

Unveiling the Coronal Magnetic Activity of Supermassive Black Holes with ALMA

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ALMA/45m/ASTE Users Meeting @ Online, 2021-01-06



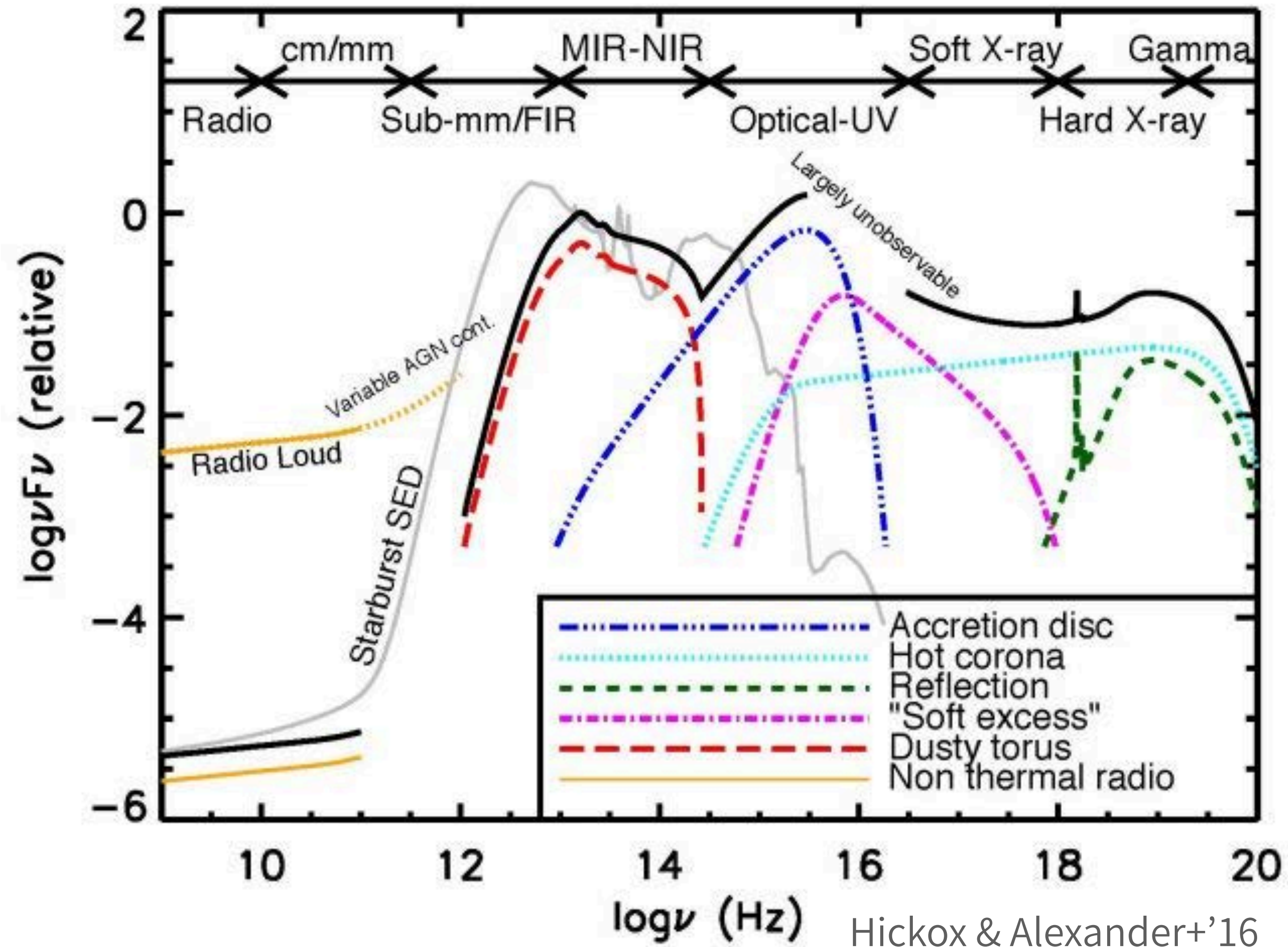
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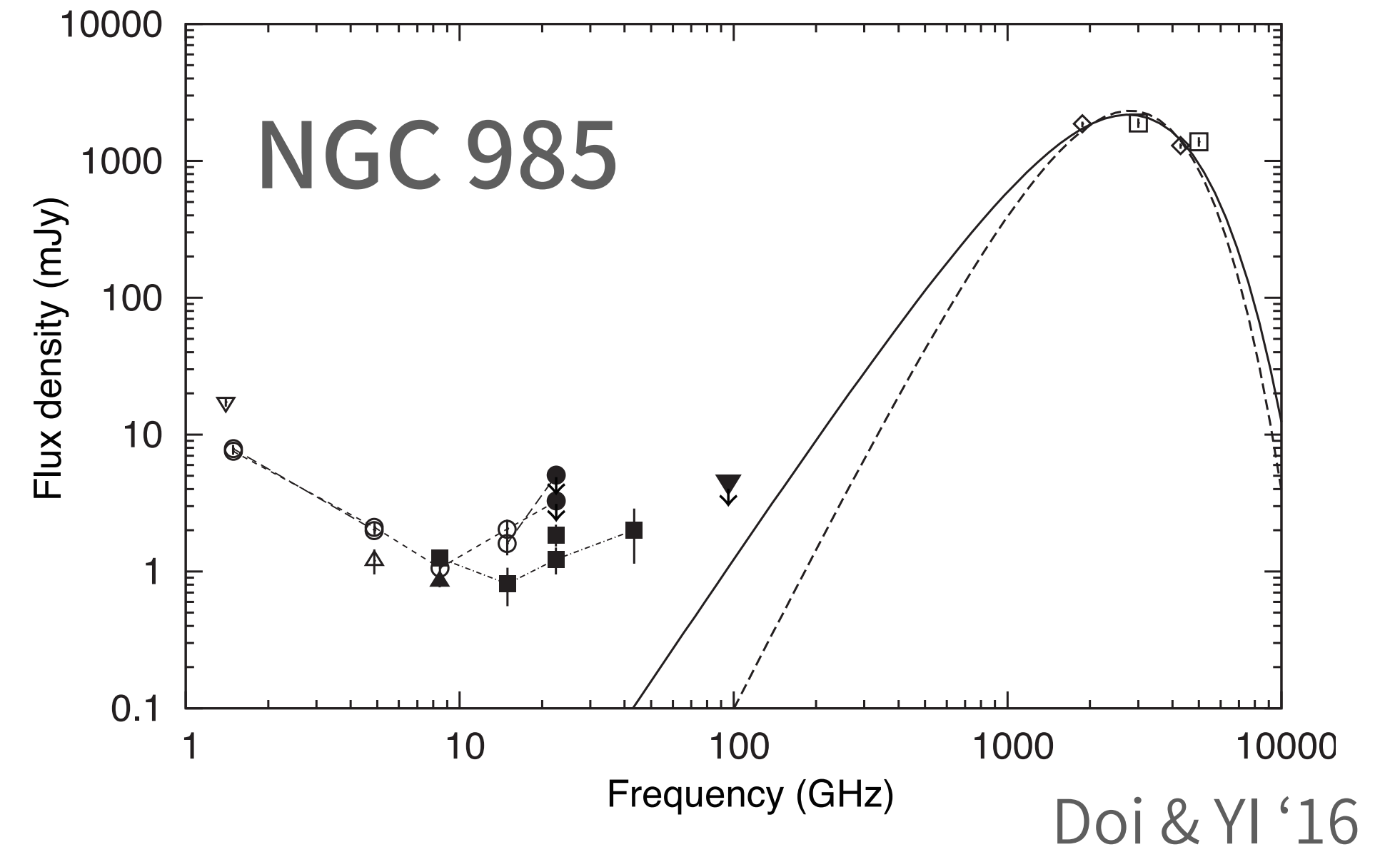
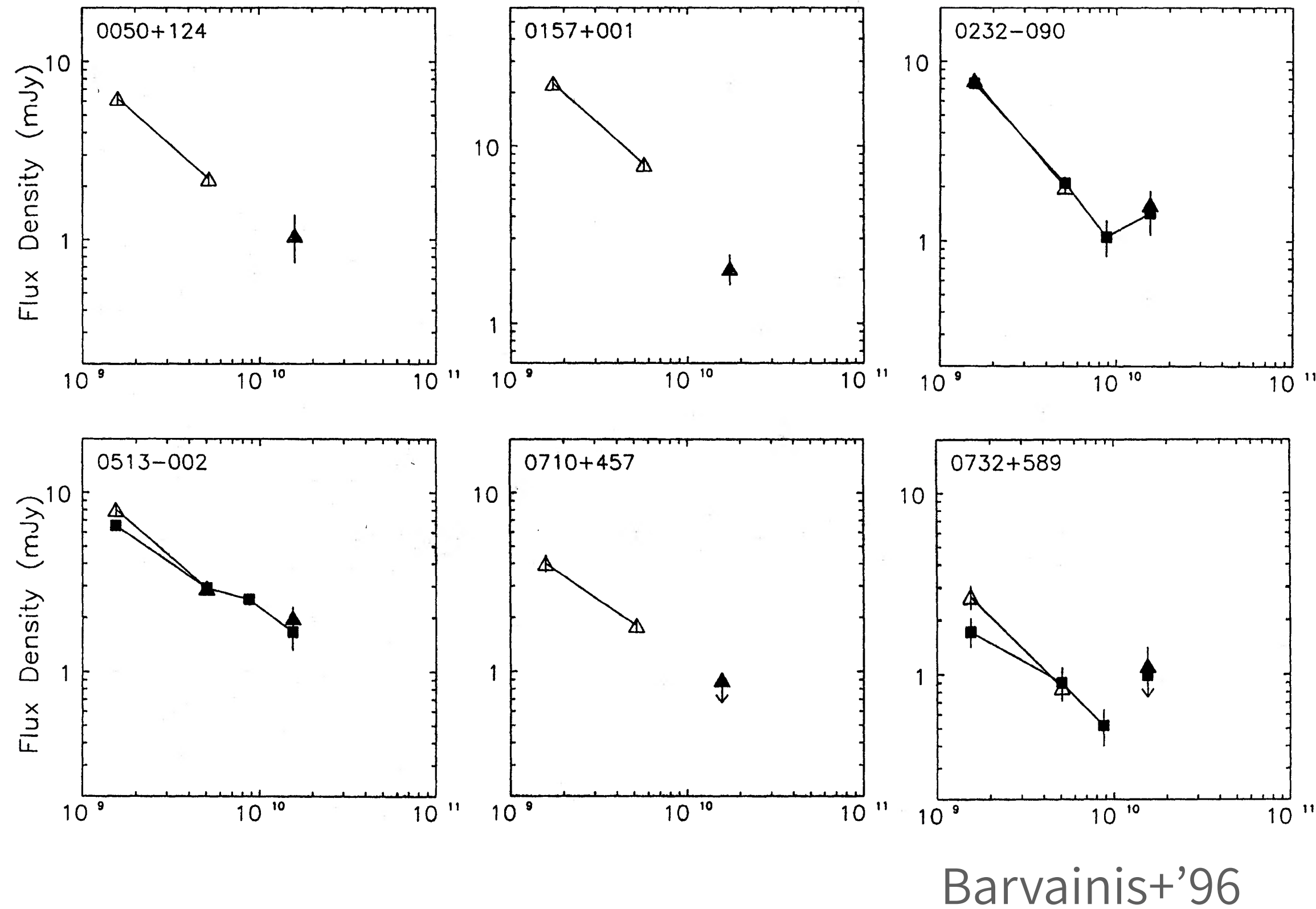


Multi-wavelength spectrum of Radio-quiet AGNs

What is the origin of the radio emission?

