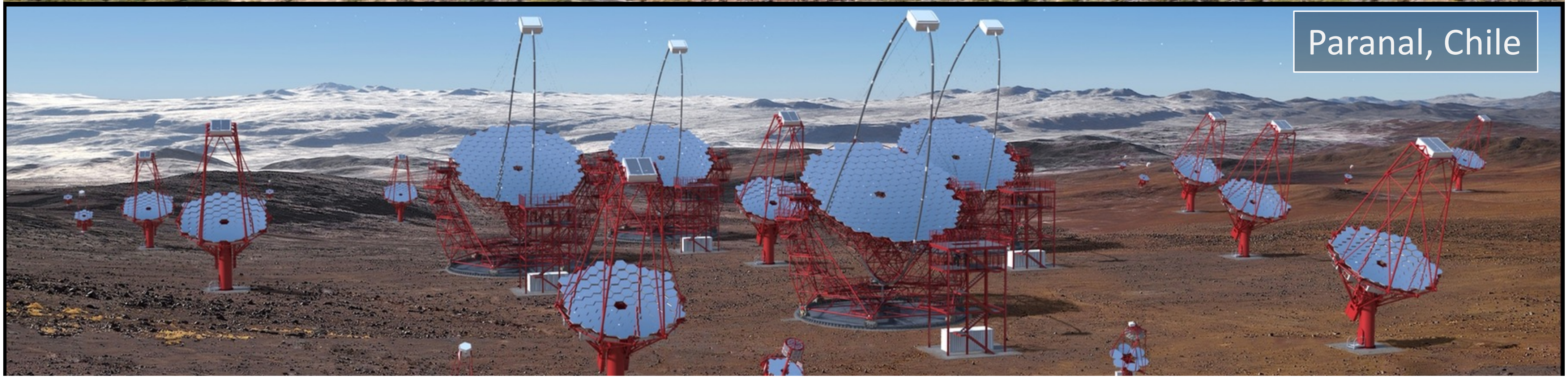
The CTA Project

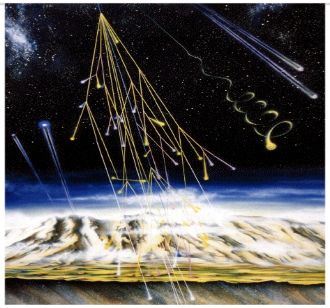
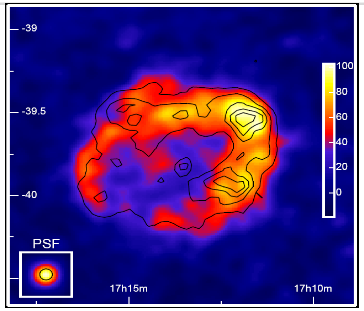
Masahiro Teshima

for the CTA Japan Consortium
Institute for Cosmic Ray Research, The University of Tokyo



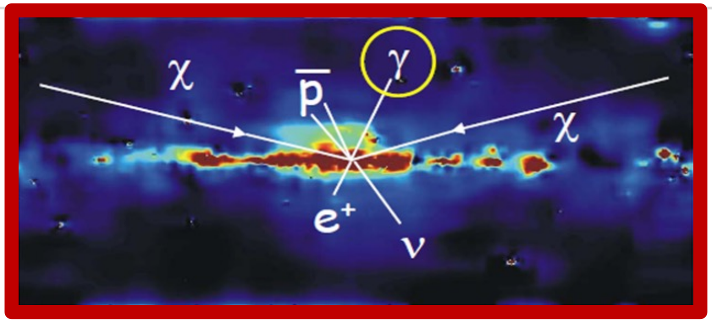
Science of CTA is very wide

CTA-LST will cover S.M.B.H., Dark Matter, AGNs, GRBs

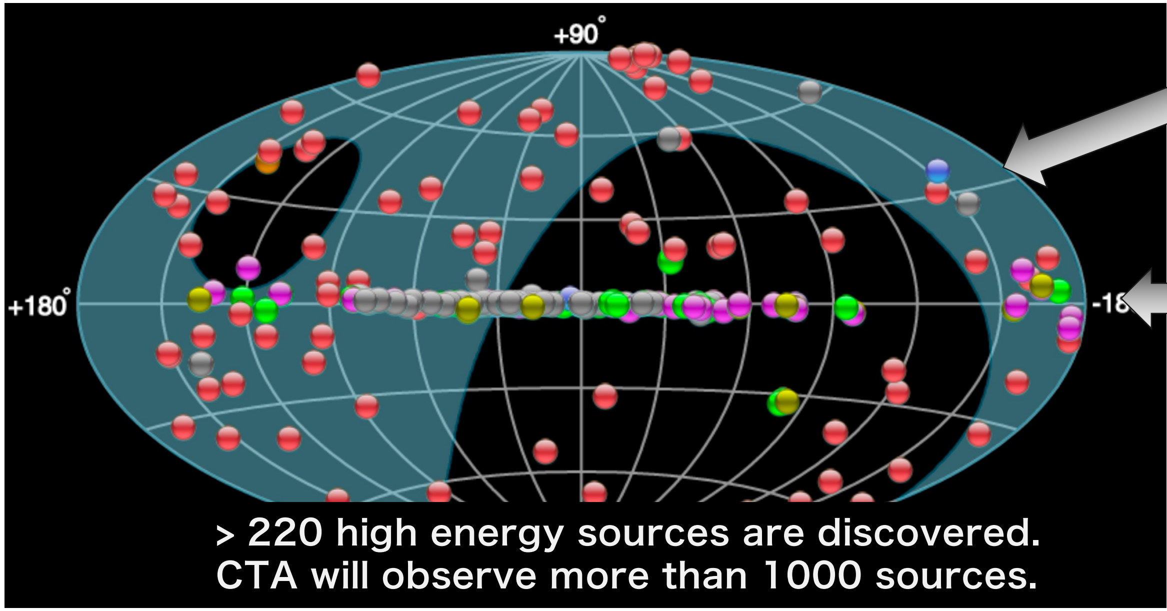
Cosmic Ray Origin

Super Massive Black Holes



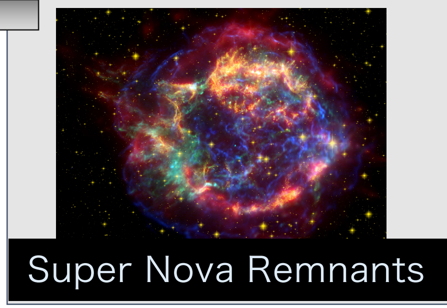
Dark Matter Search (Discovery)

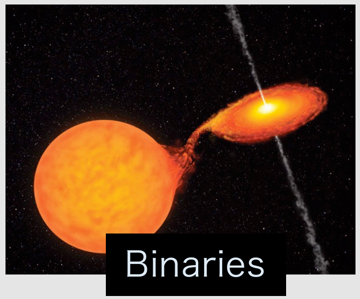
- Origin of Cosmic Rays (Big accelerators)
- Black Hole and S.M.B.H.
- Dark Matter Search



Extragalactic Sources

Galactic Sources

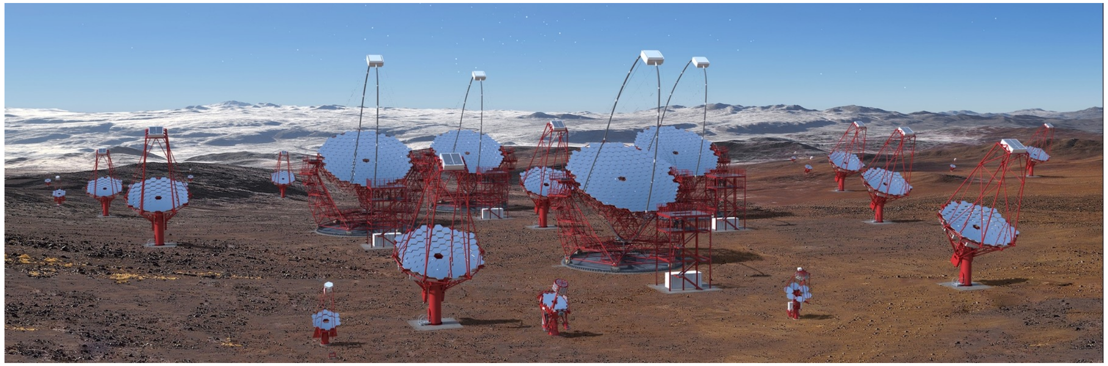


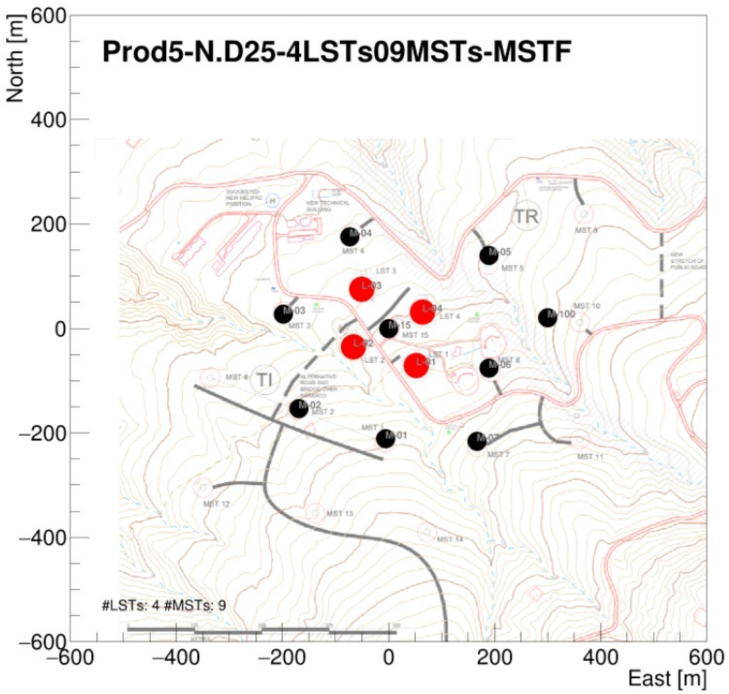


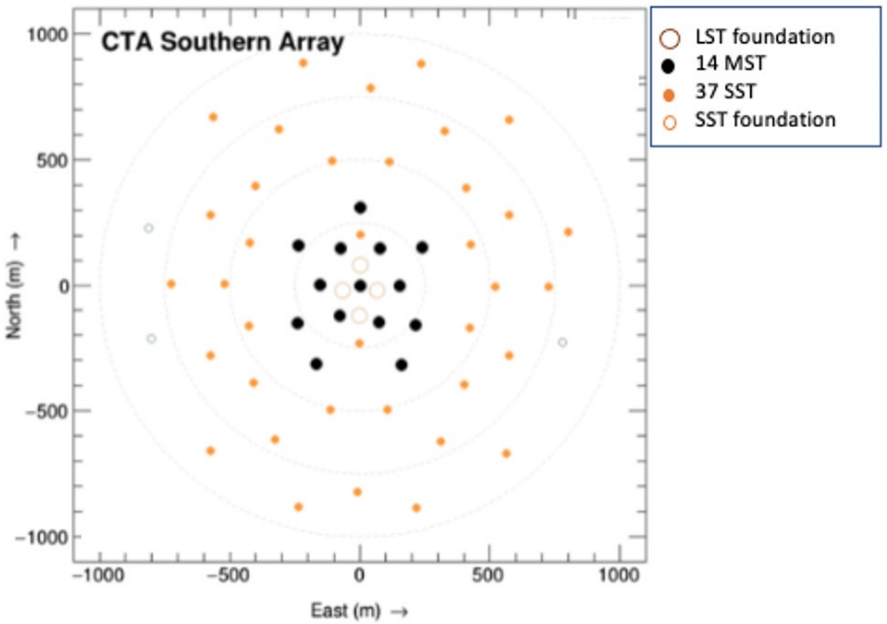
Two sites for all sky observatory Alpha Configuration

