Colliding Wind Binaries with AGILE: The Case of Eta Carinae

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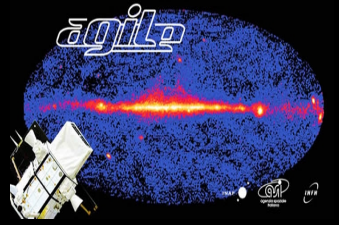
on behalf of the AGILE team

Colliding Wind Binary systems - Why?

- **Early type stars (O, B, WR) are highly massive stars (M>20 $M_\odot$) having the strongest sustained winds among Galactic Objects.**

- **WR stars have the highest known mass loss rate ~10^{-4} – 10^{-5} $M_\odot$/yr**



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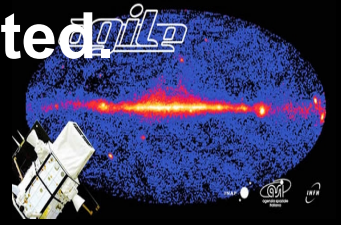
Binary systems containing such a massive star and a compact object have strong (dense and high velocity) colliding winds causing strong shocks were both e^- and p can be efficiently accelerated.



CWB systems – γ-ray modelling

- **Eichler & Usov(1993): seminal paper on non-thermal radiation from shock regions in CWB**

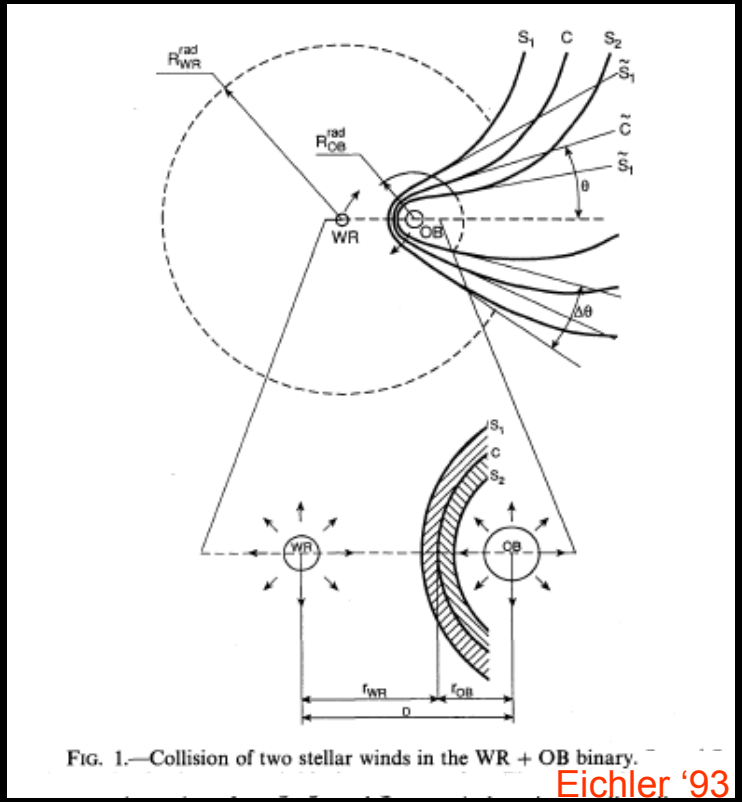


FIG. 1.—Collision of two stellar winds in the WR + OB binary.

Eichler '93

CWB systems – γ-ray modelling

- **Eichler & Usov(1993): seminal paper on non-thermal radiation from shock regions in CWB**
- **Benaglia & Romero (2003): model IC emission for WR 140**
- **Reimer Pohl & Reimer (2006): depending on the injected e^--to-p ratio IC and π^0-decay can produce γ-ray emission**

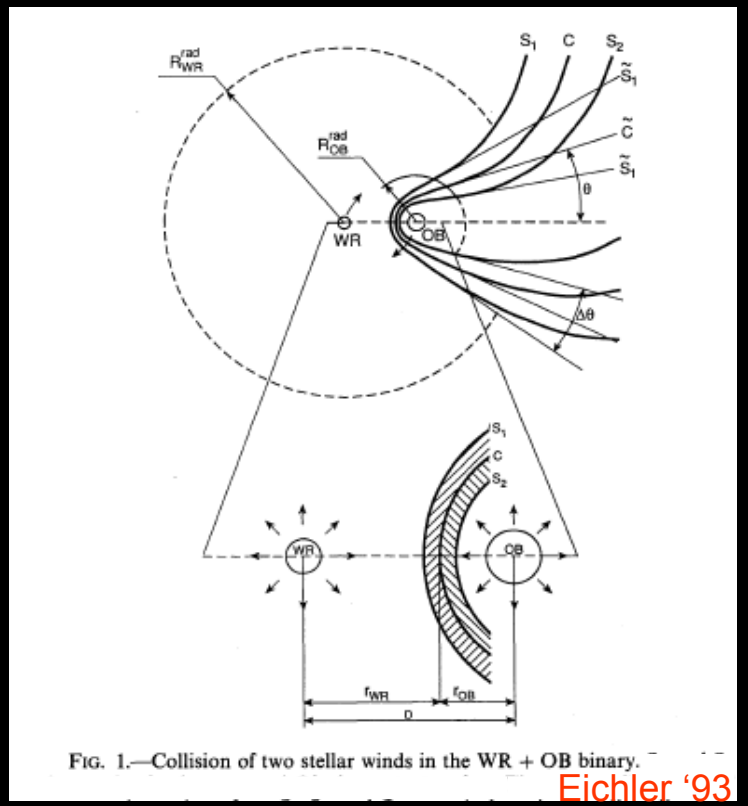


FIG. 1.—Collision of two stellar winds in the WR + OB binary.

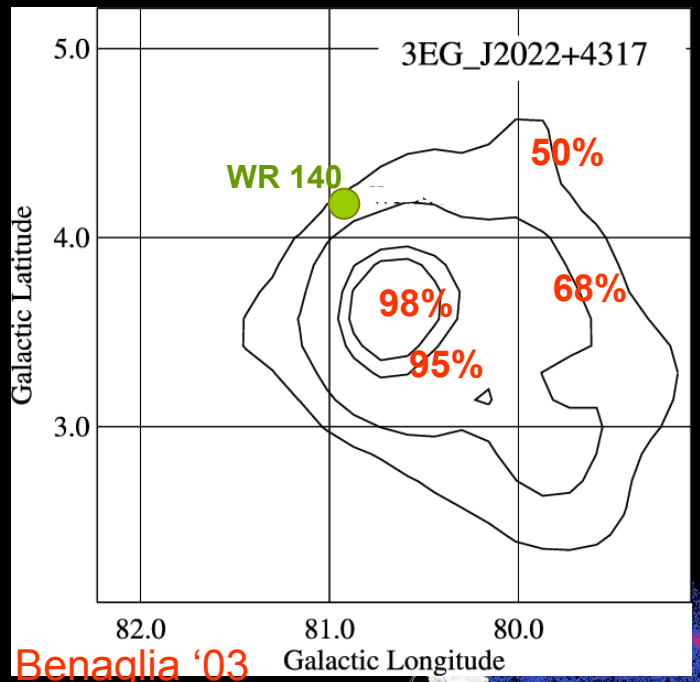
Eichler '93

CWB systems – Searches in γ-rays

- **Kaul & Mitra (1997): cross-correlation of WR and EGRET catalogues. Proposed possibile association of 8 WR stars with EGRET sources.**

