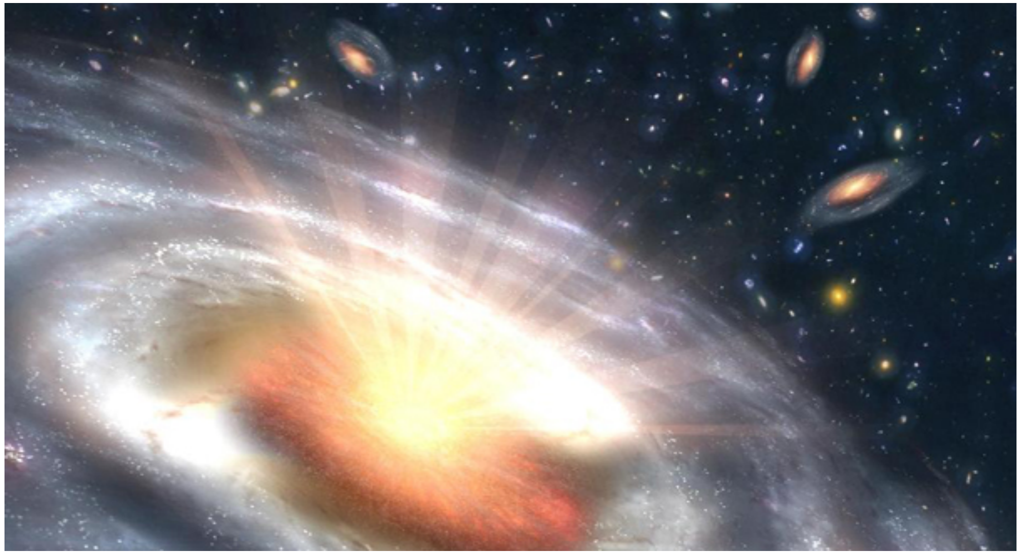
Fast winds in active galactic nuclei as sources of ultra-high-energy cosmic rays

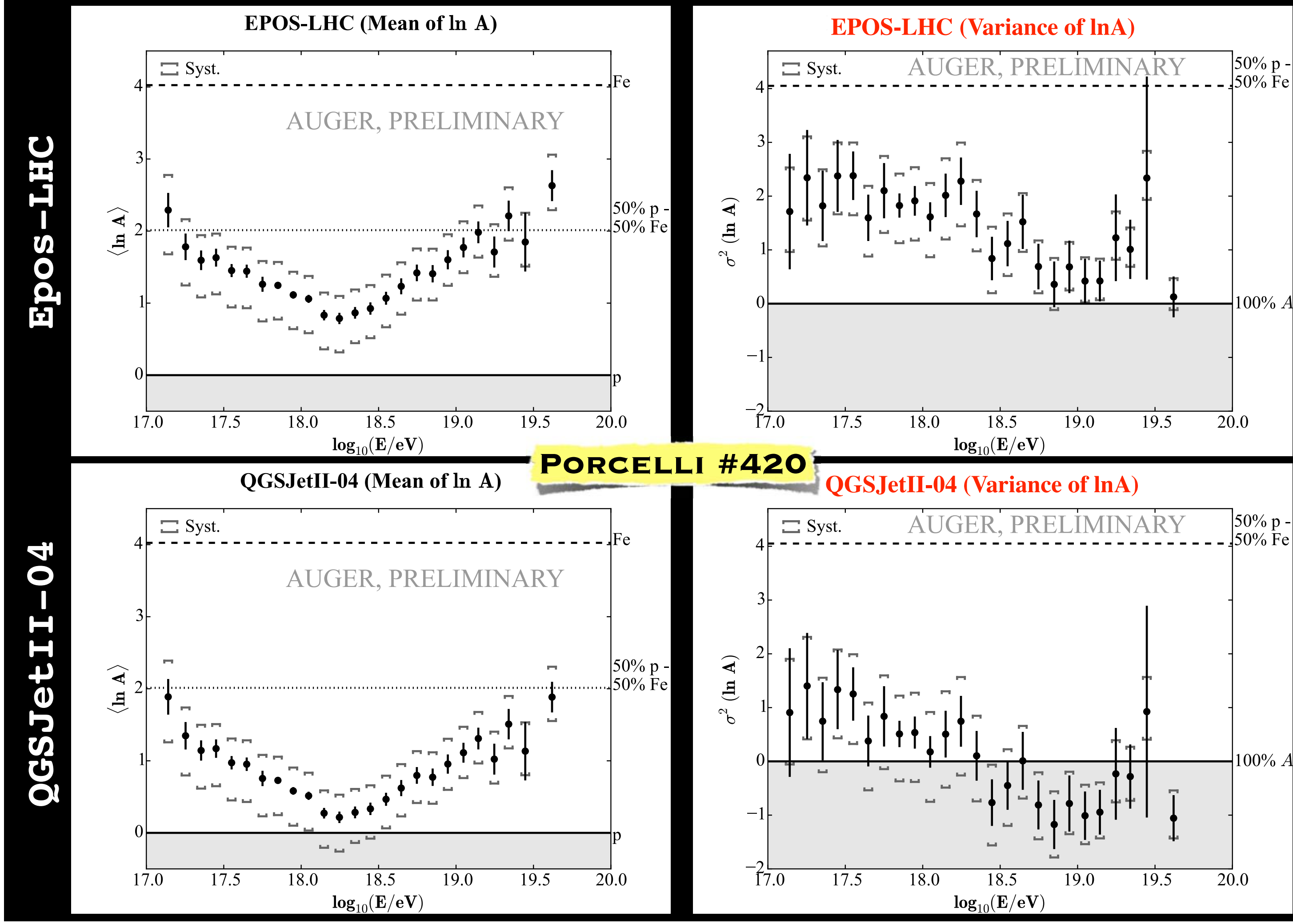
Susumu Inoue (RIKEN), Ruo-Yu Liu (MPIK)
Kohta Murase (Penn State)

The answer, my friend, is…



composition: Auger, ICRC 2015 highlight talk by Piera Ghia

From the depth of shower maximum to primary mass (lnA)



Similar trend for both models:

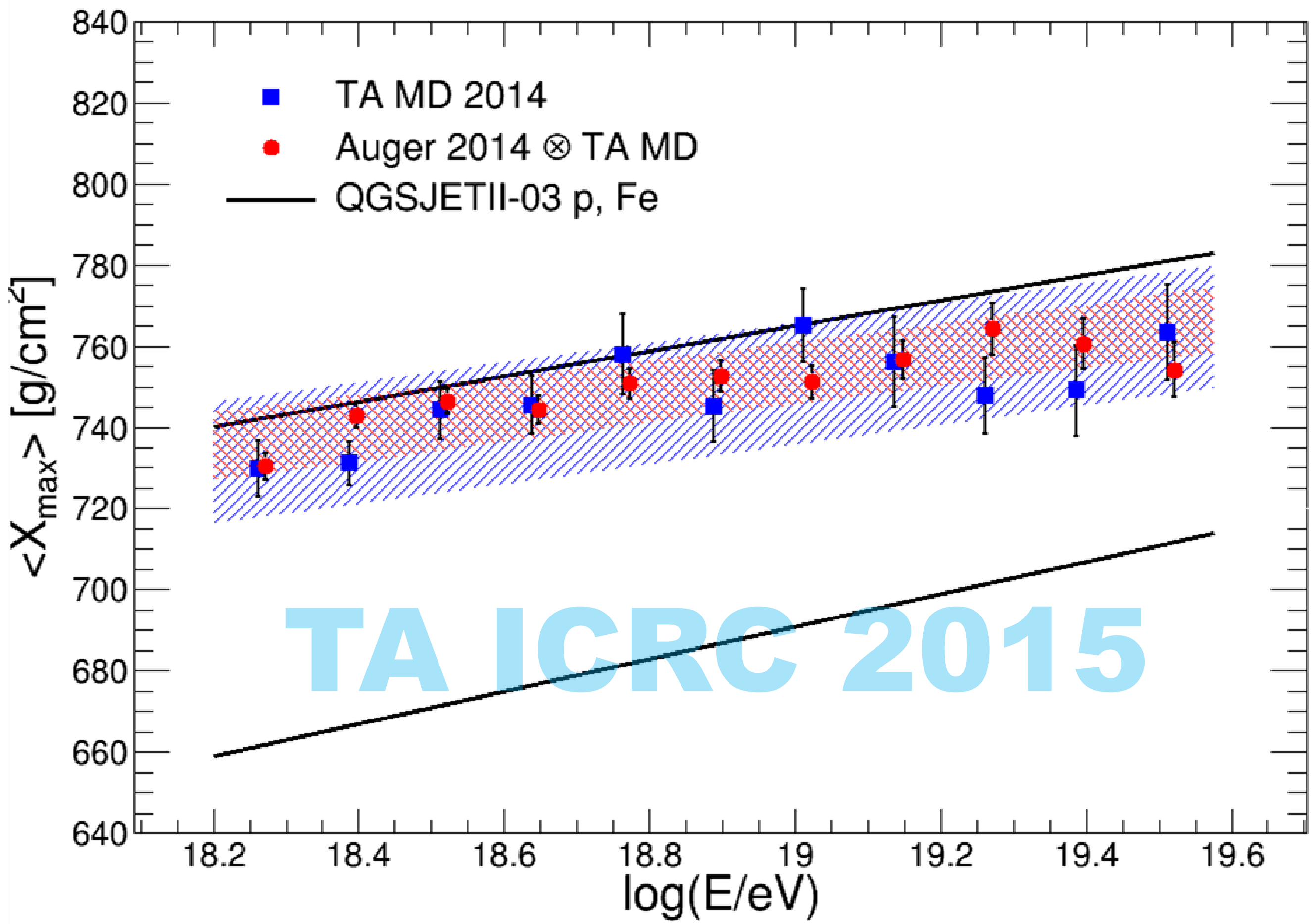
heavier composition at low energies (largest mass dispersion), lightest one at ≈ 2×10^{18} eV, getting heavier again towards higher energies (smaller mass dispersion)

[N.B: very few data above ≈ 40 EeV)

Not only inferences on mass but test of models too
The conversion to σ^2(lnA) through QGSJETII-04 yields unphysical results

composition: TA, ICRC 2015 highlight talk by Charlie Jui

Meta-analysis: Composition WG



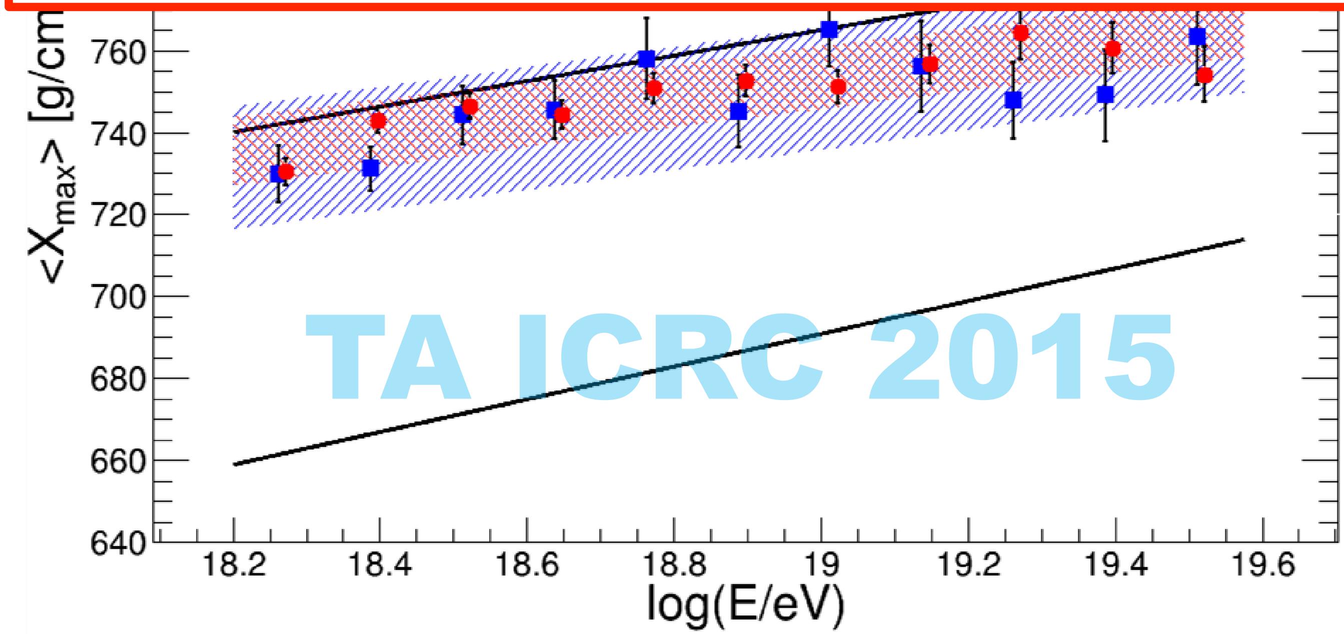
[618 - PoS 307]
Parallel CR07 EAS mass
Track: CREX, Presented by
Michael UNGER
on 31 Jul 2015 at 14:00
Unger et al, PoS 307

TA data cannot distinguish between mix and QGSJETII-03 protons at this level of systematic uncertainty.

composition: TA, ICRC 2015 highlight talk by Charlie Jui

“The TA measurements, dare I say it, is consistent with a light composition.”

