Particle acceleration and nonthermal emission from fast winds in active galactic nuclei

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and a little help from
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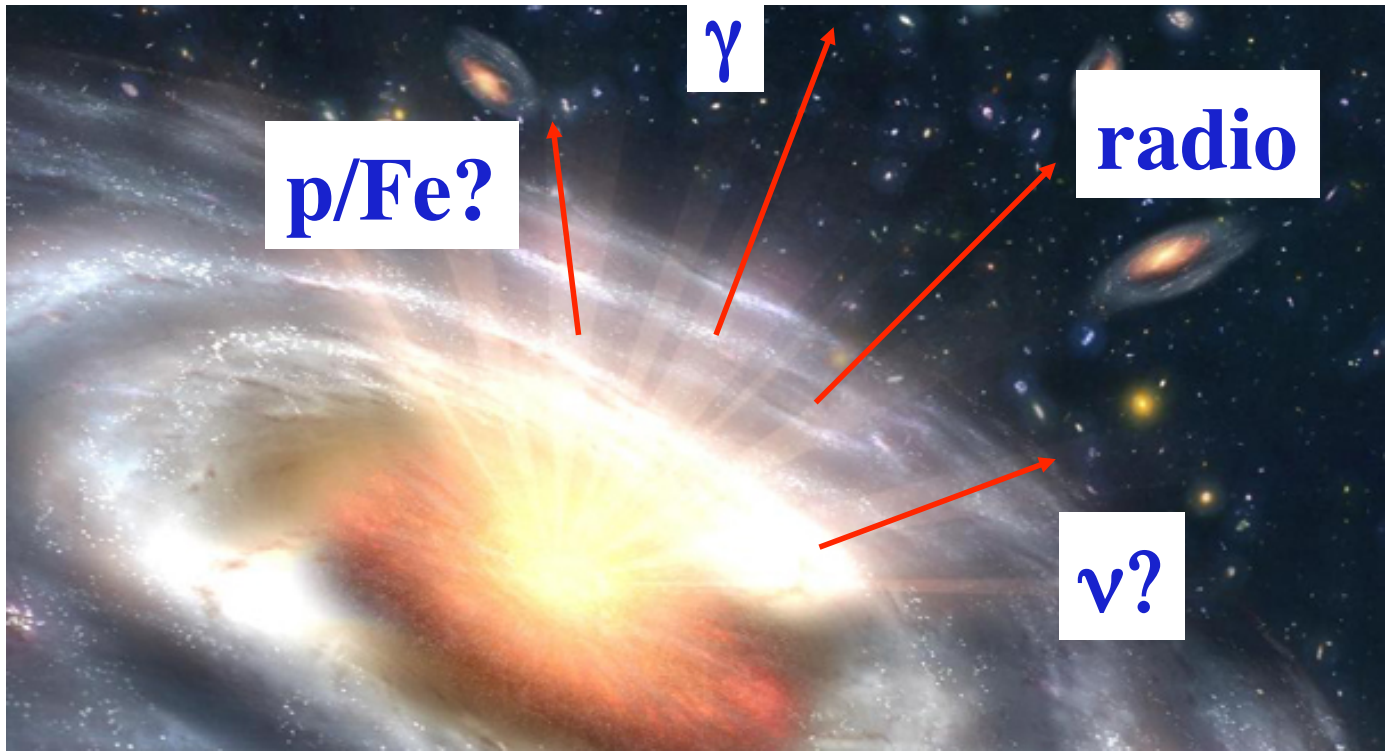
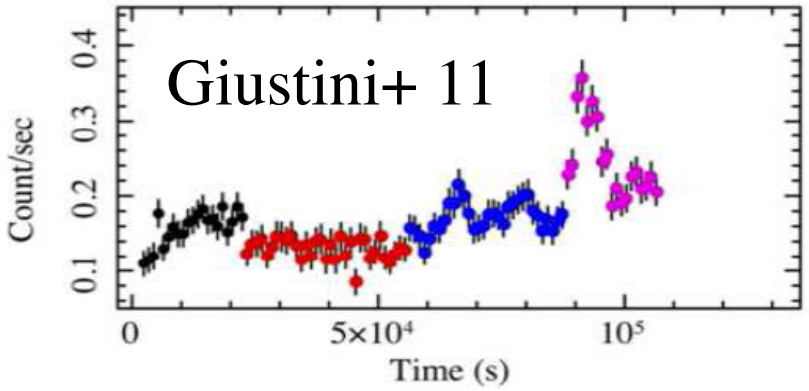
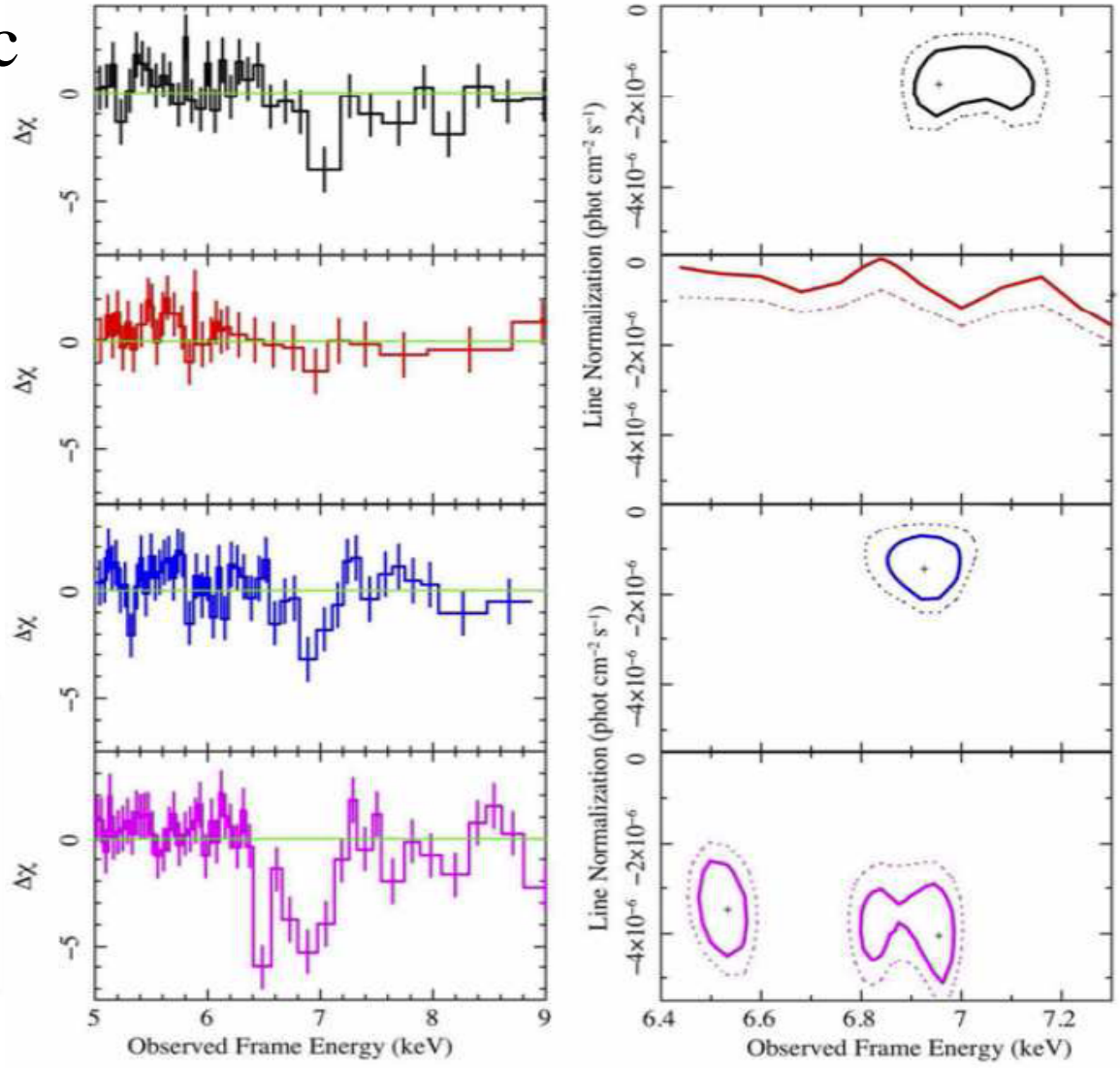


