# High-energy neutrinos and γ-rays from the AGN-driven wind and torus in NGC 1068

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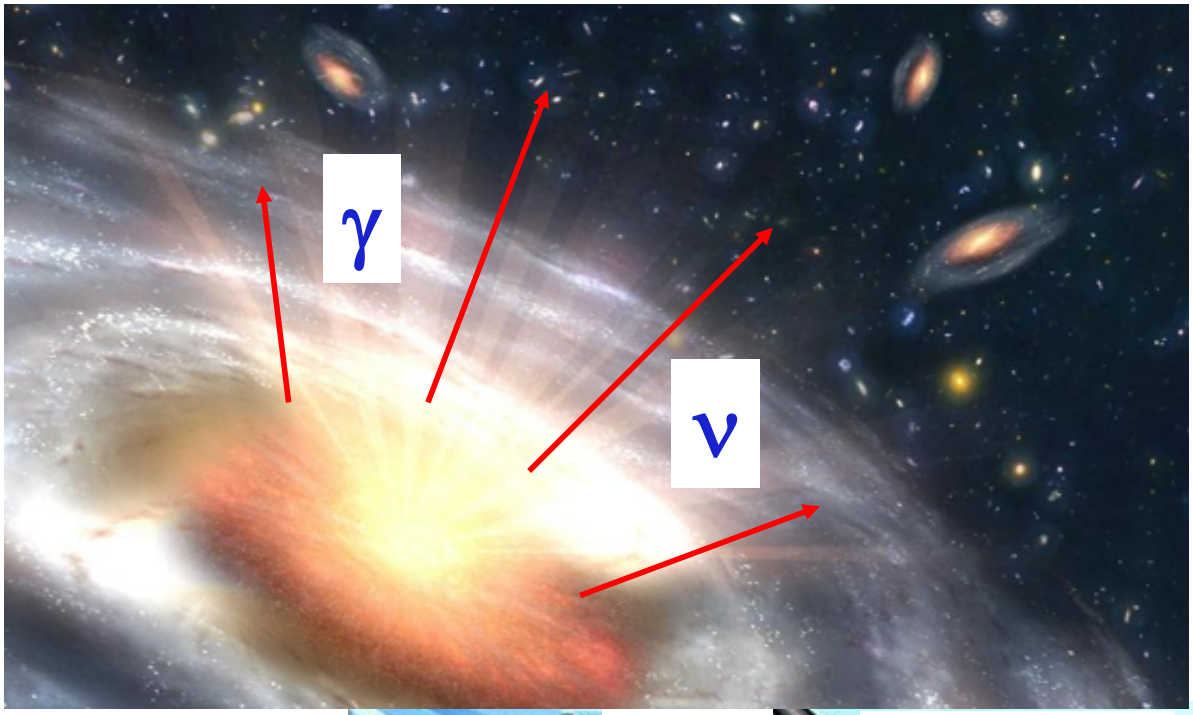
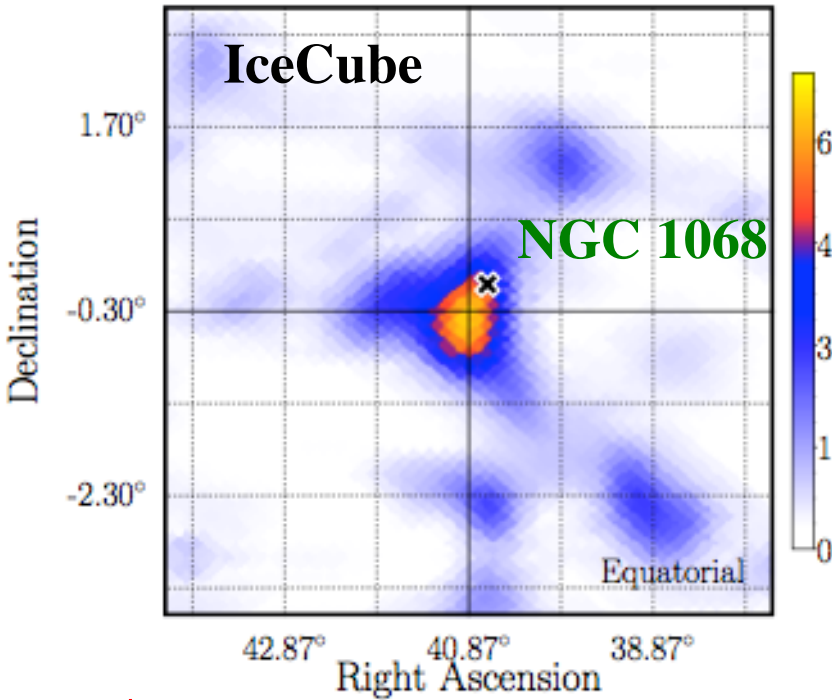



# importance of AGN winds

thermal, baryonic plasma; weakly collimated <-> rel. jets

1. Observed to exist, widespread (radio-quiet or radio-loud)

~<pc – blueshifted ion abs. (X-ray UFOs; UV BAL outflows)

v>~0.1c, $L_{kin}$~<$L_{Edd}$, $\dot{M}$~<$M_{edd}$

~<kpc – ion abs. (X-ray WAs; UV NAL), ion emi. (UV-IR)

v>~1000km/s

>~kpc – molecular emi. (CO, OH, etc.)

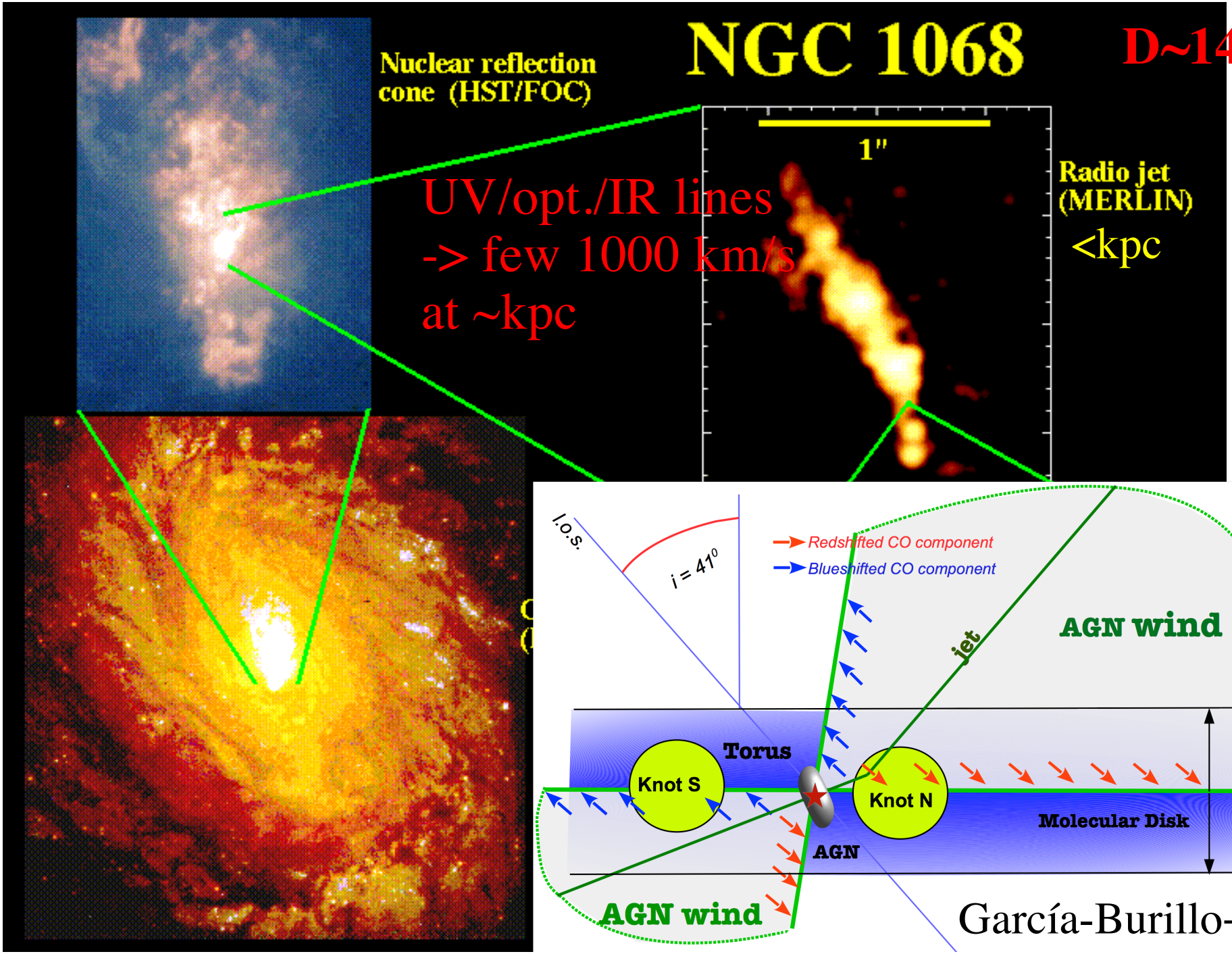
v~<1000 km/s, $\dot{M}$~<100 $M_{\Theta}$/yr, $L_{kin}$~<$L_{bol}$

