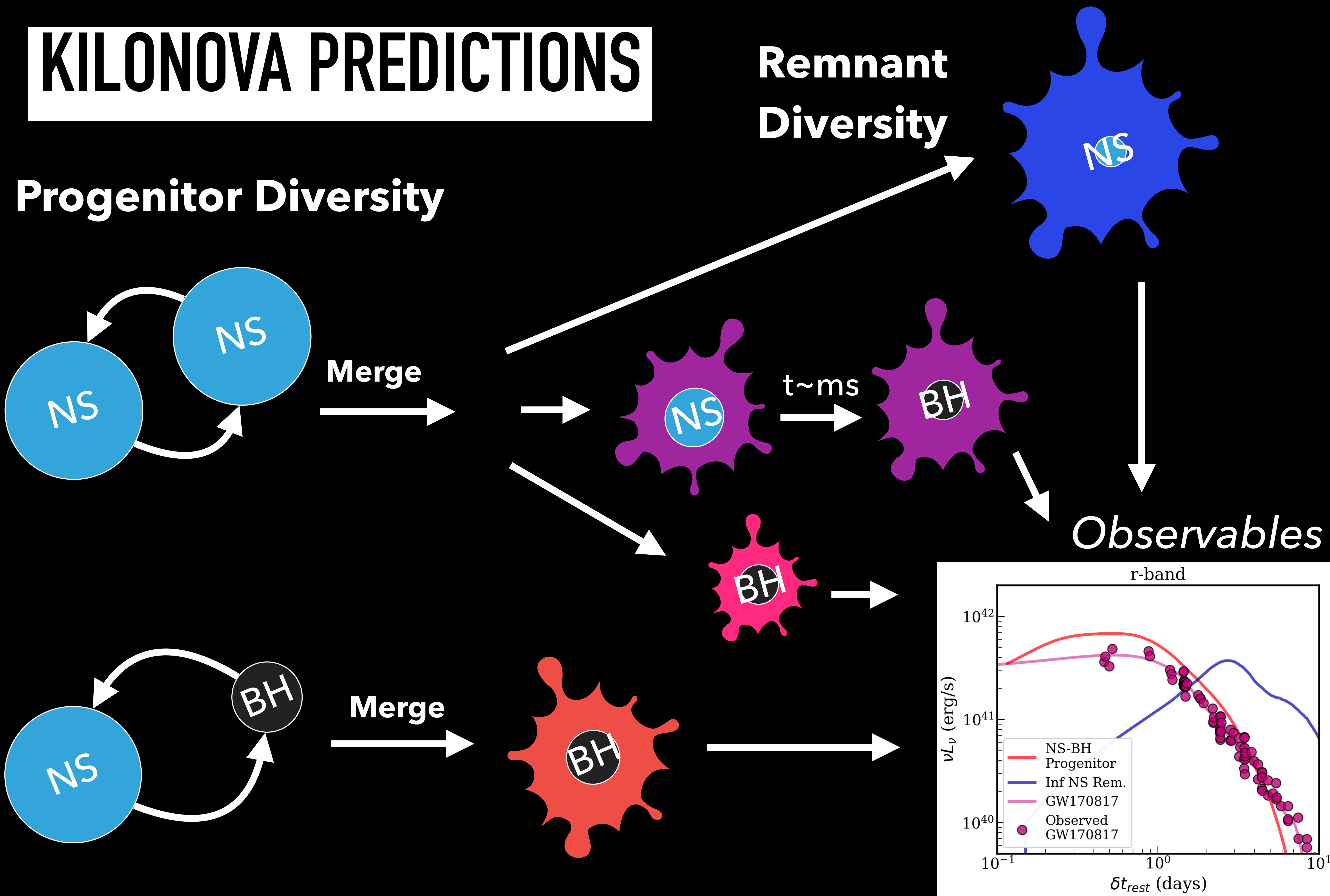
Hotokezaka et al. 2018; Goriely 1999



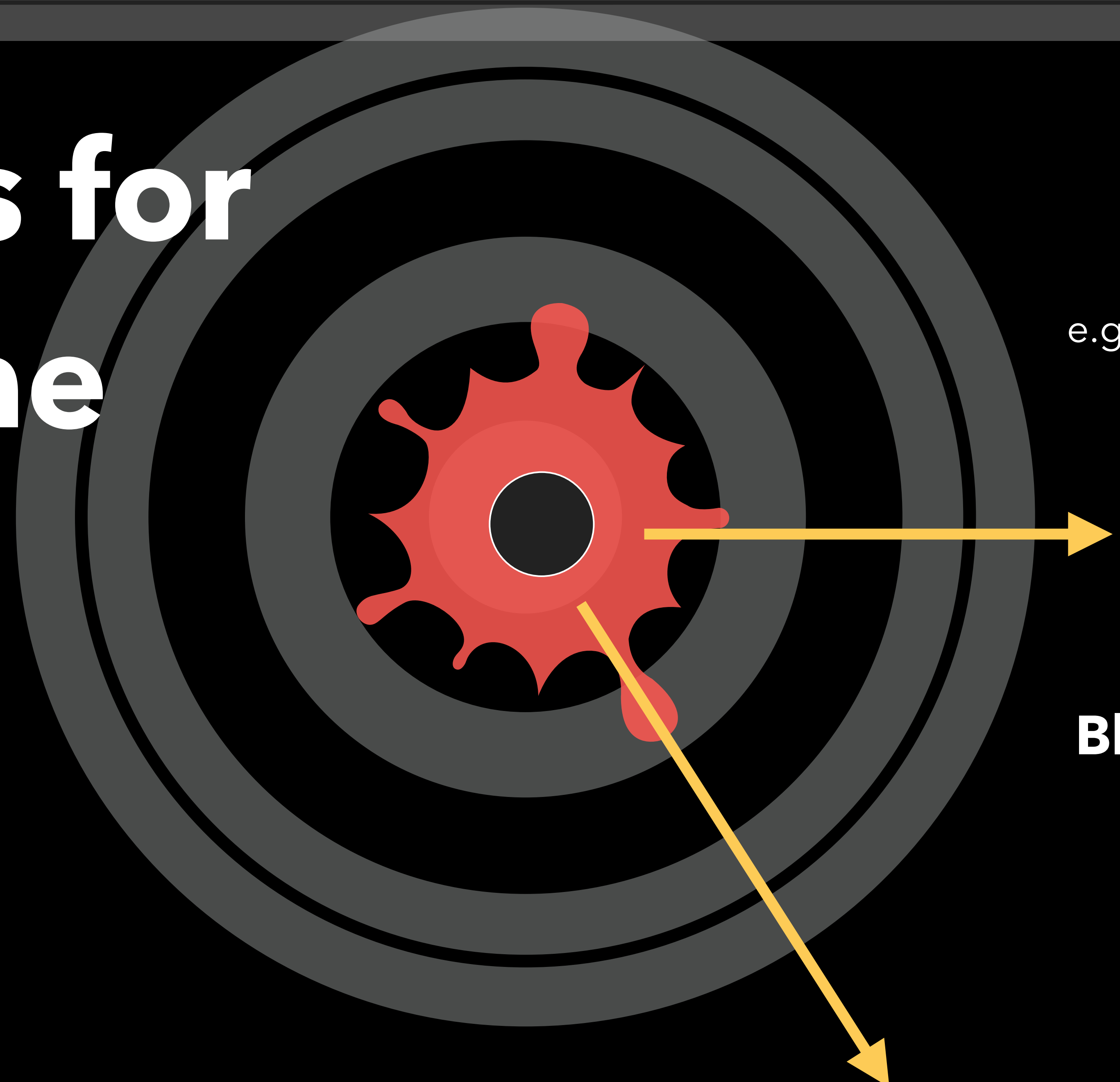
HST/Northwestern/W. Fong et al

Slide adapted from Wen-fai Fong

KILONOVA PREDICTIONS



Searches for Kilonovae



e.g., Smartt+17, Yang+18, Andreoni+21

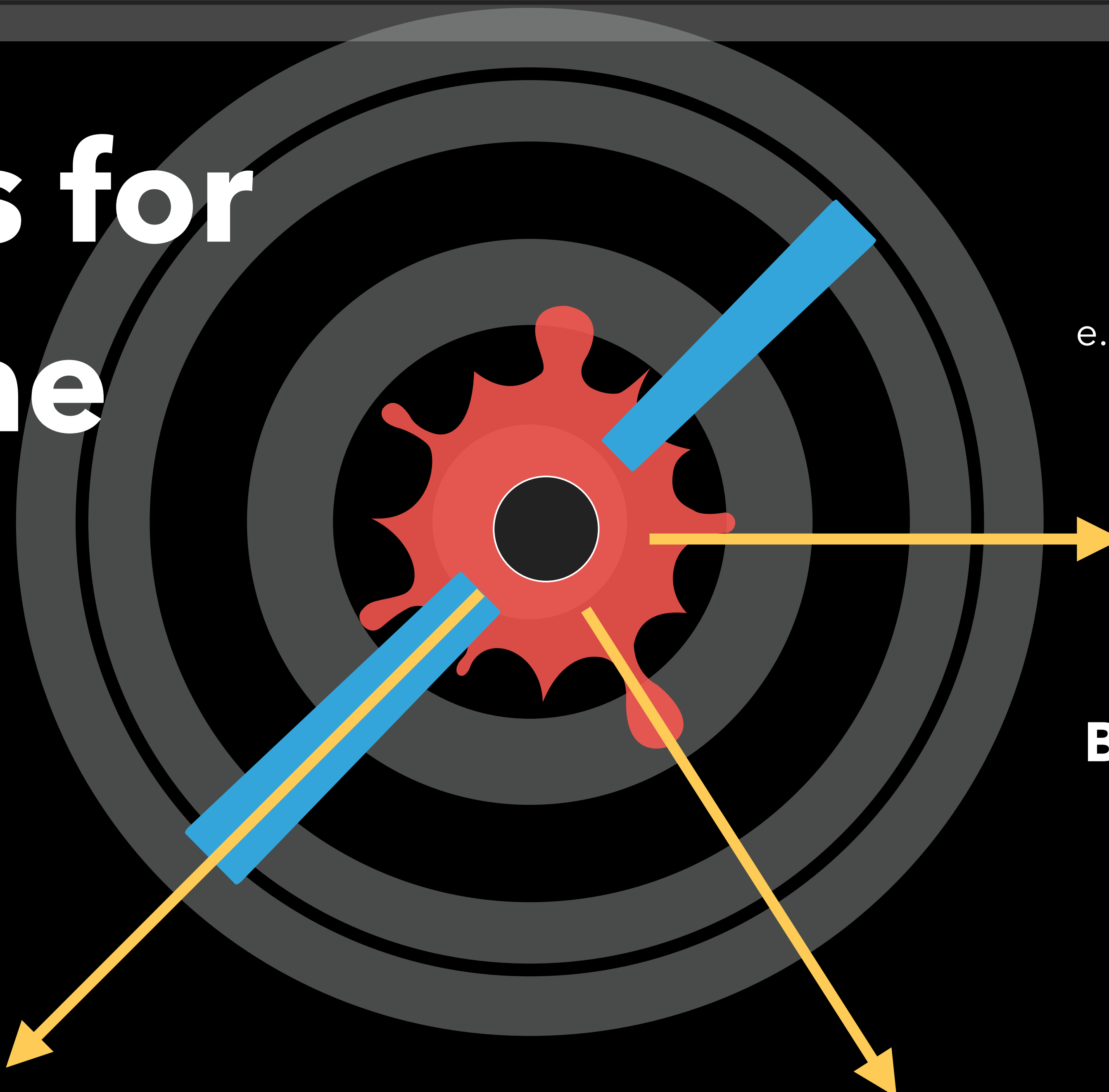
Blind Searches in Large Surveys

Virgo

LIGO

Gravitational Waves

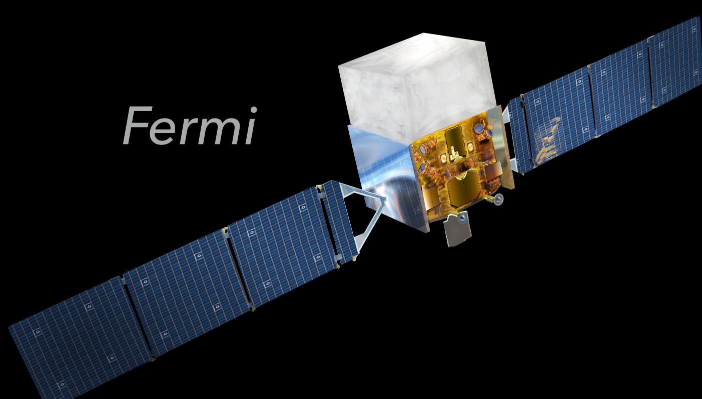
Searches for Kilonovae



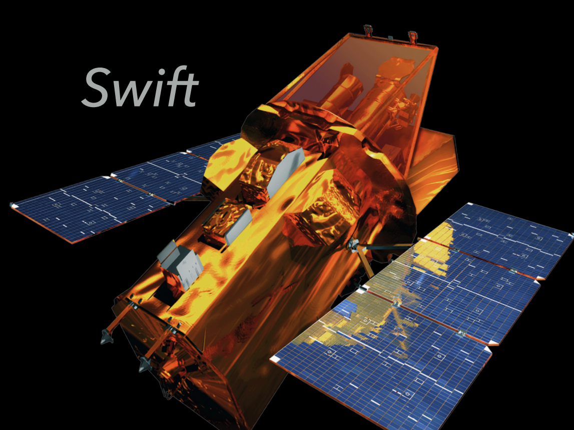
