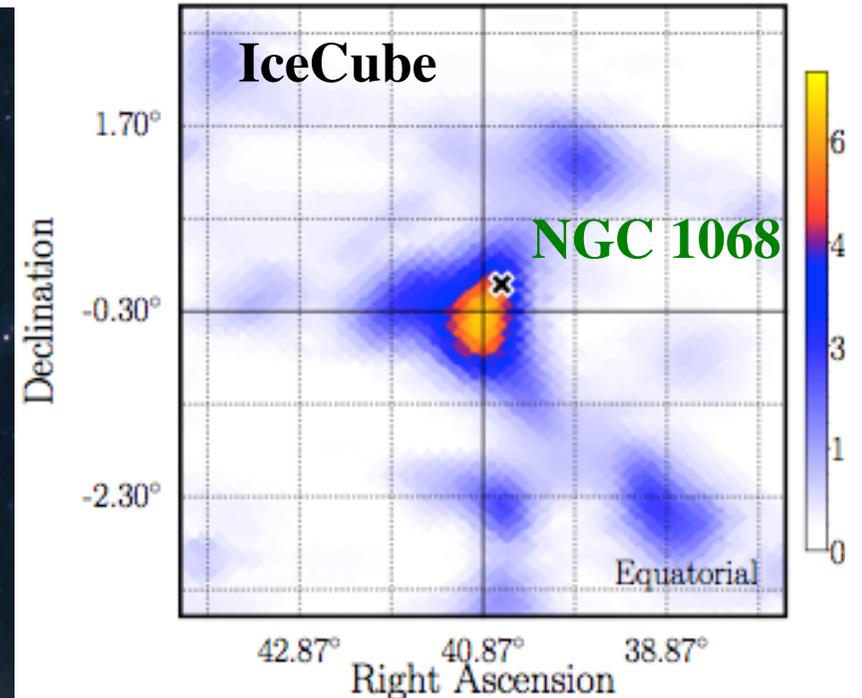
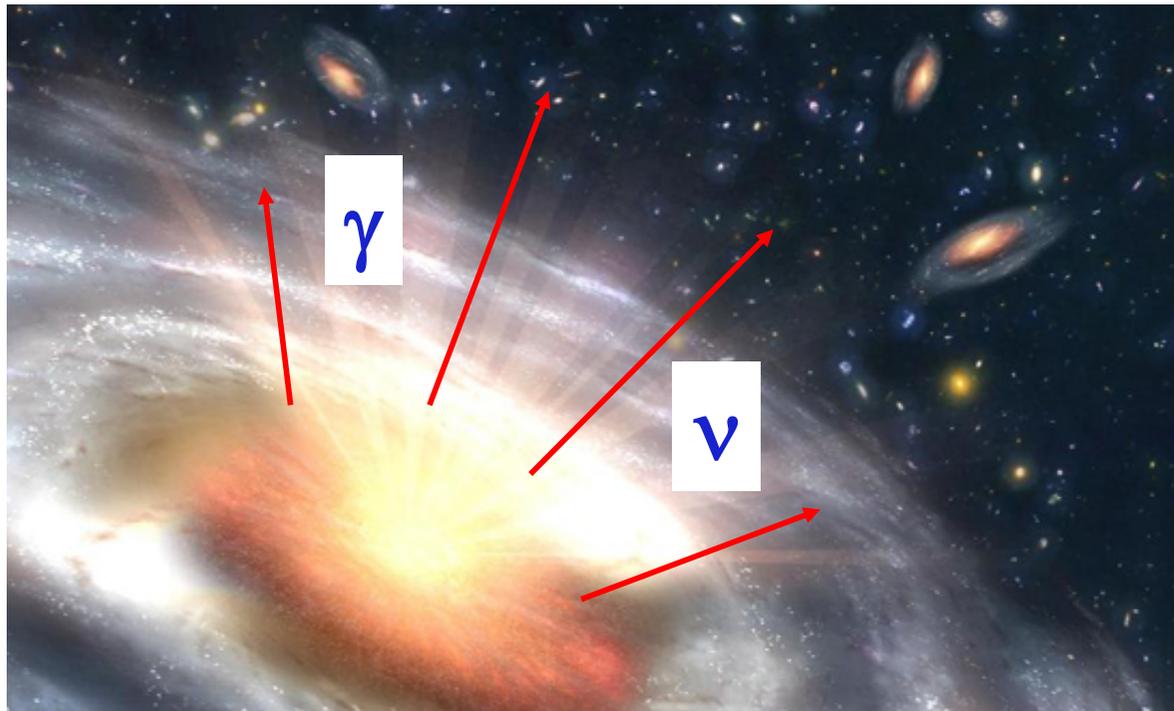


High-energy neutrino and γ -ray emission from the AGN-driven wind in NGC 1068

Susumu Inoue (Bunkyo U./RIKEN), Matteo Cerruti (APC)
Kohta Murase (PSU/YITP), Ruo-Yu Liu (Nanjing U)



importance of AGN winds

thermal, baryonic plasma; weakly collimated \leftrightarrow rel. jets

1. Observed to exist, widespread (radio-quiet or radio-loud)
 $\sim < \text{pc}$ – blueshifted ion abs. (X-ray UFOs; UV BAL outflows)

$$v \gtrsim 0.1c, L_{\text{kin}} \lesssim L_{\text{Edd}}, \dot{M} \lesssim \dot{M}_{\text{edd}}$$

$\sim < \text{kpc}$ – ion abs. (X-ray WAs; UV NAL), ion emi. (UV-IR)

$$v \gtrsim 1000 \text{ km/s}$$

$> \sim \text{kpc}$ – molecular emi. (CO, OH, etc.)