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

3. May provide mechanical/thermal feedback onto host gas -> 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 + obscuring torus

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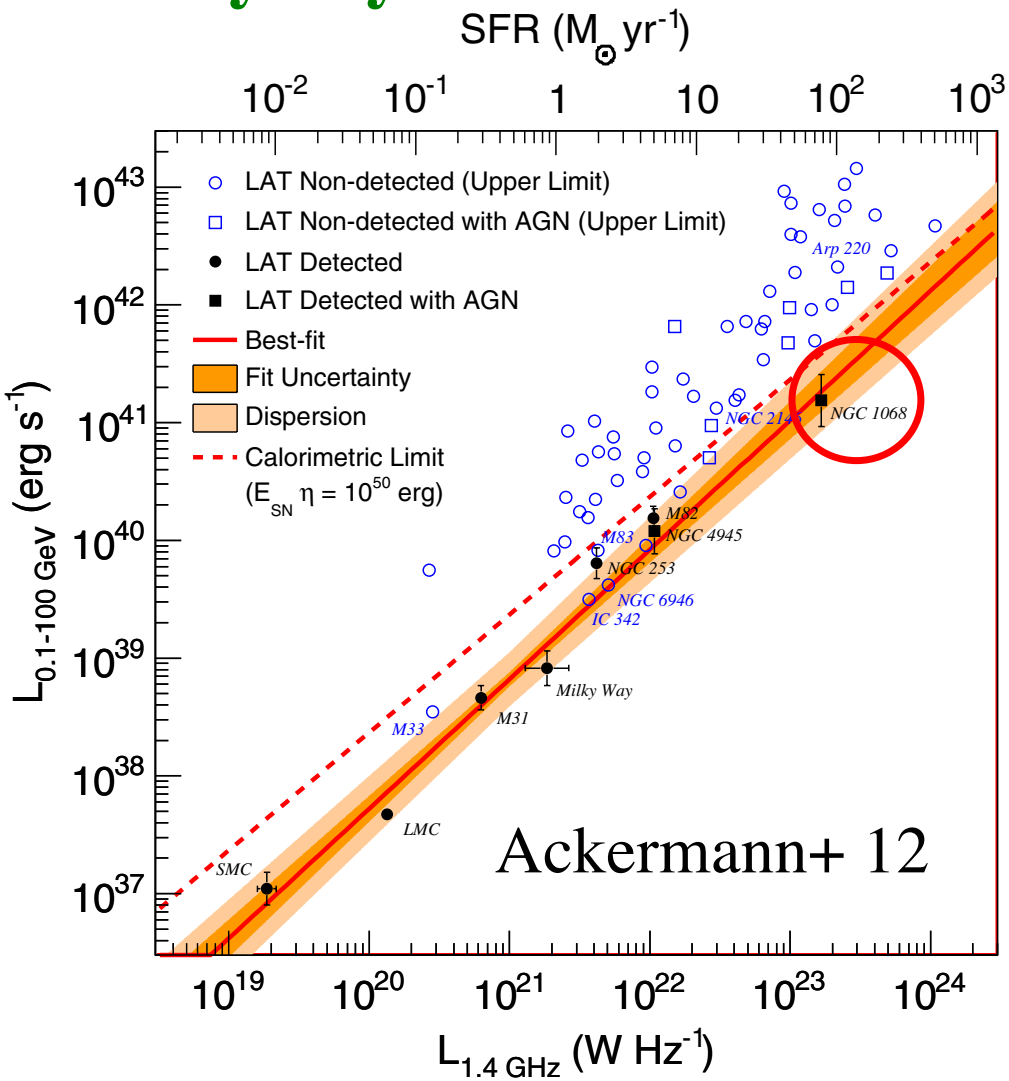
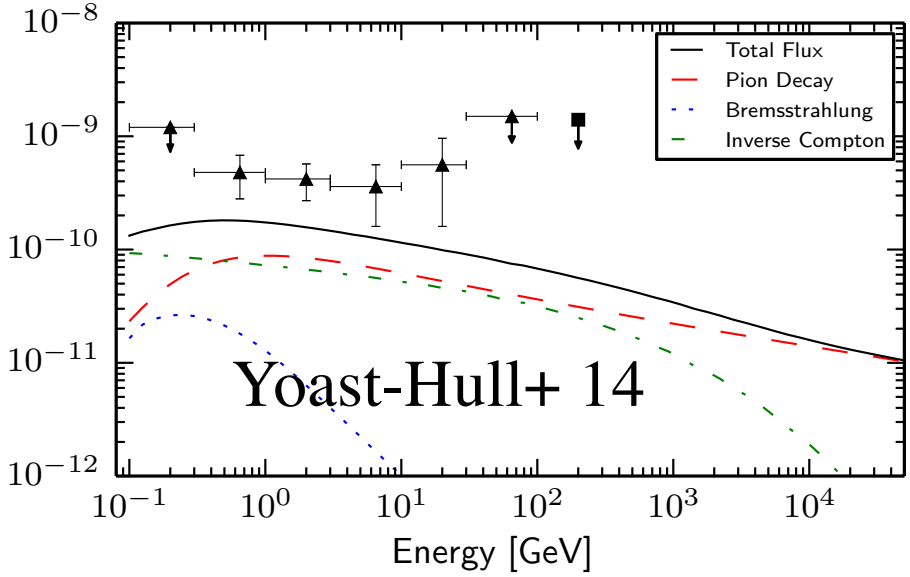
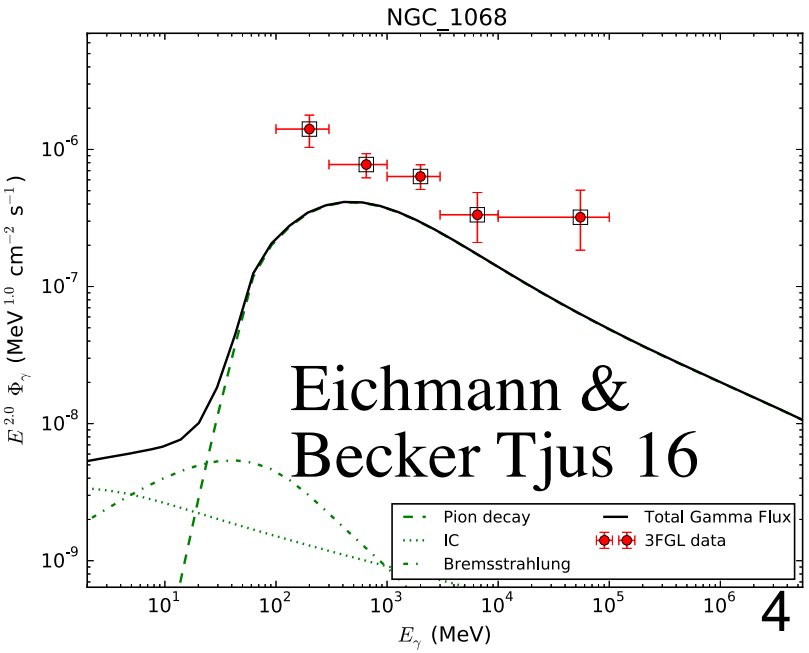
# GeV gamma rays from NGC 1068: starburst?

