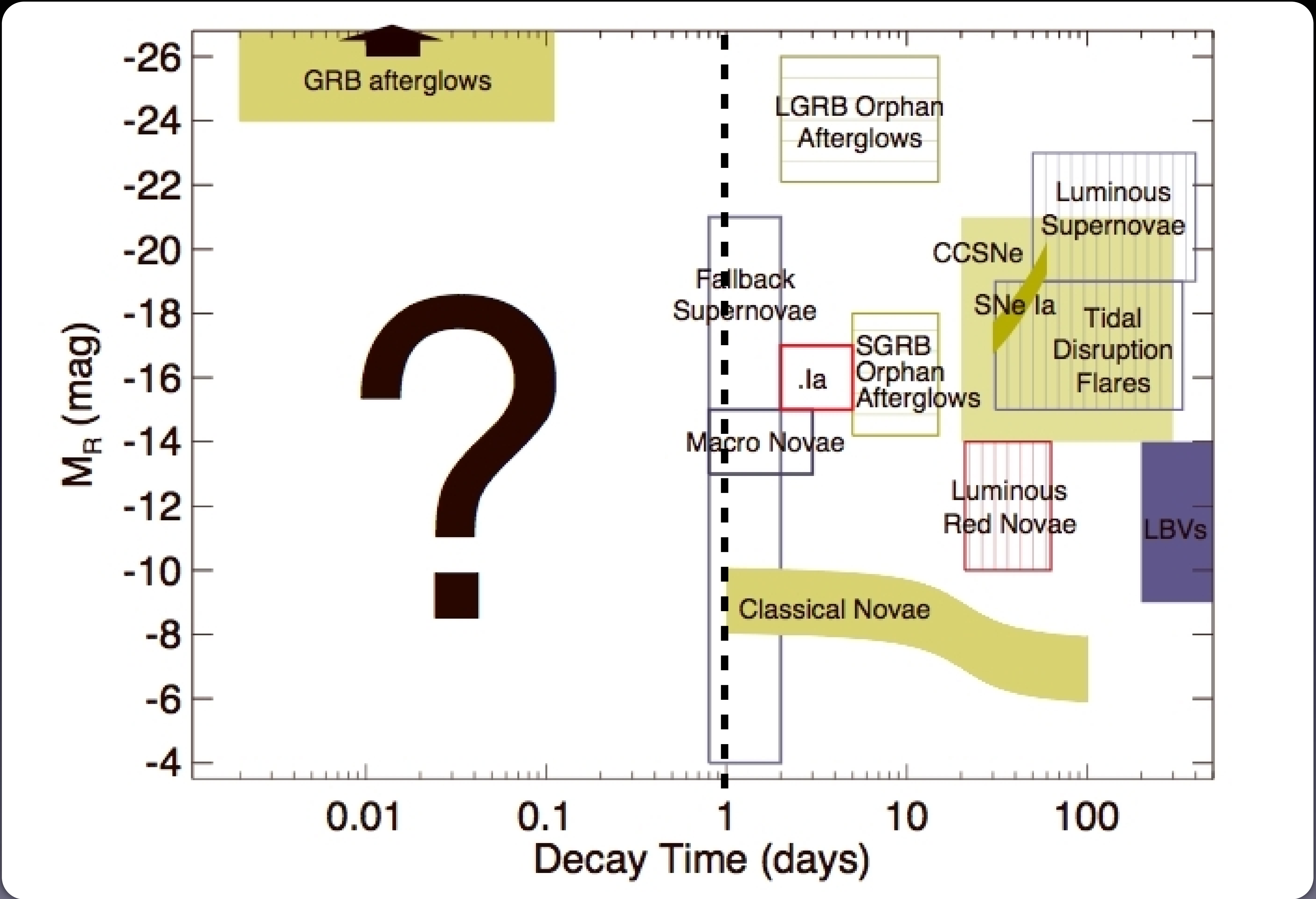
# Exploring the Transient Sky with Subaru and Keck

Masaomi Tanaka (NAOJ)

# Exploring the Transient Sky with Subaru and Keck

- Frontier of the transient survey
- Transient survey with Subaru/HSC and on-going collaboration with Keck
- Synergetic projects with Keck

# Frontier of transient sky




LSST Science Book (after Rau+09, Kasliwal+,Kulkarni+)

# The first signals from supernova explosion

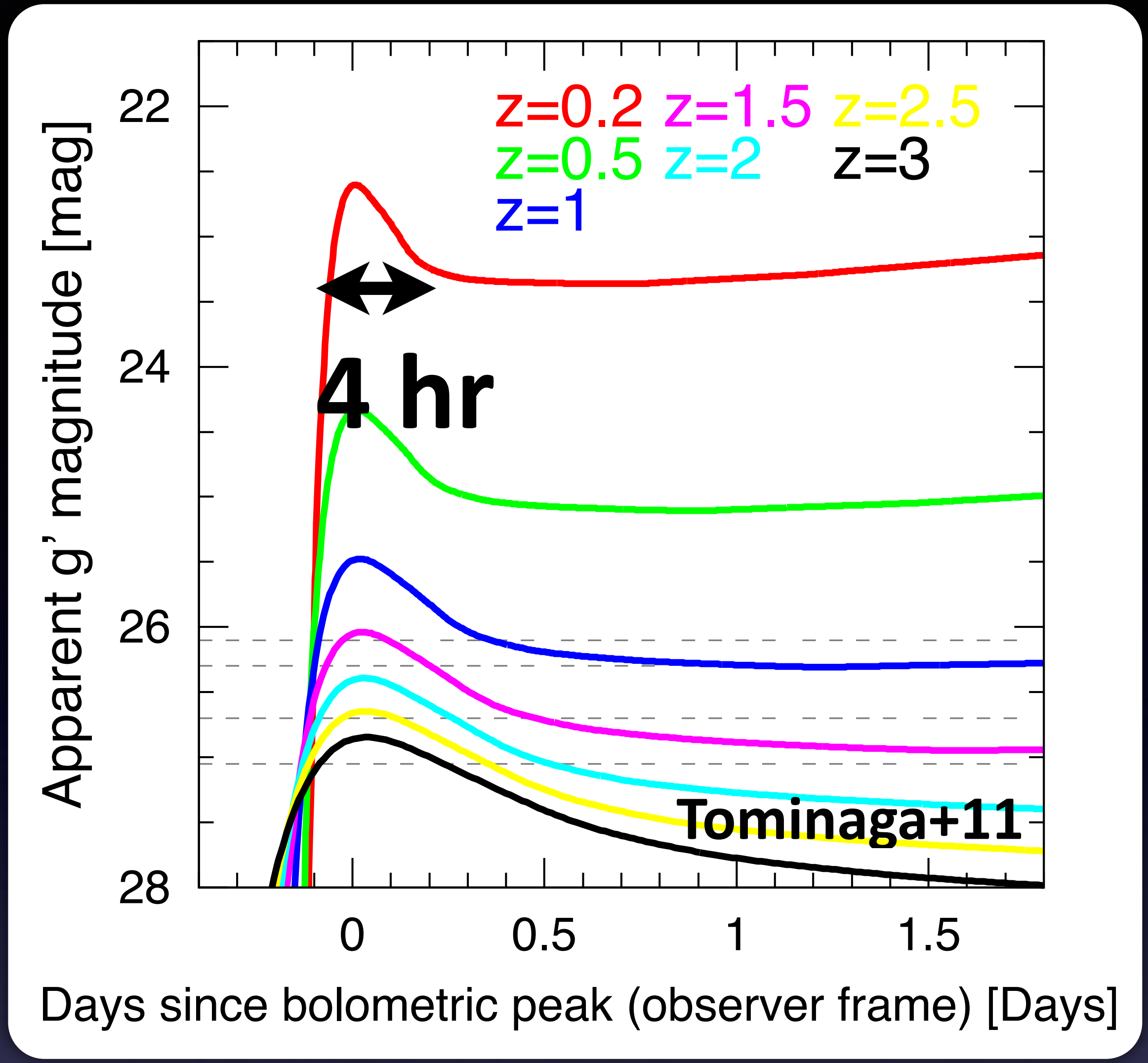
- probe of the very last stage of massive stars -