「信じてもらえないかもしれないが、TAの測定値は軽い組成と無矛盾、と言っておこう。」



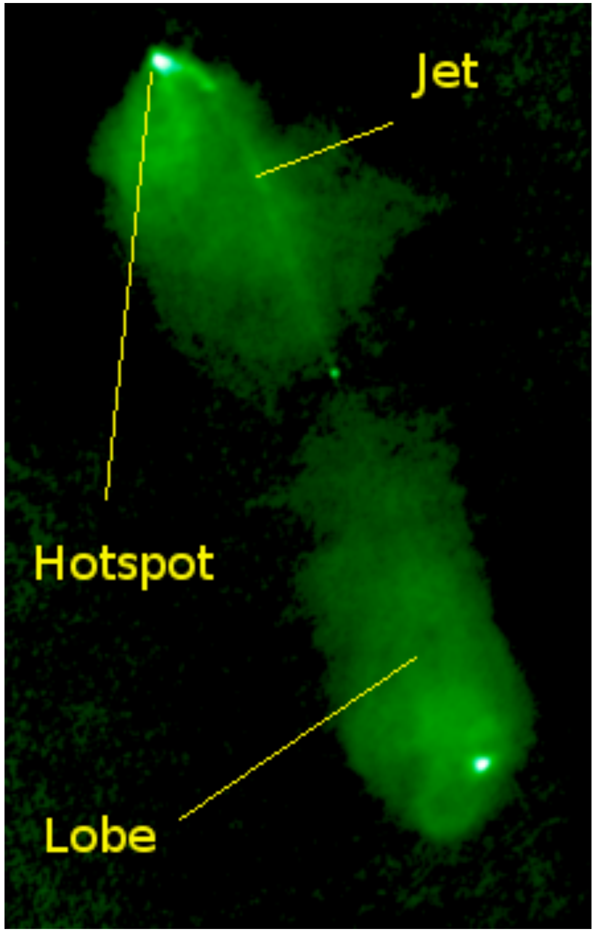
TA data cannot distinguish between mix and QGSJETII-03 protons at this level of systematic uncertainty.

TA, ICRC 2015

AGN jets as UHECR sources

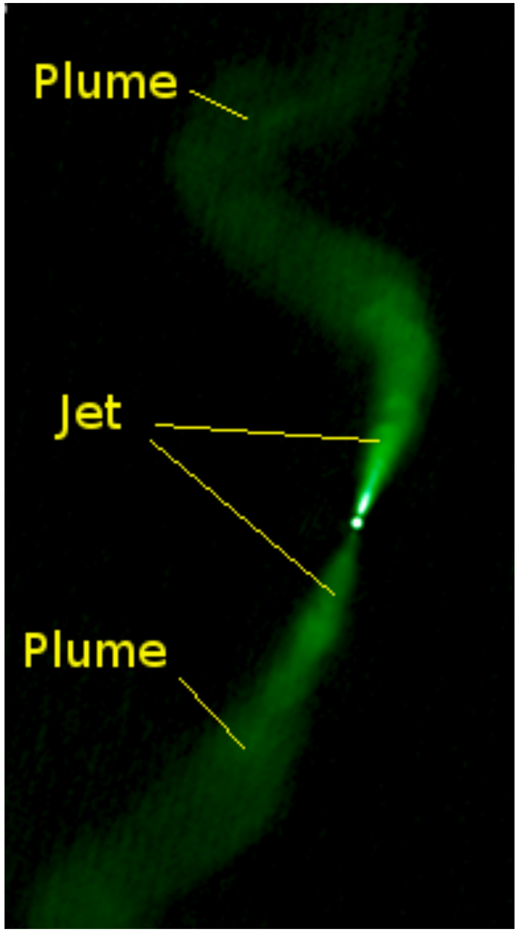
high-power (FR 2) objects

hot spot: clear accel. site BUT
too few <1 within D~<100 Mpc
non-proton composition?



low-power (FR 1) objects

relatively numerous BUT
accel. site?
inner jet-> low B? escape?
non-proton composition?

