Hunting for GW counterparts and kilonovae from the Canary Islands

Josefa Becerra González
Instituto de Astrofísica de Canarias
(jbecerra@iac.es)

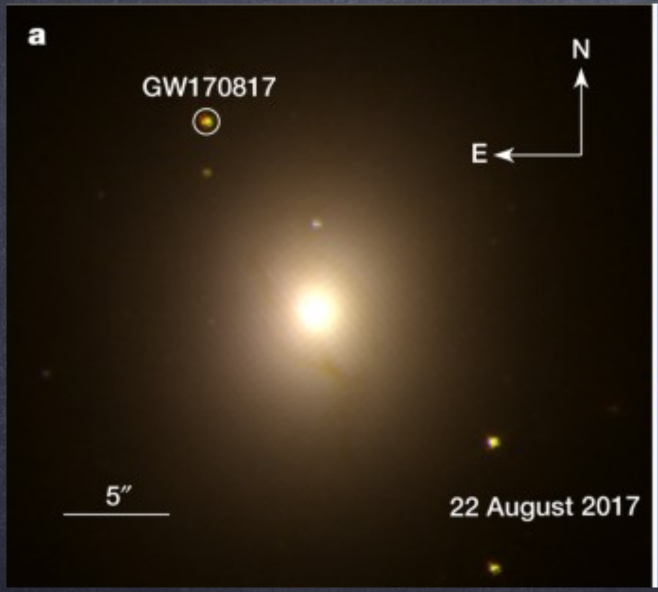
11th Iberian Gravitational Waves Meeting
11 June 2021

Team

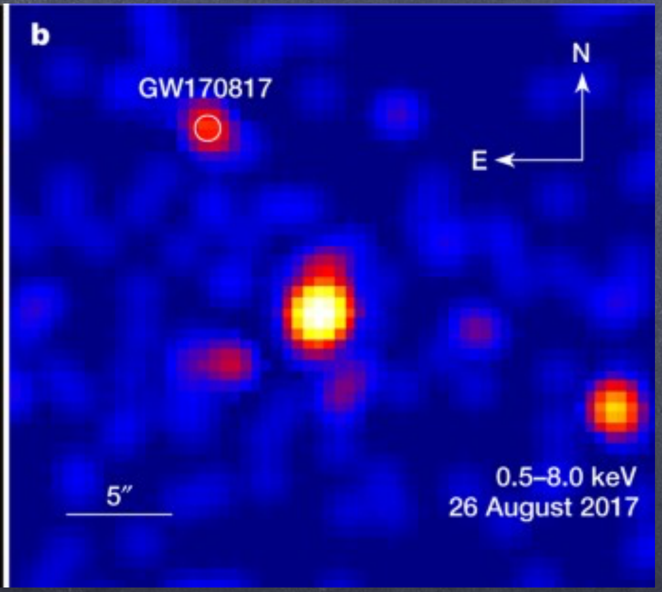
- While there is not a dedicated GW group at IAC, there is strong interest in the field from different angles and expertise
- To list some of them: Manuel Pérez Torres, Teo Muñoz Darias, José A. Acosta Pulido, Evencio Mediavilla, Alex Oscoz, Jorge Casares, Artemio Herrero…
- National/International collaborators: Eleonora Troja, Alberto J. Castro-Tirado, Luigi Piro, Rubén Sánchez-Ramírez, Alan Watson, William Lee, Amy Lien, Antonio Postigo de Ugarte++

GW170817

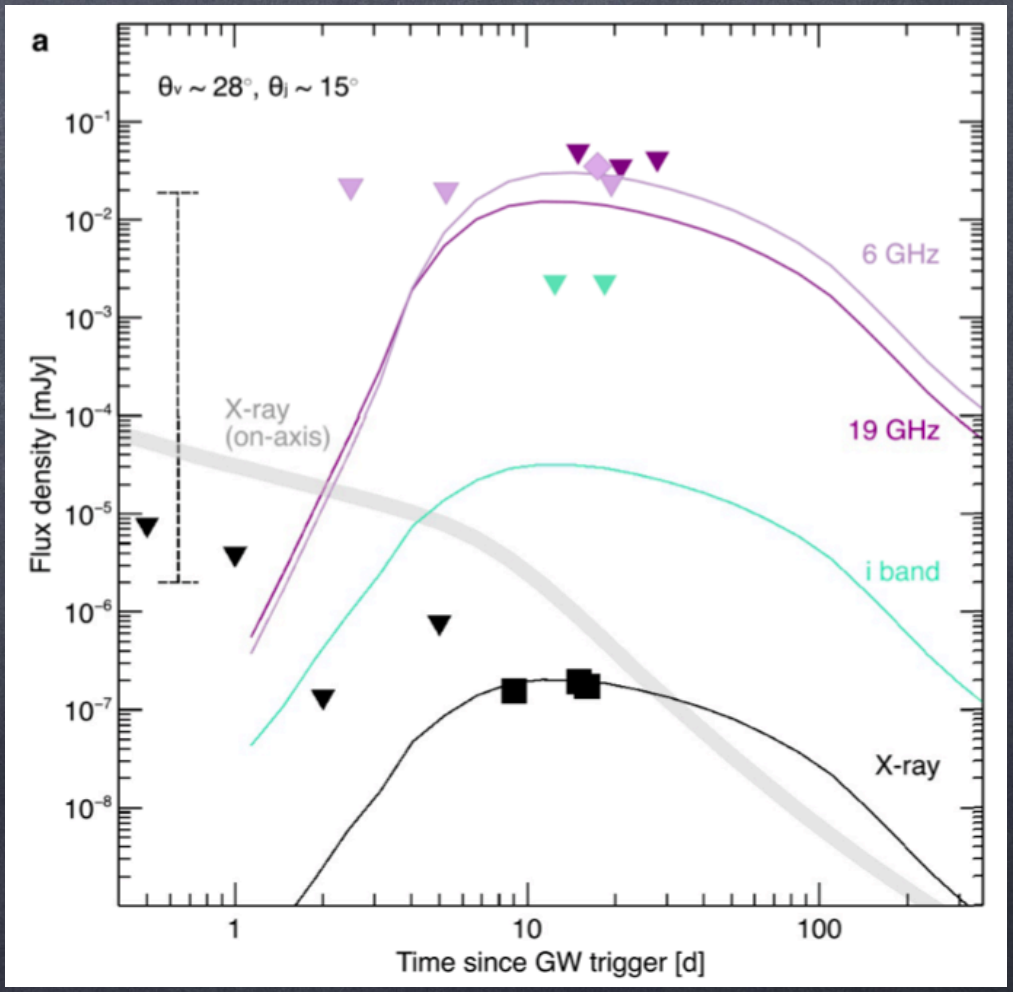
- First detection of the X-ray counterpart 9 days after the merger with Chandra
- Multi-wavelength characterization from radio to X-rays



HST (optical)



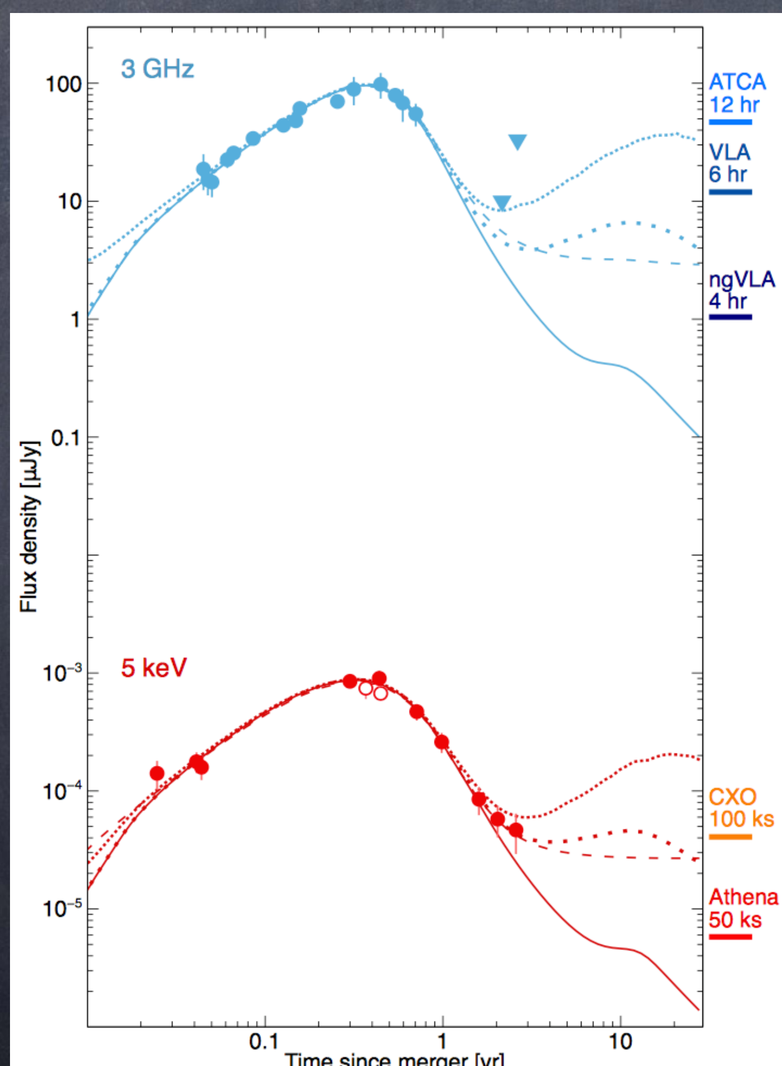
Chandra (x-rays)

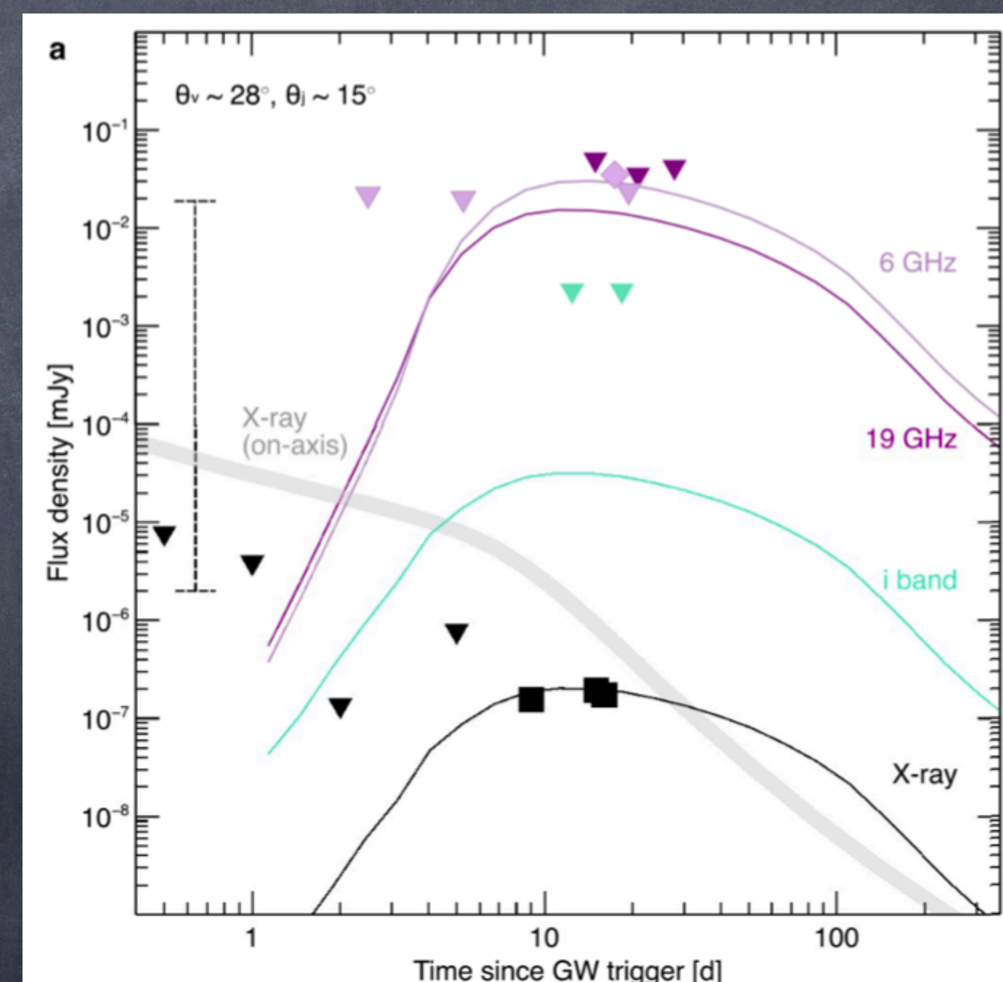


E. Troja et al. 2017, Nature, 551, 71

GW170817

- First detection of the X-ray counterpart 9 days after the merger with Chandra
- Multi-wavelength characterization from radio to X-rays