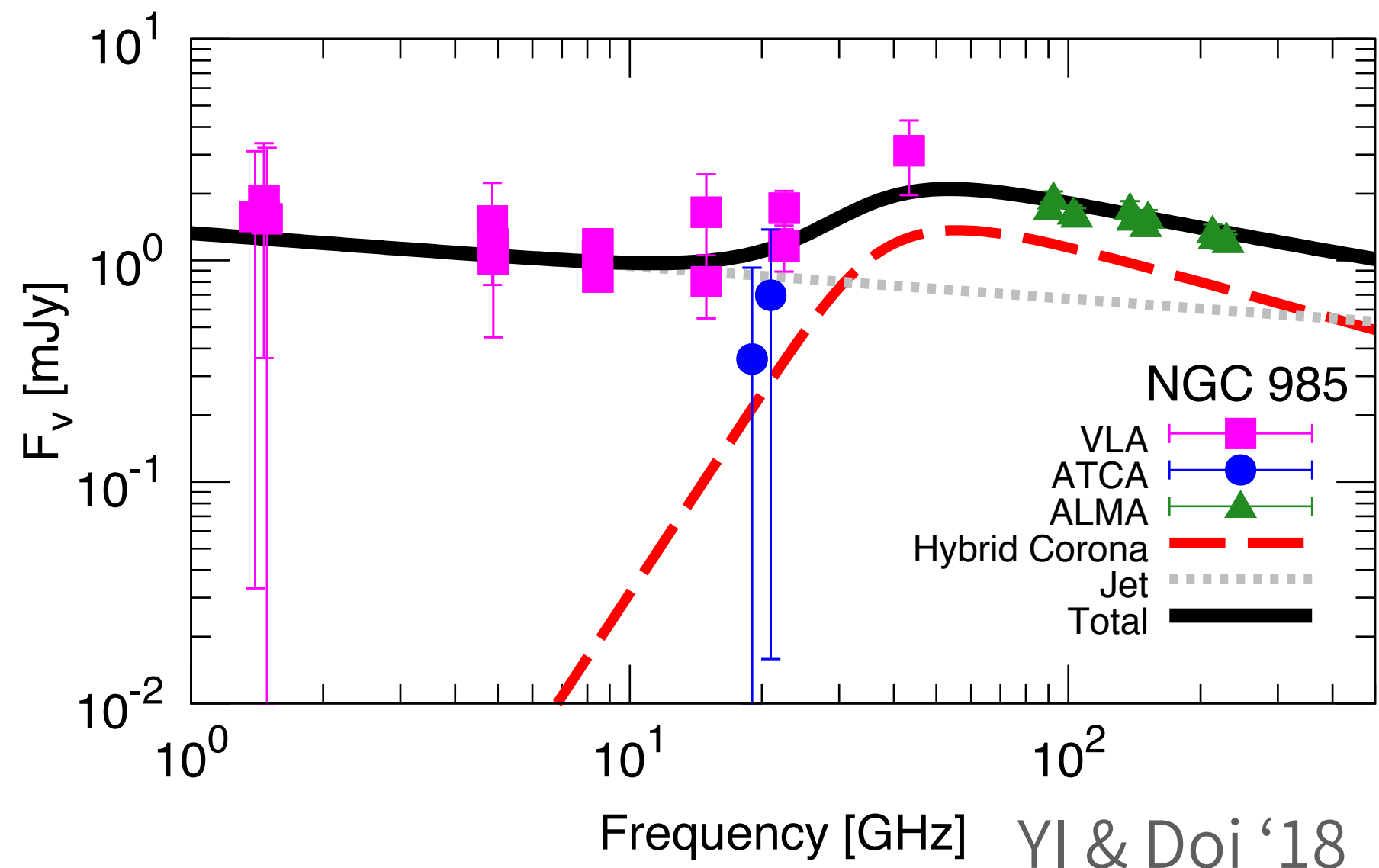
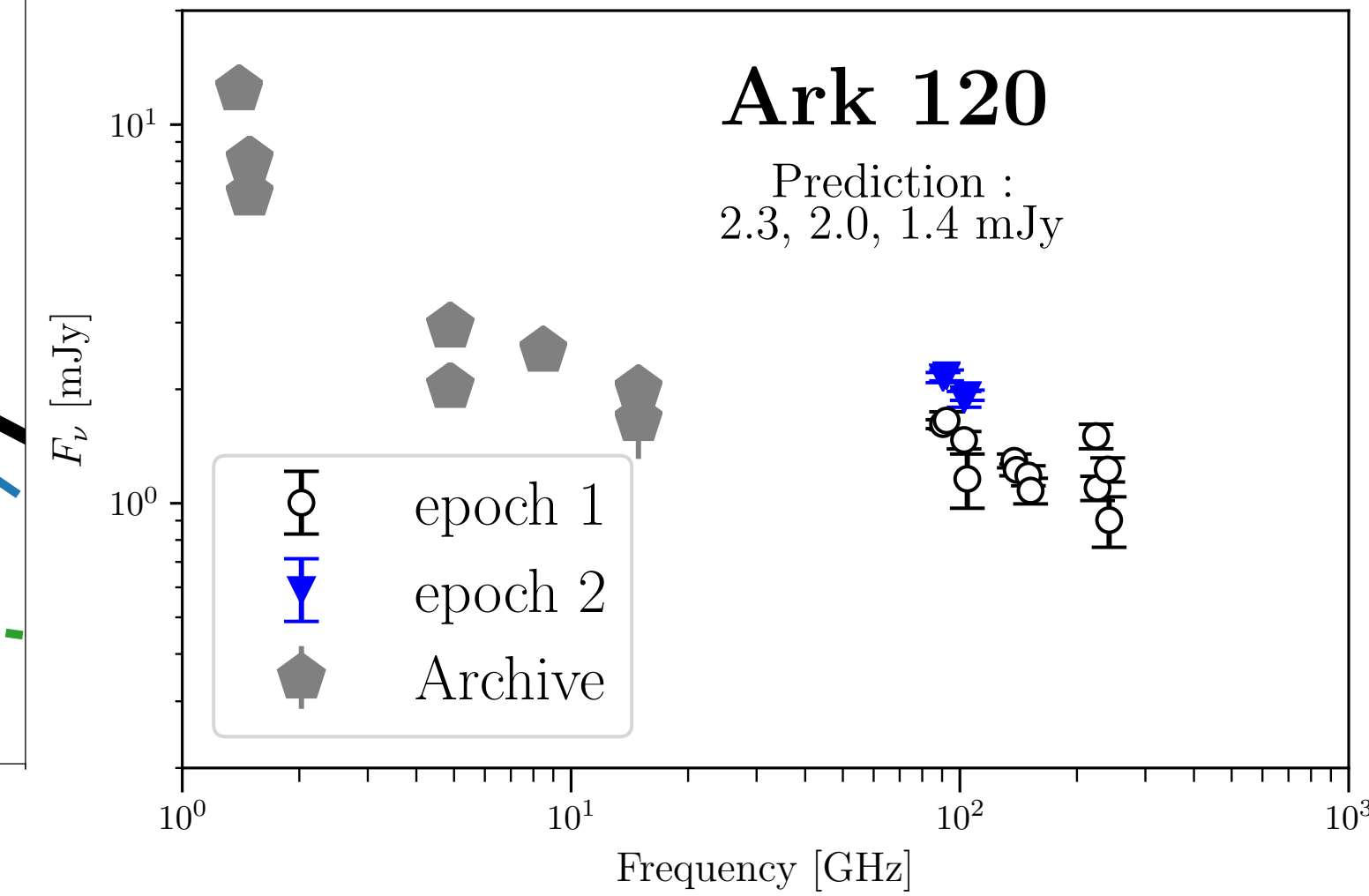
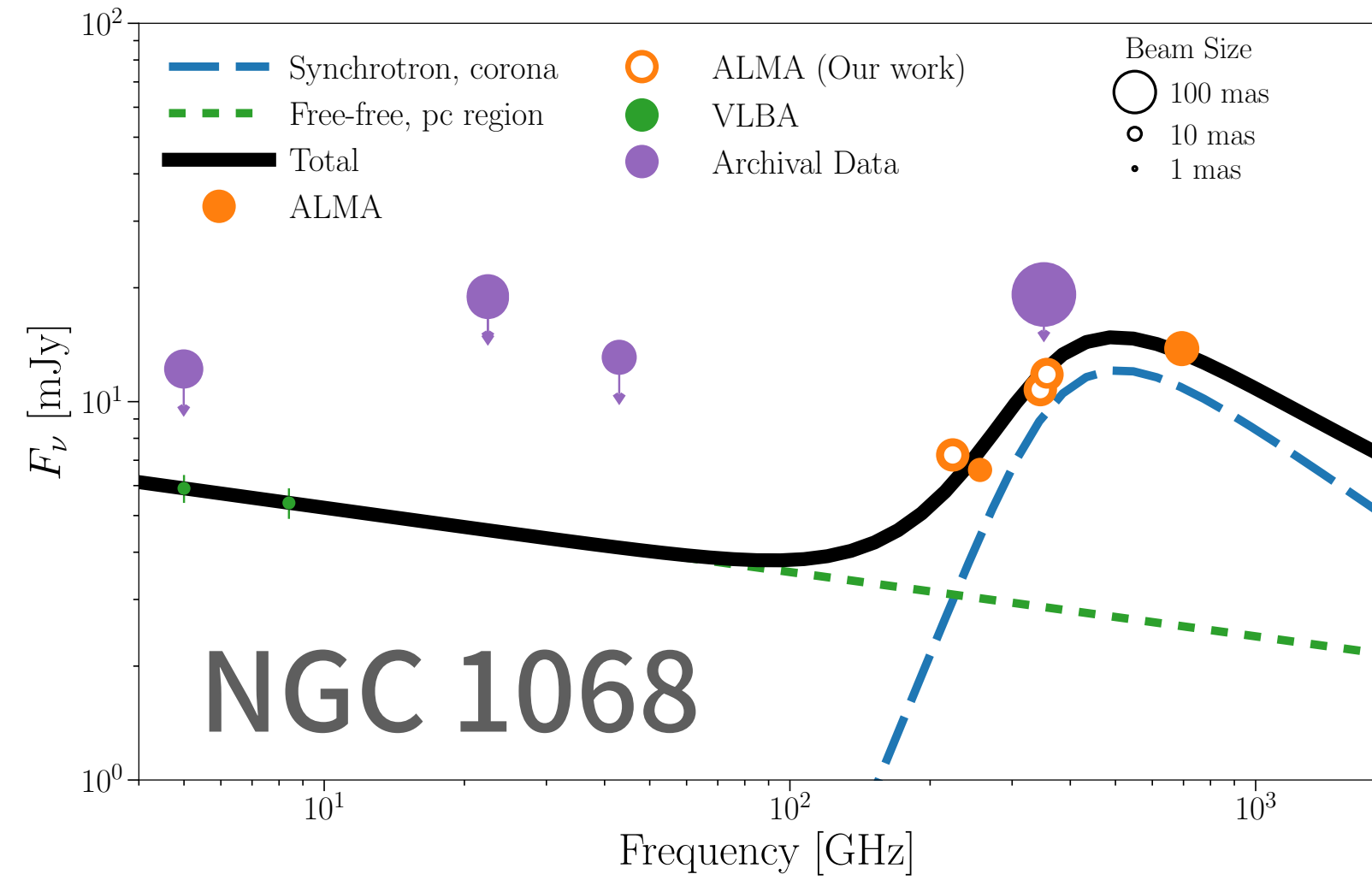
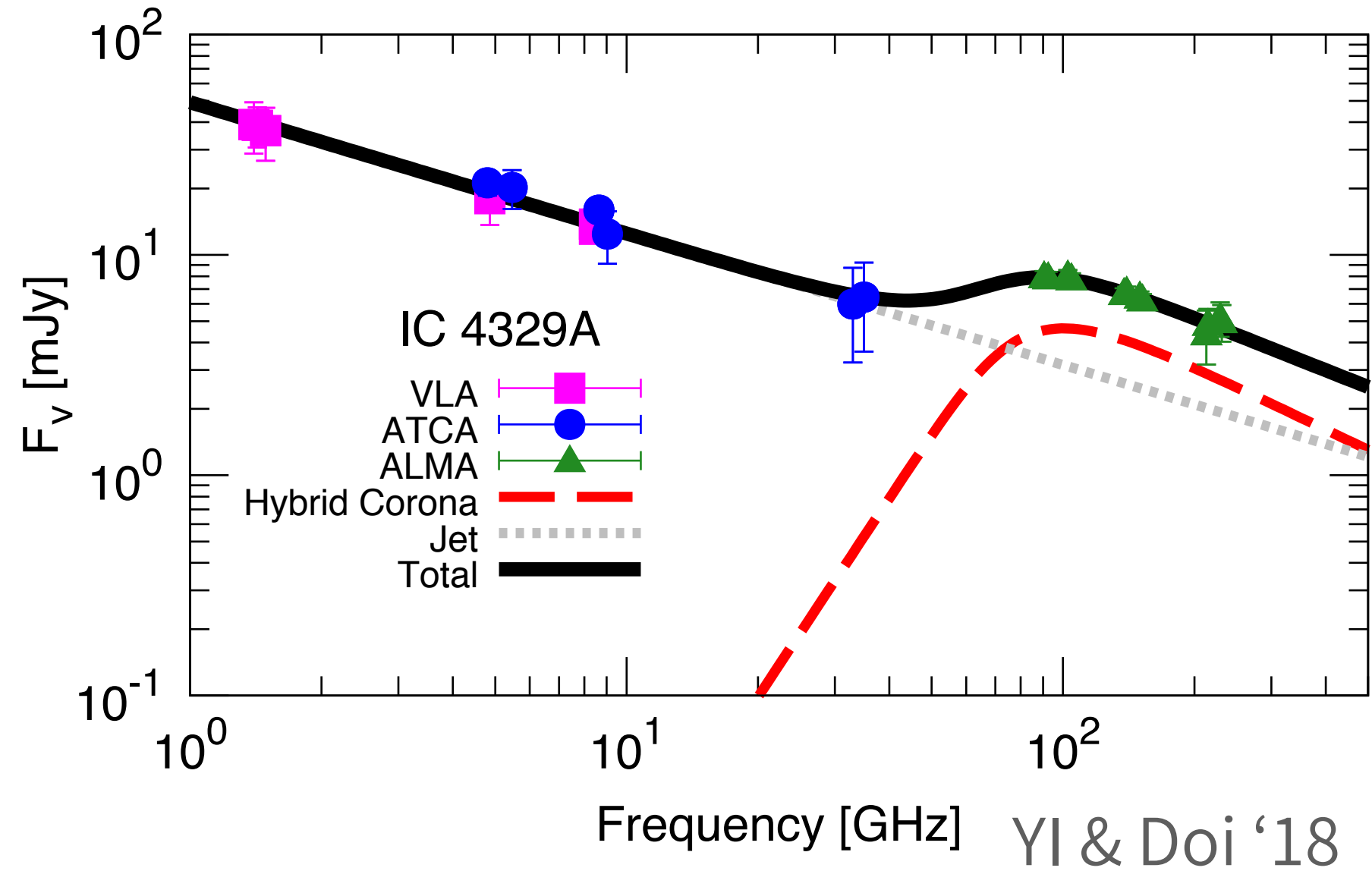


