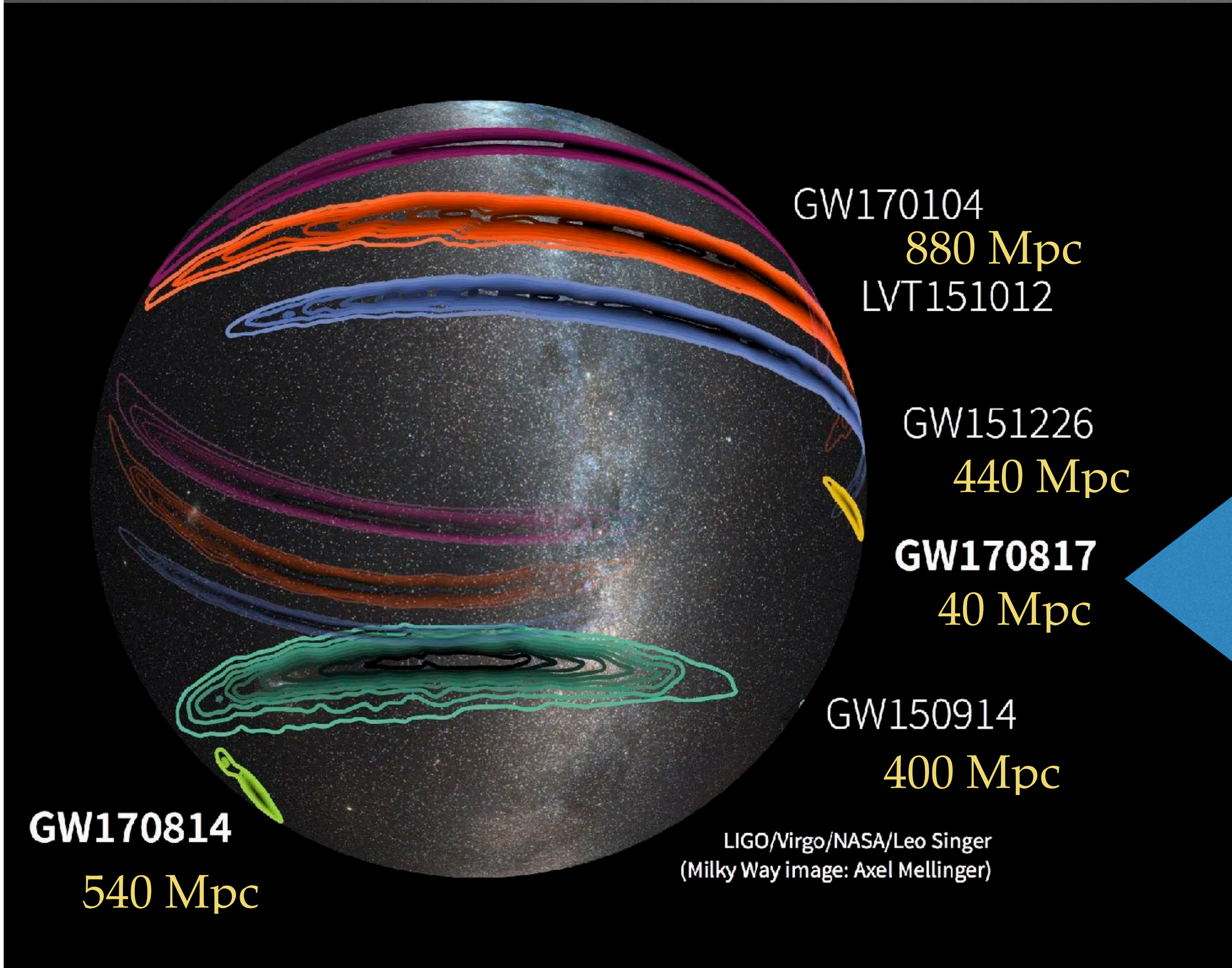
Electromagnetic facilities and observing strategies for multi-messenger science: situation and future perspectives.

Enrico Cappellaro
+GRAWITA collaboration

Search for EM counterparts



NS+NS

Where

~60 galaxies account for 85% of the stellar content in the volume (<60 Mpc)

What

kilonova: mag ~ 17-20
peak: 1day - 1week
decline: 3d / 3 weeks
SED: red/near-infrared

Search for EM counterparts

~ 80 telescopes .... > 110 papers

Search for transients

Deep survey of the full sky error map
with large telescopes

see talk of Aniello Grado

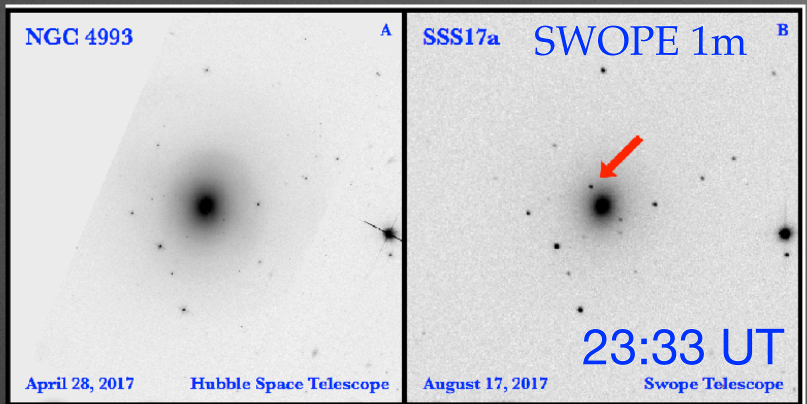
Scan galaxies at the right distance for
bright transients

see talk of Sheng Yang

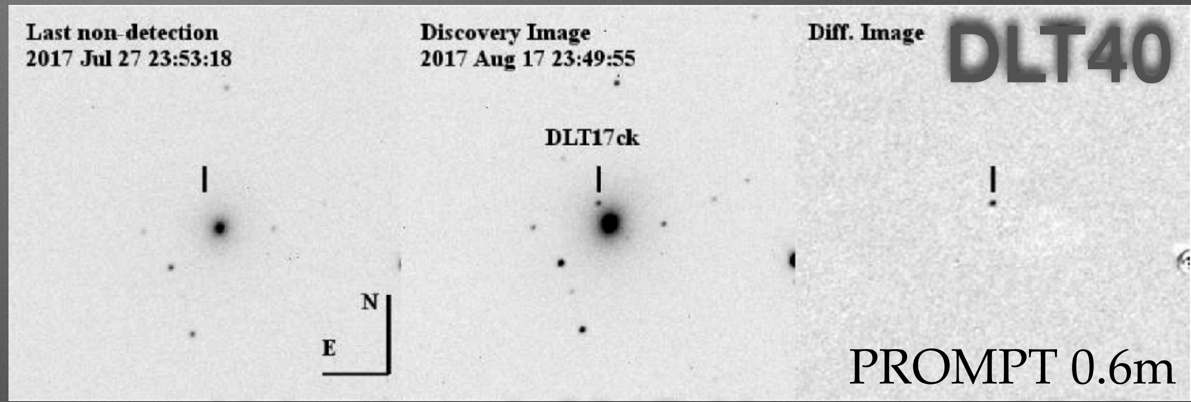
Discovery of the kilonova

SSS17a = DLT17ck = AT2017gfo

GW: 12:41:04 UT

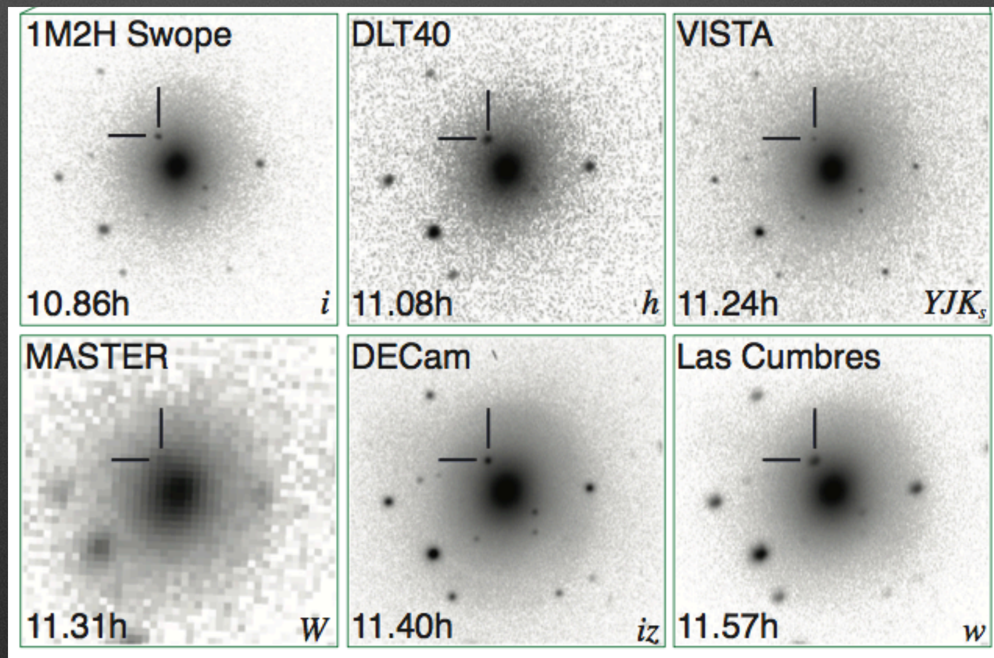


Coulter et al. 2017



Valenti et al. 2017, Yang et al. 2017

SSS17a
GCN
+12.40h



REM

12.40h

Discovery of the kilonova

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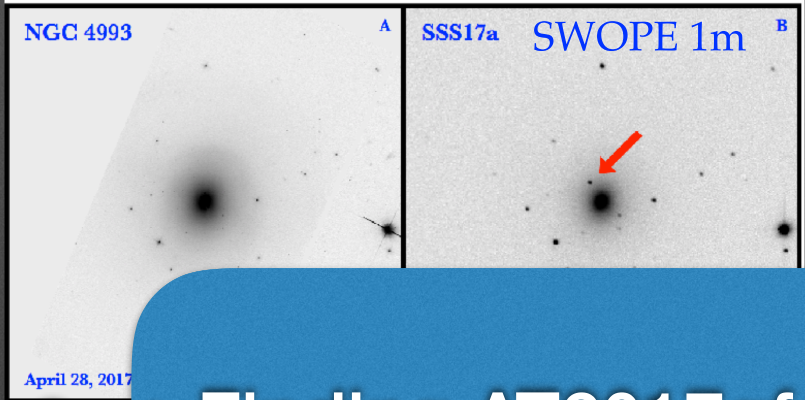
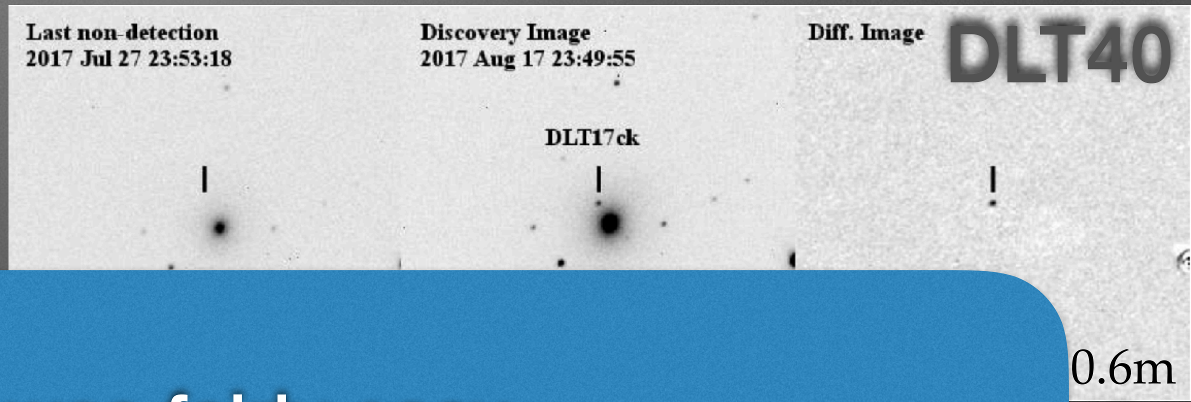
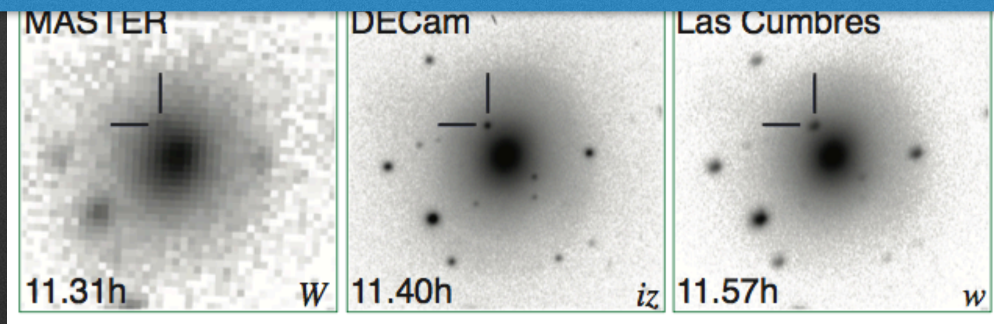
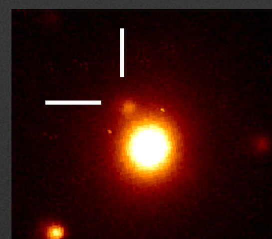




- Finding AT2017gfo was fairly easy
- Without the GW trigger AT2017gfo would not be found (wrong season)

