What do Astronomers expect from Astroparticle Physics?

Jörn Wilms, ECAP

EMERGING FIELDS INITIATIVE

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

What do Astronomers expect from Astroparticle Physics?

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- What is Astronomy?
- What is Astroparticle Physics?
- The Two Cultures
  - Sociology of the Field(s)
  - Common Themes and Interests
- Conclusions

EMERGING FIELDS INITIATIVE

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What is Astronomy?

Astronomy – The 2nd oldest profession on Earth

What is Astronomy?

Astronomy – Science with Large Facilities since 2500 BC

courtesy Marc Hempel

What is Astronomy?

"Astrophysics can be briefly characterized as a paradigmatic, established, basic, hard knowledge field with relatively clear disciplinary boundaries."

Heidler, 2011, Minerva 49:461–488

History

- well established structures since 1800s:
  - early professionalization (e.g., RAS [1820], AG [1863],. . .)
  - early large scale international collaboration (Carte du Ciel [1872–1970], Bonner Durchmusterung,. . .)

History

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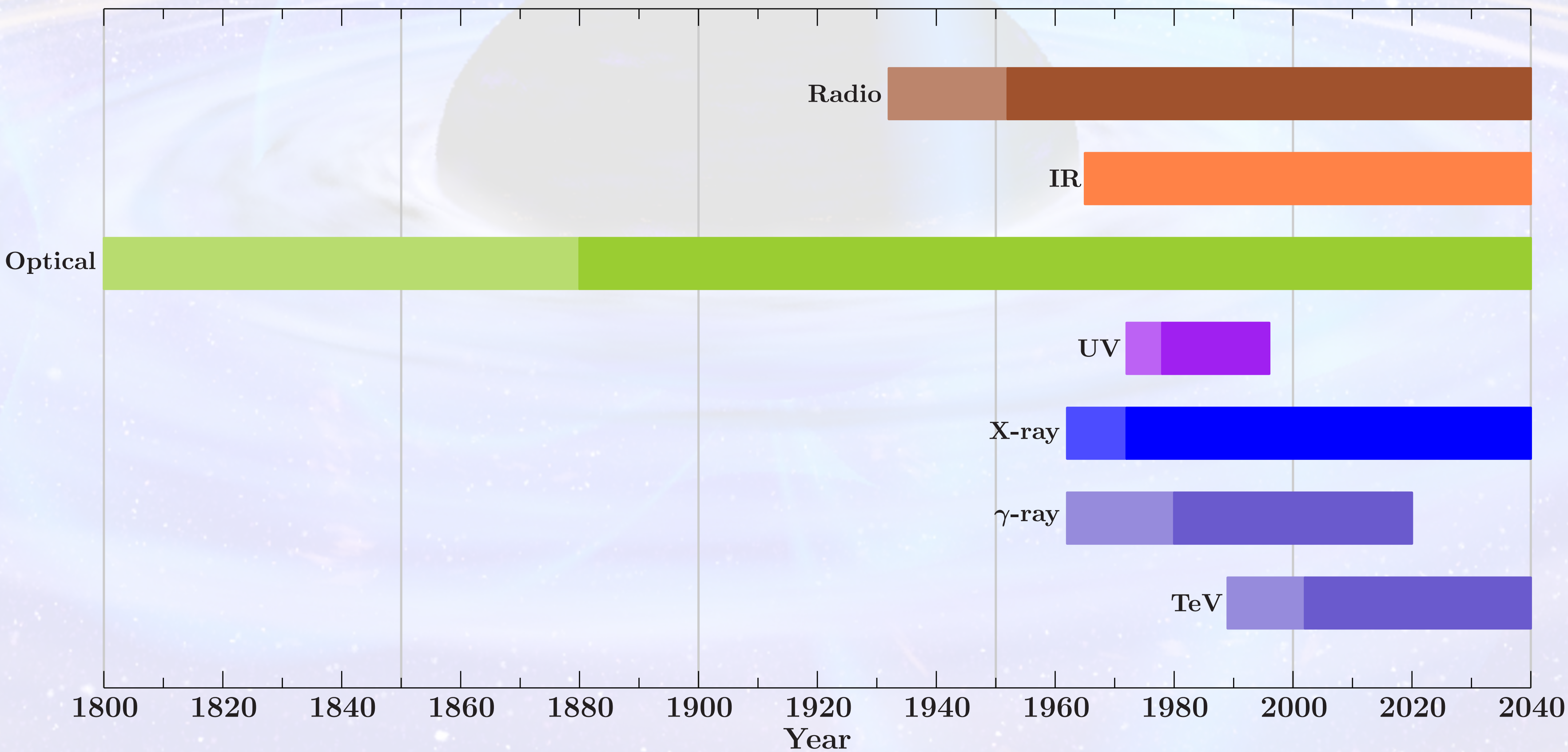
  - early professionalization (e.g., RAS [1820], AG [1863],. . .)
  - early large scale international collaboration (Carte du Ciel [1872–1970], Bonner Durchmusterung,. . .)
- long seen as separate scientific discipline

In 1923, a candidate for the position of director of Remeis observatory was rejected with the argument, a physicist should never be director of an observatory.

History

- well established structures since 1800s:
  - early professionalization (e.g., RAS [1820], AG [1863],. . .)
  - early large scale international collaboration (Carte du Ciel [1872–1970], Bonner Durchmusterung,. . .)
- part of physics since ∼1950s (“astrophysics”):



What is Astroparticle Physics?

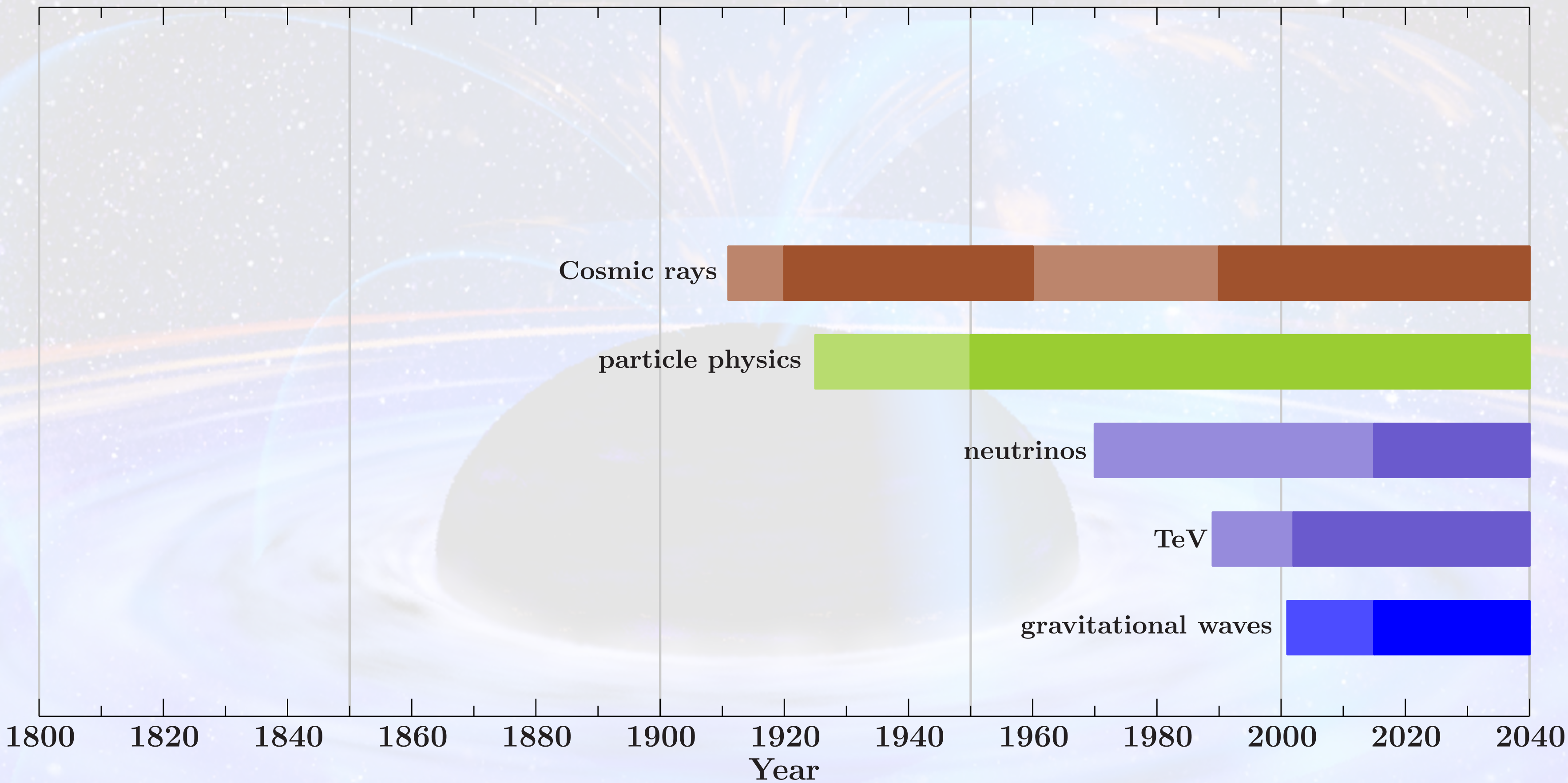
"There is no such thing as a commonly acknowledged textbook definition of 'astroparticle physics'. Though, of course, there are ideas of what astroparticle physics deals with. . .

