Very high energy gamma-ray observations of supernovae and supernovae remnants with H.E.S.S.

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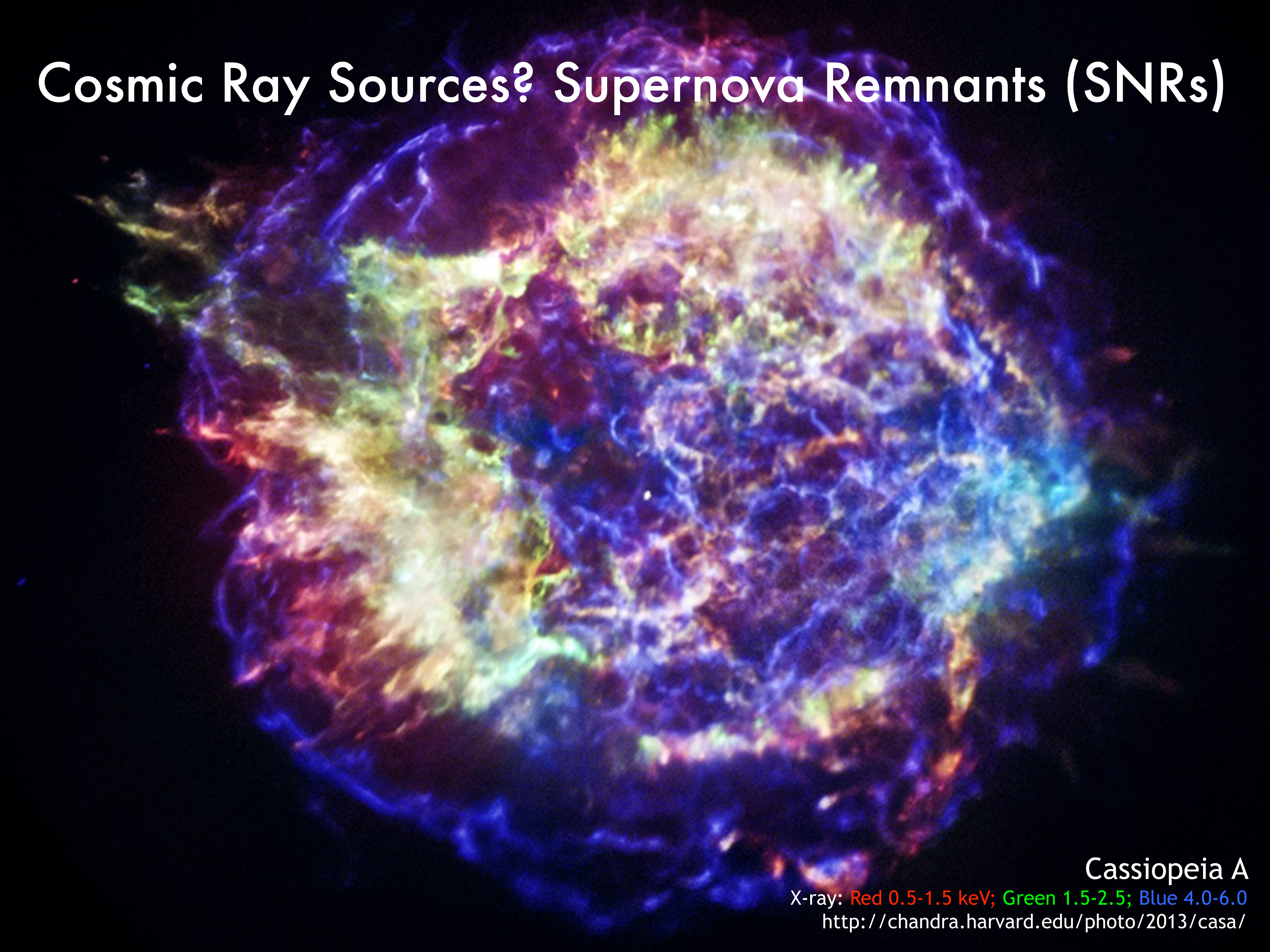
(University of Amsterdam)
On behalf of the H.E.S.S. collaboration

Cosmic Ray Sources? Supernova Remnants (SNRs)

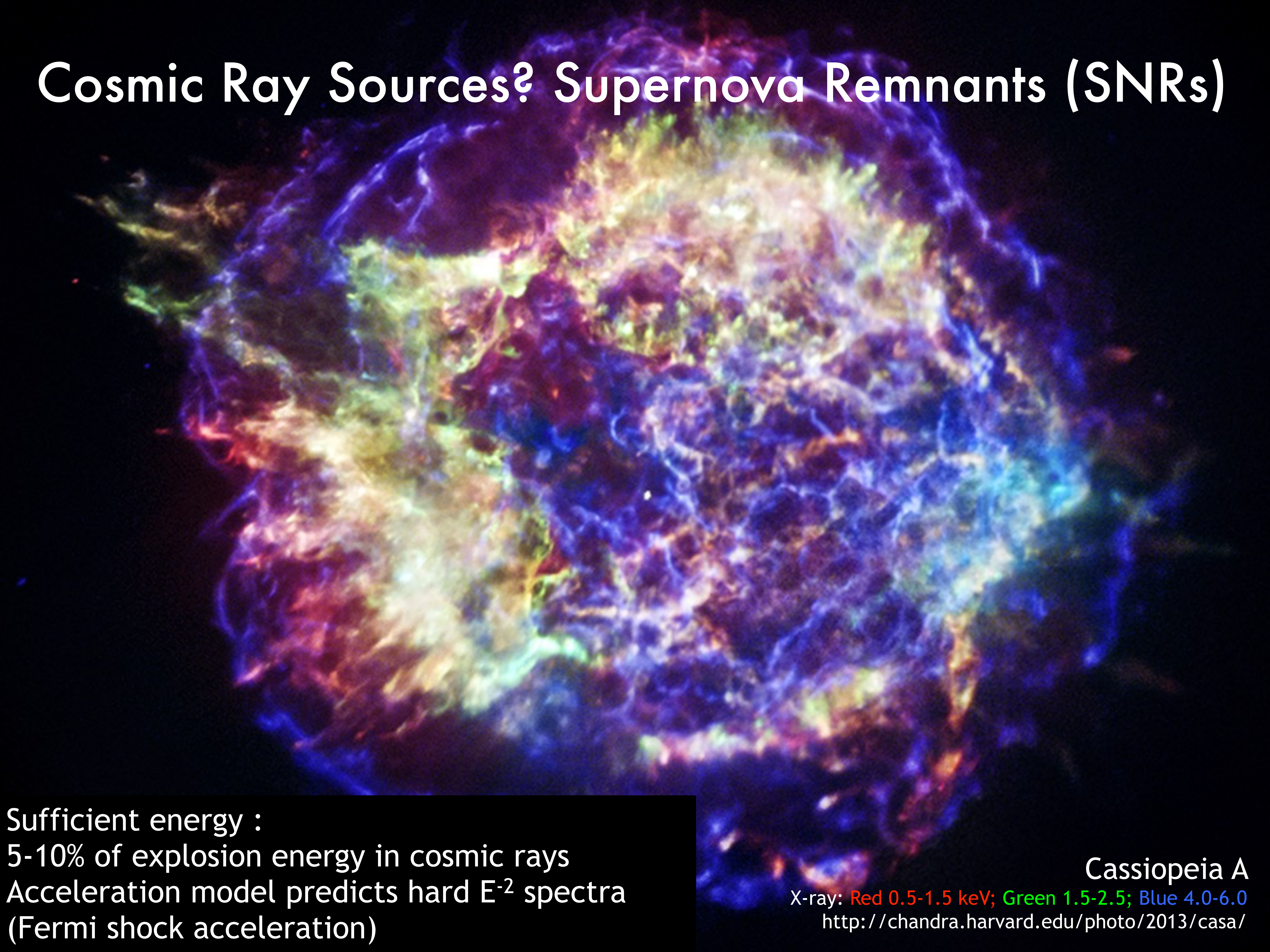


Cassiopeia A

X-ray: Red 0.5-1.5 keV; Green 1.5-2.5; Blue 4.0-6.0

http://chandra.harvard.edu/photo/2013/casa/

Cosmic Ray Sources? Supernova Remnants (SNRs)



Sufficient energy :
5-10% of explosion energy in cosmic rays
Acceleration model predicts hard E^{-2} spectra
(Fermi shock acceleration)

Cassiopeia A
X-ray: Red 0.5-1.5 keV; Green 1.5-2.5; Blue 4.0-6.0
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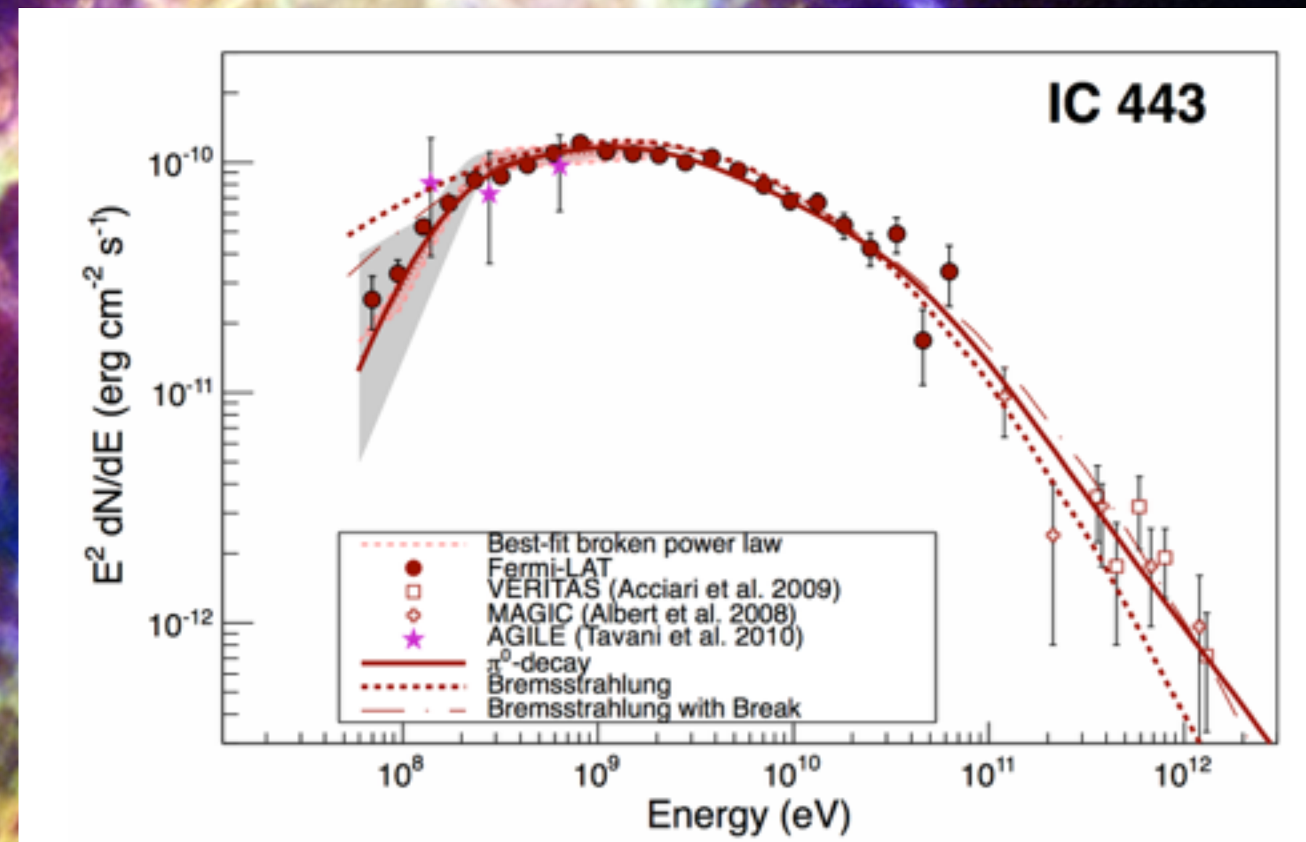
Cosmic Ray Sources? Supernova Remnants (SNRs)



