TeV Gamma-Ray Astronomy

Ph 135c

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Topics

- Sources
  - Supernova remnants, galactic center, blazars
- Detectors
  - Cherenkov radiation and a few others
- WIMP Annihilation

Causes of VHE Gamma-Rays

- Inverse Compton Scattering (IC)
  - Low energy photons scatter off relativistic electrons, gaining energy
- Synchrotron Self-Compton Scattering (SSC)
  - Synchrotron radiation (radiation emitted by relativistic particles accelerated by magnetic fields) scattering off relativistic electrons, gaining energy
- Pion Decay: π^0 -> 2γ
  - Relativistic hadronic material reacts creating pions (among other stuff) which decay into photons

Supernova Remnants: Plerions (Pulsar Wind Nebula)

- Type II Supernova -> pulsar in synchrotron nebula
- Crab nebula (SSC), Vela & PSR1706-44 (IC)
- Crab nebula- constant source TeV radiation
  - Important for calibration of future instrumentation
  - First recognized supernova (observable day and night for two years starting in 1054 by Chinese and Arab astronomers)
  - $B = 160 \mu G$
  - $E_{e-,max} \sim 10^{16}$ eV

Supernova Remnants: Pulsars

- Gamma-rays produced by SSC scattering
- Where are the gamma rays made?
  - Polar cap
  - Outer Magnetosphere
- No TeV pulses -> not in magnetosphere

Shell-type Supernova Remnants (SNRs)

- Possible source for hadronic cosmic rays?
  - Only galactic objects capable of supplying the power required for cosmic ray energy densities observed in our galaxy.
  - Diffuse shock acceleration theory produces a power law spectrum consistent with observed local cosmic ray spectrum.

SNRs contd.

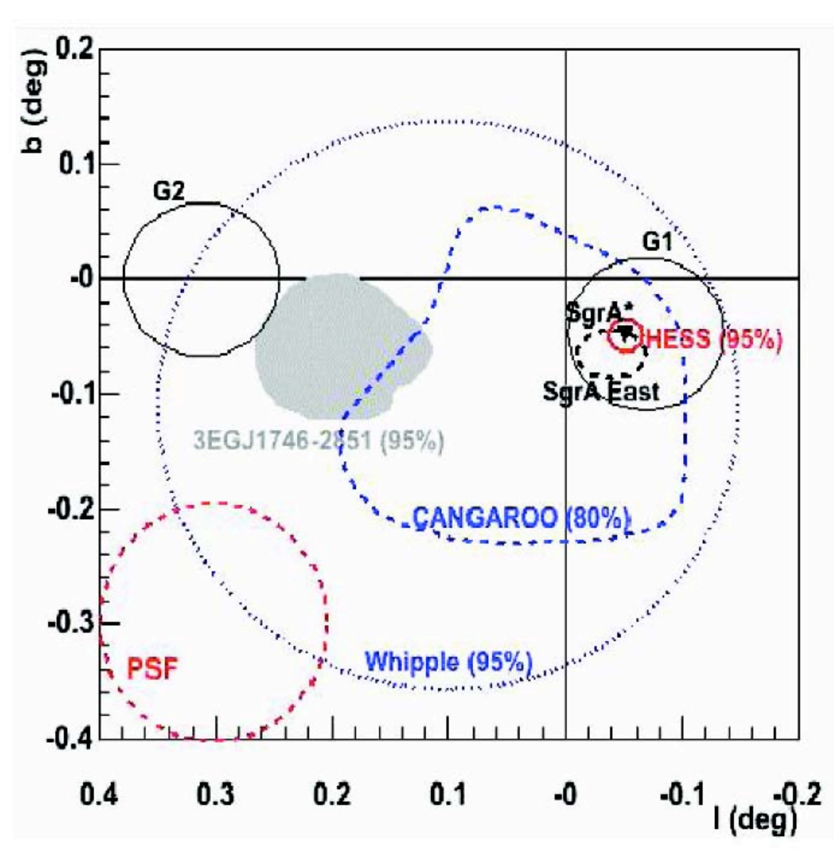
- If true, then the VHE spectrum would reflect the distribution of particles near the SNR that accelerated and collided w/ the ISM to produce the gamma-rays.
- Complicated by IC scattering of background radiation creating TeV radiation

SNRs contd.

- Observations: inconclusive
  - Most measurements need higher resolution to see bump from pion emission above background radiation sources
  - Some TeV observation correspond to X-ray emission, indicating a similar source (IC)

Galactic Center

- Definite source of VHE gamma-rays
- Corresponds with central black hole and a supernova
- Also several unknown sources
- Considerable more study is required



Other Galactic Sources

- Microquasar- normal star accreting onto compact object
- Binary pulsar- pulsar orbiting a very massive star with a disk, pulsar’s relativistic wind sweeps up particles
- Previously Unidentified- 5 sources, no x-ray flux detected, ???

