Scritunize the emission components of NGC1068: the expected neutrino emission from the kpc jet

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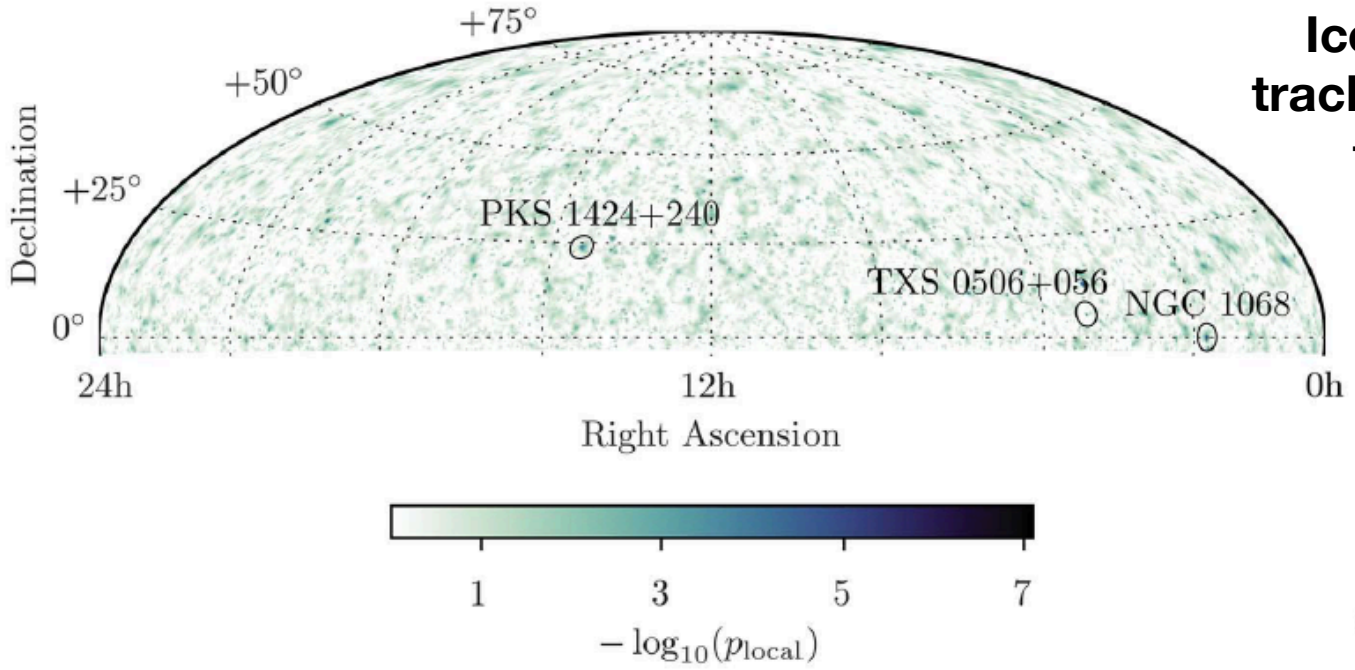
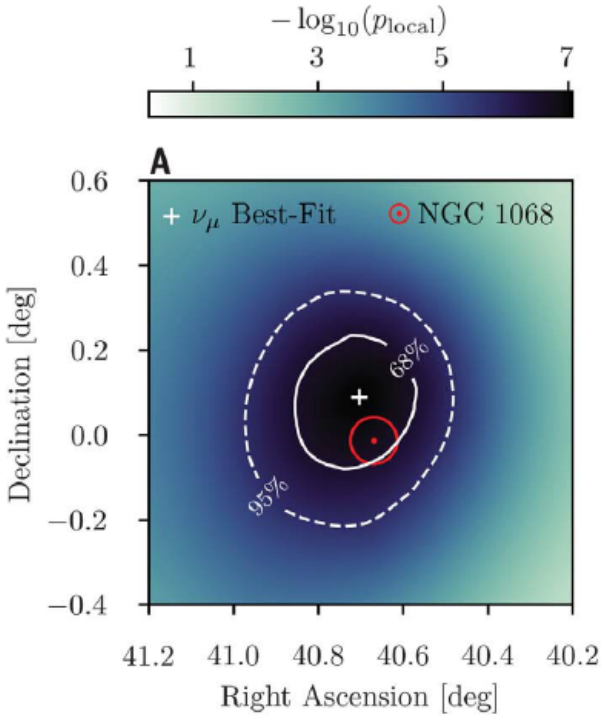
12/09/2023

ν OBSERVATIONS FROM NGC1068



IceCube Skymap with track-like events recorded from 2011 to 2020

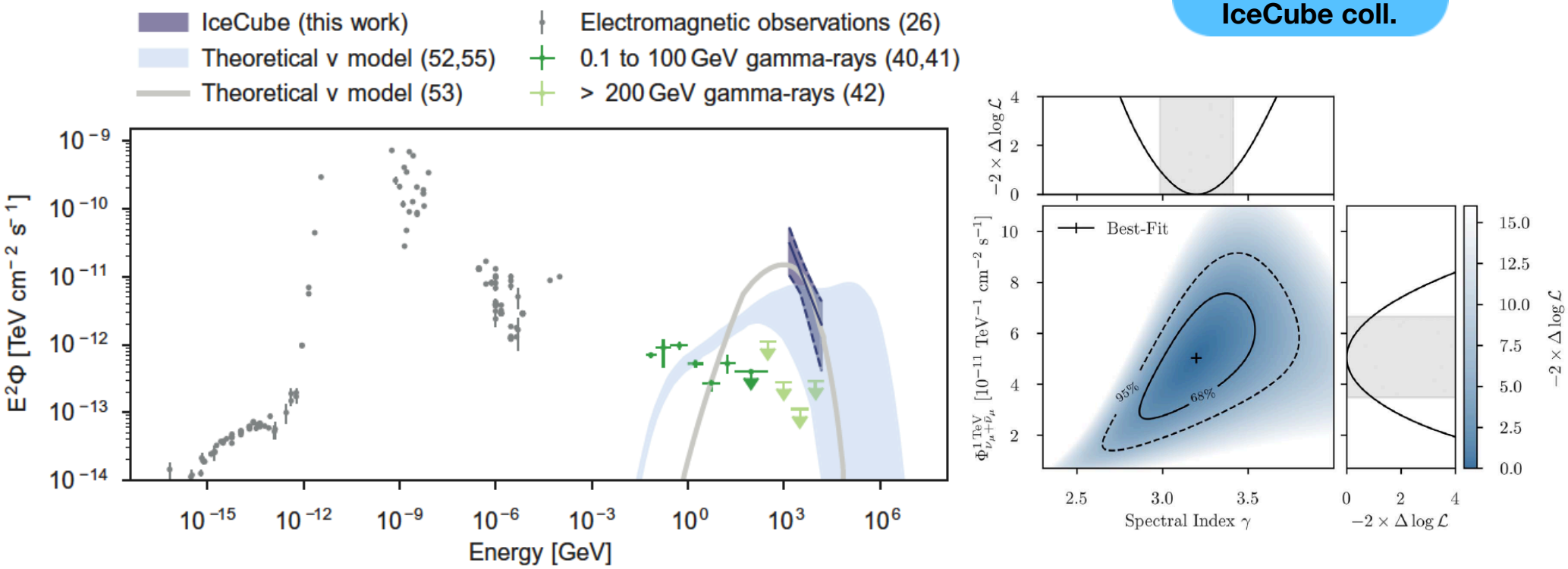
Science 378 (2022) IceCube coll.



