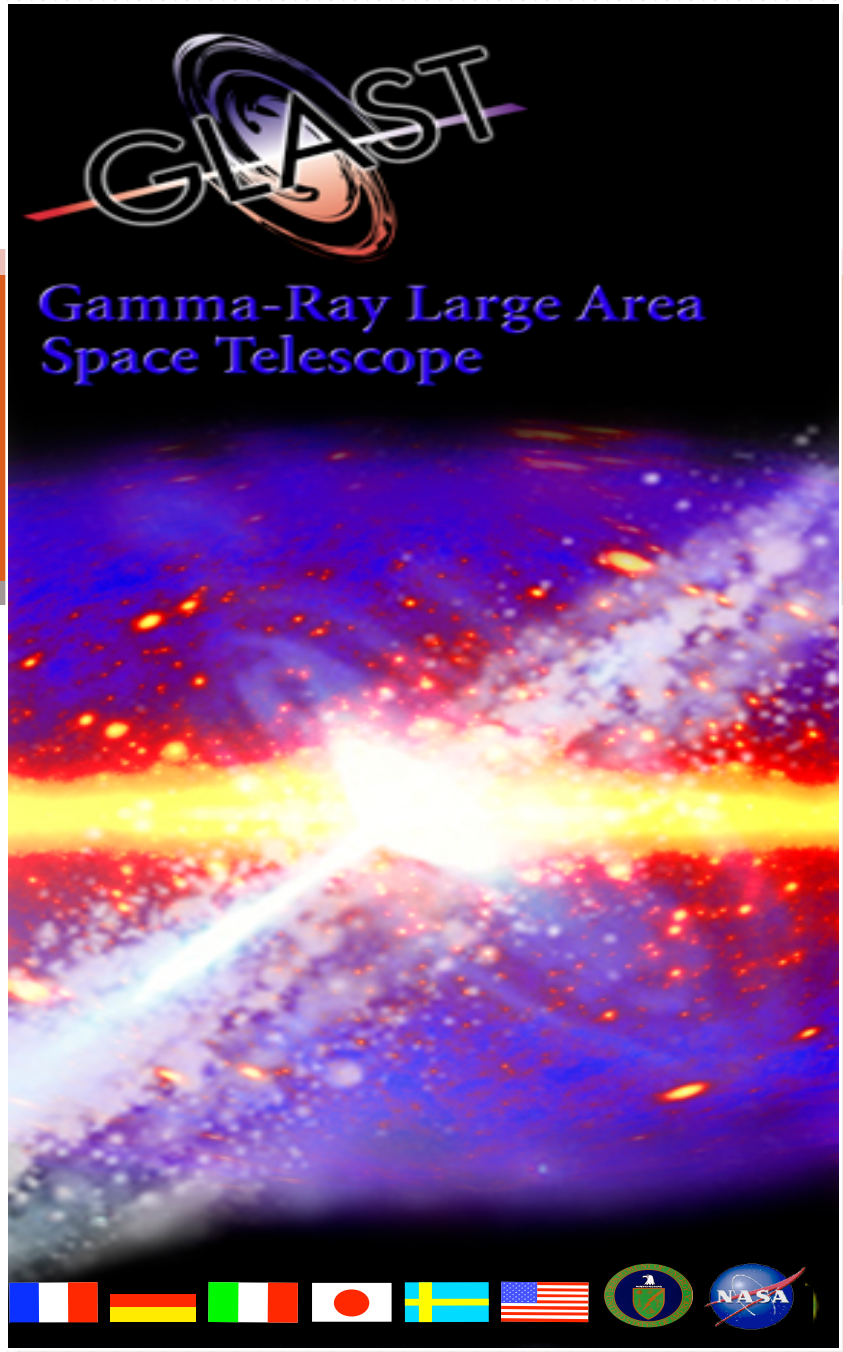


VLBI Studies of Relativistic Jets in the GLAST Era

and possibilities for US-China collaboration

Teddy C.C. Cheung
NASA Goddard Space Flight Center
for the GLAST-LAT collaboration

Teddy.Cheung@nasa.gov
21 April 2008

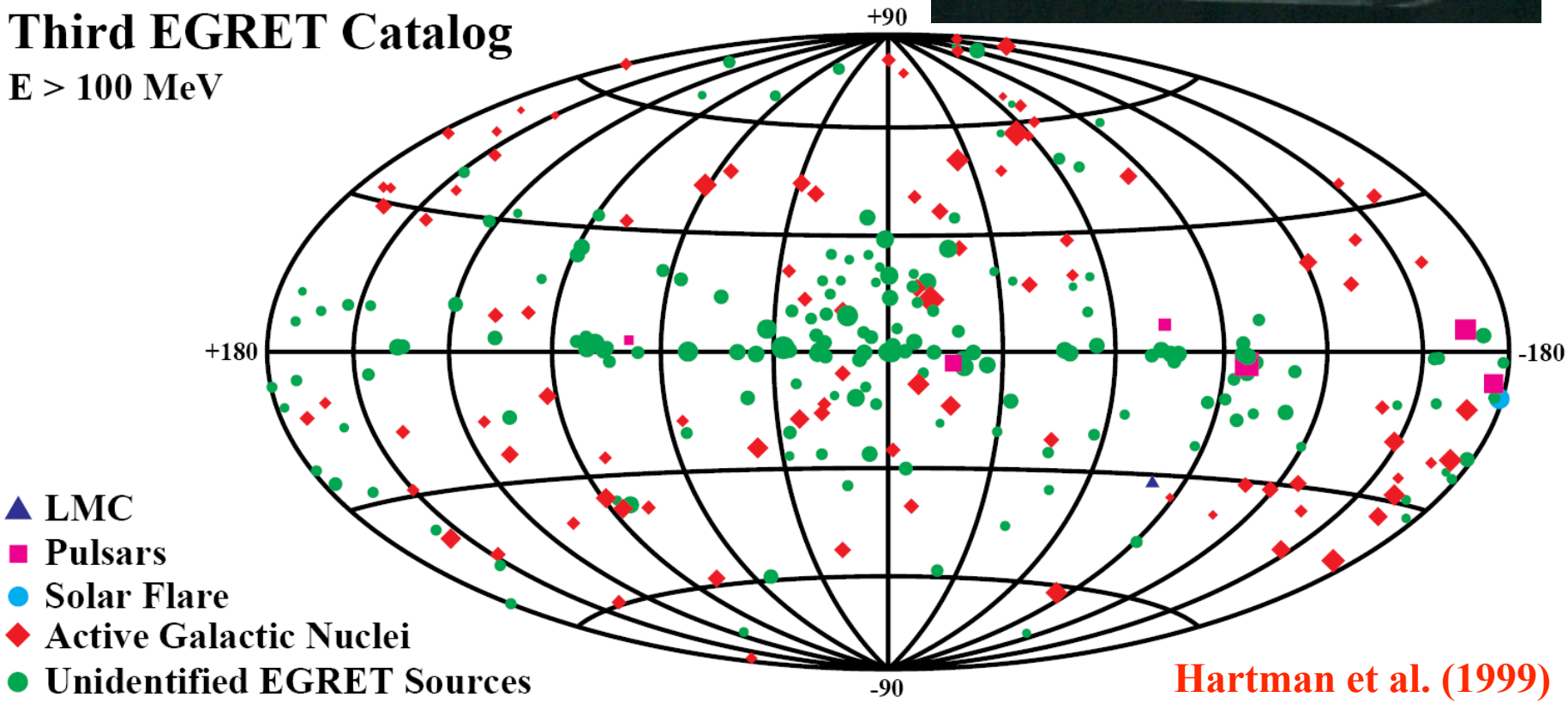
Anticipation

Scheduled launch around
May 16 on Delta II Heavy
Cape Canaveral, Florida

Compton Gamma-Ray Observatory (1991-2000)

271 EGRET sources: ~70 AGN, ~170 Unidentified.

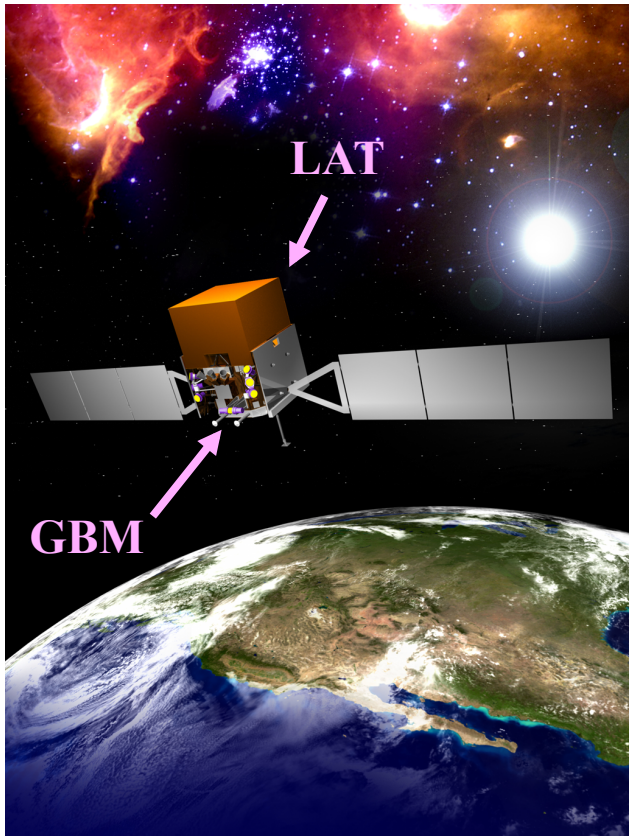
Previously, 25 COS-B sources: 1 AGN (3C273), 80% Unidentified



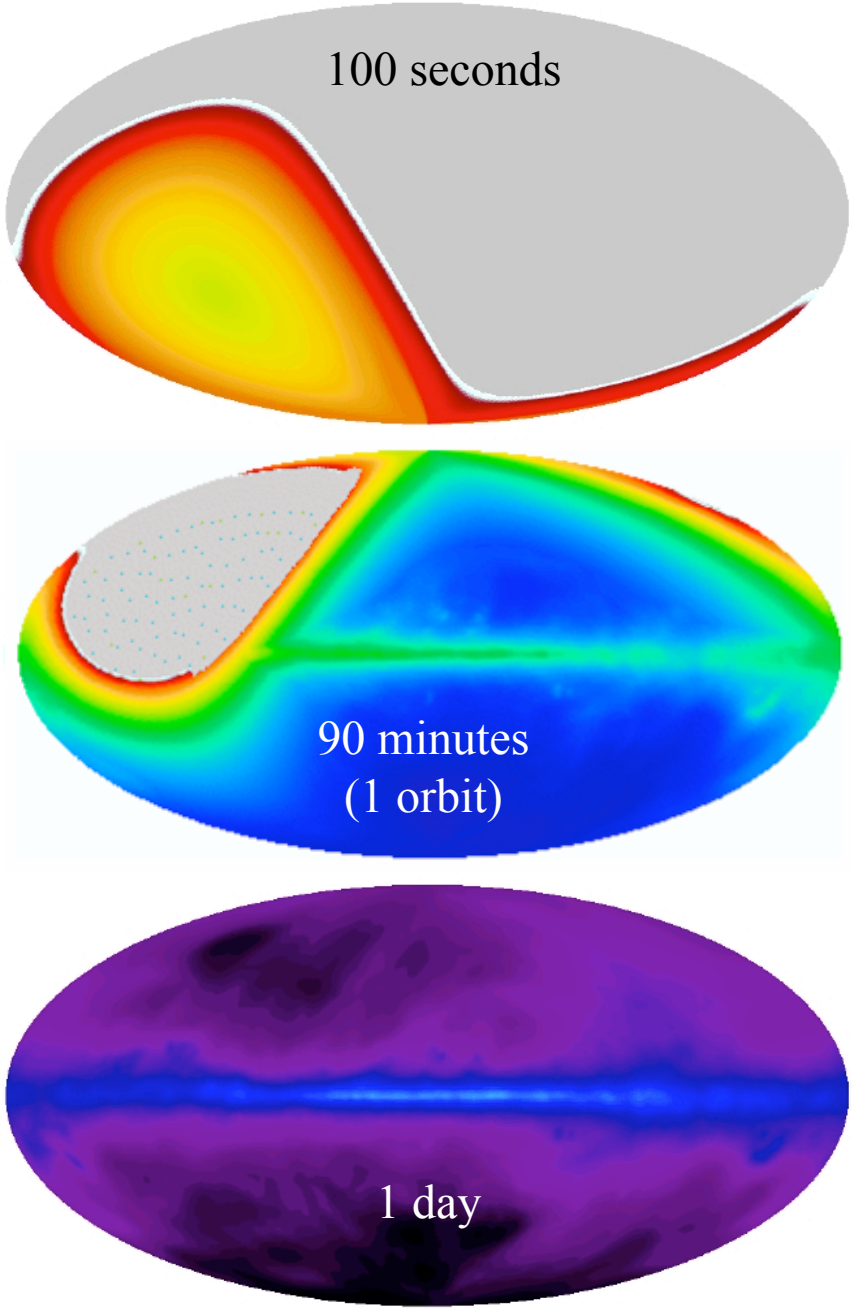
Hartman et al. (1999)