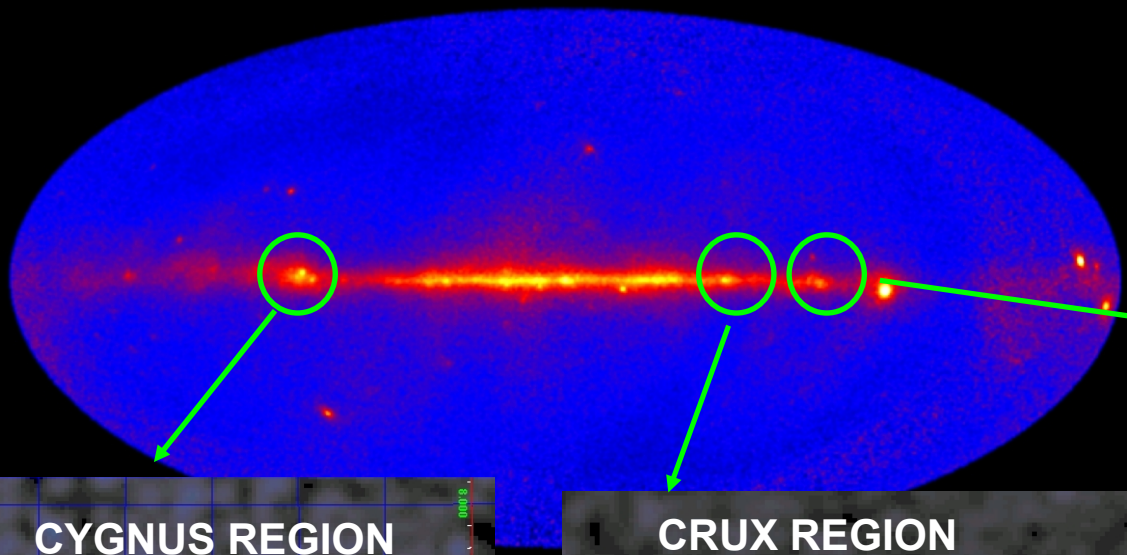
- **Romero et al(1999): revised Kaul & Mitra and reduced the possible list to 3 likely γ-ray sources.**

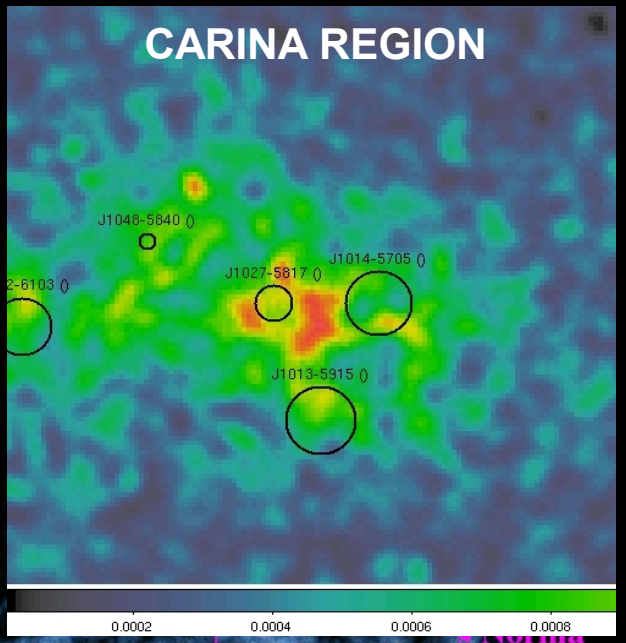
- **Benaglia & Romero (2003): only WR 140 is left as a possibile candidate (50% CL).**

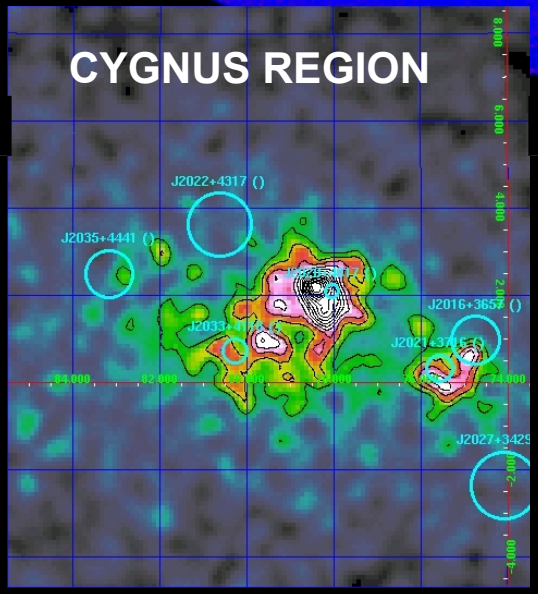


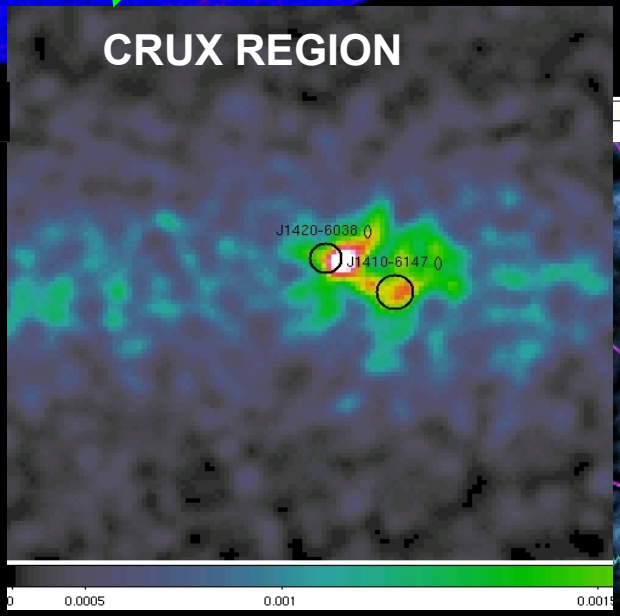
Benaglia '03

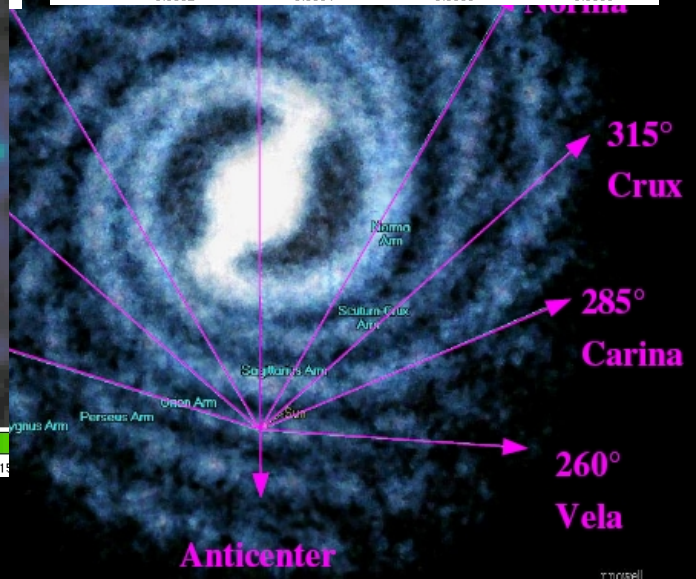
The AGILE gamma-ray 1yr sky (E > 100 MeV)









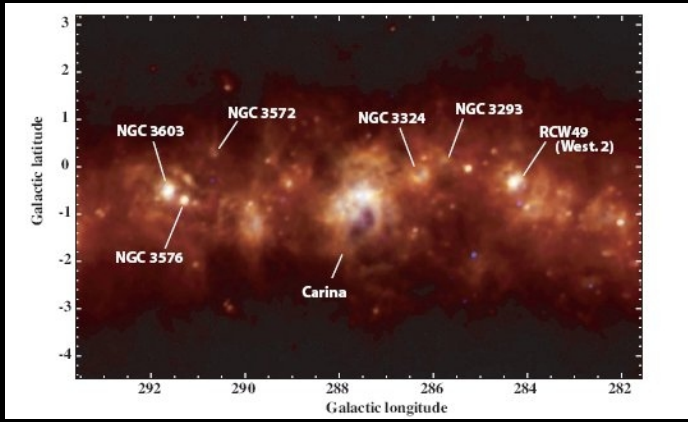


S. Sabatini - The Bright Gamma Ray Sky, ASI-ESRIN '09

The CARINA REGION (MW observations)

IRAS far-IR multicolor image

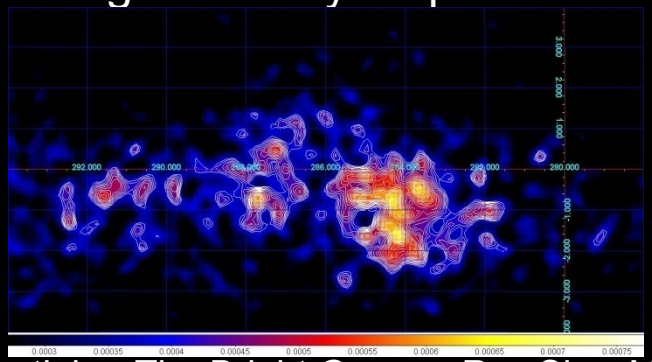
(from N. Smith 2009 Handb. Star Form. Regions II p.138)



