Observations with the High Energy Stereoscopic System

German Hermann, MPI für Kernphysik
(for the H.E.S.S. Collaboration)

www.mpi-hd.mpg.de/HESS

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- The H.E.S.S. experiment
- Overview of observations
  - Classes of Galactic sources
  - Extragalactic physics
- Quantum Gravity
- Dark Matter search
- A glance on H.E.S.S. phase 2

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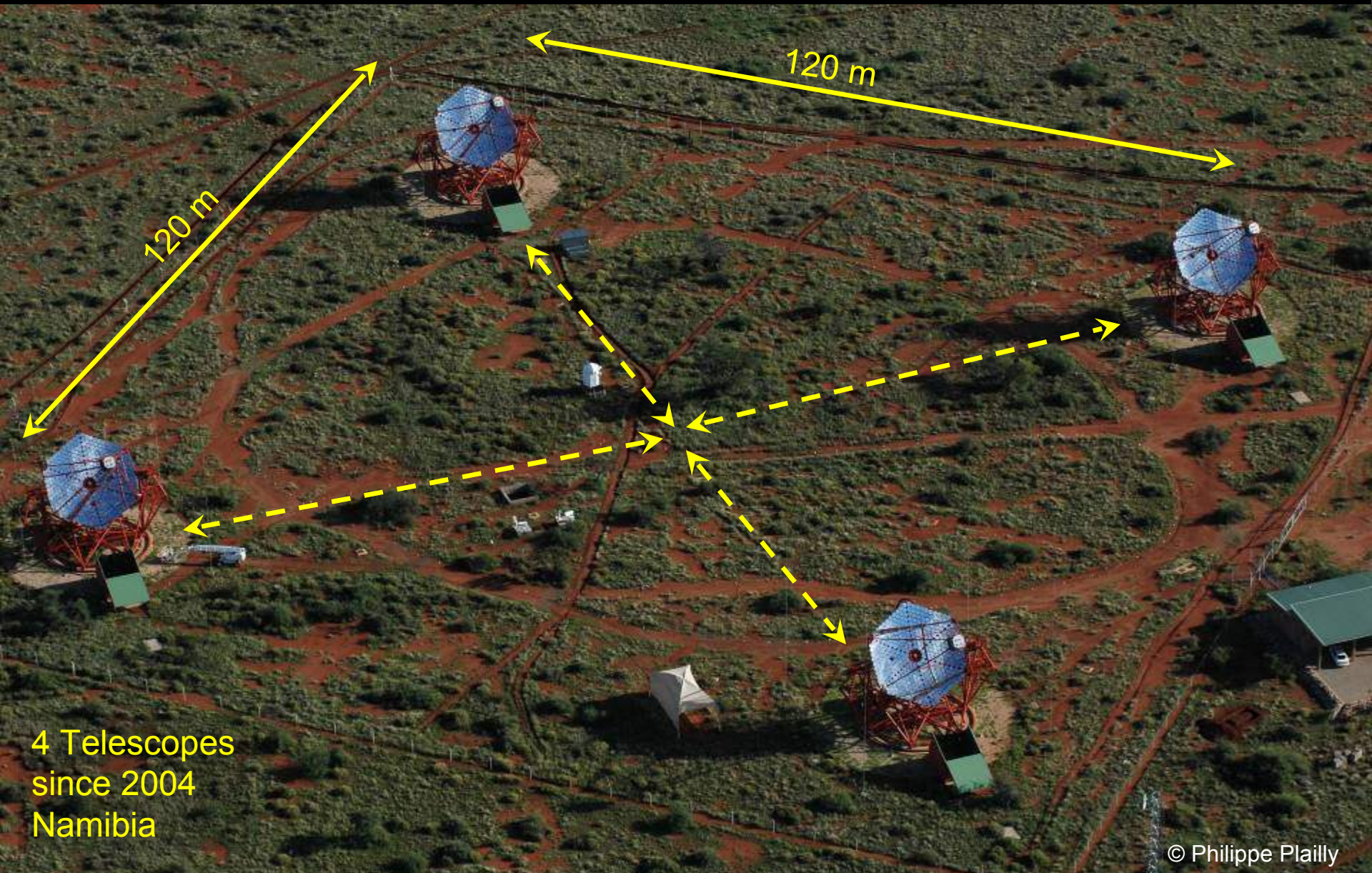
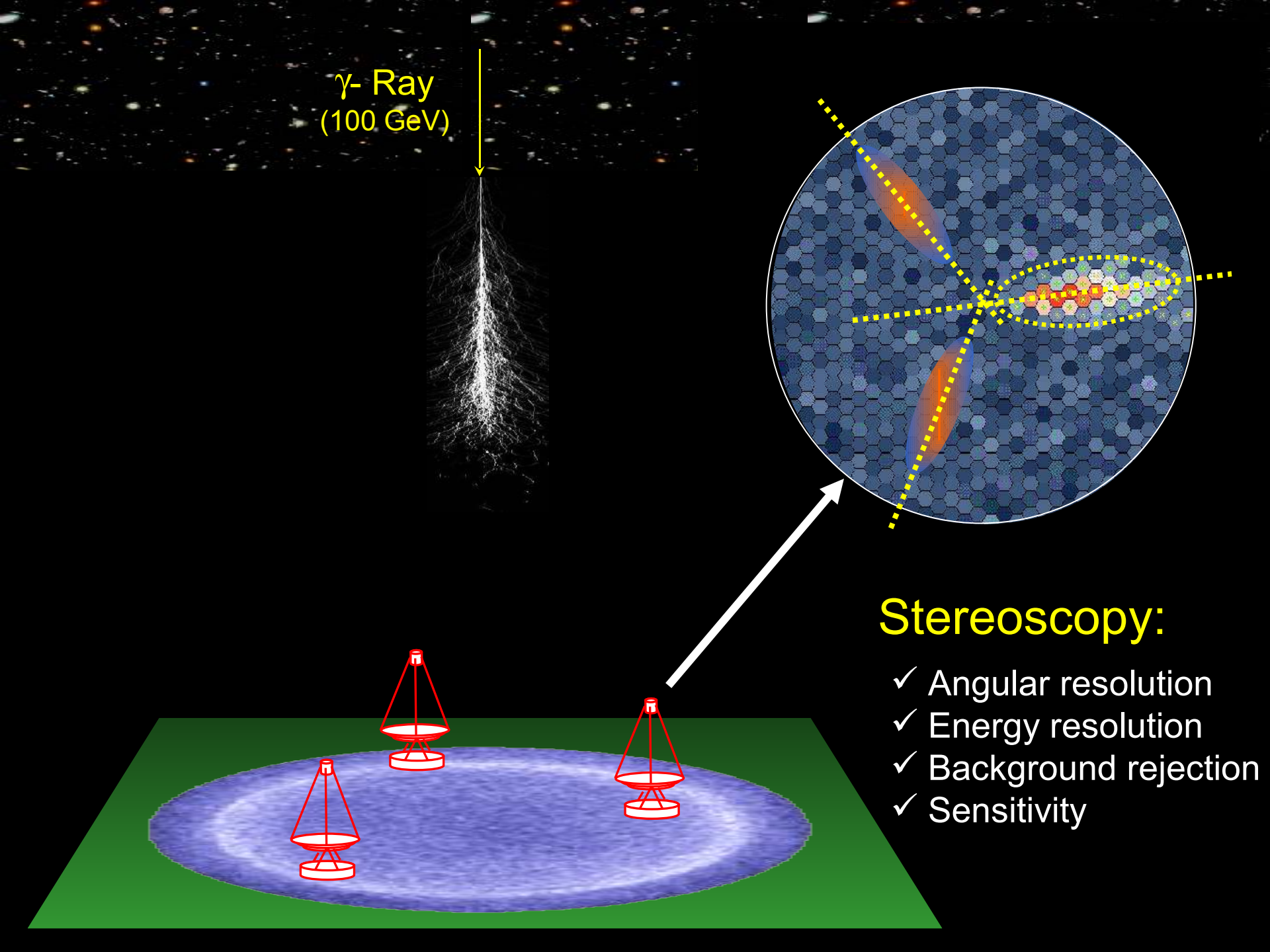
See also:
→ Bruno Khelifi
→ Andreas Zech
} Sunday morning

www.mpi-hd.mpg.de/HESS

High Energy Stereoscopic System H.E.S.S.

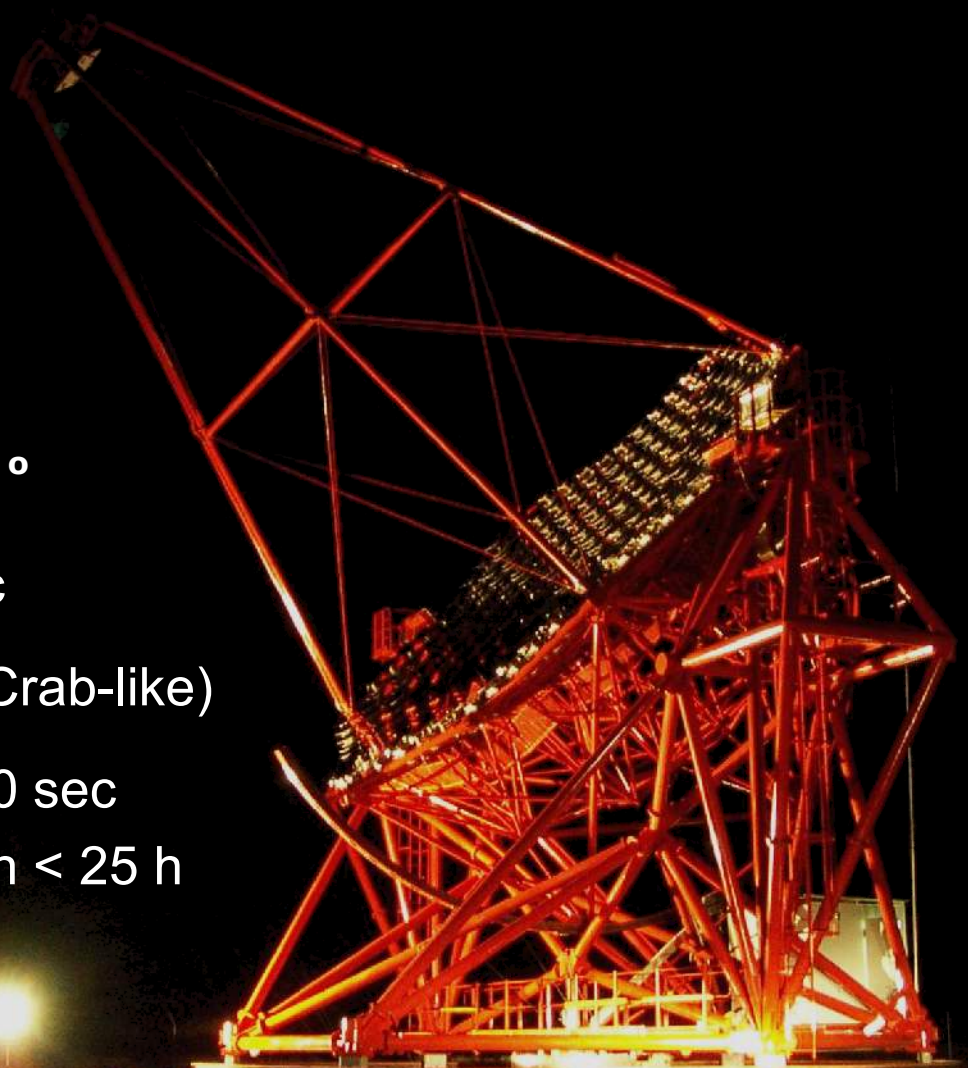



γ- Ray
(100 GeV)
Stereoscopy:
✓ Angular resolution
✓ Energy resolution
✓ Background rejection
✓ Sensitivity

Stereo Performance Parameters

State of the Art

Energy threshold:	100 GeV
Energy resolution:	15 %
Field of view:	~ 4 deg
Angular resolution:	0.05° - 0.1°
Pointing accuracy:	~ 10 arcsec
Signal Rate:	~55 / min (Crab-like)
Sensitivity:	1 Crab in 30 sec 0.01 Crab in < 25 h



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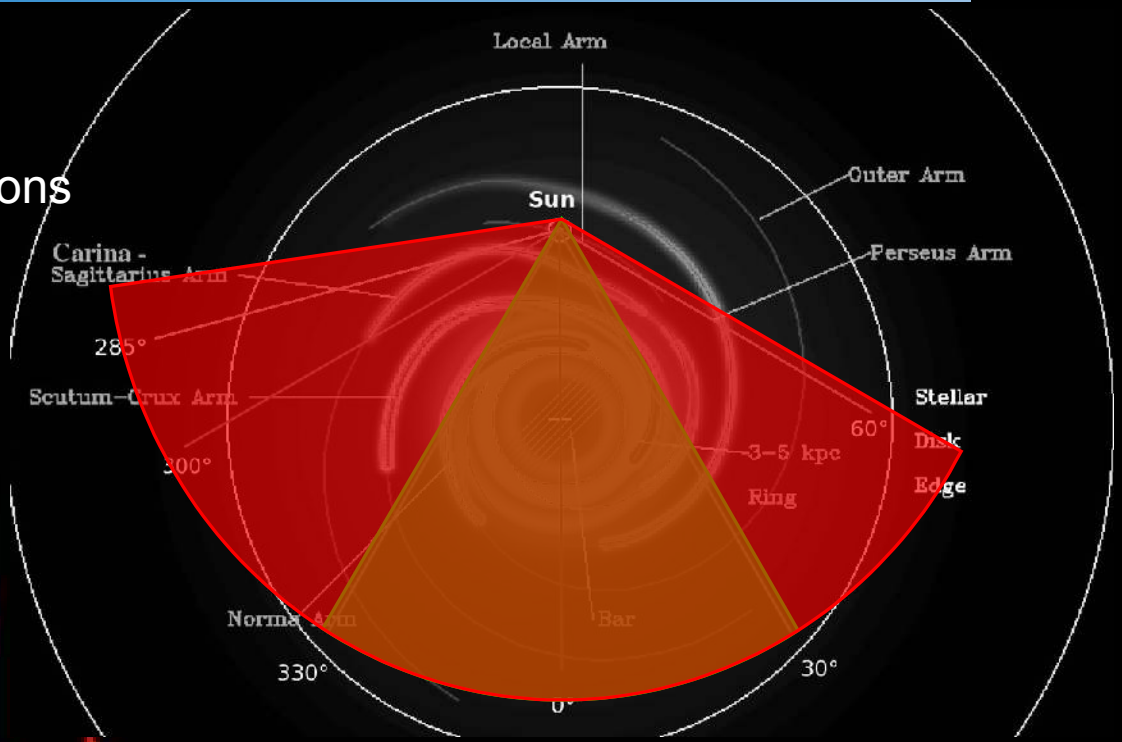
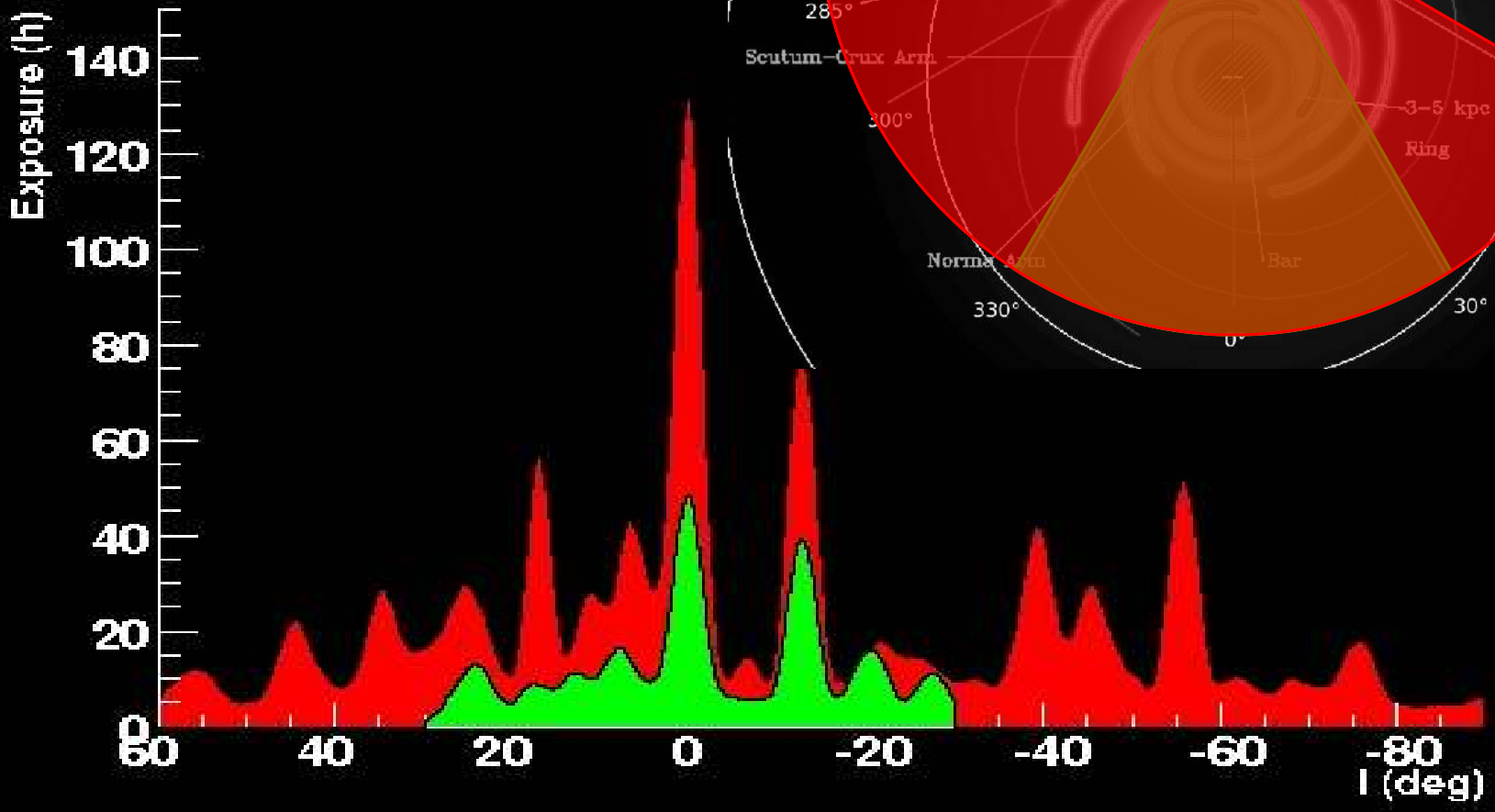
H.E.S.S. Galactic Plane Survey