ultra-fast outflows (UFOs) in AGN

blue-shifted X-ray absorption lines

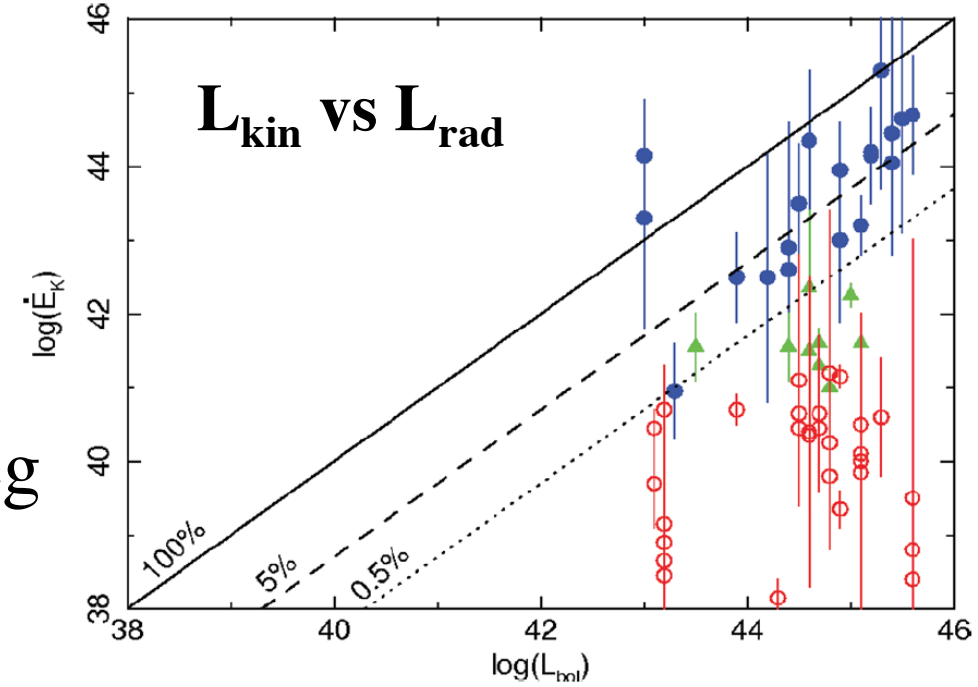
- ~40 % of all AGNs
  both radio-quiet/radio-loud
- fast outflow: v~0.05-0.3c
- highly ionized:
  Fe XXV/XXVI
  ξ_{ion}~10^3-10^6 erg s^{-1} cm
- high column density:
  N_H~10^{22}-10^{24} cm^{-2}
- variable: t_{var}>~ks





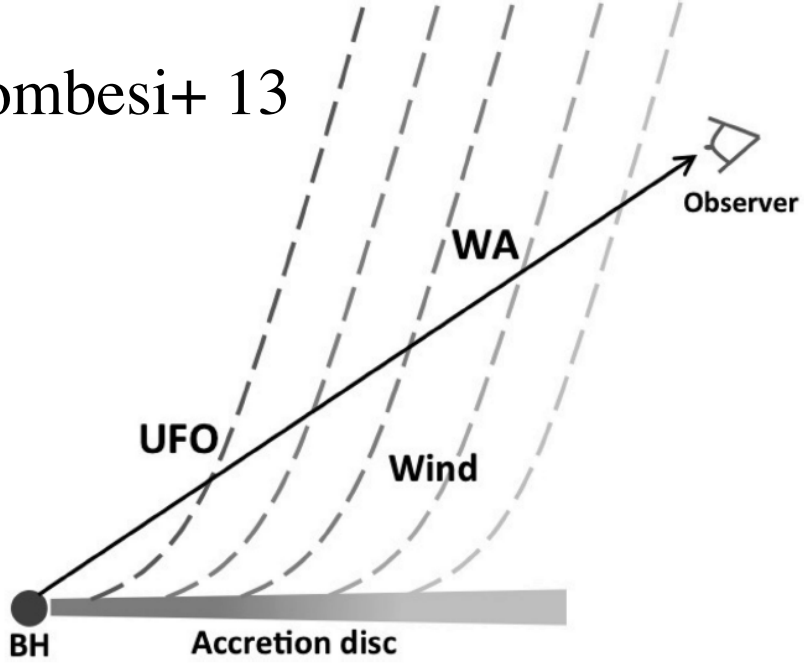
ultra-fast outflows (UFOs) in AGN

- R~0.0003-0.03 pc
  (~10-10^4 R_g)
- M~0.01-1 $\dot{M}_{sun}$/yr
  L_{kin}~0.01-1 L_{Edd}
- broad opening angle ~<100 deg
- independent of relativistic jet



