Brazilian Participation
Cherenkov Telescope Array

Vitor de Souza
vitor@ifsc.usp.br

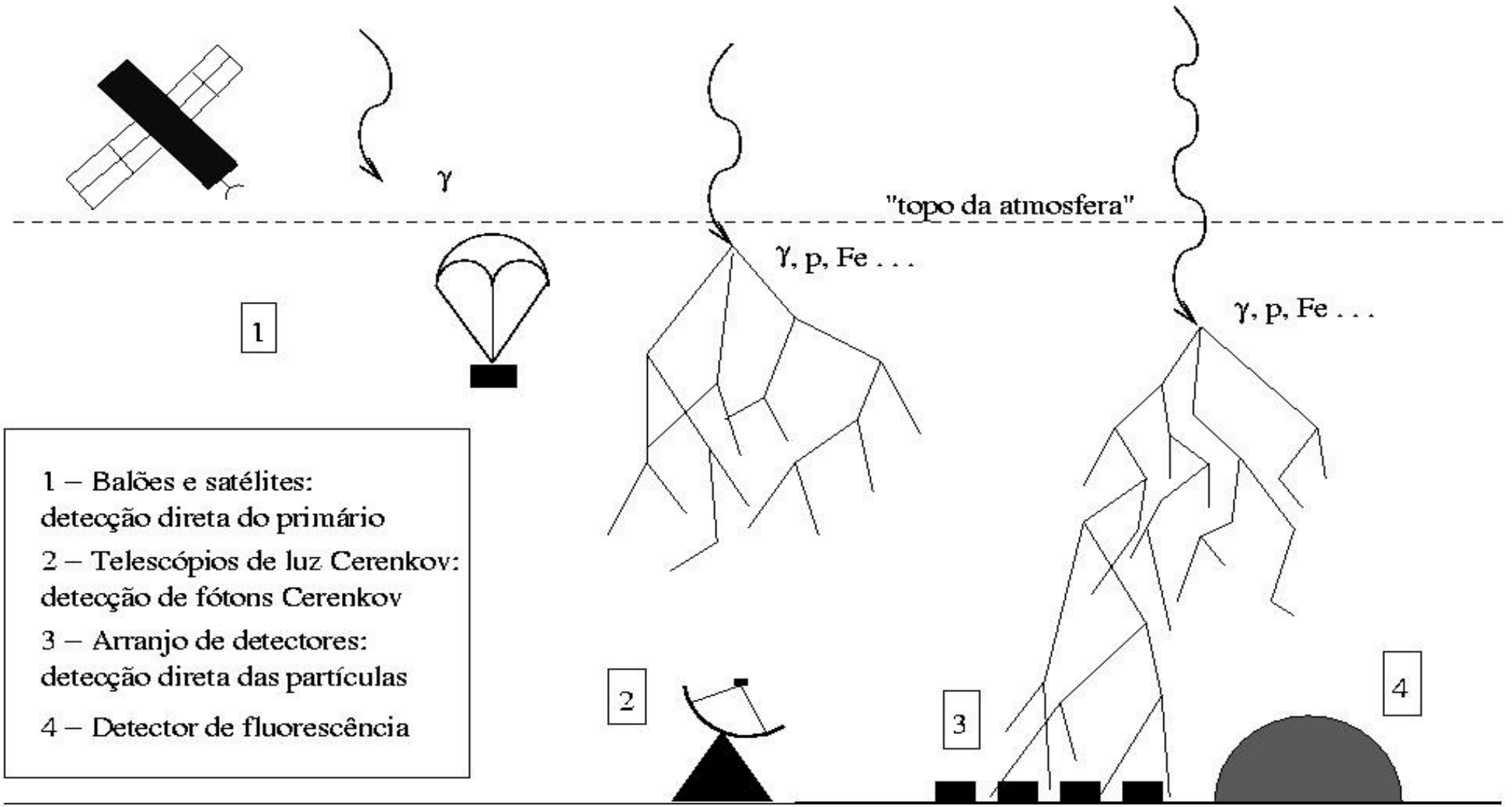
FAPESP

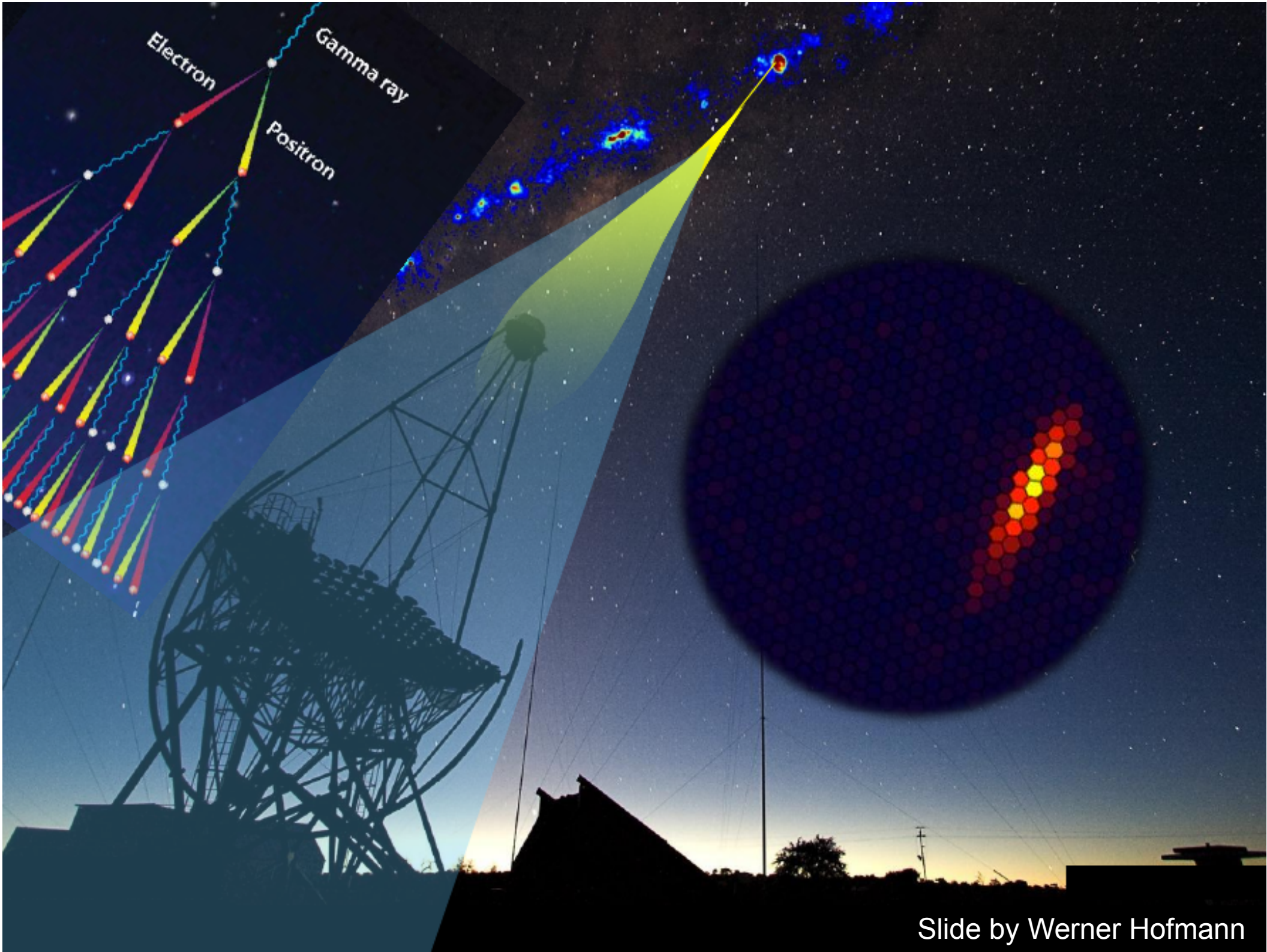
CAPES

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

Instituto de Física de São Carlos
Universidade de São Paulo

Astroparticle Physics Experiments

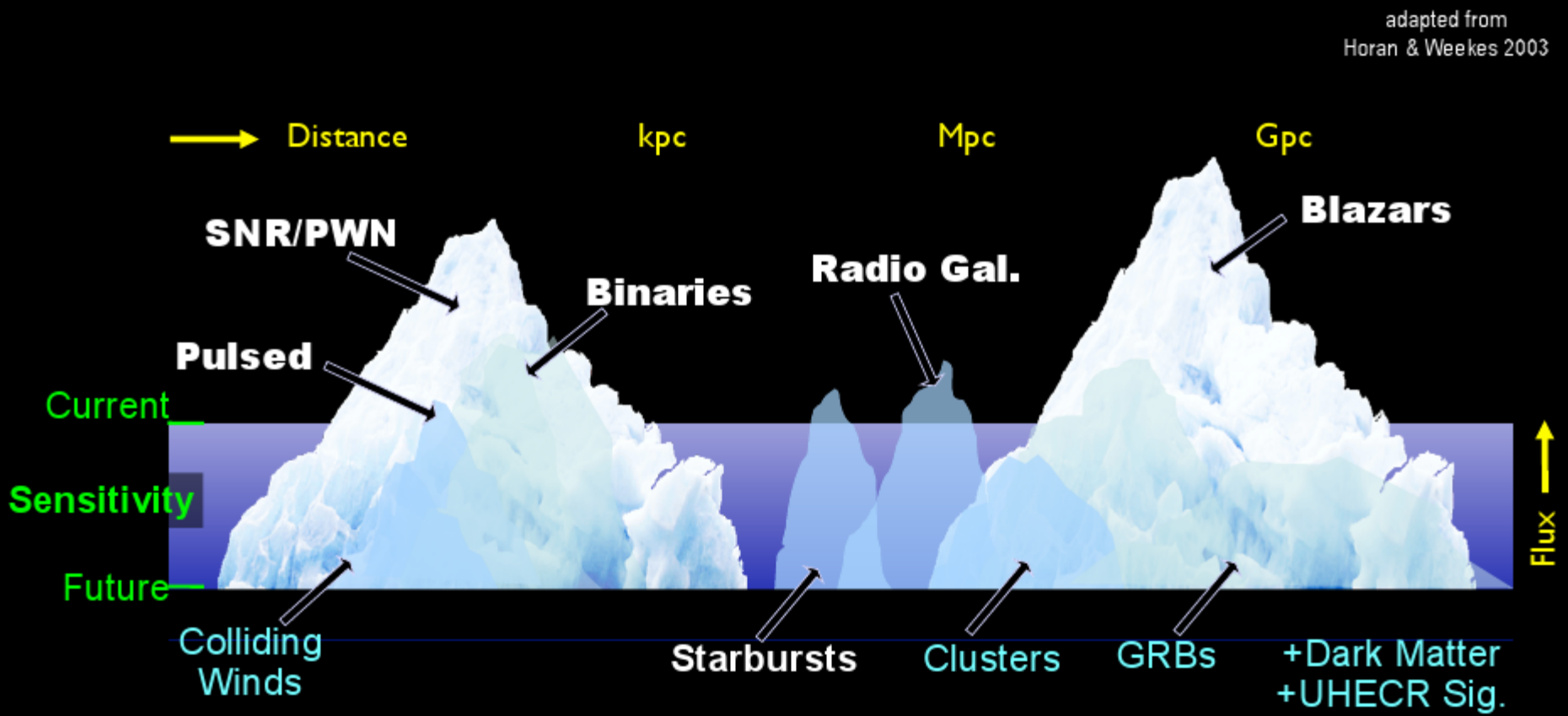



Electron
Gamma ray
Positron
Slide by Werner Hofmann

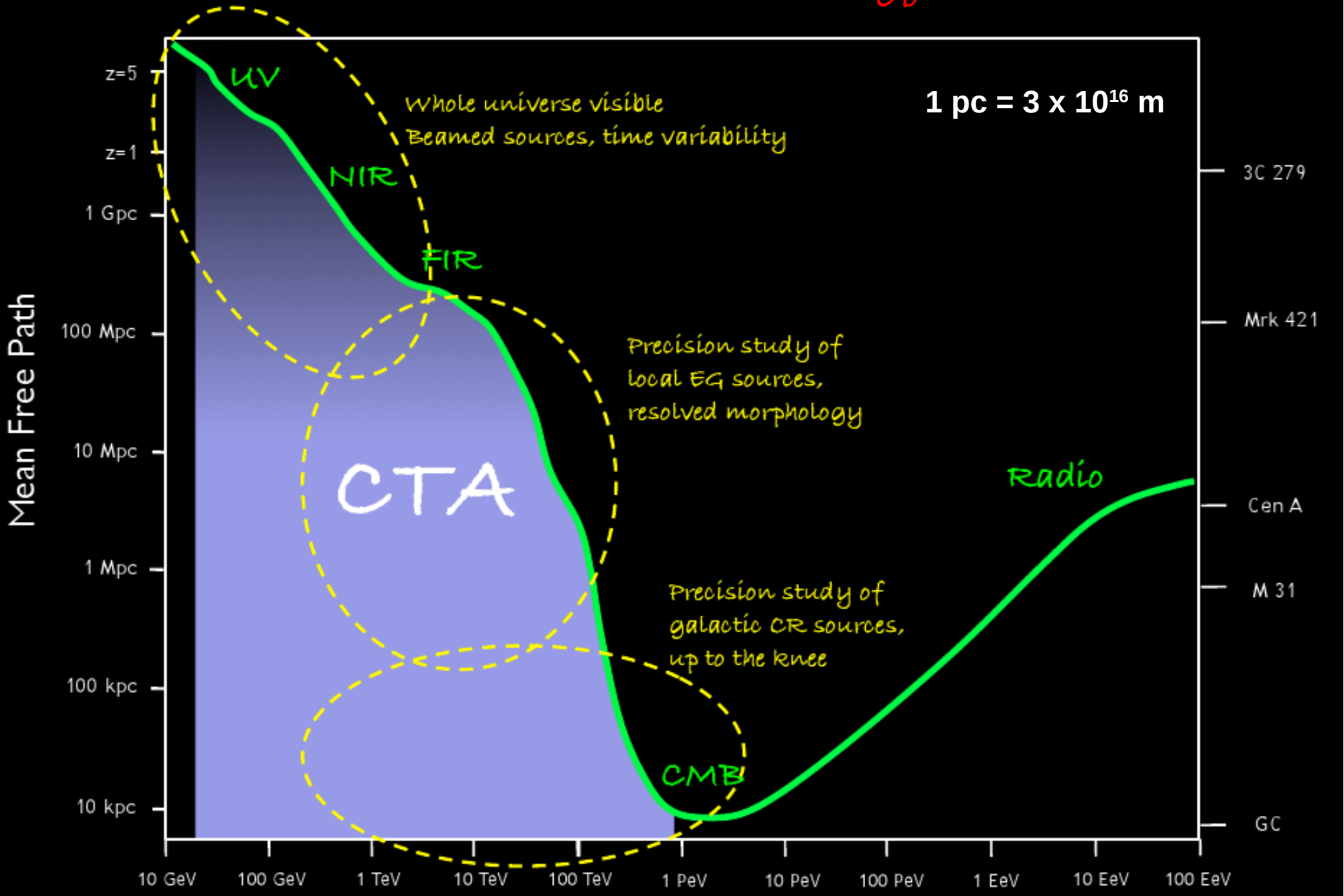
CTA Targets

- Improve the sensitivity in order of magnitude
- Increase the energy range
  - 20 GeV < E < 300 TeV
- Improve angular resolution
  - 1- 3 arcmin
- Operational flexibility