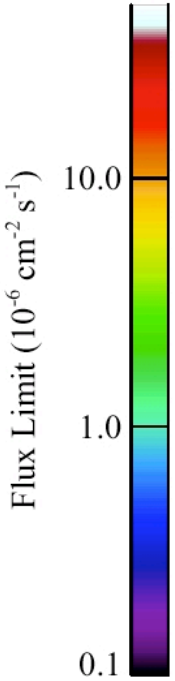
GLAST Large Area Telescope (LAT)

- Large Field of View: 2.4 Steradian
  ~20% of sky (>4x EGRET)
- Source localization: 0.4-10 arcmin
  (>3x EGRET)
- Effective area: 8000 cm^2 (>5x EGRET)
- Energy range: 20 MeV to 300 GeV
  (E>30 GeV unexplored)
- >30-100 times better sensitivity than
  EGRET
- 5 yr mission (10 yr goal)



LAT Sensitivity (sky survey mode)





EGRET Fluxes

- GRB940217 (100sec)
- PKS 1622-287 flare
- 3C279 flare
- Vela Pulsar

- Crab Pulsar
- 3EG J2020+4017 (SNR g Cygni?)

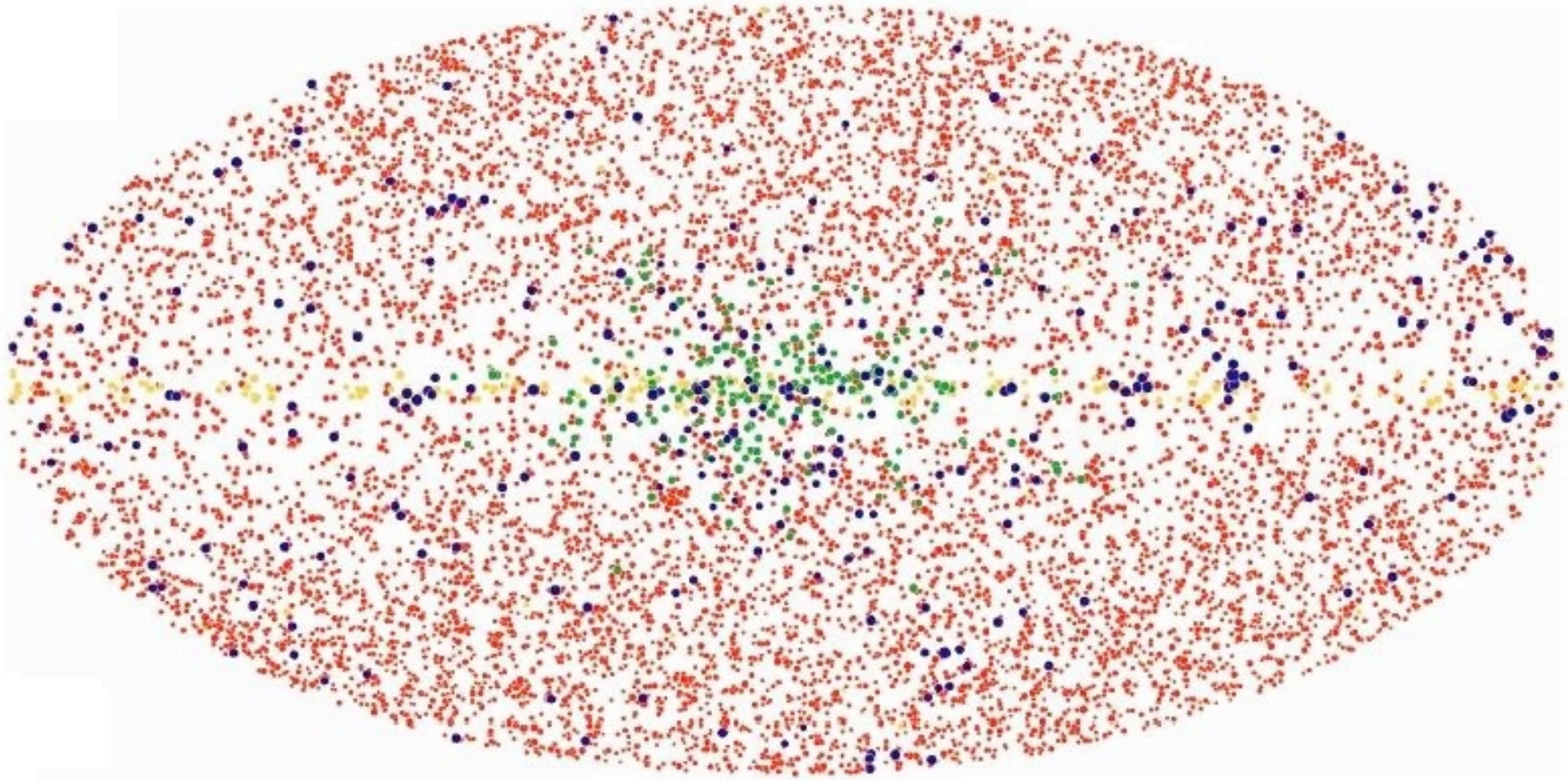
- 3EG J1835+5918
- 3C279 lowest 5σ detection
- 3EG J1911-2000 (z=1 blazar?)
- Mrk 421
- Weakest 5σ EGRET source

In 1 day, detect (at 5σ) the weakest EGRET sources.

In 2 weeks, detect # of photons that EGRET detected in entire mission.

5σ Sources from Simulated One Year All-sky Survey

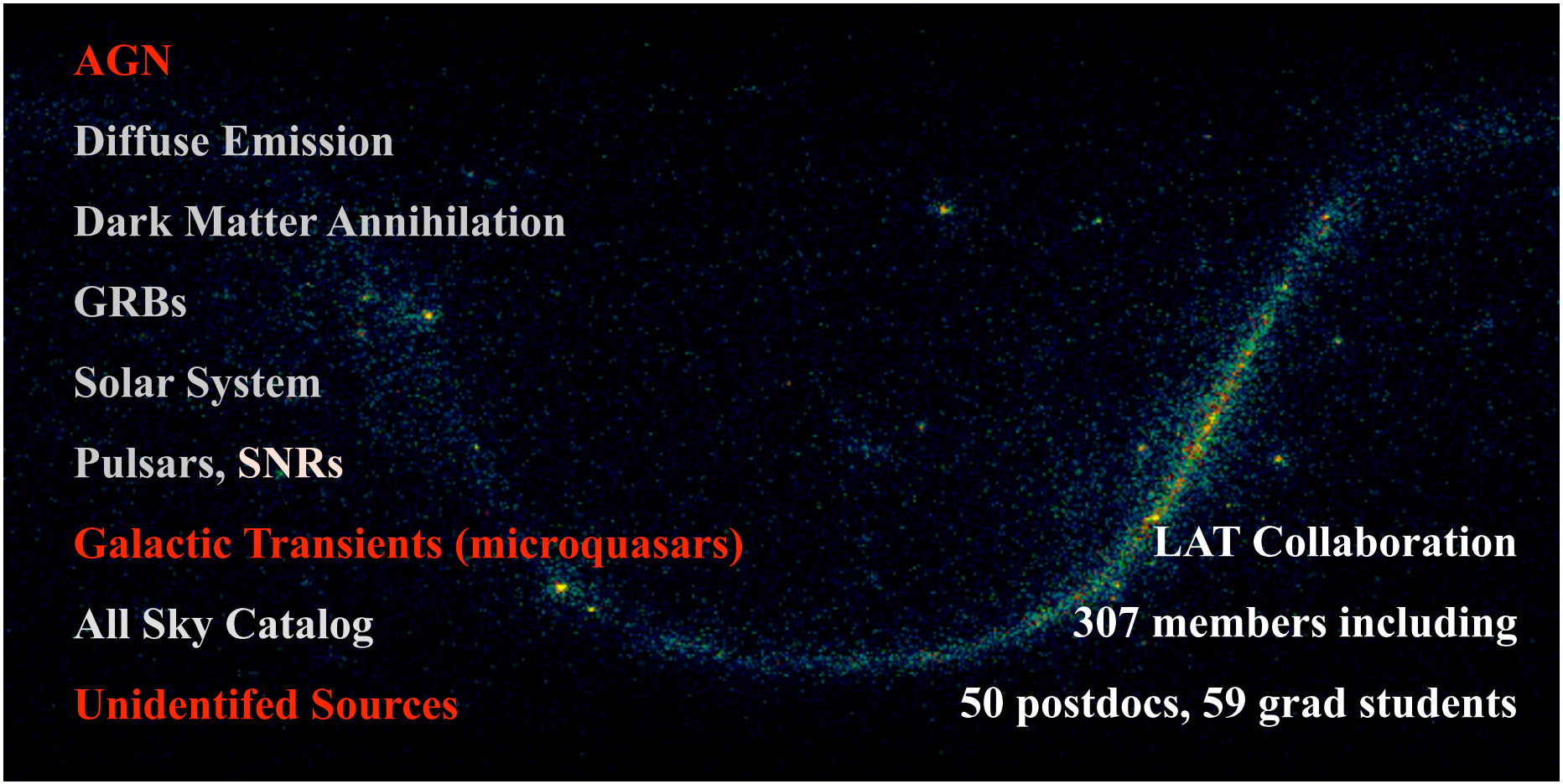
LAT 1st Catalog



Results of one-year all-sky survey.
(Total: 9900 sources)

