Cherenkov Telescope Array (CTA) Project

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（京都大学　宇宙物理学教室）

第１０回高宇連研究会「高エネルギー宇宙物理学の最新成果と将来計画」
平成２２年３月８−１０日　宇宙科学研究所

Outline

- CTA 計画の概要と現状
- 日本チームの取り組み

CTA: 次世代　高エネルギーガンマ線観測施設

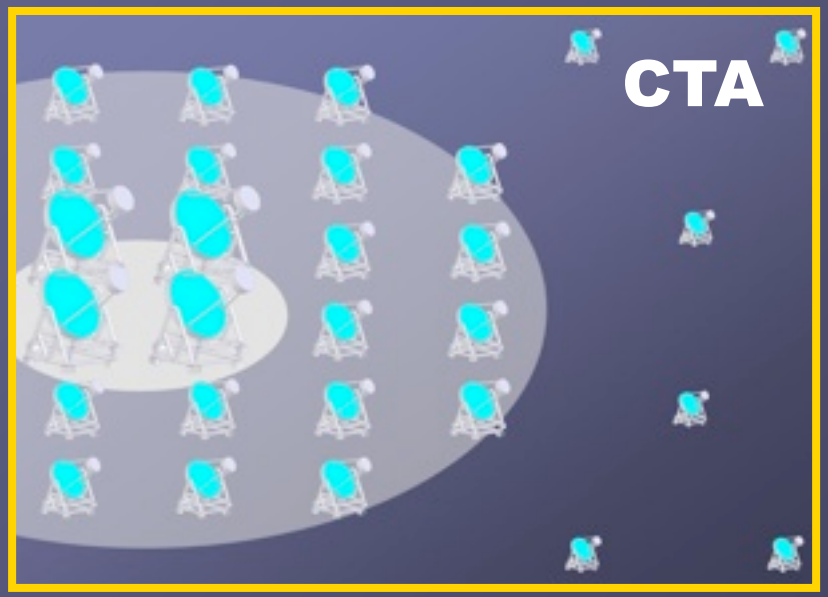
MAGIC Phase II (MAGIC-I + MAGIC-II) in 2009

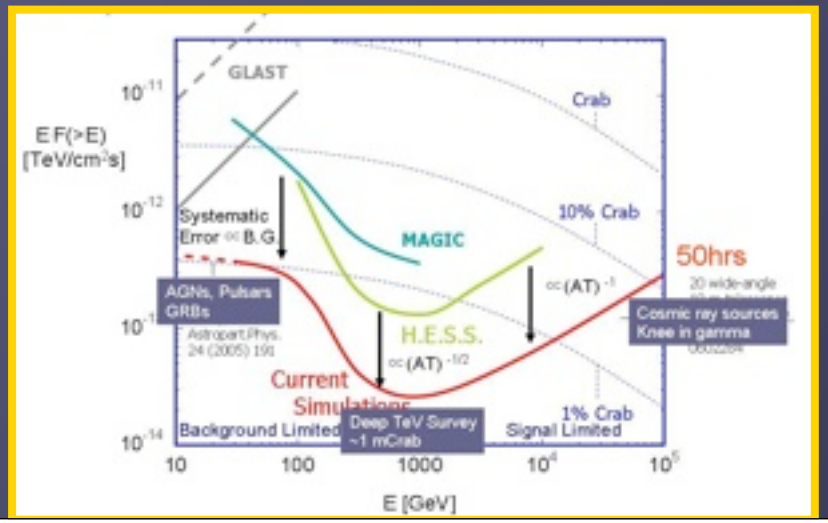
HESS Phase II (HESS + 28m Telescope) in 2010

Astronomers in EU

JAPAN, US

>1000 sources will be discovered





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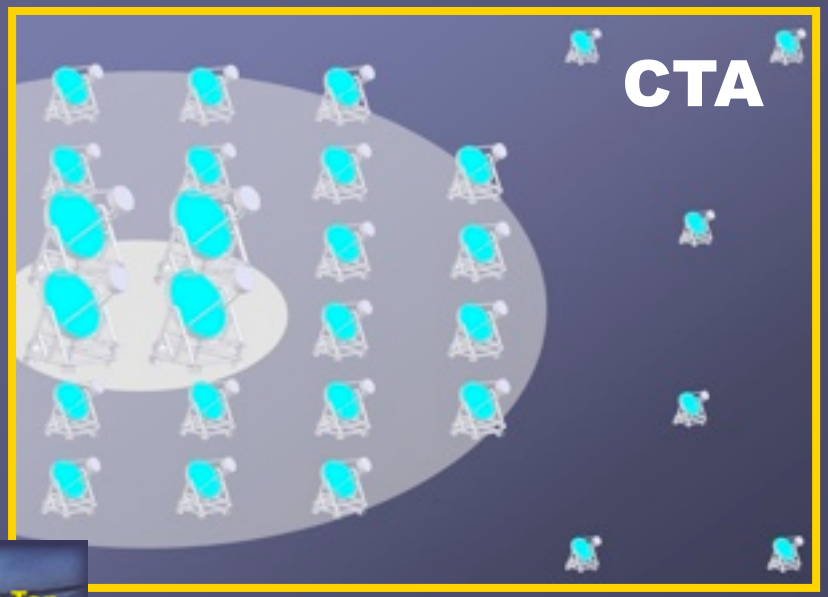

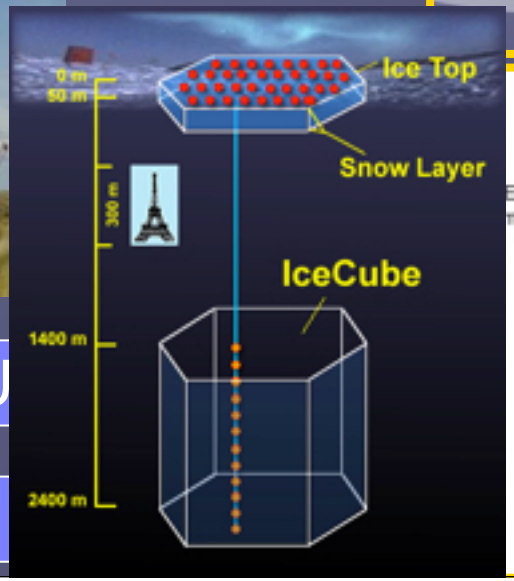

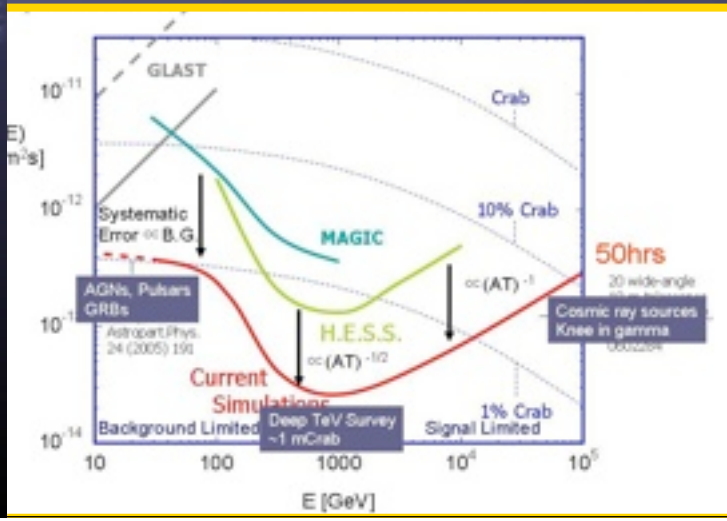

Astronomers in EU

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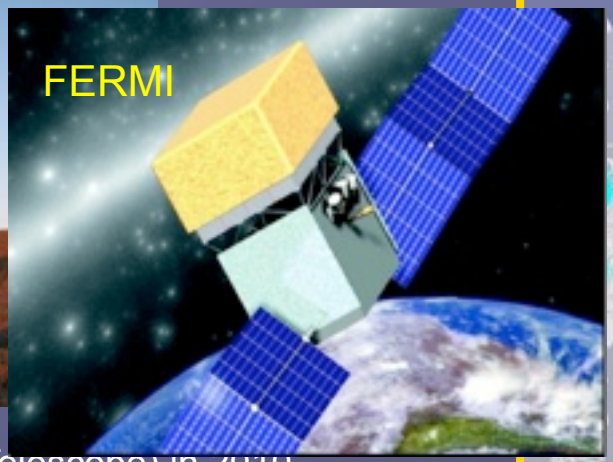

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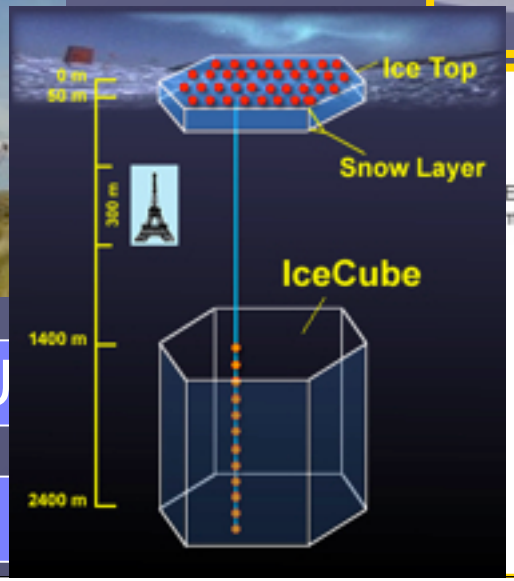

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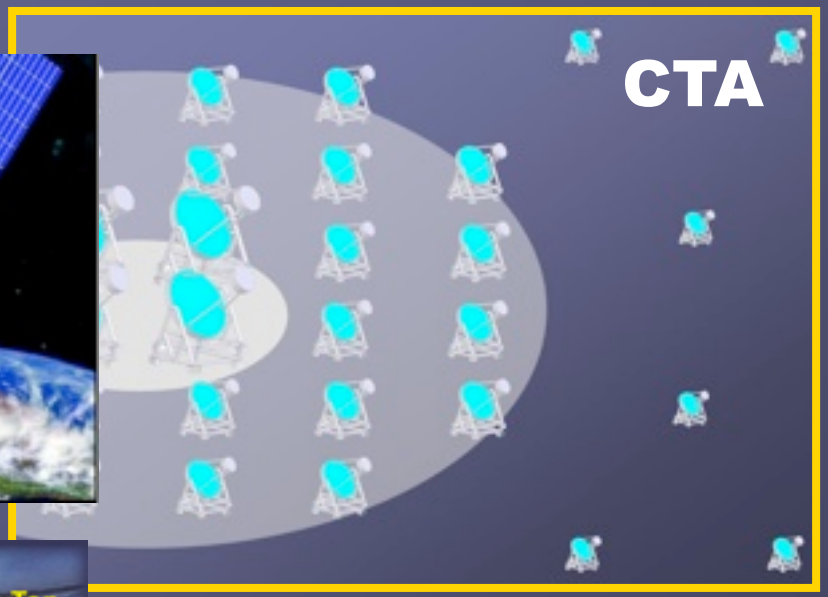
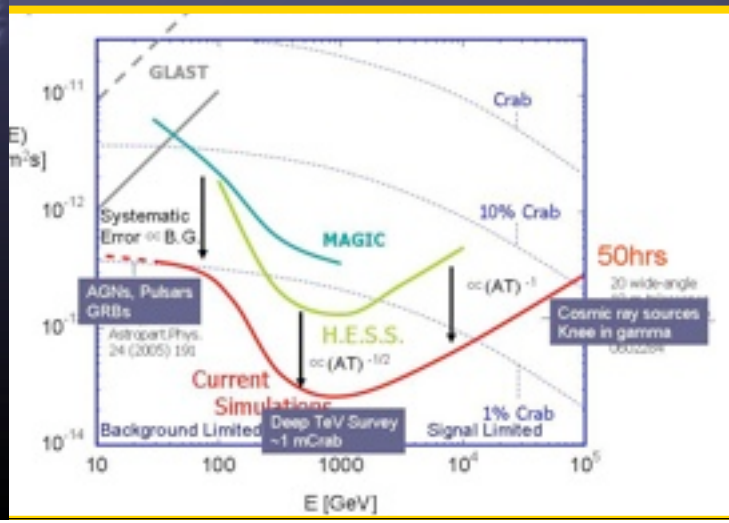
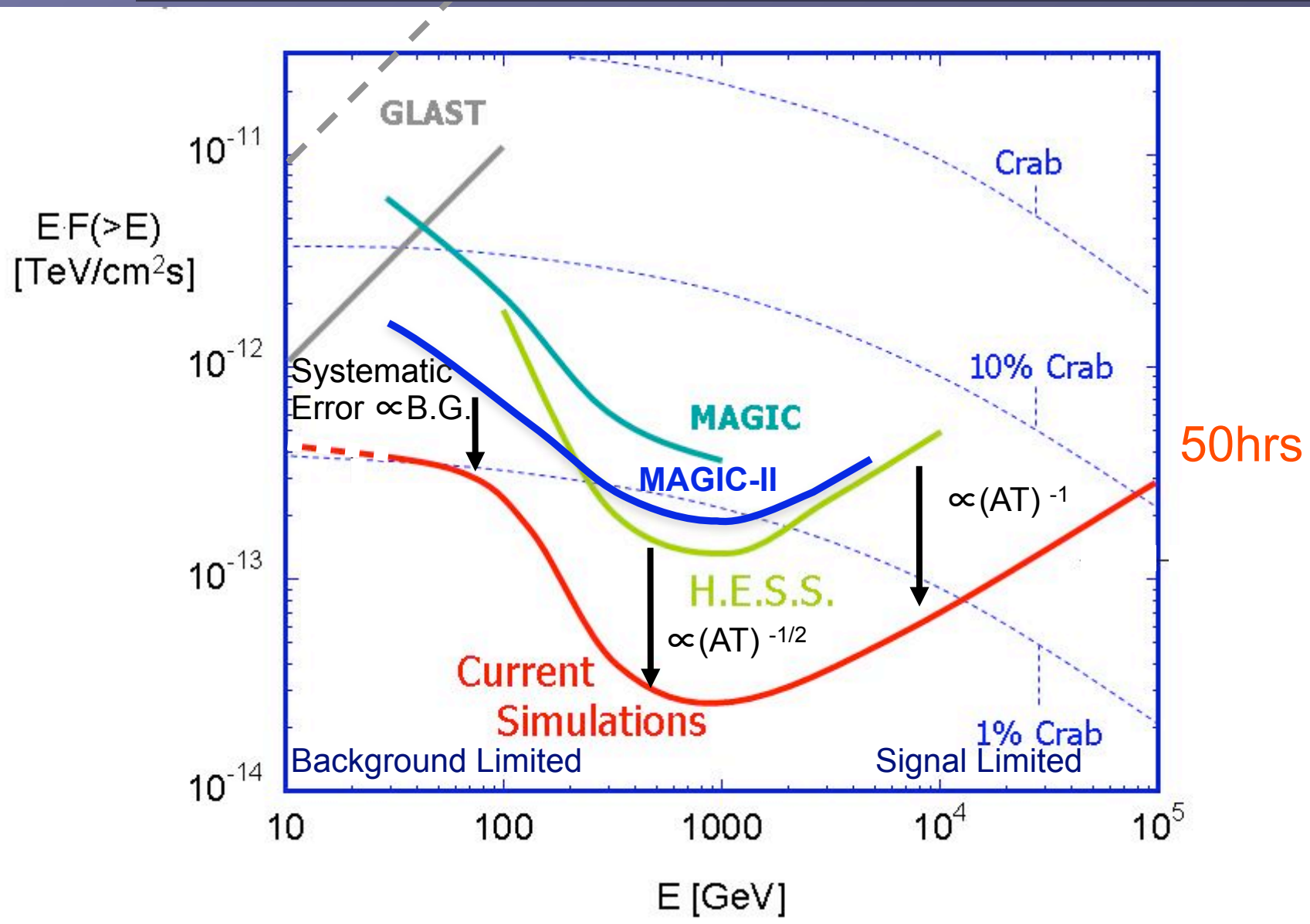


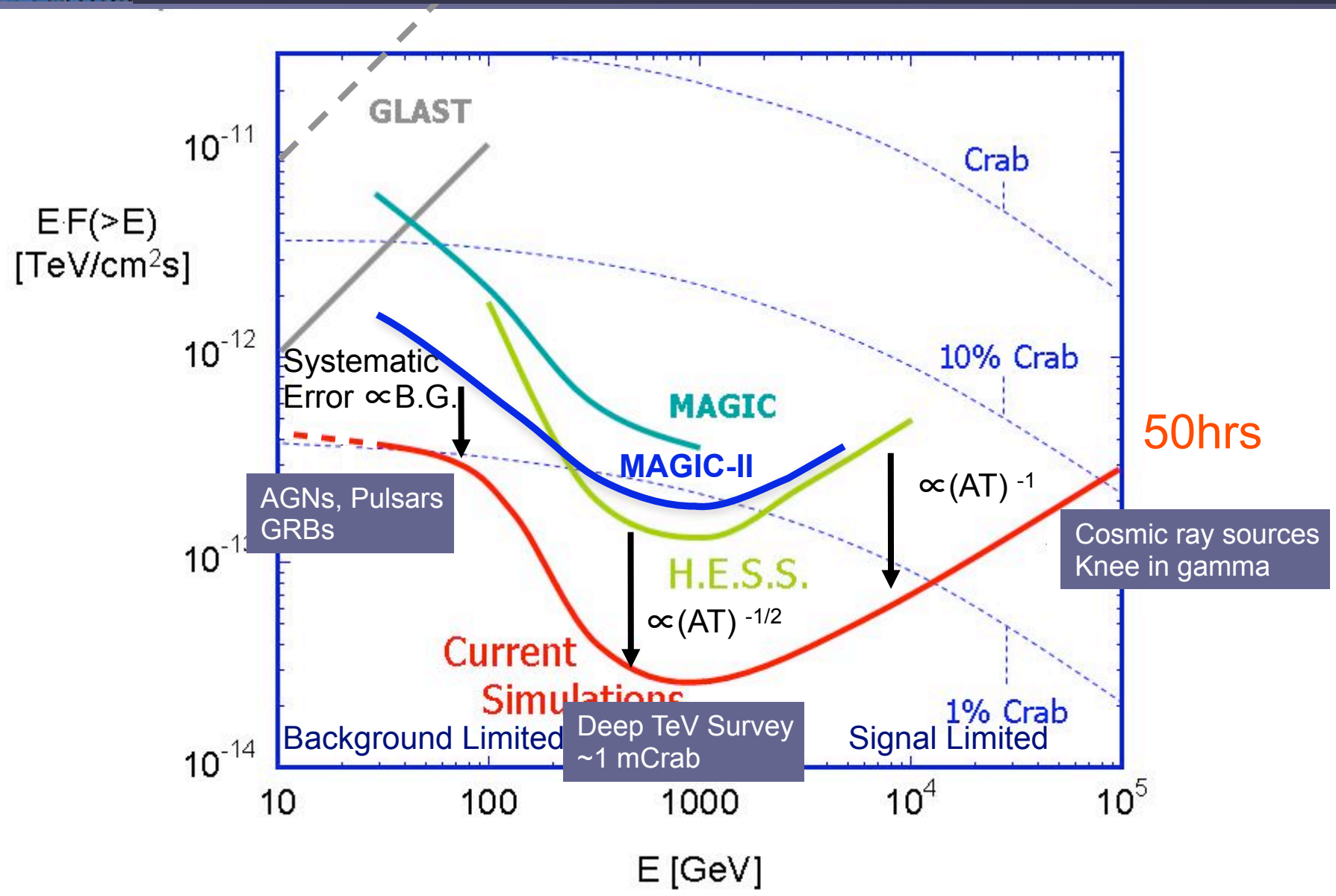


目標達成感度



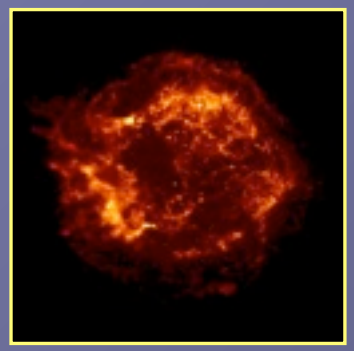
50hrs

目標達成感度


GLAST
Crab
10% Crab
1% Crab
MAGIC
MAGIC-II
H.E.S.S.
Current Simulations
Systematic Error ∝B.G.
AGNs, Pulsars GRBs
∝(AT) -1
∝(AT) -1/2
50hrs
Cosmic ray sources Knee in gamma
Deep TeV Survey ~1 mCrab
Background Limited
Signal Limited
E·F(>E) [TeV/cm2s]
10-11
10-12
10-13
10-14
10
100
1000
10^4
10^5
E [GeV]