Roque de los Muchachos Observatory
La Palma, Spain

Paranal, Chile

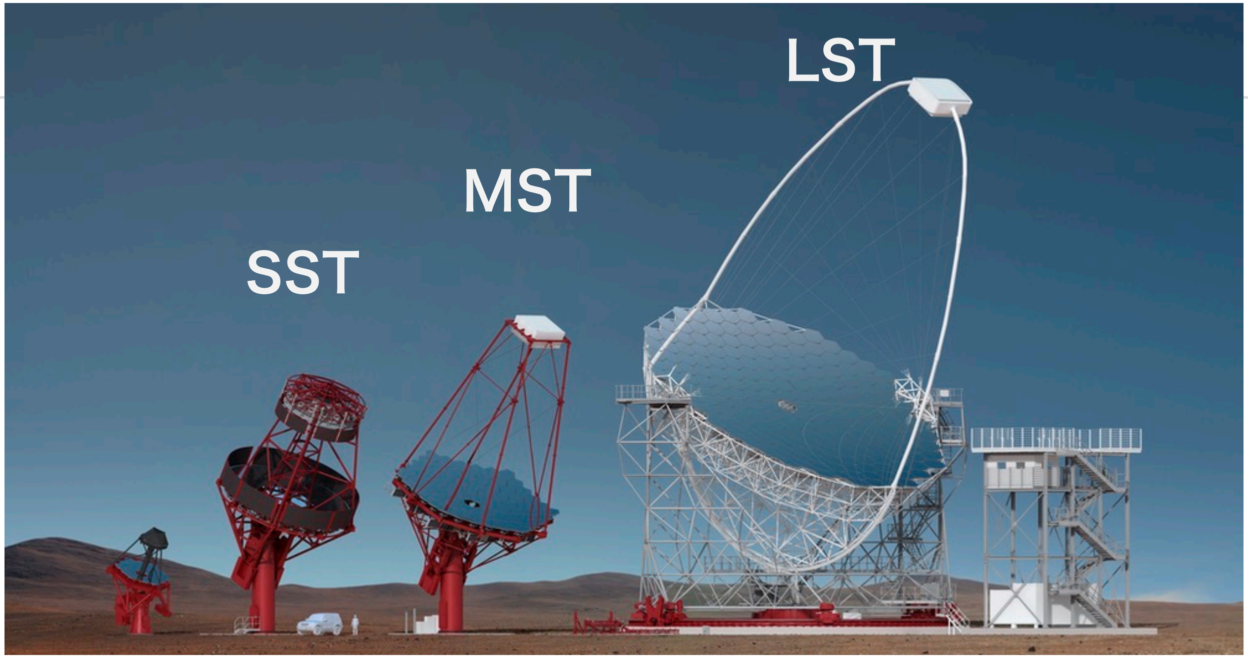






cta cherenkov telescope array

37 SSTs, 23 MSTs, and 4 LSTs



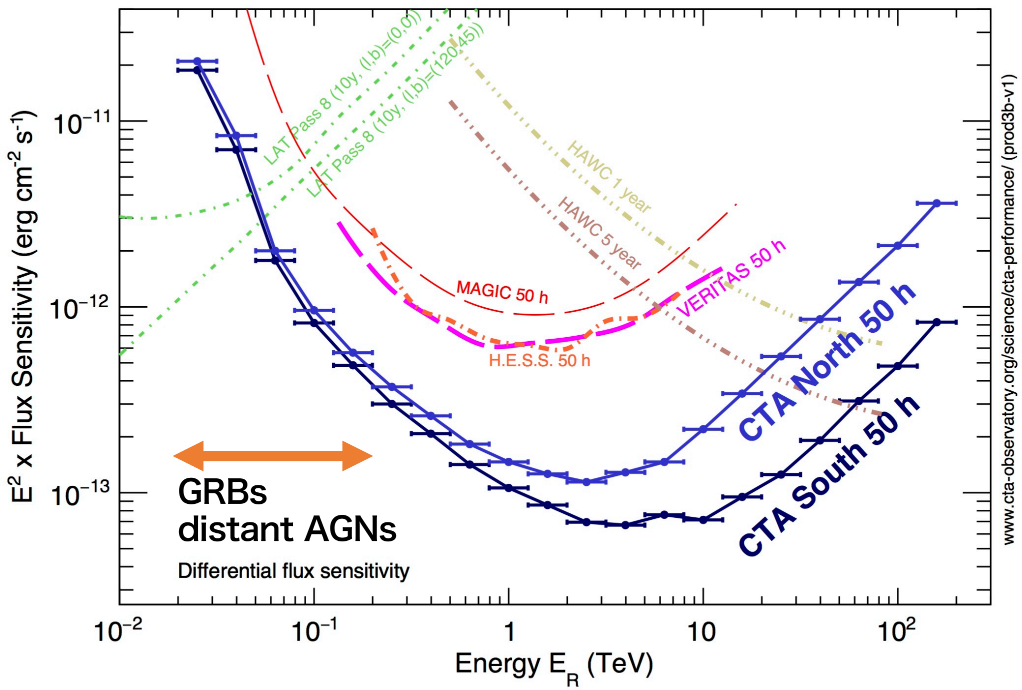
Telescope Types	SST	MST	LST
Optics	Schwarzschild-Couder	Davies-Cotton	Parabolic (Isochronous)
FoV and Camera	10.5 deg SiPM	7.5 deg PMT	4.3 deg PMT
Mirror Diameter	4.3m	11.5m	23m
Energy Range	3 TeV - 200 TeV	100GeV - 10TeV	20GeV – 2000GeV
Science Target	Galactic Sources PeVatron (UHE CR)	Galactic Sources Nearby AGNs (z<0.5) Dark Matter	Transient Sources AGNs(z<2), GRBs(z <4) Dark Matter

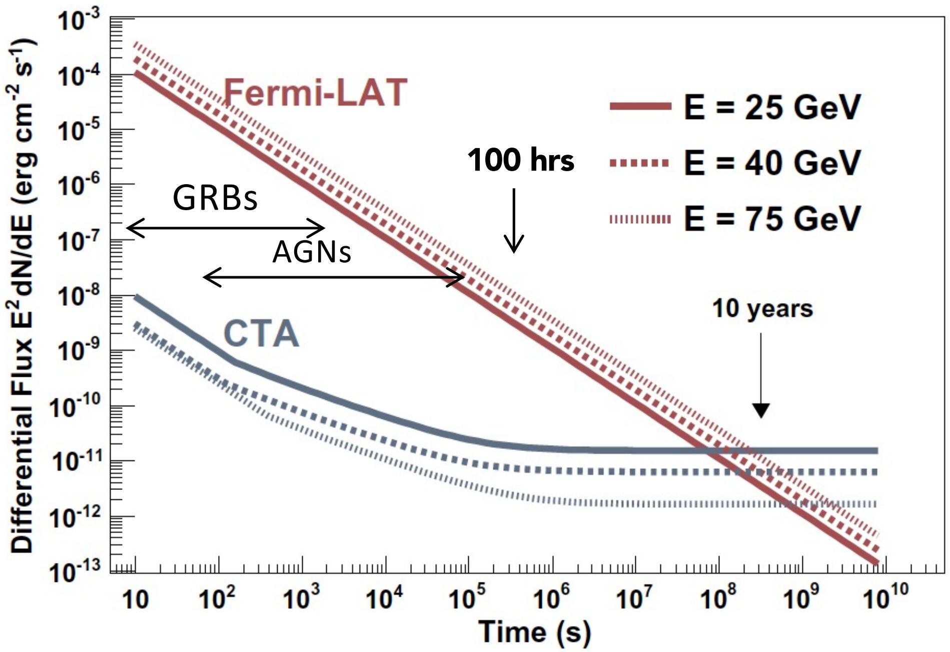
Telescope Configuration

Site	Telescope	Baseline config	Phase I Alpha config	Extension beyond Alpha
North	LST	4	4	
	MST	15	9	
South	LST	4	0	+4
	MST	25	14	
	SST	70	37	
Budget	Not including INFRA, ADM.	~400 MEur	244 MEur	60 MEur

- Phase I として、予算的に可能な望遠鏡配置とした。
- LST South +4 への期待は大きい。

感度 x10 倍以上
エネルギー帯 20GeV~200TeV（二桁拡大）





- The CTA-LST array has a good sensitivity from 20 GeV to 1000 GeV
- Distant AGNs up to z = 2 and GRBs up to z = 4 are observable
- X10000 sensitivity for GRBs and AGN flares than Fermi
- The fast rotation (20 sec) offers the observation of prompt emission of GRBs

Cost Book for Alpha Configuration
4 LSTs, 23 MSTs and 37 SSTs

CTAO Cost Book Executive Summary	Cash [M€]	IKC [M€]	Total cost [M€]
Company Related	**8.1**	**0.3**	**8.4**
001 - Director's Office	2.4	-	2.4
002 - Administration	5.8	0.3	6.0
Construction Project	**78.7**	**244.2**	**322.9**
P01 - Project Management	2.4	-	2.4
P02 - Science & Science Ops. Preparation	2.3	6.3	8.6
P03 - Systems Engineering & Integration	3.2	0.1	3.3
P04 - On-Site Construction	53.4	16.3	69.6
Northern site	3.5	15.7	19.2
Southern site	49.9	0.6	50.5
P05 - Site/Infrastructure Design & Planning	2.1	3.6	5.7
P06 - Computing	13.1	39.4	52.5
P07 - Telescopes	1.6	171.6	173.3
Large-Sized Telescopes	-	60.1	60.1
Medium-Sized Telescopes	-	72.8	72.8
Small-Sized Telescopes	-	38.7	38.7
P08 - Array Common Elements	0.7	6.8	7.5
Grand Total	**86.9**	**244.4**	**331.3**

Table 2: CTAO Cost Book Executive Summary

CTA Timeline

- 2016-2018　大口径望遠鏡 LST1 が最初のCTAサイトに建設される
- 2021-2022　Array配置、各国からの予算が決定され、CTAO ERIC が設立される。
- 2021-2024　CTA North にLST４基のアレイが建設・完成され、運用が開始される。
- 2024-2028　14MSTs、37MSTs が 建設される。

<table>
<tr><th></th><th colspan="2">2020</th><th colspan="2">2021</th><th colspan="2">2022</th><th colspan="2">2023</th><th colspan="2">2024</th><th colspan="2">2025</th><th colspan="2">2026</th><th colspan="2">2027</th><th colspan="2">2028</th><th colspan="2">2029</th><th colspan="2">2030</th></tr>
<tr><td rowspan="2">Organization</td><td colspan="6">CTAO gGmbH (Heidelberg)</td><td colspan="16"></td></tr>
<tr><td colspan="5"></td><td colspan="17">CTAO ERIC (European Research Infrastructure Consortium)</td></tr>
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<table>
<tr><th>Alpha Config</th><th colspan="2">2020</th><th colspan="2">2021</th><th colspan="2">2022</th><th colspan="2">2023</th><th colspan="2">2024</th><th colspan="2">2025</th><th colspan="2">2026</th><th colspan="2">2027</th><th colspan="2">2028</th><th colspan="2">2029</th><th colspan="2">2030</th></tr>
<tr><td rowspan="2">LST North</td><td colspan="10">Comissioning and Operation of LST1</td><td colspan="8" rowspan="2">Operation as 4 LST Array</td><td colspan="4" rowspan="5">Observatory Operation</td></tr>
<tr><td colspan="3">CDR</td><td colspan="7">Deployment of LST2-4</td></tr>
<tr><td>MST North</td><td colspan="4">Design and Finance</td><td colspan="14">Construction of 9MSTs</td></tr>
<tr><td rowspan="2">CTA South</td><td colspan="4" rowspan="2">Array config, Finance and CDR</td><td colspan="4" rowspan="2">INFRA</td><td colspan="10">Construction and Deplyment of 14 MSTs</td></tr>
<tr><td colspan="10">Construction and Deployment of 37 SSTs</td></tr>
</table>

<table>
<tr><th>Extension</th><th colspan="2">2020</th><th colspan="2">2021</th><th colspan="2">2022</th><th colspan="2">2023</th><th colspan="2">2024</th><th colspan="2">2025</th><th colspan="2">2026</th><th colspan="2">2027</th><th colspan="2">2028</th><th colspan="2">2029</th><th colspan="2">2030</th></tr>
<tr><td>LST South</td><td colspan="2"></td><td colspan="10">Advanced Design and Proto / Finance / CDR</td><td colspan="8">Construction of 4LSTs</td><td colspan="2">Operation</td></tr>
</table>

CTA 国際宇宙ガンマ線天文台 LoI より

6. 実施時期

2016 年より 4 基の大口径チェレンコフ望遠鏡を CTA 北サイト（スペイン・ラパルマ）に建設中。2023 年に 4 基の大口径望遠鏡アレイを完成し、南半球の大口径望遠鏡建設を予算化し、全天観測を現実のものとしたい。

北半球建設：	2016-2023, 32 億円（措置済）
南半球建設：	2024-2027, 34 億円
観測運用（北半球）：	2018-2043, 50 億円（一部措置）
観測運用（南半球）：	2024-2043, 40 億円

7. 必要経費および予算プロファイル

CTA 国際宇宙ガンマ線天文台の総建設費 320MEuro、運営経費 24MEuro/年であり、20 年の運営を予定している。日本は建設費 66 億円、運営費 4 億円／年を予定している。

10. 実施内容

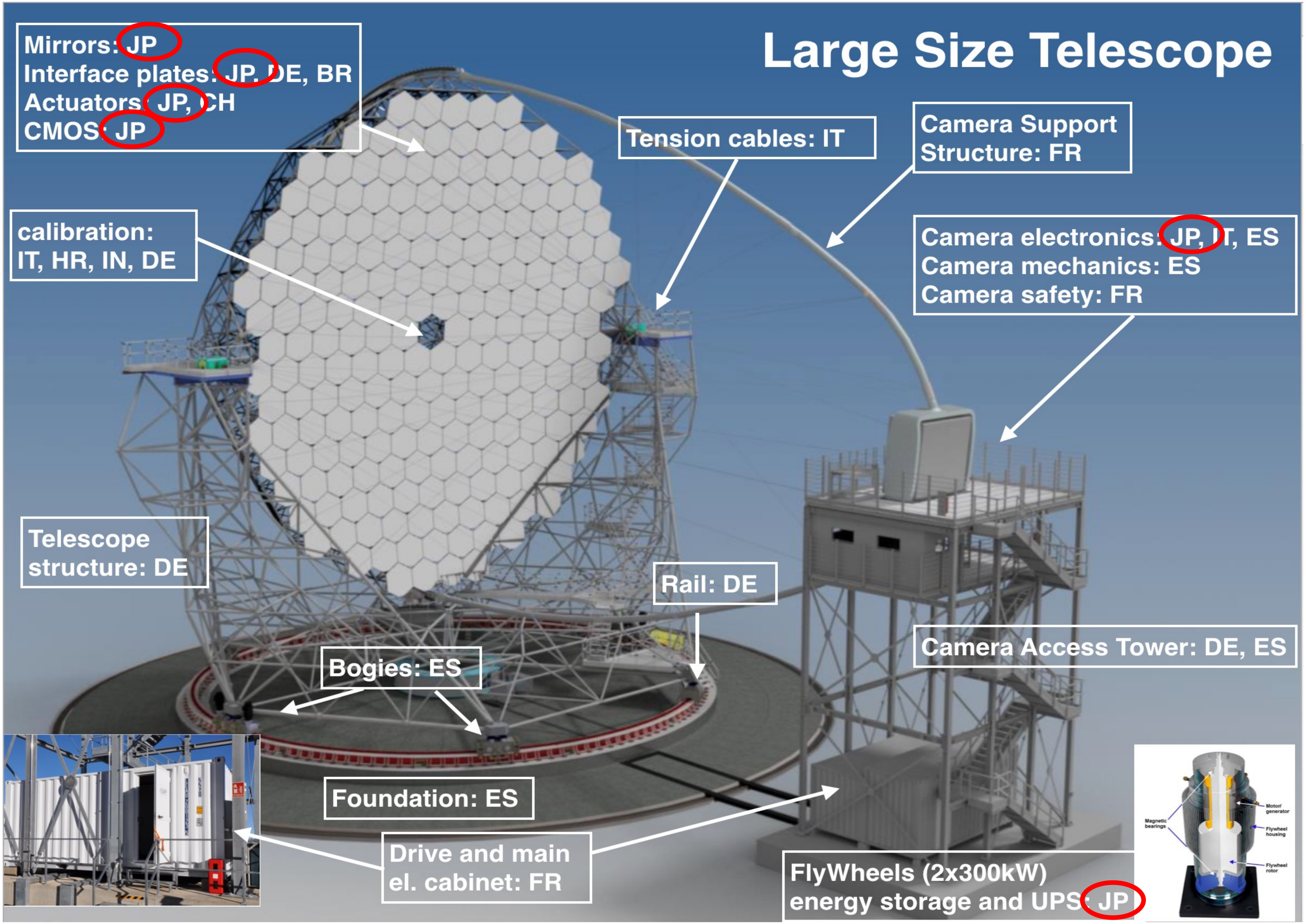
上で述べたように、CTA Consortium が実施機関・運用機関の中心であり、大型国際共同で 31 カ国 1400 名の研究者からなる。主要国は、ドイツ、イタリア、フランス、スペイン、日本の 5 カ国である。 日本グループ CTA-Japan は国際共同研究拠点・共同利用研である東京大学宇宙線研究所を中心とし、22 機関 117 名の研究者からなる。

