CHERENKOV TELESCOPE ARRAY
CTA

Massimo Persic
INAF + INFN Trieste
for CTA Consortium
Lecce, Jun 22, 2012

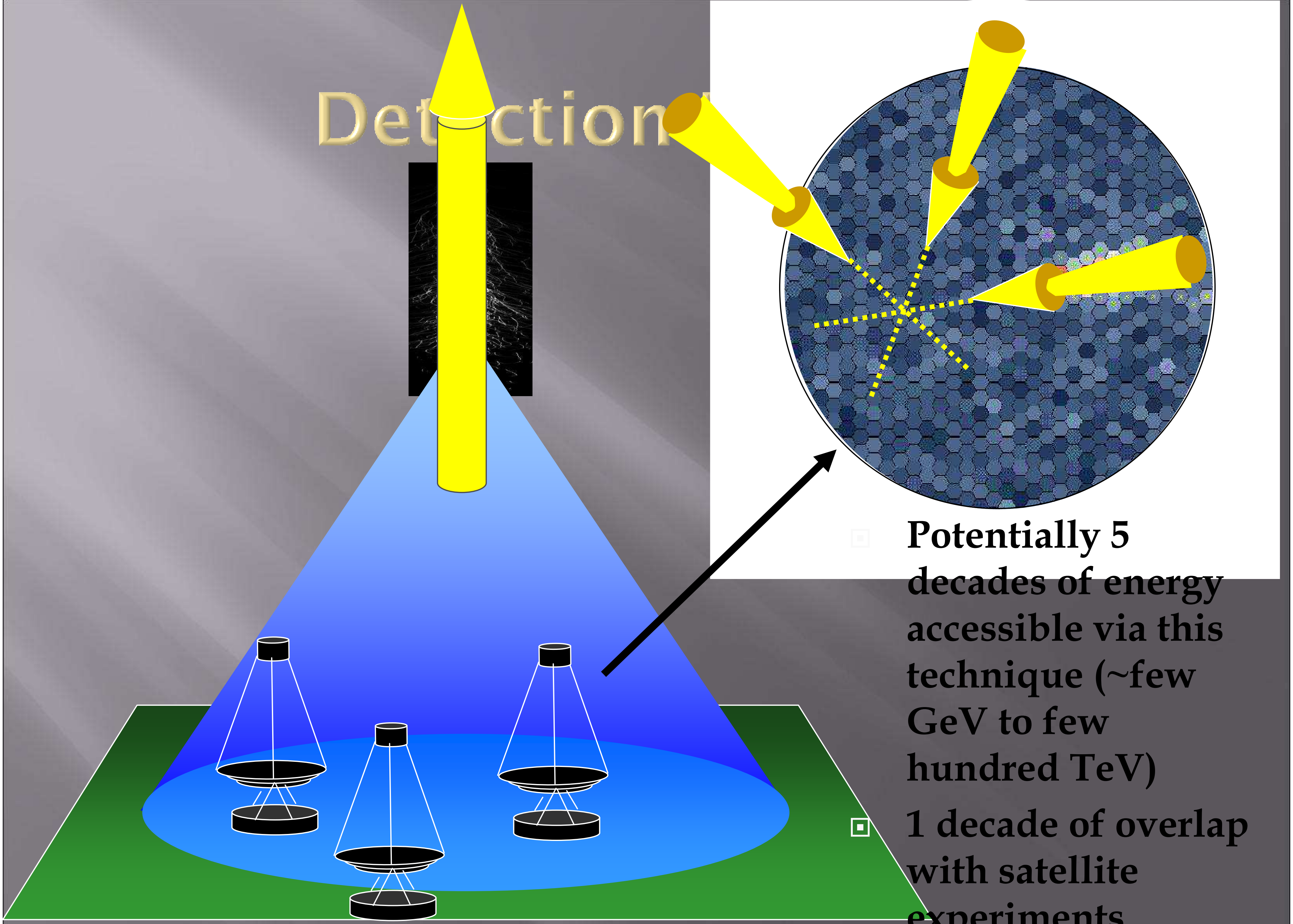
Outline

- Ground-Based gamma-ray astronomy
- Physics questions left by the current instruments
- The Cherenkov Telescope Array
  - Sensitivity Requirements
  - Current Status & Design Study, e.g.
    - Example MC simulation
    - Location Studies
- Possible Schedule
- CTA in Context
- Conclusions

Credits to:

**A. De Angelis, J. Conrad, G. Hermann, J. Hinton, W. Hofmann,
M. Martinez, M. Mariotti, D. Mazin, A. Moralejo, S. Nolan, S. Ritz,
Th. Schweizer, M. Teshima, D. Torres**

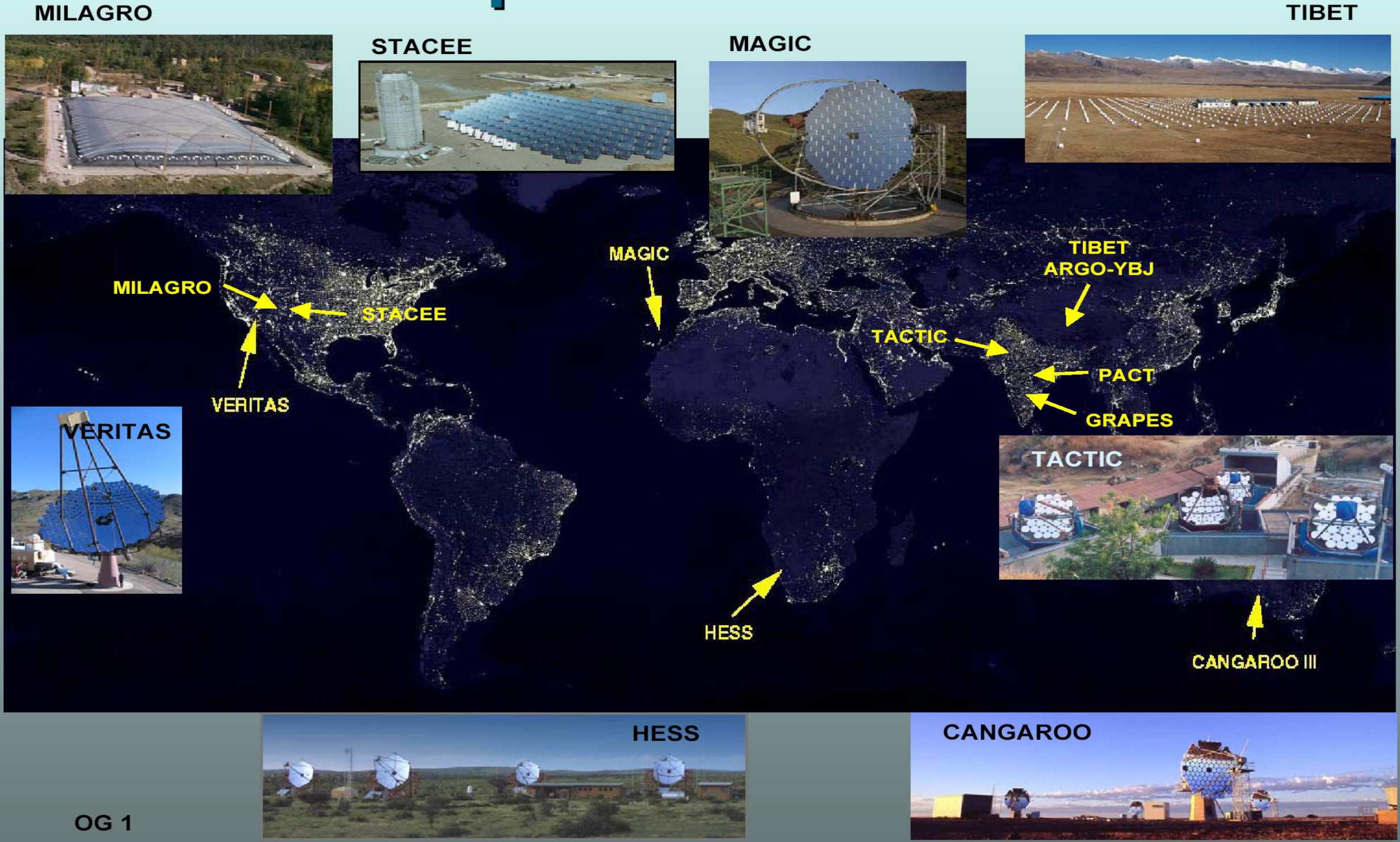
Det ction



- Potentially 5 decades of energy accessible via this technique (~few GeV to few hundred TeV)
- 1 decade of overlap with satellite experiments

Ground Based γ-ray Astronomy

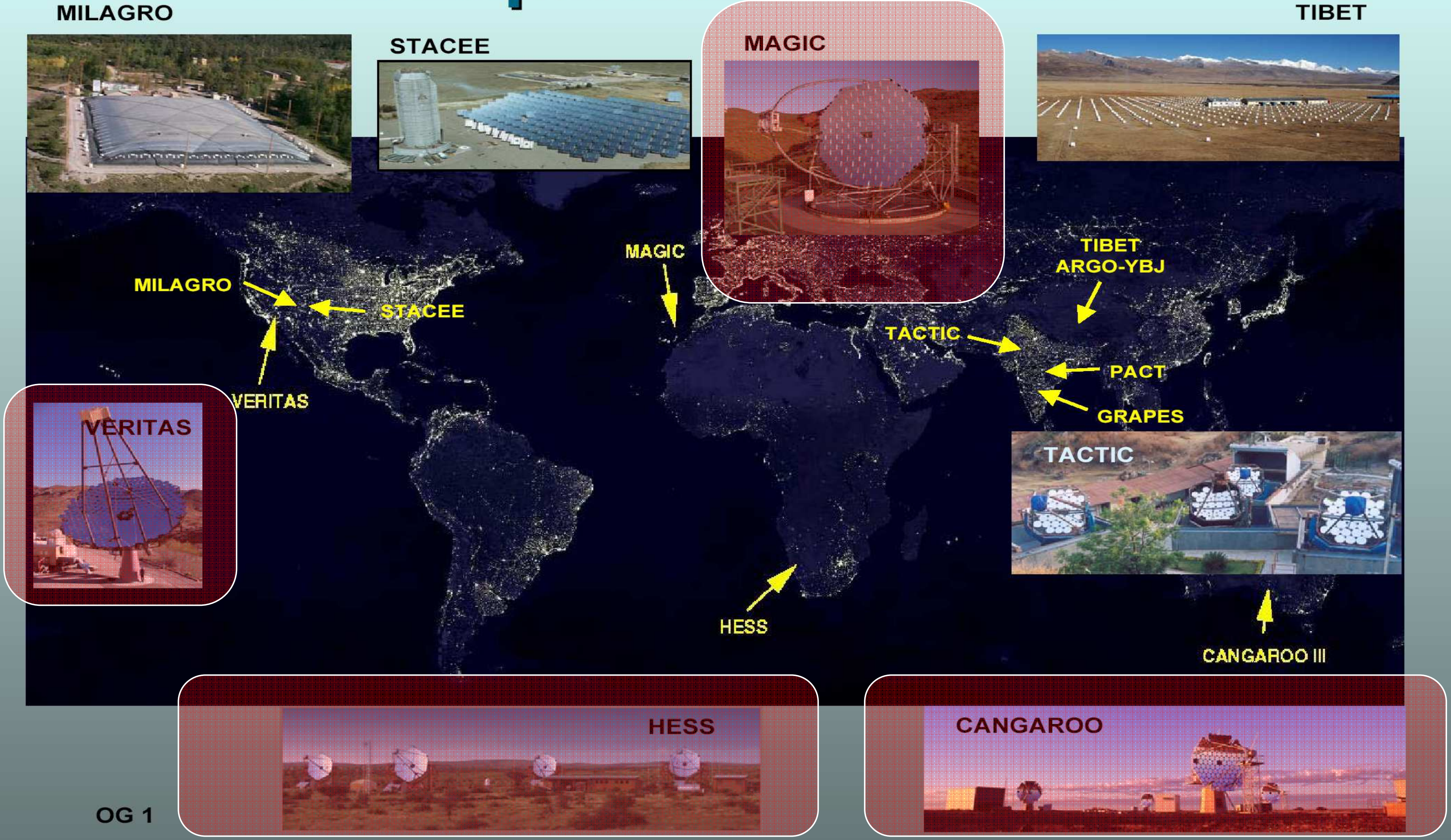
VHE Experimental World



OG 1

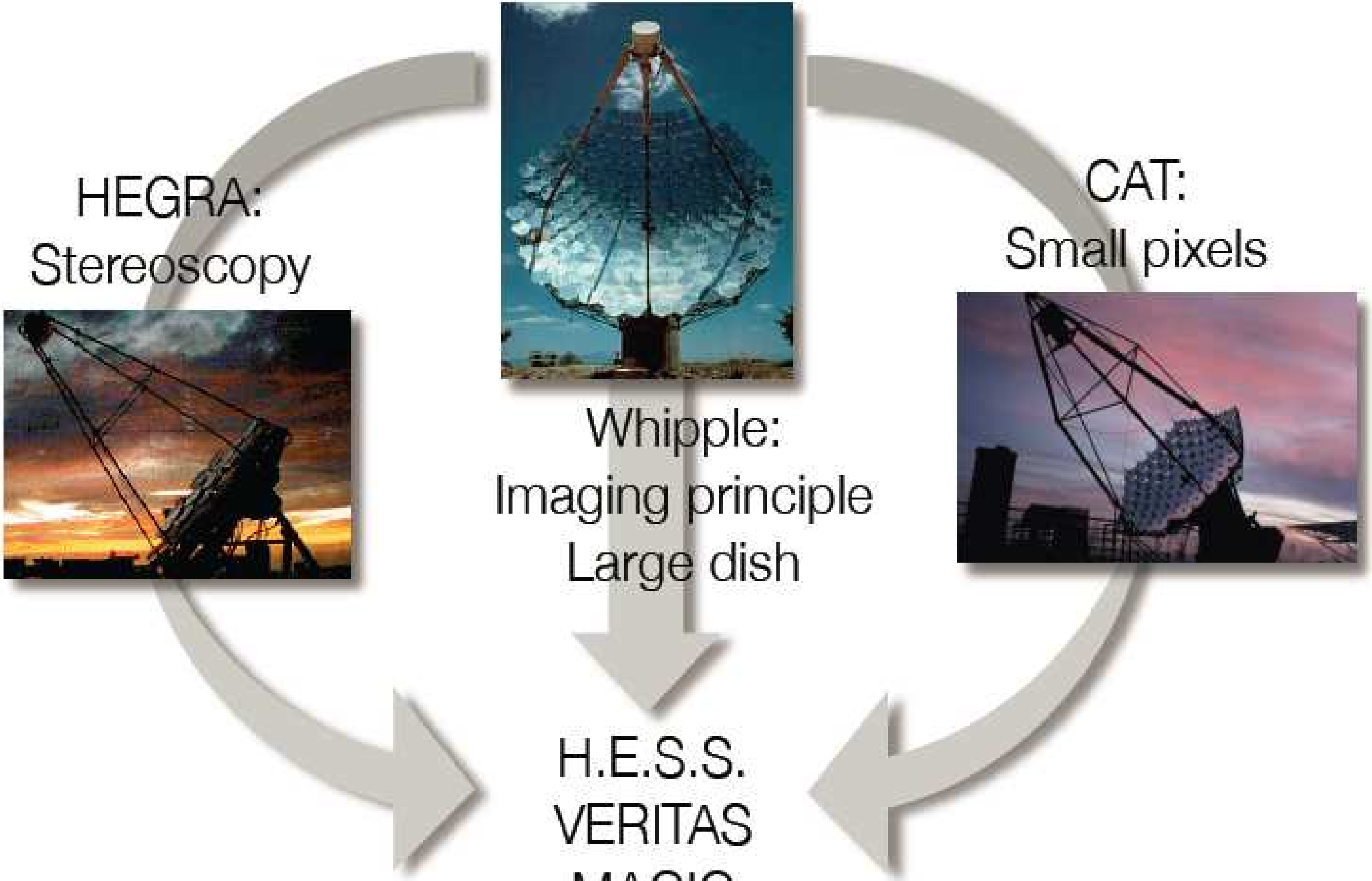
Ground Based γ-ray Astronomy

VHE Experimental World



OG 1

The family tree



HEGRA:
Stereoscopy

Whipple:
Imaging principle
Large dish

CAT:
Small pixels

H.E.S.S.
VERITAS
MAGIC

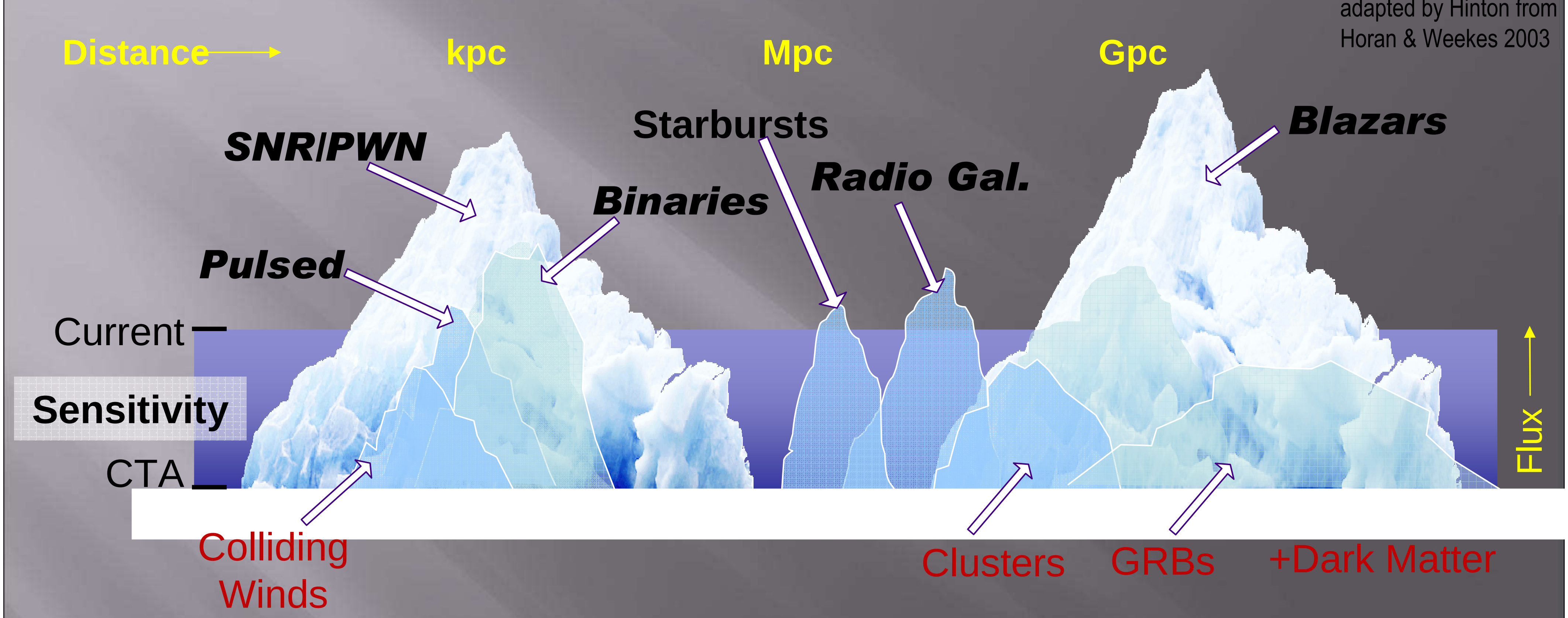
Current Status of VHE ap

- The current generation of telescopes (H.E.S.S. / MAGIC / VERITAS) have detected >100 sources.
- Several more with HESS2 / MAGIC2 / upgraded VERITAS

- Stellar Winds
- Supernova Remnants
- Pulsar Wind Nebulae
- Binary Systems
- Molecular Clouds
- Galactic Centre
- No Counterpart/Dark Sources
- AGN
- Constraints on EBL
- Constraints on QG
- CR Electron Spectrum

- Regular observations made between 70 GeV-20 TeV with few % Crab sensitivity

Science Potential



- **Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg**
- **What big science questions remain ?**

Big Science Questions

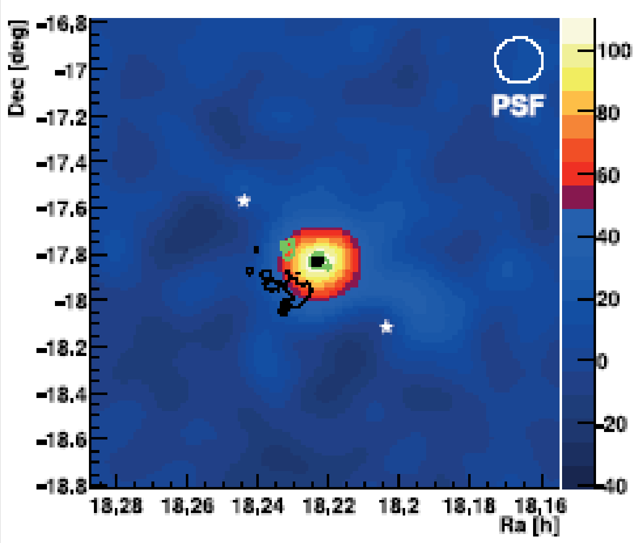
- Determining
  - Origin of galactic cosmic-rays
  - Whether γ-ray binaries emit via wind/jet
- Studying
  - Star formation regions
  - Pulsars and PWN
  - Studying Physics of AGN Jets
  - Galaxy clusters: the dark side of structure formation.
- Constraining
  - Extragalactic Background Light
  - Quantum Gravity Energy Scale
- May detect WIMP annihilation
- Dark sources / New source classes

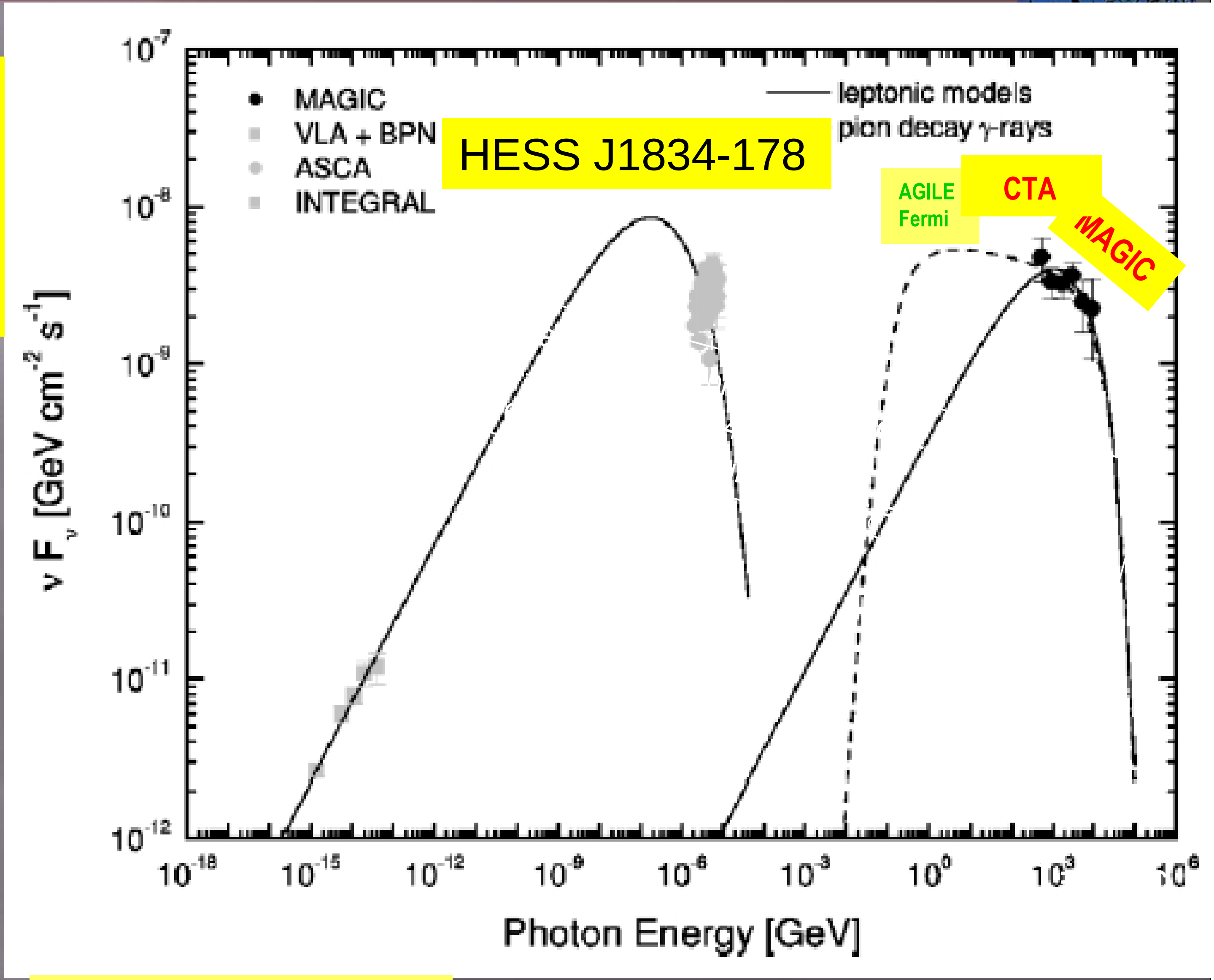
CTA tech wish list

- **Higher Sensitivity at TeV energies (x10)**
  Deep Observations → More Sources
- **Higher Detection Area**
  Greater Detection Rates → Transient Phenomena
- **Better Angular Resolution**
  Improved morphology studies → Structure of Extended Sources
- **Lower Threshold (some 10 GeV)**
  Pulsars, distant AGN, source mechanisms
- **Higher Energy Reach (PeV and beyond)**
  Cutoff region of galactic accelerators
  Sources of UHECRs?
- **Wide Field of View**
  Extended Sources, Surveys

… and a few open issues for CTA!

