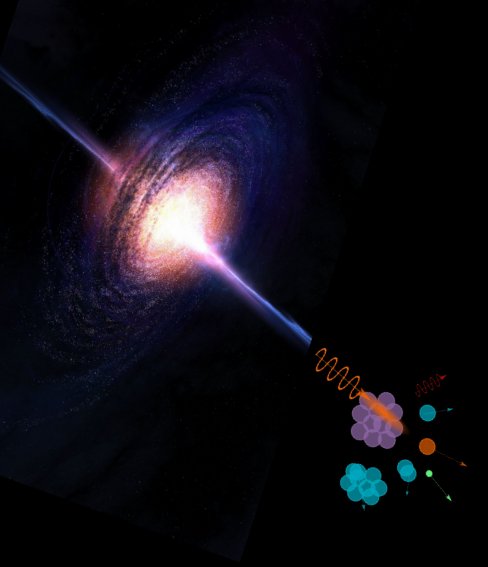

Excited-isomer photons and the VHE emission from Cen A

Session “Constraining UHECR sources”

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

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X. Rodrigues, A. Rudolph, S. Gao, W. Winter

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Take away messages:

Video here

- H.E.S.S. detected extended VHE emission from the jet of the AGN of Centaurus A
- Several works have attempted to connect the fluxes to emission by CR nuclei accelerated in the jet

This work discusses….

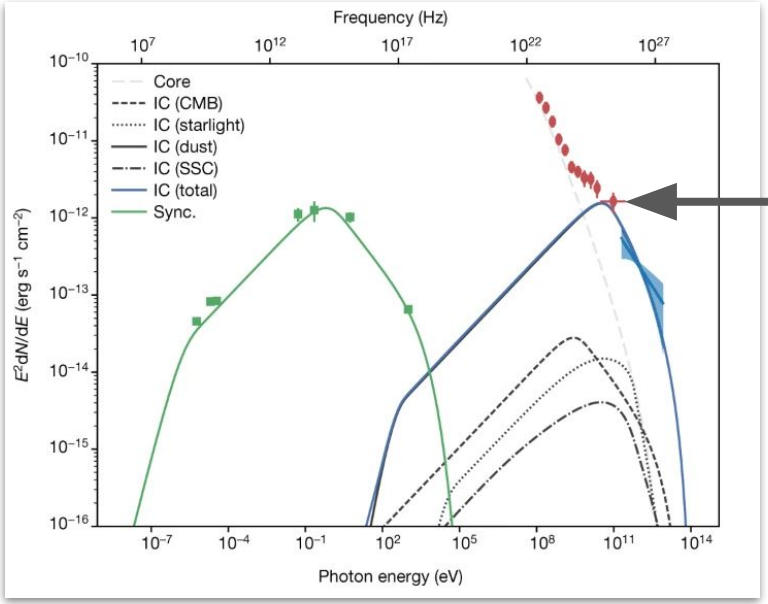
- Isomer decay of escaping nuclei
- Self-consistent simulations, incl. all photon producing channels for nuclei
- Preliminary estimates for the VHE emission with isomers

VHE from Cen A: Possible hadronic origin?

Video here

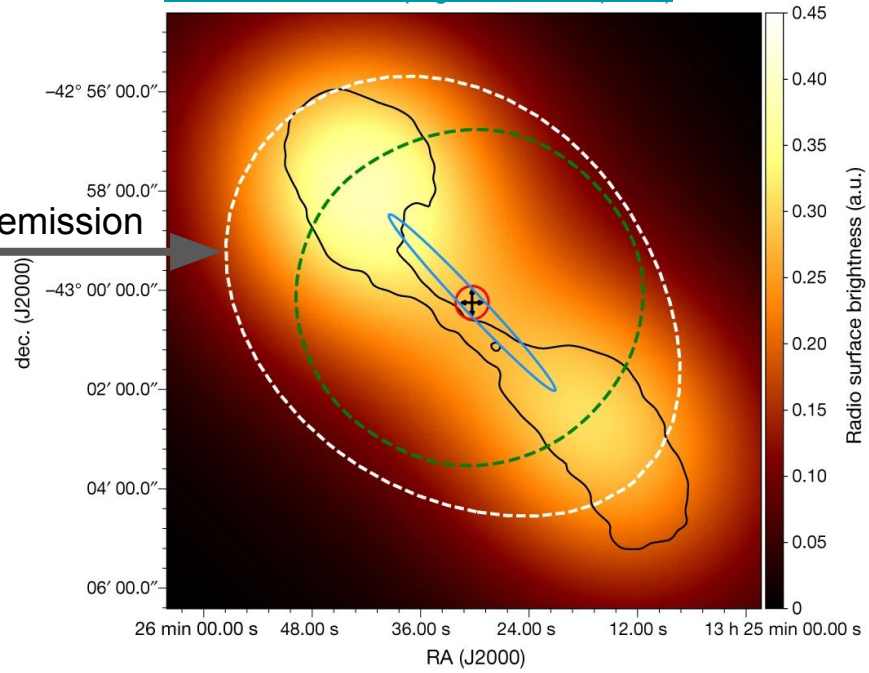
External Inverse-Compton to explain **TeV emission**.

Nature volume 582, pages 356–359 (2020)



Extended emission

Nature volume 582, pages 356–359 (2020)

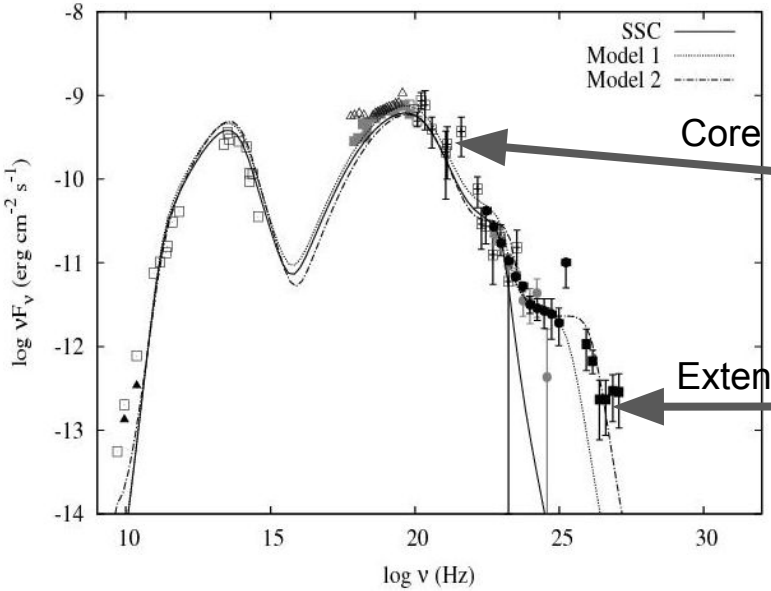


VHE from Cen A: Possible hadronic origin?

Video here

Proton synchrotron can be consistent with Fermi and HESS detection.