観測対象 & サイエンス

観測対象 & サイエンス

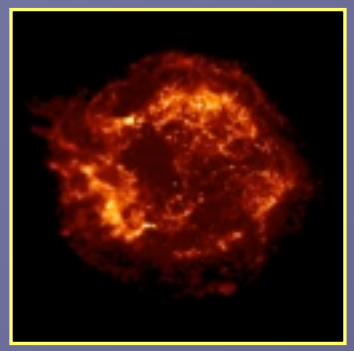


SNRs

Pulsars
and PWNe

Micro quasars
X-ray binaries

観測対象 & サイエンス



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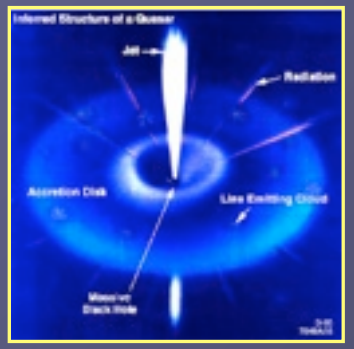
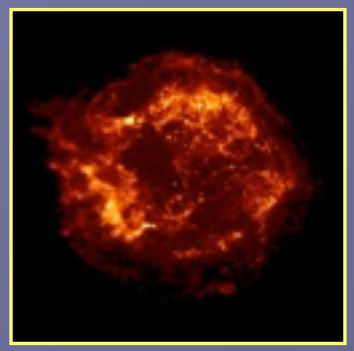


AGNs

GRBs

観測対象 & サイエンス



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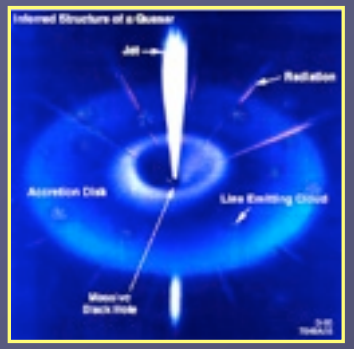

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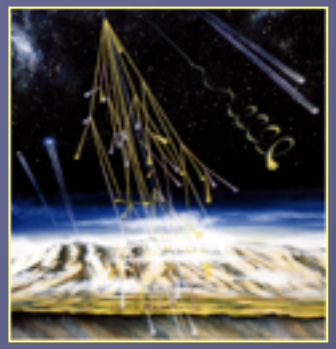
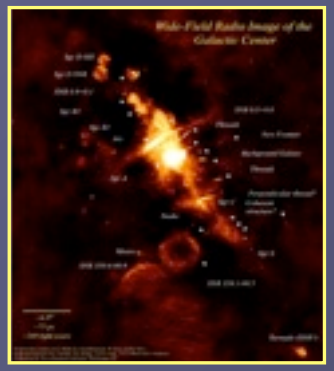
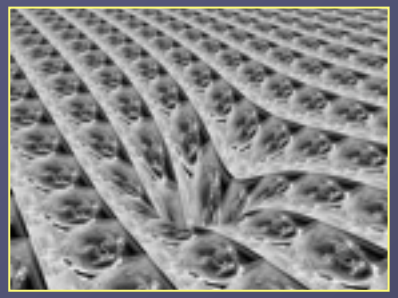


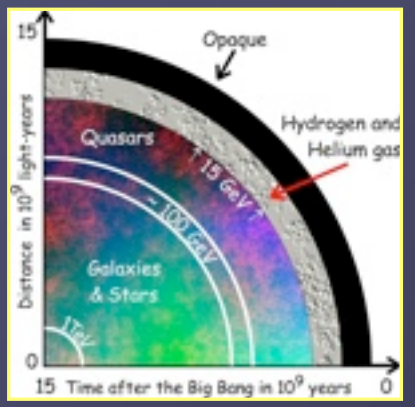
Origin of
cosmic rays



Dark matter

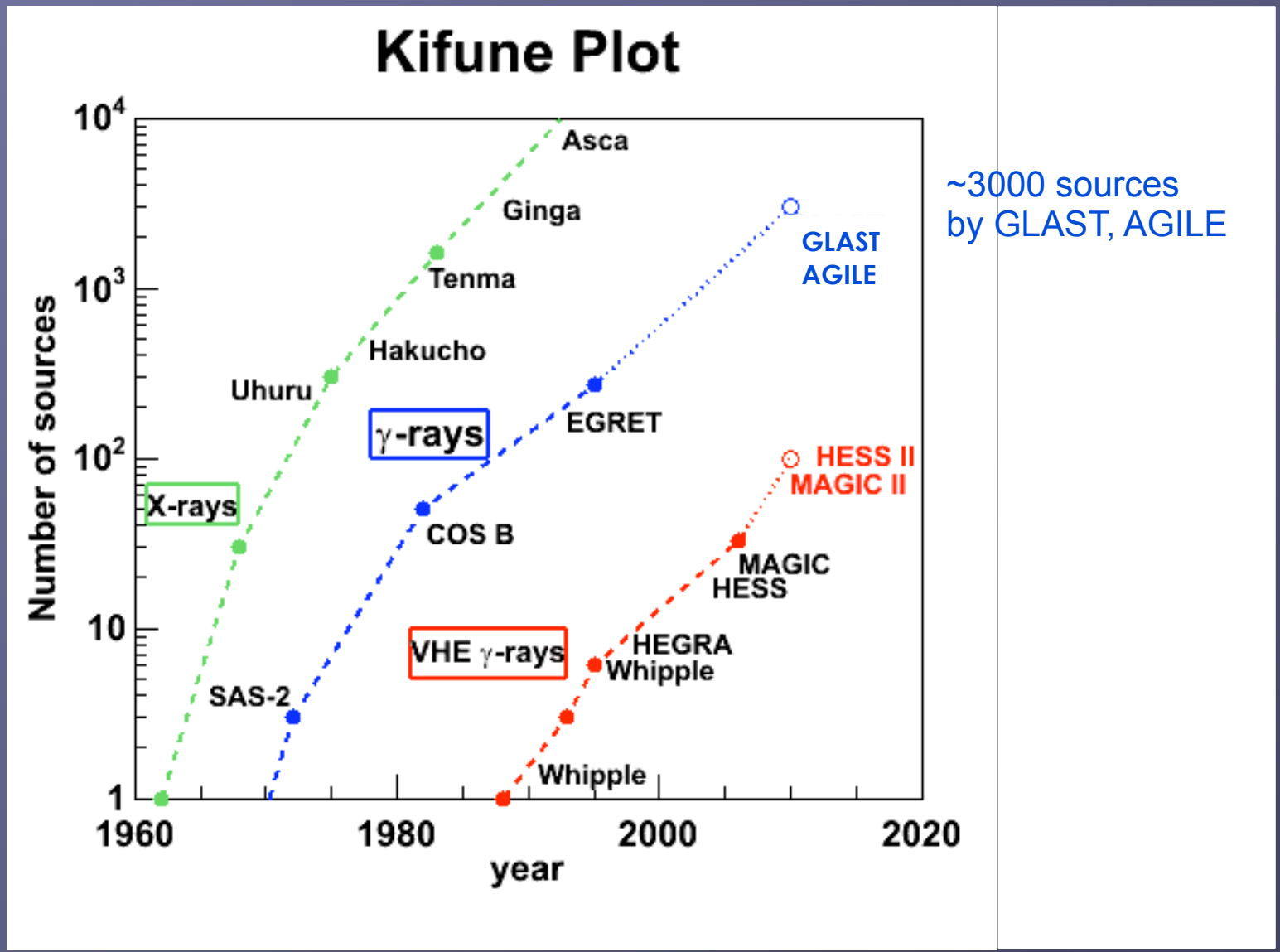


Space-time
& relativity



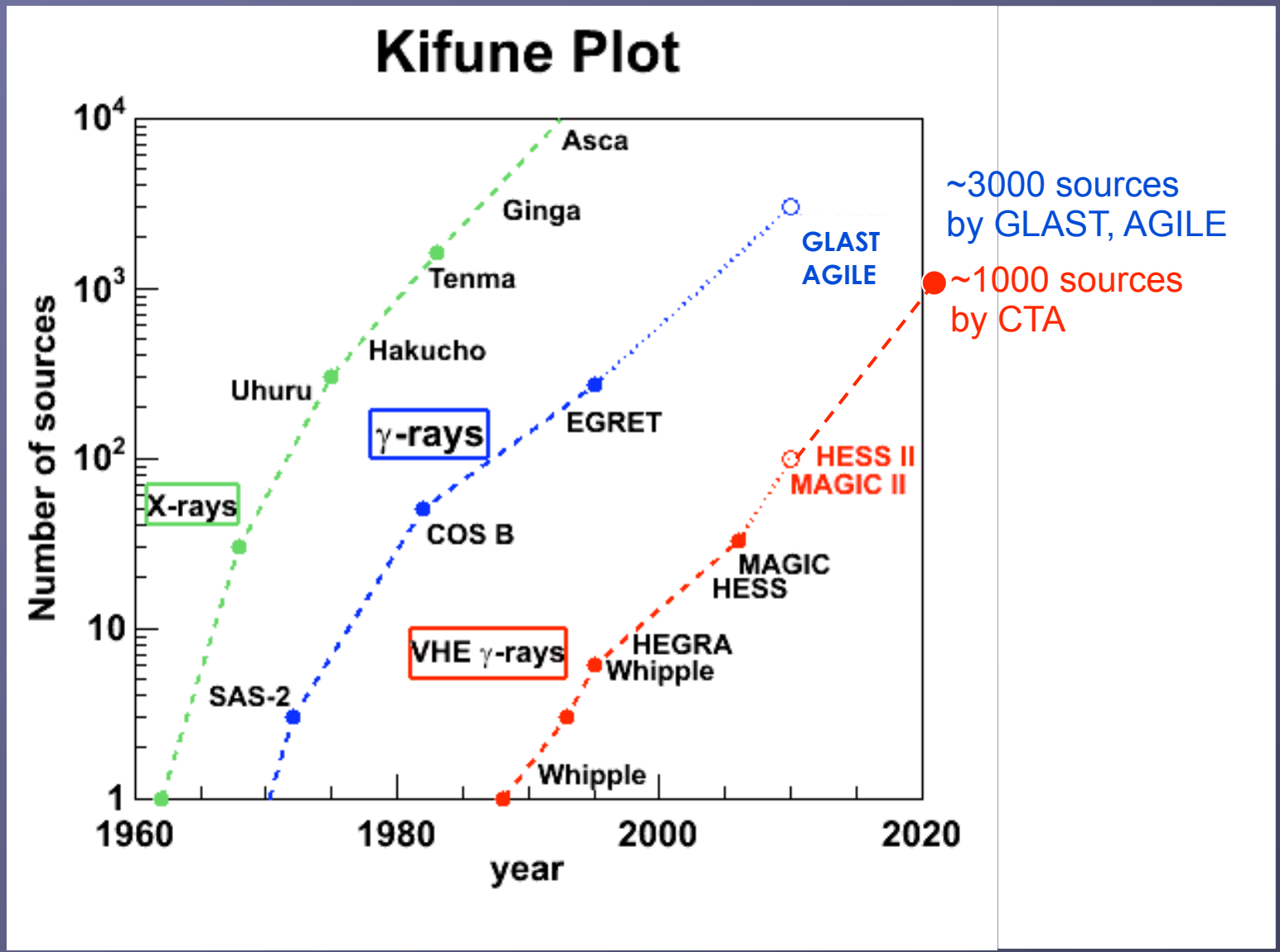
Cosmology

Kifune Plot



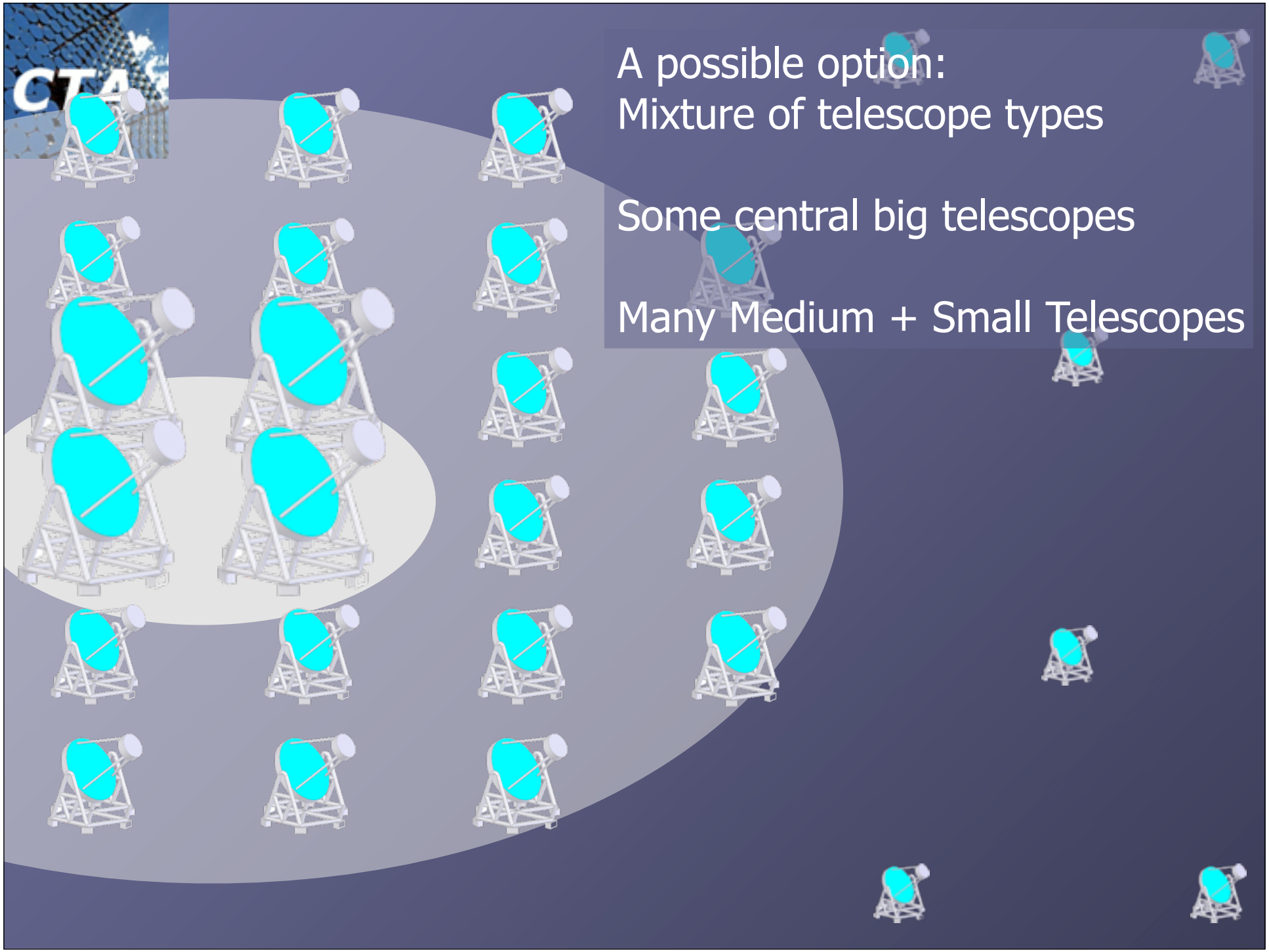
~3000 sources
by GLAST, AGILE

Kifune Plot


Kifune Plot
Number of sources
year
1960
1980
2000
2020
1
10
10^2
10^3
10^4
Asca
Ginga
Tenma
Hakucho
Uhuru
X-rays
γ-rays
EGRET
COS B
SAS-2
VHE γ-rays
HEGRA
Whipple
Whipple
MAGIC
HESS
HESS II
MAGIC II
GLAST
AGILE
~3000 sources
by GLAST, AGILE
~1000 sources
by CTA

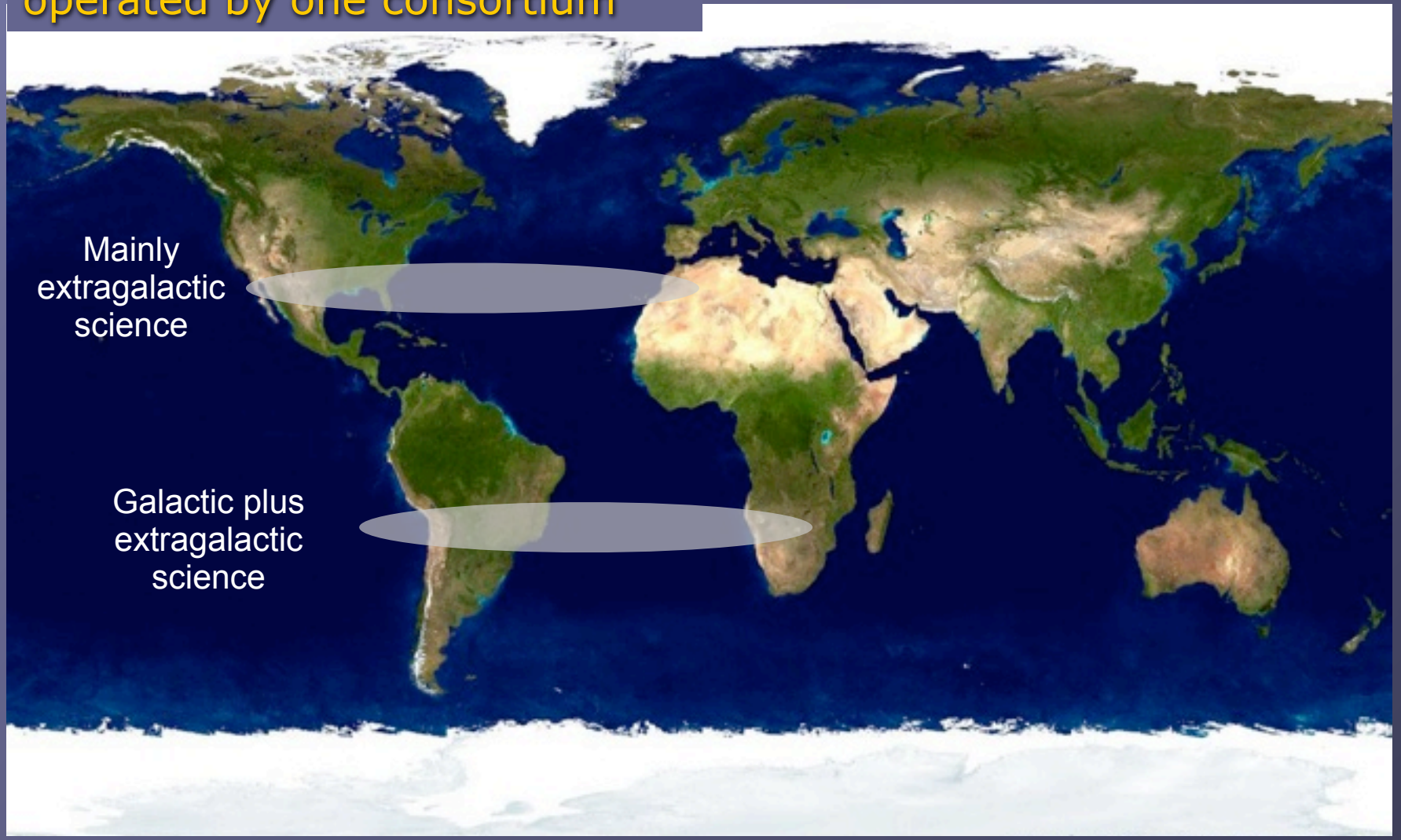
CTA 仕様・パラメーター

- 観測エネルギー領域: 20-30GeV ~ 100TeV
  - 20-30GeV ➔ 遠方の活動銀河核(z<2)の研究、系外宇宙線起源、EBL 背景放射光密度の測定(星形成史)
  - 100TeV ➔ 銀河宇宙線源の研究
- 10倍の感度向上 (HESS, MAGICから)
  - 観測される天体数30倍(1000-2000)
  - 感度 ~1mCrab
- 3倍の角度分解能
  - Better morphological study
- 全天観測
  - 北半球:20-30GeV ~ 1TeV (mainly extragalactic science)
    - Several 23m class telescopes + some 12m class telescopes
  - 南半球:20-30GeV ~ 100TeV (galactic + extragalactic science)
    - Several 23m class telescopes + many 12m class telescopes + some 6m telescopes


