Optical/Infrared Observations for Gravitational Wave Astronomy

- 重力波天文学と連携した光赤外観測の提案 -

光赤天連シンポジウム
2020年代の光赤外天文学-将来計画の再構成

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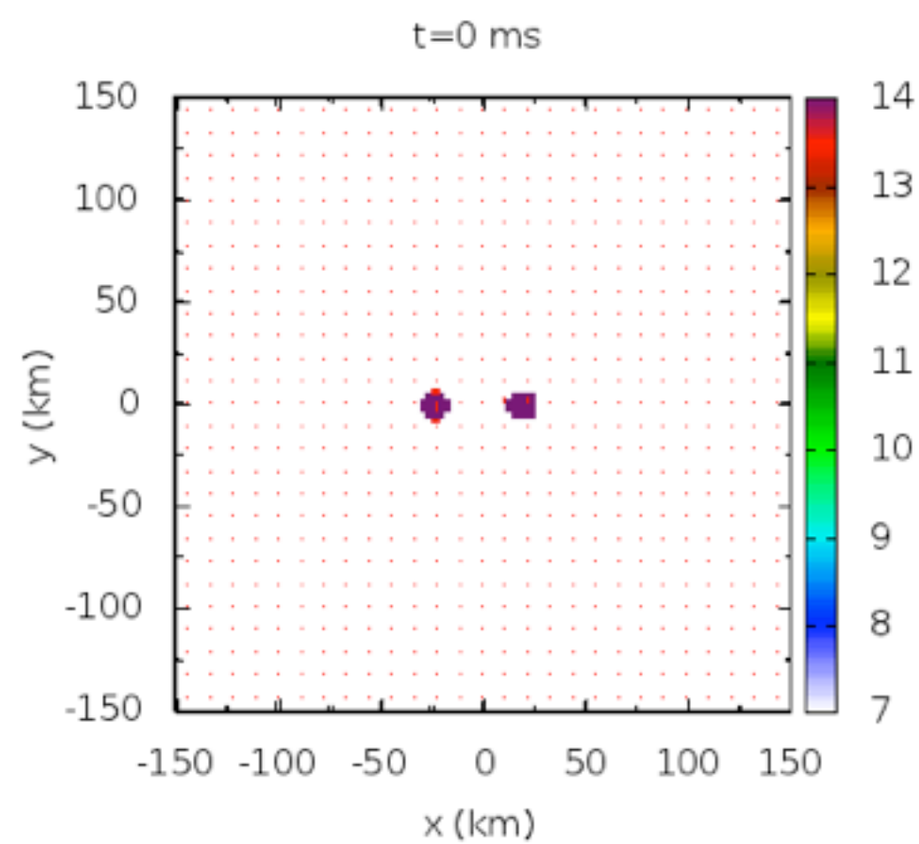
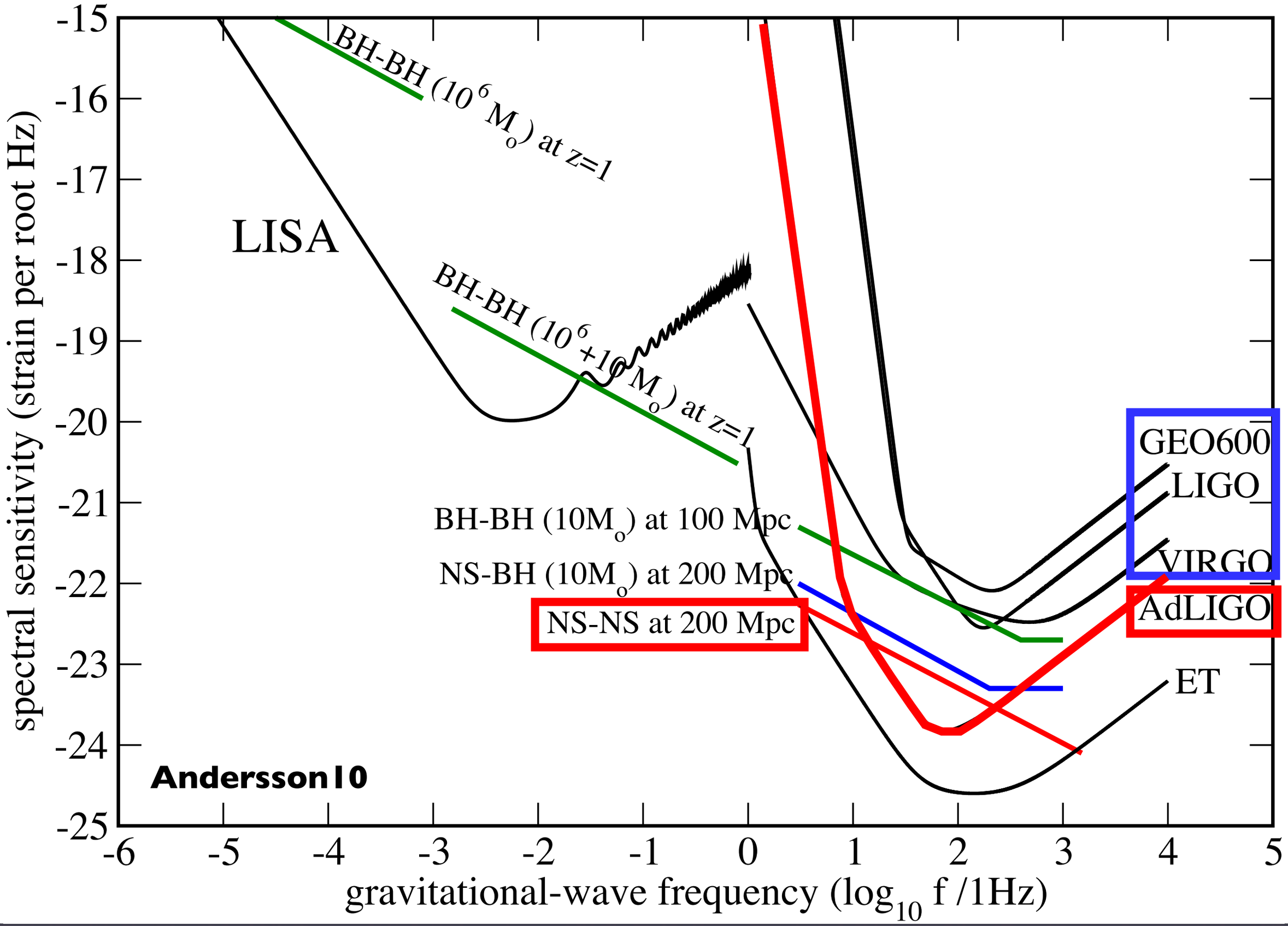
New astronomy with gravitational waves