Spectral degeneracy at TeV energies



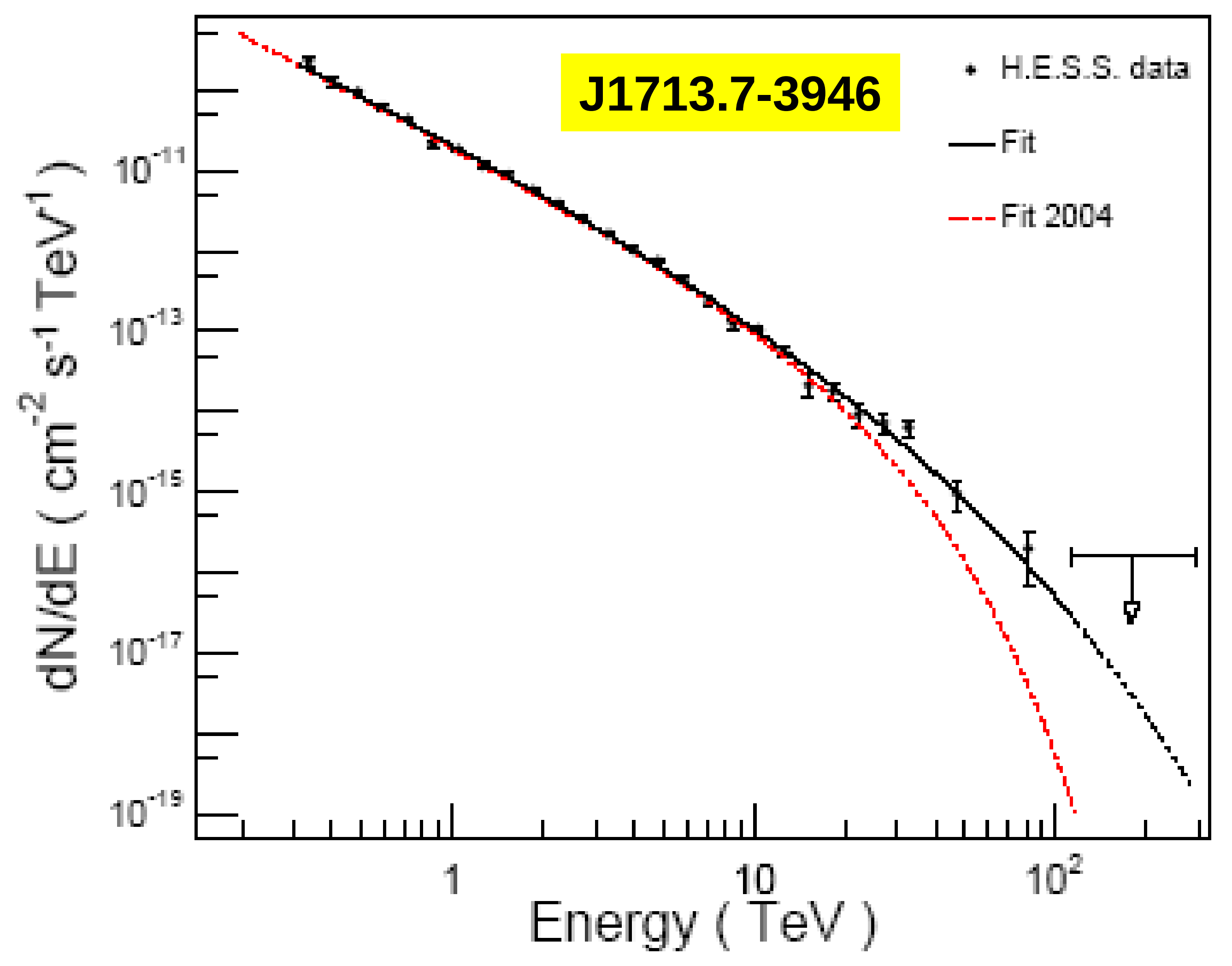


VHE γ-rays:
hadronic or leptonic ?

low E_{thr} (~10-30 GeV)
to discriminate

CTA → improved low-*E* coverage, solve spectral degeneracy

Origin of Galactic CRs from SNRs



Leptonic:

$E_e \sim 20\ (E_\gamma)^{1/2}$ TeV

~ 110 TeV … but KN sets on ..

→ ~100 TeV

Hadronic:

$E_p \sim E_\gamma / 0.15 \sim 30 / 0.15$ TeV ~

~ 200 TeV = $10^{5.3}$ GeV

Importance of improving statistics: **3 years** of HESS data

1 year

CTA: improved statistics at E_γ > 100 TeV, to probe CR knee

COSMIC RAYS AND STAR FORMATION

CR – SN relation (Ginzburg & Syrovatskii 1964)

- ❖ Fermi-I mechanism → SNRs
- ❖ SN rates, massive star formation

Test:

γ-ray (measured)

Milky Way normalization

$$U_p \sim \tfrac{1}{4} \; (\nu_{SN} \, \tau_-) \; (\eta \, E_{ej}) \; r_s^{-3}$$

observed

observed

CTA to observe (detect) more SF galaxies:
LG gals, NGC 4945, NGC 1068

Strong CR production in SF gal's:

- ❖ universal acceleration efficiency of SN?
- ❖ Fermi acceleration at work (NR strong shock)?
- ❖ CRp diffusion

NGC 253	→	250 eV cm-3
M 82	→	220
Milky Way	→	1
M31	→	0.35
LMC	→	0.25
SMC	→	0.15

$$U_p \sim \tfrac{1}{4}\,(\nu_{SN}\,\tau_{-})\,(\eta\,E_{ej})\,r_s^{-3}$$

SN rate — obs'd

particle accel. eff. — $\eta \approx 5\%$

SB radius — obs'd

protons' lifetime

kin. energy of SN ejecta — $E_{ej} \approx 10^{51}$erg

$\tau_{-} \approx$

$(\sigma_{pp}\,c n_p)^{-1} \sim 2 \times 10^7\, n_p^{-1}$ yr — pp collisions

$3 \times 10^4\,(r_s/0.3\text{ kpc})\,(v_{out}/2500\text{ km s}^{-1})^{-1}$ yr — advection

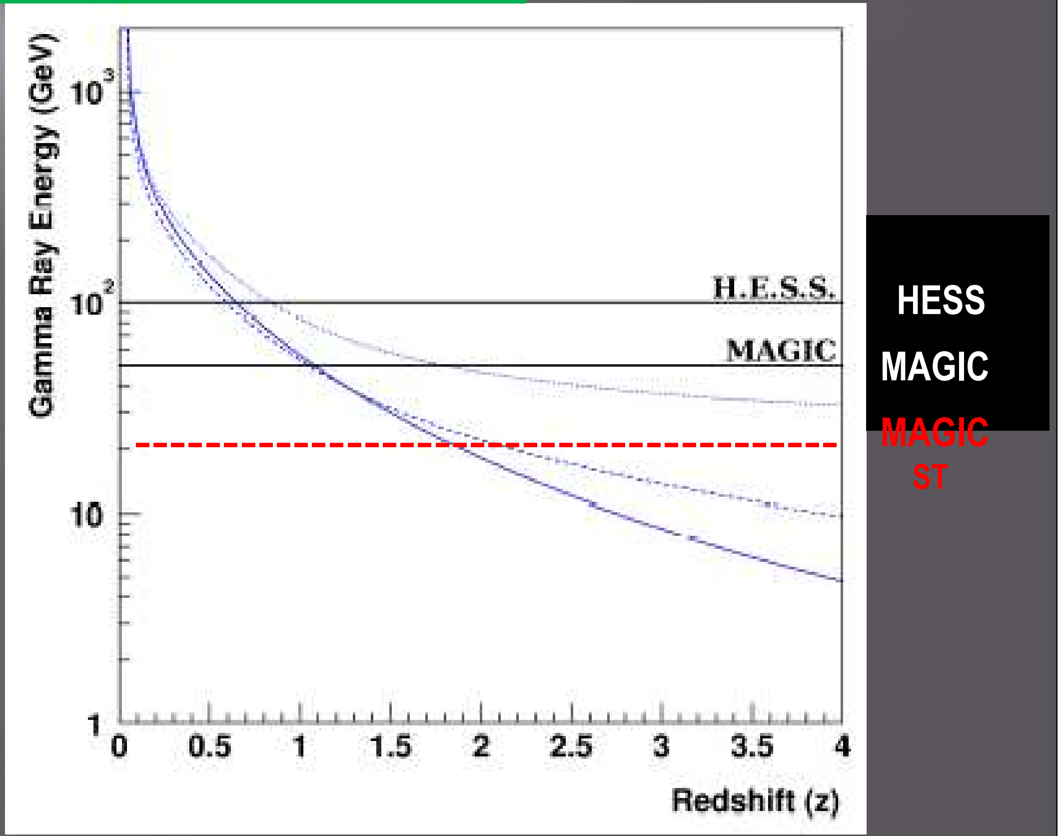
$$U_p = 85\left[\frac{\nu_{SN}}{0.3\,\mathrm{yr}^{-1}}\right]\left[\frac{\tau_{-}}{3\times10^4\,\mathrm{yr}}\right]\frac{\eta}{0.05}\,\frac{E_{ej}}{10^{51}\,\mathrm{erg}}\left[\left(\frac{r_s}{0.3\,\mathrm{kpc}}\right)^{-3}\right]\ \mathrm{eV\ cm^{-3}}$$

N 253	**191** eV cm^{-3}	0.12/yr	2.0E+4 yr	*adv*	0.20 kpc
M 82	**240** eV cm^{-3}	0.25/yr	2.6E+3 yr	*adv*	0.26 kpc
MW	**1.0** eV cm^{-3}	0.02/yr	5.0E+6 yr	*pp*	3.0 kpc
M31	**0.7** eV cm^{-3}	0.01/yr	2.0E+7 yr	*pp*	4.2 kpc
LMC	**0.2** eV cm^{-3}	2 E-3/yr	1.0E+7 yr	*pp*	3.0 kpc
SMC	**1.0** eV cm^{-3}	1 E-3/yr	4.0E+7 yr	*pp*	2.1 kpc

iif CRp advected by diffusion v_{diff}=100 km/s → U_p=0.15 eV/cm^3

Gamma-Ray Bursts (GRBs)

- Most energetic explosions since Big Bang (10^{54} erg if isotropic)
- Astrophysical setting unknown (hypernova?)
- Emission mechanism unknown (hadronic vs leptonic, beaming, size of emitting region, role of environment, … …)
- Cosmological distances (z >> 1)
  Missed *naked-eye* GRB 080319B (z=0.937)



CTA → low E_{thr} ~ 20 GeV
to see GRBs !!

GRBs

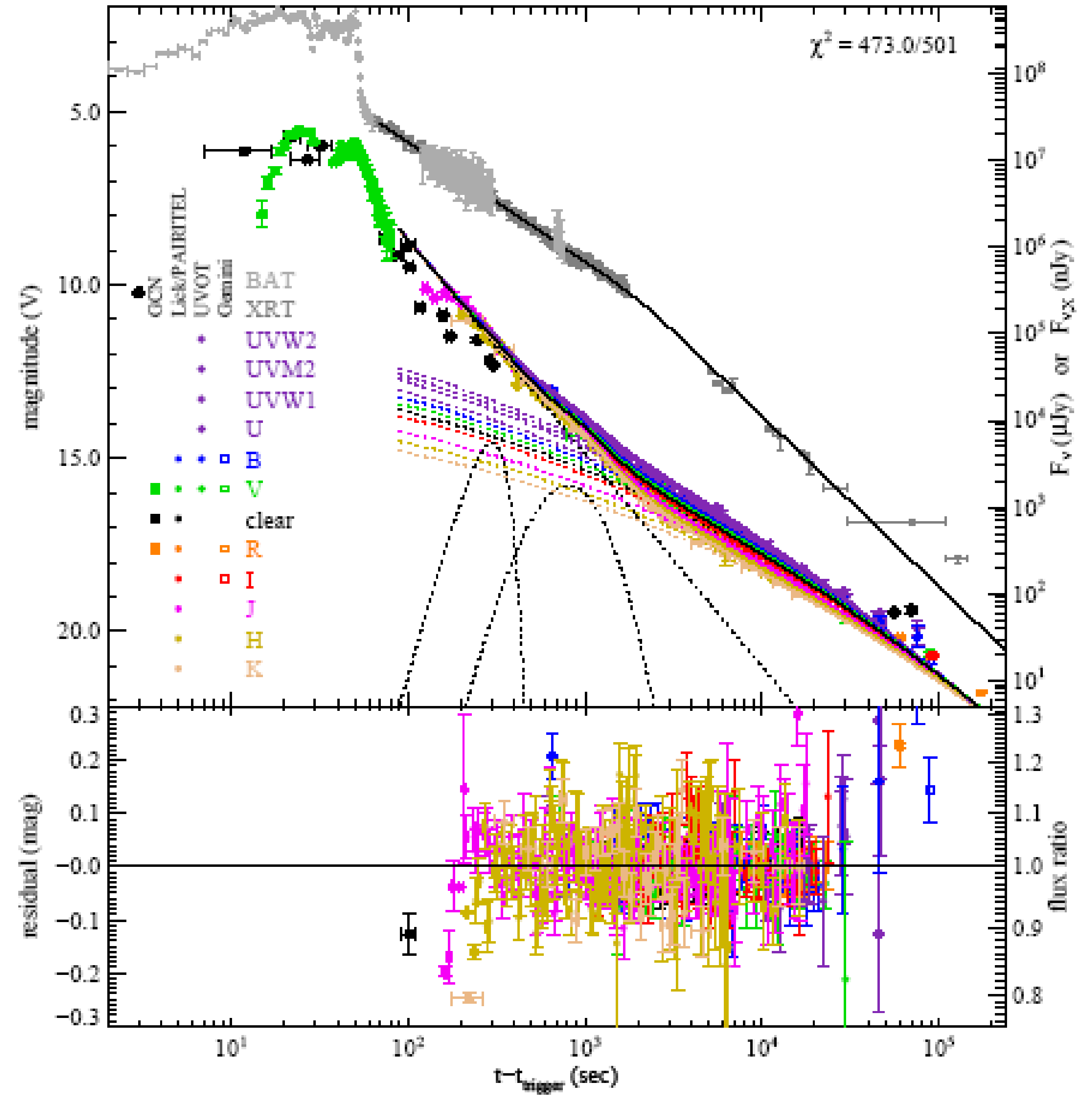
080319B → missed obs of "naked-eye" GRB

Intrinsically:
Nearby: z=0.937
Brightest ever observed in optical
Exceedingly high isotropic-equivalent in soft γ-rays

Swift/BAT could have observed it out to z=4.9
1m-class telescope could observe out to z=17

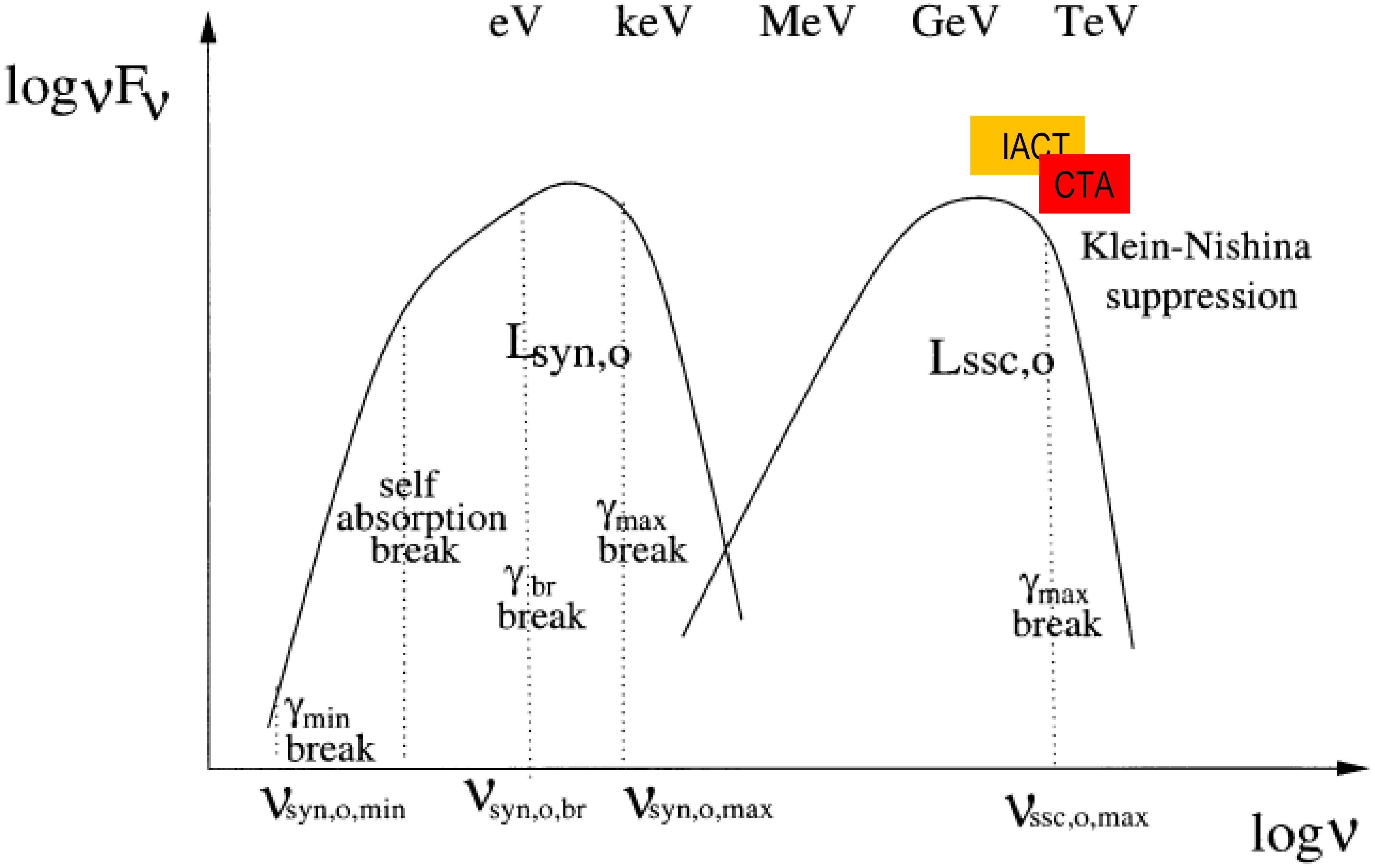
Missed by both AGILE (Earth screening) and MAGIC (almost dawn)

next BIG ONE awaited !!

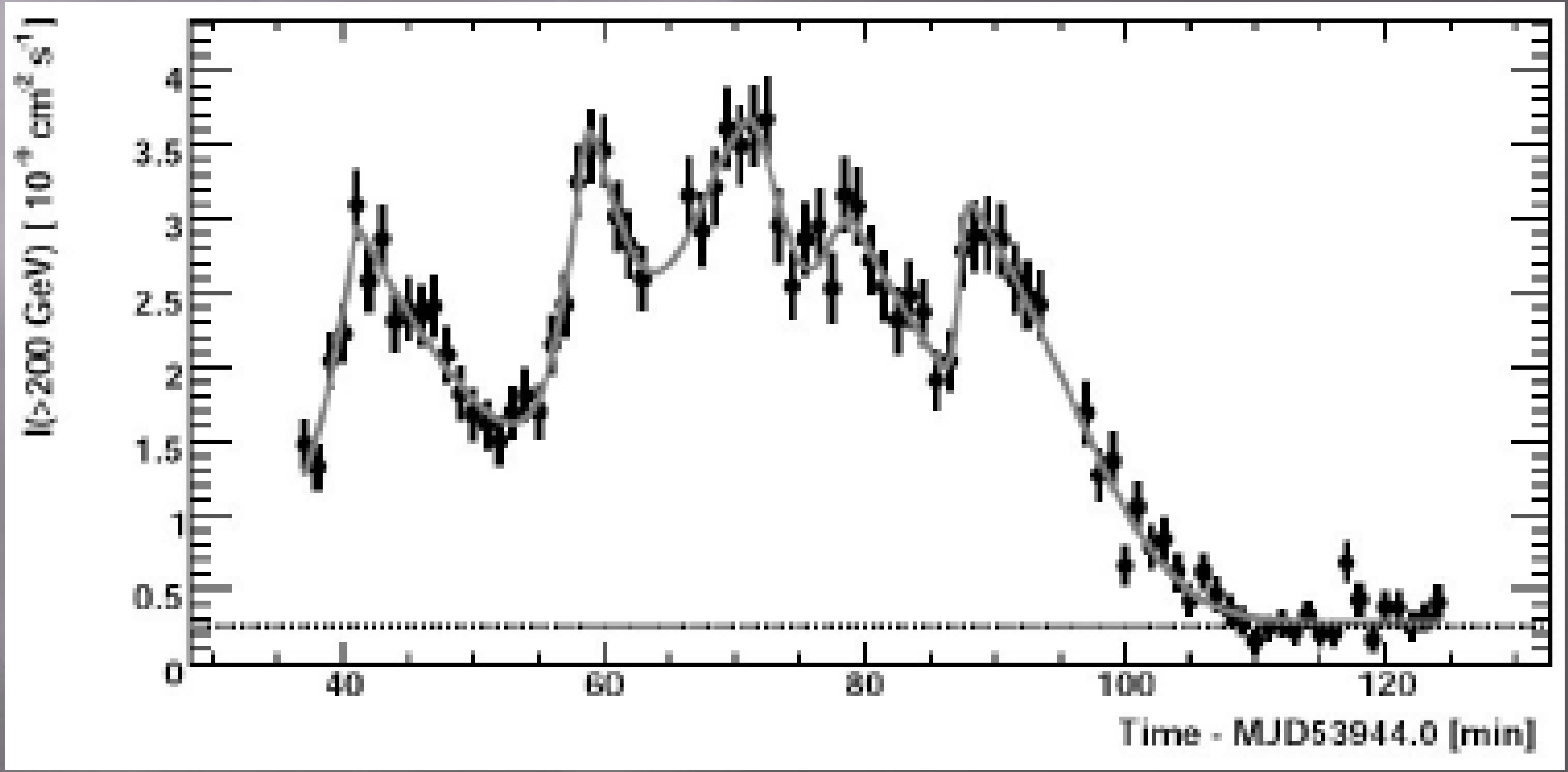


AGN

Short-term simultaneous SEDs of low-z blazars.
Quiescent states of low/intermediate-z blazars.
High states of high-z blazar.

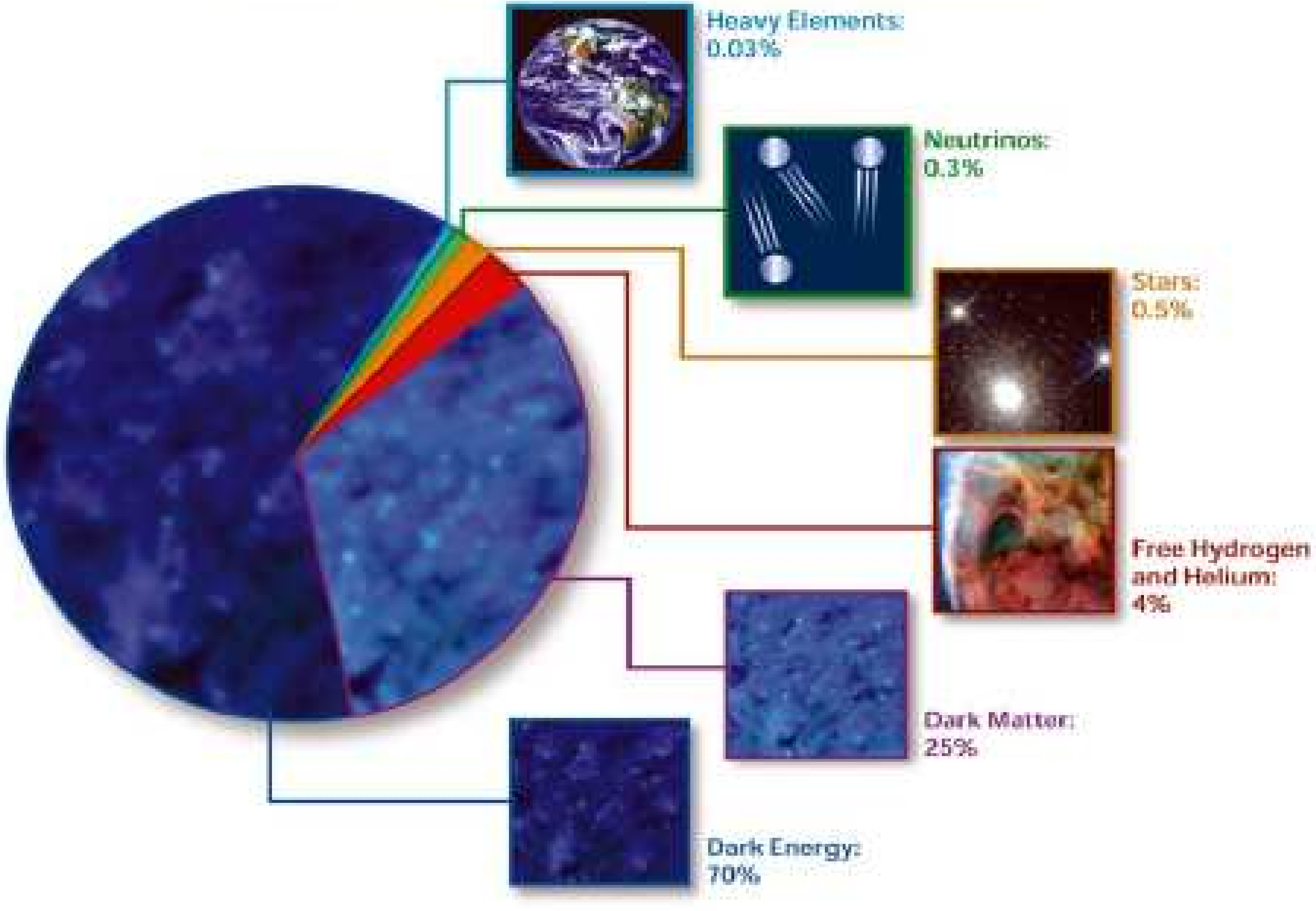


Even more importantly, jet physics is challenged by extremly fast flares.
Timescales as short as 60 sec have been revealed.
Diameters implied are 100 times smaller than the Schwarzschild radius.
Radiating region cover a tiny fraction of jet cross-section.