4.2 σ excess observed in coincidence with the position of NGC1068, the "hottest" spot in the northern IceCube neutrino Sky

LOOKING FOR ν EMITTING REGIONS IN NGC1068

Science 378 (2022)
IceCube coll.



Considerable discrepancy between the gamma-ray flux and the neutrino flux

Fermi LAT is $E_\gamma F_{E_\gamma} \sim 10^{-9}$ GeV cm^{-2} s^{-1} in the 0.1 – 100 GeV

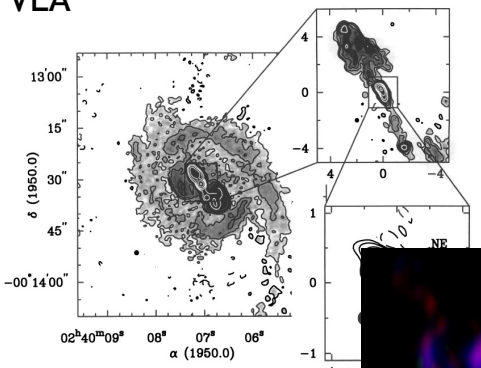
IceCube is $E_\nu F_{E_\nu} \sim 10^{-7}$ GeV cm^{-2} s^{-1} around 1 TeV

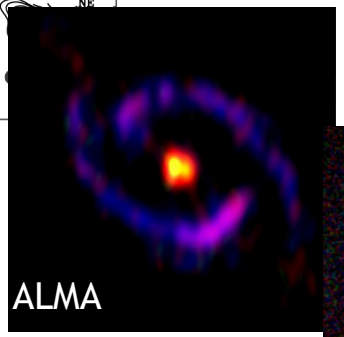
Possible answer: The region producing the neutrino flux is gamma-ray opaque

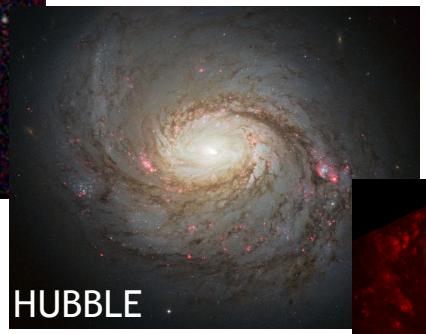
THE NGC1068 OBSERVATIONS

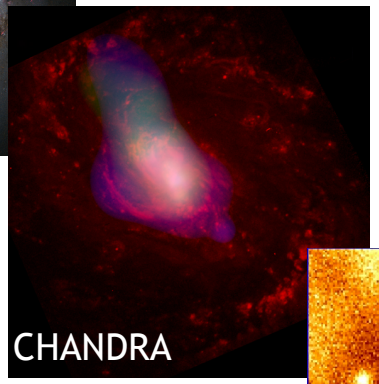
Radio **mm** **IR** **Optical** **x-ray** **gamma-ray**

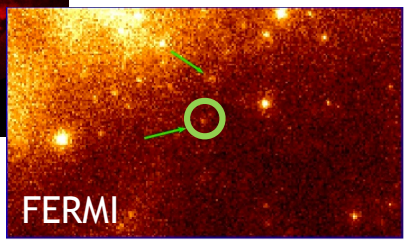
VLA











NGC1068 is a Archetypal Seyfert II Galaxy with multi-zone CR acceleration & interaction

SBG core + AGN correlated regions

- Distance *D*=14.4 Mpc
- Luminous AGN $L_{AGN}=10^{44}$-10^{45} erg/s
- Obscured AGN $N_H>10^{24}$ cm^{-2}
- Luminous infrared galaxy $L_{IR}=2.8\times10^{11}L_\odot$
- kpc-scale radio jet L= 10^43 erg/s

STUDY OF SBG COMPONENT FROM NGC1068

We apply a ***calorimetric scenario*** for the central hundred parsecs of NGC1068 **Tloss > Tesc**

parameter	value
$p_{p,\max}$	10^2 PeV
α	4.2
R	0.25 kpc
D_L	3.9 Mpc
$\xi_{\rm CR}$	0.1
$\mathcal{R}_{\rm SN}$	0.06 $\rm yr^{-1}$
B	200 μG
$n_{\rm ISM}$	100 $\rm cm^{-3}$
$v_{\rm wind}$	700 km/s
$U_{\rm rad}$	2500 $\rm eV/cm^3$

- In the calorimeter scenario, three main parameters:
  - Cut-off energy
  - Spectral index
  - Rate of Supernova explosions → **The Star Formation Rate**

MNRAS (2019) Peretti el al.

APJL 919 (2021) Ambrosone, Chianese, Fiorillo, A.M., Miele

Leaky-box-like model for CR transport

$$f(p)\left(\frac{1}{\tau_{\rm loss}(p)}+\frac{1}{\tau_{\rm adv}(p)}+\frac{1}{\tau_{\rm diff}(p)}\right)=Q(p)$$