Astroparticle physics is an interdisciplinary field lying between particle physics and cosmology that attempts to reveal the nature and structure of matter in the universe."

Cirkel-Bartelt, 2008, Living Rev. Relativity 11, 2

Note: the field of "cosmology" is perhaps even less well defined than the field of astroparticle physics. . .

History: Astroparticle Physics



1911: Hess: Cosmic Rays

1940s: Auger

1987: First International School on Astroparticle Physics, Erice

Questions: Astronomy

Most important themes of astronomy:
US Decadal Survey (European ideas such as ESA Cosmic Vision are similar)

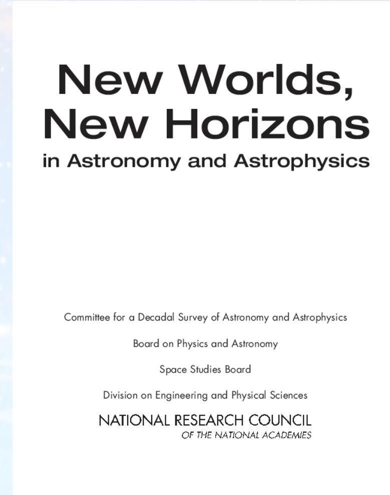
- Cosmic Dawn: Searching for the First Stars, Galaxies, and Black Holes

  galaxy formation and evolution, low Z stars

- New Worlds: Seaking Nearby, Habitable Planets

- Physics of the Universe: Understanding Scientific Principles

  "dark energy", cosmological gravitational wave background/CMB polarization, strong field gravity



New Worlds, New Horizons
in Astronomy and Astrophysics

Committee for a Decadal Survey of Astronomy and Astrophysics
Board on Physics and Astronomy
Space Studies Board
Division on Engineering and Physical Sciences
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Deutsche Forschungsgemeinschaft

Status und Perspektiven der Astronomie in Deutschland 2003–2016

Denkschrift

Redaktionskomitee:
Andreas Burkert, Reinhard Genzel, Günther Hasinger, Gregor Morfill (Vorsitz), Peter Schneider, Detlev Koester (Vorsitzender des Rates Deutscher Sternwarten)

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Main themes of Astroparticle Physics
(OECD GSF definition)

What is the role of high energy phenomena in the Universe ?

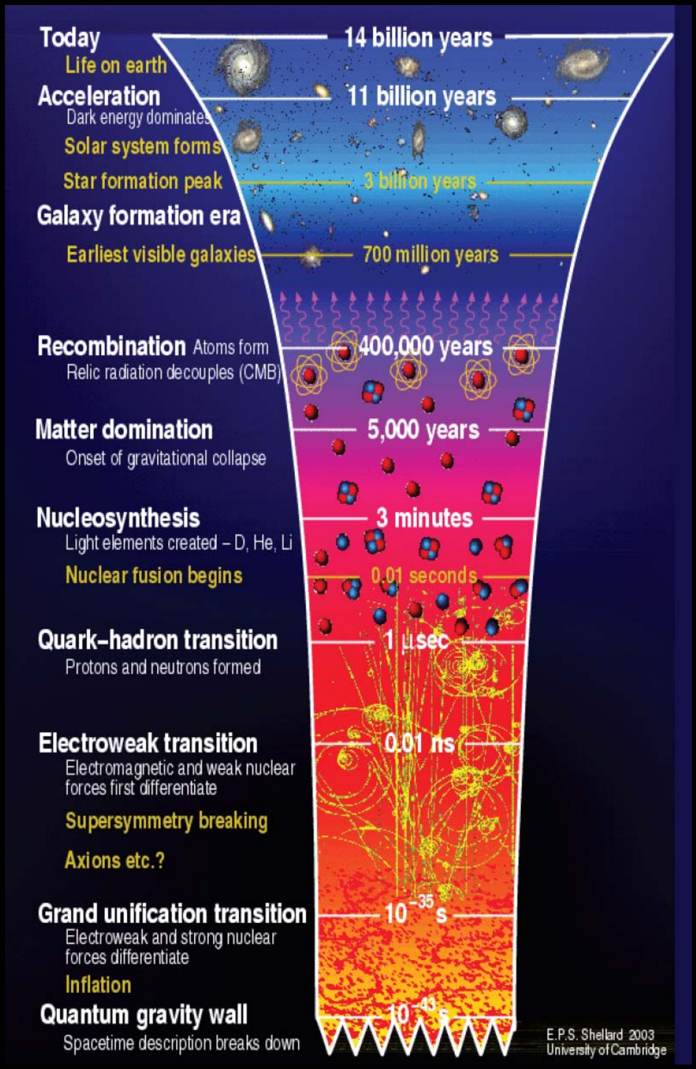
- High Energy messengers (γ, ν , p/N)
- Gravitational waves

What is the Universe made of ?

- Dark Matter
- Dark Energy

What is the nature of matter and interaction at the highest energies ?

- Neutrino Mass
- Proton decay and neutrino Properties



Katsanevas, 2011 (Aspera workshop)

Main themes of Astroparticle Physics
(OECD GSF definition)

ASPERA

What is the role of high energy phenomena in the Universe ?