Hubble Space Telescope

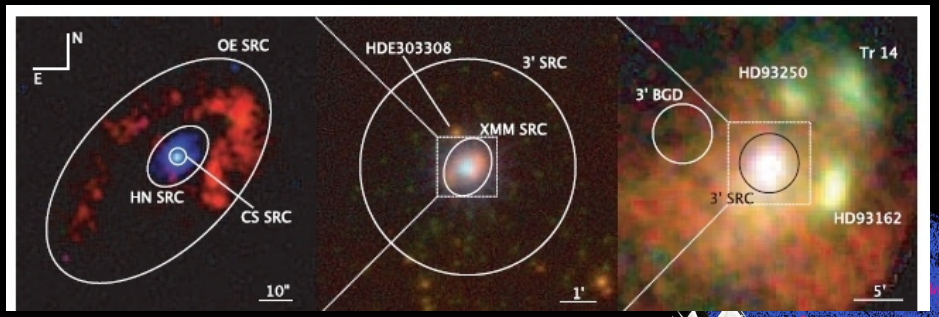
UV rays & winds of numberless young hot stars produce a wealth of spectacular nebular structures

AGILE gamma-ray map on same scale



X-Ray images

CHANDRA XMM-Newton ASCA



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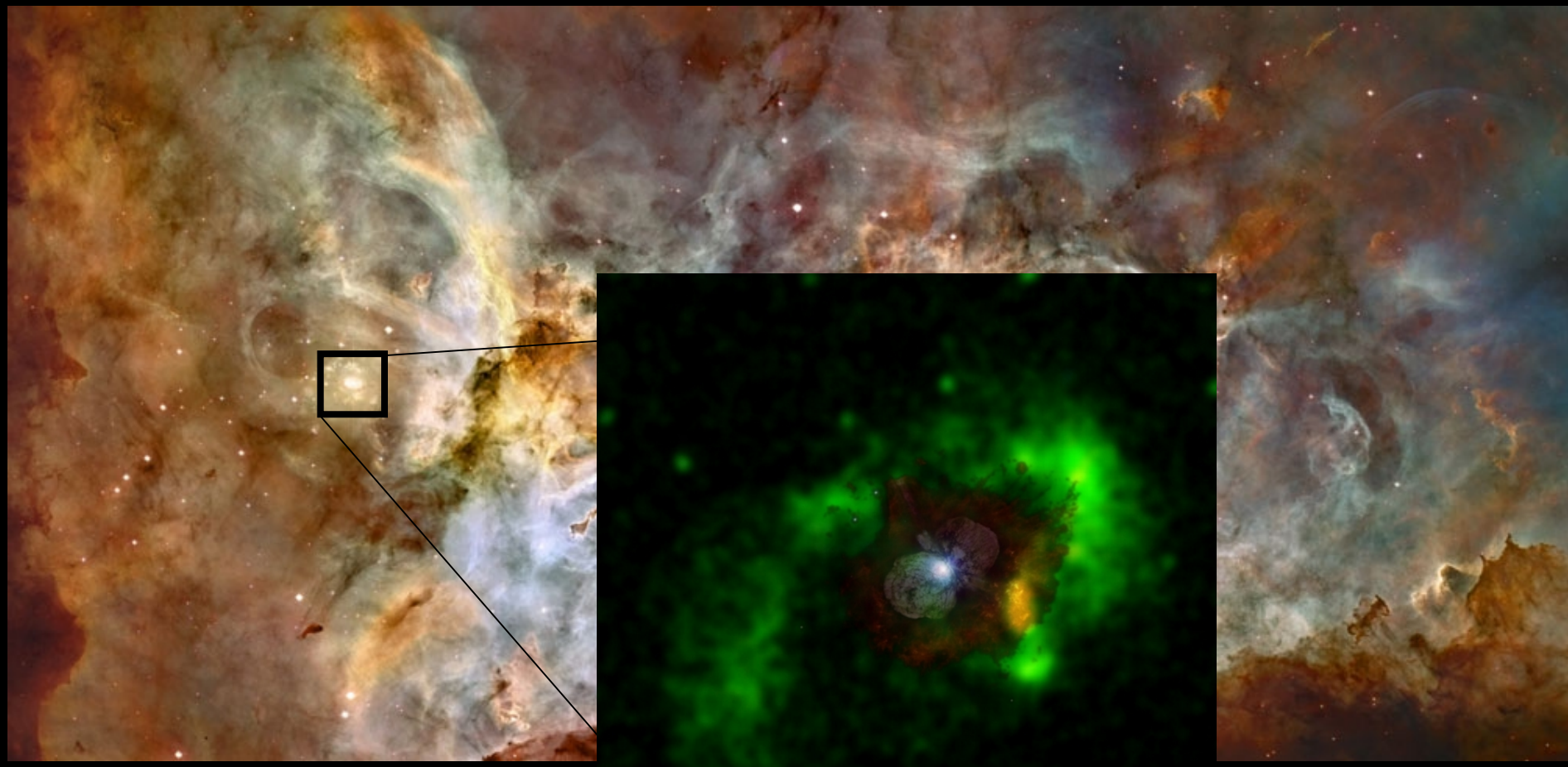
Hamaguchi et al. 2007 ApJ 663, 522

The ETA CARINAE CWB system



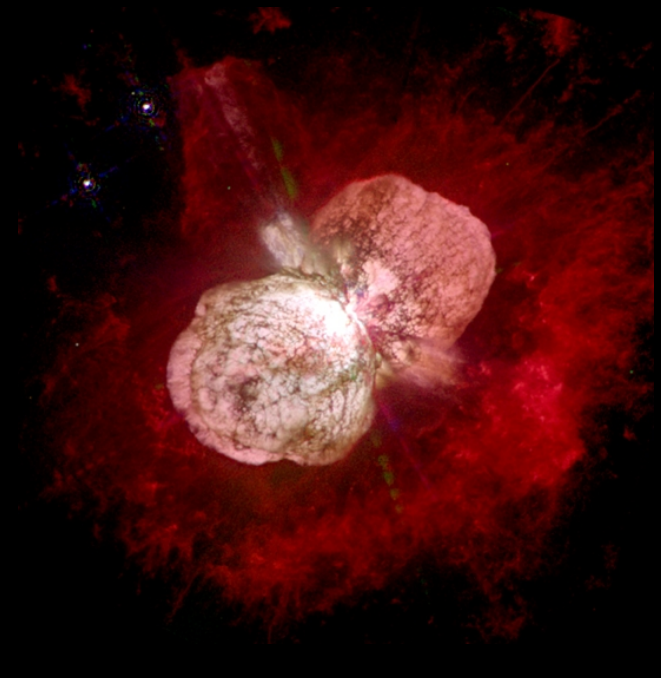
Hubble Mosaic of the Carinae Nebula

optical & X-ray

The ETA CARINAE CWB system

Eta Carinae as an interactive binary system:

SYSTEM PARAMETERS
Period: 5.54 years eccentricity: ~0.9
Last periastron: 11th January 2009
Primary: log $L/L_\odot$ = 6.7
Secondary (unseen) = O supergiant



Eta Car mass ~ **100 $M_\odot$**

mass outflow ~2 x 10^{-4} $M_\odot$/yr

wind speed ~ 600 km/s

Companion ~ **30 $M_\odot$**

mass outflow ~2 x 10^{-5} $M_\odot$/yr

wind speed ~ 3000 km/s

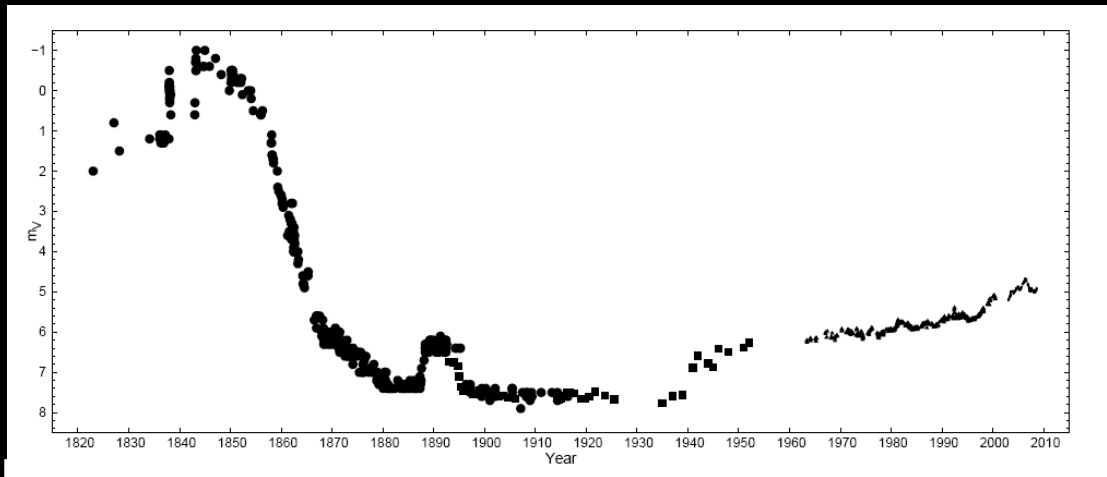


Fig. 3. Light curve of η Car since 1820 until 2008 including visual (●), photographic (■), photoelectric (▲) and our V CCD (•) observations. The maximum peak reached in 2006 and the consecutive decline are clearly visible.

