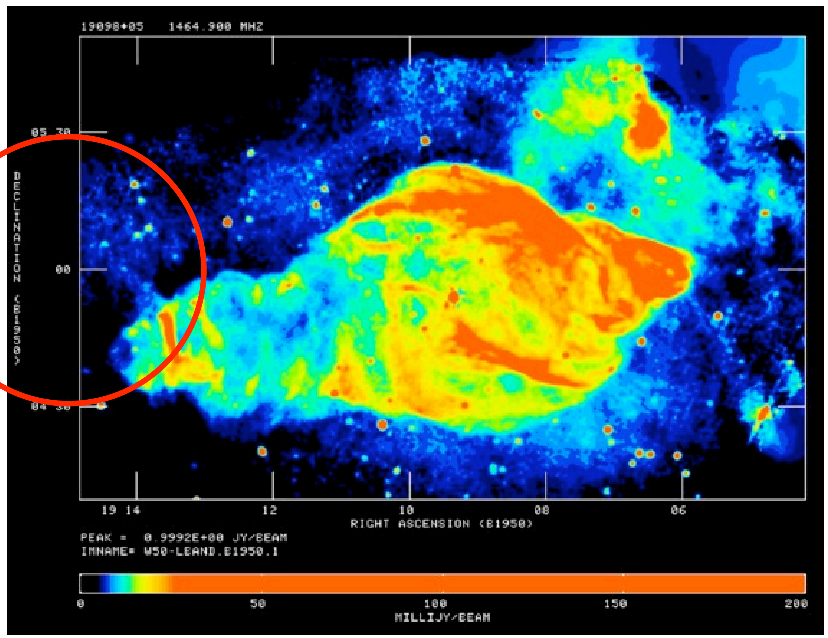
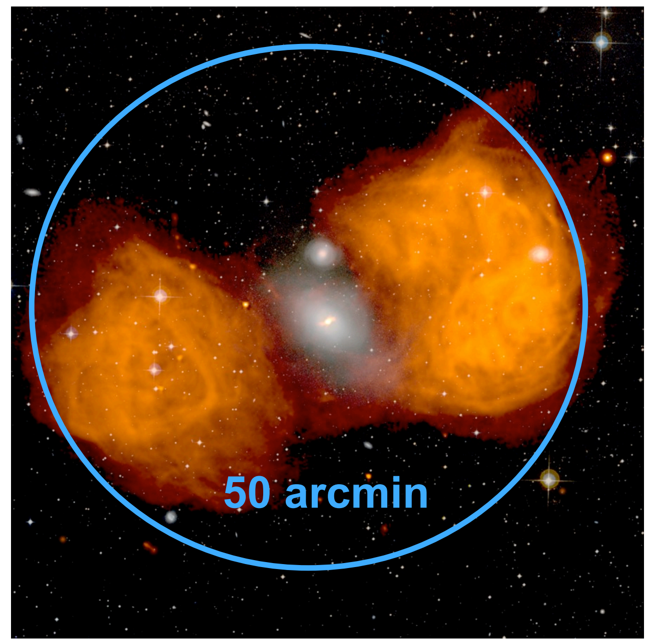
Compton X-ray and Gamma-ray Emission from "*Extended*" Radio Sources

C.C. Teddy Cheung (*NRAO and KIPAC*)

One Degree



W50/SS433 Complex at 20cm (Dubner et al.)



Fornax A at 20cm (orange) and Optical (Fomalont et al. Image by J. Uson, NRAO)

Conventional Wisdom

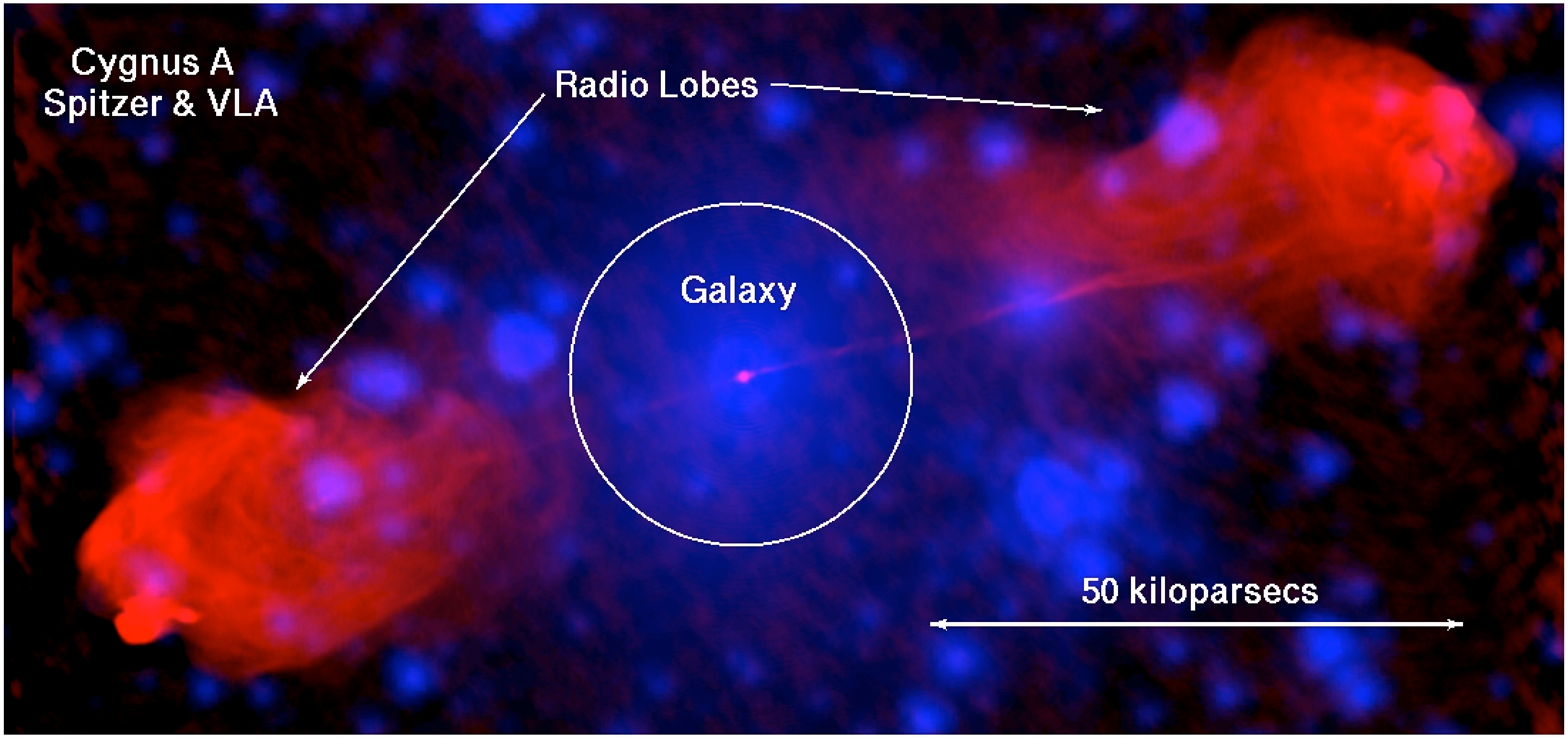
Blazars will dominate the (extragalactic) gamma-ray sky.

G-ray sources are predominantly “non-thermal”.
Radio (to X-ray) observations traces the relativistic particles through their synchrotron emission.

See previous GLAST talks: Carson, Coppi, Sikora, Healey, etc.

Why "*Extended*" Radio Sources?

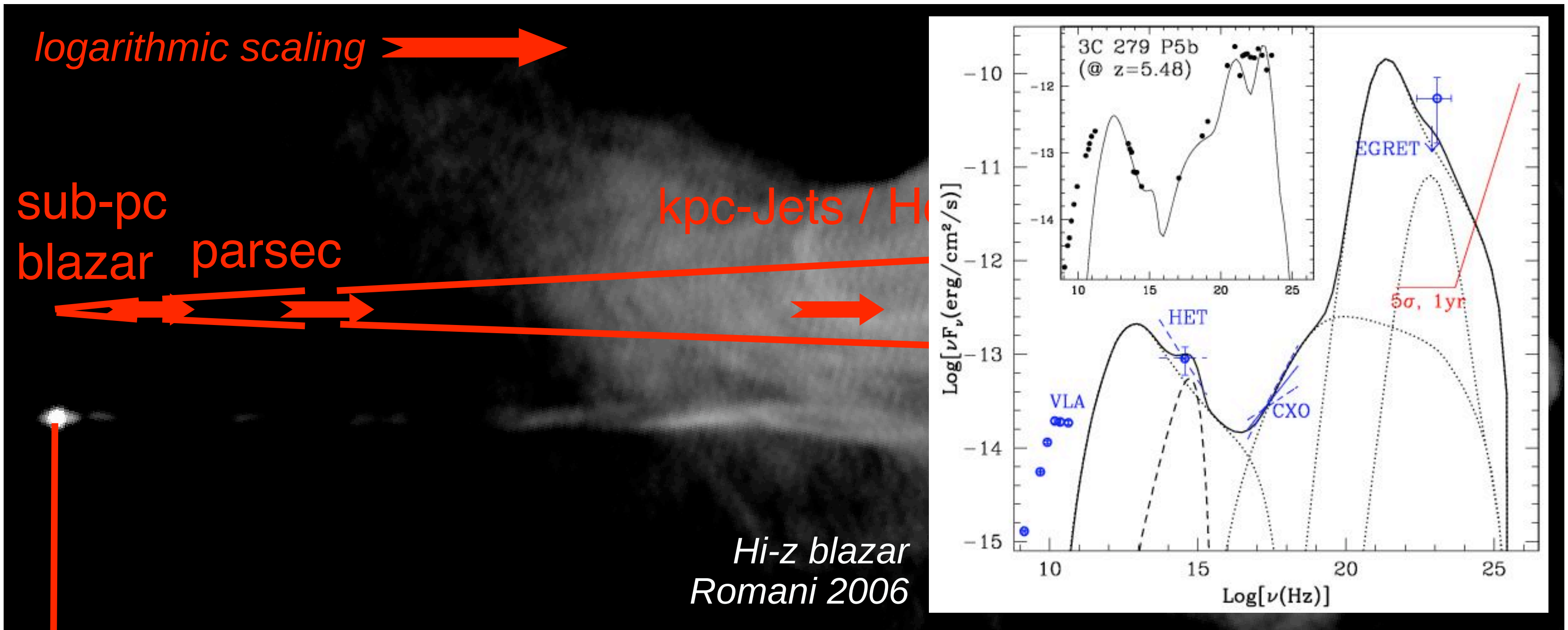
Radio Galaxies (`misaligned' blazars) are dominated by emission from extended components.



