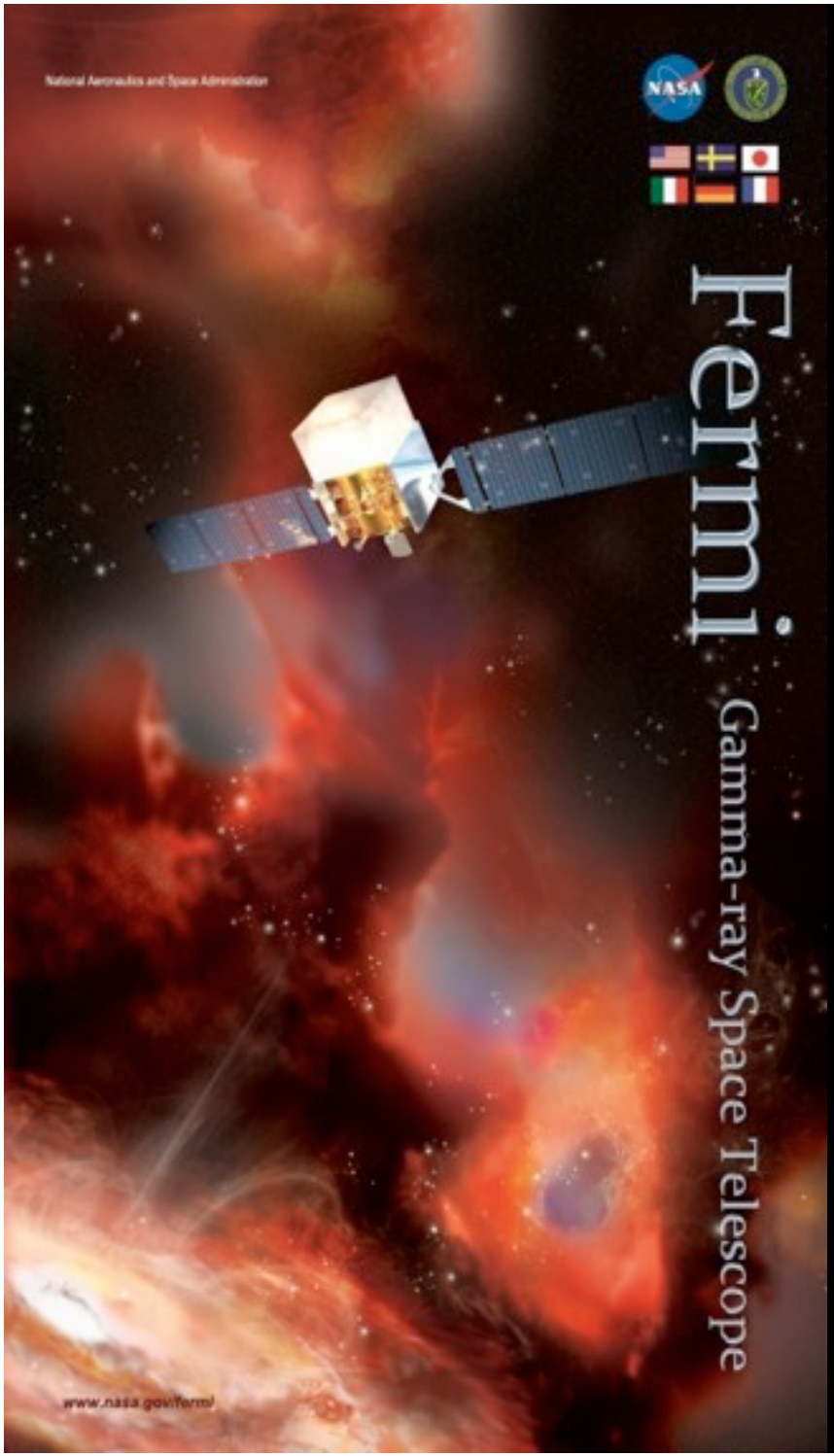

Gamma-ray observations of the pulsar wind nebula 3C58 with the Fermi-LAT

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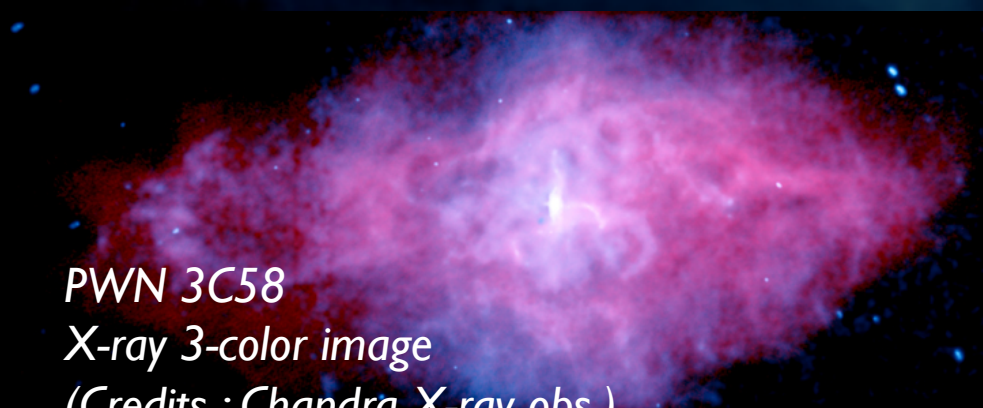
3C58 : A YOUNG CRAB-LIKE NEBULA ?

- Associated to the energetic pulsar PSR J0205+6449
  ($\dot{E}$ = 2.7x10^{37} erg/s, τ_{char} = 5.4 kyr, P = 65.7 ms)
- Angular size : 6' x 9'
- First thought to be :
  - counterpart of SN 1181 C.E. (833 yr)
    => younger than Crab (SN 1054 C.E. => 960 yr)
  - located at a distance of d = 3.2 kpc (H1 absorption, *Roberts et al, 2003*)



PWN 3C58
X-ray 3-color image
(Credits : Chandra X-ray obs.)

Crab nebula
Optical : red ; X-rays : blue
(Credits : Chandra X-ray obs.)

RECENT DISTANCE RE-ESTIMATES

- Expansion rate of the radio nebula
- Velocity of optical knots
  - PWN age > 833 yrs if d = 3.2 kpc

    OR
  - d < 3.2 kpc

- *Kothes (2013)* : based on new H1 absorption measurements
  - 3C58 lies in the Perseus spiral arm (d = 1.95 – 2.04 kpc)

