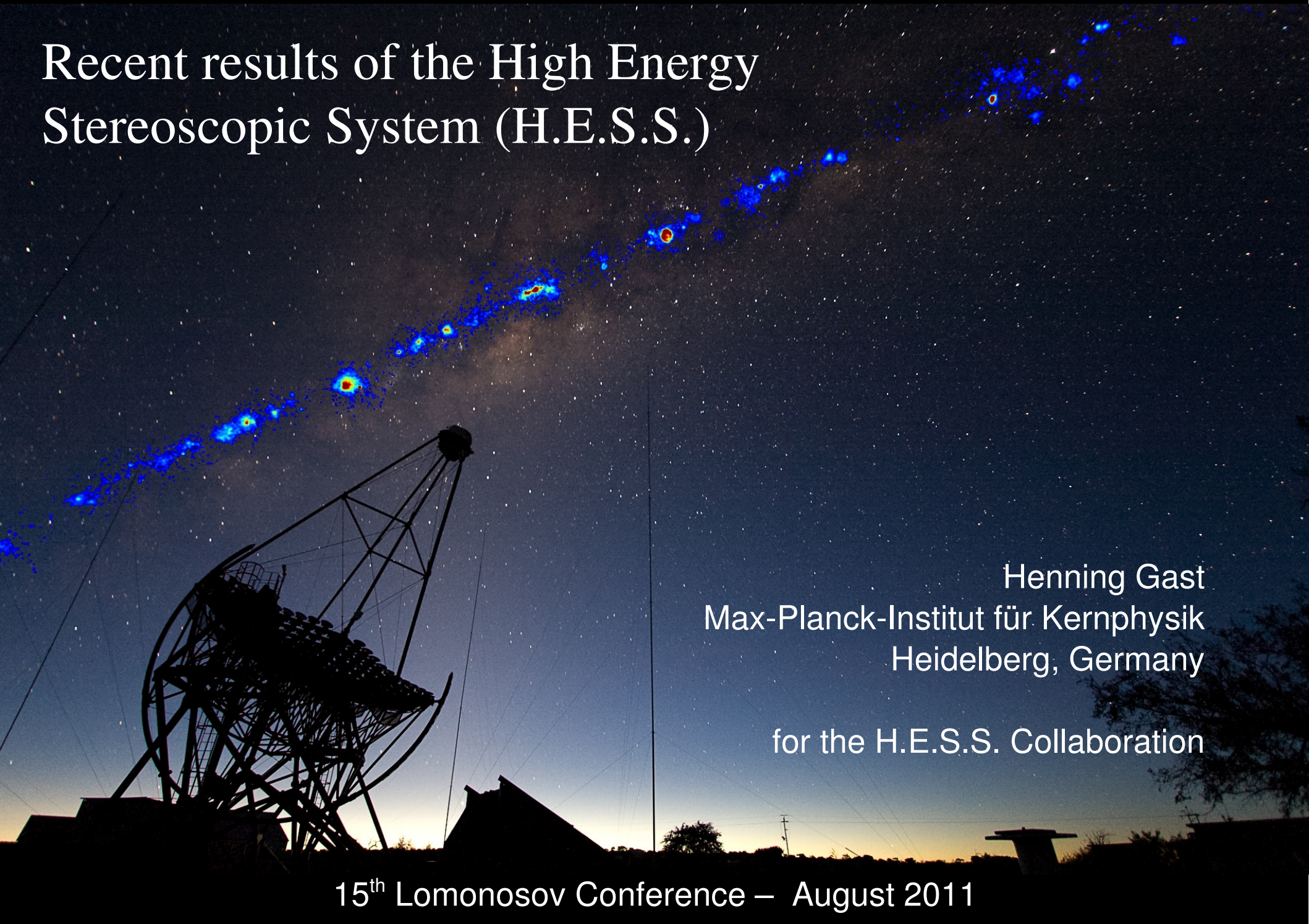
# Recent results of the High Energy Stereoscopic System (H.E.S.S.)

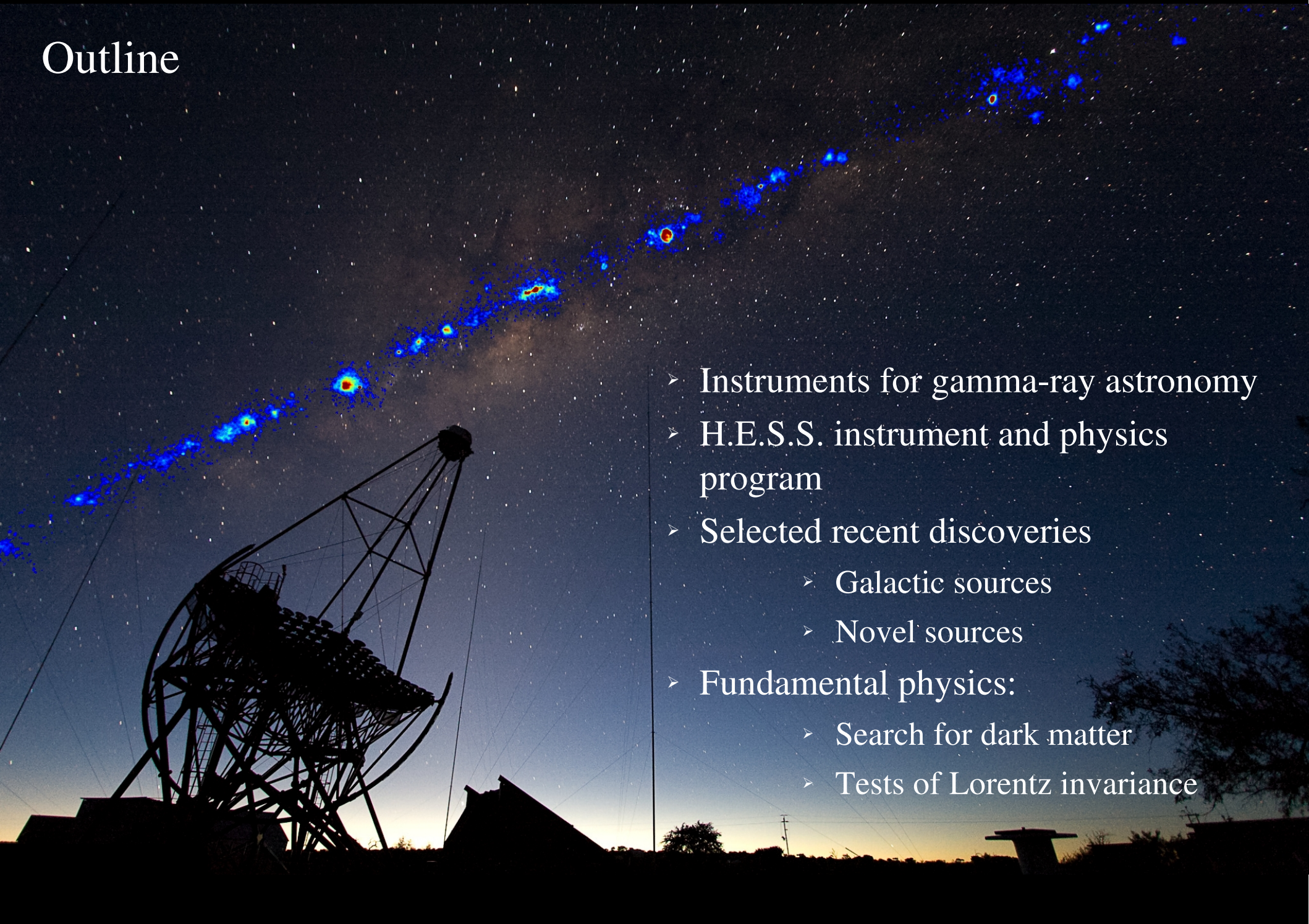


Henning Gast
Max-Planck-Institut für Kernphysik
Heidelberg, Germany

for the H.E.S.S. Collaboration

15th Lomonosov Conference – August 2011

# Outline



- Instruments for gamma-ray astronomy
- H.E.S.S. instrument and physics program
- Selected recent discoveries
  - Galactic sources
  - Novel sources
- Fundamental physics:
  - Search for dark matter
  - Tests of Lorentz invariance

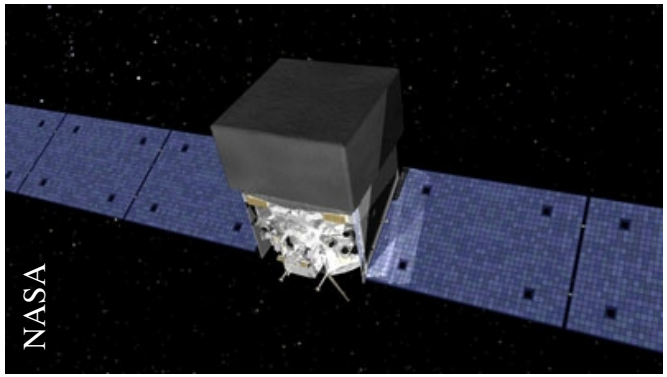
## Goal: study the universe in the GeV-TeV energy range

- non-thermal emission
- reveal cosmic accelerators
- two main emission mechanisms:
  - $\pi^0$ decay ("hadronic")
  - inverse Compton scattering of electrons ("leptonic")

