Radio-Loud AGN@INAF

Eleonora Torresi (DIFA & IASFBO)

&

P. Grandi, F. Tavecchio, G. Ghisellini, L. Foschini, M. Giroletti, M. Orienti, F. D'Ammando, G. Giovannini, A. Stamerra, A. Sandrinelli, A. Treves, S. Covino, C.M. Raiteri, A. Caccianiga, L. Bassani, T. Venturi, F. Panessa, L. Pacciani, V. Antonuccio-Delogu

Outline

Blazars

1. Multiwavelength monitoring of blazars (WEBT)
2. Periodicities in blazars
3. High-z blazars
4. VHE emission and astroparticle
5. HE flares from FSRQs

Narrow Line Seyfert 1

1. Properties of Radio-Loud NLS1 & Unification of powerful relativistic jets
2. Radio-Loud NLS1 as young sources
3. Multifrequency studies of gamma-ray NLS1

Misaligned AGN

1. New insights in the jet structure of 3C84 with RadioAstron
2. Study of a sample of gamma-ray soft radio galaxies
3. MAGN at high and very high energies
4. Simulations of AGN jets

Blazars

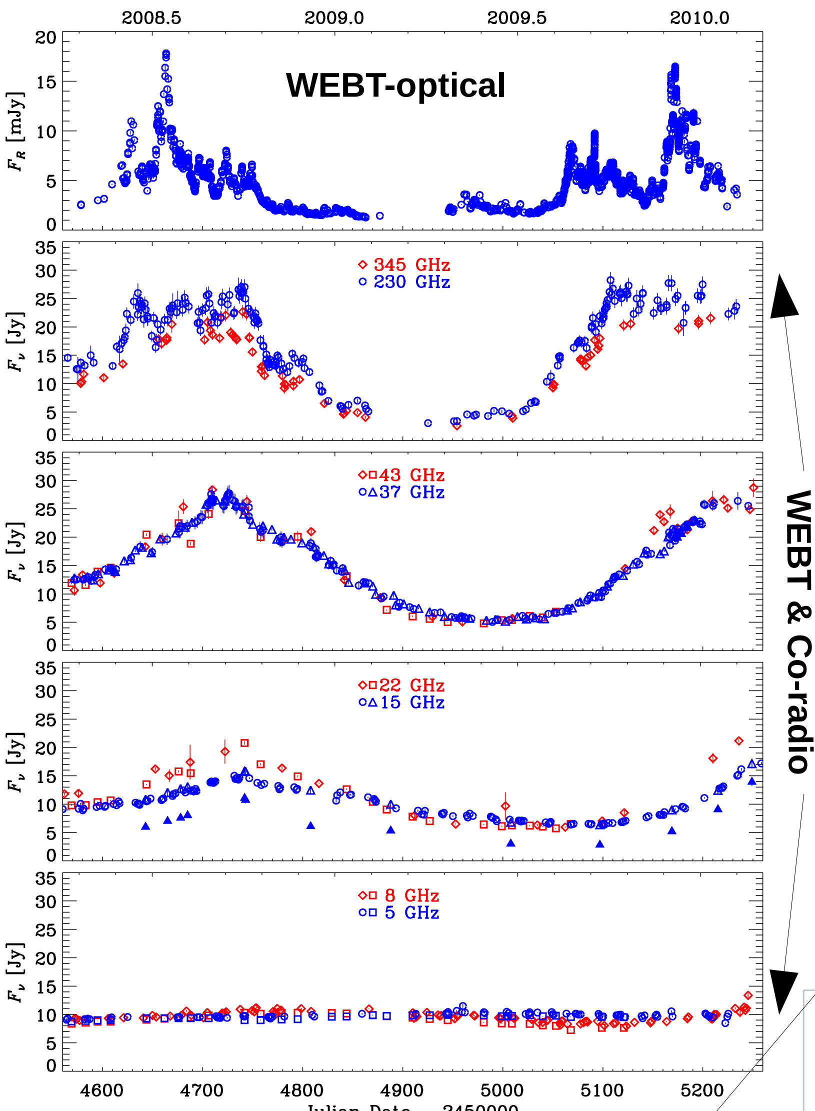
1. MW monitoring

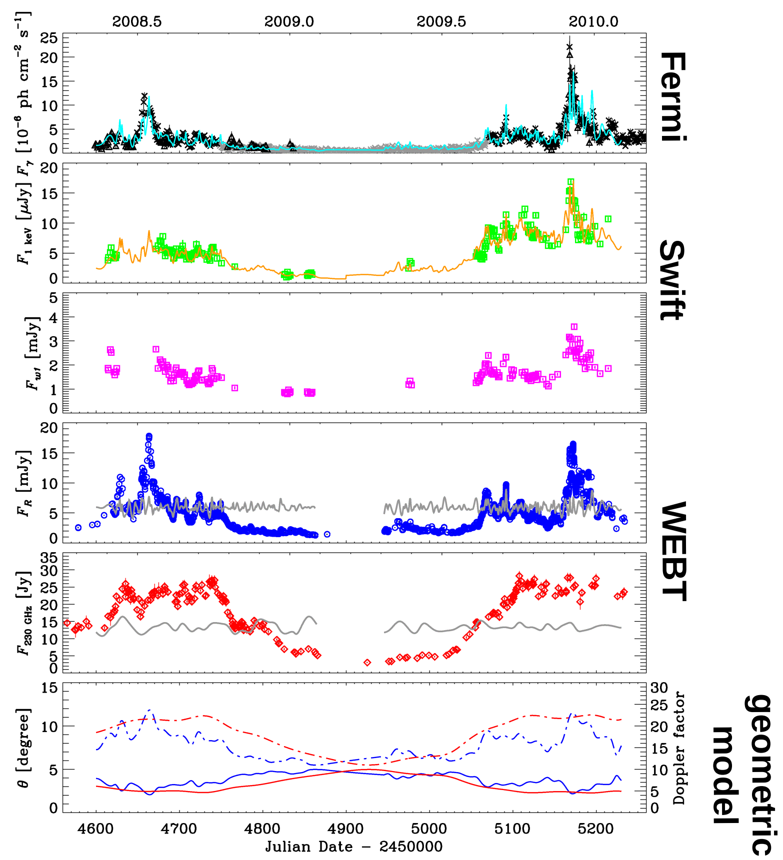
http://www.oato.inaf.it/blazars/webt/

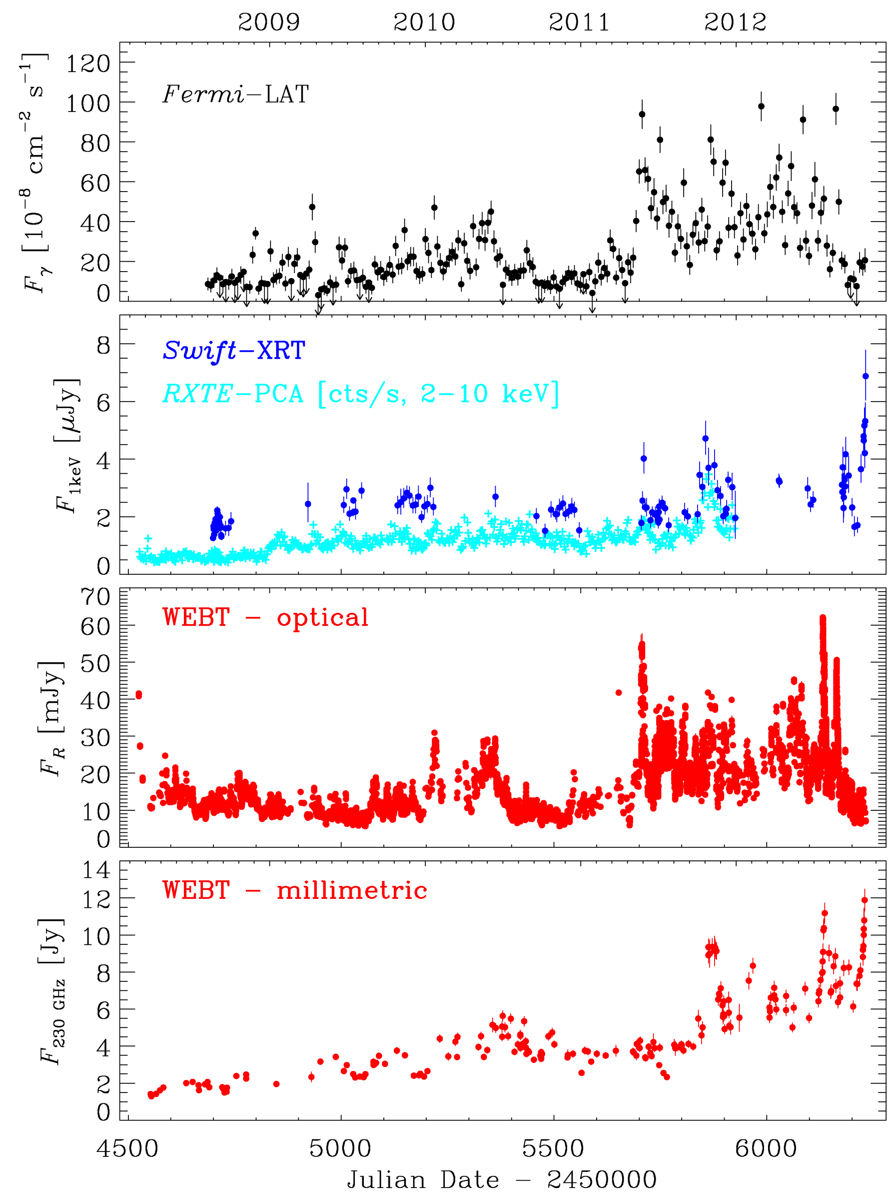
C. Raiteri (OATO)

Nato nel 1997, il **Whole Earth Blazar Telescope (WEBT)** e` un network internazionale a cui partecipano **molte decine di osservatori ottici, radio e nel vicino infrarosso**. Lo scopo e` quello di ottenere un monitoraggio ad elevata densita` temporale che, abbinato ad osservazioni ad alte ed altissime energie da satelliti e telescopi Cherenkov, consenta lo **studio multifrequenza dei blazars** nel maggior dettaglio possibile.

- Dal 2000, la **leadership** del WEBT si trova all'**Osservatorio Astrofisico di Torino** (M. Villata Presidente, C. M. Raiteri officer).
- Nel 2007 viene avviato il GLAST-AGILE Support Program (**GASP**), che prevede il monitoraggio continuo di 28 sorgenti gamma-loud.
- Tutti i dati pubblicati sono **archiviati** e disponibili dopo un anno dalla pubblicazione.







3C 454.3 (Crazy Diamond)
(da Raiteri et al. 2011, A&A 534, A87)
NB: la curva luce in banda *R* collezionata dal WEBT conta **11867** punti!

Altri WEBTers in INAF
A. Di Paola (Osservatorio Astronomico di Roma), M. Giroletti, M. Orienti, A. Orlati, S. Righini (IRA Bologna), C.S. Buemi, P. Leto, C. Trigilio, G. Umana, A. Frasca, G. Leto, R. Zanmar (Osservatorio Astrofisico di Catania), M.I. Carnerero (Osservatorio Astrofisico di Torino)

Altri collaboratori in INAF
S. Vercellone, P. Romano (IASF Palermo), A. Stamerra (Osservatorio Astrofisico di Torino)
F. Nicastro (Osservatorio Astronomico di Roma), F. D'Ammando (IRA Bologna)

Collaborazioni con I teams di AGILE, Fermi, MAGIC (in futuro: CTA)

BL Lacertae
(adattato da Raiteri et al. 2013, MNRAS 436, 1530)
NB: la curva luce in banda *R* collezionata dal WEBT conta **26462** punti!

Blazars

2. Periodicities in blazars

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

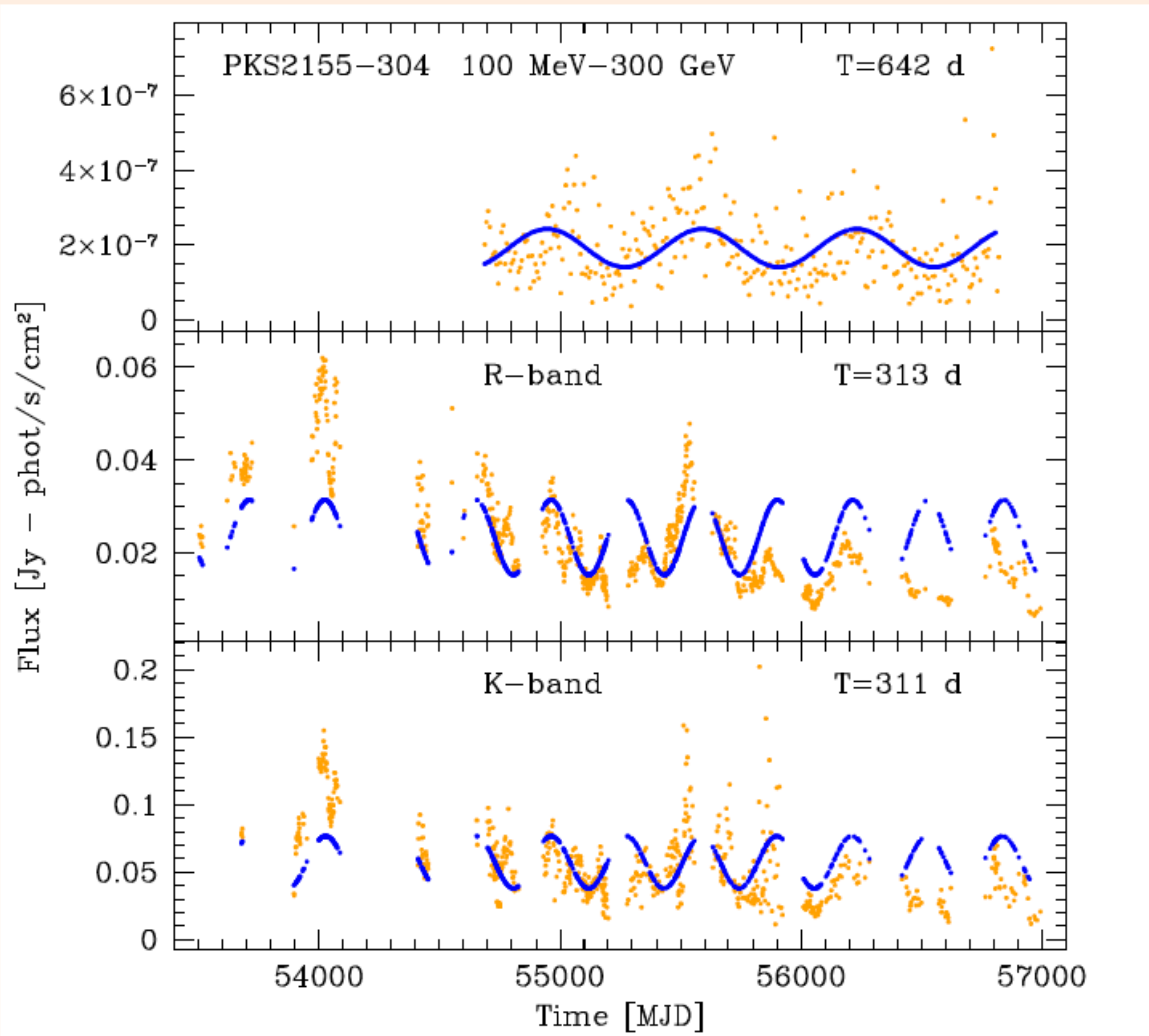
Angela Sandrinelli
Stefano Covino
Aldo Treves

OSSERVATORIO ASTRONOMICO DI BRERA

UNIVERSITAS STUDIORUM INSUBRIAE

INFN Istituto Nazionale di Fisica Nucleare Trieste

Year-like gamma-ray and optical oscillations of BL Lac Objects



ApJ 793, L1 (2014)
AJ 151, 54 (2016)
ApJ 820, 151 (2016)