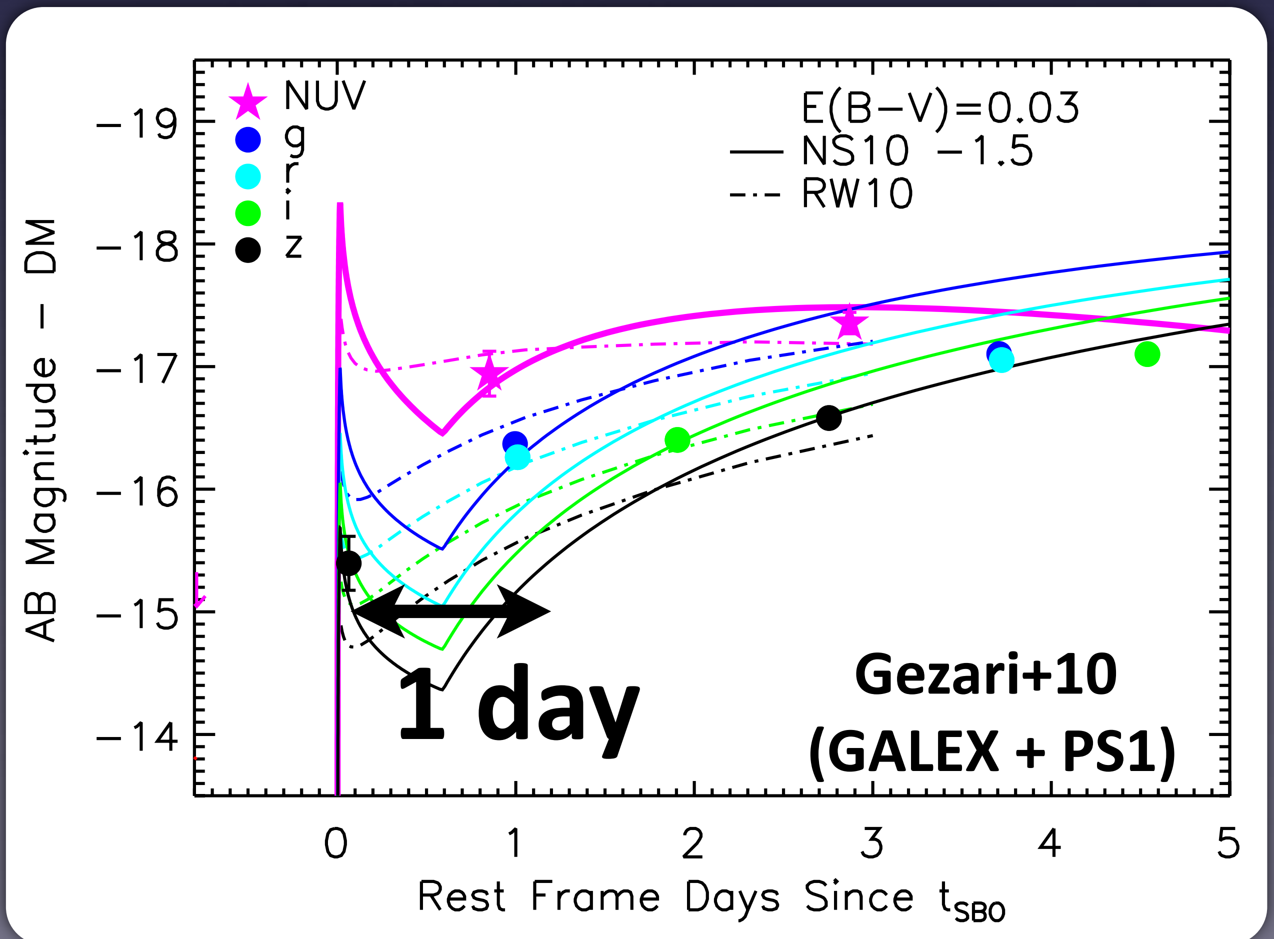
SN shock breakout

(τ ~ R/c ~ 1hr)


Subsequent cooling

(τ ~  a few days)

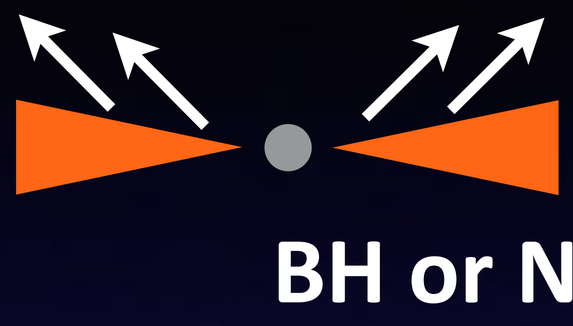


# What else??

- **BH-forming SN**
  - Disk outflow Mej ~0.01 Msun
    t ~ a few days (Kashiyama+15)
- **Accretion induced collapse of WDs**
  - Disk outflow Mej ~ 0.01 Msun
    t ~ 1 day (Darbha+10)
- **Neutron star merger**
  - Disk outflow, t ~ a few days (Kasen+15)
  - Free neutron, t ~ 1 day (Metzger+15)
- **Unknown unknown...**