e.g., Smartt+17, Yang+18, Andreoni+21

Blind Searches in Large Surveys

Fermi



Swift



Short GRBs

Virgo

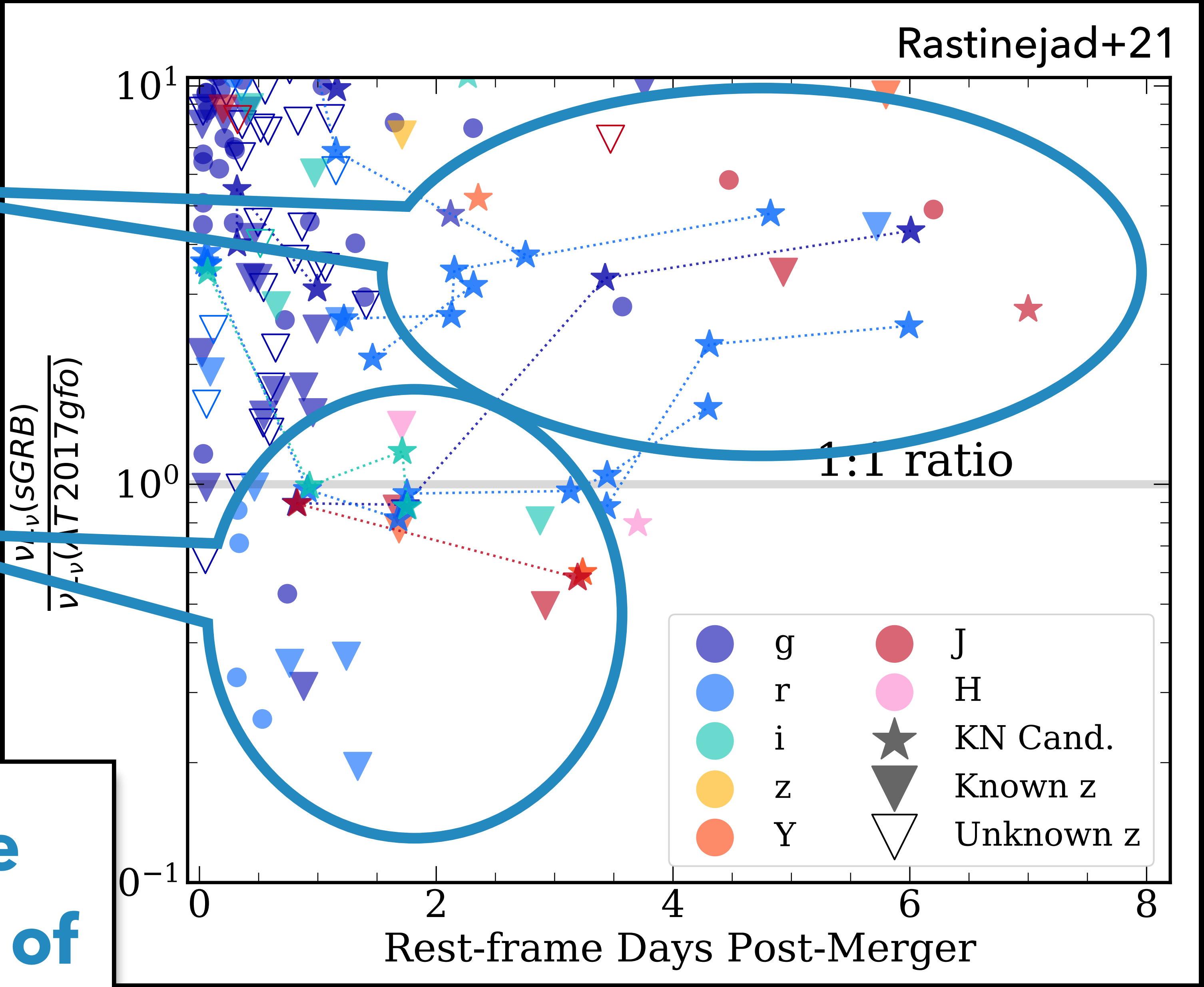
LIGO

Gravitational Waves

Comparing all SGRB KN observations to AT2017gfo

Kilonova candidates are more luminous in bluer bands than AT2017gfo

Deep upper limits of 10 bursts fall below 1:1 ratio



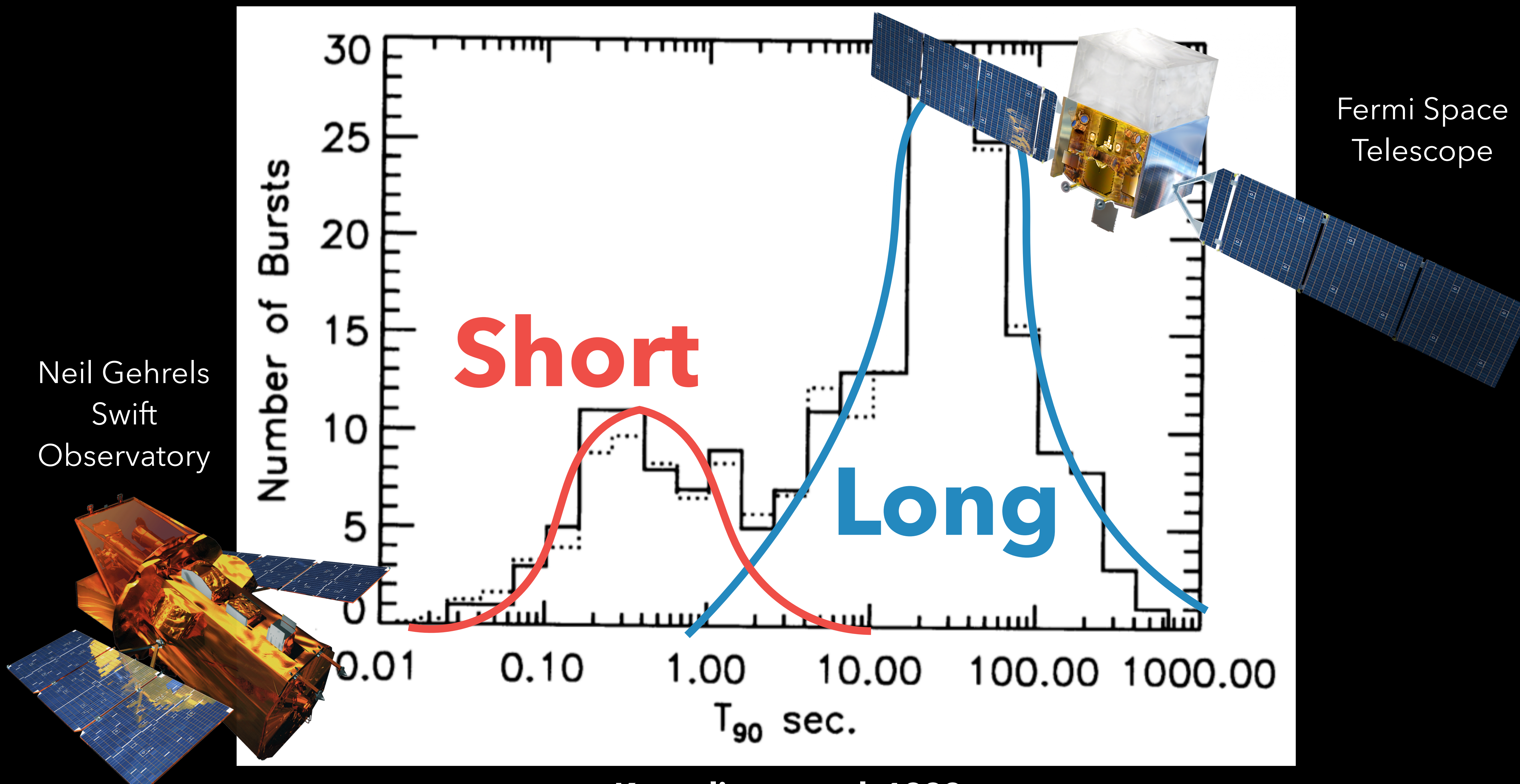
Rest-frame optical KNe observations show span of ~100 in luminosity

