Search for gamma-ray emission from AGNs with (ultra-)fast outflows as candidate cosmic-ray accelerators

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Ultra-fast outflows (UFOs)

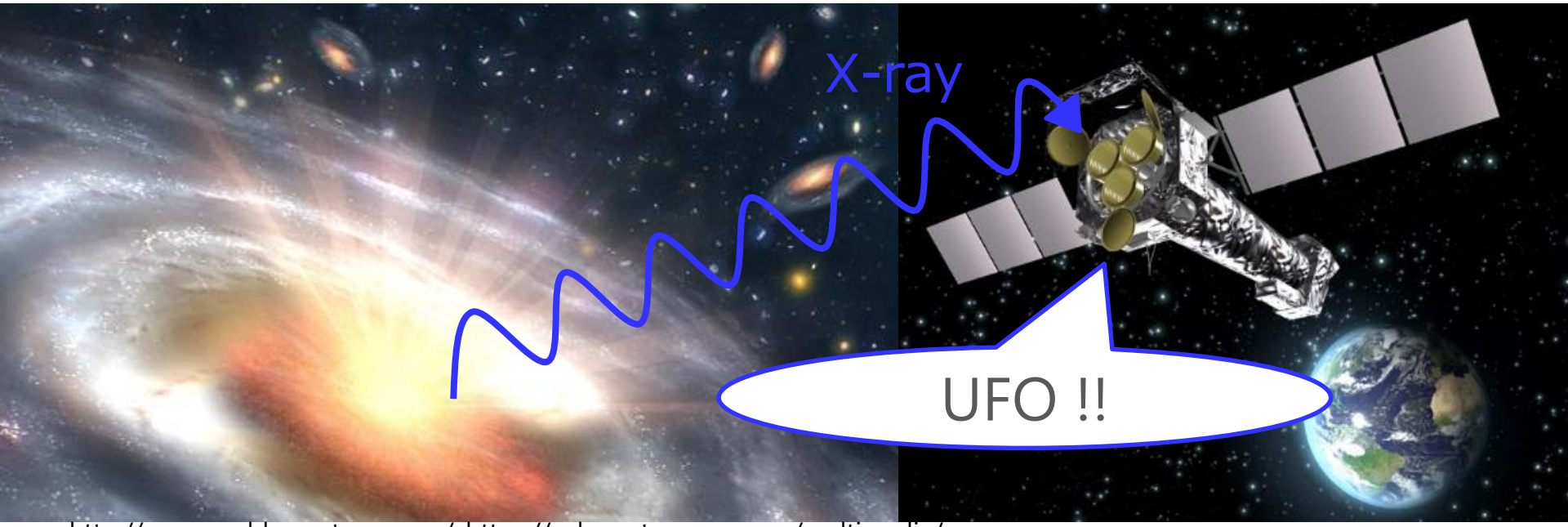
UFOs have been found in X-ray observations

– Identified by blue-shifted Fe K absorption lines e.g. Tombesi+ 2010

- Outflow velocities are v_{out}>10,000 km/s (0.033 c)
- They are located near the central back hole (r~10^2-10^5 r_s)
- They have been interpreted as winds driven by the accretion disk
- ~40% AGNs may have UFOs (radio-quiet & radio-loud)

Their formation mechanism is unclear…

- They may be driven by radiation pressure or magnetic forces



http://www.worldreportnow.com/, https://solarsystem.nasa.gov/multimedia/

UFO as possible particle acceleration site ?

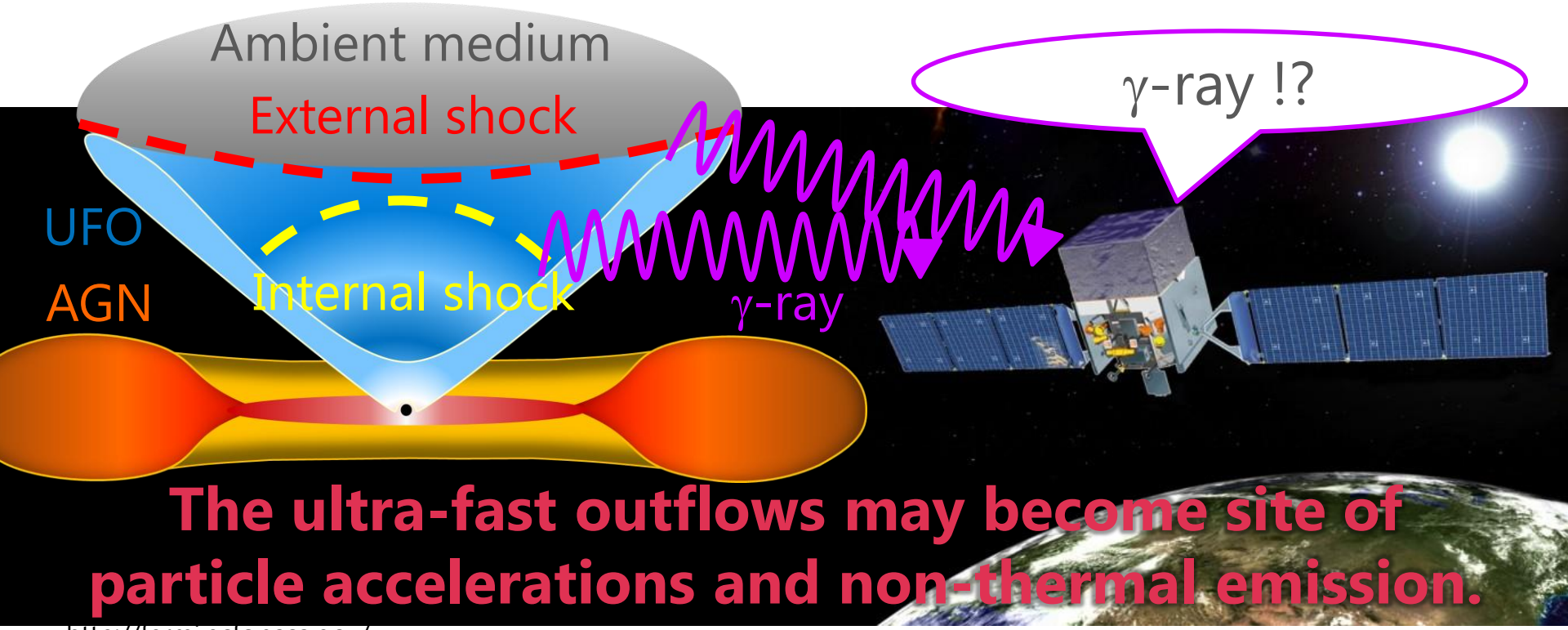
Main parameters of ultra-fast outflows :

- The mass outflow rate is $\dot{M}_{\rm out}$~10^{-4}-100 $M_\odot$ yr^{-1}
- The kinetic power is $\dot{E}_{\rm K}$~10^{41}-10^{47} erg s^{-1}

See Inoue+ Poster 1318

Shock waves can form in UFOs?!