**Mej ~ 0.01 Msun**

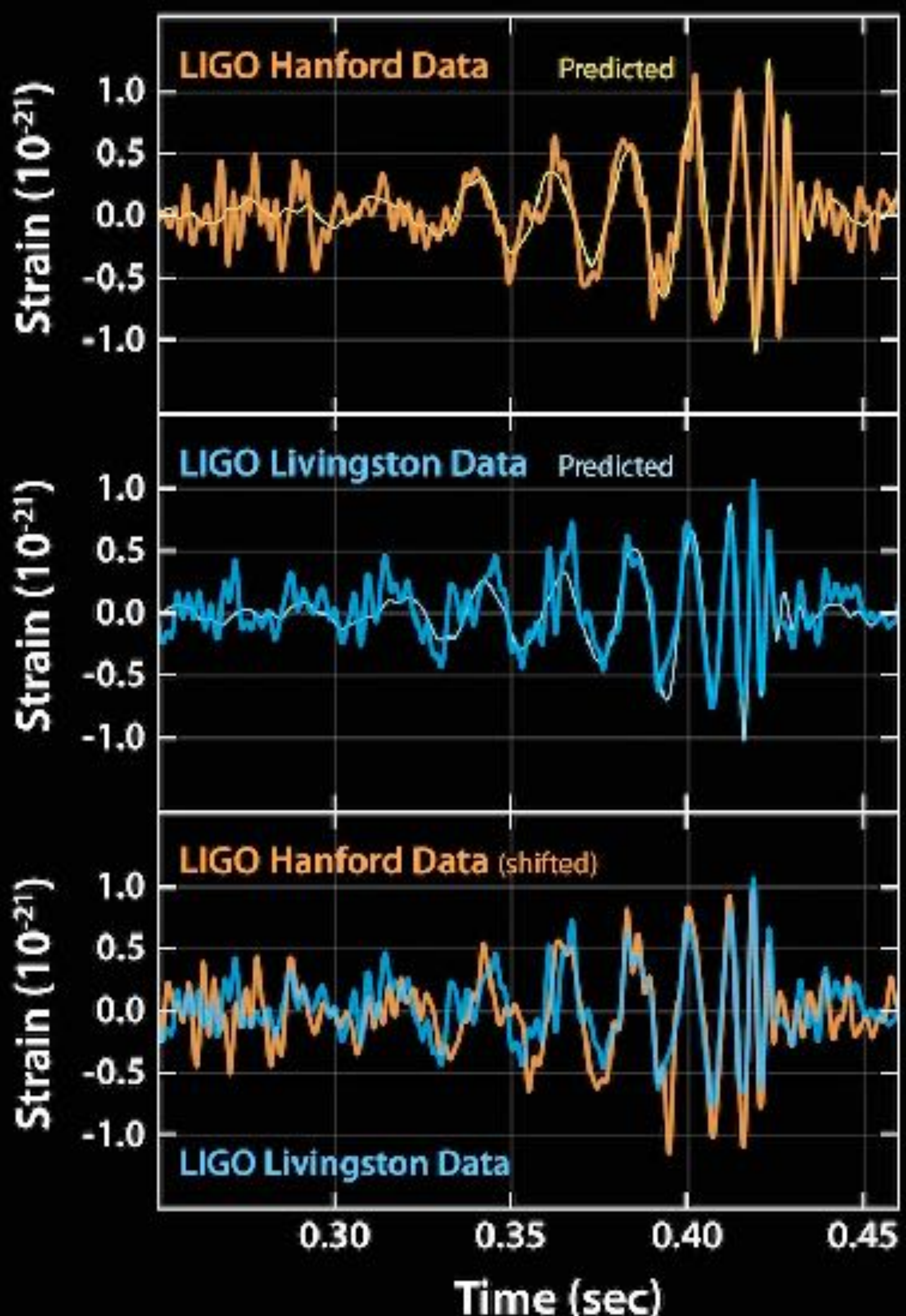



**DISCOVERY SPACE!!**

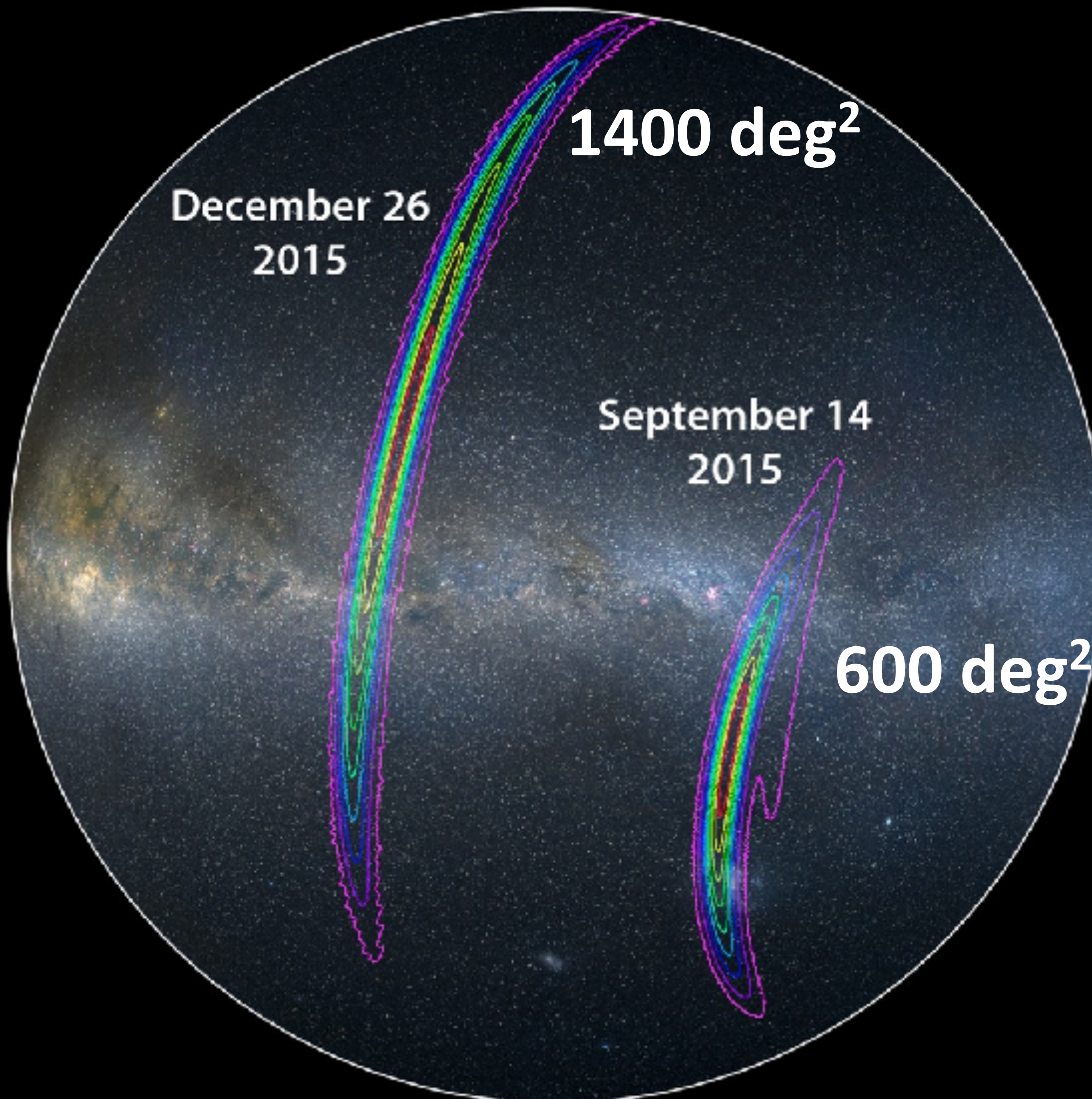
**Need real-time spectroscopy**

**=> Synergy with Keck**

# Multi-messenger astronomy

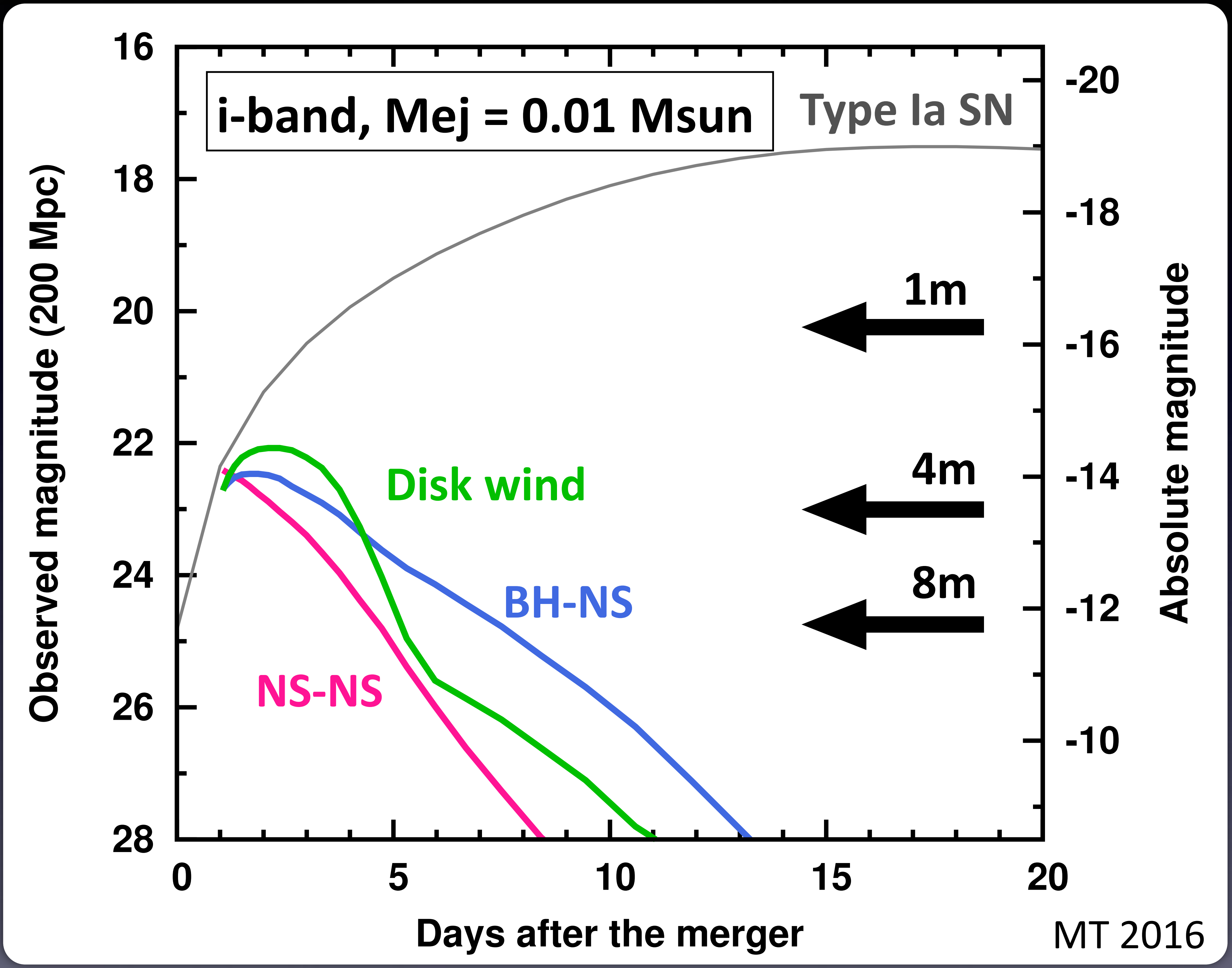



