Korean Effort for Electromagnetic Identification of GW Sources

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EM Followup of GW Sources

- Unambiguous identification of GW source
- Distance, characteristics of GW sources
- Challenges: Event Rate + Localization + Sensitivity

GW Sources to Observe in Optical/NIR

- NS-NS Merger (also responsible for short GRB)

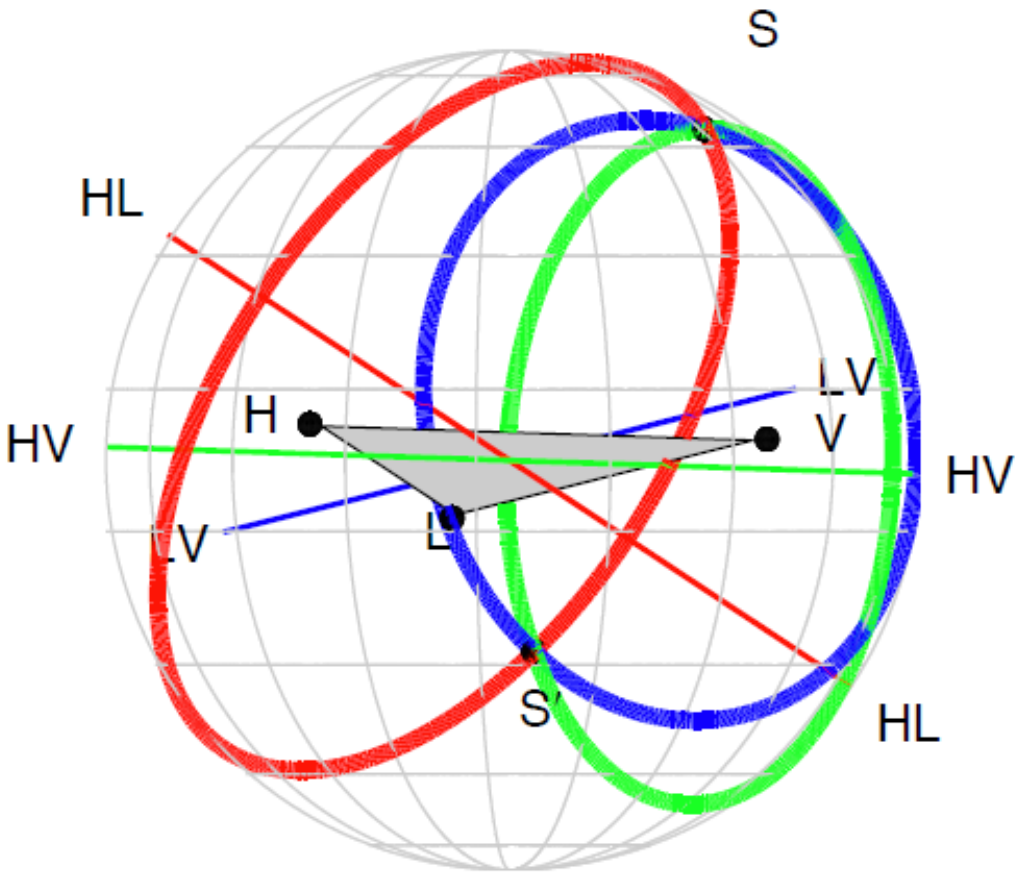
- NS-BH Merger, Core collapse SNe, Pulsar, Cosmic strings…

GW Event Rates

- BNS (Binary Neutron Star) coalescence: 10^{-8} – 10^{-5} Mpc^{-3} yr^{-1}

- 0.4 – 400 signals@S/N=8 at a final sensitivity (aLIGO/aVIRGO) per year out to ~200 Mpc

