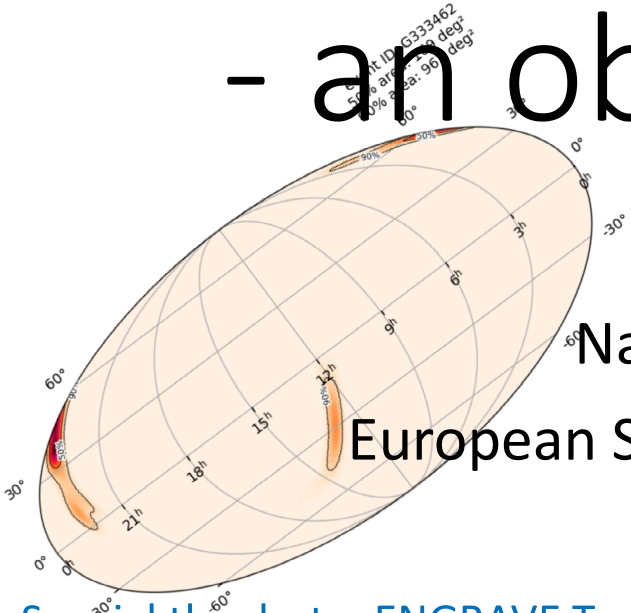
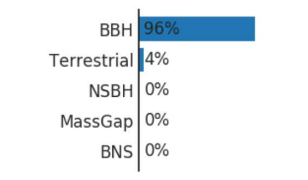
Multi Messenger Campaigns
- an observer's view -





Source classification visualization from p_astro.json p_astro.png. Submitted by LIGO/Virgo EM Follow-Up on May 19, 2019 16:34:45 UTC

Nando Patat – N&O P@@

European Southern Observatory - Germany

Special thanks to: ENGRAVE Team; E. Cappellaro, S. Piranomonte, E. Brocato & P. D'Avanzo

GWADW Elba 2019

GWADW2019 - Gravitational-Wave Advanced Detector Workshop - From Advanced Interferometers to Third Generation Observatories

19-25 May 2019

Hotel Hermitage, La Biodola, Isola d'Elba

Electromagnetic Cou**n**terparts of **Gra**vitational Wave Sources

at the

Very Large Telescope

Motivation

Exploit exceptional ESO facilities for future GW events

-4 x 8m telescopes with versatile instrumentation

Build scientific capability

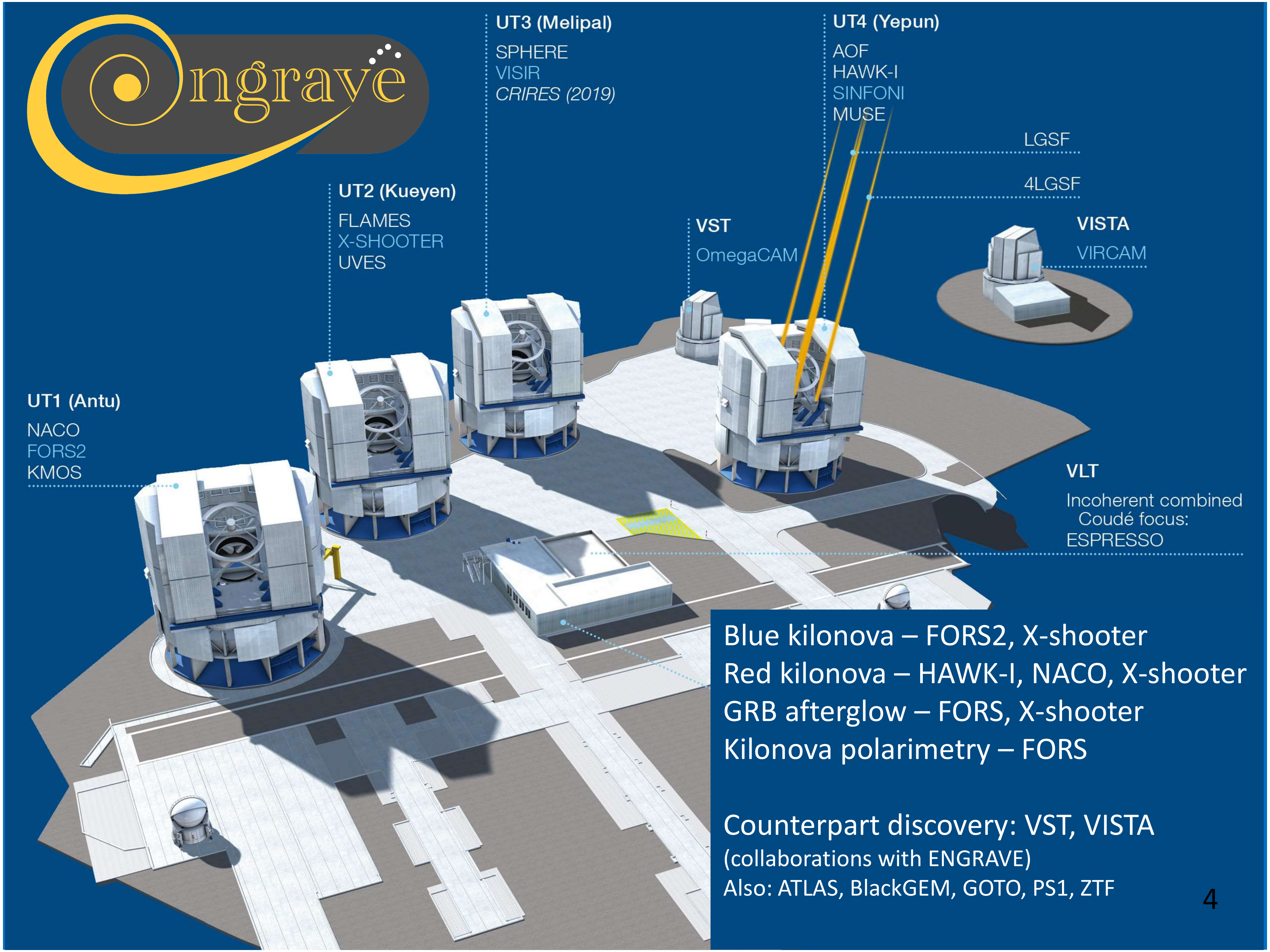
–Working groups for Imaging, Spectroscopy, Polarimetry, Radio/submm, Infrastructure, Theory, External groups, Engagement

Cohere European follow-up teams

-Efficiency is important, since GW170817 follow-up intensity can be expensive

ENGRAVE is a follow-up programme, but tightly integrated with many discovery efforts.

- Members involved in: ATLAS, BlackGEM, GOTO, PanSTARRS, VINROUGE, VST, ZTF and more



Blue kilonova – FORS2, X-shooter
Red kilonova – HAWK-I, NACO, X-shooter
GRB afterglow – FORS, X-shooter
Kilonova polarimetry – FORS

Counterpart discovery: VST, VISTA
(collaborations with ENGRAVE)
Also: ATLAS, BlackGEM, GOTO, PS1, ZTF

Depth

- 8m class imaging and spectroscopy from prime site. State of the art instrumentation.

Speed

- RRM provides <10 minutes response times
- Mostly observations in service mode, ready overrides, expert observers.

Versatility

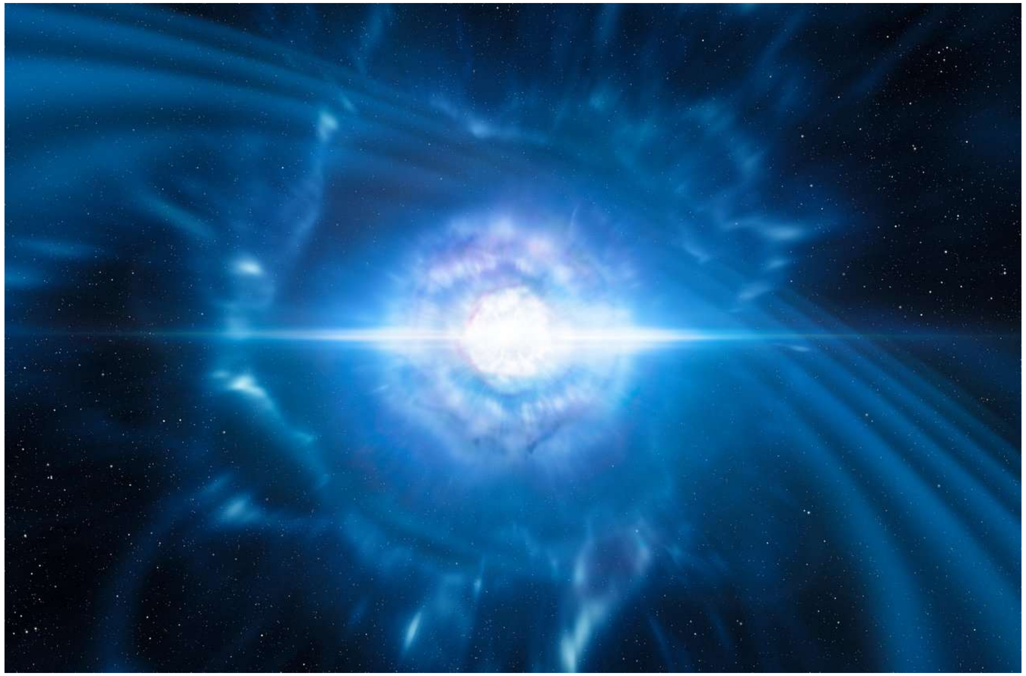
- Unique instrument set, from UV (3000A) to mid-IR (4.5 microns), imaging, low/high resolution spectroscopy, polarimetry.