Abbott et al. 2016, PRL, 061102




=> 10-100 deg2 after Virgo and KAGRA

# Optical emission from GW sources: “kilonova”



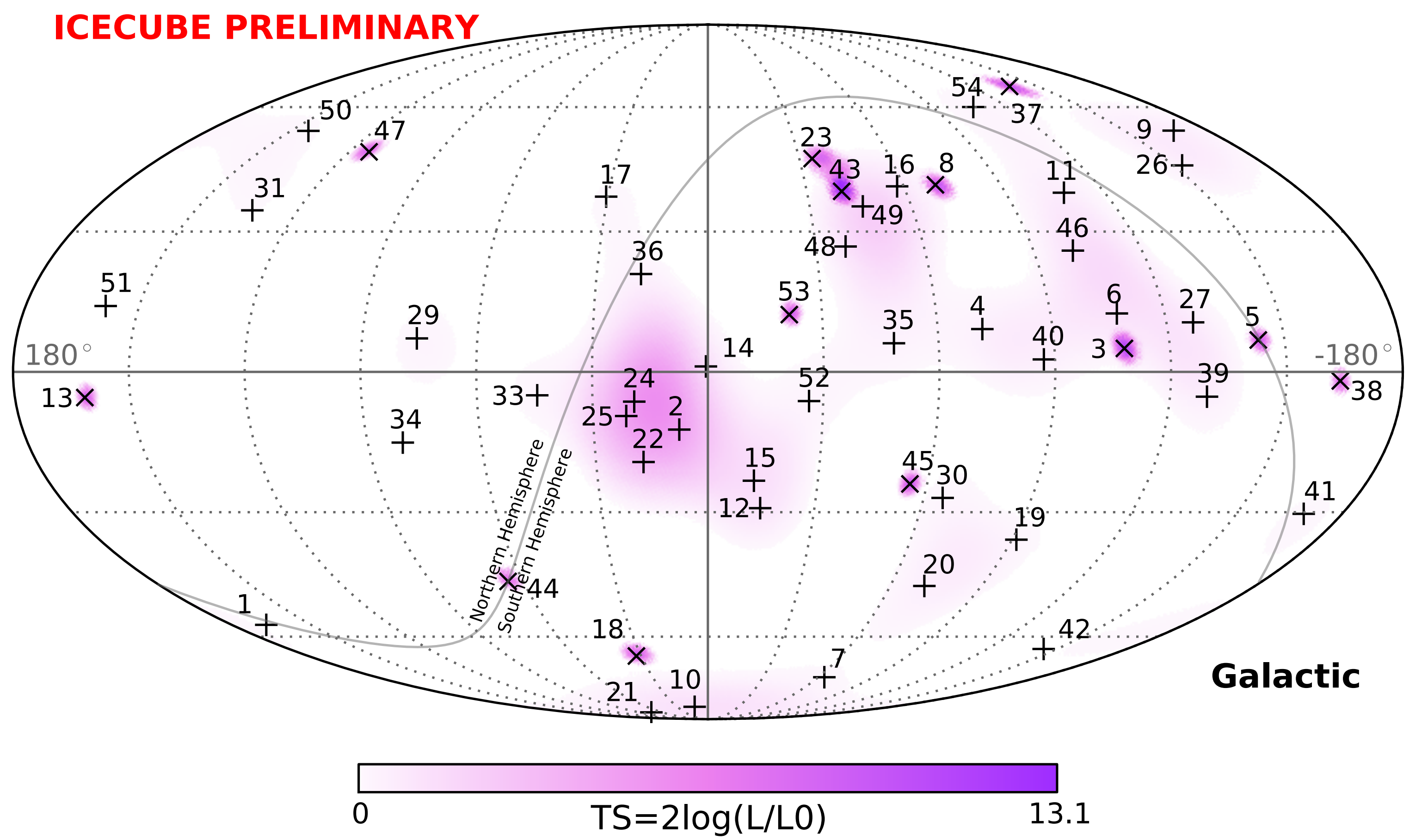

**Subaru/HSC is the unique instrument for GW follow-up**

(J-GEM= Japanese collaboration for GW-EM follow-up: Yoshida et al.)