PKS 2155-304

T_γ= 640 d; T_{opt}~ ½ T_γ

PKS 0537-441

T_γ= 280 d; T_{opt}~ ½ T_γ

Future:
By-product of robotic telescope databases and transient searches

e.g. REM, SMARTS, Tuorla, CRTS, Pan-STARRS, PTF , VST…

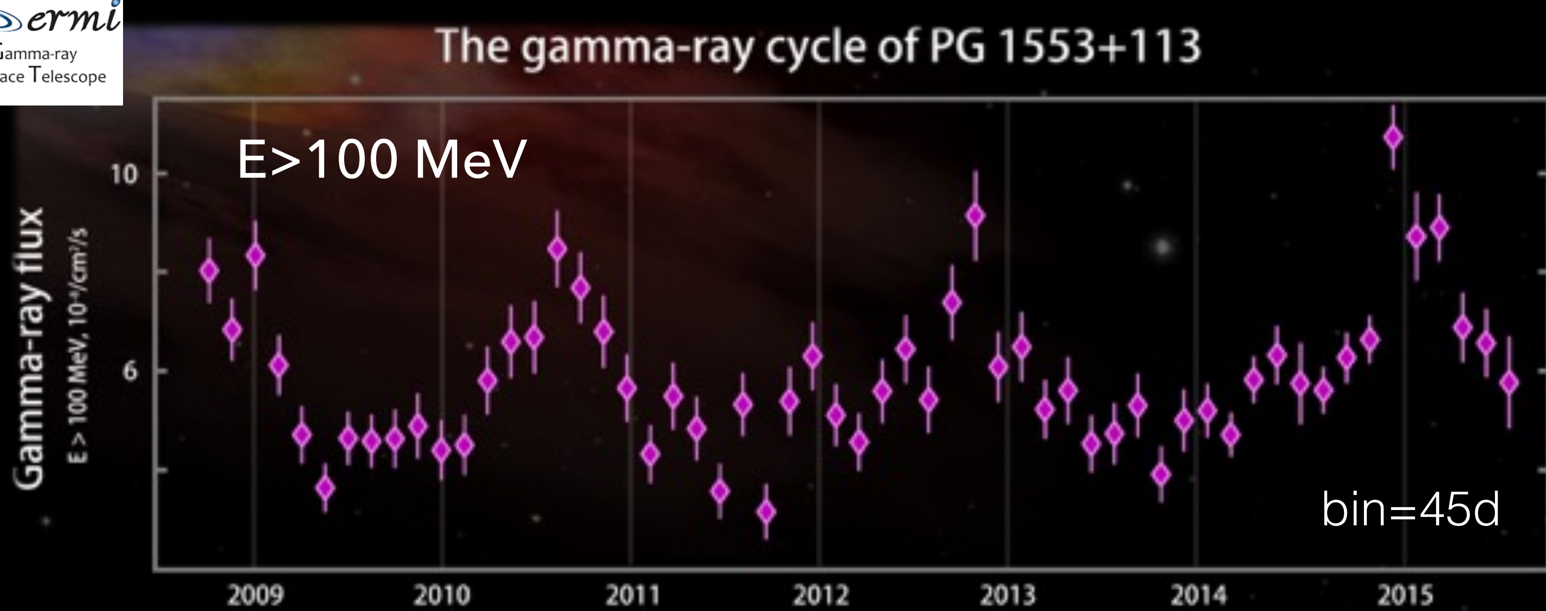
GAMMA-RAY PERIODICITY IN BLAZARS

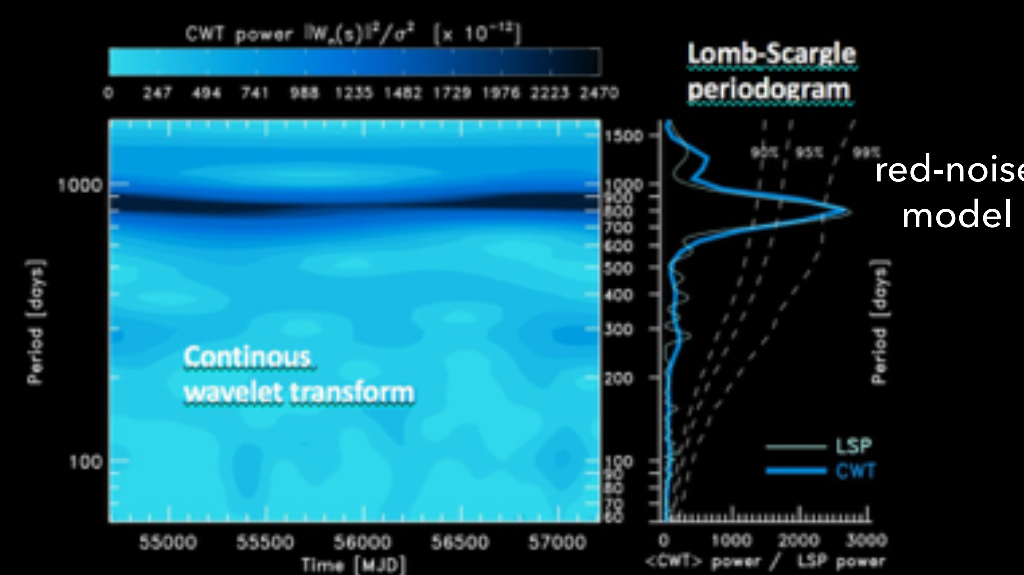
A. Stamerra (OATO)

- Note1 (reliability): short (yearly) periodicity over Myr activity ➜ QPO
- Note2: significance of periodicity depends on assumption on the spurious stochastic variability

- PG1553+113 (z~0.45): First clear detection of γ-ray periodicity in a BL Lac with Fermi/LAT, E>100 MeV and E>1 GeV (3.5 cycles over 7 years); corroborated by optical periodicity
  - *A. Stamerra (ASDC senior scientist) + Fermi/LAT team (S. Ciprini and S. Cutini INFN-Roma and ASDC)*
  - Previous claims on PKS 2155-30 Sandrinelli, Covino, Treves (2014)

Fermi/LAT Coll.+AS, ApJL, 2015, 816, 41





- Extensive MWL campaign on PG1553+113 ongoing; led by MAGIC collaboration
  - MAGIC team: *A. Stamerra (INAF-Torino), E. Prandini (Univ. Geneve), S. Paiano (INAF-Pd), P. Da Vela (INFN-Pisa)*
  - REM (A. Sandrinelli, S. Covino), Swift, possibly WEBT in 2017 (C. Raiteri)
- Promising topic with CTA and Fermi/LAT

Blazars

3. High-z blazars

High-z blazars as tools to explore the far Universe

G. Ghisellini (OA Brera), **T. Sbarrato** (Univ. Milano Bicocca), **R. Della Ceca** (OA Brera),
M. Volonteri (Institut d'Astrophysique de Paris)

High masses at high redshifts
M_{BH}>10^9 $M_\odot$
z>4

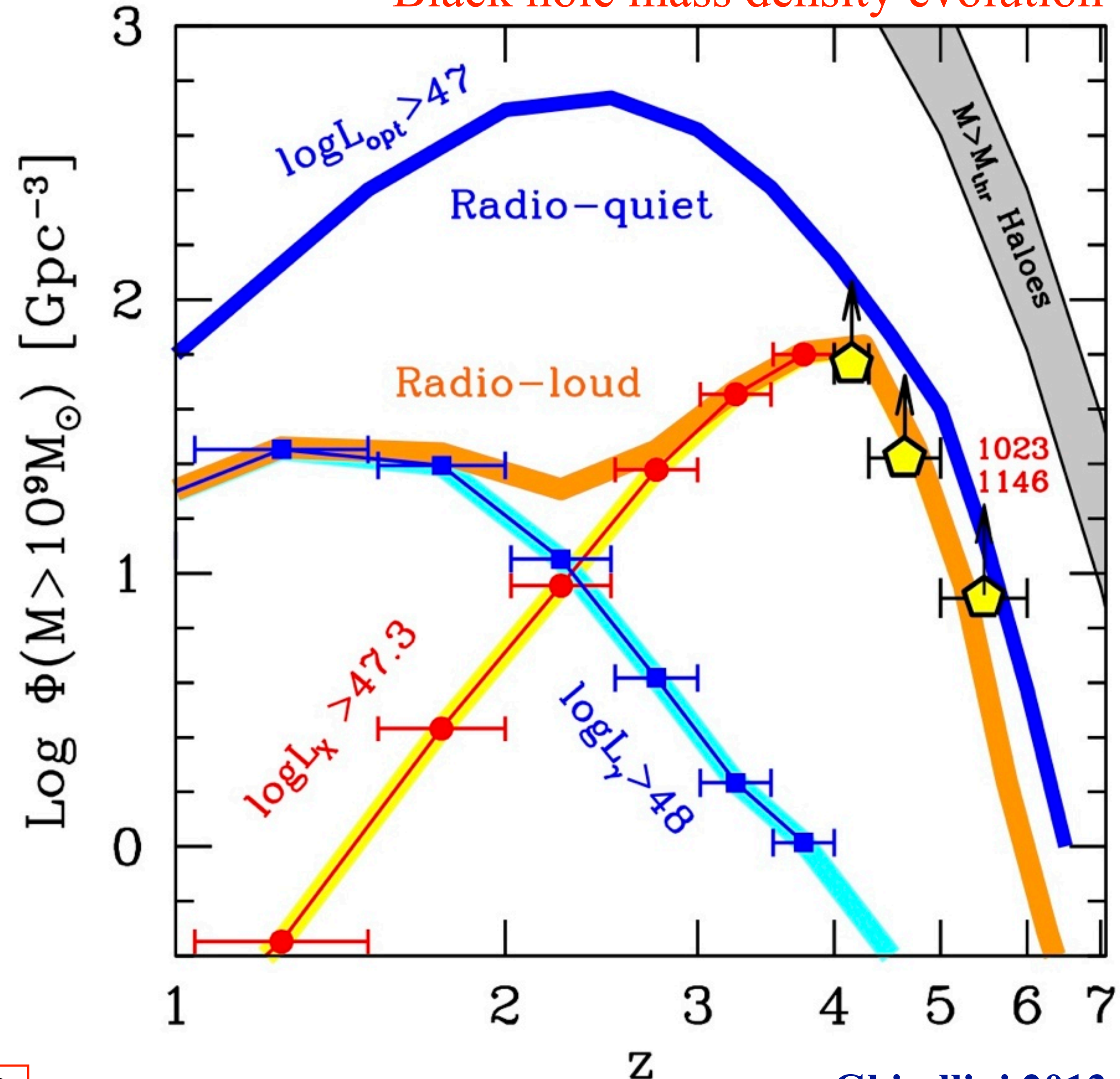
- ➡ Constraints on SMBH formation models
- ➡ Relation between jet and SMBH formation
- ➡ M_{BH}-σ relation at high-z
- ➡ Feedback

Two formation epochs of heavy BH for RQ (z~2) and RL AGN (z~4)

Jets help BH to grow faster

For each detected blazar there must be $2\Gamma^2$ misaligned sources (where Γ=15)

Black hole mass density evolution



Ghisellini 2013
Sbarrato et al. 2012, 2013ab
Ghisellini et al. 2013, 2014
Volonteri et al. 2011

Blazars

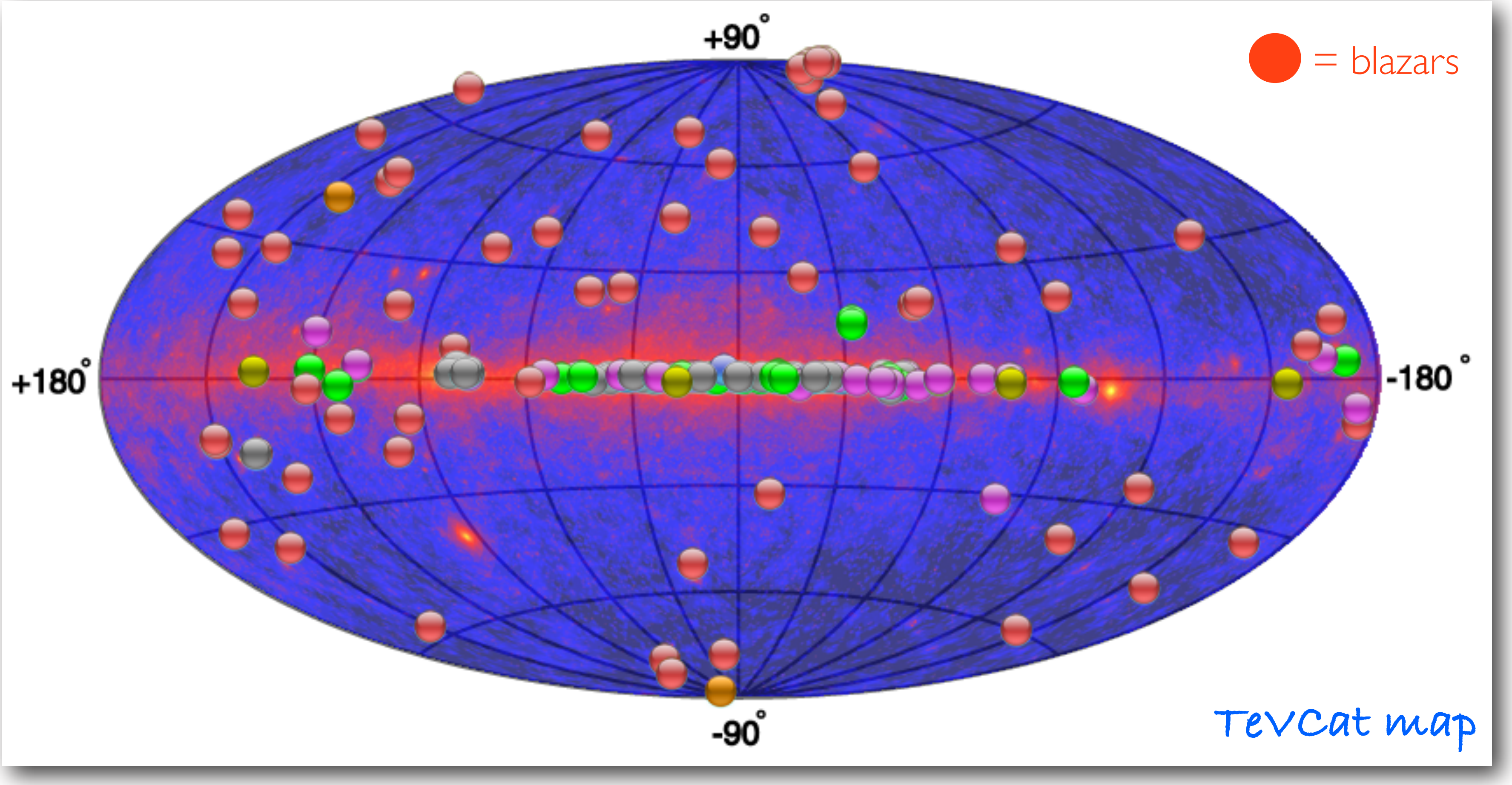
4. VHE emission and astroparticle

VHE emission and astroparticle

Funding:

PRIN-INAF 2014: *"Jet and astro-particle physics of gamma-ray blazars"*
PI: F. Tavecchio (OA Brera)

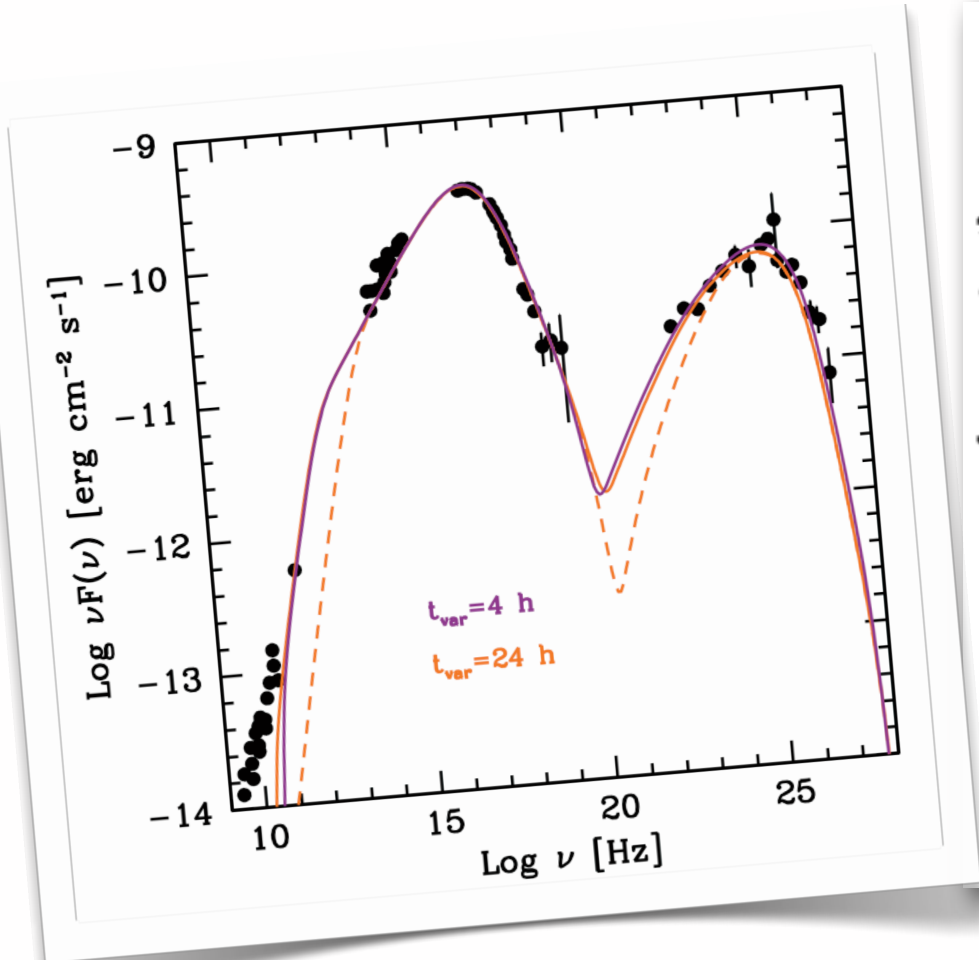
Blazars are ideal laboratories to investigate the physics of the jets and to probe fundamental astroparticle physics