consistency with $L_\gamma$-SFR relation -> **maybe yes**




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

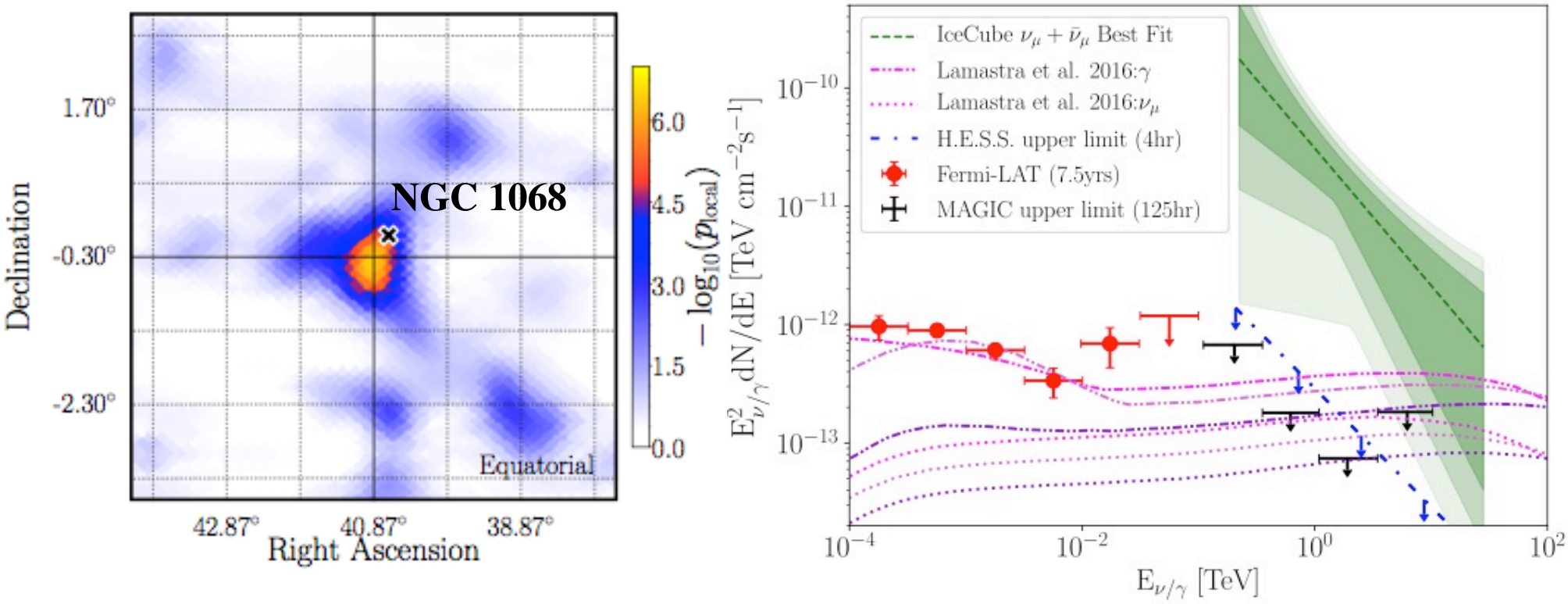



Fermi-LAT sample of "starburst"+normal galaxies

# high-energy neutrinos from NGC 1068?

IceCube 10-yr time-integrated source search 1910.08488



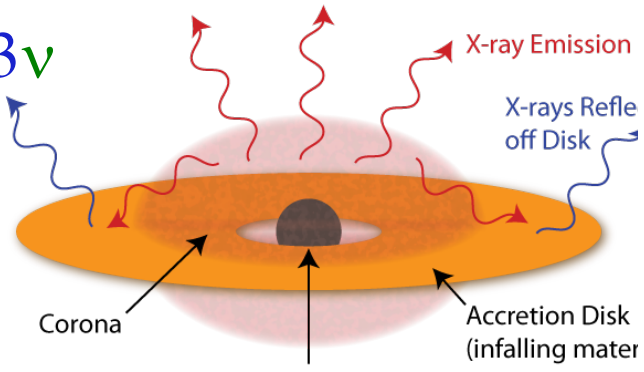

- most significant point in North from full-sky scan coincident with NGC 1068
- 2.9σ excess at position of NGC 1068 in source catalog search
- soft, TeV-range spectrum inferred
- some indications in time-dependent search 2109.05818

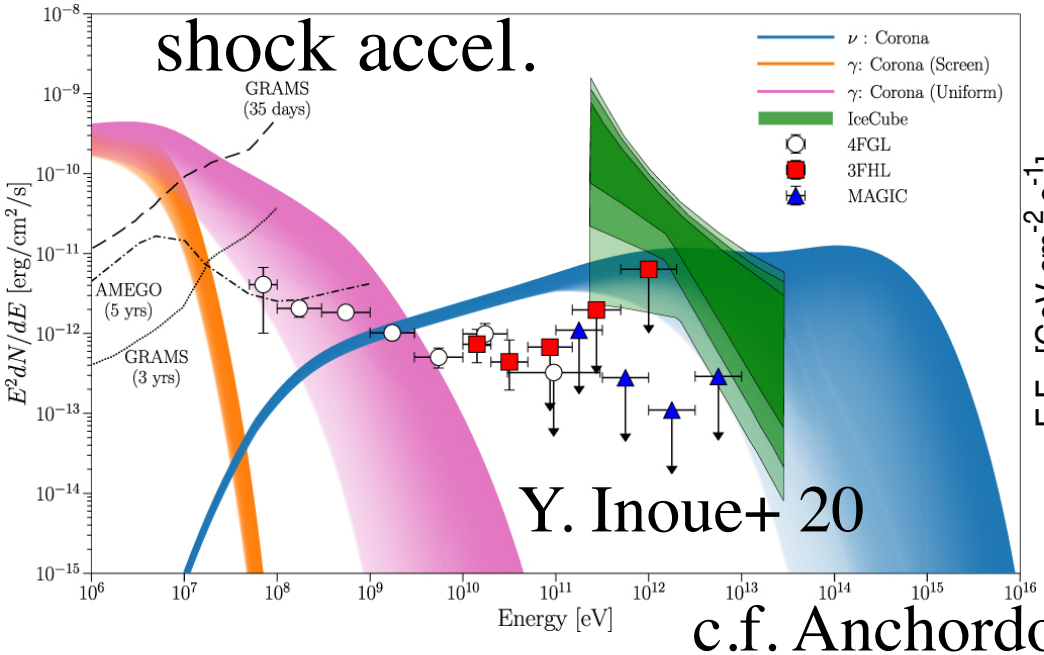
# neutrino + gamma from NGC 1068: AGN origin?

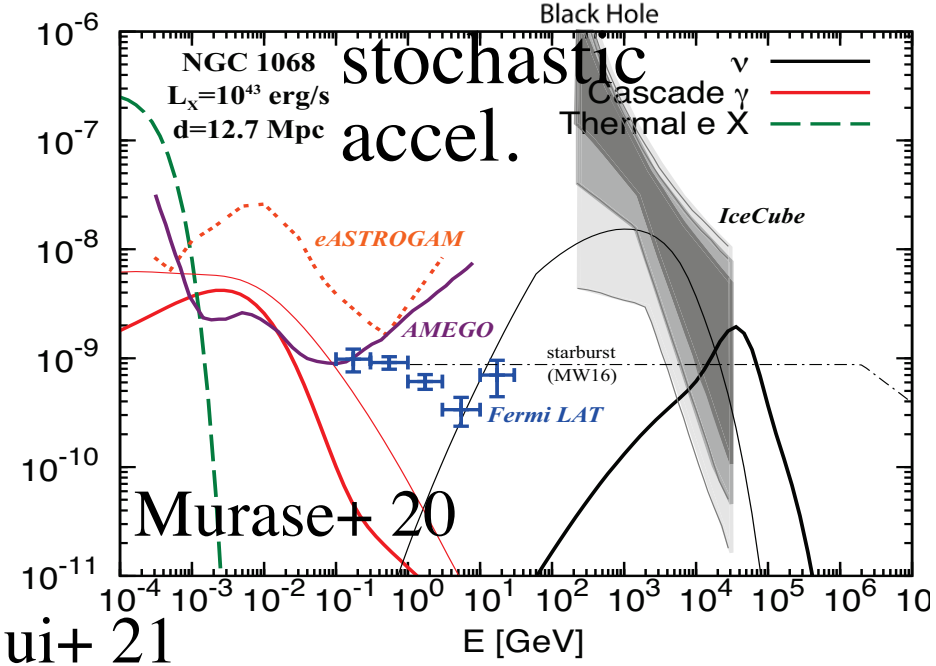
AGN wind external shock models e.g. Lamastra+ 16
(generally pp models optically thin to γγ)
strongly constrained by MAGIC TeV upper limits

$p_{CR}+p_{gas} \rightarrow N + \pi^0, \pi^\pm$ $\pi^0 \rightarrow 2\gamma$ $\pi^\pm \rightarrow \mu^\pm \nu \rightarrow e^\pm + 3\nu$

pp(+pγ) in compact regions optically thick to γγ, e.g. accretion disk coronae?