accretion disk winds

Tombesi+ 13



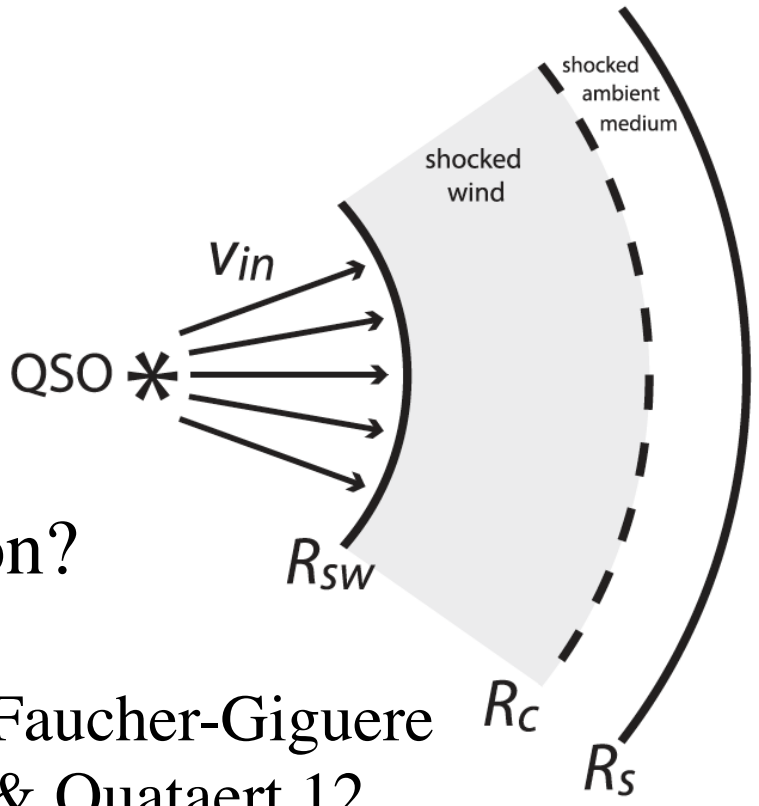
formation mechanisms:
thermal?
radiation (continuum or line)?
magnetic?
hybrid (thermal+radiation,
radiation+magnetic)?...

collisionless shocks in AGN winds

external shocks

$R_{sh,ex}$~0.1pc -few kpc

- mechanical/thermal feedback on host galaxy gas
  -> origin of M_{BH} - σ_{bulge} correlation?
- particle acceleration and nonthermal emission?

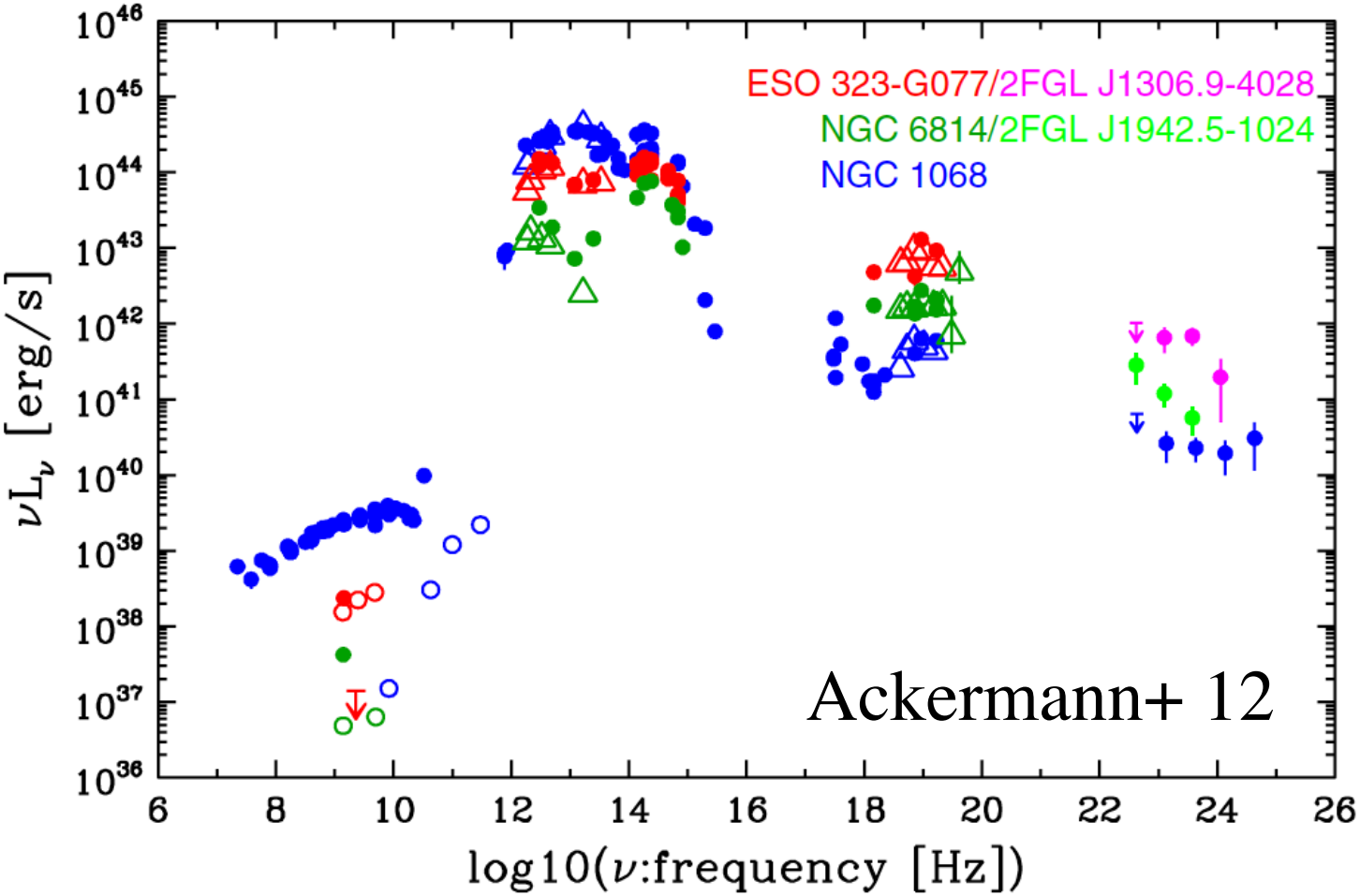


Faucher-Giguere & Quataert 12

internal shocks

observed variability of X-ray lines
-> internal inhomogeneities
-> internal shocks possible, $R_{sh,in}$~few R_g-$R_{sh,ex}$