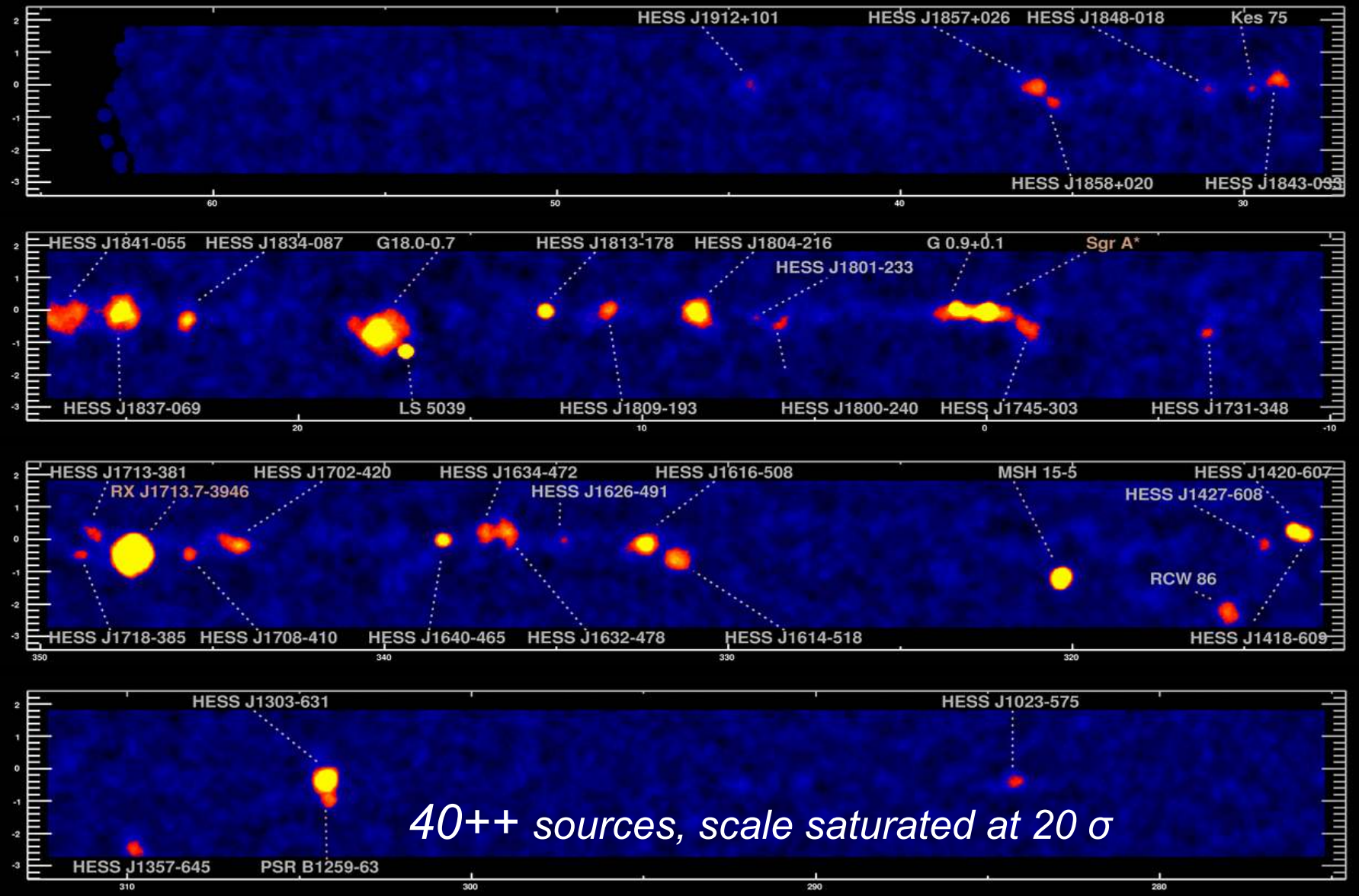
~ 400+125 h in survey mode

++ pointed follow-up observations

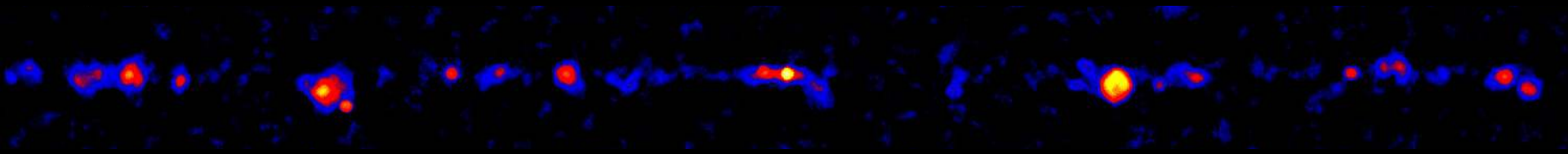




H.E.S.S. Galactic Plane Survey



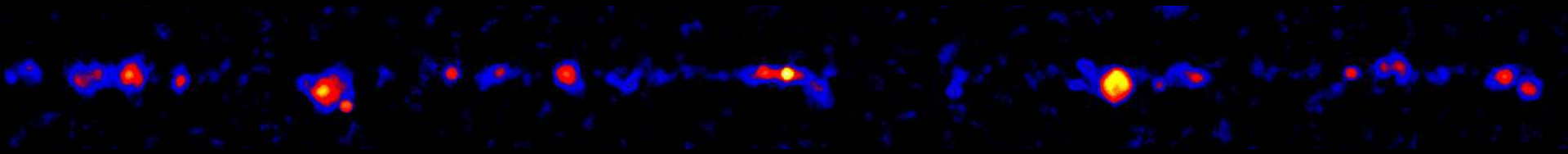
Classes of Galactic Sources



- Stellar winds
- Supernova remnants
- Pulsar wind nebulae
- Binary Systems
- Molecular Clouds

- Galactic center
- “Dark sources”

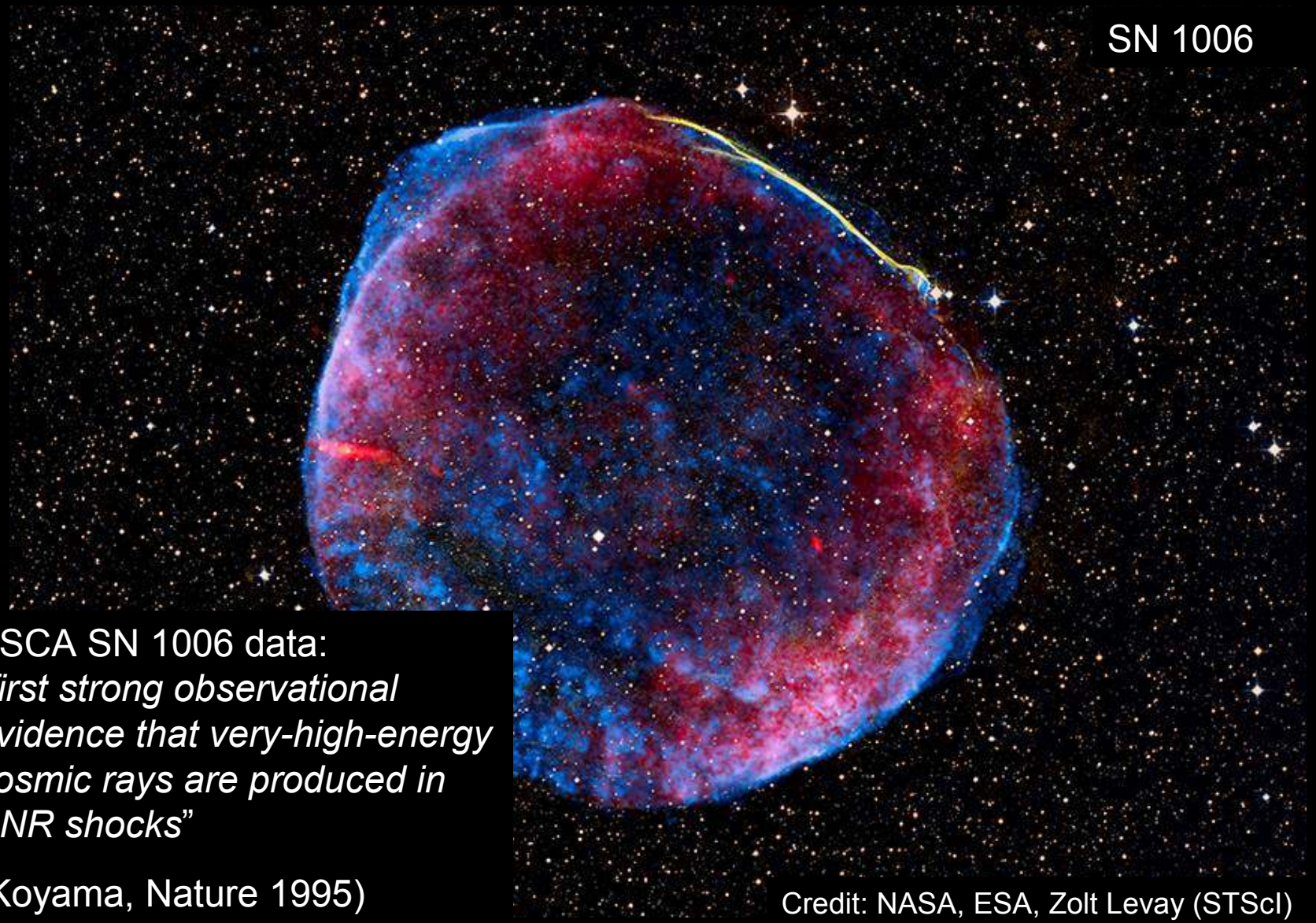
Classes of Galactic Sources



- Supernova remnants

- "Dark sources"

SNRs as Sources of Galactic Cosmic Rays



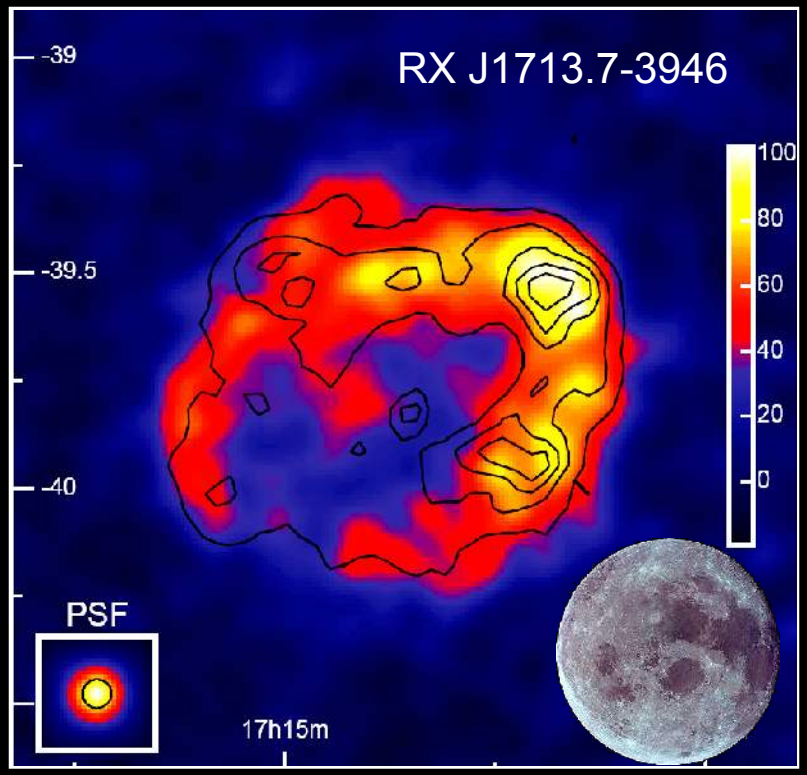
ASCA SN 1006 data:
"*first strong observational evidence that very-high-energy cosmic rays are produced in SNR shocks*"

(Koyama, Nature 1995)

Credit: NASA, ESA, Zolt Levay (STScI)