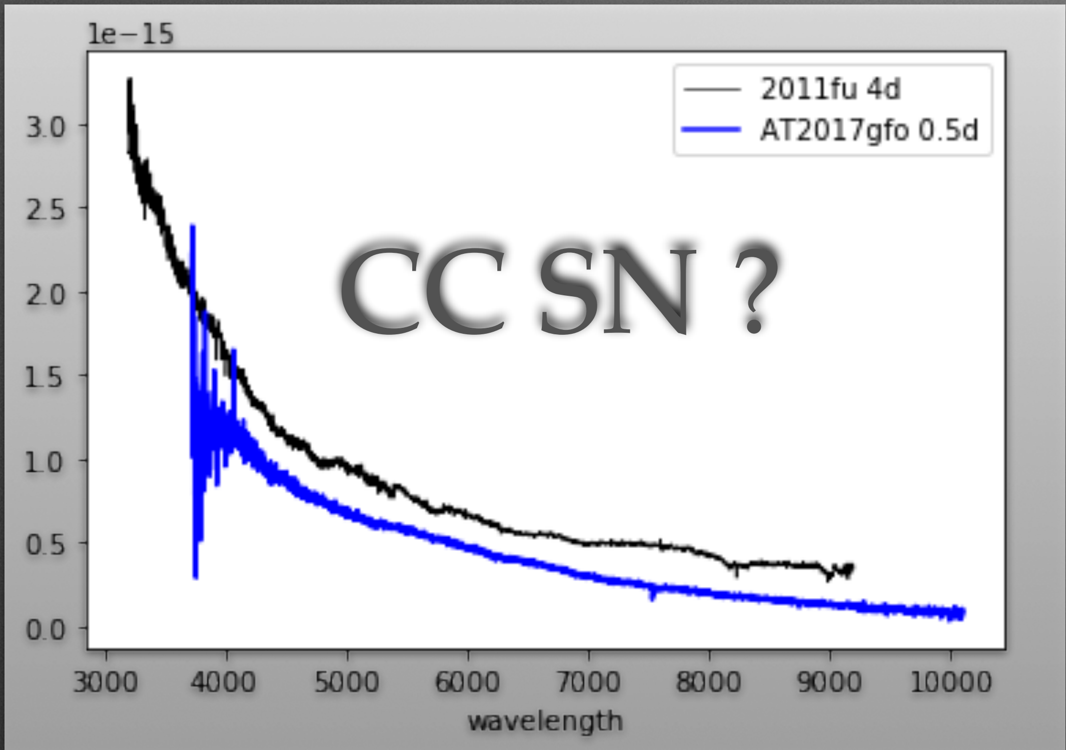




12.40h

Discovery of the kilonova

Shappee et al. 2017



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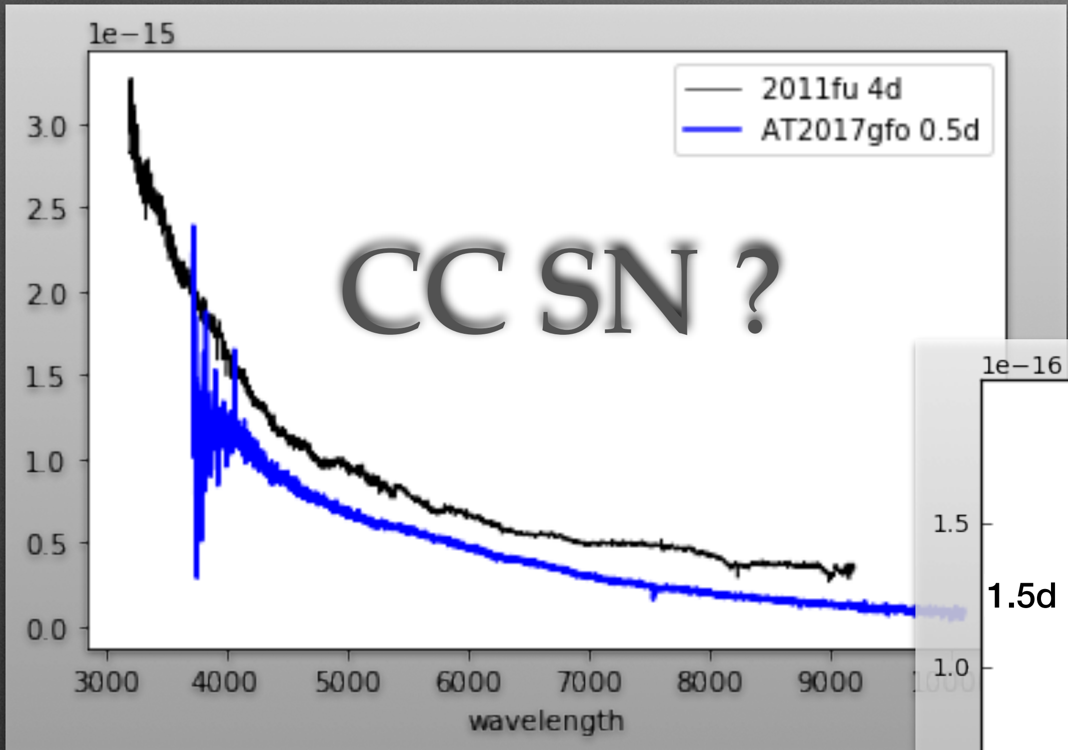
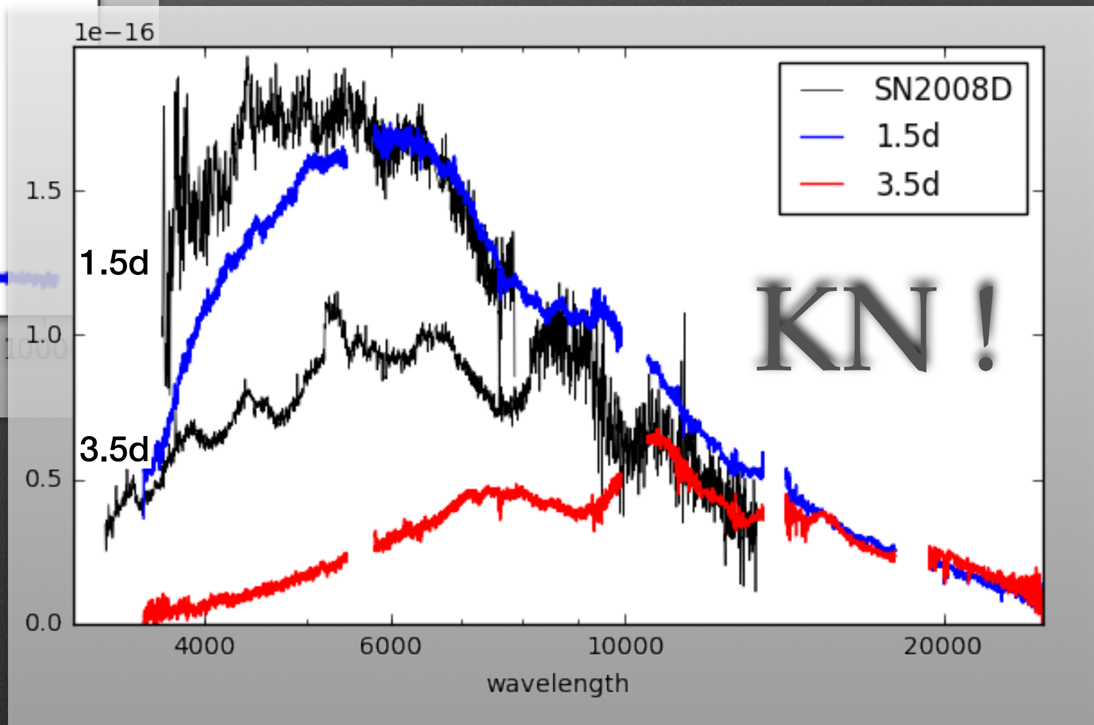
Shappee et al. 2017



Pian et al. 2017



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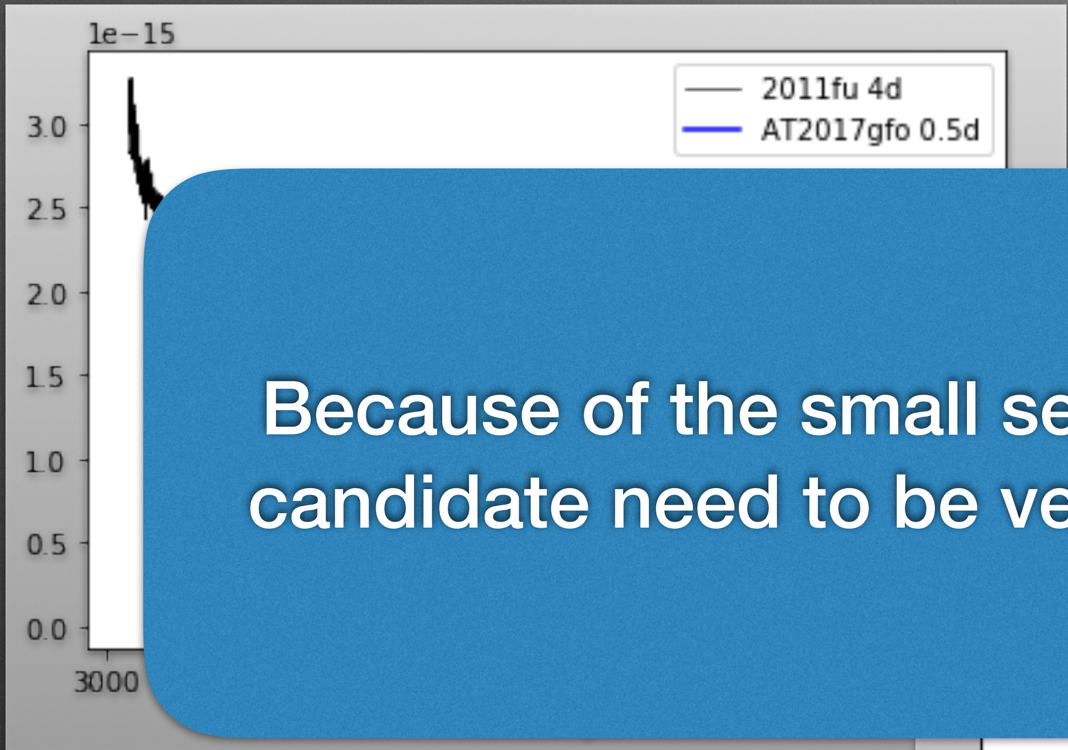
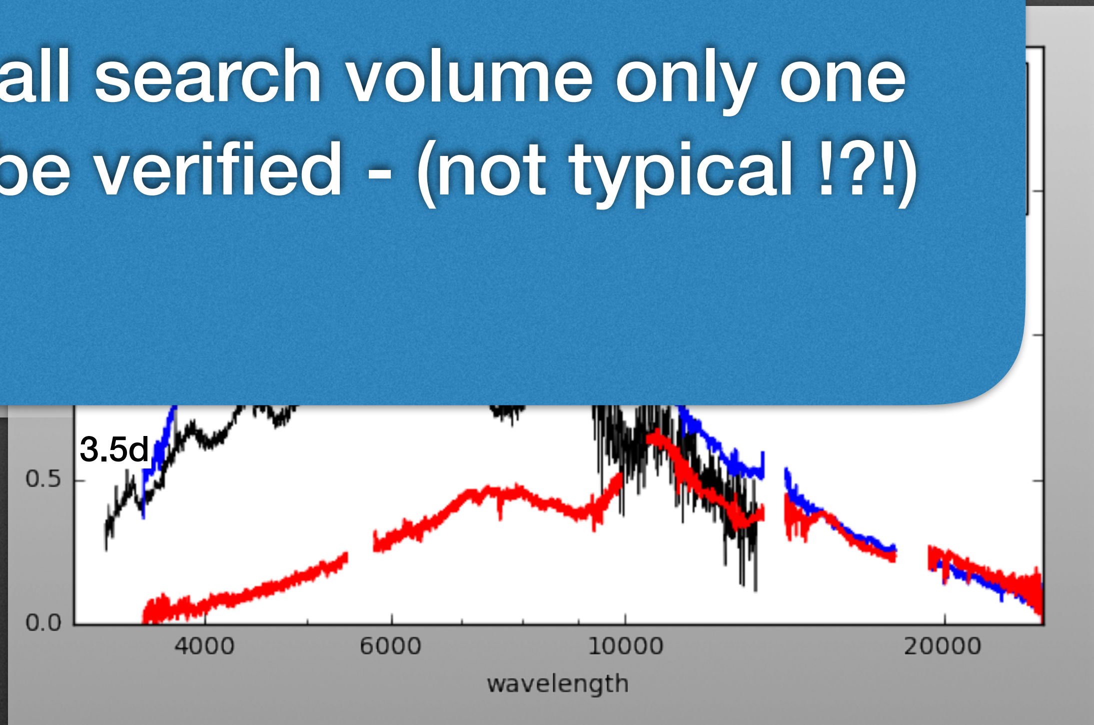
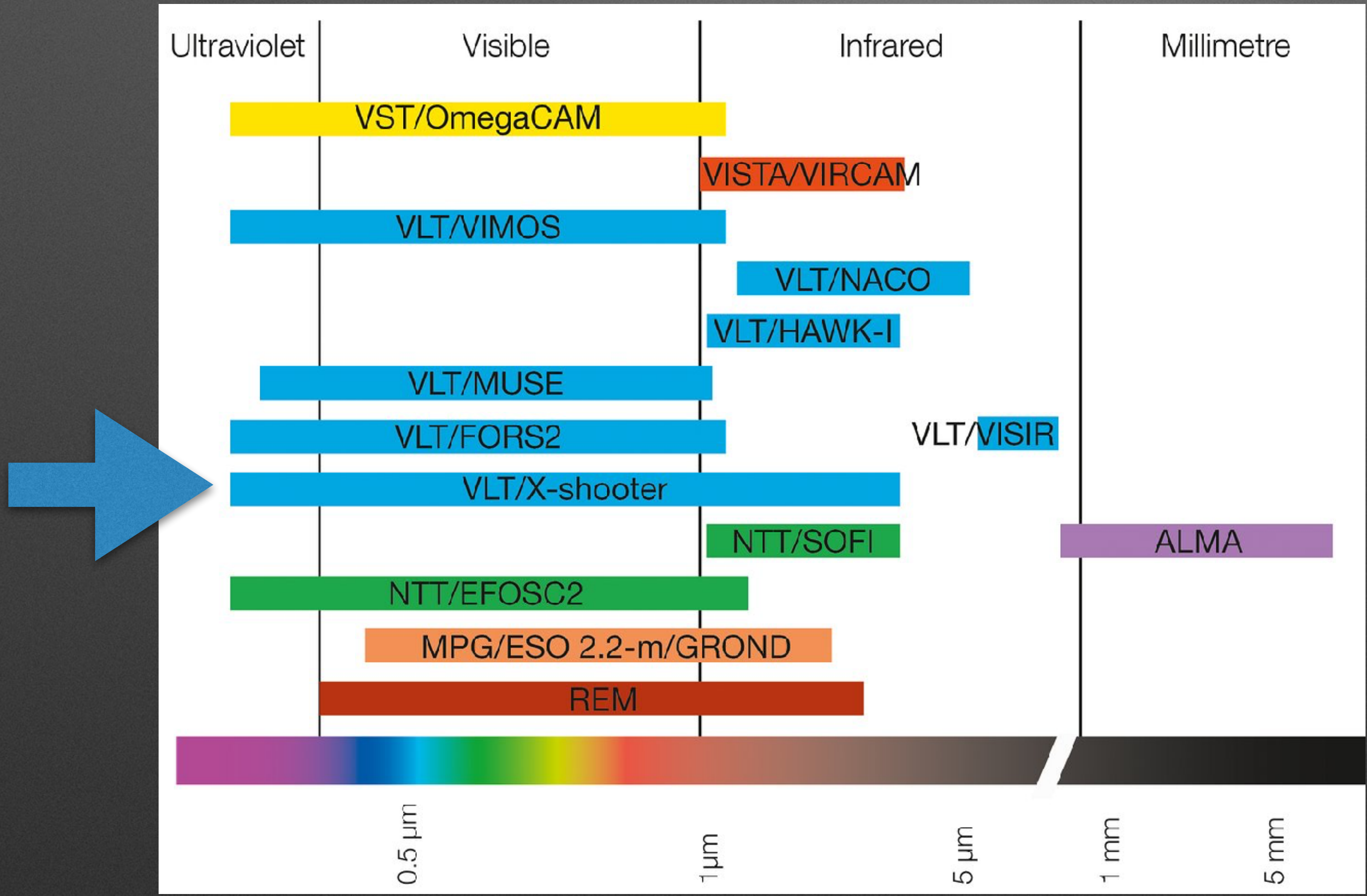




Because of the small search volume only one candidate need to be verified - (not typical !?!)

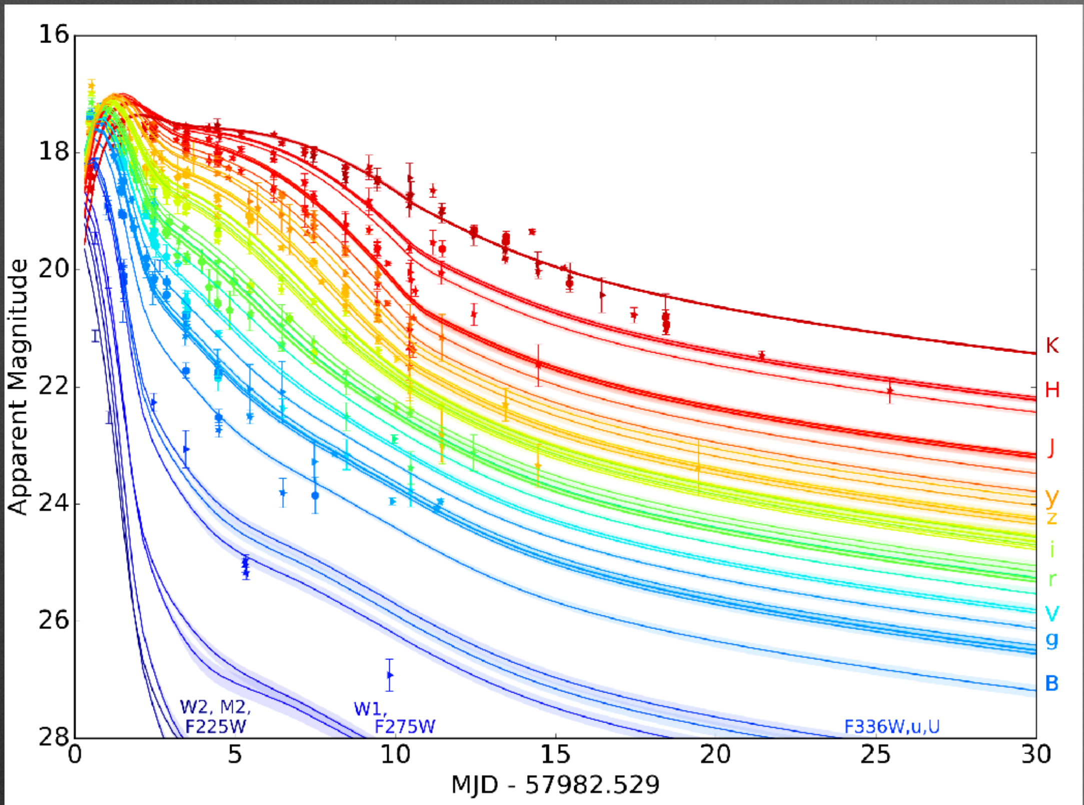
ESO leading contribution



choice of
FoV
spectral range
resolution
obs mode:
- ad.opt.
- polarimetry
- 2D spectra