– External shocks due to interaction with the ambient medium
– Internal shocks due to non-uniformity within the flow

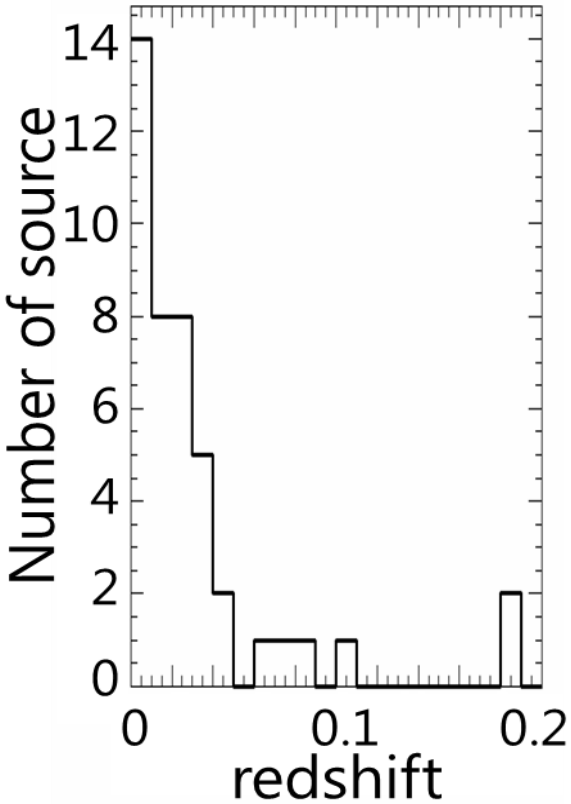


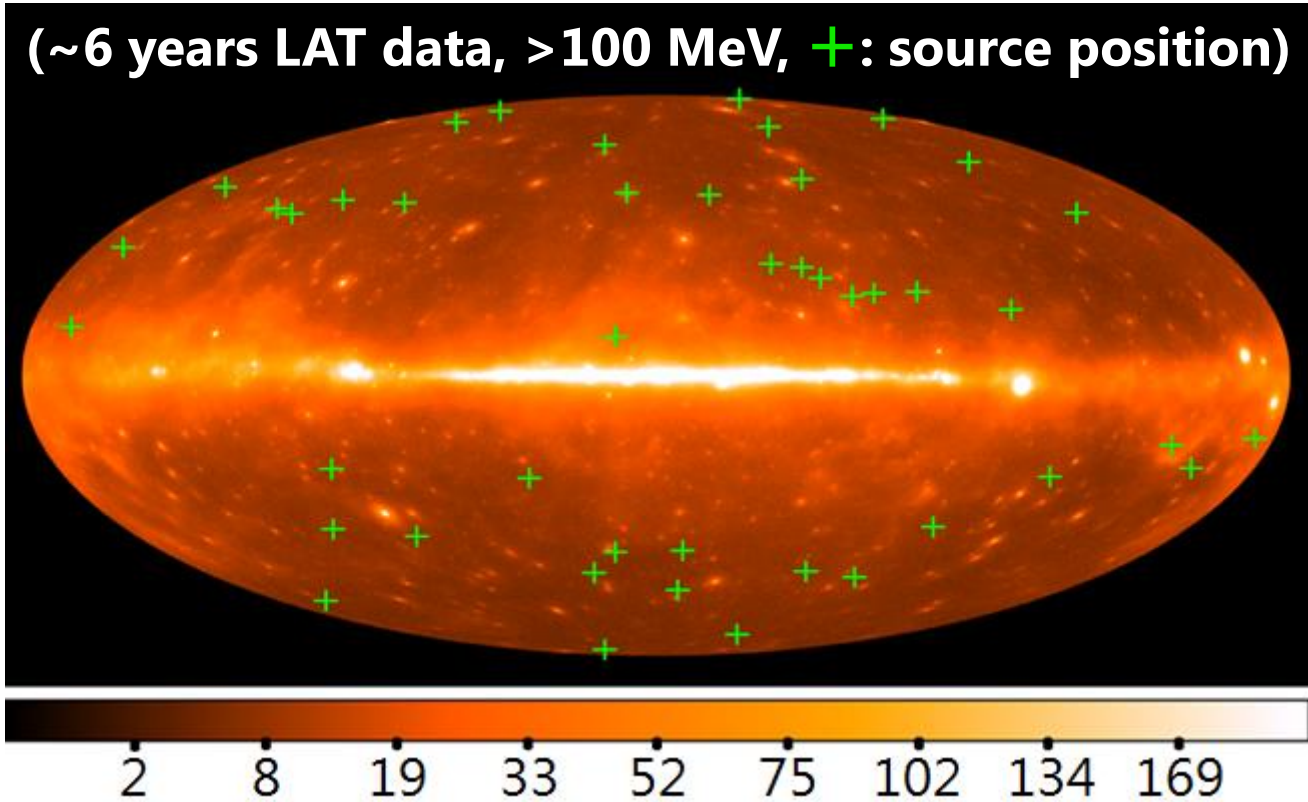
The ultra-fast outflows may become site of particle accelerations and non-thermal emission.

http://fermi.gsfc.nasa.gov/

Analyzed AGN sample for Fermi-LAT

- **We searched for γ-ray emission from 44 radio-quiet AGNs**
  Exclude radio-loud AGNs to avoid confusion with jet emission
  - 42 AGNs are taken from Tombesi+ 2010 (z<0.1)
    They were searched for blue-shifted Fe K absorption lines
  - PDS 456 (z~0.18) & IRAS F11119+3257 (z~0.19)
    additional powerful UFO sources