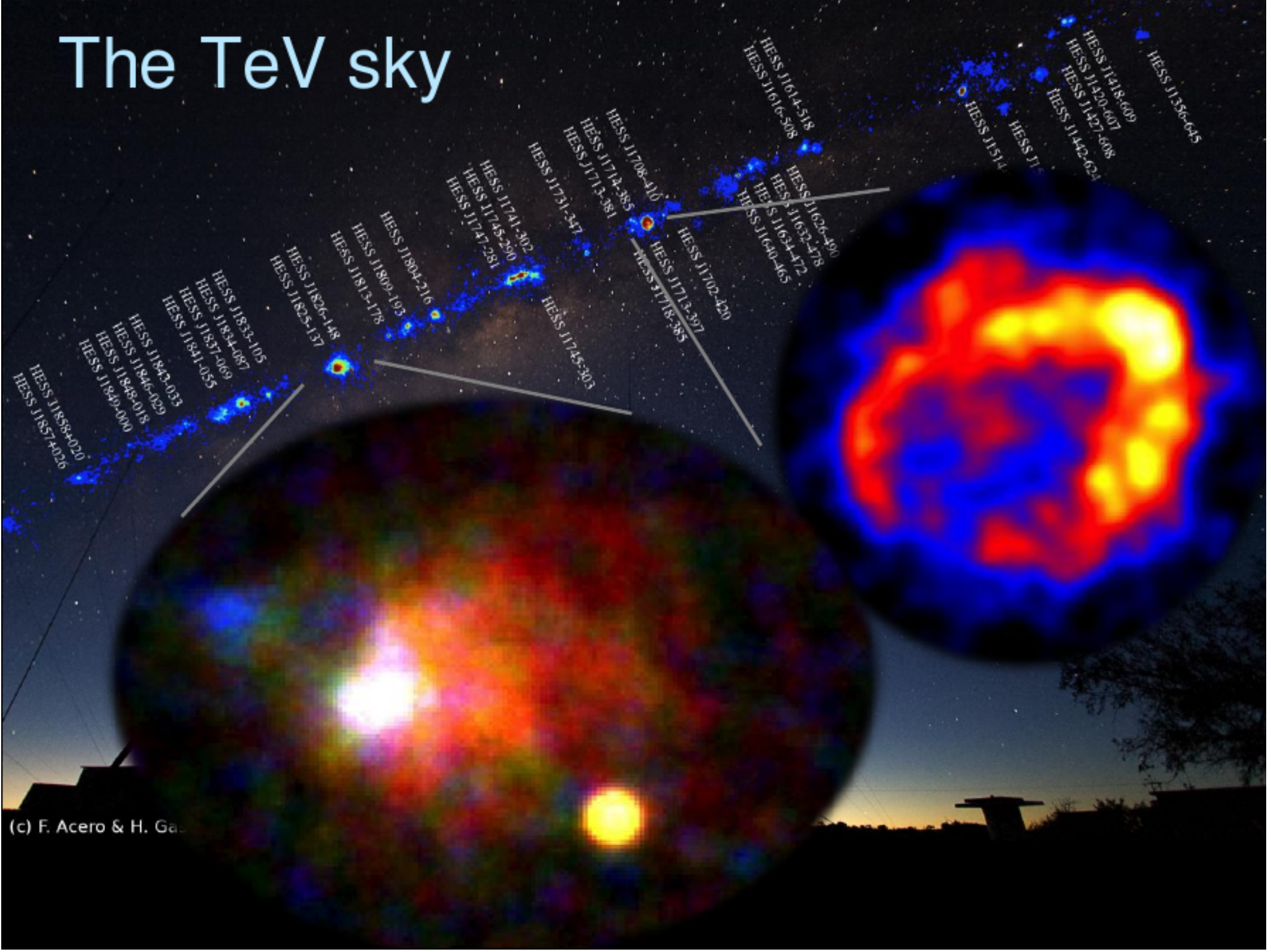
Discovery Potential

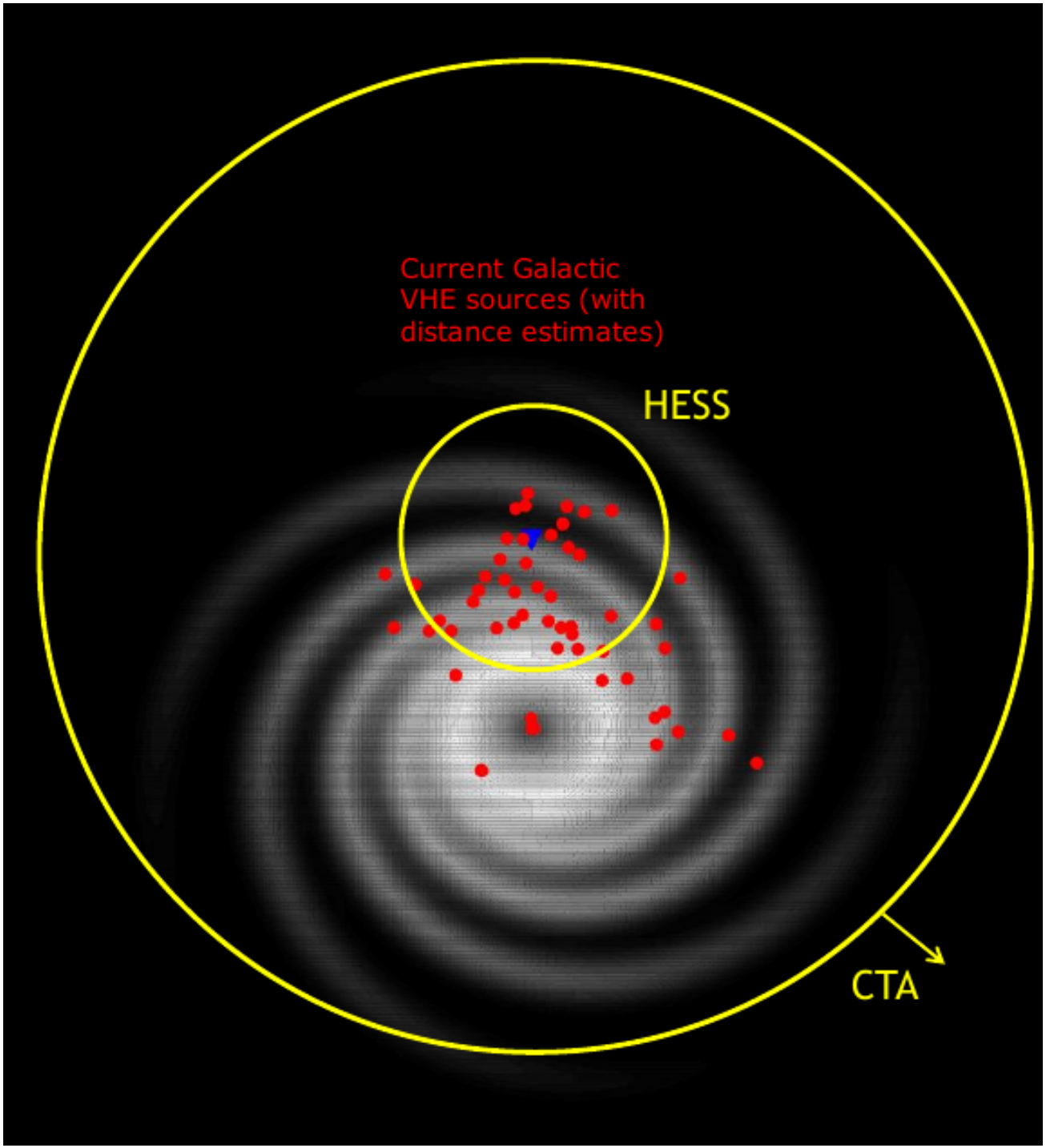


The Gamma Ray Horizon $\gamma + \gamma_{CB} \rightarrow e^+e^-$



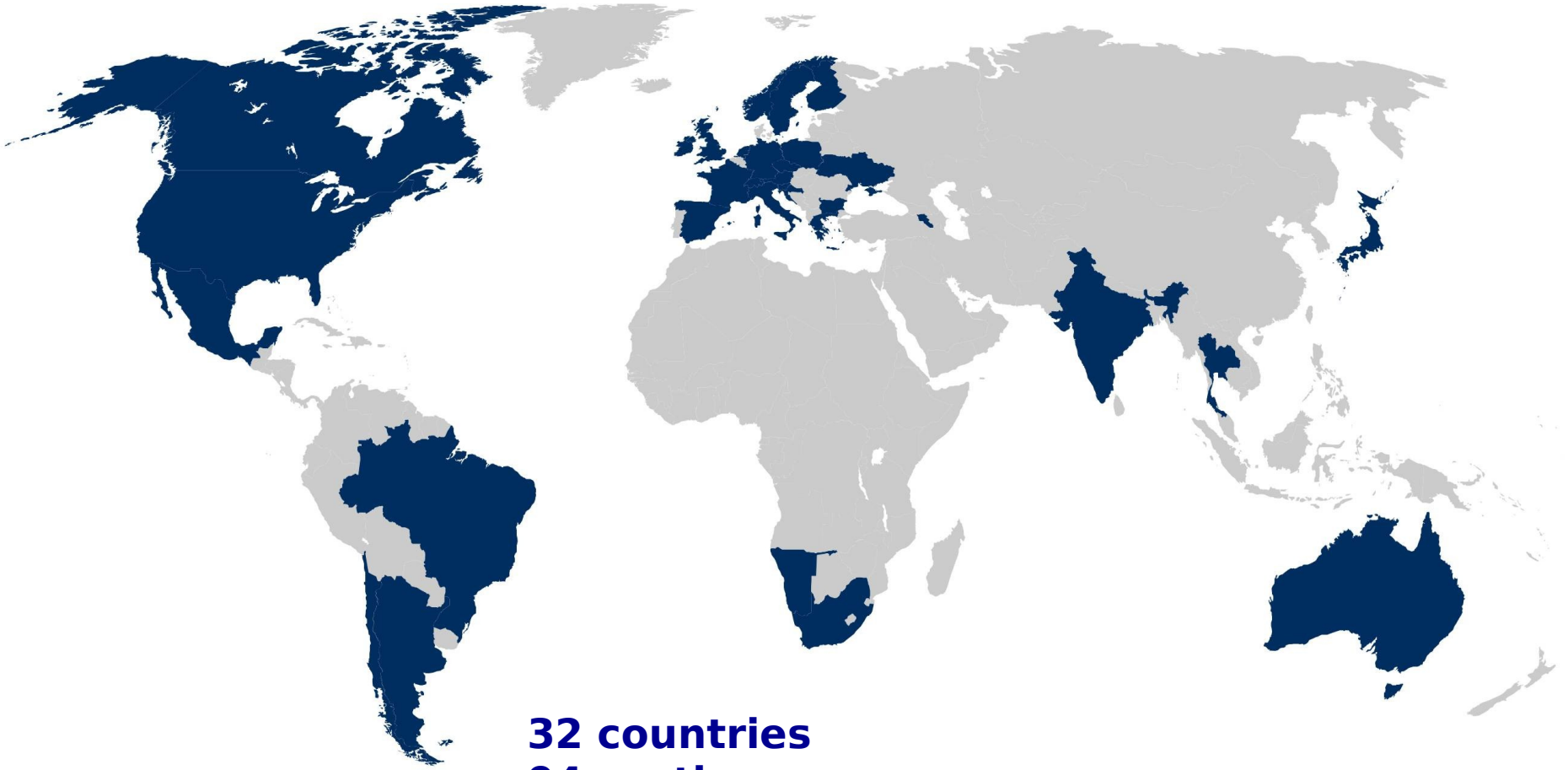
The TeV sky


HESS J1356-645
HESS J1418-609
HESS J1420-607
HESS J1427-608
HESS J1442-624
HESS J1514
HESS J1614-518
HESS J1616-508
HESS J1626-490
HESS J1632-478
HESS J1634-472
HESS J1640-465
HESS J1702-420
HESS J1708-410
HESS J1713-397
HESS J1714-385
HESS J1713-381
HESS J1718-385
HESS J1731-347
HESS J1741-302
HESS J1745-290
HESS J1747-281
HESS J1745-303
HESS J1804-216
HESS J1809-193
HESS J1813-178
HESS J1826-148
HESS J1825-137
HESS J1833-105
HESS J1834-087
HESS J1837-069
HESS J1841-055
HESS J1843-033
HESS J1846-029
HESS J1848-018
HESS J1849-000
HESS J1858+020
HESS J1857+026
(c) F. Acero & H. Ga


Current Galactic
VHE sources (with
distance estimates)
HESS
CTA

... an advanced facility for ground-based gamma-ray astronomy

CTA Consortium



32 countries
94 parties
208 institutes
1402 members (480 FTE)

KEY SCIENCE PROJECTS

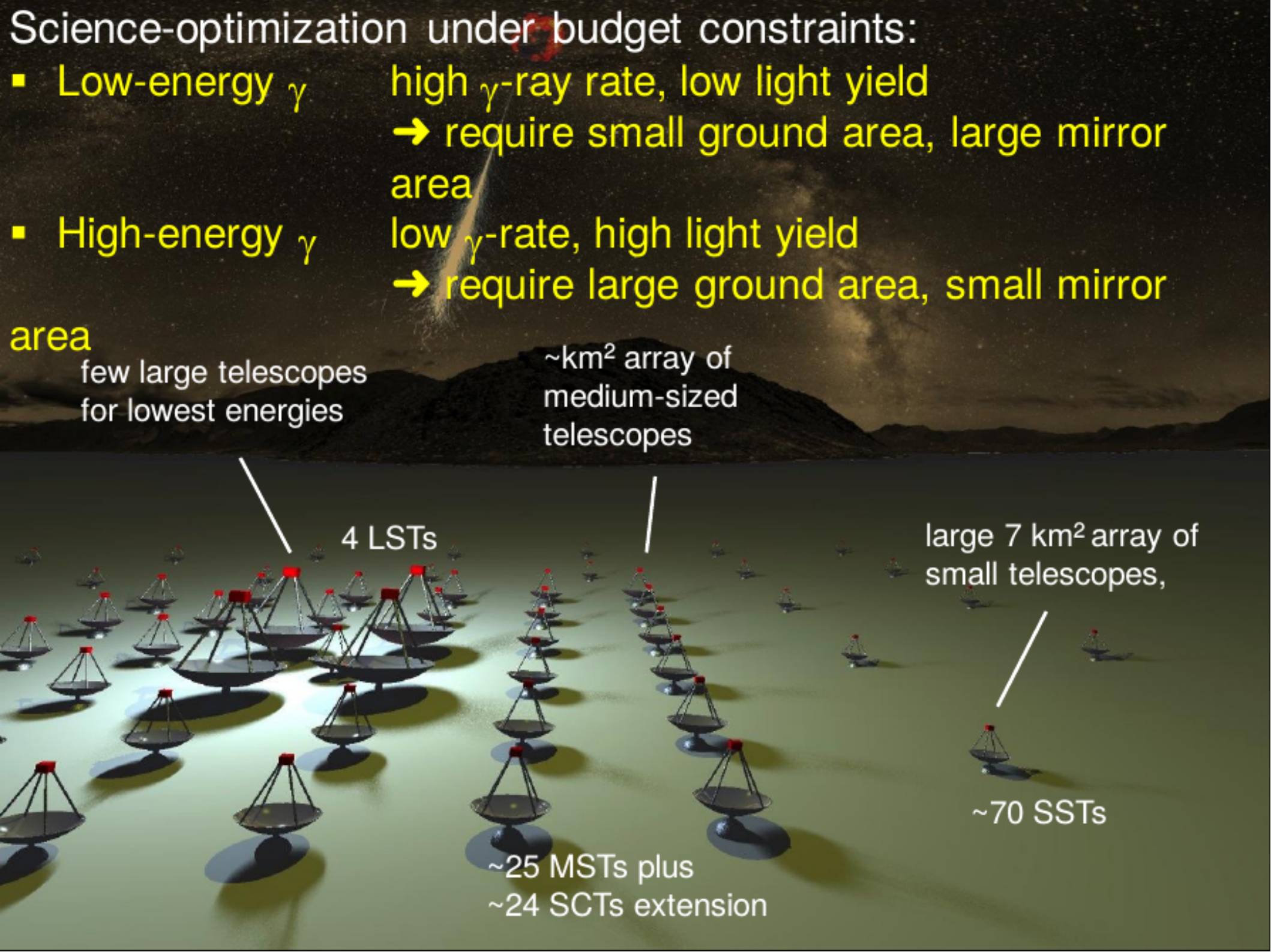
1. CTA Galactic Plane Survey
2. CTA Extragalactic Survey
3. Exploring extreme particle acceleration in the Galaxy
4. Probing DM with precision measurements of the Galactic Center
5. CTA studies on active galaxies
6. On the connection between cosmic rays and the star-formation process
7. Observations of clusters of galaxies
8. Observations of the LMC
9. Observations of the Cygnus region
10. Observation of Galactic DM dominated targets
11. Observations of transient phenomena