A possible option:
Mixture of telescope types
Some central big telescopes
Many Medium + Small Telescopes

CTA候補地（北、南　2 stations）

One observatory with two sites operated by one consortium

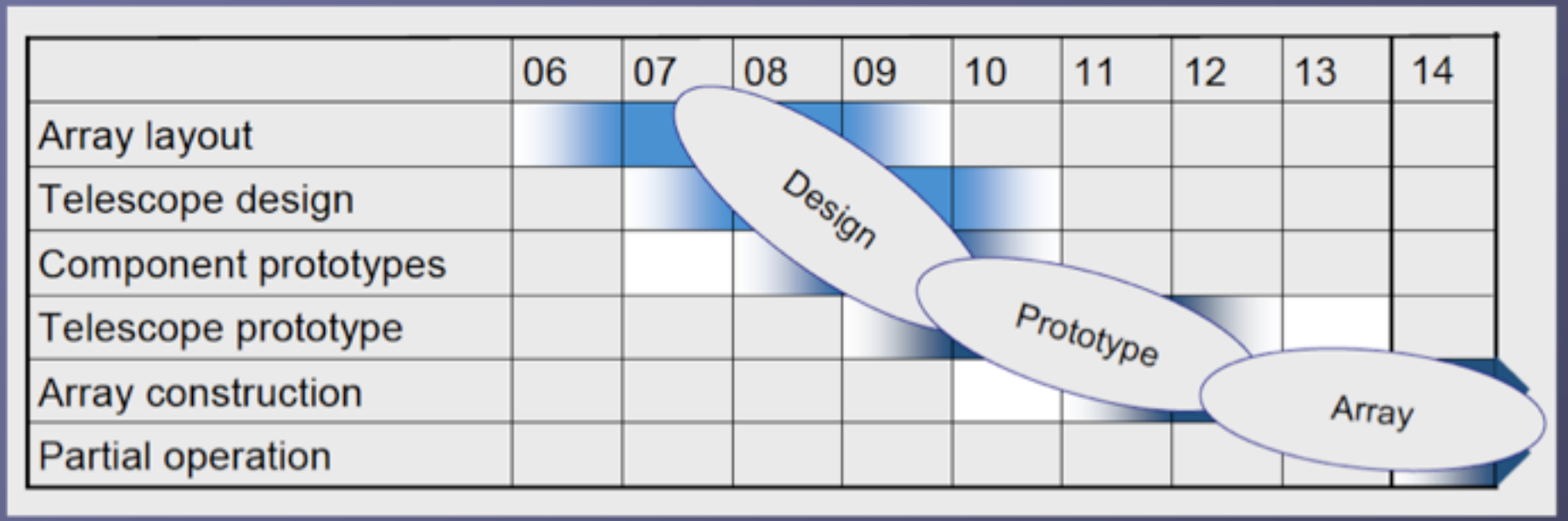


Design Study started

Milestones, tasks are defined in each WP

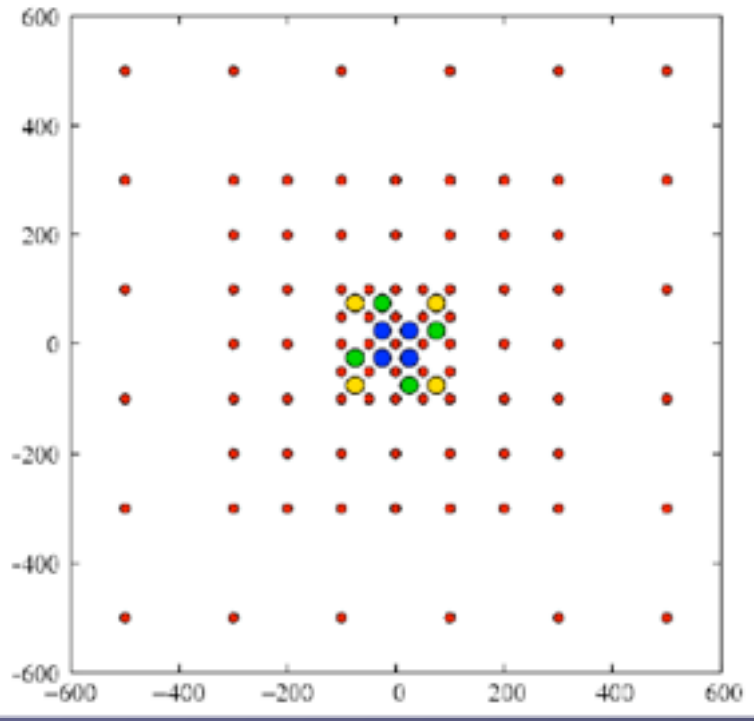
WP1	**MNG**	Management of the design study
WP2	**PHYS**	Astrophysics and astroparticle physics
WP3	**MC**	Optimization of array layout, performance studies and analysis algorithms
WP4	**SITE**	Site evaluation and site infrastructure
WP5	**MIR**	Telescope optics and mirror
WP6	**TEL**	Telescope structure, drive, control
WP7	**FPI**	Focal plane instrumentation, mechanics and photo detectors
WP8	**ELEC**	Readout electronics and trigger
WP9	**ATAC**	Atmospheric monitoring, associated science & instrument calib.
WP10	**OBS**	Observatory operation and access
WP11	**DATA**	Data handling, data processing, data management and access
WP12	**QA**	Risk assessment and quality assurance, production planning

タイムスケジュール

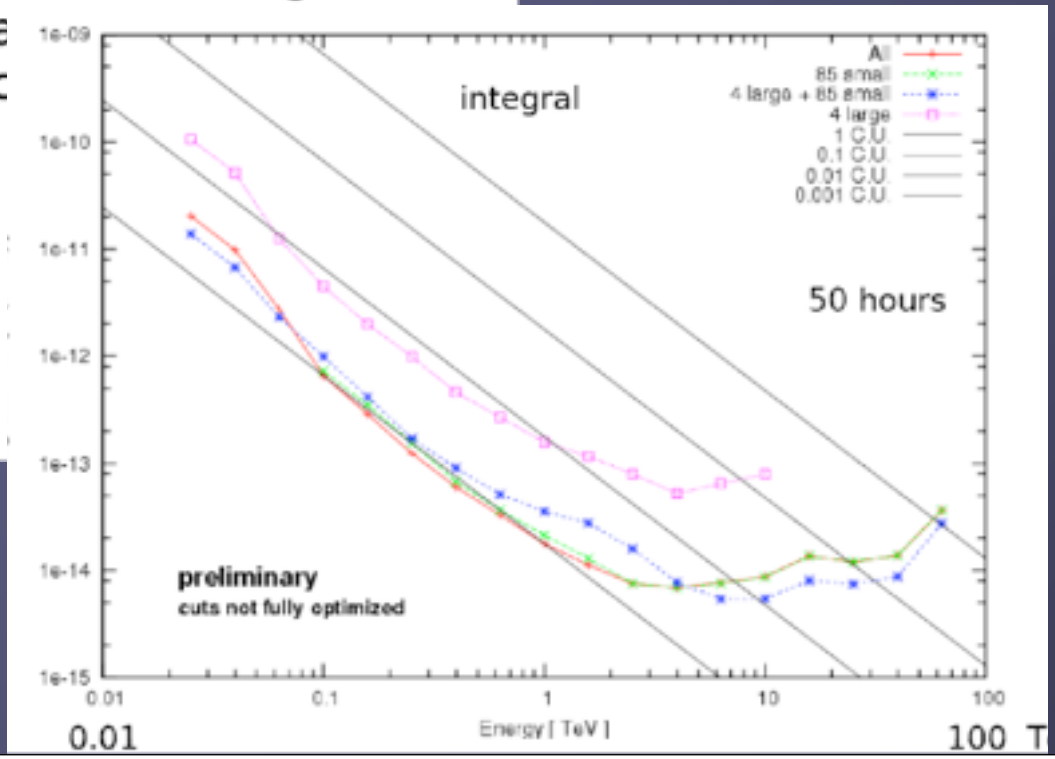

06
07
08
09
10
11
12
13
14
Array layout
Telescope design
Component prototypes
Telescope prototype
Array construction
Partial operation
Design
Prototype
Array

CTA preliminary M.C. Study

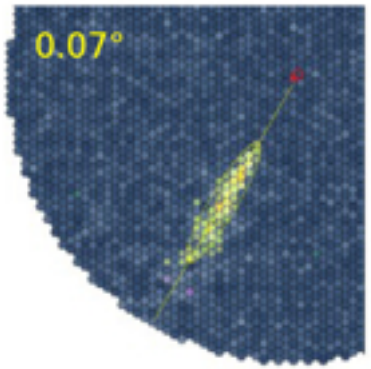
Configurations: 97 tel. hybrid system

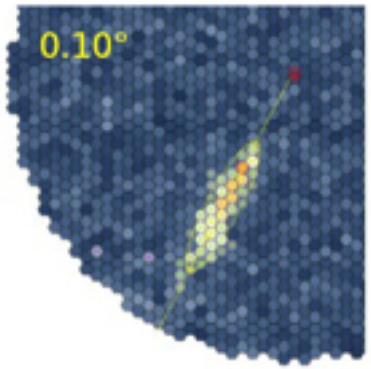


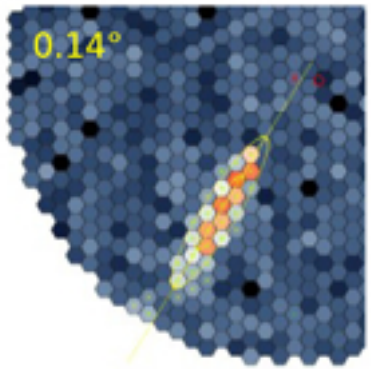
Hybrid system of
- 12 600 m² class tel.
- 85 100 m² class tel.
with 1.4* larger f.o.v.
a
c