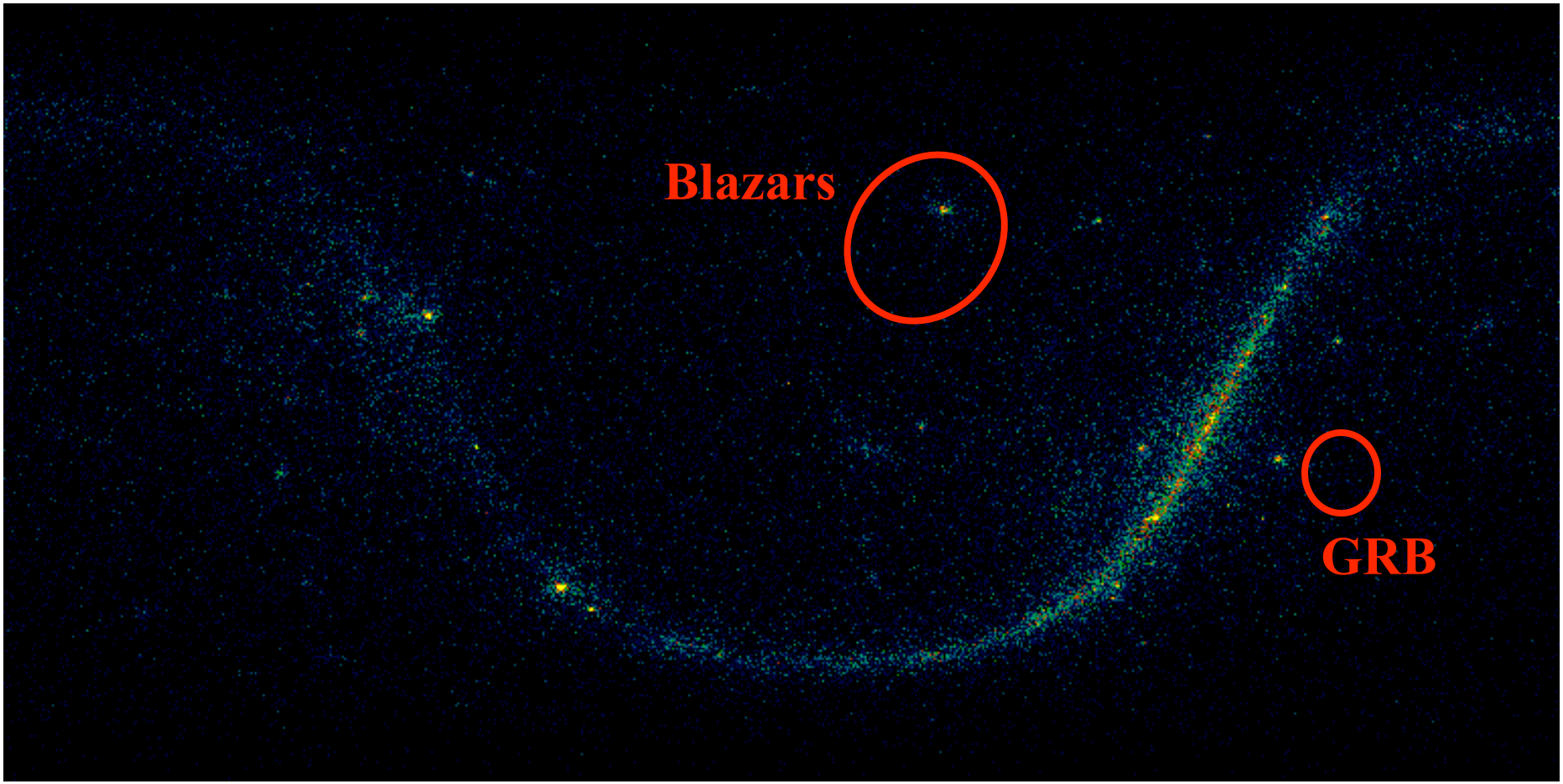
AGN
3EG Catalog
Galactic Halo
Galactic Plane

GLAST : Key Science Areas



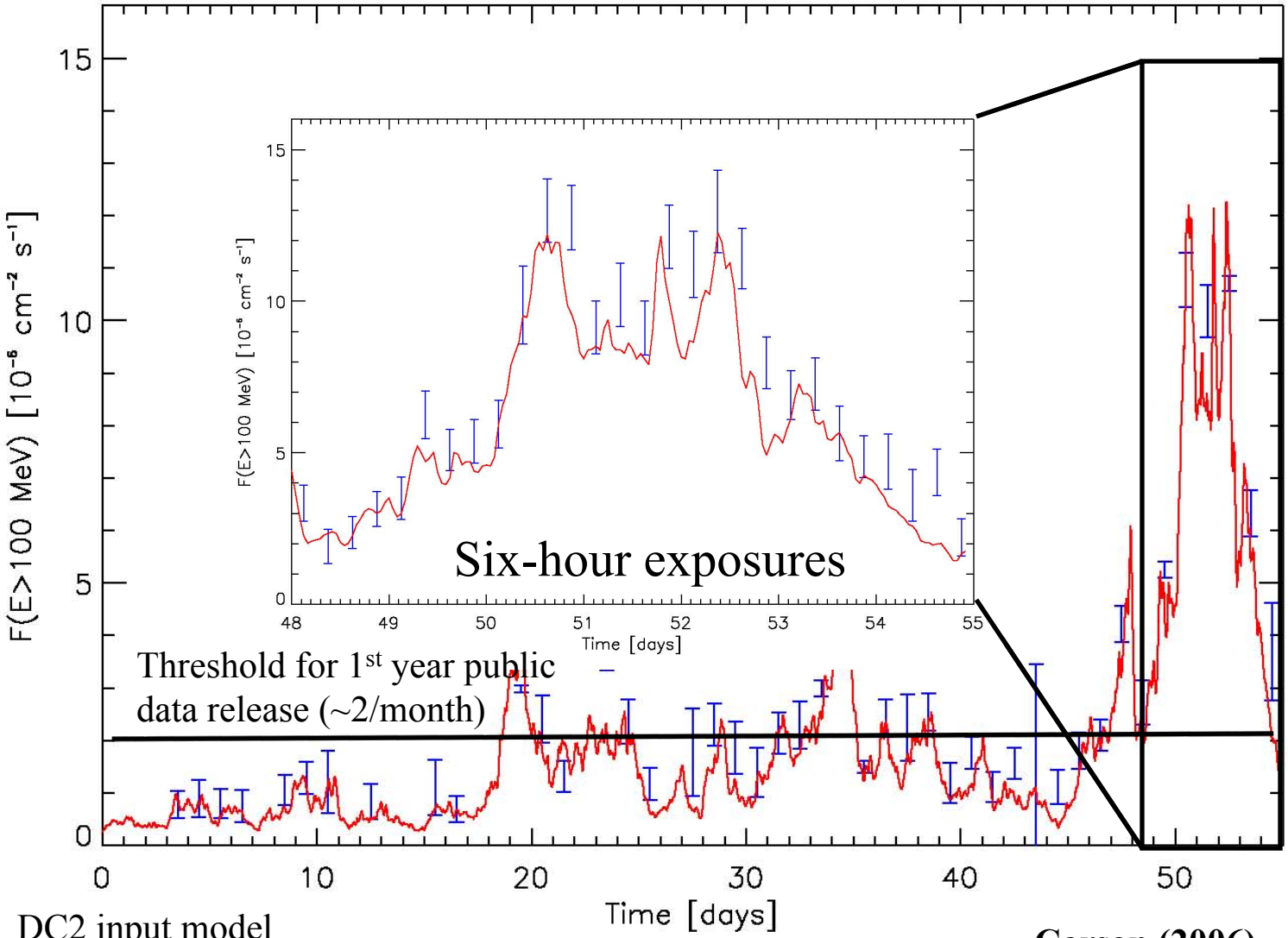
from GLAST data challenge 2
see http://antwrp.gsfc.nasa.gov/apod/

GLAST : the First 55 Days



from GLAST data challenge 2
see http://antwrp.gsfc.nasa.gov/apod/

Monitoring Variability with GLAST



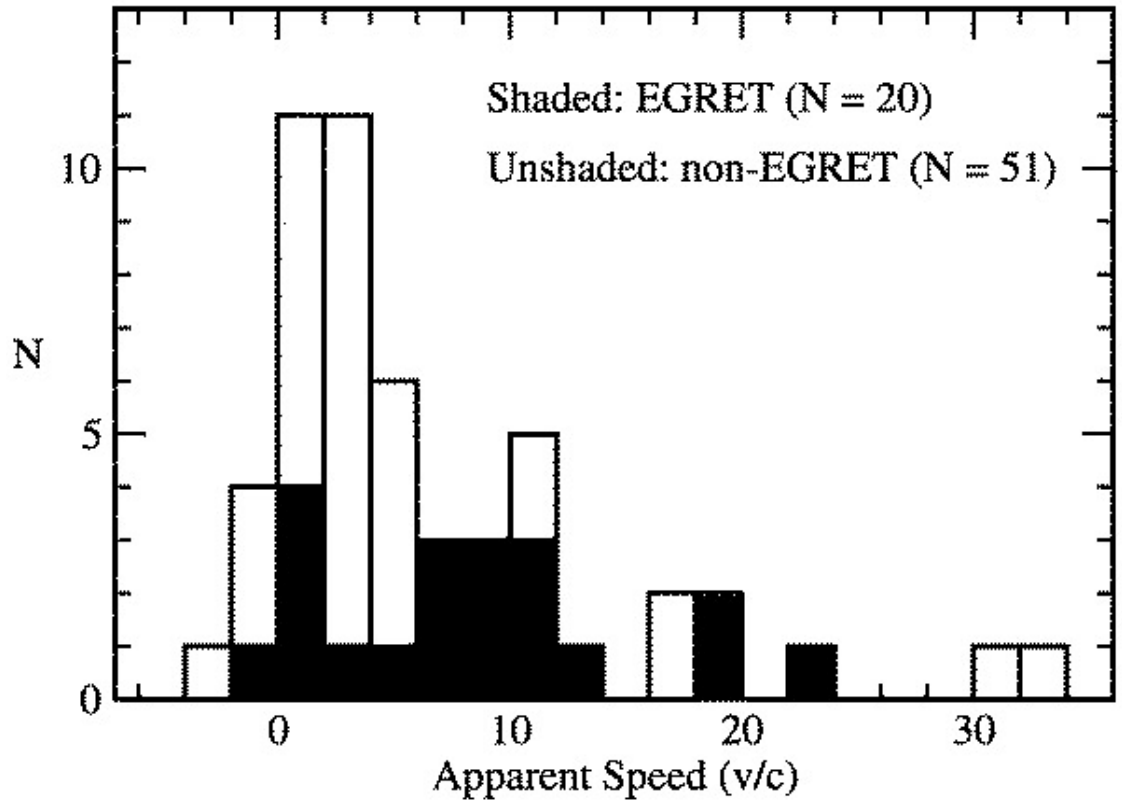
Carson (2006)

GLAST: the First Year

- The first year of science operations will be an all-sky survey. Public data include:
  - Weekly data release on 22 high-priority blazars and a microquasar (LS+61 303) through the GLAST Science Support Center (GSSC) at GSFC
  - Public data release for bright transients (>2 x 10^{-6} photons cm^{-2} s^{-1})
  - All GRB data public
- About 6 months into cycle 1:
  - LAT team will release a list of detected sources to assist investigators prepare Cycle 2 proposals; this list is not meant for research purposes during Cycle 1
  - Workshops for guest observers on science tools and mission characteristics for Cycle 2 proposal preparation
- Observing plan in subsequent years driven by Guest Observer proposal selections by peer review (default is sky survey mode).
- Get involved in Cycle 1: multi- λ coordinator (David.J.Thompson@nasa.gov)
- Get ready for Cycle 2: ground-telescope time, $$ support for U.S. investigators

The γ-ray / VLBI Connection

- EGRET blazars have typically faster superluminal motions
- EGRET flares associated (lag? or lead?) with superluminal radio ejections (Jorstad, Marscher et al. monthly VLBA 43 GHz)
- Consistent with relativistic beaming but details vague



VLBA 2cm survey
Kellermann et al. (2004)
and now MOJAVE (PI: Lister)
& TANAMI with LBA (PI: Ojha)

Beyond 2-10k Blazars: a 3-5 yr Plan

- Low luminosity AGN (Seyferts) as γ-ray sources
- Radio galaxies – `misaligned' blazars
- Young radio galaxies as γ-ray sources (CSOs)
  - Doubling current samples with VCS data
- Testing/extending the blazar sequence
  - Large new faint BL Lac (HBL?) samples, Swift follow-up
- Galactic transients, unidentified sources
  - Campaigns on known and identifying new microquasars
  - VLA/VLBA and Prompt eVLBI followup