See also Gompertz+18, Ascenzi+19, Rossi+20

The Gamma-ray Burst Paradigm

Neil Gehrels Swift Observatory

Fermi Space Telescope

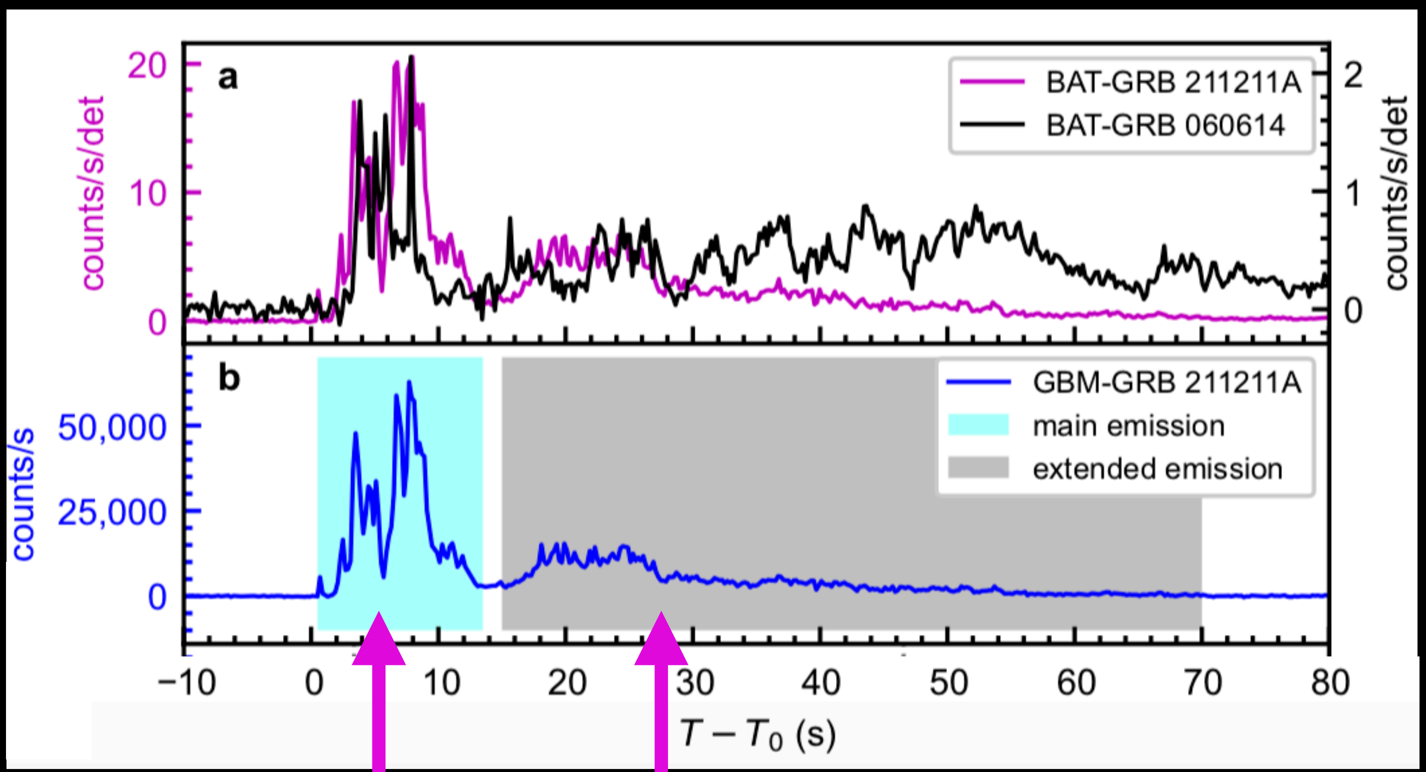


Kouveliotou et al. 1993

GRB 211211A: Exciting Ingredients

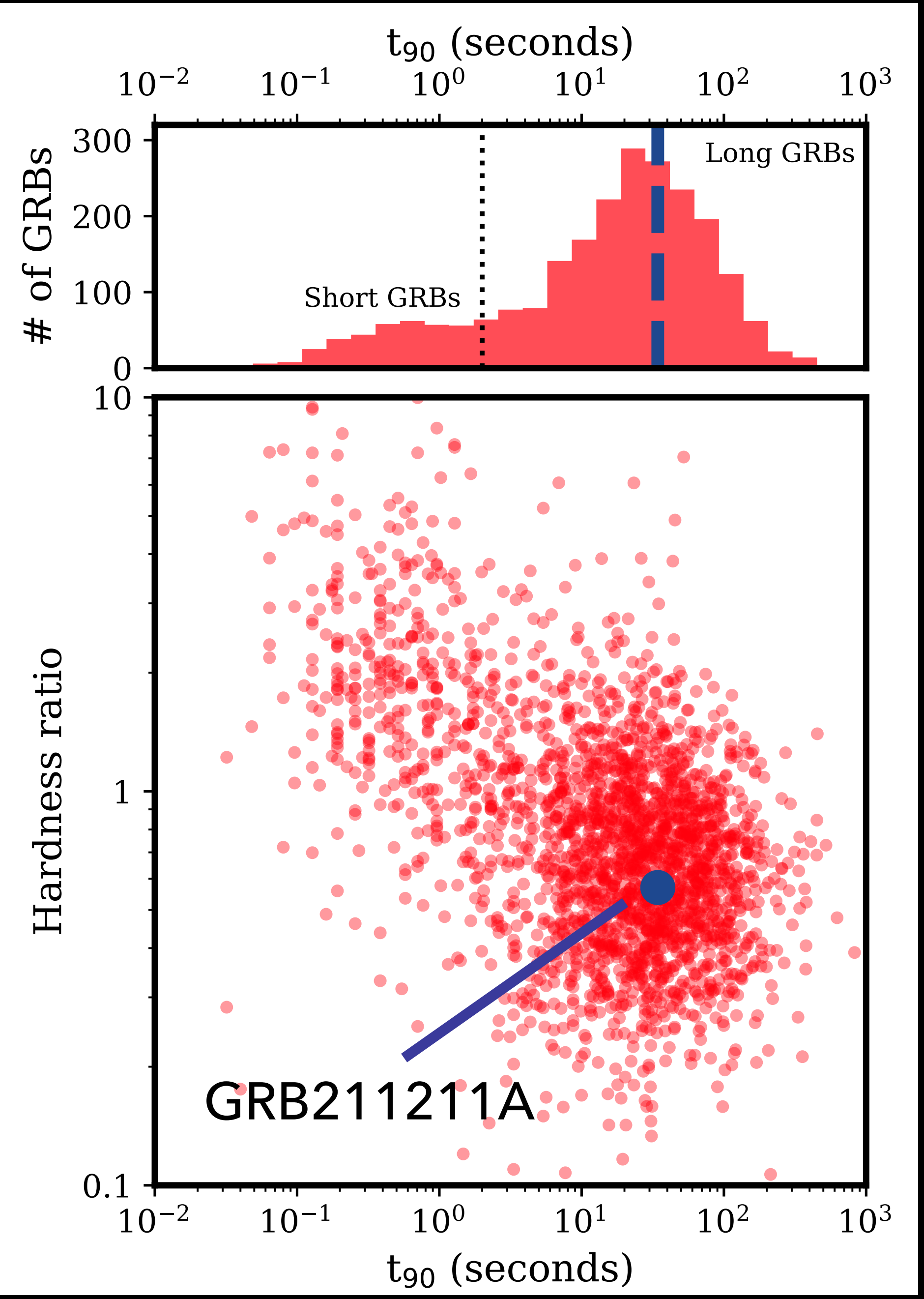
An ambiguous gamma-ray light curve

Yang+22



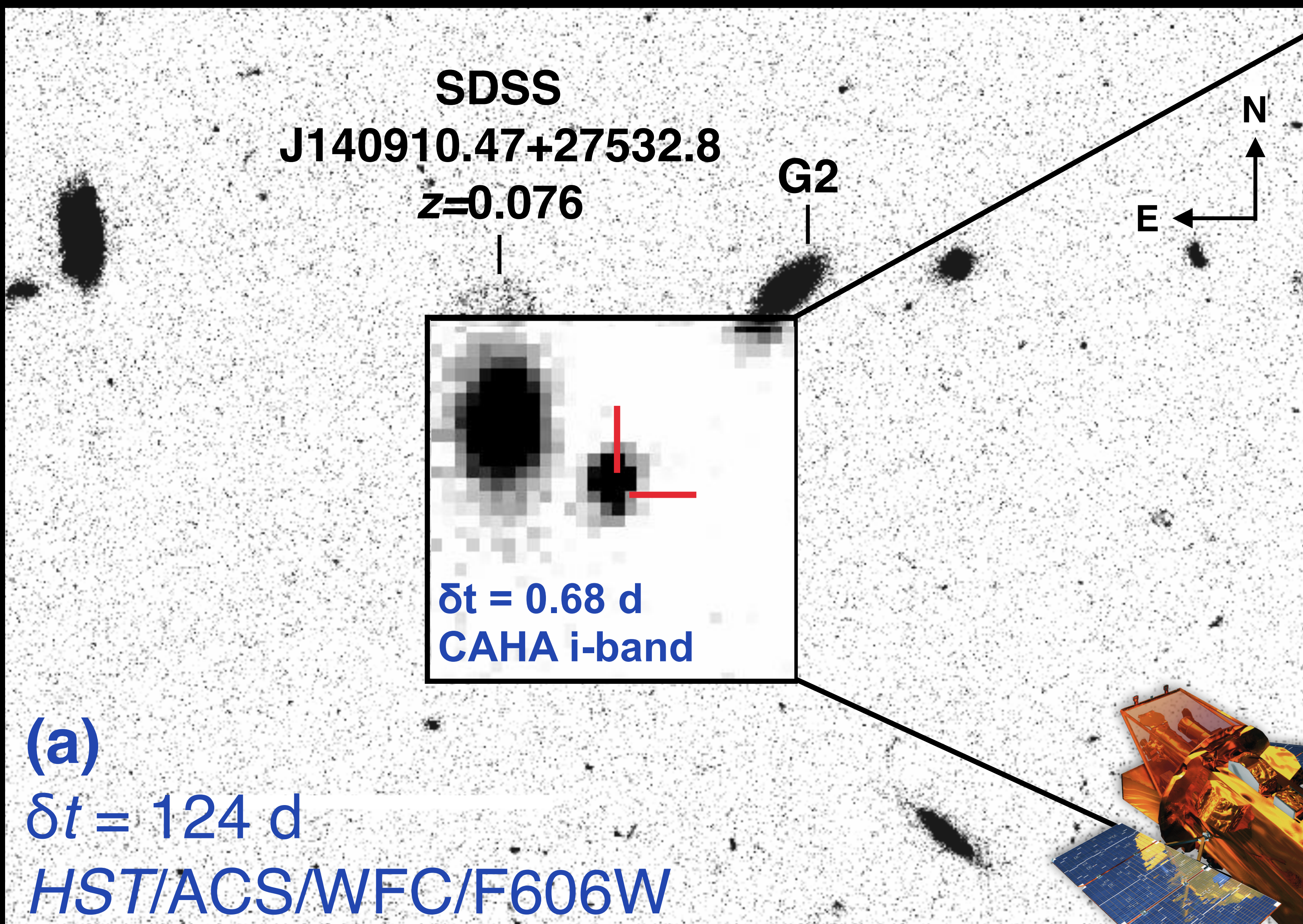
Spectrally-hard pulse complex lasting ~12s