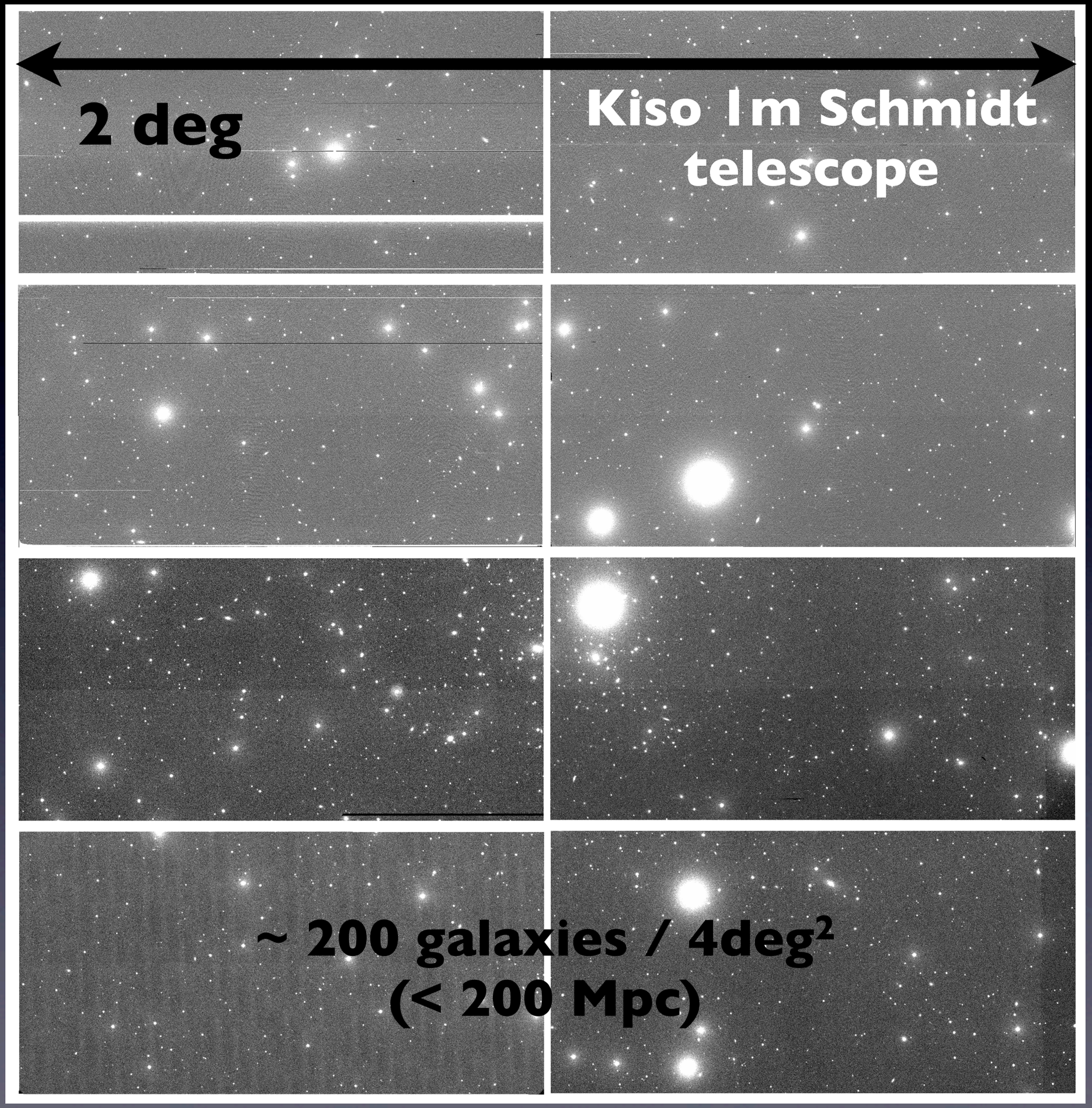
2017 -
- Advanced LIGO (US)
- Advanced VIRGO (Europe)
- KAGRA (Japan)

NS-NS merger with 200 Mpc
~ 30 events/yr
(~0.3-300)

Hotokezaka+13




spectral sensitivity (strain per root Hz)
gravitational-wave frequency ($\log_{10}$ f /1Hz)
-15
-16
-17
-18
-19
-20
-21
-22
-23
-24
-25
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
LISA
BH-BH ($10^6 M_o$) at z=1
BH-BH (10^6+10 M_o) at z=1
BH-BH ($10M_o$) at 100 Mpc
NS-BH ($10M_o$) at 200 Mpc
NS-NS at 200 Mpc
GEO600
LIGO
VIRGO
AdLIGO
ET
Andersson10


2 deg
Kiso 1m Schmidt telescope
~ 200 galaxies / 4deg²
(< 200 Mpc)

GW alert error box

e.g. 10 deg x 10 deg

~ 5000 galaxies

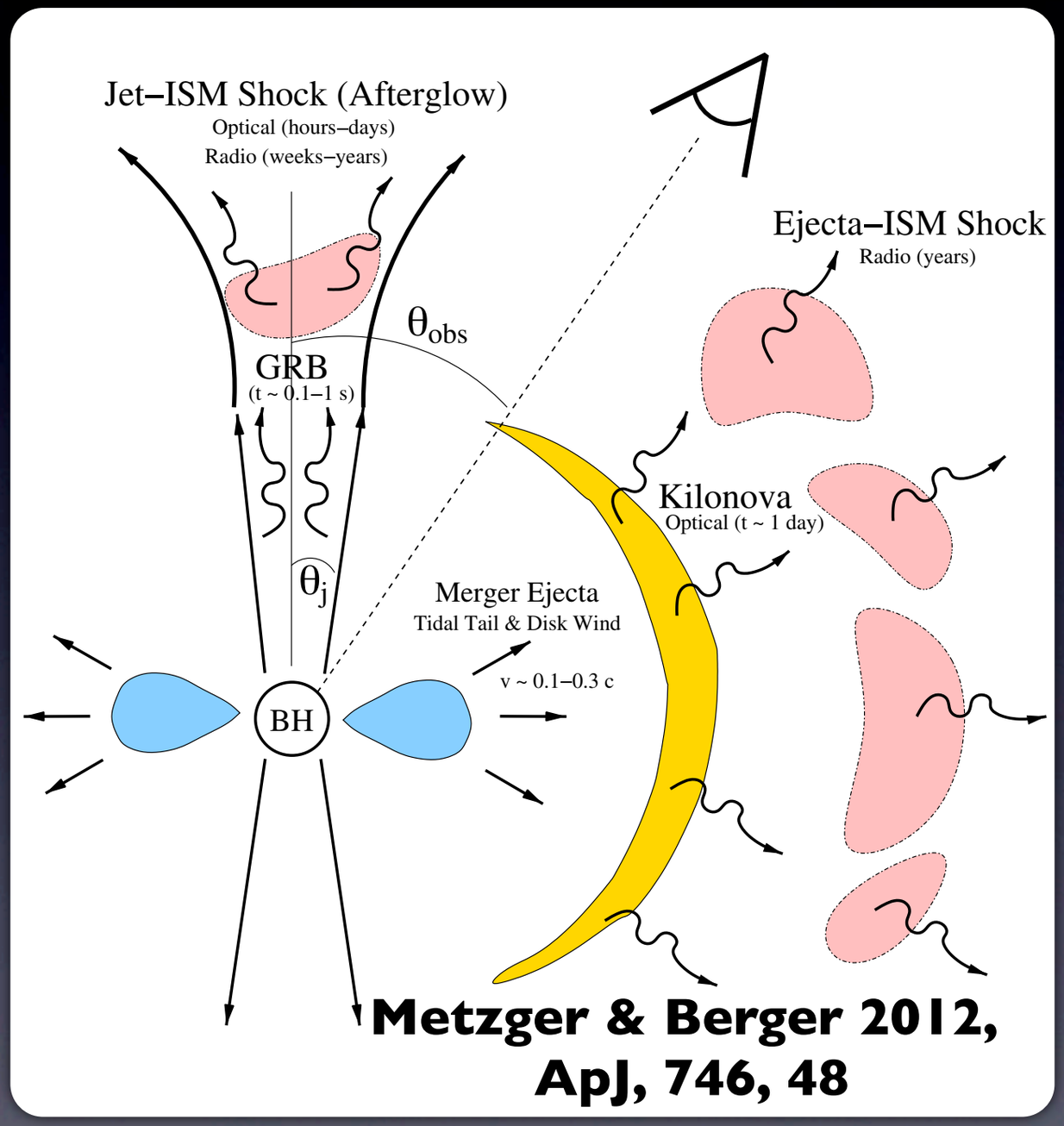
(< 200 Mpc)