CR injected and accelerated by SNRs

Kennicut at al. 1998, 2012,2021 Inoue et al. 2000

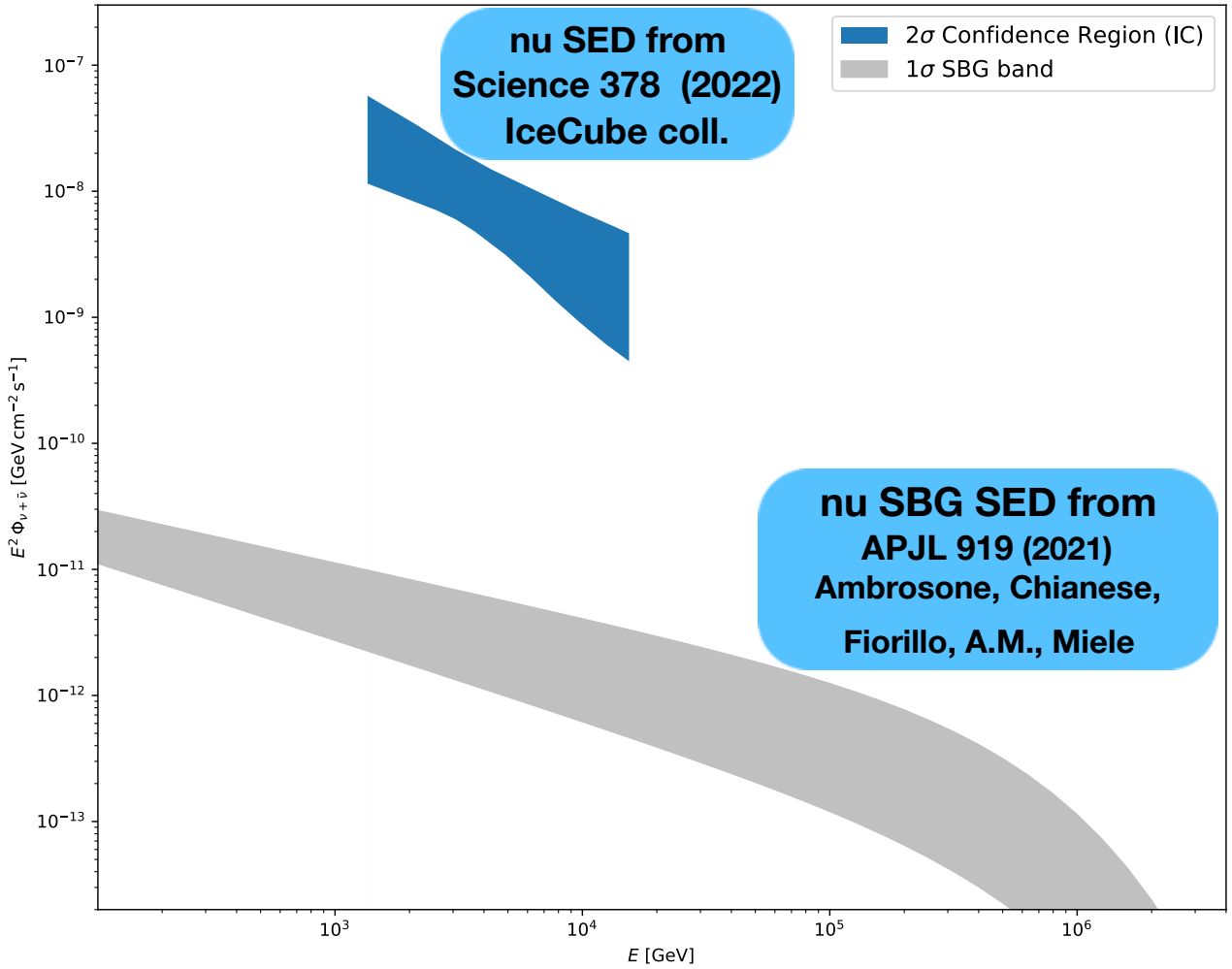
$$n_{\rm ISM}=175\left(\frac{\dot{M}_*}{5\ {\rm M}_\odot\ {\rm yr}^{-1}}\right)^{2/3}\ {\rm cm}^{-3} \qquad U_{\rm rad}=2500\left(\frac{\dot{M}_*}{5\ {\rm M}_\odot\ {\rm yr}^{-1}}\right)\ {\rm eV\ cm}^{-3}$$

Source	Uniform prior	Most-likely values	68% credible intervals	
	$\dot{M}_*$	$(\dot{M}_*, \Gamma)$	$\dot{M}_*$	Γ
NGC 1068	5 – 93	(16, 2.52)	[13, 20]	[2.45, 2.65]