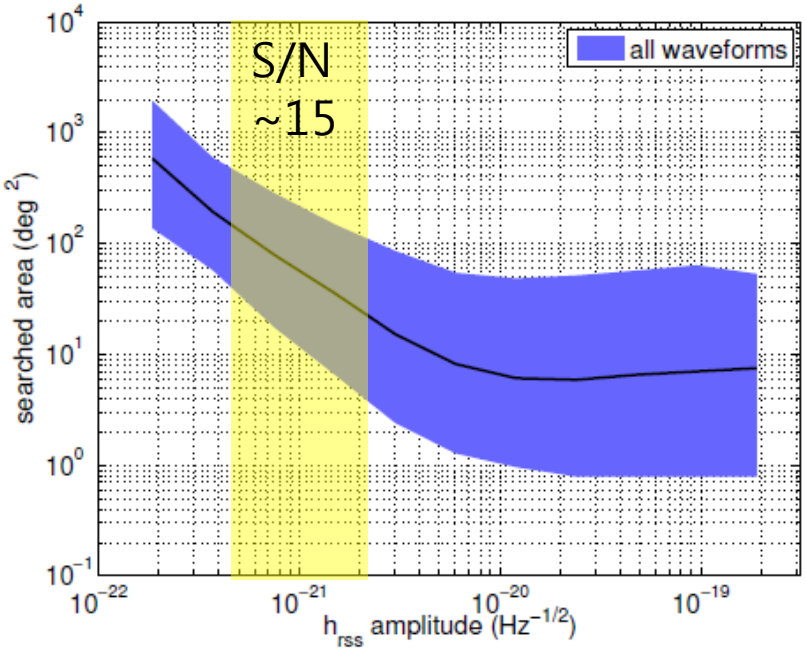
Localization of GW Sources

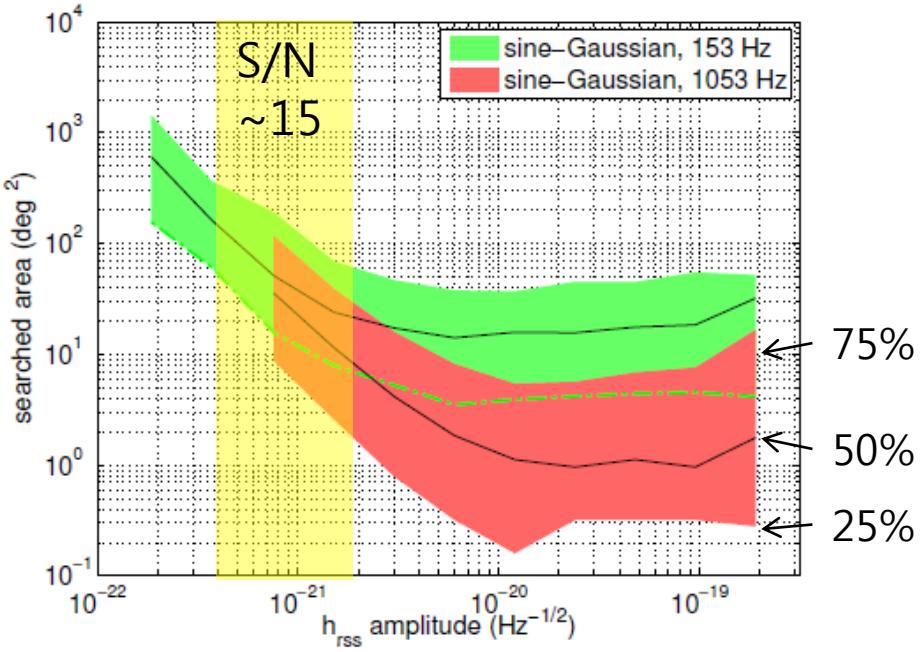


Chatterji, S. et al. 2006, PRD

Positional Accuracy

- In the beginning, ~1000 deg^2
- 20 deg^2, 90% accuracy with H1L1V at 2019+, or typically 10 – 200 deg^2





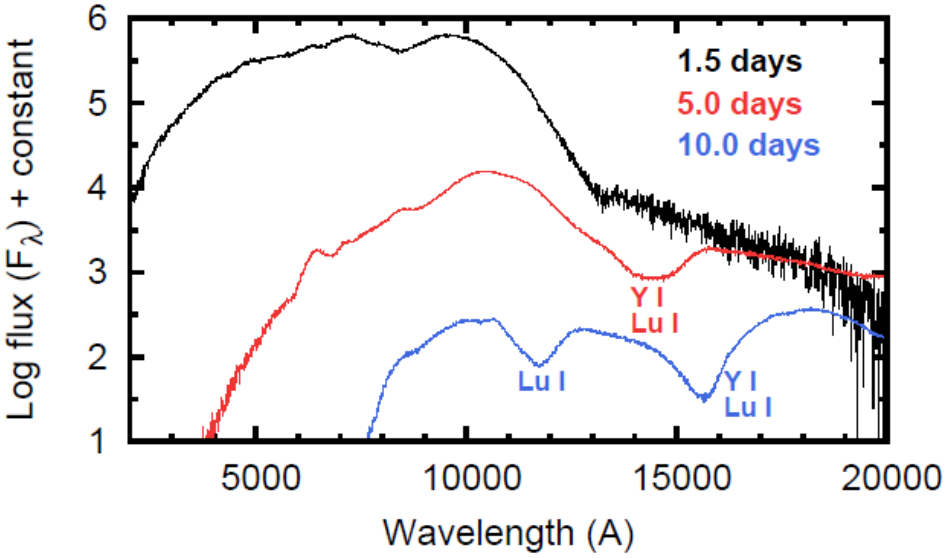
Aasi, J. et al. 2013, arXiv:1304.0670v1

Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc)		BNS Range (Mpc)		Number of BNS Detections	% BNS Localized within	
		LIGO	Virgo	LIGO	Virgo		5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