Ackermann et al (Science, 2013)

Cassiopeia A

X-ray: Red 0.5-1.5 keV; Green 1.5-2.5; Blue 4.0-6.0

http://chandra.harvard.edu/photo/2013/casa/

H.E.S.S.
High Energy Stereoscopic System

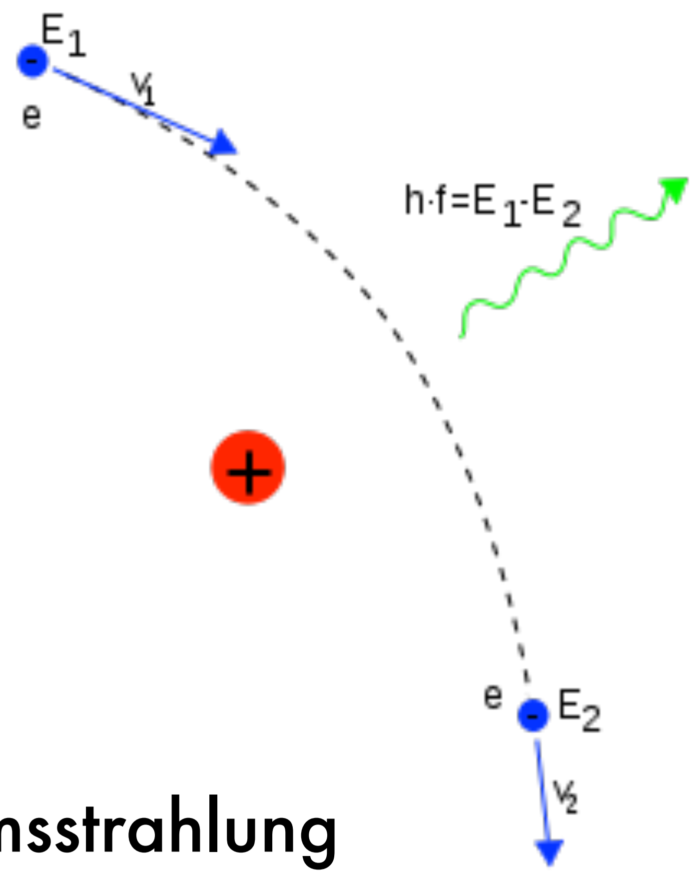
Khomas Highland
Namibia
1800m

HESSI: 2003 CT1-4
Ø 12 m,107 m^2
HESSII : 2012->CT5
Ø 28 m,600 m^2

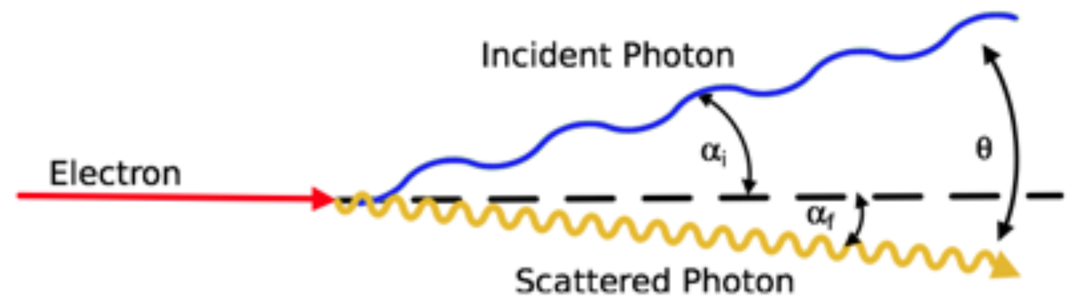
Energy range 50 GeV–100 TeV
Angular resolution up to 0.05°
Field of view 5°/3.2°

source catalogue of 83 sources
More information on https://www.mpi-hd.mpg.de/hfm/HESS/

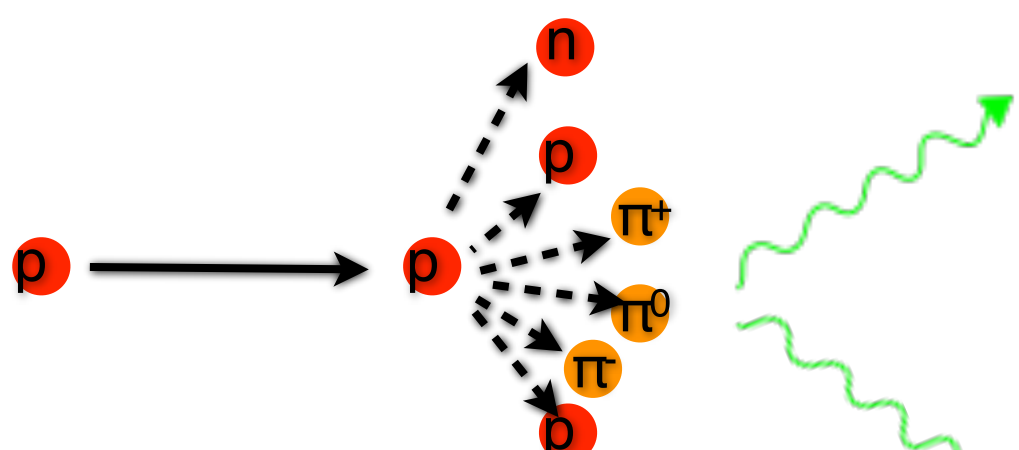
Gamma-ray radiation processes



Bremsstrahlung



Inverse Compton scattering



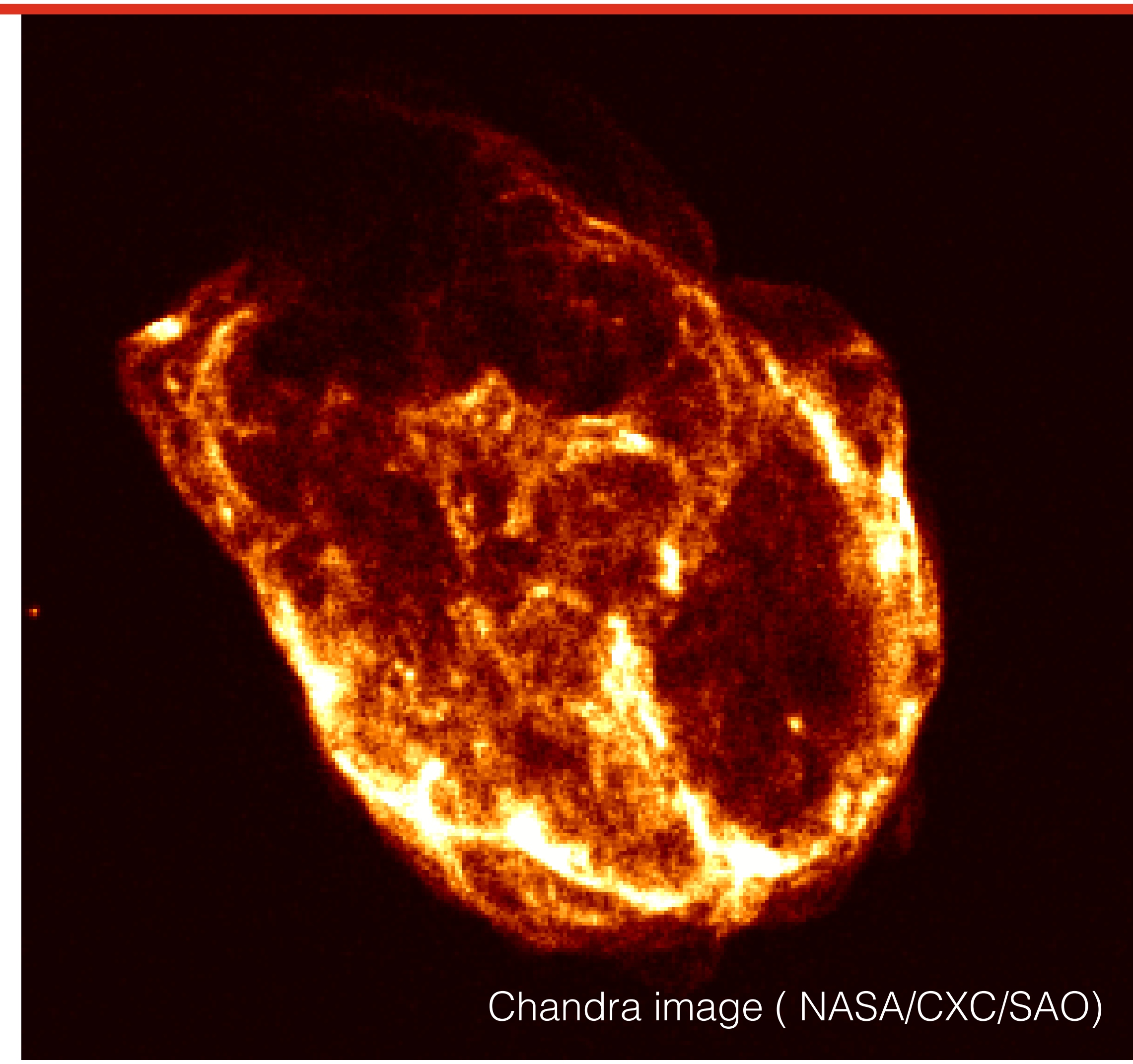
$$\pi^0 \rightarrow 2\gamma$$
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$
$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$
$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

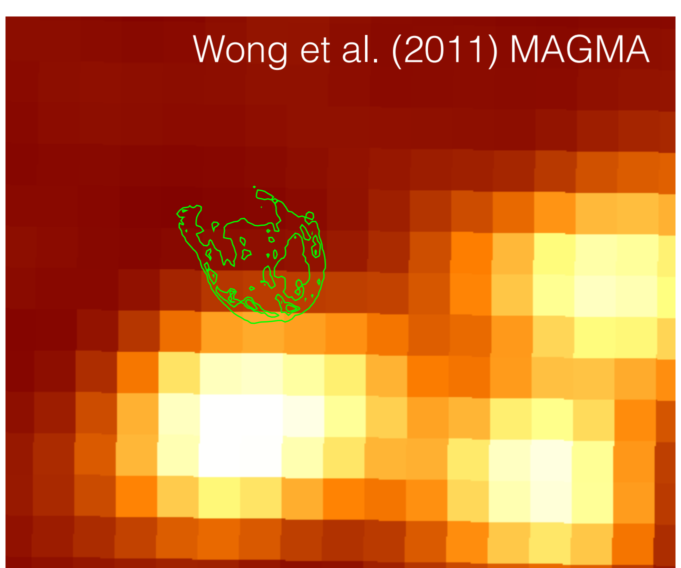
Neutral pion production/decay

SNR LMC N132D

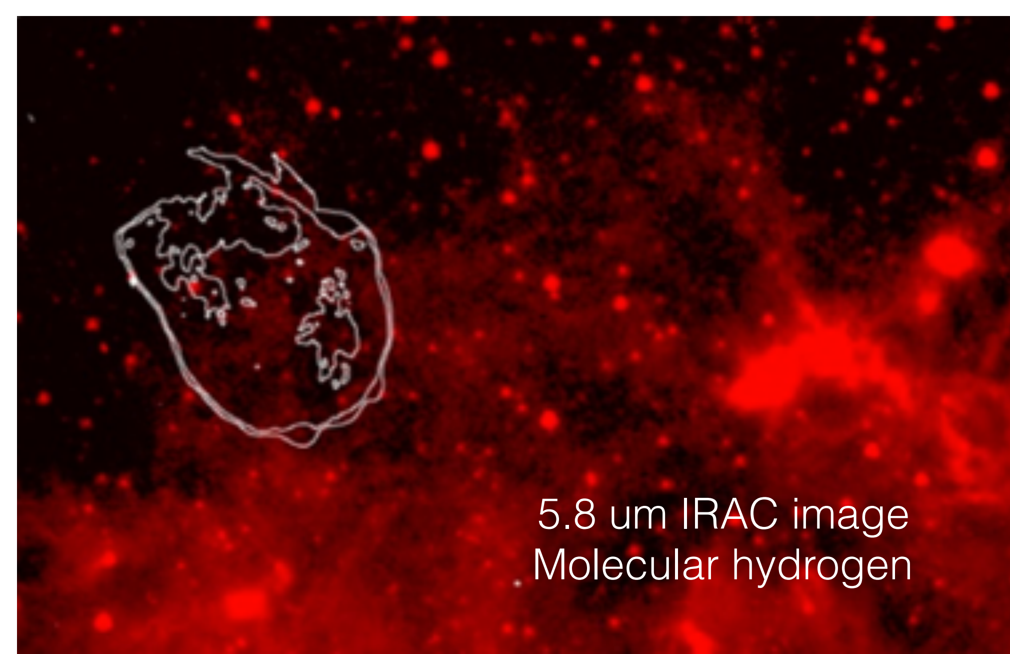
- ~1 arcminute, ~14 pc ellipsoidal shell
- Dist = 50 kpc (LMC)
- Age ~ 2500 years
- Very energetic ($E>10^{51}$erg)