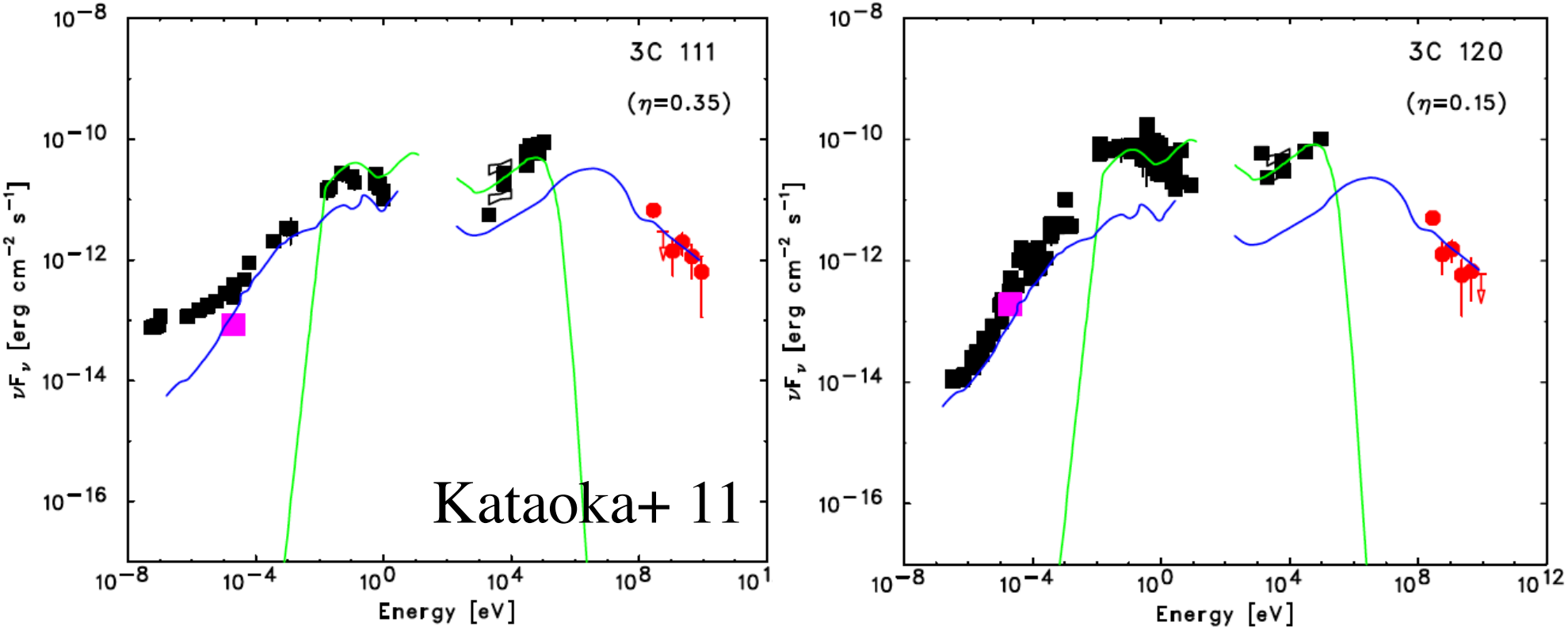
radio-quiet AGN with UFO + GeV association



ESO 323-G77: radio-quiet AGN

- known (relatively slow) UFO Tombesi+ 10,11,12
- association with Fermi source -> chance coincidence?
- correlation with Auger UHECR event Nemmen+ 10, Jiang+ 10

radio-loud AGNs with UFO + GeV association



3C 111, 3C 120: broad-line radio galaxies

- known UFOs Tombesi+ 12,14
- association with Fermi sources -> jet related?
- mixed nonthermal component in X-rays de Jong+ 12

wind shocks: electron & proton acceleration

Liu & SI
in prep.

main parameters

v_{out}, L_{nuc}: observed

$L_e, L_p < L_{kin}$: obs. constrained

R_s: few R_g- R_{bulge}

B_s ($\varepsilon_B = B^2/8\pi$ / $L_{kin}/4\pi R^2 v_{out}$)

dynamical time $t_{dyn}=R/v_{out}$, $t_{lc}=R_s/c=500$ s

acceleration time $t_{acc} \sim 10 (v_s/c)^{-2} E/ceB$

external radiation field follows Ghisellini & Tavecchio 09

accretion disk+broad line region+dusty torus

electron loss time

$t_{esyn}=3 m_e^2 c^3/4\sigma_T u_B E_e$

$t_{eIC}=3 m_e^2 c^3/4\sigma_T u_{ph} E_e$ $u_{ph} \sim u_{ext}$

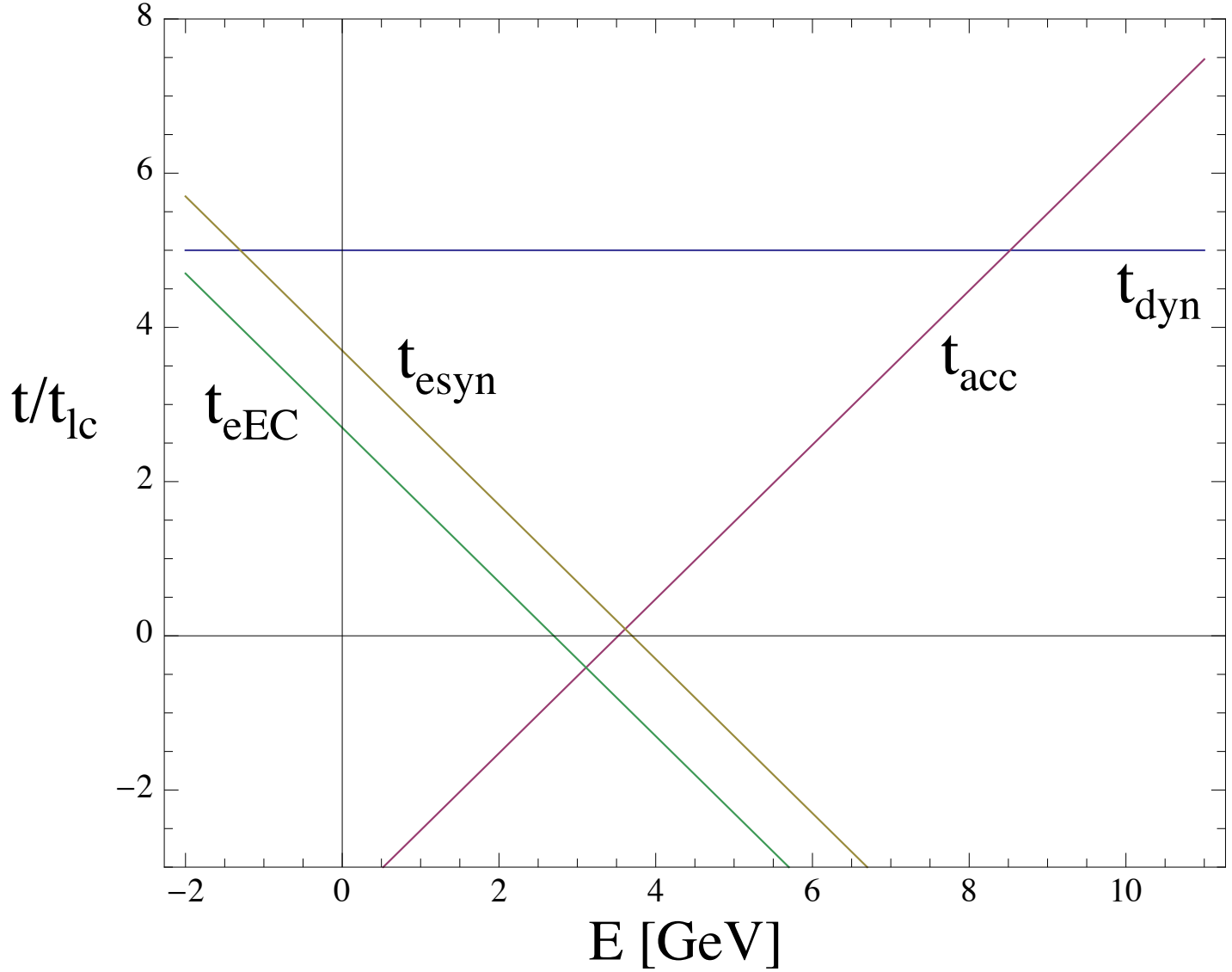
proton loss time

$t_{pp}=(\kappa_{pp}\sigma_{pp}n_p c)^{-1}$

$t_{p\gamma} \propto \int \kappa_{p\gamma}(x)\sigma_{p\gamma}(x) x\, dx \int n_{ph}(x)dx)^{-1}$ $x=h\nu/m_e c^2$