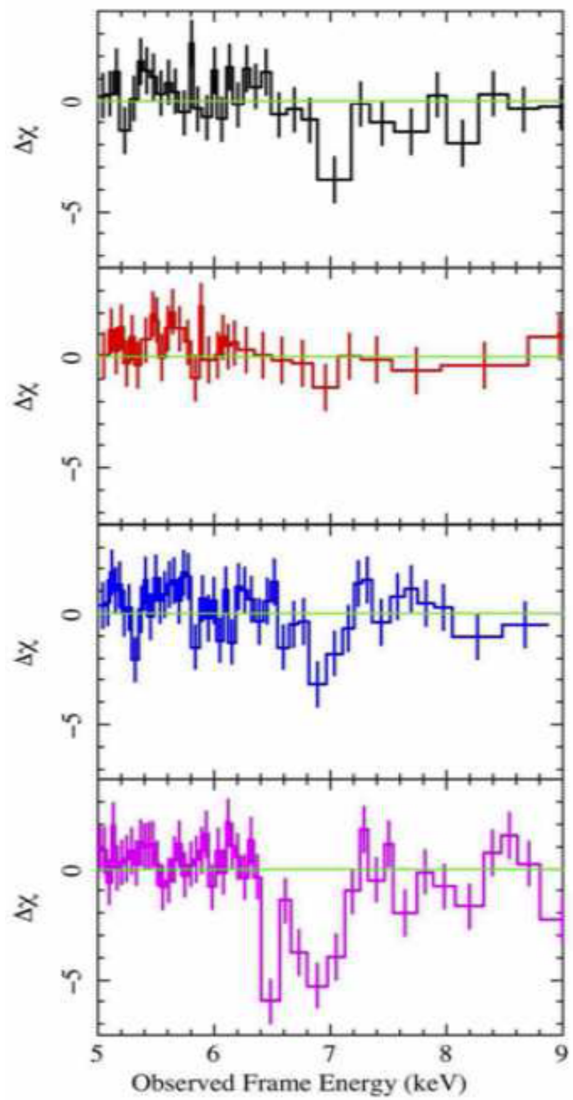


ultra-fast outflows (UFOs) in AGN

blue-shifted X-ray absorption lines

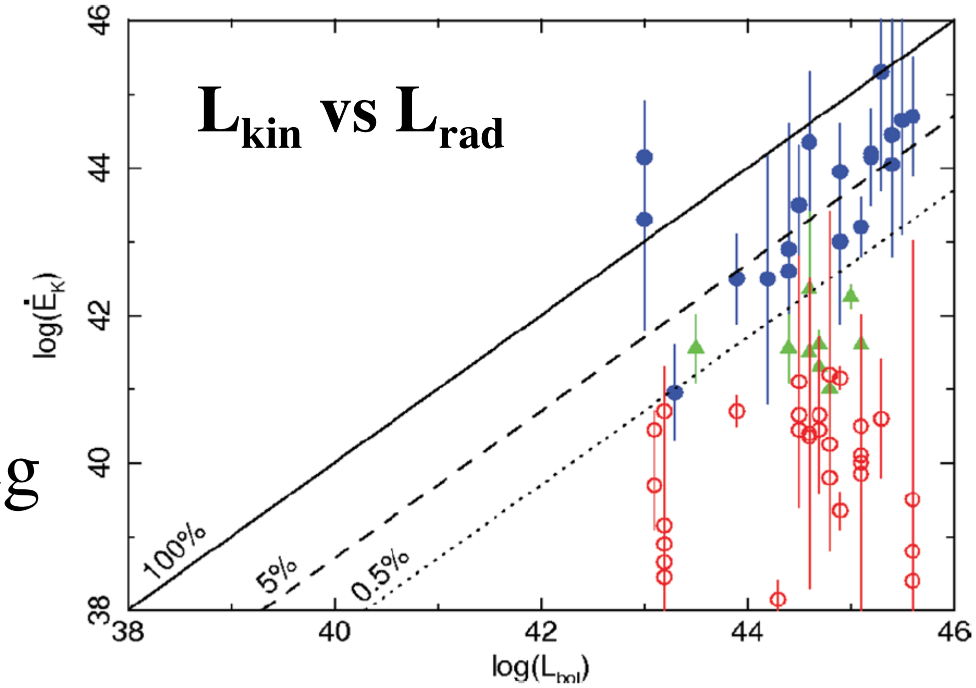
- ~40 % of all AGNs
  both radio-quiet/radio-loud
- fast outflow: v~0.05-0.3c
- highly ionized:
  Fe XXV/XXVI
  ξ_{ion}~10^3-10^6 erg s^{-1} cm
- high column density:
  N_H~10^{22}-10^{24} cm^{-2}
- variable: t_{var}>~ks

Giustini+ 11



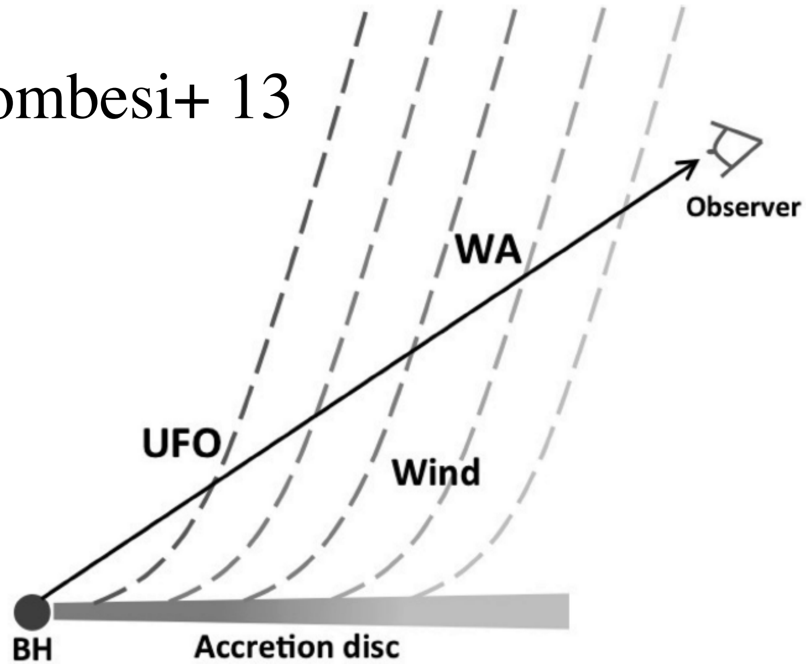
ultra-fast outflows (UFOs) in AGN

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



accretion disk winds

Tombesi+ 13



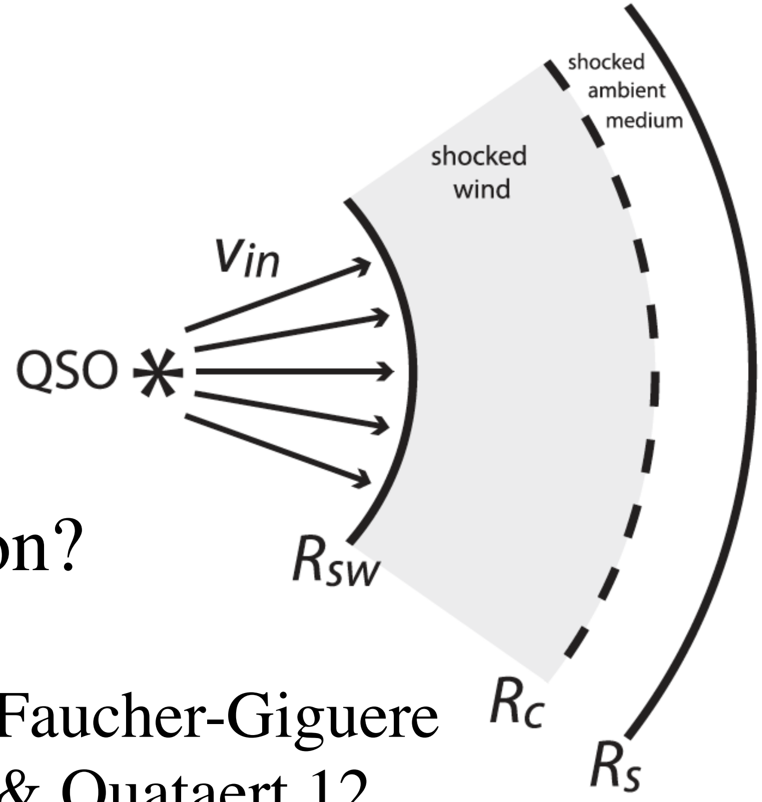
formation mechanisms:
thermal?
radiation (continuum or line)?
magnetic?
hybrid (thermal+radiation,
  radiation+magnetic)?...