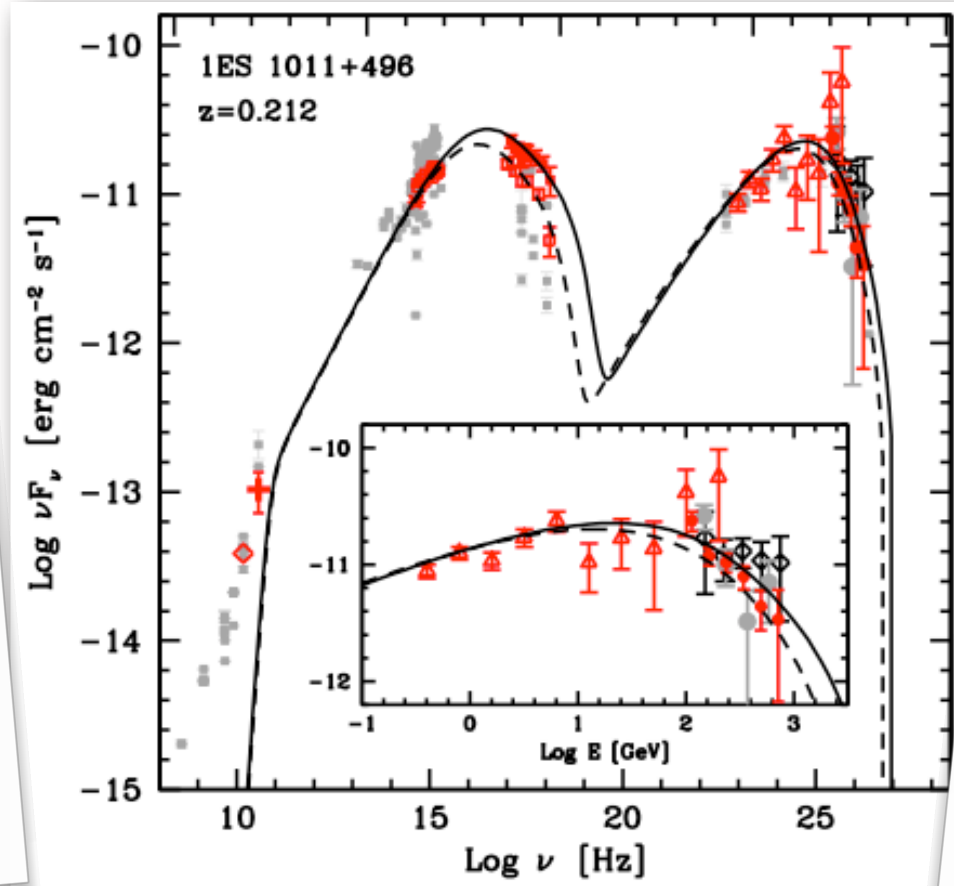


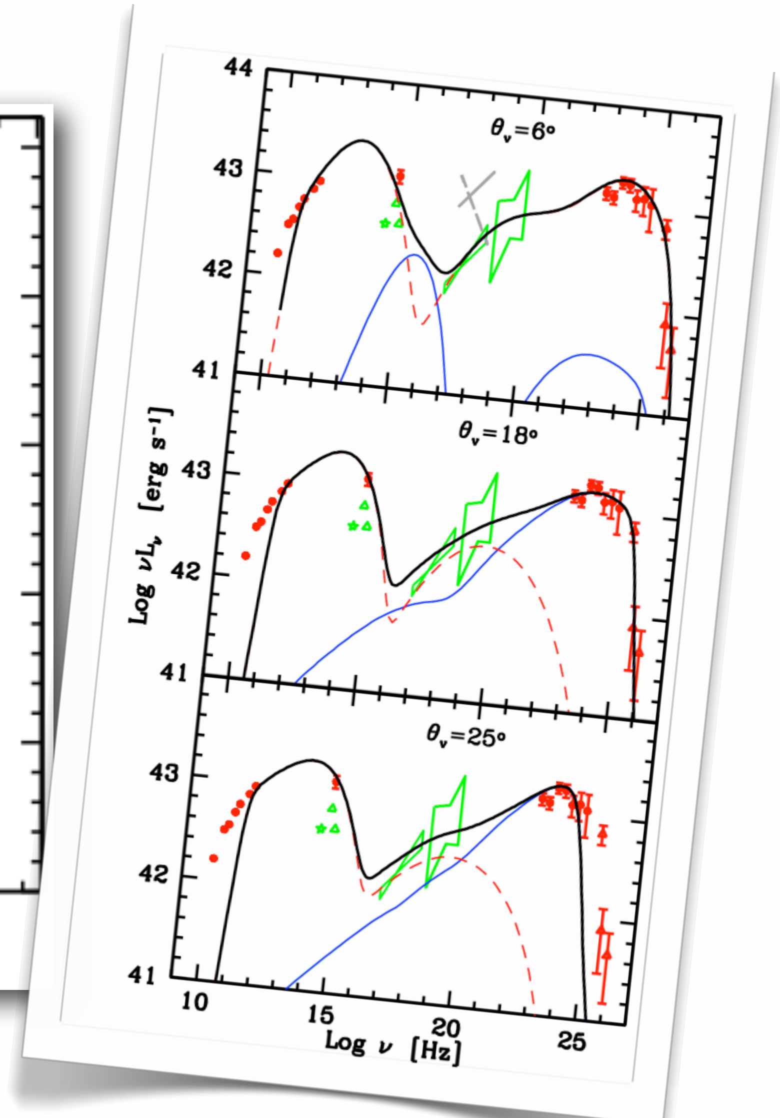
The GeV and TeV sky is dominated by blazars
(BL Lacs but also FSRQ*)

*FSRQ the most powerful blazars @ large z (recently B0218+357 at z=0.944, Magic coll. in prep.).
Expected to be opaque for VHE photons!

Jet structure







✓ From observations to physical parameters and jet physics

✓“Routine” modeling of VHE blazars observed by *MAGIC*

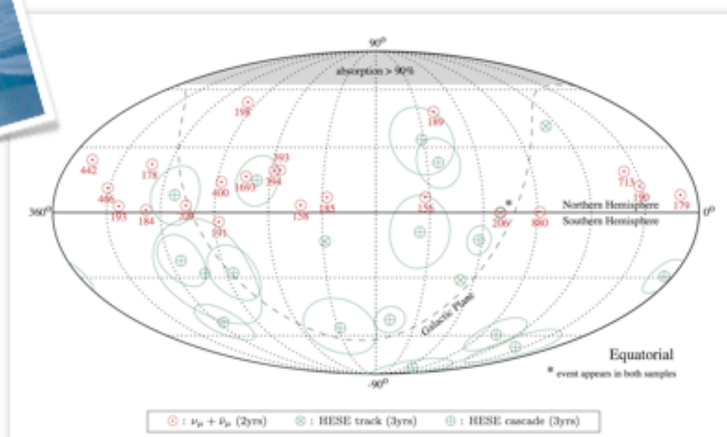
Astroparticle physics

- The beam of TeV gamma-rays can be used to probe the EBL and the IGMF (see later)
- Blazars have been invoked as possible emitters of *high and very-high energy cosmic rays* or *neutrinos*

High-energy neutrinos from blazars?

NEW

Neutrinos could also be produced within the jet



IceCube detected a ~isotropic diffuse emission of E>100 TeV ν

VHE-UHE CR!

$$p + \gamma_{\rm soft} \rightarrow \pi^+ + n$$ ⟶ decays ⟶ neutrinos

BL Lacs?

Padovani et al. 2016: hints for correlation with VHE BL Lacs!

FSRQ?

Kadler et al. 2016

Tavecchio, Ghisellini, Guetta 2014, 2015

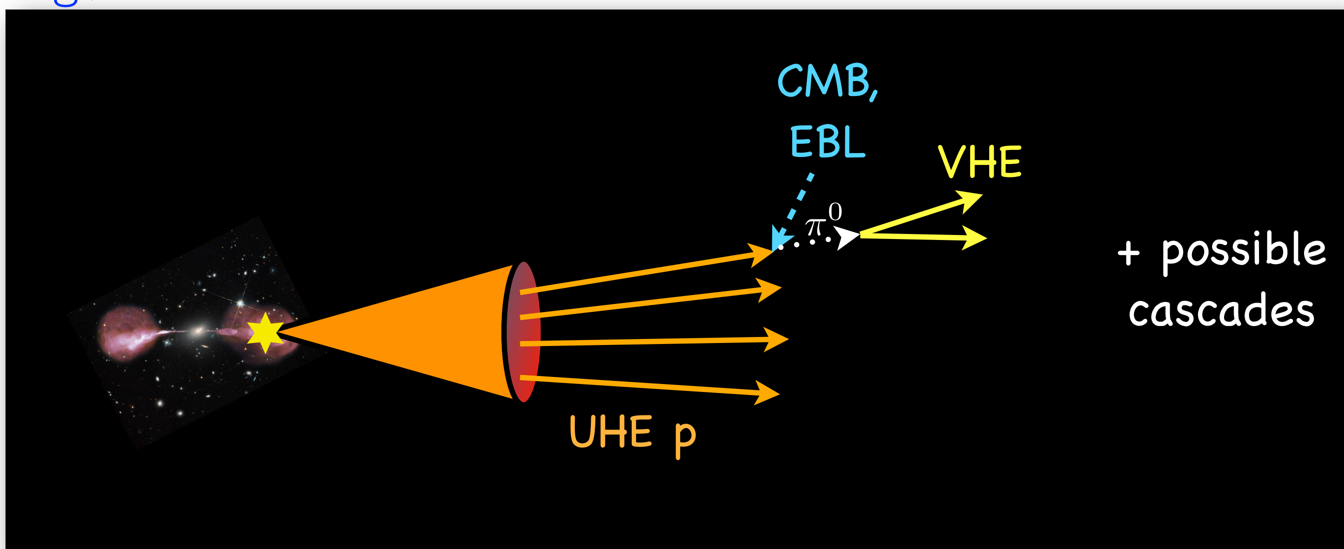
and also radio galaxies?
(Hooper 2016)

Astroparticle physics

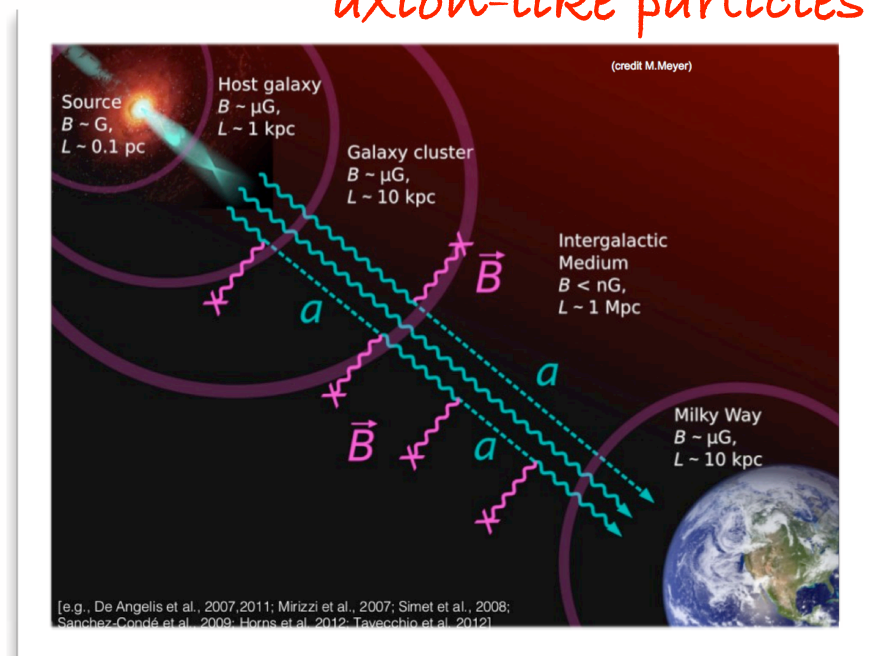
- Observations above 10 TeV can be used to show possible spectral deviations in the expected absorption (EBL) due to hadronic beams, ALPs, LIV (Tavecchio+ ‘12,‘14,‘15; Tavecchio & Bonnoli 2016)

e.g., Tavecchio 2014

hadronic beams



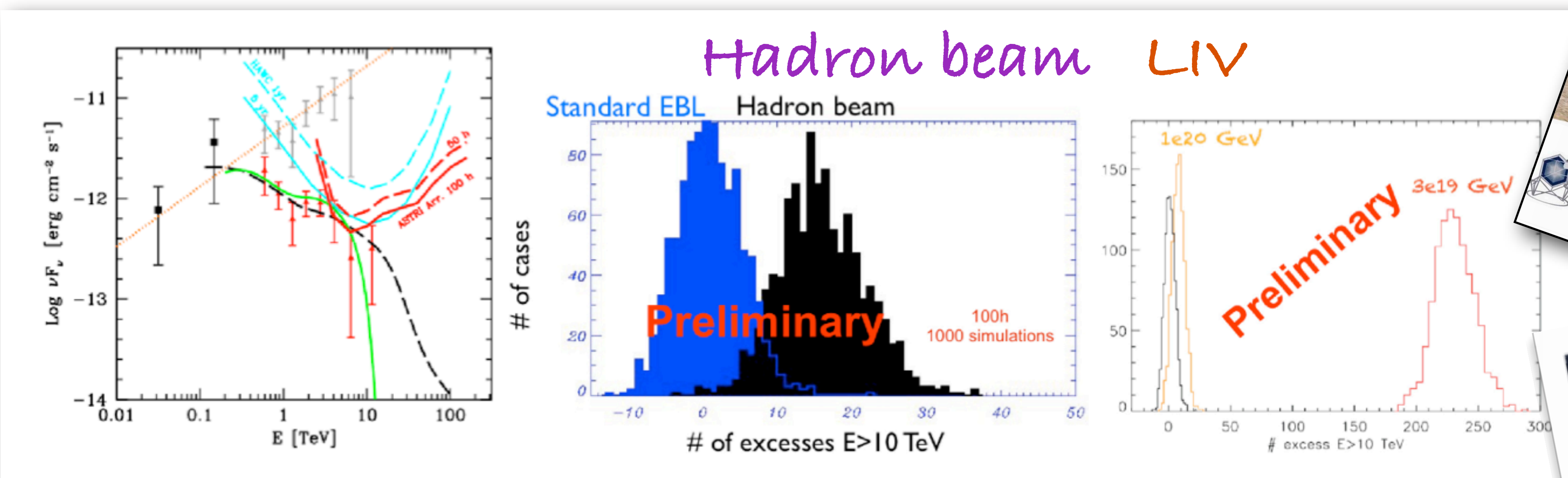
axion-like particles *

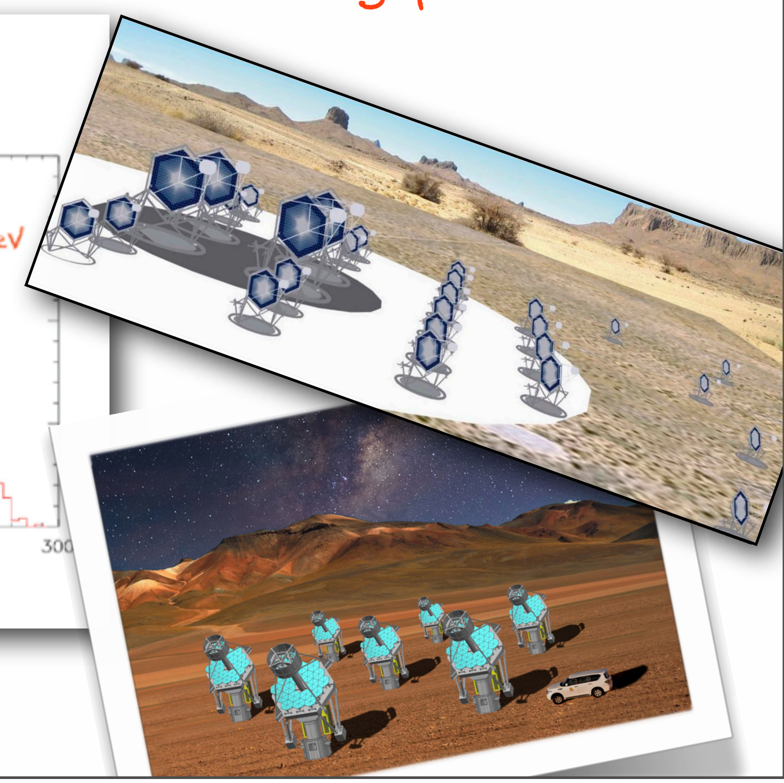


e.g., Tavecchio et al. 2012, 2015

*also interesting for XIPE

Simulations





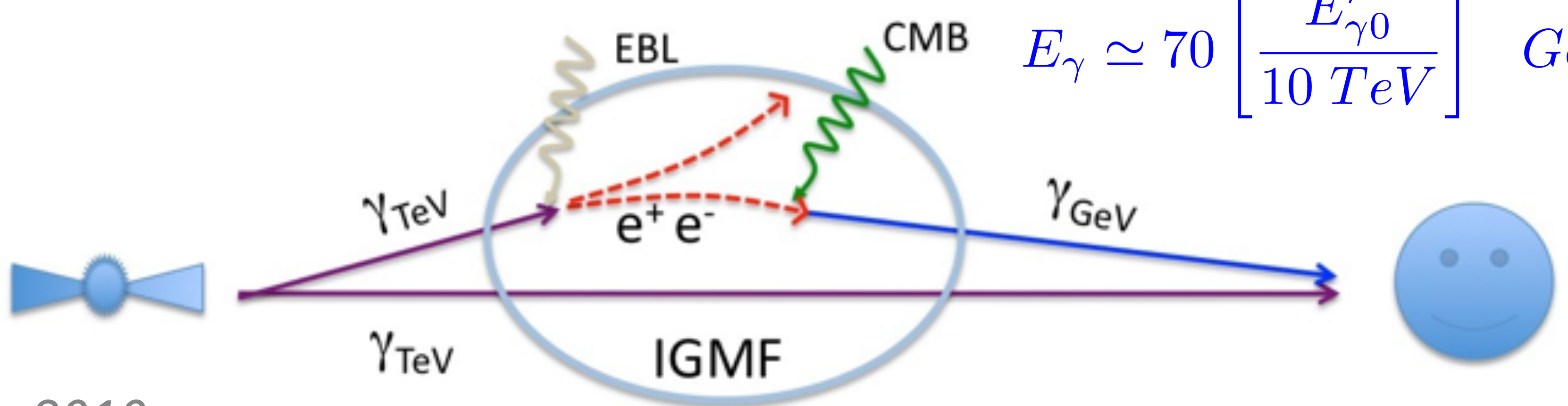
Bonnoli et al. 2016 (Proc. TAUP)