- Well observed from radio to X-ray
- G-rays (H.E.S.S. Collaboration et al. 2015, Fermi-LAT Collaboration 2015)
- Not seen in non thermal X-rays

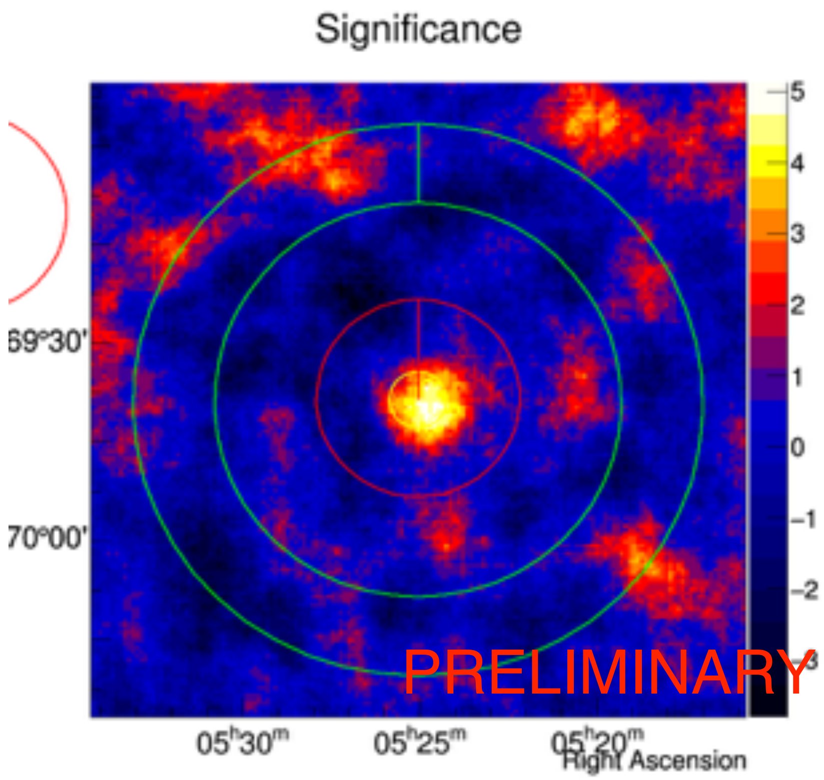


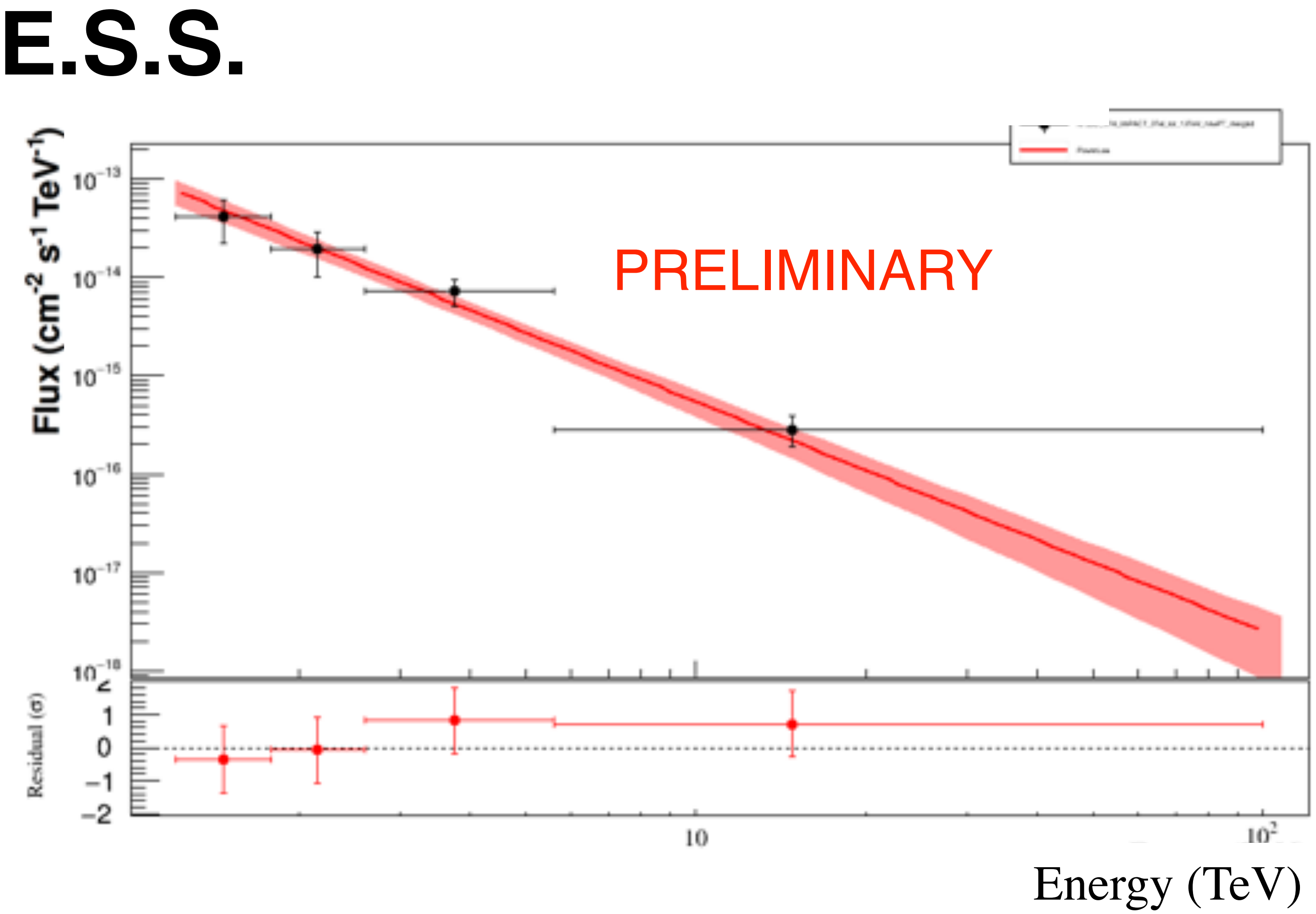


Molecular cloud projected towards the SW region.



N132D H.E.S.S. new analysis





Detection :

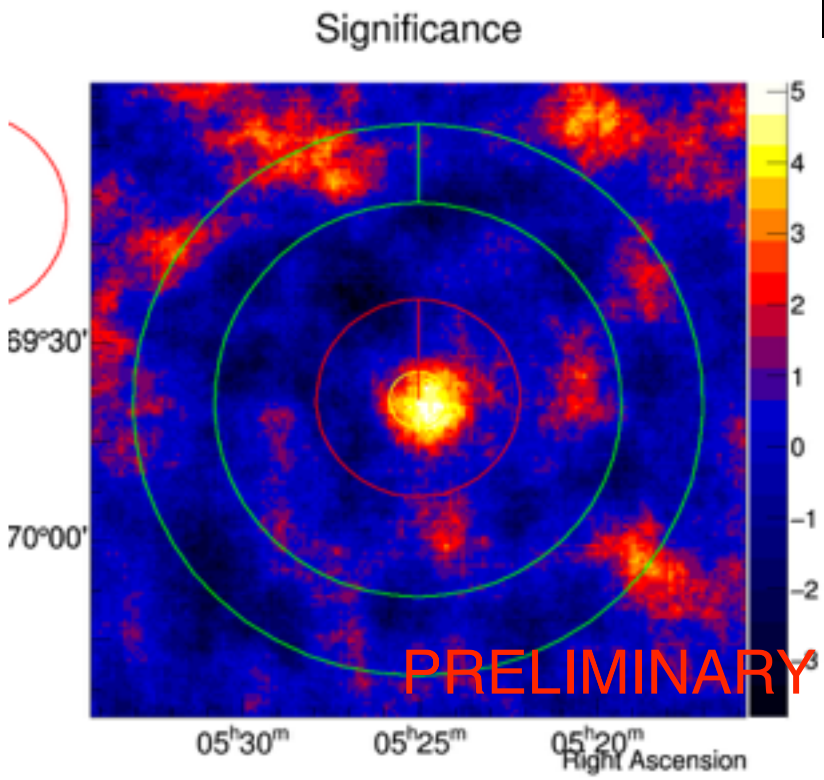
- Significance 5.6 sigma for 253 hrs

- Spectrum Fit : index : 2.2 +/- 0.12
  norm: (9.1+3.2)e-14 $TeV^{-1}.cm^{-2}.s^{-1}$
  Chi2/ndof = 0.96

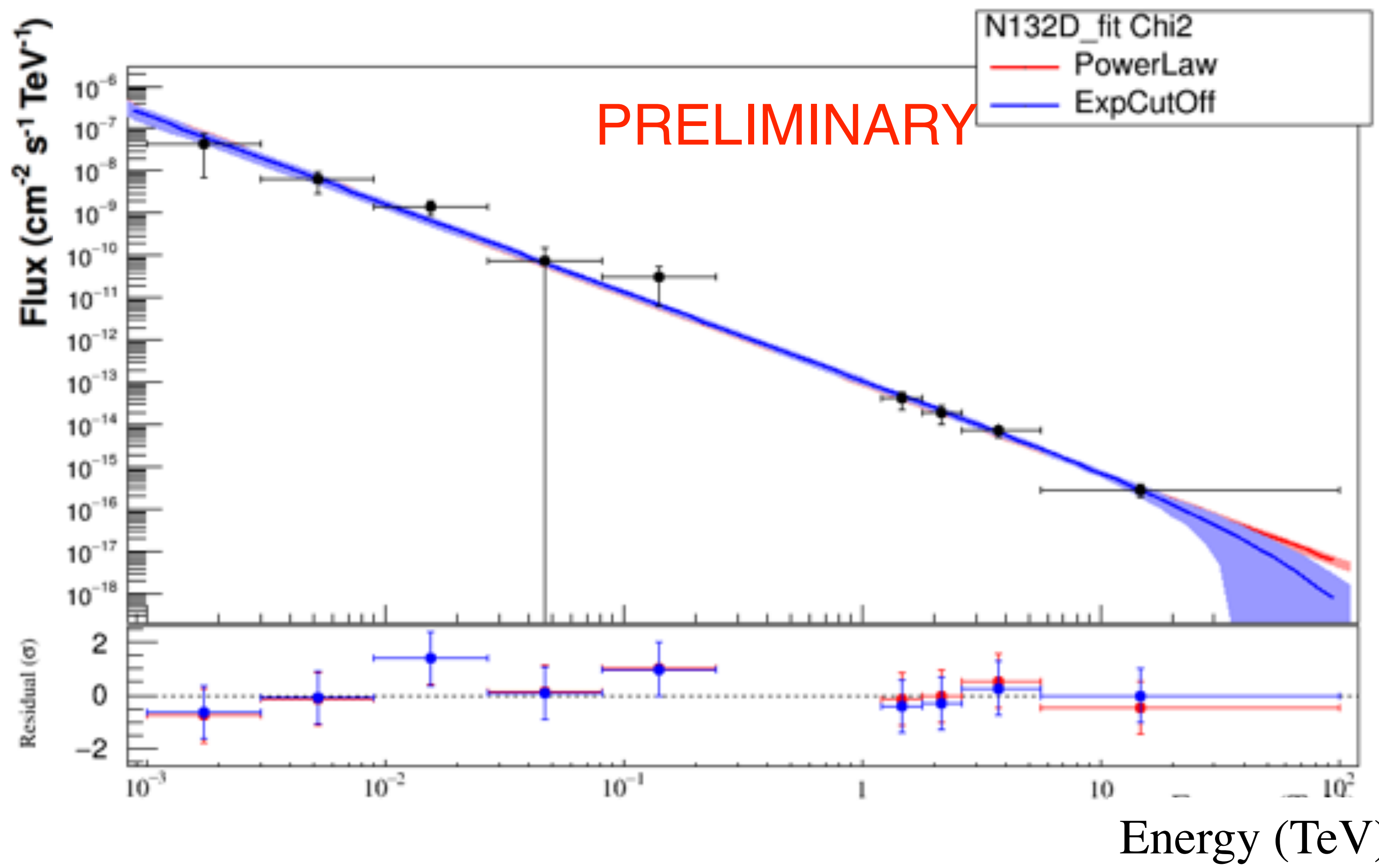
	<E> TeV	dFlux	Sig
0	1.469	4.114e-14	2.26
1	2.15	1.917e-14	2.23
2	3.75	7.170e-15	3.55
3	14.75	2.859e-16	3.37