# Instruments for gamma-ray astronomy

# Comparison of the detection methods in gamma-ray astronomy

satellite-based




e.g. EGRET, Fermi

direct detection in space
e.g. Fermi-LAT:
Si tracker with
conversion foils +
EM calorimeter

ground-based

Cherenkov telescopes


e.g. H.E.S.S., MAGIC, VERITAS

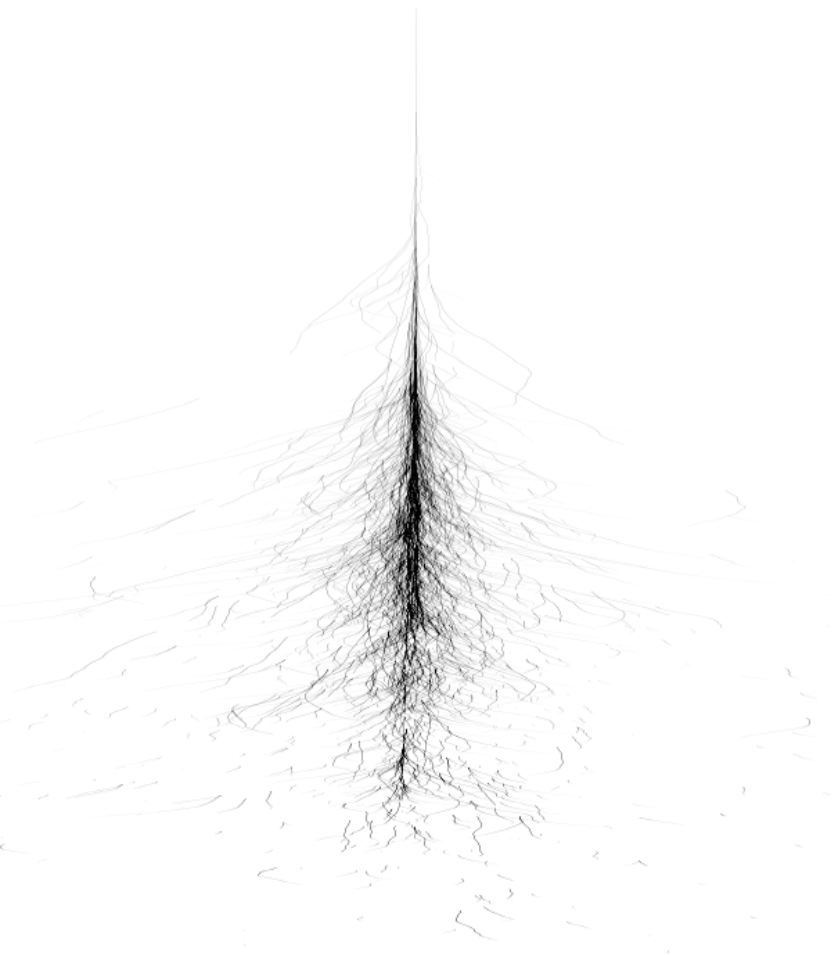
detect Cherenkov light
from gamma-ray induced
air showers

high-altitude arrays


e.g. Milagro, HAWC,
Tibet AS$\gamma$, ARGO-YBJ

detect charged particles
in tails of gamma-ray
induced air showers

# Comparison of the detection methods in gamma-ray astronomy



300 GeV gamma-ray

ground-based

Cherenkov telescopes


e.g. H.E.S.S., MAGIC, VERITAS

detect Cherenkov light from gamma-ray induced air showers

high-altitude arrays


e.g. Milagro, HAWC, Tibet AS$\gamma$, ARGO-YBJ

detect charged particles in tails of gamma-ray induced air showers

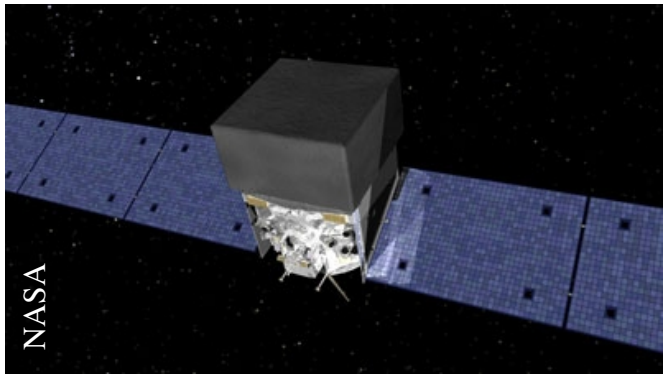
# Comparison of the detection methods in gamma-ray astronomy

satellite-based

ground-based

Cherenkov telescopes

high-altitude arrays






low energy threshold

high sensitivity

large aperture, high duty cycle

| | | | |
|---|---|---|---|
| Energy range | 0.1 - 300 GeV | 0.05 – 50 TeV | 0.1 – 100 TeV |
| Area | 1m$^2$ | 100 000 m$^2$ | 30 000 m$^2$ |
| Energy resolution | 10% @ 1 GeV | 15% | ~50% |
| Angular resolution | 0.7° @ 1GeV | 0.1° | 0.3°-0.7° |
| Background suppression | > 99.99% | 99% | > 95% |
| Aperture | 2.4 sr | 0.006 sr | > 2 sr |
| Duty cycle | > 90% | ~10% | > 90% |

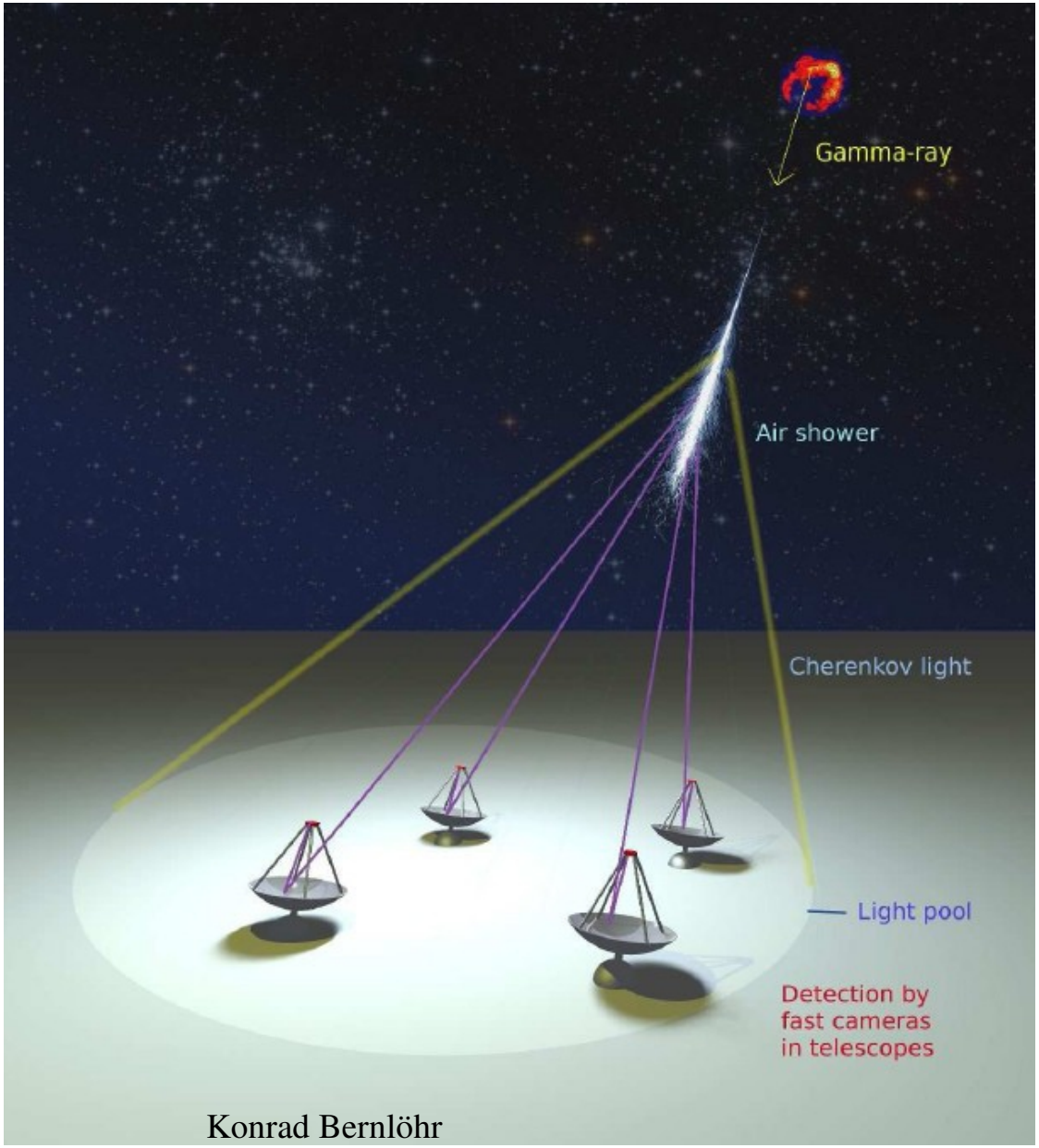
unbiased sky survey,
transients < 100 GeV
extended sources

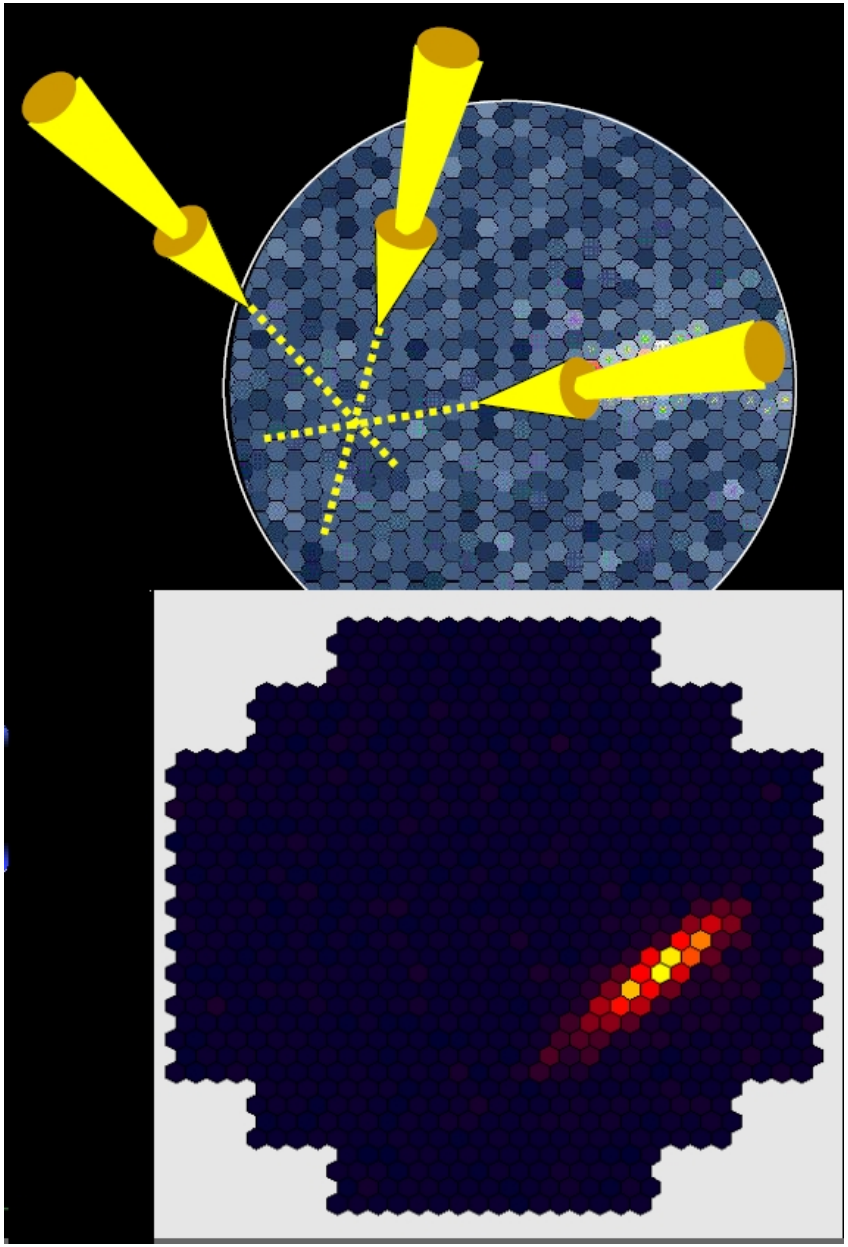
high-resolution spectra
detailed morphological analysis
survey capability for limited sky region