Count maps

- We show results using the 6 years Fermi-LAT data, above 100 MeV

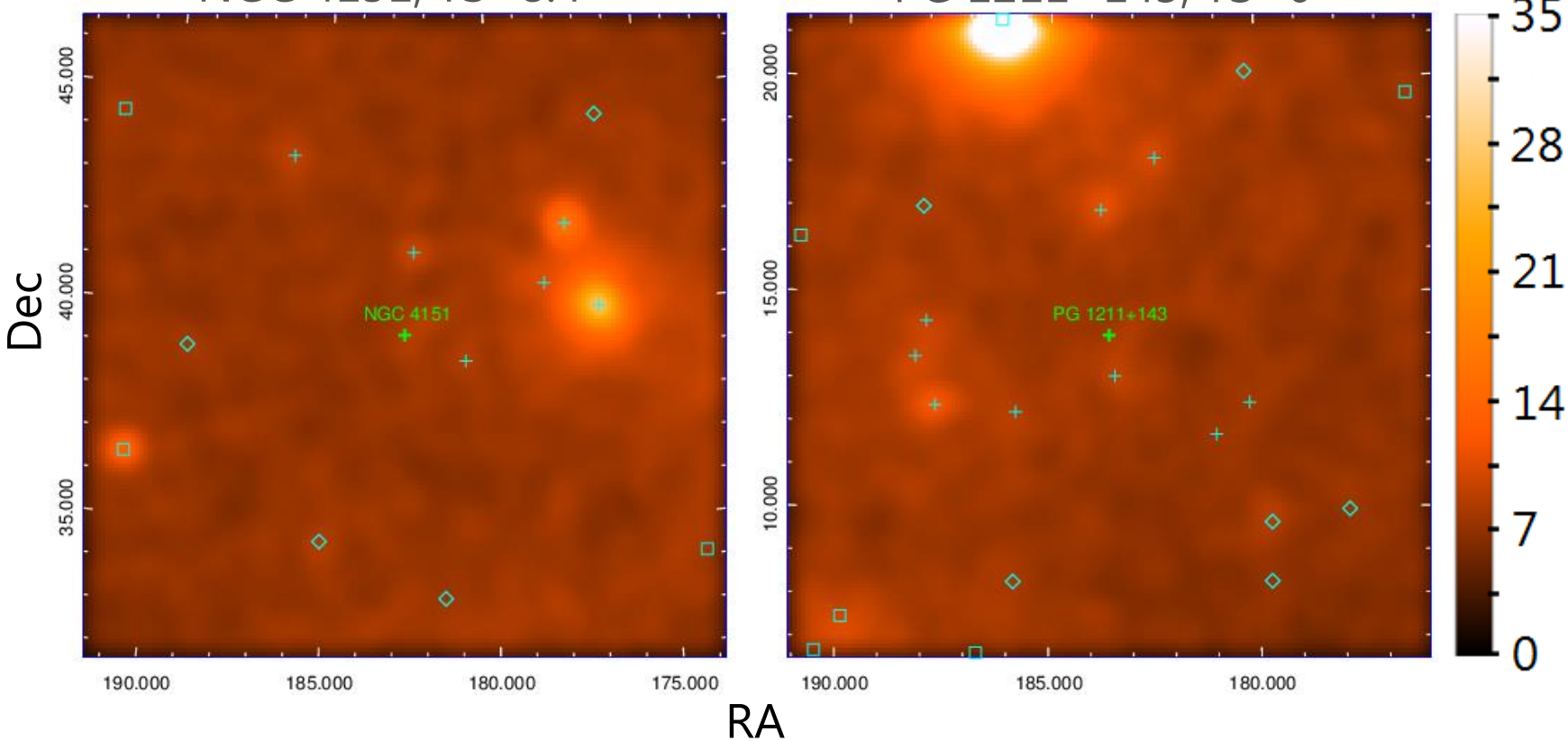
No significant γ-ray excess was found

Examples of count maps >100 MeV, 15 deg×15 deg

+: target (at center), Cyan points : 3FGL sources

NGC 4151, TS=8.4

PG 1211+143, TS~0



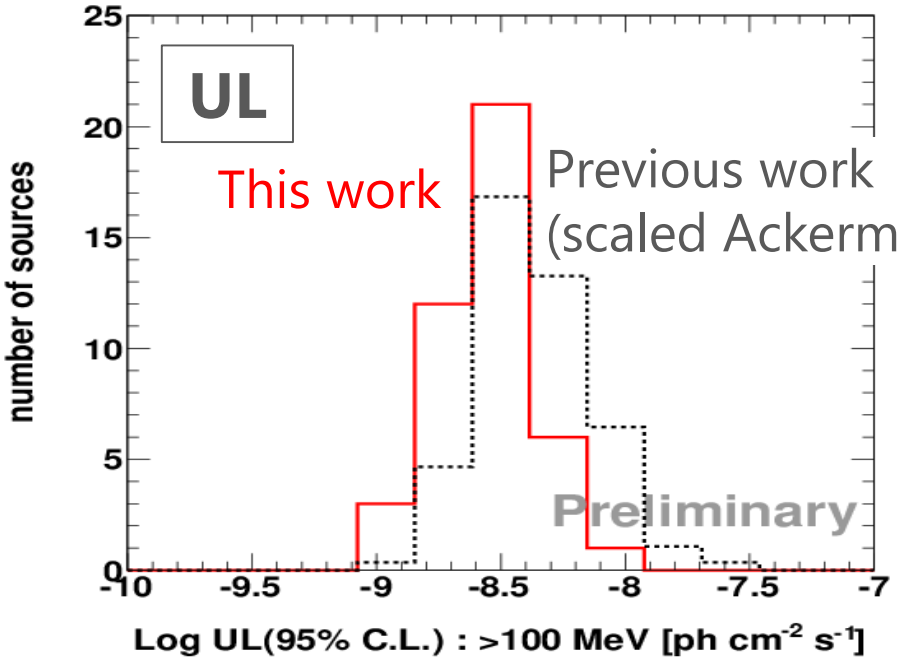
Photon integrated flux upper limits (ULs)