A. Stamerra (OATO)

IGMF: Intergalactic Magnetic Field

- Physical process: reprocessing of TeV photons in the GeV band
- Measurable effects:
  - *spectral features*
  - *extended emission*

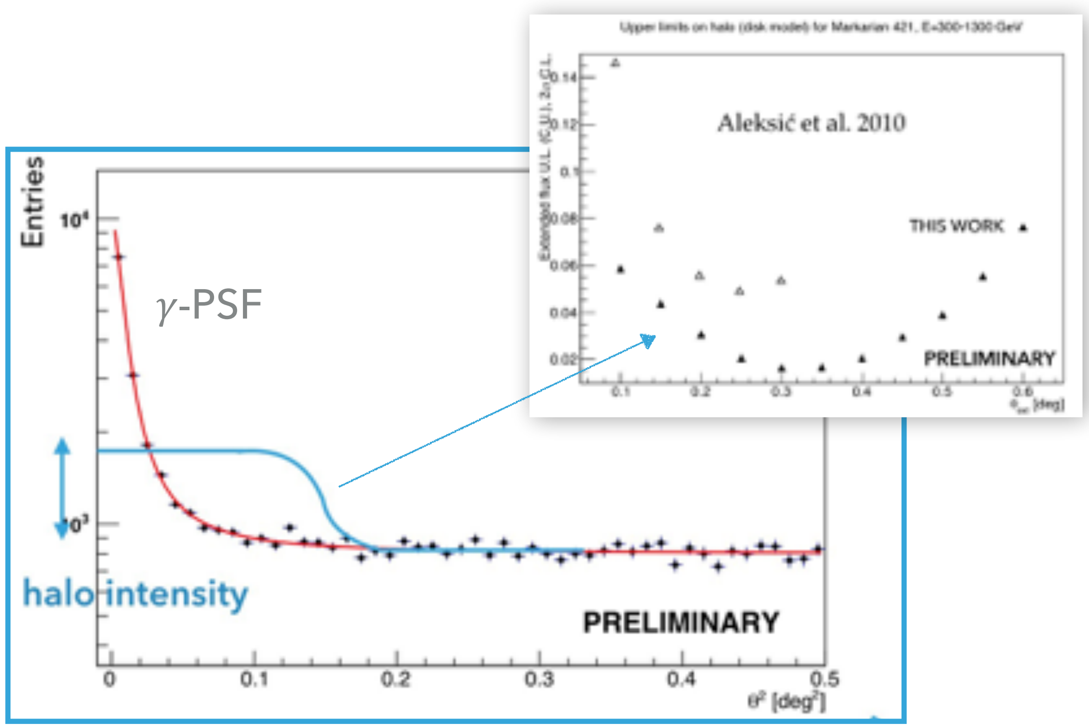
$$E_\gamma \simeq 70 \left[\frac{E'_{\gamma 0}}{10\ TeV}\right]^2 GeV$$



Lower limits on IGMF set by Neronov+2010

Recent progress:

- Claim of halos from Fermi/LAT (Chen +2015, *but not with 3FGL background subtraction…*)
- project with MAGIC: observation and U.L. on halos (P. Da Vela PhD thesis, A. Stamerra)
- Fermi/LAT + CTA: precise spectral measurements (Meyer+2016)



P. Da Vela, PhD 2015

Blazars

5. HE flares from FSRQs

HE flares of FSRQs

L. Pacciani, F. Tavecchio, A. Stamerra (TI)
I. Donnarumma (TD, finanziata da altri progetti)

PRIN INAF 2014

<u>Progetto</u>: Studio dei flare gamma di FSRQs con componente rilevante sopra i 20/(1+z) GeV

Gli argomenti di attenuazione gamma-gamma con fotoni UV delle BLR
e la soppressione di Klein Nishina ad alte energie, porta a preferire regioni di emissioni al bordo,
o fuori delle BLR nel campione che stiamo raccogliendo.

Abbiamo studiato 13 flare in dettaglio, con dati MWL strettamente simultanei

Abbiamo raccolto dati MWL simultanei per ~ altri 50 ogetti

Abbiamo individuato per primi i flare con photon index duro di FSRQs.

3 articoli prima firma, 1 articolo insieme alla collaborazione MAGIC (PKS 1441+25, z=0.939)

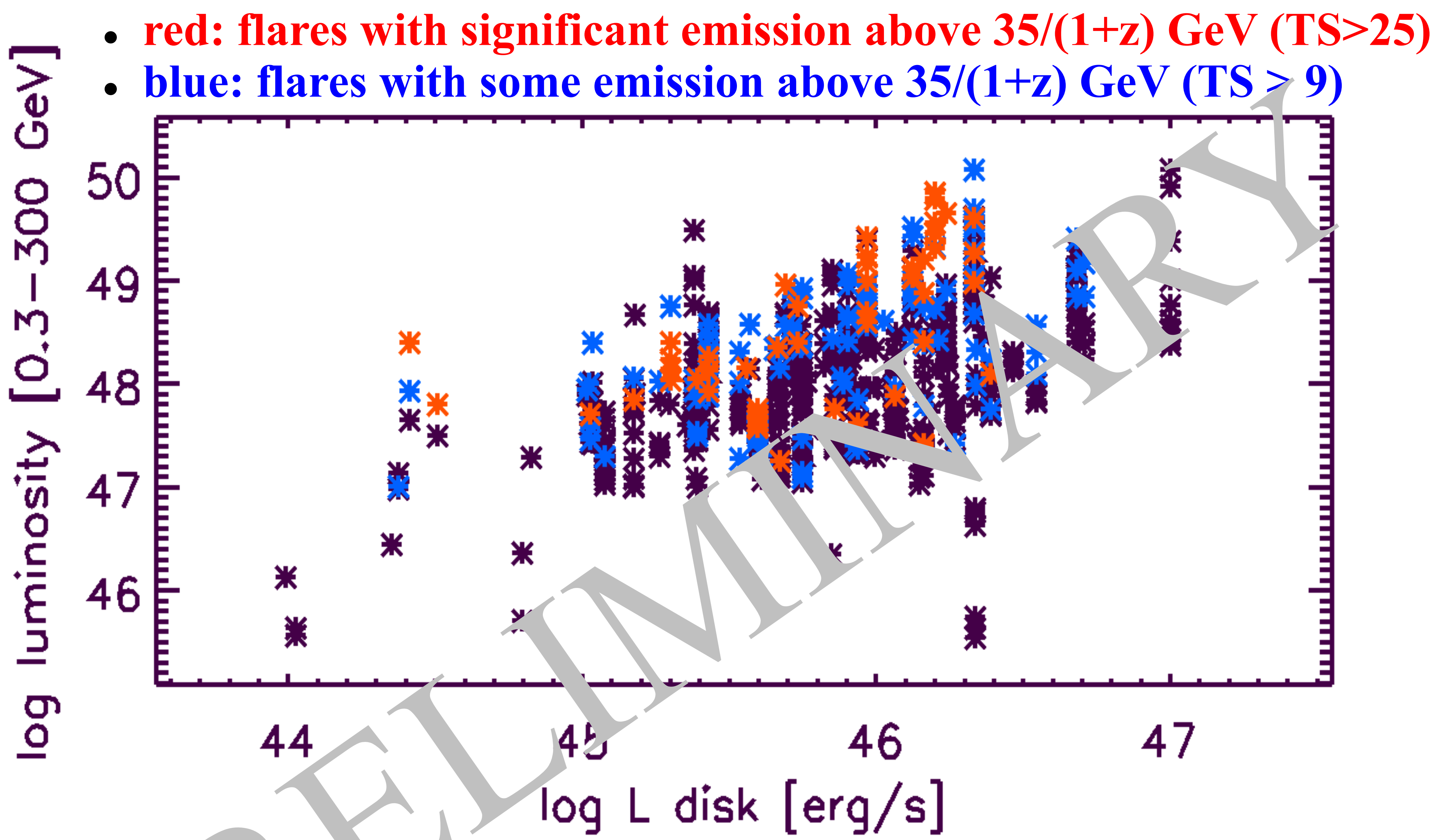
2 sorgenti triggerate per i telescopi Cherenkov e poi scoperte
(PKS 1441+25 FSRQ at z=0.939, Atel #7416
S2 0109+22 BL Lac z=0.265 Atel #7844
+ altri trigger per MAGIC, ma arrivati dopo le allerte ottiche)

11 Atel: #6086, #6165, #7267, #7402,# 7526, #7588,# 7783, #7844, #8323, #8483, #9009

In studio:
determinazione della frazione dei flare dei FSRQs che emettono a grandi distanze dalle BLR
correlazione della luminosità di flare e di disco.

The jet to disk correlation during flares

(dynamic time scales < 20 days)

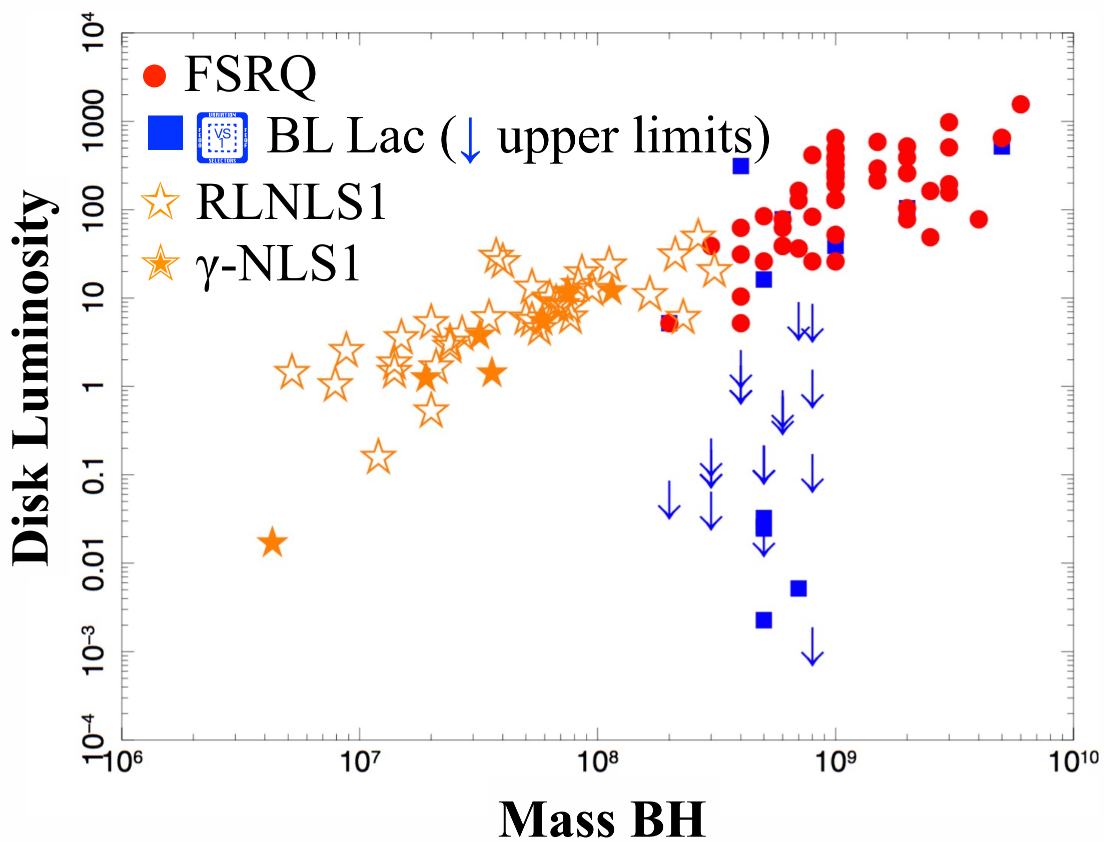


at least 26% of FSRQs flares dissipate at $R_{diss} > R_{BLR}/2$

Radio-Loud
Narrow Line Seyfert 1

Powerful relativistic jets from small-mass/high accretion AGN

L. Foschini, A. Caccianiga, V. Braito, G. Tagliaferri, L. Maraschi (OA Brera)
P. Romano, S. Vercellone (IASF Palermo)
M. Berton, S. Ciroi, V. Cracco, G. La Mura, P. Rafanelli (Università di Padova)

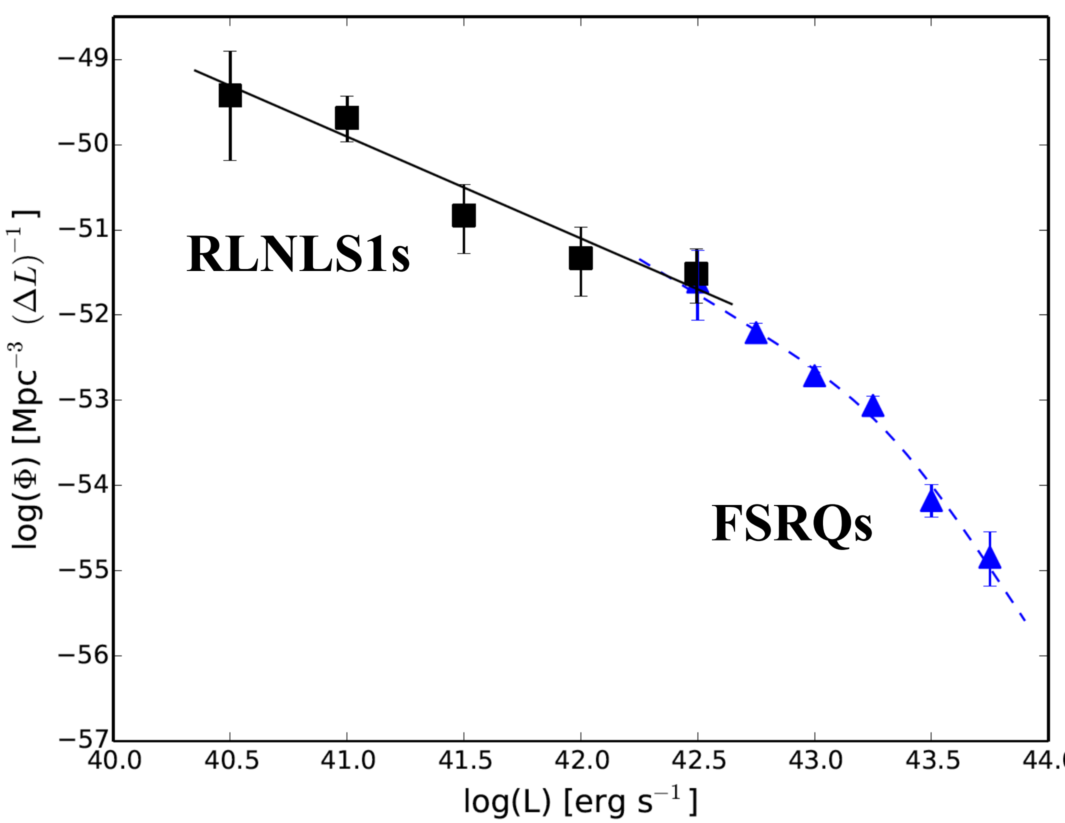


Different observational characteristics with respect to BL Lacs & FSRQs (e.g. lines width, variability, jet power) seem to be the effect of a relatively small mass of the central black hole (Foschini + 2015);

The only real difference seems to be about the **host galaxy**, which shows a **strong star formation** (Caccianiga+ 2015);

RLNLS1s seem to be the low mass (and low luminsoity) tail of FSRQs (Foschini+ 2015, Berton+ 2016);

Parent population (misaligned RLNLS1s): likely a mix of Steep-Spectrum NLS1s, Broad-Line Radio Galaxies in spiral/disk hosts, and CSS/HERG (Berton+ 2015, 2016); **RL NLS1 as young sources**



Small number of known RLNLS1s: why?