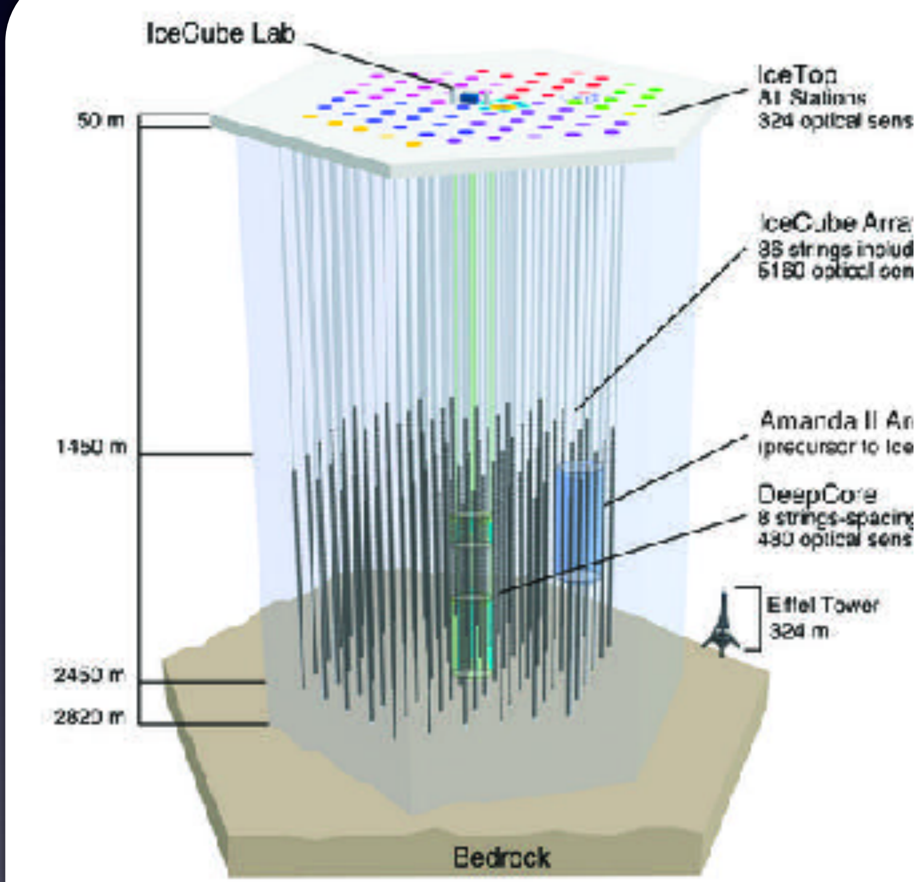
**Need spectroscopy for the smoking gun => Synergy with Keck**

# More opportunities for multi-messenger


## IceCube: high-E (TeV-PeV) neutrino
## Real-time alert (2016-)




IceCube collaboration arXiv:1510.05223




Consistent with homogeneous distribution

No correlation with TeV gamma-ray sources/GRBs

**Localization ~ 1 deg => Subaru/HSC**

## Exploring the Transient Sky with Subaru and Keck

- Frontier of the transient survey
- Transient survey with Subaru/HSC and on-going collaboration with Keck
- Synergetic projects with Keck

# Transient surveys with Subaru/HSC

## 1. Pilot high-cadence transient survey

- 2014-2016 (PI: Nozomu Tominaga)
- 1 hr cadence for 12 deg$^2$ (7 field of views), gr~25.5 mag
- Follow-up with Subaru/FOCAS, Gemini/GMOS, Keck/LRIS

## 2. SSP UltraDeep layer transient survey

- 2016 Nov - 2017 May (HSC transient WG)
- ~3 day cadence for 1.8 deg$^2$ (COSMOS), grizY ~ 25-26 mag
- Follow-up with Subaru/FOCAS, Gemini/GMOS, Keck/LRIS

## 3. GW follow-up observations

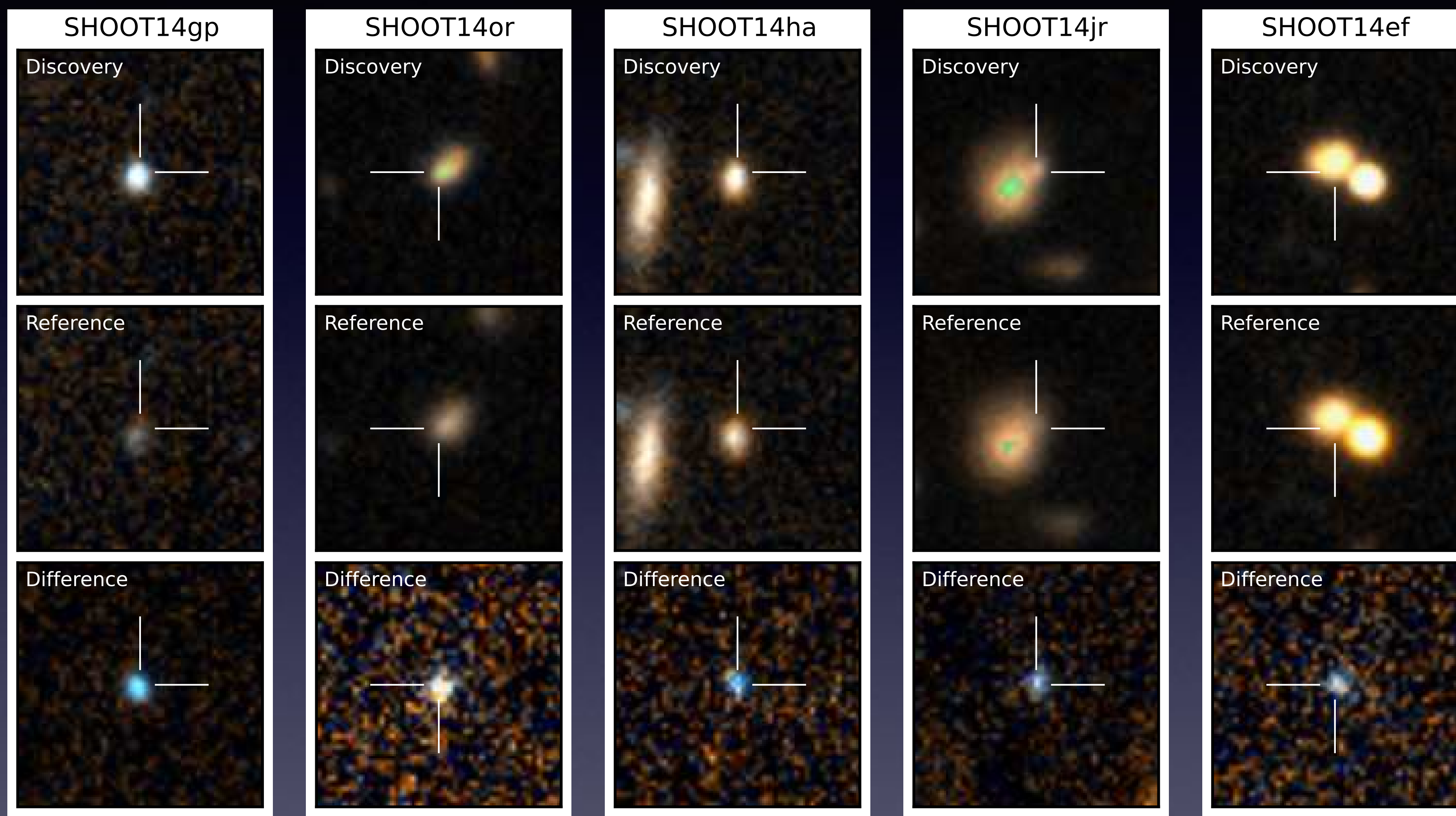
- 2015- (J-GEM collaboration, PI: Michitoshi Yoshida)
- ToO for ~60 deg$^2$, iz ~ 25-26 mag