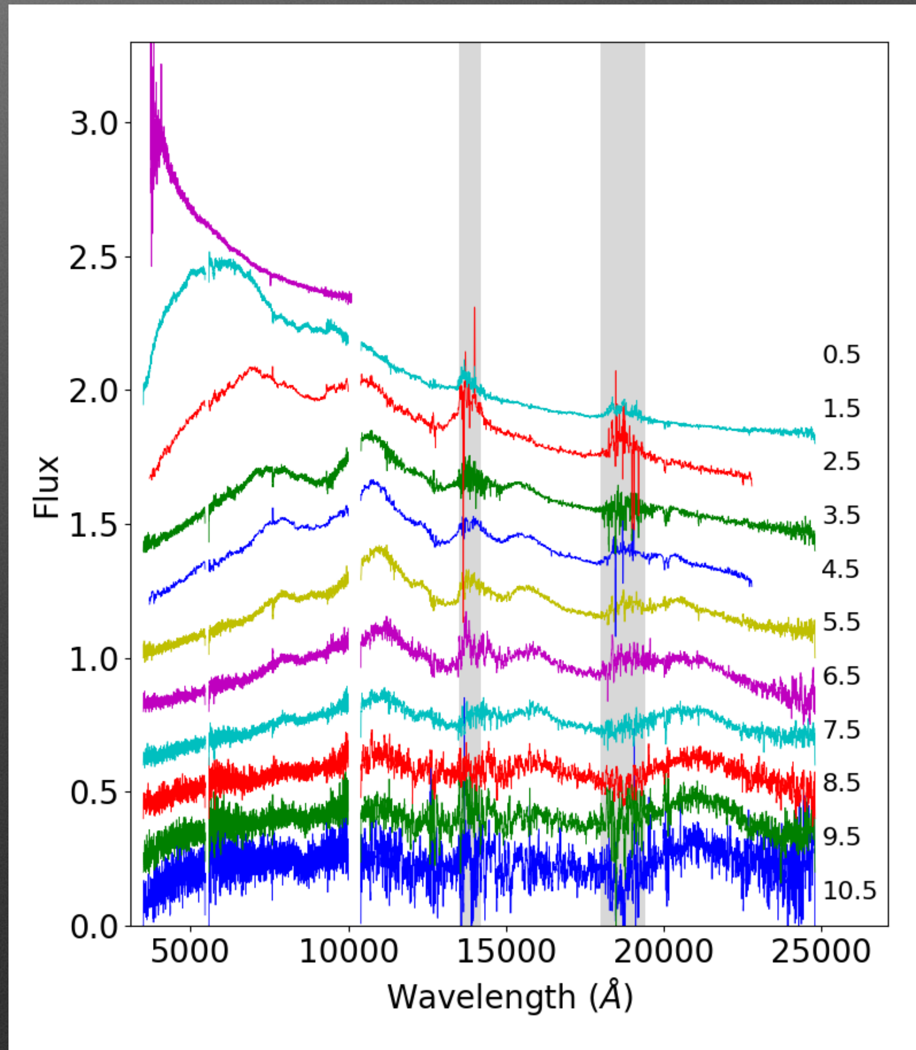
Optical-infrared monitoring

Compilation from Villar et al. 2017
Andreoni+; Arcavi+; Coulter+; Cowperthwaite+; Díaz+; Drout+; Evans+; Hu+; Kasliwal+; Lipunov+; Pian+; Pozanenko+; Shappee+; Smartt+; Tanvir+; Troja+; Utsumi+; Valenti+

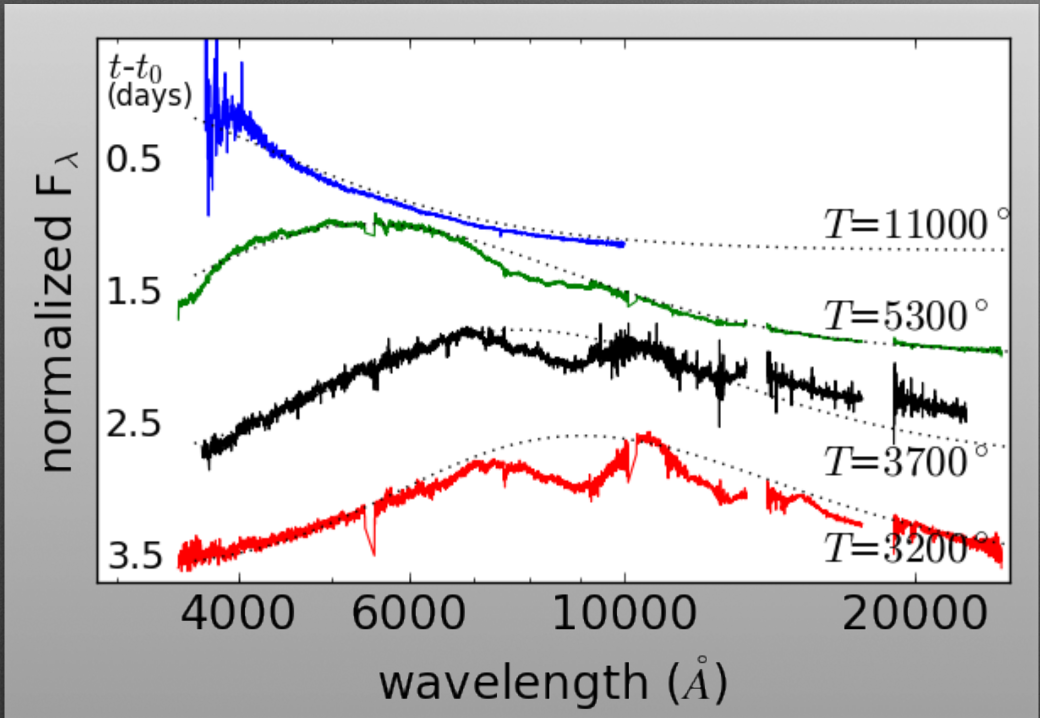


Stringent upper limits to the polarization degree
Covino et al.