acceleration vs. cooling

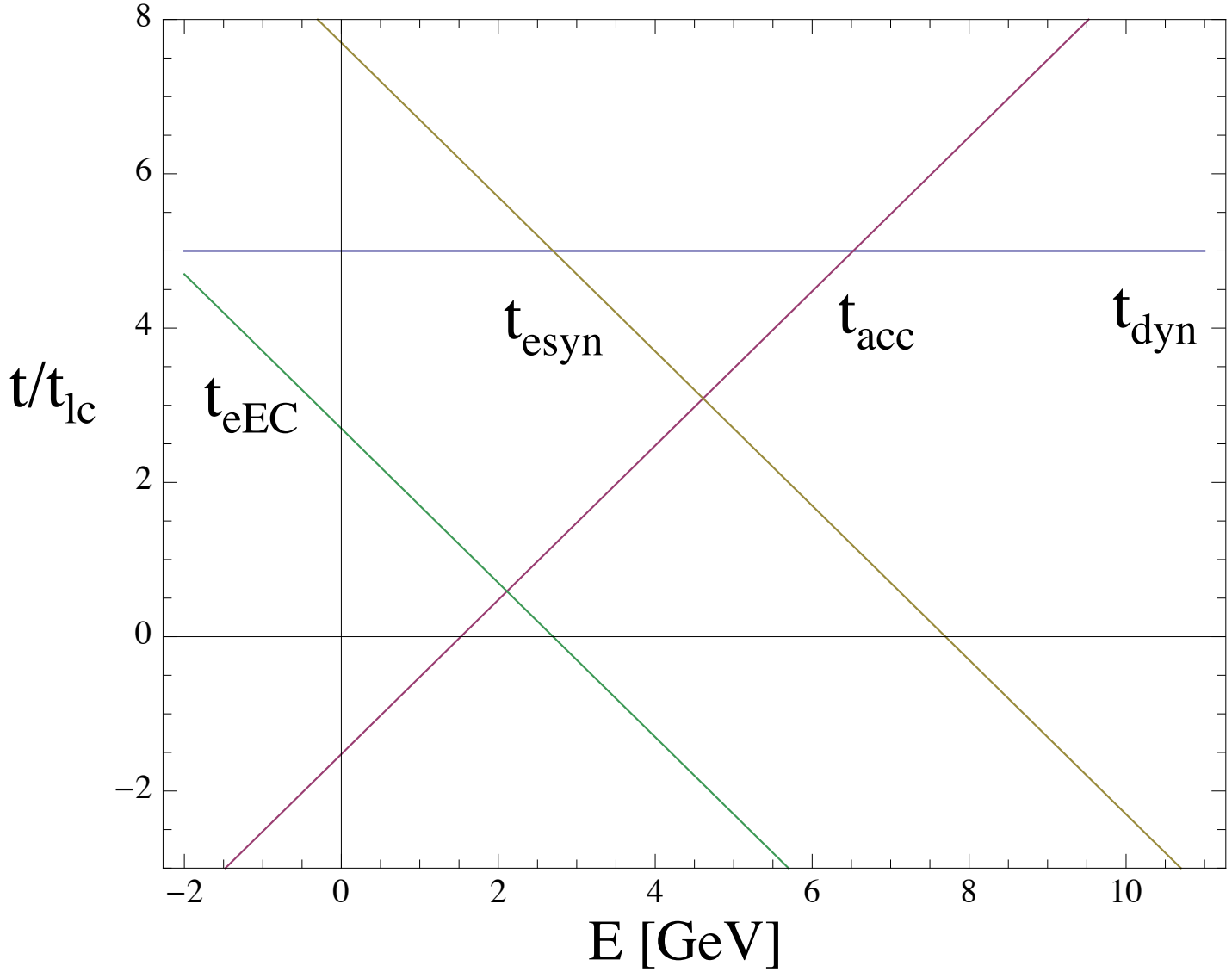
v_{out}=0.1c, L_{kin}=10^{45} erg/s
R_s=0.1 pc, B_s~3G(ε_B~1) -> n_p~5x10^3 cm^{-3}



electrons up to ~1 TeV, cooling for ~<10 MeV NB: γγ
protons up to ~3x10^{18} eV (Fe up to ~10^{20} eV)

acceleration vs. cooling

v_{out}=0.1c, L_{kin}=10^{45} erg/s
R_s=0.1 pc, B_s~0.03 G(ε_B~10^{-4})

