The Universe Viewed in Gamma-Rays
Univ. of Tokyo Workshop 2002

Rene A. Ong
Univ. of California, Los Angeles
Thanks

LOC, Mori, Yanagita, for inviting me.

All speakers and contributing authors.

Modern Computing ... ?
Apologies, etc.

Reviewing is not an easy business, so this talk will be far from perfect:

- Mostly obs/exp - see also Summary(1).
- Not comprehensive.
- Subjective!
- Concentrates on results presented here.

Note: As many review talks as contributed papers. Will not redo all those nice presentations. But will try to go beyond a simple recap of meeting.
Outline

• Historical Perspective
  How has the field changed recently?

• Big Themes
  Where is the field going?

• Selected New Results

• Summary - Future

• Comments
### Historical Perspective

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; solid detection (Crab)</td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; extragalactic (Mrk 421)</td>
<td>TMACD I Palaiseau</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suggestion – large TAs</td>
</tr>
<tr>
<td>1993</td>
<td>TMACD II</td>
<td>Calgary</td>
</tr>
<tr>
<td>1994</td>
<td>TMACD III</td>
<td>Tokyo (Kifune)</td>
</tr>
<tr>
<td>1995</td>
<td>TMACD IV</td>
<td>Padova</td>
</tr>
<tr>
<td>1997</td>
<td>Mrk 501 Flares</td>
<td>TMACD V Kruger Park</td>
</tr>
<tr>
<td></td>
<td>“Big Four” 3&lt;sup&gt;rd&lt;/sup&gt; Gen. Detectors</td>
<td></td>
</tr>
</tbody>
</table>
Historical Perspective

1999  TMACD VI  Snowbird

2002  Kashiwa

TMACD Conferences were important:
• Marked separation of $\gamma$-rays from ICRC
• Evolved - mix of reviews, theory/obs/detectors

It would be nice to have a VHE $\gamma$-ray meeting every two years, whatever the name.

Kashiwa Meeting has been in the spirit of this tradition. Consider trends since Snowbird. Also – see summary by Pohl at 27th ICRC (Hamburg).
The Universe viewed in Gamma-Rays
- Univ. Tokyo Workshop 2002 -
25-28 Sept. 2002  Kashiwa, Chiba, Japan
(Towards a Major Atmospheric
Cherenkov Detector VII)

http://icrhp9.icrr.u-tokyo.ac.jp

Not really this !
Big Themes

• Source Count increasing steadily.
VHE Sky Map

VHE Gamma Sources (E > 300 GeV)

(Status August 2000)

New Since 1999

- H1426+428
- 1ES1959+65
- Cas-A
- TeV J2032+4131

- NGC 253

Galactic Coordinates:

- Pulsar/SNR
- AGN (Blazar)
- Unconfirmed
- Confirmed

D.Petry, 9-2000
## Source List

<table>
<thead>
<tr>
<th>Year</th>
<th>Solid (6)</th>
<th>Likely (6)</th>
<th>??</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-1999</td>
<td>Crab, Mrk 421, Mrk 501, PSR 1706</td>
<td>Vela, 1ES2344, SN1006</td>
<td>PKS 2155, Cen X-3, 3C 66A</td>
</tr>
<tr>
<td>1999-2002</td>
<td>H1426, 1ES1959</td>
<td>Cas-A, RXJ 1713, TeV J2032</td>
<td>NGC 253</td>
</tr>
</tbody>
</table>
Source Notes

• At this meeting, CANGAROO reported a new source:
  NGC 253 (Starburst) – Itoh (S26)

• And showed early evidence for possible sources:
  RCW 86  (SNR) – Watanabe (S32)
  RX J0852-4622 (SNR) – Katagiri (S19)
  Galactic Center – Tsuchiya (S17)

• No confirmed detection of any SNR.

• (Solid + Likely) = 12 Total VHE Sources.
Q: How does the S compare with the N?