unbiased sky survey
extended sources
transients

following Gus Sinnis, CTA workshop, Paris, March 2007

IACT = Imaging atmospheric Cherenkov telescope



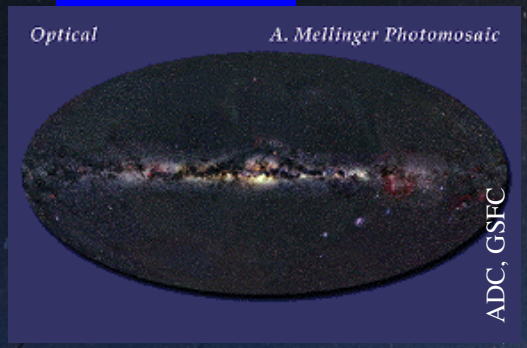



# H.E.S.S.

- array of four imaging atmospheric Cherenkov telescopes
- located in the Khomas highlands of Namibia, at 1800m ASL
- $E_{th}$ = ~100 GeV
- $\Delta E/E$ = 15%
- angular resolution ~0.1°
- 5° FoV

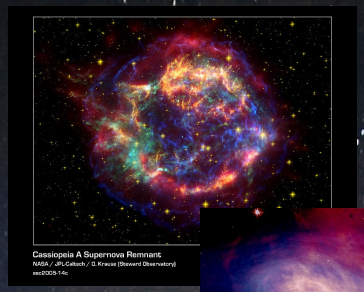
# H.E.S.S. physics program

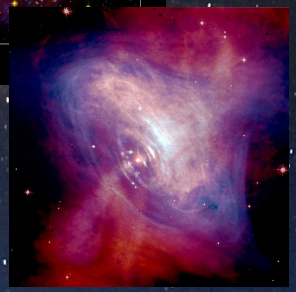
## Survey




Galactic Plane Survey and follow-up observations
Galactic Center

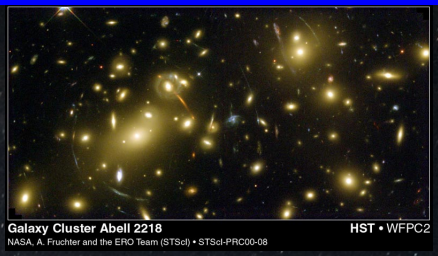
## SNRPP



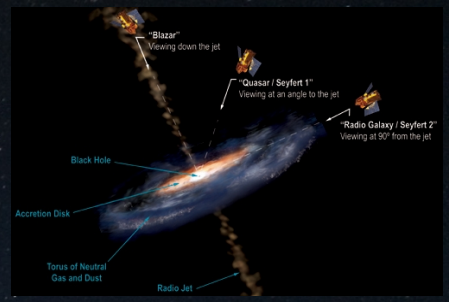
SNRs
PWNe
Plerions

## Extended extragalactic objects




starburst galaxies
galaxy clusters
pair halos

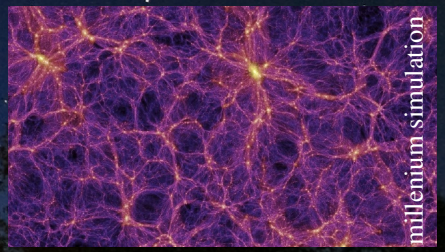
## AGN




radio galaxies
GRBs

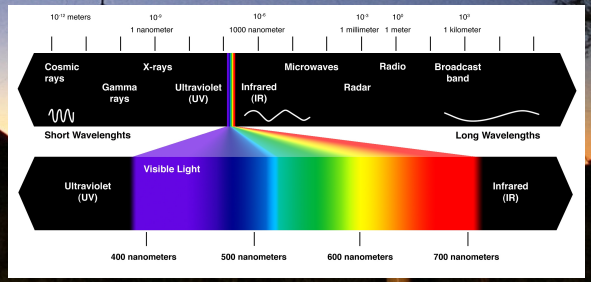
## Binaries

## Astroparticle / Exotic




Cosmic rays
Dark matter
Lorentz invariance tests

## Multiwavelength





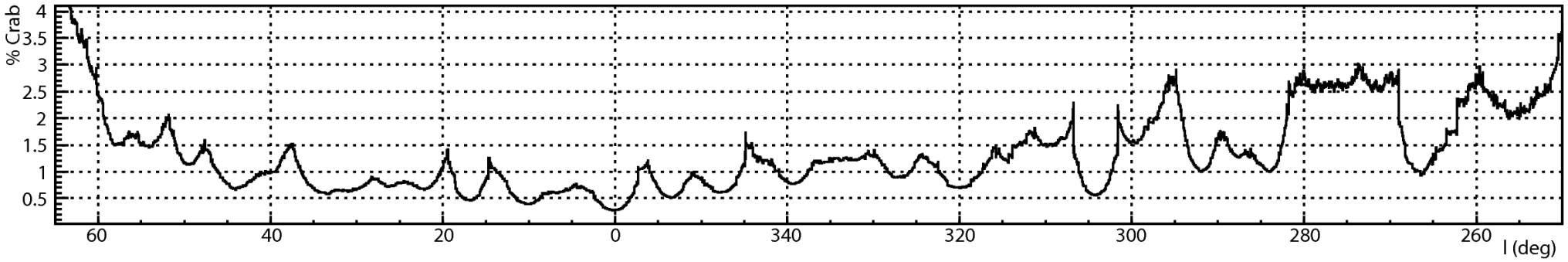

Slide following M. Daniel, with material from NASA/ESA

# Galactic sources

# Galactic Plane Survey

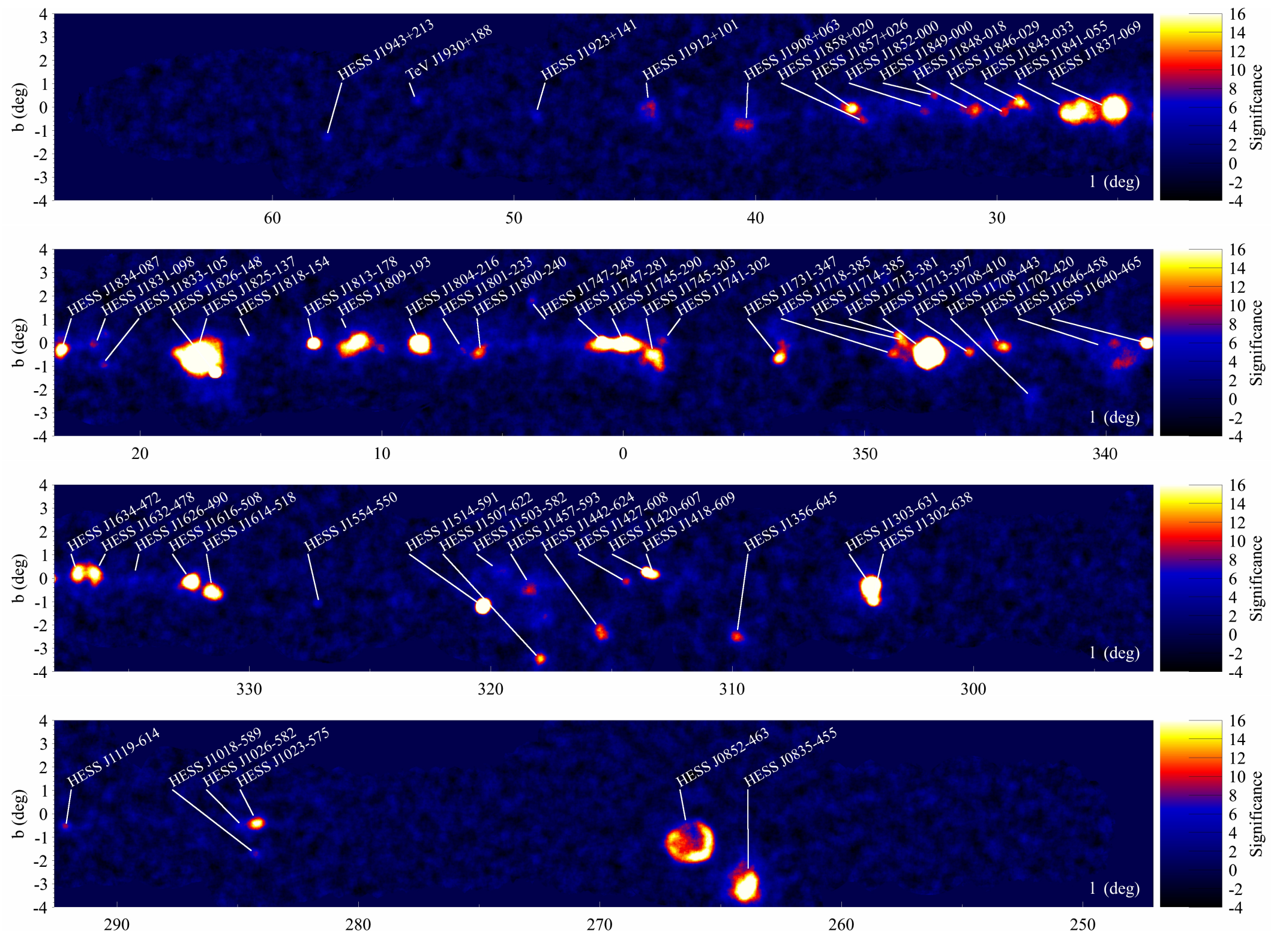
- large FoV enables systematic scan of Inner Galaxy, ongoing since 2004
- aim: discovery of new gamma-ray sources
- 2300 h of good-quality data
- dataset = pointed observations + scan mode + hotspot follow-up