VLA red (Perley et al. NRAO)
Spitzer blue (Harris, Stawarz, Ostrowski, Cheung)

Anatomy 101

Relevant question: What are relative contributions of a radio source to integrated g-ray signal detected by GLAST?

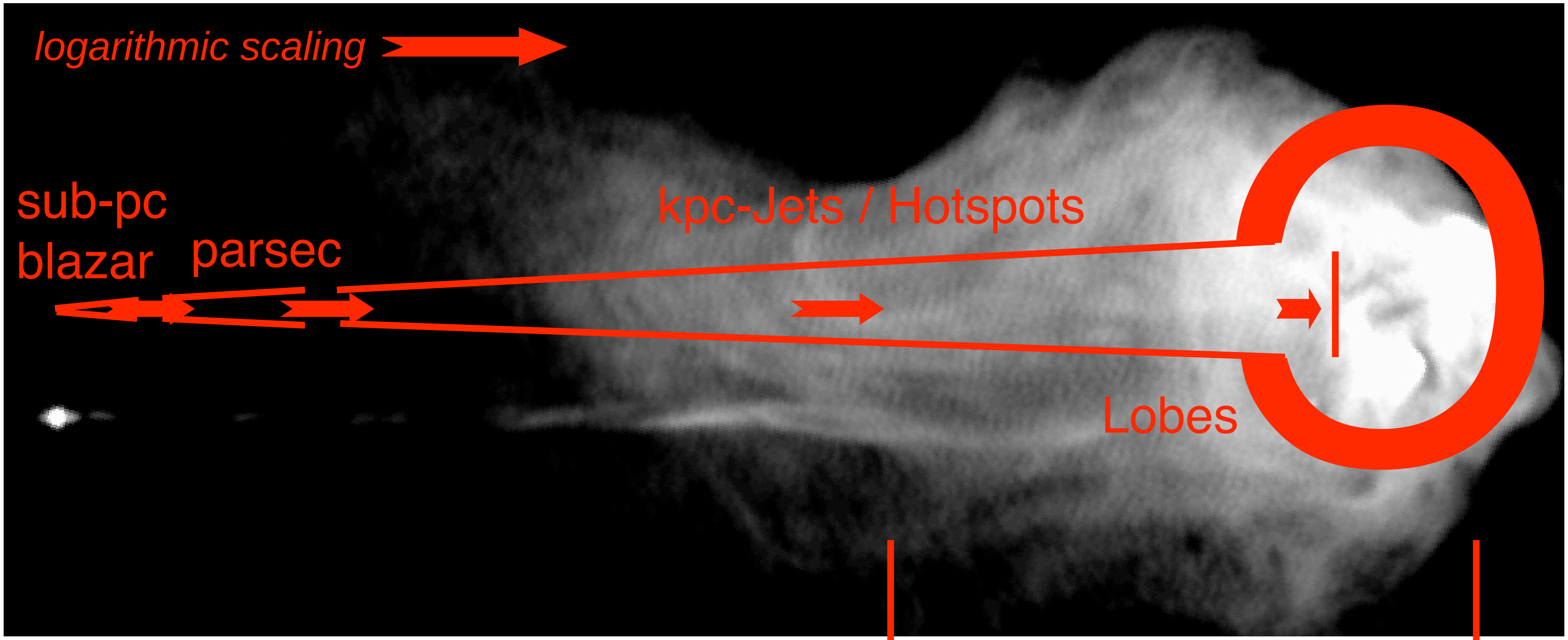


Blazar = jet axis pointed toward Earth; the central region is dominant

Complication: (unresolved) Compton scattered g-rays have contributions from accretion disk, clouds, jet (SSC), starlight (galactic scales), etc.

Anatomy 101

Relevant question: What are relative contributions of a radio source to integrated g-ray signal detected by GLAST?



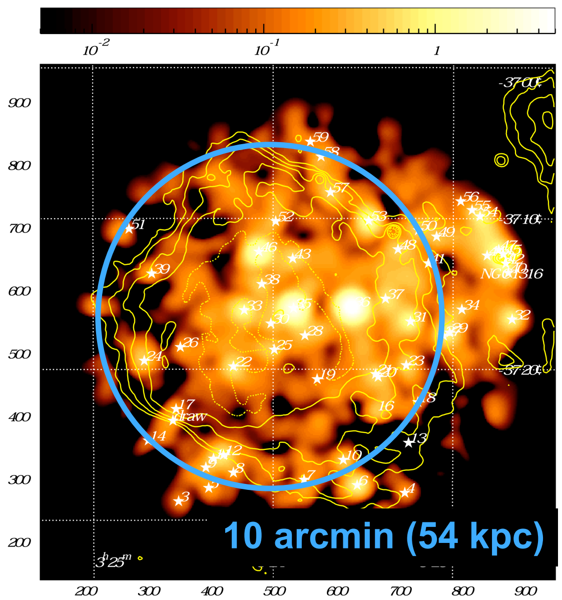
What about contribution from extended components? (classified as “radio-galaxies”)

Dominant seed photon source for Compton process on 10’s-100’s kpc scale is 3K background

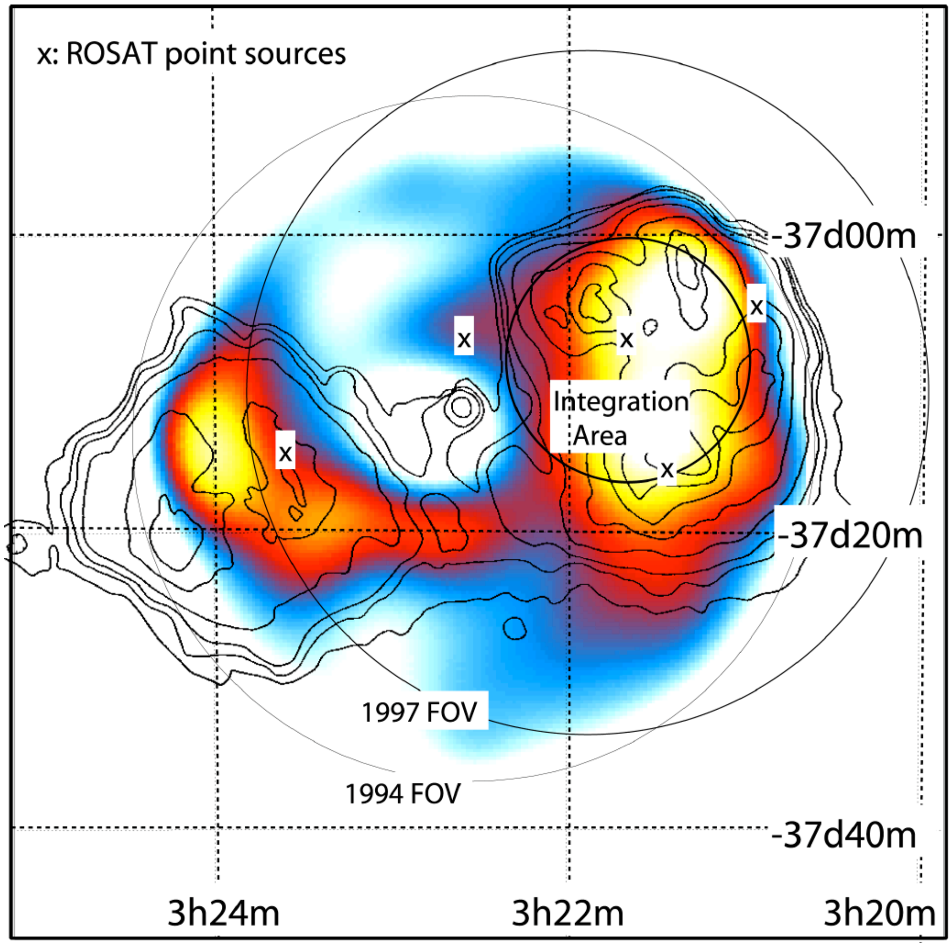

Inverse Compton Scattering of 3K
Background is an Obligatory Process
in Cosmic Synchrotron Sources
On This Rock...