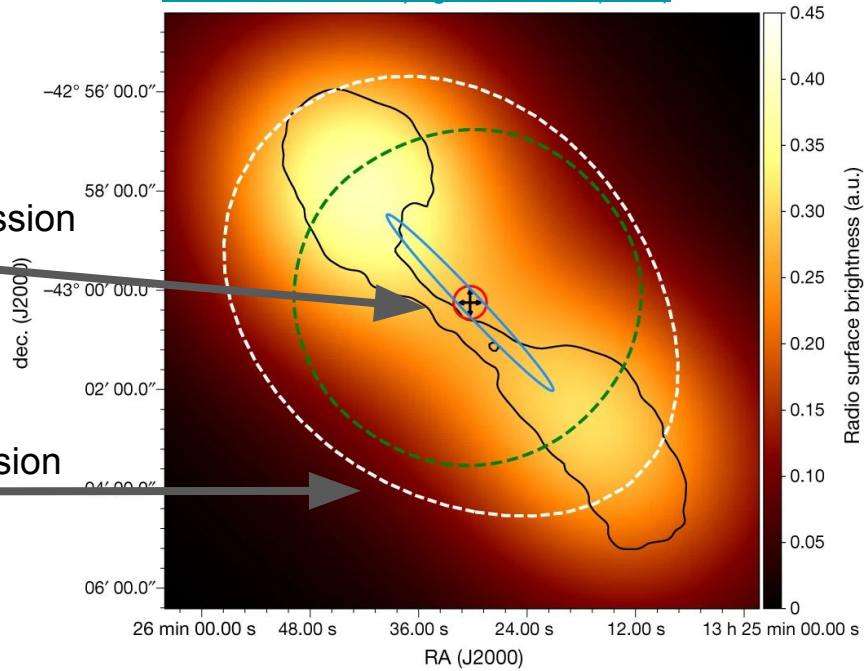
Petropoulou A&A 562 (2014)



Core SSC emission

Extended emission

Nature volume 582, pages 356–359 (2020)



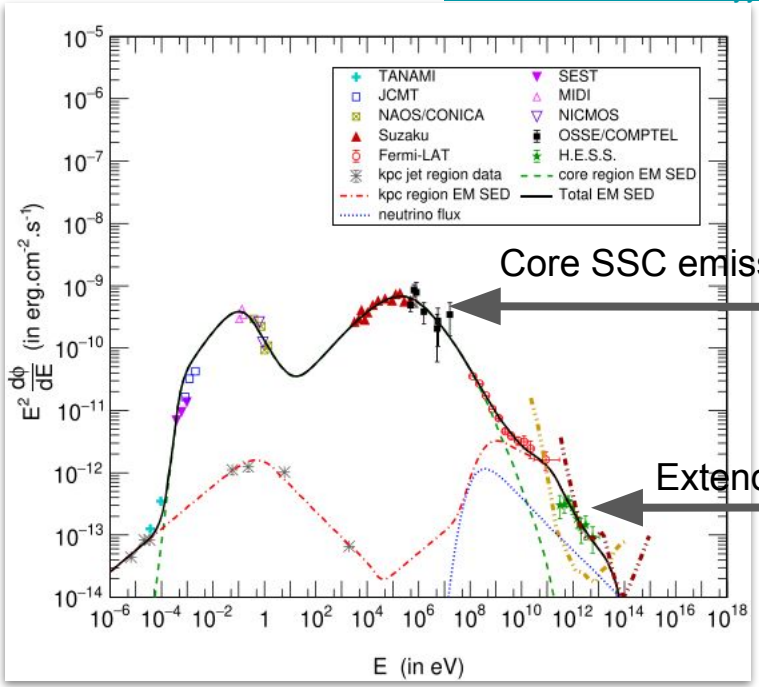
VHE from Cen A: Possible hadronic origin?

Video here

Hadronic interactions found to reproduce well the **GeV- TeV emission**.

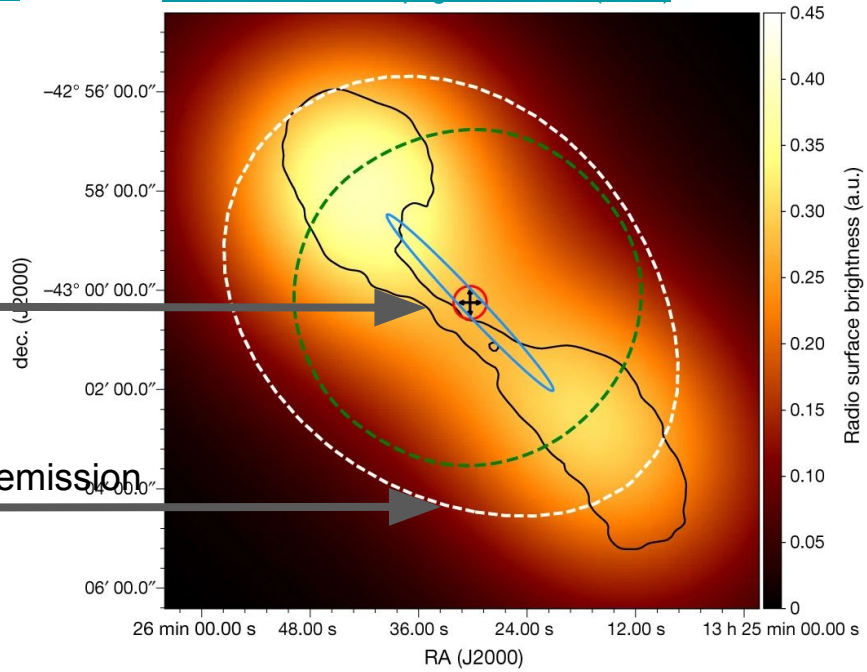
Banik, Badra Bhattacharyya, 2021

Nature volume 582, pages 356–359 (2020)



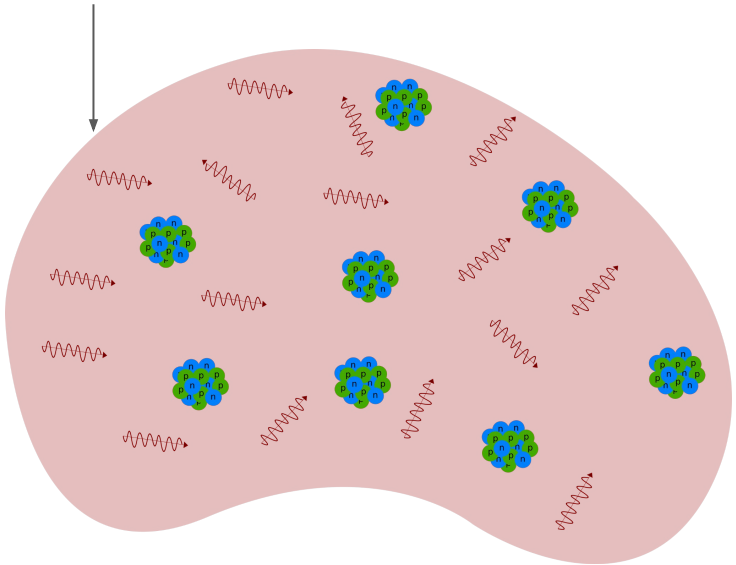
Core SSC emission

Extended emission



SED modelling: SSC

Core with high EM density
electrons / positrons
nuclei injected with a power law



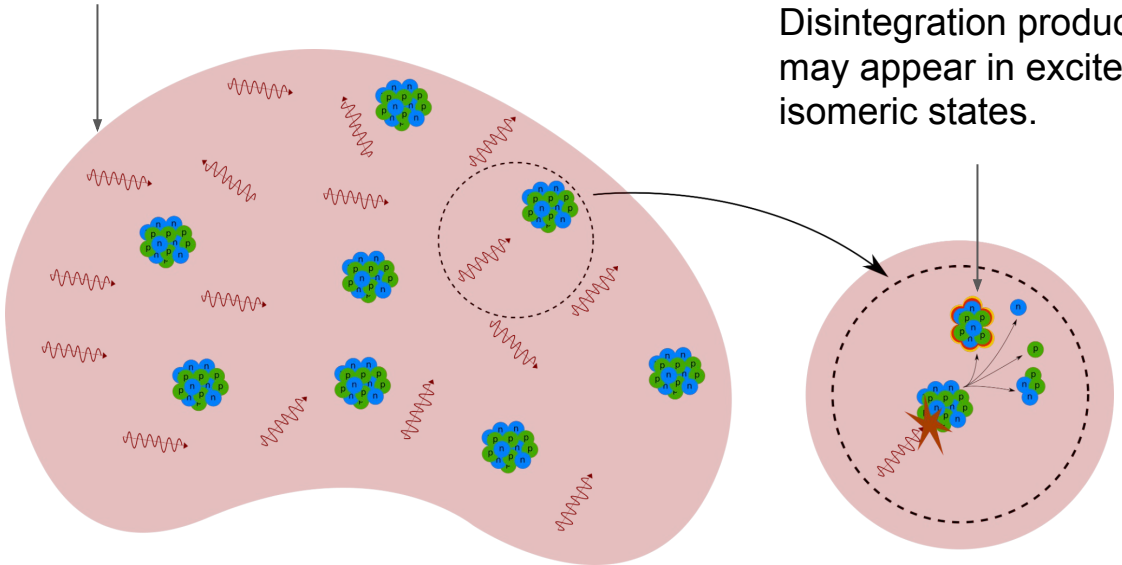
Video here

SED modelling: Isomer production

Video here

Core with high EM density
electrons / positrons
nuclei injected with a power law

Disintegration products
may appear in excited
isomeric states.



