

CANGAROO

Collaboration of Australia and Nippon (Japan) for a
GAMMA-Ray Observatory in the Outback



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for the CANGAROO Team

















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CANGAROO

- Aim: study of TeV gamma-ray sources in the southern hemisphere
- First southern Imaging Atmospheric Cherenkov Telescope (IACT) started operation in 1992
- Observation site: Woomera, South Australia

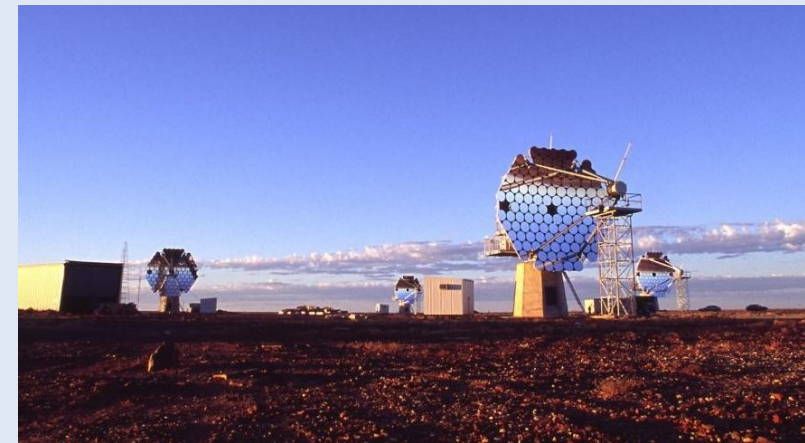


CANGAROO Team

- Univ. Adelaide 
 - ATNF 
 - ANU 
 - Ibaraki Univ. 
 - KEK 
 - Kitasato Univ. 
 - Konan Univ. 
 - Kyoto Univ. 
 - STEL, Nagoya Univ. 
 - NAOJ 
 - Ritsumeikan Univ. 
 - Tokai Univ. 
 - ICRR, Univ. Tokyo 
 - Waseda Univ. 
 - Yamagata Univ. 
 - Yamanashi Gakuin Univ. 
- 36 scientists, 16 institutes (as of 2012)

History

- CANGAROO-I
 - 3.8 m diameter
 - Single telescope
 - 1992-1998
 - First southern IACT
- CANGAROO-II
 - 7 to 10 m diameter
 - Single telescope
 - 1999-2002
- CANGAROO-III
 - 10 m diameter
 - 4 telescope stereoscopic system
 - 2002-2011



CANGAROO-III

- 4 IACTs operated since 2004
 - Mirror diameter: 10 m
 - Field of view: ~ 4 deg.
 - Telescope spacing: ~ 100 m
- 3 IACTs used since 2005
 - First telescope (T1) with different specification degraded

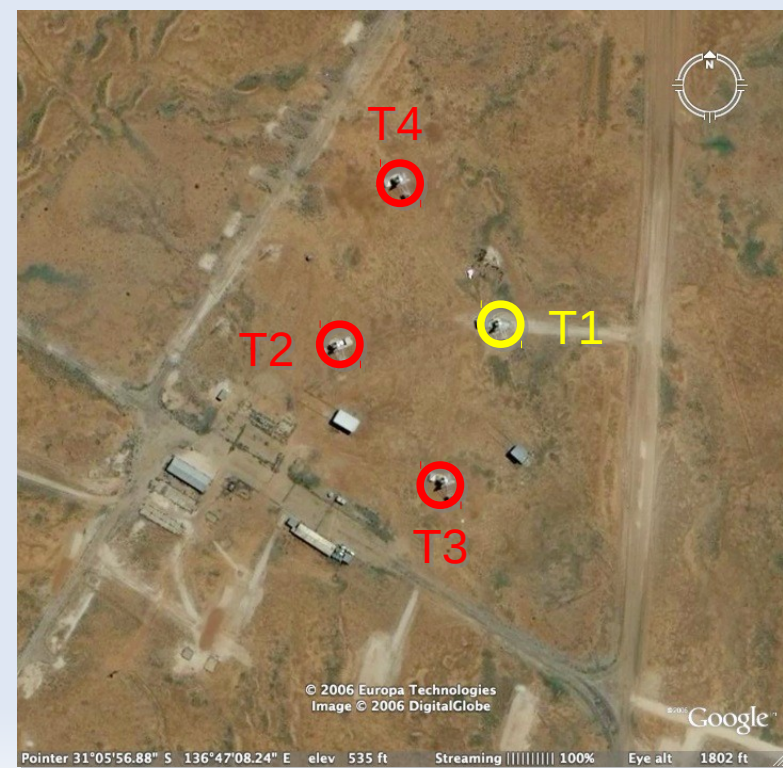
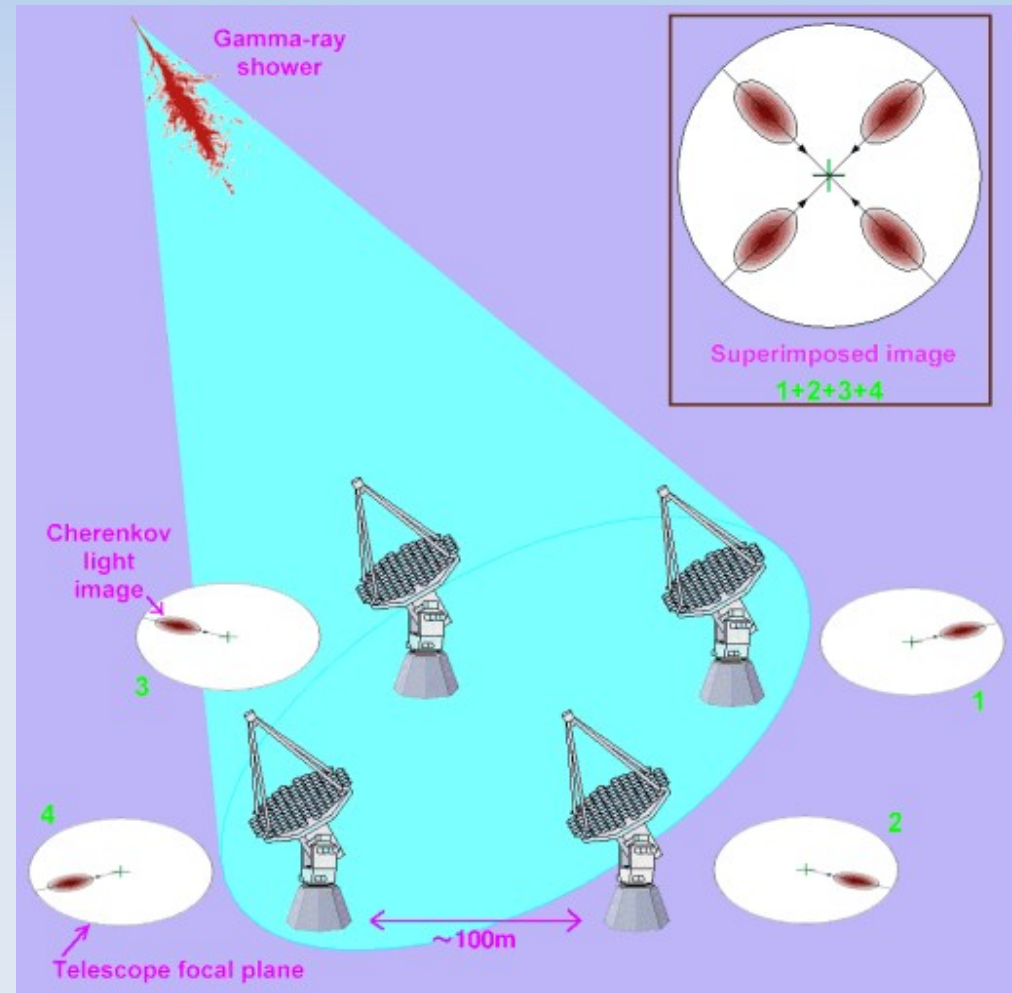


Table 1. Basic specifications of the CANGAROO-III telescopes.