Shappee et al 2017
Pian et al. 2017
Smartt et al. 2017



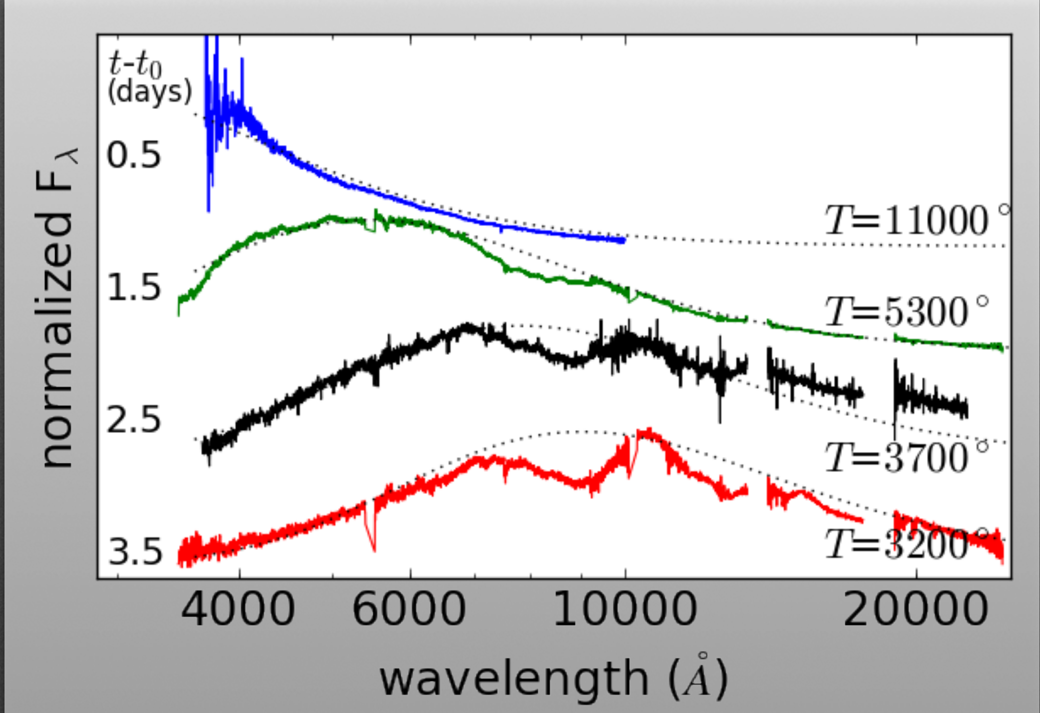
Optical-infrared monitoring

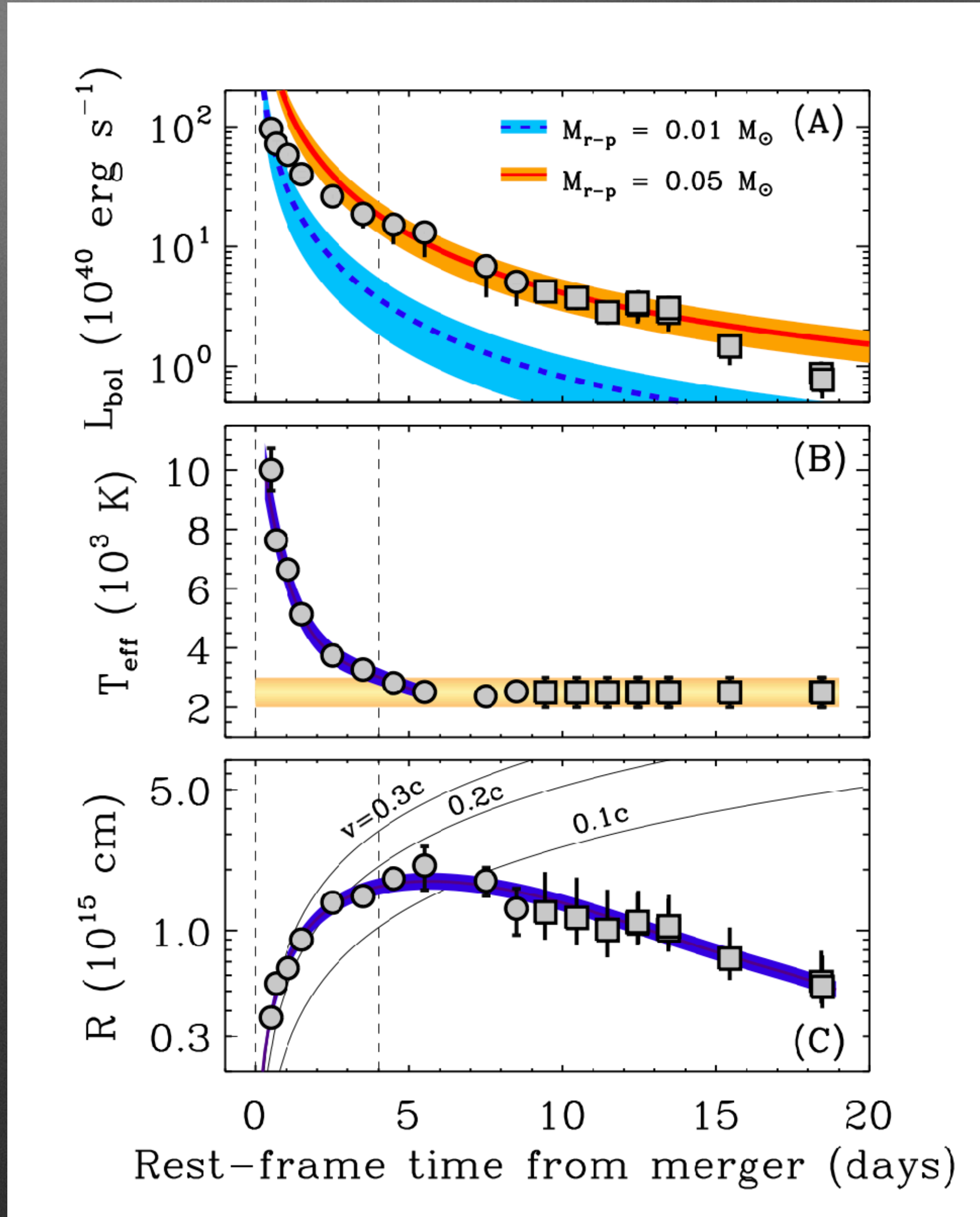


$L \propto R^2 T^4$

Optical-infrared monitoring

Drout et al. 2017



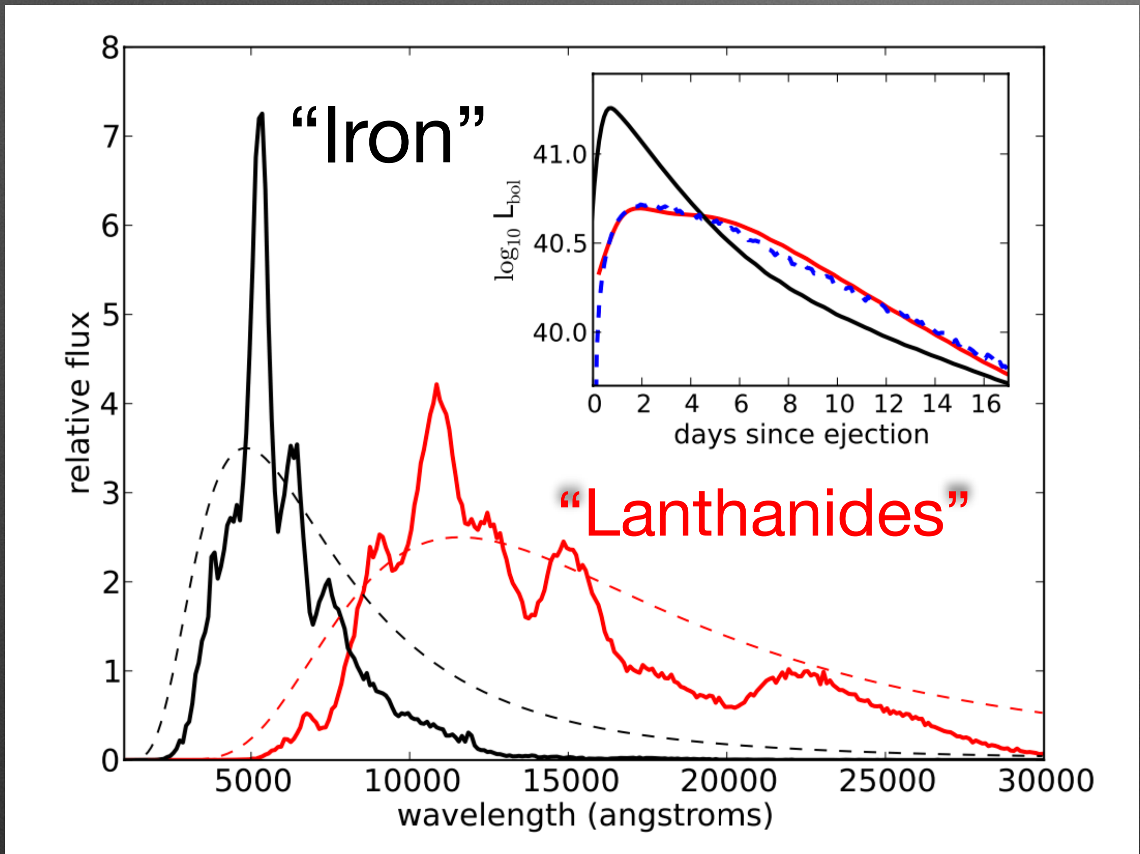


$L \propto R^2 T^4$

Radius at early epoch requires expansion velocity of ~0.3c

Nucleosynthesis

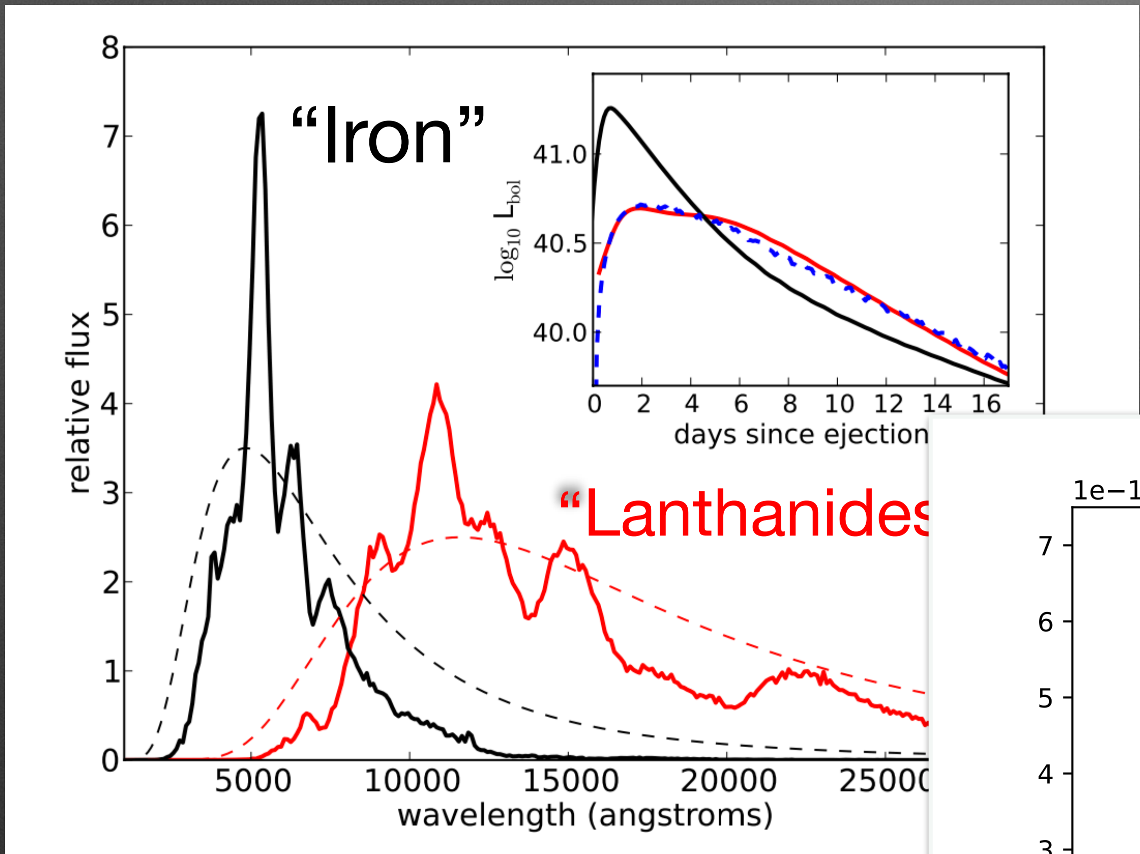
Kasen et al. 2013



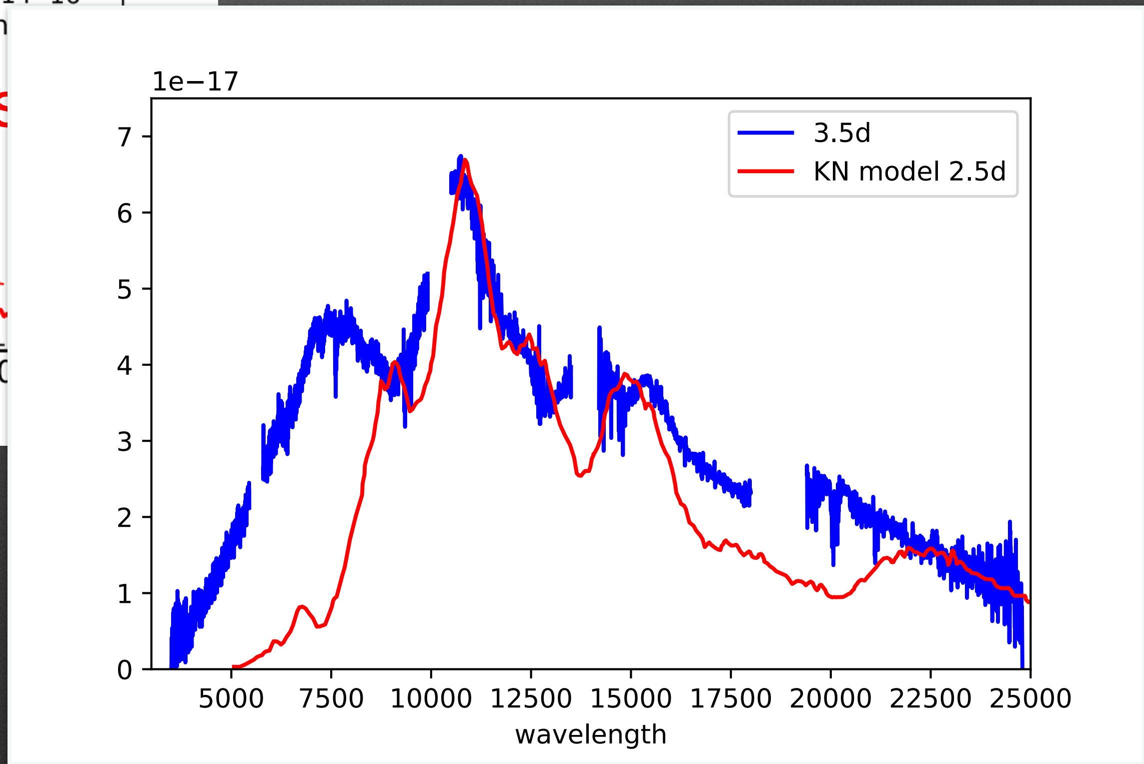
Kilonova models predict the emergence of broad features of r-process elements

Nucleosynthesis

Kasen et al. 2013

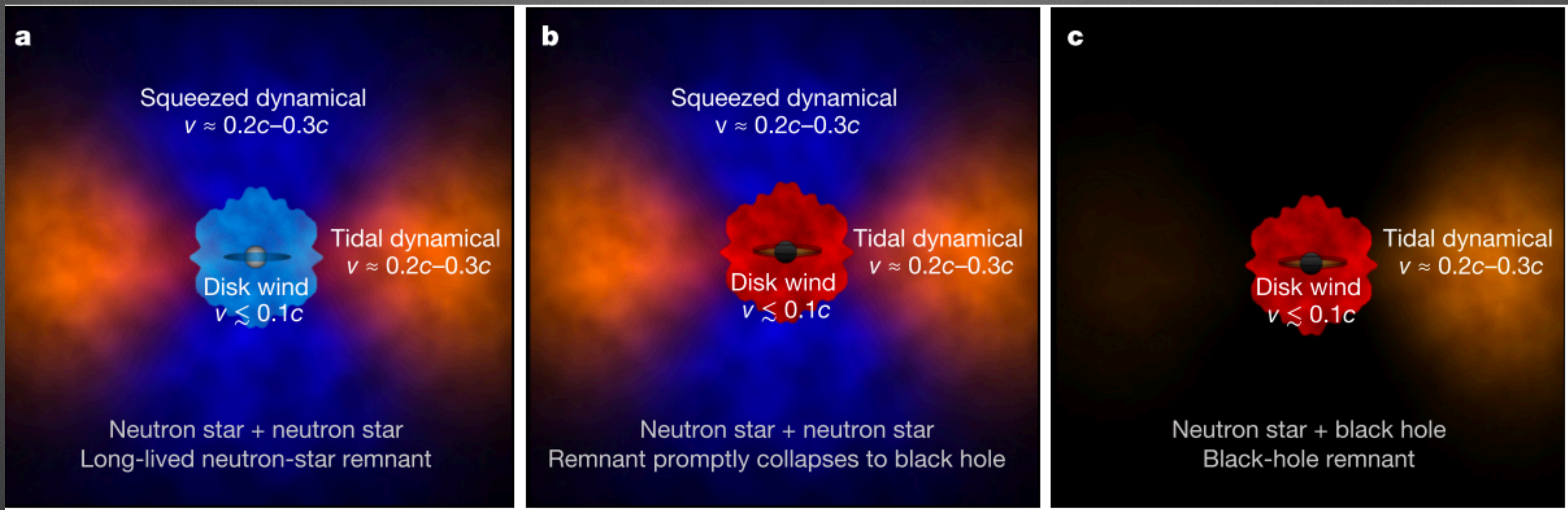


Kilonova models predict the emergence of broad features of r-process elements



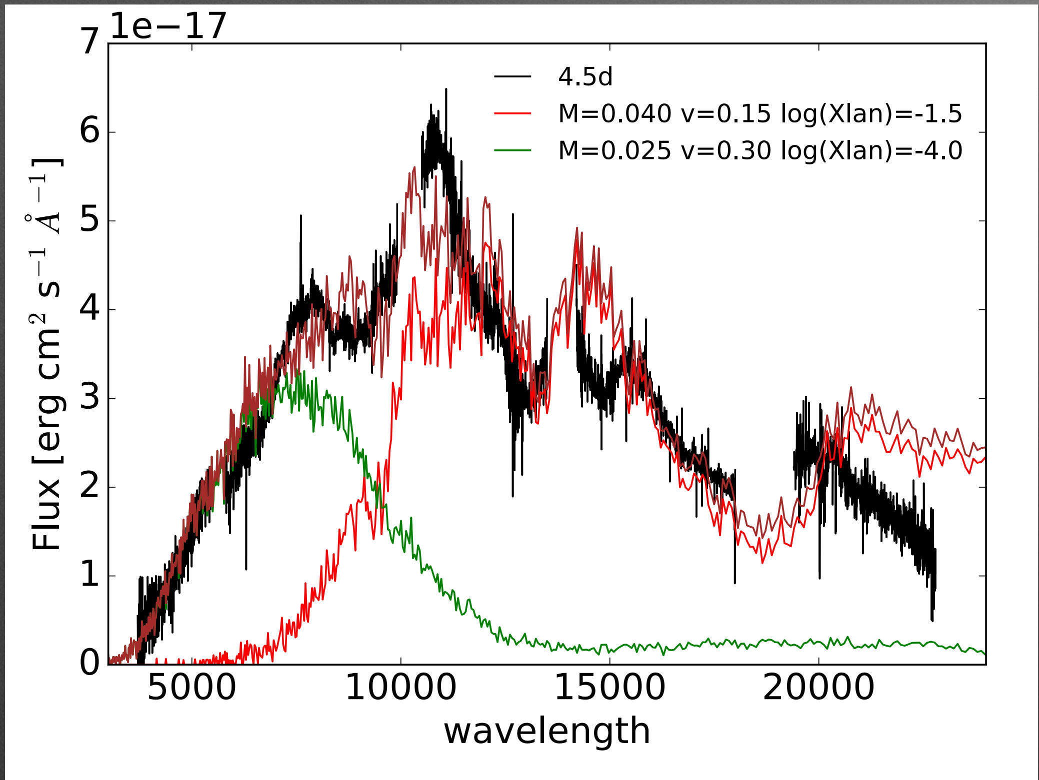
Synthetic spectra computation

Kasen et al., Tanaka et al.



- Numerically solving the Boltzmann equation for relativistic radiation transport in a radioactive plasma ....
- Models assume spherical symmetry, local thermodynamic equilibrium, and uniform abundances… Three tunable parameters are an ejecta mass, a mean velocity and a fractional lanthanide abundance. Caveat: large uncertainties in the current atomic line lists
- Simply summing the flux produced by separate single-component models is clearly questionable, but can be justified if eg. the kilonova components are spatially disjunct

Synthetic spectra computation



observations Pian et al. 2017,
Smartt et al. 2017
models Kasen 2017

Synthetic spectra computation

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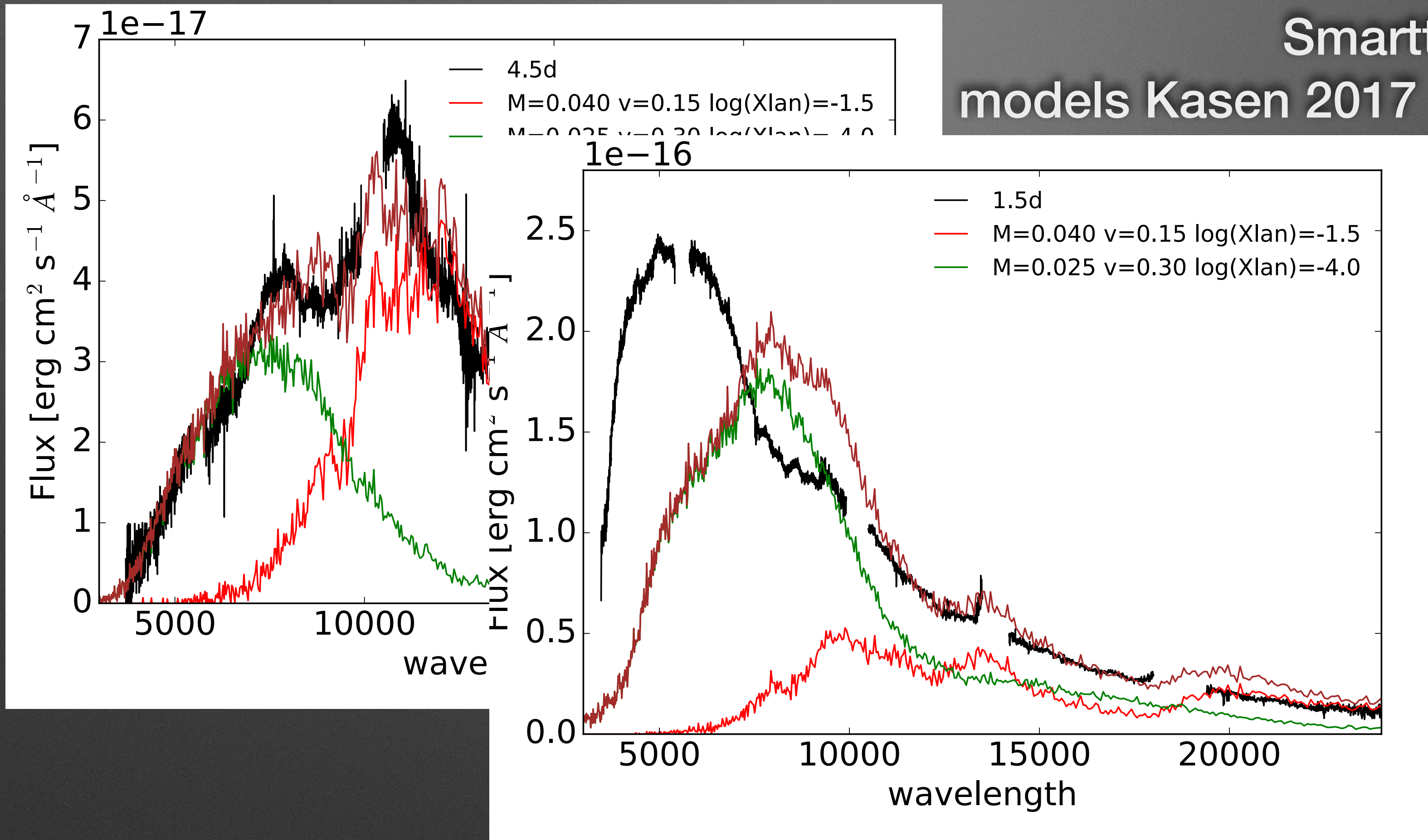

