Revisiting Disk Winds in Active Galactic Nuclei as an Origin of Cosmic Gamma-ray and Neutrino Backgrounds

Nobuyuki Sakai (The University of Osaka)

Collaborators: Yoshiyuki Inoue (Shibaura Institute of Technology) and Ellis R. Owen (RIKEN)

Sakai, Inoue, and Owen (2026, published in ApJ)
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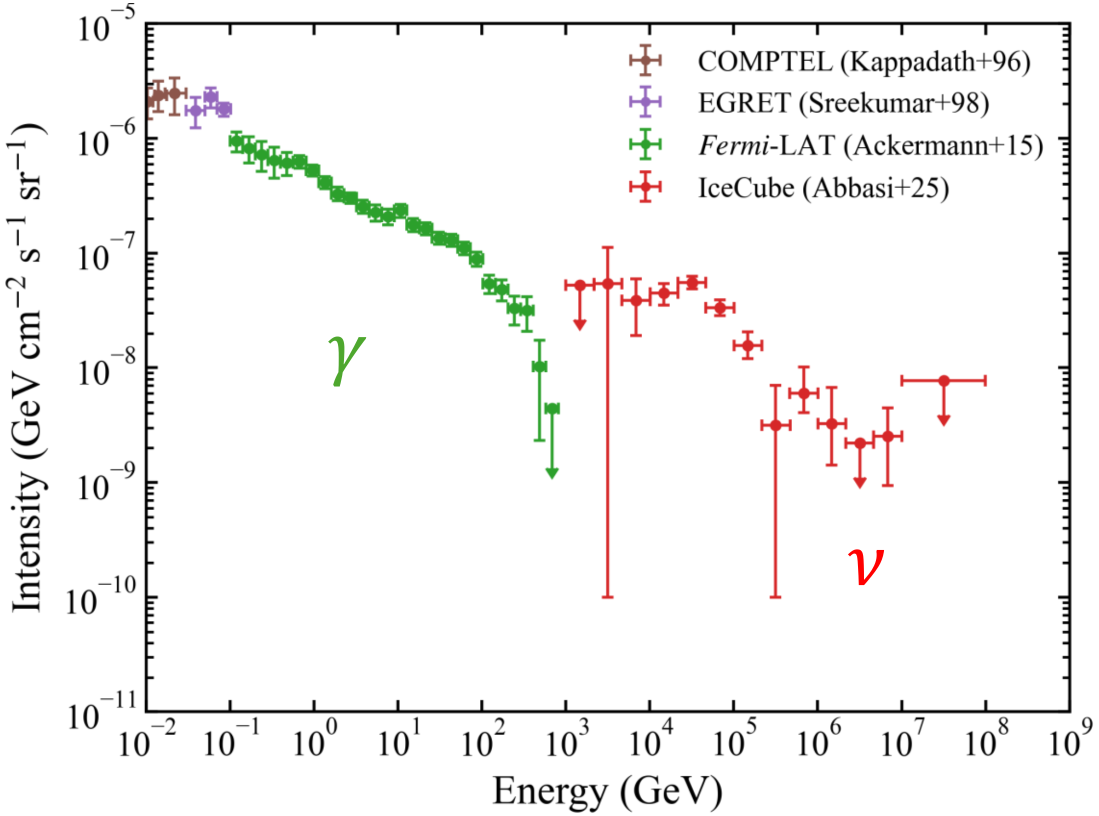
Cosmic Gamma-ray/Neutrino Background
(CGB/CNB)

Isotropic GeV gamma rays and TeV-PeV neutrinos from the Universe
(e.g., Ackermann+15; Aartsen+15; Abbasi+25a,b)

- Likely astrophysical origin
- Related to dominant cosmic-ray (CR) accelerators in the Universe

CGB and CNB spectra

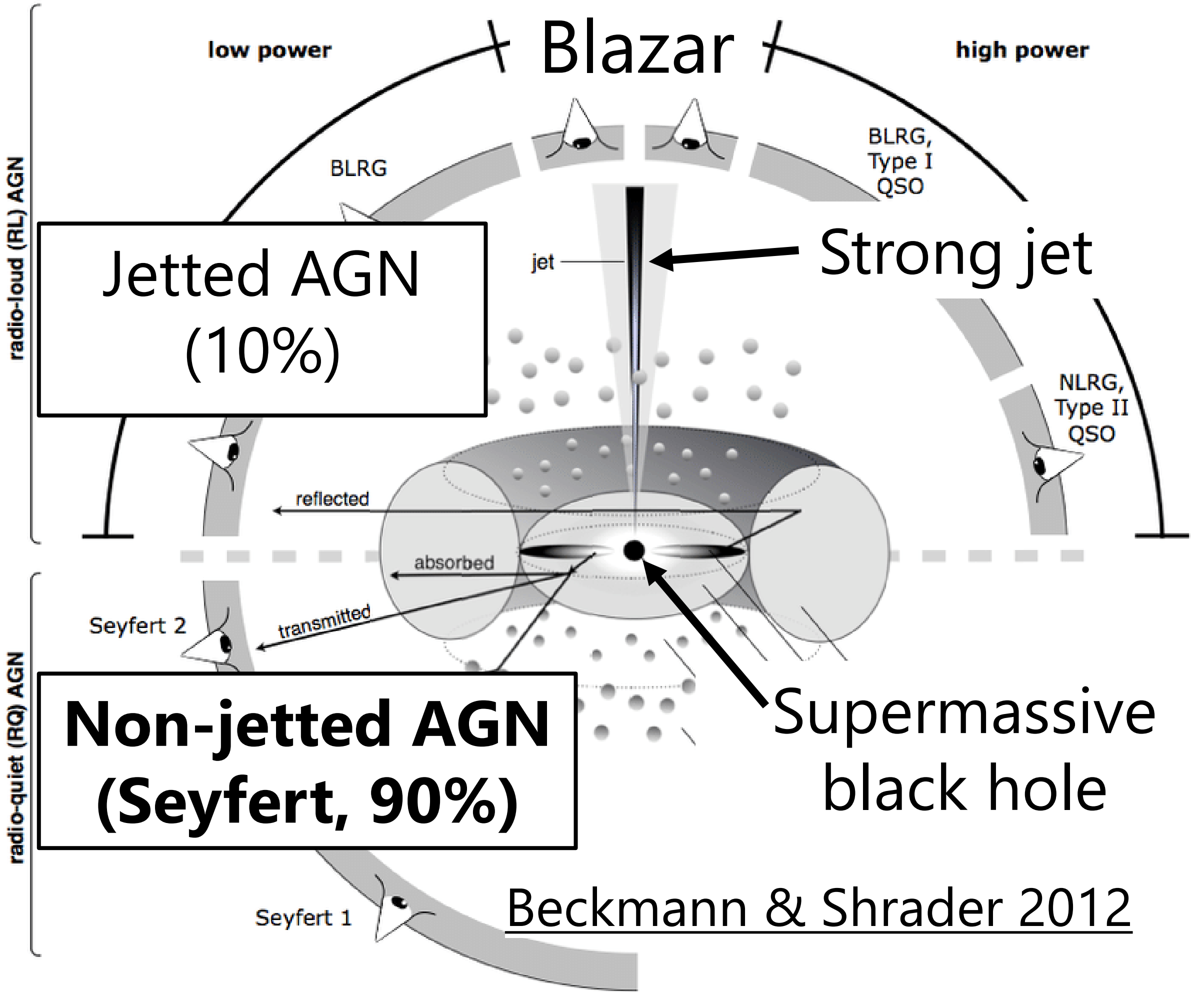


What are the origins of the CGB/CNB?

CGB and CNB origins remain uncertain.