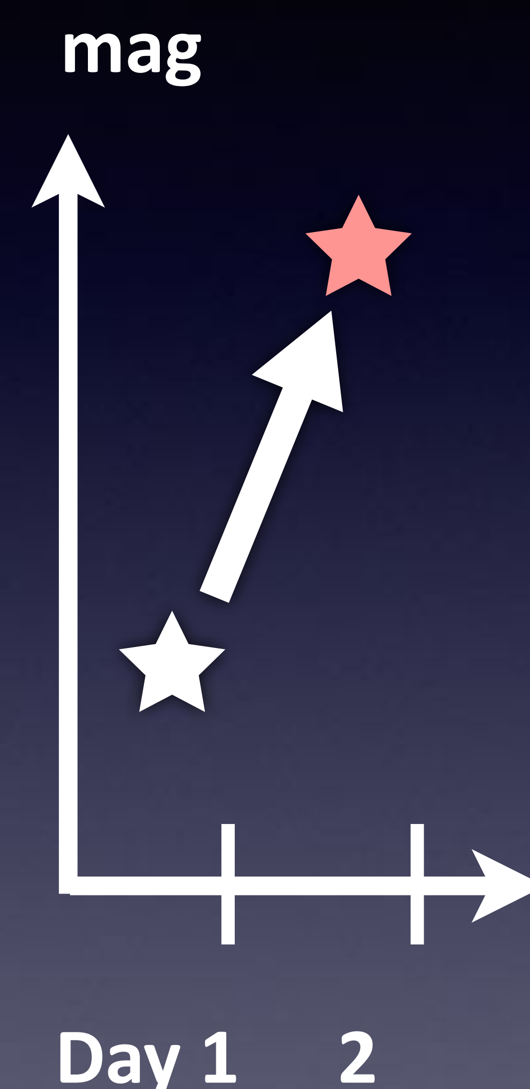
# Transients showing up in < 1 day

Day 2

Day 1

diff



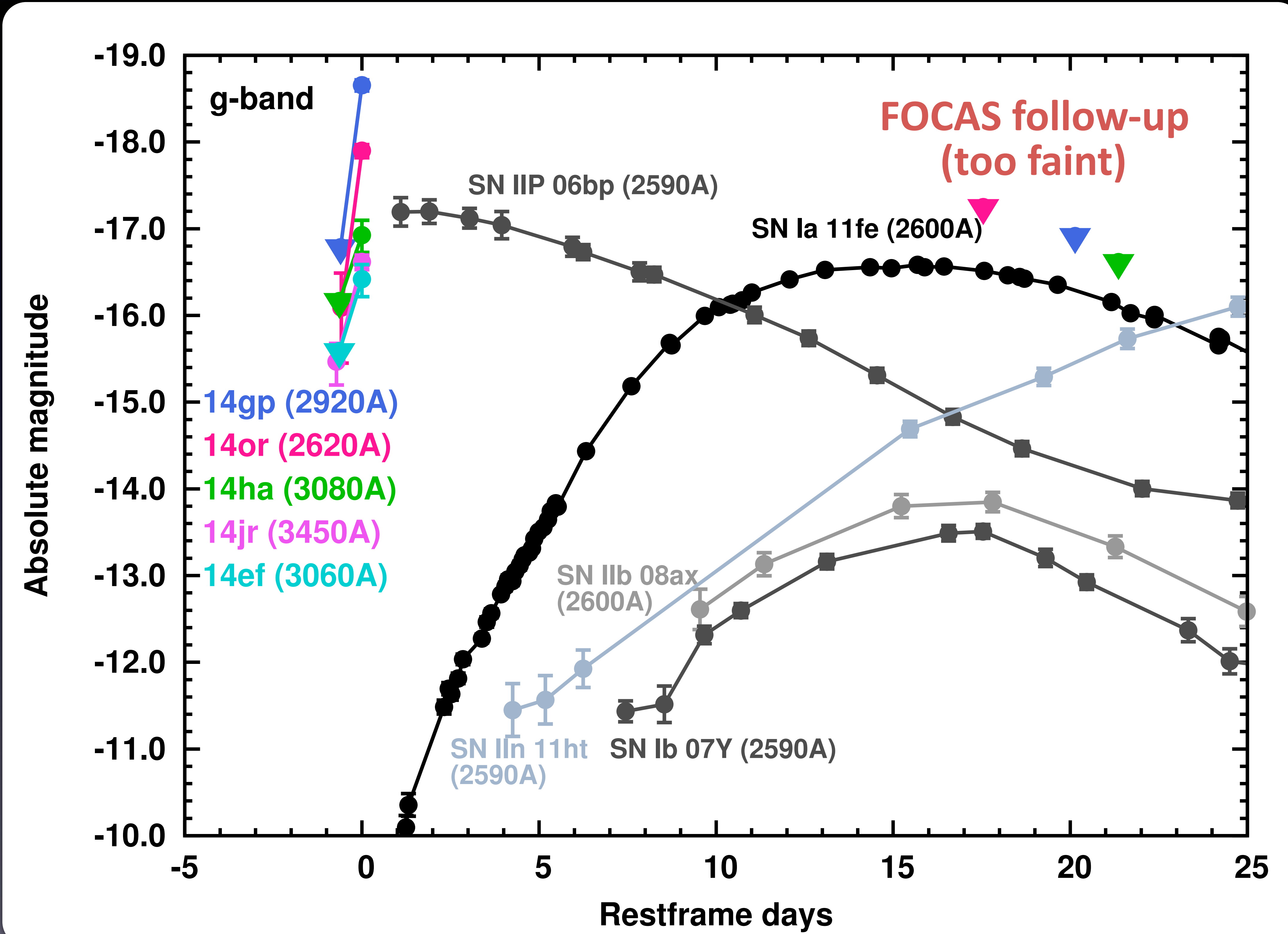




| | | | | | |
|---|---|---|---|---|---|
| z = | 0.635 | 0.821 | 0.548 | 0.384 | 0.560 |
| | 2920A | 2620A | 3080A | 3450A | 3060A |