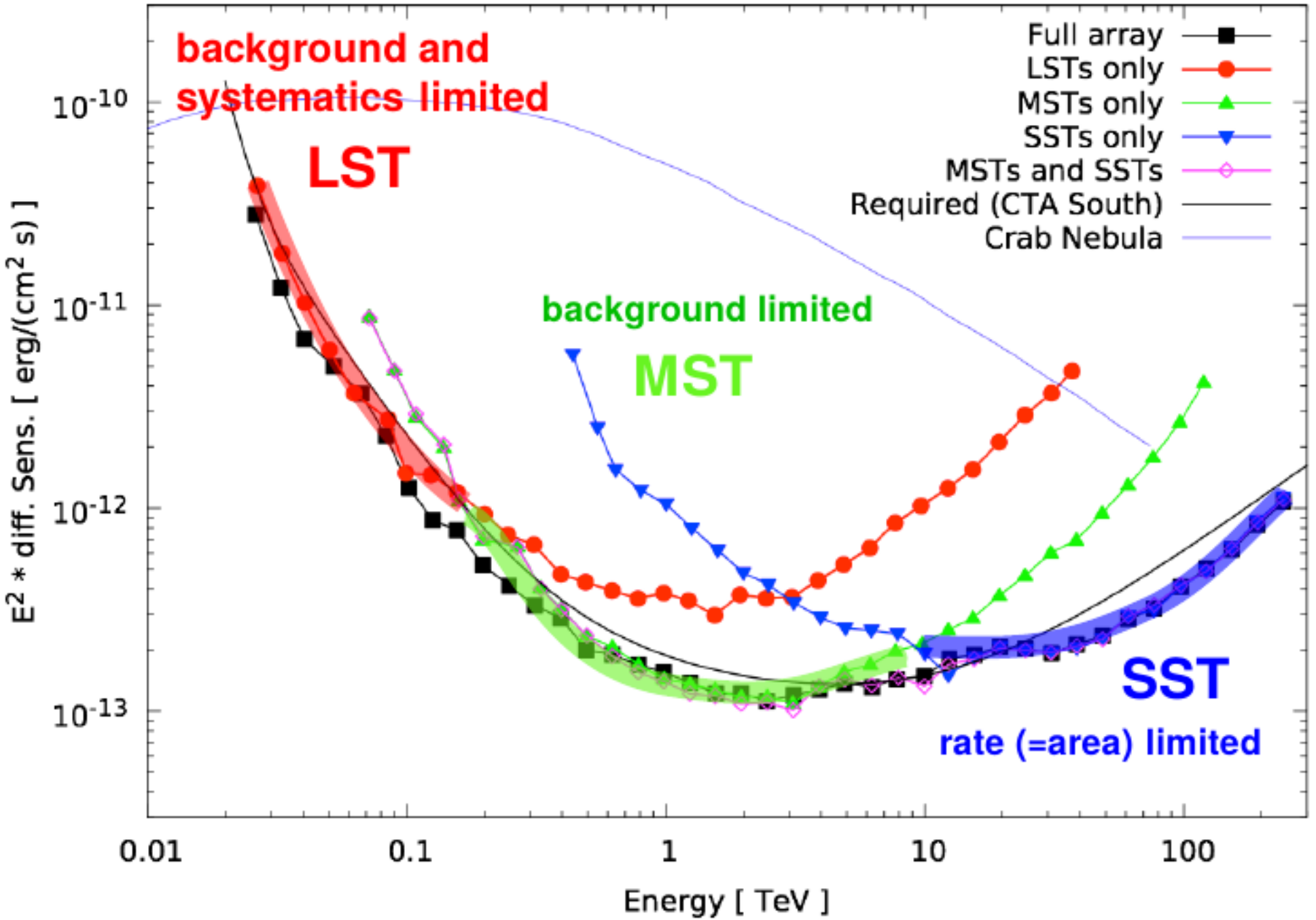
Science with CTA

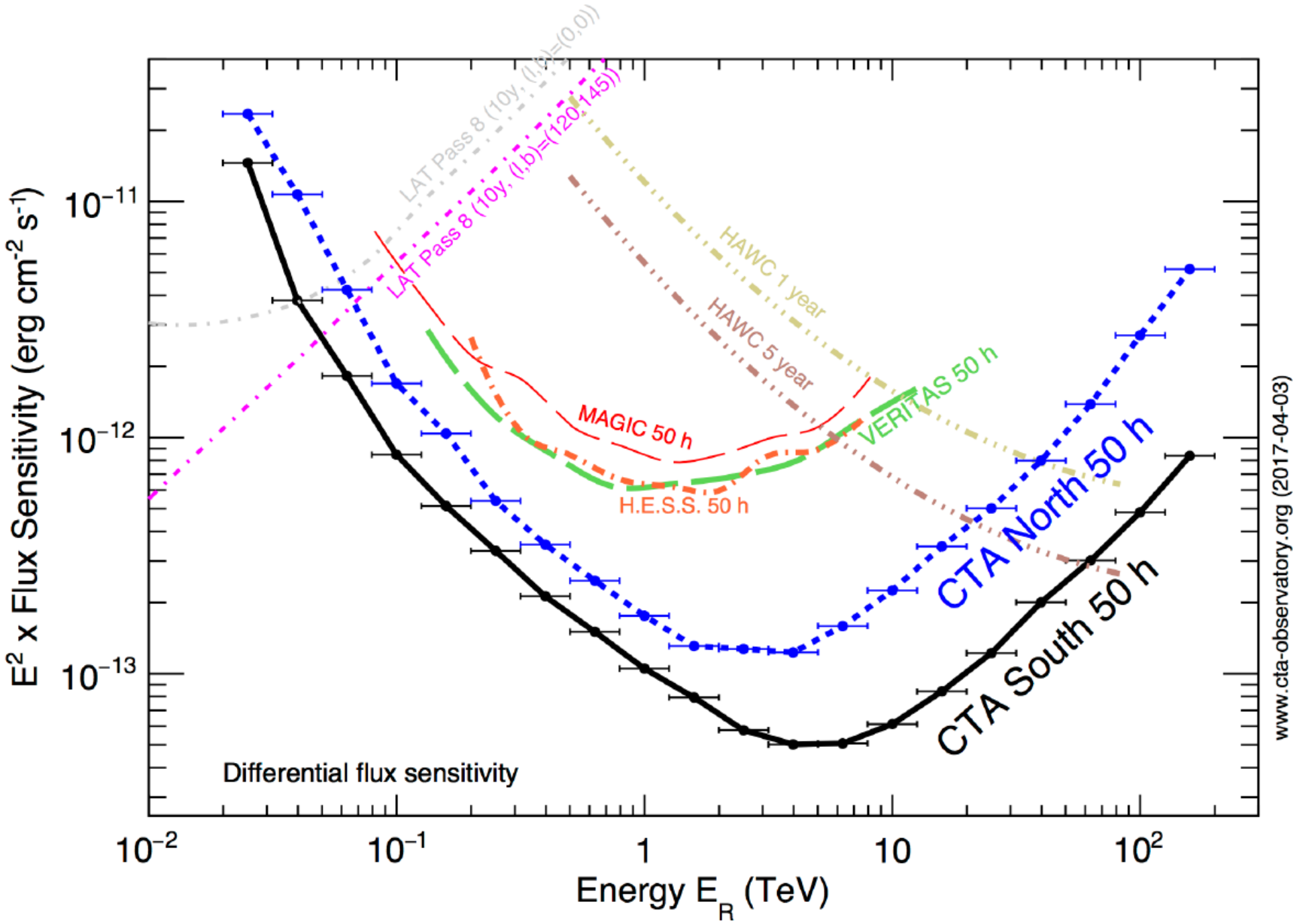
Will become a regular book /
a special journal issue

Science-optimization under budget constraints:

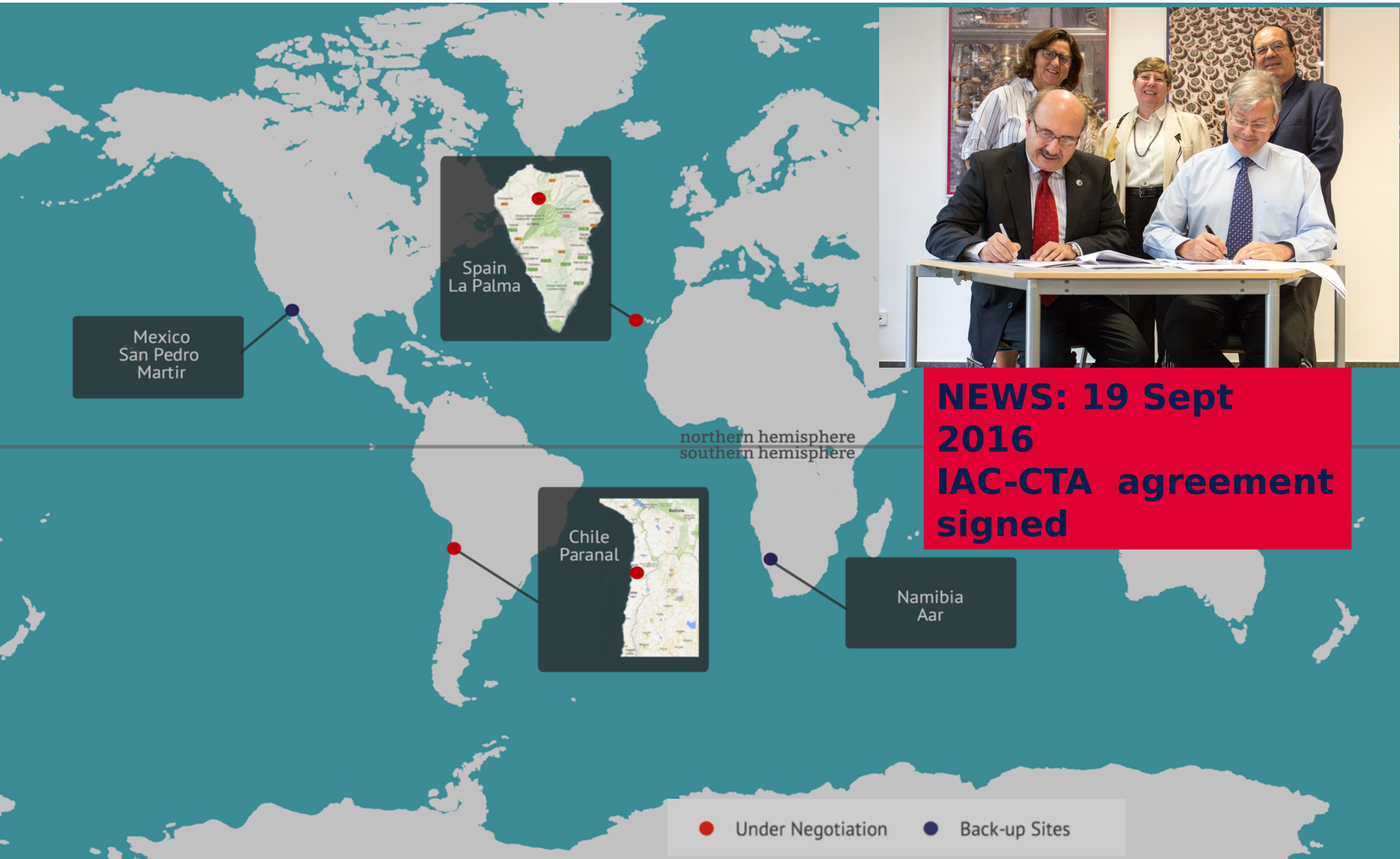
- Low-energy γ high γ-ray rate, low light yield
  ➜ require small ground area, large mirror area
- High-energy γ low γ-rate, high light yield
  ➜ require large ground area, small mirror area




background and
systematics limited
LST
background limited
MST
SST
rate (=area) limited
Full array
LSTs only
MSTs only
SSTs only
MSTs and SSTs
Required (CTA South)
Crab Nebula
E2 * diff. Sens. [erg/(cm2 s)]
10-10
10-11
10-12
10-13
0.01
0.1
1
10
100
Energy [TeV]

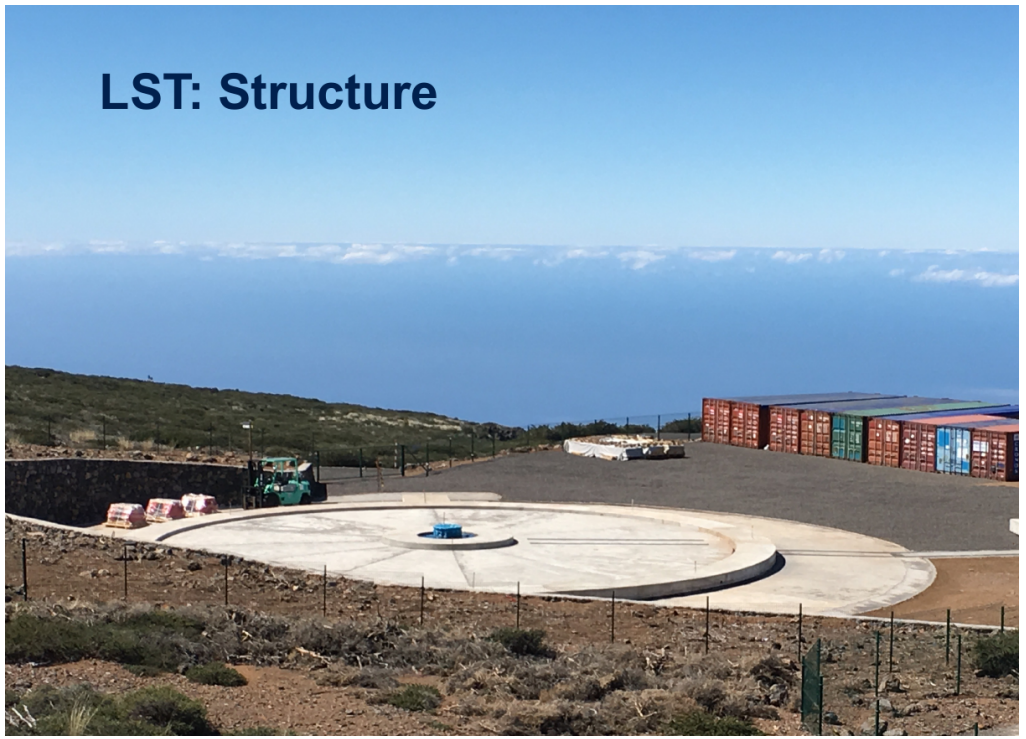

LAT Pass 8 (10y, (l,b)=(0,0))
LAT Pass 8 (10y, (l,b)=(120,145))
HAWC 1 year
HAWC 5 year
MAGIC 50 h
VERITAS 50 h
H.E.S.S. 50 h
CTA North 50 h
CTA South 50 h
Differential flux sensitivity
E² x Flux Sensitivity (erg cm⁻² s⁻¹)
Energy E_R (TeV)
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻²
10⁻¹
1
10
10²
www.cta-observatory.org (2017-04-03)

SITES



NEWS: 19 Sept 2016
IAC-CTA agreement signed

LST



MST

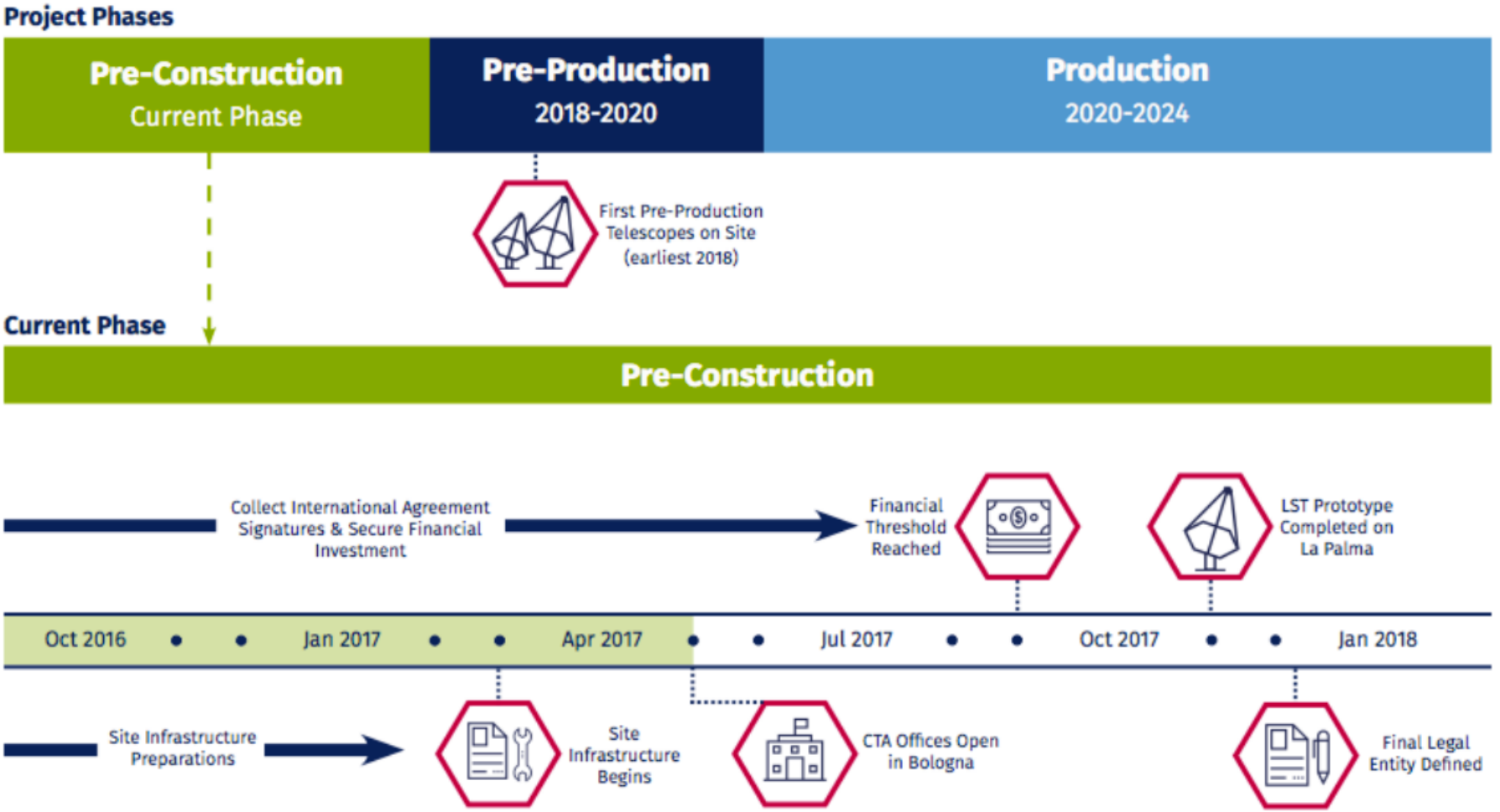
MST

SST

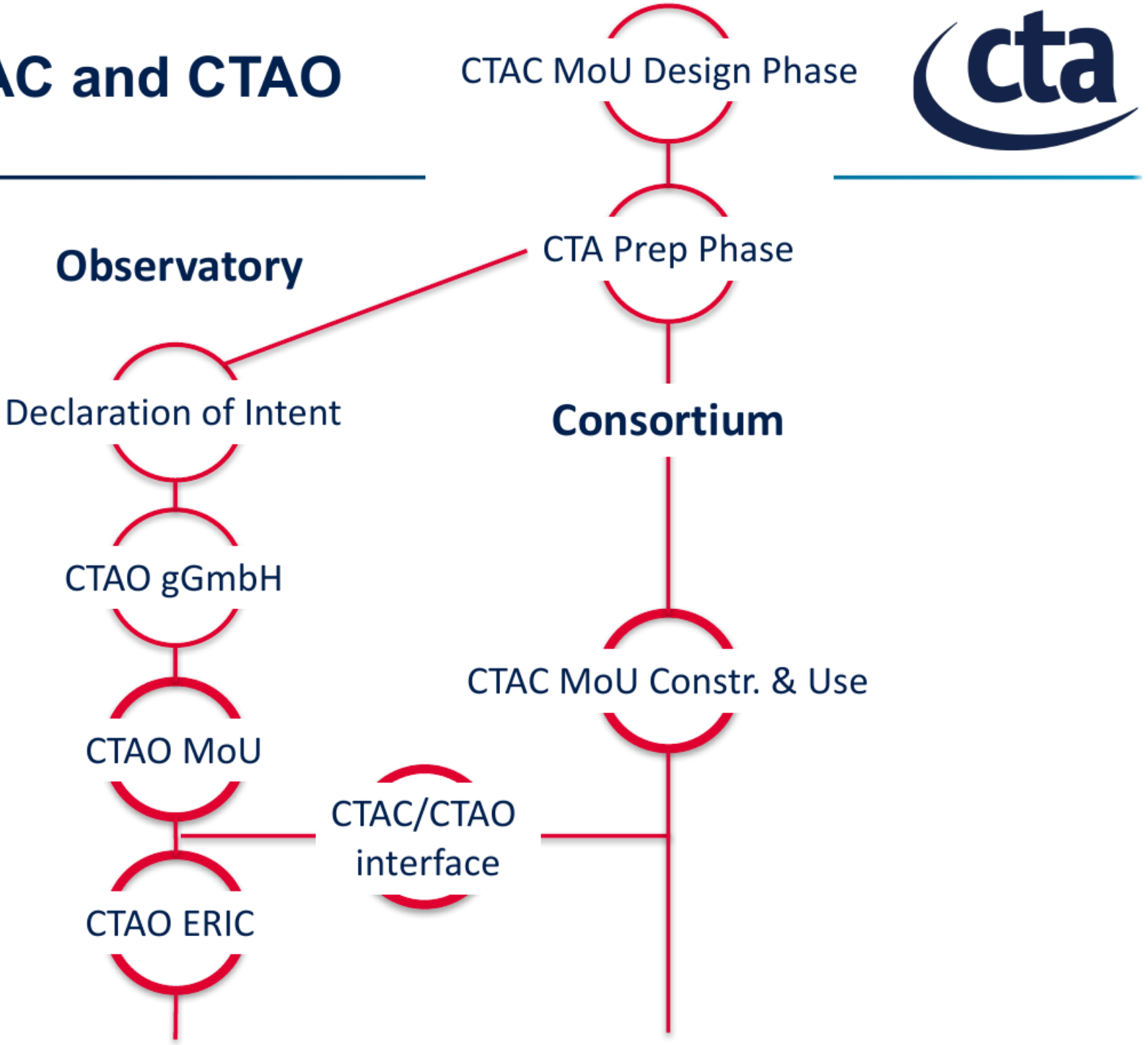
SST

SST

Deployment


Project Phases
Pre-Construction
Current Phase
Pre-Production
2018-2020
Production
2020-2024
First Pre-Production Telescopes on Site (earliest 2018)
Current Phase
Pre-Construction
Collect International Agreement Signatures & Secure Financial Investment
Financial Threshold Reached
LST Prototype Completed on La Palma
Oct 2016
Jan 2017
Apr 2017
Jul 2017
Oct 2017
Jan 2018
Site Infrastructure Preparations
Site Infrastructure Begins
CTA Offices Open in Bologna
Final Legal Entity Defined

