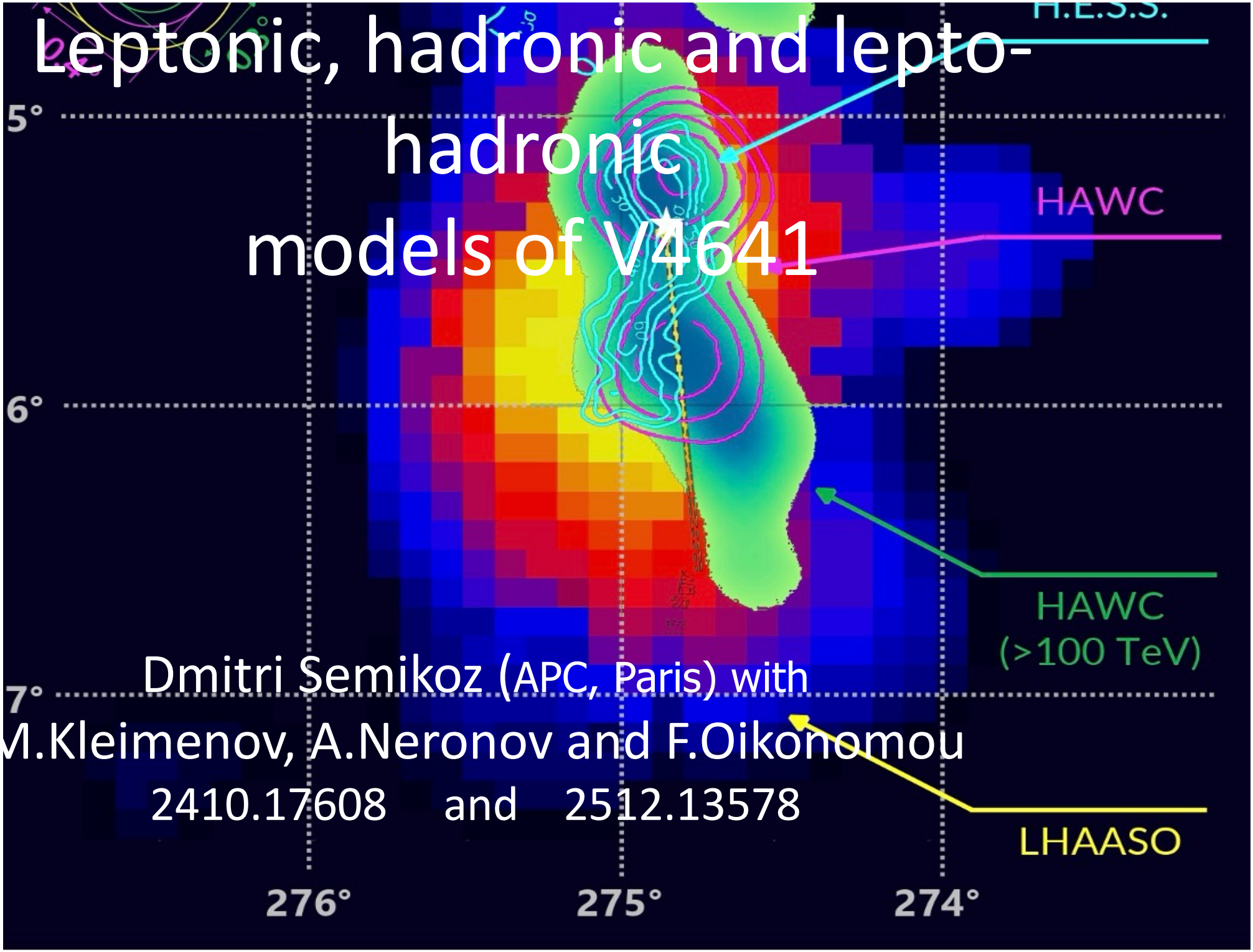
Leptonic, hadronic and lepto-hadronic models of V4641



Dmitri Semikoz (APC, Paris) with
M.Kleimenov, A.Neronov and F.Oikonomou

2410.17608 and 2512.13578

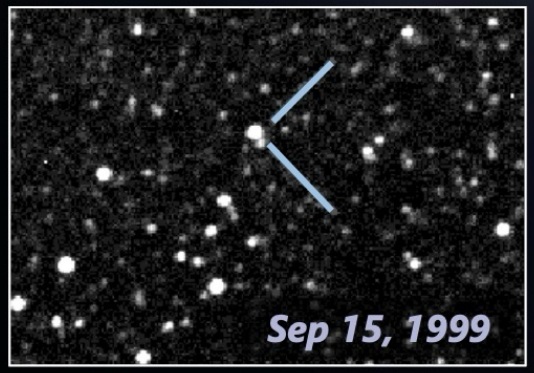
Plan:

- *Microquasar V4641*
- *Gamma-rays from V4641*
- *Leptonic models*
- *Hadronic models*
- *Lepto-hadronic models*
- *Conclusions*

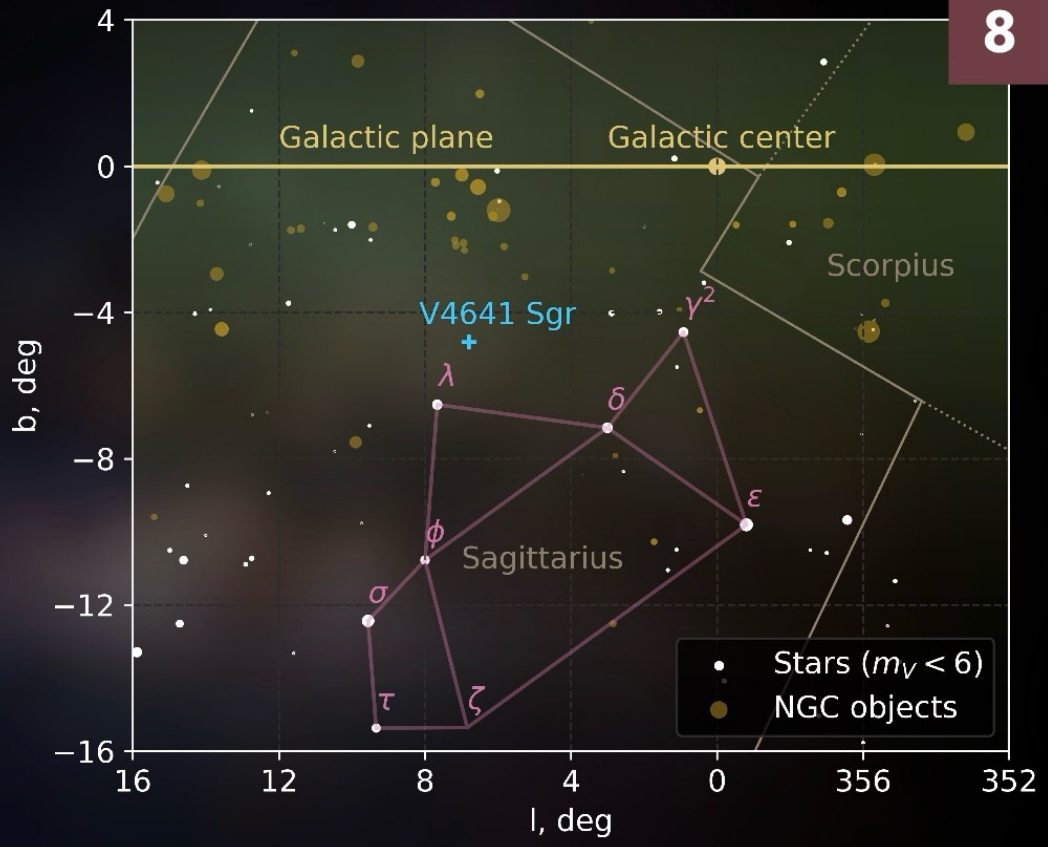
V4641 microquasar

Microquasar V4641 Sgr

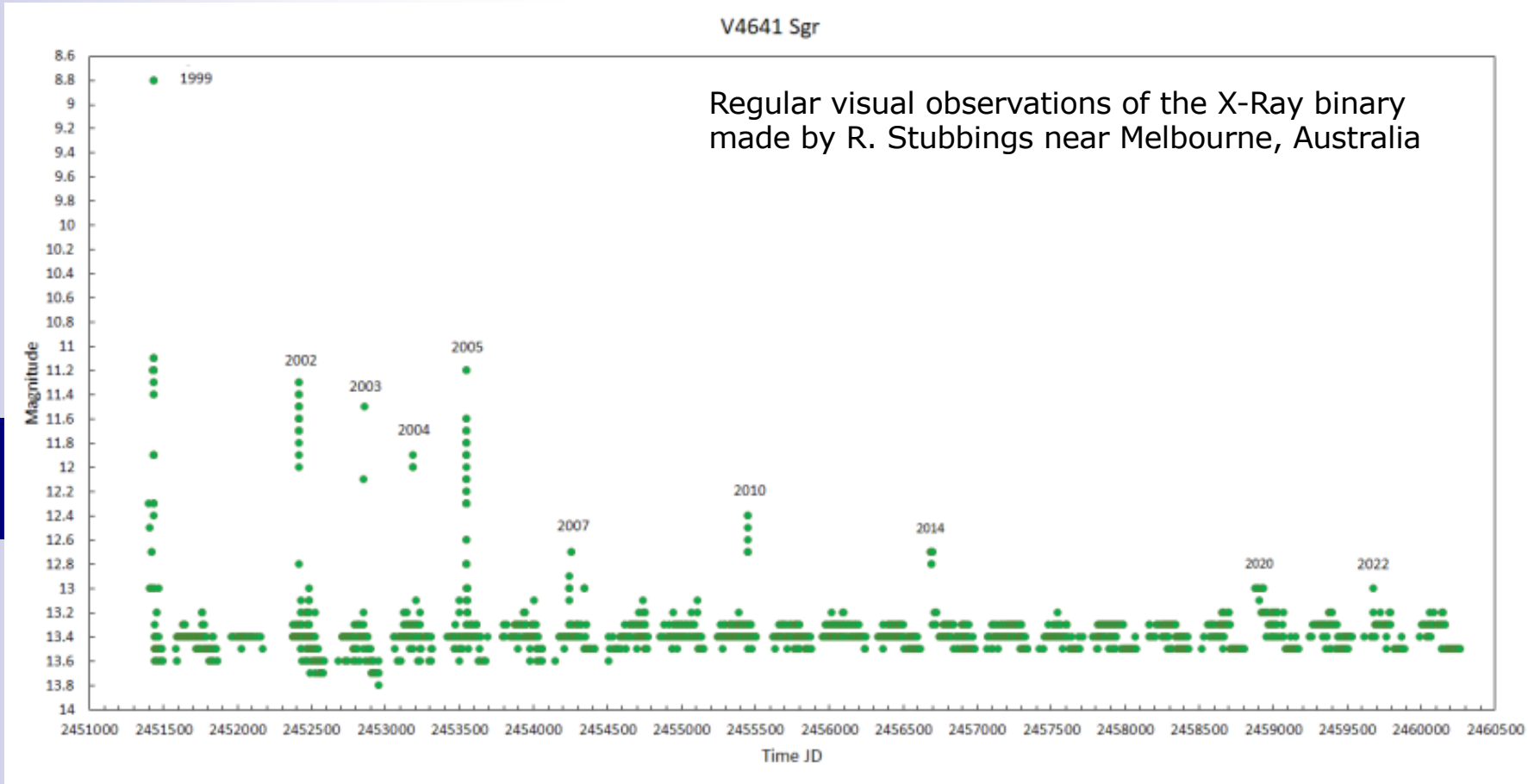
A low-mass X-ray binary (LMXB)
J2000: (274.8°, -25.41°)
Galactic: (6.8°, -4.8°)



Kyoto University 25-cm Schmidt-Cassegrain telescope [Uemura et al., 2002]

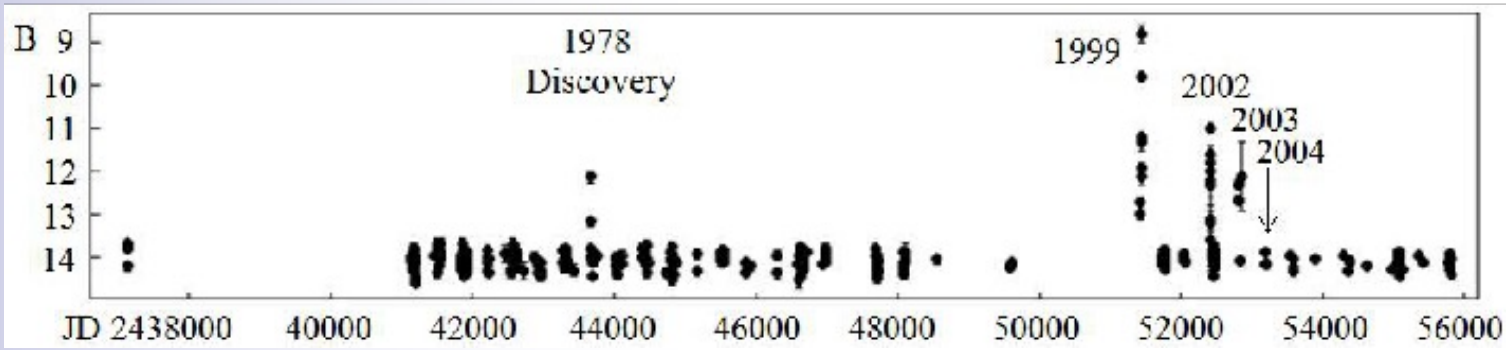


*A skymap of Sagittarius constellation in Gal. coord. with a **teapot asterism**. Plotted with V/50 (Hipparcos) and VII/118 catalogues*

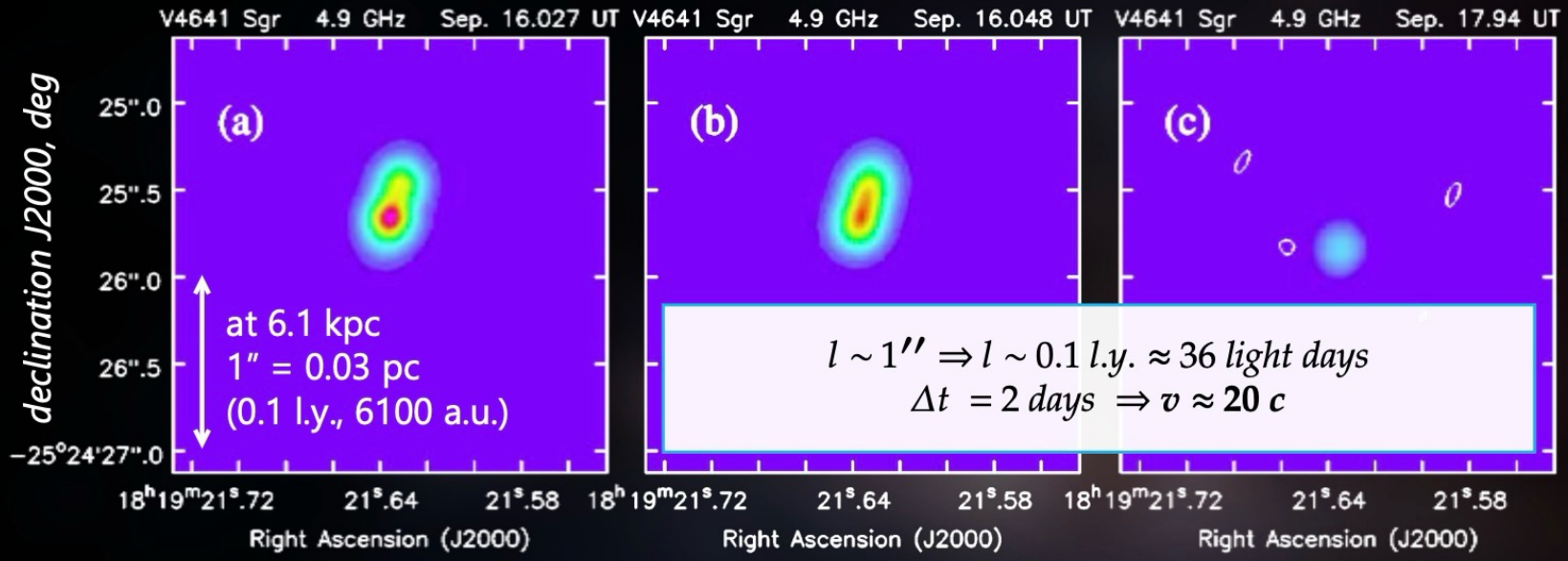


Regular visual observations of the X-Ray binary made by R. Stubbings near Melbourne, Australia