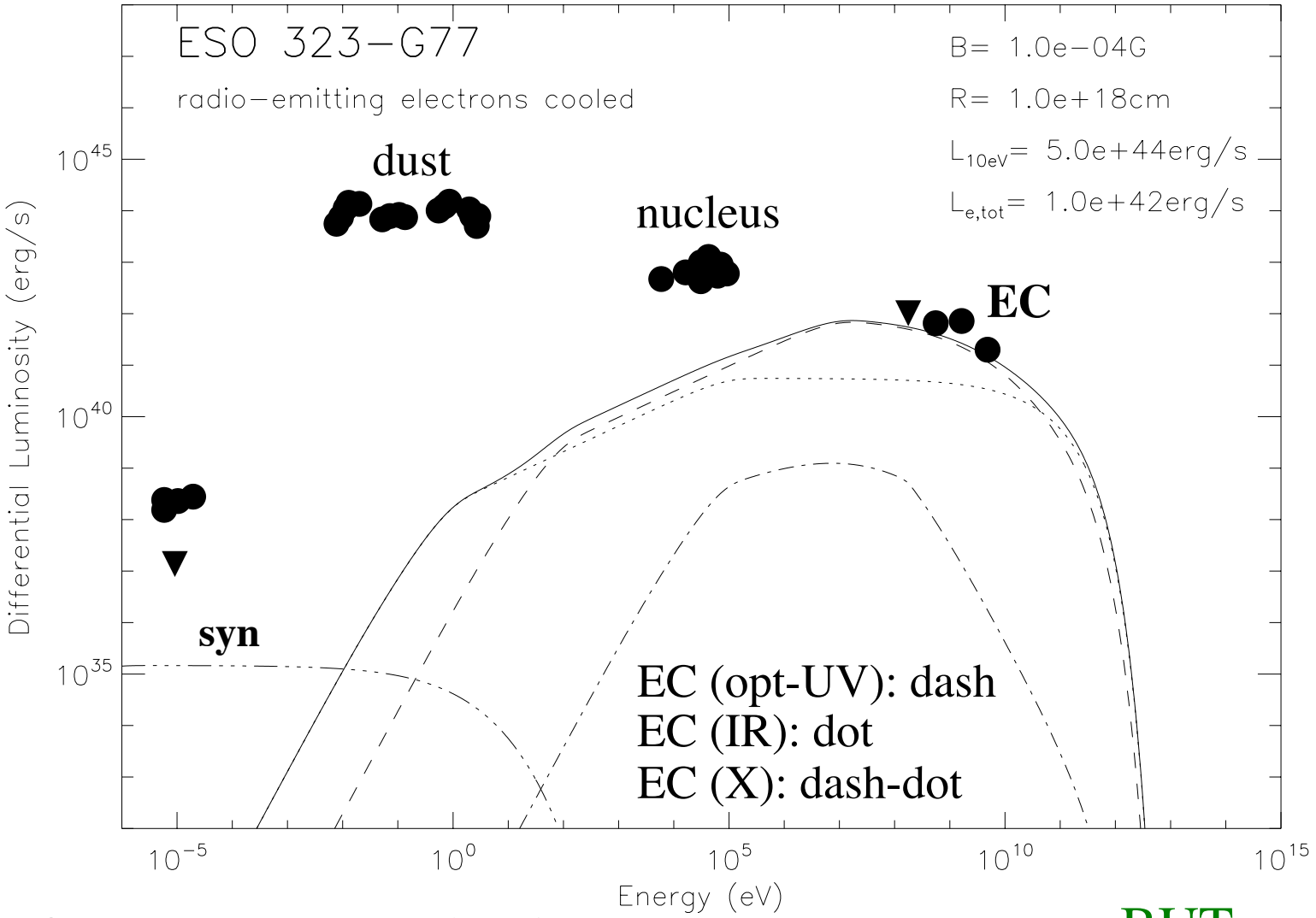


electrons up to ~100 GeV, cooling for ~<10 MeV NB: γγ
protons up to ~3x10^{16} eV (Fe up to ~10^{18} eV)

model results R=0.3 pc, B=10^{-4} G

ESO 323-G77

$L_e=10^{42}$, $L_{nuc}=5x10^{44}$ erg/s ($L_{kin}=10^{41.4-42.9}$) radio-quiet



EC of opt+UV (BLR) dominant

GeV steepening by KN effects (possibly also γγ)

necessary L_e rather high?

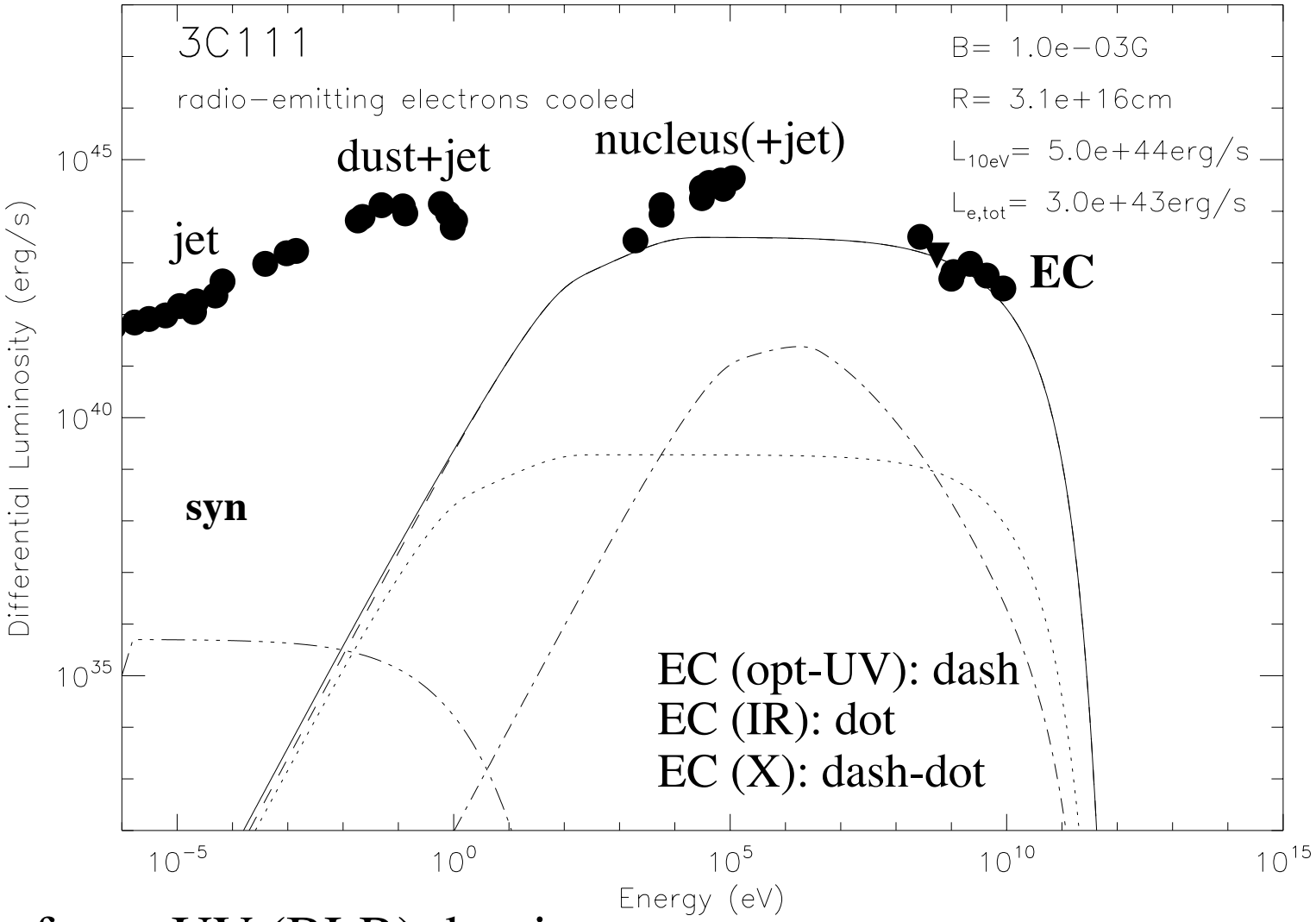
BUT

no GeV signal in 3FGL…

model results R=0.01 pc, B=10^{-3} G

L_e=3x10^{43}, L_{nuc}=5x10^{44} erg/s L_{kin}=?