L(>1 TeV) = (1.3 +-0.2)x10^{35}(d/50kpc) $erg.s^{-1}$

N132D H.E.S.S. new analysis



H.E.S.S.+Fermi-LAT (D. Prokhorov)



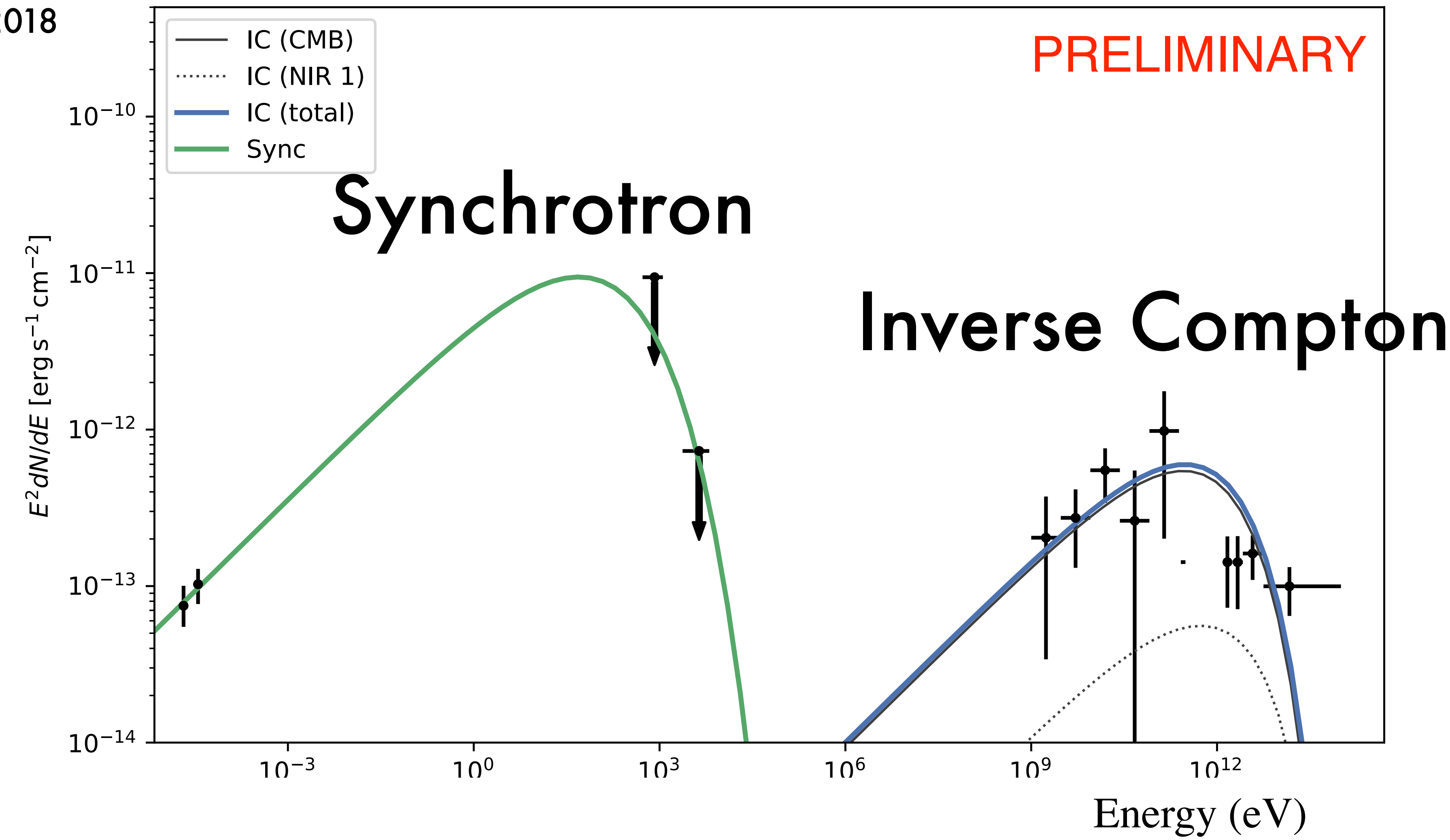
	Chi2/ndof	norm	index	
PL	5.1/7	(9.84+-1.55) e-14	2.17 +- 0.05	
ECPL	4.6/6	(1.03 +-0.22)e-13	2.10 +- 0.07	Ecut = 39 $^{+67}_{-24}$ TeV

Cut-off value can be excluded at 5 TeV with 95 % CL

Modelling: pure Leptonic scenario

Fermi points from D. Prokhorov
Radio = Dickel & Milne 1995
X-ray = Bamba et al. 2018

Modelling package : Naima



Electron distribution : ECPL with norm = 1.6 e43 eV^{-1}, index =2.22 , Ecut = 12 TeV
Inverse Compton with 2 component : CMB + NIR (T = 145K, dens = 0.1 eV.cm-3)
Magnetic Field B = 13μG

➜ Total energy in the electron : We (>1GeV) = 4.0e+50 erg

Modelling: pure Leptonic scenario

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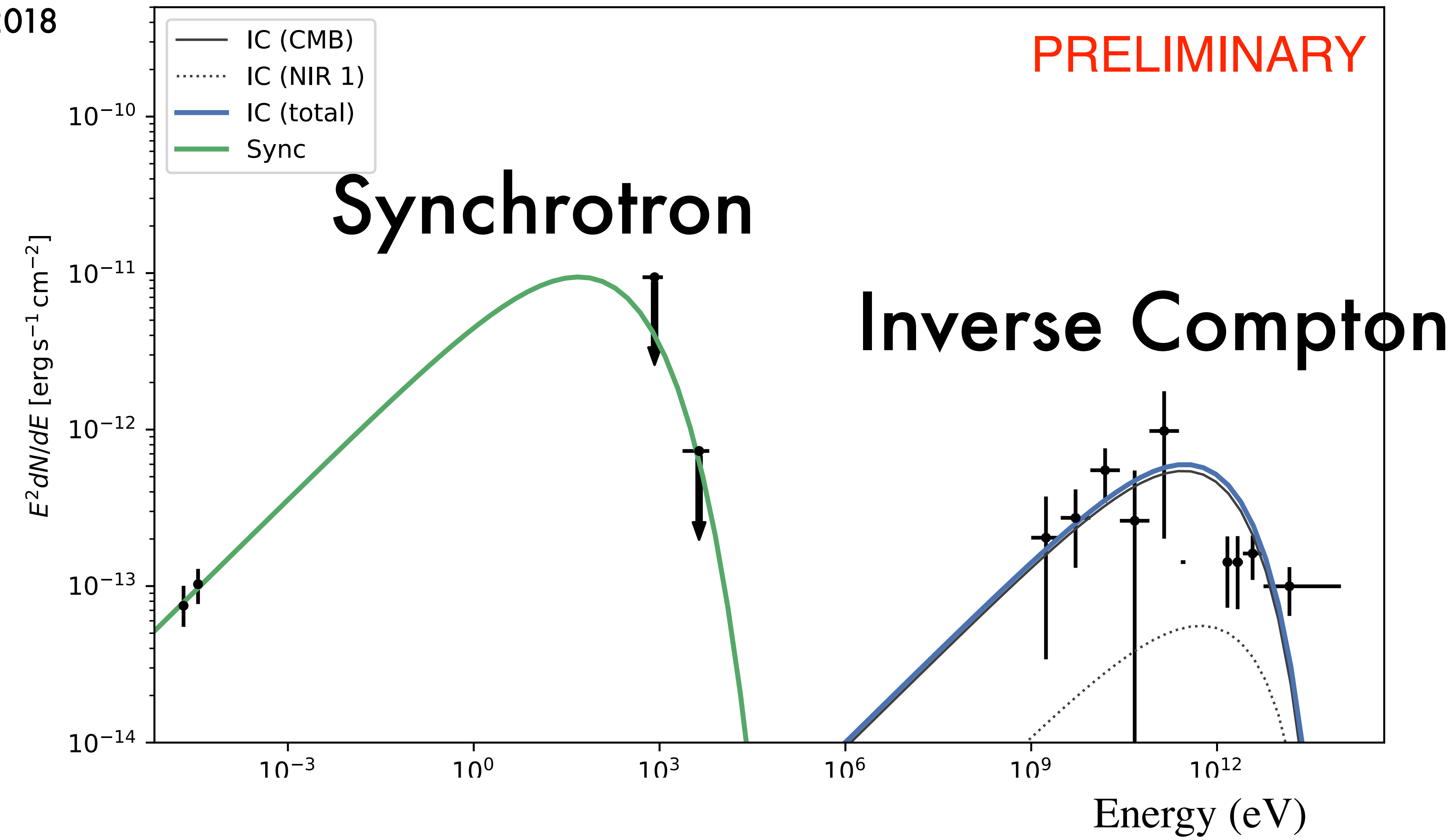
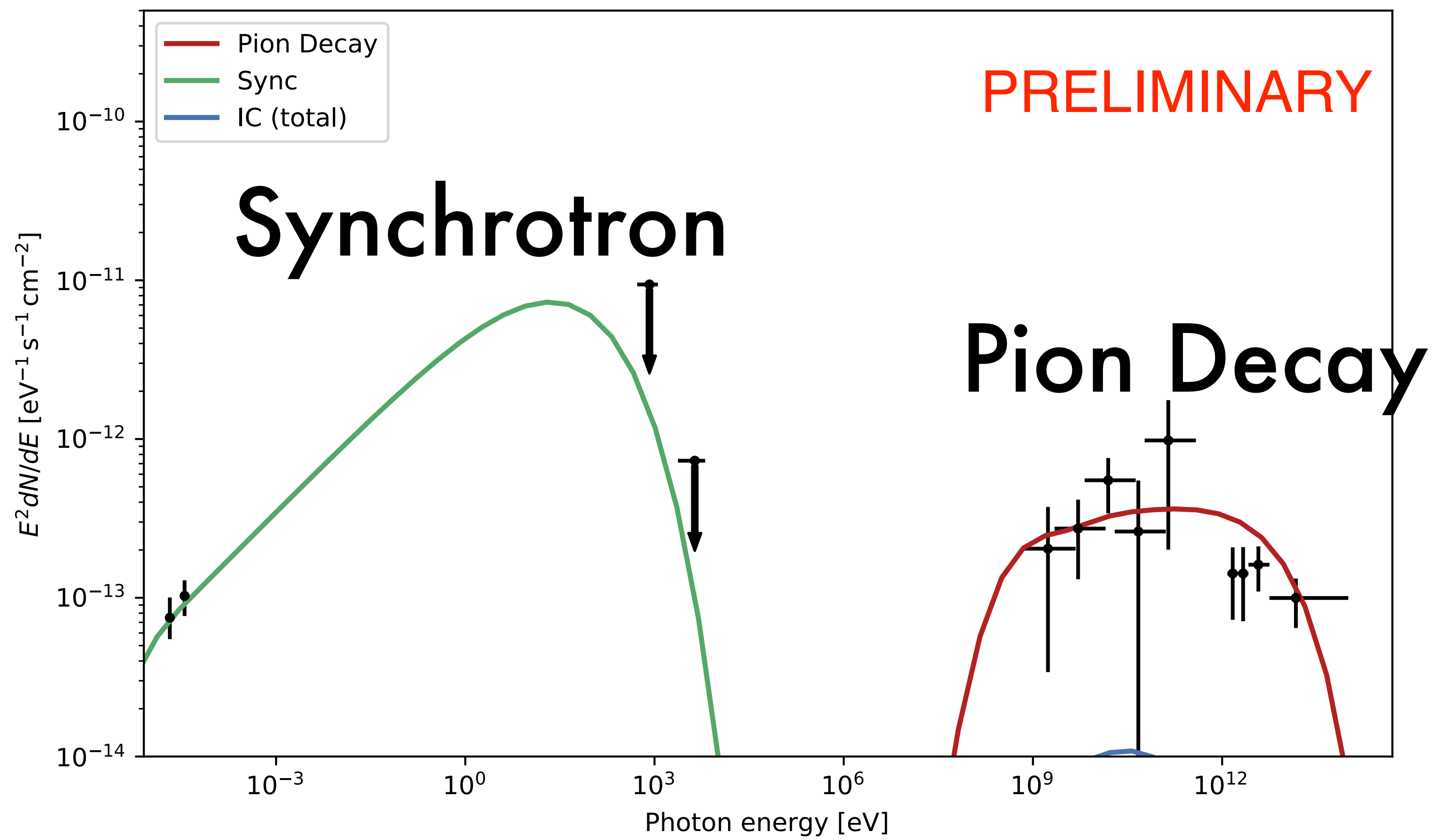