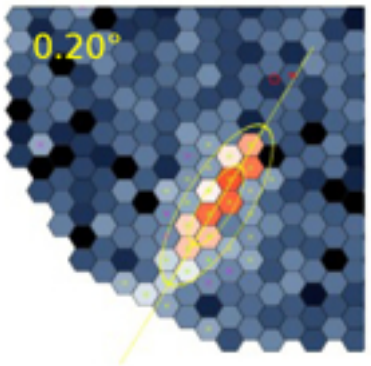


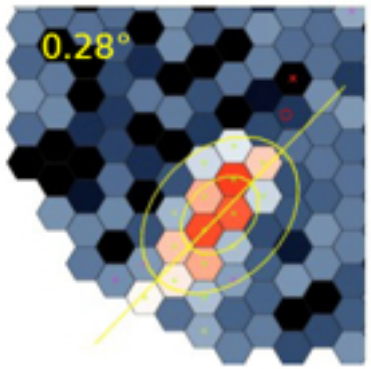
Impact of Pixel size

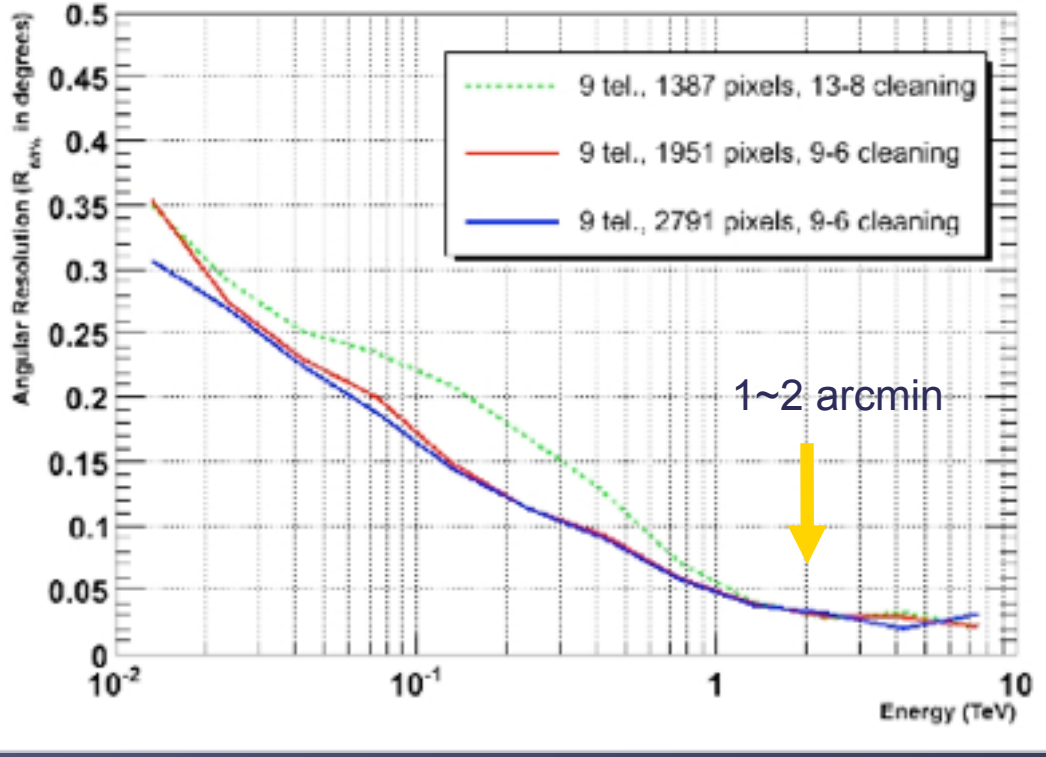




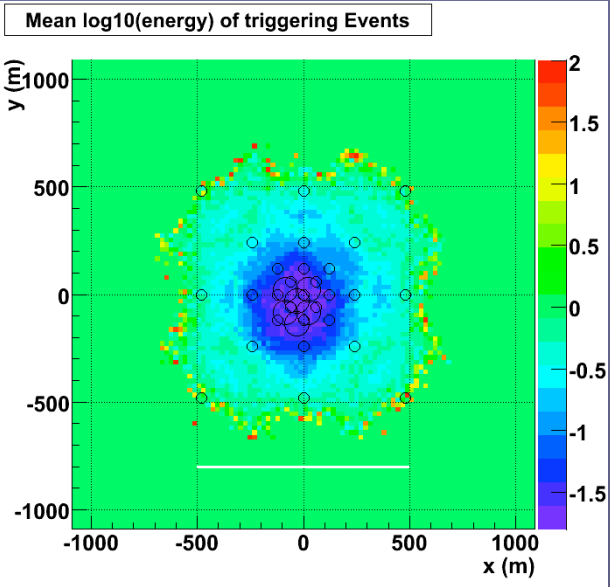


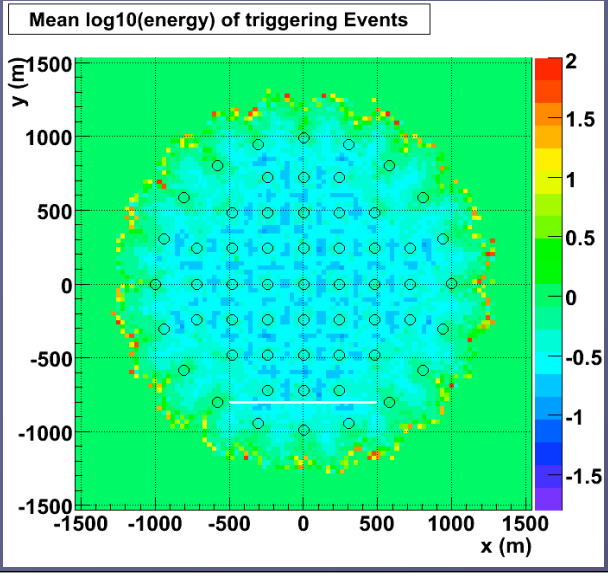


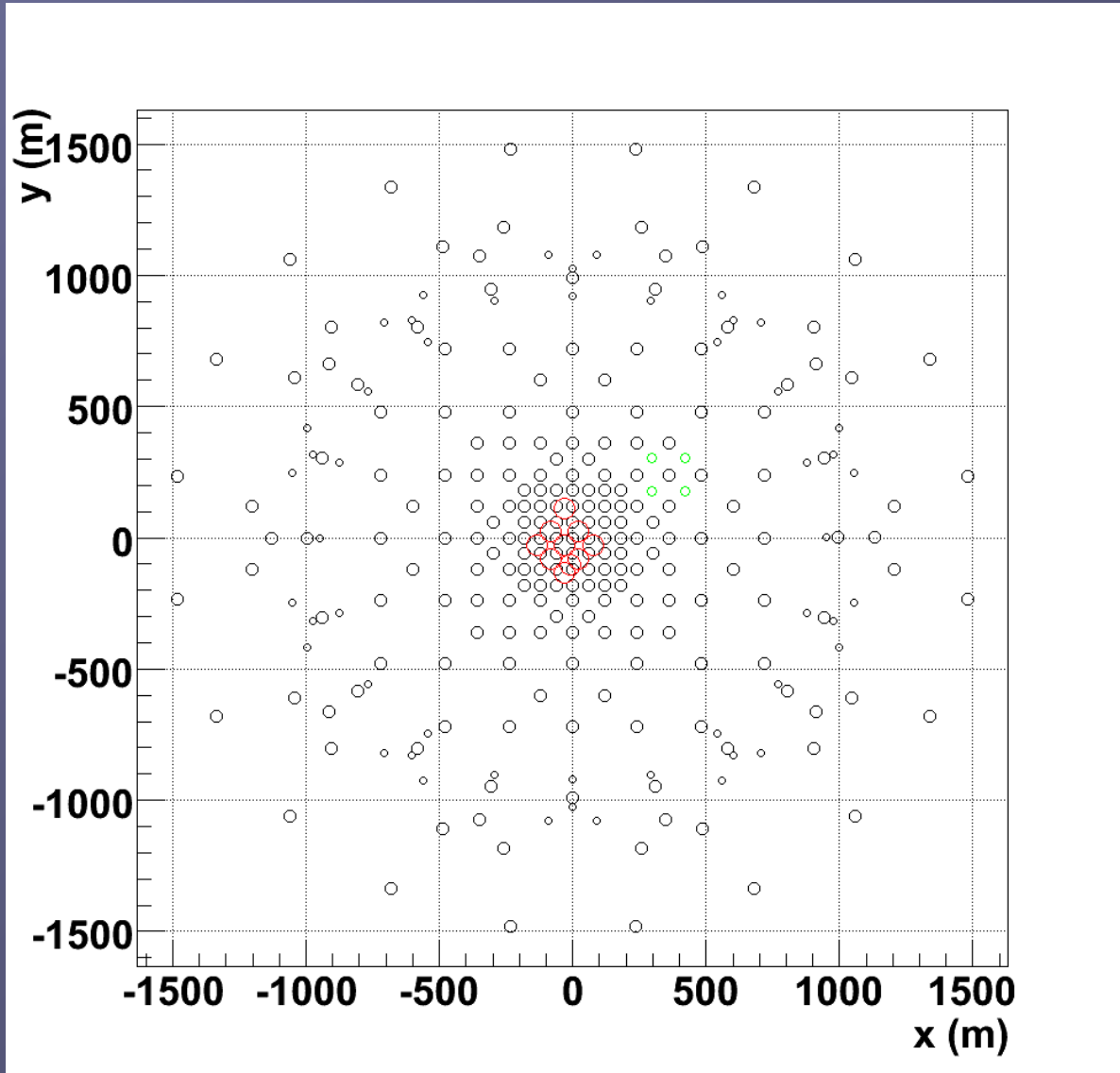




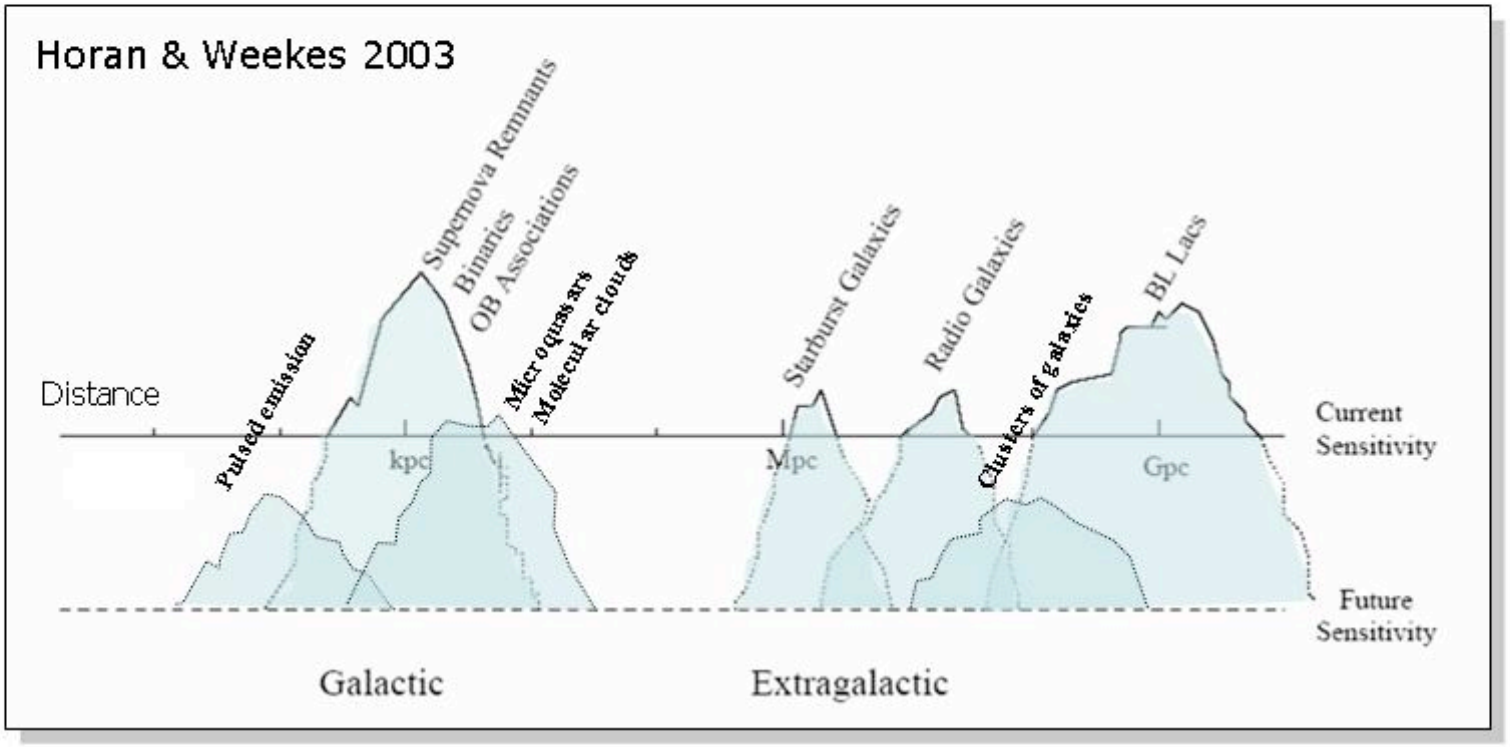
Optimization is on-going





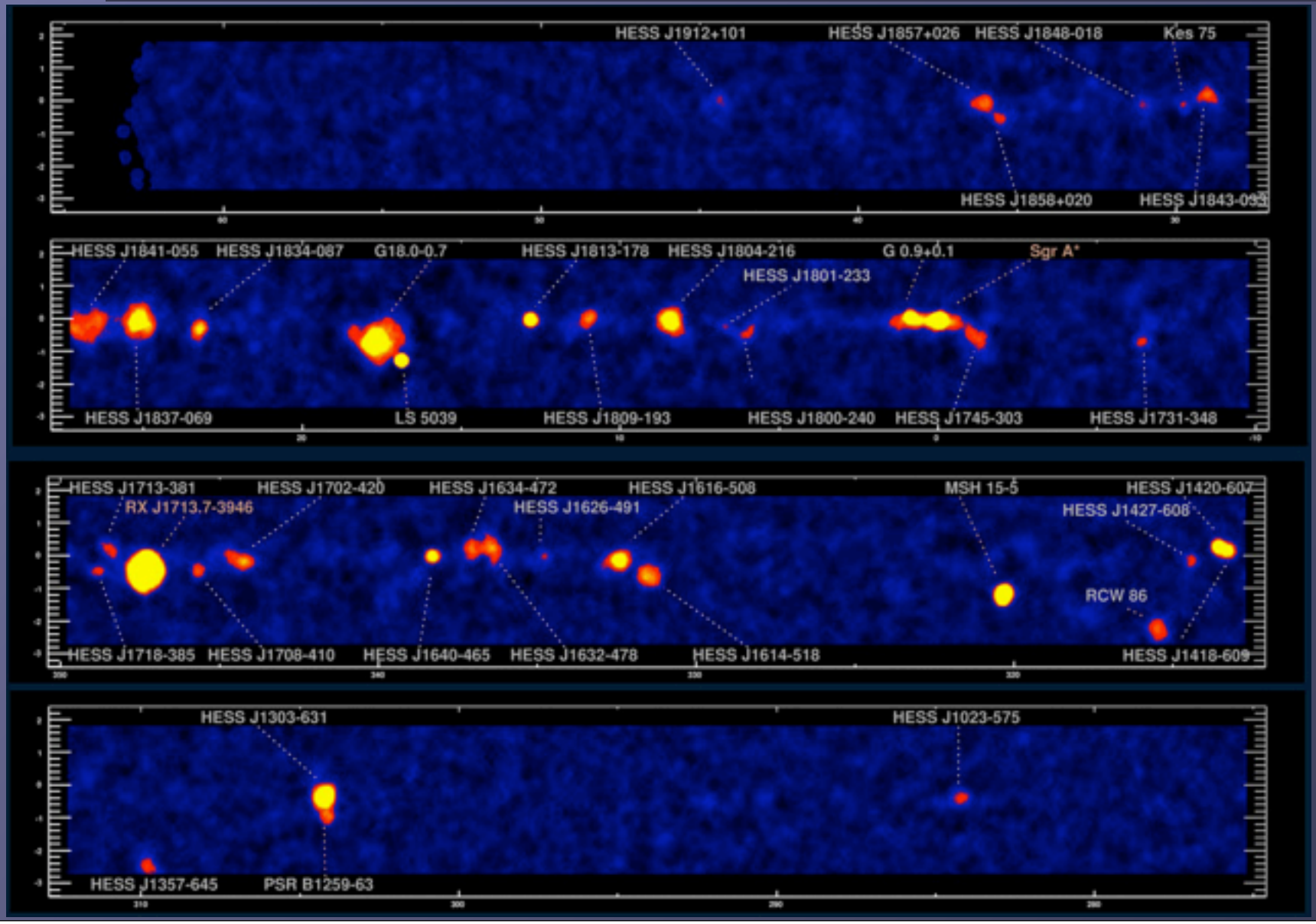


Scientific potential of CTA

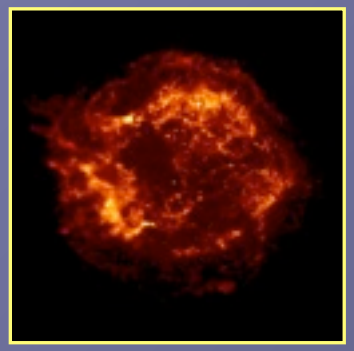


- Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg
- Broad and diverse program ahead, combining guaranteed astrophysics with significant discovery potential

Great success!!
HESS の銀河面サーベイ

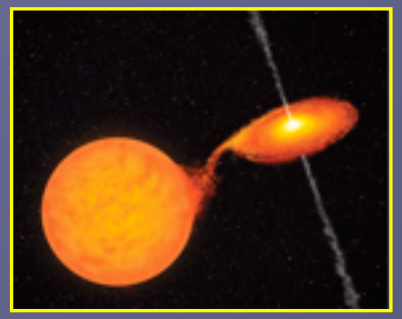


Guaranteed sources



SNRs

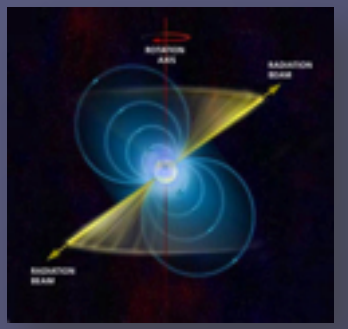
PWNe



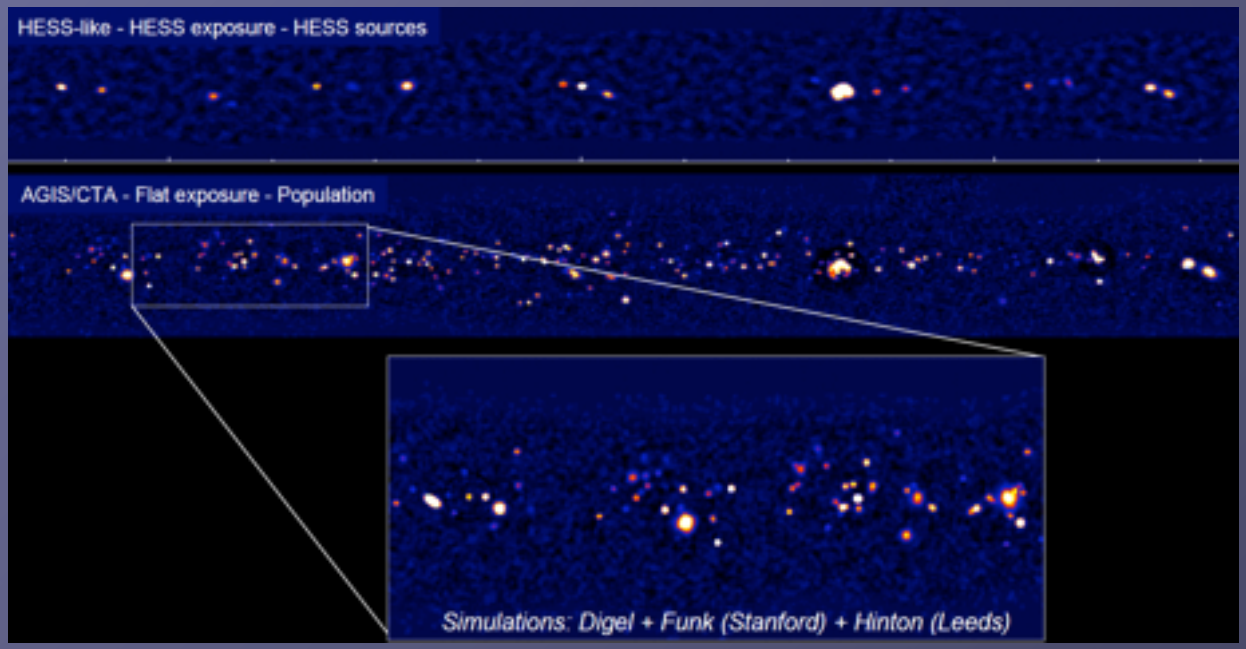
Micro quasars
X-ray binaries

?

Un-ID sources
Dark Sources



Pulsars

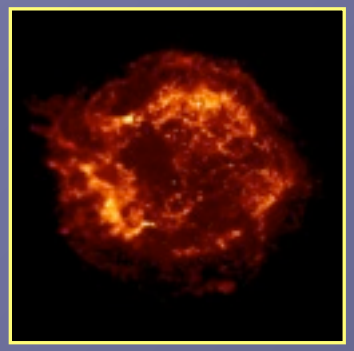


Galactic sources

200~400 sources with CTA

Where is PEVATRON???

Guaranteed sources



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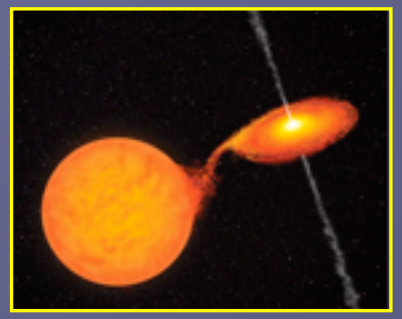

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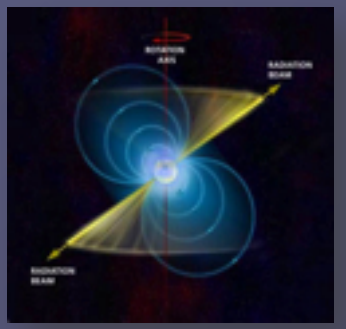
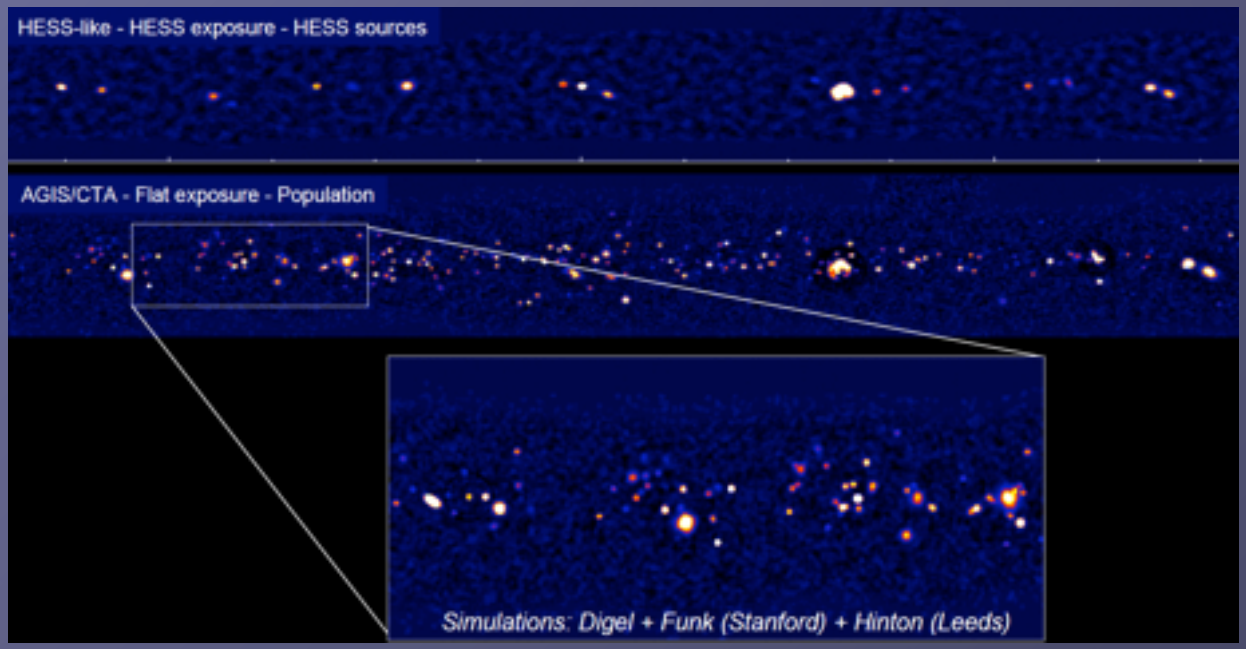


Pulsars

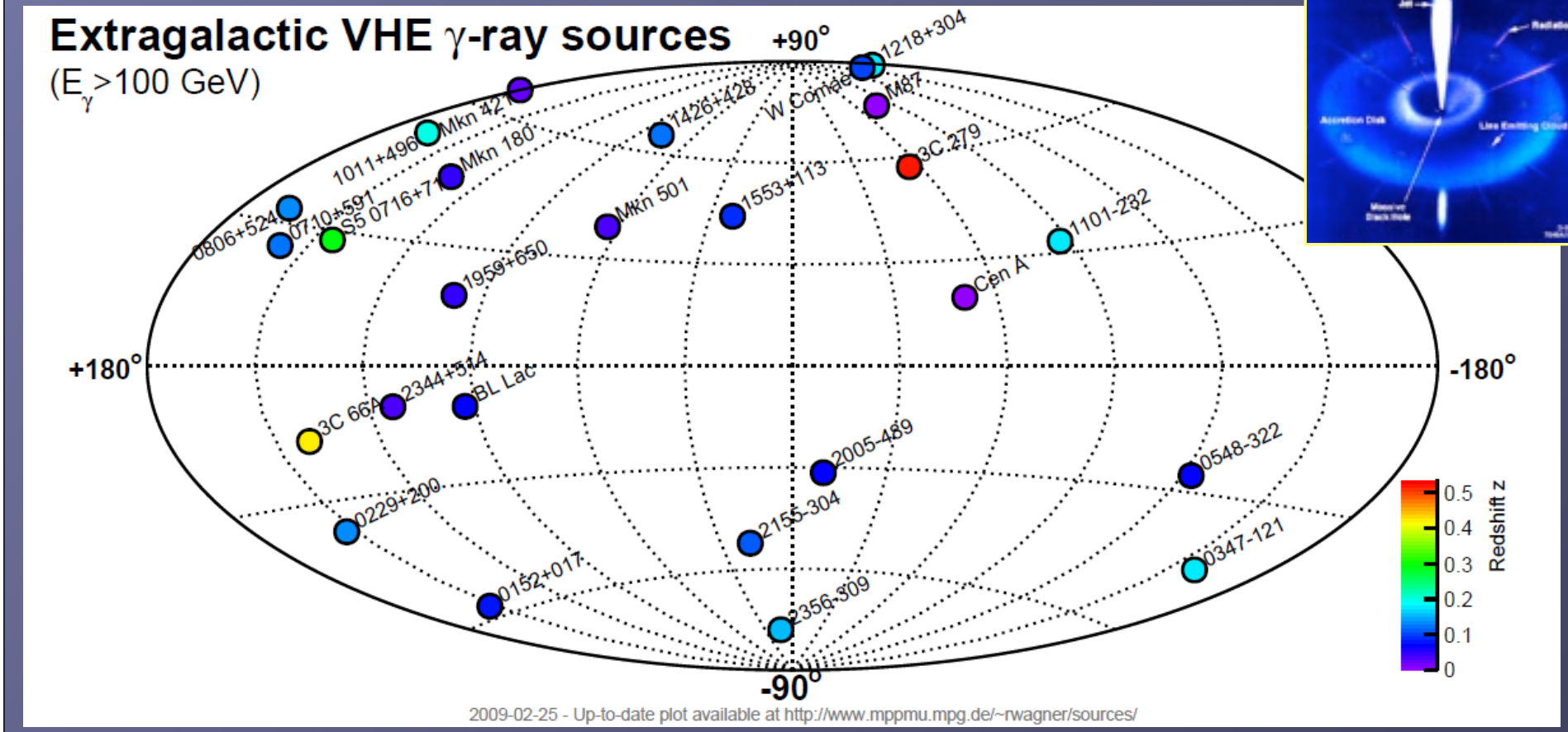


Galactic sources

200~400 sources with CTA

Where is PEVATRON???