Evidence for Extended IC/CMB

Fornax A = NGC 1316
D=19 Mpc (z=0.006)
Top 5 brightest radio source in sky



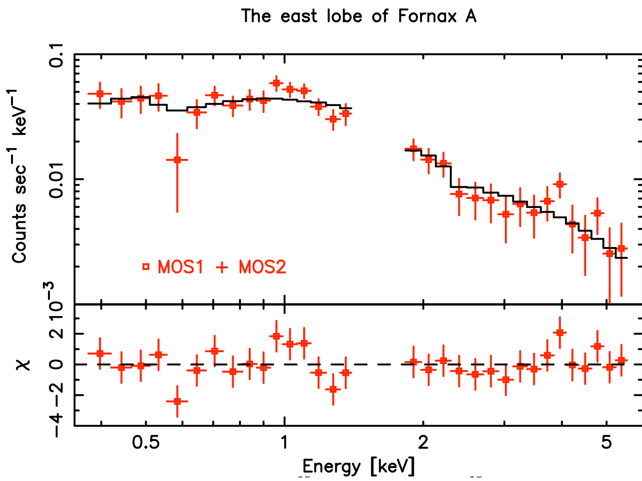
East Lobe
XMM (Isobe et al. 2006)



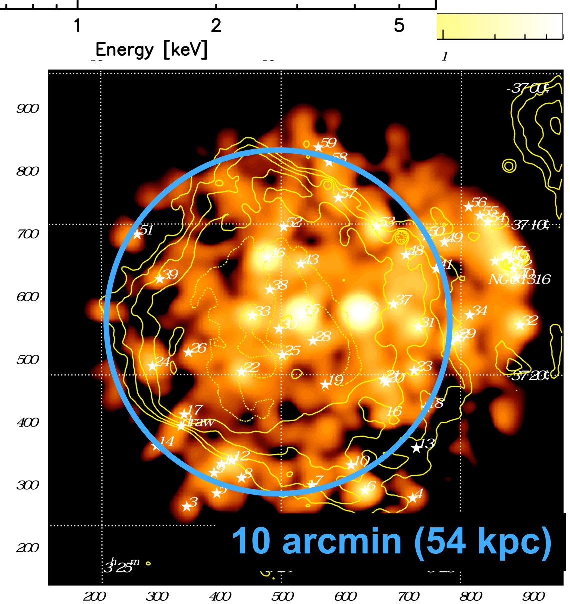
ASCA color (Kaneda et al. 1995)
see also ROSAT detection by Feigelson et al. 1995

Figures from N. Isobe talk

Evidence for Extended IC/CMB



XMM power-law spectrum of east lobe minus (thermal?) point sources



East Lobe
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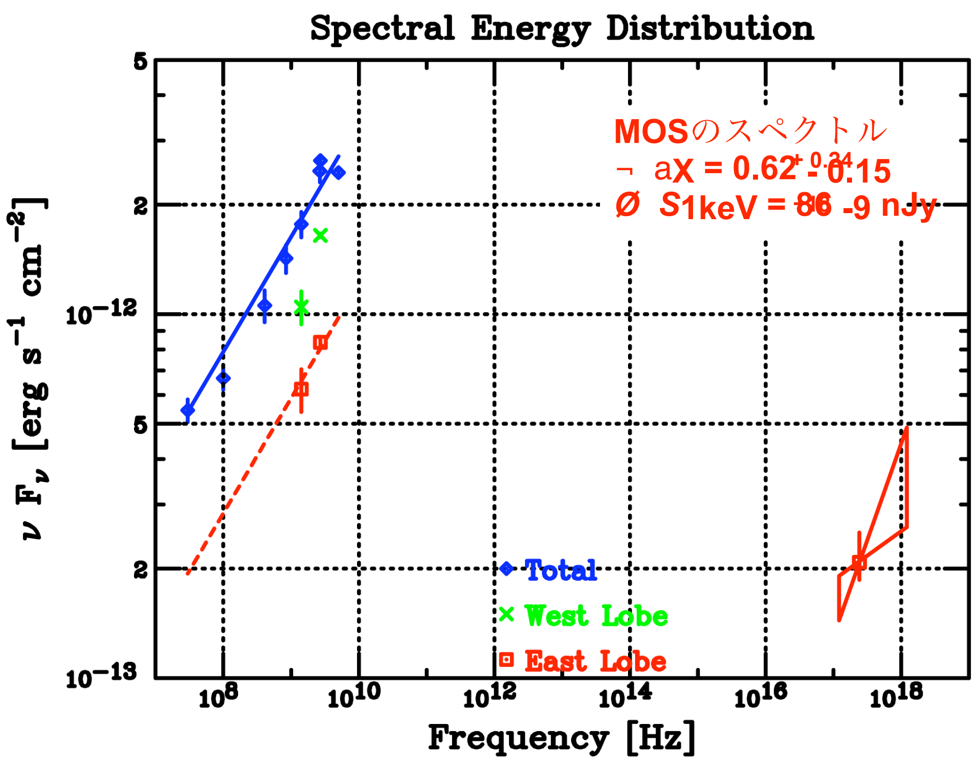


Figures from N. Isobe talk

Lobe B-Field & Energetics

IC/CMB vs. equipartition constraints on B-field.

TABLE 1

CALCULATED WEST LOBE MAGNETIC FIELD STRENGTH

η	ϕ (rad)	ν_1 (GHz)	k	B_{ME} (μG)	B_{IC} (μG)	B_{ME}/B_{IC}
1	$\pi/2$	10^{-2}	1	3.0	1.7	1.7
1	0.17	10^{-2}	1	6.3	4.6	1.4
1	$\pi/2$	10^{-4}	1	4.5	1.7	2.6
1	$\pi/2$	10^{-2}	100	9.1	1.7	5.2
0.1	$\pi/2$	10^{-2}	1	5.7	1.7	3.3
0.01	$\pi/2$	10^{-2}	1	11.0	1.7	6.4

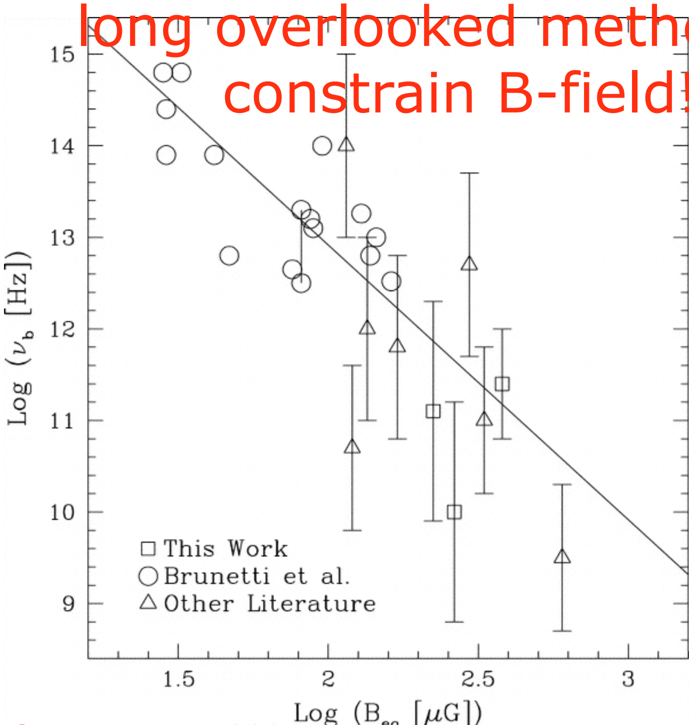
NOTE.—The calculation is based on the following: $\alpha_r = -0.8$, $S_r = 74$ Jy at $\nu_r = 1.4$ GHz, $\theta = 1020''$, and $s = 74$ kpc are derived from low-frequency synchrotron observations (Ekers et al. 1983). Fitting a $\alpha_x = -0.8$ power-law model with Galactic foreground $N_H = 2 \times 10^{20}$ cm^{-2} to the west lobe excess gives $S_x = 1.7 \times 10^{-30}$ ergs s^{-1} cm^{-2} Hz^{-1} at $E_x = 1$ keV. The upper synchrotron cutoff is taken to be $\nu_2 = 100$ GHz.

where k is the ratio of the energy in heavy particles to the energy in electrons, η is the filling factor of the synchrotron emitting region, θ is the lobe diameter in arcseconds, s is the path length through the source in kiloparsecs, ϕ is the angle between the (assumed uniform) magnetic field and the line of sight, and ν_1 and ν_2 (GHz) are the upper and lower cutoff frequencies for the radio synchrotron spectrum. While B_{ME} depends on several factors that are not well constrained by observation, the dependence is relatively weak.