- High Energy messengers (γ, ν , p/N)
- Gravitational waves

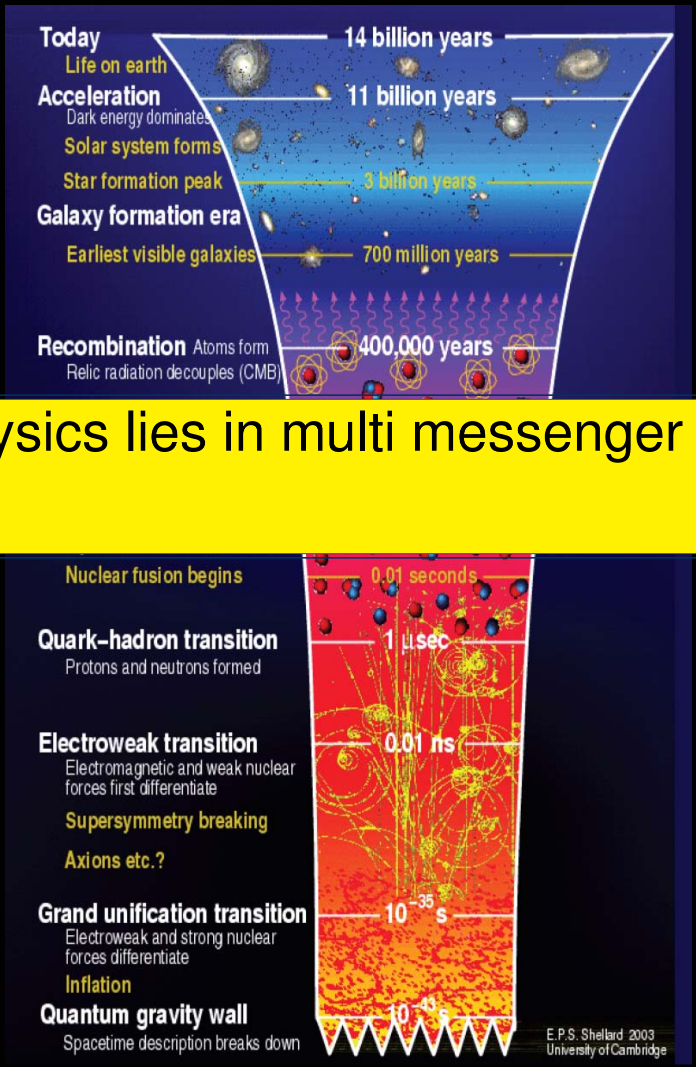
What

- Da
- Dark Energy

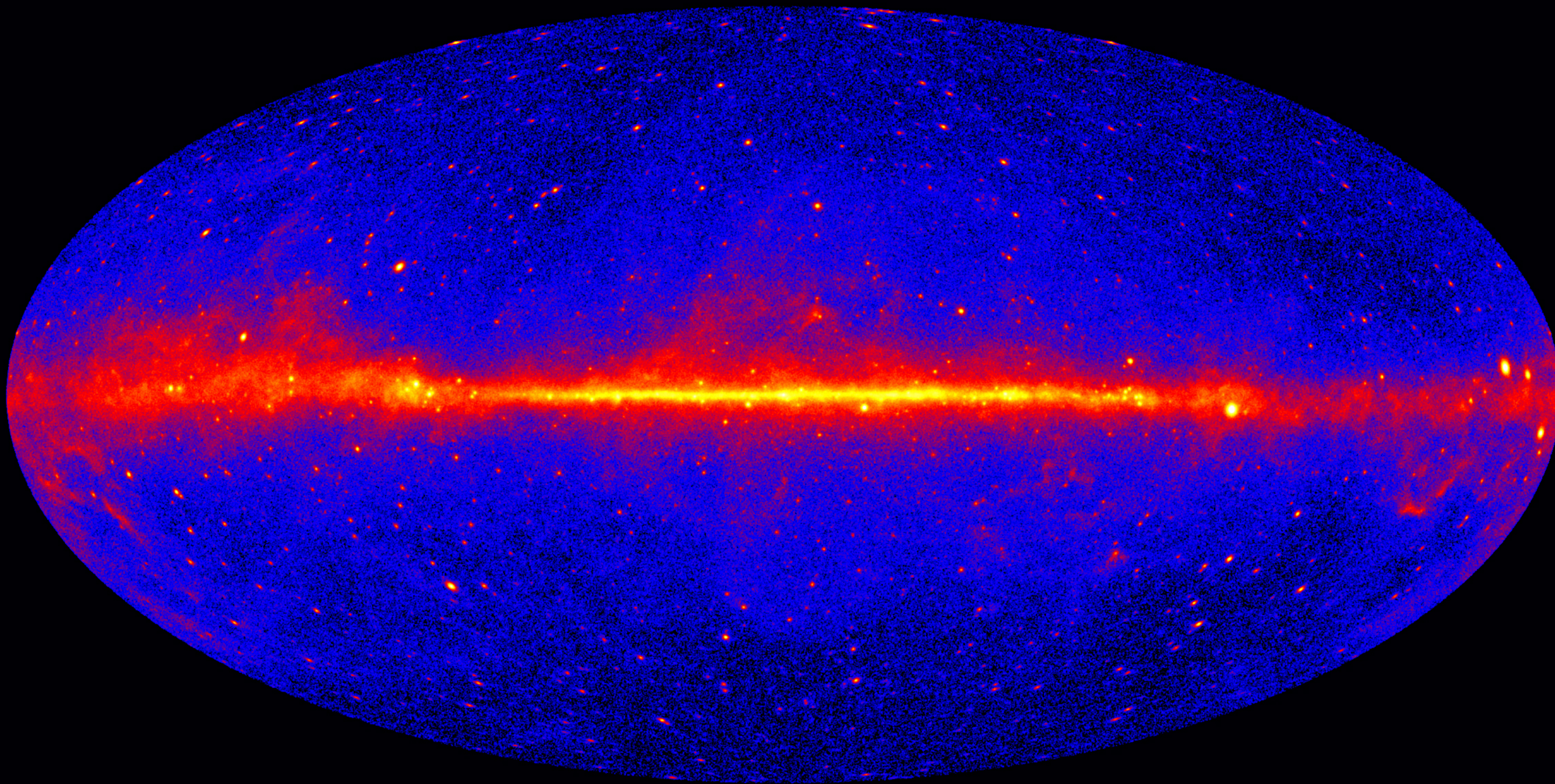
The overlap of astronomy and astroparticle physics lies in multi messenger ty
astrophysics and in DM/cosmology.

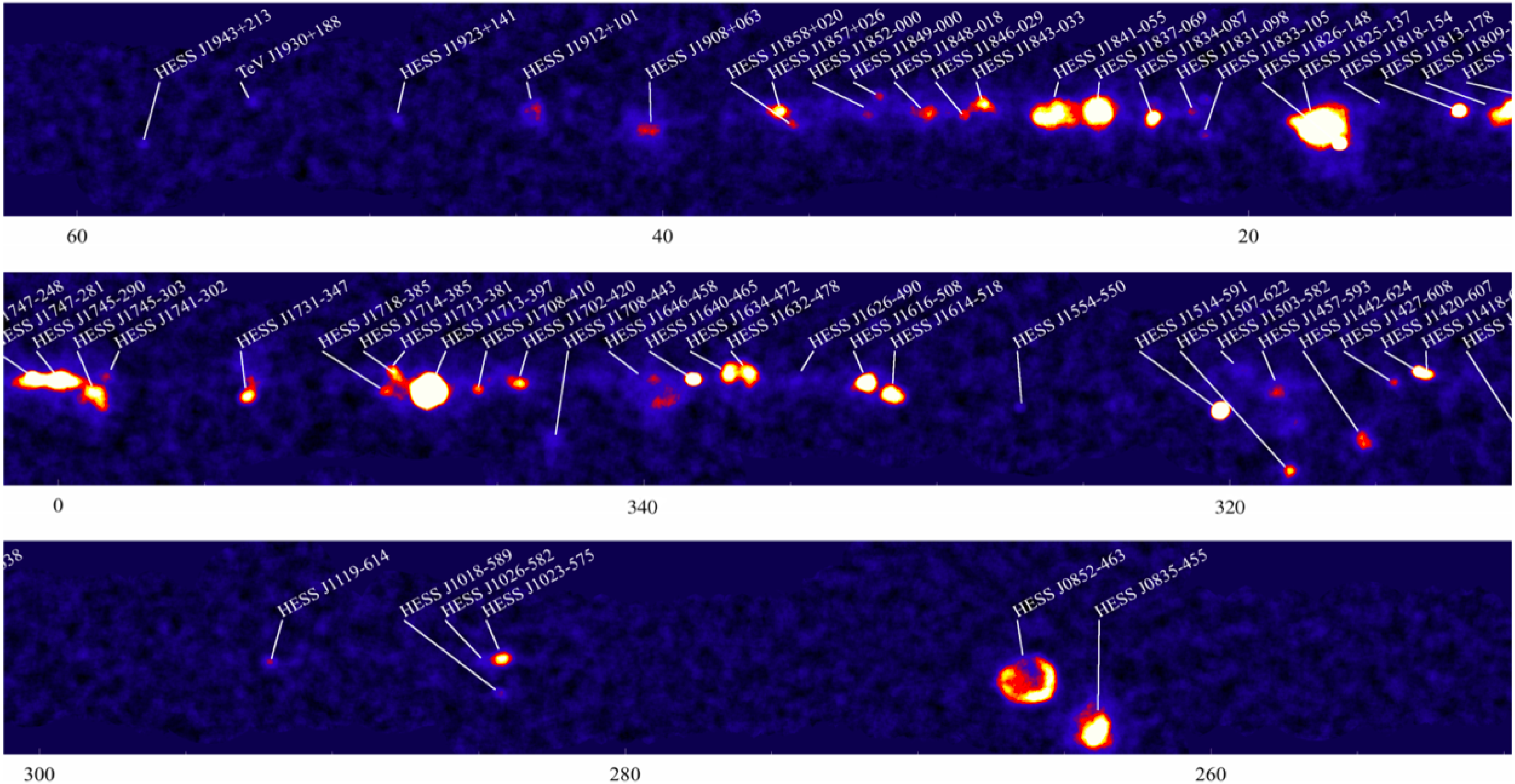
What is the nature of matter and interaction at the highest energies ?

- Neutrino Mass
- Proton decay and neutrino Properties



Katsanevas, 2011 (Aspera workshop)