➜ W_e is very high : ~10% of the initial explosion

Pure Leptonic is unlikely, an hadronic component is needed

Modelling: hadronic scenario

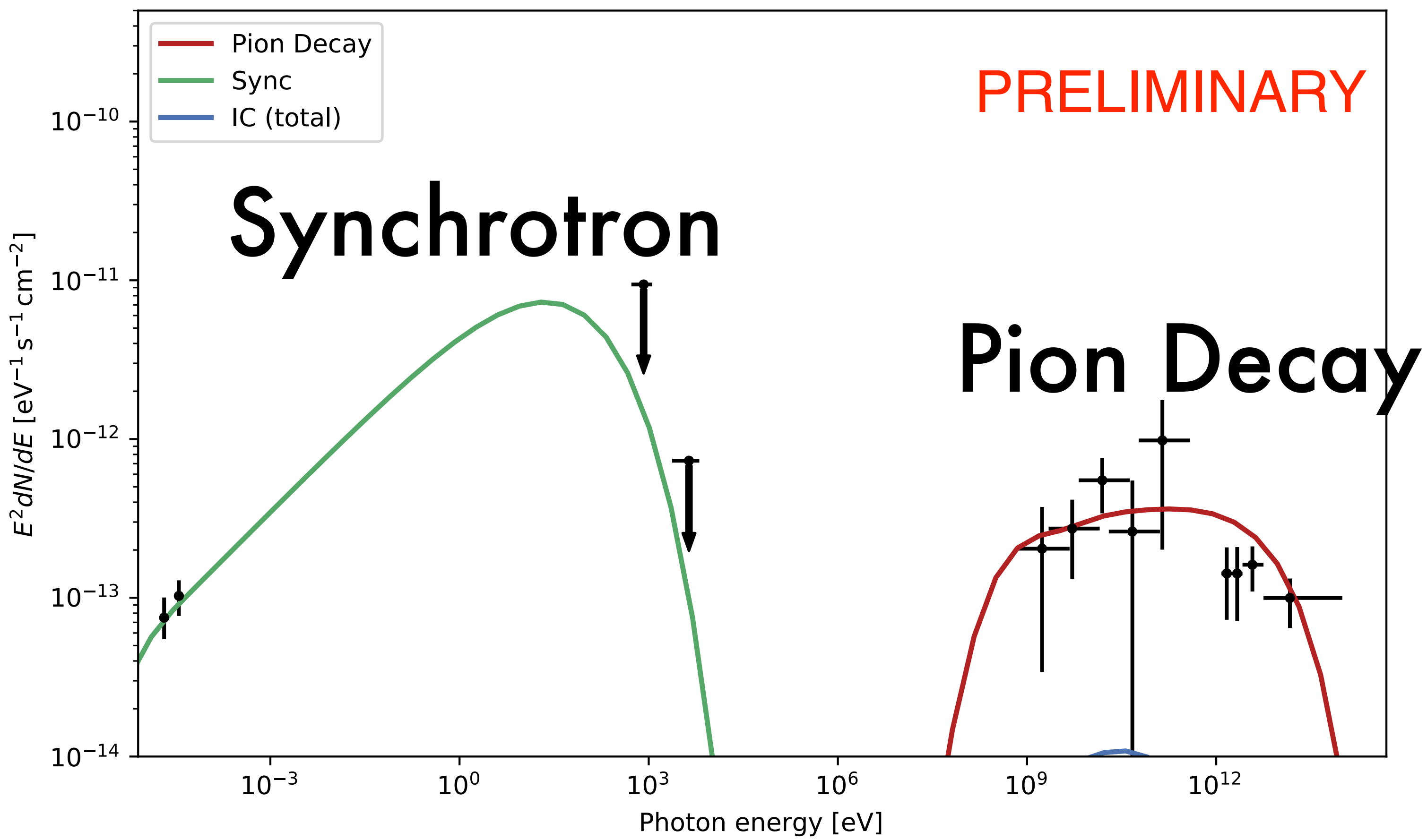
Fermi points from D. Prokhorov
Radio = Dickel & Milne 1995
X-ray = Bamba et al. 2018



Proton ditribution : ECPL with Wp = 4e50 erg, index =2.0, Ecut = 120 TeV
Electron ditribution : ECPL with We = 4e48 erg, index =2.2, Ecut = 3 TeV
proton density: np = 10 cm^{-3}
Magnetic Field : B = 90 μG

Modelling: hadronic scenario

Fermi points from D. Prokhorov ("SNR set")
Radio = Dickel & Milne 1995
X-ray = Bamba et al. 2018



This hadronic scenario seems valid.
Where do the pp collisions take place? SNR? SNR-MC?
still to investigate....

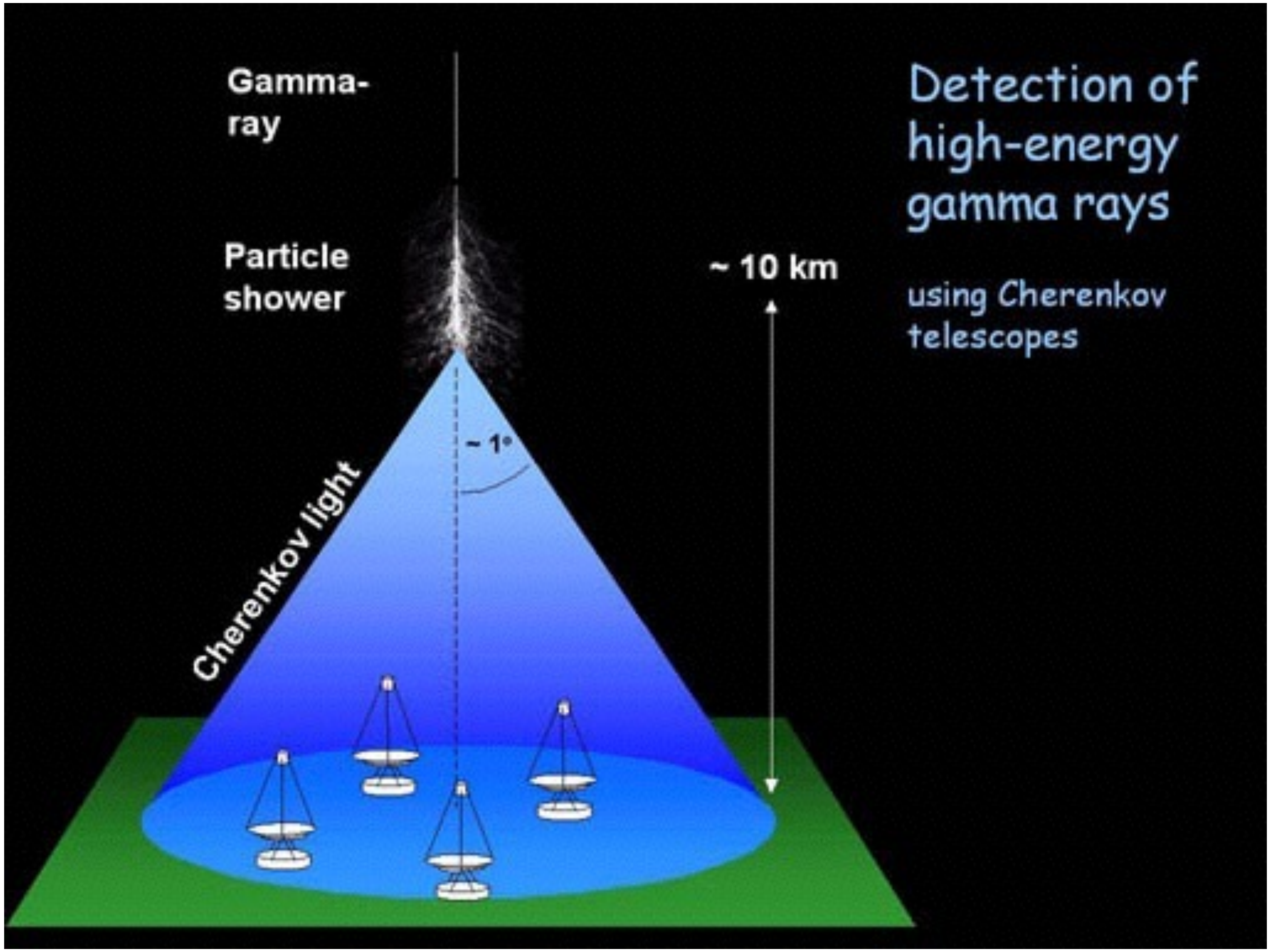
Conclusion

- We detected N132D with a significant excess of 5.6 sigma, with an exposure of 253 hours.
- The remnant is very luminous in TeV gamma-rays : among the 3 most luminous gamma-ray SNR, ~30 times more luminous than Cas A.
- SED mutliwavelenght modelling is showing that an hadronic component is necessary.
- TeV luminosity and very high energy cut-off may hint at emission from cosmic rays escaping into molecular cloud.

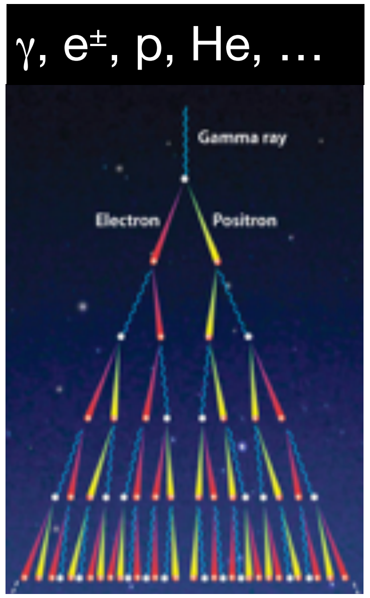
Conclusion

Thank you IIHE !