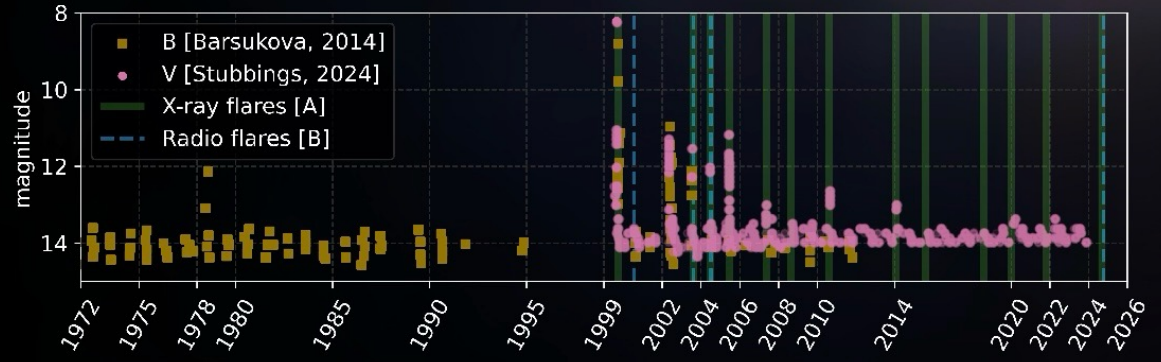
Historical light-curve of V4641 Sgr in B-band restored from photographic plates in Sternberg Astronomical Institute (Moscow, Russia) and Sonneberg Observatory (Sonneberg, Germany) [Barsukova et al., 2014]



1999 outburst: *from radio to gamma*



Very-large-base interferometry (VLBI) picture from the Very-large-array (VLA) with an overlaid color pattern [Hjellming, 1999]

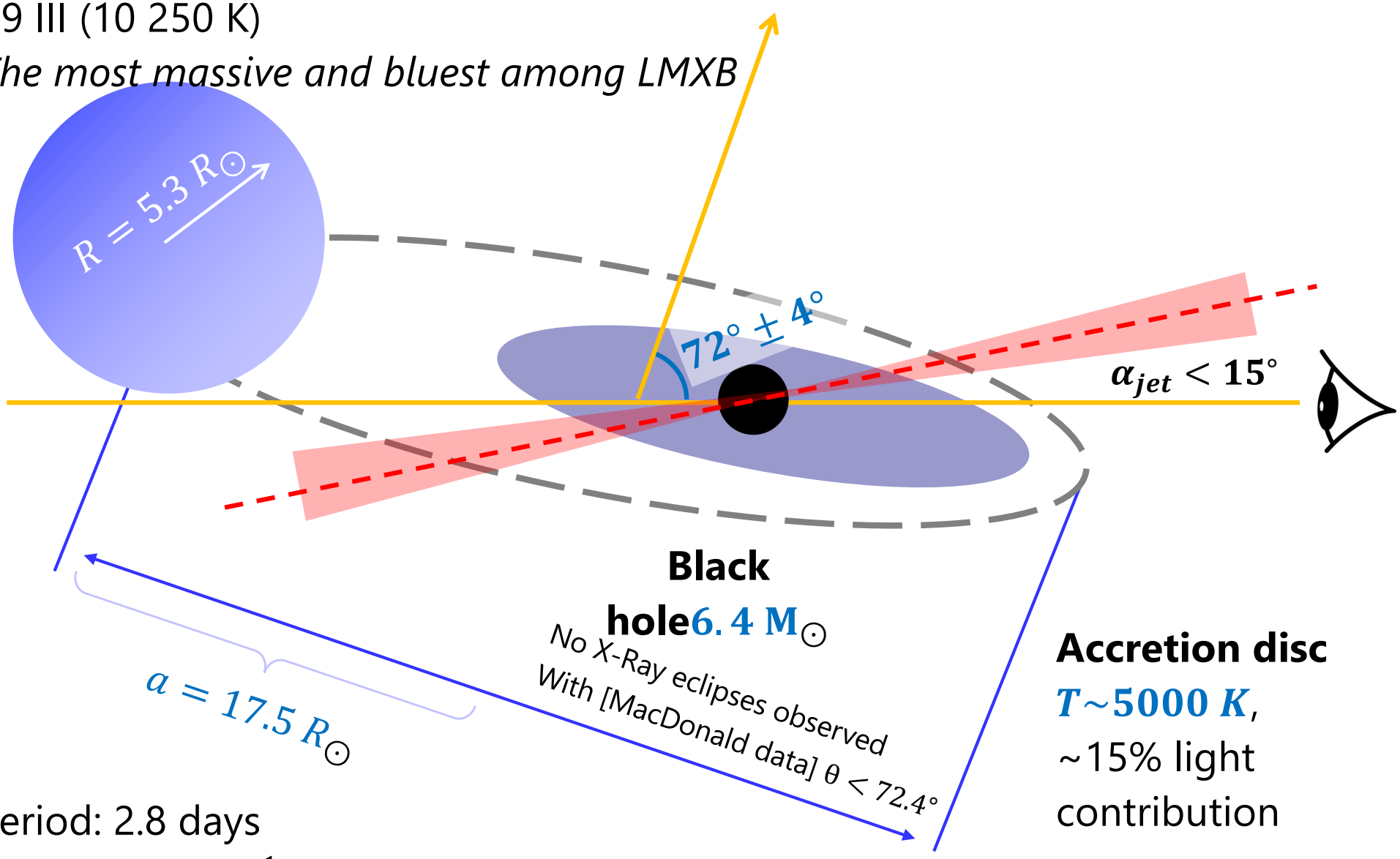


Historical lightcurve in blue (B) [Barsukova et al., 2014] and visual (V) optical bands [Stubbings, 2024] depicting several flares in 1978, 1999, 2002, 2003, 2004, 2005, 2008, 2010, 2014, 2020, 2022

Companion star: $2.9\ M_\odot$

B9 III (10 250 K)

The most massive and bluest among LMXB



Accretion disc

$T \sim 5000\ K$,

~15% light contribution

Period: 2.8 days

$V_{rot} \sim 100\ km\ s^{-1}$

Binary system

10

Companion star 2.9 $M_\odot$
B9 III (10 250 K)
The most massive and bluest among LMXB

$R = 5.3\ R_\odot$

Observed in two states: passive and active
Passive: obs. variability is consistent with orb. variations
Active: brighter and more variable condition

Superluminal jet, 1999: $\alpha_{jet} < 16^\circ$, $v_{jet} \approx 0.990c$, $v_{app} \approx 39c$
[Salvesen, Pokawanvit, 2020]
$\alpha_{jet} < 10^\circ$, $v_{jet} > 0.95\ c$
[Chaty et al., 2003]

$72^\circ \pm 4^\circ$

Accretion disc
Quiescence: $T \sim 5000\ K$, ~15% light contribution [MacDonald et al., 2014]

Black hole
6.4 $M_\odot$

$a = 17.5\ R_\odot$

Rad. velocity $\gamma = 72.7 \pm 3.3$ km s^{-1}
[Lindstrøm et al., 2005]

Distance D = 6.1 ± 0.5 kpc (parallax)

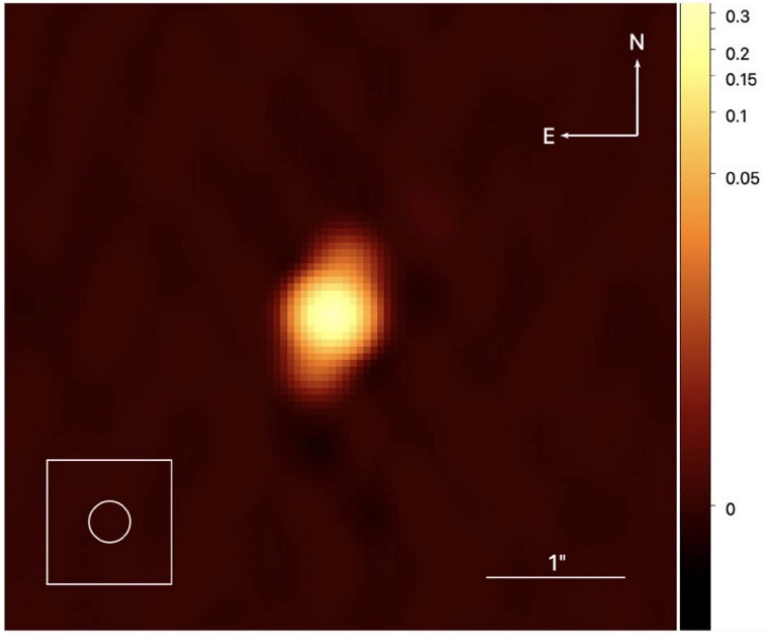
Period: 2.8 days
$V_{rot} \sim 100\ km\ s^{-1}$

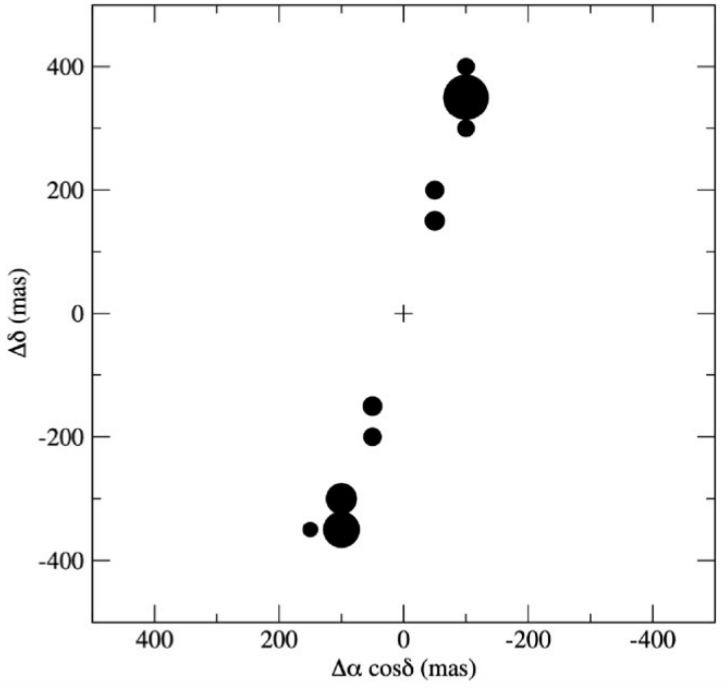
MNRAS **545,** 1–5 (2026)
Advance Access publication 2025 November 26
https://doi.org/10.1093/mnras/staf2104

Alignment of radio jets in the microquasar V4641 Sagittarii with its high-energy structures

Josep Martí [1]★ and Pedro L. Luque-Escamilla [2]

[1] *Departamento de Física. Universidad de Jaén, EPS Jaén. Campus Las Lagunillas s/n, Jaén, E-23071 Jaén, Spain*
[2] *Departmento de Ingeniería Mecánica y Minera, Universidad de Jaén, Campus Las Lagunillas s/n, Jaén, E-23071 Jaén, Spain*





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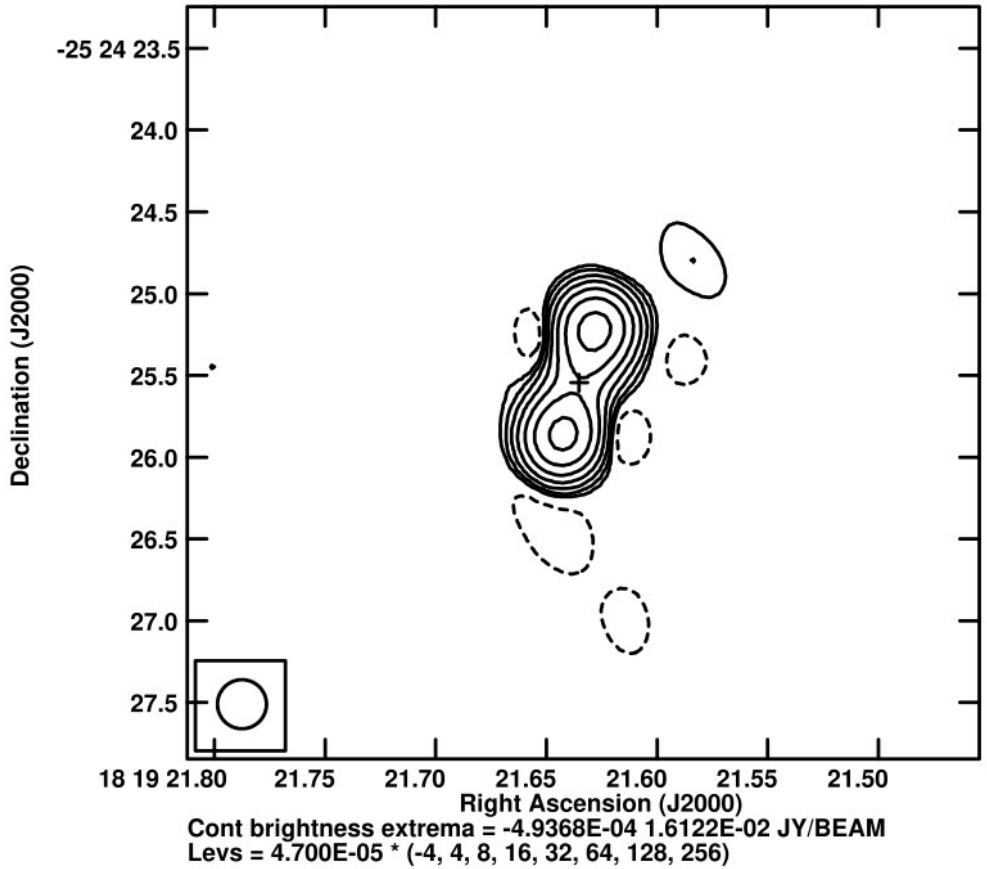
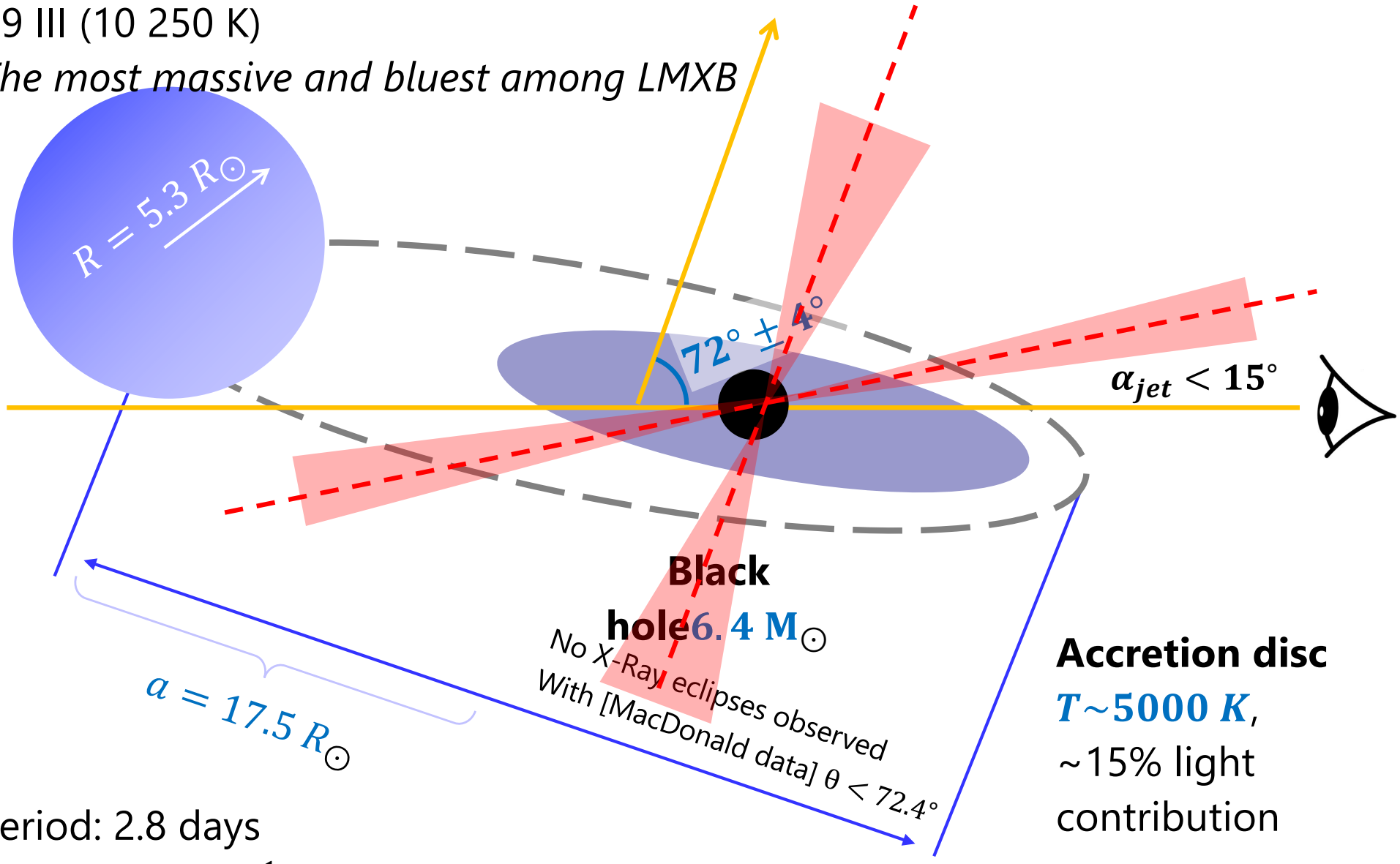