Simultaneity

- Capability to perform observations with multiple telescopes at the same time (e.g. GW170817)

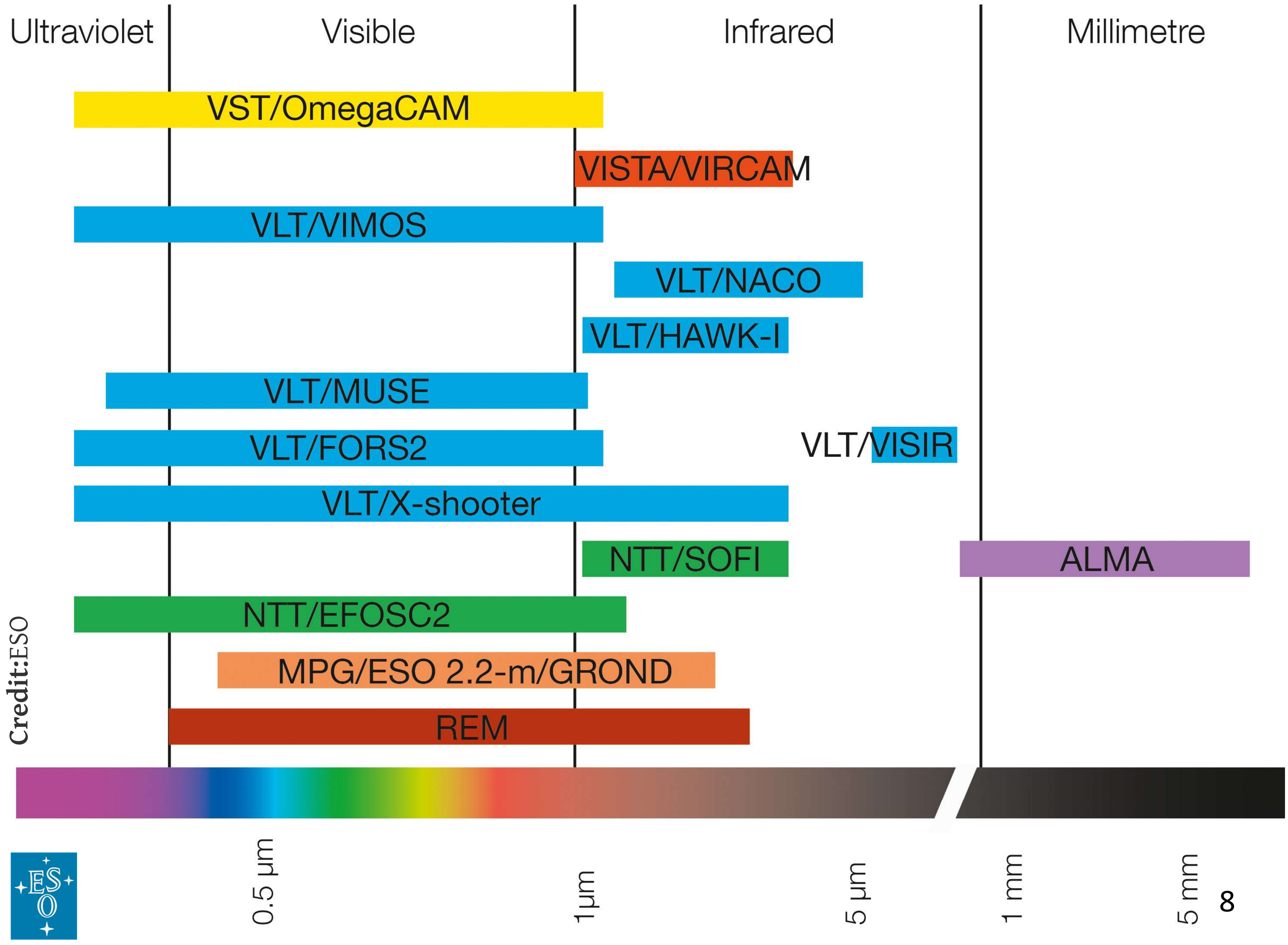

BNS 85%
Terrestrial 15%
NSBH 0%
MassGap 0%
BBH 0%
Engrave
The ENGRAVE project
The ENGRAVE project
Operations
Data
Writing
Theory
Outreach
Alerts (8)
Event Advocate
Trigger
Observations
nature
ANATOMY OF A
KILONOVA
#s190518bb
83 | 0 | Add a topic
Search
s190518bb
@Jens Hjorth created this channel yesterday. This is the very beginning of the # s190518bb channel.
Set a purpose
+ Add an app
Add people to this channel
Yesterday

GW170817 – AT2017gfo

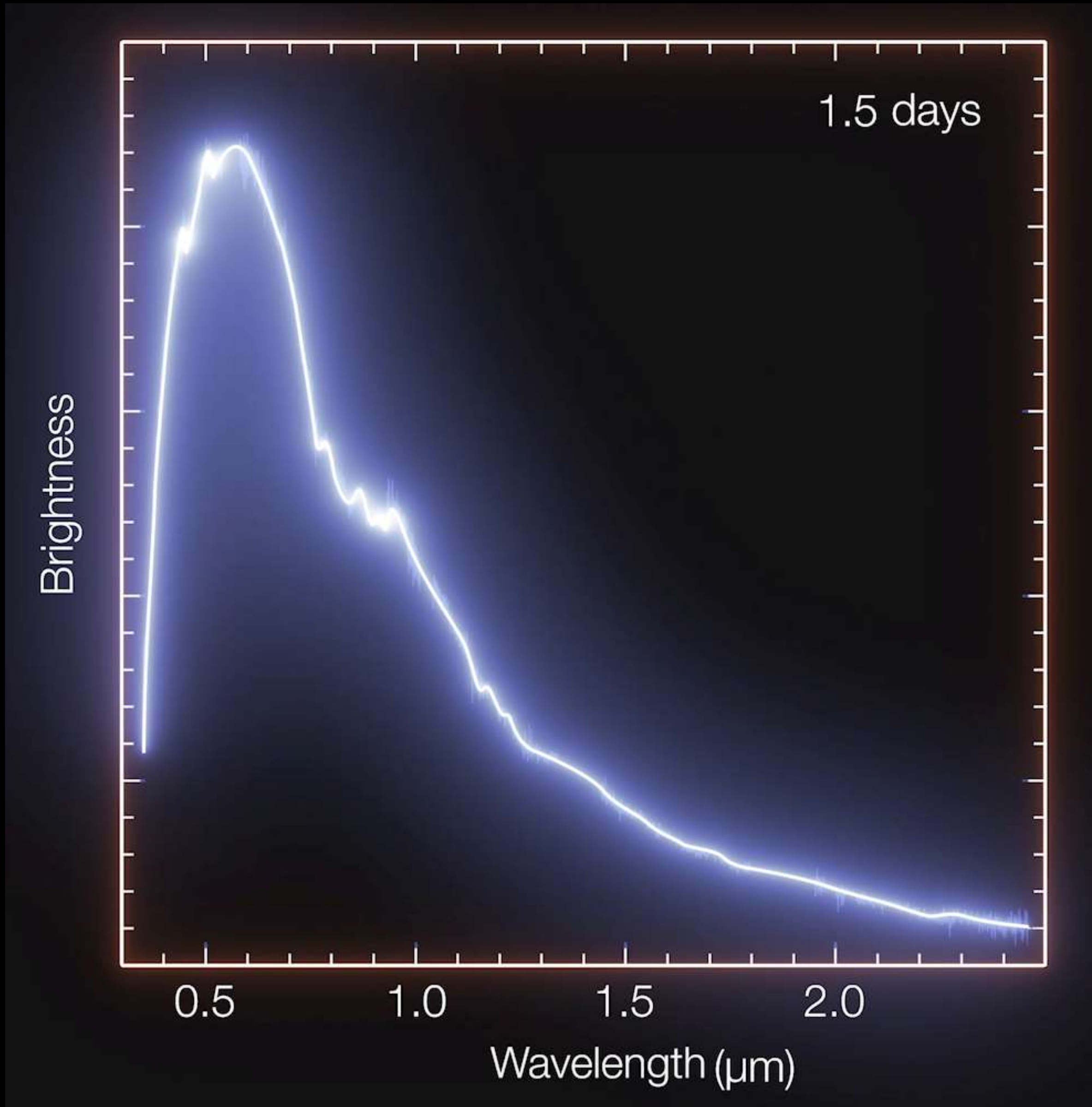


Credit:ESO/L. Calçada/M. Kornmesser

- GW from a 1.3+1.5 Msun NS merger
- 2.8 M_{sun} BH?
- 0.05 M_{sun} ejected at v ~ 0.2c
- Powered by radioactive decay of heavy, r-process elements
- Associated with short Gamma Ray Burst!