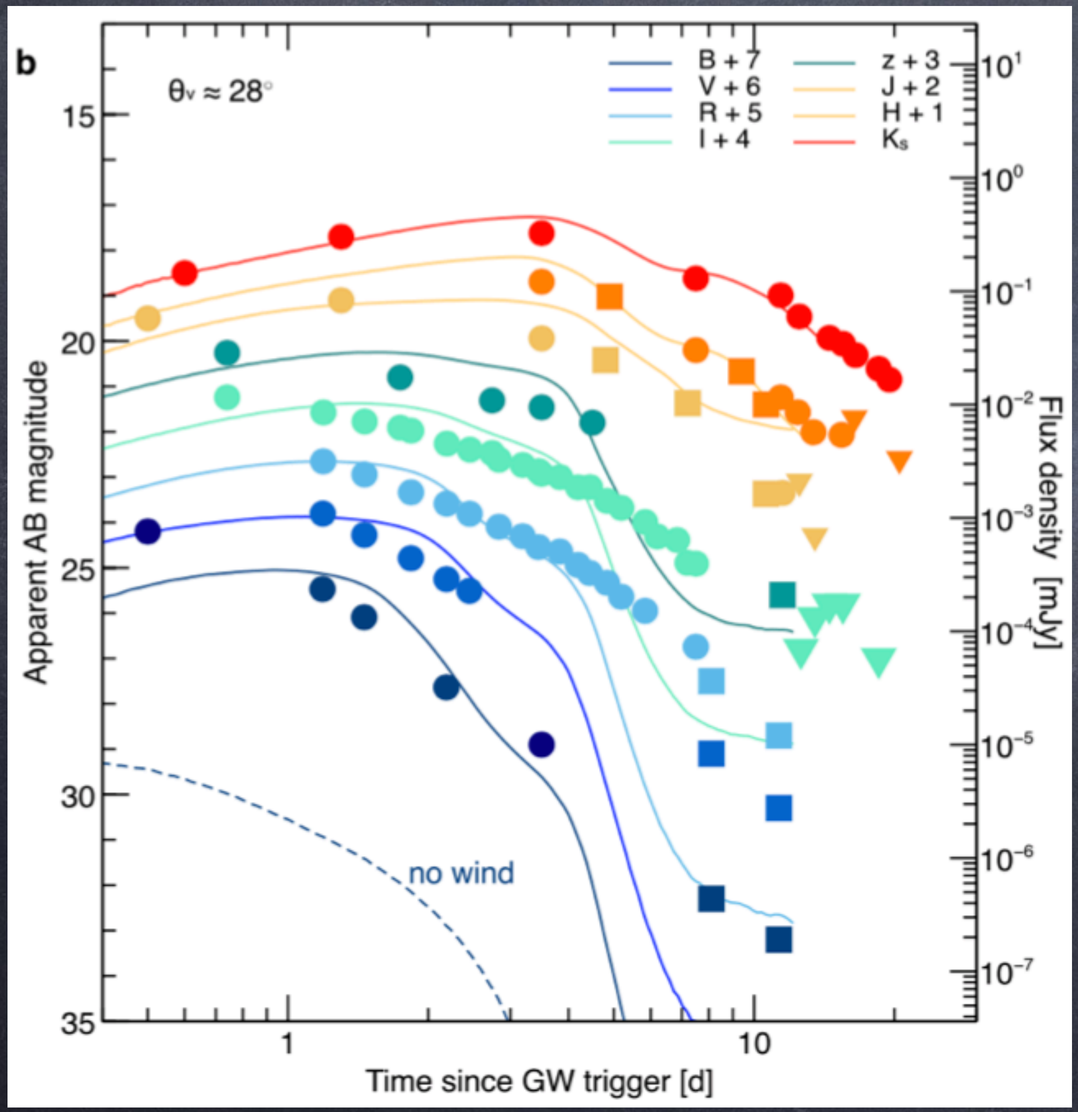


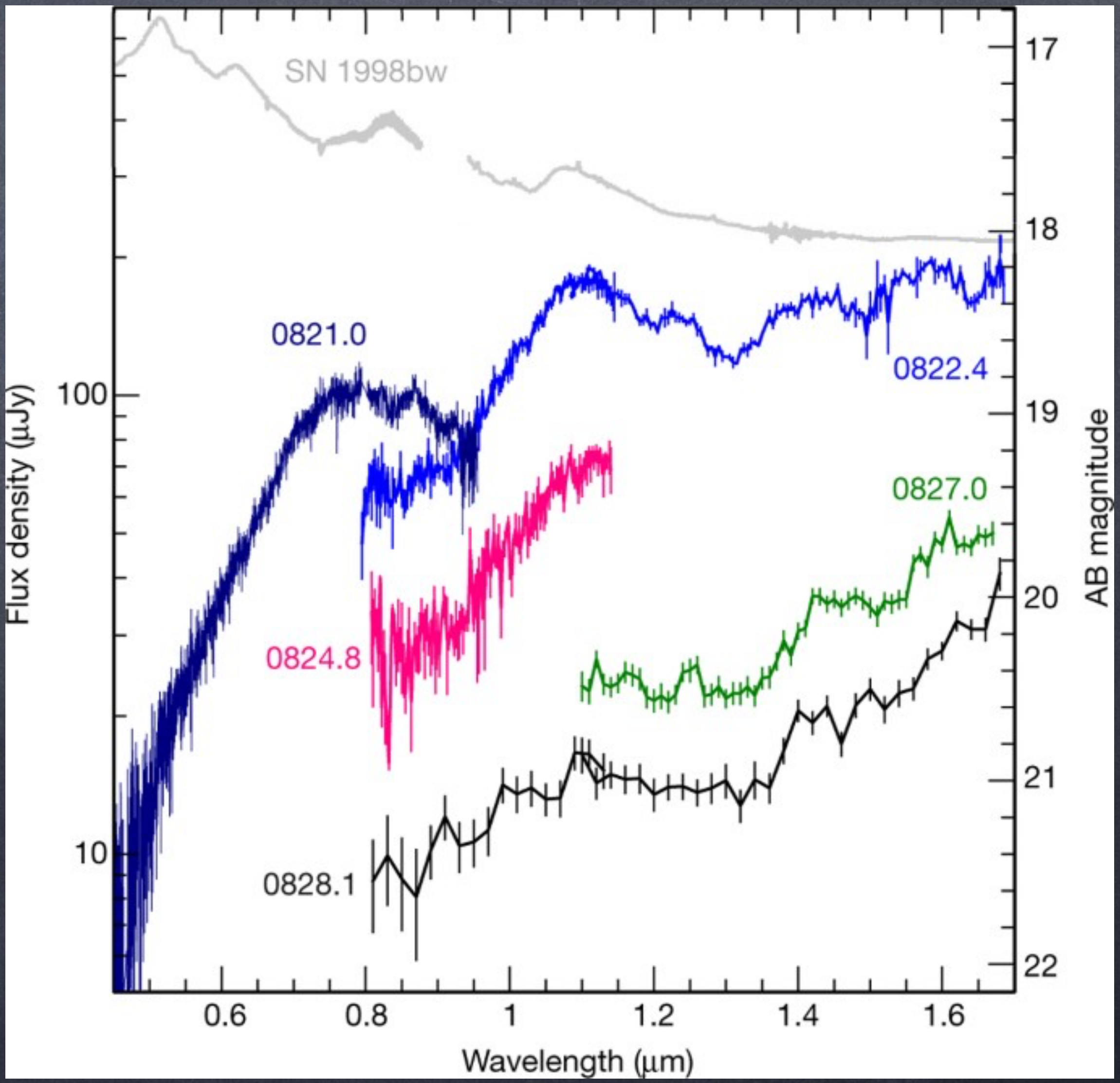
E. Troja et al. 2020, MNRAS, 498, 5643

E. Troja et al. 2017, Nature, 551, 71

GW170817

- First detection of the X-ray counterpart 9 days after the merger with Chandra
- Multi-wavelength characterization from radio to X-rays

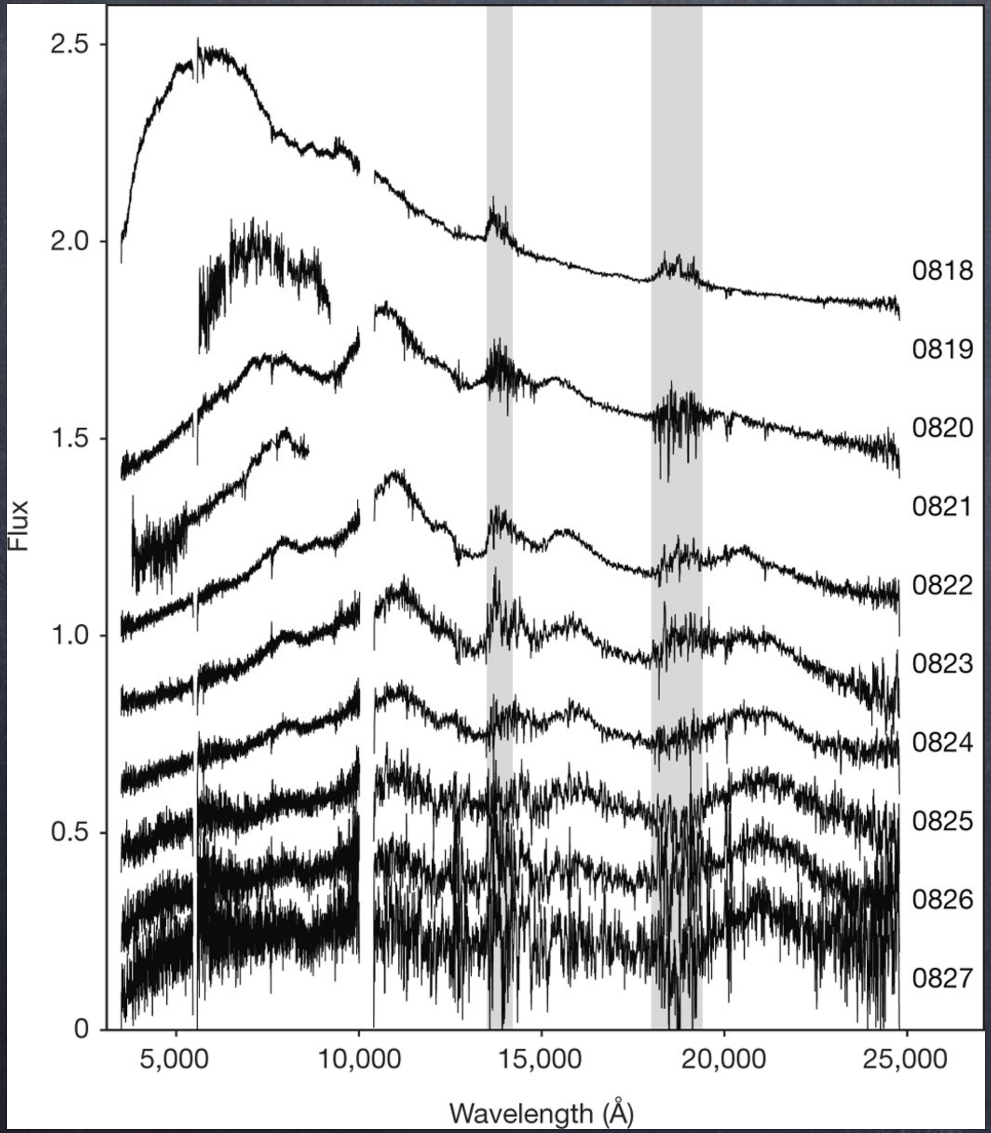


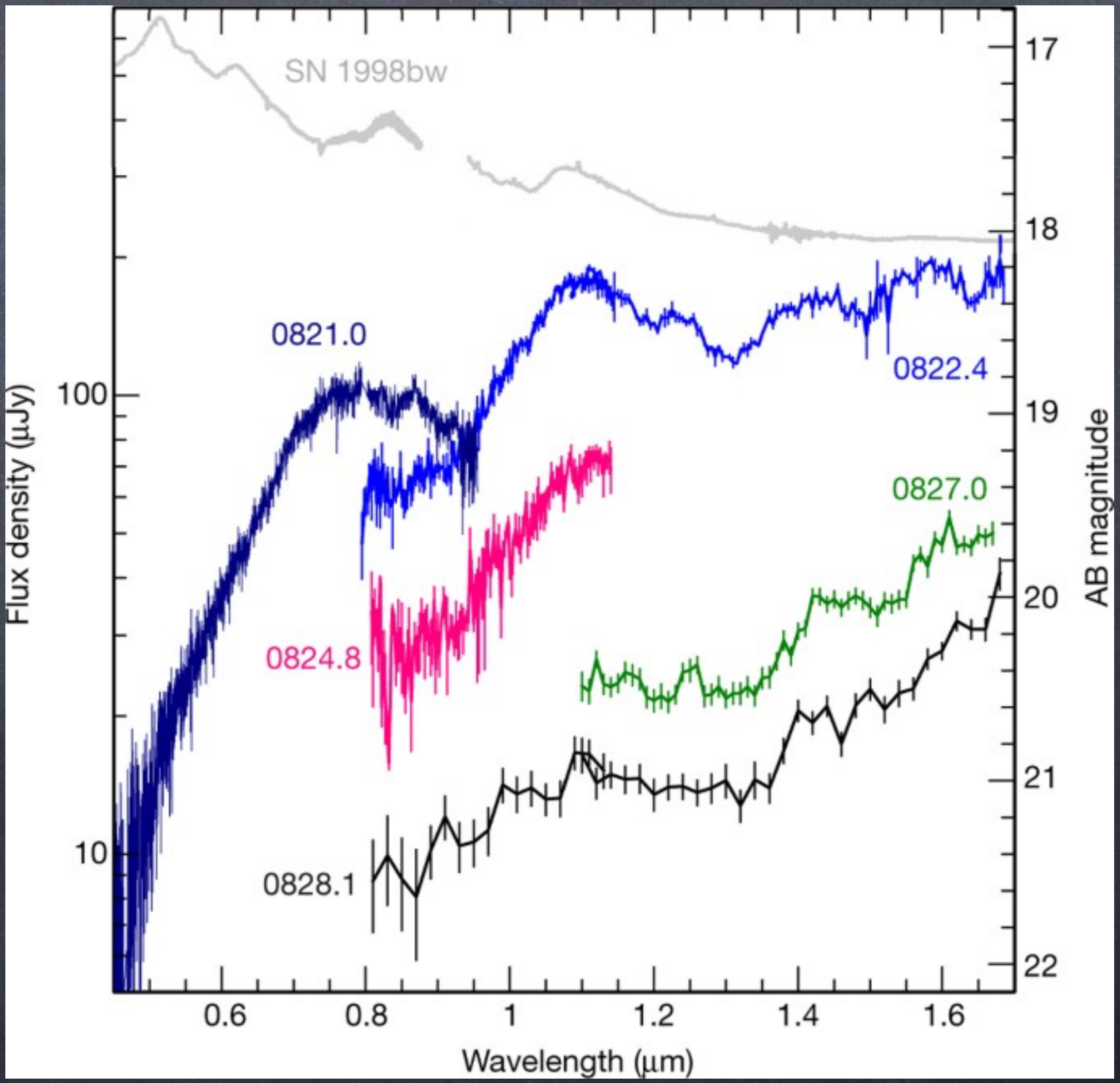


E. Troja et al. 2017, Nature, 551, 71

GW170817

- First detection of the X-ray counterpart 9 days after the merger with Chandra
- Multi-wavelength characterization from radio to X-rays

