Investigating the High-Energy Emission in the Gamma-ray Emitting CSO TXS 1146+596

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Outline

(1) Compact Symmetric Objects

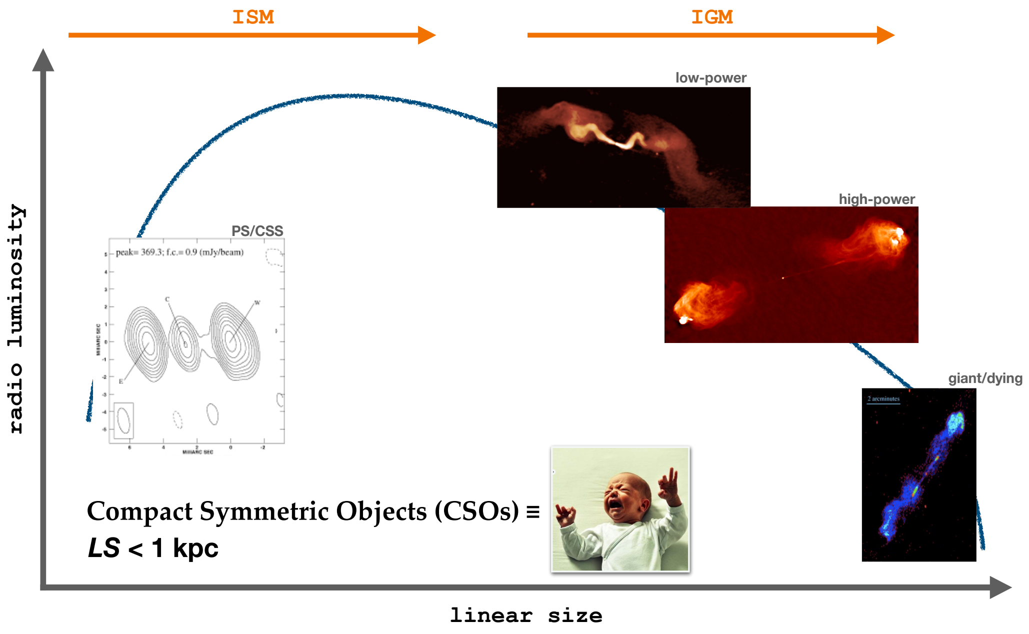
(2) TXS 1146+596

(3) Results

- X-ray analysis
- Ambient medium role
- SED modeling

(4) Conclusions

Compact Symmetric Objects (CSOs)



- Nature?
  - Youth *scenario* (e.g. Giroletti & Polatidis 09, Murgia 03)
  - Frustration *scenario* (e.g. Dicken+12)
  - Intermittent sources (e.g. Czerny+09)
- X-rays from CSOs
  - disk+corona (e.g. Tengstrand+09)
  - EC (e.g. Stawarz+08)
- γ-rays from CSOs (e.g. Migliori+16, Principe+20, Principe+21)
  - non-thermal processes (e.g. Stawarz+08, Ostorero+10, Kino&Asano+11, Migliori+14)

Scientific goals

- Investigating the nature of X- and γ-ray emission
- Probing the environment in which CSOs are expanding (X-ray imaging)
- Inferring the physical properties using the broadband SED

The source: TXS 1146+596 (aka NGC 3894)

SOURCE PROPERTIES	
parameter	**value**
redshift (z)	0.011
linear radio size (LS)	5 pc
age (t)	60 yr
BH mass ($\mathscr{M}_{BH}$)	$2 \times 10^9 \mathscr{M}_\odot$
classification	CSO/GPS

- **γ-ray emitter** CSO (Principe+20):
  - significance at $\sigma \simeq 9.7$;
  - $\Gamma_{0.1\text{-}1000\ \mathrm{GeV}} = 2.05 \pm 0.09$;
  - $\mathscr{L}_{0.1\text{-}1000\ \mathrm{GeV}} \simeq 6 \times 10^{41}$ erg/s.
- Jet-like morphology in VLBA (8.4 GHz, Fig. 1).
- Observed in X-rays with *Chandra* (39 ks, Fig. 2).
- Observed for the **first time** in hard X-rays with *NuSTAR* (77 ks).