from Feigelson et al. 1995

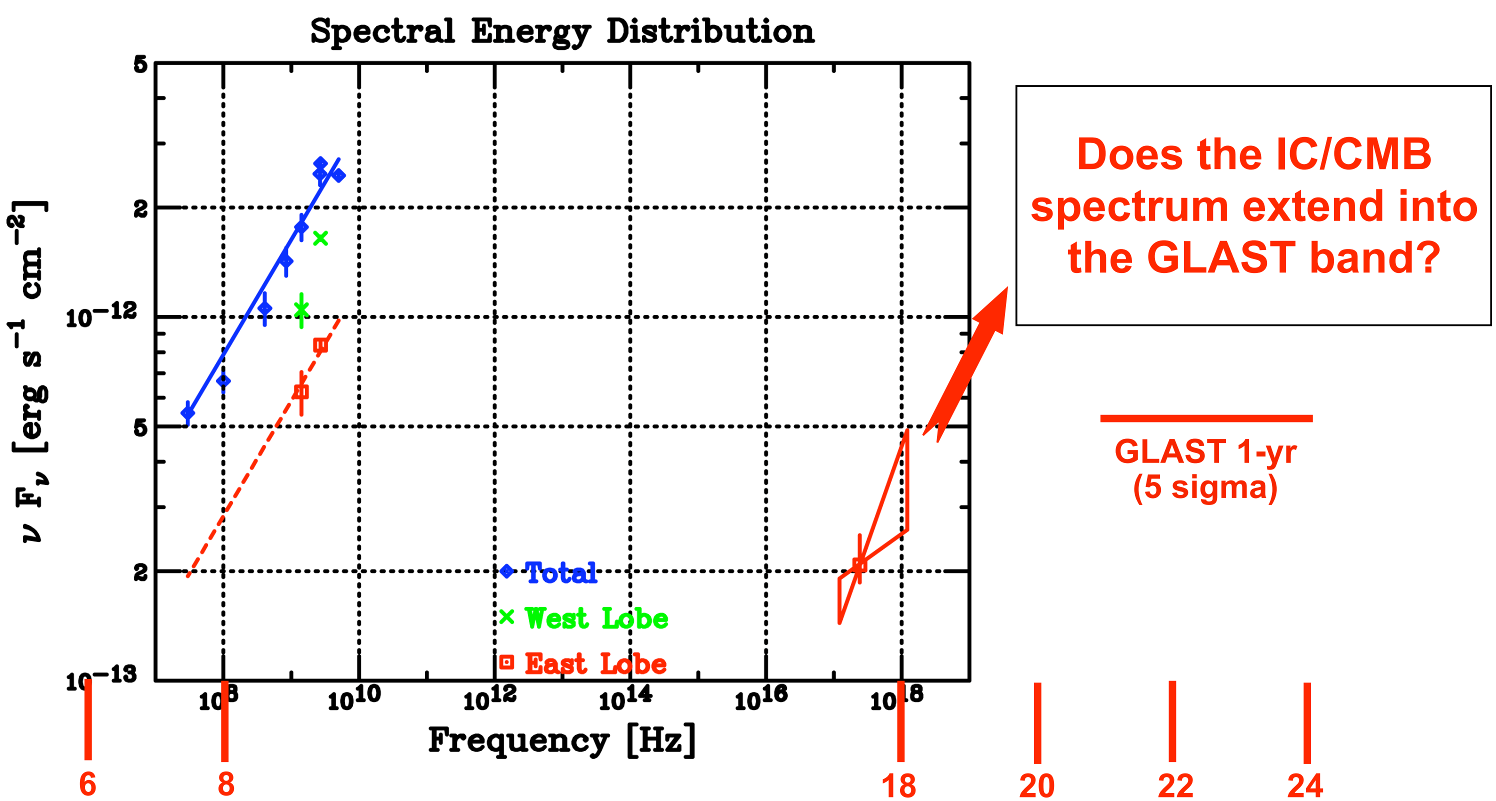
Future

Radio spectral mapping is a long overlooked method to constrain B-field!



Cheung et al. 2005

IC/CMB G-rays from Fornax A?



Spectrum from N. Isobe talk

Relevant Lorentz Factors

-Electrons that produce synchrotron (radio) emission at frequency ν have energies $\gamma_s \sim 2{*}10^4\ (\nu\ 1{+}z\ /\ d\ B)^{1/2}$.
-Electrons that Compton scatter CMB photons to energy E_c have energies $\gamma_c \sim 10^3\ (E_c\ /\ d\ G)^{1/2}$.

-Electrons with $\gamma \ll \gamma_{KN} = 2{*}10^8\ /\ (G\ 1{+}z)$ Compton scatter CMB photons in the Thomson regime. (see Dermer & Atoyan 2002)

Legend

γ = electron Lorentz factor, $E=\gamma mc^2$
ν in GHz; E_c in keV
d = Doppler beaming factor
G = jet bulk Lorentz factor
B = magnetic field in microGauss

In Fornax A Lobes...

$\gamma_s \sim 2*10^4\ (\nu\ 1{+}z\ /\ d\ B)^{1/2} = 2*10^4\ (\nu)^{1/2}$

$\gamma_c \sim 10^3\ (E_c\ /\ d\ G)^{1/2} = 10^3\ (E_c)^{1/2}$ $(\gamma \ll \gamma_{KN} = 2*10^8)$

1 keV X-ray emission from $\gamma_c \sim 10^3$ electrons which emit synch. rad. at ~2 MHz.

Emission in GLAST bands ($\sim 10^{1\text{-}3}$ MeV = $10^{4\text{-}6}$ keV) require $\gamma_c \sim 10^{5\text{-}6}$; these electrons emit synch. rad. at $\nu \sim$ 20-2000 GHz

Legend

γ = electron Lorentz factor, $E=\gamma mc^2$

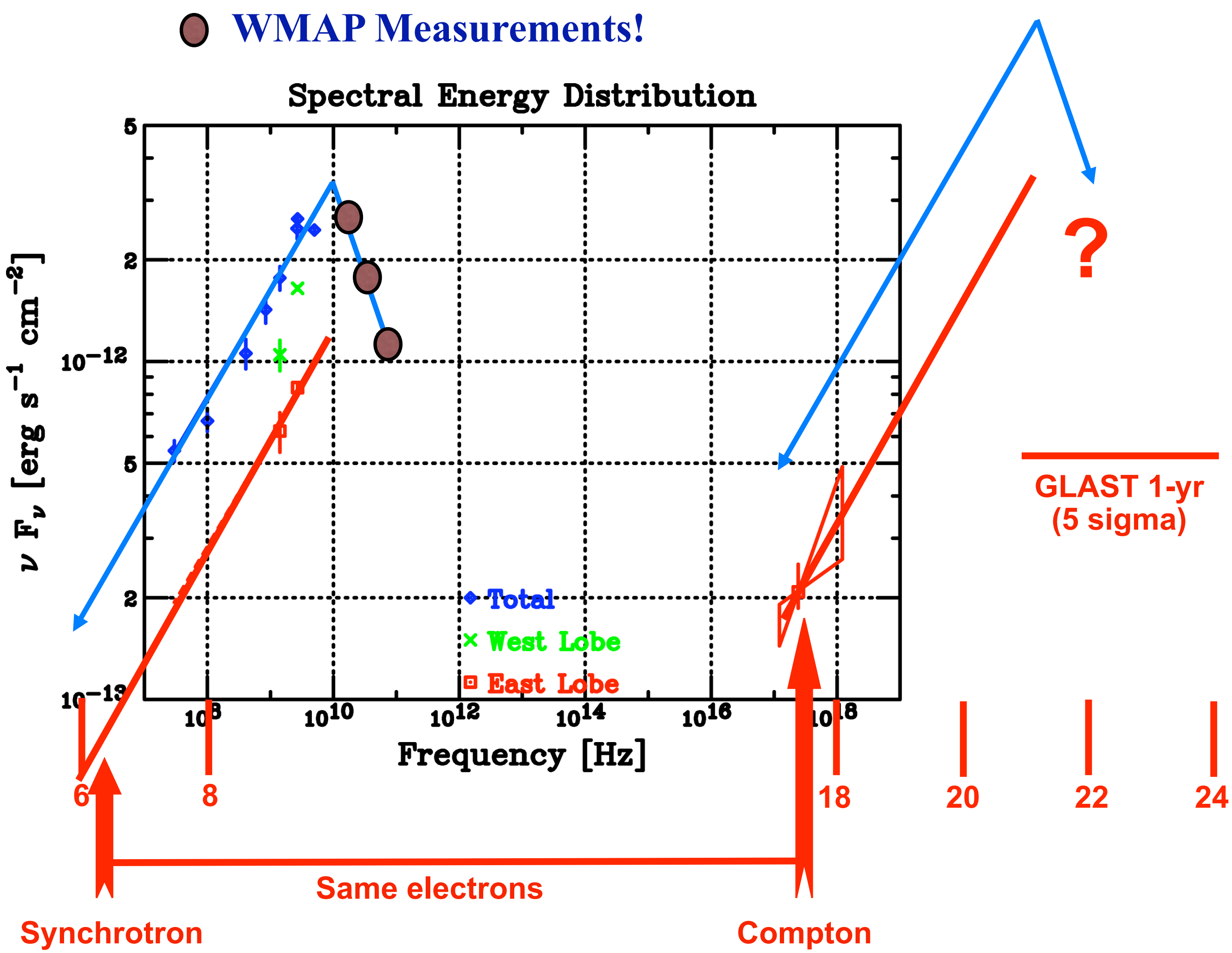
ν in GHz; E_c in keV

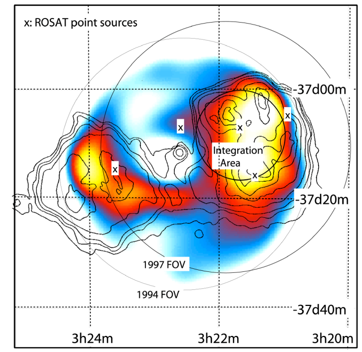
d = Doppler beaming factor = 1

G = jet bulk Lorentz factor = 1 (z~0)

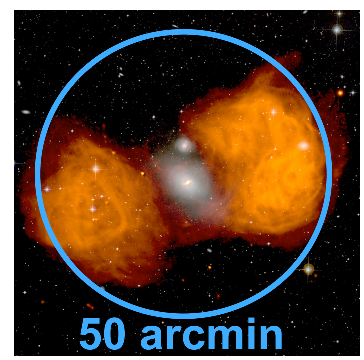
B = magnetic field in microGauss = 1.5 +/- 0.5 (Isobe et al. 2006)

Fornax A Detectable by GLAST!





