Radio Properties of Gamma-ray Emitting CSOs

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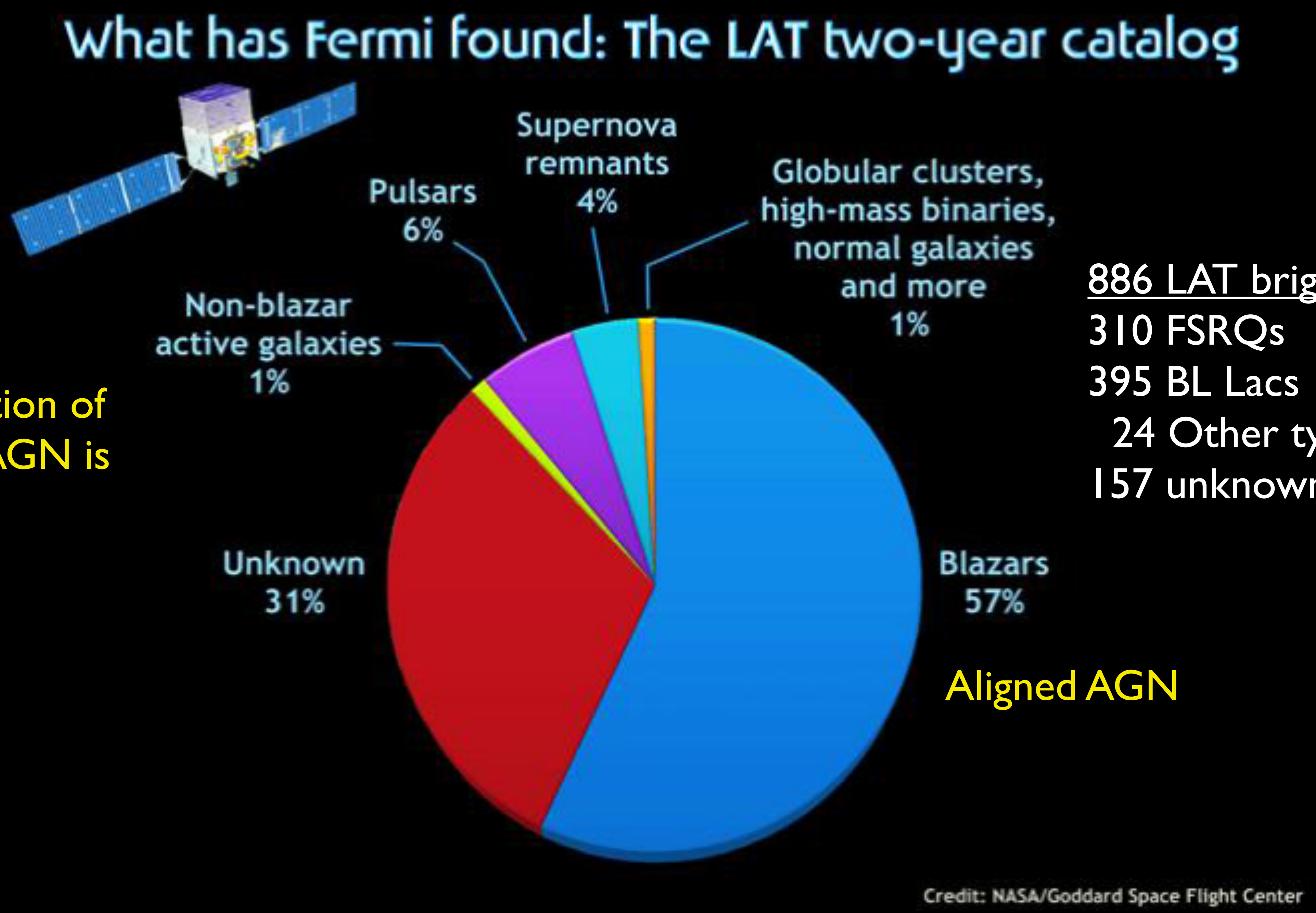
γ-ray emitting AGN



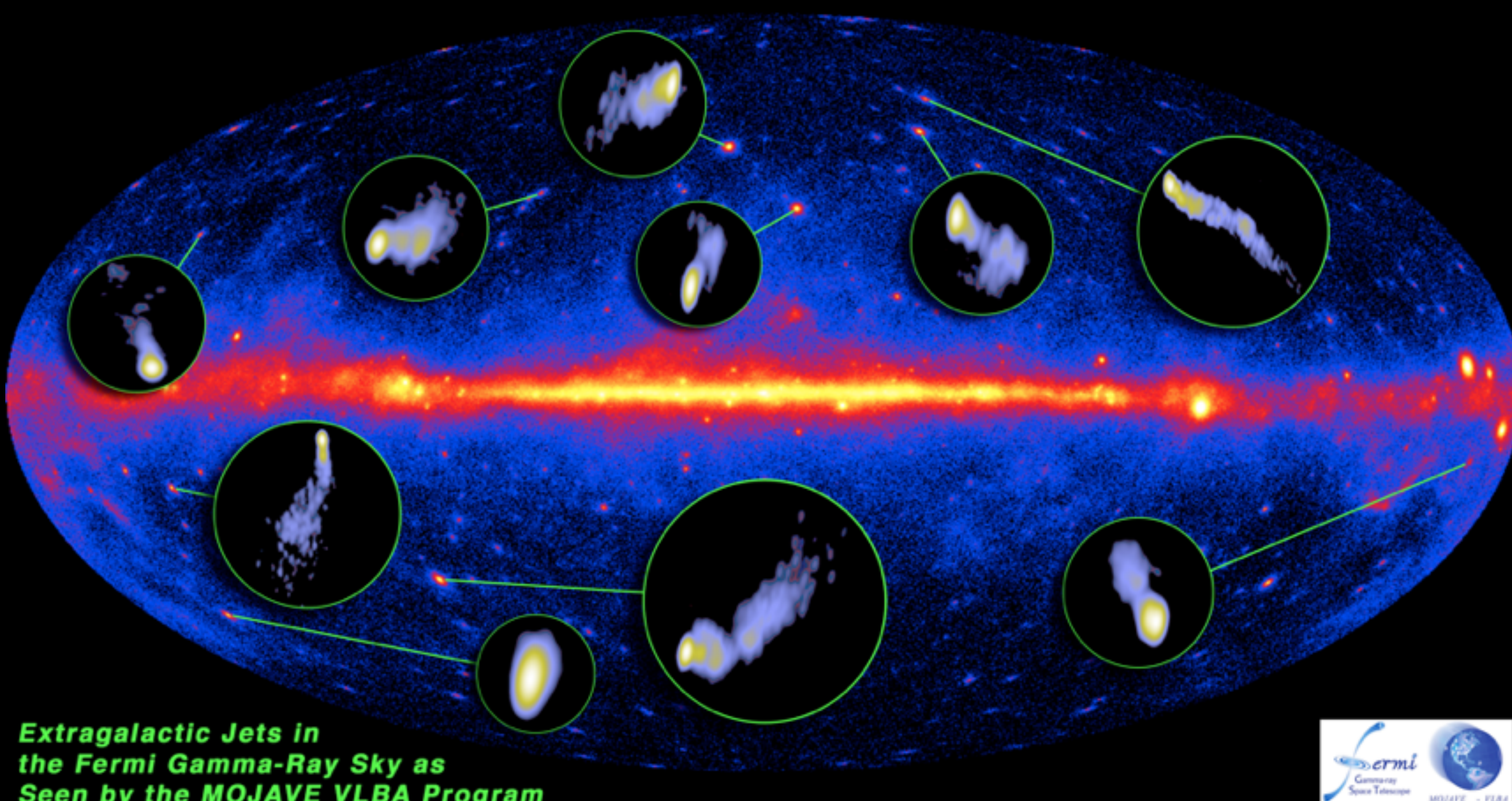
The population of misaligned AGN is increasing