Companion star: $2.9\ M_\odot$

B9 III (10 250 K)

The most massive and bluest among LMXB



Accretion disc

$T \sim 5000\ K$,

~15% light contribution

Period: 2.8 days

$V_{rot} \sim 100\ km\ s^{-1}$

Companion star: $2.9\ M_\odot$

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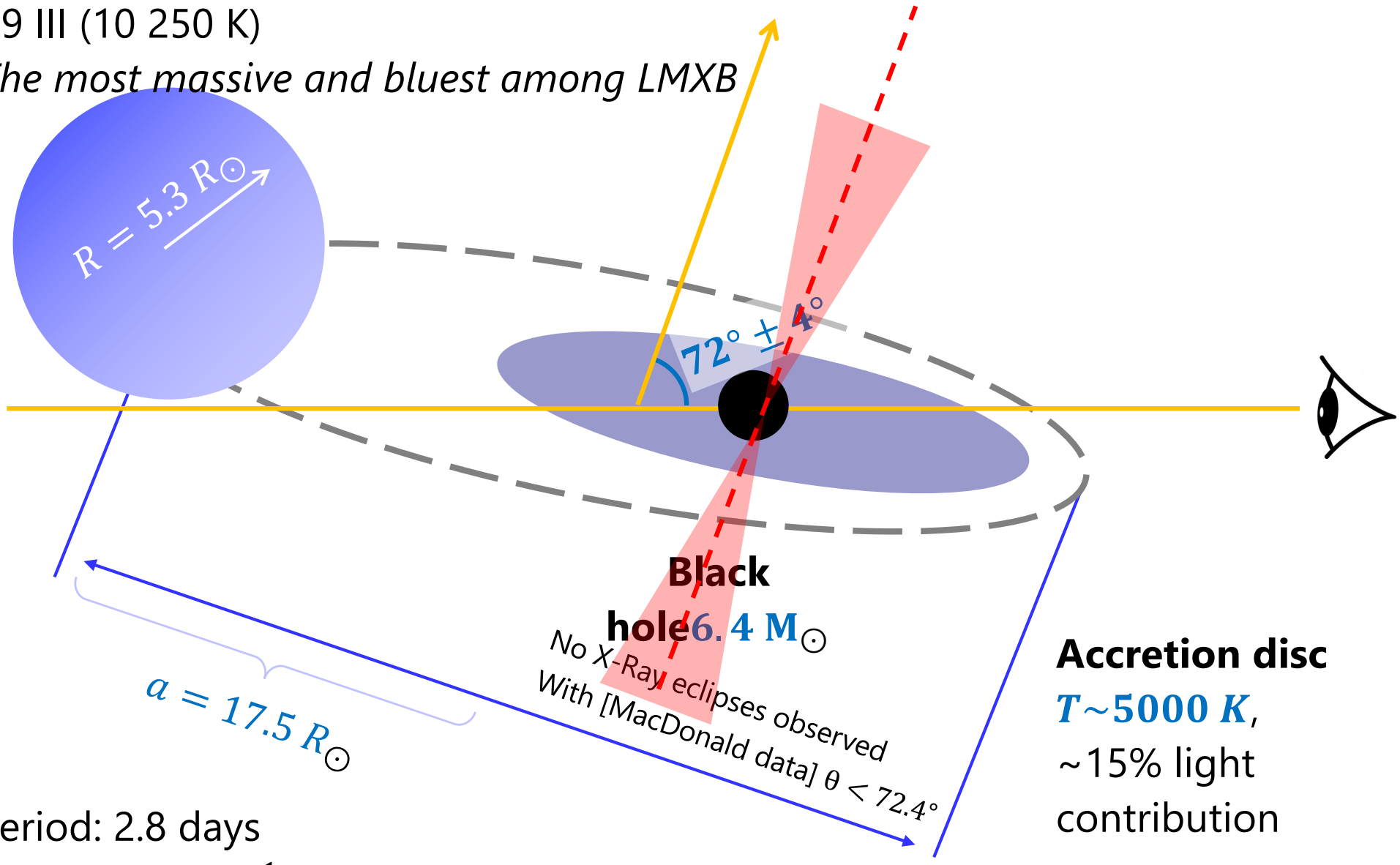