We check compatibility of model with IR emission of NGC1068

ν SED from NGC1068 starburst core

NGC1068 IC SED and SBG component SED

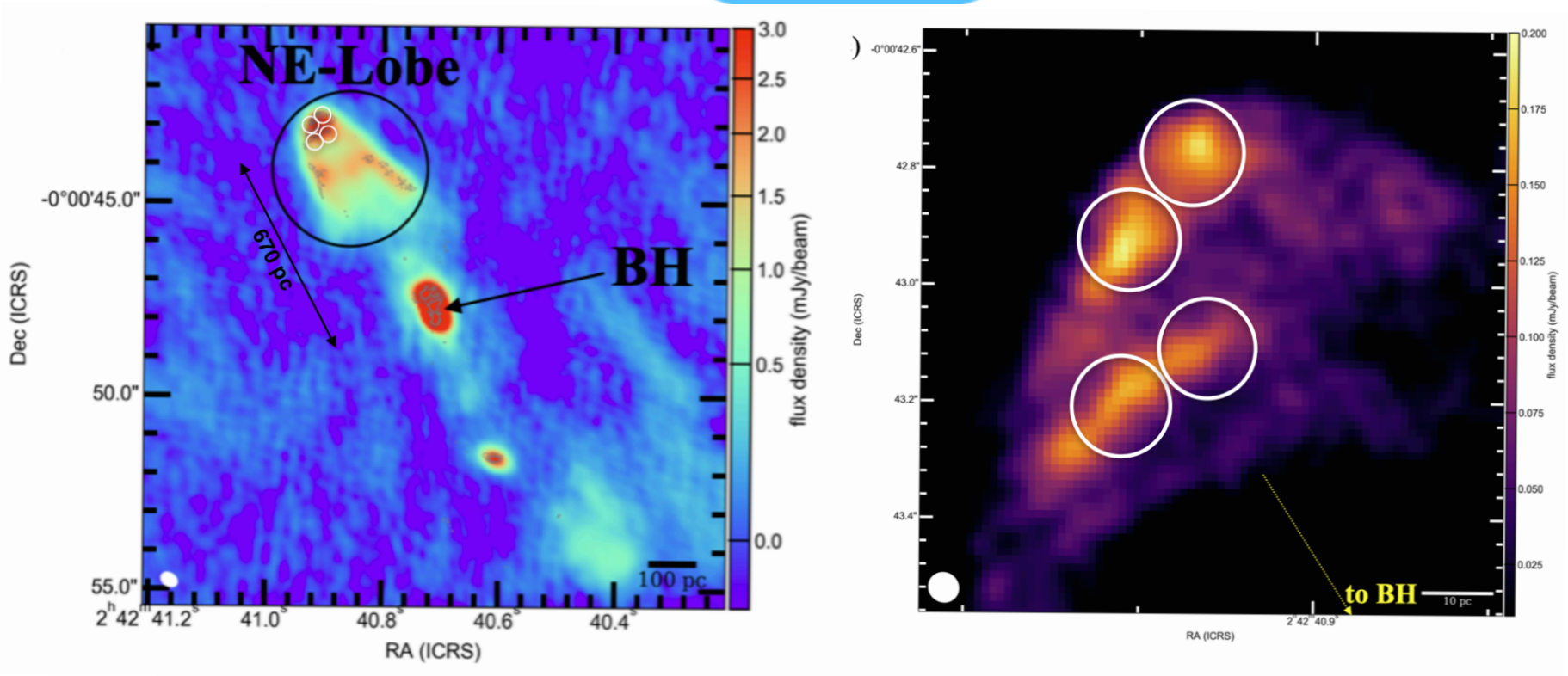


Following the procedure used in APJL 919 (2021) we built the neutrino SED expected from the core of NGC 1068 considering the SBG component.

Seems clear that a additional AGN neutrino emission is needed to explain IC observations

THE KPC JET OBSERVED BY ALMA

Michiyama et al. APJL (2022)



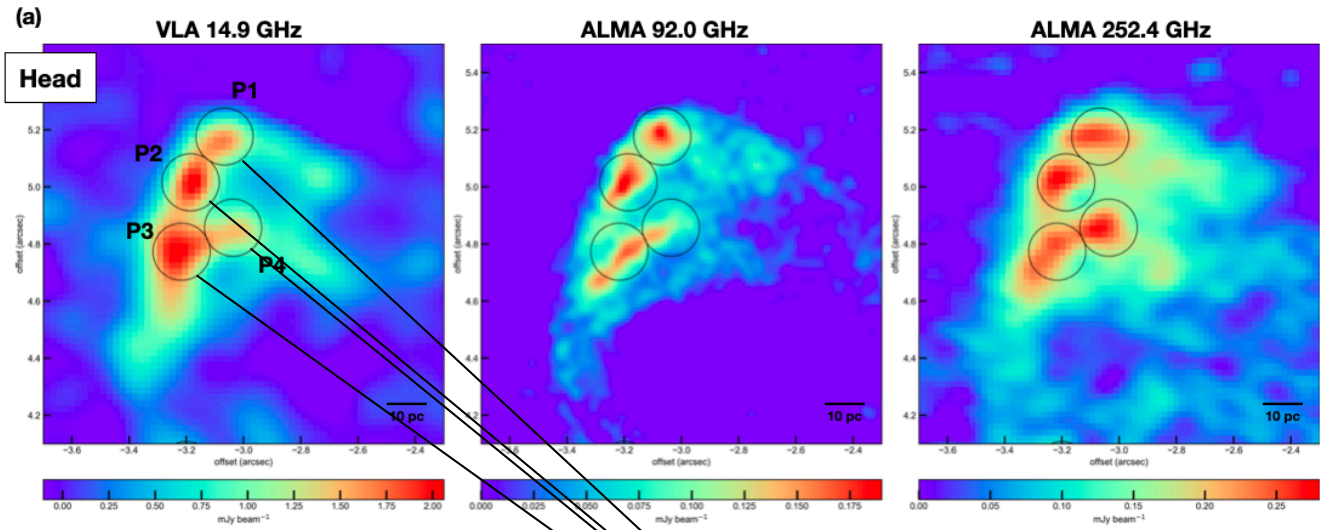
ALMA low-resolution 93 GHz map **Enlarged views around the head of the NE-Lobe**

$P_{\rm jet} = 1.8 \times 10^{43}$ erg s^{-1} based on the 1.4 GHz map

Gilmoure et al. APJL (1996)

The power of the jet can be greater than the one estimated by SN rate.
It is worth to explore the possibility of non thermal component and ν emission

A JET LEPTO-HADRONIC SCENARIO



Michiyama et al. APJL (2022)

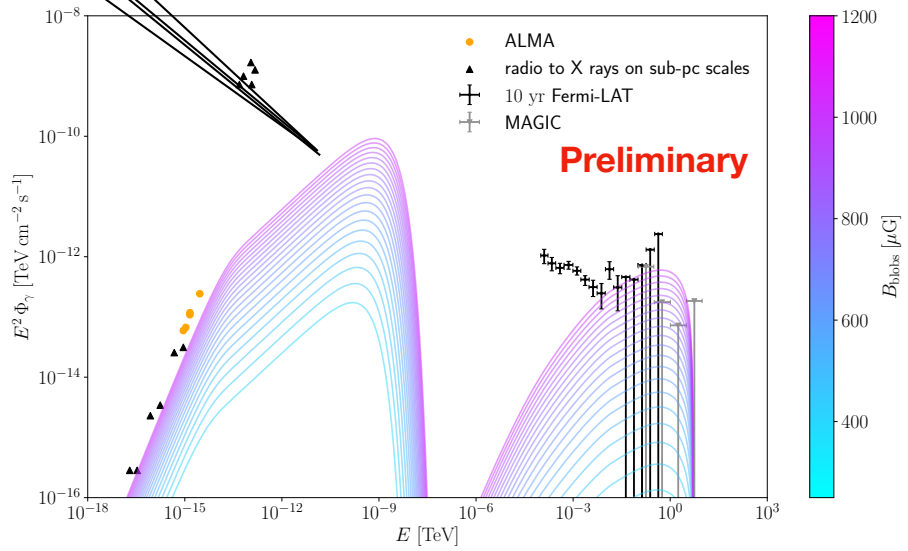
$$P(\text{jet}) > \sum P(\text{blobs})$$

SSC emission considering a electron population for each blob

A&A Vol.660 (2022) Nigro et al.