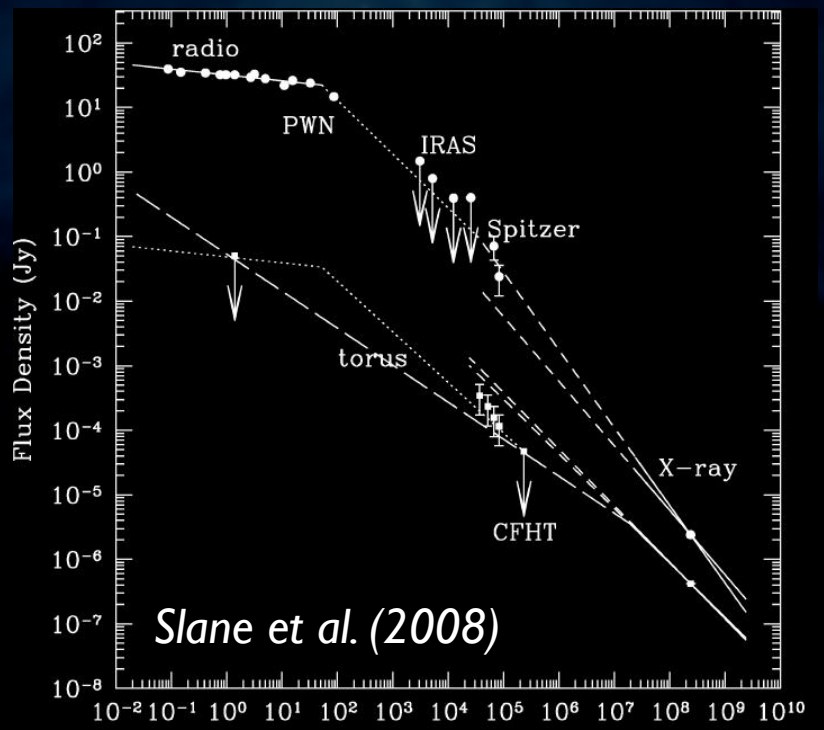
    => distance : (2.0 ± 0.3) kpc

    => age < 1000 yr

    => association with historical supernova explosion of 1181 A.D. is still viable

STATUS IN 2012

- Still one of the youngest SNR in the Galaxy
- Non-thermal emission only detected from radio to X-rays
- No detection in HE or VHE gamma-rays

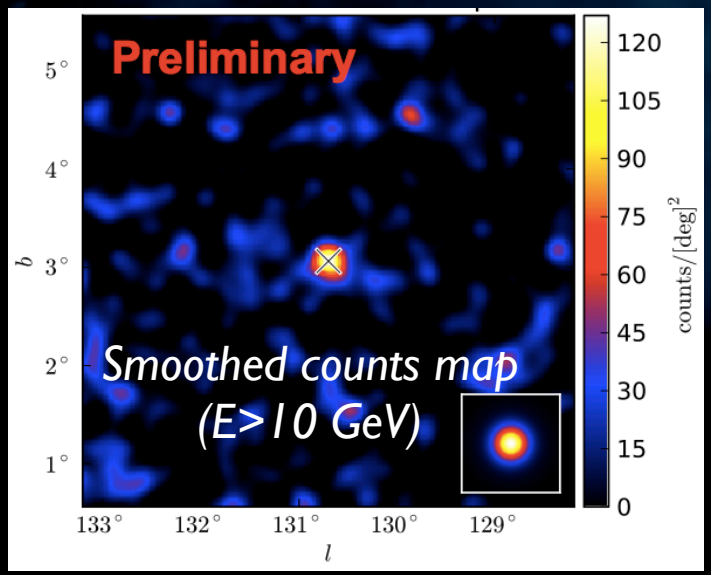


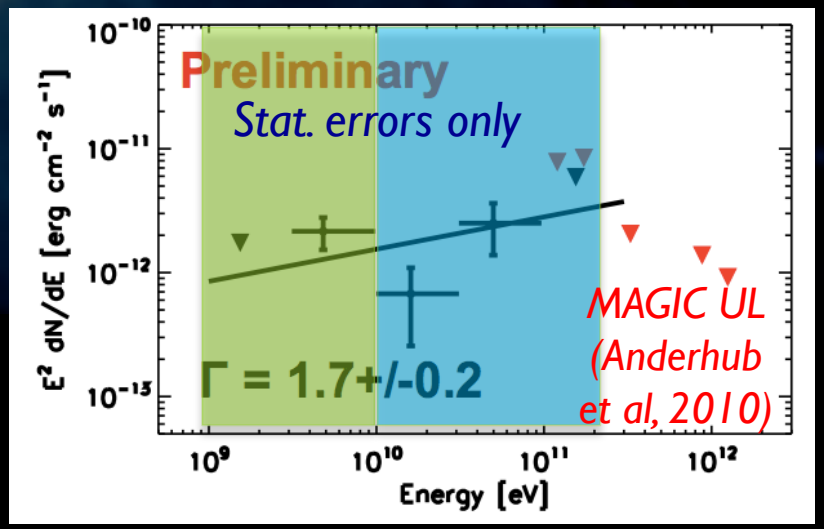
SEARCHES FOR GAMMA-RAY EMISSION FROM SNR 3C58 WITH FERMI

- 1st PWN Catalog *(Ackermann et al, 2011 – 16 months of data)* :
  - no detection in the off-pulse of the γ-ray pulsar PSR J0205+6449
- 2nd Fermi Pulsar Catalog *(Abdo et al, 2013 – 3 yrs of data)* :
  - 1st detection in the off-pulse : TS = 33 above 100 MeV
- 1FHL catalog *(Ackermann et al, 2013 – 3 yrs of data)* :
  - Confirmed as non-pulsed emission above 10 GeV : TS = 9
- Recent re-analysis of 5 years of data