<table>
<thead>
<tr>
<th>Hemisphere</th>
<th>AGN</th>
<th>Galactic</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>S</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

- At present, statistics are still limited.

- Future picture will look different:
  1. SNR detections will be confirmed.
  2. S Detectors improving dramatically.
  3. # of N Detectors is reducing.
      (TA, HEGRA, CAT…)

Hemisphere Counting
Hemisphere Counting

Galactic studies will gain in importance. SNRs, pulsars, EUIDs …
• Source Count increasing steadily.

• S hemisphere will be increasingly important for field.

• Multi-$\lambda$ Approaches are essential. Spectral, temporal, spatial correlations.
The X-ray - TeV $\gamma$ Connection

SNRs: Slane (01), Tanimori (02), Berezhko (03):
- Importance of understanding the broadband SED in SNRs and plerions.
- SN 1006 – IC models look satisfactory.
- In RX J1713 the situation is not clear at all.

AGN: Coppi (07), Mukherjee (08):
- In broad terms: x-ray and TeV data are correlated. Double-peaked SEDs, temporal relations.
- Evidence for unified picture.
- Look in detail: many complications. TeV blazars may be more tractable, interesting.

Good time for X-ray work:
Chandra, XMM/Newton, RXTE, (Astro 2E), etc.
• Thermal electrons produce line-dominated x-ray spectrum with bremsstrahlung continuum

• nonthermal electrons produce synchrotron radiation over broad energy range

• high energy tail of nonthermal electrons yields x-ray synchrotron radiation

• nonthermal X-rays indicate presence of synchrotron nebula or high energy particles accelerated in shock

- either may be indicative of potential $\gamma$-ray emission
SN 1006

- Spectrum of limb dominated by nonthermal emission
  - keV photons imply $E_e \approx 100 \text{ TeV}$

- Chandra observations show distinct shock structure in shell

- Same region as TeV emission
SN 1006

Tanimori

\[ S = -2.2 \]
\[ B \sim 4 \, \mu G \]
\[ E_{\text{max}} \sim 50\text{TeV} \]

IC Modeling works!

*Naito et al. Astron. Nach. 320, 1999*
Add EGRET Gamma-Ray Data …

Grand Unified Blazar Scheme?

(synchrotron & Compton from SAME e+/e-; $\gamma_{peak} \propto \text{Lum}^{-1}$?)

Donati et al. 2001
(cf. Fossati et al. 1998)
If electrons/pairs are primary particles, what is acceleration energy spectrum?

Is the observed high energy cutoff in some objects intrinsic or simply due to photon-photon pair production (inside source or intergalactic)?

What is the origin of the spectral breaks seen in X-rays/gamma-rays?

What are seed photons for Compton upscattering??

• Synchrotron Photons (SSC)
• Accretion Disk Photons (ERC)
• BLR Photons (reprocessed accretion disk photons)
• IR photons from hot dust in central region
• [Microwave background, probably not relevant, but always there ]

All possible => different gamma-ray spectra for same e- distribution!

∴ Lots of uncertainty for generic blazar!!
TIMESCALES (II):

TeV (and GeV) blazars appear to have discrete “flare” states...

Problem: In "standard model," single blob would be at

$$R : \delta^2 c \Delta t : 5 \times 10^{19} \delta_{25}^2 \Delta t_{\text{month}} \text{cm}!$$

Unlikely....
Main Questions left from EGRET: Pohl (05)
Prospects for Diffuse Bkgnd: Pavlidou (G07)

GeV excess is highly significant, present at high latitudes, and not understood.

Large number of unid sources. Probably > 100 are galactic in origin, but minor fraction are SNR or pulsars → New source class.

• Are the two problems (GeV Excess & UnID) related?
• What is relevant at TeV energies?