Leptonic contribution from the 4 blobs are considered through the use of AGNpy

we tried different values of Γ and B to fit the EM observations



In the jet:

$$B_{min} = 240\mu G$$

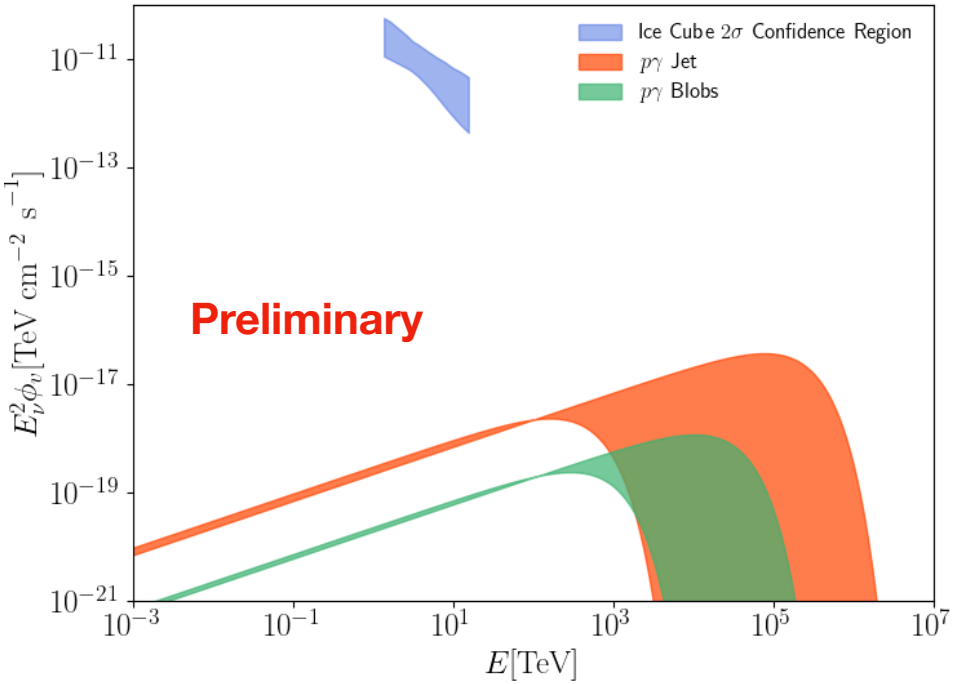
$$\frac{W_p}{W_e} \sim \frac{U_p}{U_e}$$

Emitting powers — Energy densities

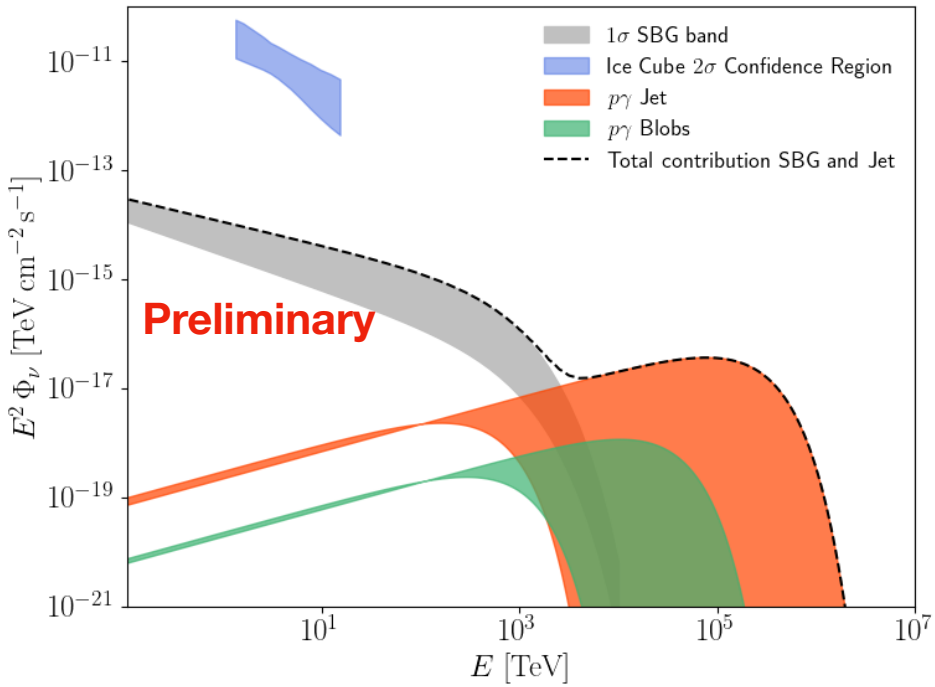
$$U_p \approx 588 U_e$$

PHOTO-HADRONIC NEUTRINO EMISSION

The interaction of proton with sinch photos emitted by electron populations, blobs and jet case.



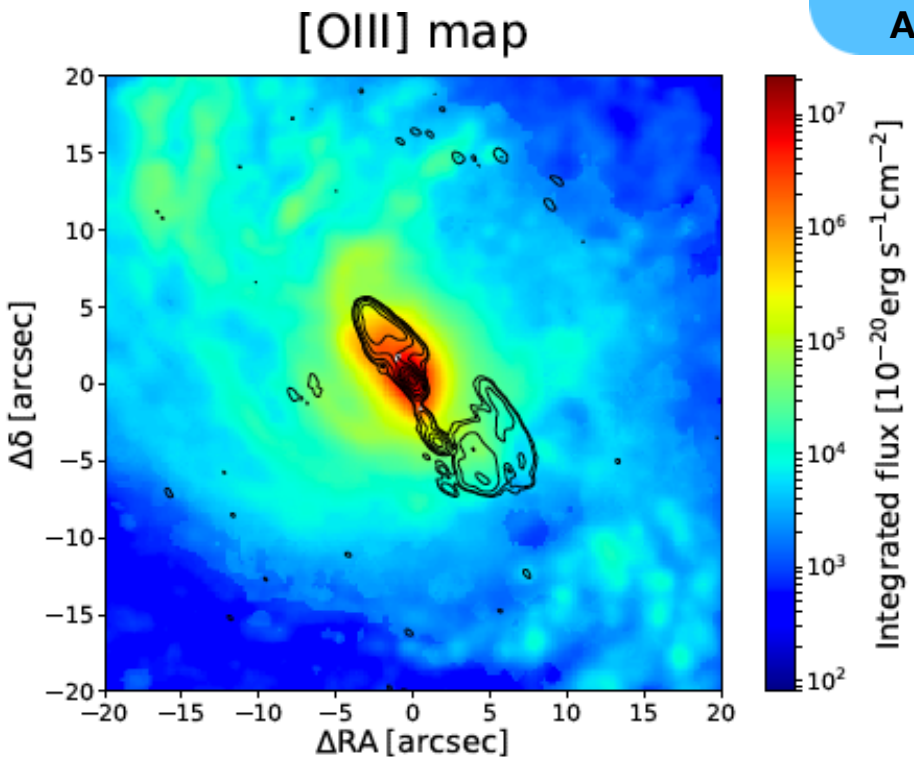
The neutrinos emitted through photohadronic emission considering these two scenarios are subdominant even respect to SBG ν component.