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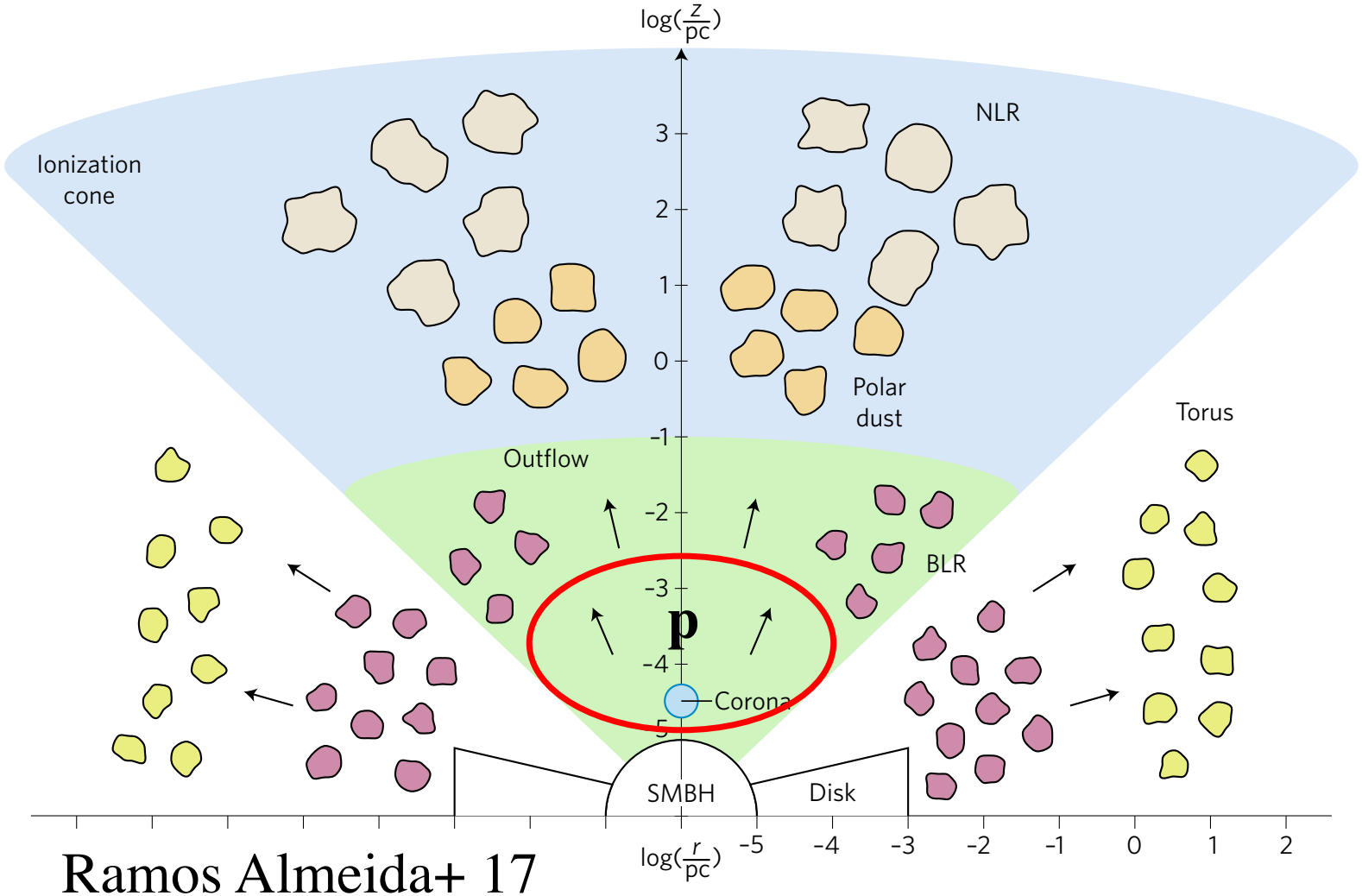
robustness of particle acceleration? GeV γ rays?

# pγ ν+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




obs.

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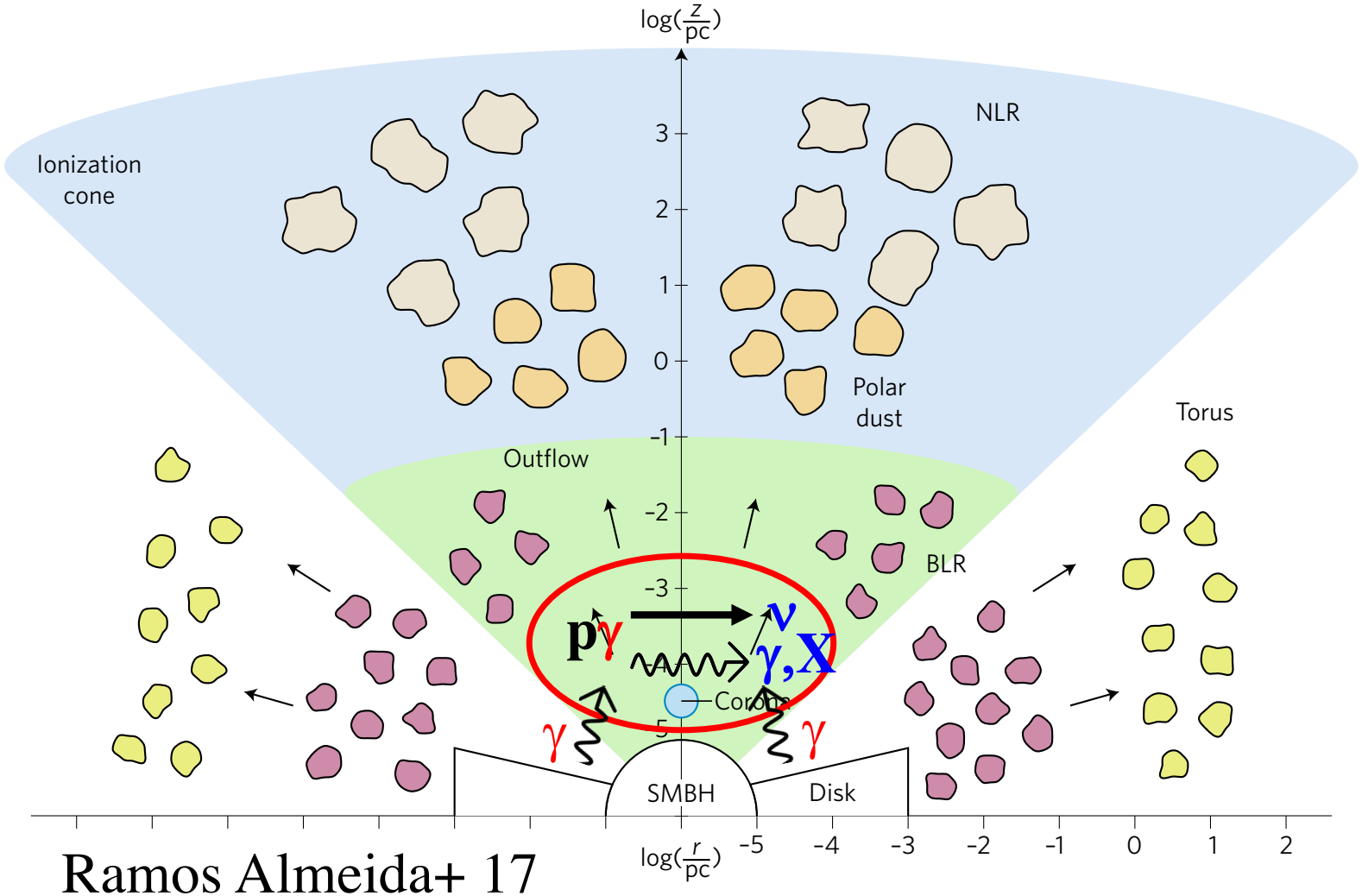