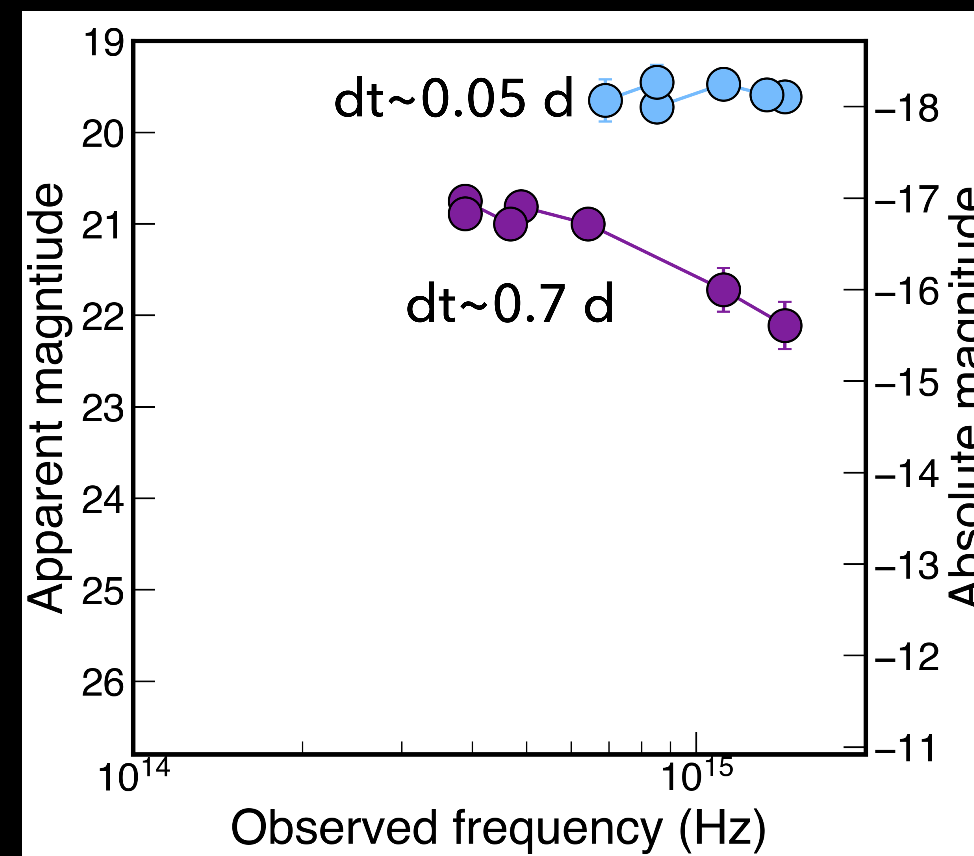
Tail of softer extended emission (seen for ~25% of SGRBs)



Rastinejad+22

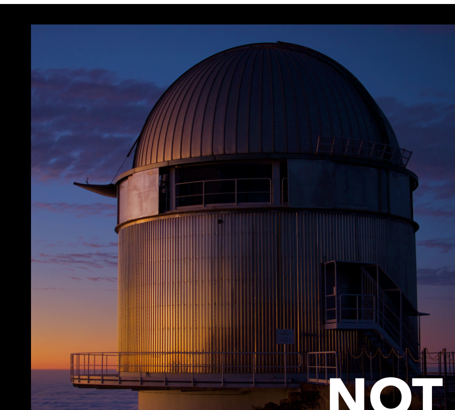
Observing a red excess following the **50-s duration GRB 211211A at 350 Mpc**





Rastinejad+22

Swift/XRT, UVOT



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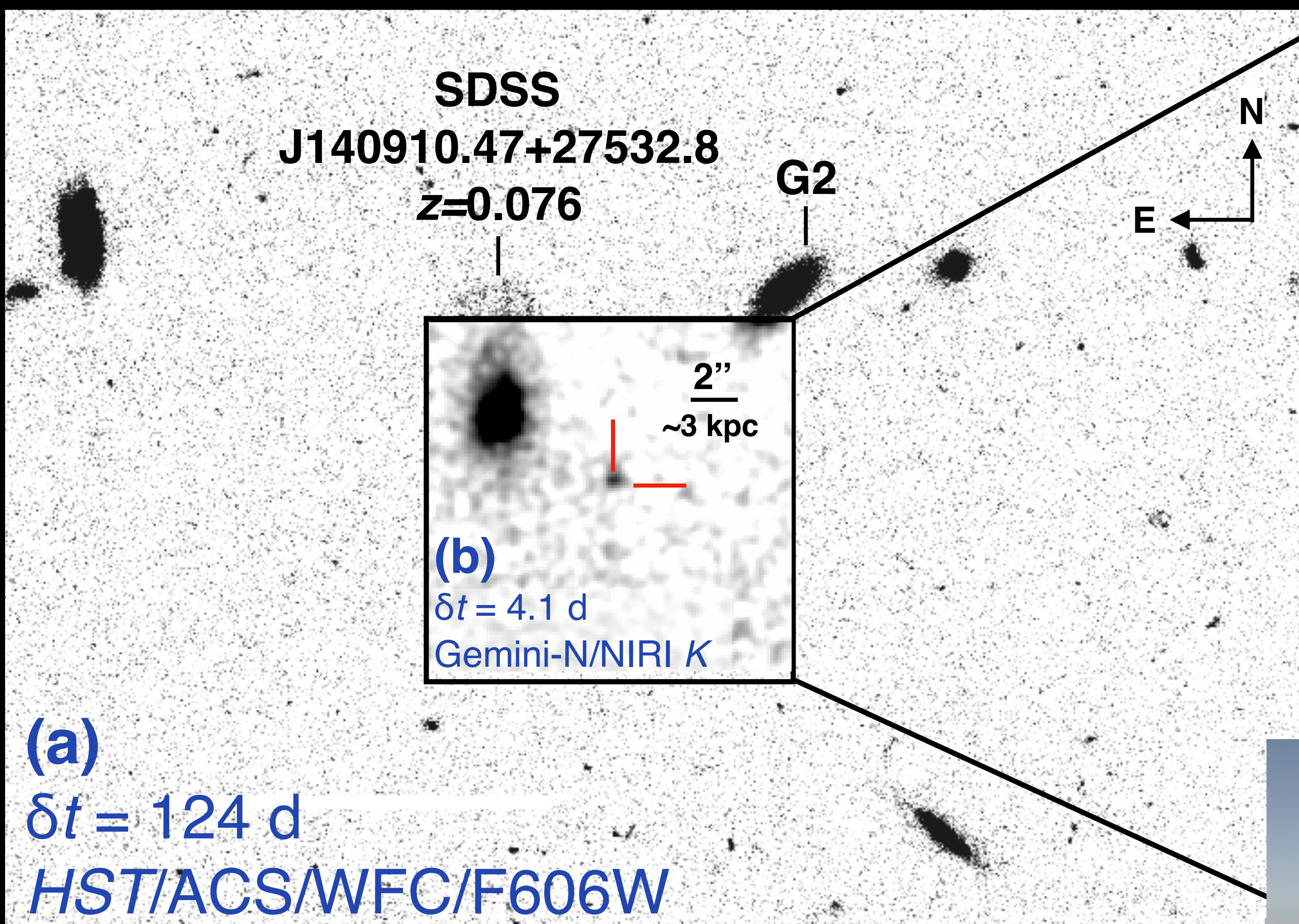
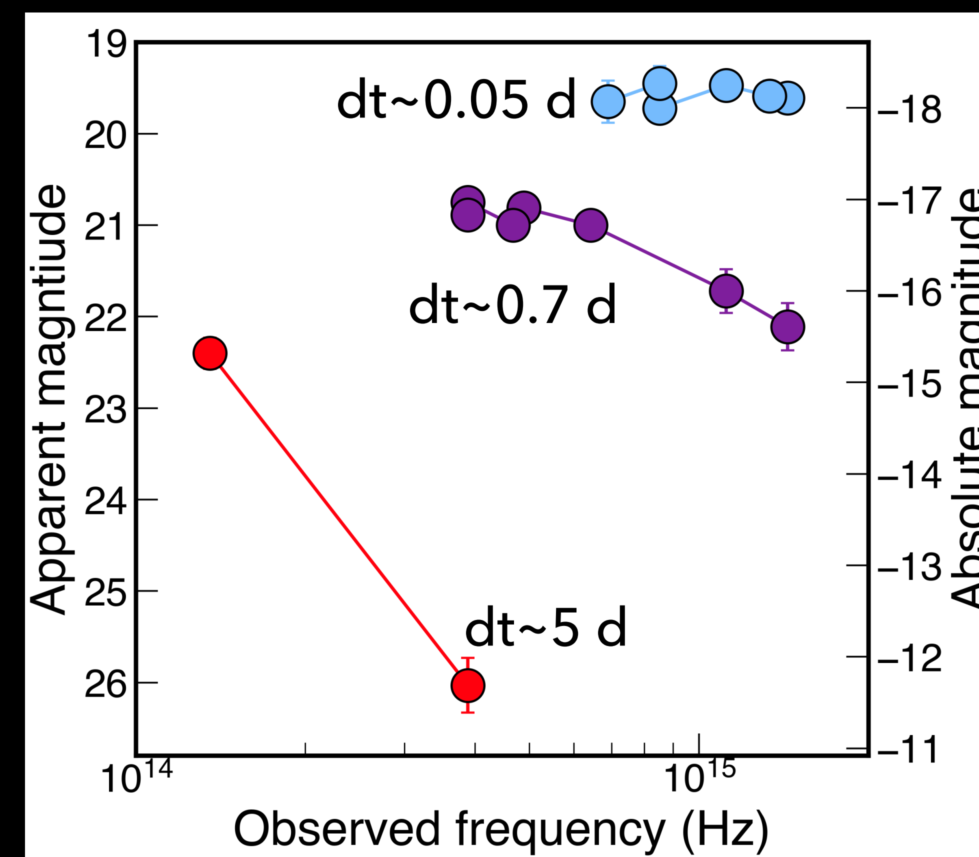
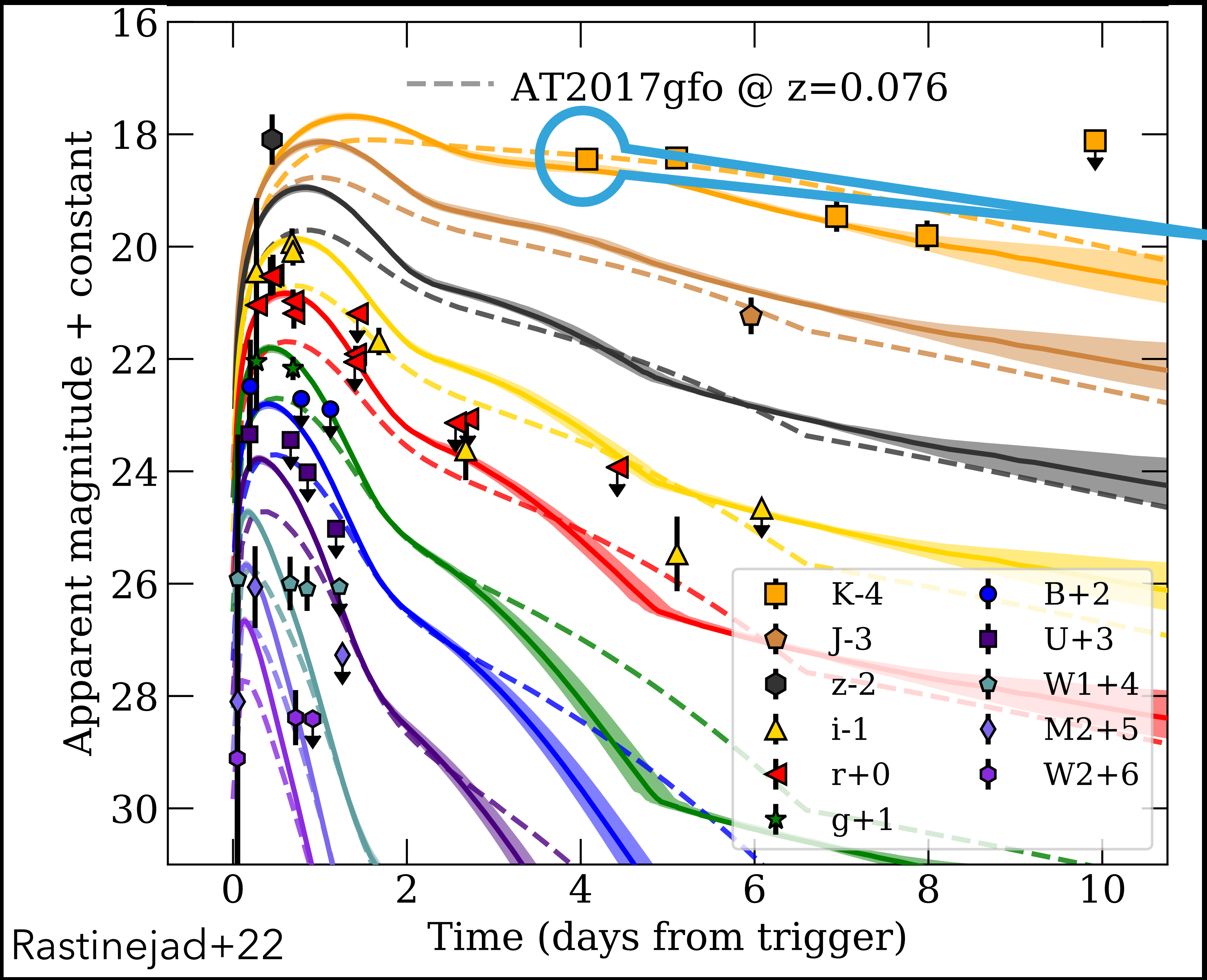