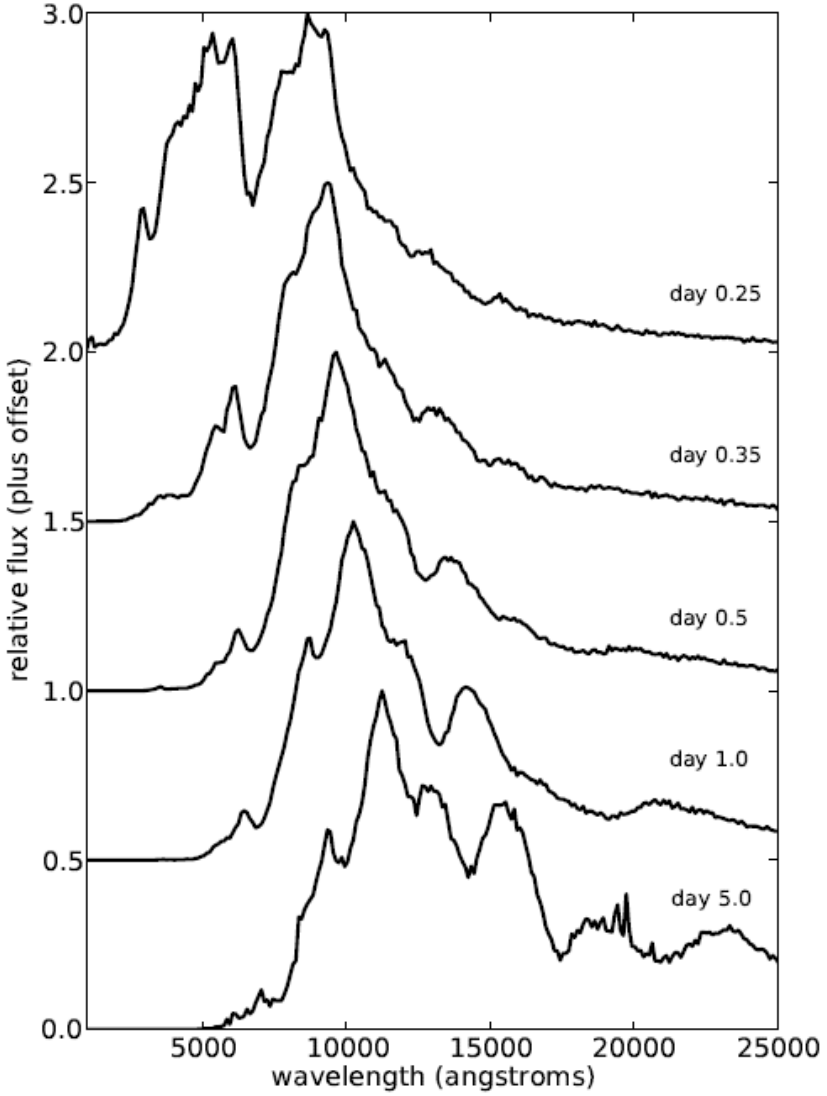
Aasi, J. et al. 2013, arXiv:1304.0670v1

Expected Spectrum of Kilonova (BNS merger)

- Very red, due to high opacity of r-process heavy elements
- Peak at ~1 μm (red spectrum)



Tanaka & Hotokezaka (2013, ApJ)

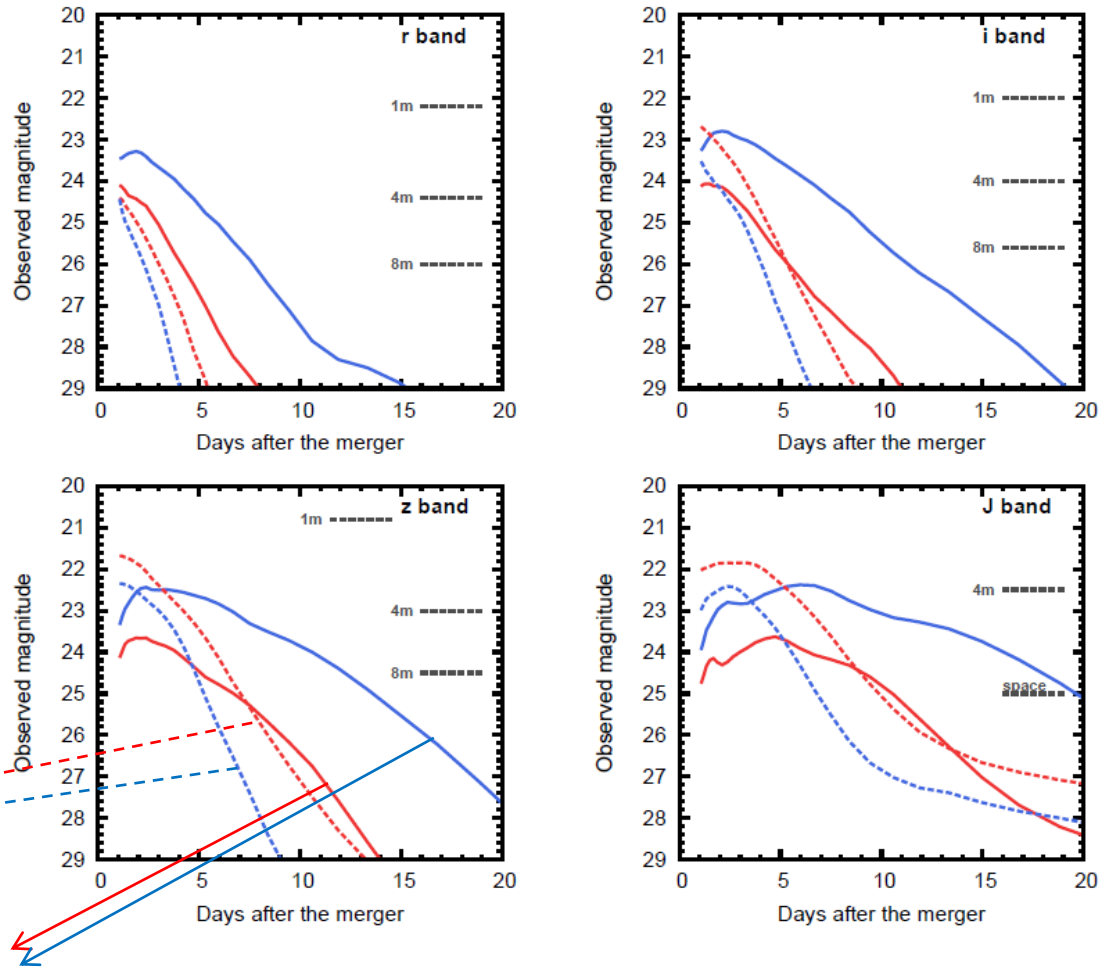


Kasen, D. et al. (2013, ApJ submitted)