CTAC and CTAO



CTA Brazil

12 Instituions

18 Researches

19 Students

5 Technicians

CTA - SP - MST

- IFSC- USP
  - Prof. Vitor de Souza
  - Profa. Manuela Vecchi
  - Profa. Cibelle Celestino
  - Dr. Humberto Huerta
  - Raul Prado
  - Rodrigo Lang
  - Rodrigo Guedes Lang
  - Danielle Kaori
- IF-USP
  - Prof. Edivaldo Moura
  - Douglas Pimentel
- UFABC
  - Prof. Marcelo Leigui
  - Raquel de Almeida
- UFSCar
  - Dr. Gustavo Rojas
- UFPR
  - Prof. Rita de Cássia
- EEL / USP
  - Prof. Fernando Catalani
  - Prof. Carlos Todero
- SAIFR / IFT - UNESP
  - Dr. Fabio Iocco
  - Maria Benito

CTA - Rio

- CBPF
  - Prof. UIisses de Almeida
  - Prof. Ronald Shellard
  - Bruno Fontes
  - Bernardo Fraga
- UFRJ
  - Prof. João Torres

CTA - SP - SST

- IAG – USP
  - Profa. Elisabete dal Pino
  - Prof. Rodrigo Nemmen
  - Dr. Claudio Melioli
  - Dr. Chandra Singh
  - Dr. Grzegorz Kowal
  - Dr. Reinaldo Lima
  - Dr. Paramita Barai
  - Dr. Luis Kadowki
  - Tania Torrejon
  - Renato Gimenes
  - Pankaj Kushwaha
  - Saib Hussain
  - Carlos Fermino
  - Raniere Menezes
  - William Bohórquez
  - Lucas Santos
- UNICSul
  - Prof. Anderson Caproni
- EACH / USP
  - Prof. Diego Falceta-Gonçalves
  - Mohammad Ali

CTA in 2010

FTEs: for weighting influence in decision taking

MOU:
Voting procedures in the CB shall take the relative contributions of Parties into account. Initially, votes will be weighted by the number FTE contributed to the CTA Design Study by a given Party. Financial contributions should be factored in once known.

Dec 2009: first complete set collected: 524 persons, 177.32 FTEs
General impression of WPCs: inflated numbers

Brazilian Consortium Proposal

How did it all started....

Invitation to participate

Dear Vitor

we would like to thank you for attending the CTA Meeting in Zeuthen and for presenting the Brazilian groups and their plans to the CTA Collaboration Board. Motivated by the wish to make CTA the world-wide premier facility for ground-based gamma ray astronomy and in recognition of your anticipated contributions to the project, the CTA Collaboration Board invites you to join CTA.

We are looking forward to a fruitful collaboration,

With best regards
Johannes Knapp (Chair of the CTA Collaboration Board)
Werner Hofmann (CTA Spokesperson)
Manel Martinez (CTA Co-Spokesperson)

Memorandum of Understanding

for the

CTA Design Study

MOU

1 CTA Consortium

A group of institutes known as the CTA Consortium - where CTA stands for "Cherenkov Telescope Array" - intends to design, construct and operate a next-generation facility for ground-based very high energy gamma ray astronomy, providing

- a sensitivity improvement compared to current instruments such as H.E.S.S., MAGIC or VERITAS of approximately one order of magnitude in the TeV energy range
- enlarged energy range, both towards lower energies and towards higher energies
- improved angular resolution
- enhanced flexibility of operation
- full-sky coverage

CTA will address astrophysical questions such as acceleration and propagation of high-energy particles in the Universe, as well as issues of fundamental physics and cosmology.

Prof. Dr. Antonio Carlos Hernandes
Name of Signatory

Brazil, May 19
Place & Date

Prof. Dr. Antonio Carlos Hernandes
Diretor
IFSC-USP

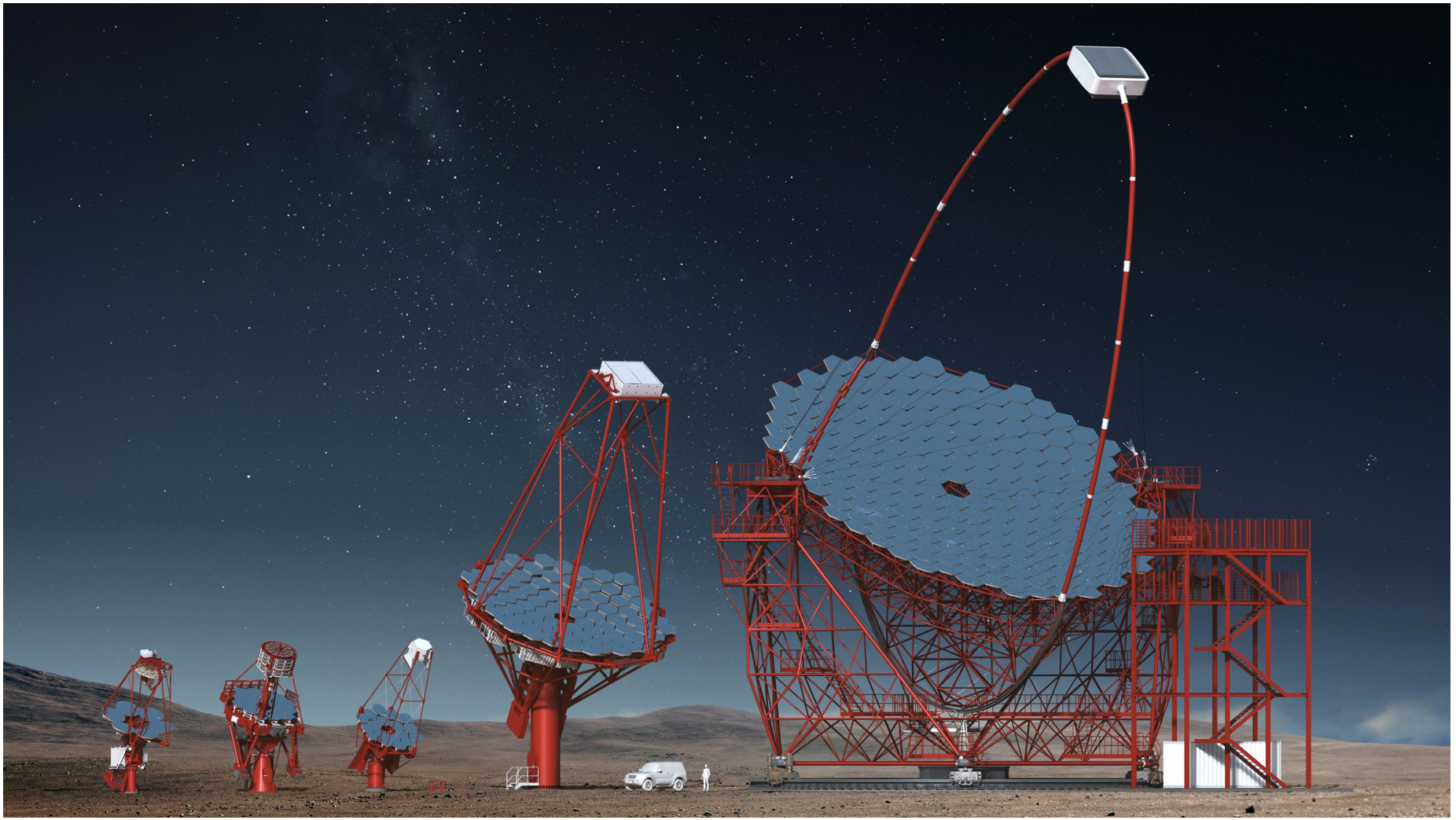
FAPESP

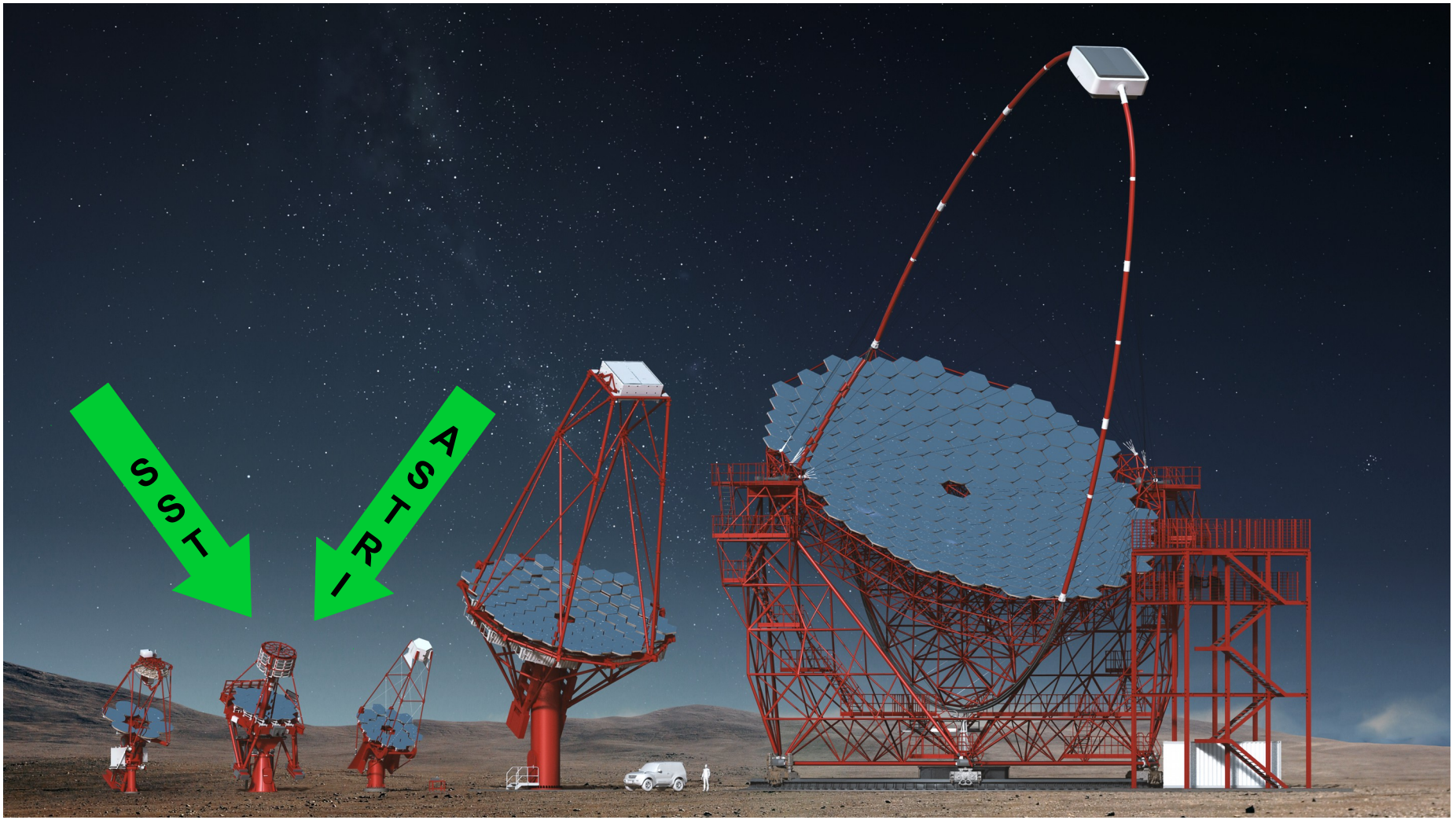
Processo: 2010/19514-6
Data impressão: 01/09/2011 08:02:33
Folha: _____
Volume: _____
Rubrica: _____

Termo de Outorga

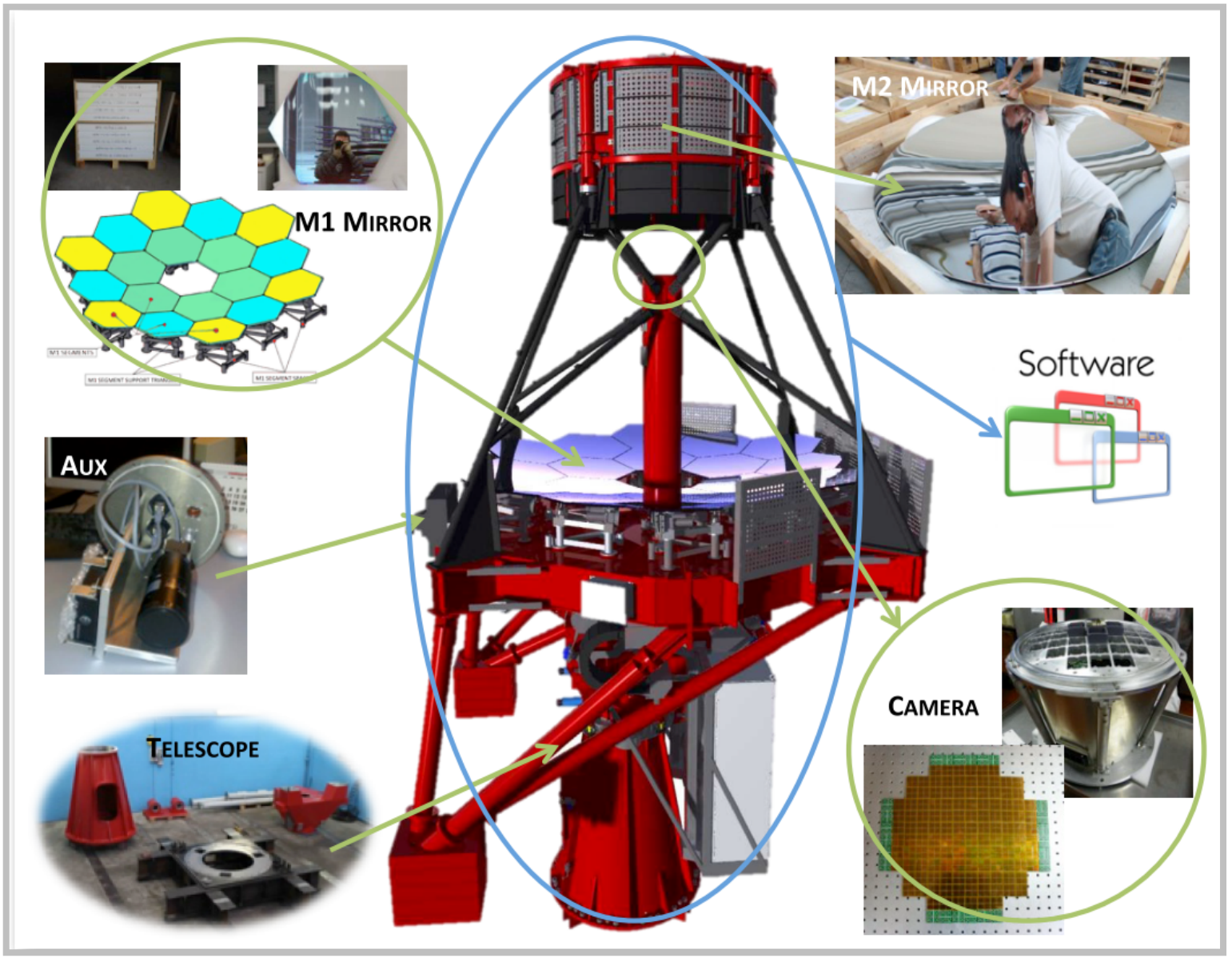
Processo 2010/19514-6

O Conselho Técnico-Administrativo da Fundação de Amparo à Pesquisa do Estado de São Paulo, doravante denominada **OUTORGANTE**, usando das atribuições que lhe confere o Artigo 14, letra "b" da lei Estadual no 5.918, de 18 de outubro de 1960, e de acordo com as especificações, cláusulas e condições descritas a seguir e nos Anexos, que são parte integrante desde Termo, concede:	
Outorgado	Luiz Vitor de Souza Filho CPF: 255.518.678-62
Instituição	Instituto de Física de São Carlos/IFSC/USP
Linha de Fomento	Programas Regulares / Auxílios a Pesquisa / Projeto de Pesquisa / Projeto de Pesquisa - Regular
Projeto	Design e construção do protótipo do Cherenkov Telescope Array Observatory
Grande Área	Ciências Exatas e da Terra
Área	Física
Sub-área	Física Das Partículas Elementares e Campos
Vigência	01/08/2011 a 31/07/2013
Relatórios Científicos até	30/07/2012,30/08/2013
Prestação de Contas até	30/07/2012,30/08/2013