- over 60 Galactic VHE gamma-ray sources
- population dominated by SNRs, PWNe, unidentified sources
- focus in 2011:
  - sensitivity goal of 2% Crab for core region
  - deepening exposure in outer Galaxy



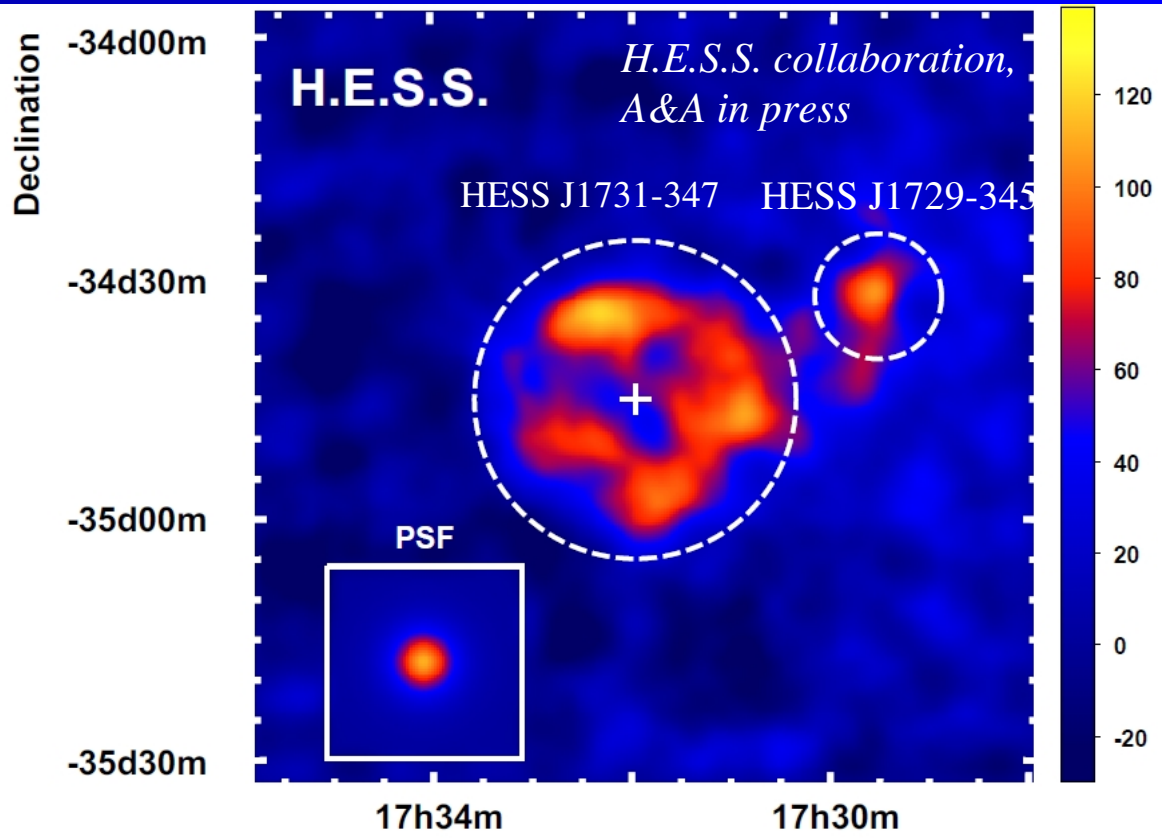

point-source sensitivity ($\Gamma$=2.5) for 5$\sigma$ detection, at latitude b = -0.3°

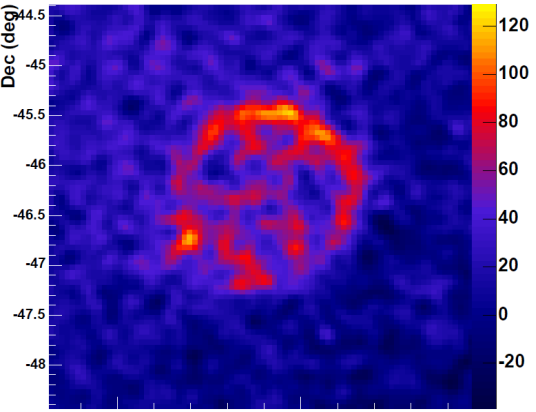
*H. Gast et al., proc. 32nd ICRC (2011)*


HESS J1943+213
TeV J1930+188
HESS J1923+141
HESS J1912+101
HESS J1908+063
HESS J1858+020
HESS J1857+026
HESS J1852-000
HESS J1849-000
HESS J1848-018
HESS J1846-029
HESS J1843-033
HESS J1841-055
HESS J1837-069
HESS J1834-087
HESS J1831-098
HESS J1833-105
HESS J1826-148
HESS J1825-137
HESS J1818-154
HESS J1813-178
HESS J1809-193
HESS J1804-216
HESS J1801-233
HESS J1800-240
HESS J1747-248
HESS J1747-281
HESS J1745-290
HESS J1745-303
HESS J1741-302
HESS J1731-347
HESS J1718-385
HESS J1714-385
HESS J1713-381
HESS J1713-397
HESS J1708-410
HESS J1708-443
HESS J1702-420
HESS J1646-458
HESS J1640-465
HESS J1634-472
HESS J1632-478
HESS J1626-490
HESS J1616-508
HESS J1614-518
HESS J1554-550
HESS J1514-591
HESS J1507-622
HESS J1503-582
HESS J1457-593
HESS J1442-624
HESS J1427-608
HESS J1420-607
HESS J1418-609
HESS J1356-645
HESS J1303-631
HESS J1302-638
HESS J1119-614
HESS J1018-589
HESS J1026-582
HESS J1023-575
HESS J0852-463
HESS J0835-455
b (deg)
l (deg)
Significance

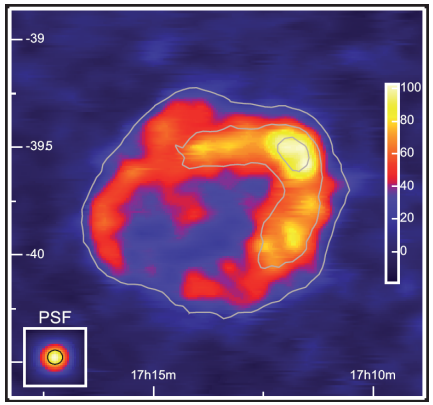
# Shell-type supernova remnants: HESS J1731-347

- First non-thermal shell SNR discovered based on gamma-ray observations!
- TeV and MWL data can be explained in either hadronic or leptonic scenario.

