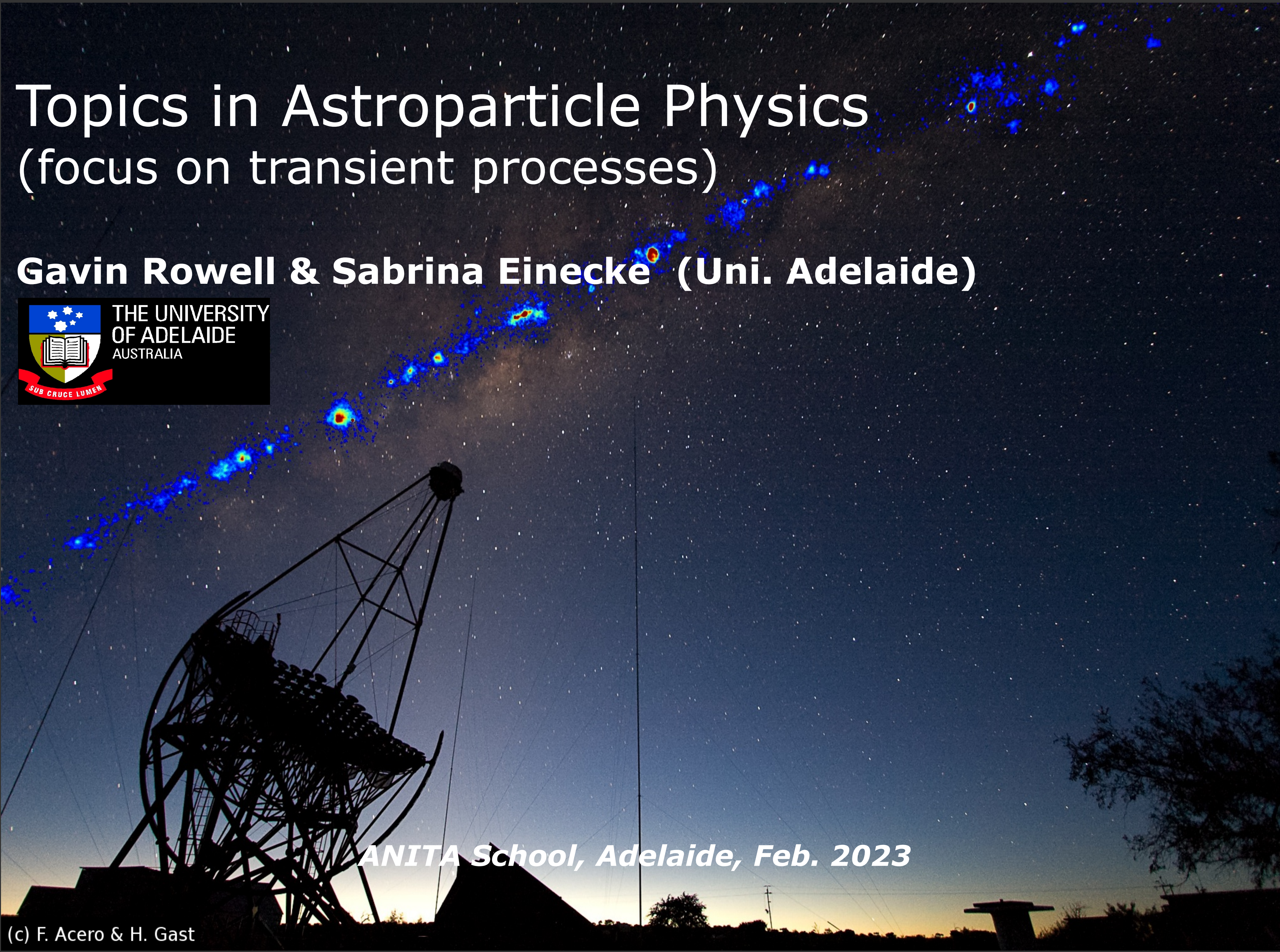


Topics in Astroparticle Physics

(focus on transient processes)

Gavin Rowell & Sabrina Einecke (Uni. Adelaide)

THE UNIVERSITY
OF ADELAIDE
AUSTRALIA
SUB CRUCE LUMEN

ANITA School, Adelaide, Feb. 2023

(c) F. Acero & H. Gast

Astroparticle Physics

- Particle physics in space!

- Extreme conditions unlike anything created on Earth

(e.g. CERN LHC ~10^{17} eV 'fixed target' energy)

Extreme energy, B-fields, E-fields, density, pressure, temperature…..

- What kinds of astrophysical environments create/accelerate particles we see at Earth? How do we trace them?

- How to they create/accelerate these particles?

- What role do these particles play in the evolution of galaxies, stars, astro-chemistry, life?

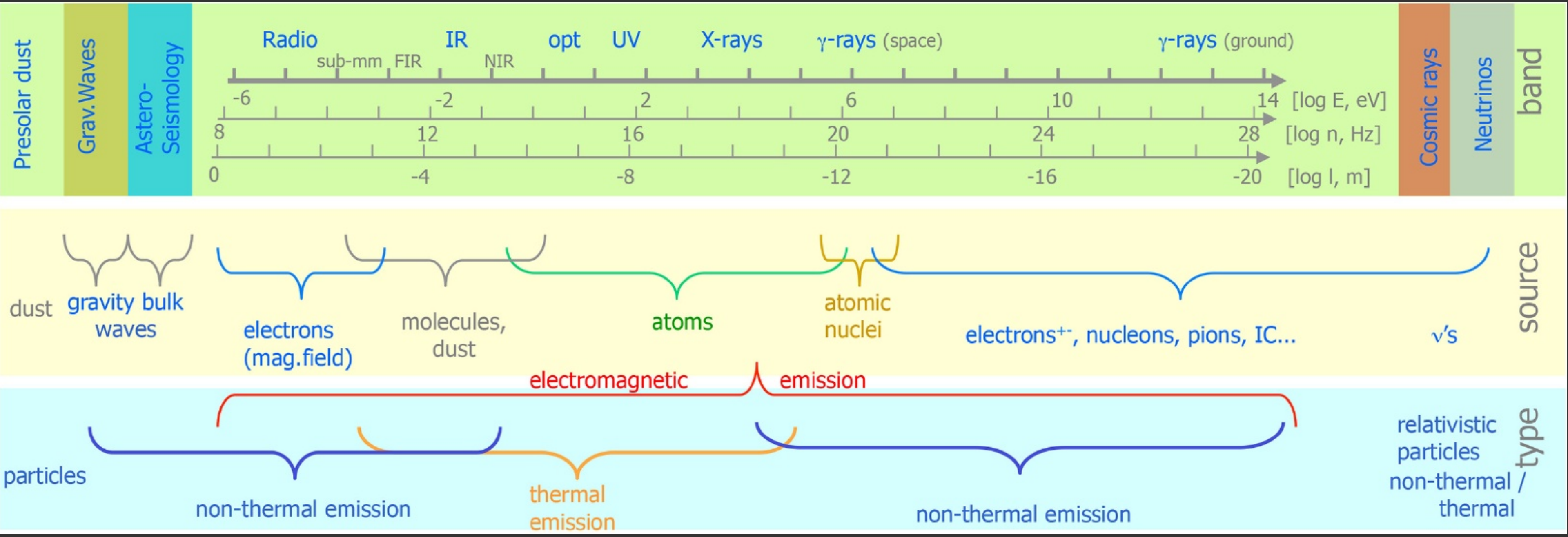
- Dark matter: What AND where is it? And Dark Energy?

- Are there any 'relics' of early-Universe particle physics?

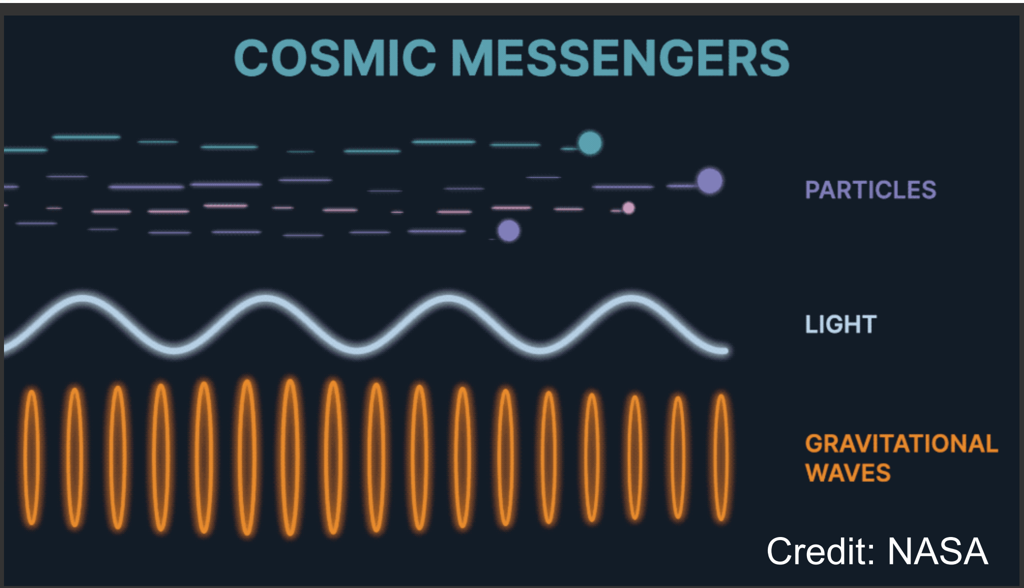
The “Multi-Messenger” Spectrum

with underlying physics

Roland 2016



Since 2015/16 →



Credit: NASA

We will look at

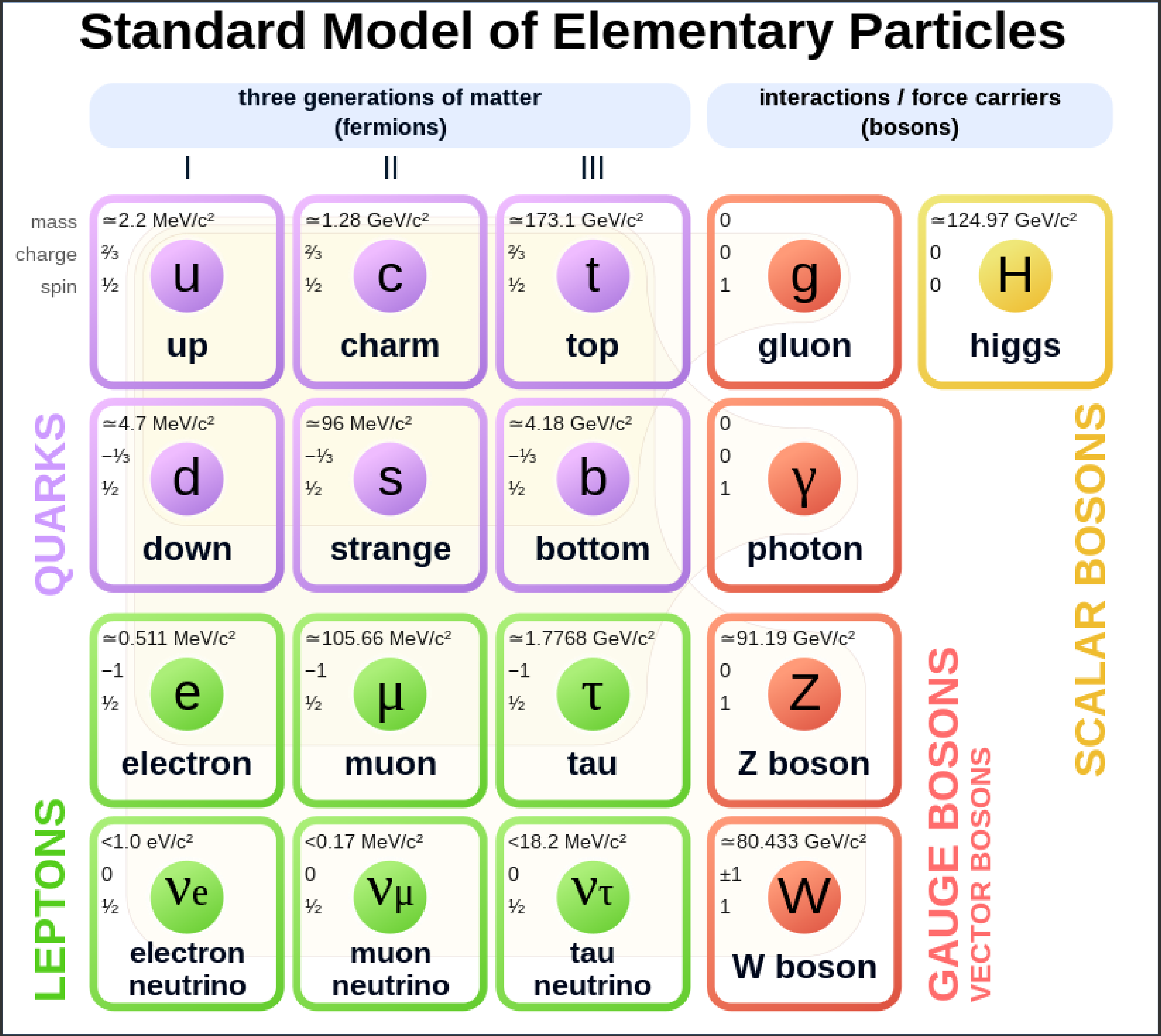
- Review of non-thermal photon & neutrino production from accelerated particles (hadrons, leptons):

  hadrons (protons, He, …   made up of 3 quarks)
  leptons (electrons, muons,..)

- Synergies between photons, neutrinos, cosmic rays, electrons, gravitational waves.

- Some case studies of transient sources from radio to gamma, neutrinos and GWs.

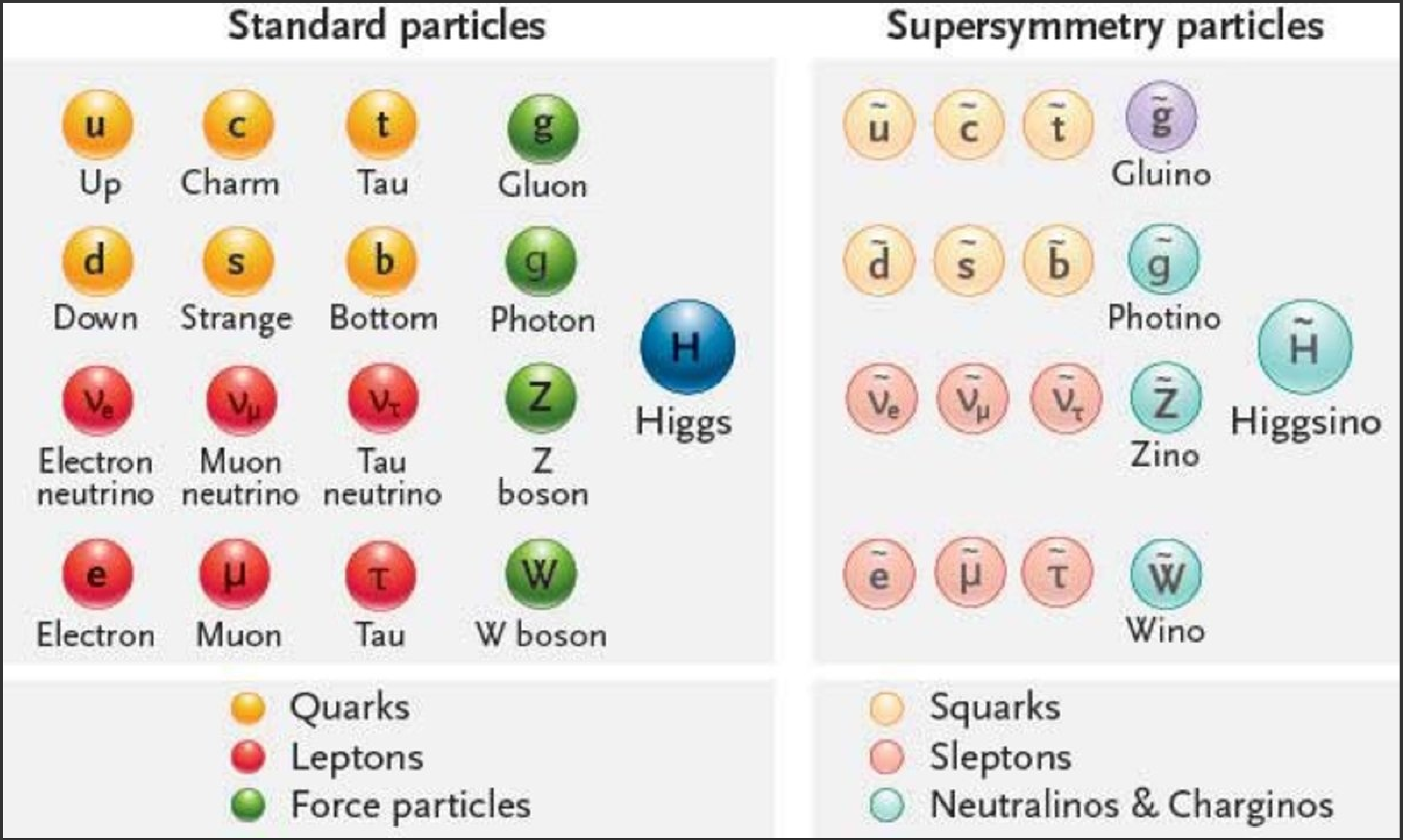
- Introduction to some publicly available codes and applications



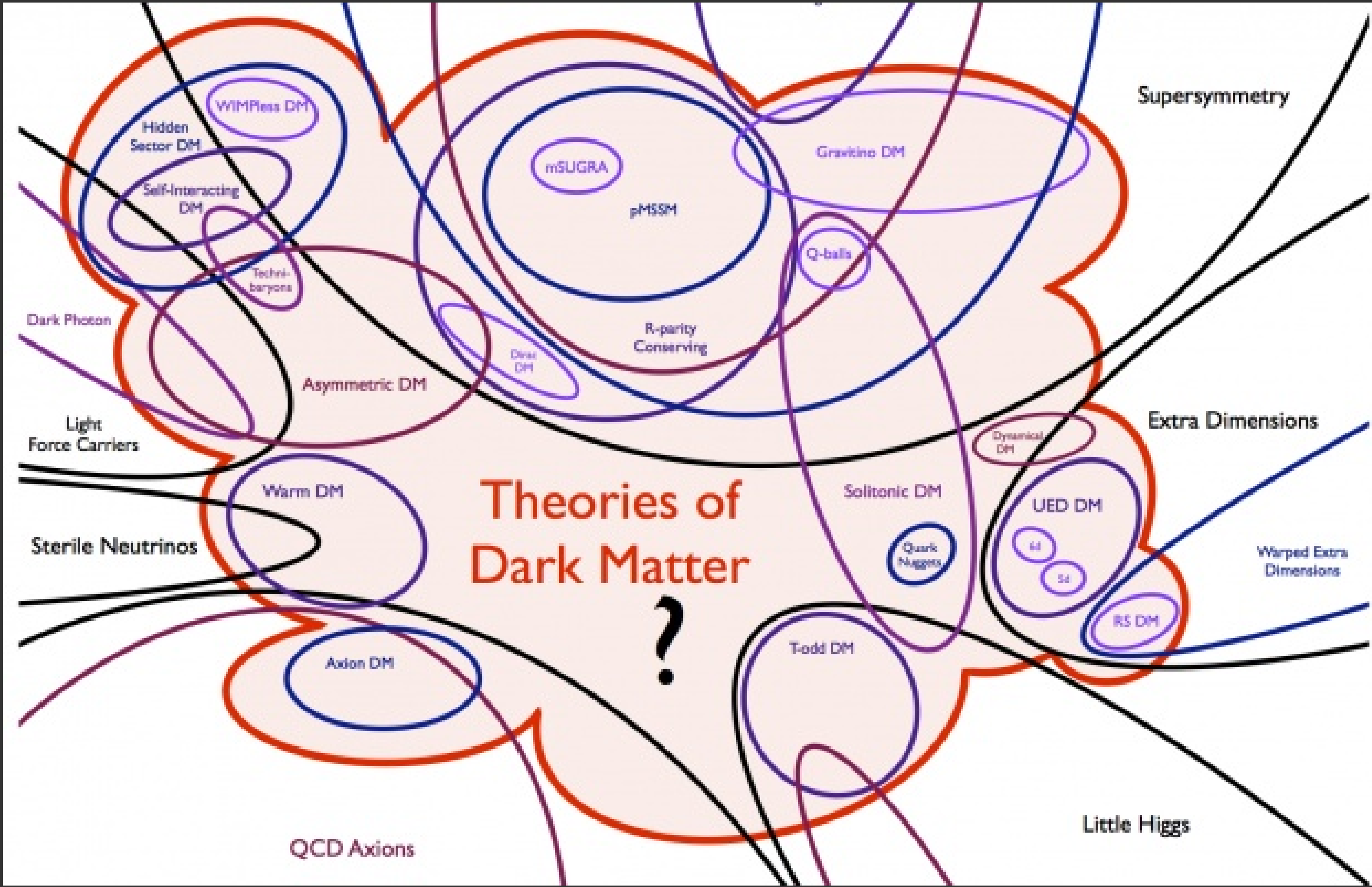
Standard Model of Elementary Particles

	three generations of matter (fermions)			interactions / force carriers (bosons)	
	I	II	III		
mass charge spin	≃2.2 MeV/c^2 ⅔ ½ u up	≃1.28 GeV/c^2 ⅔ ½ c charm	≃173.1 GeV/c^2 ⅔ ½ t top	0 0 1 g gluon	≃124.97 GeV/c^2 0 0 H higgs
QUARKS	≃4.7 MeV/c^2 −⅓ ½ d down	≃96 MeV/c^2 −⅓ ½ s strange	≃4.18 GeV/c^2 −⅓ ½ b bottom	0 0 1 γ photon	SCALAR BOSONS
LEPTONS	≃0.511 MeV/c^2 −1 ½ e electron	≃105.66 MeV/c^2 −1 ½ μ muon	≃1.7768 GeV/c^2 −1 ½ τ tau	≃91.19 GeV/c^2 0 1 Z Z boson	GAUGE BOSONS VECTOR BOSONS
	<1.0 eV/c^2 0 ½ ν_e electron neutrino	<0.17 MeV/c^2 0 ½ ν_μ muon neutrino	<18.2 MeV/c^2 0 ½ ν_τ tau neutrino	≃80.433 GeV/c^2 ±1 1 W W boson	

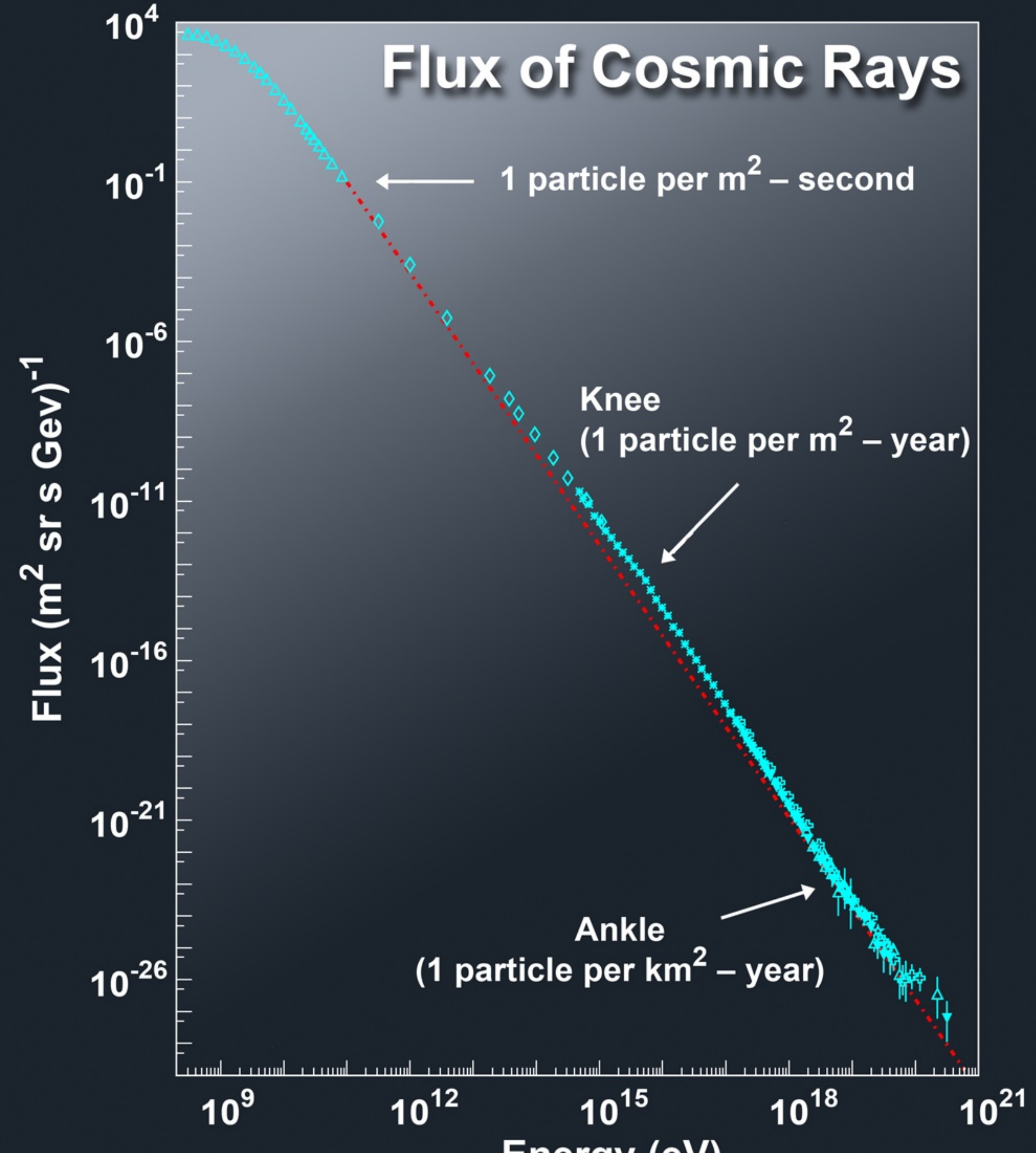
wiki


Standard particles
u
Up
c
Charm
t
Tau
g
Gluon
d
Down
s
Strange
b
Bottom
g
Photon
H
Higgs
ν_e
Electron neutrino
ν_μ
Muon neutrino
ν_τ
Tau neutrino
Z
Z boson
e
Electron
μ
Muon
τ
Tau
W
W boson
Quarks
Leptons
Force particles
Supersymmetry particles
$\tilde{u}$
$\tilde{c}$
$\tilde{t}$
$\tilde{g}$
Gluino
$\tilde{d}$
$\tilde{s}$
$\tilde{b}$
$\tilde{g}$
Photino
$\tilde{H}$
Higgsino
$\tilde{\nu}_e$
$\tilde{\nu}_\mu$
$\tilde{\nu}_\tau$
$\tilde{Z}$
Zino
$\tilde{e}$
$\tilde{\mu}$
$\tilde{\tau}$
$\tilde{W}$
Wino
Squarks
Sleptons
Neutralinos & Charginos

wiki


WIMPless DM
Hidden Sector DM
Self-Interacting DM
Techni-baryons
Dark Photon
Asymmetric DM
Light Force Carriers
Warm DM
Sterile Neutrinos
Axion DM
QCD Axions
mSUGRA
pMSSM
Dirac DM
R-parity Conserving
Gravitino DM
Q-balls
Supersymmetry
Theories of Dark Matter
?
Solitonic DM
Quark Nuggets
Dynamical DM
Extra Dimensions
UED DM
6d
5d
RS DM
Warped Extra Dimensions
T-odd DM
Little Higgs

T. Tait

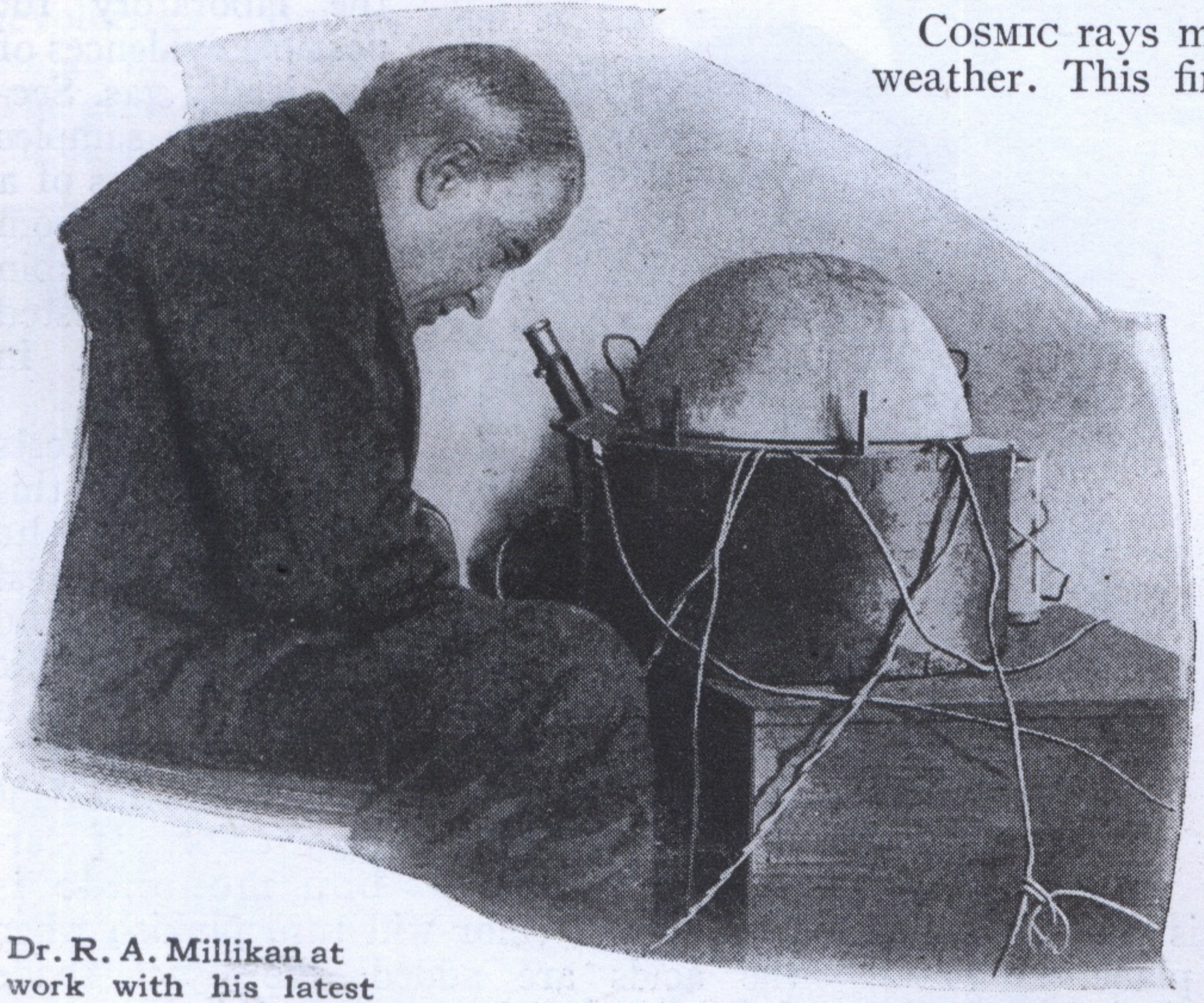


(source: Swordy – U.Chicago)

CRs discovered by Victor Hess: 1912 Balloon Flights

CR origin is still not clear, but we have clues!

COSMIC RAYS MAY FORECAST WEATHER



Dr. R. A. Millikan at work with his latest electroscope, with which he is studying the cosmic rays. He believes these mysterious rays may be used in making reliable forecasts of the weather.

COSMIC rays may help to prophesy the weather. This first practical use for the mysterious radiations from outer space was recently announced by Dr. R. A. Millikan, Calif. Institute of Technology physicist.

The "cosmic rays" are more penetrating than radium or X-rays, but it is not known whether they affect human beings.

Dr. Millikan, who discovered the source of the rays (P. S. M., July, '28, p. 13), has measured their strength with his new electroscope, and is able to determine high-altitude atmospheric conditions.

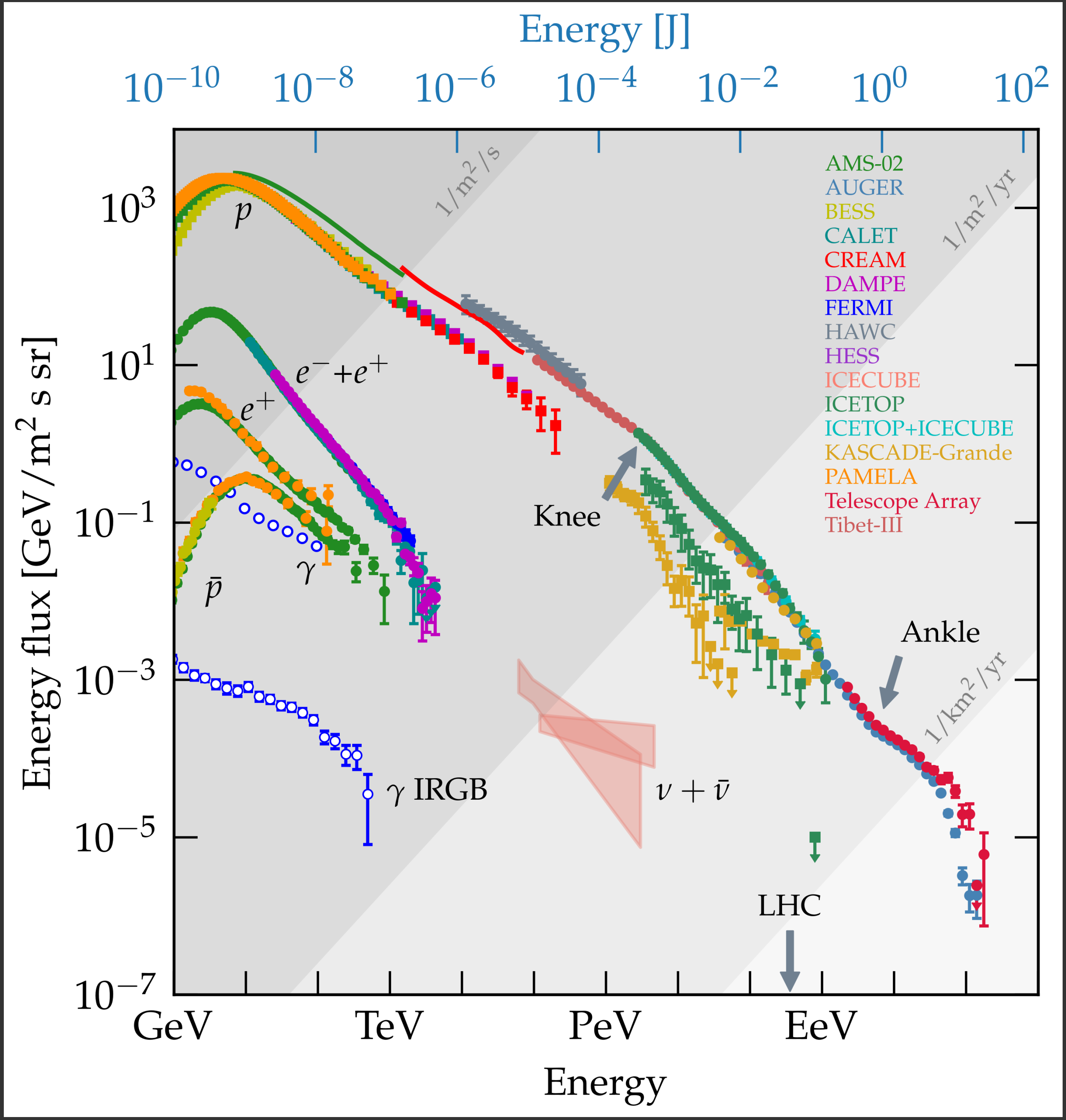
..a bit more detail

Cosmic Rays
p, He, C, N, O...

Electrons + positrons

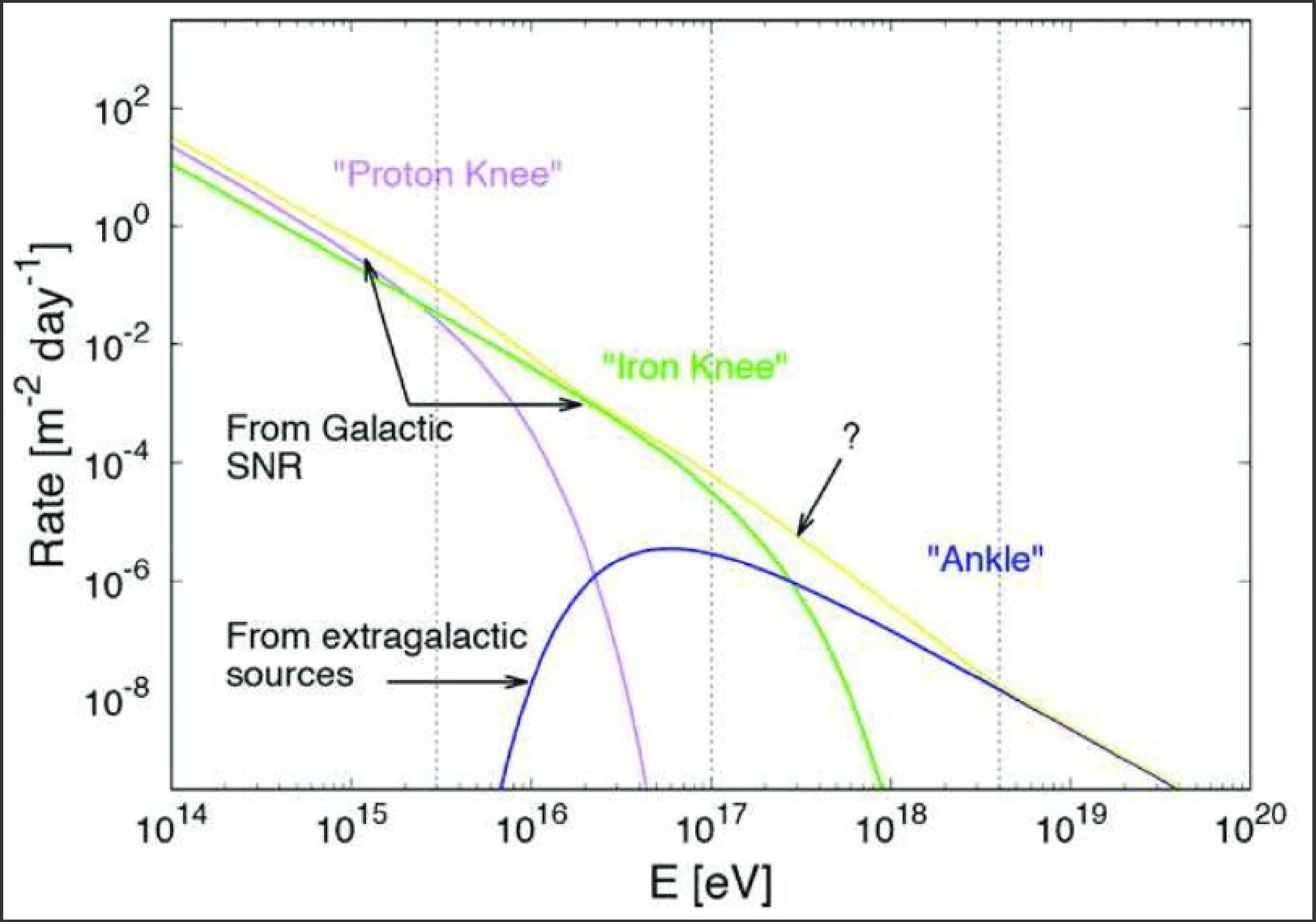
Gamma Rays (diffuse)

Neutrinos



https://github.com/carmeloevoli/The_CR_Spectrum

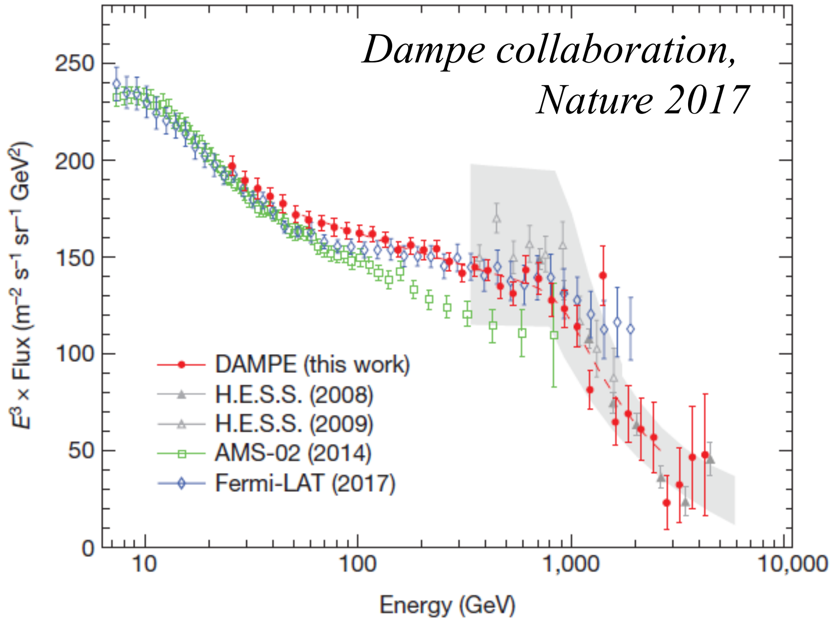
Where do Cosmic Rays come from?