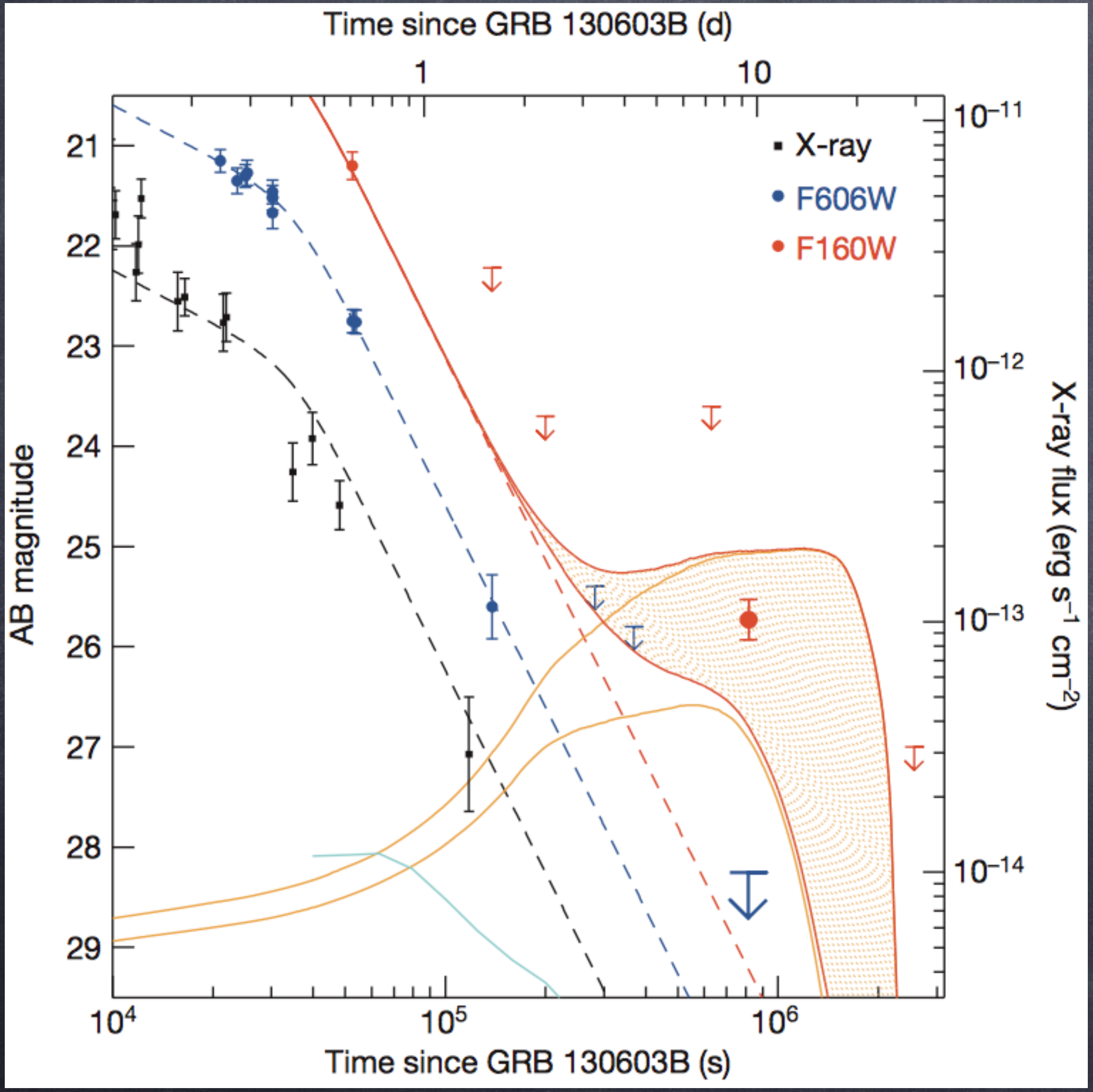




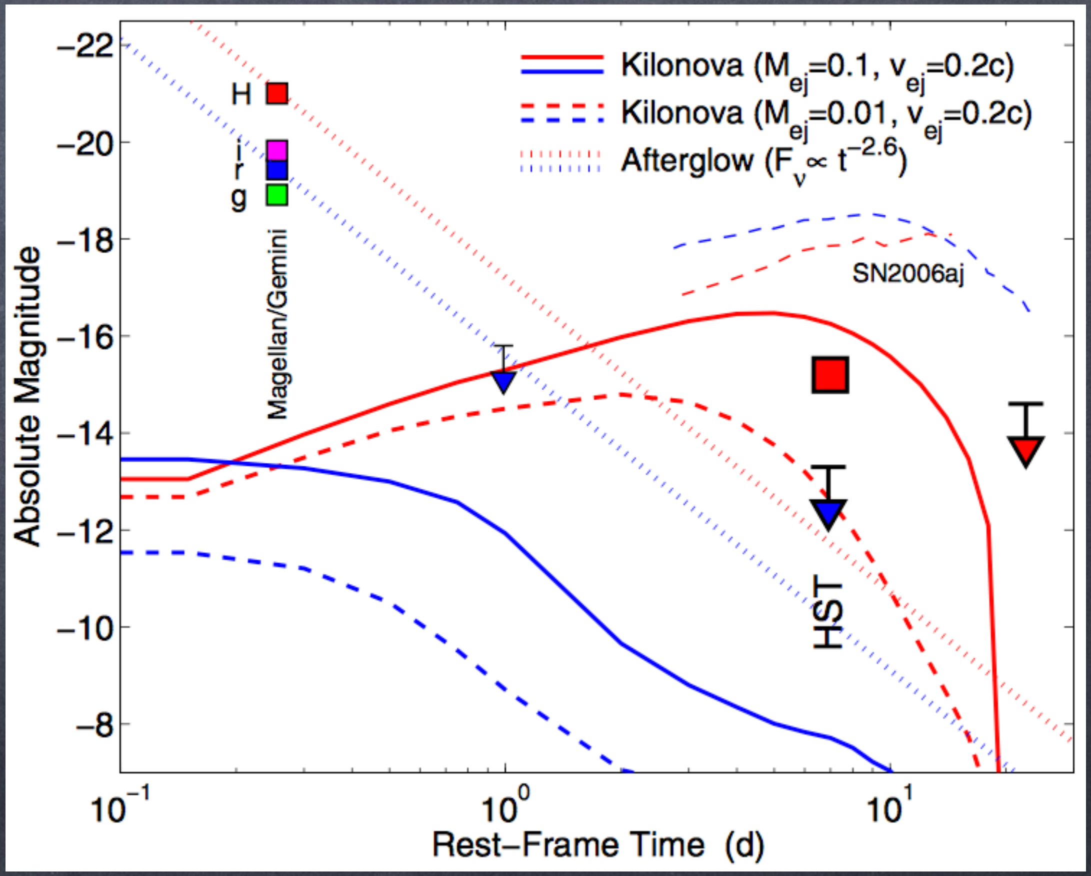
E. Pian et al. 2017, Nature, 551, 67

E. Troja et al. 2017, Nature, 551, 71

Kilonova hunting before GW170817: GRB130603B



Tanvir et al. 2013, Nature, 500, 547



Berger et al. 2013, ApJL, 774, L23

GRB160821B

- Short GRB
- z=0.16
- Analysis of the multi-wavelength archival data

Date MJD	$T–T_0$ (d)	Telescope	Instrument	Exposure (s)	Band	AB mag	Flux density[a] (μJy)
				Optical/nIR			
57621.940	0.002	*Swift*	UVOT	147	*wh*	>21.9	<8
57621.942	0.004	*Swift*	UVOT	209	*u*	>21.4	<12
57622.013	0.076	GTC	OSIRIS	270	*r*	22.67 ± 0.10	3.4 ± 0.3
57622.017	0.080	GTC	OSIRIS	270	*i*	22.39 ± 0.07	4.3 ± 0.3
57622.020	0.083	GTC	OSIRIS	180	*z*	22.28 ± 0.06	4.7 ± 0.3
57623.006	1.07	WHT	ACAM	1440	*r*	23.83 ± 0.25	1.2 ± 0.3
57623.027	1.09	WHT	ACAM	1680	*z*	23.6 ± 0.3	1.4 ± 0.4
57623.878	1.941	GTC	CIRCE	540	*H*	>23.8	<1.1
57623.895	1.958	GTC	CIRCE	1800	*J*	>24.0	<0.9
57623.921	1.984	GTC	CIRCE	600	K_s	>23.3	<1.7
57623.958	2.021	GTC	OSIRIS	800	*g*	25.67 ± 0.15	0.22 ± 0.03
57623.965	2.028	GTC	OSIRIS	720	*r*	25.12 ± 0.12	0.36 ± 0.04
57623.973	2.036	GTC	OSIRIS	450	*i*	24.56 ± 0.12	0.58 ± 0.06
57623.980	2.043	GTC	OSIRIS	420	*z*	24.31 ± 0.17	0.72 ± 0.11
57625.564	3.627	*HST*	WFC3	2484	*F606W*	26.02 ± 0.06	0.157 ± 0.009
57625.631	3.694	*HST*	WFC3	2397	*F160W*	24.53 ± 0.08	0.57 ± 0.04
57625.697	3.760	*HST*	WFC3	2397	*F110W*	24.82 ± 0.05	0.44 ± 0.02
57625.929	3.992	GTC	OSIRIS	450	*g*	>25.6	<0.24
57625.934	3.997	GTC	OSIRIS	420	*i*	>25.8	<0.19
57626.234	4.297	Keck I	MOSFIRE	160	K_s	24.0 ± 0.4	0.9 ± 0.3
57626.922	4.985	GTC	OSIRIS	800	*r*	26.49 ± 0.20	0.101 ± 0.019
57629.402	7.465	Keck I	MOSFIRE	145	K_s	>23.9	<0.9
57630.321	8.383	Keck I	MOSFIRE	110	K_s	>23.7	<1.2
57631.924	9.987	GTC	OSIRIS	720	*i*	>26.0	<0.15
57631.935	9.998	GTC	OSIRIS	1200	*g*	>25.8	<0.20
57631.950	10.013	GTC	OSIRIS	960	*r*	>26.2	<0.13
57632.325	10.388	*HST*	WFC3	1863	*F606W*	27.9 ± 0.3	0.028 ± 0.008
57632.383	10.446	*HST*	WFC3	2397	*F110W*	26.9 ± 0.4	0.07 ± 0.02
57632.449	10.512	*HST*	WFC3	2397	*F160W*	26.6 ± 0.3	0.08 ± 0.02
57645.088	23.151	*HST*	WFC3	1350	*F606W*	>27.2	<0.05
57645.108	23.171	*HST*	WFC3	1497	*F110W*	>26.6	<0.09
57645.154	23.217	*HST*	WFC3	2097	*F160W*	>25.7	<0.19
57721.2	99.2	*HST*	WFC3	5395	*F110W*	reference	–
57725.3	103.3	*HST*	WFC3	2484	*F606W*	reference	–
58333.7	711.7	*HST*	WFC3	2796	*F160W*	reference	–
				Radio			
57622.11	0.17	VLA	–	3600	C	–	26 ± 5
57623.06	1.13	VLA	–	3600	C	–	<15
57632.01	10.07	VLA	–	6480	X	–	<11
57639.04	17.10	VLA	–	6460	X	–	<33
				X-ray			
57721.995	0.057	*Swift*	XRT	185	0.3–10 keV	–	$0.15^{+0.08}_{-0.06}$
57722.001	0.063	*Swift*	XRT	566	0.3–10 keV	–	$0.05^{+0.03}_{-0.02}$
57722.008	0.070	*Swift*	XRT	784	0.3–10 keV	–	0.05 ± 0.02
57722.064	0.126	*Swift*	XRT	363	0.3–10 keV	–	$0.08^{+0.04}_{-0.03}$
57722.068	0.130	*Swift*	XRT	396	0.3–10 keV	–	$0.07^{+0.04}_{-0.03}$
57722.074	0.136	*Swift*	XRT	865	0.3–10 keV	–	$0.037^{+0.018}_{-0.014}$
57722.132	0.195	*Swift*	XRT	862	0.3–10 keV	–	0.035 ± 0.019
57722.222	0.285	*Swift*	XRT	1273	0.3–10 keV	–	$0.025^{+0.014}_{-0.010}$
57722.264	0.327	*Swift*	XRT	584	0.3–10 keV	–	0.05 ± 0.02
57722.278	0.340	*Swift*	XRT	1584	0.3–10 keV	–	0.029 ± 0.011
57722.356	0.419	*Swift*	XRT	3908	0.3–10 keV	–	0.014 ± 0.05
57722.962	1.024	*Swift*	XRT	9008	0.3–10 keV	–	$(3.6 \pm 0.2)\times 10^{-3}$
57724.725	2.327	*Swift*	XRT	8777	0.3–10 keV	–	$<4.6 \times 10^{-3}$
57625.879	3.942	XMM-Newton	EPIC/PN	10880	0.3–10 keV	–	$(2.3 \pm 0.3)\times 10^{-3}$
57631.913	9.976	XMM-Newton	EPIC/PN	22665	0.3–10 keV	–	$(2.9 \pm 1.5)\times 10^{-4}$
57737.570	15.1[illegible]2	*Swift*	XRT	26000	0.3–10 keV	–	$<10^{-3}$

Troja, Castro-Tirado, JBG et al. 2019, MNRAS, 498, 2104

GRB160821B

Optical-nIR

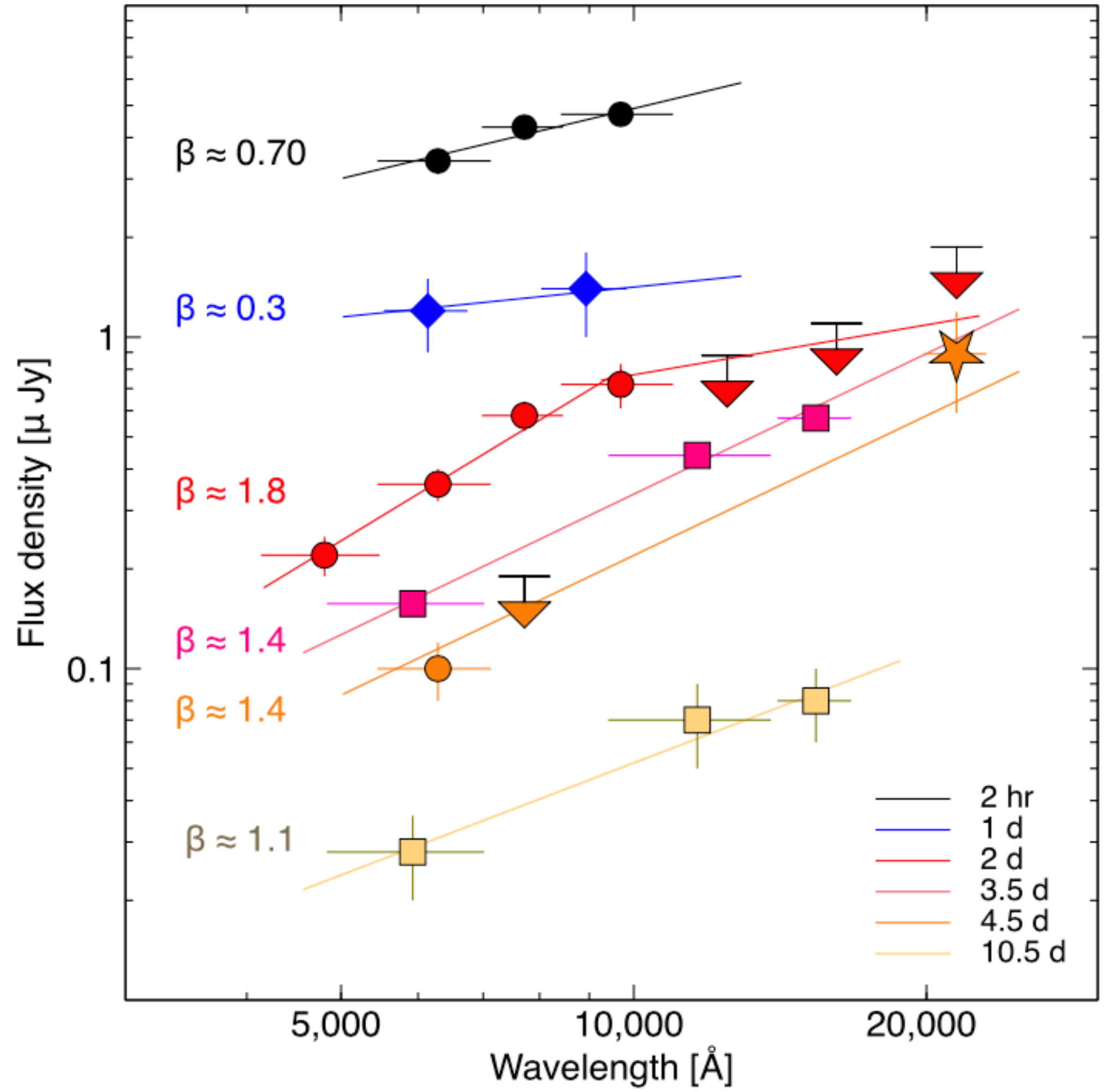


Figure 2. Colour evolution of the optical/nIR counterpart, compiled including data from GTC (circles), WHT (diamonds), Keck (star), and *HST* (squares).

X-rays

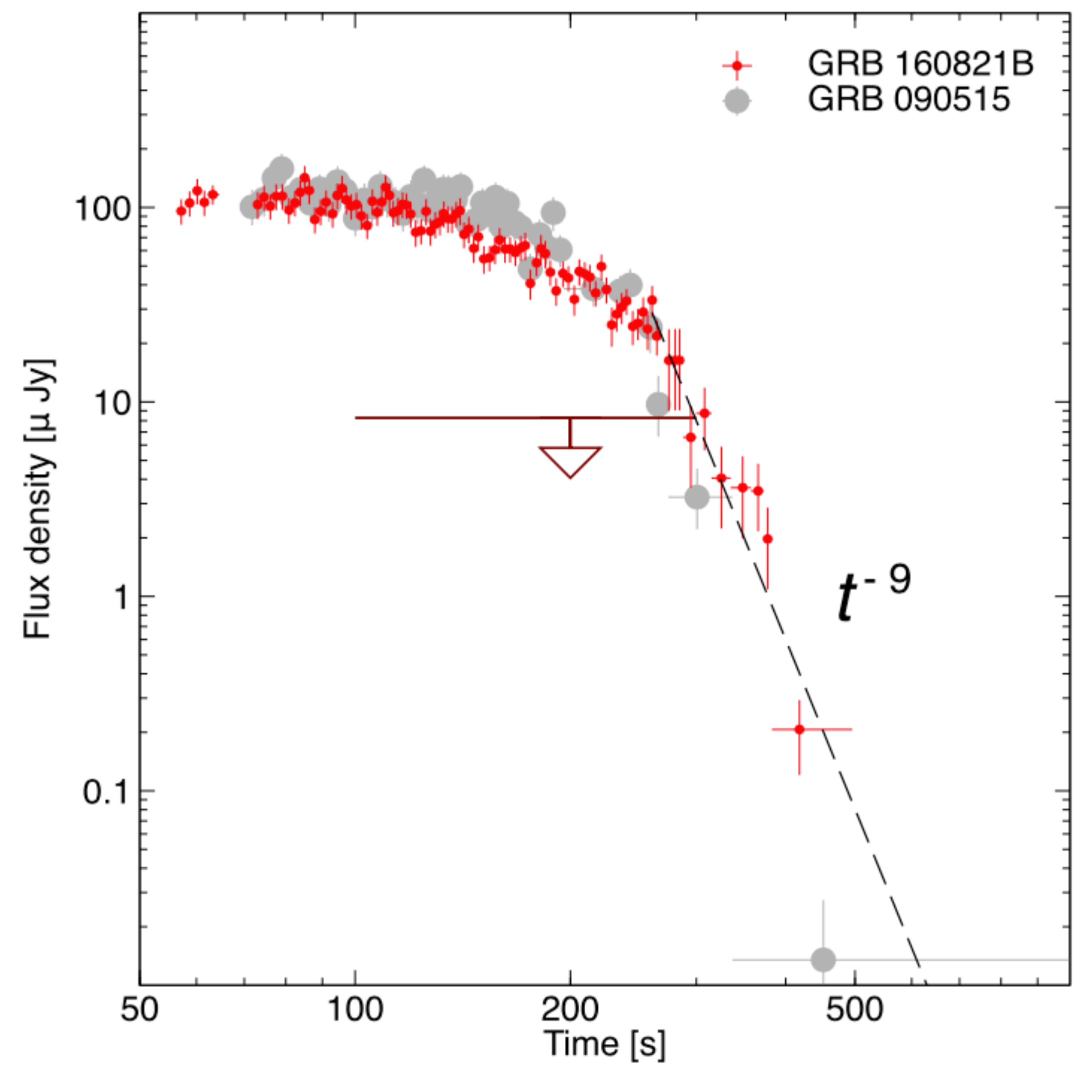
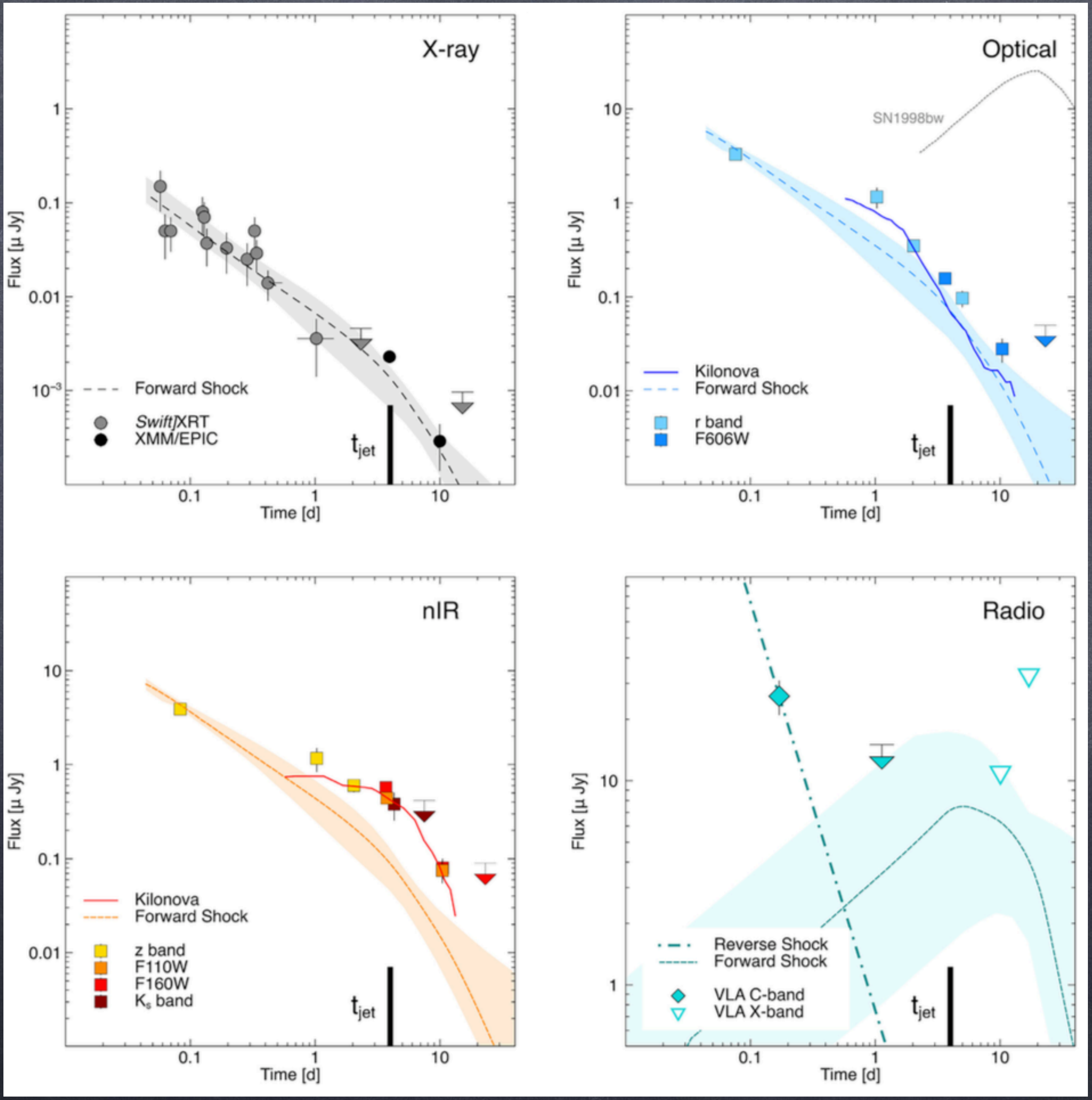


Figure 3. Temporal evolution of the early X-ray afterglow of GRB160821B (red circles) and, for comparison, GRB090515 (grey circles; Rowlinson et al. 2010). The sharp drop in flux ($\propto t^{-9}$, dashed line) and the deep upper limit from *Swift*/UVOT rule out an external shock origin for the observed X-ray emission.