	T1	T2, T3, T4
Mount	Alt-azimuth	
Focal length	8 m	
Number of mirrors	114 (57 m^2 in total)	
Reflector type	Parabola	
Number of PMTs	552 (1/2")	427 (3/4")
Camera pixel size	$0.115''$	$0.168''$
Readout	TDC (CAMAC) & ADC	TDC (VME) & ADC
Point image size	$0.20''$ (FWHM)	0.14 – $0.21''$ (FWHM)
Completion	2000.3	2002.3 (T2), 2002.11 (T3), 2003.7 (T4)

Observation / Analysis Technique

- Imaging Atmospheric Cherenkov Technique
 - Air shower development detected with a multi-pixel camera
- Stereoscopic observation of air showers with the 4 IACTs
 - Stereoscopic reconstruction of arrival direction, primary energy, etc.
- CANGAROO-III analyses based on the Fisher's discriminant
 - Background rejection optimized using Monte Carlo gamma-ray simulations and real background events

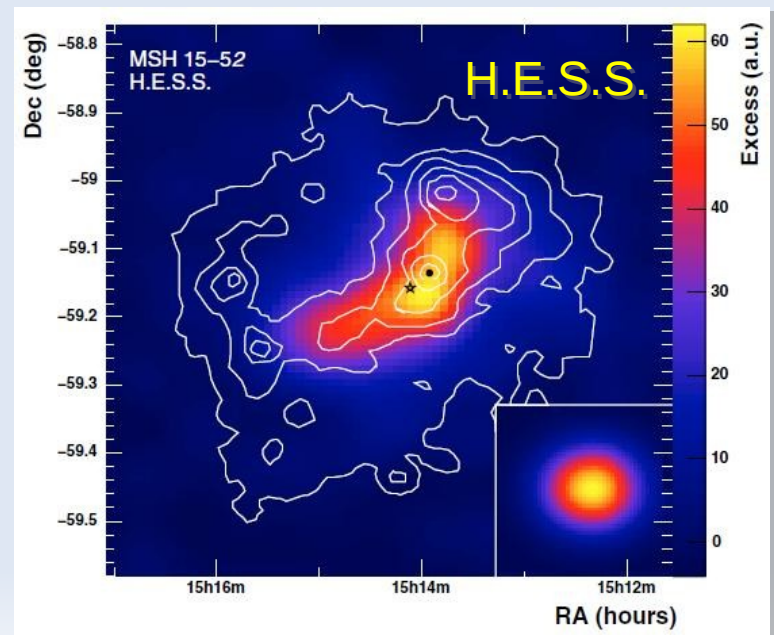
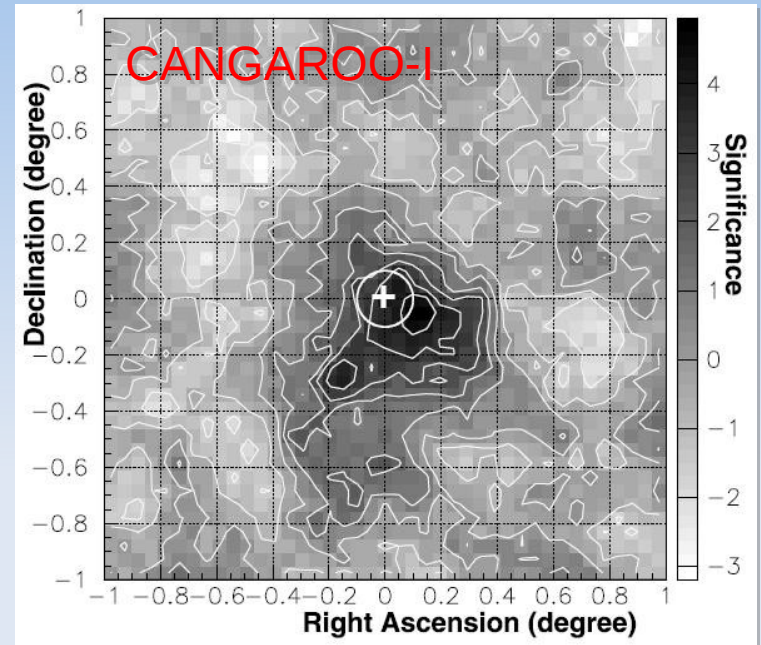


CANGAROO Results since 2006

Object	Type	Data	Result
MSH 15-52	Pulsar Wind Nebula	CANGAROO-III	Detection
PKS 2155-304	Blazar	CANGAROO-III	Detection
HESS J1804-216	Unidentified	CANGAROO-III	Detection
HESS J1614-518	Unidentified	CANGAROO-III	Detection
PSR B1706-44	Pulsar Wind Nebula	CANGAROO-III	Detection
NGC 253	Starburst Galaxy	CANGAROO-III	Upper Limit
SN 1987A	Supernova Remnant	CANGAROO-III	Upper Limit
Kepler	Supernova Remnant	CANGAROO-III	Upper Limit
Abell 3667	Cluster of Galaxies	CANGAROO-III	Upper Limit
Abell 4038	Cluster of Galaxies	CANGAROO-III	Upper Limit
H 2356-309	Blazar	CANGAROO-III	Upper Limit
PKS 0537-441	Blazar	CANGAROO-III	Upper Limit
3C 279	Blazar	CANGAROO-III	Upper Limit
SS 433 / W 50	Binary / Supernova Remnant	CANGAROO-II	Upper Limit
PSR B1706-44	Pulsar Wind Nebula	CANGAROO-I	Upper Limit
SN 1006	Supernova Remnant	CANGAROO-I	Upper Limit
Vela PWN	Pulsar Wind Nebula	CANGAROO-I	Detection

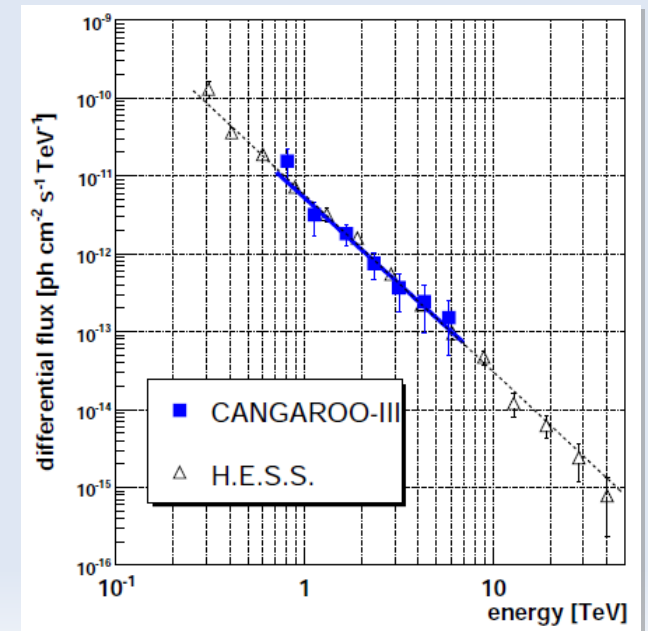
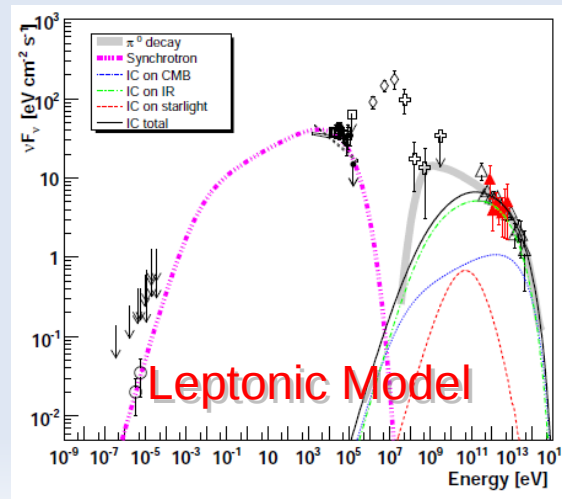
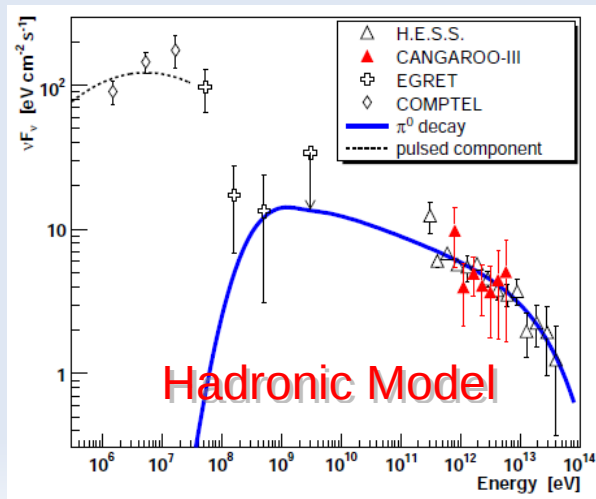
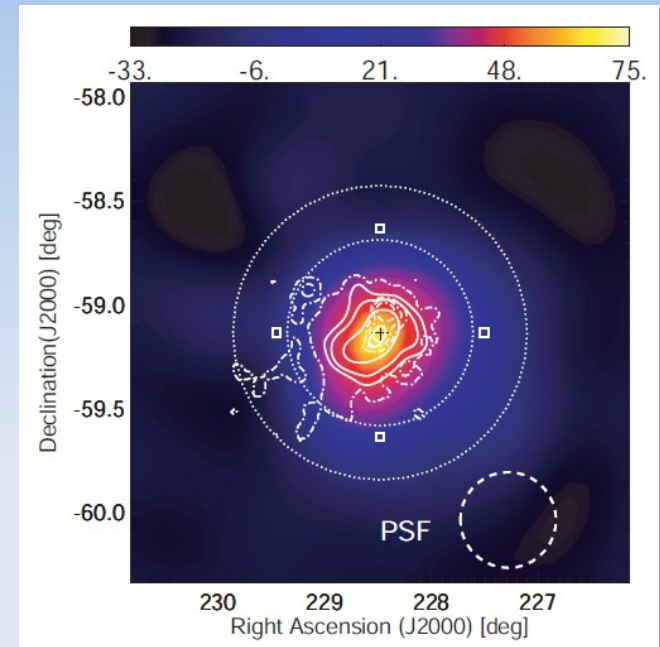
MSH 15-52