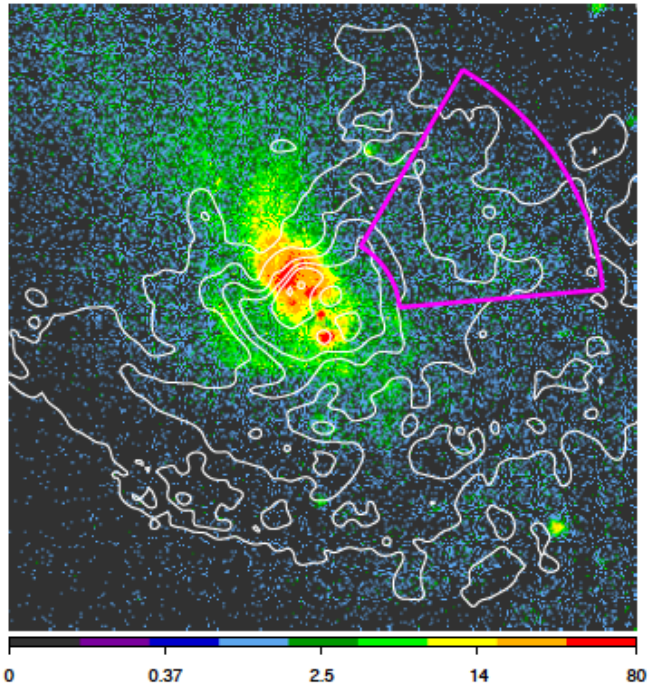
The photohadronic neutrino emission from the blobs present in the jet cannot account for a ν SED like the one observed by IceCube, especially with the parameters extracted from the ALMA paper.

HADRONIC NEUTRINO EMISSION

MAGNUM survey
Venturi et al.
A&A (2021)



VLA 5 GHz

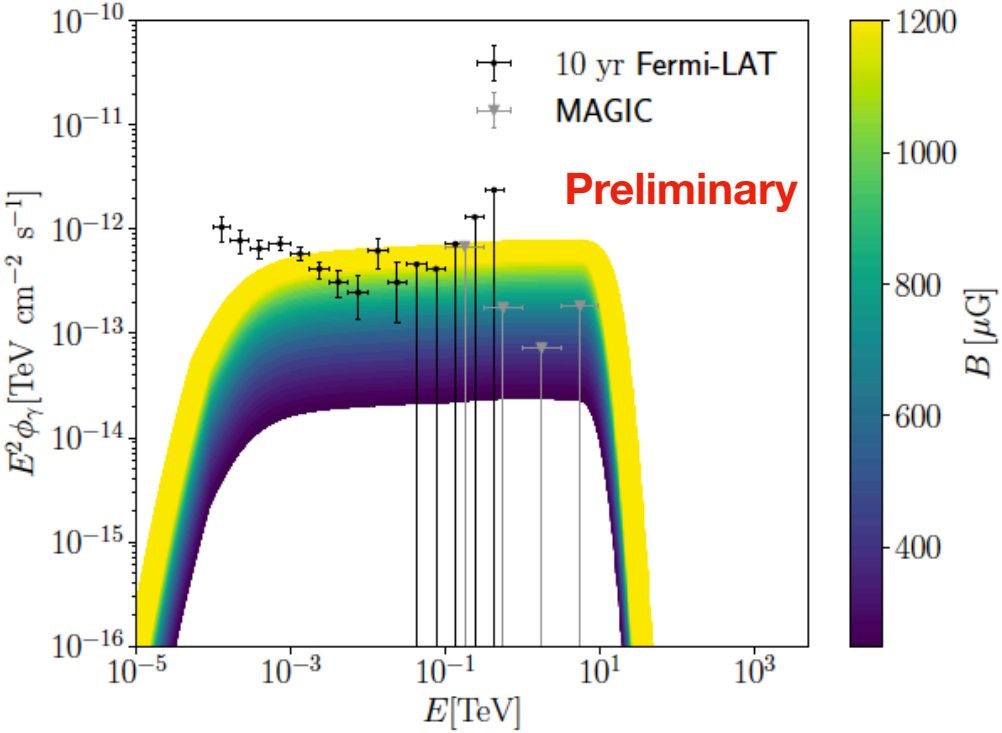


Chandra 0.3-8 keV

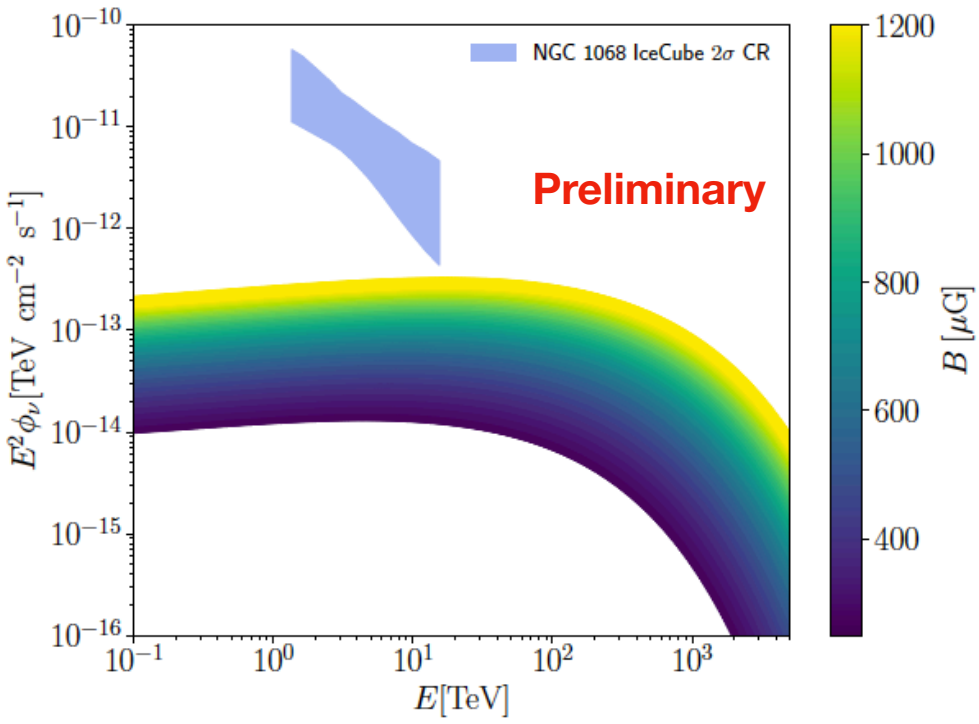
Observations indicate that we have enough gas extended up to several kpcs who can be also a region of interaction for the CR from the kpc jet.