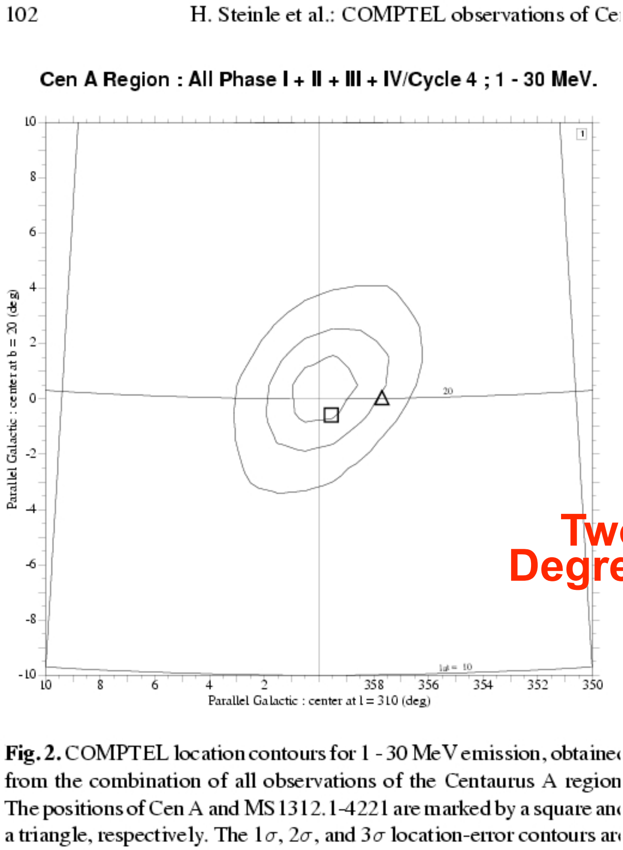
GLAST Image?



Spectrum from N. Isobe talk

Other Extended Radio Galaxies?

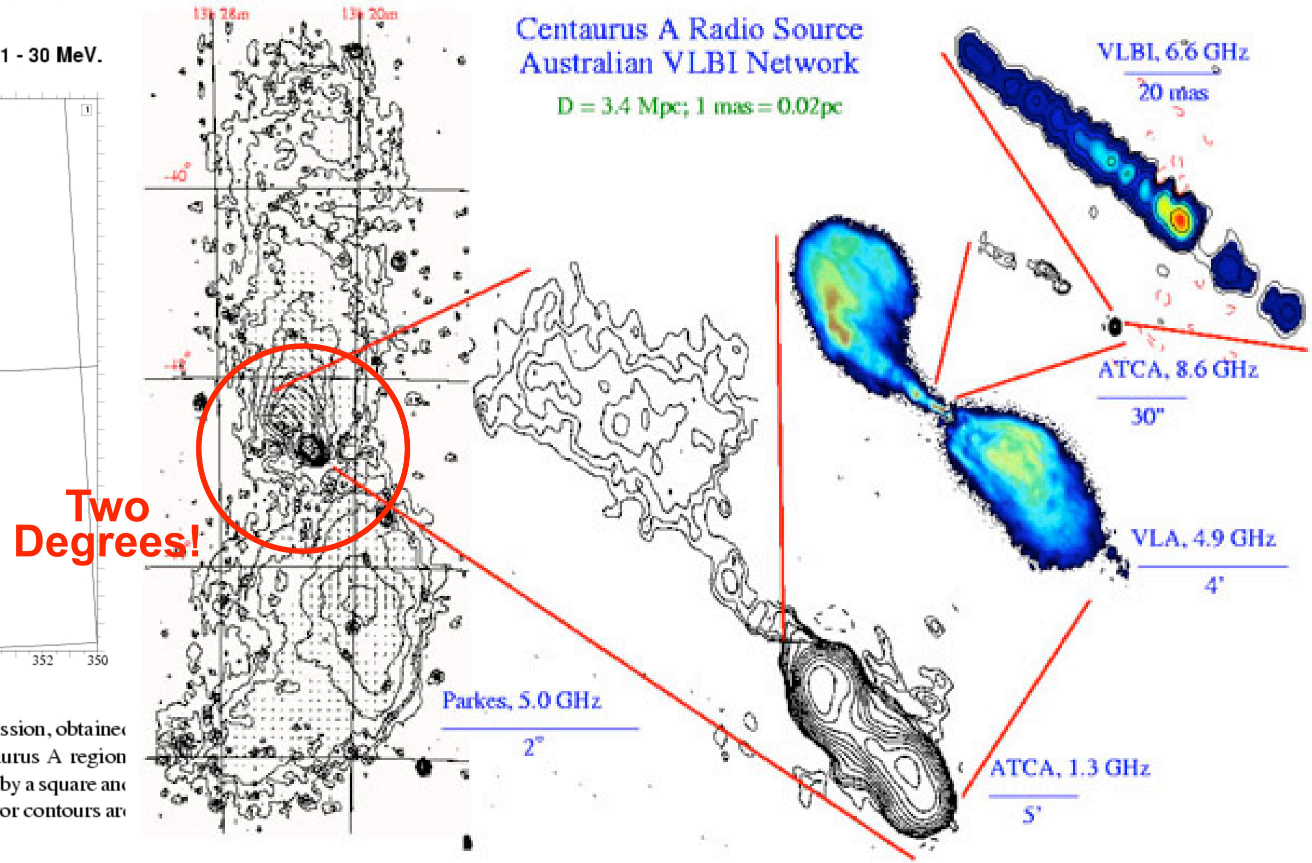
Centaurus A = 3EG J1324-4313



102 H. Steinle et al.: COMPTEL observations of Ce

Cen A Region : All Phase I + II + III + IV/Cycle 4 ; 1 - 30 MeV.

Fig. 2. COMPTEL location contours for 1 - 30 MeV emission, obtaine from the combination of all observations of the Centaurus A region The positions of Cen A and MS 1312.1-4221 are marked by a square an a triangle, respectively. The 1σ, 2σ, and 3σ location-error contours ar



Steinle et al. 1998

http://outreach.atnf.csiro.au/about/history/doverheights/

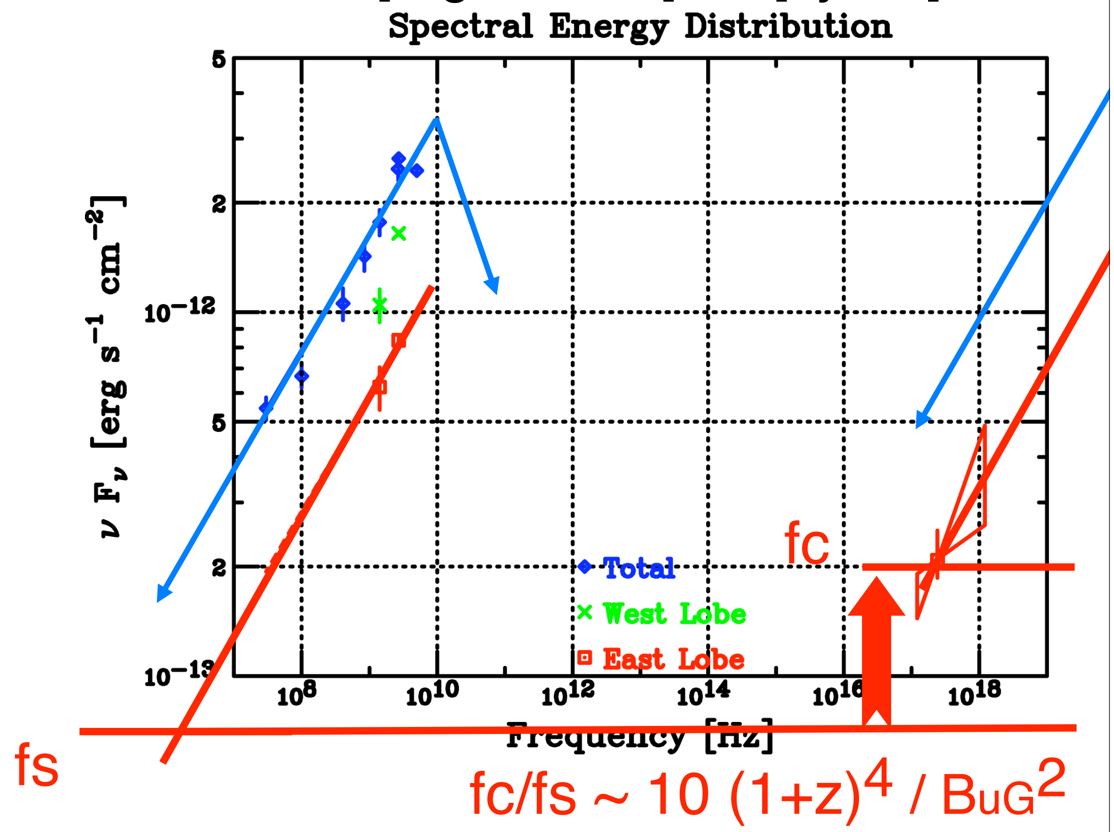
Expectations with Redshift

- Monochromatic Compton to synchrotron flux ratio (alpha=1):
  $fc/fs = u_{cmb}/u_B = aT^4 / (B^2/8*pi) = 4*10^{-13}(1+z)^4 / (B^2/8*pi)$
  $fc/fs = 10\ (1+z)^4 / (B_{uG})^2$

f[ergs/s/cm^2] or f[Jy Hz]

fc/fs will increase:
1. in low B-field regions
B(lobes)~few uG;
B(jet)~10's uG - mG;
B(blazar)~100's mG