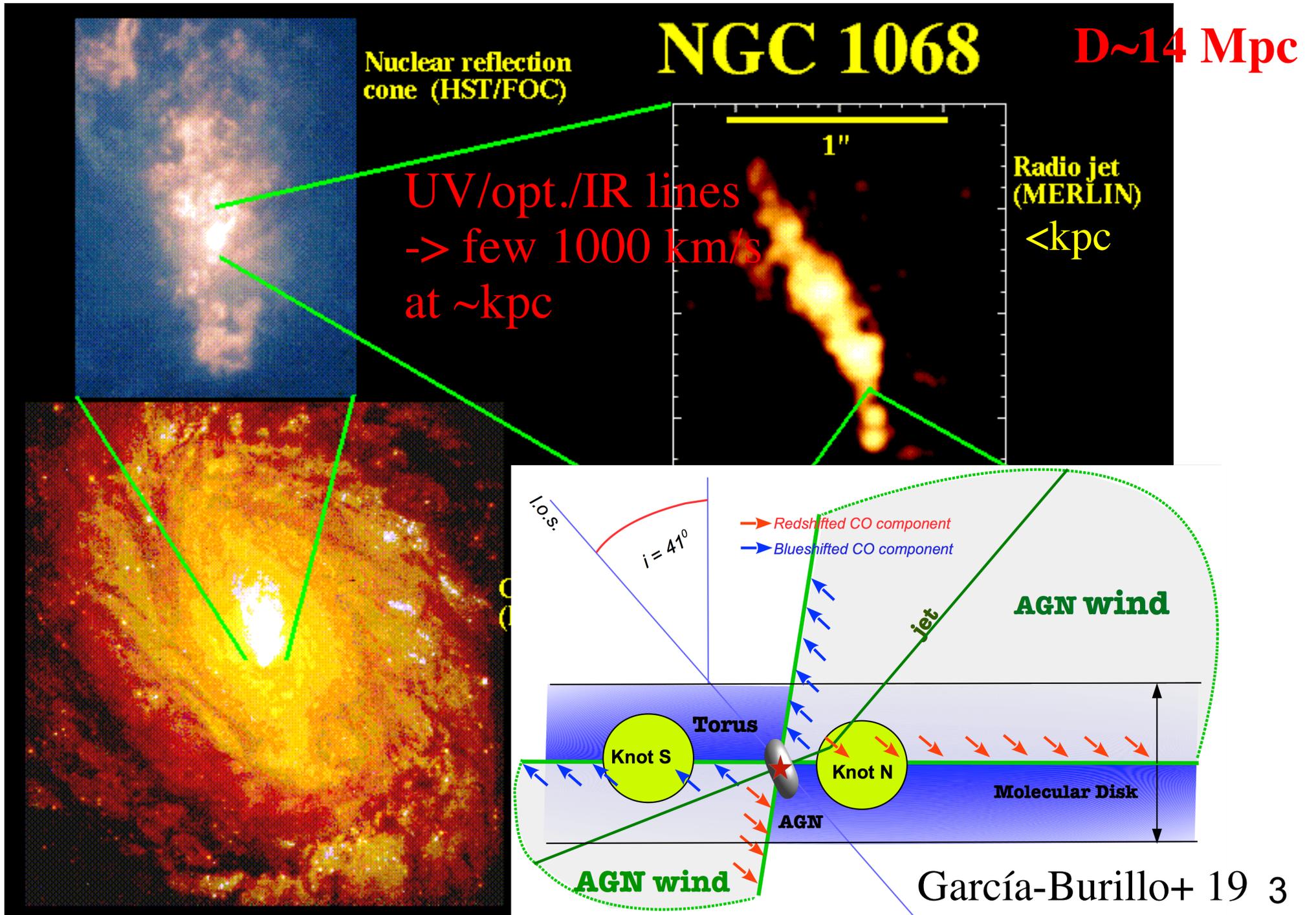
$$v \lesssim 1000 \text{ km/s}, \dot{M} \lesssim 100 M_{\odot}/\text{yr}, L_{\text{kin}} \lesssim L_{\text{bol}}$$

2. Plausibly expected from accretion disks via various mechanisms (unlike jets): thermal, radiative, magnetic...

3. May provide mechanical/thermal feedback onto host gas
 \rightarrow observed BH scaling relations, star formation quenching

