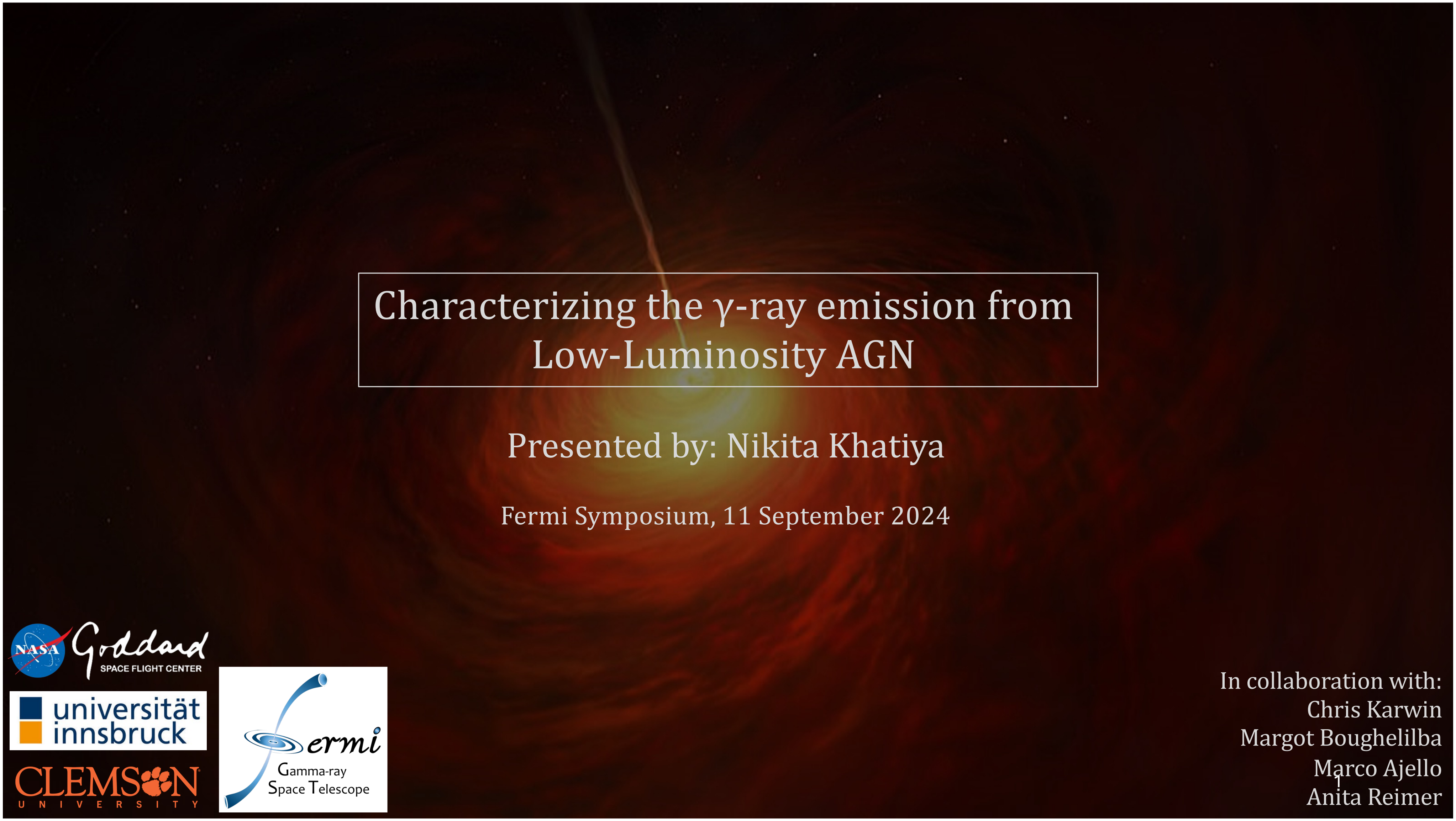


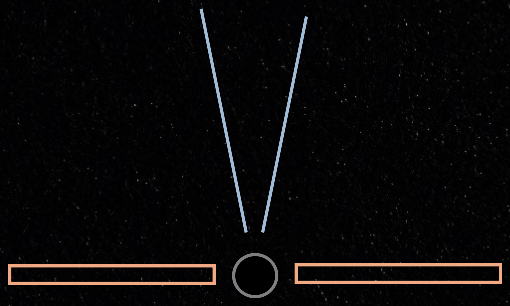
Characterizing the γ-ray emission from Low-Luminosity AGN