3C111
radio-loud



EC of opt+UV (BLR) dominant

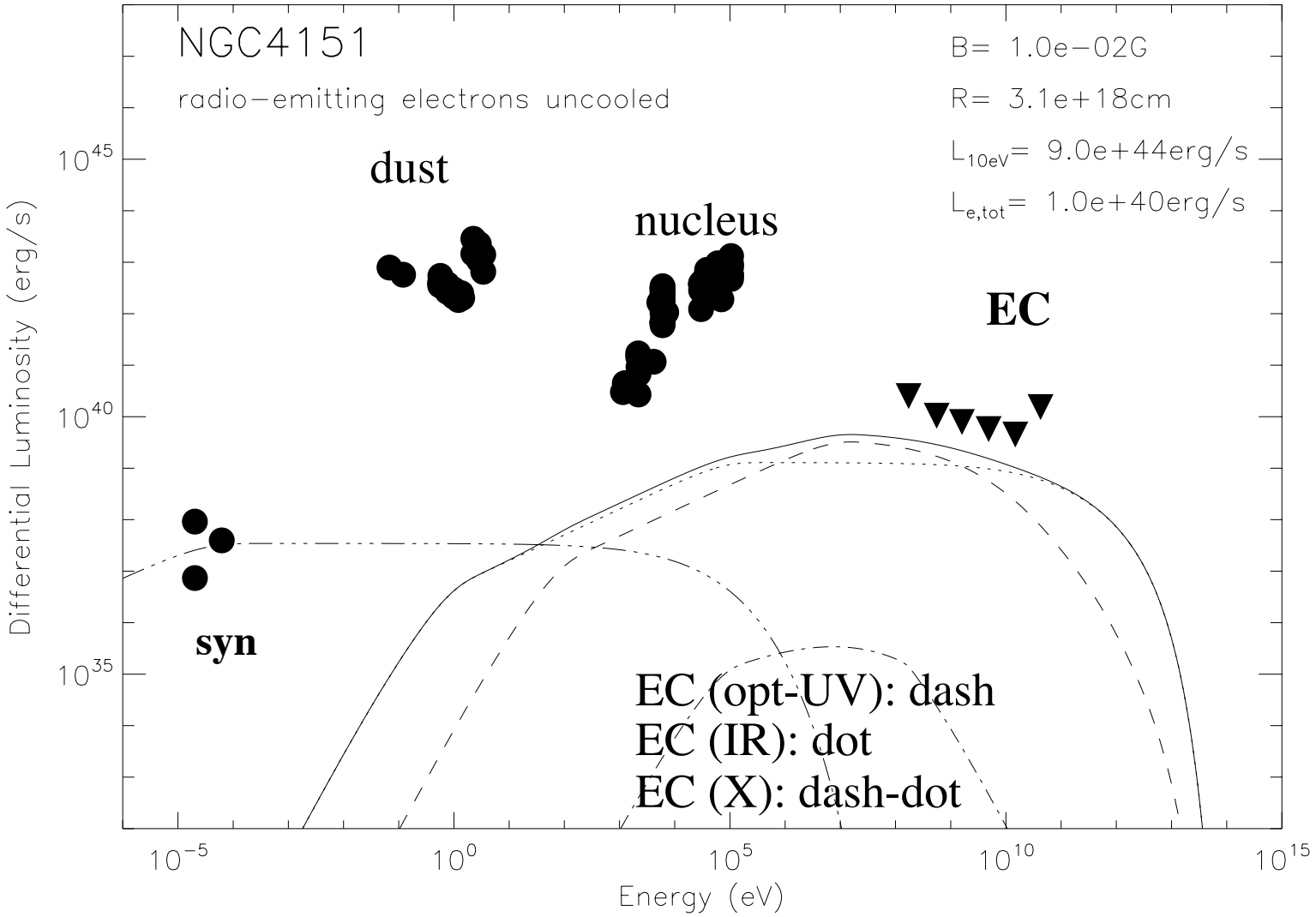
non-negligible contribution to X-rays possible c.f. de Jong+12

necessary L_e rather high?

model results R=1 pc, B>=0.01 G

NGC 4151

$L_e=10^{40}$, $L_{nuc}=9x10^{44}$ erg/s ($L_{kin}=10^{41.9\text{-}43.6}$) radio-quiet



GeV upper limits from Tomono, Hayashida, SI+, in prep.,

IF observed radio sync. from electrons in UFOs -> B>~0.01 G at R~1pc

-> ε_B~0.03-1.7, suggest B-driven wind?