Imaging Air shower Cherenkov Telescope

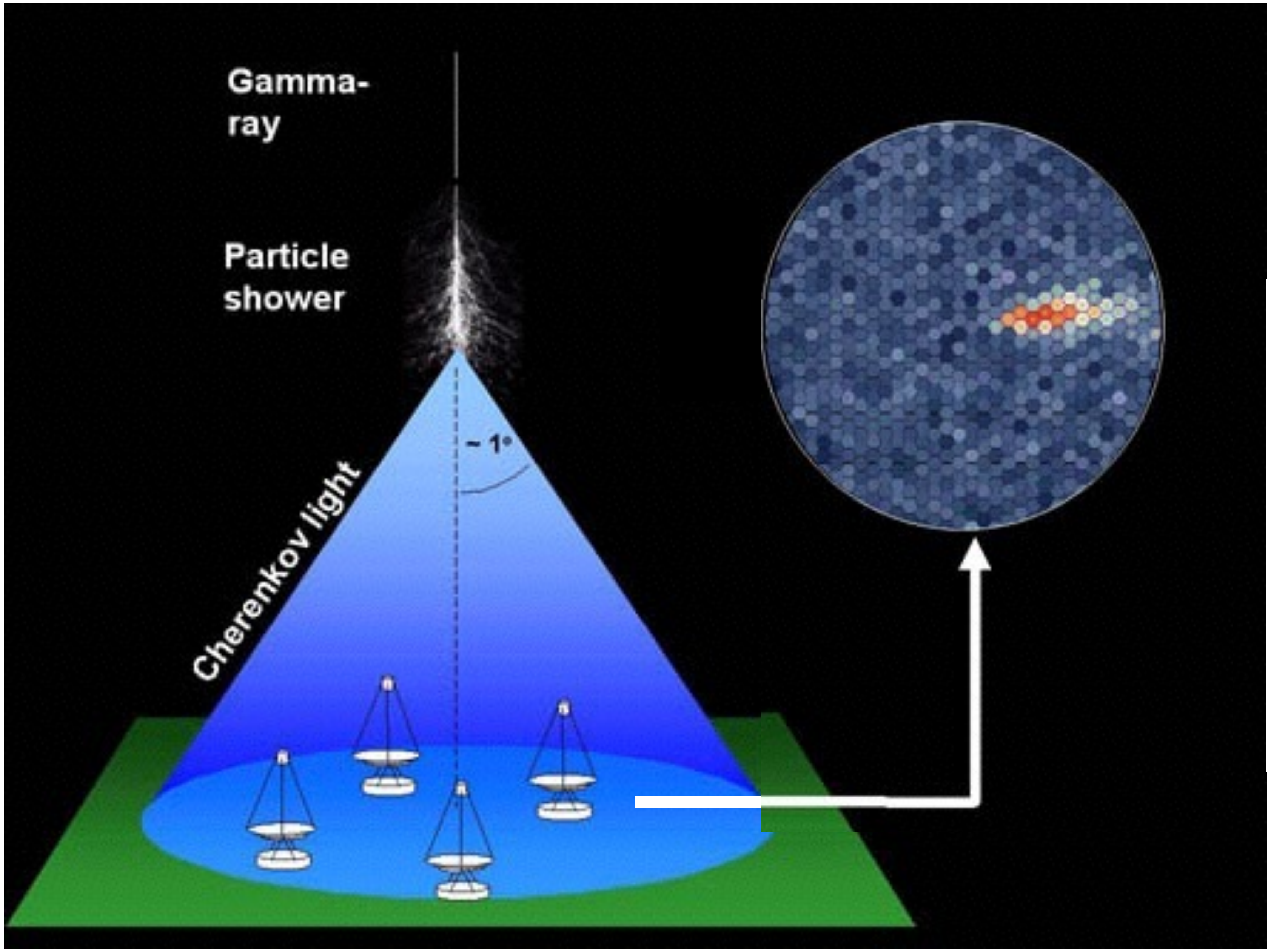


1 photon / m^2
100 000 m^2 on ground-level
10-20 ns

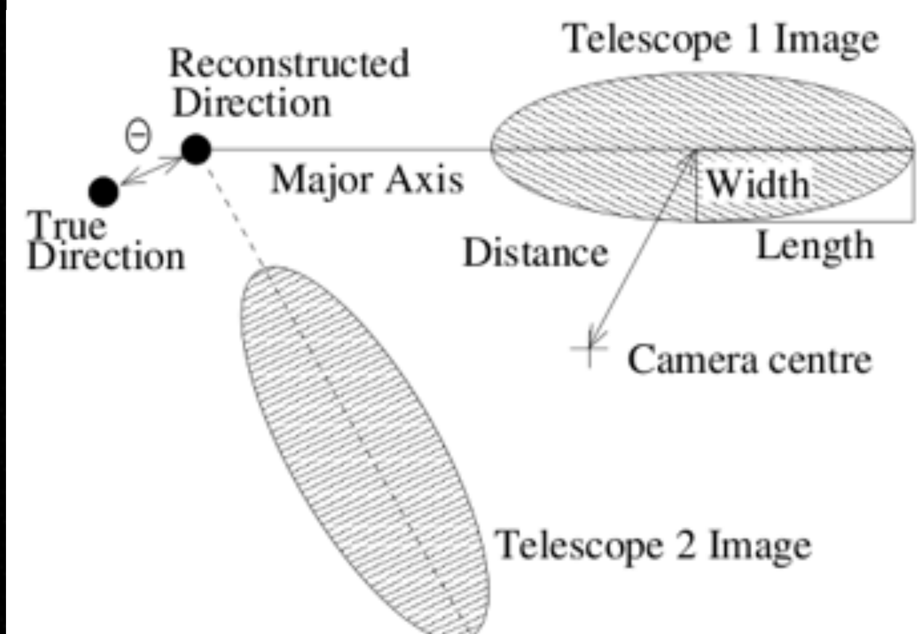


Bethe Heitler model for electronic showers

Imaging Air shower Cherenkov Telescope



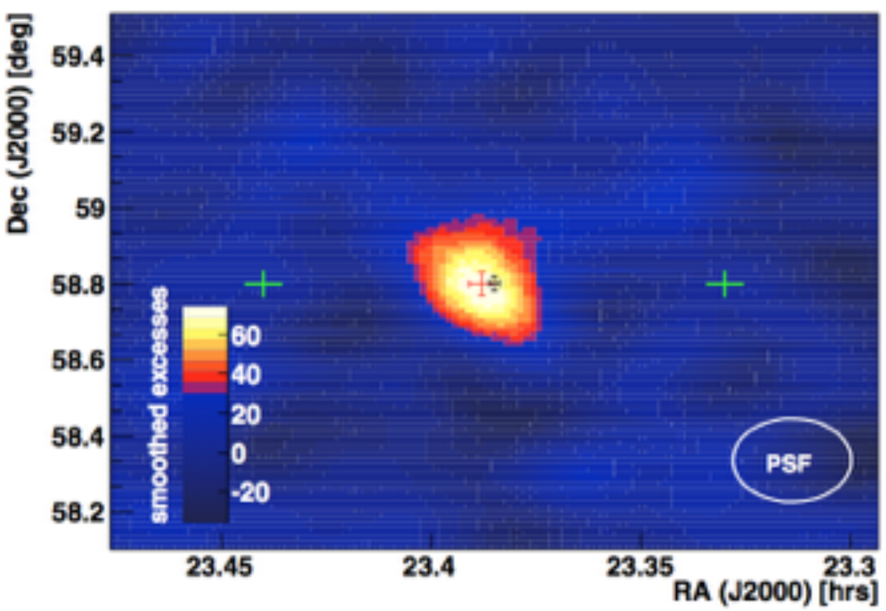
Hillas criterion
for reconstruction



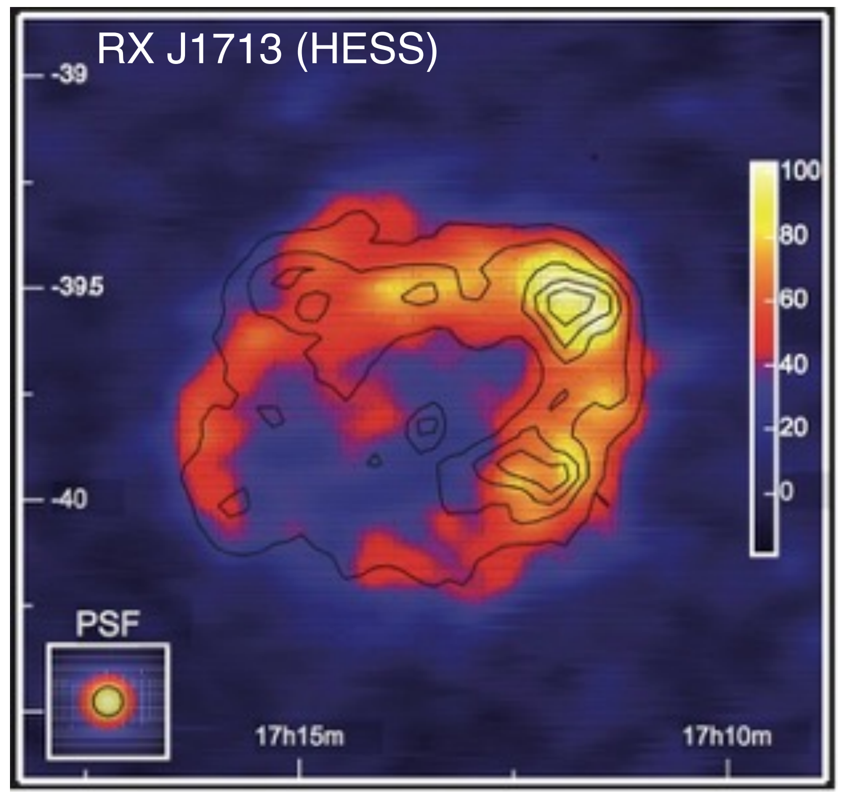
Now the analysis chains are using 2D ellipse LLH fitting method

Some SNRs in TeV gamma-rays

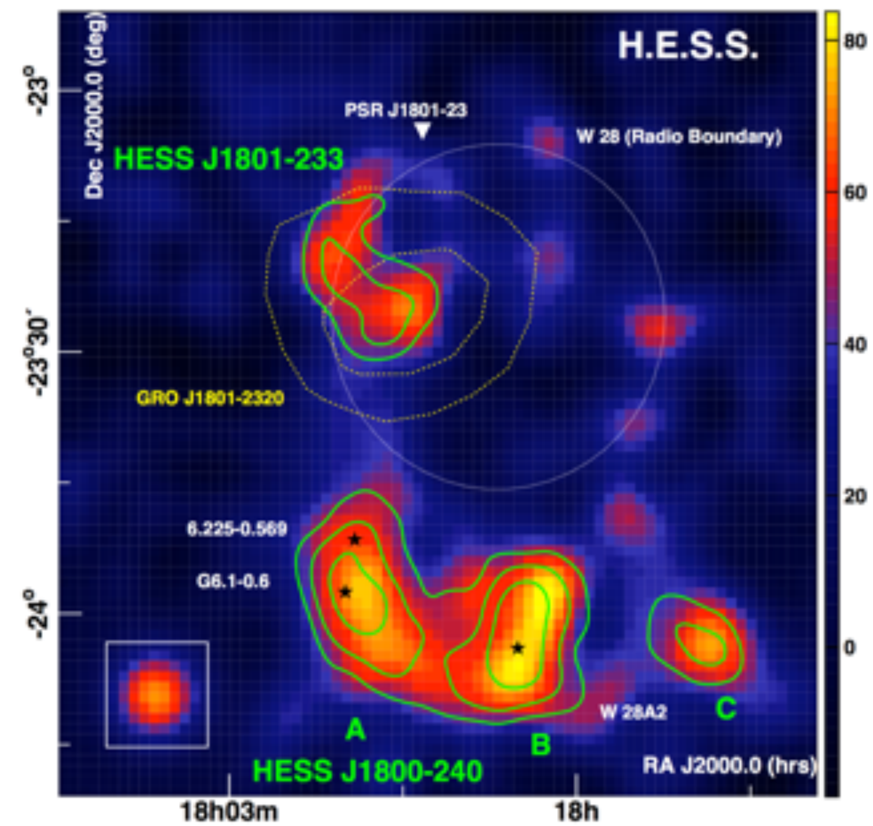
Cas A (MAGIC 2007, Veritas, Hegra)



RX J1713 (H.E.S.S. 2018)