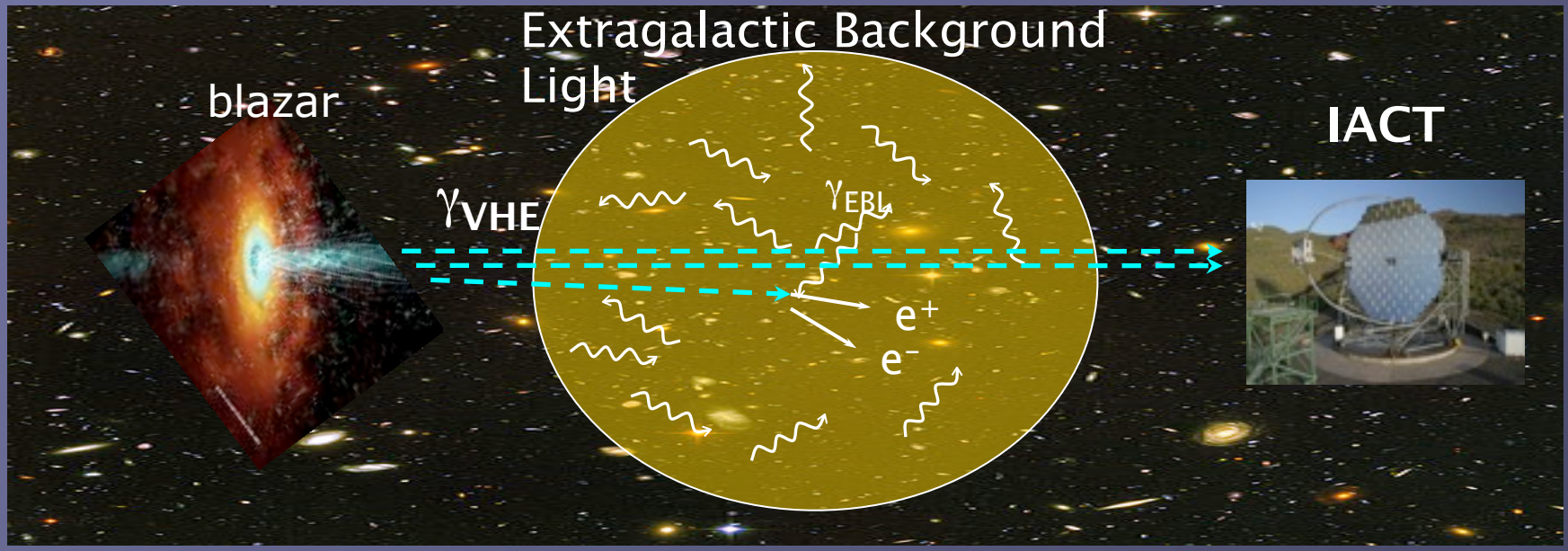
Guaranteed sources

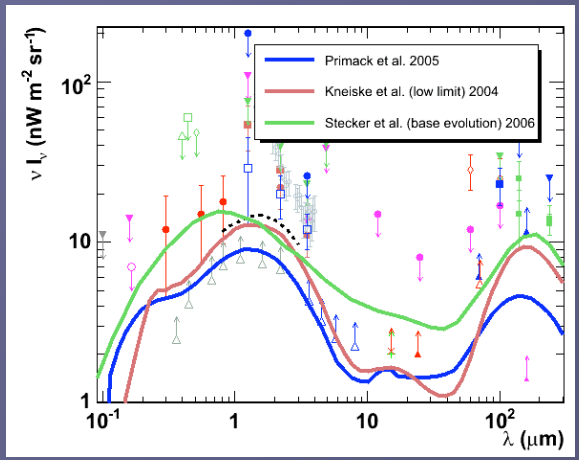


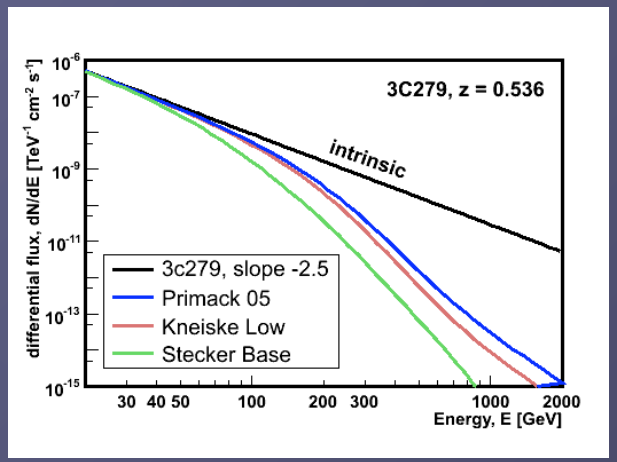
27 sources (2 x FR-I, 24 BL Lac(HBL, IBL, LBL), 1 x FSRQ)

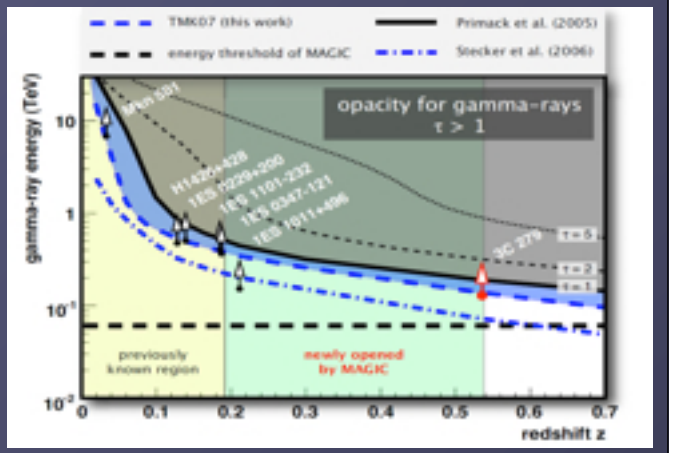
~800 sources with CTA

EBL（背景輻射）との衝突によるガンマ線吸収

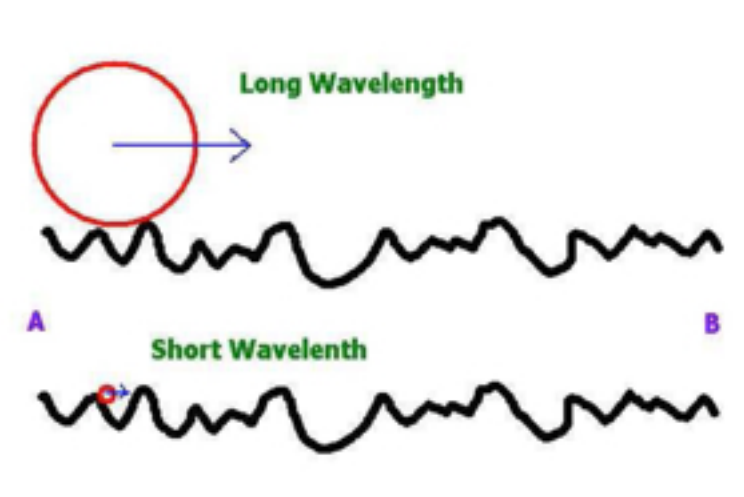








相対論・量子重力理論の検証



If Gravity is a Quantum theory,
at a very short distance it may show a very complex "foamy" structure due to quantum fluctuation.

Use gamma ray beam from AGNs/GRBs
to study the space-time structure

Energy 1000GeV ~ $10^{-16}E_{Pl}$
Distance 100~1000Mpc ($10^{16\text{-}17}$sec)

Visible time delay ~ 1 - 10 sec

$$E_{Pl} = \sqrt{\frac{\hbar c^5}{G}} \approx 1.22 \times 10^{19} GeV$$

Linear deviation:

$$\xi_1 < 0; \quad v = c(1 - \frac{E}{M_{QG1}}); \quad n(E) = 1 + \frac{E}{M_{QG1}}$$

Quadratic deviation:

$$\xi_1 = 0; \quad \xi_2 < 0; \quad v = c(1 - \frac{E^2}{M^2_{QG2}}); \quad n(E) = 1 + \frac{E^2}{M^2_{QG2}}$$

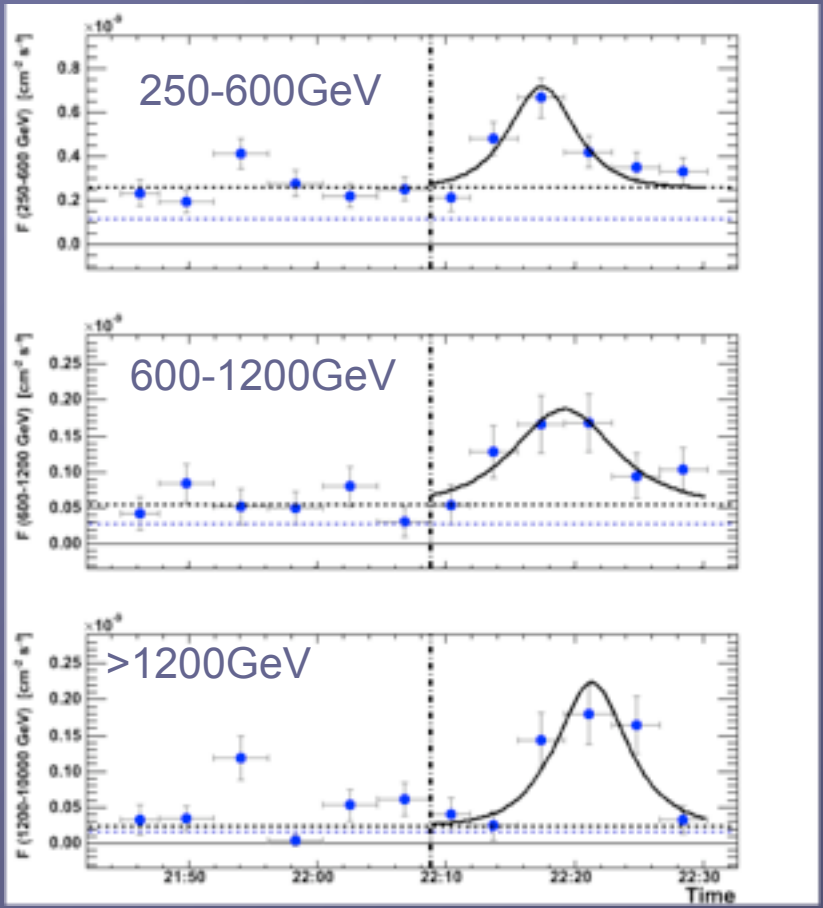
AGN からのガンマ線短時間変動
Mrk501 by MAGIC, PKS 2155 by HESS

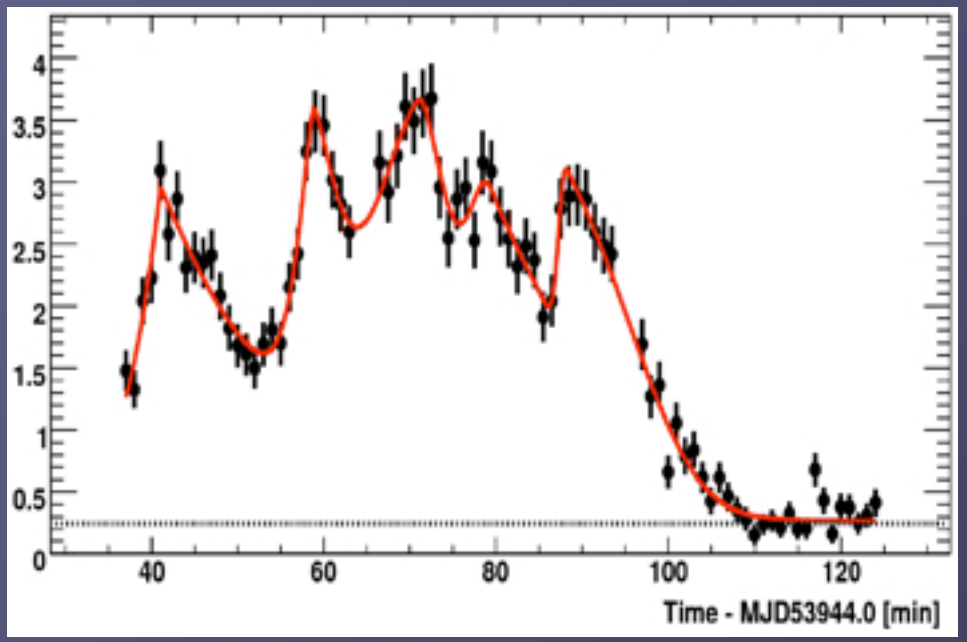
Mrk501(z=0.03) MAGIC observation

$M_{QG1} > 0.26 \times 10^{18}$GeV

PKS2155(z=0.116) HESS observation

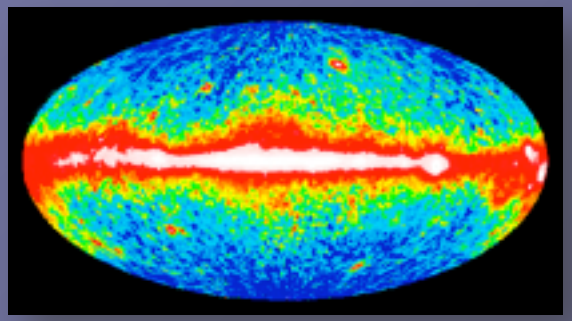
$M_{QG1} > 0.72 \times 10^{18}$GeV





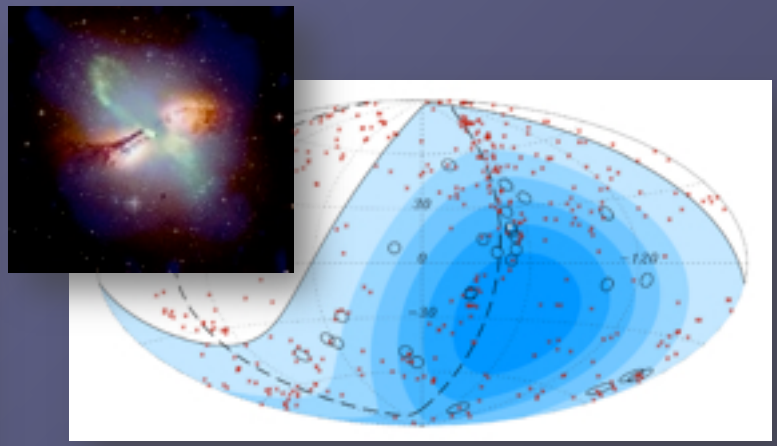
With CTA, we can have ~10sec time resolution for the fast variation

Possible New Classes of Sources



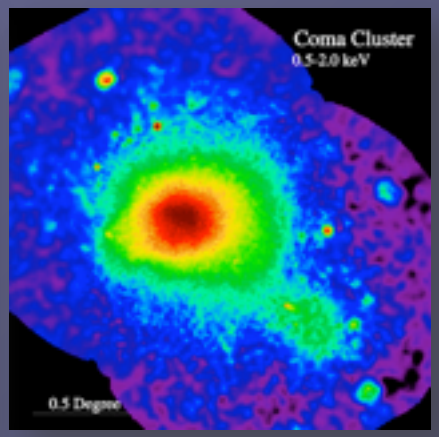
Galactic Diffuse

GRBs

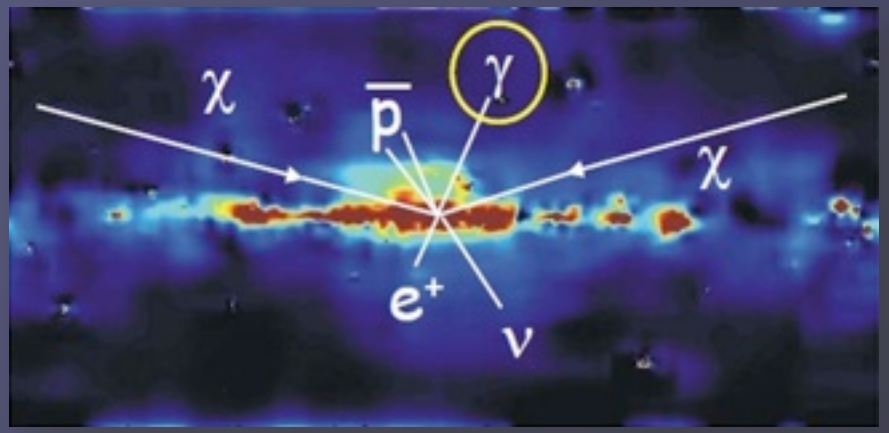


UHECR Sources

Starburst galaxies
Galaxy mergers

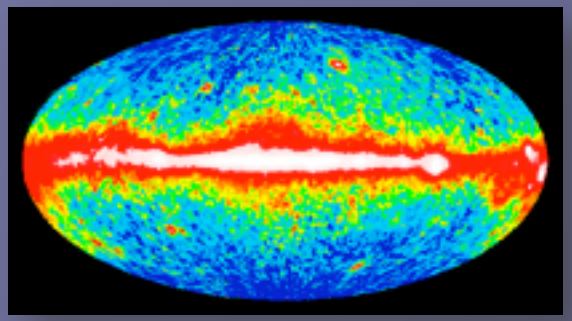


Clusters of galaxies



Dark Matter Annihilation

Possible New Classes of Sources



Galactic Diffuse

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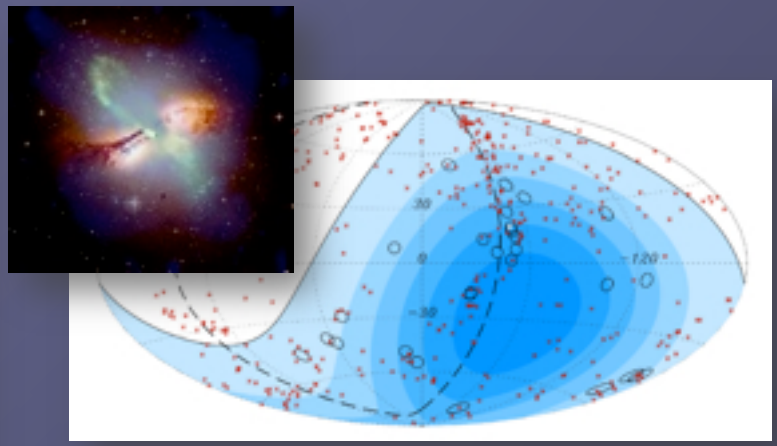
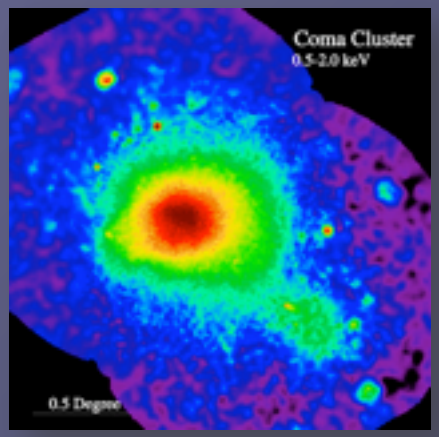
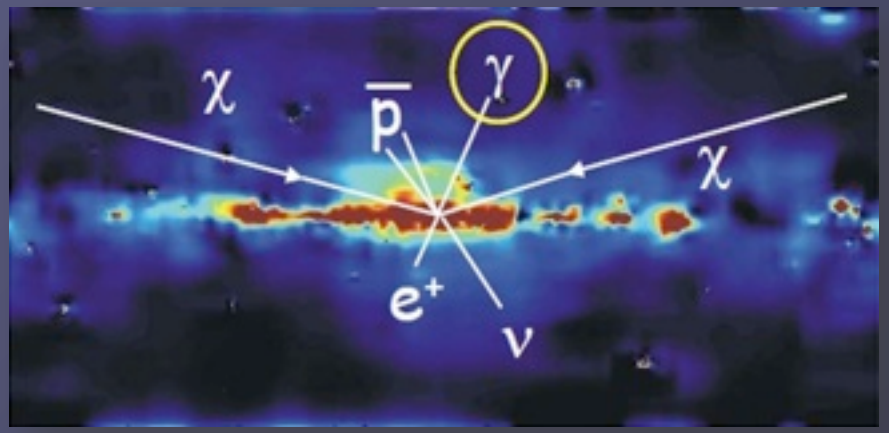