Accretion disc

$T \sim 5000\ K$,

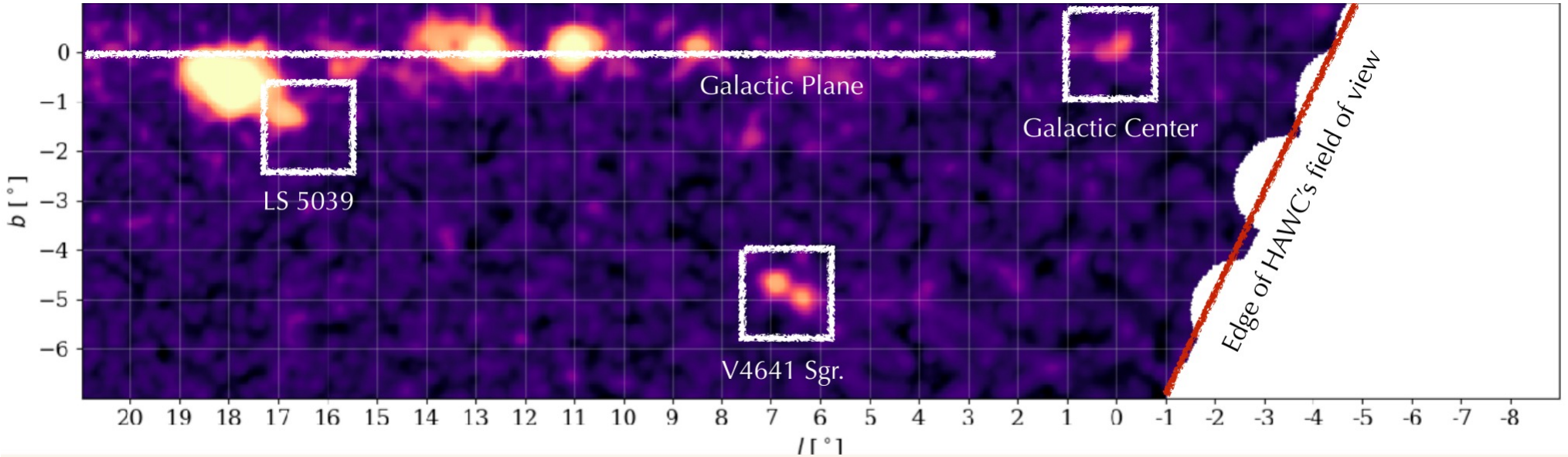
~15% light contribution

Period: 2.8 days

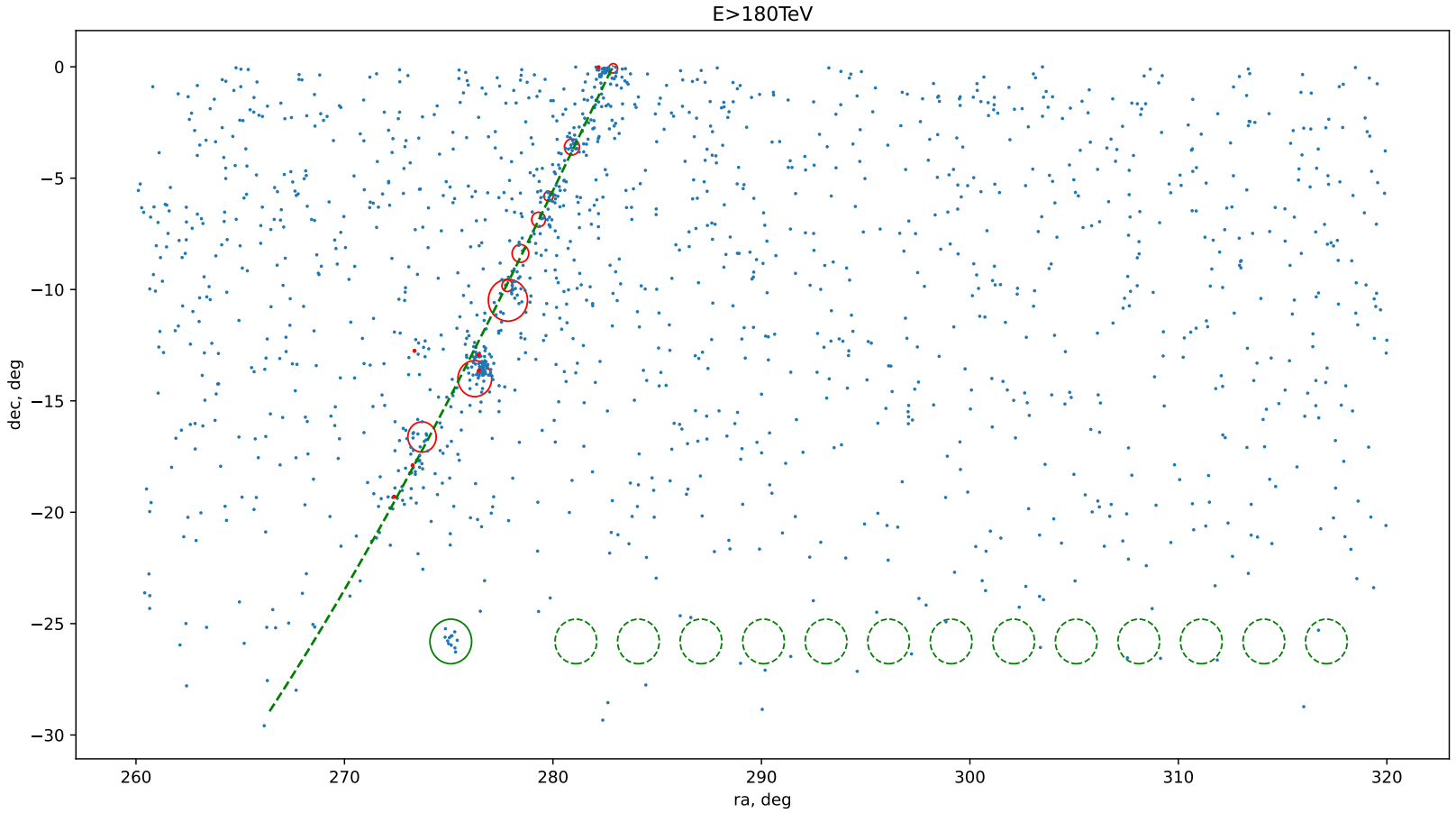
$V_{rot} \sim 100\ km\ s^{-1}$

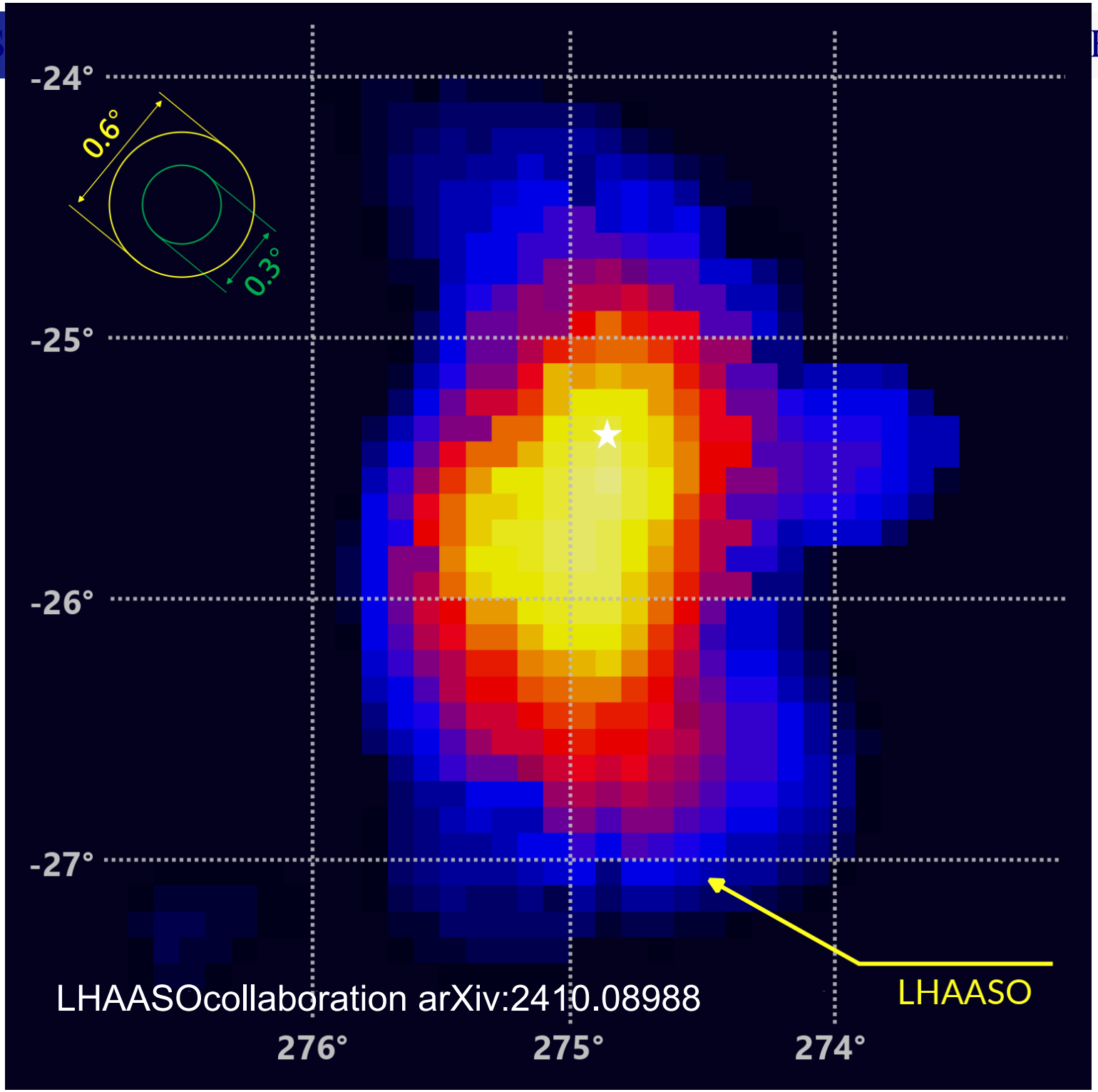
Gamma-ray emission

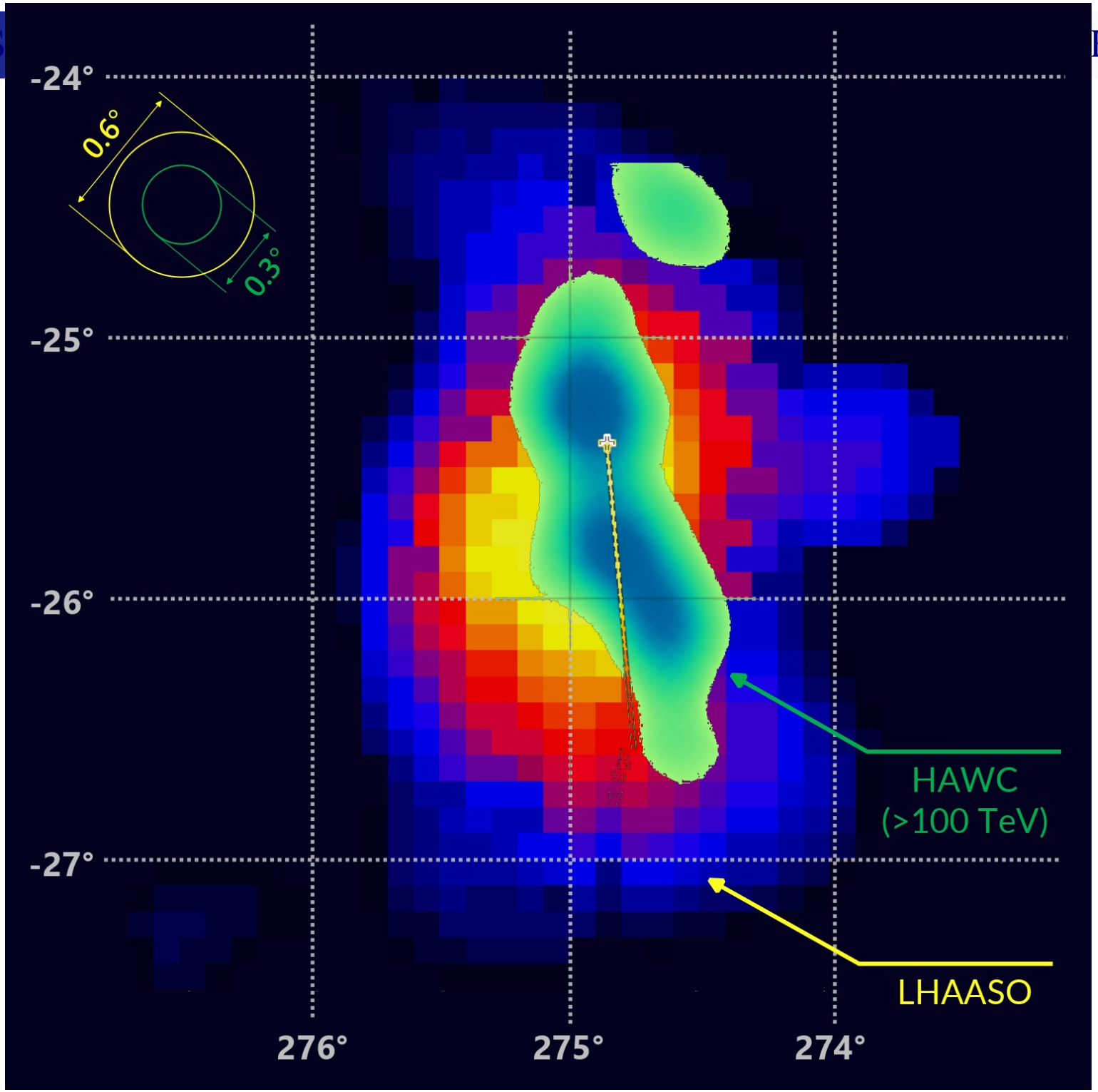
HAWC Galactic plane survey

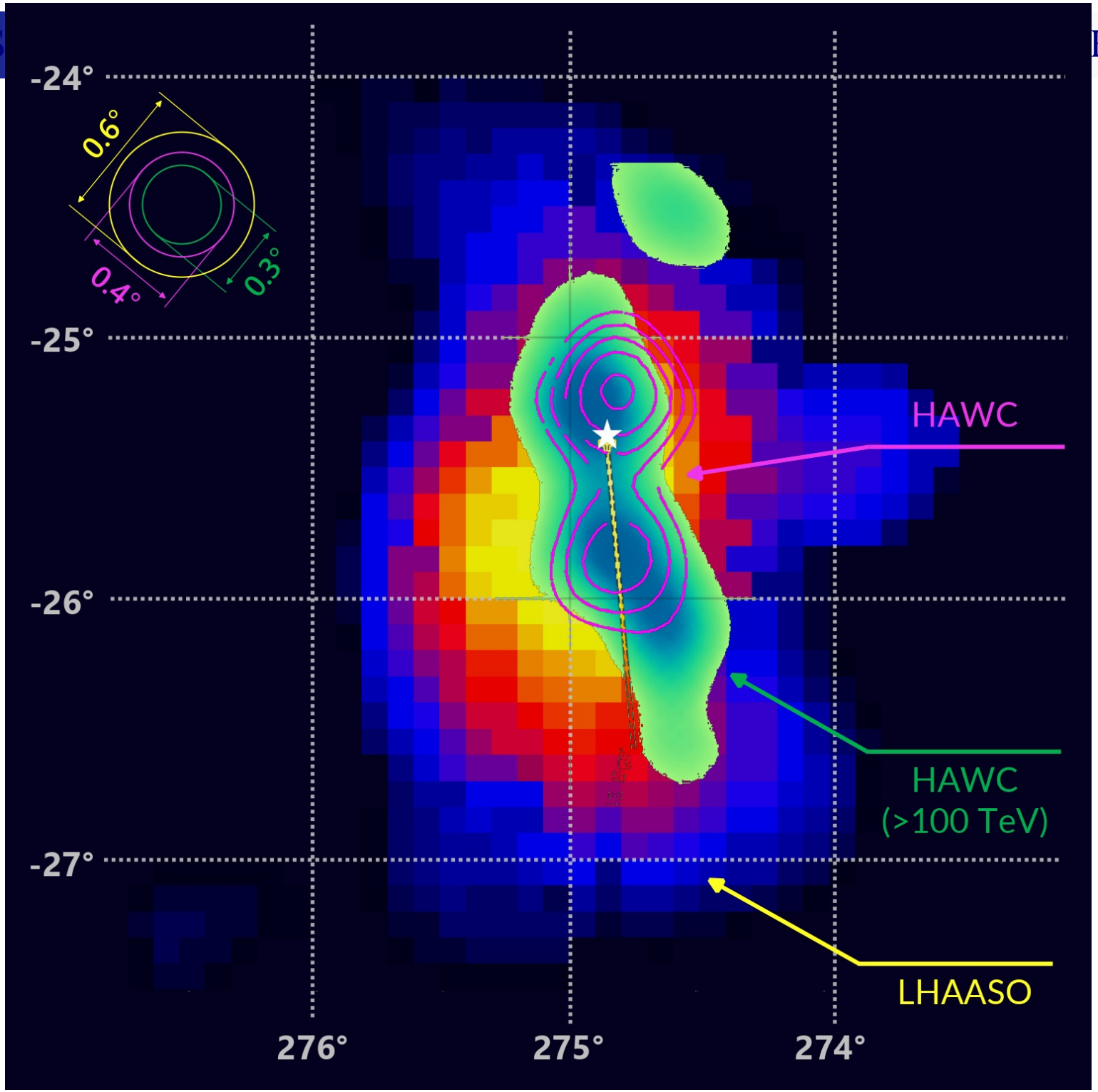


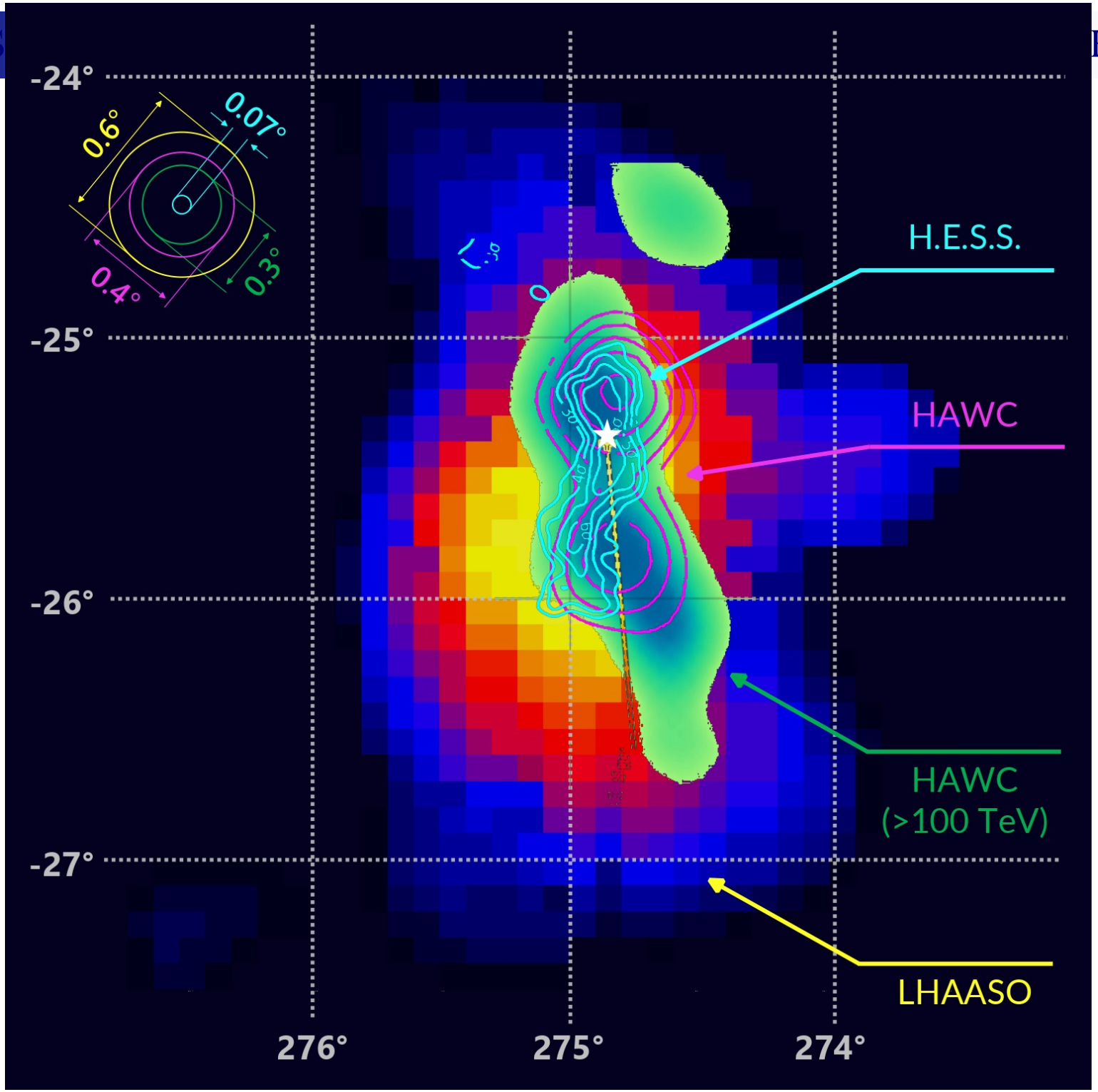
LHAASO meeting Oct 2023: first LHAASO observation of V4641

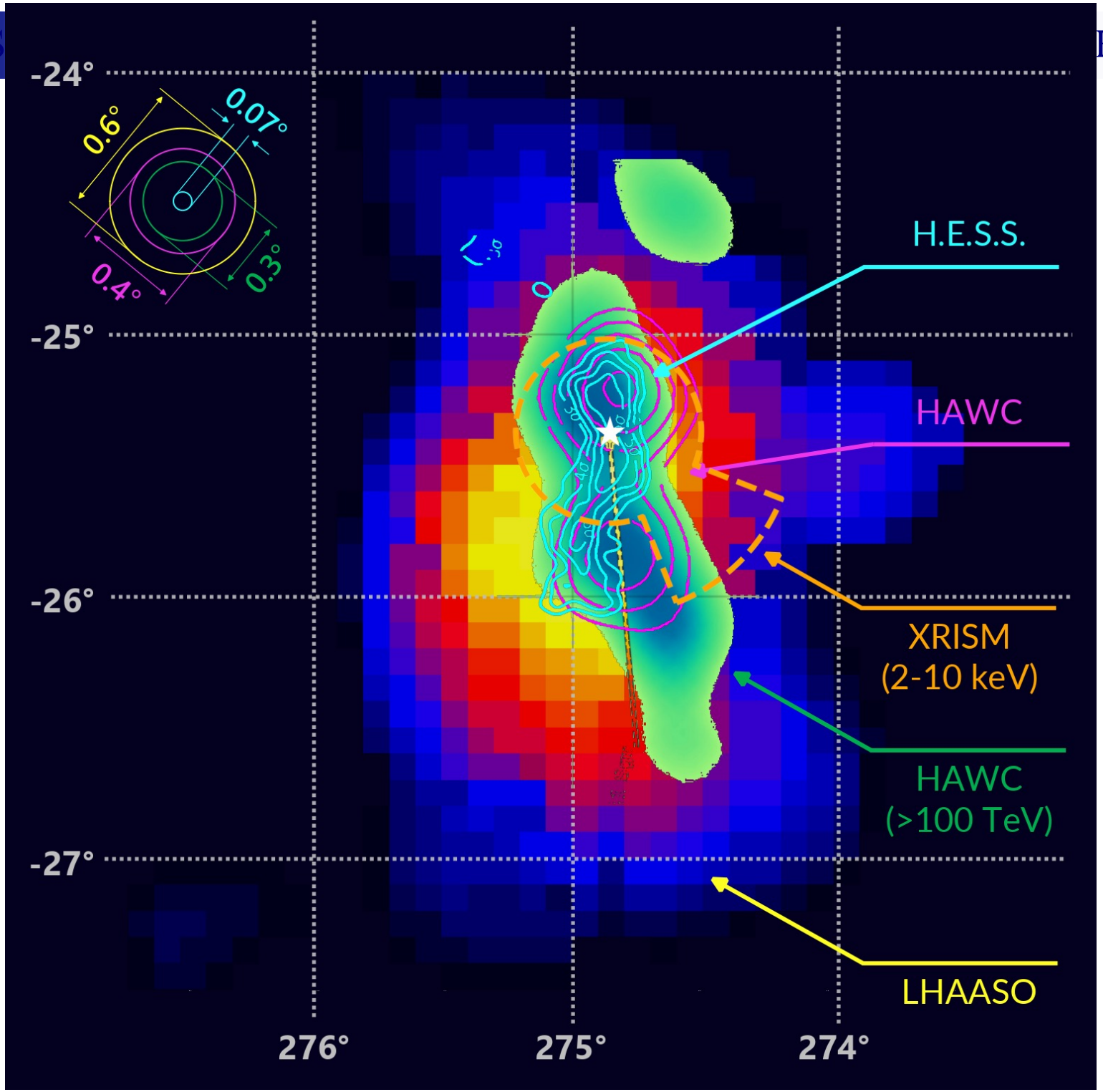



-24°
-25°
-26°
-27°
0.6°
0.3°
LHAASOcollaboration arXiv:2410.08988
LHAASO
276°
275°
274°


