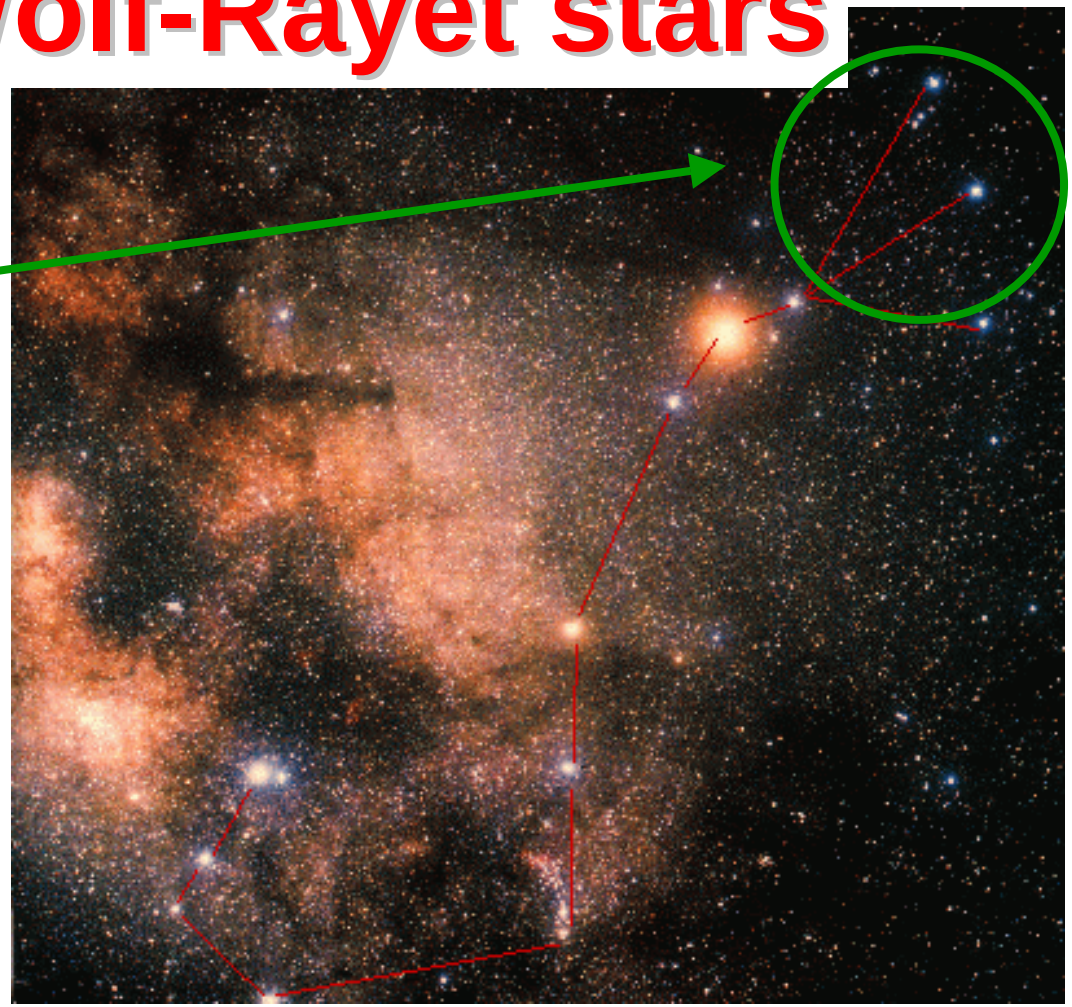
TeV gamma rays from OB and Wolf-Rayet stars

(OB association in Scorpius)



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Outline

1. Origin of the Cosmic rays: the Supernova paradigm
2. First serendipitous discovery by an Atmospheric Cherenkov gamma ray telescope: TeV J2032+4130
3. Particle acceleration in shocks in stellar winds of hot young stars ("*OB stars*") in dense environments – breaking the paradigm
4. What are "OB associations" ?
5. Two years after the discovery – what closer looks have revealed
6. Prospects for GLAST

Cosmic accelerators: the Supernova paradigm

A common conversation at cocktail parties and church socials:

Q: "What and where are the accelerators that push cosmic rays to such high energies?"

A: "Below the knee at 10^{15} eV, we believe that acceleration occurs here in the galaxy, by the Fermi mechanism, in the shocks where expanding supernova remnants sweep up the interstellar medium."

Supporting arguments –

1. **Energy budget: (sum of SN's) $\cong$ (ergs/cm^3 in cosmics)**
2. **Fermi predicts ~E^{-2}, sort of matches $E^{-2.7}$ (leaky box losses)**
3. **No other really good ideas…**

An unsatisfying paradigm…

- **Of ~300 known SNR's, a dozen are plausible test cases:**
  1. Want a nearby molecular cloud to allow "fixed-target" gamma production
  2. Want it near Earth
  3. Simply hasn't panned out…

- **Preceding numerology doesn't hold up.**
- **The high energy accelerators that we *can* study (i.e. gamma ray blazars) are best explained as electron machines, and are extragalactic – so where are the dang galactic hadron machines?**

- **Something *new* would be welcome…**

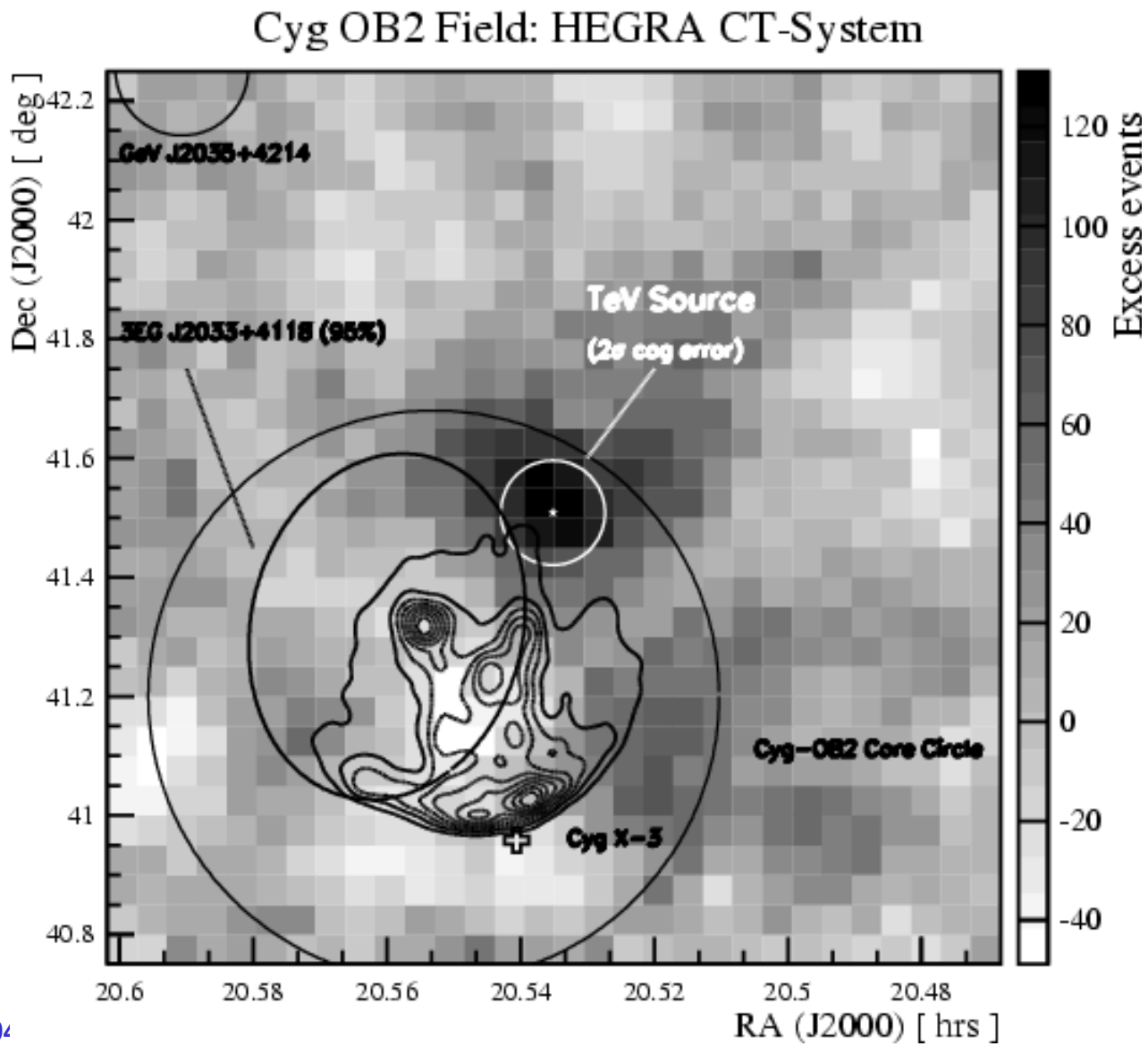
Serendipitous discovery by a Cherenkov telescope