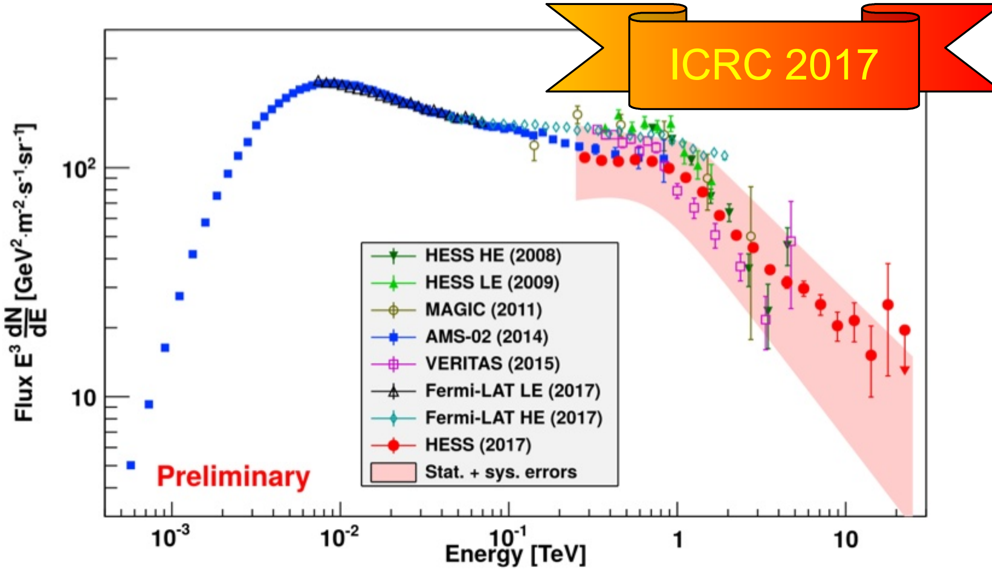


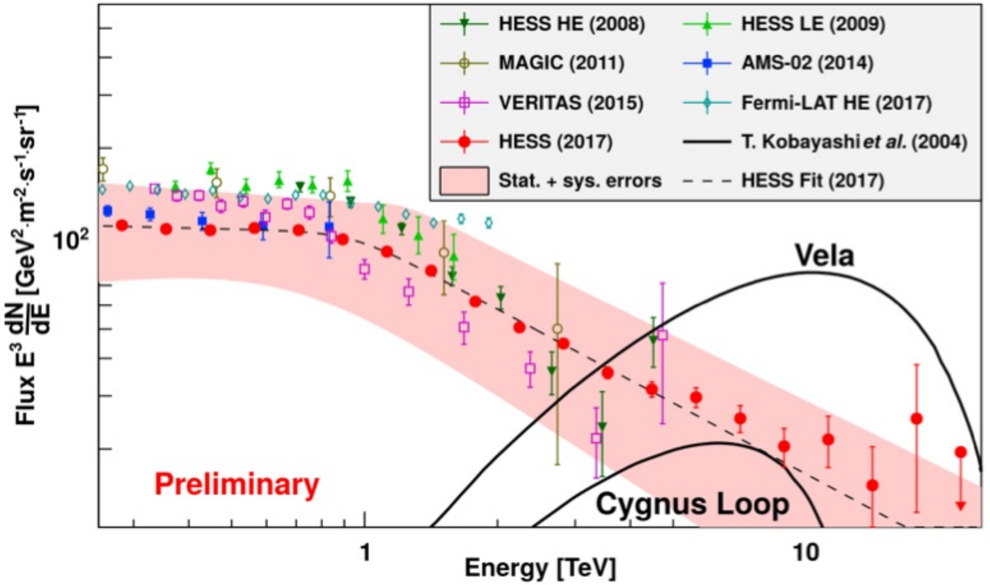
Alves Batista et al. (2019)

The local CR electron spectrum

- Electron spectrum between 0.25 TeV and 20 TeV:
  - Break at ~1 TeV (change of diffusion regime?)
  - Probing local pulsars and supernova remnants..?
- Break recently confirmed by DAMPE


Dampe collaboration, Nature 2017


ICRC 2017



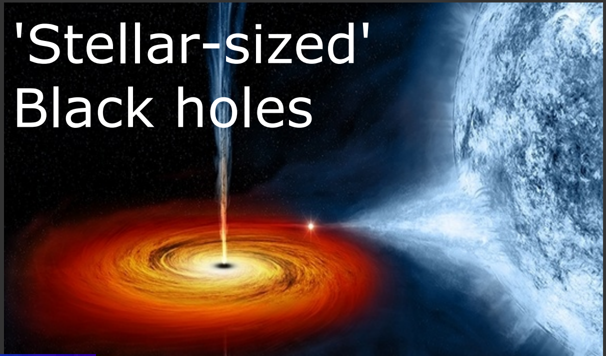
Some extreme particle accelerators in the Universe

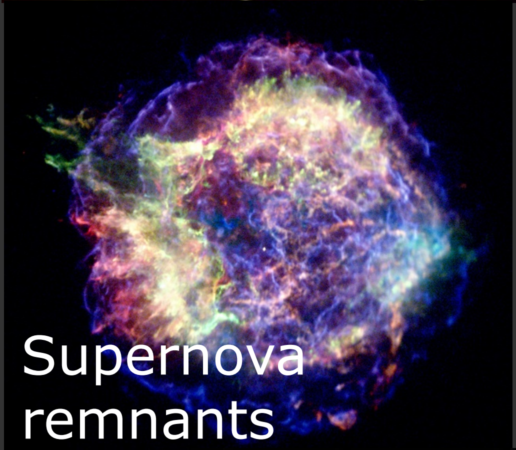

Super-massive black holes @ galaxy cores


Centre of our Milky Way


Massive star clusters

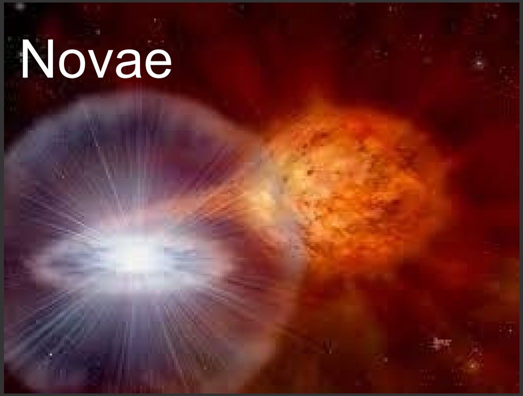

Pulsars & Pulsar Wind Nebulae


'Stellar-sized' Black holes

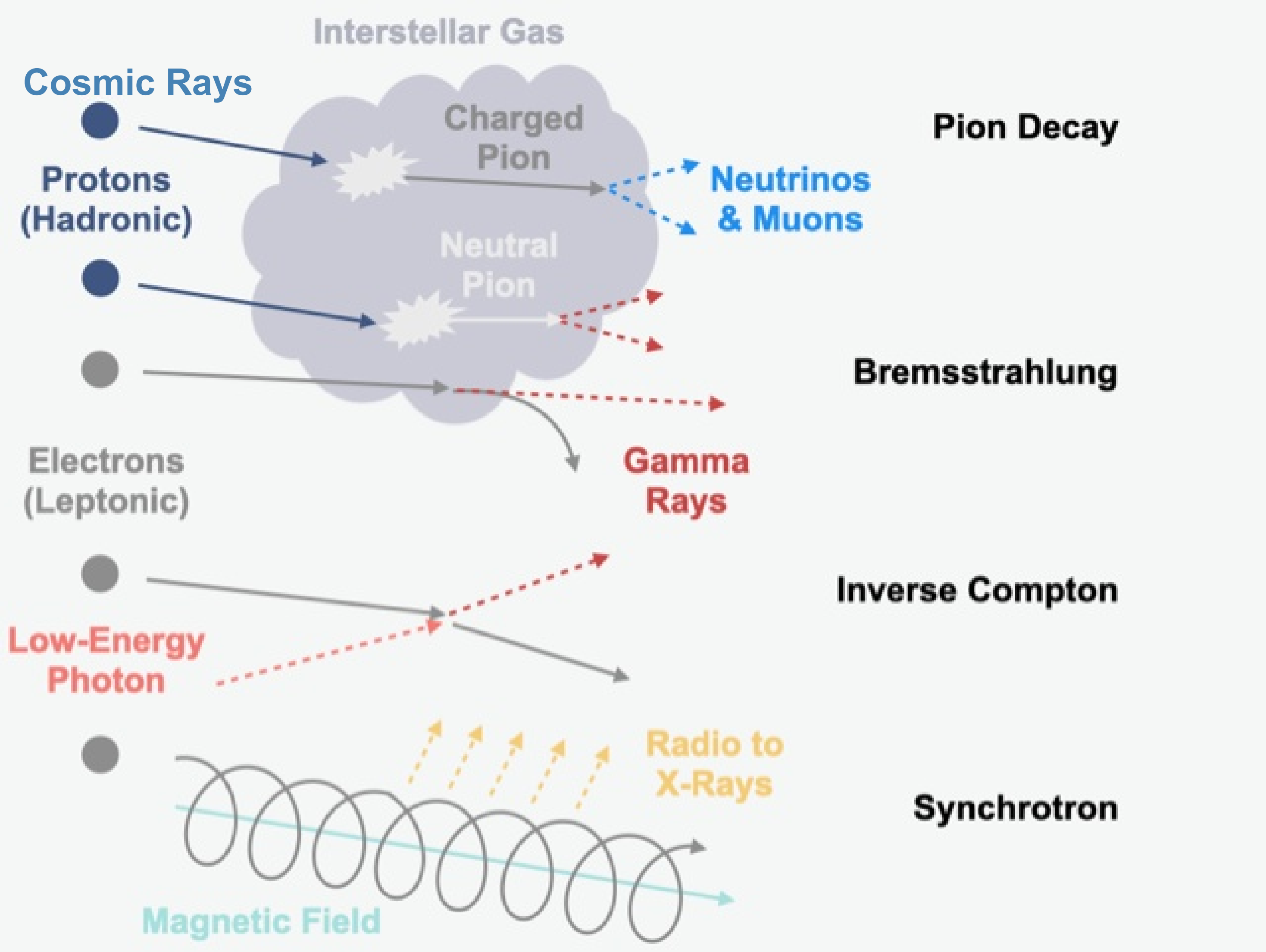

Supernova remnants


Compact object mergers


Hypernovae

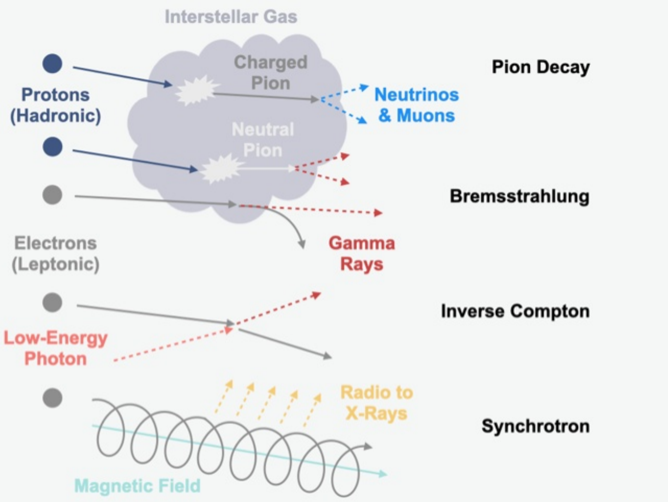

Novae

Photons from relativistic (GeV to multi-TeV) particles



→ Clear synergies across radio, optical, X-ray, gamma-ray and neutrino astronomy (incl. ISM – radio astronomy)

Photons from relativistic (GeV to multi-TeV) particles



Hadronic interaction

Cosmic ray proton (p) collides with interstellar protons or nuclei (N)

$$p + N \rightarrow N' + \pi^{\circ}\pi^{\pm} \qquad \pi \text{ in roughly equal numbers}$$

$$\pi^{\circ} \rightarrow \gamma + \gamma$$

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}, \quad \text{followed by} \quad \mu^{+} \rightarrow e^{+} + \bar{\nu}_{\mu} + \nu_{e},$$

$$\pi^{-} \rightarrow \mu^{-} + \bar{\nu}_{\mu}, \quad \text{followed by} \quad \mu^{-} \rightarrow e^{-} + \nu_{\mu} + \bar{\nu}_{e},$$

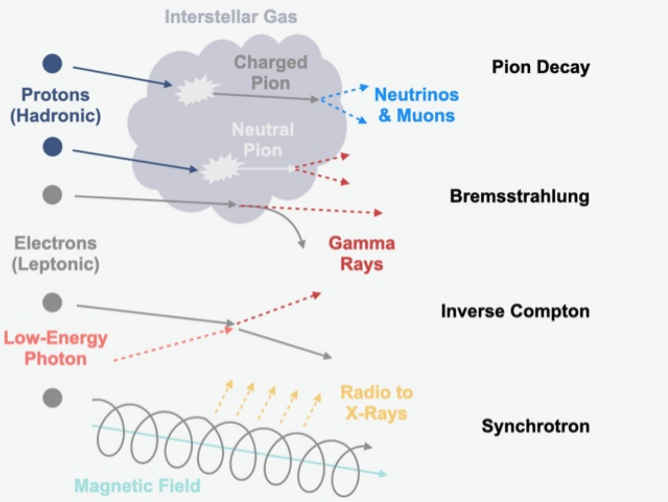
$$E_{\gamma} \sim 0.17 E_{p}$$

- Gamma rays, neutrinos and (secondary) electrons produced.

- Neutrino flavour mixing leads to similar fluxes of gamma rays and muon neutrinos.

- Secondary electrons can produce their own synchrotron emission (sometimes >= synchrotron from 'primary' electrons)

Photons from relativistic (GeV to multi-TeV) particles



Inverse-Compton

TeV electrons up-scattering ‘soft’ (low-energy) photons to > GeV energies.

$$e^- + \gamma_{\rm soft} \rightarrow e'^- + \gamma_{\rm TeV}$$

Soft photons
- CMB
- Infrared
- Optical/UV
- X-rays

can’t avoid it!

$E_\gamma \sim (E_e/20)^2$ in Thompson ‘regime

- Inverse-Compton (IC) ‘competes’ with synchrotron and Bremsstralung for an electron’s energy.

- Bremsstralung usually sub-dominant so synchrotron and IC win!

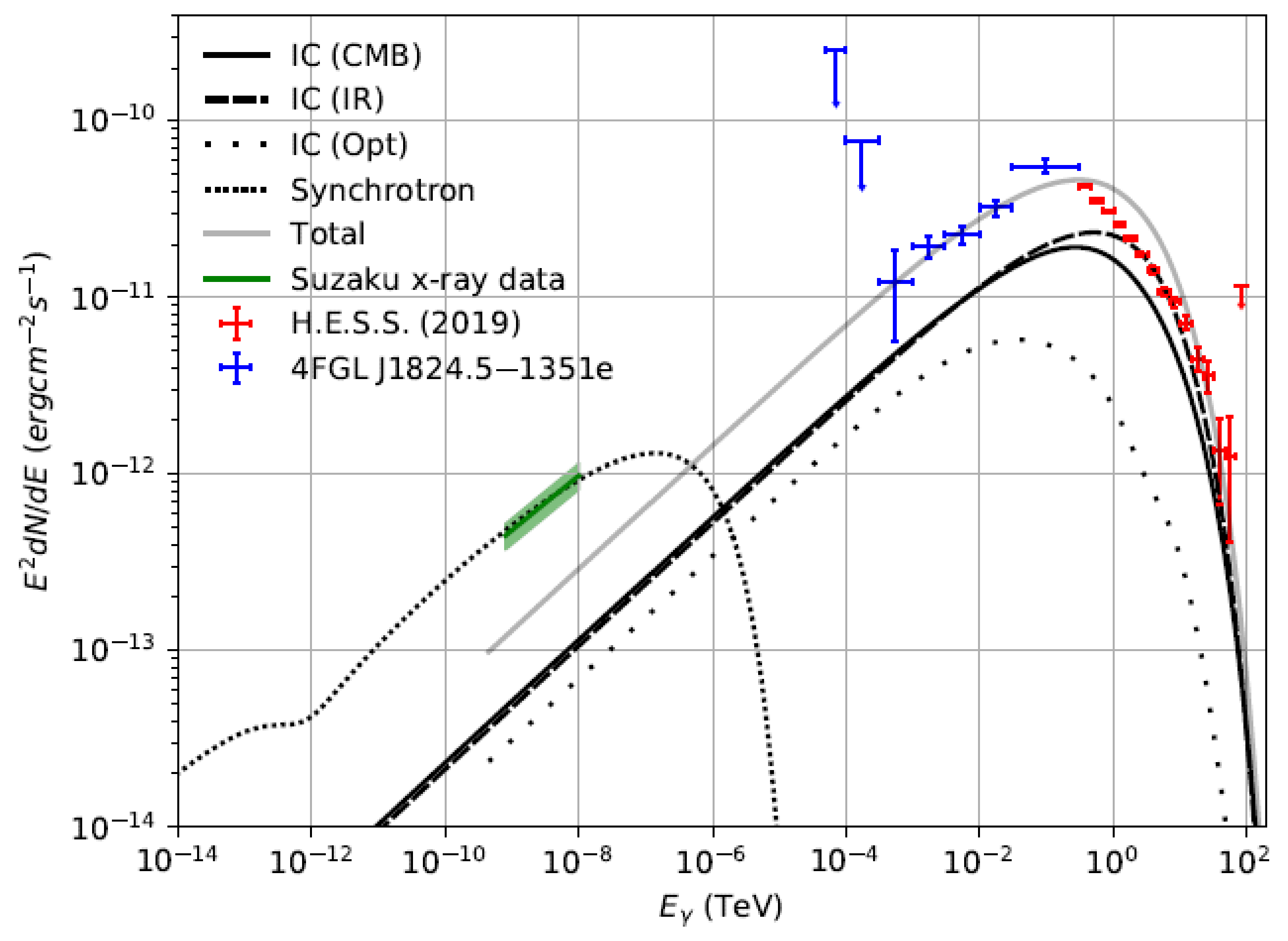
- Special case: Synchrotron ‘self’-Compton (SSC). Electrons up-scatter their own synchrotron photons (usually X-rays).

Inverse-Compton

Soft photon fields can be important

Applied to pulsar wind nebula HESSJ1826-137

T. Collins in prep (2023) & PhD thesis



Soft photons
- CMB can't avoid it!
- Infrared
- Optical/UV
- X-rays

Particle Acceleration (brief summary)

Drury 1983

- Diffusive shock acceleration DSA (1st order Fermi acceleration):

  Charged particles scatter on magnetic irregularities (diffusively) either side of shock, gaining energy each time.

  → ‘Power-law’ particle energy distribution dN/dE ~ k $E^{-\Gamma}$ where $\Gamma \sim 2$

  $$dN/dE = KE^{-\Gamma}\exp(-E/E_c)$$

  Exponential term due to acceleration limits, particle escape plus radiative losses (usually synchrotron emission – see later)

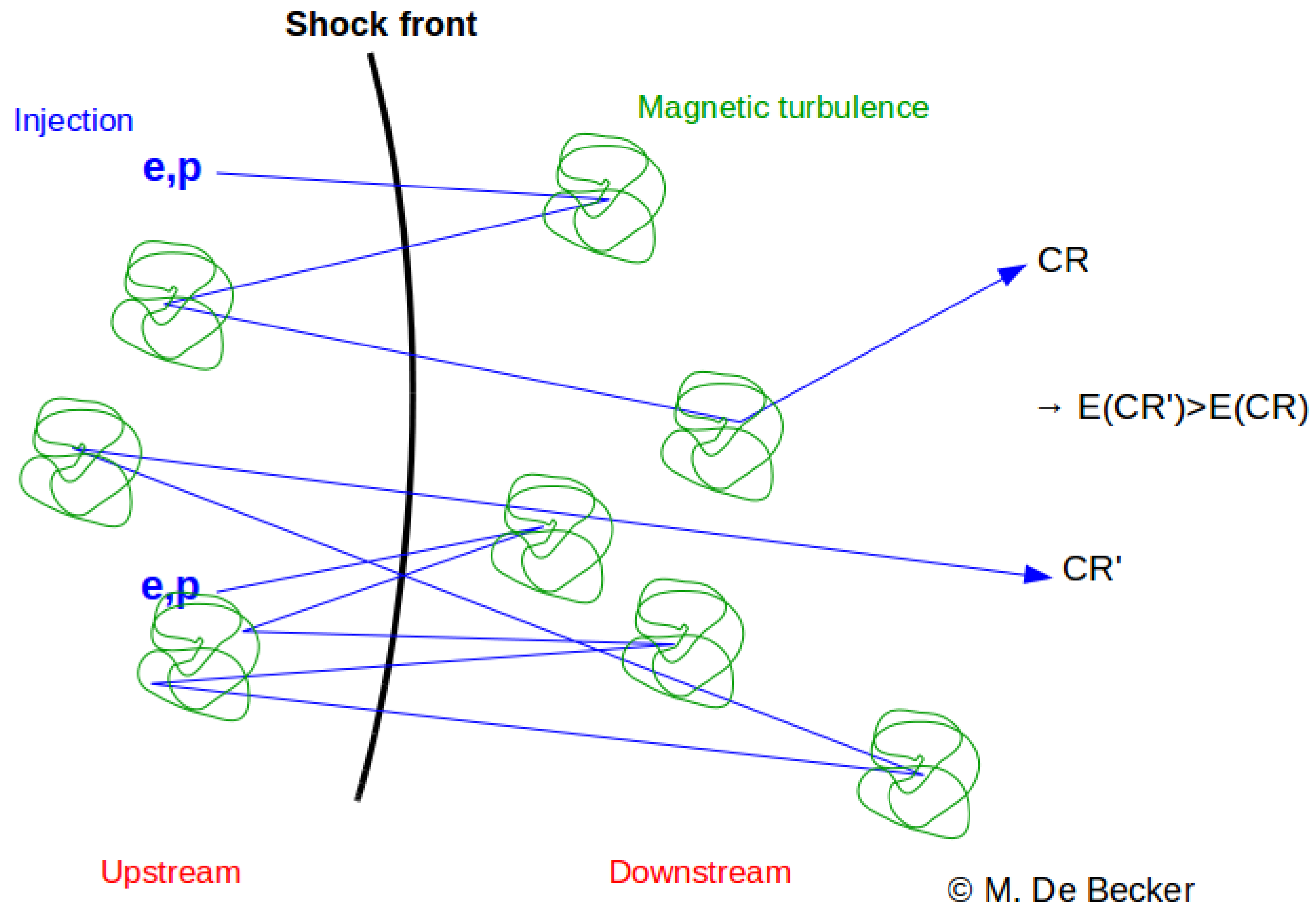
  MANY examples: supernova remnants, AGN, GRBs, kilonovae, TDEs, stellar winds, galaxy-scale and galaxy cluster shocks.

- Electric fields: Direct acceleration by E-fields: Force = qE

  e.g. pulsars, magnetised BHs

- Magnetic reconnection: Evolving B-field lines joining together can funnel charged particles *e.g. solar flares, magnetars*

- Gravitational potential energy → accretion: *BHs, neutron stars, compact binaries, compact mergers, core-collapse*


Shock front
Injection
e,p
Magnetic turbulence
CR
→ E(CR')>E(CR)
CR'
e,p
Upstream
Downstream

© M. De Becker

Maximum particle energies (“Hillas” plot)

Hillas 1984

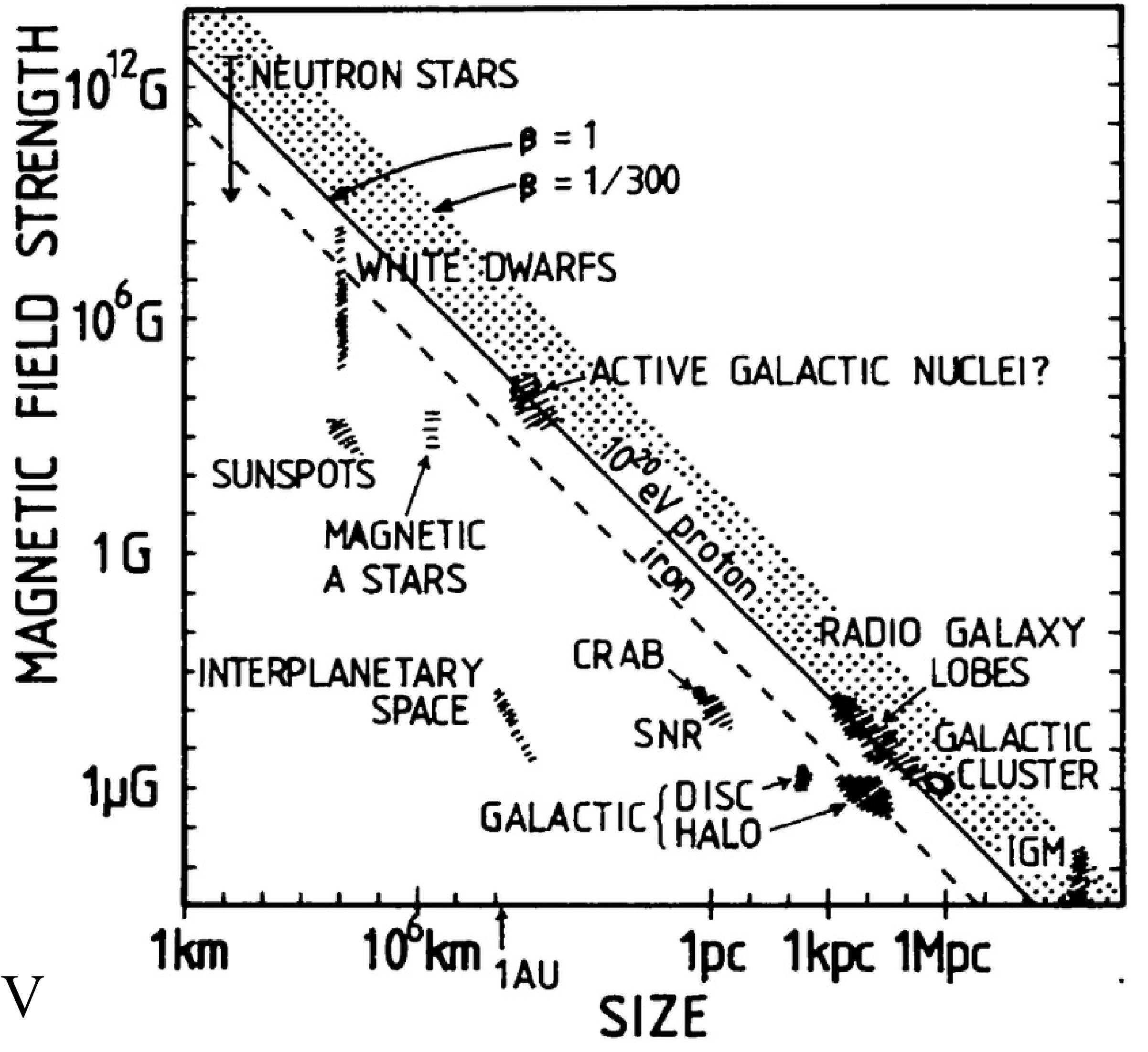
Maximum particle energy when it ‘escapes’ the shock.

This happens when particle’s gyroradius r_L exceeds the size (diameter L) of the shock $r_L > L$

→ Maximum E

$$B_{\mu G} L_{\mathrm{Mpc}} > 2E_{21}/Z(v/c)$$

$$E_{\max} \sim 10^{21}\, Z\, \beta\, B_{\mu\mathrm{G}}\, L_{\mathrm{Mpc}} \quad \mathrm{eV}$$



But, particle energy losses also influence $E_{\max}$

$\beta = v/c$ *for v* velocity of scattering centres (B-field irregularities usually)

Particle energy loss rates

Hadronic interaction

$$dE_p/dt = (n\sigma_{\mathrm{pp}} f c)E_{\mathrm{p}}$$

$f \sim 0.5$

Bremsstrahlung

$$dE_{\mathrm{e}}/dt = c m_{\mathrm{p}} n_{\mathrm{p}} (E_{\mathrm{e}}/X_o)$$

radiation length $X_o = \frac{7}{9}(\rho/(n_{\mathrm{p}}\sigma_o)$ (gm cm^{-2})

Inverse-Compton

$$dE_{\mathrm{e}}/dt = \frac{4}{3}\sigma_{\mathrm{T}} c \omega n_{\mathrm{ph}} \gamma^2$$

Lorentz factor $\gamma = E_{\mathrm{e}}/(m_{\mathrm{e}}c^2)$

Synchrotron

$$dE_{\mathrm{e}}/dt = \frac{4}{3}\sigma_T c U_{\mathrm{B}} \gamma^2$$

$U_B = B^2/8\pi$

E – energy of particle (p – proton; e – electron)

n_{ph} – number density of low-energy photons

σ – cross section for interaction (pp = proton-proton;
T = Thompson)

n_p – target number density for particle collisions

ω – average energy of low-energy photon

B – magnetic field

Particle energy loss time or ‘cooling’ time

(time taken for a particle to lose all of its energy)

$$t = \int_E^0 \frac{dE}{dE/dt}$$

For constant loss rate

$$t = \frac{E}{dE/dt}$$

Hadronic interaction

$$t_{\rm pp} = \left(n\sigma_{\rm pp} f c\right)^{-1} \approx 5.3 \times 10^7 (n/{\rm cm}^3)^{-1}\ \ {\rm yr},$$

Inverse-Compton

$$t_{\rm IC} \approx 3 \times 10^5 (U_{\rm rad}/{\rm eV/cm}^3)^{-1}(E_{\rm e}/{\rm TeV})^{-1}\Big) f_{\rm KN}^{-1}\ \ {\rm yr},$$

Synchrotron

$$t_{\rm Sync} \approx 12 \times 10^6 (B/\mu{\rm G})^{-2}(E_{\rm e}/{\rm TeV})^{-1}\ \ {\rm yr},$$

Bremsstrahlung

$$t_{\rm Br} \approx 4 \times 10^7 (n/{\rm cm}^3)^{-1}\ \ {\rm yr},$$

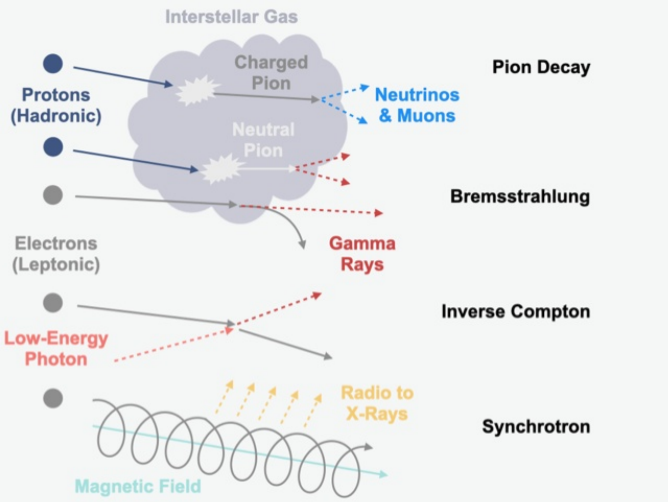
Inverse-Compton

f = Klein-Nishina suppression factor
b << 1 “Thompson regime”

$$f_{\rm KN} \approx (1 + b)^{-1.5}$$

$$b = 4\omega\gamma$$

Inverse-Compton and Synchrotron Connection



Aharonian et al. 1997 MNRAS 291, 162

Generally the same electron population will emit both synchrotron and IC emission and thus the two process are competing.

The close connection between the synchrotron F$_{\mathrm{sync}}$ and inverse-Compton fluxes F$_{\mathrm{IC}}$ can be seen:

- Flux ratio = ratio of energy loss rates = $\dfrac{dE_e/dt = \frac{4}{3}\sigma_T c \omega n_{ph}\gamma^2}{dE_e/dt = \frac{4}{3}\sigma_T c U_B \gamma^2}$

$$\rightarrow \quad \frac{F_{IC}}{F_{sync}} = \frac{\dot{E}_{IC}}{\dot{E}_{sync}} = \frac{U_{rad}}{U_B}$$

for $U_{rad} = \omega n_{ph}$

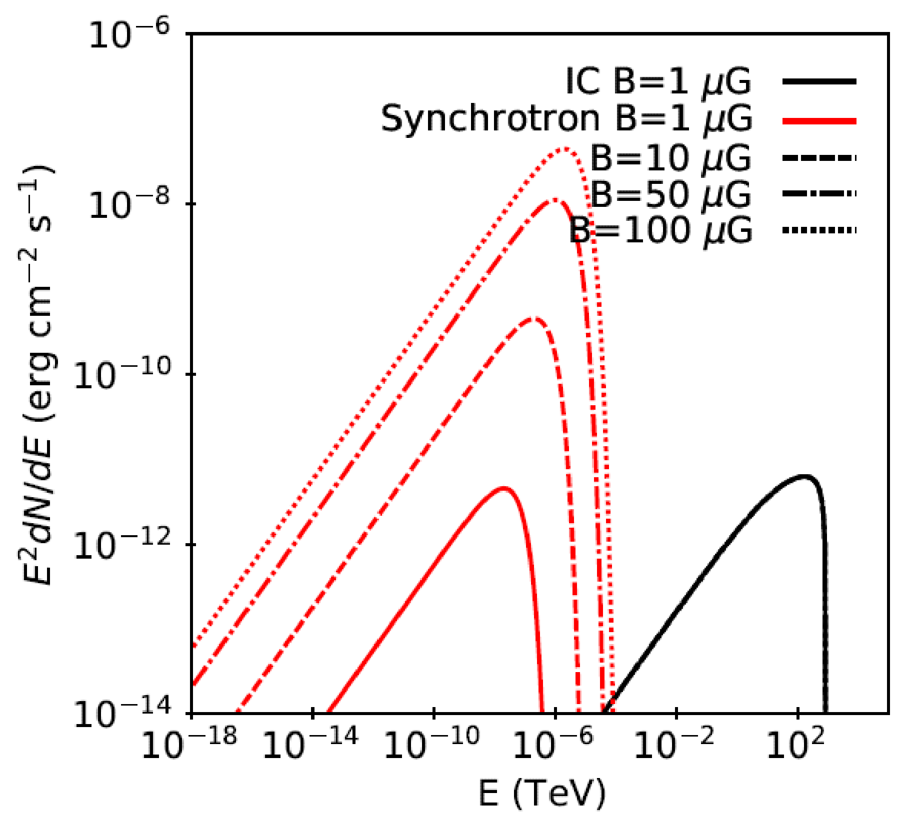
$$\rightarrow \quad F_{IC} \sim \frac{F_{sync}}{10(B/10\mu\mathrm{G})^2}$$

Assumptions:

- *Thompson regime*
- *δ-func approx for sync and IC cross sections*
- *IC scattering of CMB photons*

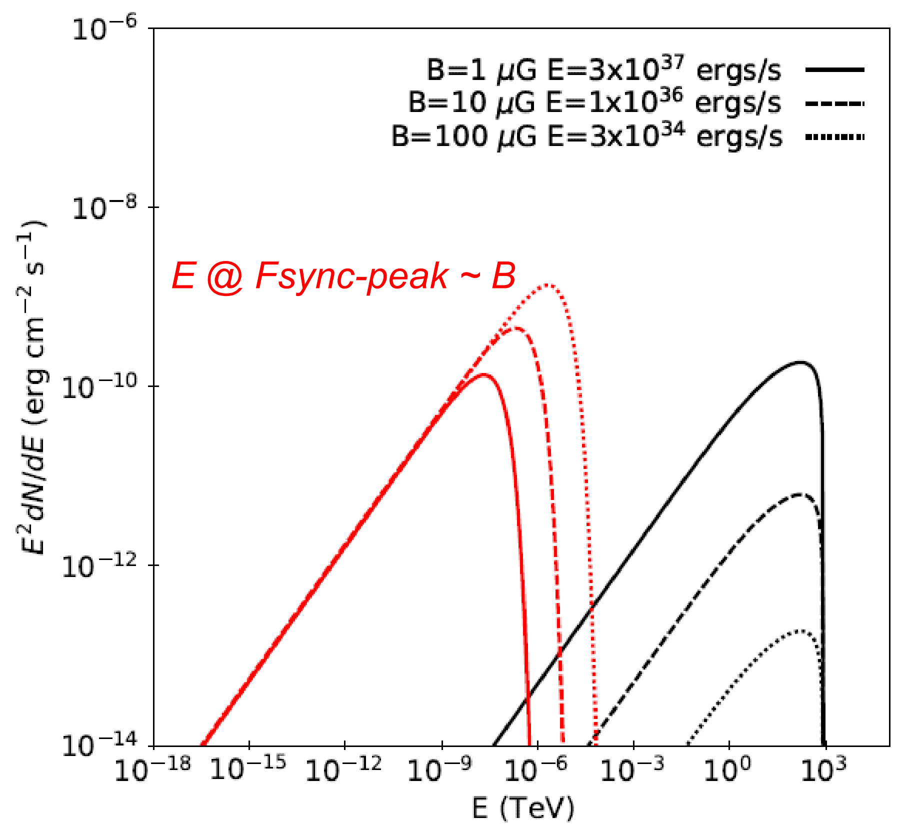
Inverse-Compton and Synchrotron Connection

- Constant electron injection (10^{37} erg/s)
- Inverse-Compton is hence fixed
- Varying B field → Varying synchrotron



- Electron injection and B-field varied for constant synchrotron emission < Fpeak

→ Varying inverse-Compton



E @ Fsync-peak ~ B

Note- Distance 4 kpc & IC scattering on CMB photons in both cases

T. Collins

Acceleration timescale (DSA) and losses: Implications

- Particles gain energy after each shock crossing at a rate ΔE/Δt

Time taken to reach energy E is given by $t_{acc} = E / \Delta E/\Delta t$

(see review by Reynolds 2008 ARAA 46,89)

With ‘upstream’ diffusion coeff D_u and shock speed u_s we have:

$$\tau_{accel} = 8D_u/u_s^2$$

(Bell 2013 Astropart. Phys. 43, 56)

But, as particles gain energy, they will also lose energy via radiation at a rate according to the ‘cooling’ time (previous slide).