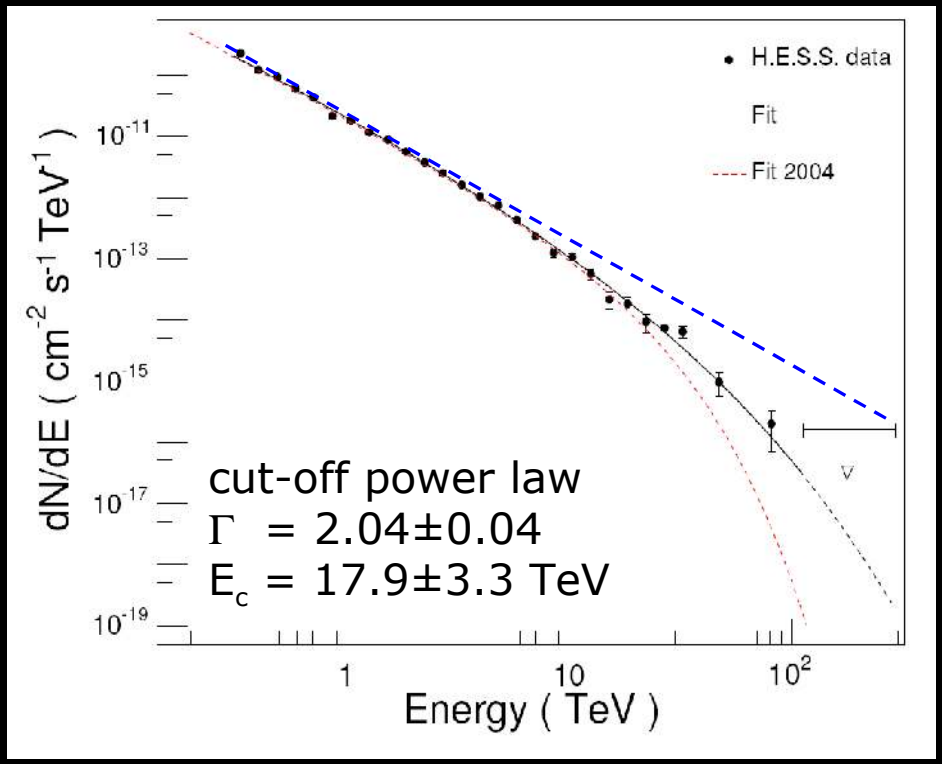
TeV Gamma-Rays from (young) SNRs

See also: H.E.S.S., Nature (2004)



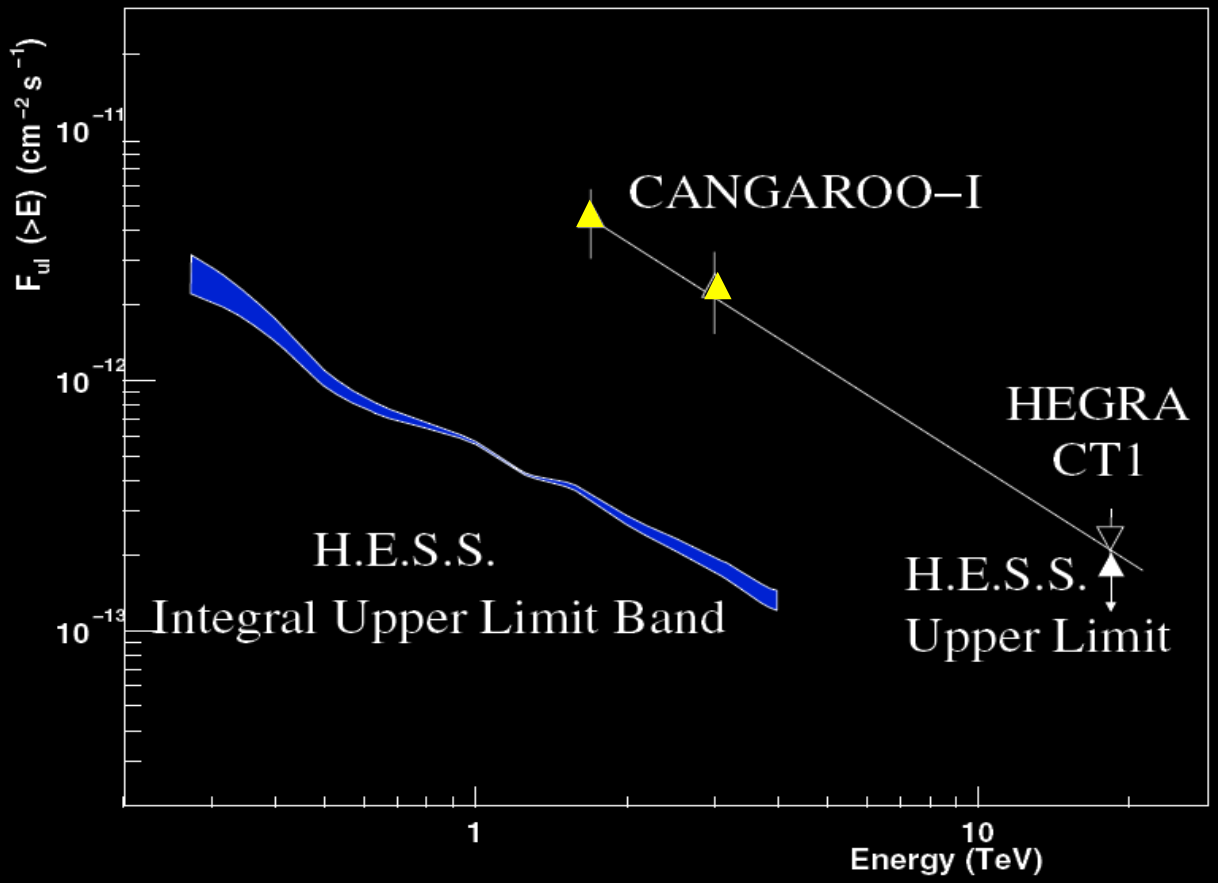
2004-2006 Data

Particle acceleration to beyond 100 TeV



Proof of TeV emission from the shell of SNRs

The dark ages of SN 1006

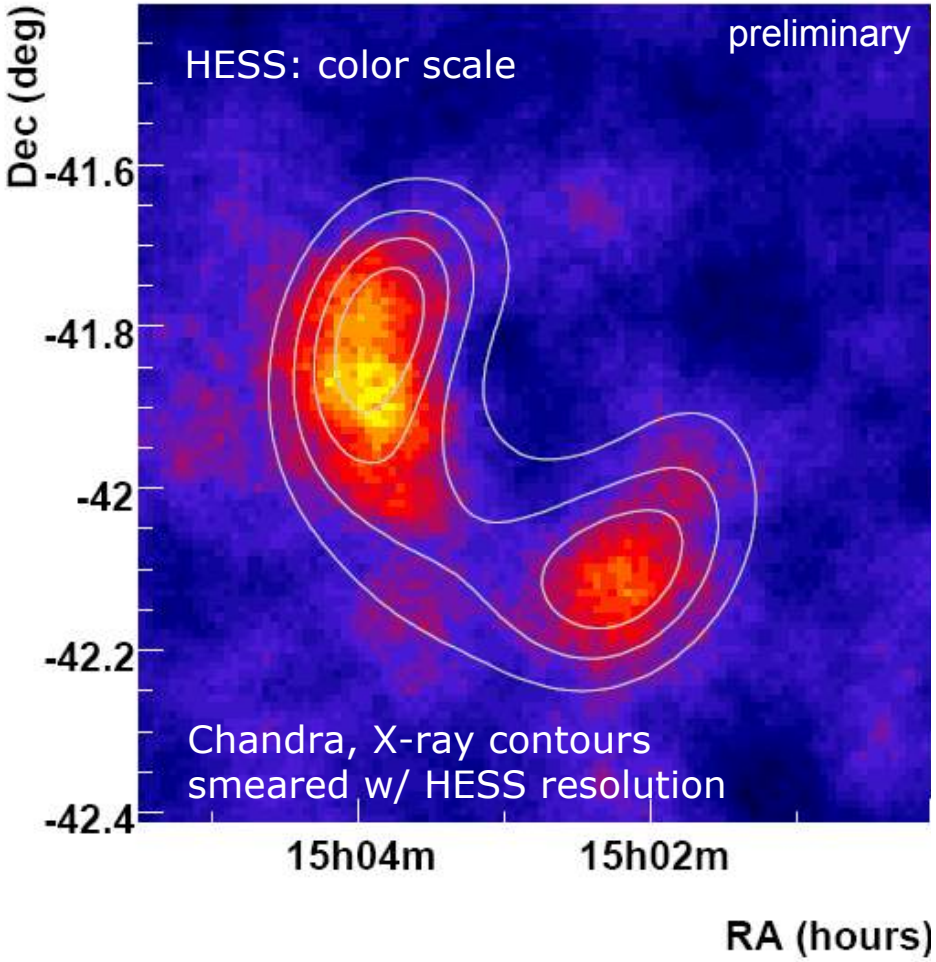


- 1998 : Detection by CANGAROO (Tanimori, ApJ 1998)
- 2005 : HESS upper limits, well below CANGAROO flux (HESS, A&A 2005)

SN 1006 revealed in TeV gamma-rays

103 h of data (2003-2008)
>5 sigma signal (~590 γ-rays) in pre-defined NE region

preliminary

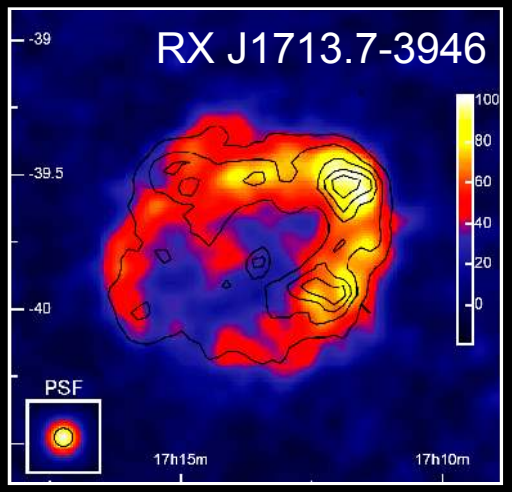


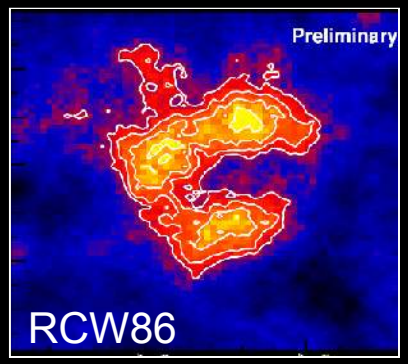
- TeV flux level: ~ 1 % of Crab
- Within statistics, both *leptonic* (B ~ 30 μG) and *hadronic* (n ~ 0.1 / cm^3) scenarios seem reasonable

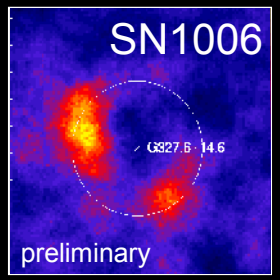
→ a clear case for GLAST and CTA

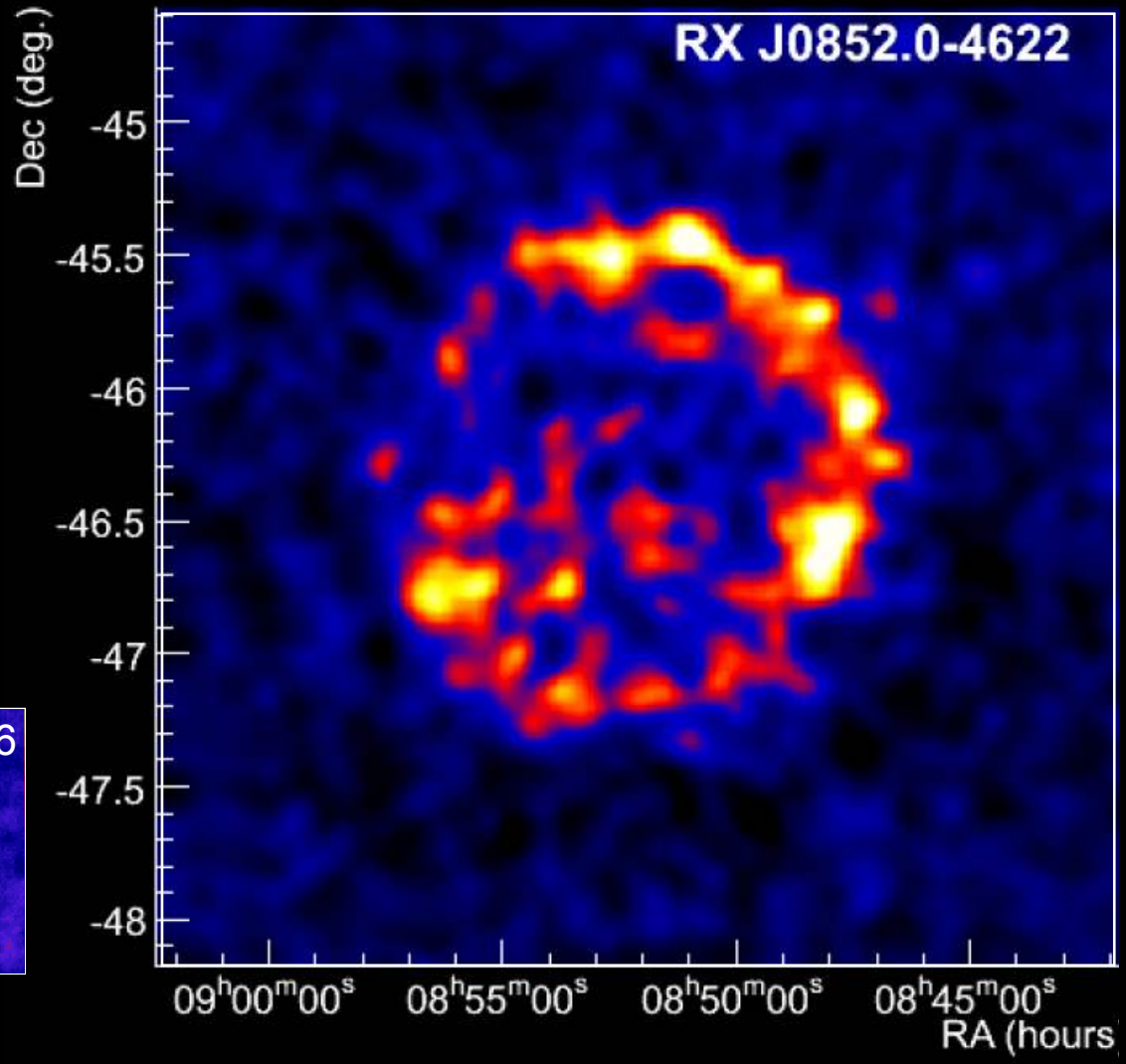
HESS (Gamma08)