collisionless shocks in AGN winds

external shocks

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

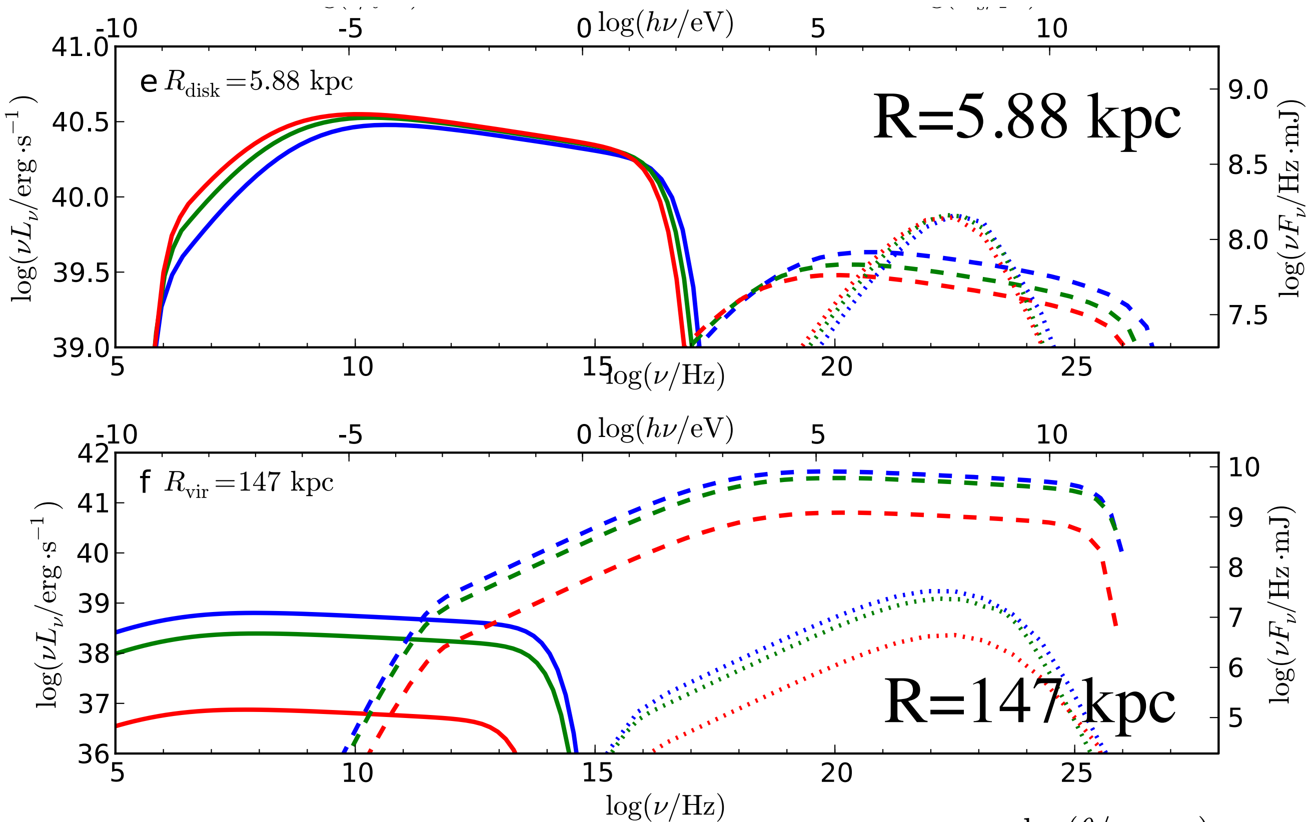
- mechanical/thermal feedback on host galaxy gas
  -> origin of M_{BH} - σ_{bulge} correlation?
- particle acceleration and nonthermal emission?

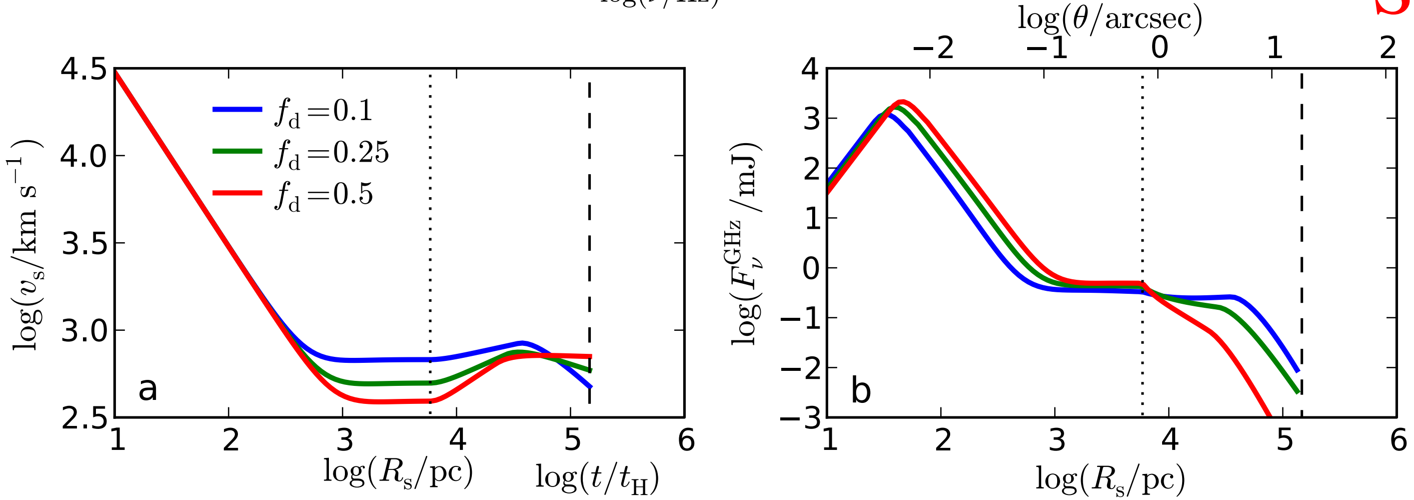


Faucher-Giguere & Quataert 12

observable signature of AGN wind external shock

Wang & Loeb 15 also Nims+ 15





radio, X-ray observable by future facilities
->
probe of SMBH feedback in action

->
UHECRs as consequence of SMBH feedback?