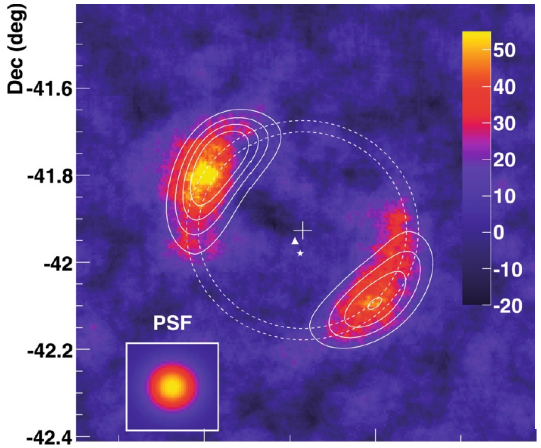


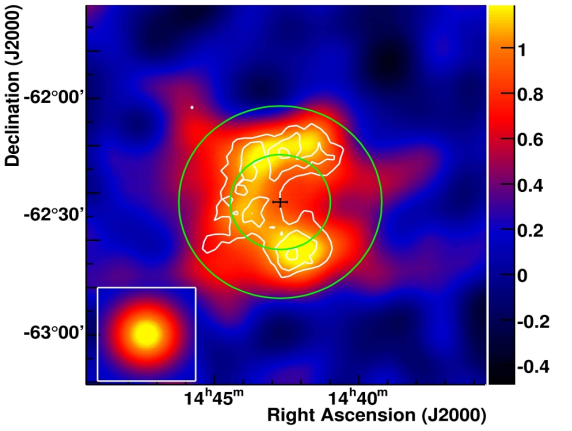

Vela Jr




RX J1713.7-3946



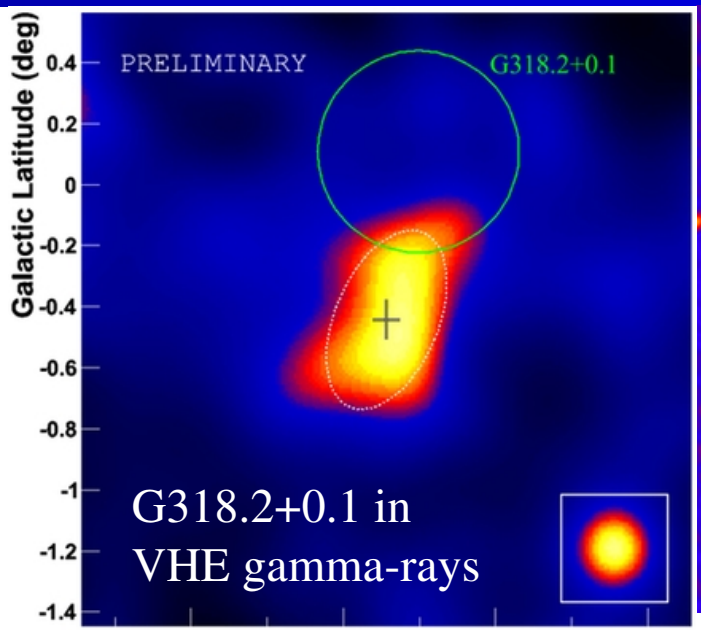

SN 1006

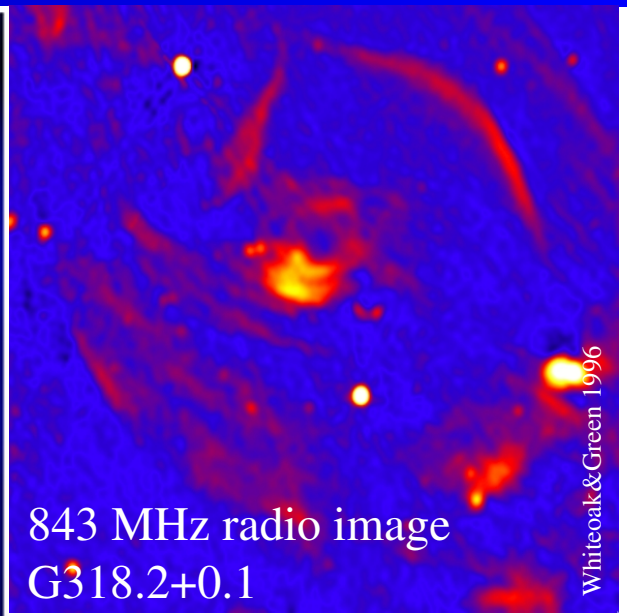


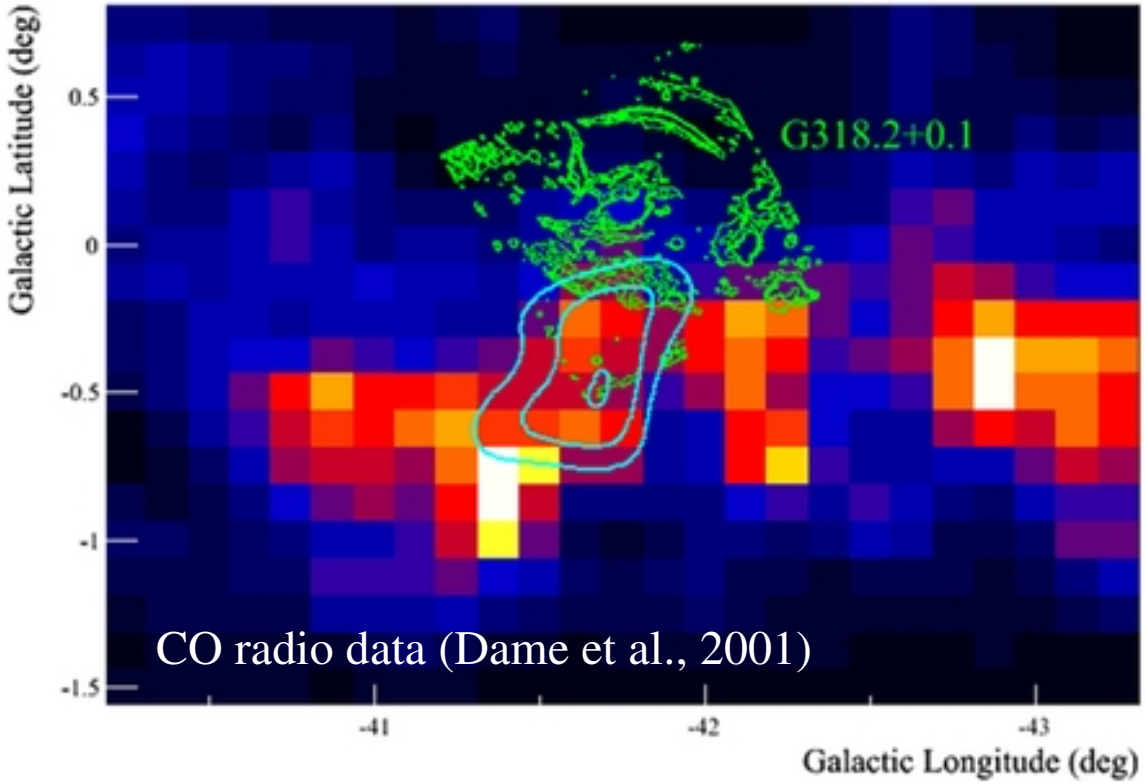

RCW 86

# possible interaction of SNR with a molecular cloud

- G318.2+0.1:
- VHE gamma-ray emission found in Galactic plane survey
- CO data: molecular cloud (~$10^6$ $M_{sun}$) found at either 3.5 or 9.2kpc
- Assuming near solution and n~1/$cm^3$: age ~8000 years: Sedov phase
- Possible scenario: emission from cosmic rays accelerated in the SNR and illuminating the MC



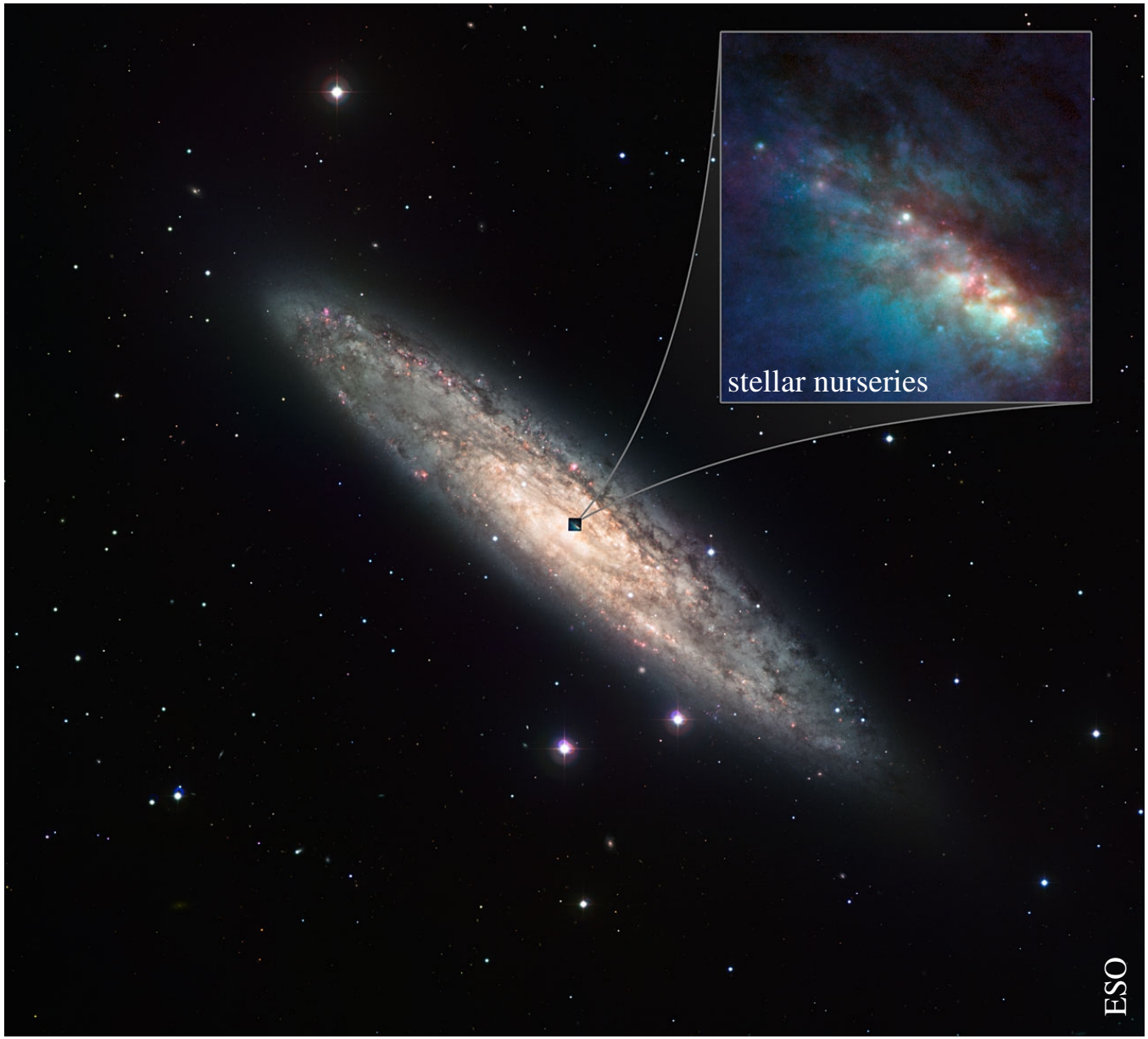

*P. Hofverberg et al.,*
*arXiv: 1104.5119*

# Novel sources

# Starburst galaxies

- Strongly enhanced star-formation rate i.e. high supernova rate
- Consequence: high cosmic ray (CR) density
- High gas density
- Intense radiation fields
- Promising conditions for gamma-ray production