-24°
-25°
-26°
-27°
276°
275°
274°
0.6°
0.3°
HAWC
(>100 TeV)
LHAASO


-24°
-25°
-26°
-27°
276°
275°
274°
0.6°
0.4°
0.3°
HAWC
HAWC
(>100 TeV)
LHAASO

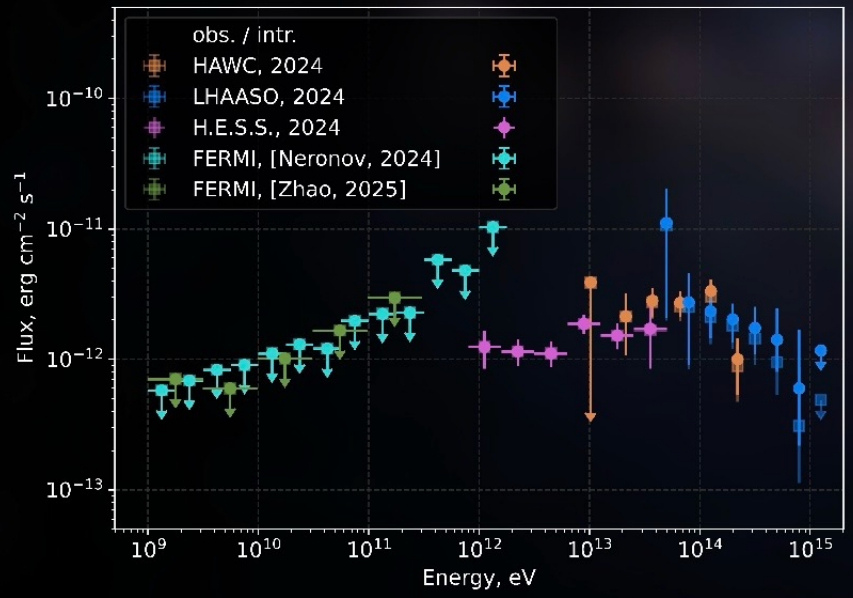

-24°
-25°
-26°
-27°
276°
275°
274°
0.6°
0.07°
0.4°
0.3°
H.E.S.S.
HAWC
HAWC
(>100 TeV)
LHAASO

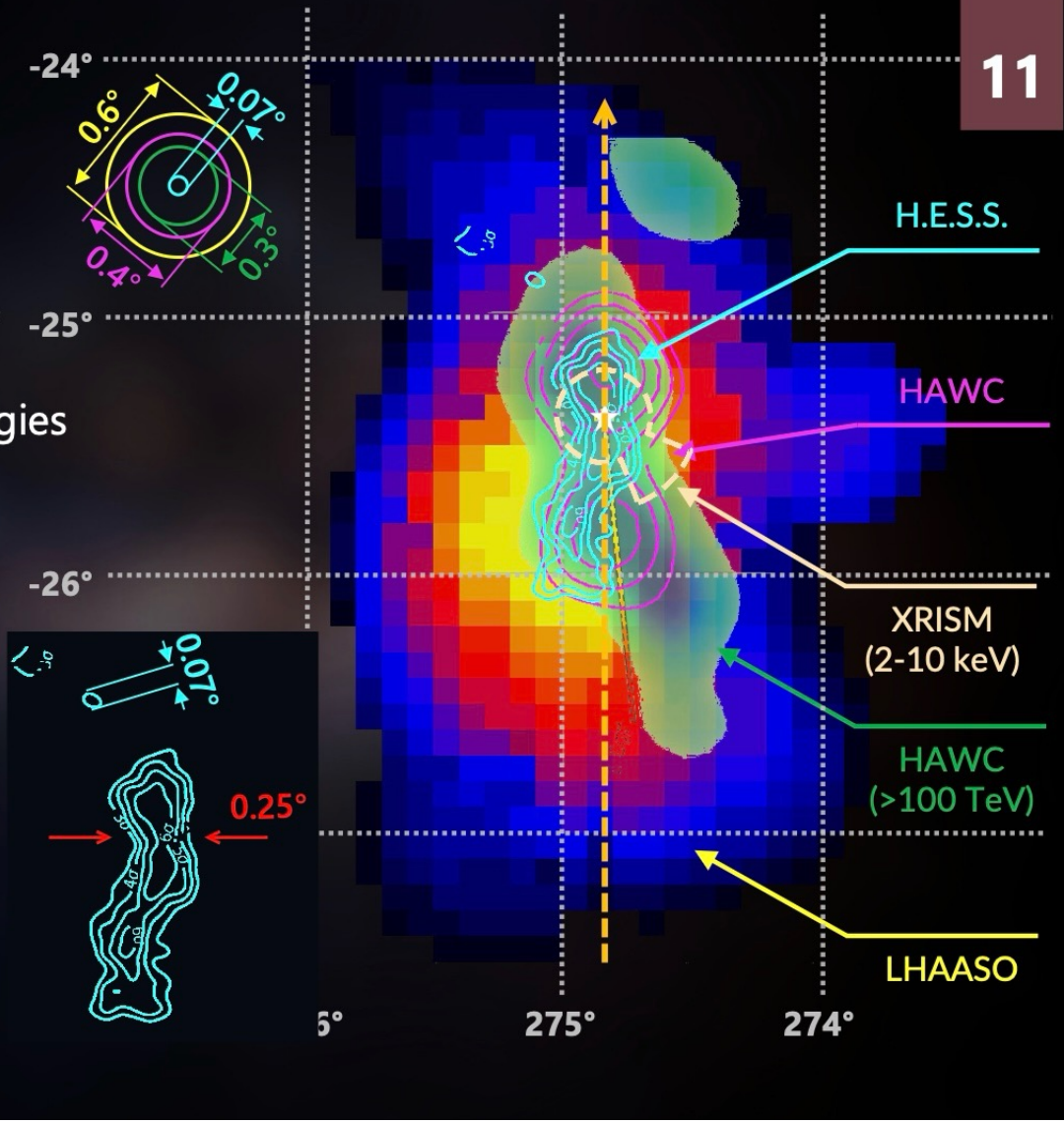

-24°
-25°
-26°
-27°
276°
275°
274°
0.6°
0.07°
0.4°
0.3°
H.E.S.S.
HAWC
XRISM
(2-10 keV)
HAWC
(>100 TeV)
LHAASO

Extended radiation:
from X-rays to gamma

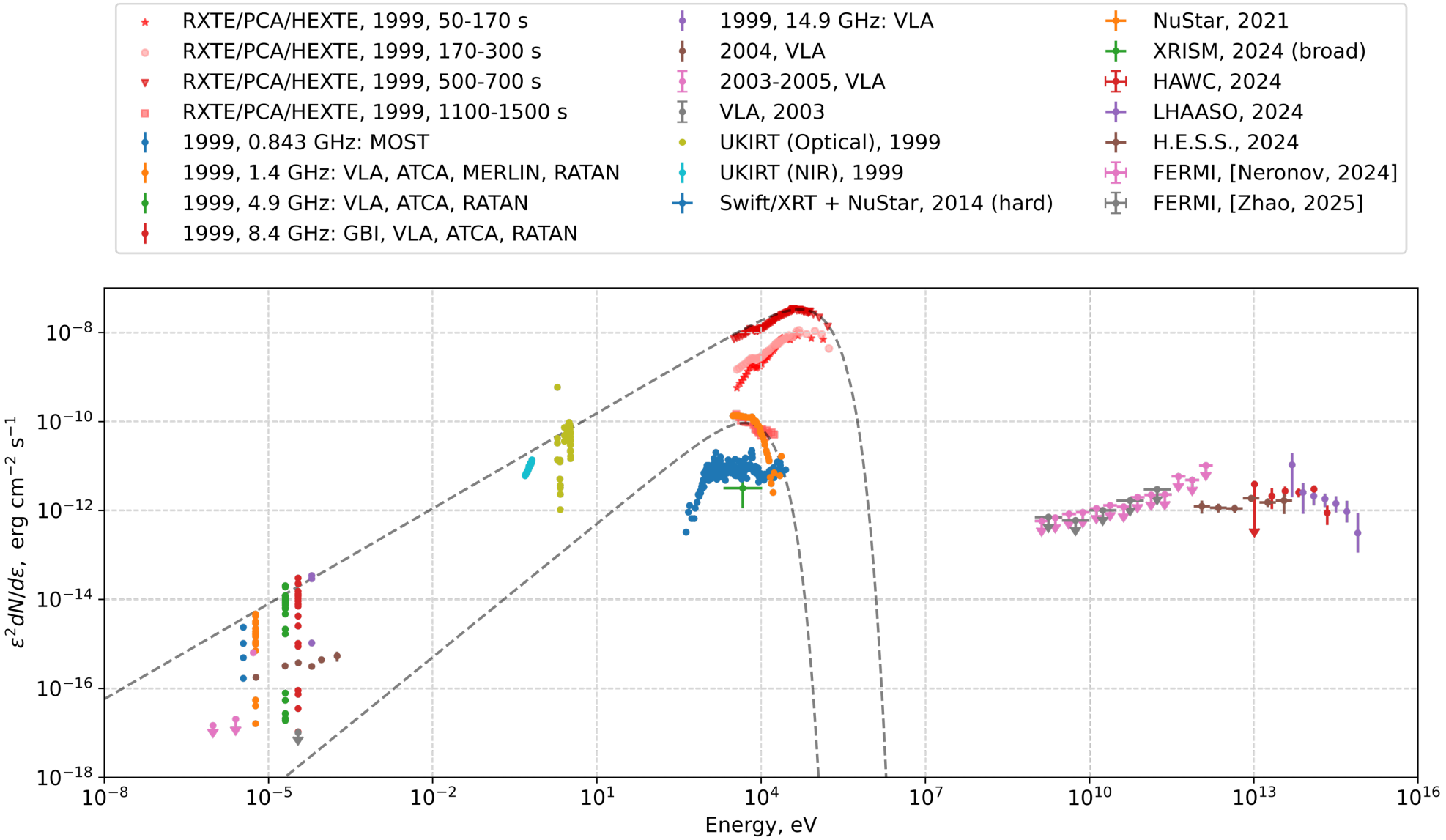
Morphological features

- Length of the nebula increases with energy
- Non-zero width (from H.E.S.S.)
- Clear North-South asymmetry at high energies



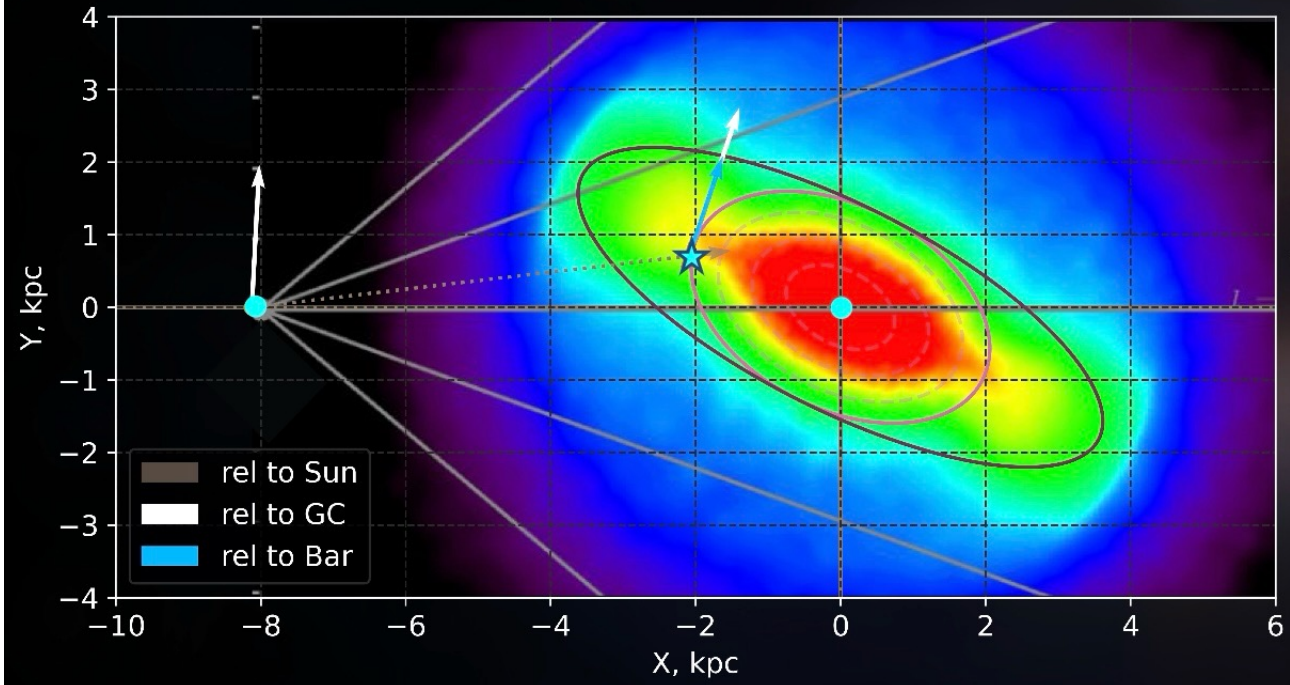


Multiwavelength observations of the binary (in radio, optical, X-rays)
and of the surrounding nebula (in gamma-rays) from 1999 to the present day

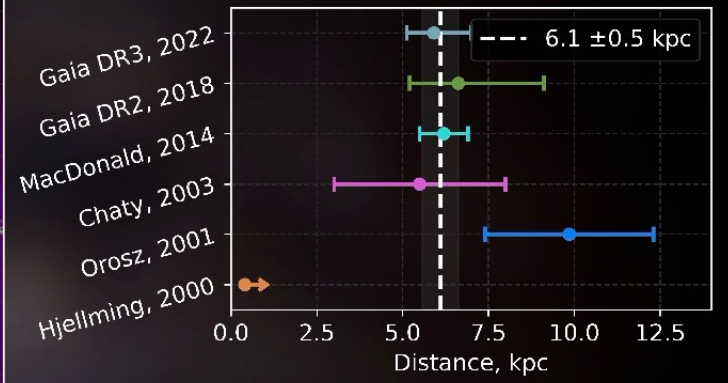


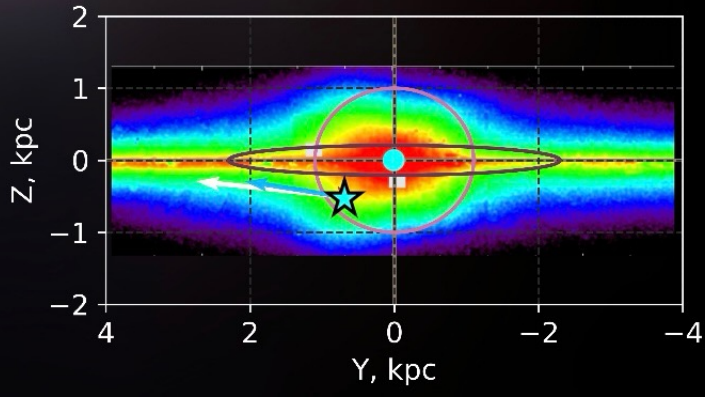
Position in the Galaxy

The source is located close to the **Galactic Bar** — an a non-axisymmetric vertically extended stellar over-density region in the Milky Way center



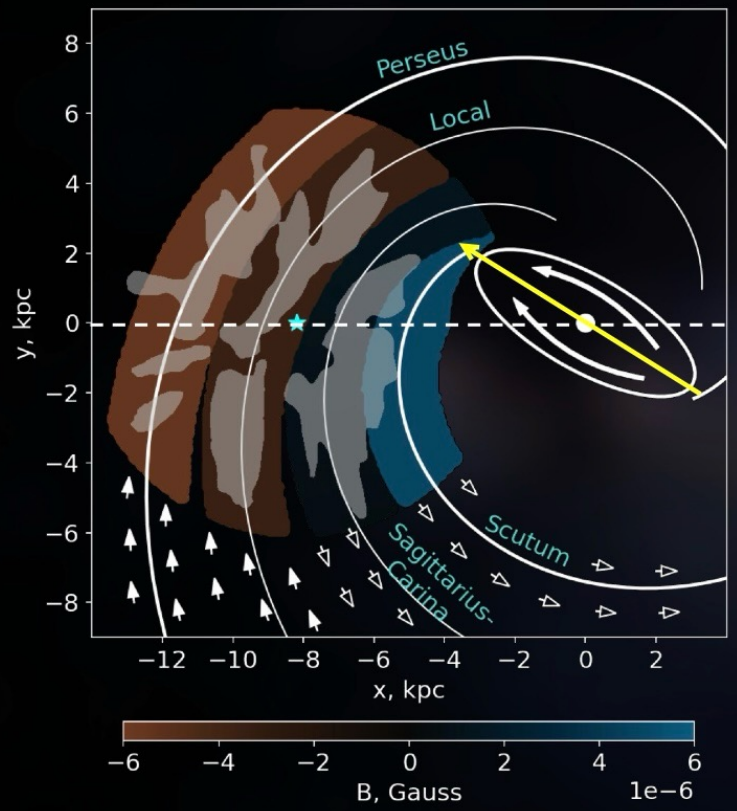
Evolution of distance measurements to V4641 Sgr