- Active galactic nuclei (AGNs)?
  - Blazars?
    (e.g., Murase+14; Rodrigues+18)
  - Coronae?
    (e.g., Kalashev+15; Inoue+19)
  - **Disk winds**?
    (e.g., Wang & Loeb16; Liu+18)
- Star-forming galaxies?
  (e.g., He+13; Carulli & Reynoso 24)
- Others

AGN standard model



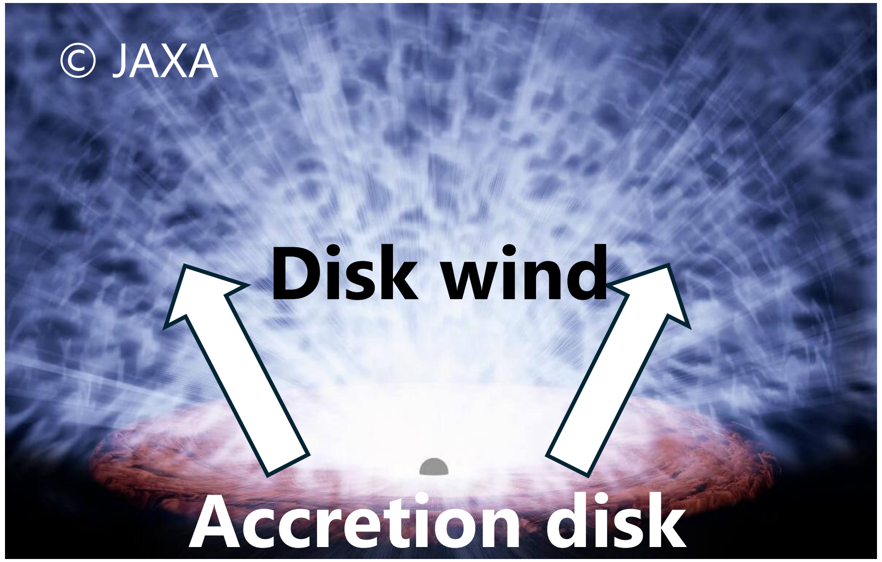
Beckmann & Shrader 2012

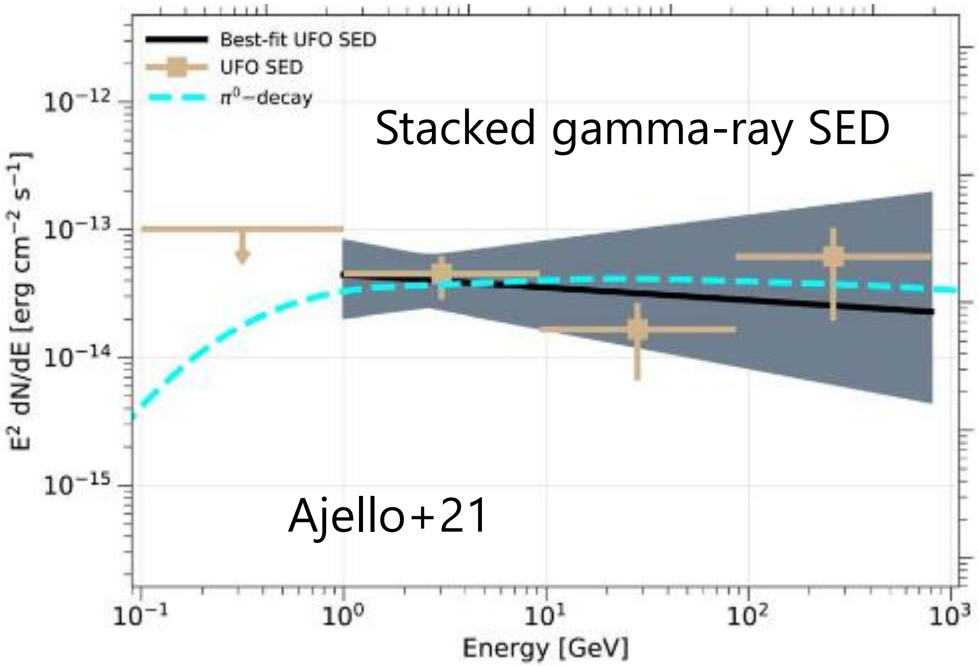
Why disk winds?

Disk winds are

- **Ubiquitous**: ~40% of nearby AGNs host them (Tombesi+10).
- **Fast** ($v \sim 0.1c$, e.g., Tombesi+10).
- **Powerful**: kinetic powers can be comparable to AGN luminosities (XRISM+25).
- Detected by stacking analysis of GeV gamma rays (Ajello+21).

Implying **CR acceleration and gamma-ray/neutrino emission** from disk winds





Can disk winds be origins of the CGB and CNB?

- Previous wind studies (Wang & Loeb16; Lamastra+17; Liu+18) determine parameters (wind power, gas density) without comparison with individual gamma-ray observations.
- We revisit disk winds **based on gamma-ray observations**.

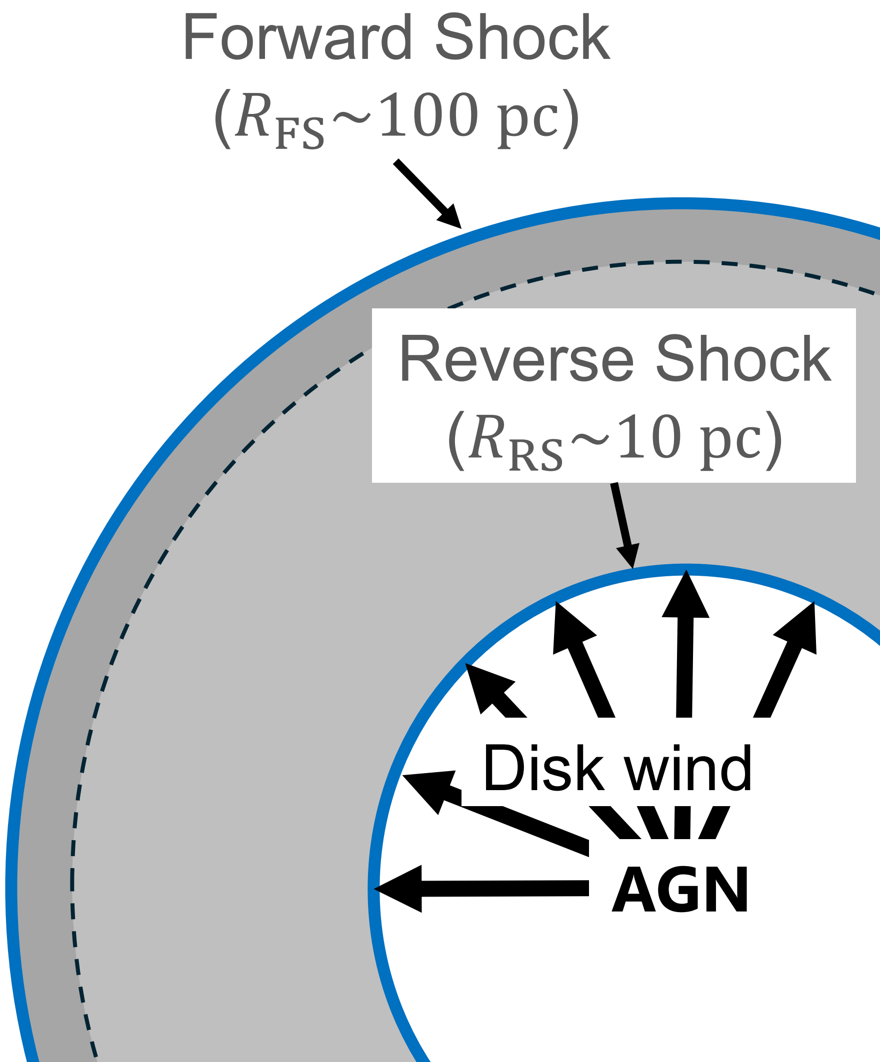
1. Model construction
2. Parameter calibration
3. Estimating the contribution of disk winds

Disk wind dynamical model

(Koo & McKee 92; Faucher-Giguere & Quataert12; **Sakai**+25; **Sakai**+26)

Disk winds interact with interstellar medium (ISM), generating shocks.

- Accretion disks launch winds (e.g., Proga+00).
  - Wind momentum rate: $\dot{M}_{\rm w} v_{\rm w} = \boldsymbol{b}_{\rm w} L_{\rm AGN}/c$
- ISM density profile: $n(r) = \boldsymbol{n}_{0}(r/100\ {\rm pc})^{-1}$
- Wind-ISM interactions create a forward shock (FS) and a reverse shock (RS).
  - Shock radii: $R_{\rm FS} \propto t_{\rm w}^{3/4}, R_{\rm RS} \propto t_{\rm w}^{5/8}$ (self-similar)
  - $\boldsymbol{t}_{\rm w}$: wind age (i.e., time elapsed since disk winds launched)