HEGRA scanned a piece of the Cygnus region, to search the Egret unidentified source and Cyg X-3.

In 113 hours of data, a post-trial 4.6σ excess, *not* where they were looking.

(ASCA 2-10 keV overlay)

Aharonian…Horns…Rowell, A&A 393 L37-40 (2002)

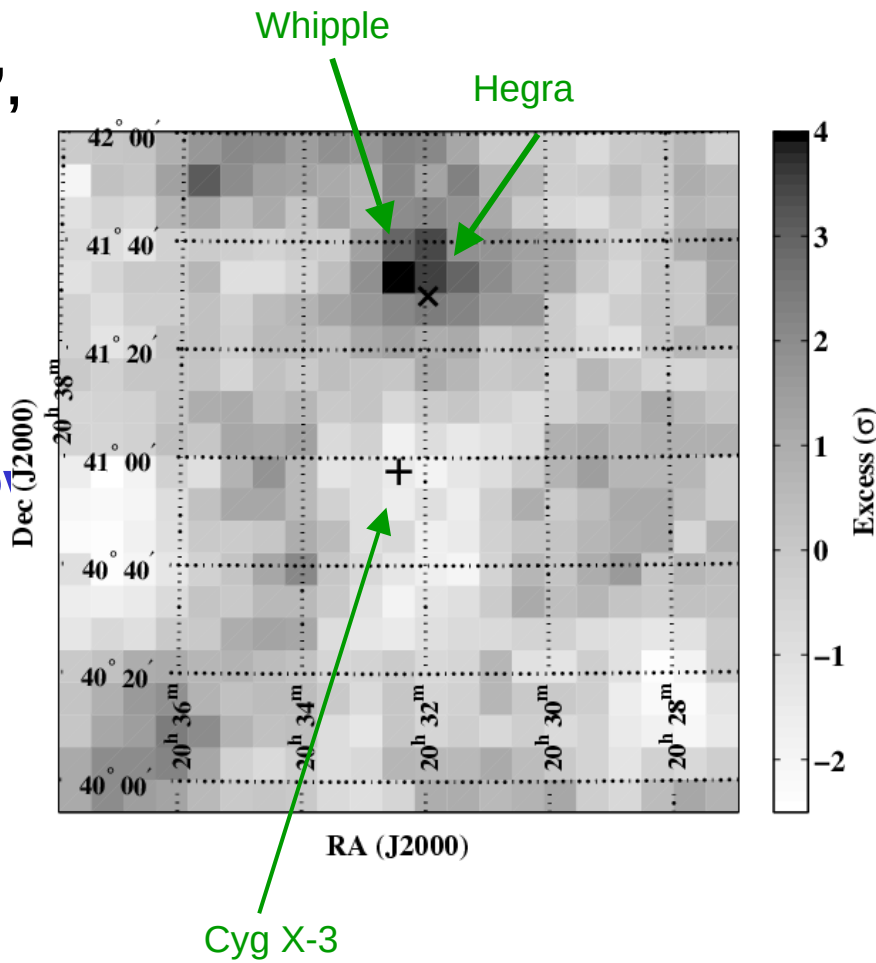


“Discovery”⇔”Confirmation”

“Evidence for γ ray emission from TeV J2032+4130 in Whipple archival data”,

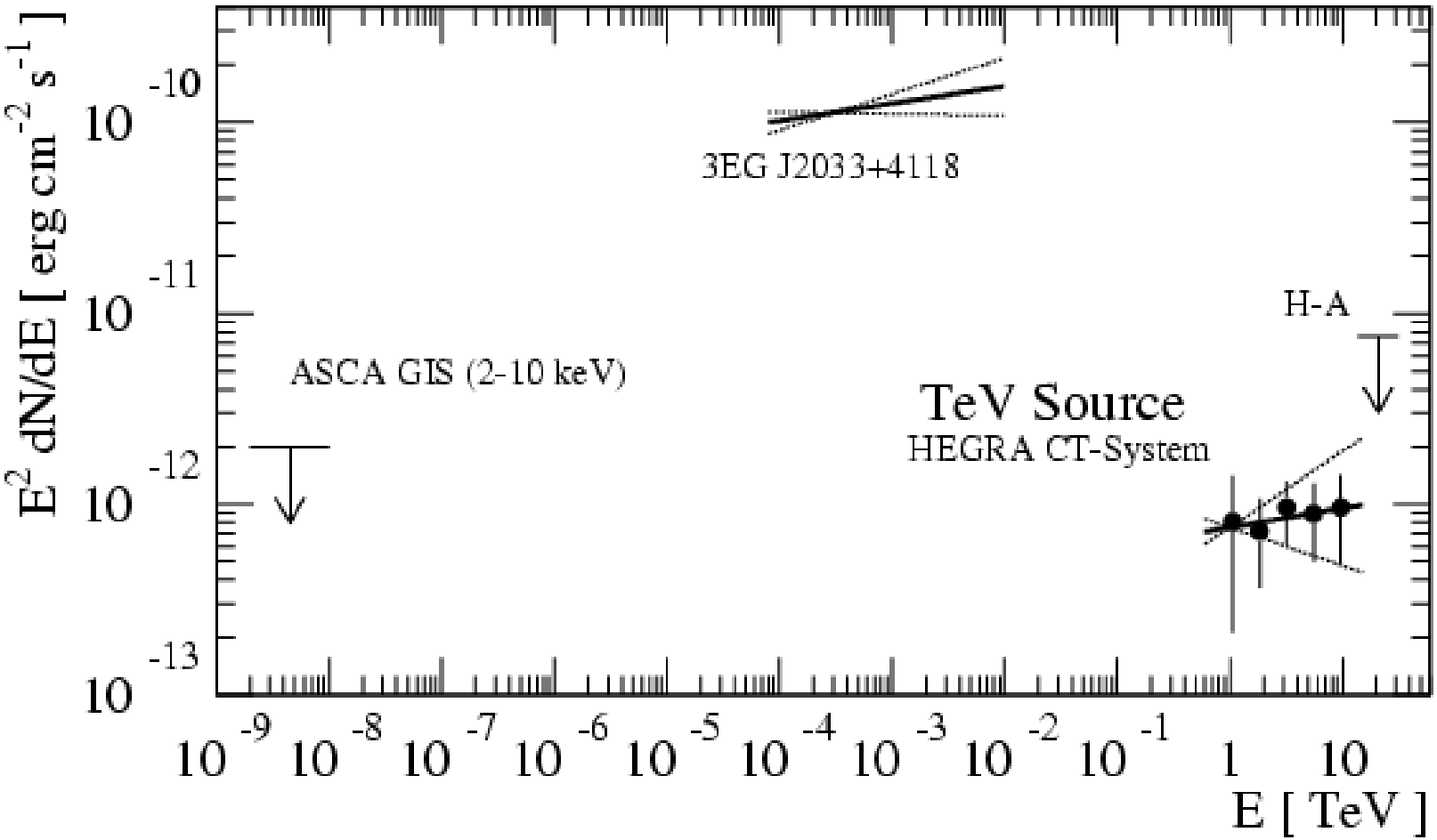
M.J. Lang et al, A&A 423, 415-419 (2004)