Not a great time for GeV $\gamma$-ray work: (… GLAST).
Big Themes

- Source Count increasing steadily.
- S hemisphere will be increasingly important for field.
- Multi-\(\lambda\) Approaches are essential.
- Experimentation & Technology march on.
New Telescopes are Here

CANGAROO 2nd
Ohishi (T04)

Hofmann (T03)

HESS

Lorenz (T02)

MAGIC
New Technology is Here: Mirrors

Al Mirrors (MAGIC)

PSF After Alignment (HESS)
New Technology is Here: Cameras

Modular Construction (HESS)

Single, lightweight (CANGAROO)
New Technology is Here: Electronics

500 MHz FADCs (VERITAS)

Analog Fiber Signal Transmission (MAGIC)
1 ns rise time
Dyn range of 60 dB

Fast Sampling (HESS)

PMT pulse sampled at 1 GHz

Hi QE HPD ... still 2 yrs off?
Posters - Instrumentation

Cortina (T10) – MAGIC Control

Kovaki (T09) – CANGAROO Camera

Covault (T15) – STACEE FADCs
### Posters - Instrumentation

**Additional contributions that I did not have time to discuss:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achara</td>
<td>(S16) – Pachmari Array of Cherenkov Telescopes</td>
</tr>
<tr>
<td>Cowsik</td>
<td>(T06) – High Altitude Observatory at Hanle</td>
</tr>
<tr>
<td>Sinitsyna</td>
<td>(T07) – Selection of Gammas from Protons – SHALON</td>
</tr>
<tr>
<td>Puelhofer</td>
<td>(T11) – Technical performance of HEGRA IACT</td>
</tr>
<tr>
<td>Cornils</td>
<td>(T12) – Mirror Alignment of HESS Telescopes</td>
</tr>
<tr>
<td>Cortina</td>
<td>(T13) – Absolute Flux Calibration for MAGIC</td>
</tr>
<tr>
<td></td>
<td>(T14) – Data Acquisition of MAGIC</td>
</tr>
<tr>
<td>Kajino</td>
<td>(T16) – High Resolution Cherenkov Telescopes</td>
</tr>
<tr>
<td>Nishida</td>
<td>(T17) – Development of DAQ of CANGAROO-III</td>
</tr>
<tr>
<td>Nishijima</td>
<td>(T18) – Trigger module for CANGAROO-III</td>
</tr>
<tr>
<td>Ohishi</td>
<td>(T19) – Plastic Spherical Mirrors of CANGAROO-III</td>
</tr>
<tr>
<td>Osone</td>
<td>(T20) – New Gamma-Ray Detector Concept</td>
</tr>
<tr>
<td>Asahara</td>
<td>(T21) – Performance of 10-100 GeV “CheSS”</td>
</tr>
<tr>
<td>F. Krennrich</td>
<td>(T22) – SGARFACE – PBH Burst Experiment</td>
</tr>
<tr>
<td>S. LeBohec</td>
<td>(T23) – Cosmic Ray Calibration of ACTs</td>
</tr>
</tbody>
</table>
The Universe viewed in Gamma-Rays

- Univ. Tokyo Workshop 2002 -

25-28 Sept. 2002   Kashiiwa, Chiba, Japan
(Reaching a Major Atmospheric Cherenkov Detector)

http://icrrhp9.icrr.u-tokyo.ac.jp

Not this either!
### Selected New Results

1. First UnID TeV Source

2. RX J1713 Mystery

3. Sky surveys are here!

4. AGN have spectral variability

5. New AGN (H1426, 1ES1959)  
   New source type (NGC 253)?

6. AGN Cutoffs – what do we make of them?

7. Spectral measurements 50-250 GeV
1. First UnID Source at TeV

Rowell (T08)

- 4.6 $\sigma$ (post-trial)
- Weak $\sim$ 30 mCrab
  - But steady.
- Not clearly identified with any EGRET source.
- Proximity of Cyg OB2.
- Finite Size? $\sim$ 6'
- Hard Spectrum.
1. Spectrum of UnID TeV Source

- Detection and Spectrum Confirmed in 2002 Data (preliminary)
1. TeV J2032+4131

Most consistent with Cyg OB2 complex, but

No apparent counterpart at TeV position.