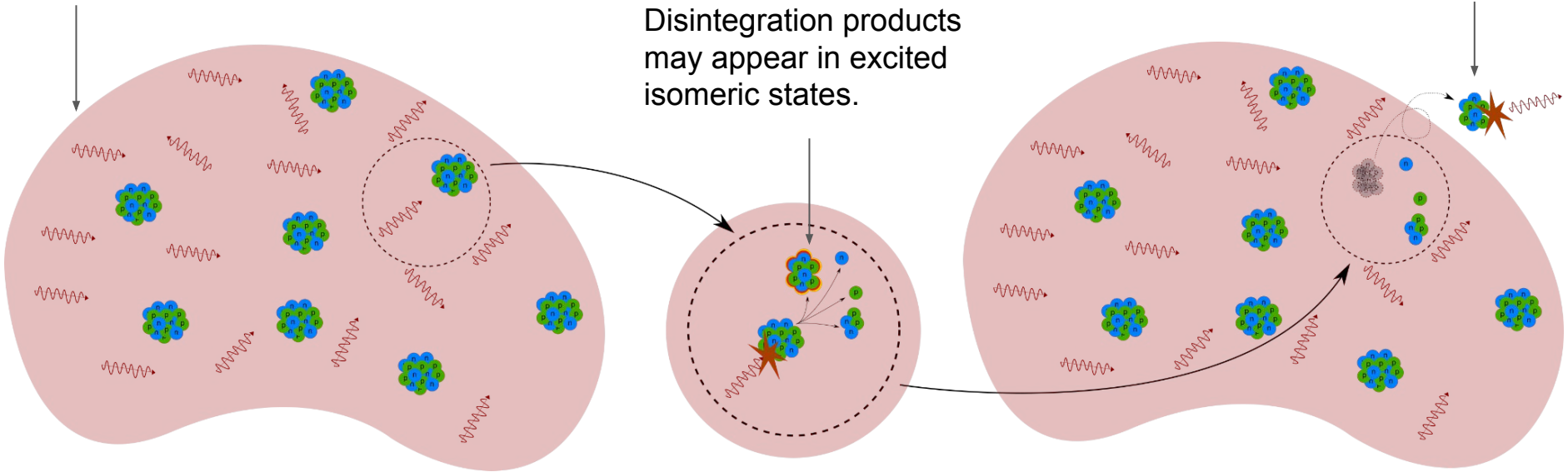
SED modelling: Isomer decay after escape

Video here

Core with high EM density
electrons / positrons
nuclei injected with a power law

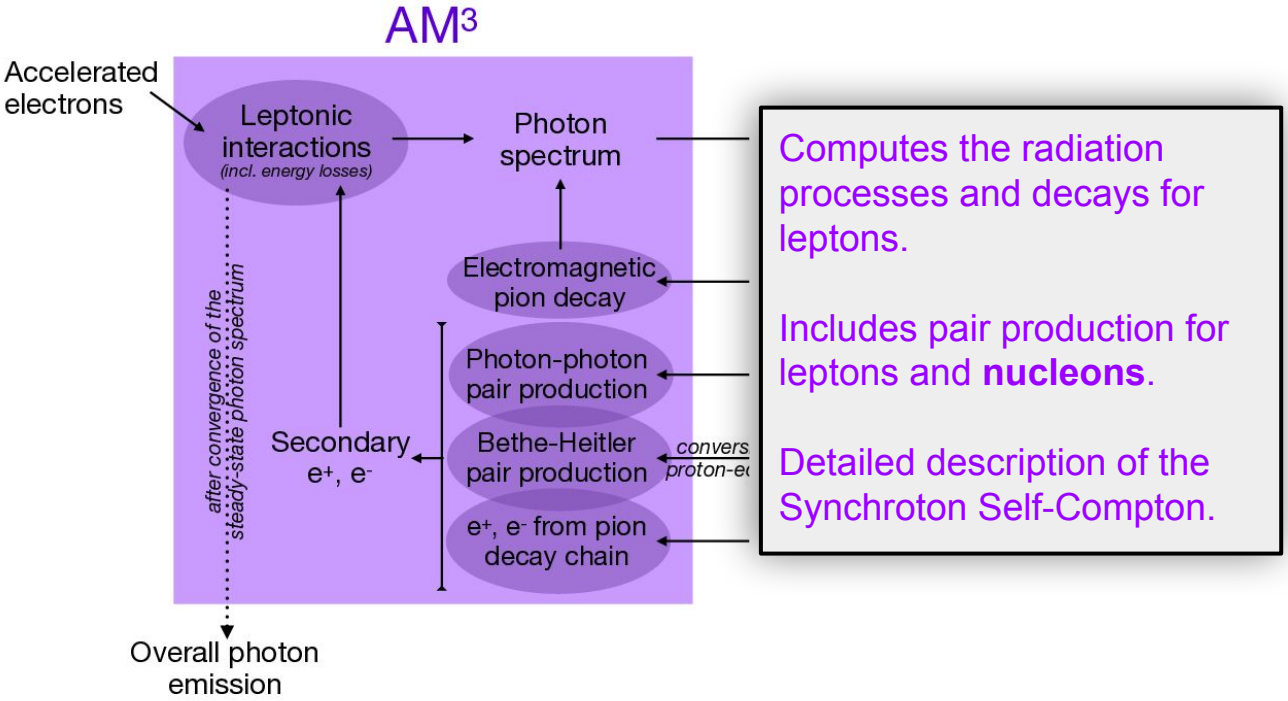
Disintegration products
may appear in excited
isomeric states.

Decay by photon emission after escape
would evade in-source attenuation.



Self-consistent simulation: AM3

Video here



Computes the radiation processes and decays for leptons.

Includes pair production for leptons and **nucleons**.

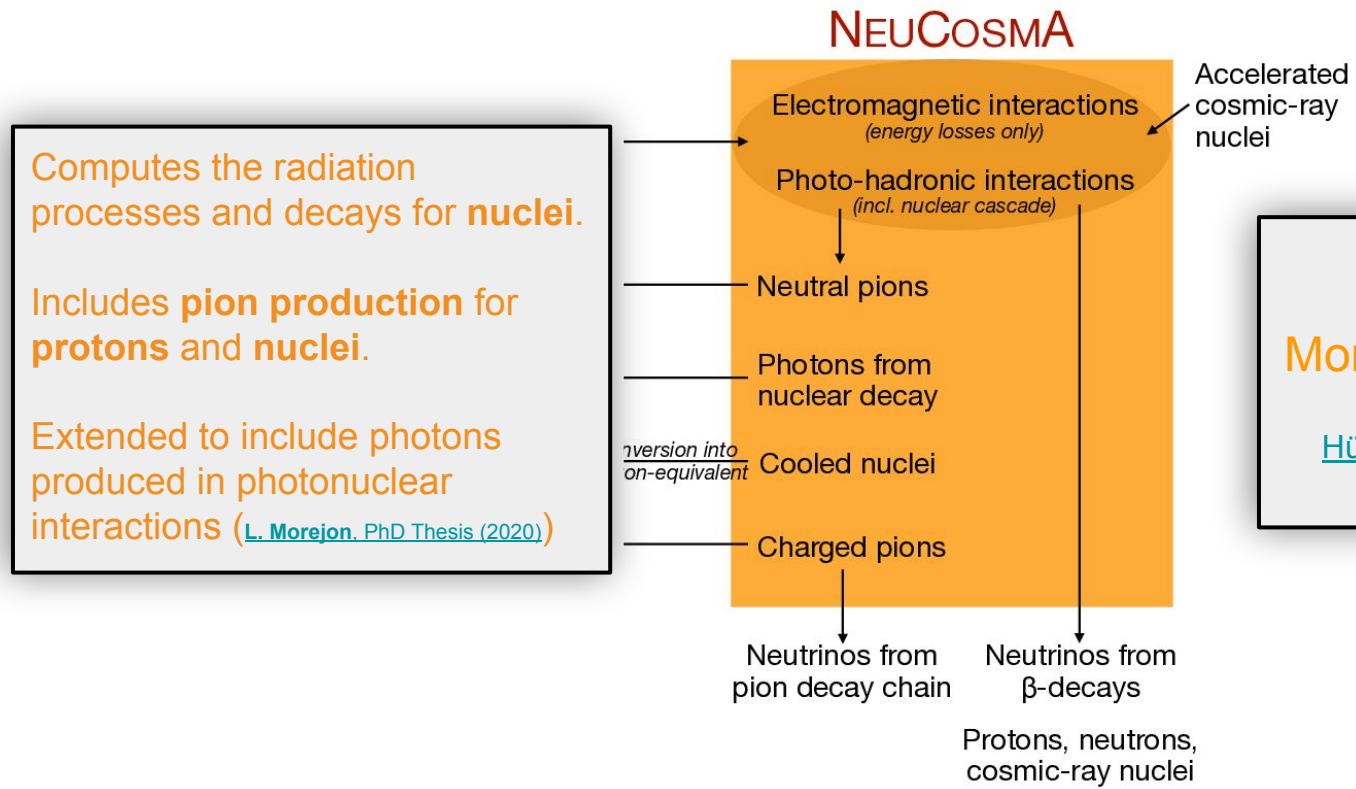
Detailed description of the Synchroton Self-Compton.