- Supernova Remnant (SNR) with high-energy pulsar PSR B1509-58
 - 3rd highest spin-down energy loss
- First marginal detection of TeV gamma rays by CANGAROO-I
 - Sako et al. (2000)
- H.E.S.S. detection in 2004
 - Extended around the pulsar
 - Emission from the pulsar wind nebula (PWN)?



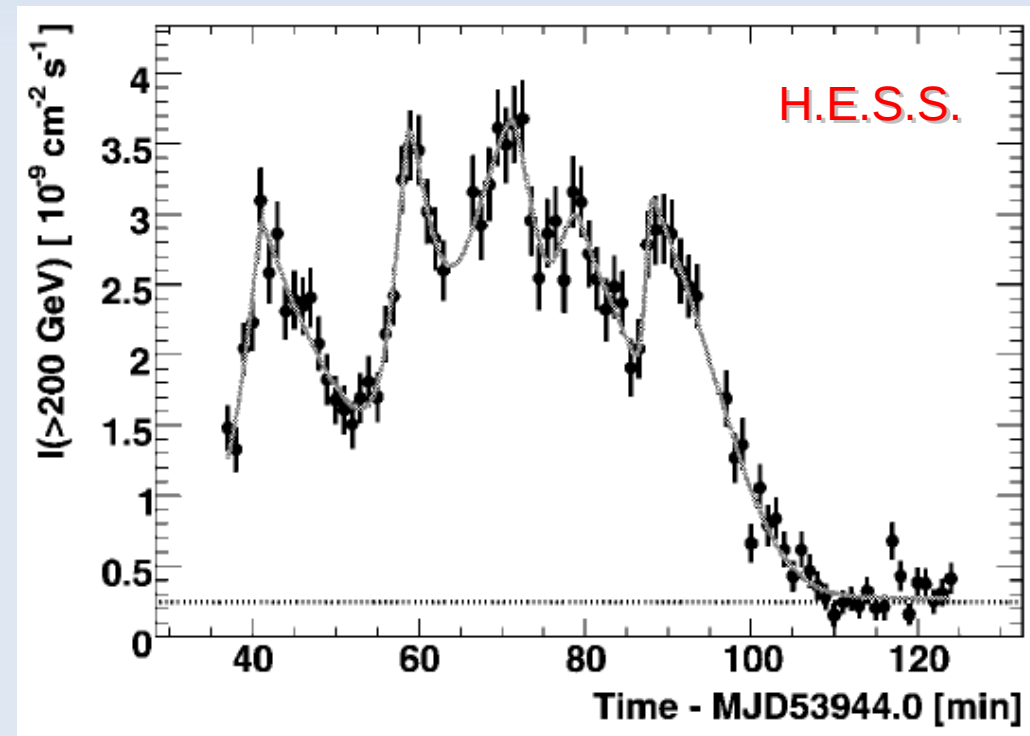
CANGAROO-III Observations of MSH 15-52

- Observed from April to June 2006
 - Total exposure: 48.4 hr
- 7 σ detection above 810 GeV
 - Nakamori et al. (2008)
 - TeV gamma-ray spectrum consistent with H.E.S.S.
- Discussion on the emission mechanism with multiwavelength SEDs



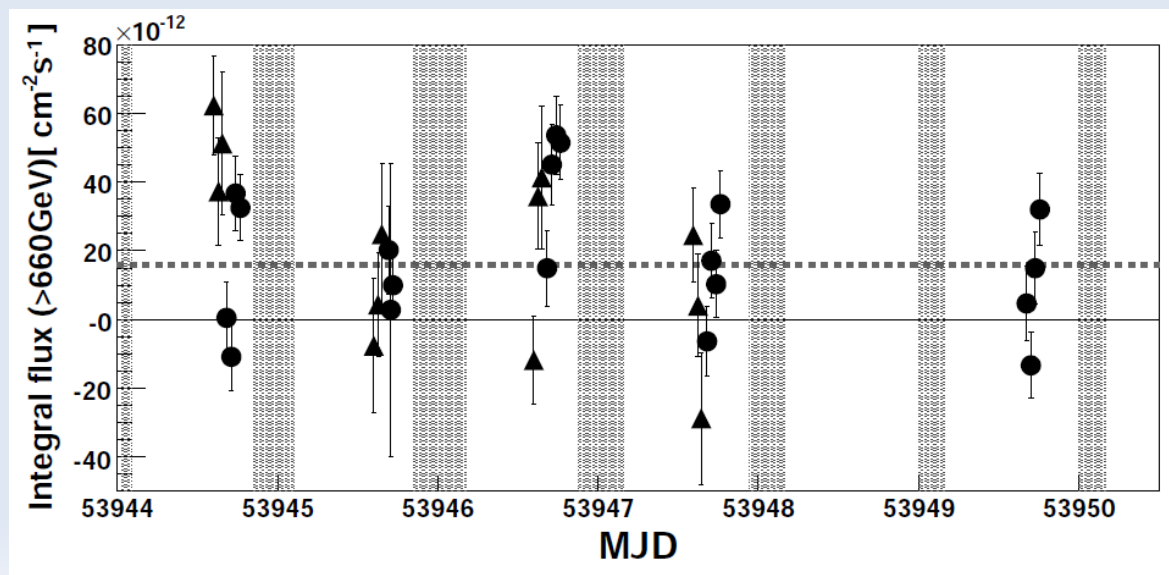
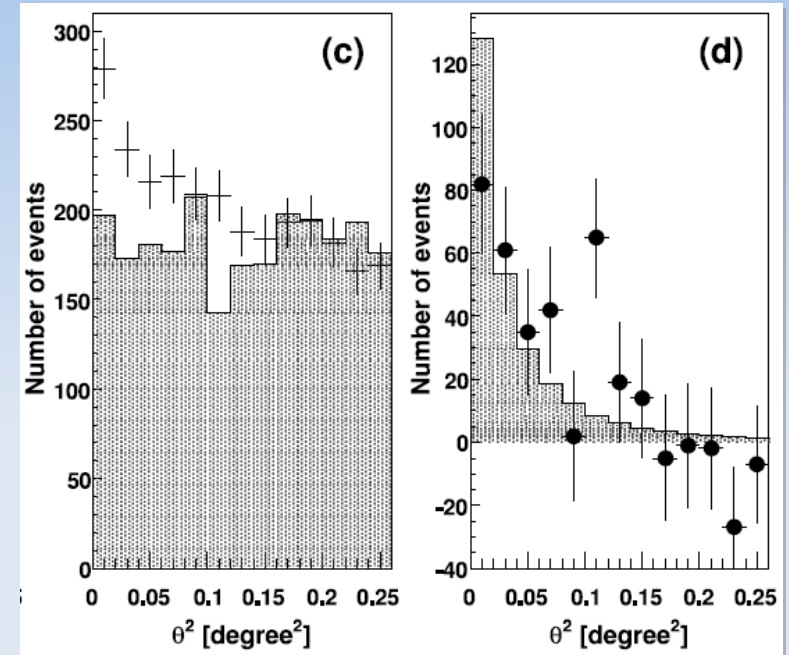
PKS 2155-304

- One of the most violent blazars in the southern sky
 - Discovered by the Durham group as a TeV source in 1997
 - Redshift = 0.116
- Historical TeV flare from PKS 2155-304 detected by H.E.S.S.
 - July 2006
 - ~7 Crab level on July 28