Blazars

- Blazars are AGN with jets pointed towards us
- Includes violent variable quasars, highly polarized quasars, and BL Lacertae objects
- Brightness of relativistic jets further enhanced by 4th power Doppler factor
- Brighter than Crab Nebula in VHE

Blazars cont.

- Markanian 421-highly variable
  - Increased in brightness by a factor of 50 in a period of 2 hours (max = 10 Crabs) and decay time of 15 minutes
  - Area of emission 1-10 light hours in diameter, corresponds to 10 R_s for 10^8 solar mass BH
- All possible sources of TeV gamma-rays have been postulated
- Need better time resolution and multiwavelength observations

Gamma-ray Bursts ?

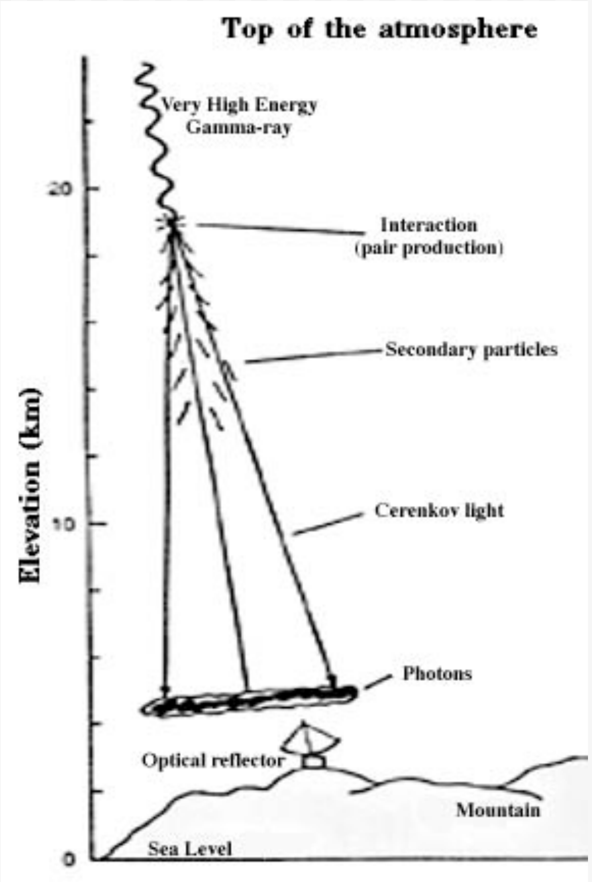
- Likely the most energetic explosions observed in the universe, makes for a good source of VHE photons
- But haven’t actually seen any TeV emission
- A function of their very short lifetime?

TeV Detector Types

- Atmospheric Cherenkov telescope
  - Imaging vs. Wavefront sampling detectors
- Air Shower Arrays
- Satellite Instruments

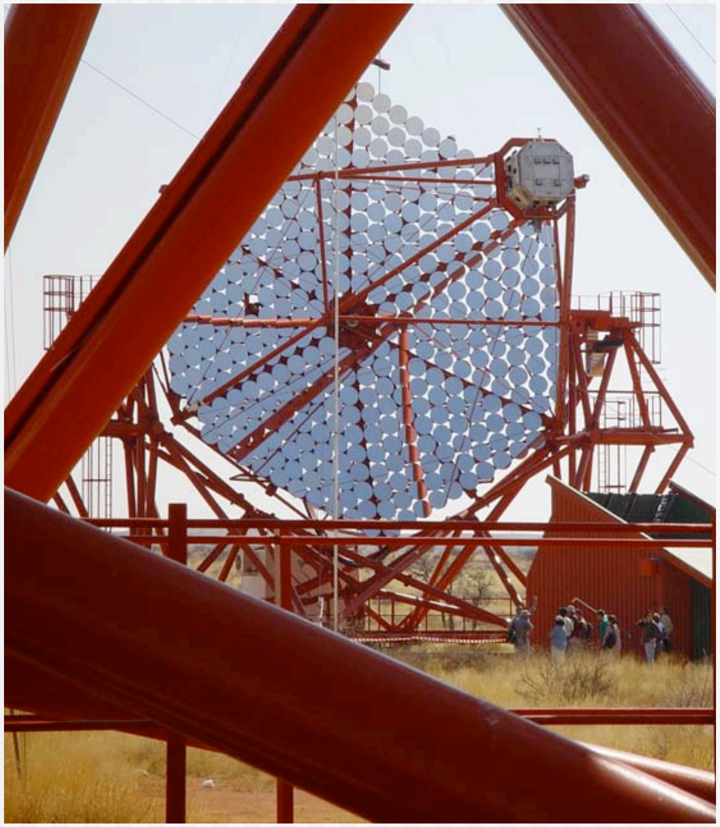
Cherenkov Radiation

- Produced when particles pass through an insulator at speeds greater than the local speed of light
- Air shower created when gamma-ray interacts with atmosphere to make e^-e^+ pairs, which interact via Bremsstrahlung and Compton scattering, creating more photons, etc.
- Local atoms are polarized by the fields of the passing particles, and they emit a faint blue glow as a result