- We show results using the 6 years Fermi-LAT data, above 100 MeV

No significant γ-ray excess was found

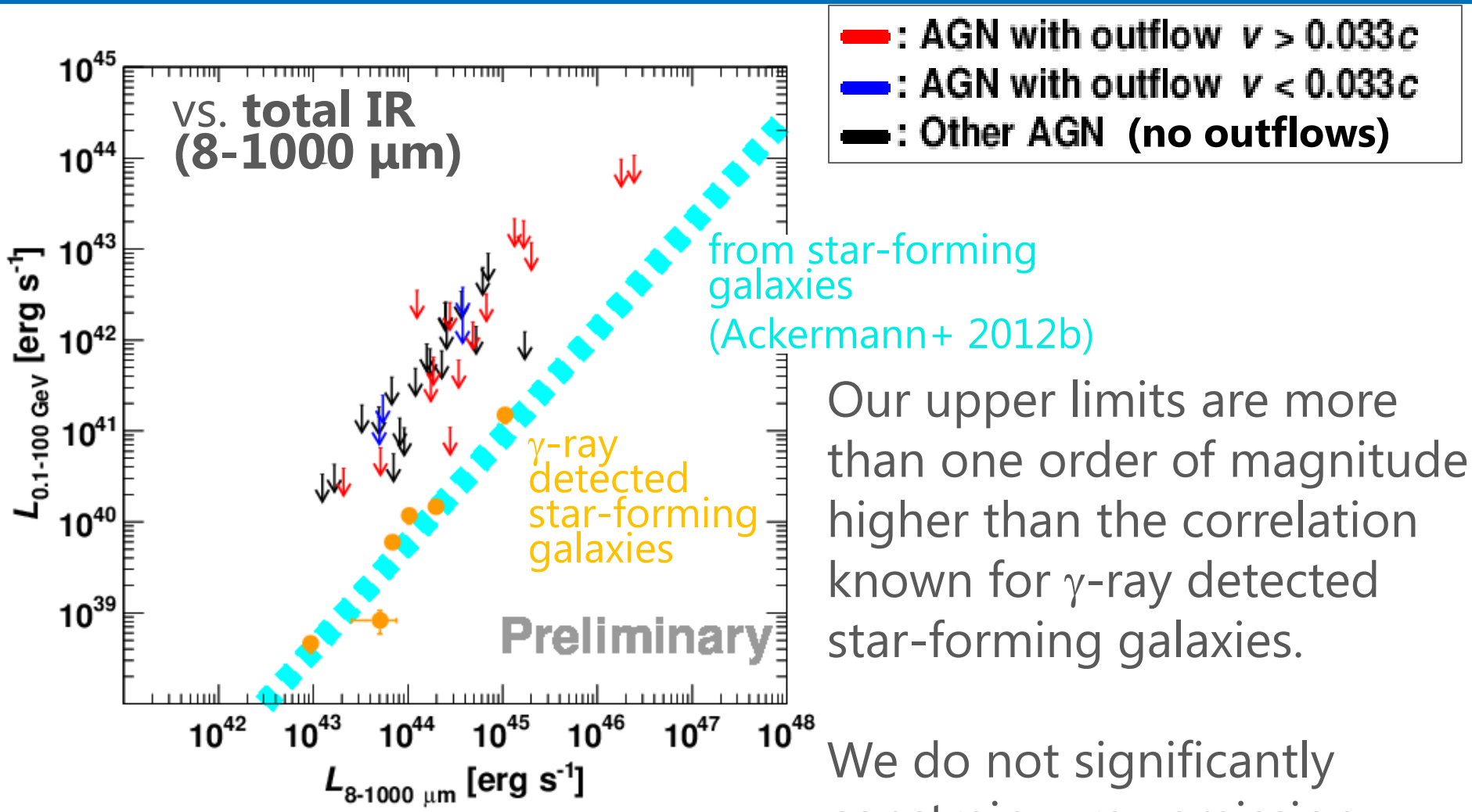
ULs (>100 MeV) : ~3×10^{-9} ph cm^{-2} s^{-1} (median)
(95% Confidence level, Γ=2.5)

ULs of γ-ray luminosity : 10^{41}-10^{44} erg s^{-1}



Our results have improved from the previous ULs of 120 Seyferts with 3 years Fermi-LAT data.
ULs (>100 MeV) :
~4×10^{-9} ph cm^{-2} s^{-1} (median)

Comparison with IR observations

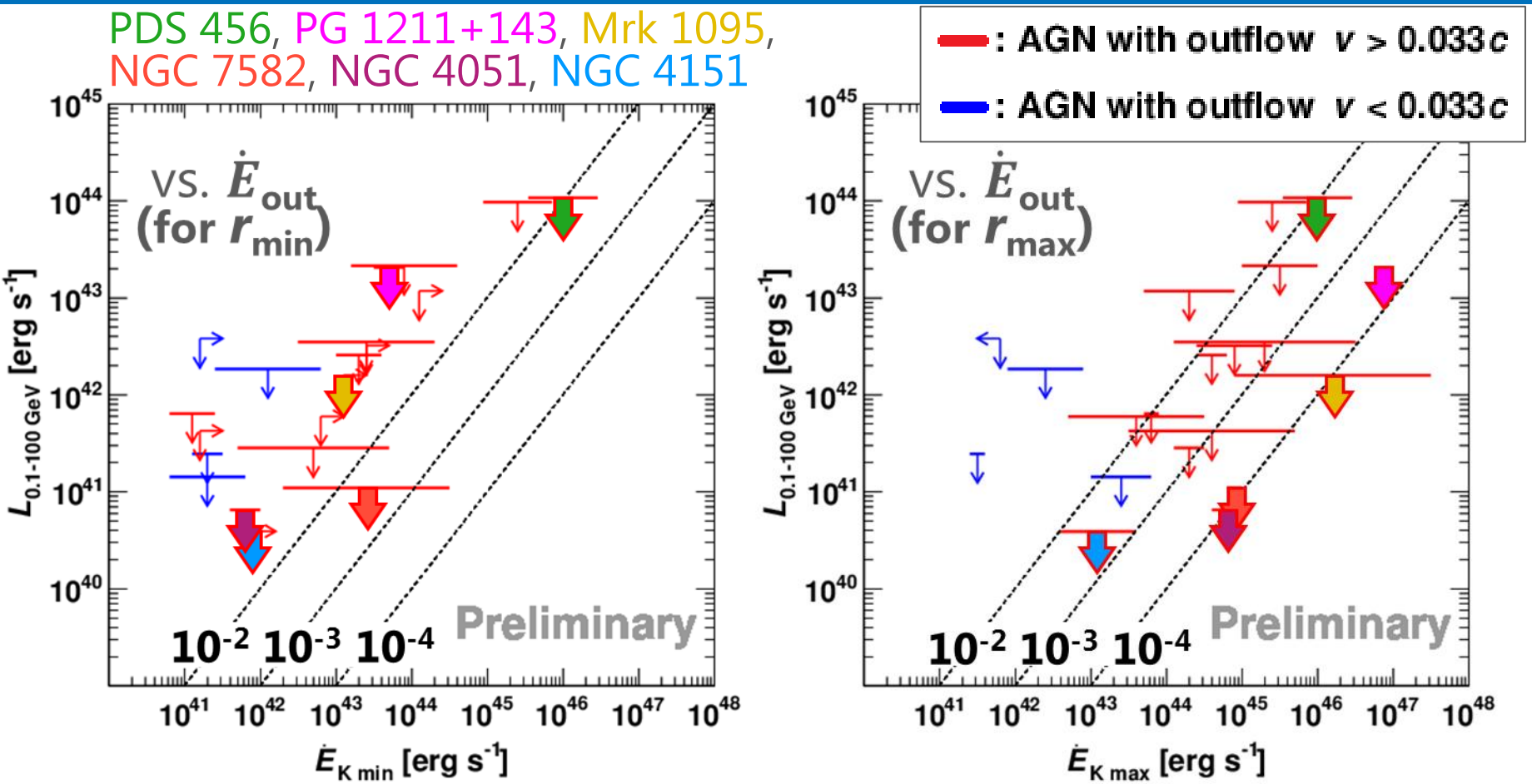


Our upper limits are more than one order of magnitude higher than the correlation known for γ-ray detected star-forming galaxies.