Principe et al. 2020

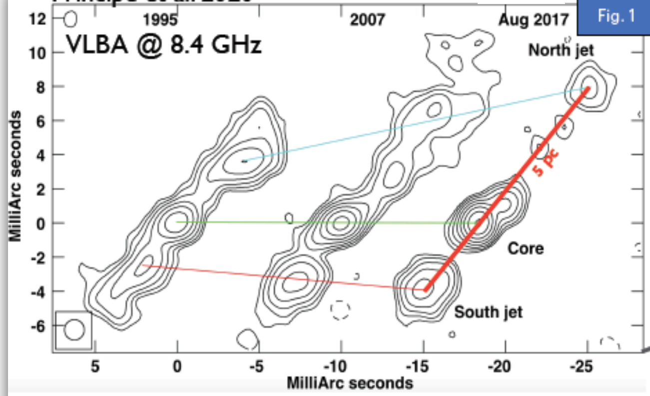


Fig. 1

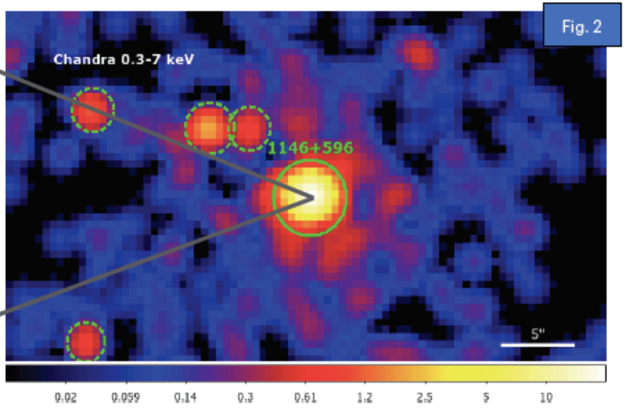


Fig. 2

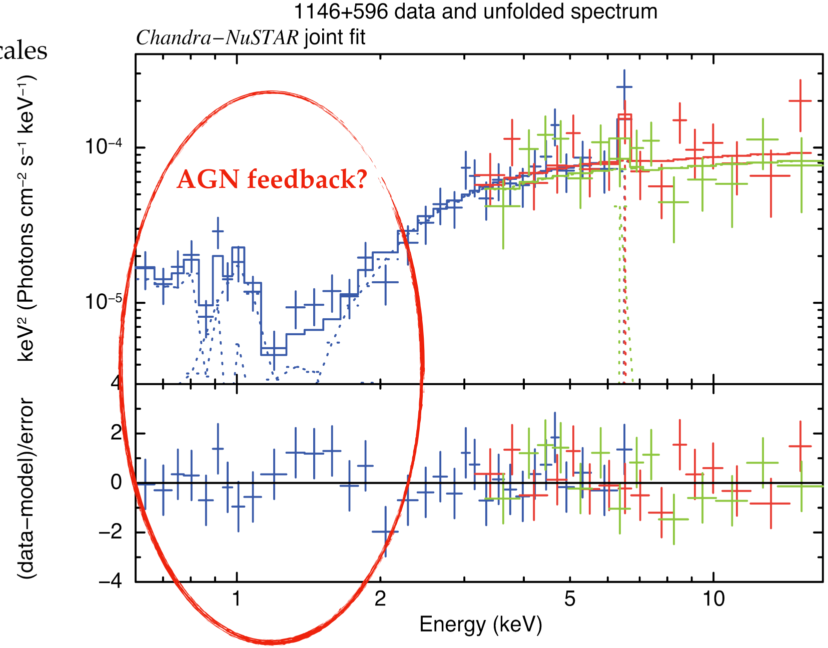
1″ corresponds to 228 pc at $z \simeq 0.011$

X-RAY ANALYSIS

X-ray analysis results

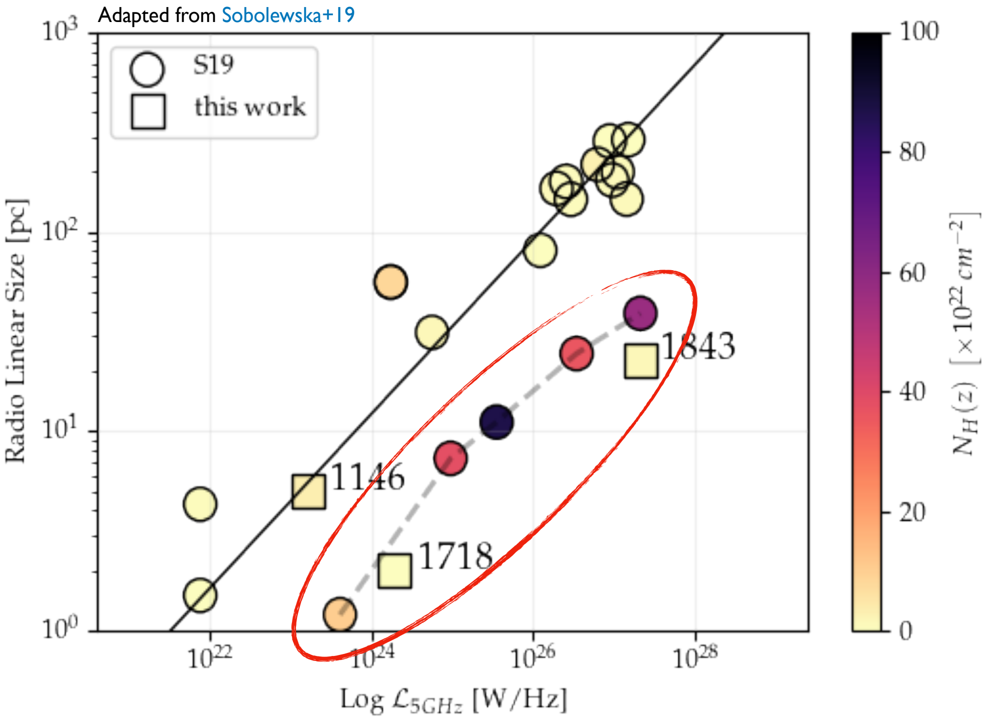
Model: **absorbed power-law model including Galactic absorption, the intrinsic absorption of the source, two thermal emitting gas, and a Gaussian line**