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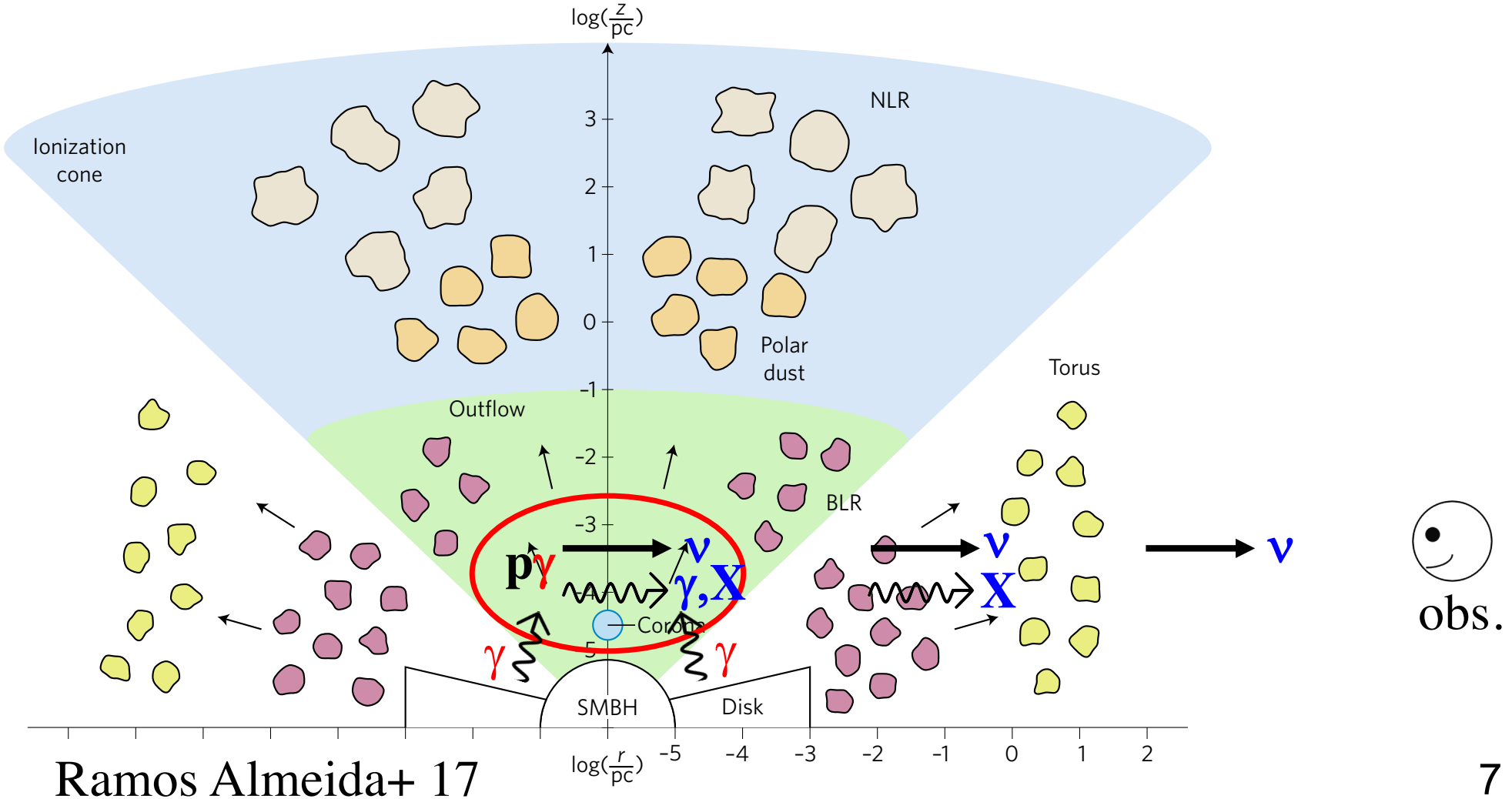


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pγ interactions with nuclear radiation
- neutrinos ~<TeV-PeV
- cascade ~<MeV-GeV

$p+\gamma \rightarrow N+ \pi^0, \pi^{\pm}$

$\pi^0 \rightarrow 2\gamma$ $\pi^{\pm} \rightarrow \mu^{\pm}\nu \rightarrow e^{\pm}+3\nu$

$\mu^{\pm}+B \rightarrow \mu^{\pm}+\gamma$ muon synchrotron

$\gamma+\gamma \rightarrow e^+e^-$ electron-positron

$e^+e^-+B/\gamma \rightarrow e^+e^-+\gamma$ sync./IC cascade

$p+\gamma \rightarrow p+e^+e^-$ Bethe-Heitler pair production

$p+B \rightarrow p+\gamma$ proton synchrotron

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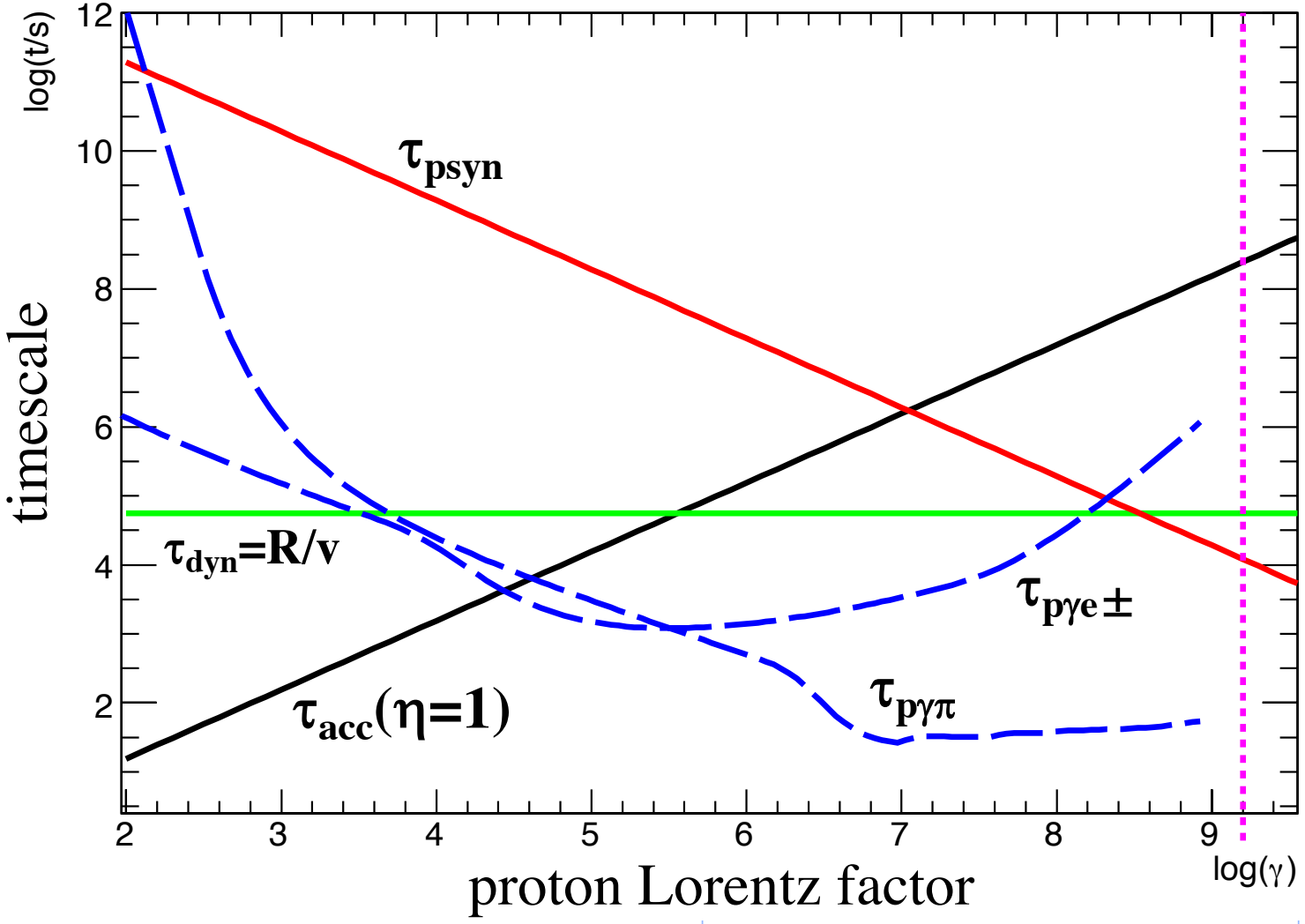
NB: photoelectric abs. + extinction in torus -> mid IR - soft X significantly attenuated