Presented by: Nikita Khatiya

Fermi Symposium, 11 September 2024

In collaboration with:
Chris Karwin
Margot Boughelilba
Marco Ajello
Anita Reimer

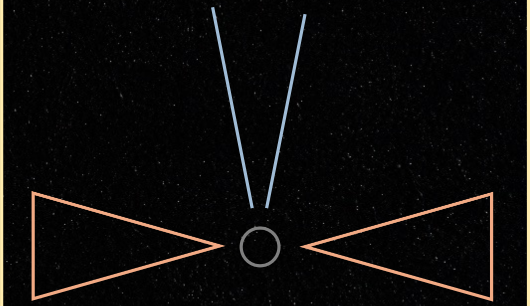
Case: $\eta \sim 0.1$



Geometrically thin, optically thick
accretion disk
e.g. Luminous AGNs

Artist impression of BH accreting matter

Case: $\eta < 0.1$



Geometrically thick, optically thin
accretion disk
e.g. Low Luminosity AGNs

$$L_{Bol} = \eta \dot{\mathrm{M}}_{\mathrm{BH}} c^2$$

Credit: Adobe Stock

Previous Work

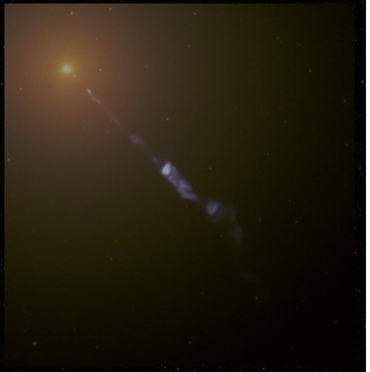
Menezes+20: Gamma-ray observations of low-luminosity active galactic nuclei

Results:

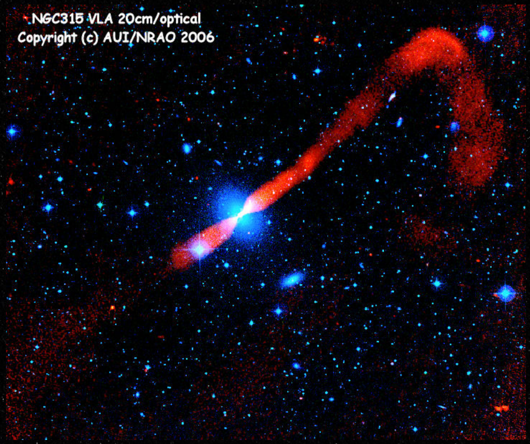
- γ-ray detection of 4 significant sources by *Fermi*-LAT
- All 4 are classified as FRI radio galaxies
- SED modeling (NGC 315 & NGC 4261):

  One-zone Synchrotron Self-Compton (SSC) can better explain γ-rays instead of RIAF model, however, neither models completely explain the γ-ray data points