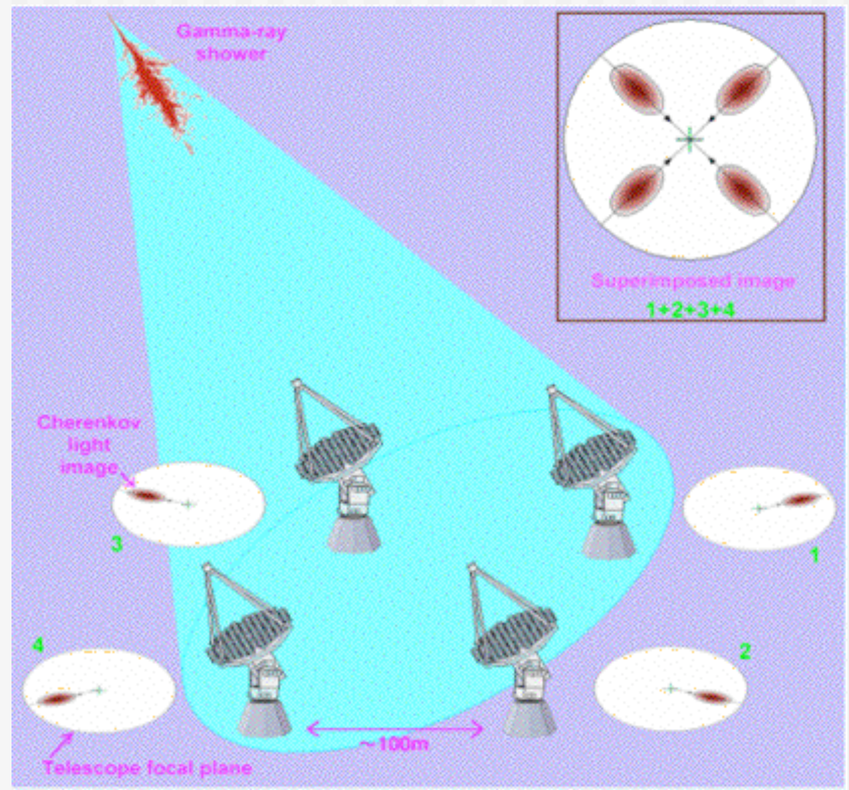
Cherenkov Imagers

- Light is focused from large mirrors onto photomultiplier tubes and very fast electronics record the signal
- Shape of incoming detected light and arrival time is used to screen out cosmic ray contamination



Ex. VERITAS

- 4, 12m telescopes
- 499 photomultiplier tubes each
- Stereoscopic imaging
- 50 GeV - 50 TeV
- Flux sensitivity to .5% of Crab nebula extends search to 2/3 of galaxy
- Angular resolution at 100 GeV is less than 0.1°



Water Cherenkov Detector MILAGRO

- Why water?
  - About 1400 times more photons are produced per unit track length
  - Cherenkov angle in water is 41° vs 1° for air, spreading the “image” for better resolution

Other Air Shower Arrays
Tibet AS-gamma Experiment

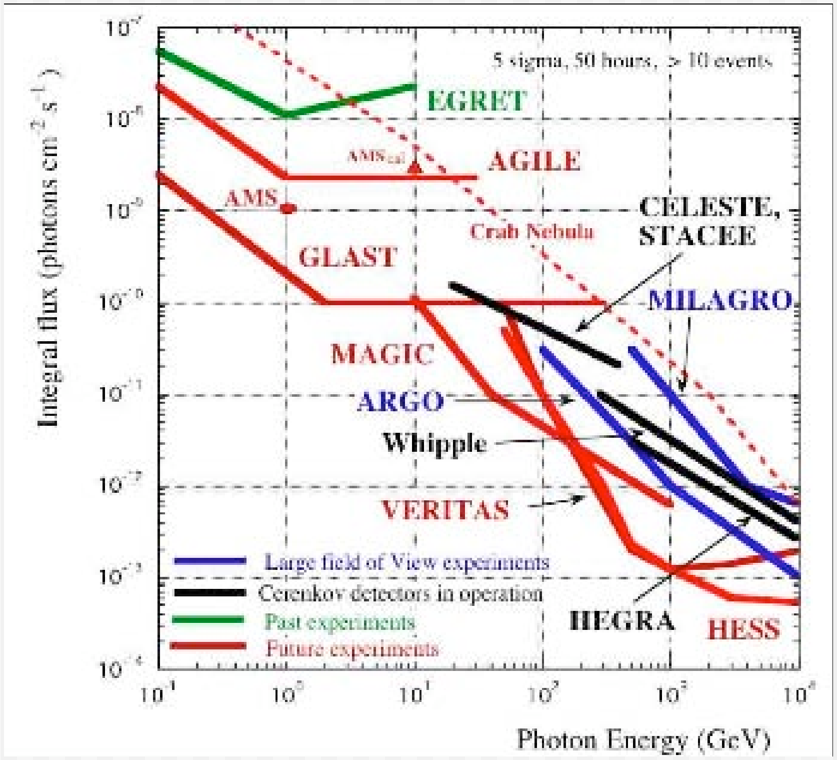
- 697 scintillators with photomultiplier tubes (PMTs) covering 50,400 m^2
- Subsets of array have fast-timing PMTs and wide dynamic range PMTs