If $t_{acc} > t_{cool}$ → Increased time to reach a certain energy

→ And/or, maximum energy of particle reduced

This mostly applies to electrons losing energy to synchrotron emission (photon energy ε) in situations B> few μG, e.g. Uchiyama etal 2007

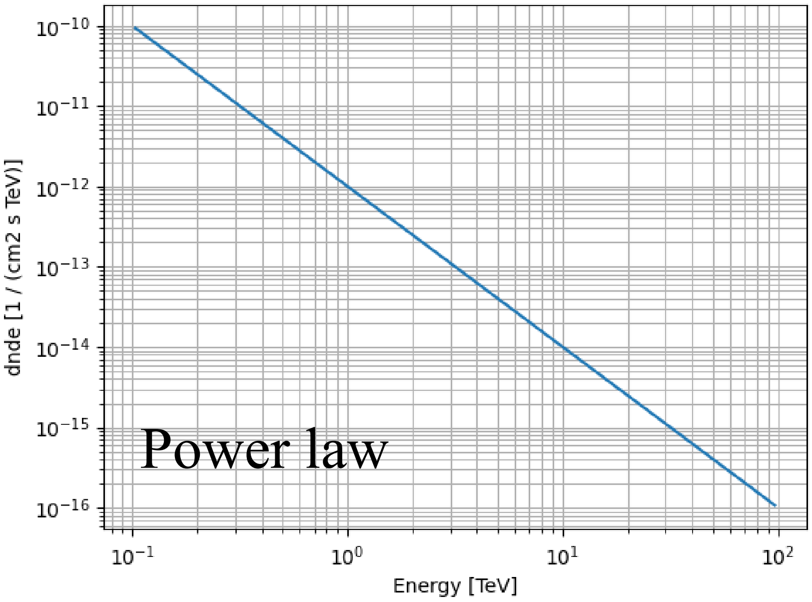
$$t_{acc} \approx 1\eta(\varepsilon/\mathrm{keV})^{0.5}(B/\mathrm{mG})^{-1.5}(v_s/3{,}000\ \mathrm{km\ s^{-1}})^{-2}\ \mathrm{years}$$

η ~ 1 for efficient shock acceleration

Typical result: Power law + exp. cutoff

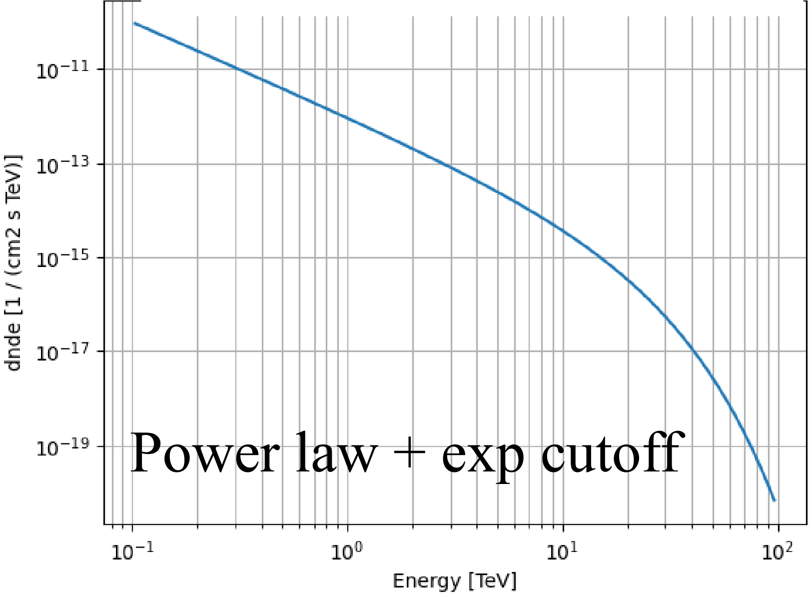
$$dN/dE = K\,E^{-\Gamma} \exp(-E/E_c)$$

$$dN/dE = K\,E^{-\Gamma}$$



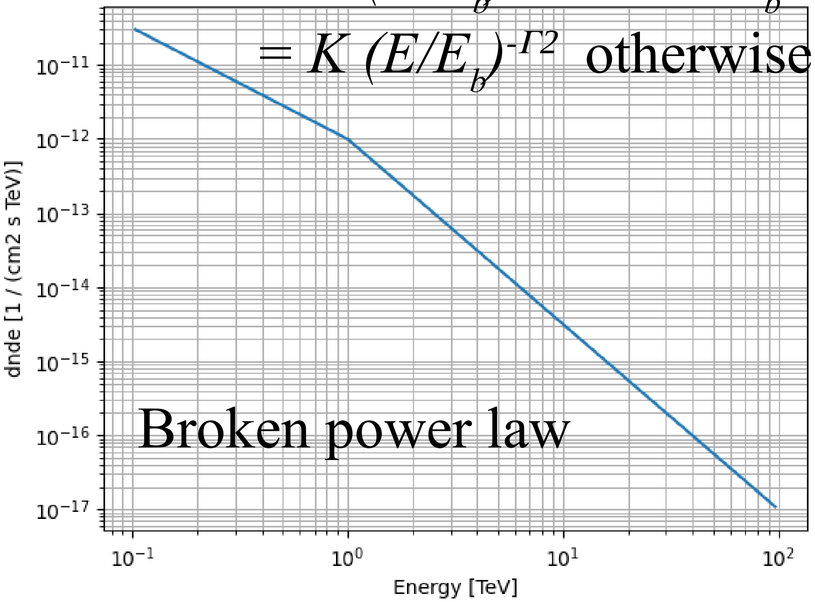
Power law

$$dN/dE = K\,E^{-\Gamma}\,\exp(-E/E_c)$$



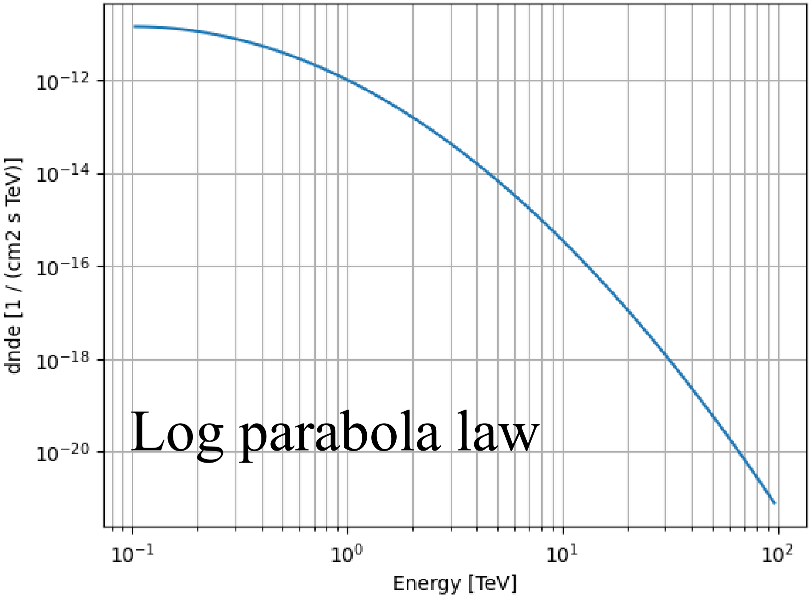
Power law + exp cutoff

$$\begin{aligned} dN/dE &= K\,(E/E_b)^{-\Gamma 1} \text{ if } E < E_b \\ &= K\,(E/E_b)^{-\Gamma 2} \text{ otherwise} \end{aligned}$$

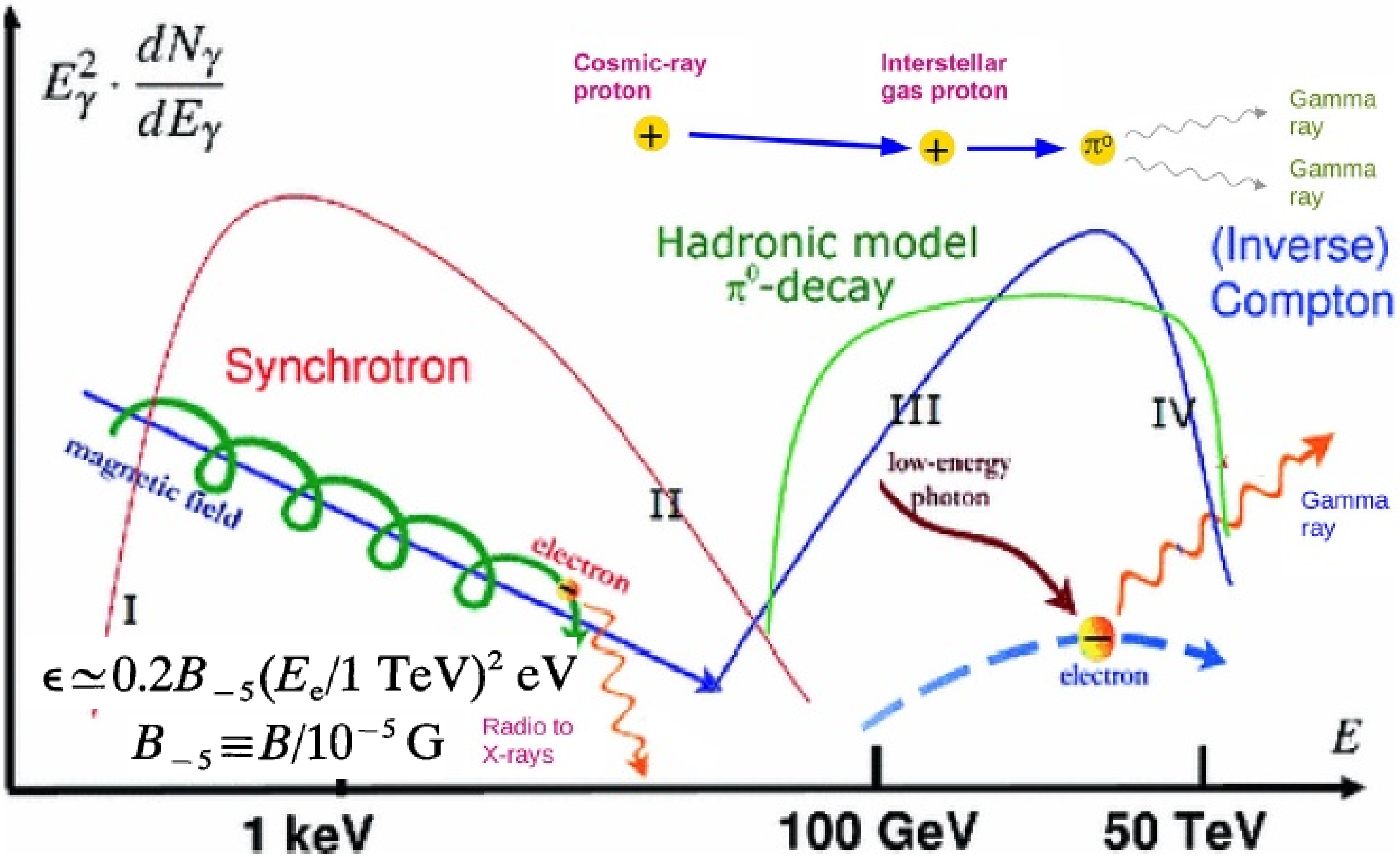


Broken power law

$$dN/dE = K\,E^{-\alpha\ -\beta\ \log(E/Eo)}$$



Log parabola law



$$\epsilon \simeq 0.2 B_{-5} (E_e/1\ \mathrm{TeV})^2\ \mathrm{eV}$$

$$B_{-5} \equiv B/10^{-5}\ \mathrm{G}$$

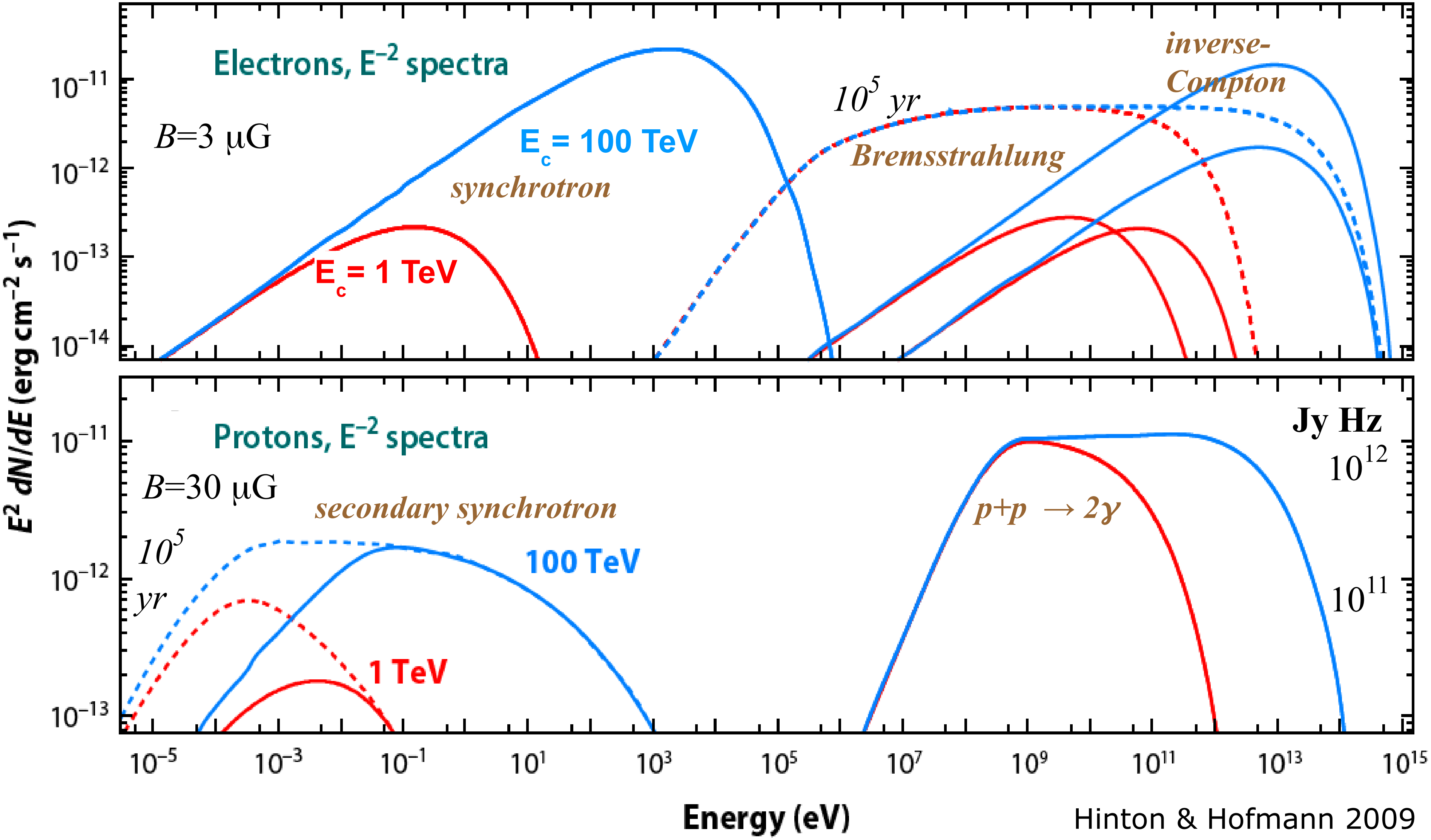
Adapted from Spurio 2016

Non-Thermal Photon Energy fluxes (hypothetical particle accelerator)

Particle Spectrum

$$\frac{dN}{dE} = E^{-2}\exp\left(-E/E_c\right)$$

$W_p = W_e = 10^{48}$ erg; d = 1 kpc; Age = 10^4 yr,
CMB+FIR+Opt; n=100 cm^{-3}



Hinton & Hofmann 2009

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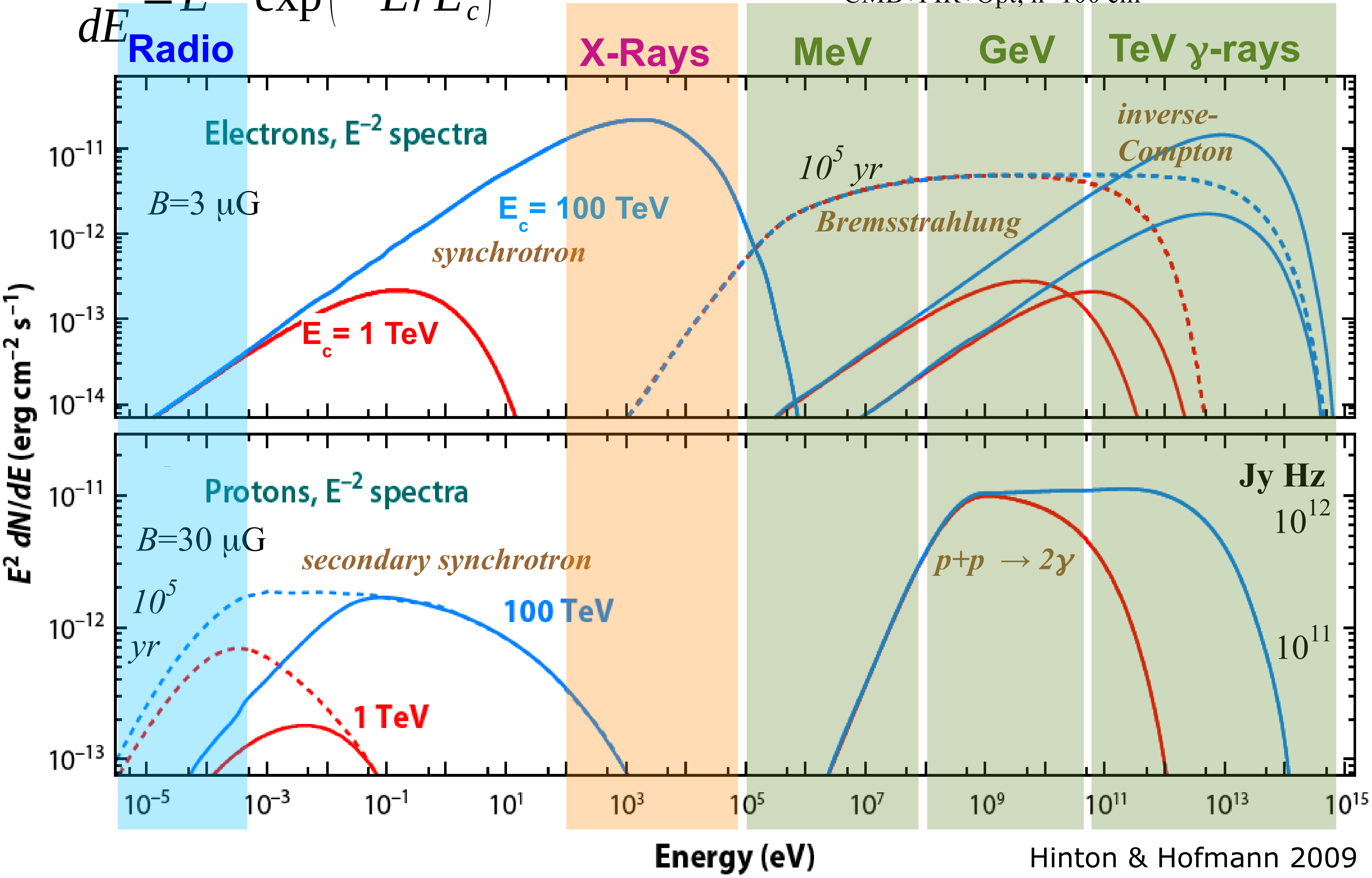

Hinton & Hofmann 2009

Non-Thermal Photon Energy fluxes (hypothetical particle accelerator)

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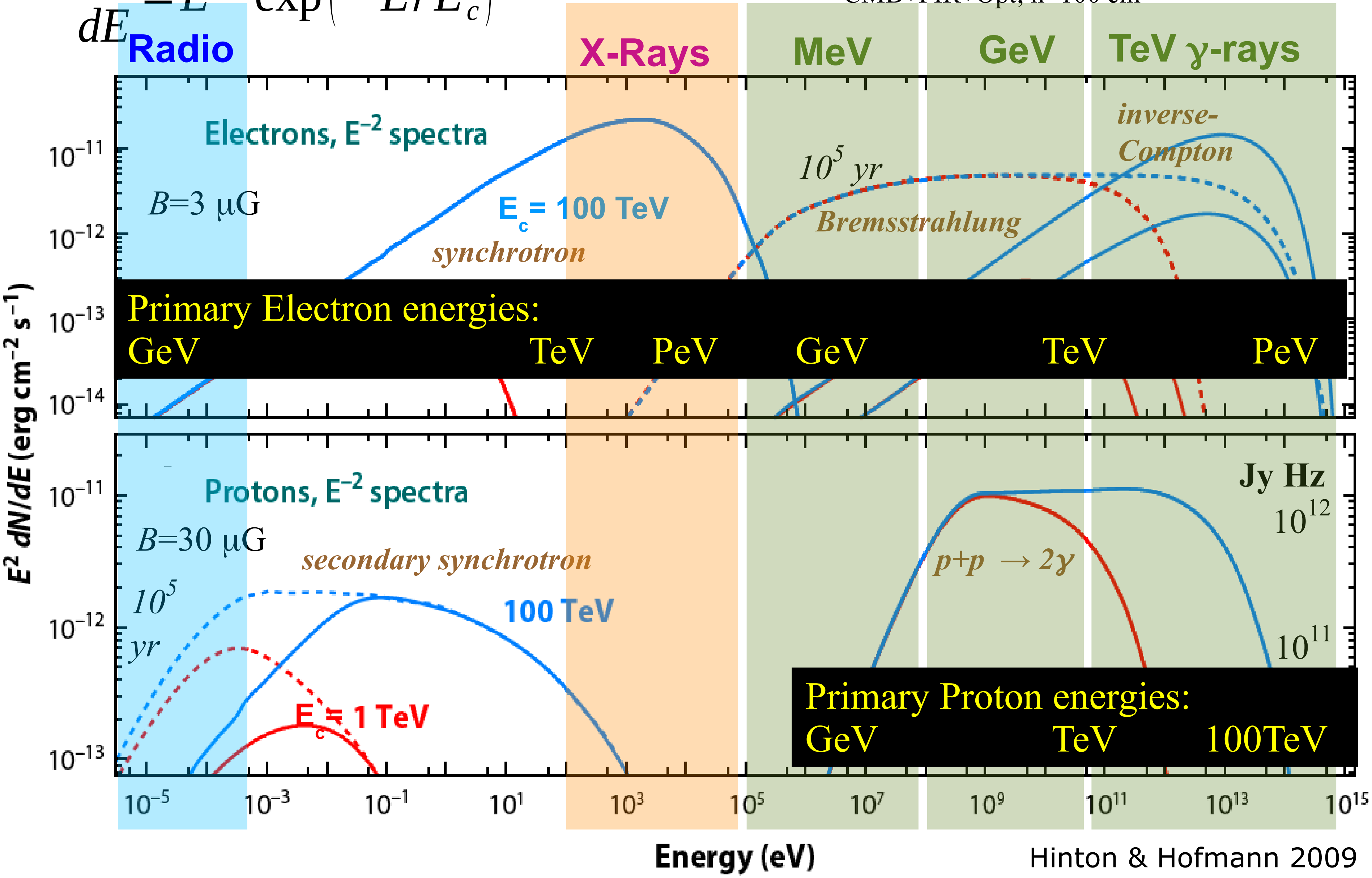
$W_p = W_e = 10^{48}$ erg; d = 1 kpc; Age = 10^4 yr,
CMB+FIR+Opt; n=100 cm^{-3}

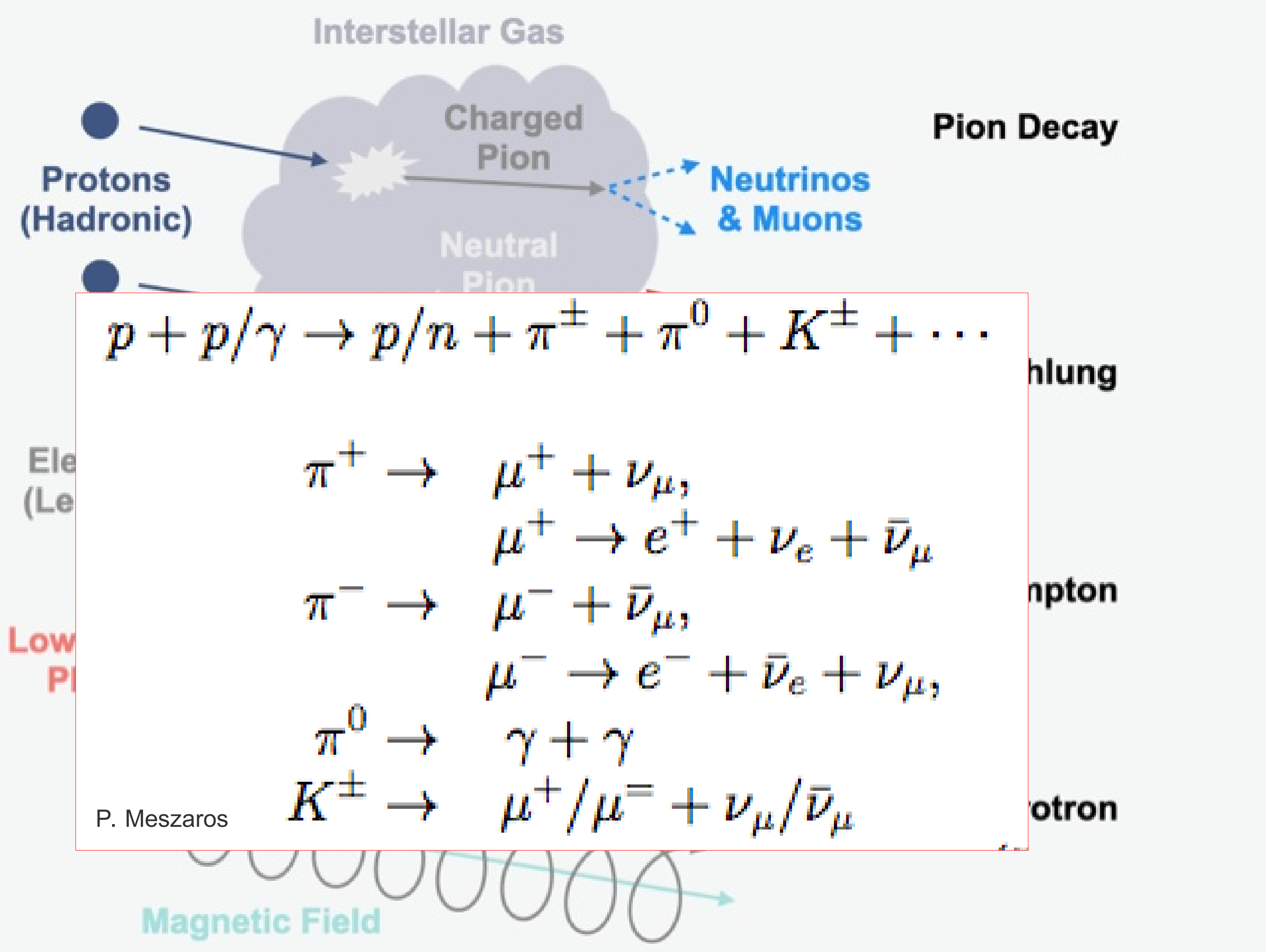


Primary Electron energies:
GeV TeV PeV GeV TeV PeV

Primary Proton energies:
GeV TeV 100TeV

Hinton & Hofmann 2009

Neutrinos from multi-TeV protons (further details)



$$p + p/\gamma \to p/n + \pi^{\pm} + \pi^{0} + K^{\pm} + \cdots$$

$$\begin{aligned}
\pi^{+} &\to \mu^{+} + \nu_{\mu}, \\
&\qquad \mu^{+} \to e^{+} + \nu_{e} + \bar{\nu}_{\mu} \\
\pi^{-} &\to \mu^{-} + \bar{\nu}_{\mu}, \\
&\qquad \mu^{-} \to e^{-} + \bar{\nu}_{e} + \nu_{\mu}, \\
\pi^{0} &\to \gamma + \gamma \\
K^{\pm} &\to \mu^{+}/\mu^{-} + \nu_{\mu}/\bar{\nu}_{\mu}
\end{aligned}$$

P. Meszaros

For p+p → gamma-rays and neutrinos and gas targets spatially correlated (need to map atomic and molecular ISM → mm radio astronomy)

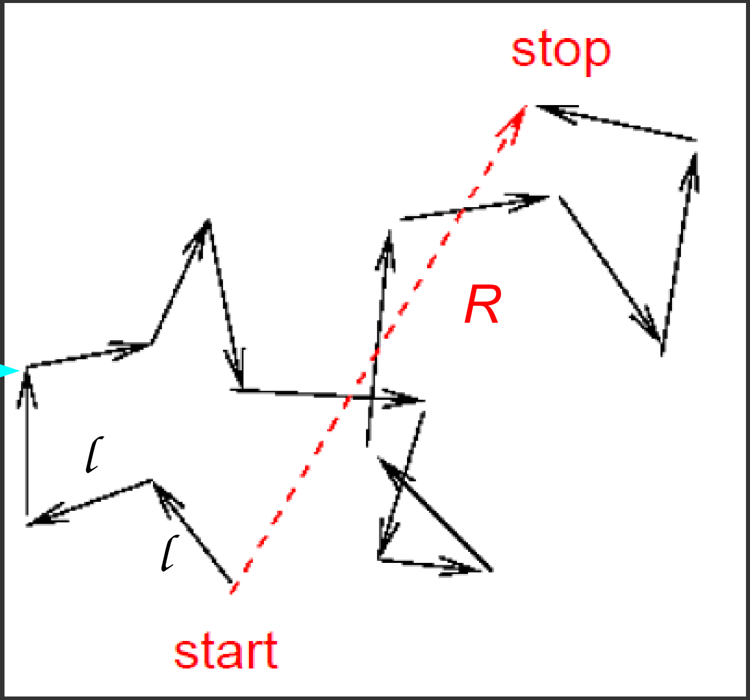
For p+γ → neutrinos and photon targets (e.g. in AGN cores) spatially correlated

Particle Transport - Diffusion

Charged particles and photon are not often able to travel ballistically due to scattering in the medium in which they travel. They take a “random walk” path since the scattered particle/photon continues on in a random direction after each scattering.

What causes the scattering?

For charged particles, it's usually the turbulence or irregularity of the magnetic field acting as scattering sites



Let ℓ be the mean free path the particle travels between scattering steps (or events), and *n* be the number of steps taken. The distance R the particle will travel from its original position is:

$$R = \ell \, (n)^{0.5}$$

If the mean time between scattering is given by τ, the number of scattering steps taken in total time t is $n = t/\tau$, we have

$R = \ell\,(t/\tau)^{0.5}$

For the 1D case, we find that the projected RMS distance onto one axis is:

$R = (2Dt)^{0.5}$ where the “diffusion coefficient” $D = \ell^2/(2\tau)$.

Extending to 2D and 3D situations we have $R = (4Dt)^{0.5}$, $R = (6Dt)^{0.5}$ resp.

Solving for t we have the ‘diffusion time’ it takes a particle to travel distance R

$t = R^2/(2D)$

Also, D is usually energy dependent $D \sim D_o E^{\delta}$ $(\delta \sim 0.3$ *to* $0.7)$

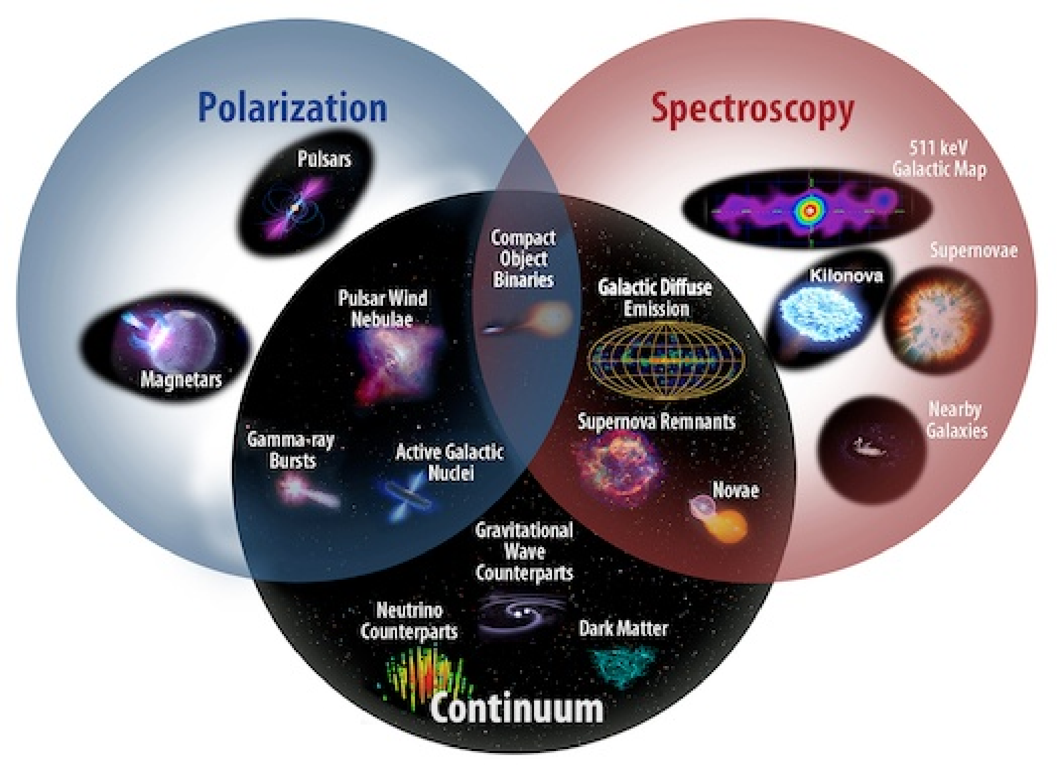
Diffusion critical in:
- Shock acceleration (DSA) as it regulates particle scattering across shocks
- Transport of particles (mostly cosmic rays) from their accelerators
  → *Energy-dependant morphology in GeV-TeV gammas*
  → *Specific GeV-TeV gamma-ray spectra*

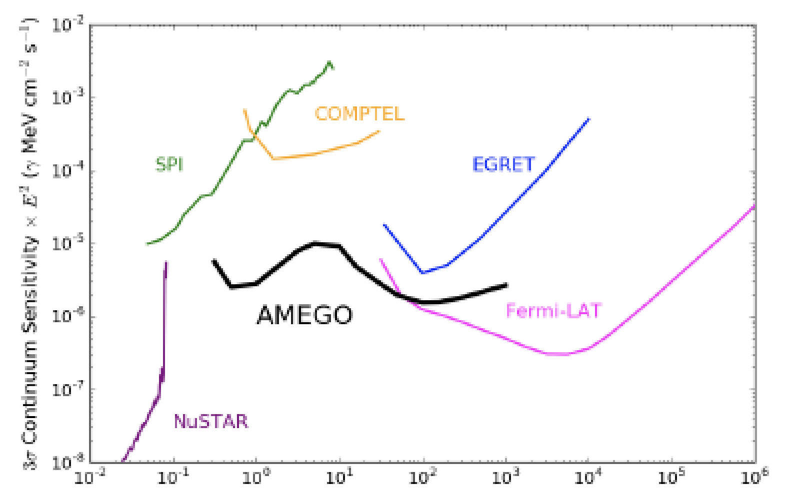
High-energy astrophysical sources

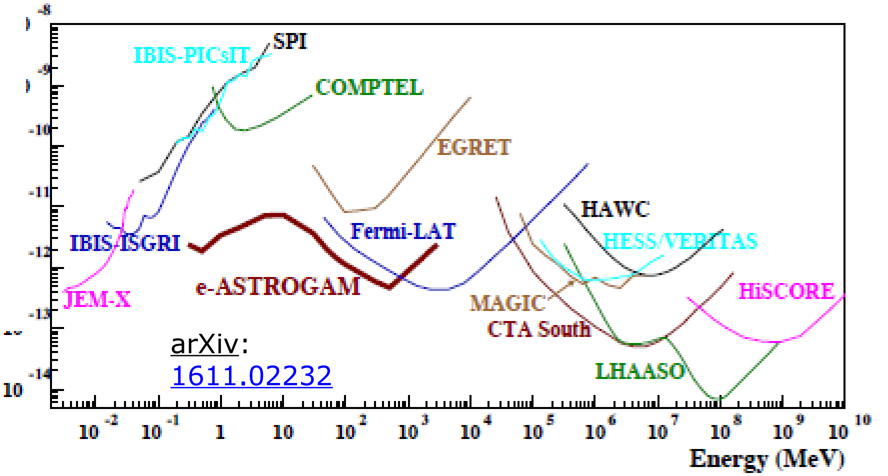
Emphasis on transient/variable sources

We’ll start with results in GeV-TeV gamma-ray astronomy and look at the ‘multi-messenger’ connections

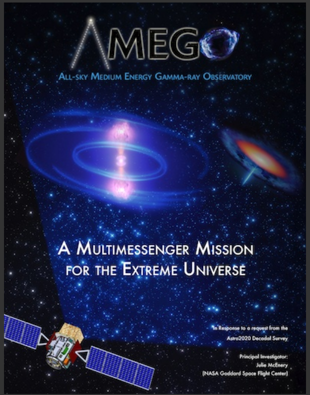
MeV Gamma Rays







arXiv: 1611.02232



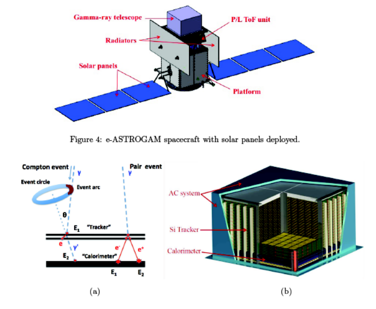
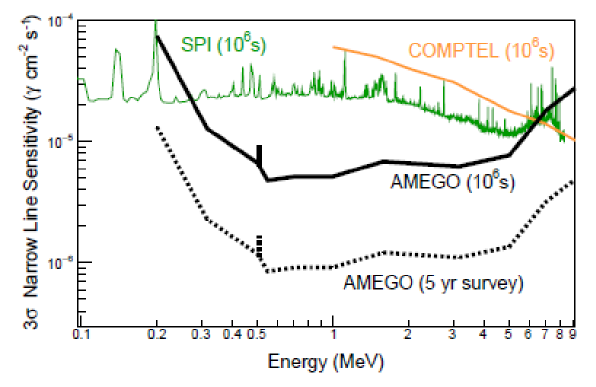


Figure 4: e-ASTROGAM spacecraft with solar panels deployed.

(a)

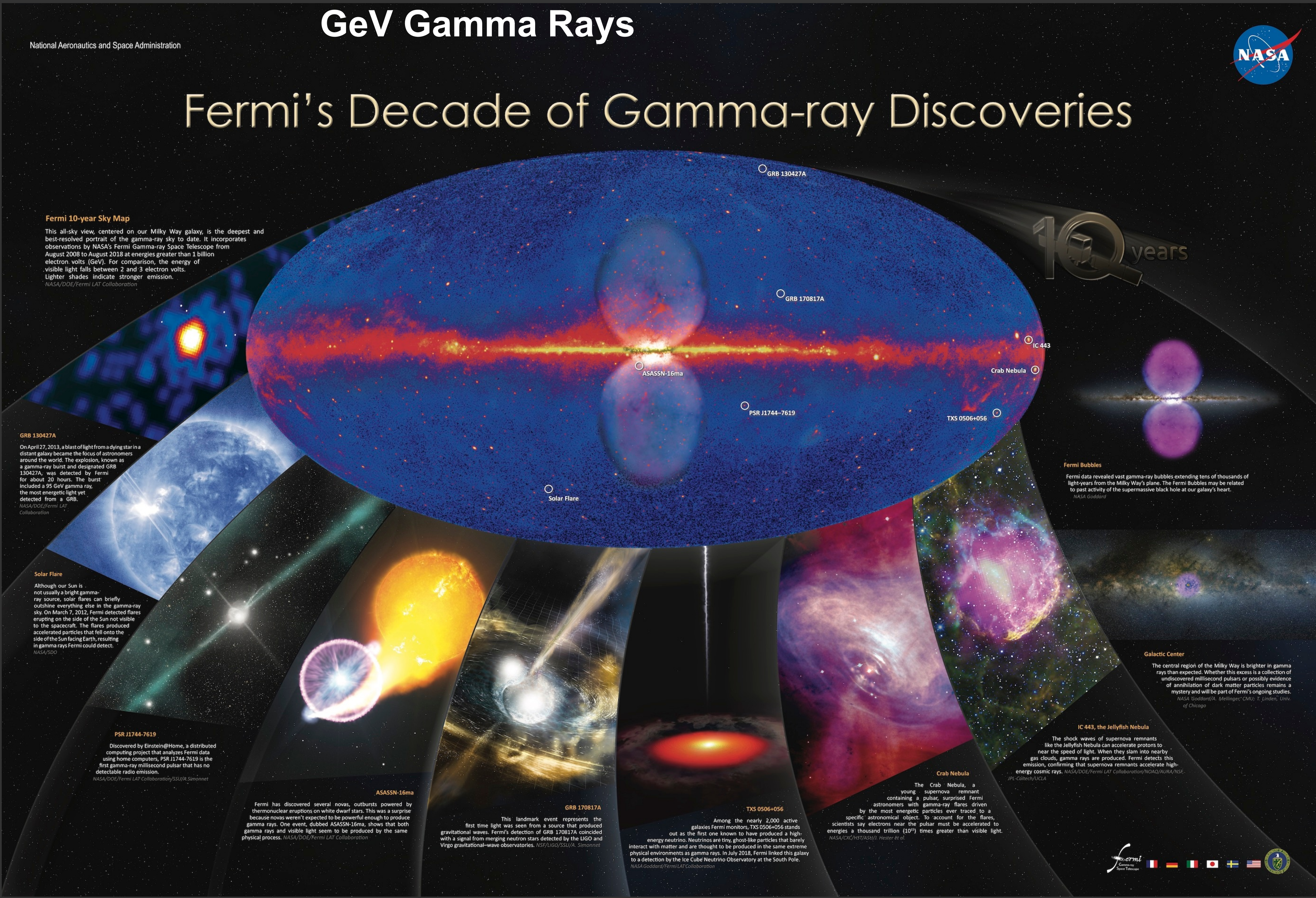
(b)



AMEGO & e-ASTROGAM

https://asd.gsfc.nasa.gov/amego/index.html

GeV Gamma Rays



National Aeronautics and Space Administration

Fermi's Decade of Gamma-ray Discoveries

Fermi 10-year Sky Map

This all-sky view, centered on our Milky Way galaxy, is the deepest and best-resolved portrait of the gamma-ray sky to date. It incorporates observations by NASA's Fermi Gamma-ray Space Telescope from August 2008 to August 2018 at energies greater than 1 billion electron volts (GeV). For comparison, the energy of visible light falls between 2 and 3 electron volts. Lighter shades indicate stronger emission.
NASA/DOE/Fermi LAT Collaboration

GRB 130427A

On April 27, 2013, a blast of light from a dying star in a distant galaxy became the focus of astronomers around the world. The explosion, known as a gamma-ray burst and designated GRB 130427A, was detected by Fermi for about 20 hours. The burst included a 95 GeV gamma ray, the most energetic light yet detected from a GRB.
NASA/DOE/Fermi LAT Collaboration

Solar Flare

Although our Sun is not usually a bright gamma-ray source, solar flares can briefly outshine everything else in the gamma-ray sky. On March 7, 2012, Fermi detected flares erupting on the side of the Sun not visible to the spacecraft. The flares produced accelerated particles that fell onto the side of the Sun facing Earth, resulting in gamma rays Fermi could detect.
NASA/SDO

PSR J1744-7619

Discovered by Einstein@Home, a distributed computing project that analyzes Fermi data using home computers, PSR J1744-7619 is the first gamma-ray millisecond pulsar that has no detectable radio emission.
NASA/DOE/Fermi LAT Collaboration/SSU/A.Simonnet

ASASSN-16ma

Fermi has discovered several novas, outbursts powered by thermonuclear eruptions on white dwarf stars. This was a surprise because novas weren't expected to be powerful enough to produce gamma rays. One event, dubbed ASASSN-16ma, shows that both gamma rays and visible light seem to be produced by the same physical process. *NASA/DOE/Fermi LAT Collaboration*

GRB 170817A

This landmark event represents the first time light was seen from a source that produced gravitational waves. Fermi's detection of GRB 170817A coincided with a signal from merging neutron stars detected by the LIGO and Virgo gravitational–wave observatories. *NSF/LIGO/SSU/A. Simonnet*

TXS 0506+056

Among the nearly 2,000 active galaxies Fermi monitors, TXS 0506+056 stands out as the first one known to have produced a high-energy neutrino. Neutrinos are tiny, ghost-like particles that barely interact with matter and are thought to be produced in the same extreme physical environments as gamma rays. In July 2018, Fermi linked this galaxy to a detection by the Ice Cube Neutrino Observatory at the South Pole.
NASA Goddard/Fermi LAT Collaboration

Crab Nebula

The Crab Nebula, a young supernova remnant containing a pulsar, surprised Fermi astronomers with gamma-ray flares driven by the most energetic particles ever traced to a specific astronomical object. To account for the flares, scientists say electrons near the pulsar must be accelerated to energies a thousand trillion (10^{15}) times greater than visible light.
NASA/CXC/HST/ASU/J. Hester et al.

