

Microquasars: the nearest black hole particle accelerators

black hole

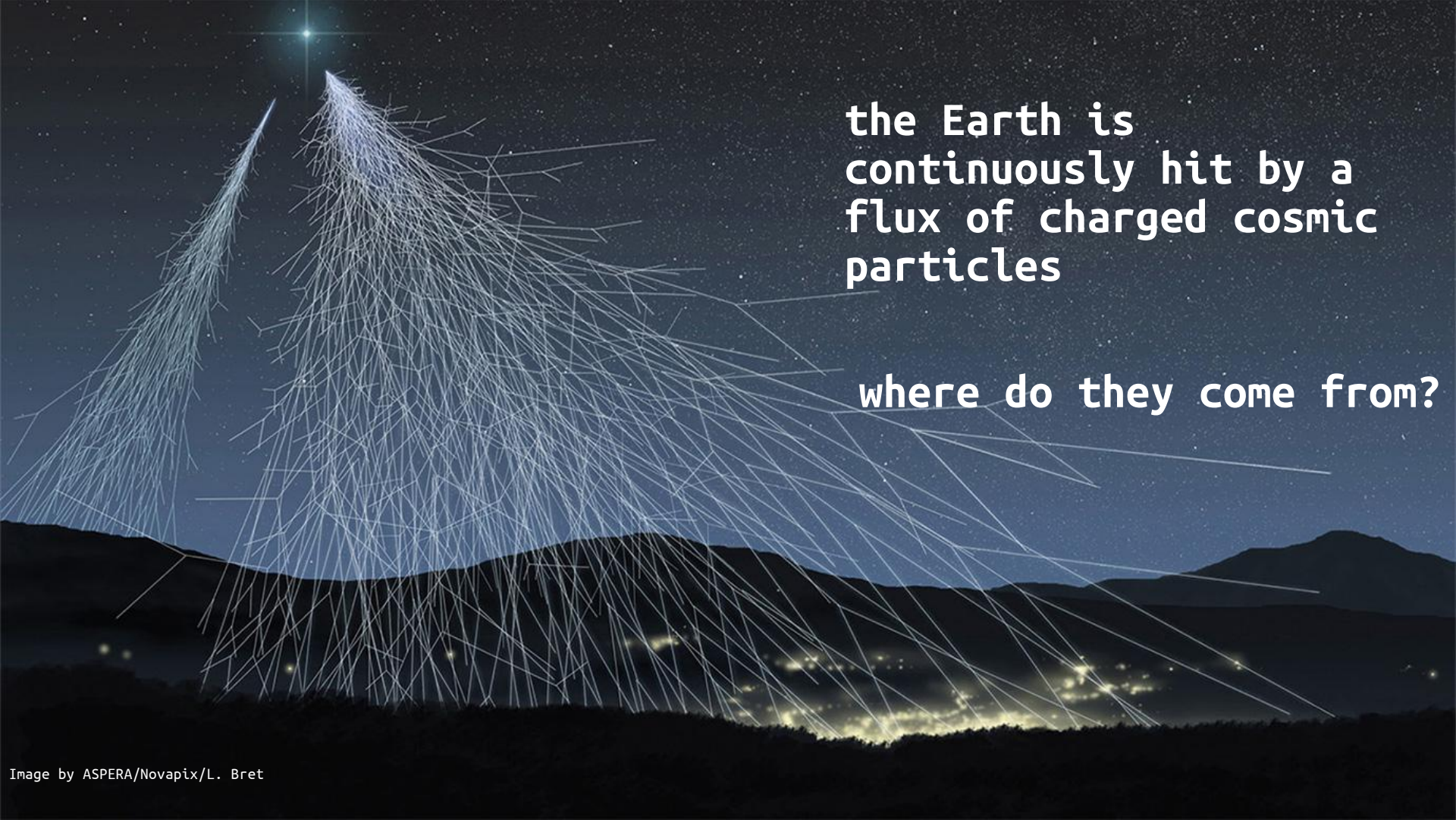
type A supergiant

CDY Seminar

October 30th 2024

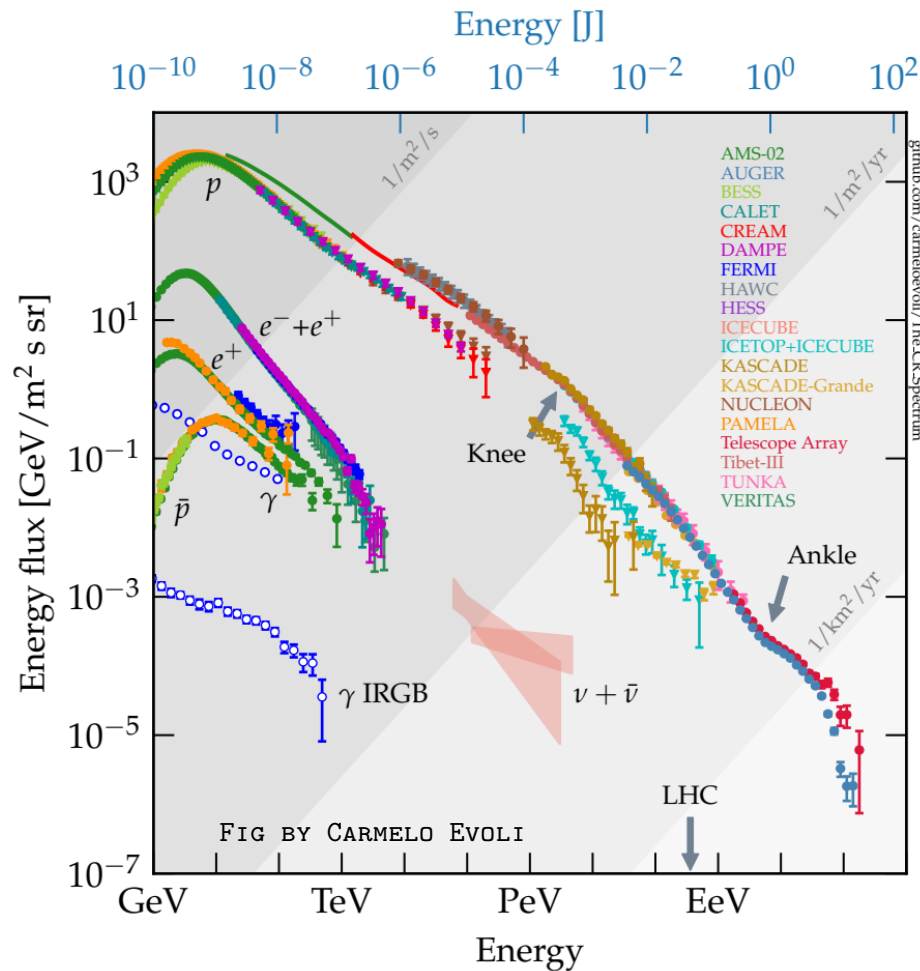
Laura Olivera-Nieto



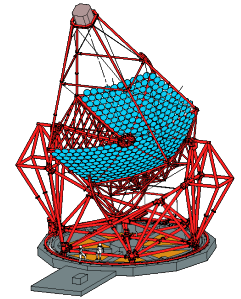
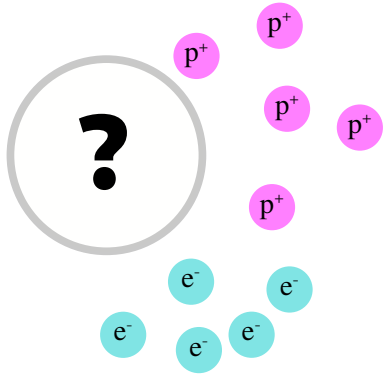
A night sky with a star and a shower of white lines representing cosmic rays hitting the Earth's surface. The lines are concentrated in two main areas, one on the left and one in the center, and spread out towards the horizon. The background is a dark blue night sky with stars. The foreground shows a dark silhouette of a landscape with hills and some distant lights.

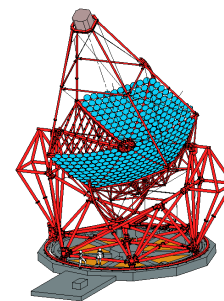
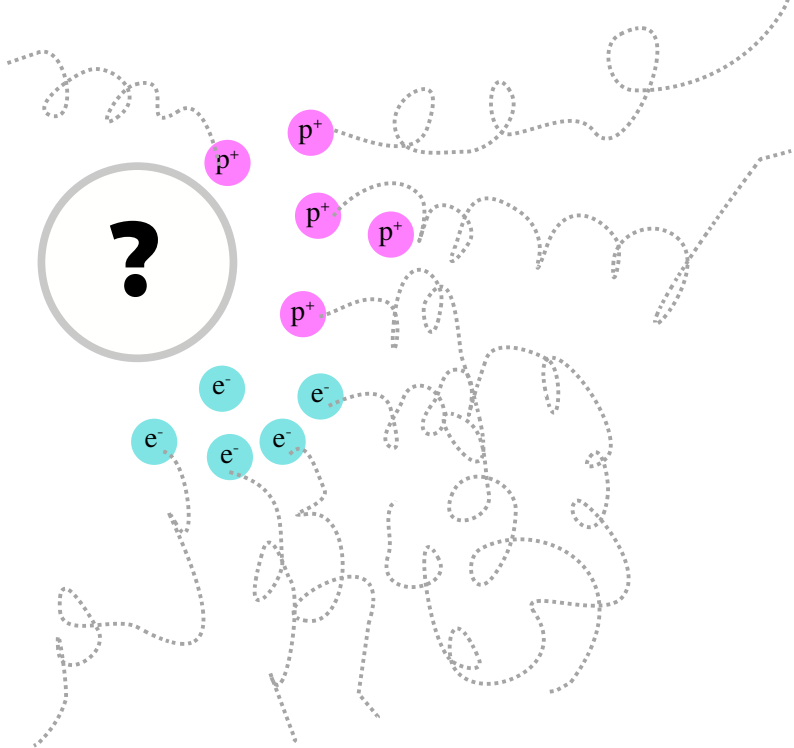
the Earth is
continuously hit by a
flux of charged cosmic
particles

where do they come from?

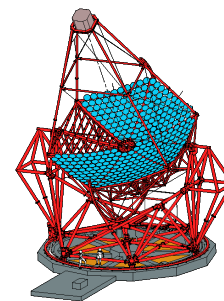
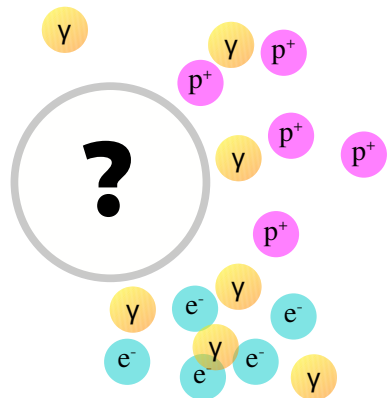


- FLUX OF CHARGED PARTICLES CONSTANTLY ARRIVING TO EARTH FROM THE UNIVERSE.
- REACHES EXTREMELY HIGH ENERGIES.
- WHERE AND HOW ARE THEY ACCELERATED?

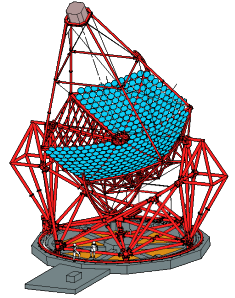
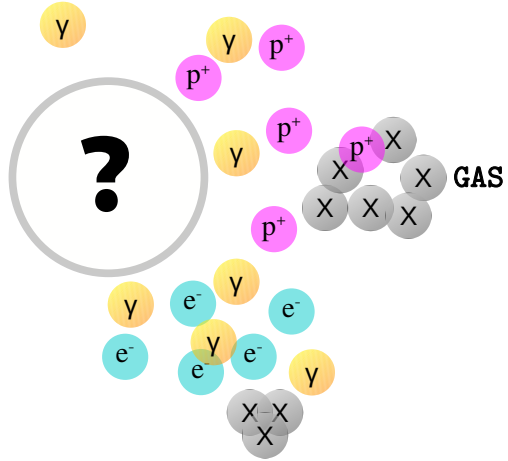




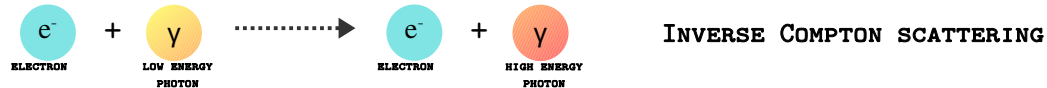
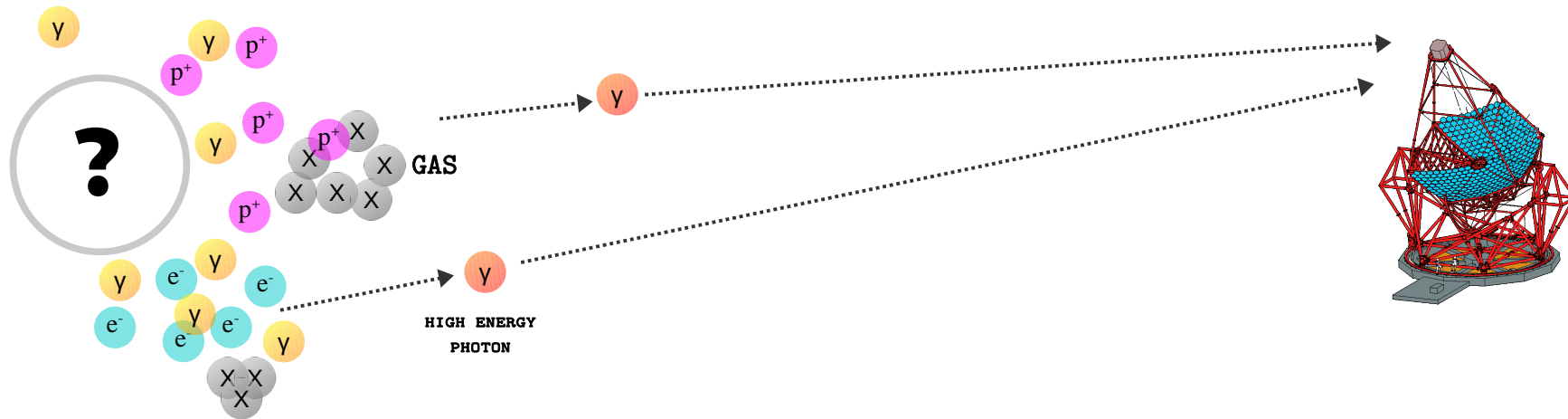
LOW ENERGY
PHOTONS



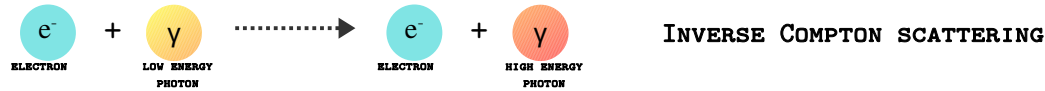
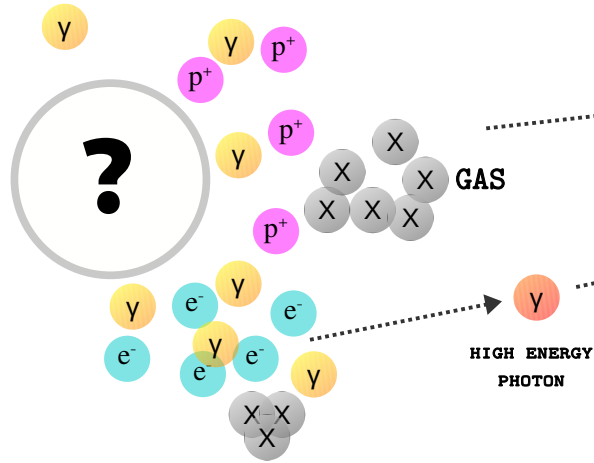
LOW ENERGY
PHOTONS



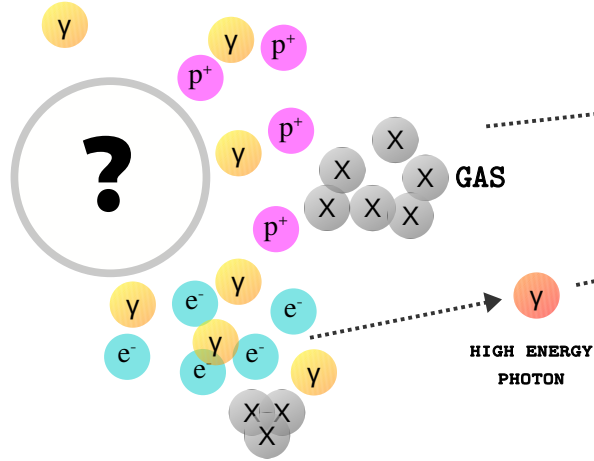
LOW ENERGY
PHOTONS



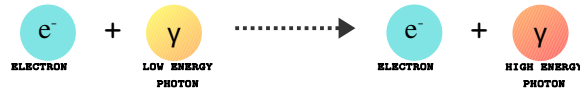
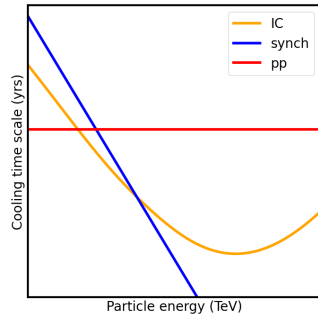
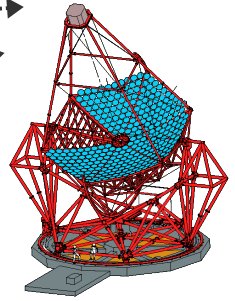
LOW ENERGY
PHOTONS



LOW ENERGY
PHOTONS

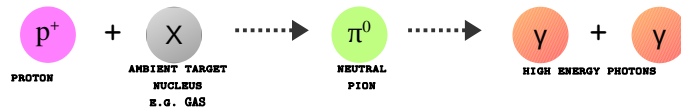


HIGH ENERGY
PHOTON



INVERSE COMPTON SCATTERING

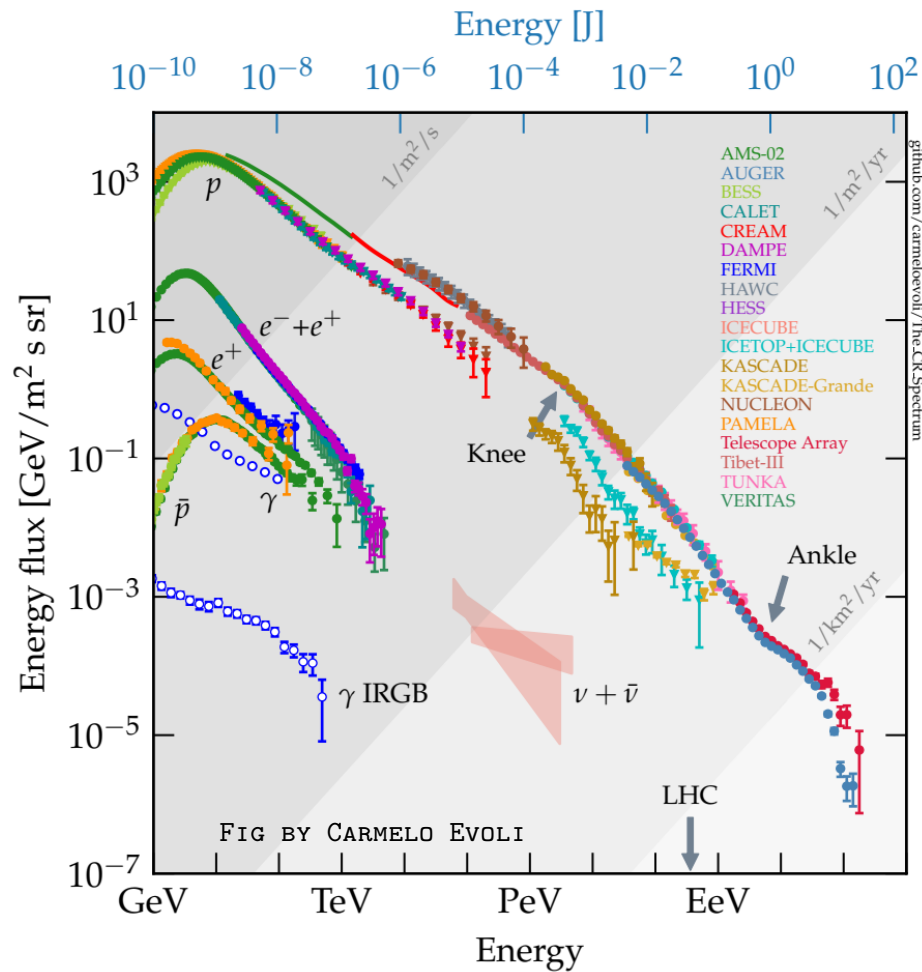
$$E_{\text{GAMMA}} \sim 0.4 E_{\text{ELECTRON}}^{1.3}$$

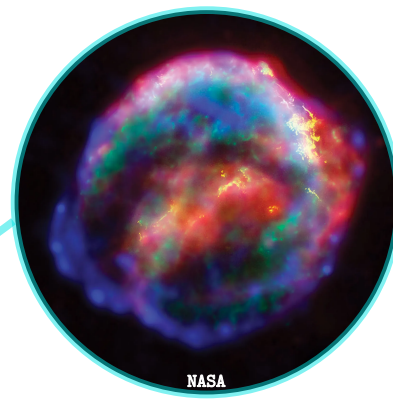
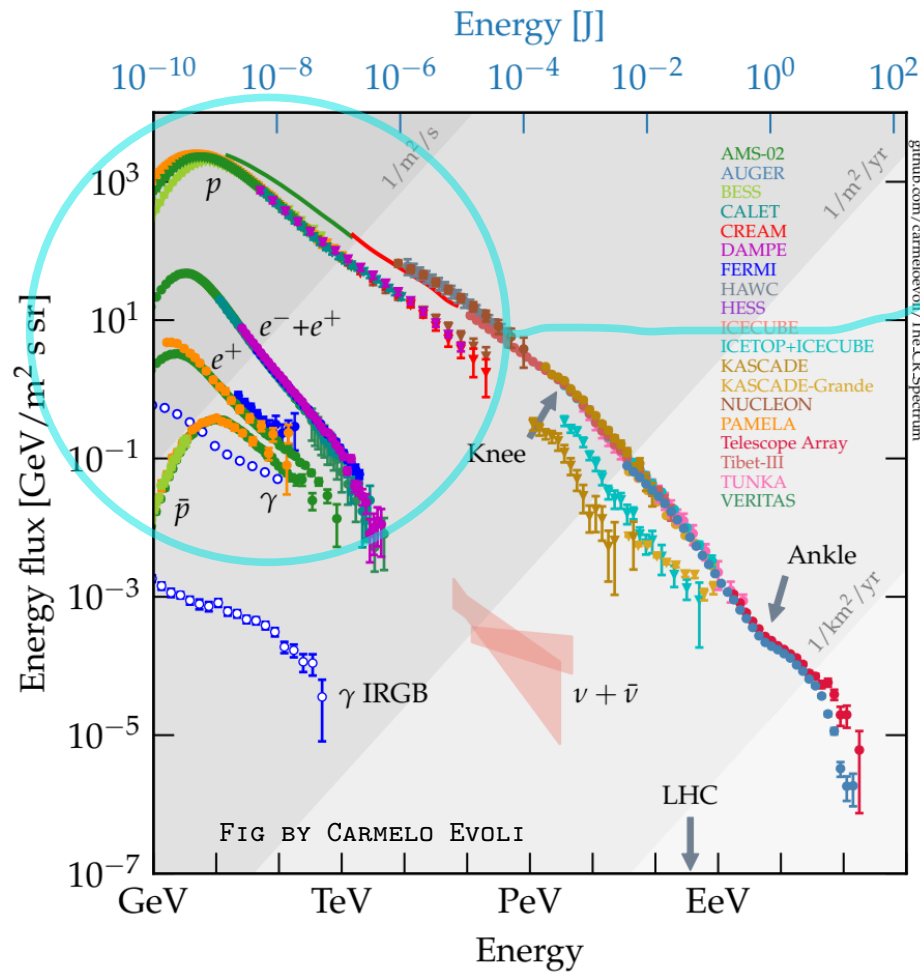


PP INTERACTIONS

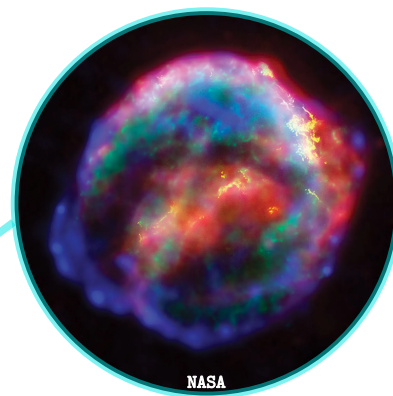
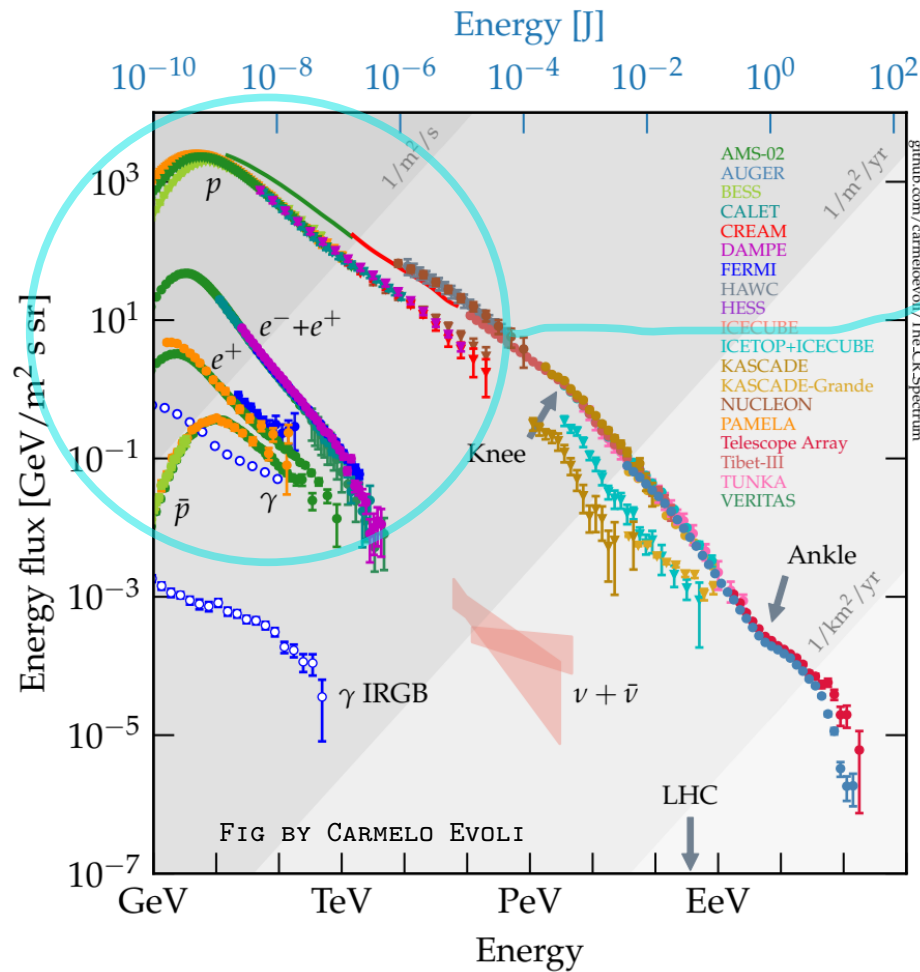
$$E_{\text{GAMMA}} \sim 0.1 E_{\text{PROTON}}$$



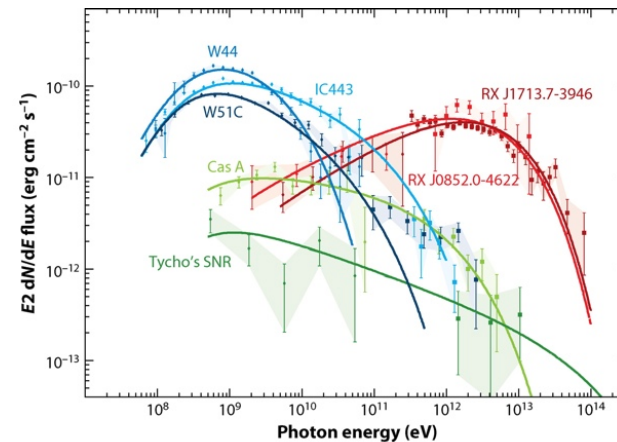




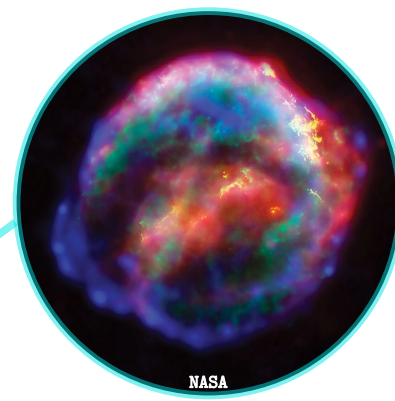
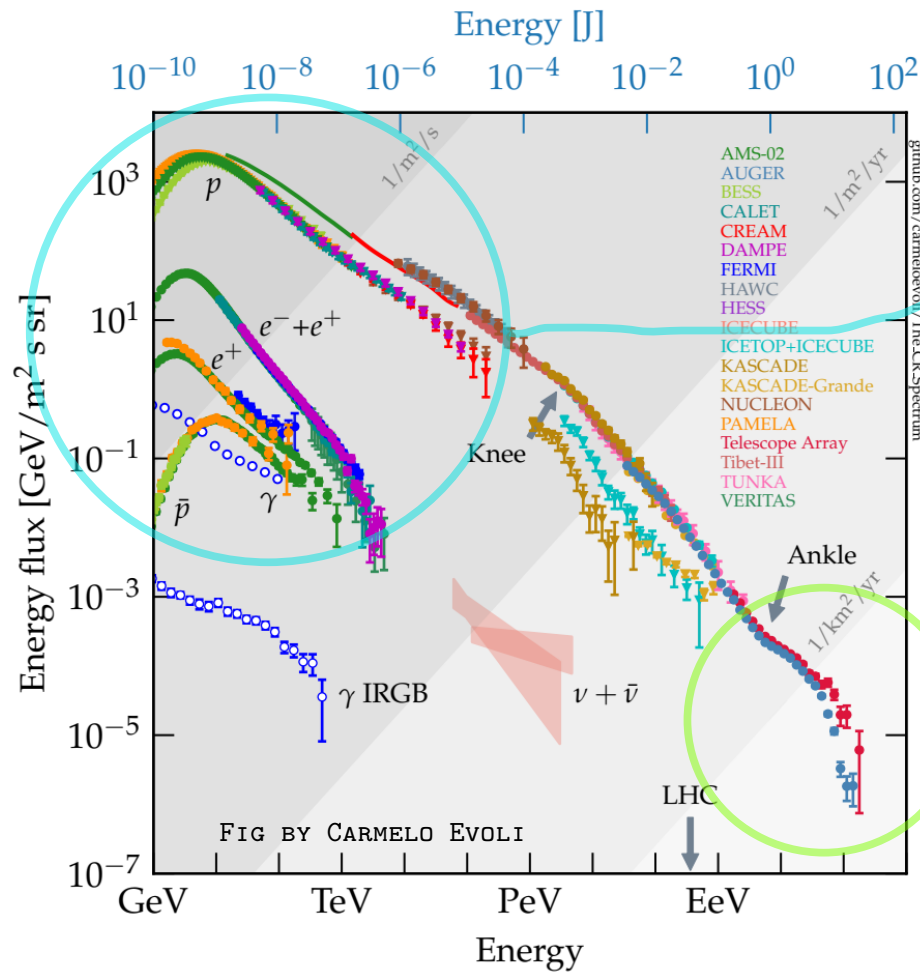
SUPERNOVA
REMNANTS