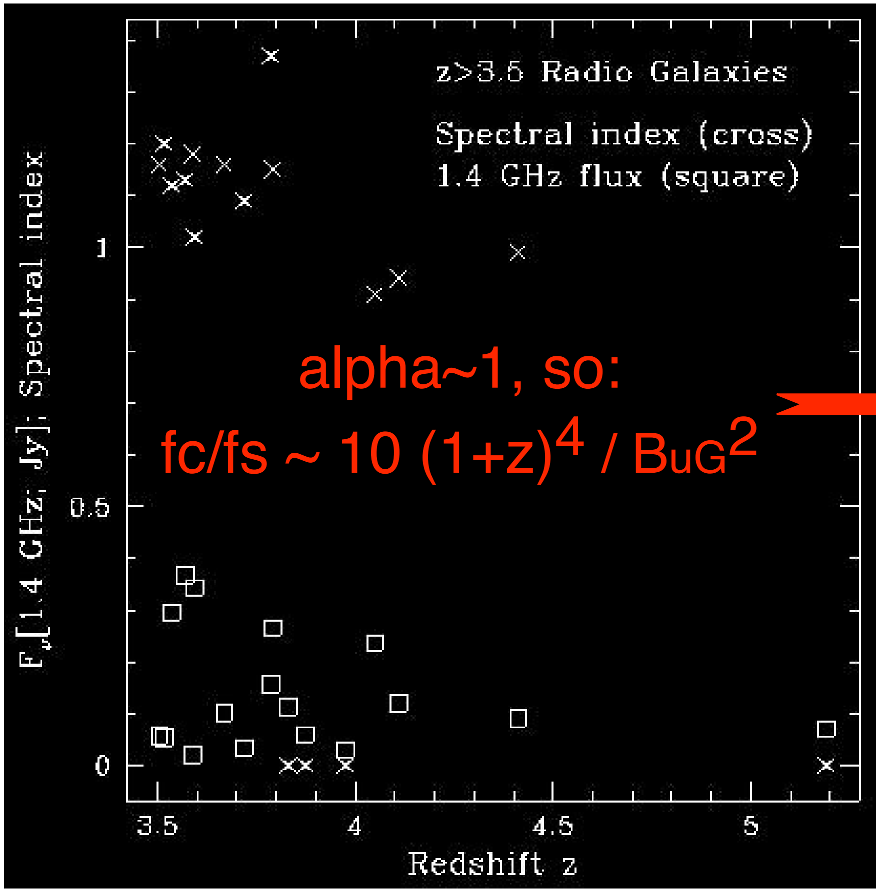
2. at higher-redshifts
$u_{cmb}(z=4) \sim 10\ u_{cmb}(z=0.8) \sim 100\ u_{cmb}\ (z=0)$, so...

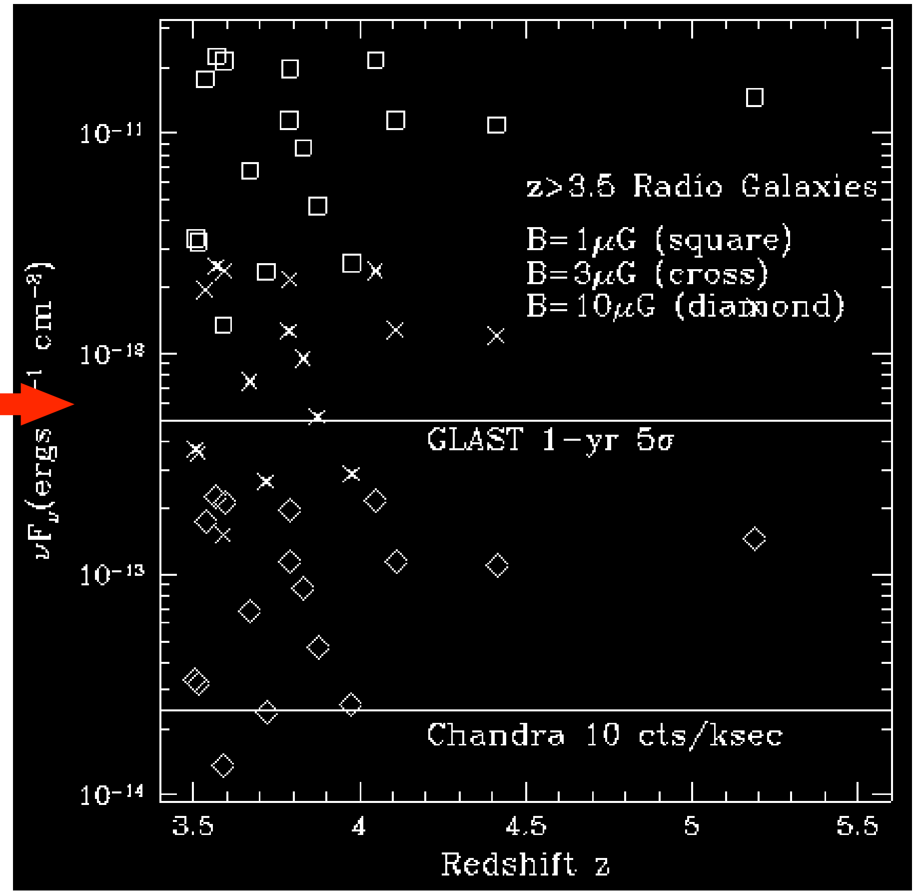


The Highest-Redshift Radio Galaxies

17 z>3.5 Radio Galaxies

GLAST/Chandra Predictions

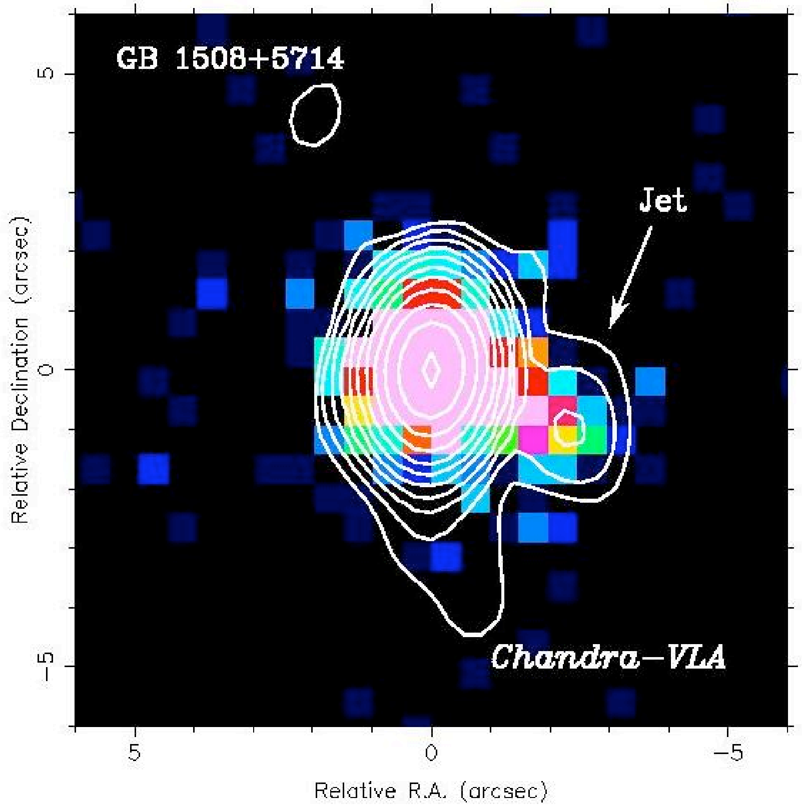




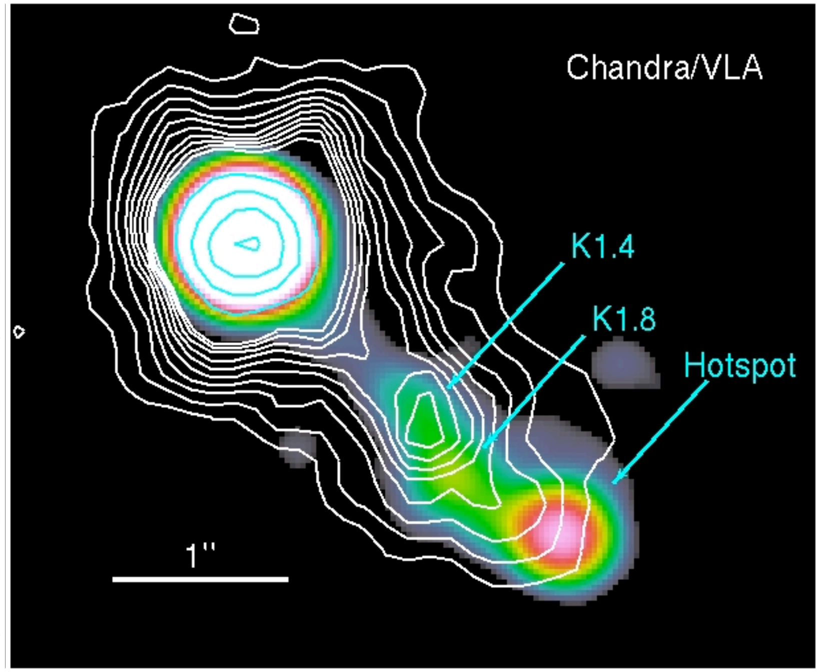
Chandra corresponds to 1-10 MHz (B=1 uG) and 10-100 MHz (B=10 uG) radio
GLAST corresponds to 20-2000 GHz (B=1 uG) and 2e11-2e13 Hz (B=10 uG)