DARK MATTER

COMPOSITION OF THE COSMOS



Small, nearby galaxies … or … large, faraway clusters?

Let's start from signal from self-interacting DM decay

$$\Phi_\epsilon^{PP}(>E_0) = \frac{1}{4\pi}\frac{\langle\sigma_{\rm ann}v\rangle}{2m_\chi^2}\int_{E_0}^{m_\chi}\sum_{i=1}^{n}B^i\frac{dN_\gamma^i}{dE}\,dE$$

$$\Phi(>E_0,\Delta\Omega) = \boxed{\Phi_\epsilon^{PP}(>E_0)}\,\boxed{J(\Delta\Omega)}\,\boxed{D^{-2}}$$

→ small distances best!

$$J(\Delta\Omega)=\int_{\Delta\Omega}\int_{los}\rho^2(r(s,\Omega))\,ds\,d\Omega$$

→ small guys win!

→ cosmology: dSph **halos** are best candidates for DM signal

→ astrophysics: dSph **stellar pops**. are most silent astroph bkgd

Some background on galaxy structure ..

$$I(r) = I_0 \exp(-r/R_d)$$

same profile at all luminosities!

1000 galaxies
Persic + 1996

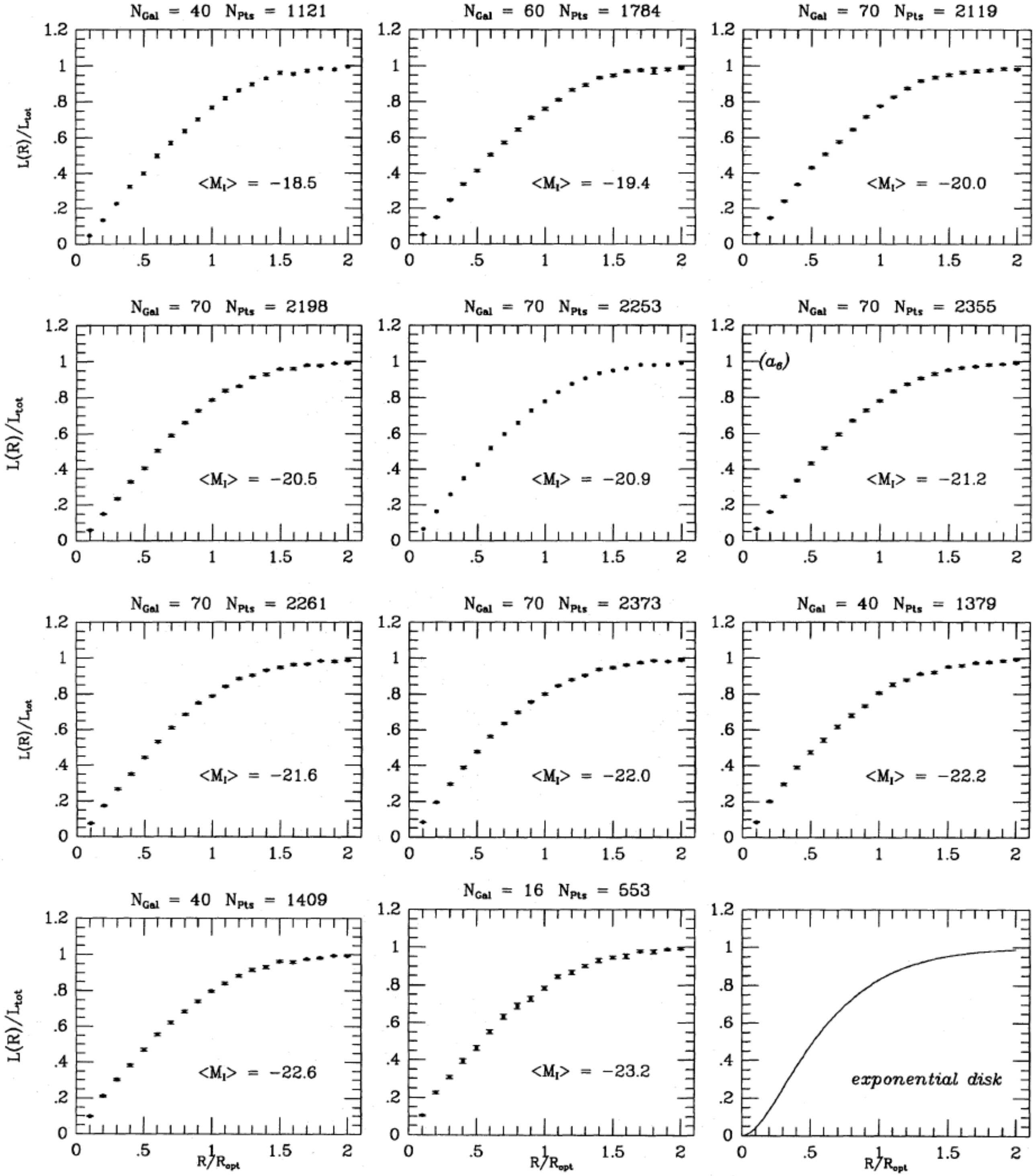


Figure A1. The luminous mass profiles for the galaxies in Sample B, grouped by luminosity bins. For each individual object, the light profile $L(r) \propto \int_0^r I(r')\, r'\, \mathrm{d}r'$ is normalized to its total value L_∞; the radius is normalized to $R_{\rm opt}$. Grouping the light profiles by velocity amplitude yields a similar result.

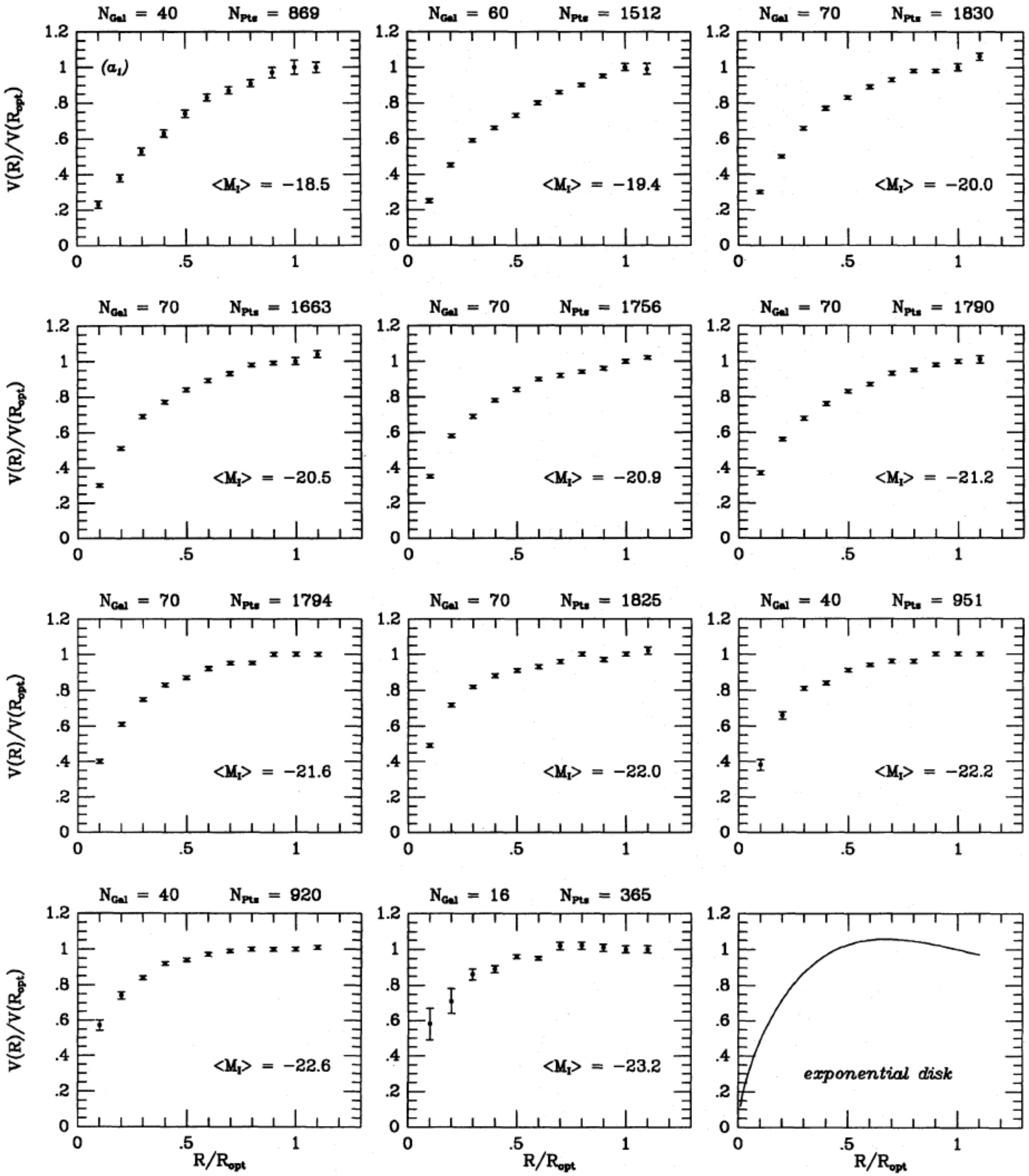


Figure 1. Synthetic rotation curves for Sample B arranged by luminosity. Galactocentric radii are normalized to R_{opt}, the radius encompassing 83 per cent of the total I luminosity. The last panel shows the rotation curve predicted for a pure self-gravitating exponential thin disc.

Rotation curves are **not** self-similar with luminosity!

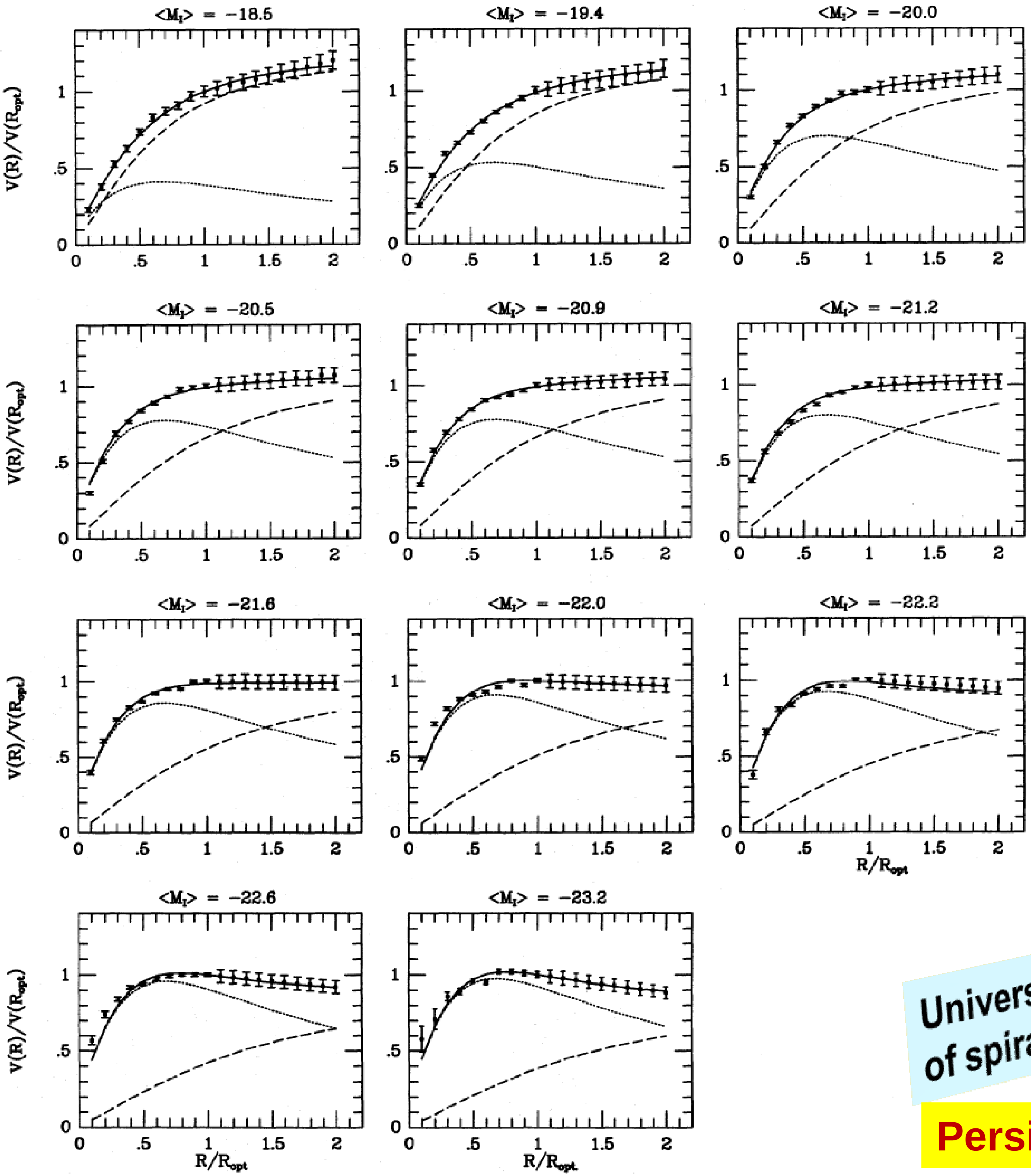
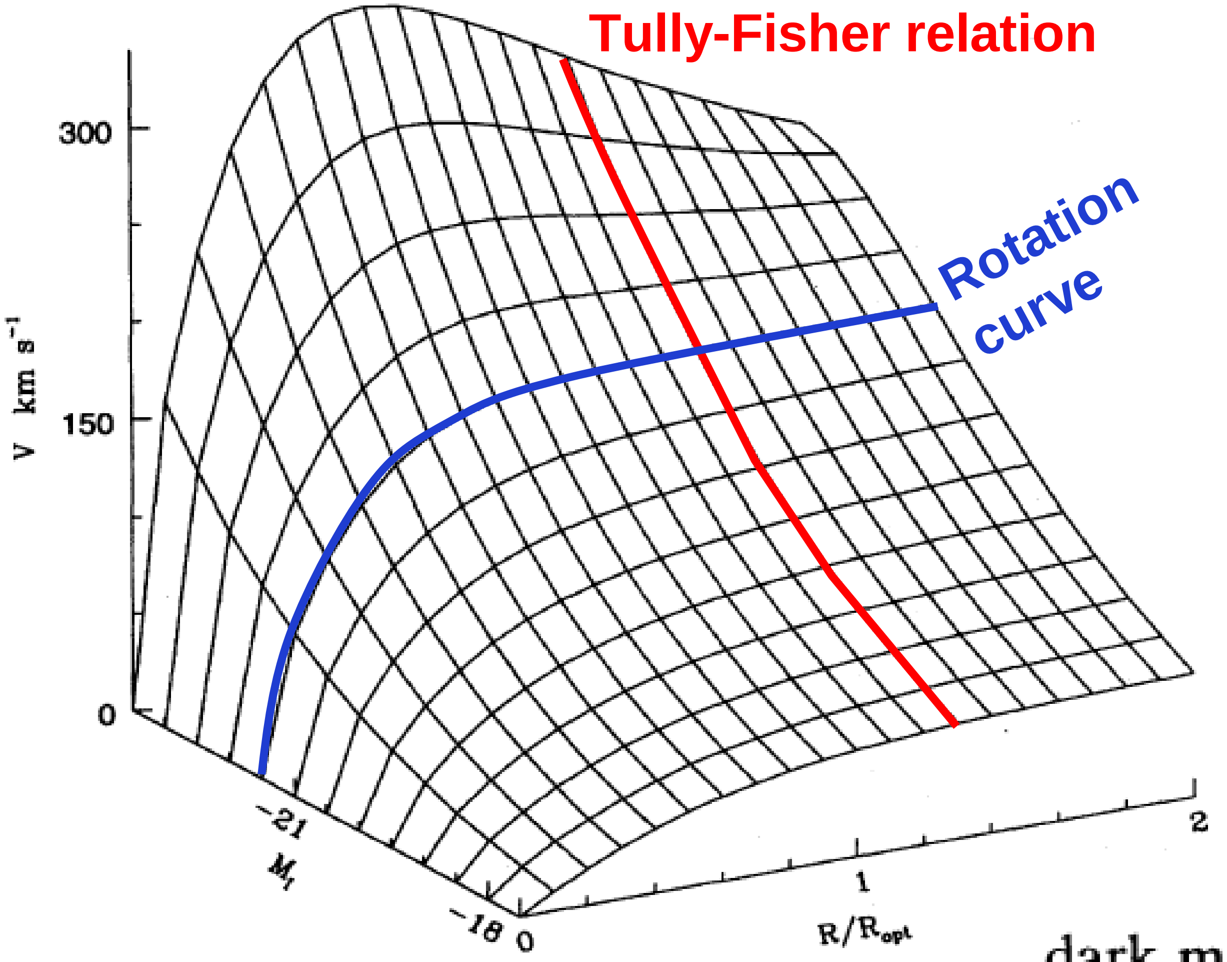


Figure 6. Best two-component fits to the universal rotation curve (dotted line: disc; dashed line: halo).

Smooth progression of RC shape, and disk/halo interplay, with luminosity

Universal Rotation Curve of spiral galaxies

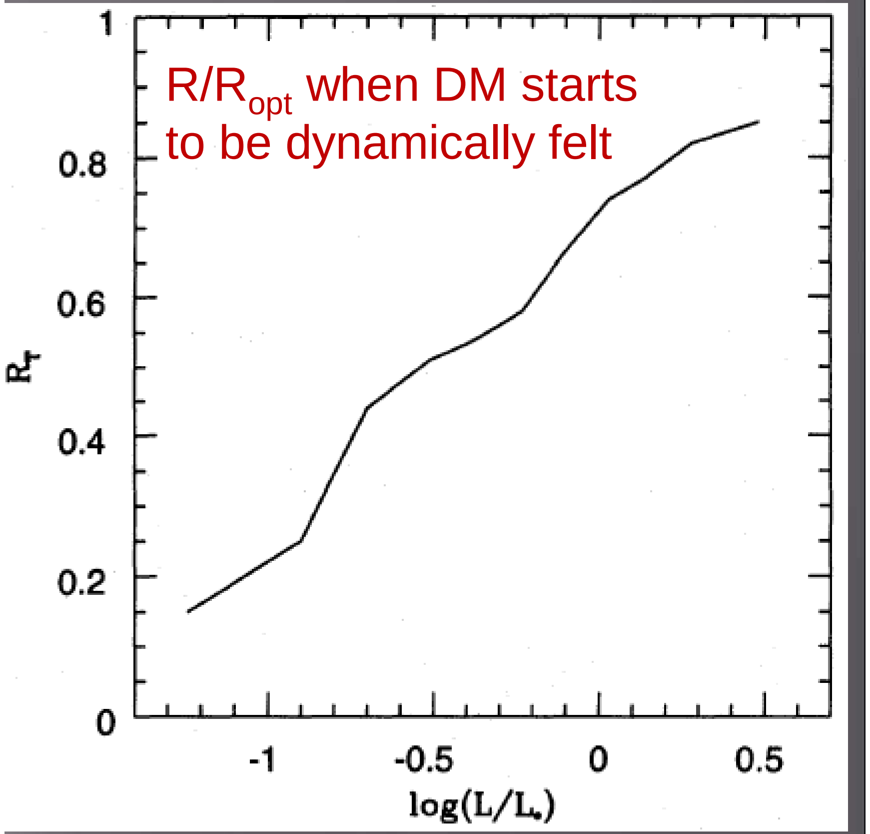
Persic et al. 1996



Tully-Fisher relation

Rotation curve

Figure 10. The URC surface.



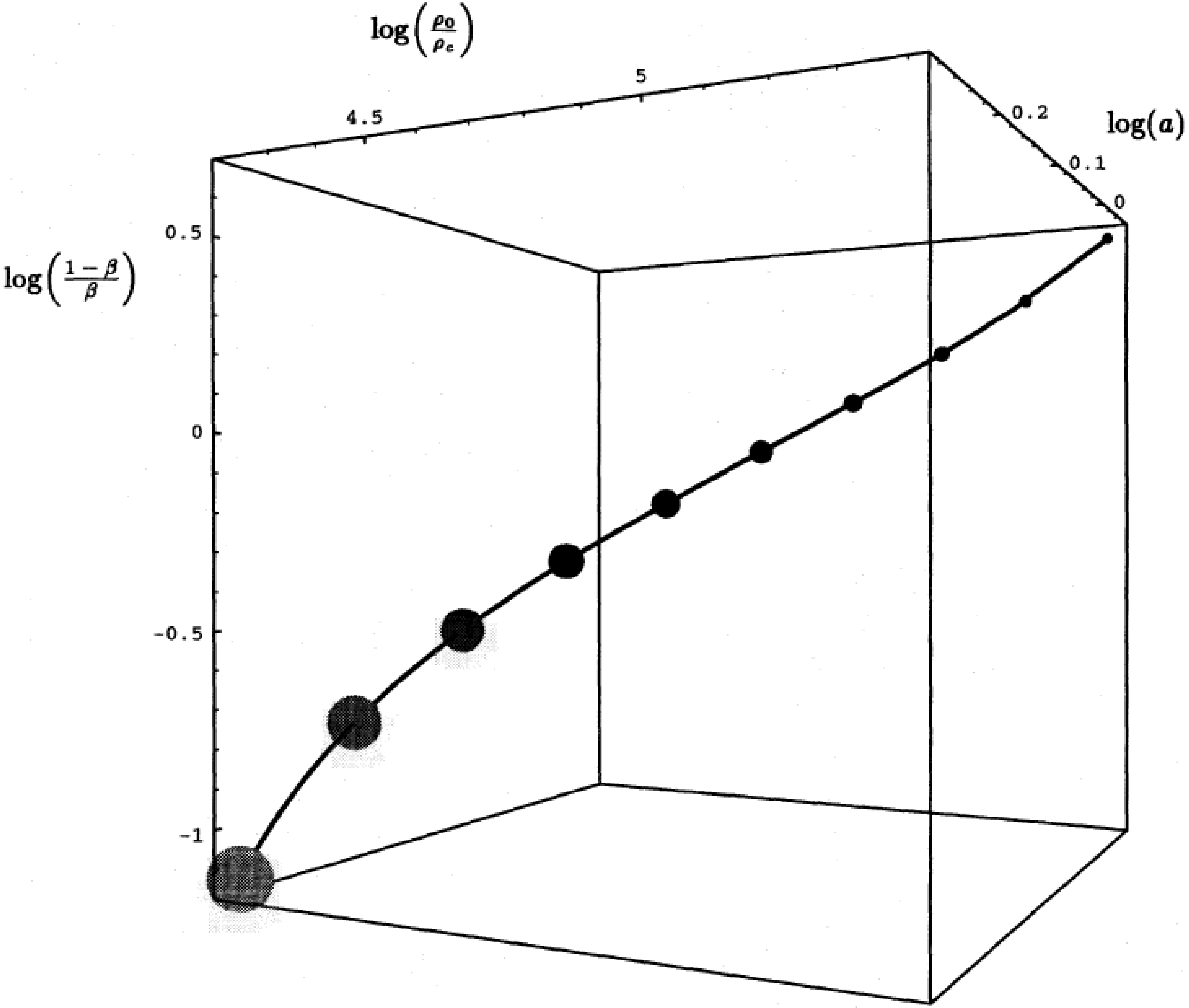
R/R_{opt} when DM starts to be dynamically felt

$$\frac{\text{dark mass}}{\text{visible mass}} = 0.4\left(\frac{L}{L_*}\right)^{-0.9}$$

$$\text{halo mass} = 1.6 \times 10^{12}\left(\frac{L}{L_*}\right)^{0.56} M_\odot$$

$$\frac{\text{halo central density}}{\text{critical density}} = 3.5 \times 10^{4}\left(\frac{L}{L_*}\right)^{-0.7}$$

Persic + 1996


$\log\left(\frac{\rho_0}{\rho_c}\right)$
5
4.5
0.2
0.1
0
$\log(a)$
$\log\left(\frac{1-\beta}{\beta}\right)$
0.5
0
-0.5
-1

Whence these properties?