FERMI RE-ANALYSIS OF SNR 3C58

- Detection of significant emission (improved statistics wrt 2nd PC) :
  - Morphology : point-like compared to the LAT PSF
  - Spectrum : reproduced with a hard power-law ($\Gamma = 1.7 \pm 0.2_{stat}$) :
    - Off-pulse, E >1 GeV : TS = 53 (~7.3 σ)
    - All-phase, E >10 GeV : TS = 41 (~6.4 σ)

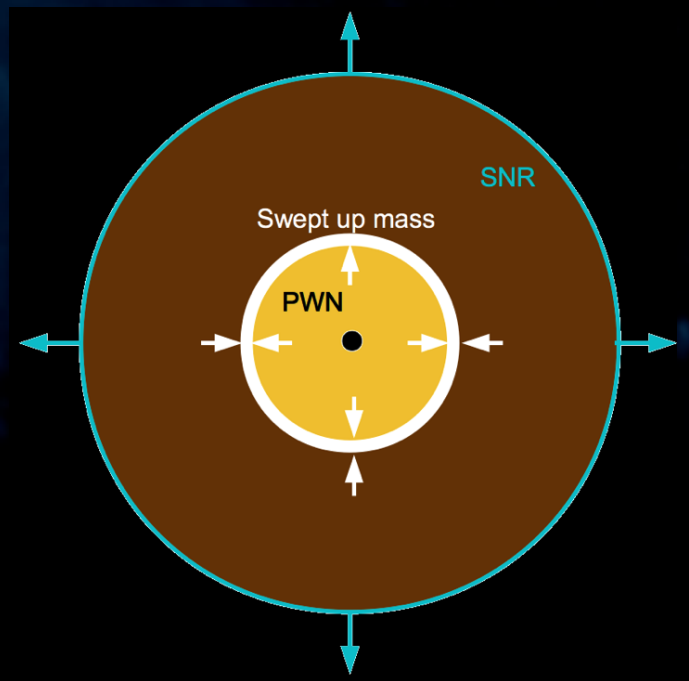




APPLYING A 1-D EVOLUTIONARY MODEL

- 1-D model reproduces PWN spectrum & dynamics (cf *Gelfand, et al. 2009*):
  1. Pulsar injects energy to particles e^- (η_e) and magnetic field (η_B)
  2. PWN sweeps up ejecta during expansion
  3. SNR compresses shell of material

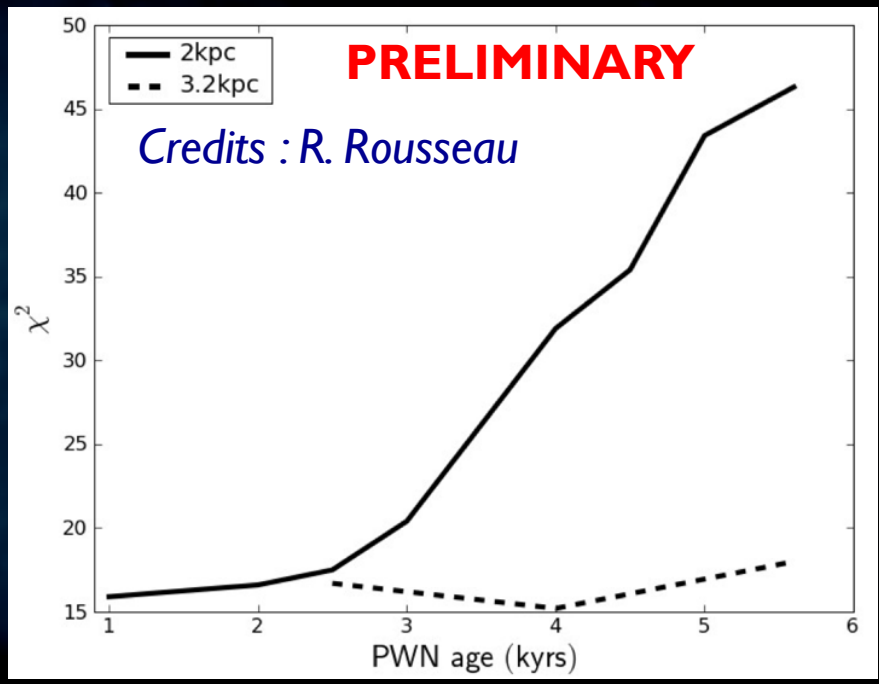
+ fit of the multi-wavelength spectrum



MODELING RESULTS FAVOR A YOUNG AGE

Scan of the distance and age :