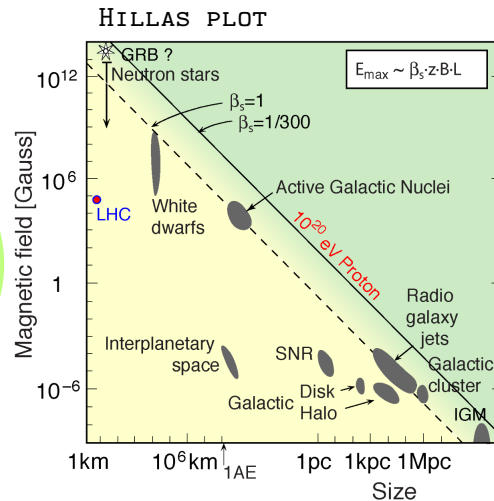
SUPERNOVA
REMNANTS



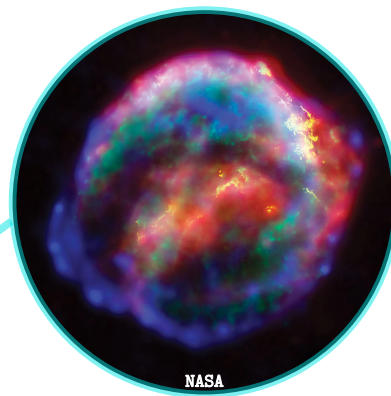
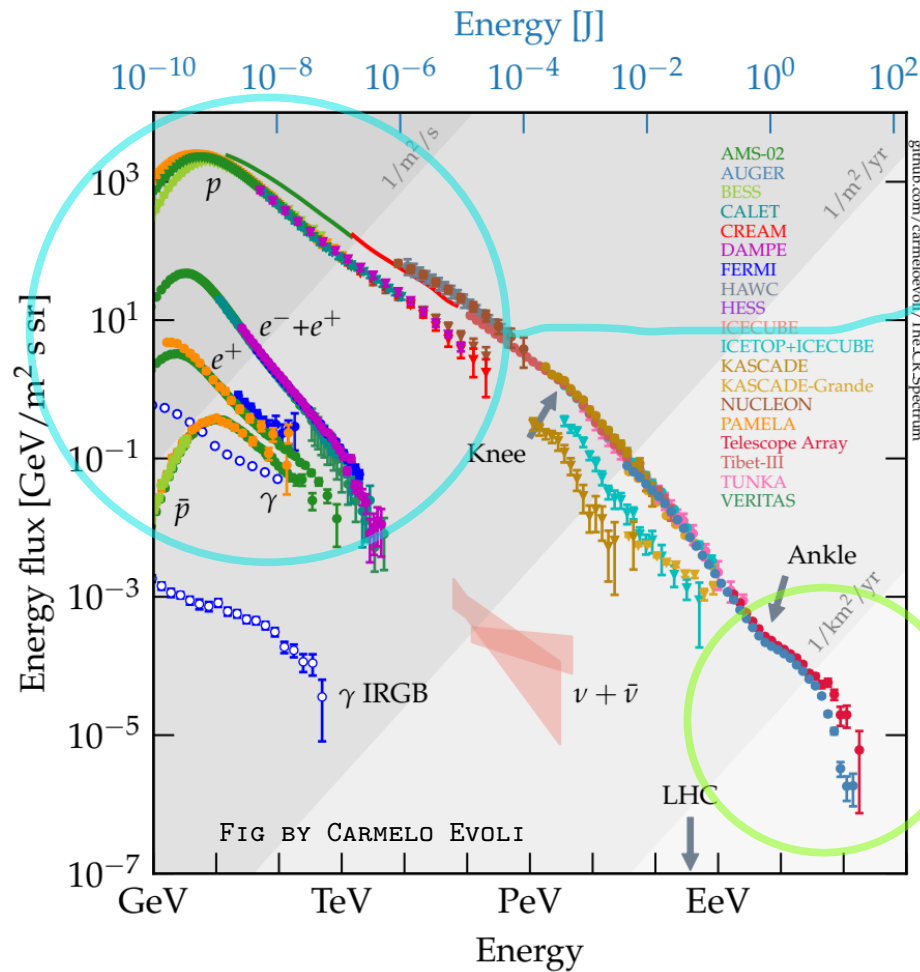
 Funk S. 2015.
Annu. Rev. Nucl. Part. Sci. 65:245–77



SUPERNOVA
REMNANTS



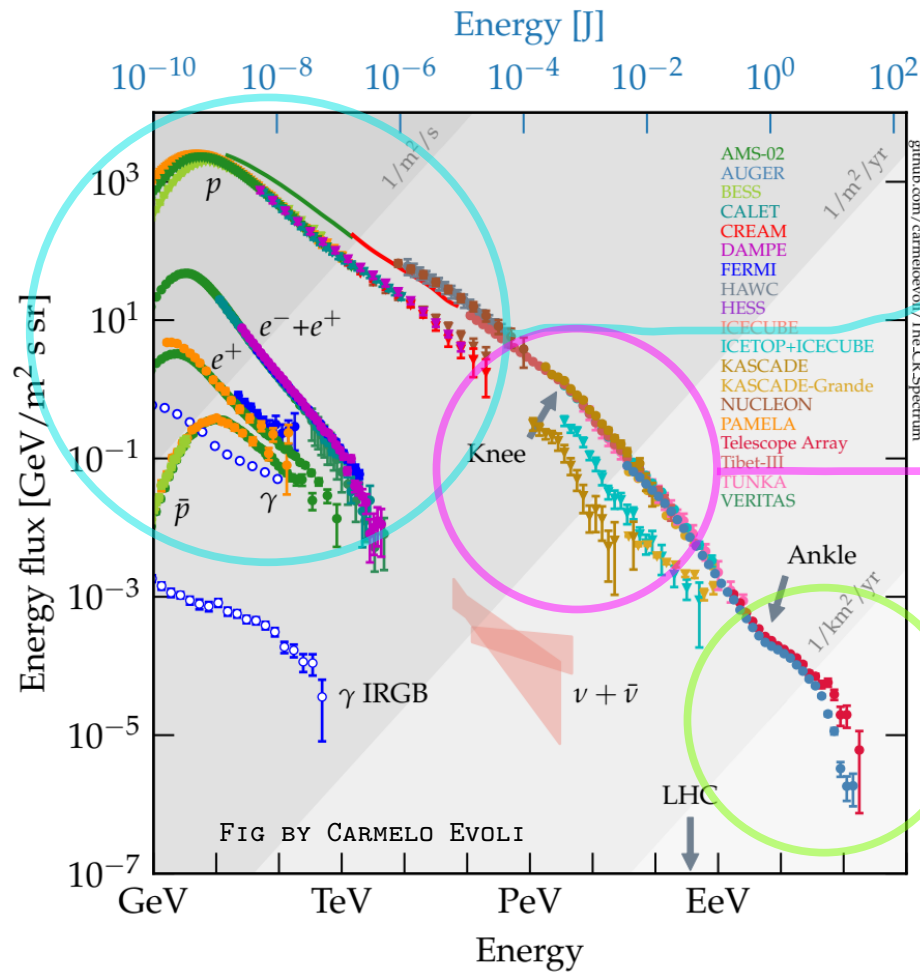
IN ORDER TO
ACCELERATE
PARTICLES, YOU
NEED TO KEEP
THEM CONFINED!



SUPERNOVA
REMNANTS



SOURCES OUTSIDE
OUR GALAXY



SUPERNOVA
REMNANTS



SOURCES OUTSIDE
OUR GALAXY

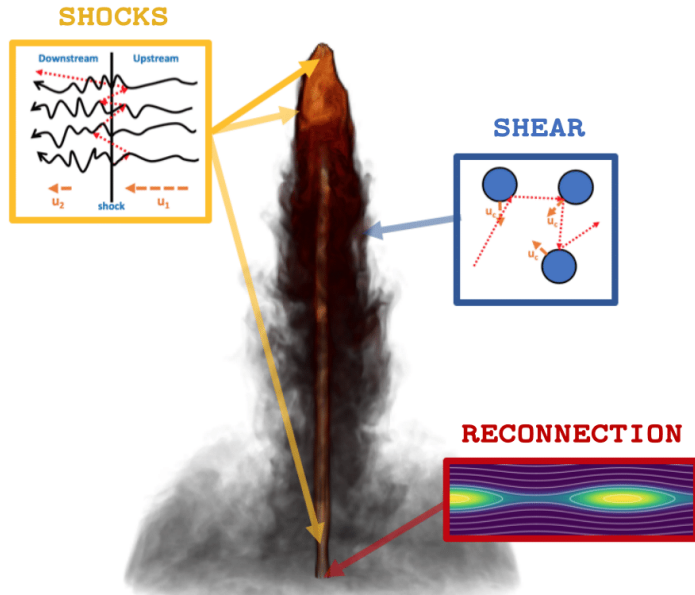
ASTROPHYSICAL JETS



CENTAURUS A: THE NEAREST ACTIVE
GALACTIC NUCLEUS

- ▶ FAST OUTFLOWS OF PLASMA MOVING AT RELATIVISTIC SPEEDS.
- ▶ ORIGINATE DUE TO ACCRETION OF MATTER ONTO A BLACK HOLE.
- ▶ PERFECT CANDIDATE FOR ACCELERATION OF PARTICLES TO THE HIGHEST ENERGIES: POWERFUL ENOUGH, LARGE ENOUGH.
- ▶ BUT HOW DOES THIS ACCELERATION HAPPEN EXACTLY?

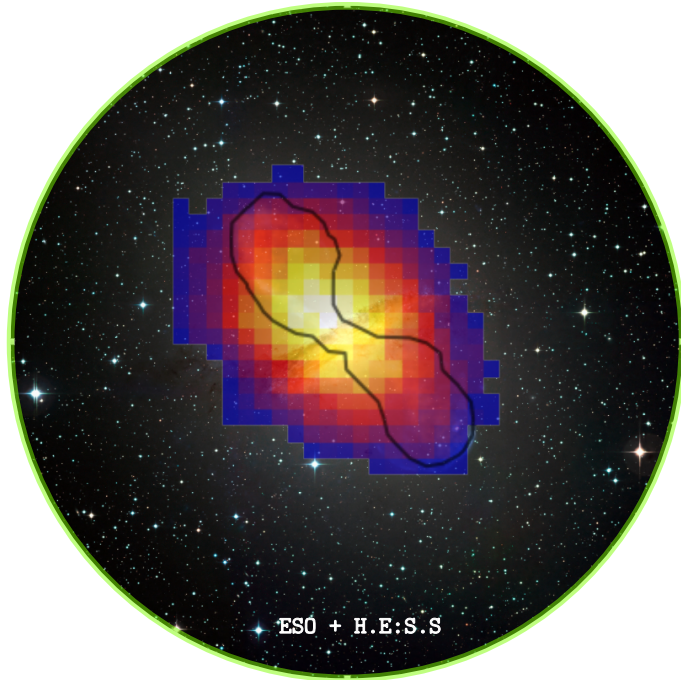
ASTROPHYSICAL JETS



(SOME) POSSIBLE MECHANISMS FOR
PARTICLE ACCELERATION IN JETS
MATTHEWS ET AL 2020

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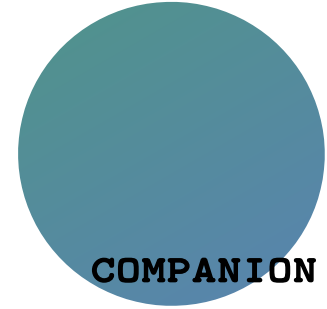
MEET MICROQUASARS

STELLAR MASS
BLACK HOLE



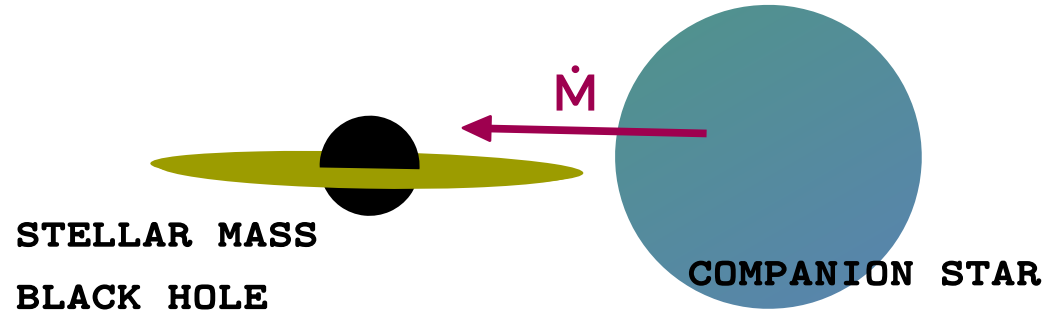
MEET MICROQUASARS

**STELLAR MASS
BLACK HOLE**

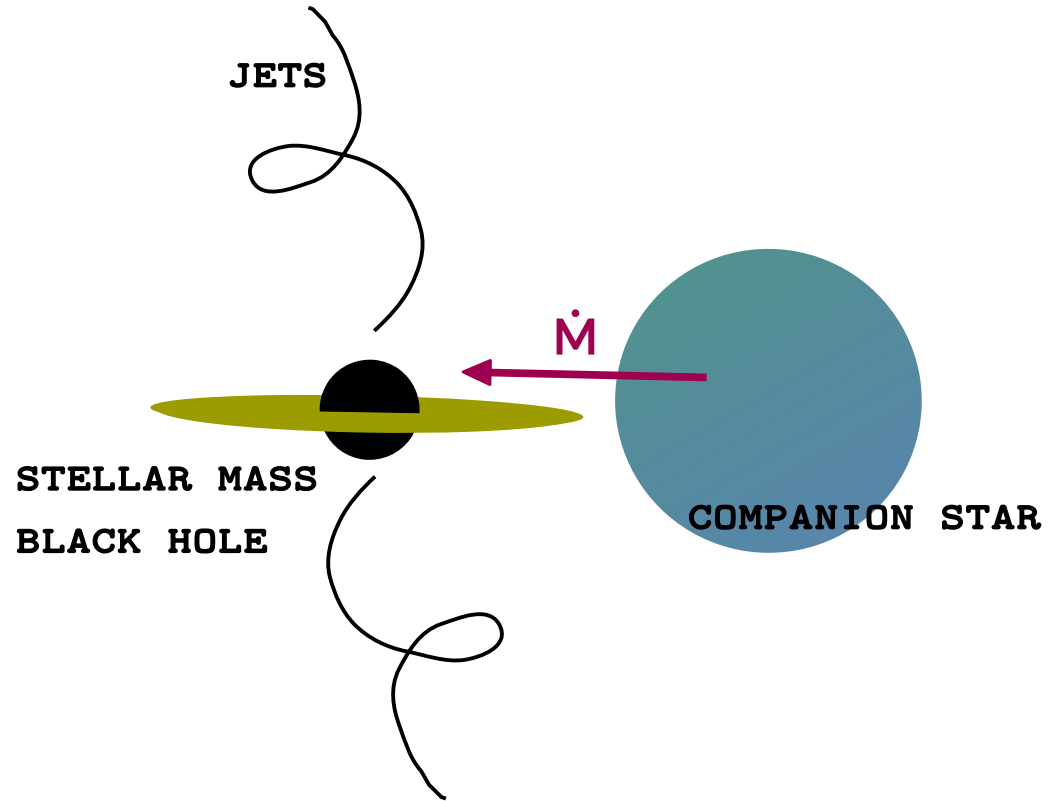


COMPANION STAR

MEET MICROQUASARS

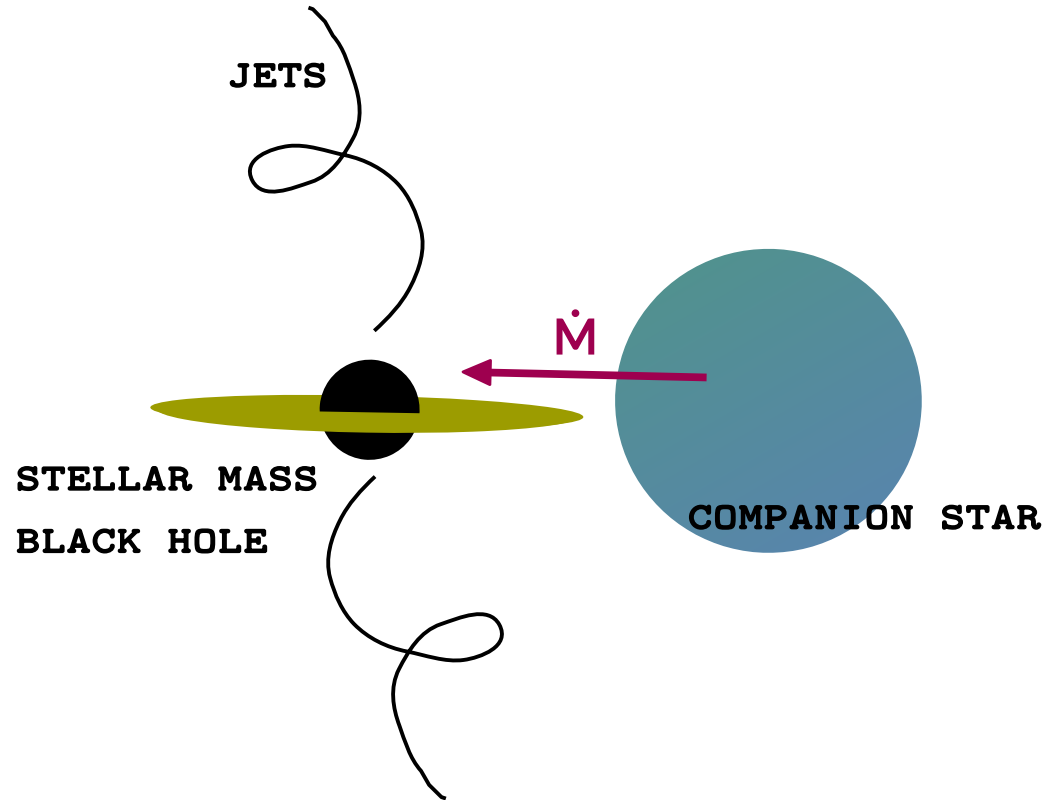


MEET MICROQUASARS



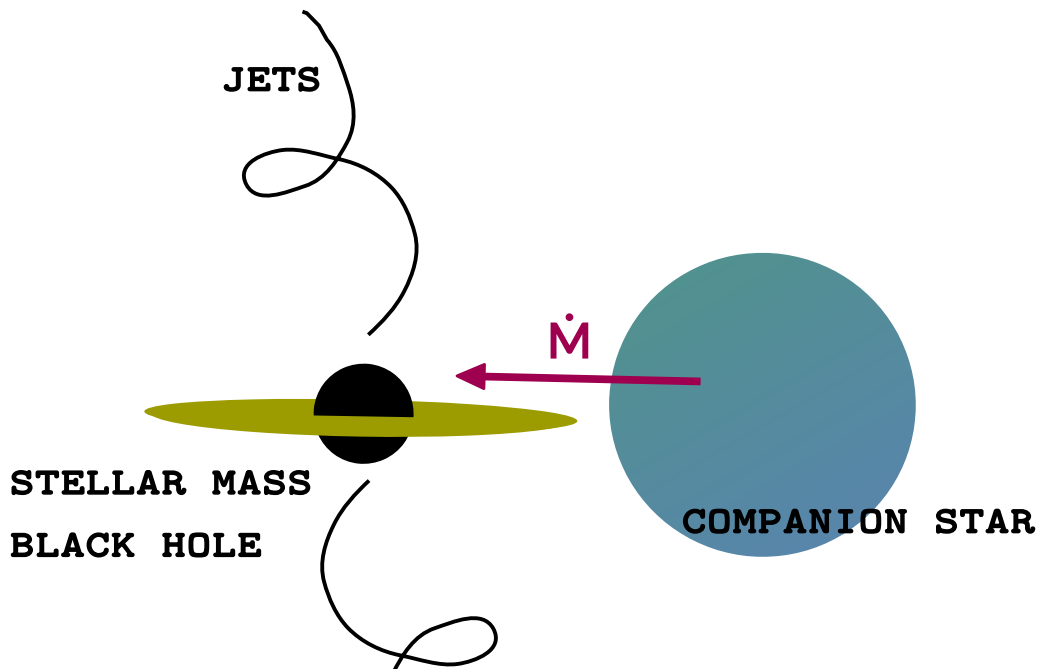
MEET MICROQUASARS

- ▶ INSIDE OUR GALAXY: CLOSER TO EARTH!
- ▶ MUCH LESS POWERFUL THAN AGN:
 $L_{\text{EDD}} \sim 10^{39} \text{ERG/S}$
- ▶ HIGHLY VARIABLE: SHORT-LIVED PHASES OF ACTIVITY



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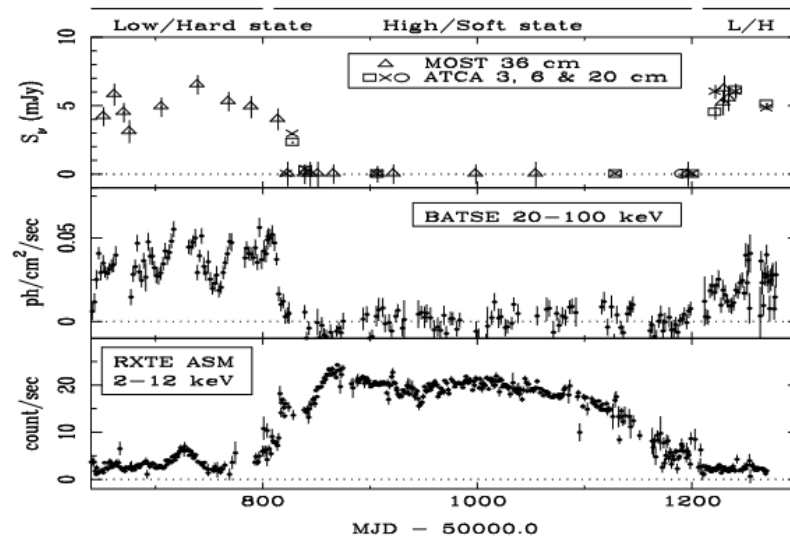
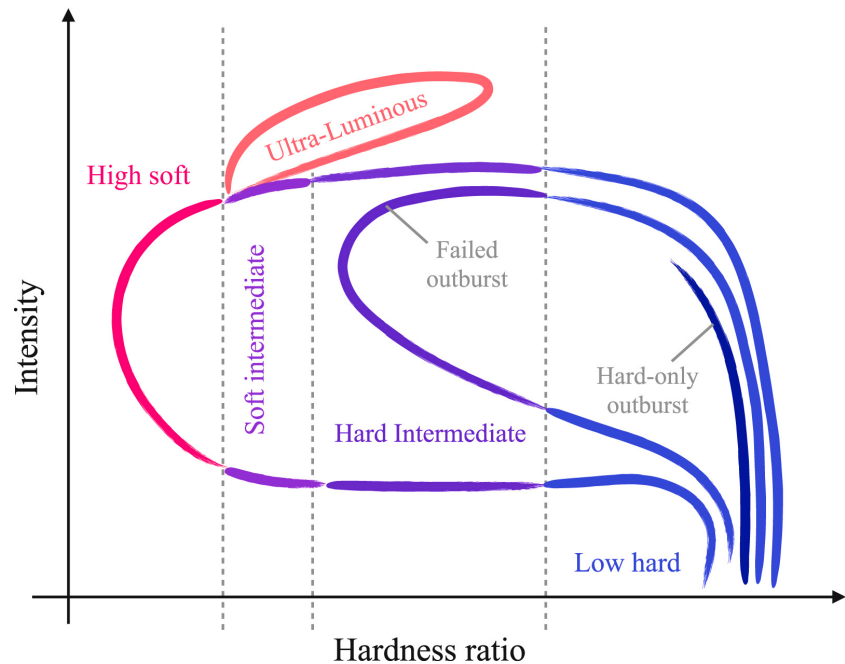


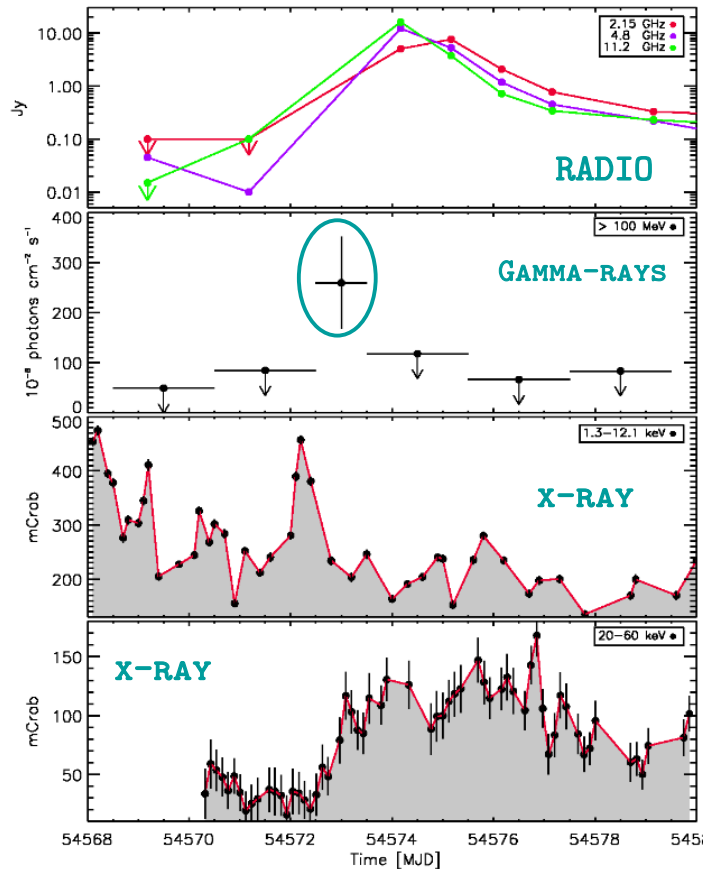
1. WHAT CAN WE LEARN ABOUT PARTICLE ACCELERATION IN JETS USING MICROQUASARS?
2. DO MICROQUASARS CONTRIBUTE TO GALACTIC COSMIC RAYS UP TO THE "KNEE"?

? TOTAL MICROQUASARS IN THE GALAXY

FEW TENS KNOWN

4-6 IN GAMMA-RAYS



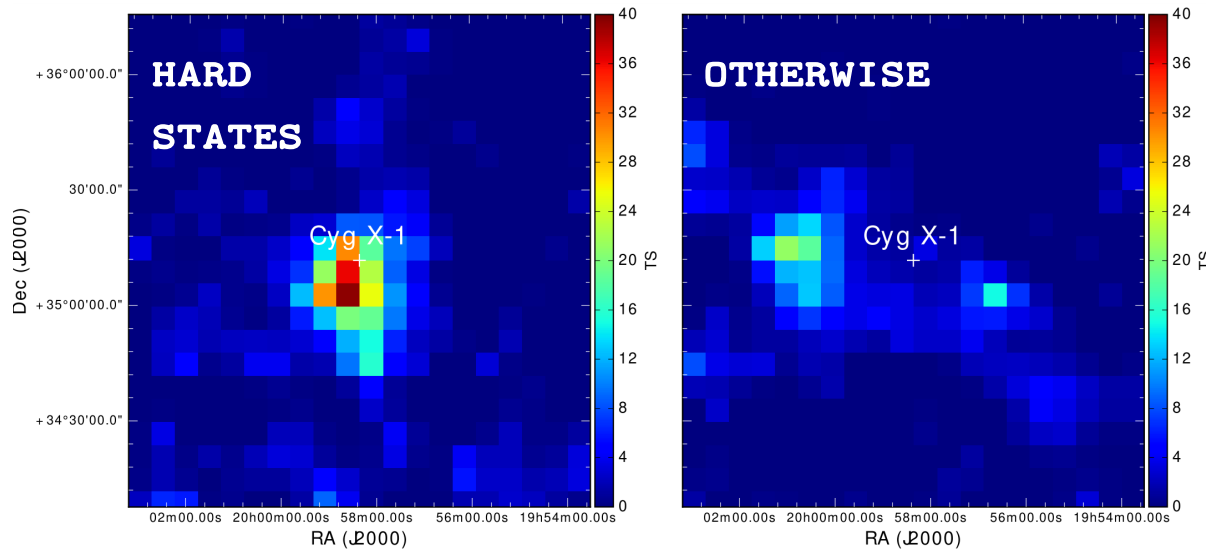


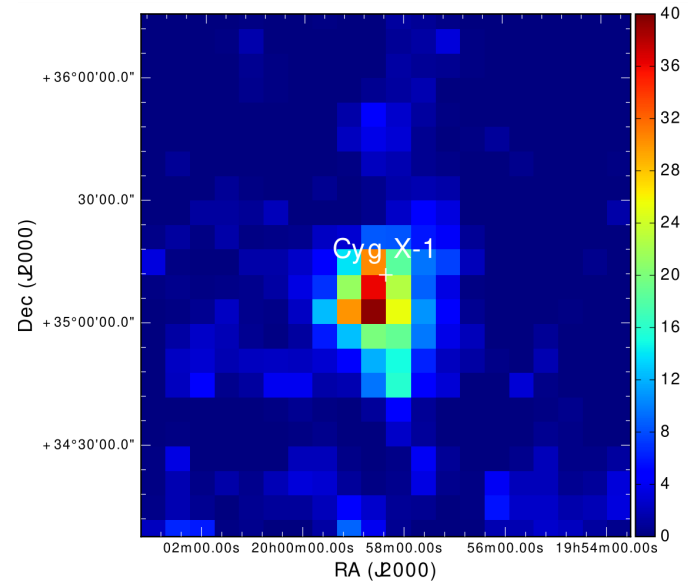
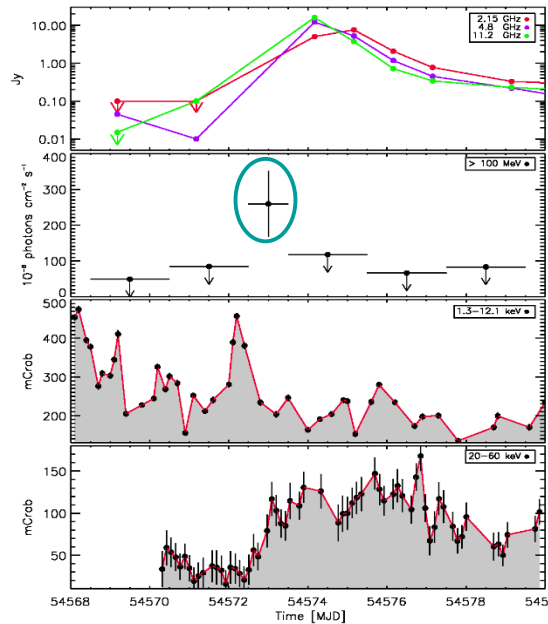
2009: PHOTONS ABOVE 100 MEV
DETECTED FROM CYGNUS X-3 BY
AGILE SATELLITE

FOUR DIFFERENT FLARES
COINCIDENT WITH SPECIAL
RADIO/X-RAY STATES AND
PRECEDING STRONG RADIO FLARES

ZANIN ET AL 2016: PHOTONS UP TO 20 GeV DETECTED FROM CYGNUS X-1 BY
FERMI-LAT SATELLITE

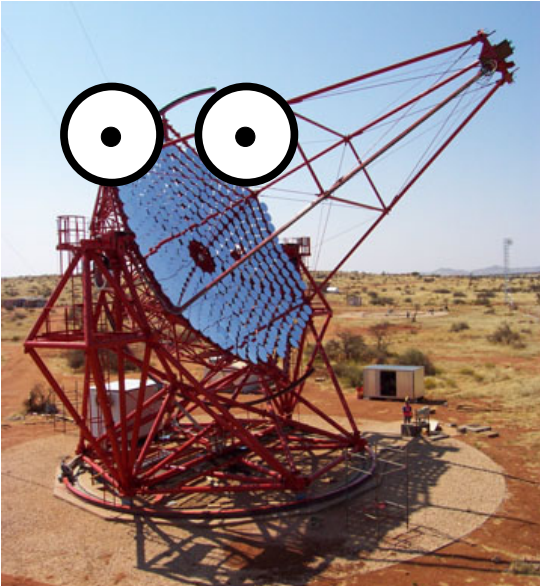
EMISSION CORRELATED WITH "HARD" SPECTRAL INDEX IN THE X-RAY BAND



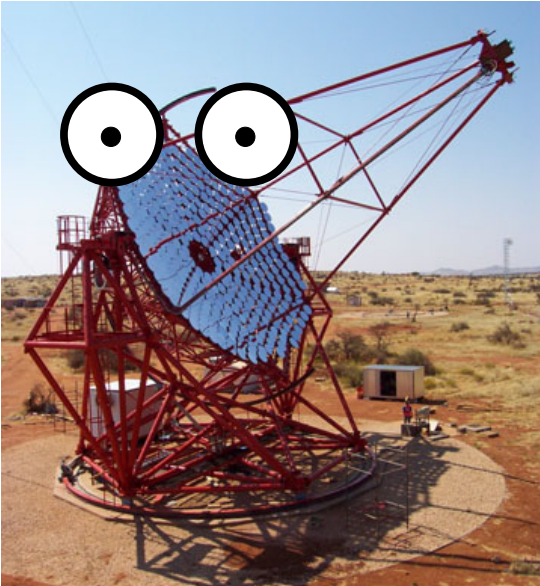


EVIDENCE BEFORE 2018: GeV EMISSION IS VARIABLE AND CORRELATES WITH TRANSIT FLARES OR SPECTRAL CHANGES

LET'S POINT AT MICROQUASARS
DURING FLARES/SPECIAL TIMES!