Millimeter excess in nearby Seyferts



- Spectral excess in the mm-band
(e.g., Antonucci & Barvainis'88; Barvainis+'96; Doi & Inoue '16; Behar+'18).
- Contamination of extended components?
- Multi-frequency property?

ALMA observations toward nearby Seyferts



YI, Khangulyan, & Doi '20

YI+'in prep.

- Clear excess in nearby Seyferts

(YI & Doi '18; YI, Khangulyan, & Doi '20; YI+'in prep.)

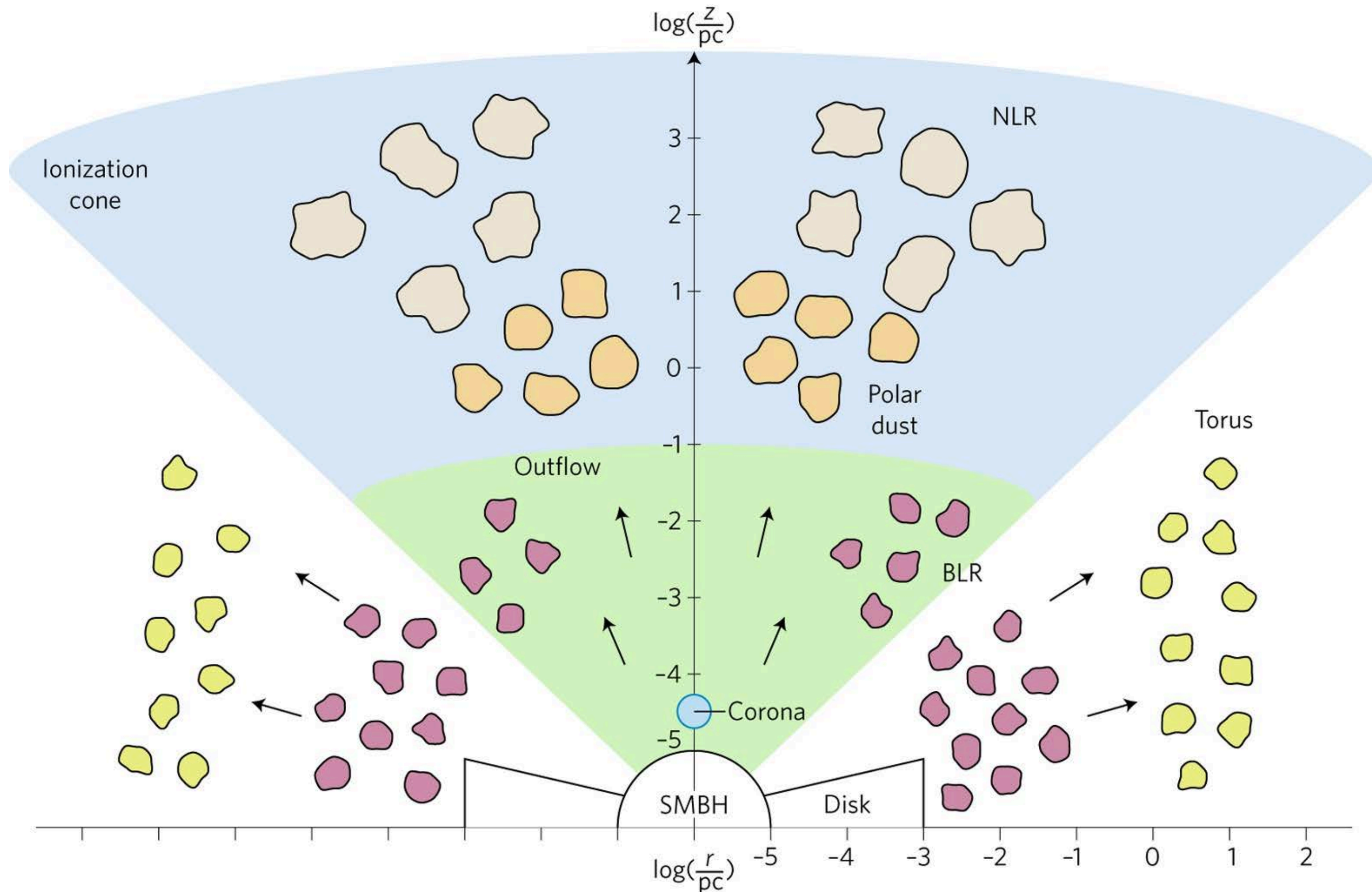
- Flux ~ 1-10 mJy peaking @ a few tens GHz

- Some shows time variability ~1 month (see also Behar+'20)

- Size : < 10 pc → Nucleus

Structure of AGN core in the <10 pc scale

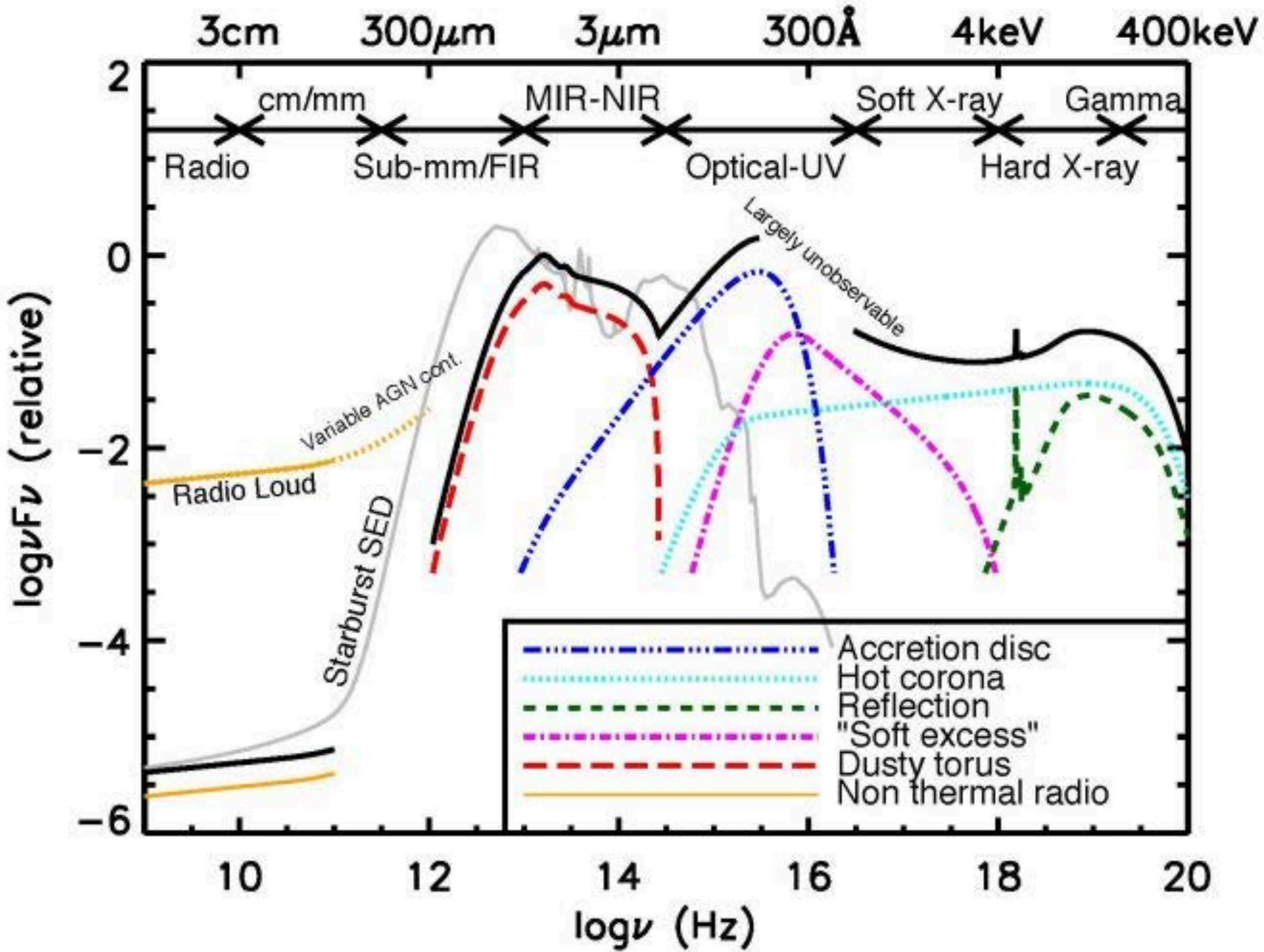
Where is the origin of the mm excess?