No electromagnetic counterpart,
No gravitational-wave astronomy!

2 deg

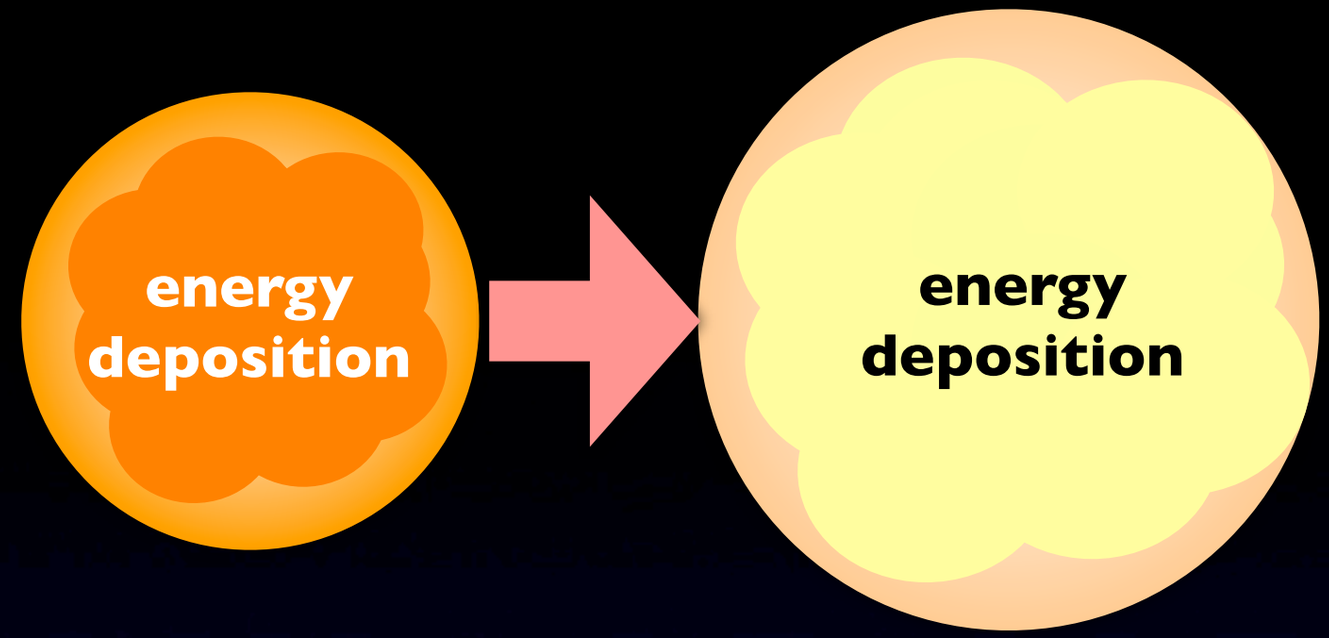
EM signature from NS-NS merger

- On-axis short GRB
- Off-axis radio/optical afterglow
- Radioactive emission (r-process nuclei)
  - kilonova
  - macronova
  - mini SN



Metzger & Berger 2012, ApJ, 746, 48

Expected emission



Timescale

$$t_p \sim 1\ \mathrm{day} \left(\frac{M}{0.01 M_\odot}\right)^{1/2} \left(\frac{v}{0.2c}\right)^{-1/2} \left(\frac{\kappa}{0.1\ \mathrm{cm}^2\ \mathrm{g}^{-1}}\right)^{1/2}$$

Luminosity

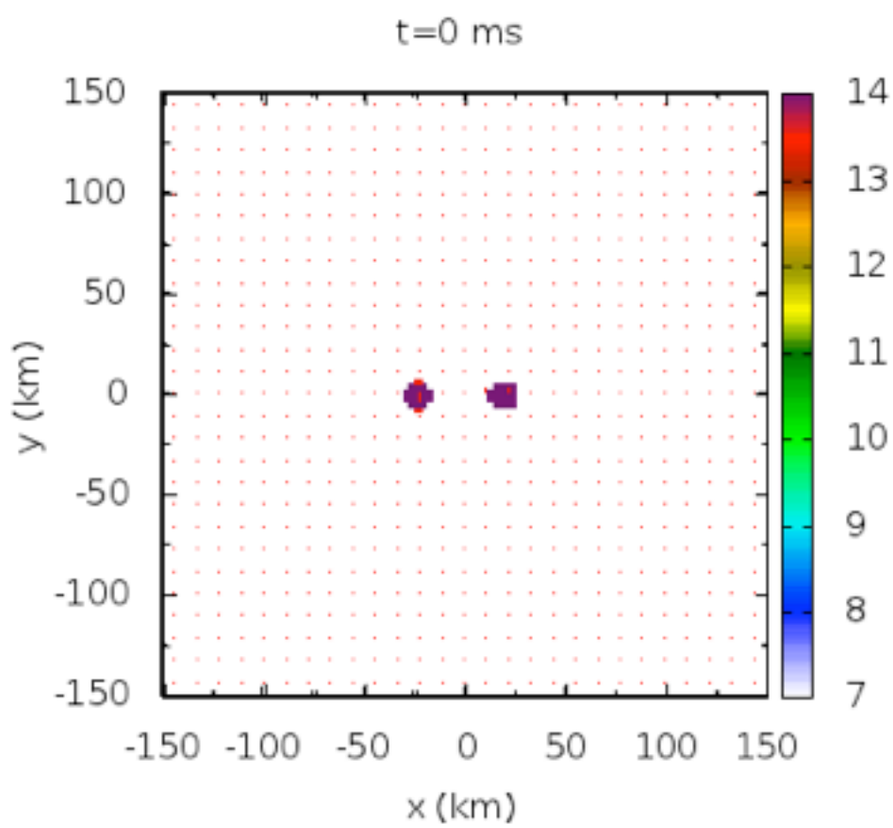
$$L \sim 10^{42}\ \mathrm{erg\ s}^{-1} \left(\frac{M}{0.01 M_\odot}\right)^{1/2} \left(\frac{v}{0.2c}\right)^{1/2} \left(\frac{\kappa}{0.1\ \mathrm{cm}^2\ \mathrm{g}^{-1}}\right)^{-1/2}$$