Rastinejad+22; PIs: Fong, Rastinejad

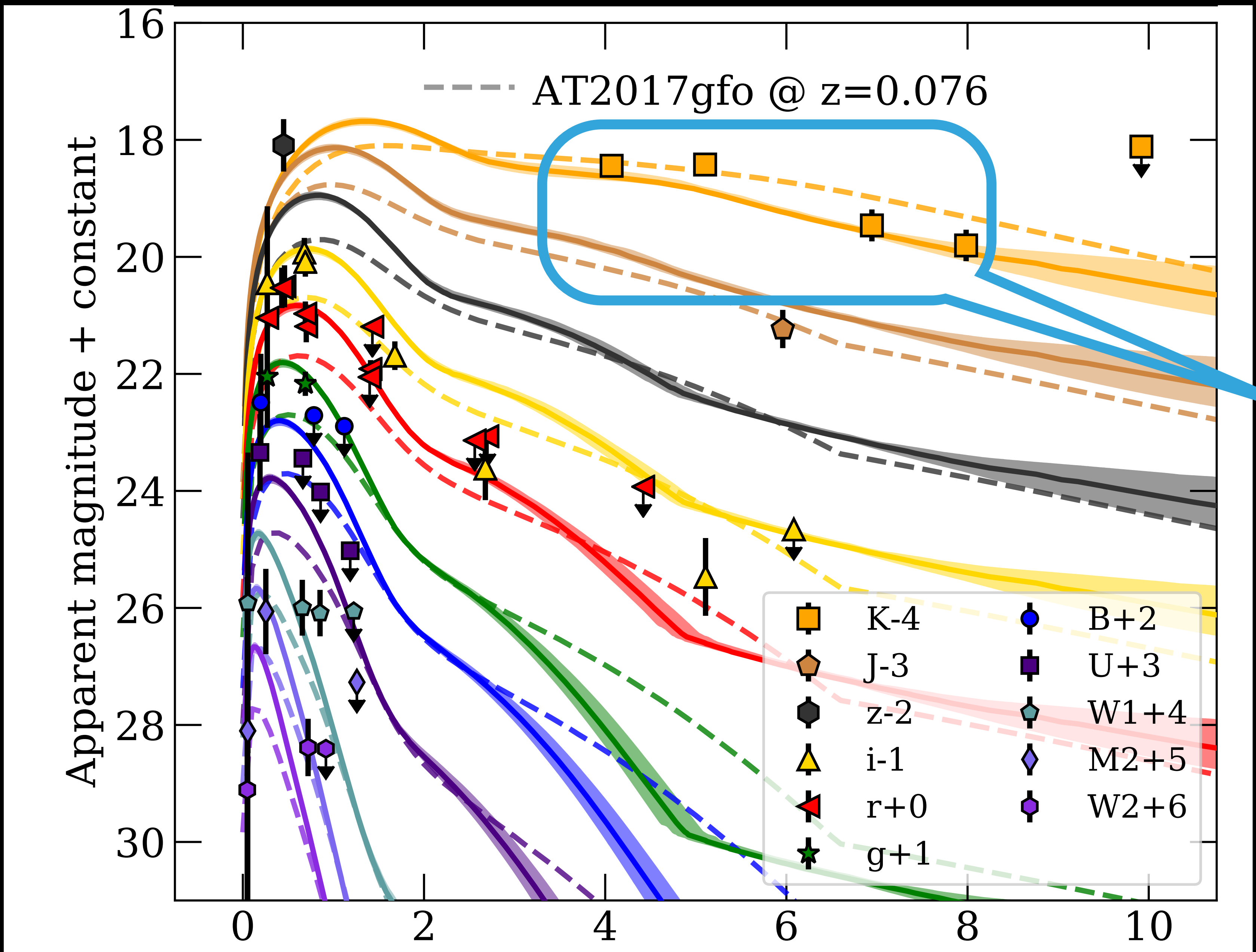
The 2nd-closest kilonova to date comes from a surprising source: the **50-s duration GRB 211211A**



Afterglow-subtracted Optical/NIR data + KN Model

Nearly the same K-band luminosity as AT2017gfo

The 2nd-closest kilonova to date comes from a surprising source: the **50-s duration GRB 211211A**



Rastinejad+22

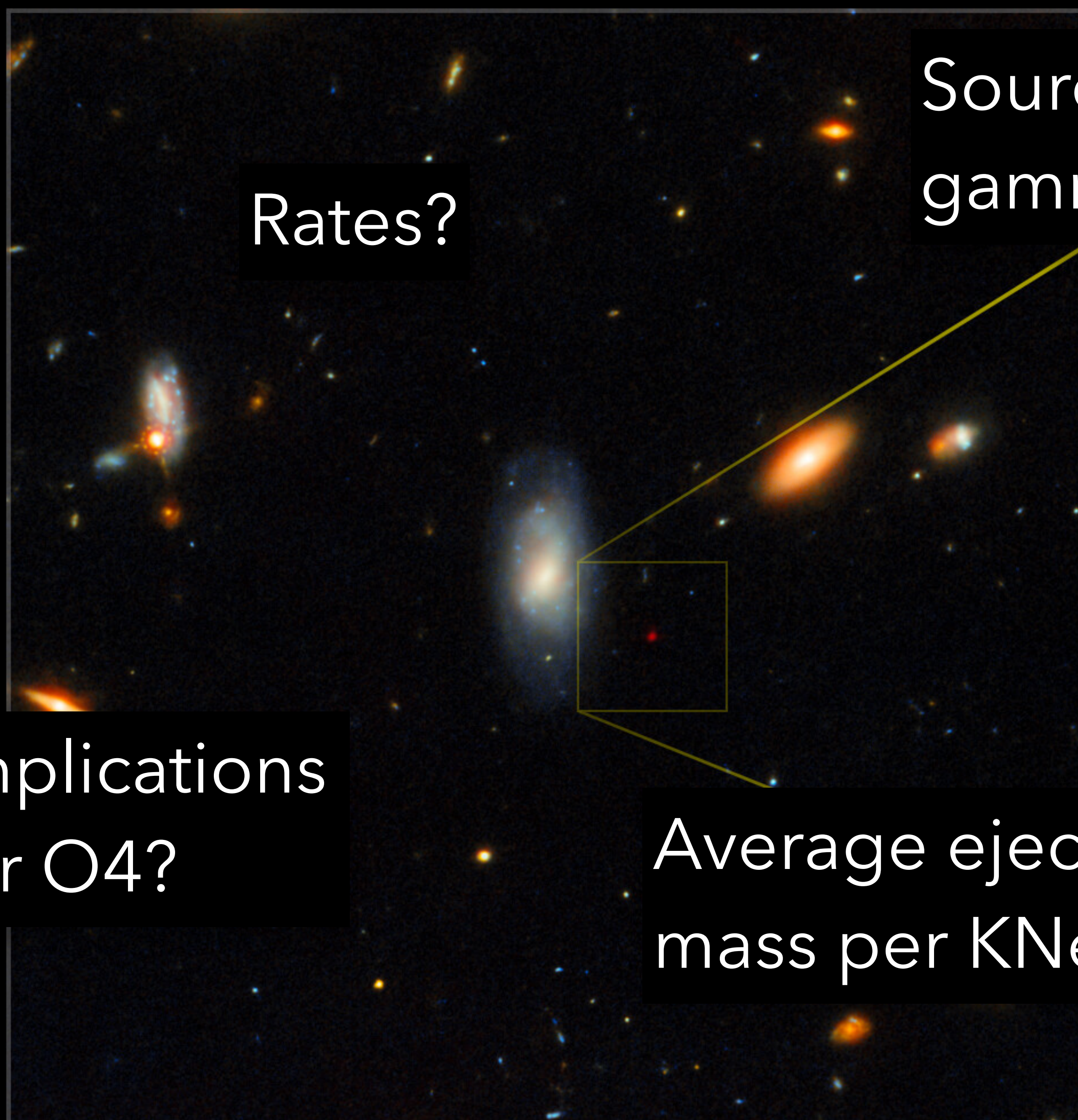
Afterglow-subtracted Optical/NIR data + KN Model

Nearly the same K-band luminosity as AT2017gfo

K-band fades on similar timescales to AT 2017gfo

Good fit to kilonova model of M_{ej}~0.04 $M_{\odot}$

The 2nd-closest kilonova to date comes from a surprising source: the **50-s duration GRB 211211A**



Source of extended gamma-rays?