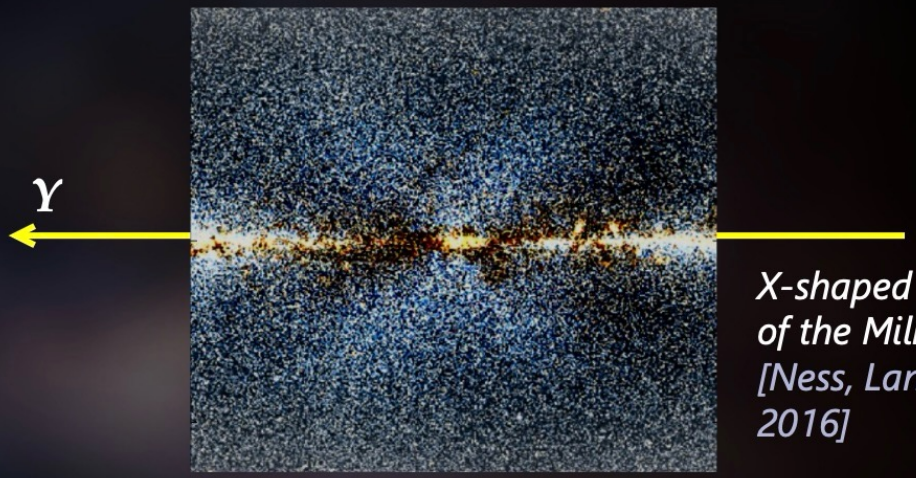
The source and the bar in galactocentric coordinates; stellar overdensity in the bar (top-view, upper panel; observer view, right panel)
[Wegg et al., 2015]

Galactic Magnetic field



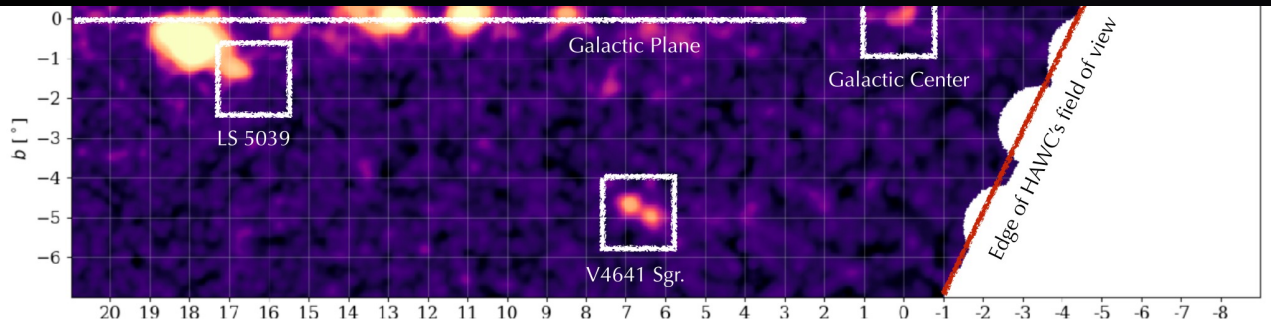
Schematic picture of the Galactic arms as viewed from the north Galactic pole [Korochkin et al., 2025]

Galactic Magnetic field has two components:
- a **regular** magnetic field B_0
- a **turbulent** component δB



X-shaped bulge of the Milky Way [Ness, Lang, 2016]

Magnetic field in the Bar is weakly constrained:
- we expect a horizontal component (in Galactic Plane)
- and an X-shape component perpendicular to the Galactic Plane



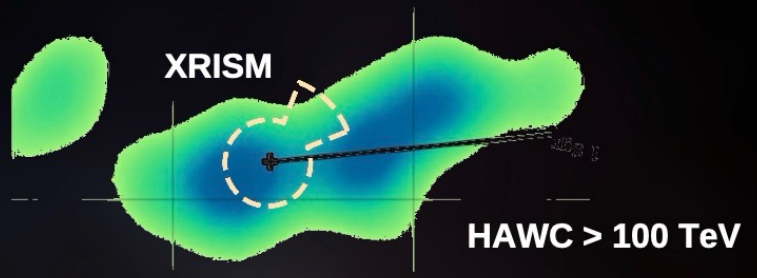
Leptonic models

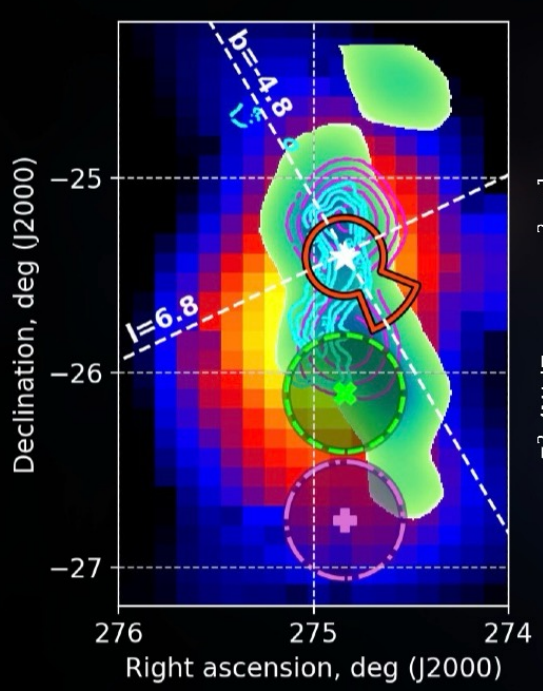
Leptonic model: spectrum

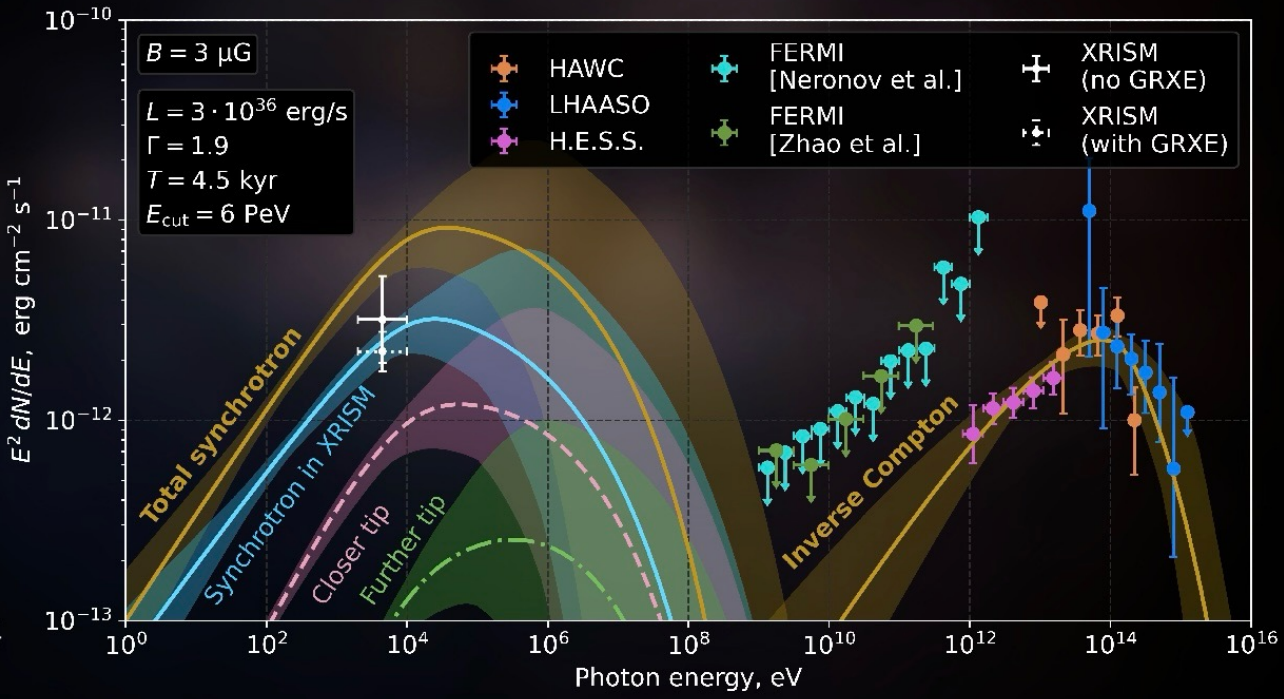
Continuous emission

Continuously ejecting electrons

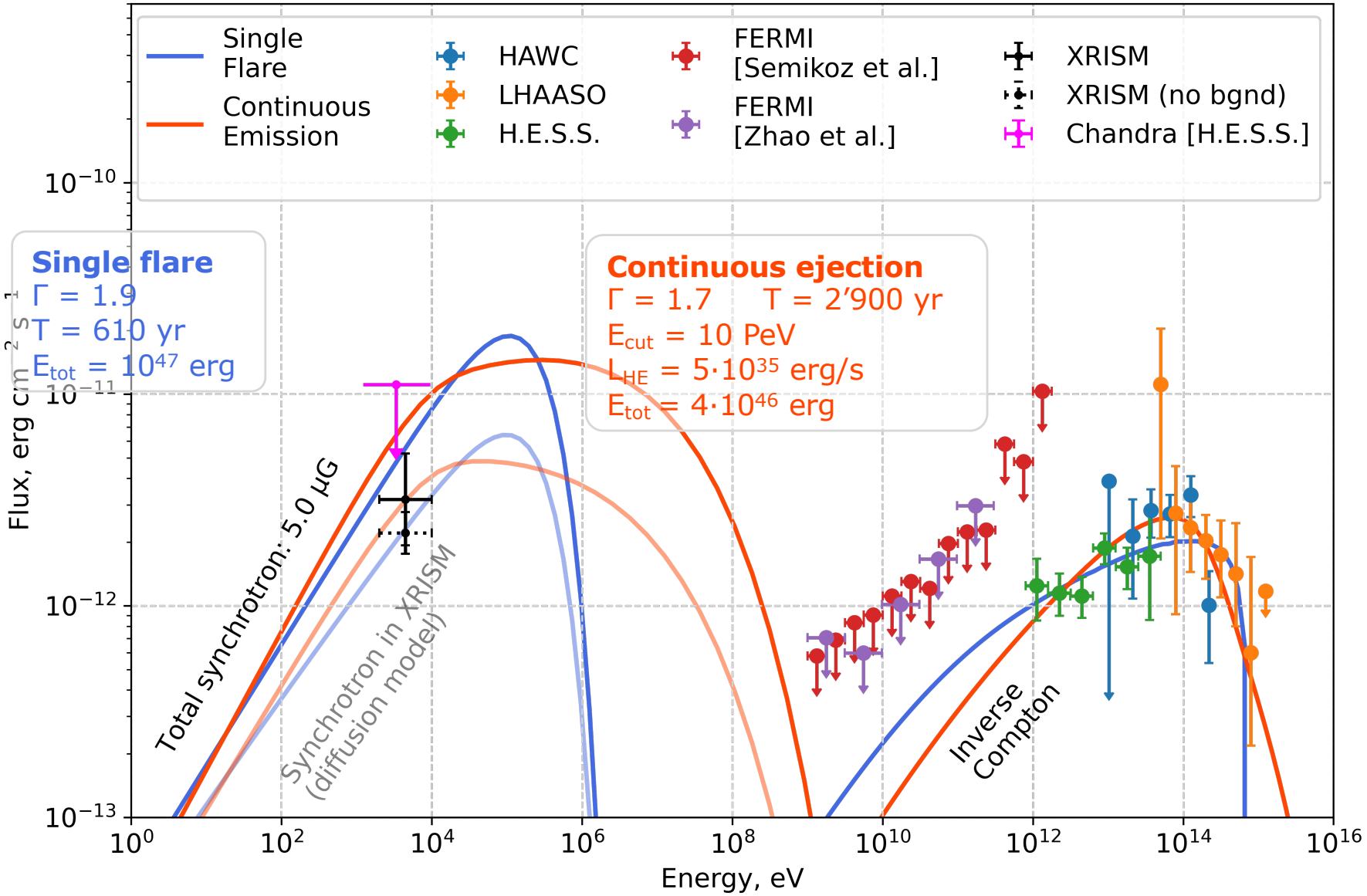
Magnetic field $B = 3\ \mu G$.