- **3.3σ (*a priori*) in 50 hours from ‘89-’90**
- **Nearly same position.**
- **12% of Crab flux (Hegra saw 3%).**
- **Neshpor et al 1995 (Crimea Cherenkov telescope) reported a 6σ excess at ~90% Crab flux at same position**
  (which they attributed to Cyg X-3)
  (few believed their result).
- **Apparently variable…**



Hegra spectral measurement

- Some would say, no match with Egret.
- Some would say, looks like Crab spectrum.



Omit from talk, save an hour

- Do not describe Atmospheric Cherenkov gamma ray telescopes.
- Do not explain that Hegra was the first stereo system (powerful!)
- Do not describe Cherenkov imaging via poetical analogies.
- Do not go into angular resolution and flux sensitivity.
- Do not tell personal anecdotes about CELESTE, ***my*** 50 GeV telescope.

Thémis
(Pyrénées)

CELESTE

CAT imager

ASGAT

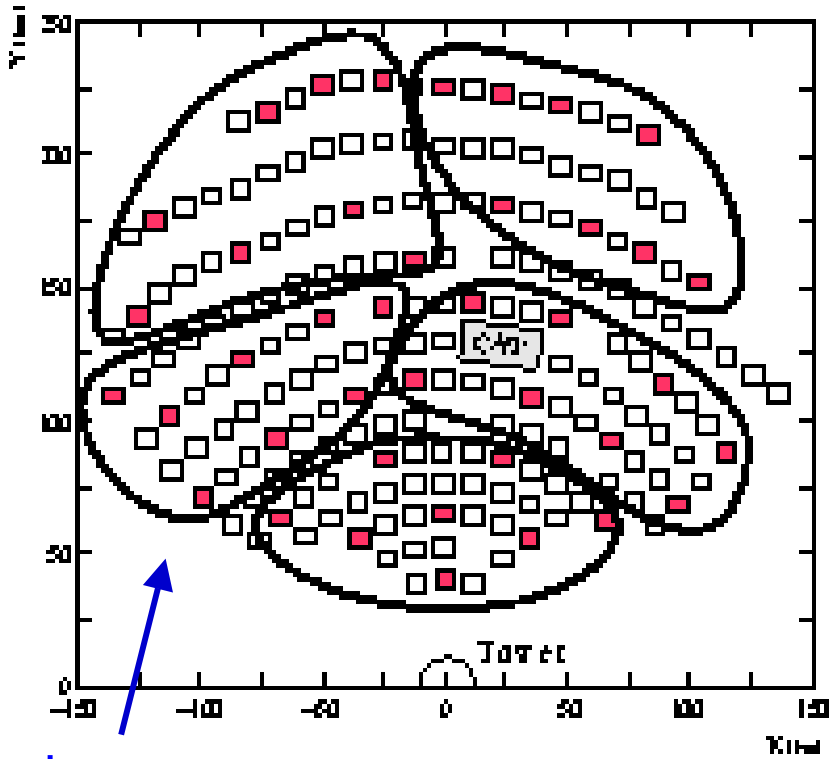
Themistocle

40 heliostats since 1999.

Trigger threshold: 30 GeV

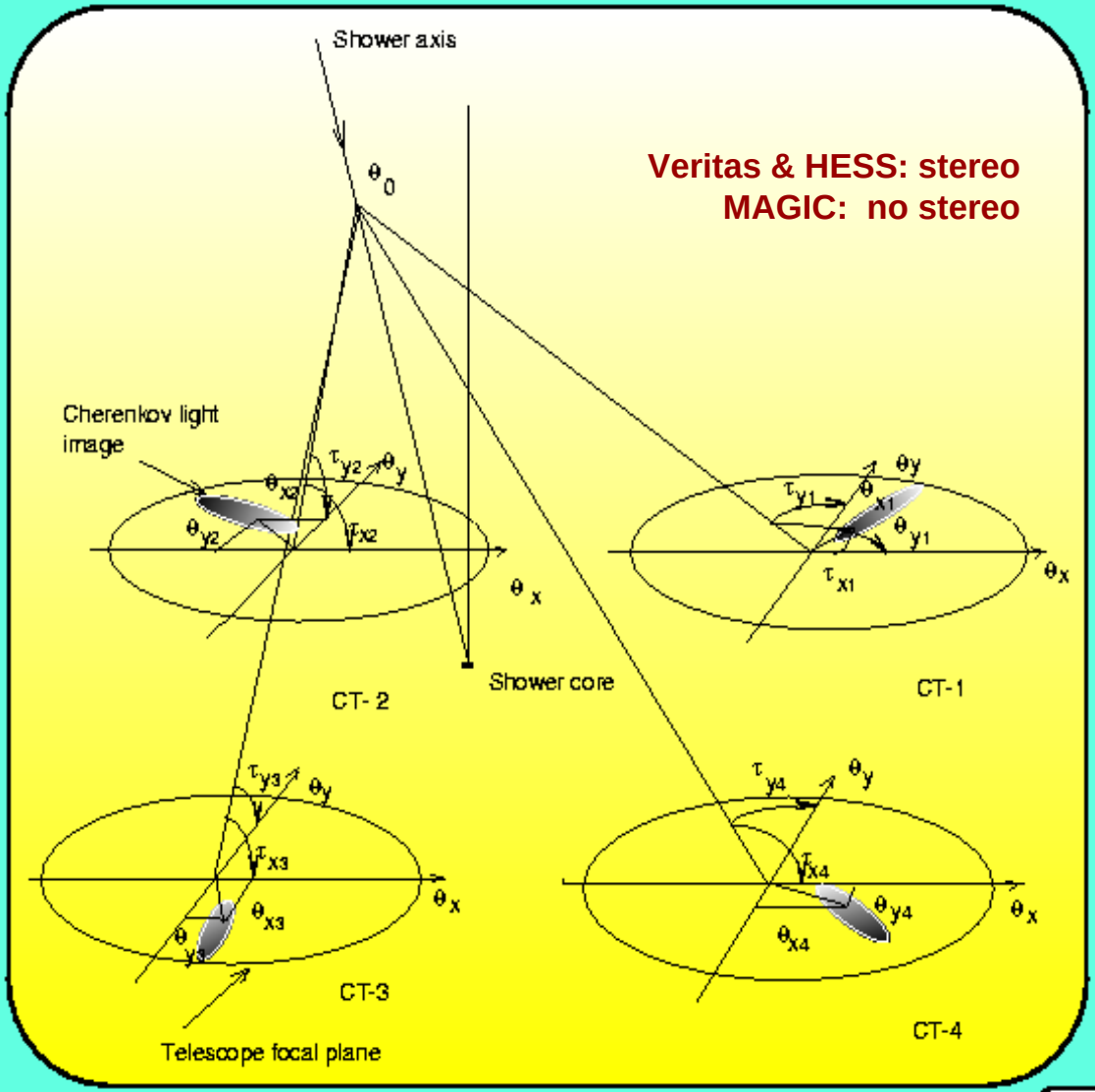
Analysis threshold: 50 GeV
(at transit)

13 heliostats added in 2001.