- An age between 1 and 2.5 kyrs is preferred if the PWN distance is 2 kpc
- For a distance of 3.2 kpc, the fits are equivalent
- Both distances :
  - Age > 3 kyr give unbelievable values of E_{SN} (<< 0.1 X 10^{51} erg)



MODELING (assuming d = 2 kpc, age = 2 kyr)

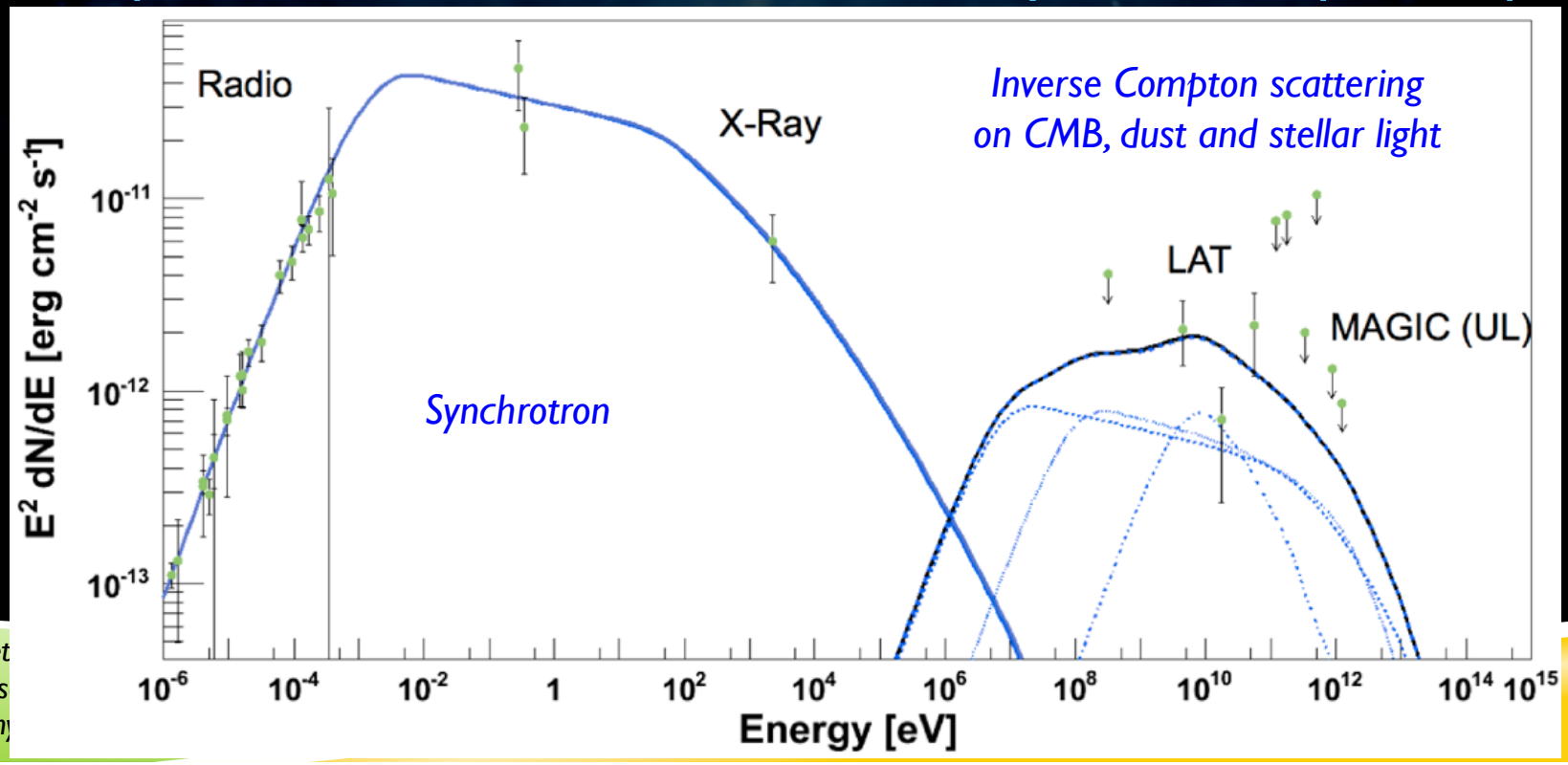
- Fixed parameters (related to the powering pulsar) :
  - Shape of the injection spectrum: Broken-PL
  - Braking index n = 2.5
  - P, $\dot{P}$ and $\dot{E}$ to the current values