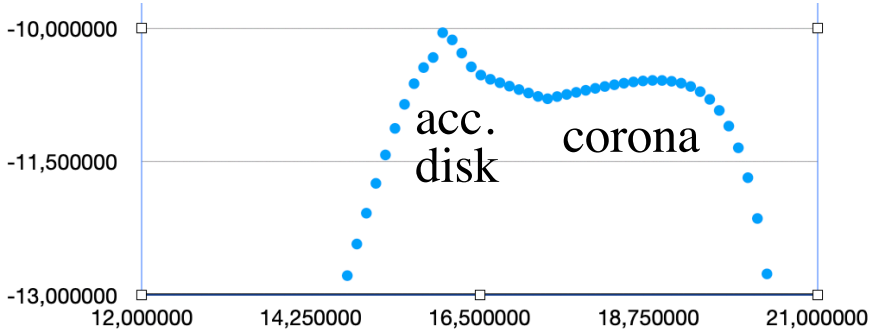
# pγ in inner regions of AGN winds: timescales



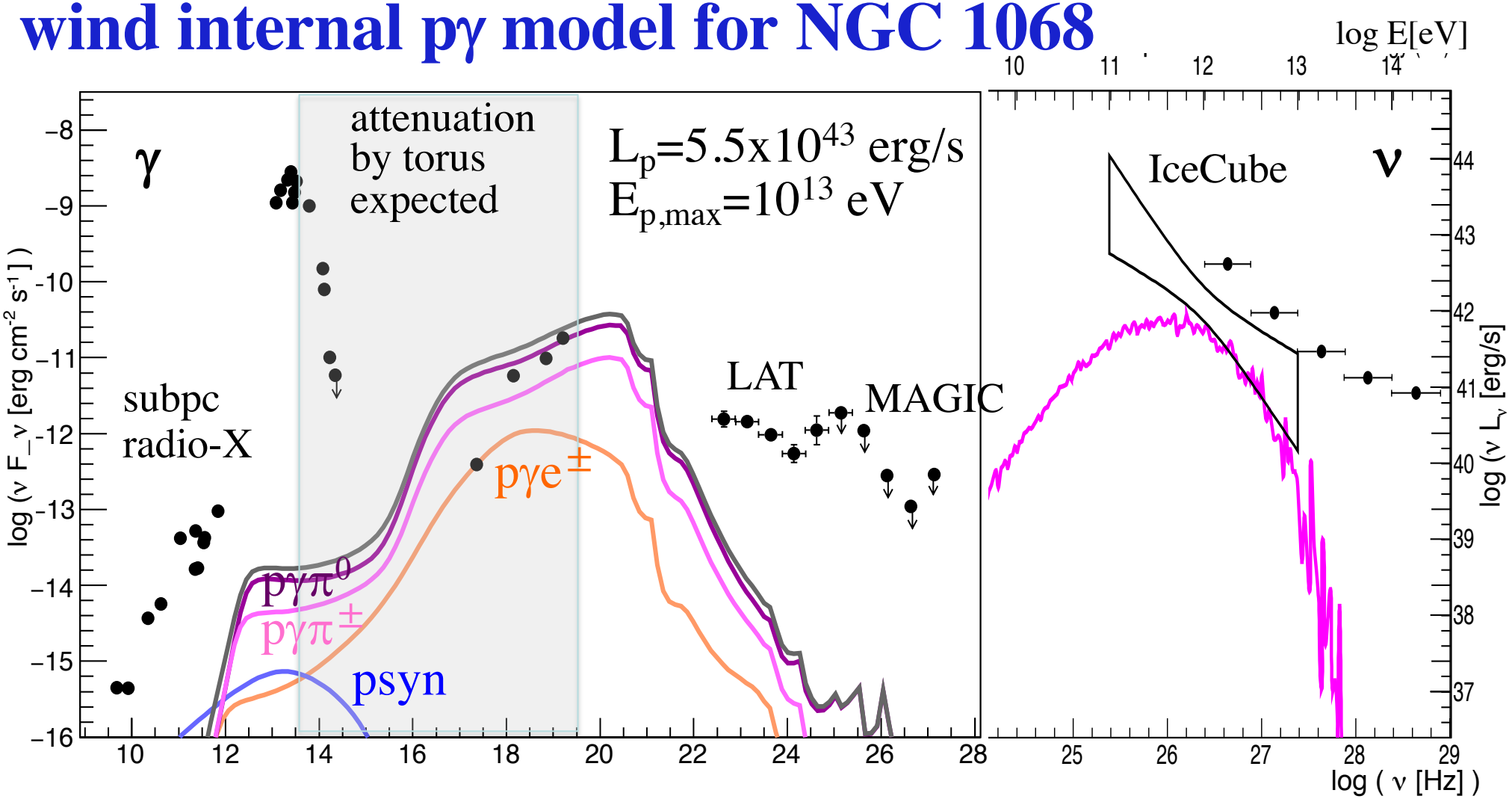

R=$10^{13}$ cm ($3R_s$)
z=$10^{14}$ cm ($30R_s$)
B=500 G
(c.f. $\varepsilon_B$~0.08 for
$L_{kin}=10^{44}$ erg/s)