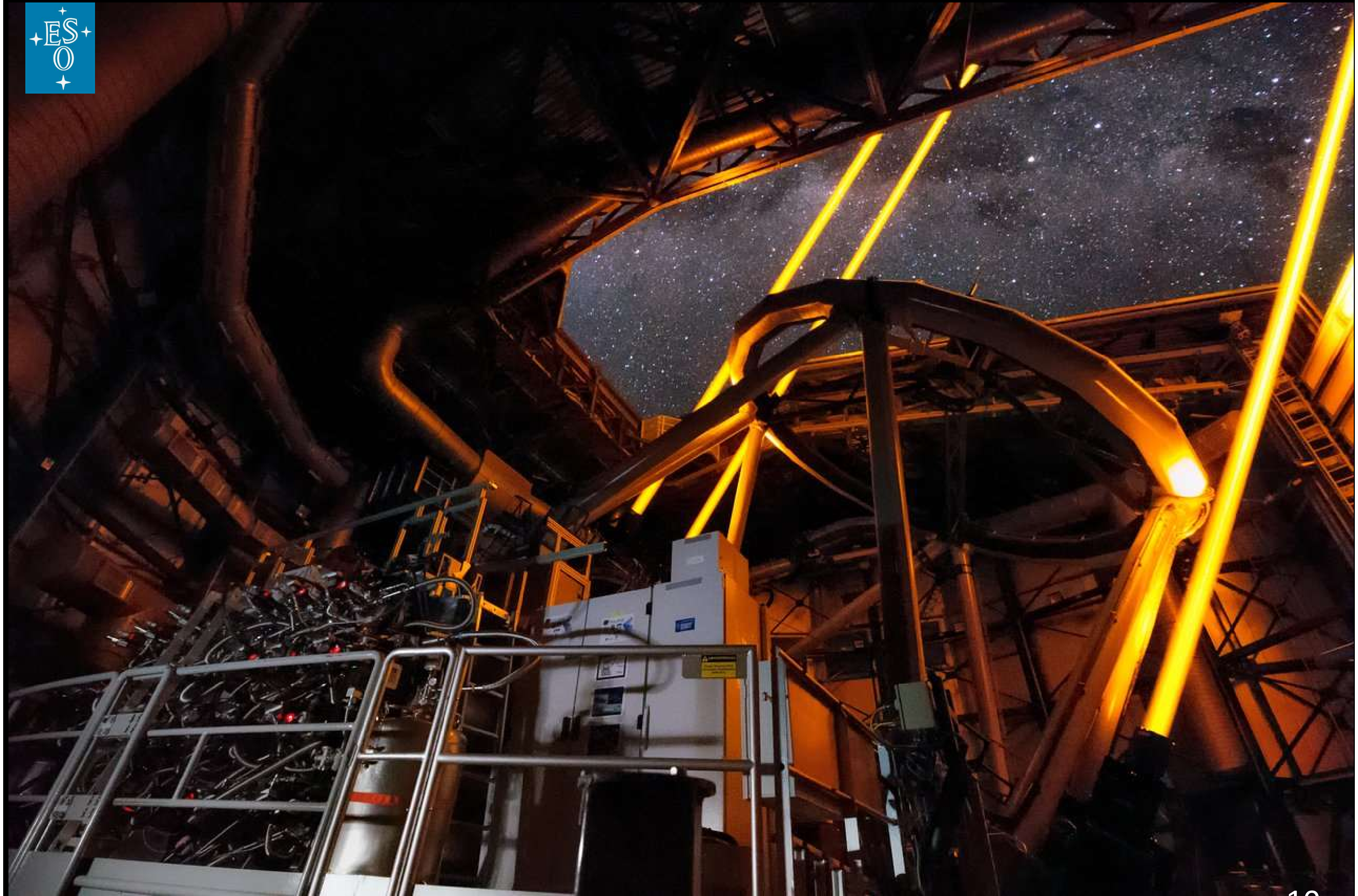


Ultraviolet
Visible
Infrared
Millimetre
VST/OmegaCAM
VISTA/VIRCAM
VLT/VIMOS
VLT/NACO
VLT/HAWK-I
VLT/MUSE
VLT/VISIR
VLT/FORS2
VLT/X-shooter
NTT/SOFI
ALMA
NTT/EFOSC2
MPG/ESO 2.2-m/GROND
REM
Credit:ESO
ESO
0.5 µm
1µm
5 µm
1 mm
5 mm



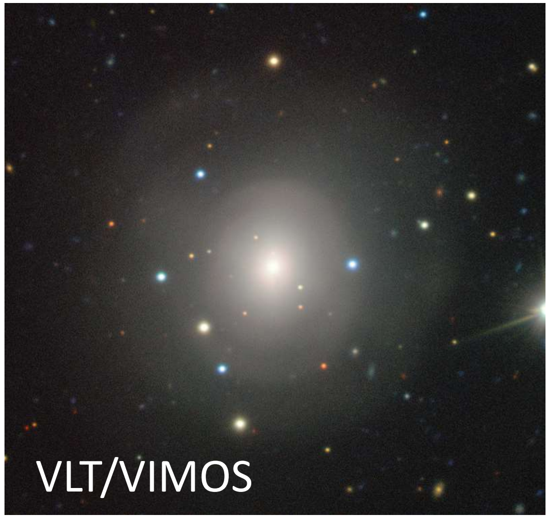
Credit: ESO/E. Pian et al./S. Smartt & ePESSTO/L. Calçada

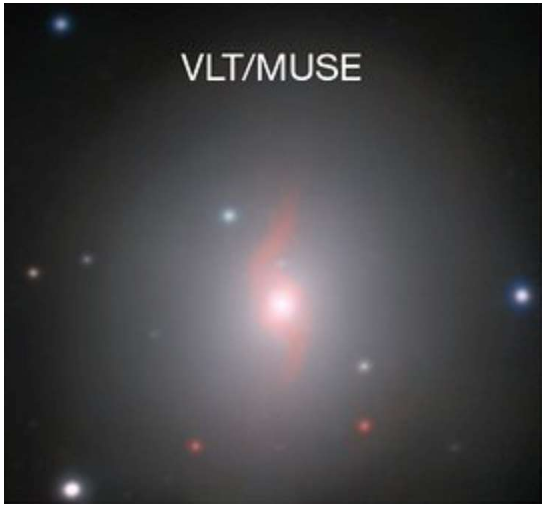
MUSE - Multi Unit Spectroscopic Explorer