IC/CMB (Jet) Detections at High-z

GB1508+5714 z=4.3



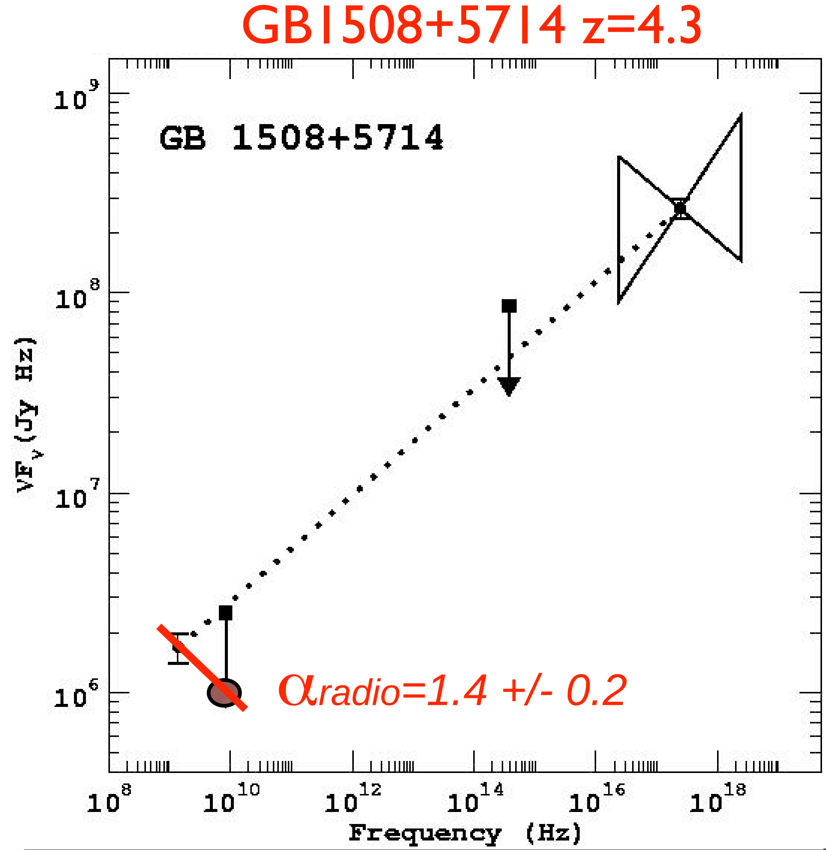
1745+624 z=3.9



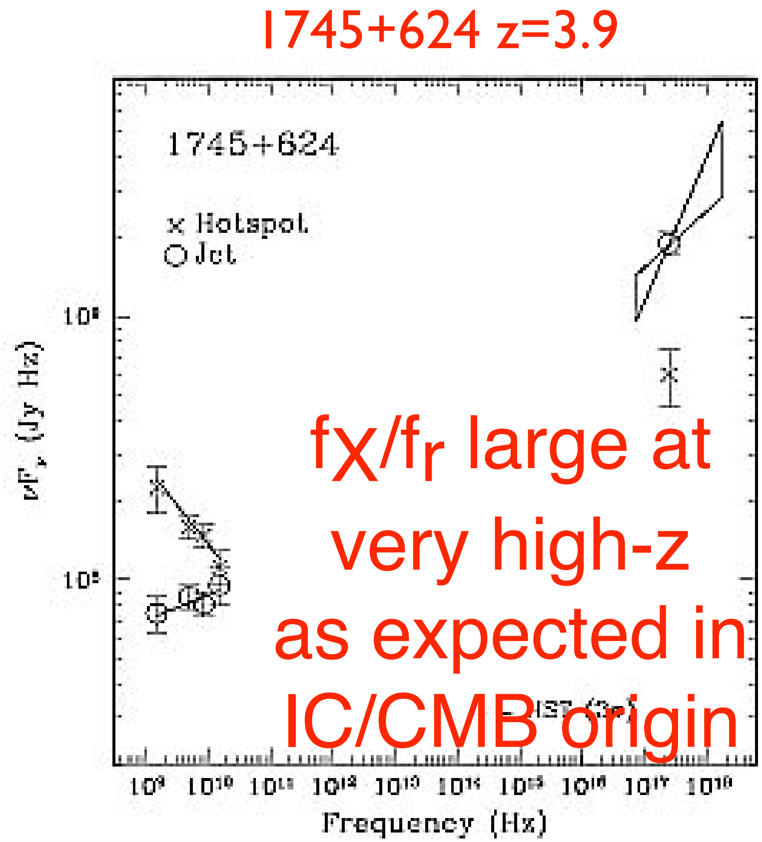
X-ray contours, radio color
Cheung, Stawarz, & Siemiginowska 2006

VLA contours, Cheung 2004
X-ray color, Siemiginowska et al. (2003), Yuan et al. (2003)

IC/CMB Jets at High-Redshift

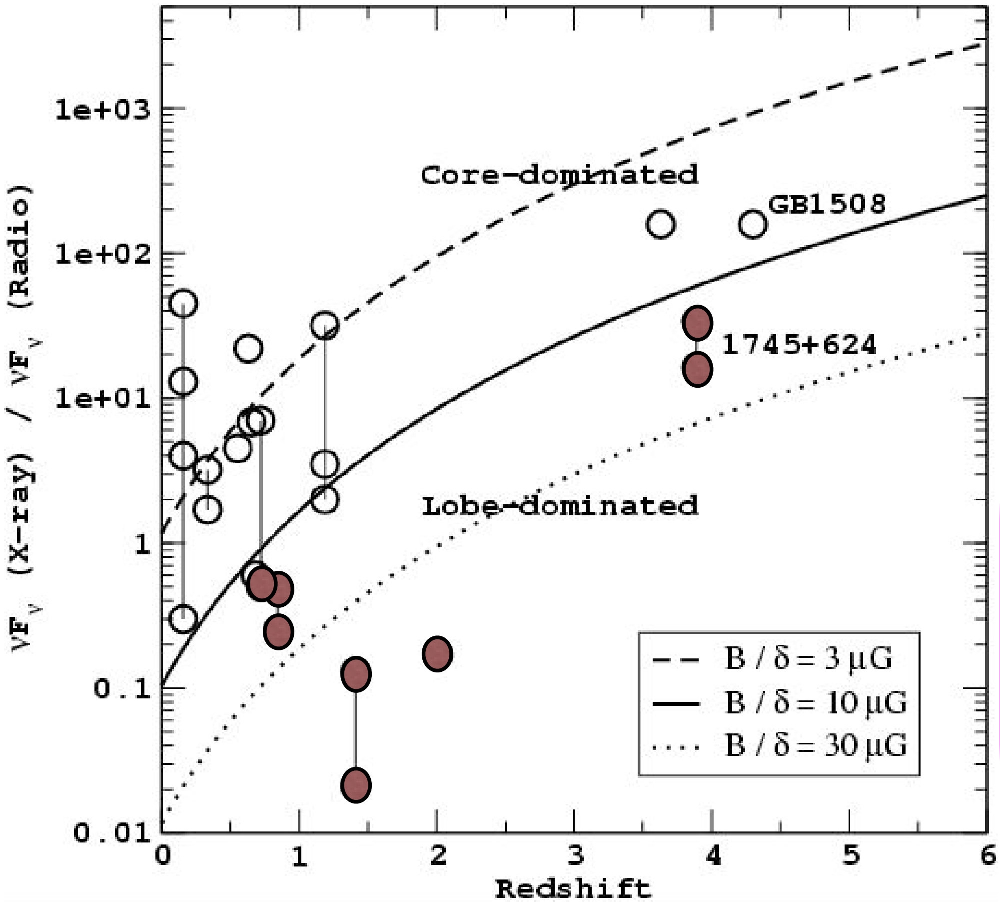


Cheung (2004)



Cheung, Stawarz, Siemiginowska (2006)

IC/CMB Jets at High-Redshift



f_X/f_r for jets depends also on beaming in addition to other parameters (e.g., *B*)

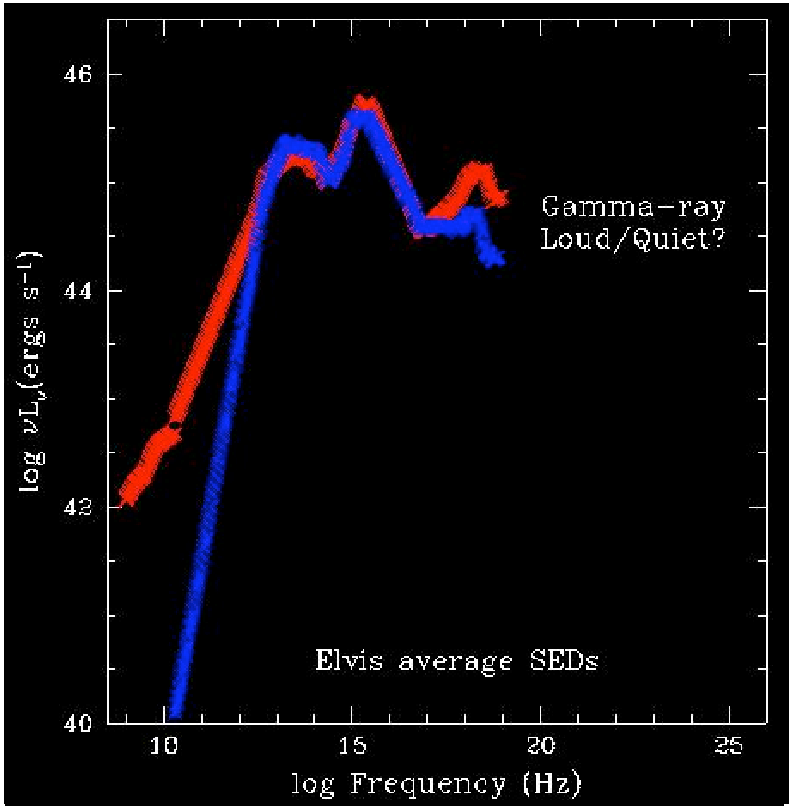
Advantage Radio Galaxy: emission is negligibly/ not beamed; spectral shapes, dimensions better measured than jets (to constrain B-field)

Issues of Wider Interest

Recall that radio-loud sources are a *special* subset of AGN/Quasars (~10%) and Blazars are special subset of these radio-loud sources...

I considered radio-galaxies (i.e. "misaligned" blazars) but...

What about the other 90% of the general (radio-quiet, but not radio-silent) AGN population? e.g. Seyferts



Perspective: Radio-loudness may be linked with black hole mass (see e.g., McLure & Jarvis 2004)? BH Spin (e.g., Wilson & Colbert 1995), Accretion (e.g., Rawlings & Saunders 1991)?