The ETA CARINAE CWB system

ηCar provides some crucial ingredients for the formation of high energy emission in CWBs:

1) strong variability in the mass outflows

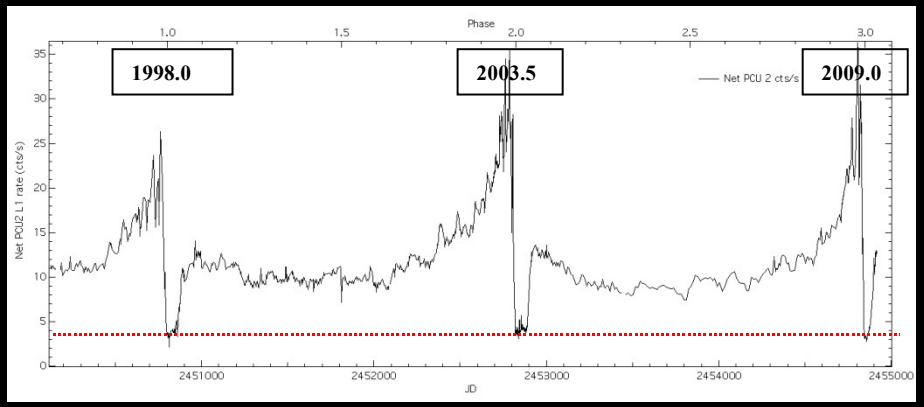
2) high speed wind from the less massive companion

3) a radiative environment with a specific bath of soft photons from both stars.

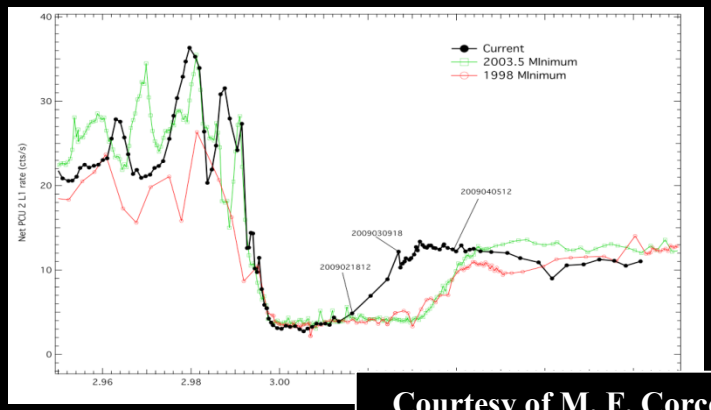
X-ray MONITORING

- **2-10 keV rays from eta Carinae**

The RossiXTE light curve during 1996-2009



Overlap of the 3 X-ray minima

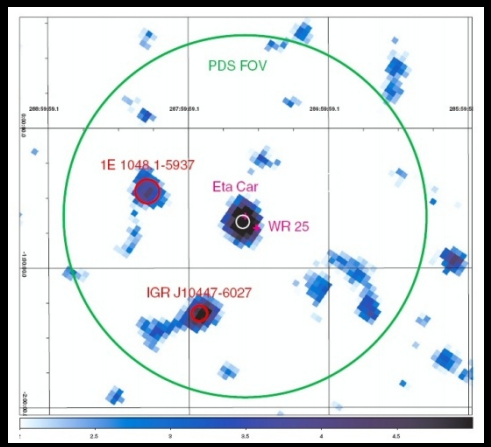


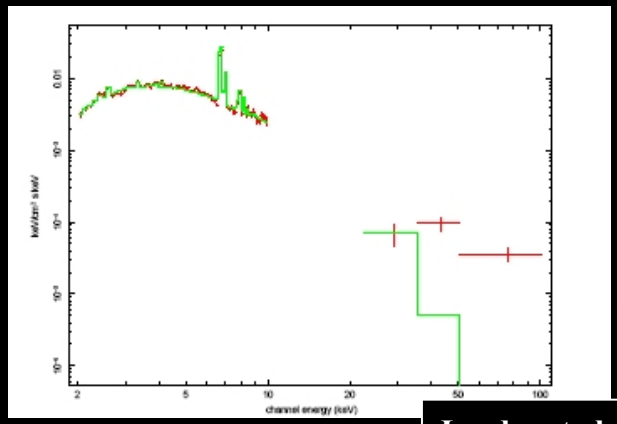
Courtesy of M. F. Corcoran

- **INTEGRAL 20-50 keV image**

3 sources found by INTEGRAL in PDS FoV, Eta Car is the strongest.

No emission from the CW binary WR25.