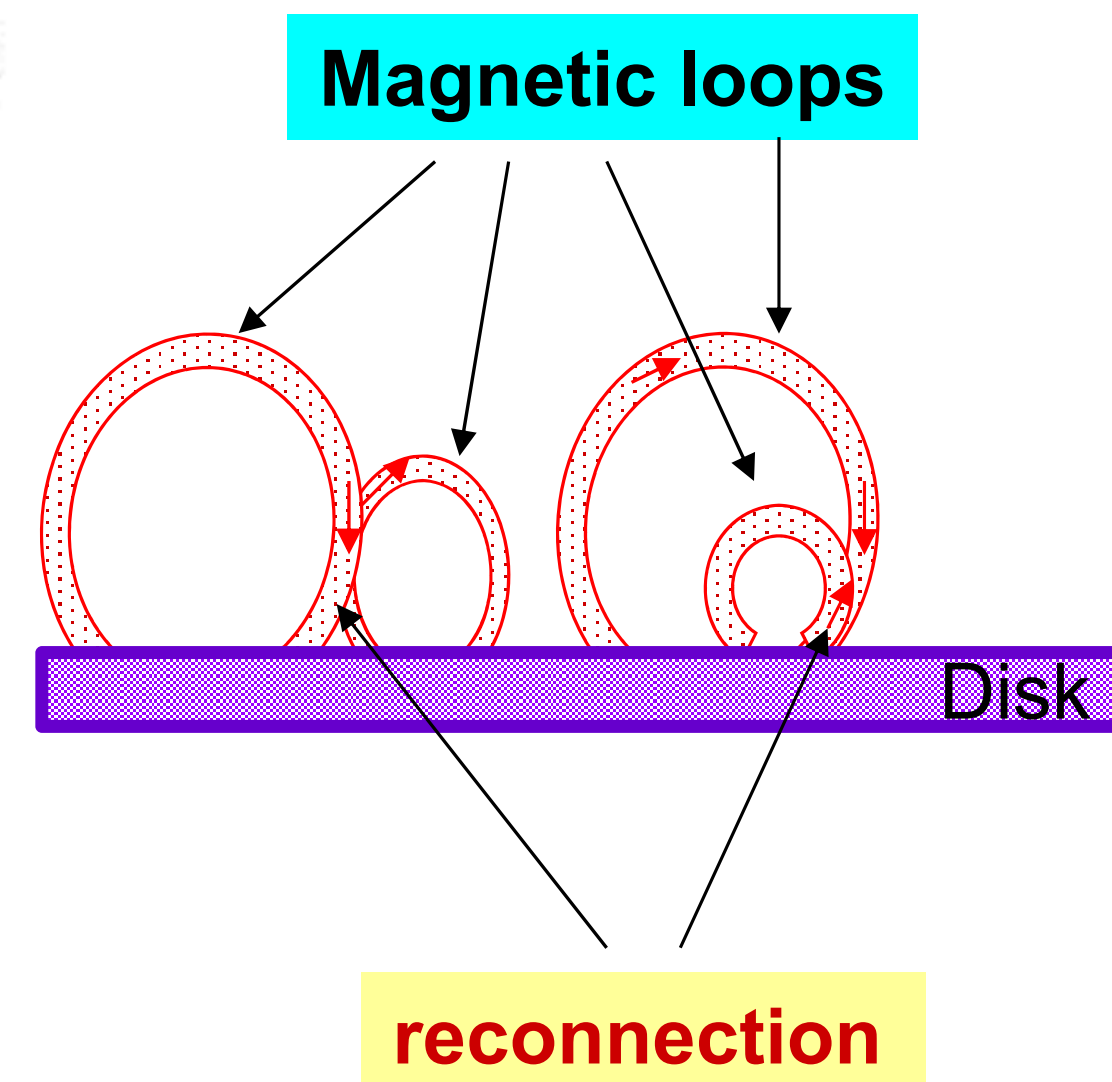
Ramos-Almeida & Ricci '17

- Dust torus?
 - spectral shape, not enough, variability
- Free-free?
 - spectral shape, not enough
- Jet?
 - radio-quiet, no blazar like activity
- Corona?

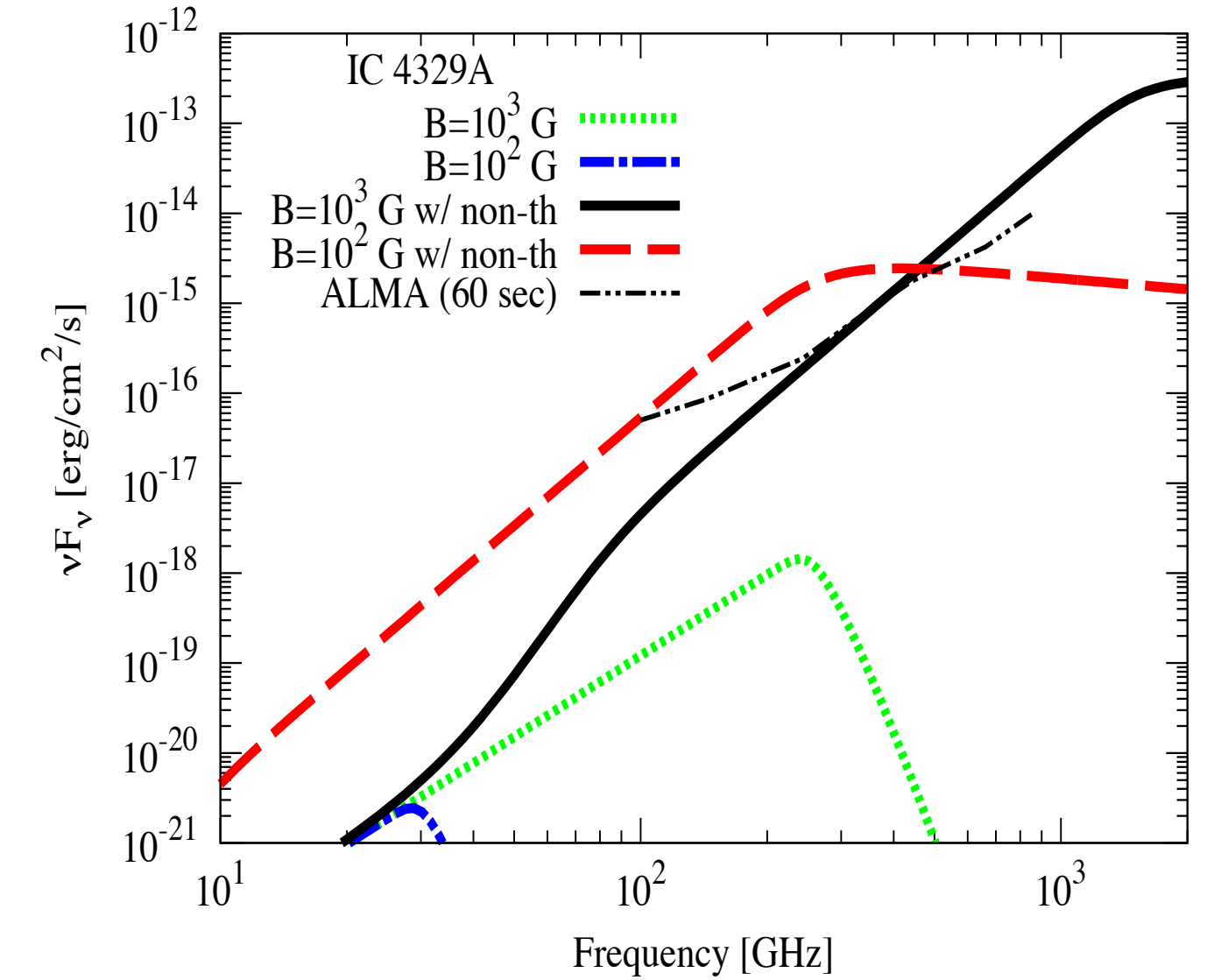
Supermassive black hole corona?



Hickox & Alexander+'16



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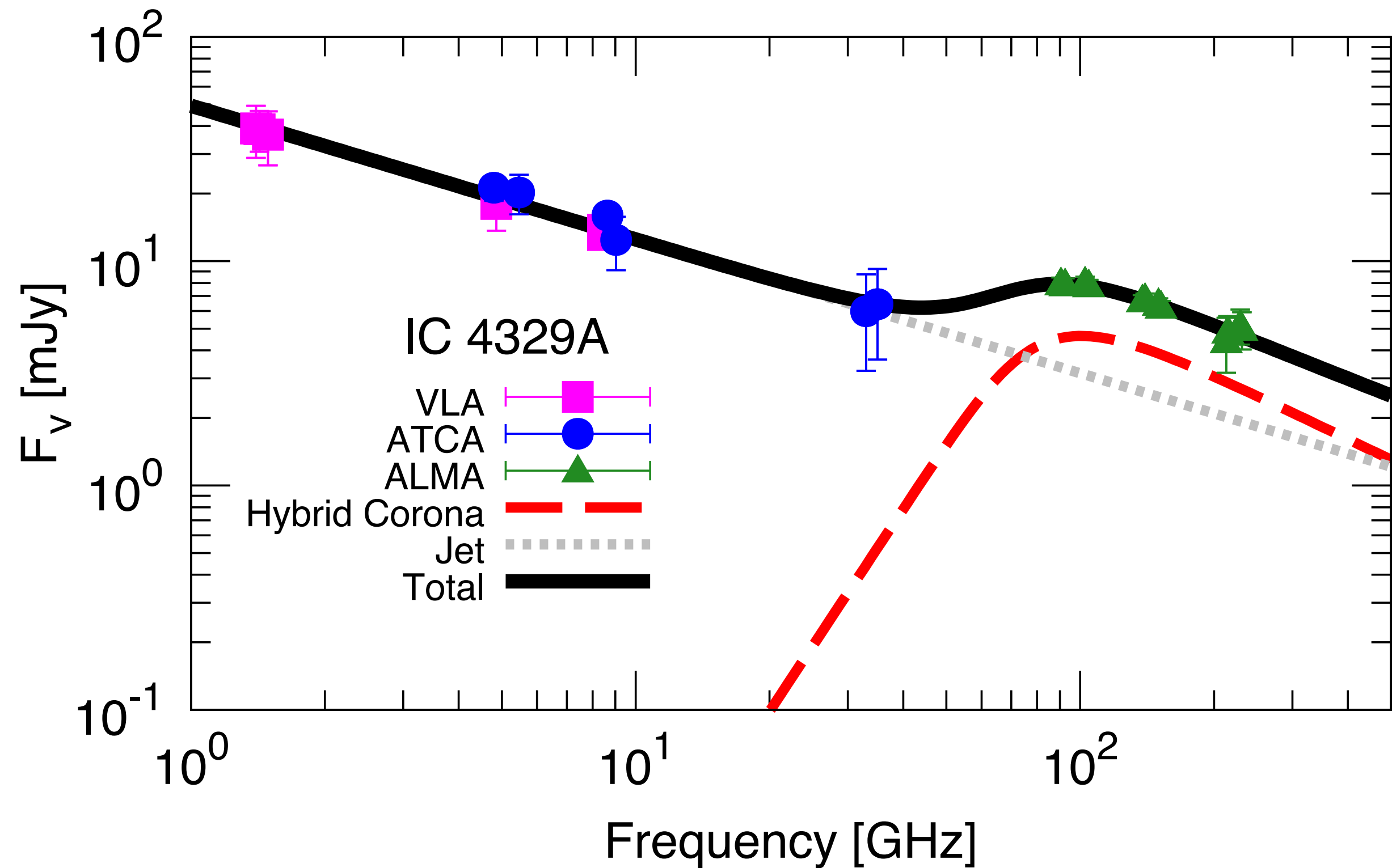


YI & Doi '14

- Hot corona (~100 keV)
- Heated by magnetic activity ?
(e.g., Haardt & Maraschi '91; Liu, Mineshige, & Shibata '02)
- If so, coronal synchrotron radiation is expected
(Di Matteo+'97; YI & Doi '14; Raginski & Laor '16)

cm-mm spectrum of AGN core

A case of IC 4329A



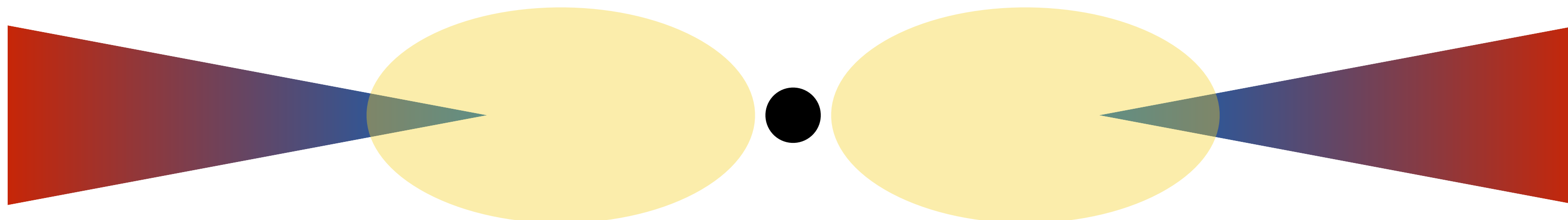
YI & Doi '18

- Hybrid corona model (YI & Doi '14)
- Non-thermal electron fraction : $\eta = 0.03$ (fixed)
- Consistent with the MeV gamma-ray background spectrum (YI, Totani, & Ueda '08; YI+'19)
- Non-thermal spectral index: $p = 2.9$
- Size: $40 r_s$
- B-field strength : 10 G

Reconnection Corona Heating?