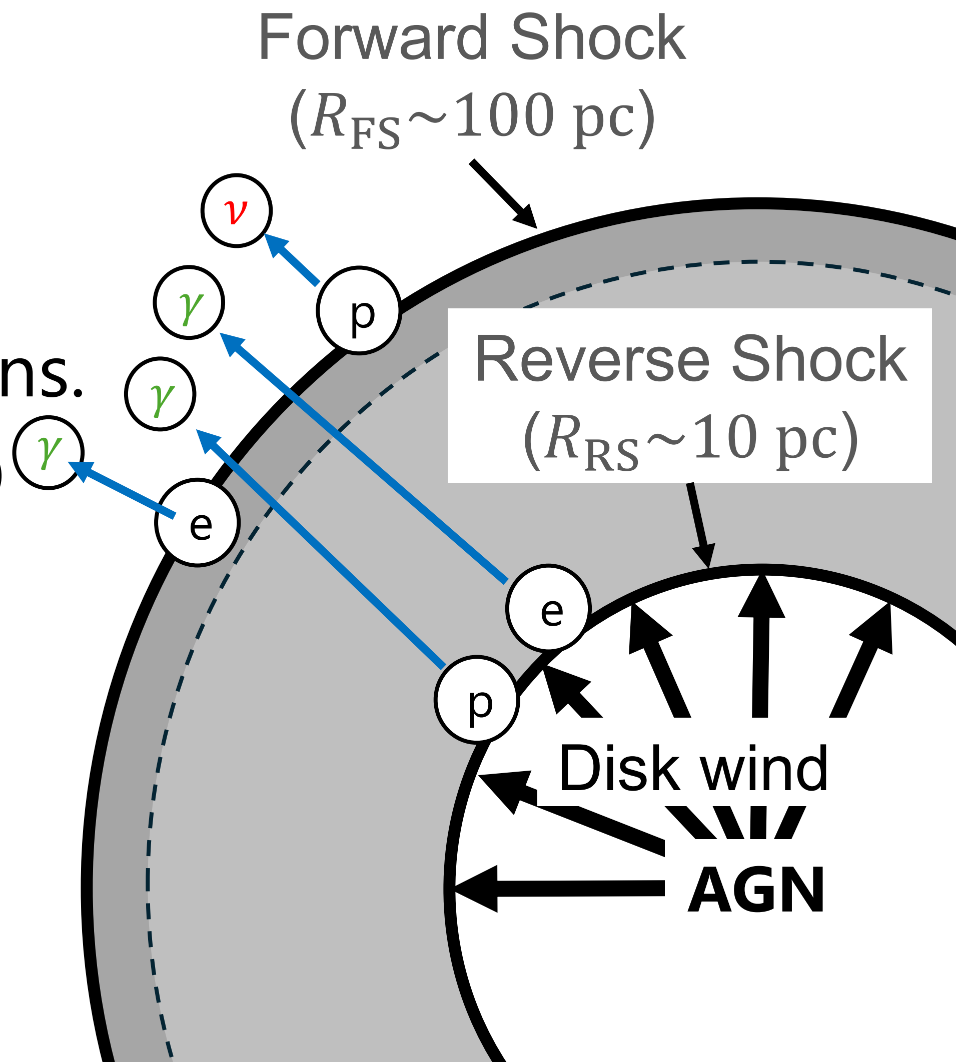


Disk wind emission model

(Nims+15; Yamada+24; **Sakai**+25; **Sakai**+26)

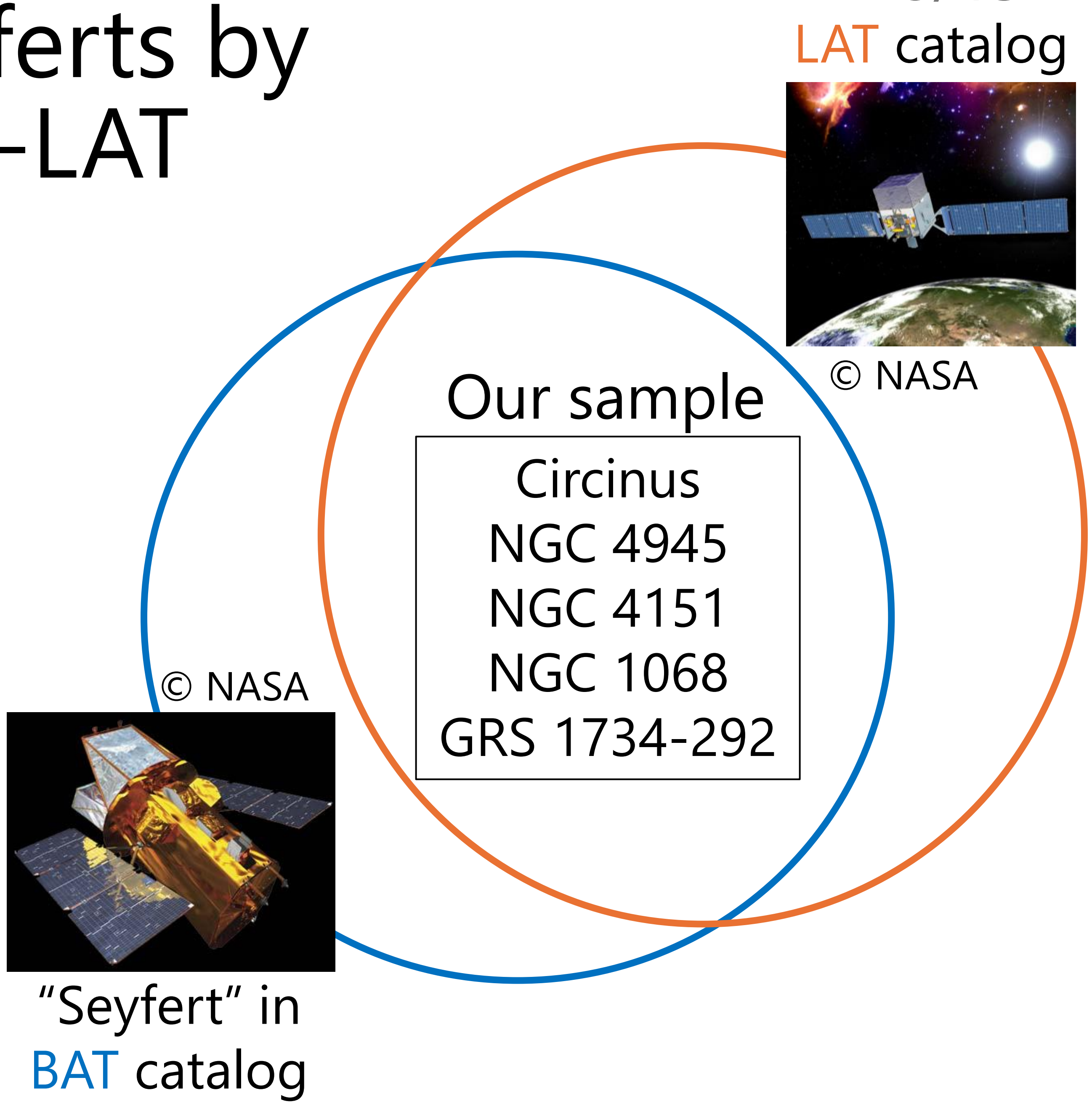
Particles are accelerated at shocks and produce γ rays and neutrinos.

- Shocks accelerate CR electrons and protons.
    - Diffusive shock acceleration (e.g., Drury 83)
    - Injected spectrum $\propto E^{-p_{\mathrm{CR}}}$
- CRs produce gamma rays and neutrinos mainly through external inverse Compton (**EC**) and pp interactions.



Selecting GeV Seyferts by Swift-BAT × Fermi-LAT

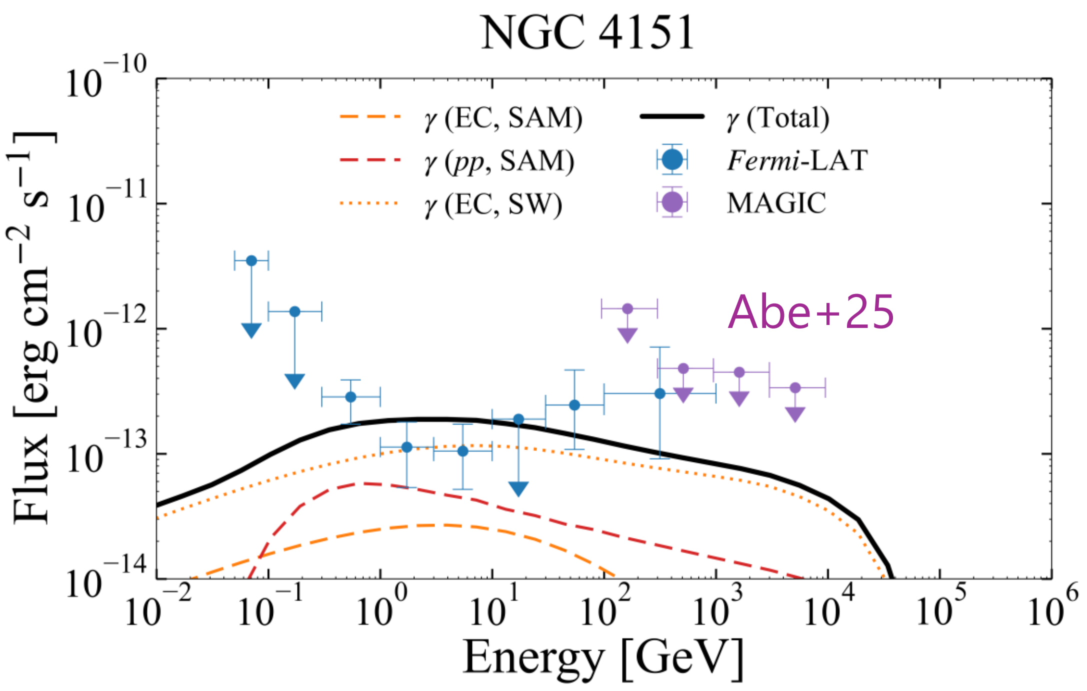
- Fermi catalog contains 3814 AGNs, but 98% are blazars (Abdollahi+23).
- We remove blazars using **BAT×LAT cross-match** (Tsuji+21).