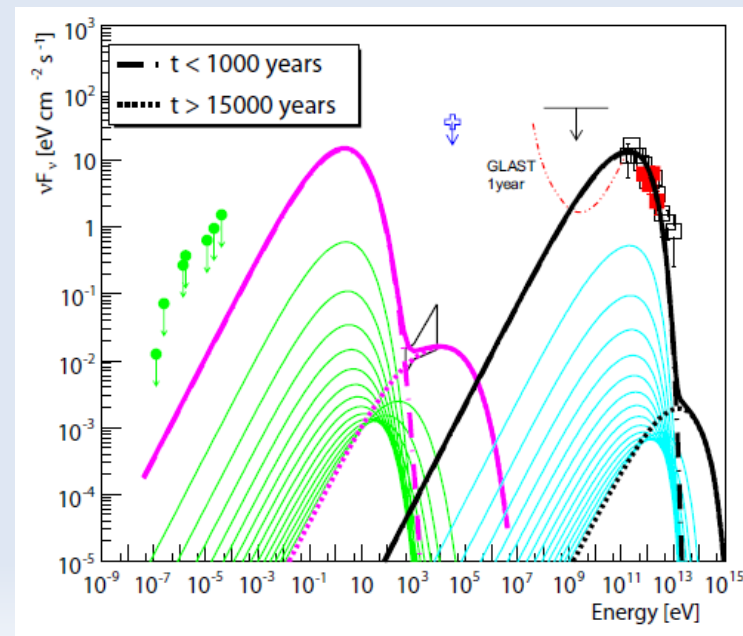
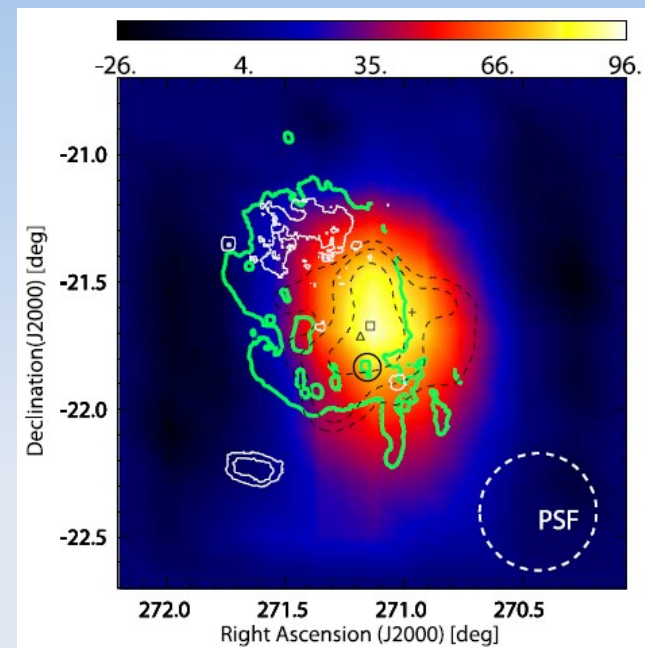
CANGAROO-III Observations of PKS 2155-304 2006 Flare

- CANGAROO-III observations triggered by the H.E.S.S. detection
 - 25.1 hr from July 28 to August 2, 2006
- 4.8σ detection above 660 GeV
 - ~ 0.45 Crab level
 - Sakamoto et al. (2008)
- 8 hr observation time difference between H.E.S.S. and CANGAROO-III
 - First continuous monitoring in the southern sky



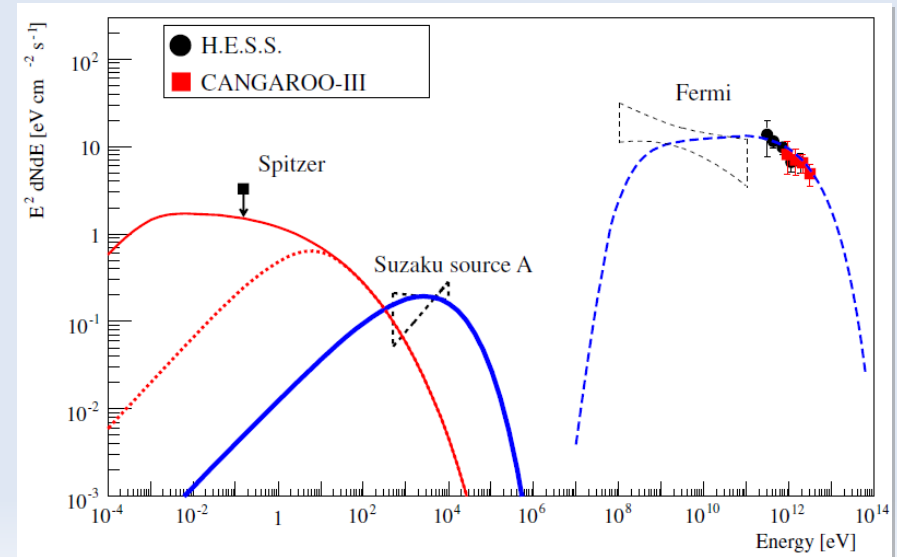
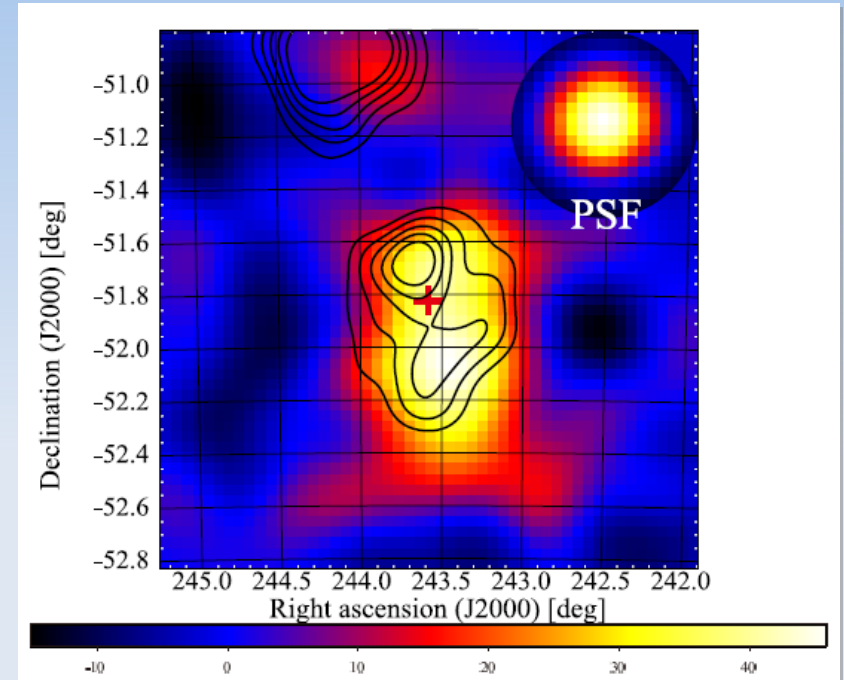
HESS J1804-216

- One of the brightest H.E.S.S. unidentified sources
 - Discovered in a Galactic plane survey in 2004
- CANGAROO-III observations from May to July 2006
 - Effective exposure 76 hr
- 10σ detection above 600 GeV
 - Higashi et al. (2008)
 - Confirmed the extended morphology
- Discussion on the counterpart
 - Leptonic model for the PWN of PSR B1800-21 requires a quite high efficiency