The growing family of shell-type TeV SNRs …



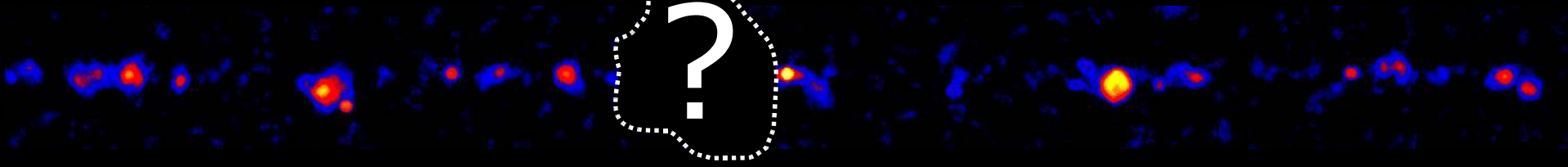






Maps ~ to scale

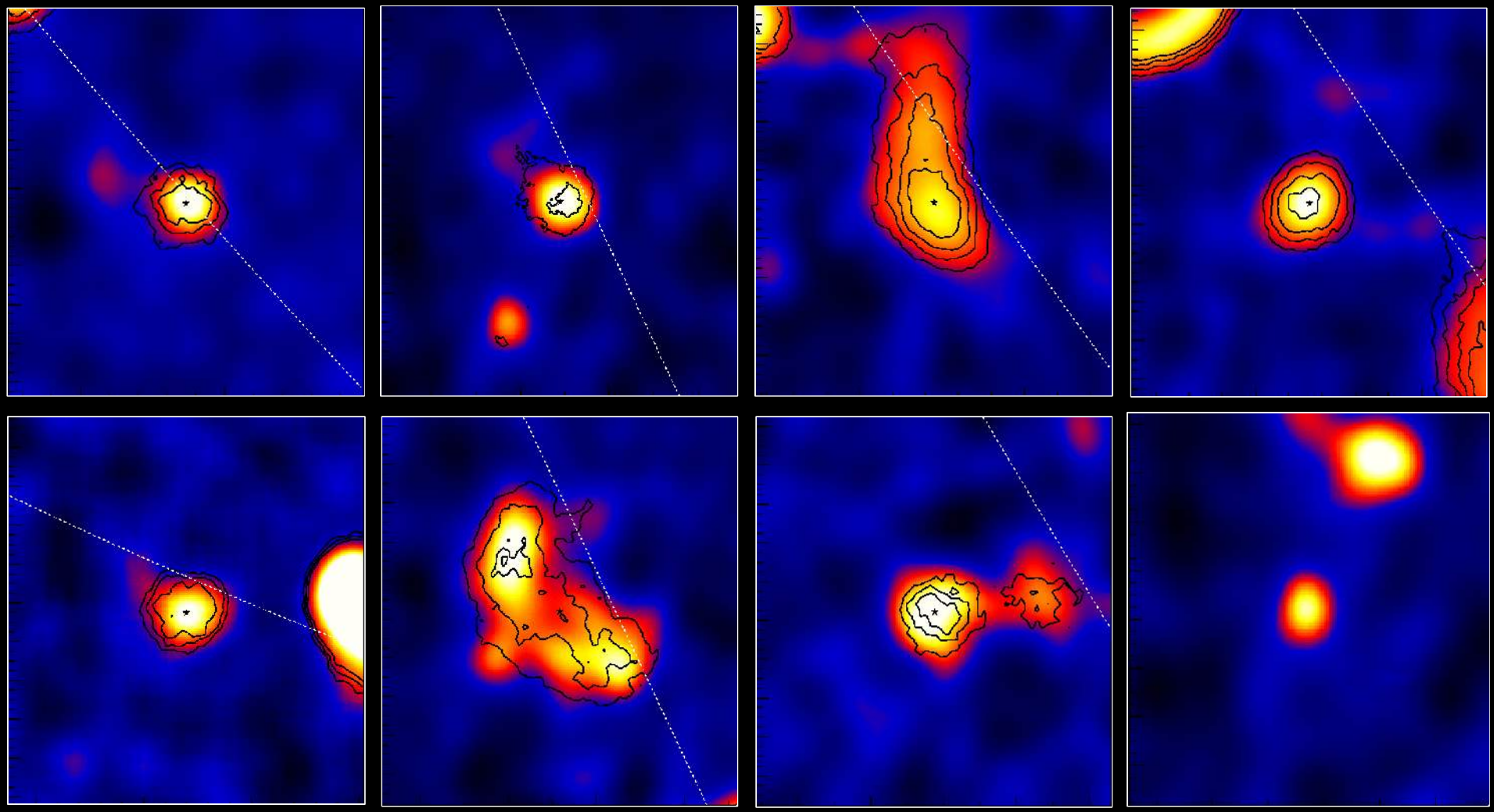
Classes of Galactic Sources



- "Dark sources"

Discovery Potential: "Dark Sources"

A bias free view on the sky: → new class of TeV sources



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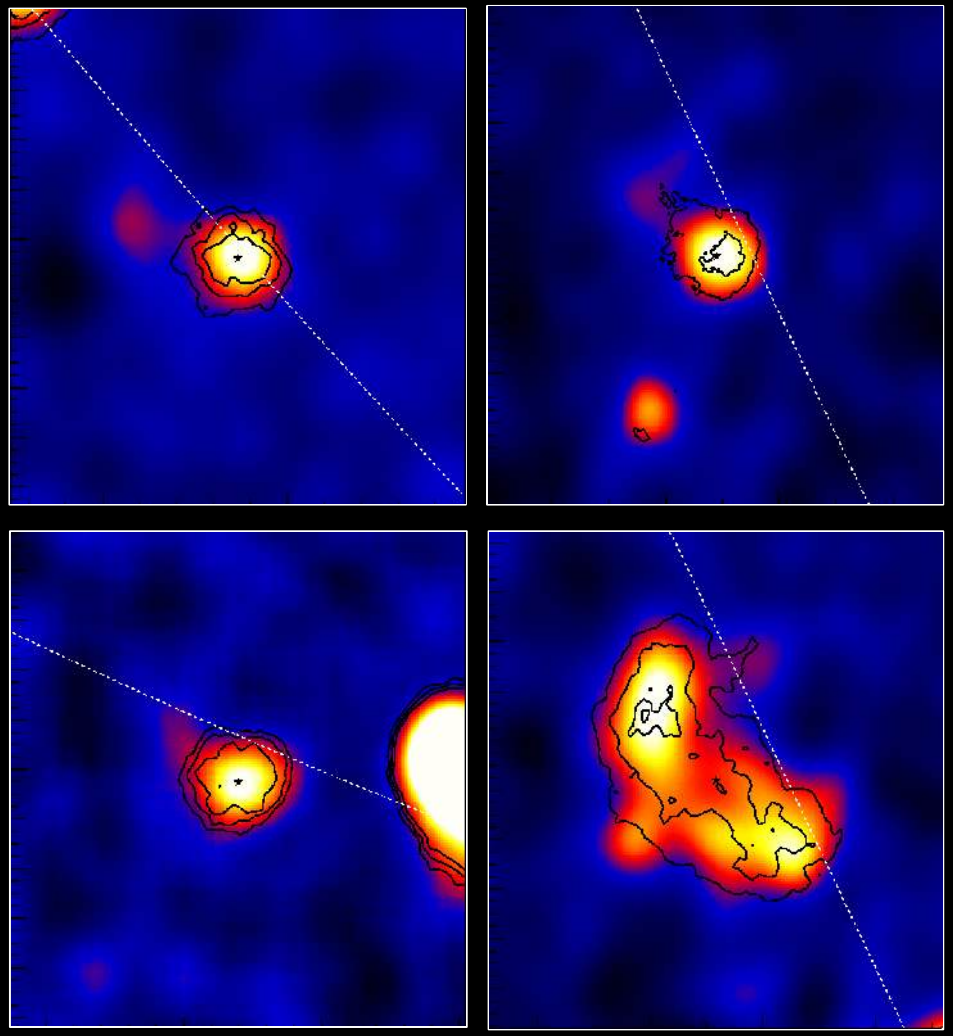


No counterparts in other energy bands seen (radio, IR, optical, X-ray, …)

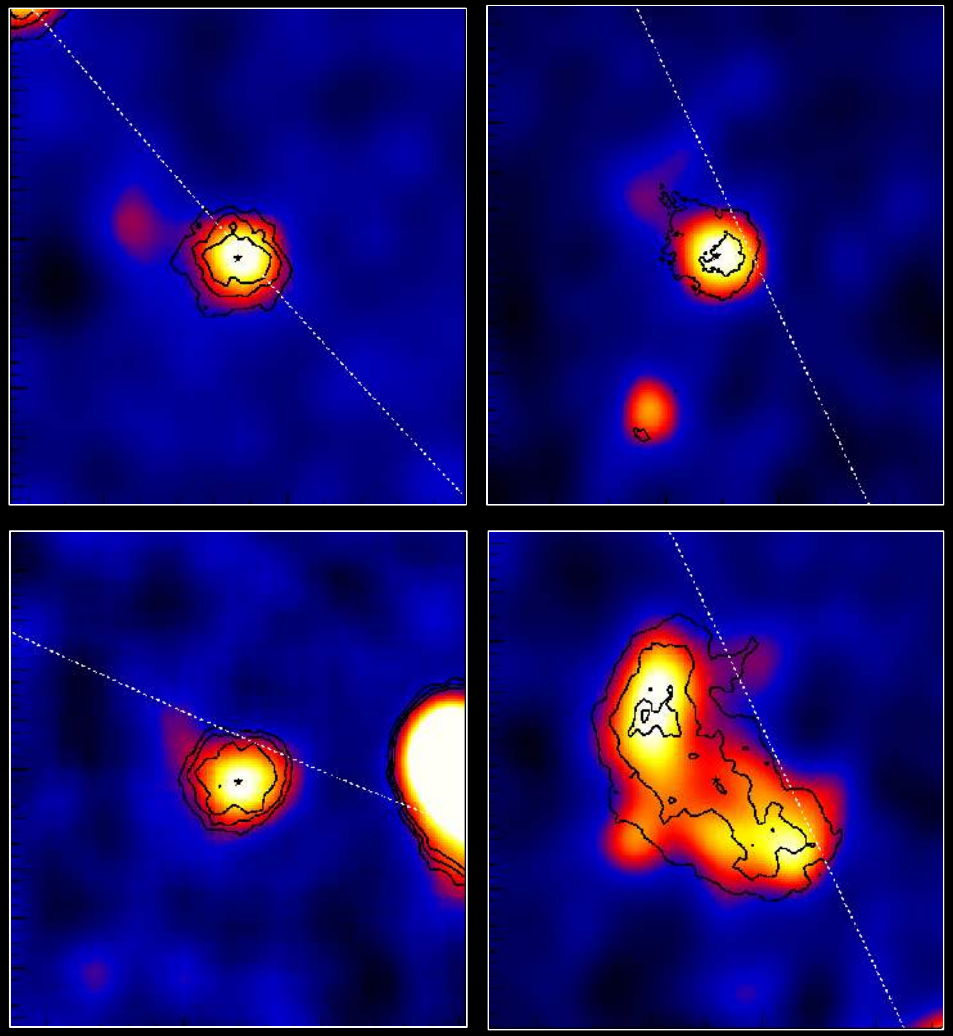
Aligned with Galactic plane
All are extended: O (10 arcmin)
Hard spectrum: $\Gamma \sim$ 2.1 … 2.5

→ Maximum energy output of these sources in TeV γ-rays
→ Hadron accelerator ?
→ Old PWN ?
→ GRB remnant ?
→ Dark Matter ?

HESS A&A 477 (2008)

Discovery Potential: "Dark Sources"

A bias free view on the sky: → new class of TeV sources

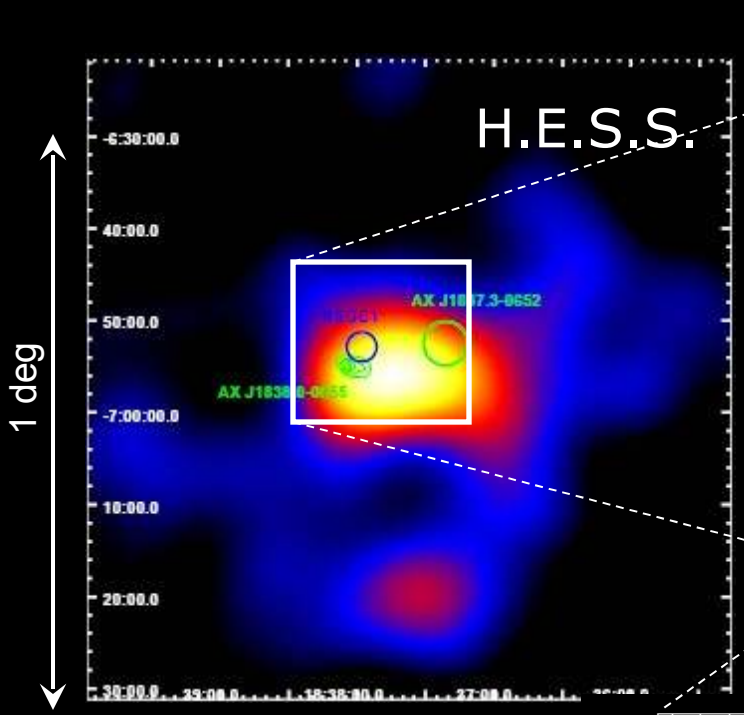


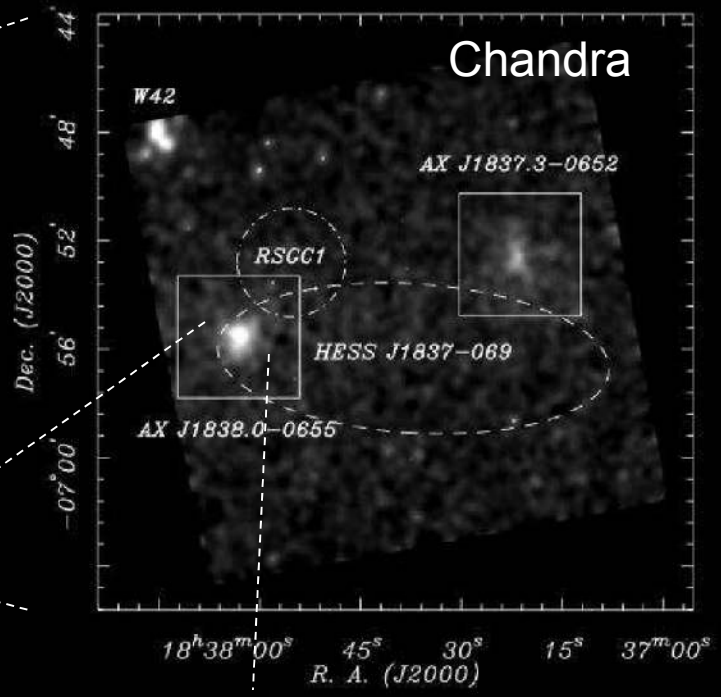
No counterparts in other energy bands seen (radio, IR, optical, X-ray, …)

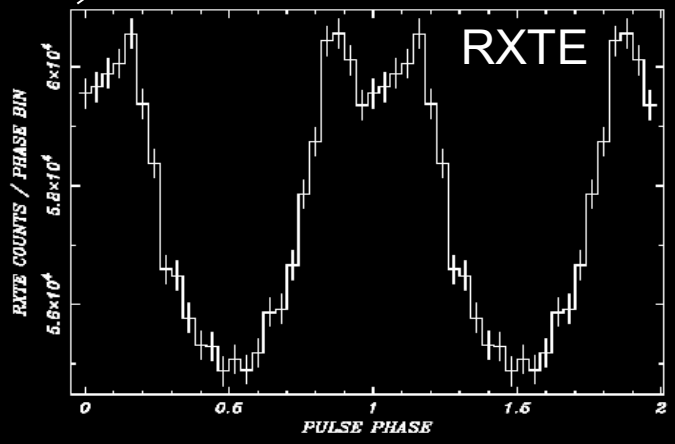
→ More sensitive X-ray and radio observations following the TeV detection

HESS A&A 477 (2008)

Pulsar discovery triggered by H.E.S.S.







HESS J1837:
7 ‘ x 3 ‘ extension
Flux ~ 0.13 Crab

2 % of dE/dt of Pulsar needed to power TeV flux !