<u>886 LAT bright AGN:</u>
310 FSRQs
395 BL Lacs
24 Other type AGN
157 unknown

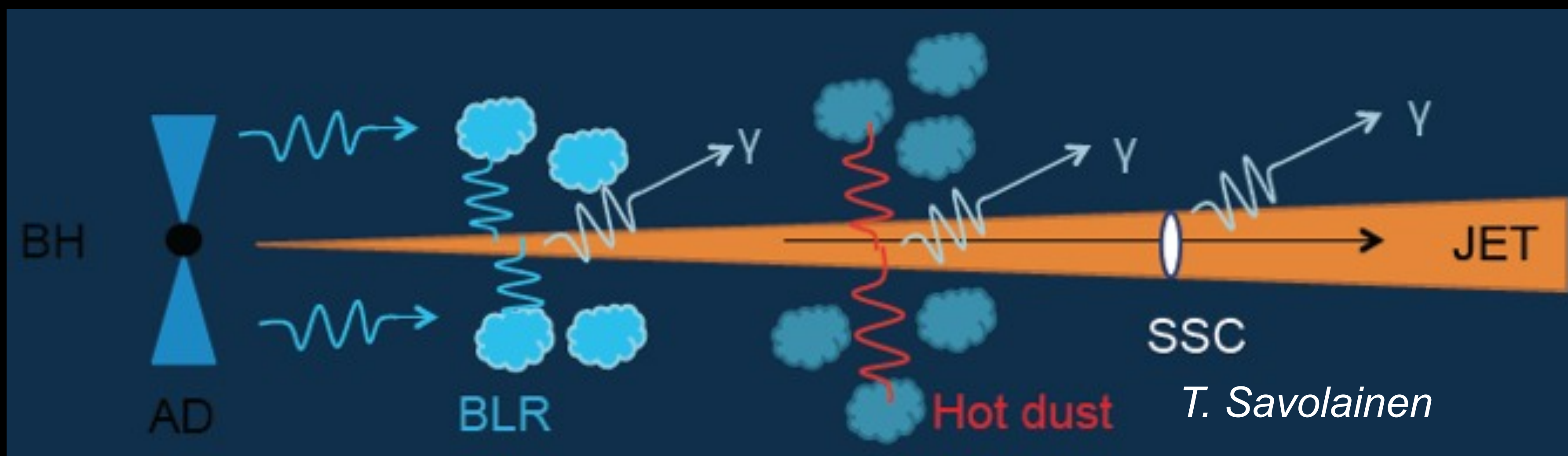
Aligned AGN

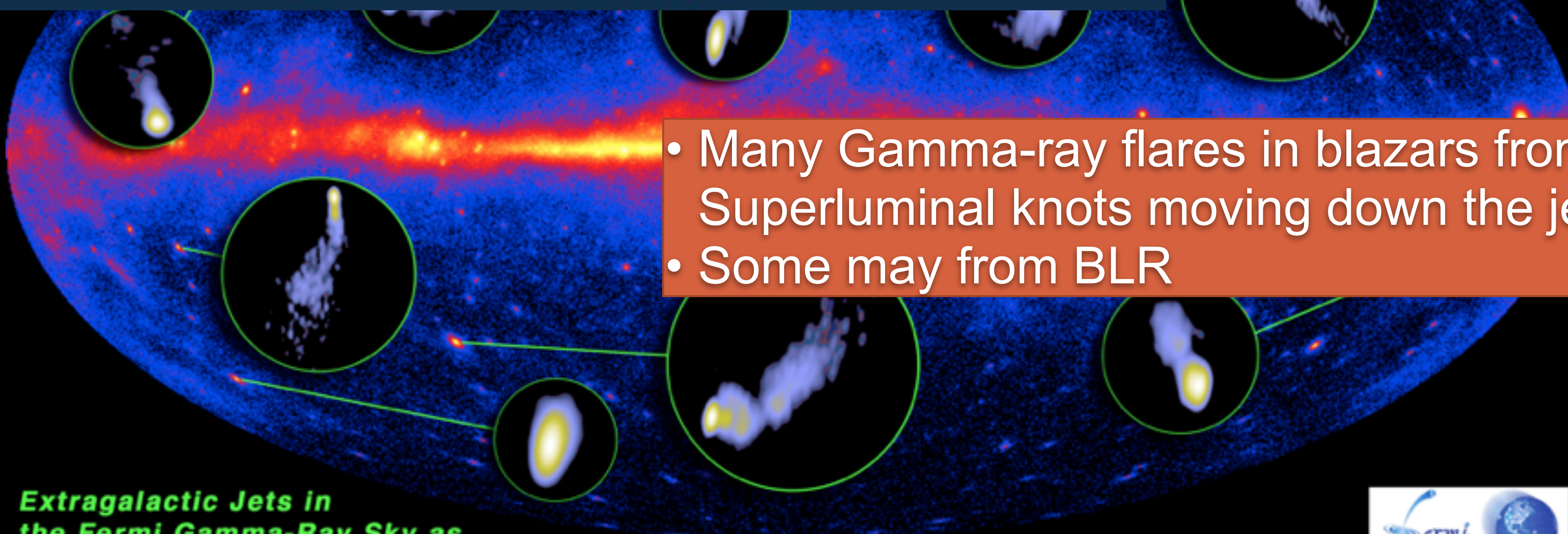
Ackermann et al. 2011 ApJ 743,171

Where does the γ-ray come from?



Where does the γ-ray come from?

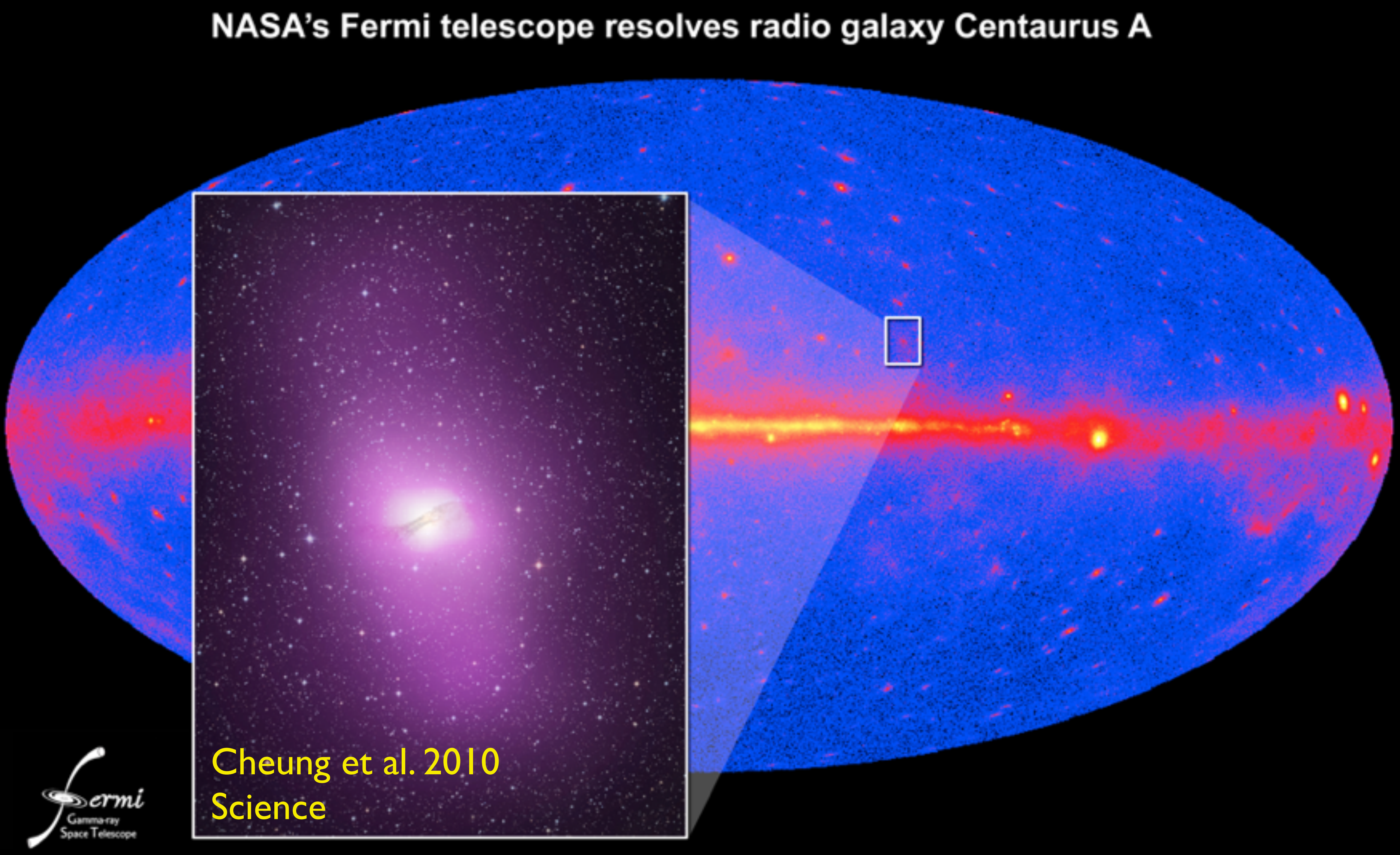




- Many Gamma-ray flares in blazars from Superluminal knots moving down the jets
- Some may from BLR

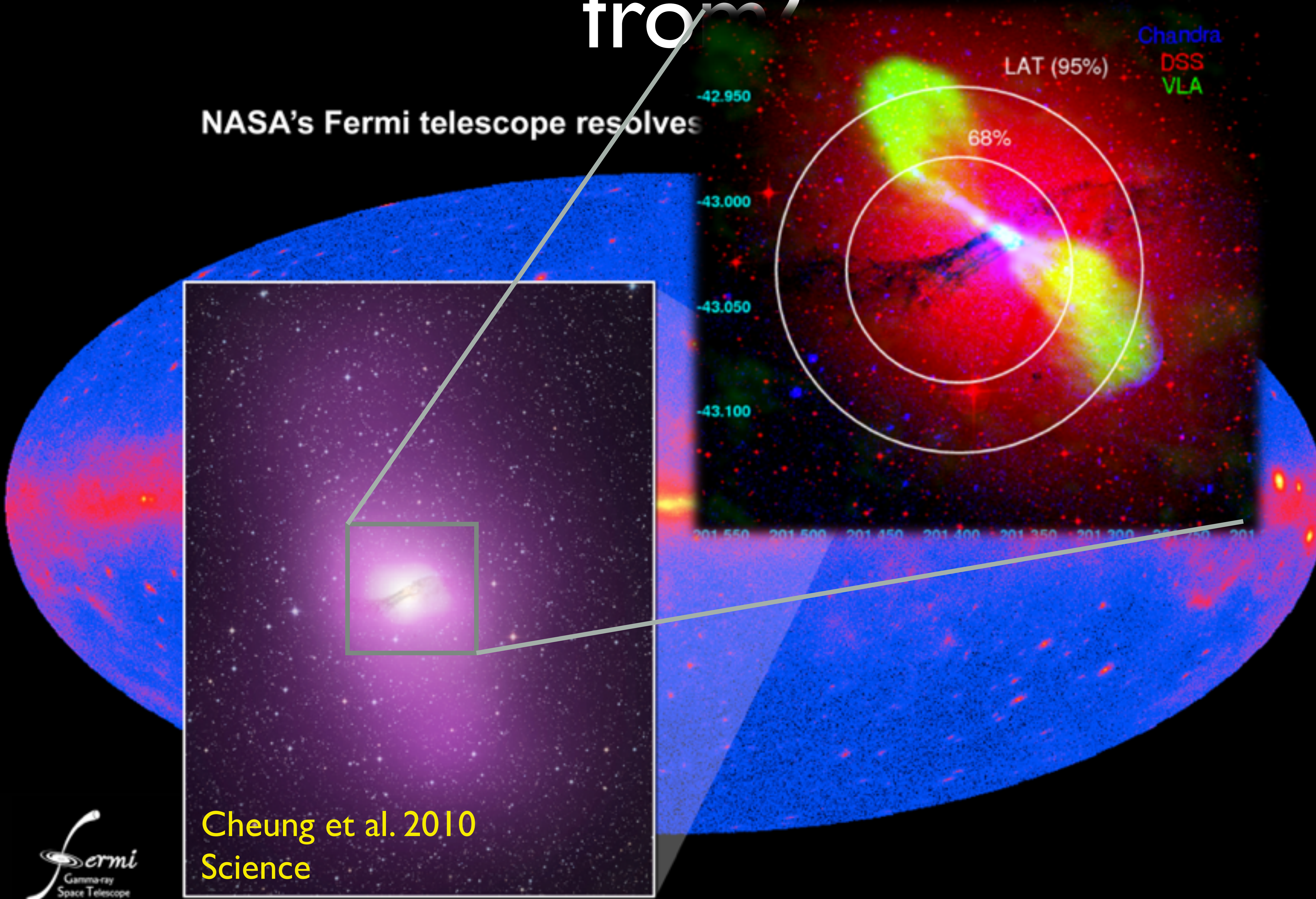
Extragalactic Jets in the Fermi Gamma-Ray Sky as Seen by the MOJAVE VLBA Program

Where does the γ-ray come from?