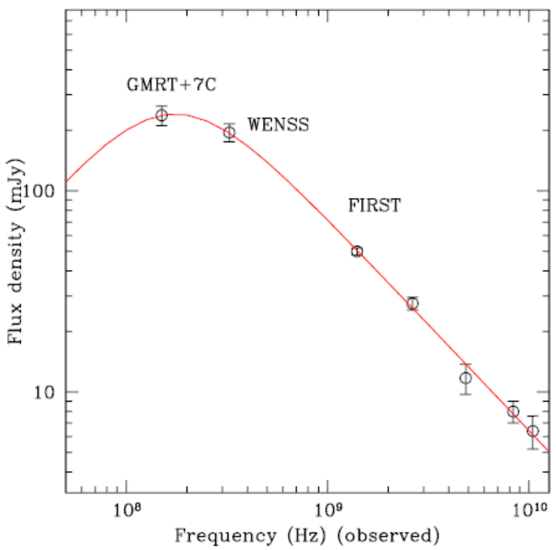
- Low observed power because of small mass, strong variability (intermittent jet)
- Actual small number? Hopes from new facilities (e.g. SKA, Berton+ 2015)

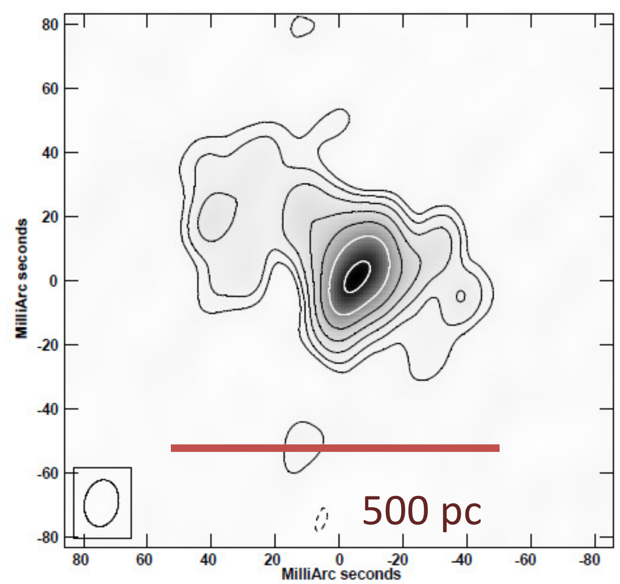
RADIO-LOUD NLS1 AS YOUNG SOURCES

From INAF/University: *A.Caccianiga, L.Ballo, R.Della Ceca, L.Foschini, T.Maccacaro, P.Severgnini (OABrera), M.Berton (OAPadova), D.Dallacasa (UniBo), K-H.Mack (IRA Bo), E.Sani (OA Arcetri)*

Radio-loud Narrow-line Seyfert1 are peculiar sources whose nature is still under debate

- J1432+30: A rare case of mis-oriented RLNLS1 (→ parent population)

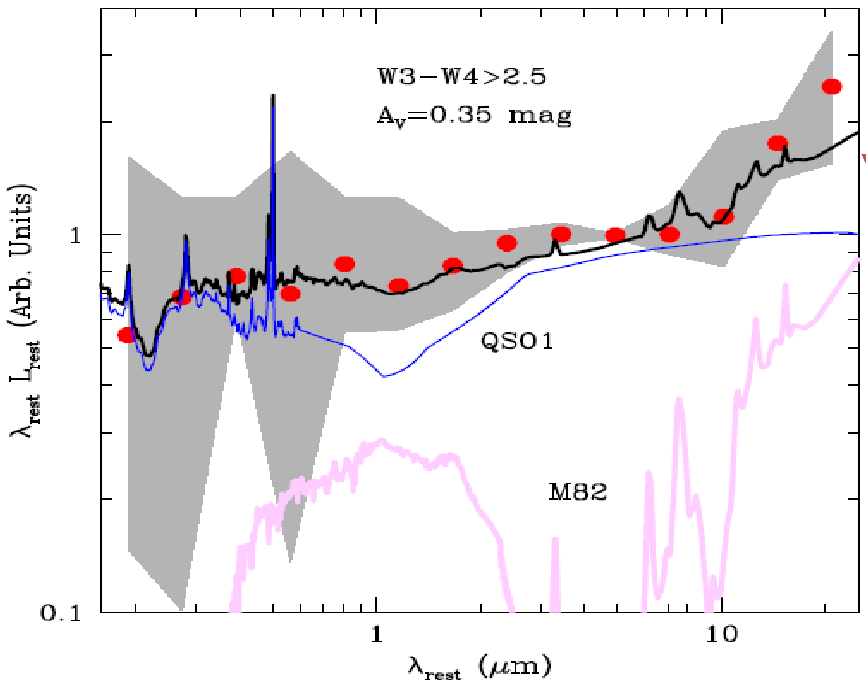




→ Compact Steep Spectrum radiogalaxy
(Caccianiga+14; Caccianiga+16 in prep)

Young ($t<10^5$ y) from the radio point of view

- Combined SED of the RLNLS1 with red WISE colours (~50% of the known RLNLS1)



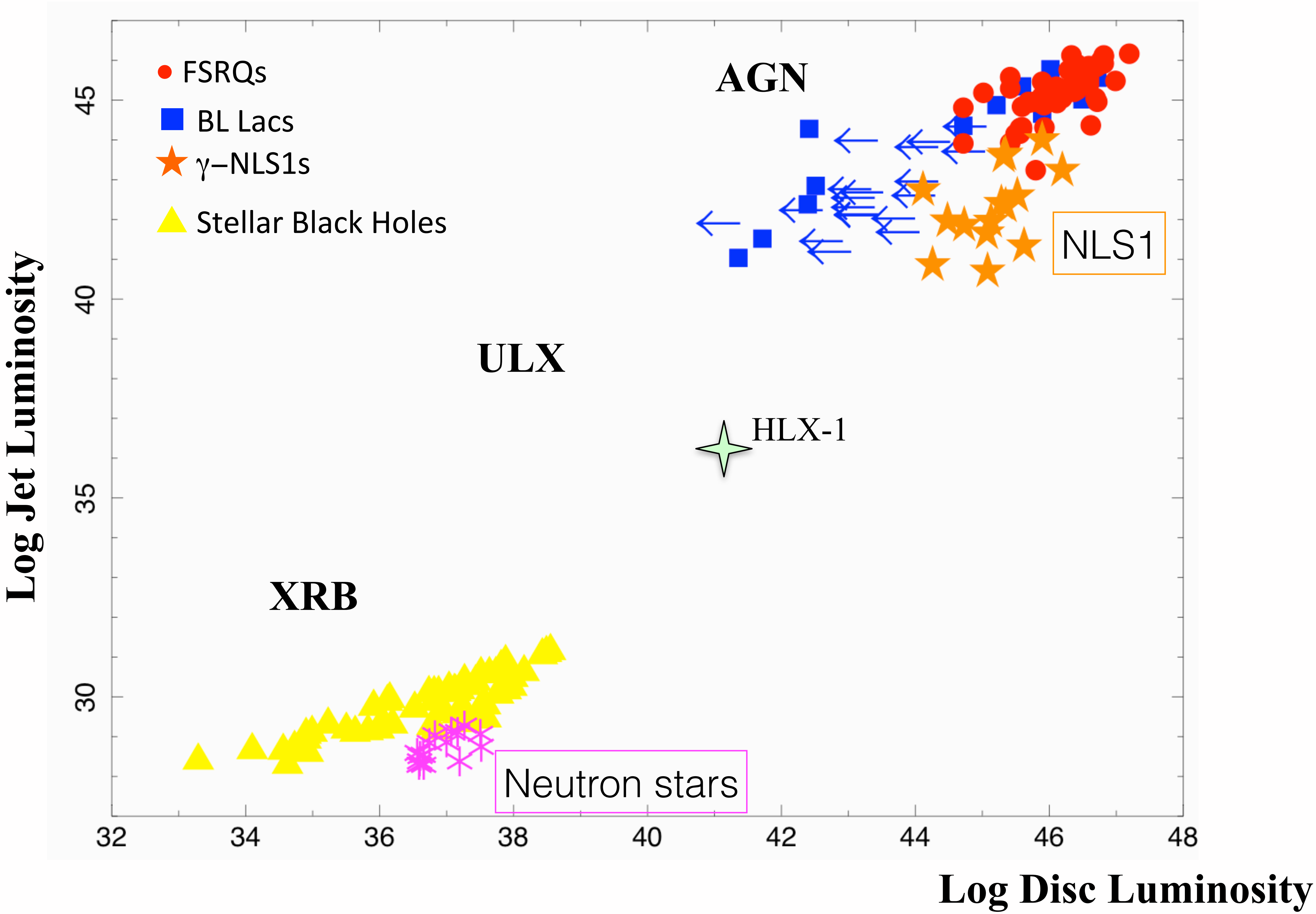
→ Intense star-formation
(SFR~10-500 M_{sun}/y, *Caccianiga+15)*

Young (active in SF) host-galaxies

RLNLS1 appear as new-born (or re-born) AGN, probably triggered by a recent gas-rich merger. Similarities with high-z QSO?

Unification of Powerful Relativistic Jets in XRB-ULX-AGN

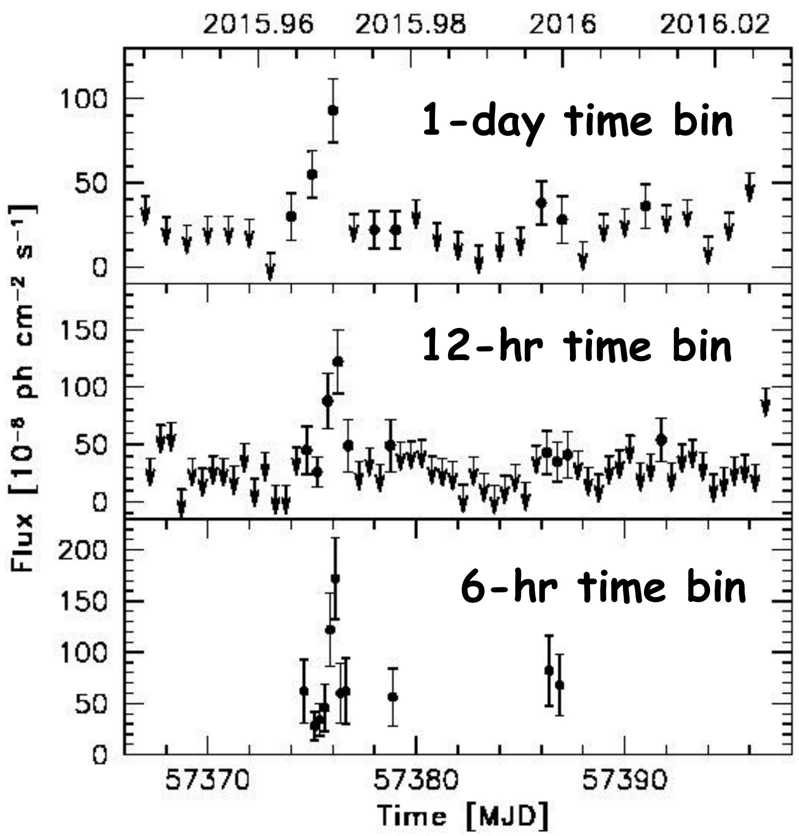
Normalisation depends mostly on the mass and less on the accretion rate
(theory Heinz & Sunyaev 2003; confirmed by observations Foschini 2011-2014);



Multifrequency studies of γ-ray NLSy1

Filippo D'Ammando, Monica Orienti, Marcello Giroletti, Claudia Raiteri, Justin Finke, Josefin Larsson, et al.

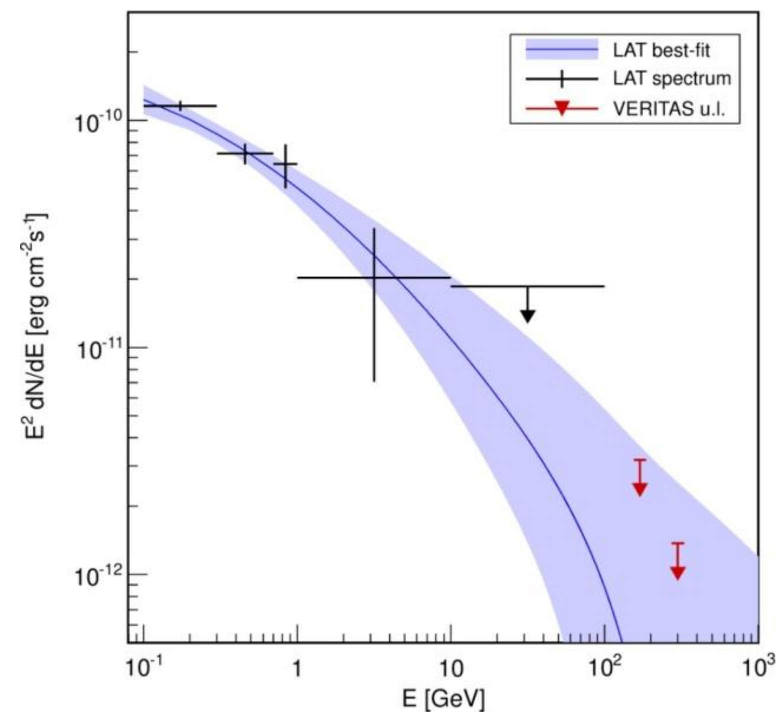
PKS 1502+036



D'Ammando et al. 2016

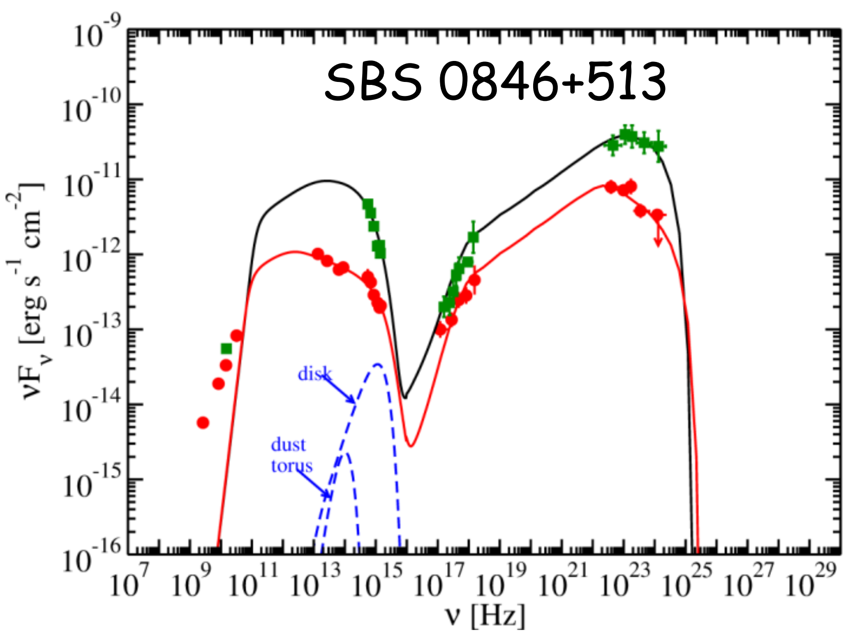
Narrow-line Seyfert 1 showed strong γ-ray flaring activity, with an apparent isotropic luminosity up to ***~10^{48} erg s^{-1}, comparable to that of the bright FSRQ.*** Thus, NLSy1 are good targets for ToO at VHE with CTA.

PMN J0948+0022



D'Ammando et al. 2015

The γ-ray flares from NLSy1 are usually accompanied by an increase of flux from radio to X-rays.