More on AM3

Gao,Pohl, Winter, APJ 843 (2017)

Self-consistent simulation: NeuCosmA

Video here



Computes the radiation processes and decays for **nuclei**.

Includes **pion production** for **protons** and **nuclei**.

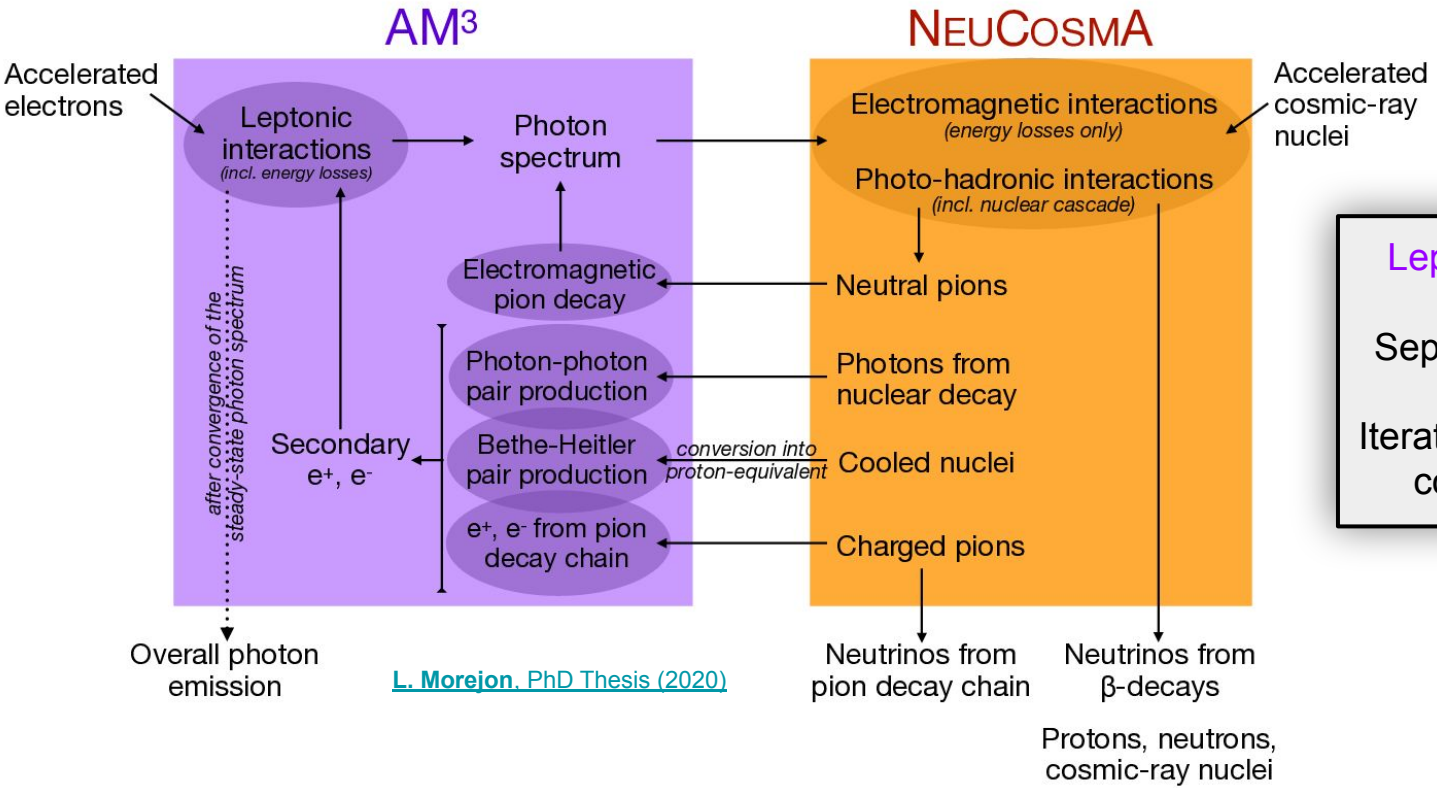
Extended to include photons produced in photonuclear interactions (**L. Morejon**, PhD Thesis (2020))

More on NeuCosmA

Hümmer, Rüger, Spanier, Winter, 2010

Self-consistent simulation: Code coupling

Video here



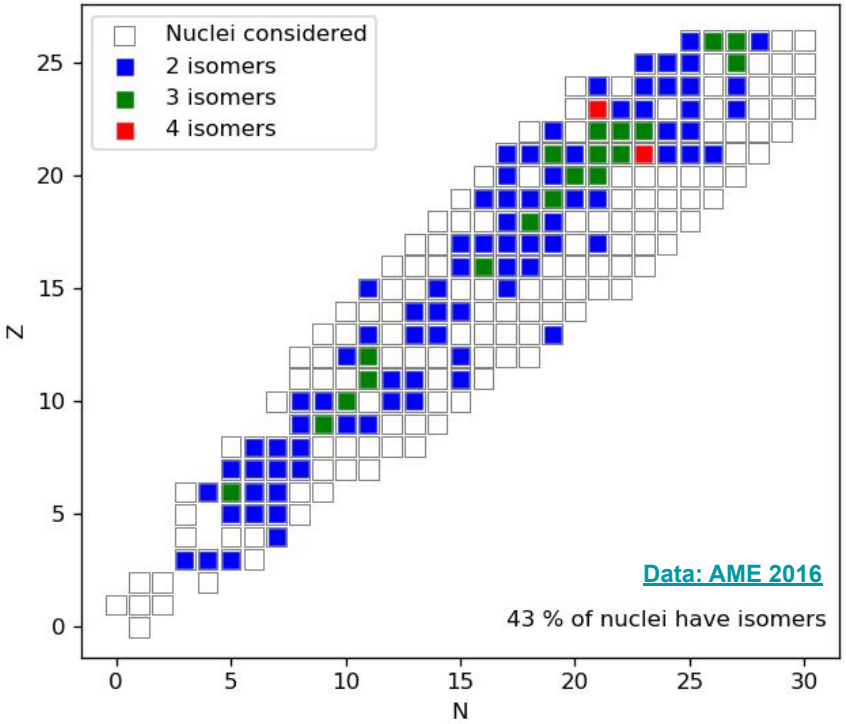
Leptonic ⟷ Hadronic

Separate codes, coupled

Iterative method to reach a convergent solution.

Nuclear isomers: available data

Video here



L. Morejon, *et al.* 2021 (in preparation)

The fraction of luminosity in isomers is estimated by nuclear thermostatistics (microcanonical ensemble).