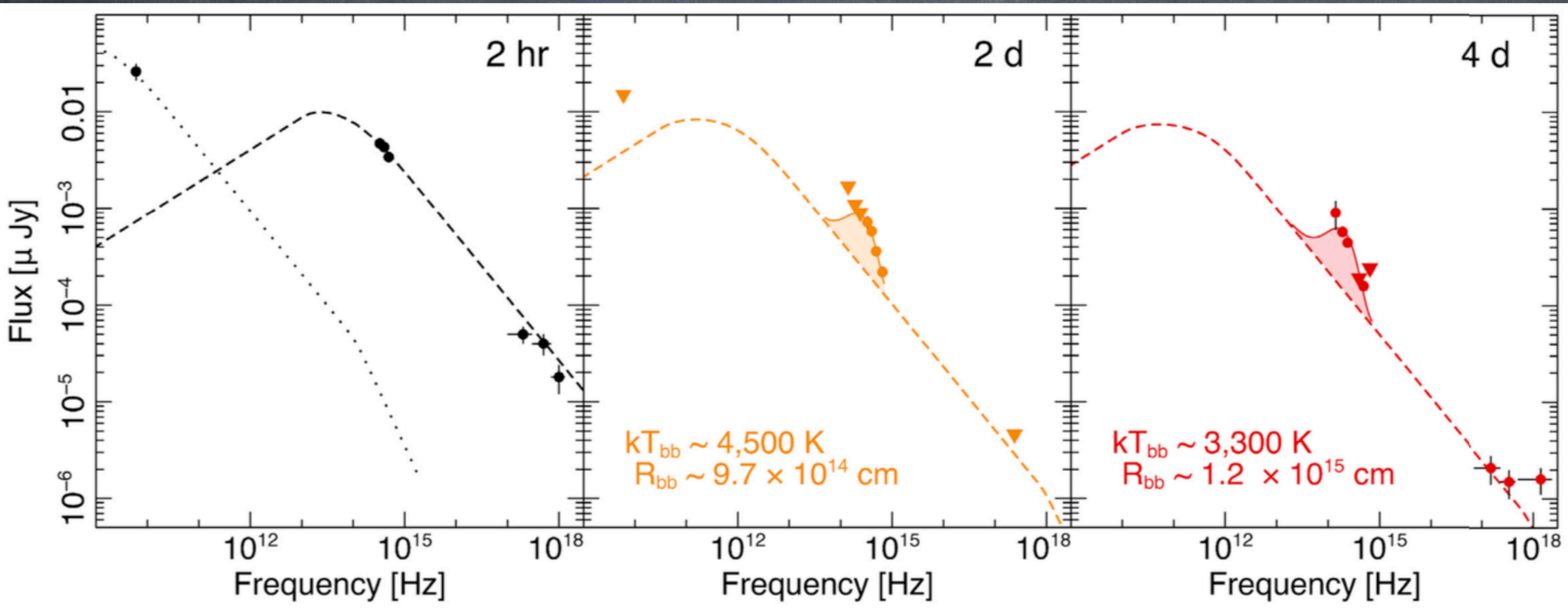
Troja, Castro-Tirado, JBG et al. 2019, MNRAS, 498, 2104

GRB160821B



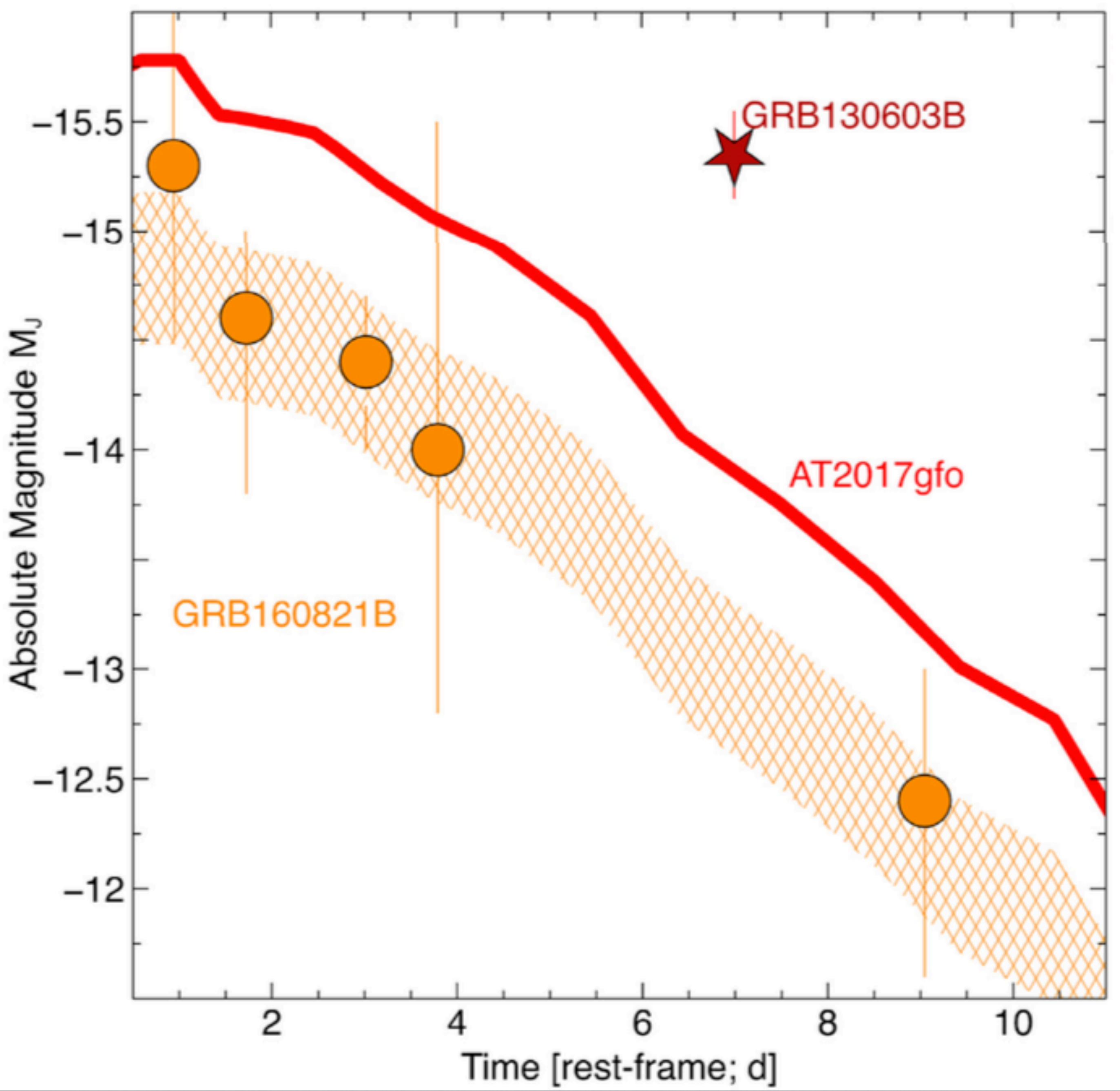
Troja, Castro-Tirado, JBG et al. 2019, MNRAS, 498, 2104

GRB160821B



Troja, Castro-Tirado, JBG et al. 2019, MNRAS, 498, 2104

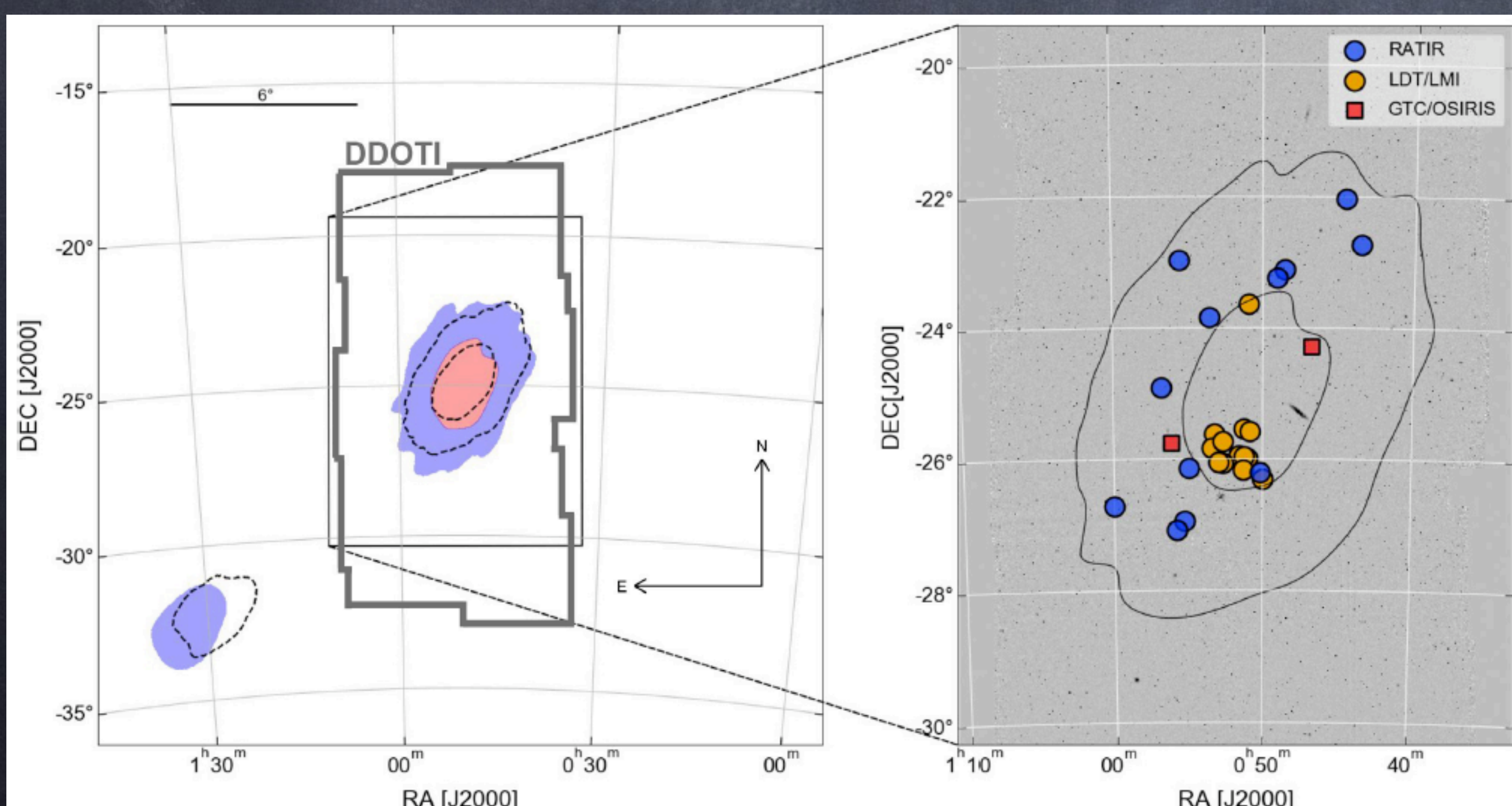
GRB160821B



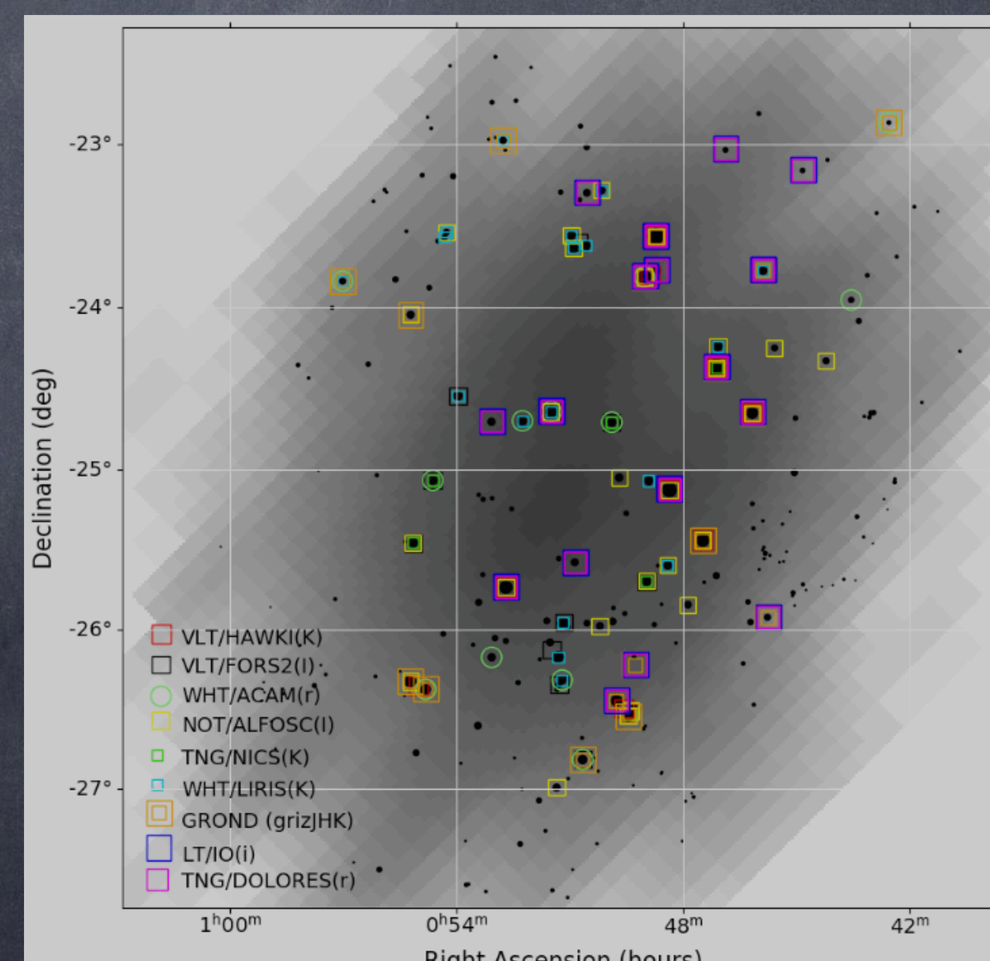
Troja, Castro-Tirado, JBG et al. 2019, MNRAS, 498, 2104

GW counterpart hunting O3

- GTC: We had several proposals approved for GW counterpart searchings since few years
- Observational campaigns with WHT (4.2 m) and NOT (2.6 m) telescopes
- Unfortunately, no GW counterpart was found during O3
- GCNs/ATels from follow up observations



Thakur et al. 2020, MNRAS, 499, 3868



Ackley et al. 2020, A&A, 643, A113

Subaru-GTC collaboration

- GW electromagnetic counterpart searches were the main driver for the collaboration during O3 run
- Subaru 8.2m telescope located in Hawaii
  - HyperSuprime Camera (HSC): 1.5 degrees diameter
  - Great instrument to search for possible counterparts.
  - Spectroscopic confirmation is needed
  - Subaru cannot easily change instruments