SST
ASTRI

ASTRI: Astrofisica con Specchi a Tecnologia Replicante Italiana

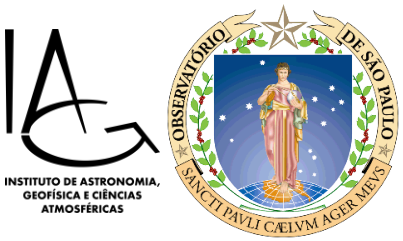


ASTRI PROTOTYPE INAUGURATION

September 24th, 2014
Mt. Etna (Catania, Sicily)

Slide by Elizabete dal Pino

Brazil @ ASTRI CTA Mini-Array

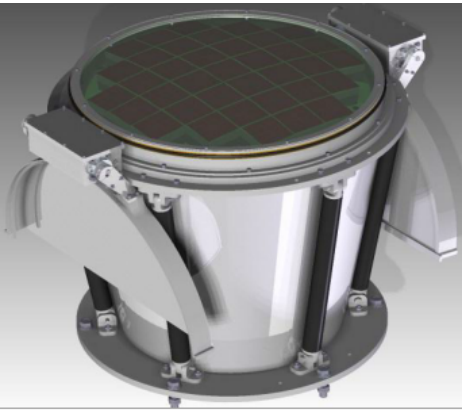


- ✓ **Prototype testing, camera development, re-assessment**
- ✓ **Engineering cooperation**
- ✓ **Knowhow acquisition**
- ✓ **Development of hardware/software**
- ✓ **Construction and deployment of the SST 2M Mini-Array**
- ✓ **Production of components for SSTs for CTA in Brazil; hand over to industry**
- ✓ **Science case developments (galactic & extragalactic targets)**
- ✓ **Human resources formation: several students & postdocs**

Slide by Elizabete dal Pino

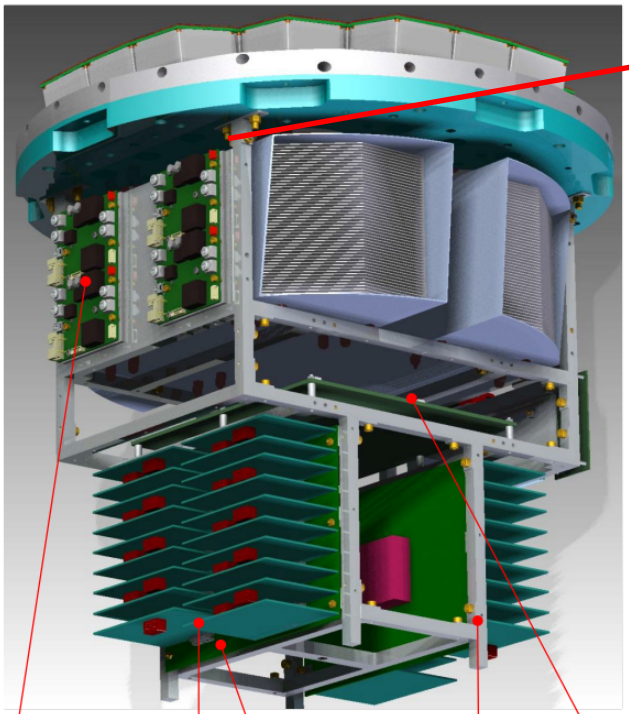
Brazilian engineers @ ASTRI: Camera construction

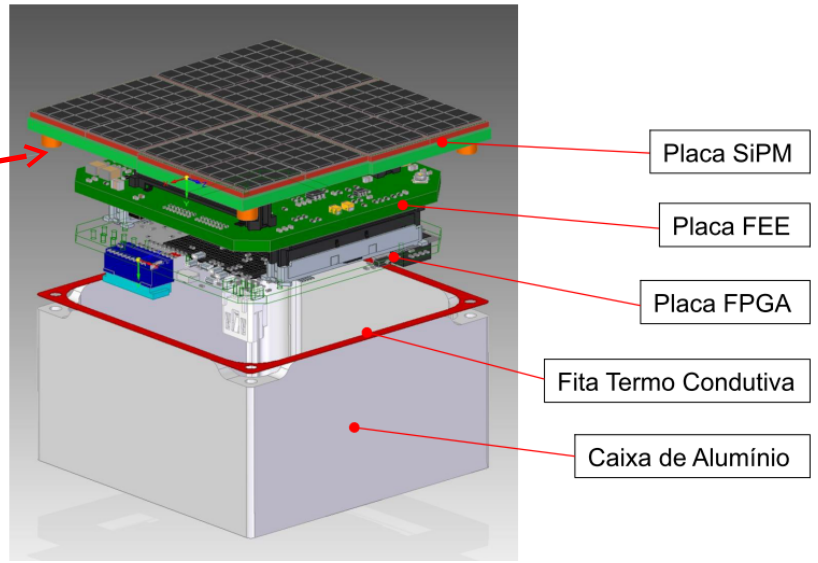
Thermal Model Validation - telescope structure (Catania)

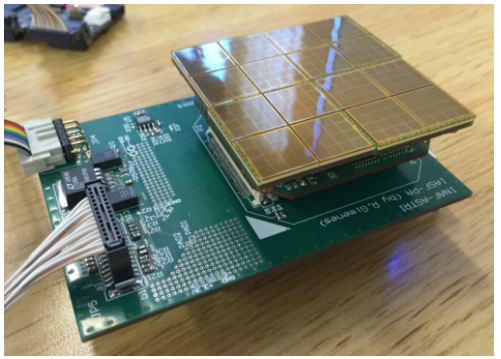


CAMERA: Nano Adapter PCB (Palermo)

- FEE (Front End Electronics)







Slide by Elizabete dal Pino

Brazilian engineers @ ASTRI: structure/software development

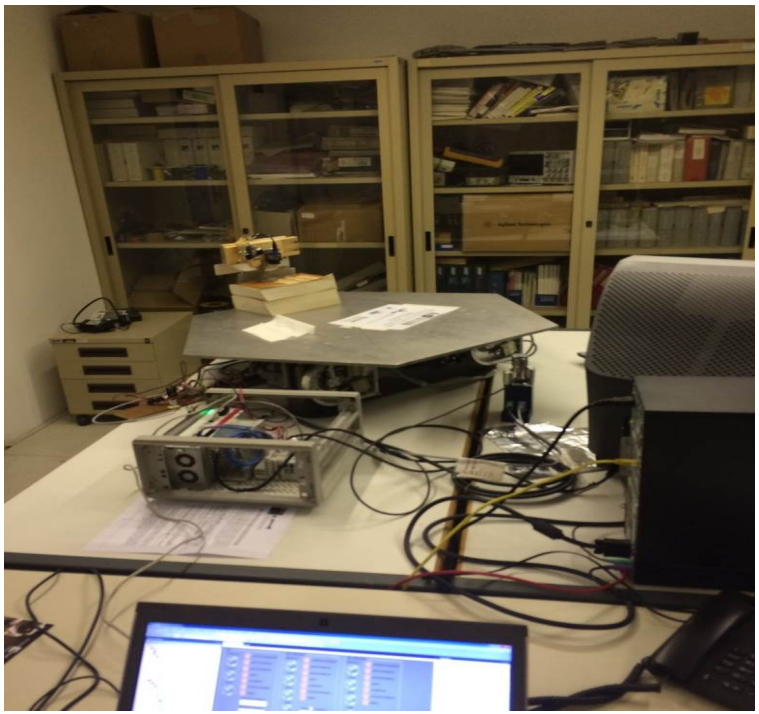
Slide by Elizabete dal Pino

Active optics tests (Torino)

- With Daniele Gardiol & Federico Russo

Performed task:

- Segment motion
- Data colection and callibration
- Repeatability verification

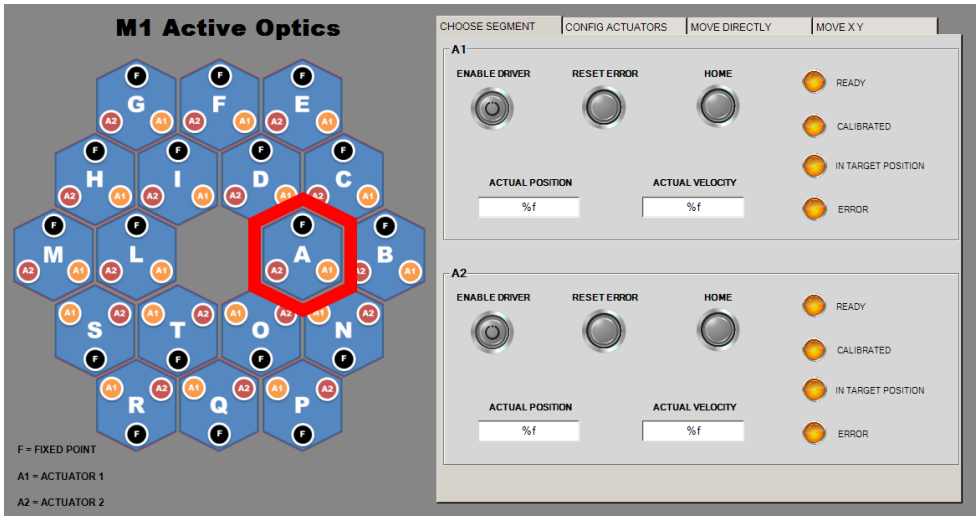


M1 Interface elaboration (Catania)

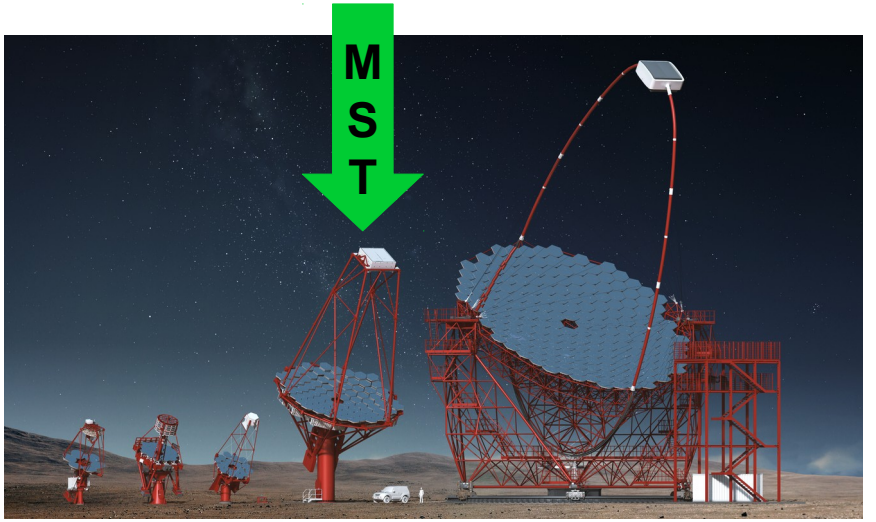
- W/ Matteo Munari, Salvo Scuderi, Enrico Giro, Luca Stringhetti, Elisa Antolini

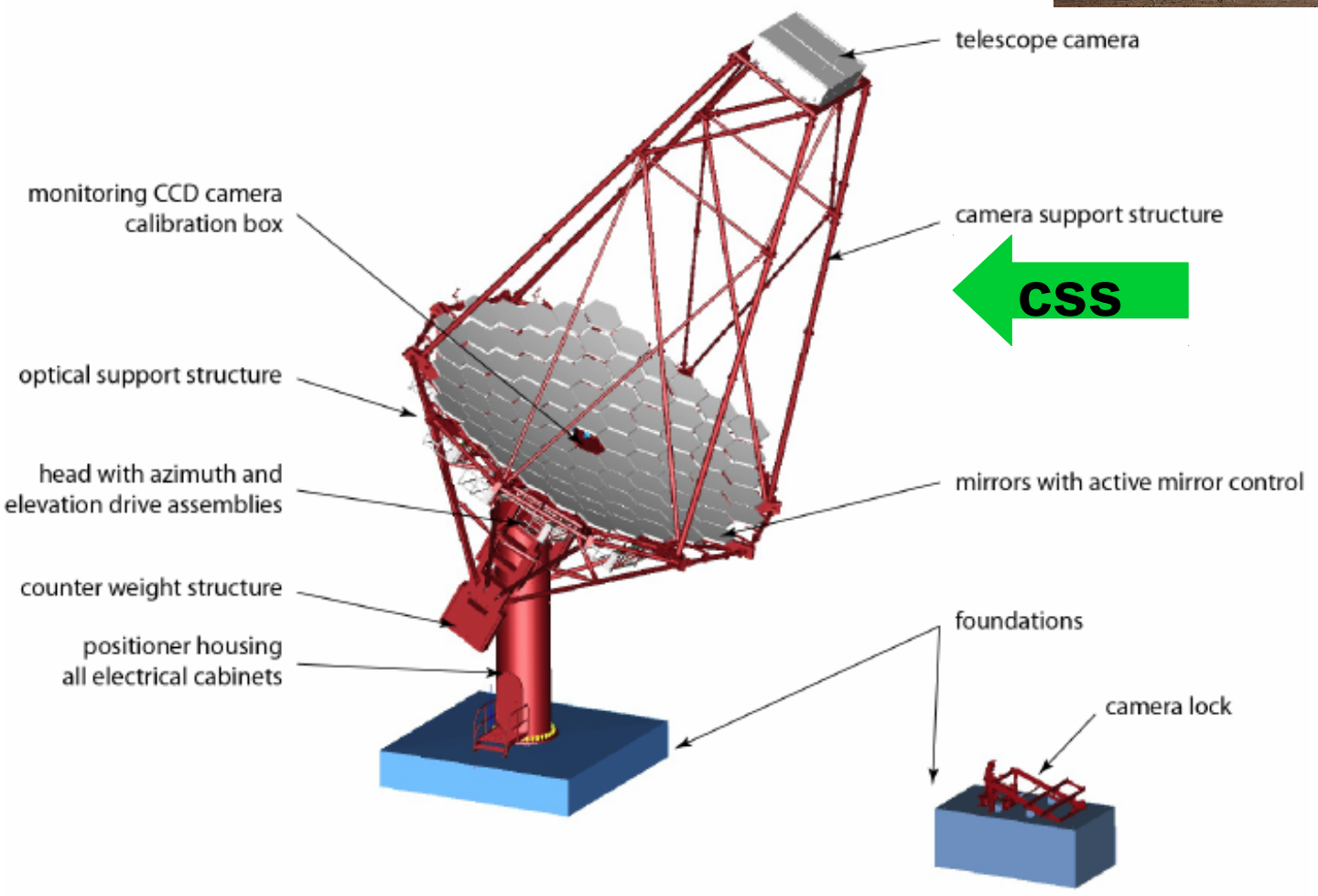
Performed task:

- Actuator configuration as in CANopen
- Screens preparation for driving motors
- interface implementation with users, scheduling tests, etc.
- Teaching on operation of logics for future change and implementation
- Teatching hardware & software Beckhoff



Brazilian contribution
MST





Building Brazilian CSS

- 2010: Regular Project FAPESP: Start.
- 2011: Studying the structure and looking for partners
- 2012: Regular Project FAPESP: design and prototype
- 2013: Design developed and approved
- 2014: Construction and installation of the prototype
- 2015: Prototype approved and improvements suggested
- 2016: Thematica project FAPESP: implement improvements in the design and preproduction
- 2017: Re-design finished - preproduction starting
- 2018: Instalation in the observatory site
- 2019-20: Data taking.