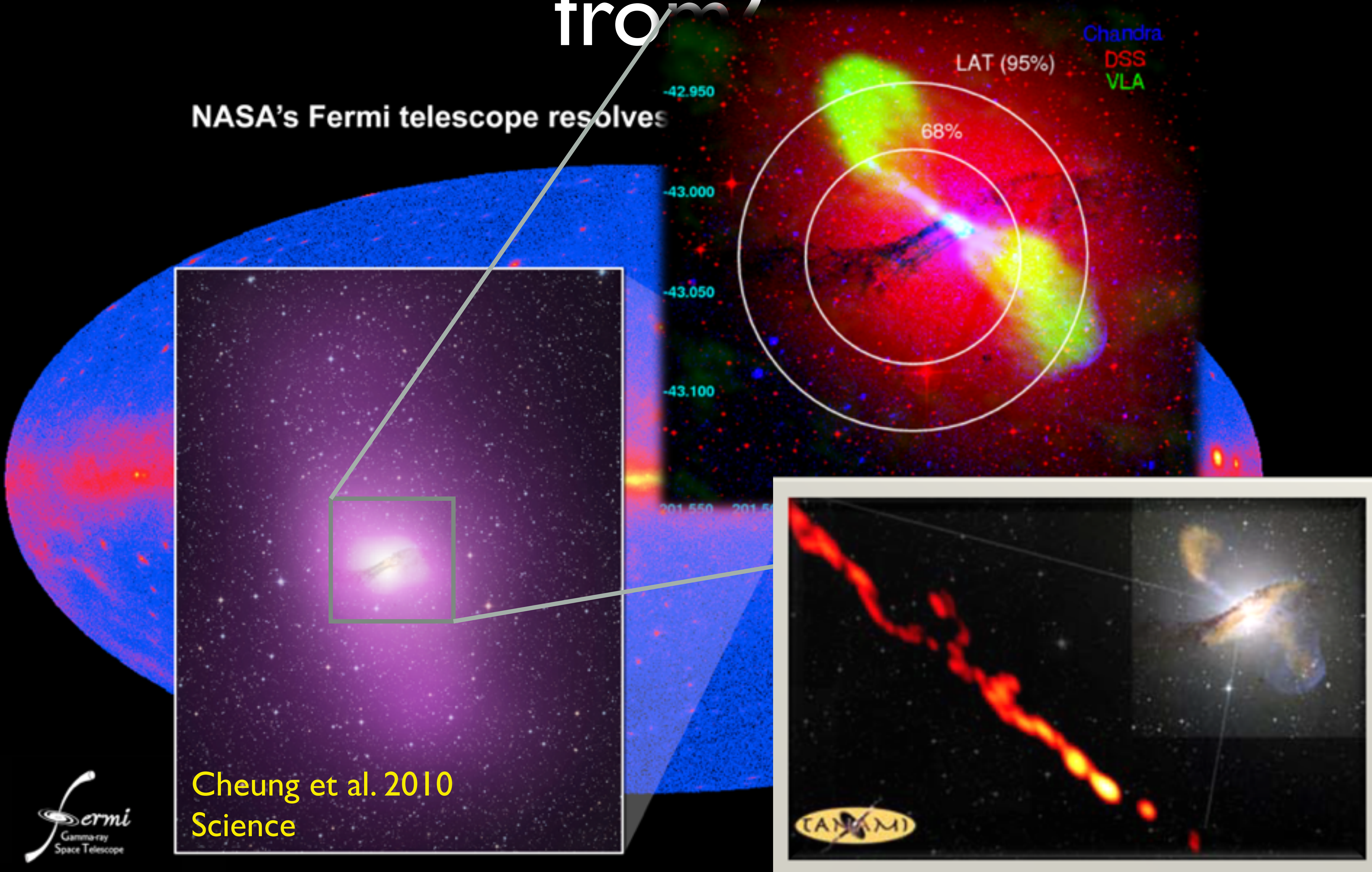
Cheung et al. 2010
Science

Where does the γ-ray come from?



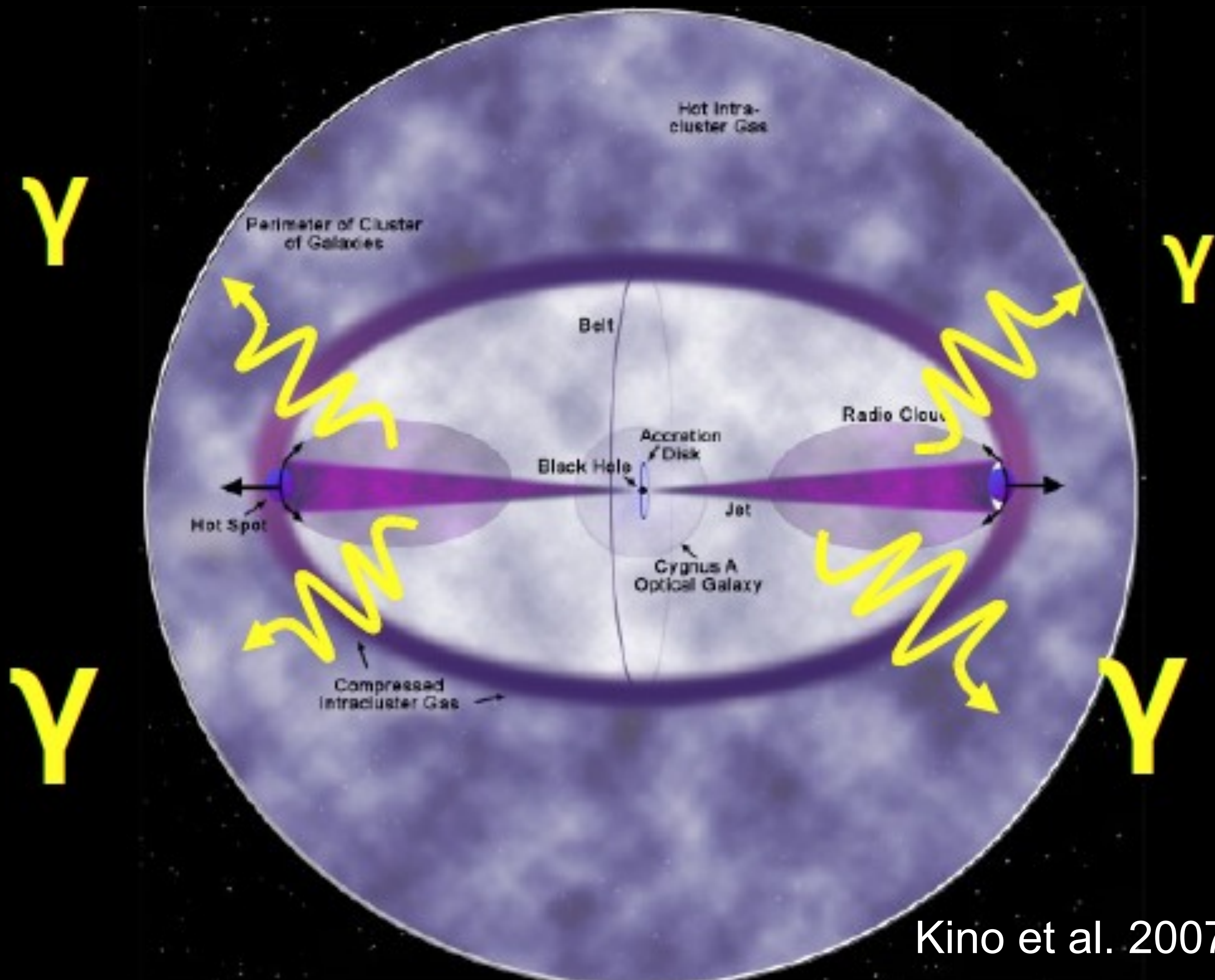
Cheung et al. 2010 Science

Where does the γ-ray come from?