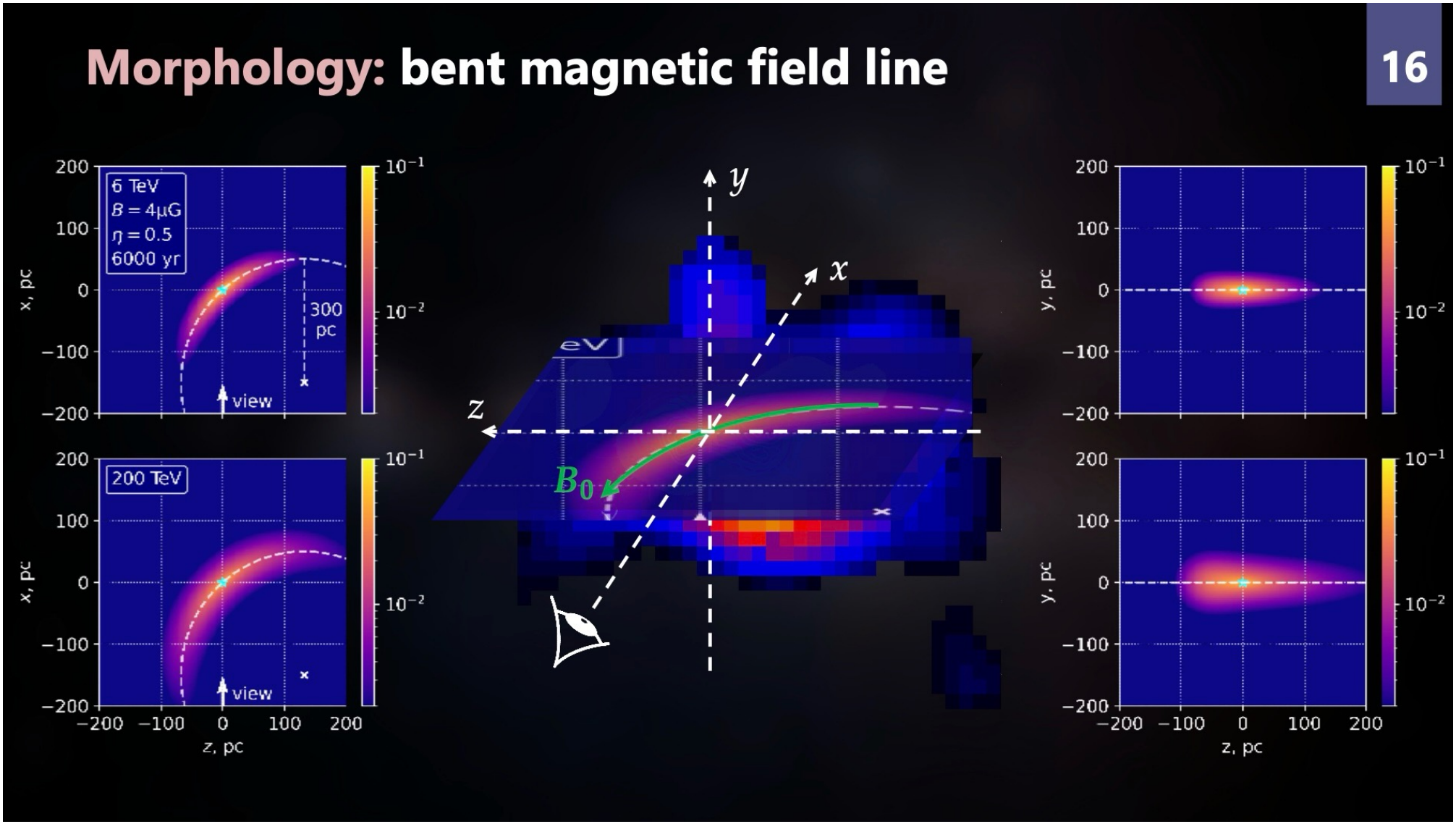


Photon flux from an UHE electron distribution

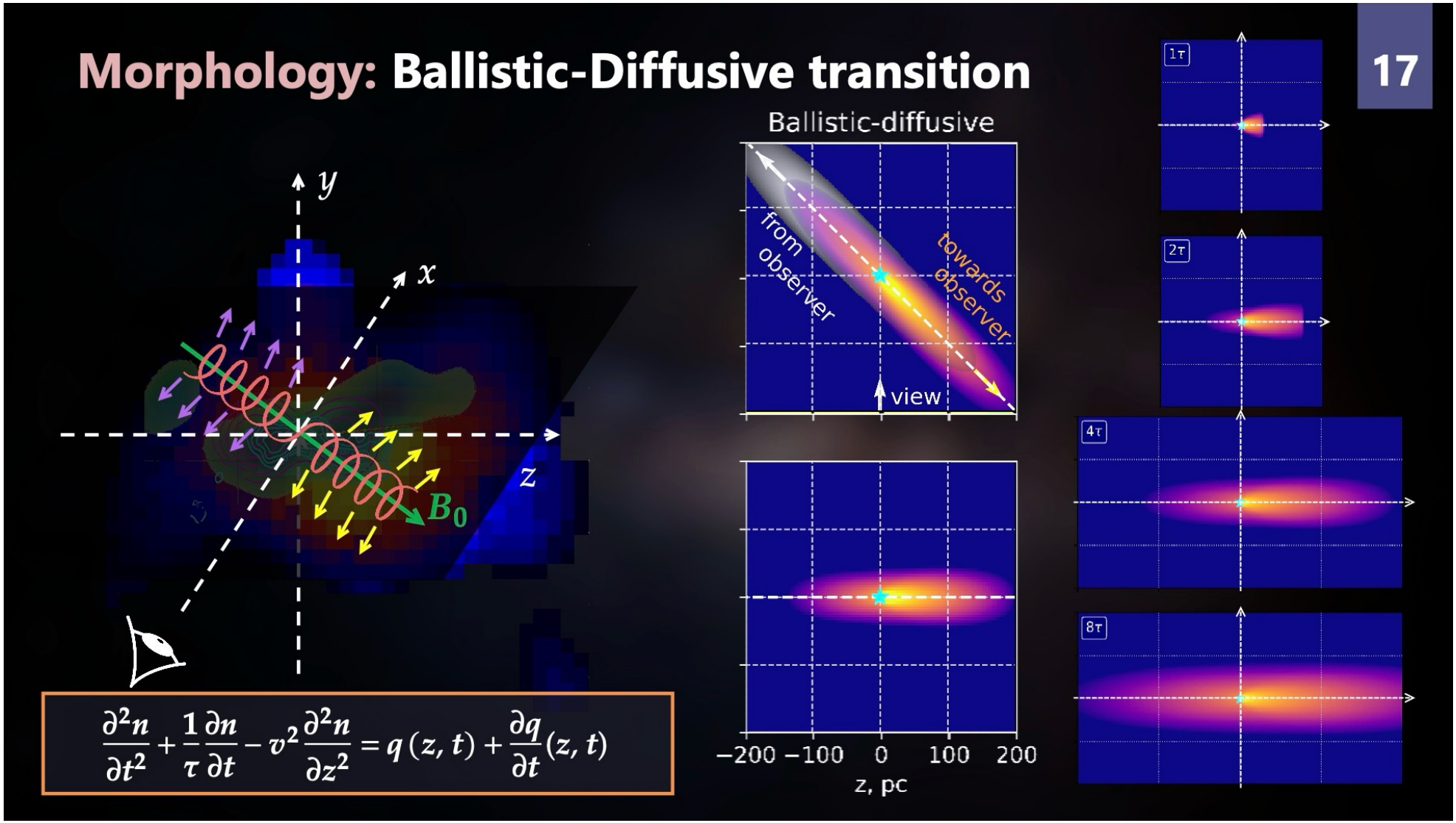


M.Kleimenov, A.Neronov, F.Oikonomou and D.S., in preparation

Leptonic model: morphology

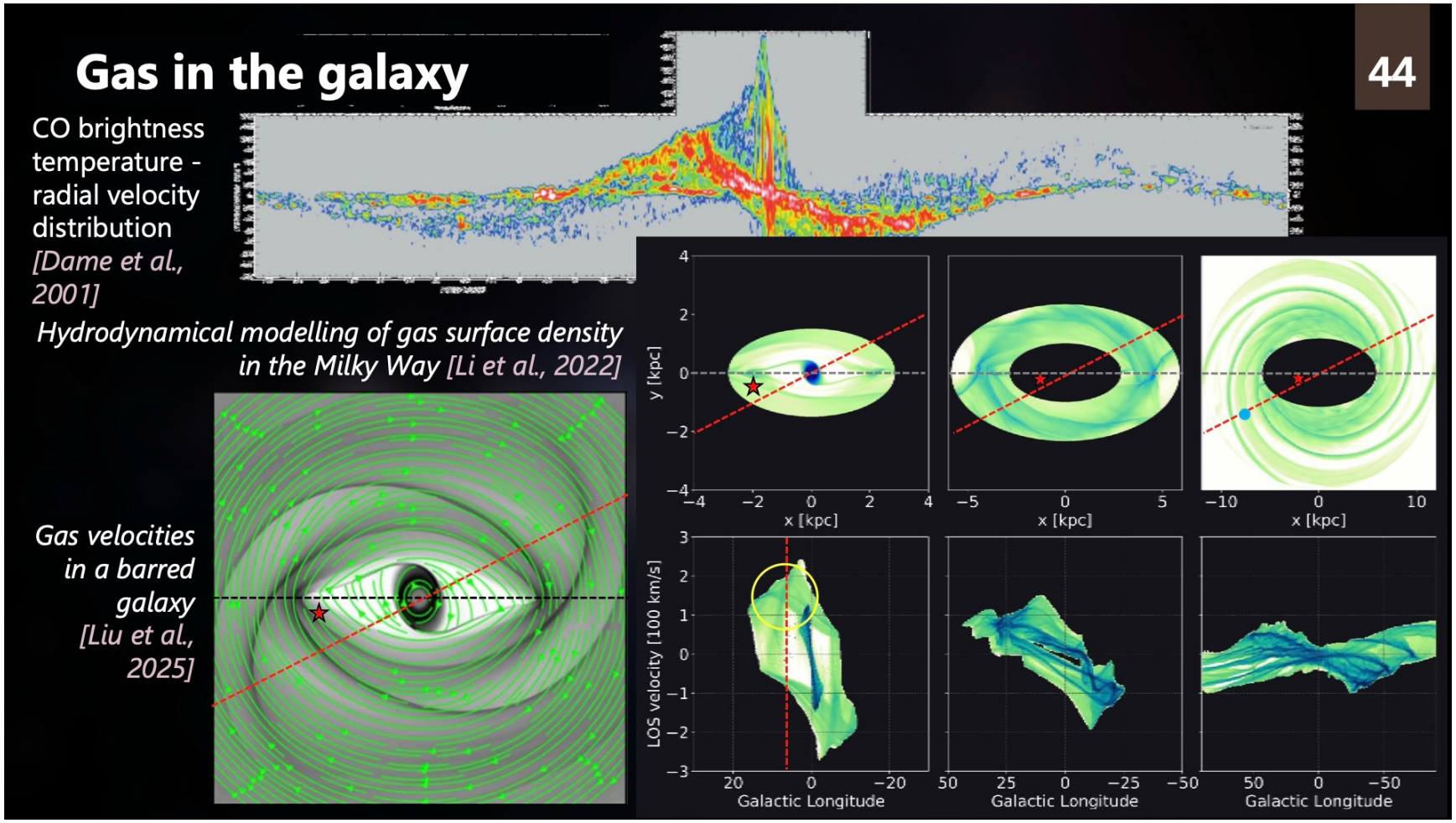


Leptonic model: morphology

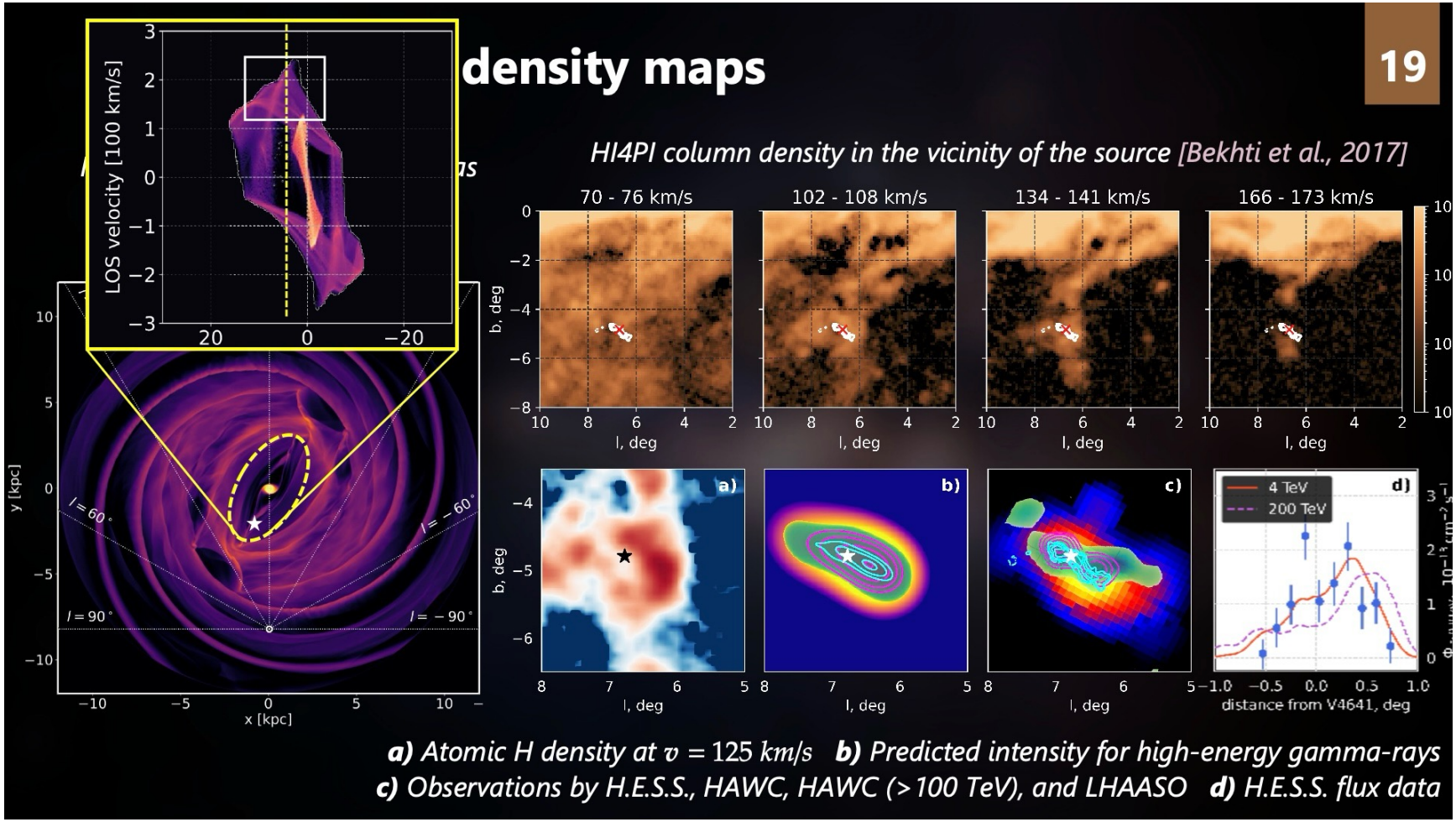


Hadronic models

Hadronic models: gas model



Hadronic models: target gas



Hadronic models: spectrum

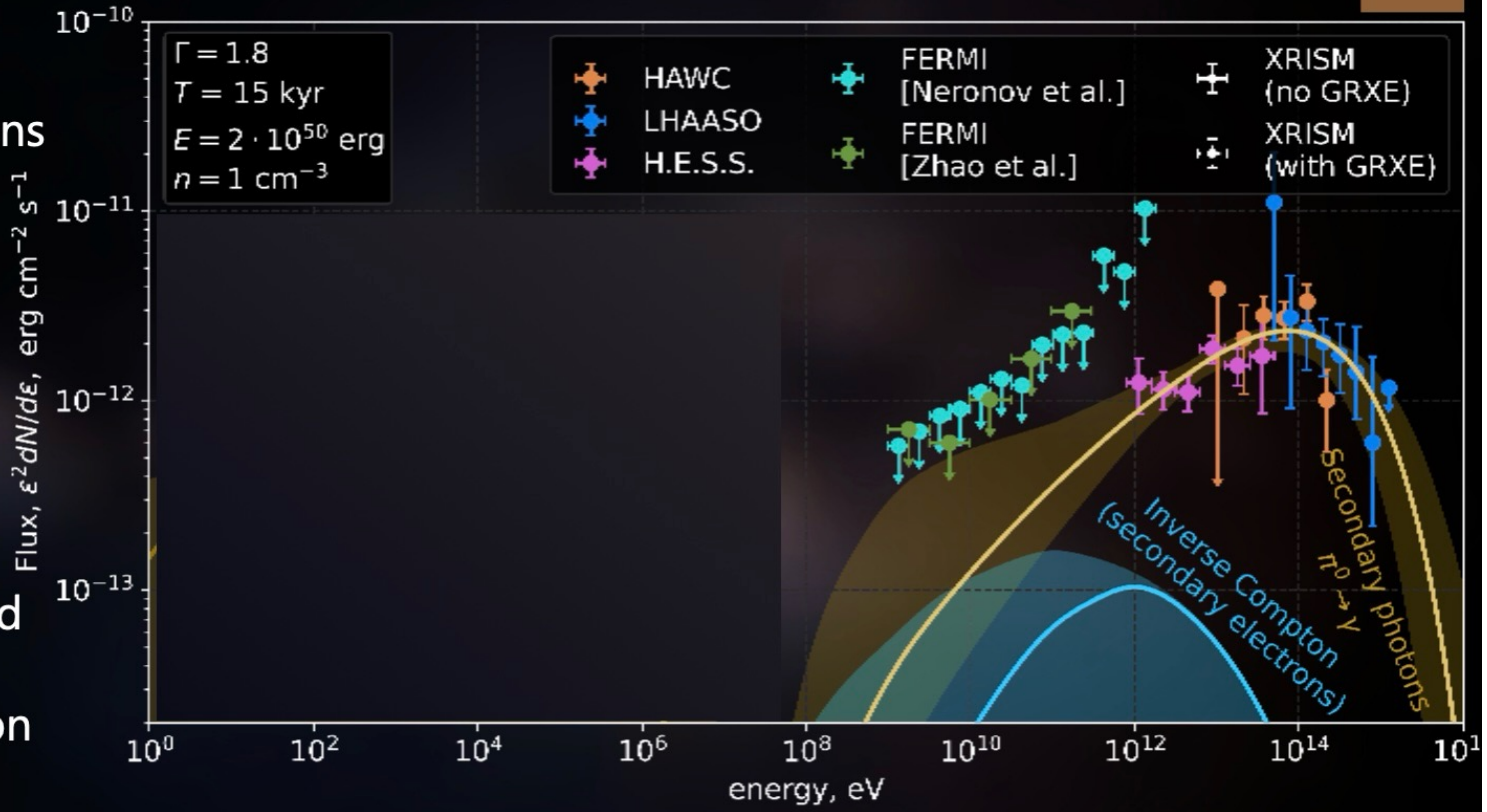
Proton-flash model

20

A single ejected population of protons at t = 0

Synchrotron radiation can be produced by secondary electrons only!