cta cherenkov telescope array

CTA-LST Project

LST1 is Inaugurated on 10 October 2018

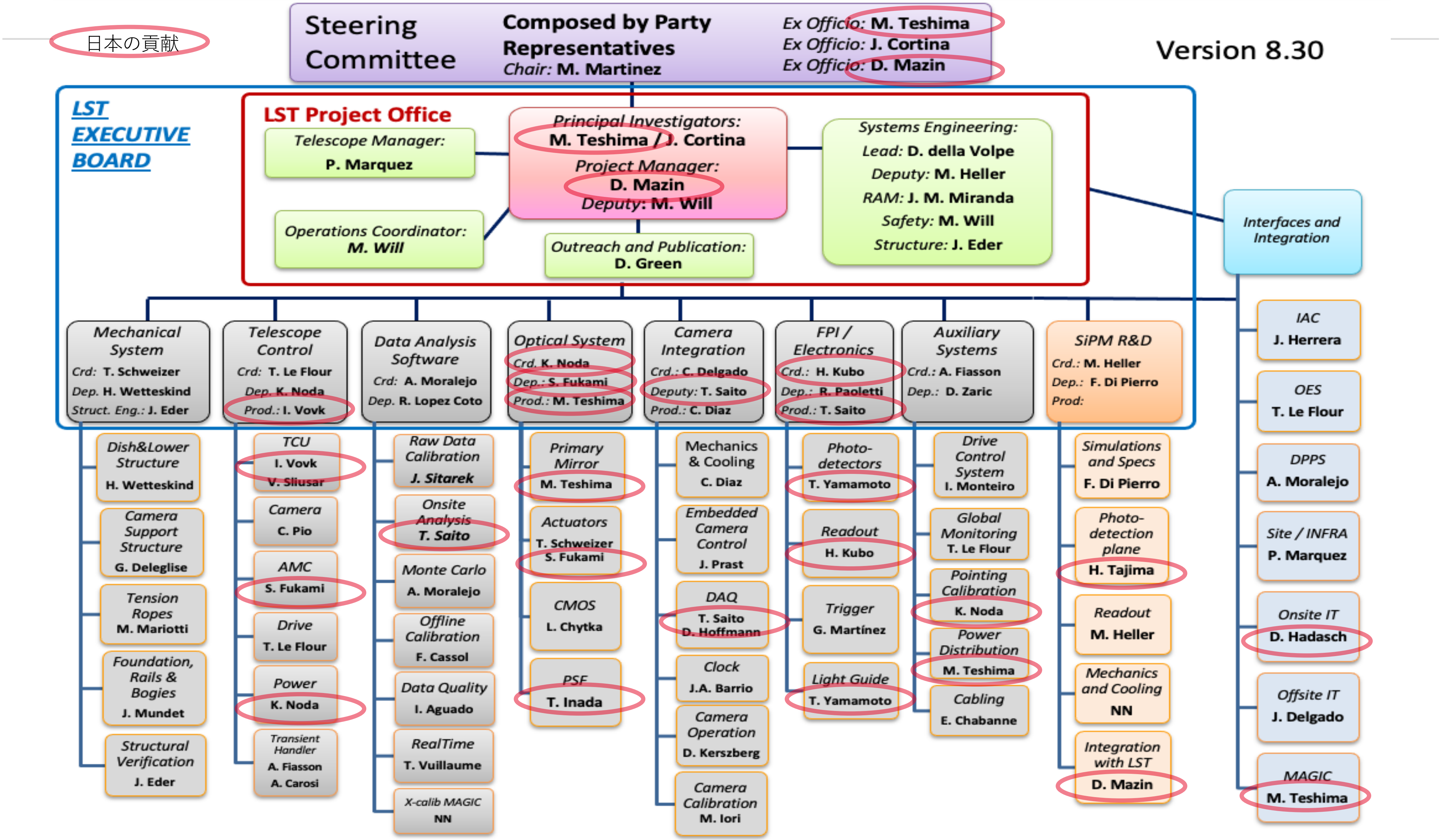
In Feb 2019 LST1 is awarded with 21st Cent. Technology 2019


Large Size Telescope
Mirrors: JP
Interface plates: JP, DE, BR
Actuators: JP, CH
CMOS: JP
Tension cables: IT
Camera Support Structure: FR
calibration: IT, HR, IN, DE
Camera electronics: JP, IT, ES
Camera mechanics: ES
Camera safety: FR
Telescope structure: DE
Rail: DE
Camera Access Tower: DE, ES
Bogies: ES
Foundation: ES
Drive and main el. cabinet: FR
FlyWheels (2x300kW) energy storage and UPS: JP
Motor/generator
Magnetic bearings
Flywheel housing
Flywheel rotor

CTA-LSTプロジェクト組織図

~300研究者、技術者（日本から~100名の研究者）

手嶋がスポークスマン、Mazin（宇宙線研特任准教授）がプロマネ

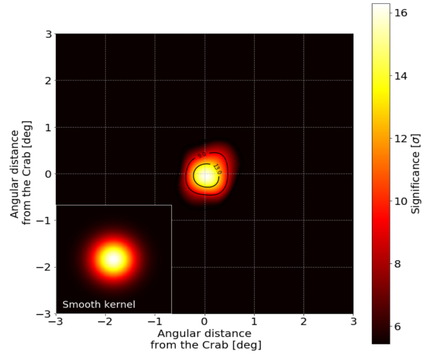


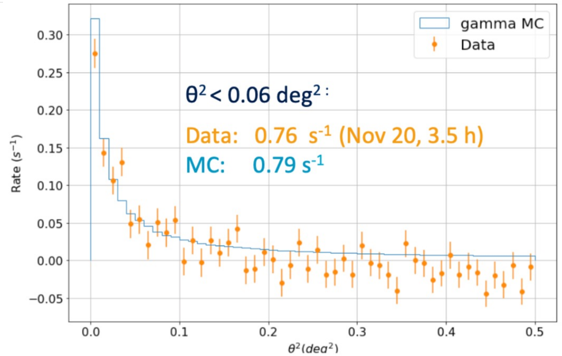
LST1 observations and LST Science

LST1　CTA サイトに設置された最初の望遠鏡

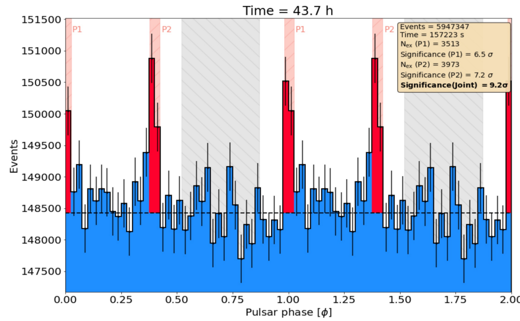
2018年10月完成記念式典
2019年1月　Technology 21st Cent. Award

2020年11月、カニ星雲の高精度観測 (LST1)

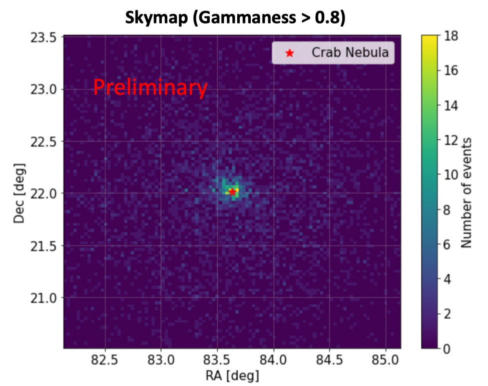


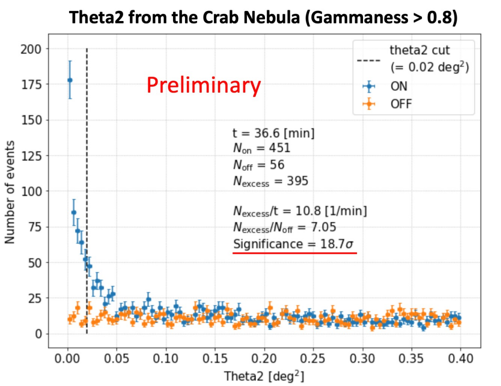


2020年12月、カニパルサーの高感度観測(LST1)

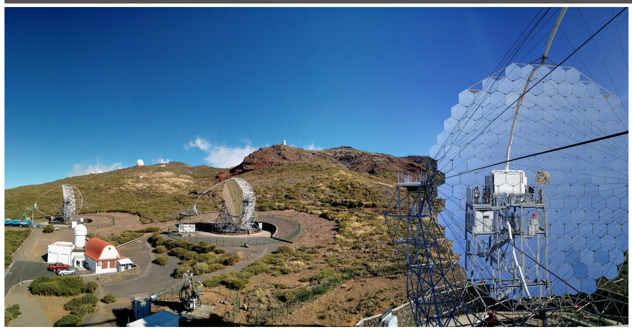


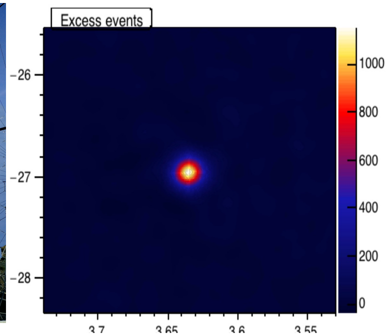
2020年12月、MAGIC+LST1 の共同運用　(世界最高感度達成）

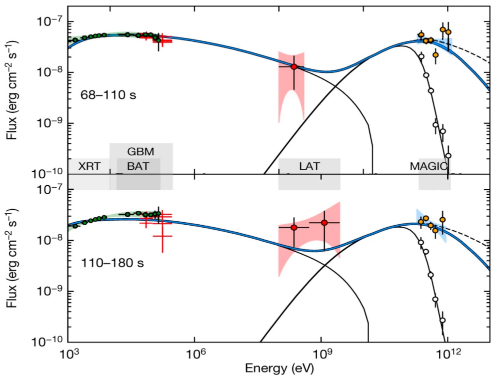


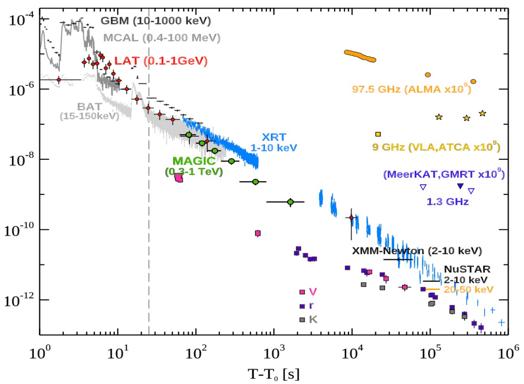


2019年1月　ガンマ線バーストの史上初観測　（MAGIC)