What is this object?

... we don’t know.

Catalog of UnID TeV Sources is started.
2. RX J1713-3946 Mystery

Tanimori (02)  
Kawachi (S06)

TeV-Gamma  
3.8m Tele.

7m Tele. 1999 (16hours))  
\[ E_\gamma > \sim 1 \text{TeV} \ (E^{-2.5}) \]
2. Mystery I

Enomoto et al 2002
Hard to explain with IC.

Reimer & Pohl 2002
Proton fit inconsistent with actual EGRET limit.
2. Mystery II

Slane

Showed IC fit in agreement with CANGAROO, EGRET. Large B, small filling factor.

Tanimori

EGRET Source is 0.8° away

Doesn’t seem exp. valid!
RX J1713+4131 is Unsolved

- RX J1713 picture is not clear – one cannot claim from this source that there is evidence for VHE proton acceleration.

- In general, SNRs will have both an e – IC component and a proton – $\pi^0$ component, but separating the two is challenging. “Smoking Gun” is not so smoking!

Q: Is there good, direct evidence for VHE proton acceleration in any SNR? Cas-A is possible (Berezhko, Voelk) Relies on large B field reported for remnant. Resolved in future (HESS, CANGAROO-III).
3. Sky Surveys are Here!

Sinnis (S13)
Northern Hemisphere Sky Survey – Milagro

E ~ 4 TeV
3 locations in sky ~ Crab
Crab, Mrk 421, “Hot Spot”

Sakata (S30) Tibet As-\(\gamma\)
Similar, Crab only source
3. Sky Surveys – Cherenkov

Puelhohofer (S09)
Survey using archival HEGRA

0.4 sr covered – 3.5% of sky.
No strong new sources seen (except TeV J2032+4131)

TeV $\gamma$-ray Sky is not bright (Northern Hemisphere)
4. Spectral Variability of AGN

General trend is shown on short (30 min) time scales as well, but with lots of scatter.

Complicated system. Is spectral variability a general trend of blazars?
4. Spectral Variability of AGN

Horns HEGRA – Mrk 421, Similar behavior seen

Diurnal variation – “hysteresis” effect.

Implications were discussed by Mukherjee, Coppi.

Shift of synch peak to higher E.

Mukherjee: Evidence with EGRET.
5. New AGN 1ES1959+650

Holder (S07) - VERITAS
2002 Light Curve
Schroedter (S21) – Multi-\(\lambda\)

5. AGN H1426+428

Seen by Whipple, HEGRA, CAT. Weak source, z=0.129
Very soft spectrum, $\alpha \sim -3.0$

Krennrich: VERITAS & HEGRA data

Horns: Is HEGRA seeing Pile-up near 5 TeV – absorption?
5. New Source? NGC 253

NGC 253 in X-rays, EGRET UL
Starburst galaxy, near by

Voelk: Enhanced SFR, 0.1-0.3 SN/yr
Higher CR prod by factor 10-100

Itoh (S26) CANGAROO

Q: What is a realistic theoretical estimate?
Voelk: M82 weak, HEGRA < 0.02 Crab.
6. AGN Spectra Cutoffs

VERITAS data show similar Cutoff for Mrk 421/501 ~ 4 TeV

Okumura (S15) – CANGAROO Data has 4σ excess above 20 TeV

HEGRA did not show new results here – get somewhat different values for Mrk 421 & 501.

Possibly not intrinsic?

Dwek (2): Full review of IR measurement & implications.
7. Spectral Measurements 50-250 GeV

Piron (S02)
CELESTE has measured diff. spectrum for Crab, Mrk 421.

de Jager discussed the Crab pulsar search – getting close!