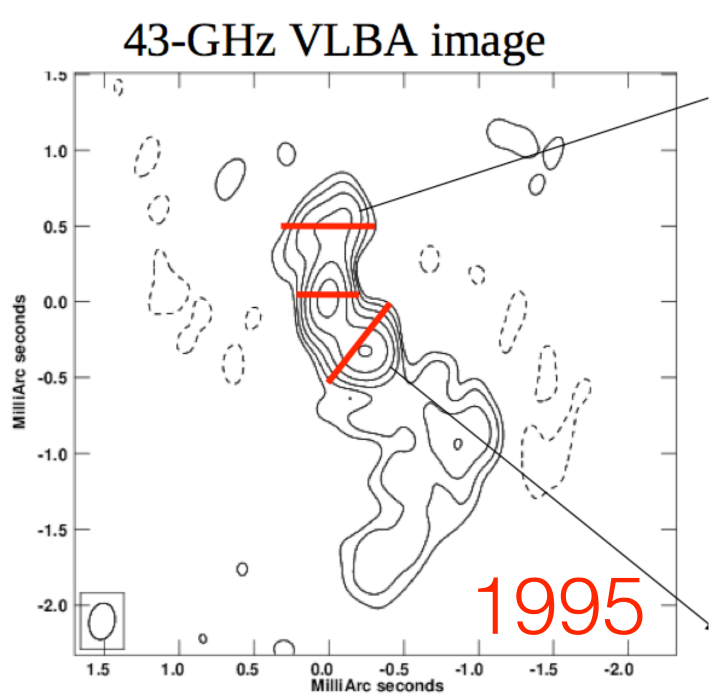
D'Ammando et al. 2013

The SED of the NLSy1 resembles those of blazars, in particular FSRQ, with a Compton Dominance > 1 and the γ-ray emission due to external Compton of IR photons from the torus or optical/UV photons from BLR.

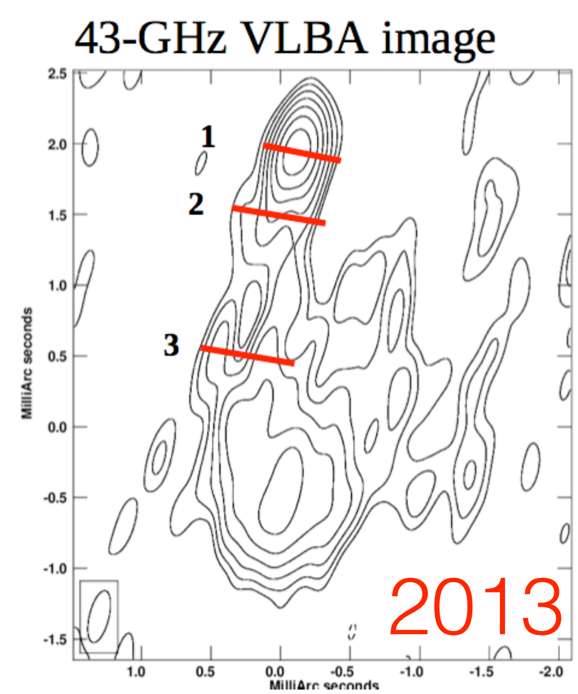
Misaligned AGNs

New insights in the jet structure of 3C 84 with RadioAstron (KSP)

Monica Orienti (IRA-BO), **Gabriele Giovannini** (DIFA & IRA-BO),
Marcello Giroletti (IRA-BO), **Filippo D'Ammando** (DIFA & IRA-BO),
T. Savolainen, H. Nagai, K. Hada, G. Bruni, T. Krichbaum, J. Hodgson

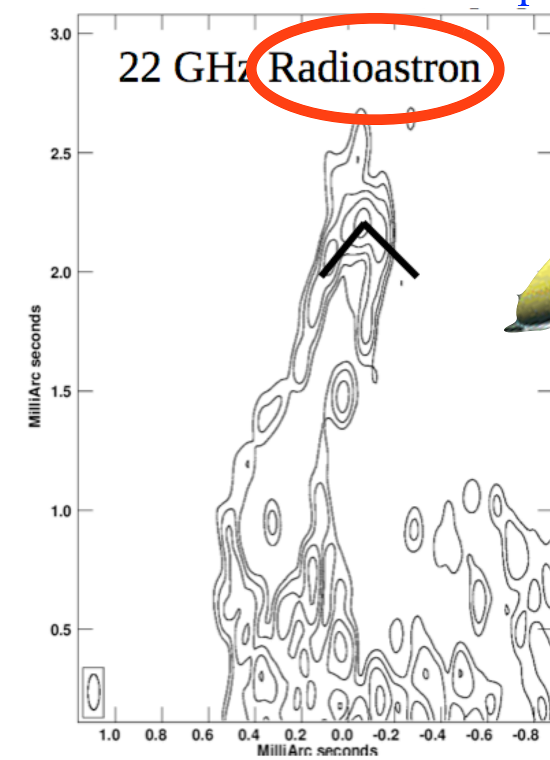


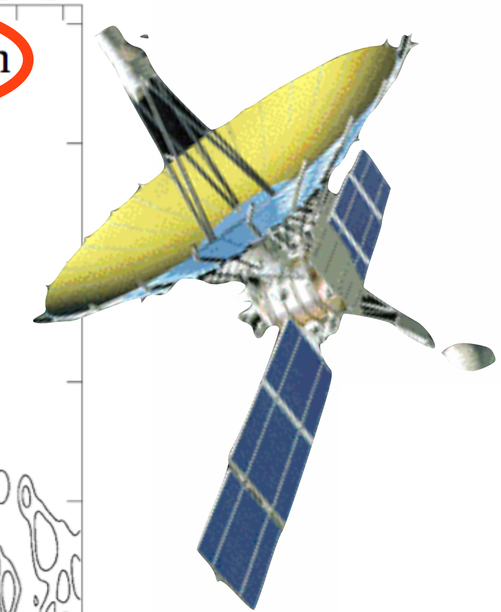
No gamma-ray detection



Gamma-ray detection

G. Giovannini et al. in prep.



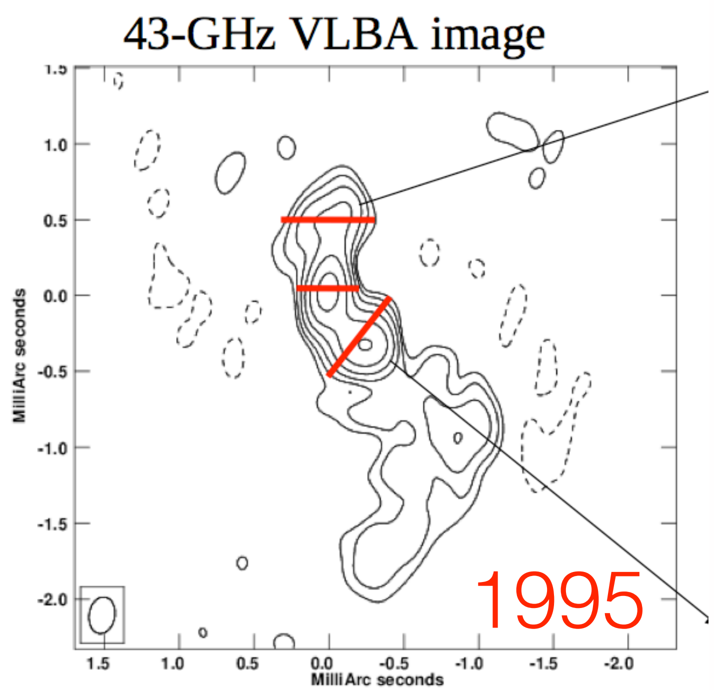


RadioAstron (Space-VLBI) observation detects a **large jet opening angle**

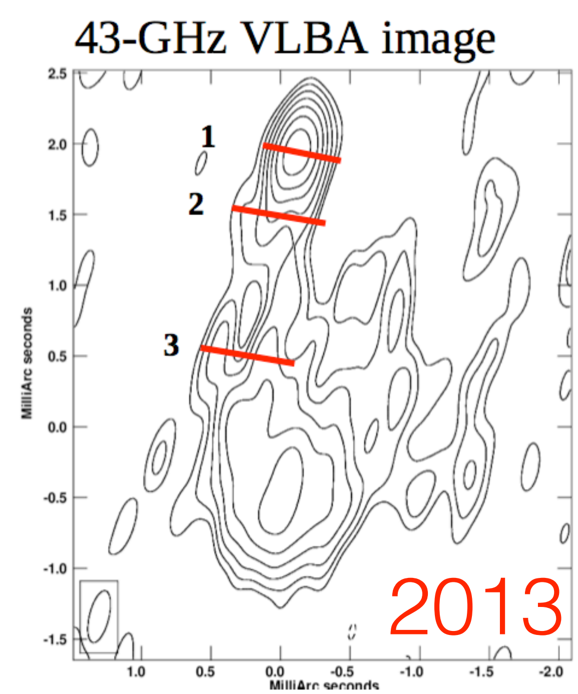
- Opening angle of 90° at 0.1 mas (500 R_S), corresponding to an intrinsic angle of 25°
- Similar to M87 (~100°) but at 10 R_S (Hada et al 2013)
- Limb-brightened structure may be the observable manifestation of a structured jet -- spine-layer scenario (Tavecchio & Ghisellini 2014)

New insights in the jet structure of 3C 84 with RadioAstron (KSP)

Monica Orienti (IRA-BO), **Gabriele Giovannini** (DIFA & IRA-BO),
Marcello Giroletti (IRA-BO), **Filippo D'Ammando** (DIFA & IRA-BO),
T. Savolainen, H. Nagai, K. Hada, G. Bruni, T. Krichbaum, J. Hodgson

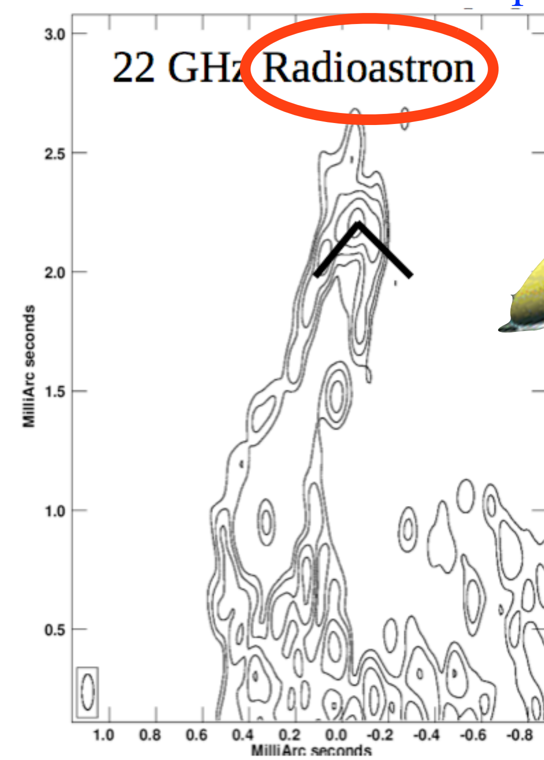


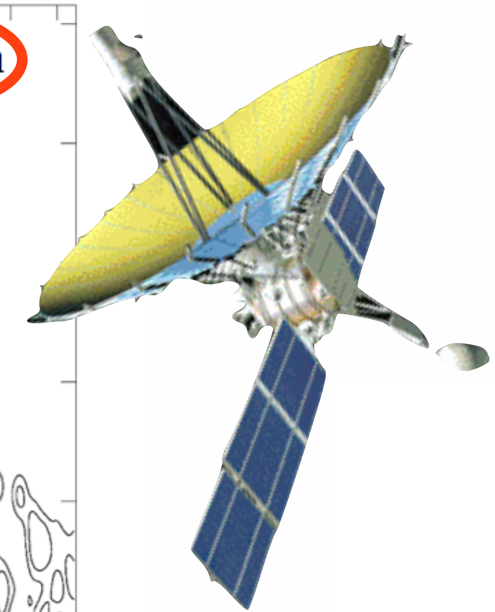
No gamma-ray detection



Gamma-ray detection

G. Giovannini et al. in prep.





RadioAstron (Space-VLBI) observation detects a **large jet opening angle**

- Opening angle of 90° at 0.1 mas (500 R_S), corresponding to an intrinsic angle of 25°
- Similar to M87 (~100°) but at 10 R_S (Hada et al 2013)
- Limb-brightened structure may be the observable manifestation of a structured jet -- spine-layer scenario (Tavecchio & Ghisellini 2014)

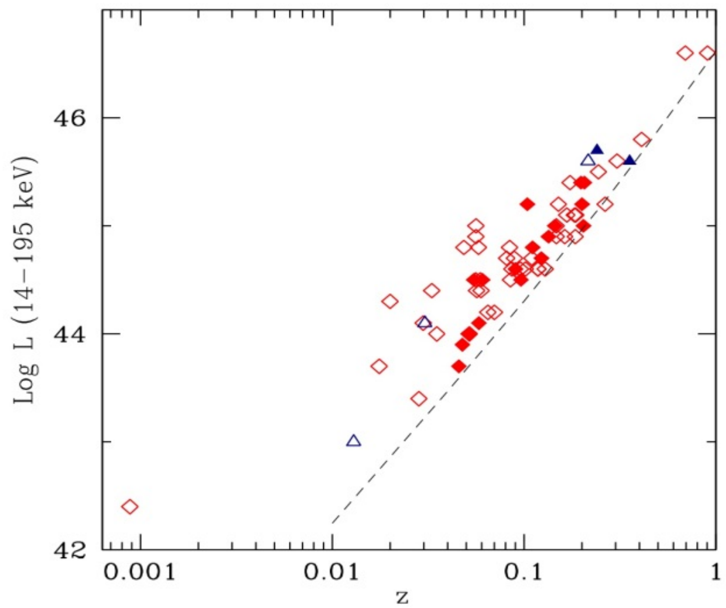
Latest news about VLBI and EHT see **M. Giroletti's slides** @Round Table session G

Study of a sample of soft gamma-ray selected radio Galaxies (I)

INTEGRAL AGN Team, T. Venturi & D. Dallacasa

Sample less biased in absorption and useful for many objectives: broad band studies (radio versus X-ray properties), comparison with radio quiet objects, connection with blazars , etc

Selected from all INTEGRAL/IBIS & Swift/BAT AGN
64 Radio Galaxies+3 candidate objects



$F_{14\text{-}195\ keV} > 9\ 10^{-12}$ erg/cm^2 sec

Optical type	*Radio Morphology*
25 type1	**51 FR II**
12 Type 1.1-1.5	**6 FR I**
9 type 1.8-1.9	**6 FRI/FRII**
19 type 2	**1C**
2 Unkn	**3 Unknown**

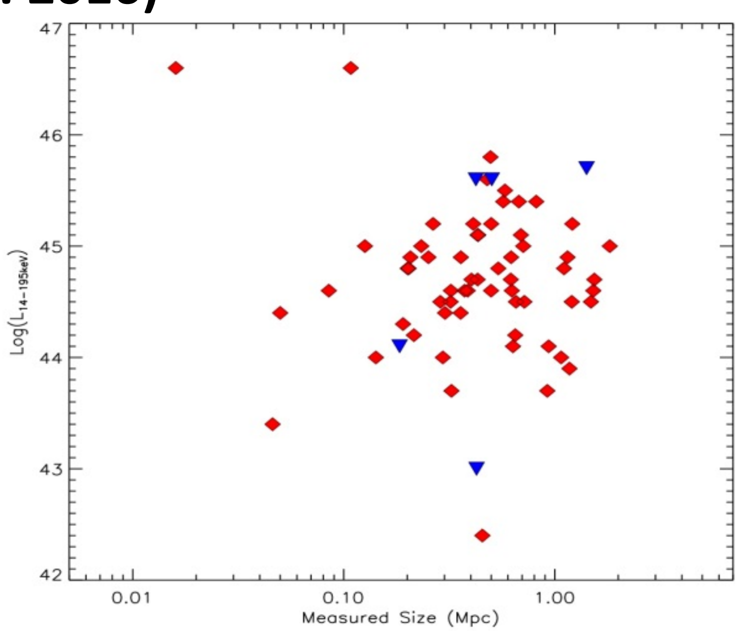
Mostly HERG
Log L_{Bol}/L_{Edd}>0.01

60% have LAS > 0.4 Mpc
20% have LAS > 0.7 Mpc , i.e Giant Radio Galaxies or GRGs
Fraction of GRGs in the sample much more than in radio surveys (typically 2-6 %)

BUT

No correlation LAS versus 14-195 KeV Luminosity

First Result: objects have Large Radio Size
(Bassani et al. 2016)



Study of a sample of soft gamma-ray selected radio Galaxies (II)

Second Result: new GRGs discovered and characterized in radio and high energies

IGR J14488-4008 (Molina et al. 2014), IGR J17488-2338 (Molina et al. 2015), PKS 2331-240 (Panessa et al. in prep)