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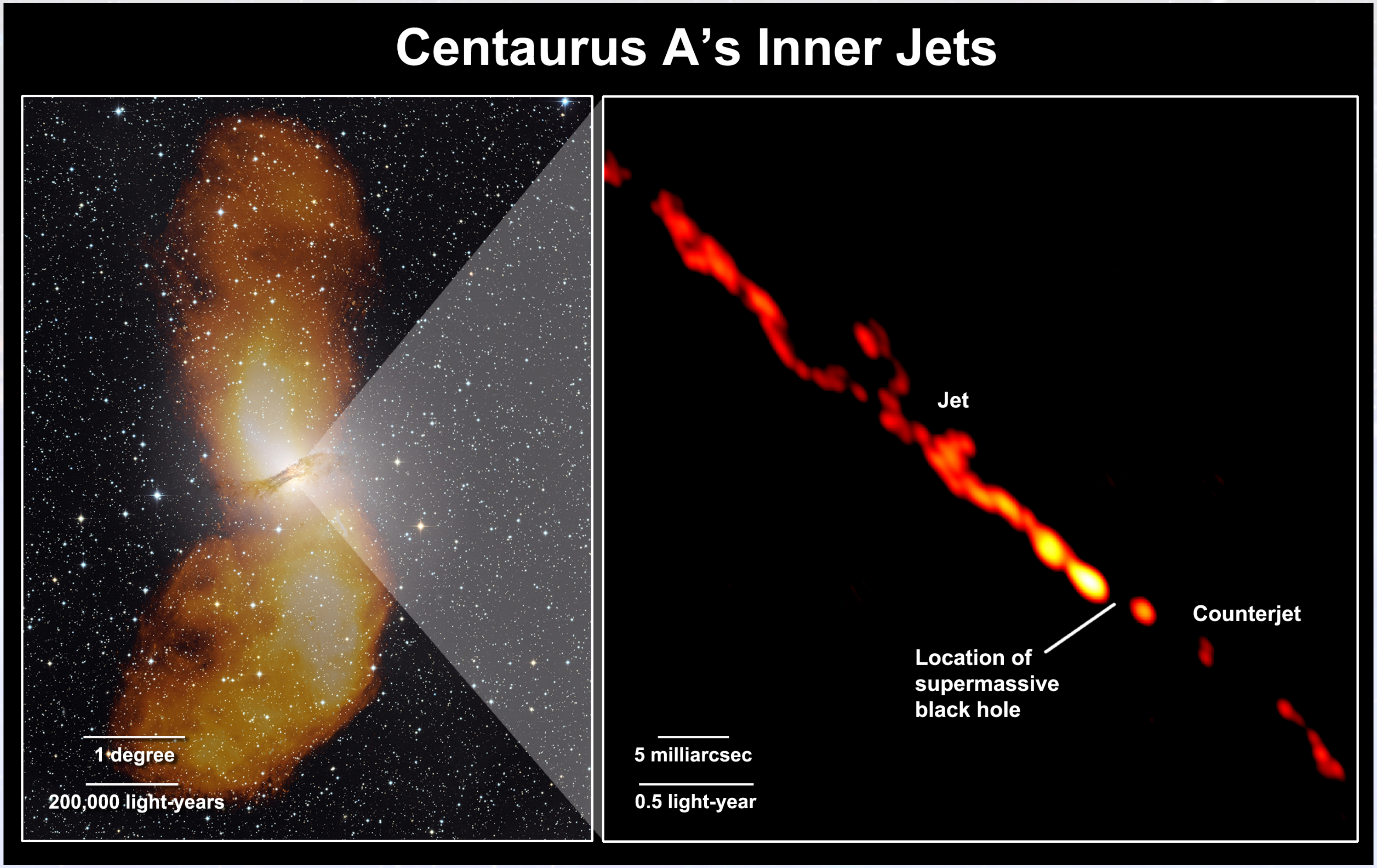
Accreting Black Holes



Müller et al., 2011, A&A 530, L11

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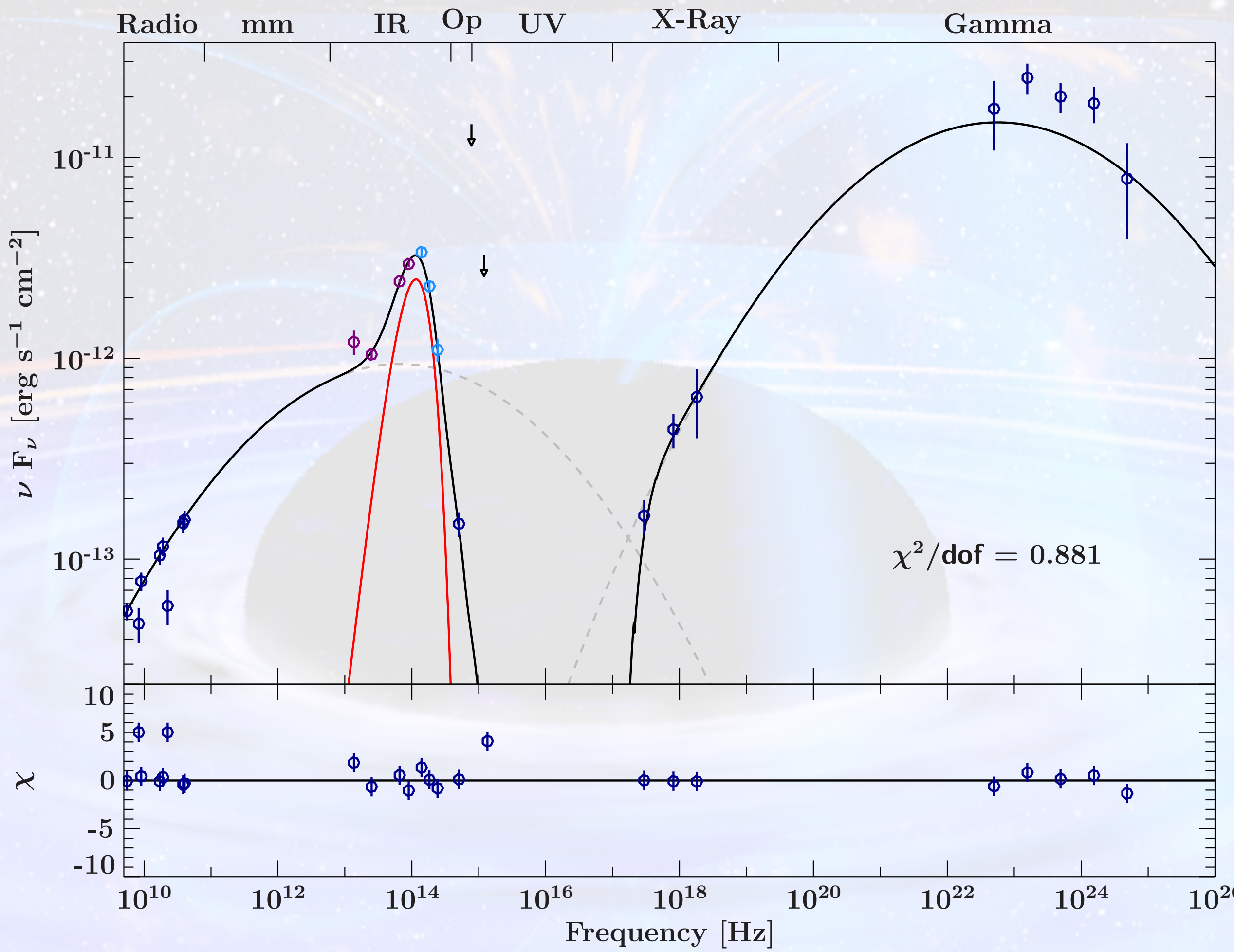
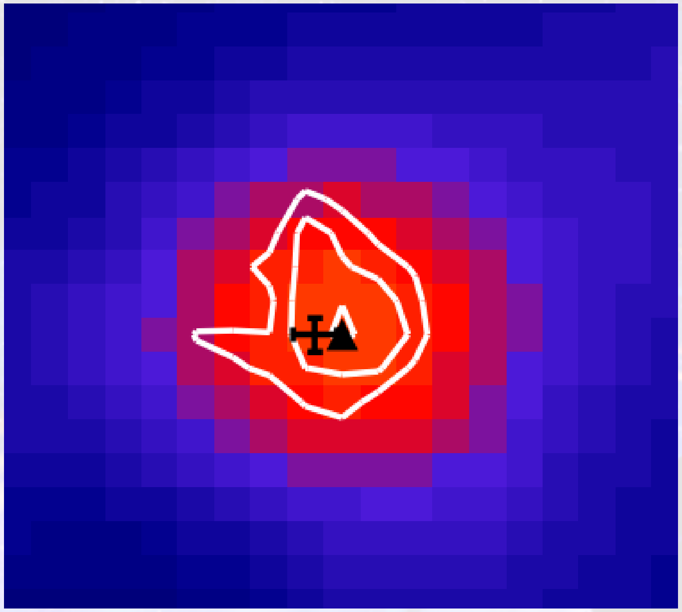


Müller et al., in prep. (*not* Cen A)

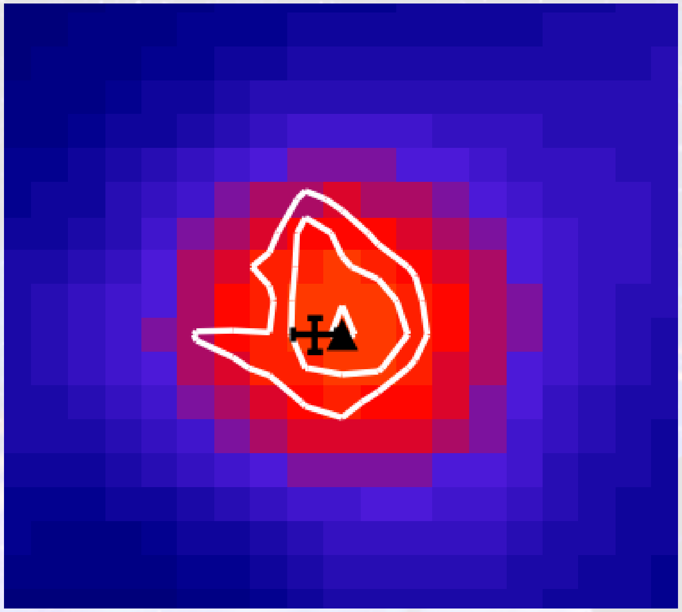
Jets: hadronic vs. leptonic, origin of cosmic rays $\Longrightarrow$ HESS2, CTA, neutrino experiments

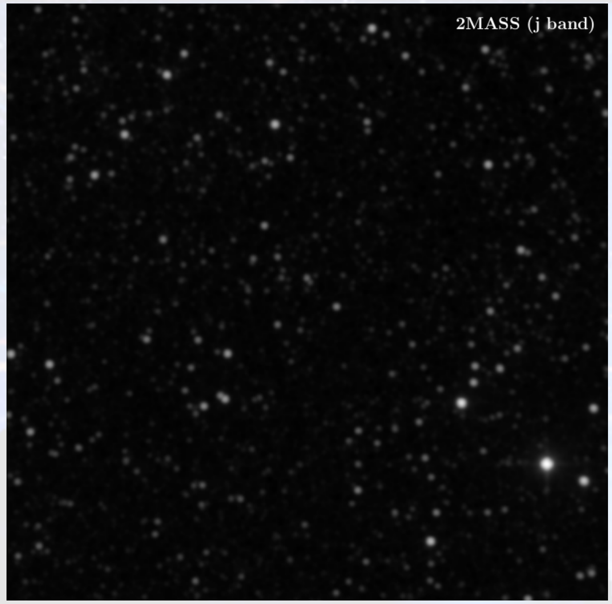
High Energy Universe



Willmann et al., in prep.