5 trigger groups

Geometrical Reconstruction of γ-Ray Air Shower



Veritas & HESS: stereo
MAGIC: no stereo

A. Konopelko,

γ 2000 Heidelberg

Alpha: perspective angle of parallel lines viewed from an offset position.
Like, looking up at tall trees. Or looking at meteor paths in the sky.

Digitally combined composite of nine 8-minute exposures, November 18th 1999, 1h29-2h46 TU, Sharm ElSheihk, Egypt, by Nigel Evans, courtesy of Sky & Telescope, June 2000. All Leonid meteors radiate from a point just inside the sickleof Leo, whose bottom star, Regulus, is the brightest star at lower left

Particle acceleration in OB associations

Hypothesis: the particle acceleration could occur via the Fermi mechanism in shocks between the stellar winds of hot young stars ("*OB stars*") in dense environments.

This was predicted (but we'd never heard of it**…) : see e.g.**

"On gamma-ray sources, supernova remnants, OB associations, and the origin of the cosmic rays", Thierry Montmerle, ApJ 231, 95-110 (1979)

"Local gamma rays and cosmic ray acceleration by supersonic stellar winds", Michel Cassé & Jacques Paul, ApJ 237, 236-243 (1980)

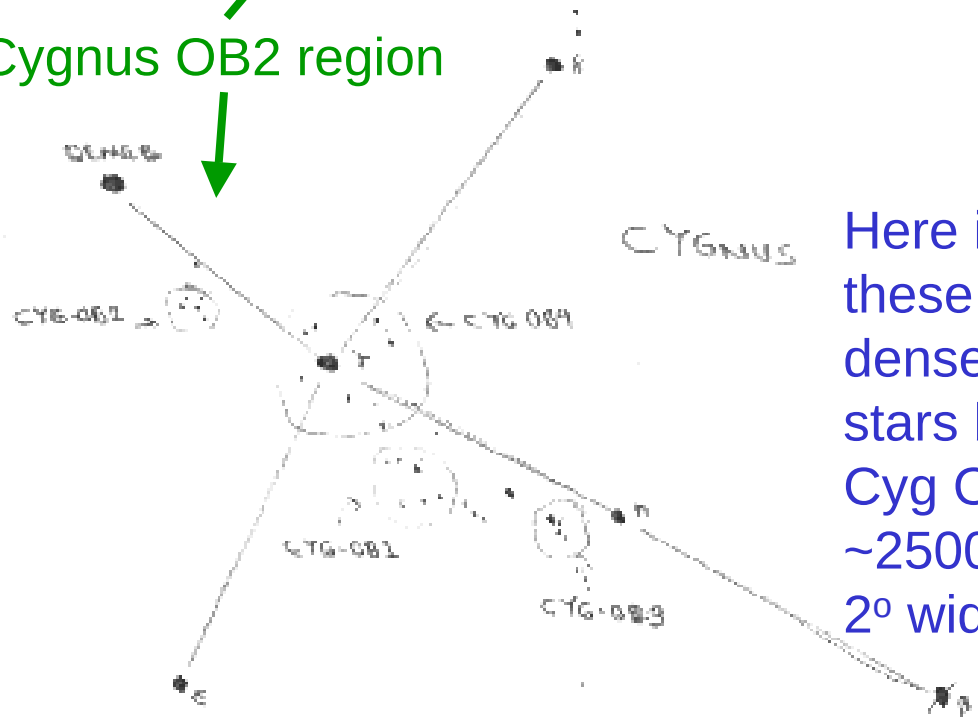
Advantages:

1. **E^{-2} argument still works**
2. **energy budget argument still (almost) works**
3. **Breaks the SNR monopoly**

So… what are “OB associations”?

Cygnus OB2 region

Scorpius
(intro slide of talk)



Here in the Milky Way, about 50 of these groupings (“clusters” are even denser). Full of young, hot, short-lived stars blowing off material at high rates. Cyg OB2 is one of the biggest, with ~2500 stars. It is ~1.7 kpc away, only 2^{o} wide (60 pc).

Oh Be A Fine Girl Kiss Me

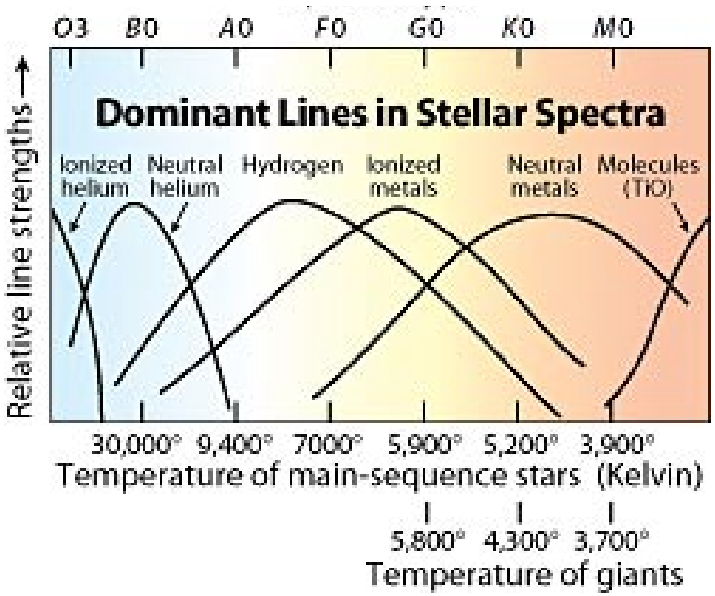
Only Boys Accepting Feminism Get Kissed Meaningfully

Hottest ➔ ➔ ➔ ➔ ➔ ➔ ➔ ➔ ➔ Coolest

Stellar spectral classification system:

1. Black-body temperature sets the star's color and determines its *surface brightness:*
2. Atmospheric pressure depends on the star's surface gravity and so, roughly, on its size —a giant, dwarf, or in between.

The size and surface brightness yield the star's luminosity and often its evolutionary status (young, middle-aged, or nearing death). Apparent brightness then gives an idea of the star's distance. Appended to the basic spectral type may be letters for chemical peculiarities, an extended atmosphere, unusual surface activity, fast rotation, or other special characteristics.