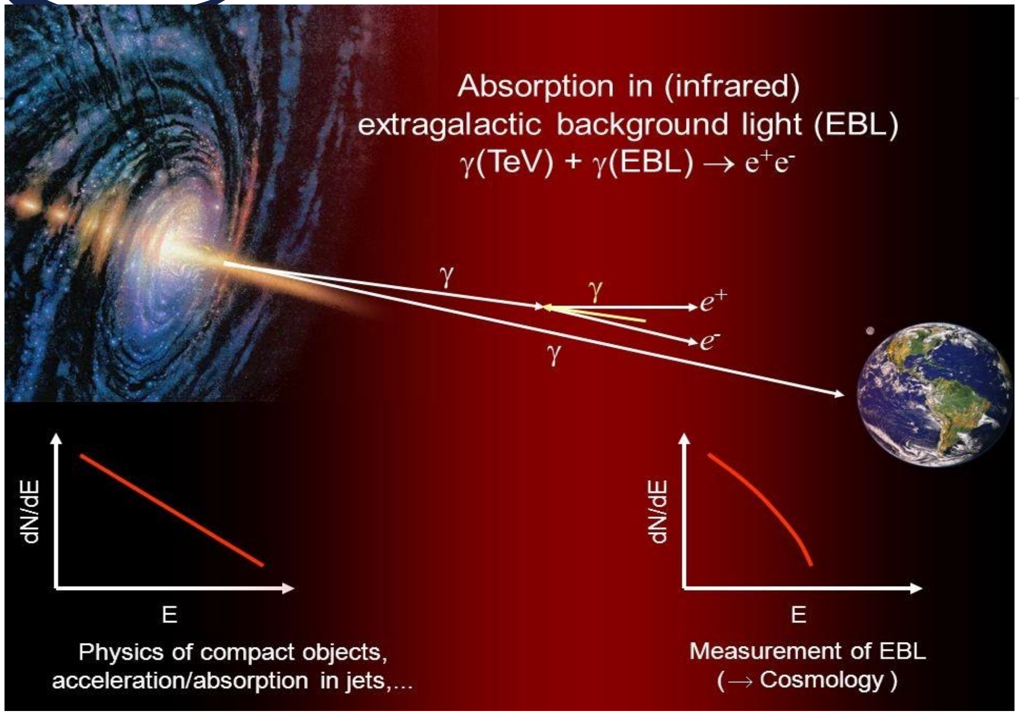


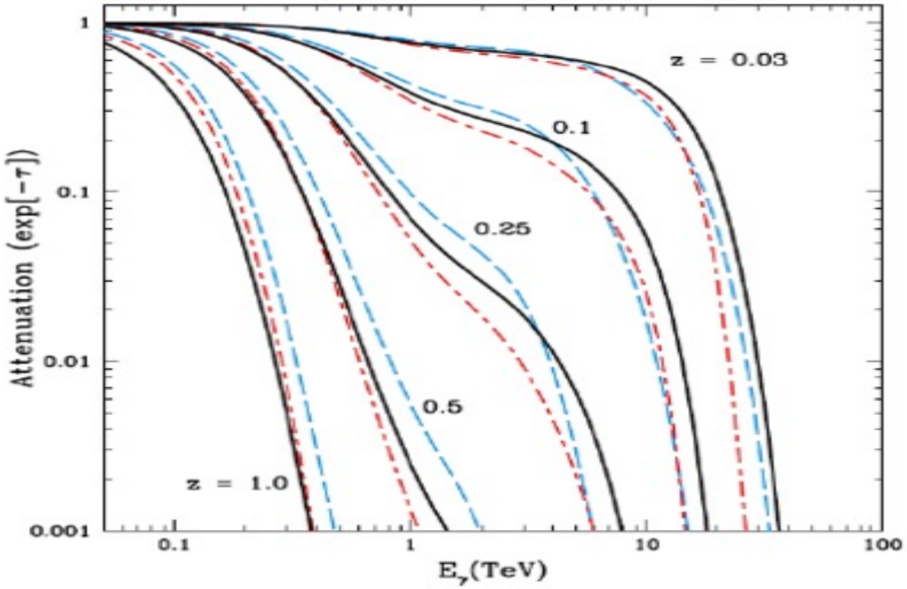


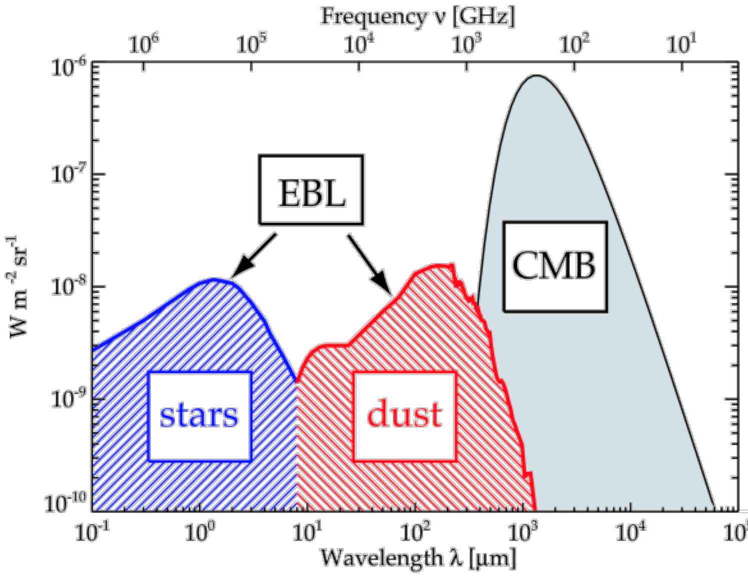


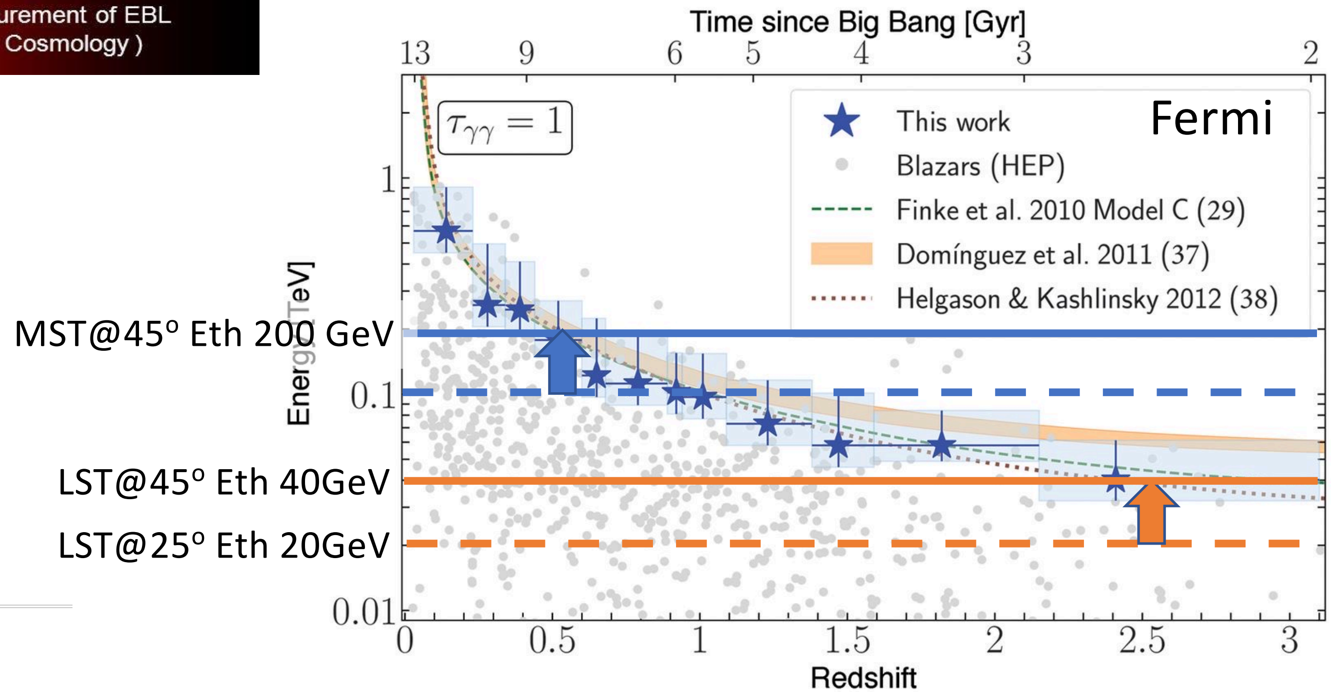


Gamma Ray Horizon

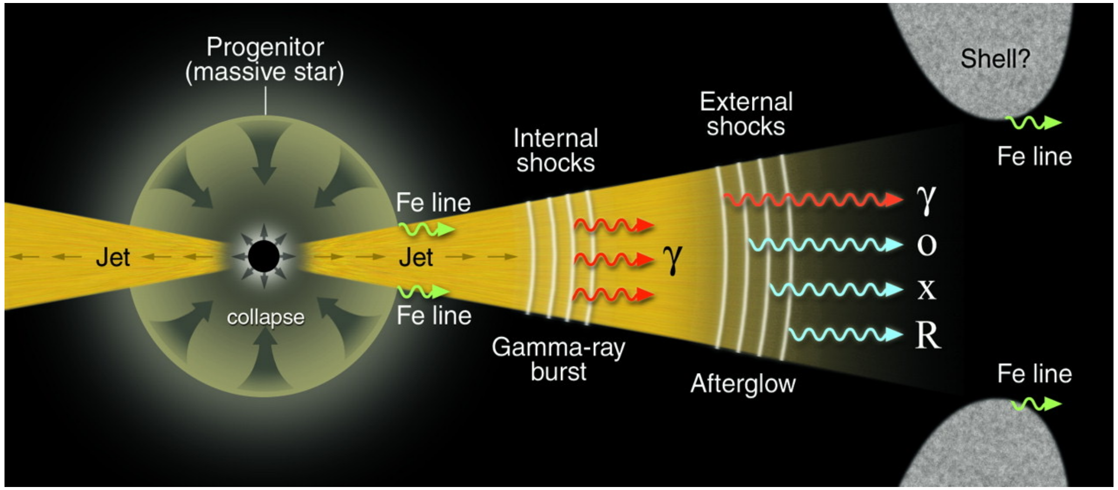


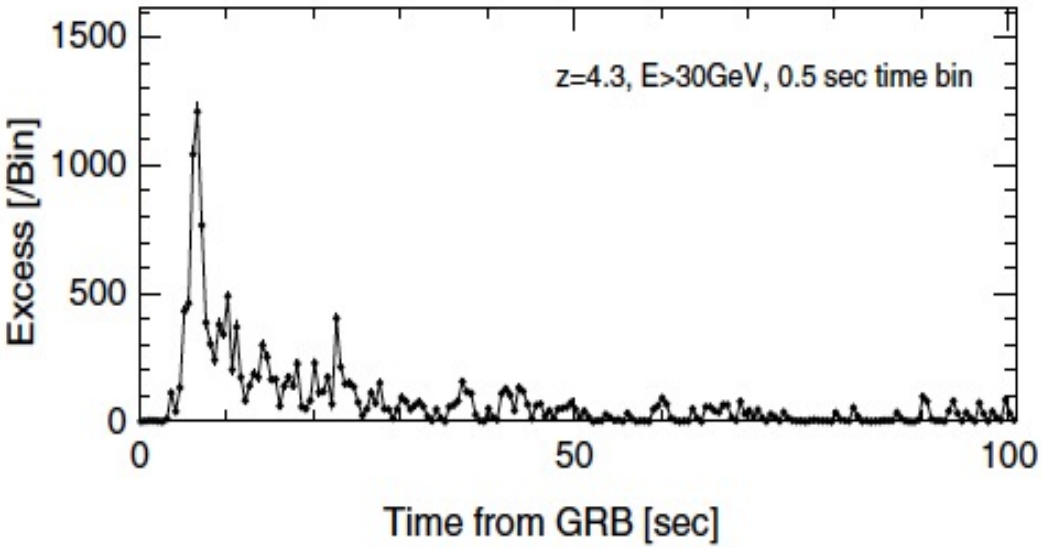


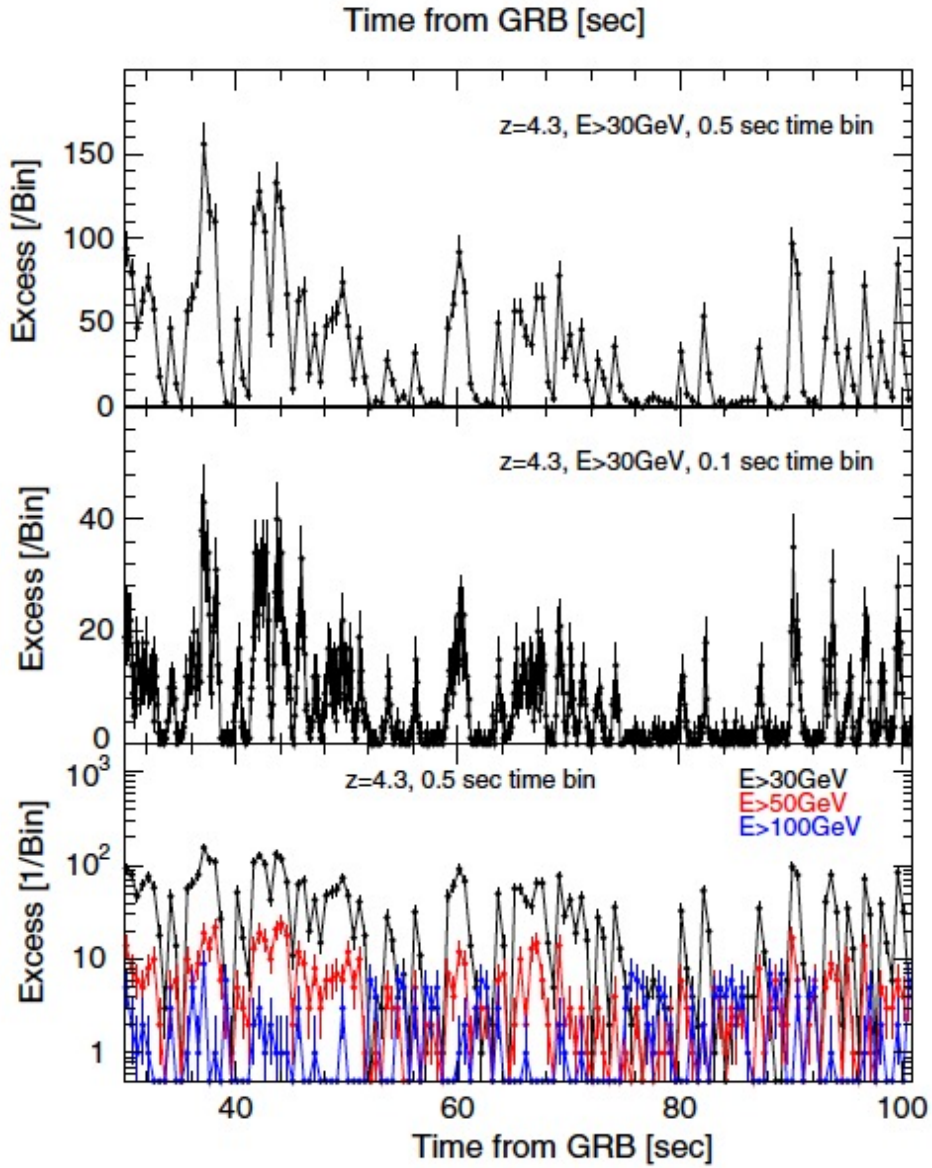




GRB: Simulated light curve (template: GRB080916C)