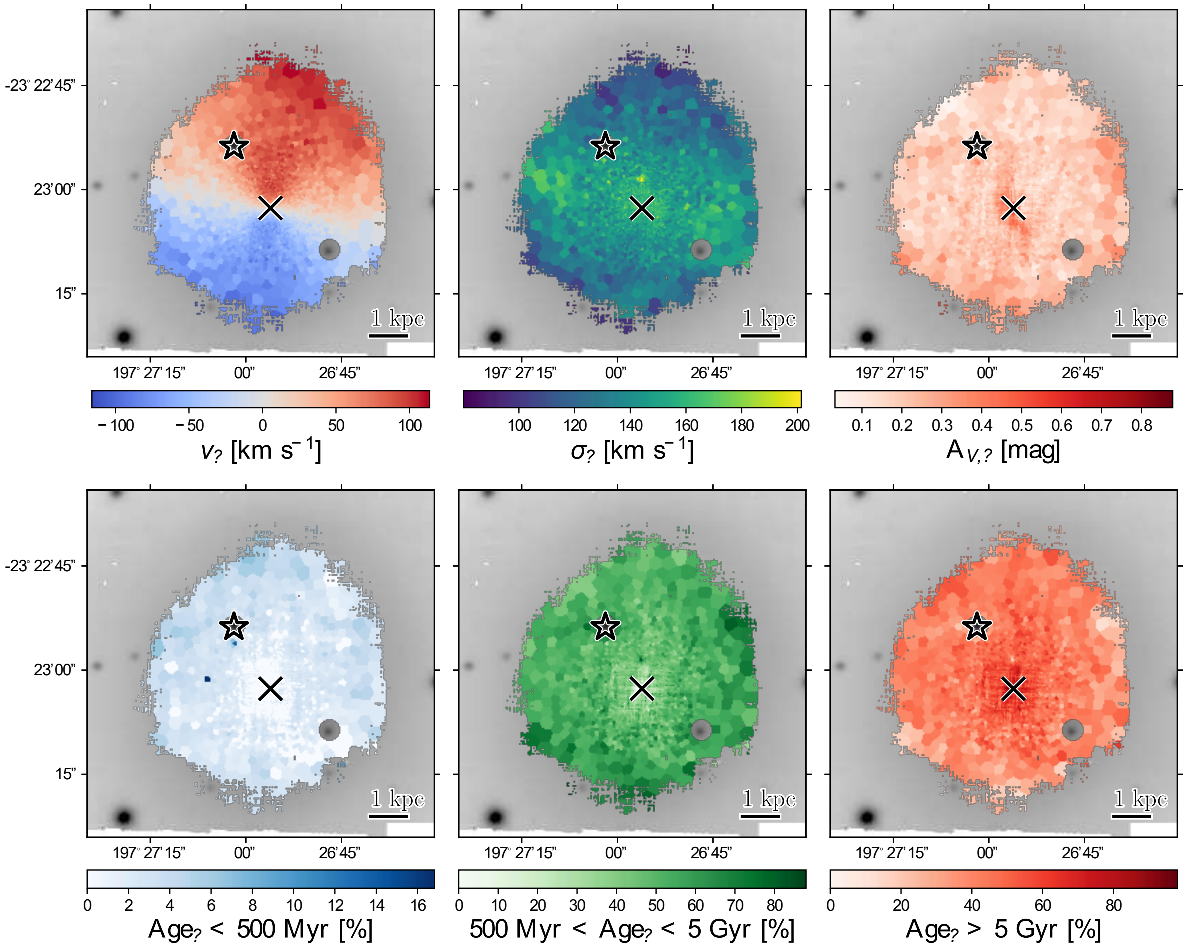


MUSE

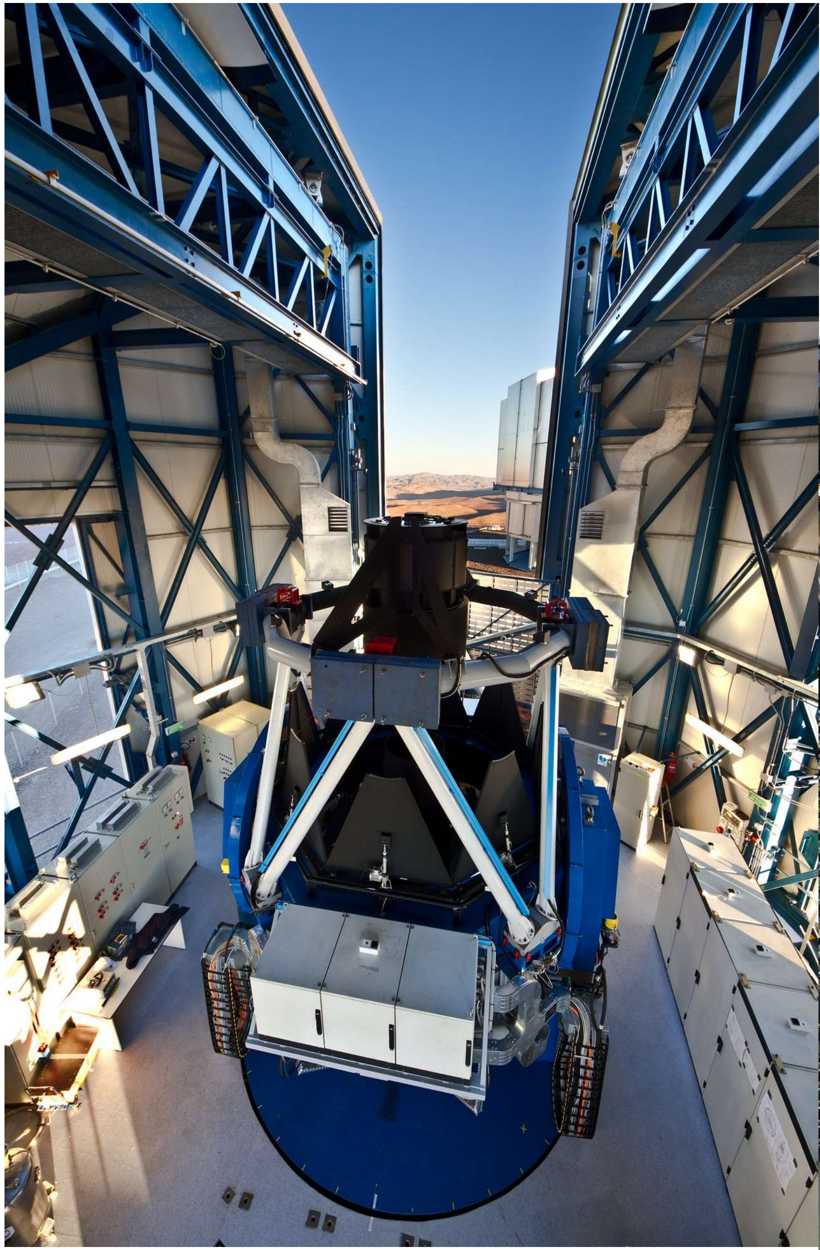
Fast afterglows/Environments/Distances



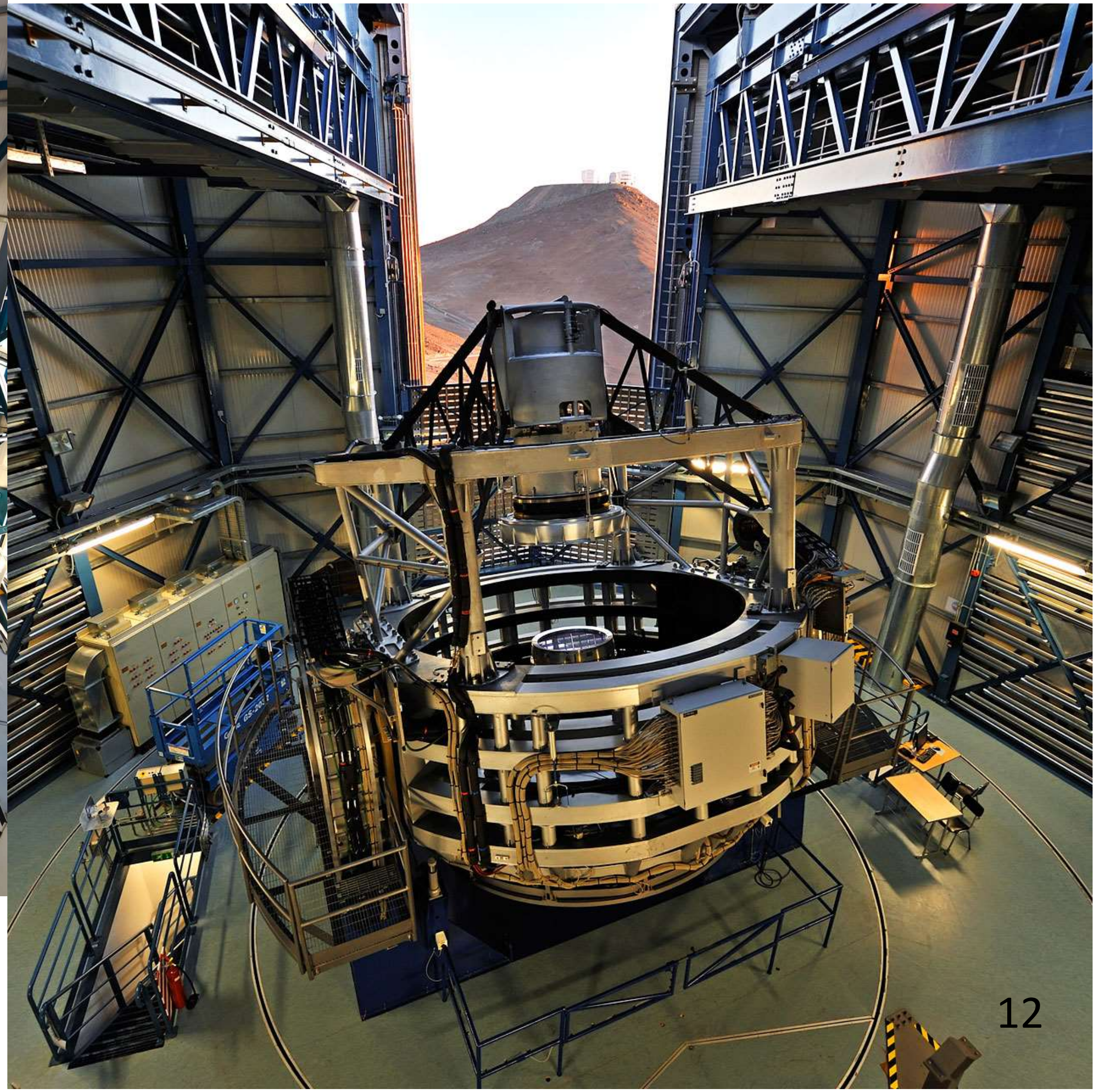




MUSE Levan et al. 2017, Hjorth et al. 2017

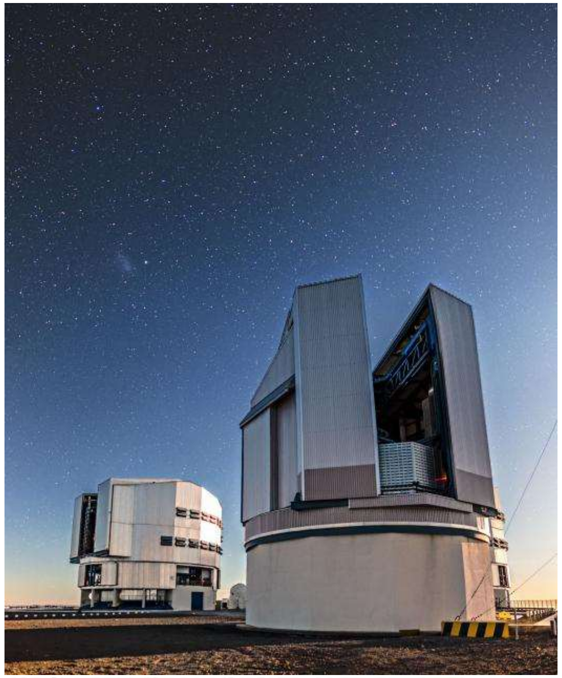


One needs to find them…

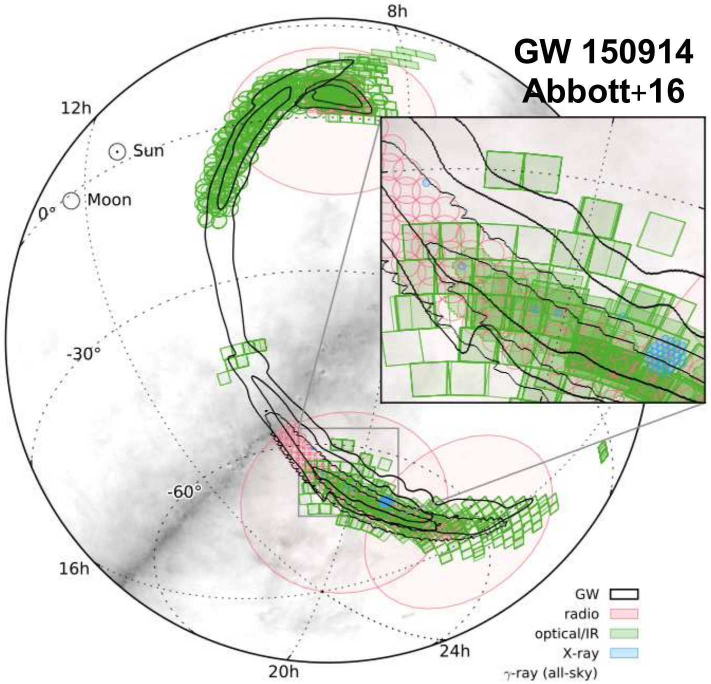


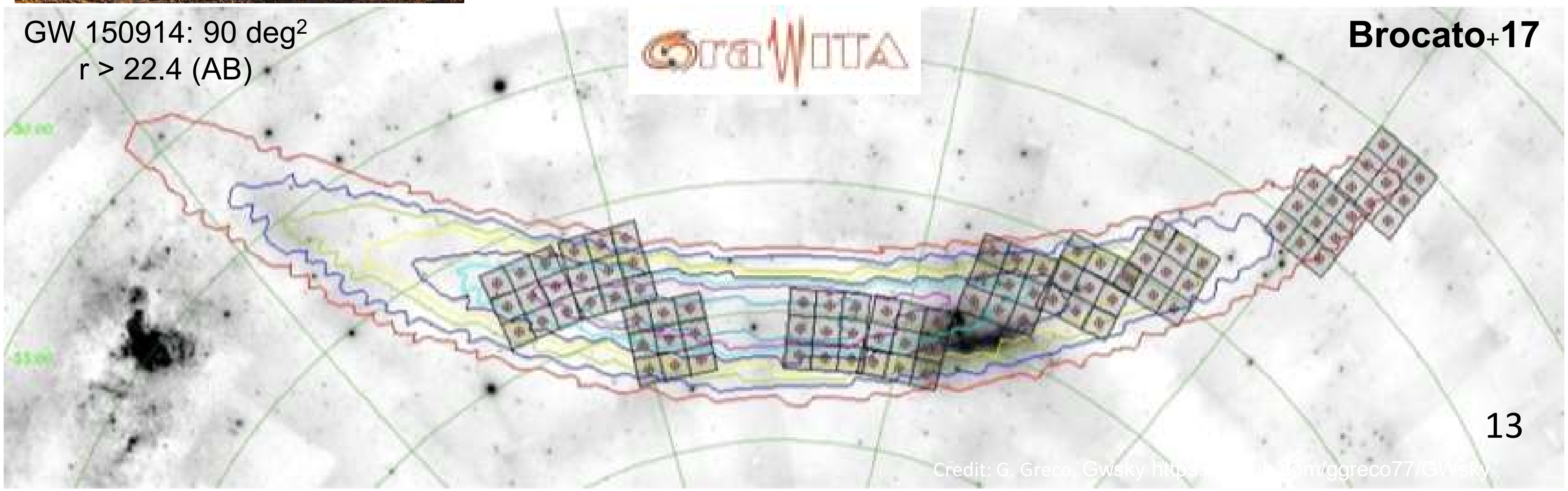
…first!