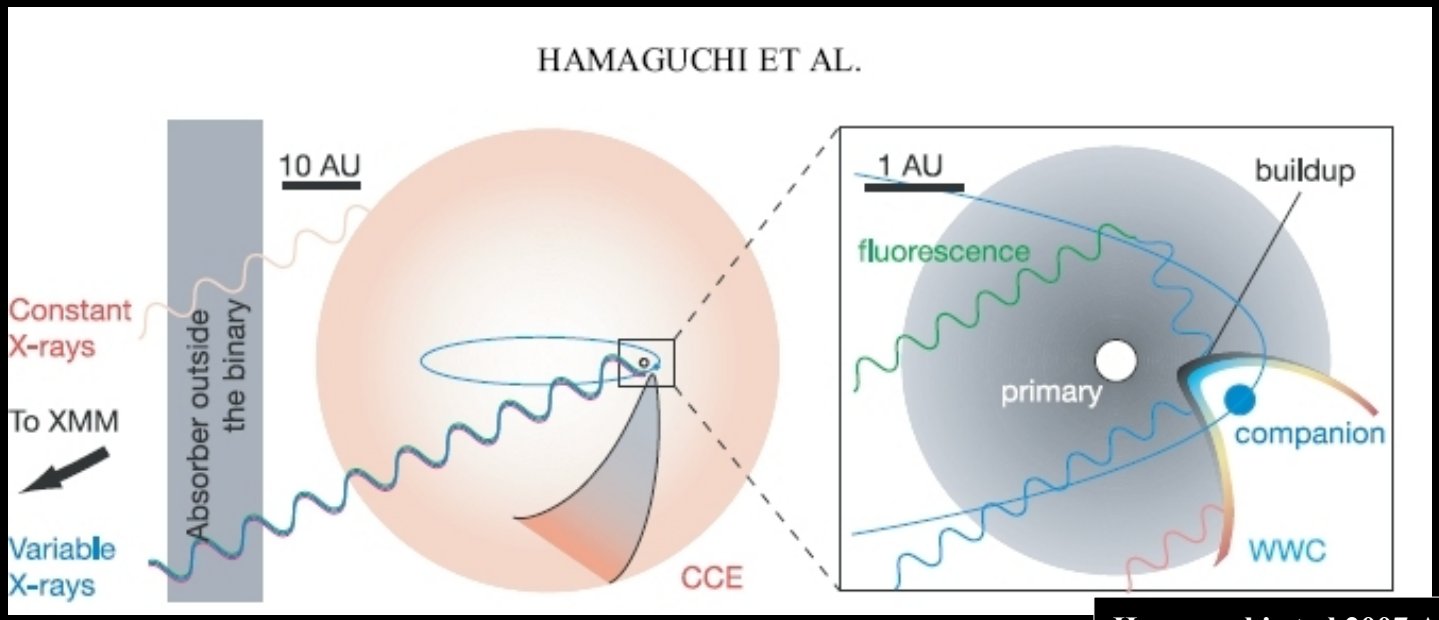




Leyder et al. 2008 A&A 477, L29

Possible Model for the X-ray emission

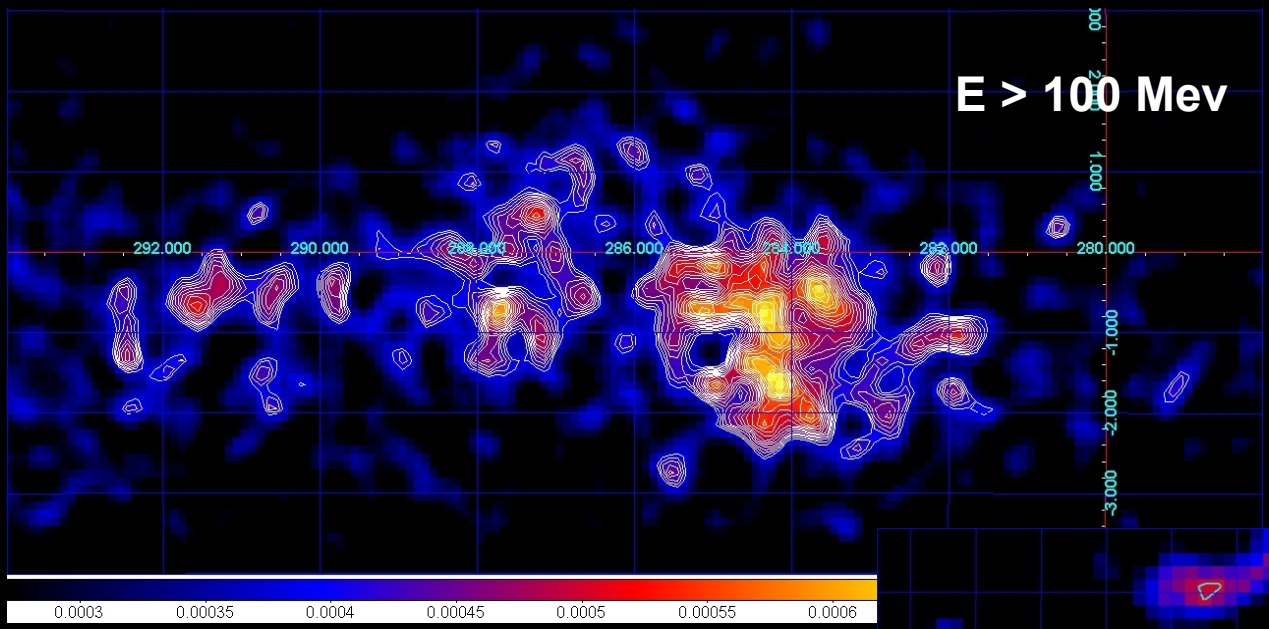
Two components: *soft* from circumstellar matter (constant) and *hard* from wind-wind collision region (increasing when approaching periastron, then eclipsed by opaque matter)

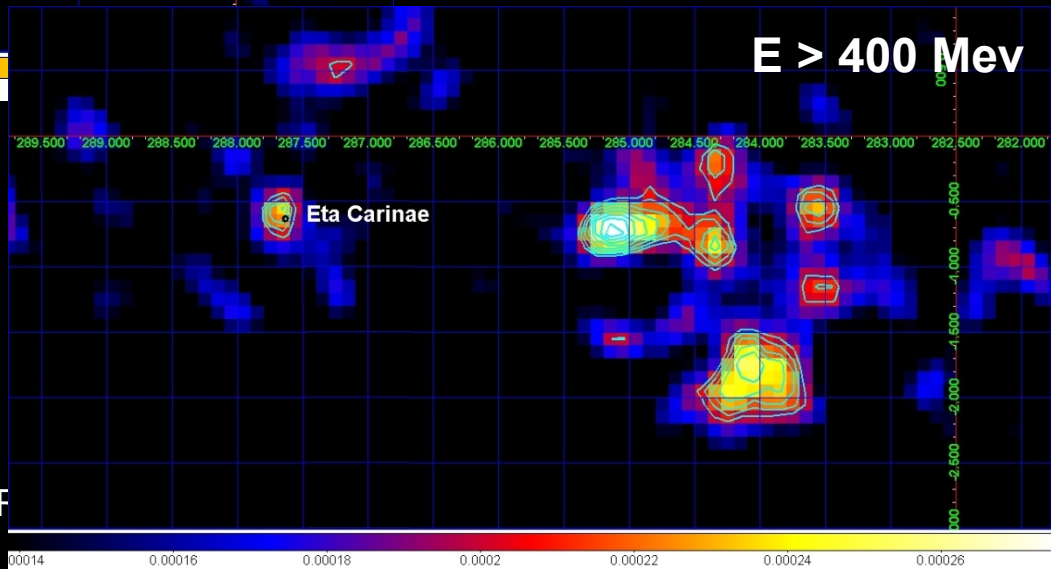


Hamaguchi et al 2007 ApJ 663, 522

The AGILE map of the Carina Region

AGILE accumulated a large exposure in the Carina Region, equivalent to ~ 5 months of effective livetime for an exposure of 10^9 cm^2 sec and flux sensitivity of 10^{-7} ph. $cm^{-2}s^{-1}$ above 100 MeV.





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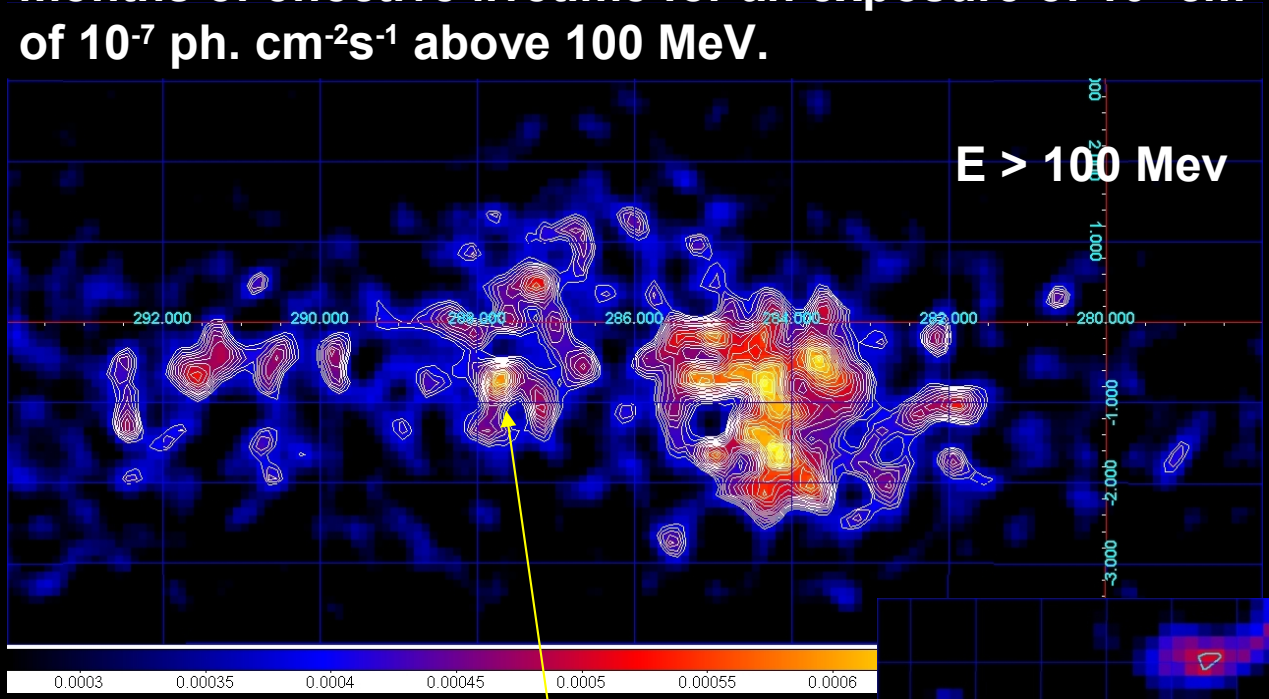
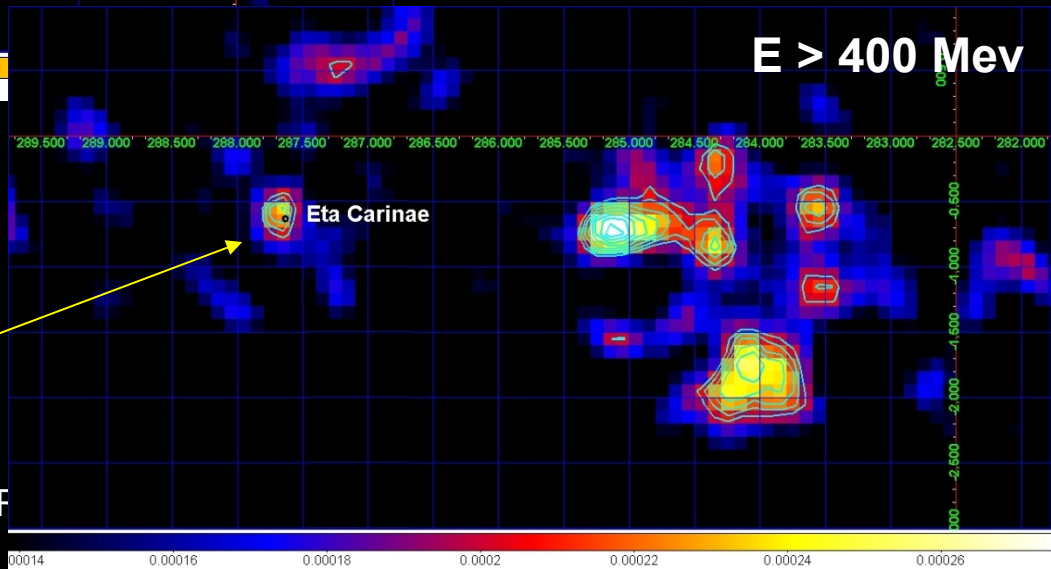