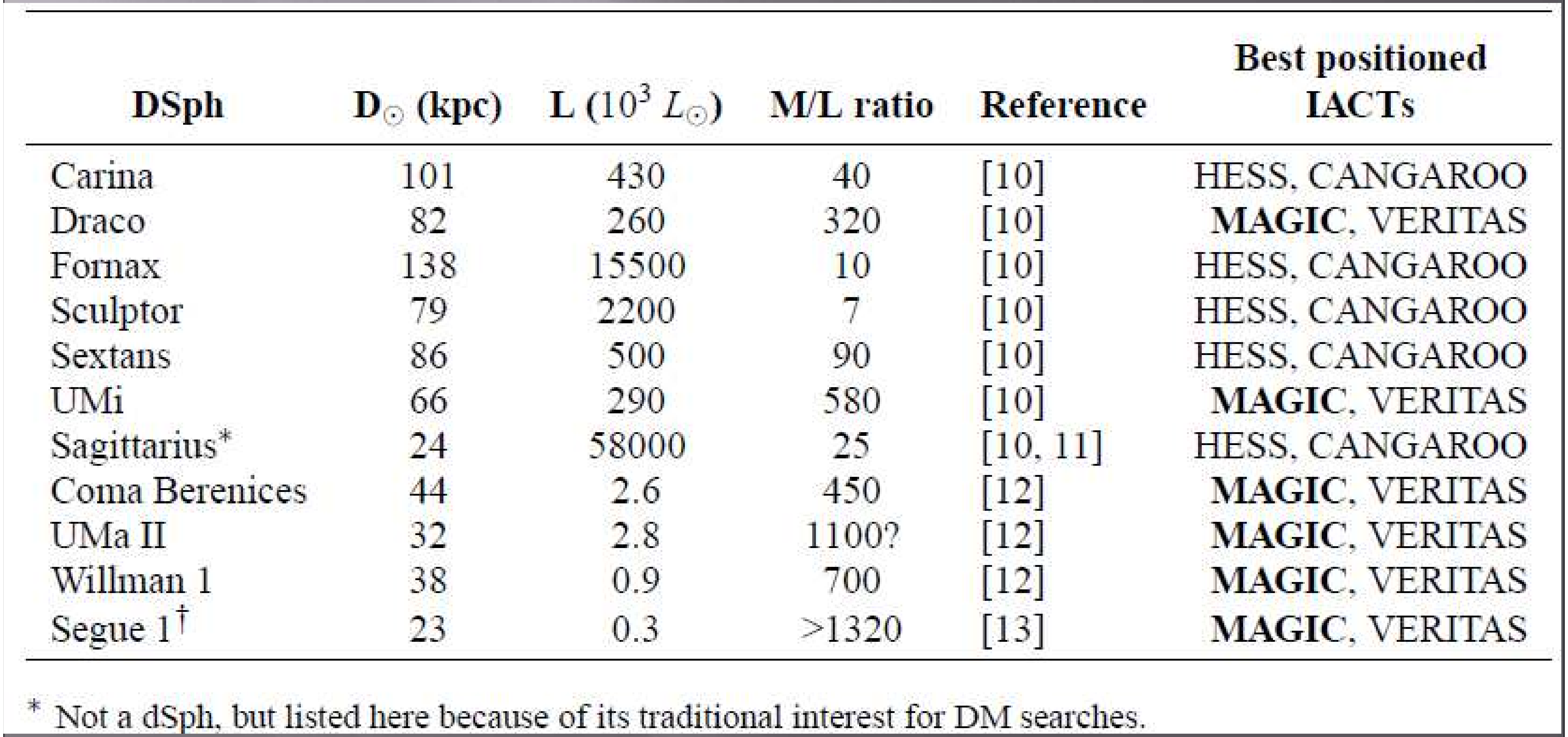
- Bottom-up cosmology: small galaxies formed first, hence their density retains the cosmological density at the epch of their turnaround ($\delta\rho/\rho \sim 1.8$).

- Baryon infall: SF → SN expl. → winds → most of infalling baryons **lost** in small gals., but **retained** in bigger ones.

- Smaller, denser gals. have little/no SF. Bigger, less dense gals. do have gas and SF.

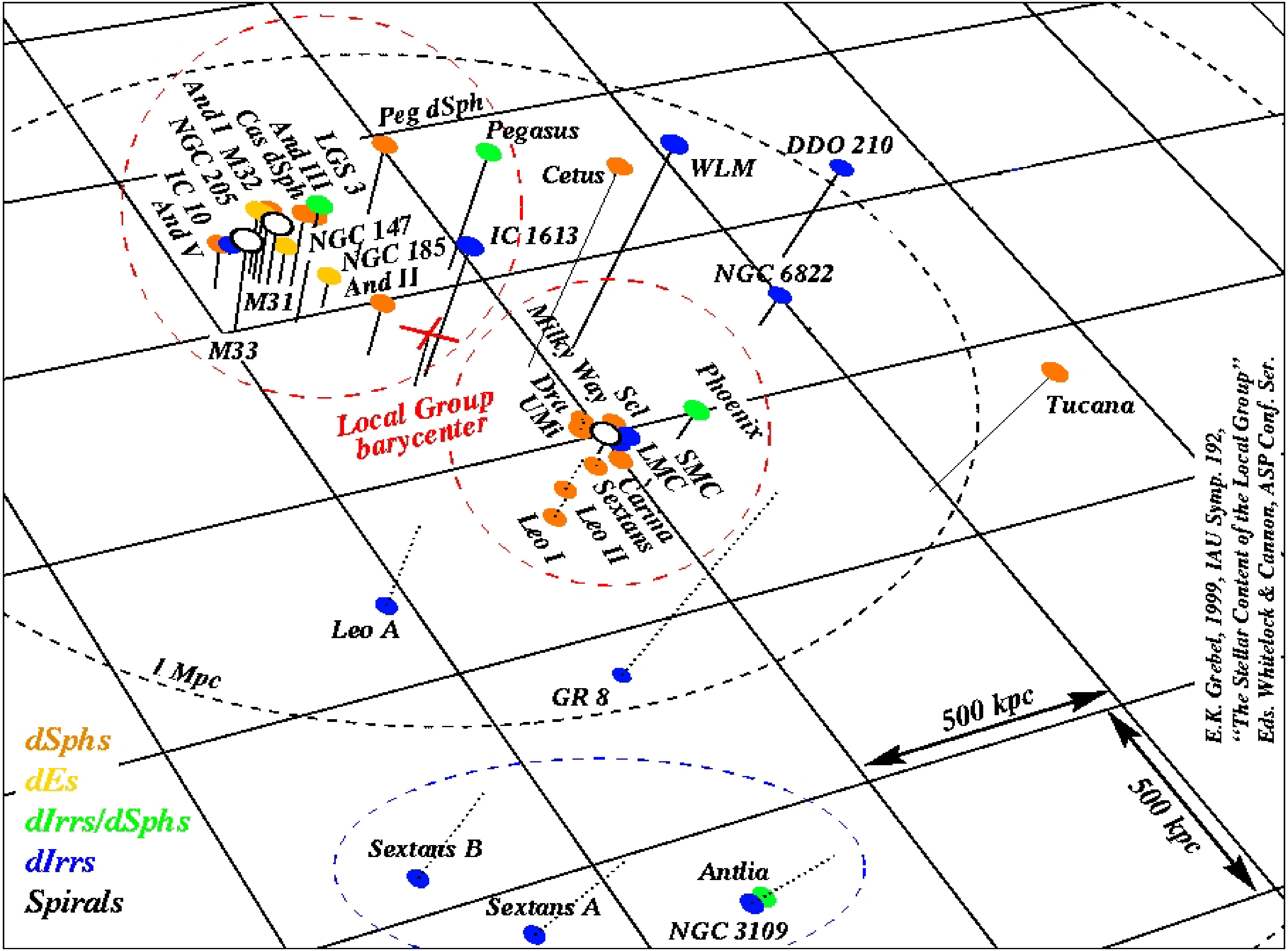
→ Dwarf Spheroidals: ideal DM candidates

Milky Way satellites → **nearby**
High M/L → **DM dominated**
Old stellar pop. → **no ongoing SF**



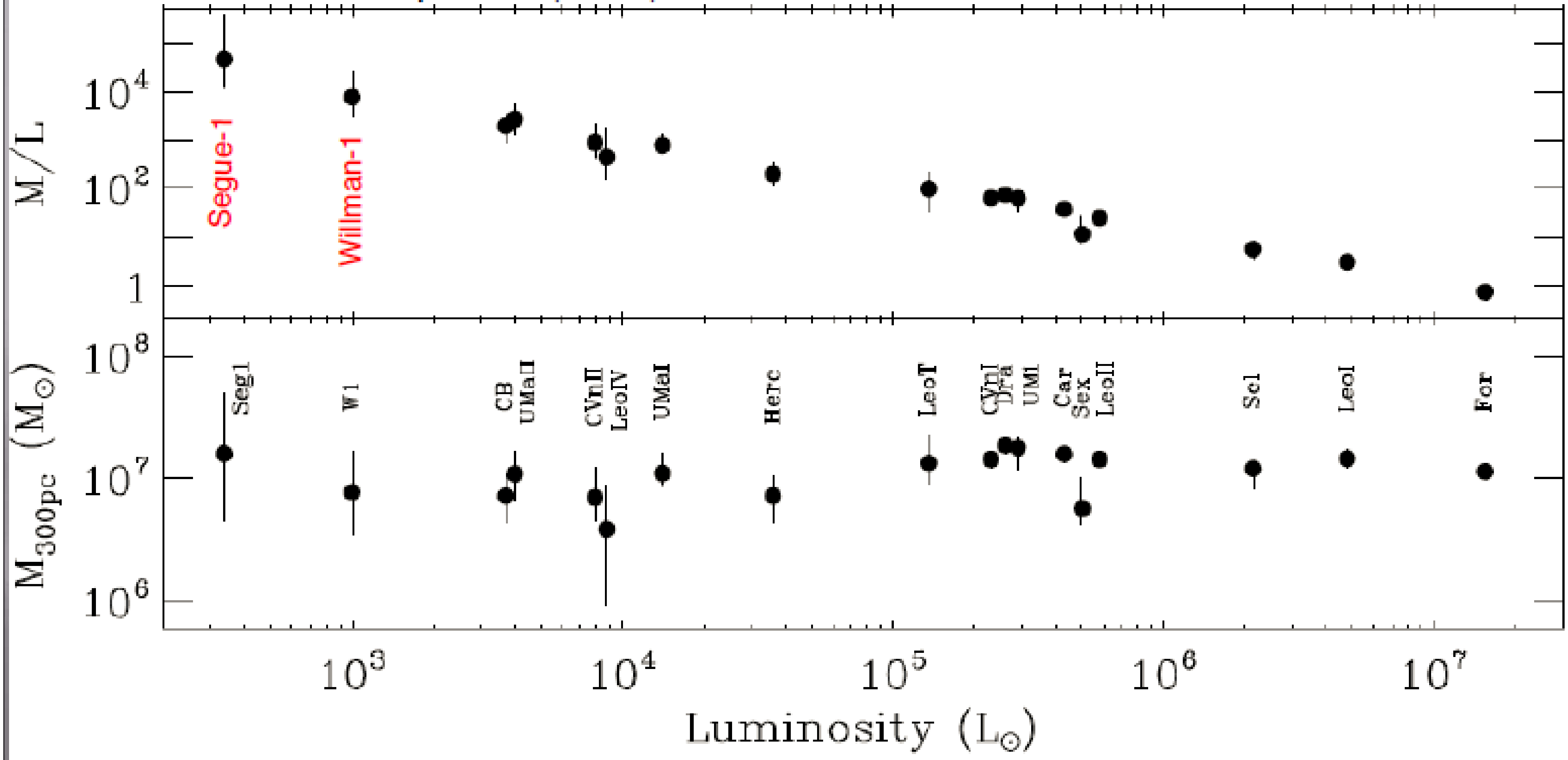
DSph	$D_\odot$ (kpc)	L ($10^3 L_\odot$)	M/L ratio	Reference	Best positioned IACTs
Carina	101	430	40	[10]	HESS, CANGAROO
Draco	82	260	320	[10]	**MAGIC**, VERITAS
Fornax	138	15500	10	[10]	HESS, CANGAROO
Sculptor	79	2200	7	[10]	HESS, CANGAROO
Sextans	86	500	90	[10]	HESS, CANGAROO
UMi	66	290	580	[10]	**MAGIC**, VERITAS
Sagittarius*	24	58000	25	[10, 11]	HESS, CANGAROO
Coma Berenices	44	2.6	450	[12]	**MAGIC**, VERITAS
UMa II	32	2.8	1100?	[12]	**MAGIC**, VERITAS
Willman 1	38	0.9	700	[12]	**MAGIC**, VERITAS
Segue 1†	23	0.3	>1320	[13]	**MAGIC**, VERITAS

* Not a dSph, but listed here because of its traditional interest for DM searches.



E.K. Grebel, 1999, IAU Symp. 192,
"The Stellar Content of the Local Group"
Eds. Whitelock & Cannon, ASP Conf. Ser.

Geha et al, ApJ 692 (2009)



Example: Draco dSph modeling

d~80 kpc

Bergström &
Hooper 2006

total DM annihil. rate

$$\Phi_A = \int_{r_{min}}^{r_a} dr\, 4\pi r^2 \frac{\langle\sigma_A v\rangle}{2} \left(\frac{\rho(r)}{m_\chi}\right)^2$$

$<\sigma_A v>$, m_χ: WIMP annihil. cross section, mass

γ-ray flux

$$F_\gamma = \frac{\Phi_A N_\gamma}{4\pi D^2}$$

N_γ: γ-rays / annihil.

$$y = r/r_s$$

upper limit

cusped profile

$$\rho(r) = \frac{\rho_0}{y\,(1+y)^2}$$

$$F_\gamma = \frac{\rho_0^2 r_s^3 N_\gamma}{3 m_\chi^2 D^2}\frac{\langle\sigma_A v\rangle}{2}\left[\frac{1}{(1+y_{min})^3} - \frac{1}{(1+y_a)^3}\right]$$

cored profile

$$\rho(r) = \frac{\rho_0}{(1+y)\,(1+y^2)}$$

$$F_\gamma = \frac{\rho_0^2 r_s^3 N_\gamma}{4 m_\chi^2 D^2}\frac{\langle\sigma_A v\rangle}{2}\left[\frac{2+y_{min}+y_{min}^2}{1+y_{min}+y_{min}^2+y_{min}^3} + \arctan(y_{min}) - \frac{2+y_a+y_a^2}{1+y_a+y_a^2+y_a^3} - \arctan(y_a)\right]$$

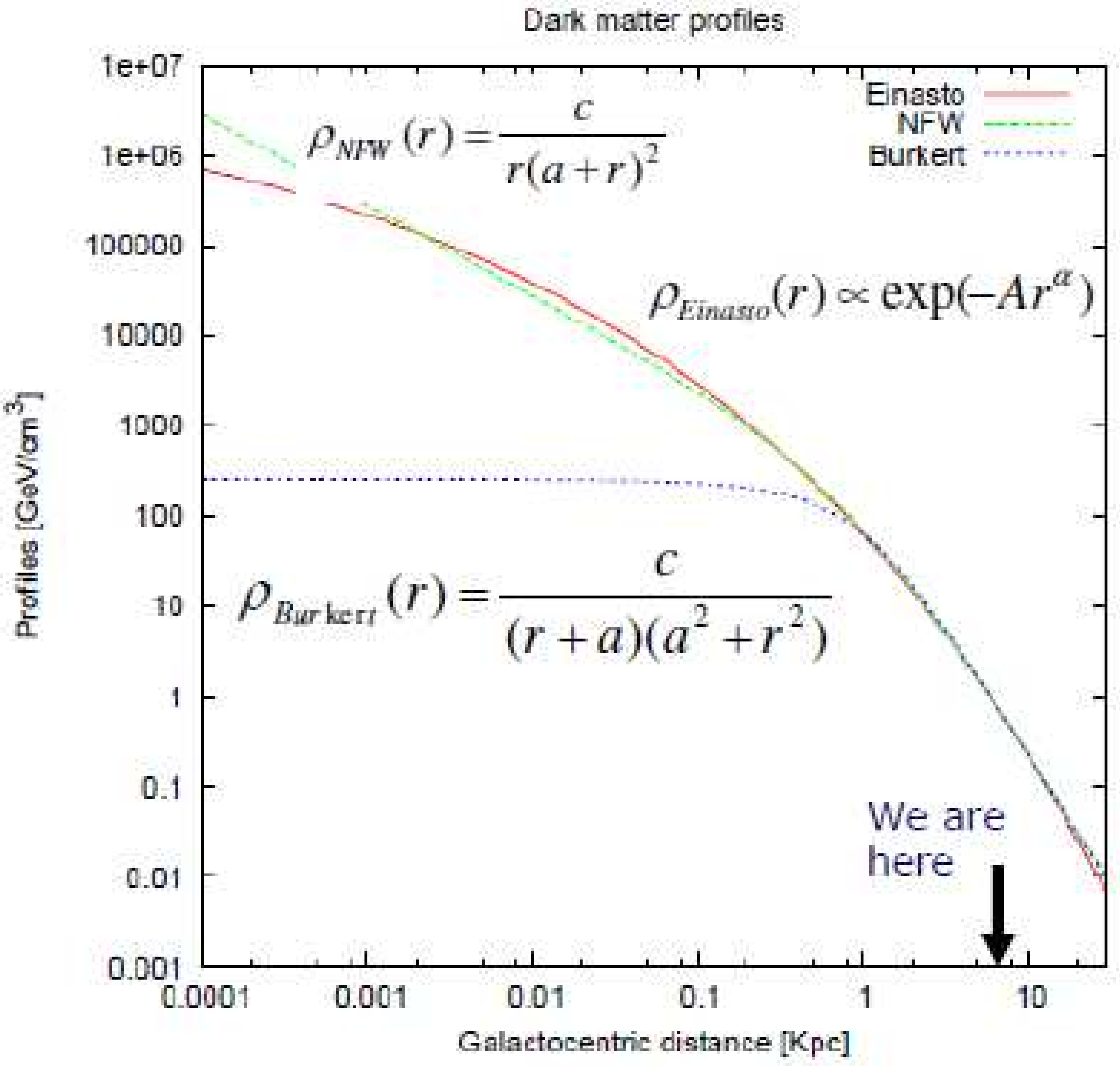
γ-ray flux

$$F_\gamma = \frac{\boxed{\rho_0^2 r_s^3} N_\gamma}{3 \boxed{m_\chi^2} D^2}\frac{\boxed{\langle\sigma_A v\rangle}}{2} \times \boxed{A}$$

part. phys
astrophys

Profile Type	$A(r_a = r_s)$	$A(r_a \gg r_s)$
NFW	0.875	1.0
Core	0.160	0.323
Cusp, $\gamma = 1.1$	1.29	1.52
Cusp, $\gamma = 1.2$	2.16	2.63
Cusp, $\gamma = 1.3$	4.03	4.12
Cusp, $\gamma = 1.4$	11.1	12.5
Cusp, $\gamma = 1.45$	25.7	27.4

r_s = 7 – 0.2 kpc
$\rho_0 = 10^7 - 10^9\ M_{\check{z}}\ \mathrm{kpc}^{-3}$
$\rho_0^2 r_s^3 = 0.03 - 6\ M_{\check{z}}^2\ \mathrm{kpc}^{-3}$



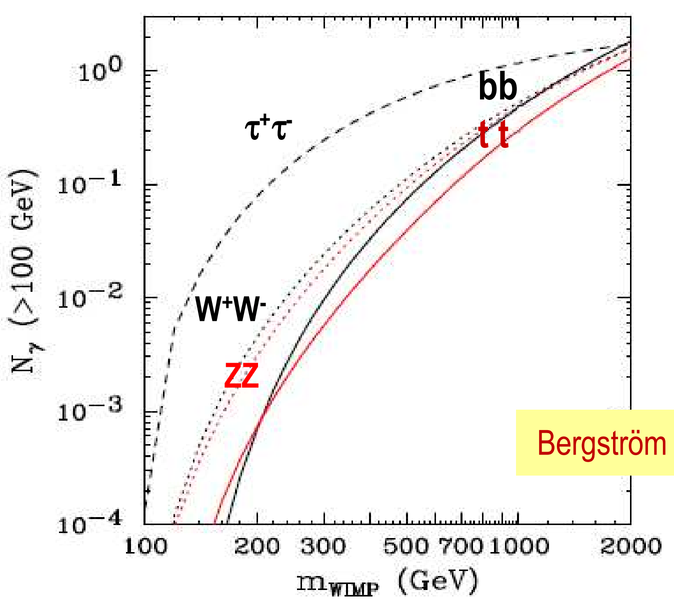
Dark matter profiles

$$\rho_{NFW}(r) = \frac{c}{r(a+r)^2}$$

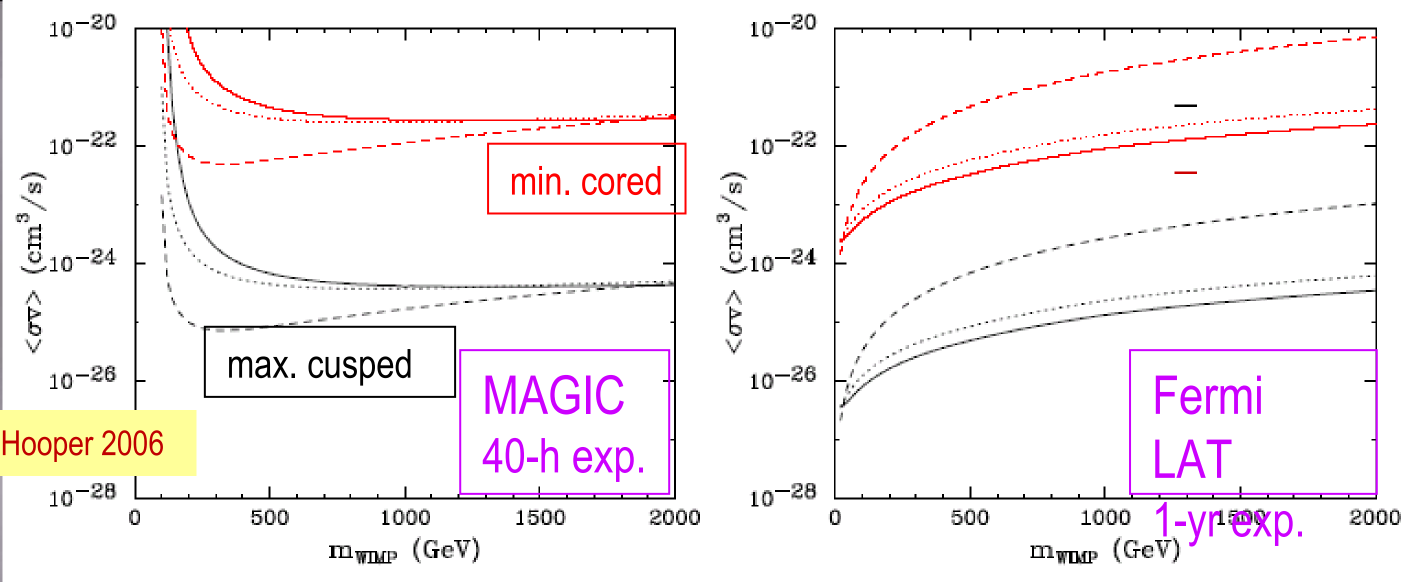
$$\rho_{Einasto}(r) \propto \exp(-Ar^{\alpha})$$

$$\rho_{Burkert}(r) = \frac{c}{(r+a)(a^2+r^2)}$$

We are here



Bergström & Hooper 2006



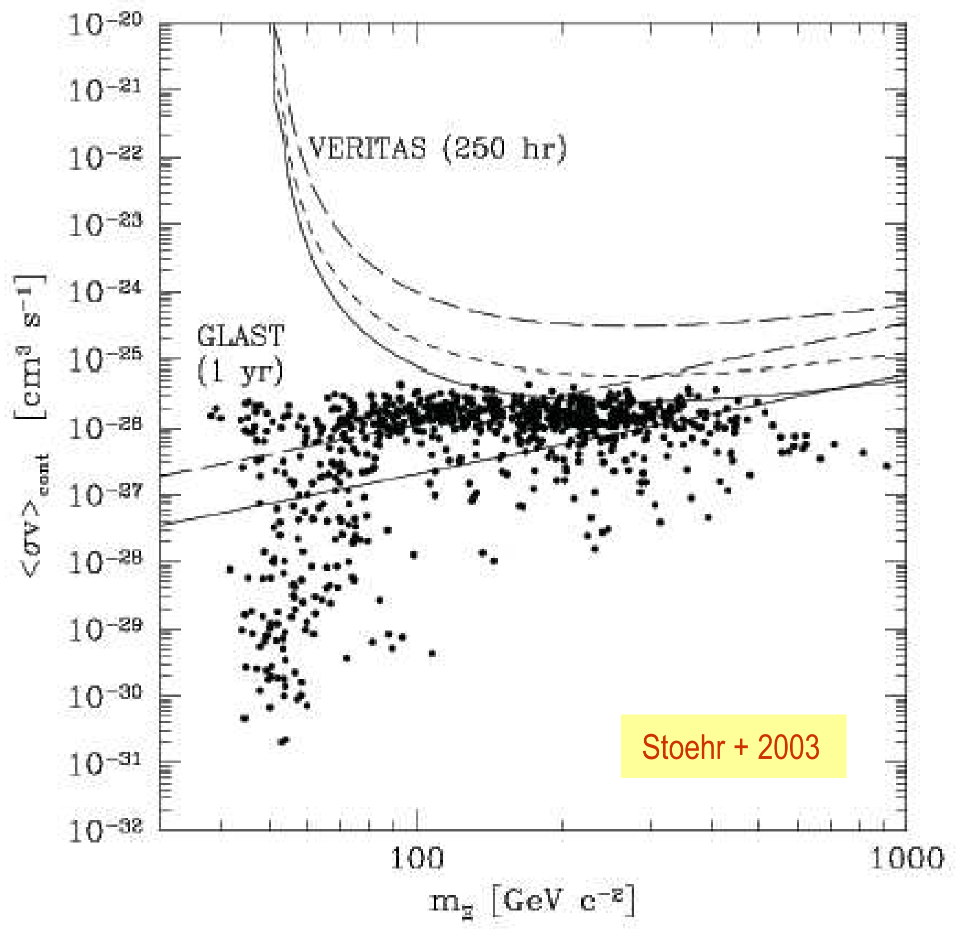
$$F^{\max}_{\gamma,\mathrm{NFW}} \approx 2.4\times10^{-10}\left(\frac{100\ \mathrm{GeV}}{m_\chi}\right)^2\left(\frac{\langle\sigma_A v\rangle}{3\cdot10^{-26}\ \mathrm{cm^3s^{-1}}}\right)\left(\frac{N_\gamma}{10}\right)\mathrm{cm^{-2}s^{-1}}$$

$$F^{\min}_{\gamma,\mathrm{NFW}} \approx 9.8\times10^{-13}\left(\frac{100\ \mathrm{GeV}}{m_\chi}\right)^2\left(\frac{\langle\sigma_A v\rangle}{3\cdot10^{-26}\ \mathrm{cm^3s^{-1}}}\right)\left(\frac{N_\gamma}{10}\right)\mathrm{cm^{-2}s^{-1}}$$