Light Curve

- At 200 Mpc,
  r(AB) ~ 24.5 mag
  i(AB) ~ 23 mag
  z(AB) ~ 22.0 mag
  J(AB) ~ 22-22.5 mag

[1.5 mag brighter, at D=100 Mpc]



NS-NS Merger at D=200 Mpc

NS-BH Merger at D=400 Mpc

Tanaka, M. et al. (2014, ApJ)

KU (Korea-Uzbekistan Consortium)

- SNU, KHU, KASI (Korea) + UBAI(Uzbekistan)
- MOU is signed to participate in the GW EM follow-up (2014 April 7)
- Access to the first (~4) GW events locations for EM follow-up

LIGO-M1400070,VIR-0126-14

Memorandum of Understanding between KU and LIGO and VIRGO regarding follow-up observations of gravitational wave event candidates

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Date April 7, 2014

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Date April 5, 2014

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Director of LIGO Laboratory
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Date April 5, 2014

Bernard Schutz
GEO 600 Principal Investigator for Data Analysis
Signature
Date April 5, 2014

Facilities

Maidanak:
1.5m Telescope

Korea:
SNUO 0.6m, KHAO 0.76m,
SOAO 0.6m, BOAO 1.8m,
SRAO 6m(Radio)

US: LOAO 1-m

Australia: 0.43m (SSO)

US: McDonald 2.1-m

Observations with Current Network

- GRB and transient follow-up observation
- Monitoring of nearby galaxies

Currently Operating Network

SNUO 0.6m Telescope (RC)
Currently, 20′ x 20′ CCD
1 degree imager in future
with a focal reducer

Maidanak 1.5m (RC)
SNUCAM 4k x 4k Camera
(20′ x 20′; Im et al. 2010)

McDonald 2.1m
CQUEAN (Park et al. 2012)
4.7′ x 4.7′ but **red sensitive**
(with Kyunghee Univ. S. Pak)

KHAO 0.76m
(Recently added!)

KASI Facilities

SOAO 0.6m (RC)
2k x 2k CCD camera
(20′ x 20′)

LOAO 1m (RC)
4k x 4k Camera
(20′ x 20′)
Workhorse for
GRB follow-up

BOAO 1.8m
KASINICS NIR Camera

0.43m LSG(Lee Sang Gak) Telescope

- Manufacturer: Planewave Instruments
- Coma-free, curvature corrected field of view out to 2 degree
- Remote operation through internet + automatic operation
- To be installed at SSO/Australia (2014 August)

CQUEAN (on 2.1m telescope), limiting magnitude (bright/grey)

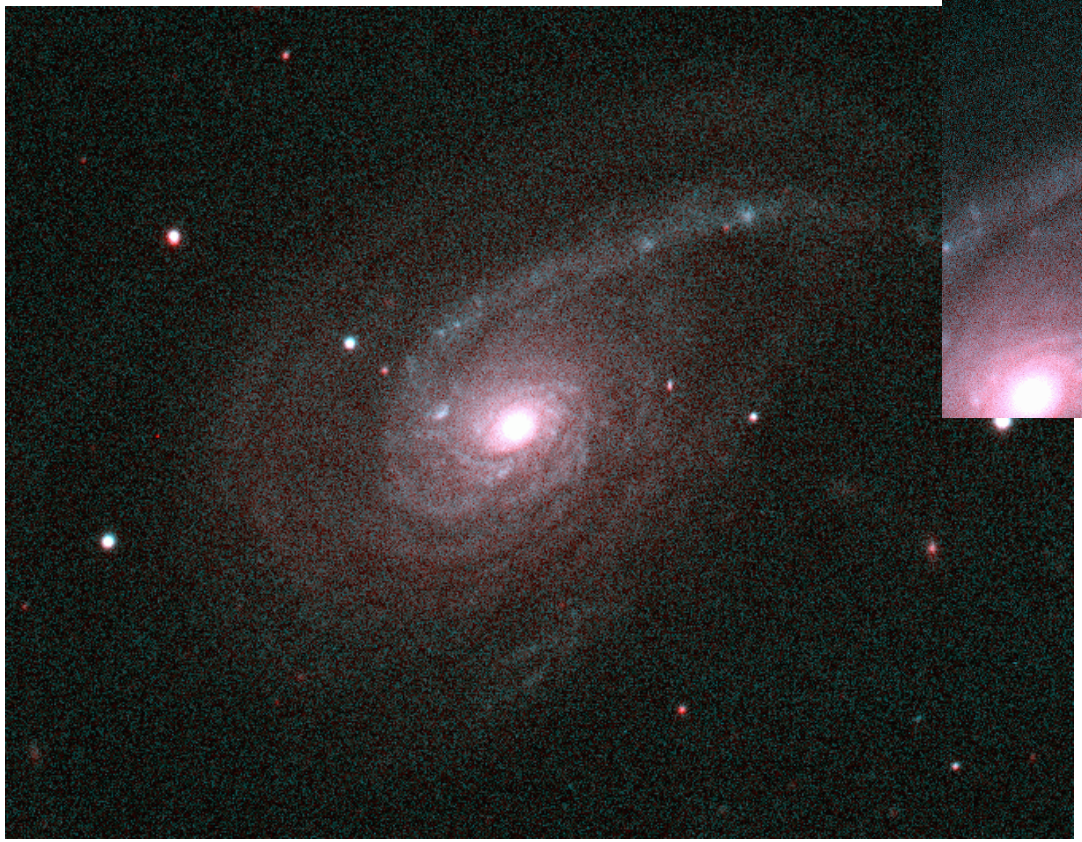
Filter	λ_{eff} (μm)	Sky Count (DN/sec)	Sky Brightness (mag/arcsec2)	Magnitude Limit (mag at 5-σ, 1hr integration)	T_{eq} (sec)
r	0.623	4.1	19.8	23.4	15.2
i	0.768	11.1	19.7	23.8	6.1
is	0.739	8.4	19.7	23.7	8.0
iz	0.849	11.7	19.3	23.5	5.3
z	0.877	8.4	19.1	23.1	8.1
Y	0.991	6.2	17.9	21.8	10.8