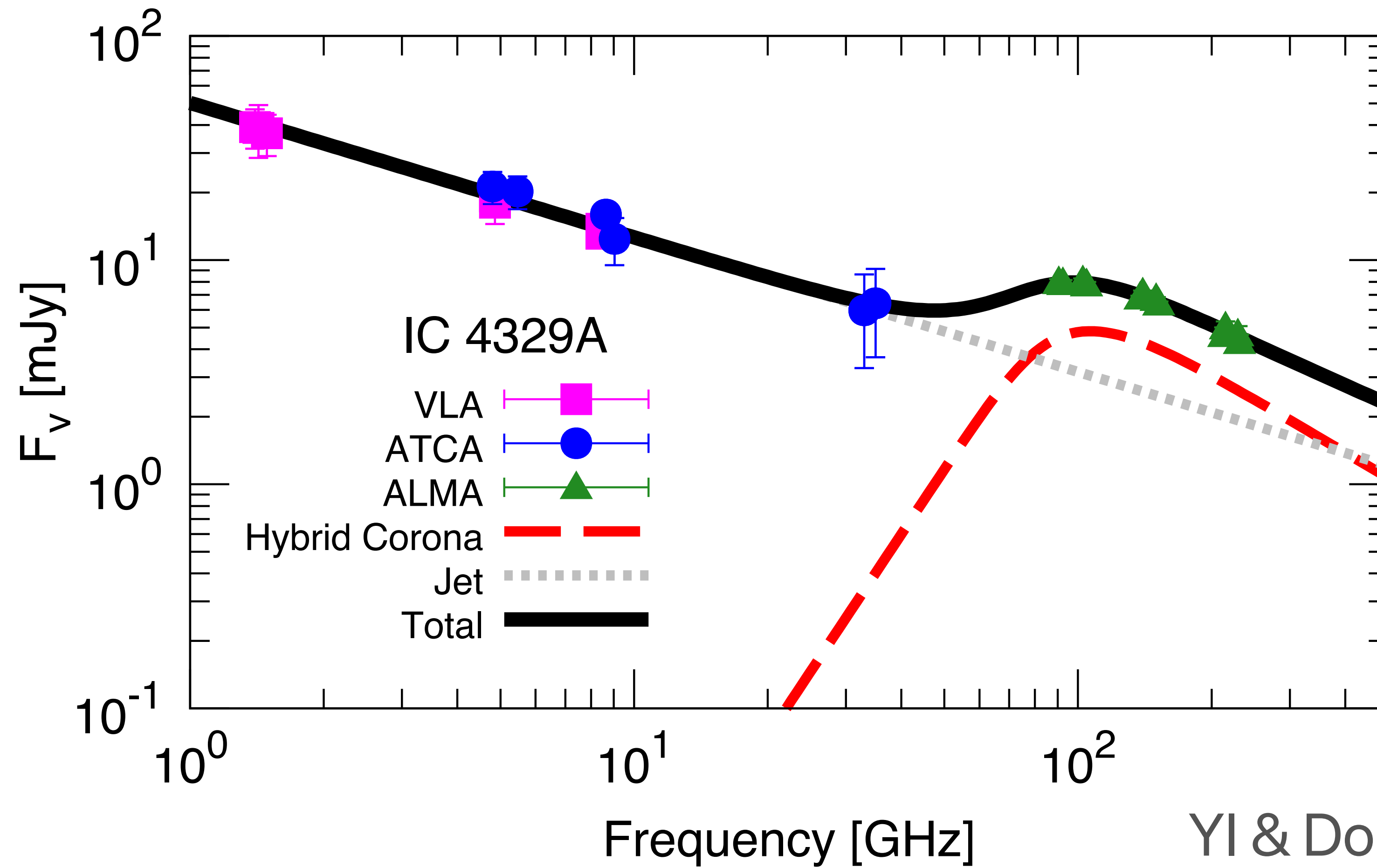
Implication for the truncated accretion disk structure.

- Heating and Cooling
 - Magnetic Heating: $B^2 V_A / 4\pi$
 - $Q_{B, \text{heat}} \sim 10^{10} \text{ erg/cm}^2/\text{s}$
 - Compton Cooling: $4kTn_e\sigma_T c U_{\text{rad}} l / m_e c^2$
 - $Q_{\text{IC, cool}} \sim 10^{13} \text{ erg/cm}^2/\text{s}$
 - Magnetic field energy is **NOT** sufficient to keep coronae hot.
- Disk truncation at some radii (e.g. $\sim 40 r_s$)
 - The inner part = hot accretion flow (Ichimaru '77, Narayan & Yi '94, '95).
 - Heated by advection.
 - Suggested for Galactic X-ray binaries. (e.g. Poutanen+'97; Kawabata+'10; Yamada+'13).
- Simultaneous model fitting to X-ray and radio data is required.



Radio Spectrum of AGN Core

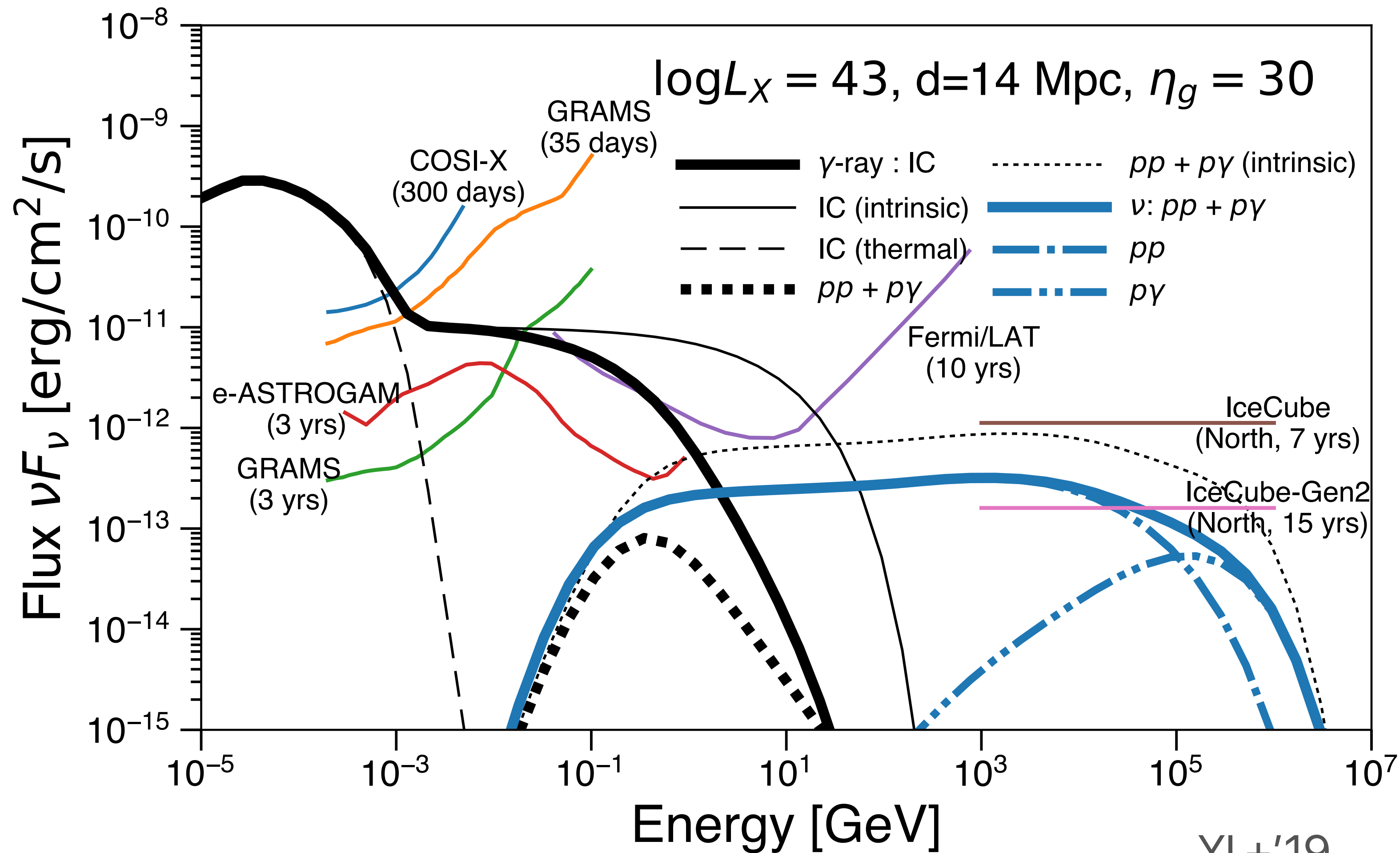
Non-thermal tail in the mm spectrum



YI & Doi '18

High energy emission from AGN coronae

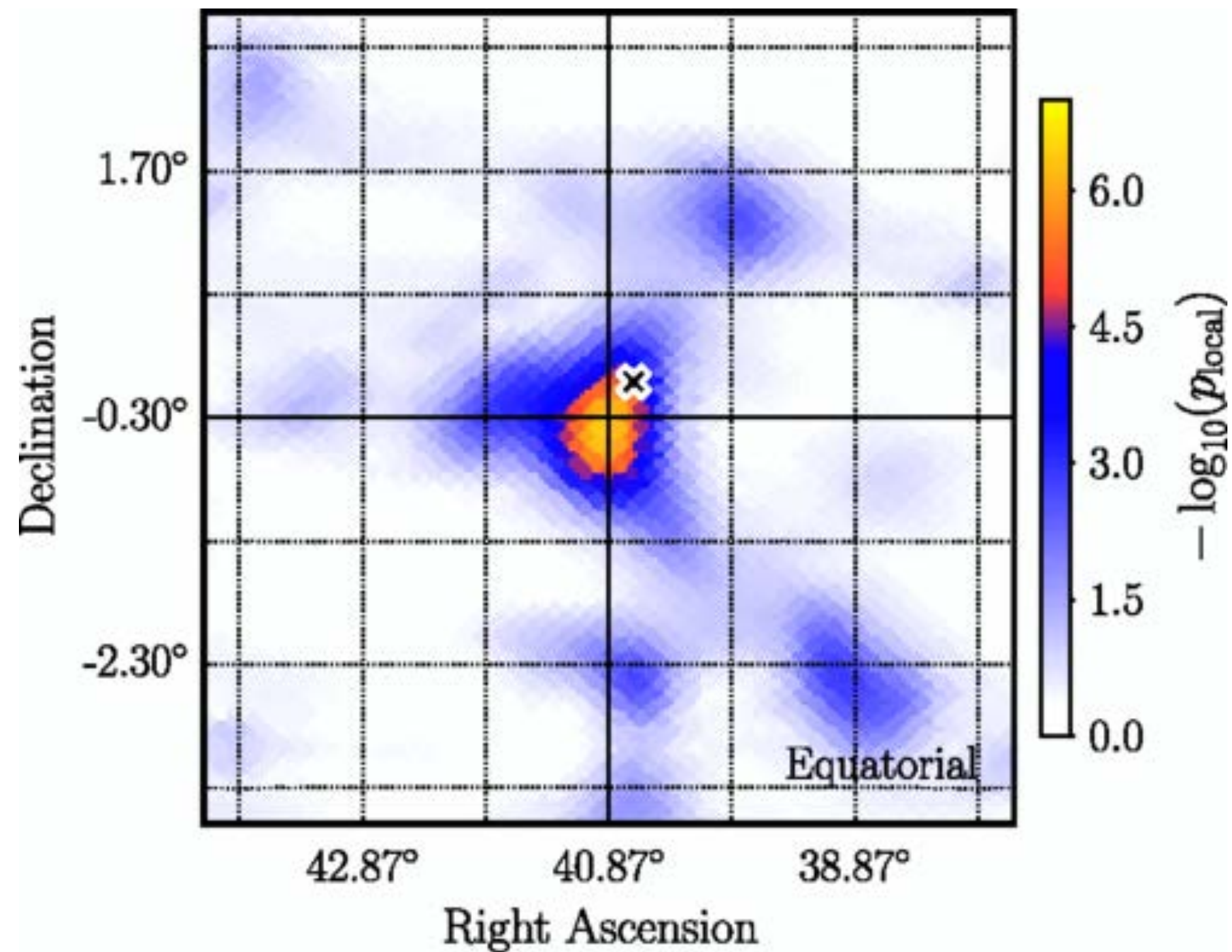
Multi-messenger Signature: MeV Gamma-ray & TeV Neutrinos