IC 443, the Jellyfish Nebula

The shock waves of supernova remnants like the Jellyfish Nebula can accelerate protons to near the speed of light. When they slam into nearby gas clouds, gamma rays are produced. Fermi detects this emission, confirming that supernova remnants accelerate high-energy cosmic rays. *NASA/DOE/Fermi LAT Collaboration/NOAO/AURA/NSF, JPL-Caltech/UCLA*

Galactic Center

The central region of the Milky Way is brighter in gamma rays than expected. Whether this excess is a collection of undiscovered millisecond pulsars or possibly evidence of annihilation of dark matter particles remains a mystery and will be part of Fermi's ongoing studies.
NASA Goddard/A. Mellinger, CMU; T. Linden, Univ. of Chicago

Fermi Bubbles

Fermi data revealed vast gamma-ray bubbles extending tens of thousands of light-years from the Milky Way's plane. The Fermi Bubbles may be related to past activity of the supermassive black hole at our galaxy's heart.
NASA Goddard

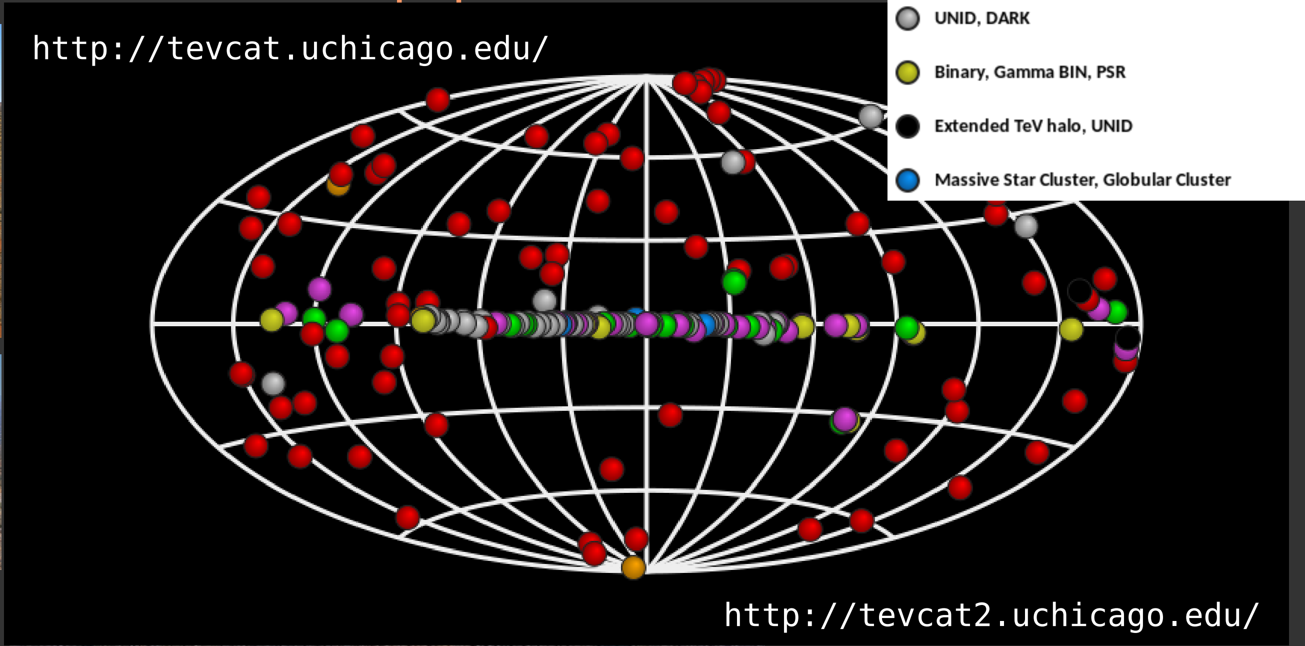
11 June 2018

https://www.nasa.gov/feature/goddard/2018/nasa-s-fermi-satellite-celebrates-10-years-of-discoveries

Gamma-rays (~30 GeV to ~500TeV)

Ground-based detection of Cherenkov emission

V.High impact > 20 Nature, Science, PRL papers since 2004



- ● PWN, BIN
- ● HBL, IBL, FSRQ, FRI, Blazar, BL Lac (class unclear), LBL
- ● Shell, SNR/Molec. Cloud, Composite SNR
- ● Starburst, Superbubble
- ● UNID, DARK
- ● Binary, Gamma BIN, PSR
- ● Extended TeV halo, UNID
- ● Massive Star Cluster, Globular Cluster

Great success with HESS, VERITAS, MAGIC, HAWC, building on previous generations

Continued operations of HESS/VERITAS/MAGIC/HAWC 2025+

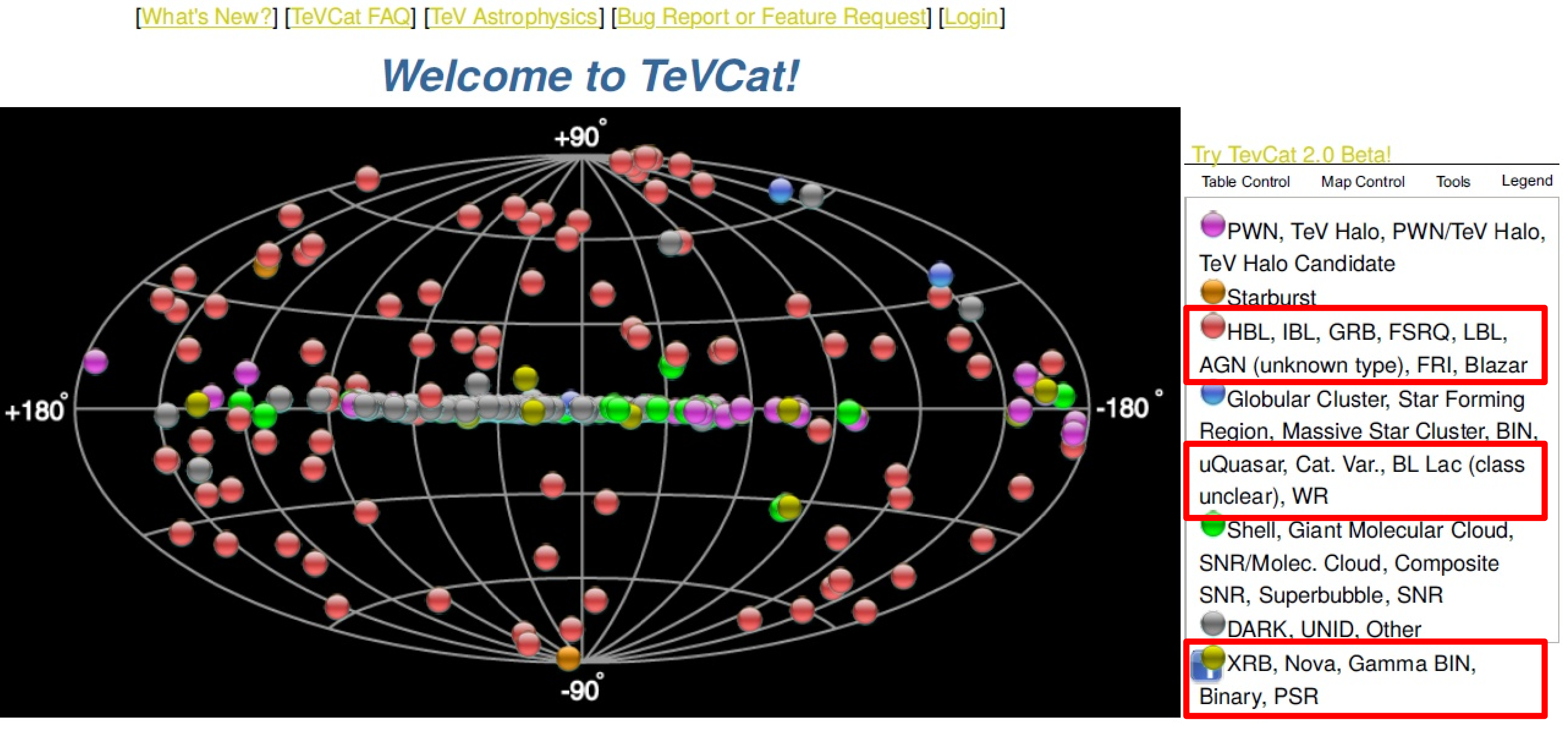
Next generation → CTA, SWGO…

Gamma-rays (GeV to >PeV Energies)

- **Gamma rays: Highly effective tracer of particle acceleration**
- **Many are transient or variable sources**
  - *Supernova remnants*
  - *Pulsars*
  - *Pulsar-wind nebulae & their halos*
  - *Compact binaries, stellar black holes*
  - *Gamma-ray bursts (hypernovae & compact mergers)*
  - *Novae*
  - *Galactic centre region*
  - *Massive stellar clusters*
  - *PeVatrons → our galaxy's extreme accelerators*
  - *Relativistic outflows; stellar winds; colliding wind interactions*
  - *ISM molecular & atomic gas; ISM magnetic fields*
  - *Unidentified & Dark TeV sources*
  - *Active Galaxy Cores; super-massive black holes*
  - *Star-burst galaxies*
  - *Globular clusters (millisecond pulsars and/or X-ray binaries?)*
  - *Extragalactic IR background constraints → cosmology*
  - *Indirect dark matter search, quantum gravity, axions, beyond SM physics*
  - *Cosmic ray electrons*

TeVCat

http://tevcat.uchicago.edu/

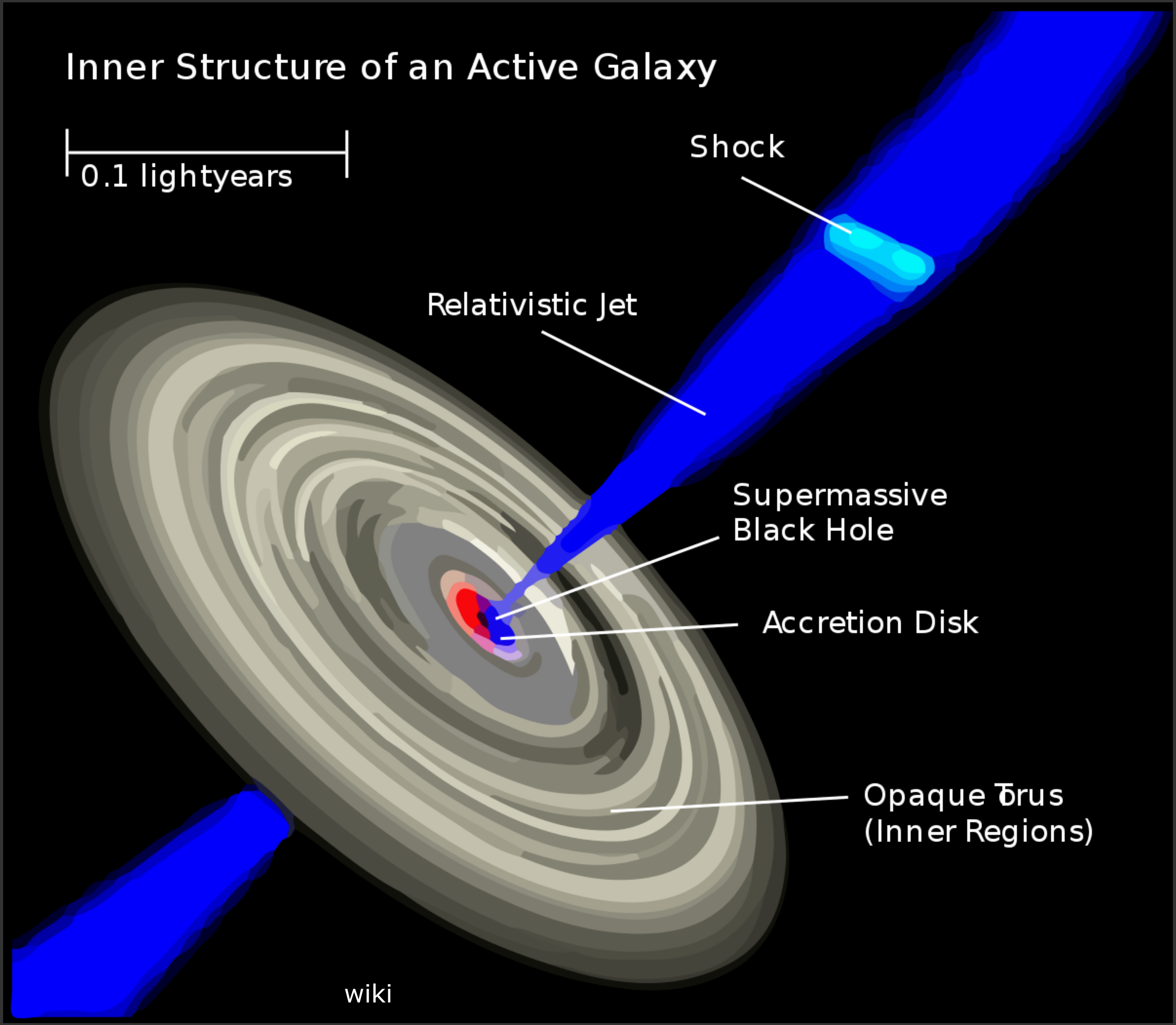


[What's New?] [TeVCat FAQ] [TeV Astrophysics] [Bug Report or Feature Request] [Login]

Welcome to TeVCat!

- ● PWN, TeV Halo, PWN/TeV Halo, TeV Halo Candidate
- ● Starburst
- ● HBL, IBL, GRB, FSRQ, LBL, AGN (unknown type), FRI, Blazar
- ● Globular Cluster, Star Forming Region, Massive Star Cluster, BIN, uQuasar, Cat. Var., BL Lac (class unclear), WR
- ● Shell, Giant Molecular Cloud, SNR/Molec. Cloud, Composite SNR, Superbubble, SNR
- ● DARK, UNID, Other
- ● XRB, Nova, Gamma BIN, Binary, PSR

AGN Blazars : Radio to TeV



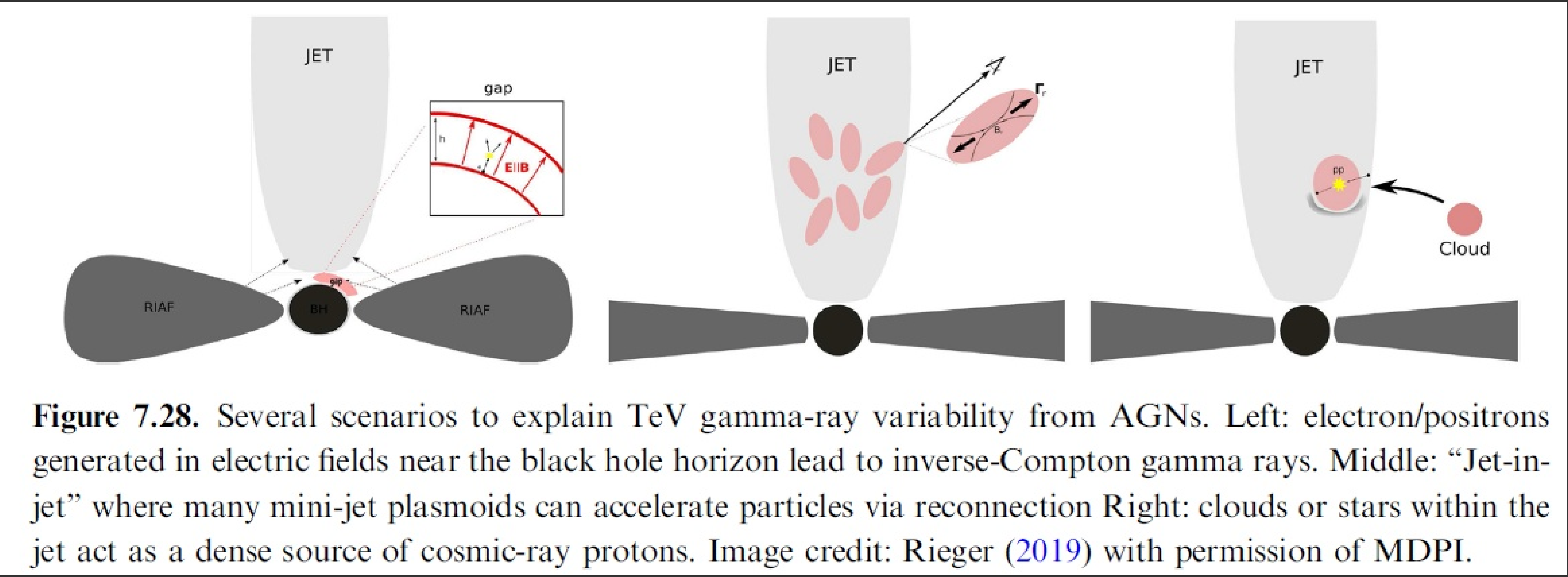
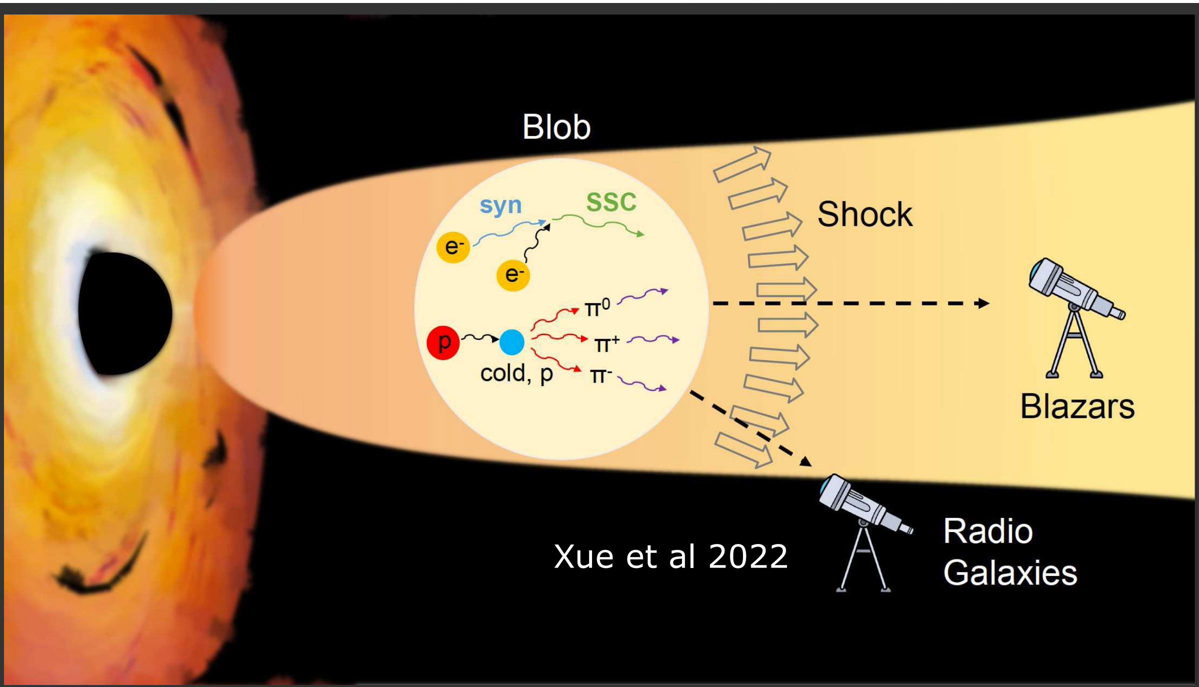


Figure 7.28. Several scenarios to explain TeV gamma-ray variability from AGNs. Left: electron/positrons generated in electric fields near the black hole horizon lead to inverse-Compton gamma rays. Middle: "Jet-in-jet" where many mini-jet plasmoids can accelerate particles via reconnection Right: clouds or stars within the jet act as a dense source of cosmic-ray protons. Image credit: Rieger (2019) with permission of MDPI.



Xue et al 2022

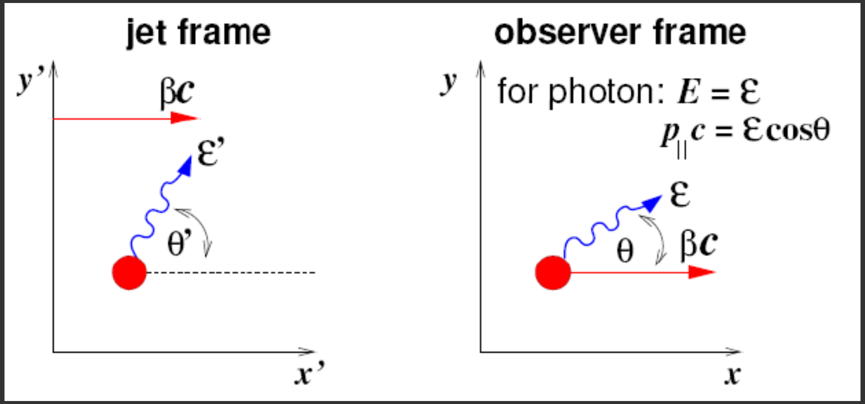
Observing a Relativistic Jet at Angle θ

Doppler factor

$$\delta = \gamma\,(1 - \beta \cos\theta)^{-1} = \gamma\,(1 + \beta \cos\theta')$$

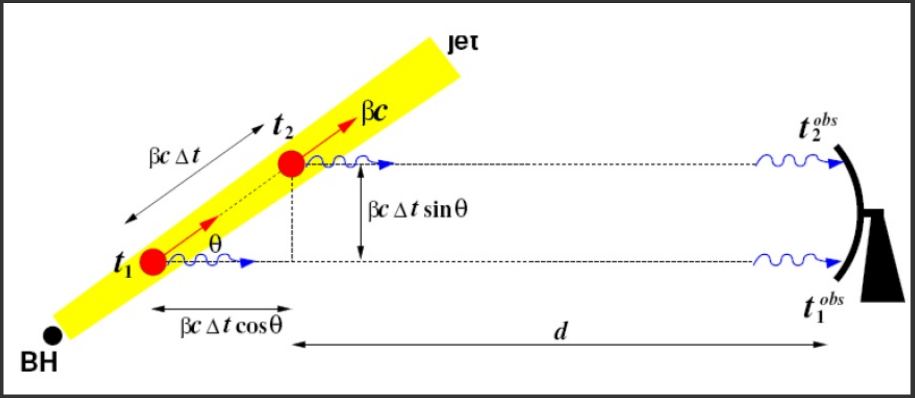
- Photon energies boosted

$$\varepsilon = \delta\varepsilon'$$



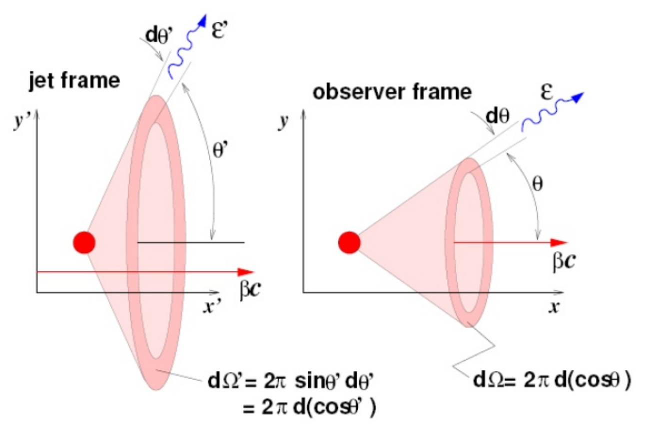
- Photon arrival times contracted

$$\Delta t = \Delta t'/\delta$$



- Photon arrival directions beamed

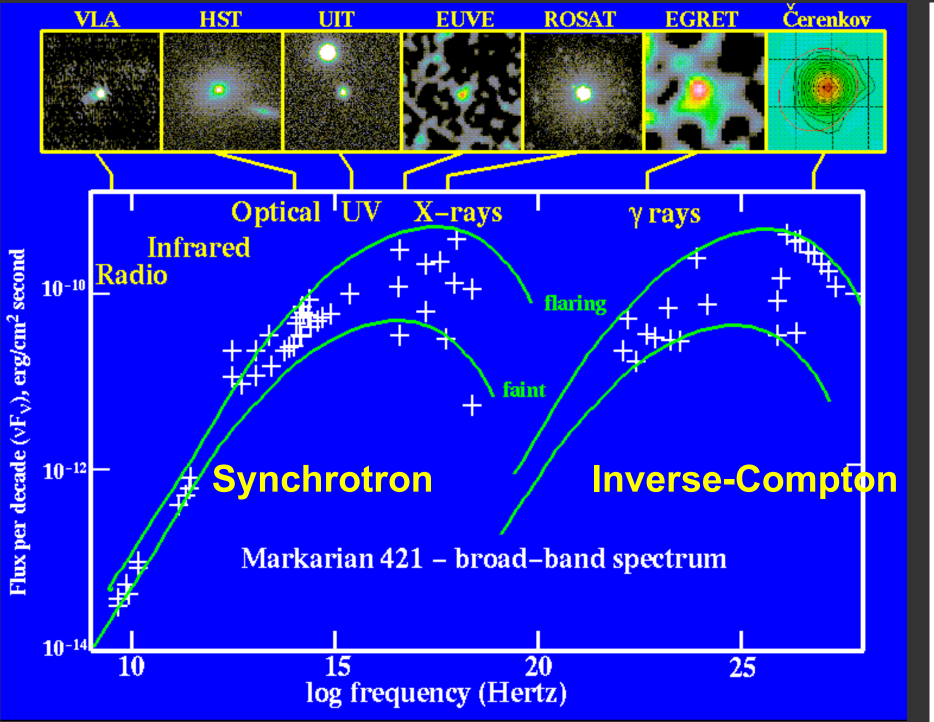
$$d\Omega' \,/\, d\Omega = d\cos\theta' \,/\, d\cos\theta = \delta^2$$



Observed luminosity

$$L = (\varepsilon/\varepsilon')\,(\Delta t'/\Delta t)\,(d\Omega'/d\Omega)\,L'$$

$$L = \delta^4 L'$$



http://vega.bac.pku.edu.cn/~wuxb/agn/text.html

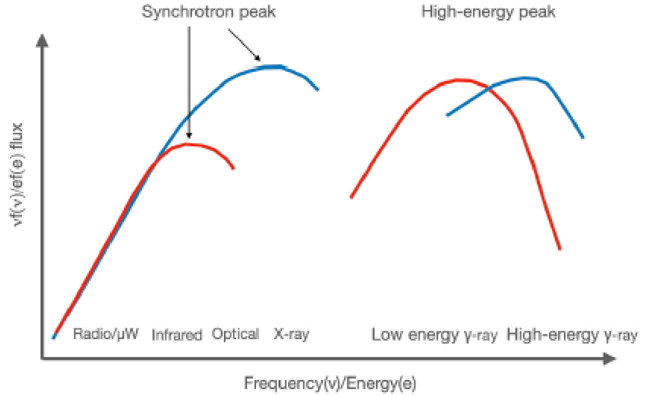


Figure 1: A schematic view of the SED of different types of blazars. The vertical axis shows the energy flux against the emission frequency (or energy) on the horizontal axis. The peak of the synchrotron component (ν^S_{peak}) spans a wide range of frequencies, from the far infrared in LBL objects (red curves) to the X-ray band in HBL sources (blue curves).

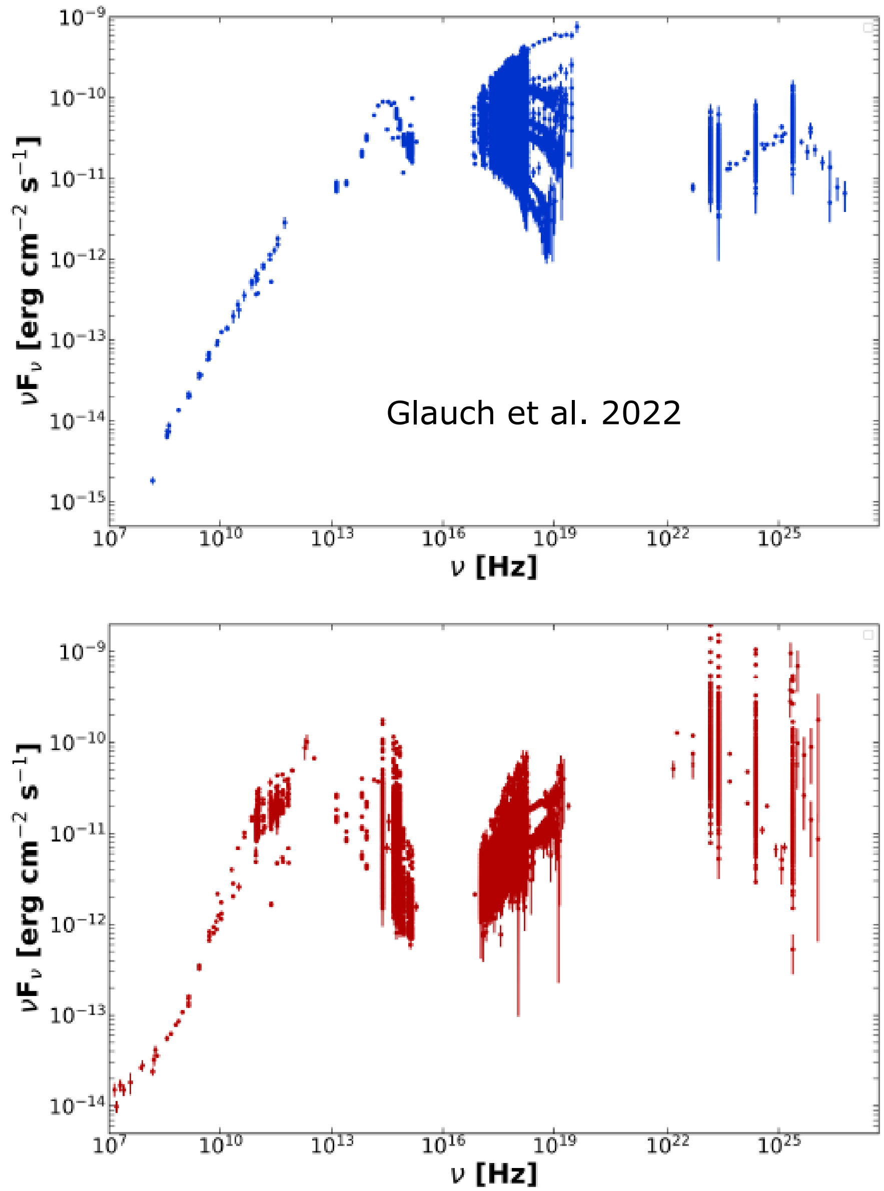
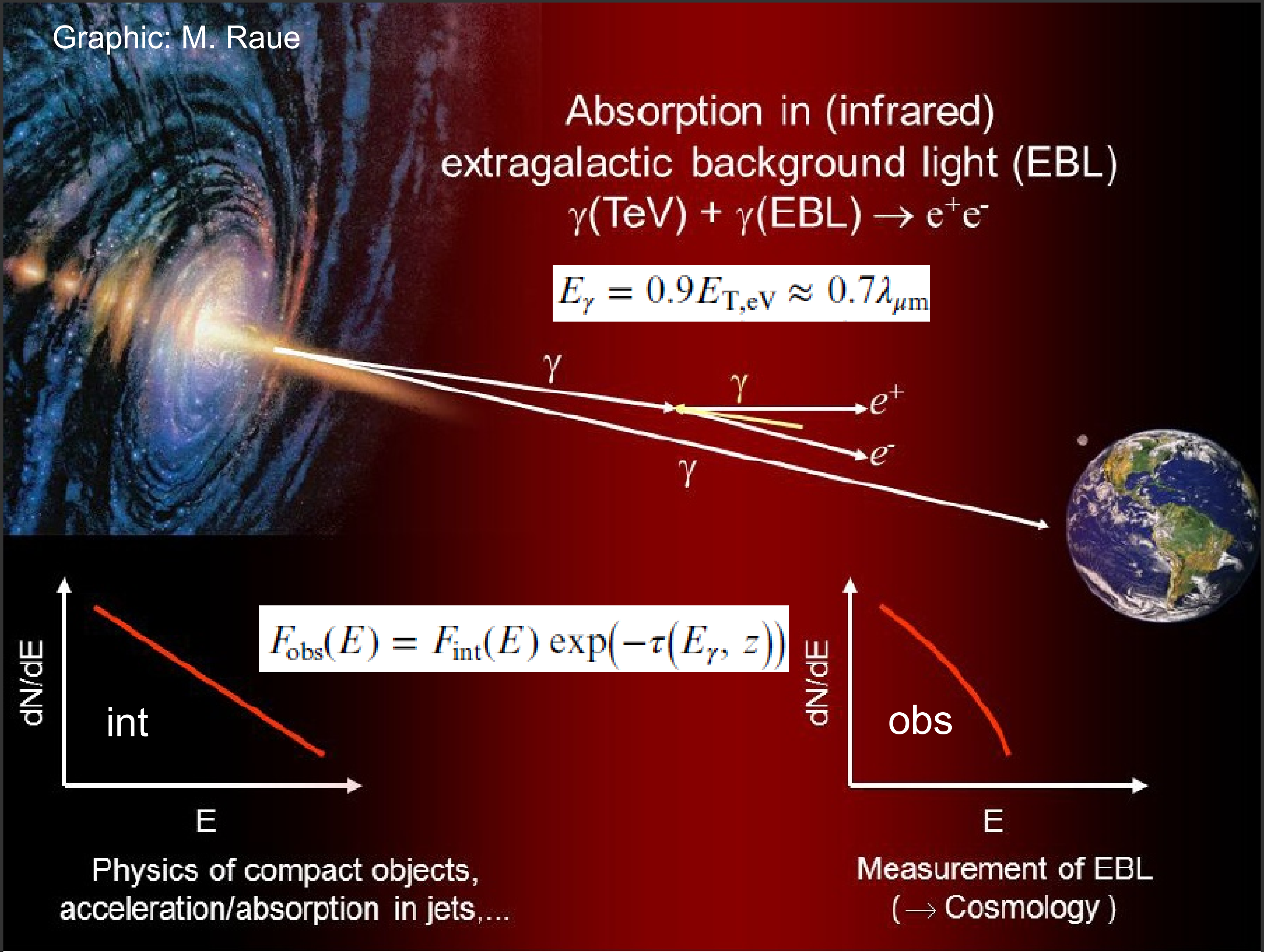

Glauch et al. 2022

Figure 2: Examples of well populated (time-integrated) SEDs of blazars with high ν^S_{peak} (MRK 501, top panel) and low ν^S_{peak} (3C 279, lower panel), corresponding to the blue and red lines in the schematic representations of Fig.1. Note the large flux variability in both cases.

Extragalactic Background Light (EBL)



Graphic: M. Raue

Absorption in (infrared) extragalactic background light (EBL)

$\gamma(\text{TeV}) + \gamma(\text{EBL}) \rightarrow e^+e^-$

$$E_\gamma = 0.9 E_{\mathrm{T,eV}} \approx 0.7 \lambda_{\mu\mathrm{m}}$$

$$F_{\mathrm{obs}}(E) = F_{\mathrm{int}}(E) \exp\left(-\tau\left(E_\gamma,\, z\right)\right)$$

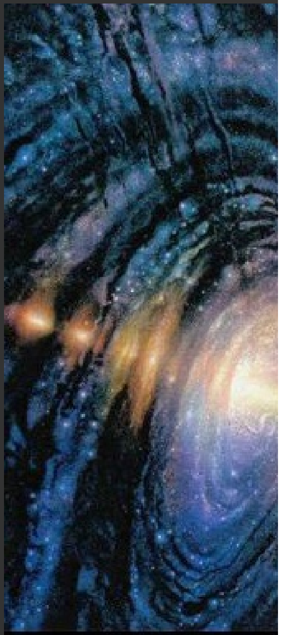
Physics of compact objects, acceleration/absorption in jets,...

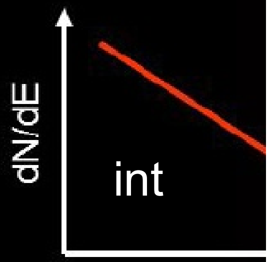
Measurement of EBL (→ Cosmology)

- Opt. depth τ depends on gamma-ray enegy and redshift (IR photon density)
- Constrain EBL → IR density vs. z → cosmology e.g. Hubble const constraints

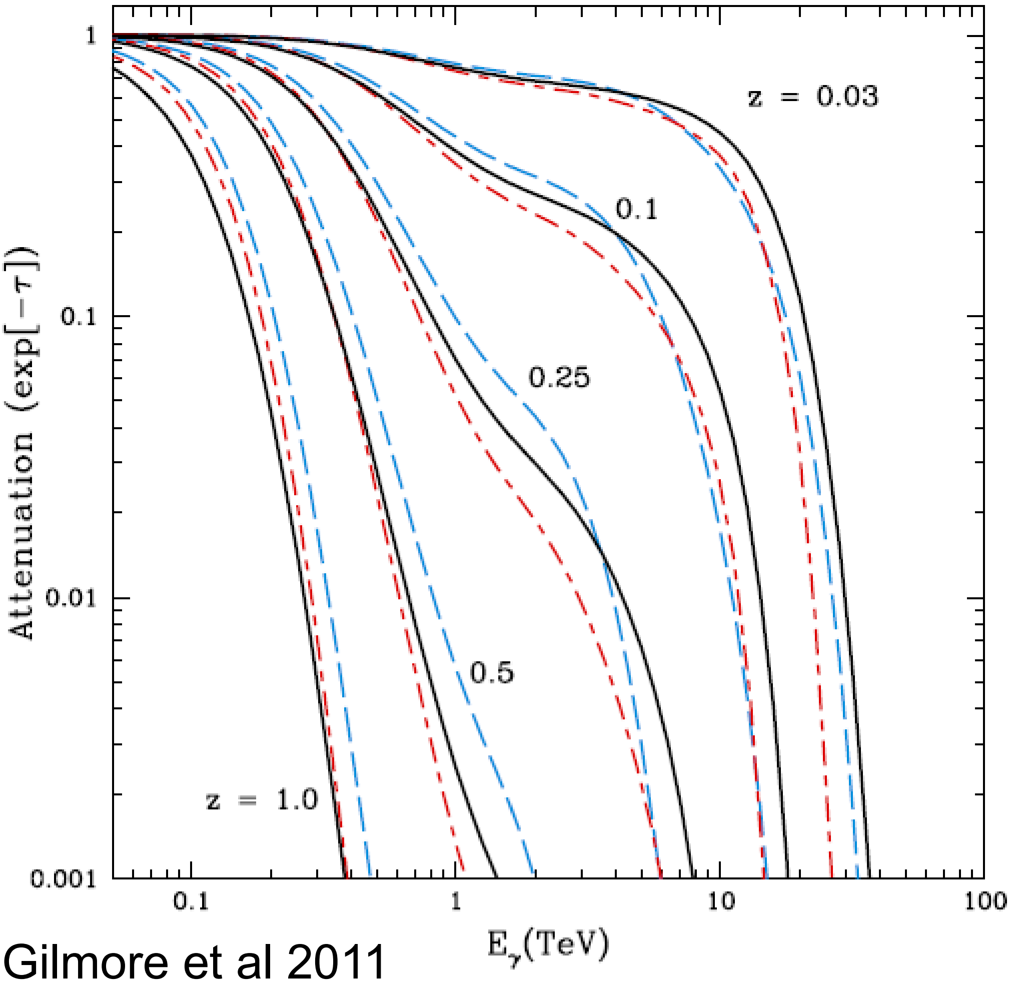
Dominguez et al 2019

Extragalact



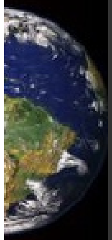


Physics of
acceleration/



Gilmore et al 2011

Figure 8. The attenuation $e^{-\tau}$ of gamma-rays vs. gamma-ray energy, for sources at $z = 0.03$, 0.1, 0.25, and 0.5, and 1. Results are compared for our fiducial WMAP5 (solid) and fixed+DGS99 (dashed blue) models, as well as the model of D11 (red dash-dotted). Increasing distance causes absorption features to increase in magnitude and appear at lower energies. The plateau seen between 1 and 10 TeV at low redshift is a product of the mid-IR valley in the EBL spectrum.