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}

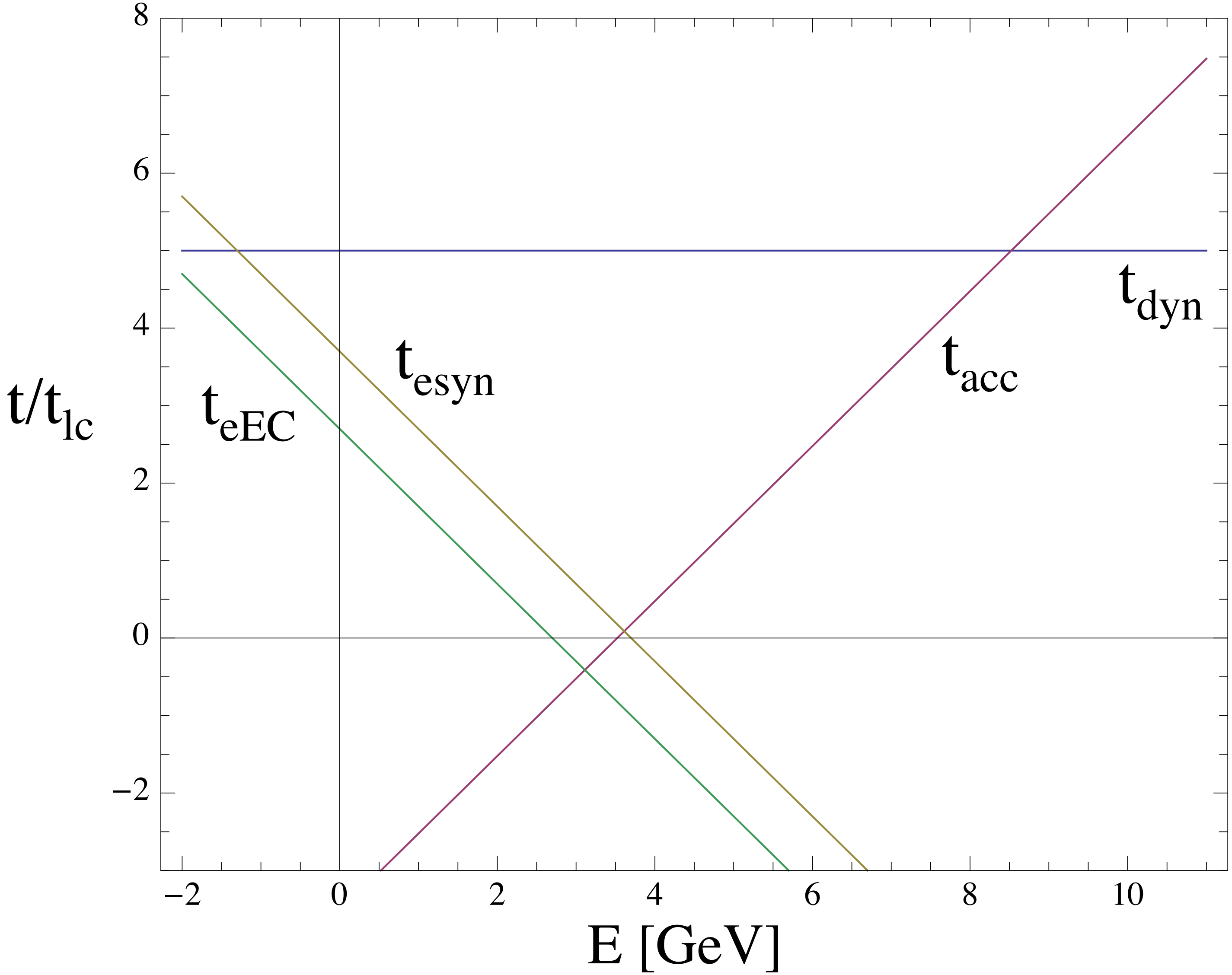
B_s ($\varepsilon_B = B^2/8\pi \,/\, L_{kin}/4\pi R^2 v_{out}$)

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

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

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}

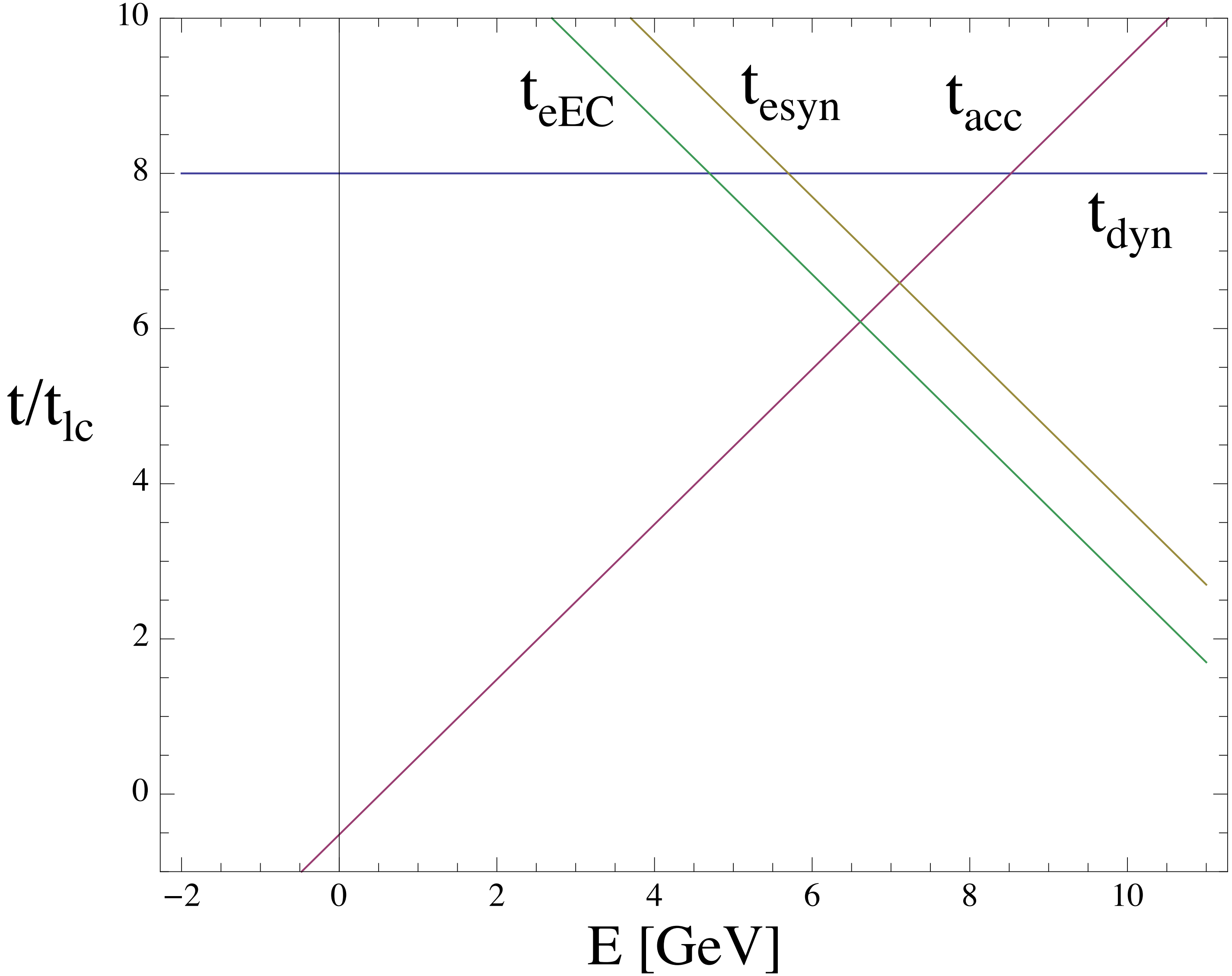


electrons up to ~1 TeV, cooling for ~<10 MeV NB: γγ
protons up to ~3x10^{18} eV, Fe up to ~10^{20} eV

acceleration vs. cooling

v_{out}=0.01c, L_{kin}=10^{45} erg/s

R_s=100 pc, B_s~3mG(ε_B~1)