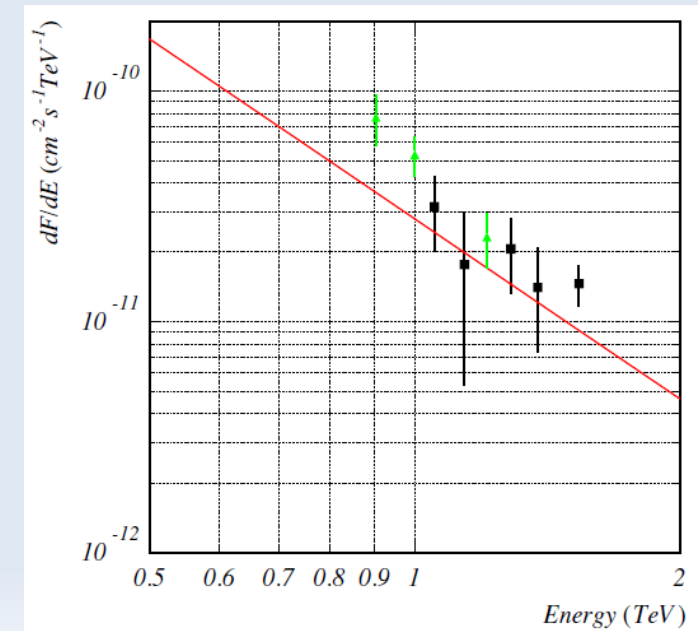
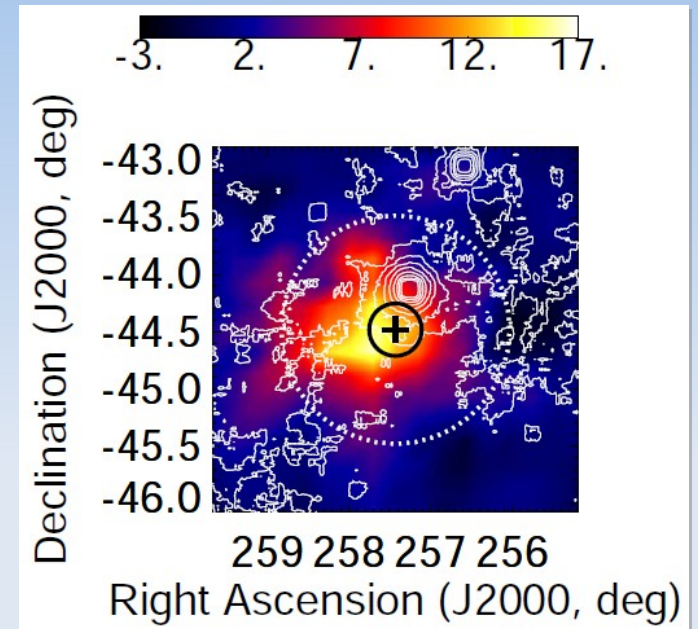
HESS J1614-518

- Another H.E.S.S. unidentified source
- CANGAROO-III observations from May to July 2008
 - Effective exposure 54 hr
- 8.9σ detection above 760 GeV
 - Mizukami et al. (2011)
 - TeV spectrum consistent with H.E.S.S.
- Hadronic model preferred
 - Spin-down powers of known pulsars insufficient to produce the observed TeV luminosity



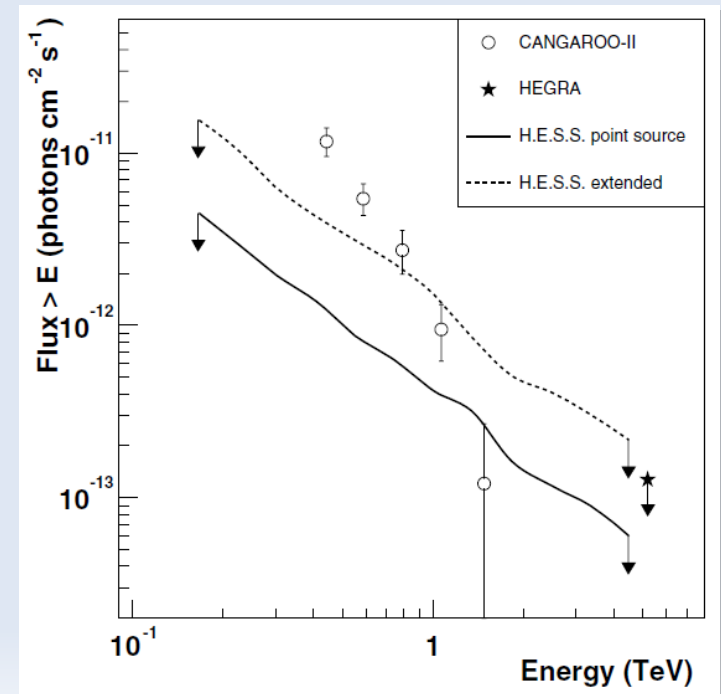
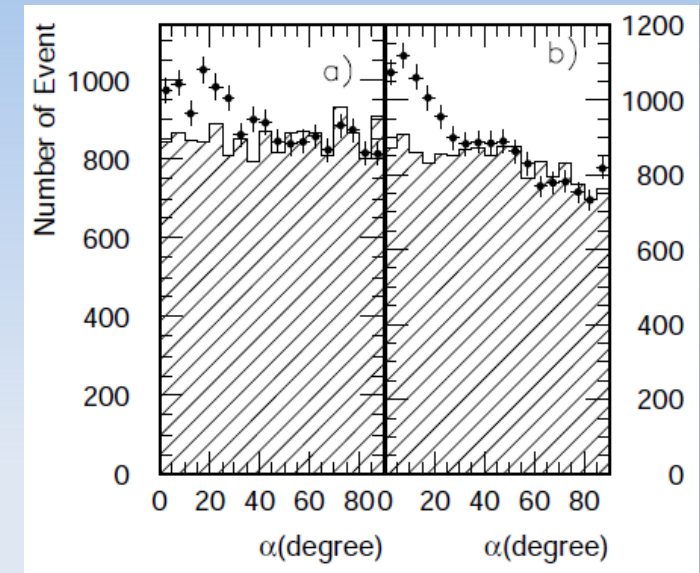
PSR B1706-44 and Its Vicinity

- One of the high-energy pulsars
 - TeV signal from the pulsar position reported by CANGAROO-I
- CANGAROO-III observations
 - 53 hr effective exposure
 - July 2004 and April to June 2007
- Diffuse excess found around the pulsar
 - Enomoto et al. (2009)
 - 6.1σ detection
 - Extended over 1 deg.
 - 1 Crab level flux within 1 deg.
- Point-like emission from the pulsar position not found



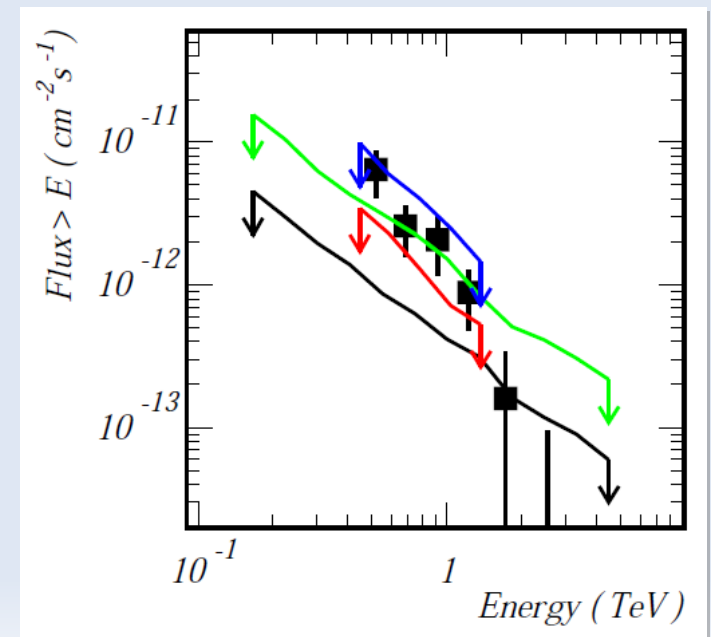
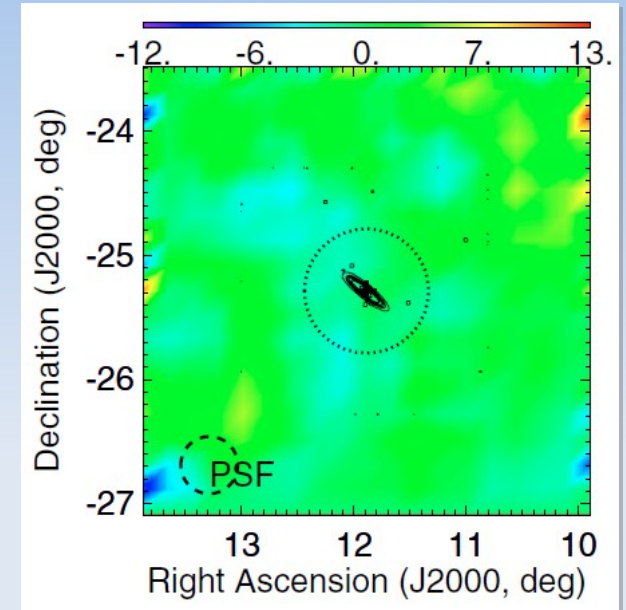
NGC 253

- Starburst galaxy
 - TeV source candidate due to the high supernova rate
- TeV signal detection reported by CANGAROO-II in 2002
 - 11 σ level excess above 500 GeV
 - Diffuse emission
- H.E.S.S. did not detect at the same flux level (2005)
 - Detection of a point-like source with more data in 2009



CANGAROO-III Observations of NGC 253 (Erratum)