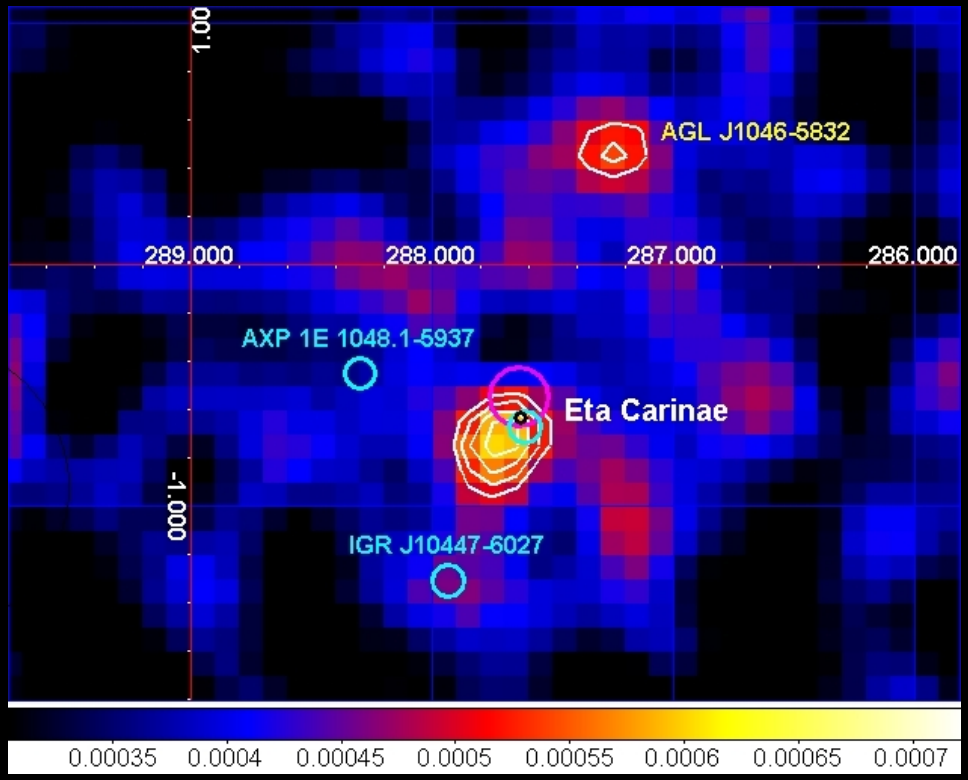
Several old and new gamma-ray sources are detected, some are time variable

Detection of Eta Carinae (pre-periastron)



Gamma-ray emission from Eta Carinae

Analysis of the deep AGILE integration around eta Carinae:

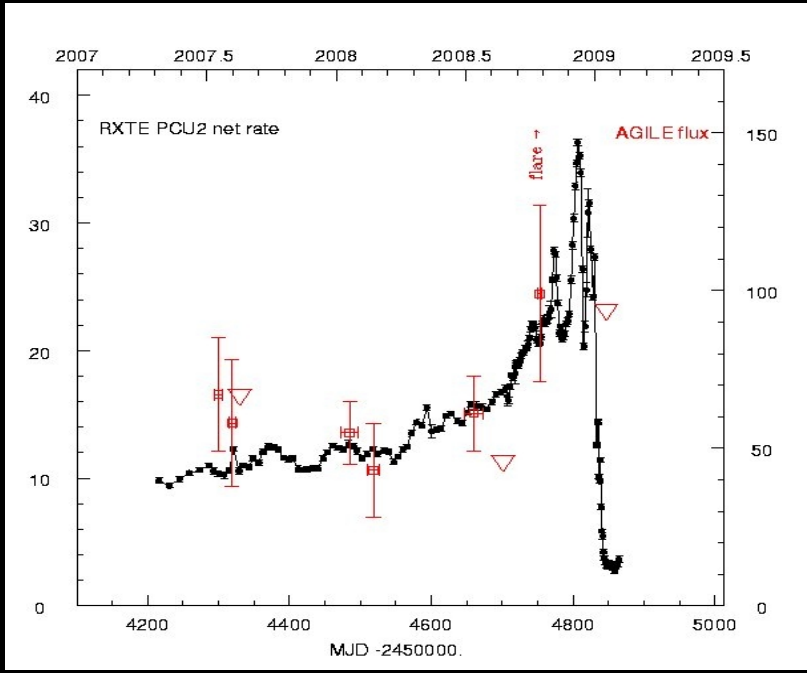


Eta Car average gamma ray properties

7.8σ detection
(l,b) = 287.6, -0.7 ± 0.3 (stat) ± 0.1 (syst)
F_γ = (37 ± 5) x 10^{-8} ph/cm²/s
L_γ = 3.4 x 10^{34} erg/s (2.3 Kpc dist)

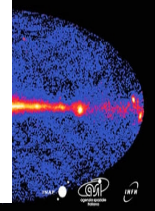
Tavani et al. 2009 ApJ, 698, L142, 2009 (arXiv:0904.2736)

Gamma-ray emission from Eta Carinae

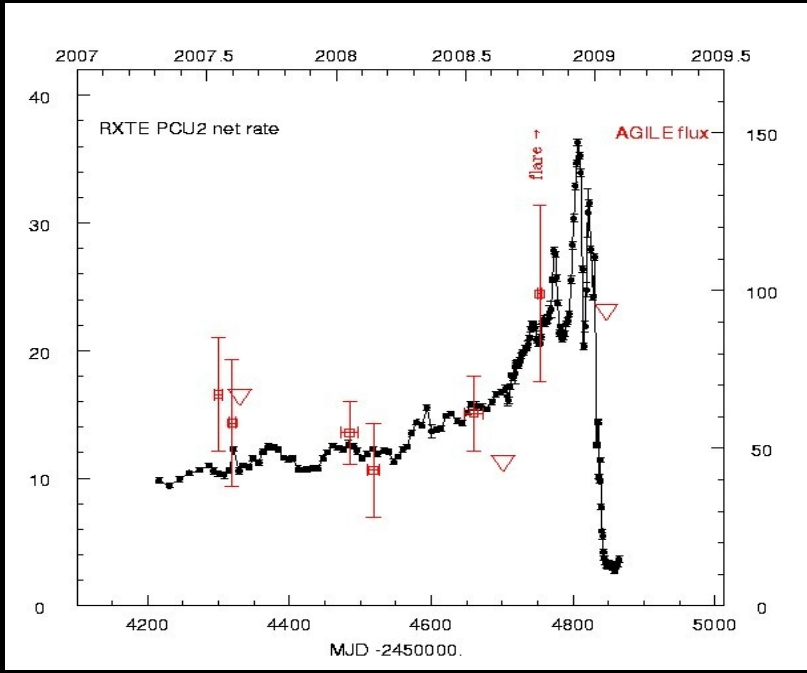


The source was positively detected during several individual observing runs showing a roughly constant gamma-ray flux over the whole observations period.