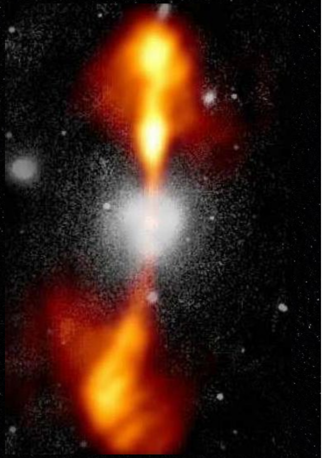
Credit: Université de Montréal



Credit:NASA



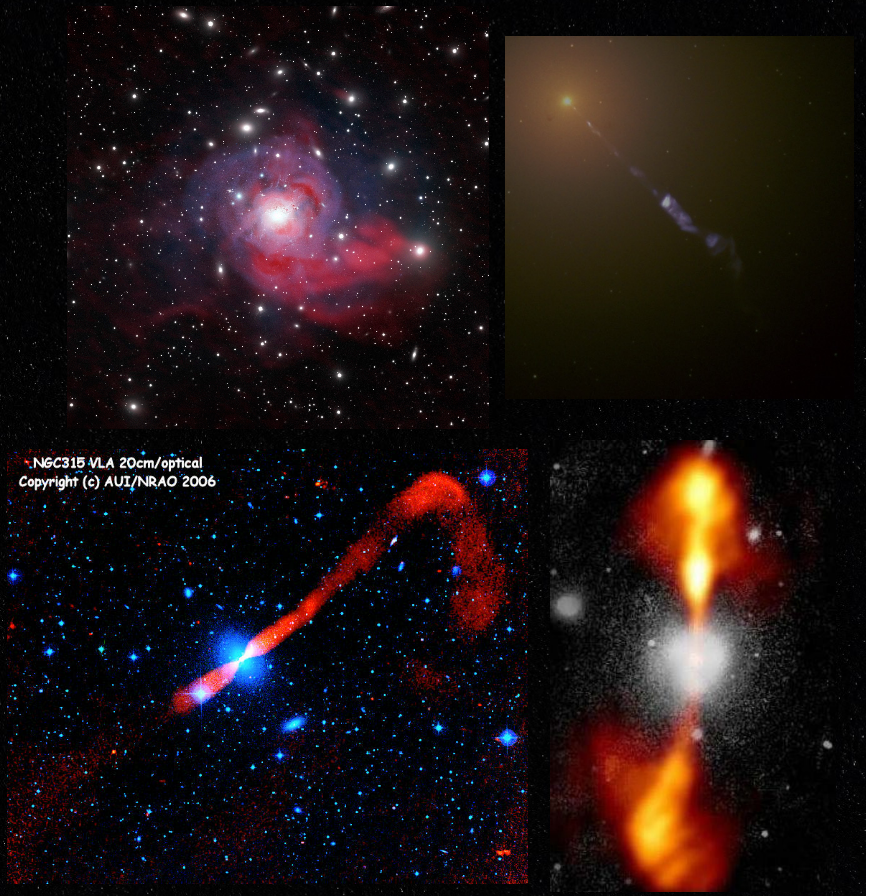
NGC315 VLA 20cm/optical
Copyright (c) AUI/NRAO 2006



Credit:NRAO

Why analyze γ-rays from LLAGNs?

- Plausible contribution to EGB, Icecube neutrinos and UHECRs
- Source of γ-ray production (from jet, disk or star formation and their relative contribution)
- Particle acceleration mechanism (leptonic, hadronic or a combination)



Sample Selection

- Built from Palomar Survey: optical spectroscopic survey of 486 nearby galaxies from 1984 to 1990 [Ho, Filippenko and Sargent]

  LLAGN: $L_{H\alpha} \leq 10^{40}$ erg/s

- Our sample:
  - Has Seyferts, LINERs and Transition Nuclei (LINERS contaminated by nearby HII region)
  - Exclude:
    - * 4 cross-corelated BZCAT sources
    - * NGC 4151 (known Ultra-Fast Outflow and nearby Blazar)
    - * 4 γ-ray detected sources (Menezes+20)

Subthreshold Sample: 186 sources

Observe γ-rays from LLAGNs with *Fermi* - Large Area Telescope (LAT)


Credit: NASA

Challenge: γ-ray flux from a single LLAGN source is lower than LAT flux sensitivity

Use **Stacking Analysis** (average γ-ray signal for the sample)
to study the LLAGN Population

Data Selection (*Fermi*-LAT)


Credit: NASA

- Sample size : 186 LLAGNs
- Energy range : 1 - 800 GeV
- Data: P8R3
- irfs: P8R3_SOURCE_V3
- time = 14.4 years

  (4 Aug, 2008 - 5 Jan, 2023)