- Extended X-ray emission up to 2.3 kpc ($\gg$ radio *LS*), i.e. galaxy scales
- Fitting parameters:
  - $N_H = 3.49^{+1.28}_{-1.04} \times 10^{22}\,\mathrm{cm}^{-2}$
  - $\Gamma = 1.92^{+0.34}_{-0.33}$
  - $kT_1 = 0.32^{+0.17}_{-0.09}\,\mathrm{keV}$
  - $kT_2 = 1.16^{+0.31}_{-0.18}\,\mathrm{keV}$
  - $E_{Fe} = 6.73^{+0.24}_{-0.35}\,\mathrm{keV}\ (\sigma = 10\,\mathrm{eV})$
  - $\mathscr{L}_{2-10\,\mathrm{keV}} = 6.0\ (\pm 0.4) \times 10^{40}\,\mathrm{erg\,s^{-1}}$



Ambient medium role

Study of the ambient medium role in confining the source expansion (leading to the observed compact sizes) **through X-ray obscuration**: separation between obscured/frustrated and unobscured/freely-expanding sources?

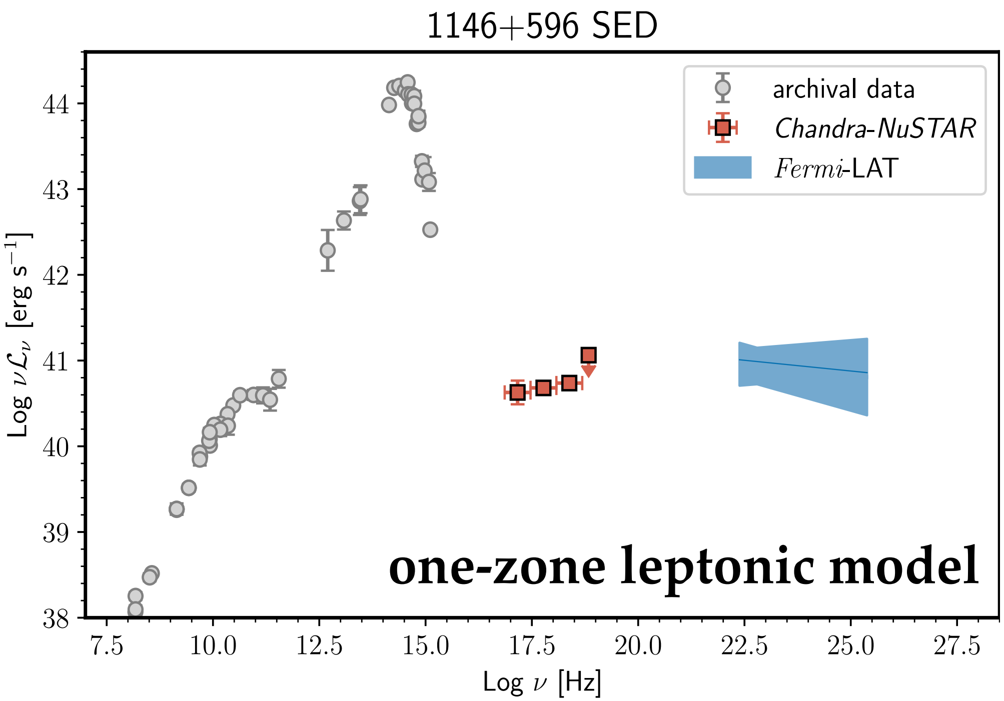


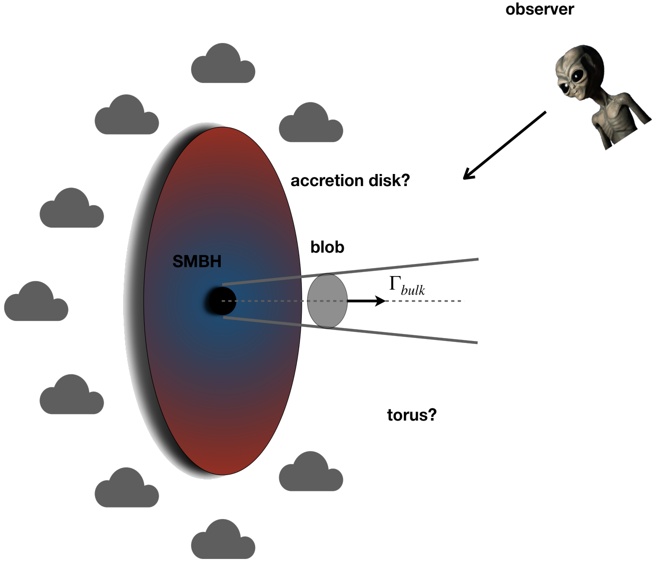
BROAD-BAND SED MODELING

SED modeling (I)