Parameter calibration for GeV Seyferts (Model A: EC-dominated)

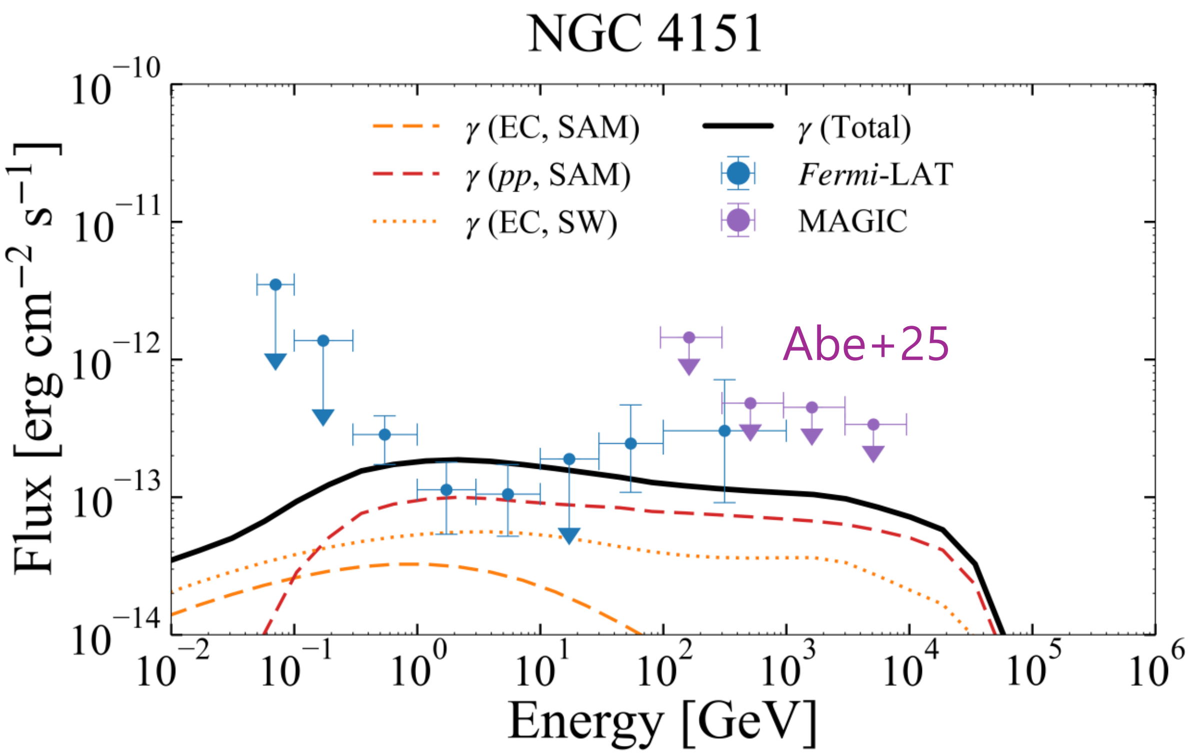
We **calibrate parameters** using GeV-detected Seyferts.

- **EC-dominated** cases (Model A)
- Free parameters: $(b_\mathrm{w}, t_\mathrm{w}, B_\mathrm{FS}, p_\mathrm{CR})$
  - B_FS: magnetic field at forward shock
- $(1, 10^5\ \mathrm{yr}, 59\ \mu\mathrm{G}, 2.27)$ reproduces gamma-ray SED of e.g., NGC 4151.



Parameter calibration for GeV Seyferts (Model B: *pp*-dominated)

- ***pp*-dominated** cases (Model B).
- Free parameters: $(b_{\mathrm{w}}, n_0, B_{\mathrm{FS}})$
  - n_0: gas density at 100 pc
- For e.g., NGC 4151, $(1, 100\ \mathrm{cm}^{-3}, 230\ \mu\mathrm{G})$ is viable.
- Note: GeV emission could also originate from other components (e.g., weak jet, Inoue & Khangulyan 23).

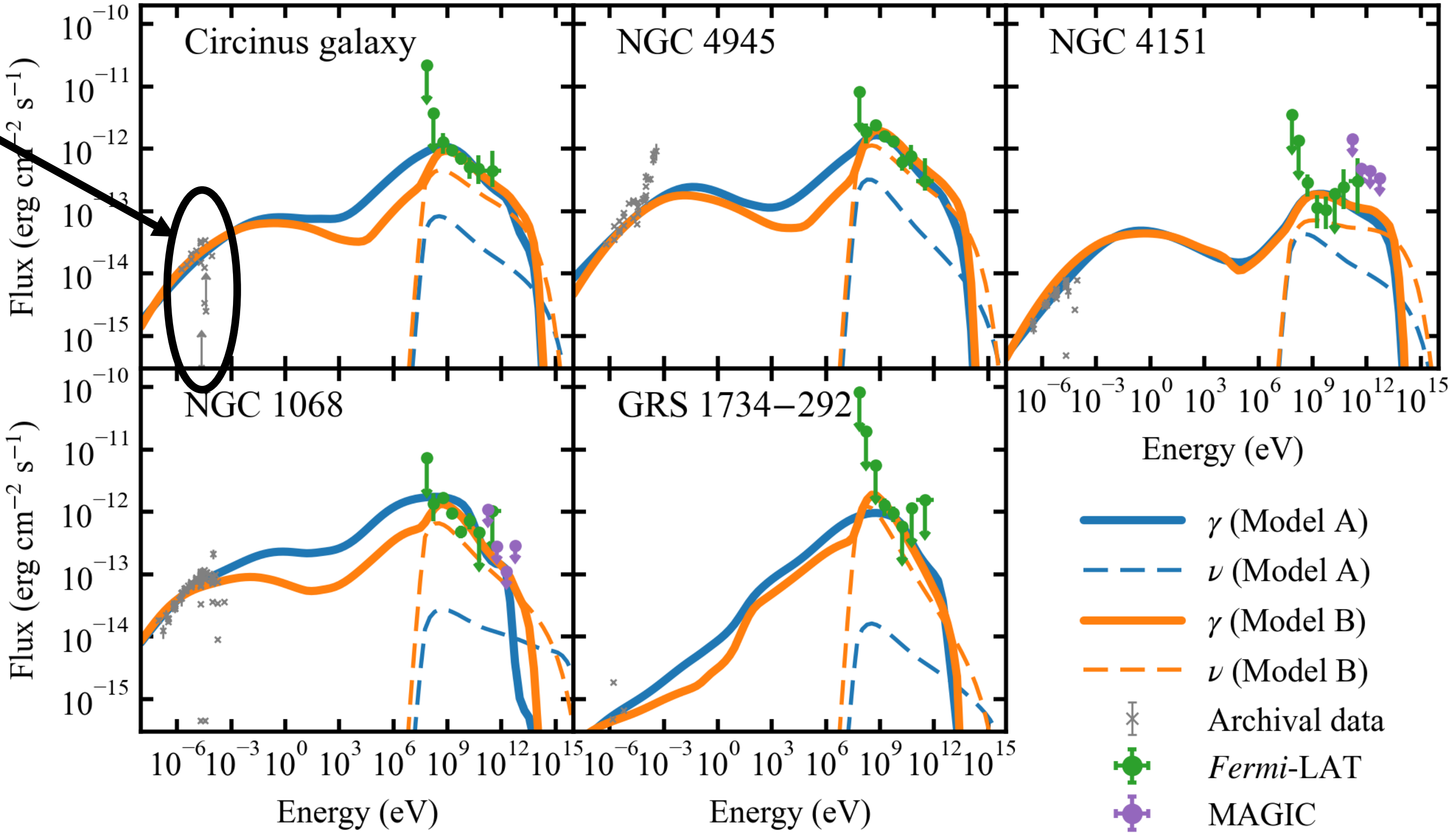


Parameter calibrations for other objects

$b_{\mathrm{w}} = \dot{M}_{\mathrm{w}} v_{\mathrm{w}} / (L_{\mathrm{AGN}}/c)$

- Consistent with radio observations
- Median $b_w^{\prime}$ values:
  - 40 (Model A)
  - 3 (Model B),