LET'S POINT AT MICROQUASARS
DURING FLARES/SPECIAL TIMES!



A search for very high-energy flares from the microquasars
GRS 1915+105, Circinus X-1, and V4641 Sgr using
contemporaneous H.E.S.S. and RXTE observations

H.E.S.S. Collaboration

JOURNAL ARTICLE

MAGIC observations of the microquasar V404 Cygni during the 2015 outburst FREE

M. L. Ahnen, S. Ansoldi, L. A. Antonelli, C. Arcaro, A. Babić, B. Banerjee, P. Bangale,
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Monthly Notices of the Royal Astronomical Society, Volume 471, Issue 2, October 2017,
Pages 1688–1693, <https://doi.org/10.1093/mnras/stx1690>

Published: 08 July 2017 **Article history** ▼

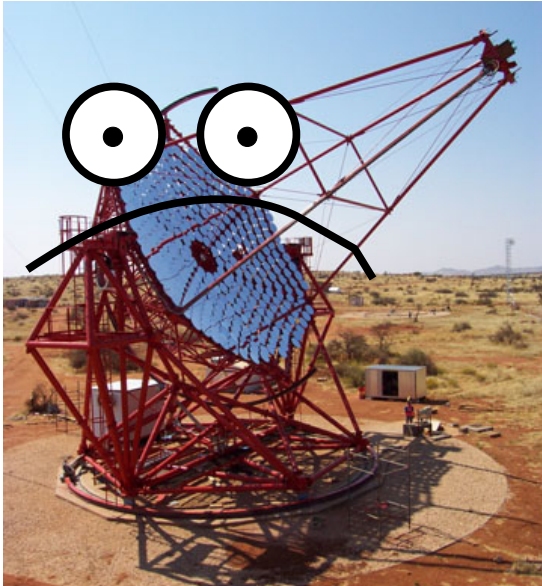
Advance Access publication 2022 September 23

<https://doi.org/10.1093/mnras/stac268>

Gamma-ray observations of MAXI J1820+070 during the 2018 outburst

H. Abe,¹ S. Abe,¹ V. A. Acciari,² T. Aniello,³ S. Ansoldi,^{4*} L. A. Antonelli,³ A. Arbet Engels,⁵
C. Arcaro,⁶ M. Artale,⁷ K. Asano,¹ D. Baek,⁸ A. Babić,⁹ A. Bagnato,¹⁰ U. Barres de Almeida,¹¹

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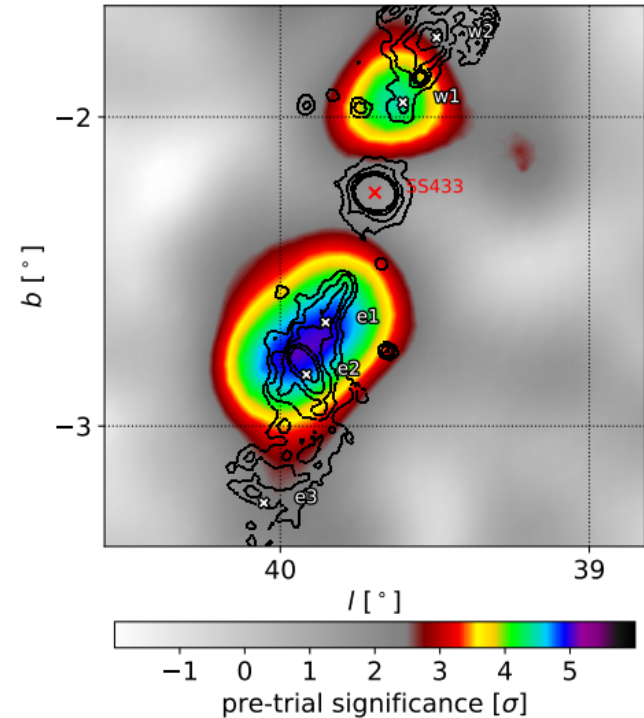
Letter | Published: 03 October 2018

Very-high-energy particle acceleration powered by the jets of the microquasar SS 433

[A. U. Abeysekara](#), [A. Albert](#), [R. Alfaro](#), [C. Alvarez](#), [J. D. Álvarez](#), [R. Arceo](#), [J. C. Arteaga-Velázquez](#), [D. Avila Rojas](#), [H. A. Ayala Solares](#), [E. Belmont-Moreno](#), [S. Y. BenZvi](#), [C. Brisbois](#), [K. S. Caballero-Mora](#), [T. Capistrán](#), [A. Carramiñana](#), [S. Casanova](#), [M. Castillo](#), [U. Cotti](#), [J. Cotzomi](#), [S. Coutiño de León](#), [C. De León](#), [E. De la Fuente](#), [J. C. Díaz-Vélez](#), [S. Dichiara](#), ... [H. Zhou](#)  [+ Show authors](#)

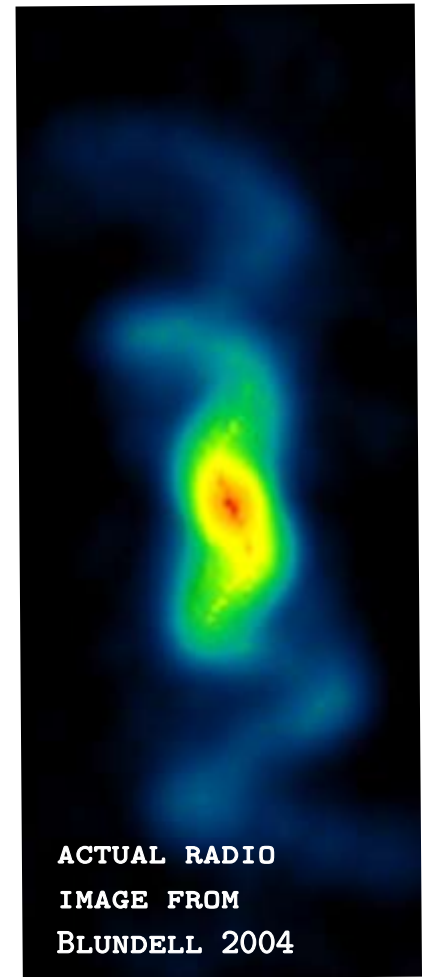
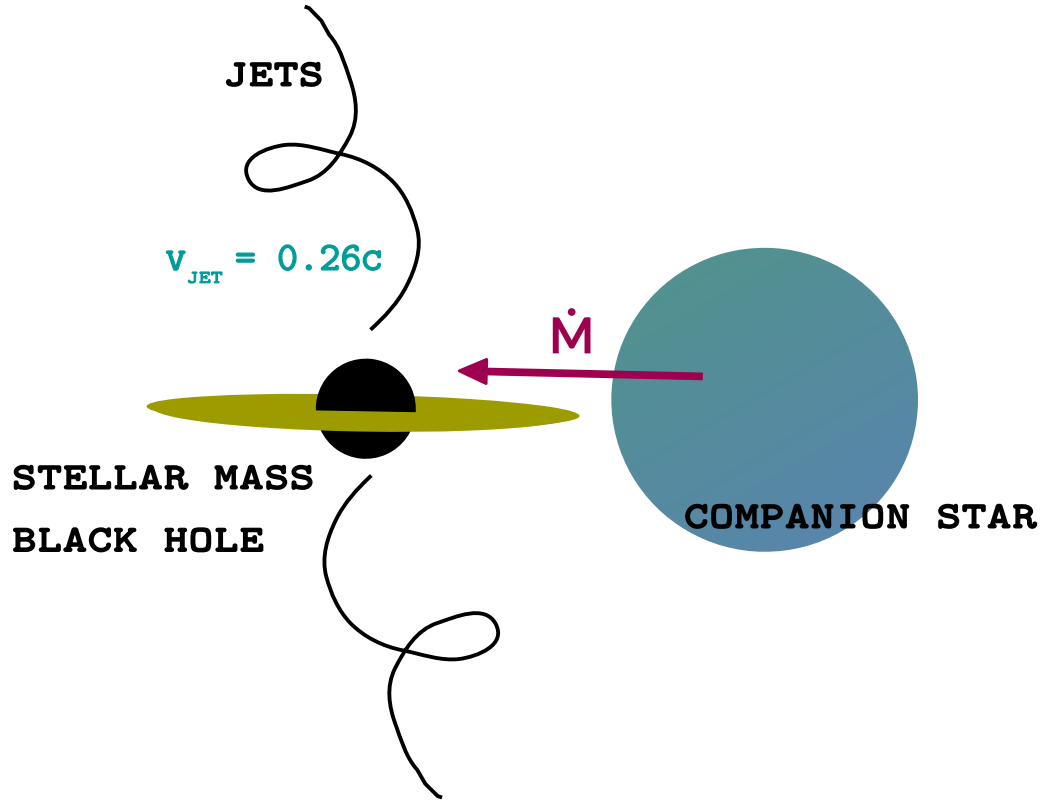
[Nature](#) **562**, 82–85 (2018) | [Cite this article](#)

HAWC OBSERVATORY



SEE NEXT SEMINAR BY SABRINA!

MEET THE MICROQUASAR SS 433

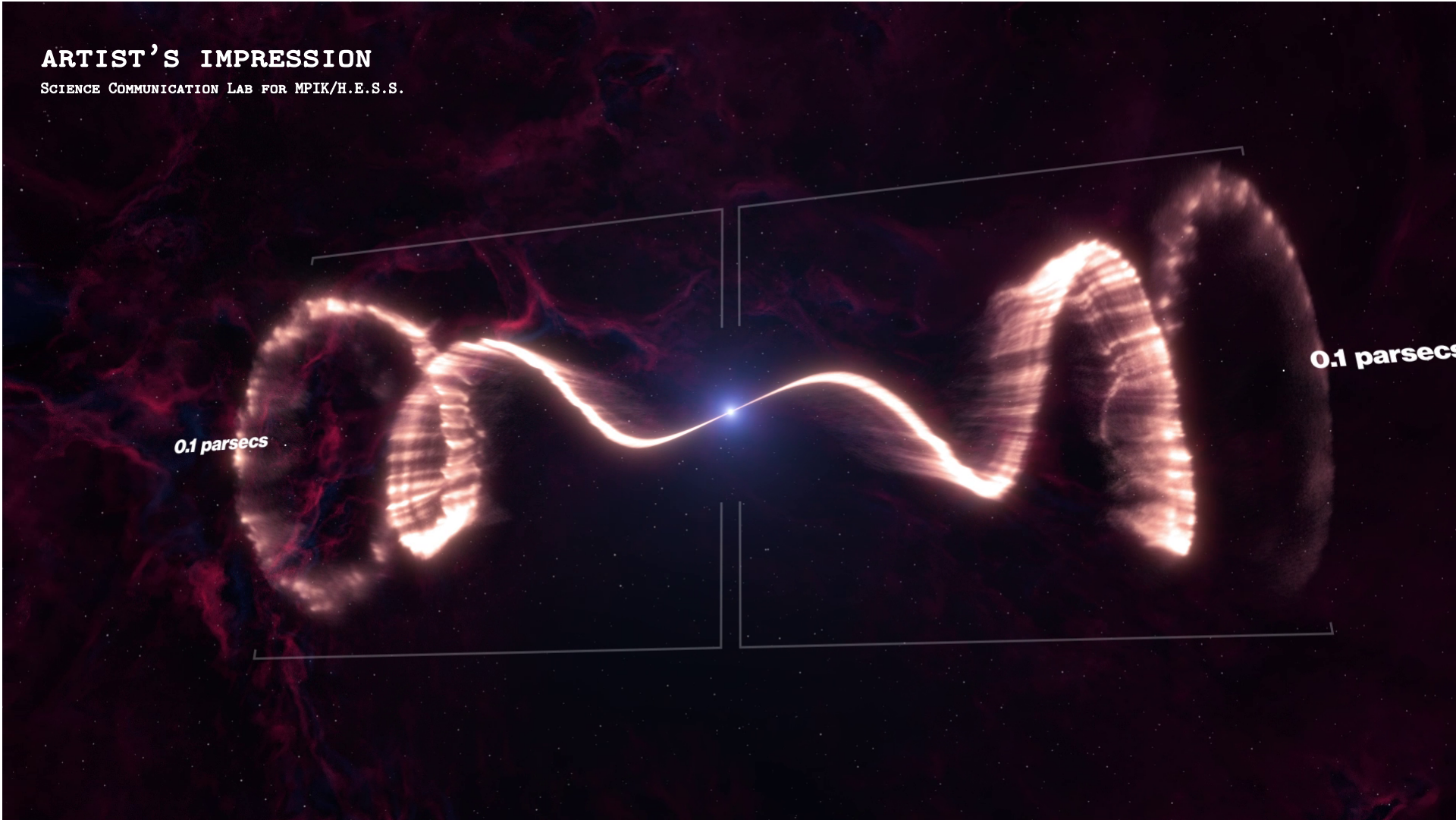


ARTIST'S IMPRESSION

SCIENCE COMMUNICATION LAB FOR MPIK/H.E.S.S.

0.1 parsecs

0.1 parsecs



ARTIST'S IMPRESSION

SCIENCE COMMUNICATION LAB FOR MPIK/H.E.S.S.



ARTIST'S IMPRESSION

SCIENCE COMMUNICATION LAB FOR MPIK/H.E.S.S.



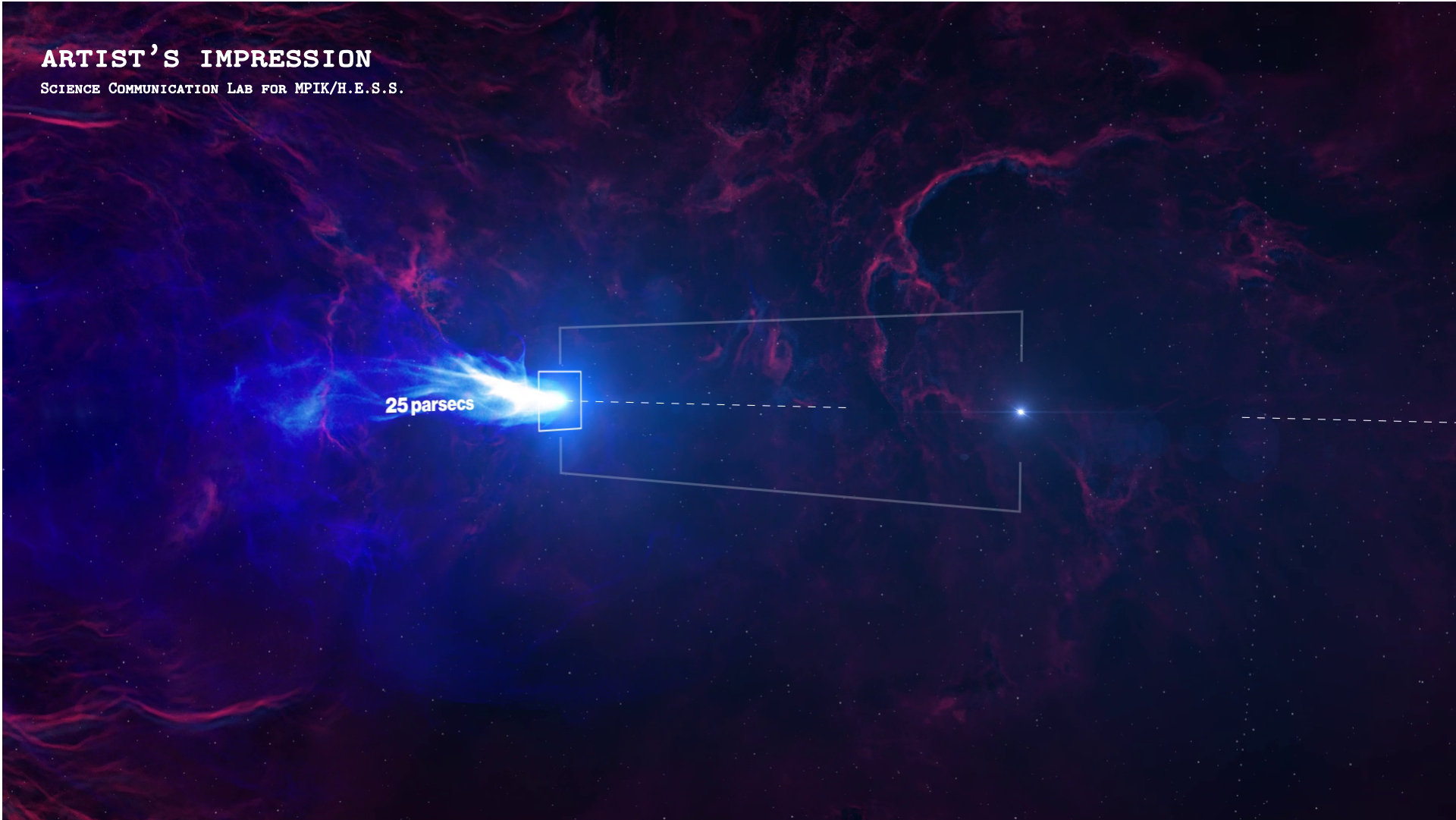
ARTIST'S IMPRESSION

SCIENCE COMMUNICATION LAB FOR MPIK/H.E.S.S.



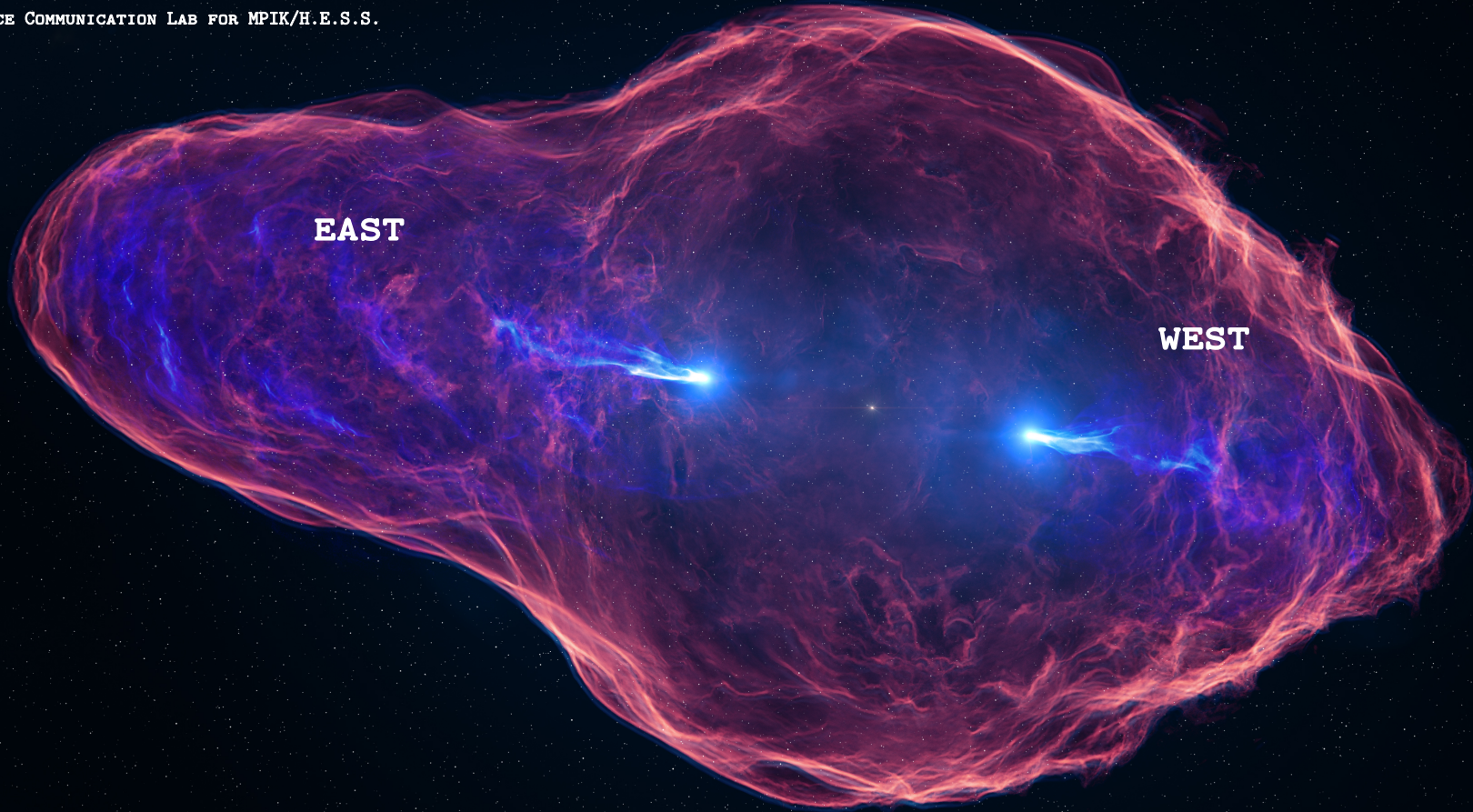
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SCIENCE COMMUNICATION LAB FOR MPIK/H.E.S.S.



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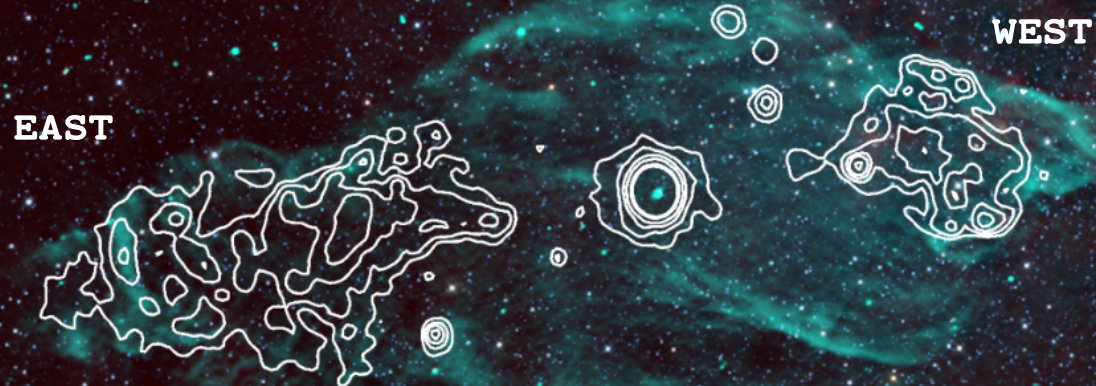
SCIENCE COMMUNICATION LAB FOR MPIK/H.E.S.S.



ACTUAL DATA

BLUE: RADIO EMISSION FROM NEBULA

WHITE: OUTLINE OF JETS IN X-RAY



~200 PC

$(6 \cdot 10^{18} \text{ M})$

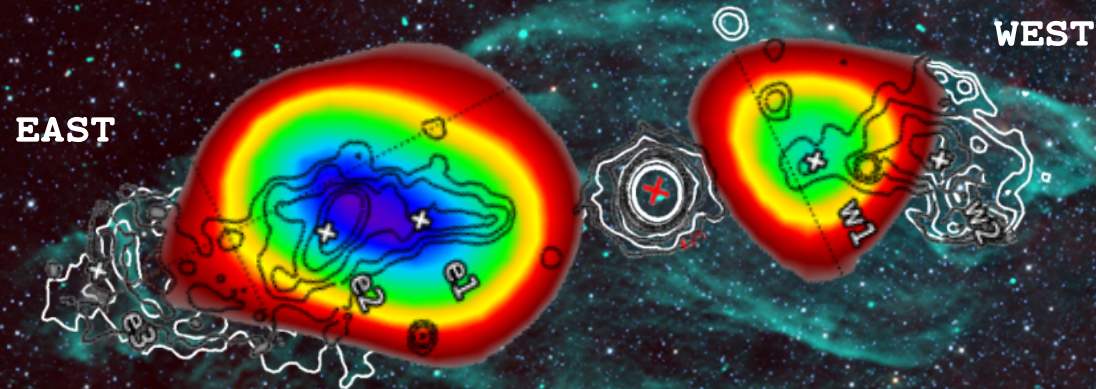
BACKGROUND: NRAO/AUI/NSF, K. GOLAP, M.
GOSS; NASA'S WIDE FIELD SURVEY EXPLORER
(WISE); X-RAY (GREEN CONTOURS): ROSAT/W.
BRINKMANN; TeV (RED COLORS): H.E.S.S.
COLLABORATION.

ACTUAL DATA

BLUE: RADIO EMISSION FROM NEBULA

WHITE: OUTLINE OF JETS IN X-RAY

RAINBOW: TEV EMISSION FROM HAWC



~200 PC

$(6 \cdot 10^{18} \text{ M})$

BACKGROUND: NRAO/AUI/NSF, K. GOLAP, M.
GOSS; NASA'S WIDE FIELD SURVEY EXPLORER
(WISE); X-RAY (GREEN CONTOURS): ROSAT/W.
BRINKMANN; TeV (RED COLORS): H.E.S.S.
COLLABORATION.

SS 433: OPEN QUESTIONS

- ▶ **WHERE AND HOW ARE PARTICLES ACCELERATED?**
- ▶ **ELECTRONS OR PROTONS?**
- ▶ **WHY DO THE JETS REAPPEAR?**

THE H.E.S.S. ARRAY OF TELESCOPES

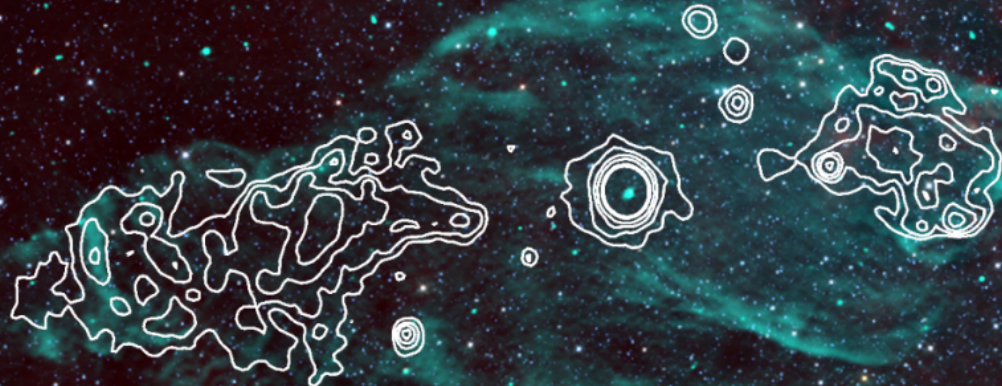
- ▶ ARRAY OF 5 CHERENKOV TELESCOPES LOCATED IN NAMIBIA
- ▶ 4 "SMALL" (12M, CT1-4), ONE "BIG" (28M, CT5) TELESCOPES
- ▶ DETECTING 100 GEV TO 100 TEV GAMMA RAYS
- ▶ ANGULAR RESOLUTION $\sim 0.07^\circ$, ENERGY RESOLUTION $\sim 10\%$ (CT1-4)
- ▶ NOVEL REJECTION METHOD: USING CT5 AS A MUON VETO [OLIVERA-NIETO ET AL EPJC 82 1118 \(2022\)](#)



ACTUAL DATA

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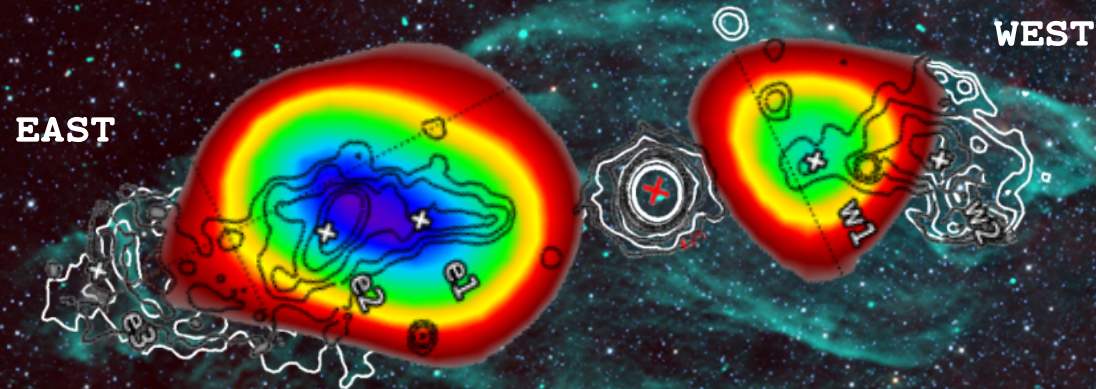
BACKGROUND: NRAO/AUI/NSF, K. GOLAP, M. GOSS;
NASA'S WIDE FIELD SURVEY EXPLORER (WISE); X-
RAY (GREEN CONTOURS): ROSAT/M. BRINKMANN;
TeV (RED COLORS): H.E.S.S. COLLABORATION.

ACTUAL DATA

BLUE: RADIO EMISSION FROM NEBULA

WHITE: OUTLINE OF JETS IN X-RAY

RAINBOW: TEV EMISSION FROM HAWC



~200 PC

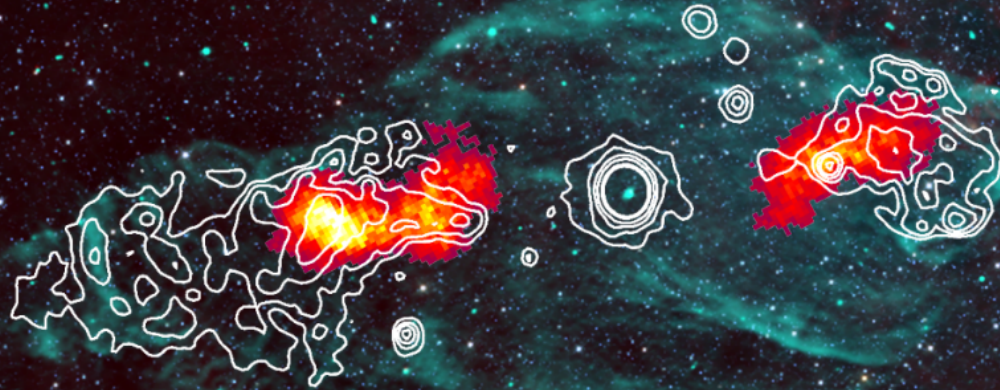
$(6 \cdot 10^{18} \text{ M})$

BACKGROUND: NRAO/AUI/NSF, K. GOLAP, M.
GOSS; NASA'S WIDE FIELD SURVEY EXPLORER
(WISE); X-RAY (GREEN CONTOURS): ROSAT/W.
BRINKMANN; TeV (RED COLORS): H.E.S.S.
COLLABORATION.