JetSeT
Jets SED modeler and fitting Tool

by A. Tramacere





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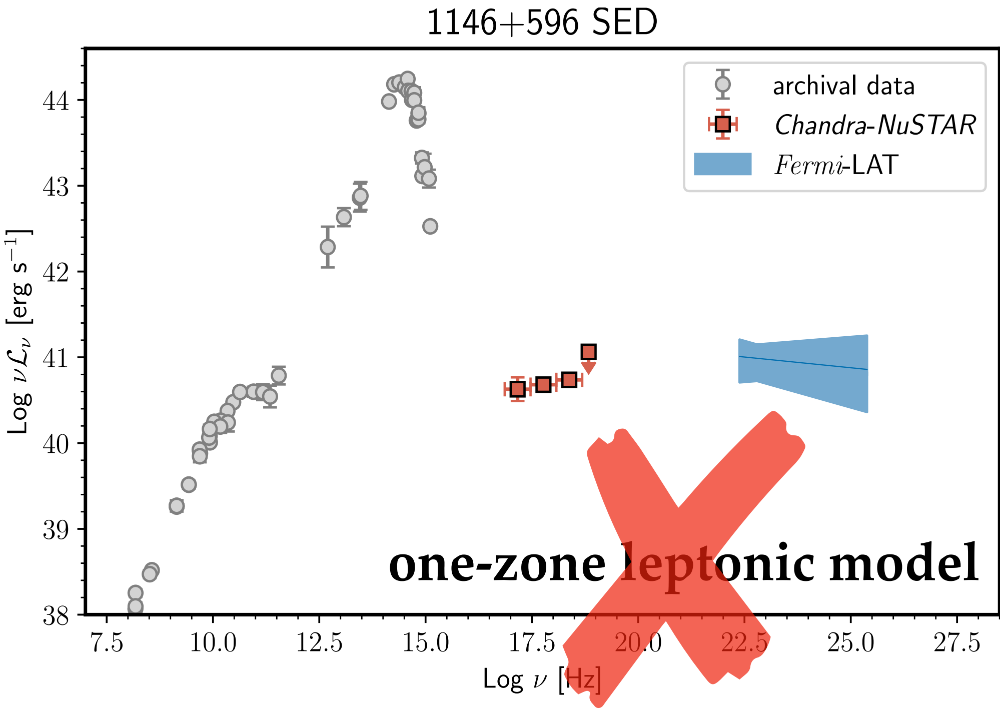
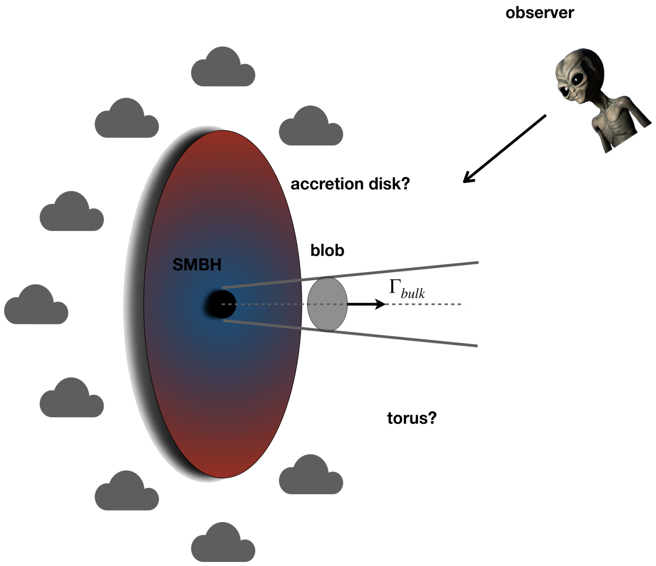
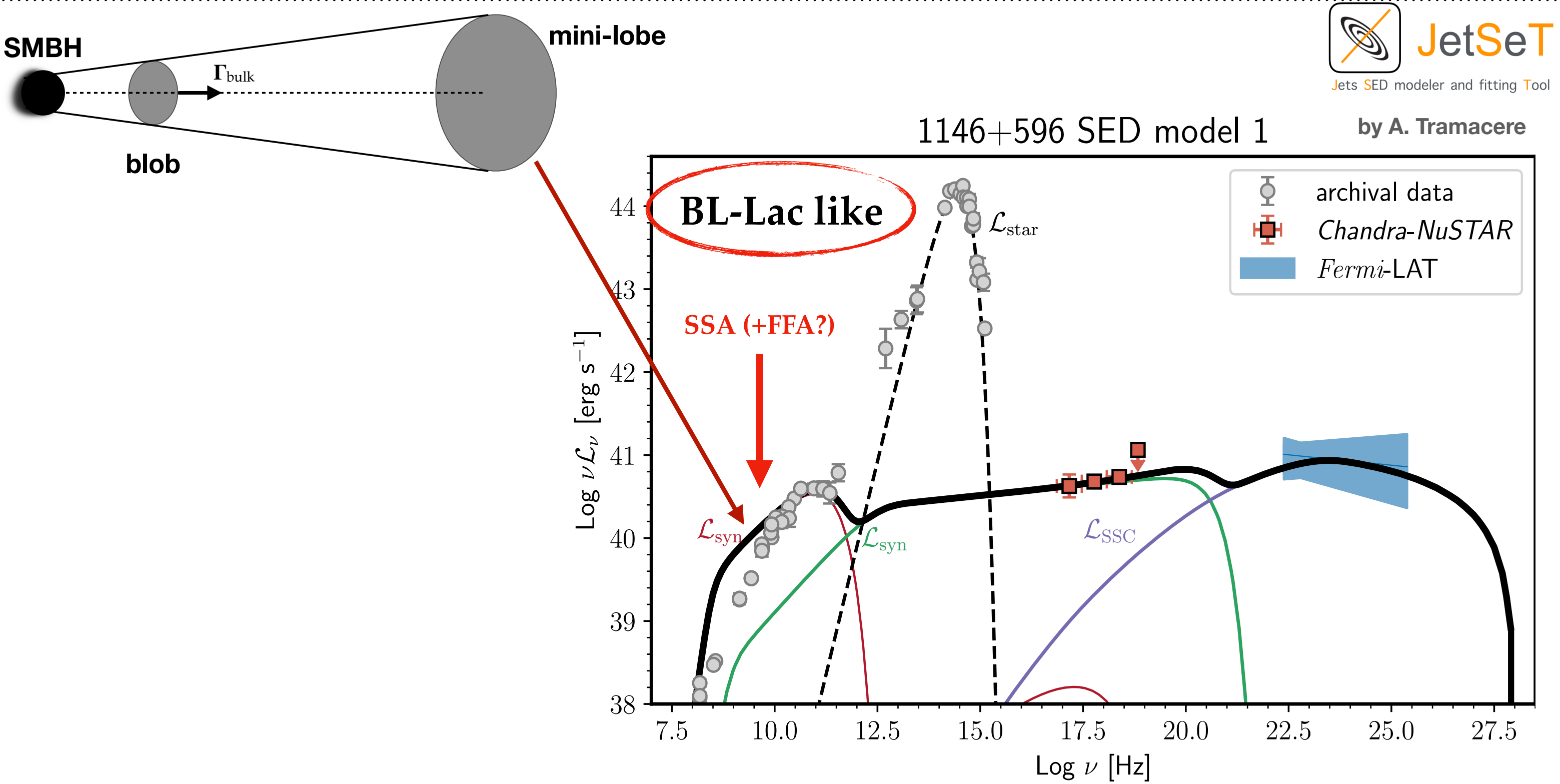