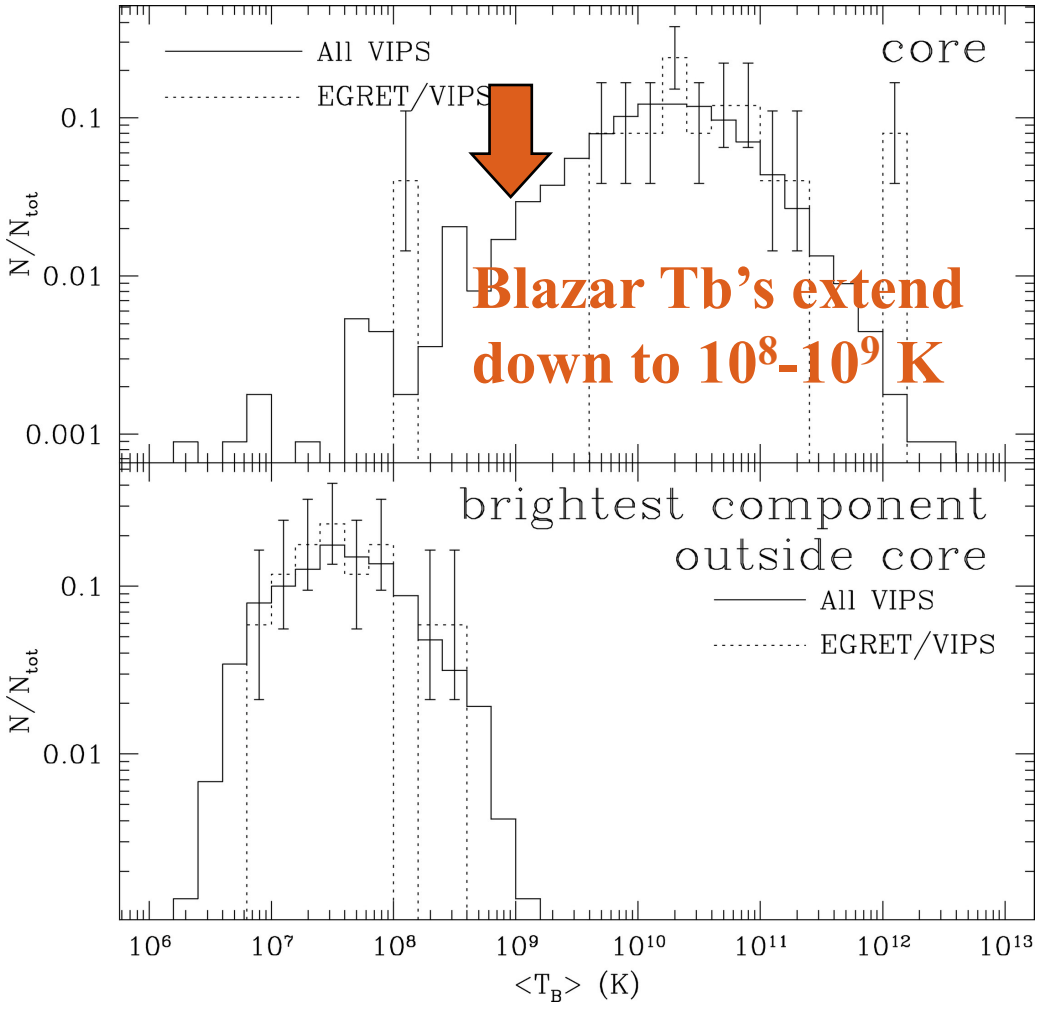
LS I+61 303 VLBA 8.4 GHz
Full orbital period (26.5 days)
Dhawan et al. (2006)

VLBA Brightness Temperatures

$$T_b = \frac{(1.221\times10^{12})S_{\rm core}}{\nu_{\rm obs}^2 a_{\rm maj} a_{\rm min}}\ {\rm K},$$

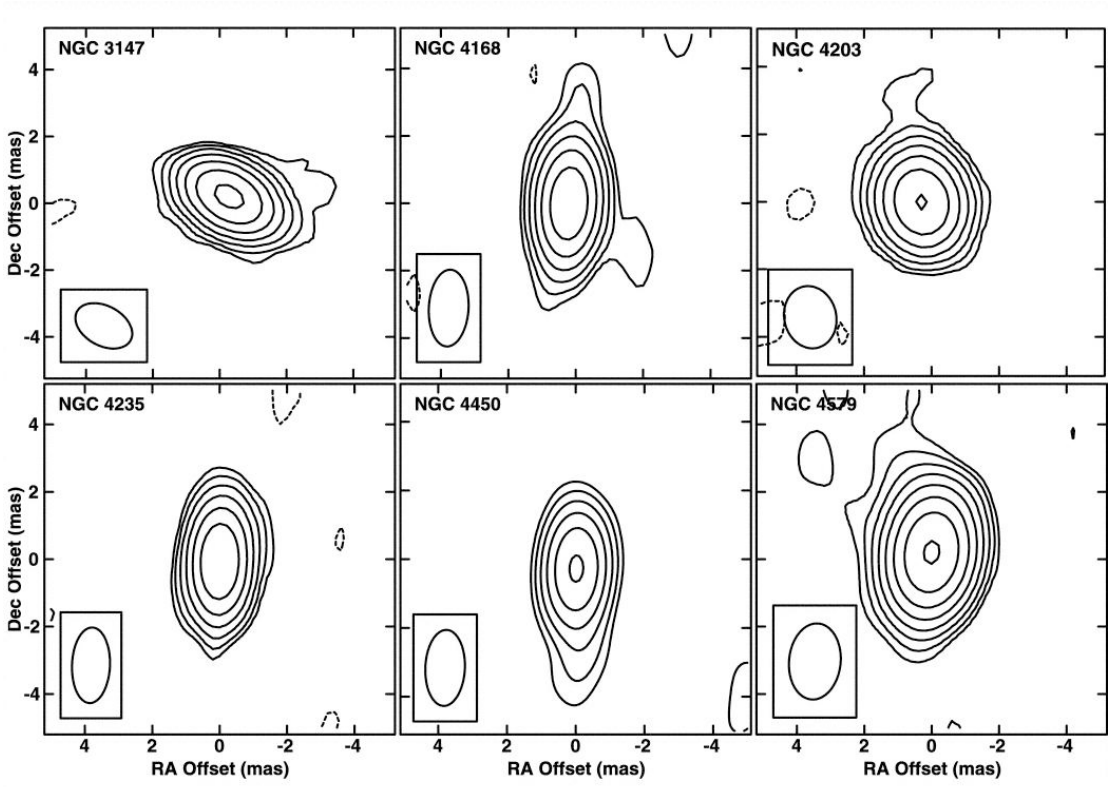
- T_b distributions for EGRET and non-EGRET blazars have 4-11% probability of being drawn from the same population

1127 AGN from the VLBA Imaging and Polarimetry Survey (VIPS)
Fflux densitites down to ~100 mJy



Helmboldt et al. (2007), Taylor et al. (2007)

Low(er) Luminosity Blazars?

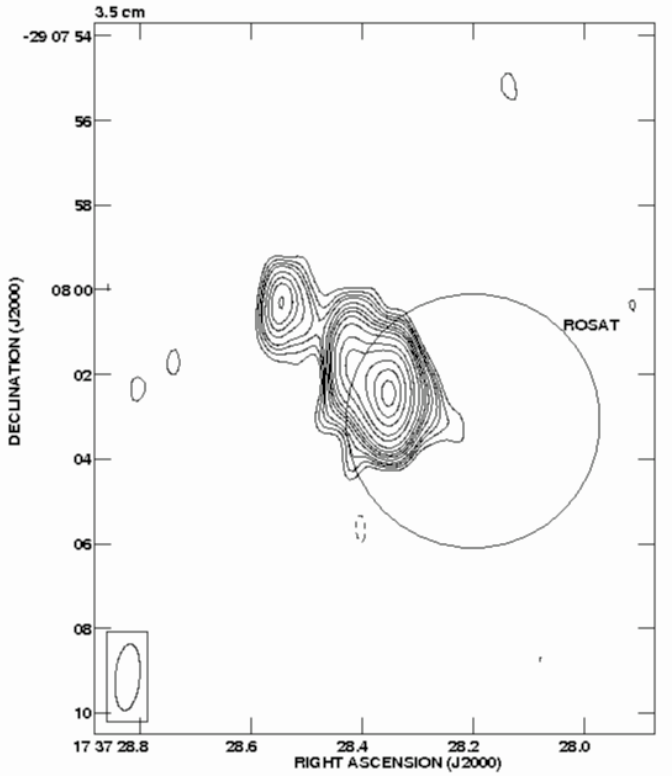


VLBA 8.4 GHz images
Anderson, Ulvestad, & Ho (2004)

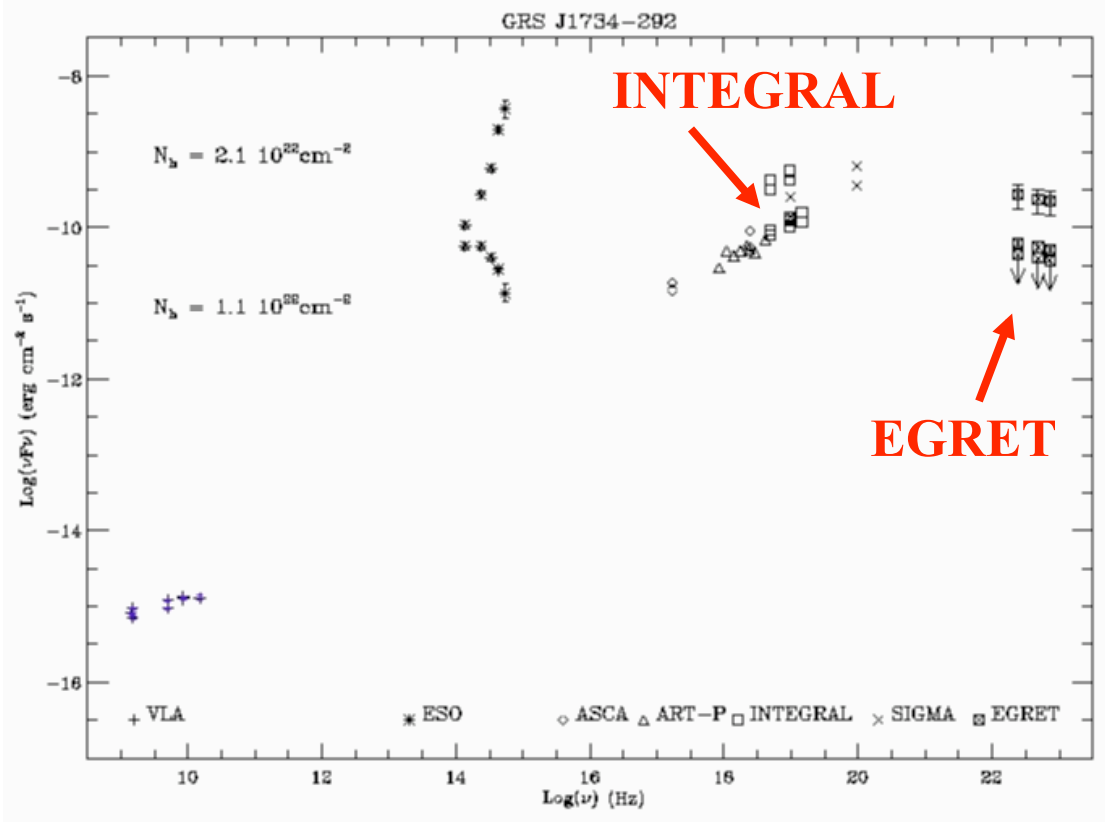
- Seyferts have $T_b > 10^9$ K radio cores (jet? or ADAF?); extra credit: nature of hard X-ray emission?
- Seyferts can have blazar-like properties (Zhou et al. 2007, Maraschi 2008)
- Extending the mass scale ($M_{bh} \sim 10^7 M_{sun}$)

Extreme Accelerators?

Seyfert GRS 1734-292 = 3EG J1736-2908?



VLA 8.4 GHz image
Marti et al. (1998)

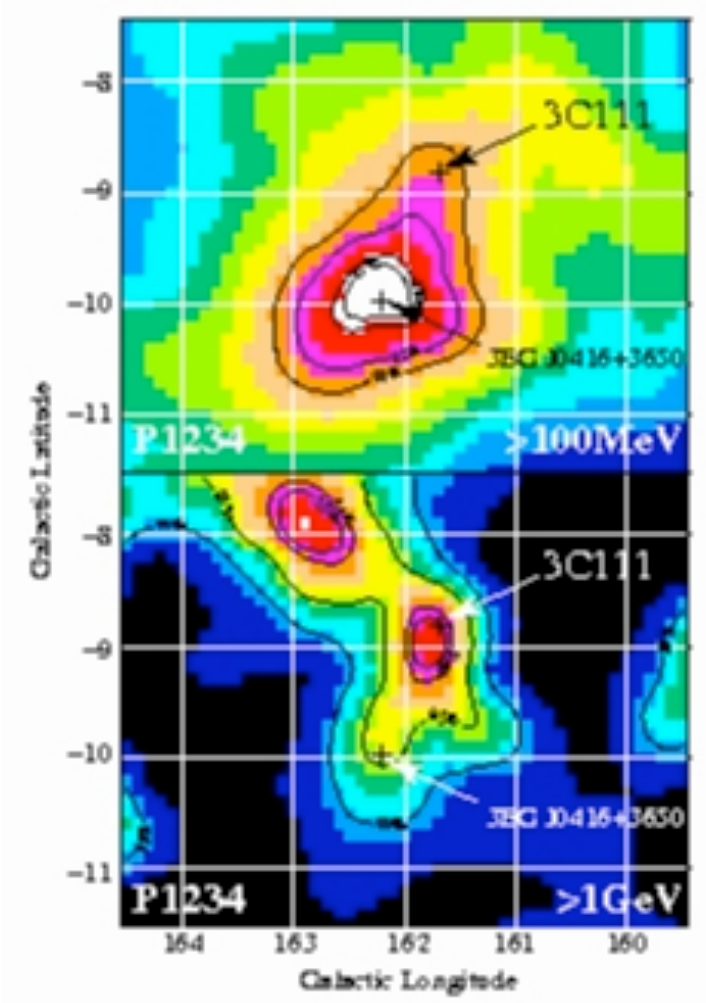


INTEGRAL hard X-ray detection
Di Cocco et al. (2004)

z=0.02, 1arcsec =0.4 kpc

Misaligned Blazars?