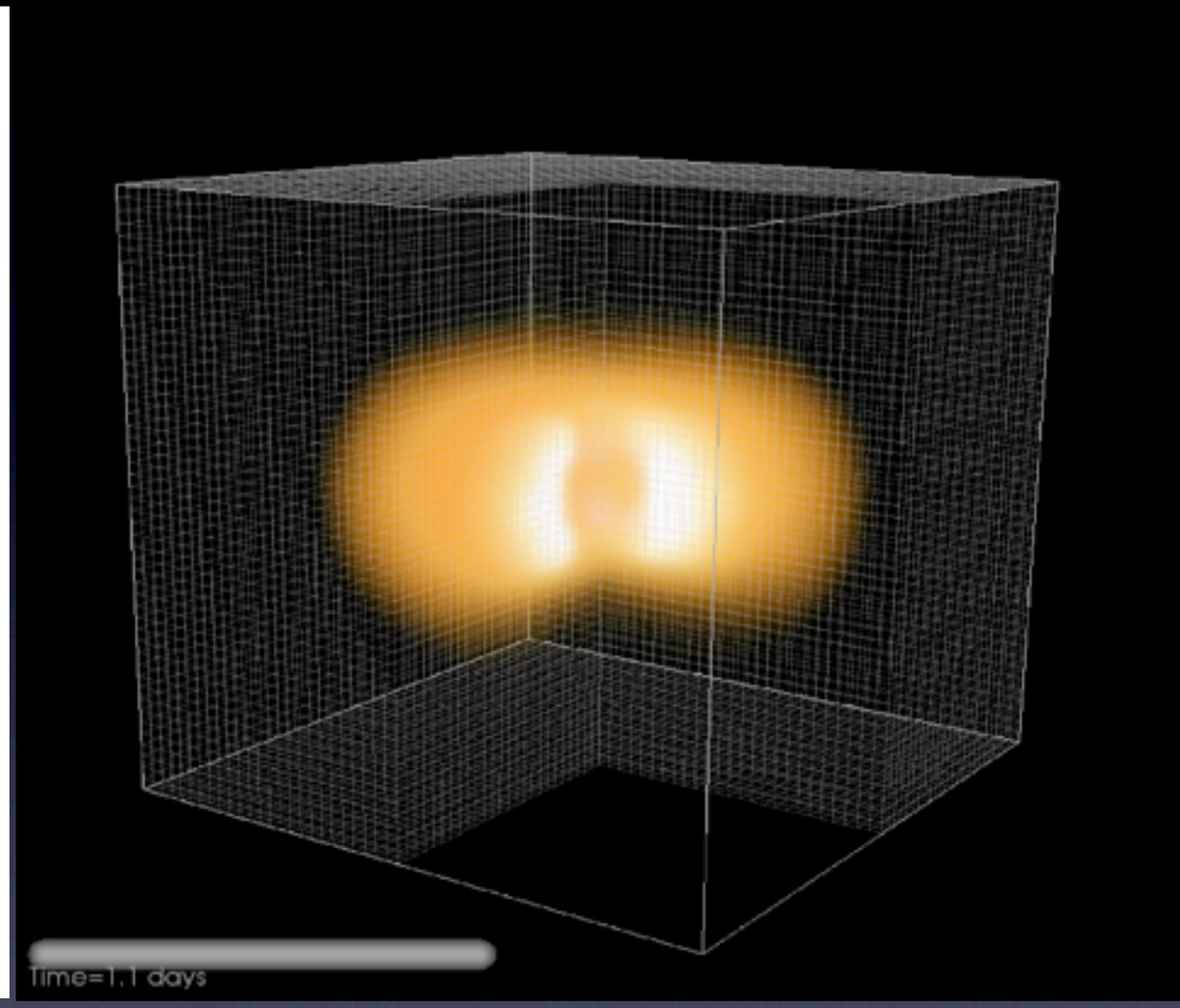
Li & Paczynski 98
Metzger+10

~ 20 mag at 200 Mpc

Survey with 1m-class wide-field telescopes

Numerical relativity simulation → **3D radiative transfer simulation**





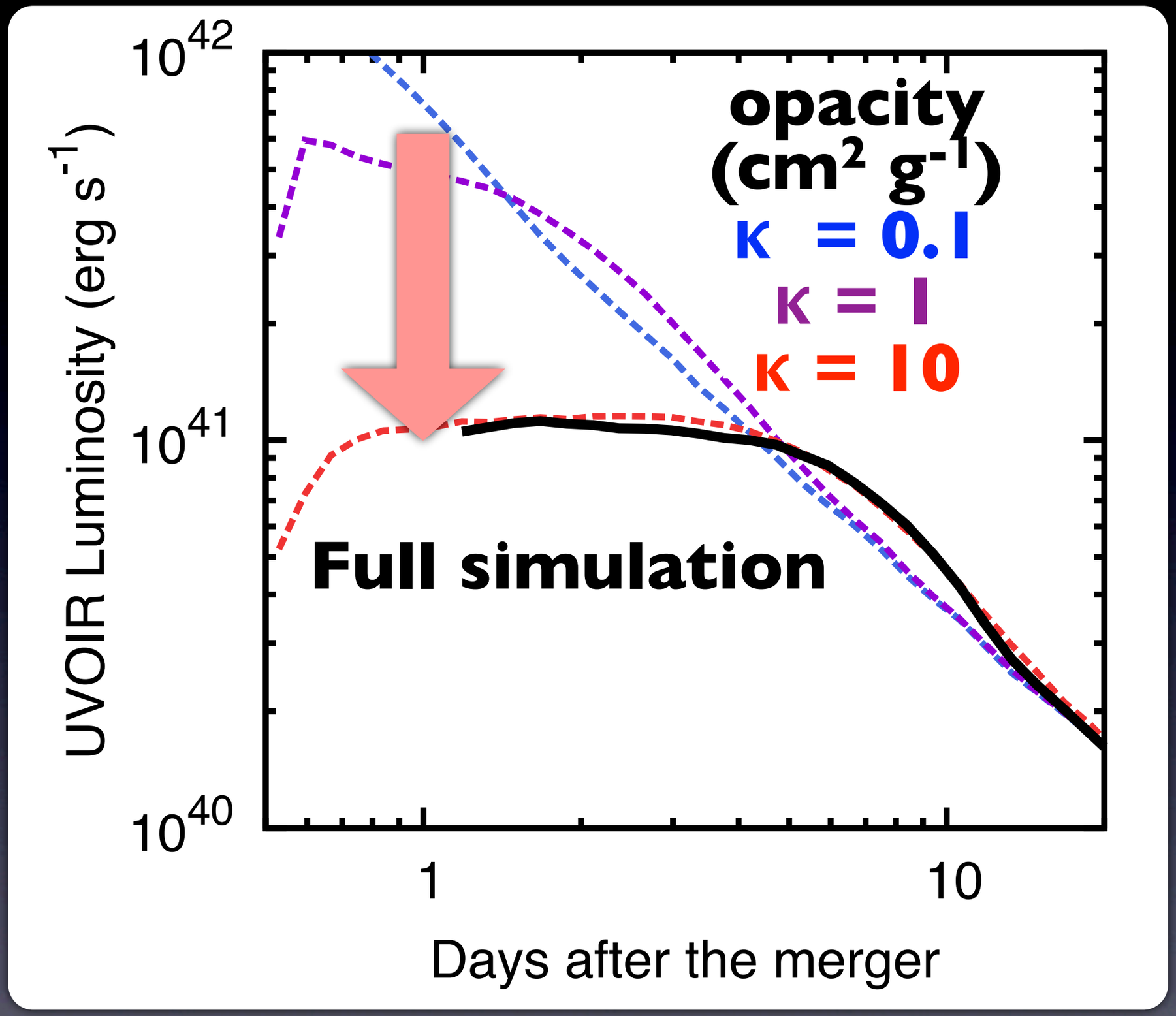
Hotokezaka et al. 2013