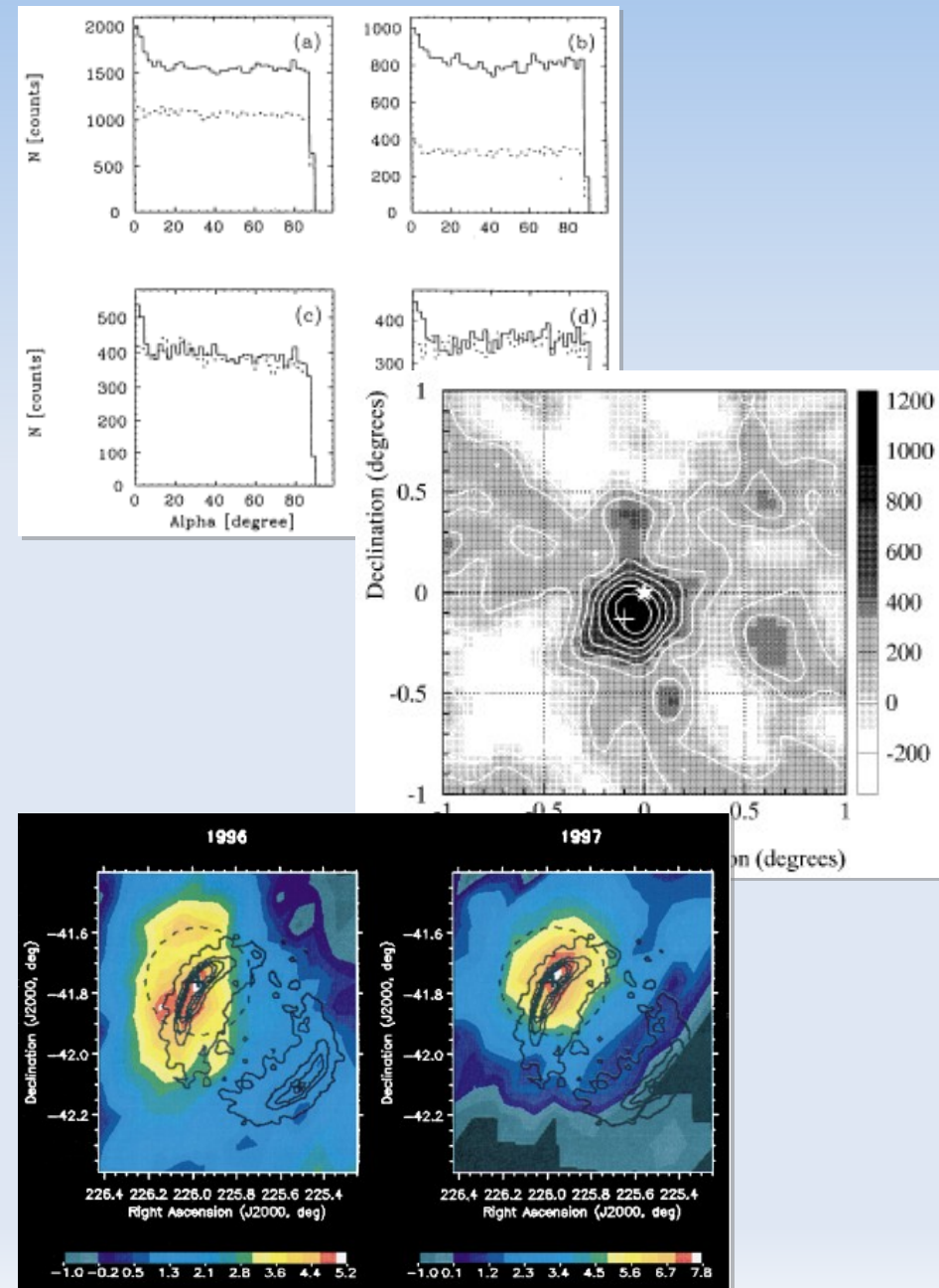
- CANGAROO-III observations in October 2004
 - Total observation time: 20 hr
- No TeV signal found from CANGAROO-III
 - Itoh et al. (2007)
 - Upper limit: 5.8 % Crab level at 580 GeV
- CANGAROO-II excess lowered to less than 4σ after assessing treatment of malfunction of PMTs
 - Possible error in treatment of hot pixels



CANGAROO-I Reanalysis

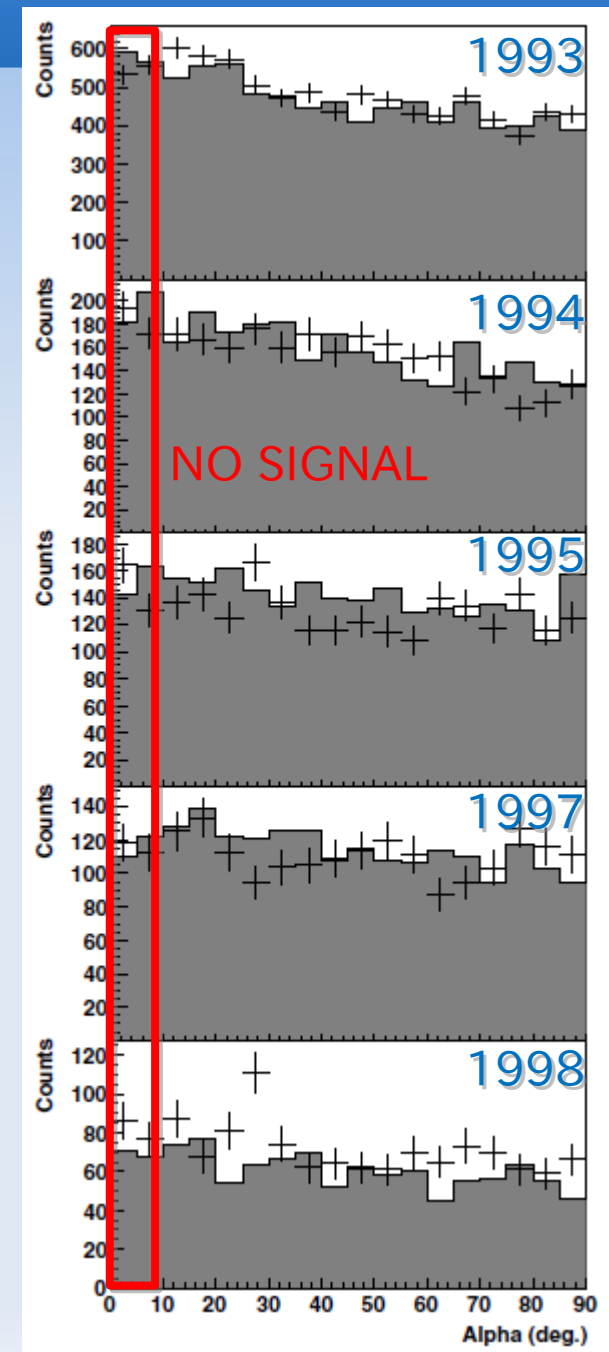
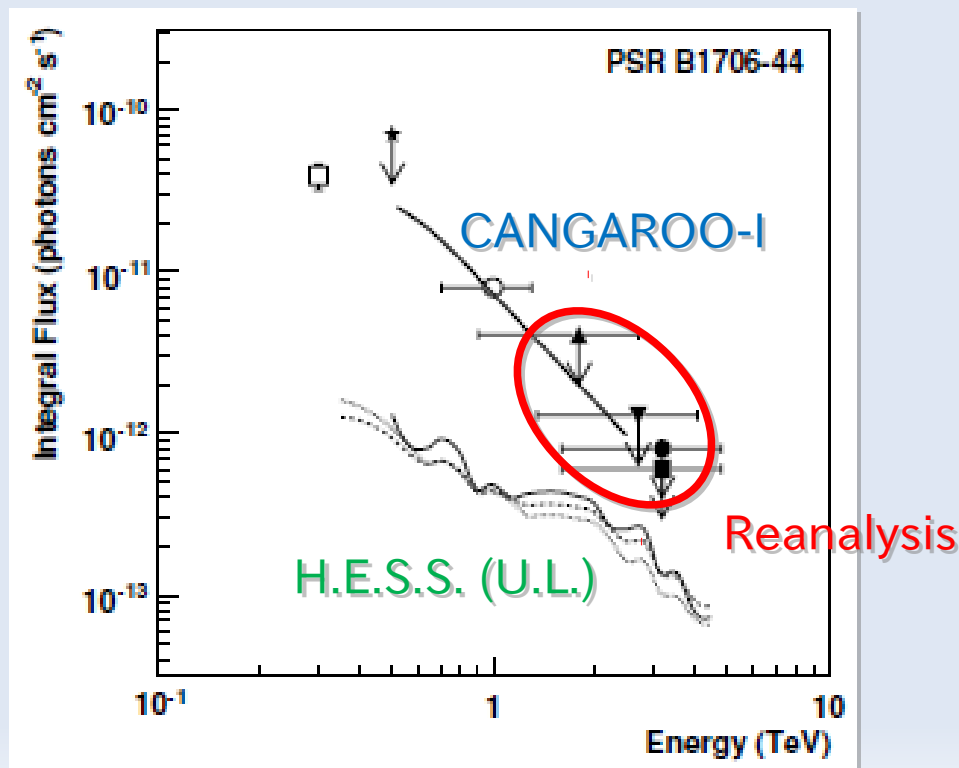
History