Synthetic spectra computation

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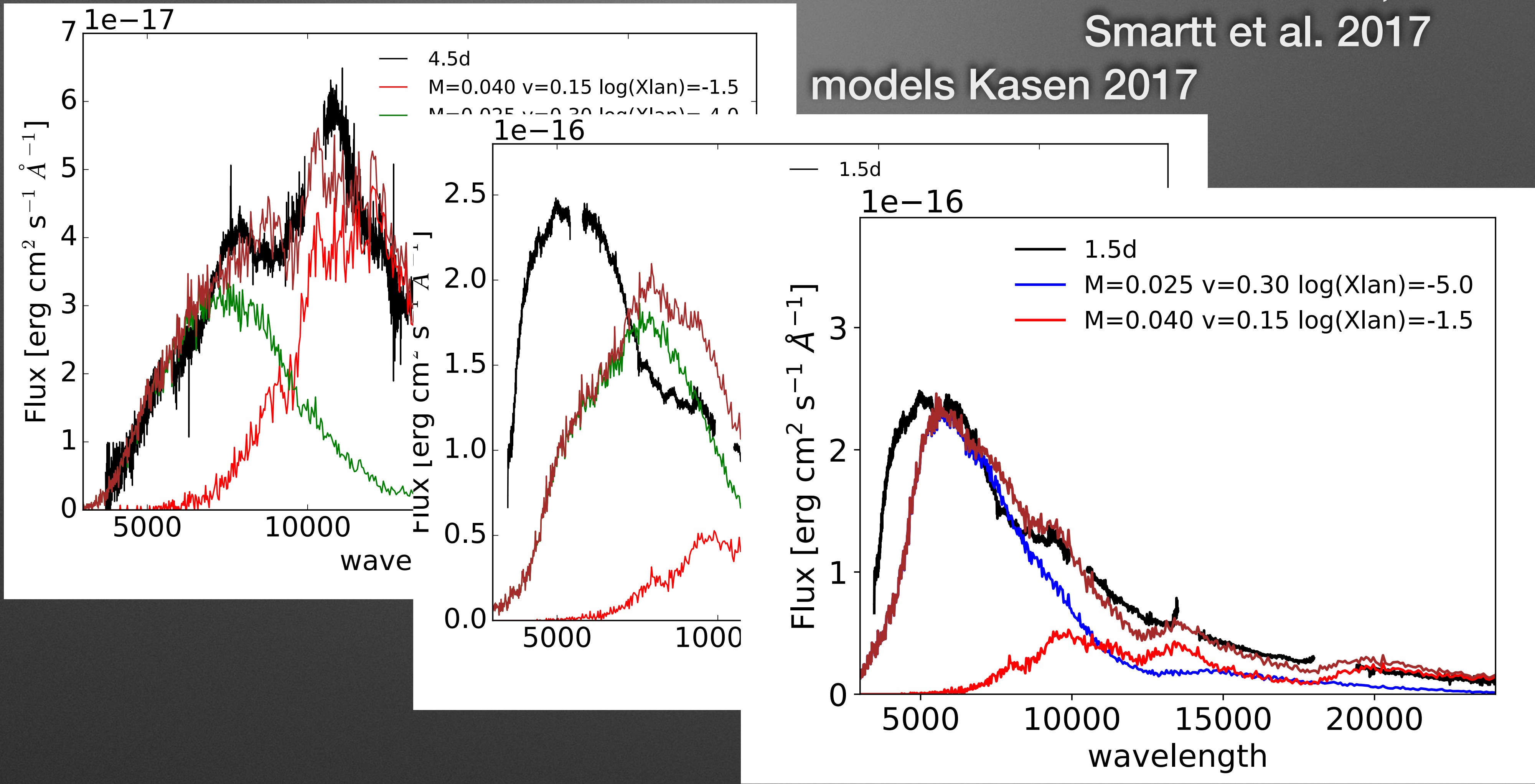

Synthetic spectra computation

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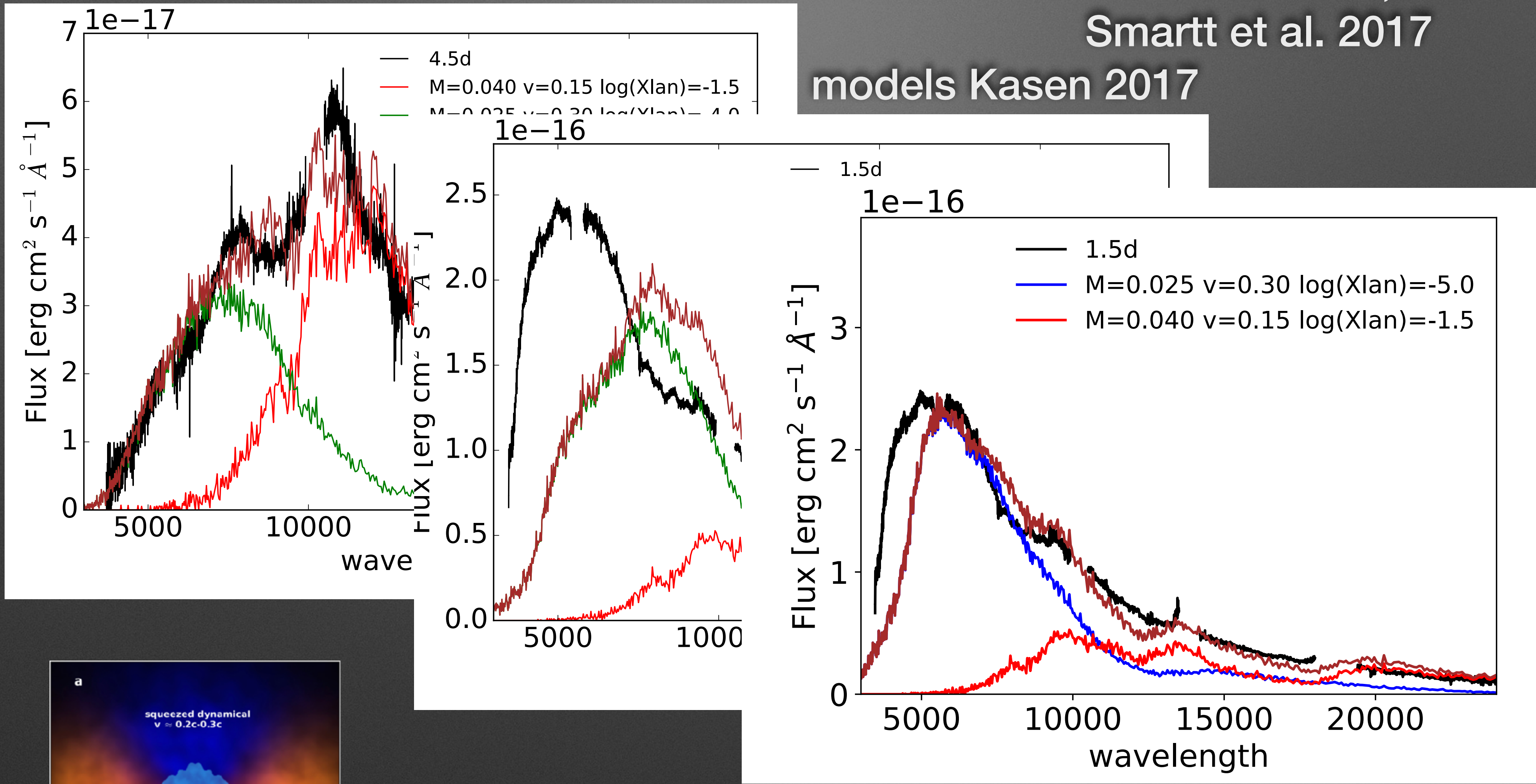
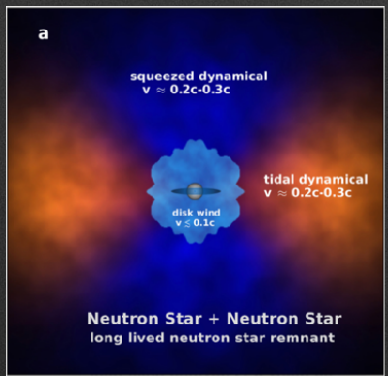
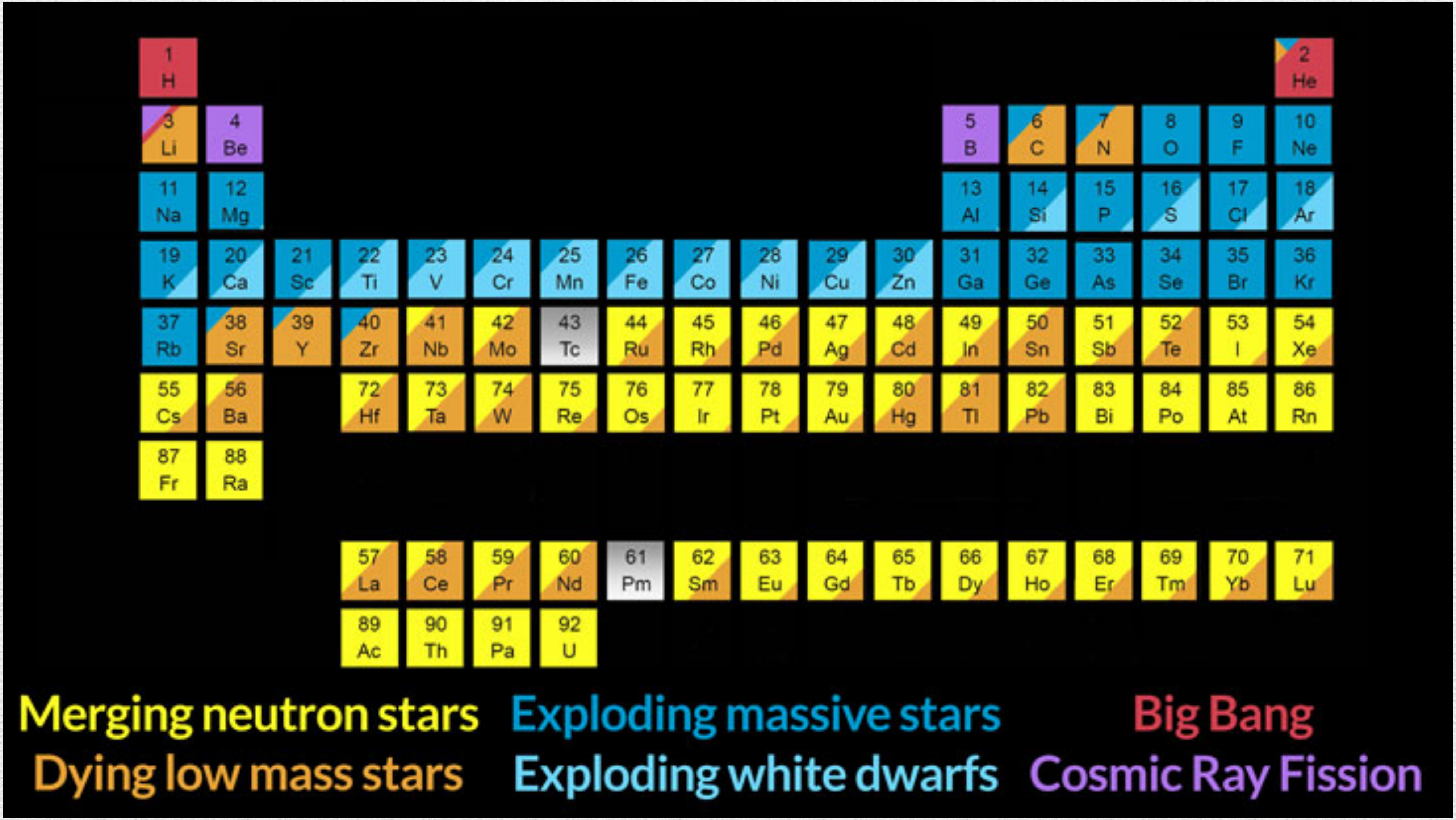




modelling seems on the right track
long lived NS scenario is favoured

Heavy elements pollution



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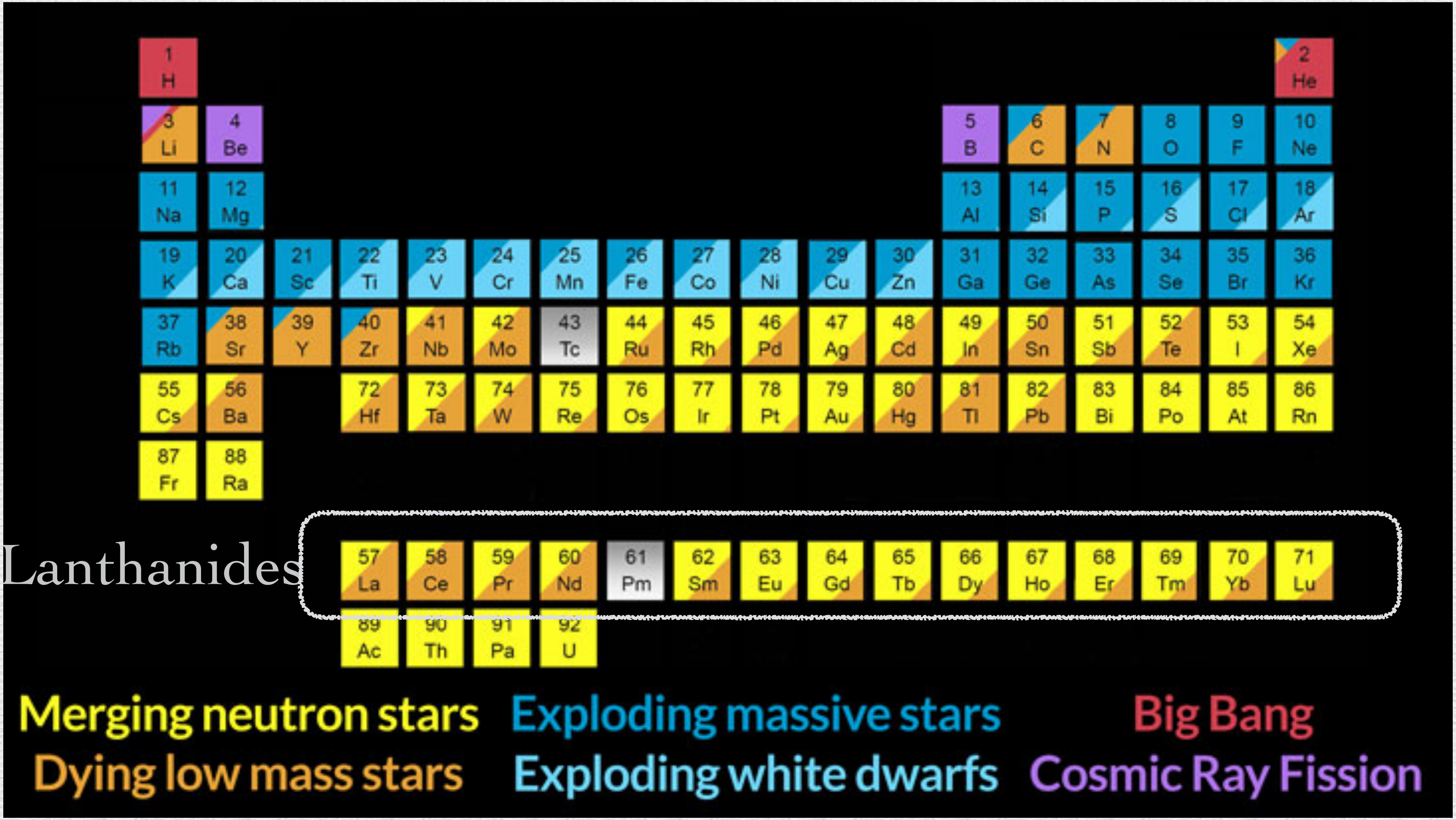