We do not significantly constrain γ-ray emission related to star formation.

Comparison with outflow kinetic power

PDS 456, PG 1211+143, Mrk 1095, NGC 7582, NGC 4051, NGC 4151

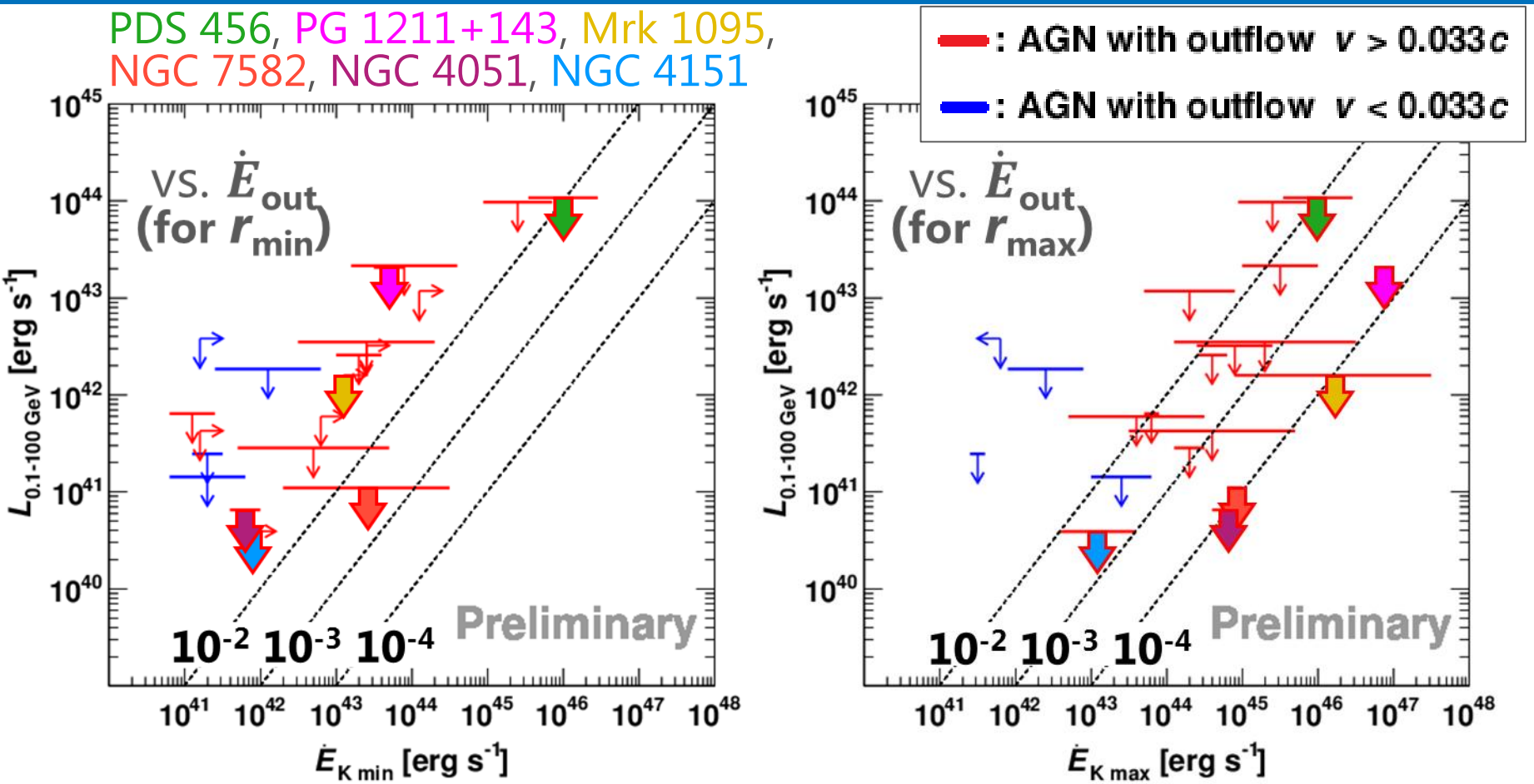


Outflow kinetic power $\dot{E}_K$ can be estimated from X-ray observations, but with large uncertainties.

We take minimum (left) and maximum (right) values from Tombesi+ 2012.

Comparison with outflow kinetic power

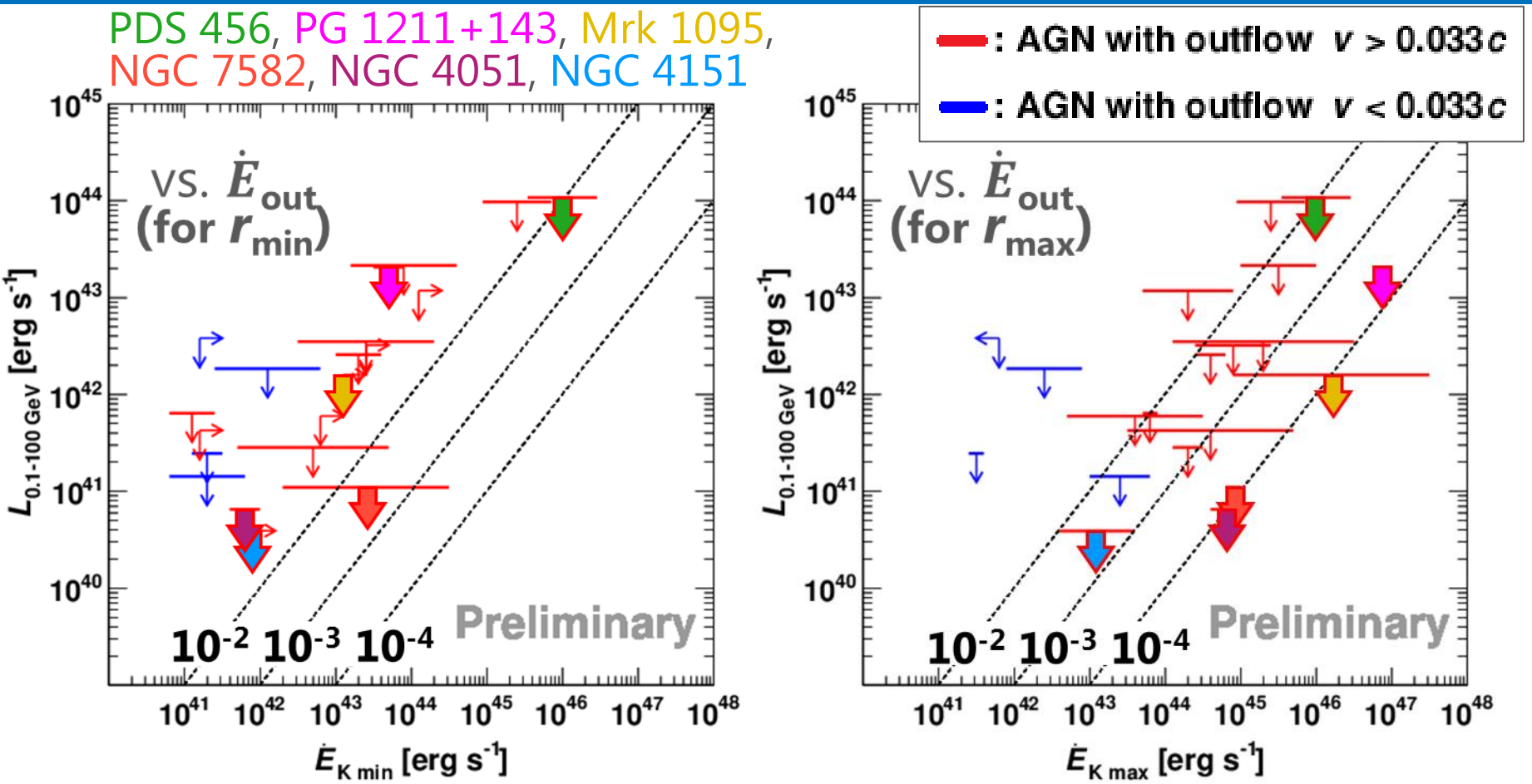
PDS 456, PG 1211+143, Mrk 1095, NGC 7582, NGC 4051, NGC 4151