  => P_0 = 47.3 ms

RESULTS (assuming d = 2 kpc, age = 2 kyr)

- Fitted parameters (related to the powering pulsar & surrounding SNR):
  - Γ_1= 1.07 (+0.3/-1.0)
  - Γ_2= 3.16 (+0.9/-0.3)
  - η_e= 99.7(+0.5/-2)%
  - E_{break}= 40(+58/-26) GeV
  - E_{SN} = 1.2(+10/-1.2)x10^{51} erg
  - M_{ej} = 9 (+10/-8) M_o

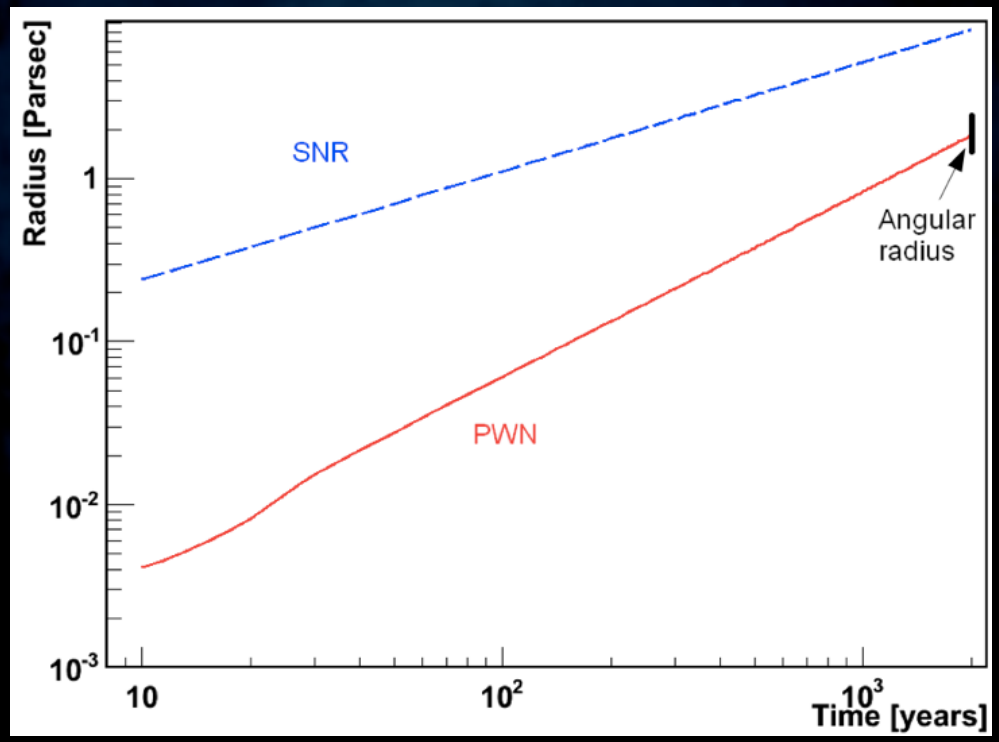
This set of parameters matches the Radio, X-Ray and LAT spectral points



M.H. Grondin et
Gamma-ray obs
Astroparticle Ph

Evolution of the PWN radius with time

- Derived PWN model matches observed angular radius
- PWN in free expansion inside the SNR