CSS Detailed Analysis

LOAD CASE 03:

- Horizontal
- 50 km/h
- Ice load
- Wind load X

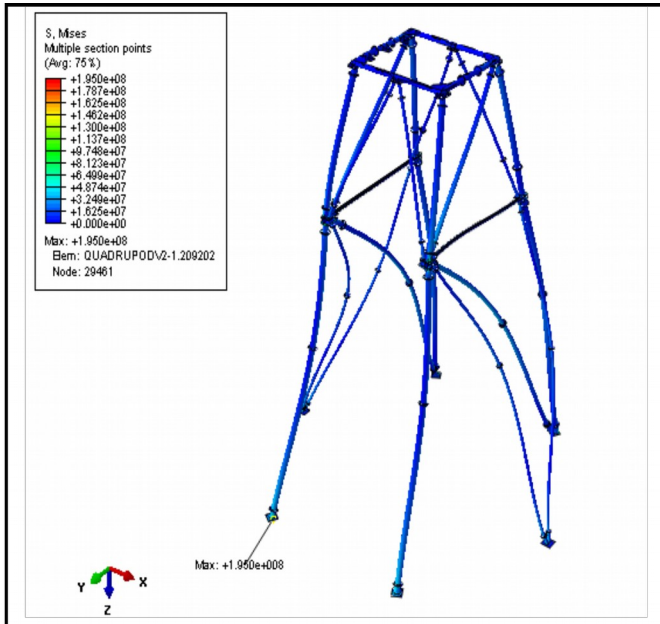


Figure 14: Case 03 stress and displacement analysis

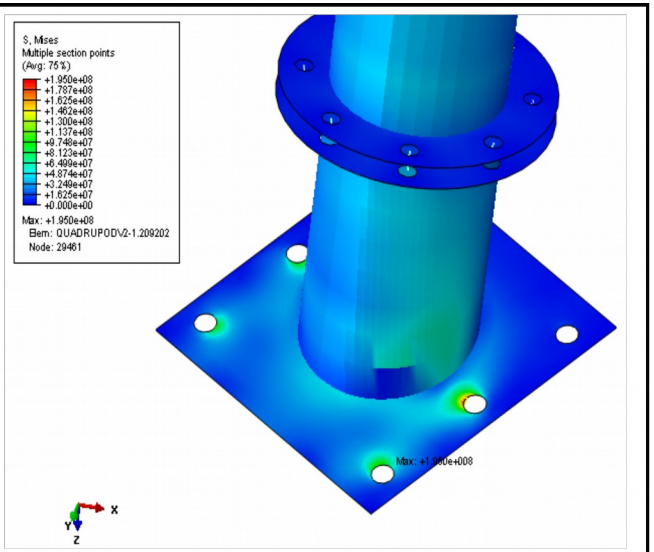
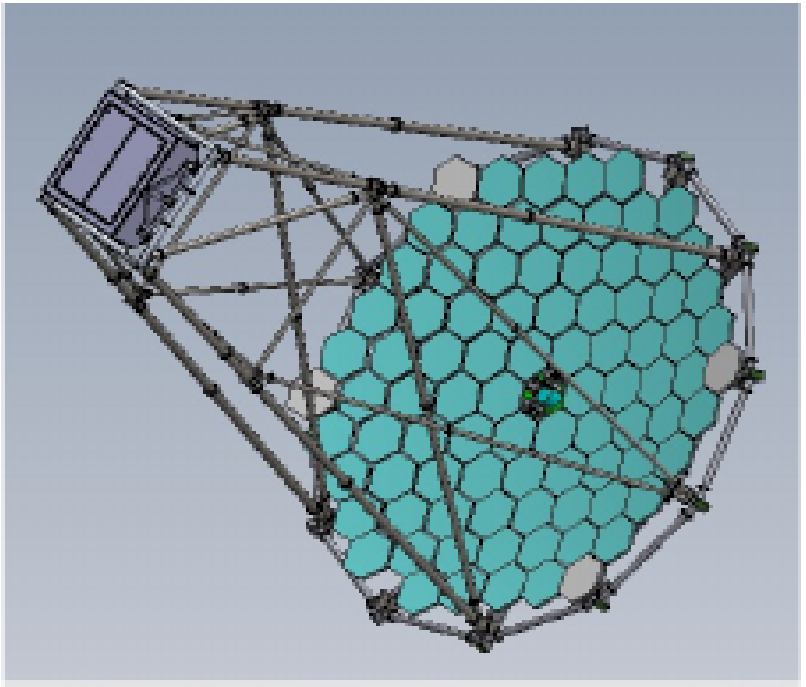


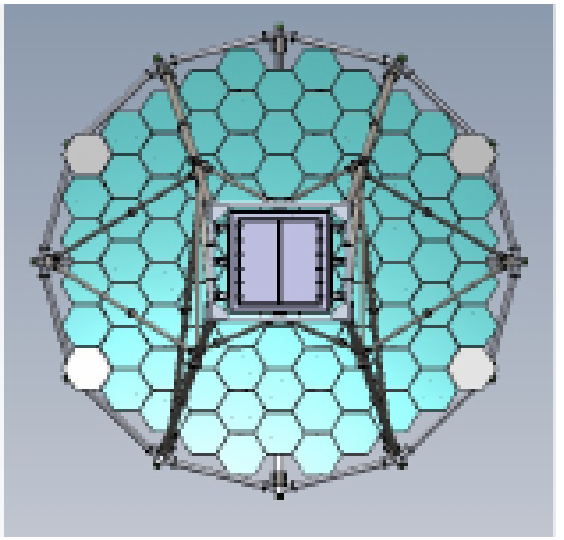
Figure 15: Case 03 stress detail

Input				Output				
Case	Wind Load	Ice Load	Gravity	Global Displacement (mm)	Camera Displacement (mm)	Stress (MPa)	Buckling factor	Safety Coefficient
3	X+ 50 km/h	Superior	Y-	23,31	5,31	195	7,11	**1,59**

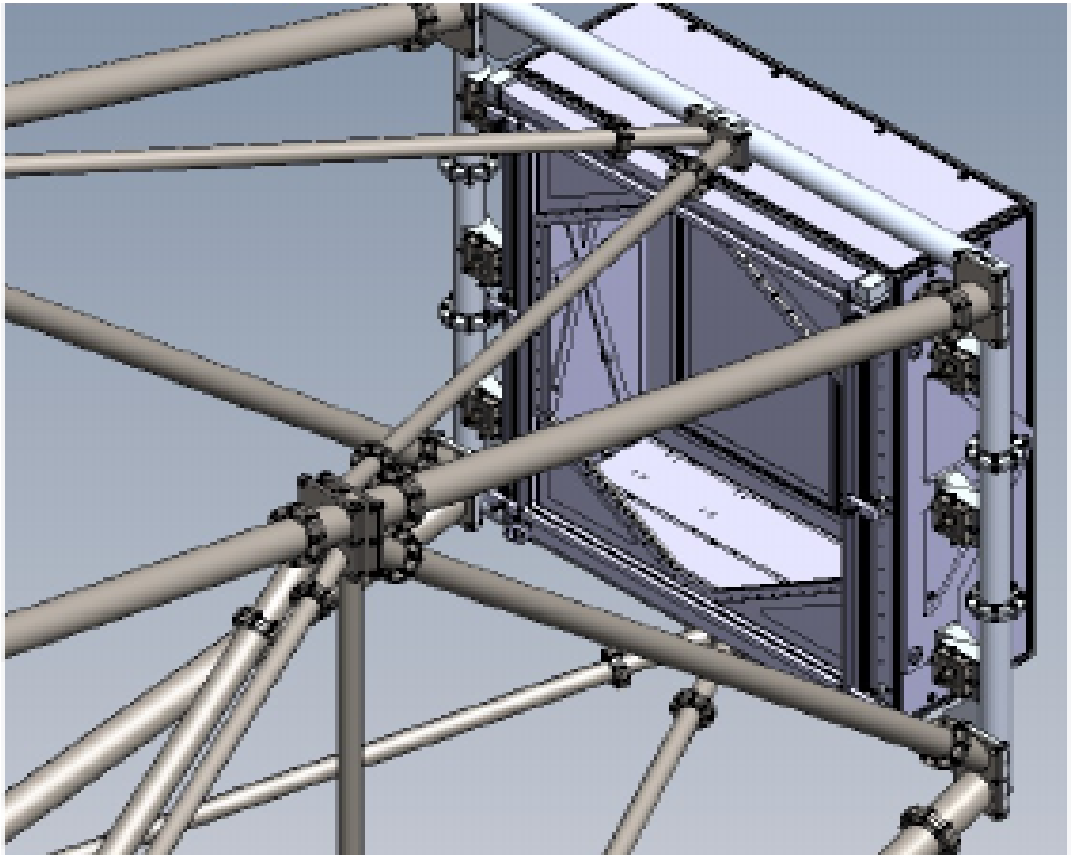
PASSED ALL LOAD CASES

CSS Construction





Adjustment Device



Move tons with milimiter precision

Brazilian technology for CTA

Patent requested

IFSC 21 YEARS Sustainable

Universidade Federal do ABC

ORBITAL ENGENHARIA

USP inovação

Brazilian CSS: Mounting @ Berlin

Brazilian CSS: Mounting @ Berlin

Brazilian CSS: Mounting @ Berlin

Brazilian CSS: Mounting @ Berlin

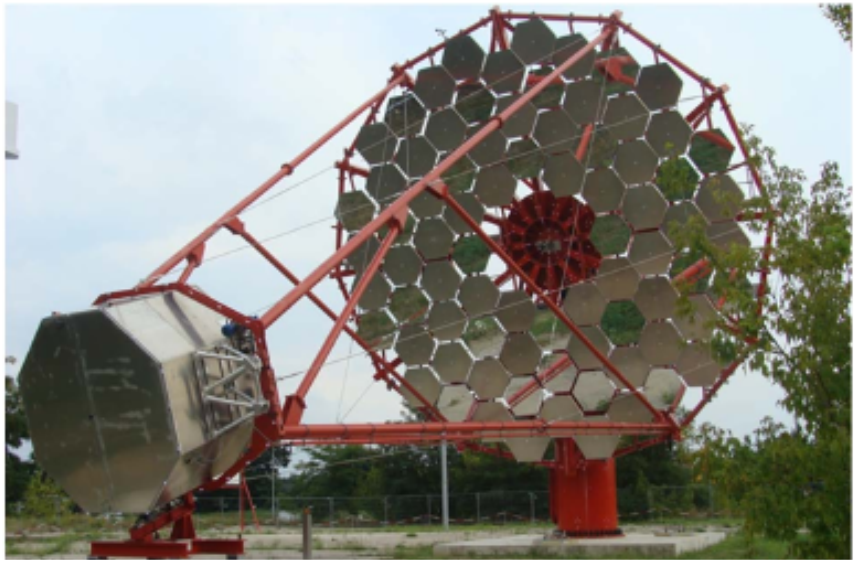
Brazilian CSS: Mounting @ Berlin

Brazilian CSS: Mounting @ Berlin

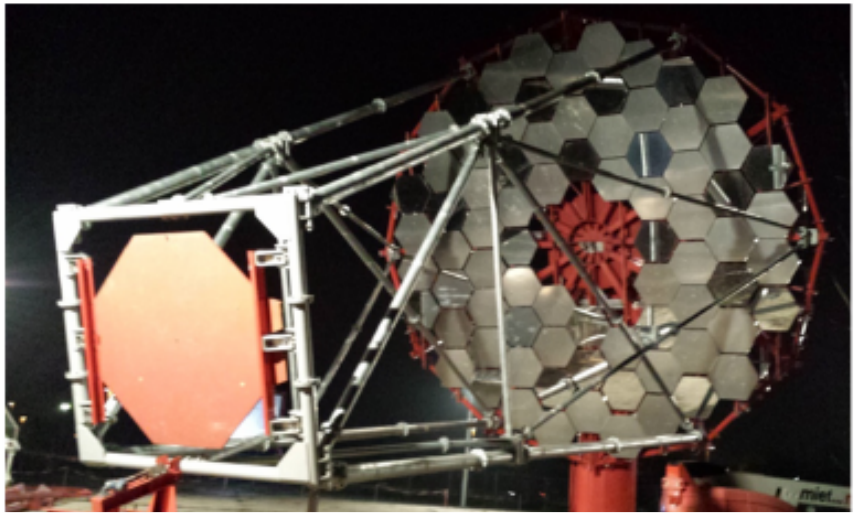
CSS Test Report

DESY and Humboltd University Berlin

Authors: Anja Schubert, Dirk Naumann,
Stefan Schlenstedt,
Louise Oakes and Ulrich Schwanke



CEA/IRFU - France

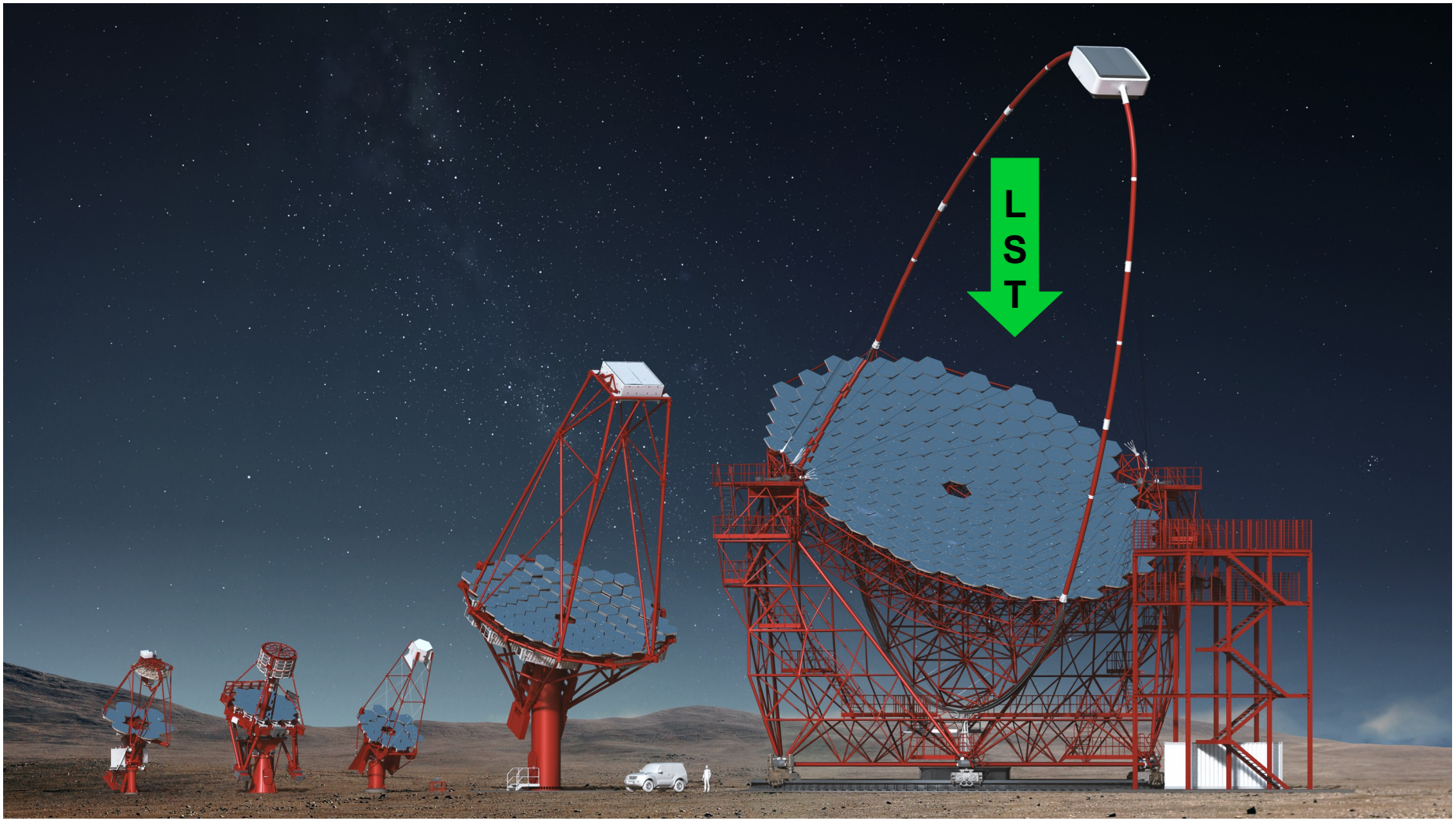


IFSC/USP - UFABC - Orbital Brazil

CSS Test Report: Conclusions

- Vibration studies: both proposals meets the requirements
- Displacement under control for both structures
- Lack of pre-tension ropes is an **advantage** of the Brazilian proposal
- **Better** temperature balance of the Brazilian proposal
- Galvanized steal in the Brazilian structure **garantees** 30 years operation
- Adjustment device in the Brazilian proposal is **advantange**
- The increased shadowing of the Brazilian structure can be compensated with the use of two extra mirror facets - improved in the re-design

Authors: Anja Schubert, Dirk Naumann, Stefan Schlenstedt,
Louise Oakes and Ulrich Schwanke
Desy and Humboltd University Berlin


L
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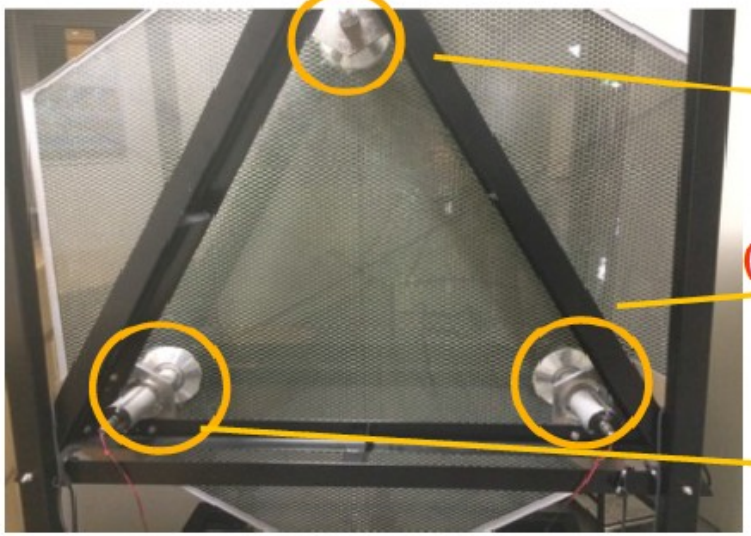
T

Active Mirror Control (AMC)

ICRR, U ZURICH HAMBURG

Introduction : Devices of AMC system



fixed point

Zurich Actuators

actuator
(1-axis free)

actuator
(2-axes free)

laser
(near-infrared)

CMOS camera (Imaging Source DMK023GM021) + IP67 hood

wireless module
(XBee)

others :

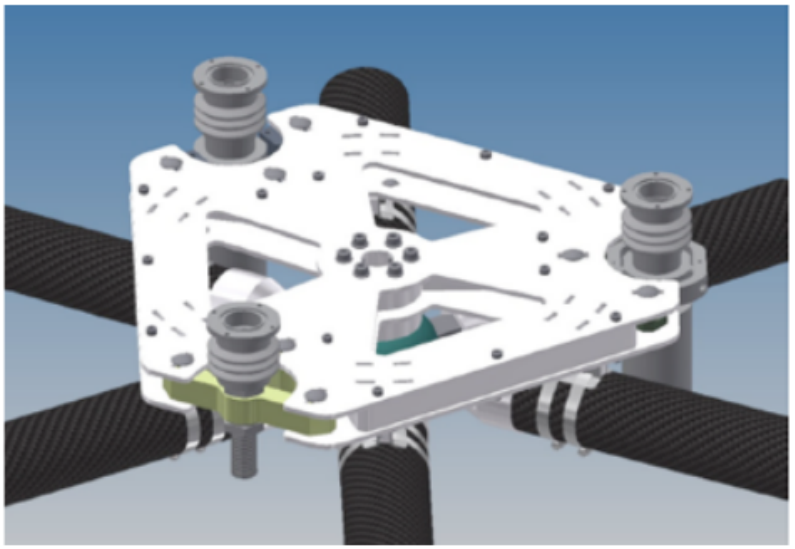
- PC (PCM3363 -> NUC5PPYH)
- network switch
- thermometer etc...