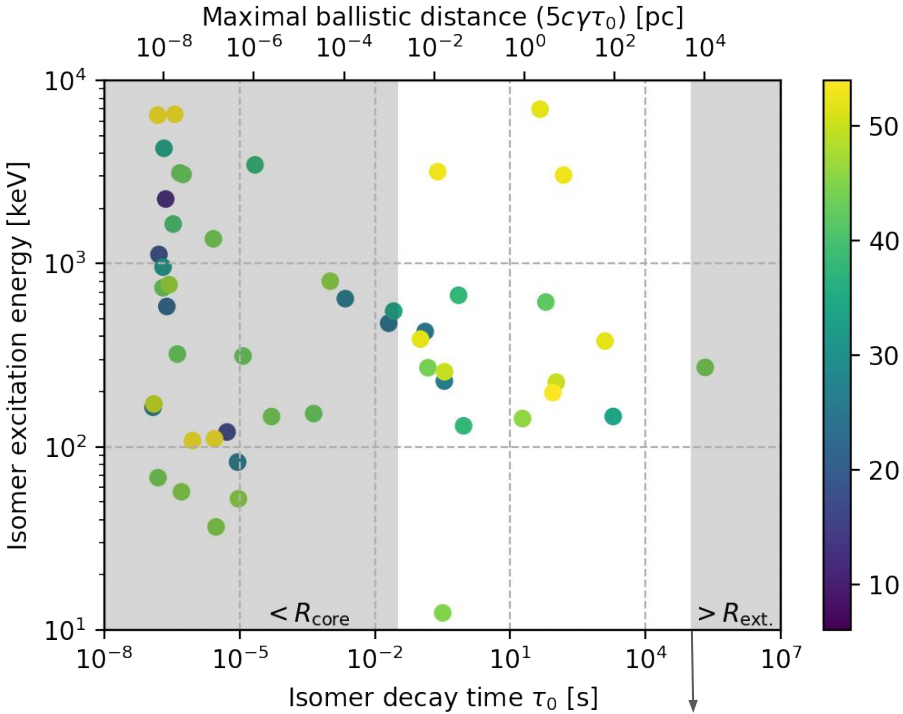
$$\frac{Ln^*}{Ln} \sim \frac{\exp(-Mn^*/kT)}{\exp(-Mn/kT)}$$

Mn*, Mn: mass of isomer, basic state

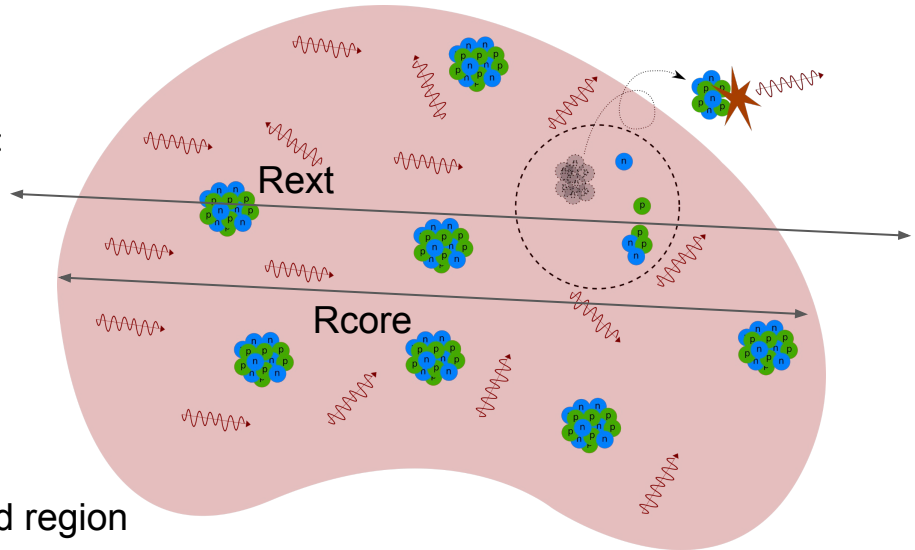
For this work, the nuclear temperature or average excitation employed T=1 MeV

Selection of isomers by decay time

Video here



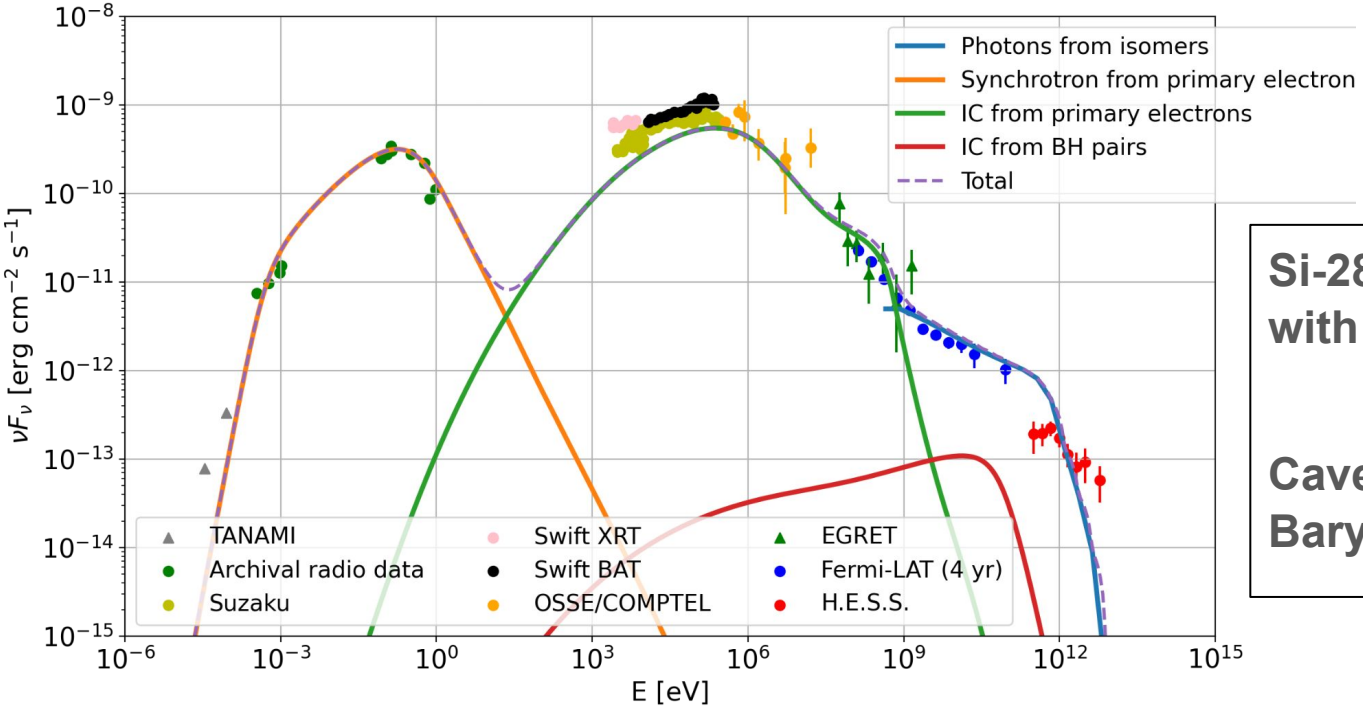
Isomers should live long enough to escape and short enough to decay in the vicinity of the source.