- roi_width: 10 deg
- src_roiwidth: 15 deg
- pixel size: 0.08 deg
- binsperdec: 8
- zmax: 105 deg

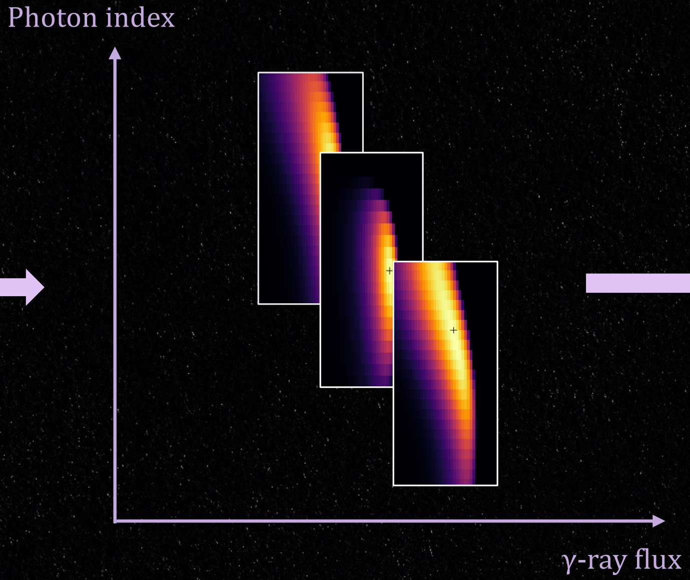
Joint likelihood analysis (PSF0-PSF3)

Background model:

- Galdiff: gll_iem_v07 (free norm and index, enable energy dispersion)
- Isotropic: iso P8R3_SOURCE_V3_PSFi_v1, for i =0-3 (free normalization, disable energy dispersion)
- Point sources: 4FGL DR3 + new sources (found with Fermipy)

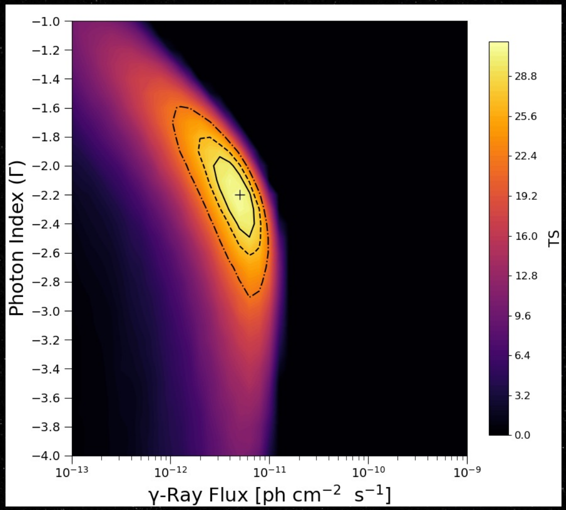
Stacking Pipeline

TS Profiles



Preliminary

Stacking



Test Statistic (TS) = -2 log(L_0/L)

Best fit parameters:

Flux = $5.01^{+2.93}_{-1.85} \times 10^{-12}$ ph cm^{-2} s^{-1}

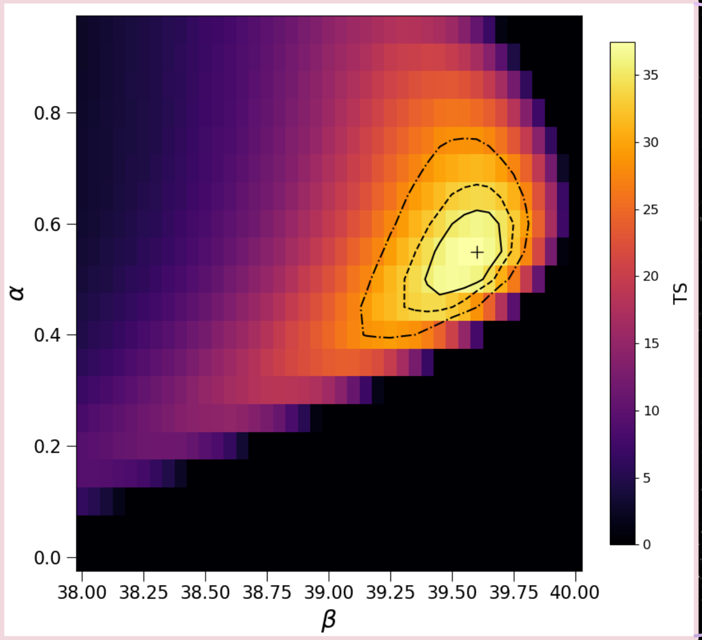
Index = $2.2^{+0.3}_{-0.2}$, TS = 31.27 (5.24 σ)