Rates?

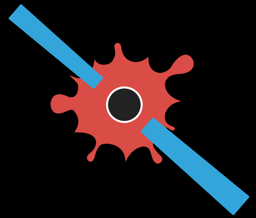
Implications for O4?

Average ejecta mass per KNe?

International Gemini Observatory/NOIRLab/NSF/AURA/M. Zamani; NASA/ESA

BIG thanks to Charles Blue + Amanda Kocz at NOIRLab for their beautiful press release!

Gemini Observatory is uniquely poised to observe **short GRB counterparts** & their **host galaxies**



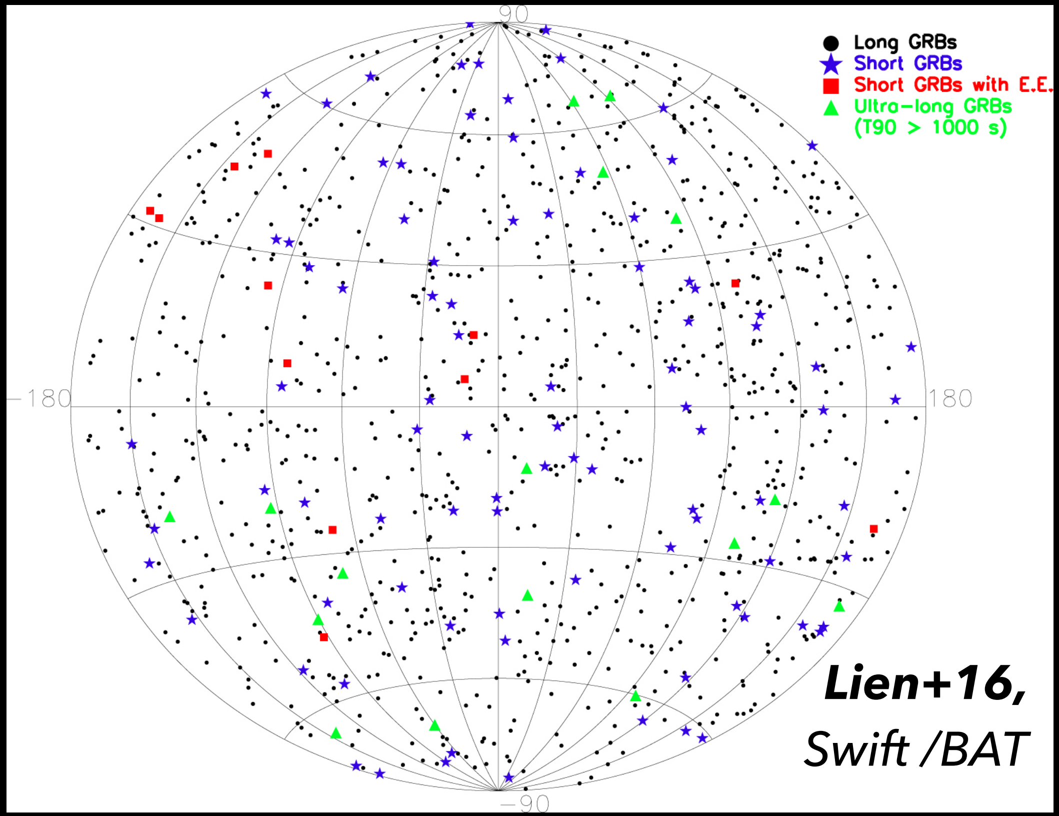
Observational Clues

1. Discovered across the sky by Fermi + Swift

Gemini Observatory

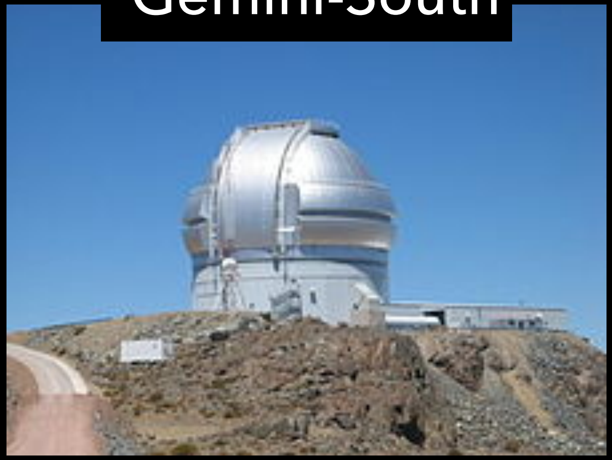
Wide coverage of Northern and Southern sky

Gemini-North



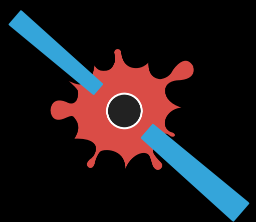
Lien+16,
Swift /BAT

Gemini-South



Think about what images are best here - maybe just show F2 + NIRI + GMOS?
Anything that shows rapid response?

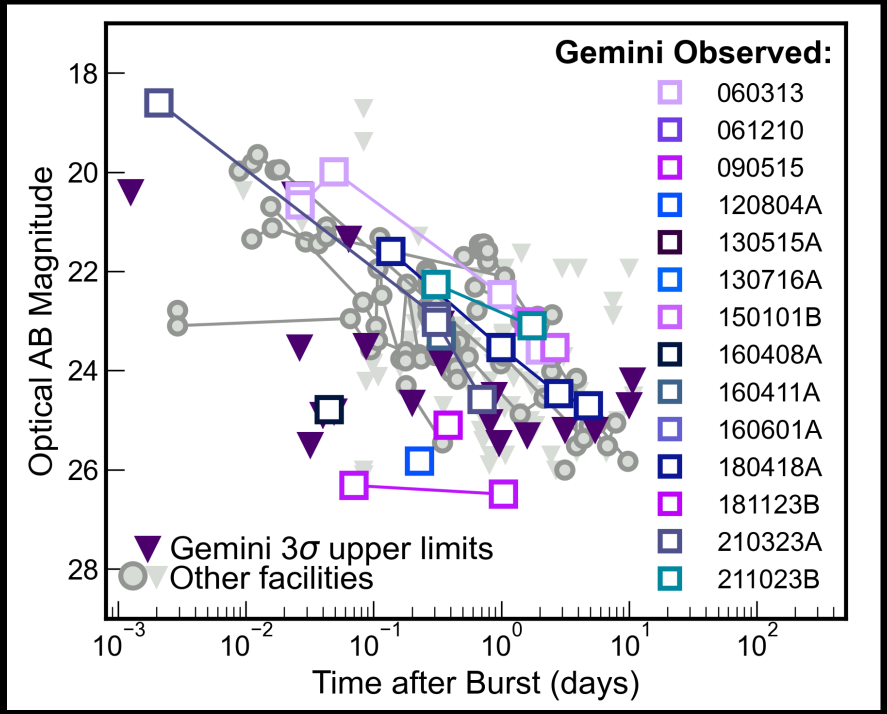
Gemini Observatory is uniquely poised to o[…] **counterparts** & their **host galaxies**



Observational Clues

1. Discovered across the sky by Fermi + Swift

2. Accompanied by broadband afterglows & fast-fading kilonovae



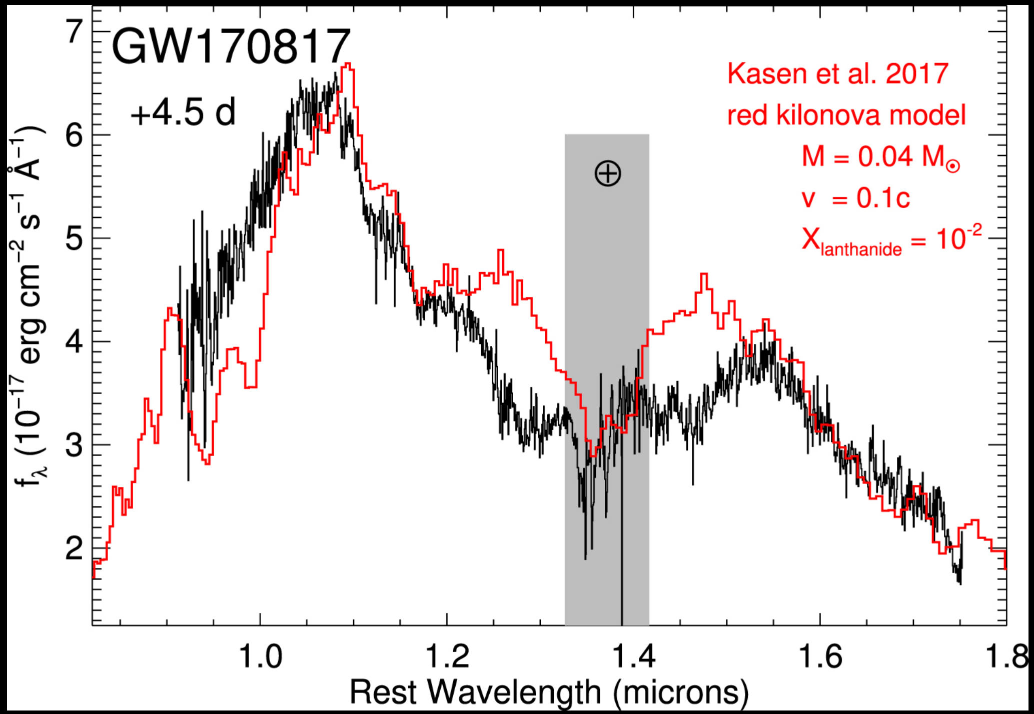
Rapid TOO Gemini observations account for ~1/3 of detected sGRB optical afterglows

Gemini Observatory

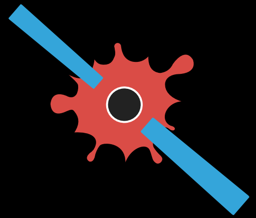
Wide coverage of Northern and Southern sky

Rapid ToO response + diverse suite of instruments

Chornock+17; GMOS-S spectra complemented GMOS + F2 imaging of r-process kilonova



Gemini Observatory is uniquely poised to observe **GRB counterparts** & their **host galaxies**



Observational Clues

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2. Accompanied by broadband afterglows & fast-fading kilonovae