MT & Hotokezaka 13, ApJ, in press (arXiv:1306.3742)

1. Opacity of r-process-dominated ejecta?

($\kappa \sim 0.1$ cm^2 g^{-1} for SNe)

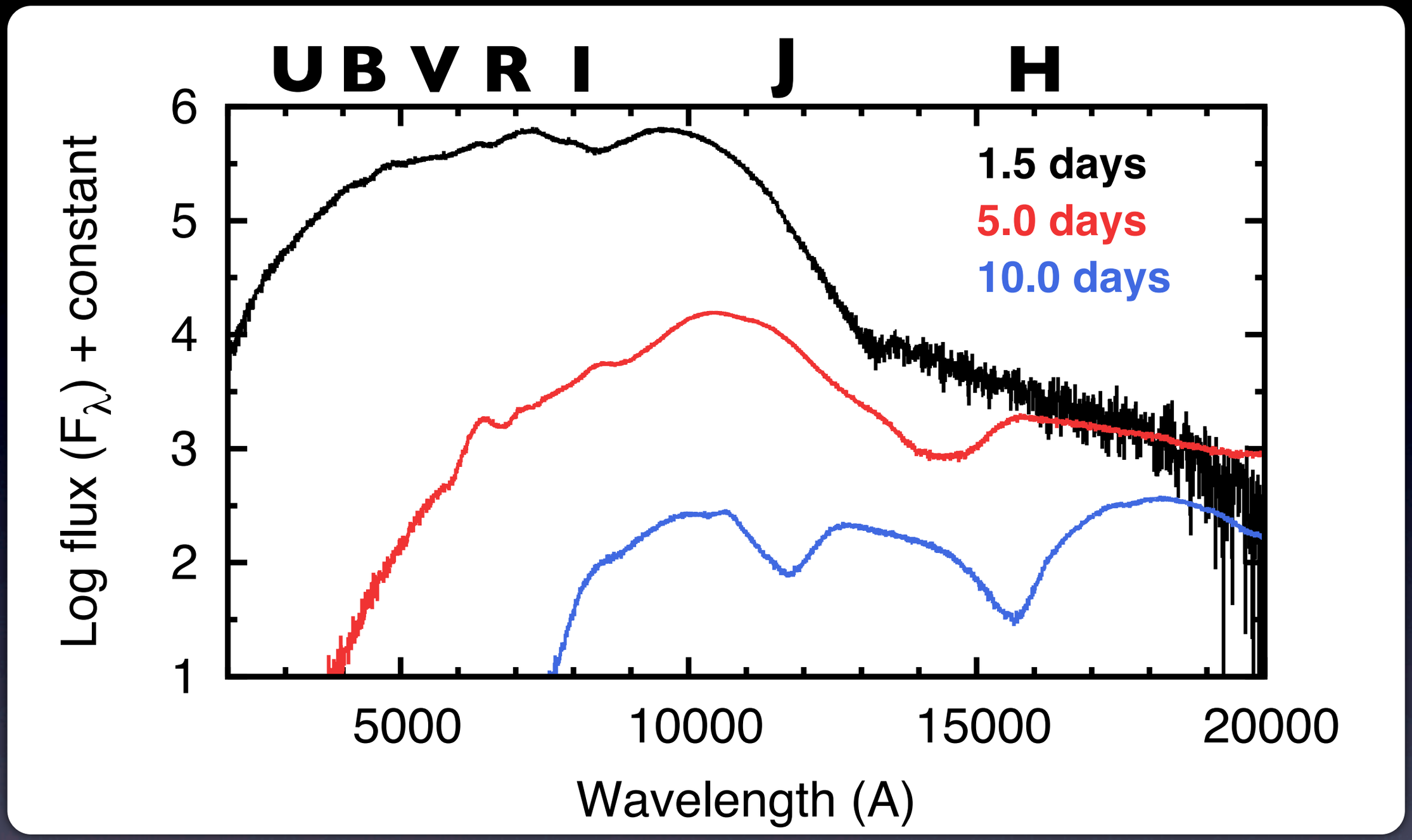
2. Characteristic feature of NS merger?



Higher opacity by factor of 100 (!)