- CANGAROO-I detections
 - PSR B1706-44 (1995)
 - Vela PWN (1997)
 - SN 1006 (1998)
- H.E.S.S. non-detection of these sources (2005)
 - Upper Limits an order of magnitude lower
- H.E.S.S. deeper observations revealed TeV signals from these sources (2006-2011)
 - But flux levels / morphology different from CANGAROO-I
- Reanalyses of the old CANGAROO-I data motivated by the inconsistencies
 - Yoshikoshi et al. (2009)
 - Simple and common analyses
 - Background cuts optimized using simulations



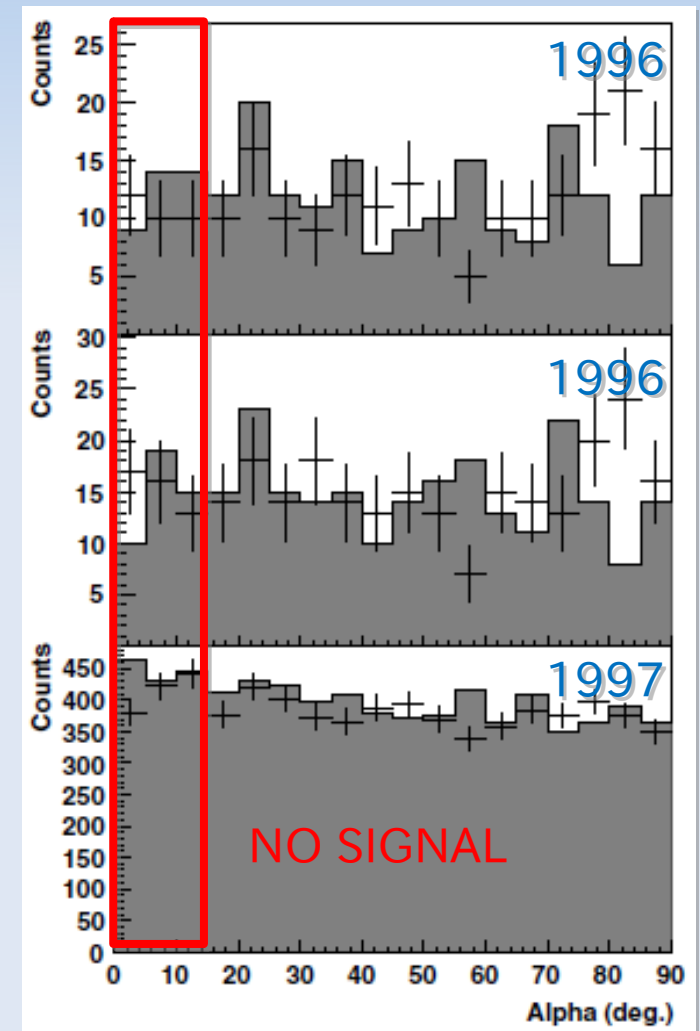
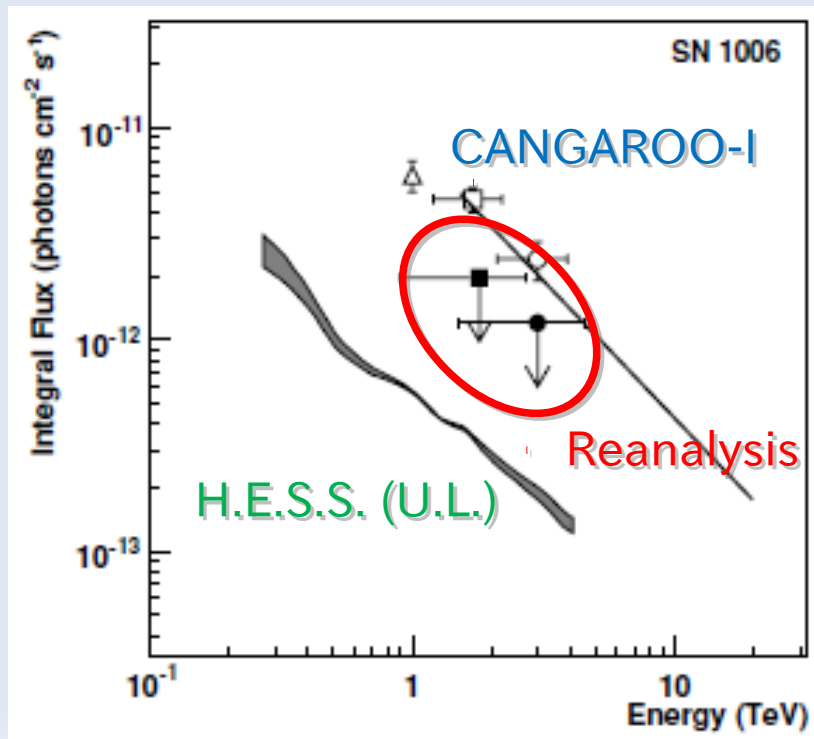
PSR B1706-44 CANGAROO-I Reanalysis

- Original result not reproduced
 - No TeV signal from the pulsar position found in any dataset
- Upper limits consistent with H.E.S.S.



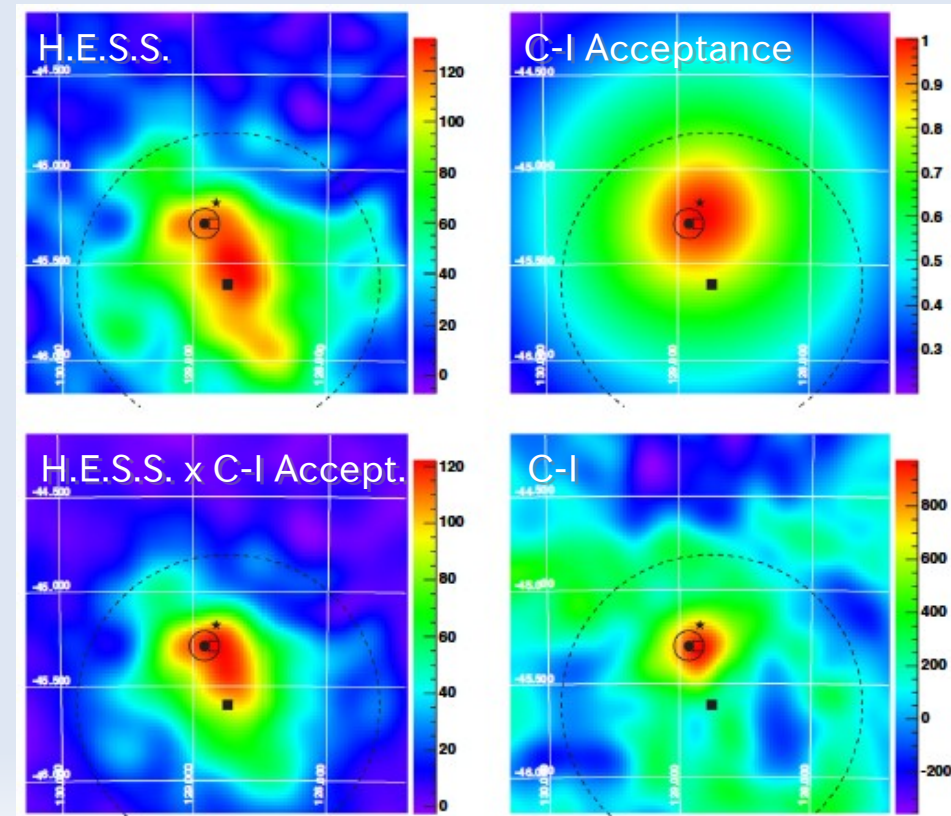
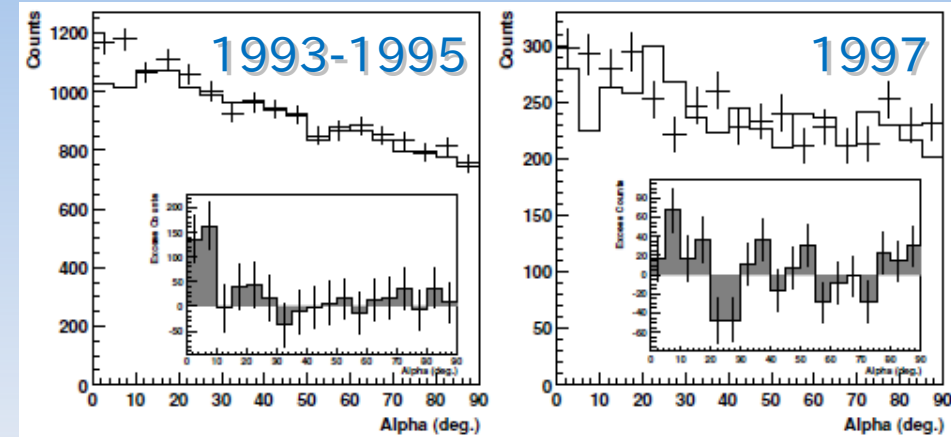
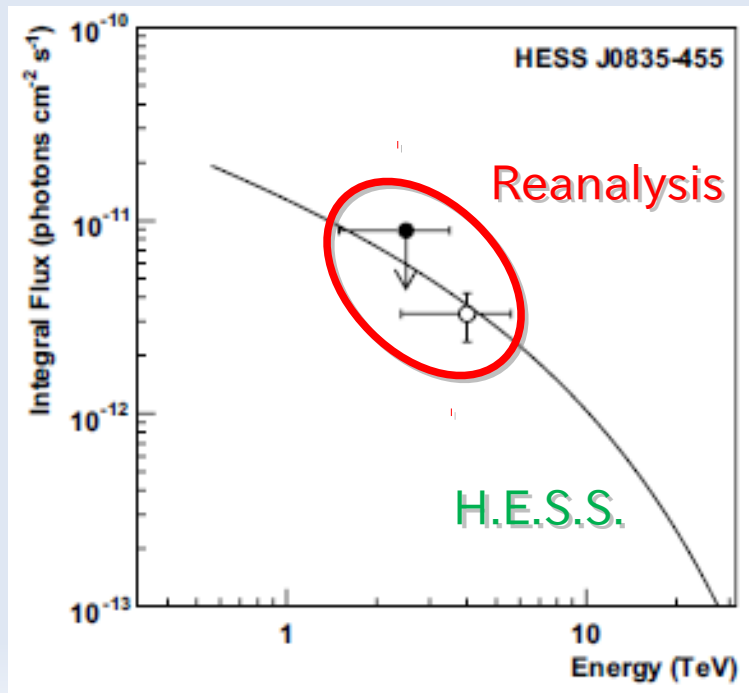
SN 1006 CANGAROO-I Reanalysis