Our γ-ray ULs can constrain the $L_{\gamma,UL}/\dot{E}_{K\,max}$ down to values as low as 10^{-4}.

Comparison with outflow kinetic power

PDS 456, PG 1211+143, Mrk 1095, NGC 7582, NGC 4051, NGC 4151



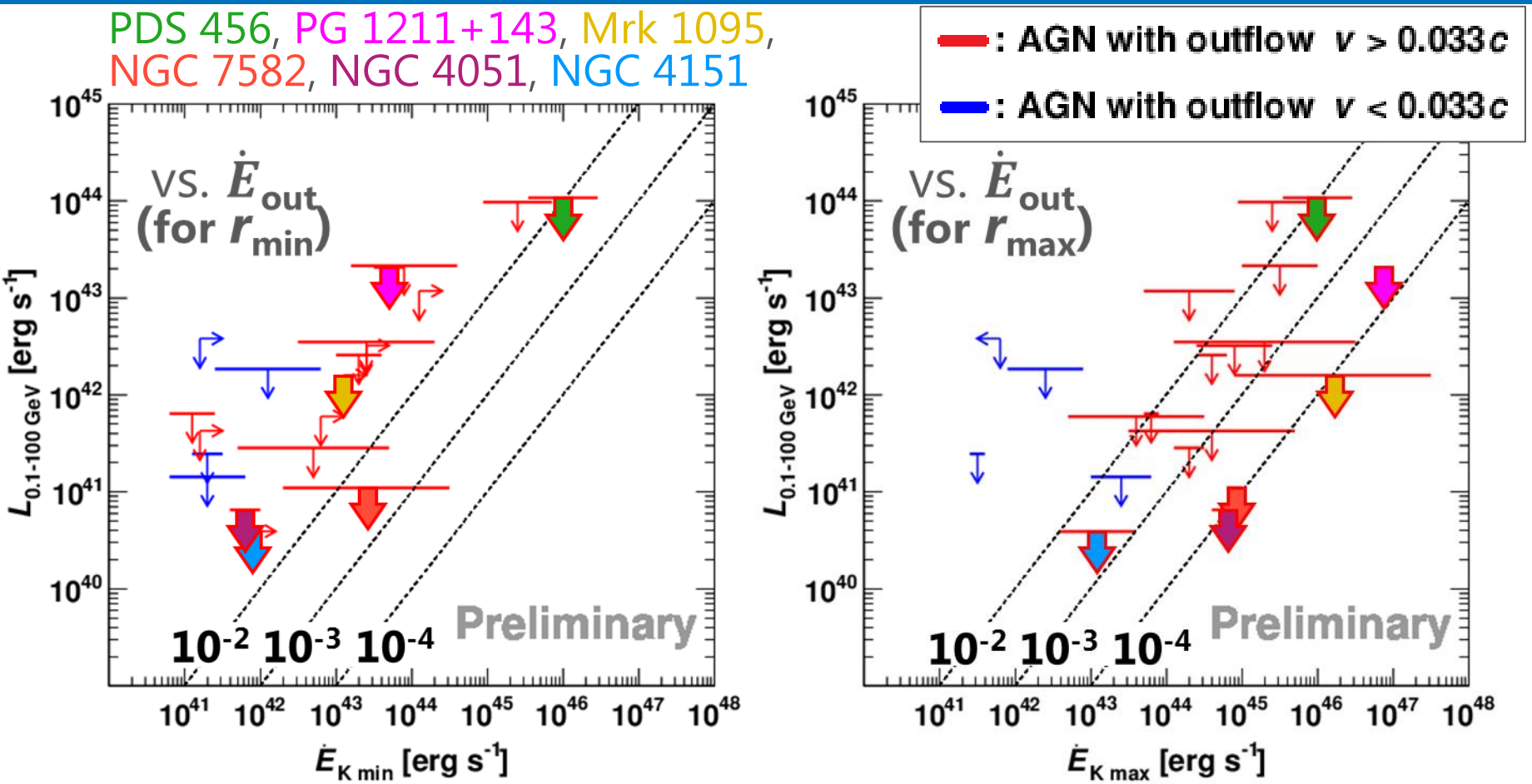
Electrons can be typically accelerated up to ~TeV (Inoue+ 2015). For acceleration efficiency $\zeta \sim 0.01$, the expected inverse-Compton γ-ray luminosity is