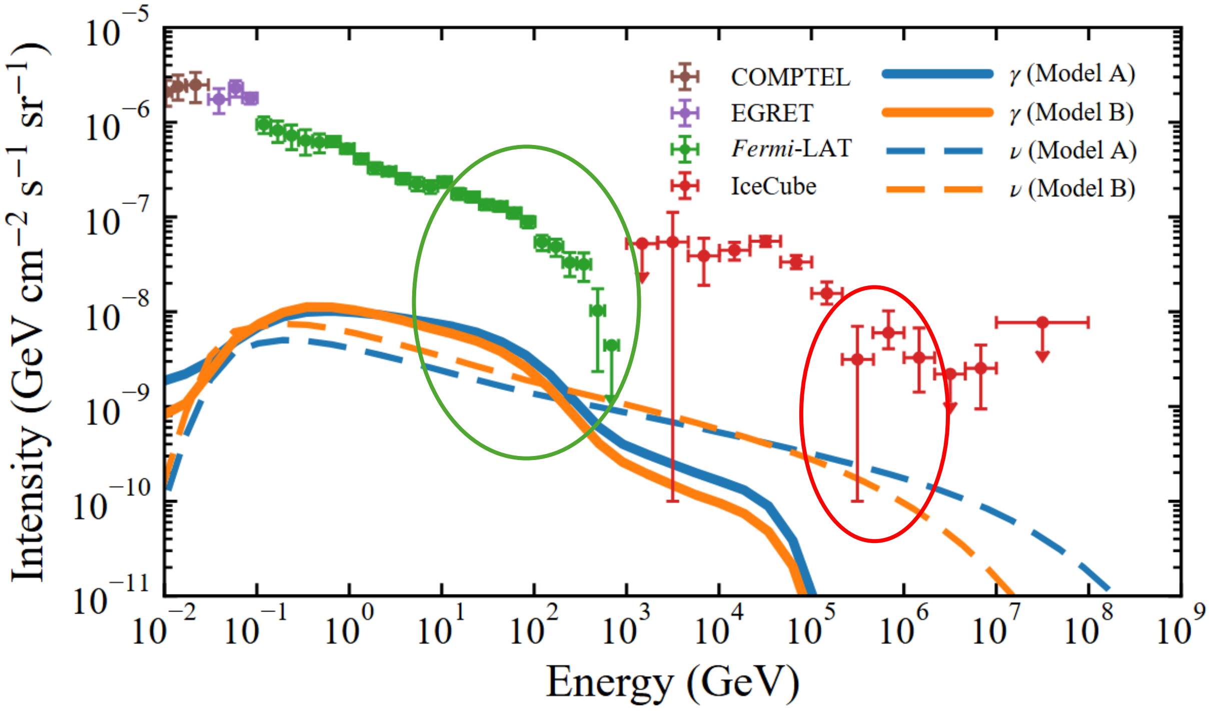
  below those inferred from XRISM (Xiang+25).
- We calibrate other parameters as well.



Disk wind contributions to CNB and CGB

Disk winds subdominantly contribute to CGB and CNB.

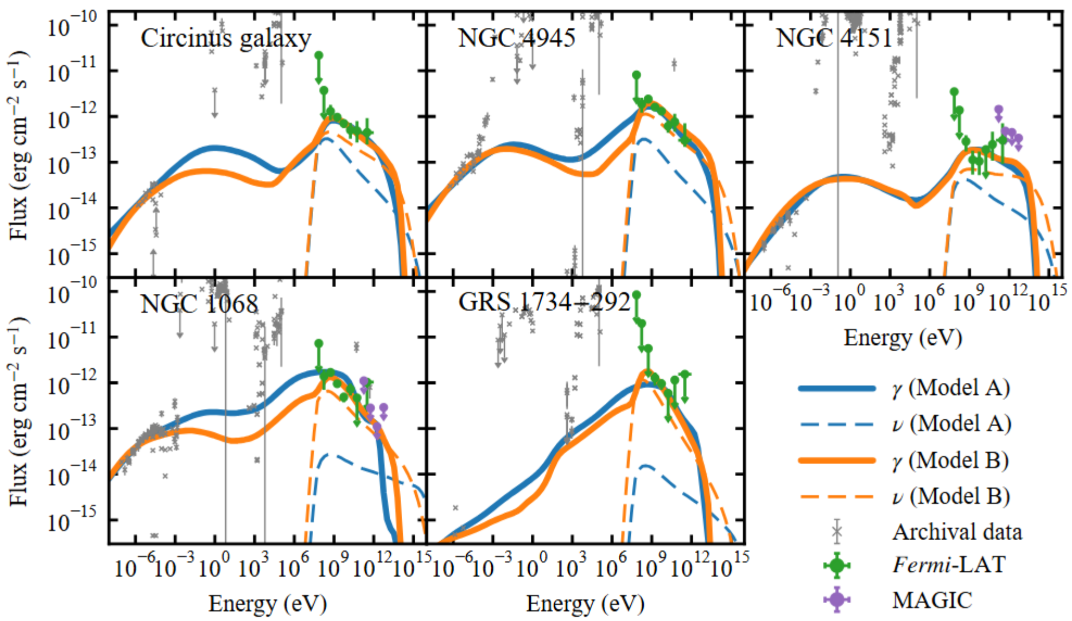
- Assuming all disk winds have median calibrated values
- X-ray-based AGN luminosity function (Ueda+14)
- Uniform age distribution
- Contributions:
  - CGB: $\sim 5\%$ (> 10 GeV)
  - CNB: $\sim 10\%$ (~ 100 TeV)

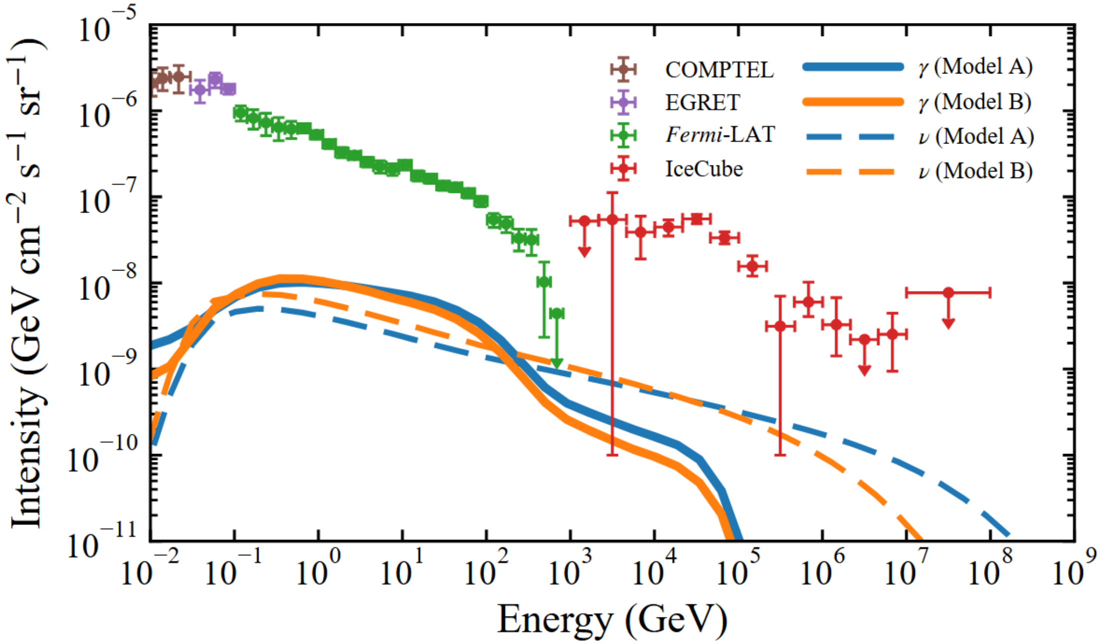


Summary

- Our disk wind model reproduces GeV gamma rays from Seyferts.
- Disk-wind contributions are ~ 5% (CGB) and $\lesssim$ 10% (CNB), using calibrated parameters.

Disk winds are unlikely main CGB and CNB origins.