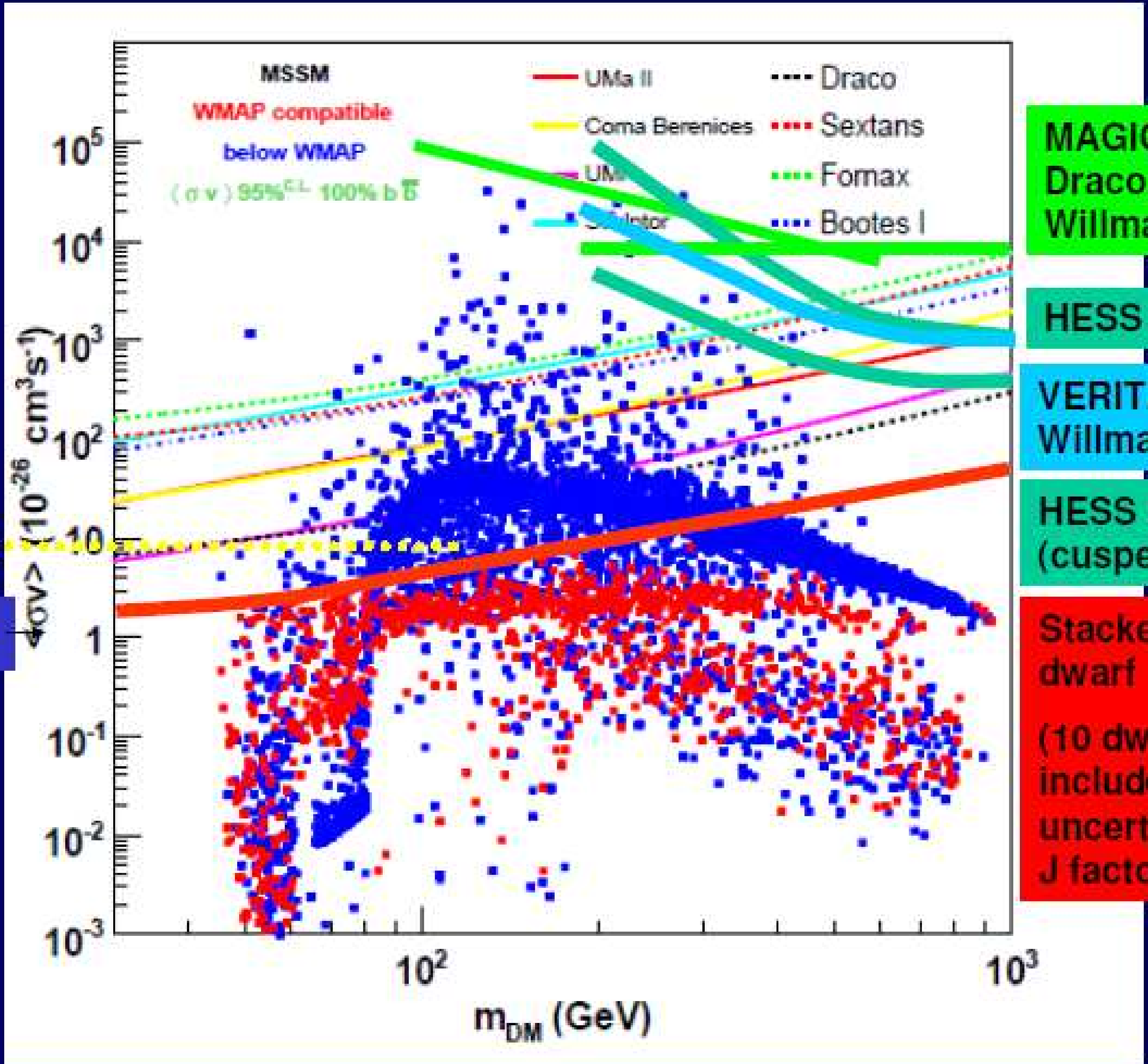
$$F^{\max}_{\gamma,\mathrm{core}} \approx 4.2\times10^{-11}\left(\frac{100\ \mathrm{GeV}}{m_\chi}\right)^2\left(\frac{\langle\sigma_A v\rangle}{3\cdot10^{-26}\ \mathrm{cm^3s^{-1}}}\right)\left(\frac{N_\gamma}{10}\right)\mathrm{cm^{-2}s^{-}}$$

$$F^{\min}_{\gamma,\mathrm{core}} \approx 3.5\times10^{-13}\left(\frac{100\ \mathrm{GeV}}{m_\chi}\right)^2\left(\frac{\langle\sigma_A v\rangle}{3\cdot10^{-26}\ \mathrm{cm^3s^{-1}}}\right)\left(\frac{N_\gamma}{10}\right)\mathrm{cm^{-2}s}$$

IACT neutralino detection:
$\langle\sigma_A v\rangle \geq 10^{-25}\ \mathrm{cm^3s^{-1}}$



Stoehr + 2003



10^{-26}

MAGIC Draco, Willman

HESS Canis M

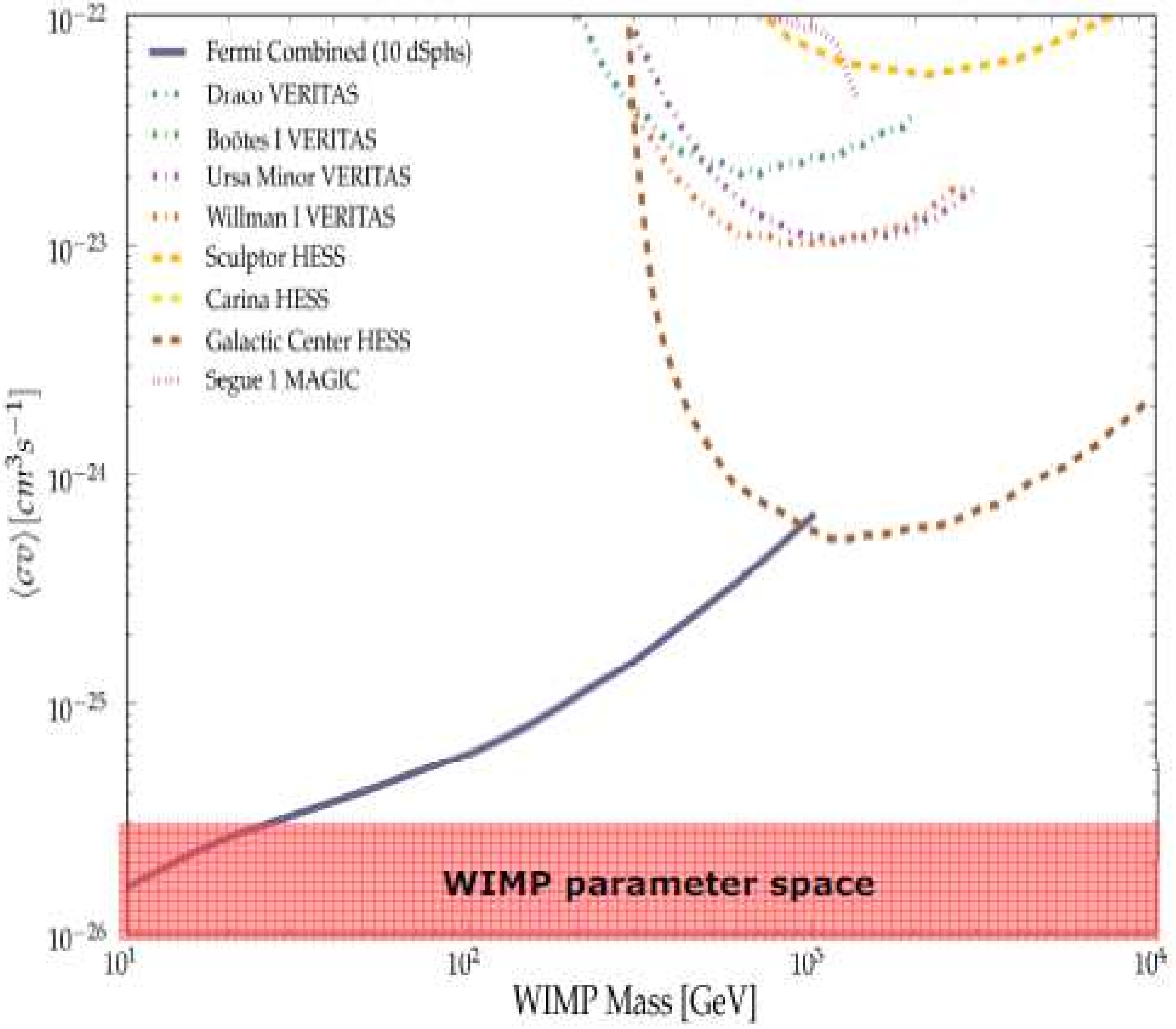
VERITAS Willman

HESS Sag (cusped)

Stacked Fermi dwarf

(10 dwarfs, includes uncertainties in the J factor

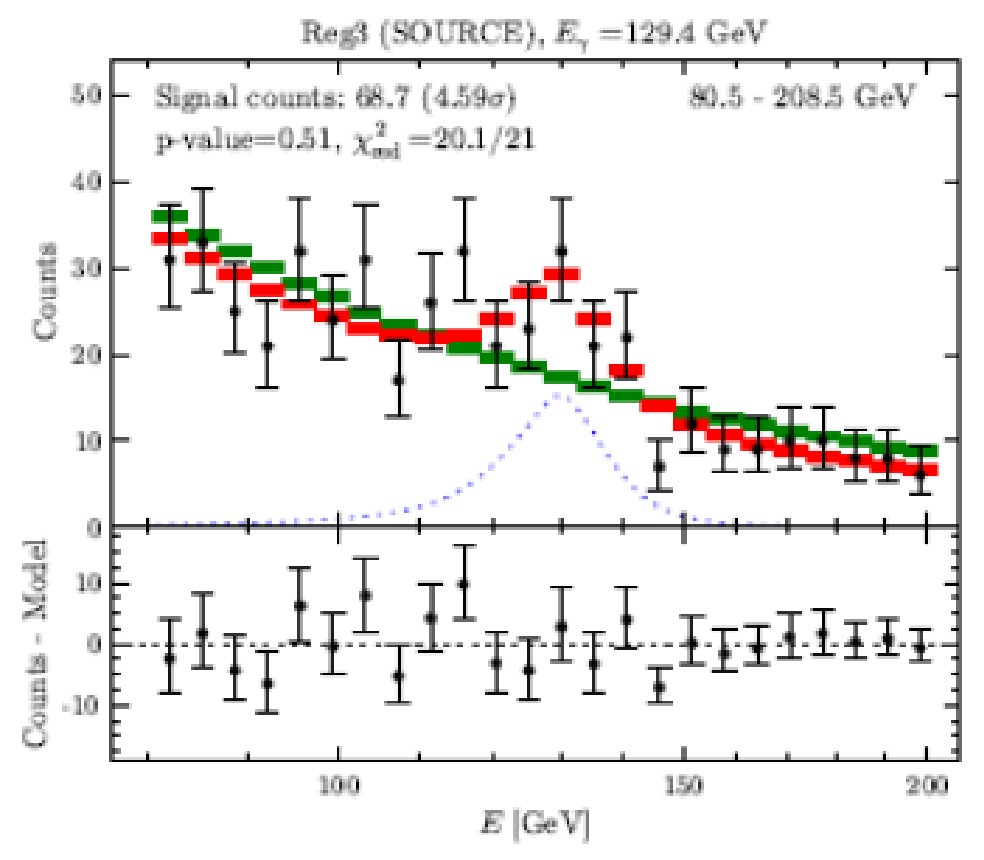
… present status



Weniger’s line?

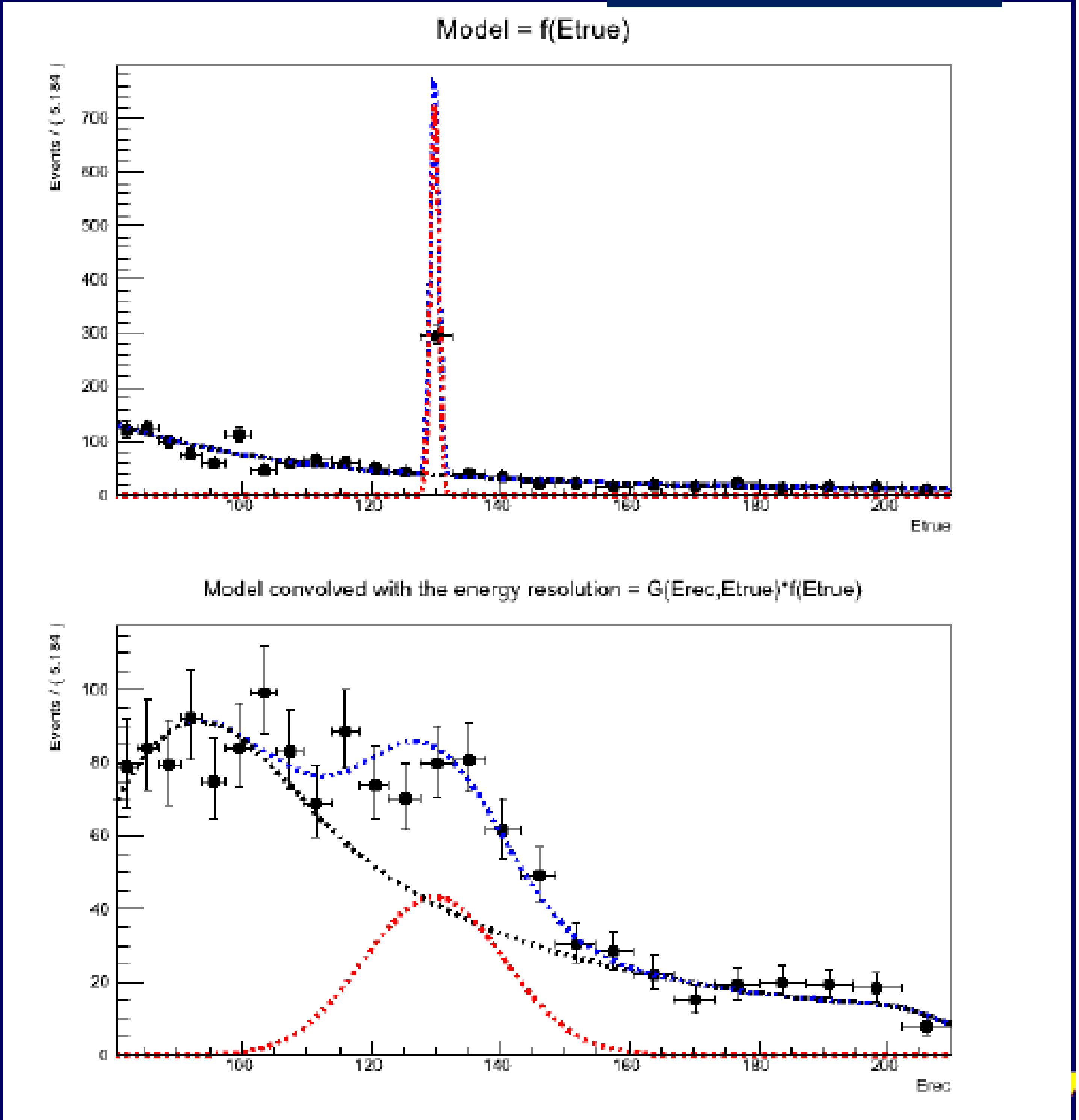
- 3.3σ trial corrected (based on 50 events)

- Be aware: lines of similar significance have been seen in Fermi-LAT data before, and turned out to be instrumental!



Weniger line in CTA?

- 500 h observation, GC region
- σ(E) ~ 10 % (somewhat better than current estimates)


Model = f(Etrue)

Model convolved with the energy resolution = G(Erec,Etrue)*f(Etrue)

Galaxy clusters with CTA

- Disentangling DM from CR emission will be hard!
- Masking central part? ⇒ less integrated flux, worse sensitivity

ApP CTA special issue

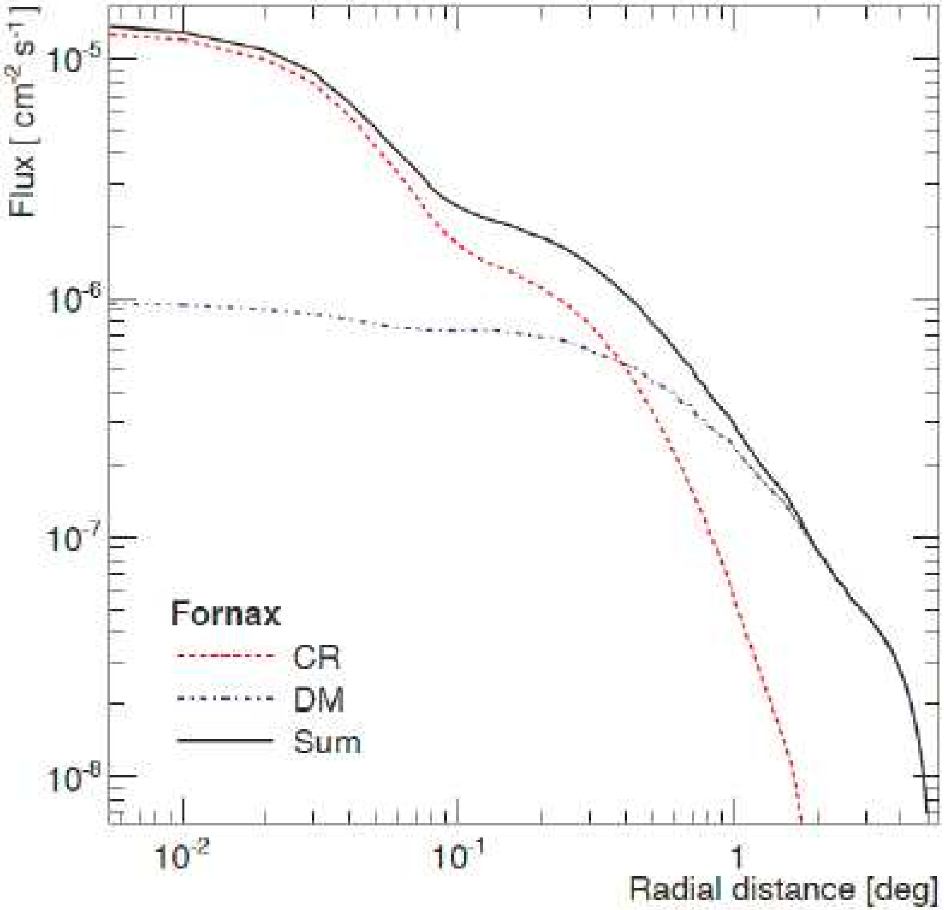
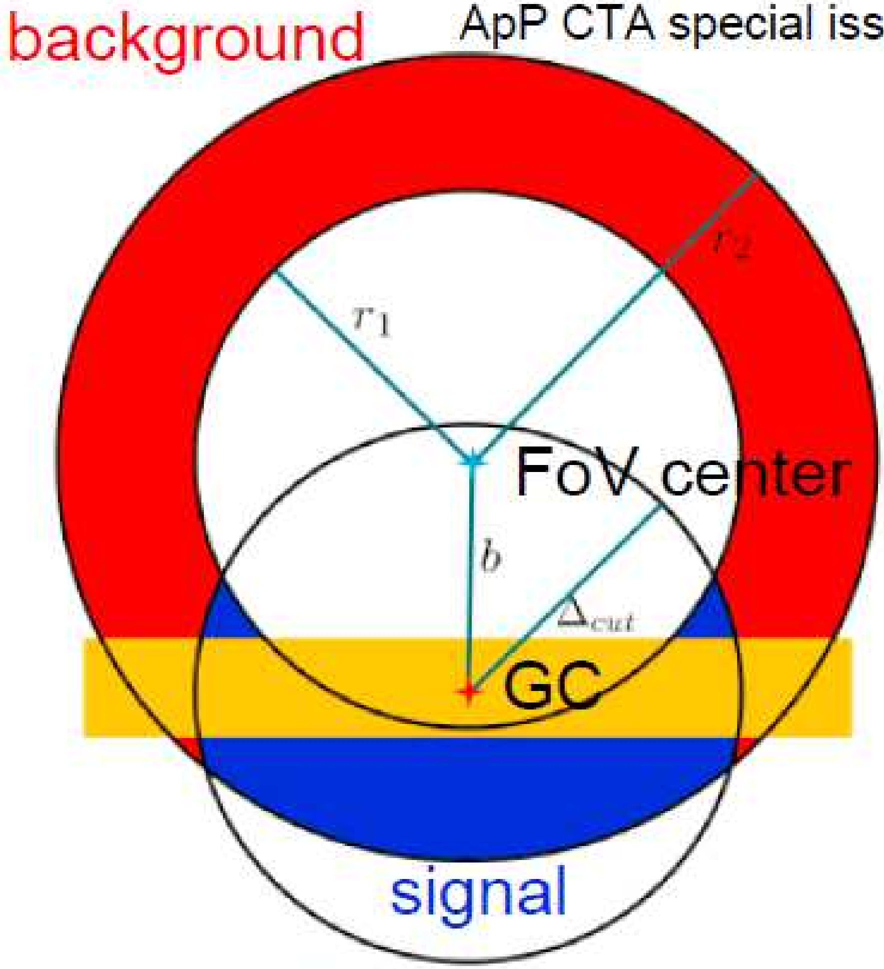


Figure 1.8: The surface brightness (above 1 GeV) of the gamma-ray emission from the Fornax cluster expected from CRs (red), DM (blue) and the sum of the two contributions (black).