AGILE orbits	Date interval	MJD	N. days	η Car phase (*)	$\sqrt{TS}$ (**)	Counts	Average flux(***)
1146-1299	2007.07.13-2007.07.24	54294.5-54305.5	11	0.732	4.1	105 ± 29	67 ± 18
1429-1567	2007.08.02-2007.08.12	54314.5-54324.5	10	0.741	3.3	80 ± 27	58 ± 20
1584-1708	2007.08.13-2007.08.22	54325.5-54334.5	9	0.747	1.1	< 73	< 67
3673-4009	2008.01.08-2008.02.01	54473.5-54497.5	24	0.824	4.1	166 ± 45	55 ± 14
4194-4418	2008.02.14-2008.03.01	54510.5-54526.5	16	0.840	3.1	96 ± 33	43 ± 15
6129-6480	2008.06.30-2008.07.25	54647.5-54672.5	25	0.910	5.6	214 ± 42	61 ± 12
6778-7001	2008.08.15-2008.08.31	54693.5-54709.5	16	0.930	1.3	< 105	< 46
7569-7664	2008.10.10-2008.10.17	54749.5-54756.5	7	0.956	4.0	80 ± 23	99 ± 28 (****)
8899-8995	2009.01.12-2009.01.19	54843.5-54850.5	7	0.002	2.2	48 ± 22	< 94



Gamma-ray emission from Eta Carinae



The source was positively detected during several individual observing runs showing a roughly constant gamma-ray flux over the whole observations period.

- Very weak or absent emission near periastron (AGILE ToO observation, Jan. 9-17, 2009)
- Weak or absent emission detected post-periastron (during AGILE pointings in April and August 2009).

NOTE: The October 2008 maximum is due to a flare (see next slide) rather than to a flux increase before periastron as in X-rays.

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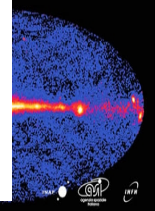
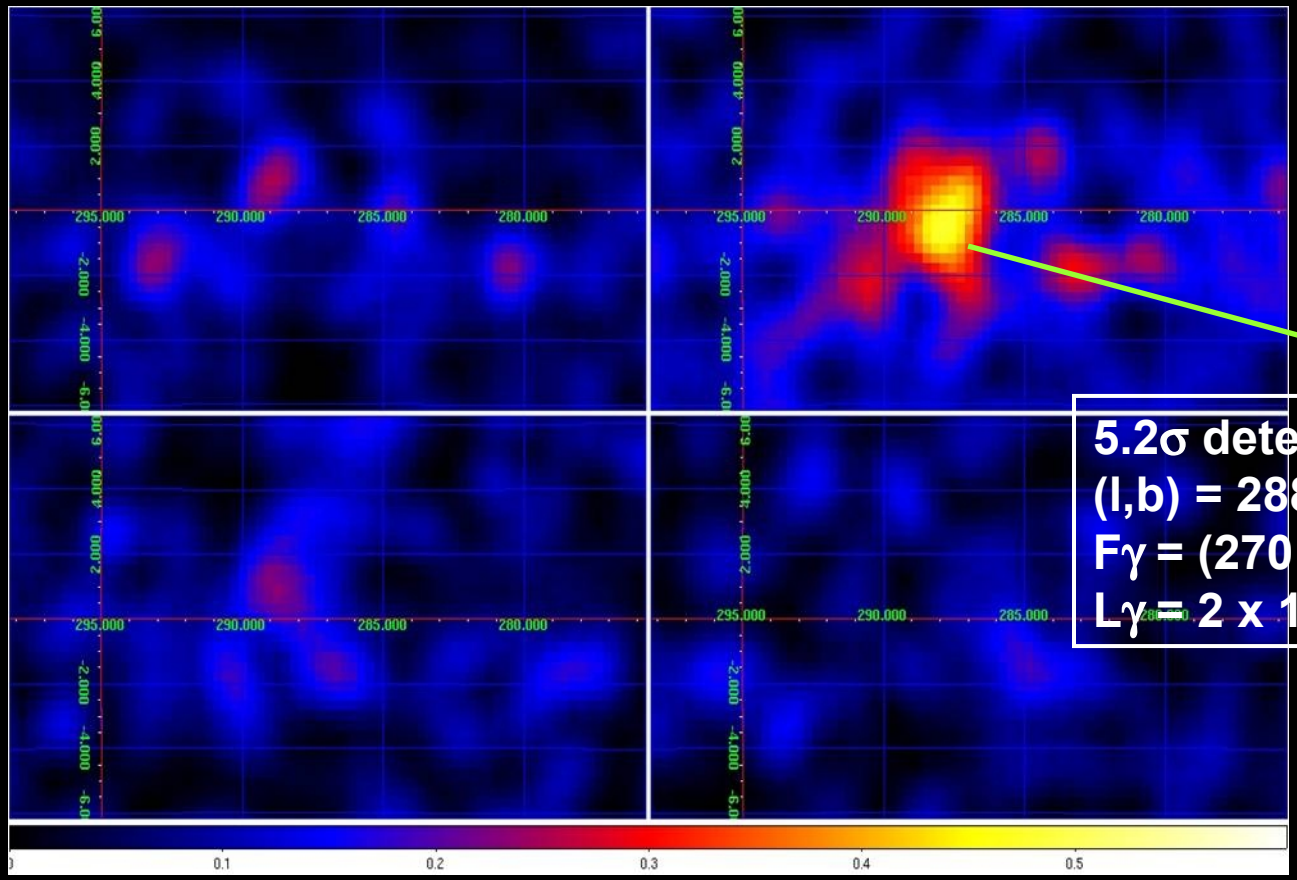


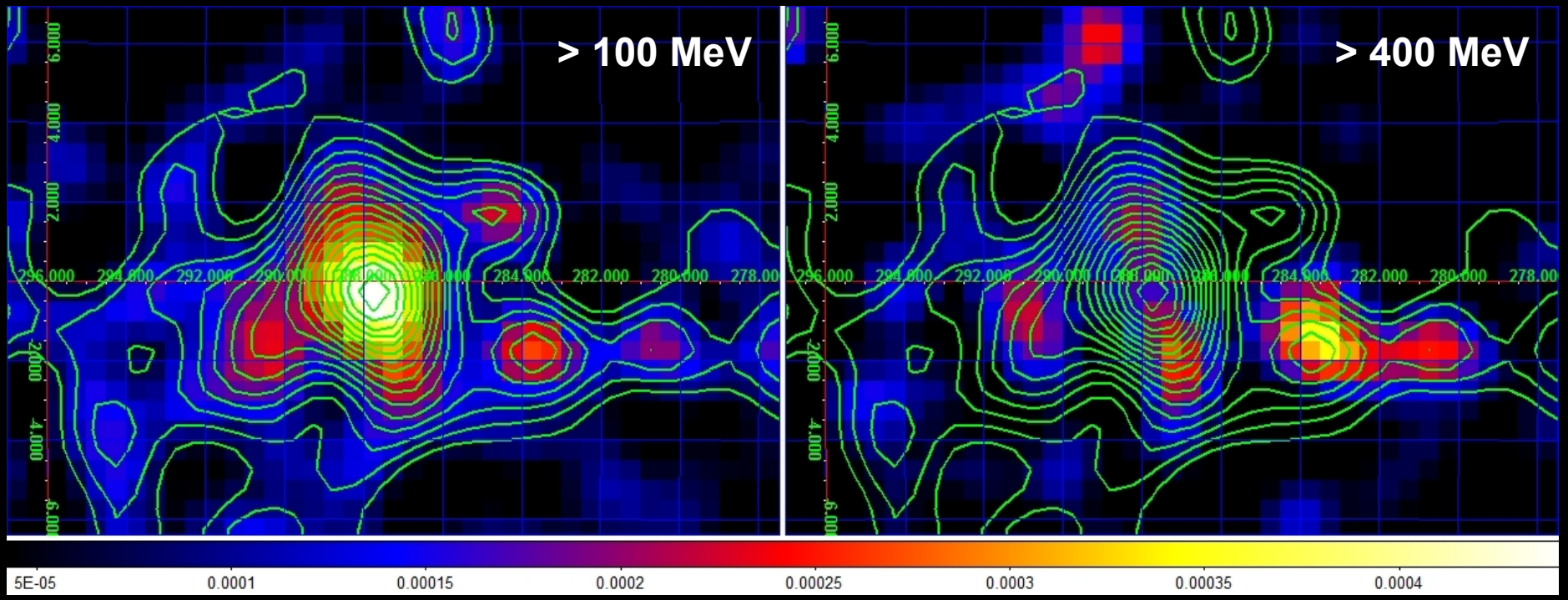
The 11-13th Oct 2008 Eta Car Flare



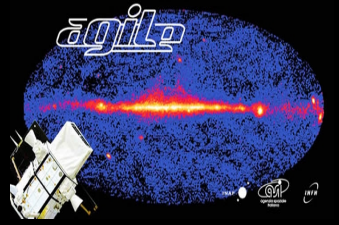
5.2σ detection
(l,b) = 288.0, -0.4 ± 0.6
F_γ = (270 ± 65) x 10^{-8} ph/cm^2/s
L_γ = 2 x 10^{35} erg/s