Hanna (S01)
STACEE data on Mrk 421 2001 flare, light curve and flux comparison.
See also Boone (S22).
Additional contributions that I did not have time to discuss:

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edwards</td>
<td>G07</td>
<td>VLBI Observations of $\gamma$-ray sources</td>
</tr>
<tr>
<td>Tamagawa</td>
<td>G04</td>
<td>Properties of GRBs localized by HETE-2</td>
</tr>
<tr>
<td>Sinitsyna</td>
<td>S14</td>
<td>Detection of AGN with Shalon</td>
</tr>
<tr>
<td>Borisov</td>
<td>S18</td>
<td>TeV emission from SNRs and Cyg X-3</td>
</tr>
<tr>
<td>Cortina</td>
<td>S23</td>
<td>HEGRA CT1 spectrum of Mrk 421</td>
</tr>
<tr>
<td>Hayashi</td>
<td>S24</td>
<td>CANGAROO obs. of SS433/W50</td>
</tr>
<tr>
<td>Kawachi</td>
<td>S27</td>
<td>CANGAROO obs. of PSR B1259-63</td>
</tr>
<tr>
<td>Kushida</td>
<td>S28</td>
<td>Multi-$\lambda$ study of PSR B1706-44</td>
</tr>
<tr>
<td>Osone</td>
<td>S29</td>
<td>Periodicity studies of blazars</td>
</tr>
<tr>
<td>Ueno</td>
<td>S31</td>
<td>Non-thermal emission near 30 Dor</td>
</tr>
<tr>
<td>Yamamoto</td>
<td>S33</td>
<td>Diffuse gamma-rays search with Tibet</td>
</tr>
<tr>
<td>Nakase</td>
<td>S34</td>
<td>CANGAROO obs. of PKS 2155-304</td>
</tr>
<tr>
<td>Hattori</td>
<td>S35</td>
<td>CANGAROO search for clusters of galaxies</td>
</tr>
</tbody>
</table>
Big Themes - Recap

- Source Count increasing steadily.
- S hemisphere will be increasingly important for field.
- Multi-$\lambda$ Approaches are essential.
- Experimentation & Technology march on.
- First UnID TeV source.
- VHE Proton acceleration in SNRs still open.
- AGN are complicated beasts, but VHE data may be the most interesting.
- $\gamma$-ray sky is not bright at VHE (same as UHE).
- There are prospects for exotica e.g. Bergstrom (10) talk on dark matter.
With the advent of HESS, MAGIC, CANGAROO, (VERITAS) – we are entering a new era for observations. Field has always been observationally driven (lack of sources!), but now telescopes will provide lots of results for theorists.

VHE astrophysics is changing, and it will continue to change. Sources we would like to study include:

- GRBs (SWIFT era)
- Diffuse emission (Galactic, Isotropic)
- Something completely new!
Experimentally, great progress has been made – but, it has taken 10 years to reach the Major Atm. Cherekov Detector!

People are looking ahead:
- High altitude arrays (5@5, etc.)
- High precision optical systems (see T16)
- Advanced technologies (see T05)
- Wide FOV instruments – several groups across the world (e.g. Kifune)
Last year – we had hoped to have this meeting.

Coincide with the “retirement” of Tadashi Kifune.

The field of VHE g-ray Astrophysics owes a great deal to Tadashi –

One of the pioneers of the field, of the AC technique, and of observations in the Southern Hemisphere.
Kifune Pictures
Kifune-san “Retirement”
“Kifune Plot”

The diagram shows a log scale plot of the number of sources against years from 1970 to 2000. Key events and missions include:

- **X-rays**
- **SAS-2**
- **Uhuru**
- **COS B**
- **Ginga**
- **Asca**
- **Japanese X-ray Satellites**
- **Compton GRO/EGRET**
- **VHE γ-rays**
- **Ground-based Observation**

Notable locations mentioned are Tokyo and Kashiwa.
Thank you Tadashi !!

http://icrhp9.icrr.u-tokyo.ac.jp