JetSeT
Jets SED modeler and fitting Tool
by A. Tramacere



SED modeling (II)



SED modeling (II)

JetSeT
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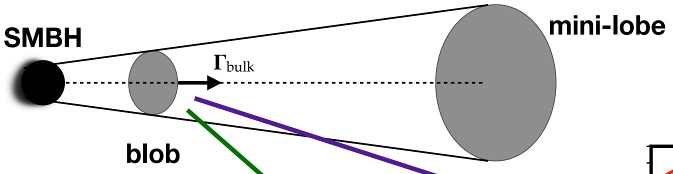
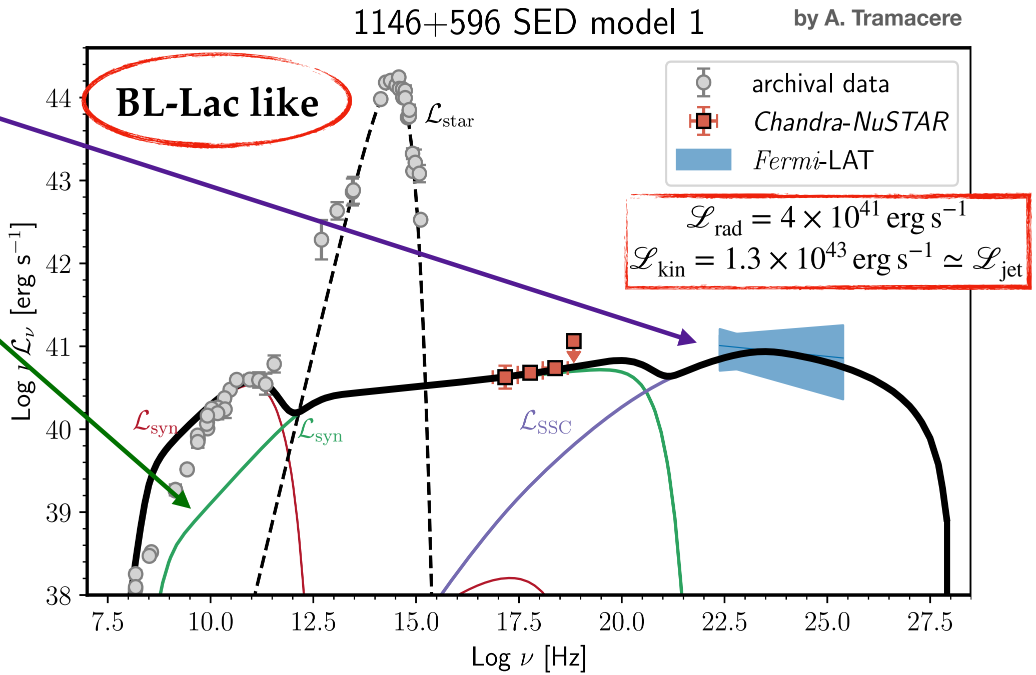
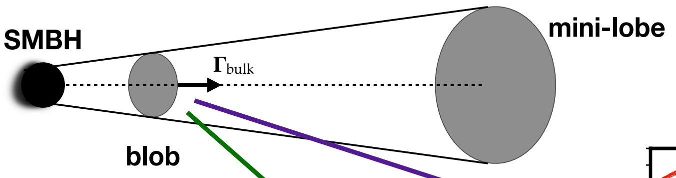
by A. Tramacere



- $R = 3 \times 10^{17}$ cm
- $\Gamma_{bulk} = 1.04$
- $B = 10$ mG
- $p_1 = 1.9$
- $p_2 = 2.9$
- $\gamma_{min} = 10^2$
- $\gamma_{max} = 10^8$
- $\gamma_{break} = 10^4$



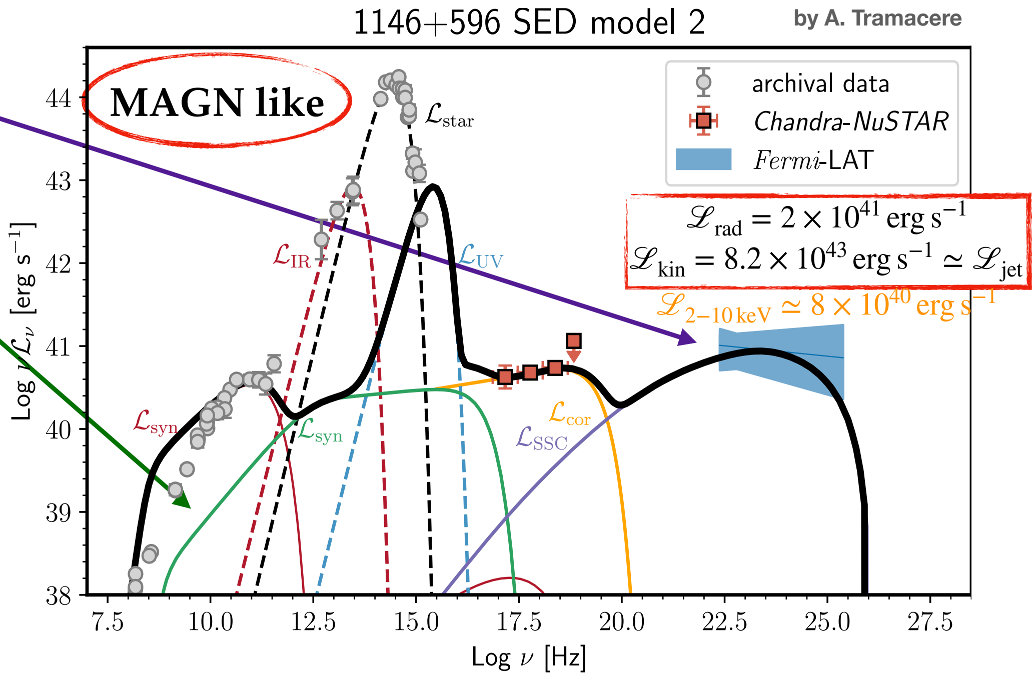
SED modeling (III)



- $R = 2 \times 10^{17}$ cm
- $\Gamma_{bulk} = 1.11$
- $B = 9$ mG
- $p_1 = 1.8$
- $p_2 = 2.9$
- $\gamma_{min} = 10$
- $\gamma_{max} = 10^6$
- $\gamma_{break} = 10^6$

Need for corona emission also for PKS 1718-649 (Sobolewska+22)