**Rest-frame near-UV survey**

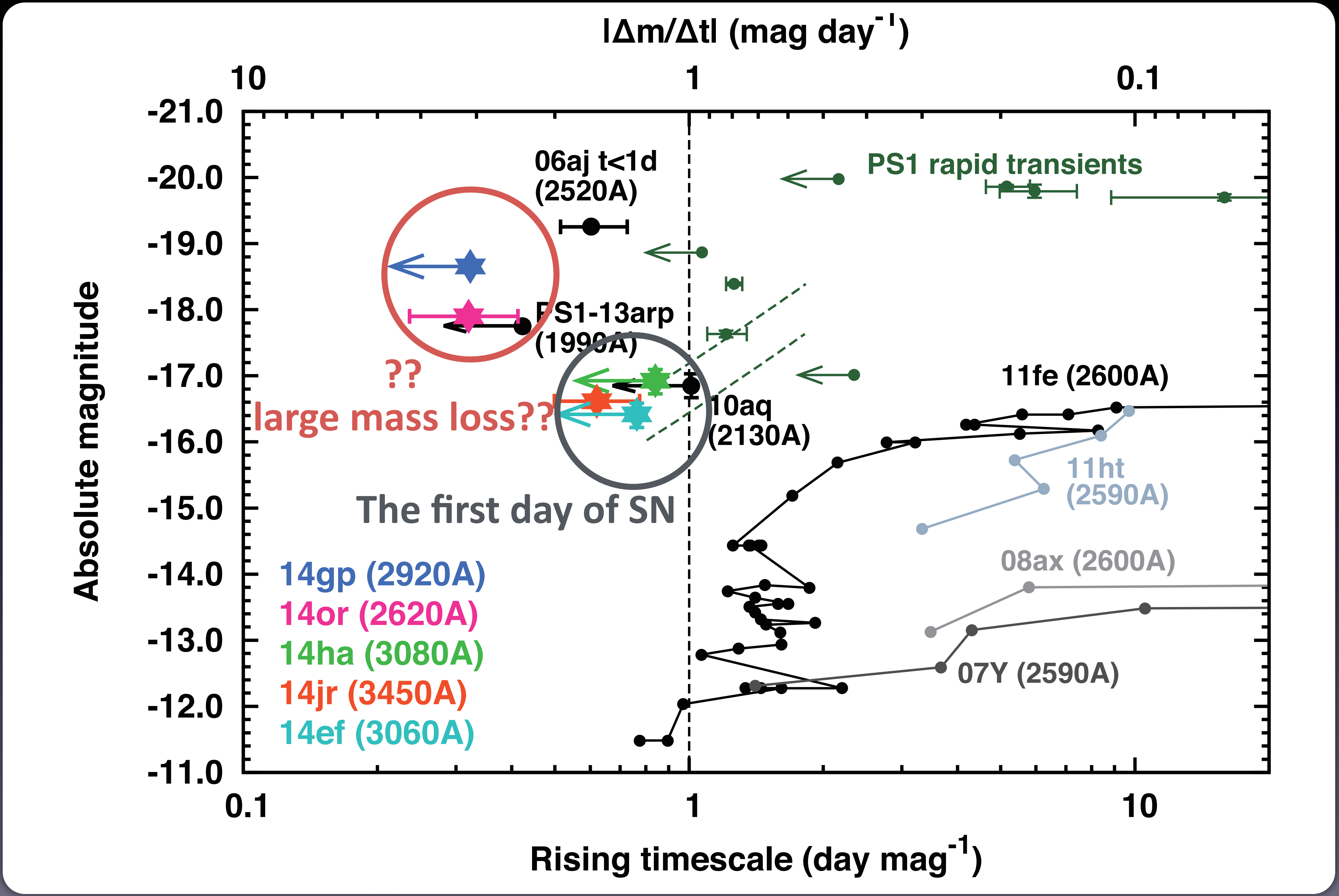
MT, Tominaga, Morokuma, Yasuda+2016

# Light curves




As bright as SN peak, but very fast rise

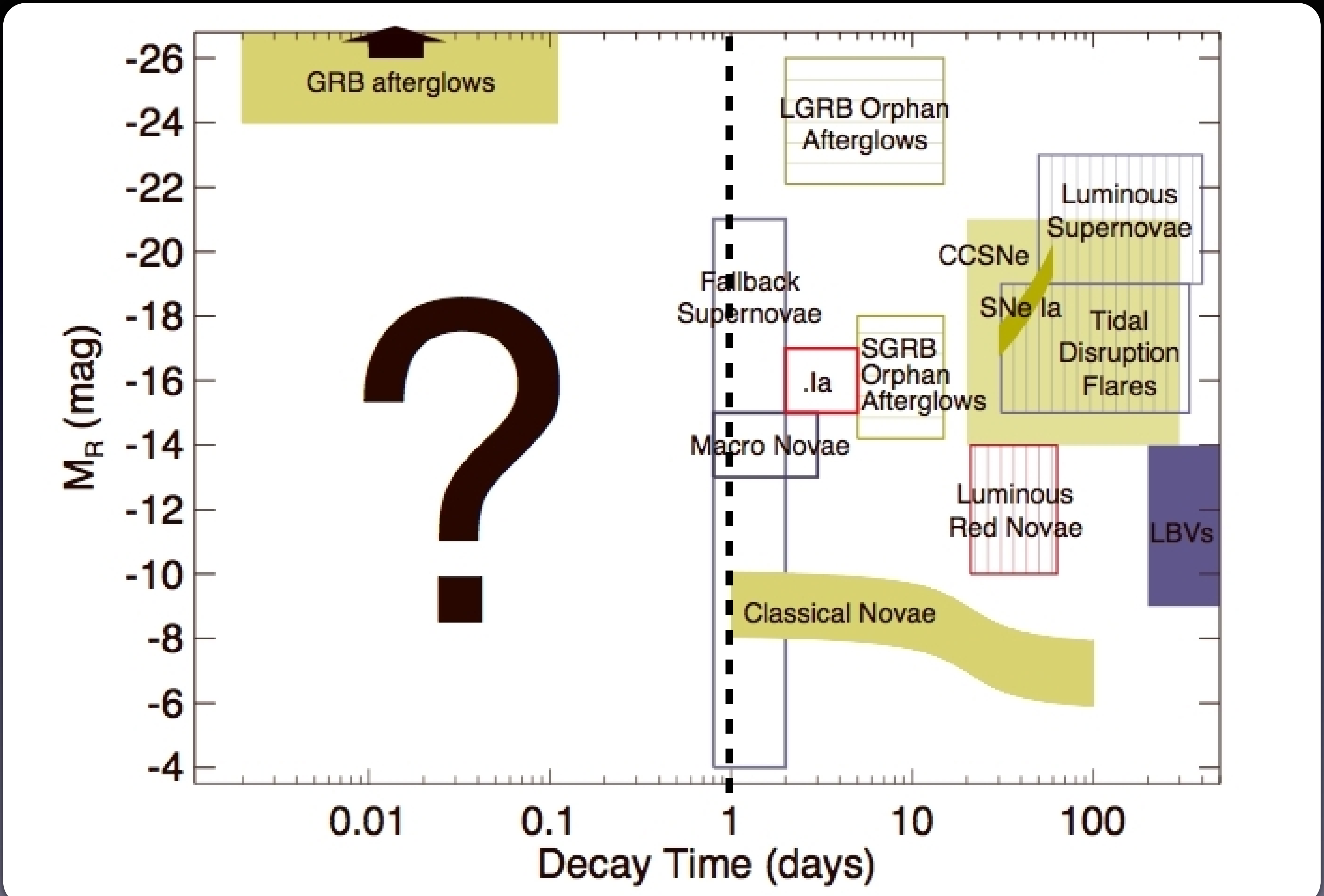
# Rising timescale vs magnitude




MT, Tominaga, Morokuma, Yasuda+2016

see also Ofek et al.; Gezari et al.

# Frontier of transient sky




LSST Science Book (after Rau+09, Kasliwal+,Kulkarni+)

# High-cadence survey: synergy with Keck

Collaboration with Shri Kulkarni (Caltech)

led by Nozomu Tominaga

# SSP Transient survey (2016 Nov-)

led by the HSC transient working group:
Naoki Yasuda, Nozomu Tominaga, Tomoki Morokuma, Nao Suzuki, Ichiro Takahashi, Takashi Moriya, Keiichi Maeda, Masaki Yamaguchi, et al.

**The deepest/widest transient survey as ever**

**Collaboration with Keck**

with Jeff Cooke (Swinburne)