ACTUAL DATA

BLUE: RADIO EMISSION FROM NEBULA

WHITE: OUTLINE OF JETS IN X-RAY

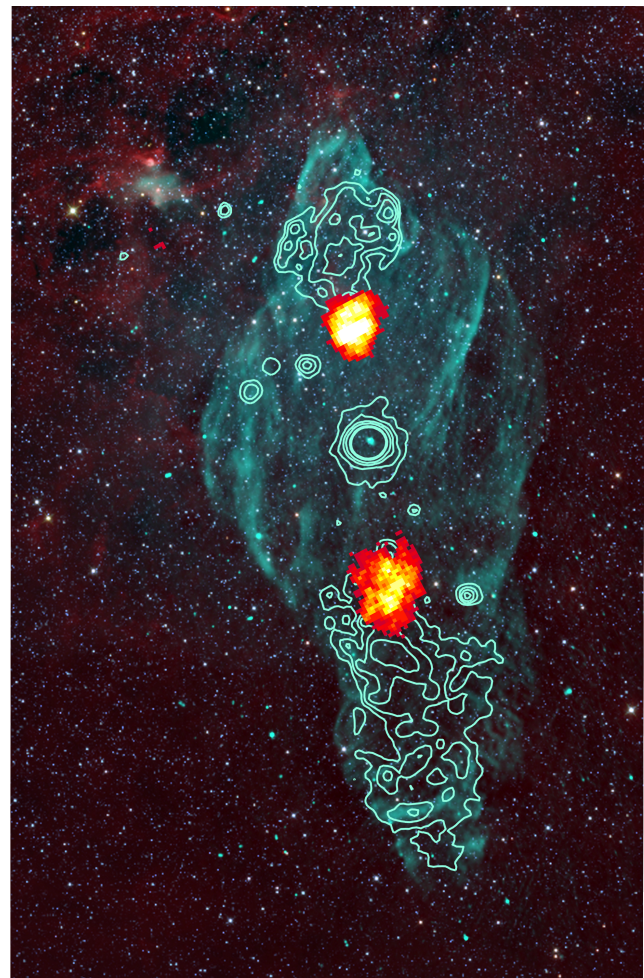


H.E.S.S. COLLABORATION SCIENCE 383 6681, 2024 (LON LEADING AUTHOR)

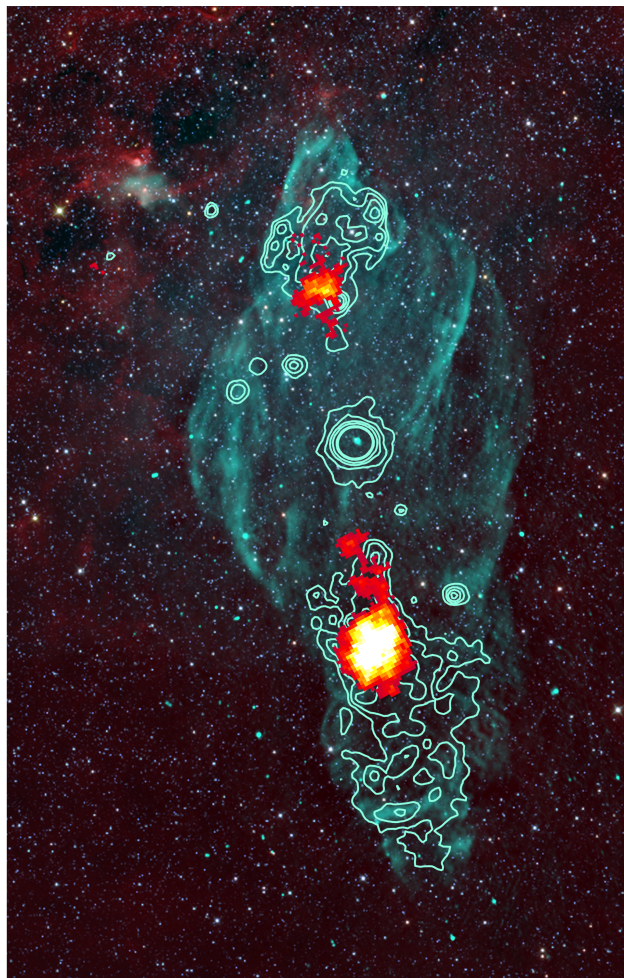


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NASA'S WIDE FIELD SURVEY EXPLORER (WISE); X-
RAY (GREEN CONTOURS): ROSAT/M. BRINKMANN;
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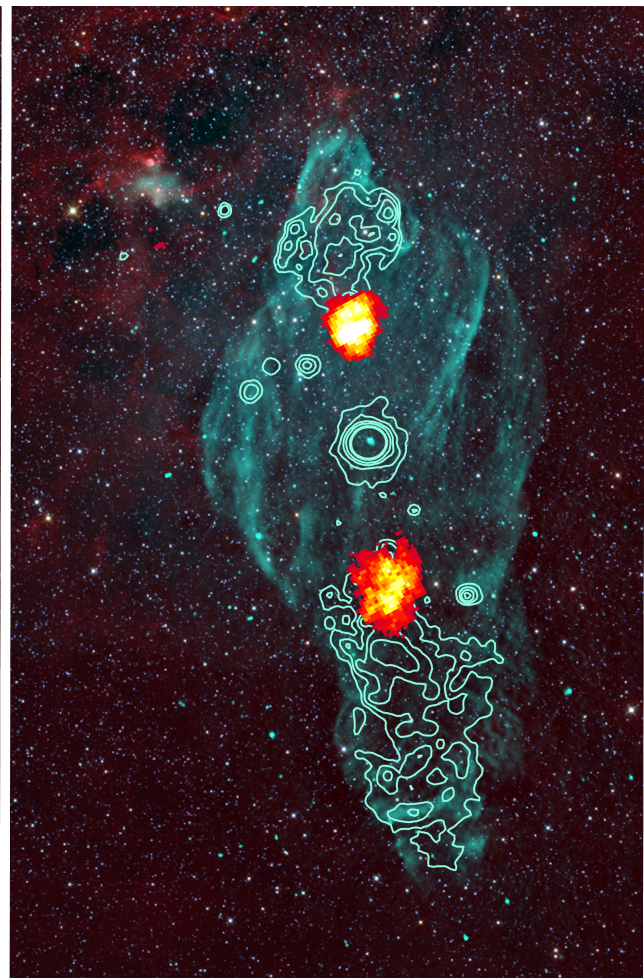
ABOVE 10 TeV



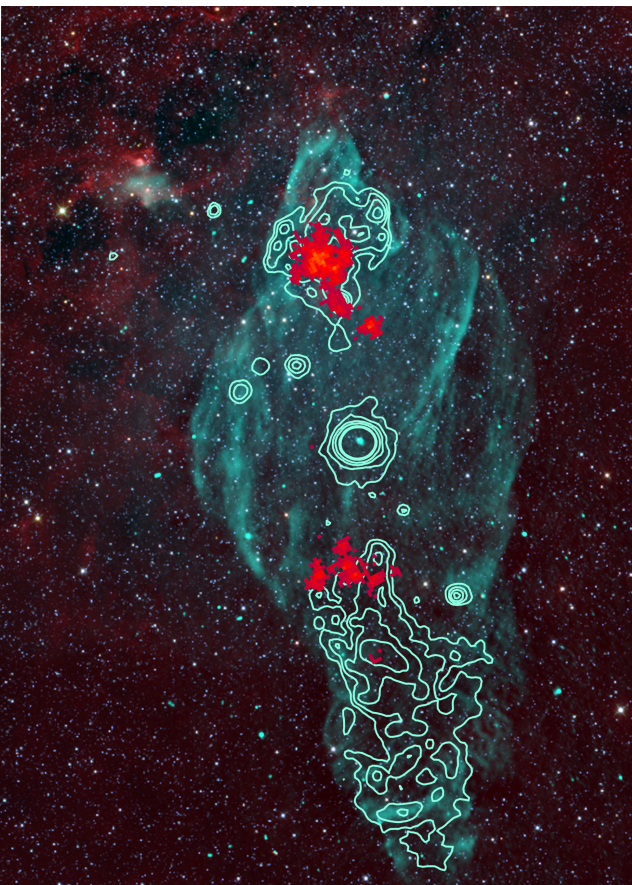
2.5 TO 10 TEV



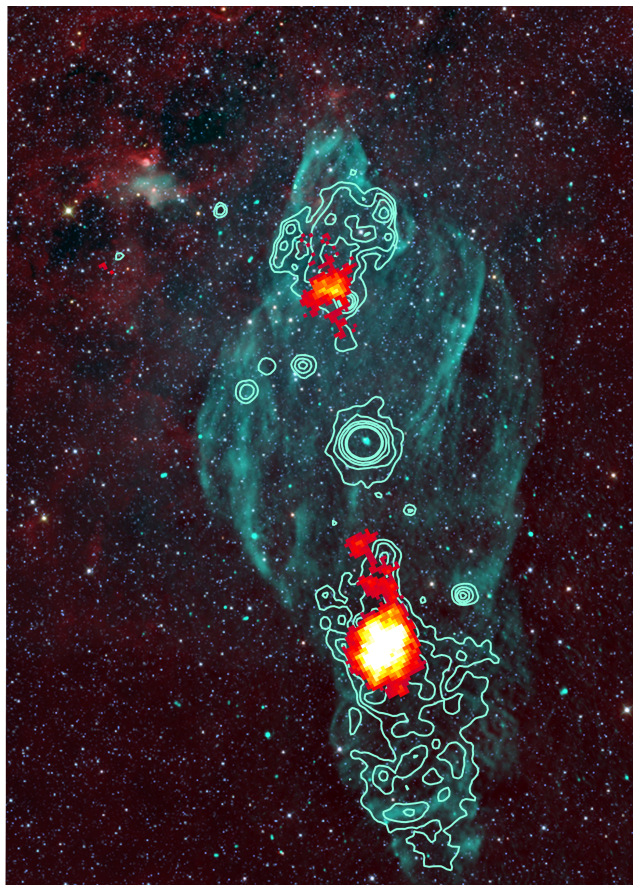
ABOVE 10 TEV



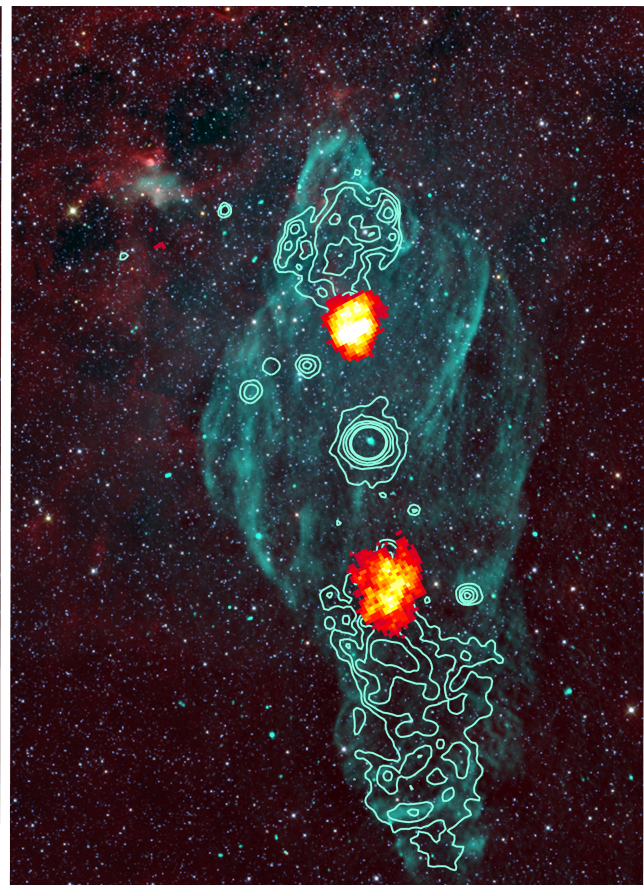
0.8 TO 2.5 TeV



2.5 TO 10 TeV



ABOVE 10 TeV

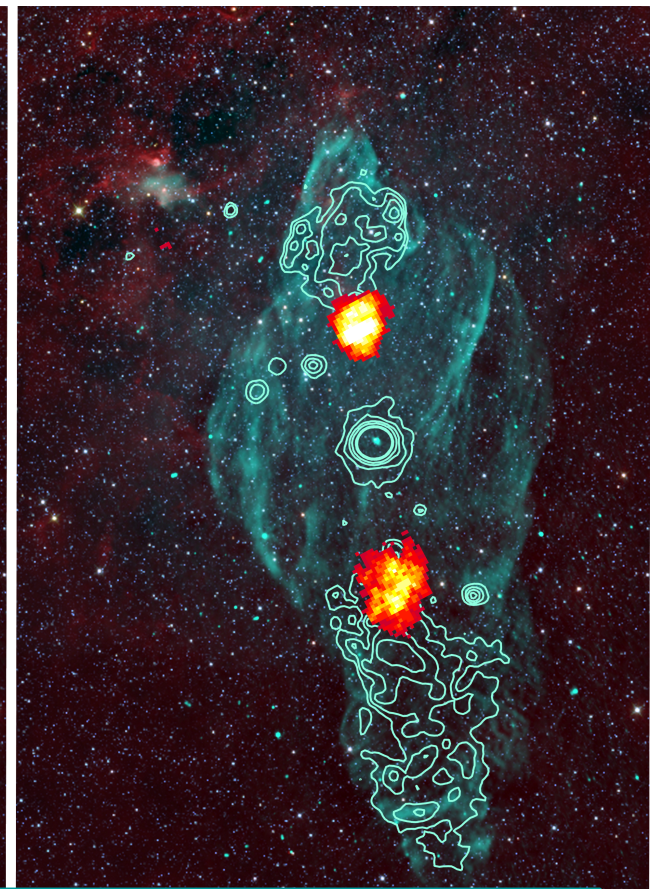
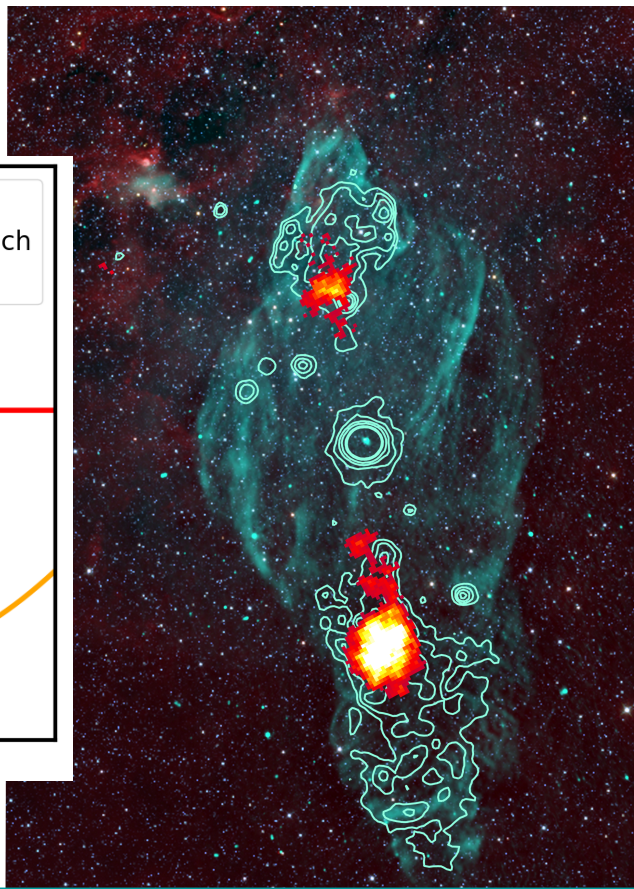
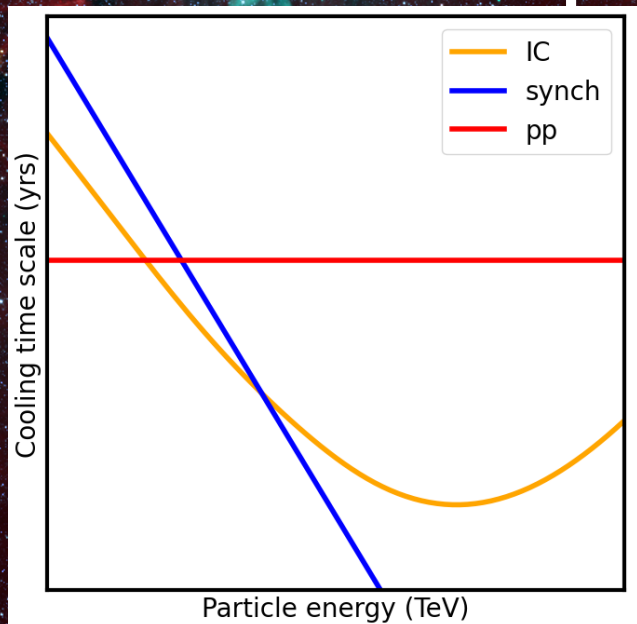


FIRST OBSERVATION OF ENERGY-DEPENDENT MORPHOLOGY IN TeV EMISSION OF A JET!

0.8 TO 2.5 TeV

2.5 TO 10 TeV

ABOVE 10 TeV

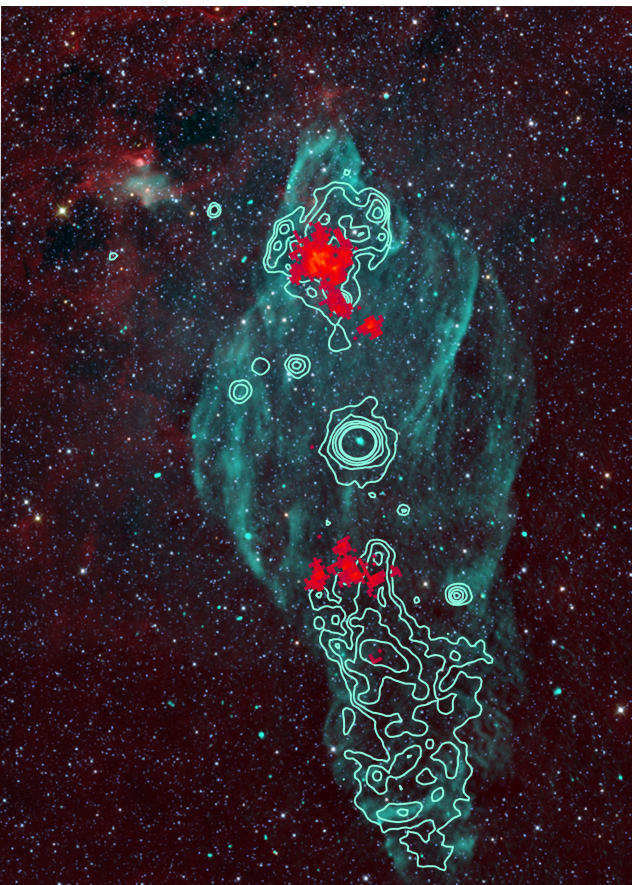


FIRST OBSERVATION OF ENERGY-DEPENDENT MORPHOLOGY IN TeV EMISSION OF A JET!

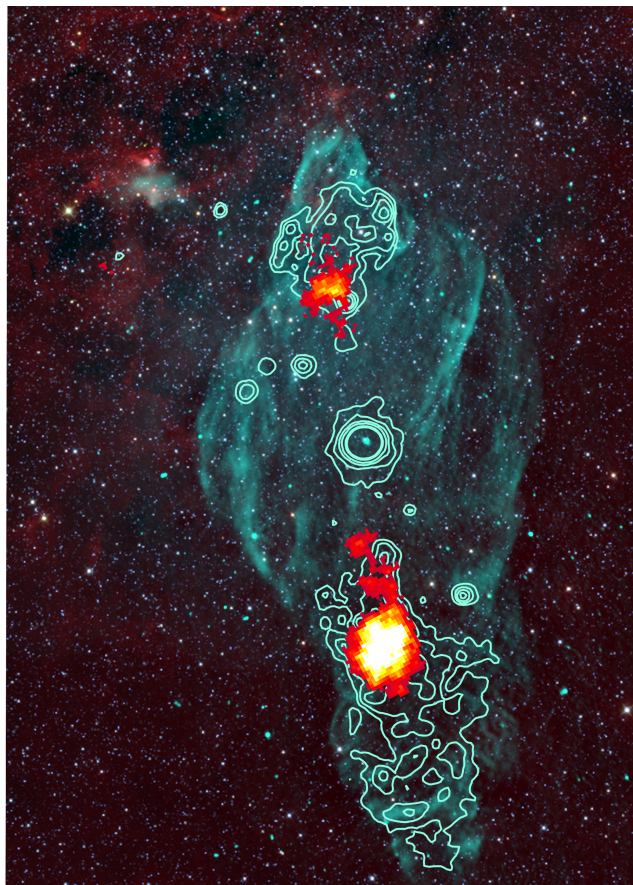
SS 433: OPEN QUESTIONS

- ▶ **WHERE AND HOW ARE PARTICLES ACCELERATED?**
- ▶ **ELECTRONS OR PROTONS?** ELECTRONS RADIATE BUT PROTONS ARE PRESENT
IN THE JET AND MIGHT BE ACCELERATED TOO
- ▶ **WHY DO THE JETS REAPPEAR?**

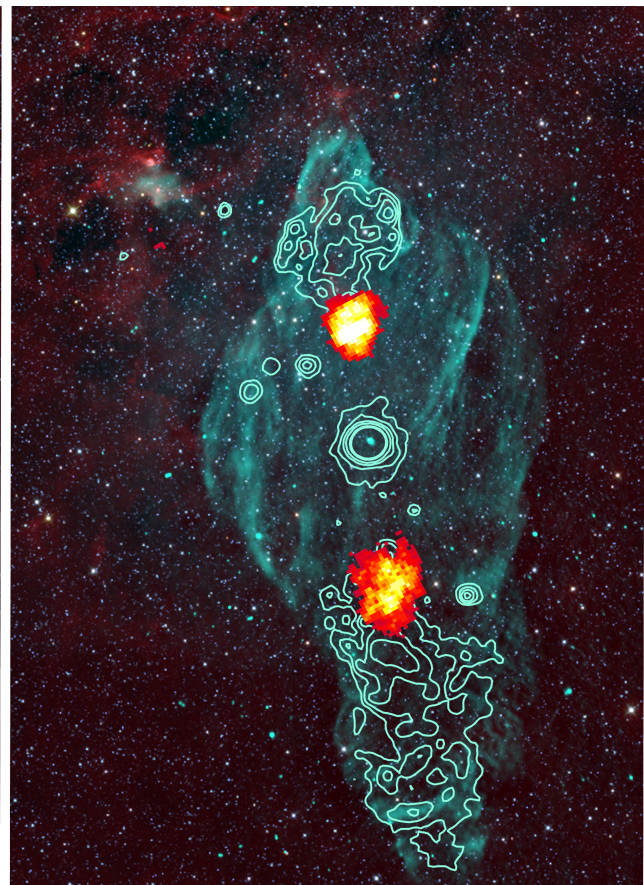
0.8 TO 2.5 TeV



2.5 TO 10 TeV



ABOVE 10 TeV

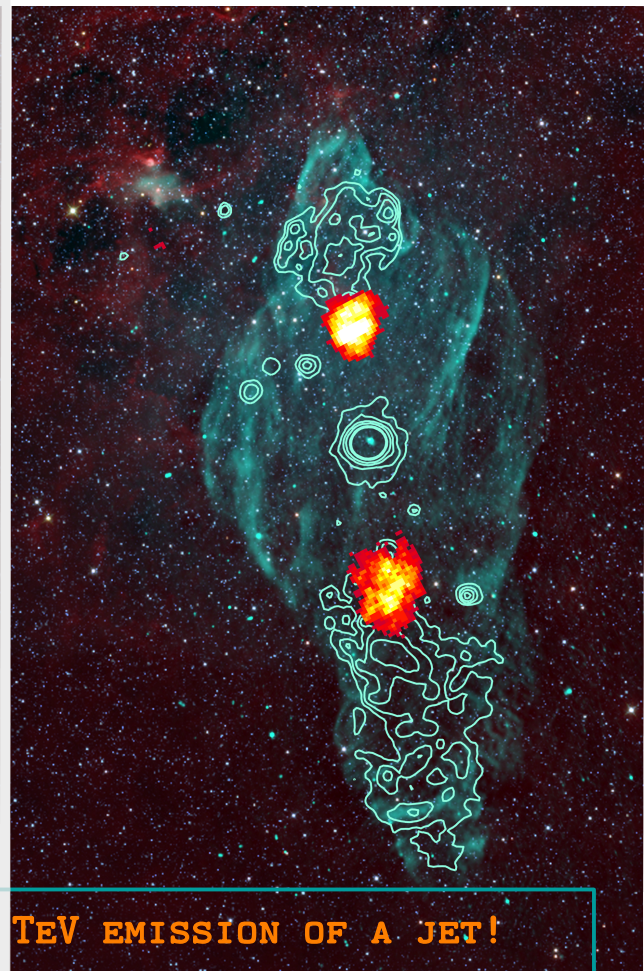
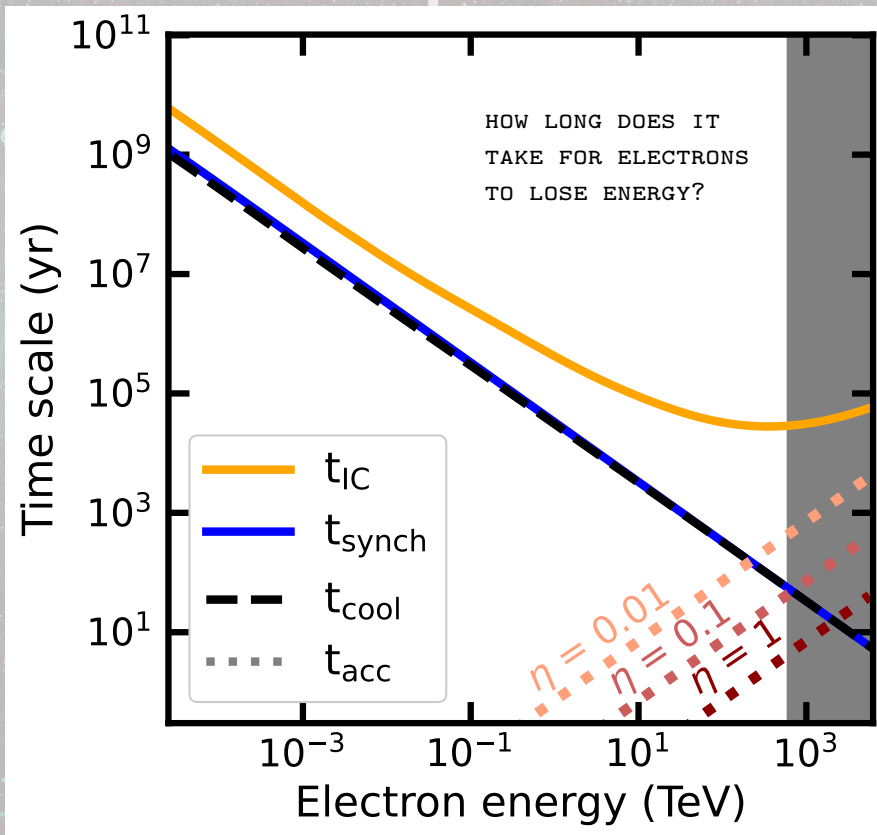


FIRST OBSERVATION OF ENERGY-DEPENDENT MORPHOLOGY IN TeV EMISSION OF A JET!

0.8 TO 2.5 TeV

2.5 TO 10 TeV

ABOVE 10 TeV



FIRST OBSERVATION OF ENERGY-DEPENDENT MORPHOLOGY IN TeV EMISSION OF A JET!

SS 433: OPEN QUESTIONS

- ▶ **WHERE AND HOW ARE PARTICLES ACCELERATED?**

WHERE THE JETS REAPPEAR IN X-RAY

- ▶ **ELECTRONS OR PROTONS?** ELECTRONS RADIATE BUT PROTONS ARE PRESENT
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- ▶ **WHY DO THE JETS REAPPEAR?**

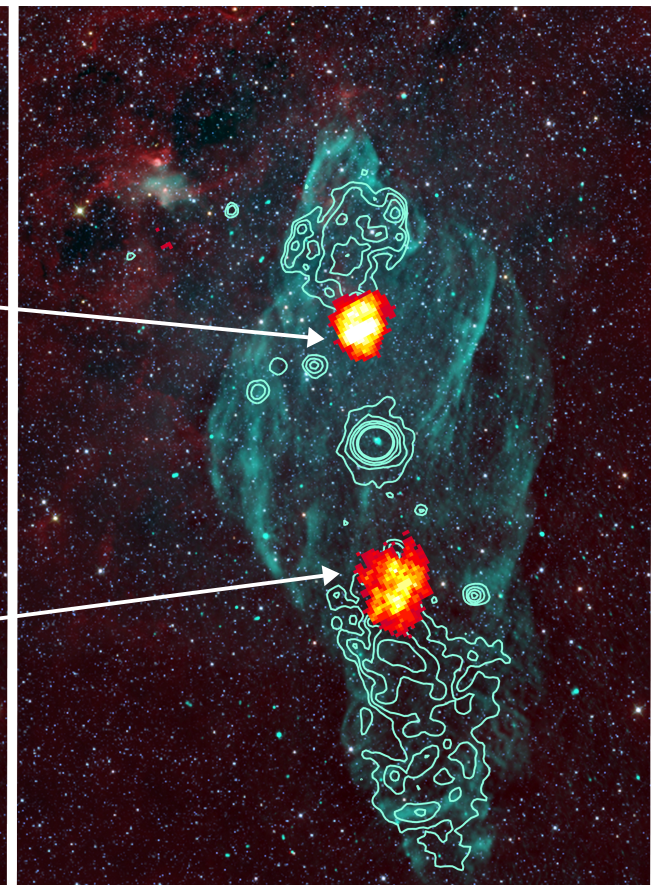
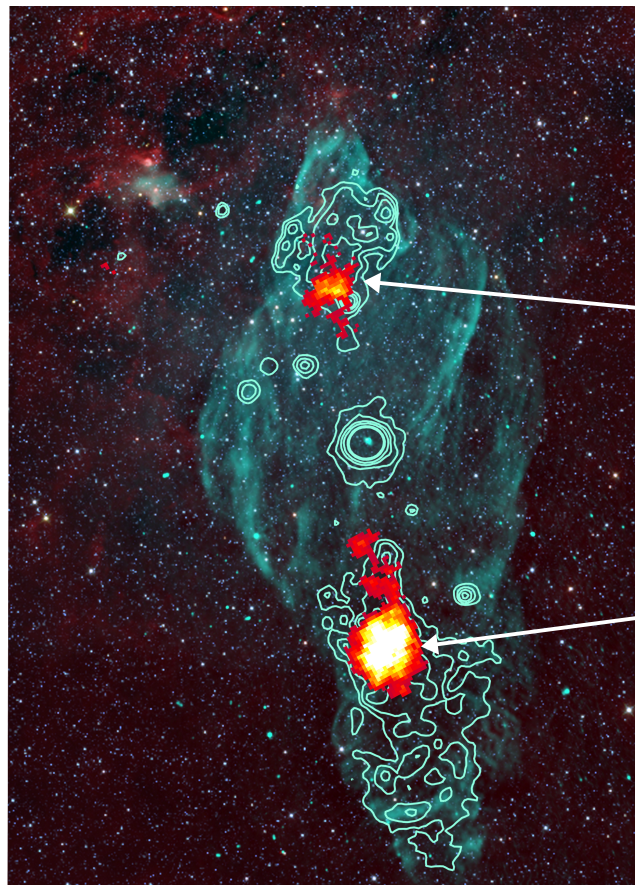
0.8 TO 2.5 TeV

HOW FAST DO ELECTRONS
NEED TO BE MOVING TO
PRODUCE THIS SHIFT?