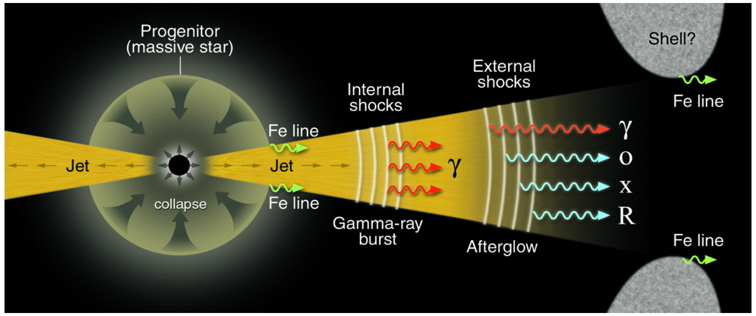


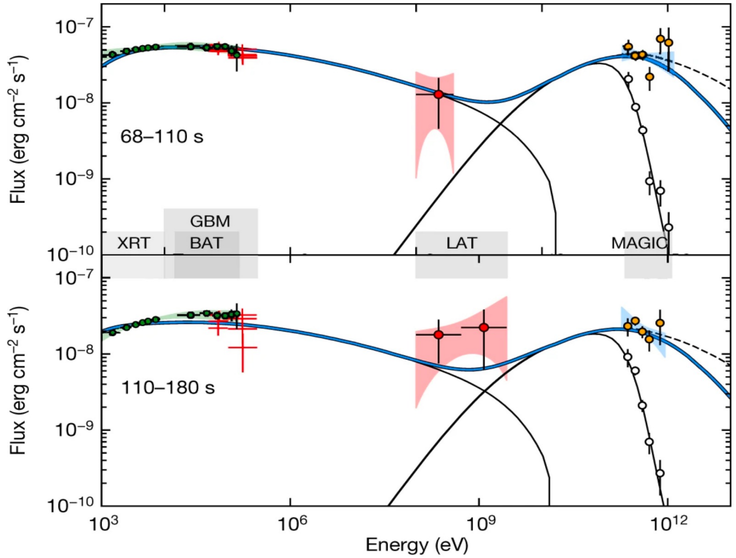


cherenkov telescope array

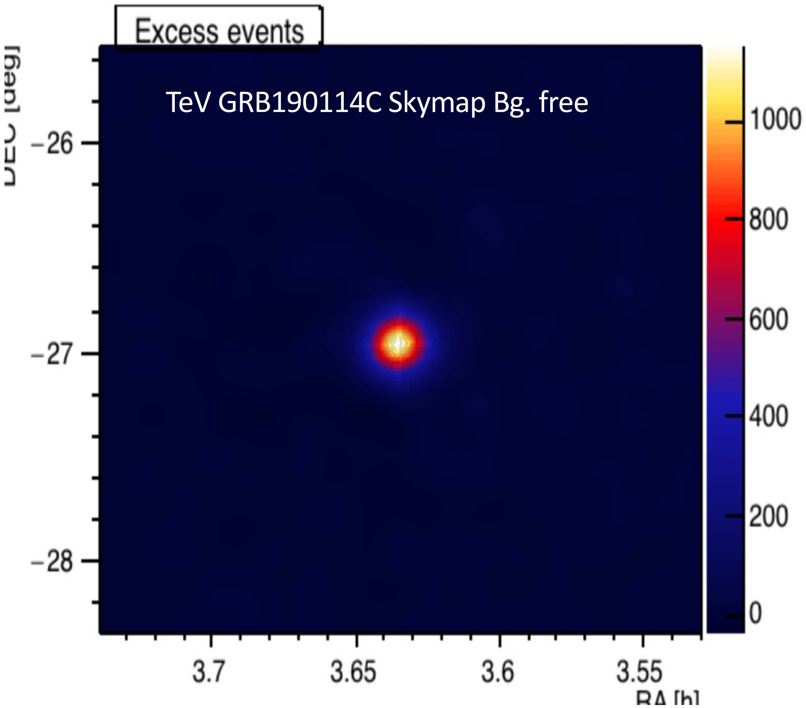
TeV-GRB 190114C observation with MAGIC

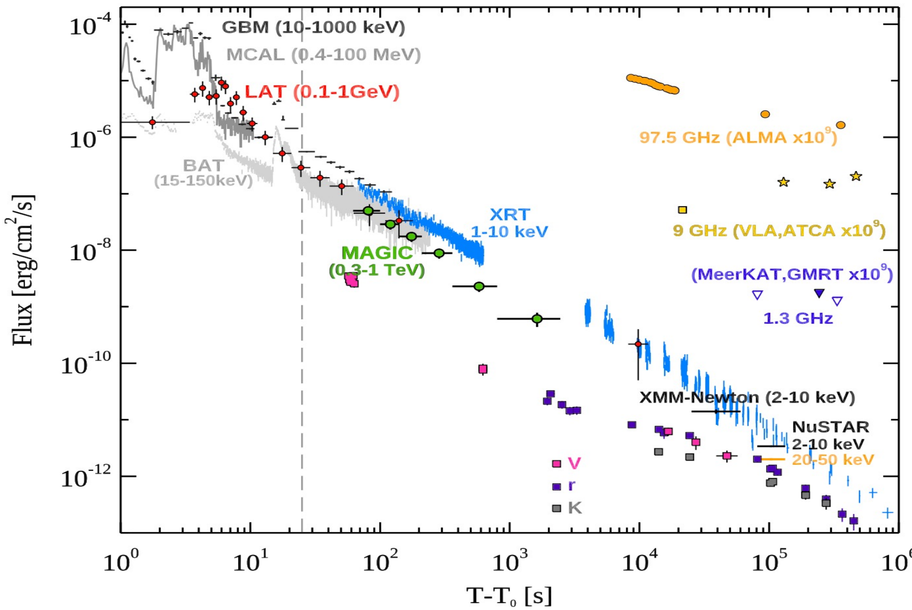
Two Nature Papers 21. Nov. 2019





- Energy spectrum is extending to TeV energies
- Significant energy released in TeV domain
- Afterglow curve is parallel to X-Ray afterglow
- LST will detect 10 times more events than MAGIC and HESS

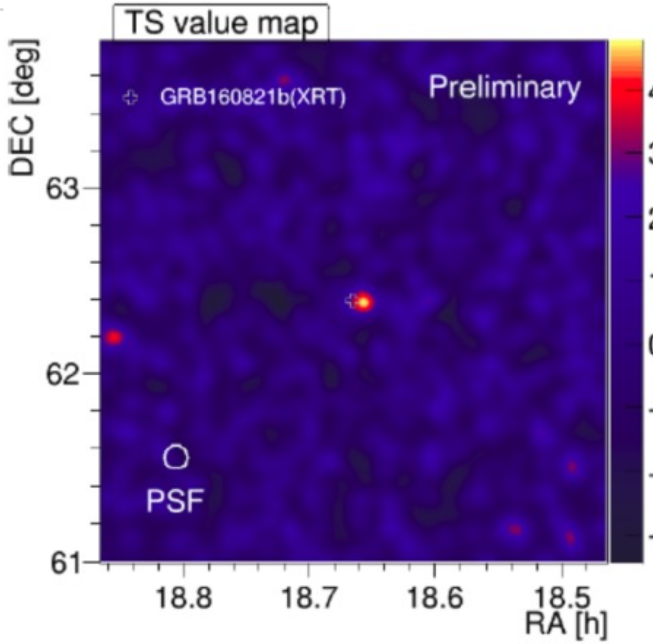


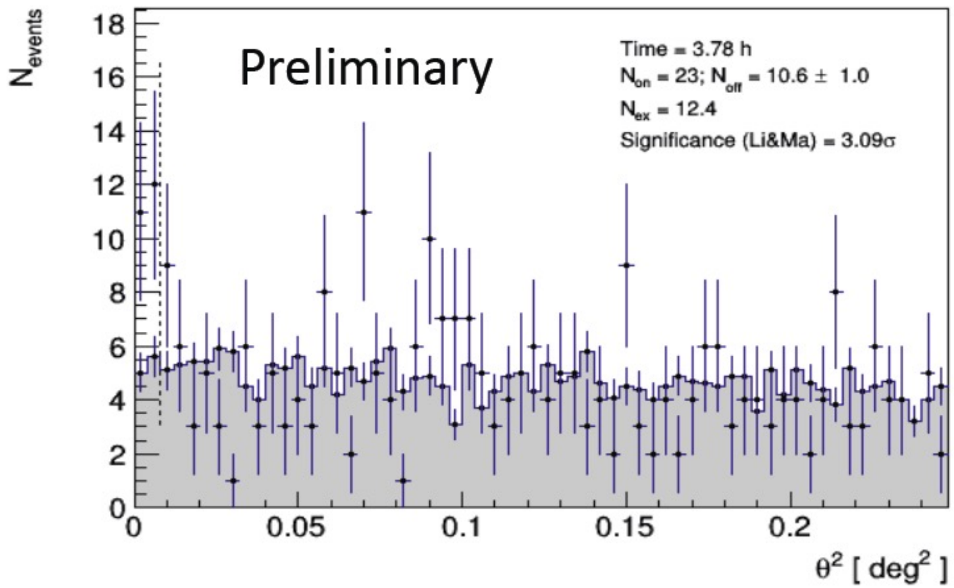


MAGIC Observation, GRB 160821B (Short GRB), published ApJ 2021

- ❑ **Short GRB** (T90 ~= 0.5 s) at **z = 0.162**, triggered by Swift-BAT
- ❑ Swift-XRT: t < 300 s extended emission + steep decay, t < 30 ks plateau?
- ❑ HST: **Kilonova feature, BNS merger**
- ❑ **MAGIC: 24 s - 4 hr**. Moon (3-9 x dark LoNS)
- ❑ **3.1 sigma (post-trial)**
- ❑ **At E ≥ 600-800 GeV**

❑マルチメッセンジャー天文学への展望を開く





GRB 201015A (Long GRB)

GCN 28659, >3sigma detection

ICRC2021_797 Y. Suda et al.

Name/type of the alert: GRB 201015A
Triggered by: Swift-BAT , T0=2020-10-15 22:50:13 UT
Alert coordinates: RA=23h37m22.248s Dec=+53d23m35.520s (J2000)
Alert arrival time: 2020-10-15 22:50:32 UT

Observation started 40 seconds after T0.
GTC, z = 0.426

TITLE: GCN CIRCULAR
NUMBER: 28659
SUBJECT: MAGIC observations of GRB 201015A: hint of very high energy gamma-ray signal
DATE: 20/10/16 16:48:37 GMT
FROM: Oscar Blanch at MAGIC Collaboration <blanch@ifae.es>

O.Blanch (IFAE-BIST Barcelona), M. Gaug (UAB Barcelona), K. Noda (ICRR University of Tokyo),
A. Berti (INFN Torino), E. Moretti (IFAE-BIST Barcelona), D. Miceli (University of Udine and INFN Trieste),
P. Gliwny (University of Lodz) S. Ubach (UAB Barcelona), B. Schleicher (University of Wuerzburg),
M. Cerruti (University of Barcelona) and A. Stamerra (INAF Rome) on behalf of the MAGIC collaboration
report:

On October 15, 2020, the MAGIC telescopes observed GRB 201015A following the Swift-BAT trigger (D'Elia et al., GCN 28632).
MAGIC started observations under good conditions about 40 seconds after the initial Swift trigger, revealing a hint of signal
with significance >3 sigma in the very high energy band. Refined off-line analyses of the data are ongoing.

Further MAGIC observations on GRB 201015A are planned in the coming night. We strongly encourage follow-up
observations by other instruments at all wavelengths.

The MAGIC point of contact for this burst is O. Blanch (blanch@ifae.es). Burst Advocate for this burst is
M. Gaug (Markus.Gaug@uab.cat)

MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes
located at the Observatory Roque de los Muchachos on the Canary island
La Palma, Spain, and designed to perform gamma-ray astronomy in the energy
range from 50 GeV to greater than 50 TeV.

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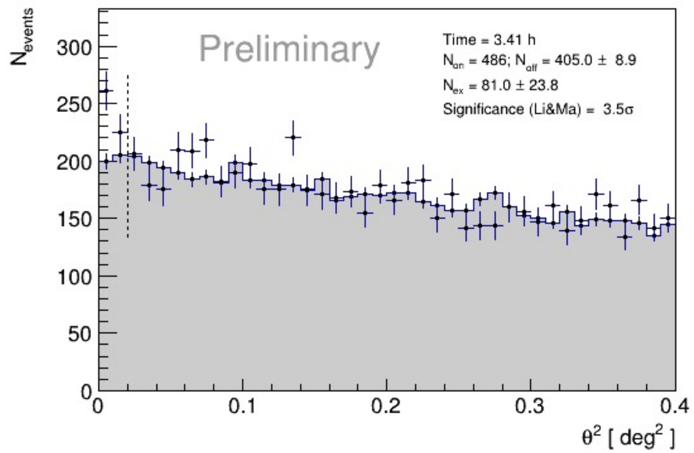

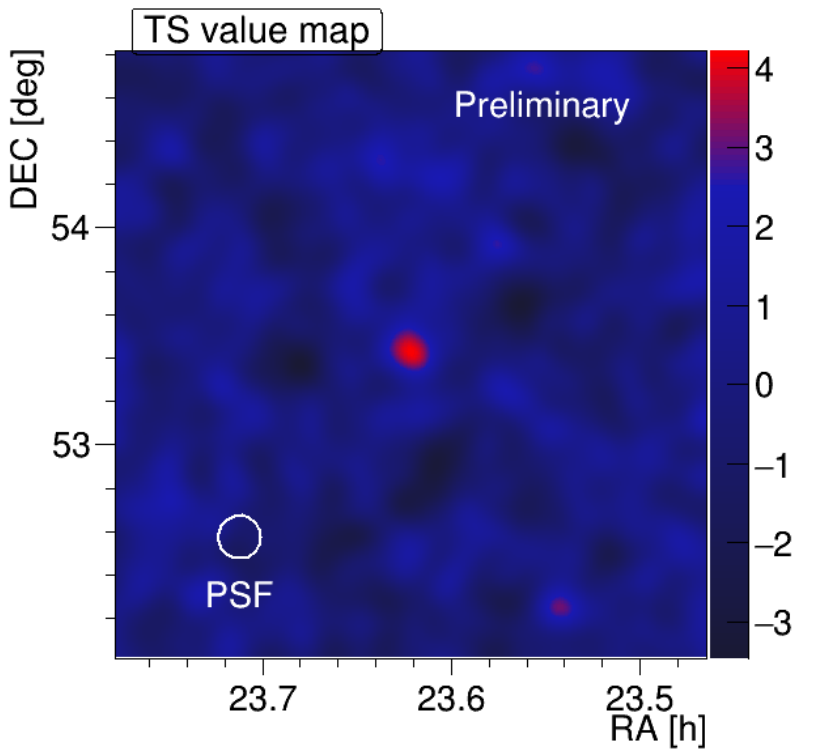

MAGIC observation of GRB 201216C

(long GRB), z = 1.10 most distant object >100GeV
ICRC2021_838, A. Carosi et al.