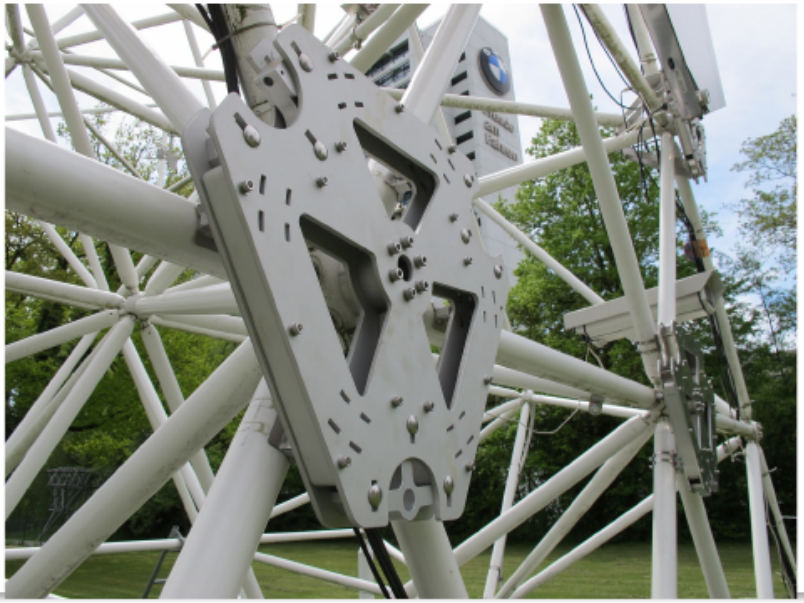
Slide by Ulisses Barres de Almeida

IF plate: Brazilian contribution

CBPF, MPI, ICRR

- Mirrors are supported by 3 triangle parts called “interface plate”.
  - Concept started by ICRR, design by MPP
  - Discussions/improvements by all, including CBPF, Brazil
  - Mass-production for LST-1 by CBPF





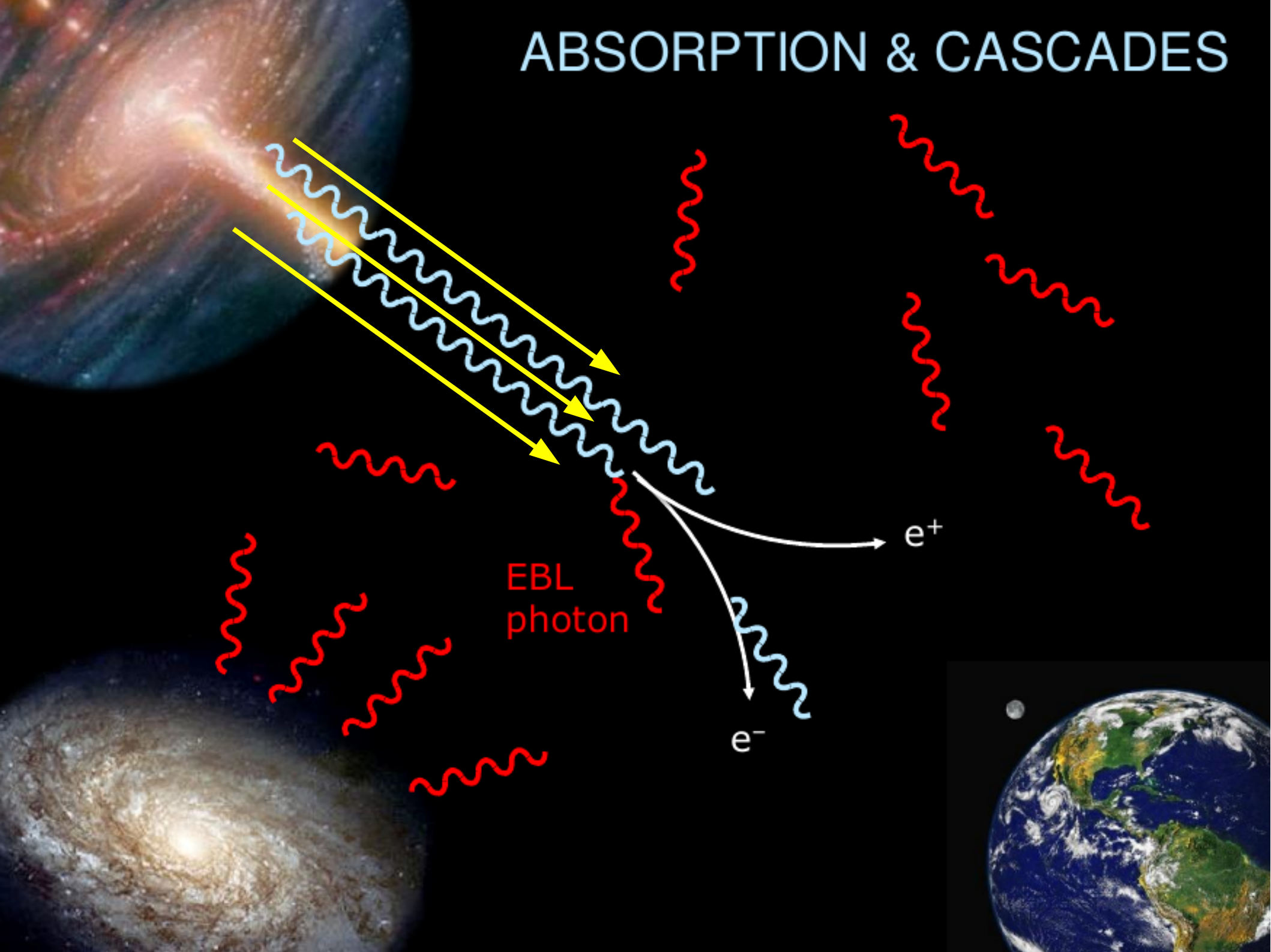
- Checks on lab: no major problem. minor issues feedback to CBPF
- Final check on the test structure done in the last week => production

Slide by Ulisses Barres de Almeida

While CTA is not ready....

- We are warming up:
  - Dark matter
  - Lorentz Invariance Violation
  - Cosmic acceleration and gamma rays
  - **And much more: see Profa. Elisabete and Prof. Ulisses talks along these weeks.**

ABSORPTION & CASCADES



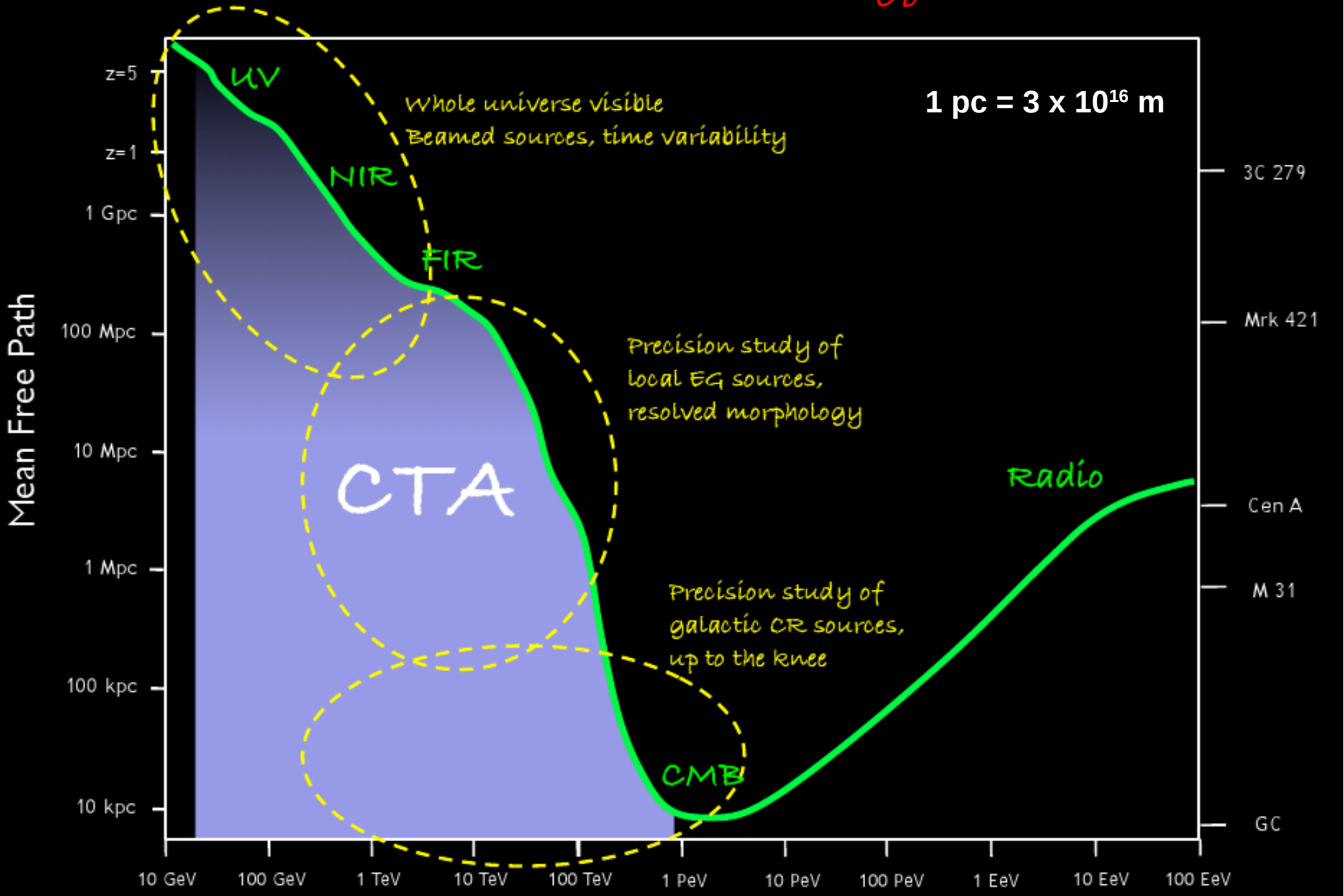
UHECR produces gamma rays

Cascade in the radiation background

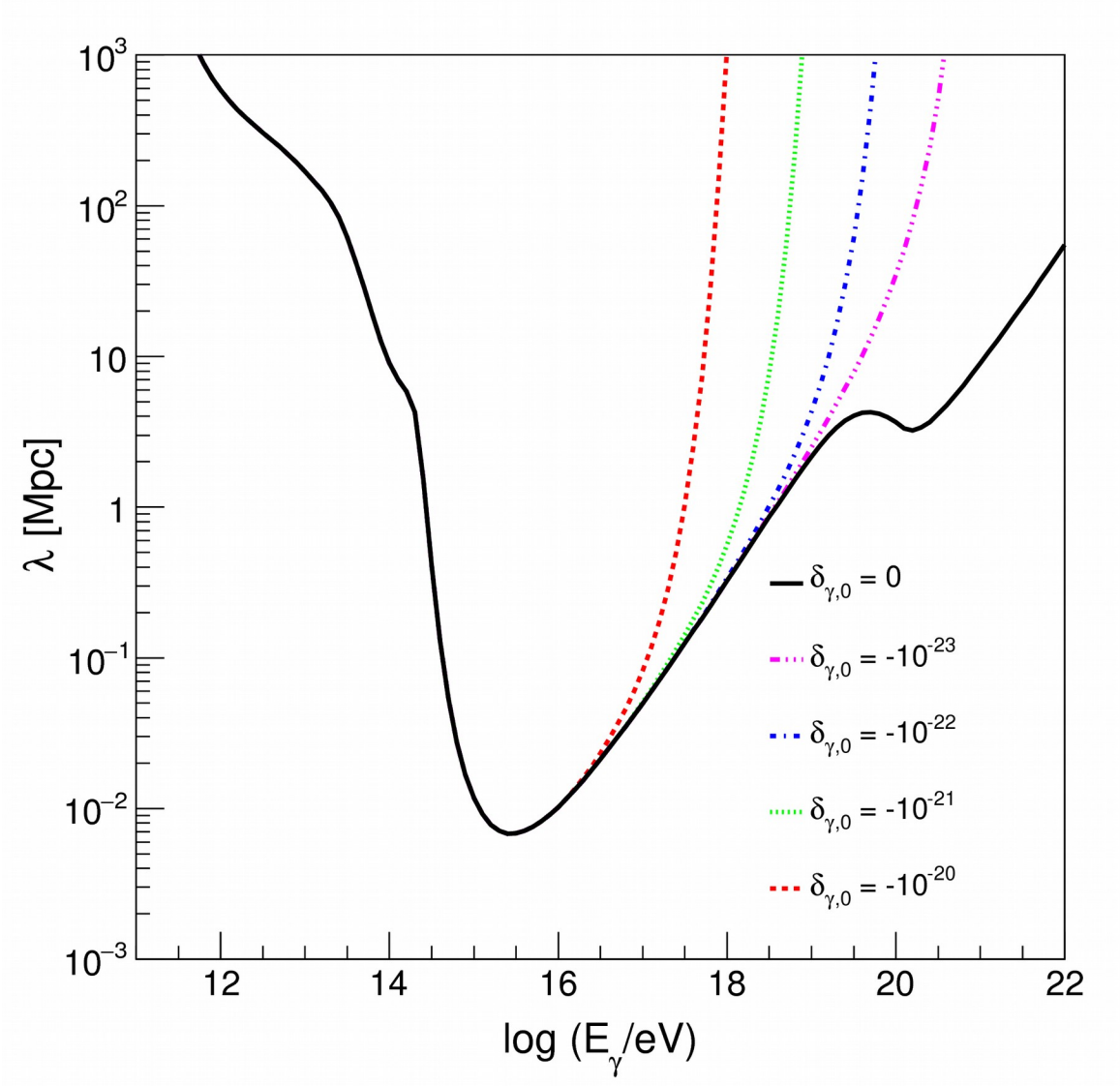
- Pair-production
- Nuclear fragmentation
- Photo pion production
- Pion decay
- Neutron decay
- Pair production
- (Inverse) Compton scaterring

Large number of GeV-TeV gamma-rays produced

The Gamma Ray Horizon $\gamma + \gamma_{CB} \rightarrow e^+e^-$



Mean Free Path with LIV



Rodrigo Lang - Master Dissertation - IFSC/USP - submitted (2017).