High Energy Universe





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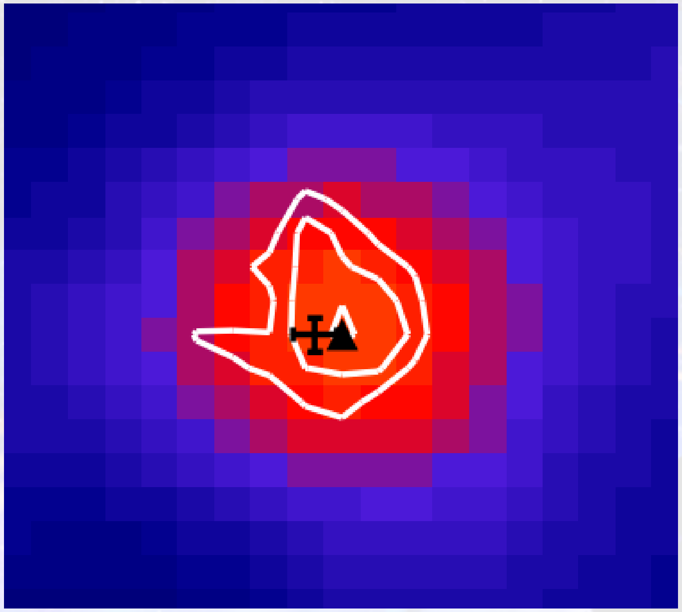

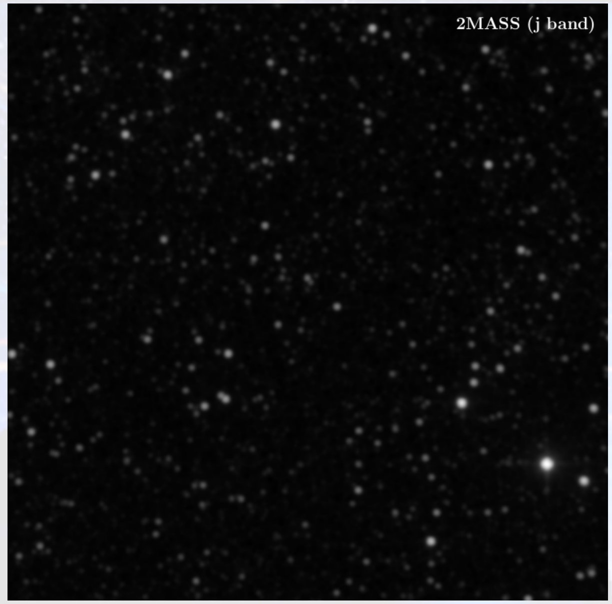

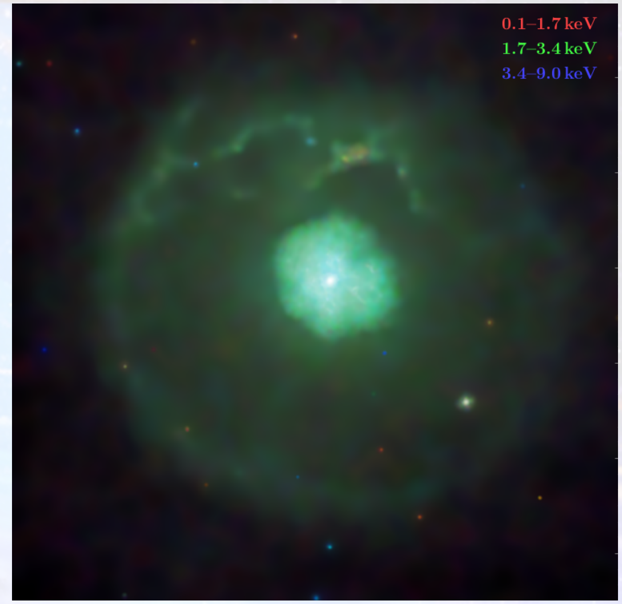

Willmann et al., in prep.

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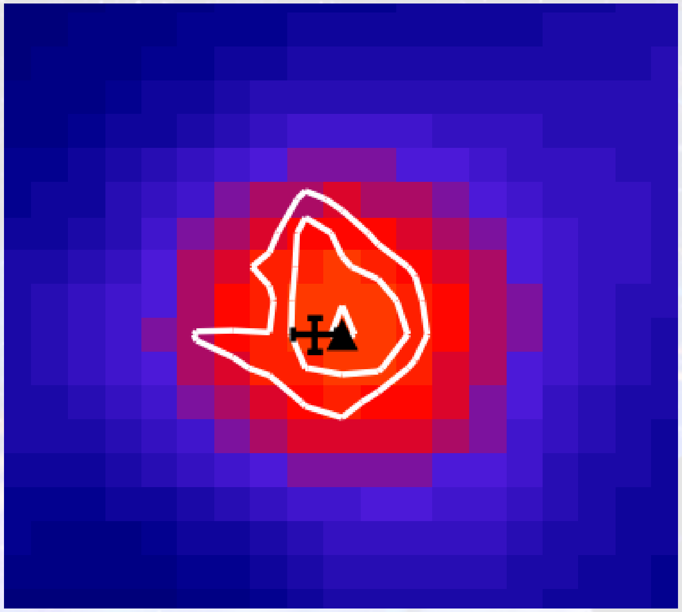
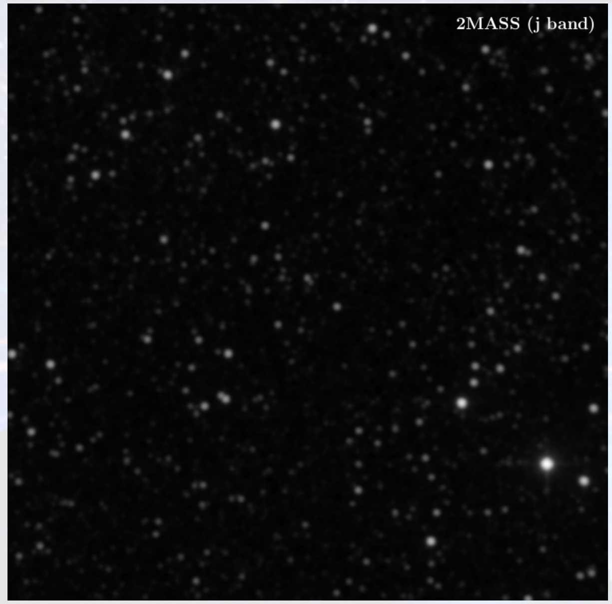
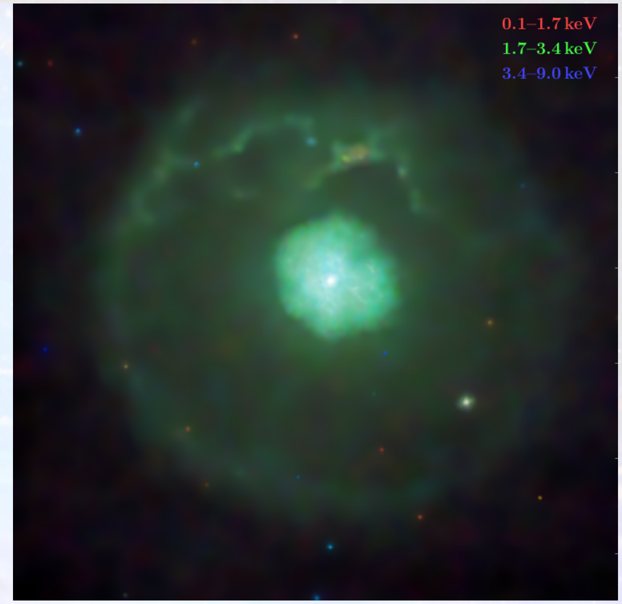