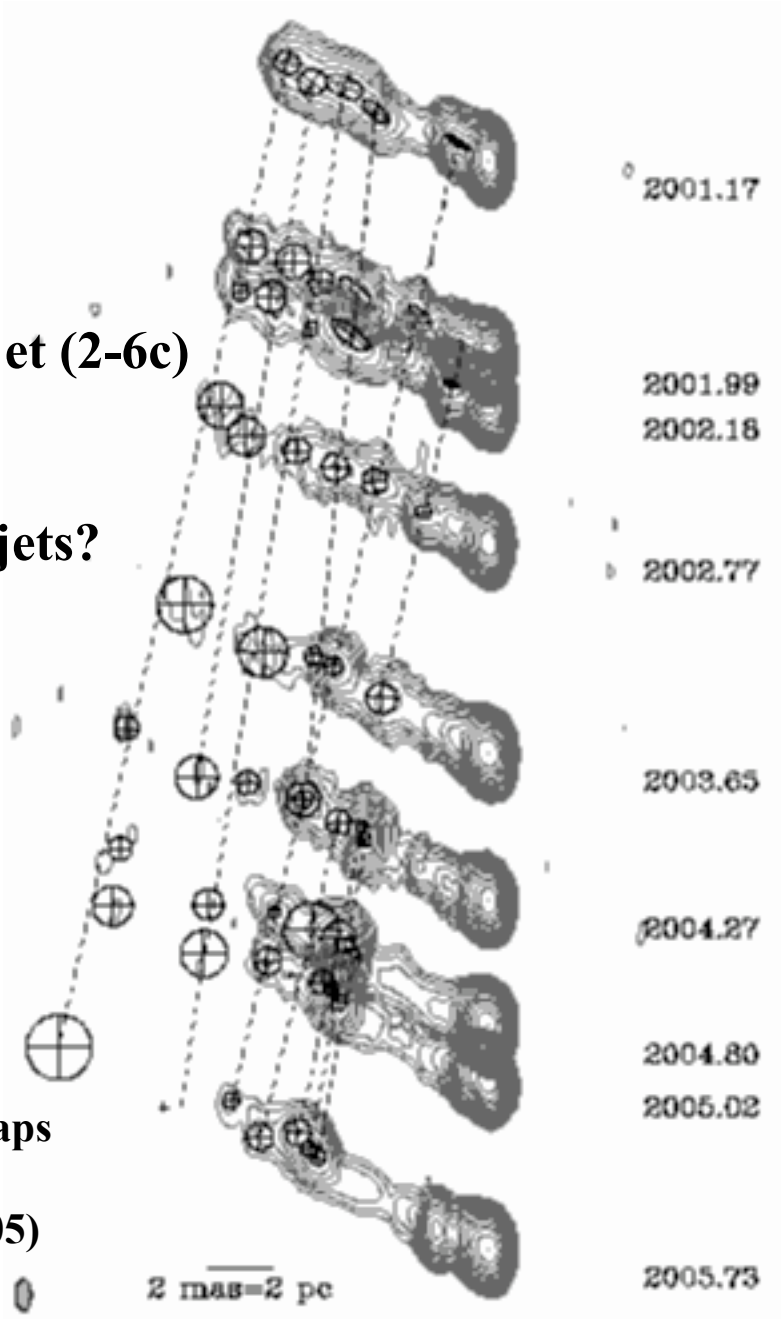
3C111 = 3EG J0416+3650?



EGRET maps
Hartman et al. 2008, in prep.

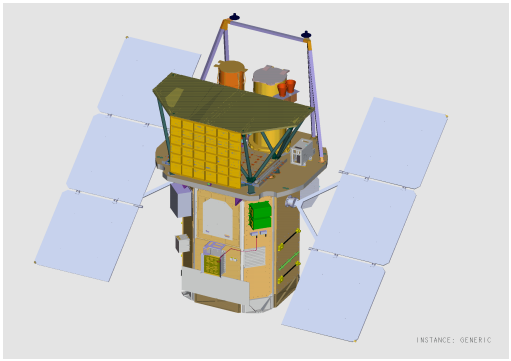
Superluminal jet (2-6c)

Spine (γ-ray)-
sheath (radio) jets?

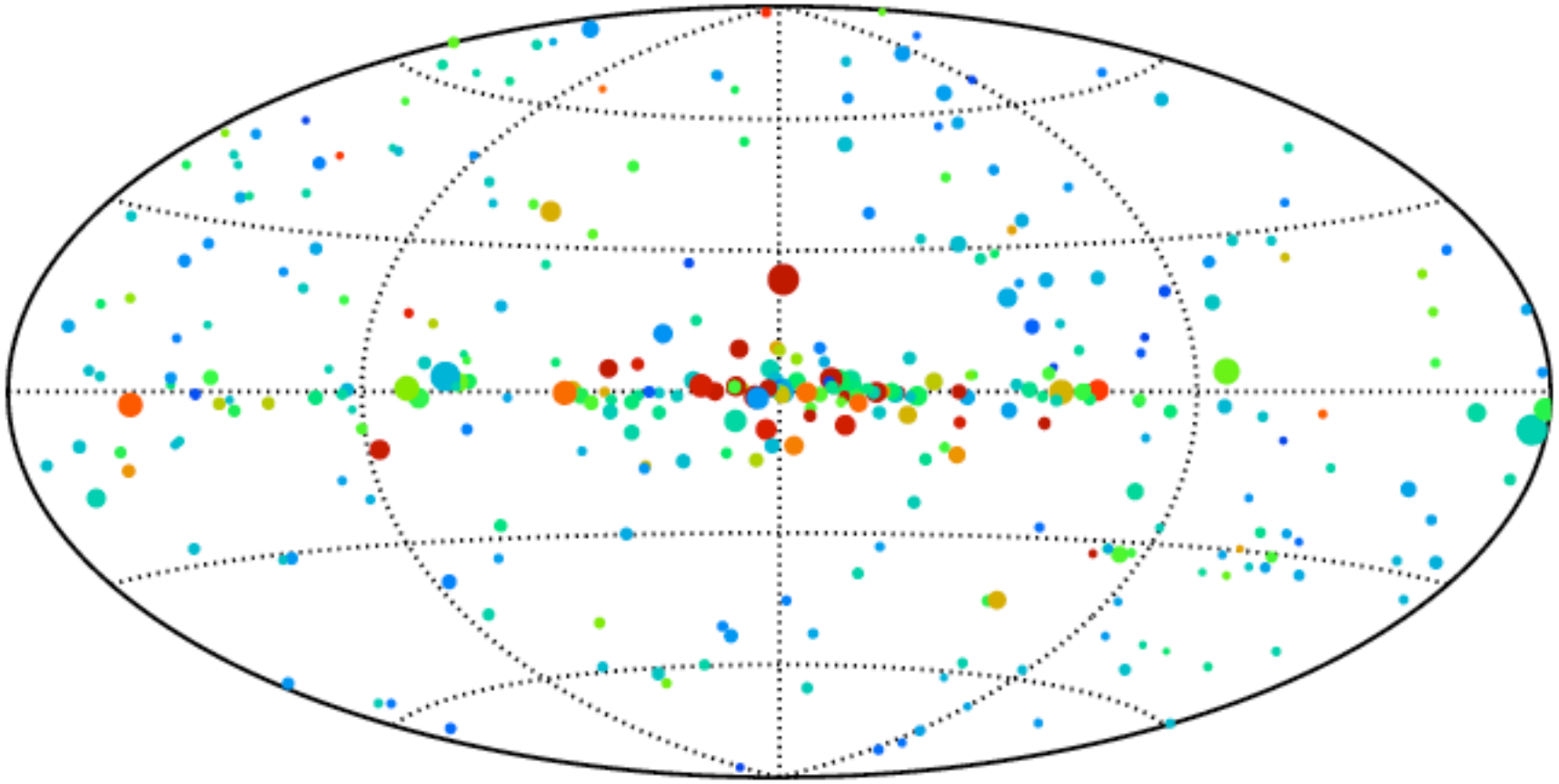


VLBA 15 GHz maps
Kadler et al. 2008
1mas = 1pc (z=0.05)

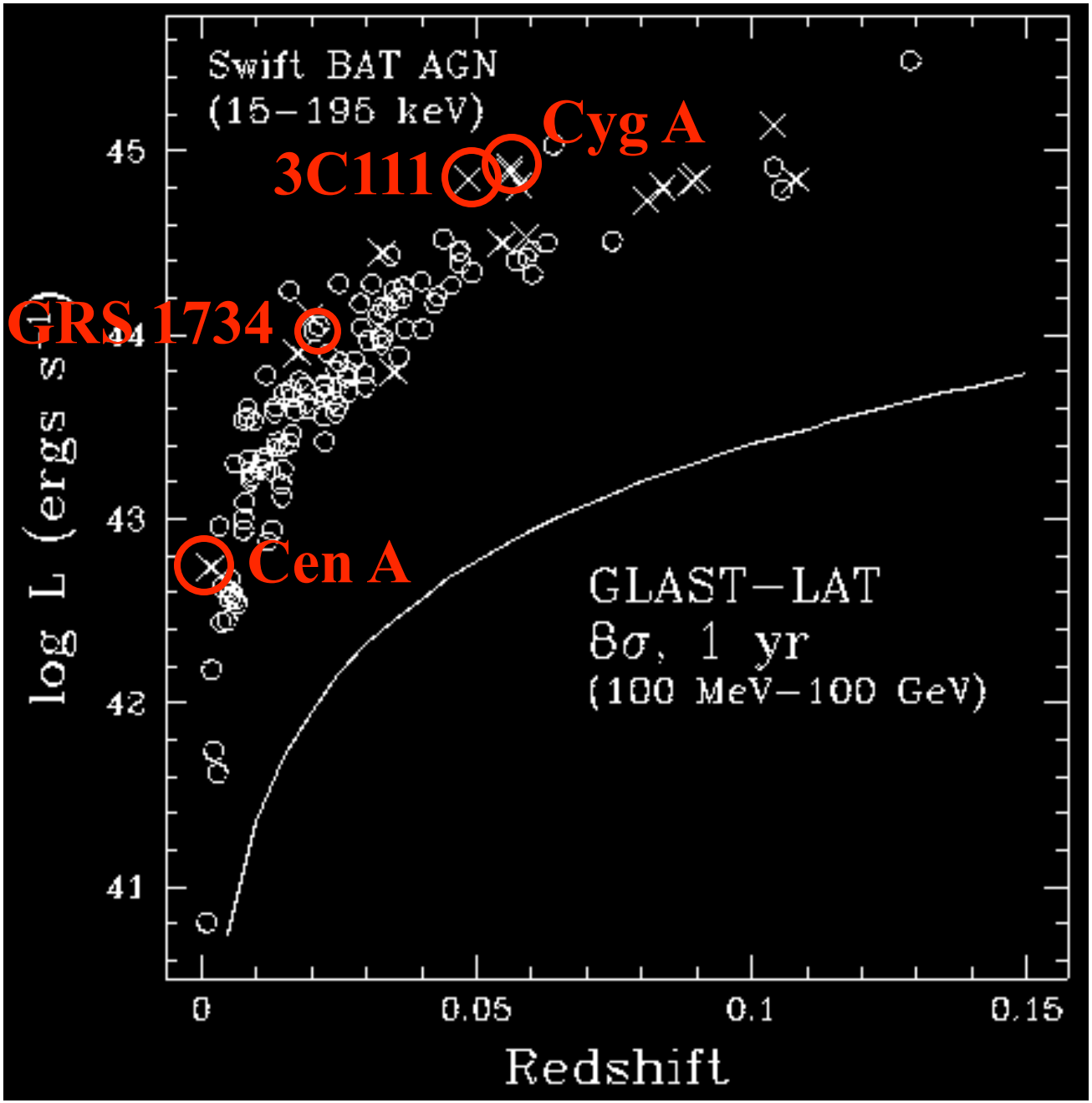
Swift/BAT Hard X-ray Survey



- 111 Seyferts, 17 radio galaxies in 9-month catalog
- Extensive radio, optical, and X-ray follow-up (but little systematic VLBI work)