Source at distance D

UHECR flux observed on Earth

$$I_{CR}(E) = \frac{L_{CR}}{4\pi D_s^2\ (1+z_s)\langle E\rangle_0}\ K_{CR}\ P_{CR}(E)$$

gamma-ray flux

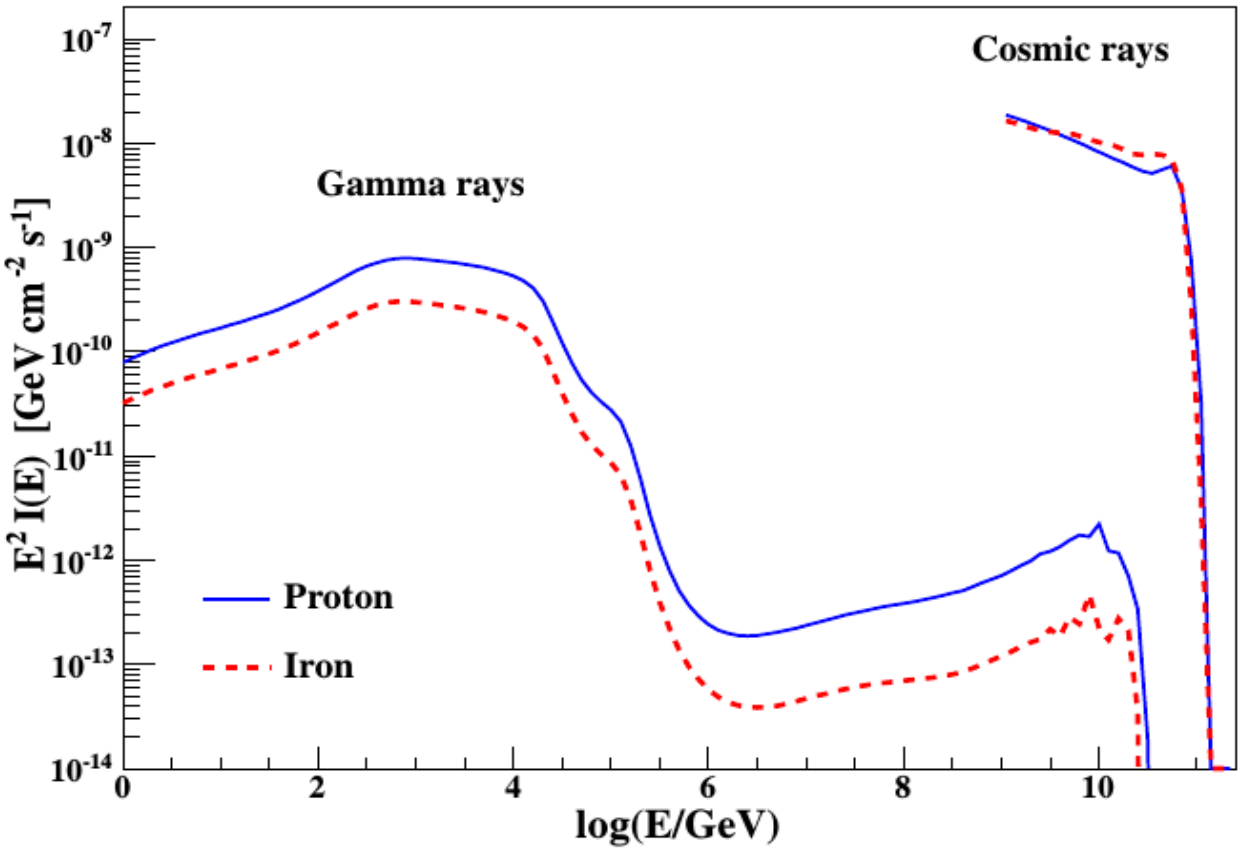
↓

Proporcional do UHERC luminosity

$$I_{\gamma}(E_{\gamma}) = \frac{L_{CR}}{4\pi D_s^2\ (1+z_s)\langle E\rangle_0}\ K_{\gamma}\ P_{\gamma}(E_{\gamma})$$

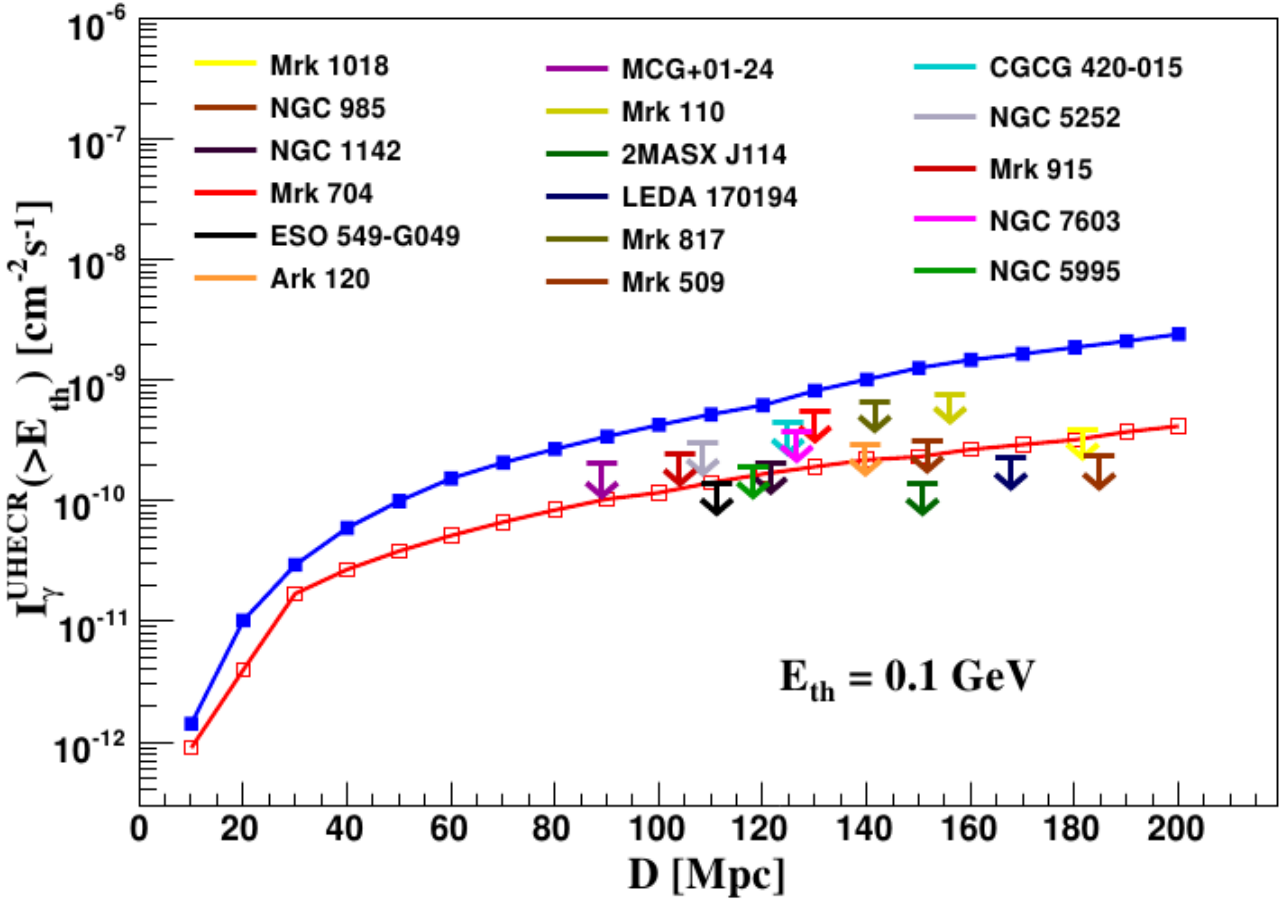
An upper limit on the cosmic-ray luminosity of individual sources from gamma-ray observations

A.D Supanitsky and V. de Souza, JCAP 12 (2013) 023



$$L_{CR}^{UL} = I_{\gamma}^{UL}(> E_{\gamma}^{th}) \; \frac{4\pi D_s^2 \; (1+z_s)\langle E\rangle_0}{K_{\gamma} \int_{E_{\gamma}^{th}}^{\infty} dE \; P_{\gamma}(E_{\gamma})},$$

Upper limits on the total cosmic-ray luminosity of individual sources



Sources:

3 Radio Galaxies

21 Seyfert

25 Fermi

1 MAGIC

2 VERITAS

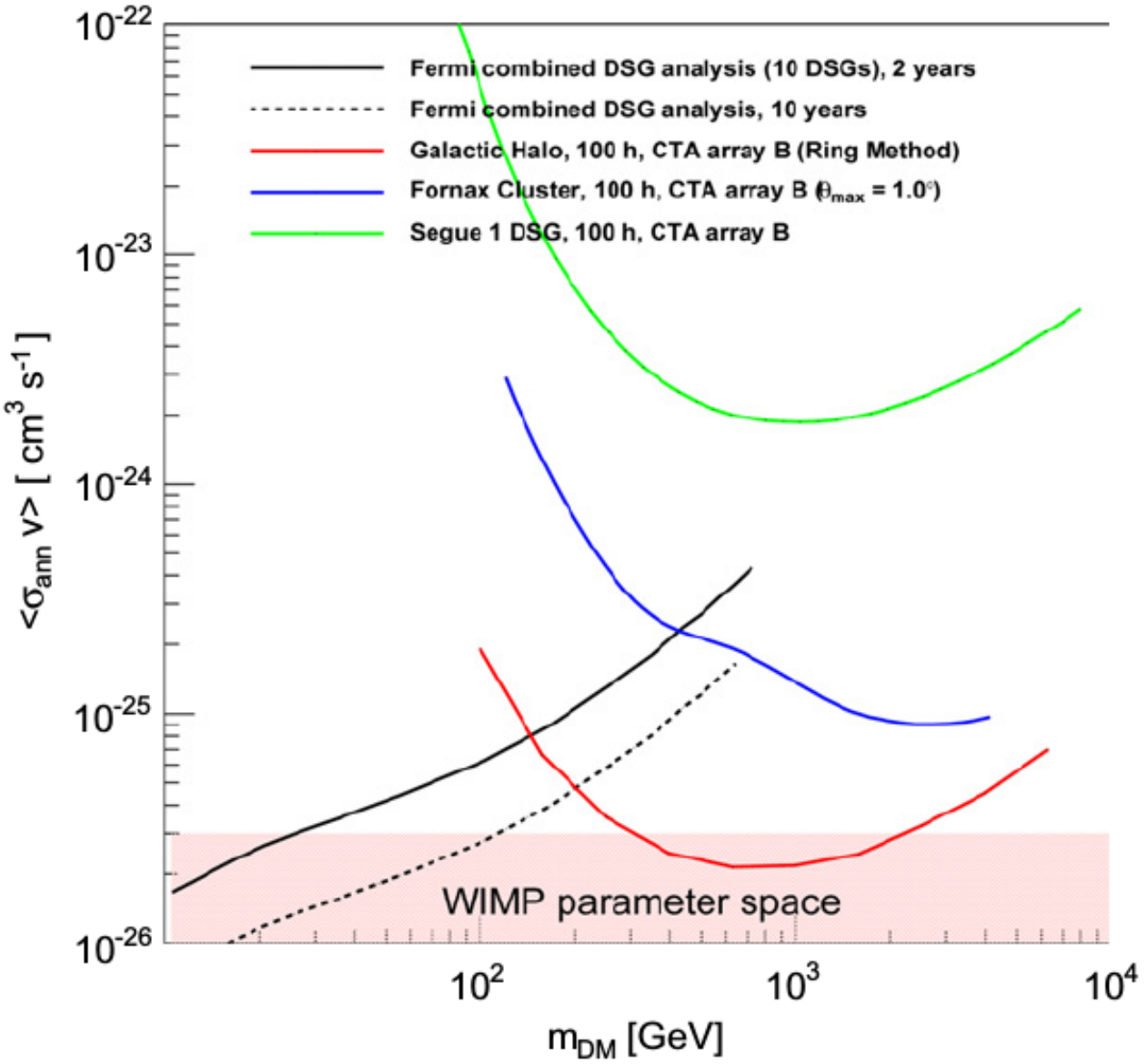
R.C. Anjos, V. de Souza and A.D.Supanitsky JCAP 07 (2014) 049

Nome da fonte	**D** [Mpc]	**UL:** $\mathcal{F}$ (> 0.1 GeV) [10^{-9} ph cm^{-2} s^{-1}]	$\mathbf{L_{pr}^{UL}}$ (Próton) [erg s^{-1} $\times 10^{45}$]	$\mathbf{L_{CR}^{UL}}$ (Total) [erg s^{-1} $\times 10^{45}$]
Mrk 1018	181.5	2.1	1.04	-
NGC 985	184.7	1.8	1.03	2.19
NGC 1142	121.5	1.1	0.49	-
2MASX J07595347+2323241	127.7	2.2	1.01	-
Mrk 704	130	2.0	0.91	-
MCG+04-22-042	143.6	1.6	0.75	1.74
Mrk 417	147.4	3.7	1.72	-
ESO 121-IG028	177.8	1.2	0.64	-
ESO 549-G049	111.1	2.5	1.11	-
CGCG 420-015	124.8	2.1	0.95	-
Ark 120	139.7	1.6	0.74	-
MCG-01-24-012	89.0	1.5	0.65	-
Mrk 110	156	1.9	0.90	-
2MASX J11454045-1827149	150.7	2.8	1.30	3.16
LEDA 170194	167.7	3.1	1.48	3.71
NGC 5252	108.4	1.4	0.62	-
Mrk 817	141.5	1.6	1.72	-
NGC 5995	118.1	2.0	0.90	-
Mrk 509	151.6	2.7	1.27	-
Mrk 520	115.5	2.2	0.98	-
Mrk 915	104	2.4	1.06	-
NGC 7603	126.5	2.0	0.91	-

Nome da Fonte	**D** [Mpc]	**UL:** $\mathcal{F}\ (> E_{th})$ [ph cm^{-2} s^{-1}]	$\mathbf{E_{th}}$ [GeV]	**Medido por**	$\mathbf{L_{pr}^{UL}}$ (Próton) [erg s^{-1} $\times 10^{45}$]	$\mathbf{L_{CR}^{UL}}$ (Total) [erg s^{-1} $\times 10^{45}$]
Pictor A	149	2.45×10^{-12}	330	H.E.S.S.	1.6	-
NGC 7469	60	1.38×10^{-12}	330	H.E.S.S.	0.2	-
3C 111	196	2.5×10^{-12}	300	VERITAS	0.32	0.87
NGC 1275	75	5.11×10^{-12}	190	VERITAS	0.13	-
IC 310	78.5375	3.1×10^{-12}	300	MAGIC	0.11	-

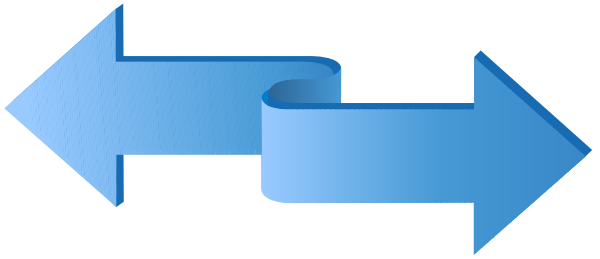
Nome da fonte	**D** [Mpc]	**UL:** $\mathcal{F}\ (10 < E < 100$ GeV) [ph cm^{-2} s^{-1}]	$\mathbf{L_{CR}^{UL}}$ (Próton) [erg s^{-1} $\times 10^{45}$]
NGC 1218	120.83	1.47×10^{-10}	1.27
4C+04.77	112.5	8.59×10^{-11}	0.31
RX J0008.0+1450	187.5	1.22×10^{-10}	1.36

Dark Matter

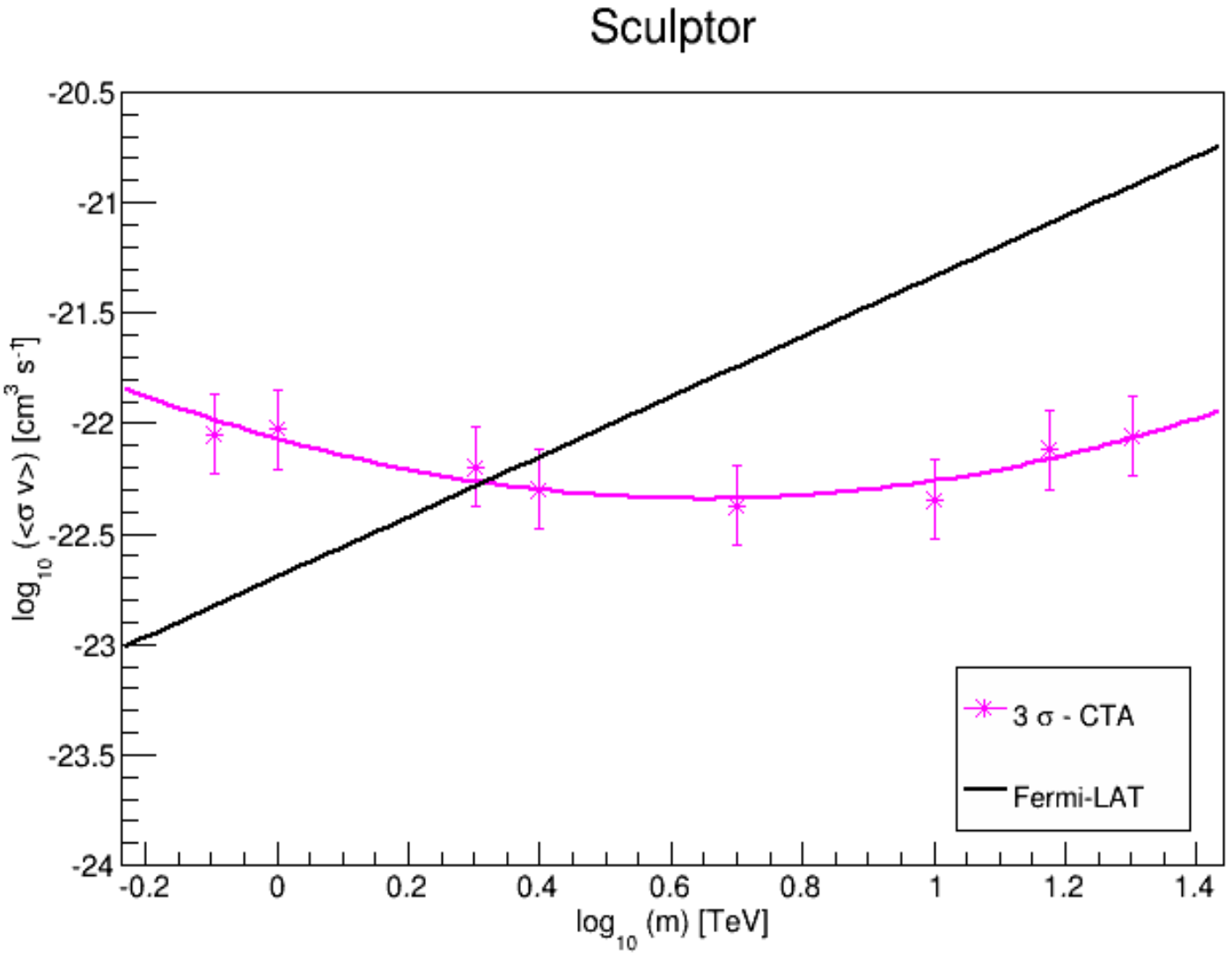


M. Doro et al. Astroparticle Physics 43 (2013) 189–214

Fermi



CTA


Sculptor
-20.5
-21
-21.5
-22
-22.5
-23
-23.5
-24
log10 (<σ v>) [cm3 s-1]
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
log10 (m) [TeV]
3 σ - CTA
Fermi-LAT

Take away message

- CTA is the next astroparticle physics experiment
- CTA Consortium is fit
- The Brazilian community is very actively participating
- Collaborators are welcome

Thank you !