interesting test of standard paradigm for cosmic-ray production

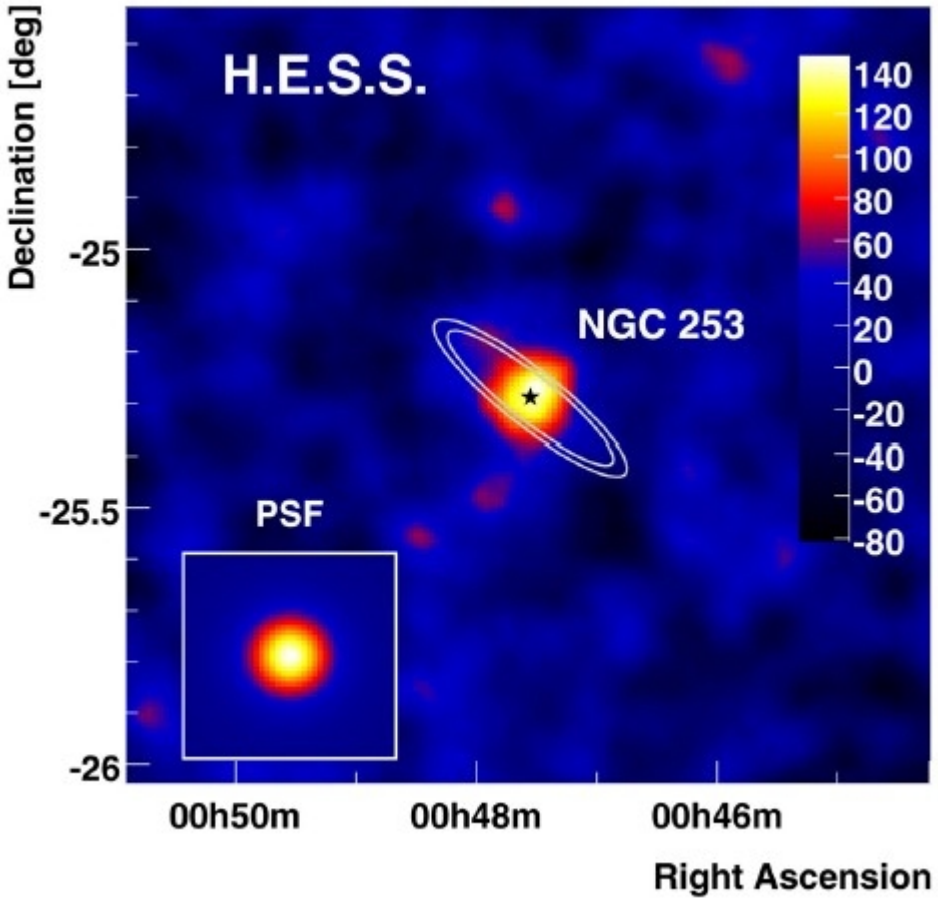


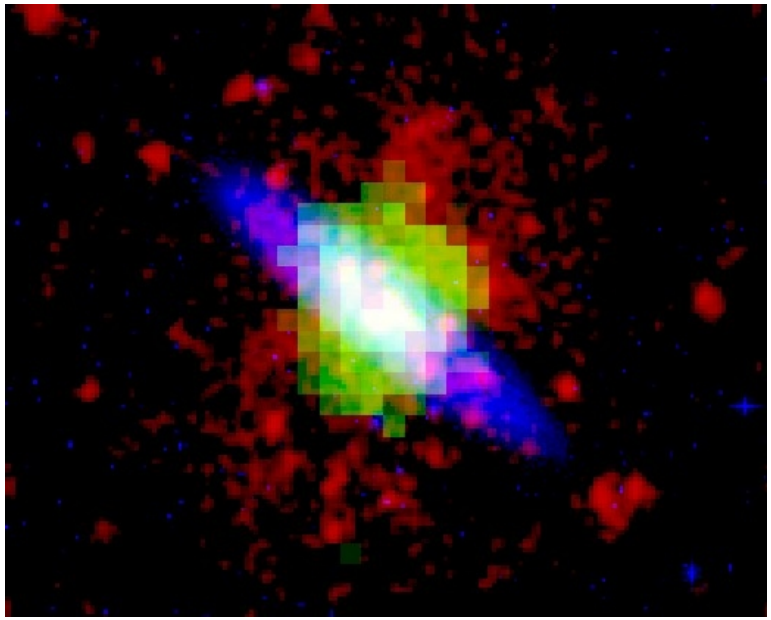

Starburst galaxy NGC 253 (optical)

# Starburst galaxy NGC253

- 119 hours of good observations
- advanced image analysis techniques
- integral flux roughly 0.3% Crab: one of the faintest sources detected so far in VHE gamma rays
- Point-like emission, consistent with starburst nucleus

*H.E.S.S. collaboration, Science 326 (2009) 1080-1082*

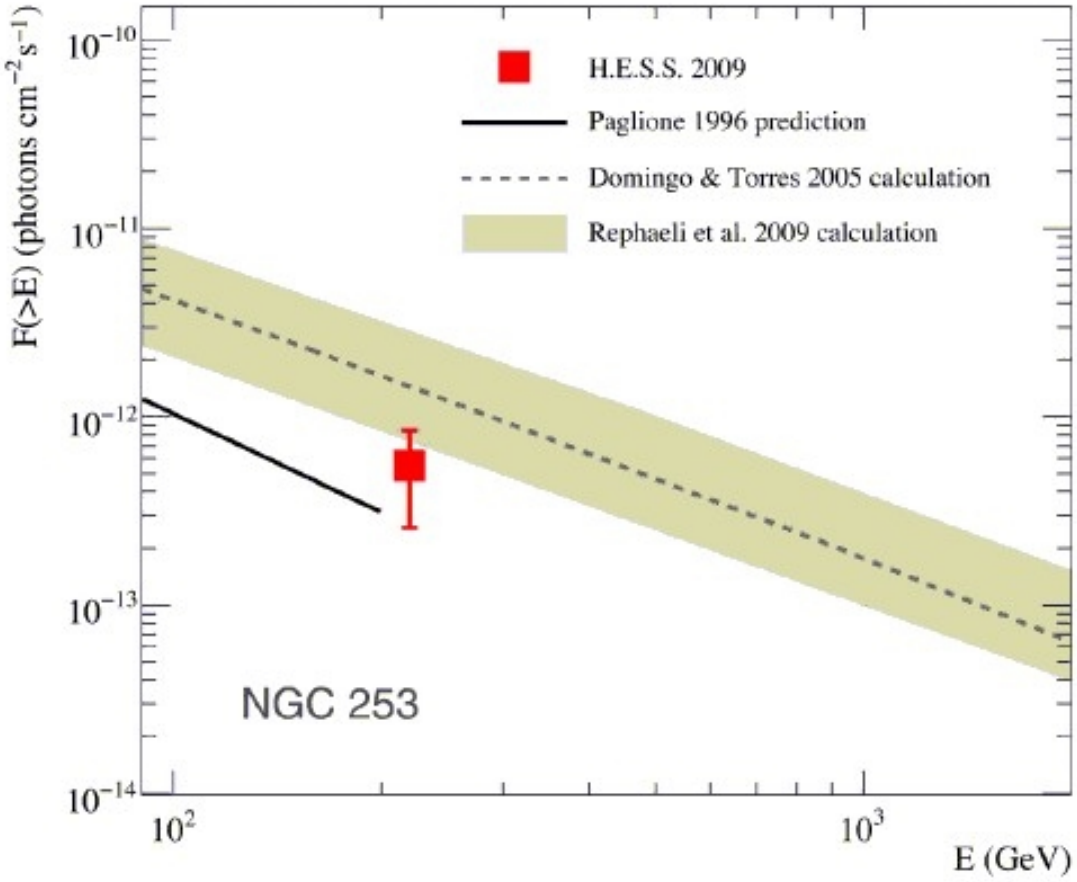


x-ray
VHE gamma-ray
optical

# Starburst galaxy NGC253

- Hadronic scenario: TeV cosmic-ray density in the starburst region about three orders of magnitude larger than at the location of the Earth
- About 5% of the energy in CRs converted into gamma rays
- Veritas detection of M82, Fermi detection of NGC253 and M82

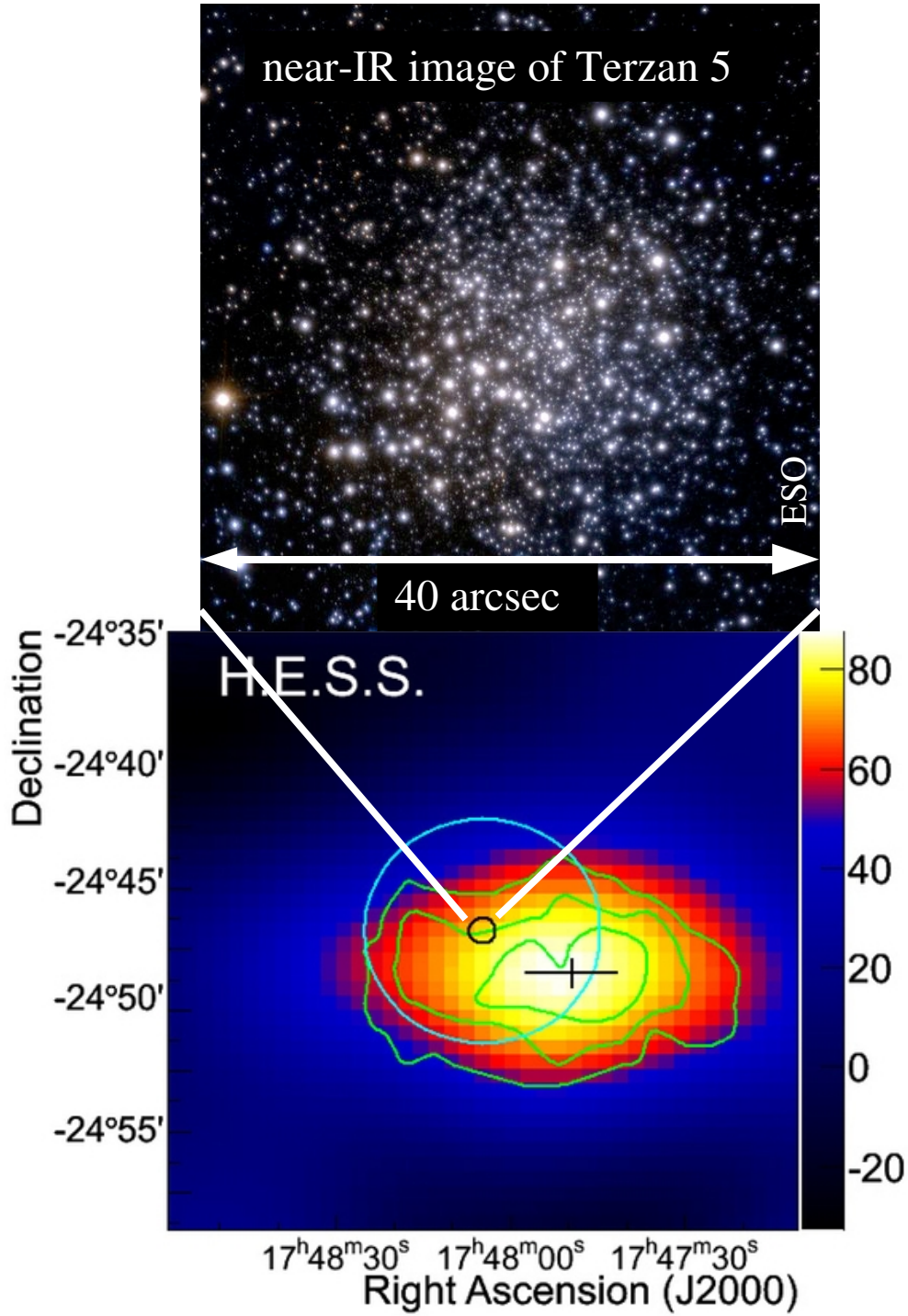



starburst galaxies emerging as new source class in gamma-ray astronomy

*F. Acero et al.,*
*Science 326 (2009) 1080*

# Terzan 5

- globular cluster Terzan 5:
  largest population of identified millisecond pulsars and high stellar density at its core
- electrons accelerated by millisecond pulsars themselves or in their colliding winds
- intense stellar radiation field
- integral VHE gamma-ray flux matches predictions
- chance coincidence unlikely
- but extension and offset hard to explain