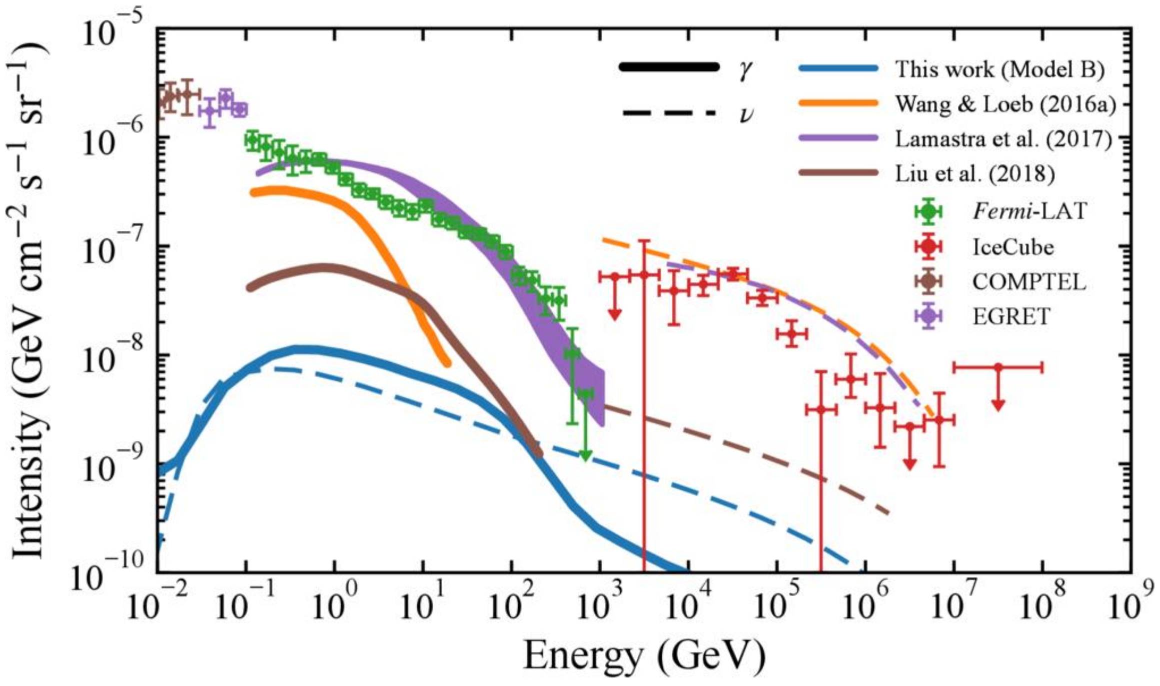


Comparison with previous works

Our **Seyfert-calibrated** models predict lower intensities.

- Previous works determined wind parameters without comparison with individual gamma-ray data.
  (Wang & Loeb 16ab; Lamastra+17; Liu+18)
- We **calibrate** them against GeV-detected Seyferts.

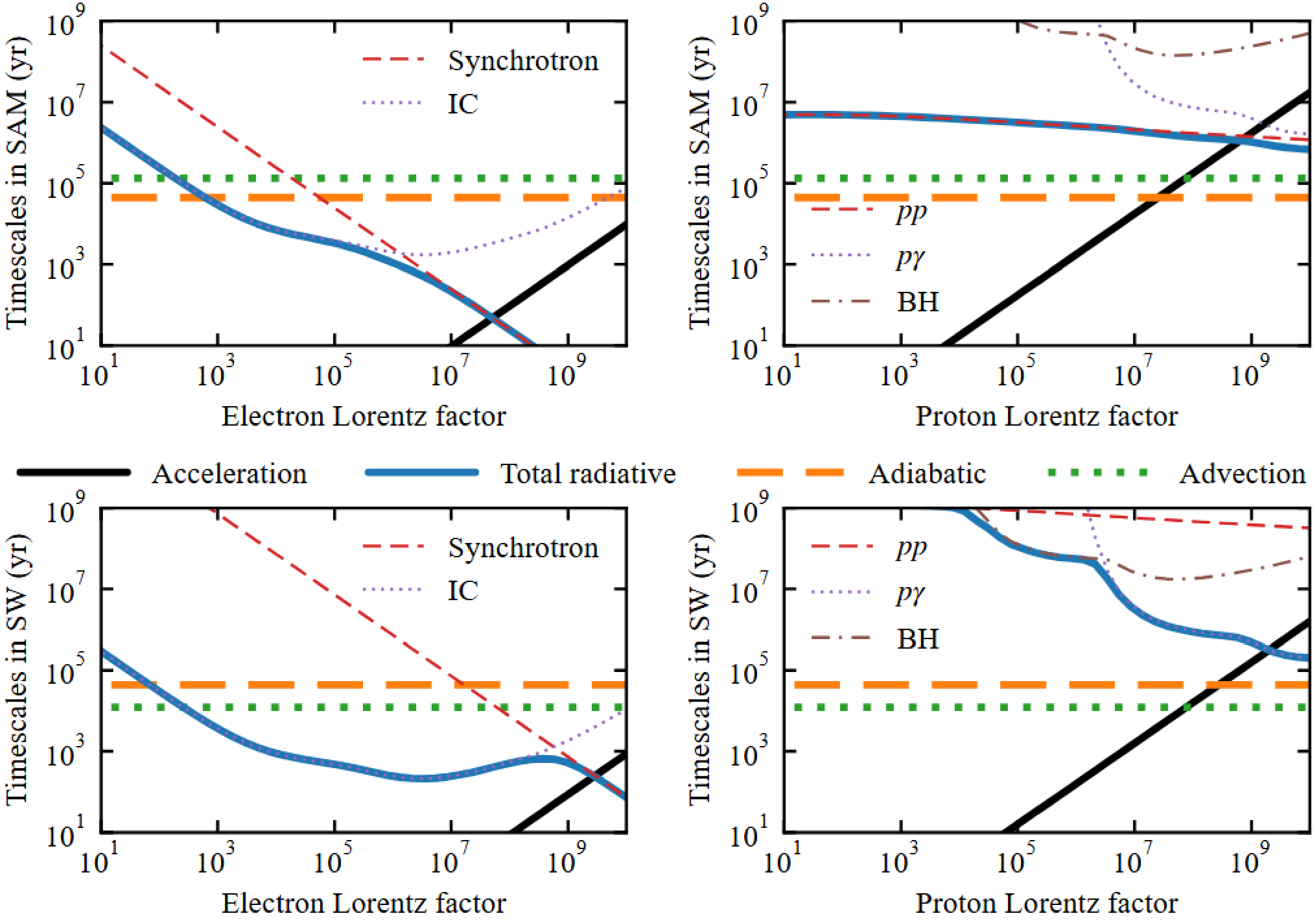
→ More robust and conservative predictions by adopting stronger winds and less dense gas



Appendix

Fiducial parameters and timescales

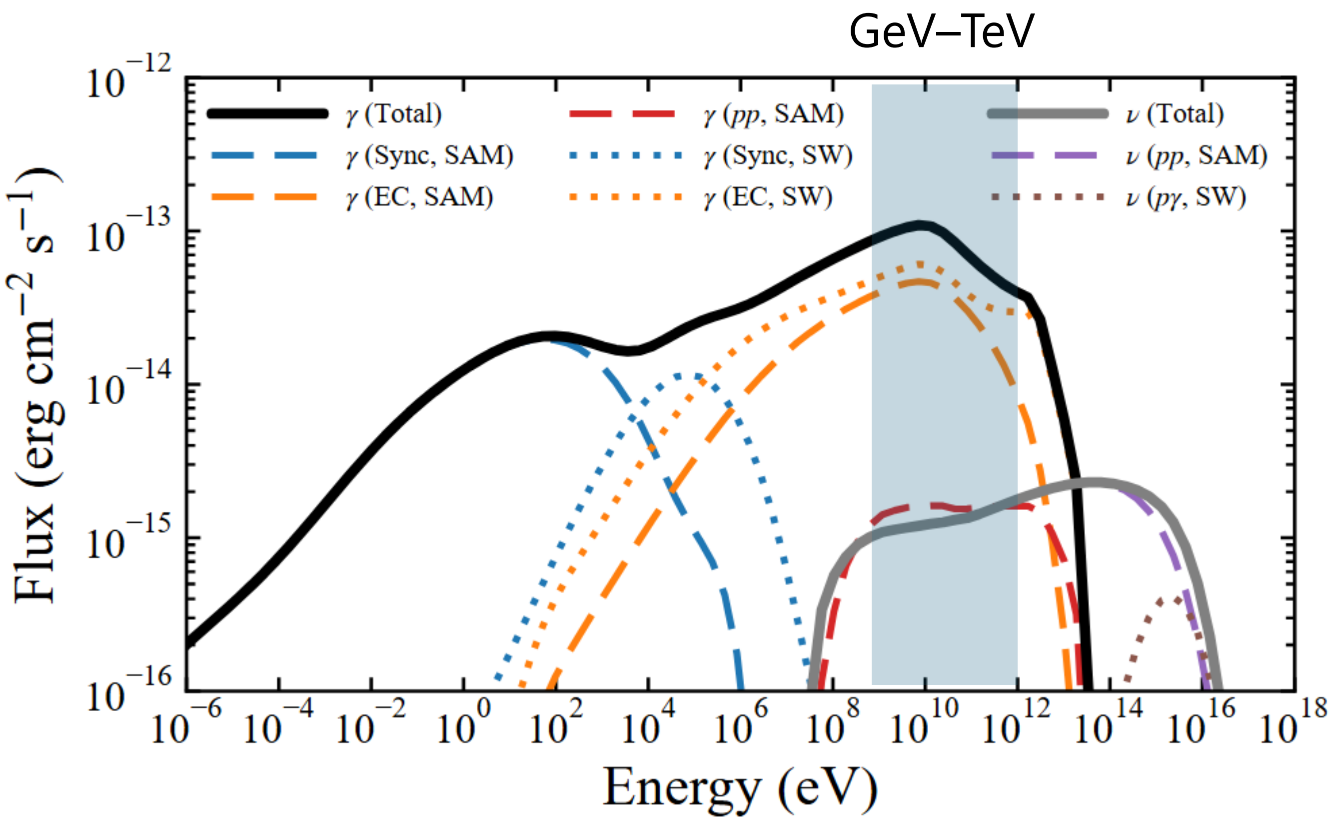
Parameter	Value
$L_{\rm AGN}$ (erg s^{-1})	10^{46}
$b_{\rm w}$	1
$t_{\rm w}$ (yr)	10^5
$v_{\rm w}$ (c)	0.1
n_0 (cm^{-3})	10
β	1
$k_{\rm B}T_{\rm disk}$ (eV)	10
$k_{\rm B}T_{\rm torus}$ (eV)	0.03
$B_{\rm SAM}$ (μG)	100
$\epsilon_{B,\rm SW}$	10^{-5}
$p_{\rm CR}$	2.0
ξ_e	0.01
ξ_p	0.1