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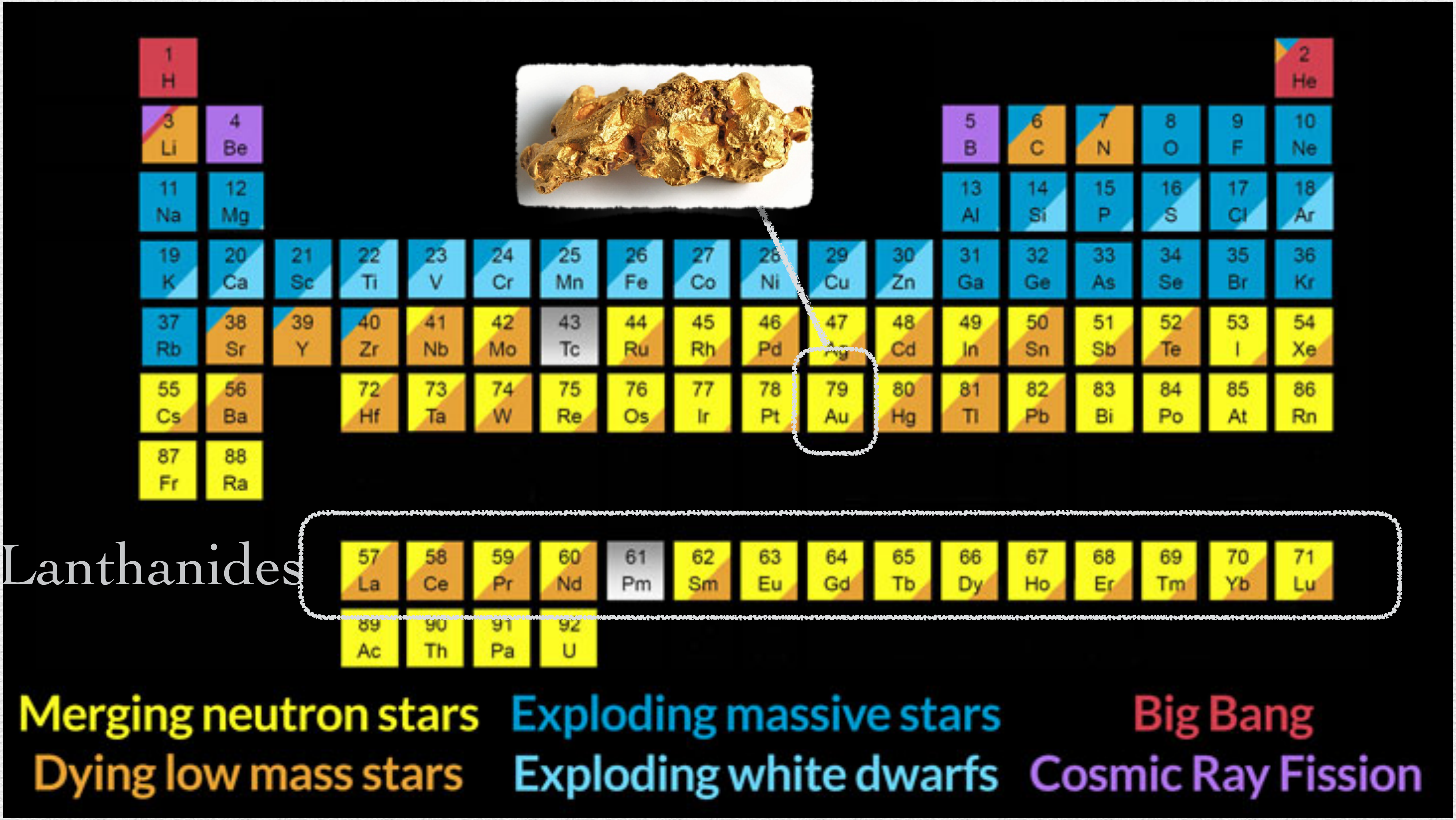

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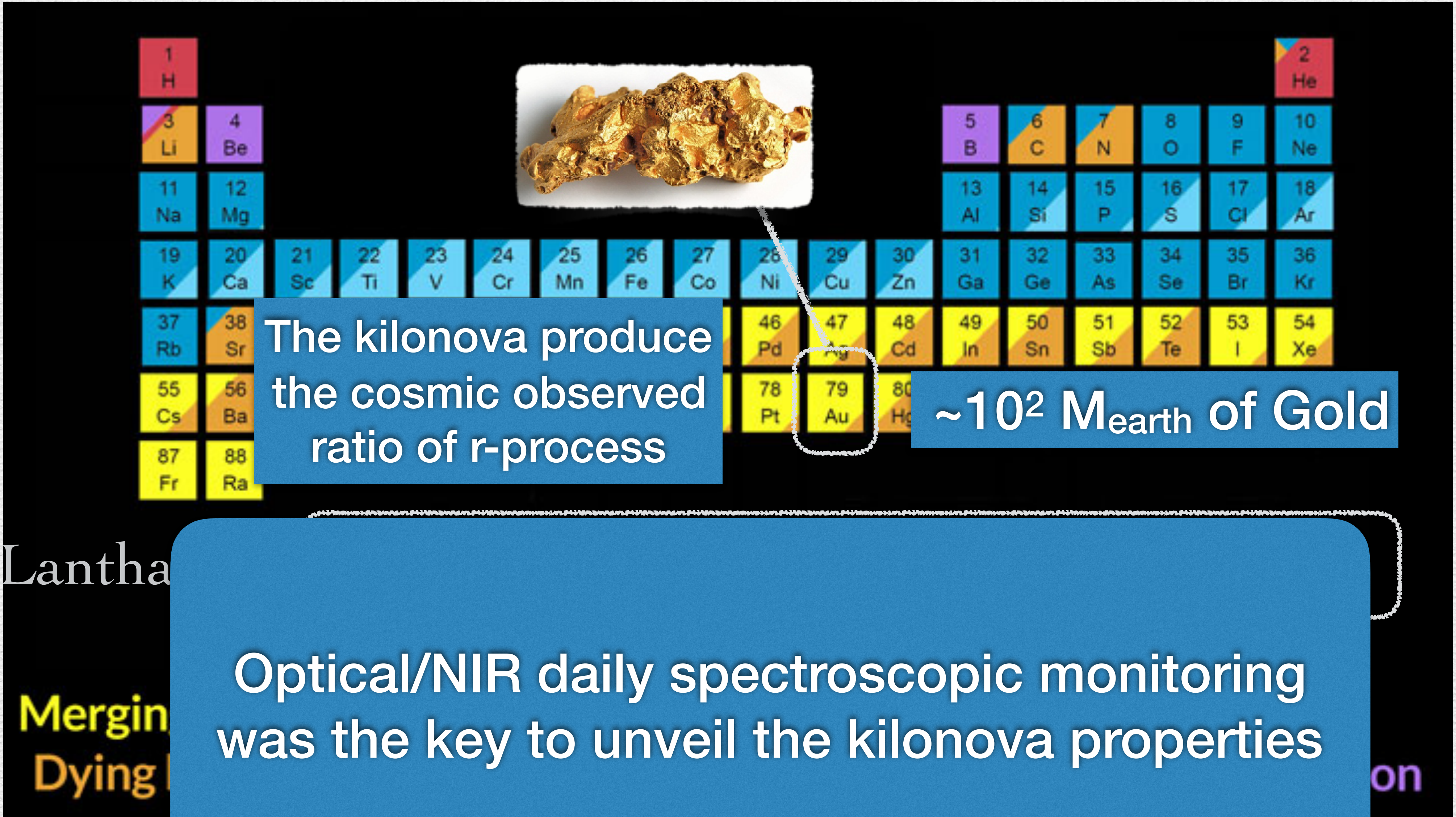


The kilonova produce the cosmic observed ratio of r-process

~10^2 M_{earth} of Gold

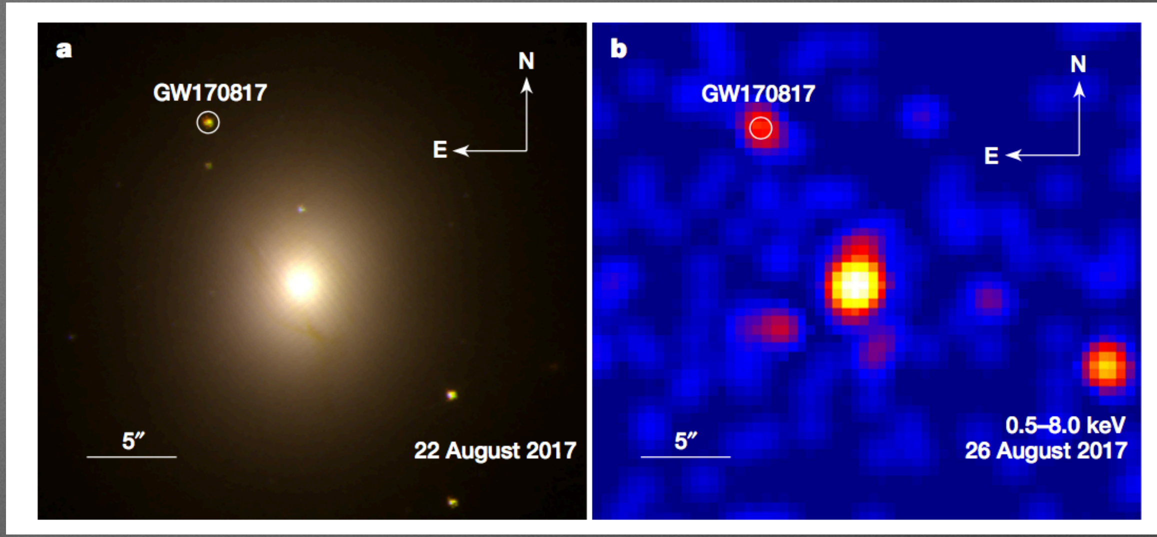
Optical/NIR daily spectroscopic monitoring was the key to unveil the kilonova properties

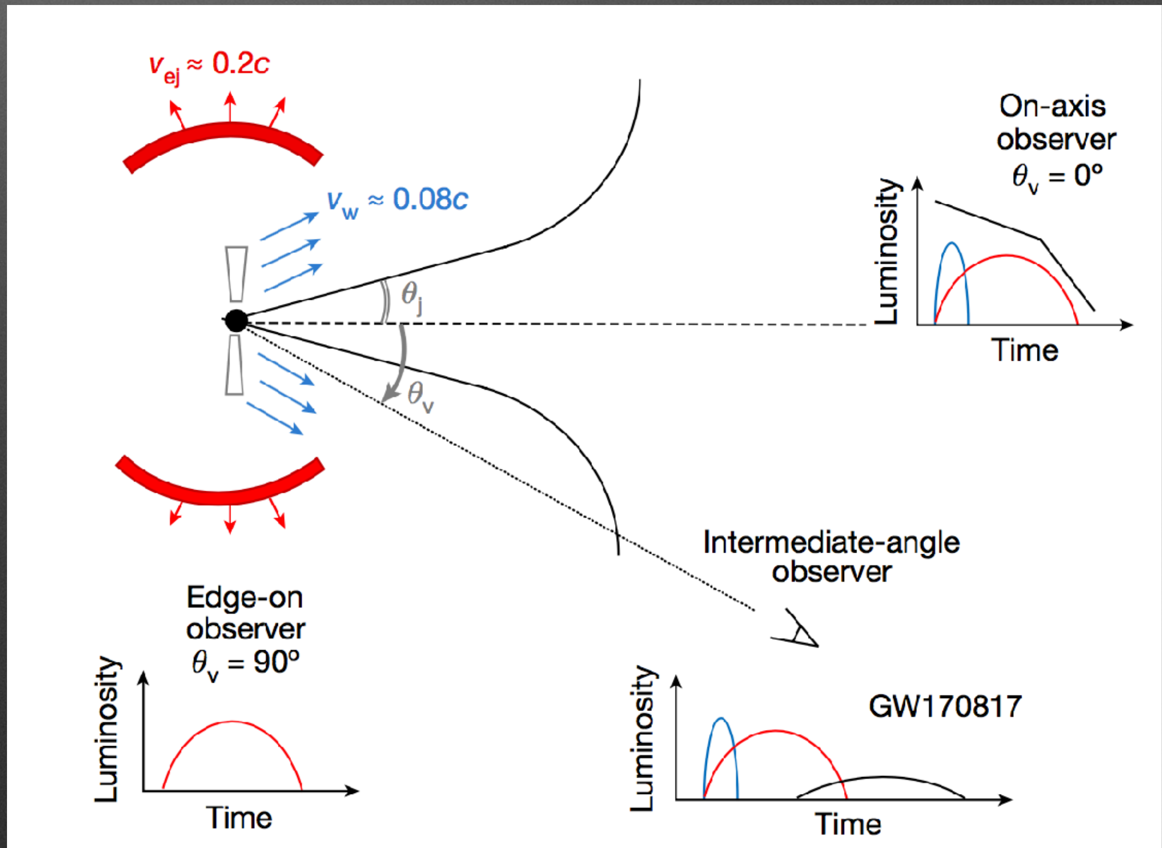
X-ray

First detection
tc = +9d with
Chandra

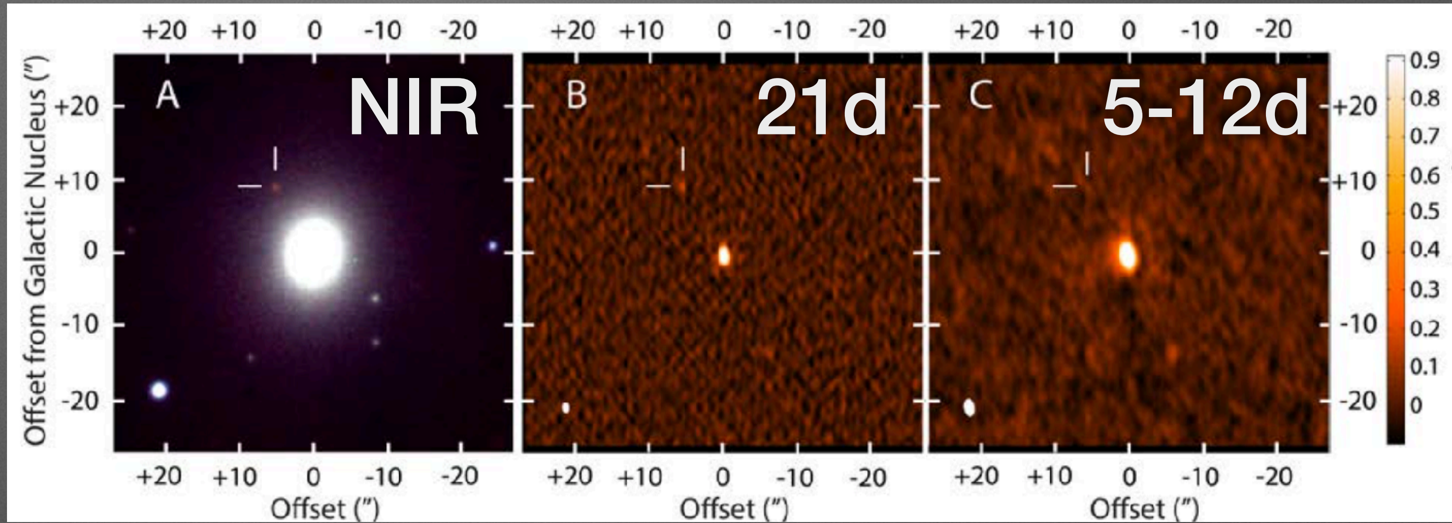
Short GRB view off-axis by 20-40 deg or cocoon emission