JetSeT
Jets SED modeler and fitting Tool
by A. Tramacere



Conclusions

Bronzini et al. *in prep.*

- We reported, for the first time, on the detection of 1146+596 with *NuSTAR* at energies >10 keV
- Joint *Chandra* and *Nustar* data allowed us to unveil the true X-ray continuum shape
- **First evidence for a multi-T gas component** in 1146+596
- SED modeling (multi-zone leptonic models):
  - Model 1 —> sync+SSC, assuming γ_{max} too high?? —> $\mathscr{L}_{jet} = 1.3 \times 10^{43}$ erg s^{-1}
  - Model 2 —> sync+SSC+cor —> $\mathscr{L}_{jet} = 8.2 \times 10^{43}$ erg s^{-1}
  - Mukherjee+17 argued that jets with power $\lesssim 10^{43}$ erg s^{-1} may be too weak to break out the ISM confinement
- Separation between obscured / frustrated and unobscured / freely-expanding sources not so straightforward in the linear size vs. radio power plane

Future steps

Bronzini et al. *in prep.*

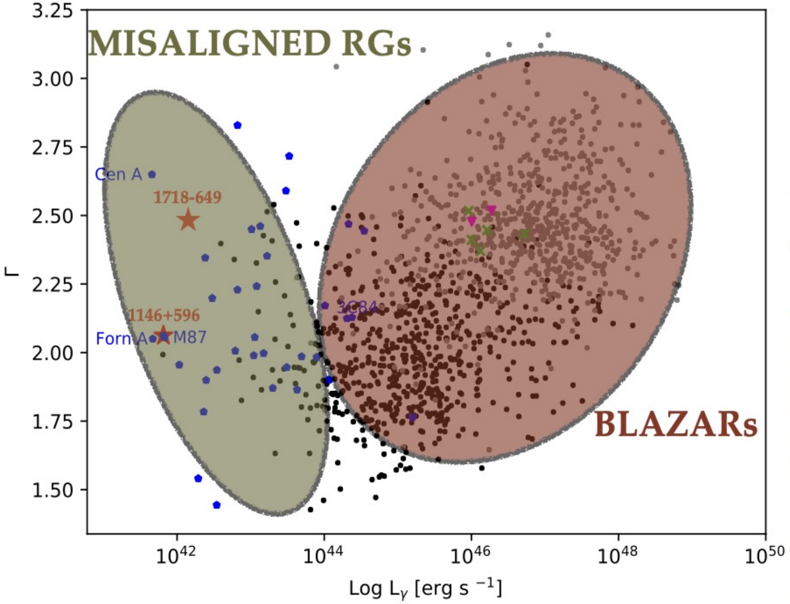
- Publishing the paper
- Testing EC models
- XMM-*Newton* observations (already obtained)

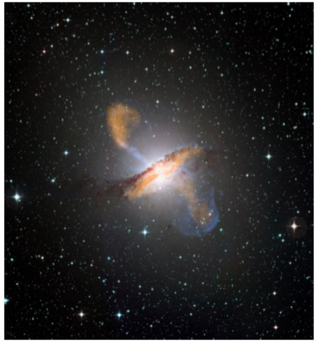

That's all Folks!

SED modeling

			Jet		Mini lobe
Description	Symbol	Unit	Model 1	Model 2	Model
(1)	(2)	(3)	(4)	(5)	(6)
		Input Parameters			
Radius of the emitting region	$\log_{10} R$	cm	17.47	17.40	18.74
Lorentz factor	Γ		1.04	1.11	1.00
Magnetic field	B	mG	10	9	10
Emitting electron number density	$\log_{10} N$	cm^{-3}	0.40	1.2	0.09
Low-energy slope	p_1		1.9	1.8	2
High-energy slope	p_2		2.9	2.9	—
Lorentz factor (min)	$\log_{10} \gamma_{min}$		2	1	1
Lorentz factor (break)	$\log_{10} \gamma_{break}$		4	4	—
Lorentz factor (max)	$\log_{10} \gamma_{max}$		8	6	3.4
Energy density ratio of magnetic field and electrons	U_B/U_e		3*e*-3	2*e*-3	1
		Additional Power-law X-Ray Component			
Photon index	Γ		—	1.9	—
Luminosity	$\mathcal{L}_{2-10\,keV}$	$erg\,s^{-1}/10^{41}$	—	0.8	—
		Jet Power			
Radiative power	$\mathcal{L}_{rad}$	$erg\,s^{-1}/10^{41}$	4.1	2.2	0.40
Electrons kinetic power	$\mathcal{L}_e$	$erg\,s^{-1}/10^{42}$	3.5	6.4	1.6*e*-3
Protons kinetic power	$\mathcal{L}_p$	$erg\,s^{-1}/10^{43}$	0.92	7.6	5.4*e*-3
Total kinetic power	$\mathcal{L}_{kin}$	$erg\,s^{-1}/10^{43}$	1.3	8.2	5.6*e*-3
Magnetic power	$\mathcal{L}_B$	$erg\,s^{-1}/10^{40}$	0.97	1.0	0.16
Total jet power	$\mathcal{L}_{jet}$	$erg\,s^{-1}/10^{43}$	1.3	8.2	9.8*e*-3

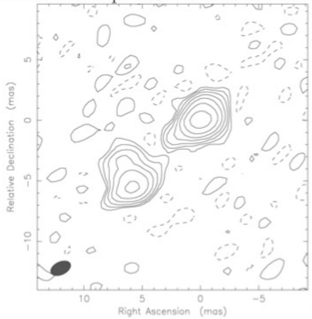
Radio-GeV connetion?