Indicates LLAGN population are indeed γ-ray emitters!

L_γ- L_{15GHz} correlation:

$$\log L_\gamma = \beta + \alpha \log\left(\frac{L_{15GHz}}{10^{40}\ erg/s}\right)$$

Preliminary

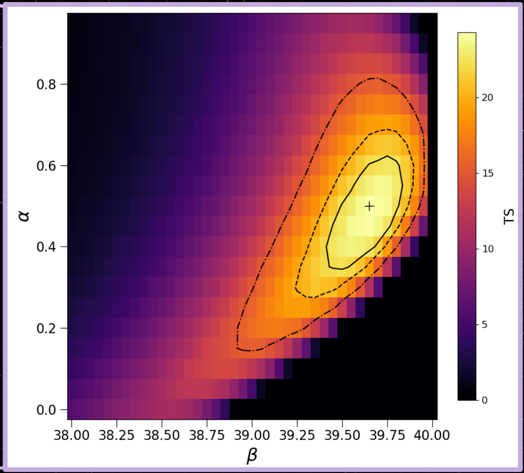


Subthreshold Sample (Count = 129)

$(\alpha, \beta) = \left(0.55^{+0.09}_{-0.10}, 39.59^{+0.15}_{-0.19}\right)$

TS = 37.5 (5.5 σ)

Spirals



Subthreshold Sample (Count = 77)

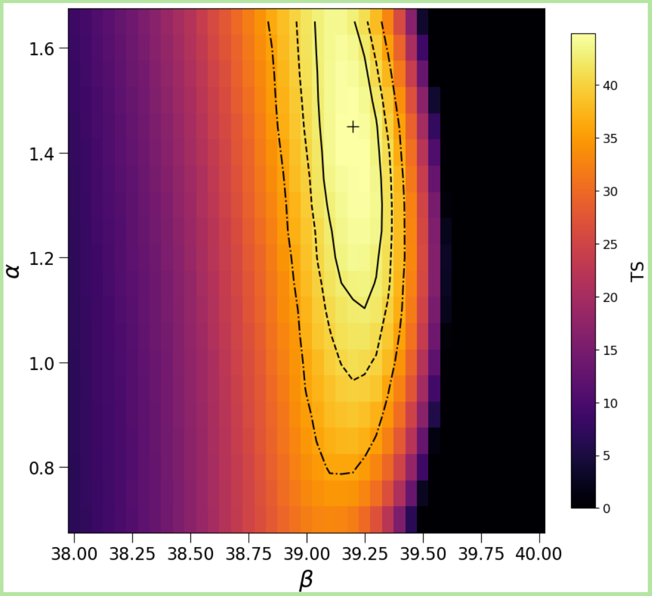
$(\alpha, \beta) = \left(0.5^{+0.15}_{-0.15}, 39.65^{+0.19}_{-0.19}\right)$

TS = 24.33 (4.25 σ)

L_γ- L_{IR} correlation:

$$\log L_\gamma = \beta + \alpha \log\left(\frac{L_{8-1000\mu m}}{10^{43.6}\ erg/s}\right)$$