- Original result not reproduced
 - No TeV signal from the NE rim found in any dataset
- Upper limits consistent with H.E.S.S.



Vela PWN CANGAROO-I Reanalysis

- 4.5 σ level excess remains
 - Morphology comparable after considering CANGAROO-I acceptance
- Recalculated flux for Vela X region consistent with H.E.S.S.

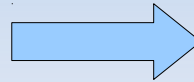


Degradation of CANGAROO-III Mirrors

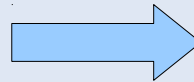
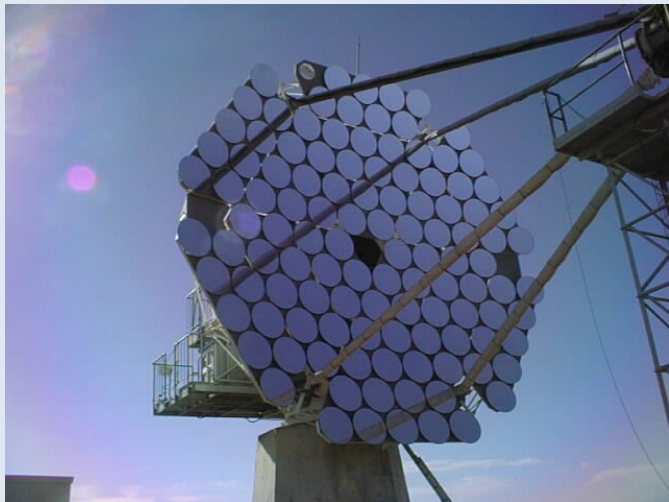
May 2006

August 2011

T3

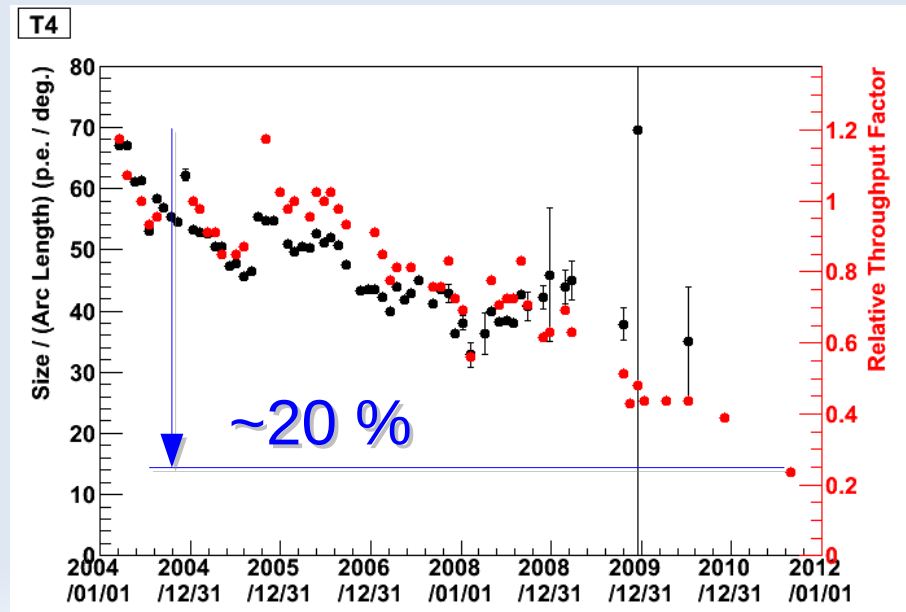
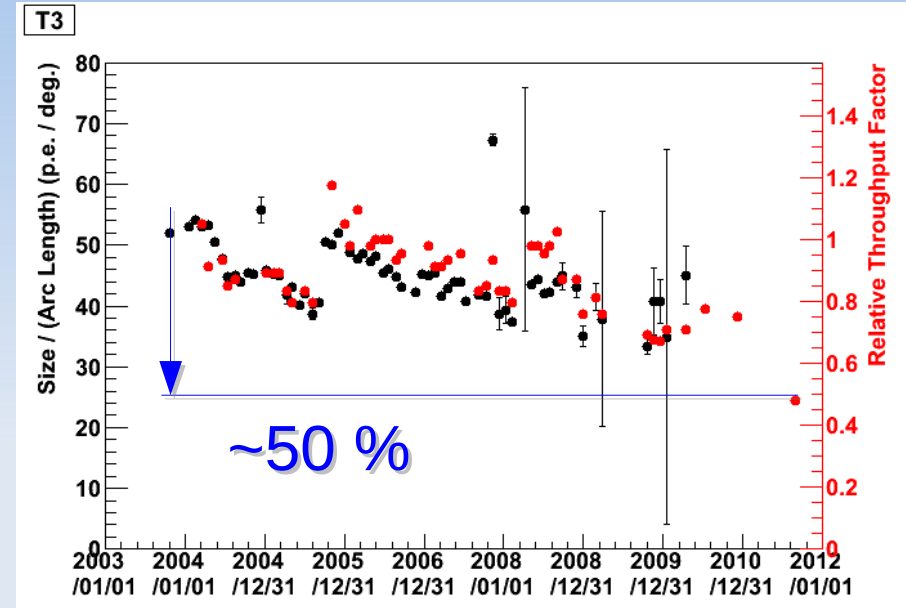


T4



CANGAROO-III Termination

- System throughput of each telescope monitored using
 - Single muon events
 - Background event rates
- Telescope performance degraded down to ~20-50 %
- Stopped observations in 2011
 - Upgrade plan was not approved
 - Activity should be turned into future projects



CANGAROO Site after Cleanup



Summary (2006-2011)

- CANGAROO has played a pioneering role in the southern TeV sky for 20 years
- Various TeV gamma-ray sources have been observed by CANGAROO-III since 2006
 - Confirmations of H.E.S.S. sources, discussion on their emission mechanisms, etc.
 - Continuous monitoring of a PKS 2155-304 flare with H.E.S.S.
- Reanalysis of CANGAROO-I data
 - Inconsistency problems now solved
- CANGAROO observations ended in 2011
 - Summary review paper in preparation
- Future
 - Activity turned into future projects