Troja et al. 2017





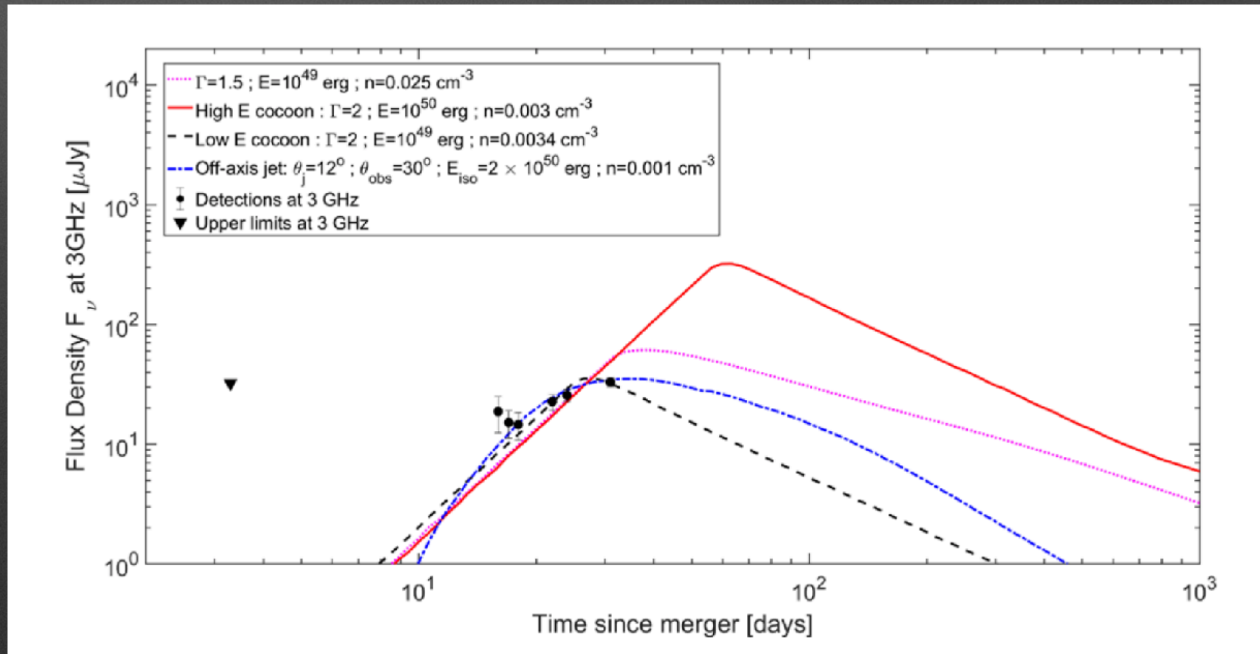
Radio



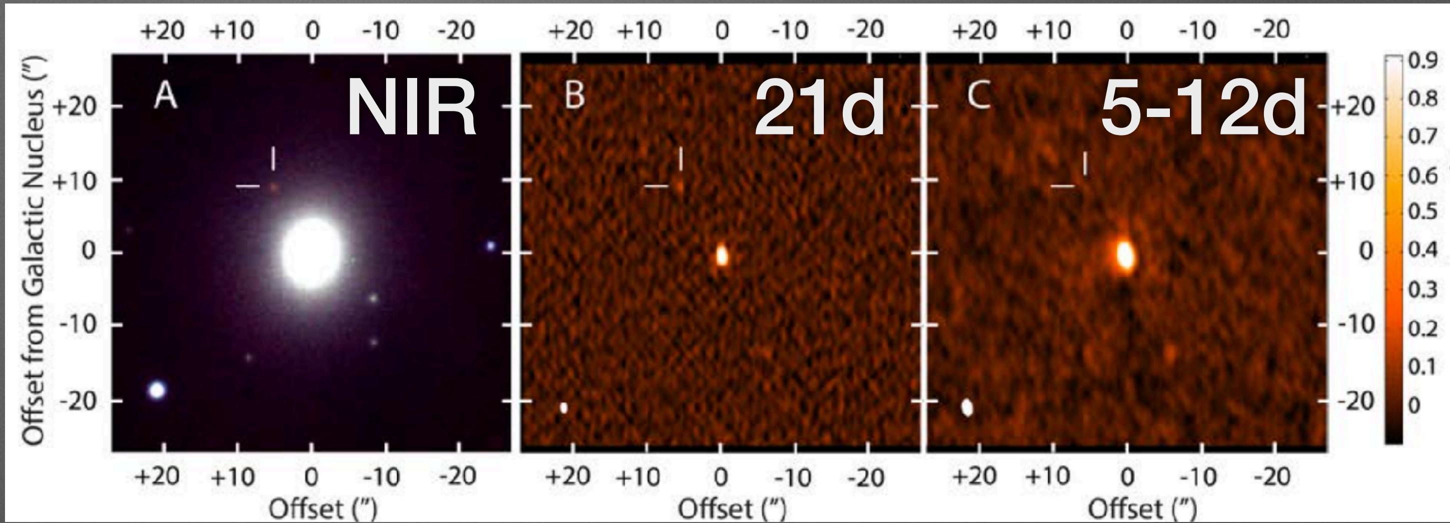
First detection tc = +16d with VLA at 3-6 GHz

Hallinan et al. 2017

Short GRB view off-axis by 20-40 deg or cocoon emission



Radio



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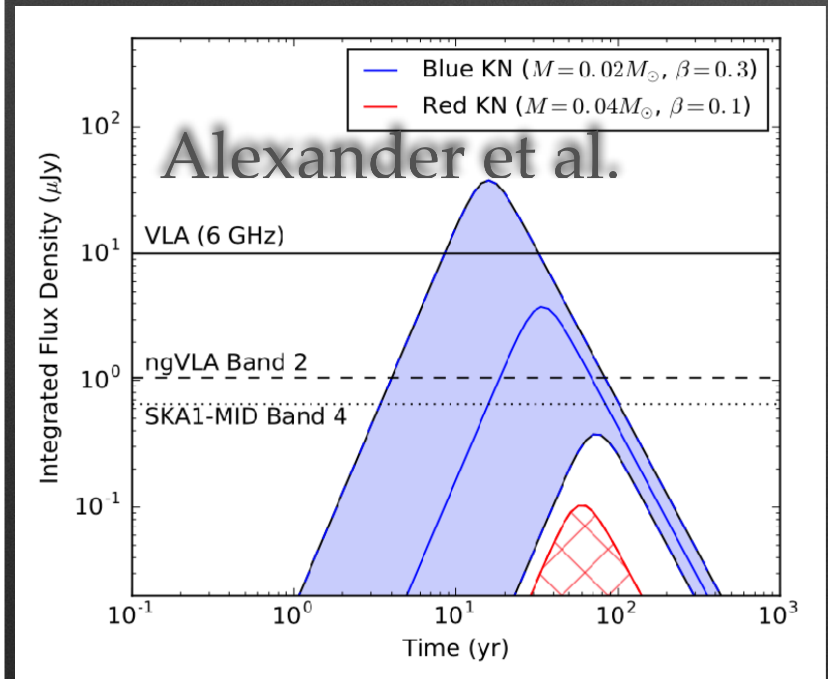
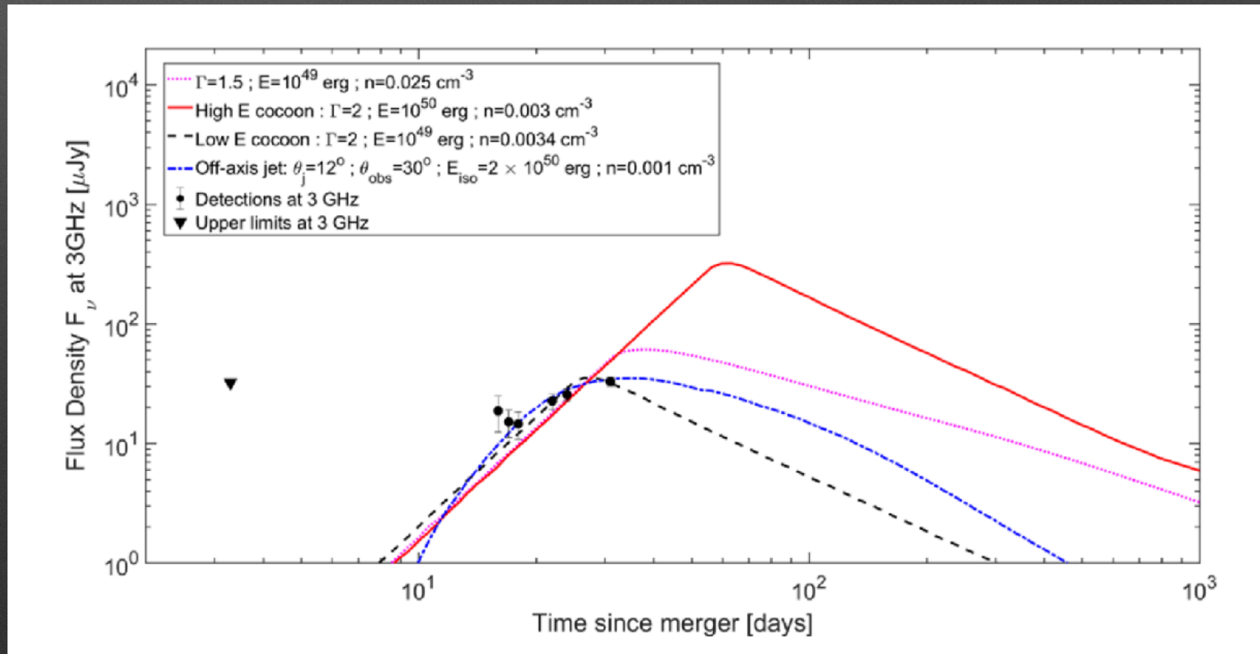
Short GRB view off-



Alexander et al.



What next

GW170817

- GRB and X-rays: jet, cocoon or isotropic
- ejecta: origin, composition and geometry of different “components”
- remnant: compact (BH or NS) and extended (ejecta/ISM interaction)

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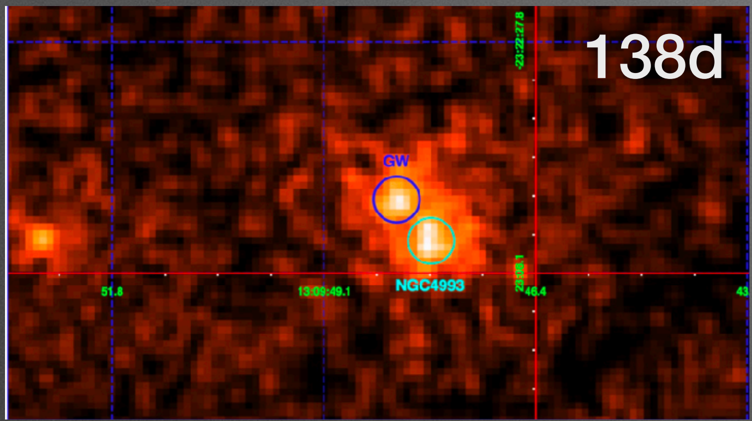
new radio, X-ray, optical observations

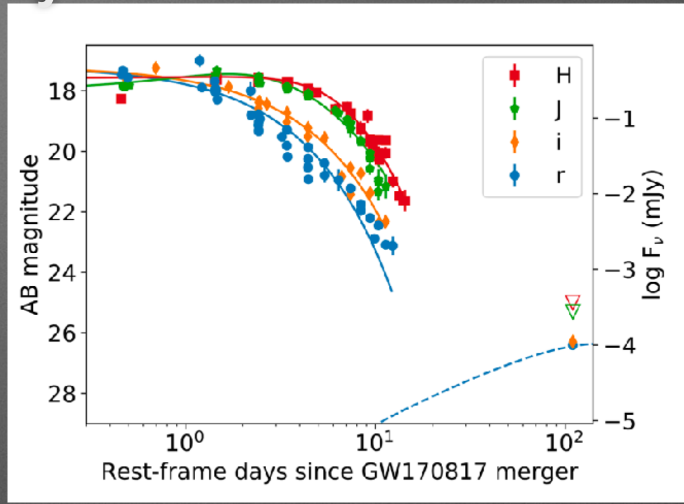
We are still receiving EM radiation from AT2017gfo