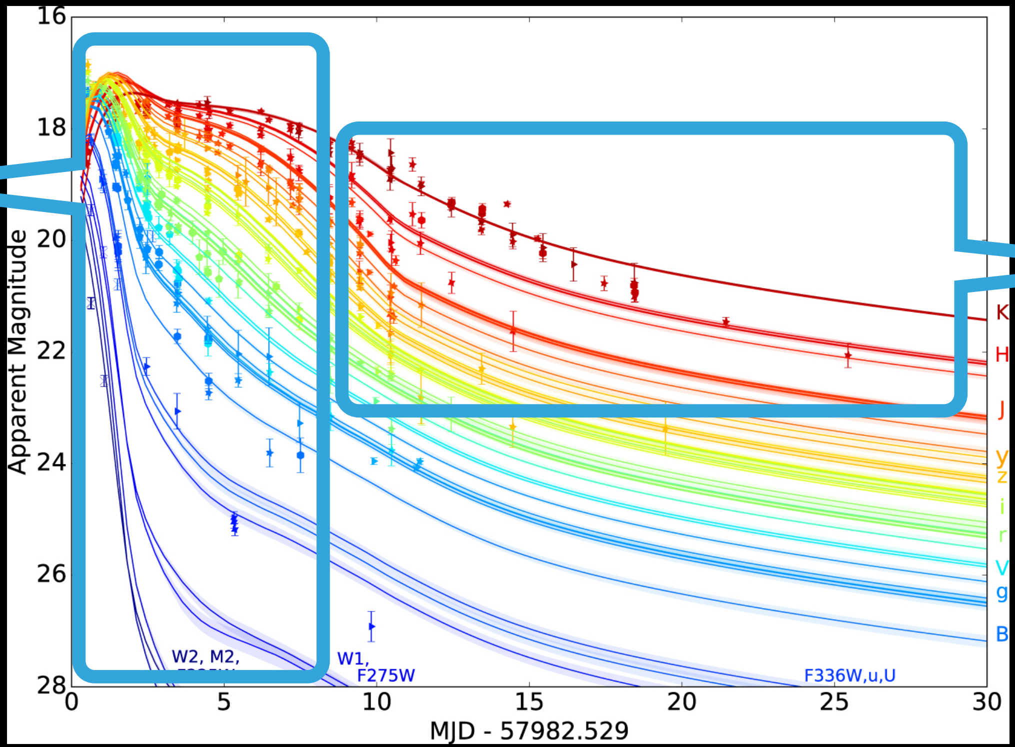
Gemini Observatory

Wide coverage of Northern and Southern sky

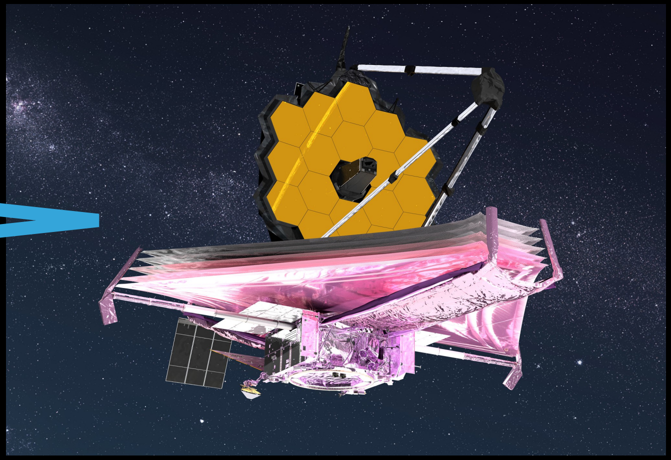
Rapid ToO response + diverse suite of instruments

Scorpio

Rapid simultaneous broadband imaging will constrain AG contribution, KN ejecta mass & composition, etc.



GW170817's kilonova AT2017gfo, *Villar+17*



Cycle 1 JWST program to obtain late-time IR spectra of SGRB kilonova (PI: Berger)

Gemini Observatory is uniquely poised to observe **GRB counterparts** & their **host galaxies**

Observational Clues

1. Discovered across the sky by Fermi + Swift
2. Accompanied by broadband afterglows & fast-fading kilonovae
3. Associated with galaxies across z ~ 0 - 3

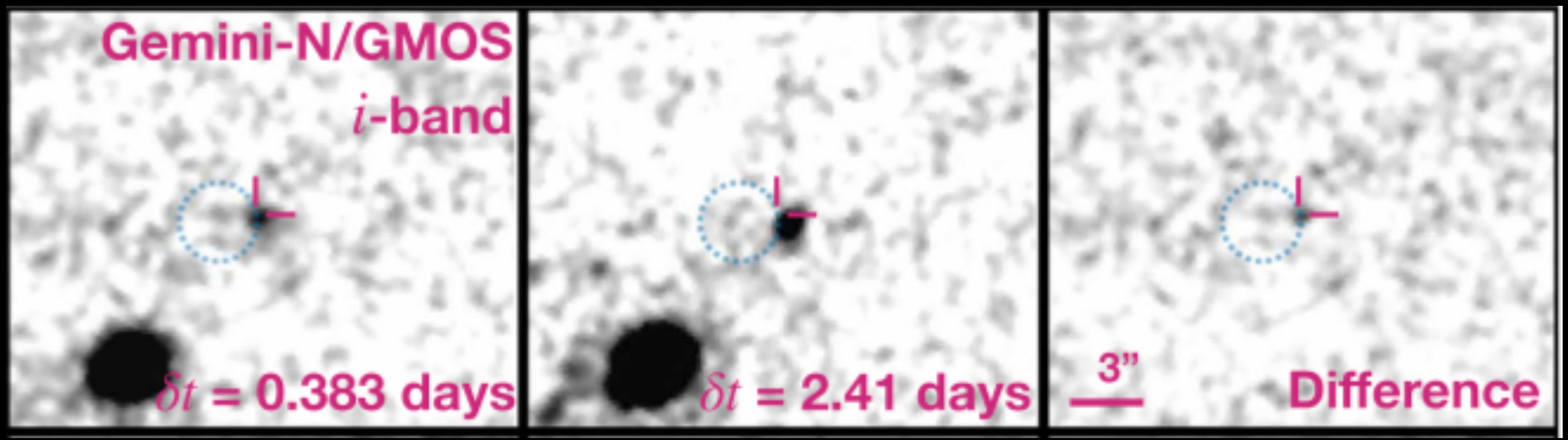
Gemini Observatory

Wide coverage of Northern and Southern sky

Rapid ToO response + diverse suite of instruments

Optical depths to ~26th mag, NIR to ~24th mag

sGRB181123B



GMOS afterglow detection 9 hours post-burst, Paterson+20

Gemini Observatory is uniquely poised to observe **short GRB counterparts** & their **host galaxies**

Observational Clues

1. Discovered across the sky by F

2. Accompanied by broadband a fast-fading kilonovae

3. Associated with galaxies acros

Gemini Observatory

rage of Northern and Southern sky

nse + diverse suite of instruments

s to ~26th mag, NIR to ~24th mag

GMOS afterglow detection 9 hours post-burst, Paterson+20

Offsets from hosts and number of events over time –> NS merger kick velocities, delay time distribution
see Paterson+20, Fong+22, Nugent+22, O'Connor+22, Zevin+22

Conclusions

I. Rapid ToO Gemini programs made major contributions to a large catalog of afterglow and kilonova observations, uncovering diversity in the kilonova population.

II. In 21B, Gemini/NIRI uncovered a NIR transient accompanying the long GRB 211211A that peaked at ~same K-band luminosity at AT2017gfo and faded at a similar rate. The afterglow-subtracted photometry is well-fit with a kilonova model of ejecta mass ~0.04 $M_{\odot}$.

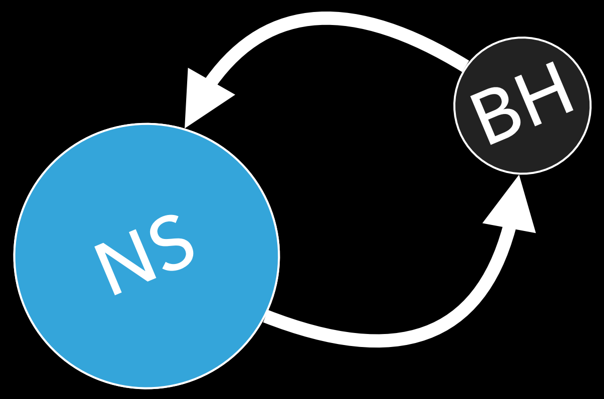
III. In the future, Gemini instruments (including SCORPIO) will complement space-based follow-up of short GRB kilonovae, probing their ejecta masses and compositions.

Thanks to a large team, including Wen-fai Fong, Charlie Kilpatrick, Kerry Paterson, Andrew Levan, Ben Gompertz, Matt Nicholl, Gavin Lamb, Nial Tanvir, Daniele Malesani and **our invaluable Gemini astronomers, including Jen Andrews and Kristin Chiboucas**.

GRB 211211A: Implications

What causes the extended gamma-ray emission? Favored explanations:

NSBH Merger: late-time fall-back accretion from tidally-disrupted material; e.g. Rosswog+07, Desai+19



*Tentatively disfavored due to larger blue component

Magnetar Remnant: rotational energy imparted into relativistic wind; e.g. Metzger+08, Gompertz+14, Gompertz+22

*Tentatively favored due to ability to explain consistent EE timescales (~100s when system becomes optically-thin neutrinos)

GRB 211211A: Implications

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NSBH Merger: late-time fall-back accretion from tidally-disrupted material; e.g. Rosswog+07, Desai+19

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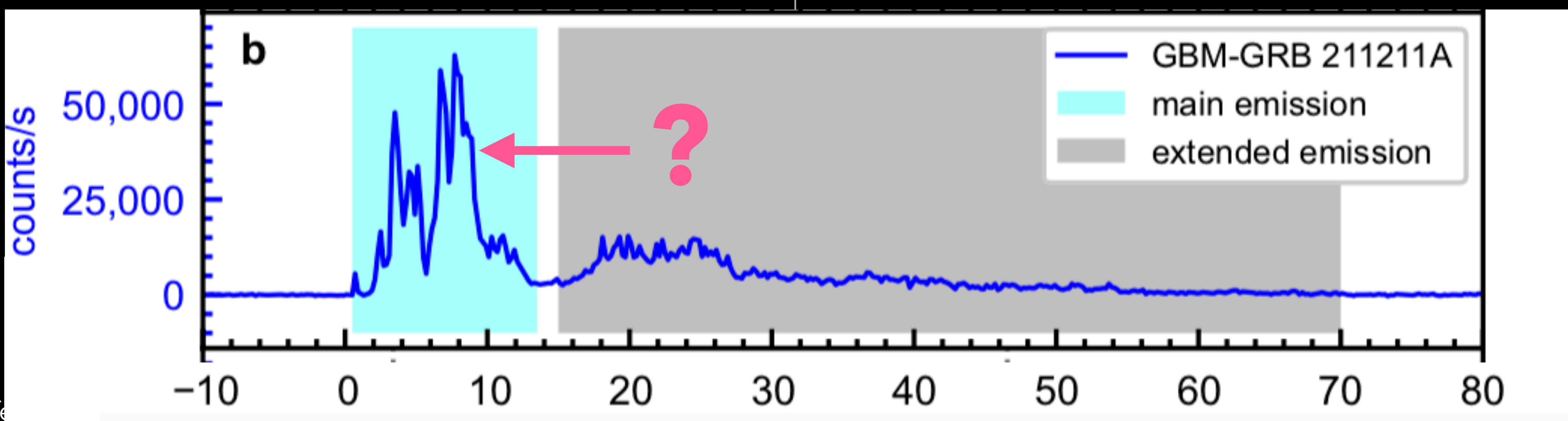