ν AND γ PRODUCED BY PP JET-GAS

gamma rays



neutrinos



- **We consider a hemisphere of 40 pc diameter at the end of the Kpc jet**
- **We show the case with a gas density of n ~ 10 cm^{-3}**
- **We take into account $\gamma\gamma$ absorption and EBL**

ν from pp of kpc jet can account for 1% of IC at 1.5 TeV and 15% of IC at 15 TeV

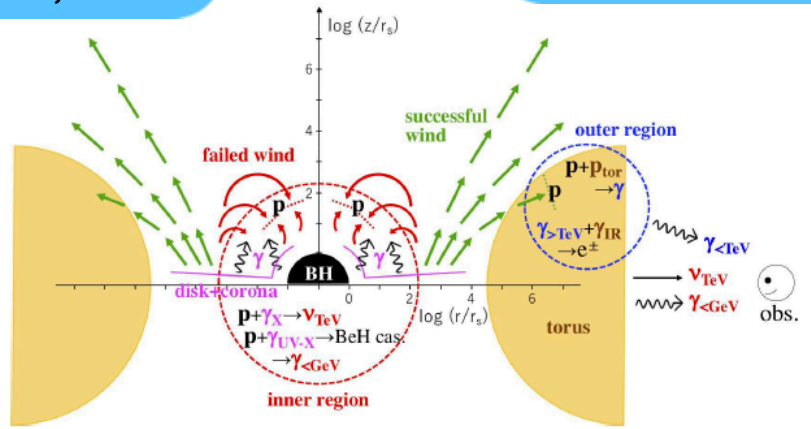
Gamma-ray SED represent a bound on hadronic production at kiloparsec scale.

EM MULTI-COMPONENT ANALYSIS

ArXiv: 2207.02097
Inoue, Cerruti, Murase

Corona

Look at Inoue presentation



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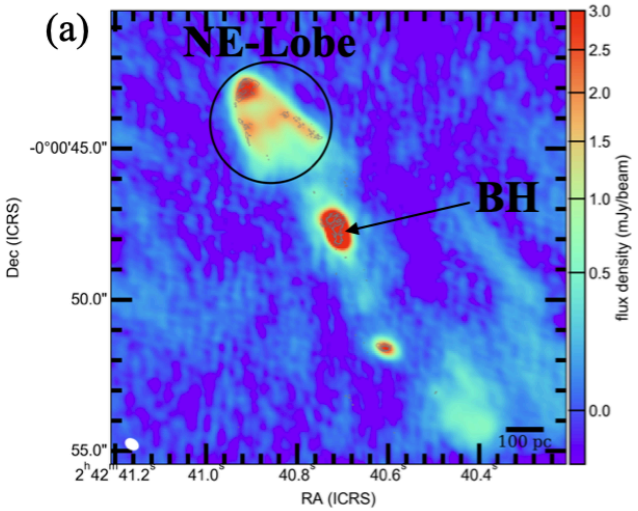
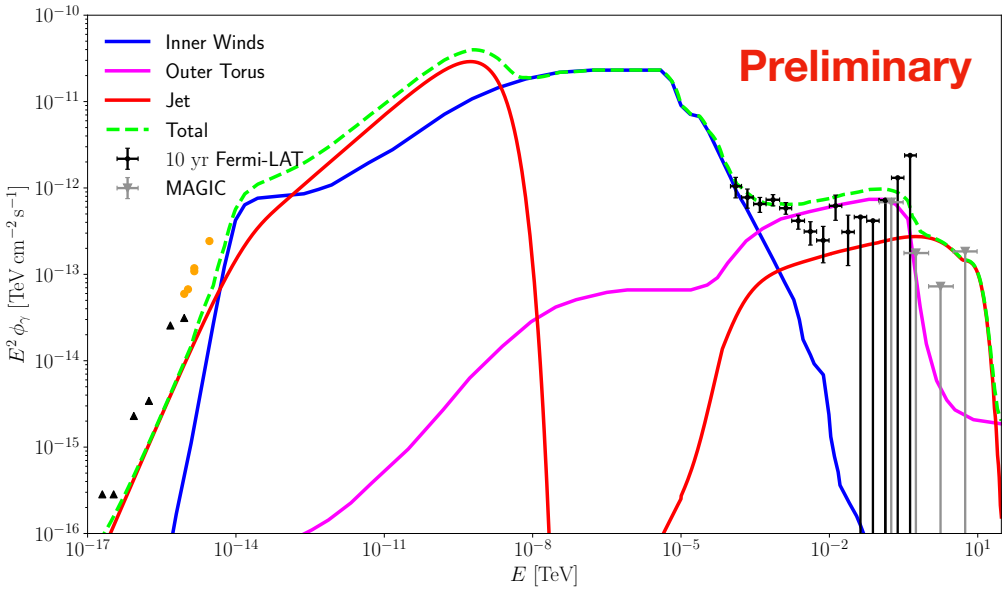
JeT

Michiyama et al. APJL (2022)





For the jet we consider the leptonic+hadronic emission

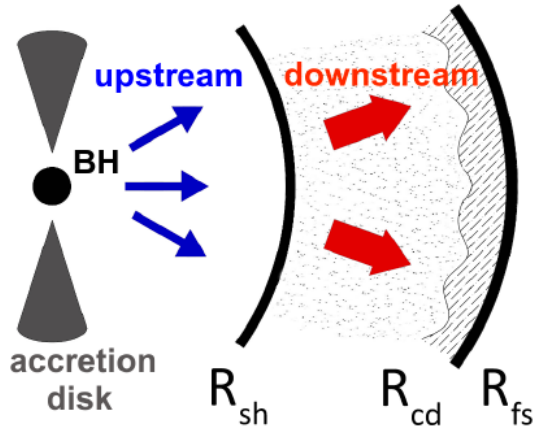
NGC1068 multi-component EM analysis can help to constrain the hidden part

EM MULTI-COMPONENT ANALYSIS

ArXiv:2301.13689
Peretti, Lamastra et al.

UFO

A&A 2016
Lamastra et al.