D’Avanzo et al. 2018



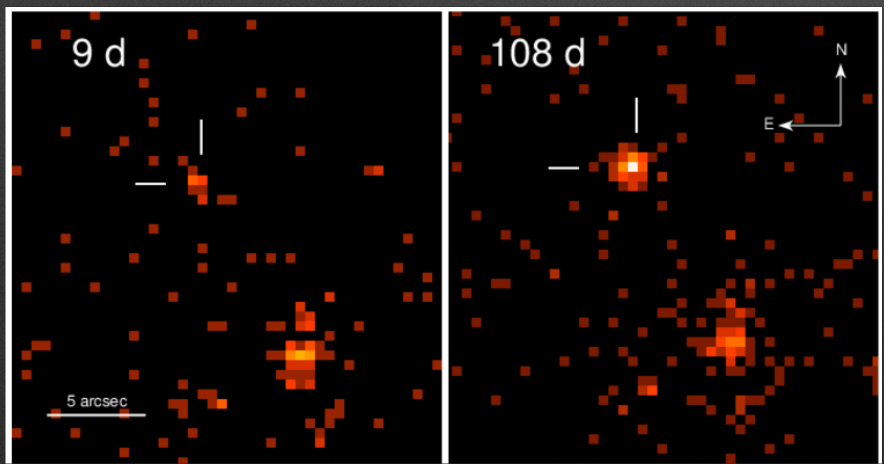
Xray XMM-Newton

Lyman et al. 2018



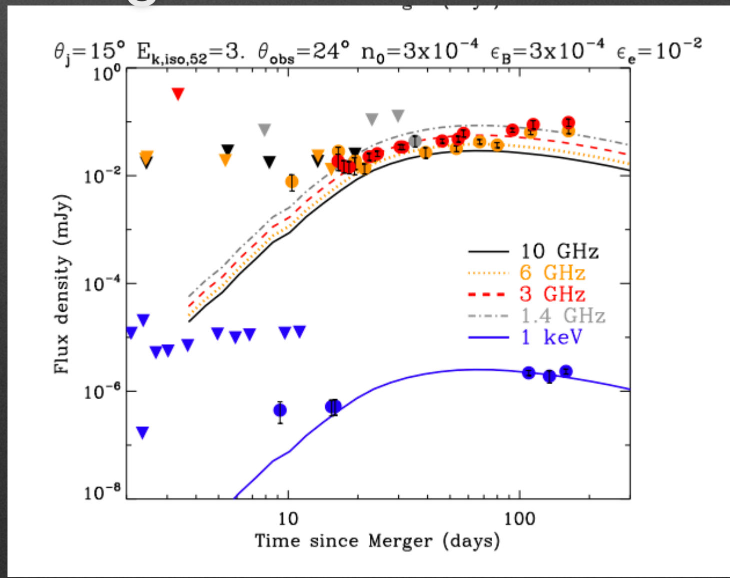
NIR
HST
117d

Troja et al. 2018



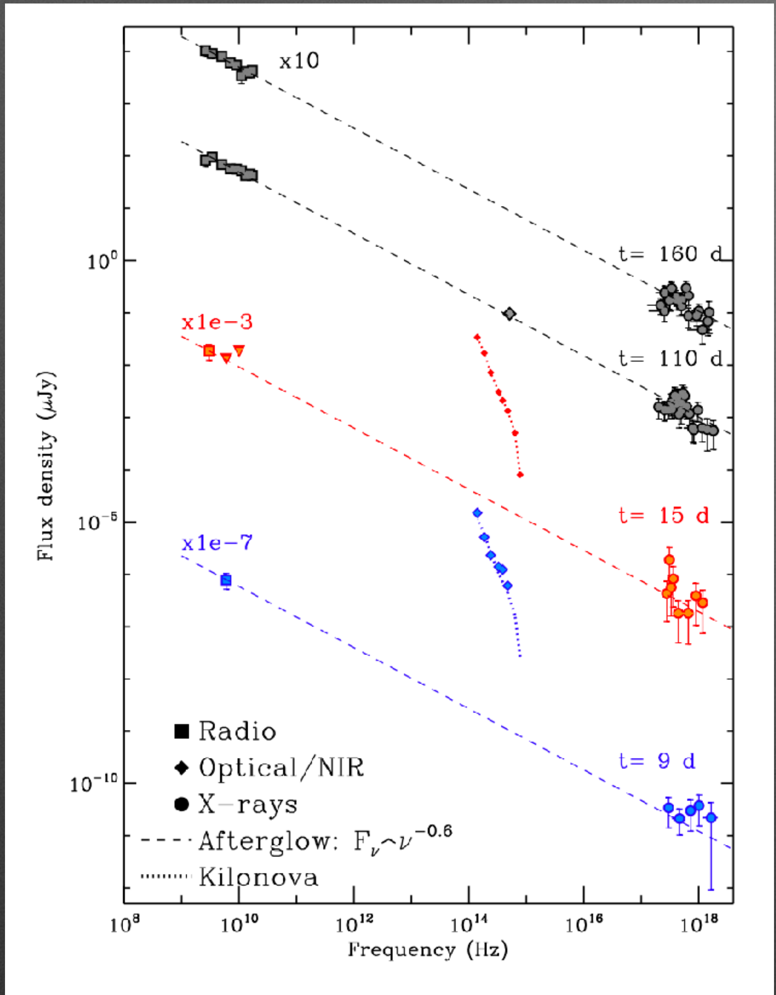
X-ray Chandra

Margutti et al. 2018

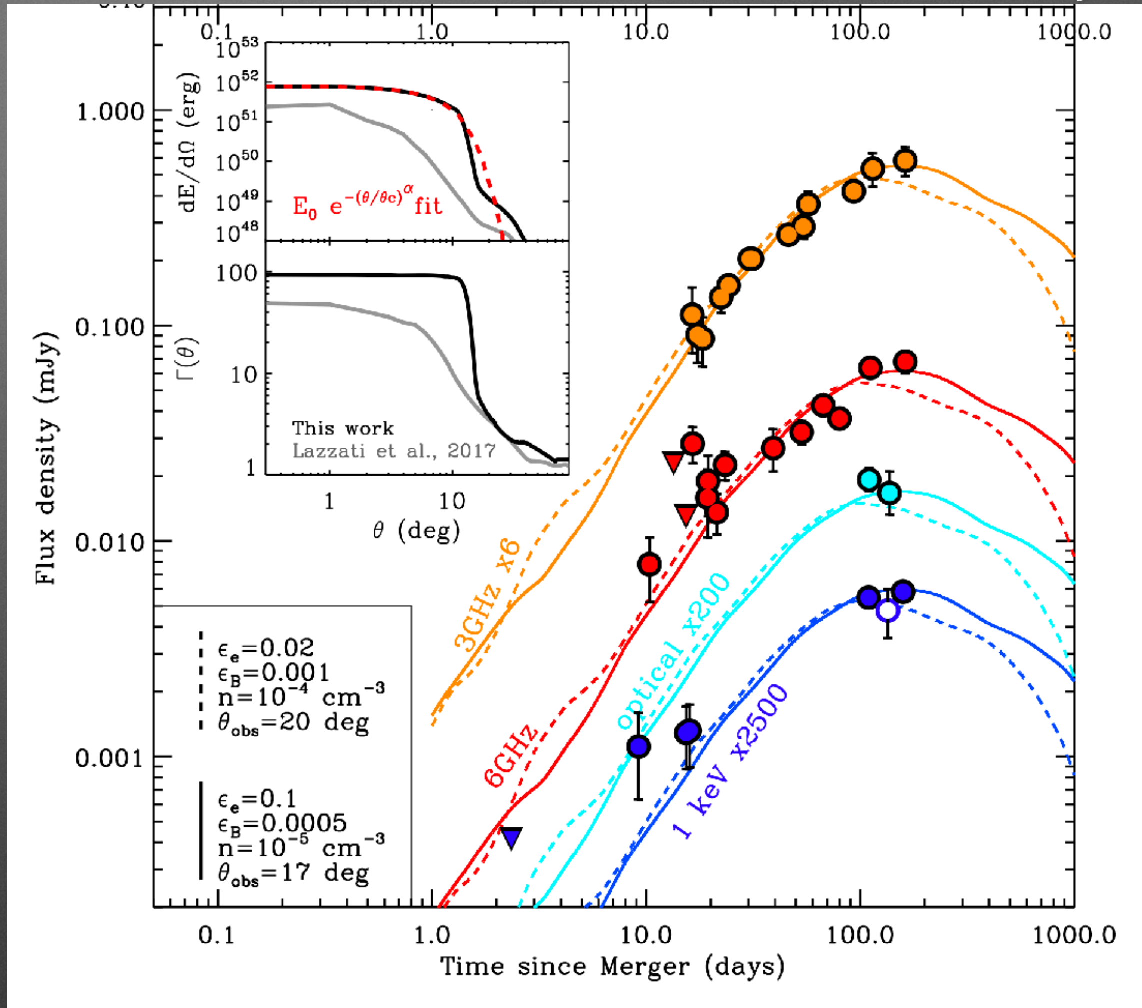


Radio
VLA

Margutti et al. 2018



model for off-axis relativistic jet



The non-thermal synchrotron emission is **consistent with both** radially stratified **quasi-spherical ejecta** traveling at mildly relativistic speeds, and **off-axis collimated ejecta characterized** by a narrow cone of ultra-relativistic material with slower wings extending to larger angles.

What next

GW170817

- GRB and X-rays: jet, cocoon or isotropic
- ejecta: origin, composition and geometry of different “components”
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Kilonovae

learn from diversity:

- binary mass (NS+NS, NS+BH)
- viewing angle

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BH+BH

really zero EM emission ?

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Supernova

10^{-12} - 10^{-7} $M_{sun}c^2$

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10^{-12} - 10^{-7} $M_{sun}c^2$

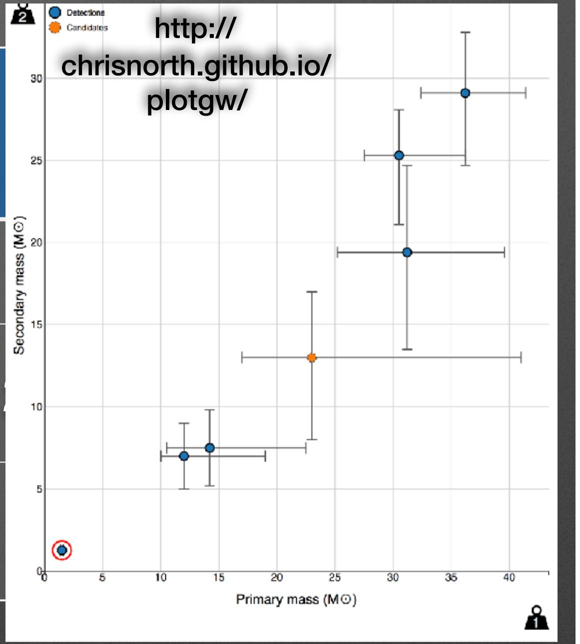
Statistics

Reconcile GW event rates with astrophysical scenarios

What next

Binary mergers

	LOW [Mpc³ Myr]	HIGH	REF	D_{LIM}	O2 118 DAYS	FOUND
NS+NS	0.01	10	Abadie 2010	78 Mpc	0.006-6	1
NS+BH	6E-04	1	Abadie 2010	150 Mpc	0-0.6	0
BH+BH	9E-03	0.24	Abbott 2016	900 Mpc	5-140	5/6



What next

Binary mergers

	LOW [Mpc^3	HIGH Myr]	REF	D_{LIM}	O2 118 DAYS	FOUND	D_{LIM}	O3 200 DAYS
NS+NS	0.01	10	Abadie 2010	78 Mpc	0.006-6	1	120 Mpc	**0.04-40**
NS+BH	6E-04	1	Abadie 2010	150 Mpc	0-0.6	0	240 Mpc	0.02-27
BH+BH	9E-03	0.24	Abbott 2016	900 Mpc	5-140	5/6	1Gpc 100 Mpc	12-320 0.02-0.5

What next

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Supernova

5 Kpc neutrino driven — Gossan et al. 2016
50 Kpc rapidly rotating
5 Mpc extreme scenario (eg. collapsar)
rate ~1/3 yr (~300yr for collapsar…)

Triggered GW search for very nearby events
We (astronomers) need to provide accurate explosion time

What next

Follow-up facilities for O3

Optical/IR

- search: VST, Schmidt Campo Imperatore & Asiago, REM
- candidate selection: ESO NTT, TNG, NOT, Asiago
- follow-up instruments: ESO-VLT, LBT

X-ray

- SWIFT, XMM, CHANDRA

RADIO

- SRT, EVN

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X-ray
- SWIFT, XMM, CHANDRA

RADIO
- SRT, EVN

European collaboration for a joint proposal of all ESO-VTL units/instruments

Search for transients is "easy"

if we know where and what to search

Distilling the right source becomes the bottleneck

SOXS @ NTT

SON OF X-SHOOTER NEWS SCIENCE INSTRUMENT TIMELINE TEAM DOCUMENTS MEETINGS INTERNAL DOCS

SOXS is built by an international consortium led by Italy and involving Israel, Chile, UK, Finland and Denmark.

Son Of X-Shooter

SOXS (Son Of X-Shooter) will be a unique spectroscopic facility for the ESO-NTT 3.5-m telescope in La Silla (Chile). The design foresees a high-efficiency spectrograph with a resolution-slit product of ~ 4,500, capable of simultaneously observing the complete spectral range 350 - 2000 nm with a good sensitivity, and with imaging capabilities in the visible band (ugrizY) over a 3'x3' field of view.

Instrument development page @ ESO (link)

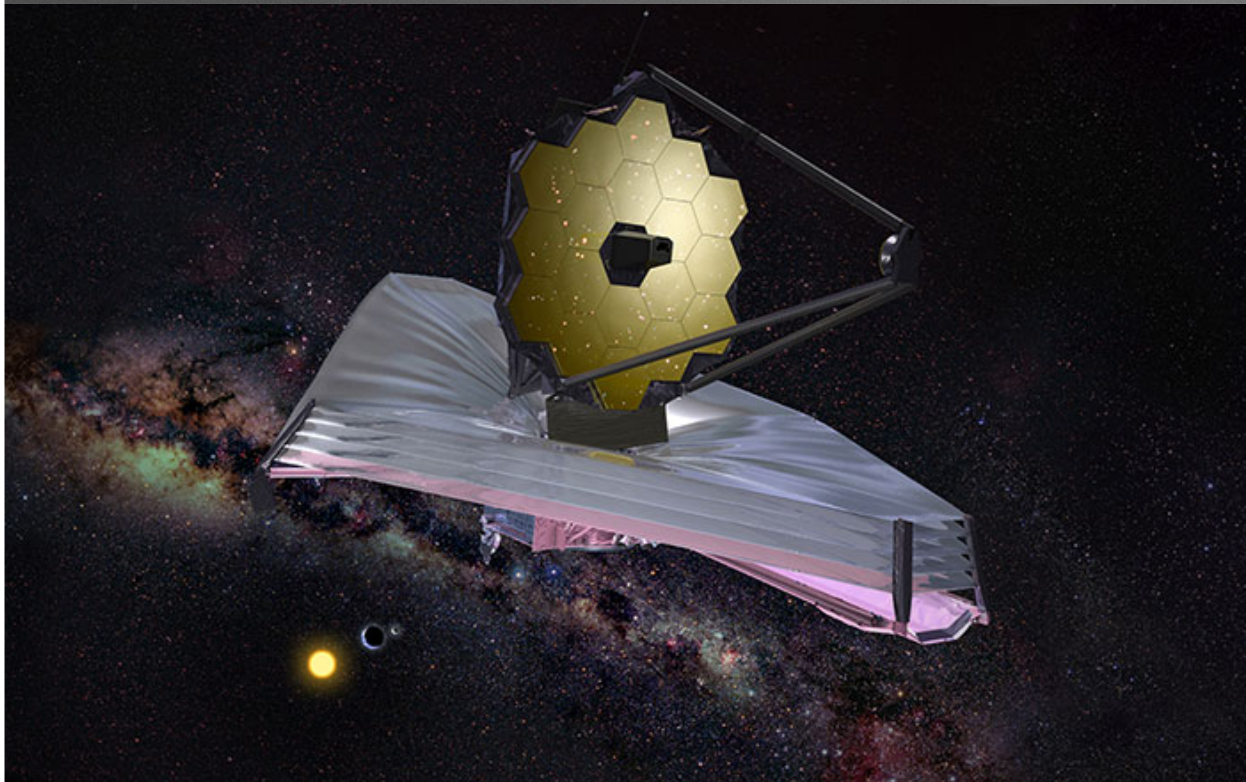
La Silla Instruments page @ ESO (link)

The SOXS logo has been created by a collaborative effort from Sergio Campana & Federica Loiacono

JWST

6.5m space telescope

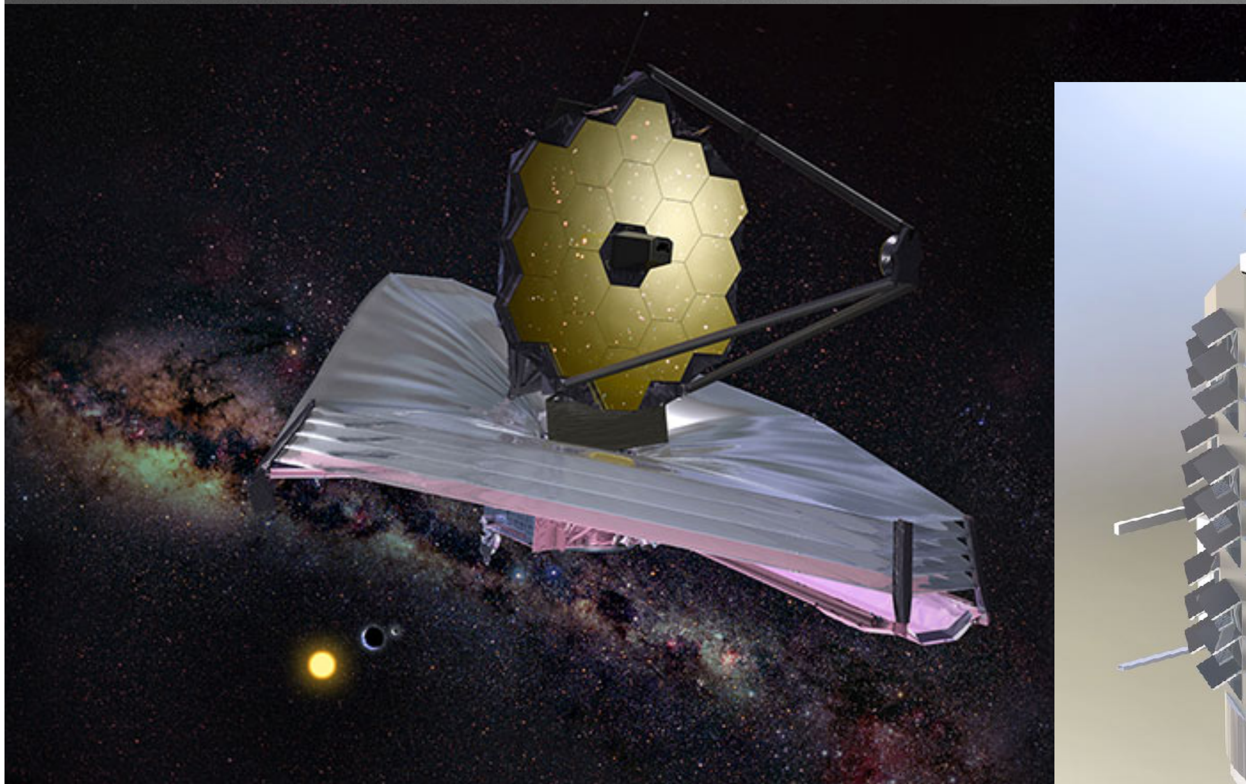
near-mid infrared



launch spring 2019

JWST

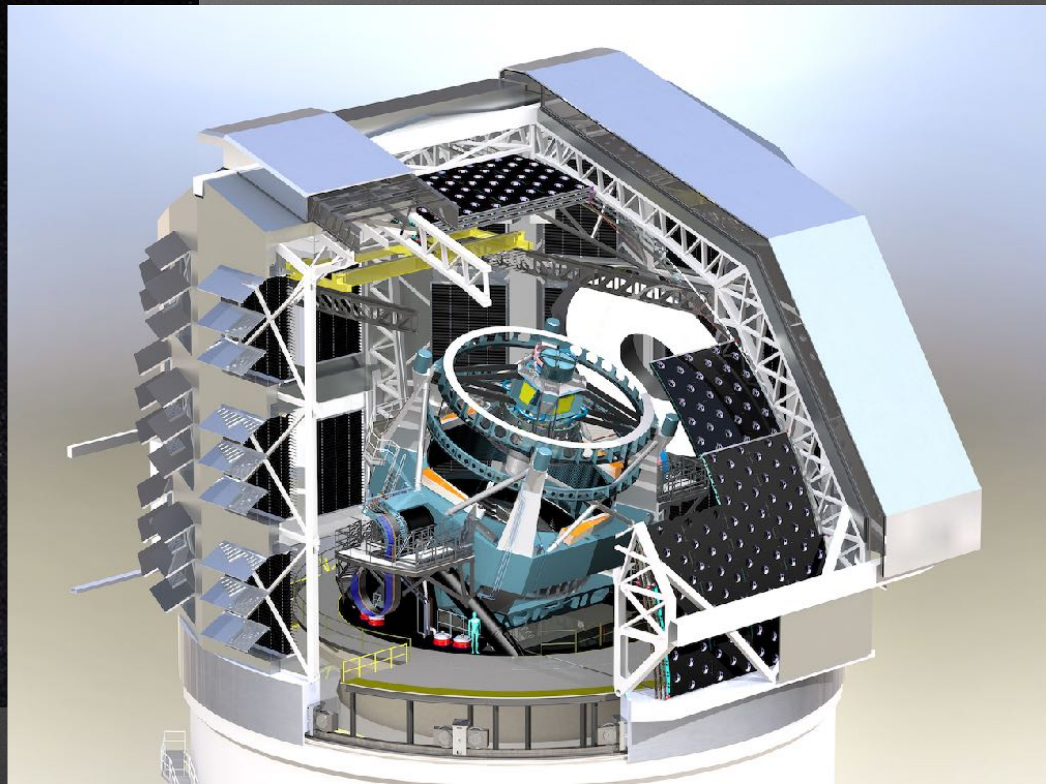
6.5m space telescope
near-mid infrared



launch spring 2019

LSST

8.4m optical telescope
3.5 deg FoV



2023

10 million alerts, 1000 pairs of exposures, 15 Terabytes of data .. every night!

The four INAF cornerstones for the future of multi-wavelength observatories

E-ELT
OPTICAL/NIR

CTA
VHE

2024-2030

Theseus

SKA
RADIO

ATHENA
X-RAY

The four INAF cornerstones for the future of multi-wavelength observatories

Because of the expected high number of triggers a network of dedicated, flexible small scale facilities are needed to distill the target for highly over-subscribed facilities

SKA ATHENA

RADIO X-RAY