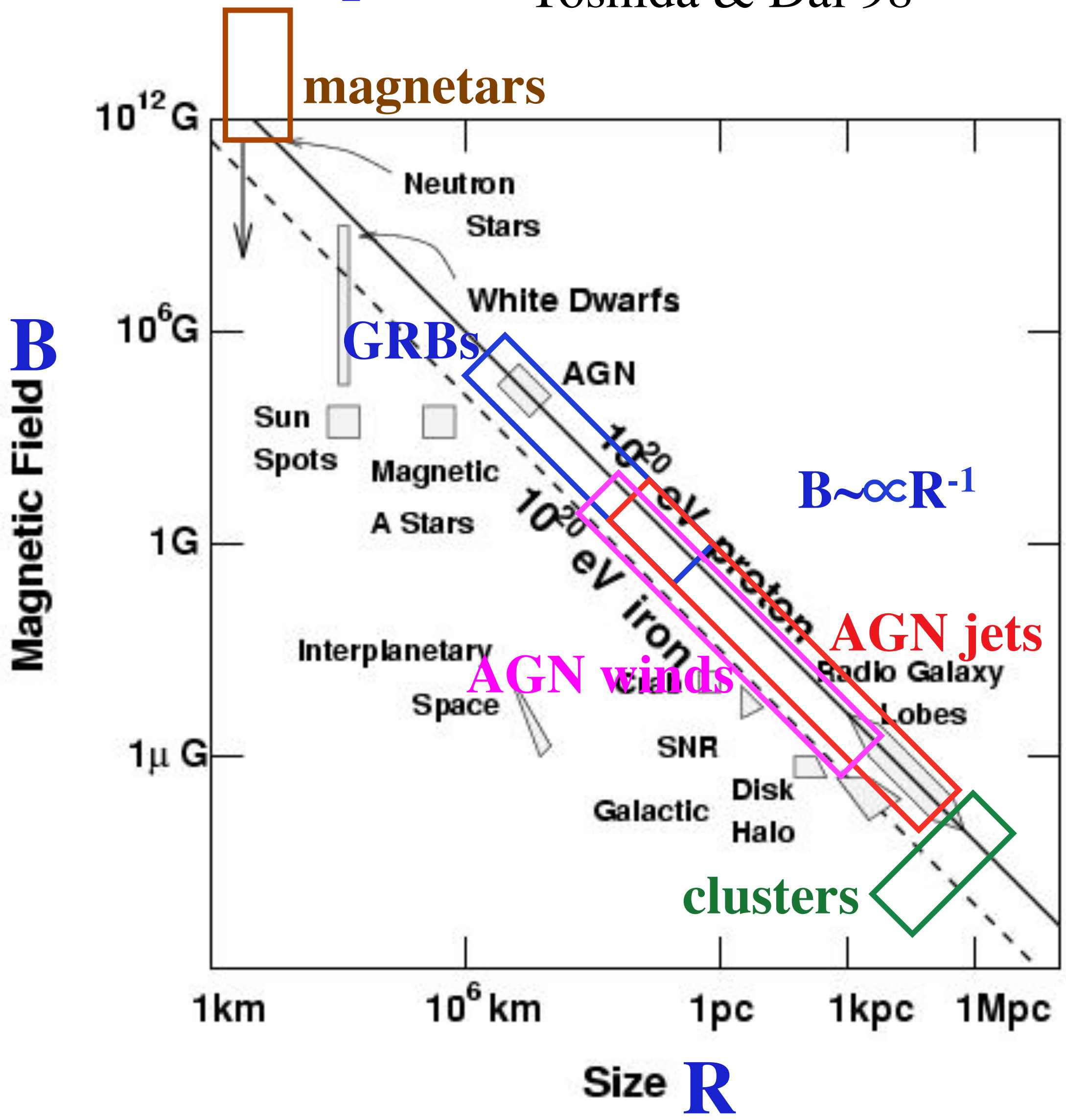


protons up to ~3x10^{18} eV (Fe up to ~10^{20} eV)

(electrons up to ~PeV)