Cheung et al. 2010 Science

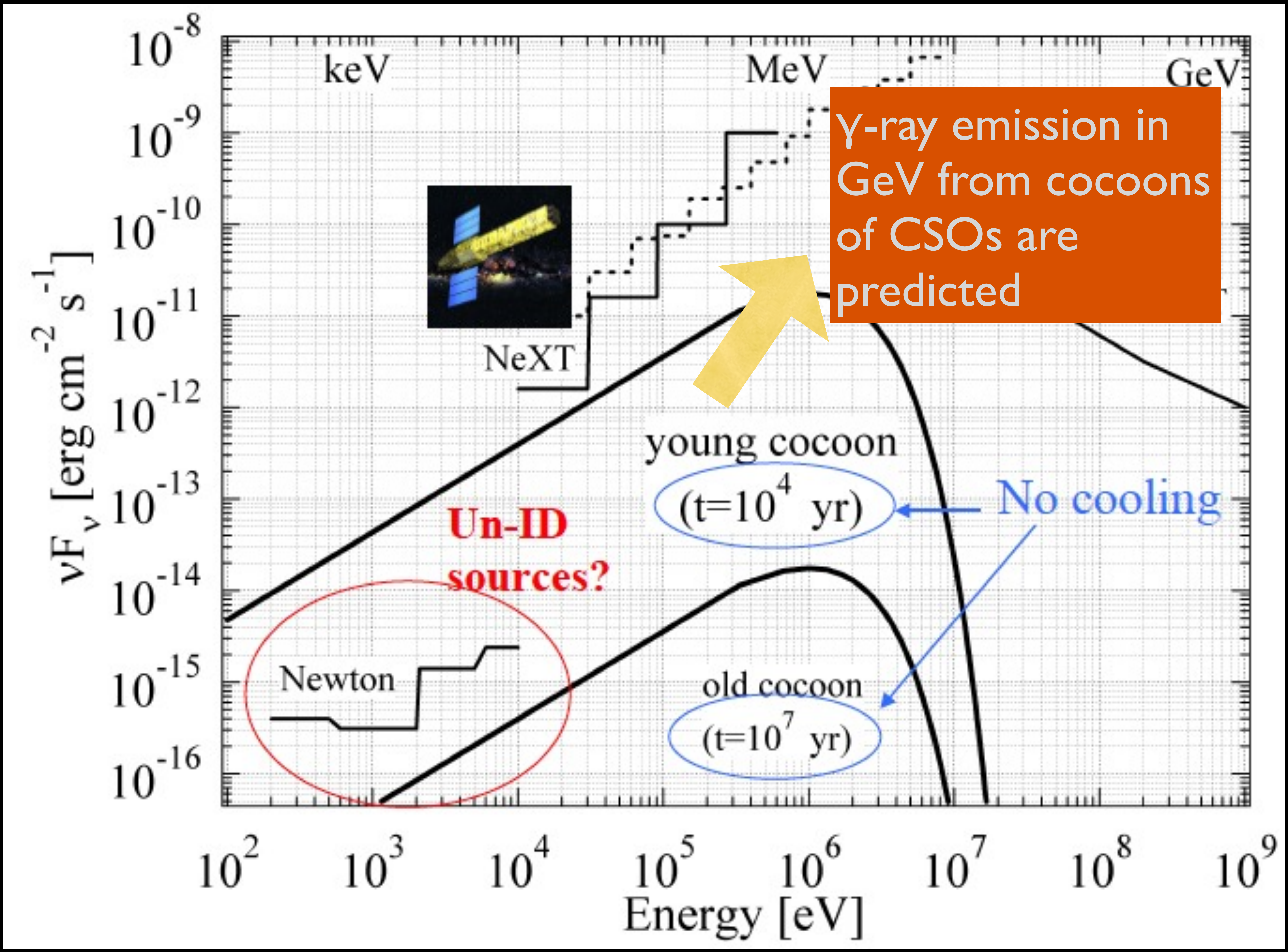
γ-ray emission from CSOs



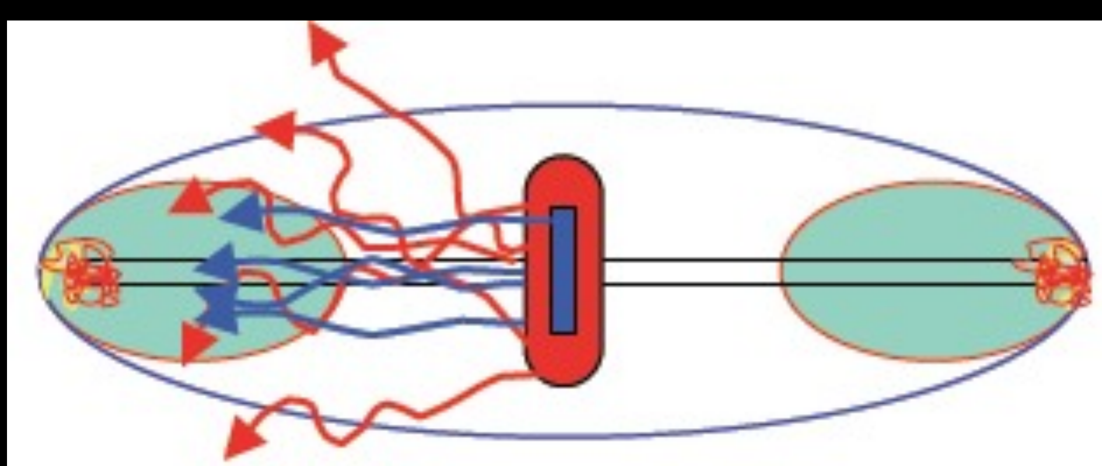
Kino et al. 2007

Sideways expansion of compact lobes/cocoons ⇒MeV bremsstrahlung

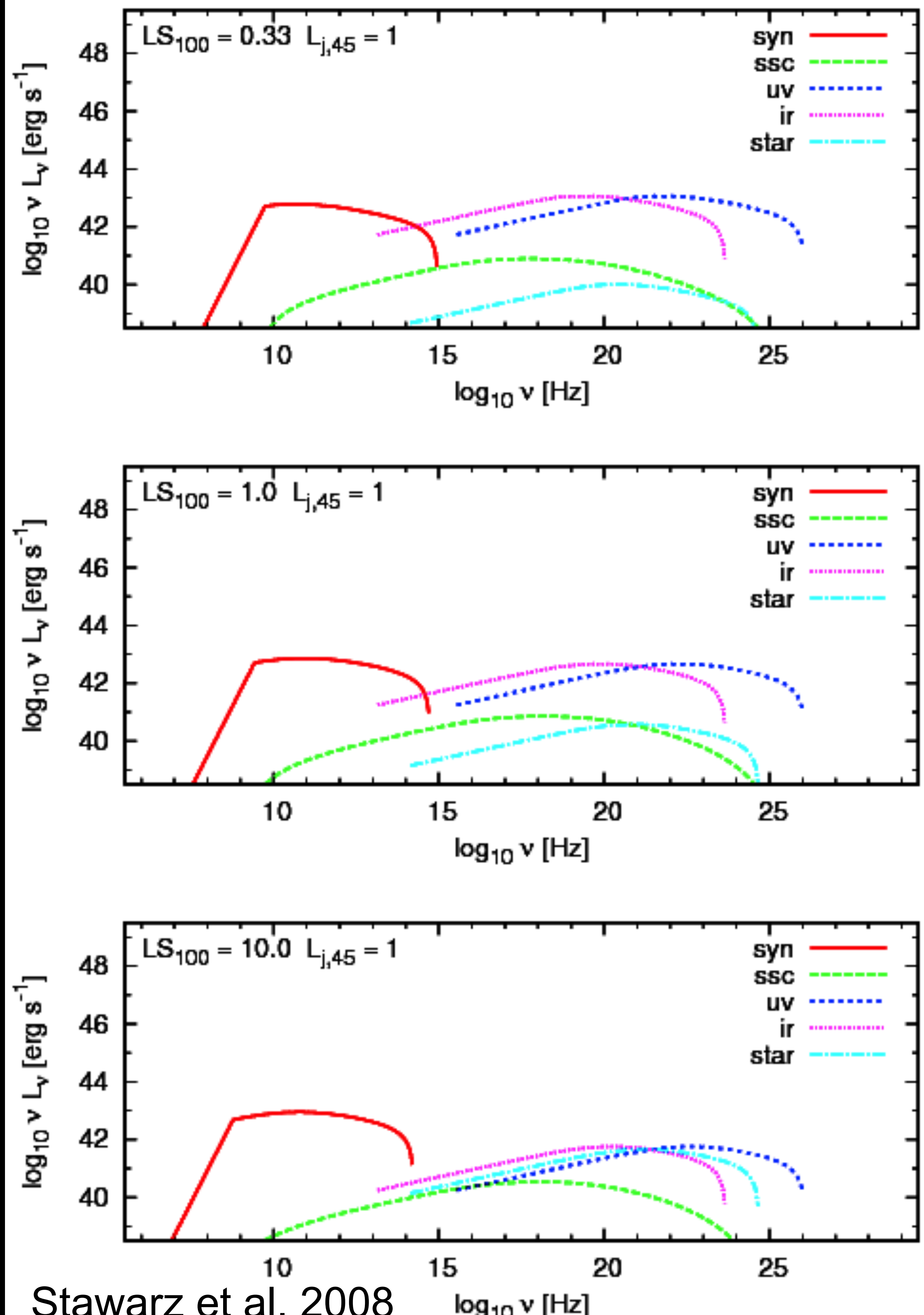
The younger the cocoons, the brighter the γ-ray emitter.


γ-ray emission in GeV from cocoons of CSOs are predicted
keV
MeV
GeV
NeXT
Newton
Un-ID sources?
young cocoon
(t=10^4 yr)
No cooling
old cocoon
(t=10^7 yr)
νF_ν [erg cm^-2 s^-1]
Energy [eV]
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Inverse Compton scattering of synchrotron photons or external photon fields within lobes ⇒ non-thermal X-ray and γ-ray emission