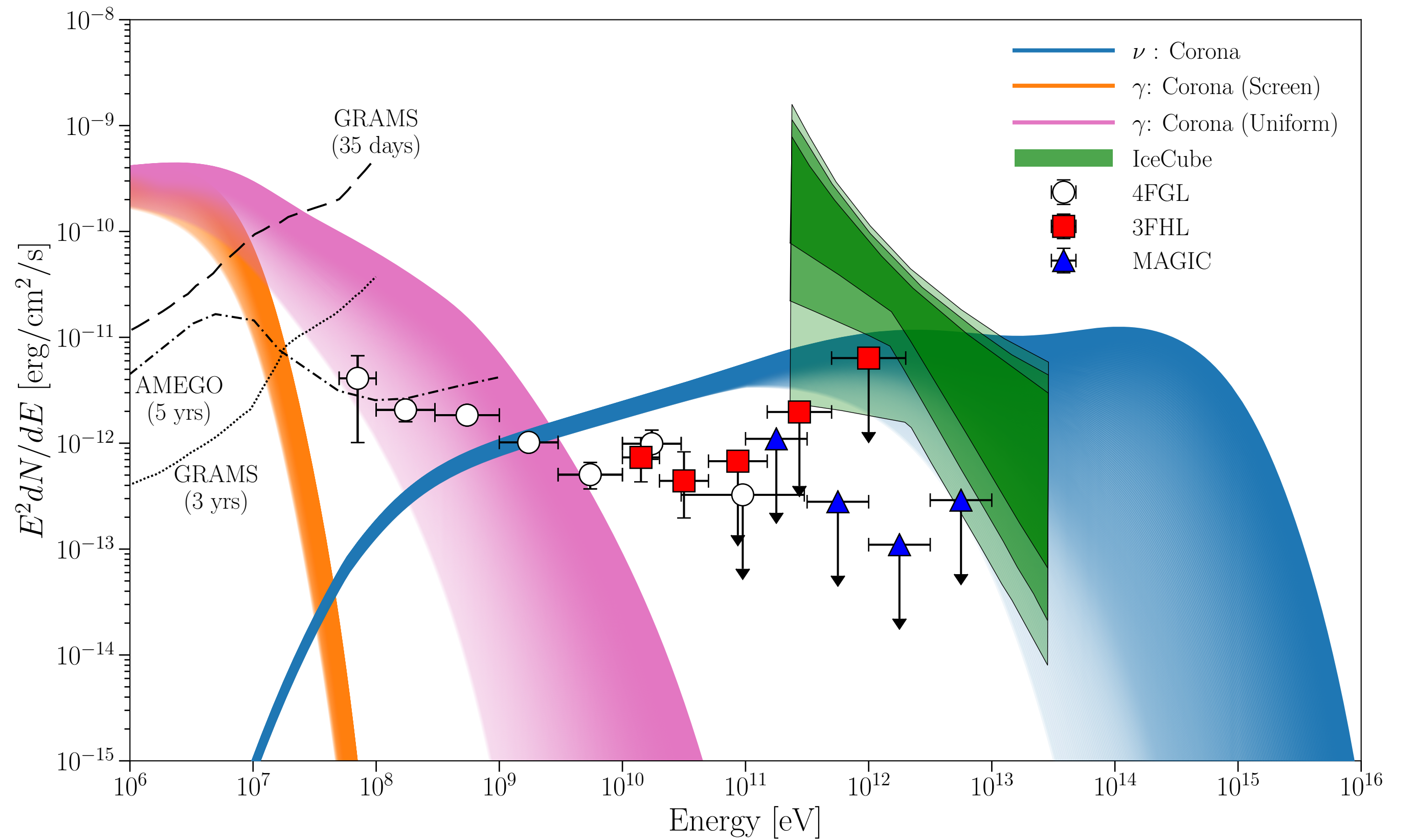
- Non-thermal electrons
- ➔ Comptonization
- ➔ MeV emission
- But, no GeV emission
- Non-thermal protons
- ➔ High energy neutrinos

IceCube Hottest Spot

NGC 1068 (no strong jet)



IceCube 2020



YI, Khangulyan, & Doi, '20

- Type-2 Seyfert NGC 1068 is reported at 2.9- σ .
- If the signal is real, corona can be a plausible neutrino production site (see also Müller & Romero '20, Murase+'20).

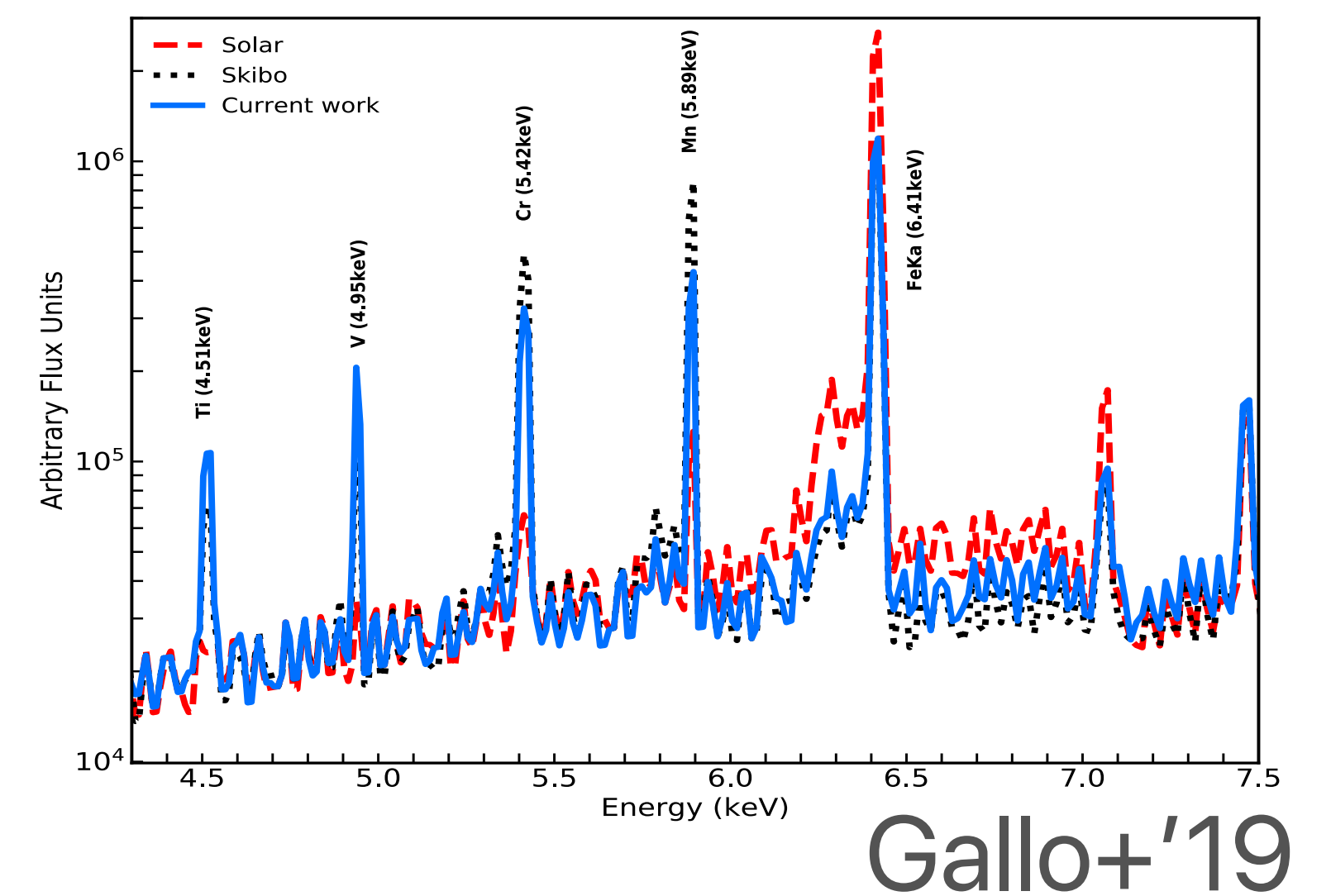
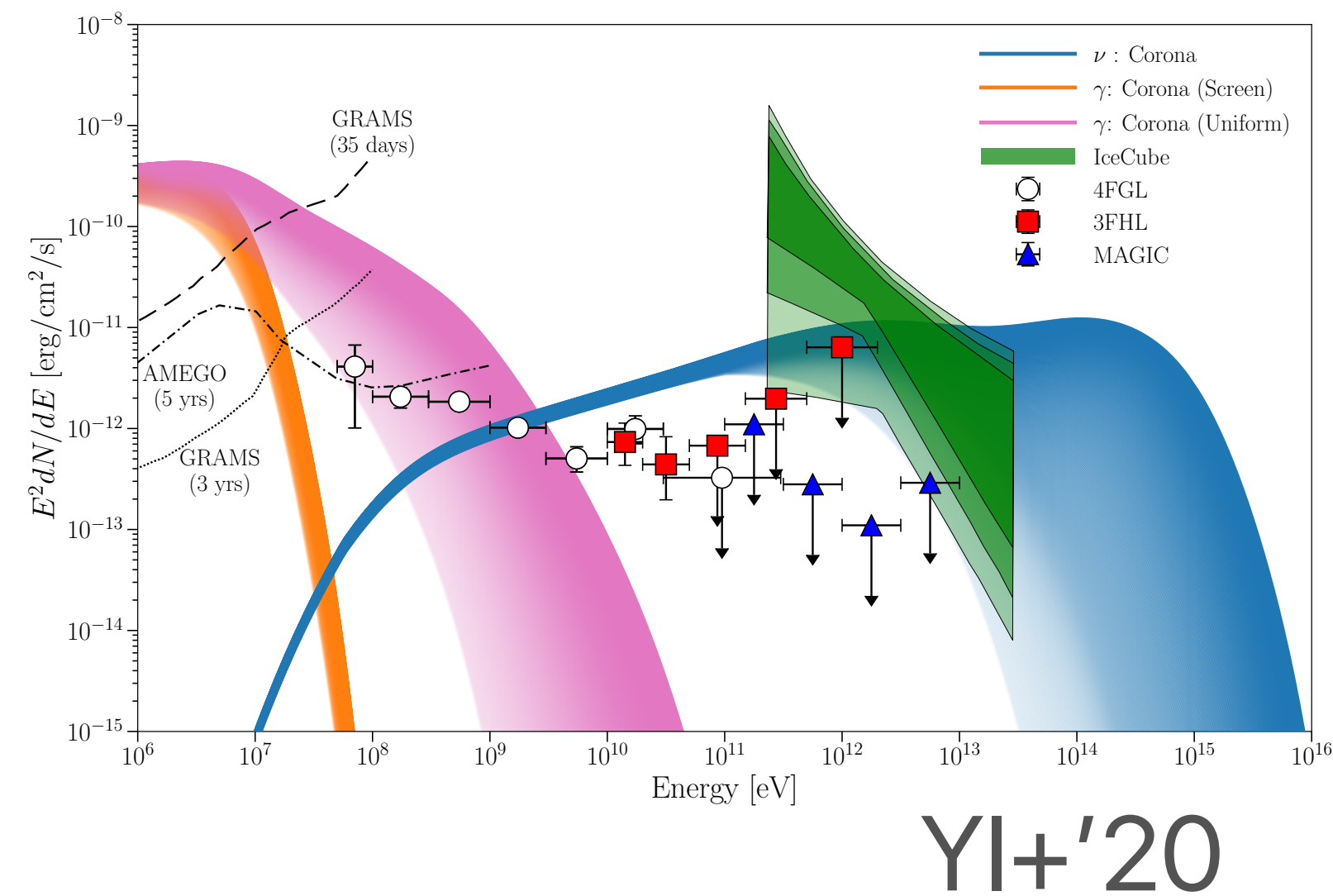
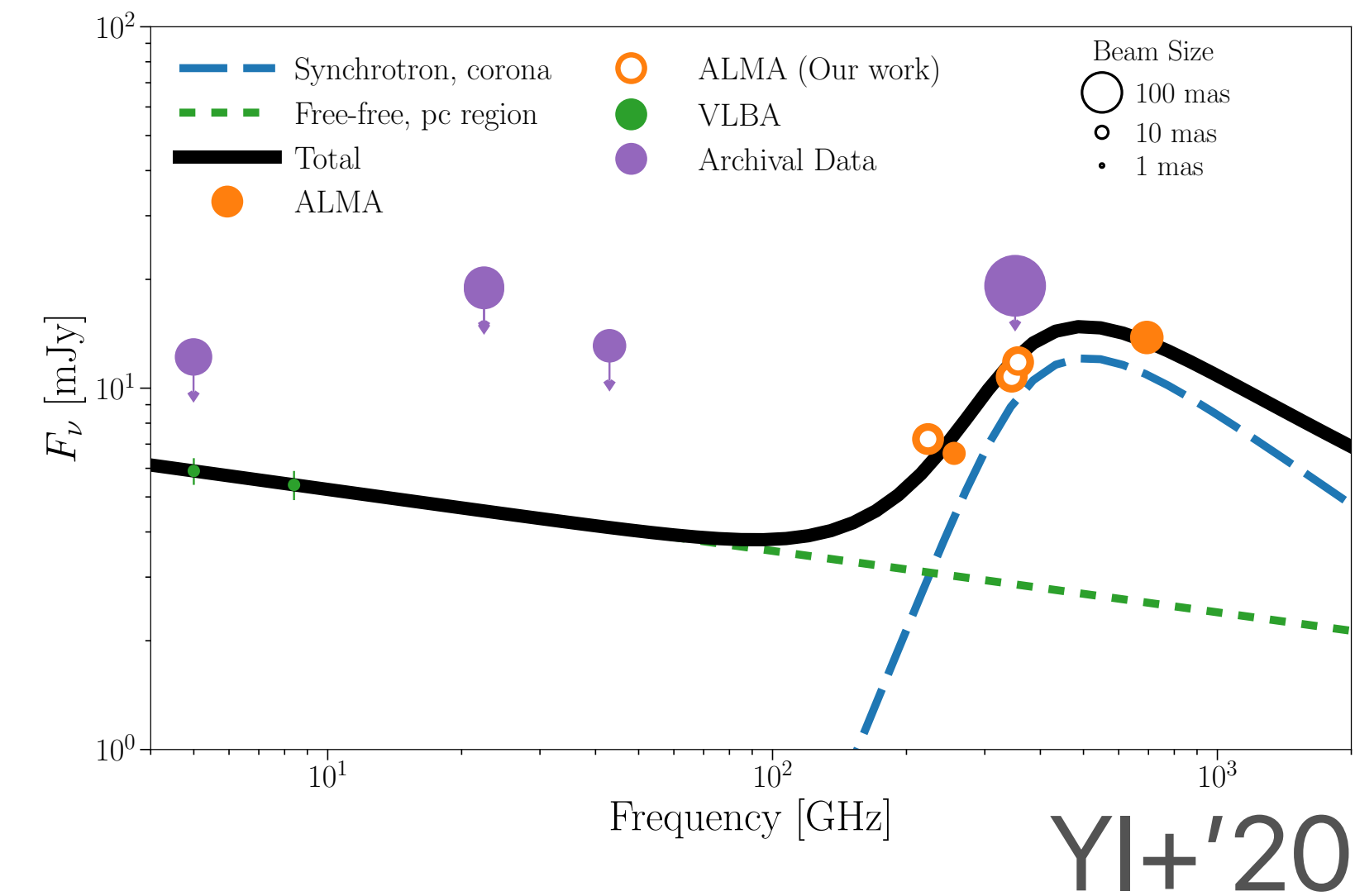
How can we test the model?