WE NEED TO KNOW HOW
FAST THEY LOSE ENERGY
(AND THUS ARE NO
LONGER ABLE TO
GENERATE >10 TeV
PHOTONS)

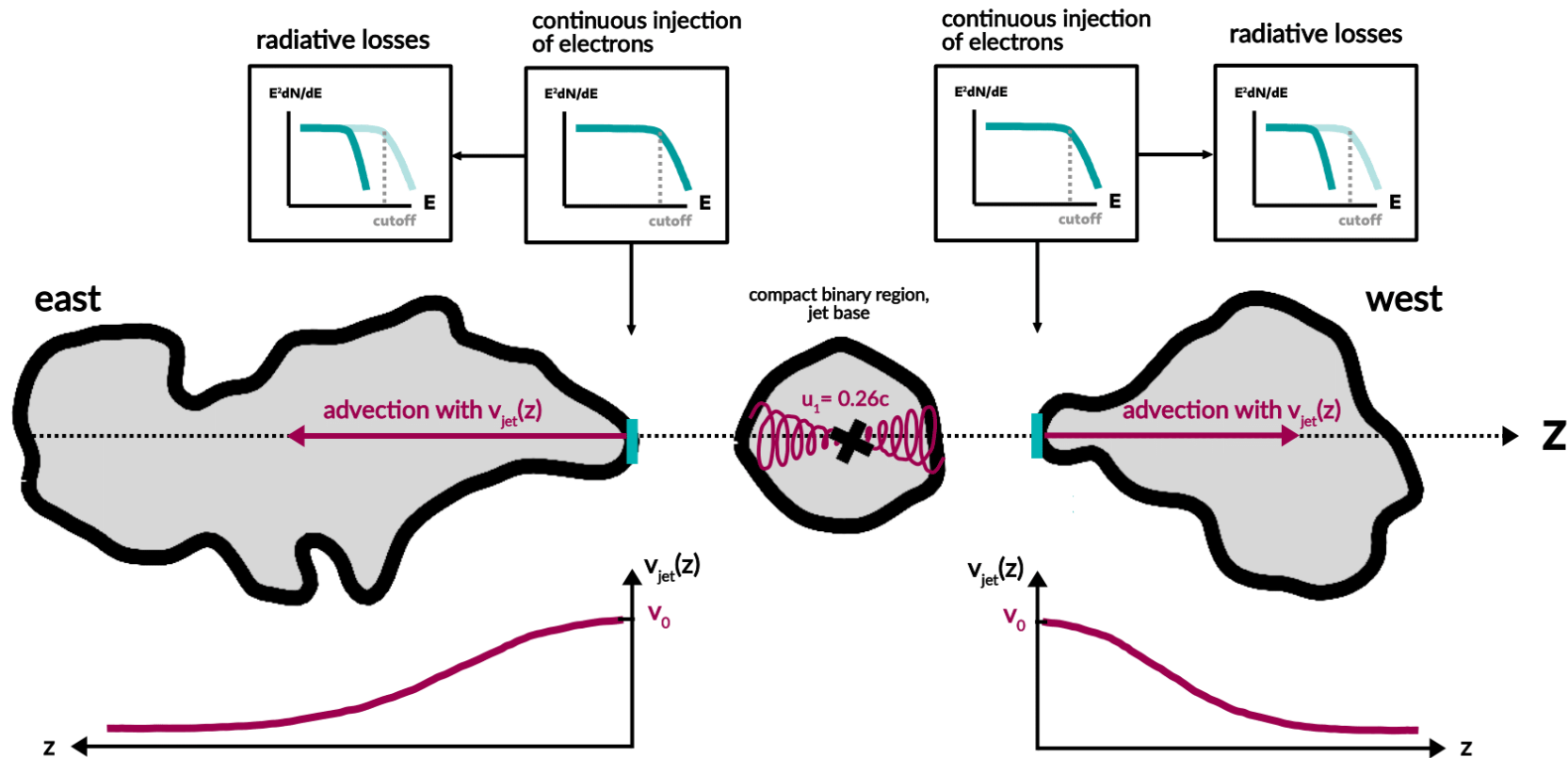
2.5 TO 10 TeV

ABOVE 10 TeV

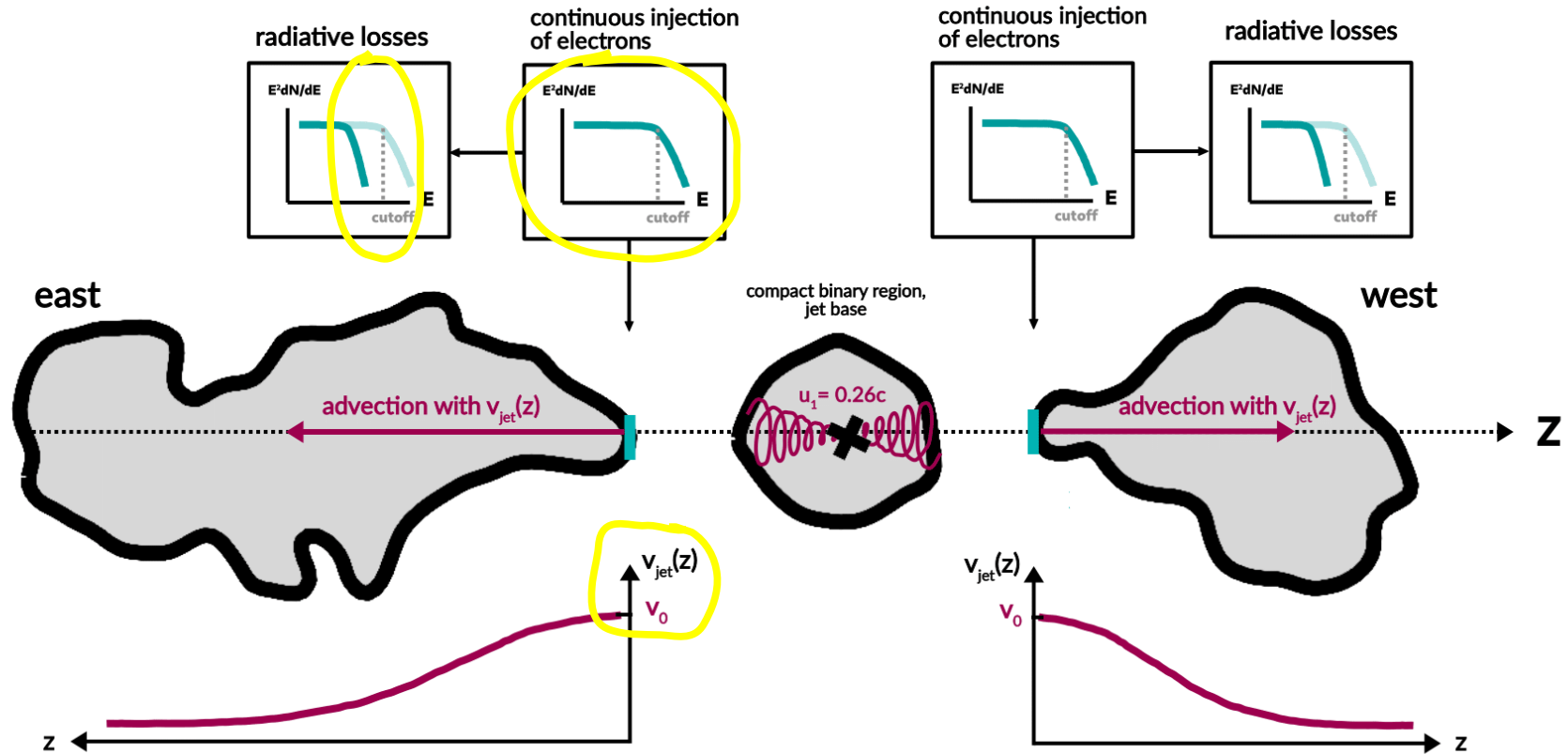


FIRST OBSERVATION OF ENERGY-DEPENDENT MORPHOLOGY IN TeV EMISSION OF A JET!

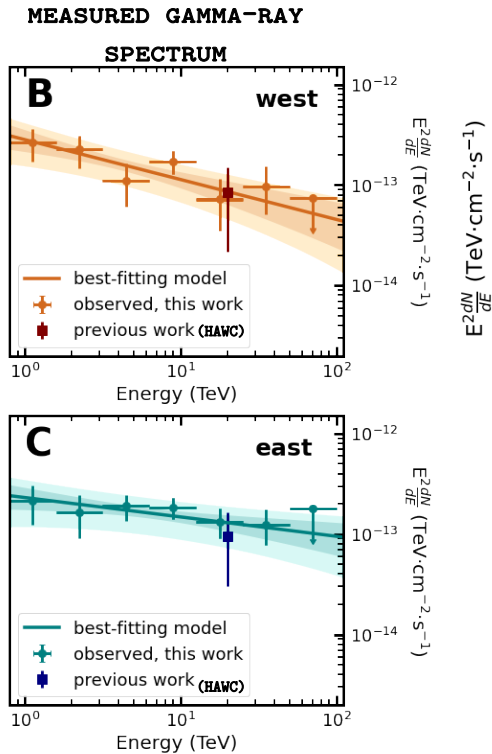
SIMULATING TRANSPORT AND RADIATION OF ELECTRONS



SIMULATING TRANSPORT AND RADIATION OF ELECTRONS

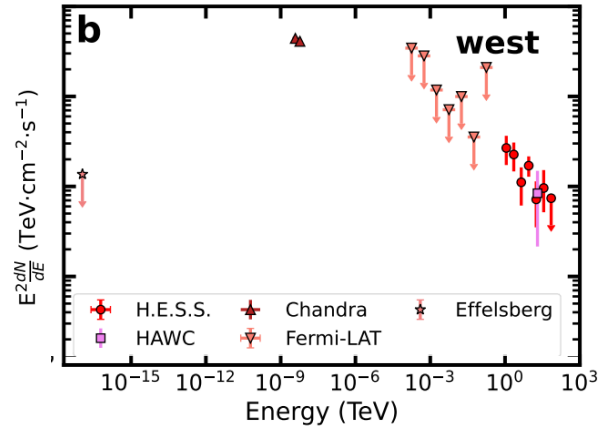
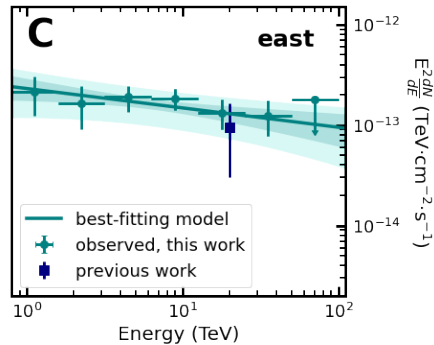
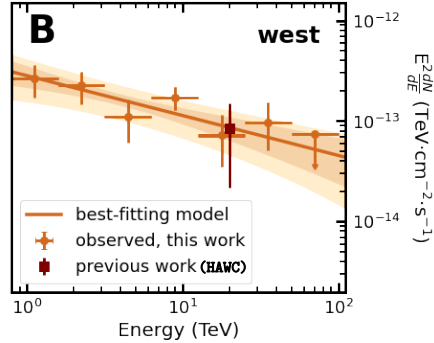


HOW FAST DO ELECTRONS LOSE ENERGY?



HOW FAST DO ELECTRONS LOSE ENERGY?

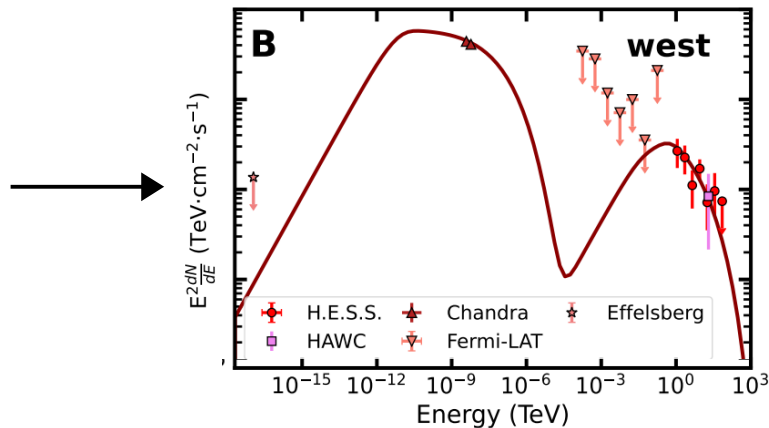
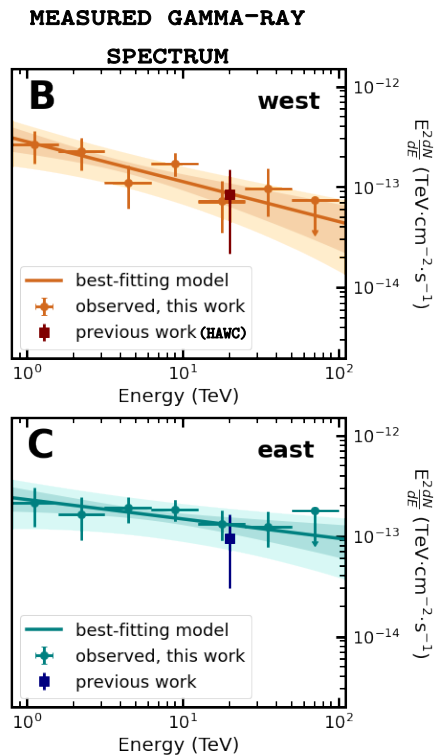
MEASURED GAMMA-RAY
SPECTRUM



ELECTRONS RADIATE DUE TO:

- ▶ INVERSE COMPTON
- ▶ SYNCHROTRON

HOW FAST DO ELECTRONS LOSE ENERGY?

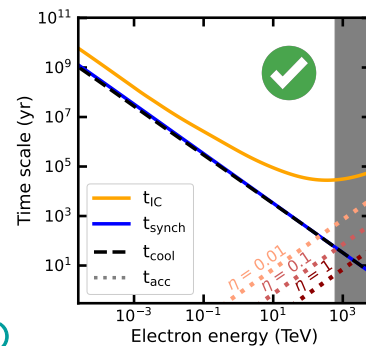


ESTIMATED:

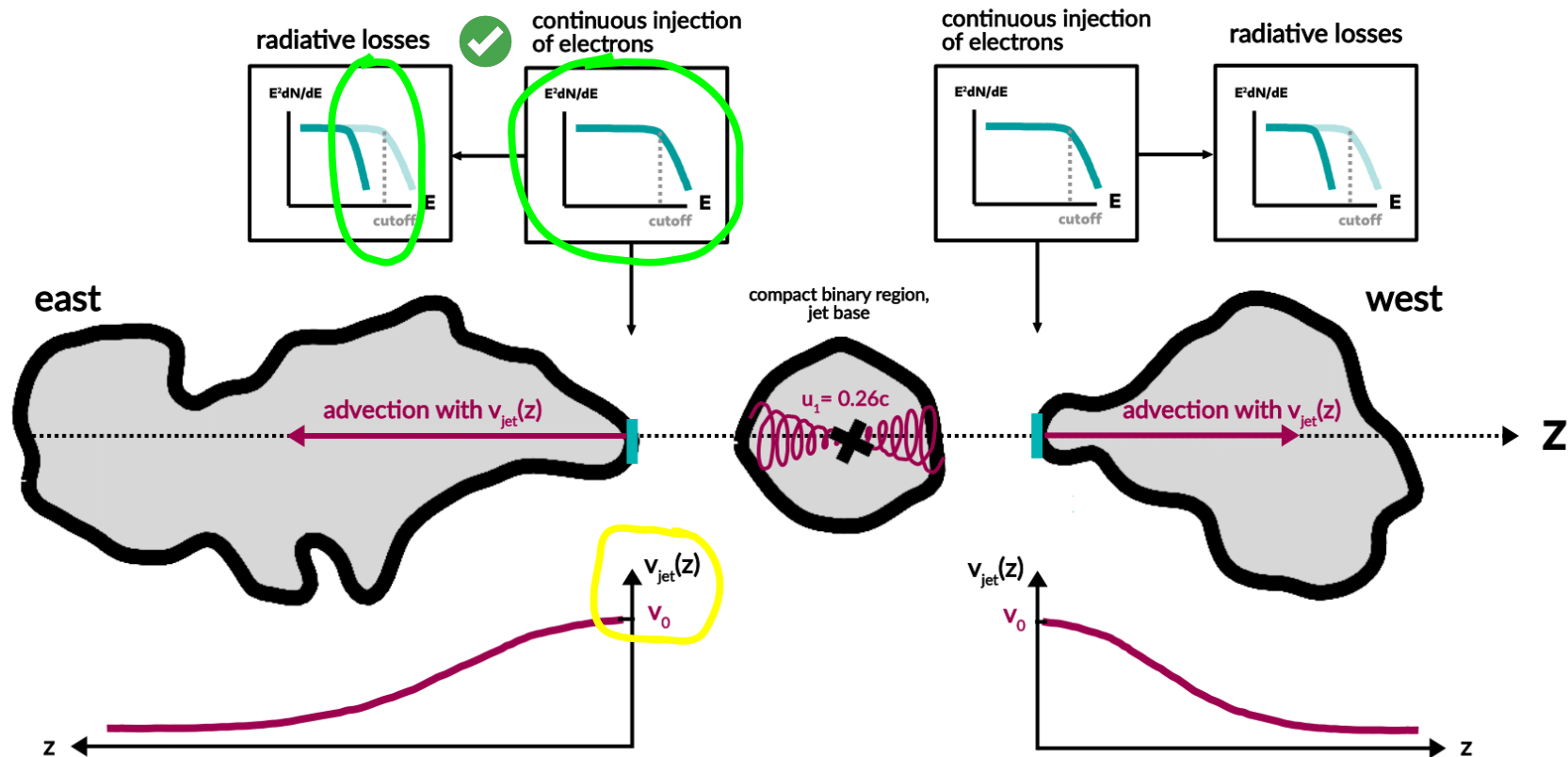
- ▶ MAGNETIC FIELD (B) ~ 20 μG
- ▶ INJECTED ELECTRON SPECTRUM:
 - ▷ NORMALIZATION: 0.1% OF JET KINETIC POWER
 - ▷ SPECTRAL SHAPE: E^{-2} WITH **NO CUTOFF** ($E_c > 200 \text{ TeV}$)

ELECTRONS RADIATE DUE TO:

- ▶ INVERSE COMPTON
- ▶ SYNCHROTRON

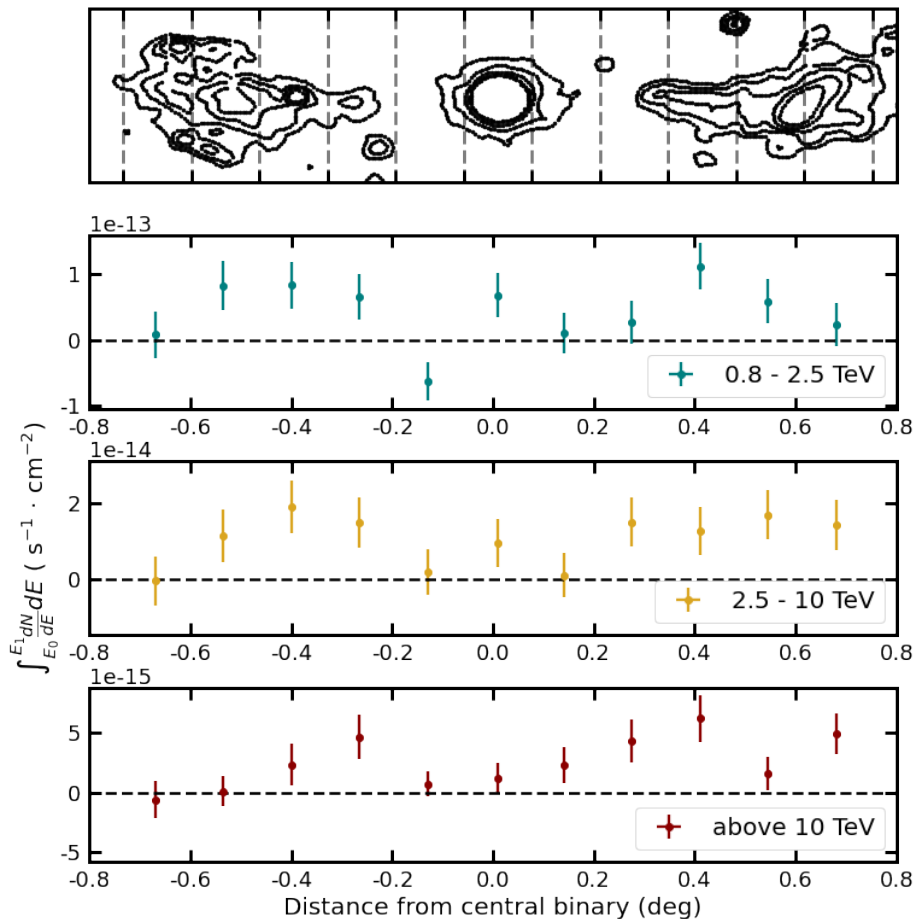


SIMULATING TRANSPORT AND RADIATION OF ELECTRONS



MEASURING v_0

- ▶ FOR EACH GAMMA-RAY ENERGY RANGE, MEASURED FLUX PROFILE ALONG THE JET.
- ▶ MODEL TRANSPORT AND RADIATION WITH A 1D MONTE CARLO SIMULATION.
- ▶ COMPARE RESULTS TO DATA AND FIT FOR v_0 .



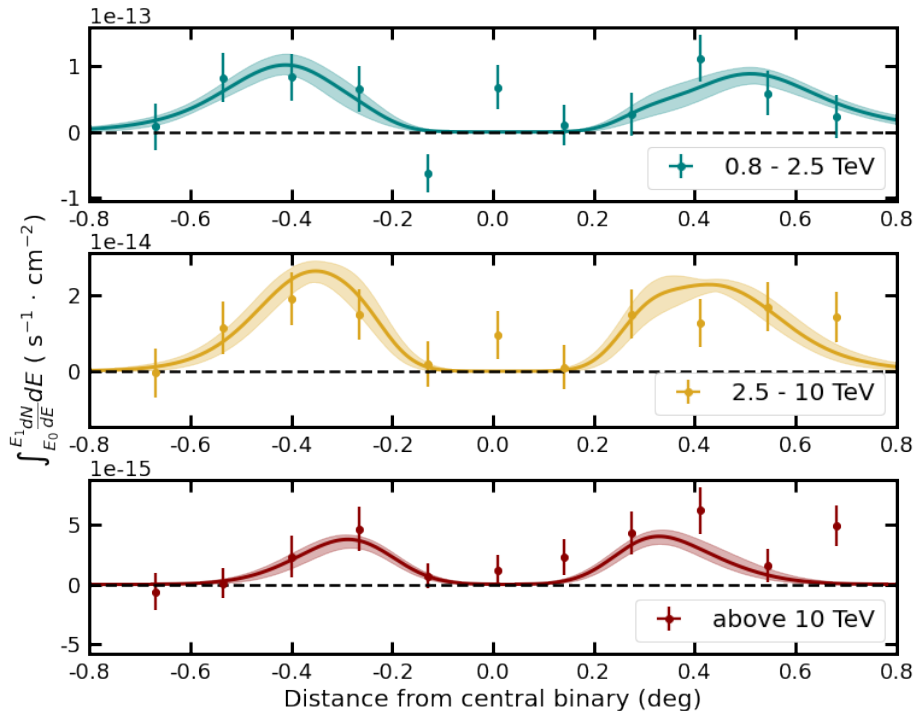
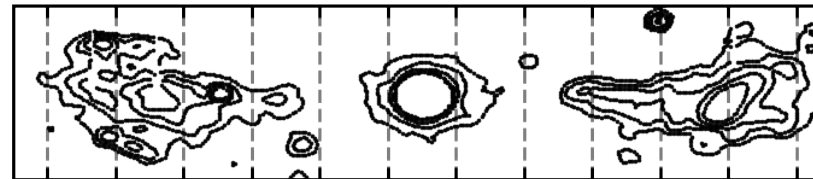
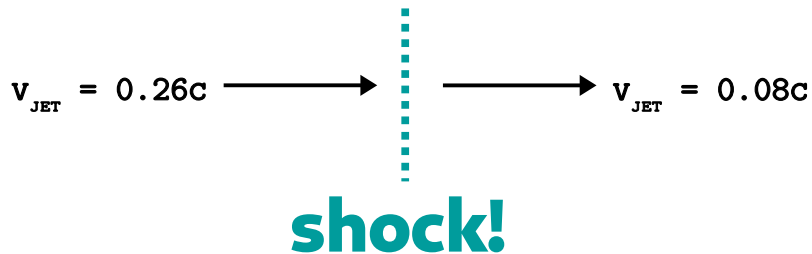
MEASURING v_0

► $v_0 = (0.08 \pm 0.03_{\text{STAT}} \pm 0.01_{\text{SYST}})c$

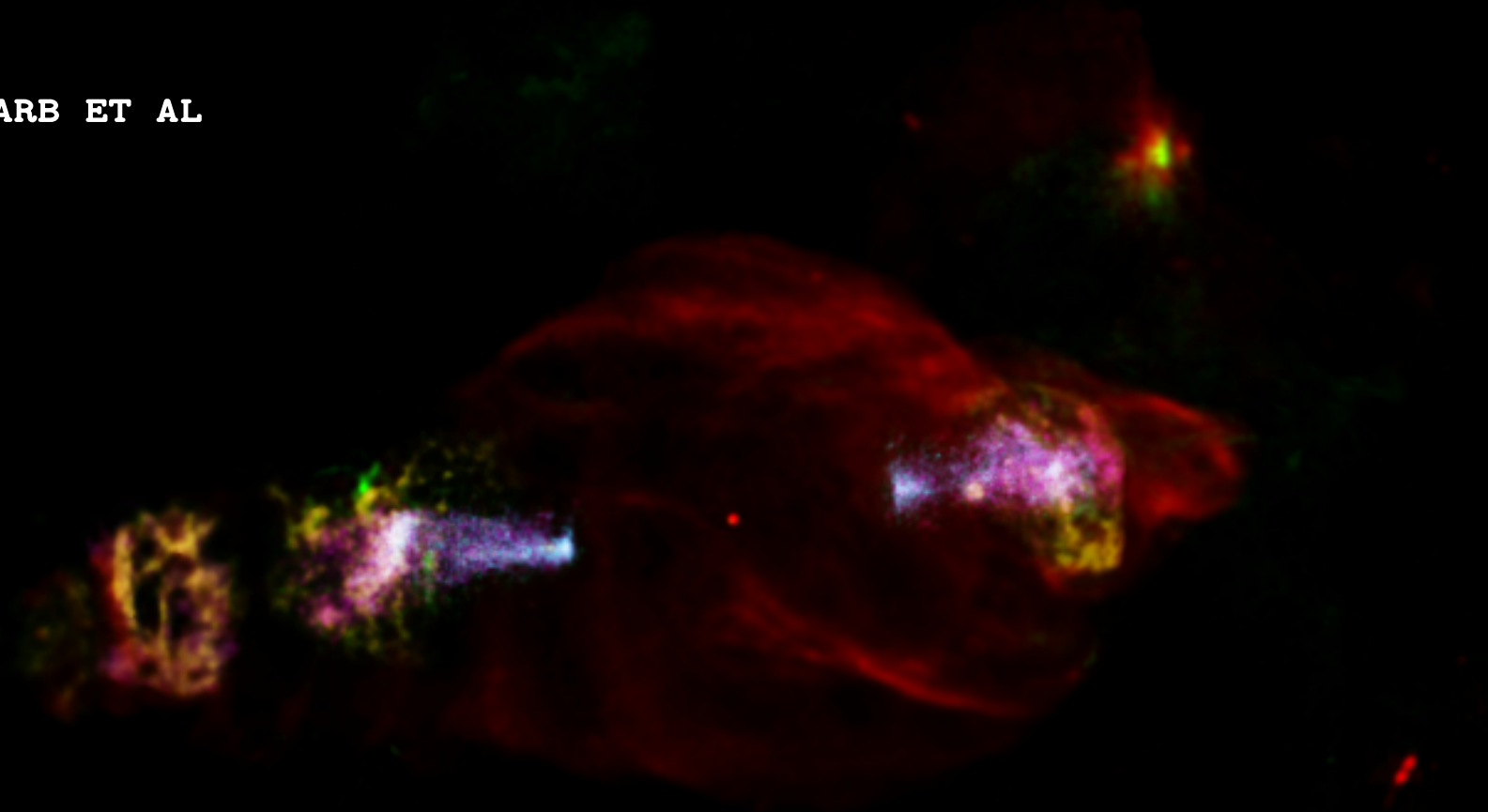
► RECALL THAT THE JETS LAUNCHED WITH

$$v_{\text{JET}} = 0.26c$$

► $E_c > 200$ TEV REQUIRES EFFICIENT ACCELERATION, MEANING v_{JET} CANNOT HAVE DECREASED MUCH BEFORE REACHING THE OUTER JET



SAFI-HARB ET AL



SEE DEC 11TH SEMINAR BY SAMAR!

SS 433: OPEN QUESTIONS

- ▶ **WHERE AND HOW ARE PARTICLES ACCELERATED?**

WHERE THE JETS REAPPEAR IN X-RAY BY A SHOCK

- ▶ **ELECTRONS OR PROTONS?** ELECTRONS RADIATE BUT PROTONS ARE PRESENT
IN THE JET AND MIGHT BE ACCELERATED TOO

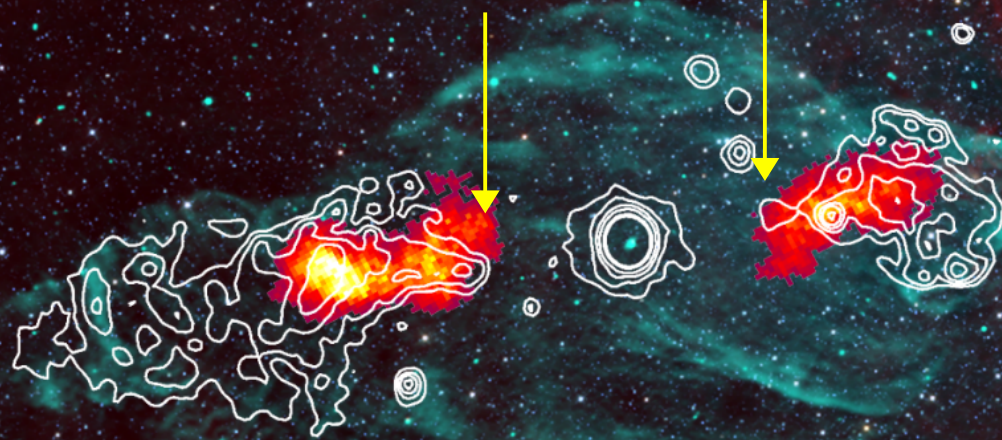
- ▶ **WHY DO THE JETS REAPPEAR?** BECAUSE THERE IS A SHOCK!

ACTUAL DATA

BLUE: RADIO EMISSION FROM NEBULA

WHITE: OUTLINE OF JETS IN X-RAY

SHOCKS EFFICIENTLY
ACCELERATING PARTICLES!



THE JETS OF SS 433 HOST SHOCKS THAT CAN ACCELERATE
PARTICLES TO ENERGIES OF AT LEAST HUNDREDS OF TEV



BACKGROUND: NRAO/AUI/NSF, K. GOLAP, M. GOSS;
NASA'S WIDE FIELD SURVEY EXPLORER (WISE); X-
RAY (GREEN CONTOURS): ROSAT/M. BRINKMANN;
TeV (RED COLORS): H.E.S.S. COLLABORATION.

1. WHAT CAN WE LEARN ABOUT PARTICLE ACCELERATION IN JETS USING MICROQUASARS?

- ▶ WITH SS 433 WE COULD IDENTIFY THE MECHANISM BY WHICH PARTICLES ARE ACCELERATED IN AN ASTROPHYSICAL JET FOR THE FIRST TIME
- ▶ MANY JET PROPERTIES FOLLOW A SIMPLE SCALING WITH BLACK HOLE MASS → NOT CRAZY TO EXTRAPOLATE
- ▶ BUT SS 433 MIGHT BE A TOTAL OUTLIER - **HARD TO MAKE A STATEMENT WITH ONLY ONE DATA POINT**

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2. DO MICROQUASARS CONTRIBUTE TO GALACTIC COSMIC RAYS UP TO THE "KNEE"?