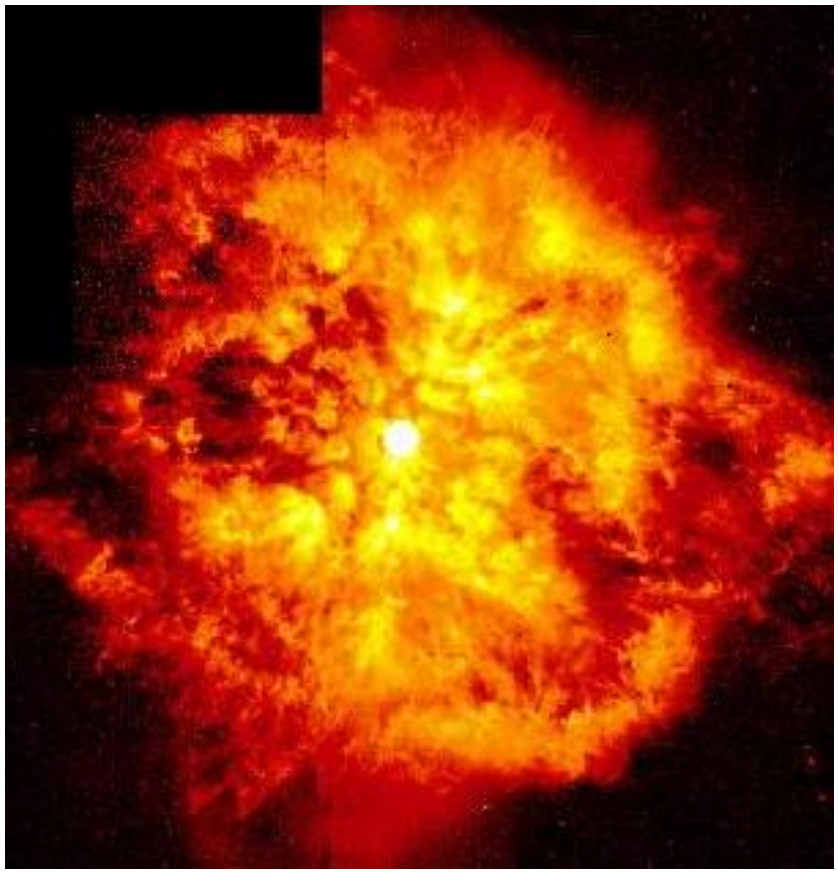


(From skyandtelescope.com)

Wolf-Rayet

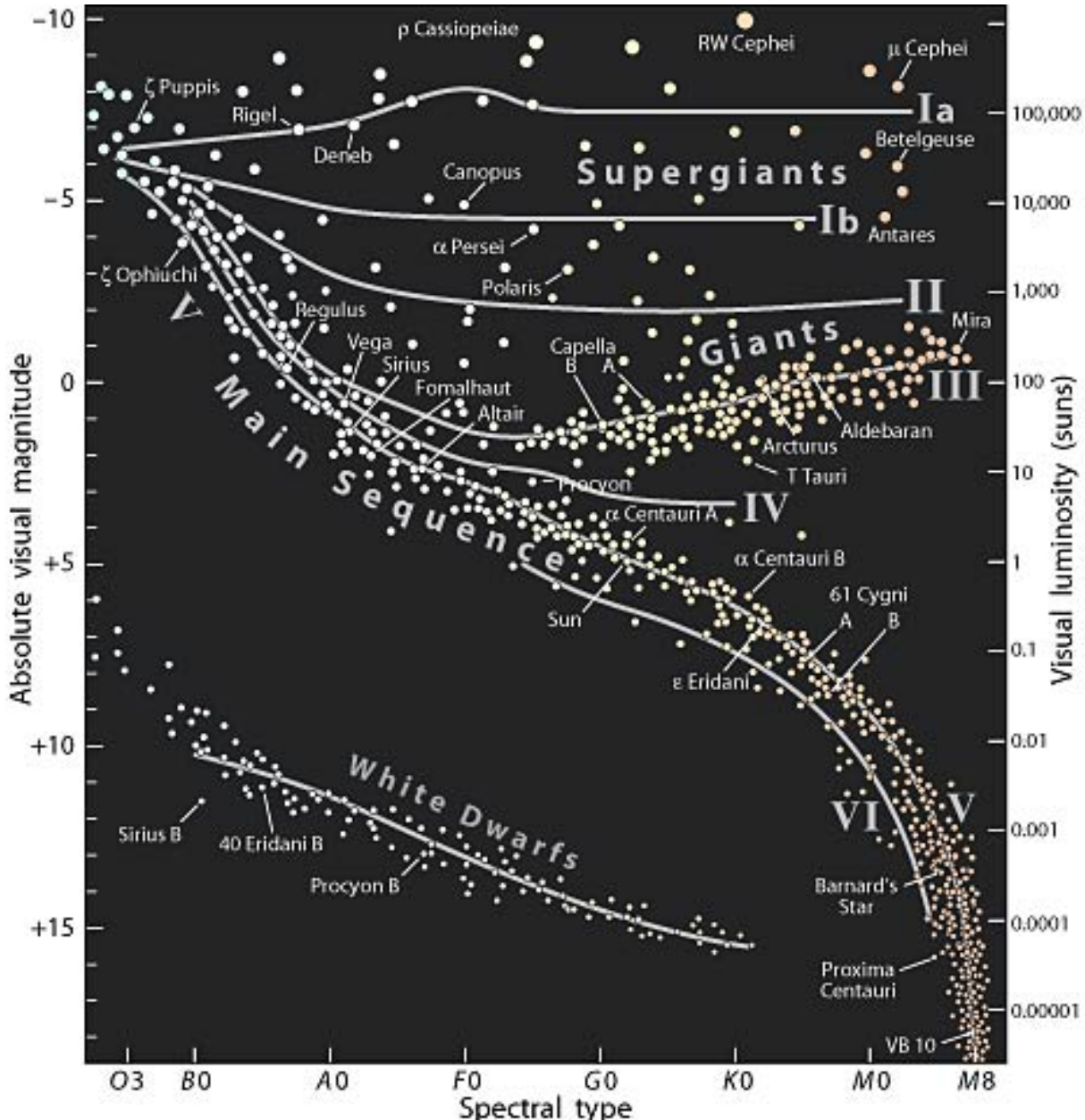
Wolf-Rayet stars are hot (25-50,000+ degrees K), massive stars (20+ solar mass) with a high rate of mass loss.

(This is WR124, at 19h11 +16)



A few other spectral types don't fit the sequence but instead parallel it. Type *W* or **Wolf-Rayet stars** are as hot and blue as the hottest *O* stars but show strong emission lines, either of nitrogen (*WN*), carbon and oxygen (*WC*), or neither (*WR*). Emission lines indicate an especially large, thick shroud of hot gas surrounding these stars. The *W* stars appear to have blown off their original outer layers of hydrogen, exposing other materials beneath.