4. May be particle accelerators + nonthermal emitters
weakly beamed, quasi-isotropic

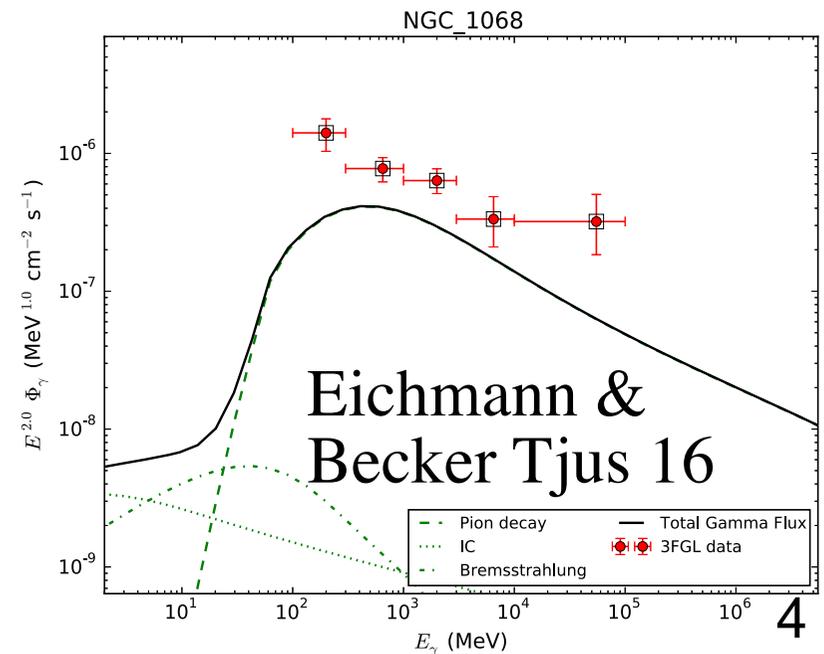
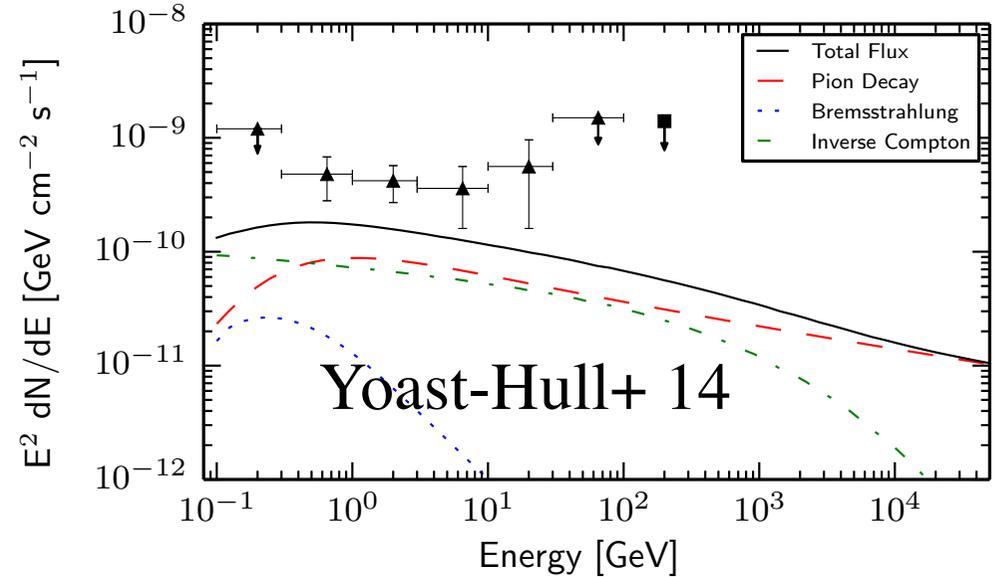
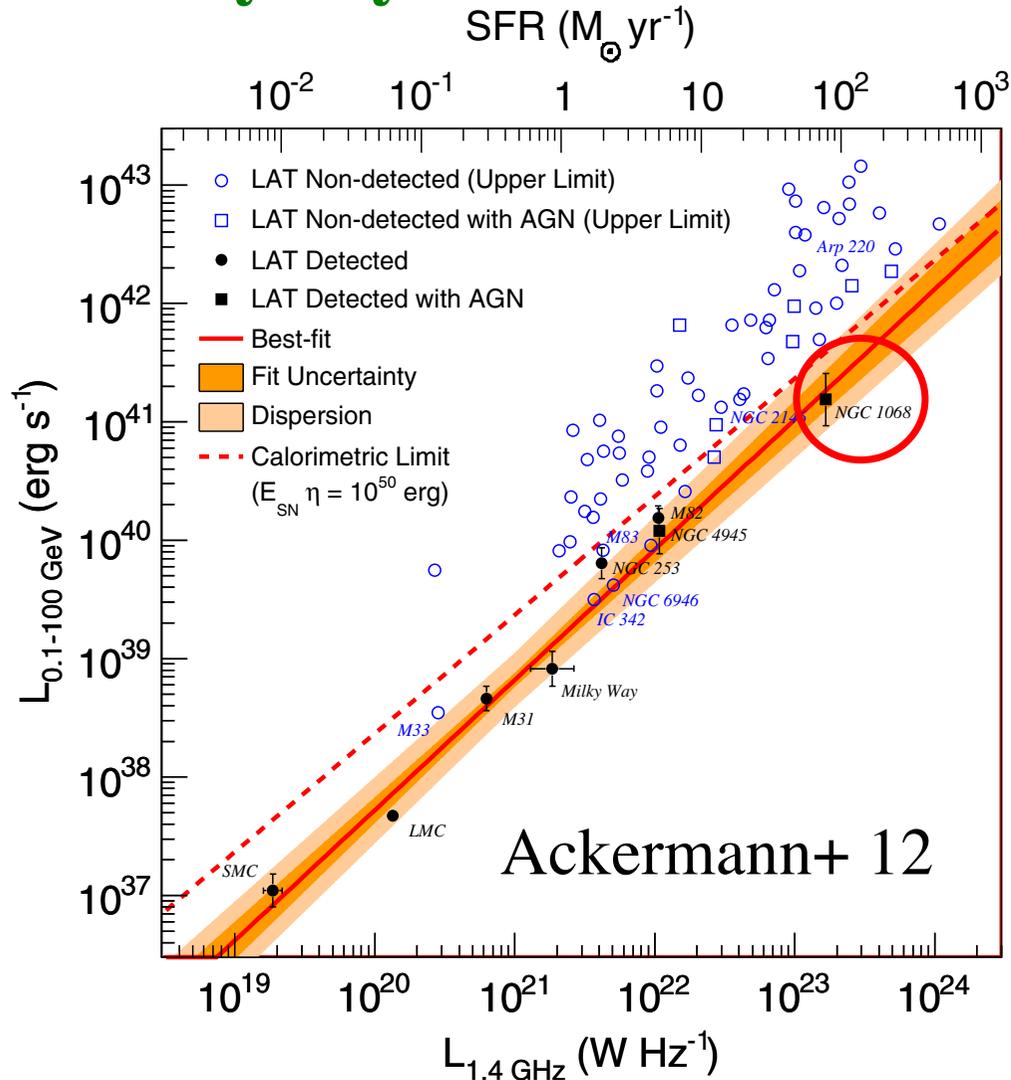
NGC 1068: Seyfert II with fast wind + molecular outflow



GeV gamma rays from NGC 1068: starburst?