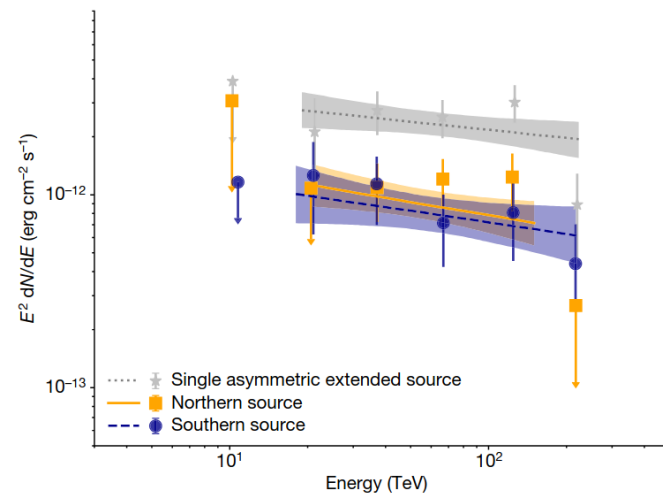
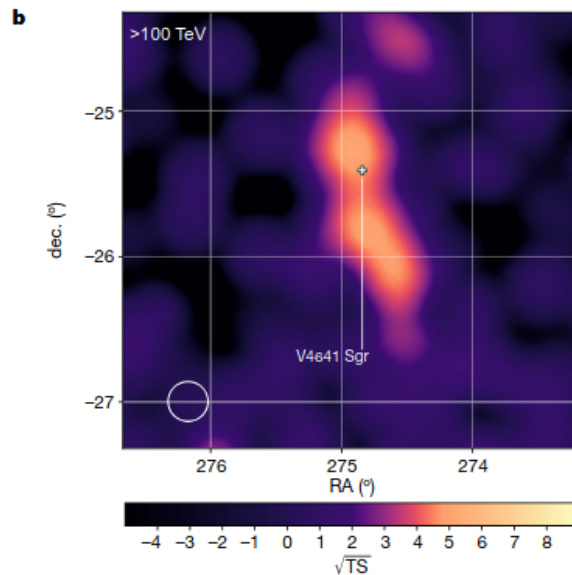
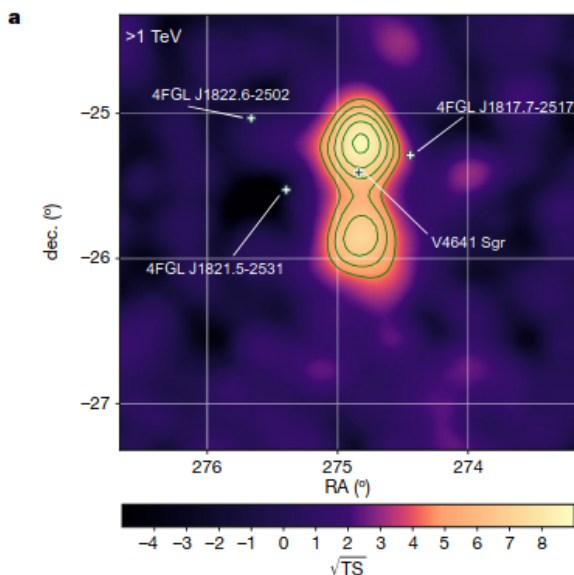
$$E_{\text{Hillas}} \approx 10Z \left(\frac{B}{20\mu\text{G}} \right) \left(\frac{u_1}{0.26c} \right) \left(\frac{R}{1.6\text{pc}} \right) \text{PeV},$$

- ▶ IN PRINCIPLE POSSIBLE - BUT VERY HARD TO MAKE A STATEMENT WHEN WE ONLY KNOW ONE!

HAWC COMES TO THE RESCUE (AGAIN)



GAMMA2022: REPORT OF TEV EMISSION SURROUNDING A SECOND MICROQUASAR

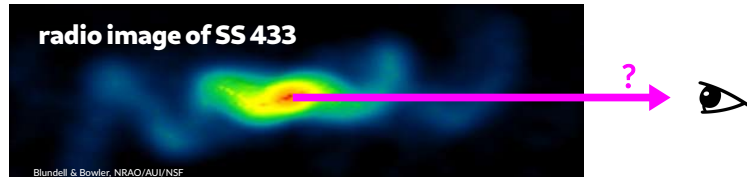


SEE NEXT SEMINAR BY SABRINA!

HAWC COLL. NATURE 2024

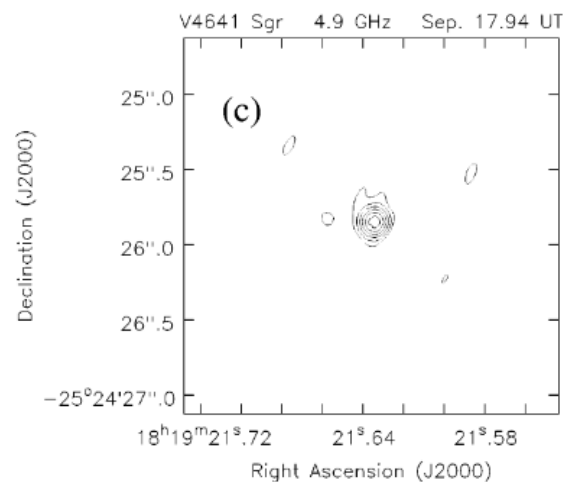
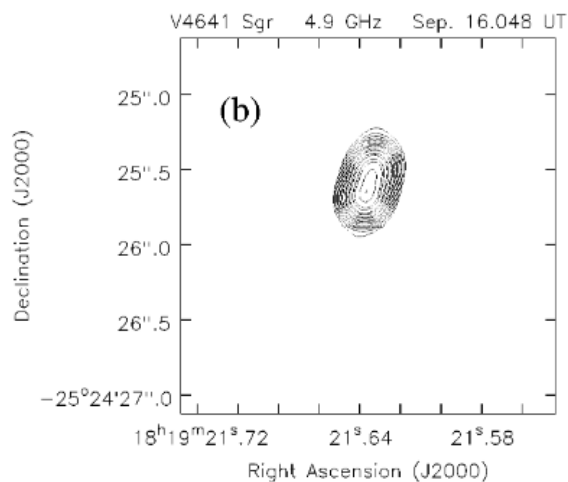
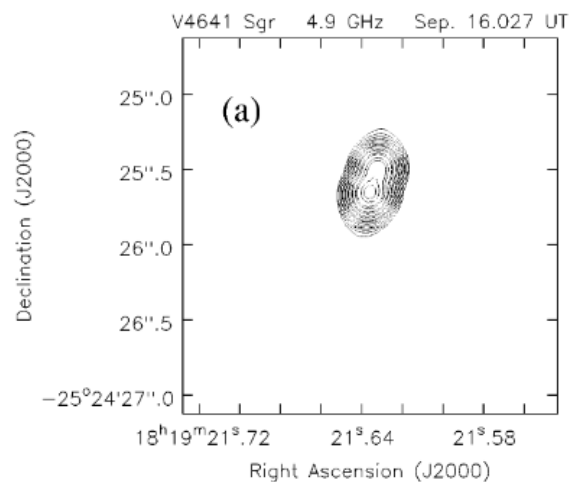
MEET V4641 SGR

radio image of SS 433

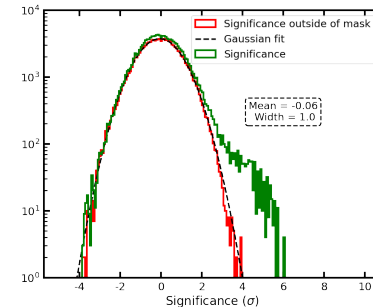
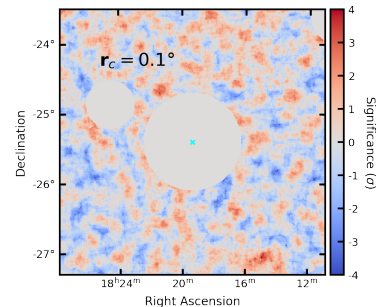
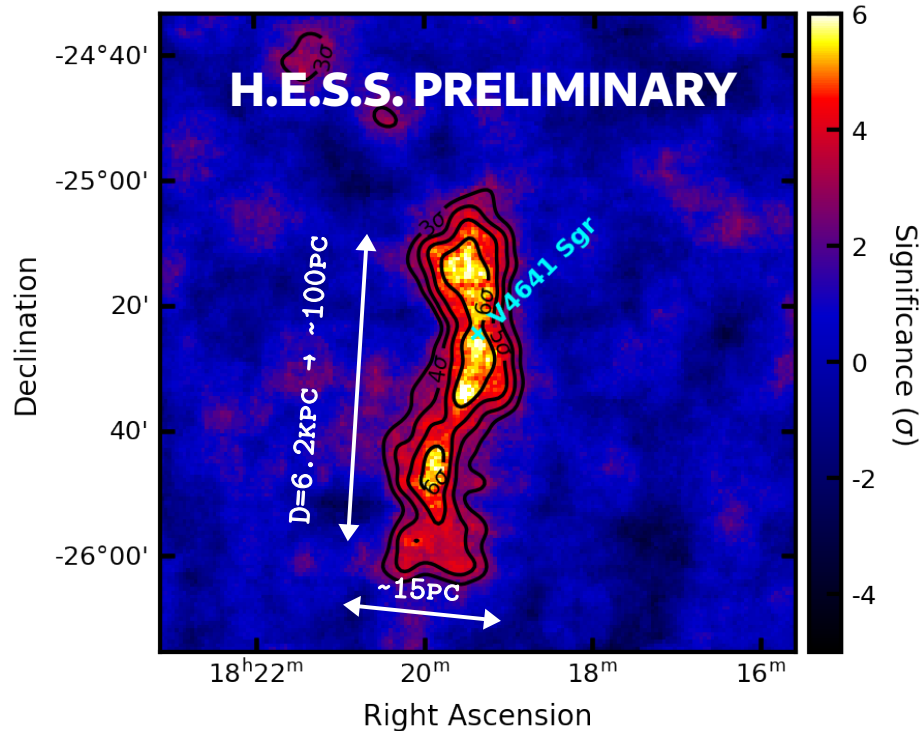


- ▶ LMXB WITH A B9III COMPANION STAR (2.8 DAYS PERIOD)
- ▶ GIANT X-RAY FLARE IN 1999
- ▶ RADIO OBSERVATIONS IMPLY SUPERLUMINAL MOTION
- ▶ INDICATION OF RELATIVISTIC MOTIONS AT LOW INCLINATION ANGLE WRT TO LINE OF SIGHT
- ▶ PRESENCE OF A FAST JET POINTING TOWARDS US

HJELLMING ET AL



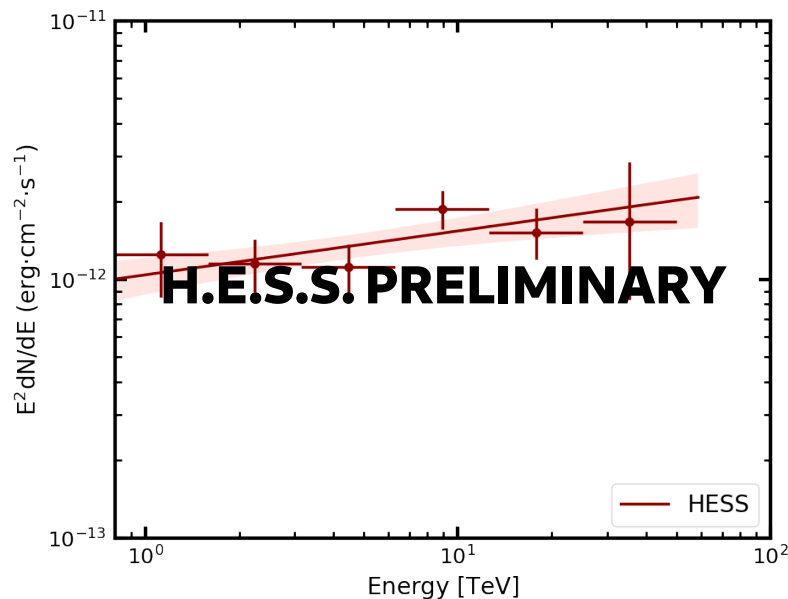
H.E.S.S. DETECTION



- ▶ CLEARLY DETECTED, ELONGATED AND ASYMMETRIC
- ▶ ASSUMING $D=6.2 \text{ kpc}$ (MACDONALDS ET AL) THE EMISSION IS $\sim 100 \text{ pc}$ LONG (!)
- ▶ V4641 NOT AT THE CENTRE OF EMISSION
- ▶ NO BETTER COUNTERPART (5° BELOW GPLANE)

H.E.S.S. PRELIMINARY

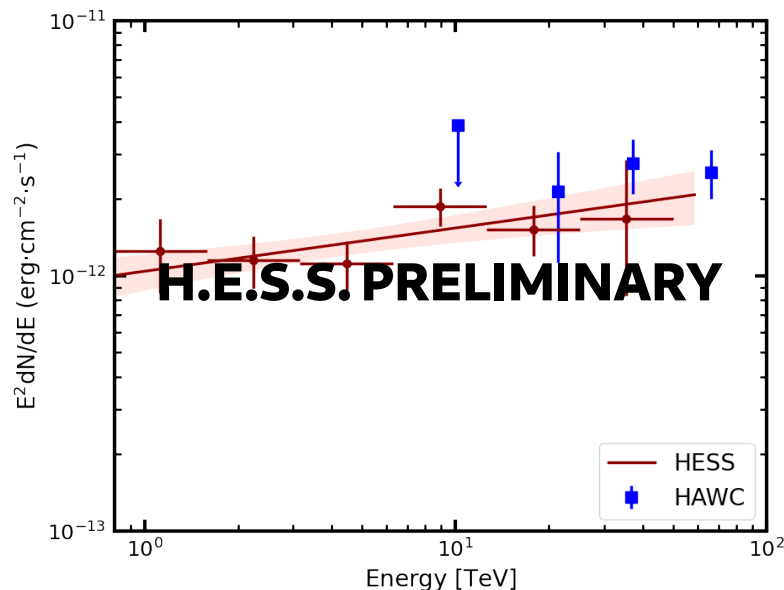
H.E.S.S. DETECTION



- ▶ BEST FIT MODEL: SINGLE ELLIPTICAL COMPONENT WITH A VERY HARD PHOTON SPECTRUM ($\Gamma=1.8$)
- ▶ TWO COMPONENT MODEL NOT PREFERRED
- ▶ SPECTRAL PROPERTIES CONSISTENT ACROSS THE EMISSION REGION
- ▶ NO EVIDENCE OF DISTINCT EMISSION REGIONS OR LOBES

H.E.S.S. PRELIMINARY

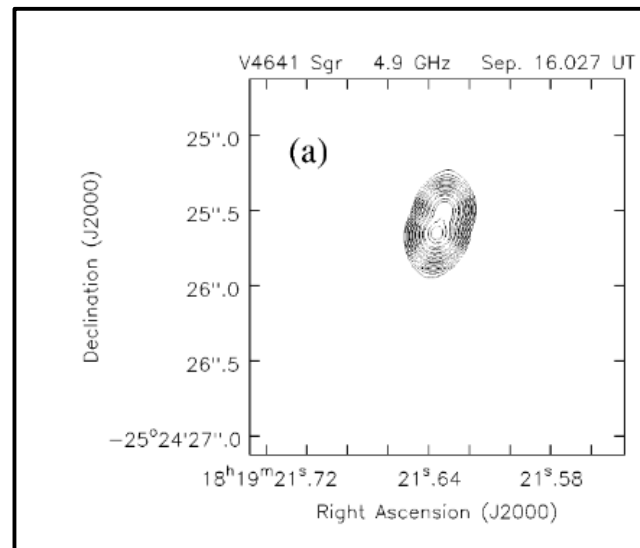
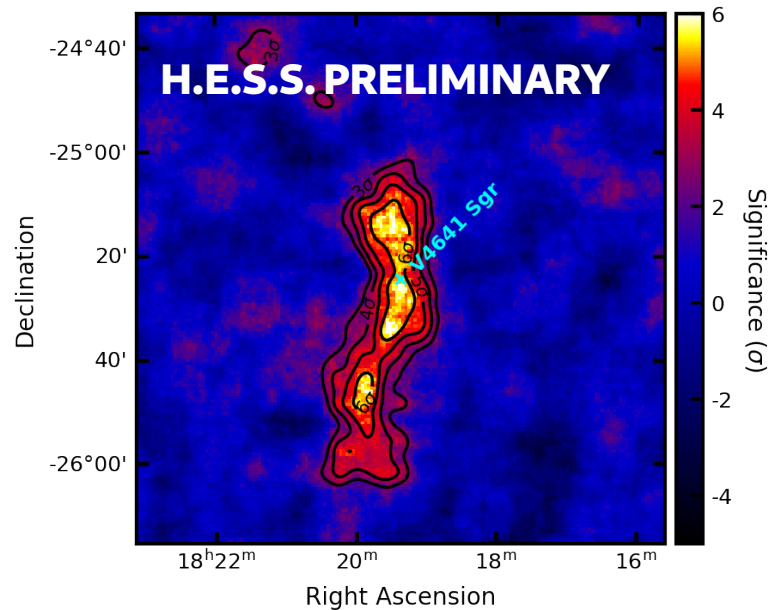
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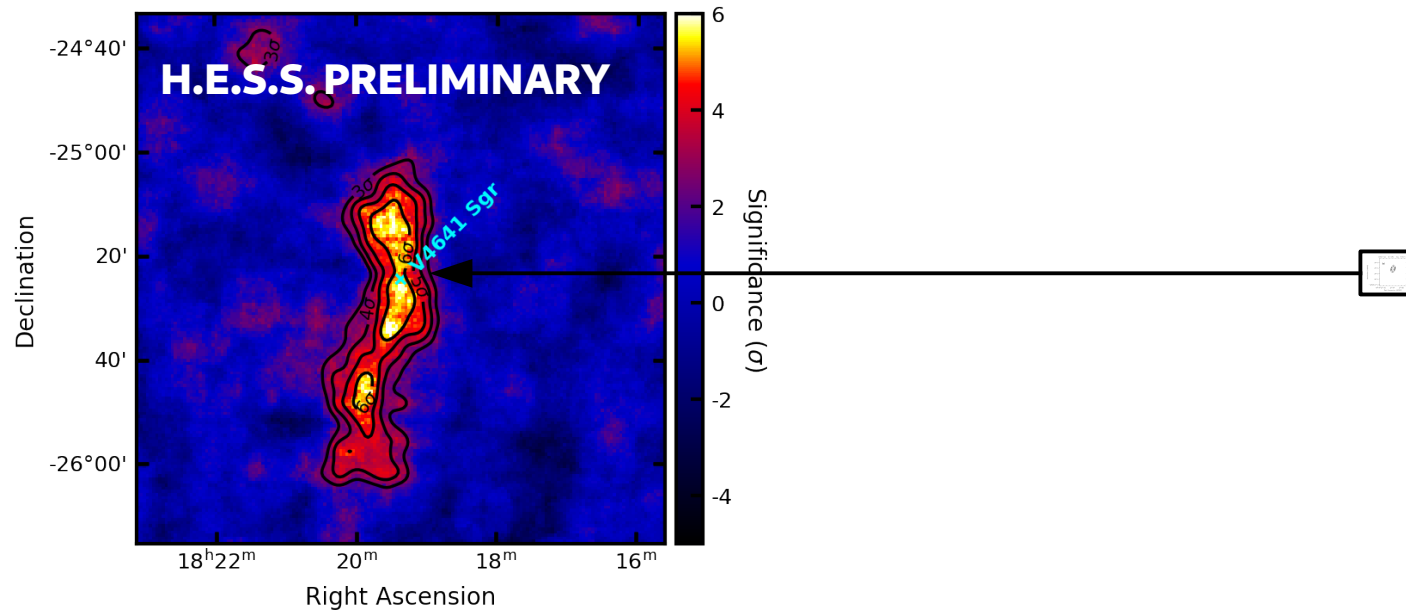
H.E.S.S. PRELIMINARY

WHAT IS THIS THING?



H.E.S.S. PRELIMINARY

WHAT IS THIS THING?



H.E.S.S. PRELIMINARY

ANY HELP FROM OTHER WAVELENGTHS?

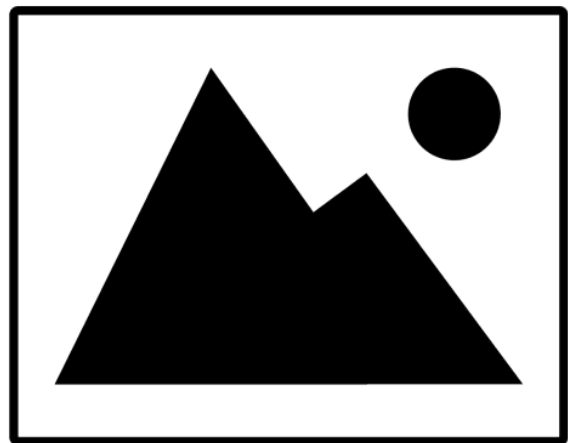


IMAGE NOT FOUND

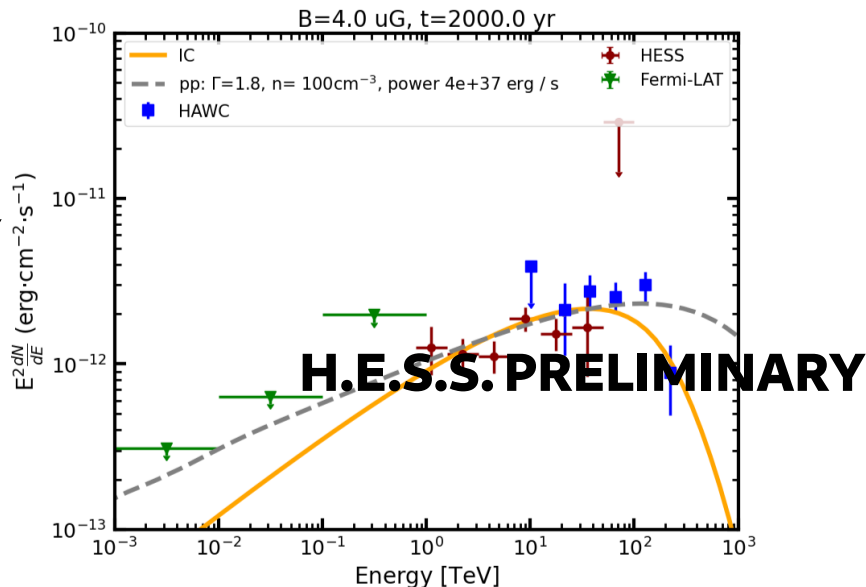
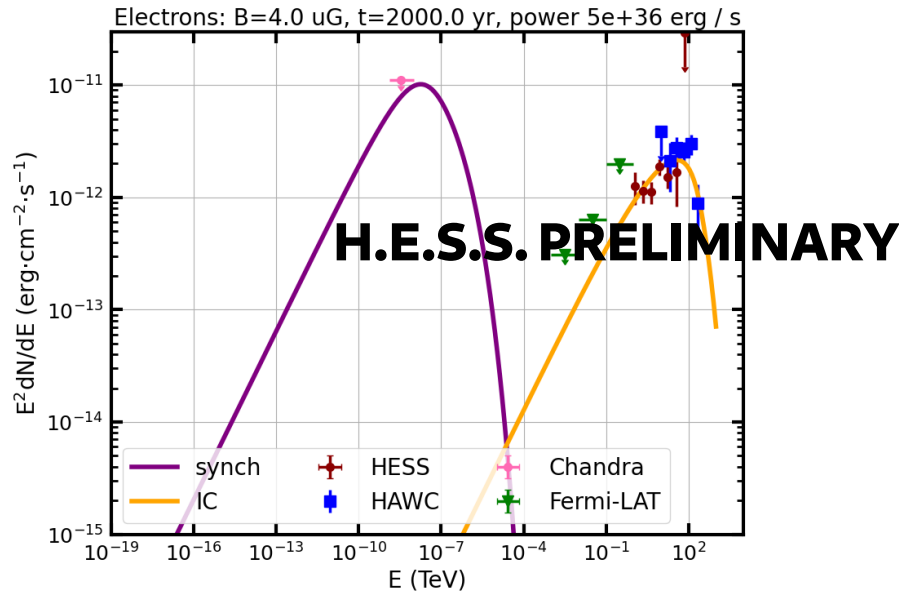
- ▶ PREVIOUS OBSERVATIONS FOCUSED ON THE NARROW FIELD AROUND THE BINARY.
- ▶ NO KNOWN X-RAY EMISSION ON LARGE SCALES, CHANDRA UL DERIVED BY NAOMI TSUJI
- ▶ NO COMPARABLE KNOWN RADIO STRUCTURE

SOME SIMPLE MODELING USING GAMERA

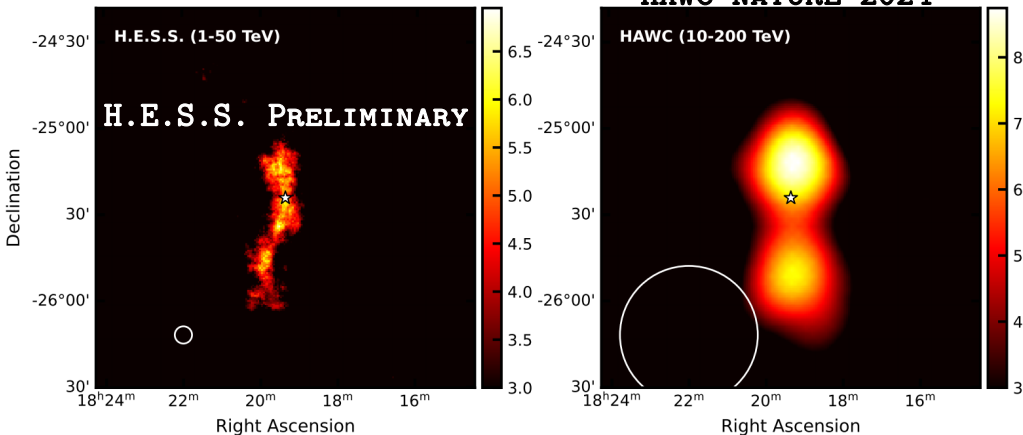
FERMI-LAT ANALYSIS: M. LEMOINE-GOUMARD

X-RAY ANALYSIS: N. TSUJI

- ▶ LEPTONIC: ASSUMING POPESCU ET AL RADIATION MODEL, $T=2000$ YR (TOTAL GUESS)
 - ▷ B FIELD HAS TO BE RELATIVELY LOW ($<5 \mu\text{G}$), ($\text{SS } 433 \rightarrow 20 \mu\text{G}$), HIGH POWER REQUIREMENT
- ▶ HADRONIC: EITHER HIGH DENSITY OR HIGH TOTAL ENERGY: $E_{\text{TOT}} = 3 \cdot 10^{49} (10 \text{cm}^{-3}/N) \text{ ERG}$



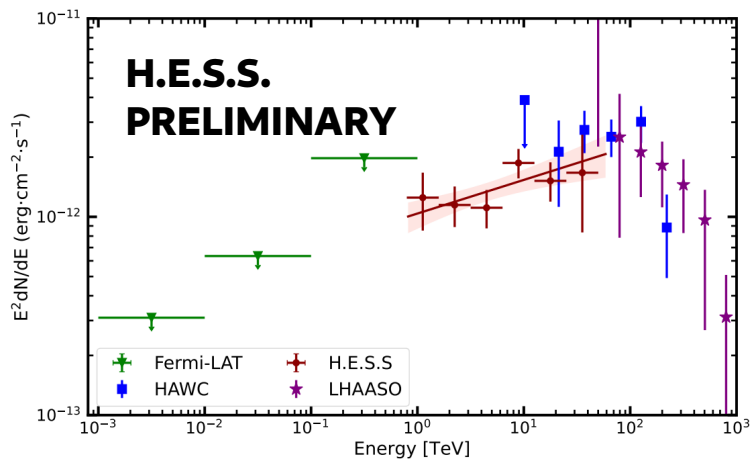
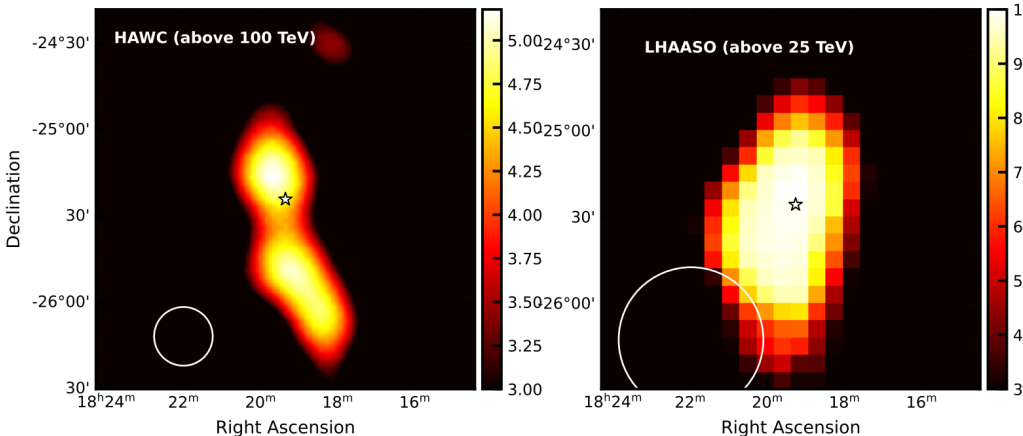
HAWC NATURE 2024

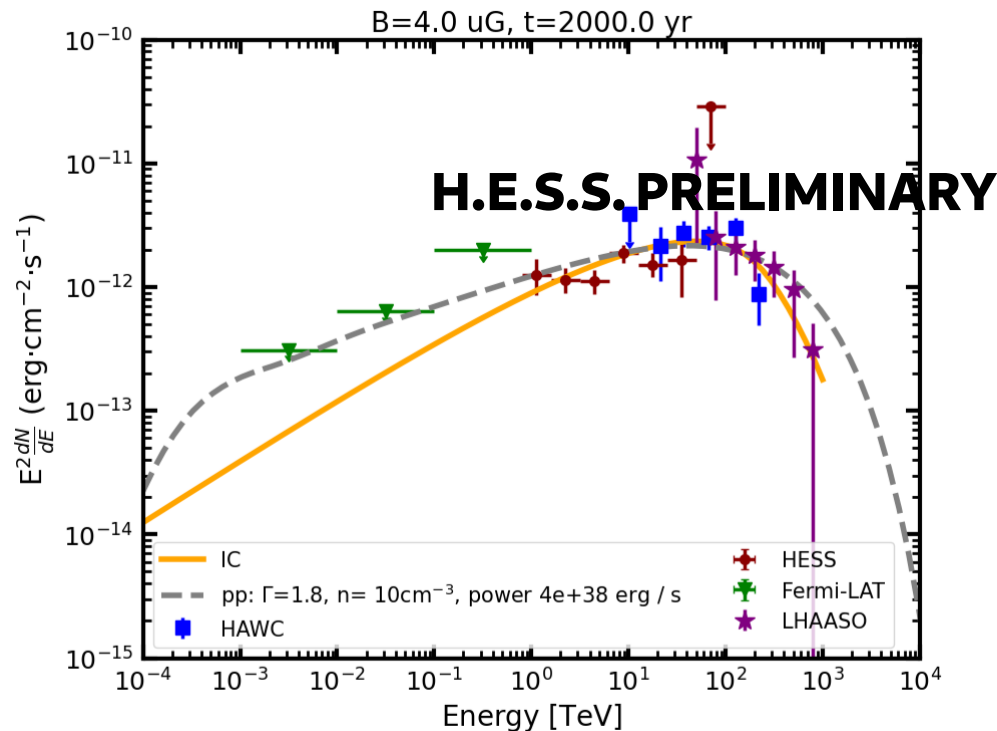


LHAASO DETECTED PHOTONS UP TO 800 TeV FROM V4641 SGR !!