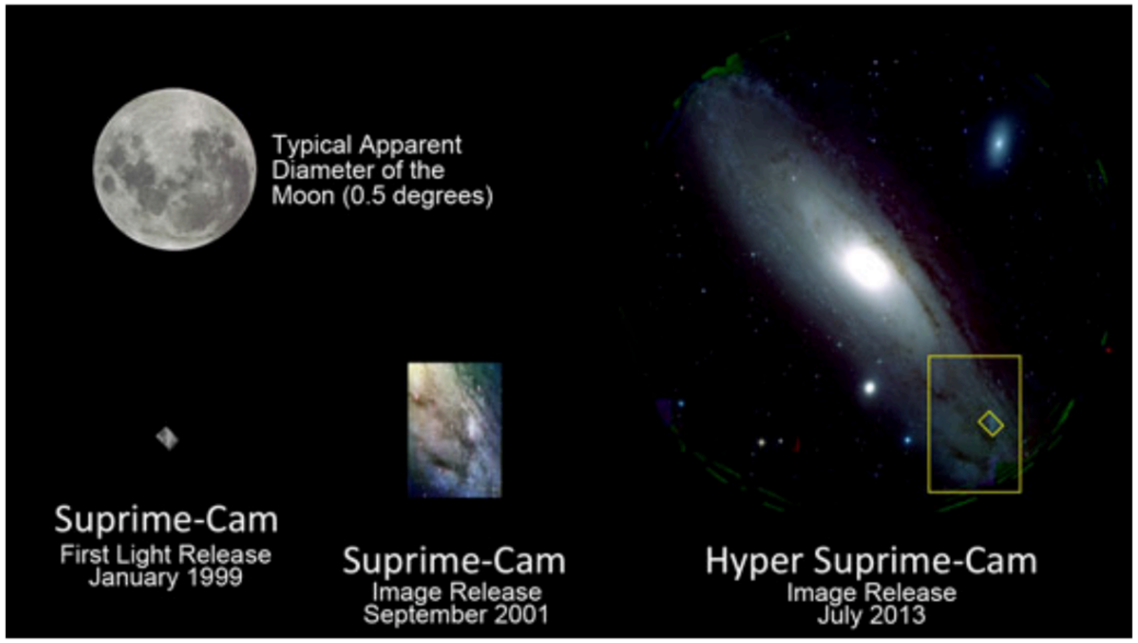


Figure 2: A comparison of the images of M31 captured by Suprime-Cam (bottom left and middle) and HSC (right). The yellow-outlined boxes within HSC's image illustrate the dramatic difference between Suprime-Cam's field of view and HSC's as well as the high quality of resolution in the HSC image. An image of the apparent diameter of the Moon is shown as a standard by which to compare the fields of view of the Suprime-Cam and HSC images. Credit: NAOJ

Subaru-GTC collaboration

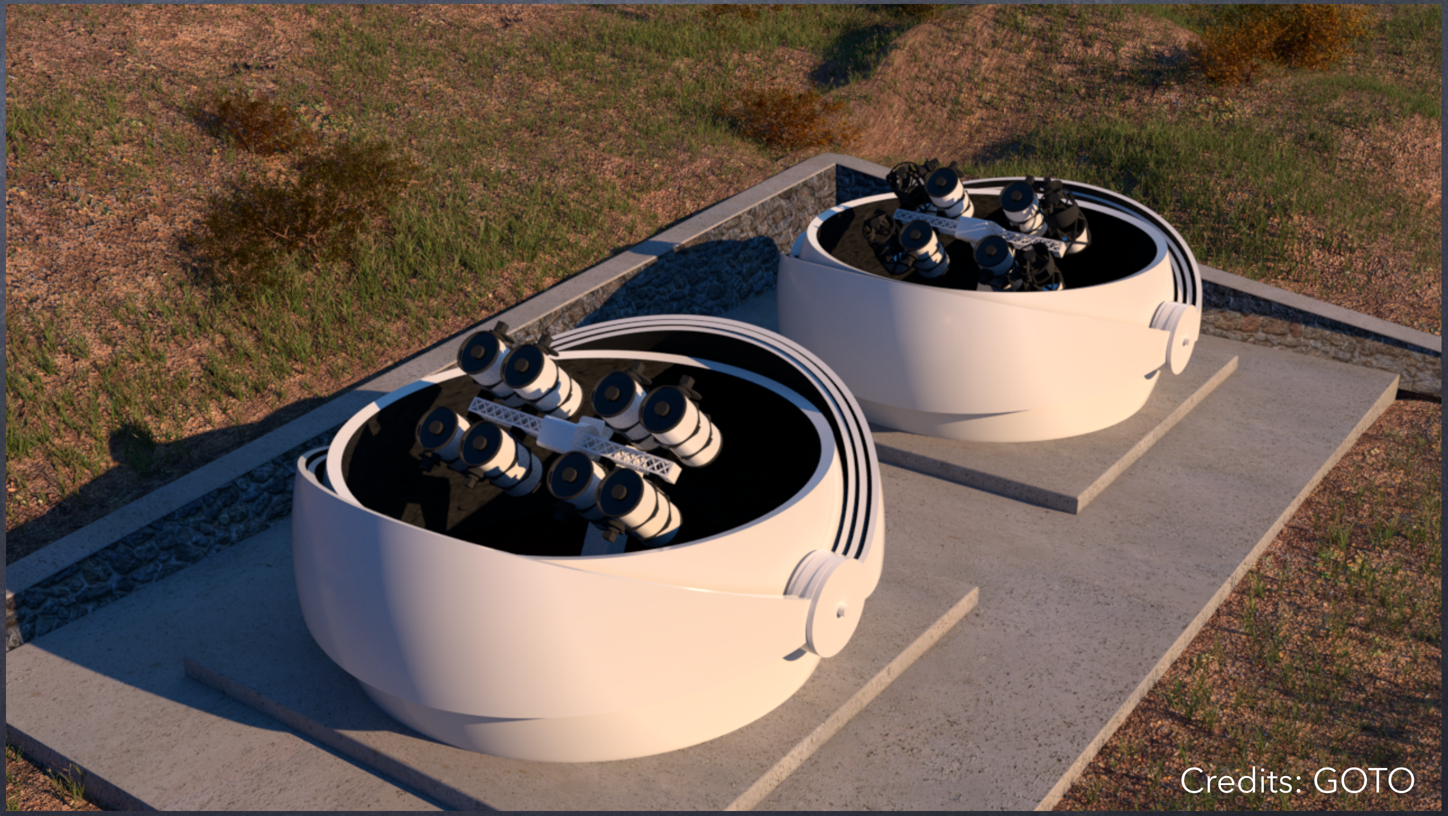
- GTC 10.4 m @ La Palma
  - Ideal for spectroscopic characterization (OSIRIS, EMIR)
  - The time difference between the two observatories allow us to reduce and analyze the Subaru data

Subaru-GTC collaboration

- O3 run:
  - Unfortunately, it finished earlier than expected
  - The BBH merger S200224a detected by LIGO & Virgo with a localization uncertainty of 72 deg (90% containment)
  - Subaru HSC observed around 80% of the area
  - 5 transients were found as possible candidate counterpart from different epoch observations. However, only photometric redshift of the host galaxies were available
  - Due to COVID-19, the spectroscopic observations of the host galaxies have been performed early 2021 in order to confirm their redshifts
  - Work in progress...

GOTO project

- Two domes @ La Palma
- 8 telescopes per mount
- 40 cm diameter
- The full telescope configuration will allow to scan the visible sky down to ~19-20 magnitud every 2-3 days
- Quick response, ~10 degrees/second
- Quick reduction and data analysis
- The project will be extended to Australia



Now hiring!

Instituto de Astrofísica de Canarias • IAC

0 items | EN

ABOUT US · OBSERVATORIOS DE CANARIAS · SCIENCE AND TECHNOLOGY · POSTGRADUATE TRAINING · OUTREACH · INTRANET

Home › Employment › Un contrato postdoctoral GOTO 2019 / One Postdoctoral contract GOTO 2019 (PS-2019-088)

Un contrato postdoctoral GOTO ~~2019~~ / One Postdoctoral contract GOTO ~~2019 (PS-2019-088)~~ 2021

The call will be opened soon!

BOOKMARK THIS

APPLICATION DEADLINE:	[redacted] 15/09/2021
ADVERTISED ON:	[redacted]
MANAGEMENT UNIT / INFORMATION:	RESEARCH DIVISION secinv@iac.es
POSITION CODE:	[redacted]
JOB VACANCIES:	1
PROFESSIONAL CATEGORY:	Postdoc
CONTRACTUAL MODALITY:	Postdoc assigned to specific scientific or technical project
DURATION:	Temporary
MONTHS:	30

STATE:	RESOLVED
PROFESSIONAL PROFILE:	POSTDOCTORAL RESEARCHER
REQUIRED DEGREE:	DOCTORATE (QF-EHEA THIRD CYCLE)

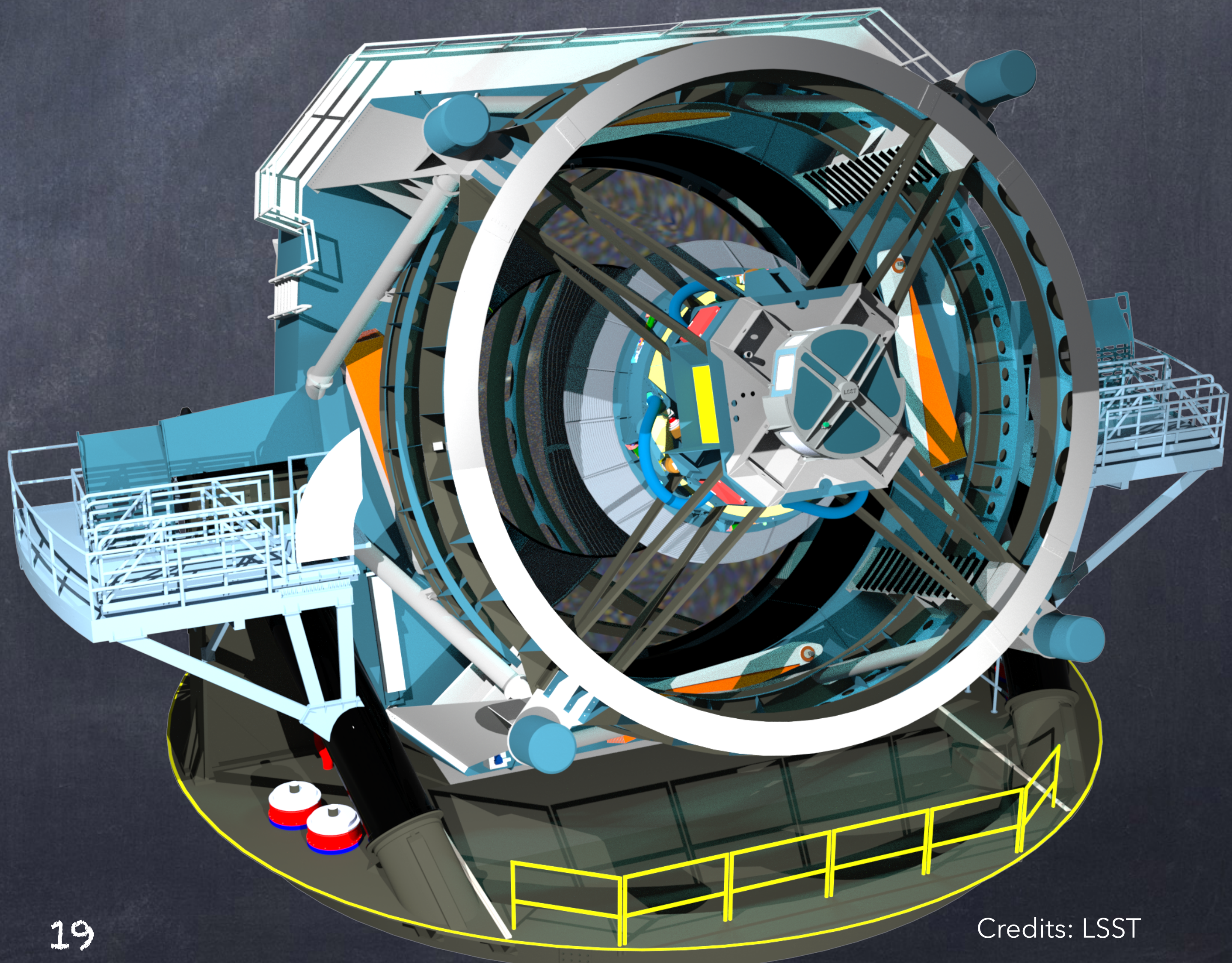
PS-2019-088 Bases Convocatoria GOTO

Contact us if you are interested:

jbecerra@iac.es, mapt@iac.es

Vera C. Rubin Observatory

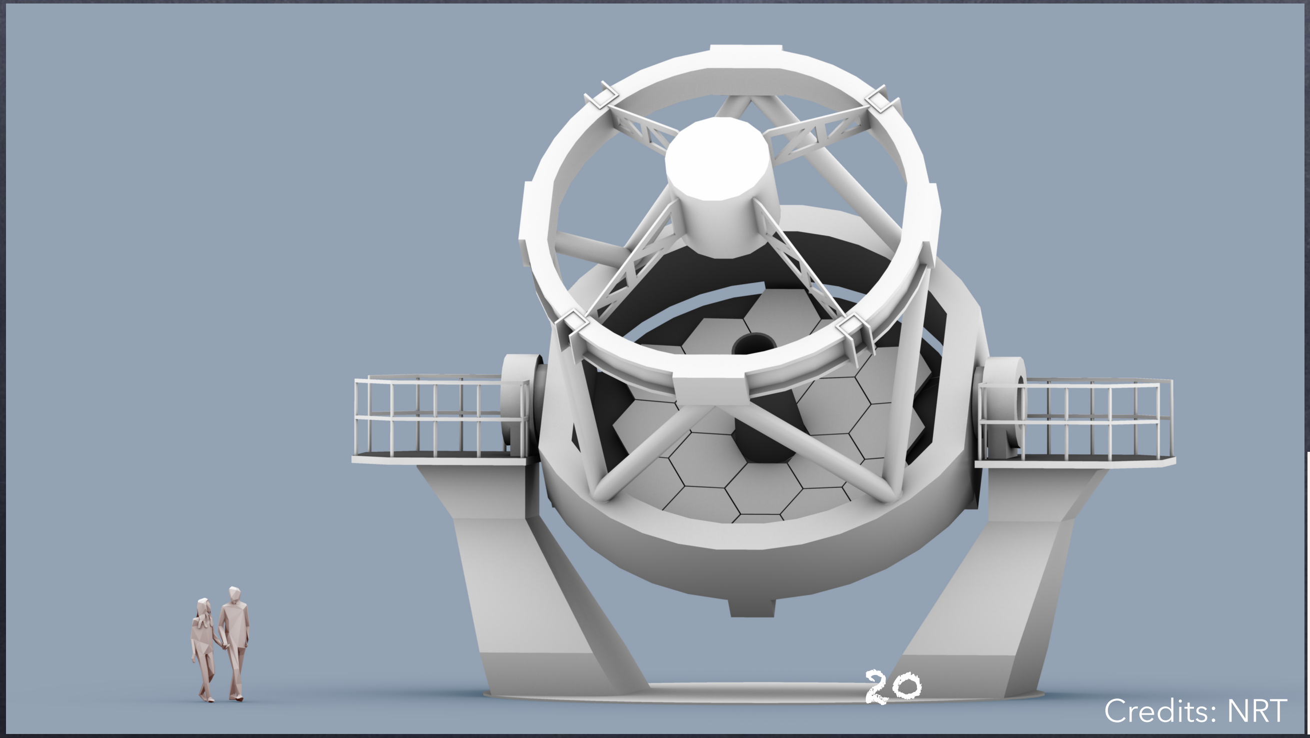
- The transient machine
- Large Synoptics Survey Telescope
- 8.4m telescope
- Large FoV~9.6 deg^2
- Limiting magnitude g~25 in 30 s
- Synergies with GTC for spectroscopic follow up of good GW counterpart candidates



Credits: LSST

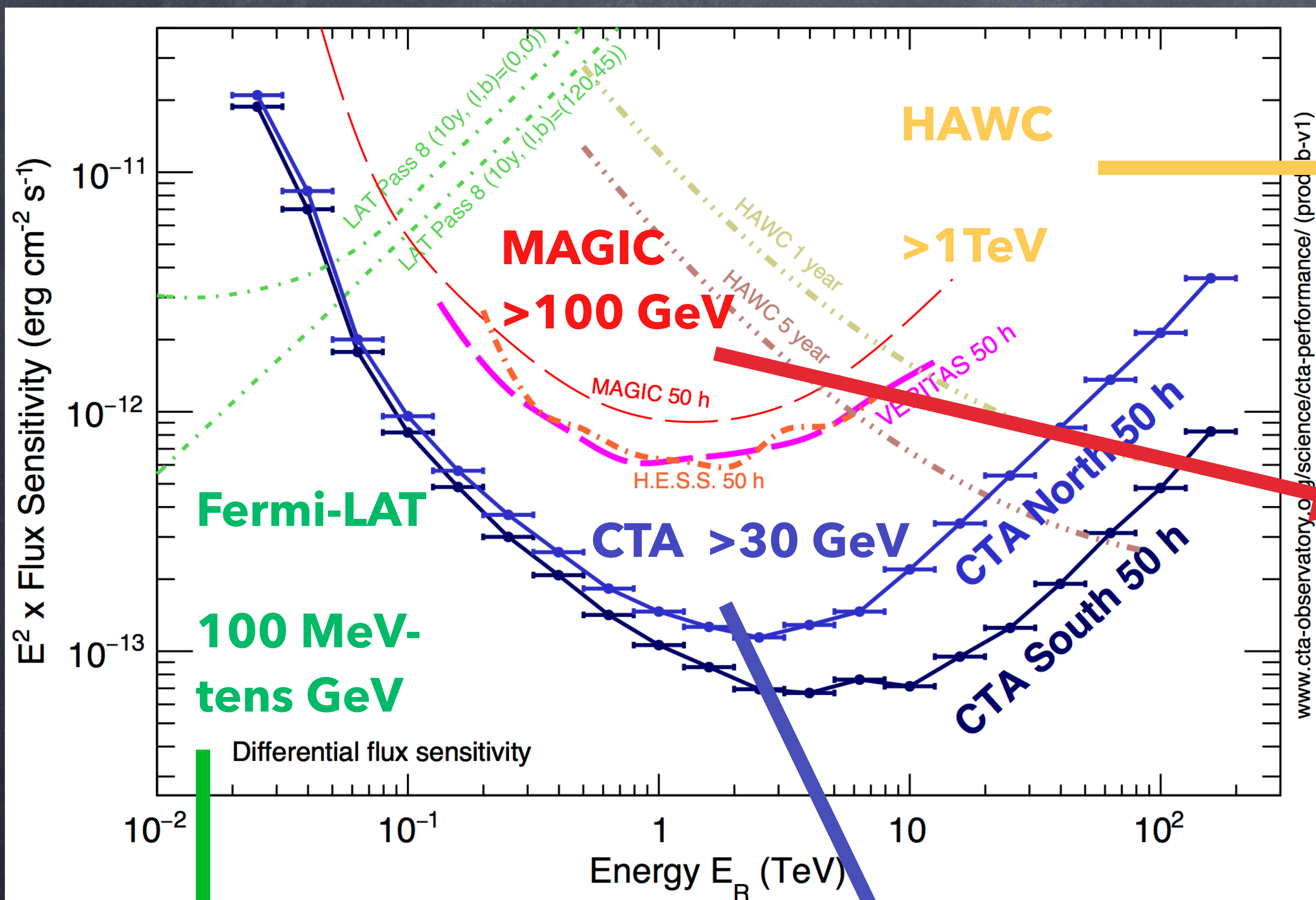
New Robotic Telescope (NRT)