*H.E.S.S. collaboration, A&A 531 (2011) L18*

# Fundamental physics

# The dark matter paradigm

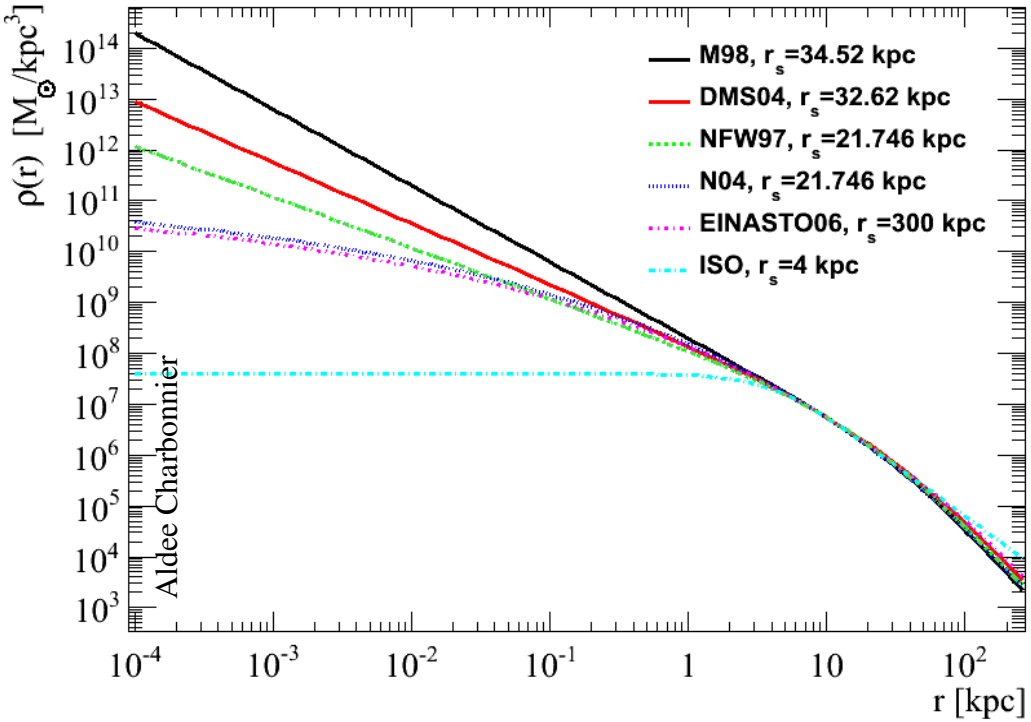
- Large amount of energy density of the Universe in the form of non-luminous "dark" matter
- relic density from freeze-out:

$$\Omega_\chi h^2 \approx \frac{3 \cdot 10^{-27}\,\mathrm{cm^3 s^{-1}}}{\langle \sigma v \rangle}$$

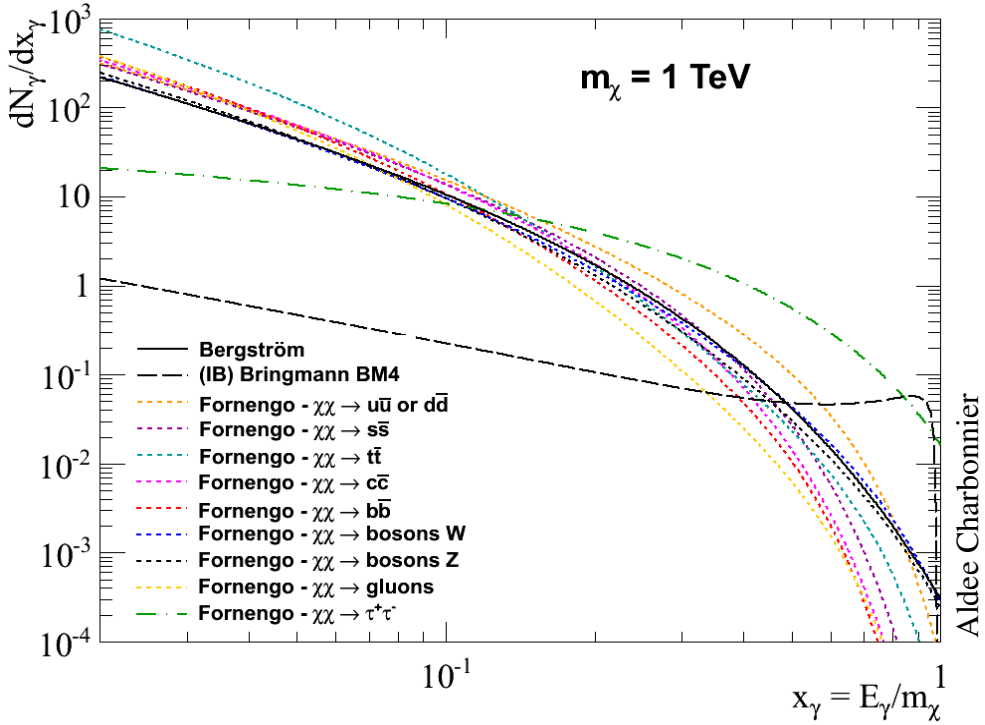
- generic scenario:
  - Weakly interacting massive particles (WIMPs)
  - annihilation to standard model final states, hadronization process
  - gamma-rays from $\pi^0$ decays
- if $m_{WIMP}$ at or above TeV scale, gamma-ray astronomy promising for indirect search
- Promising targets have high dark matter density. Recently published:
  - **Galactic Center Halo**
  - **dwarf galaxies**

- gamma-ray flux from dark matter annihilations:

$$\frac{d\Phi}{dE_\gamma}(E_\gamma, \Delta\Omega) = \Phi^{\mathrm{ASTRO}}(\Delta\Omega) \cdot \frac{d\Phi^{\mathrm{PP}}}{dE_\gamma}(E_\gamma)$$