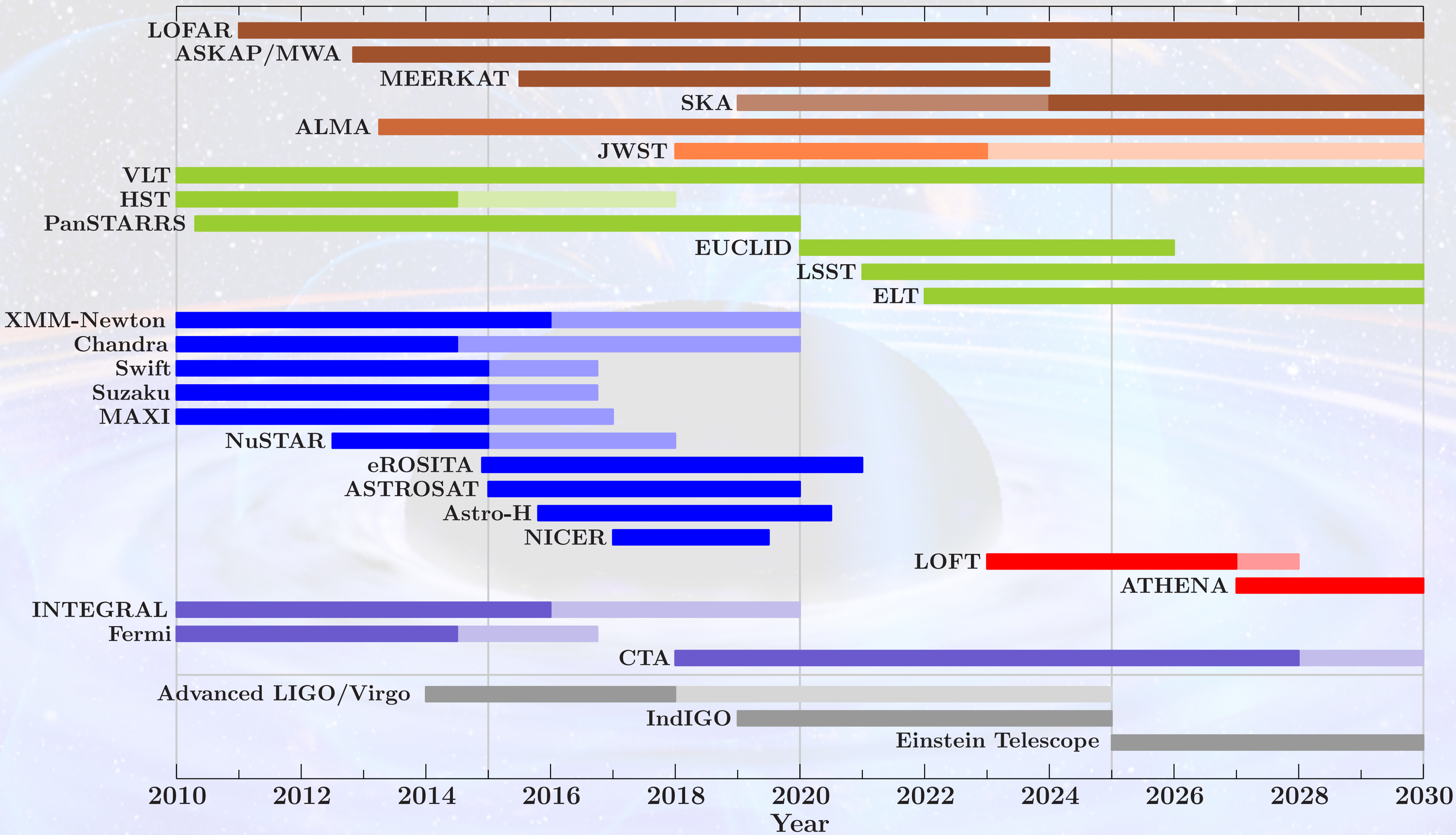




Willmann et al., in prep.

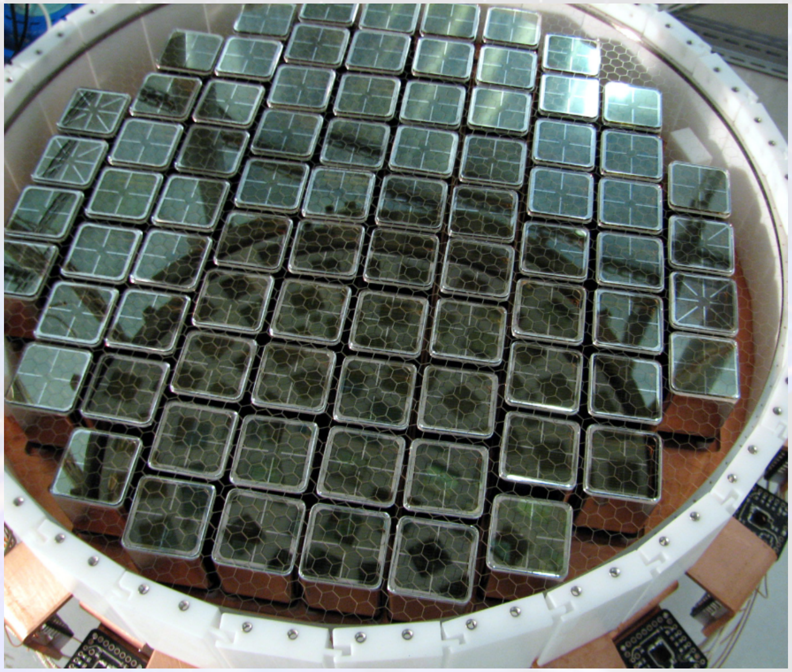
Supernova Remnants: acceleration processes, origin of high energy cosmic rays,... $\Longrightarrow$ TeV Astronomy

High Energy Universe



High Energy Astronomy needs support to be able to continue providing coverage of the whole electromagnetic spectrum in the 2020s.

Dark Matter, Gravitational Waves



Dark Matter Searches:

- more seen as “parallel endeavour”
- close connection to physics of early universe, not so much to “practical” questions in extragalactic astrophysics.

Gravitational Waves:

- very interesting physics
- astronomical implications less clear, but potentially interesting
  BH merger rates, neutron star formation, CV population

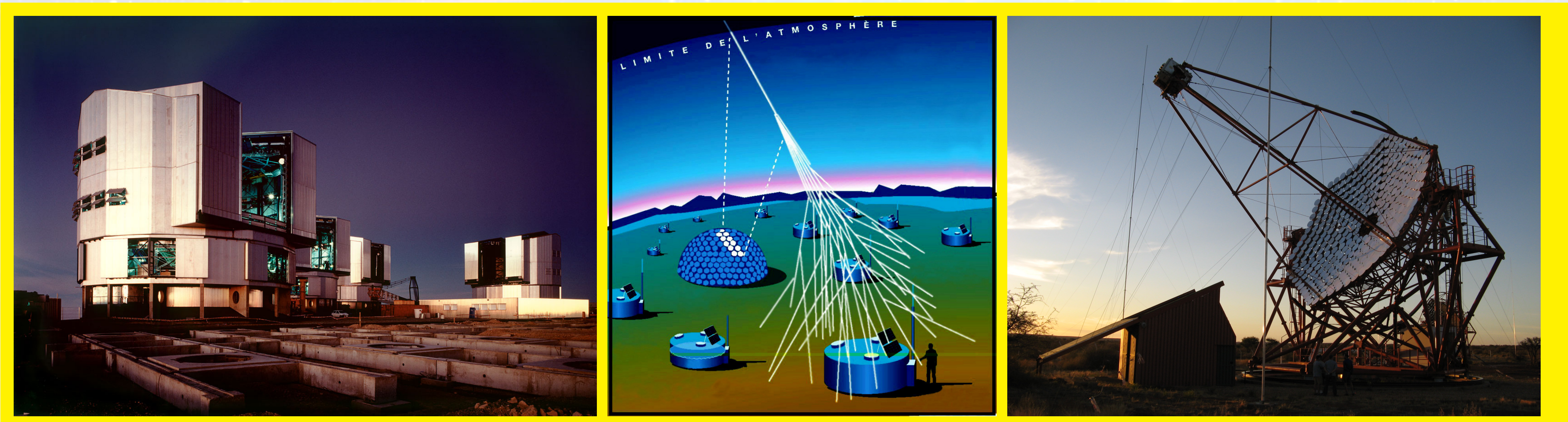
Methodology

Astrophysics	Astroparticle Physics

White, 2007, Rep. Prog. Phys., 70, 223 $\Longleftrightarrow$ Kolb, 2007, Rep. Prog. Phys., 70, 1583

Methodology

	Astrophysics	Astroparticle Physics
facilities	multi-purpose, large scale internatio-nal observatories	experiments