- 4 m robotic telescope @ La Palma
- Focused on the study of transients
- Quick response
- Quick data reduction and analysis
- Telescope design is almost fixed
- Instrumentation design in progress

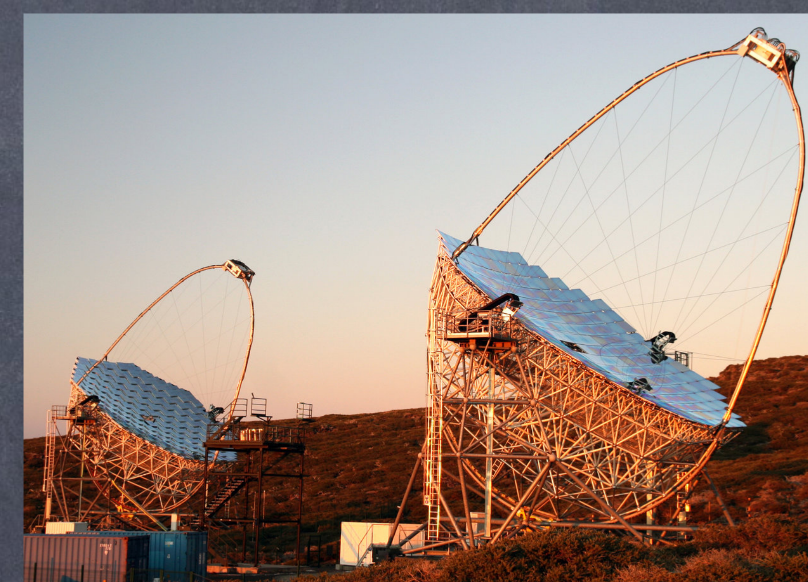


Credits: NRT

Gamma-ray observations



HAWC: Water Cherenkov



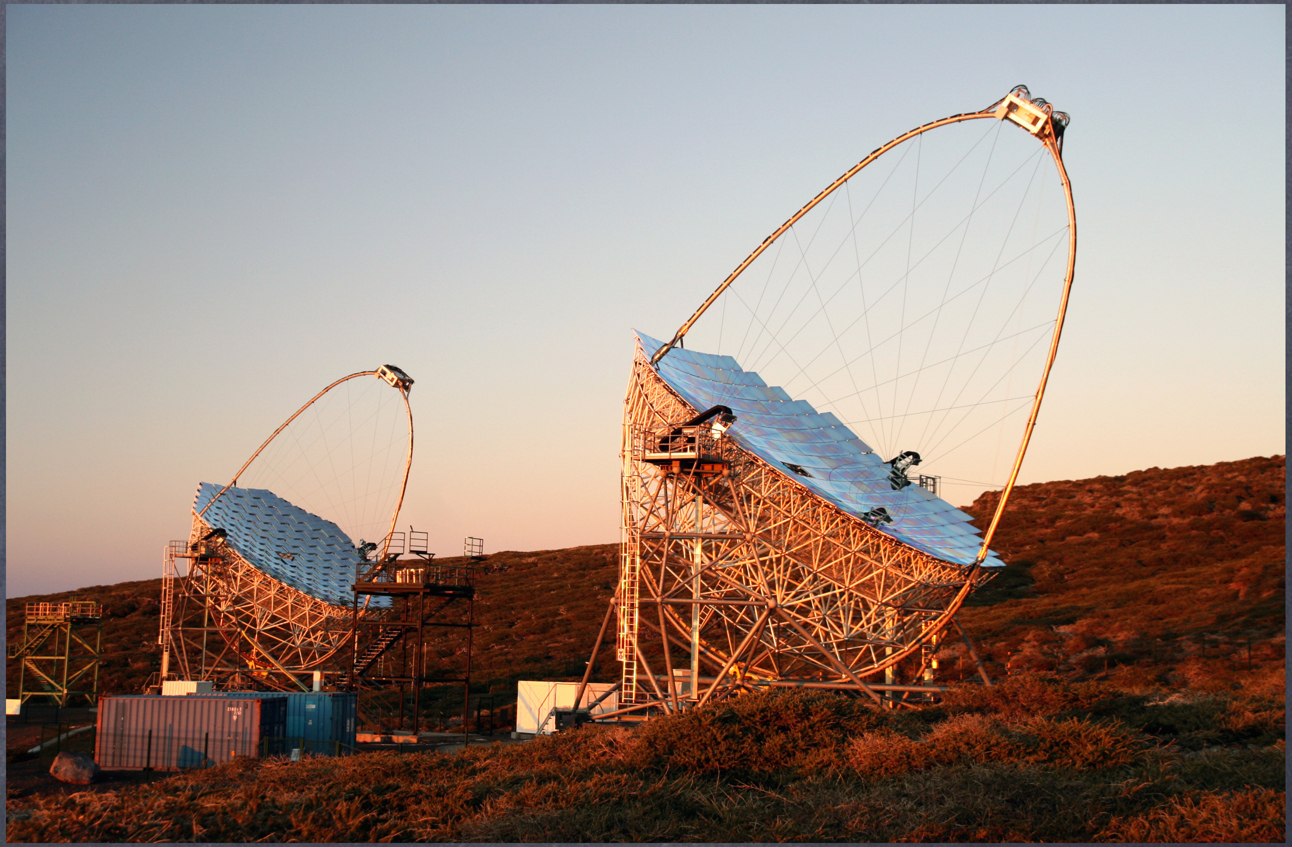
MAGIC: Air Cherenkov

Satélite **Fermi-LAT**

CTA: Air Cherenkov

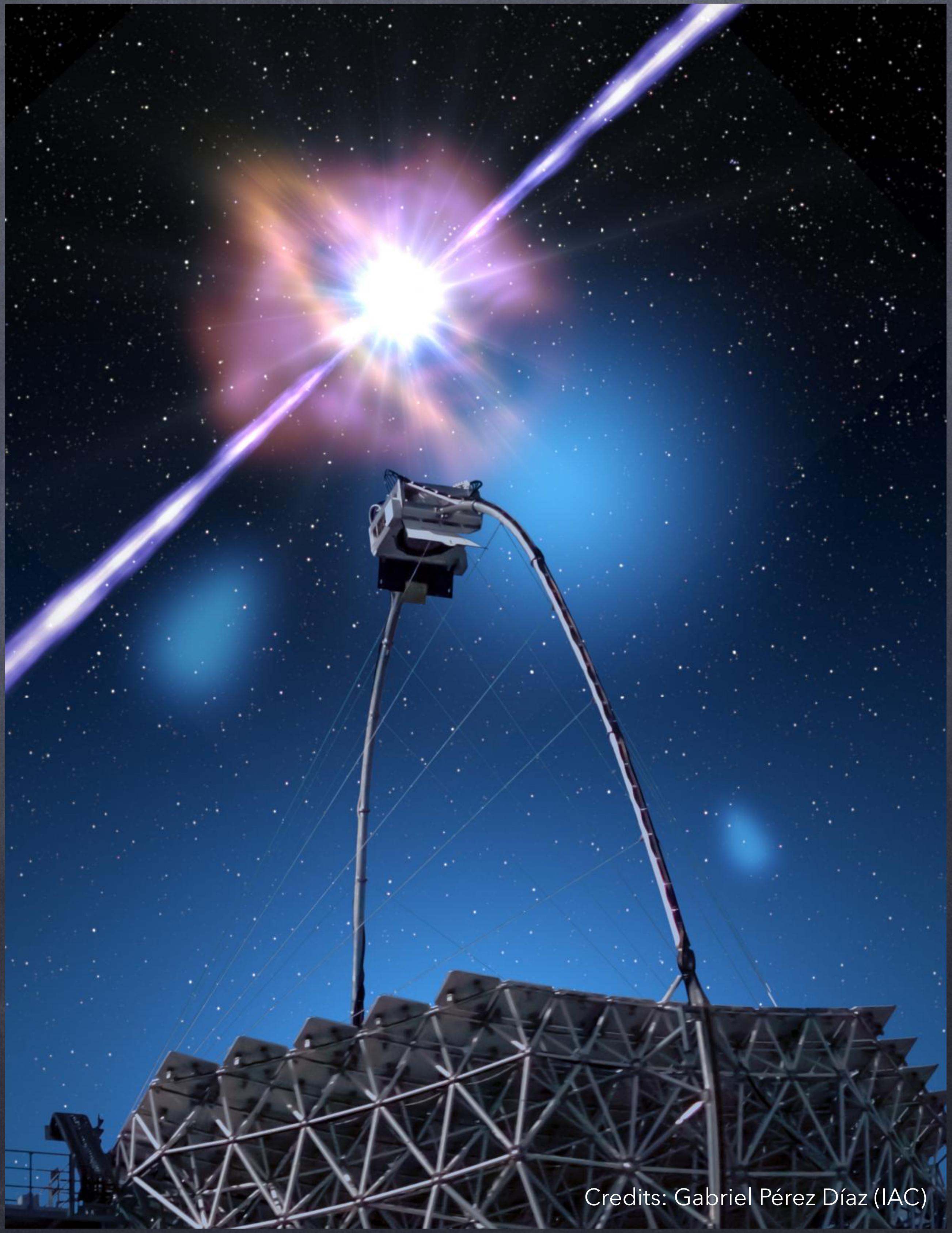
MAGIC telescopes

- 2 x 17 m diameter @ La Palma
- Stereoscopic operation
- FoV~3.5 degrees
- MAGIC was designed for GRB follow up, able to repoint in 30 s
- First detection of a GRB (GRB190114C) in the VHE gamma-ray band
- This detection open the door of the very-high-energy sky to GW counterparts
- GW counterpart searches already at work



MAGIC telescopes

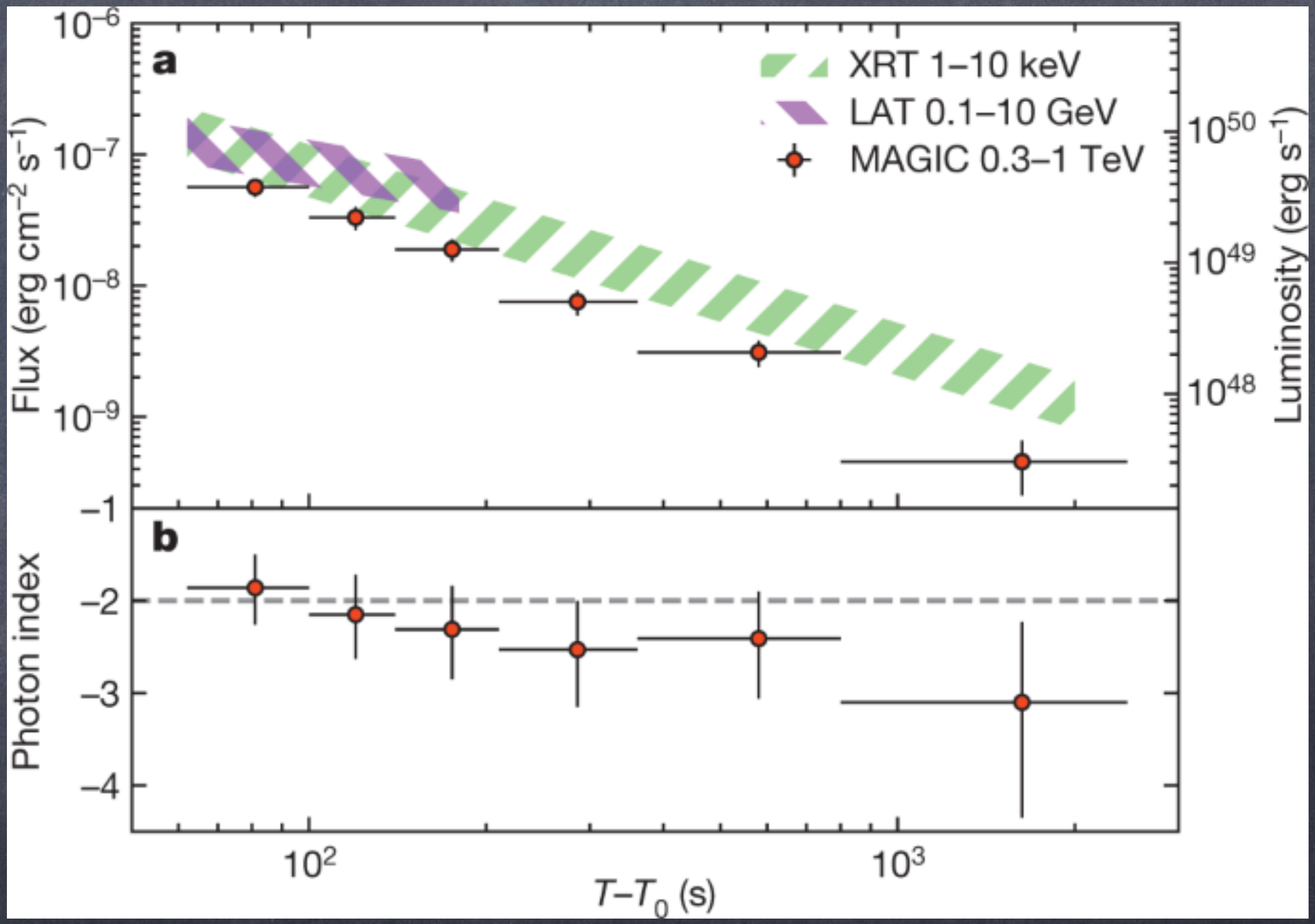
- 2 x 17 m diameter @ La Palma
- Stereoscopic operation
- FoV~3.5 degrees
- MAGIC was designed for GRB follow up, able to repoint in 30 s
- First detection of a GRB (GRB190114C) in the VHE gamma-ray band
- This detection open the door of the very-high-energy sky to GW counterparts
- GW counterpart searches already at work



Credits: Gabriel Pérez Díaz (IAC)

MAGIC telescopes

- 2 x 17 m diameter @ La Palma
- Stereoscopic operation
- FoV~3.5 degrees
- MAGIC was designed for GRB follow up, able to repoint in 30 s
- First detection of a GRB (GRB190114C) in the VHE gamma-ray band
- This detection open the door of the very-high-energy sky to GW counterparts
- GW counterpart searches already at work



MAGIC coll. Nature, 2019, 575, 455

Cherenkov Telescope Array (CTA)

Credits: Gabriel Pérez Diaz (IAC)

Cherenkov Telescope Array (CTA)

Credits: Gabriel Pérez Diaz (IAC)