consistency with L_γ -SFR relation
 -> **maybe yes**

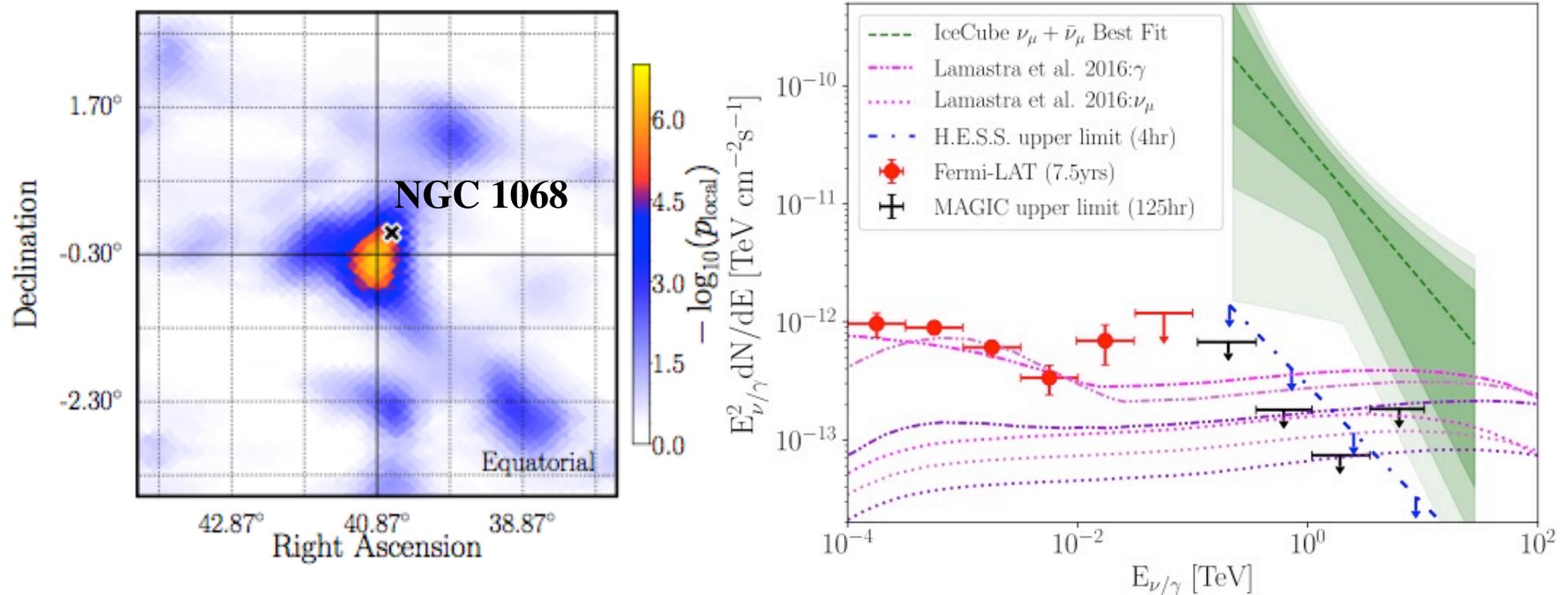
modeling of detailed
 MWL data -> **NO**



Fermi-LAT sample of
 "starburst"+normal galaxies

high-energy neutrinos from NGC 1068?

IceCube 10-yr time-integrated source search 1910.08488



- most significant point in North from full-sky scan coincident with NGC 1068
- 2.9σ excess at position of NGC 1068 in source catalog search

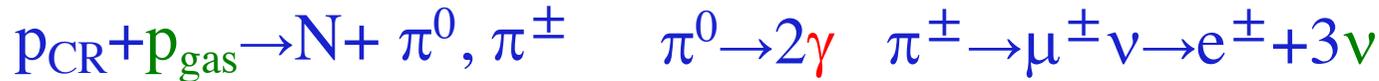
neutrino + gamma from NGC 1068: AGN origin?

AGN wind external shock models

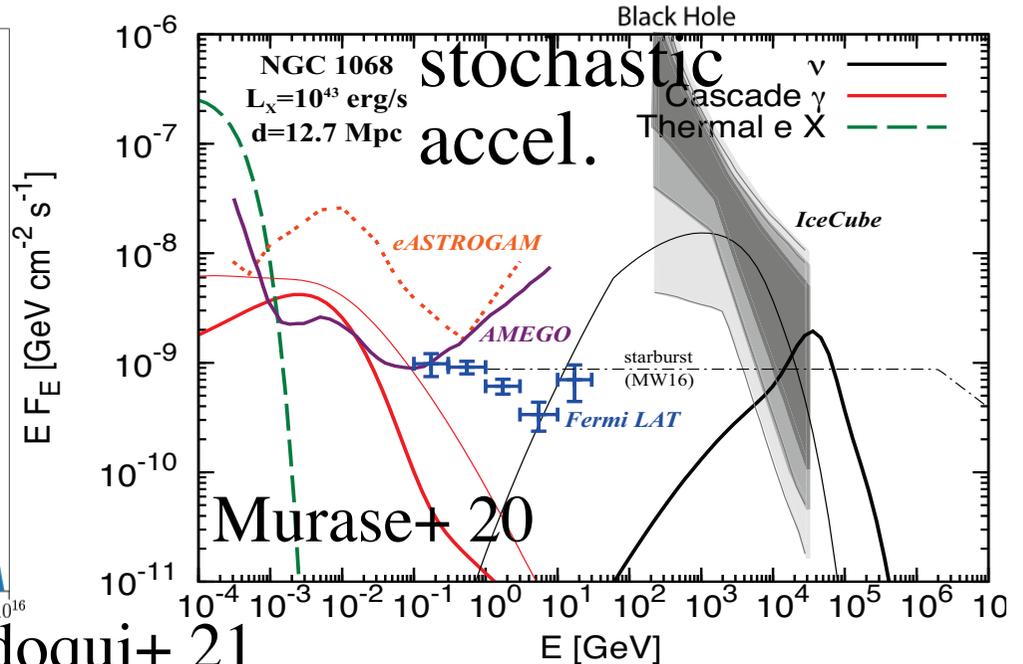
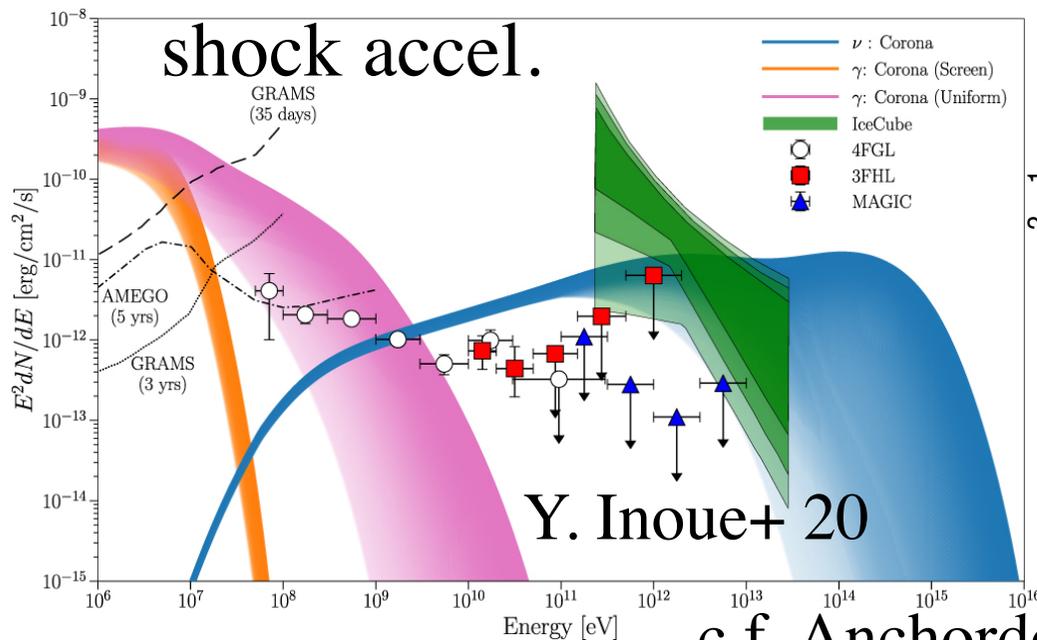
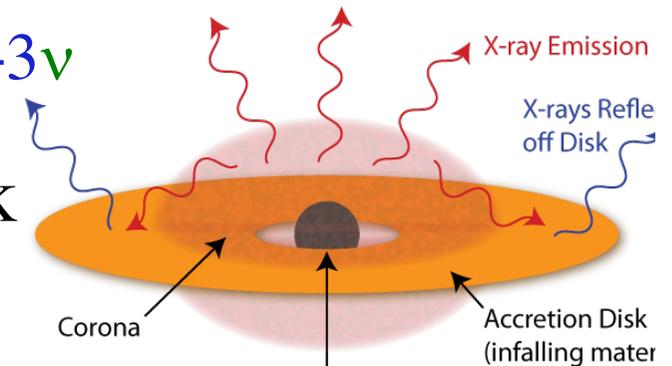
e.g. Lamastra+ 16