$$L_\gamma \approx 2.0 \times 10^{-4} \frac{\zeta}{0.01} \dot{E}$$

Nims+ 2015

Comparison with outflow kinetic power

PDS 456, PG 1211+143, Mrk 1095, NGC 7582, NGC 4051, NGC 4151

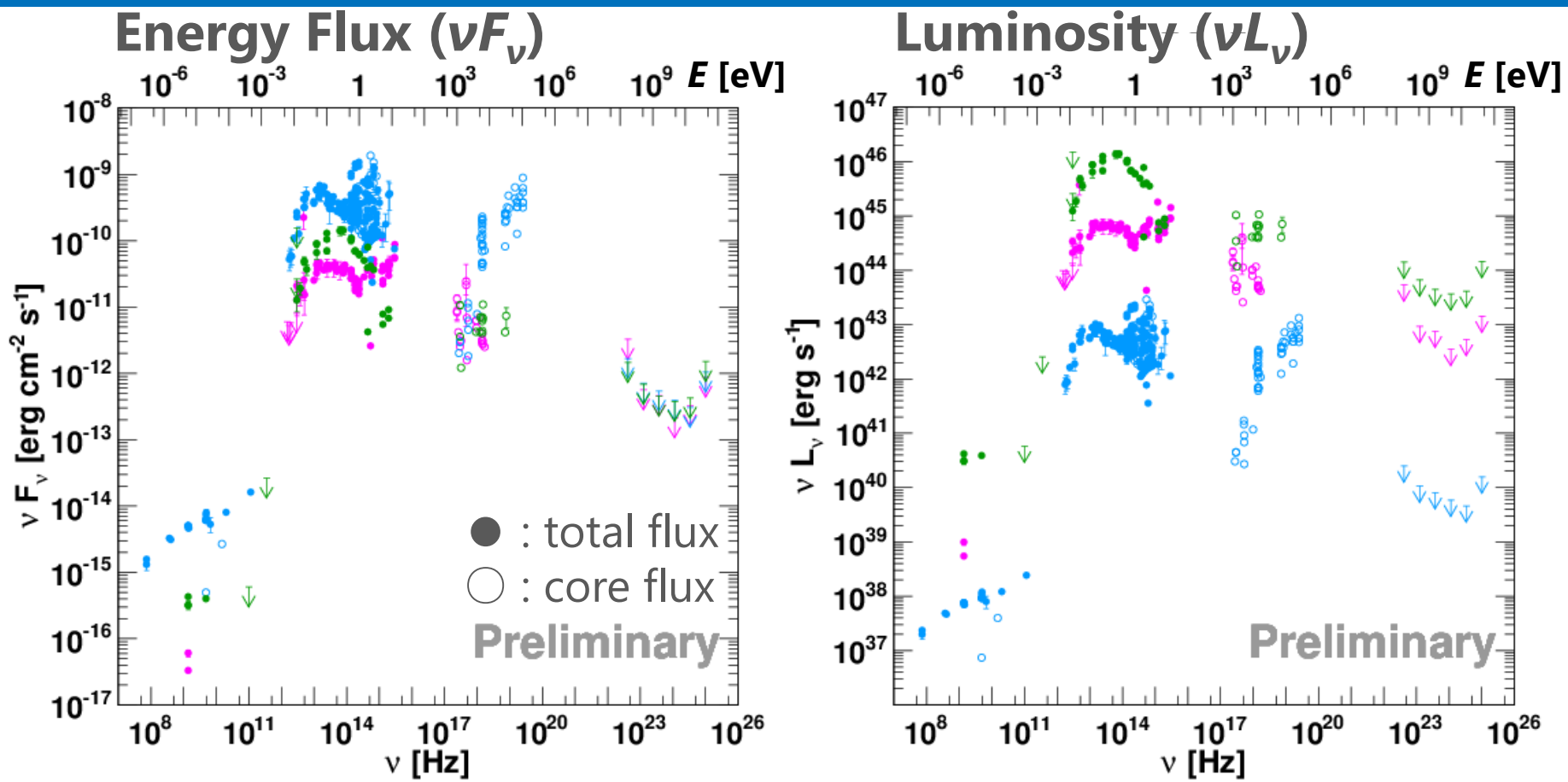


The upper limits of 4 objects (although it is in the maximum case) are already lower than the expected γ-ray luminosity from this equation.

$$L_\gamma \approx 2.0 \times 10^{-4} \frac{\zeta}{0.01} \dot{E}$$

Nims+ 2015

Broadband SED of 3 UFO sources



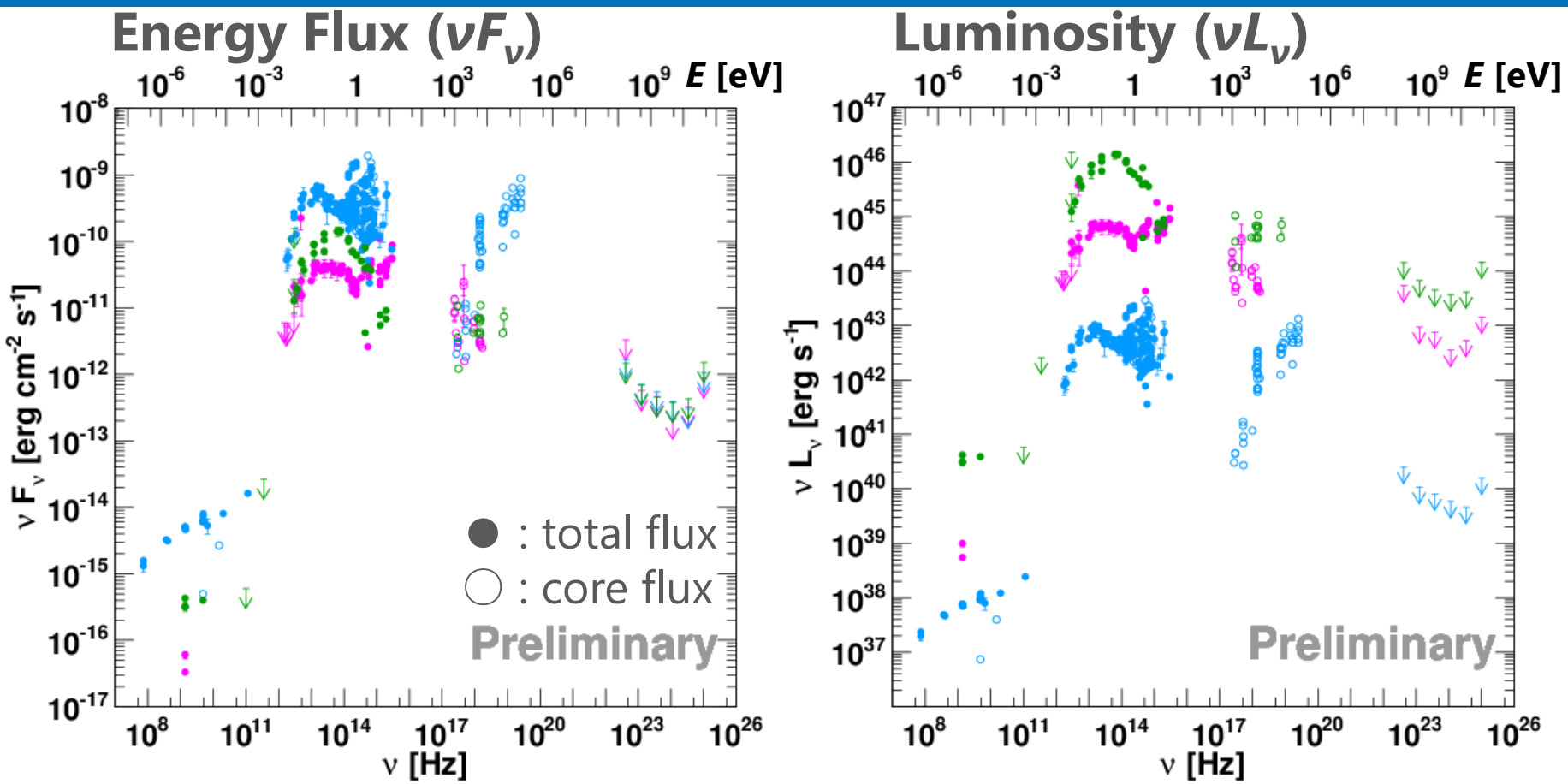
Outflow kinetic power ($\dot{E}_K$)