Fainter than previously expected by a factor of 10

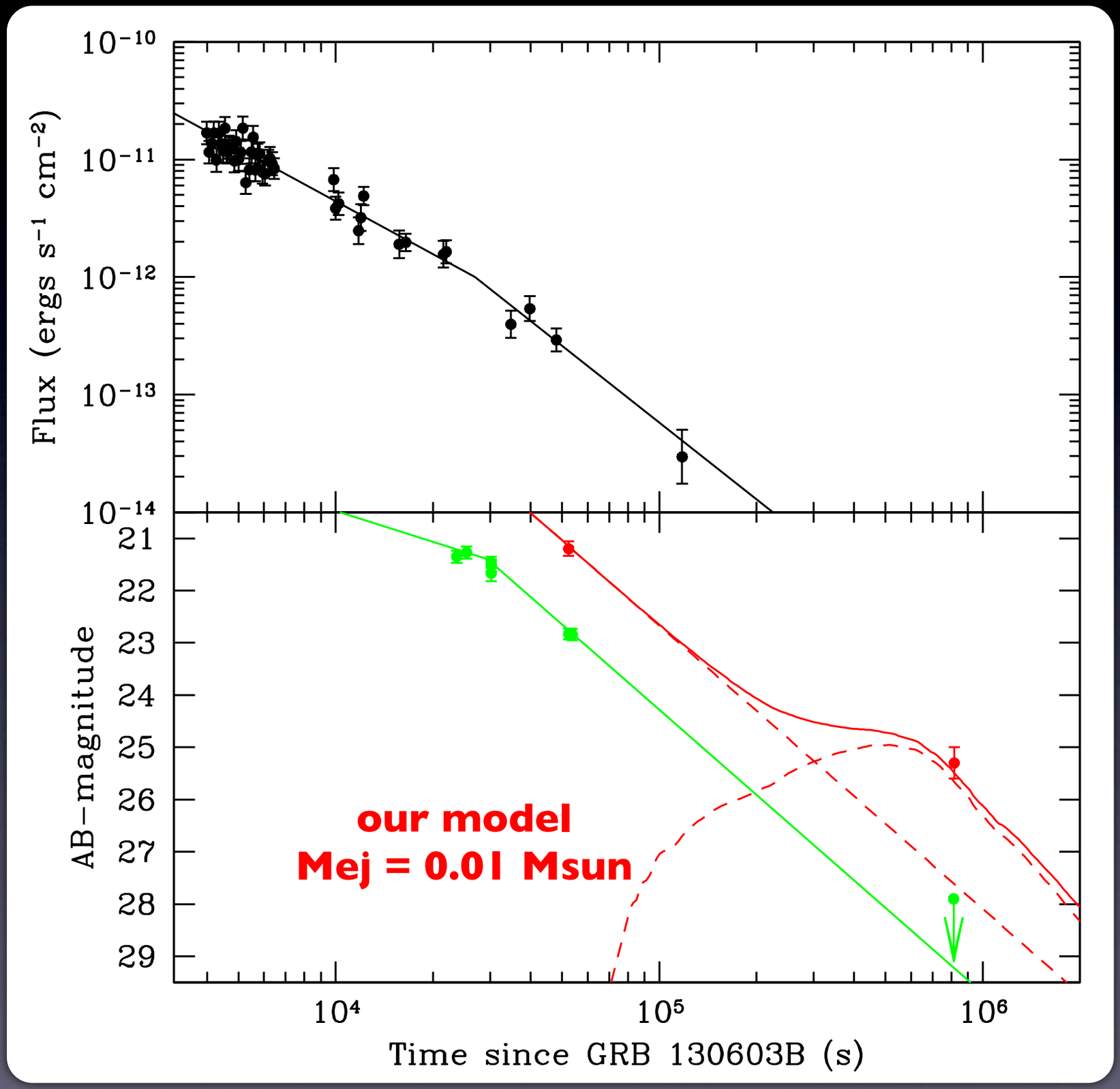
(see also Kasen+13, Barnes & Kasen 13)

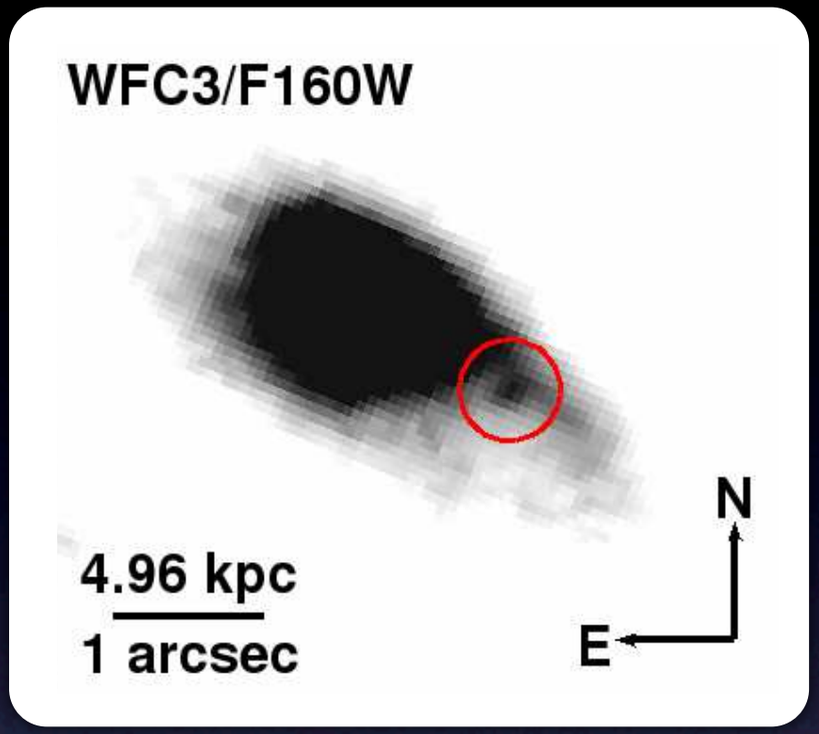


- **Very red SED (peak at NIR)**
- **Extremely broad-line (feature-less) spectra**

(Identification of r-process elements seems difficult)