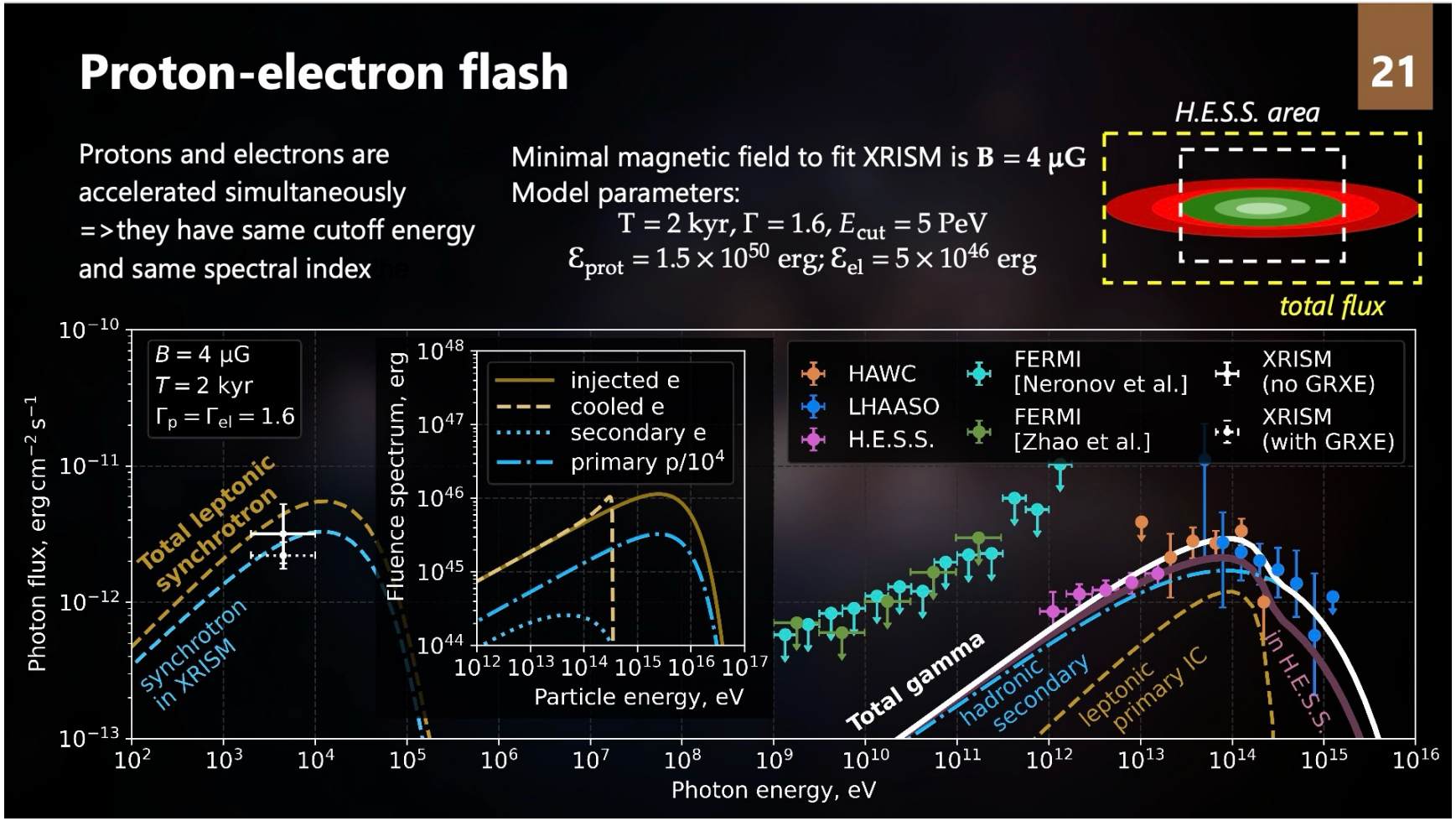
In any magnetic field from 1 to 40 μG synchrotron emission is insufficient



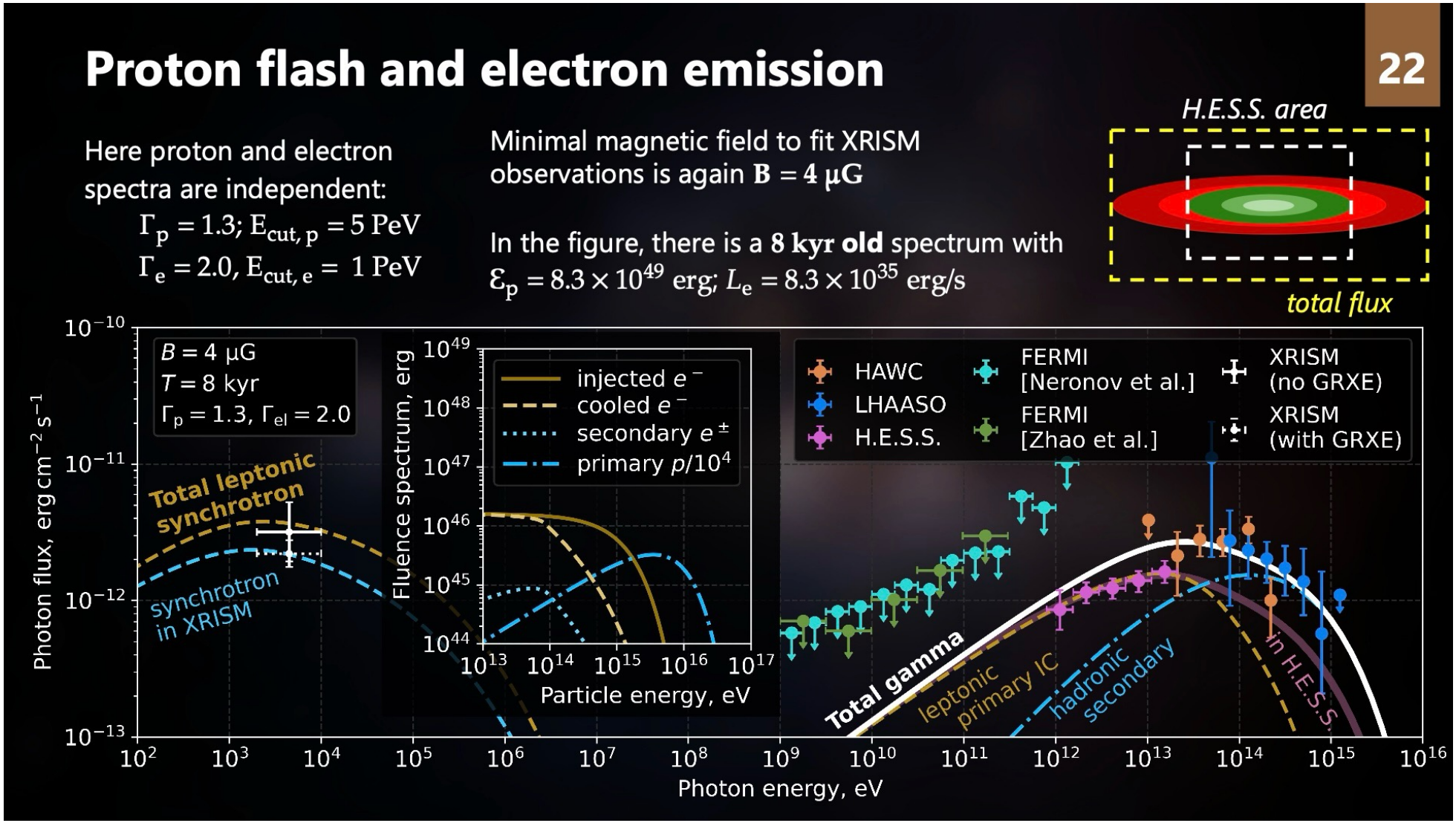
inconsistent with X-ray observations

Lepto-hadronic models

Leptohadronic models

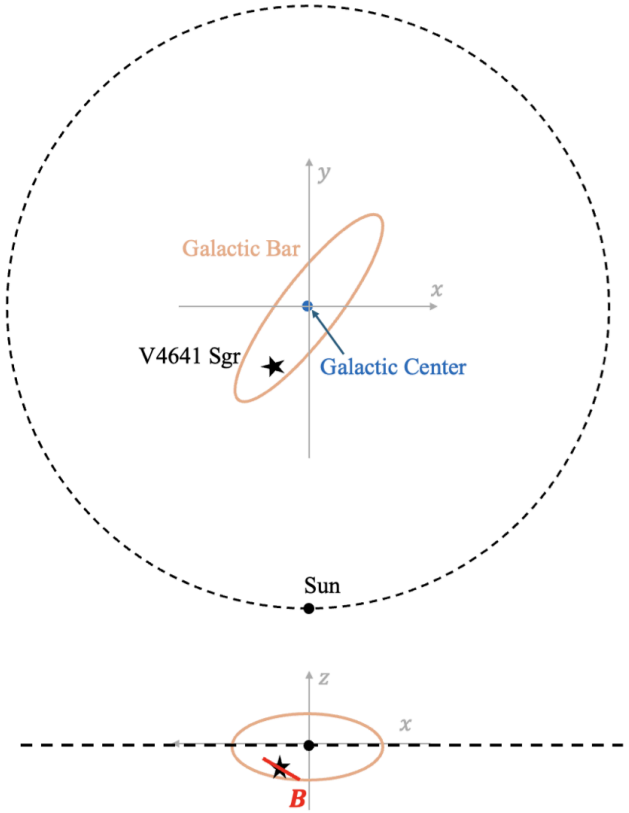


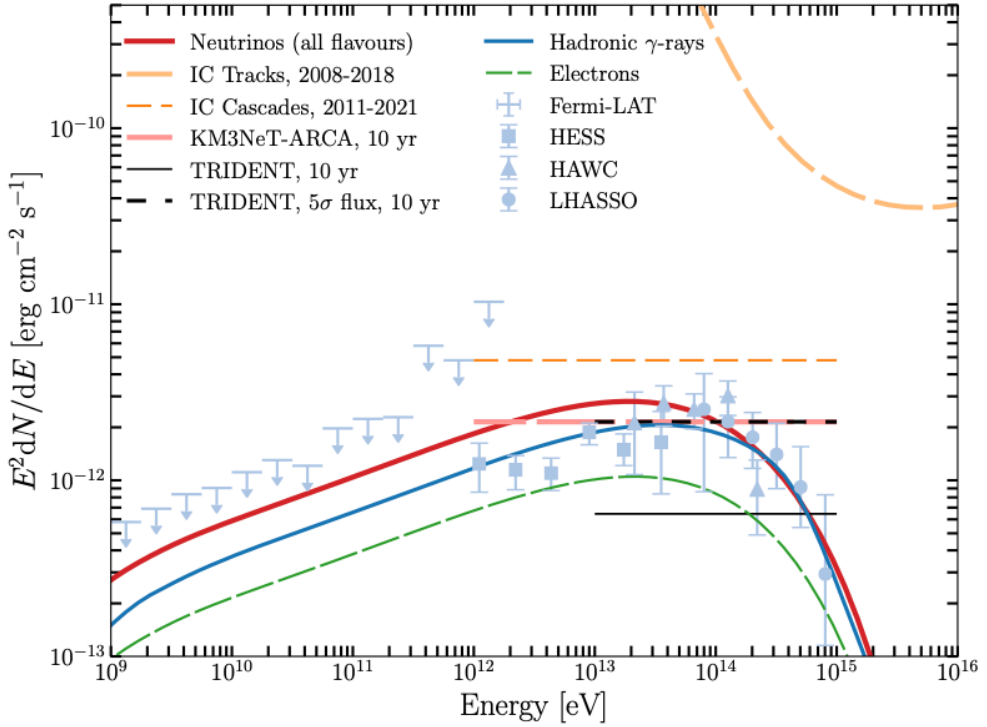
Leptohadronic models



Neutrinos from V4641 sgr

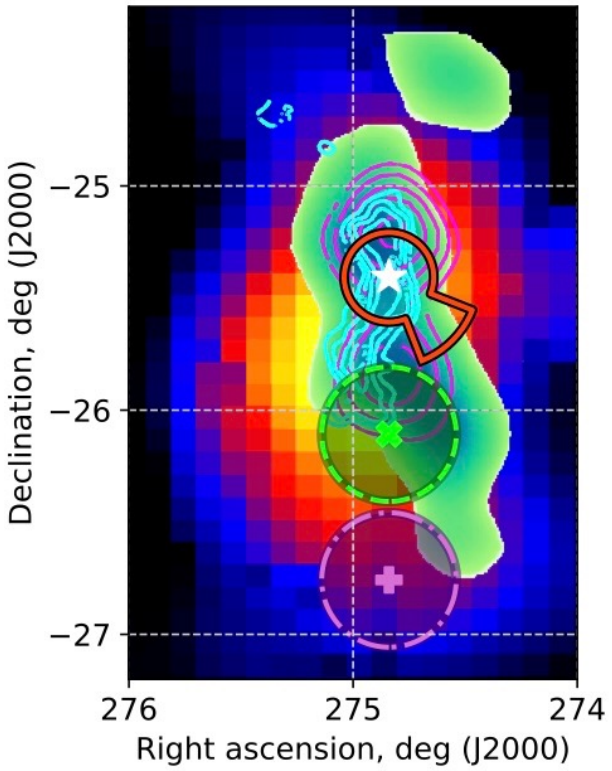
Neutrinos from V4146, hadronic model

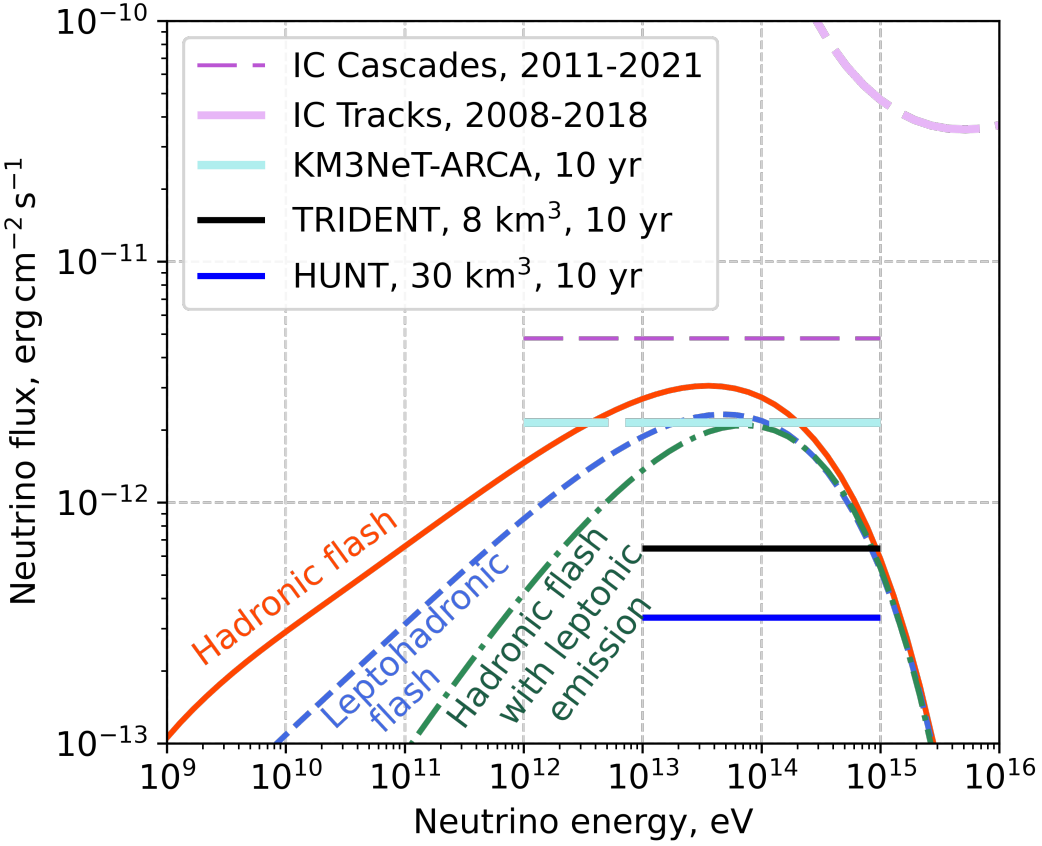




A.Neronov, F.Oikonomou and D.S., arXiv:2410.17608

Neutrinos from V4146





M.Kleimenov, A.Neronov, F.Oikonomou and D.S., arXiv:2512.13578

Summary

- *Gamma-ray emission from V4641 extend to 100 pc from source at high energy on south and around 60 pc both sides at low energies.*
- *Leptonic models explain low energies, but difficult to explain north/south asymmetry at high energy*
- *Hadronic emission explains asymmetry, but contradict to X-ray*
- *Leptohadronic models explain all data*
- *One need to check X-rays from south E>100 TeV emission*
- *Future 8-30 km3 neutrino detectors can try to get neutrino flux after several years of observation*