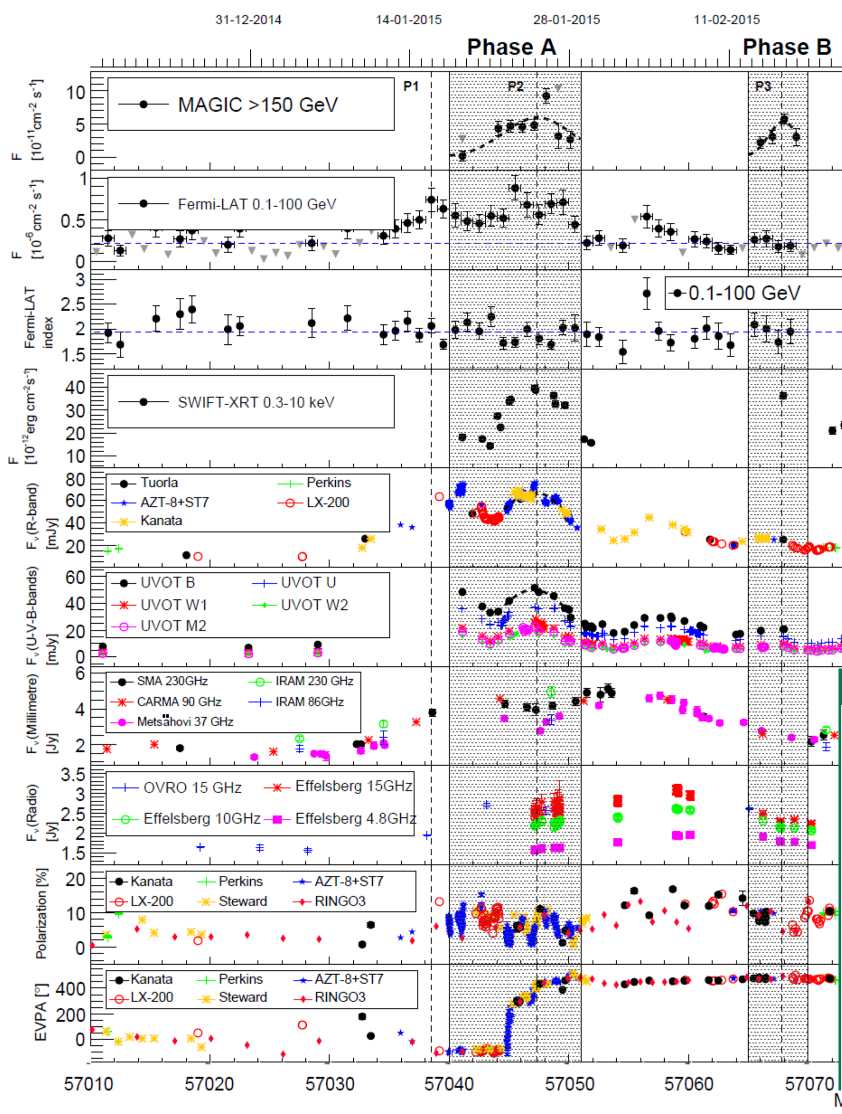
- Opt. depth τ de density)
- Constrain EBL constraints

t al 2019

AGN Blazar Flares: MWL Synergies

MWL light-curve (MAGIC 2018)

BL-Lac S5 0716+714



Enhanced HE and VHE gamma-ray activity from the FSRQ PKS 0346-27

ATel #15020; *S. Wagner (U. Heidelberg, Germany), for the H. E. S. S. collaboration an*
B. Rani (KASI, S. Korea), on behalf of the Fermi Large Area Telescope Collaboratio
on ***6 Nov 2021; 18:38 UT***
Credential Certification: Stefan J. Wagner (swagner@lsw.uni-heidelberg.de)

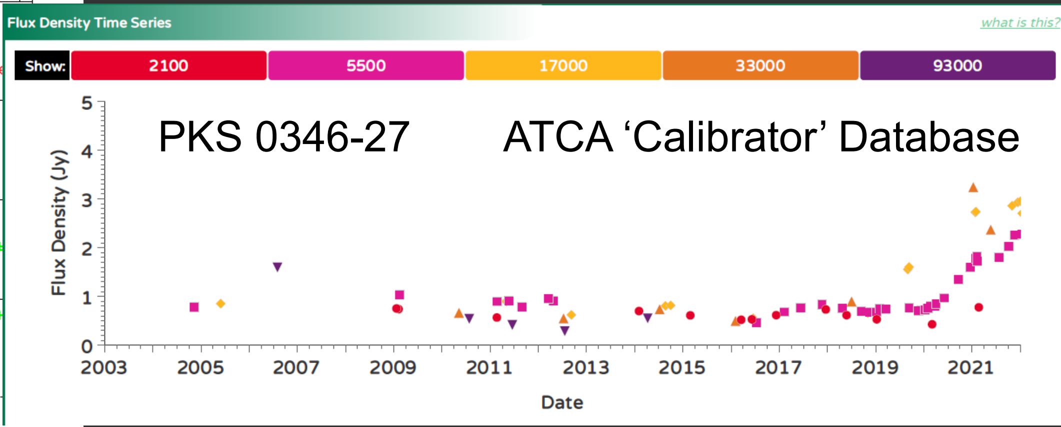
Subjects: Gamma Ray, >GeV, VHE, AGN, Blazar, Quasar

Referred to by ATel #: 15092

Tweet

The Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, has observed enhanced gamma-ray activity from a source positionally consistent with the flat-spectrum radio quasar PKS 0346-27, also known as 4FGL J0348.5-2749 (The Fermi-LAT collaboration 2020, ApJS, 247, 33), with coordinates RA=03h 48m 38s, Dec=-27d 49' 14" (J2000; Beasley et al. 2002 ApJS, 141, 13), and a reported redshift of z=0.991 (White et al. 1988 ApJ, 327, 561).

The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out observations of PKS 0346-27. On November 03 (MJD 59521.9), a two hour observation shows a >5 sigma excess in the very-high-energy gamma-ray band compatible with the direction of PKS 0346-27. Preliminary analysis shows a very soft power law (photon spectral index > 4). H.E.S.S. observations are ongoing.



PKS 0346-27 ATCA 'Calibrator' Database

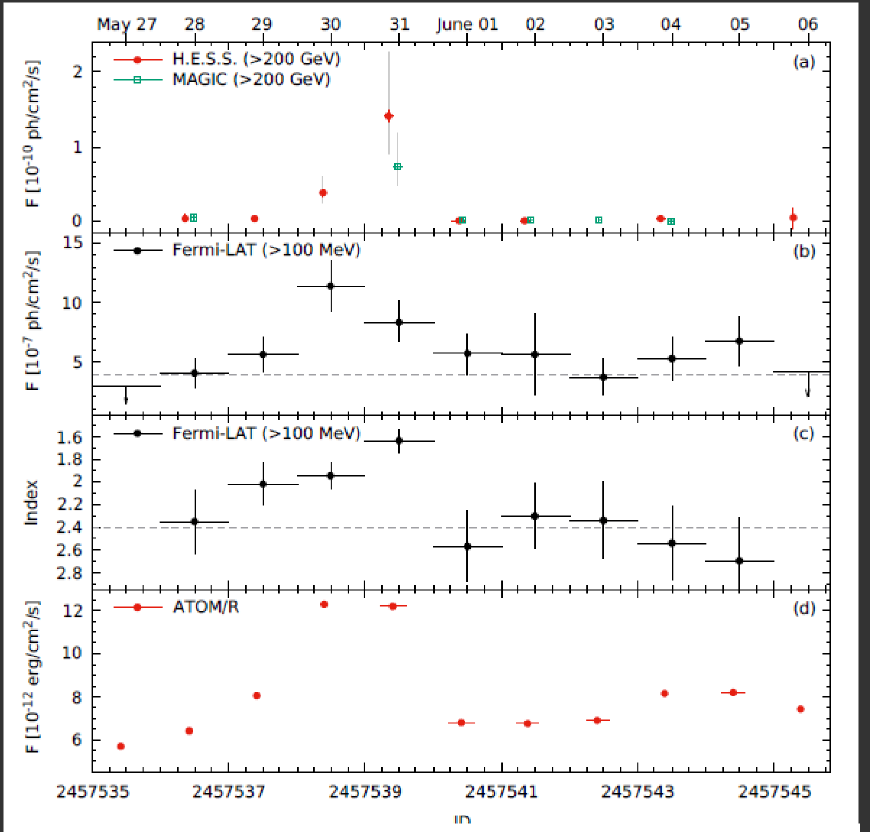
PKS1510-089 FSRQ   z=0.361

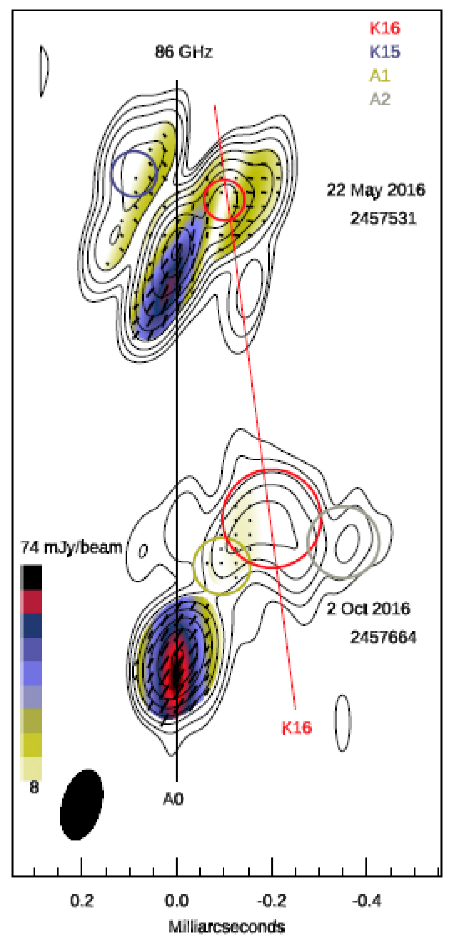
HESS, MAGIC , A&A 648, A25 (2021)

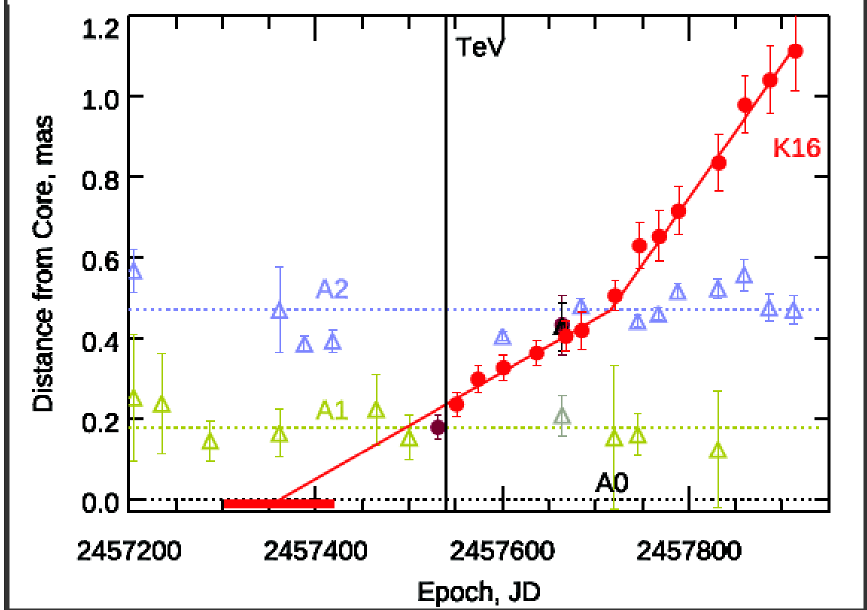
TeV & optical intra-day variation (May 2016)

HESS+MAGIC+Femri-LAT (gamma)
ATOM (optical R-band)
VLBA + GMVA (radio 43 &

- Rapid cessation of TeV and optical flaring on sub-day timescale
- GeV+TeV spectral curvature → absorption from EBL, not BLR.
- Gamma emission $>2.6R_{\_BLR}$ from BH
- Flare associated with rapidly moving radio knot K16?







Ojha etal 2010,
Mueller et al 2018

Studies of >100 AGN (southern)
+ some gamma-ray binaries

[northern - MOJAVE Lister etal 2018]

- Radio monitoring + VLBI >1 GHz
- X-ray to gamma-rays

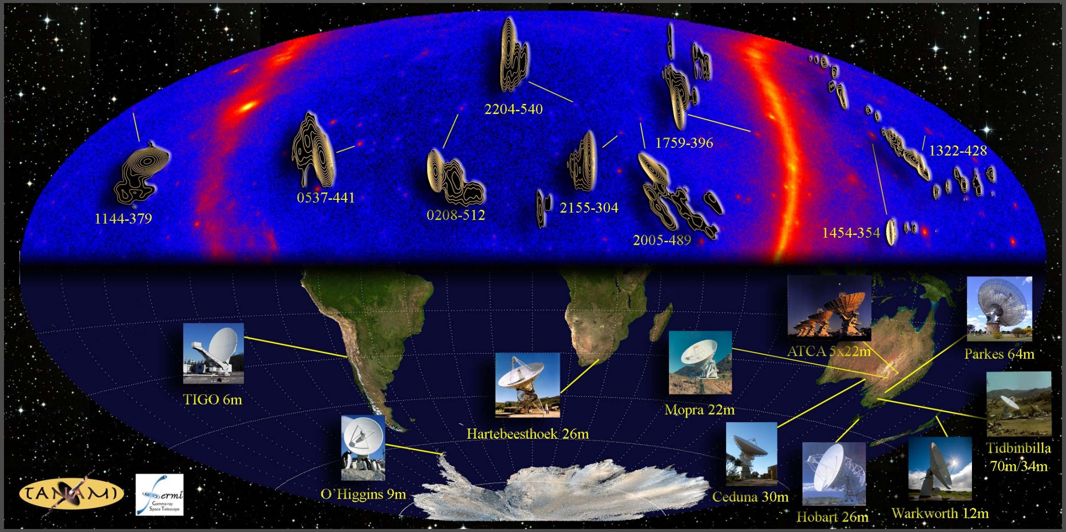
VLBI triggered by activity in Radio, X-ray and gamma-rays

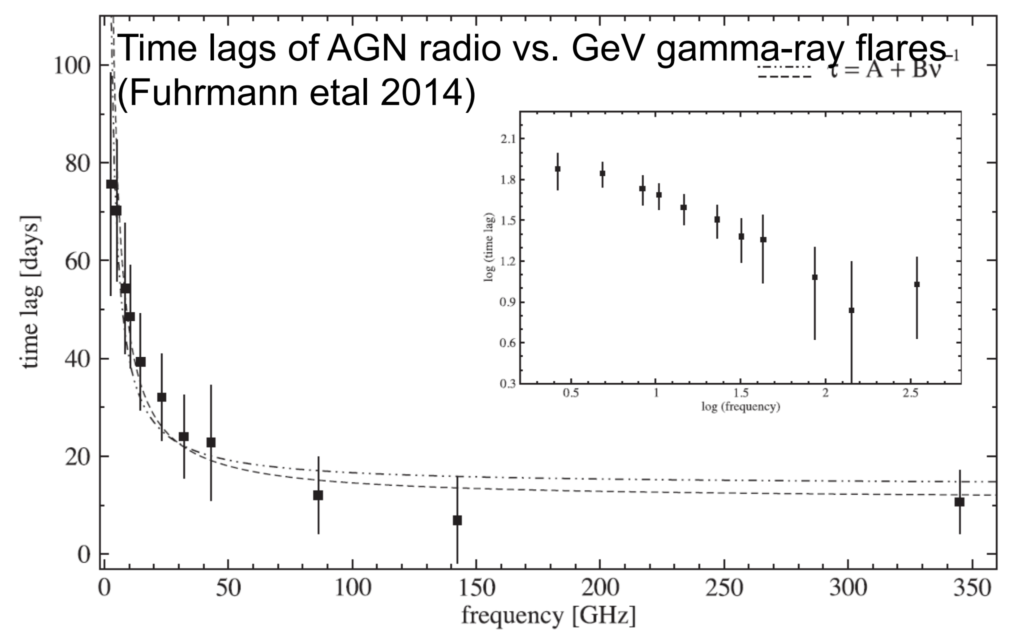
GeV gamma-rays with Fermi-LAT

More recently

→ AGN overlapping IceCube neutrino events

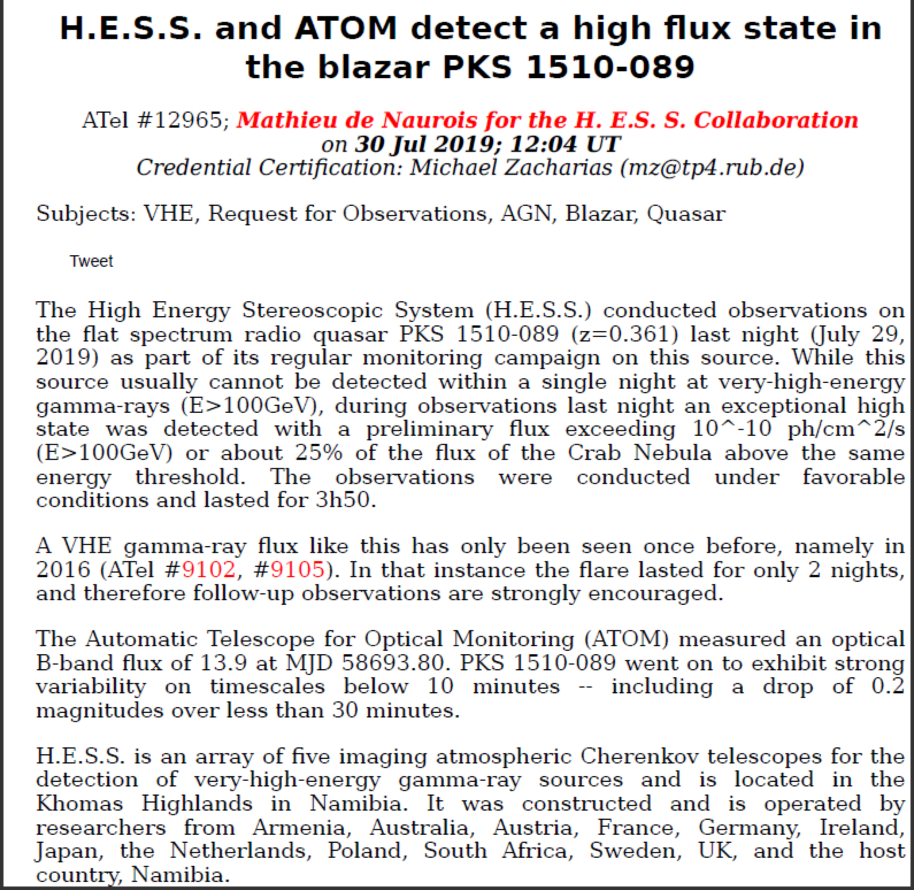
→ TeV-active AGN with HESS, and eventually, CTA.




Time lags of AGN radio vs. GeV gamma-ray flares
(Fuhrmann etal 2014)

High freq favoured for radio-gamma correlation (although there are exceptions!)..

Flat Spectrum Radio Quasar PKS1510-089 (z=0.361)



H.E.S.S. and ATOM detect a high flux state in the blazar PKS 1510-089

ATel #12965; **Mathieu de Naurois for the H. E.S. S. Collaboration**
on ***30 Jul 2019; 12:04 UT***
Credential Certification: Michael Zacharias (mz@tp4.rub.de)

Subjects: VHE, Request for Observations, AGN, Blazar, Quasar

Tweet

The High Energy Stereoscopic System (H.E.S.S.) conducted observations on the flat spectrum radio quasar PKS 1510-089 (z=0.361) last night (July 29, 2019) as part of its regular monitoring campaign on this source. While this source usually cannot be detected within a single night at very-high-energy gamma-rays (E>100GeV), during observations last night an exceptional high state was detected with a preliminary flux exceeding 10^-10 ph/cm^2/s (E>100GeV) or about 25% of the flux of the Crab Nebula above the same energy threshold. The observations were conducted under favorable conditions and lasted for 3h50.

A VHE gamma-ray flux like this has only been seen once before, namely in 2016 (ATel #9102, #9105). In that instance the flare lasted for only 2 nights, and therefore follow-up observations are strongly encouraged.

The Automatic Telescope for Optical Monitoring (ATOM) measured an optical B-band flux of 13.9 at MJD 58693.80. PKS 1510-089 went on to exhibit strong variability on timescales below 10 minutes -- including a drop of 0.2 magnitudes over less than 30 minutes.

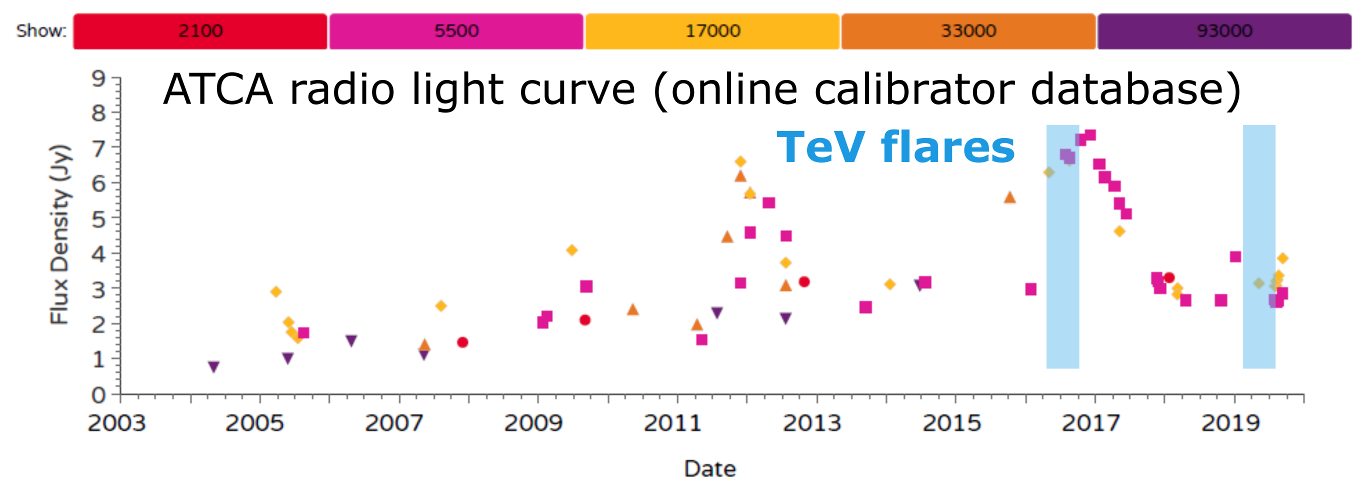
H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia. It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, South Africa, Sweden, UK, and the host country, Namibia.

- TeV/optical flare again in July 2019
- Previous TeV flare late 2016 with lag for ATCA radio (2-20 GHz) high state

→ waiting for another ATCA rise?

- mm-VLBI (Boston) obs > 40 GHz
  Probe initial jet outflows

→ mm-VLBI very important!
Australia (LBA ~20 GHz max)



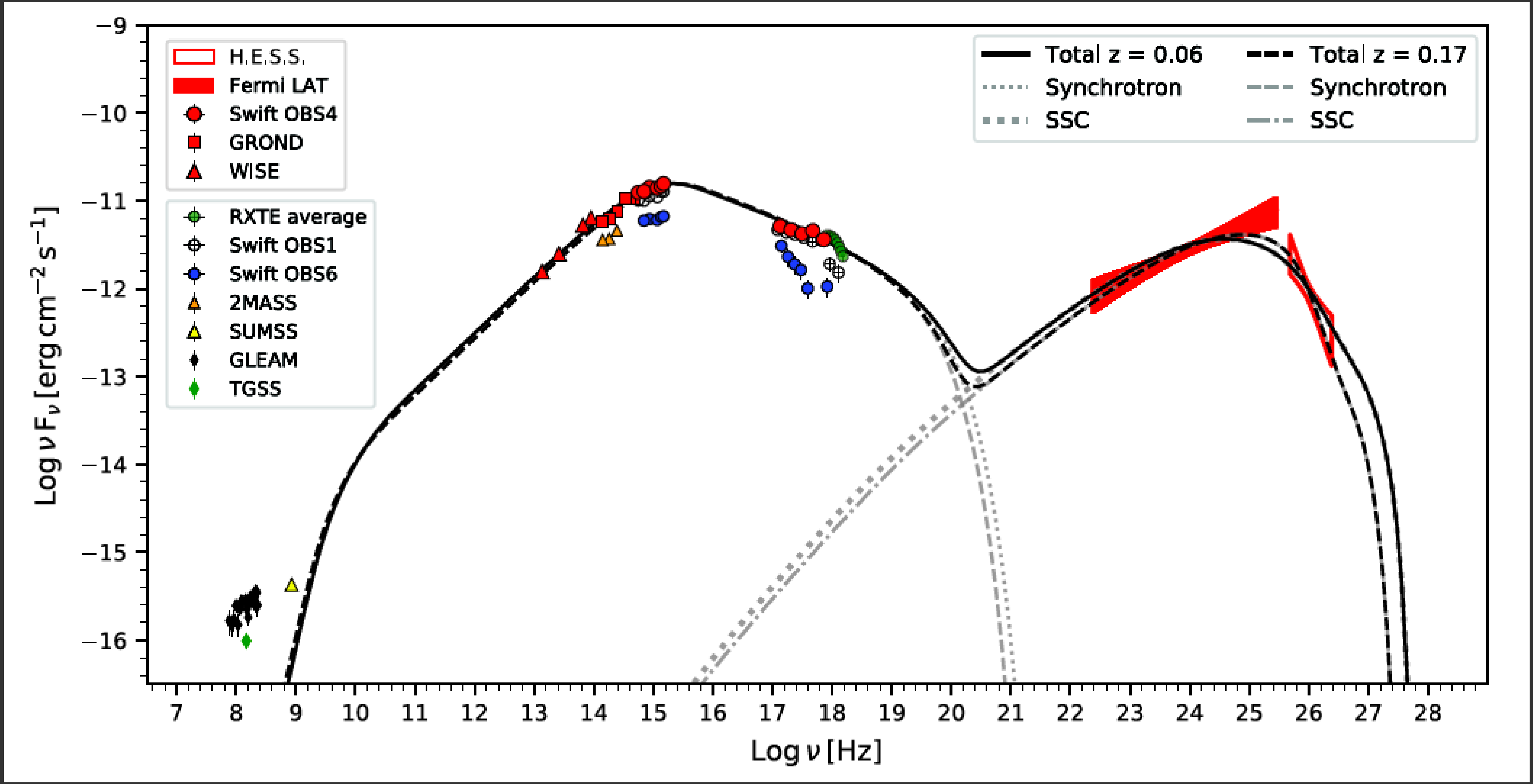
ATCA radio light curve (online calibrator database)

TeV flares

1ES2322-409 (z~0.174?)

HESS 2018

- Steady emission in GeV (Fermi-LAT) and TeV gammas (HESS)
- Variable in hard-Xrays (Swift)
- Visible down to low-freq radio (<100 MHz) MWA-GLEAM
- Model: inverse-Compton up scattering synchrotron photons (sync-self-Compton SSC) with a ‘one-zone’ electron population.
- Redshift uncertainty → different EBL absorption > 1 TeV!



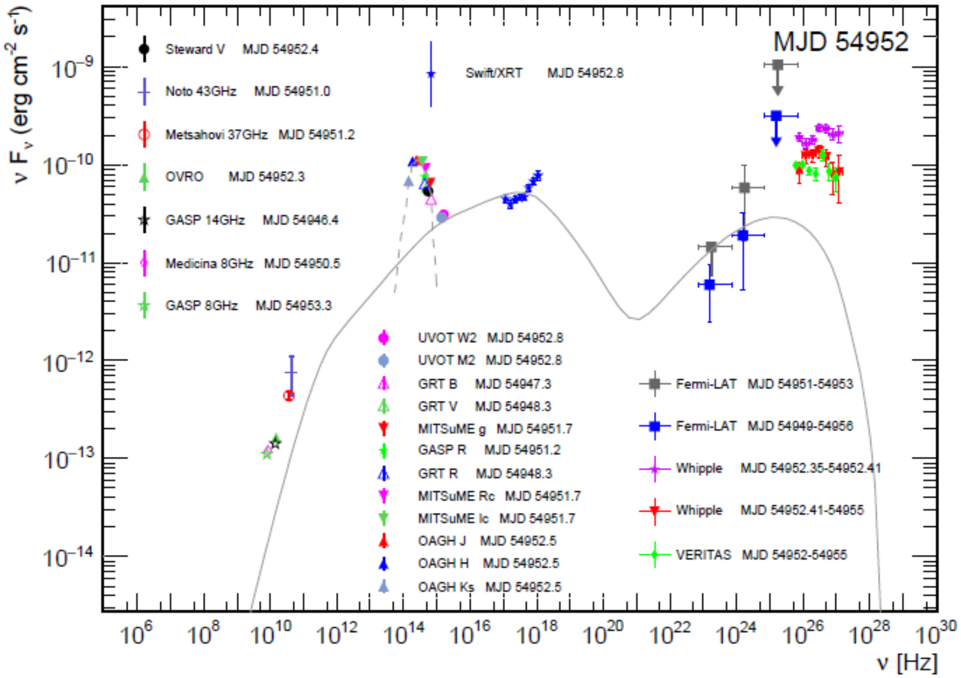
Mk 501 (z=0.034)

Ahnen etal 2016

- X-ray and gamma-ray flaring
- Strongest variability in gammas

- Sync-self-Compton (SSC) model

- Quiescent (one zone of electrons)
- Flares (2nd zone of electrons)



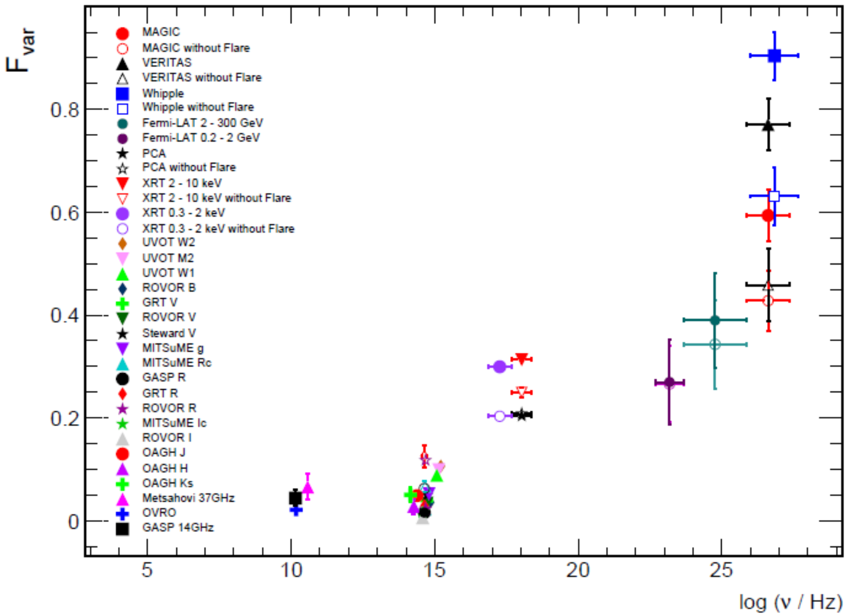
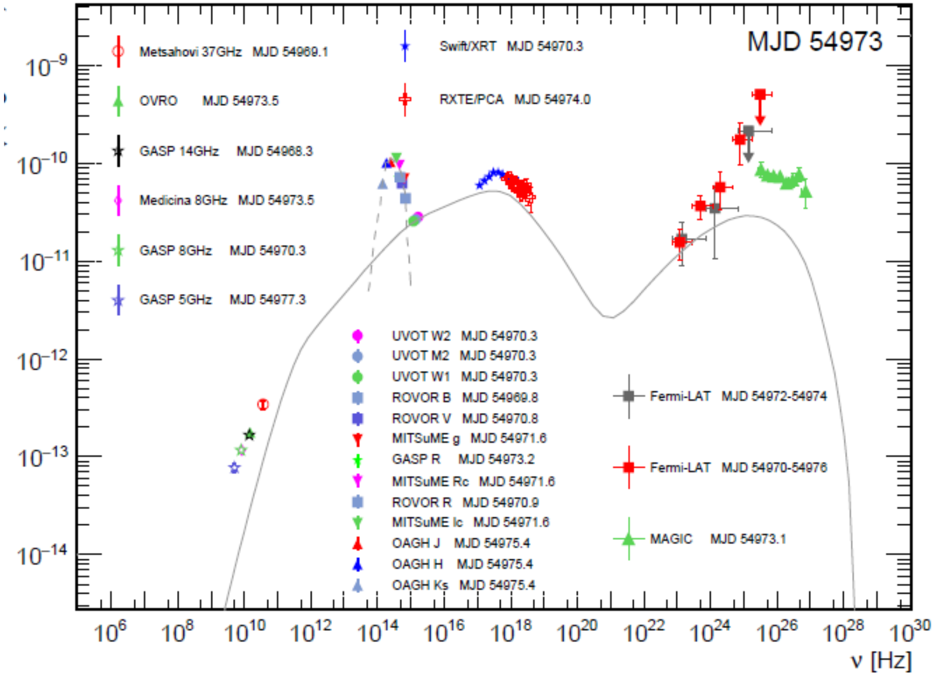
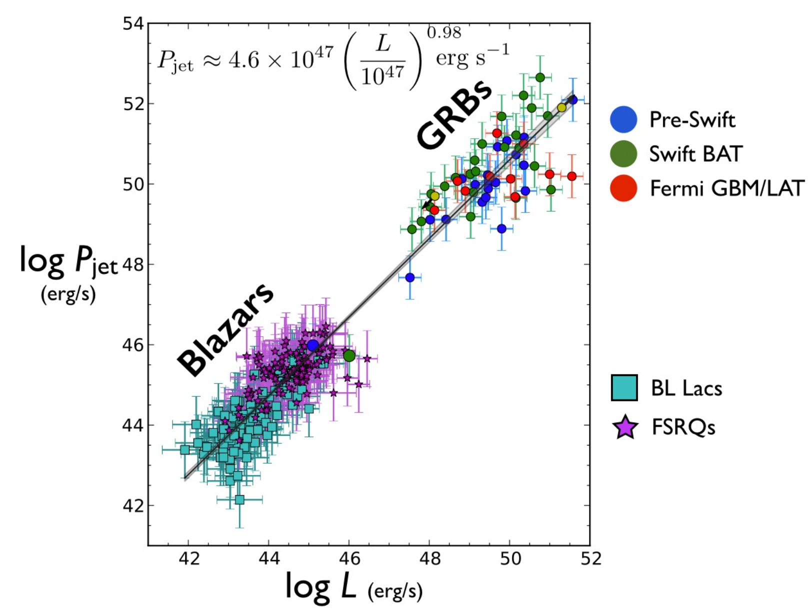


Fig. 7. Fractional variability at different frequencies. All the F_{var} values are computed with the single observations reported in Fig. 1, with the exception of the F_{var} values related to *Fermi*-LAT which were computed with 15-day and 30-day time intervals, and depicted with full circles and open light-coloured circles respectively. Open symbols for optical bands indicate the fractional variability after subtracting the host galaxy contribution, as determined in Nilsson et al. (2007). For the X-ray and the VHE γ-ray band, open markers depict the variability after removal of flaring episodes from the light curves as described in the text.