Preliminary

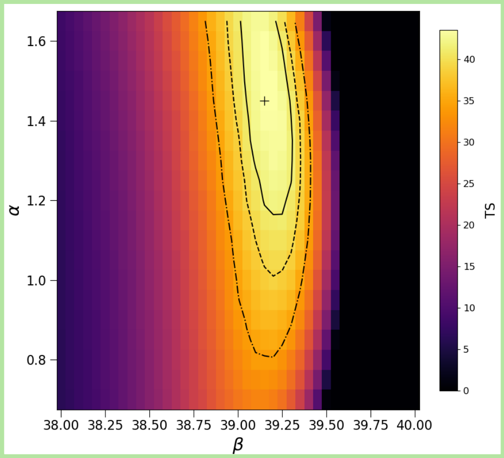


Subthreshold Sample (Count = 122)

$(\alpha, \beta) = \left(1.45^{+0.25}_{-0.35}, 39.19^{+0.15}_{-0.15}\right)$

TS = 45 (6.1 σ)

Spirals



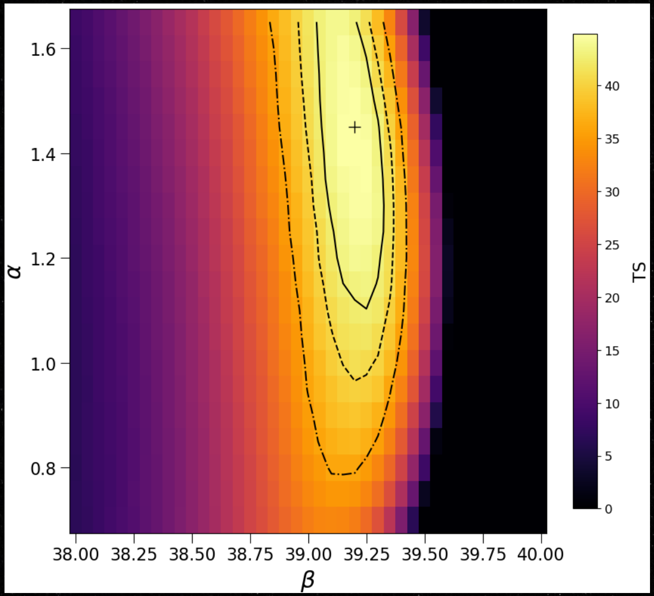
Subthreshold Sample (Count = 98)

$(\alpha, \beta) = \left(1.45^{+0.3}_{-0.3}, 39.15^{+0.15}_{-0.15}\right)$

TS = 43.6 (6.01 σ)

L_γ- L_{IR} correlation: $\log L_\gamma = \beta + \alpha \log(\frac{L_{8-1000\mu m}}{10^{43.6}\ erg/s})$

Preliminary

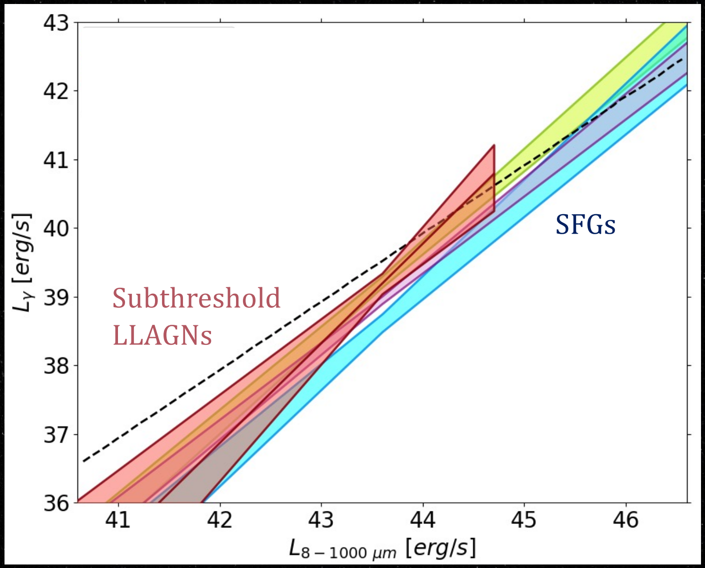


Subthreshold Sample (Count = 122)

$(\alpha, \beta) = \left(1.45^{+0.25}_{-0.35}, 39.19^{+0.15}_{-0.15}\right)$

TS = 45 (6.1 σ)

Comparison of LLAGNs to Star Forming Galaxies (SFGs) from Ajello+20:



Majority of the γ-rays are most likely produced due to star formation activity!