LHAASO COLLABORATION [2410.08988](https://arxiv.org/abs/2410.08988)

HAWC NATURE 2024

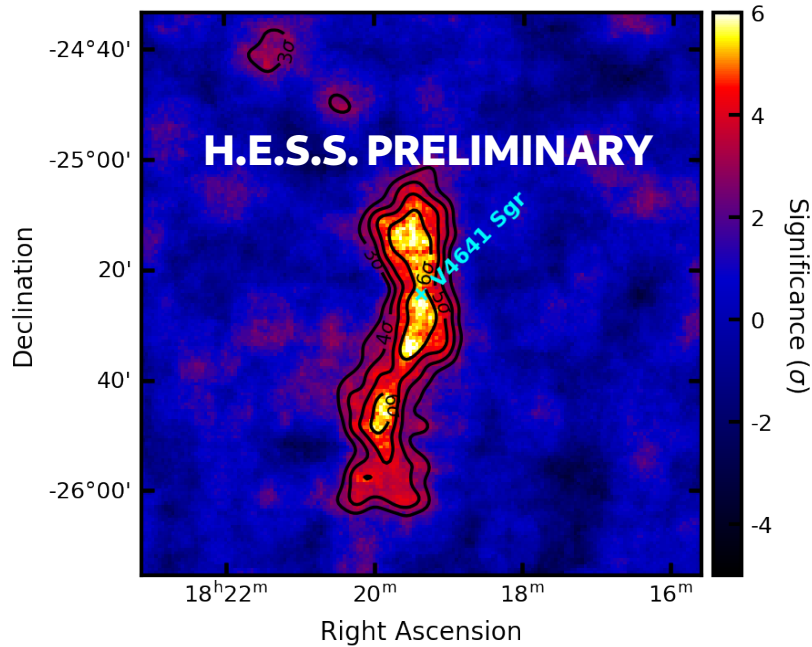




- ▶ LET'S PASS SOME LINES THROUGH POINTS AGAIN
- ▶ PARTICLE CUTOFF ENERGY AT A FEW PEV NO MATTER THE SCENARIO
- ▶ **ONE-ZONE MODELING IS NOT THE WHOLE STORY!** ONE HAS TO CONSIDER TRANSPORT AND COOLING OVER LARGE SCALES

H.E.S.S. PRELIMINARY

WHAT CAN THIS BE?



1) THE STRUCTURE WE SEE IS THE JETS

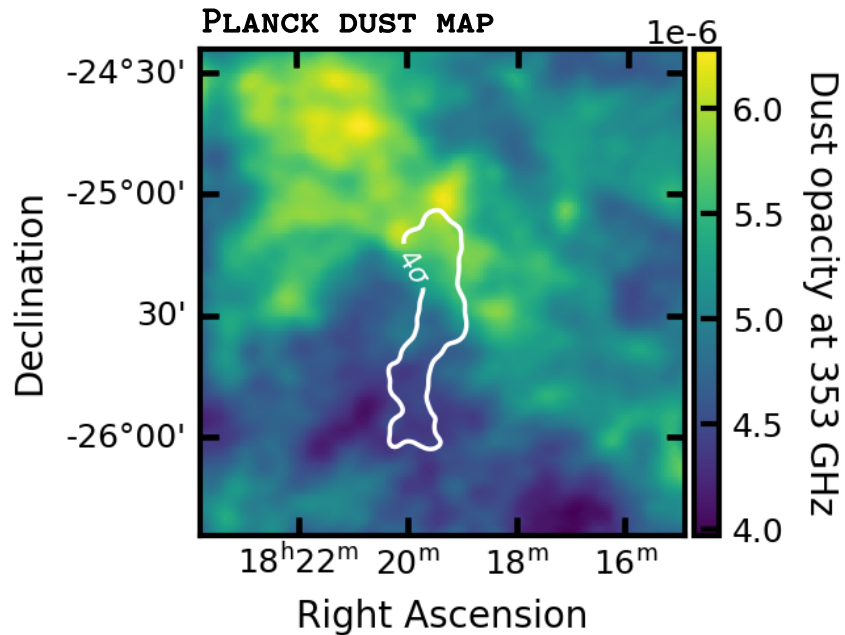
- WHY SO DIFFERENT FROM THE RADIO?

2) THE STRUCTURE WE SEE IS CREATED BY PARTICLES ACCELERATED BY THE JETS WHICH ESCAPED

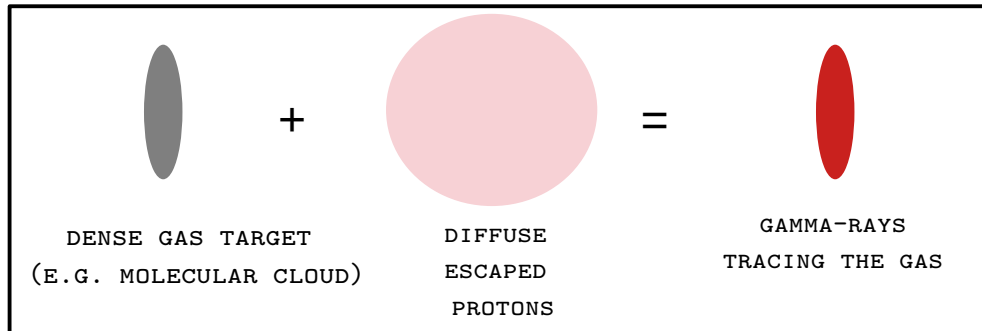
- WHY DOES IT HAVE THAT SHAPE?

H.E.S.S. PRELIMINARY

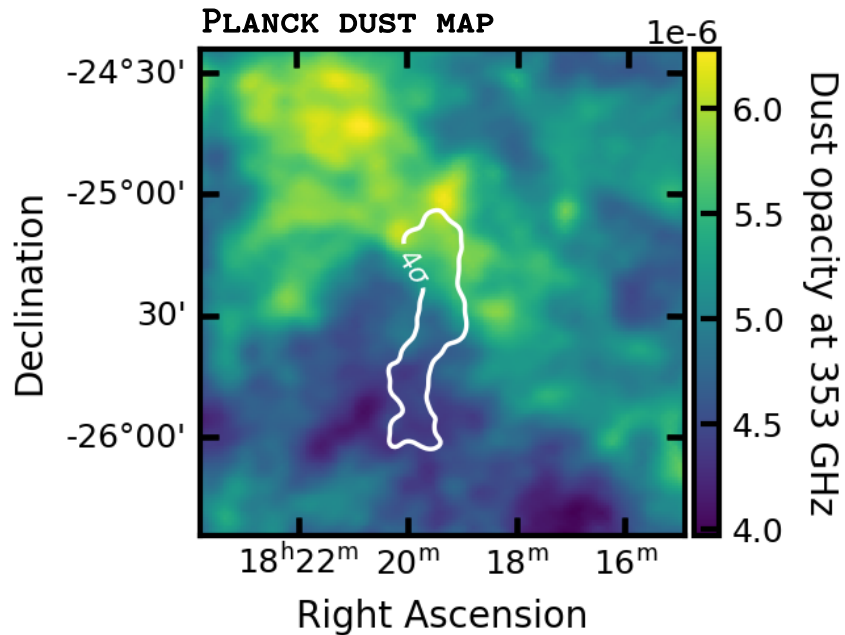
ESCAPED PARTICLES INTERACTING WITH...



1) GAS?



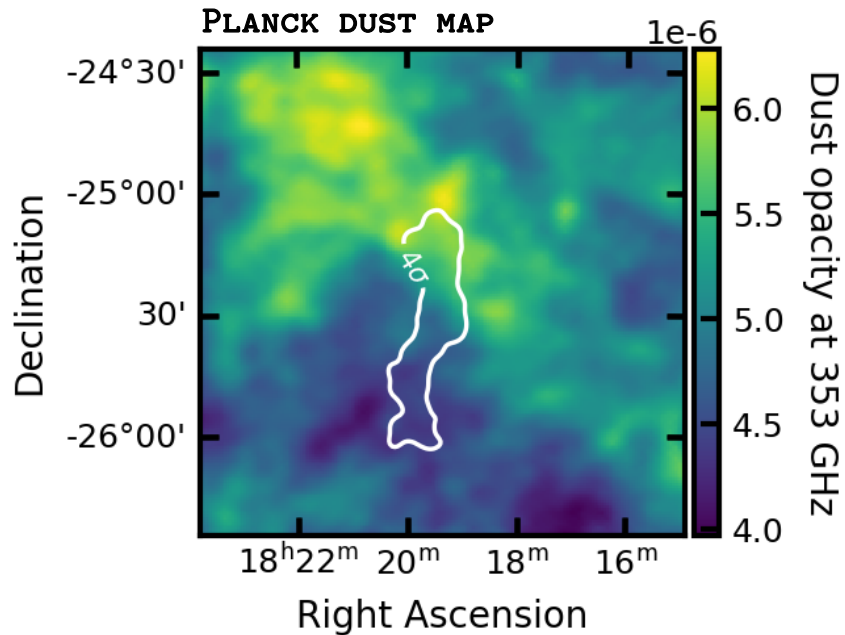
ESCAPED PARTICLES INTERACTING WITH...



1) GAS?

- THERE DOESN'T SEEM TO BE MUCH THERE!
- DEDICATED OBS SOON (PI: N. TSUJI)

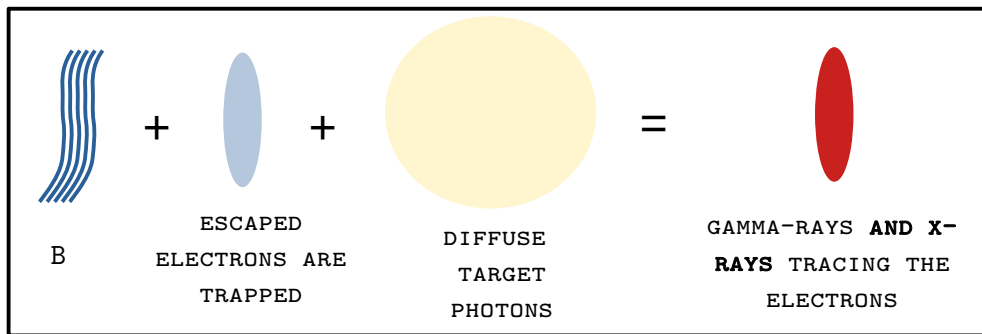
ESCAPED PARTICLES INTERACTING WITH...



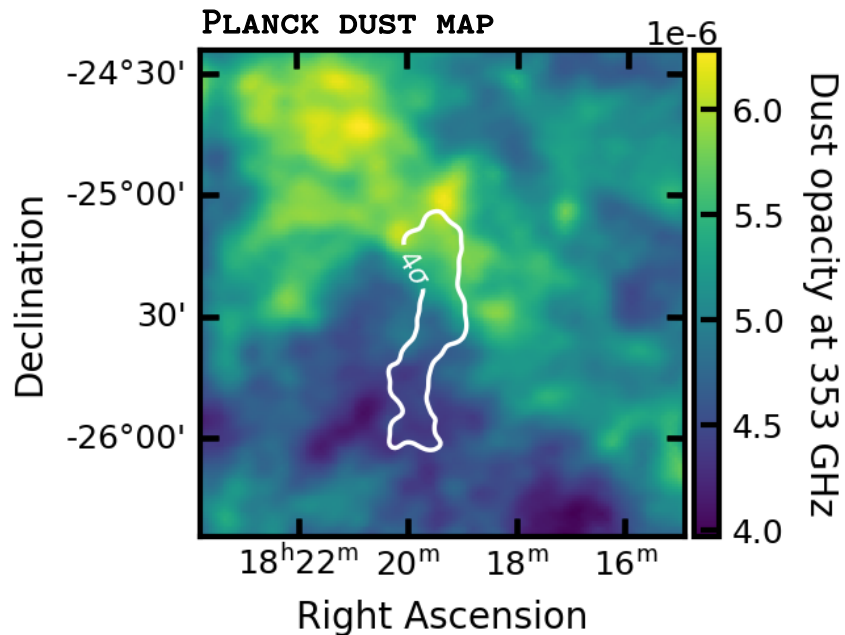
1) GAS?

- THERE DOESN'T SEEM TO BE MUCH THERE!
- DEDICATED OBS SOON (PI: N. TSUJI)

2) A MAGNETIC FIELD STRUCTURE?



ESCAPED PARTICLES INTERACTING WITH...



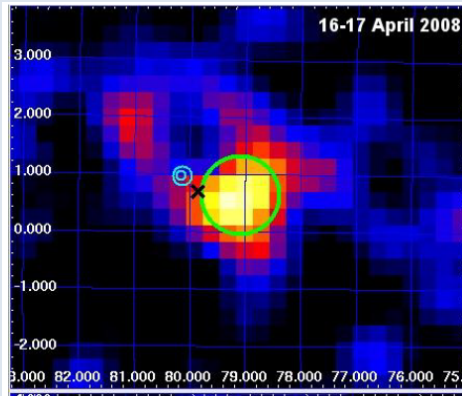
1) GAS?

- THERE DOESN'T SEEM TO BE MUCH THERE!
- [DEDICATED OBS SOON \(PI: N. TSUJI\)](#)

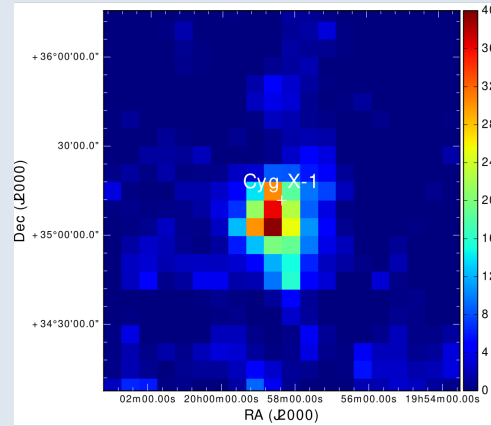
2) A MAGNETIC FIELD STRUCTURE?

- ELECTRONS WOULD RADIATE IN X-RAY
- [XMM PROPOSAL SUBMITTED \(PI: X. WANG\)](#)

AGILE COLL 2009

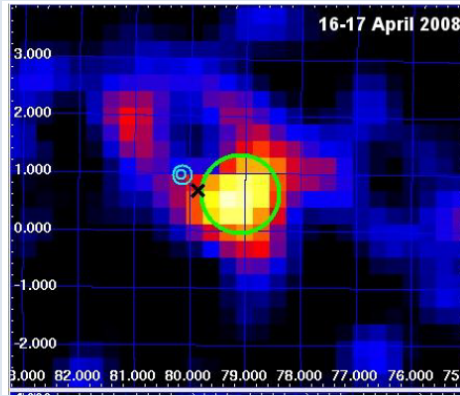


ZANIN ET AL 2016



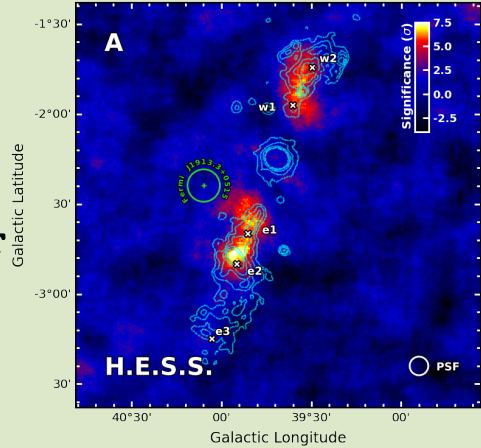
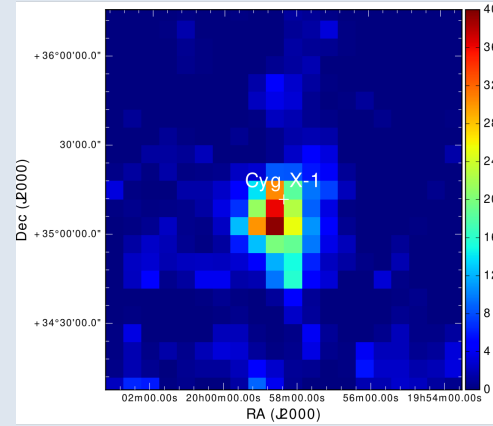
GeV,
TRANSIENT

AGILE COLL 2009



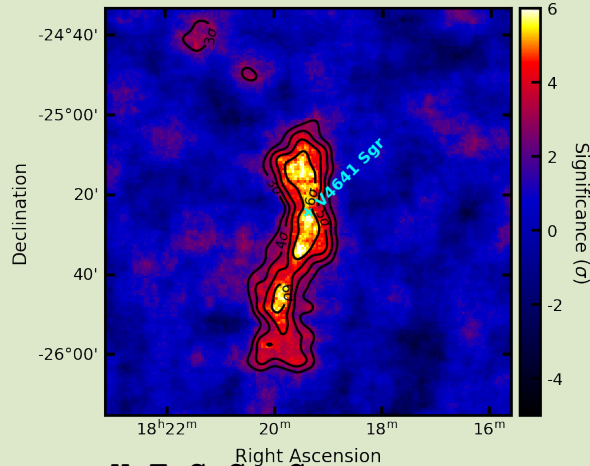
GeV,
TRANSIENT

ZANIN ET AL 2016



TeV,
PERSISTENT

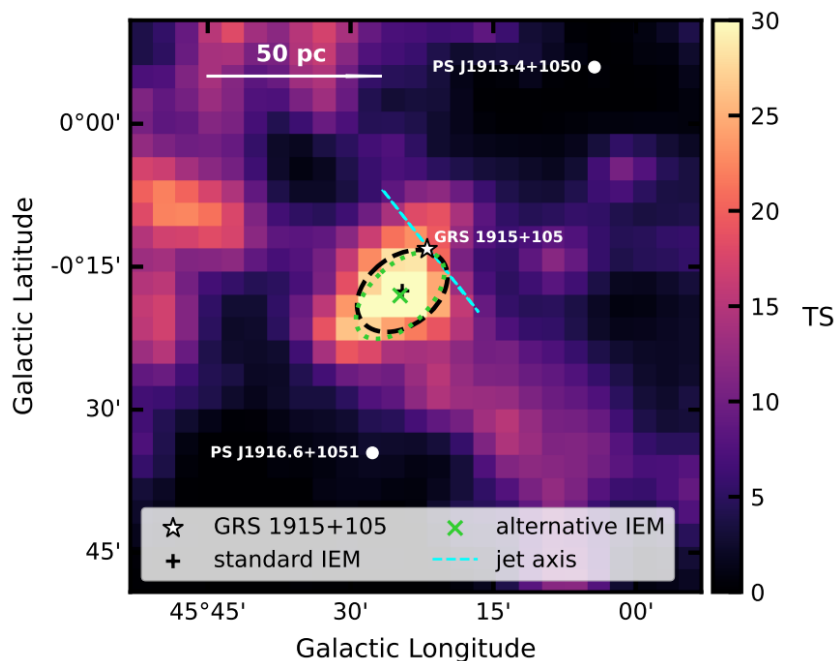
H.E.S.S. COLL 2024



H.E.S.S. COLL IN PREP



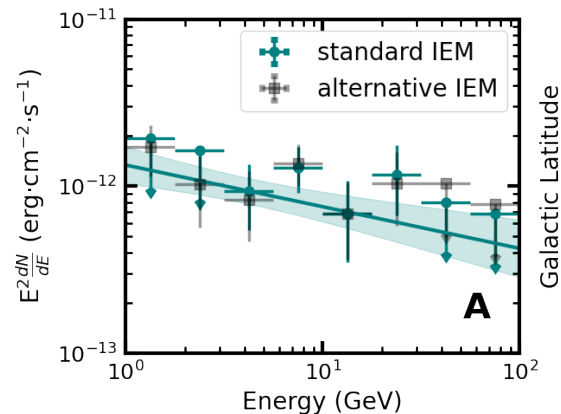
IS EVERYTHING TRANSIENT IN THE GEV BAND?



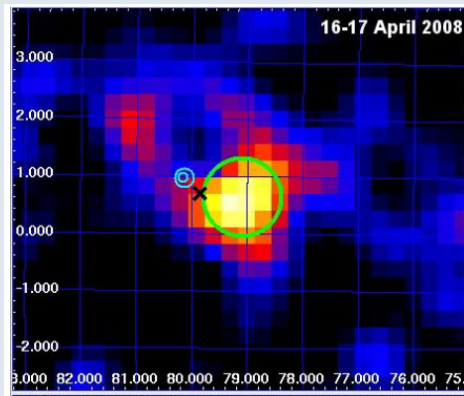
MARTI-DEVESA & LON, SUBMITTED

[2410.10396](https://arxiv.org/abs/2410.10396)

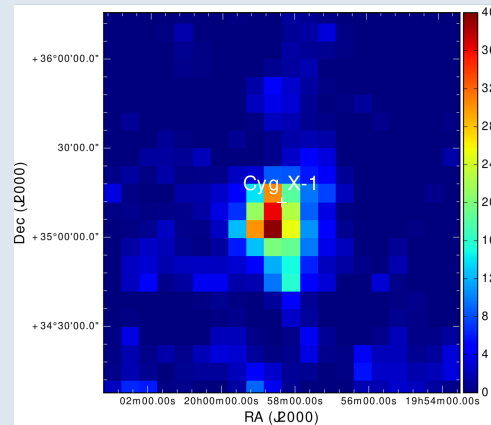
- ▶ THIS SUMMER WE LOOKED AT ENTIRE FERMI-LAT DATA AROUND GRS 1915+105
- ▶ FOUND PERSISTENT NEW SOURCE, BEST COUNTERPART IS THE MICROQUASAR
- ▶ LIKELY HADRONIC ORIGIN



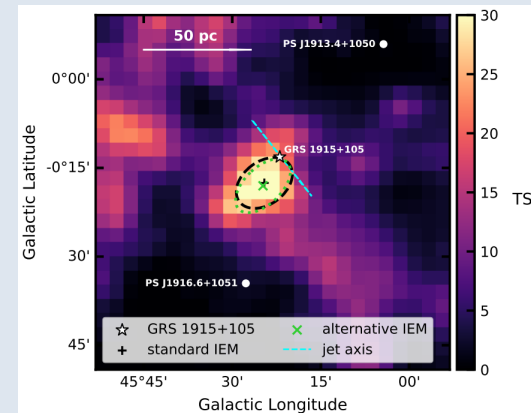
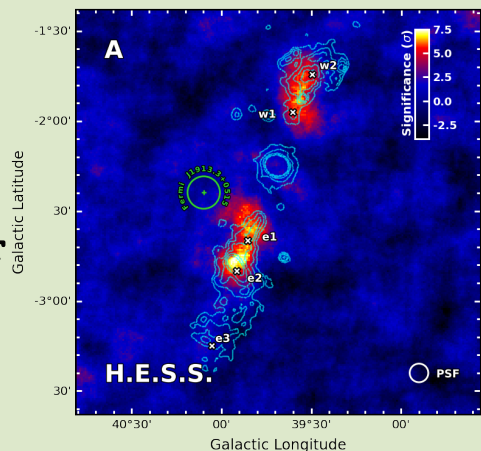
AGILE COLL 2009



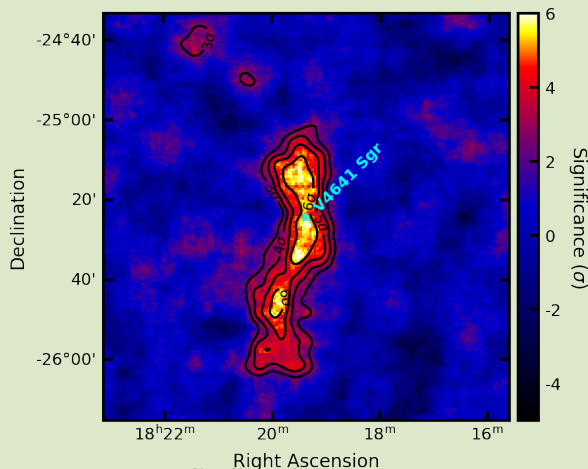
ZANIN ET AL 2016



MARTI-DEVESEA & LON, SUBMITTED

TEV,
PERSISTENT

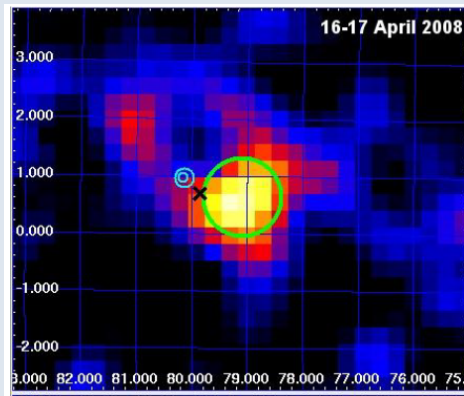
H.E.S.S. COLL 2024



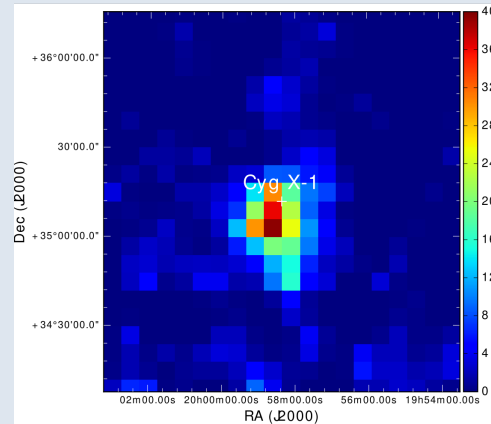
H.E.S.S. COLL IN PREP

GeV, TRANSIENT

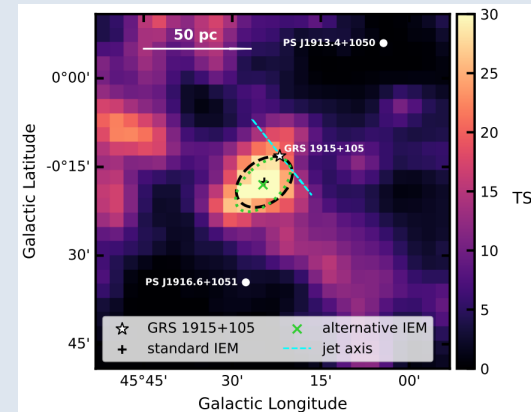
AGILE COLL 2009



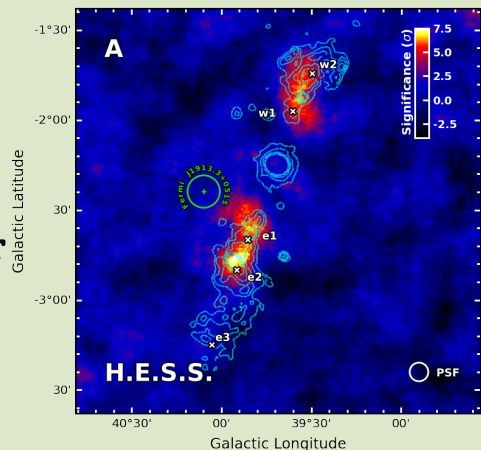
ZANIN ET AL 2016



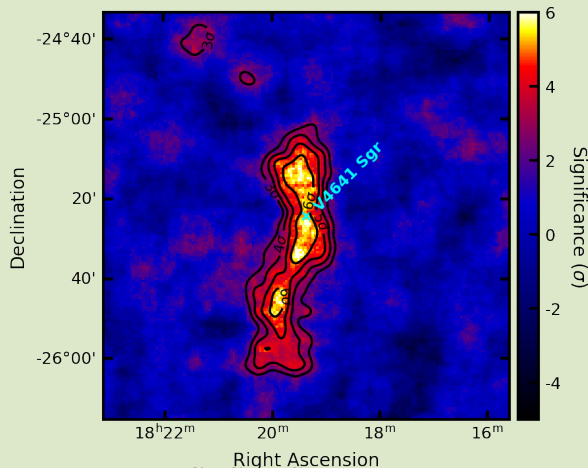
MARTI-DEVESEA & LON, SUBMITTED



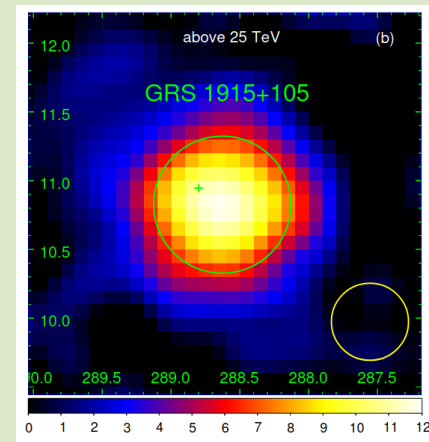
TeV, PERSISTENT



H.E.S.S. COLL 2024



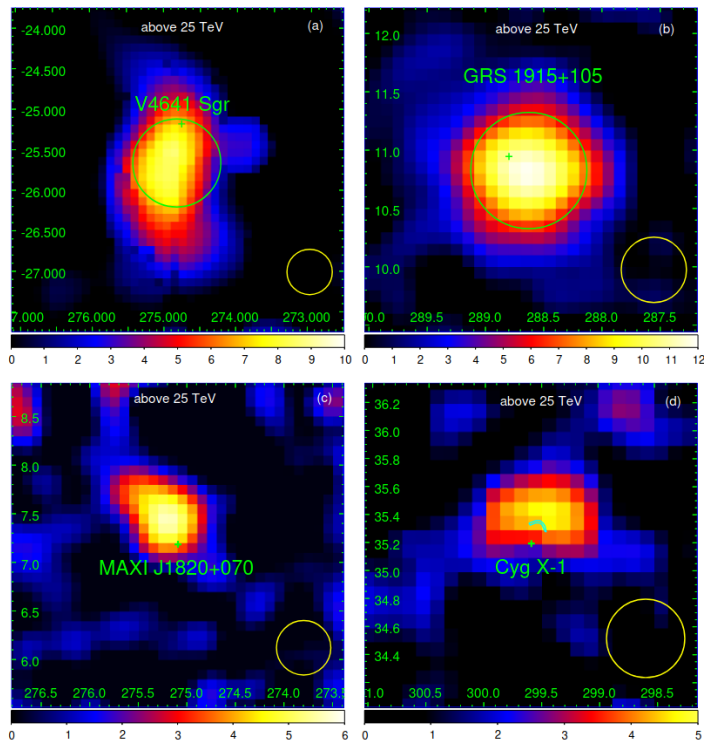
H.E.S.S. COLL IN PREP



LHAASO COLL. ARXIV



THE LHAASO REVOLUTION

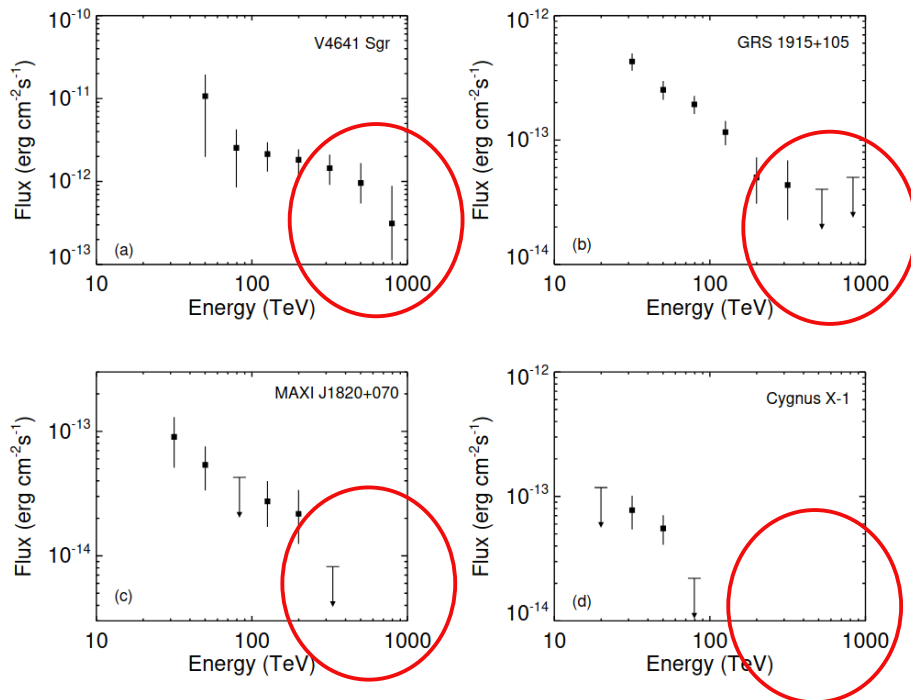


- ▶ ON ARXIV LAST WEEK!
- ▶ REPORT >25 TEV PHOTONS FROM 5 SOURCES
- ▶ Two "KNOWN": SS 433, V4641 Sgr
- ▶ THREE NEW! GRS 1915+105, Cyg X-1, MAXI J1820+070
- ▶ ALL WITH PERSISTENT EMISSION, AND EXTENDED WHEN STATISTICS ARE HIGH ENOUGH

SEE NOV 27TH SEMINAR BY RUOYU!