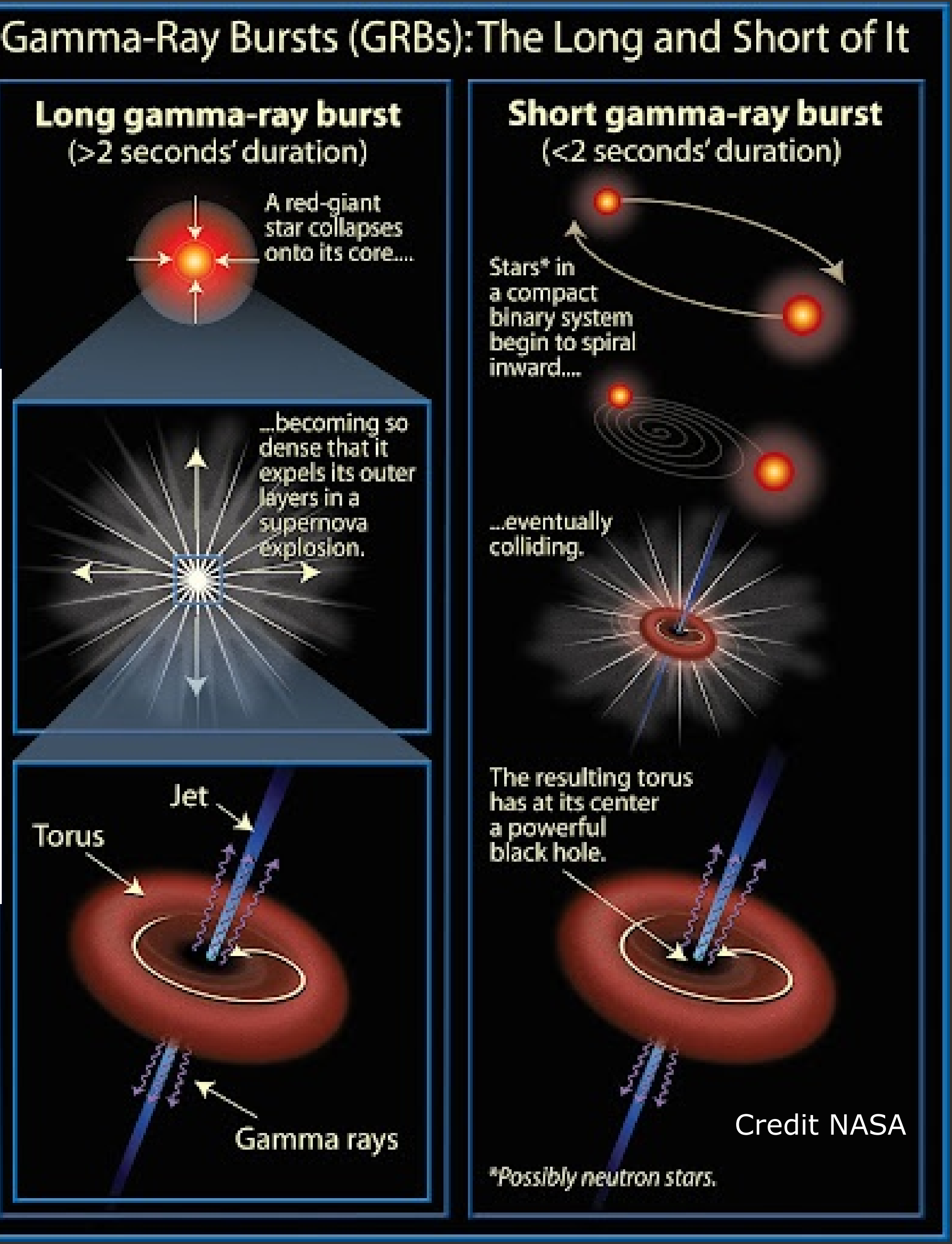


Gamma Ray Bursts

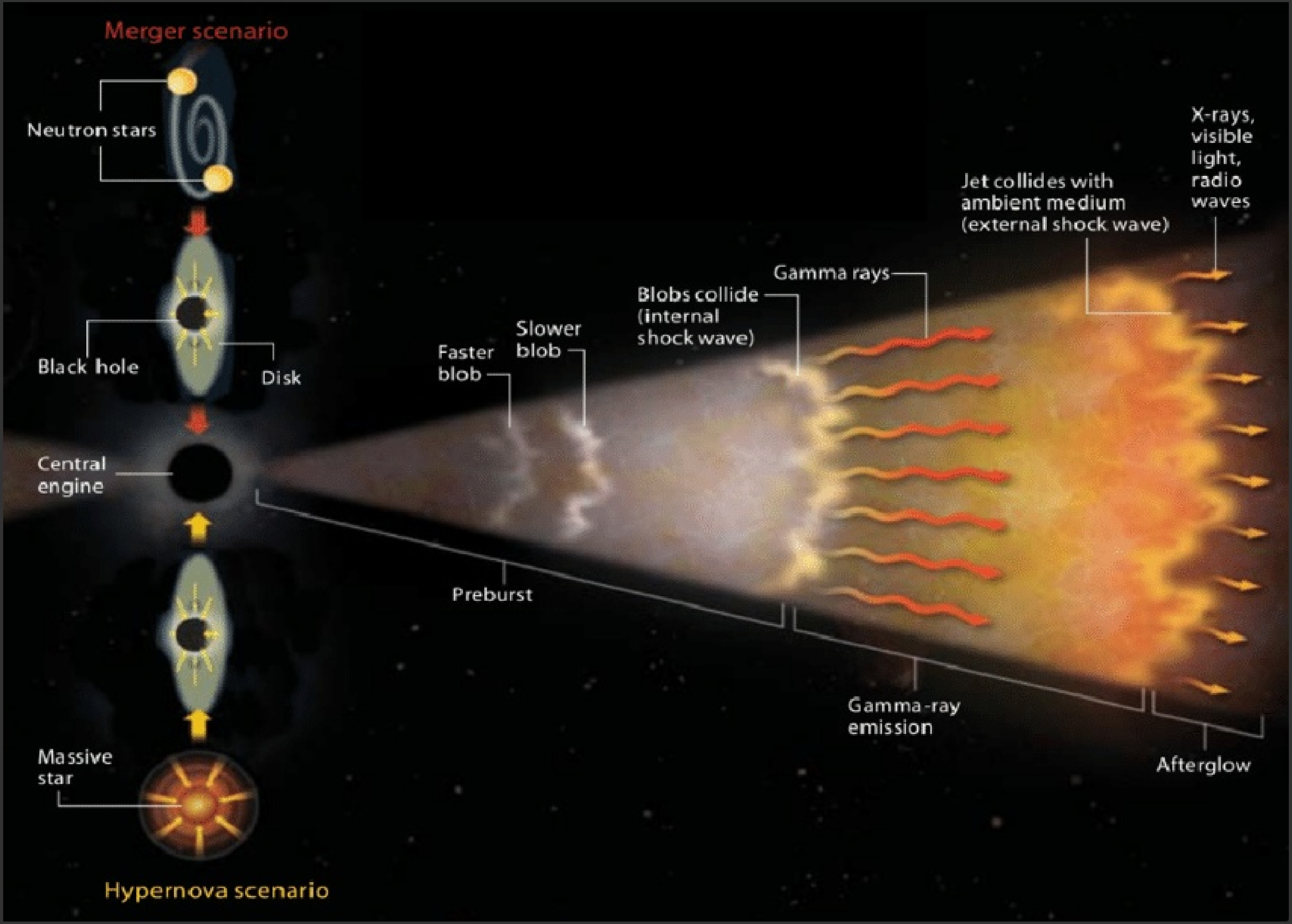
Jet power P (kinetic) > 10^4 times more powerful than in AGN



Jet kinetic power P vs. gamma-ray luminosity L (Nemmen et al. 2012)



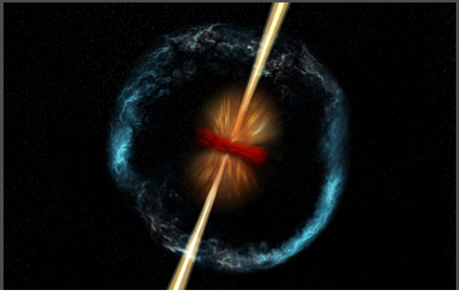
Credit NASA

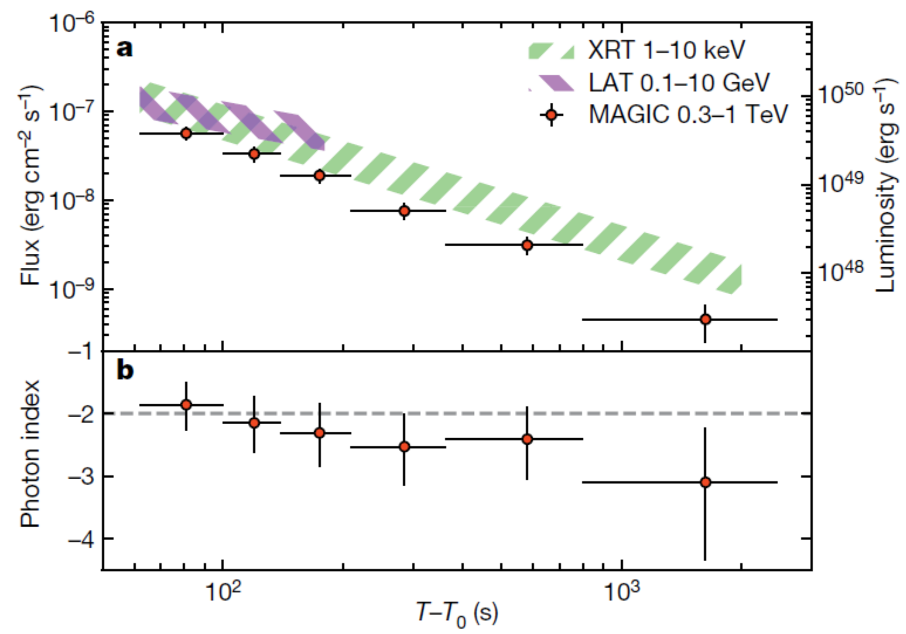

Merger scenario
Neutron stars
Black hole
Disk
Central engine
Massive star
Hypernova scenario
Faster blob
Slower blob
Preburst
Blobs collide (internal shock wave)
Gamma rays
Gamma-ray emission
Jet collides with ambient medium (external shock wave)
X-rays, visible light, radio waves
Afterglow

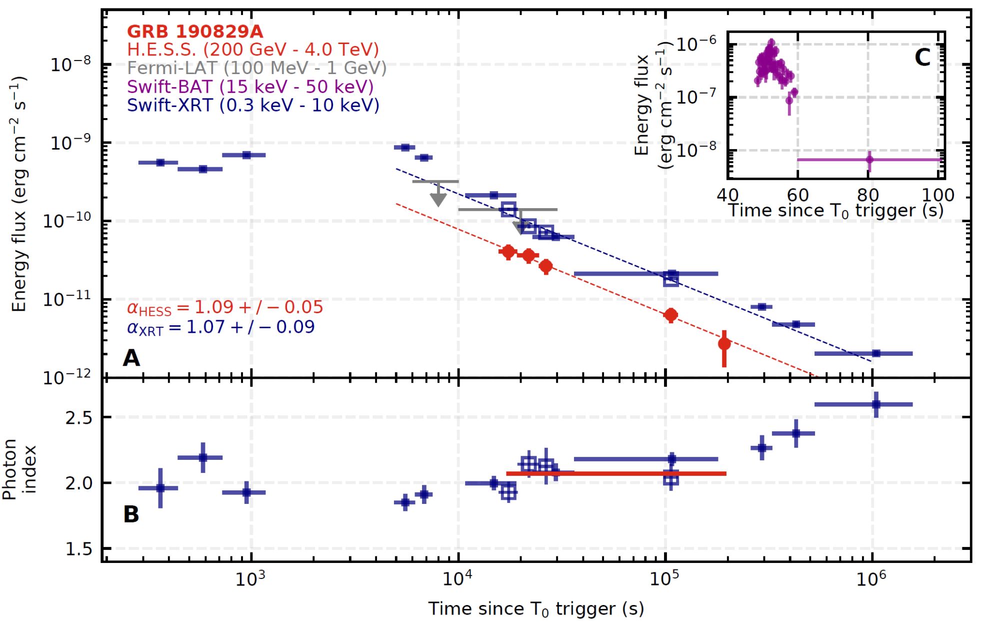
Piron 2015

TeV Gamma Ray Bursts : A New Era Begins

(MAGIC 2019, 2021, HESS 2019, 2021)







- Three Long GRBs GRB180720B, GRB190114C, GRB1900829A

  z=0.653 0.424 0.079

- One Short GRB GRB160821B (z=0.162) marginal!

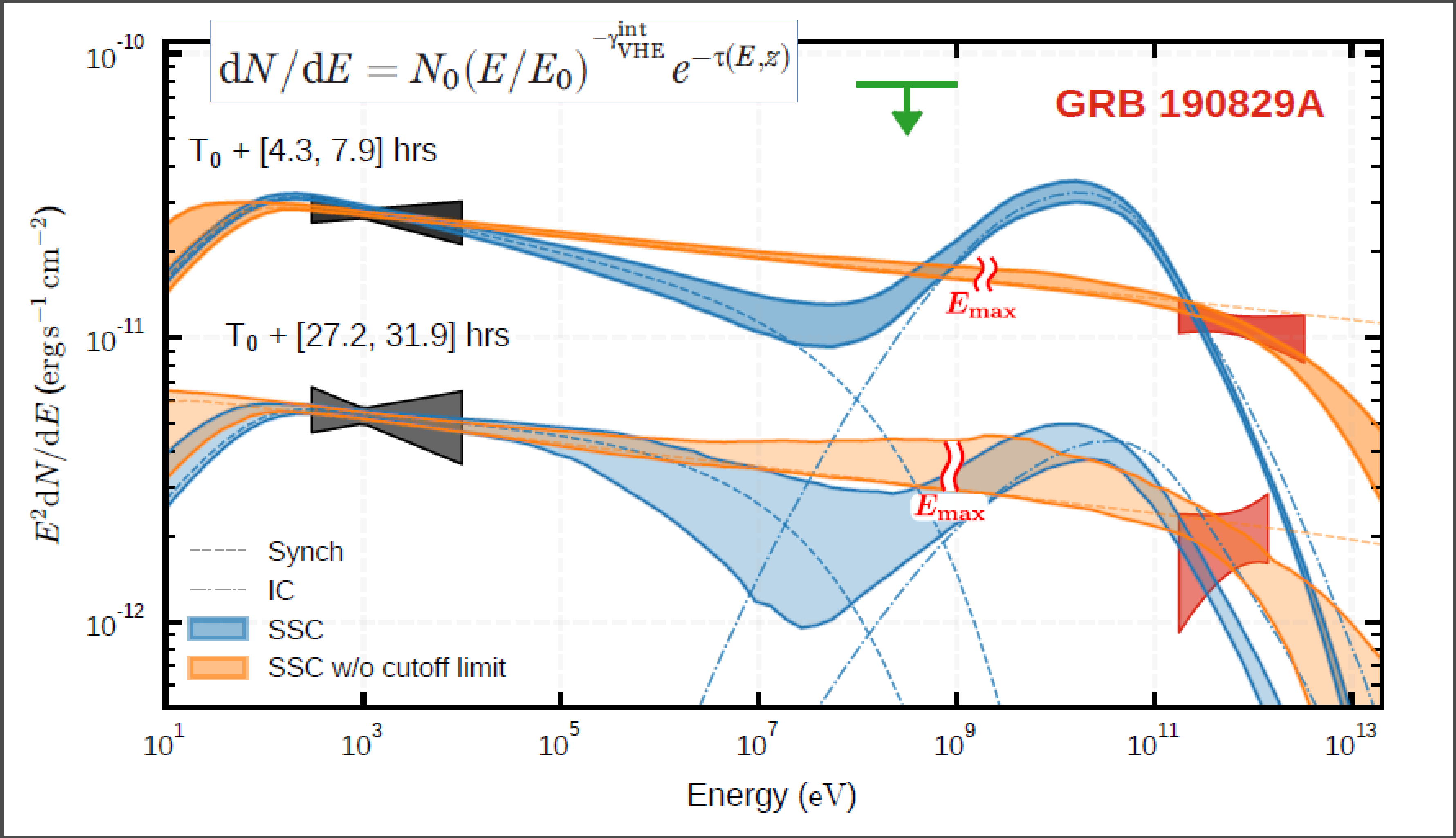
- GRB190114C seen at >300 GeV at low elevation during moonlight!
- GRB1900829A seen T+2 days

  > 1000’s photons > 50 GeV → gamma-ray spectra on hourly timescales

- Rapid radio follow-up in place (HESS+ATCA; e.g. Anderson etal 2022 submitted)

HESS 2021

GRB1900829A Afterglow X-ray (Swift) and TeV (HESS)



- ‘Hard’ TeV spectra with HESS suggest direct connection with X-ray
- SSC model with ‘no-cutoff’ energy preferred
  - → Electrons reaching >PeV energies in GRB jet!
  - → Challenges models of particle acceleration in jets (B ~ few G expected)

TeV Gamma Ray Bursts: The Extraordinary GRB221009A

- Originally classified as X-ray + optical transient Swift J1913.1+1946
- Later confirmed as a GRB with Fermi GBM + LAT detections up to 99 GeV

- Seen by >10 facilities ($z=0.151$)

→ One of brightest ever GRBs

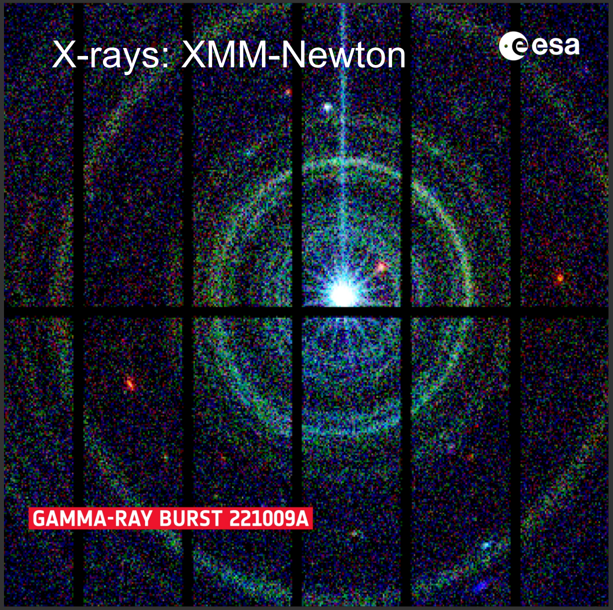
- LHASSO detection GCN32677

  E>500 GeV $>100\sigma$

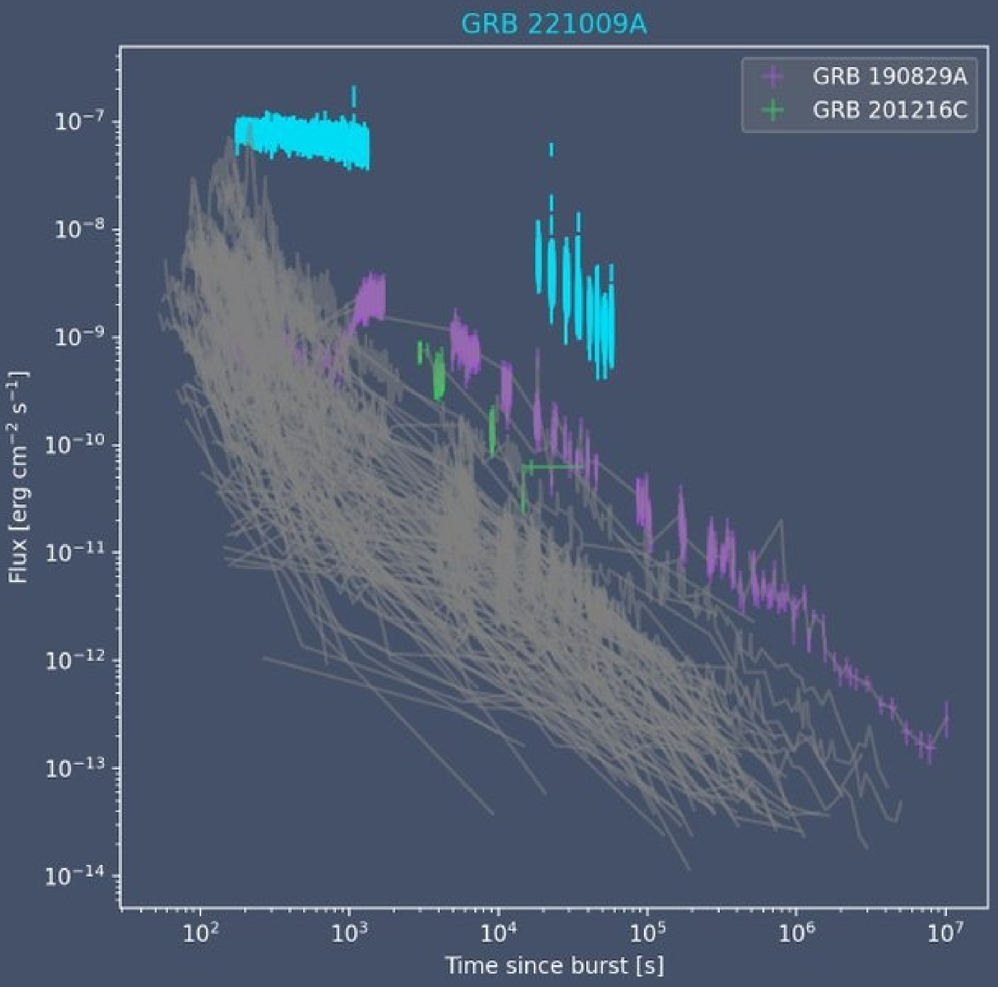
  Emax = 18 TeV

→ Axions or Neutrino origin?

(7 arXiv papers)

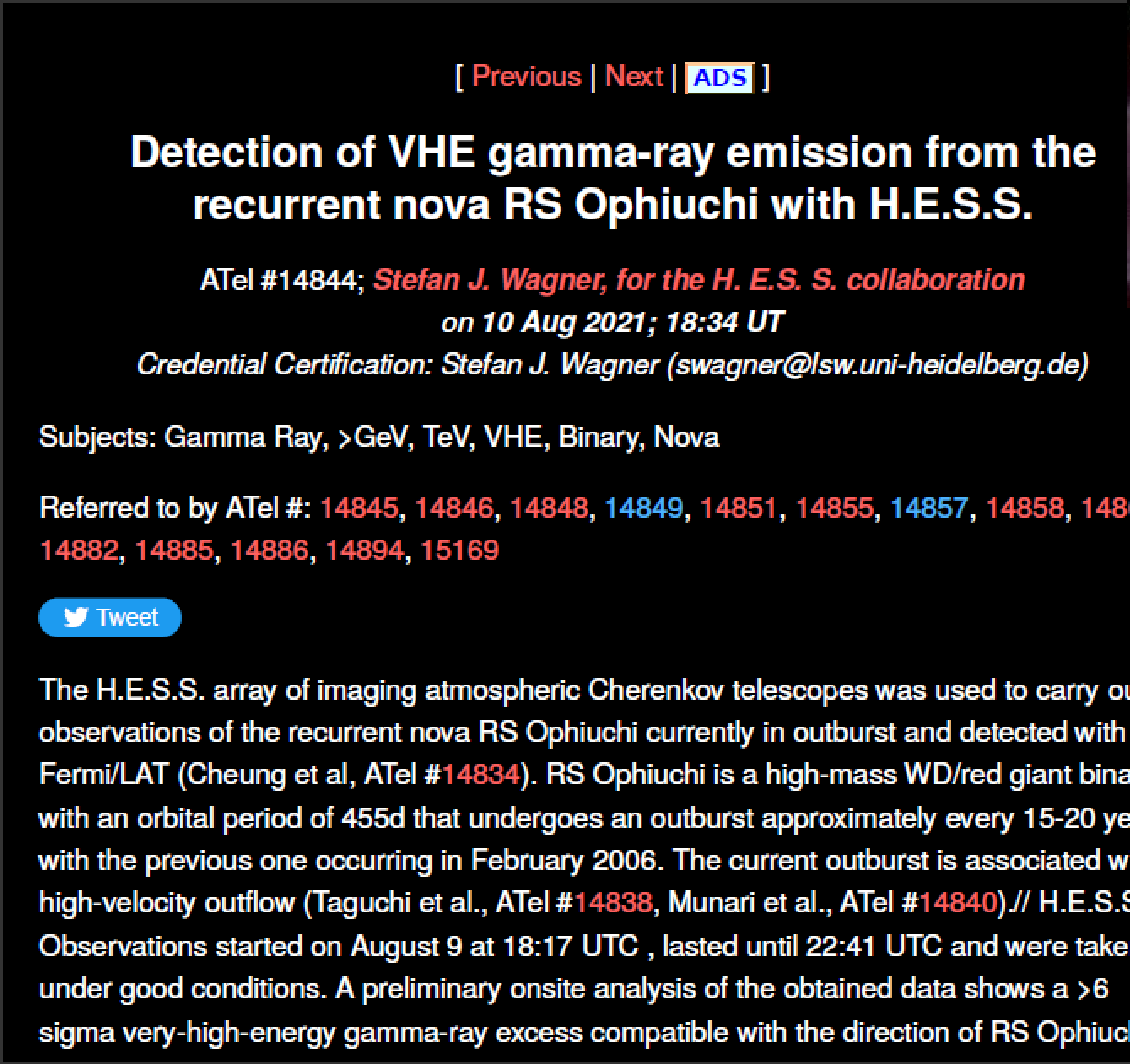


https://twitter.com/astrocolibri/status/1579478412678561792



Novae are now also TeV sources!

RS-Oph recurrent nova



Detection of VHE gamma-ray emission from the recurrent nova RS Ophiuchi with H.E.S.S.

ATel #14844; *Stefan J. Wagner, for the H. E.S. S. collaboration*
on 10 Aug 2021; 18:34 UT
Credential Certification: Stefan J. Wagner (swagner@lsw.uni-heidelberg.de)

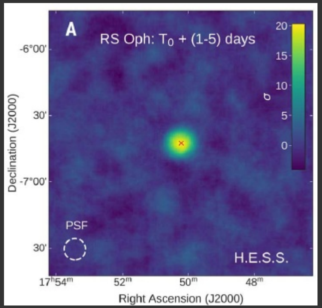
Subjects: Gamma Ray, >GeV, TeV, VHE, Binary, Nova

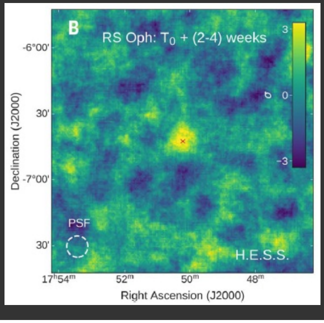
Referred to by ATel #: 14845, 14846, 14848, 14849, 14851, 14855, 14857, 14858, 14860, 14882, 14885, 14886, 14894, 15169

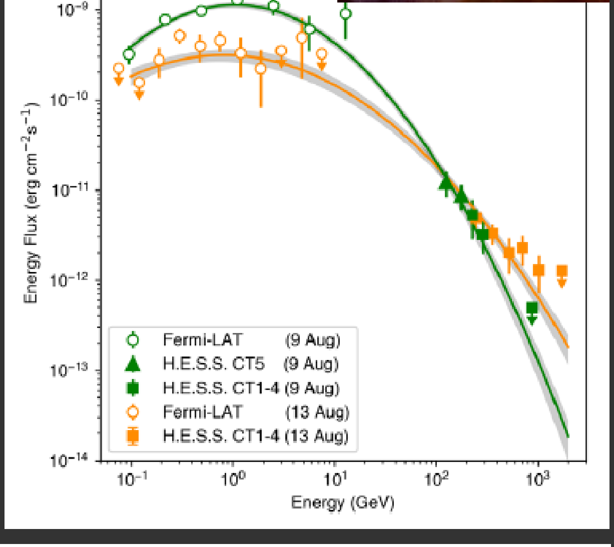
The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out observations of the recurrent nova RS Ophiuchi currently in outburst and detected with Fermi/LAT (Cheung et al, ATel #14834). RS Ophiuchi is a high-mass WD/red giant binary with an orbital period of 455d that undergoes an outburst approximately every 15-20 years, with the previous one occurring in February 2006. The current outburst is associated with a high-velocity outflow (Taguchi et al., ATel #14838, Munari et al., ATel #14840).// H.E.S.S. Observations started on August 9 at 18:17 UTC , lasted until 22:41 UTC and were taken under good conditions. A preliminary onsite analysis of the obtained data shows a >6 sigma very-high-energy gamma-ray excess compatible with the direction of RS Ophiuchi.

RS-Oph Recurrent Nova – First Galactic TeV Transient

HESS, Science 376, 6588 (2022)

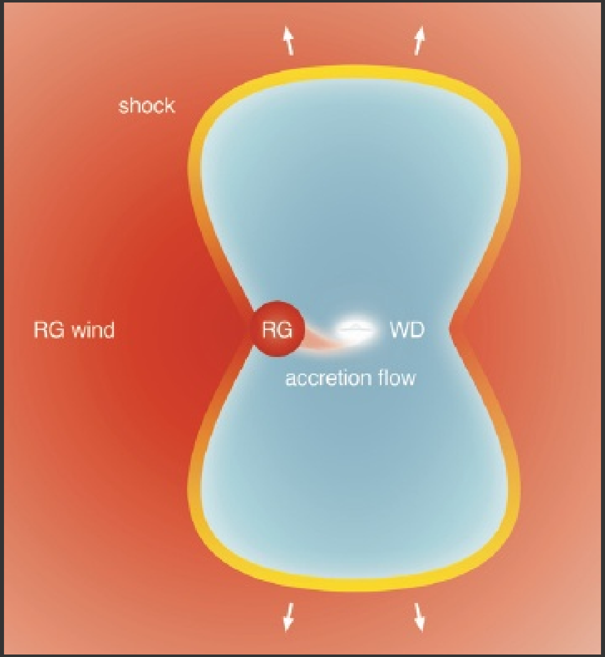


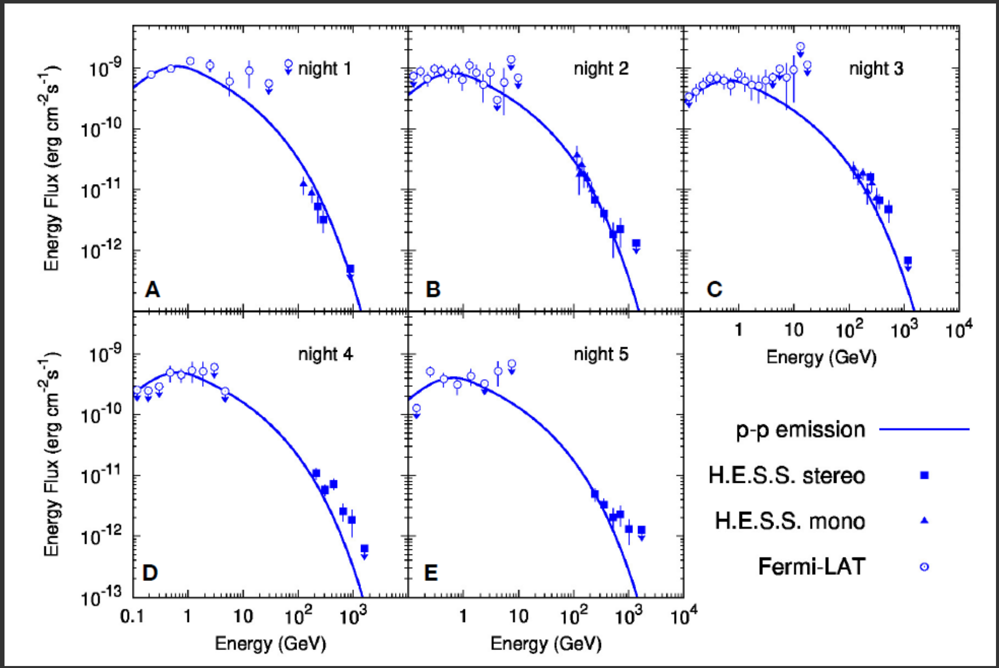


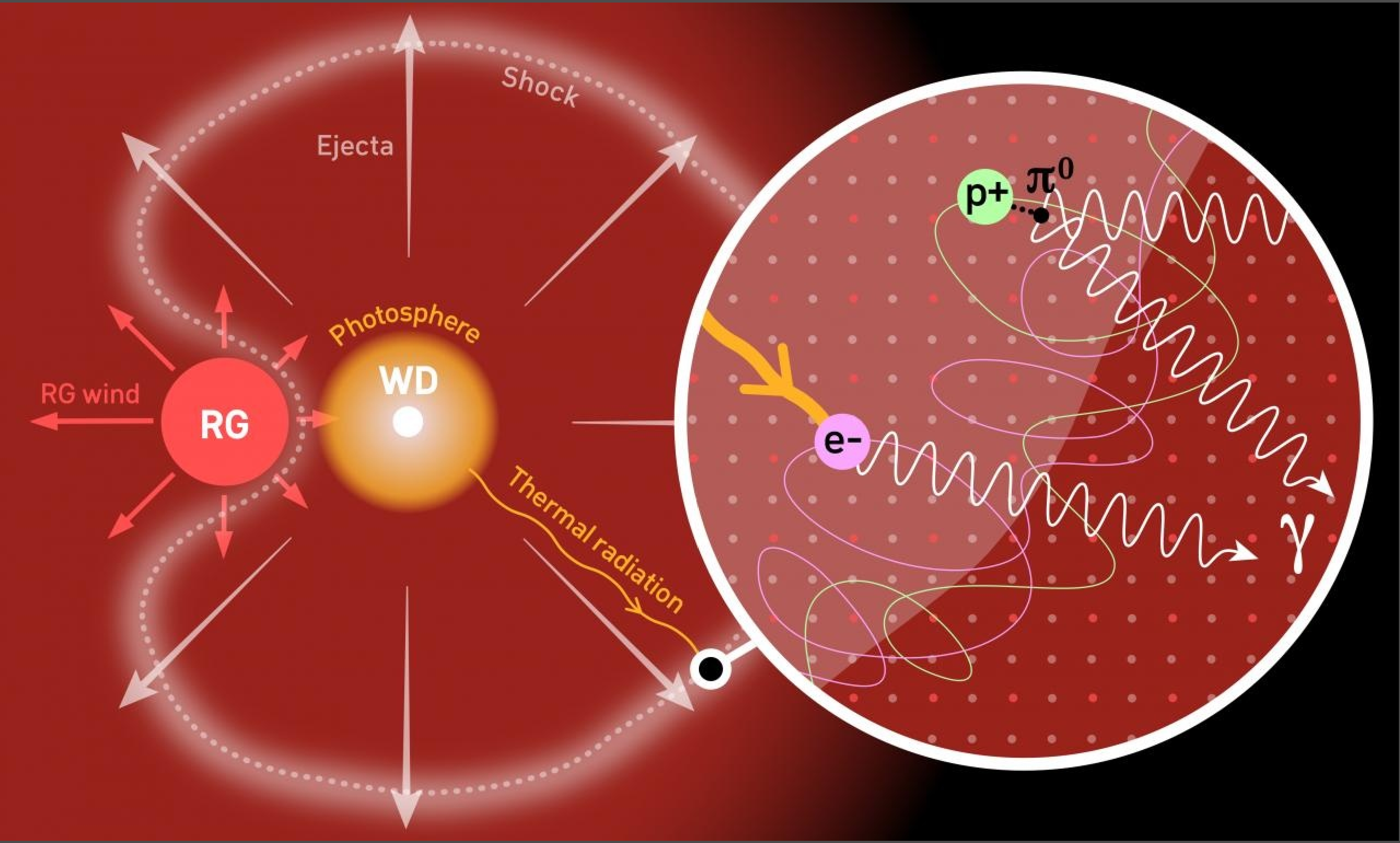


- WD and massive companion RG star
- Flaring via thermonuclear detonation and particle acceleration.
- GeV emission from Fermi-LAT
- HESS obs. of 2021 outburst triggered by optical flare (prev. outburst ~9-26 yrs)
- >6sigma/day in first 5 nights with HESS

  (also seen by MAGIC Acciari etal 2022)
- Hadronic model preferred.

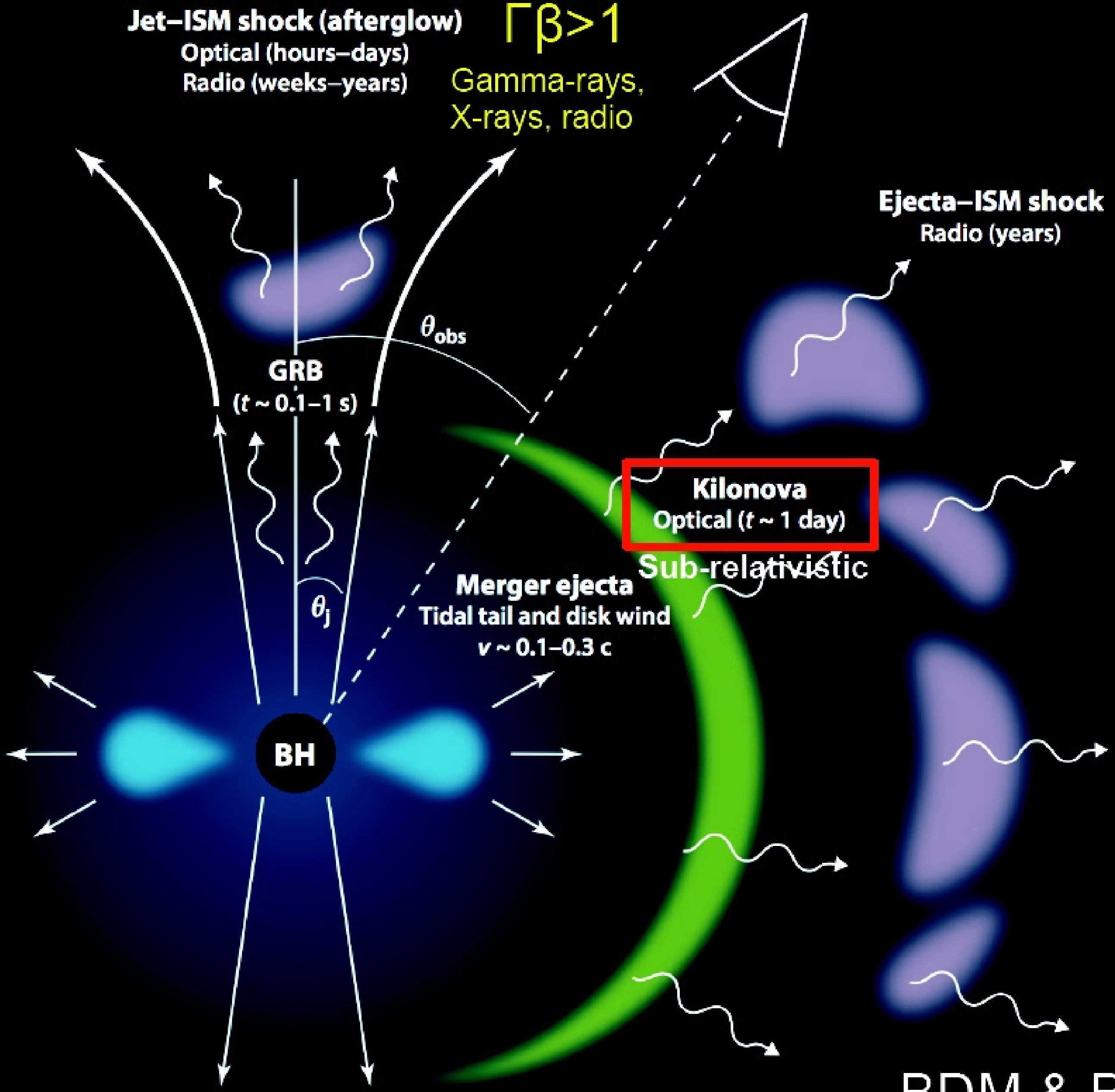






MAGIC Collab. (Science 2022)

Electromagnetic Counterparts of NS Mergers



BDM & Berger 12

GW170817

- HESS prompt follow-up
  (onlu upper limit)
  HESS, ApJ Lett 850, L22 (2017)

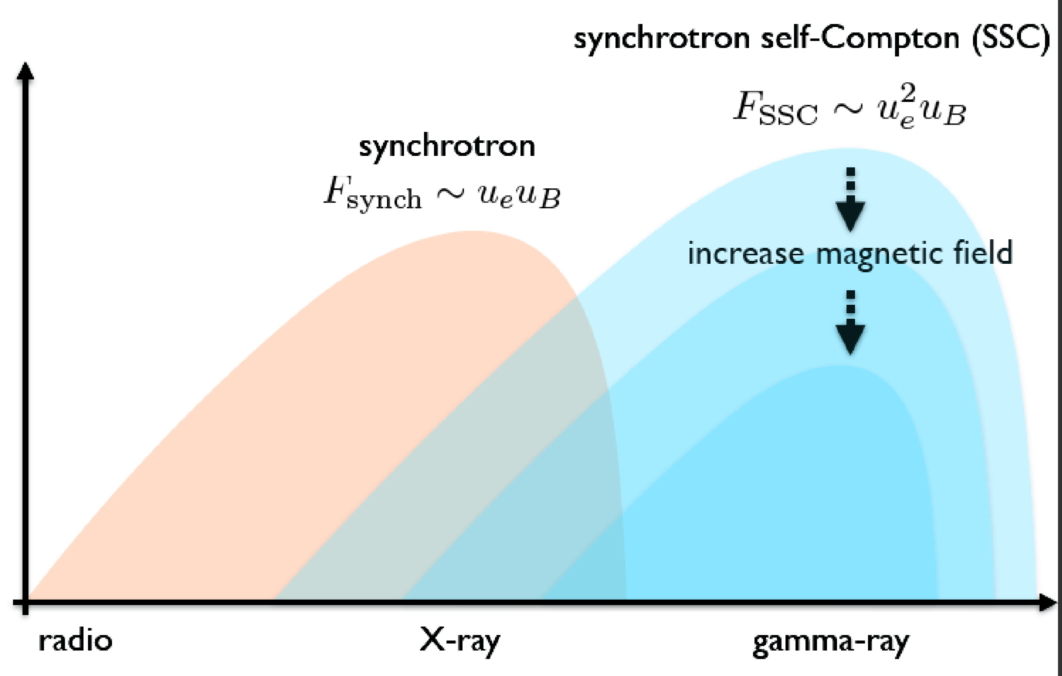
But after ~100 days, expect strong X-ray synchrotron emission – seen with Chandra
Troja et al (2017)

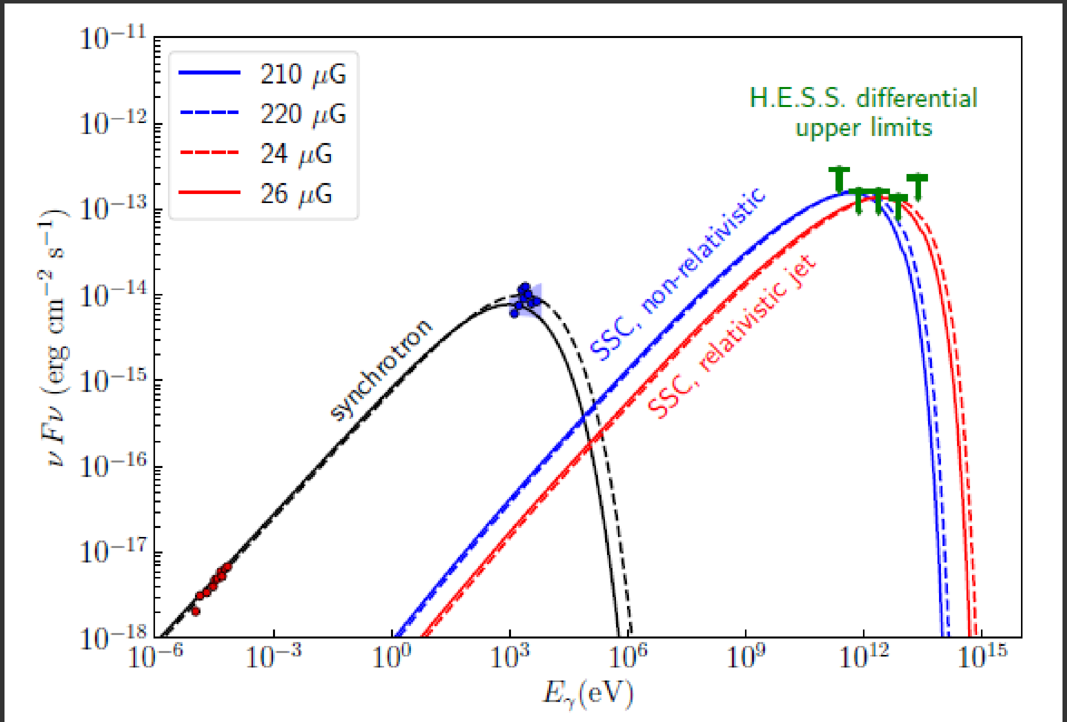
→ TeV inverse-Compton!