UHECR sources: acceleration

“Hillas plot” adapted from Yoshida & Dai 98



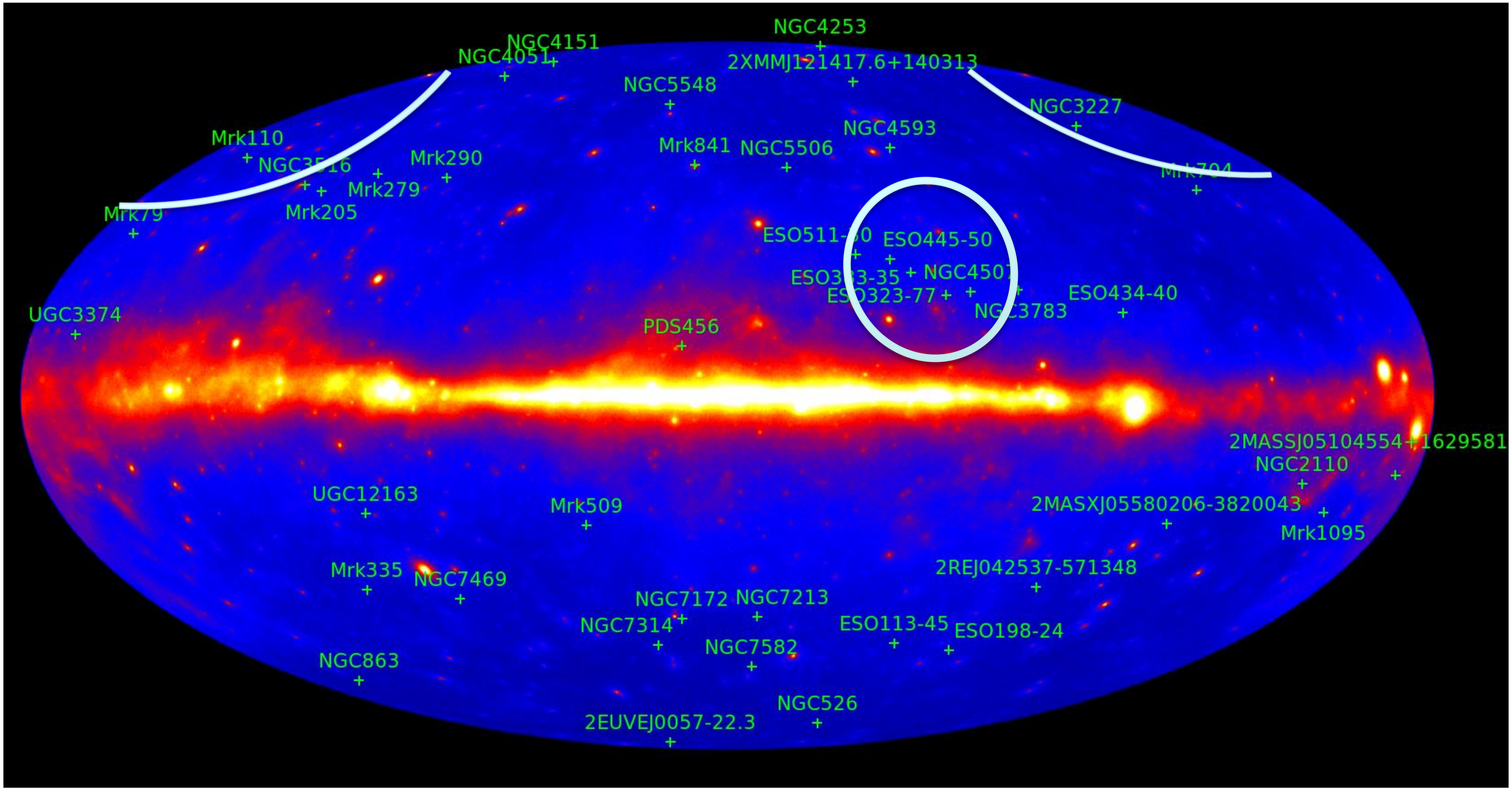
$E \leqq Ze\,B\,R\,(v/c)$

confinement

E_{max} acceleration vs:

escape
source lifetime
adiab. expansion loss
radiative loss

UFO AGN skymap



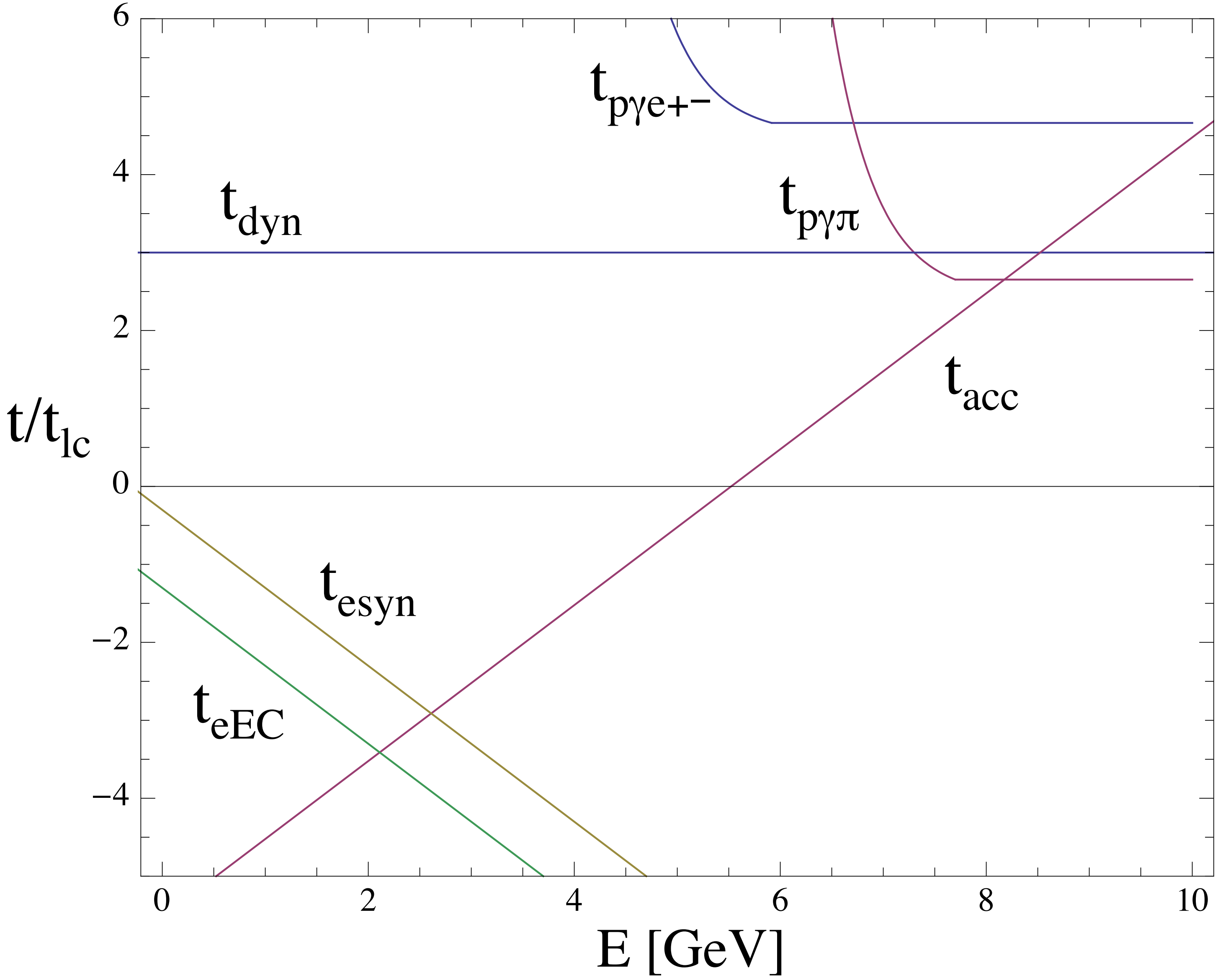
NB: far from a uniform sample of such objects

summary AGN winds as UHECR sources

- widespread existence of powerful, mildly relativistic baryonic(ionic) outflows in AGN, independent of rel. jets
- collisionless external shocks
  "action site" of SMBH feedback onto host galaxies
  potential particle acceleration site
- potential sources of UHECRs
  - acceleration OK IF B~Beq
  - number, energetics OK
  - guaranteed Fe composition
  - direct consequence of SMBH feedback

- more detailed modeling in progress
- potential PeV neutrino sources if internal shocks occur near nucleus (~wind launching site)

acceleration vs. cooling R=0.001 pc -> B_{eq}~300 G, n_p~5x10^7 cm^{-3}



electrons only to ~100MeV NB: internal photons, γγ

protons up to ~10^{16} eV, limited by photomeson -> ν,n emission

potential consequences of near-nucleus pγ interactions

no UHECRs, no GeV-TeV emission but:
- non-thermal X/MeV emission
- TeV-PeV neutrino emission <-> IceCube results
  -> broad-line region from neutrino-heated stars?
- TeV-PeV neutron injection
  -> decay back to protons within 1-100 pc, CR-driven wind?
  -> mass loading of jets?

revival of "old ideas"
(but with more concrete prospects for proton acceleration)

Kazanas & Protheroe 83, Zdziarski 86, Sikora+87, Rudak+ 89, Begelman+ 90
Mannheim & Biermann 89, Stecker+ 91, Atoyan 92, Szabo & Protheroe 92…