ASTRI Mini-Array

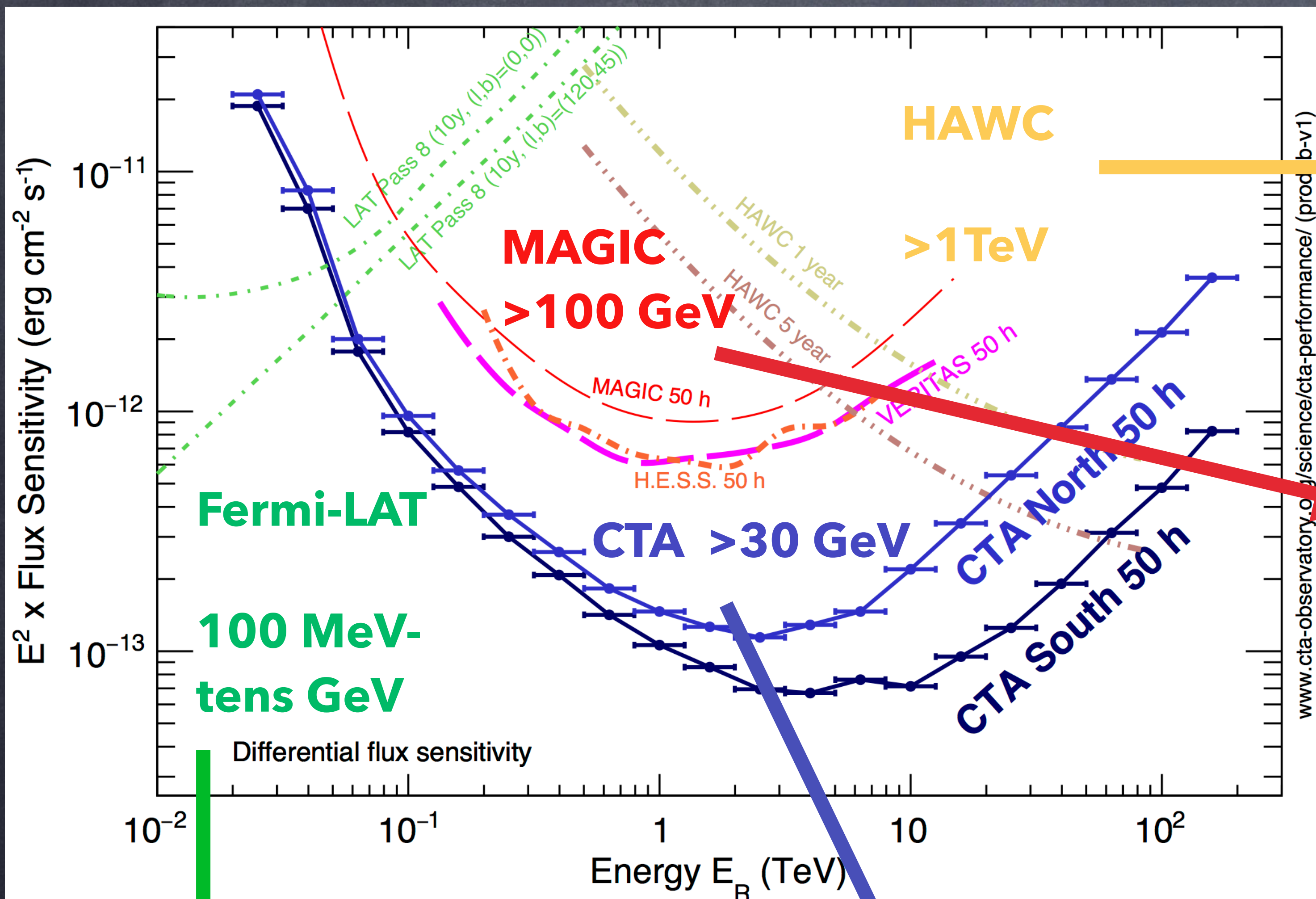
- Array of 9 Small Size Telescopes (SST)
- Precursor for CTA south observatory
- Installation at Teide Observatory (Tenerife)

Credits: ASTRI

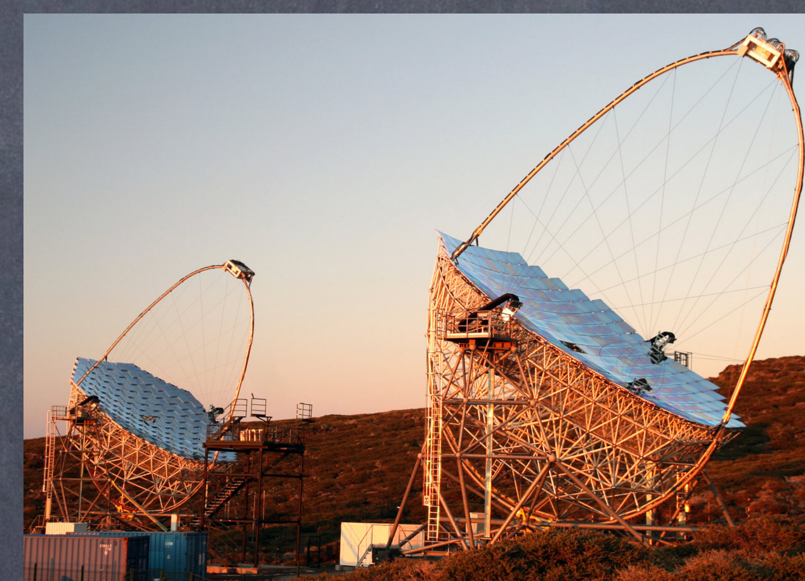
Key information for VHE follow up

- While the FoV (~3.5-10 degrees) is relatively large w.r.t. optical telescopes, the sensitivity is limited mainly due to the strong background
- Large area surveys cannot be performed with an acceptable sensitivity in short time. Divergent pointing can help, although it is energy dependent
- Small error boxes/pointing observations are required
- It is crucial to know the distance of the target

Gamma-ray observations



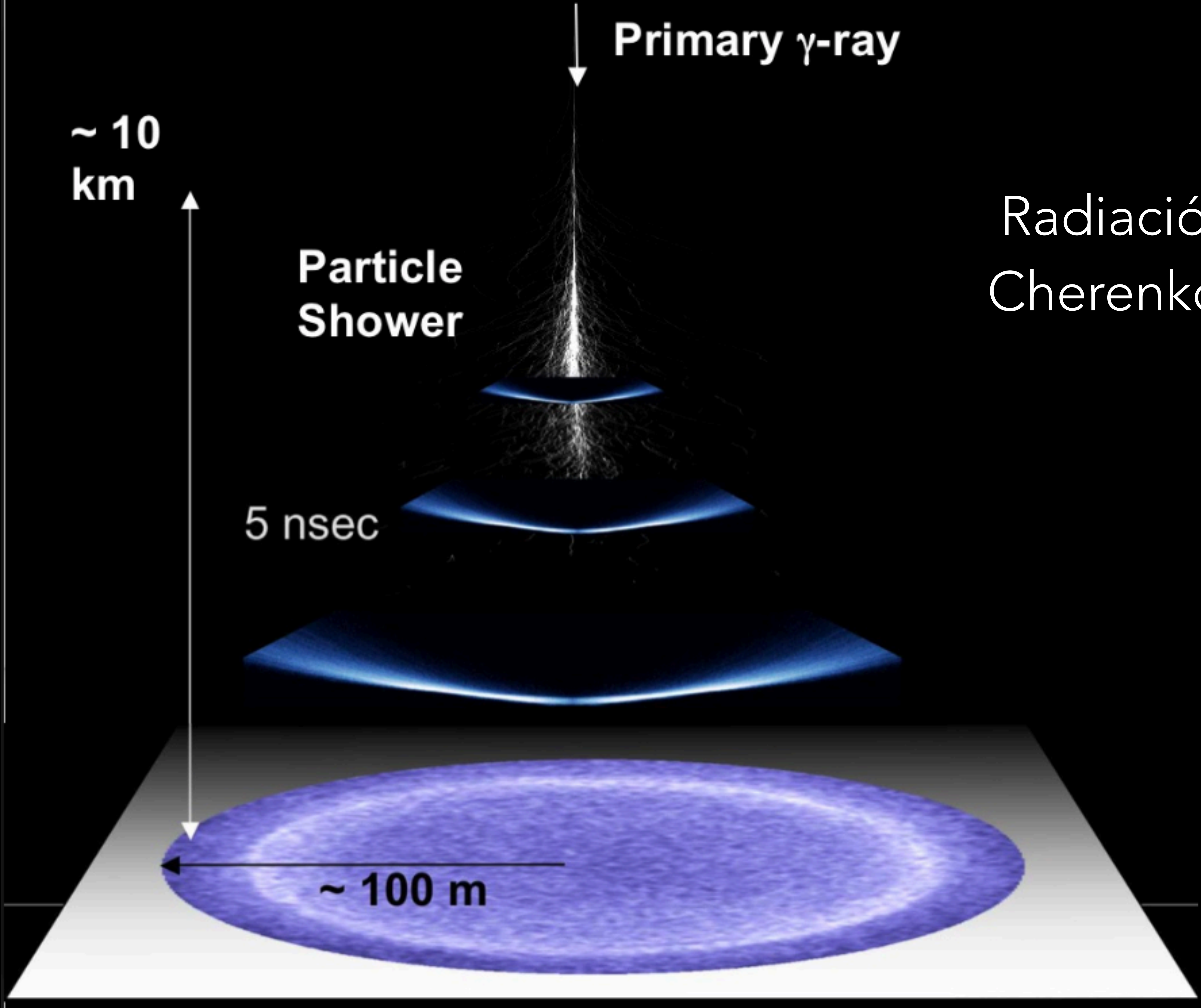
HAWC: Water Cherenkov



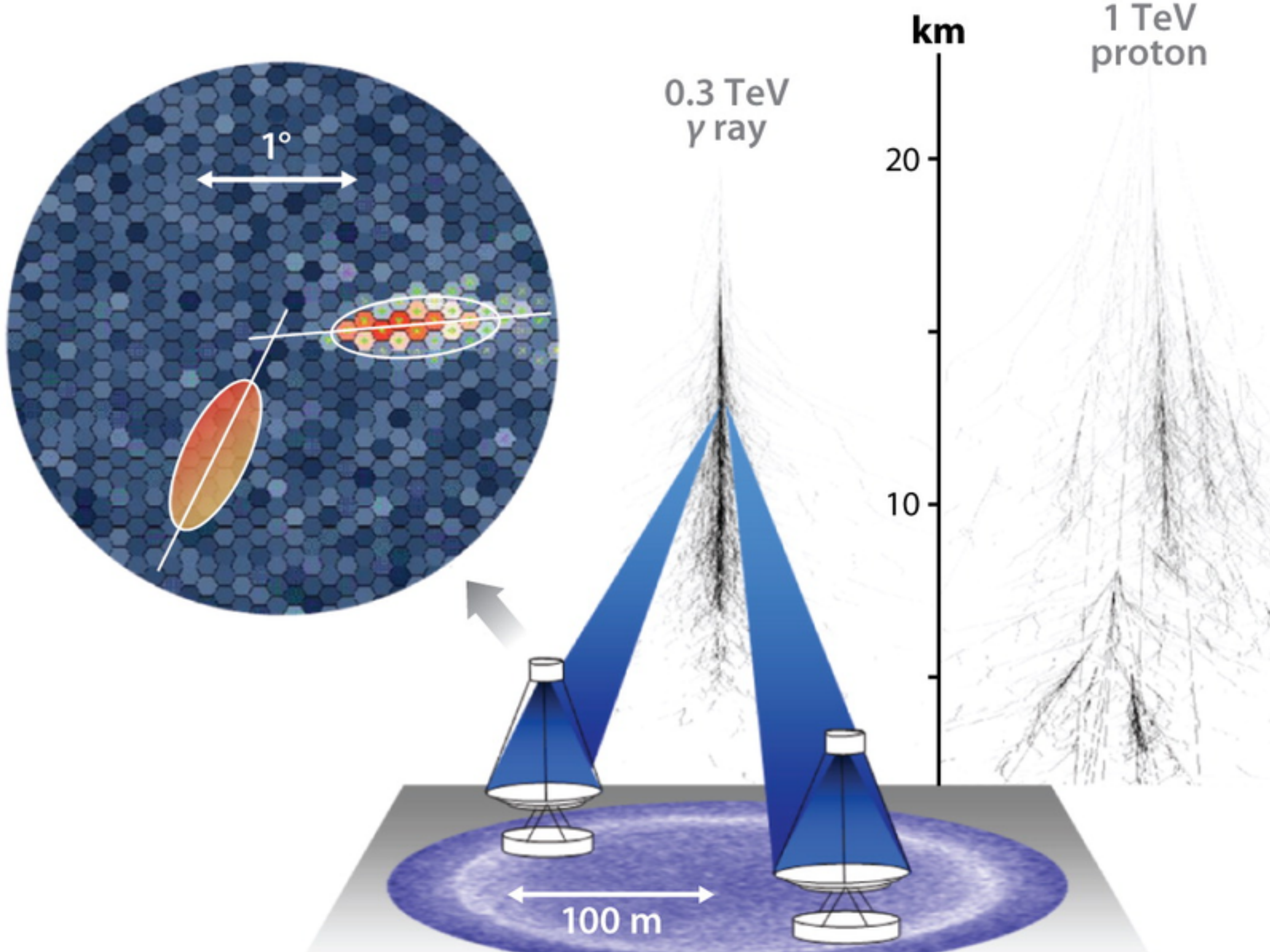
MAGIC: Air Cherenkov

Satélite **Fermi-LAT**

CTA: Air Cherenkov



Radiación Cherenkov

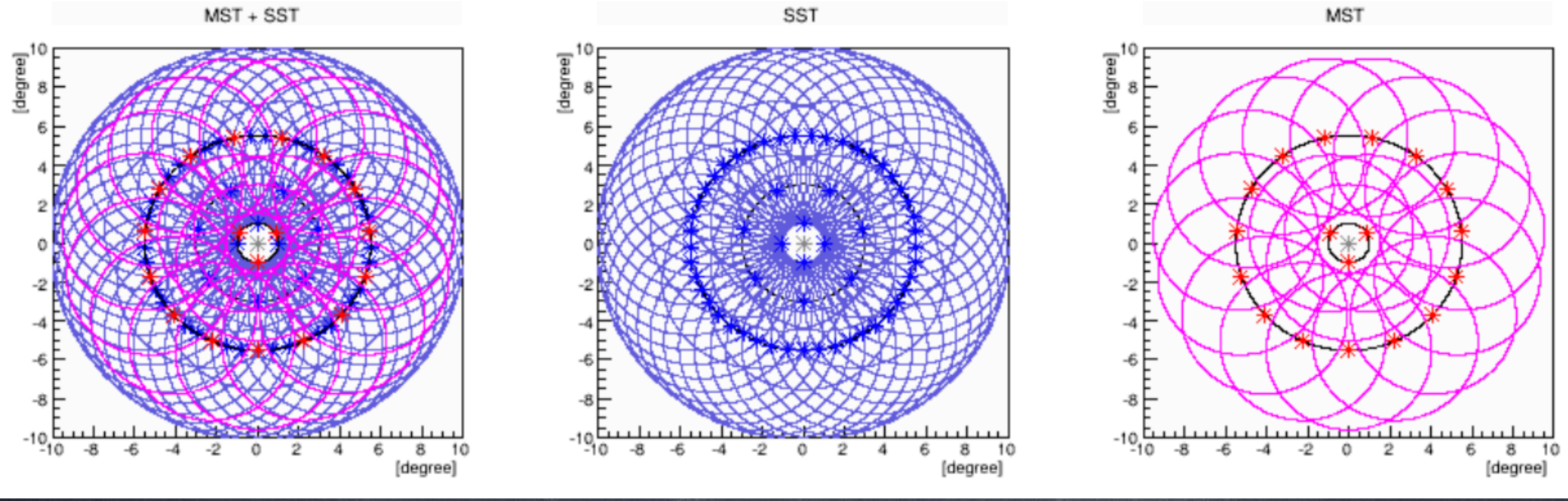


1°
0.3 TeV
γ ray
km
1 TeV
proton
20
10
100 m

Key information for VHE follow up

- While the FoV (~3.5-10 degrees) is relatively large w.r.t. optical telescopes, the sensitivity is limited mainly due to the strong background
- Large area surveys cannot be performed with an acceptable sensitivity in short time. Divergent pointing can help, although it is energy dependent
- Small error boxes/pointing observations are required
- It is crucial to know the distance of the target