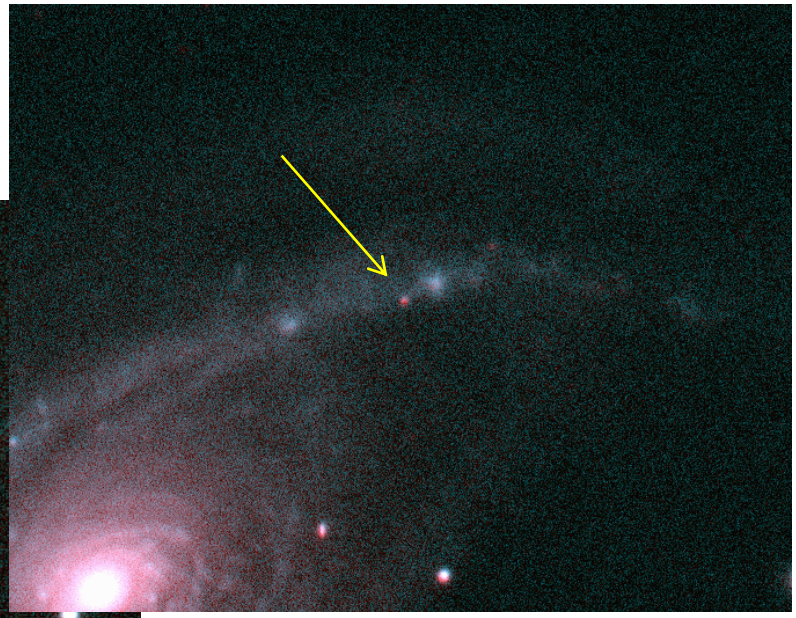
Park, Pak, Im, et al. 2012 PASJ

10 min to achieve z ~ 22 AB mag (NS-NS merger at D=200 Mpc)

< 1 min for z ~ 20.5 AB mag (NS-NS merger at D=100 Mpc)

NGC 772 (Red Variable)