The GW era: EM search – wide FoV

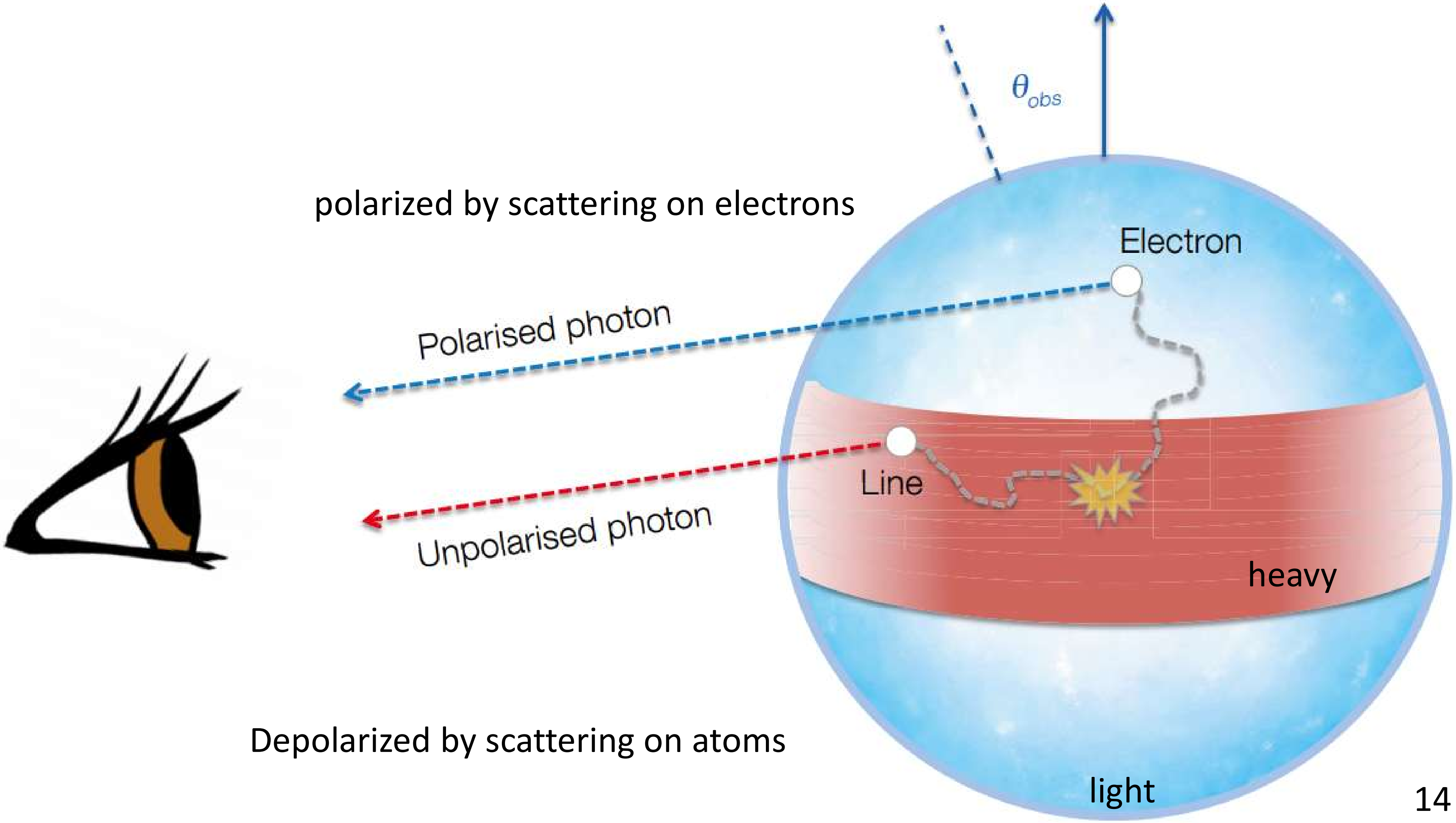


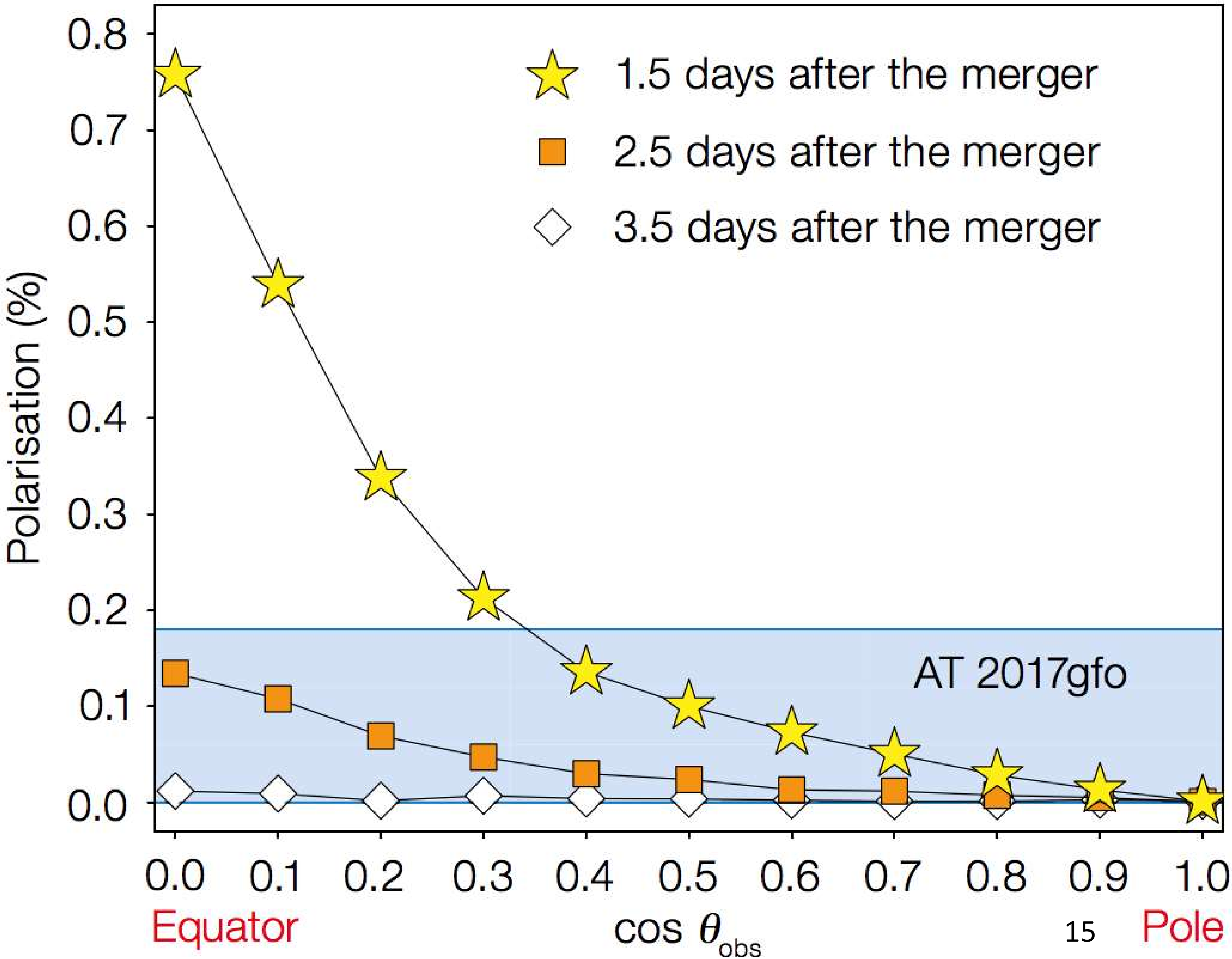
VLT Survey Telescope (VST)
- 2.6m
- 1 deg^2 FoV
- optical multiband imaging
- ToO mode



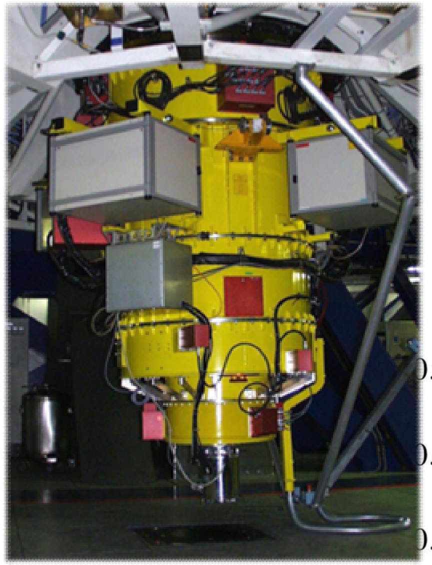


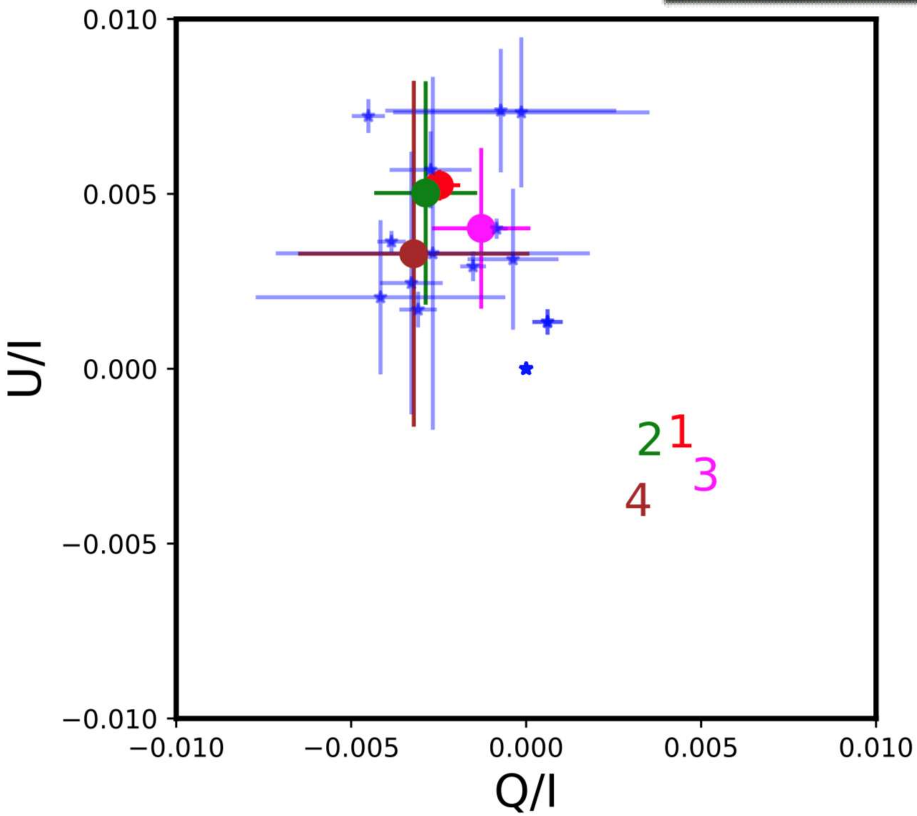
Probing Asymmetries
the promise of polarimetry