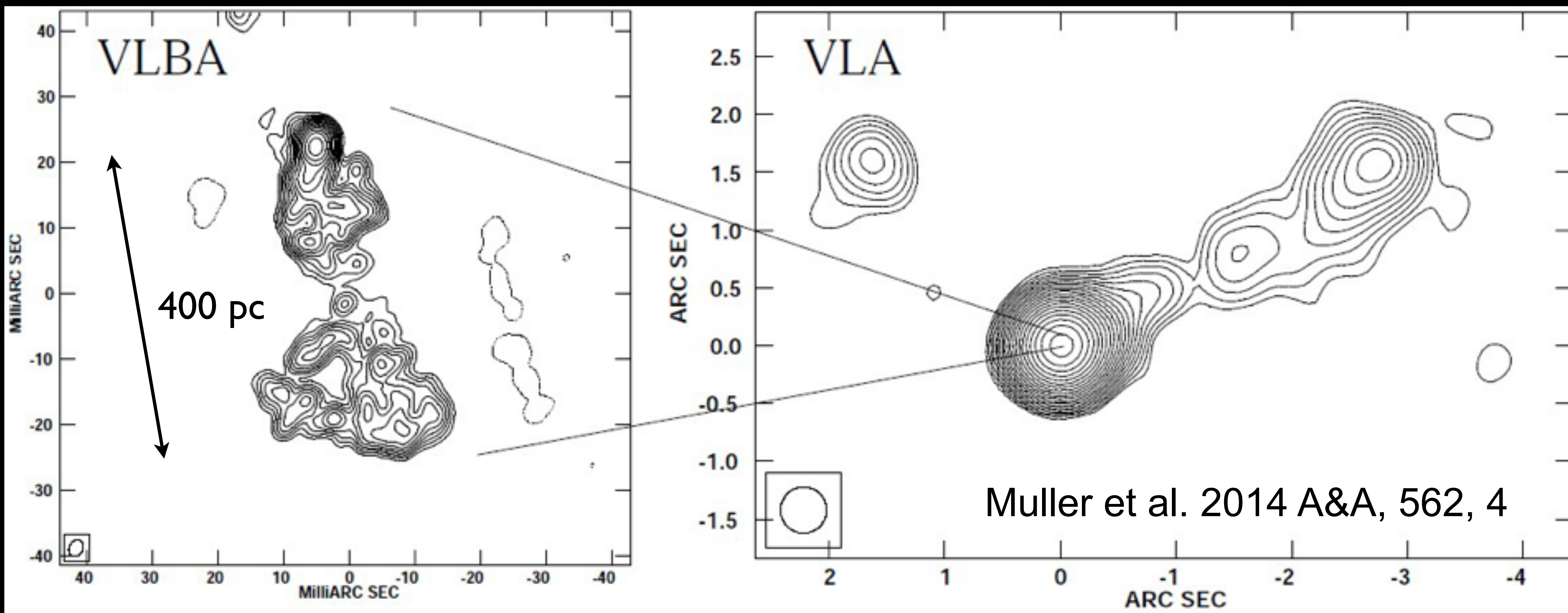


Siemiginowska et al. 2007



Stawarz et al. 2008

γ-ray CSOs: 4C +55.17

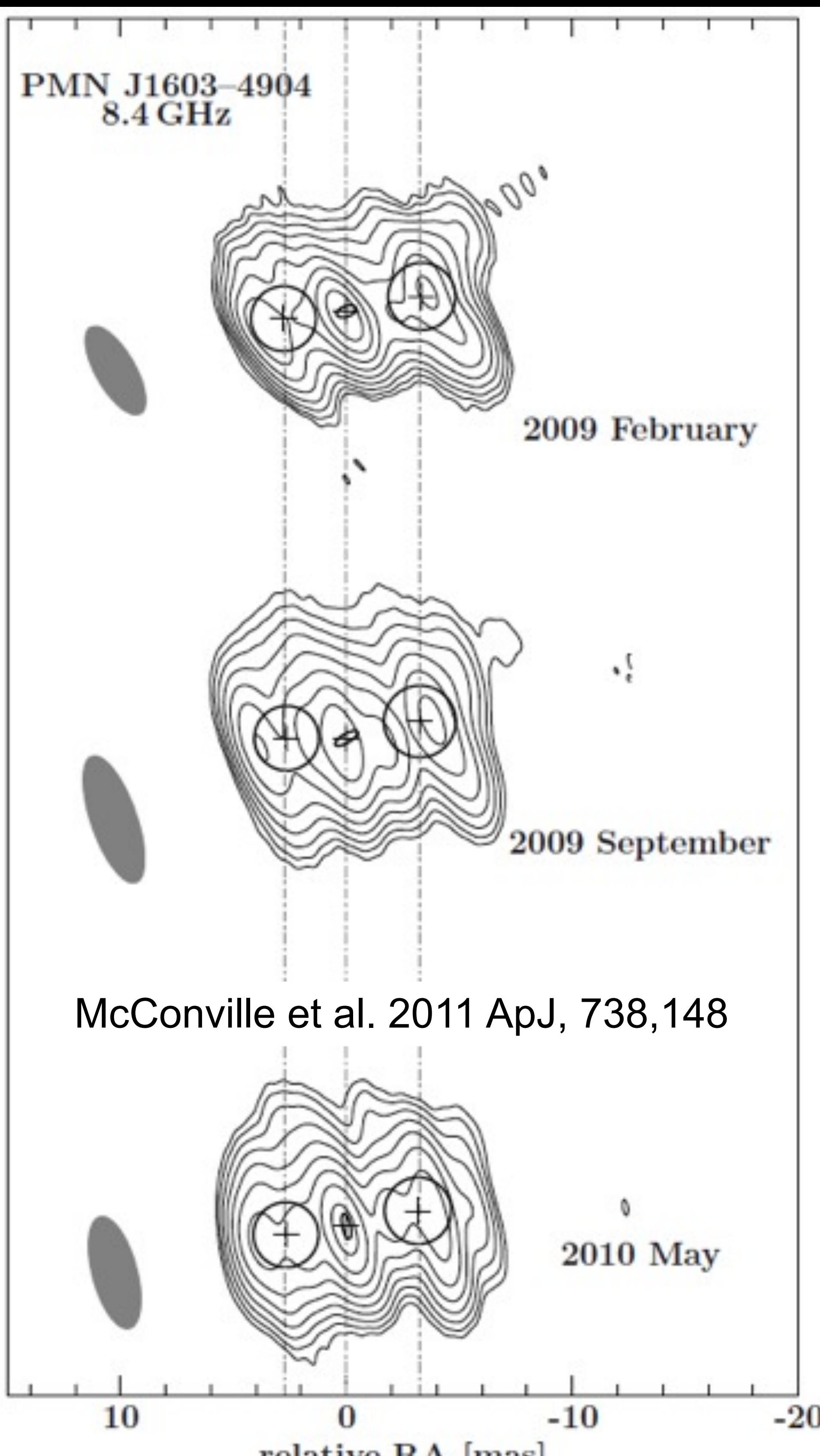


z=0.896
EGRET: yes
Fermi: yes
First confirmed γ-ray CSO

Different from γ-ray blazars:

- Hard γ-ray spectrum
- SED can be fitted with SSC+IC
- No relativistic beaming
- No variability in radio and γ-rays
- $T_B \sim 10^8$ K
- Extended radio morphology
- Low radio polarization

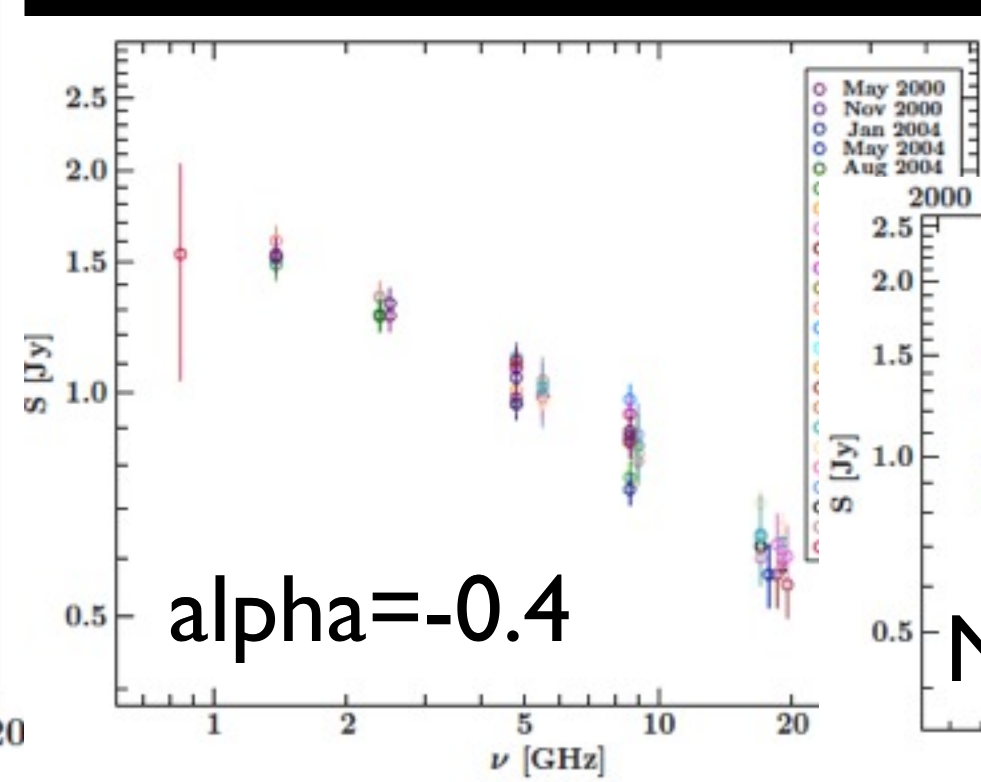
γ-ray CSOs: PMN J1603-4904

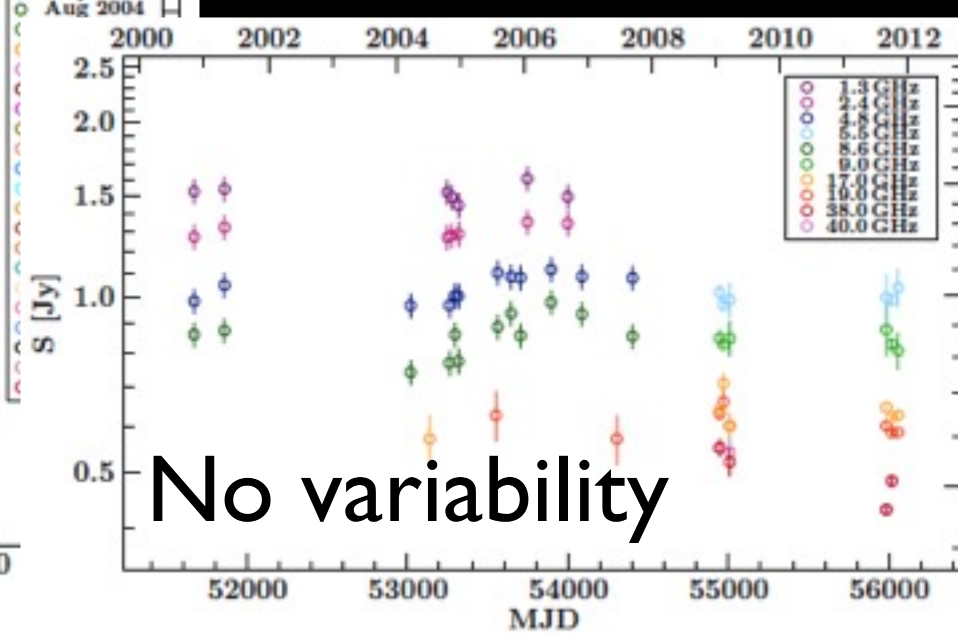


Different from γ-ray blazars:

- A diffuse, extended emission component
- SED can be fitted with SSC+IC
- No variability in radio and γ-rays
- Spectral index: -0.4
- $T_B \sim 10^{9\text{-}10}$ K
- CSO radio morphology