Synch-self-Compton (SSC) in fact.

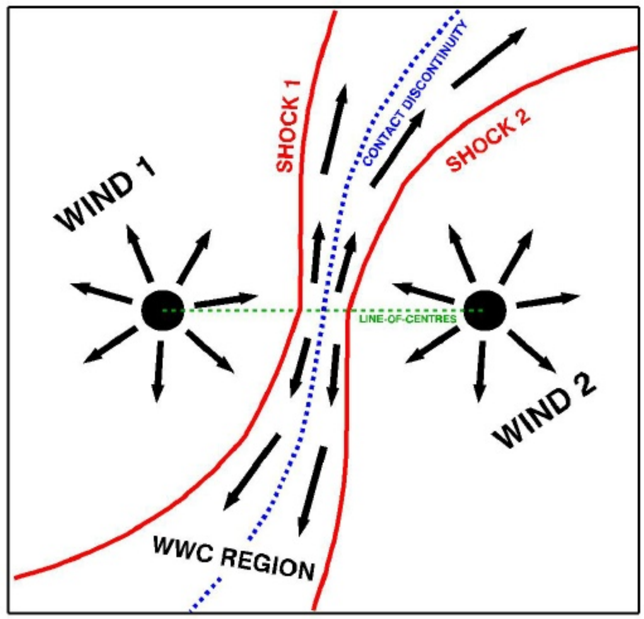
Isotropic non-relativistic wind or relativistic jet (observed slightly off-axis at 20 degrees)
(Takami etal 2014, Rodrigues etal 2019, HESS 2020)

→ Constrain B-field with HESS
HESS, ApJLett 894, L16 (2020)



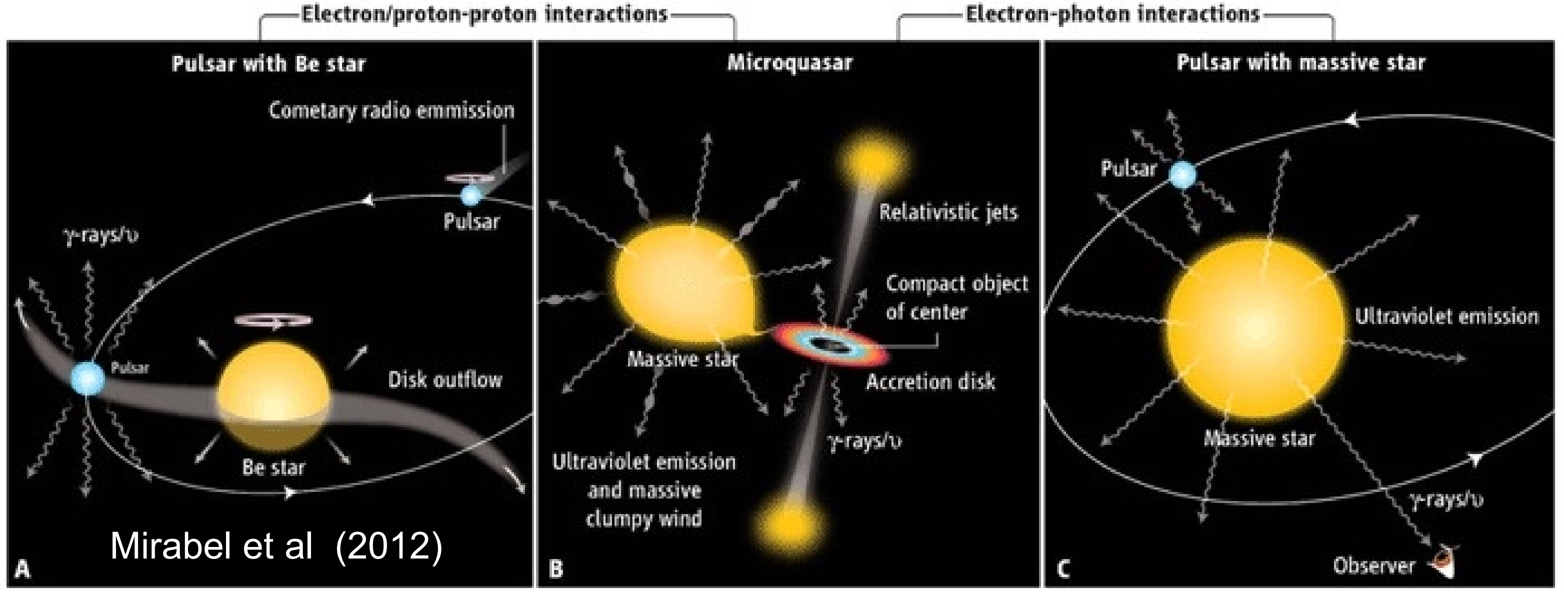


Colliding Stellar Winds



Johnstone et al (2015)

‘Compact’ Binary System (NS/BH + stellar)



Mirabel et al (2012)

Eta-Carina

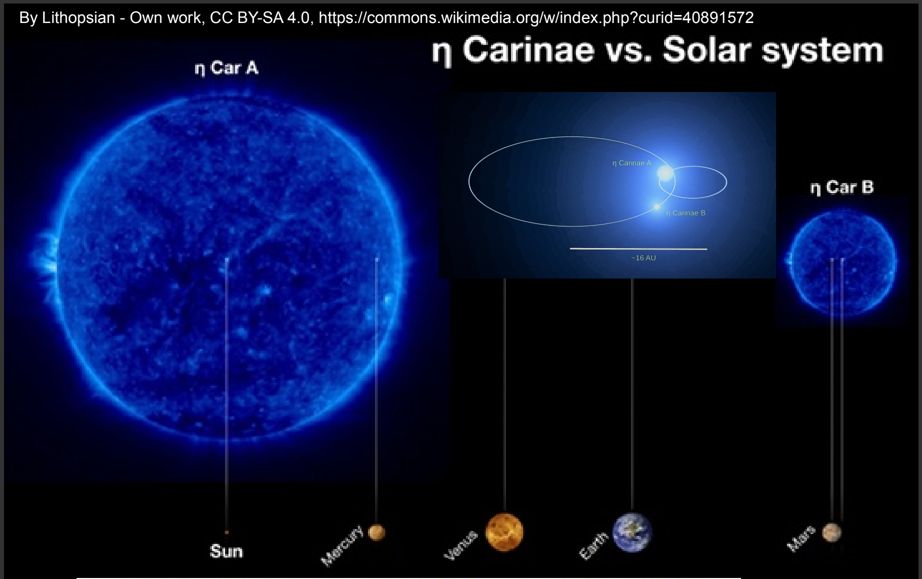
HESS, A&A 635, A167 (2020)

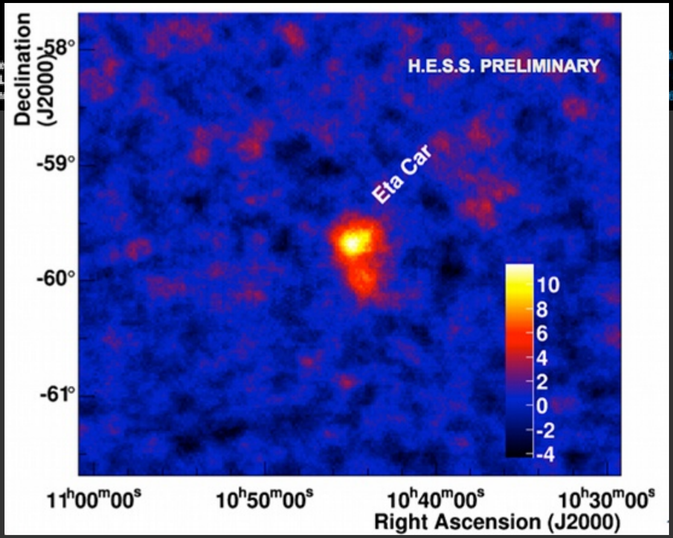
- Colliding wind **stellar** binary system (LBV + O/B); 5.54 yr orbit
- TeV emission just prior and around periastron

LMC P3

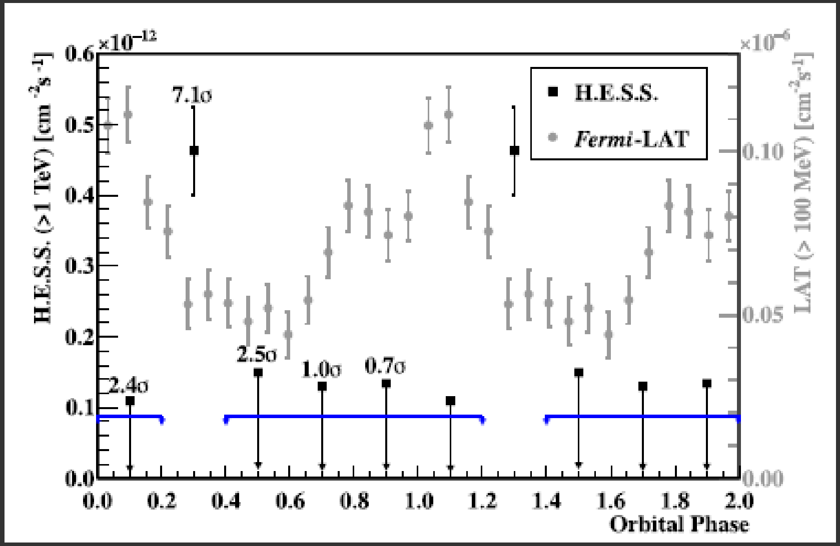
- O5 III and NS (BH also possible)
- Discovered by Fermi-LAT (GeV)
- TeV emission at phase ~ 0.3
- Most luminous gamma-ray binary.

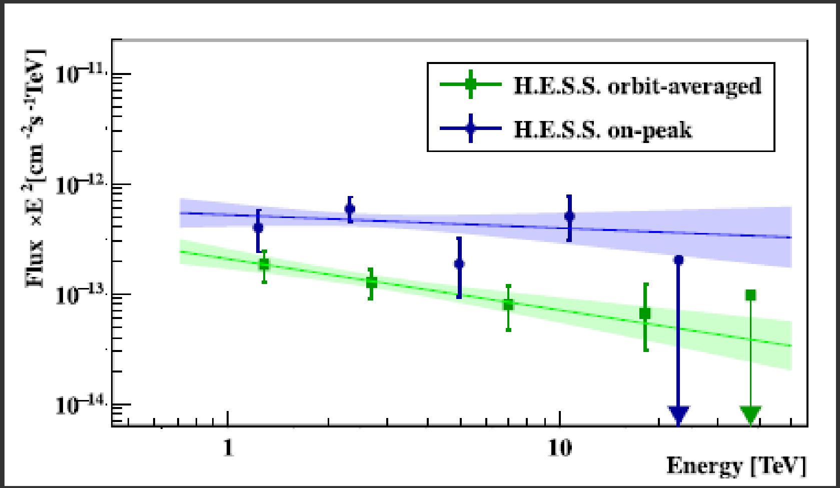
By Lithopsian - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=40891572





HESS, A&A 610, L17 (2018)





Some Other Transients Studies with HESS, MAGIC...

SGR/Magnetar flares

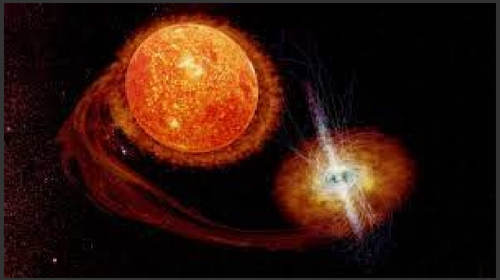
HESS, ApJ 919, 106 (2021)

- Triggers from Swift-BAT, Fermi-LAT
- SGR1935+2154 'Cluster' of X-ray bursts in 2021 with radio bursts
  → First links to repeating FRBs!

HESS, MNRAS 515, 1365 (2022)

Fast Radio Bursts

- Triggers from UTMOST & Parkes-SUPERB
- Campaigns on three repeating FRBs with MeerKAT, eMERLIN, & Swift



X-Ray Binaries (Low-Mass)

HESS, MNRAS 517, 4736 (2021)

- MAXI J1820+070 2018 outburst
- HESS, MAGIC, VERITAS campaign
  → constraints on B field and emission region

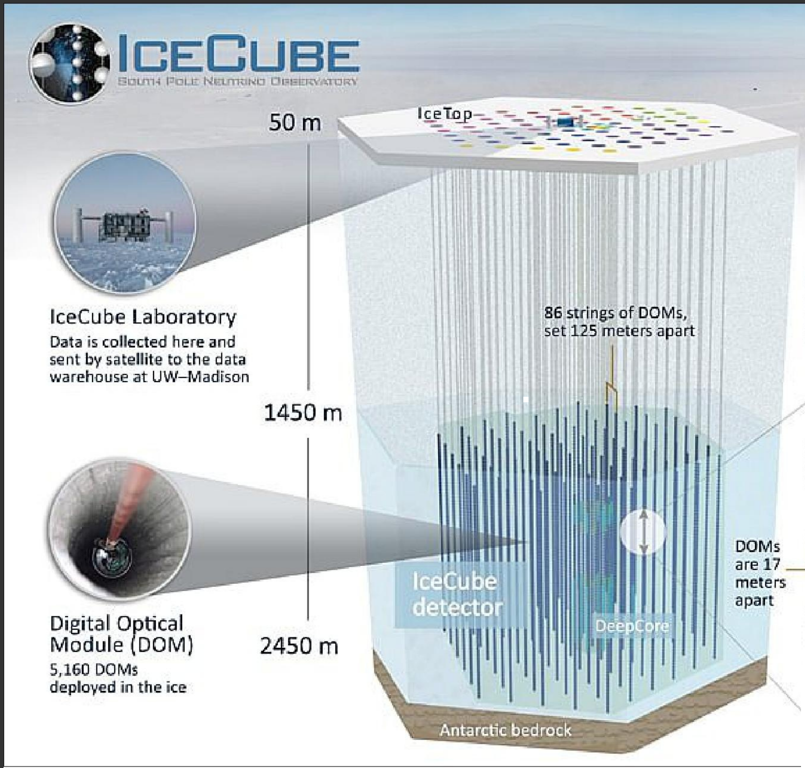
HESS, MNRAS 626, A57 (2019)

Nearby Core-Collapse Supernovae

- Ten SN 4 to 54 Mpc distant (incl. SN2016adj in CenA)
- Constraints on mass loss rates fewx10^{-5} to 10^{-3} Msun/yr

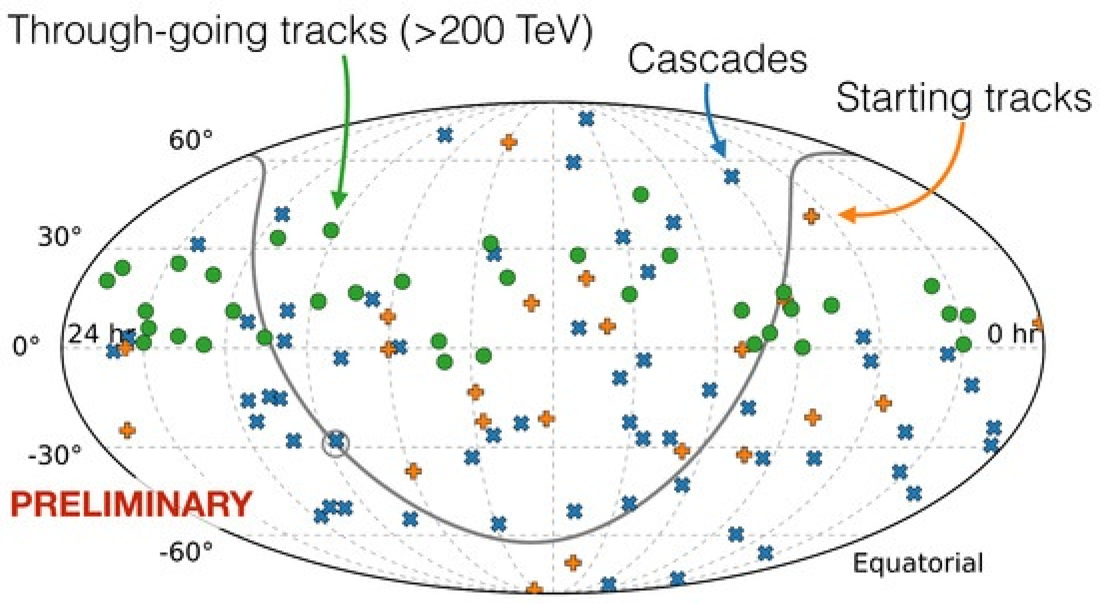
Real-Time (TeV-PeV) Neutrino Alerts from IceCube

https://icecube.wisc.edu/science/real-time-alerts/
https://gcn.gsfc.nasa.gov/amon_icecube_gold_bronze_events.html



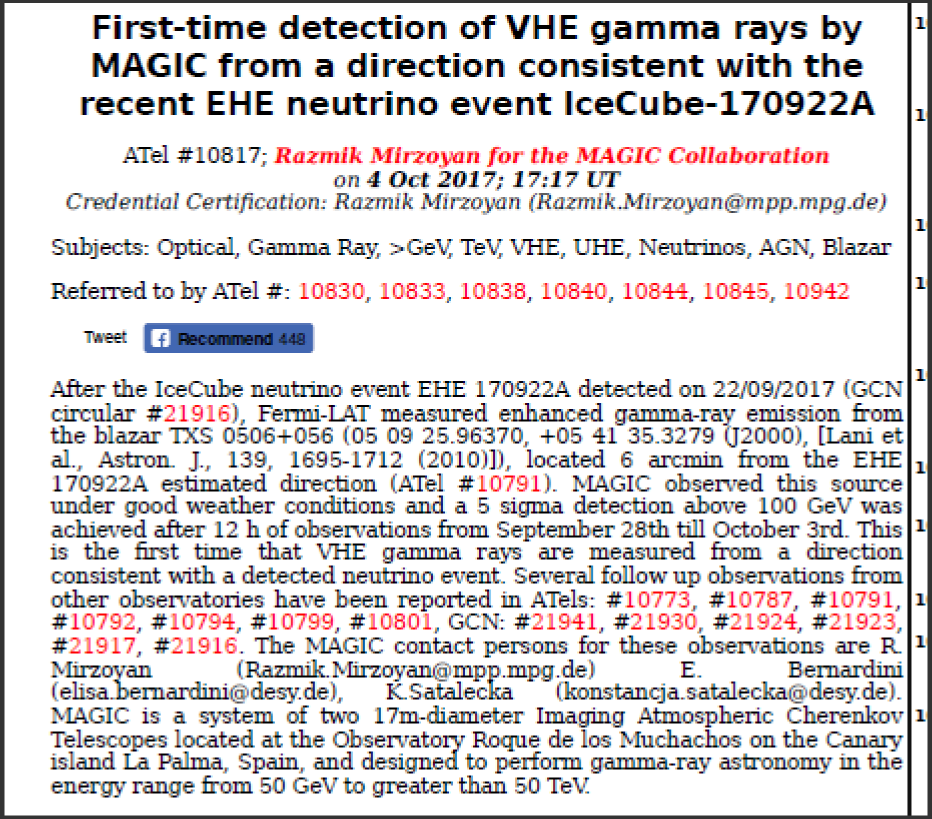
Neutrino alerts from IceCube trigger many follow-ups from radio to TeV gamma rays.

Relmann 2019



Neutrino Event (IceCube EHE 170922A)

- TeV flare (5σ) from MAGIC
ATel #10817



First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

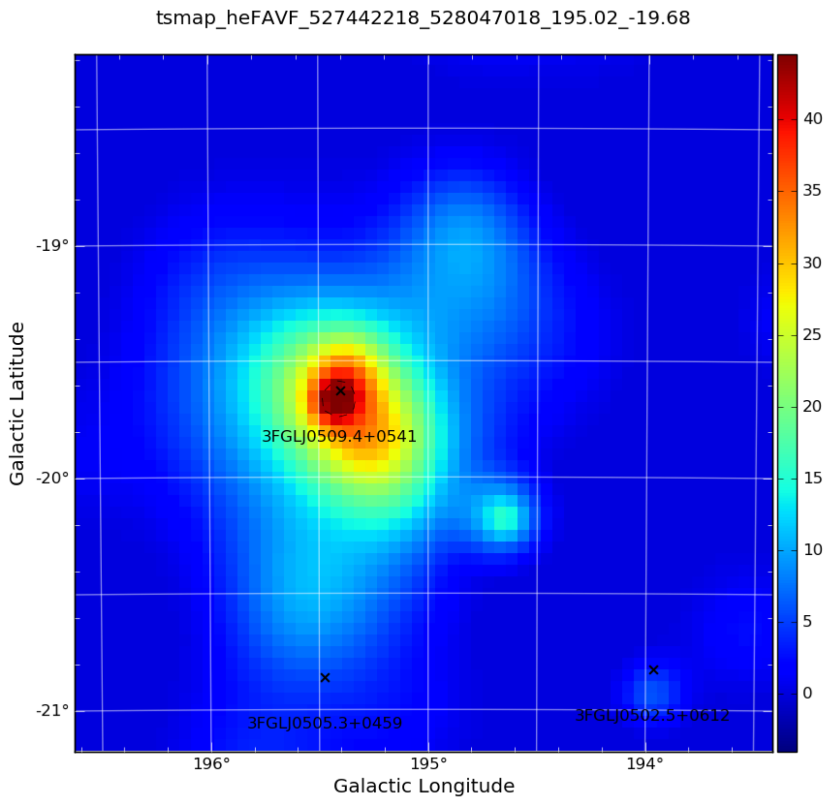
ATel #10817; ***Razmik Mirzoyan for the MAGIC Collaboration***
on ***4 Oct 2017; 17:17 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

Referred to by ATel #: 10830, 10833, 10838, 10840, 10844, 10845, 10942

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi-LAT measured enhanced gamma-ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of observations from September 28th till October 3rd. This is the first time that VHE gamma rays are measured from a direction consistent with a detected neutrino event. Several follow up observations from other observatories have been reported in ATels: #10773, #10787, #10791, #10792, #10794, #10799, #10801, GCN: #21941, #21930, #21924, #21923, #21917, #21916. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) E. Bernardini (elisa.bernardini@desy.de), K.Satalecka (konstancja.satalecka@desy.de). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

- GeV flare from Fermi-LAT
ATel #10791
(0.8-300 GeV TS map)



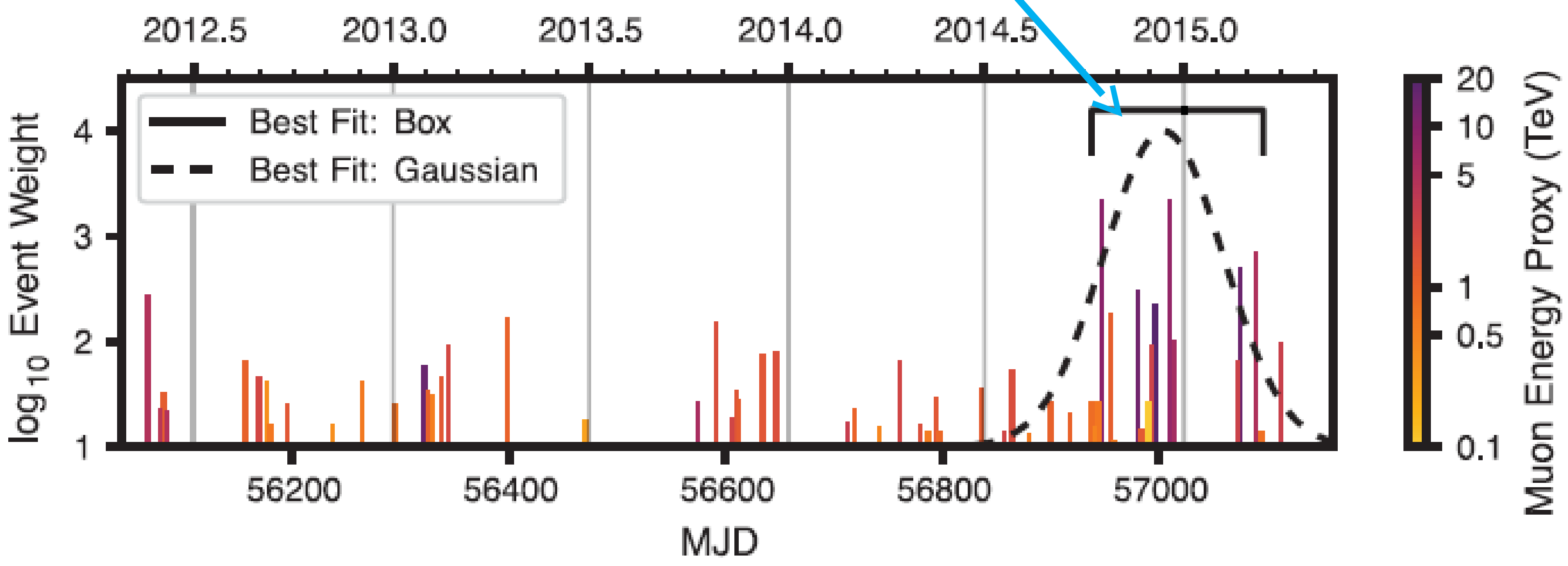
→ Linked to AGN TXS 0506+056

→ Six-month-long cluster of neutrinos 2015/15 at 3.5 sigma

IceCube ++ Science (2017)

Also, looking back in time: there was a burst of neutrinos over 6 months back in 2014/2015

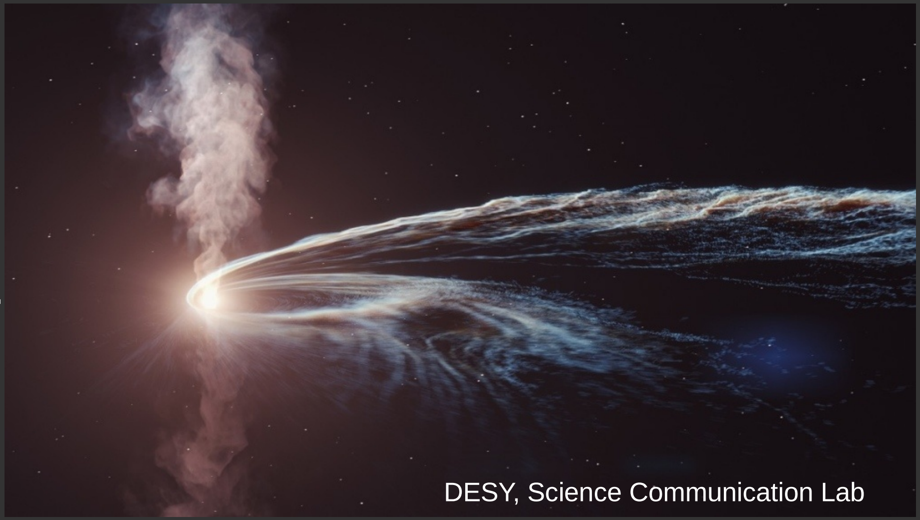
Neutrino time-clustering significance: 3.5 sigma



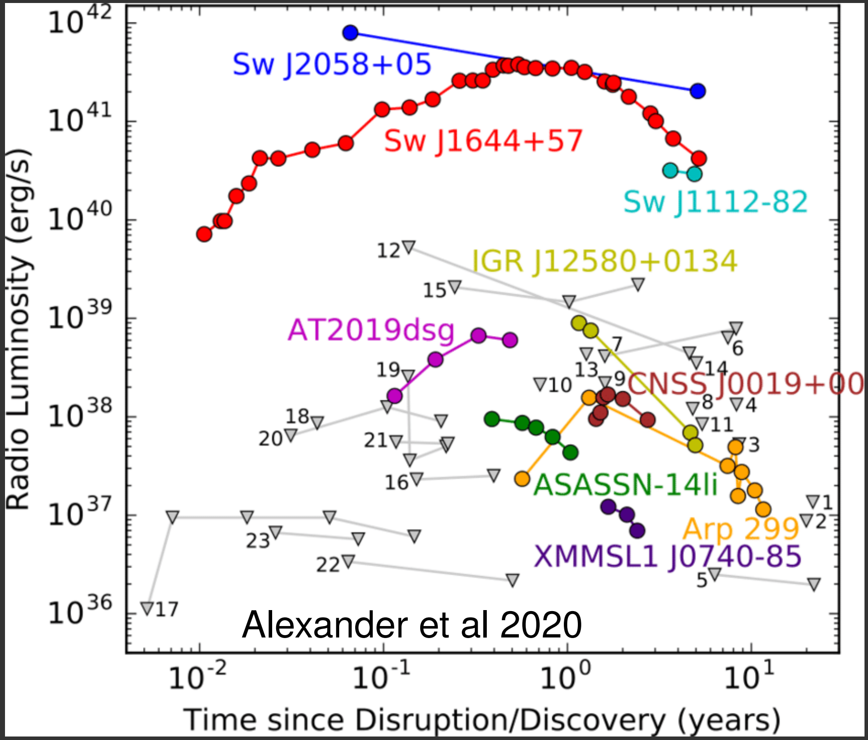
Tidal Disruption Events (TDEs) – stars crushed by massive BHs

- Radio, optical, X-ray emission
- Some have jets
- Neutrino events linked to two very bright TDEs AT2019dsg, AT2019fdr

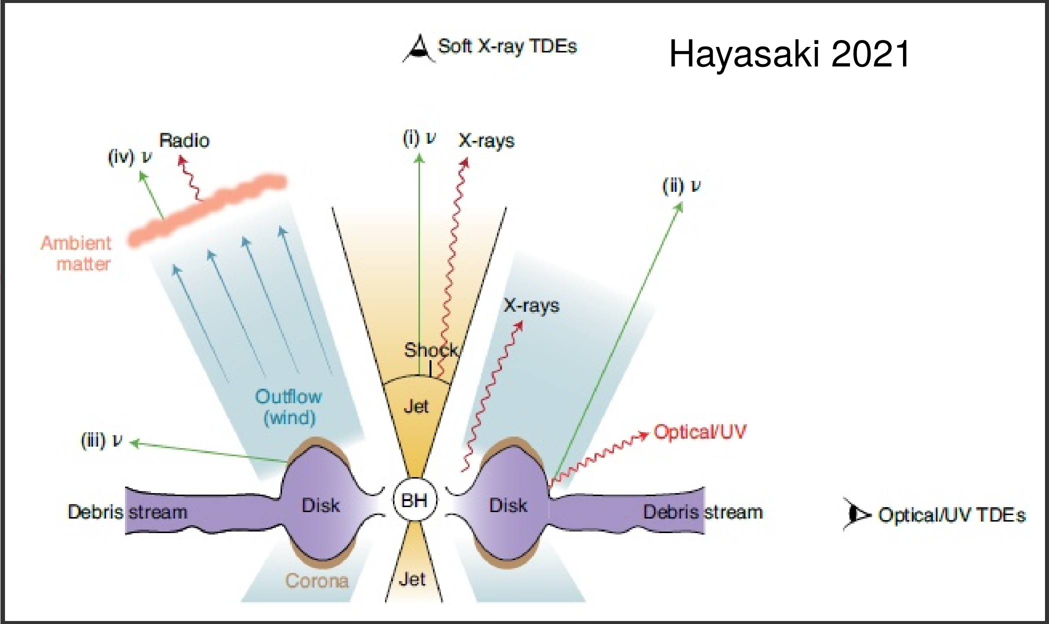
See e.g. Reusch etal 2022



DESY, Science Communication Lab



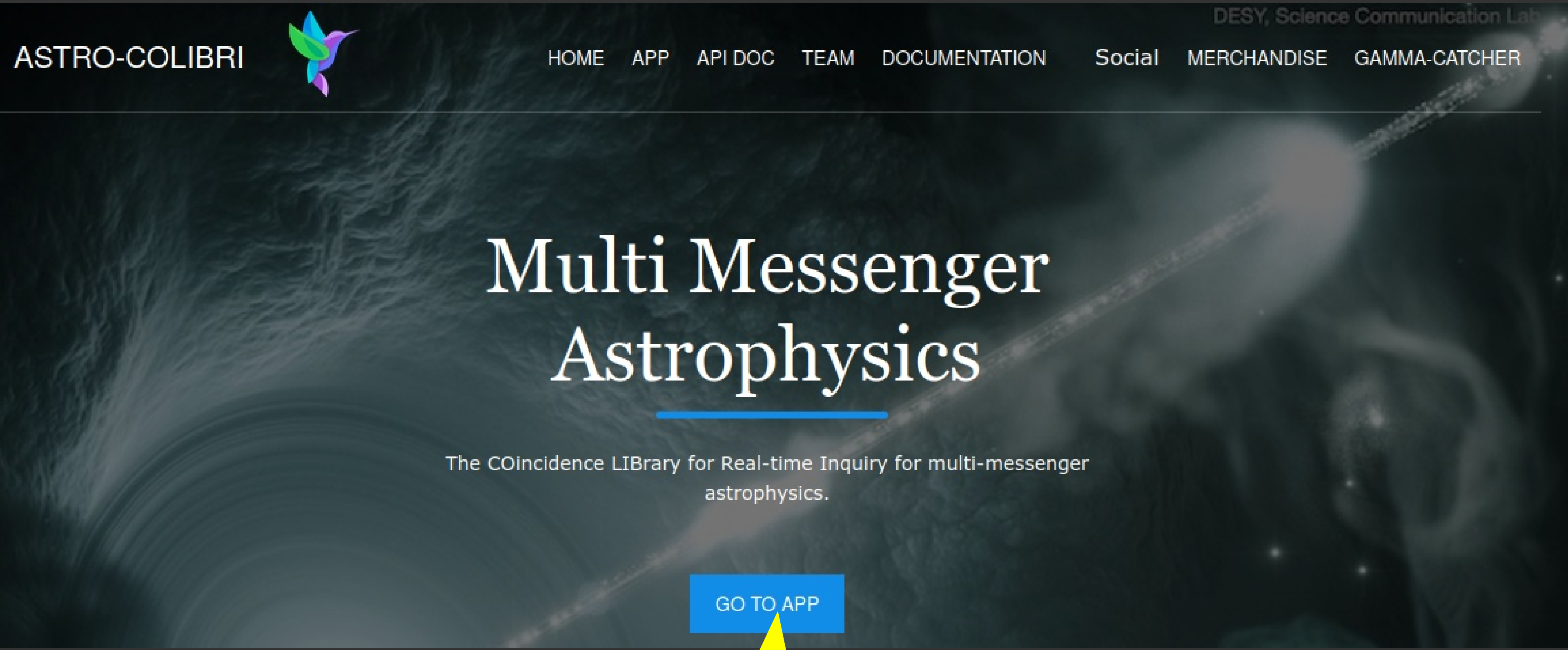
Alexander et al 2020



Hayasaki 2021

ASTRO-COLIBRI Multi-messenger transients in real-time!

https://astro-colibri.science/

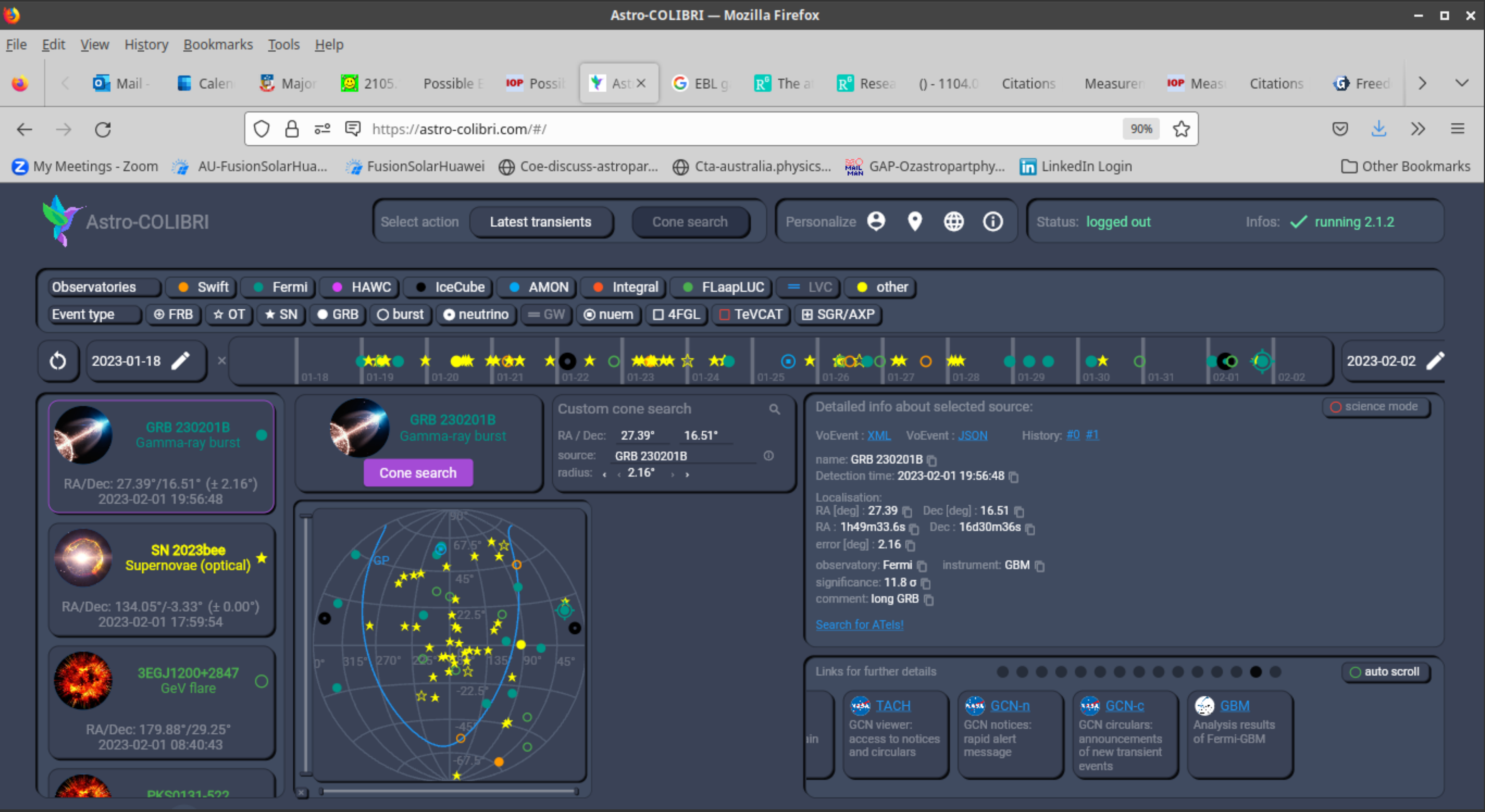


Multi Messenger Astrophysics

The COincidence LIBrary for Real-time Inquiry for multi-messenger astrophysics.

Press here

ASTRO-COLIBRI Multi-messenger transients in real-time!



Status: logged out

Infos: ✓ running 2.1.2

GRB 230201B
Gamma-ray burst
RA/Dec: 27.39°/16.51° (± 2.16°)
2023-02-01 19:56:48

SN 2023bee
Supernovae (optical)
RA/Dec: 134.05°/-3.33° (± 0.00°)
2023-02-01 17:59:54

3EGJ1200+2847
GeV flare
RA/Dec: 179.88°/29.25°
2023-02-01 08:40:43

PKS0131-522

GRB 230201B
Gamma-ray burst
Cone search

Custom cone search
RA / Dec: 27.39° 16.51°
source: GRB 230201B
radius: 2.16°

Detailed info about selected source:

VoEvent : XML VoEvent : JSON History: #0 #1

name: GRB 230201B
Detection time: 2023-02-01 19:56:48

Localisation:
RA [deg] : 27.39 Dec [deg] : 16.51
RA : 1h49m33.6s Dec : 16d30m36s
error [deg] : 2.16

observatory: Fermi instrument: GBM
significance: 11.8 σ
comment: long GRB

Search for ATels!

Links for further details

TACH: GCN viewer: access to notices and circulars

GCN-n: GCN notices: rapid alert message

GCN-c: GCN circulars: announcements of new transient events

GBM: Analysis results of Fermi-GBM

Some Future TeV Gamma-Ray, Neutrino Facilities and Multi-messenger Connections

CTA- The next step in TeV gamma-ray astronomy

- Building on HESS, MAGIC, VERITAS...

~ 0.03 to 100 TeV

~ 330 MEuro for construction (cash+in-kind) funds available

CTA Arrays “alpha” Configuration

– Northern Array: 4 LSTs + 9 MSTs (La Palma, Spain)
1st telescope in operation!