Significant γ-ray sources:

NGC 1275

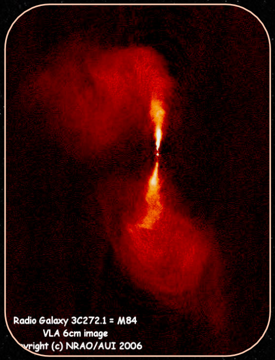
TS = 90195.3

NGC 4486 (M87)

TS = 1874.3

New detection!

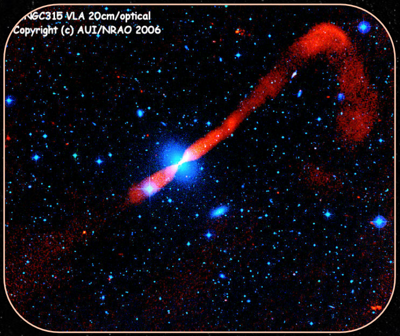
NGC 4374



Radio Galaxy 3C272.1 = M84
VLA 6cm image
yright (c) NRAO/AUI 2006

FRI galaxy (16.99 Mpc)
TS = 31.42

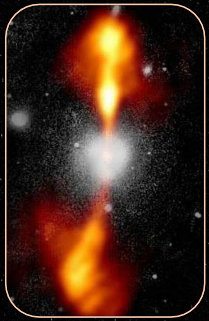
NGC 315



NGC315 VLA 20cm/optical
Copyright (c) AUI/NRAO 2006

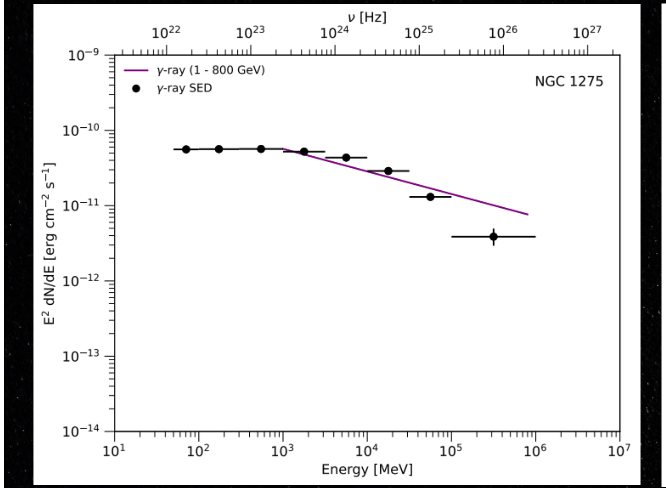
TS = 95.07

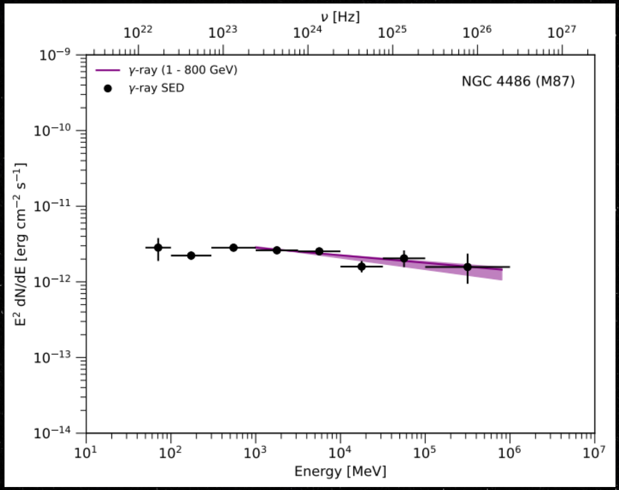
NGC 4261



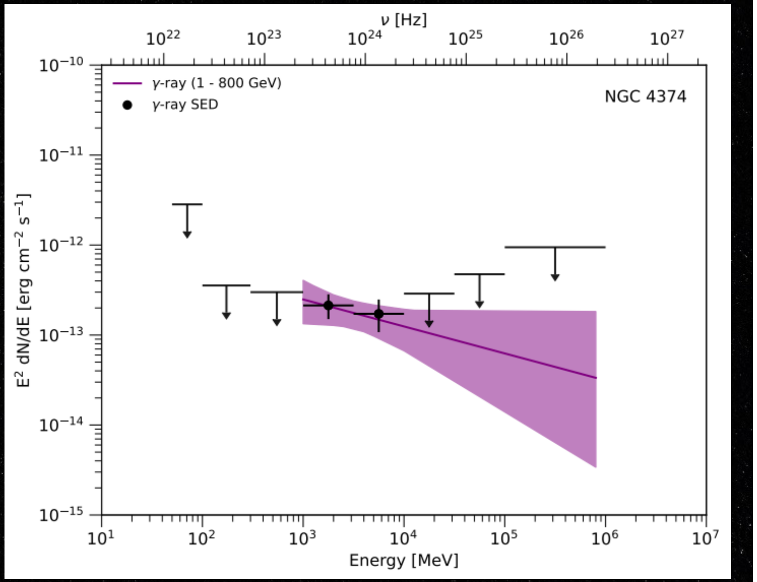
TS = 84.25

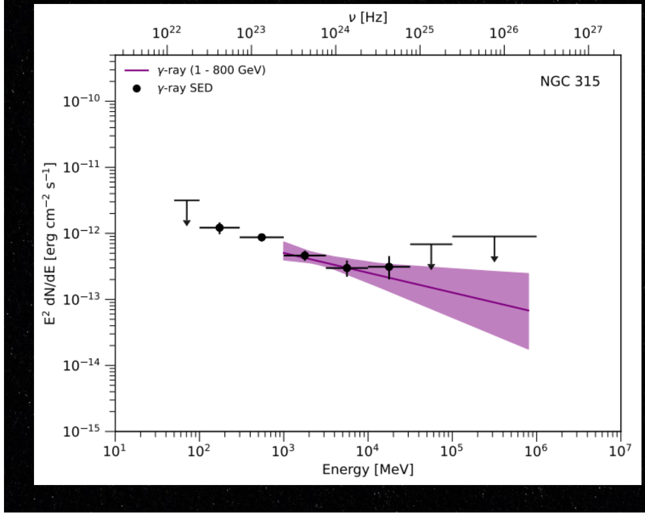