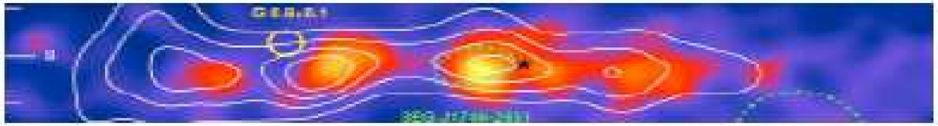
The Milky Way halo



ApP CTA special issue

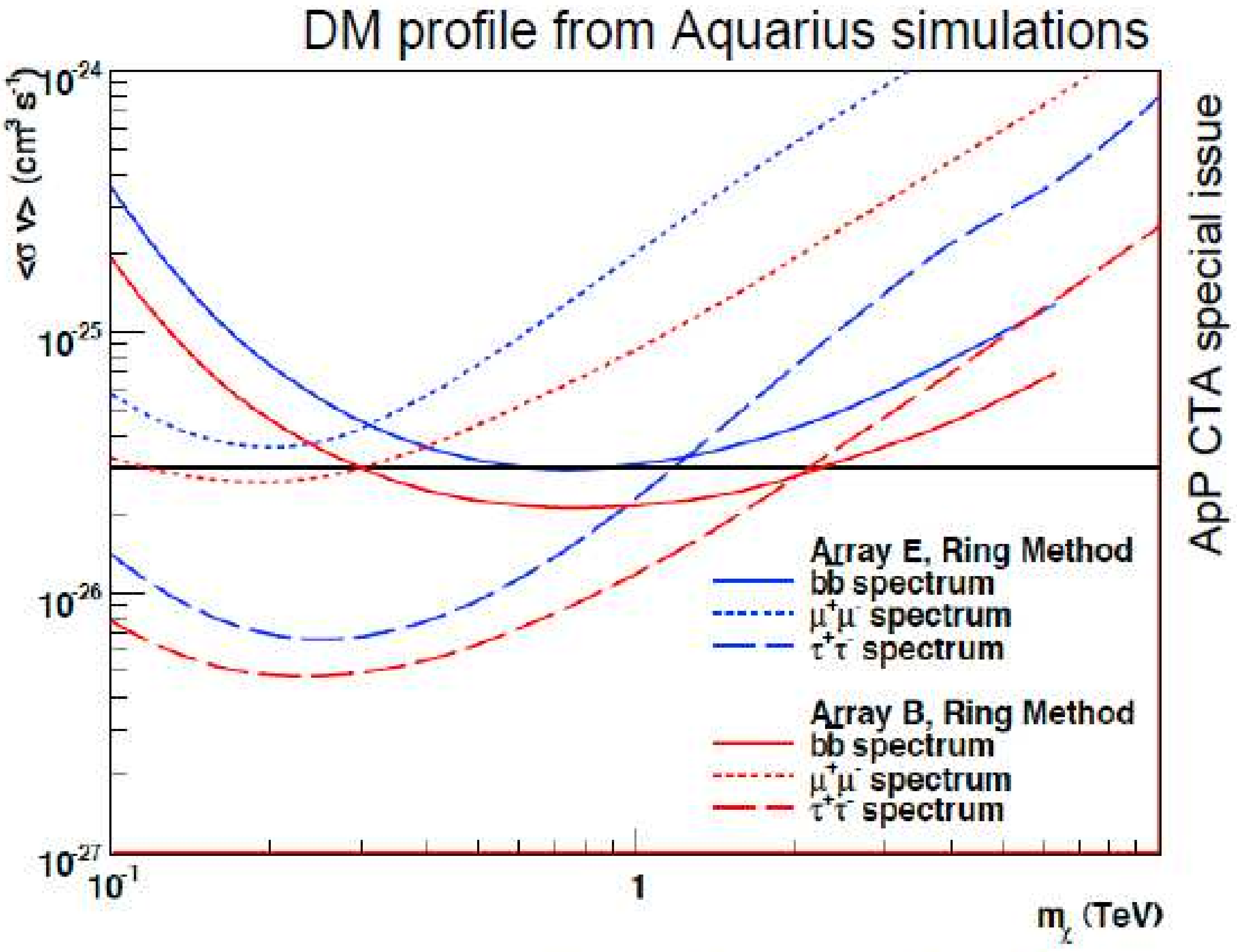
Ring method

- Galactic Center (GC) and ridge too contaminated by other γ-ray sources



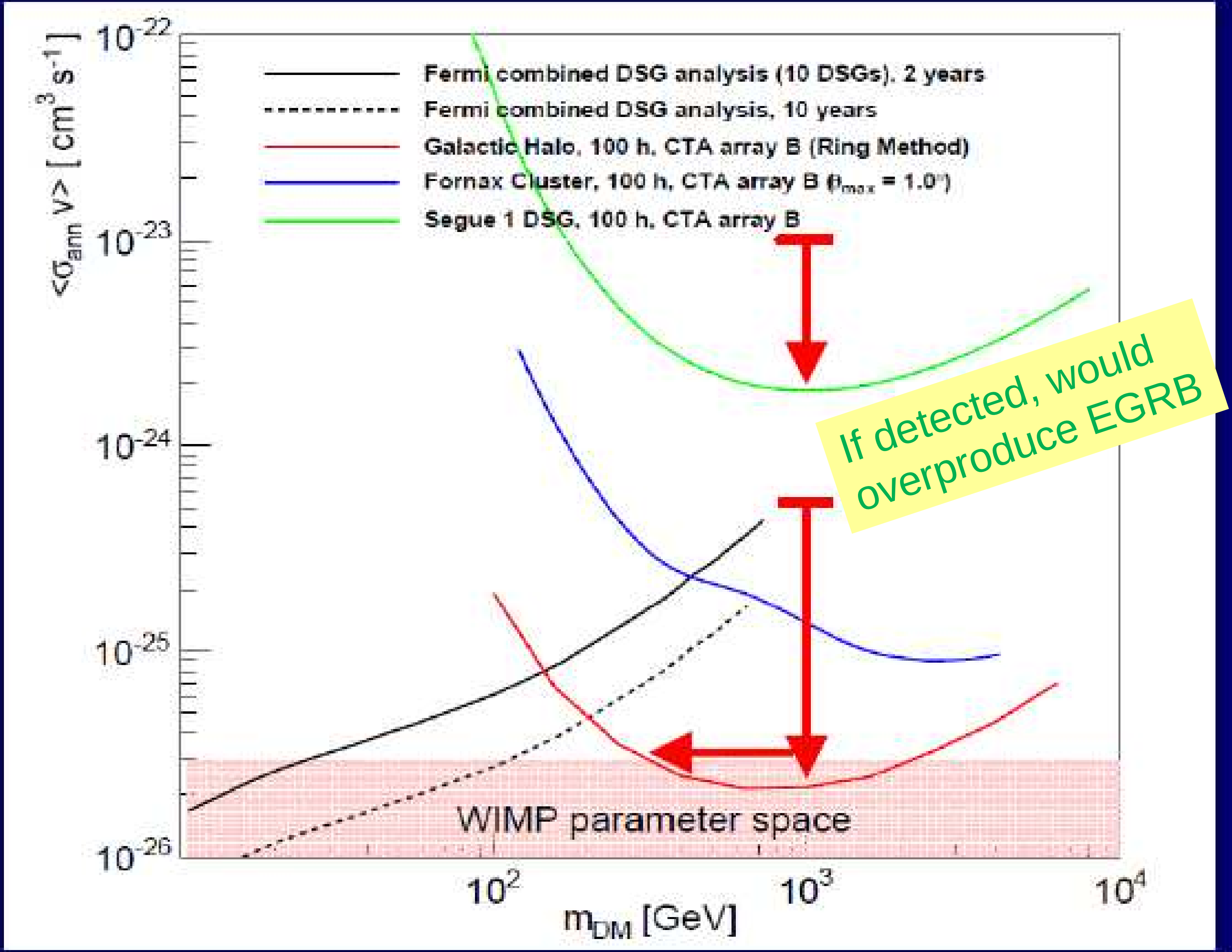
- ⇒ Study the MW halo excluding the centralmost part
- Need simultaneous view of *signal* and *background* regions ⇒ large FoV
- $r_1 \sim 0.5^\circ$ $r_2 \sim 2.5^\circ$

The Milky Way halo



- The only target where the relevant ⟨σv⟩ region can be probed by CTA with no extra “boost factor” needed

DM: future status



If detected, would overproduce EGRB

Conclusions on DM

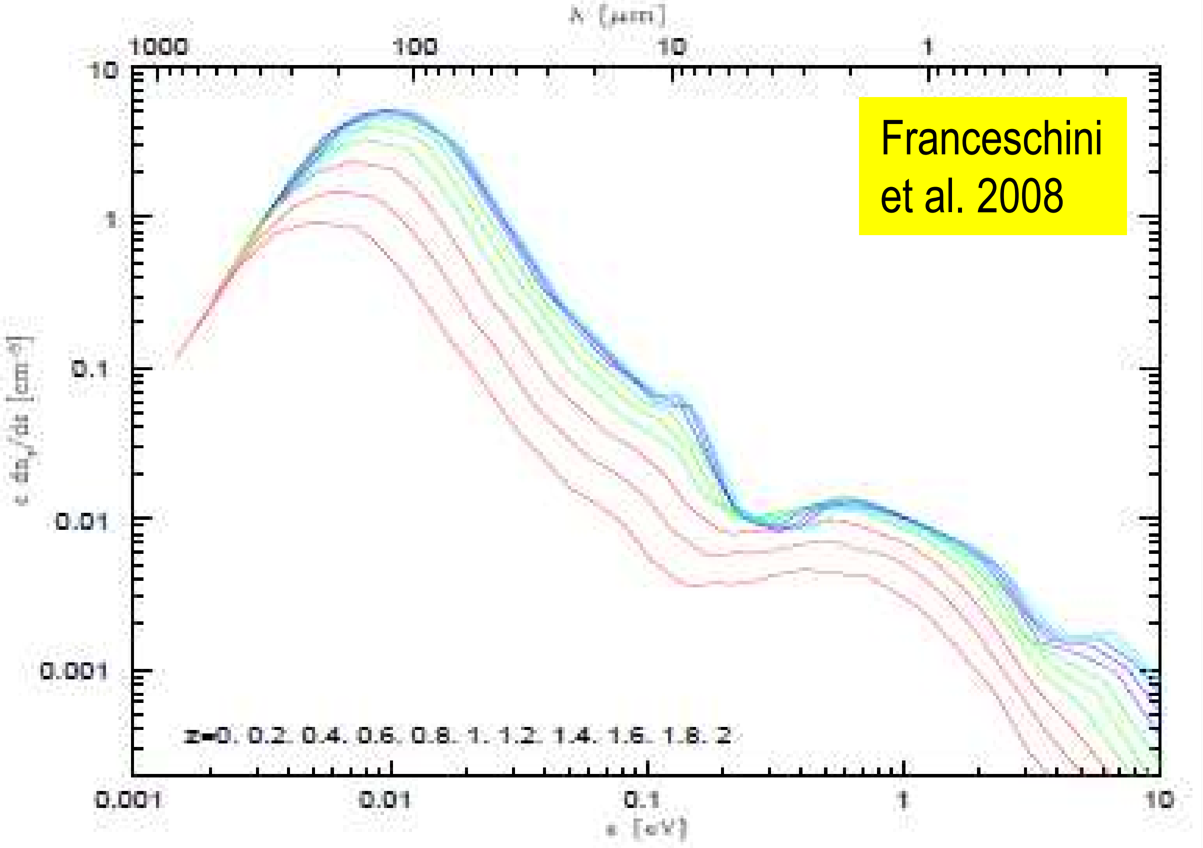
- Gamma-ray telescopes are just now starting to probe the most interesting parameter space (~thermal cross section excluded below 30 GeV, Fermi-LAT)
- Best target for Fermi-LAT: dwarfs for constraints, clusters for discovery (if lucky).
- Best target for Air Cherenkov telescopes: GC halo
- IACTs are gaining ground: H.E.S.S. halo provides strongest constraints >1 TeV.
- H.E.S.S II coming up → analysis threshold ~ 30 GeV?
- The future is CTA: thermal cross-section can be probed from ~10 GeV to ~ 10 TeV (in combination with Fermi-LAT)

Evolution of cosmic star formation rate

Distant sources suffer from extinction by pair creation along the los.
Lowering the threshold allows to penetrate deeper into the universe.

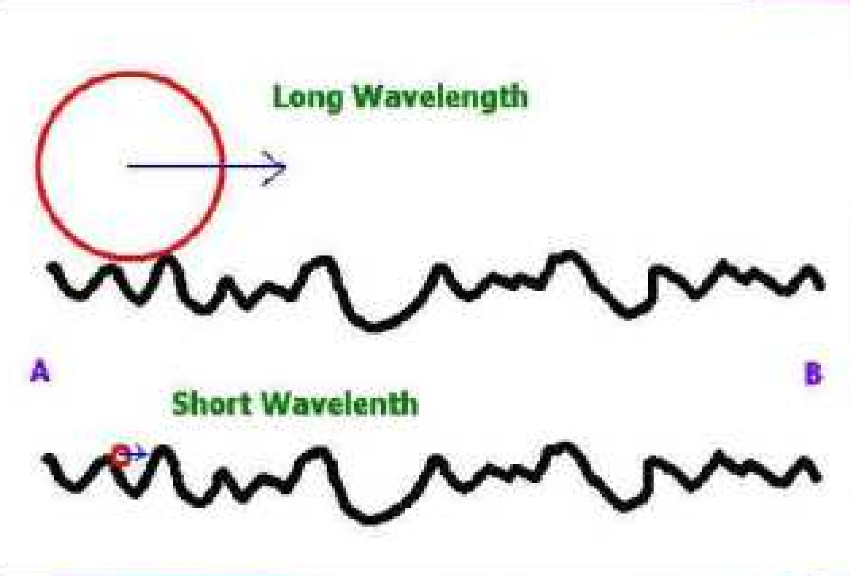
This problem can be turned into an advantage, i.e. to probe the diffuse extragalactic radiation fields in situ. This provides a redshift-resolved determination of the radiative output at any cosmic epoch.

CTA's higher-E extension (e.g. 50 TeV) will allow us to probe poorly known sub-mm EBL.



Franceschini et al. 2008

Probing Quantum Gravity



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

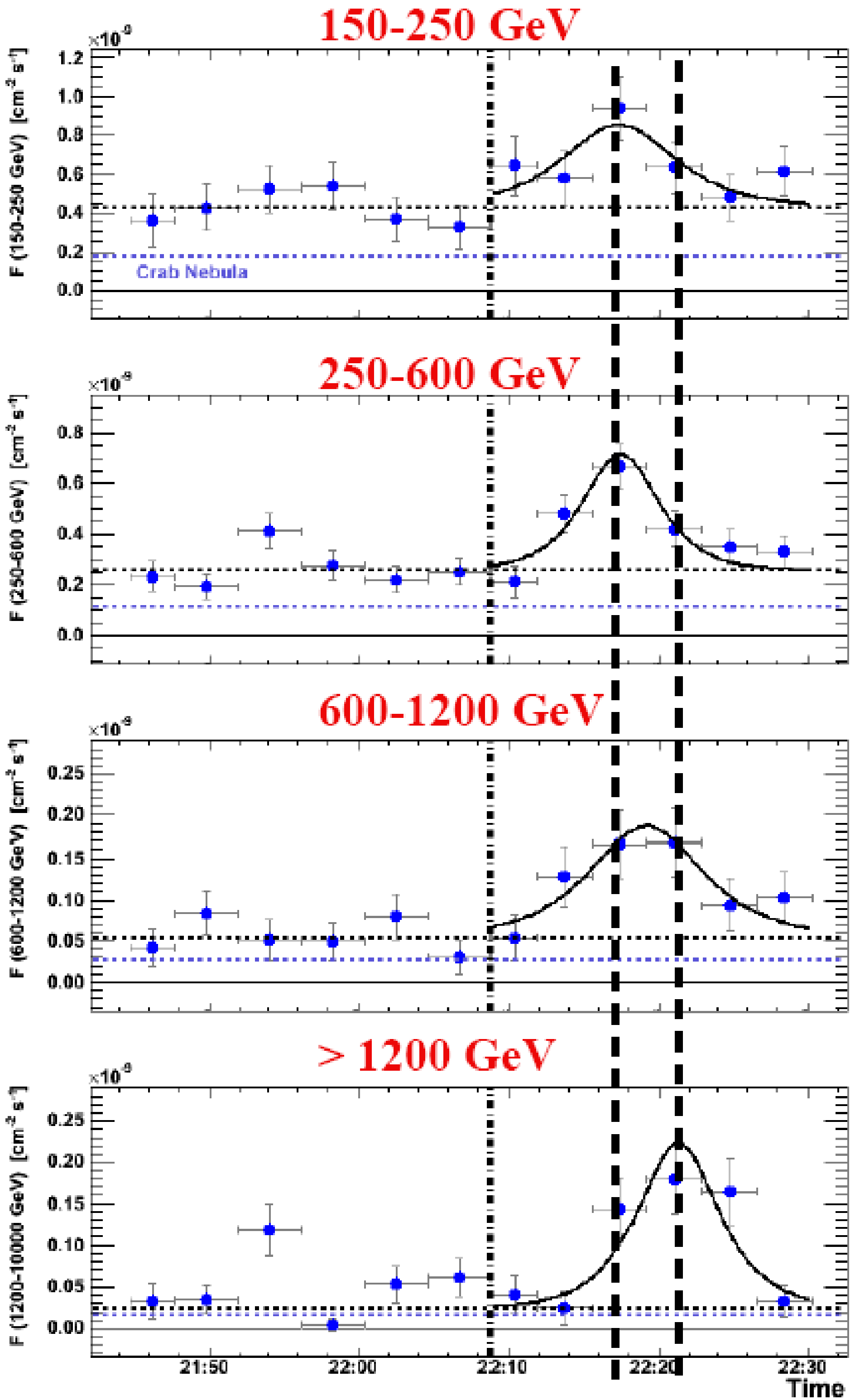
$$E_{Pl} = \sqrt{\frac{\hbar c^5}{G}} \approx 1.22\times10^{19}\,GeV$$

Linear deviation:

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

Quadratic deviation:

$$\boxed{\xi_1 = 0; \quad \xi_2 < 0; \quad v = c(1 - \tfrac{E^2}{M_{QG2}^2}); \quad n(E) = 1 + \tfrac{E^2}{M_{QG2}^2}}$$



$E_{QG} \sim 0.05\ M_P$

Major improvements expected from CTA

IF

Photons at different energies were emitted simultaneously

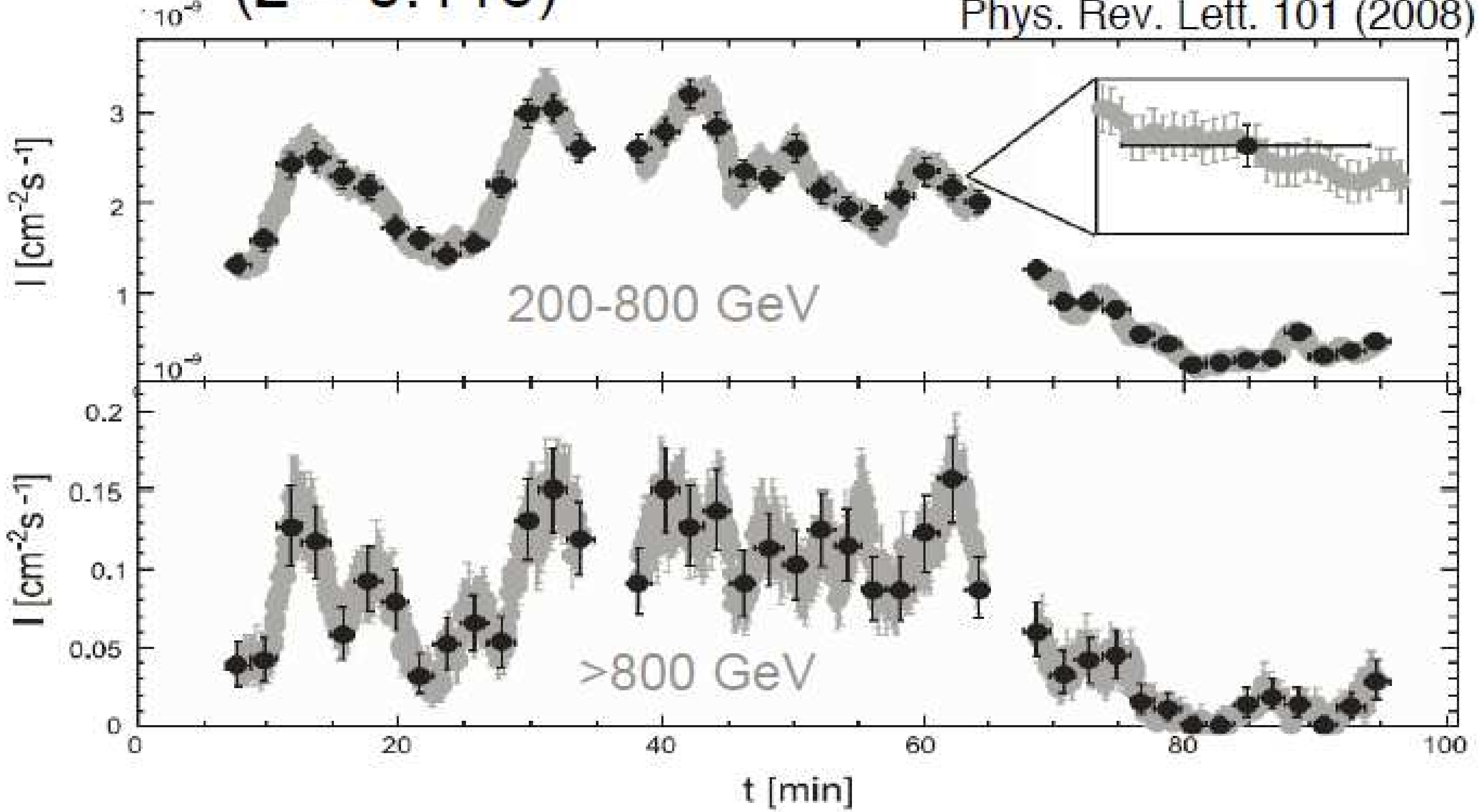
and ∃ no conventional explanations →

ΔT = 4 ± 1 min; ΔE ~ 1 TeV

$$E_{QG} = \frac{L}{c}\,\frac{\Delta E}{\Delta t} = (0.6 \pm 0.2)\cdot 10^{17}\,\mathrm{GeV}$$

HESS observations of PKS-2155 in 2006

(z = 0.116)



Phys. Rev. Lett. 101 (2008)

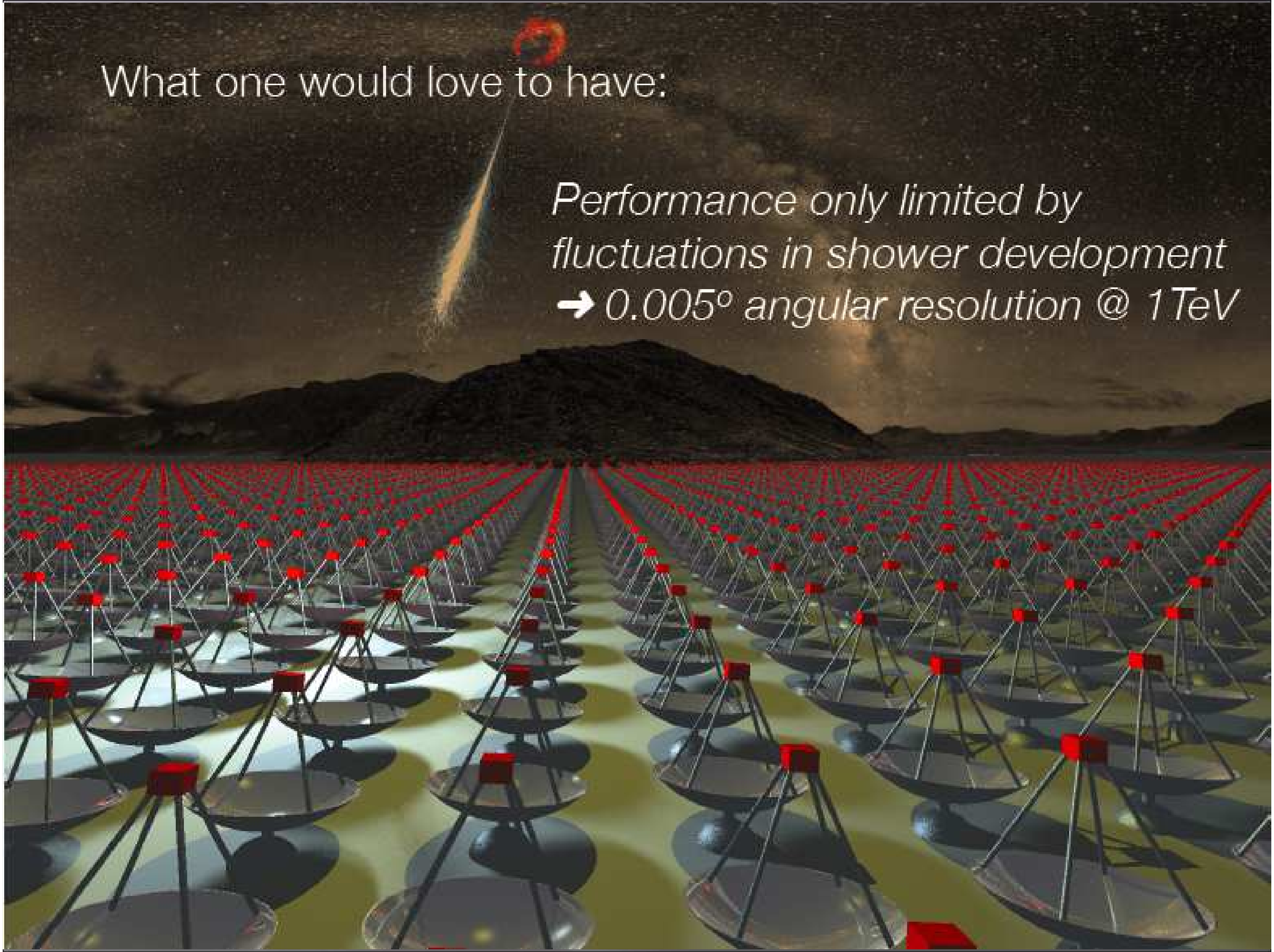
- No delay observed ⇒ $M_{QG1,\ 95\%CL} > 2.1 \times 10^{18}$ GeV

(Astropart.Phys.34, 2011) $M_{QG2,\ 95\%CL} > 6.4 \times 10^{10}$ GeV

CTA

- A world-wide consortium of > 900 researchers
- FP7- supported Prep. Phase: Fall 2010 – Fall 2013
  - Technical design, sites, construction and operation costs
  - Legal, governance and finance schemes
  - Small + medium-sized telescope prototypes
- Aim for
  - start of deployment in early 2014
  - first data in 2016/17
  - base arrays complete in late 2018

What one would love to have:

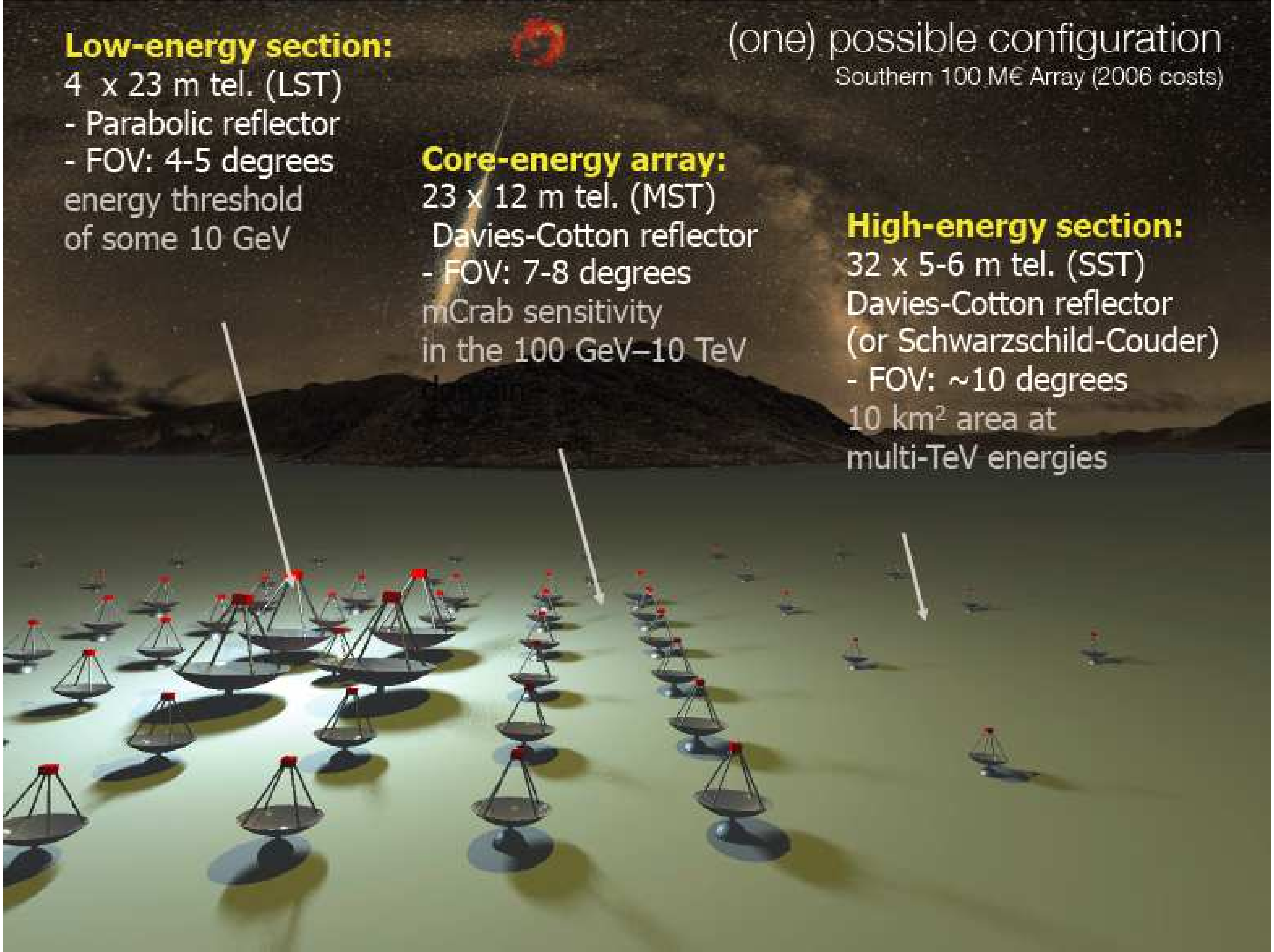


Performance only limited by fluctuations in shower development
➜ 0.005º angular resolution @ 1TeV

What one can (hopefully) afford:

Key design goals:

- 10-fold increased sensitivity at TeV energies
- 10-fold increased effective energy coverage
- Larger field of view for surveys
- Improved angular resolution
- Full sky coverage: and array in each hemisphere

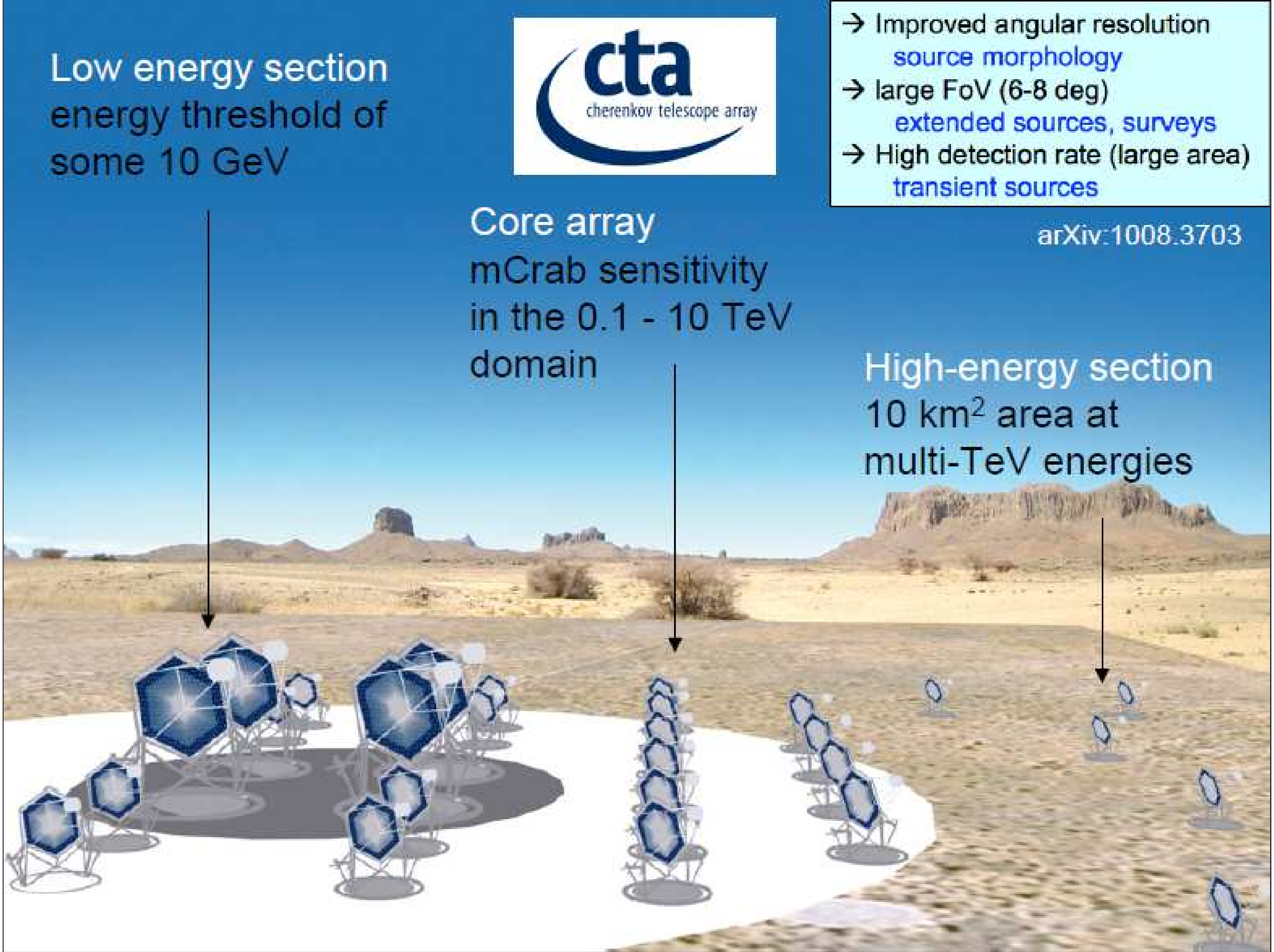


(one) possible configuration
Southern 100 M€ Array (2006 costs)

Low-energy section:
4 x 23 m tel. (LST)
- Parabolic reflector
- FOV: 4-5 degrees
energy threshold
of some 10 GeV

Core-energy array:
23 x 12 m tel. (MST)
Davies-Cotton reflector
- FOV: 7-8 degrees
mCrab sensitivity
in the 100 GeV–10 TeV
domain

High-energy section:
32 x 5-6 m tel. (SST)
Davies-Cotton reflector
(or Schwarzschild-Couder)
- FOV: ~10 degrees
10 km^2 area at
multi-TeV energies



cta
cherenkov telescope array

→ Improved angular resolution
source morphology
→ large FoV (6-8 deg)
extended sources, surveys
→ High detection rate (large area)
transient sources

arXiv:1008.3703

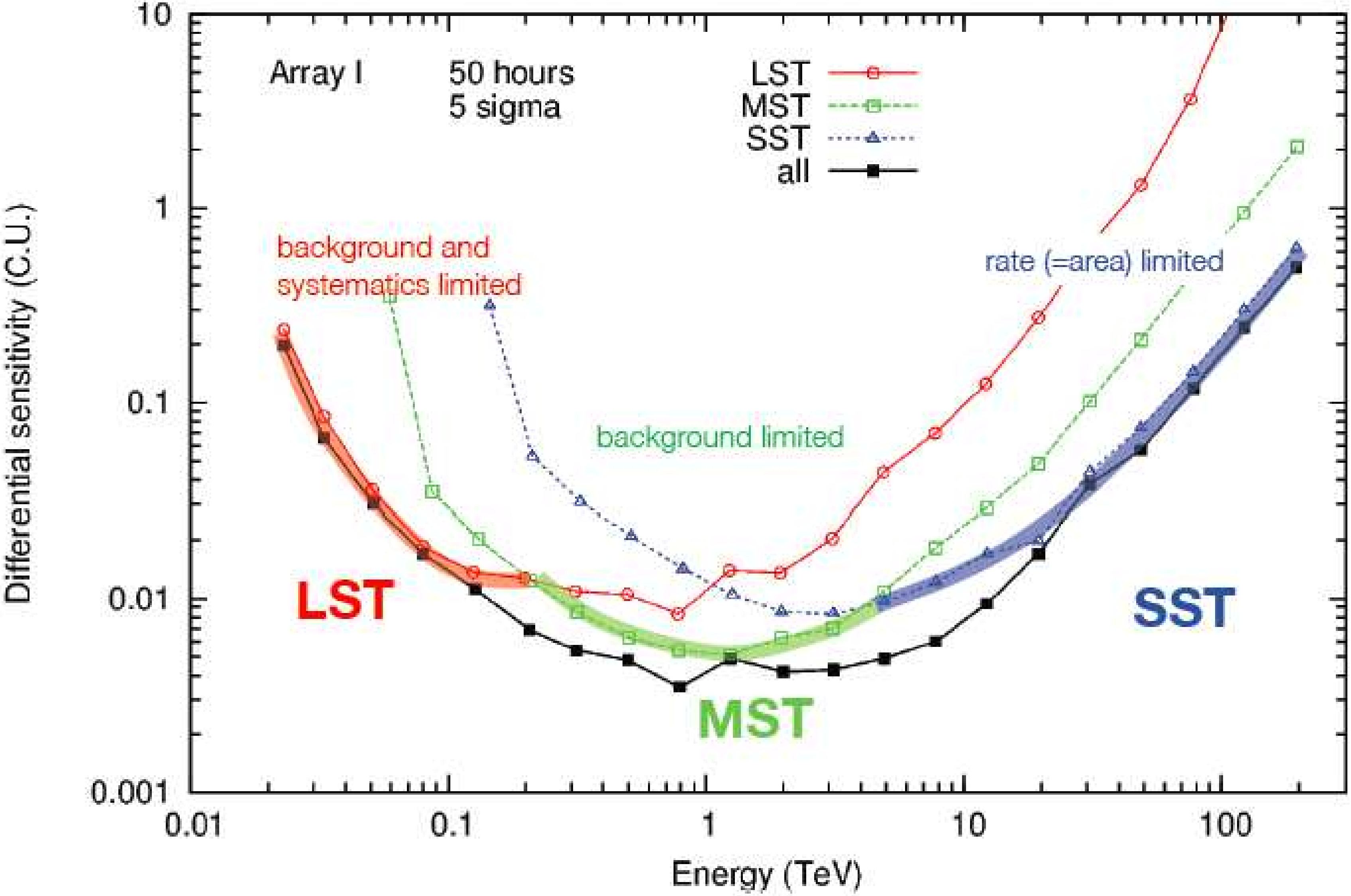
Low energy section
energy threshold of
some 10 GeV

Core array
mCrab sensitivity
in the 0.1 - 10 TeV
domain

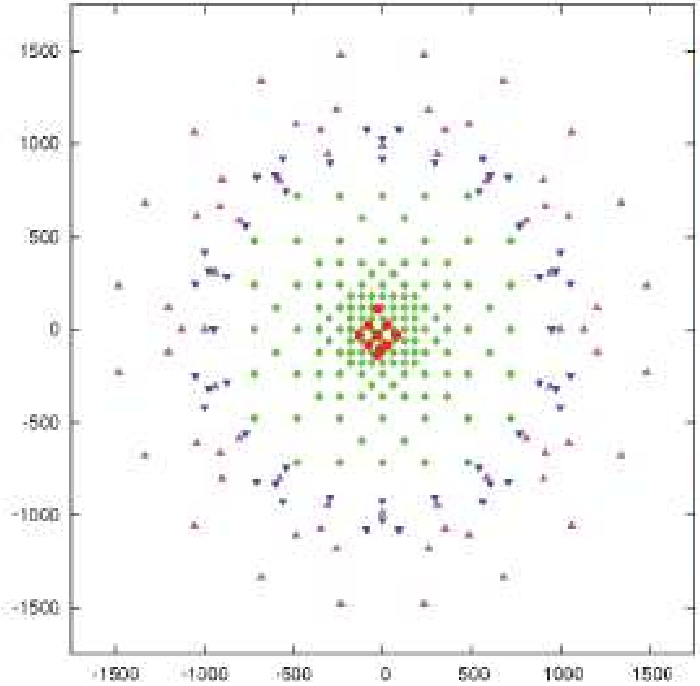
High-energy section
10 km^2 area at
multi-TeV energies

Sensitivity (in units of Crab flux)

for detection in each 0.2-decade energy band



CTA considered arrays



From Padova 2008 CTA meeting, plot by Konrad.

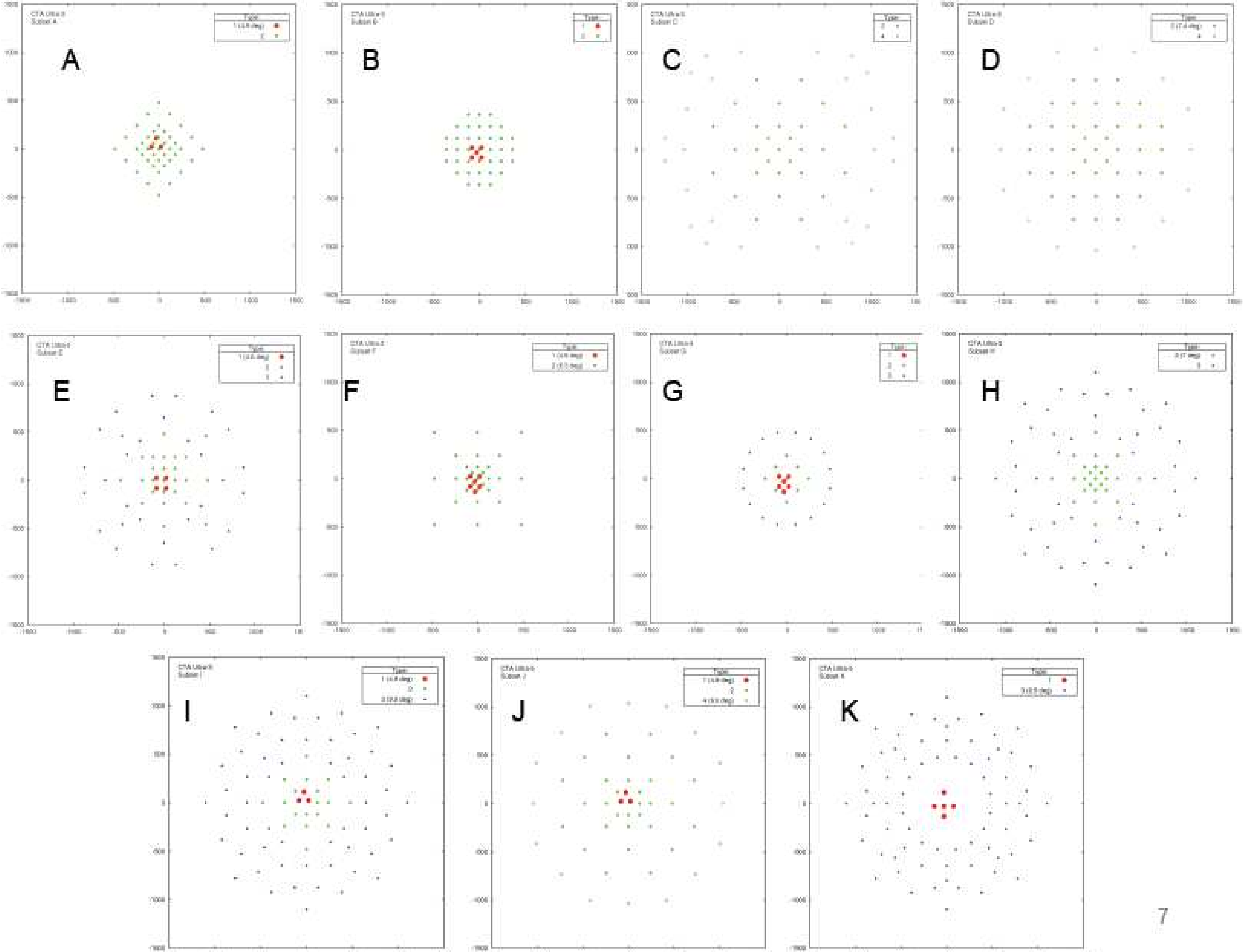
field of view

angular resolution

Types of telescopes:

Area	Diameter	F.o.V.	Pixels	
412 m²	~ 23 m	5°	0.09°	(1)
100 m²	~ 11 m	8°	0.18°	(2)
37 m²	~ 7 m	10°	0.25°	(3)
100 m²	~ 11 m	10°	0.18°	(4)

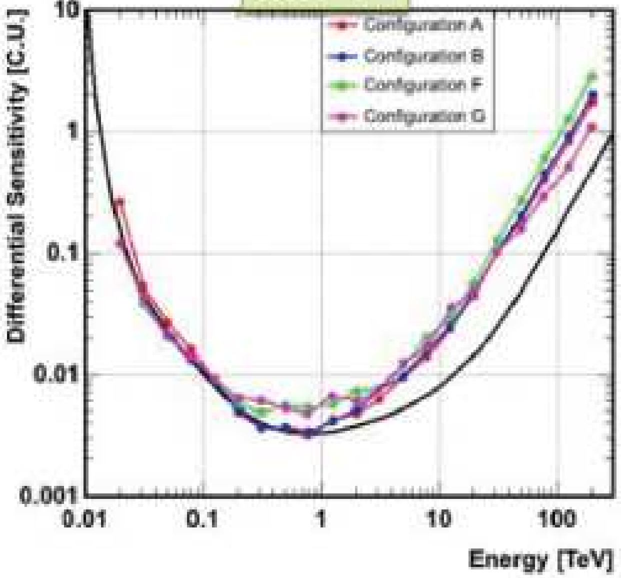
Configurations proposed with ~50 or more telescopes of 2-3 different types.


A
CTA Ultra 3
Subset A
Type
1 (4.9 deg)
2
B
Subset B
C
Subset C
D
Subset D
E
Subset E
F
Subset F
G
Subset G
H
Subset H
I
Subset I
J
Subset J
K
Subset K
-1500
-1000
-500
0
500
1000
1500

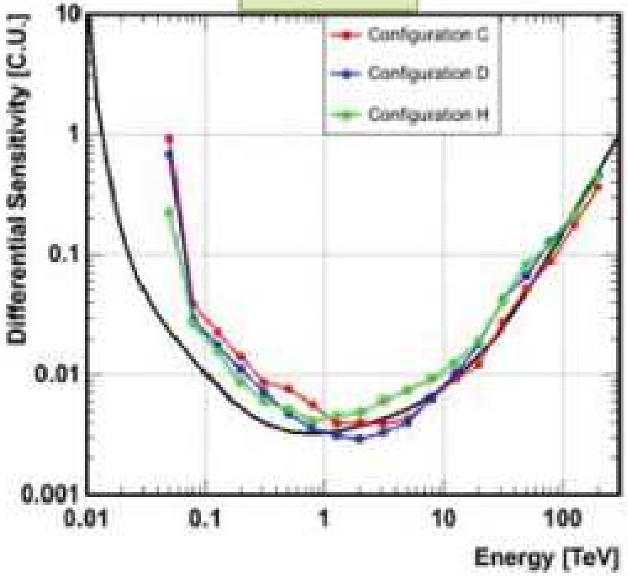
Grouping by similar sensitivities

Area	Diameter	F.o.V.	Pixels	
412 m^2	~ 23 m	5°	0.09°	(1)
100 m^2	~ 11 m	8°	0.18°	(2)
37 m^2	~ 7 m	10°	0.25°	(3)
100 m^2	~ 11 m	10°	0.18°	(4)

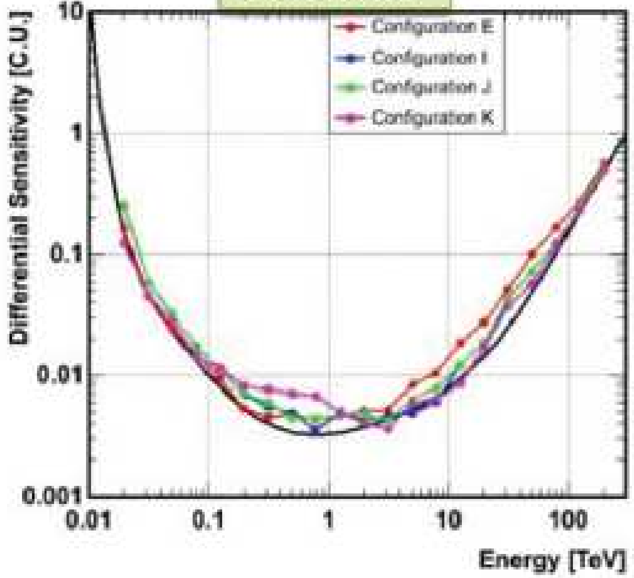
Low E



High E



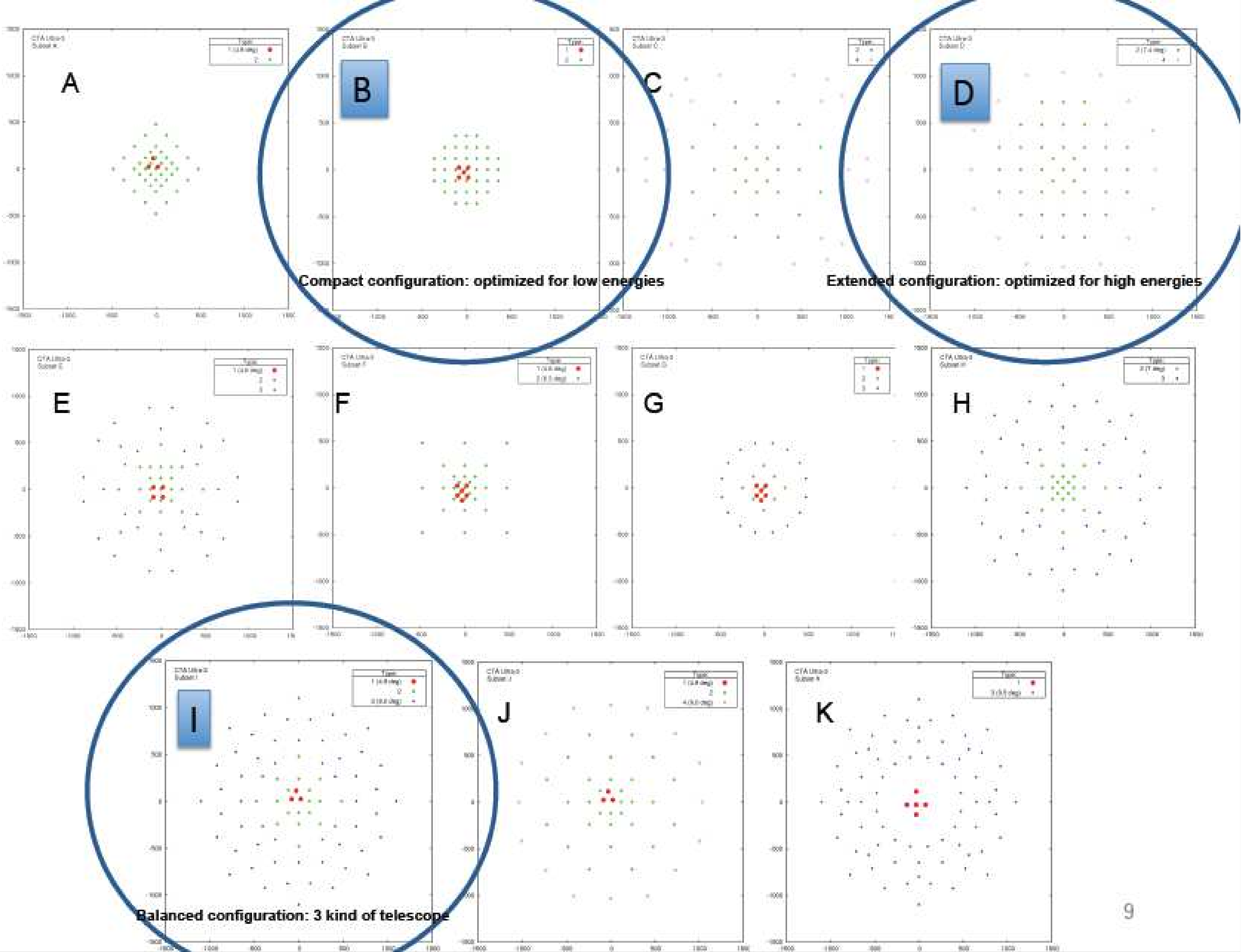
Balanced



Array	1	2	3	4
A	3 (4.9°)	41	-	-
B	5	37	-	-
F	6 (4.8°)	29 (6.3°)	-	-
G	6	9	16	-

Array	1	2	3	4
C	-	29	-	26
D	-	41	-	16
H	-	25 (7°)	48	-

Array	1	2	3	4
E	4 (4.6°)	23	32	-
I	3 (4.9°)	18	56 (9°)	-
J	3 (4.9°)	30	-	16 (9°)
K	5	-	72	-