Third Result: X-ray absorption studied performed **(Panessa et al 2016)**

a) Unified theory confirmed, most NLRG are absorbed while BLRG are unabsorbed, but 15% are outliers (type 1 absorbed and type 2 not absorbed)

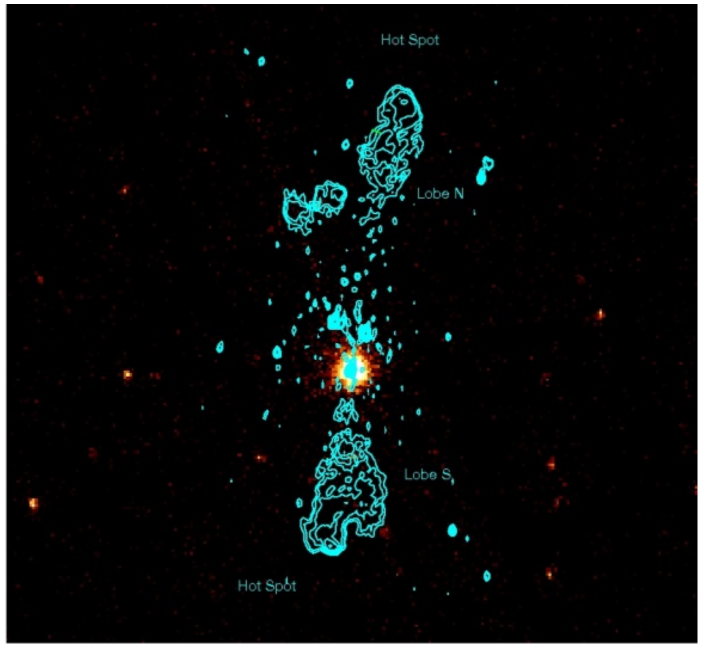
b) Fraction of Compton thick objects only 2-3%

c) Anticorrelation Radio Core Dominance Absorption

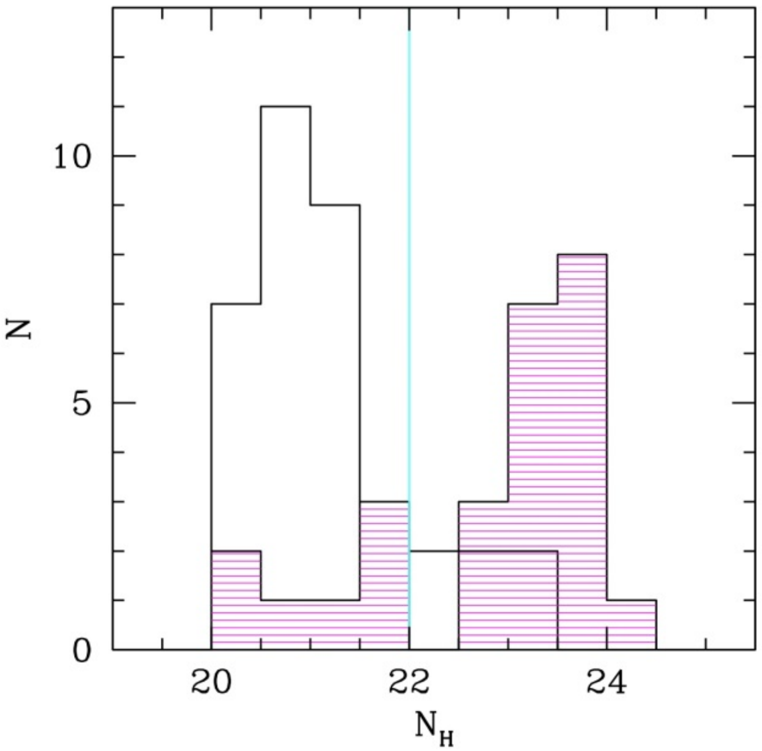
Future:

- Broad band 0.1-200 keV observations (most objects have XMM and IBIS/BAT data) to study X-ray features and compare to those observed in radio quiet objects (warm absorbers, reflections feautures etc)

- Radio observations of GRGs (archival +proprietary GMRT data) to understand the phenomenon from a different perspective.



GMRT image on top of XMM image for IGR J14488-4008

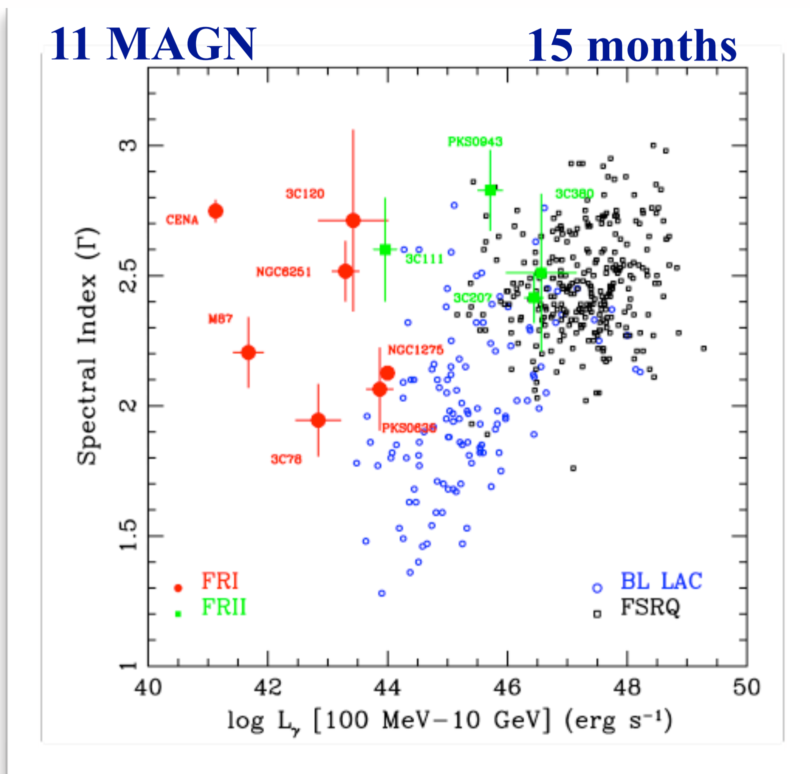


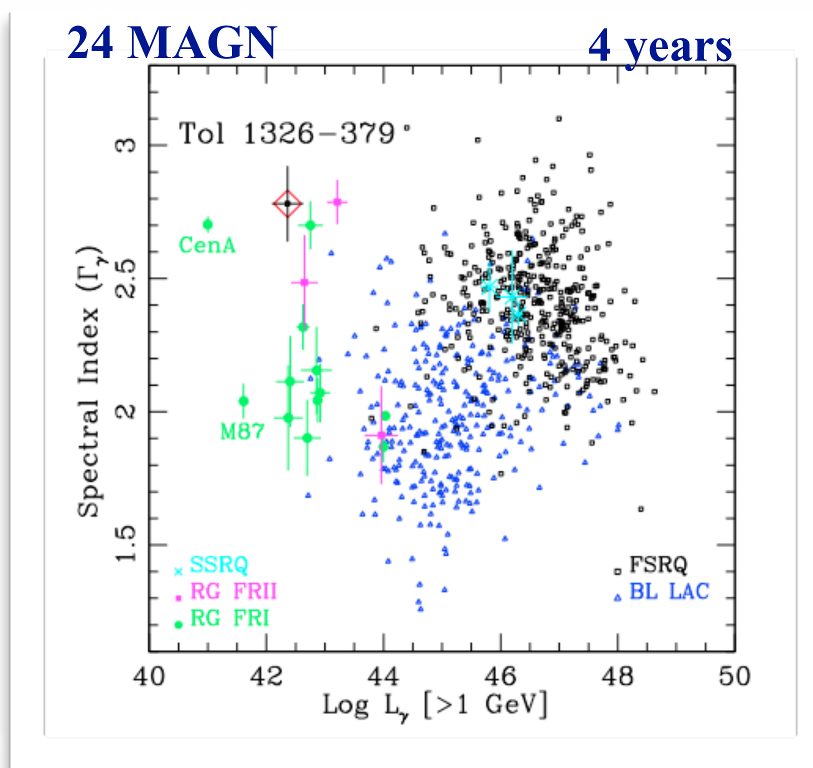
Absorption distribution: black Type 1, red Type 2

Misaligned AGNs at high and very high energies

Paola Grandi (INAF IASFBO), **ET** (DIFA & IASFBO),
Alessandro Capetti (INAF OATO), **Gabriele Giovannini** (DIFA & IRA BO), **Cristian Vignali** (DIFA)
Roberto Angioni (MPIFR), Ranieri D. Baldi (Univ. of Southampton)

Fermi-LAT has given a great contribution to the discovery of MAGNs as GeV emitters





Main issues:

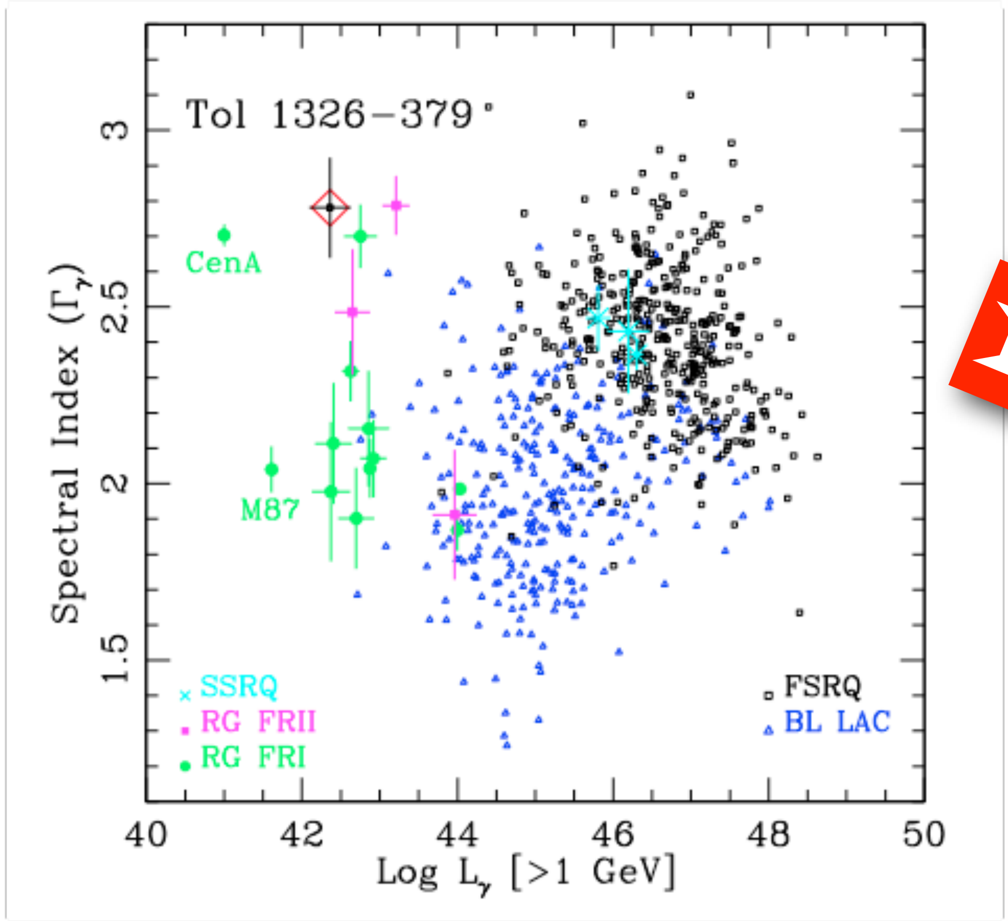
- Different detection rate between FRIs and FRIIs
- Variability study of FRI and FRII light curves
- Localization of the high-energy dissipation region

Results:

✓ Different jet structure between FRIs and FRIIs (spine-layer scenario)
✓ In 3C111 the high-energy photons dissipation region is at 0.3 pc from the BH (Grandi et al. 2012).

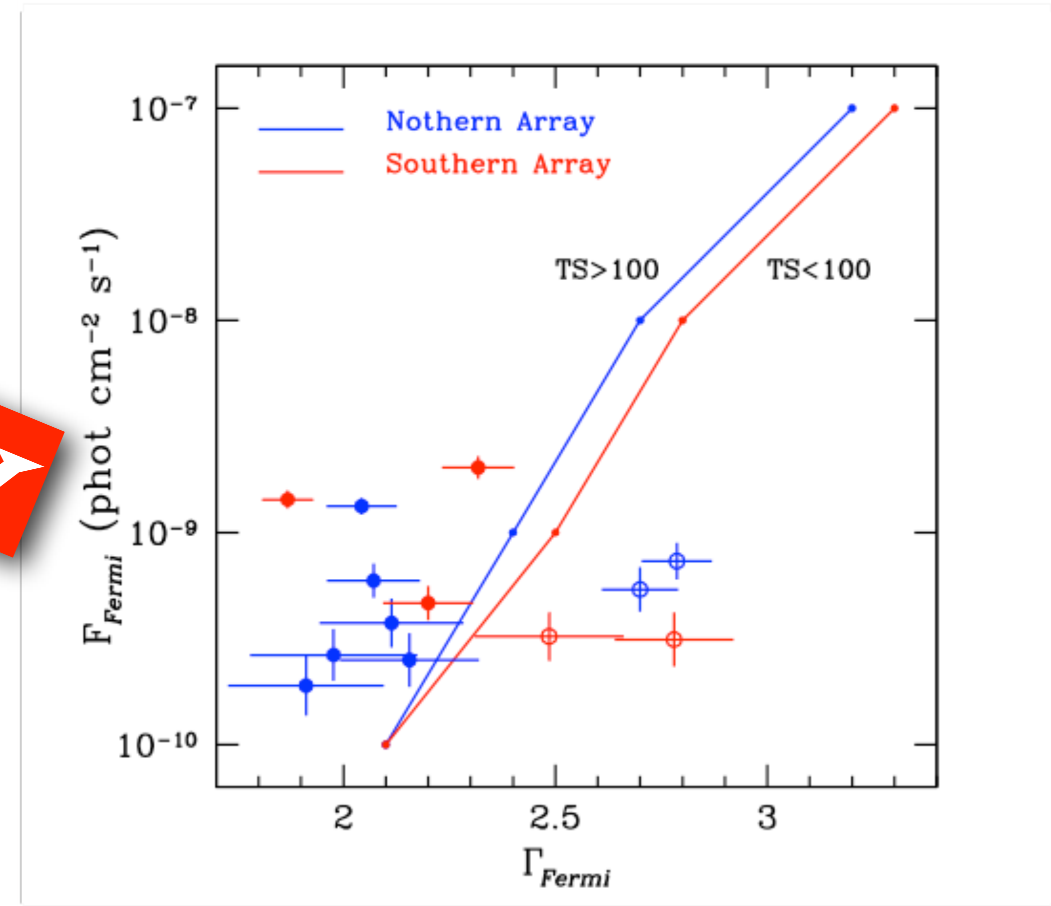
Misaligned AGNs at high and very high energies

Discovery of a FR0 in the GeV sky
(Grandi et al. 2016)

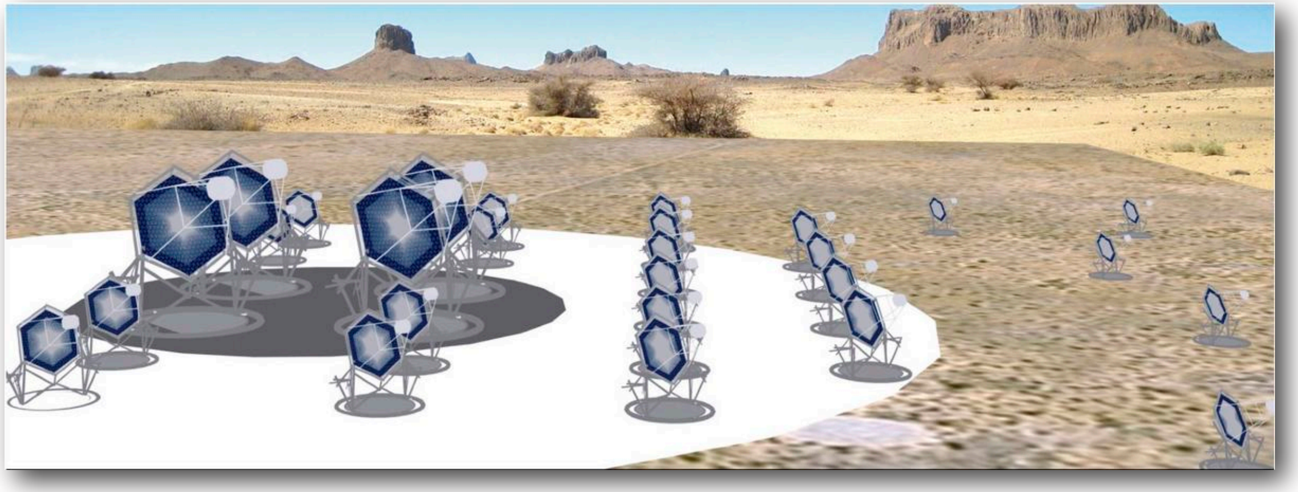


NEW

Radio Galaxies with the CTA
(Angioni et al. in prep.)