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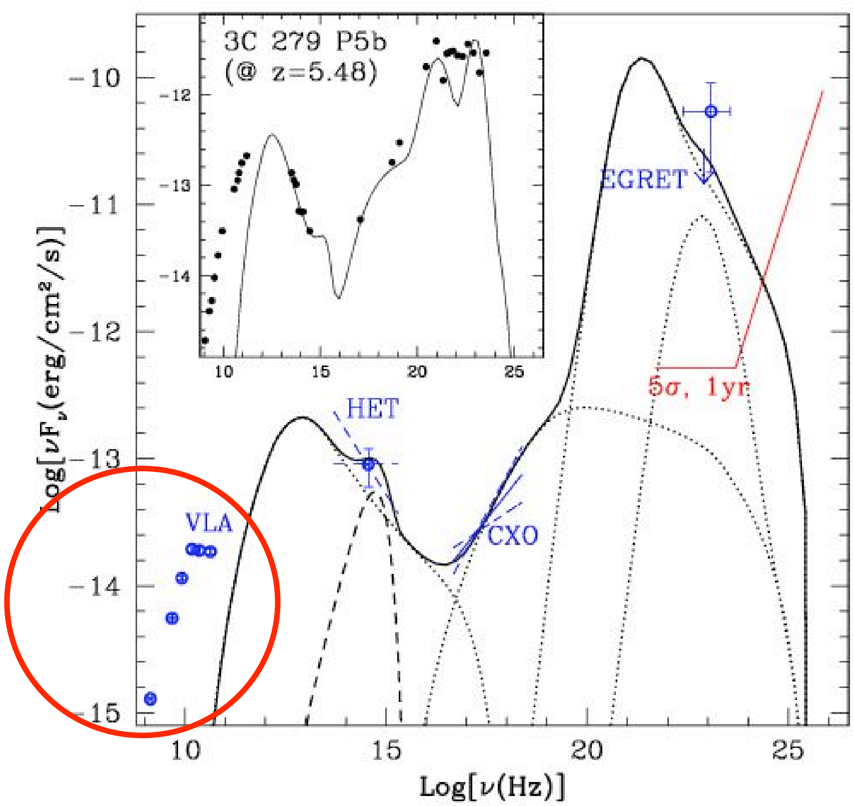

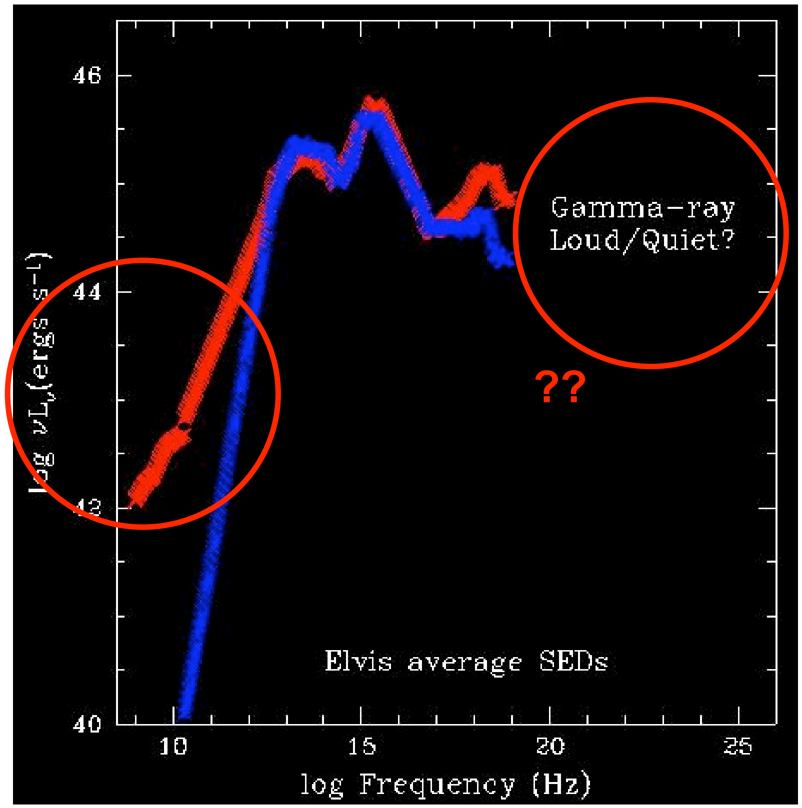

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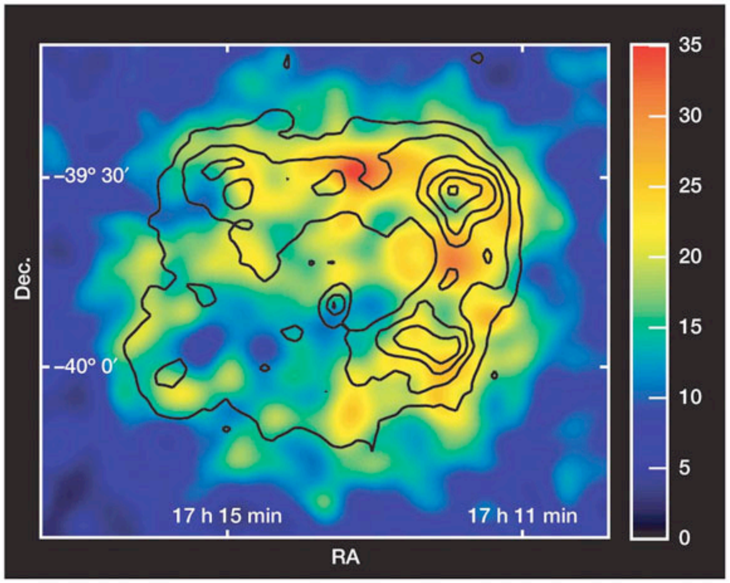
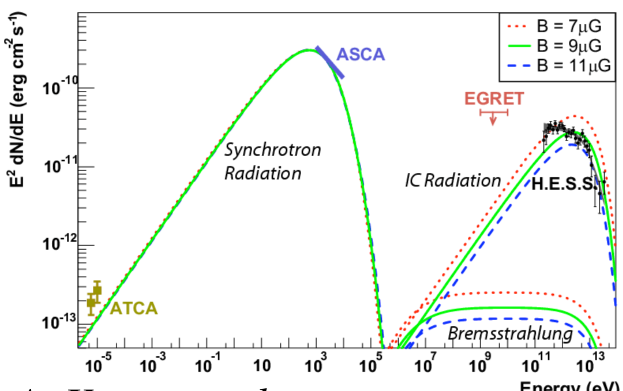
Other IC/CMB G-ray Sources?



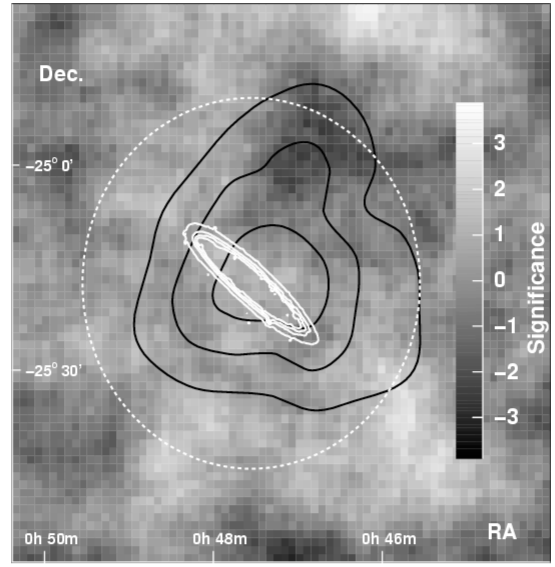
RXJ1713 (Aharonian et al. 2005)

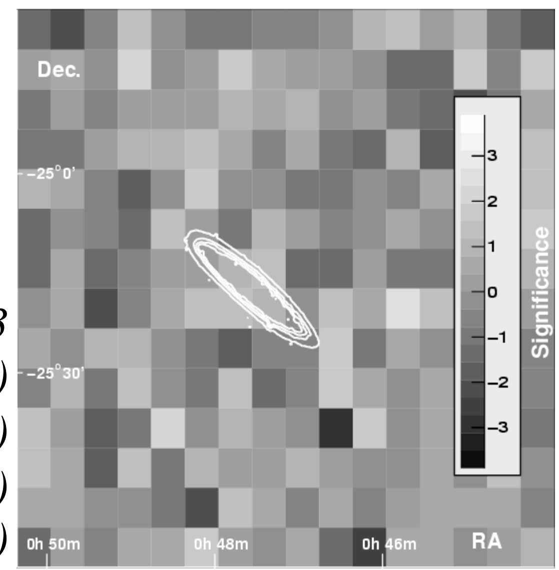


A. Kappes webpage

This process is relevant to any synchrotron radiating system

Other galaxies (particularly with larger SN rates) should emit X to g-rays via IC/ CMB channel





Starburst galaxy NGC253 (D~2.6 Mpc)
Optical DSS (white contours)
HEGRA TeV 40, 65, 80% conf. levels (Itoh+ 02)
HESS collab (Aharonian et al. 2005)

Summary

- I considered g-rays from radio galaxies through IC/CMB process (thermal extended and point source contribution negligible; cf. issues in X-ray studies)
- GLAST *images* of nearby large angular size RGs (e.g. Fornax A)
- GLAST may detect high-z RGs; as radio galaxies outnumber blazars; what is their contribution to a (soft) g-ray background?
- High-z RGs as "standard lamps" (radio data define e- distribution); are g-rays absorbed at high-z?
- TO DO: Identify more "Fornax A type" and high-z radio galaxies
  - obtain relevant radio data (define synchrotron spectrum from 10's MHz - 100's GHz)
  - obtain relevant X-ray data (XMM, Chandra): determines extended/ point source thermal contribution
- Other extended sources with relativistic particles (synchrotron emitters): SNRs, Cluster halos (hard X-ray sources)