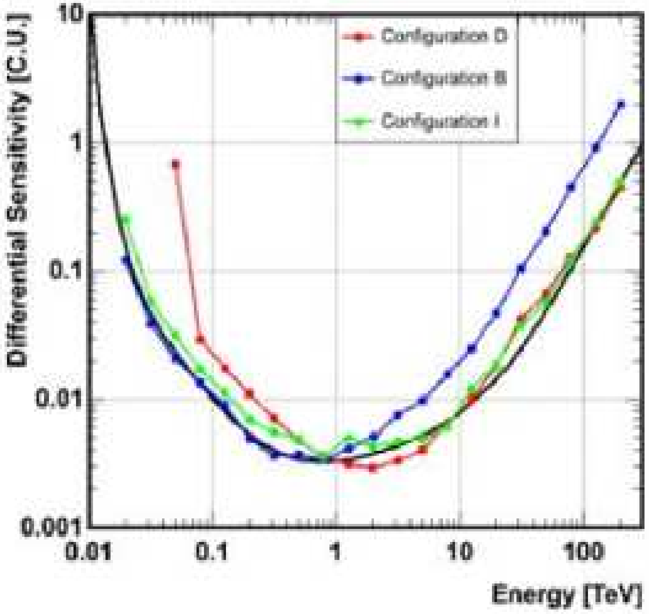


Compact configuration: optimized for low energies

Extended configuration: optimized for high energies

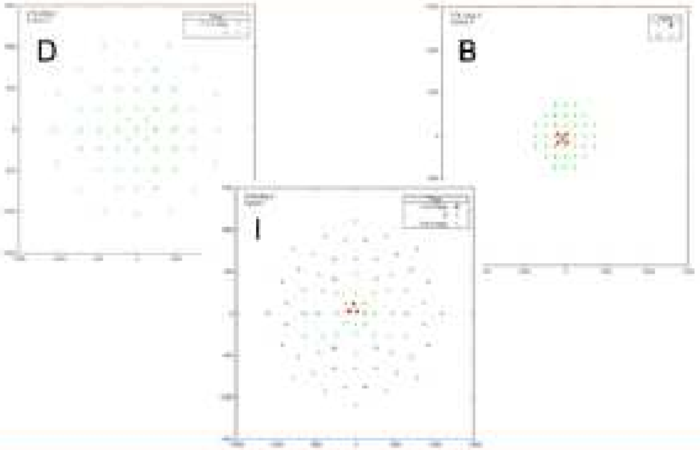
Balanced configuration: 3 kind of telescope

3 representative candidates for starters



Number of telescopes:

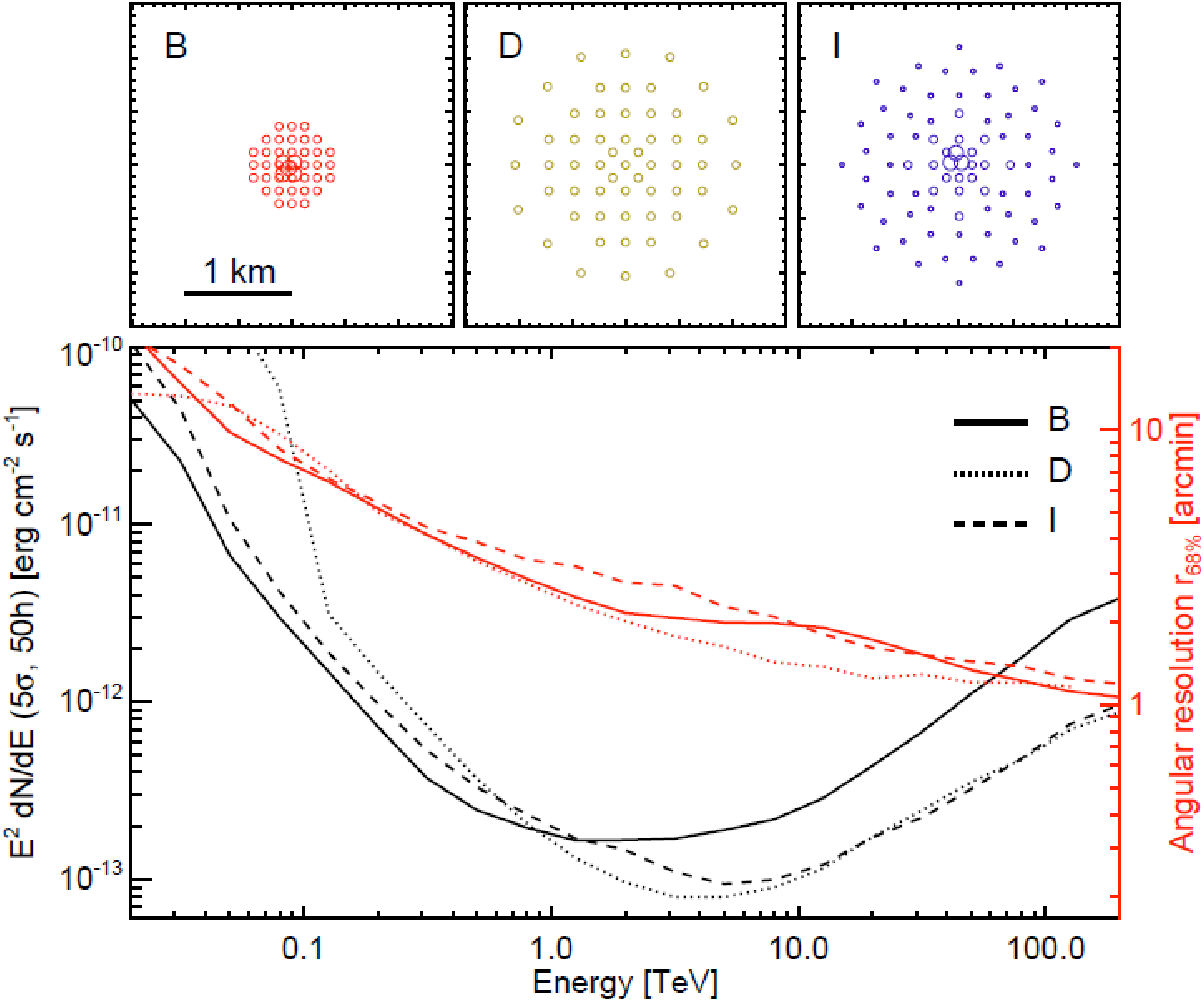
Array	1	2	3	4
D [HE]	-	41	-	16
B [LE]	5	37	-	-
I [wholeE]	3	18	56	-



-B, D, I, not necessarily always better in every aspect with respect to their fellow members in their groups..

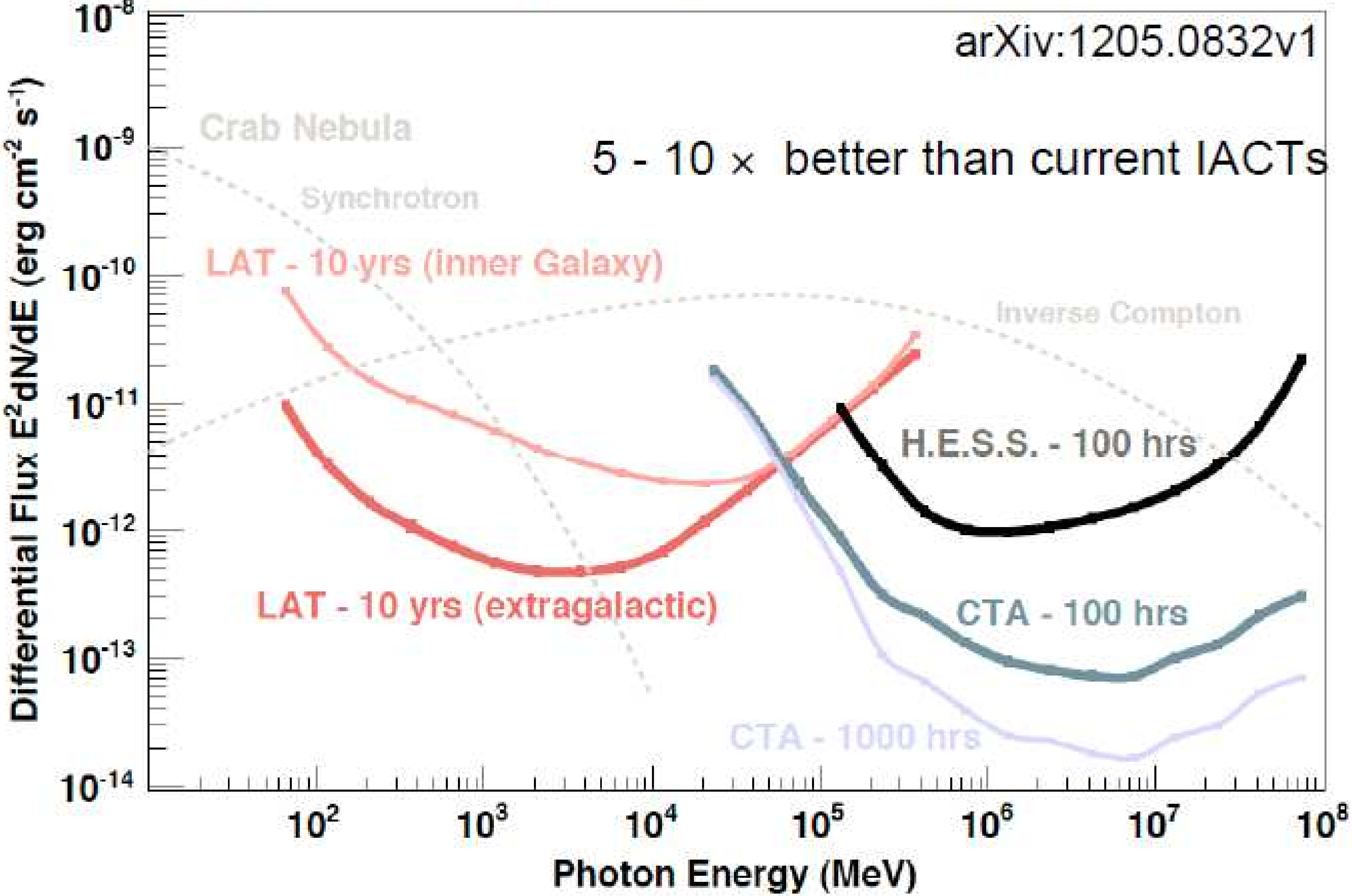
-..but differences within each group are (except a few cases) minimal in other aspects, and sensitivity alone is a good order parameter

B, D, I are best-sensitivity configurations in their corresponding groups (the PHYS-WP has been comparing these configurations thoroughly)

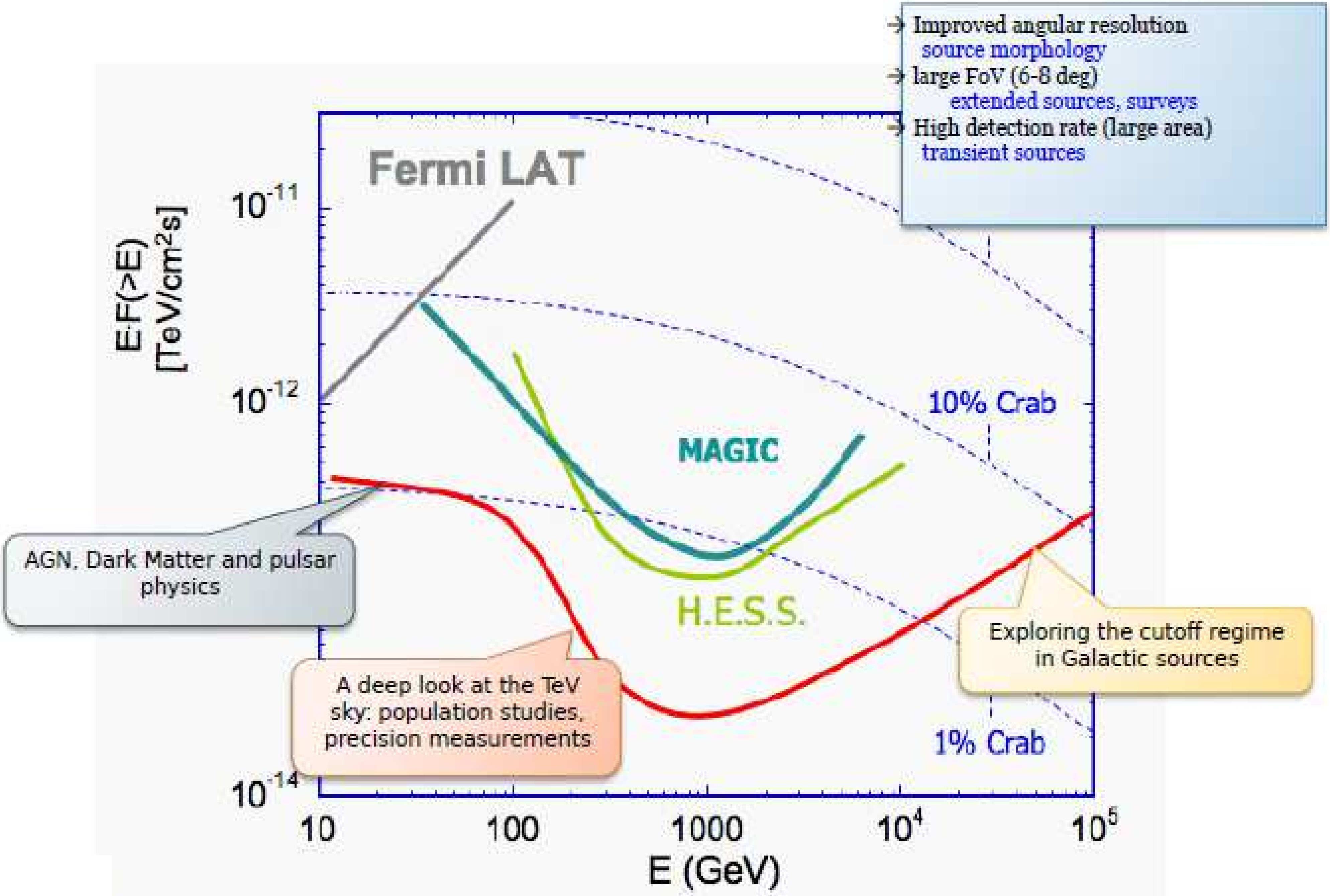

B
1 km
D
I
10^-10
10^-11
10^-12
10^-13
E^2 dN/dE (5σ, 50h) [erg cm^-2 s^-1]
B
D
I
10
1
Angular resolution r_68% [arcmin]
0.1
1.0
10.0
100.0
Energy [TeV]

CTA sensitivity

(Southern site) point-like source



CTA sensitivity



- → Improved angular resolution
  source morphology
- → large FoV (6-8 deg)
  extended sources, surveys
- → High detection rate (large area)
  transient sources

AGN, Dark Matter and pulsar physics

A deep look at the TeV sky: population studies, precision measurements

Exploring the cutoff regime in Galactic sources

CTA Design started !

Expected Design Study Results

- Detailed knowledge of characteristics, availability of a few good site candidates.
- Array layout which optimises physics performance for a given cost (and which is about 1 order of magnitude better than we have now).
- Detailed design and industrial cost estimates for telescopes and associated equipment
- Plan how to organise, produce, install commission, operate the facility; estimate for operating cost
- Model and prototype how to handle and analyse the data
- Small prototype series of common components, to ensure that production issues and costs are understood.

CTA design challenge: finding the right balance

time-proven,
but modest
performance and
limited comfort

too fancy,
not for daily use

or maybe
this

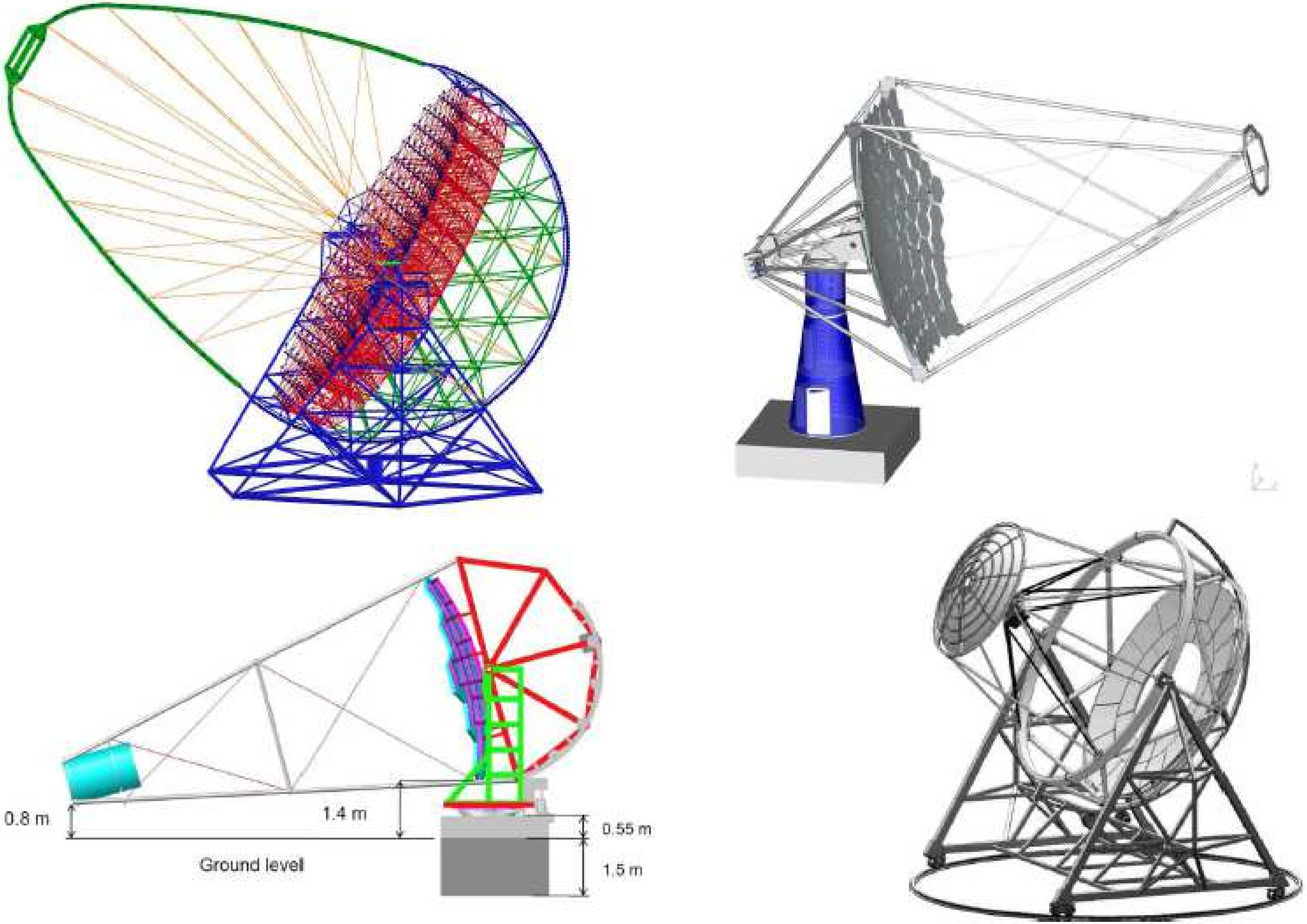


Fig. 5. – **Top left**: consept of a 23 m diameter LST with parabolic dish and f/d=1.2. **Top right**: consept of a 12 m diameter MST with a Davies-Cotton dish and f/d=1.4. **Bottom left**: consept of a 6 m diameter SST with a Davies-Cotton dish and f/d=1.4. **Bottom right**: consept of a dual mirror Schwarzschild-Couder telescope.

Cost per telescope, complexity

Lesson from MC:
Hard to beat telescope numbers & area covered

Big challenge:
cost effective production and high reliability

Expect best overall science performance about here

Performance

Possible CTA sites

Site choice

- How to compare different sites? Issues include
  - Astronomical quality
  - Infrastructure cost
  - Access
  - Risks
  - …

- In the end, it basically boils down to a cost argument: For a given budget, which site will provide best sensitivity?

- E.g. higher access cost at a remote site will imply fewer telescopes, compensating a possible gain in observation time
- … of course, quantifying everything may be hard …

Cost

- Given for ESFRI: 150 M€ investment cost (in 2006)
  - 100 M€ south site
  - 50 M€ north site
- Escalates to about 190 M€ for 2013-2018 construction period
- Update only once we have semi-realistic numbers
- What if there is not enough funding secured at t_0?
  - An issue for the Resource Board …

Operating costs

- Typical facilities require annual operating costs of 7% to 10% of investment cost
- For CTA this would imply 13 – 19 M€ per year
- For 500 CTA scientists, this is 25-40 k€ per person
  - About 10 x more than current instruments
- Major concern for (some) funding agencies

→ Need to

- Understand operating costs very well
- Minimize operating costs

→ Is >10 M€ operating costs plausible?

Contributions to operating costs

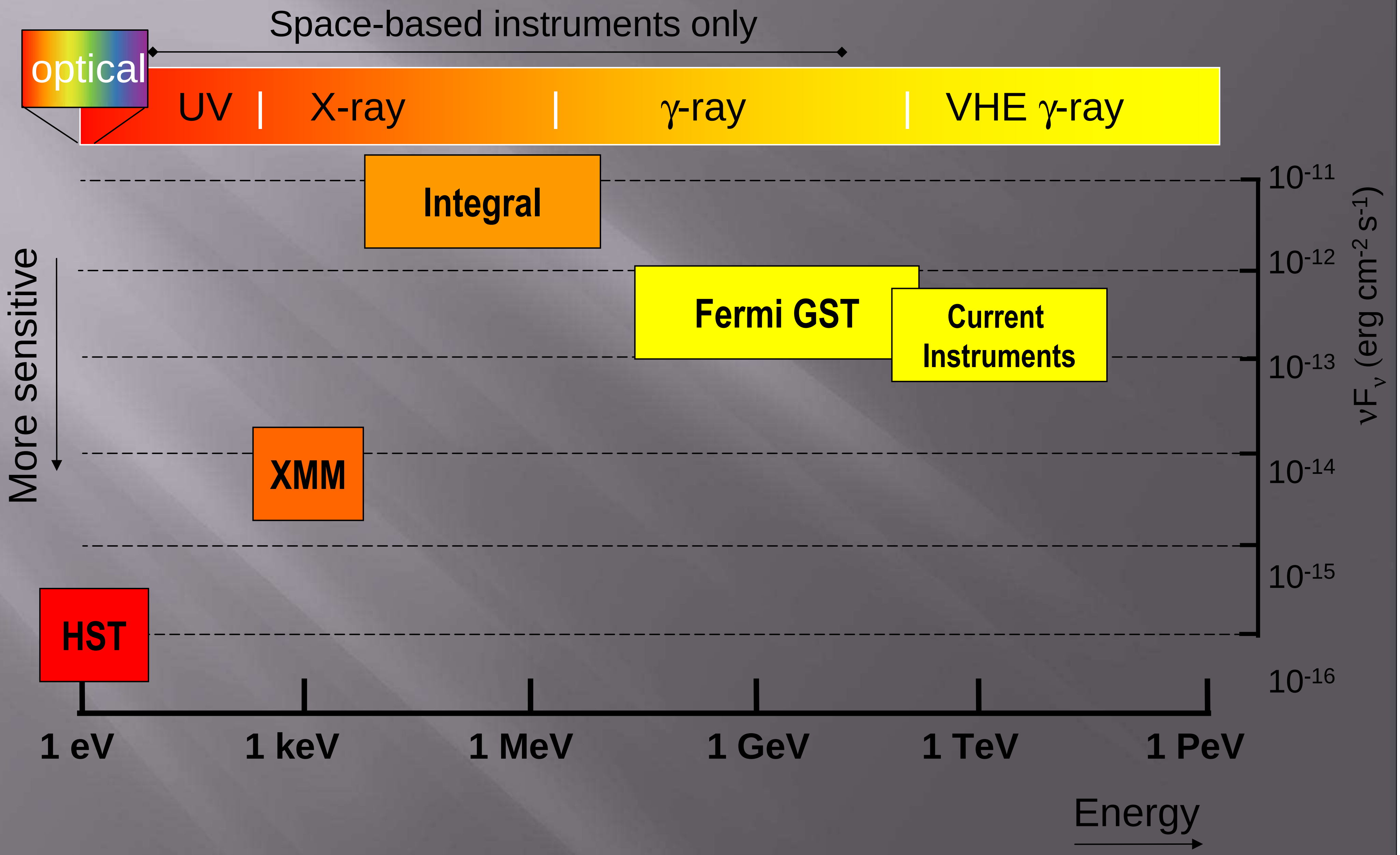
- Personnel
  - Management
  - User interfacing & proposal handling
  - Shift operation
  - Instrument maintenance
  - Data centers & user support
- Utilities
  - Power
  - Telecommunications
- Infrastructure
  - Site services (rooms, food, …)
  - Site & building maintenance
- Instrument maintenance
  - Mirror recoating
  - Photosensor replacement
- Travel
- …

Non-exhaustive list

CTA : The Observatory

- CTA will be a normal astrophysical observatory, open to the community, with professional operators, A0s and support for data analysis.
- Data will be public after some time (1 year ?)
- 50% of observation time for construction consortium

CTA: In Context



Space-based instruments only

optical

UV | X-ray | γ-ray | VHE γ-ray

Integral

Fermi GST

Current Instruments

XMM

HST

More sensitive

10^{-11}

10^{-12}

10^{-13}

10^{-14}

10^{-15}

10^{-16}

νF_ν (erg cm^{-2} s^{-1})

1 eV **1 keV** **1 MeV** **1 GeV** **1 TeV** **1 PeV**

Energy

Summary

- The current generation of ground-based γ-ray telescopes have provided a wealth of information on many new sources
- Many open physics questions remain
- CTA aims to answer many of these, and provide an observatory for the wider astrophysical community
- Highly ranked in many European roadmaps
- The design study is underway

Thanks!