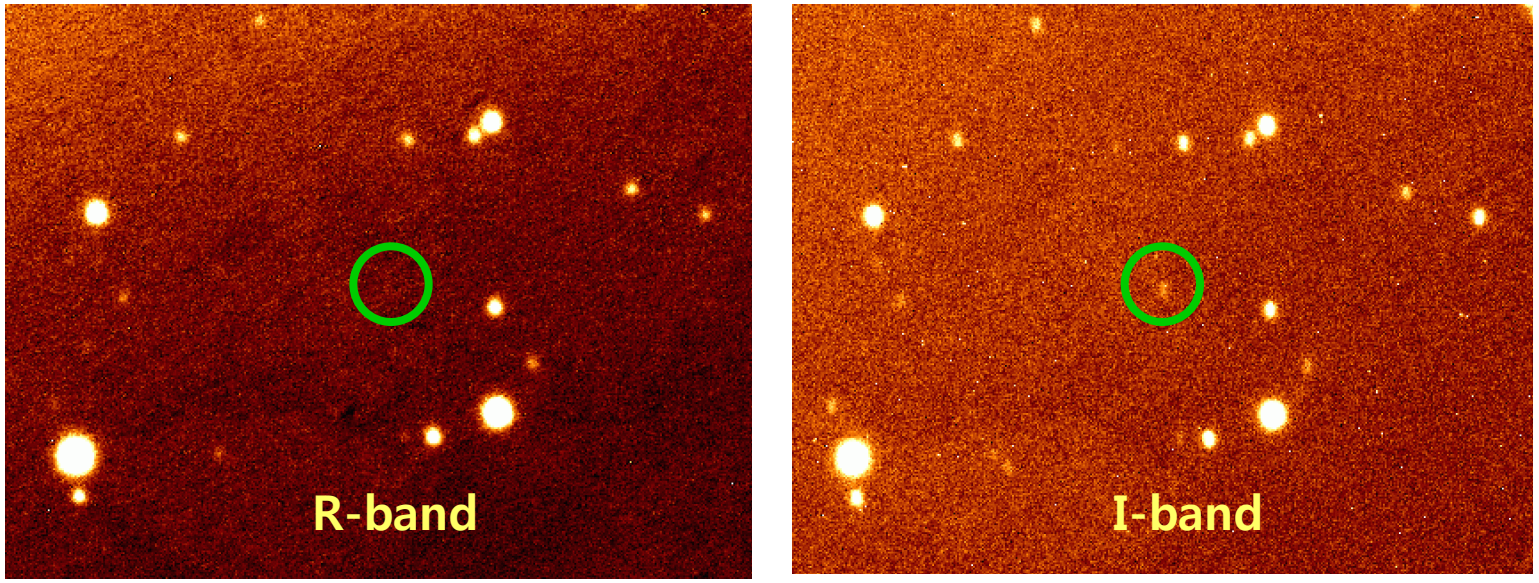




- 1.5m data
- Faint, new transient (unknown kind) → 1min exposure!

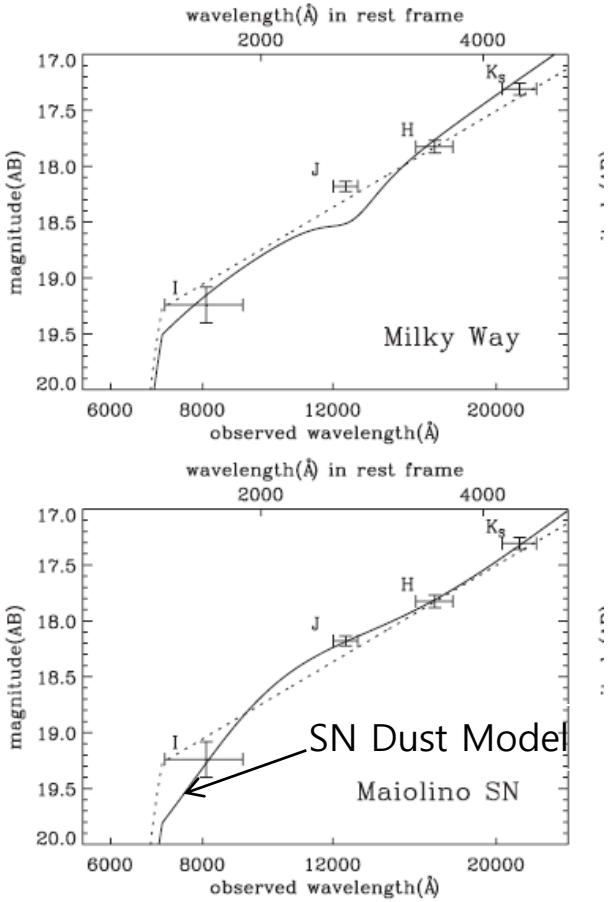
GRB 071025

- GRB at z ~ 5 (Im et al. 2007; Lee, Im, Urata 2010; Perley et al. 2010; Jang et al. 2011)
- Red SED (bright in NIR) ➔ Dusty GRB?
- SN-Dust? Perley et al. (2010) Yes, but..



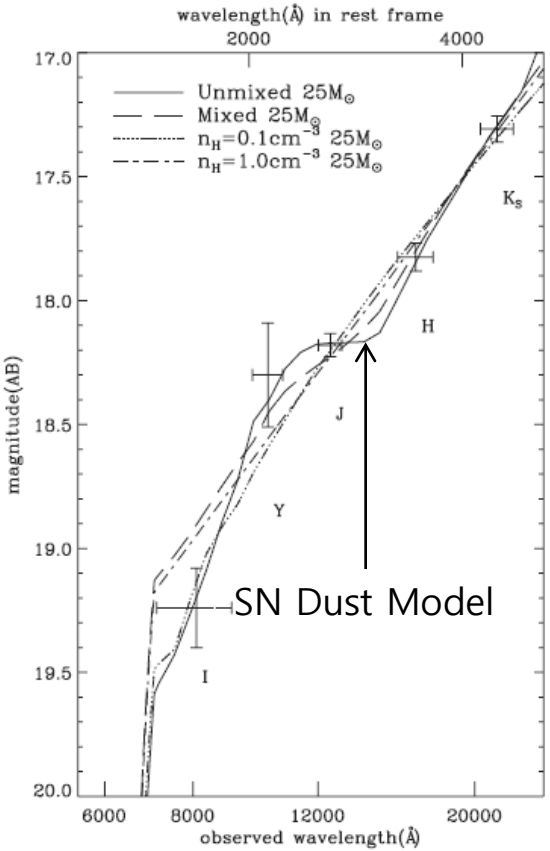
LOAO Follow-up Images (~20min post-burst)