HESS extended region

Cen A emission: core + extended region

Video here

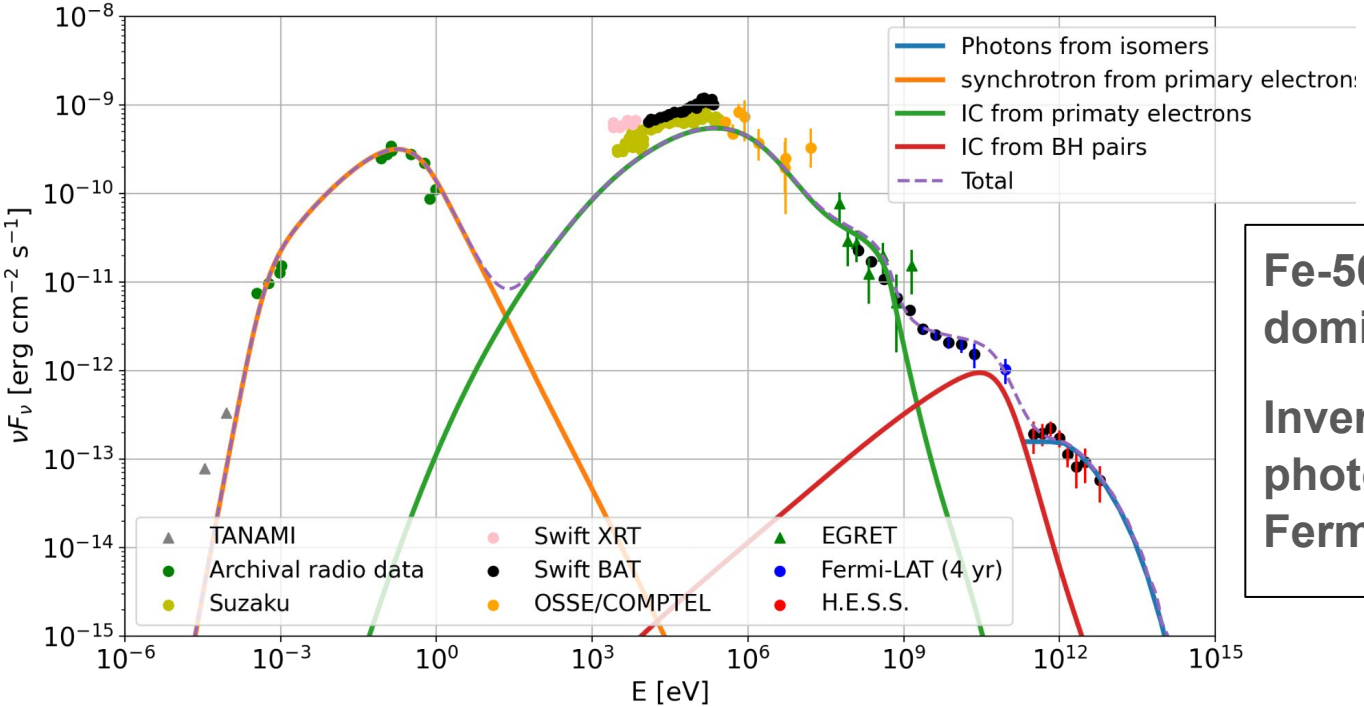


Si-28 injection compatible with Fermi and HESS data.

Caveat:
Baryonic loading ~1E4

Cen A emission: core + extended region

Video here

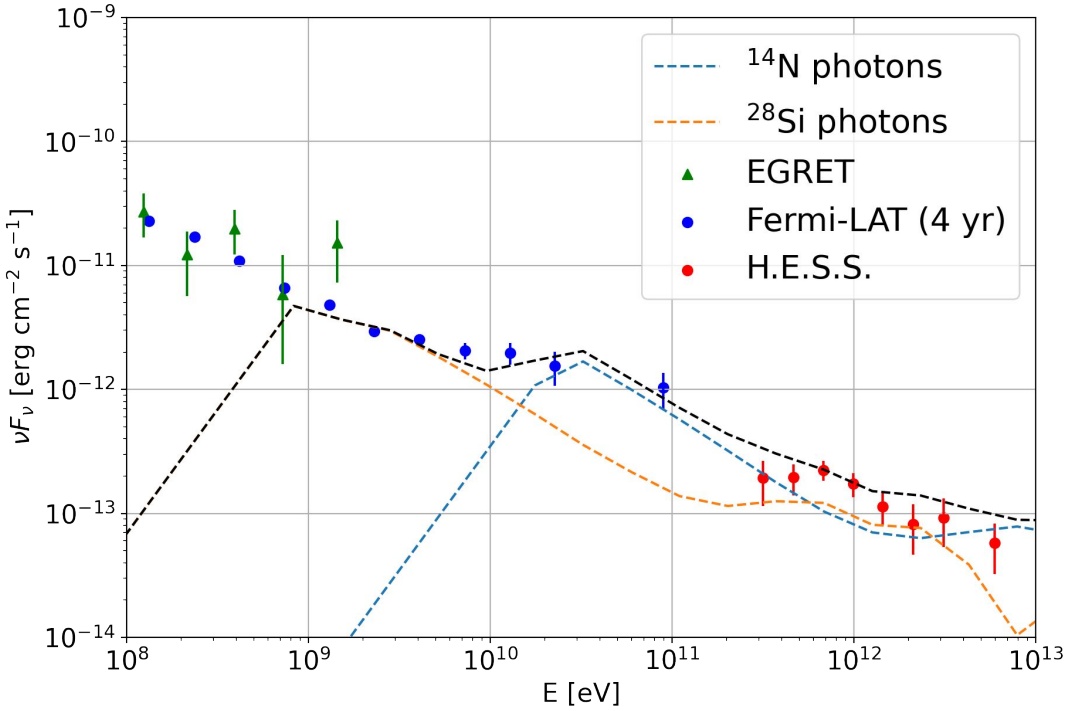


Fe-56 injection, isomers dominate the HESS fluxes.

Inverse Compton by photopairs dominates the Fermi data.

Mixed injection: Nitrogen-14 & Silicon-28

Video here



Lighter nuclei may explain the VHE emissions with lower CR luminosity.

Luminosity fractions in percentage:

- N 32%,
- Si 68%

Conclusions

Video here

- We explored the scenario where TeV emission from the jet of Centaurus A originates in interactions and subsequent decay of CR nuclei heavier
- For that we used a self-consistent numerical model including all nuclear photon emission mechanisms and the full nuclear cascade
- Isomer decay another connection of VHE to cosmic rays

Ongoing work...

- Performing a full parameter scan, improve baryonic loading values
- Looking for mixed injection scenarios
- Paper in preparation

Extra slides…..

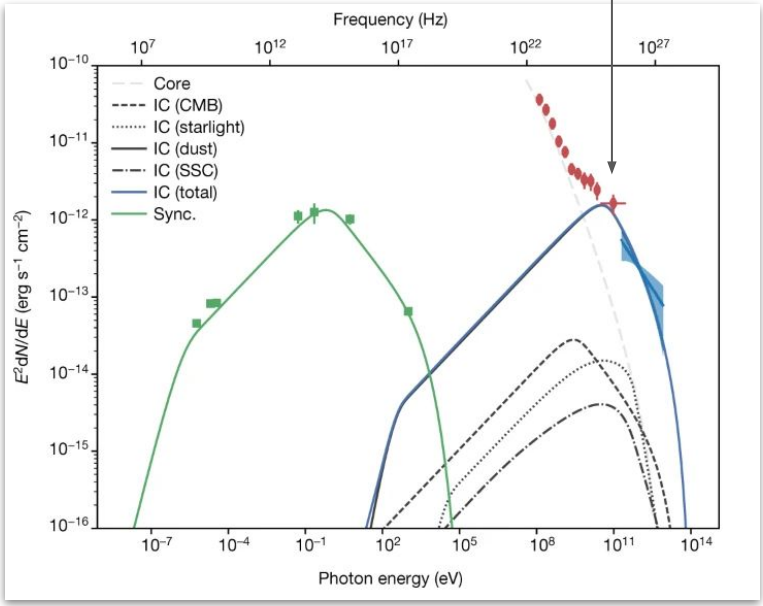
Video here

VHE from Cen A: Possible hadronic origin?