v=1000 km/s
-> $E_{p,max}$~10 TeV
-> $t_{p\gamma\pi}(X)/t_{dyn}$~<1

$M_{BH}=10^7\,M_\odot$
$L_{disk}=10^{45}$ erg/s
$L_{cor}=0.1\,L_{disk}$



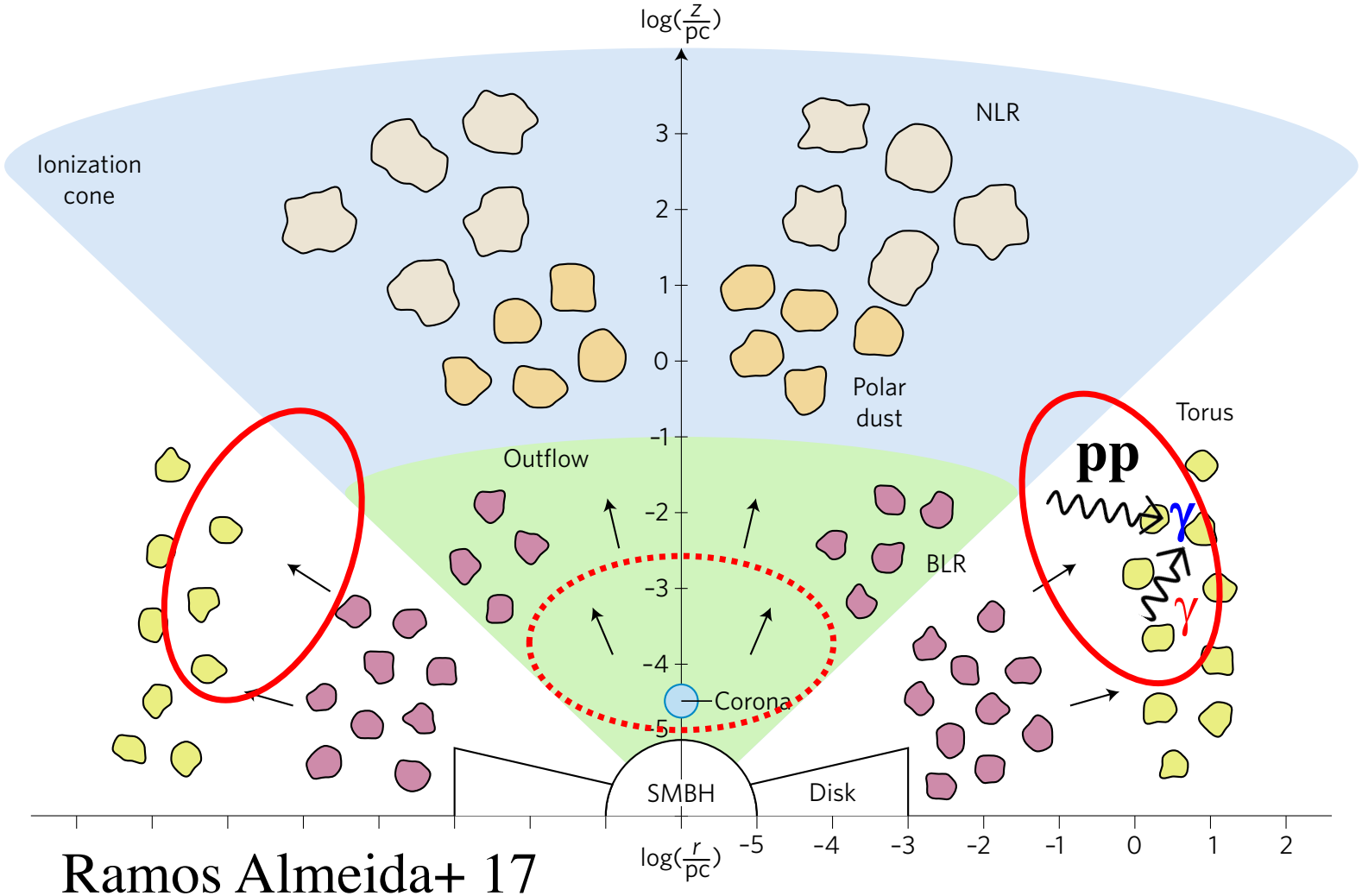
# wind internal pγ model for NGC 1068




- neutrinos: flux and spectrum reasonable wrt IceCube
- photons: hadronic cascade consistent wrt available MWL
  γγ attenuated at GeV-TeV by disk UV-X
  prominent at (keV-)MeV -> interesting for future instruments

# pp γ(+ν) from AGN wind+torus interaction

wind + torus interaction (inevitable)
-> external shock formation -> proton acceleration
-> pp interactions with torus gas
-> GeV escape, TeV γγ attenuated with torus IR




GeV γ

obs.

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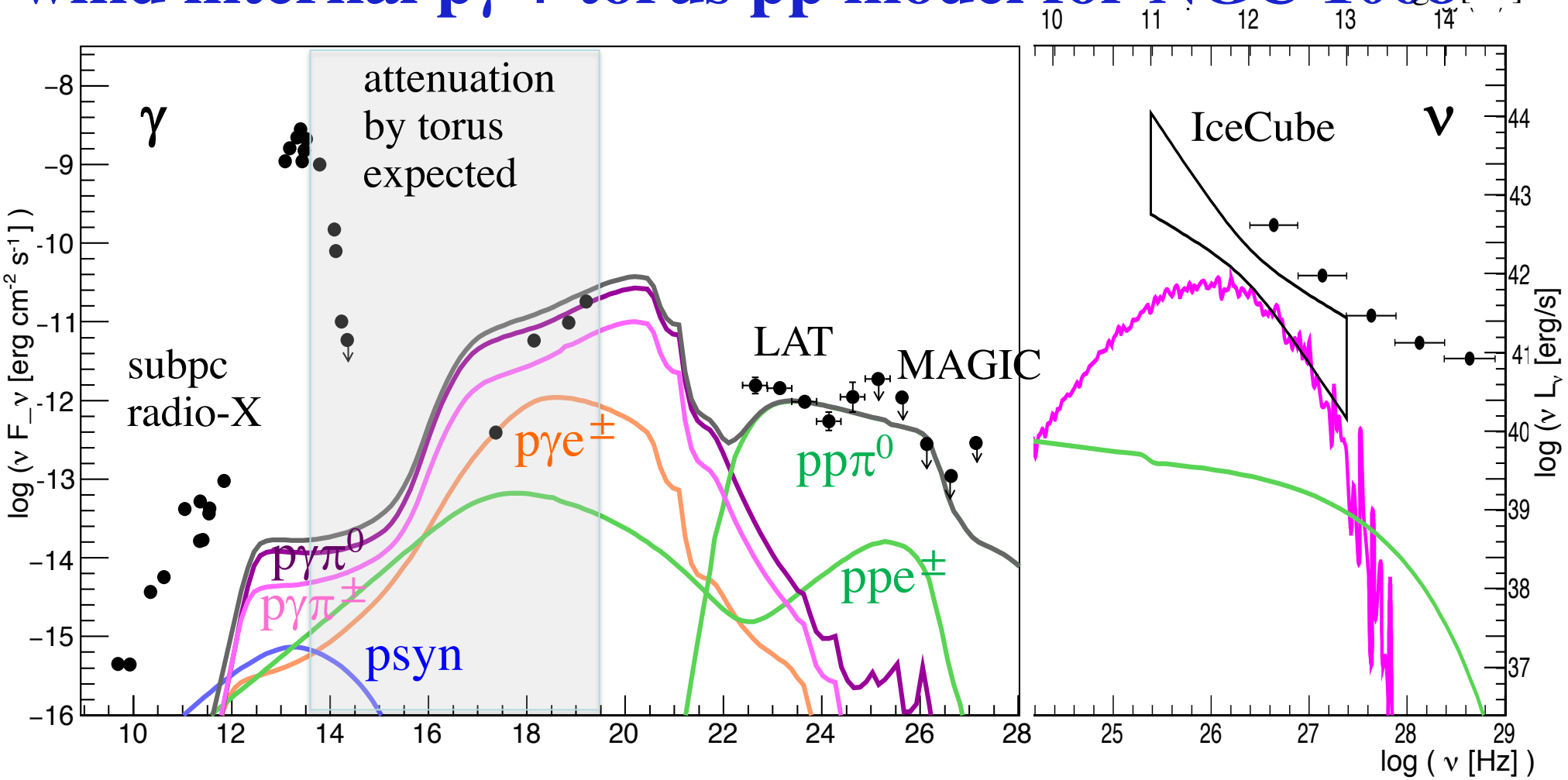
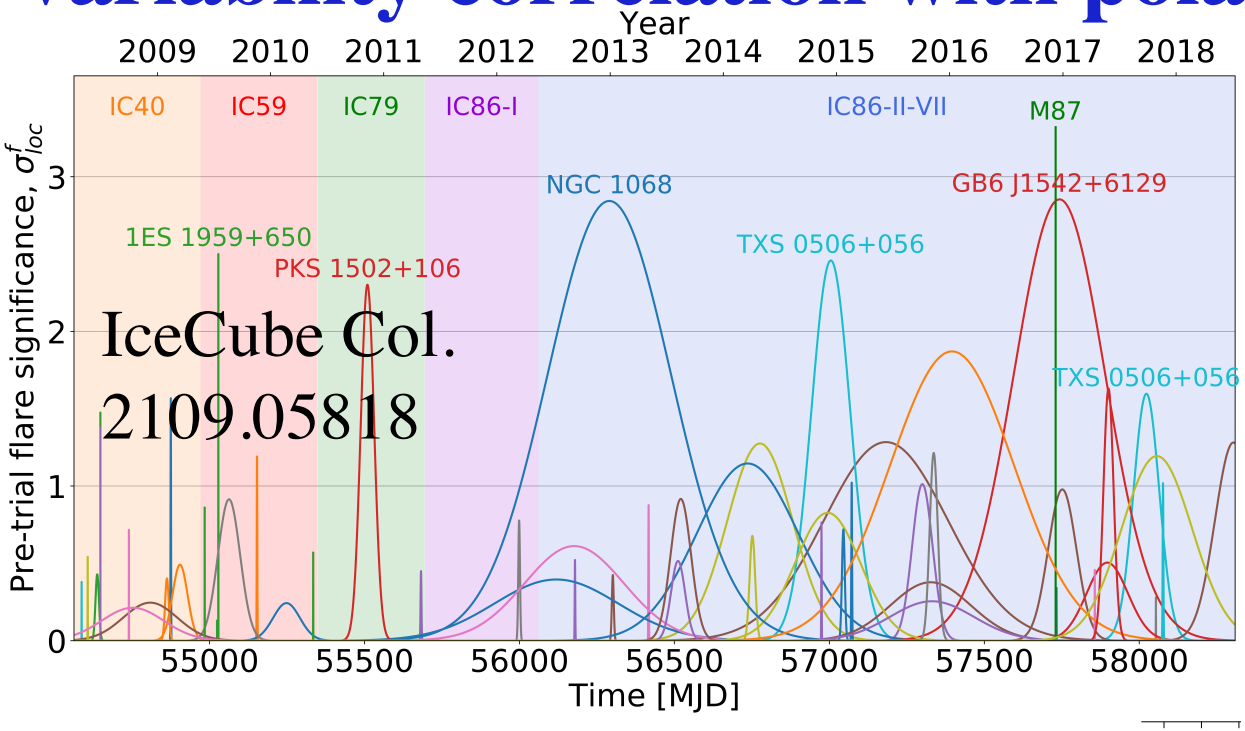
# wind internal pγ + torus pp model for NGC 1068