(generally pp models optically thin to $\gamma\gamma$)

strongly constrained by MAGIC TeV upper limits



pp(+p γ) in compact regions optically thick to $\gamma\gamma$, e.g. accretion disk coronae?



c.f. Anchordoqui+ 21
GeV γ rays? robustness of particle acceleration?

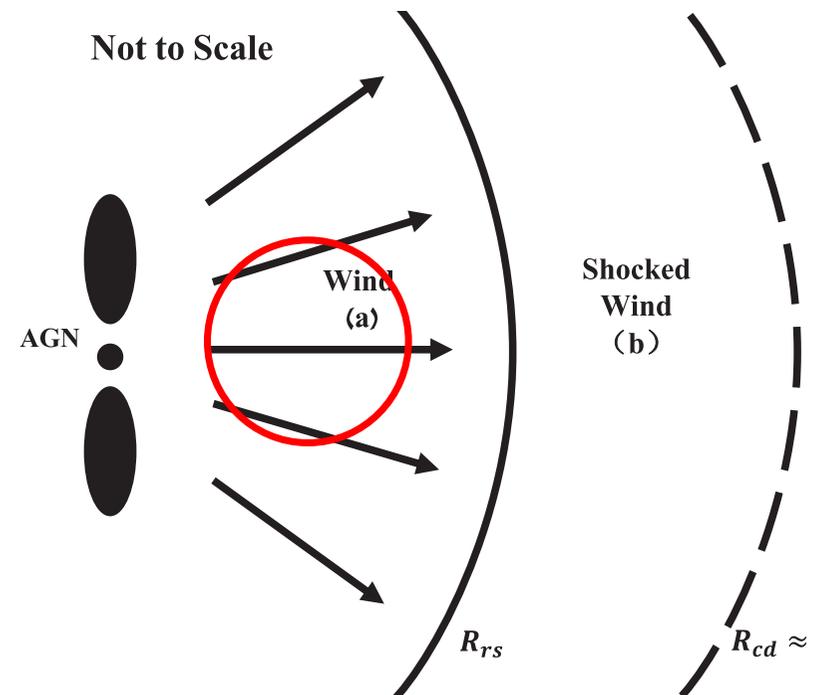
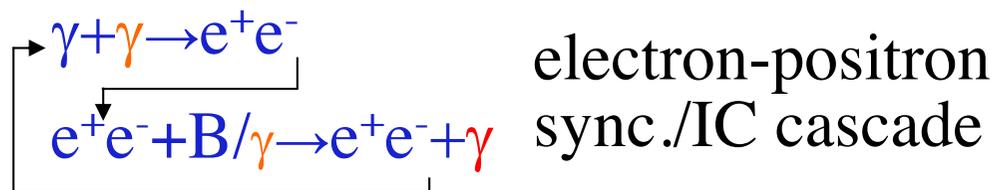
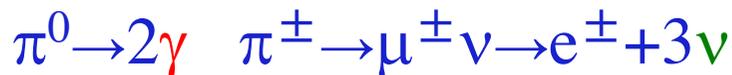
py v+γ from inner regions of AGN winds

potential particle acceleration via:

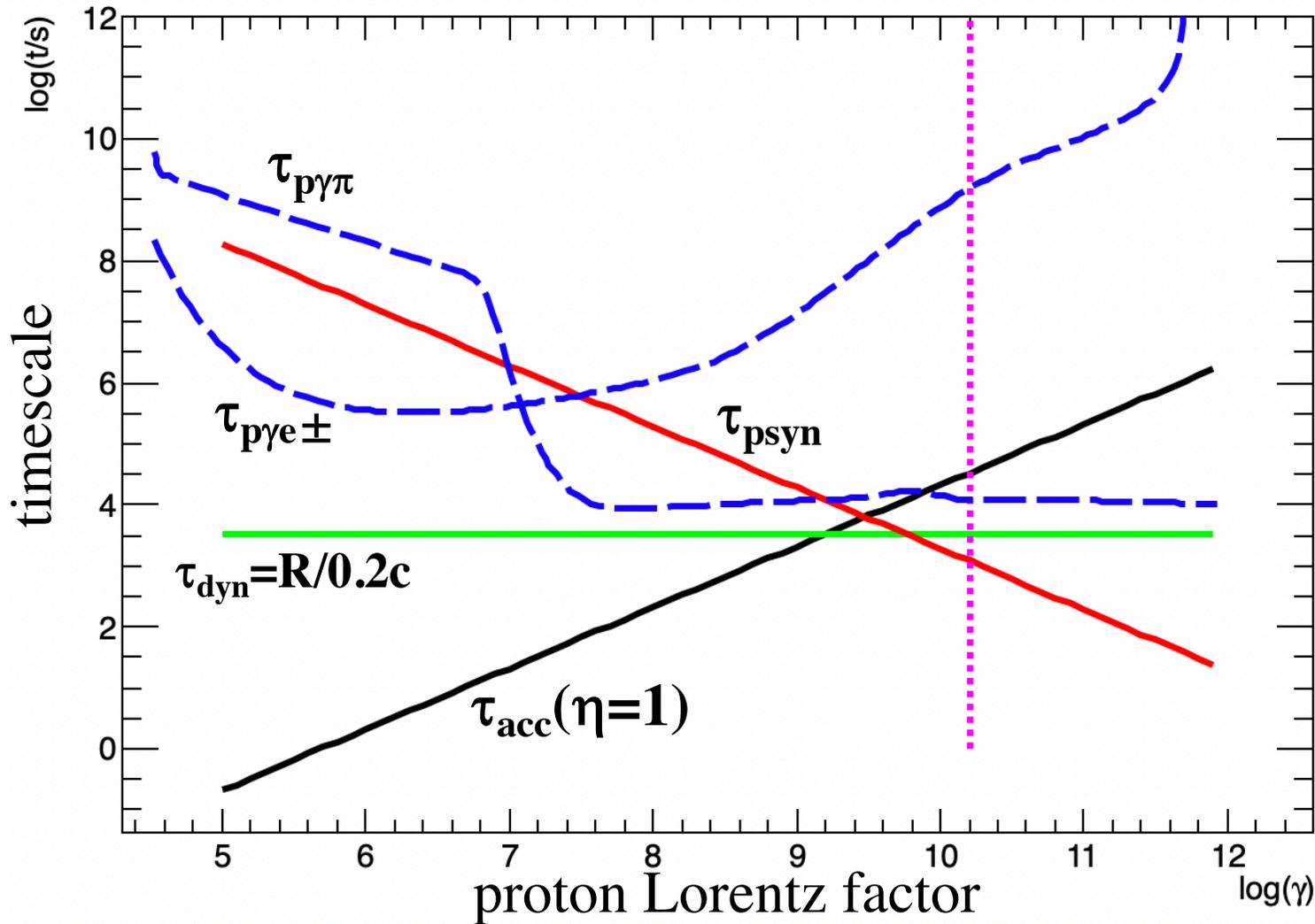
- internal shocks caused by highly variable wind ejection (observational evidence + theoretical support)
- “interaction” shocks with external or internal clouds/stars

py interactions with nuclear radiation