⇒ either a peculiar BL Lac or a CSO



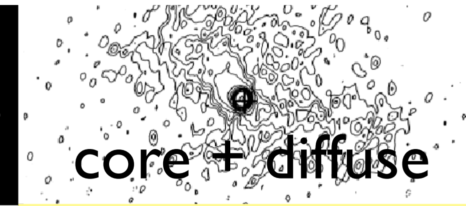
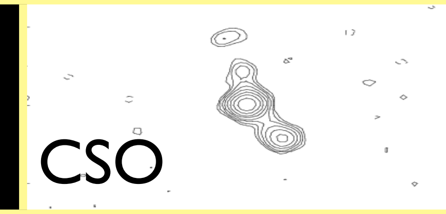
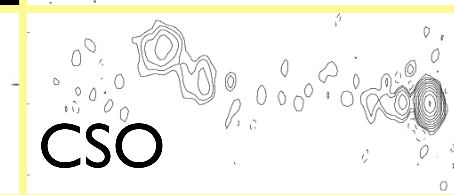
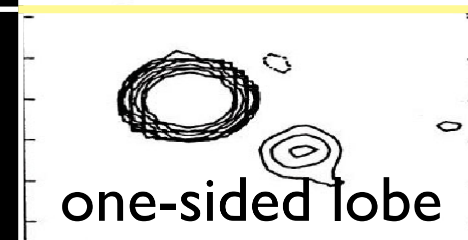
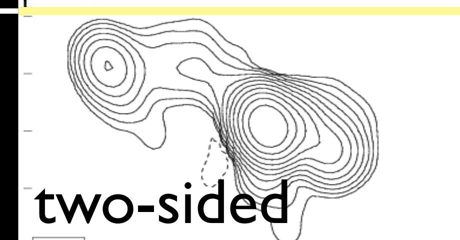
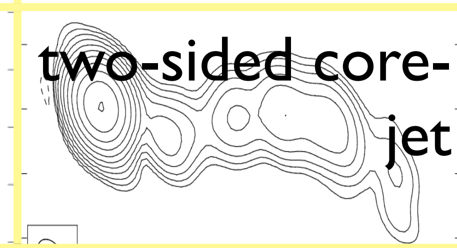
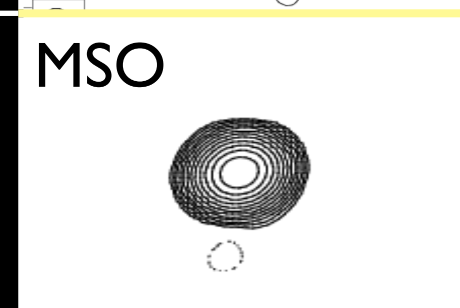
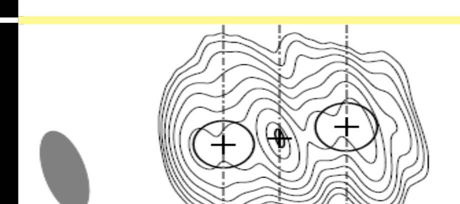
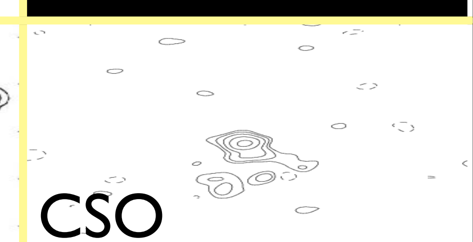


CSO - a new γ-ray AGN population?

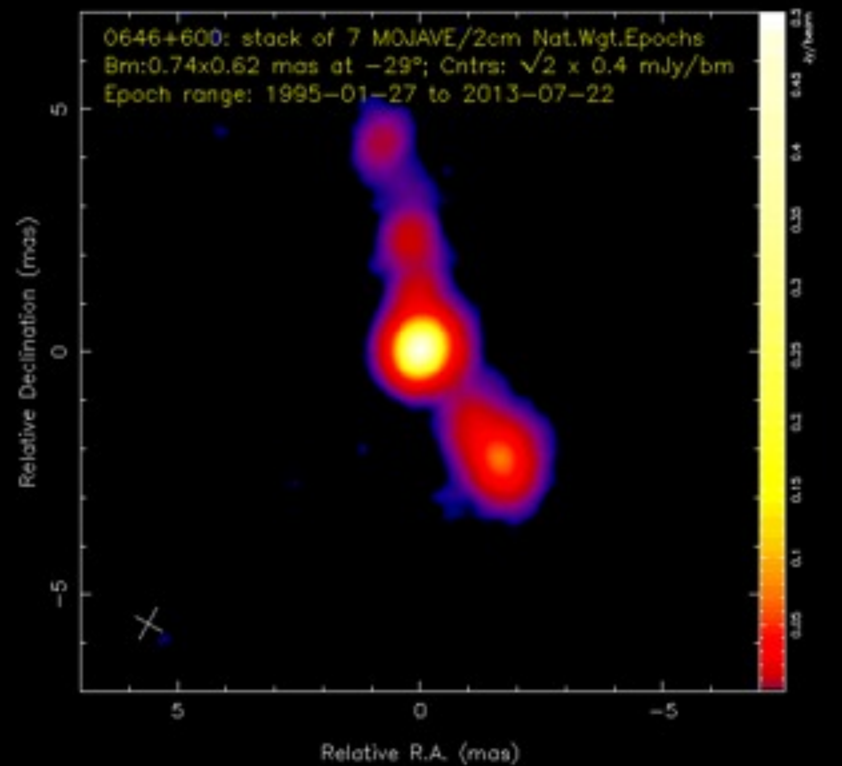
Sample selection

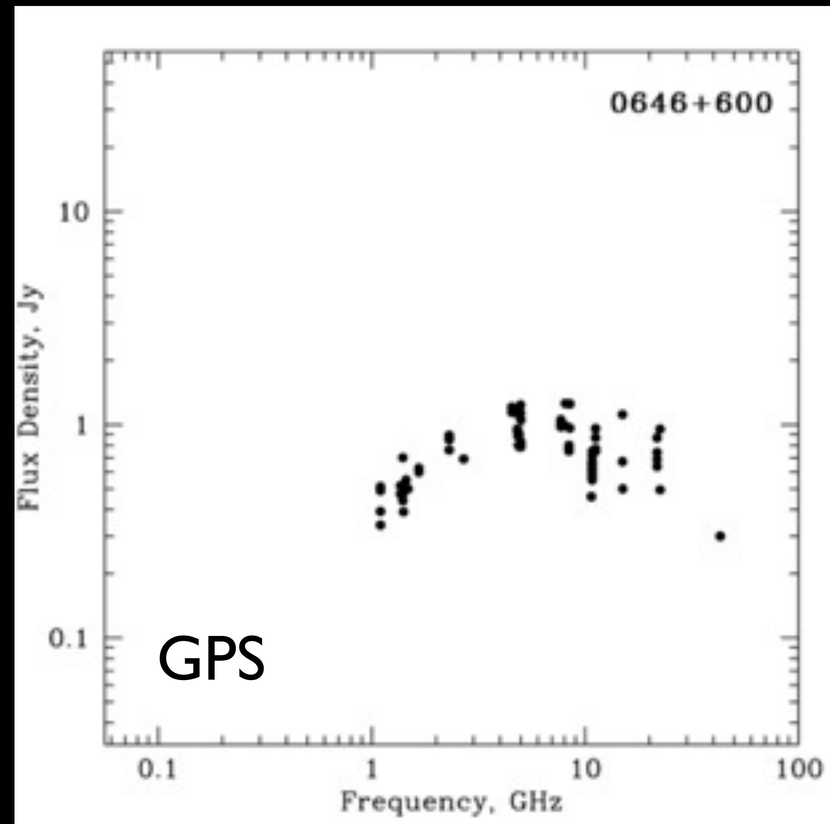
From Fermi AGN catalog select:

- GPS or steep spectrum
- CSO morphology at pc-scale

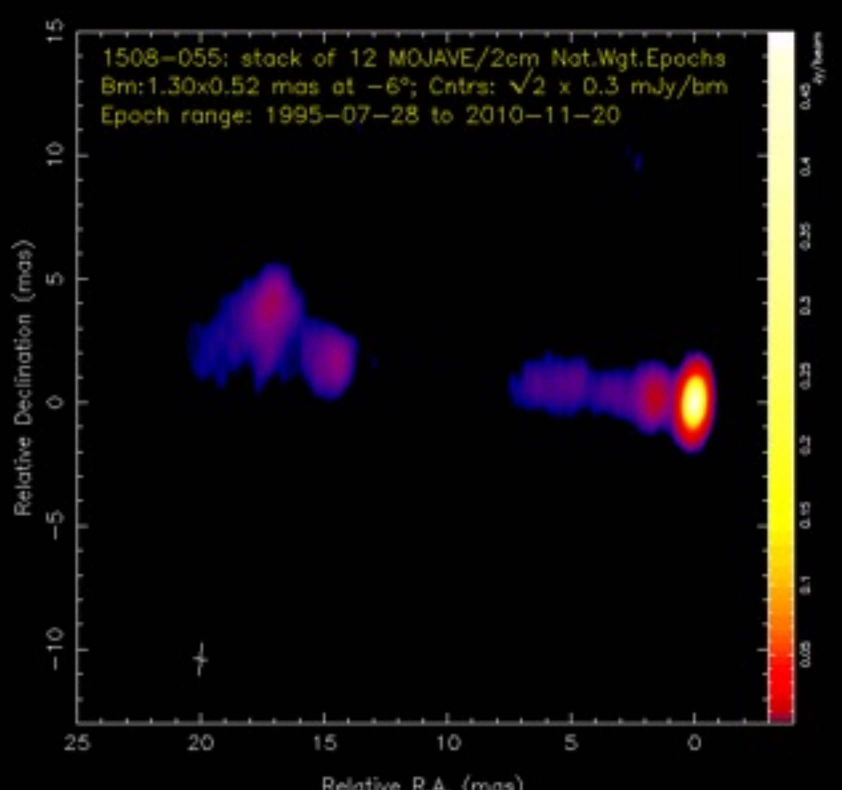
Name	Fermi name	z	S_{radio} (Jy)	Morphology (kpc)	Morphology (pc)	Ref.
0305+039	J0308.3+0403	0.029	0.25 - 0.36	 core + diffuse	 core-jet	
0646+600	J0650.9+6524	0.455	0.21 - 0.34		 CSO	
1508-055	J1510.9-0542	1.191	0.43 - 0.73	 Compact core	 CSO	
2234+282	J2236.2+2828	0.79	0.44 - 1.49	 one-sided lobe	 CSO	
1229-021	EGRET detection	1.045	0.339 - 0.397	 two-sided	 two-sided core-jet	Zhao et al. in prep.
0202+149	J0204.5+1516	0.405	0.307 - 1.905	 MSO	 core-jet	An et al. in prep.
PMNJ1603-404	J1603.9-4903	?	0.57 - 0.59			McConville et al. 2011
0954+556	J0957.6+5523	0.79	0.098	 triple	 CSO	Muller et al. 2014