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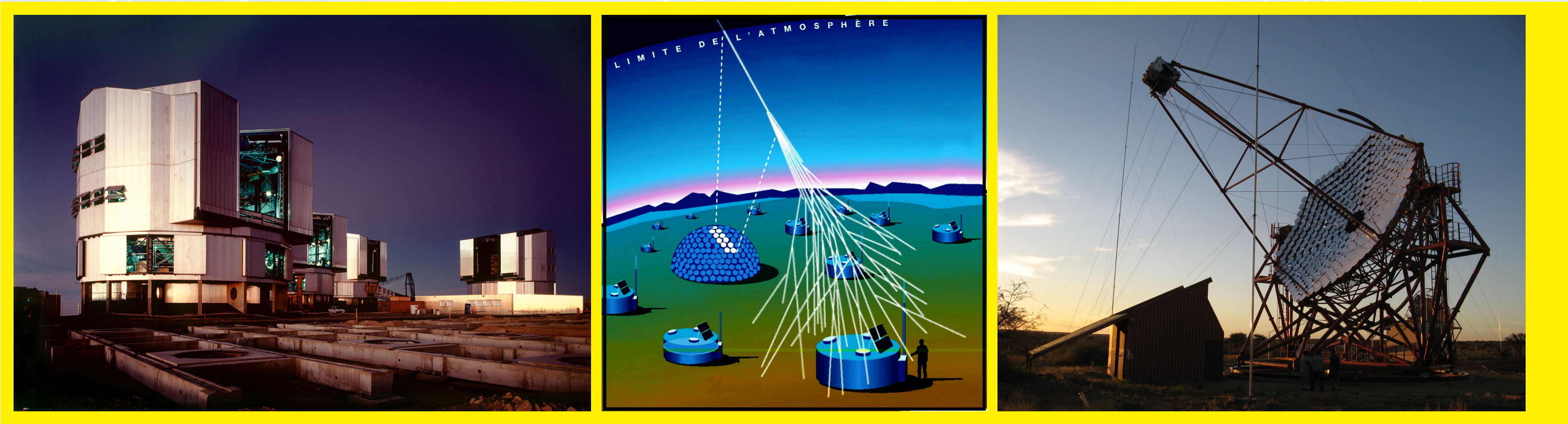

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analysis approach	standardized software	less reliance on standards
data policy	public after $\sim$1 yr	proprietary

White, 2007, Rep. Prog. Phys., 70, 223 $\Longleftrightarrow$ Kolb, 2007, Rep. Prog. Phys., 70, 1583

Methodology

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The Astrophysical Journal, 775:98 (15pp), 2013 October 1 doi:10.1088/0004-637X/775/2/98

GAMMA-RAY OBSERVATIONS OF THE MICROQUASARS CYGNUS X-1, CYGNUS X-3, GRS 1915+105, AND GX 339−4 WITH THE *FERMI* LARGE AREA TELESCOPE

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Received 2013 March 21; accepted 2013 July 25; published 2013 September 11

ABSTRACT

Detecting gamma-rays from microquasars is a challenging but worthwhile endeavor for understanding particle acceleration and the jet mechanism and for constraining leptonic/hadronic emission models. We present results from a likelihood analysis on timescales of 1 day and 10 days of ∼4 yr worth of gamma-ray observations (0.1–10 GeV) by *Fermi*-LAT of Cyg X-1, Cyg X-3, GRS 1915+105, and GX 339−4. Our analysis reproduced all but one of the previous gamma-ray outbursts of Cyg X-3 as reported with *Fermi* or *AGILE*, plus five new days on which Cyg X-3 is detected at a significance of $\sim5\sigma$ that are not reported in the literature. In addition, Cyg X-3 is significantly detected on 10 day timescales outside of known gamma-ray flaring epochs, which suggests that persistent gamma-ray emission from Cyg X-3 has been detected for the first time. For Cyg X-1 we find three low-significance excesses (~3–4σ) on daily timescales that are contemporaneous with gamma-ray flares reported (also at low significance) by *AGILE*. Two other microquasars, GRS 1915+105 and GX 339−4, are not detected, and we derive 3σ upper limits of 2.3×10^{-8} photons cm^{-2} s^{-1} and 1.6×10^{-8} photons cm^{-2} s^{-1}, respectively, on the persistent flux in the 0.1–10 GeV range. These results enable us to define a list of the general conditions that are necessary for the detection of gamma-rays from microquasars.

Key words: black hole physics – gamma rays: stars – stars: neutron – X-rays: binaries – X-rays: individual (Cygnus X-3, Cygnus X-1, GRS 1915+105, GX 339−4)

Online-only material: color figures

1. INTRODUCTION

A microquasar (μQSO) consists of a compact object (CO; a neutron star (NS), or a black hole (BH)) that accretes matter from a normal stellar companion. The characteristic that distinguishes μQSOs from other X-ray binaries (XRBs) is the presence of non-thermal synchrotron emission from relativistic jets launched near the CO (Mirabel & Rodríguez 1999). These radio jets are believed to be powered by BH spin and/or by strong electromagnetic currents in the inner accretion disk (e.g., Blandford & Znajek 1977; Meier 2001).

The presence of jets interacting with plasmas within strong electromagnetic and gravitational fields leads μQSOs to display rapid variability across a broad range of frequencies: from radio to IR and X-rays. A few of these objects have been detected in the gamma-rays (> 100 MeV) with *AGILE* (Tavani et al. 2009a), *Fermi*-LAT (Atwood et al. 2009), and MAGIC (Lorenz 2004 and references therein). These are Cyg X-3 (Abdo et al. 2009c; Tavani et al. 2009b; Corbel et al. 2012; Piano et al. 2012) and Cyg X-1 (Albert et al. 2007; Bulgarelli et al. 2010a; Sabatini et al. 2010a, 2010b, 2013). While the XRBs LS I +61°303 (Albert et al. 2006; Abdo et al. 2009a) and LS 5039 (Paredes et al. 2000; Aharonian et al. 2005; Abdo et al. 2009b) have been detected at MeV–TeV energies, it is still uncertain whether they should be classified as μQSOs (e.g., Paredes 2011a).

Leptonic and hadronic processes are generally invoked to explain gamma-ray emission from μQSOs. In the former, relativistic electrons in the jet emit synchrotron radiation (with some loss due to self-absorption), or they can Compton upscatter low-energy (IR and UV) photons from the accretion disk or from the stellar companion to gamma-ray energies (e.g., Kaufman Bernadó et al. 2002; Romero et al. 2002; Bosch-Ramon et al. 2006; Sitarek & Bednarek 2012 and references therein). In hadronic models, inelastic collisions between jet protons and those of the dense stellar wind produce neutral pions which decay into gamma-rays and neutrinos (e.g., Romero et al. 2003 and references therein). Interactions between the jet and the clumpy winds from massive donor stars in HMXB microquasars can lead to gamma-ray emission from both leptonic (inverse compton; IC) and hadronic (neutral pion decay) processes (Araudo et al. 2009; Owocki et al. 2009). These winds can also serve as the site for the initiation of $e^- - e^+$ cascades from a primary source of very high-energy (VHE) gamma-rays within the system; the secondary emission resulting from these pair cascades should be detectable in the low-energy gamma-rays (Bednarek 1997; Romero et al. 2010). Some of these photons can be absorbed by the wind, leading to variable gamma-ray emission (Dubus 2006). Shocks at the termination zone where the jet meets the interstellar medium are also believed to produce gamma-ray photons (Bosch-Ramon et al. 2011).

The common trait shared by these emission models is that gamma-rays are tied to the presence of radio jets (Paredes 2011b). These jets appear during specific emission states for BH XRBs (BHXBs; e.g., Fender et al. 2004; McClintock & Remillard 2006 and references therein). Indeed, this link between radio and gamma-ray emission was demonstrated for several gamma-ray outbursts of Cyg X-3 (Corbel & Hays 2010; Williams et al. 2011; Corbel et al. 2012). It is clear then that

1

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S. Adrián-Martínez et al JCAP06(2013)008 doi:10.1088/1475-7516/2013/06/008

A first search for coincident gravitational waves and high energy neutrinos using LIGO, Virgo and ANTARES data from 2007