LHAASO COLLABORATION [2410.08988](#)

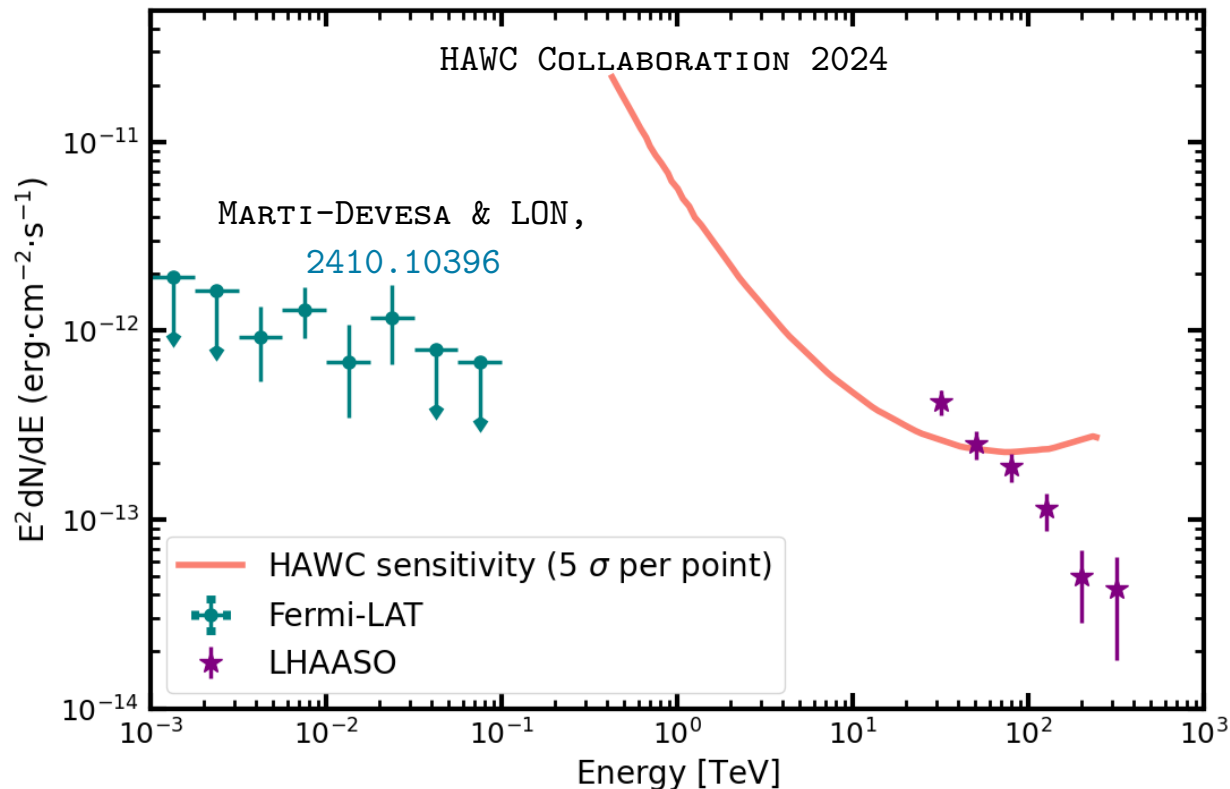
THE LHAASO REVOLUTION



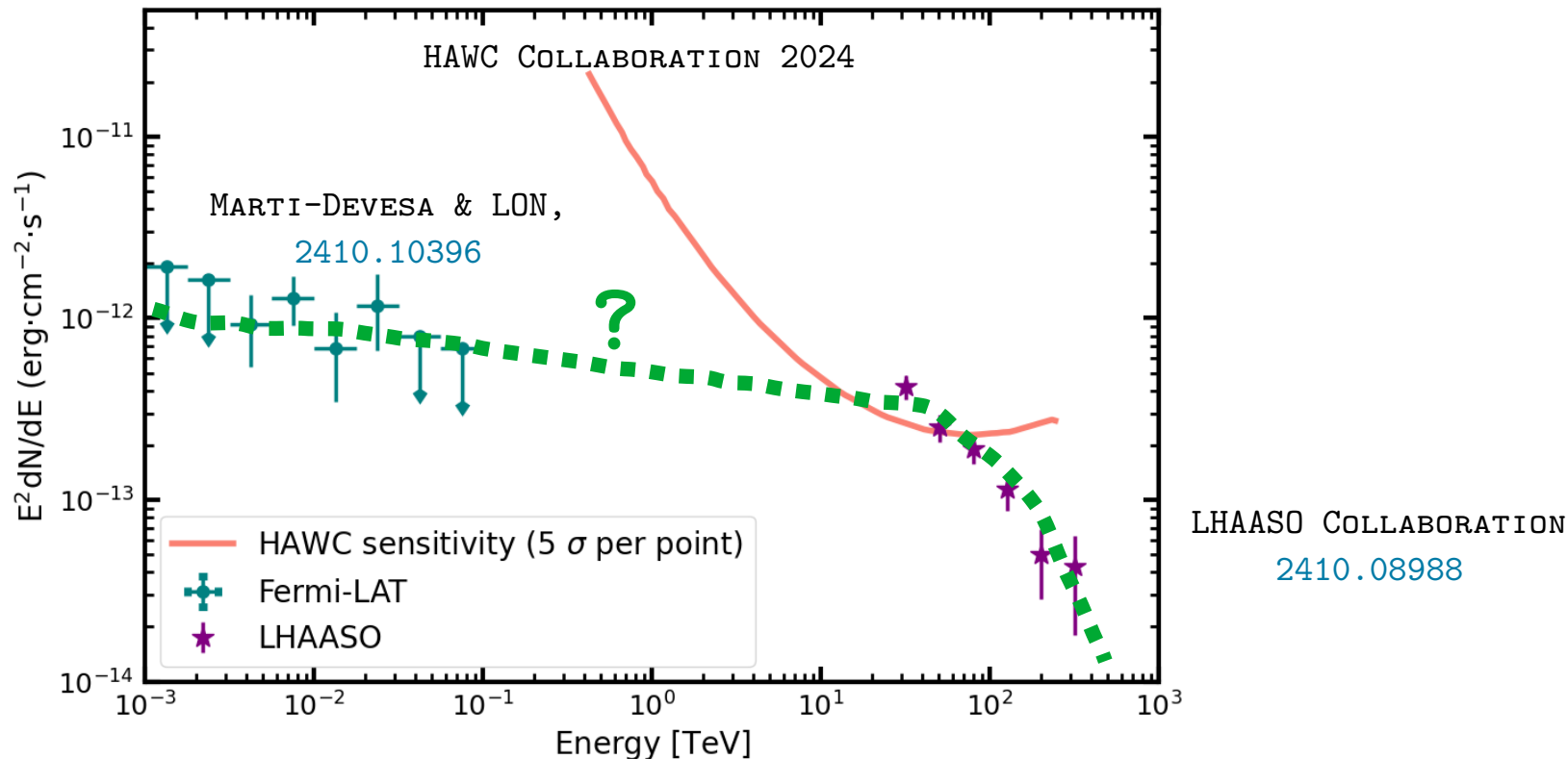
LHAASO COLLABORATION [2410.08988](#)

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- ▶ V4641 SGR BY FAR THE BRIGHTEST AND MOST ENERGETIC

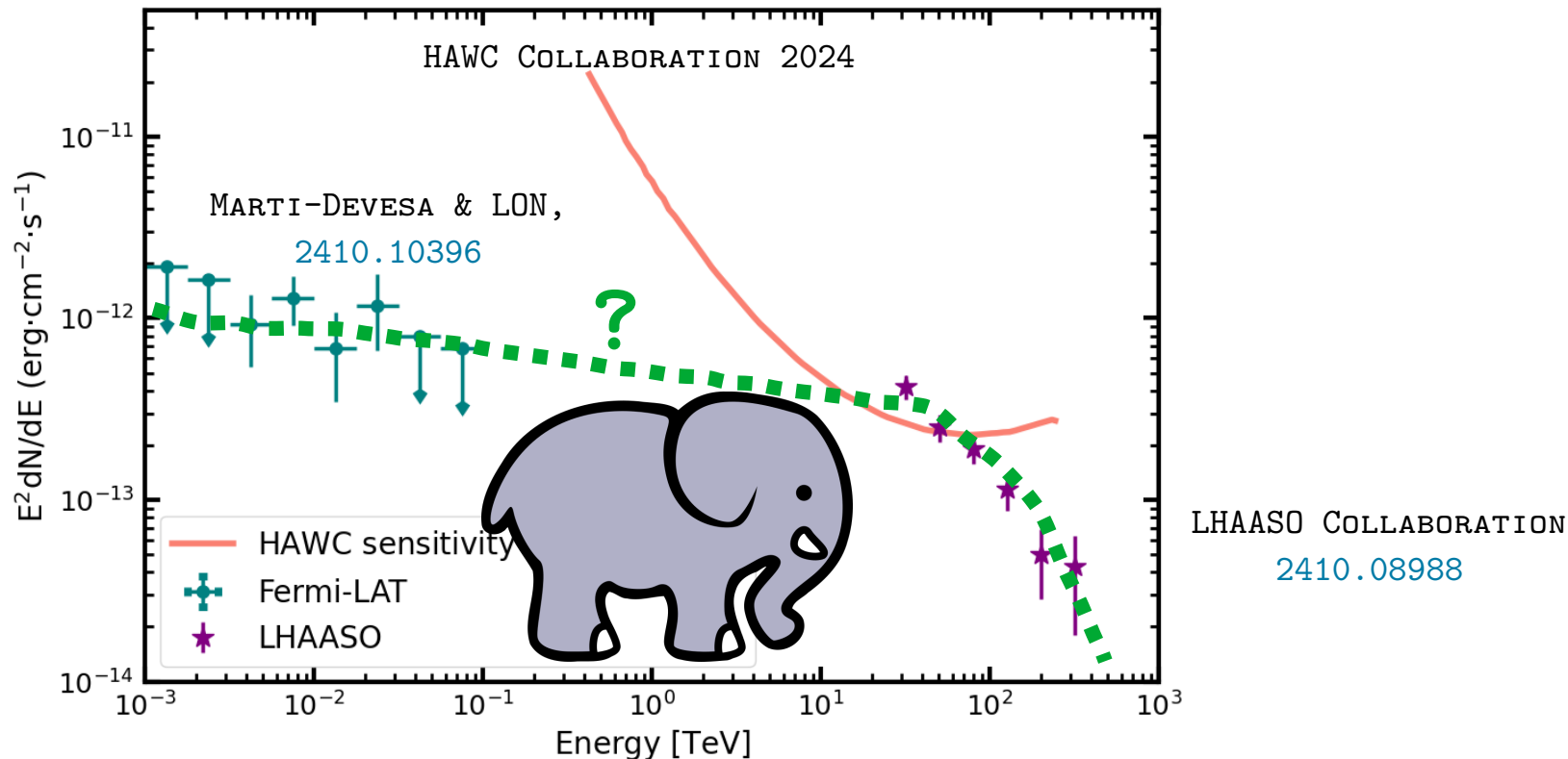
THE LHAASO REVOLUTION: GRS 1915+105



THE LHAASO REVOLUTION: GRS 1915+105



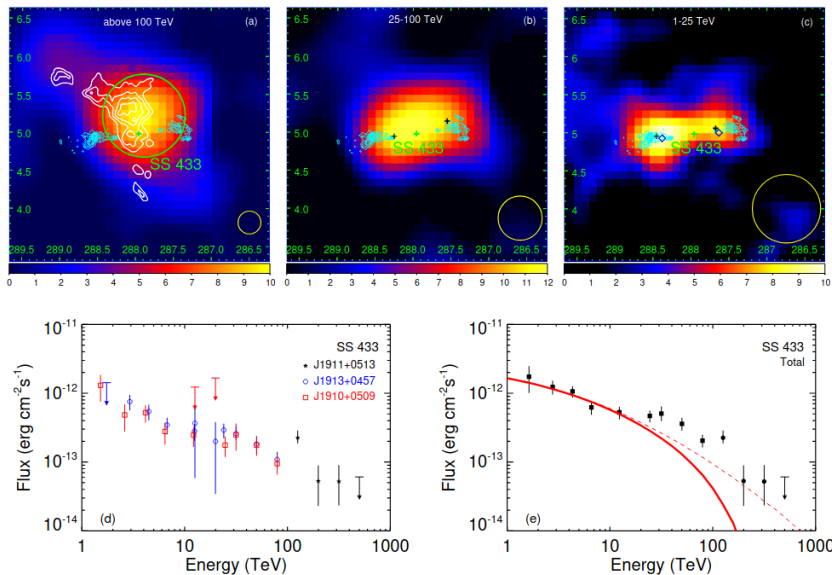
THE LHAASO REVOLUTION: GRS 1915+105



THE LHAASO REVOLUTION: SS 433

SEE NOV 27TH SEMINAR BY RUOYU!

- ▶ NEW COMPONENT ABOVE 100 TeV!
INTERPRETED AS HADRONIC

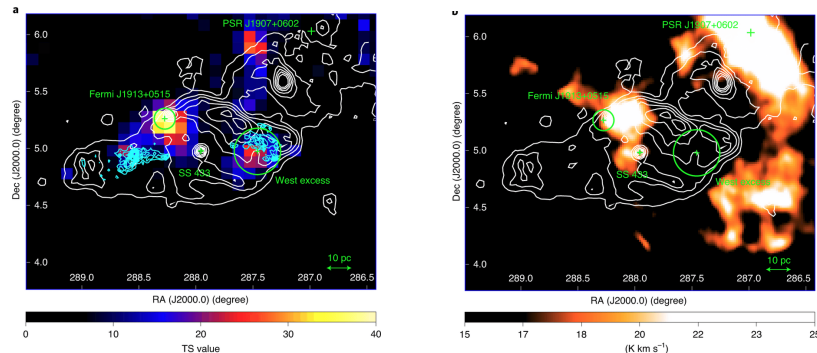
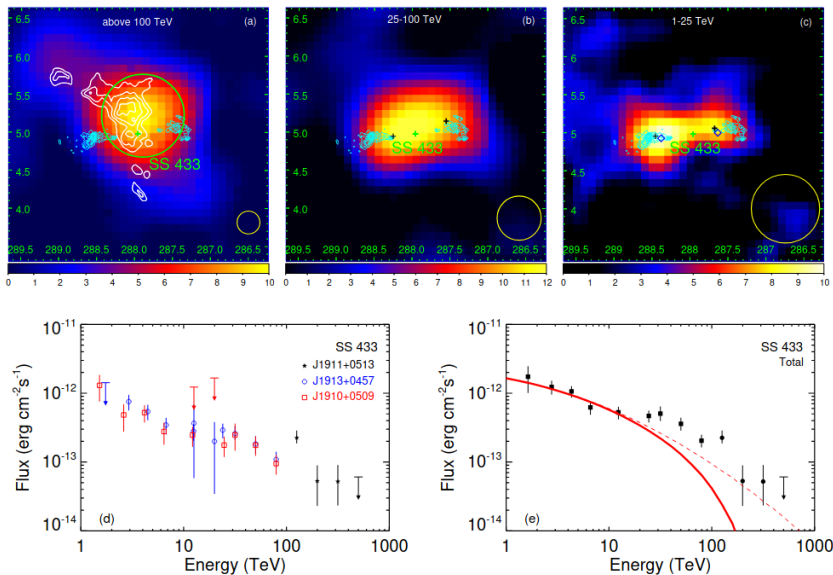


LHAASO COLLABORATION [2410.08988](https://arxiv.org/abs/2410.08988)

THE LHAASO REVOLUTION: SS 433

SEE NOV 27TH SEMINAR BY RUOYU!

- ▶ NEW COMPONENT ABOVE 100 TeV!
INTERPRETED AS HADRONIC
- ▶ PRESENCE OF NEUTRAL GAS PREVIOUSLY
ASSOCIATED WITH A PULSATING FERMI-
LAT SOURCE



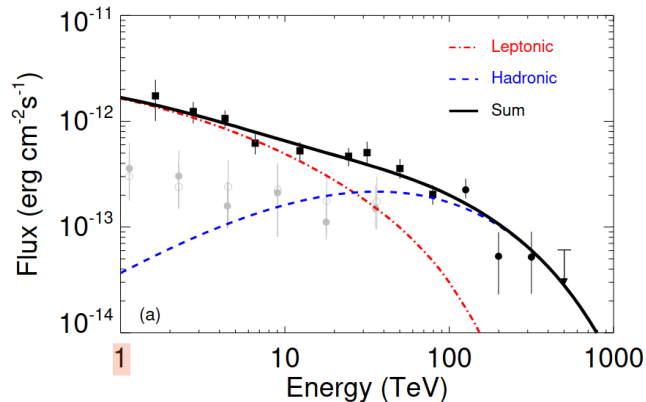
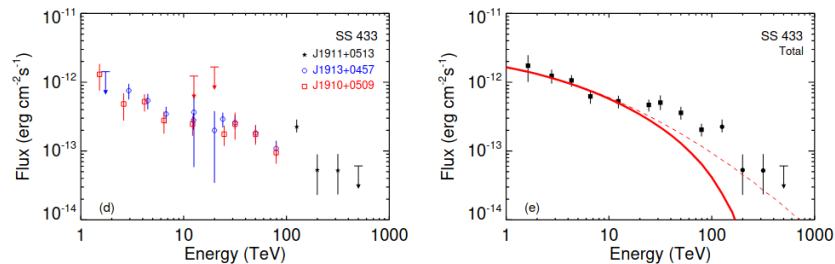
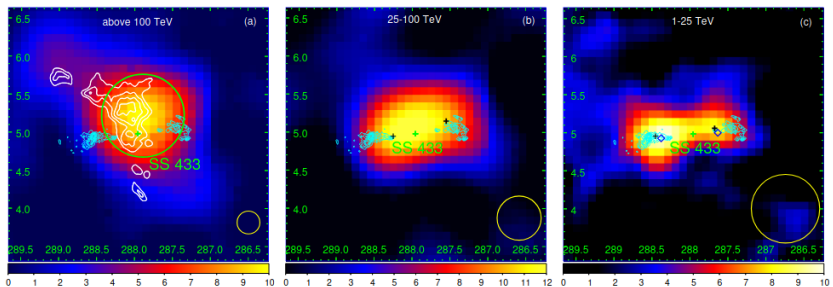
LHAASO COLLABORATION [2410.08988](https://arxiv.org/abs/2410.08988)

LI ET AL 2020

THE LHAASO REVOLUTION: SS 433

SEE NOV 27TH SEMINAR BY RUOYU!

- ▶ NEW COMPONENT ABOVE 100 TeV!
INTERPRETED AS HADRONIC
- ▶ BELOW 100 TeV CONSISTENT PICTURE
WITH PREVIOUS STUDIES (ALTHOUGH THE
FLUX BELOW 10 TeV...?)

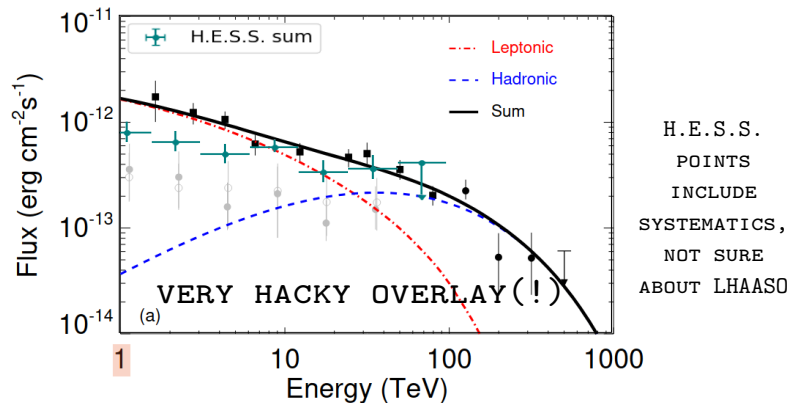
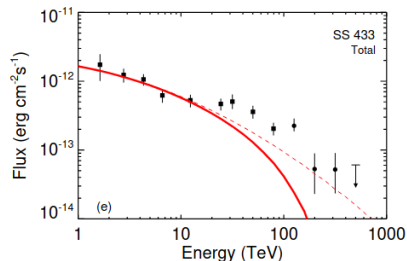
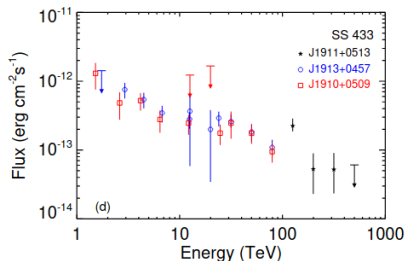
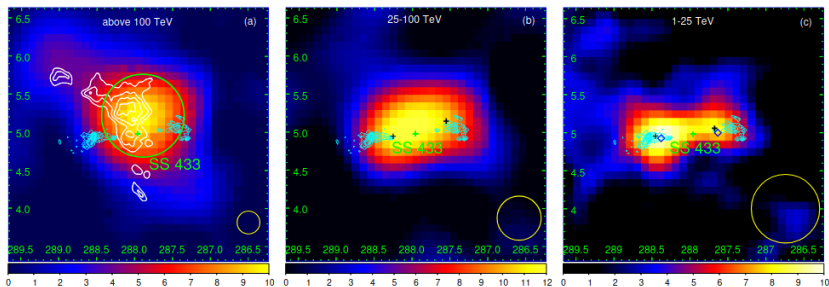


LHAASO COLLABORATION [2410.08988](https://arxiv.org/abs/2410.08988)

THE LHAASO REVOLUTION: SS 433

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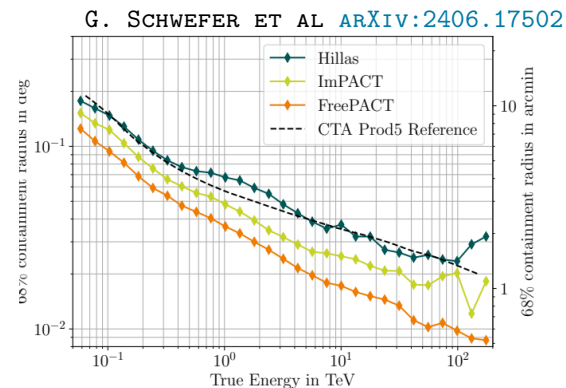
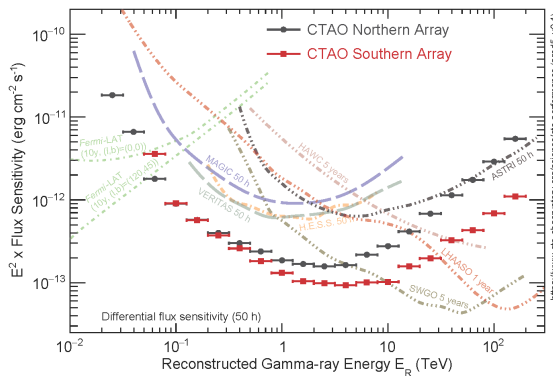


LHAASO COLLABORATION [2410.08988](https://arxiv.org/abs/2410.08988)

H.E.S.S.
POINTS
INCLUDE
SYSTEMATICS,
NOT SURE
ABOUT LHAASO

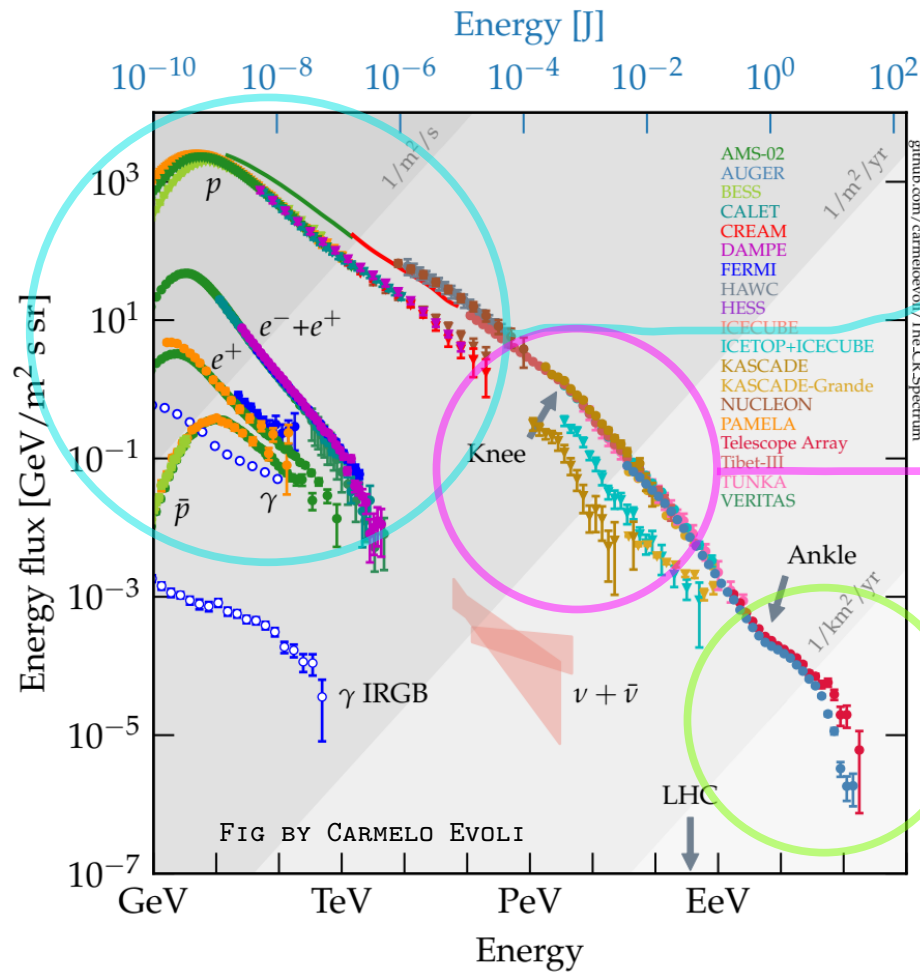
1. WHAT CAN WE LEARN ABOUT PARTICLE ACCELERATION IN JETS USING MICROQUASARS?

- ▶ WITH SS 433 WE COULD IDENTIFY THE MECHANISM BY WHICH PARTICLES ARE ACCELERATED IN AN ASTROPHYSICAL JET FOR THE FIRST TIME
- ▶ THIS COULD ONLY BE DONE **BECAUSE OF GOOD ANGULAR RESOLUTION!**
- ▶ ONLY OTHER SOURCE DETECTED BY AN IACT (**SO FAR**) IS V4641 SGR → STAY TUNED
- ▶ X-RAY/RADIO PICTURE CRUCIAL
- ▶ FUTURE IS BRIGHT!!!
- ▶ AND **SHARP**



2. DO MICROQUASARS CONTRIBUTE TO GALACTIC COSMIC RAYS UP TO THE "KNEE"?

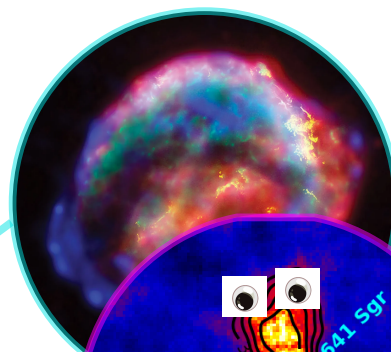
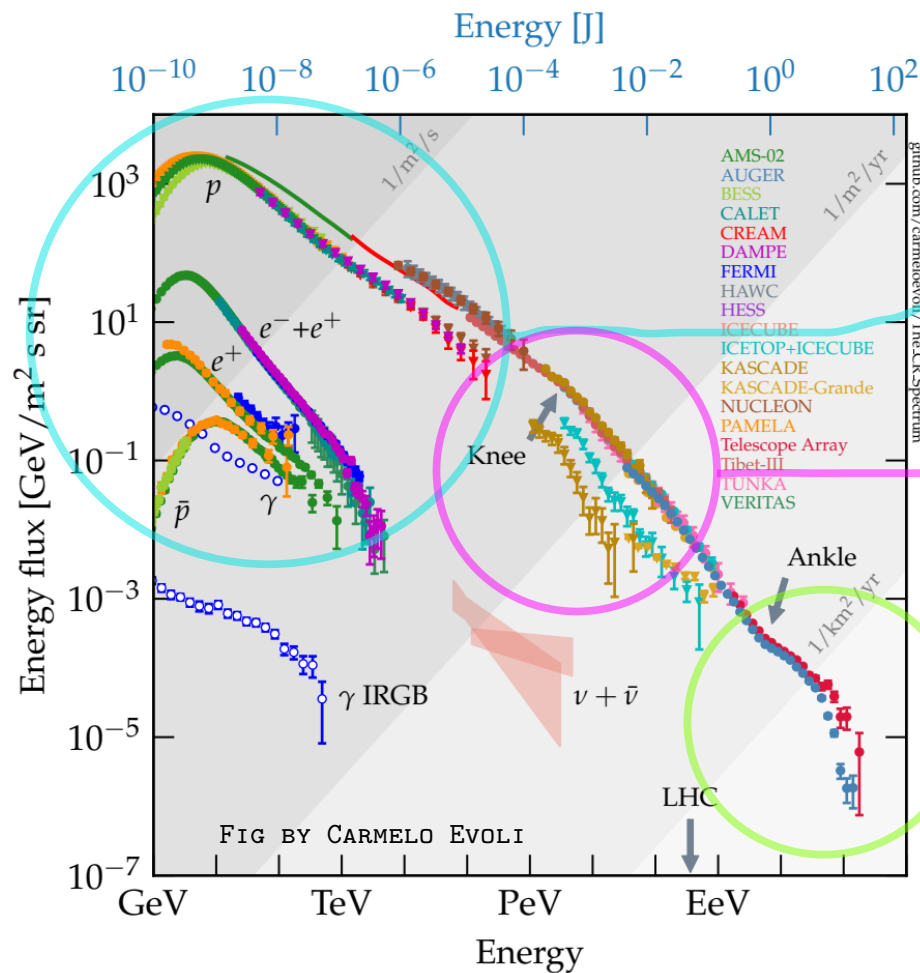
- ▶ BEFORE LAST WEEK I WOULD HAVE SAID: IN PRINCIPLE YES.
- ▶ AFTER LHAASO RESULTS I THINK IT IS FAIR TO SAY **YES**. NOW THE QUESTION IS - HOW MUCH?
- ▶ THE ANSWER DEPENDS ON HOW COMMON SOMETHING LIKE V4641 SGR/SS 433 IS IN THE GALAXY
- ▶ THERE ARE $> \sim 30$ X-RAY BINARIES FROM WHICH OBSERVATIONAL EVIDENCE OF A RELATIVISTIC JET IS REPORTED. WHAT MAKES THE 5 THAT LHAASO SEES SPECIAL?
- ▶ WIDE RANGE OF JET SPEEDS, COMPACT OBJECT MASS, COMPANION MASS, DISTANCES...
- ▶ EXTENDED EMISSION $\rightarrow$ INTERACTIONS JET-ENVIRONMENT ? (BUT NOT EXCLUSIVE!)
- ▶ **WE HAVE WORK TO DO!**



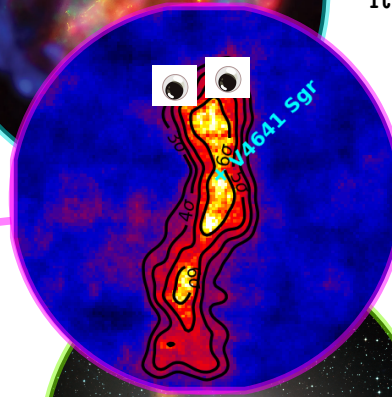
SUPERNOVA
REMNANTS



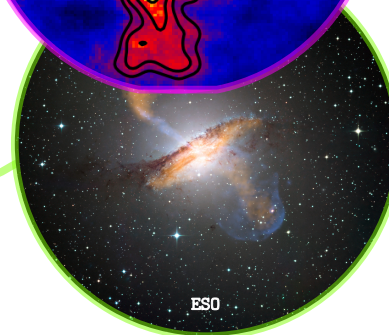
SOURCES OUTSIDE
OUR GALAXY



SUPERNOVA
REMNANTS



?



SOURCES OUTSIDE
OUR GALAXY