Discovery of PSR J1838−0655
Gotthelf & Halpern (2008)
period 70.5 ms,
spin-down energy loss
~5.5 x 10^{36} ergs/s

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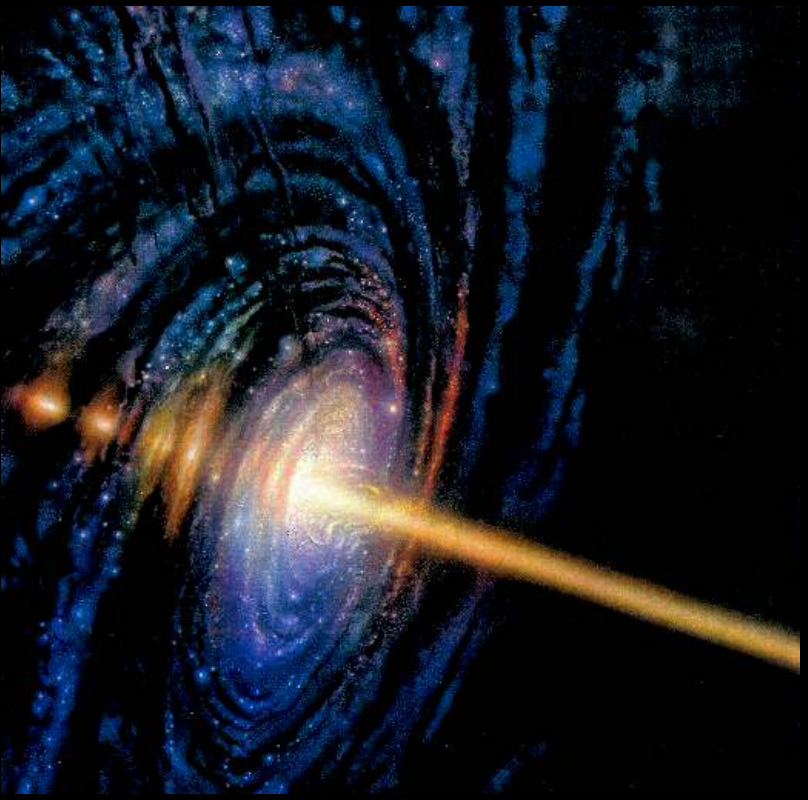
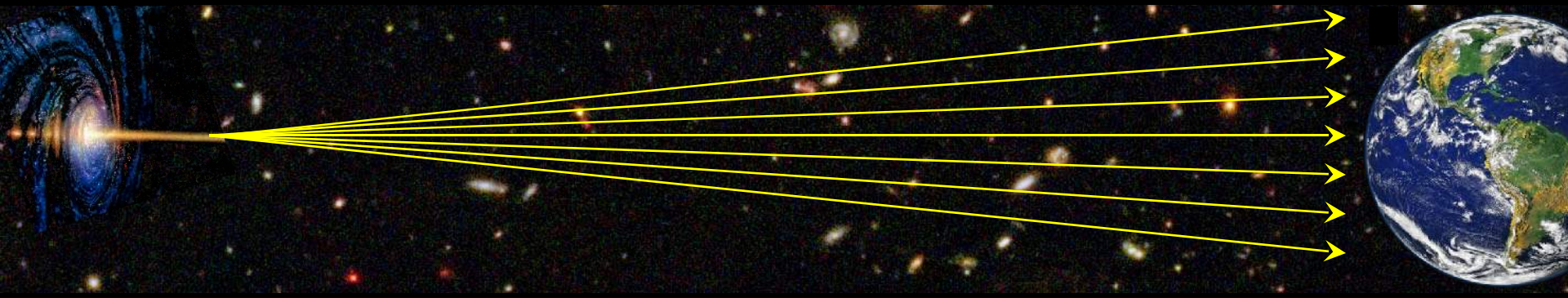
Extragalactic Physics with H.E.S.S.



Object	Z	Type
M87	0.004	AGN (FR I)
Mkn 421	0.030	BLLac (HBL)
PKS 0548-322	0.069	BLLac (HBL)
PKS 2005-489	0.071	BLLac (HBL)
RGB J0152+017	0.08	BLLac (HBL)
PKS 2155-304	0.116	BLLac (HBL)
1ES0229+200	0.139	BLLac (HBL)
H2356-309	0.165	BLLac (HBL)
1ES 1101-232	0.186	BLLac (HBL)
1ES 0347-121	0.188	BLLac (HBL)
PG 1553+113	>0.25 ?	BLLac (HBL)

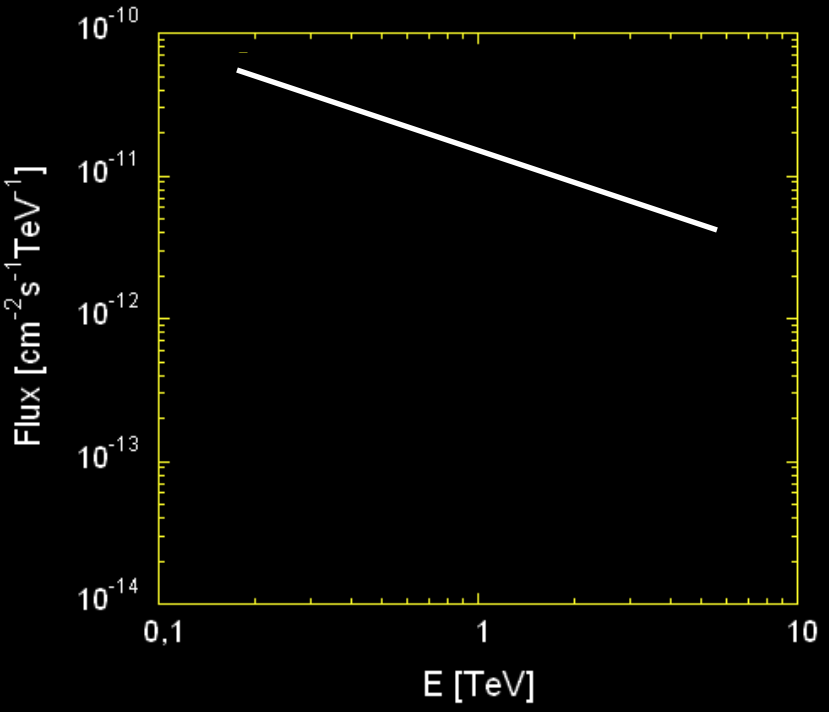
Detection of 11 AGN
Discovery of 8 AGN
Upper Limits on >20 Objects (< 0.01 … 0.05 Crab)

The Extragalactic Background Light



EBL contains information on history of star- and galaxy formation

→ Direct measurement very difficult due to foreground light



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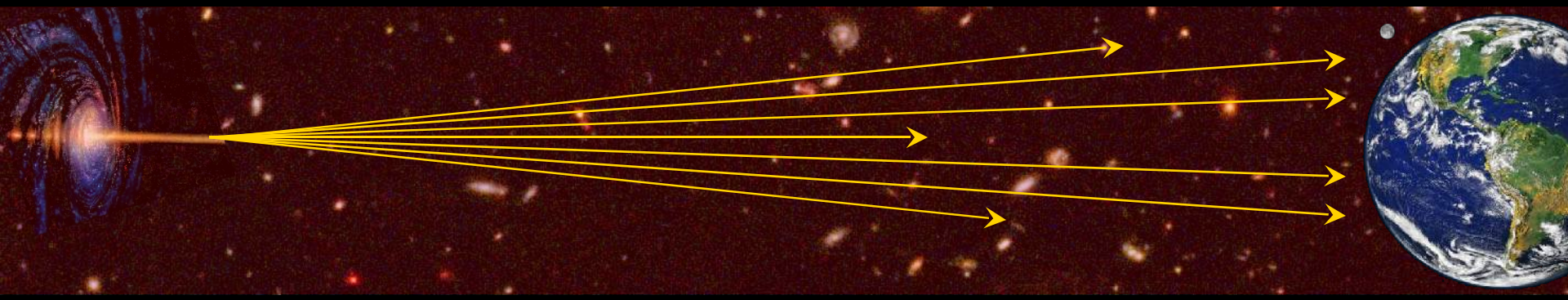
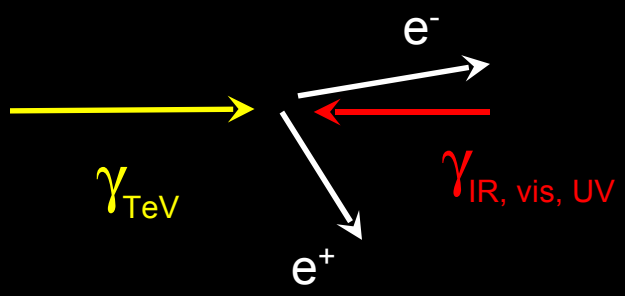
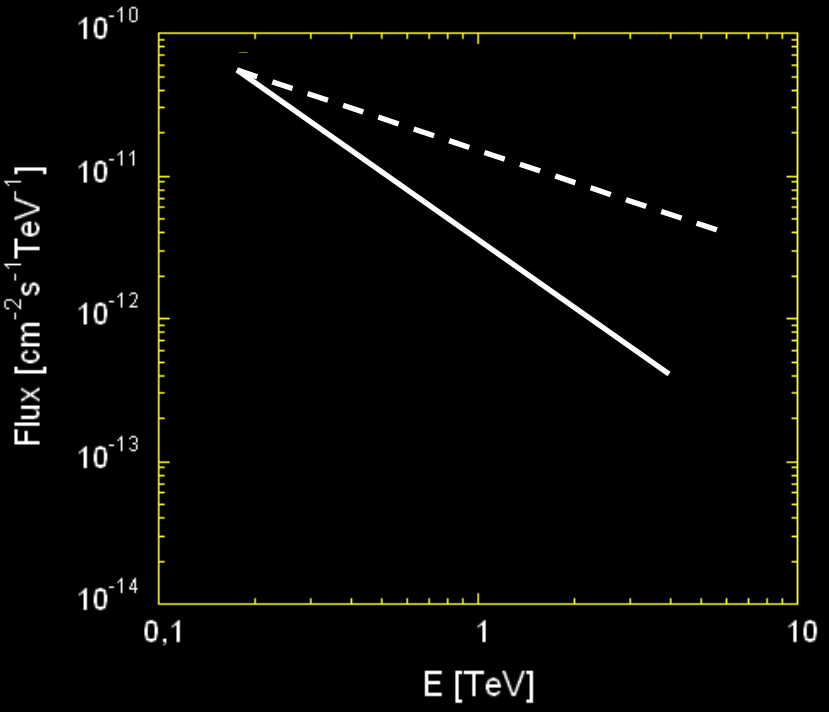




Absorption through pair production with diffuse EBL in FIR to UV (for TeV to GeV)



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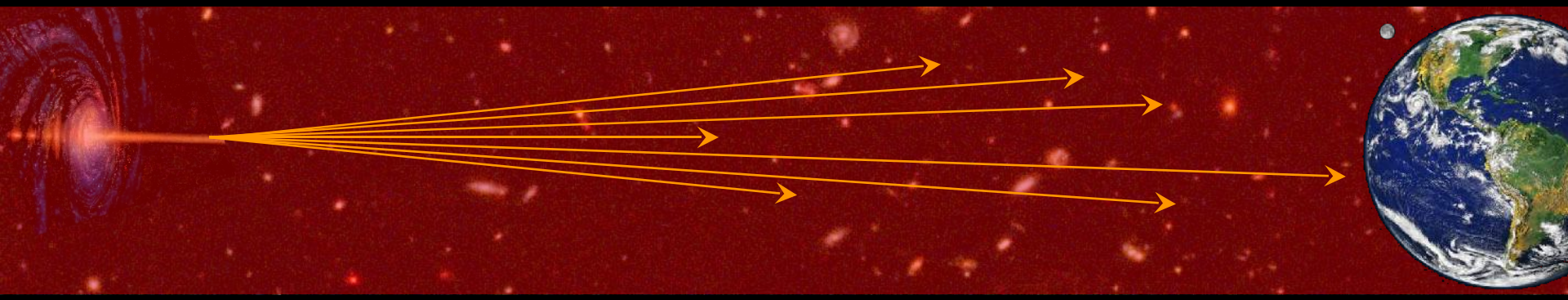

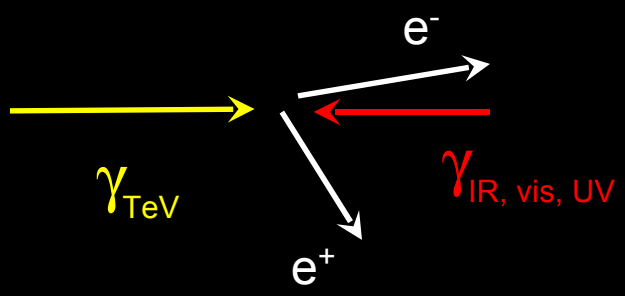

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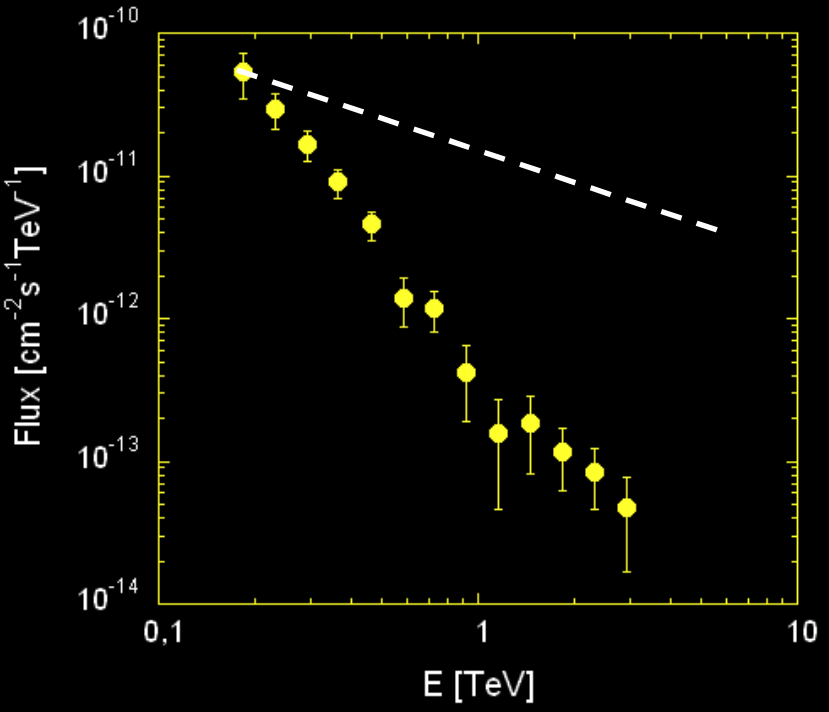
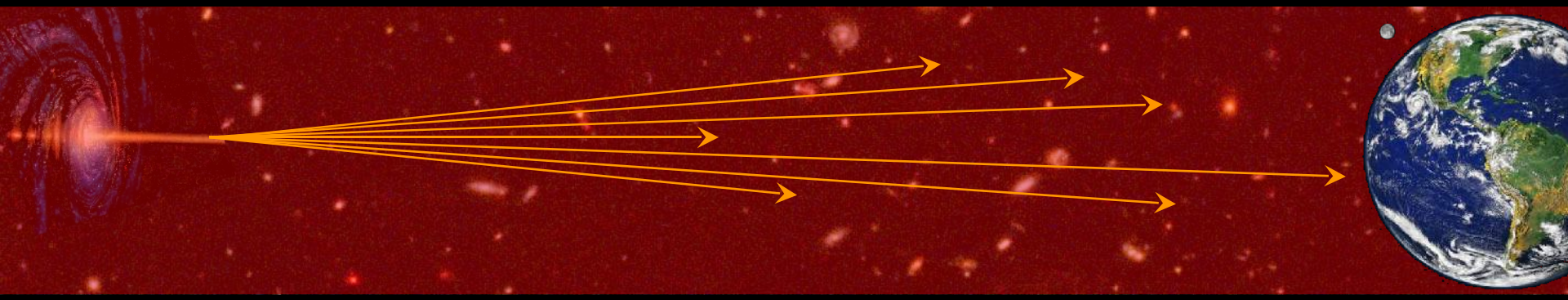
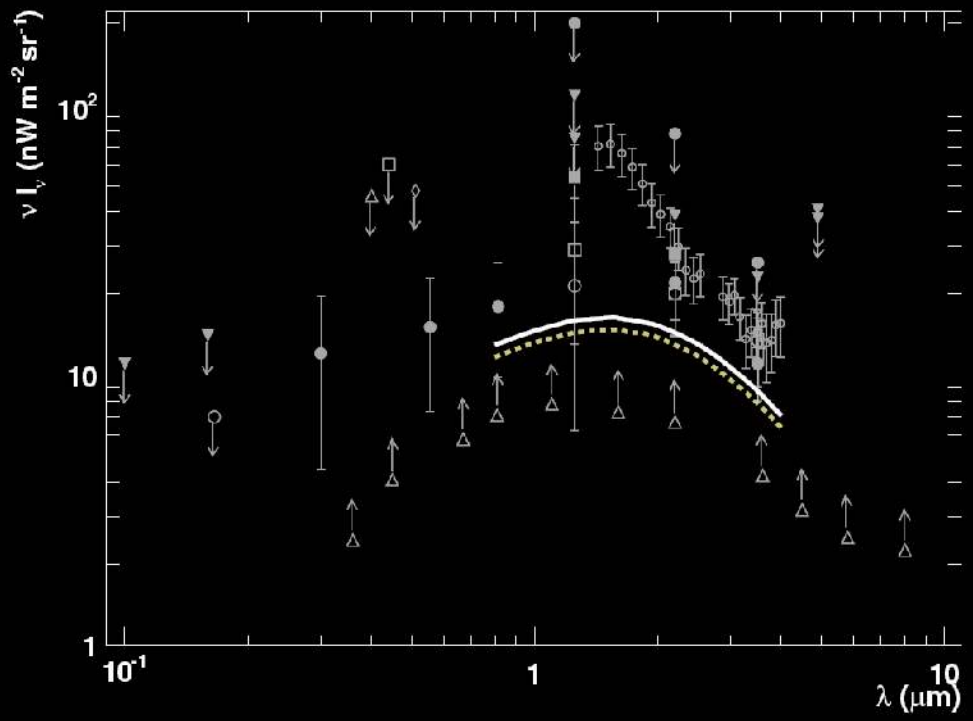