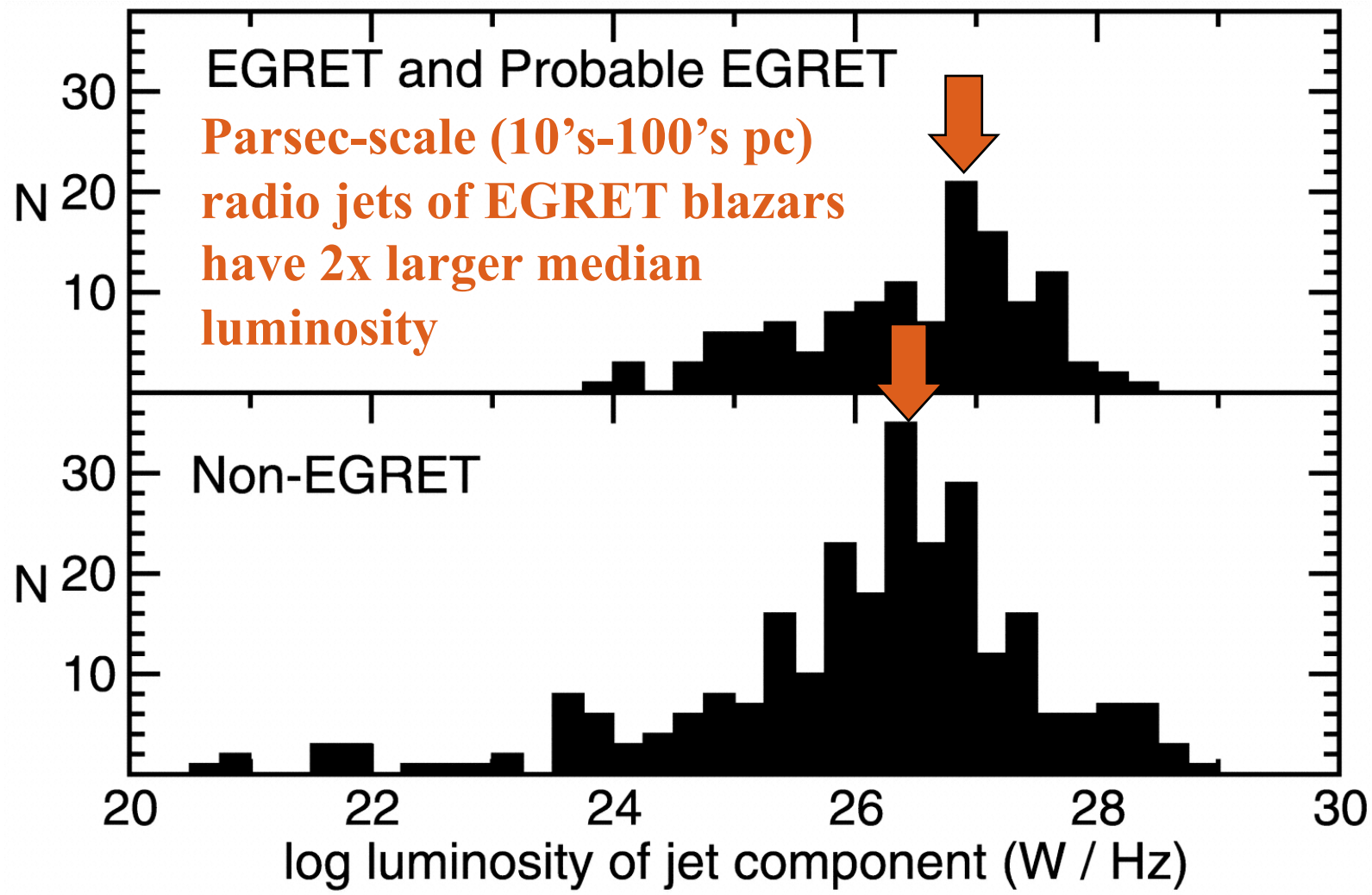
energy coded color; Tueller et al. (2008)



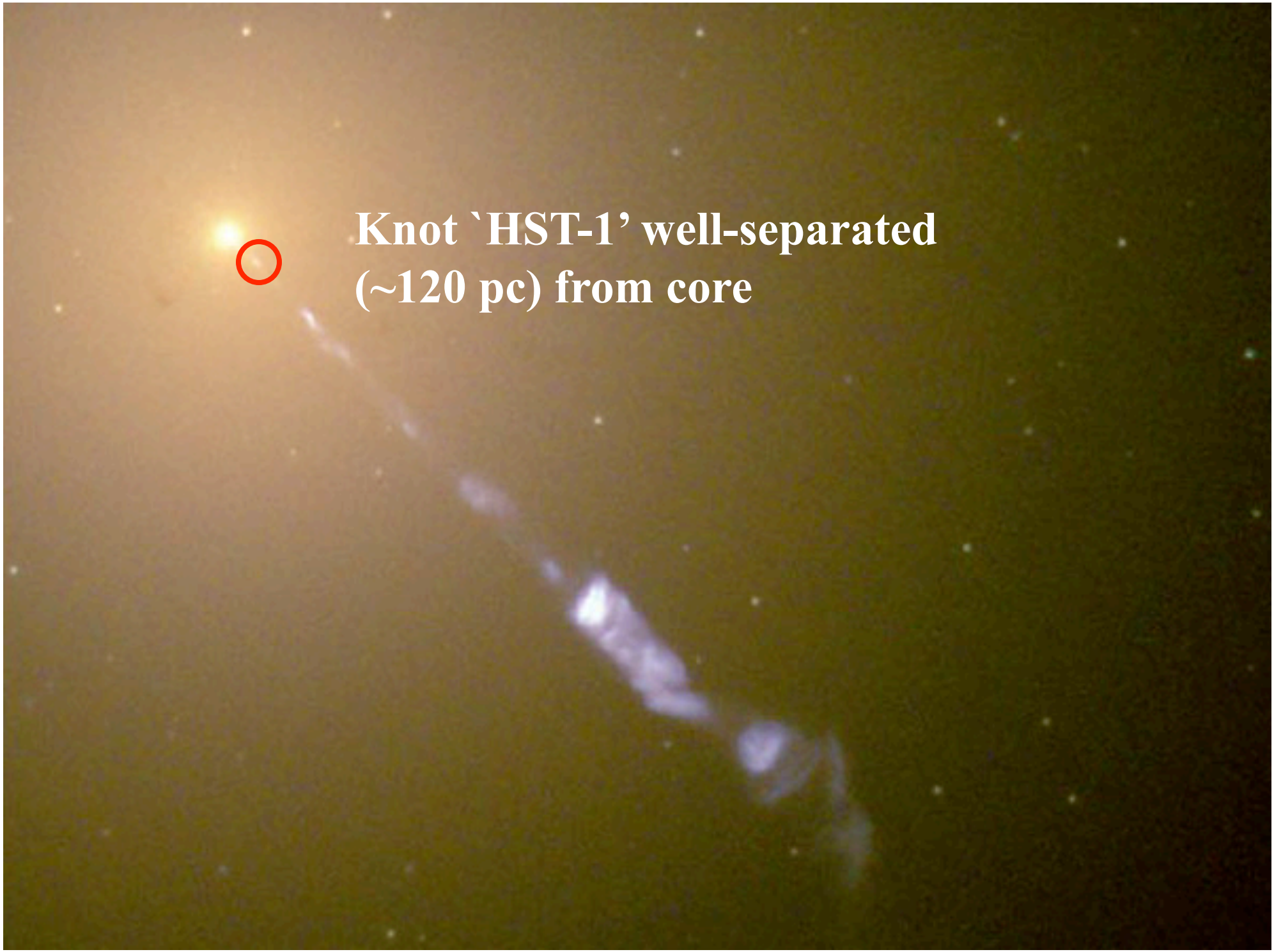
- Seyferts (circles)
- Radio galaxies (crosses)

Data from Tueller et al. (2008) ApJ in press

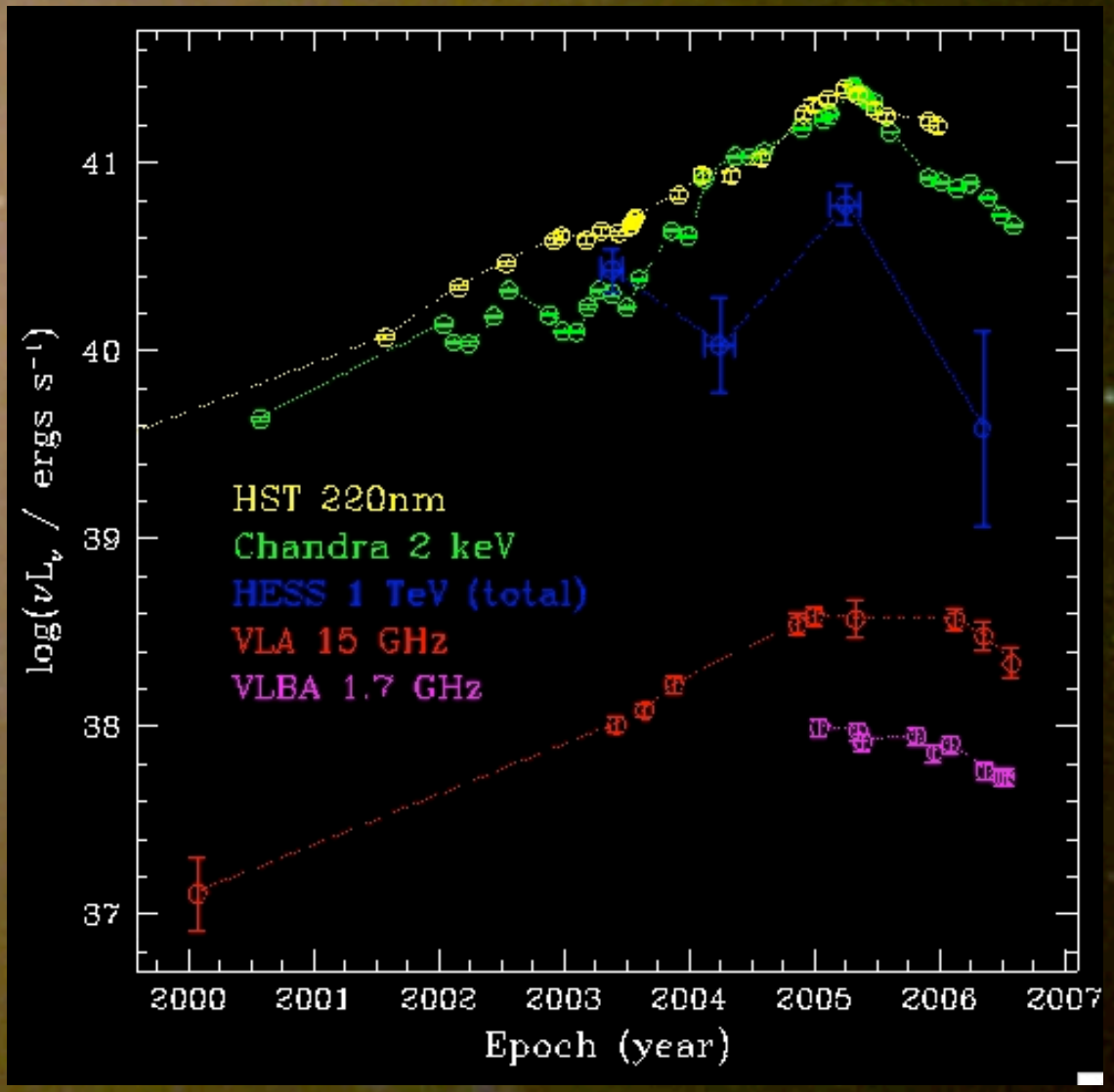
Parsec-scale Radio Jets



MOJAVE: Lister & Homan (2005)