UHECR Sources



Clusters of galaxies



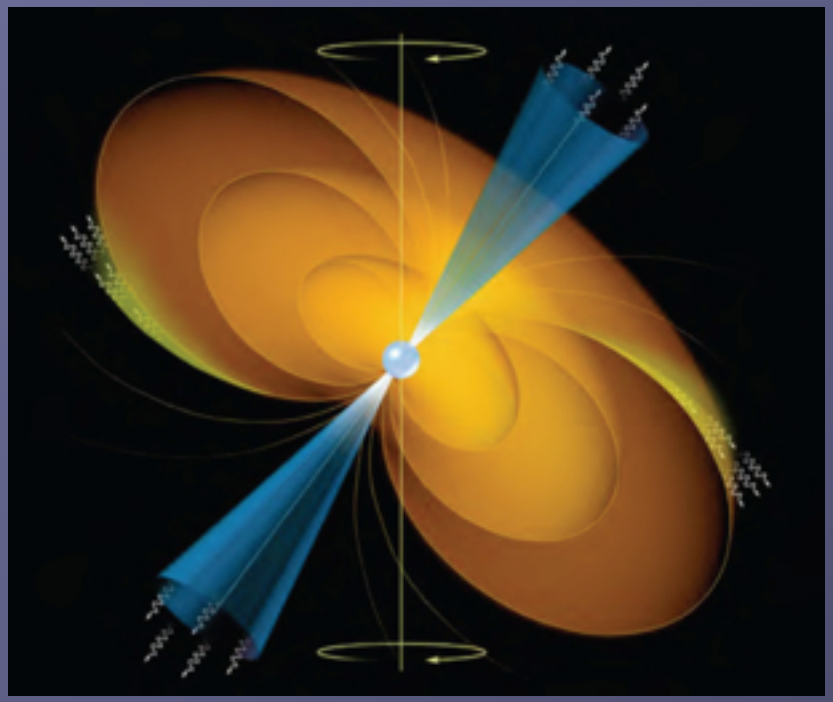
Dark Matter Annihilation

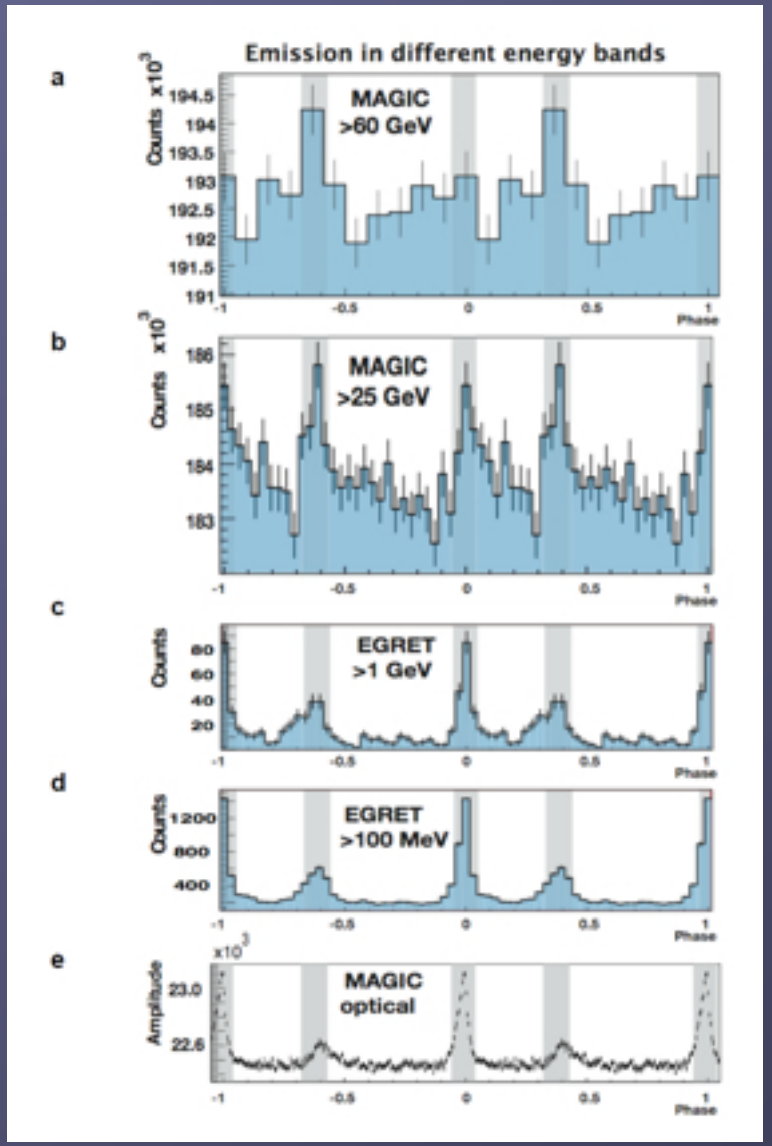
For pulsar studies the low threshold energy is essential

MAGIC result: Published in Science in 2008

By measuring the spectrum around cutoff or at high energies is important to distinguish the emission model

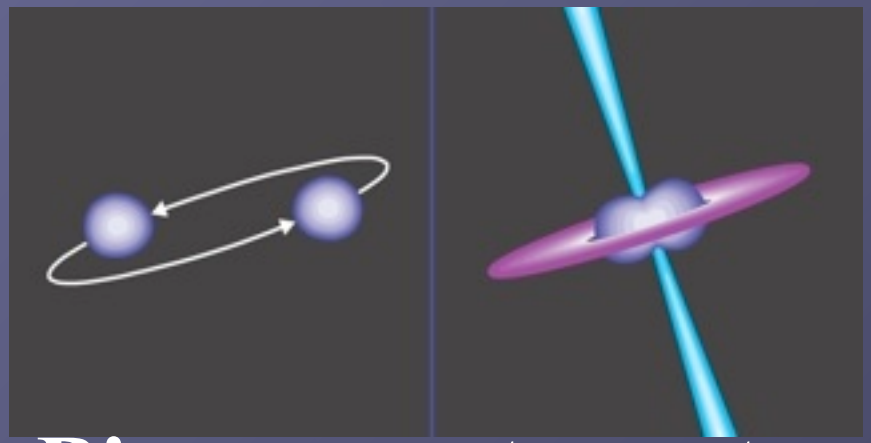
Polar cap: double exponent
Outer gap: simple exponent



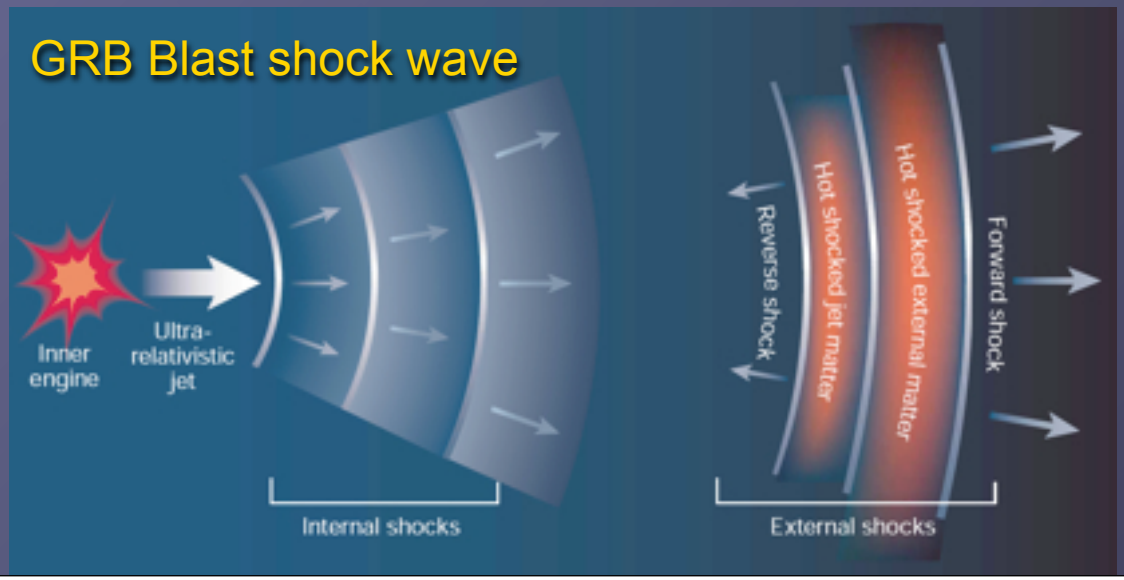


Gamma ray bursts

Hypernova!



Binary neutron stars



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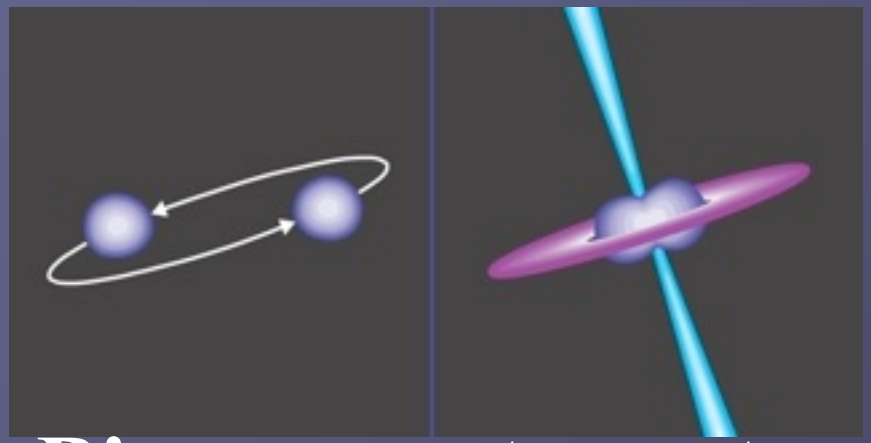
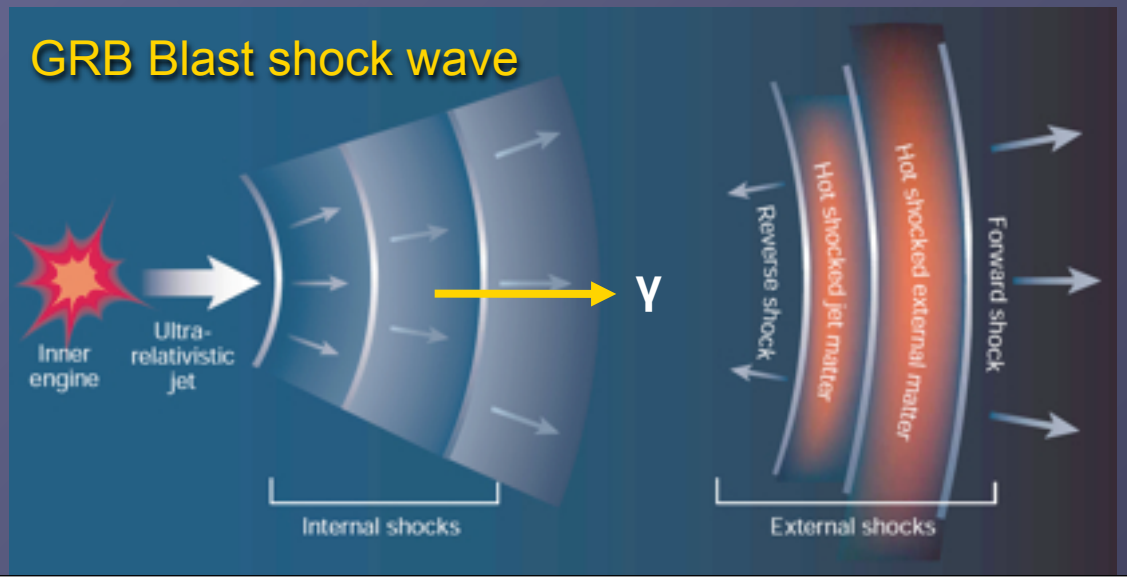


Binary neutron stars



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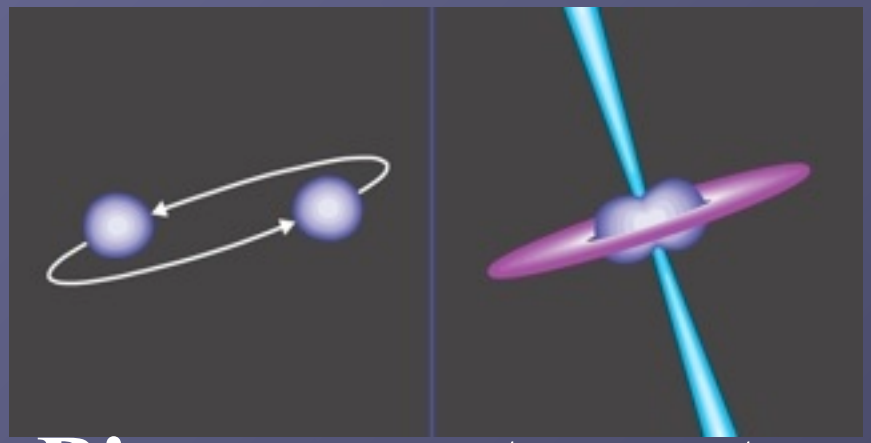

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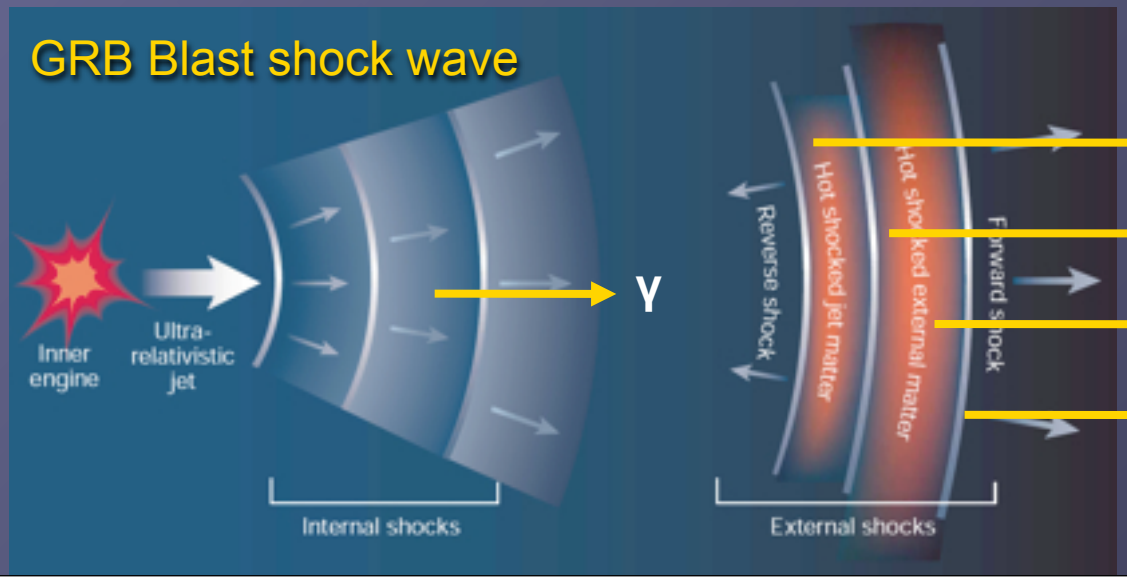


After glow

γ

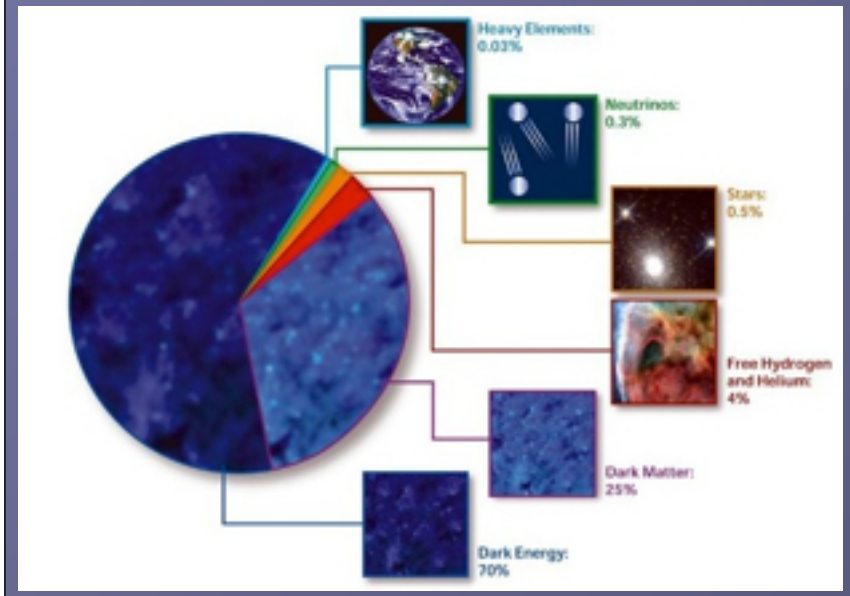
X

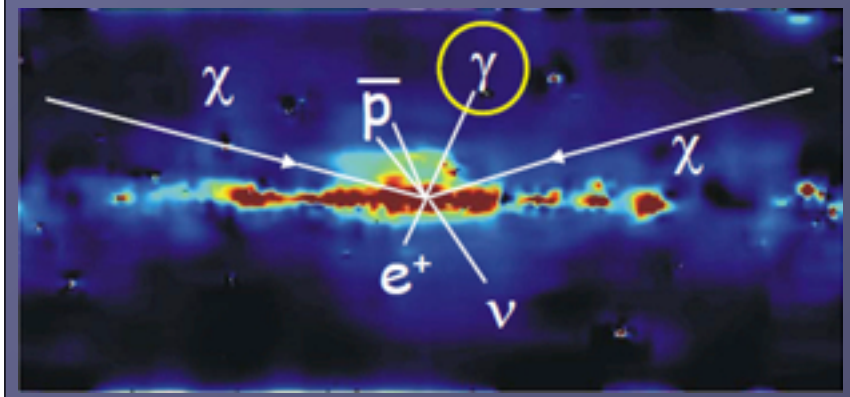
Optical

Radio

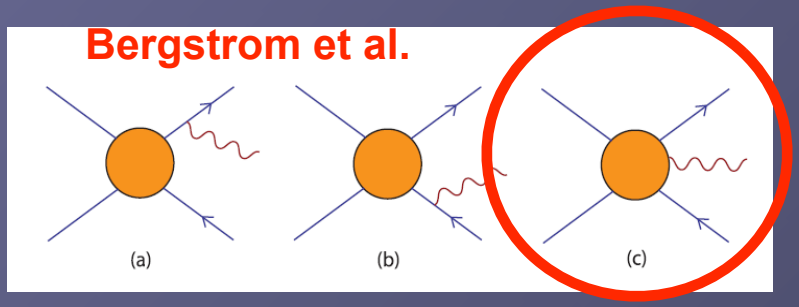
Gamma ray emission process from DM Annihilation

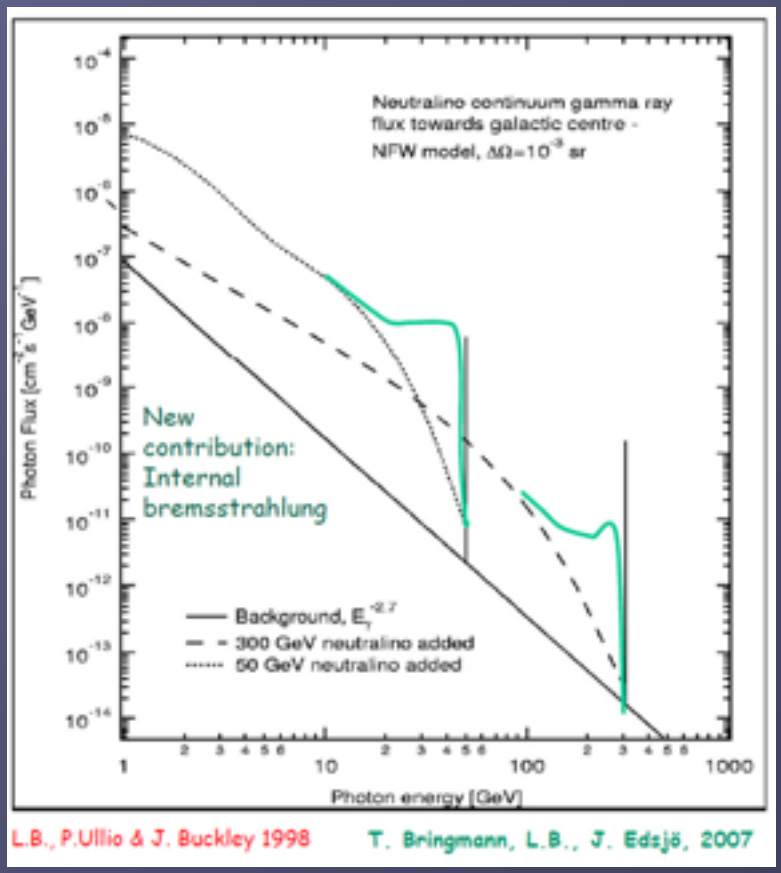
Dark Matter Annihilations





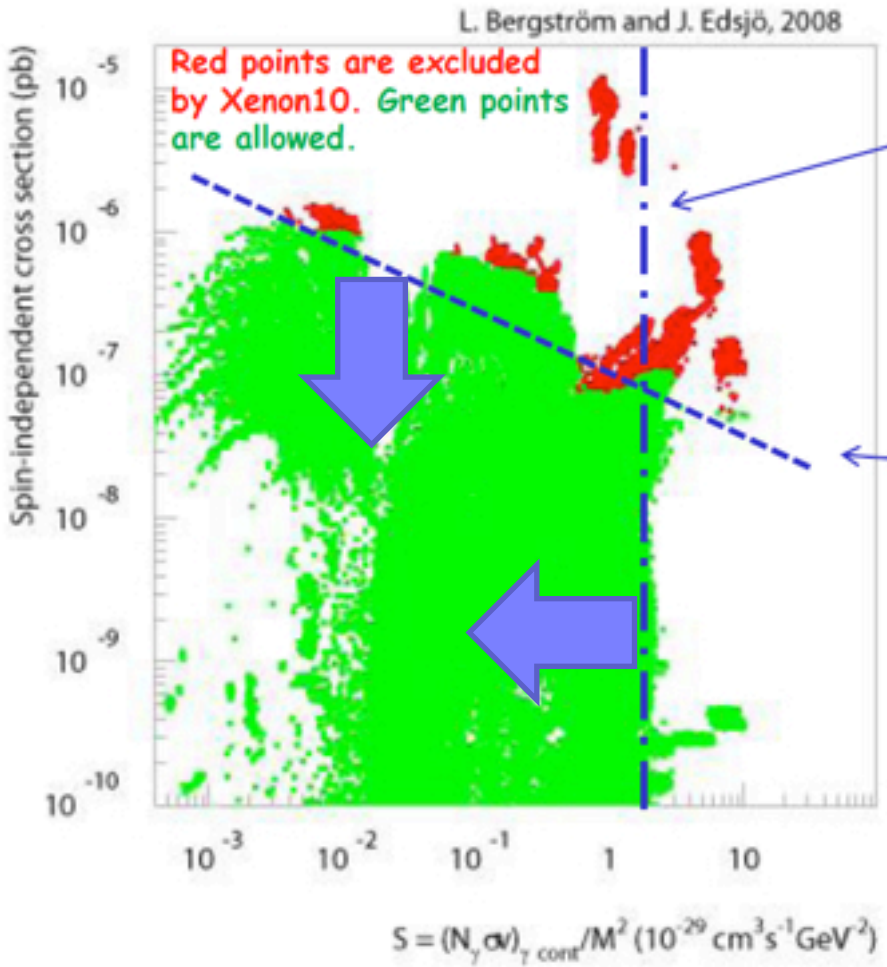
Bergstrom et al.