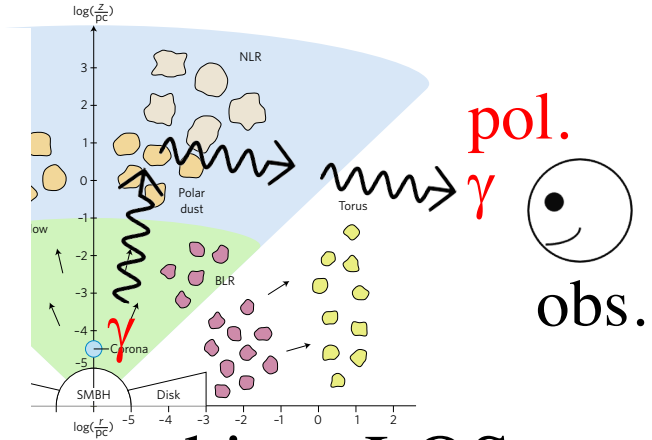

- GeV: pp γ-rays from wind-torus interaction shock
  TeV: γγ attenuated by torus IR

$R_{tor}=10^{17}$ cm, $n_{tor}=10^{7}$ cm$^{-3}$, $B_{tor}=0.1$ G
v=1000 km/s
$L_p=2.3\times10^{41}$ erg/s, $E_{p,max}=2.5\times10^{14}$ eV

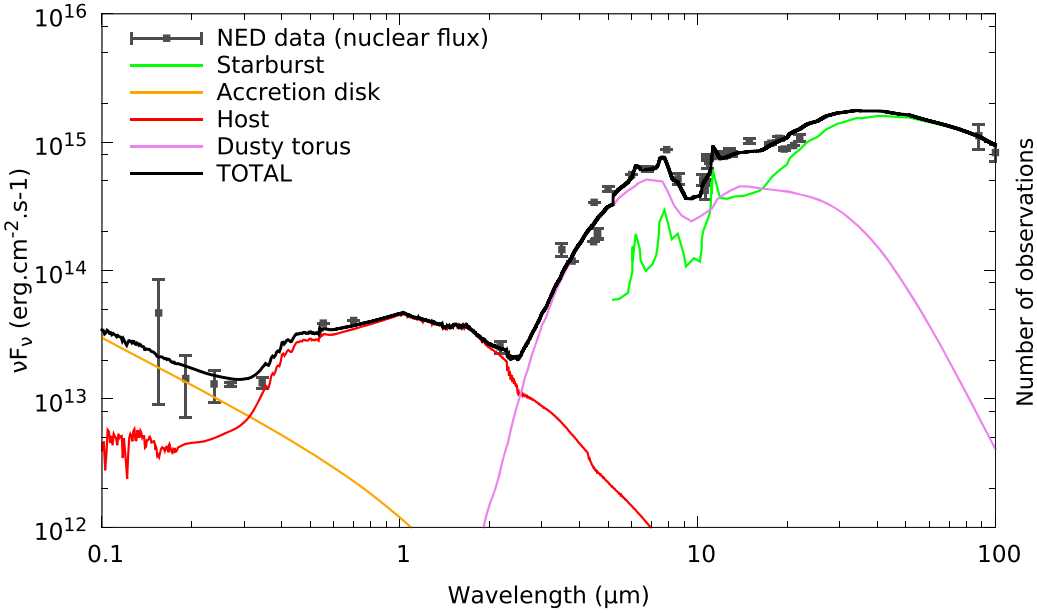
# variability correlation with polarized opt.-NIR?

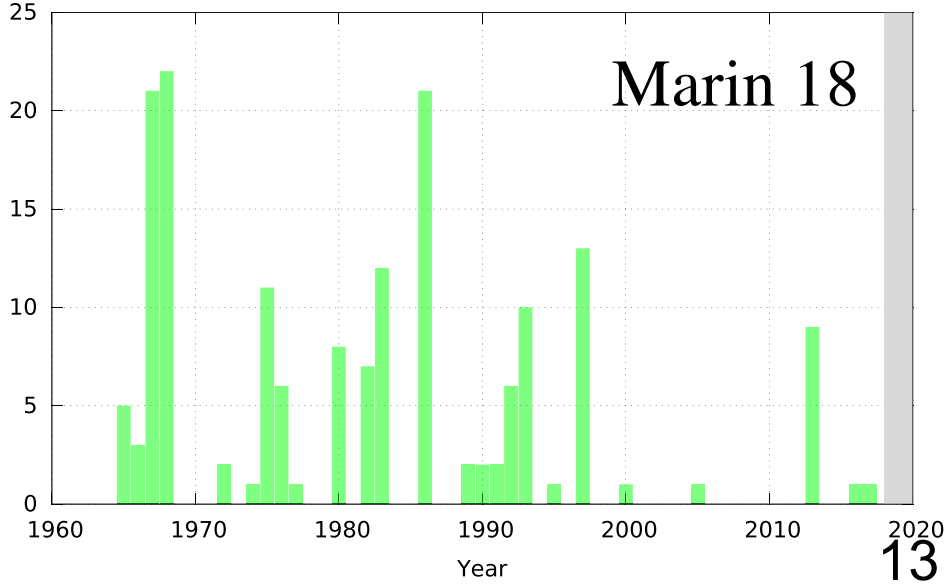



yr-timescale variability?
-> if real, likely due to accretion rate variations




polarized optical-NIR: nuclear emission scattered into LOS



## summary

fact: AGN winds - fast, powerful, widespread, inc. NGC 1068

interpretation of TeV ν + GeV γ for NGC 1068

- p accel. in inner regions near nucleus
- assuming v~1000 km/s, pγ neutrinos with soft TeV spectrum
- cascade photons γγ attenuated at GeV-TeV, prominent at MeV
- p accel. in wind-torus interaction shock, pp γ-rays at GeV

future tests and prospects

- cascade MeV, variability correlation w. polarized optical-NIR
- other nearby Seyferts with winds by IceCube-Gen2, CTA, etc
- contribution to diffuse ν background
- unique info on AGN winds (B field, etc)

Paper to be submitted soon
please stay tuned!