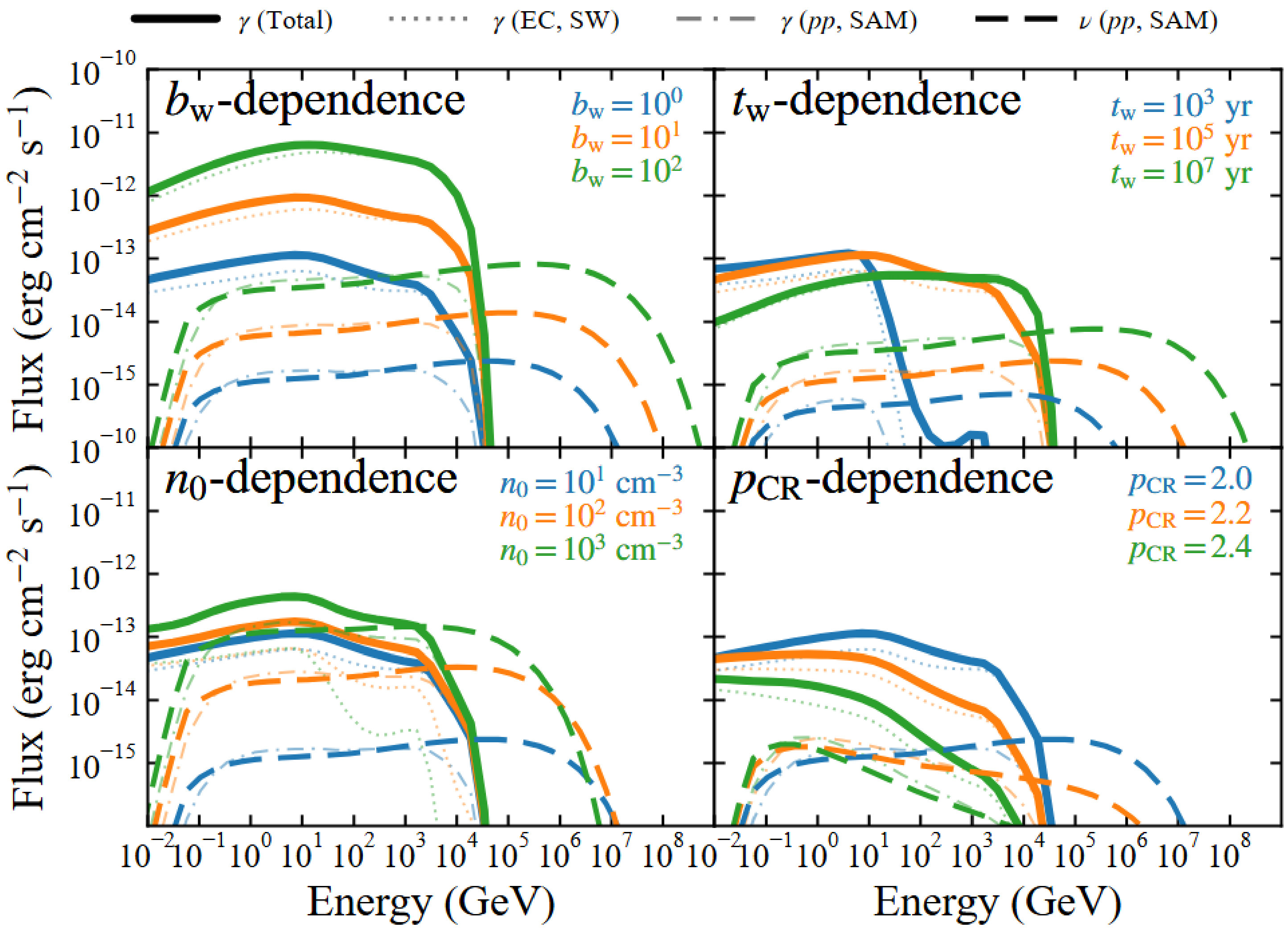
Spectral energy distribution

EC dominates gamma rays and *pp* dominates neutrinos.

- Example parameters:
  - $b_{\mathrm{w}} = 1$
  - $p_{\mathrm{CR}} = 2.0$
- *pp* interactions produce subdominant gamma rays.
- Synchrotron emission dominates radio band.