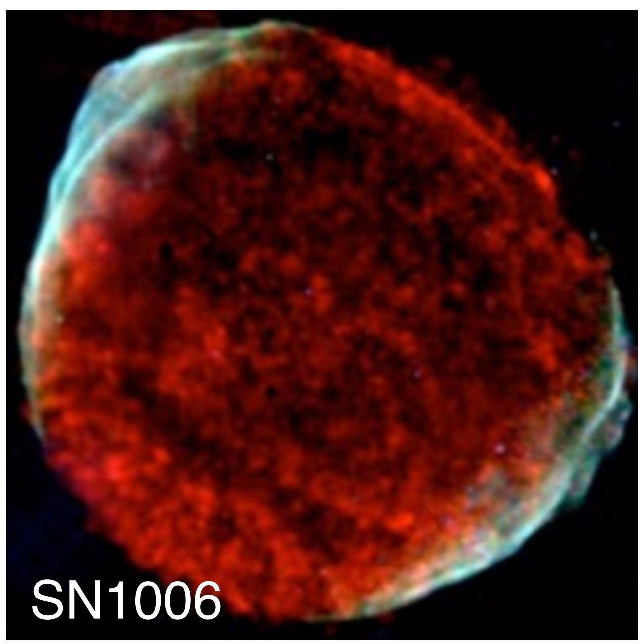
W28 (H.E.S.S. 2008)

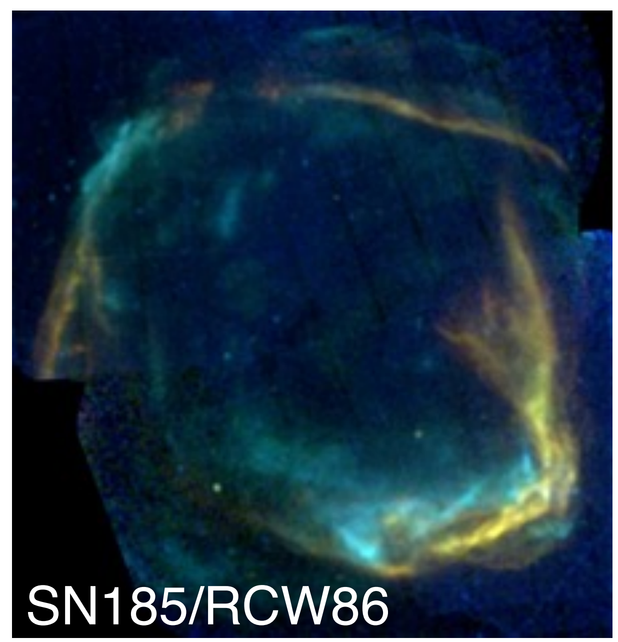


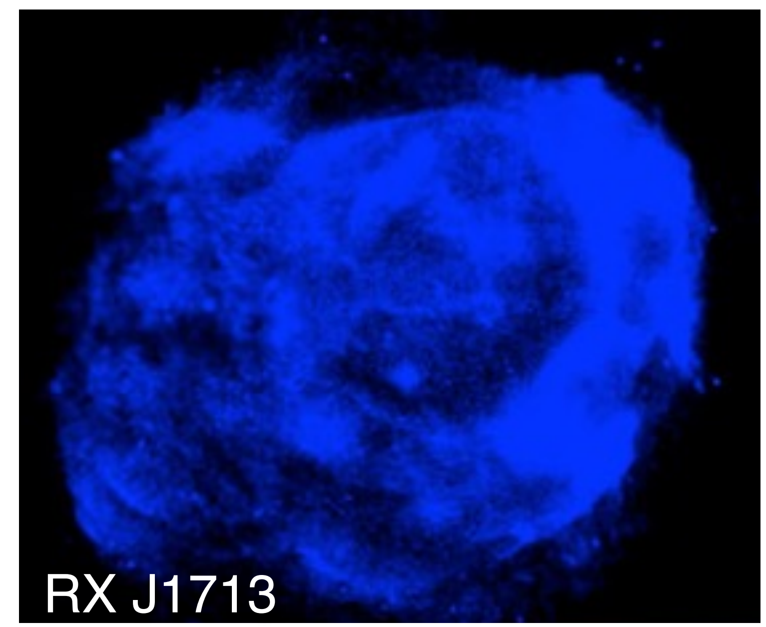
TeV emission from molecular cloud

All young (100-1000 yr) SNRs show X-ray synchrotron

Acceleration of electrons beyond 10 TeV
→ Requires turbulent magnetic field
→ Narrow rims → high B-fields → fast acceleration





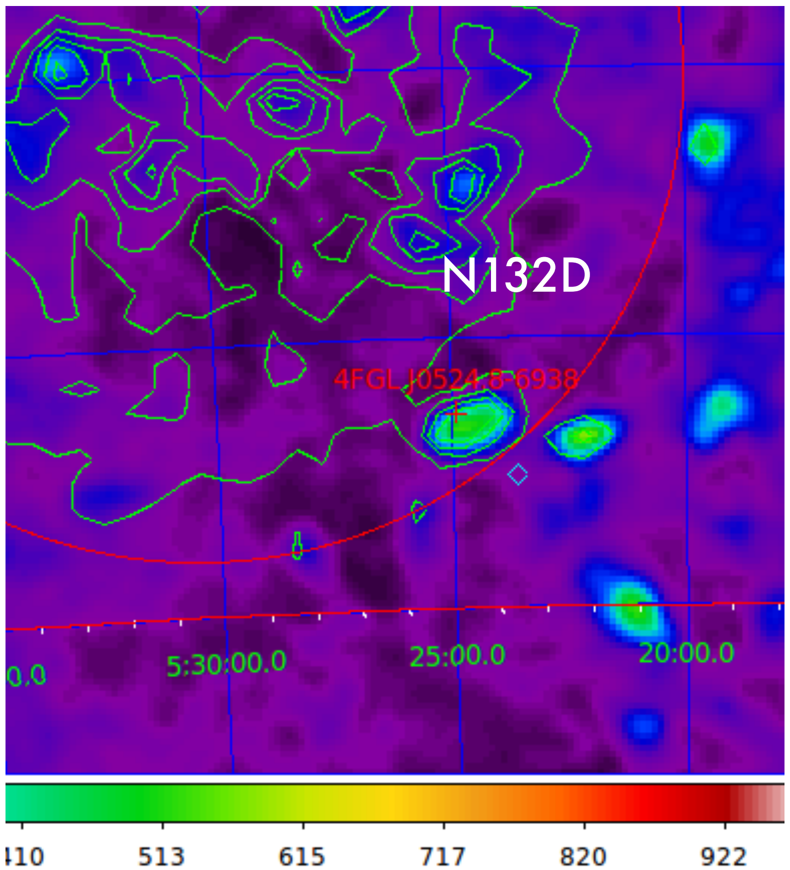


- ***What about protons, and what about the cosmic ray knee?***

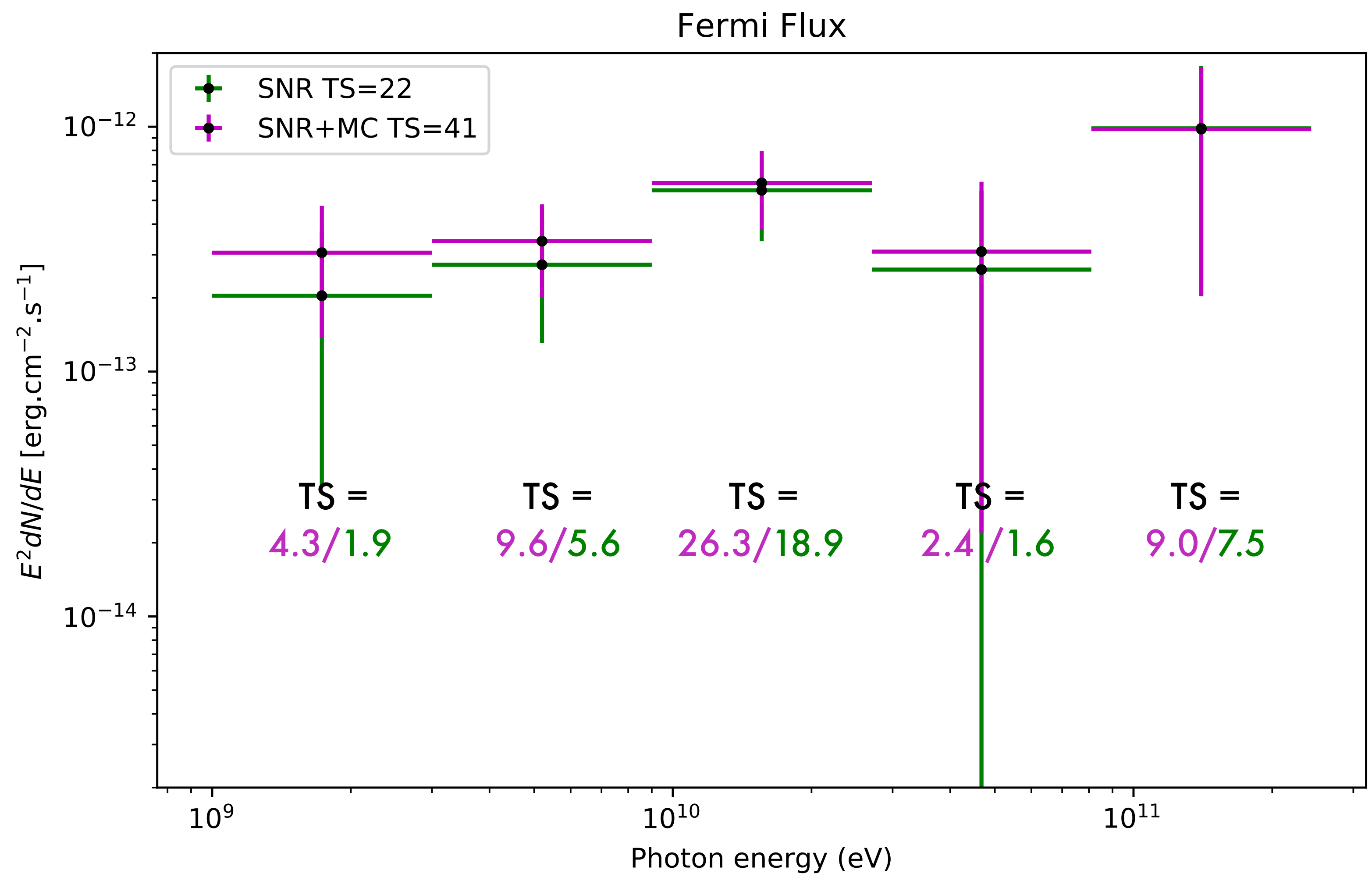
N132D new Fermi analysis

Dmitry Prokhorov

Diffuse templates



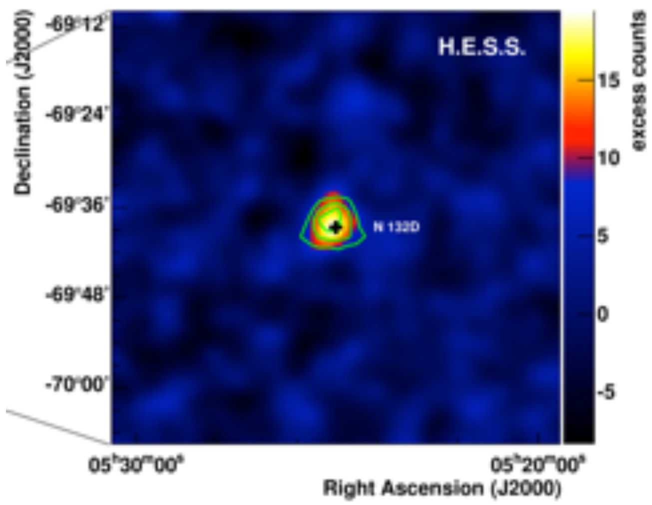
- More data compared to 2015 publication (Aug 2008-May 2019)
- Pass8 R3 analysis framework
- LMC Background modelling:
  set of 4 templates including Molecular clouds (see green contours)
- 2 analysis depending on the modeling of Molecular Clump (MC) near N132D.