Other Air Shower Arrays ARGO-YBJ

- Resistive Plate Chambers- space and time resolution (~ 1ns)
- Sensitivty increase by going to very high altitudes (Tibet), and very large surface areas (~10,000 m^2)

Other Gamma-ray Telescopes

- Space telescopes like GLAST
  - Mostly for below TeV observations
  - Wide field of view for complete sky survey
  - Pixel-like layout of layers of Si-strip tracker and Pb converter planes for directionality, and CsI calorimeters
- Wavefront Analysis of Atmospheric Cherenkov Radiation like HAGAR (proposed)



WIMP Annihilation

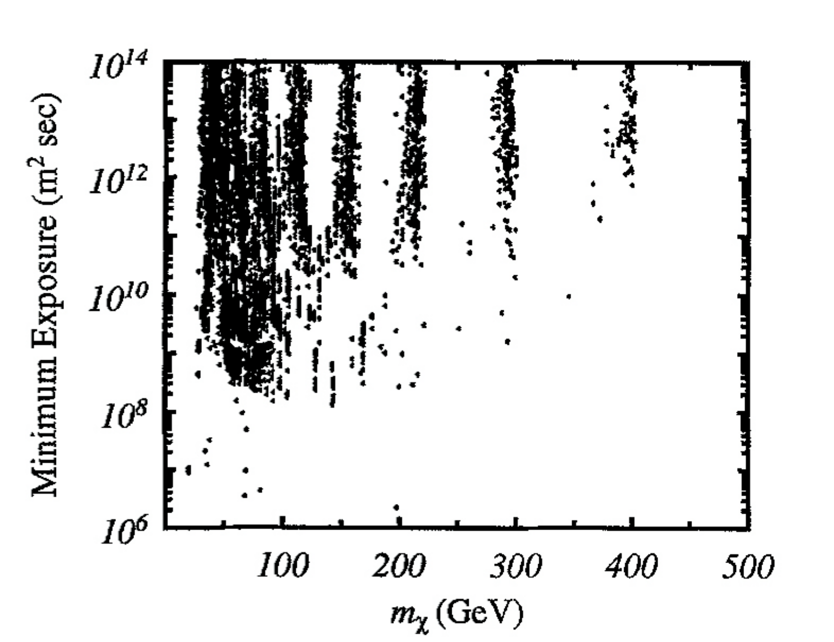
- Popular form of WIMP, dark matter: neutralino
- Neutralino annihilation can result in the creation of any number of particle pairs, most relevant to this lecture being fermion anti-fermion pairs
- Hadronization of these quarks would result in a shower of gamma-rays
- Despite that WIMPs practically by definition do not couple to radiation, it is also possible that through loop diagrams, for two WIMPs to directly annihilate into gamma-rays

WIMP Gamma-rays

- When produced during hadronization, the resulting gamma-rays have a very broad energy spectrum around 1/10 WIMP mass -> blend into background
- Only hope of detection is from direct annihilation into gamma-rays in either the halo or galactic center
- But, the slow velocity of WIMPs in the halo means that gamma-rays produced in this method would have a broad energy spectrum as well -> blends into the gamma-rays made by hadronization

WIMP Gamma-Rays from the Galactic Center

- Density enhancement of DM at the core by ~10 over halo could result in detectable monochromatic gamma-rays
- If included contributions from all relevant diagrams, a 10^4 m^2 atmospheric Cherenkov telescope observing for a few years should be able to detect this



Summary

- TeV astronomical sources are few and poorly understood
- Improvements in detectors are needed
- Improved observations could also lead to better understanding of dark matter

Sources

- Assorted Telescope Websites
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