“News” on the Extragalactic Background Light





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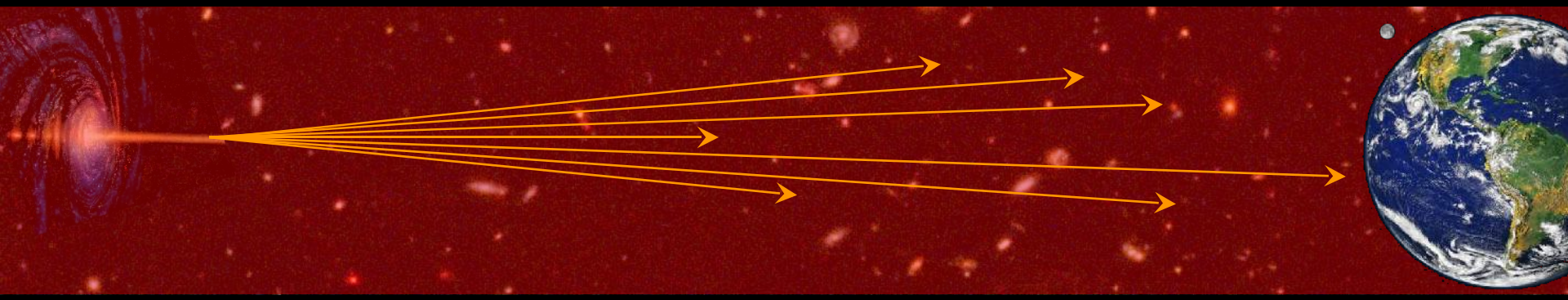
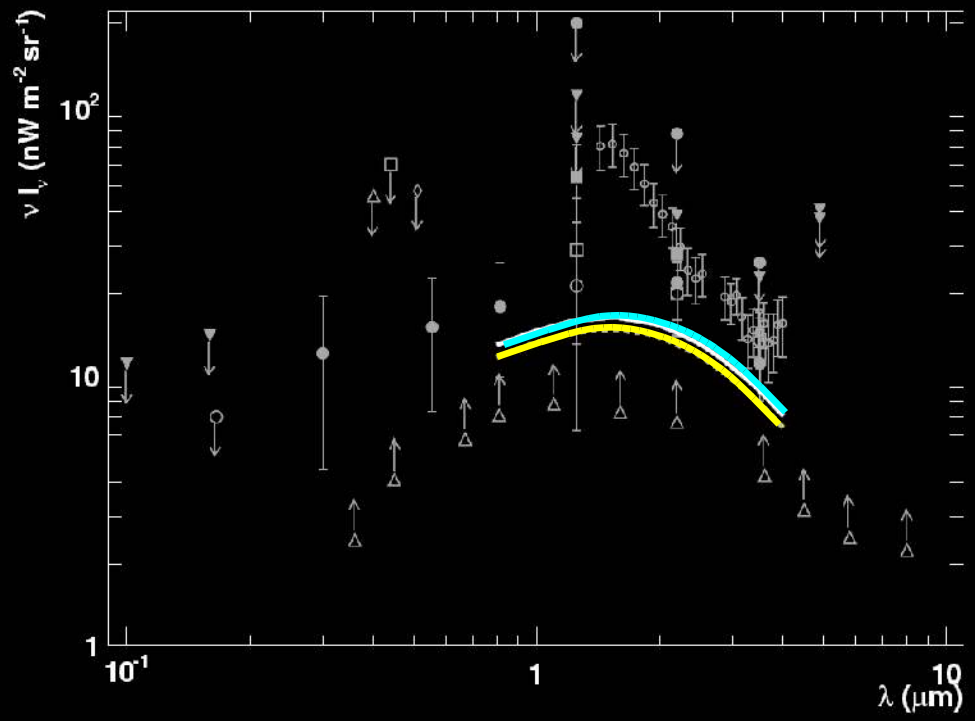




- EBL is at lower limit, as obtained from Hubble galaxy count

  H.E.S.S., Nature (2006)

- Confirmed by 1ES0347, z = 0.188

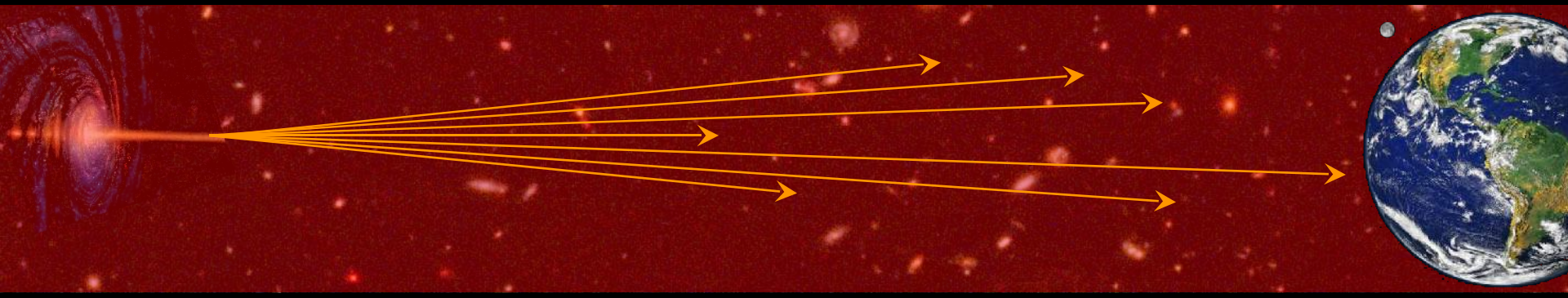
  H.E.S.S., A&A 473 (2007)

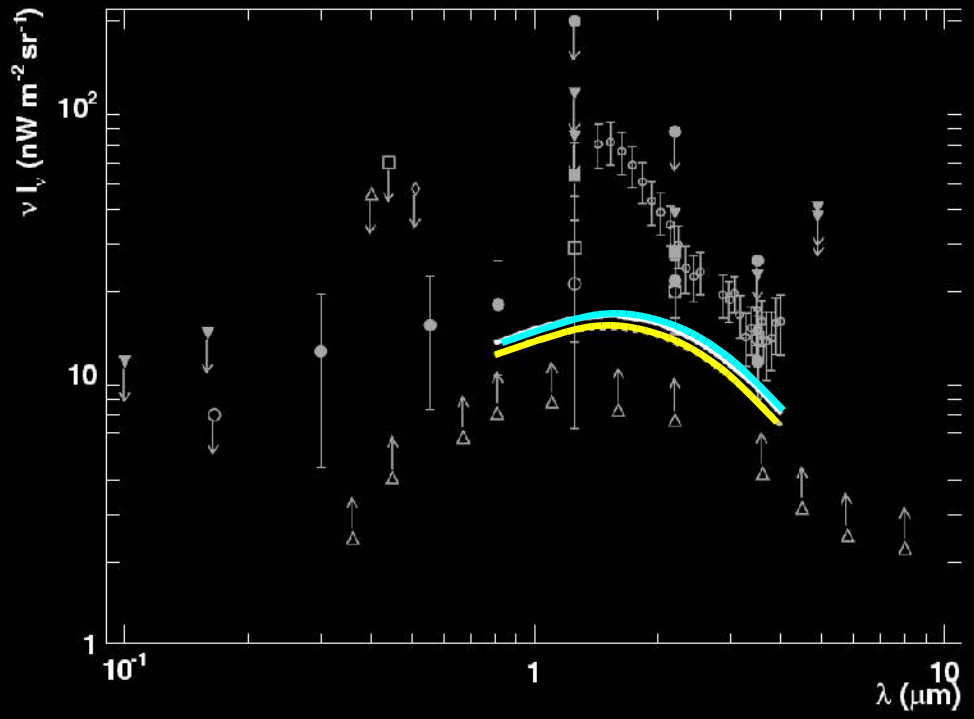
- Additional constraints on Mid-IR by 1ES 0229 w/ hard spectrum :

  → EBL (2-10 μm) ~ λ^{-1}

  H.E.S.S., A&A 475 (2007)

The Extragalactic Background Light





- EBL is at lower limit, as obtained from Hubble galaxy count
- No significant contribution of pop III stars (z ~ 7…15)
- The Universe is more transparent to Gamma-Rays than expected
- We can “see” further than expected, more sources accessible

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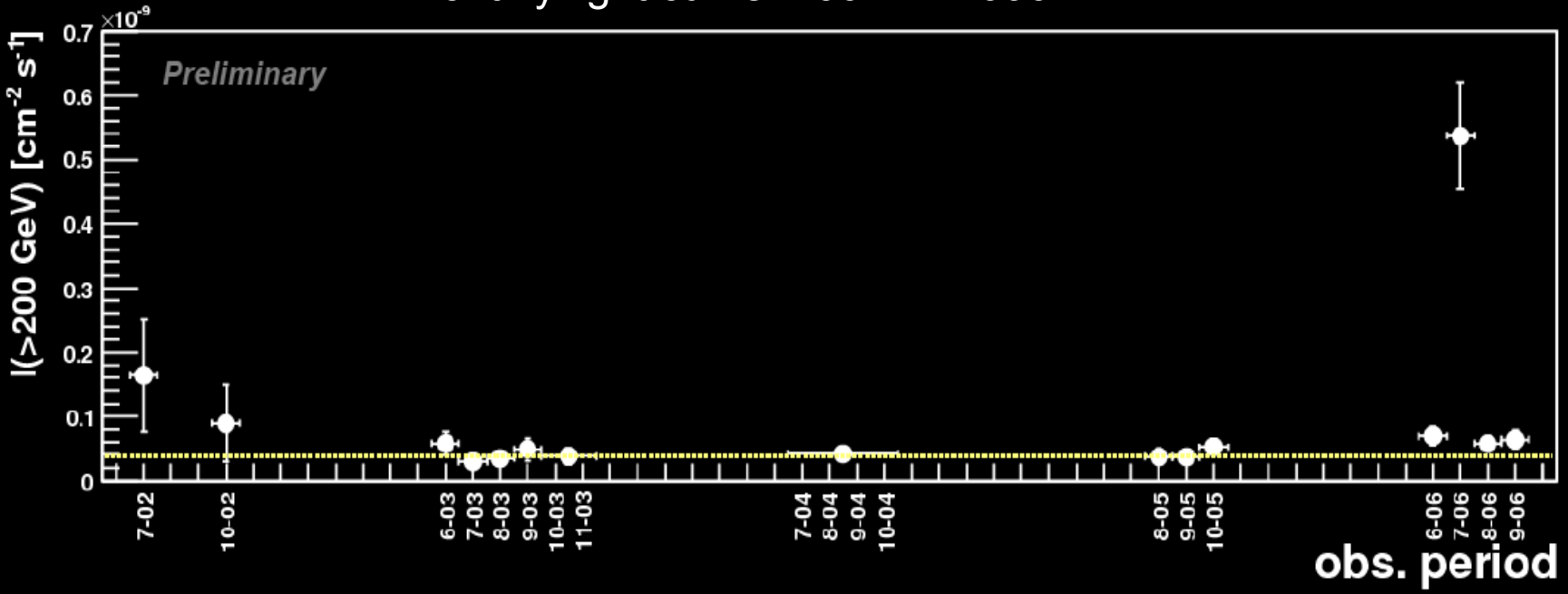
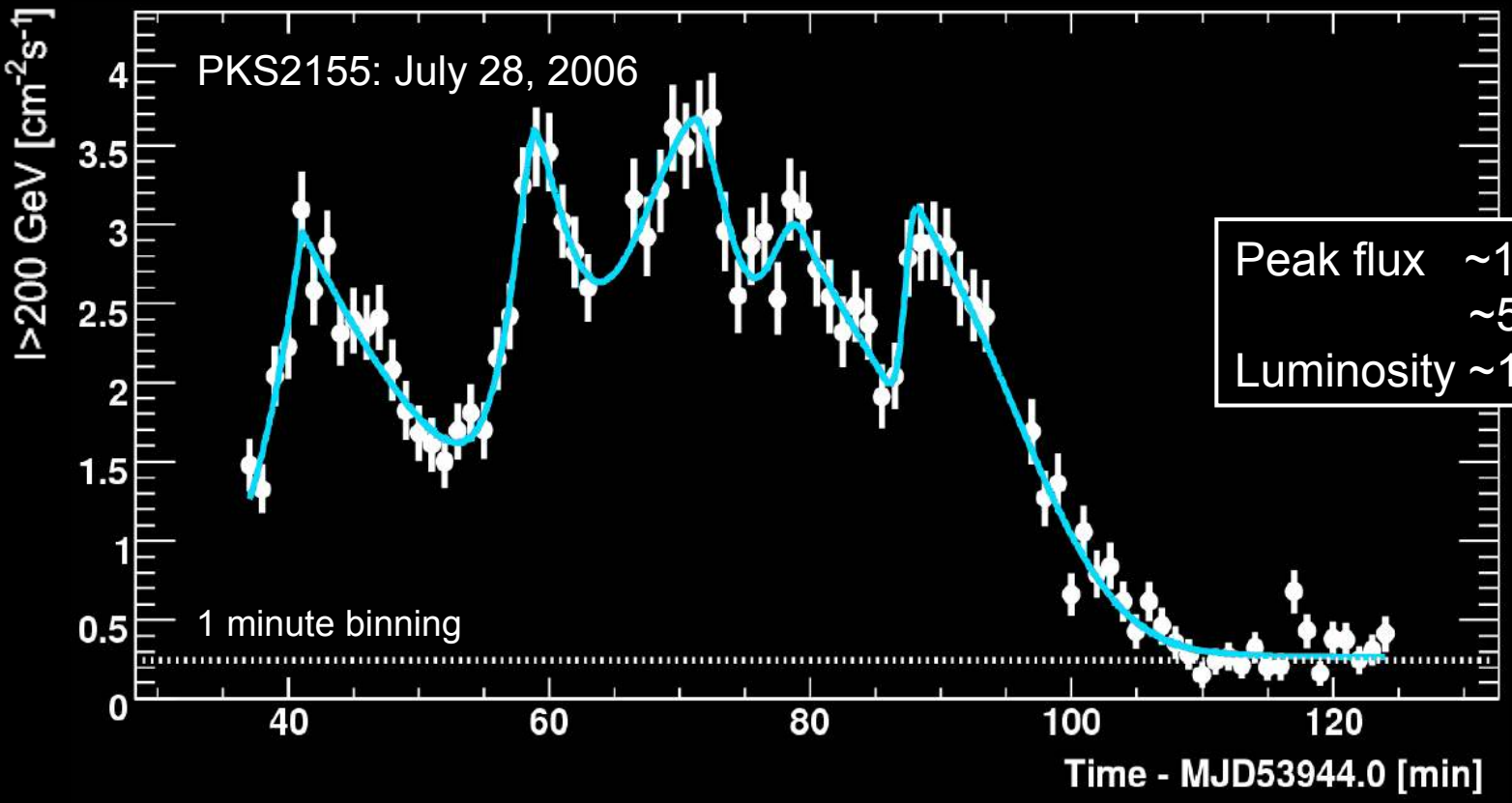
PKS 2155 Monitoring