Detection :

- SNR only : 4.7 sigma
- SNR+MC : 6.4 sigma
- Spectra are compatible
  - $index_{SNR}$ = 1.86 +/- 0.25
  - $index_{SNR+MC}$ = 1.91 +/-0.20

N132D: previous results

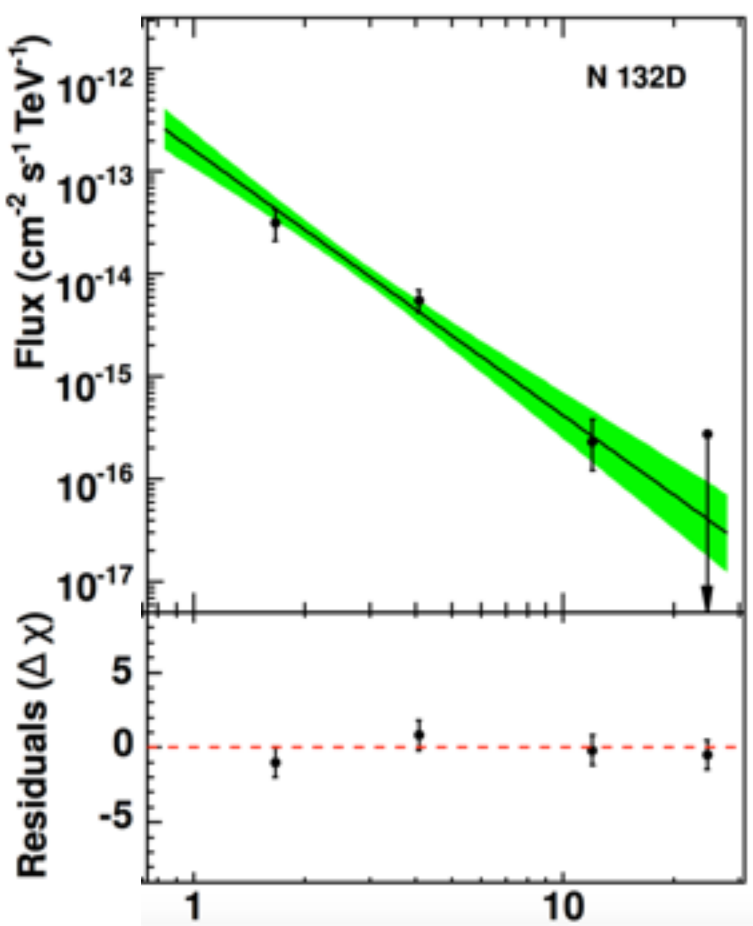


Detection by H.E.S.S. reported in:
"The exceptionally powerful TeV gamma-ray emitters in the Large Magellanic Cloud". Science 347, 406–412 (2015).

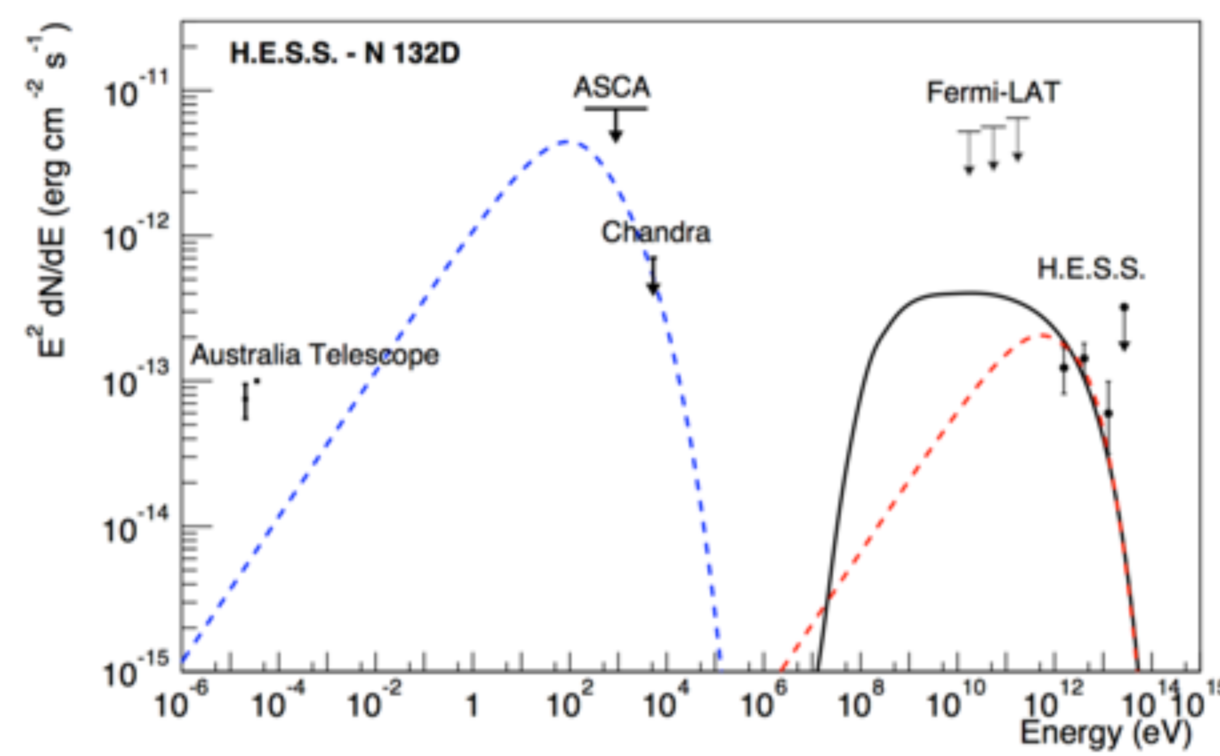
- Significance 4.7 sigma for 148hrs
- Spectrum Fit : Index 2.4 ± 0.3

  Norm = 0.13 ± 0.05 [$10^{-12} cm^{-2} s^{-1} TeV^{-1}$]

  L = 0.9 ± 0.2 [10^{35} erg s^{-1}]



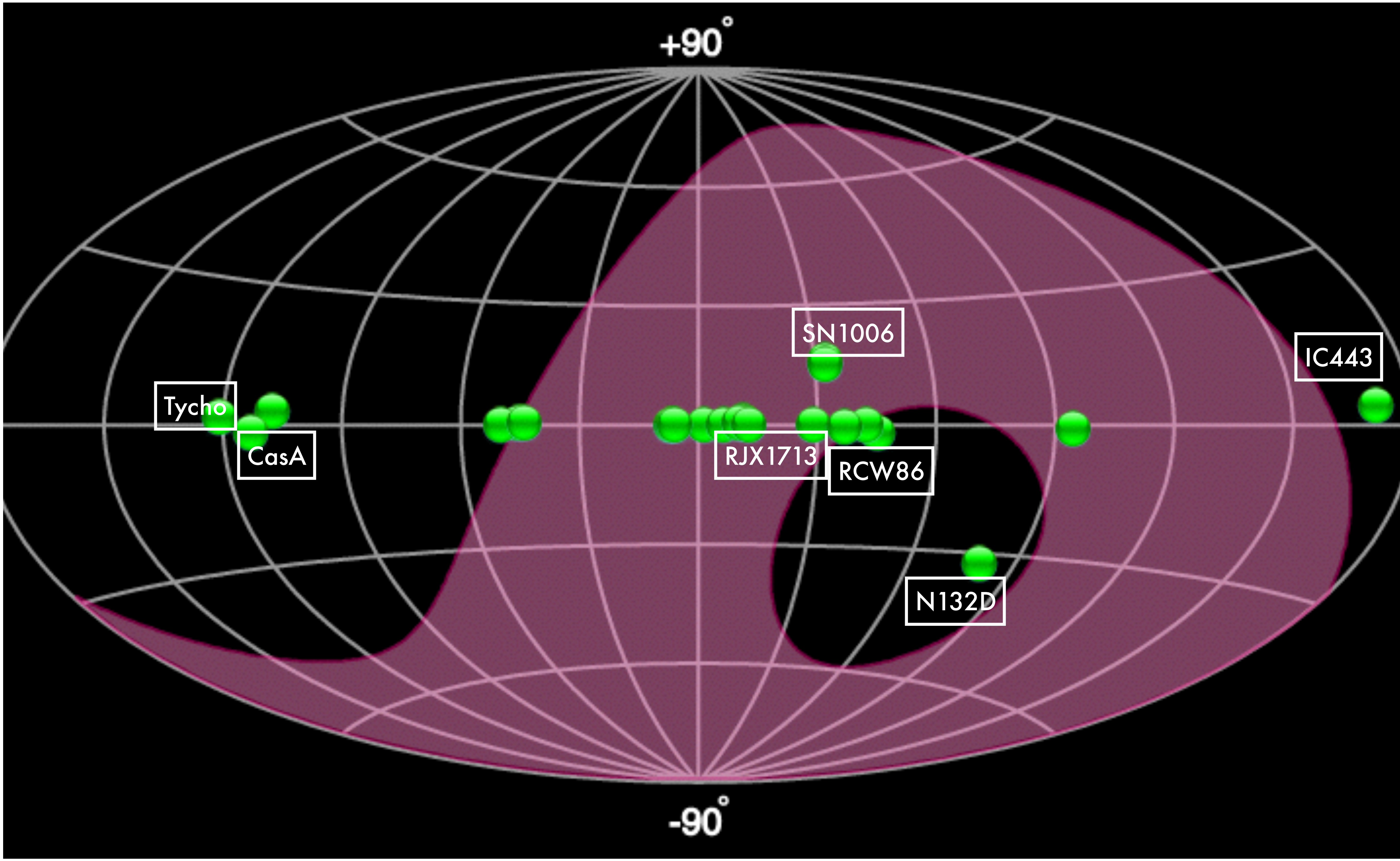
Energy (TeV)



Leptonic or hadronic?

Some shell SNRs in TeV gamma-rays

24 Shell +SNR/MC object in TeVCat Catalogue



http://tevcat.uchicago.edu/

Upper limit on SNe

R.Simoni, N.Maxted, M.Renaud, J.Vink

A&A 626, A57 (2019)
https://doi.org/10.1051/0004-6361/201935242

Astronomy & Astrophysics

Upper limits on very-high-energy gamma-ray emission from core-collapse supernovae observed with H.E.S.S.

H.E.S.S. Collaboration: H. Abdalla[1], F. Aharonian[3,4,5], F. Ait Benkhali[3], E. O. Angüner[19], M. Arakawa[37], C. Arcaro[1], C. Armand[22], H. Ashkar[17], M. Backes[8,1], V. Barbosa Martins[33], M. Barnard[1], Y. Becherini[10], D. Berge[33], K. Bernlöhr[3], R. Blackwell[13], M. Böttcher[1], C. Boisson[14], J. Bolmont[15], S. Bonnefoy[33], J. Bregeon[16], M. Breuhaus[3], F. Brun[17], P. Brun[17], M. Bryan[9], M. Büchele[32], T. Bulik[18], T. Bylund[10], M. Capasso[25], S. Caroff[15], A. Carosi[22], S. Casanova[20,3], M. Cerruti[15,42], N. Chakraborty[3], T. Chand[1], S. Chandra[1], R. C. G. Chaves[16,⋆⋆], A. Chen[21], S. Colafrancesco[21,†], M. Curylo[34], I. D. Davids[8], C. Deil[3], J. Devin[24], P. de Wilt[13], L. Dirson[2], A. Djannati-Ataï[27], A. Dmytriiev[14], A. Donath[3], V. Doroshenko[25], L. O'C. Drury[4], J. Dyks[30], K. Egberts[31], G. Emery[15], J.-P. Ernenwein[19], S. Eschbach[32], K. Feijen[13], S. Fegan[26], A. Fiasson[22], G. Fontaine[26], S. Funk[32], M. Füßling[33], S. Gabici[27], Y. A. Gallant[16], F. Gaté[22], G. Giavitto[33], D. Glawion[23], J. F. Glicenstein[17], D. Gottschall[25], M.-H. Grondin[24], J. Hahn[3], M. Haupt[33], G. Heinzelmann[2], G. Henri[28], G. Hermann[3], J. A. Hinton[3], W. Hofmann[3], C. Hoischen[31], T. L. Holch[7], M. Holler[12], D. Horns[2], D. Huber[12], H. Iwasaki[37],

https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2019/07/