Evidence for SN-dust

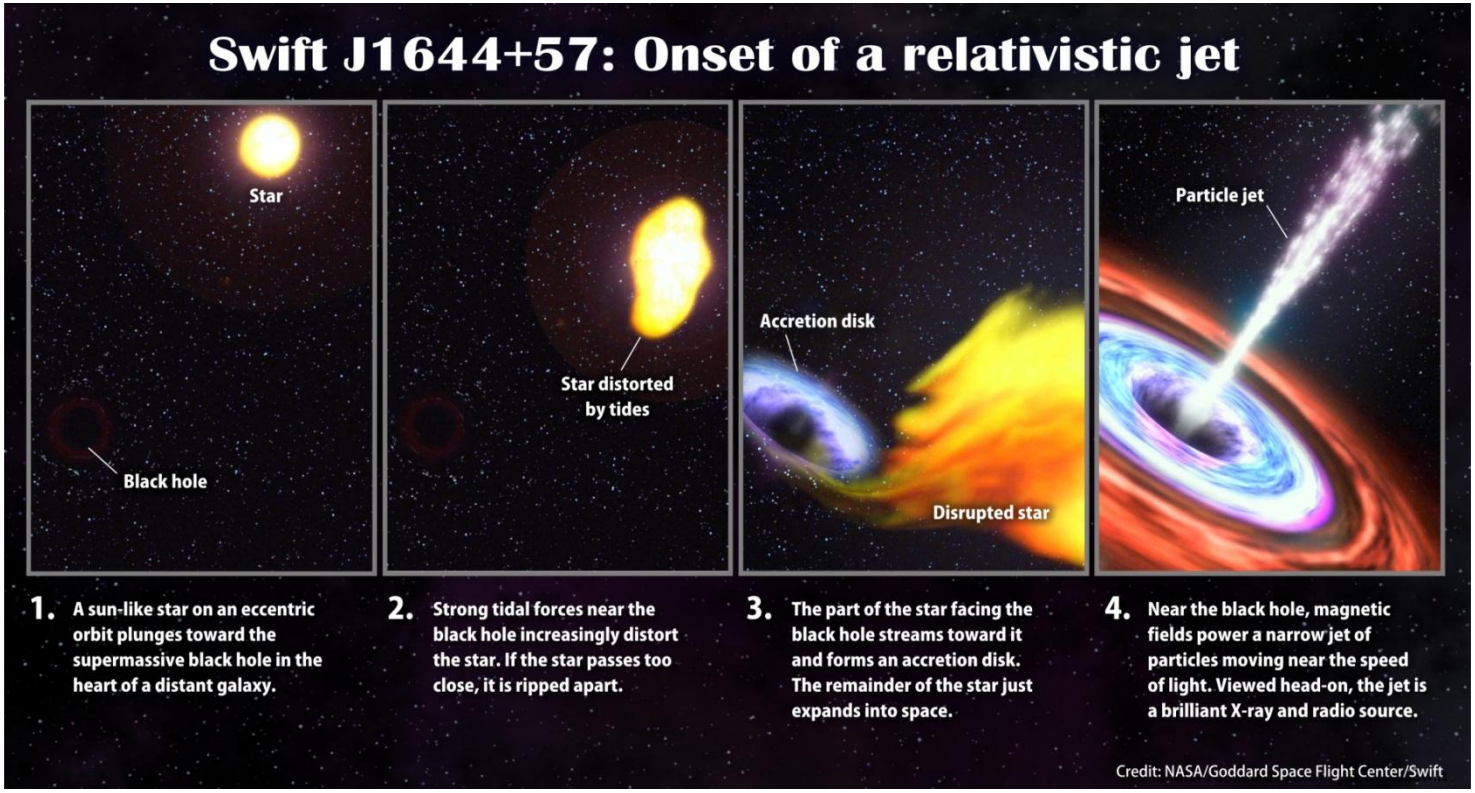


- SN dust model fits the data best
- 10-30 $M_\odot$ progenitor
- Dust were produced by SNe in early universe

Jang, Im, et al. (2011, ApJ)