- neutrinos $\sim < 10$ PeV
- cascade $\sim < \text{MeV-GeV}$

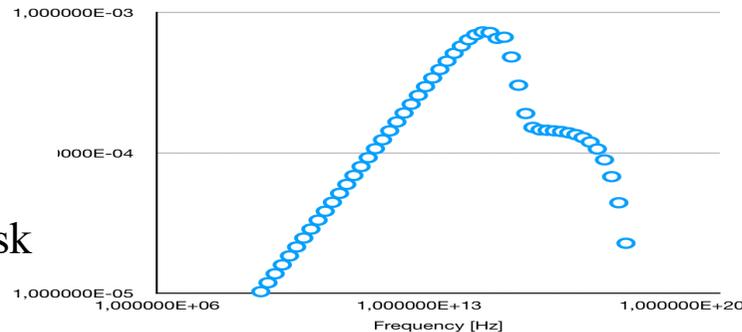


py in inner regions of AGN winds: timescales

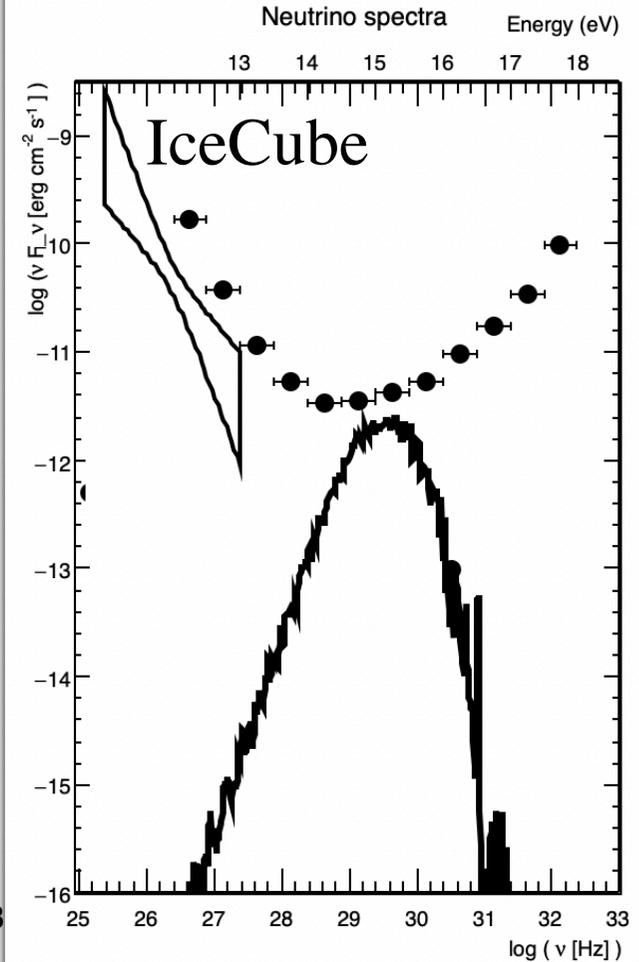
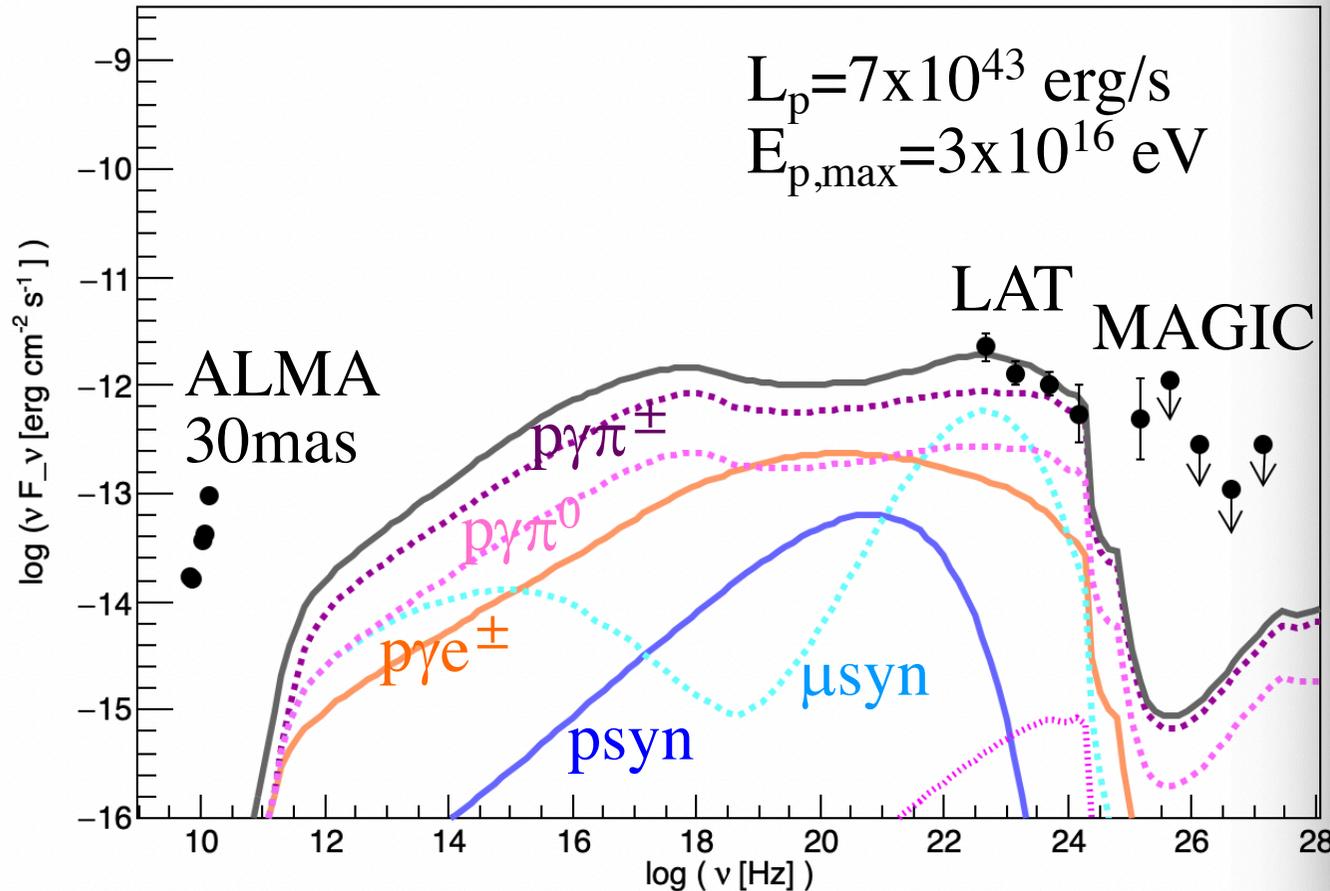