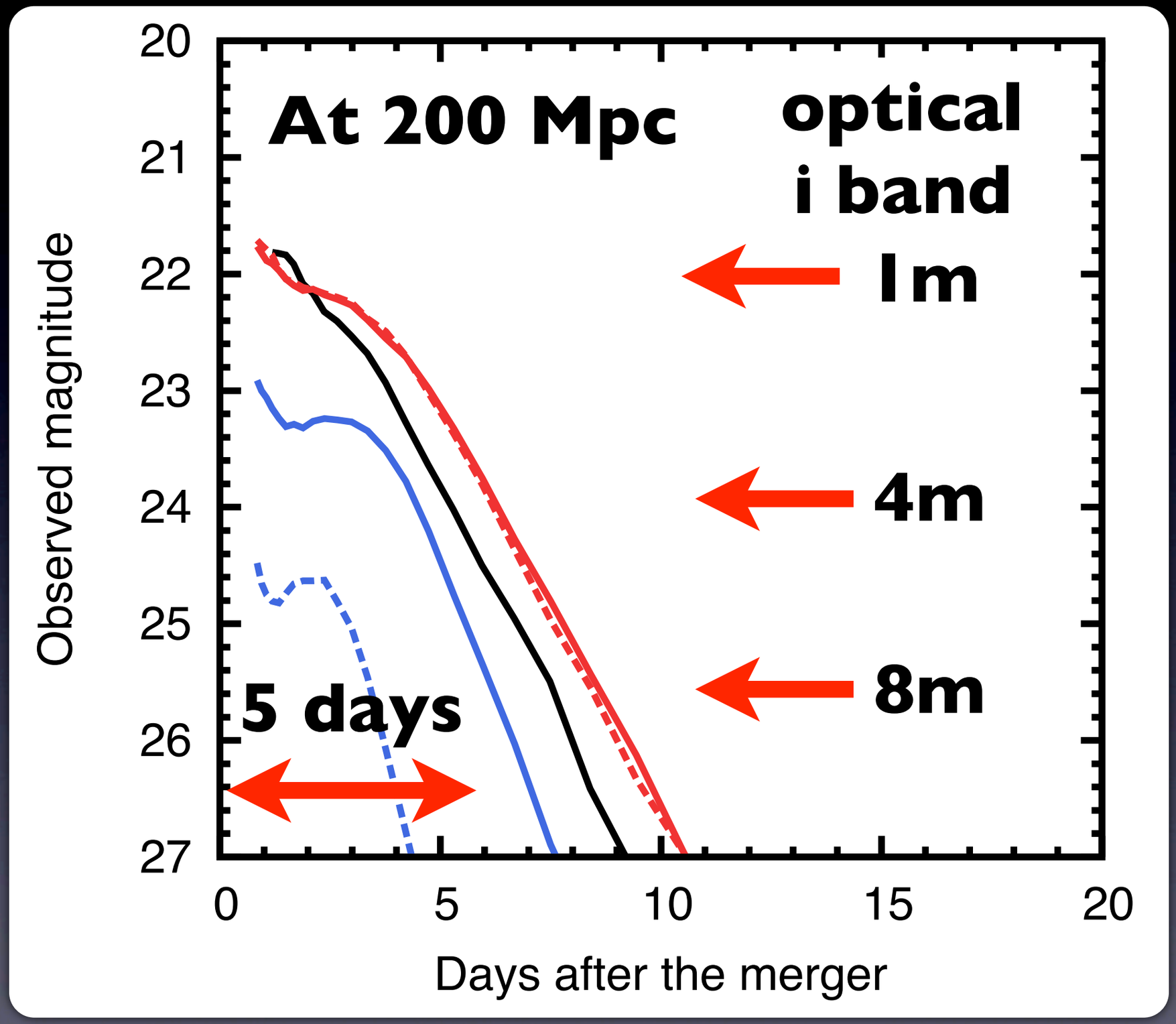
Radioactive emission in short GRB





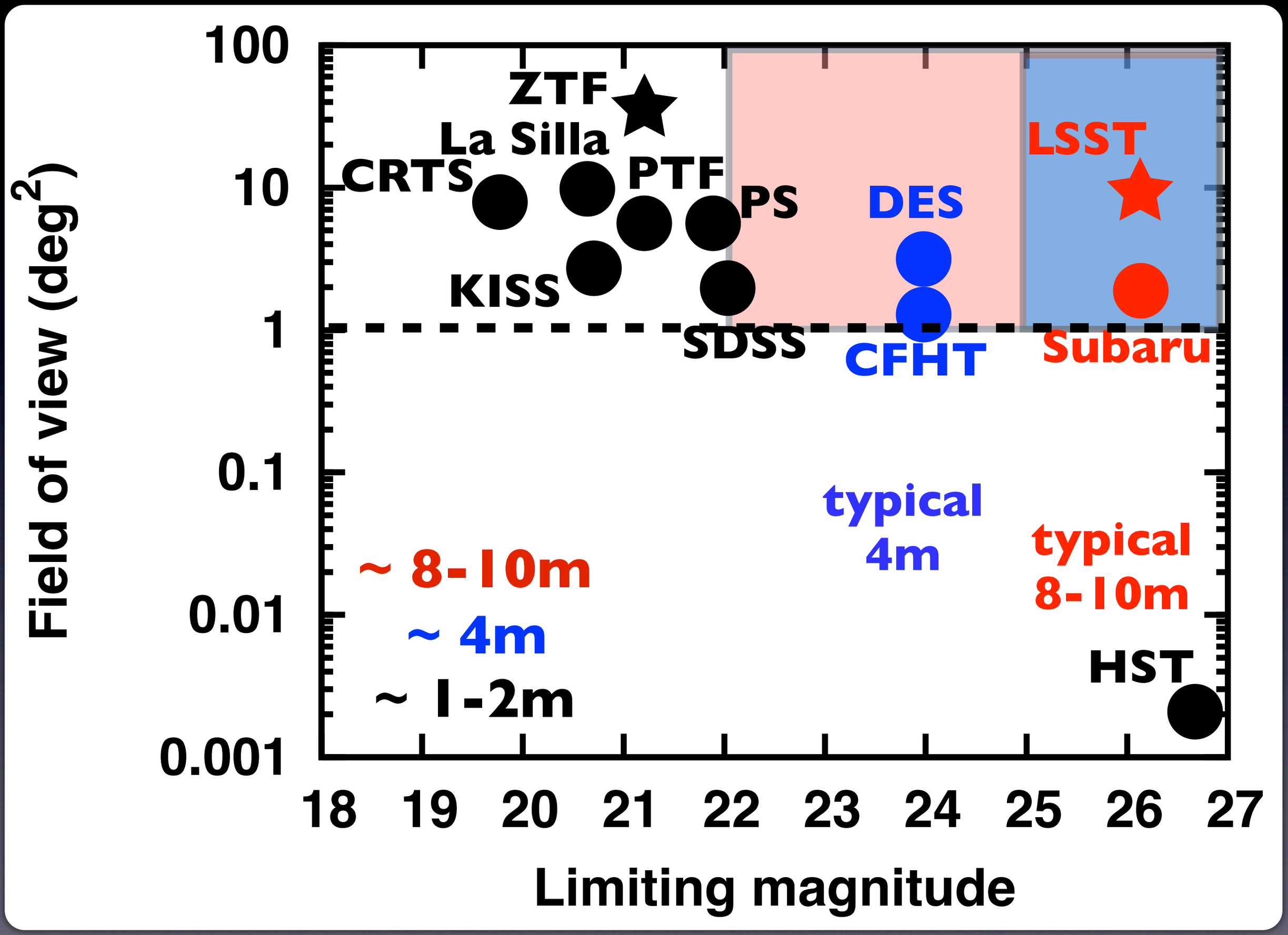
Berger+13 arXiv: 1306.3960
Tanvir+13
(Nature, arXiv:1306.4971)