Monthly light curve: 2002 … 2006



- Source monitored since 2002 (~240 h)
- Average flux : 3.95 +- 0.39 10^{-11} cm^{-2} s^{-1}
- Huge outburst in July 2006 - two main flares of 28 and 30 July

"Photons from hotter hell" (T.Weekes)



Peak flux ~15 x Crab
~50 x average
Luminosity ~10^{12} x Crab

→ Time resolved VHE spectroscopy of AGN jets (→ Andreas Zech)

→ Variability on timescales 2-3 minutes

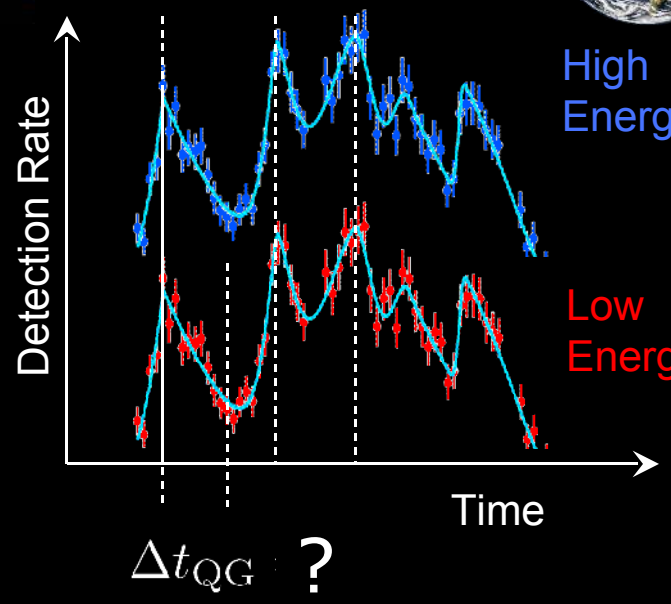
HESS, A&A (2007)

Probing Quantum Gravity: c(E) ≠ c(E') ?

$$c' = c\,(1 \pm \frac{E}{k \cdot M_{\mathrm{p}}} \pm \frac{E^2}{p^2 \cdot M_{\mathrm{p}}^2})$$

$$M_{\mathrm{p}} = 1.22 \cdot 10^{19} GeV$$

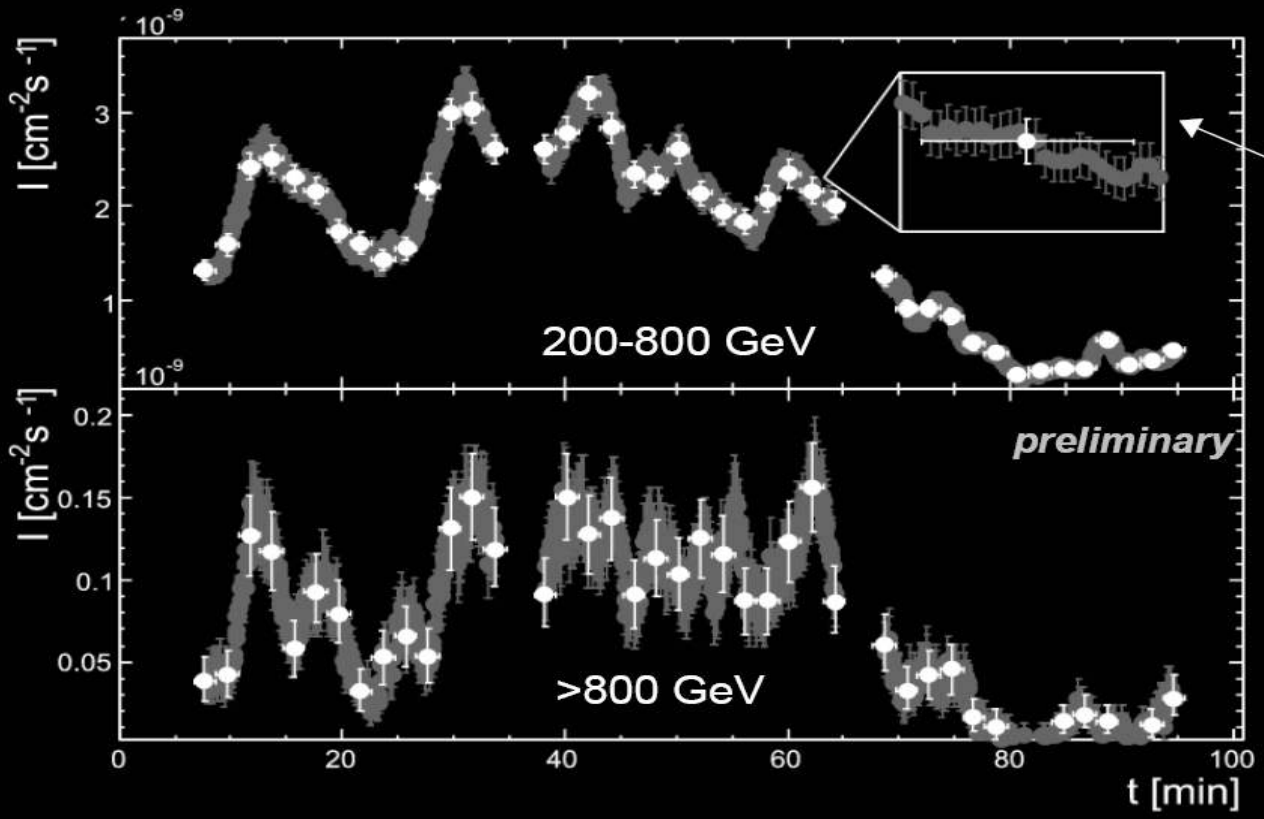
$$\Delta t_{\mathrm{QG}} = L\,(\frac{1}{c_1} - \frac{1}{c_2}) \approx \frac{\Delta E \cdot L}{k \cdot M_{\mathrm{p}} \cdot c}$$



→ Look a distant objects (O(100) Mpc)
→ Look at real high energies (TeV)

→ Be aware of *astrophysical* source effects (spectral changes)

Probing Quantum Gravity: c(E) ≠ c(E′) ?



Oversampled
2-min bin

ΔE = 1 TeV

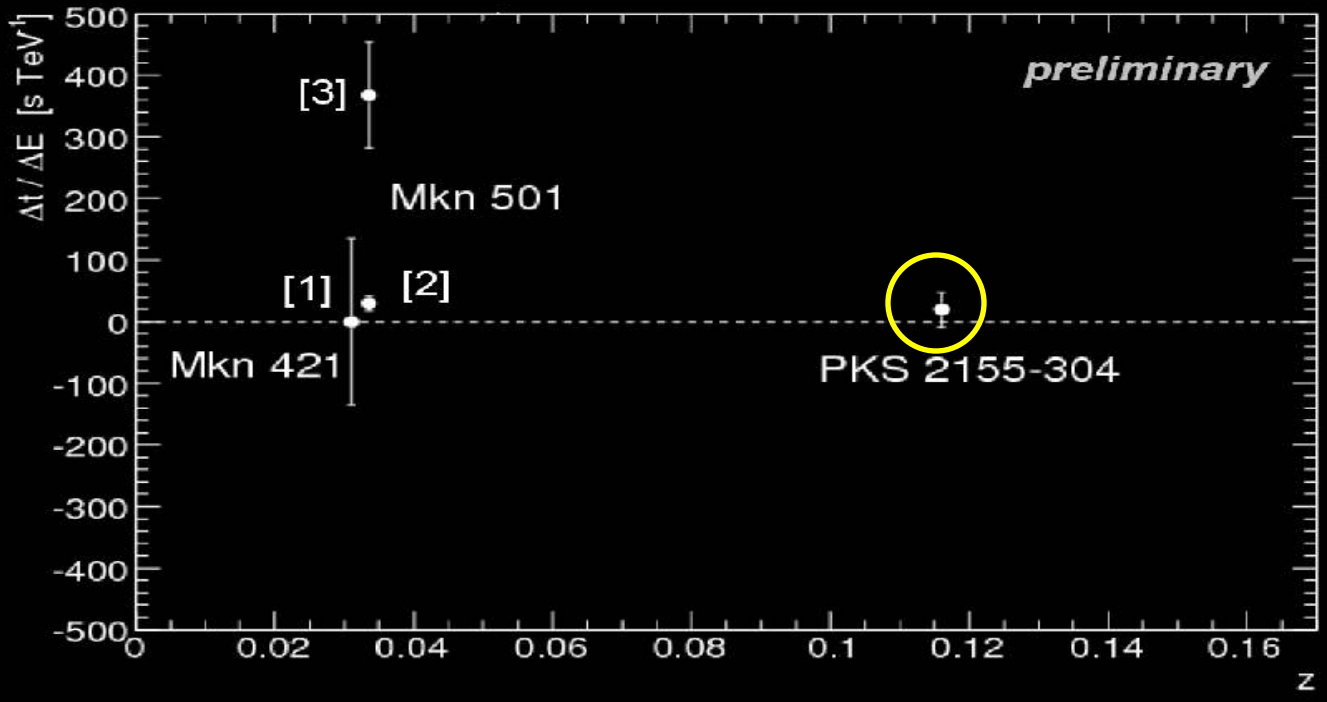
Modified cross correlation function:

→ no significant lag with energy found!

Probing Quantum Gravity: c(E) ≠ c(E') ?

Most constraining limit on speed of light modification to date:
(model independent)

$E_{QG} > 5\ \%\ M_P$



No trend with redshift observed

HESS, PRL (accepted)

Observations with the High Energy Stereoscopic System

German Hermann, MPI für Kernphysik
(for the H.E.S.S. Collaboration)

- The H.E.S.S. experiment
- Overview of observations
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- Quantum Gravity
- Dark Matter search
- A glance on H.E.S.S. phase 2

Indirect search for Dark Matter

Search for Dark Matter:

2) Accelerator: SUSY ? How to prove it is DM ?
3) Direct Detection: probes DM in halo
4) Indirect detection: probes DM outside the solar system

Search for (self) annihilation of WIMPs (e.g. neutralinos)

Where to search ? $F \sim \rho^2$ → regions of high density

→ The Galactic Centre
- Nearby and massive (other potential γ-ray sources

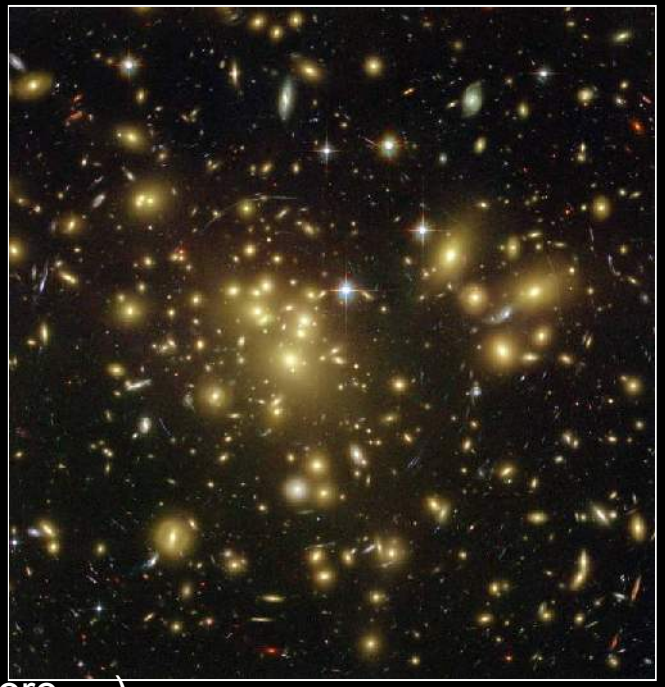
Galactic Halo "Clumps"
- Nearby, no astrophysical background?

→ Dwarf Galaxies
- Relatively nearby, very high mass to light ratios

Galaxy clusters
- Very massive (but far!)

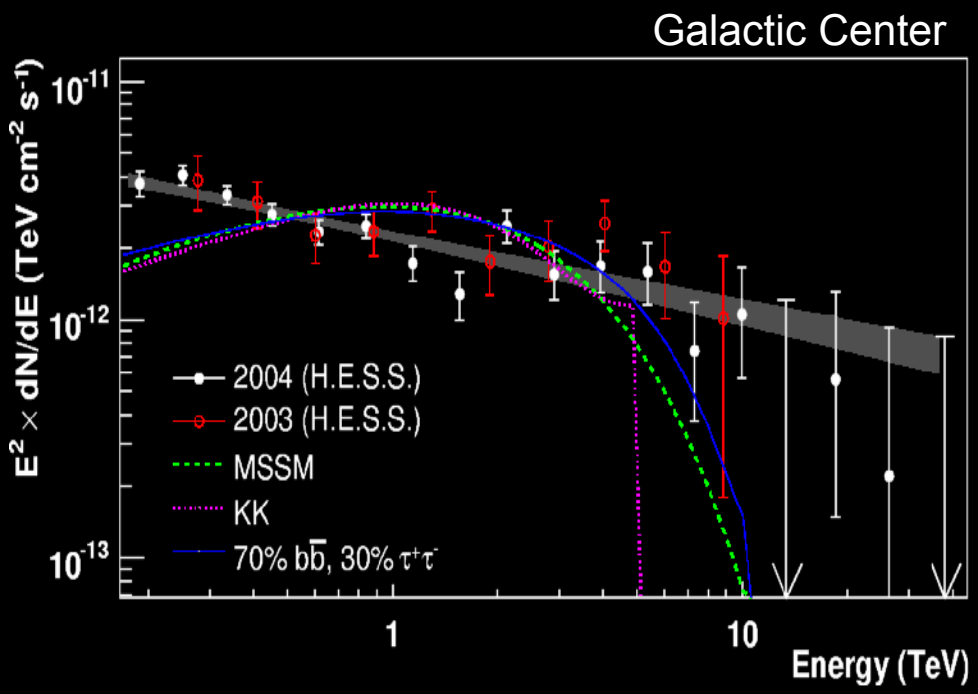
How dense?