Herzsprung-Russel Diagram

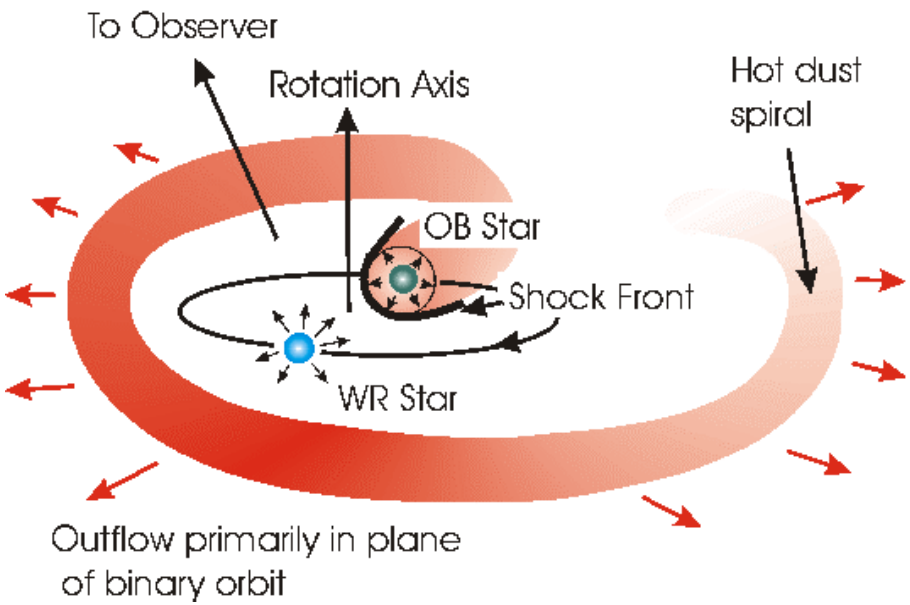


The “OB” phase lasts about a million years.

Very turbulent places

- **At least 20% of stars are in binary systems – 50% for OB's.**
- **Here: OB-WR pair in the southern sky (*not* Cygnus)**
- **In associations, stars being born, others dying, dust, winds.**

Interacting Binary Wind Model
of Spiral Outflow Around WR 104



(about a 220 day orbit)

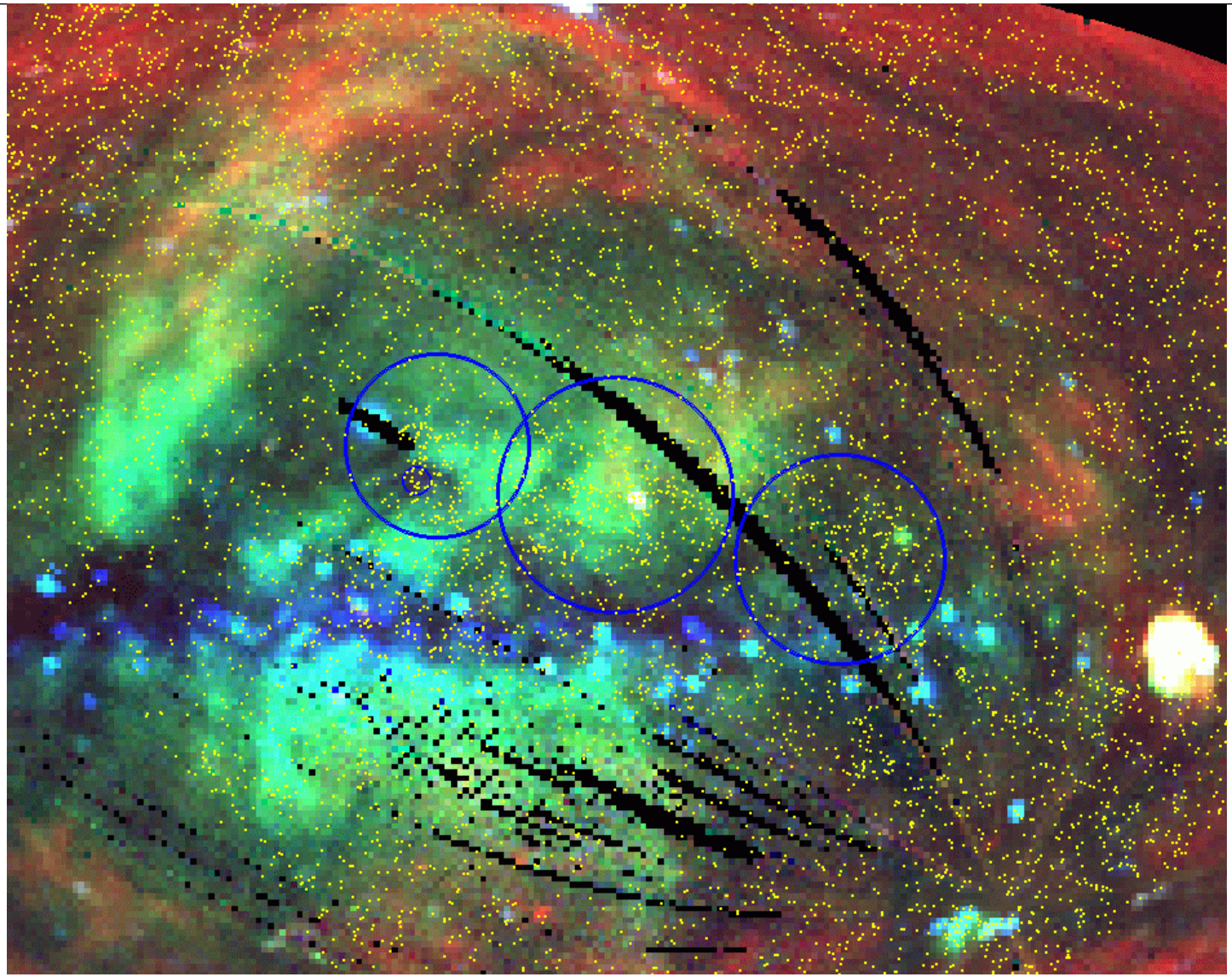
More fun facts

- Many OB stars have anomalously high proper motions – probably kicked by supernovas – recognized by their bright bow shocks.
  (e.g. 100 km/s, or 10x that of normal stars)
- Winds & motion are supersonic (in their local medium)
- OB associations are the main stellar birthplaces in our galaxy
  (important for understanding galactic evolution)
- Low surface brightness, much dust, large angular size – hard to see
- Young low-mass stars are bright X-ray sources – see next slide.
- Several OB associations coincident with Egret unidentifieds

Each yellow point is a ROSAT x-ray source – only brightest 10% shown.

Here: head of Scorpio, with 3 distinct OB associations (have more yellow points).

The huge green-ish bubble was blown by a supernova about a million years ago.



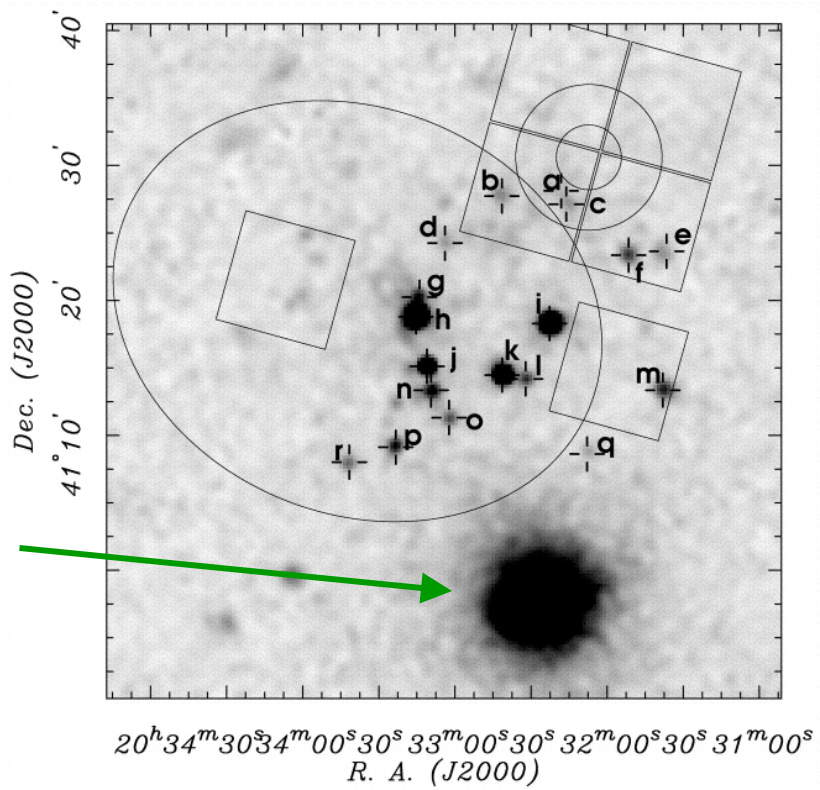
2 years later – what closer looks show (1 of 2)