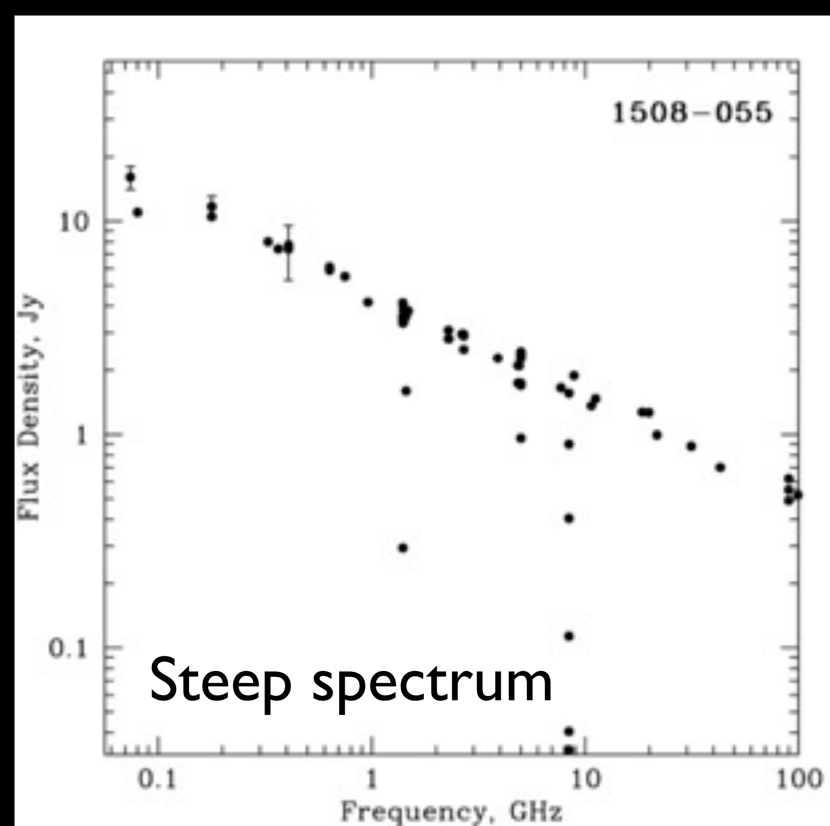
VLBI images of γ-ray CSO candidates





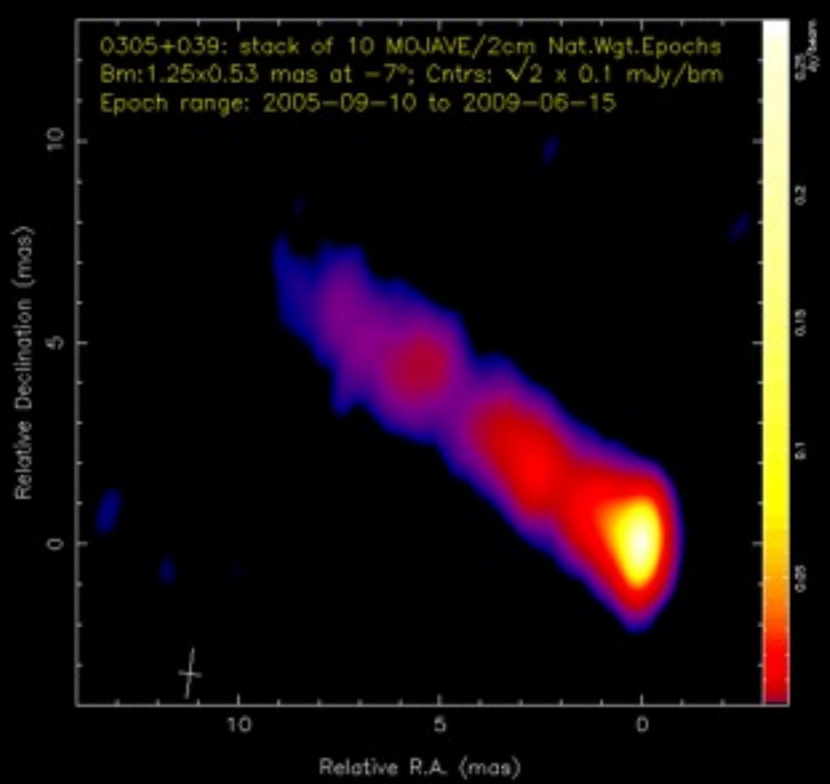
3FGL J0650.9+6524:
compact double lobes

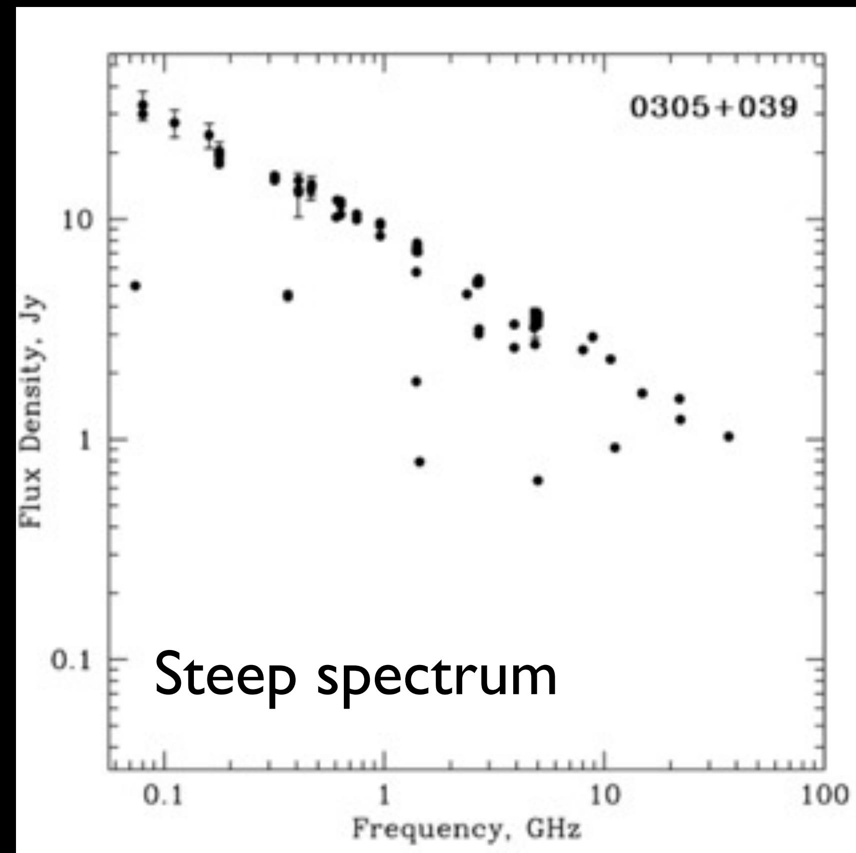




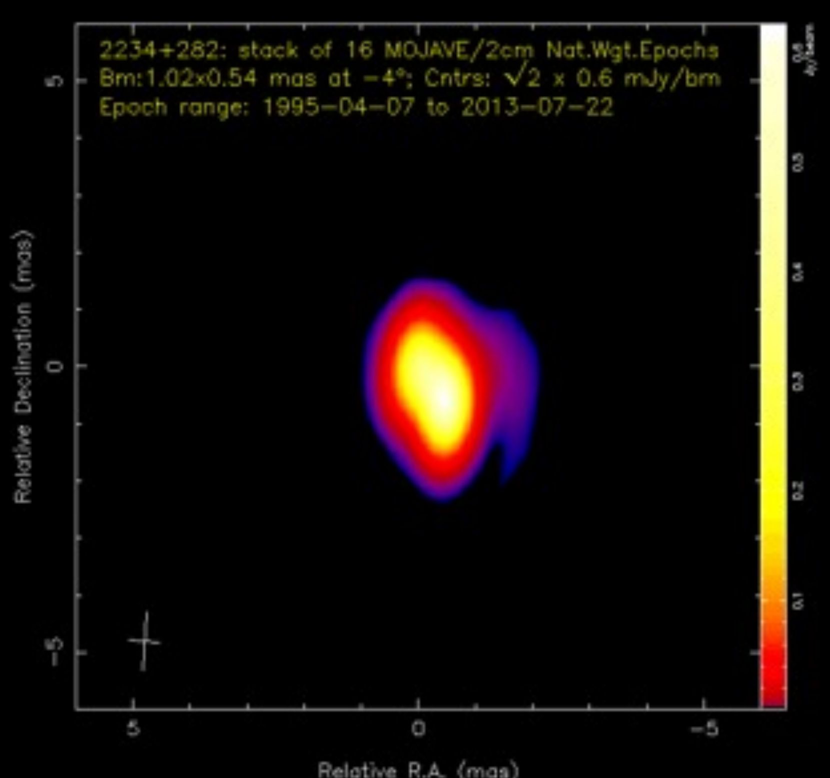
1FGL J1511.1-0545:
compact double jets/lobes