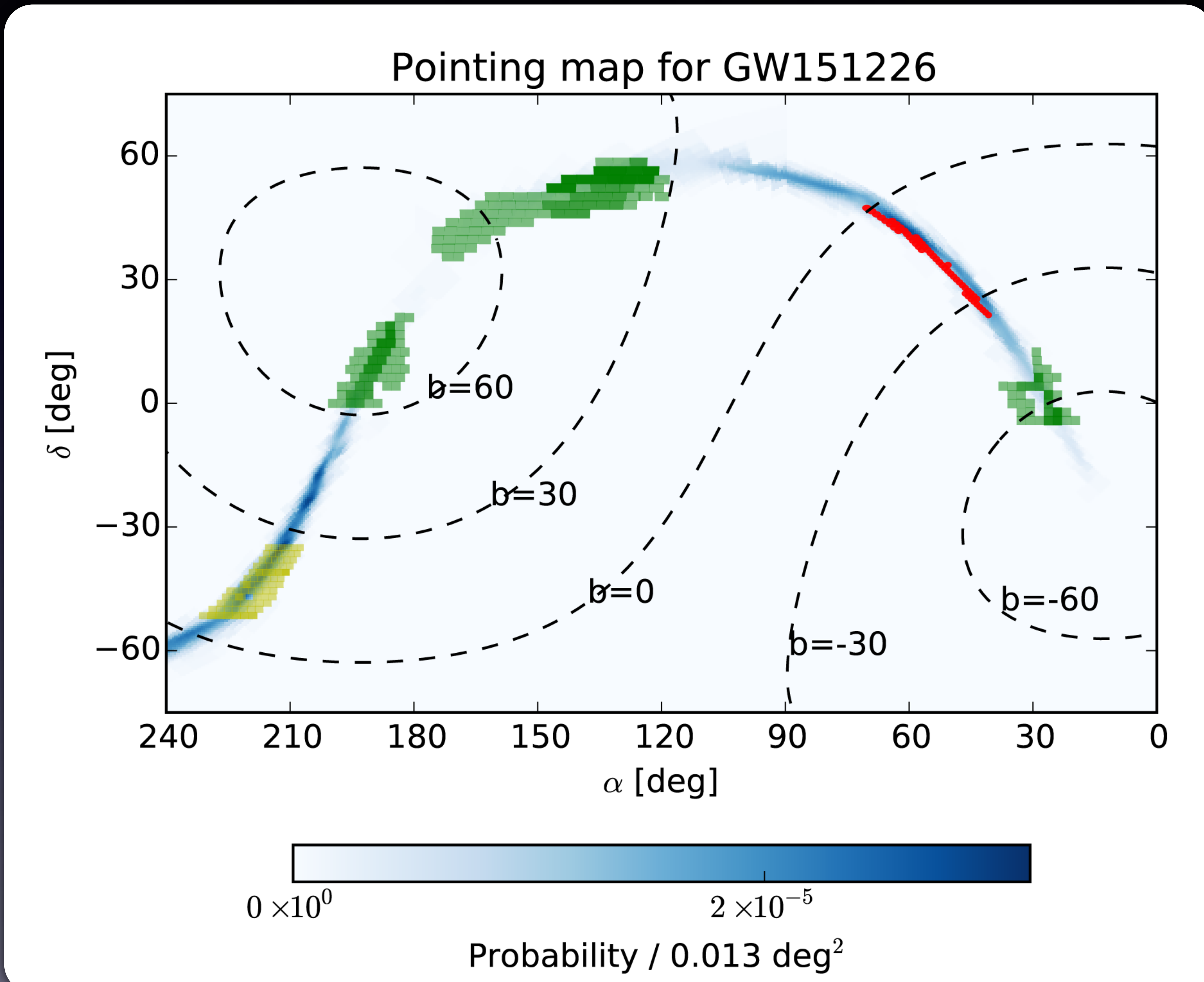
led by Takashi Moriya

with Peter Nugent (LBL), Thomas de Jaeger (Berkley)

led by Keiichi Maeda

# J–GEM observations for GW151226

Yoshida, Utsumi, Tominaga et al. (J-GEM) 2016, PASJ, in press, arXiv:1611.01588




**987 deg$^2$**

- **Subaru/HSC: 64 deg$^2$ (7%)**
- **Kiso/KWFC: 778 deg$^2$ (9%)**
- **MOA: 145 deg$^2$ (13%)**

**HSC: 1256 candidates and ~60 likely extragalactic transients**

**=> Need spectroscopy for firm identification**

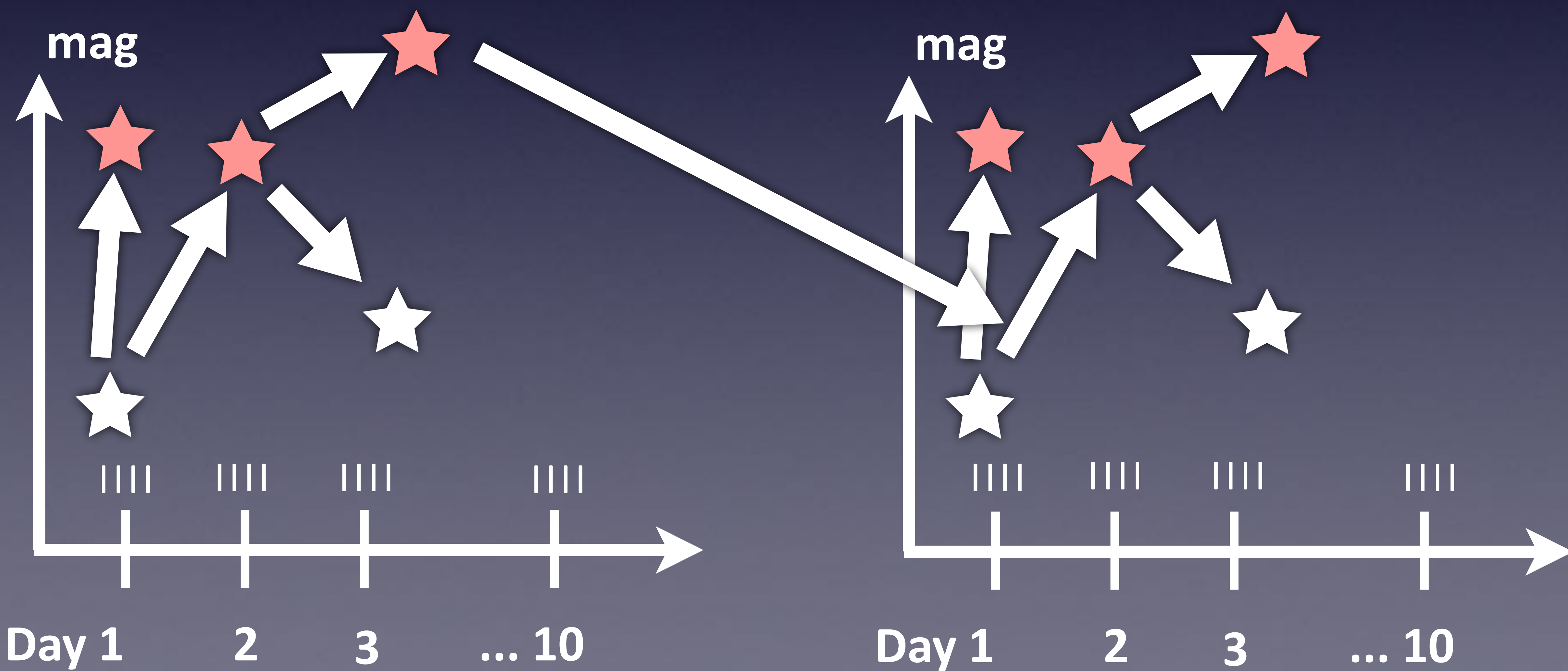
## Exploring the Transient Sky with Subaru and Keck

- Frontier of the transient survey
- Transient survey with Subaru/HSC and on-going collaboration with Keck
- Synergetic projects with Keck

# Exploring short-timescale transient sky with Subaru/Keck

- New survey with HSC (10 nights x 2)
  - Depth:  25 mag (1 min exposure)
  - Cadence: ~ 1hr
    "1 hr + 1 day + 1 month cadence"
  - Area: ~75 $deg^2$ (~ 50 pointing)

+ Spectroscopy with Keck/LRIS (~10 nights)



# Summary

- **Frontier of transient science**
  - Short-timescale of < 1 day
  - Multi-messenger astronomy (GW and neutrino)
- **What we did/are doing**
  - Pilot high-cadence survey
  - SSP transient survey => Follow-up with Keck (and Gemini)
  - Follow-up of GW sources
- **Possible synergetic projects**
  - NEW HSC survey dedicated to explore short-timescale transient sky
    - Size: ~20 nights Subaru/HSC + ~10 nights Keck/LRIS
    - Timeline: can start NOW (unique before LSST)
  - Collaboration on GW (and neutrino) follow-up?