H.E.S.S. observations of massive star clusters

Stefan Ohm for the H.E.S.S. collaboration

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collaborators: J. Hinton, D. Horns, O. Reimer, G. Rowell and others

High Energy Stereo. System

Four 13m diameter telescopes in the Khomas highlands of Namibia

Latitude 23° south → good for galactic sources
100 GeV – 100 TeV, 15% energy resolution
5' angular resolution, 5° field of view

The TeV Sky in 2003



The TeV Sky in February 2009





What are the galactic TeV sources?

Original expectation

- TeV emission should trace the acceleration sites of the galactic cosmic rays
- Paradigm of cosmic ray acceleration in supernova remnant (SNR) shells
 - Well established acceleration mechanism
 - Sufficient energy output
- We should see SNRs!

Observations

TeV sources cluster tightly along the galactic plane, scale height = that of molecular gas and hence young SNR...













Individual y-ray binaries

• Different sources discussed in this meeting:

- PWN binaries (e.g. PSR B1259-63)
- Microquasars (e.g. LS I +61 303, LS 5039?)
- HESS J0632+057

Shared properties:

- Massive star (e.g. Be-type) with large radiation field as companion star
- Compact object as central engine

γ-ray sources linked to star clusters

Common approach:

•Use MWL information -> search for potential VHE γ-ray sources

γ-ray sources linked to star clusters

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•Use MWL information -> search for potential VHE γ-ray sources

• Putting the cart before the horse:

Take (un-)identified VHE source -> find counterpart in other wavelengths

HESS J1813-178

- H.E.S.S. source¹ coincident with composite SNR and central PWN candidate
- Detected by ASCA² and Integral³
- 2 SNRs⁴ in the vicinity of HESS J1813, physically related to W33 complex

- ¹ Aharonian et al 2005
- ² Brogan et al 2005
- ³ Ubertini et al 2005
- ⁴ Brogan et al 2005, Helfand et al 2005

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- Star Cluster recently found⁵
- d ~ 4.7kpc, age of 6-8Myrs
- M ~ 2000 6500Msol

¹ Aharonian et al 2005

- ² Brogan et al 2005
- ³ Ubertini et al 2005
- ⁴ Brogan et al 2005, Helfand et al 2005

⁵ Messineo et al 2008

HESS J1837-069

- Previously unidentified TeV source¹ but possibly associated to a PWN⁶
- Coincident with young pulsar²
- Cluster of red super giants (RSGC 1) was found in 2006³
- ASCA⁴, Integral⁵ & Suzaku⁶ sources closeby
- RSGC 1 properties:
 - massive (2-4) *10⁴ M_{sol}
 - rich 14 RSGs, 1 YSG
 - d = 5.8kpc
 - age 7-12 Myrs
- ¹ Aharonian 2005, Aharonian 2006
- ² Gotthelf & Halpern 2008
- ³ Figer et al 2006
- ⁴ Bamba et al 2003
- ⁵ Malizia et al 2005

(°) 0.2 Dec 0.5 70 60 50 G25.5+0.0 40 30 - 0 20 10 0-0655 -10 -0.5 **ASCA** Suzaku RSGG4.5 25 24.5 b (°)

⁶ Anada 2008

But what about the star cluster itself?

VHE y-rays from Star Clusters

Several acceleration mechanisms are possible:

- Binaries -> Colliding winds^{1,2}
- Massive stars -> SN explosions
- Age -> most massive stars already evolved into SNe
- •All together -> Collective effects^{3,4}

- ¹ Bednarek 2005
- ² Reimer et al 2006
- ³ Domingo-Santamaria et al 2005
- ⁴ Bykov 2001

Most promising candidates

List of potential targets directly from:

- Massive stars -> need a lot of them
- Binaries -> large binary fraction

Age -> evolutionary state (wind/wind and/or wind/SN ejecta)