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

Name/type of the alert: GRB 201216C
Triggered by: Swift-BAT , T0=2020-12-16 23:07:31 UT
Alert coordinates: RA=01h05m25.872s Dec=16d32m12.12s (J2000)
Alert arrival time: 2020-12-16 23:07:51 UT

Exact time and date of start/stop of data-taking: 2020-12-16 23:08:27 UT to 2020-12-17
Overall available observation time: 2.2h

❑ GCN Circ. #29075, Atel #14275

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GRB 201216C: MAGIC detection in very high energy gamma rays

ATel #14275; ***Oscar Blanch (IFAE-BIST) on behalf of the MAGIC Collaboration***
on 17 Dec 2020; 17:23 UT
Credential Certification: Oscar Blanch (blanch@ifae.es)

Subjects: Gamma Ray, >GeV, TeV, VHE, Gamma-Ray Burst

Referred to by ATel #: 14277

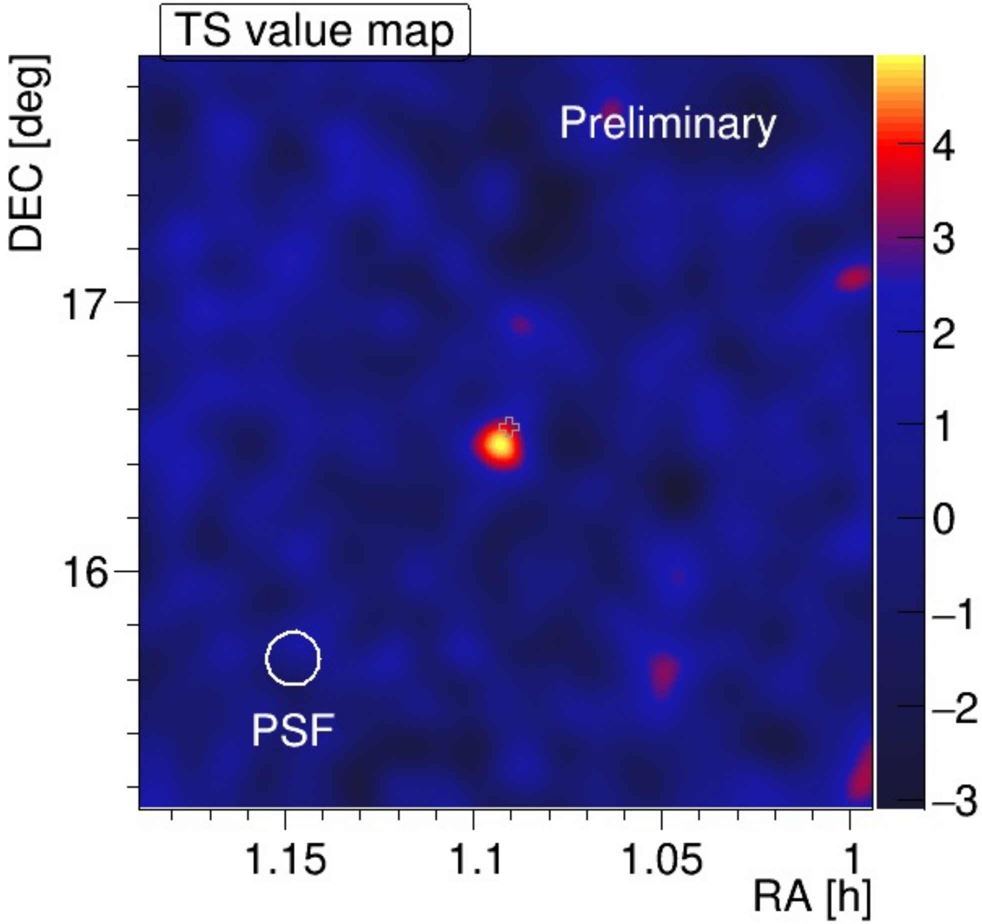
Tweet

On December 16, 2020, the MAGIC telescopes observed GRB 201216C following the trigger by Swift-BAT and Fermi-GBM (Beardmore et al., GCN 29061, Fermi/GBM team GCN 29063). MAGIC started observations under good conditions about 57 seconds after the GRB onset. The preliminary off-line analyses show an excess above 5 sigma, compatible with the GRB position reported by the Swift and Fermi teams. Refined off-line analyses of the data are ongoing.

We strongly encourage follow-up observations by other instruments at all wavelengths.

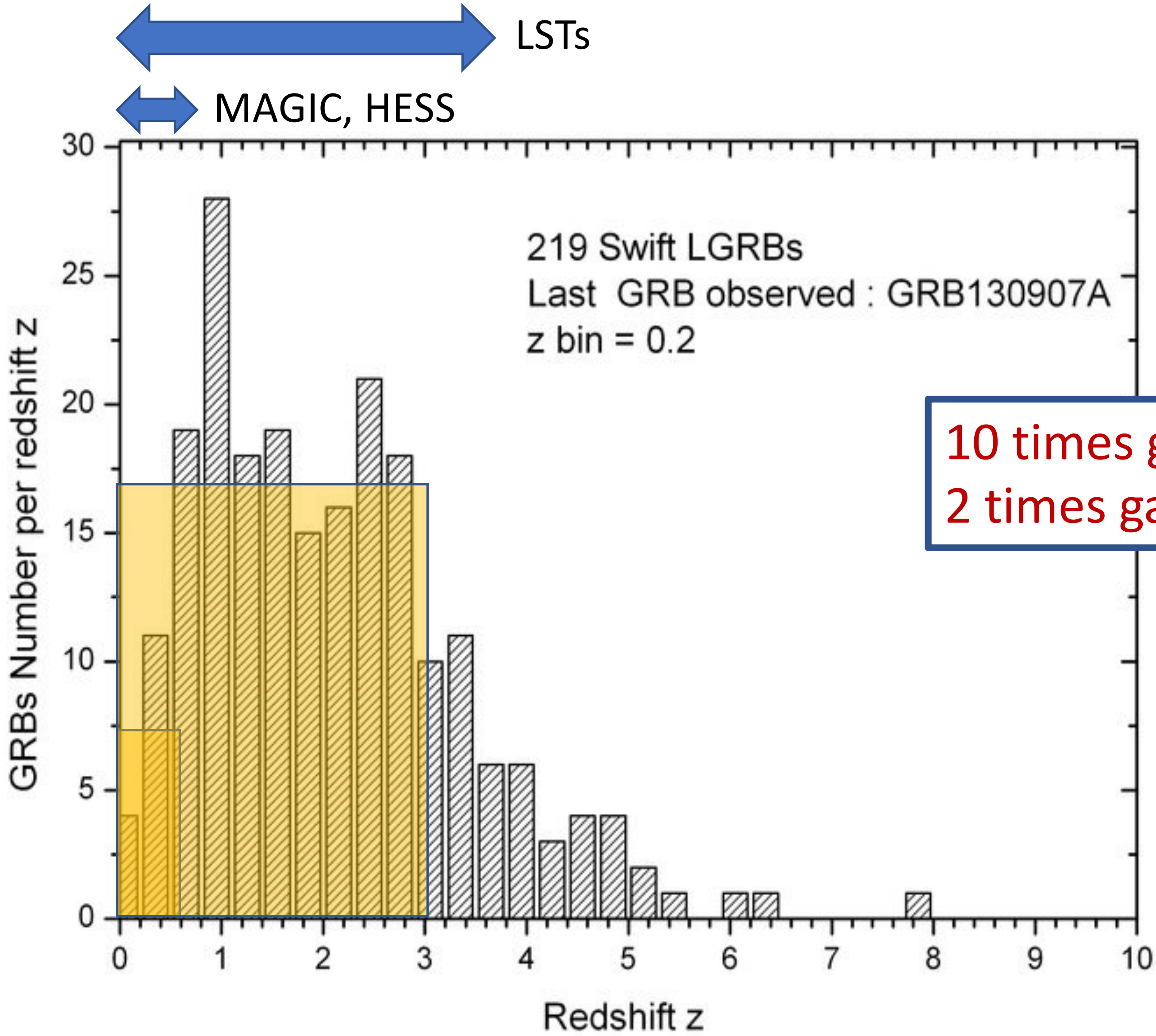
The MAGIC point of contact for this burst is O. Blanch (blanch@ifae.es). Burst Advocate for this burst is F. Longo (francesco.longo@ts.infn.it).

MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.



Redshift Distribution from SWIFT GRBs

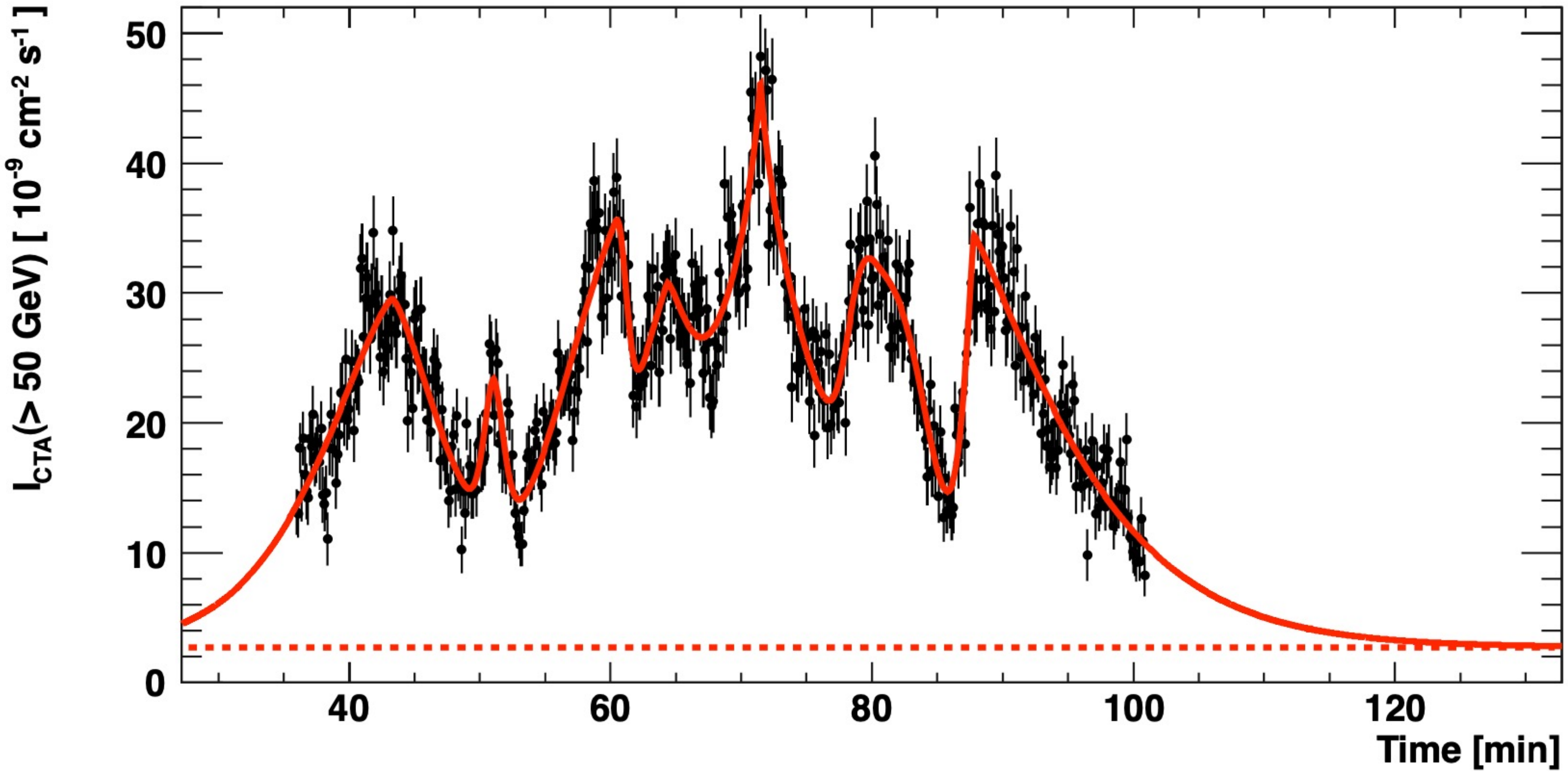
W. J. Azzam et al. 2014



15 GRBs in z < 0.5
112 GRBs in z < 2.0
164 GRBs in z < 3.0

10 times gain with Low En. Th.
2 times gain with LST South

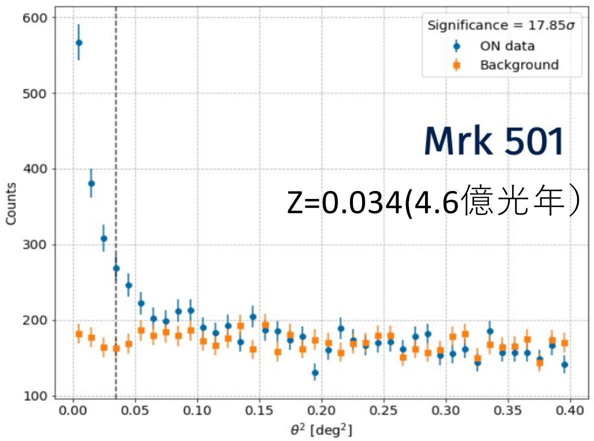
Simulated AGN Flares
Template: the 2006 flare of PKS2155-304

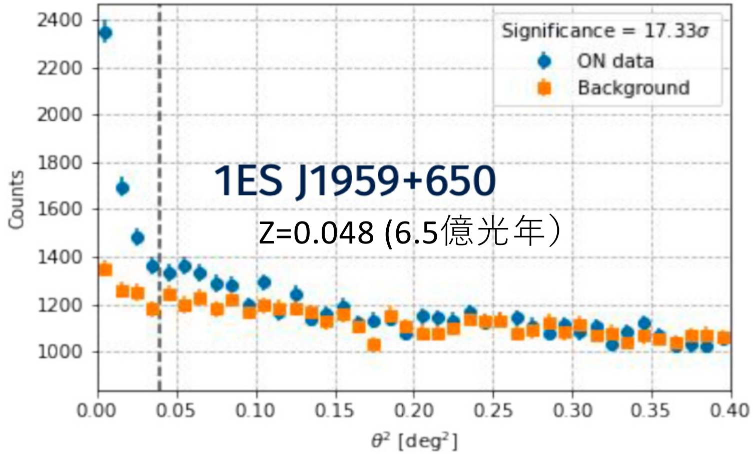


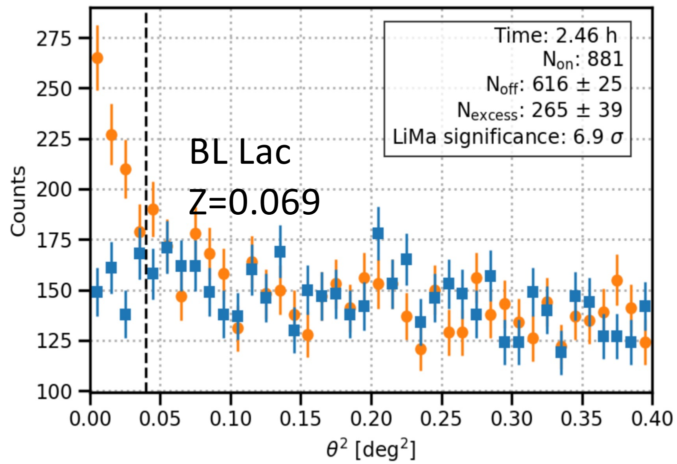
- ❑ Light curve can be examined, a few minutes scale structure ➔ a few 10s of seconds
  - ❑ Particle acceleration mechanism, Cooling process
  - ❑ Light curve vs. Energy dependence ➔ Q.G. Energy scale > Planck Mass scale