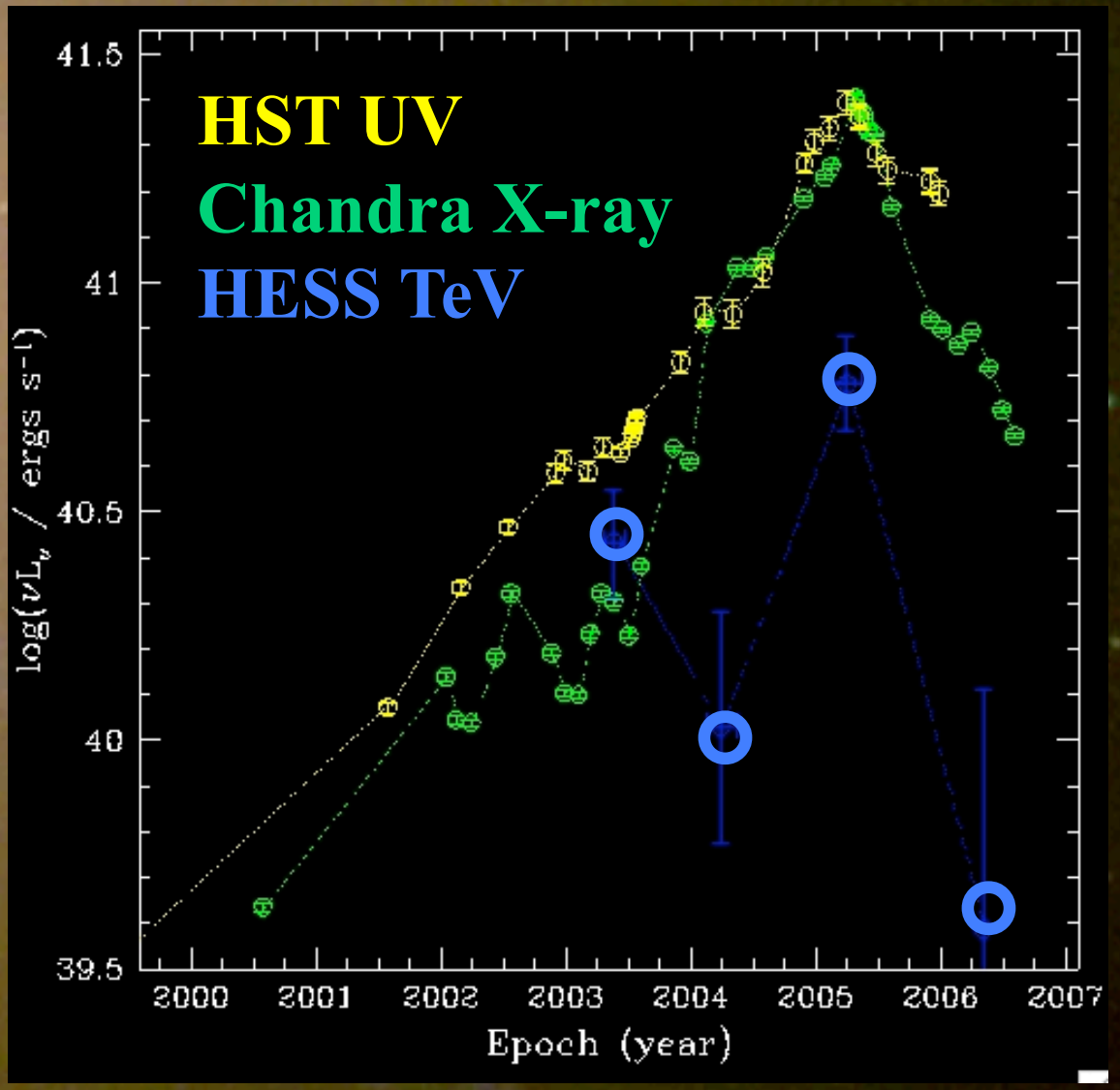

Knot `HST-1' well-separated
(~120 pc) from core

X-ray, optical, radio variability in HST-1



Harris et al. (2006, 2008)
Aharonian et al. (2006)
Cheung et al. (2007)

X-ray, optical, radio variability in HST-1



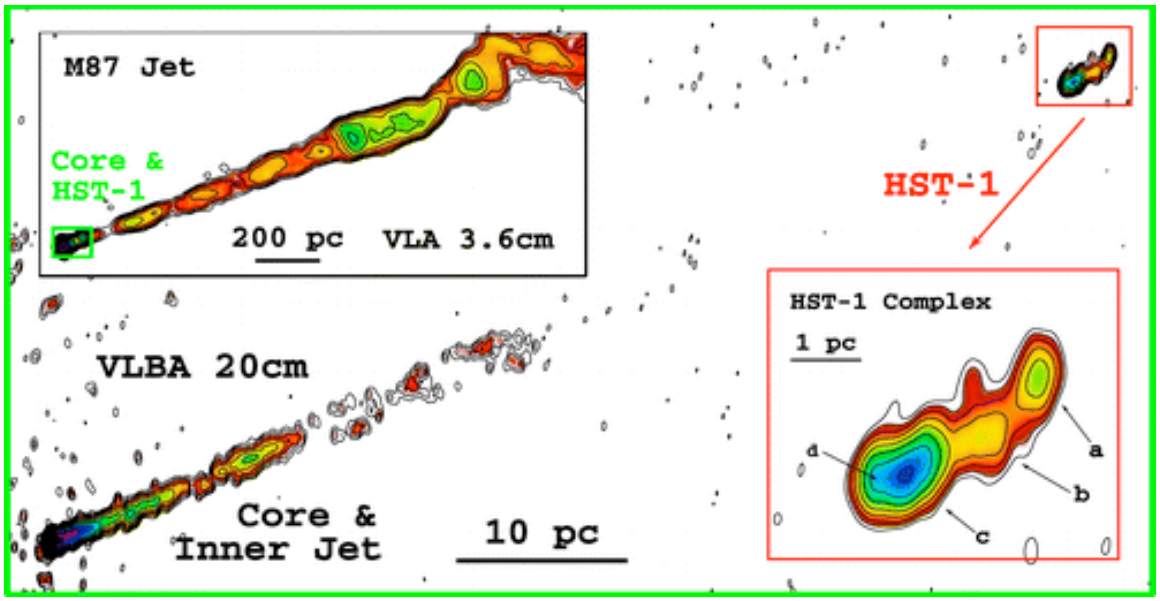
HST-1 lightcurves follow integrated TeV

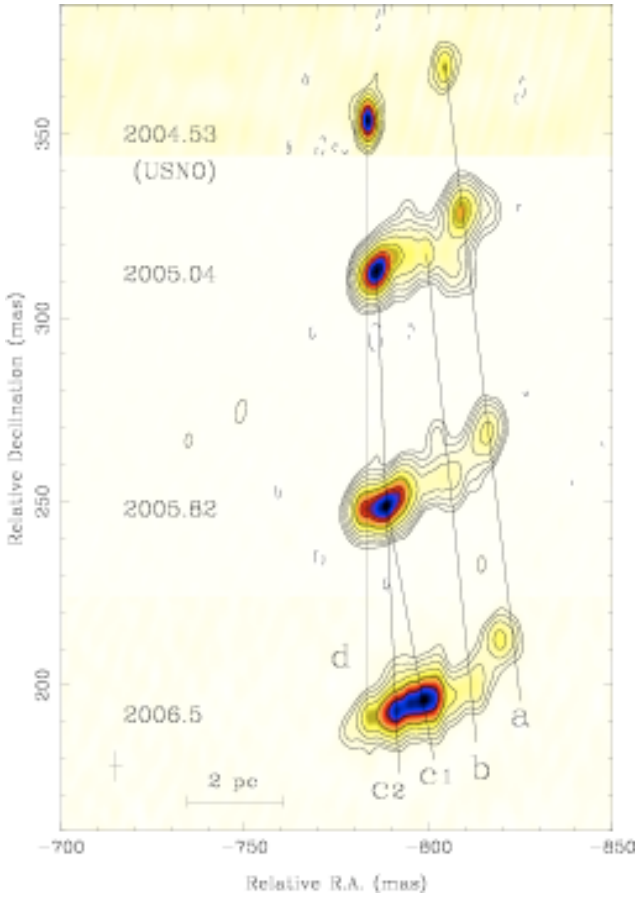
Harris et al. (2006, 2008)
Aharonian et al. (2006)
Cheung et al. (2007)

Gamma-ray Production Site?

Superluminal motion and dramatic X-ray, optical, radio, and? TeV variability

=> Resolved blazar-like emission zone!

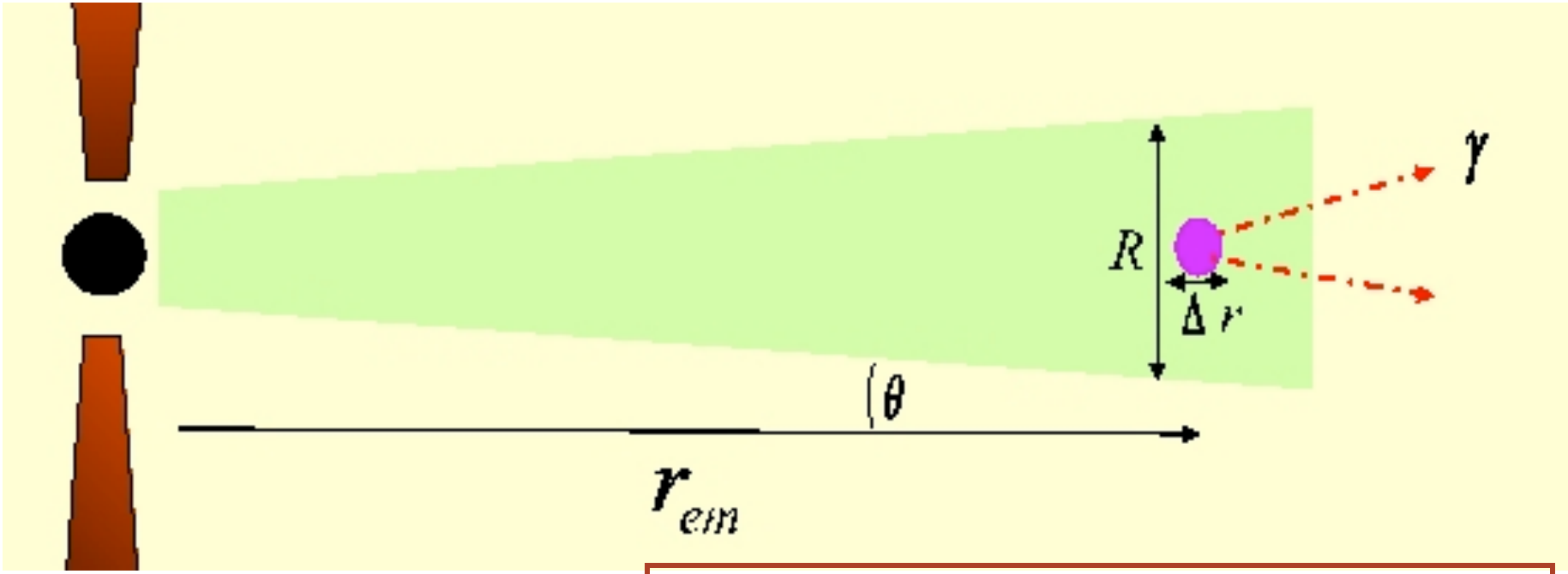




Cheung, Harris & Stawarz (2007)

Gamma-ray Production Site?