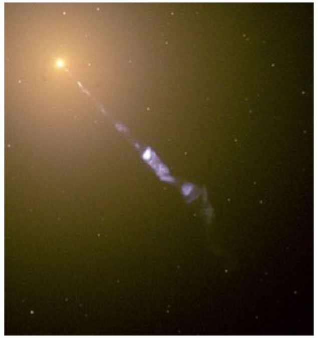


$\Gamma \simeq 2.6$

$1'' \equiv 305$ pc at $z = 0.014$

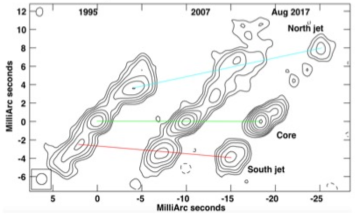


$\Gamma = 2.54 \pm 0.17$



$\Gamma \simeq 2.1$

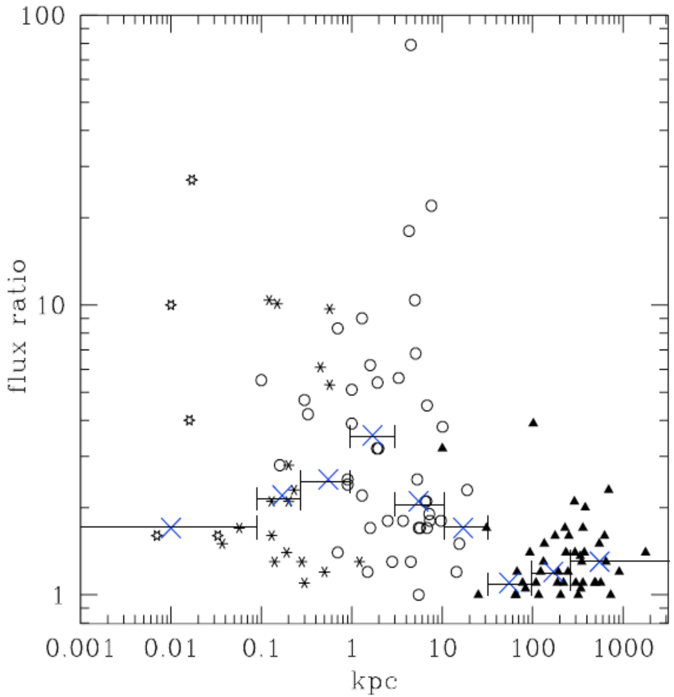
$1'' \equiv 228$ pc at $z = 0.011$



$\Gamma = 2.05 \pm 0.09$

Principe+20

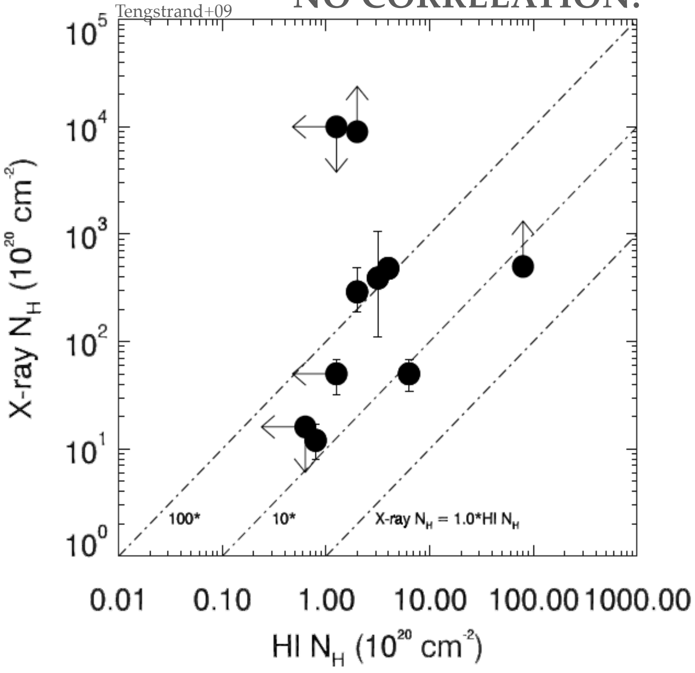
Radio asymmetries



Orienti & Dallacasa 2008

NH vs. NHI

NO CORRELATION!



CORRELATION!