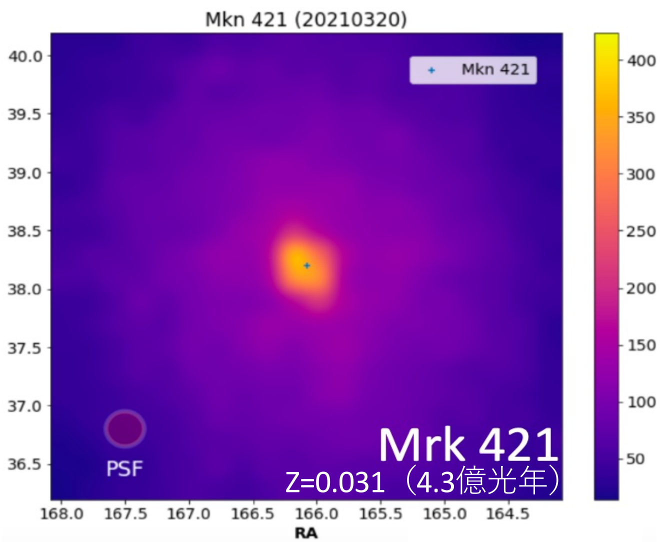
LST1 による活動銀河核の観測 2020-2021Q1

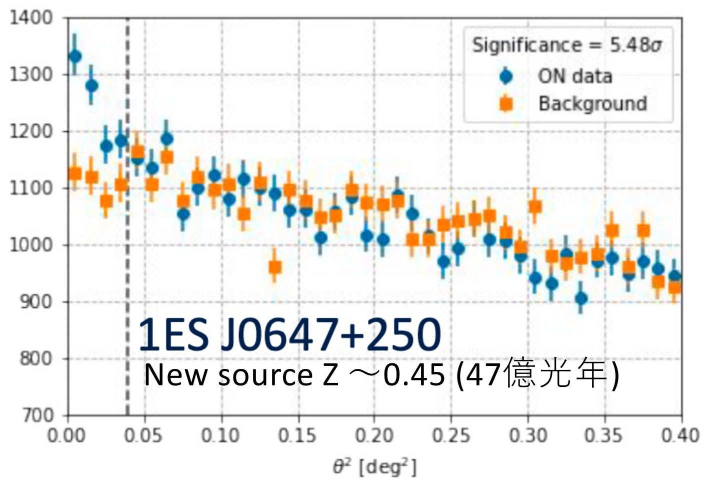
- 近傍の活動銀河核 Mrk501, Mrk421, 1ES 1959+650
- 遠方の活動銀河 1ES0647+250(New), PG1553+113
- LSTによる観測を数億光年から50億光年へ拡張
- 活動銀河核、ガンマ線バーストの観測を120億光年まで拡張観測を目指す（宇宙年齢137億光年）

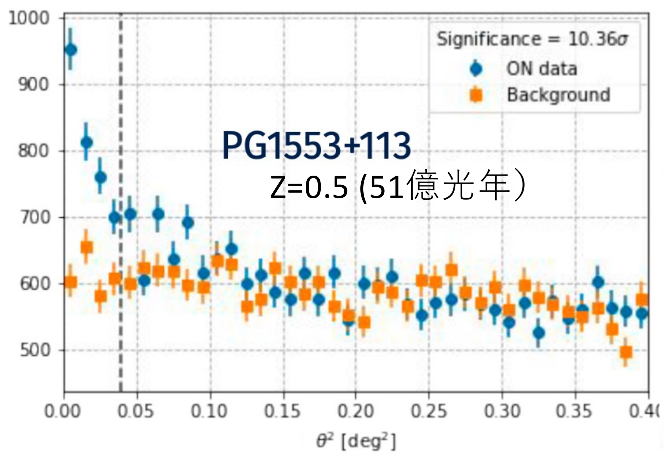






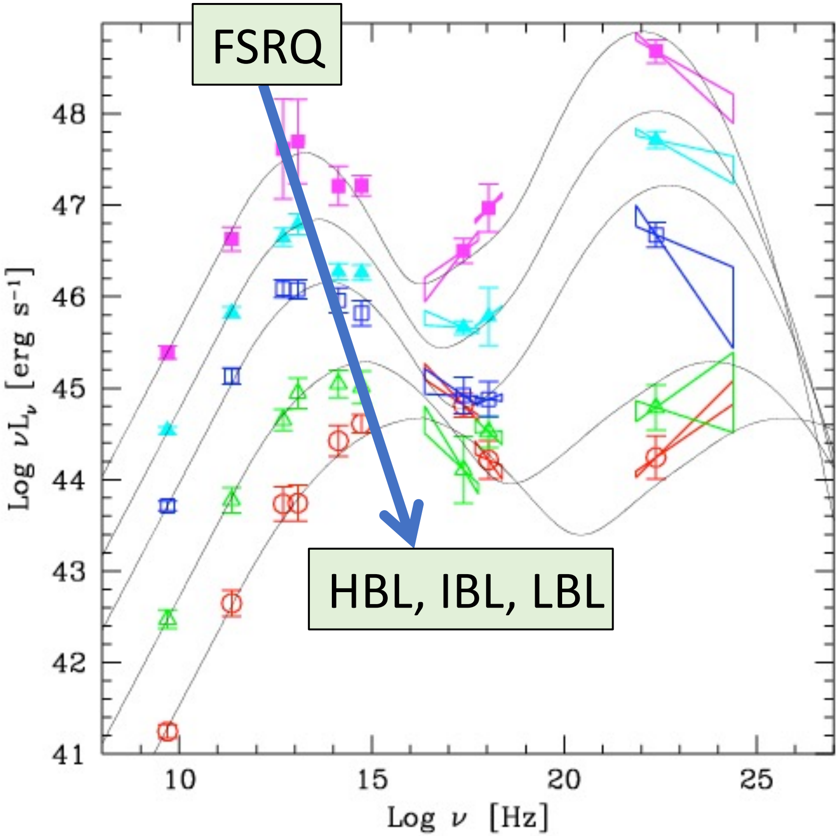






Flat Spectrum Radio Quasars

Blazar Sequence



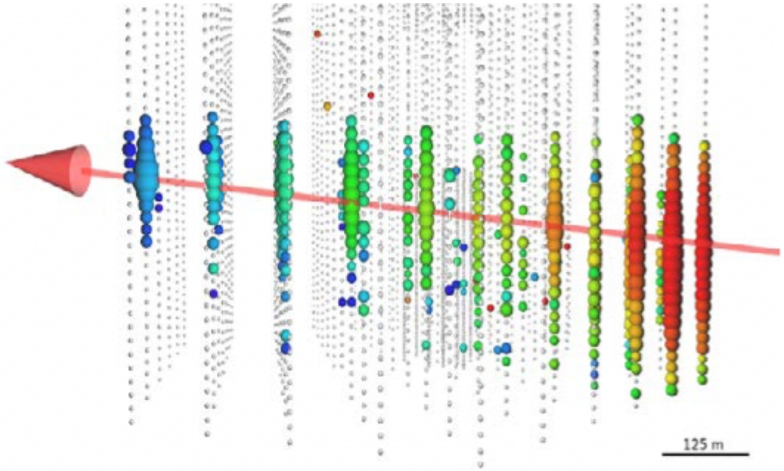
- FSRQ is much brighter than HBL and LBL (3-4 orders of Magnitudes --- high accretion rate)
- Only 6 FSRQs are observed among about 60 Blazars
- Useful to explore super massive black hole in the Early Universe
- MAGIC observed 6 FSRQs

Source	Redshift	Discoverer	Year
3C 279	0.5362	MAGIC	2006
PKS 1510-089	0.361	HESS	2009
4C +21.35 (PKS 1222+216)	0.432	MAGIC	2010
S30218+35	0.936	MAGIC	2014
S4 0954+65*	0.368	MAGIC	2015
PKS 1441+25	0.939	MAGIC	2015

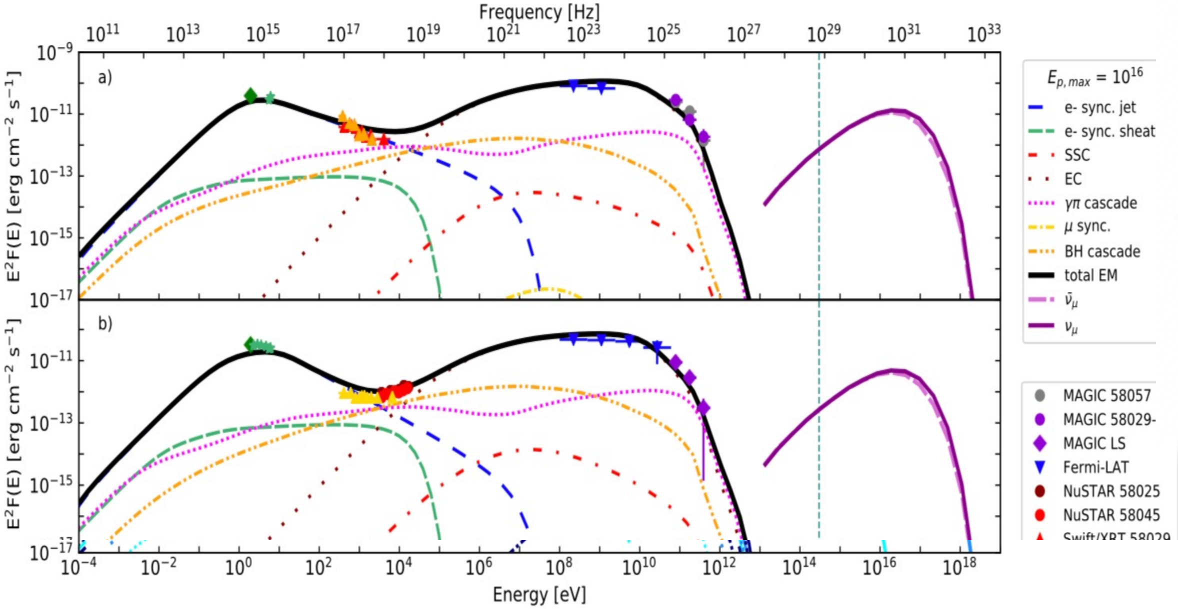
* Classification is not clear, FSRQ/IBL/LBL

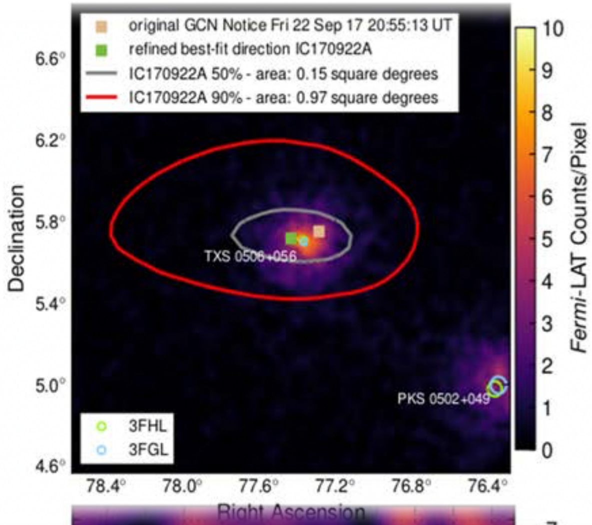
Multi Messenger Astronomy IC170922A / TXS 0506+056 HE ν : Star formation epoch?

Ice Cube Observation (~300TeV)

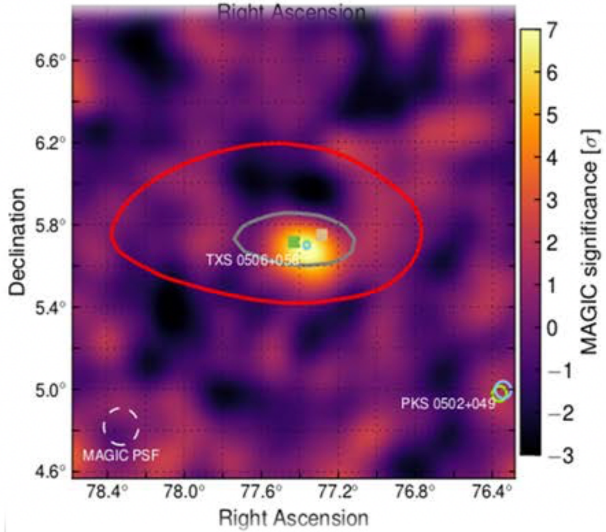


Lepto-Hadronic Scenario





Fermi LAT (>100 MeV)

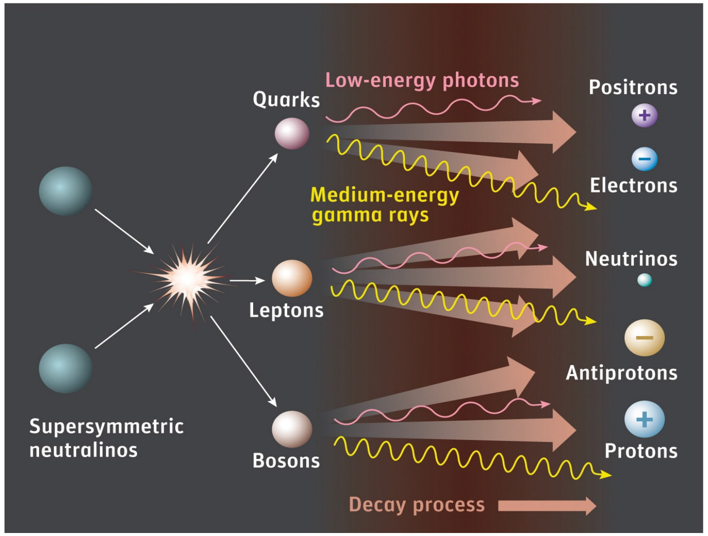


MAGIC (>100GeV)