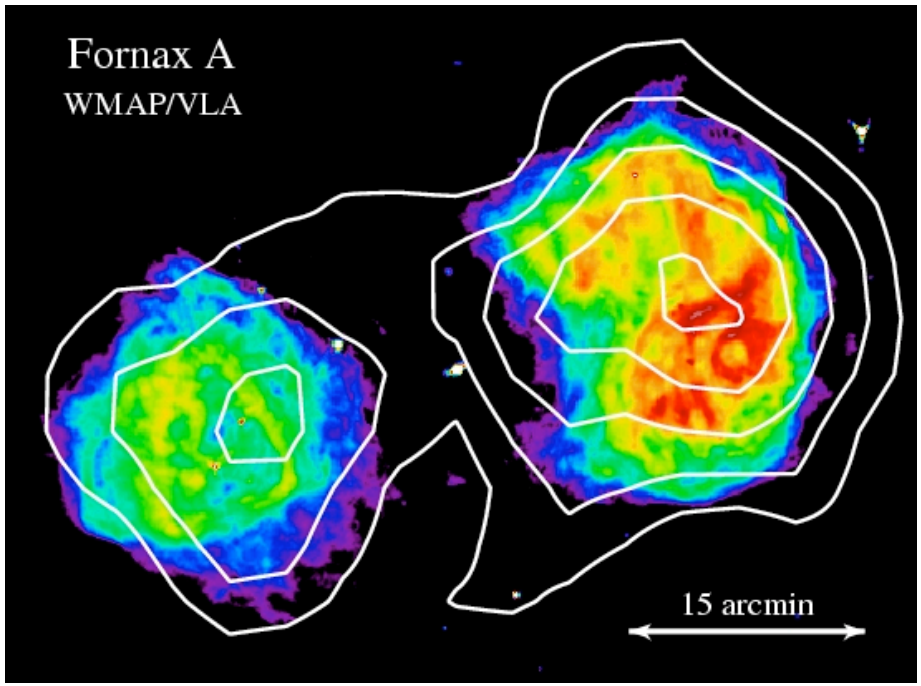
- Relationship between gamma and radio (optical, X-ray) emissions
- Jet powers, radiative efficiency, and relationship to accretion disk



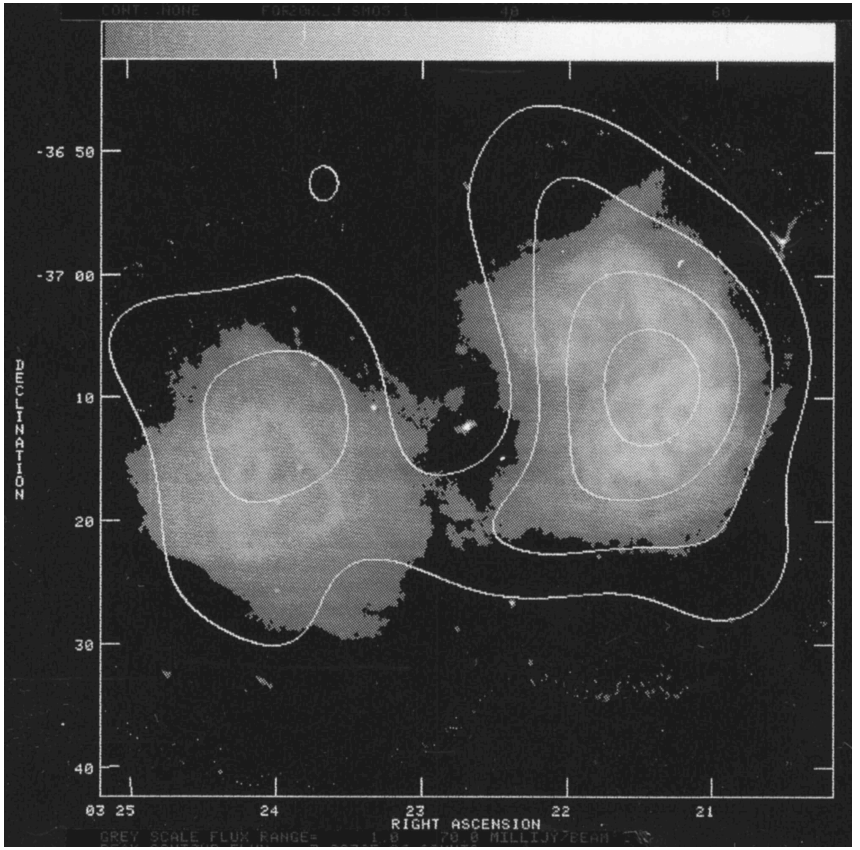
Levinson (2007)

But only a small fraction $(\Delta r/R)^2$ of jet energy used for γ-ray production

Gamma-Ray Lobes?



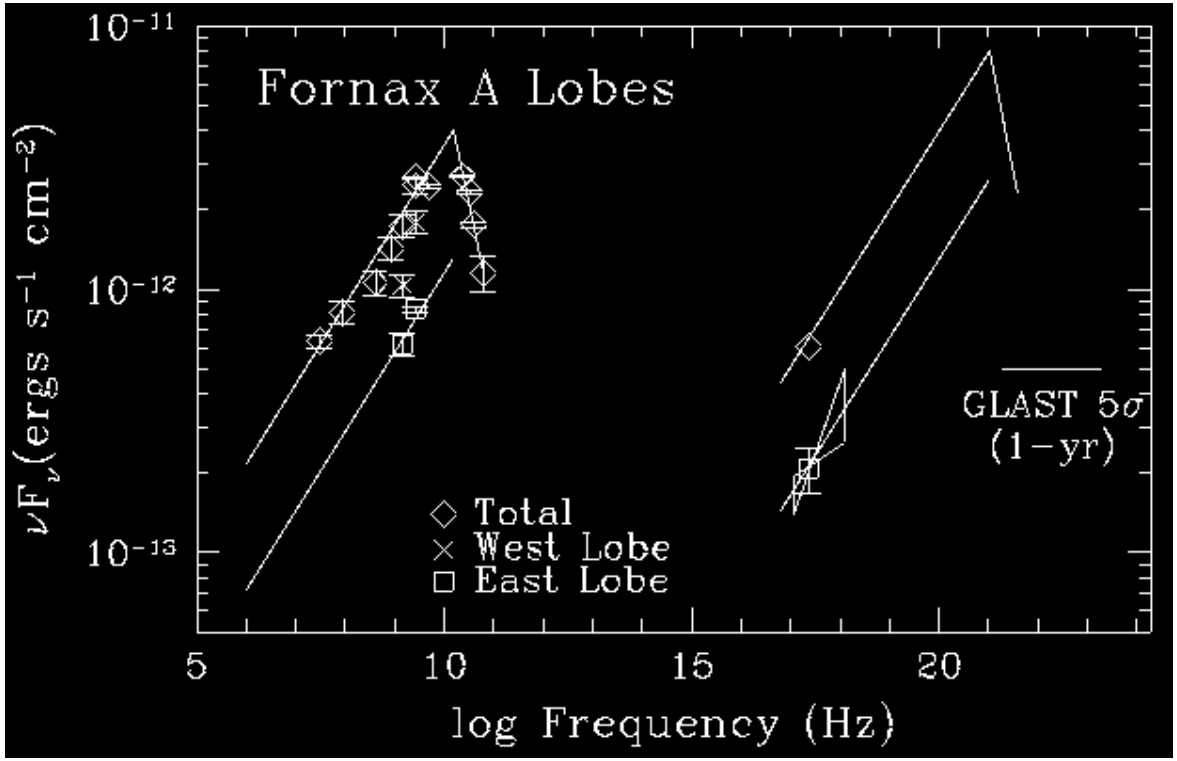
VLA 1.4 GHz color (Fomalont et al. 1989) and WMAP 61 GHz contours (Nils Odegard)



VLA 1.4 GHz grayscale and ROSAT X-ray contours (Feigelson et al. 1995)

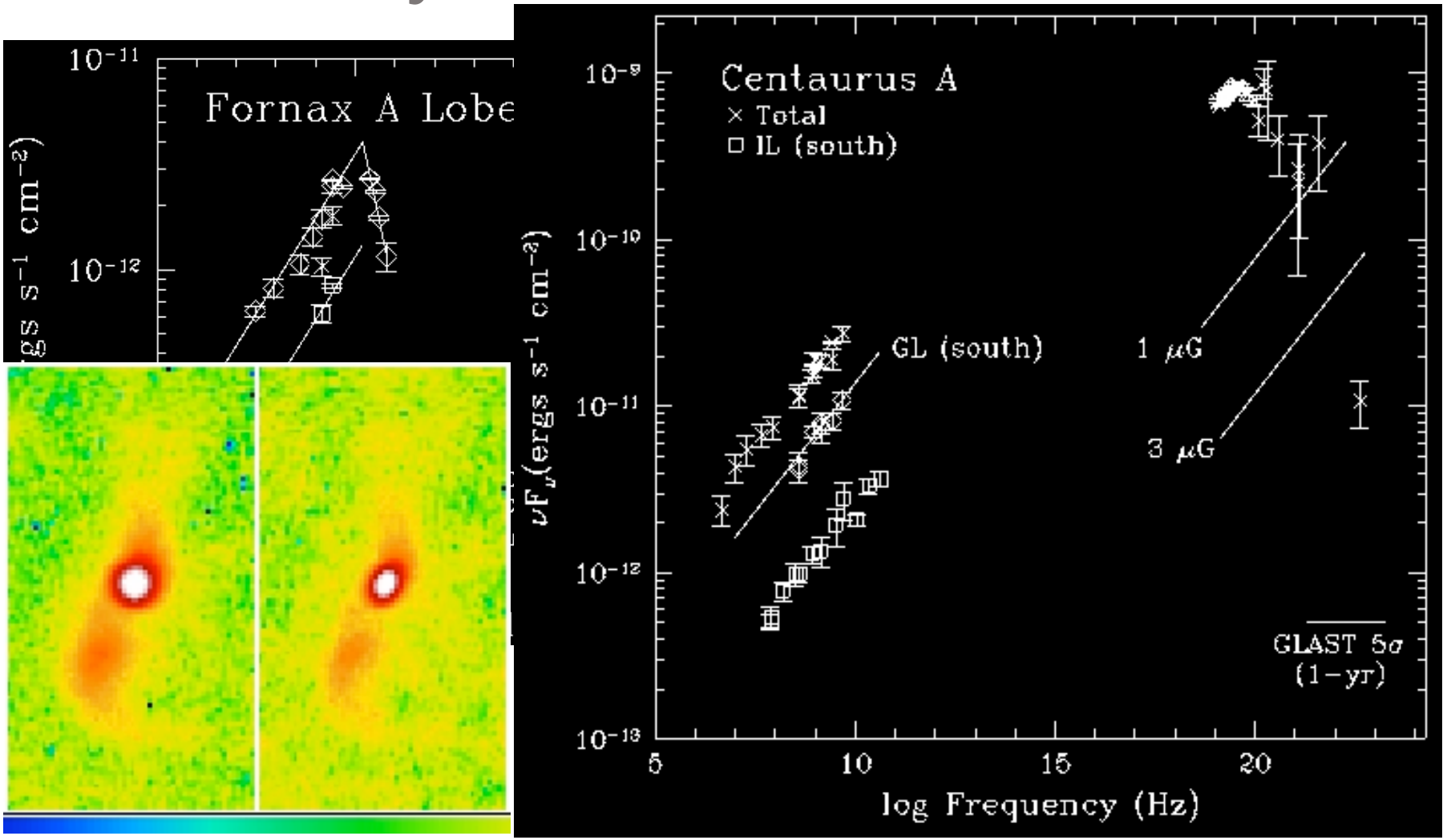
Electrons with $\gamma \sim 10^5$ in extended lobes!

Gamma-Ray Lobes?



Cheung (2007)
Georganopoulos et al. in prep.

Gamma-Ray Lobes?



Cheung (2008)
Hardcastle et al. in prep.

Much to Do… Join the Excitement!

Dawn Launch on Delta II Heavy
27 September 2007