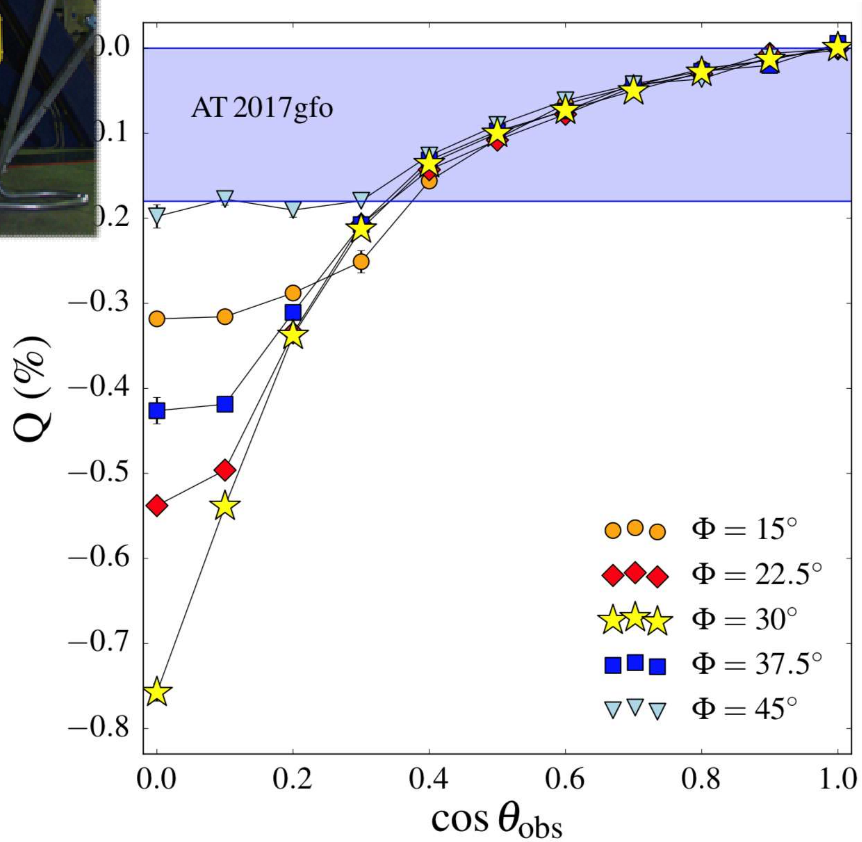




1.5 days after the merger
2.5 days after the merger
3.5 days after the merger
AT 2017gfo
Polarisation (%)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Equator
cos θ_{obs}
Pole







Covino et al. 2017, Bulla et al. 2018

A look into the future/1

	LOW	HIGH	Ref.	D_{LIM}	O2	Found
	[Myr^{-1} Mpc^{-3}]			Mpc		
NS+NS	10^{-2}	10	Abadie 2010	78	0.006-6	1
NS+BH	$6x10^{-4}$	1	Abadie 2010	150	0-0.6	0
BH+BH	$9x10^{-3}$	0.24	Abbott 2016	900	5-140	7

O3 expected rates

Event	Rate
BBH	1/month to 1/week
BNS	1/month – median 2/year
BHNS	>0

Gravitational Wave Transient Catalog

	GW Event	Area deg^2	Distance Mpc	Primary $M_\odot$	Secondary $M_\odot$	Remnant $M_\odot$
	GW 150914	179	430^{+150}_{-170}	35.6 (BH)	30.6 (BH)	63.1 (BH)
O1	GW 151012	1555	1060^{+540}_{-480}	23.3 (BH)	13.6 (BH)	37.5 (BH)
	GW 151226	1033	440^{+180}_{-190}	13.7 (BH)	7.7 (BH)	20.5 (BH)
	GW 170104	924	960^{+430}_{-410}	31.0 (BH)	20.1 (BH)	49.1 (BH)
	GW 170608	396	320^{+120}_{-110}	10.9 (BH)	7.6 (BH)	17.8 (BH)
	GW 170729	1033	2750^{+1350}_{-1320}	50.6 (BH)	34.3 (BH)	80.3 (BH)
O2	GW 170809	340	990^{+320}_{-380}	35.2 (BH)	23.8 (BH)	56.4 (BH)
	GW 170814	87	580^{+160}_{-210}	30.7 (BH)	25.3 (BH)	53.4 (BH)
	GW 170817	16	40^{+10}_{-10}	1.5 (NS)	1.3 (NS)	$\leq$ 2.8 (NS)
	GW 170818	39	1020^{+430}_{-360}	35.5 (BH)	26.8 (BH)	59.8 (BH)
	GW 170823	1651	1850^{+840}_{-840}	39.6 (BH)	29.4 (BH)	65.6 (BH)
	S190408an	387	1473^{+358}_{-358}	$>$ 5 (BH)	$>$ 5 (BH)	$>$ 5 (BH)
	S190412m	156	812^{+194}_{-194}	$>$ 5 (BH)	$>$ 5 (BH)	$>$ 5 (BH)
	S190425z	7461	155^{+45}_{-45}	$<$ 2.2 (NS)	$<$ 2.2 (NS)	$<$ 4.3 (?)
	S190426c	1131	377^{+100}_{-100}	? (BH)	? (NS)	? (?)
O3	S190503	448	421^{+105}_{-105}	$>$ 5 (BH)	$>$ 5 (BH)	$>$ 5 (BH)
	~~S190510g~~	~~1166~~	~~227±92~~	~~$<$2.16 (NS)~~	~~$<$2.16 (NS)~~	~~$<$4.32 (?)~~
	S190512at	399	1331±341	>5 (BH)	>5 (BH)	?
	S190513bm	691	1987±501	>5 (BH) ?	>5 (BH) ?	?
	S190517h	**939**	**2950±1038**	**>5 (BH) ?**	**>5 (BH) ?**	**?**

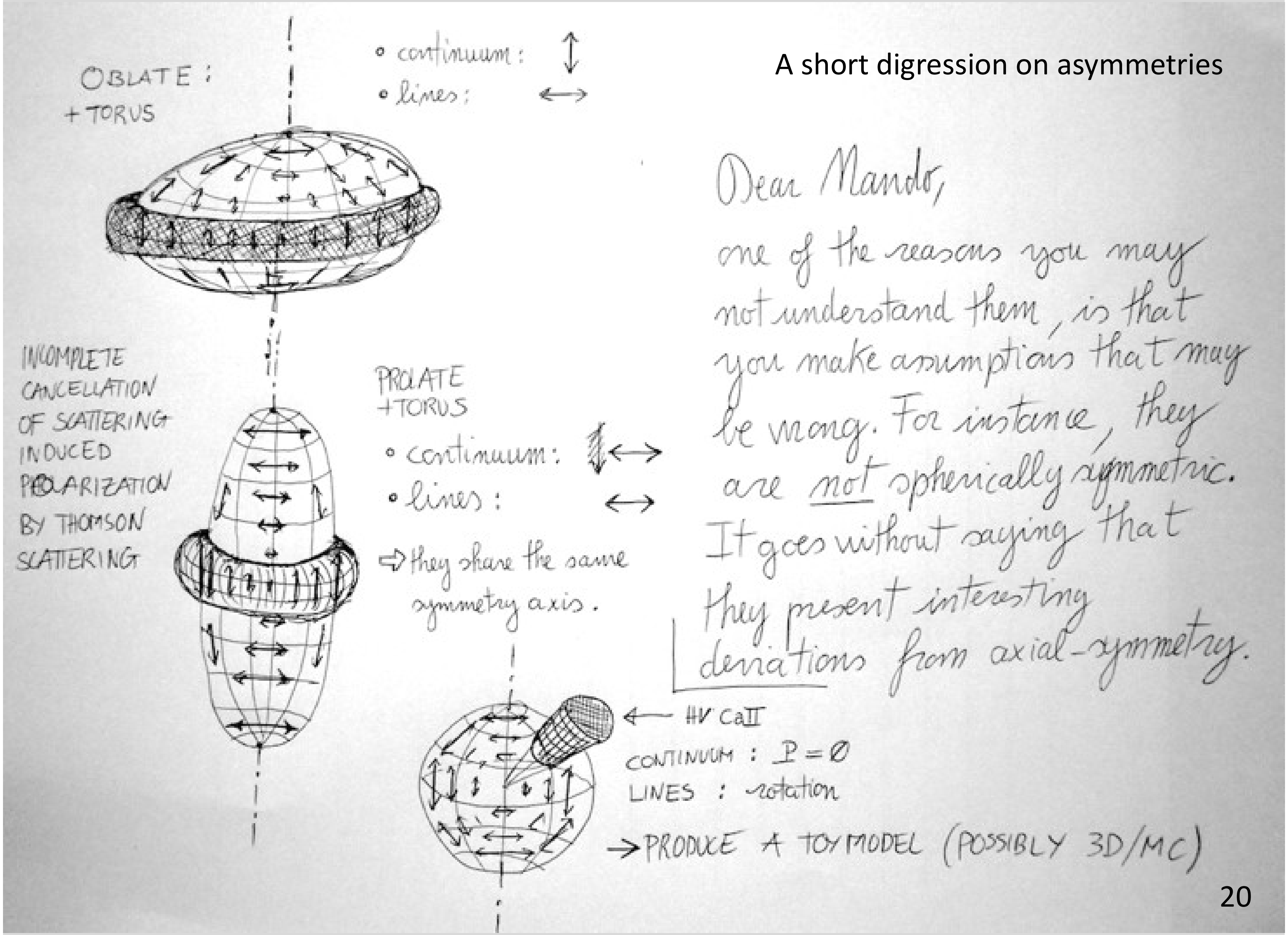
A look into the future/2
(though closer to my hearth)