GTC Observation z = 0.3365
S. Paiano et. al 2018

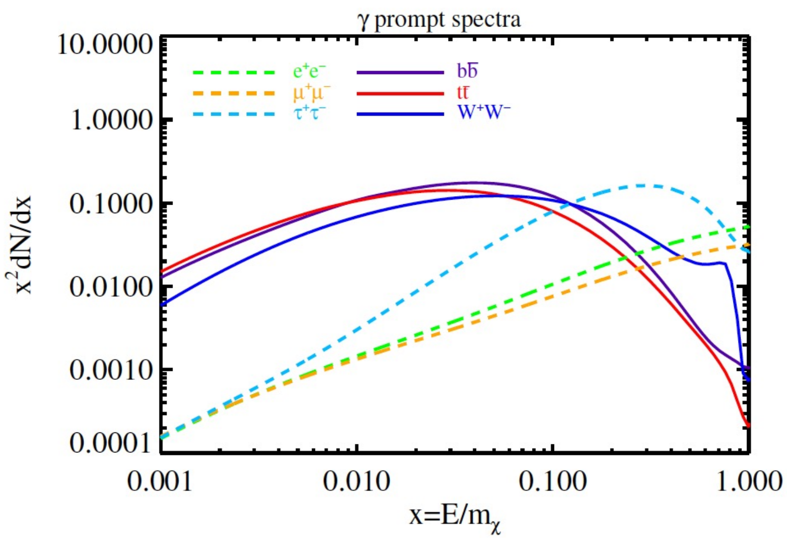
Dark Matter Search

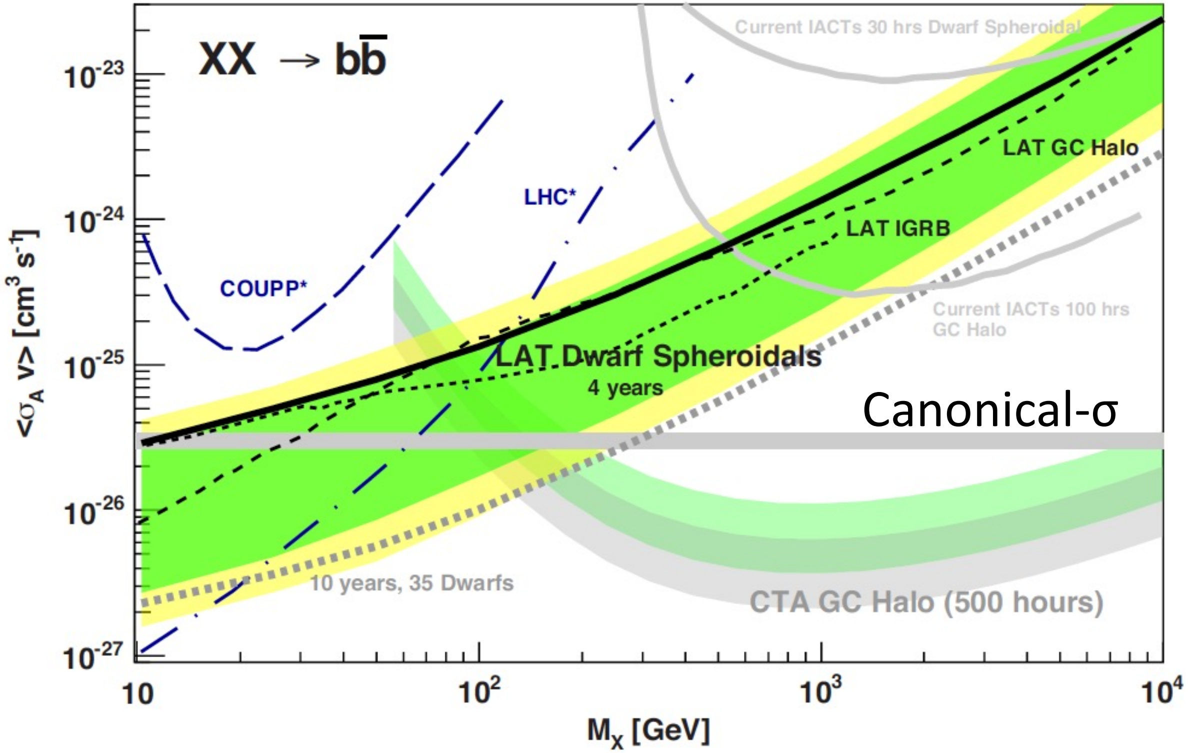
Sensitive M_χ: 200GeV - 10TeV



$$\frac{d\Phi_\gamma}{dE_\gamma} = \underbrace{\frac{1}{4\pi} \frac{<\sigma_{\rm ann} v>}{2 m^2_{\rm WIMP}} \sum_f \frac{dN^f_\gamma}{dE_\gamma} B_f}_{\text{'Particle Physics'}} \times \underbrace{\int_{\Delta\Omega} d\Omega' \int_{\rm los} \rho^2 dl(r,\theta')}_{\text{'Astrophysics' or } J(E)}$$

Particle Physics   Astrophysics





Gamma rays from Annihilation produce the bump around 1/10 -1/20 Mχ ➔ 20GeV-1TeV gamma

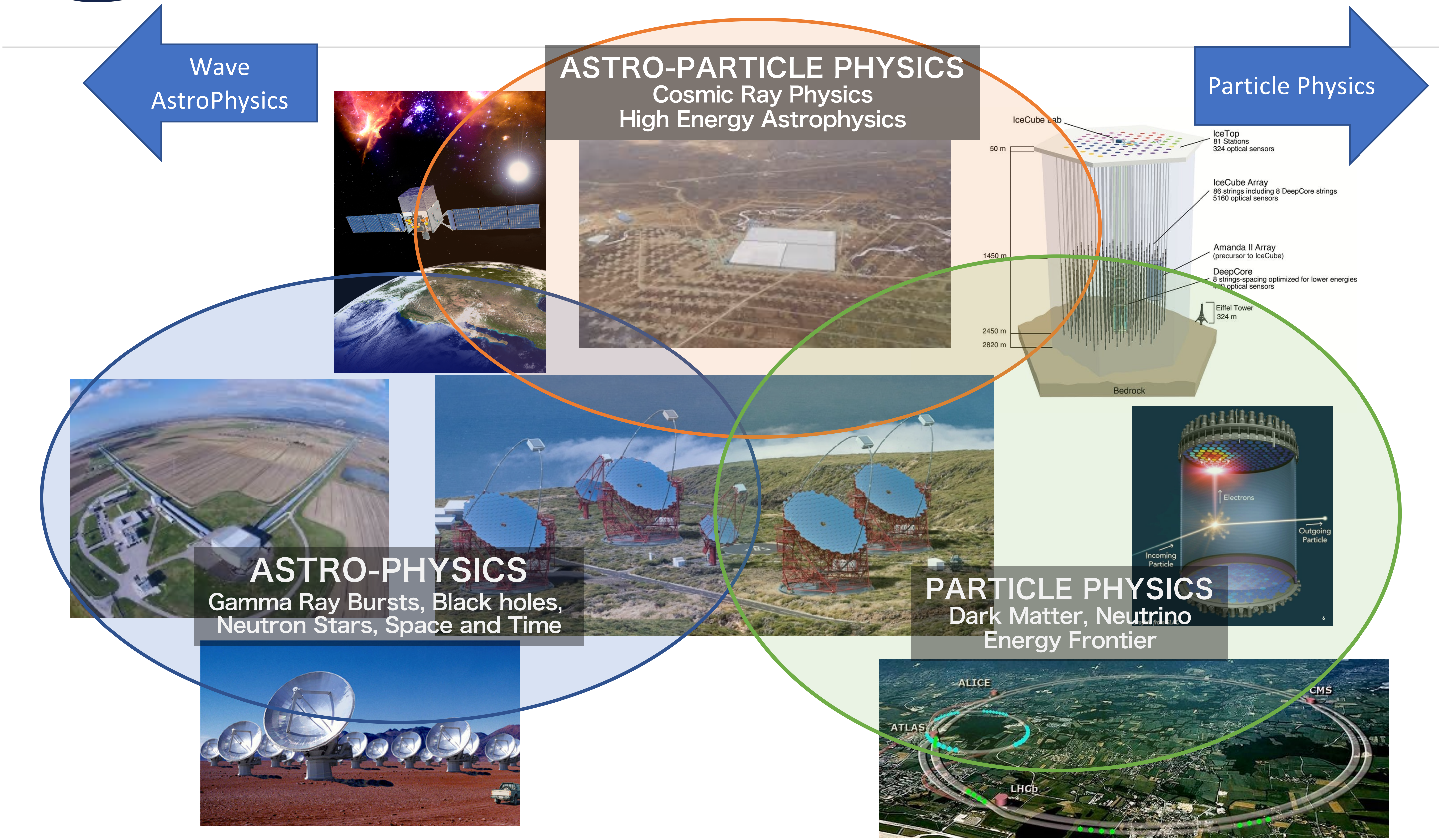
CTA gives the stringent upper limit.
Stefan Funk 2015

Status of CTA Project and LST Project

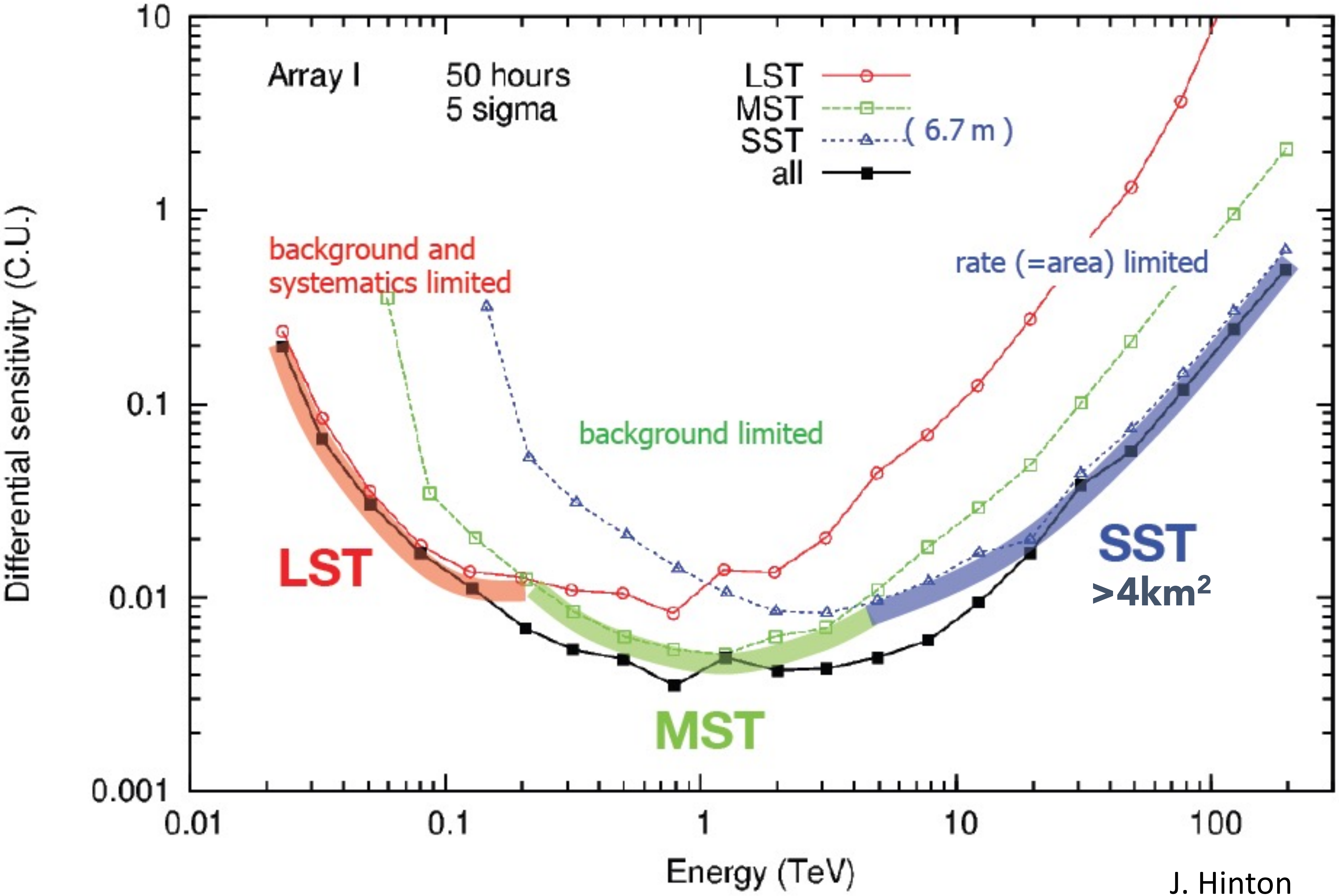
- 2022年に、CTAO ERIC を設立
  - 2025年に北半球が運用開始、2029年に南半球が運用開始
  - 南半球にLSTが必要 ➔ Transients, GRBs, AGN Flares, 銀河ハローに暗黒物質探索
  - 日本の貢献は12% であり、バランスがよくない。 ドイツ26%、イタリア19%、 フランス17%、スペイン13%であり、バランスがよくない。➔ 観測時間に反映される
  - LST5-8の建設(2026年以降)により、日本の貢献度20%以上となる。
- 2025年より LST1-4 運用開始(20GeV-3000GeVで世界最高)
  - Transient Sources、GW、PeV νとのマルチメッセンジャー観測が重要なターゲット
  - GRB 観測、従来の10倍の頻度 ➔ 高エネルギーガンマ線放射機構
  - AGN 現在の10倍(Redshift z<2)、 Accretion powered/Spin Powered, Blazar の進化
  - EBL, Inter Galactic Magnetic Field、Lorentz Invariance の高精度測定、
  - 銀河ハローに暗黒物質探索
- LST South（LST5-8） ➔ 建設費 34億円、運用費 2+2億円／yr
  - 暗黒物質 質量レンジ１００GeV－3TeVで世界最高感度
  - マルチメッセンジャー観測、GRB、AGN観測を倍増することができる
  - Specific な天体 SgrA*、Cen A、NGC253 Star burst galaxy

cherenkov
telescope
array

Multi-messenger and Multi-wavelength Astrophysics



cherenkov
telescope
array


Array I
50 hours
5 sigma
LST
MST
SST
all
(6.7 m)
background and
systematics limited
background limited
rate (=area) limited
LST
MST
SST
>4km²
Differential sensitivity (C.U.)
Energy (TeV)
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
J. Hinton