PDS 456 : (3-30)×10^{45} erg s^{-1}

PG 1211+143 : (6-10)×10^{46} erg s^{-1} ($\dot{E}_{K\,max}$)

NGC 4151 : (4-40)×10^{42} erg s^{-1} ($\dot{E}_{K\,max}$)

Broadband SED of 3 UFO sources



We assume the observed radio emission is synchrotron from electrons accelerated in UFOs. Then, from the γ-ray ULs, we can get lower limits to the magnetic fields in UFOs.

Broadband SED of 3 UFO sources

We use these relations.

ex) NGC 4151

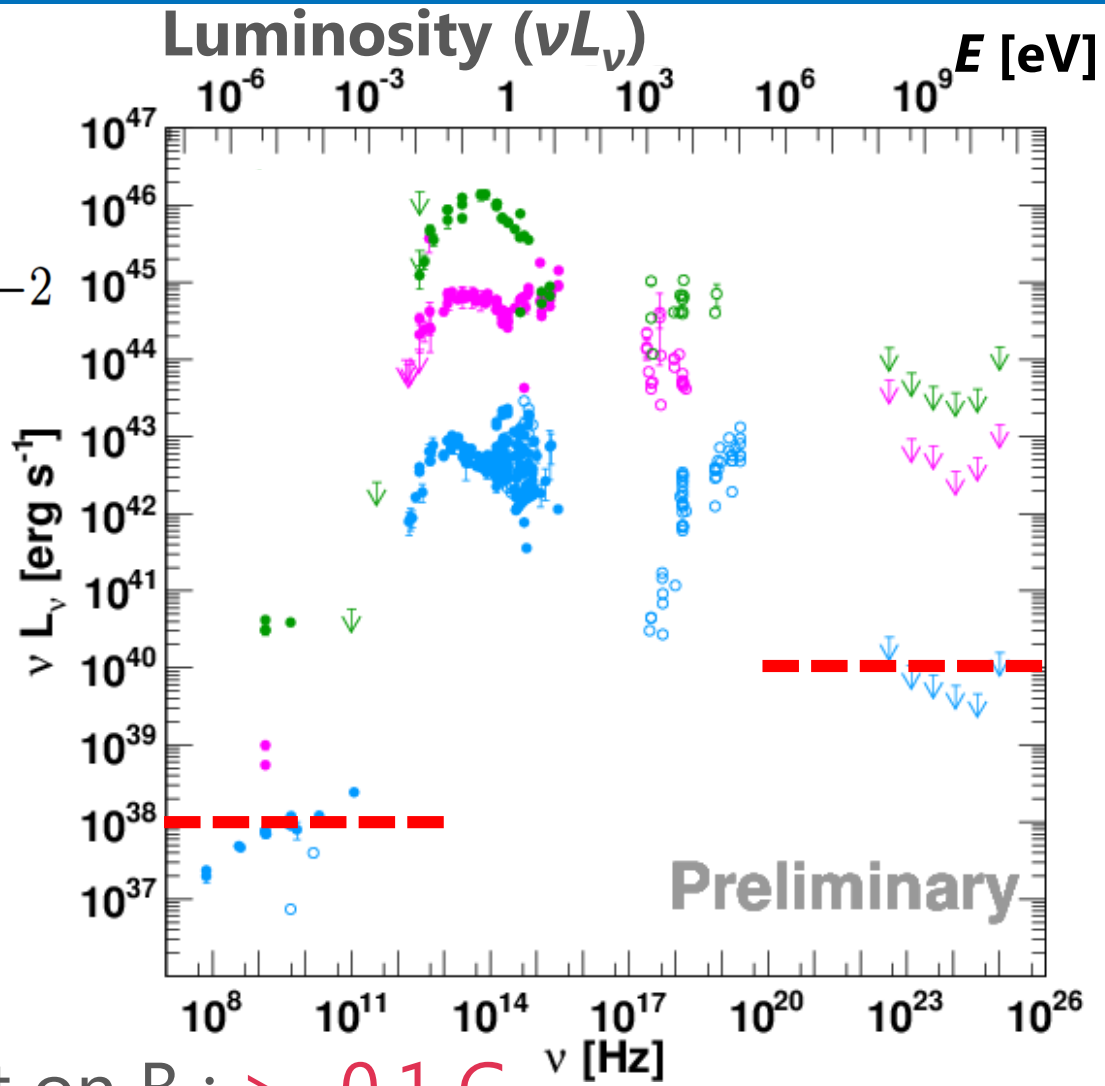
$$\frac{U_{\rm B}}{U_{\rm ph}} \sim \frac{L_{\rm syn}}{L_{\rm IC}} > \frac{\nu L_{\rm radio}}{\nu L_{\gamma,\rm UL}} \sim 10^{-2}$$

assume seed photons :

U_{ph}~0.03 erg cm^{-3}

(BLR photon, Ghisellini+ 2008)

$U_B = B^2/8\pi$



We get this lower limit on B : > ~0.1 G

The first attempt to constrain B in UFOs.

Summary

We searched for γ-ray emission from 44 radio-quiet AGNs with ultra-fast outflows using 6 years Fermi-LAT data above 100 MeV.

- No significant γ-ray excess was found
  - Upper limits (>100 MeV) : $\sim 3\times10^{-9}$ ph cm^{-2} s^{-1} (median)
- Compared γ-ray upper limits with IR observations
  - Our upper limits are still one order higher than correlation lines expected from star-forming galaxies
- Compared with outflow kinetic power($\dot{E}_{\mathrm{K\ max}}$)
  - Our sample reach $L_{\gamma,\mathrm{UL}}/\dot{E}_{\mathrm{K\ max}}$ as low as 10^{-4}
- Created Broadband SED of 3 UFO sources
  - First attempt to constrain magnetic fields by comparing γ-ray upper limits with radio emission : B>~0.1 G