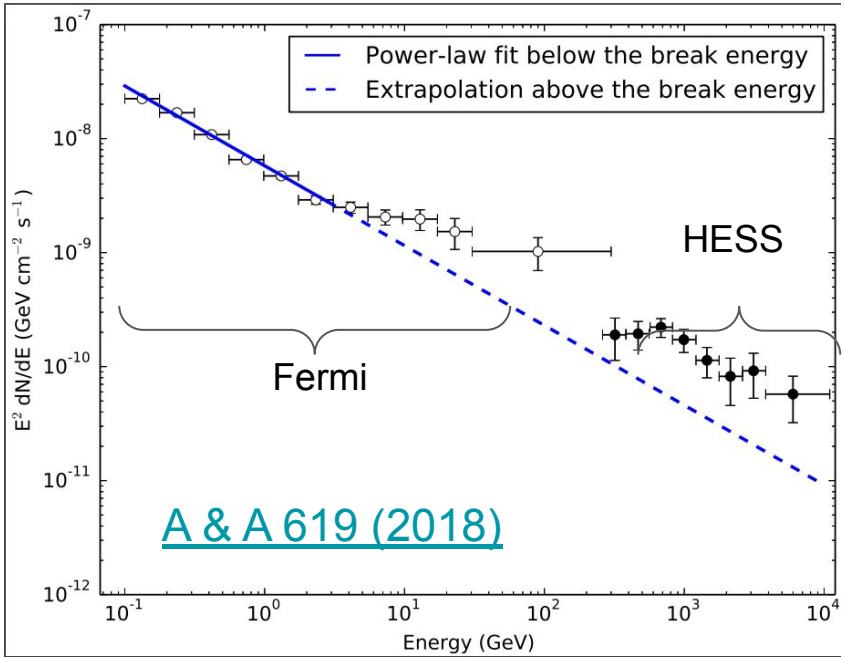
Video here

Extended emission reported. Suggested Leptonic Inverse-Compton to explain **TeV emission**.

Nature volume 582, pages 356–359 (2020)

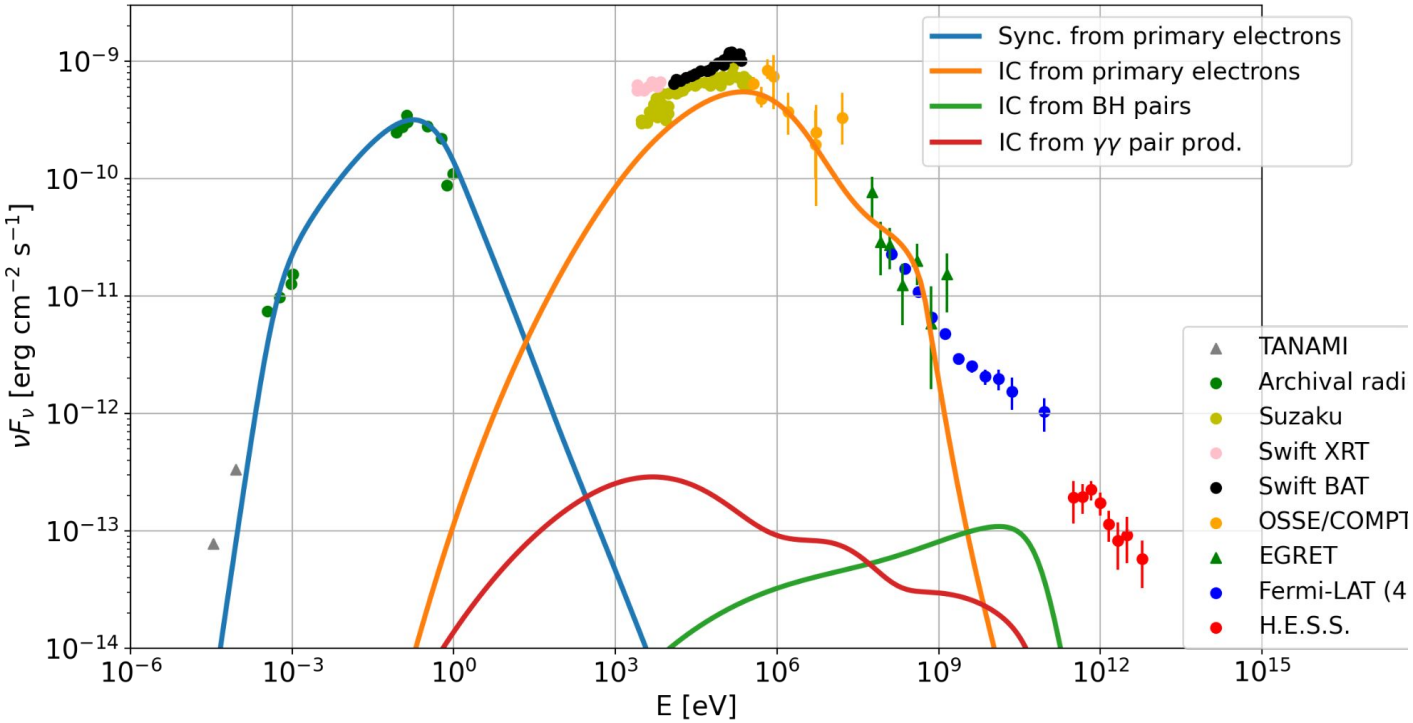


Above TeV emission reported from the core..



Small coupling electrons-nuclei: convergence

Video here



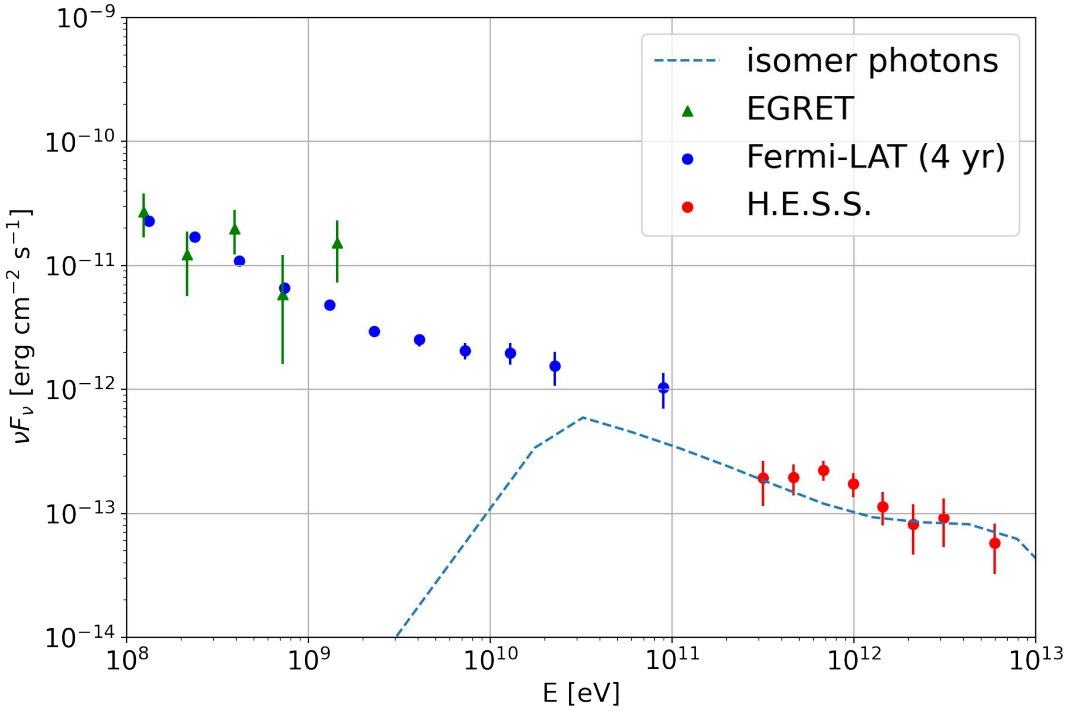
In this example, nuclear Bethe-Heitler, photon - photon annihilation, are subdominant.