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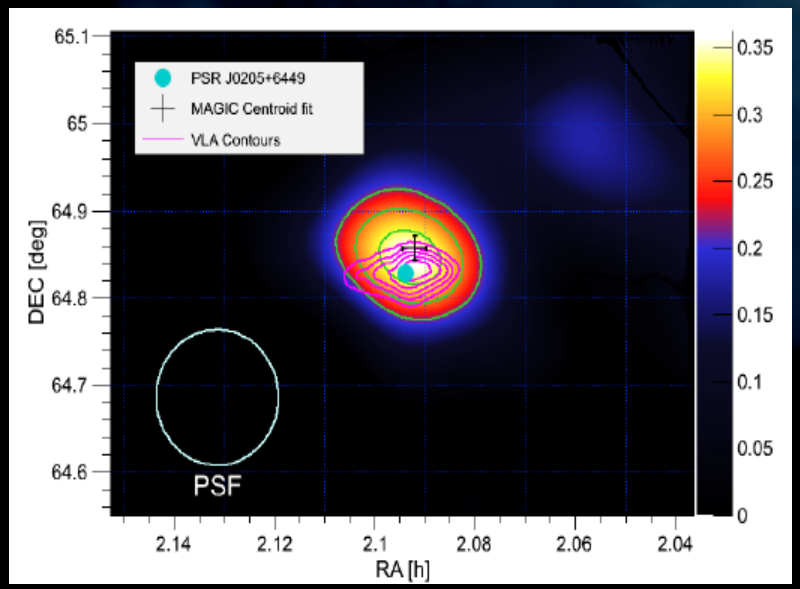
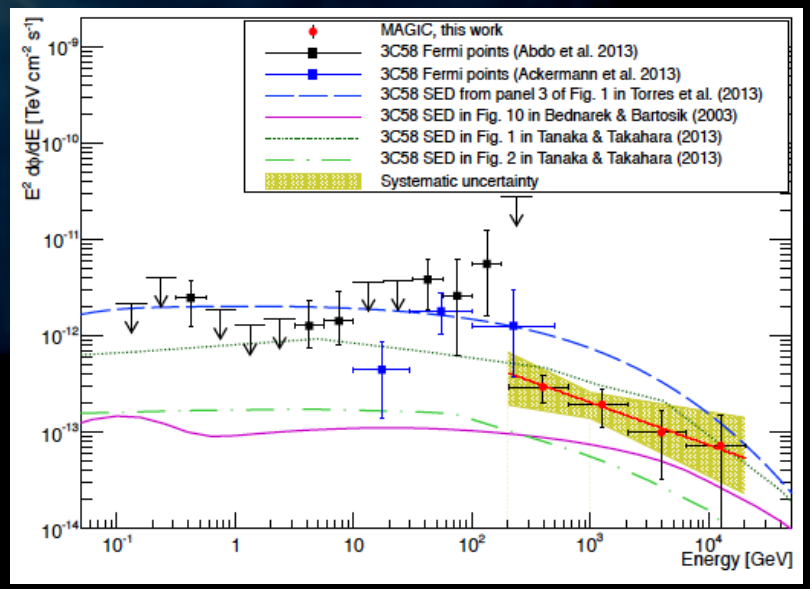
RECENT DISCOVERY OF VHE EMISSION BY MAGIC

- Detection of VHE emission at a 5.7 σ level (*Aleksic et al, 2014*) :
  - Morphology : point-like compared to the PSF
  - Spectrum : reproduced by a power-law :
    - $\Gamma = 2.4 \pm 0.2_{stat} \pm 0.2_{syst}$
    - $F(E > 1\ TeV) = 1.4 \times 10^{-13}\ cm^{-2}\ s^{-1}$