Gossan+ 2016;
Dall'Osso+ 17,18

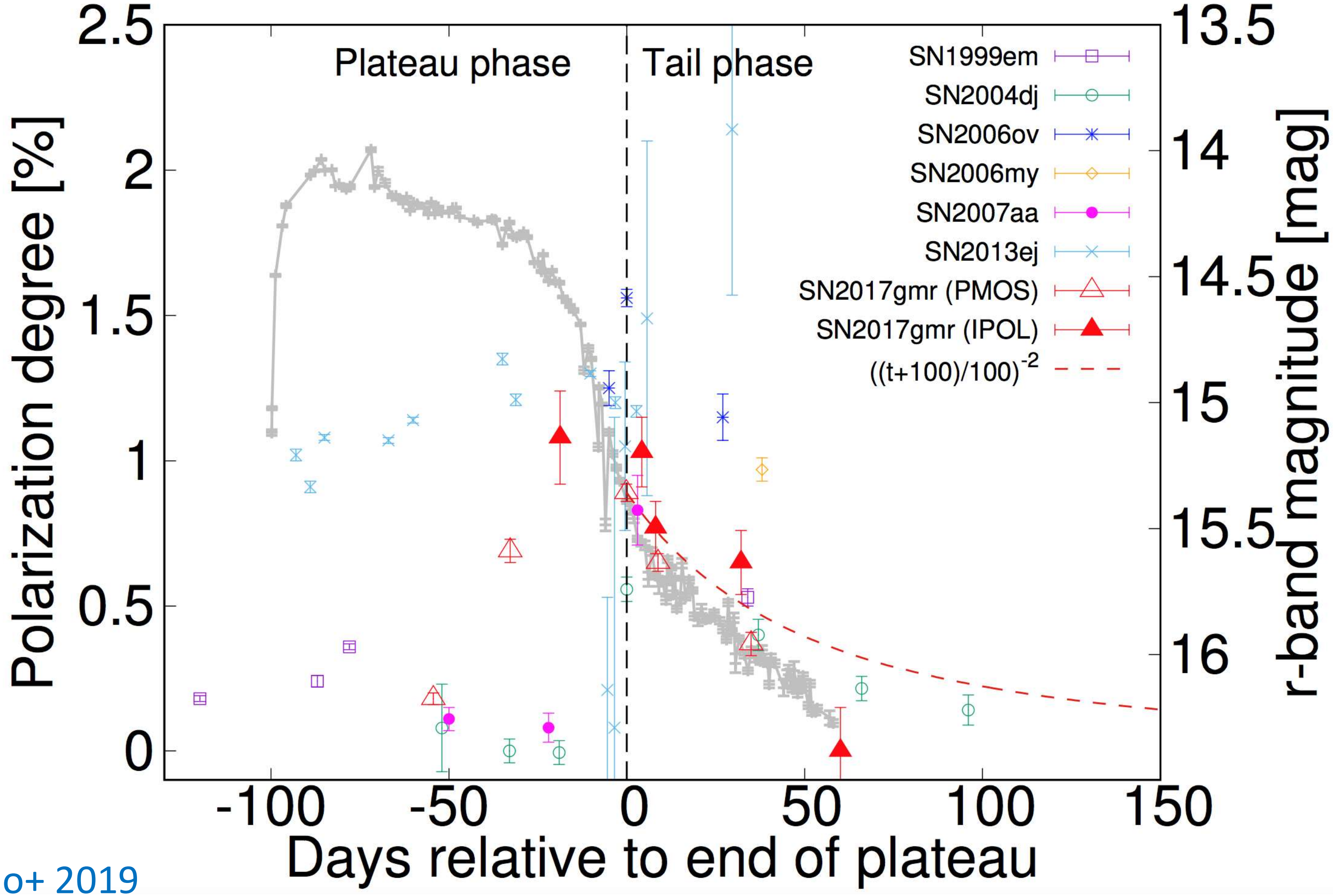
- GW emission requires [strong] asymmetries
- There are indications (from observations) and expectations (from theory) that symmetries may be present in C-C SNe
- Simulation (e.g. Gossan+ 2016) show that signals are low ($10^{-12} – 10^{-7}\ M_{sun}\ c^2$); 1 hz – 1Khz, 1 ms – 1s
- Extreme cases may exist (e.g. rotational instability in proto-NS; accretion disk fragmentation): $0.01\ M_{sun}\ c^2$
- Spin-flip of new-born magnetar

5 Kpc : neutrino driven
50 Kpc : rapidly rotating
5 Mpc : extreme scenarios (e.g. collapsar)

A short digression on asymmetries



Asymmetries in C-C supernovae



Nagao+ 2019

- At some point we will get a Galactic C-C Supernova.
- However, the C-C rate for the MW is about 2 per century.
- While we will probably not miss it, it may take a while before this happens!
- Being more realistic, we should start considering extra-galactic SNe, in the Local Group.

The contribution of EM searches

- We are very confident that we do not miss any SN event within 10-20 Mpc
- BUT: SN event timing becomes crucial
- A reverse approach: the EM transient triggers an a-posteriori, targeted search for the GW signal in the interferometric data.
- The ET era will greatly enhance this business.
- That is the are were we (meaning EW people) should work.
- Requires a higher coordination level: not yet there.
- LSST era: see talk by A. Palmese

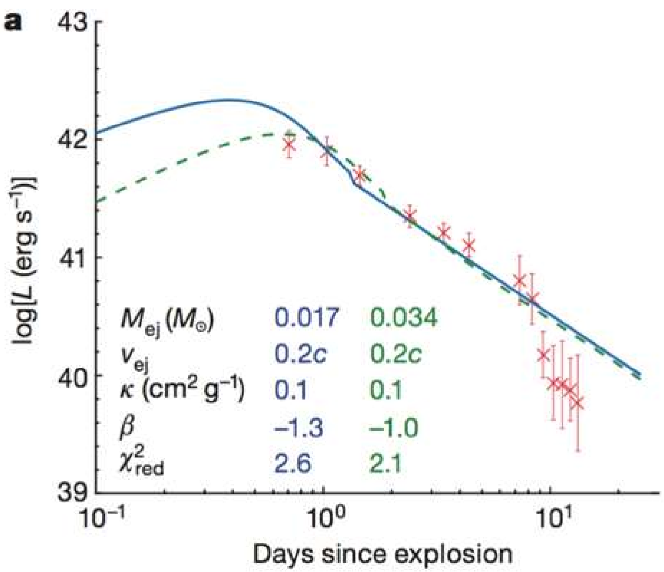

And even more into the future

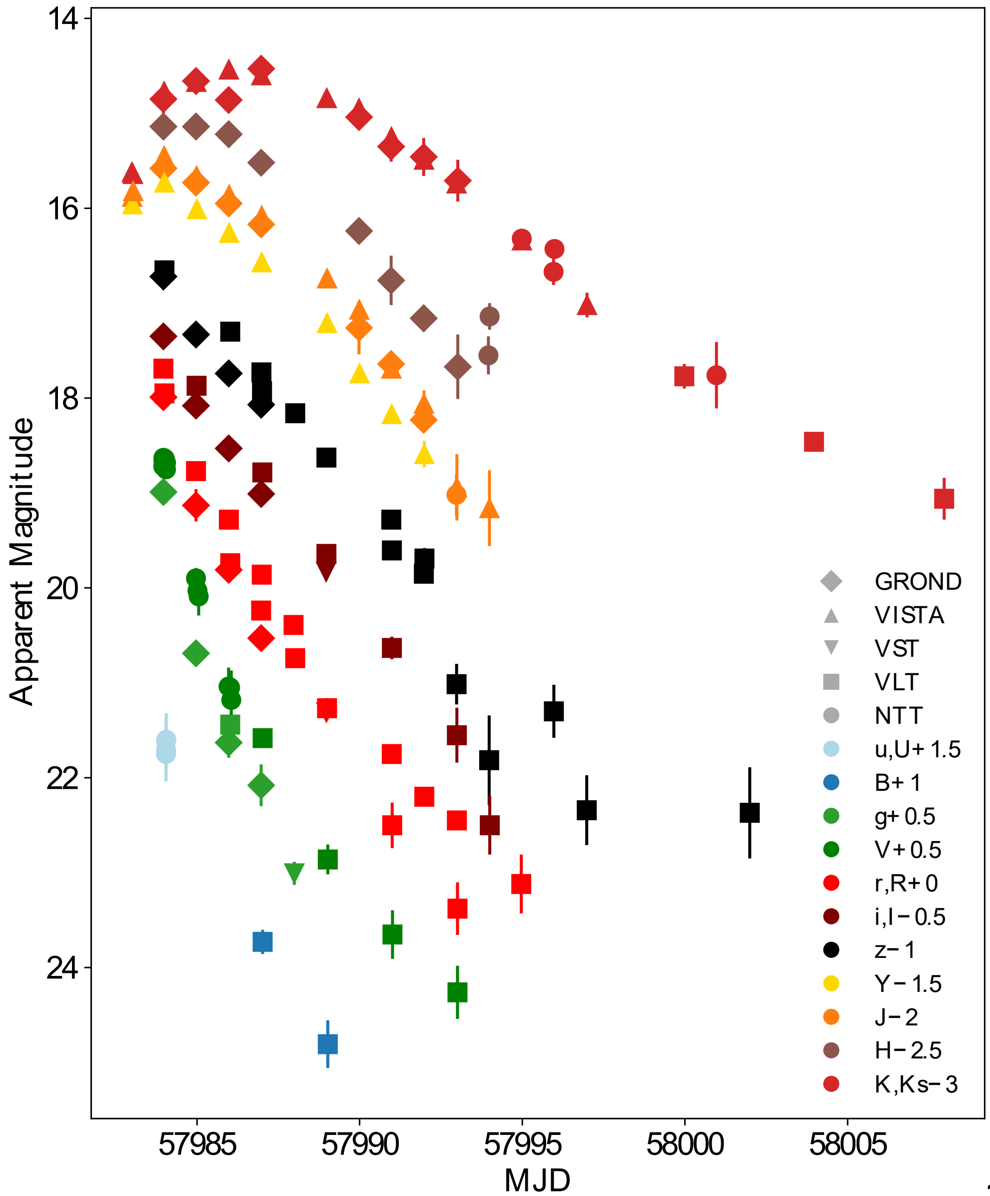
Thanks!

Summary and [some] open questions

- Multi-messenger approach is fundamental
- What is the emission geometry?
- Rates, redshift distribution, luminosity functions?
- Are Kne always associated to short-GRBs?
- Are there more than one KN species?
- What are the NS-BH merger properties/rates?
- Will we ever get to observe GWs from CCs?