Parameters in figure:

- Lum. Dist: 3.4 Mpc
- B : 10 G
- Rcore : 1.2E15 cm
- Le : 6.8 E 42 erg/s
- Index elect. : 3.3
- Min. lorentz e : 1.3E3
- Max. lorentz e : 1.E6

Single nucleus injection: Nitrogen-14

Video here



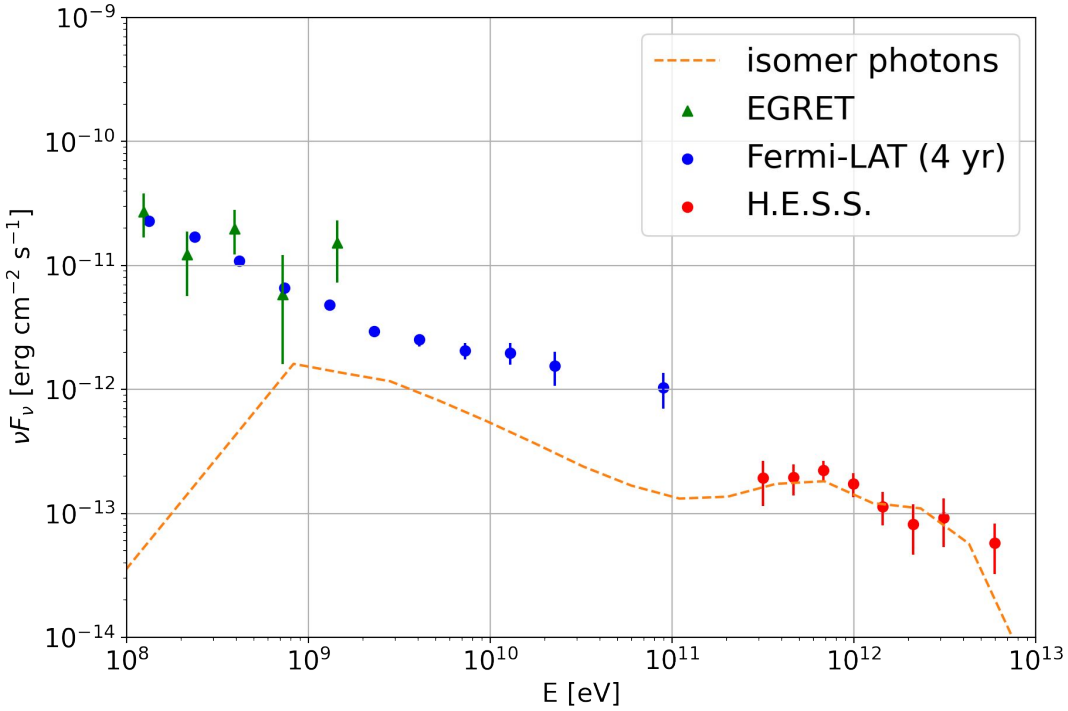
Lighter nuclei may explain the VHE emissions with less luminosity.

Injection parameters:

- Emax: 27 PeV
- Index: 1.8
- Loading (Ln/Le): 1E5

Single nucleus injection: Silicon-28

Video here



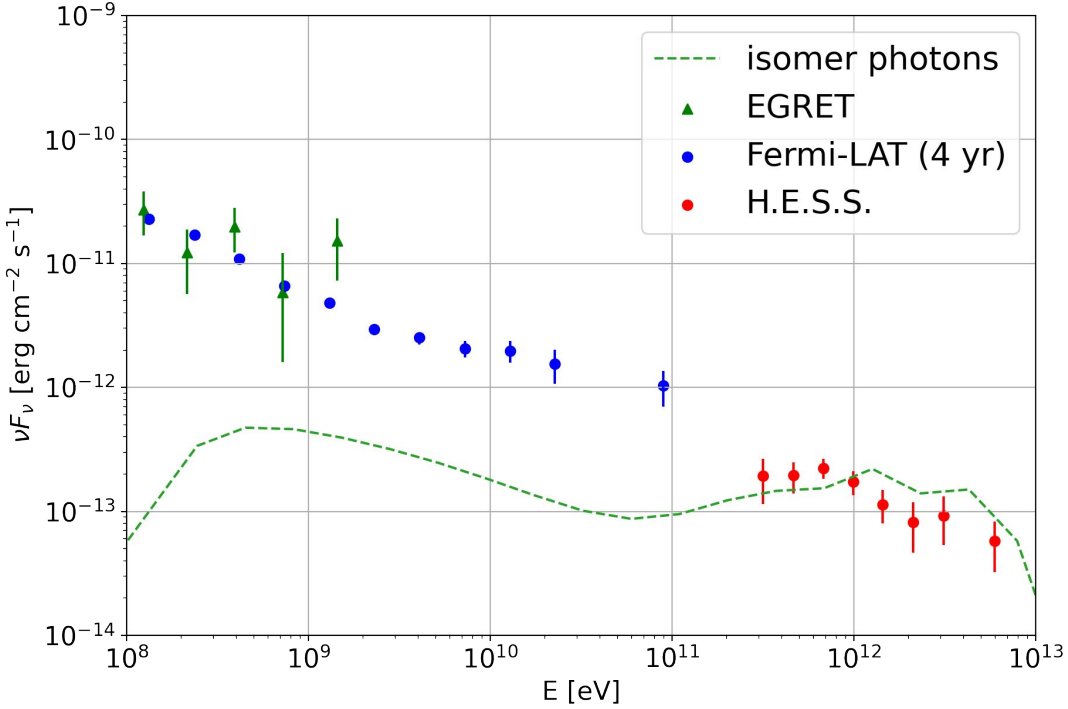
The Fermi data is under. Likely, indication of mixed injection.

Injection parameters:

- Emax: 214 PeV
- Index: 1.8
- Loading (Ln/Le): 6E4

Single nucleus injection: Calcium-40

Video here



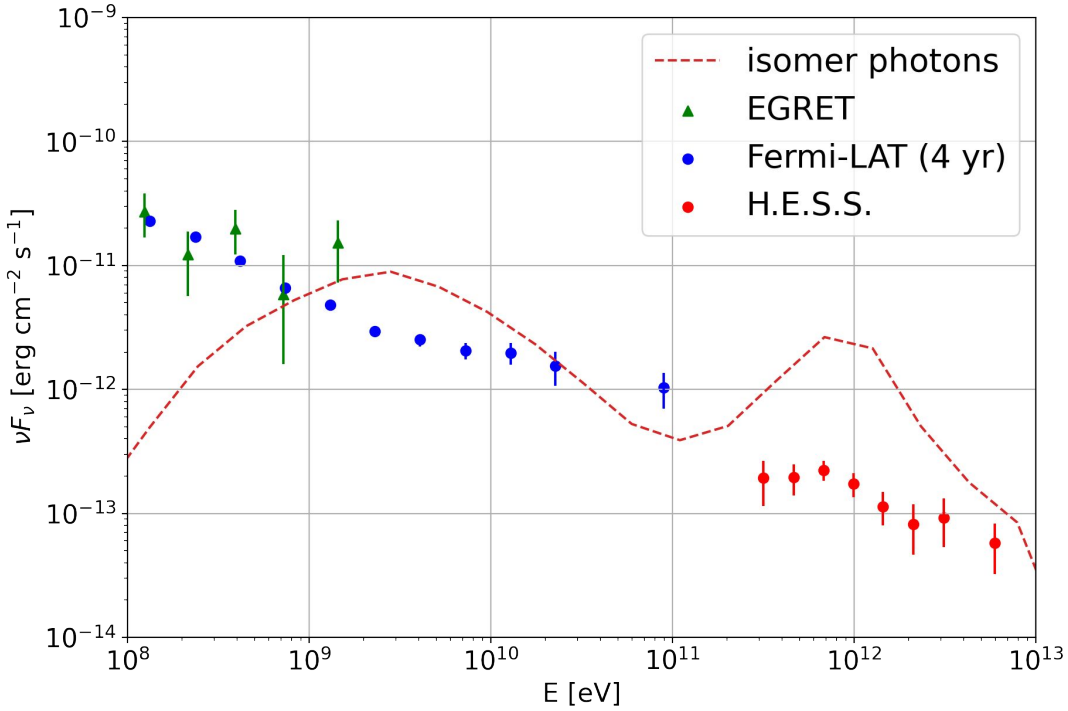
The resulting shape is incompatible with data. Likely, indication of mixed injection.

Injection parameters:

- Emax: 214 PeV
- Index: 1.8
- Loading (Ln/Le): 9E4

Single nucleus injection: Iron-56

Video here



Iron injection is very inefficient compared to lighter nuclei. The luminosity needed is too large.

Injection parameters:

- Emax: 190 PeV
- index: 3.08
- Loading Ln/Le: 4E11