ALMA? GRAMS? AMEGO? IceCube? XRISM?

mm-band

MeV & TeV ν

X-ray



- mm-excess

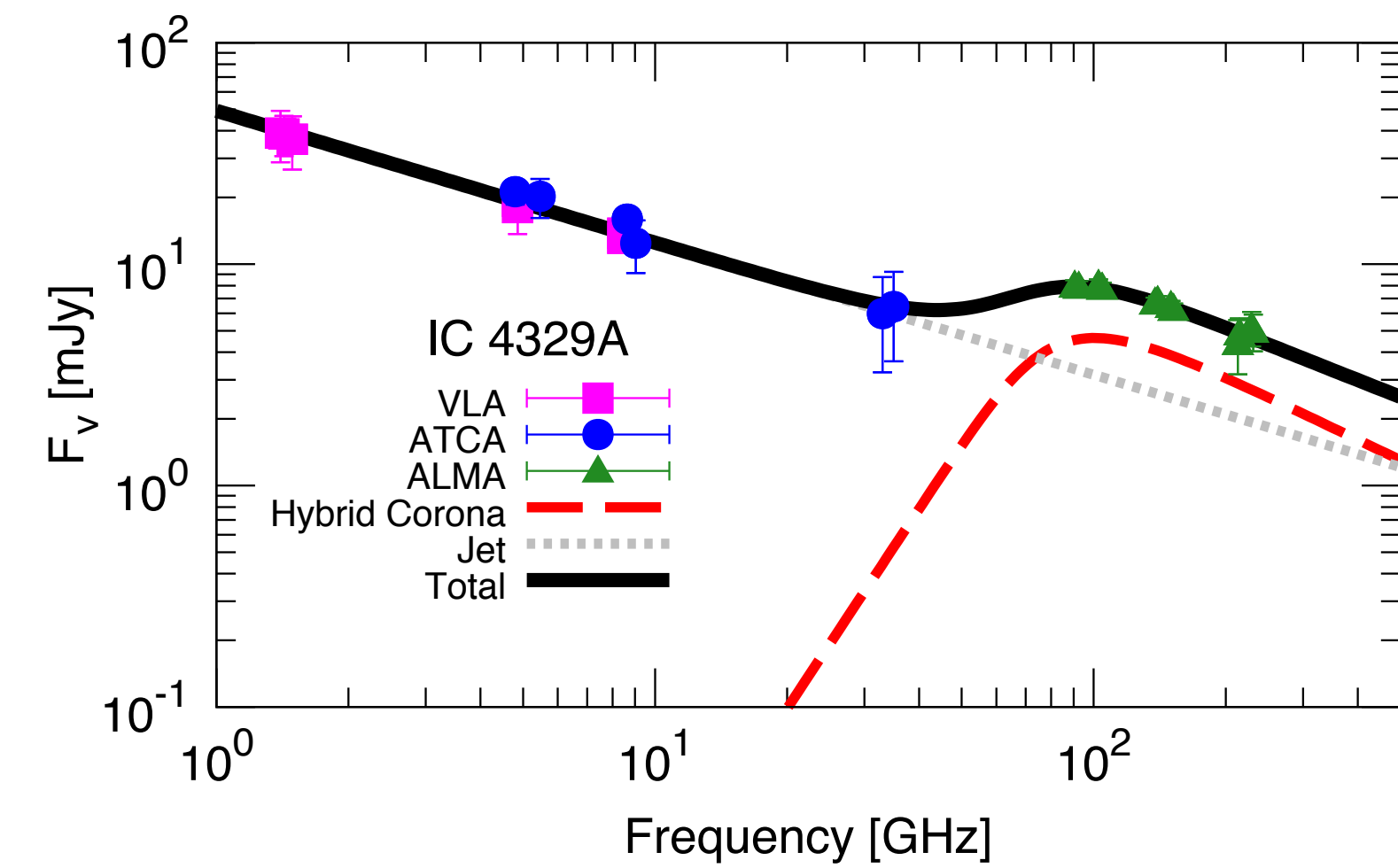
- MeV PL tail

- TeV ν without GeV-TeV γ

- Nuclear spallation in X-ray

Summary

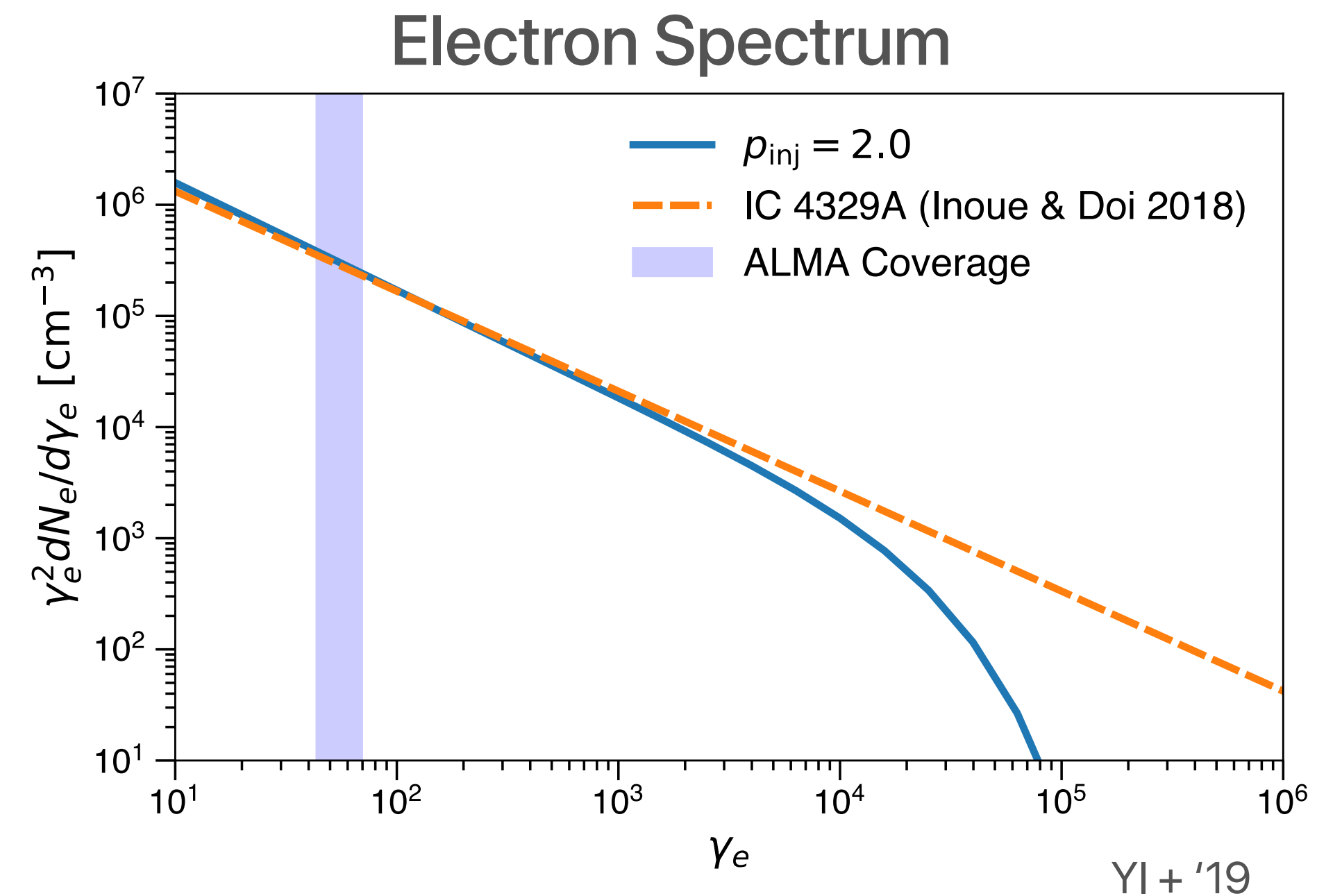
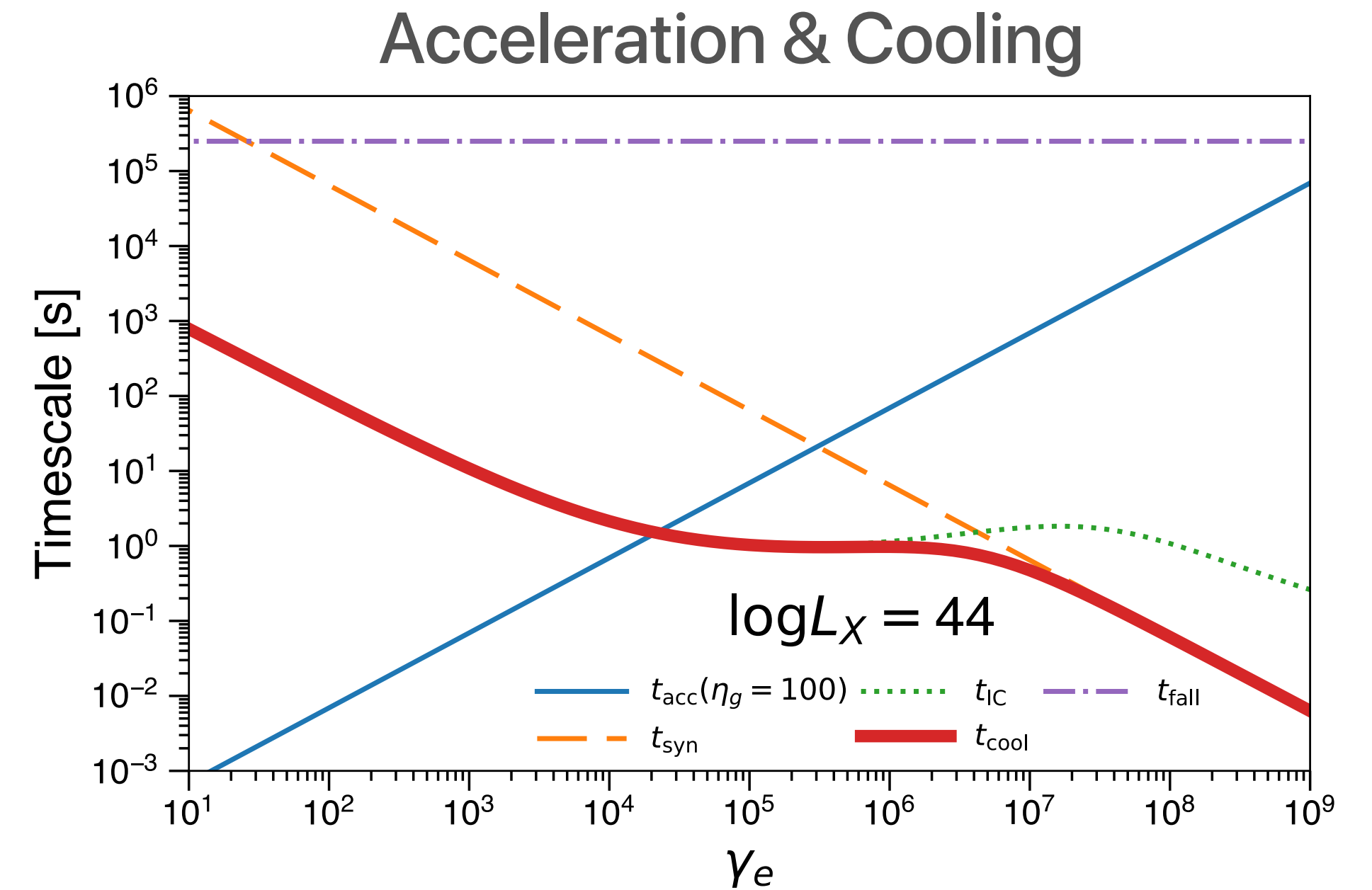
- Radio spectra (mm-band) of Seyferts are still not well understood.
- The mm-excess seems exist ubiquitously in nearby Seyferts.
 - ~1-10 mJy
 - Probably, originated from coronal synchrotron emission.
- Magnetic field are not strong enough to keep coronae hot.
- AGN Corona is a production site of high energy particles.
 - Can explain IceCube neutrino events (NGC 1068)