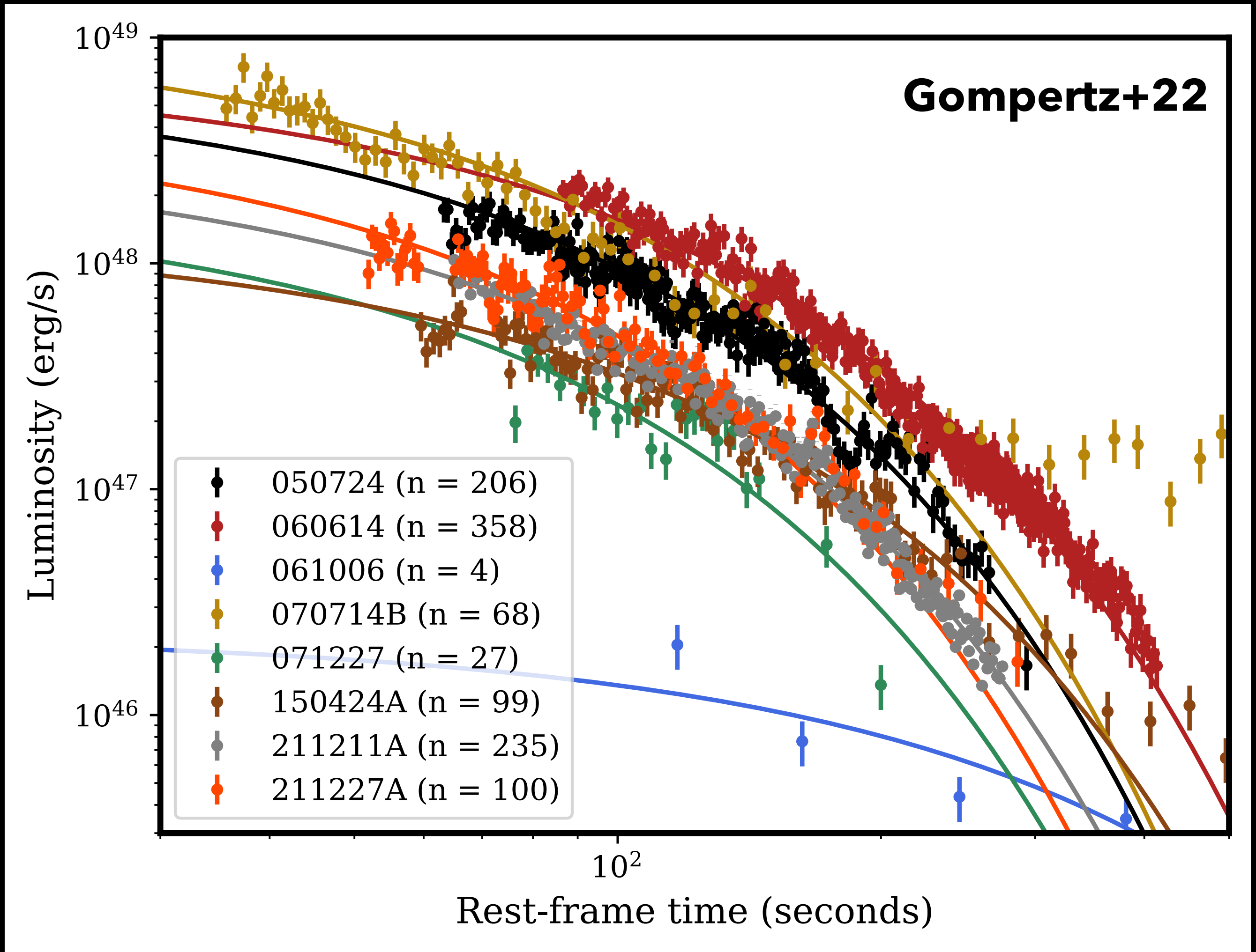
Yang+22 (see for WD-NS merger explanation)

Future coincident GWs + LGRBs may decide!*

*see Sarin, Lasky & Nathan 2022

GRB 211211A: Implications

X-ray Light Curves as a Blueprint for Future LGRBs from NS mergers

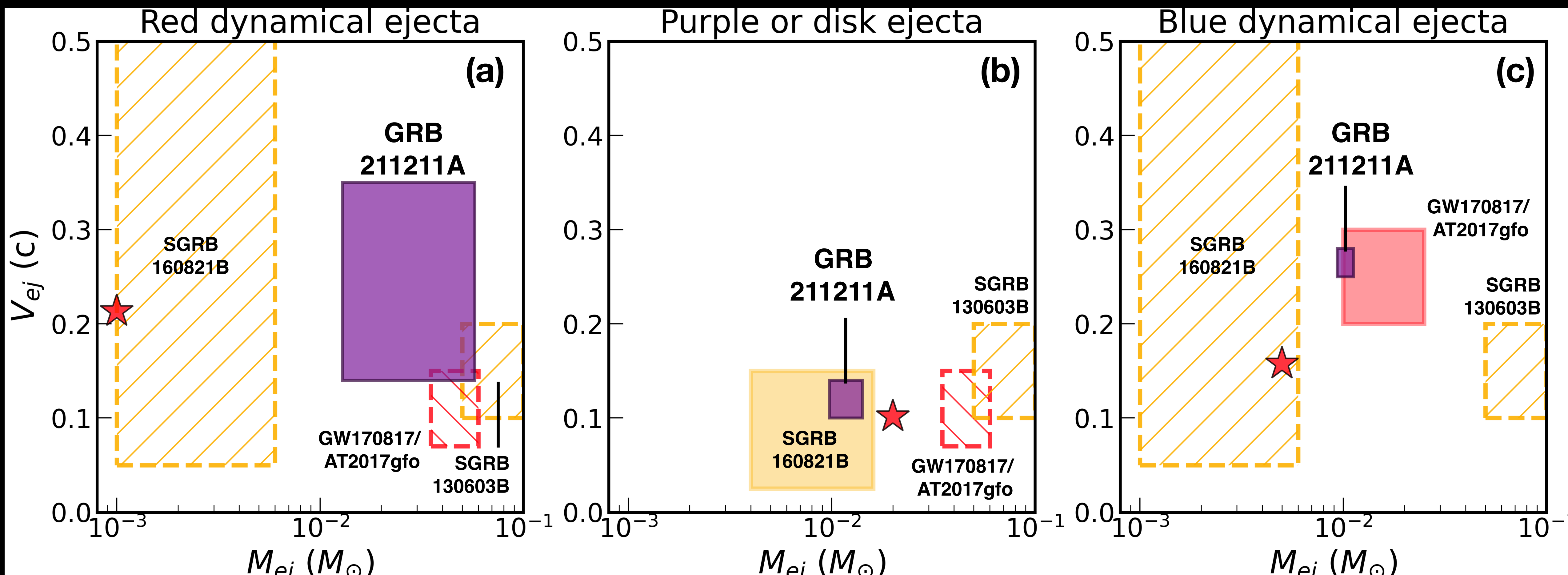


Spectral evolution and X-ray light curves of EE-SGRBs and GRB 211211A show strong similarities (e.g., Gompertz+14, 22)

Blueprint for identifying future mergers with >2s gamma-ray durations

GRB 211211A: Implications

Comparison of ejecta masses + velocities



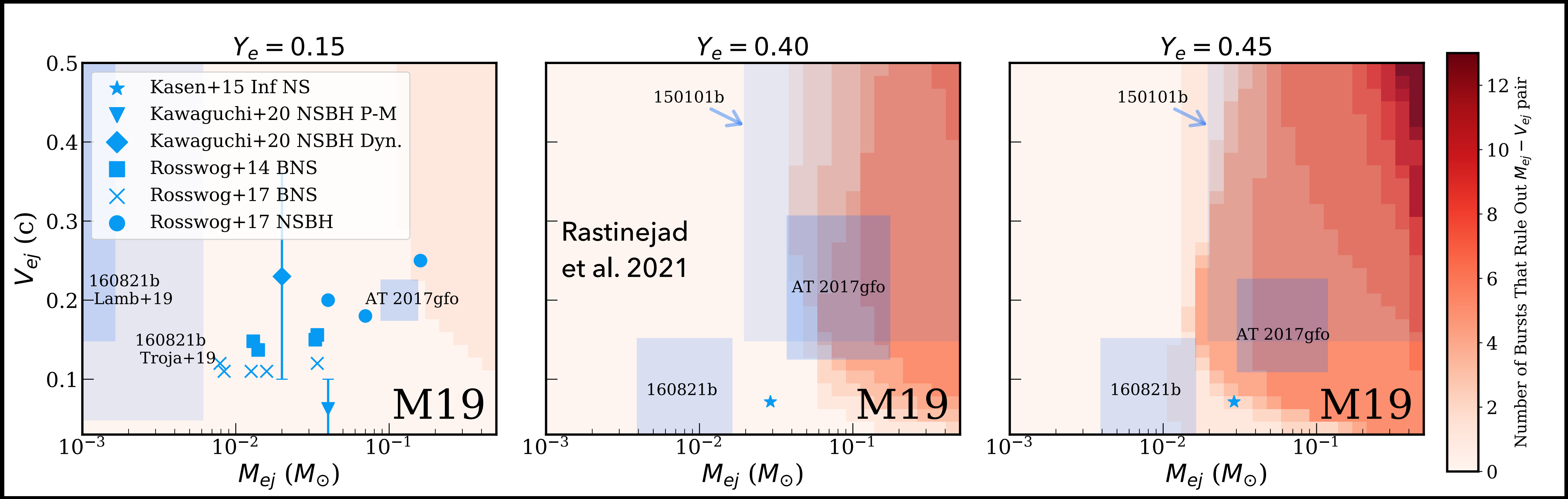
Rastinejad+22

3-component KN model: red + blue dynamical, purple disk ejecta (Nicholl+21)

Comparable ejecta mass and velocity compared to past kilonovae

Ejecta Mass & Velocity Constraints

Metzger et al. 2019



Redder KN

Bluer KN

Current short GRB observations constrain blue ejecta diversity **better than red ejecta**

Also compare to Kasen+17 grids: ejecta mass & velocity constraints are **model dependent** and can vary on the order of ~0.1 $M_\odot$ (also see Ascenzi+19)