Example divergent pointing for CTA

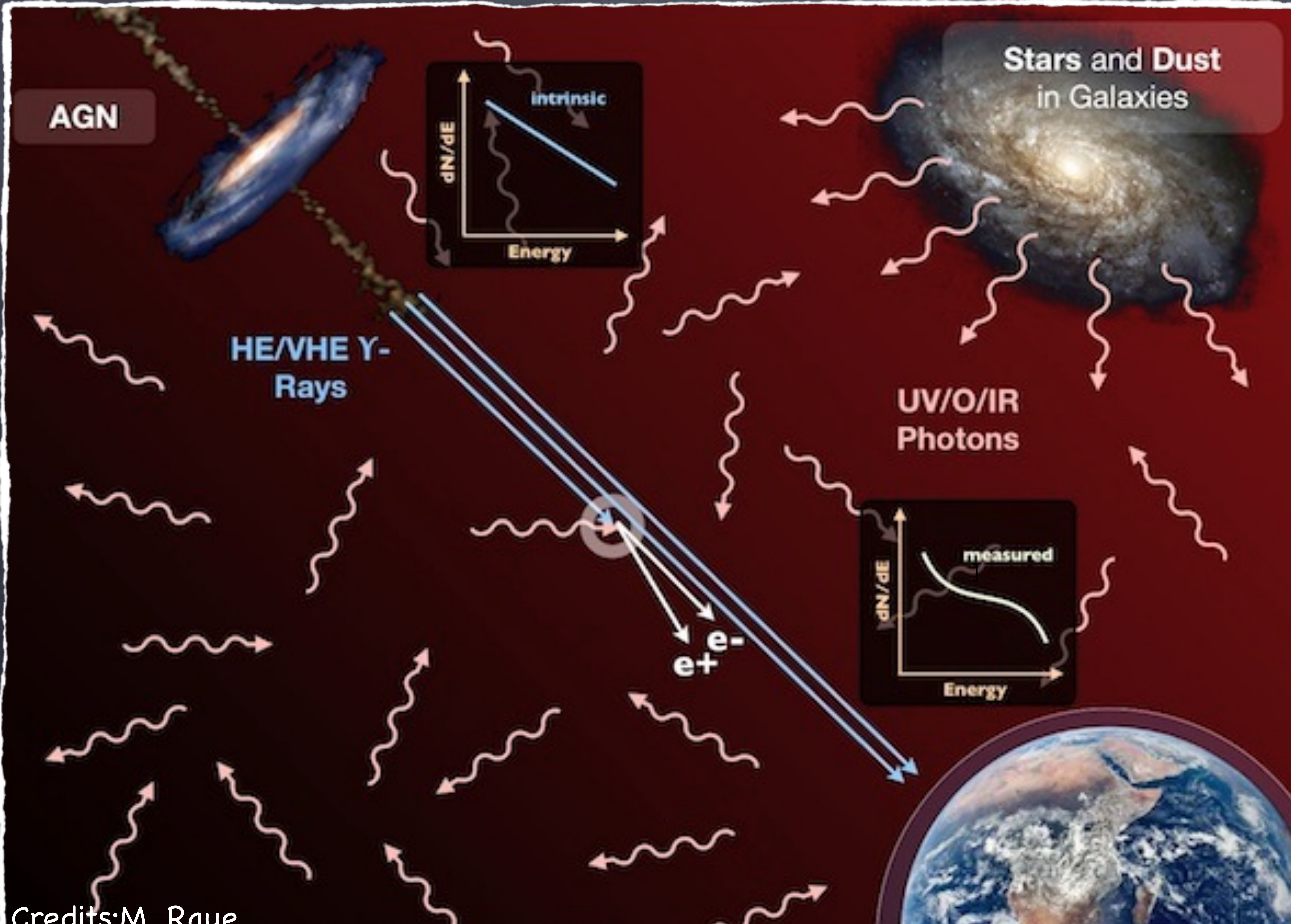


Gérard, CTA coll. 2015, ICRC

Key information for VHE follow up

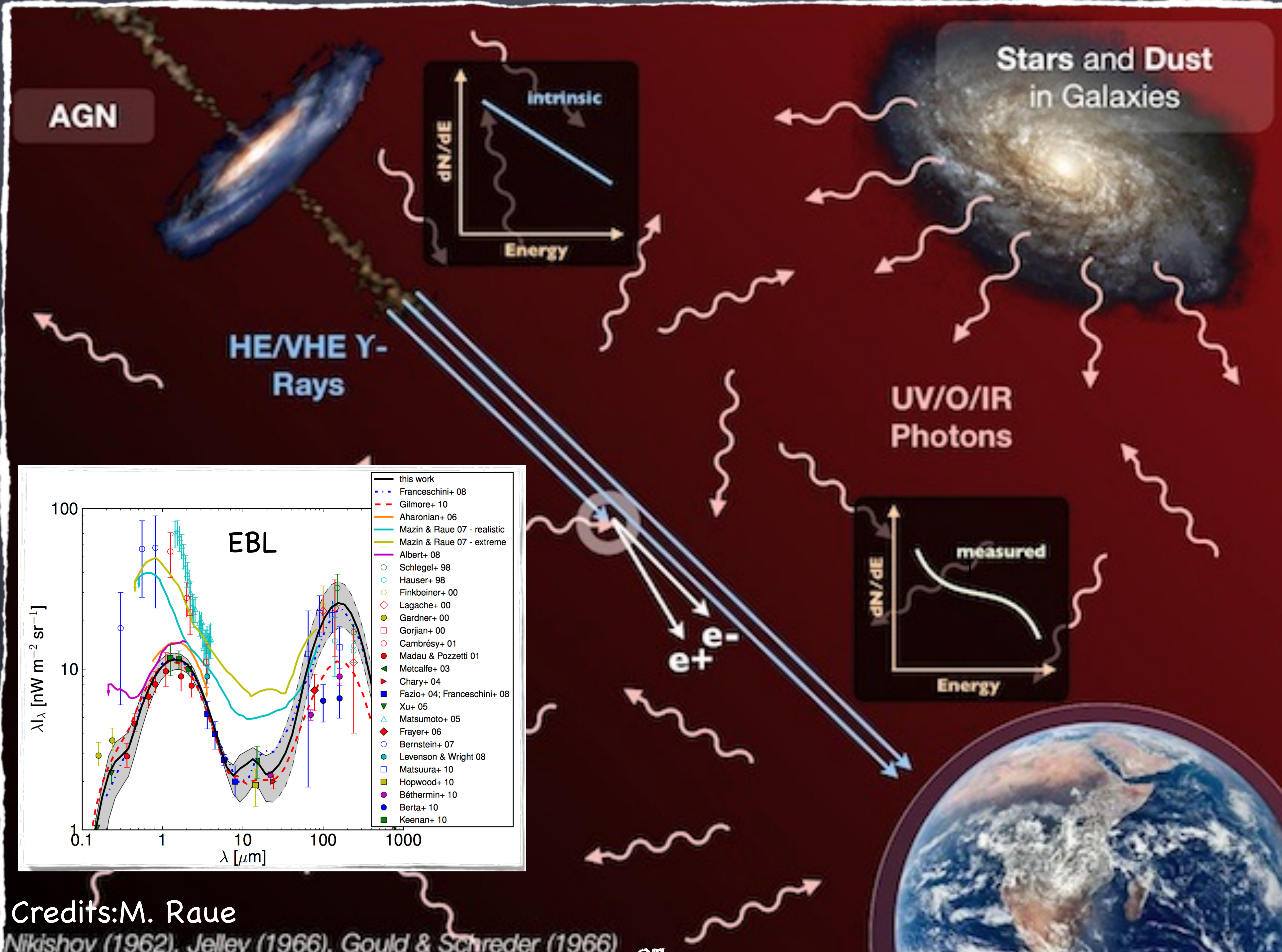
- While the FoV (~3.5-10 degrees) is relatively large w.r.t. optical telescopes, the sensitivity is limited mainly due to the strong background
- Large area surveys cannot be performed with an acceptable sensitivity
- Small error boxes/pointing observations are required
- It is crucial to know the distance of the target

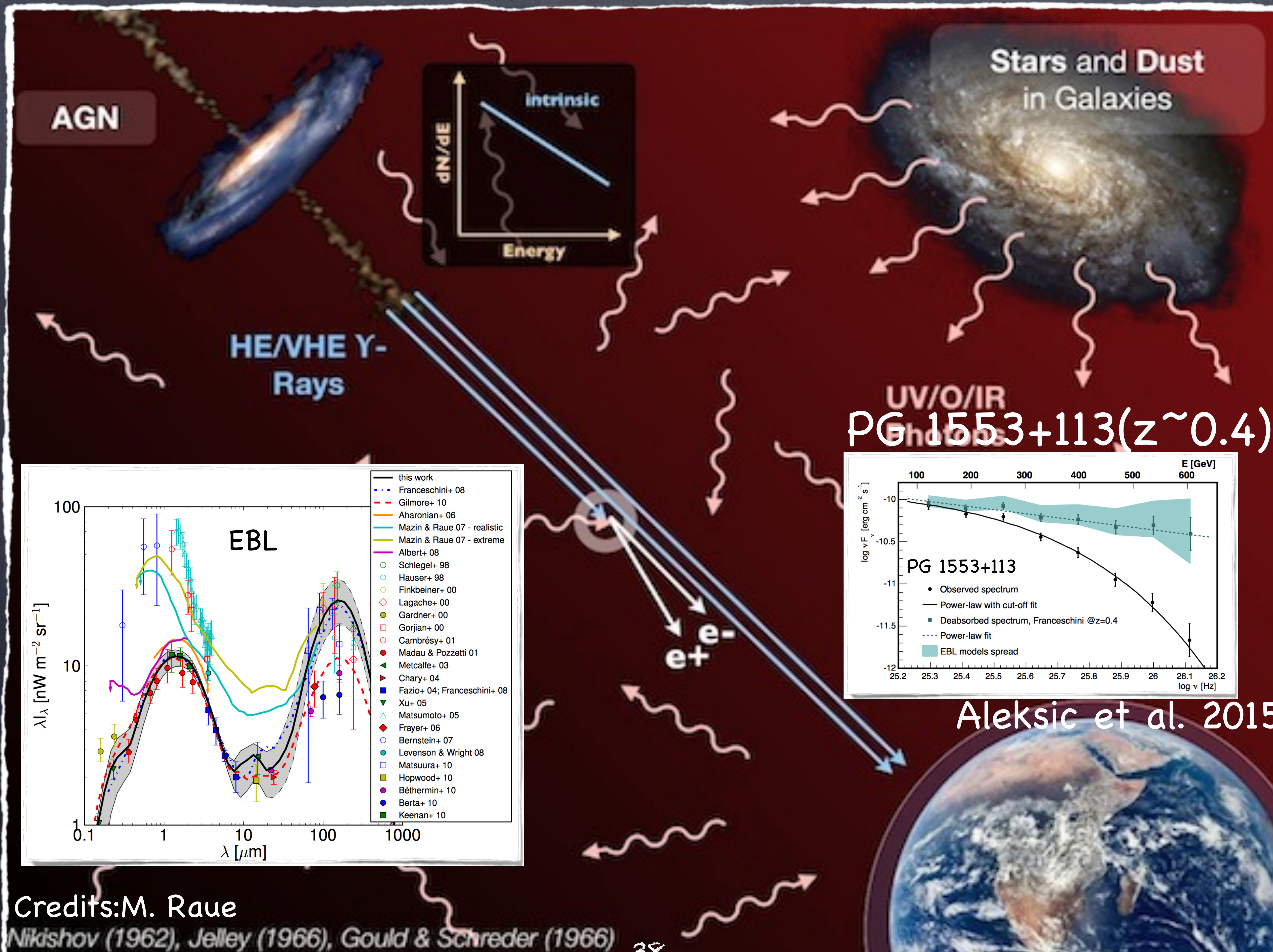
Extragalactic Background Light (EBL)

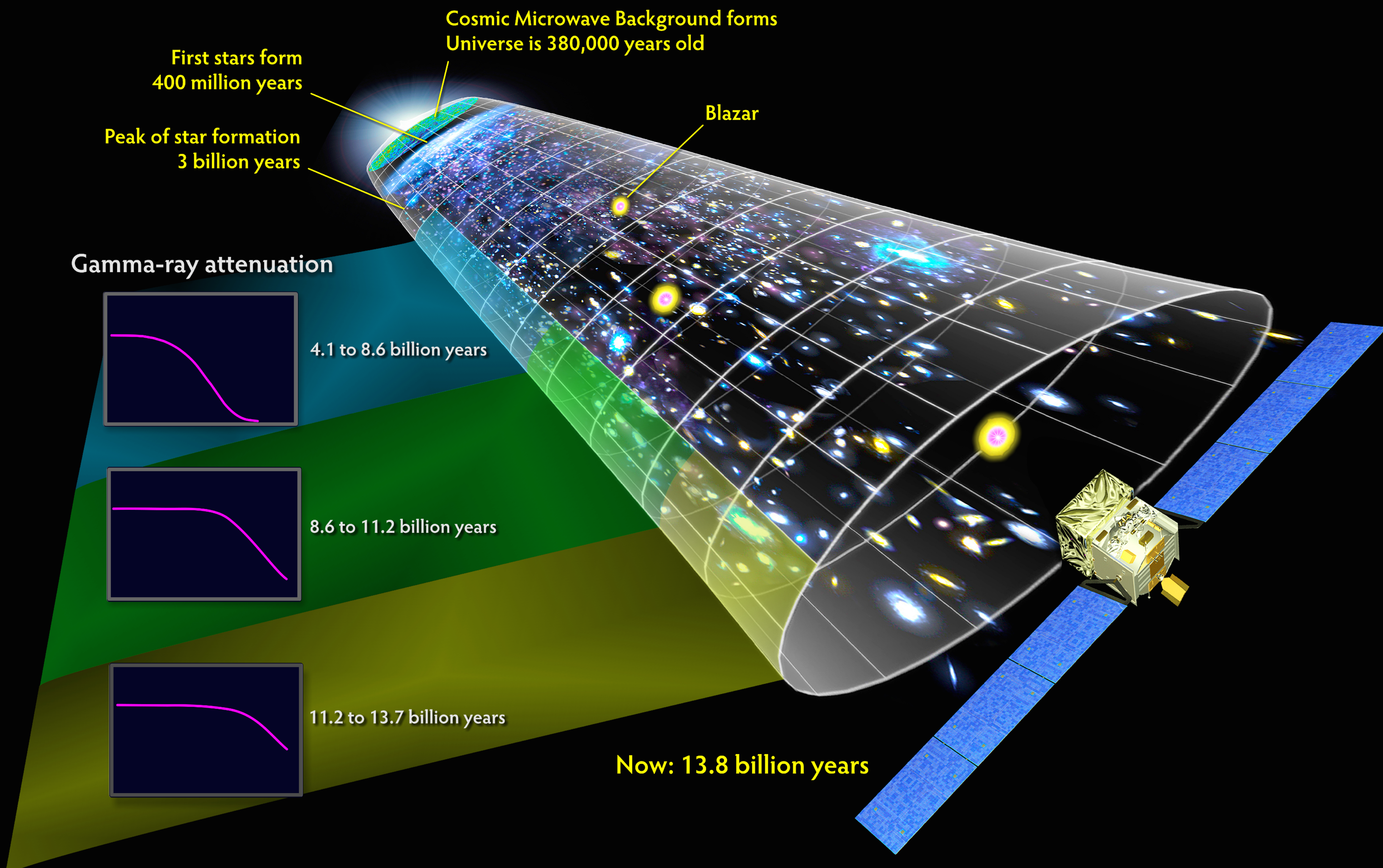


Credits:M. Raue

Nikishov (1962), Jelley (1966), Gould & Schreder (1966)


AGN
Stars and Dust in Galaxies
intrinsic
dN/dE
Energy
HE/VHE γ-Rays
UV/O/IR Photons
e-
e+
measured
dN/dE
Energy
EBL
λI$_λ$ [nW m^{-2} sr^{-1}]
λ [μm]
100
10
1
0.1
1
10
100
1000
this work
Franceschini+ 08
Gilmore+ 10
Aharonian+ 06
Mazin & Raue 07 - realistic
Mazin & Raue 07 - extreme
Albert+ 08
Schlegel+ 98
Hauser+ 98
Finkbeiner+ 00
Lagache+ 00
Gardner+ 00
Gorjian+ 00
Cambrésy+ 01
Madau & Pozzetti 01
Metcalfe+ 03
Chary+ 04
Fazio+ 04; Franceschini+ 08
Xu+ 05
Matsumoto+ 05
Frayer+ 06
Bernstein+ 07
Levenson & Wright 08
Matsuura+ 10
Hopwood+ 10
Béthermin+ 10
Berta+ 10
Keenan+ 10
Credits:M. Raue
Nikishov (1962), Jelley (1966), Gould & Schreder (1966)


AGN
Intrinsic
dN/dE
Energy
Stars and Dust in Galaxies
HE/VHE γ-Rays
UV/O/IR Photons
e-
e+
PG 1553+113(z~0.4)
EBL
λI$_λ$ [nW m^{-2} sr^{-1}]
λ [μm]
this work
Franceschini+ 08
Gilmore+ 10
Aharonian+ 06
Mazin & Raue 07 - realistic
Mazin & Raue 07 - extreme
Albert+ 08
Schlegel+ 98
Hauser+ 98
Finkbeiner+ 00
Lagache+ 00
Gardner+ 00
Gorjian+ 00
Cambrésy+ 01
Madau & Pozzetti 01
Metcalfe+ 03
Chary+ 04
Fazio+ 04; Franceschini+ 08
Xu+ 05
Matsumoto+ 05
Frayer+ 06
Bernstein+ 07
Levenson & Wright 08
Matsuura+ 10
Hopwood+ 10
Béthermin+ 10
Berta+ 10
Keenan+ 10
E [GeV]
log νF$_ν$ [erg cm^{-2} s^{-1}]
log ν [Hz]
PG 1553+113
Observed spectrum
Power-law with cut-off fit
Deabsorbed spectrum, Franceschini @z=0.4
Power-law fit
EBL models spread
Aleksic et al. 2015
Credits:M. Raue
Nikishov (1962), Jelley (1966), Gould & Schreder (1966)



Credits: NASA

Take home message

- Interest from IAC in the field, very happy to build collaborations within the GW Spanish community
- The lessons learned from GW170817 shed light on kilonovae searches even not associated with GW detections
- Different collaborations and instruments are being developed within the Spanish community for the GW electromagnetic counterpart searches
- The gamma-ray community is rapidly developing and getting ready with new instrumentation to discover the first GW counterpart at the most energetic electromagnetic radiation regime

Now hiring!

Instituto de Astrofísica de Canarias • IAC

ABOUT US | OBSERVATORIOS DE CANARIAS | SCIENCE AND TECHNOLOGY | POSTGRADUATE TRAINING | OUTREACH | INTRANET

Home › Employment › Un contrato postdoctoral GOTO 2019 / One Postdoctoral contract GOTO 2019 (PS-2019-088)

Un contrato postdoctoral GOTO ~~2019~~ / One Postdoctoral contract GOTO ~~2019 (PS-2019-088)~~ 2021

The call will be opened soon!

BOOKMARK THIS

APPLICATION DEADLINE:	[redacted] **15/09/2021**
ADVERTISED ON:	[redacted]
MANAGEMENT UNIT / INFORMATION:	RESEARCH DIVISION secinv@iac.es
POSITION CODE:	[redacted]
JOB VACANCIES:	1
PROFESSIONAL CATEGORY:	Postdoc
CONTRACTUAL MODALITY:	Postdoc assigned to specific scientific or technical project
DURATION:	Temporary
MONTHS:	30

STATE: RESOLVED
PROFESSIONAL PROFILE: POSTDOCTORAL RESEARCHER
REQUIRED DEGREE: DOCTORATE (QF-EHEA THIRD CYCLE)

PS-2019-088 Bases Convocatoria GOTO

Contact us if you are interested:

jbecerra@iac.es, mapt@iac.es