See E. Carmona's talk yesterday





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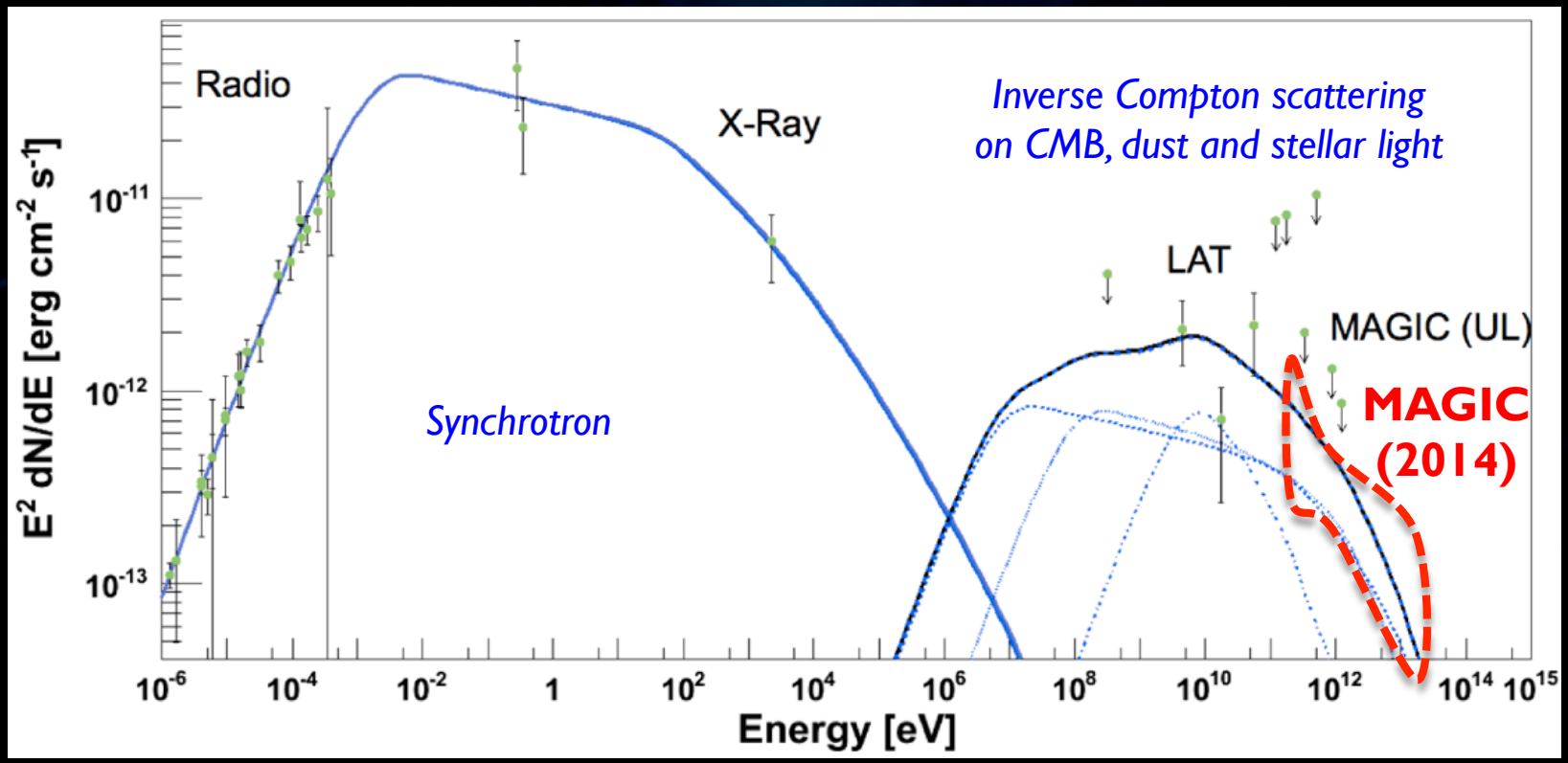
MULTIWAVELENGTH VIEW OF 3C58

- MAGIC spectrum compatible with the current modeling



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SUMMARY

- PWN 3C58 significantly detected by Fermi LAT, with a hard PL (Γ =1.7)
- A 1-D evolutionary model can reproduce the PWN radius and dynamical parameters as well as the broadband spectrum
- A young age ≤ 2.5 kyr is indicated for the revised distance of 2 kpc.
- Spectral modeling taking into account MAGIC spectral points in progress

=> to be reported in a paper by the Fermi-LAT collaboration

THANK YOU FOR YOUR ATTENTION