YI & Doi '18

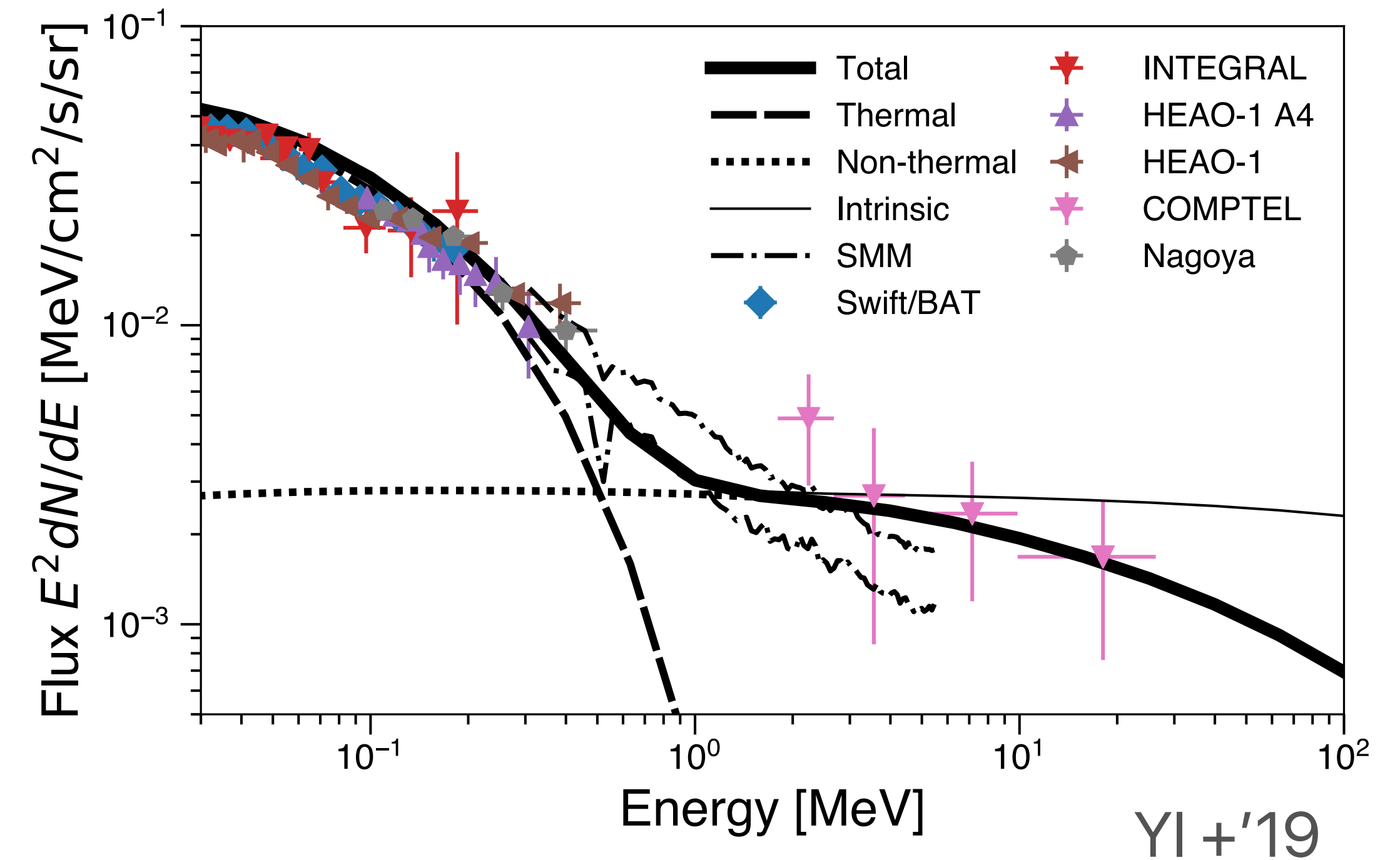
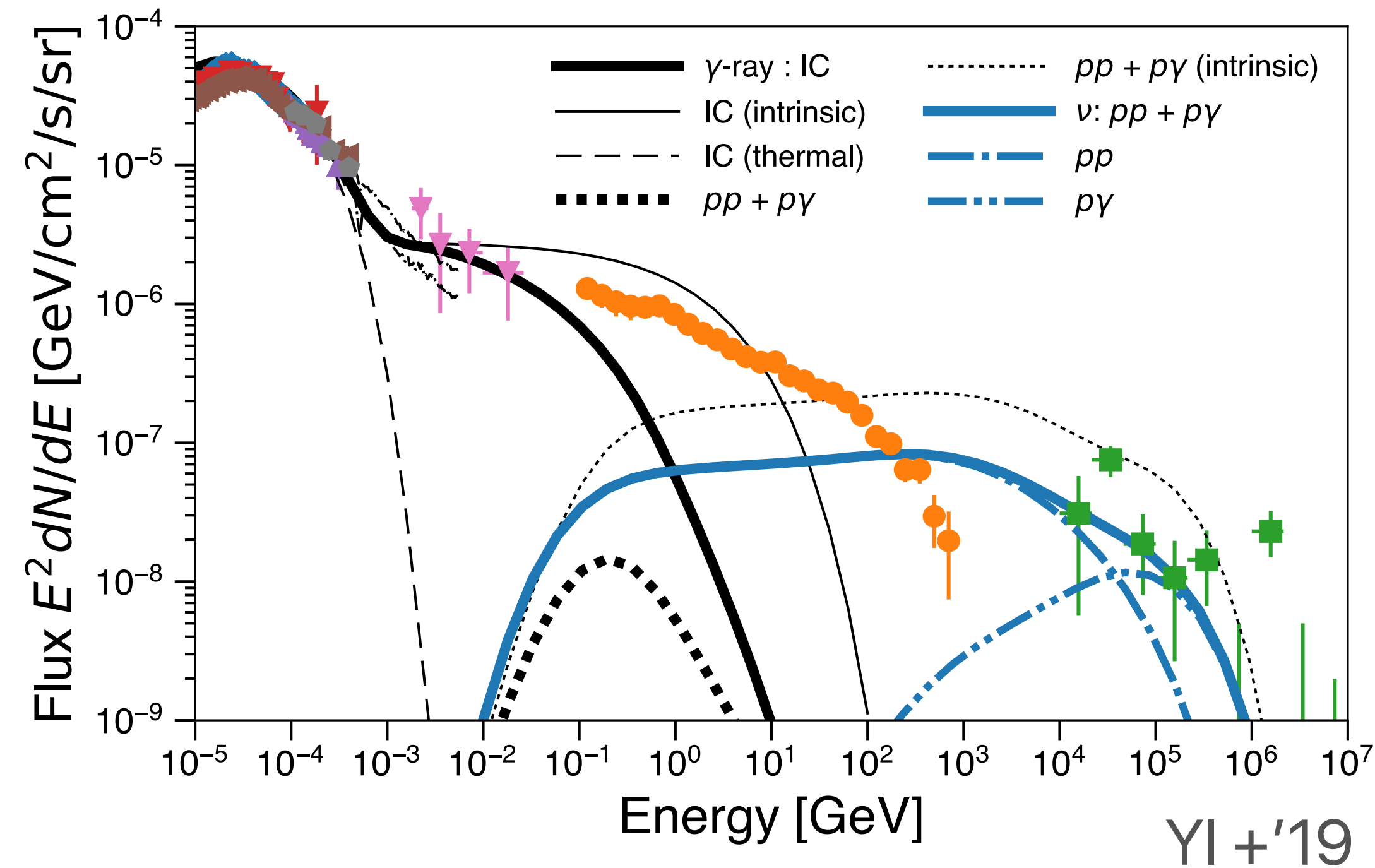
Generation of Non-thermal Electrons in Coronae

- 1st-order Fermi acceleration can explain the observed electrons
- Injection index of 2
- Where is the acceleration site?
- Other mechanisms may be difficult.
- Because of low magnetic field and accretion rate.



Cosmic High Energy Background Radiation

Integrated history of the Universe



- Seyferts can explain TeV neutrino background (see also Begelman+'90; Stecker+'92; Kalashev+'15; Murase+'20).
- Seyferts can explain X-ray & MeV gamma-ray background (YI+'08, YI+'19).
 - But, if both protons and electrons carry $\sim 5\%$ of the shock energy and gyrofactor is 30.