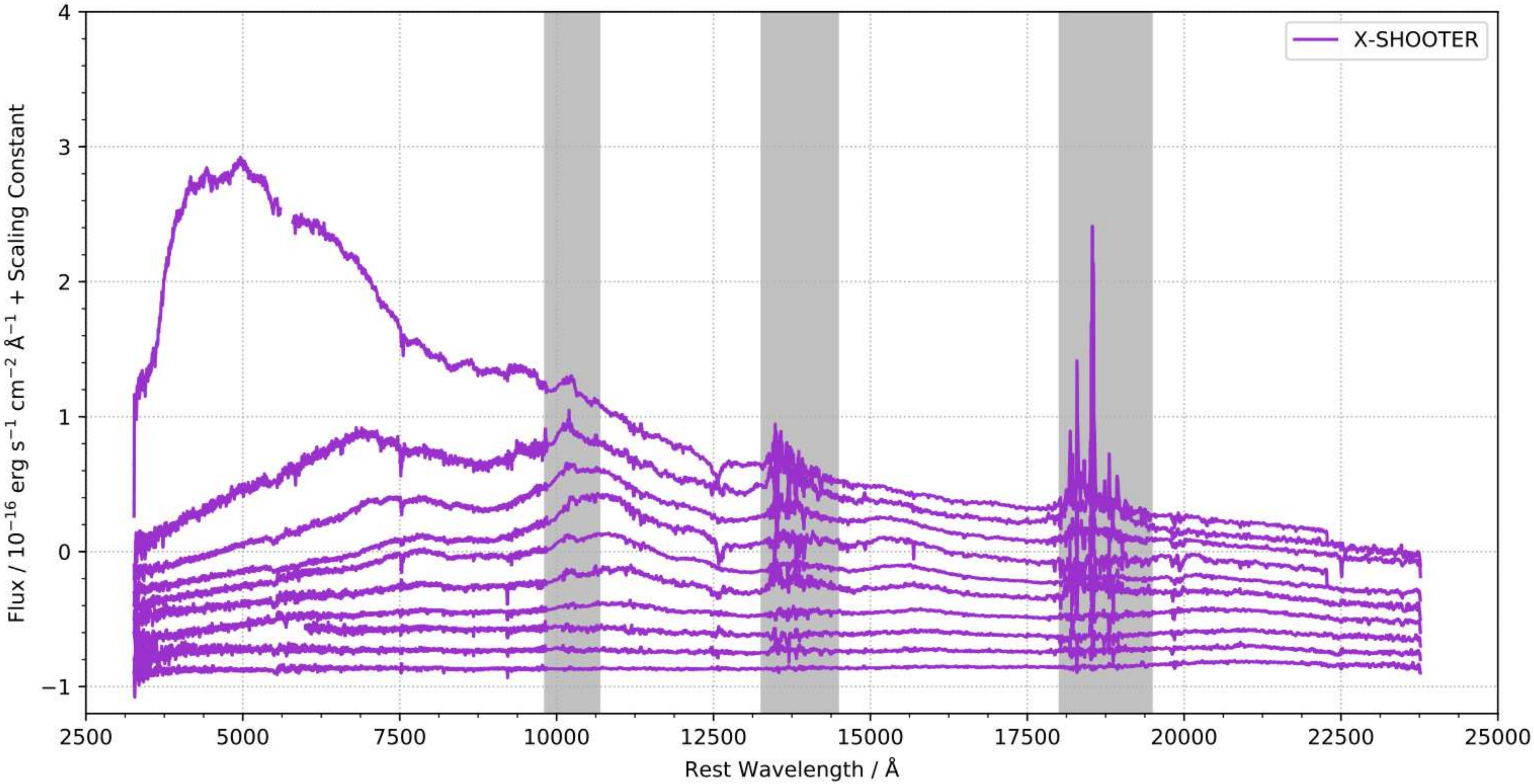
ESO photometry





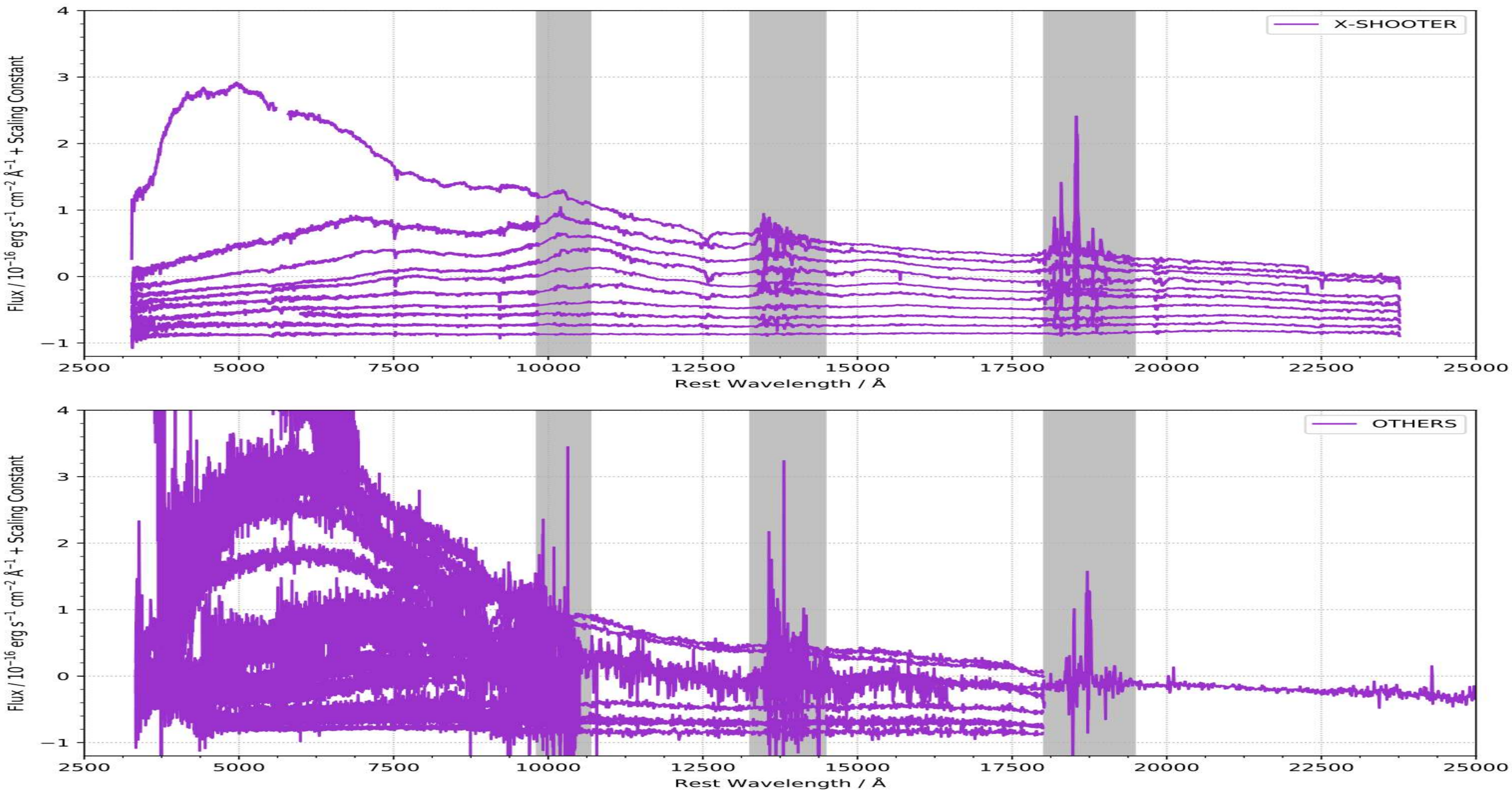
Pian et al. 2017
Smarrt et al. 2017
Tanvir et al. 2017

X-SHOOTER spectra AT2017gfo



James Gillanders (Pian et al. 2017, Smartt et al. 2017)

All other spectra from open KN catalog



Membership

Amati **Anderson** Antier **Ascenzi** Ashall **Barbarino** Belloni **Benetti** Bensch **Bernardini** Bersier **Berton**
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Grado **Greco** Greiner **Gromadzki** Groot **Gutiérrez** Götz **Heintz** Higgins **Hirai** Hjorth **Horesh** Hu **Hunt**
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Ragosta **Raimondo** Ramsay **Ravasio** Razzano **Reynolds** Rossi **Rosswog** Roy **Rubin** Ruiter **Sabha** Salafia **Salmon**
Salvaterra **Savaglio** Sbordone **Schady** Schipani **Schroetter** Schulze **Seitenzahl** Selsing **Shingles** Sim
Skillen **Smartt** Smith **Smith** Sollerman **Stanway** Starling **Steeghs** Stella **Stratta** Stritzinger **Sullivan**
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Stefano Covino, Andrew Levan, Kate Maguire, Daniele Malesani, Susanna Vergani

- le SNe “brillanti” locali secondo me sono scoperte tutte (tutte per me vuol dire 80-90% entro 10 Mpc)
- io la vendo come nella slide qui sotto.
- piu in generale, parlando anche con quelli di ligo/virgo capisco che il punto e’ che visto che la waveform per le GW da core collapse e’ sostanzialmente ignota , la sensibilita’ deli rivelatori GW e’ decisamente inferiore (e gia’ il segnale in se e’ molto inferiore)
- Per aumentare le chance di detection, la chiave a’ poter dare un timing di esplosione ricavato dal segnale elettromagnetico piu’ accurato possibile. Questo consente di fare una triggered search sulla time serie degli interferometri.
- Sapendo dove e come cercare (in particolare la direzione della sorgente nota consente di fissare a monte il delay time fra i rivelatori) migliora di molto la sensibilita. E’ qui che a mio modo di vedere gli ottici dovrebbero lavorare .
- Quelli di asass-sn l’hanno capito, ma non hanno una survey adatta perche non vanno abbastanza fondi da beccare le SNe molto early.
- Servirebbe un coordinamento delle SN searches ma gli astronomi sono restii al coordinamento

- in realtà sulle SN (core-collpase) le ultime simulazioni sembrano indicare energie in GW molto basse < 10^-9 Mo c^2 (una binary system di stelle di neutroni emette 10^-2 Mo c^2). Con Advanced LIGO e Virgo il segnale è visibile nella nostra galassia. Con modelli più ottimistici e esotici (che includono rotational instabilities nella proto-NS, nonaxisymmetric instabilities of the accretion disk, o fragmentation of the collapsing core, per esempio Fryer and New 2011) si potrebbe arrivare ad una decina di Mpc. L'emissione in GW è fortemente legata al livello di assimmetria dell'esplosione di cui si sa poco.

- In LIGO e Virgo facciamo una ricerca triggerata dalla SN, ovvero usiamo la posizione, la distanza e l'explosion time (estrapolato dalla curva di luce) nella ricerca del segnale GW e qui andiamo a vedere tutte le SN entro 15-20 Mpc. ET avrà una sensibilità 10 volte maggiore degli Advanced detector (10^3 in volume).

-

- Una sorpresa dalle SN secondo me arriverà dal segnale del remnant, nel caso di un magnetar ci si aspetta un segnale GW visibile entro il Virgo cluster (papers di Dall'Osso e Stella).

- Sicuramente parlerei di ENGRAVE, delle potenzialità osservative per la kilonova/afterglow e galassia ospite
- Un po' sui wide-FOV telescope per ricerca iniziale
- Le prospettive future partendo da SOX e poi quelle dei rivelatori GW di terza generazione ET e E-ELT
- Per terza generazione metterei qualcosa anche su survey di SN vicine (< 20 Mpc)