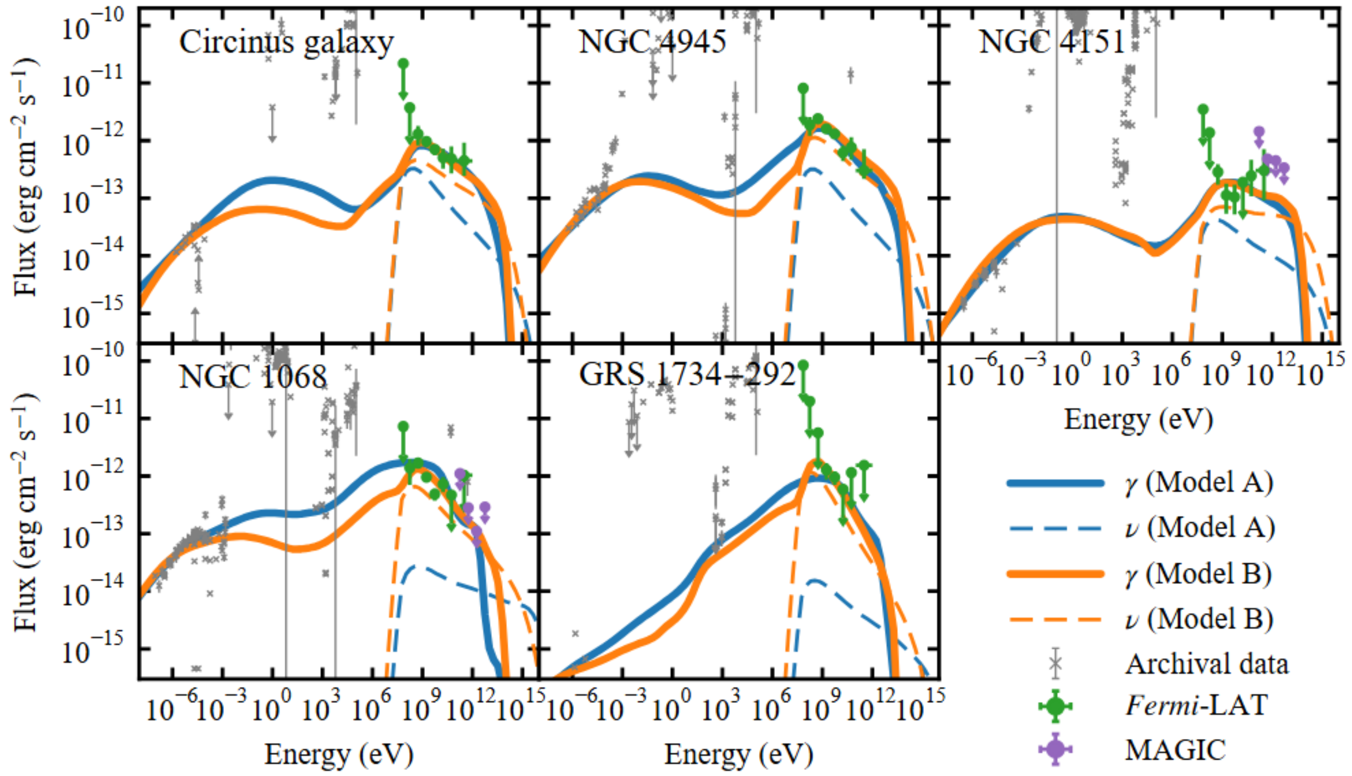
Parameter dependence of SEDs



Overview of parameter calibrations

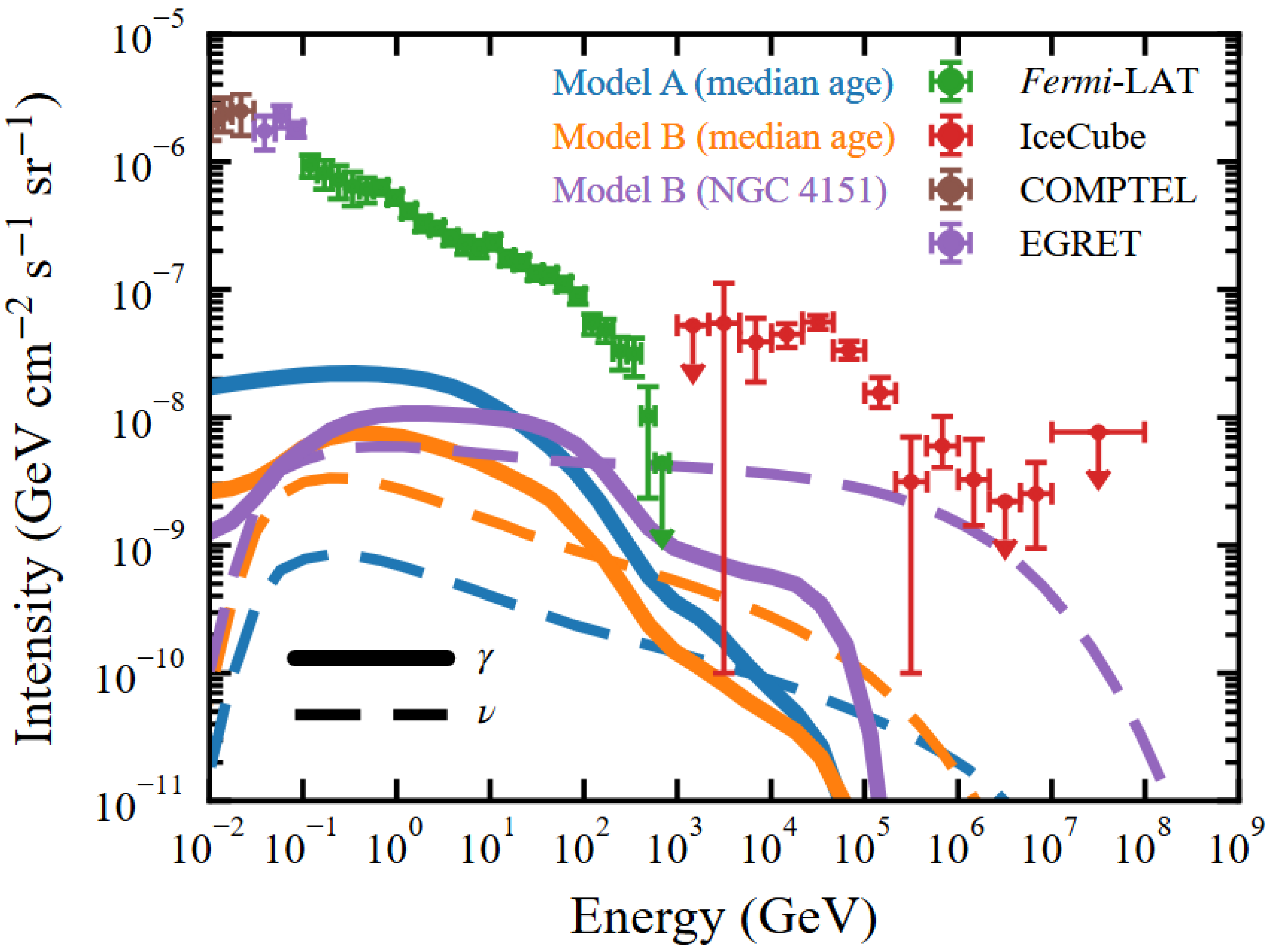
We also calibrate parameters for other GeV Seyferts.

Object	Model	$b_{\rm w}$	$B_{\rm SAM}$	$t_{\rm w}$	n_0	$p_{\rm CR}$
		–	(μG)	(yr)	(cm^{-3})	–
		(1)	(2)	(3)	(4)	(5)
Circinus	A	8	450	5×10^3	$10^\dagger$	2.30
	B	1	170	$10^{5\dagger}$	100	$2.24^\dagger$
NGC 4945	A	50	400	7×10^3	$10^\dagger$	2.40
	B	5	170	$10^{5\dagger}$	75	$2.30^\dagger$
NGC 4151	A	40	59	1×10^5	$10^\dagger$	2.27
	B	3	230	$10^{5\dagger}$	100	$2.11^\dagger$
NGC 1068	A	2	2000	3000	$10^\dagger$	2.20
	B	1	350	$10^{5\dagger}$	100	$2.35^\dagger$
GRS 1734–292	A	130	120	2×10^3	$10^\dagger$	2.30
	B	130	17	$10^{5\dagger}$	200	$2.54^\dagger$
Median	A	40	400	5×10^3	$10^\dagger$	2.30
	B	3	170	$10^{5\dagger}$	100	$2.30^\dagger$

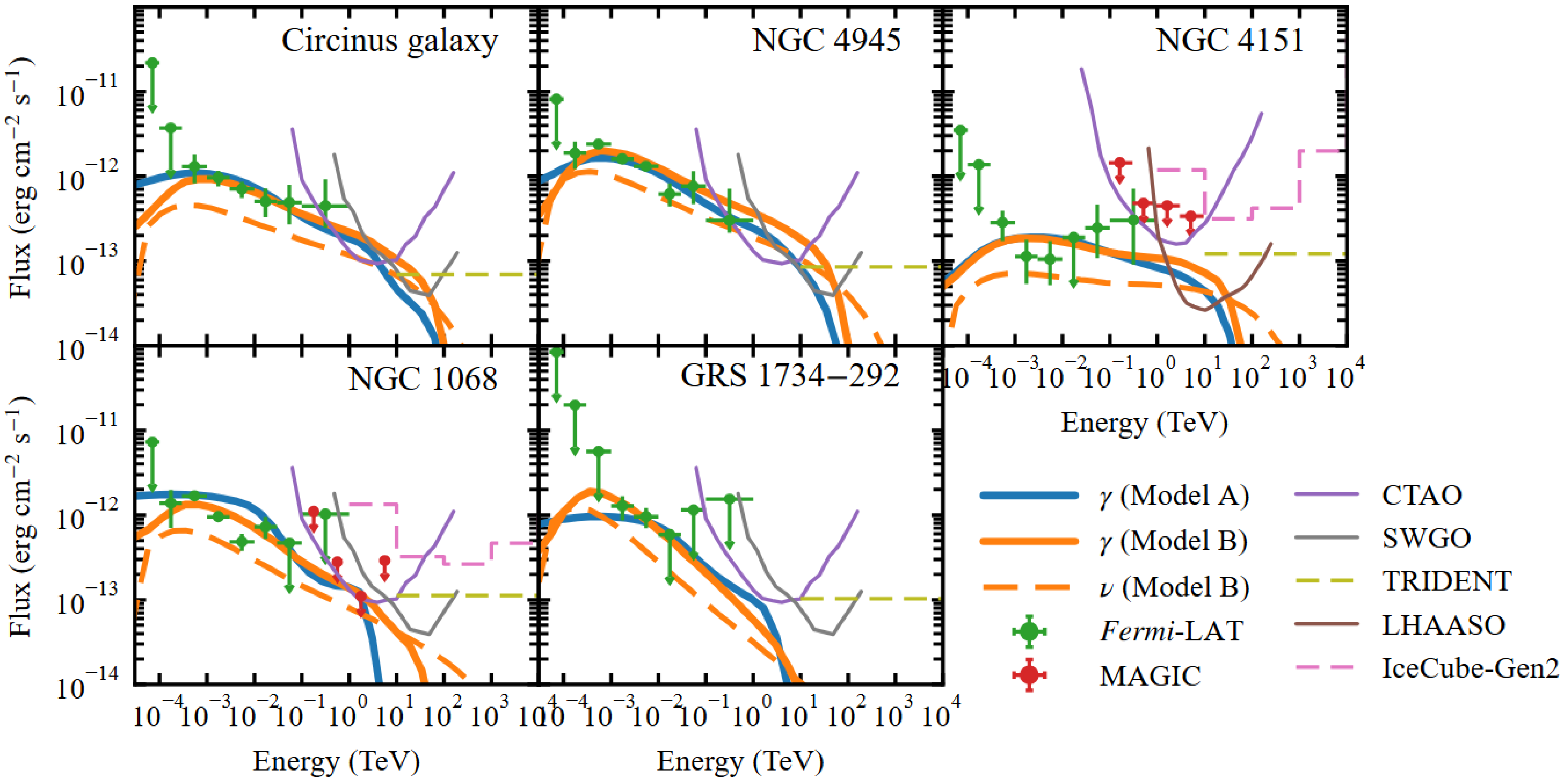


Disk wind contribution to background

- **Fixing wind** ages amplifies the contribution.
- NGC 4151 parameter set predicts significant contribution.



Prospects (Fermi Seyferts)



Prospects (UFO Seyferts)