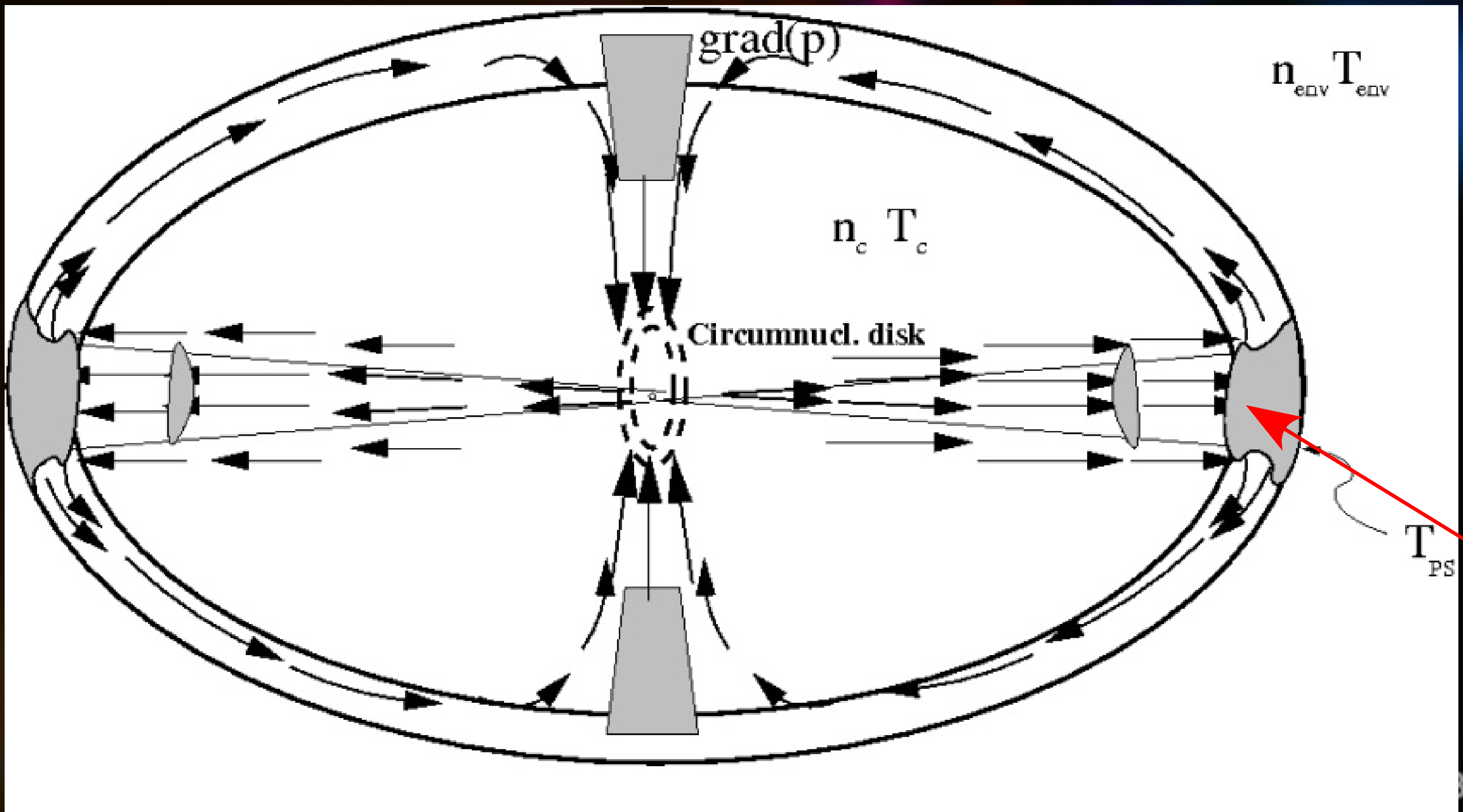


X-ray study of a sample of FR0s
(ET et al. in prep.)



Backflows within AGNs relativistic jets

V. Antonuccio-delogu (INAF-OACt) + J. Silk (IAP, JHU, Oxford), S. Cielo (IAP), A. Babul (U. Victoria), A. Romeo (Mt. Purple Obs., China)



Backflow: gas streaming opposite to and along the boundary of the cocoon.

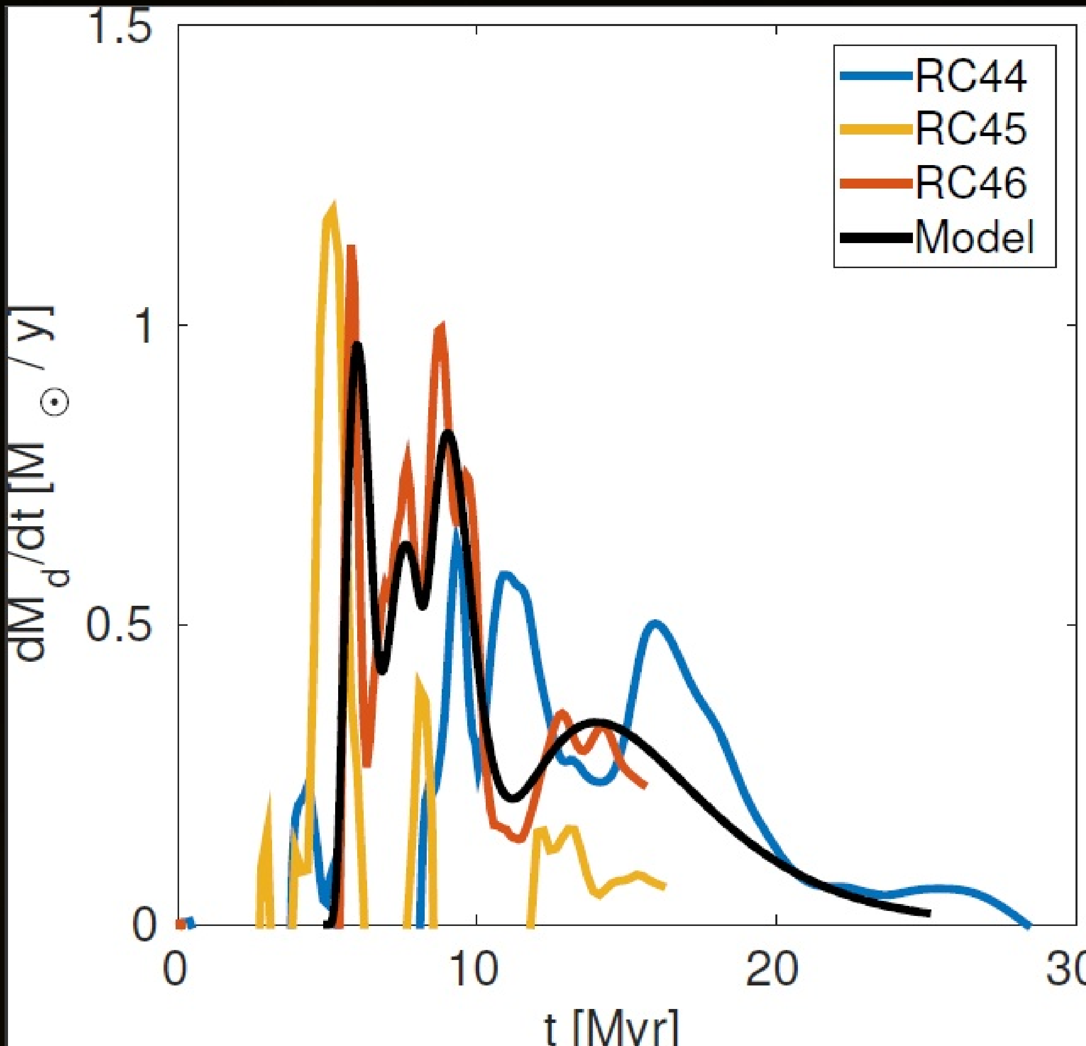
- Origin is *thermodynamical* : vorticity is produced from jet's gas crossing the shock before the Hot Spot

C 321 HUBBLESITE.org

- Backflow is *spatially coherent* and *intrinsically axisymmetric* all way down to the accretion region

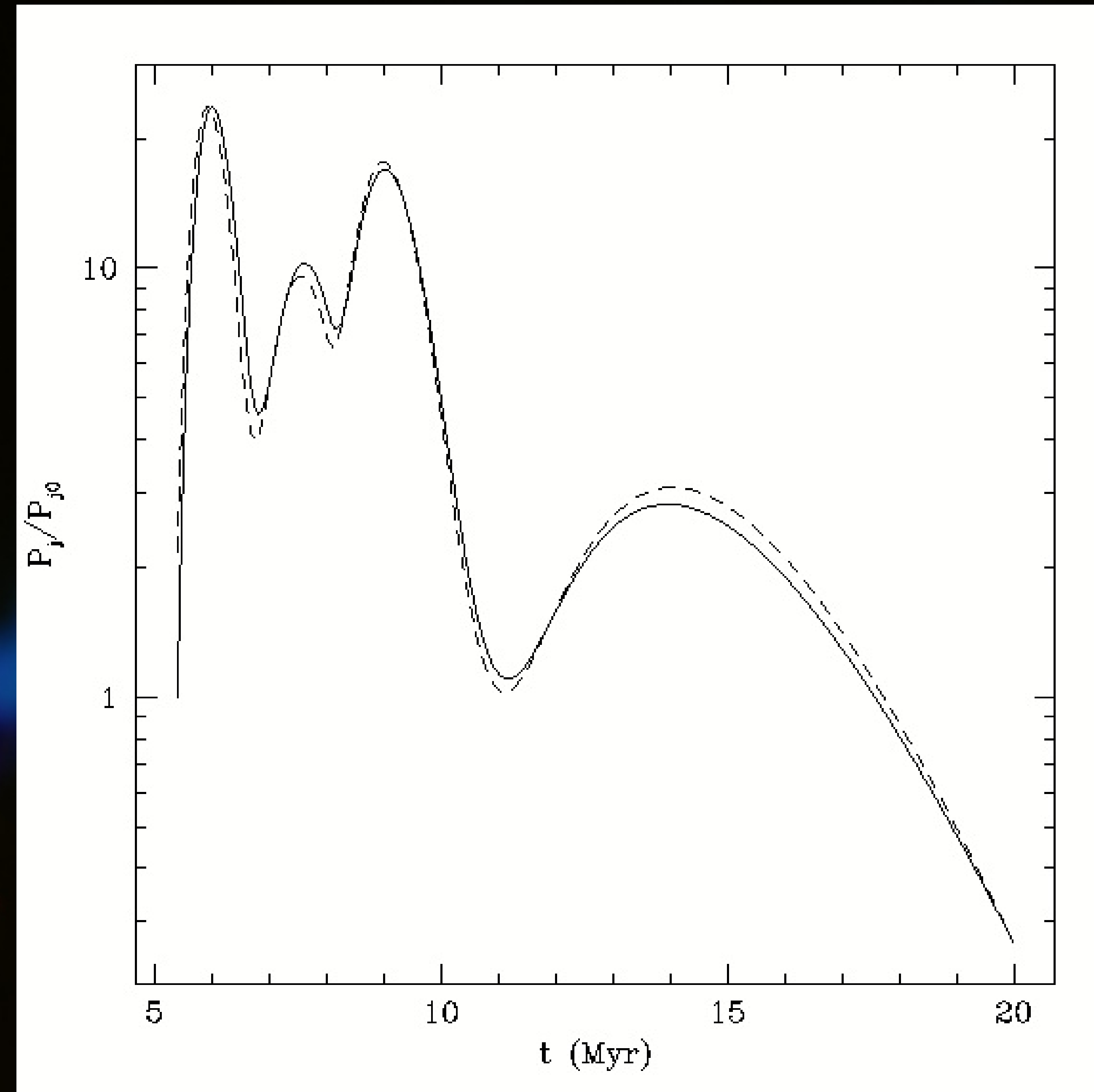
see also Antonuccio-Delogu & Silk 2010; Cielo et al. 2014

Backflow → enhanced mass accretion → P_{jet} change with time



Black curve: template mass flow model

On the right plot the predicted change in $P_{jet} \propto \Sigma^{3/2}(\rho v_z)^{1/2}$



- P_{jet} enhanced by a factor ~ 10 on 15-20 Myrs.
- EUV ($\lambda \lesssim 1100$ Å) correlates with GHz synchr for RLQ

Observational evidence for backflows

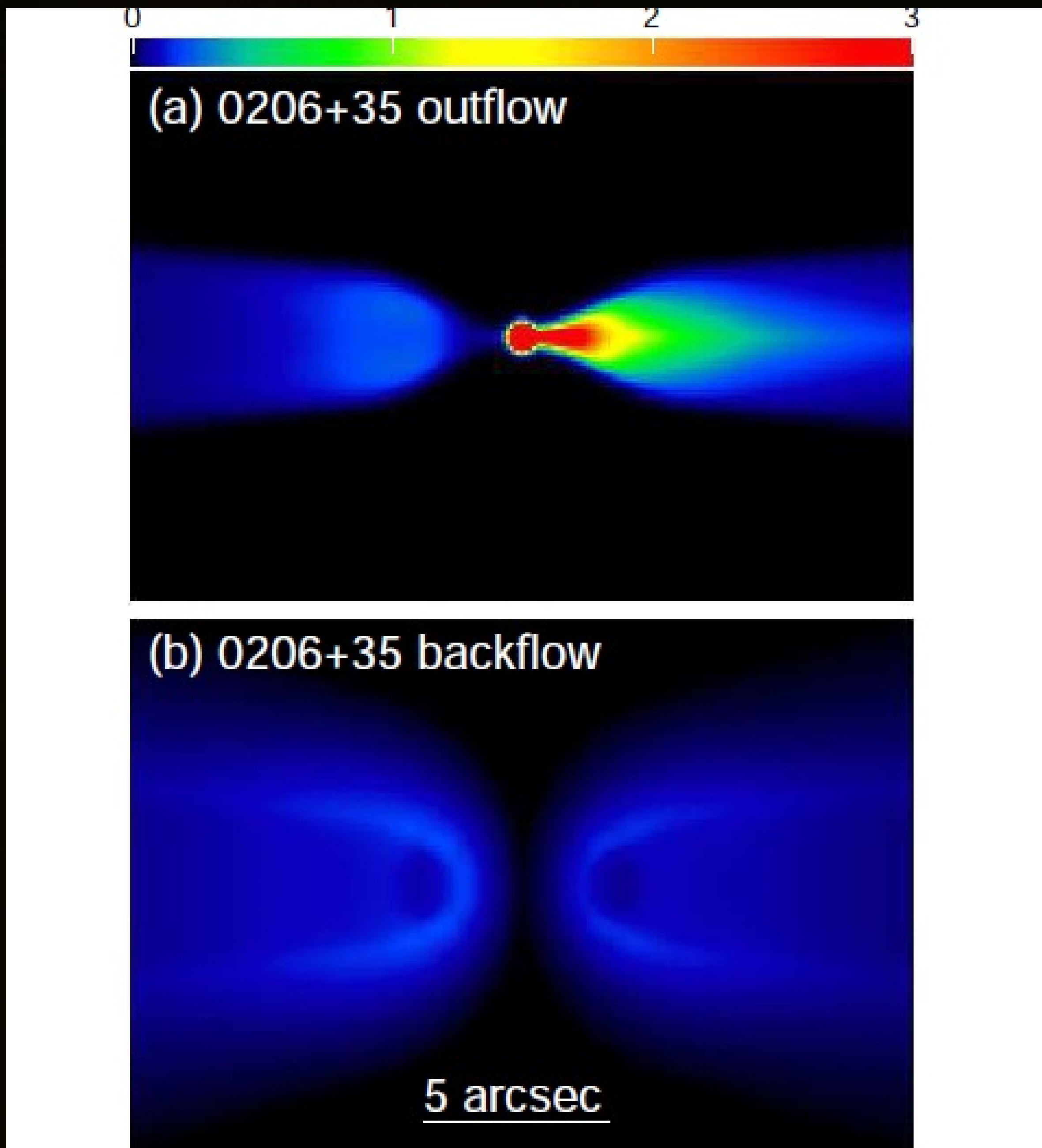


Figure 9. Predicted brightness distributions for the outflowing and backflowing parts of the model for 0206+35. (a) outflow; (b) backflow.

Laing & Bridle, 2012: FRI, mildly relativistic velocities

- Backflows are the product of the interaction between the jet and the local host galaxy's environment
- Backflows feed the central accretion disc (ADAF)
- A connection between galaxy scale feedback and central accretion develops over time-scales <= 1/10 of the AGN duty cycle