$R=10^{14}$ cm ($3R_s$)
 $z=10^{15}$ cm ($30R_s$)
 $B=500$ G
 (c.f. $\epsilon_B \sim 0.08$ for
 $L_{kin}=5 \times 10^{44}$ erg/s)

$M_{BH}=10^8 M_{\odot}$
 $L_{disk}=10^{44}$ erg/s
 $L_{cor}=0.01-0.1 L_{disk}$

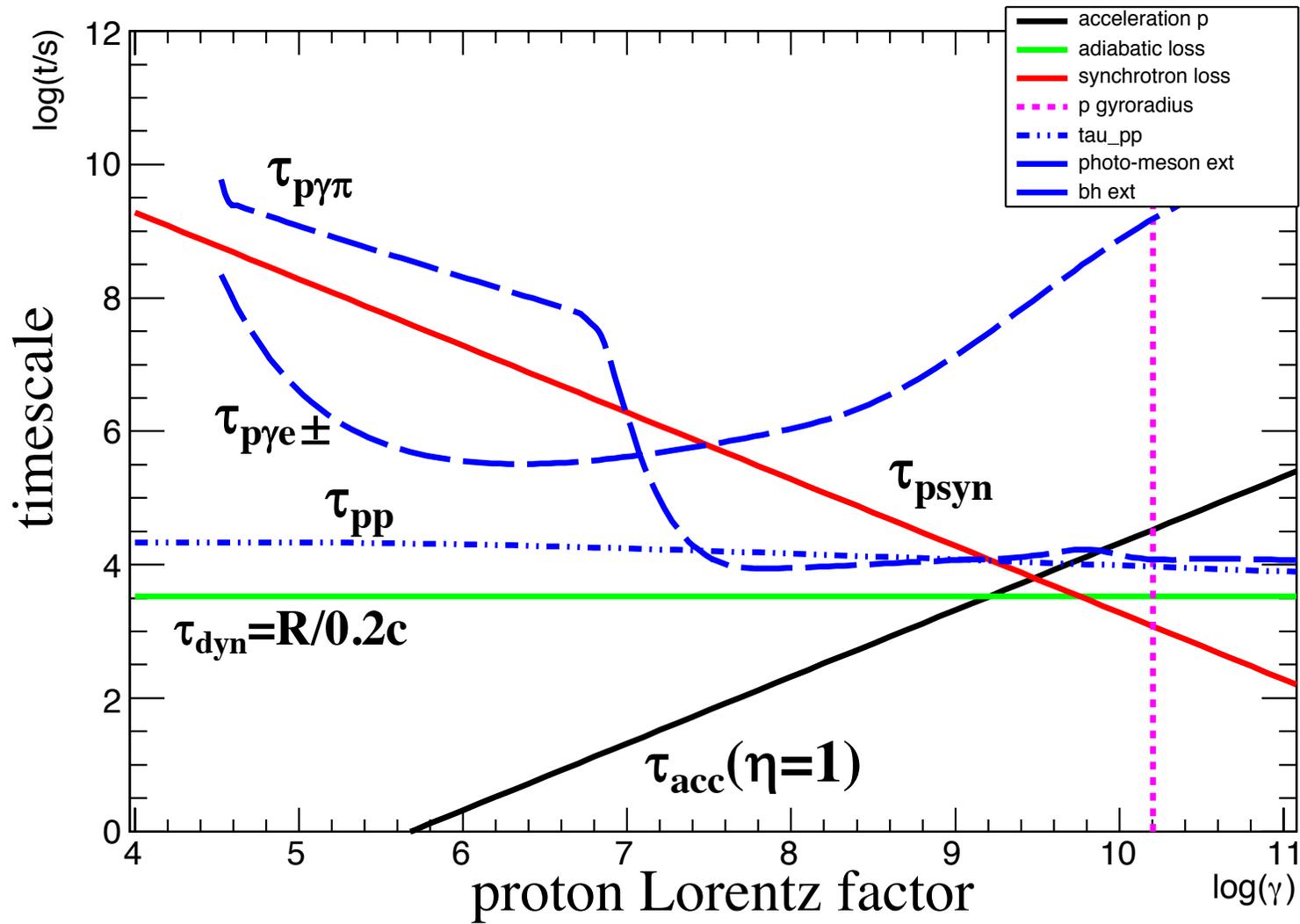


wind internal py model for NGC 1068: example



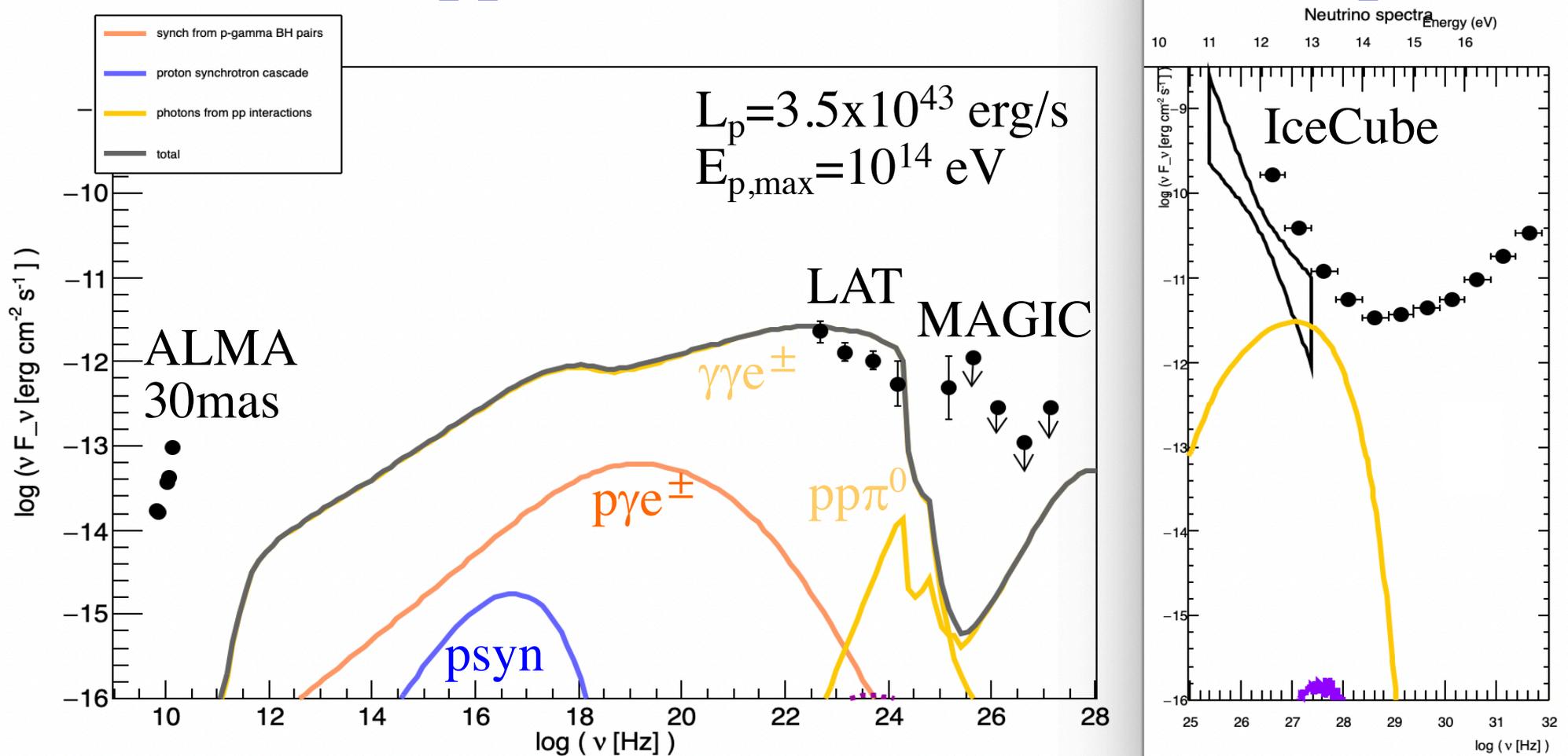
- plausible GeV-TeV γ by hadronic cascade, clear break due to $\gamma\gamma$ on disk field
- cascade spectrum: $f_\nu \propto \nu^{-1}$ @keV-GeV, $\propto \nu^{-0.5}$ <keV below observed radio/submm
- plausible ν flux, but spectrum too hard?

py + pp in inner regions of AGN winds: timescales



$R=10^{14}$ cm ($3R_s$)
 $z=10^{15}$ cm ($30R_s$)
 $B=500$ G
 (c.f. $\epsilon_B \sim 0.08$ for
 $L_{\text{kin}}=5 \times 10^{44}$ erg/s)
 $n_g=10^{11}$ cm $^{-3}$

wind internal pp model for NGC 1068: example



- plausible(?) ν if proton spectrum hard ($\sim E^{-0.5}$) up to $E_{p,max}$
 e.g. via escape process from acceleration region
- GeV-TeV γ by $\gamma\gamma$ cascade of $pp \pi^0 \gamma$

summary

High-energy $\nu+\gamma$ emission from AGN wind in NGC 1068

fact: AGN winds - fast, powerful, widespread
known in NGC 1068

interpretation of GeV γ + sub-PeV ν for NGC 1068

- particle acceleration plausible in inner regions near nucleus
- $p\gamma$ with nuclear radiation field, pp with BLR clouds
- potentially plausible for pp for protons with hard spectrum (via e.g. escape from acceleration region)
- > paper in prep., please stay tuned

outlook

- nearby Seyferts by IceCube-Gen2, CTA, etc
- contribution to diffuse ν background
- unique info on AGN winds (B field, etc)