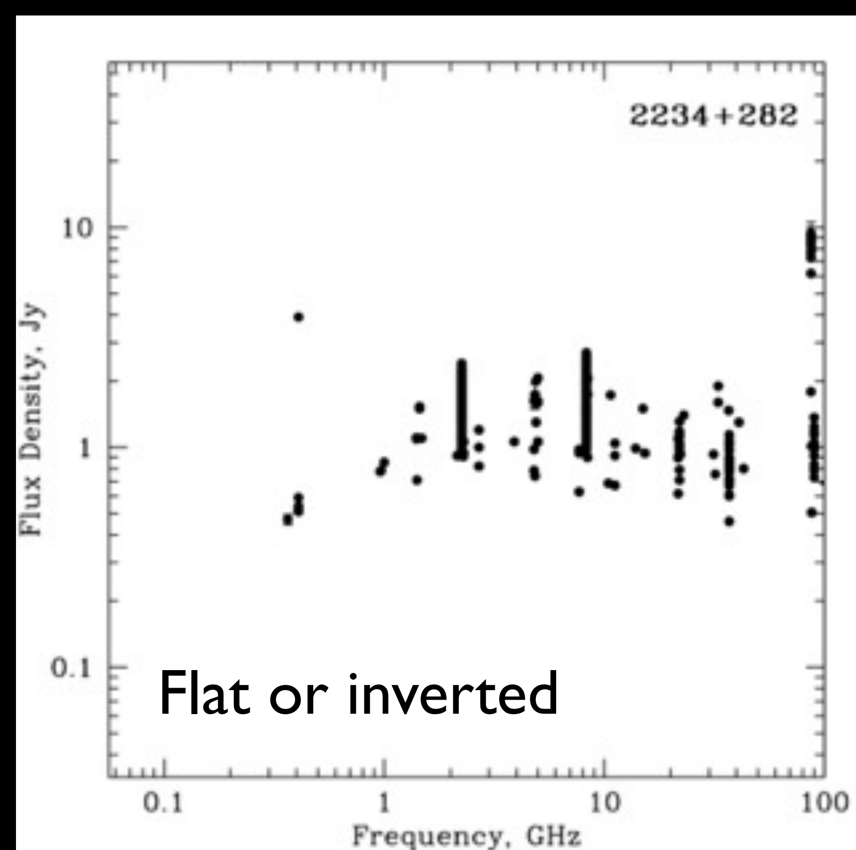
VLBI images of γ-ray CSO candidates





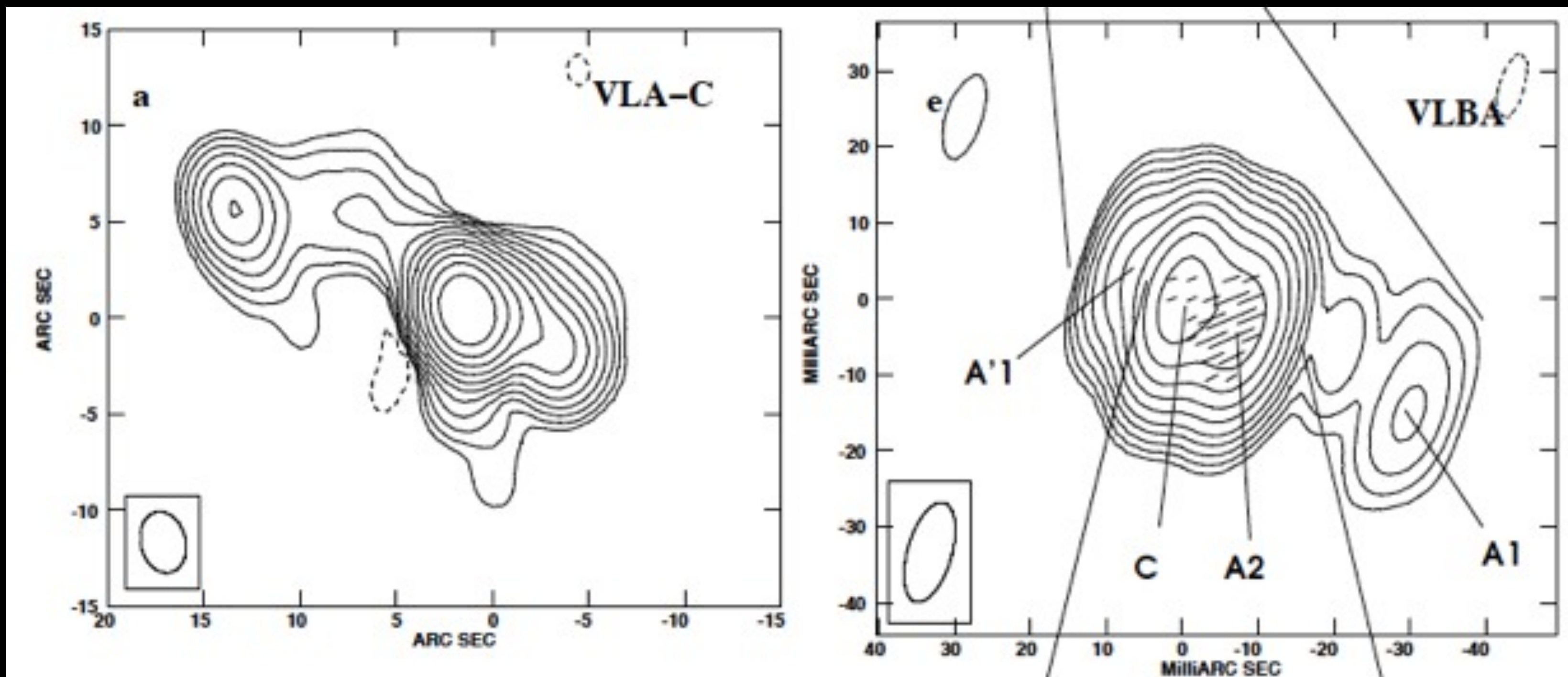
1FGL J0308.3+0403:
one-sided core-jet





1FGL J2236.2+2828:
compact double

VLBI images of γ-ray CSO candidates

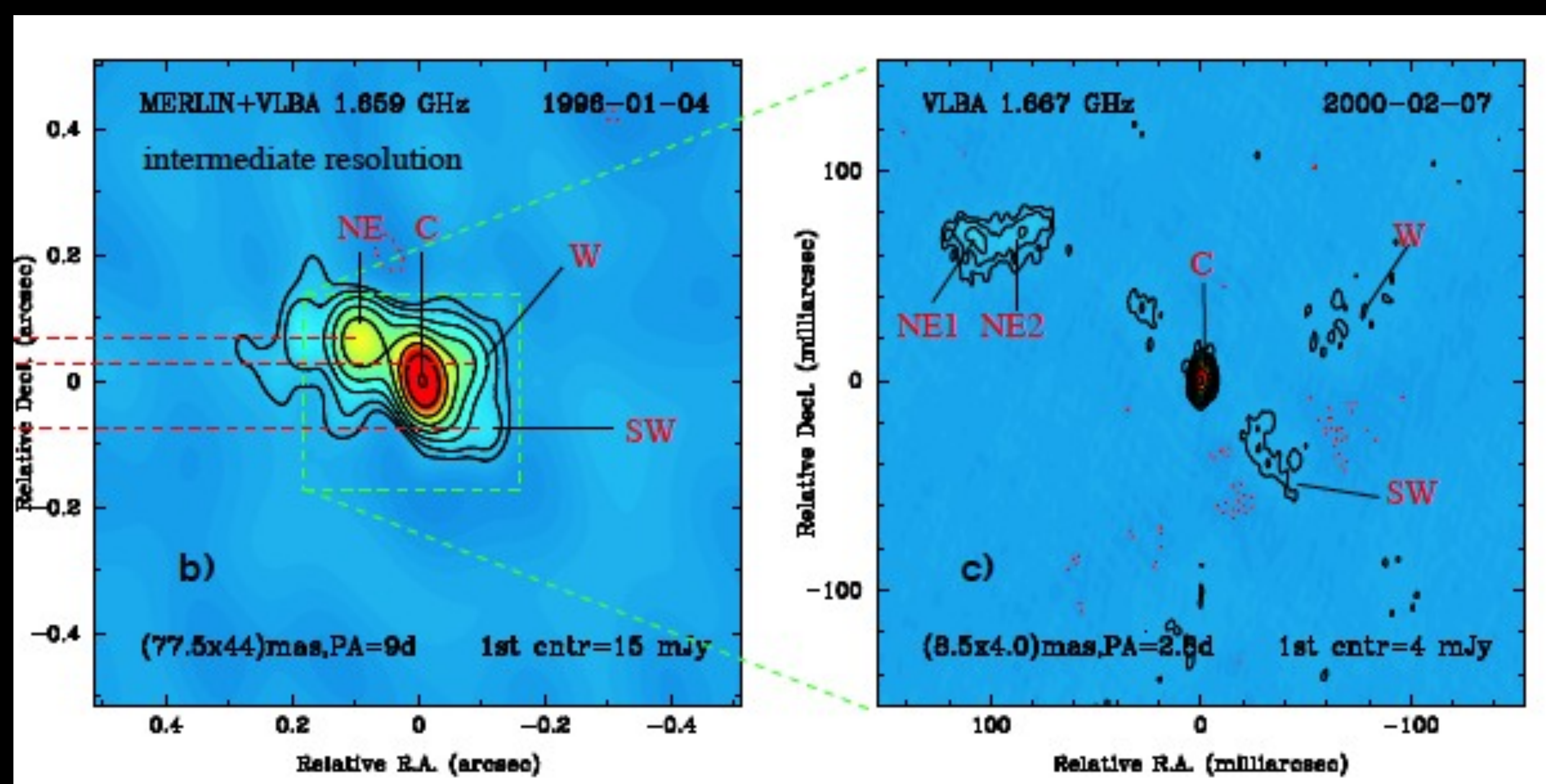


[HB89] 1229-021:

- EGRET: yes
- Fermi/LAT: no
- Steep spectrum
- Core + two-sided jets lobes
- Mild relativistic beaming

1FGL J0204.5+1516:

- EGRET: yes
- Fermi/LAT: yes
- Flat spectrum
- MSO at kpc-scale
- Core-jet at pc-scale
- $T_B^{core} \sim 10^{10\text{-}11}$K
- $v_{app} \sim 2c$



γ-ray CSOs behave differently from γ-ray blazars in radio bands

- Compact radio structure (<1 kpc)
- Radio morphology: CSO, core-jet, or diffuse extended
- Low brightness temperature, low apparent speed ⇒ no Doppler boosting
- Mild or moderate Lorentz factor
- No significant variability in radio or in γ-ray
- Low polarization

Open questions

- CSO a compact lobe - a new but important γ-ray origin?
- A large fraction of unindentified Fermi sources could be misaligned AGN, some could be CSOs
- γ-ray CSOs provide laboratory to study jet-ISM interactions

Future work:

Radio properties (jet proper motion, core brightness temperature, VLBI core dominance, degree of polarization) together with other information (SED, photon index) should be studied based on a mini-sample to constrain γ-ray radiation mechanisms in young radio AGN

Thank you!