"Search for a point-source counterpart of the unidentified gamma-ray source TeV J2032+4130 in Cygnus" R. Mukherjee et al, ApJ 589, 487-494 (2003)

- Obtained optical spectroscopy and *Chandra* time to search bright ROSAT sources within the 3EG and the TeV error boxes. No compelling counterpart.
- Brightest *Chandra* source is 7' from TeV source (TeV 2σ box has r ≈ 5'), weak evidence as a binary. Possibly LMXRB behind the OB association.
- Is a faint, reddish object – no spectral features so no stellar i.d.
- Possibly a "proton blazar" candidate, *far* behind the OB association…

Ellipse : 3EG J2033+4118 error box
Squares: *Chandra* fields-of-view
Small circle: Hegra error box
Big circle: Hegra 1s gaussian
Letters: tabulated, mostly known O stars

Cyg X-3



CHANDRA follow-up

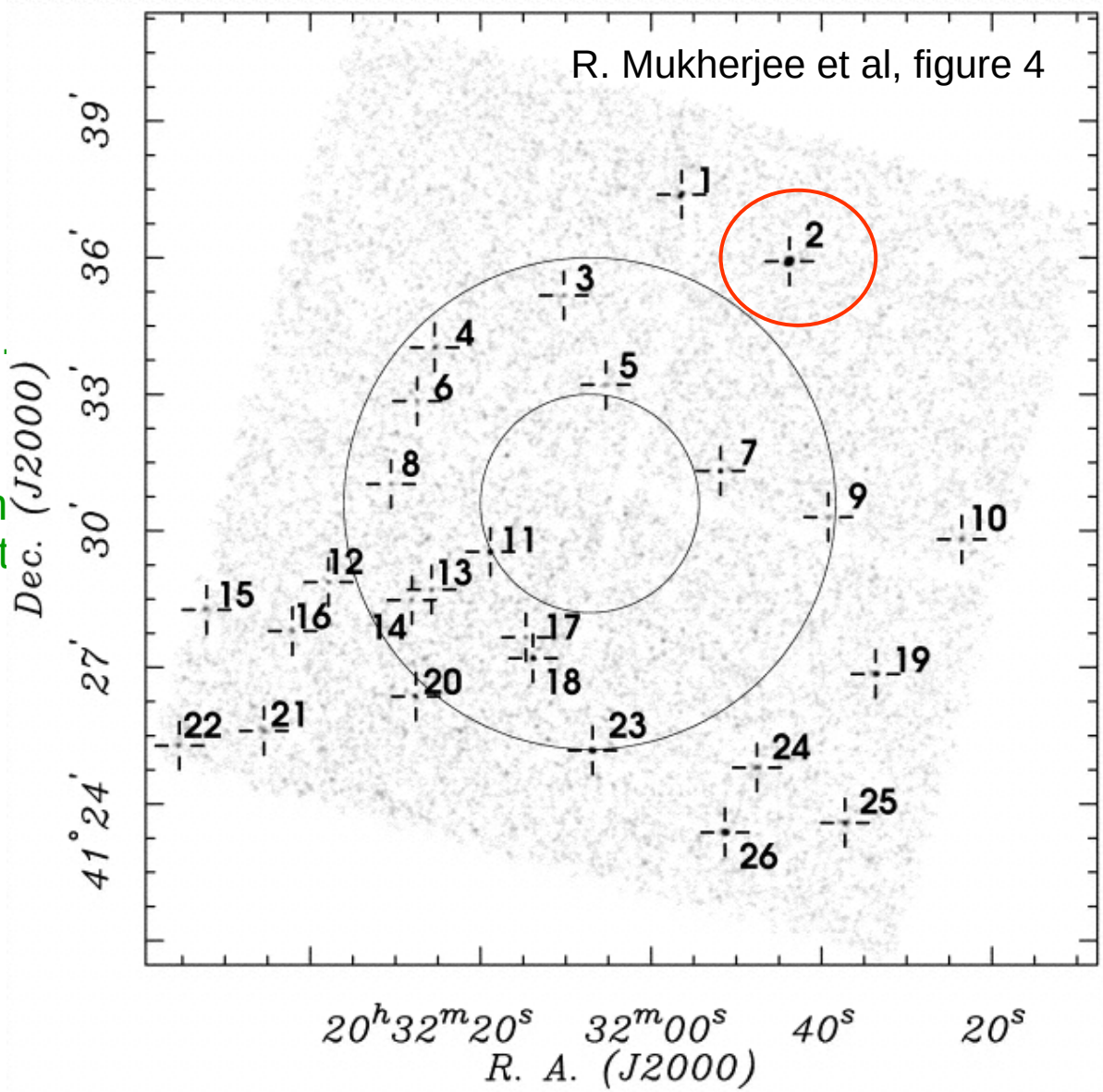
The 4 ROSAT sources became 27 Chandra sources.

All four are identified as stars (O7 III, G6 V, G3 V, O9)

Source 2 is brightest, variable. Possible background LMXRB.

8 1.4 GHz radio sources >2 mJy within 10' of TeV, none match the X-ray sources, so TeV not like gamma blazars.

4 Chandra sources have no optical counterpart (M<23). Hardest X-ray sources, likely AGNs.



2 years later – what closer looks show (2 of 2)