2 days integration maps - clockwise

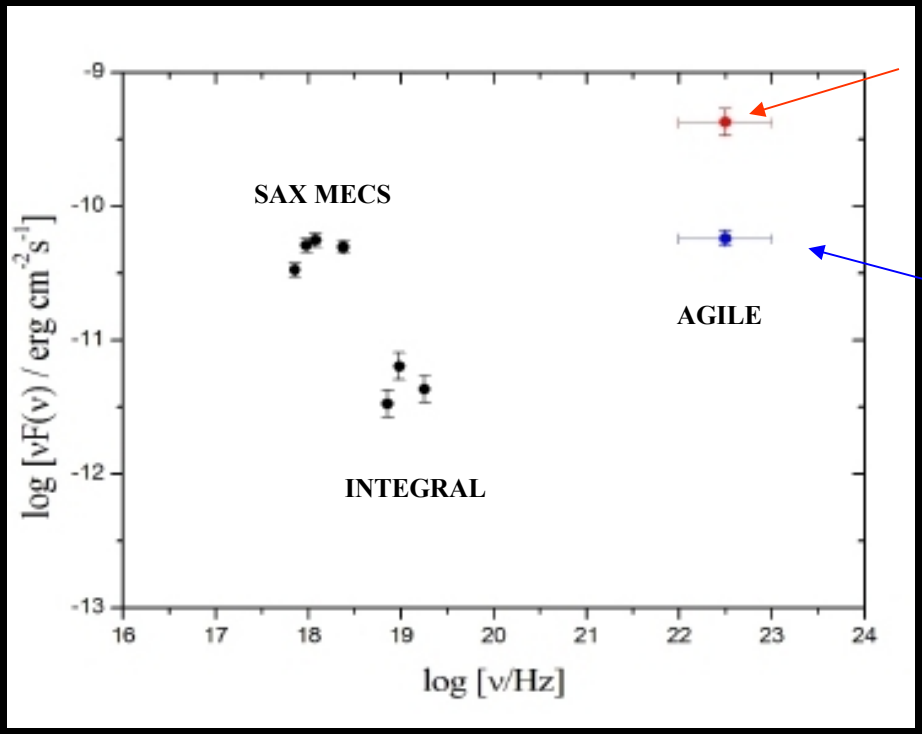
A relatively “soft” flare (100 MeV vs 400 MeV maps)



The gamma-ray flare of Oct 11-13th 2008 is mainly due to photons of energy lower than 400MeV



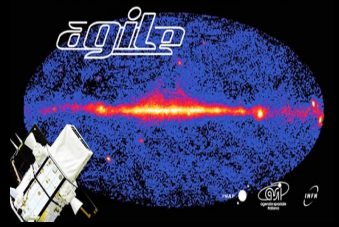
The keV to MeV Energy Spectrum of eta Carinae



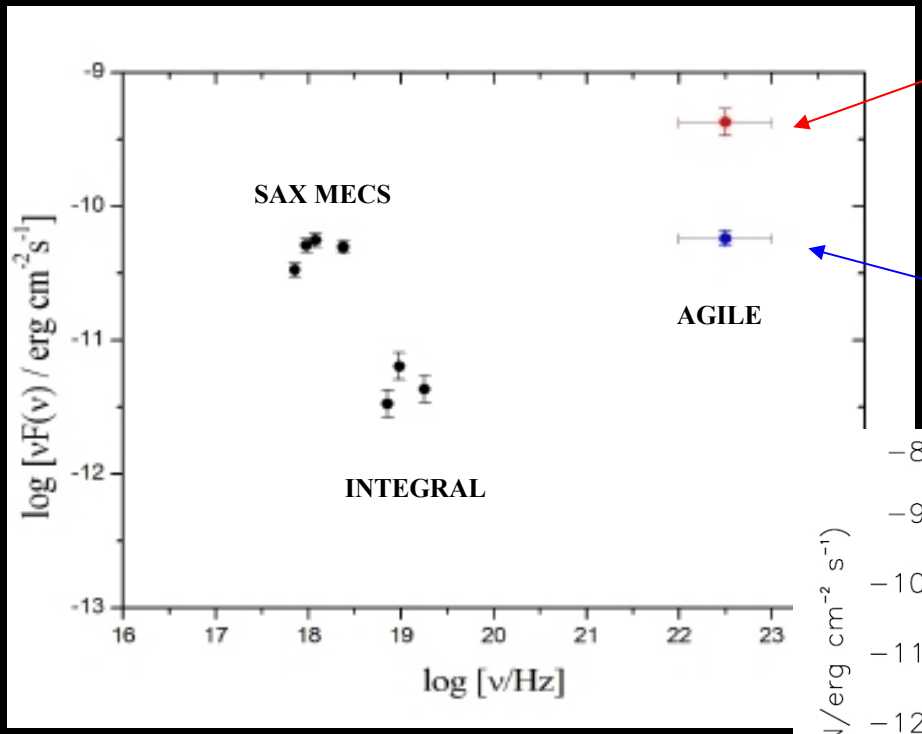
Oct 2008 Flare

Average emission

Although data are not simultaneous, it is interesting to note that the average AGILE spectrum together with the INTEGRAL historical spectrum is in qualitative agreement with expectations based on **inverse Compton and/or pion decay models of gamma-ray emission from colliding wind binaries** (Raimer et al, 2006)

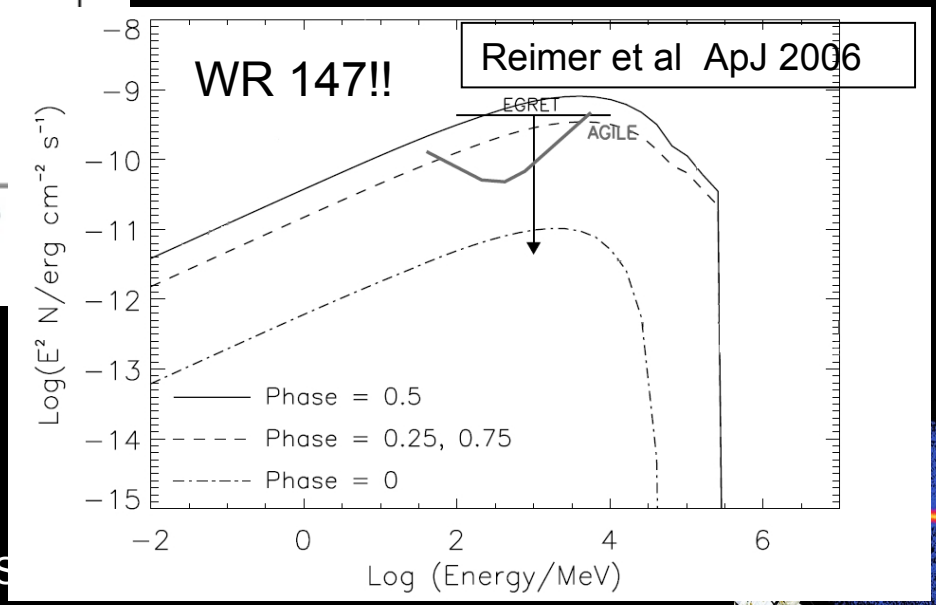


Comparison with model predictions



Oct 2008 Flare

Average emission



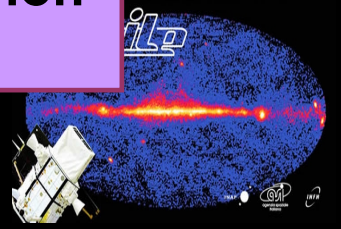
Conclusions

AGILE detected a point source centered on the object Eta Carinae

Identification with the Eta Carinae is supported by:

- Eta Car is a very massive and powerful CW binary system
- It has a non-thermal X-ray excess (BSAX, INTEGRAL, SUZAKU)
- It is the strongest and hardest 2-10 and 22-100 KeV source in the field
- The two nearby hard X-ray sources detected by INTEGRAL are outside the AGILE error box
- Time variability both in X- and gamma-rays
- Multiple gamma-ray sources within the AGILE detection error box are unlikely
- No alternative identification so far

This would be the first remarkable detection above 100 MeV of a colliding wind binary system, confirming the efficiency of particle acceleration and the highly non-thermal nature of the strong shock in a CWB.



Searching for similar systems