L.B., P.Ullio & J. Buckley 1998 T. Bringmann, L.B., J. Edsjö, 2007

Complimentarity with the direct search experiment



Expected sensitivity by Fermi

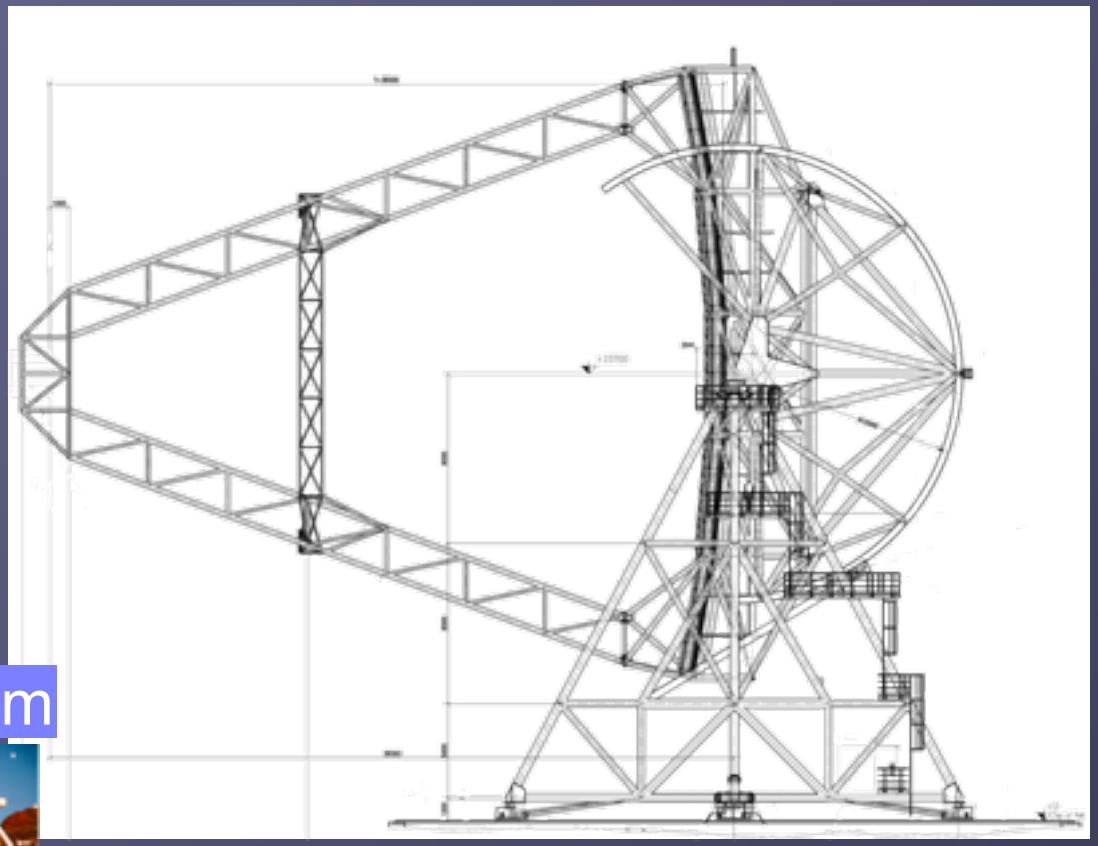
Present approximate limit from direct searches (Xenon10 experiment)

Telescope structures:

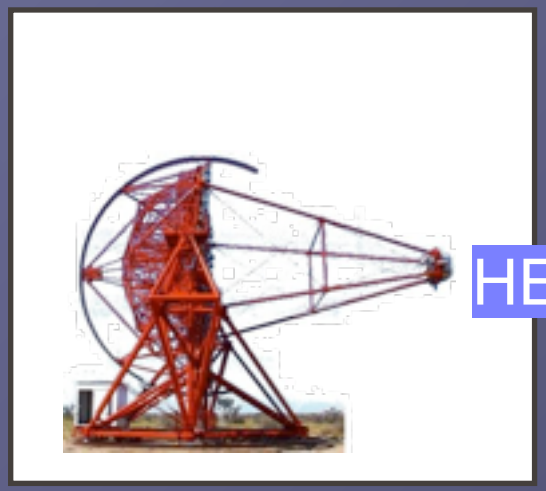
HESS / MAGIC / HEGRA as prototypes

MAGIC: 17m

HESS II: 28m



H.E.S.S. 12m



HEGRA: 4m

MAGIC vs...

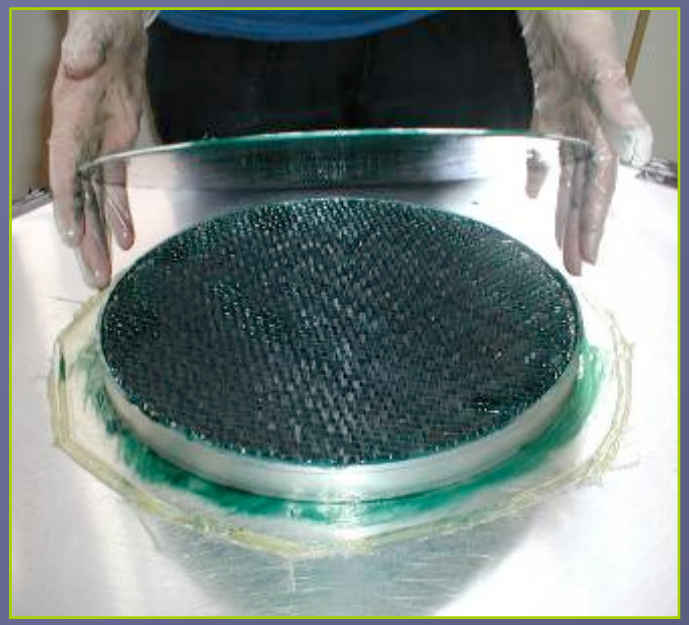
MAGIC: 17m

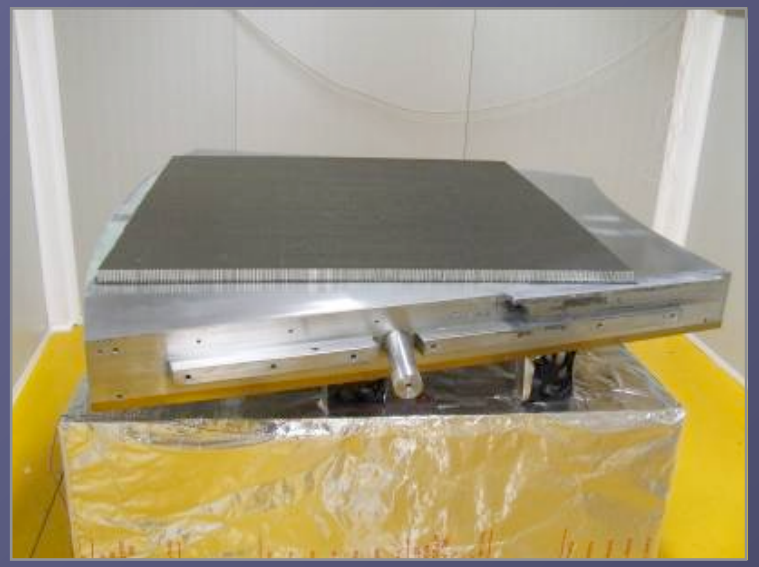
MAGIC vs...

MAGIC: 17m

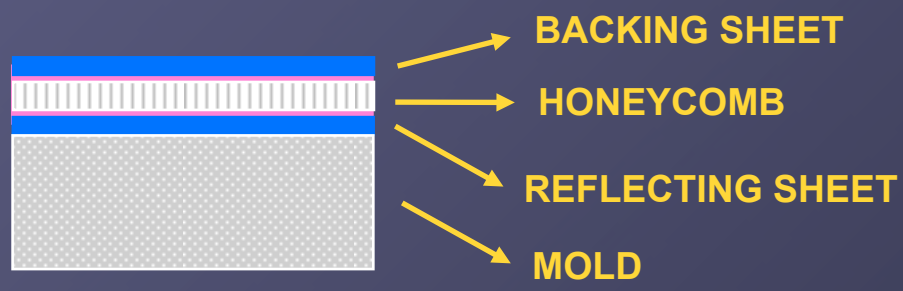
RX-78-2: 18.0m, 43.4t

Mirrors must be cheap and good quality

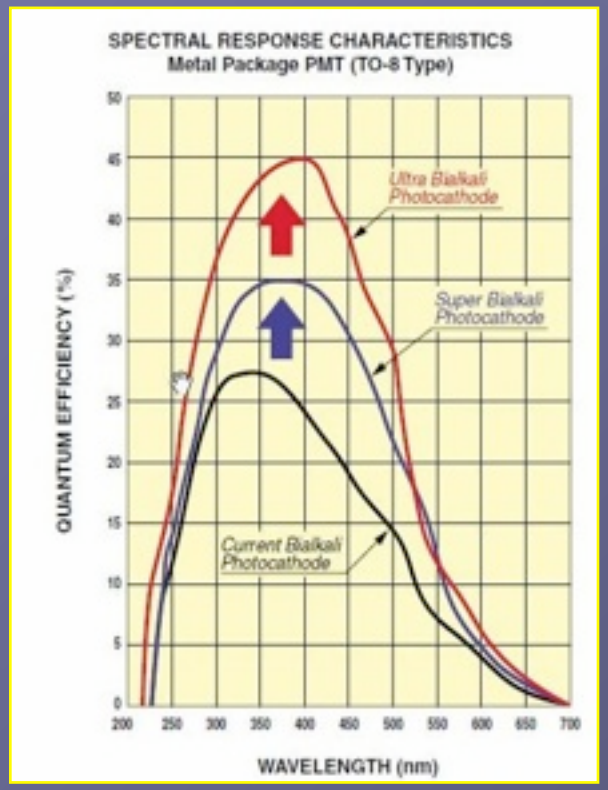




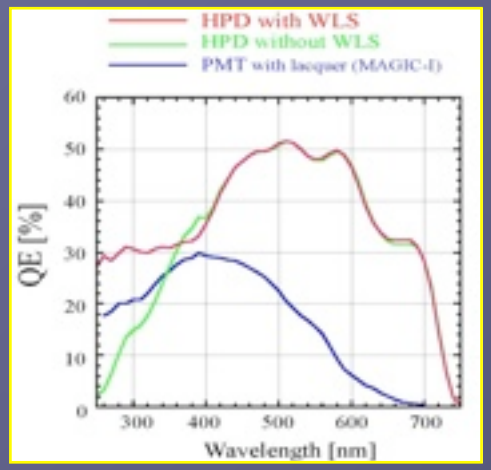
Replication techniques probably more promising for large-scale low-cost production, compared to grinding / milling of mirrors



High QE photosensors

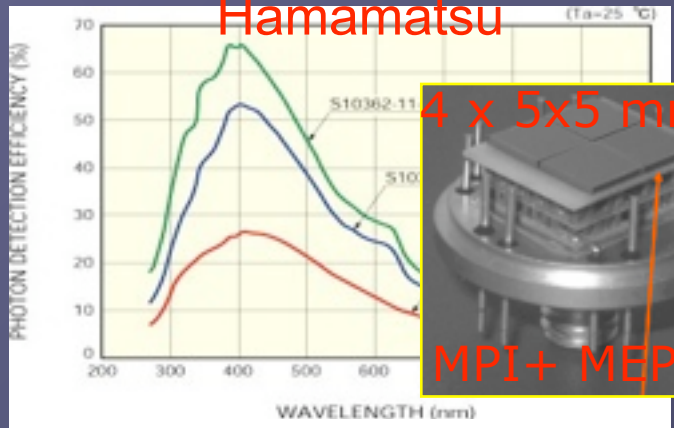


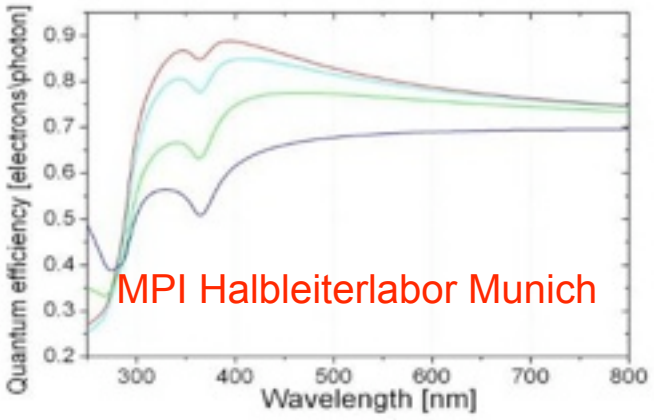
Hamamatsu & Photonis reach 45% QE ==> 40% PDE



GaAsP HPD: 50% PDE

Hamamatsu





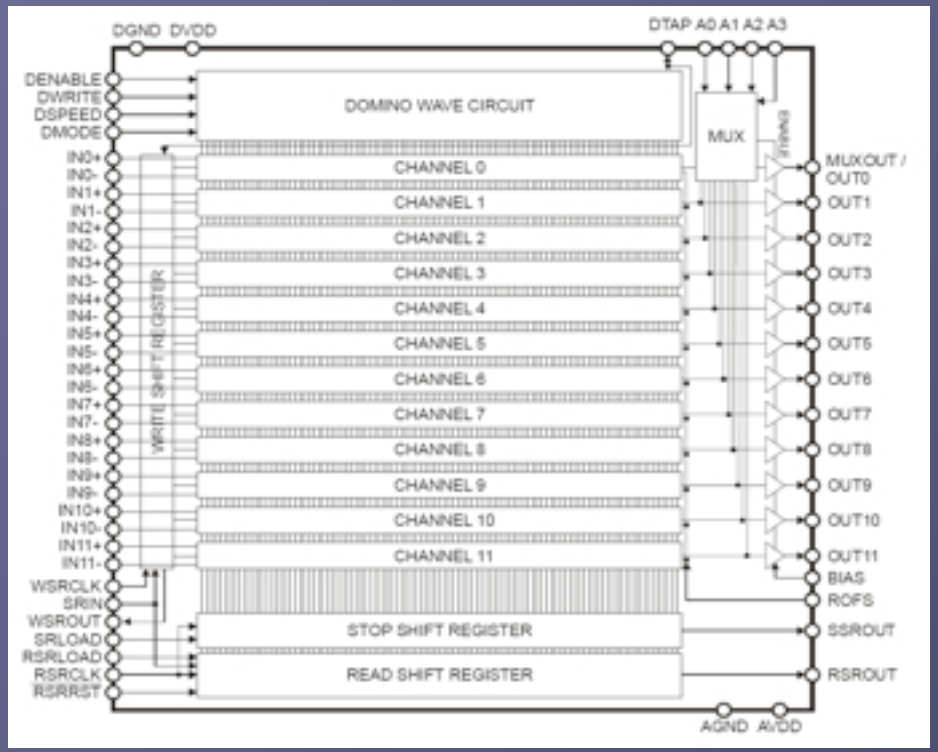
SiPM
About 60% effective PDE will be realistic

Analogue Ring Samplers

economic high performance readout

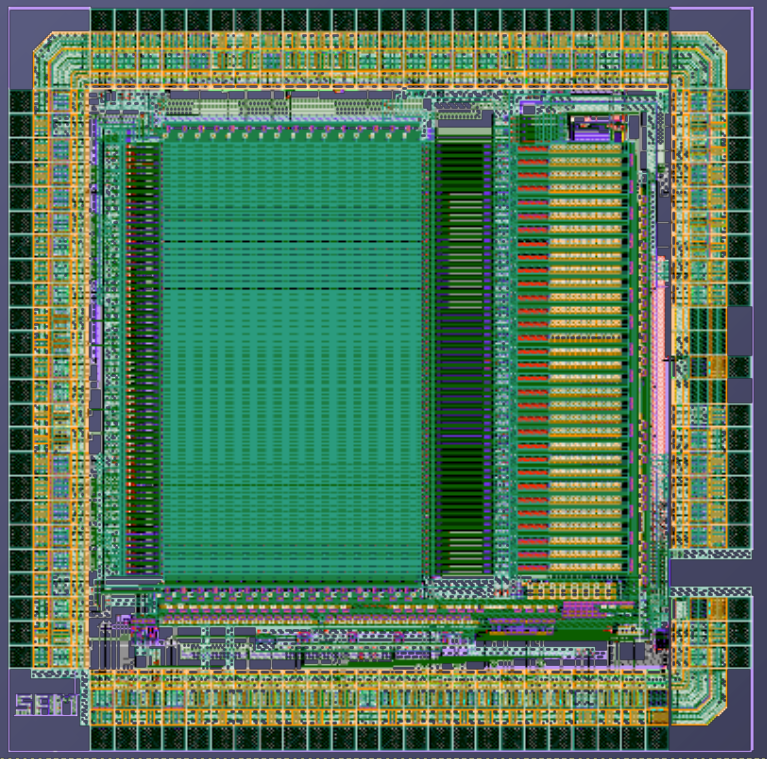
DRS3 (--> DRS4)

12 x 1024 samples
up to 5 Gsamples/s
11.5 bit effective range
450 MHz bandwidth
25 mm^2

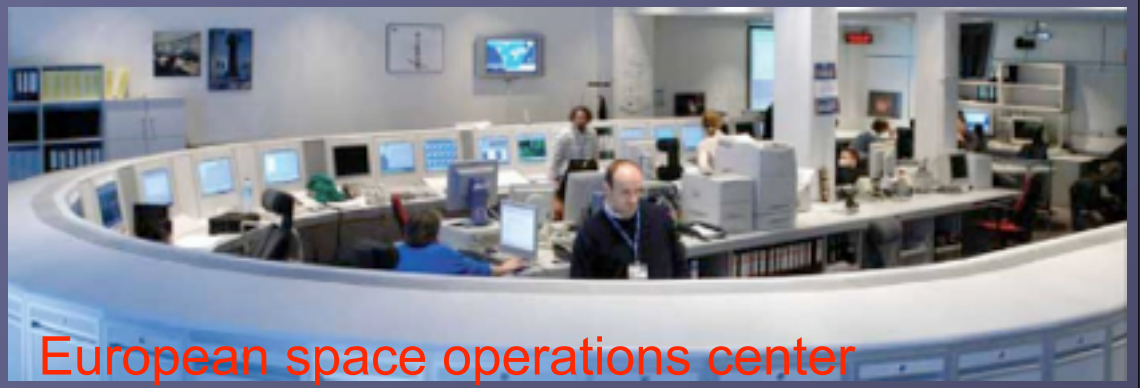


SAM

2 x 256 samples
up to 2 Gsamples/s
12 bit effective range
350 MHz bandwidth
11 mm^2