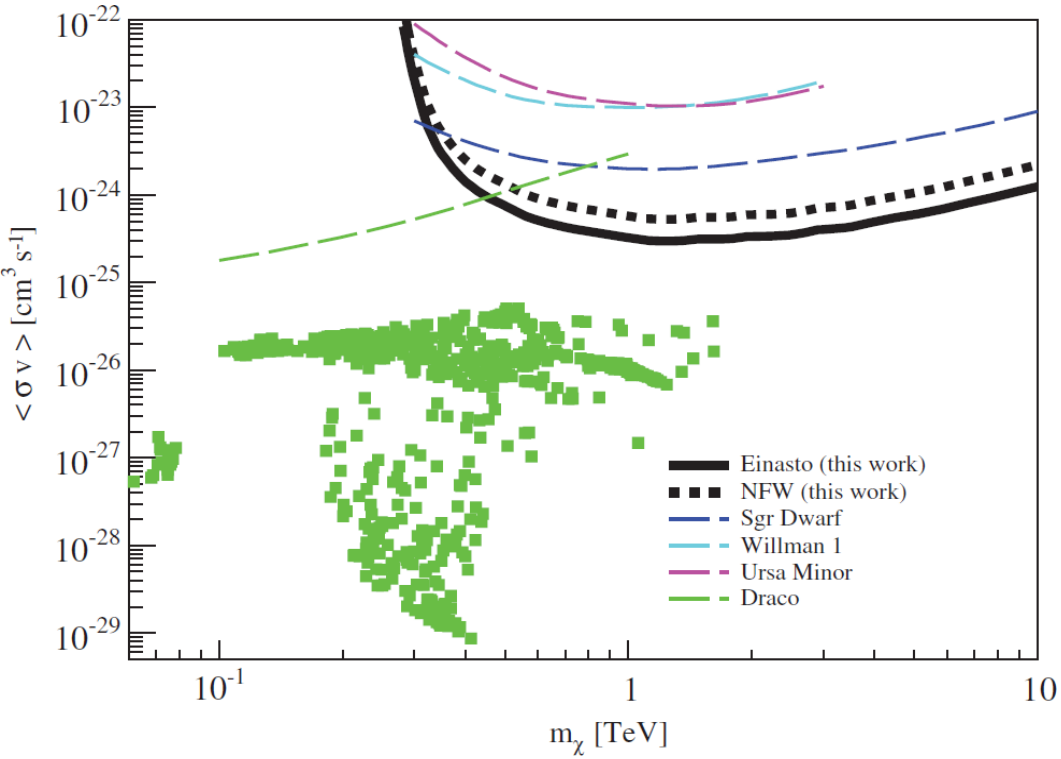



DM density profiles of the Galactic halo

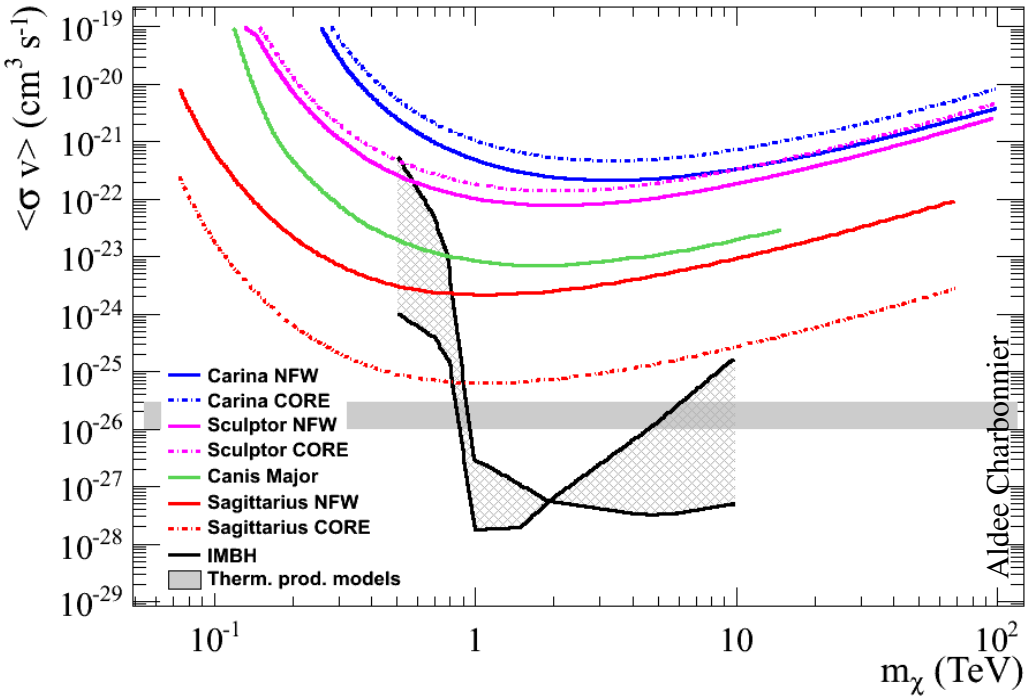



annihilation spectra for different WIMP models

# Recent results of indirect dark matter search




compilation of limits for neutralino LSP



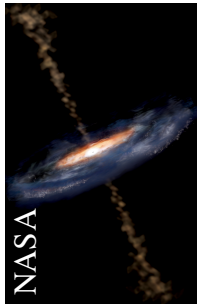

- Galactic Center Halo
  - $|b| > 0.3°$ to exclude astrophysical backgrounds
  - $\rho_{source} > \rho_{bg\text{-}region}$

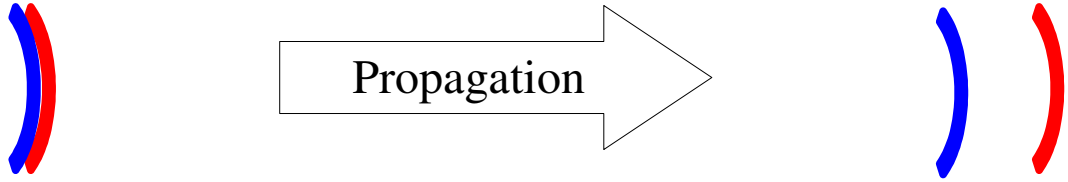
- dwarf galaxies
  systems dominated by dark matter

Best H.E.S.S. limits currently in the range $3 \times 10^{-25}$ to $3 \times 10^{-24}$ cm$^3$ s$^{-1}$.

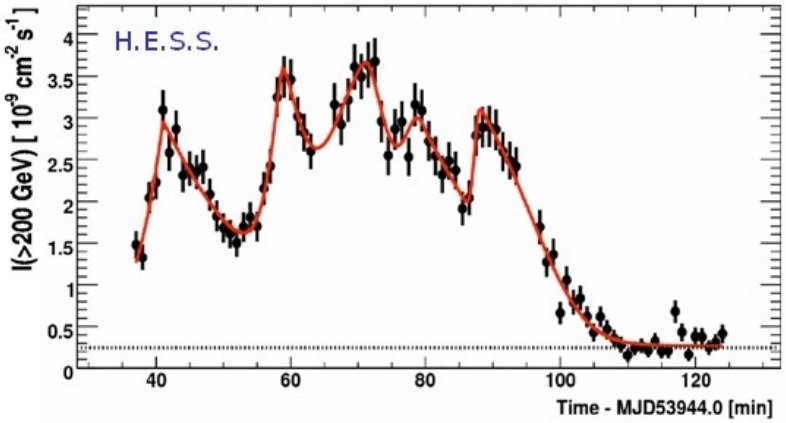
*H.E.S.S. Collaboration,*
*PRL 106 (2011) 161301*
*Astropart. Phys. 34 (2011) 608*
*ApJ 735 (2011) 12*

# Test of Lorentz invariance




$$v = c(1 - \xi(E/M)) \quad \text{or} \quad v = c(1 - \zeta(E/M)^2)$$




$$\xi \propto \frac{\Delta t}{\Delta E} \qquad \zeta \propto \frac{\Delta t}{\Delta E^2}$$

*HESS Collaboration, Astropart. Phys. 34 (2011) 738*

- Use pulse-shape of giant AGN flare, to search for energy-dependent velocity of gamma-ray photons. Ideal candidate: PKS 2155 flare of July 28th, 2006.
- Lightcurve for low energy range (0.25-0.28 TeV) as temporal template.
- Calculate event-by-event likelihood, with $\Delta t/\Delta E$ (or $\Delta t/\Delta E^2$) as parameter, using known effective area, source spectrum, and energy resolution.
- No hint for Lorentz invariance violation found. 95% CL upper limits:

$\Delta t/\Delta E = (-5.5 \pm 10.9 \pm 10.3)$ s TeV$^{-1}$ $\quad$ $\Delta t/\Delta E^2 = (1.7 \pm 6.3 \pm 6.6)$ s TeV$^{-2}$

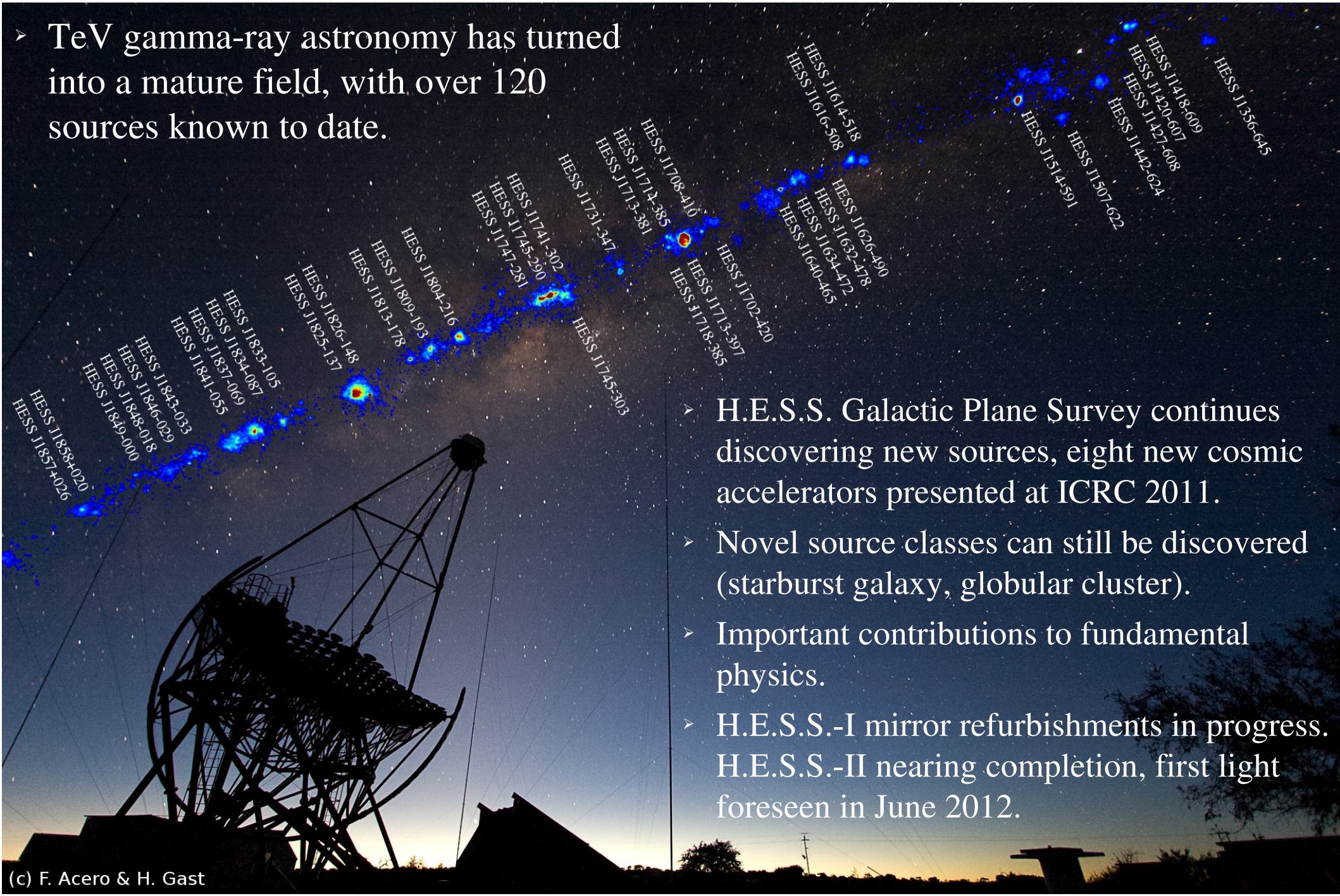
$M_{QG}{}^{1} > 2.1 \times 10^{18}$ GeV $\quad$ $M_{QG}{}^{q} > 6.4 \times 10^{10}$ GeV

# H.E.S.S. II

- lower threshold to ~50 GeV:
  - pulsar physics
  - AGN physics
  - dark matter search
  - overlap with Fermi-LAT energy range
- on track for first light in June 2012

# Summary

- TeV gamma-ray astronomy has turned into a mature field, with over 120 sources known to date.




- H.E.S.S. Galactic Plane Survey continues discovering new sources, eight new cosmic accelerators presented at ICRC 2011.
- Novel source classes can still be discovered (starburst galaxy, globular cluster).
- Important contributions to fundamental physics.
- H.E.S.S.-I mirror refurbishments in progress. H.E.S.S.-II nearing completion, first light foreseen in June 2012.