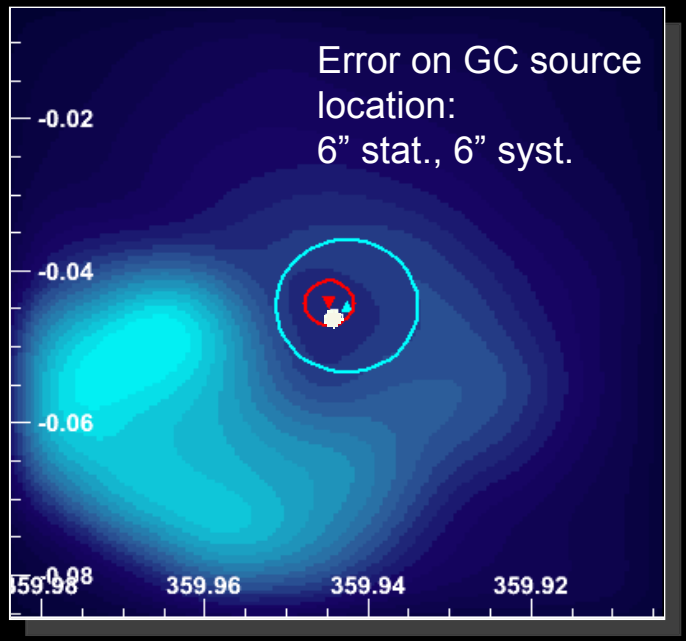
Depends on models for DM halo shapes (…NFW, Moore …)



Abell 1689, NASA/HST

Indirect search for Dark Matter



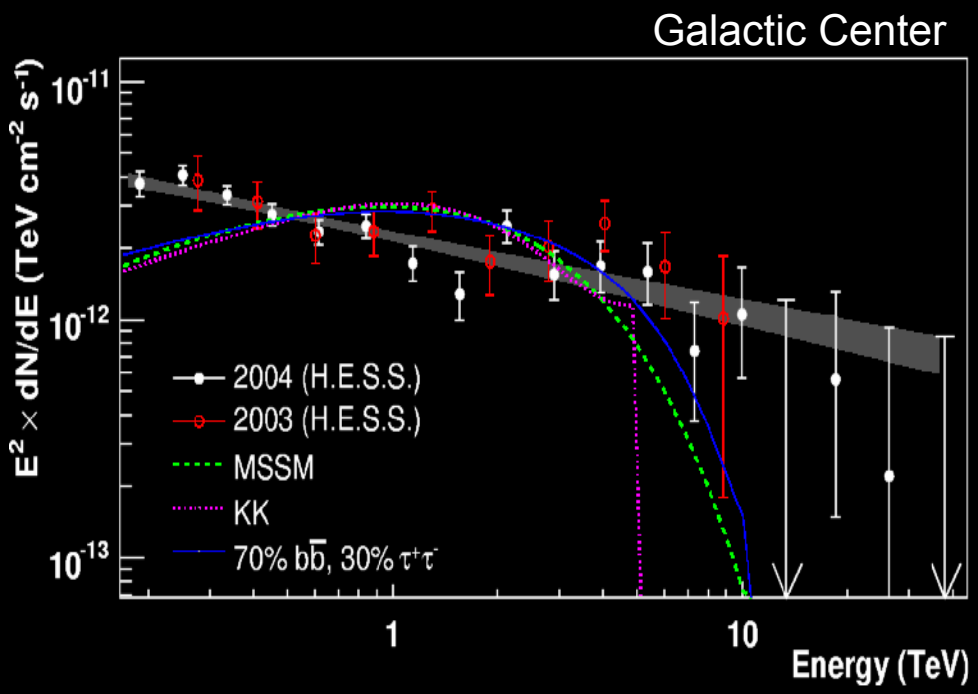


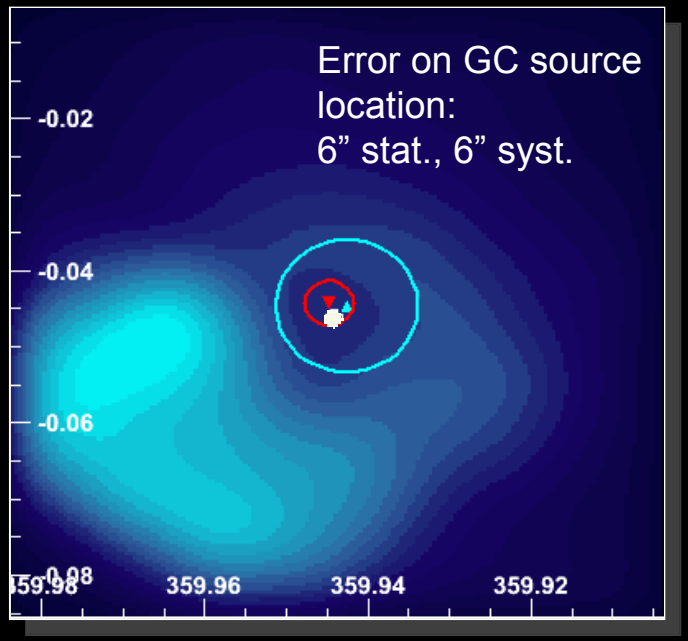
- Power law spectrum 160 GeV … 30 TeV
- No curvature in this regime
  exponential cutoff: E_C > 9 TeV @ 95% CL

- No indications for line emission

Radial profile ~ PSF
Upper limit on extension: < 1.2’

Indirect search for Dark Matter



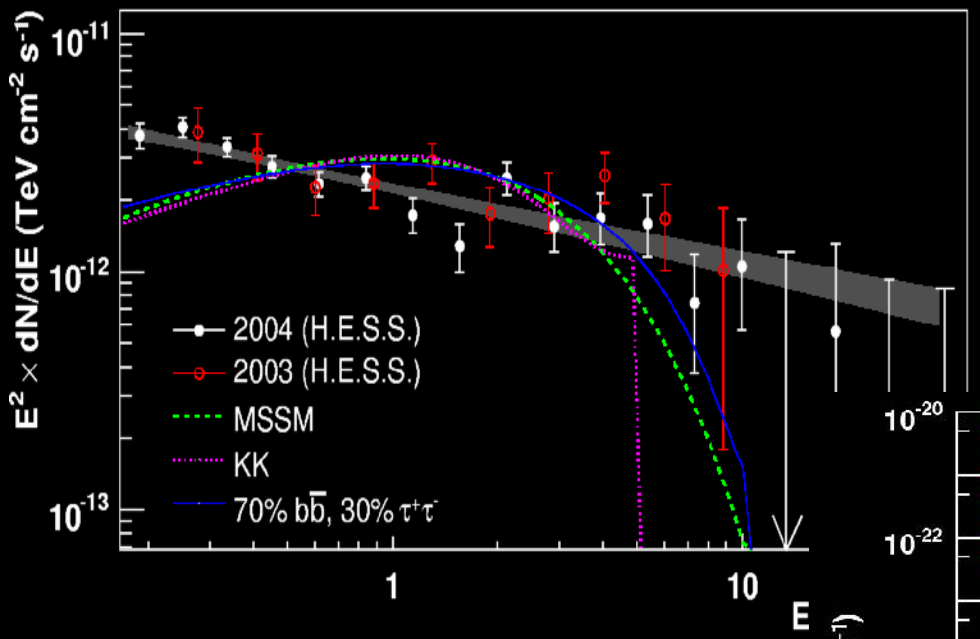


Signal is most probably of *astrophysical* origin !
Try anyway to fit DM models:

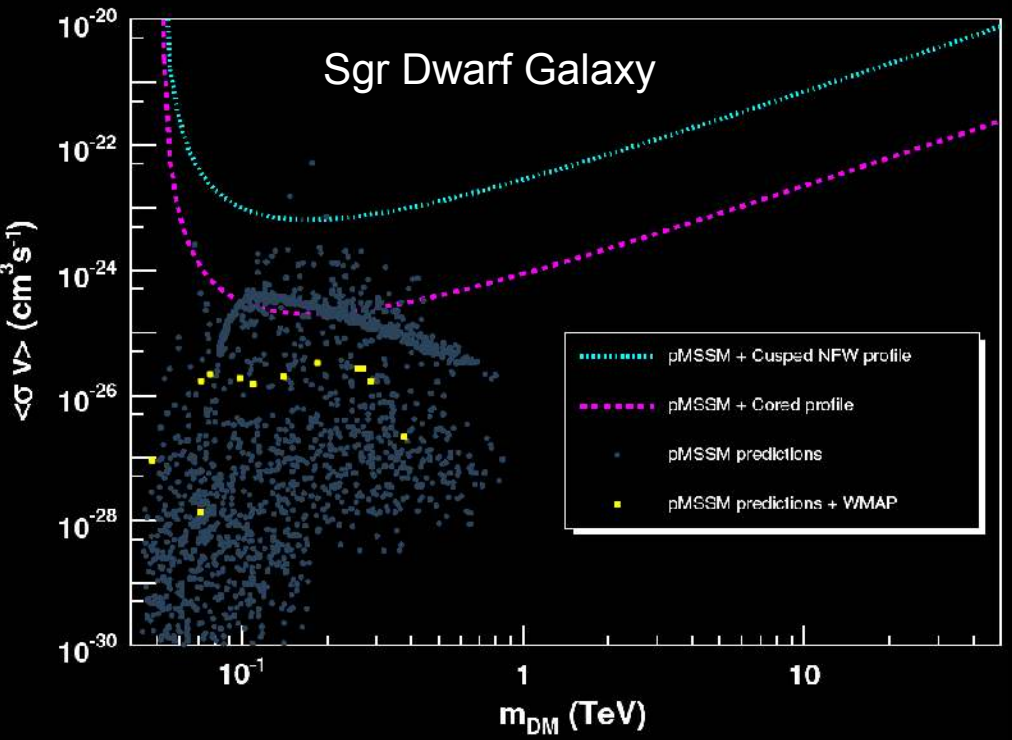
→ M ~ 14 TeV (a bit high …)

Indirect search for Dark Matter

Galactic Center



No signal → upper limit on flux and cross-section



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HESS, PRL 97 (2006)
HESS, ApP 29 (2008)
HESS, ApJ (in press)

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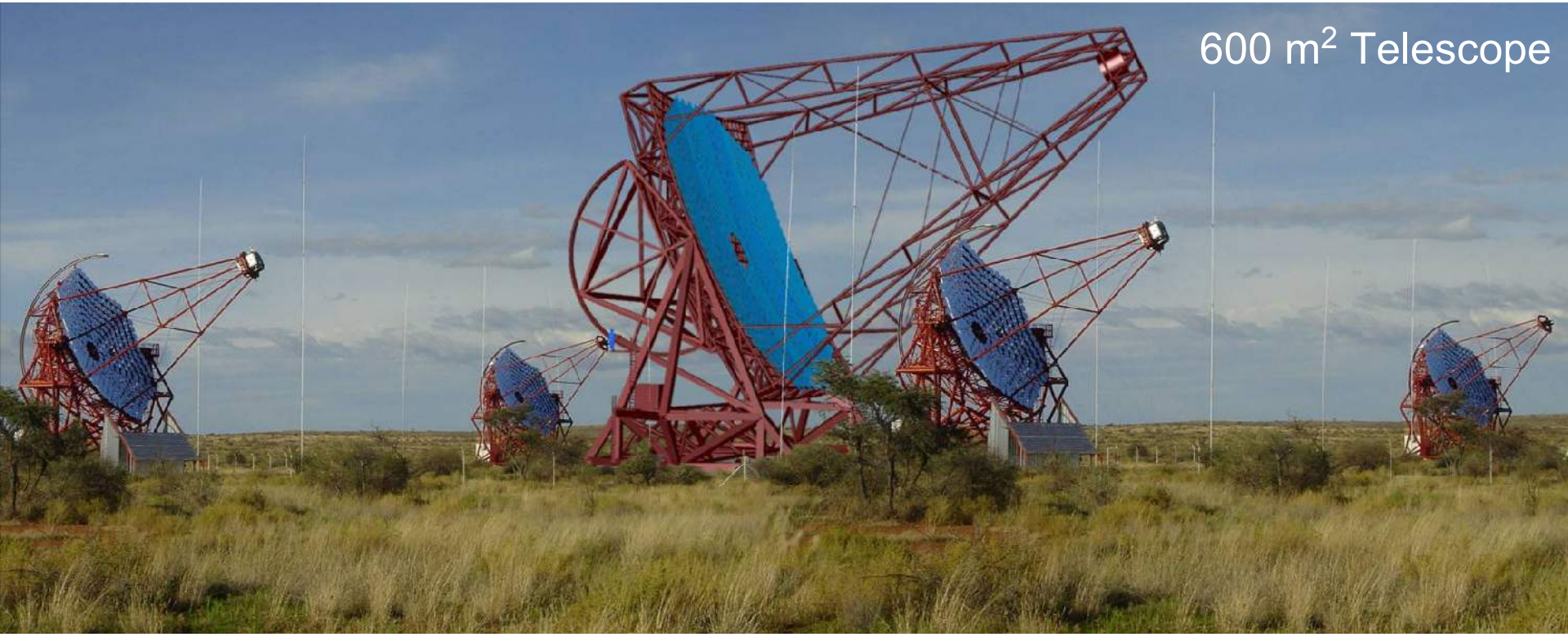
Near Future: H.E.S.S. Phase II



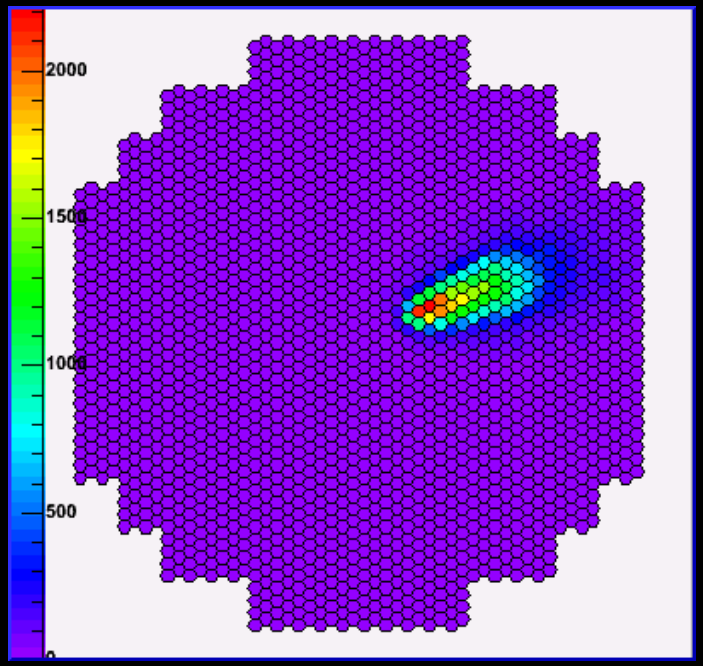
Improved sensitivity (x1.5 - 2)
in current regime up
to ~ 1 TeV

Energy range down
to ~50 GeV will finally
become accessible

Near Future: H.E.S.S. Phase II

Near Future: H.E.S.S. Phase II

H.E.S.S. Phase II Camera



2048 Pixels

Pixel size: 0.07°

FoV : ~ 3.6°

Same principle as in Phase I:

Analog pipeline for signal buffering

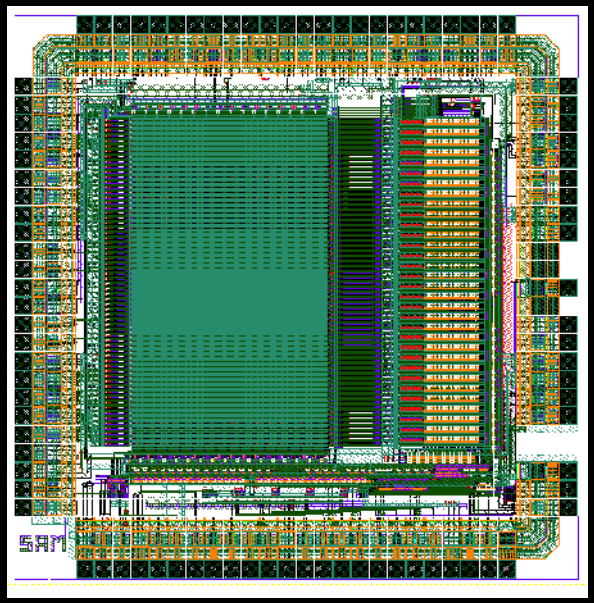
New pipeline chip: SAM

On board signal integration

SAM

Sampling:	1 GS/sec
Depth	256 cells
Bandwidth	> 300 MHz
Dyn. Range	> 11 bit

Sampling Analog Memory



Last week in Annecy …

H.E.S.S. collaboration in front of camera mechanics test setup (09/2008)

Conclusions from the High Energy Stereoscopic System

From source hunting to real astrophysics ….

- Many discoveries, population studies now possible
- ‘Precision’ measurements
- Cosmology and particle physics
- Composition ($e^{\pm}$, Fe)
- Still more in the pipeline

The path towards *CTA* is paved

German Hermann, MPI für Kernphysik
(for the H.E.S.S. Collaboration)

www.mpi-hd.mpg.de/HESS
and …/HESS/public/HESS_catalog.htm