Data center and operation center for CTA


European space operations center

- Challenges
  - Huge data rates (~PBytes/yr)
  - Observatory
    Automatic calibration and analysis for users
- Organization structure
  - Array operation center
  - Data handling and analysis center
  - Science operation center
- Lots of man power (local technician, operation crew, professional data analyzers for the science operation)

Recommendations and supports

ASPERA Roadmap

Magnificent Seven

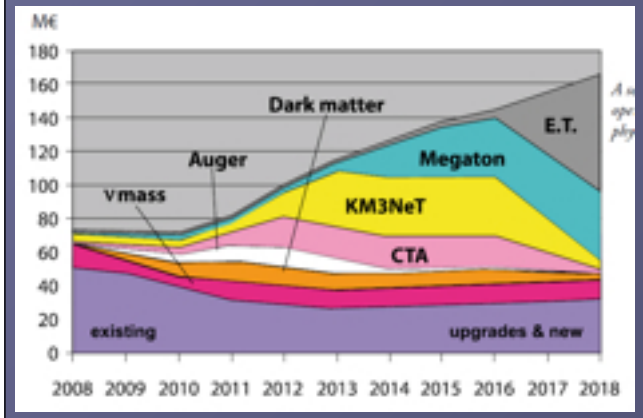
ASTRONET Roadmap

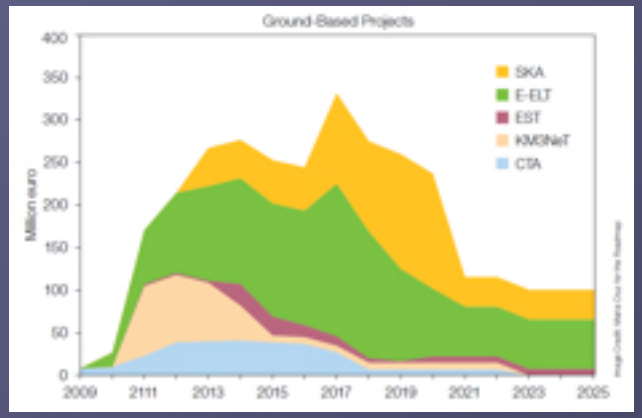
High Priority project

Ground based projects

日本で言うと学術会議

Phys & Technology の中で、５プロジェクトのみ支援。CTA はその一つ





総予算規模：150 MEuro

CTA Japan 組織体制

- PI　戸谷　友則（京都大学）
  (PI は任期二年程度でグループ内公選制の予定)
- Chair of Institutional Panel　柳田　昭平（茨城大学）
- 各 work package coordinators
  - ELEC (電子回路)　窪　秀利 （京都大学）
  - FPI （焦点面検出器）　折戸　玲子　（徳島大学）
  - MC (Monte Carlo)　吉越　貴紀（ICRR）
  - PHYS (Physics)　井岡　邦仁 (KEK)
- アドバイザー
  - 手嶋　政廣 (Max Planck Institute for Physics)
  - 田島　宏康 (SLAC→名古屋大学)

- 総メンバー数４０名以上
  - (CTA Japan ホームページをご覧ください http://cta.scphys.kyoto-u.ac.jp/)

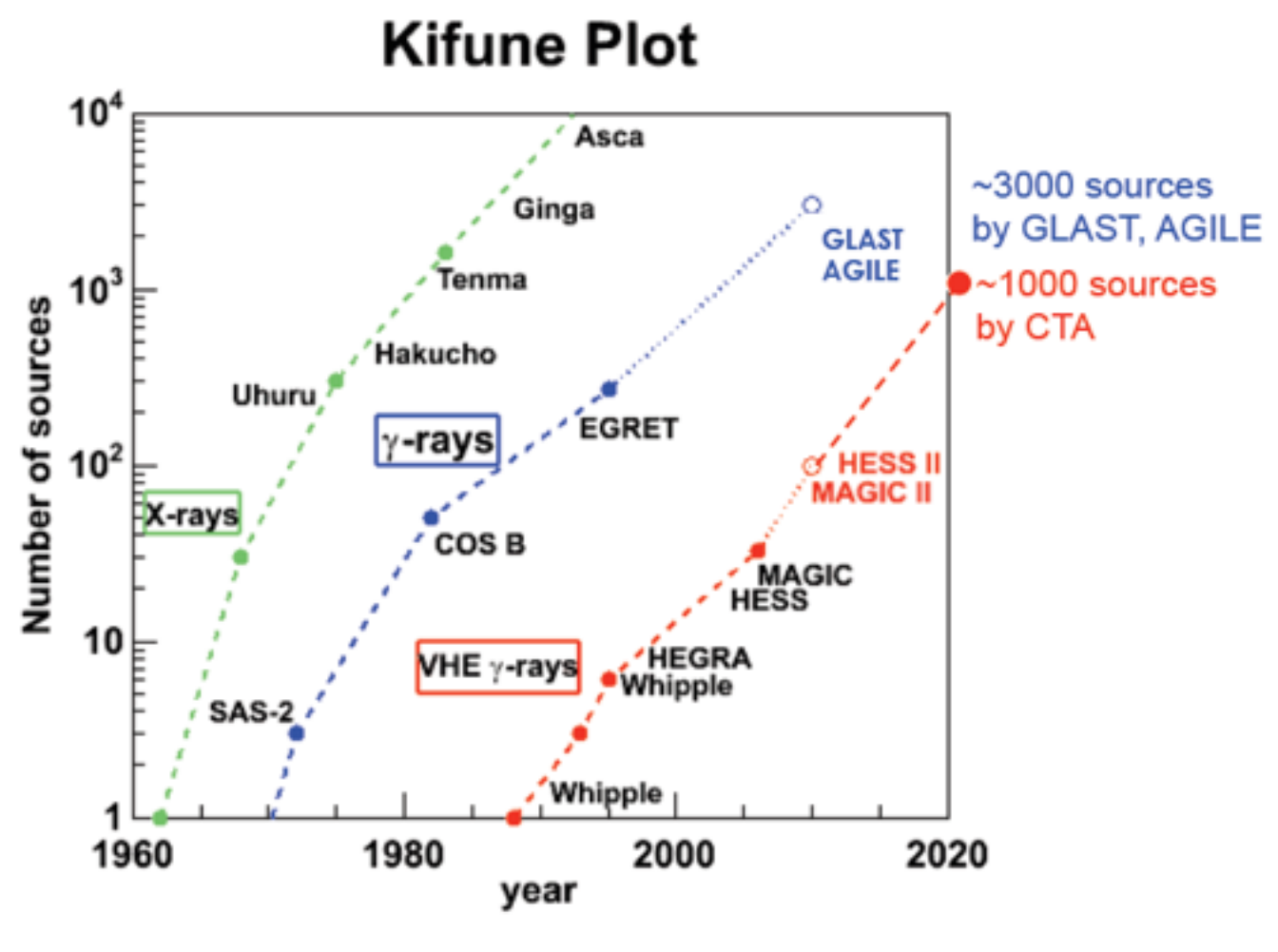
CTA Japan が目指すもの

- ヨーロッパ全体に対して10-20% 程度の貢献
  - 予算規模 20-40 億円
  - 人的貢献　>50 人　c.f. ヨーロッパでは500人規模
  - 単に予算だけでなく、Science, Mirror, Camera, Electronics で本質的に重要な人的貢献を目指す
    - CTA 全体の建設で膨大なマンパワー必要
      - （もちろん開発で本質的貢献があればさらに良い）
    - 層の厚い理論グループ（すでに work package で存在感）
    - PMT については浜松の advantage

なぜ、CTA Japan か？

高エネルギー宇宙物理の将来と CTA

- 「明確」かつ「多様」かつ「確実」な科学的重要性
- 天体数が数十から１０００へ！
  - 発見（革命）から、発展の時代へ



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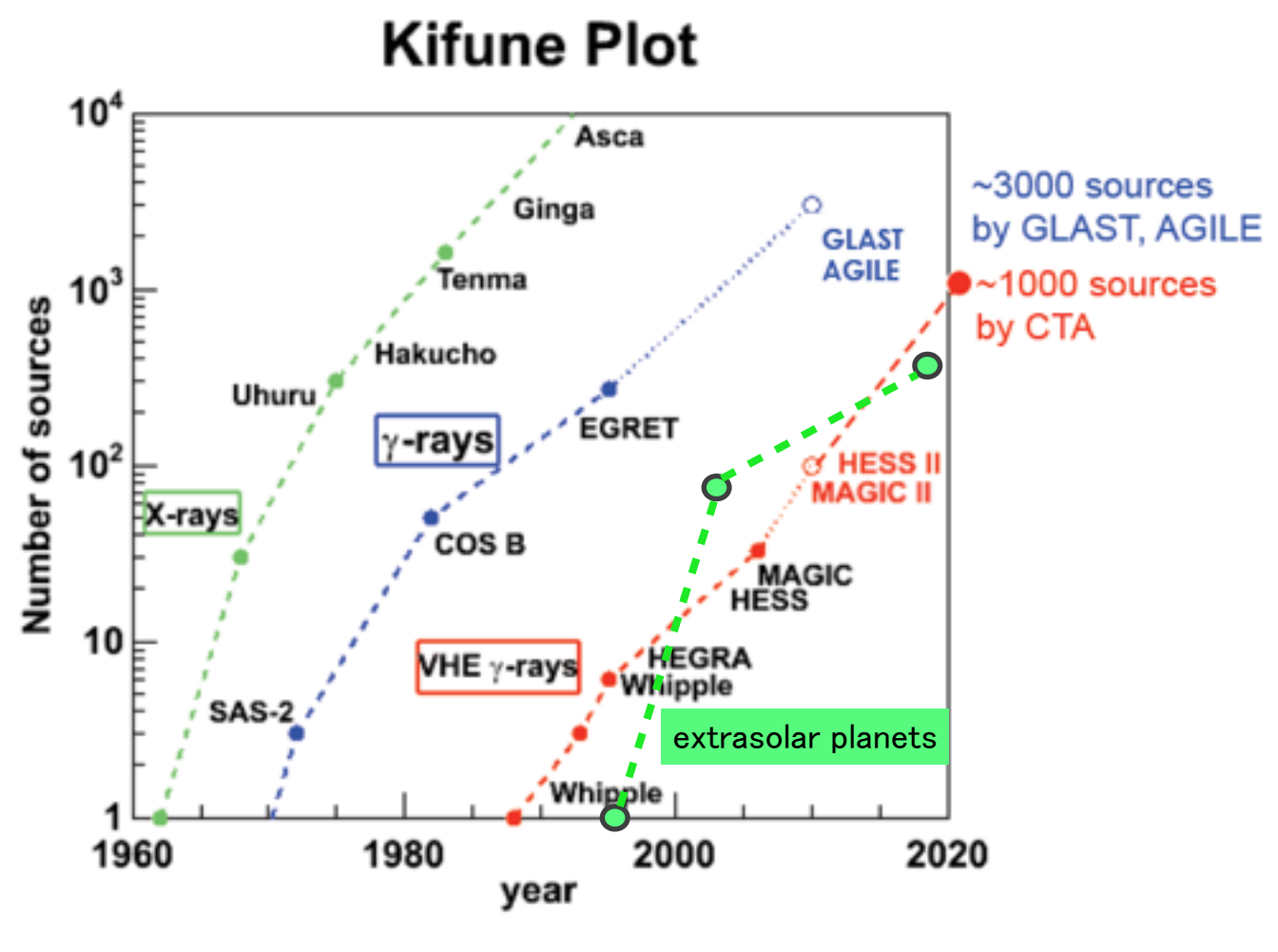

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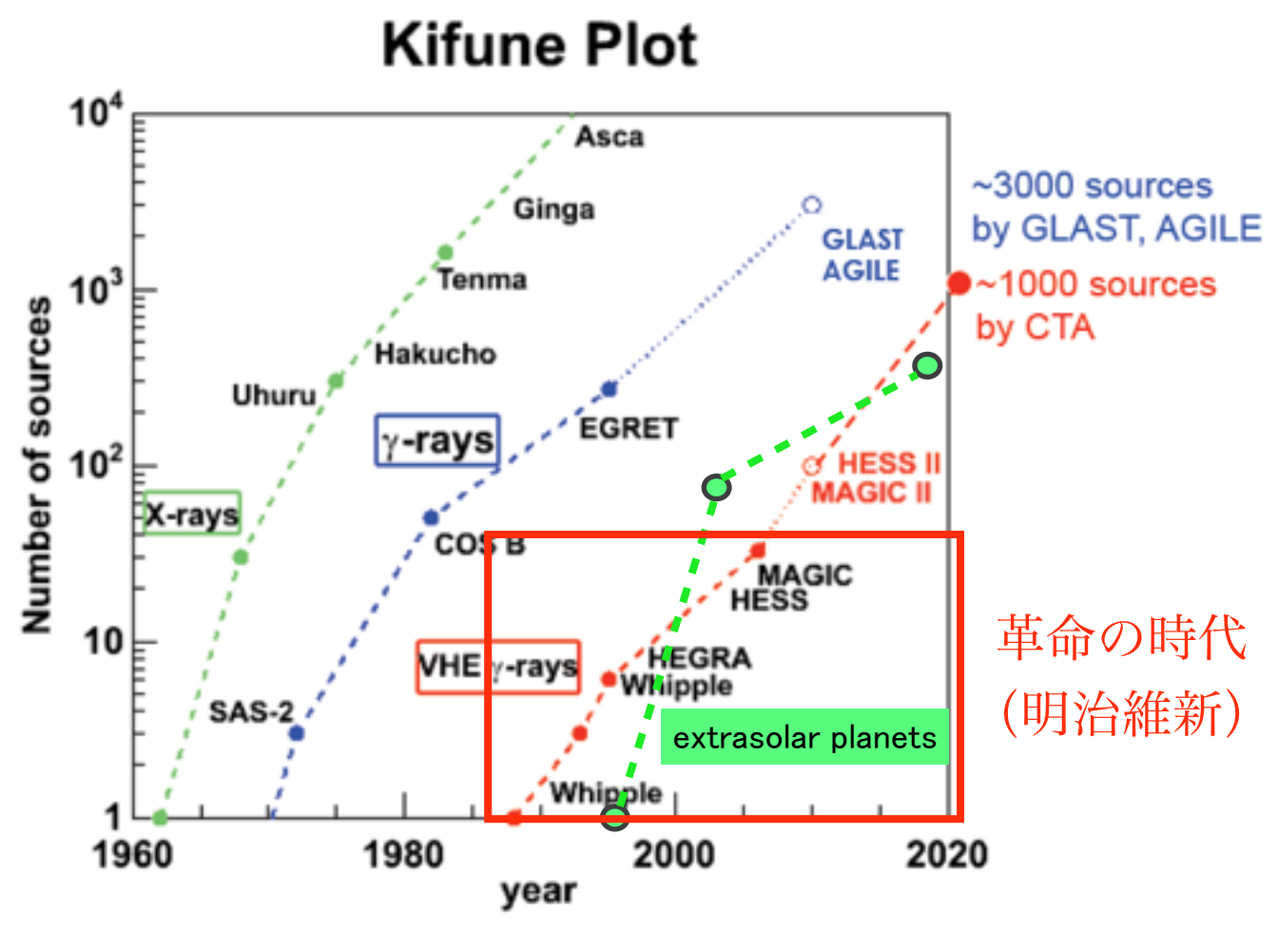

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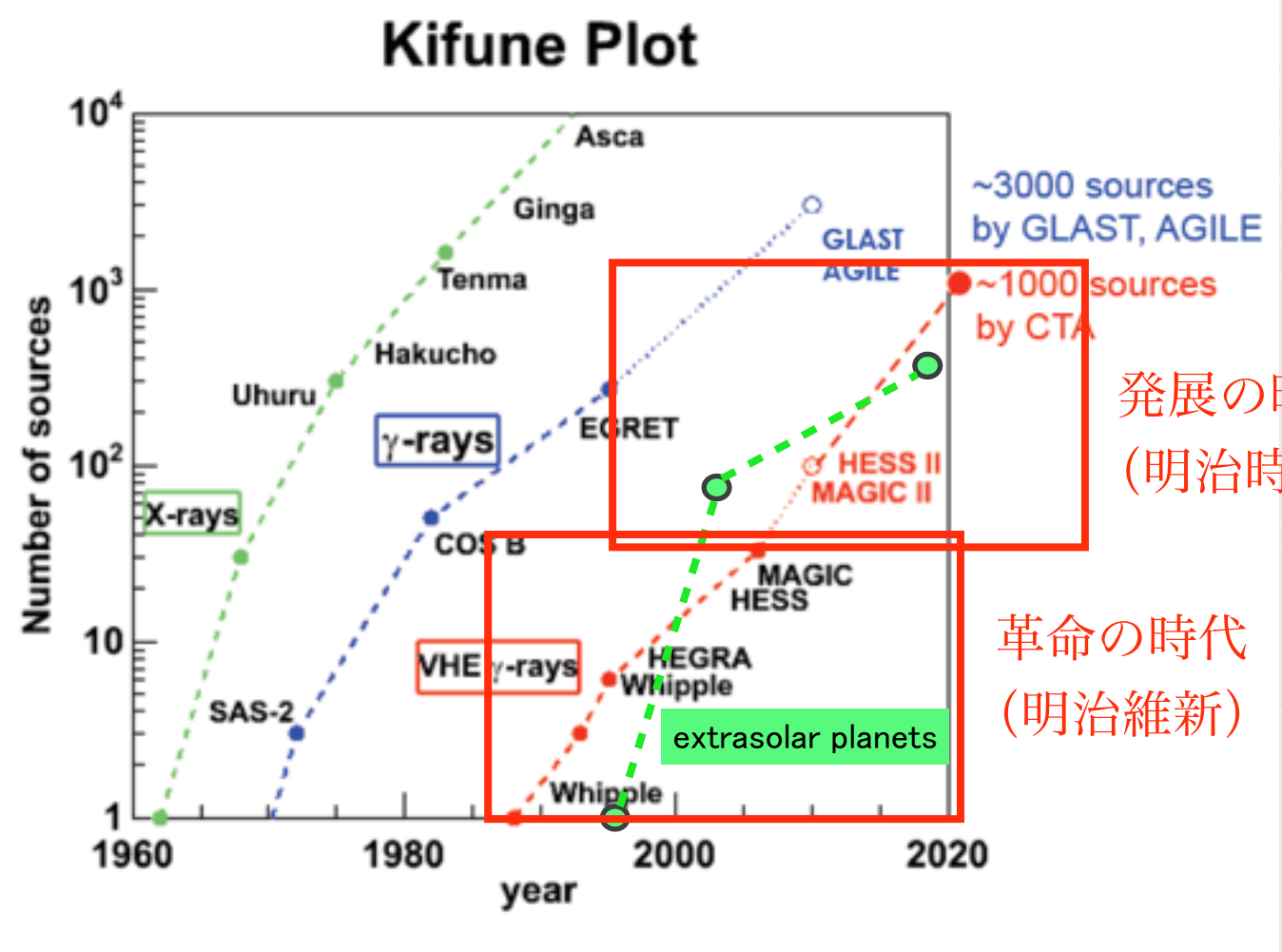

CTAの時代へ

- 現在の高エネルギー宇宙物理学は、フェルミを中心に回っている
- 次の時代は CTA が中心になる
- 日本として何らかの形で参加することが重要
  - ASTRO-H とのシナジー
  - 理論コミュニティとしても世界最新データにアクセスしたい
- 理論を含めた幅広い高エネルギー宇宙物理コミュニティで All Japan の形の参加を！

のぼってゆく坂の上の青い天に
もし一朶（いちだ）の白い雲がかがやいているとすれば、
それのみをみつめて坂をのぼってゆくであろう。
　　司馬遼太郎　「坂の上の雲」

これまでの活動

- PHYS グループを中心に、欧州での CTA ドキュメント作成のサイエンス部分に貢献
- Design Study に関する覚書 (MoU) 締結に参加（昨年１１月）
  - CTA Japan Consortium として正式に参加
- 組織体制を刷新
- ホームページ開設
  - http://cta.scphys.kyoto-u.ac.jp/
- 予算申請
  - 科研費、宇宙線研共同利用など
  - デザインスタディのための予算、旅費など

今後の活動、方向

- 各 work package のコーディネーター中心に、CTA デザインスタディに積極的に貢献
- 最終的に、数十億規模の予算獲得の上、CTA 本格建設に参加を目指す
- 新メンバー随時大歓迎
  - 特に若手の実験屋さん