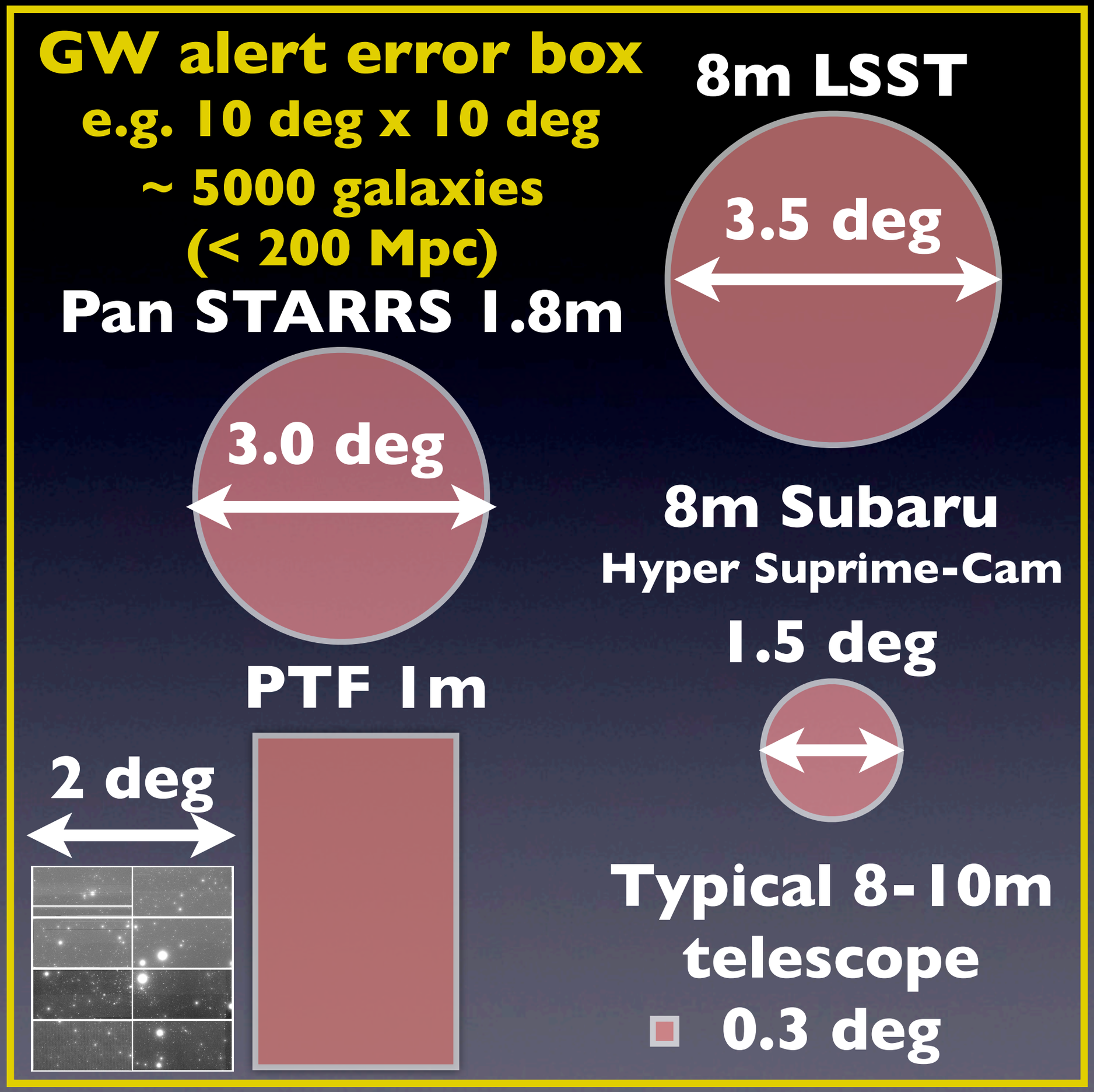
Observing strategy



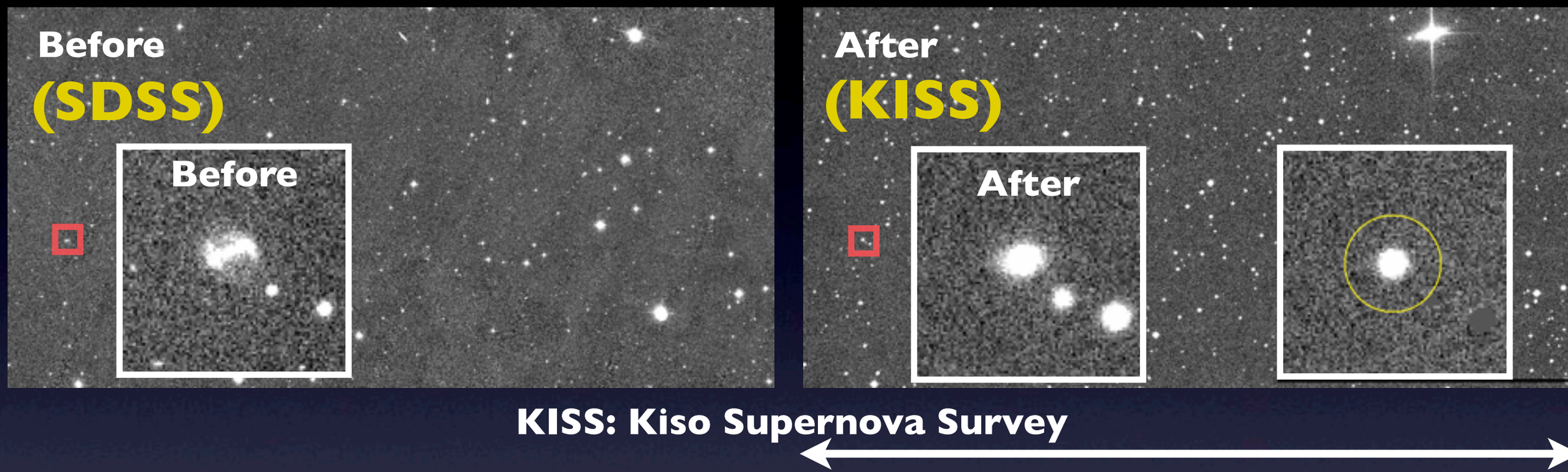
10 min
5 sigma

Best with i band (0.8 um)
NIR ?? (~21 AB mag in NIR)


100
10
1
0.1
0.01
0.001
Field of view (deg^2)
18
19
20
21
22
23
24
25
26
27
Limiting magnitude
ZTF
La Silla
CRTS
PTF
PS
KISS
SDSS
DES
CFHT
LSST
Subaru
typical
4m
typical
8-10m
HST
~ 8-10m
~ 4m
~ 1-2m


GW alert error box
e.g. 10 deg x 10 deg
~ 5000 galaxies
(< 200 Mpc)
8m LSST
3.5 deg
Pan STARRS 1.8m
3.0 deg
8m Subaru
Hyper Suprime-Cam
1.5 deg
PTF 1m
2 deg
Typical 8-10m
telescope
0.3 deg

Big challenge



- **Need all-sky reference image!**
  (with i ~ 25 mag)
  => ~350 nights with Subaru/HSC... (half sky)

- **Or detection of declining object?**
  => Spectroscopy of <26 mag objects (=> TMT!)

Toward the Dawn of GW Astronomy

- GW detectors in 2017 -
  - NS merger at < 200 Mpc
  - Localization ~ 100 deg^2
- EM counterpart is crucial
  - Short GRBs are not always expected
  - Radioactive emission
- Observing strategy
  - Wide field search with 22-25 mag (i band)
  - Detection of declining object?
    (or all sky reference image with i=25 mag)
  - Extremely broad line spectrum
  - Subaru/HSC => TMT