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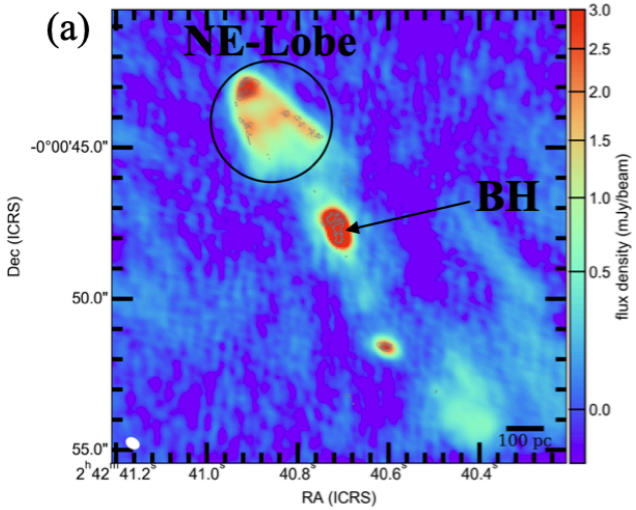
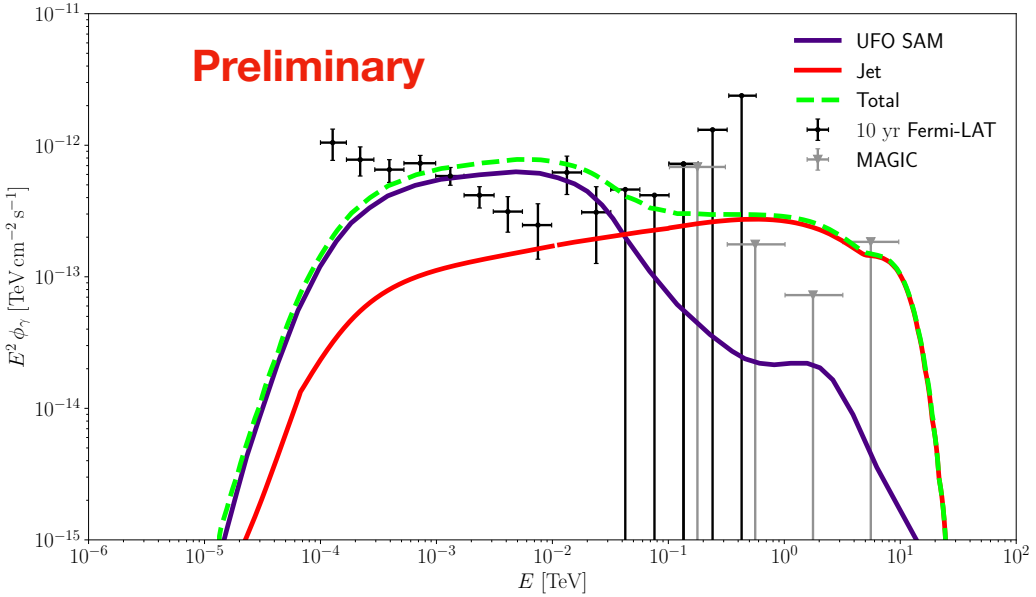
JeT

Michiyama et al.
APJL (2022)





For the jet we consider the leptonic+hadronic emission

At HE the UFO component is more constrained from the Fermi-LAT data while the JeT component from the MAGIC ULs

EM MULTI-COMPONENT ANALYSIS

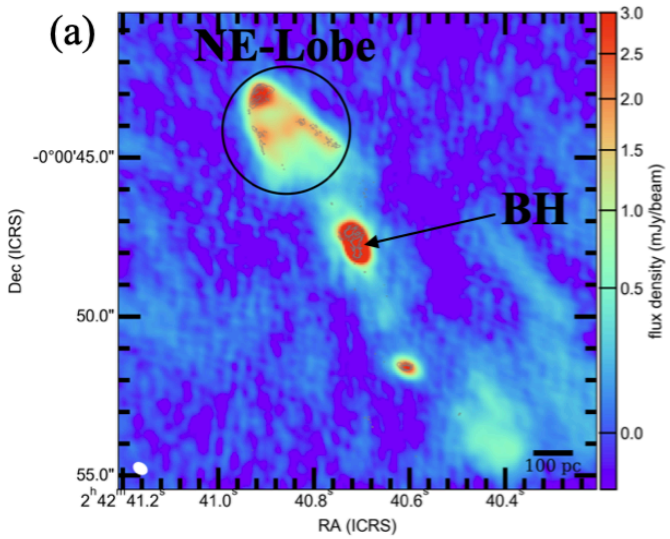
APJL 919 (2021) Ambrosone, Chianese, Fiorillo, A.M., Miele

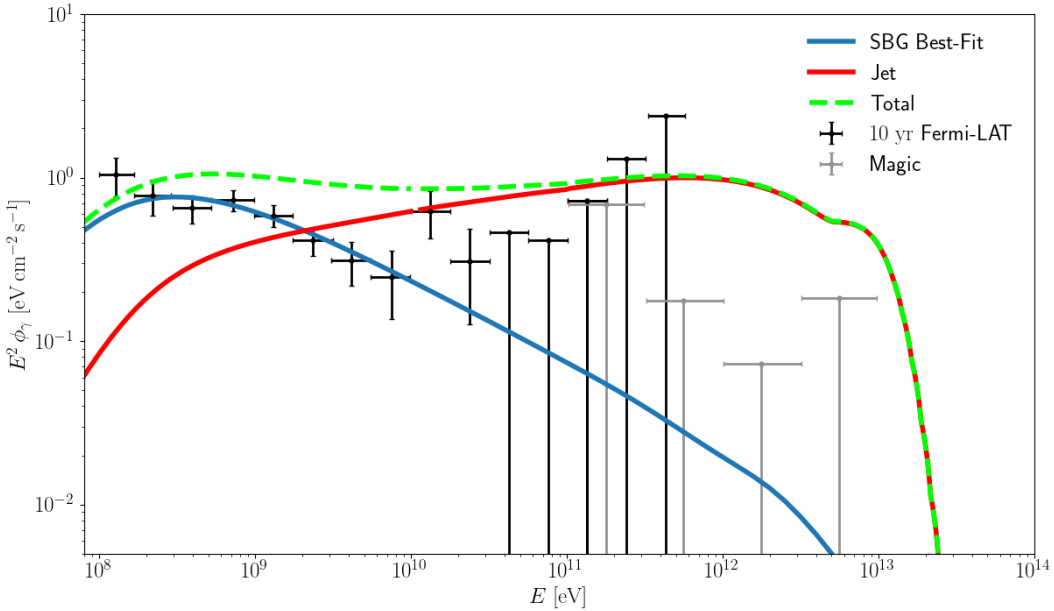
SBG

+

JeT

Michiyama et al. APJL (2022)





For the jet we consider the leptonic+hadronic emission

SBG + Jet components in NGC1068
While SBG component can saturate FGL data, Jet components can saturate FHL data.

SUMMARY

- ALMA provide us important parameters to compute the lepto-hadronic emission for the kpc jet of NGC1068.
- While photohadronic emission, considering the four resolved blobs, seems negligible the hadronic emission jet-gas can contribute up to 15 % of NCG1068 ν flux at 15 TeV.
- The kpc jet play an important role in the EM multi-component study of NGC1068.
- Possibly the ν “light curve” of NGC1068 can help us to disentangle the different ν emitting regions of this Seyfert galaxy.