summary AGN winds as accelerators/nonthermal emitters

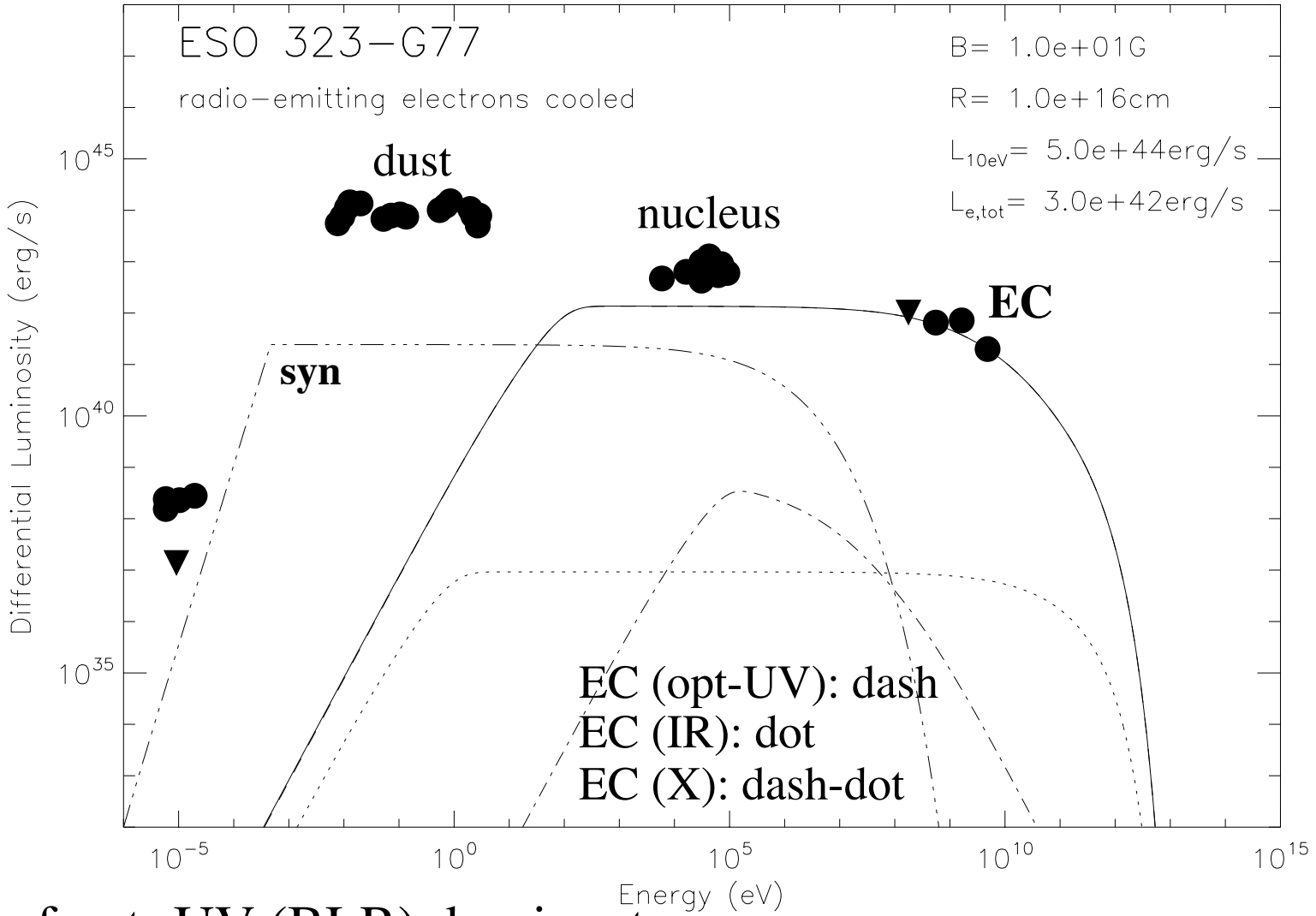
- widespread existence of powerful, mildly relativistic baryonic outflows in AGN, independent of relativistic jets
- collisionless external or internal shocks potential acceleration site of electrons and hadrons
- electron synchrotron may account for the radio emission of some radio-quiet AGN with (U)FOs
- external inverse Compton may explain the gamma rays (+X-rays in some objects) from nonblazar AGN with (U)FOs and GeV associations such as ESO 323-G77, 3C 111, 3C 120
- lower limits on B fields in winds can be derived for objects with GeV upper limits, e.g. NGC 4151, IF their radio flux is associated synchrotron -> suggest B-driven wind?

- prospects for UHECRs (+PeV neutrinos)
  -> talk in next UHE session

model results R=0.003 pc, high B=10 G

ESO 323-G77
radio-quiet

$L_e=3x10^{42}$, $L_{nuc}=5x10^{44}$ erg/s ($L_{kin}=10^{41.4-42.9}$)



EC of opt+UV (BLR) dominant

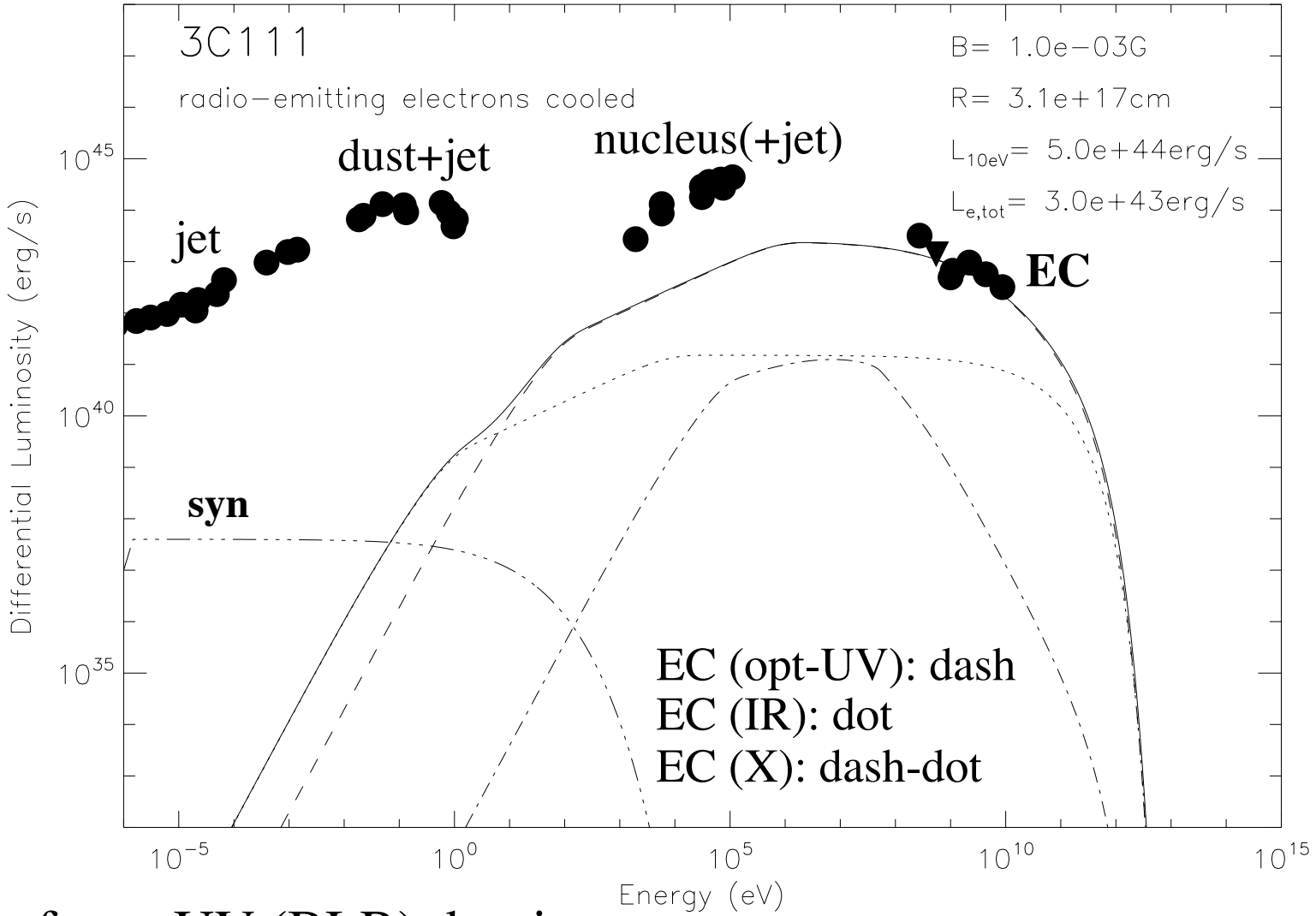
synchrotron high >~100 GHz but low ~GHz due to self absorption

may allow UHECR acceleration with Fe

model results R=0.1 pc, $B=10^{-3}$ G

$L_e=3\times10^{43}$, $L_{nuc}=5\times10^{44}$ erg/s

3C111
radio-loud



EC of opt+UV (BLR) dominant

necessary L_e rather high?