– Southern Array: 14 MSTs + 37 SSTs (Paranal, Chile)
site prep. work underway

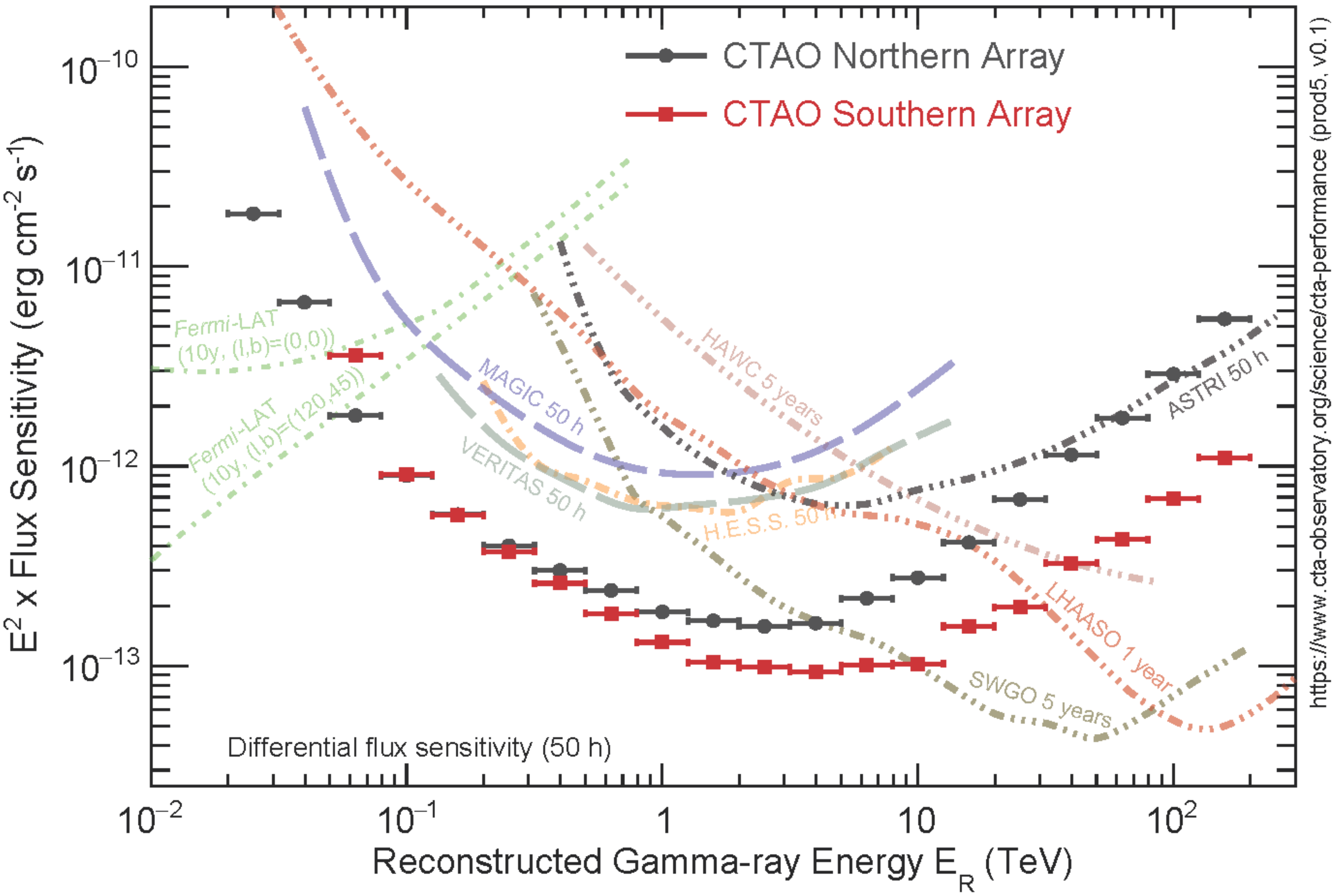
- CTA HQ, Bologna

- CTA Data Centre, Berlin

https://www.cta-observatory.org/

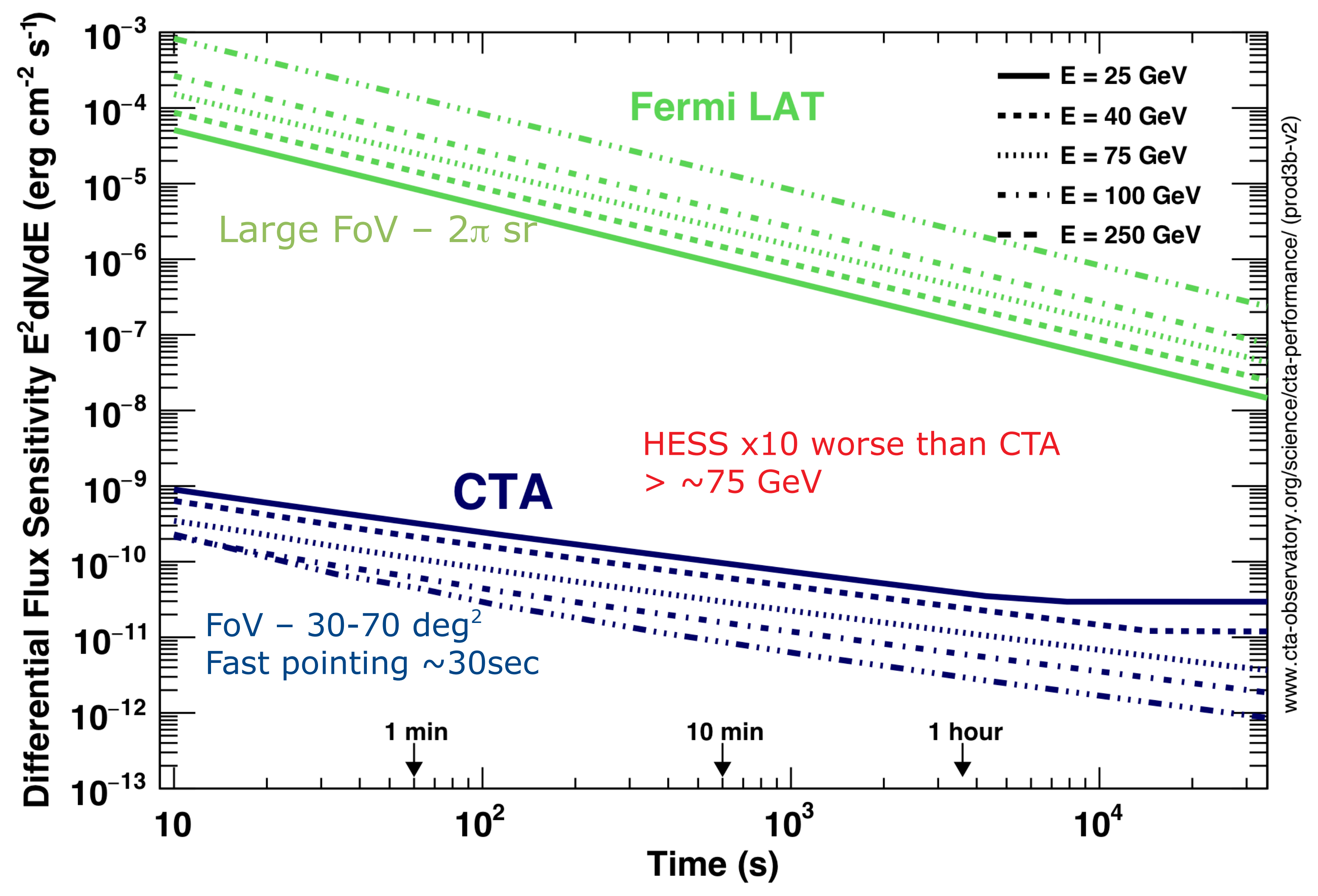
SST – small sized telescopes
MST – mid-sized
LST – large sized

CTA Flux Sensitivity (50hr) vs. Others



Transients & Variable Sources: CTA Sensitivity vs. Time

(CTA Collab 2019)



CTA >10,000 times more sensitive than Fermi-LAT in multi-GeV range

→ GRBs, AGN, giant pulses, FRBs, GW, SGR bursts......

CTA's Prospects for AGN

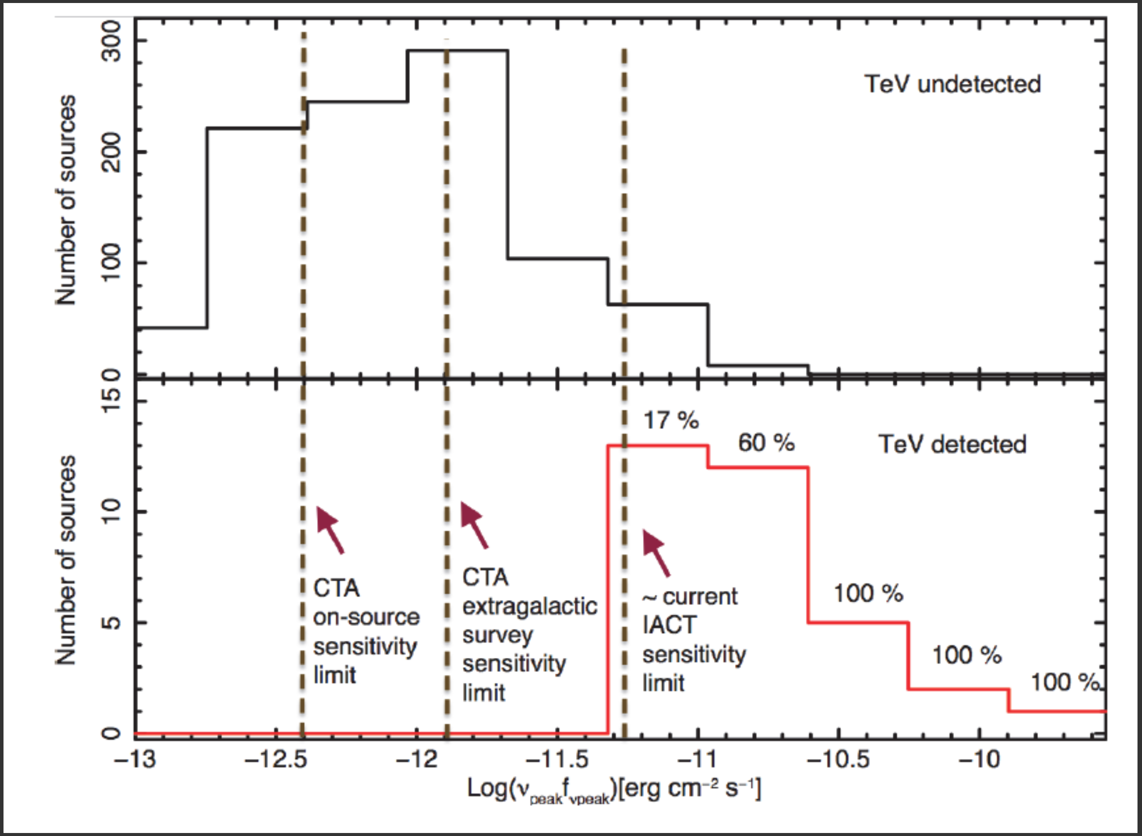
CTA will detect many 100s of AGN to z~2

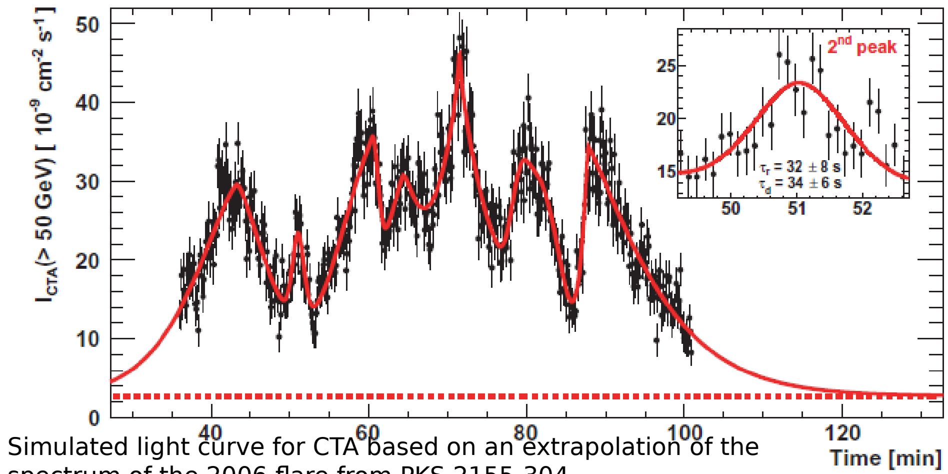
FoV up to 10 degrees → several AGN in FoV at same time.

Light curve details down to sub-minutes.

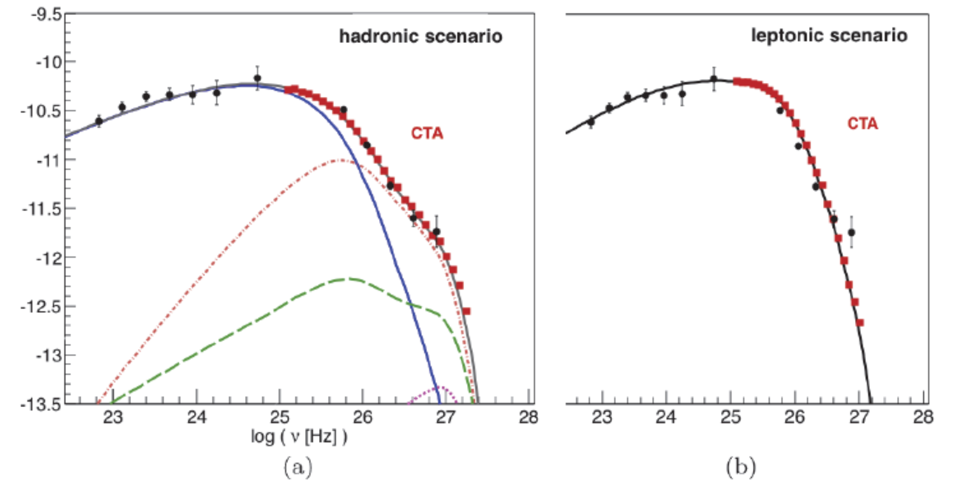
Spectral resolution to reveal sub-components:

- Hadronic (synchrotron from protons, muons, + secondaries)
- Leptonic (SSC)





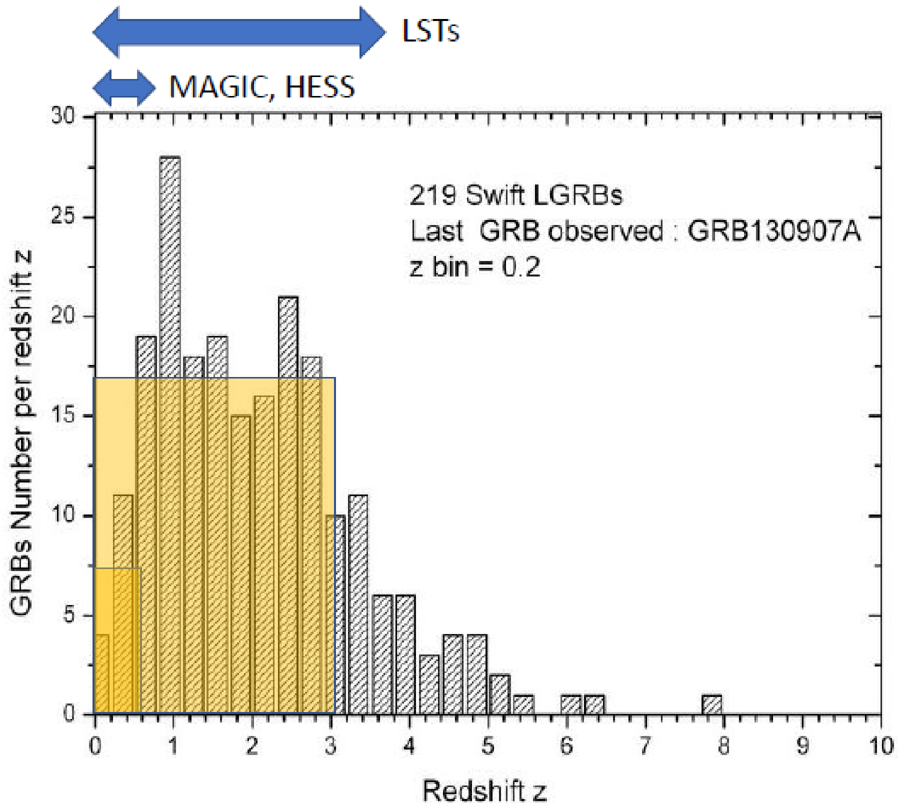
Simulated light curve for CTA based on an extrapolation of the spectrum of the 2006 flare from PKS 2155-304



CTA's Prospects for TeV GRBs

CTA will reach GRBs out to z ~4

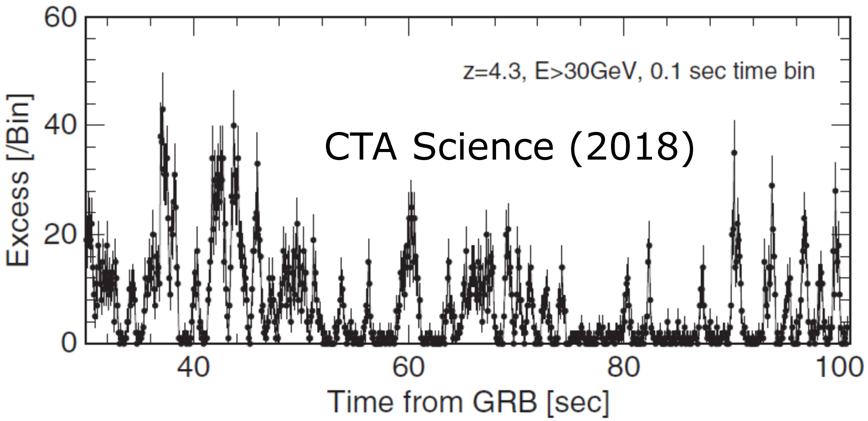
Light curves and seconds resolution and spectra within a minute!



15 GRBs in z < 0.5
112 GRBs in z < 2.0
164 GRBs in z < 3.0

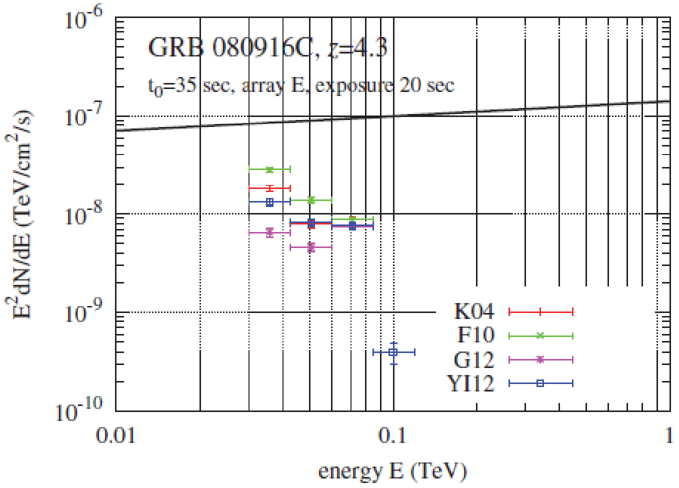
LST will increase the detection probability x10

M. Teshima (2020)

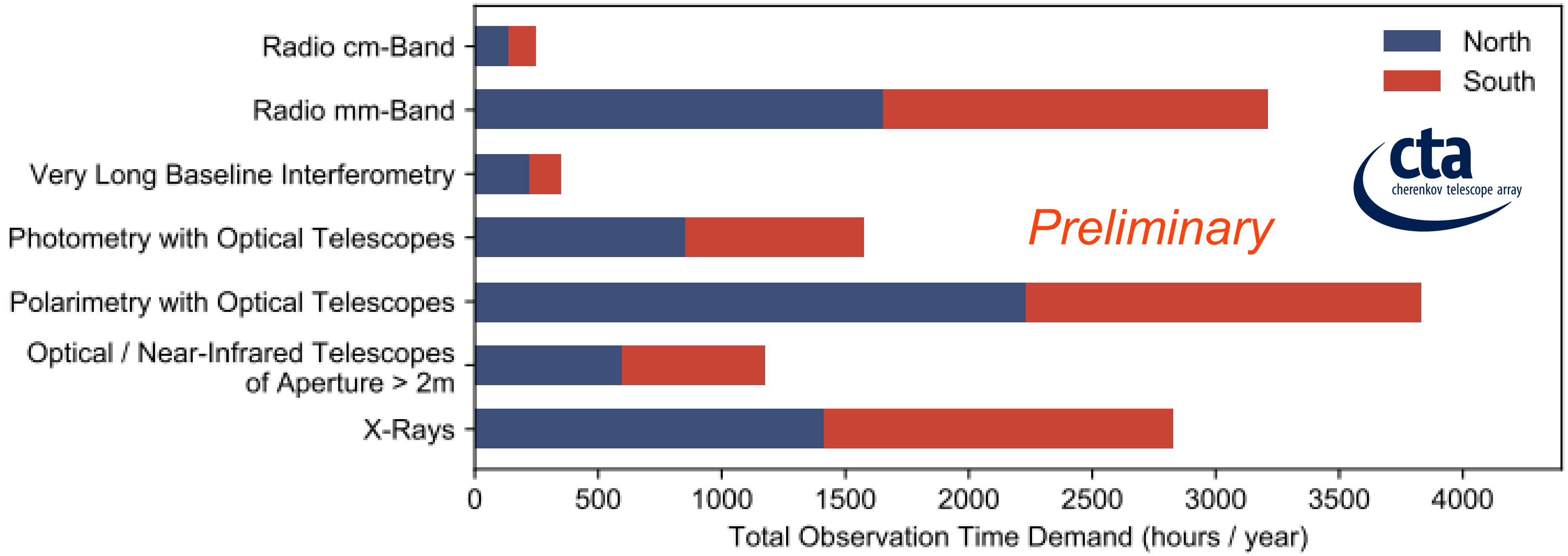


CTA Science (2018)

Figure 1.6: Simulated CTA GRB light curve, based on the Fermi-LAT-detected GRB 080916C at $z = 4.3$. See Figure 9.1 for more details.



Radio, optical & X-ray observations required to support CTA's Key Science Projects (x2 including other projects)



ESO facilities will provide much of these optical needs!

→ significant increase in ESO usage from CTA scientists and colleagues

→ significant roles for Australian scientists

→ CTAO+ESO science synergies "White Paper" under discussion

– CTA supports enhancing optical facilities in Australia (e.g. 2.3m tel.)

SKAO+CTAO MoU in place for future radio linkages

– expand on gamma+radio links in place: HESS + ATNF, MWA, UTMOST

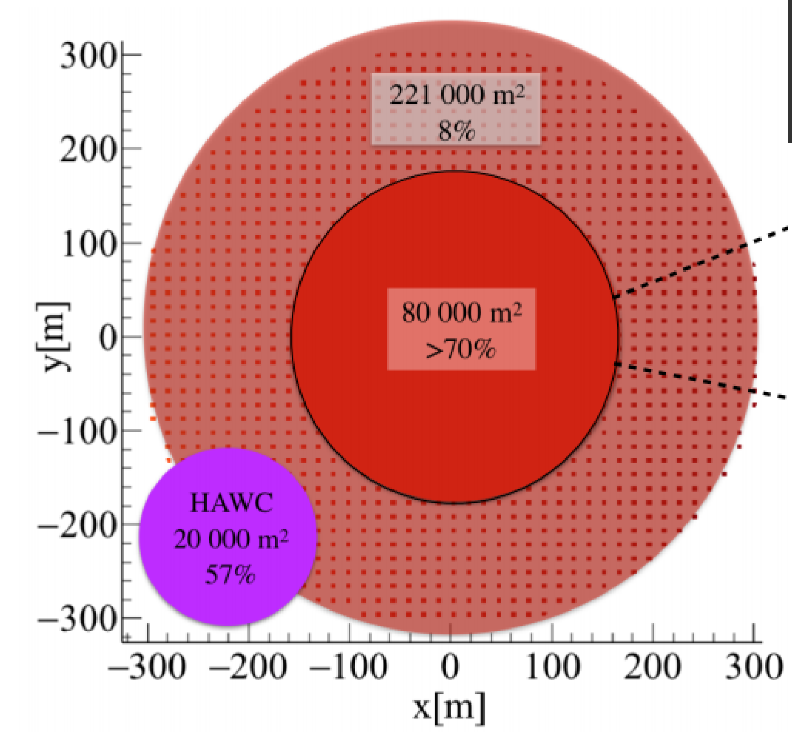
→ *All three are involved in the EU ESCAPE initiative*

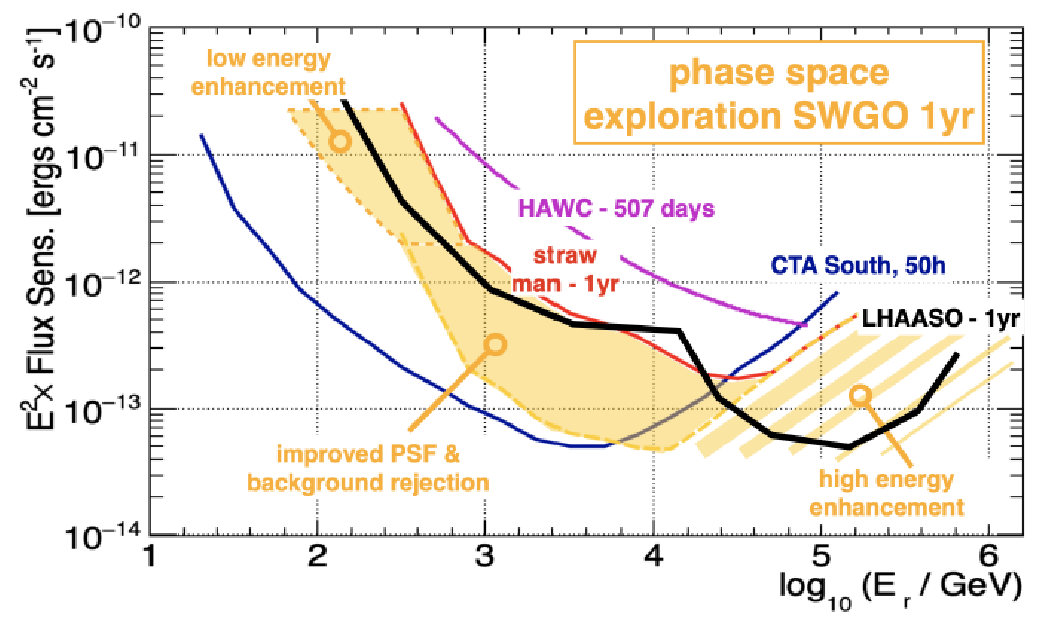
SWGO – Southern Widefield Gamma ray Observtory

https://www.swgo.org

- Building on experience from HAWC and LHAASO
- Array of >6000 tanks or array of bags/bladders in a lake?
- Potential sites in Peru, Bolivia, Chile, Argentina (5000m a.s.l.)
- Australian (Adelaide) company identified to supply tanks & bags >A$30M

The Southern Wide-field Gamma-ray Observatory





ATNF Facilities: Current (with HESS) & Future (with CTA)

ATCA

- AGN monitoriing ‘calibrator’ C1730 (P. Edwards)	HESS AGN included
- TANAMI (P. Edwards)	increased TeV focus
- Auto-follow-up of TeV GRBs C3374 (G. Anderson)	HESS trigger
- StarFISH C3145 (S. Breen)	dense ISM
- C3348 (N. Tothill)	ionised ISM

Parkes

- SPLASH OH (J. Dawson)	first comparison to HESS
- SUPERB FRB (Petroff etal.)	HESS follow-up

Mopra

- CO Survey (Burton etal.)	Data release 4 almost ready!
- *Many projects* on dense ISM	see http://www.physics.adelaide.edu.au/astrophysics/MopraGam/

VLBI

- cm & mm	esp. mm for rapid timescales

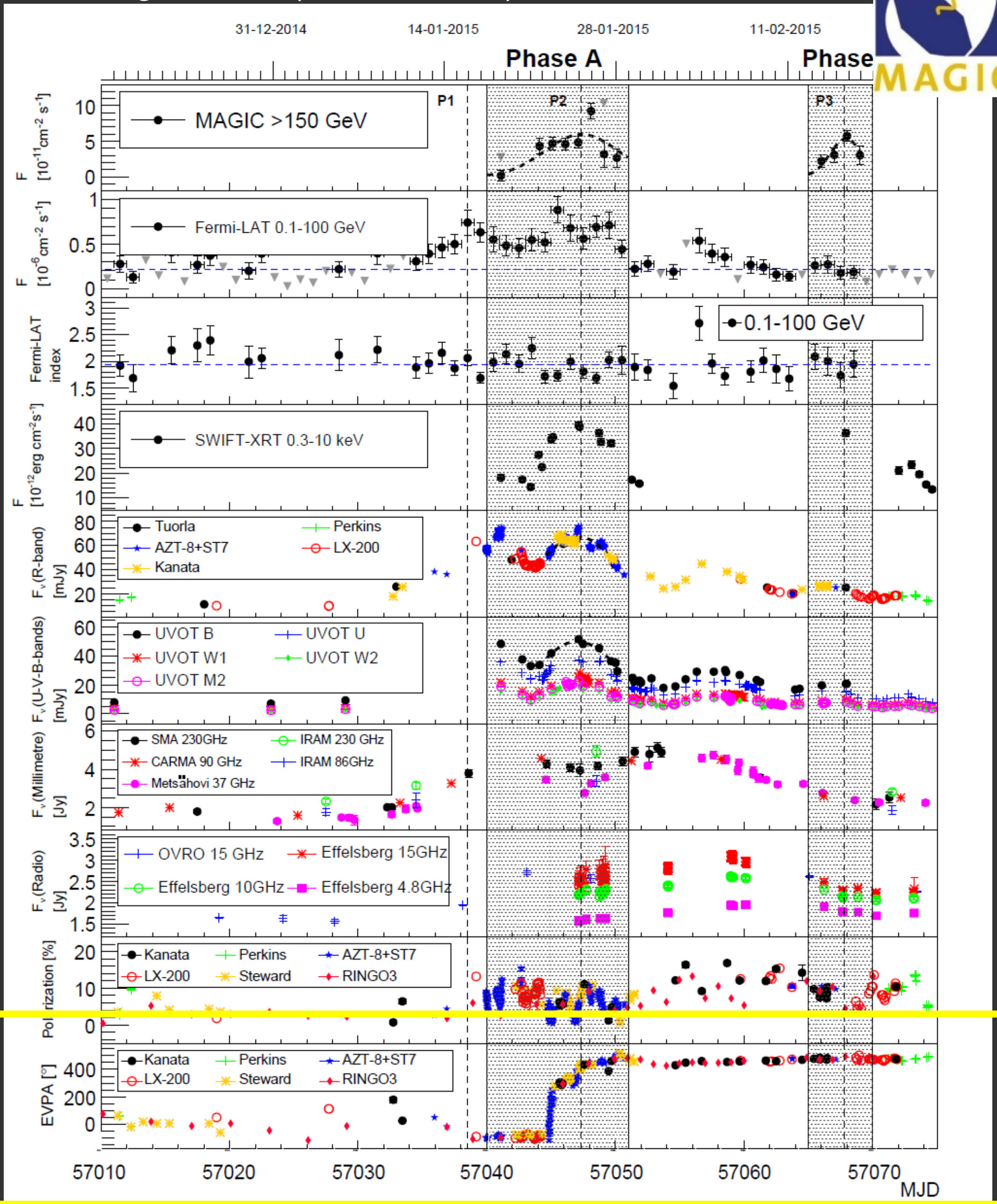
ASKAP (R. Norris, M. Filipovic,J. Dawson, K. Jameson, N. Pingel..)

- GASKAP HI + OH	pilot region includes HESS source
- RACS & EMU	synchrotron
- POSSUM	B-fields
- HESS + ASKAP ‘shadowing’ obs.	discussions commenced

[+ MWA (synchrotron) and UTMOST (FRBs) linkages to HESS in place]

AGN Flares : Many Synergies!

MWL light-curve (MAGIC 2018)



BL-Lac S5 0716+714

- AGN flare radio to TeV.

- Polarisation angle swing looks very interesting! Related to distinct electron populations..

- CTA is considering its own on-site 1m class telescopes

- 2m class telescope access via MoUs etc.

<u>Australia:</u>
Unique longitude coverage
in S hemisphere (optical/radio)

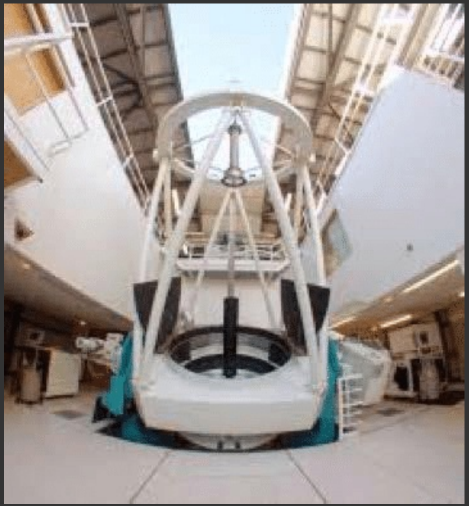
Synergies with Optical Astronomy

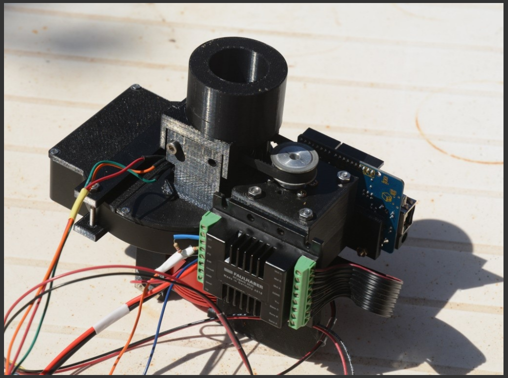
- Transient follow-up and monitoring of AGN, XRBs, Novae, SGRs, GWe

- Photometry and polarimetry needed.

- ANU 2.3m ideal workhorse - CTA-Australia + ANU MoU finalised
- ANU 2.3m - LIEF automation funded.
- CTA-North + GOTO → GOTO south at SSO
- LSST (VeraRubin) synergies → now discussing LSST data brokers
- ESO facilities for deeper follow up and studies.

- CTA LIEF#3 New polarimeter for AGN, GRBs etc. (J. Bailey design)





Explosive Astrophysics from Siding Spring Observatory

New LIEF - LE230100063

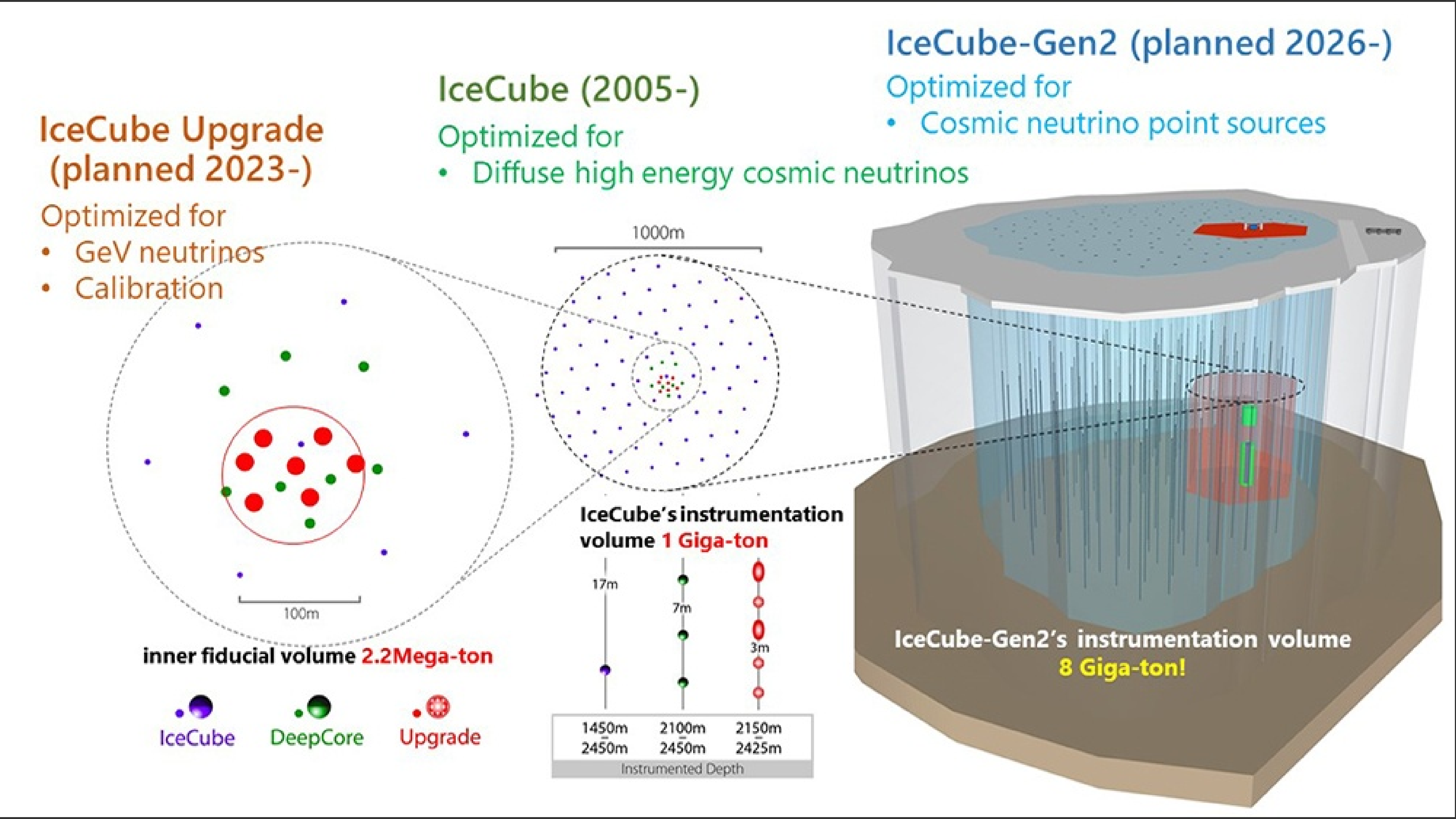
Associate Professor Christopher Lidman; Professor Matthew Colless; Professor Sarah Brough; Associate Professor Christian Wolf; Associate Professor Tony Travouillon; Dr Ivo Seitenzahl; Dr Anais Möller; Associate Professor Michael Brown; Dr Devika Kamath; Dr Sabrina Einecke; Professor Alexander Heger; Dr Ashley Ruiter; Associate Professor Duncan Galloway; Professor Linqing Wen; Dr Simon O'Toole

- Complete automation of the 2.3m telescope
- Software for rapid transient information flow and linkage to transient ‘brokers’
- Create a network of optical/IR telescopes at SSO (2.3m, DREAMS, GOTO-S)
- Tertiary mirror for 2.3m telescope for rapid/auto switching across foci

Funding Awarded: $595,295.00

→ New era in rapid-response optical/IR followup of transients in Australia

IceCube – Upgrade & Gen-II (8x bigger volume)



IceCube Upgrade (planned 2023-)

Optimized for
- GeV neutrinos
- Calibration

IceCube (2005-)

Optimized for
- Diffuse high energy cosmic neutrinos

IceCube-Gen2 (planned 2026-)

Optimized for
- Cosmic neutrino point sources

inner fiducial volume 2.2Mega-ton

IceCube's instrumentation volume 1 Giga-ton

IceCube-Gen2's instrumentation volume 8 Giga-ton!

Next up: Some Coding and Application to some Recent Results (AGN, GRBs)

Naima - https://naima.readthedocs.io/en/latest/index.html

Computes non-thermal photon emission from particle spectra.
Monte Carlo fits of particle spectra to observed fluxes.

GammaPy - https://docs.gammapy.org/0.20/index.html

Open-source package to analyse data from gamma-ray facilities: HESS, MAGIC, VERITAS, HAWC, Fermi-LAT and core software for CTA

agnpy - https://agnpy.readthedocs.io/en/latest/index.html

Libraries with detailed models of AGN particle spectra

Gamera - http://libgamera.github.io/GAMERA/docs/main_page.html

Similar to Naima but also include *time-evolution* of particle spectra.

Time-Evolution of Particle Spectra (Further Work)

In reality, the energy distribution of particles will evolve with time as they lose energy via radiative (or interaction) losses.

‘Injection’ spectra of particles from an accelerator can be either impulsive (transients/variables, cataclysmic events Δt<year) or continuous (e.g. pulsars, stellar clusters) with $\Delta t > 10^3$ years.

Due to strong synchrotron losses (& sometimes inverse-Compton when soft photon fields are strong), electron spectra can evolve rapidly (secs, mins, hrs, years…).

Question: Under what conditions would cosmic-ray proton spectra evolve on <years timescale?

Suggested further details of time-evolution of electron spectra:
- Manolaku et al A&A 2007 474, 689
- Moderski, et al 2005 MNRAS, 364, 1488 + citations!