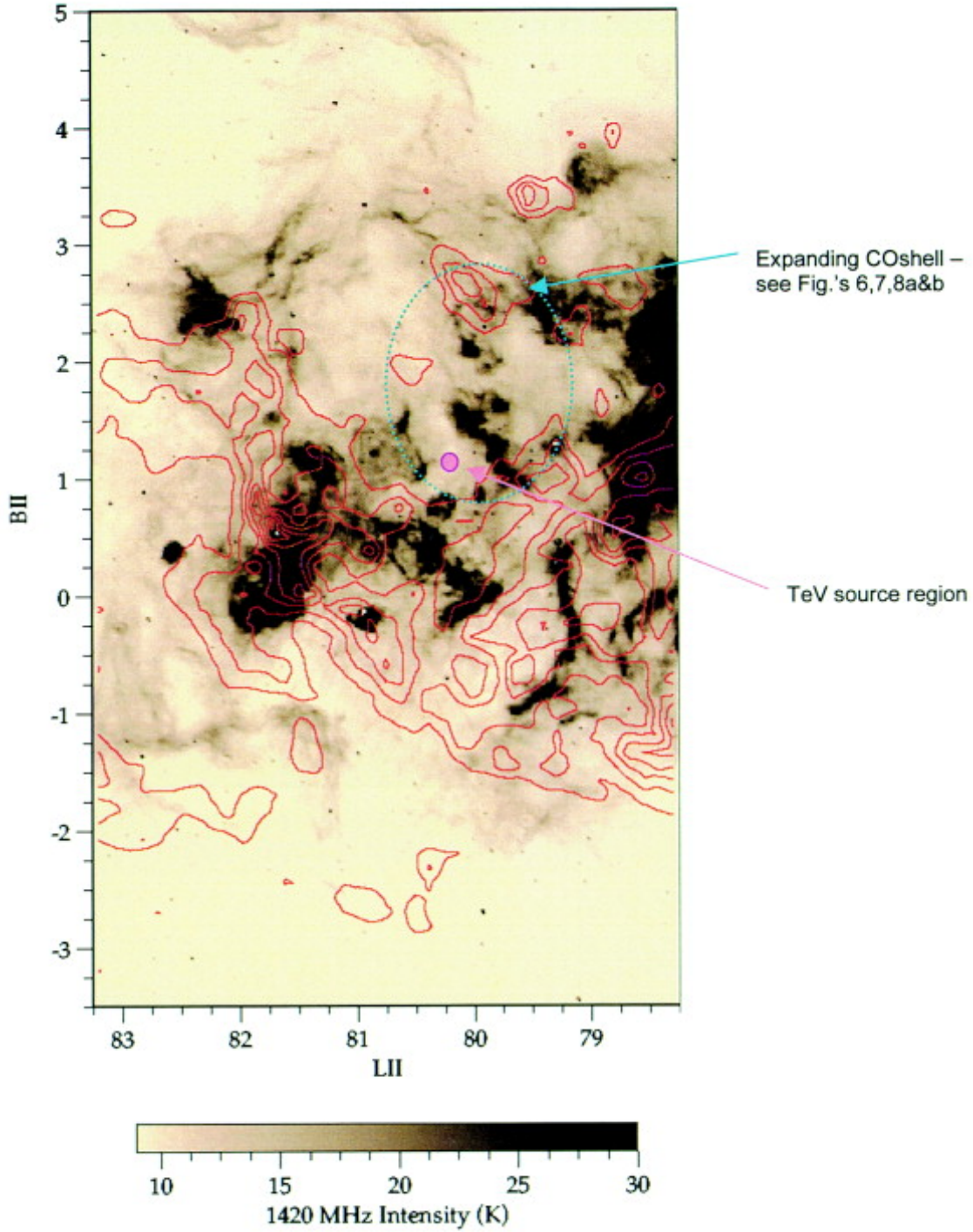
"Chandra/VLA Follow-up of TeV J2032+4131, the only unidentified TeV gamma-ray source" Y.M. Butt et al, ApJ 597, 494-512 (2003)

- Same spirit as preceding paper, but *even more* gory detail.
- Drop "point source" assumption – radio evidence for a large SNR-like structure
- Modeling of hadronic acceleration within the OB association.

Dave's tentative conclusions:

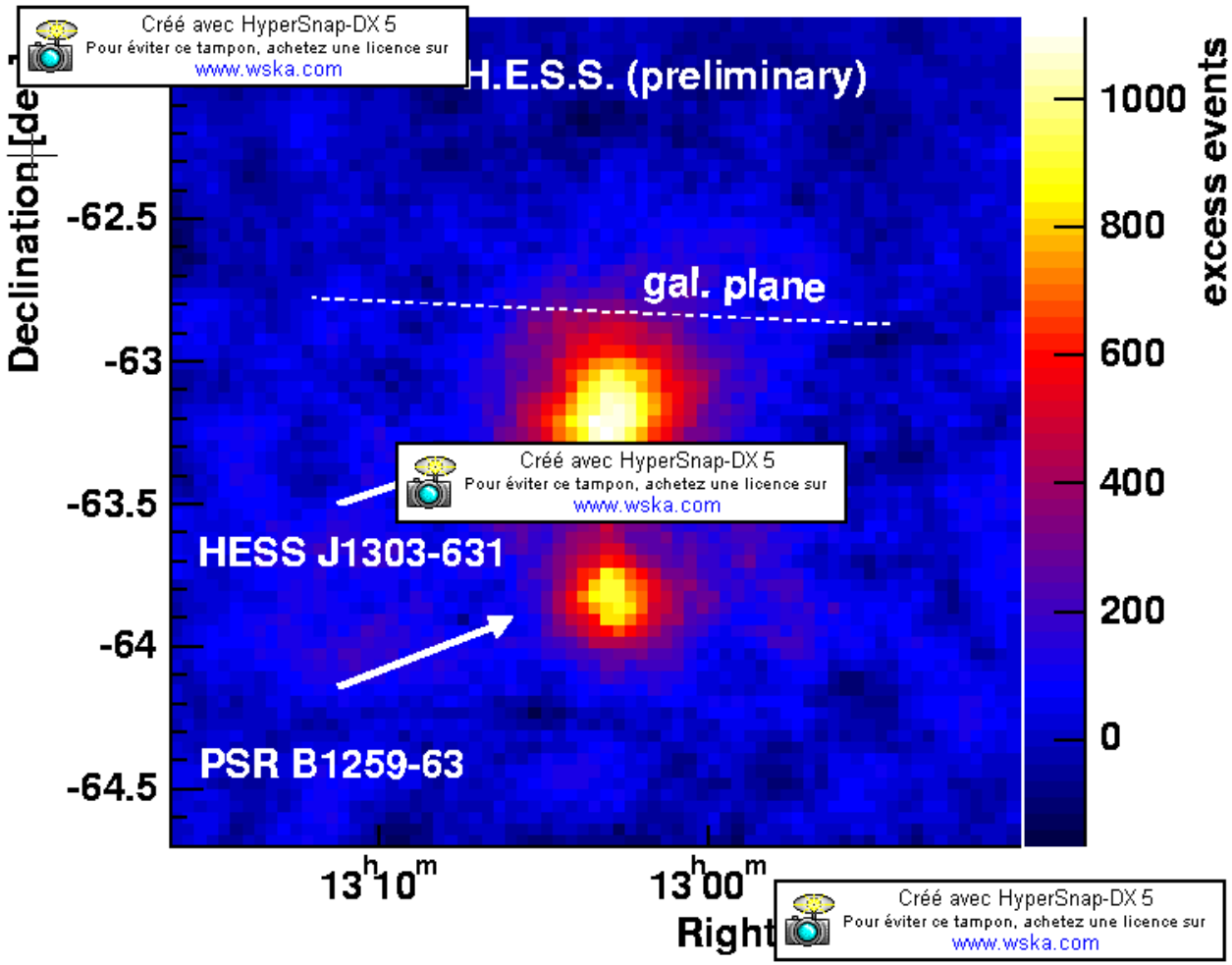
a) doesn't match Egret source
b) Mukherjee et al suggestion that it could be far behind OB association unsatisfying
c) Butt et al favor acceleration in the OB complex by slightly extended source.

Y.M. Butt et al,
ApJ 597, 494-512 (2003)
figure 9



2nd unidentified TeV Source HESS J1303-631

- Presented by Martin Tluczykont at Glast collaboration meeting.
- First time ever for ***two*** TeV sources in same field-of-view.
- No counterpart at other wavelengths yet seen.



Prospects for GLAST

- **Montmerle (1979) tabulates ~30 "SNOBS"** (SNRs close to OBs)
  [He discusses mainly (but not only) nucleon ➔ π^o ➔ $\gamma\gamma$]
- **Torres, Grenier, Knödlseder, and others have presumably already updated those lists.**
- **These are good candidates for gamma-loud, optical-quiet sources.**
- **By 2007 HESS will have more TeV unidentifieds.**
- **VERITAS, CANGAROO, MAGIC should as well.**