Cluster	$Log(M) \\ M_{\odot}$	Radius pc	$\begin{array}{c} \operatorname{Log}(\rho) \\ M_{\odot} \ \mathrm{pc}^{-3} \end{array}$	Age Myr	$\substack{ \text{Log}(\mathcal{L}) \\ L_{\odot} }$	$\frac{\rm Log(Q)}{\rm s^{-1}}$	OB	YSG	RSG	LBV	WN	WC
Westerlund 1^{b}	4.7	1.0	4.1	4 - 6				6	4	2	16	8
$RSGC2^{c}$	4.6	2.7	2.7	14 - 21			0	0	26	0	0	0
$RSGC1^d$	4.5	1.3	3.5	10 - 14			1	1	14	0	0	0
$\operatorname{Quintuplet}^{e}$	4.3	1.0	3.2	4 - 6	7.5	50.9	100	0	1	2	6	13
$\operatorname{Arches}^{f}$	4.3	0.19	5.6	2 - 2.5	8.0	51.0	160	0	0	0	6	0
$\operatorname{Center}^{g}$	4.3	0.23	5.6	4 - 7	7.3	50.5	100	0	4	1	18	12
NGC 3603^h	4.1	0.3	5.0	2 - 2.5			60	0	0	0	3	0
Trumpler 14^i	4.0	0.5	4.3	$<\!\!2$			31					
Westerlund 2^{j}	4.0	0.8	3.7	1.5 - 2.5							2	
Cl 1806-20 ^k	3.8	0.8	3.5	4 - 6			5	0		1	2	2

Table 1. Properties of massive clusters in the Galaxy^a

Arches, Quintuplet & Galactic Center clusters

Galactic Center - pointsource: SMBH Sgr A* and PWN are potential counterparts But, what about the star clusters

Arches, Quintuplet & GC clusters

Galactic Center - diffuse:

Believed to originate from cosmic rays interacting with GMCs
 Contribution to observed VHE flux is not excluded

Hard to pin down

HESS J1614-518

HESS J1023-575, Westerlund 2

- Extended TeV emission¹
- Sources could be:
 - WR binary WR20a
 - Cluster itself
 - CR accelerated in bubble interacting with environment

Faint, soft, diffuse X-ray emission²

¹ Aharonian et al 2007 ² Naze et al 2008

Coming back to the list...

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What about the most massive one?

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Westerlund 1 - properties:

- The most massive star cluster
- > 24 WR stars (60-70% binaries), YSGs, RSGs, LBVs
- Hard, diffuse X-ray component¹
- Magnetar candidate¹

CXO J164710.2-4557

Westerlund 1 region in TeV y-rays

- Extended TeV emission
- Observed between 2004 and 2008 for ~30 hrs
- Total Significance of > 15σ

Westerlund 1 region in TeV y-rays

- Extended TeV emission
- Observed between 2004 and 2008 for ~30 hrs
- Total Significance of > 15σ
- Large structure with diameter > 2°
- PSR J1648-4611 not energetic enough
- LMXB GX340+0 would be pointlike
- Neither SNR, nor other potential counterpart

Westerlund 1 region in TeV γ-rays

Westerlund 1 region in HI

HI channelmap at a radial velocity of -55km/s (contours from 20K - 90K)

Westerlund 1 region in HI & TeV y-rays

- H.E.S.S. contours overlaid on SGPS map
- H.E.S.S. emission partially overlaps with higher density regions in HI
- Spectral analysis of H.E.S.S. data is underway
- More results will come soon

Conclusions

Binary systems:

- Special types are well established VHE sources
- Consisting of a compact object + massive companion star

TeV sources connected to star cluster:

- Examples, where a star cluster has been identified after a VHE source was detected
- HESS J1813-178 or HESS J1837-069

•VHE emission from the star cluster itself:

HESS J1023-575 (Westerlund 2), HESS J1614-518 are systems which are coincident with the cluster

Westerlund 1:

- Extended VHE γ-ray (~1° radius) detected
- Detailed analysis is underway