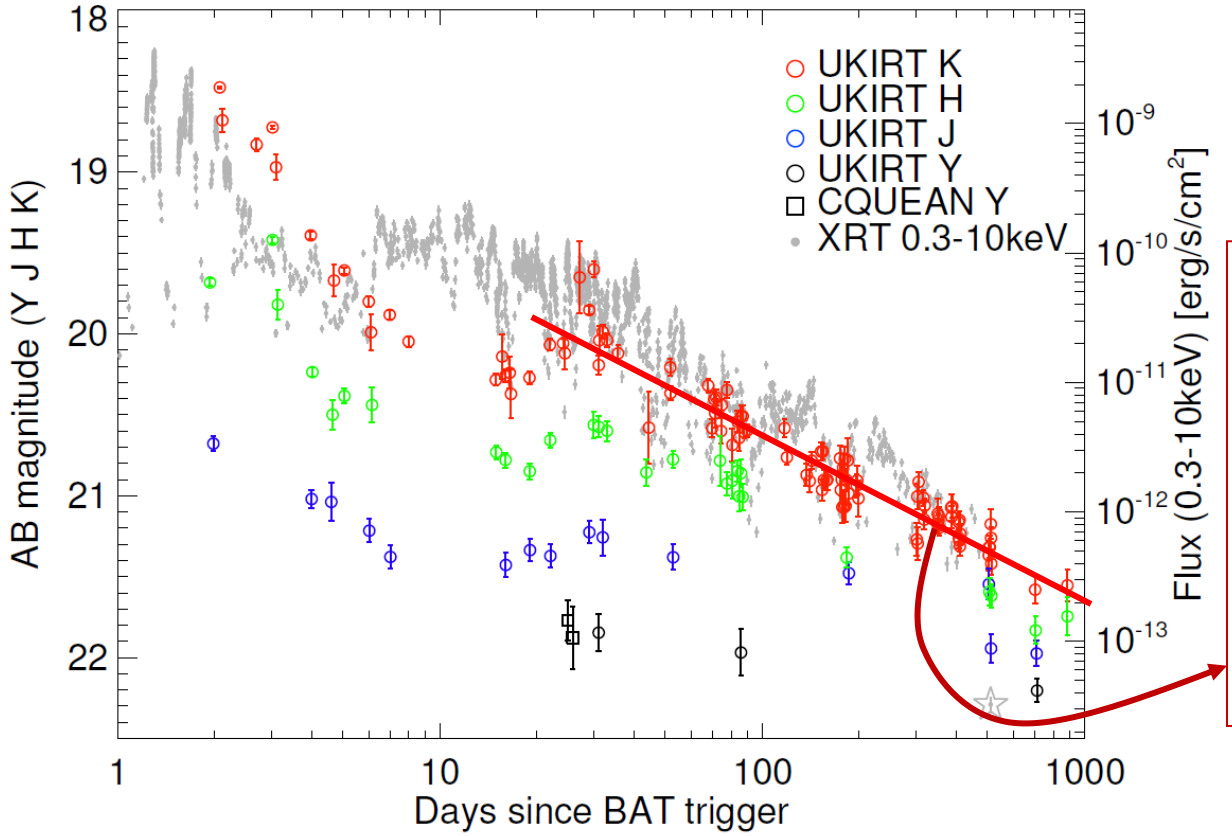


Swift J164449.3+573451: Tidal Disruption (GRB 100328A)



- Slowly declining X-ray light curve → onset of jet from tidal disruption event

Long-term Light Curve

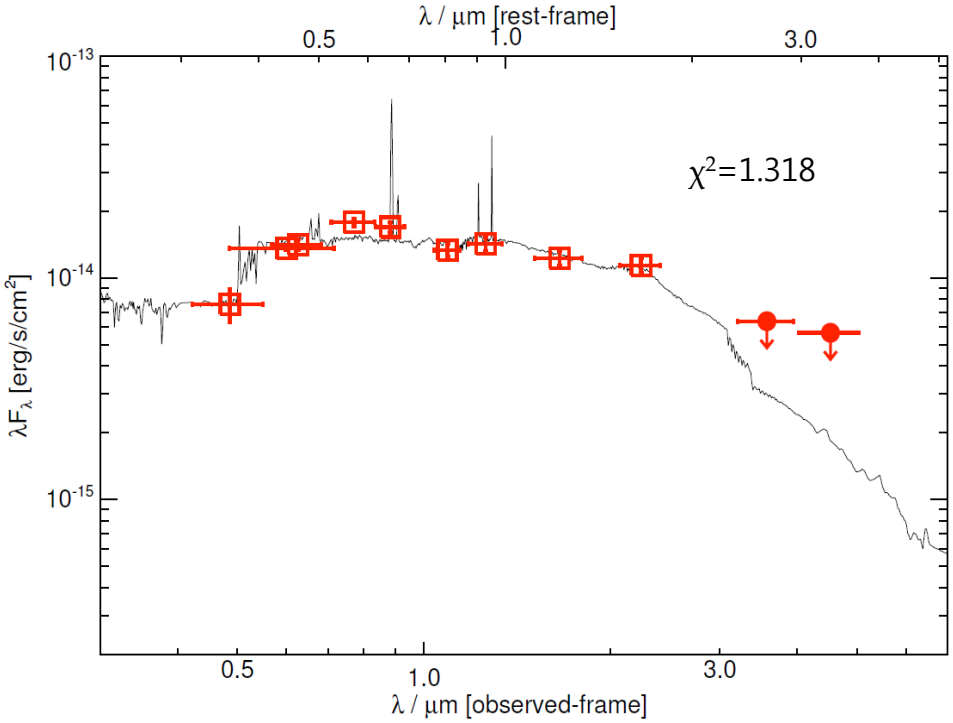


Before host subtraction
$\propto t^{-0.4}$

After host subtraction
$\propto t^{-1.1}$

(TD $\propto t^{-5/3}$)

Host Galaxy + BH Mass



$M_{\rm star}$	$10^{8.98\pm0.28}M_\odot$
instantaneous SFR	$\sim 0.9M_\odot/{\rm yr}$
mass weighted age	$\sim$0.9 Gyr
bolometric luminosity	$10^{10.08\pm0.24}L_\odot$

- $\mathrm{Log}(M_{BH}/M_\odot) \sim 6.5 \pm 0.4$

(Yoon, Im, et al. 2014)

Summary

- GW detection in 2015-2019???
- Positional accuracy, ~1000 deg^2 (2015, <50 Mpc), 20 – 200 deg^2 (2016-2018, <100 Mpc), 20 deg^2 (2019+, < 200 Mpc)
- Expected brightness z ~ 20.5 AB mag at D=100 Mpc
- Korea-Uzbek Consoritium joined LIGO/VIRGO EM follow-up activity