S. Adrián-Martínez[1], I. Al Samarai[2], A. Albert[3], M. André[4], M. Anghinolfi[5], G. Anton[6], S. Anvar[7], M. Ardid[1], T. Astraatmadja[8,39], J-J. Aubert[2], B. Baret[9], S. Basa[10], V. Bertin[2], S. Biagi[11,12], C. Bigongiari[13], C. Bogazzi[8], M. Bou-Cabo[1], B. Bouhou[9], M.C. Bouwhuis[8], J. Brunner[2], J. Busto[2], A. Capone[14,15], C. Cârloganu[16], J. Carr[2], S. Cecchini[11], Z. Charif[2], Ph. Charvis[17], T. Chiarusi[11], M. Circella[18], R. Coniglione[19], L. Core[2], H. Costantini[2], P. Coyle[2], A. Creusot[9], C. Curtil[2], G. De Bonis[14,15], M.P. Decowski[8], I. Dekeyser[20], A. Deschamps[17], C. Distefano[19], C. Donzaud[9,21], D. Dornic[13,2], Q. Dorosti[22], D. Drouhin[3], T. Eberl[6], U. Emanuele[13], A. Enzenhöfer[6], J-P. Ernenwein[2], S. Escoffier[2], K. Fehn[6], P. Fermani[14,15], M. Ferri[1], S. Ferry[23], V. Flaminio[24,25], F. Folger[6], U. Fritsch[6], J-L. Fuda[20], S. Galatà[2], P. Gay[16], K. Geyer[6], G. Giacomelli[11,12], V. Giordano[19], J.P. Gómez-González[13], K. Graf[6], G. Guillard[16], G. Hallewell[2], M. Hamal[26], H. van Haren[27], A.J. Heijboer[8], Y. Hello[17], J.J. Hernández-Rey[13], B. Herold[6], J. Hößl[6], C.C. Hsu[8], M. de Jong[8,39], M. Kadler[28], O. Kalekin[6], A. Kappes[6,40], U. Katz[6], O. Kavatsyuk[22], P. Kooijman[8,29,30], C. Kopper[8,6], A. Kouchner[9], I. Kreykenbohm[28], V. Kulikovskiy[31,5], R. Lahmann[6], G. Lambard[13], G. Larosa[1], D. Lattuada[19], D. Lefèvre[20], G. Lim[8,30], D. Lo Presti[32,33], H. Loehner[22], S. Loucatos[23], F. Louis[7], S. Mangano[13], M. Marcelin[10], A. Margiotta[11,12], J.A. Martínez-Mora[1], S. Martini[20], A. Meli[6], T. Montaruli[18,34], M. Morganti[24,41], L. Moscoso[9,23], H. Motz[6], M. Neff[6], E. Nezri[10], D. Palioselitis[8], G.E. Păvălaş[35], K. Payet[23], J. Petrovic[8], P. Piattelli[19], V. Popa[35], T. Pradier[36], E. Presani[8], C. Racca[3], C. Reed[8], G. Riccobene[19], C. Richardt[6], R. Richter[6], C. Rivière[2], A. Robert[20], K. Roensch[6], A. 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Araya[42], S. Ast[52,53], S. M. Aston[49], P. Astone[14], D. Atkinson[59], P. Aufmuth[53,52], C. Aulbert[52,53], B. E. Aylott[60], S. Babak[61], P. Baker[62], G. Ballardin[63], S. Ballmer[64], Y. Bao[58], J. C. B. Barayoga[42], D. Barker[59], F. Barone[46,48], B. Barr[44], L. Barsotti[65], M. Barsuglia[9], M. A. Barton[59], I. Bartos[66], R. Bassiri[44,67], M. Bastarrika[44], A. Basti[24,25], J. Batch[59], J. Bauchrowitz[52,53], Th. S. Bauer[8], M. Bebronne[45], D. Beck[67], B. Behnke[61], M. Bejger[70], M.G. Beker[8], A. S. Bell[44], C. Bell[44], I. Belopolski[66], M. Benacquista[74], J. M. Berliner[59], A. Bertolini[52,53], J. Betzwieser[49], N. Beveridge[44], P. T. Beyersdorf[75], T. Bhadbade[67], I. A. Bilenko[76], G. Billingsley[42], J. Birch[49], R. Biswas[74], M. Bitossi[24], M. A. Bizouard[77], E. Black[42], J. K. Blackburn[42], L. Blackburn[79], D. Blair[80], B. Bland[59], M. Blom[8], O. Bock[52,53], T. P. Bodiya[65], C. Bogan[52,53], C. Bond[60], R. Bondarescu[81], F. Bondu[83], L. Bonelli[24,25], R. Bonnand[84], R. Bork[42], M. Born[52,53], V. Boschi[24], S. Bose[85], L. Bosi[86], S. Braccini[24], C. Bradaschia[24], P. R. Brady[56], V. B. Braginsky[76], M. Branchesi[88,89], J. E. Brau[90], J. Breyer[52,53], T. Briant[91], D. O. Bridges[49], A. Brillet[82], M. Brinkmann[52,53], V. Brisson[77], M. Britzger[52,53], A. F. Brooks[42], D. A. Brown[64], T. Bulik[69], H. J. Bulten[8,54], A. Buonanno[92], J. Burguet–Castell[93], D. Buskulic[45], C. Buy[9], R. L. Byer[67], L. Cadonati[94], G. Cagnoli[74,84], E. Calloni[46,47], J. B. Camp[79], P. Campsie[44], K. Cannon[95], B. Canuel[63], J. Cao[96], C. D. Capano[92], F. Carbognani[63], L. Carbone[60], S. Caride[97], S. Caudill[98], M. Cavaglià[99], F. Cavalier[77], R. Cavalieri[63], G. Cella[24], C. Cepeda[42], E. Cesarini[89], T. Chalermsongsak[42], P. Charlton[100], E. Chassande-Mottin[9], W. Chen[96], X. Chen[80], Y. Chen[101], A. Chincarini[5], A. Chiummo[63], H. S. Cho[102], J. Chow[103], N. Christensen[104], S. S. Y. Chua[103], C. T. Y. Chung[105], S. Chung[80], G. Ciani[58], F. Clara[59], D. E. Clark[67], J. A. Clark[94], J. H. Clayton[56], F. Cleva[82], E. Coccia[106,107], P.-F. Cohadon[91], C. N. Colacino[24,25], A. Colla[14,15], M. Colombini[15], A. Conte[14,15], R. Conte[48], D. Cook[59], T. R. Corbitt[65], M. Cordier[75], N. Cornish[62], A. Corsi[42], C. A. Costa[98,109], M. Coughlin[104], J.-P. Coulon[82], P. Couvares[64], D. M. Coward[80], M. Cowart[49], D. C. Coyne[42], J. D. E. Creighton[56], T. D. Creighton[74], A. M. Cruise[60], A. Cumming[44], L. Cunningham[44], E. Cuoco[63], R. M. Cutler[60], K. Dahl[52,53], M. Damjanic[52,53], S. L. Danilishin[80], S. D'Antonio[106], K. Danzmann[52,53], V. Dattilo[63], B. Daudert[42], H. Daveloza[74], M. Davier[77], E. J. Daw[110], R. Day[63], T. Dayanga[85], R. De Rosa[46,47], D. DeBra[67], G. Debreczeni[111], J. Degallaix[84], W. Del Pozzo[8], T. Dent[50], V. Dergachev[42], R. DeRosa[98], S. Dhurandhar[112], L. Di Fiore[46], A. Di Lieto[24,25], I. Di Palma[52,53], M. Di Paolo Emilio[106,108], A. Di Virgilio[24], M. Díaz[74], A. Dietz[45,99], F. Donovan[65], K. L. Dooley[52,53], S. Doravari[42], S. Dorsher[113], M. Drago[114,115], R. W. P. Drever[118], J. C. Driggers[42], Z. Du[96], J.-C. Dumas[80], S. Dwyer[65], T. Eberle[52,53], M. Edgar[44], M. Edwards[50], A. Effler[98], P. Ehrens[42], G. Endrőczi[111], R. Engel[42], T. Etzel[42], K. Evans[44], M. Evans[65], T. Evans[49], M. Factourovich[66], V.

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White, 2007, Rep. Prog. Phys., 70, 223 $\Longleftrightarrow$ Kolb, 2007, Rep. Prog. Phys., 70, 1583

Methodology

	Astrophysics	Astroparticle Physics
facilities	multi-purpose, large scale internatio-nal observatories	experiments
technology	instrumentalists	scientists
observing time	peer reviews, only small share of guaranteed time	consortium driven
analysis approach	standardized software	less reliance on standards
data policy	public after $\sim$1 yr	proprietary
publications	mainly small groups (2–20 authors)	consortia (100+)
reputation	individual	collaboration

"As it is typical for paradigmatic, hard science disciplines, the field is strongly reputation oriented... and self reflexive towards bibliometric measures of reputation ... Despite a growing collaboration intensity the reputation system in astrophysics is still based on individuals. Here it differs from high-energy physics, where papers have several hundred authors and there is no epistemic subject any longer." Heidler, 2011, Minerva 49:461–488

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reputation	individual	collaboration

Note: Field structures are approaching each other:

- Astronomy: dedicated, large special purpose experiments are on the rise, especially in extragalactic astro (e.g., "survey science" [SDSS, PanSTARRS, LSST], but also facilities such as Gaia, LOFAR/SKA,...)
- Astroparticle Physics: move towards observatories (CTA)

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Conclusions

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  - observatories, not experiments,
  - reasonable data access capabilities,

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  - reasonable, standardized data analysis tools.

  This implies a strong reduction of the “consortium think”:
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- gravitational wave astronomy: prove that template fitting works, then move to observations