Significant γ-ray sources: Preliminary

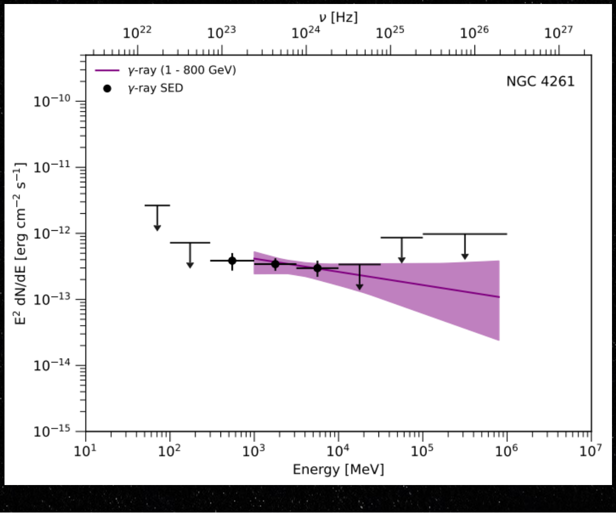




New detection!







Since all of them are FRIs in nature, γ rays are likely produced due to the radio jets

Takeaway Points:

- Subthreshold LLAGNs (186 sources): Detection at 5.24 σ and best index of $2.2^{+0.3}_{-0.2}$, majority contribution from Spirals

- L_γ scales with L_{IR} for subthreshold LLAGNs, consistent with expectations from star formation activity!

⇓

γ rays produced are most likely due to star formation activity!

- Apart from 4 significant γ-ray sources, we have a new γ-ray source detection (NGC 4374)!

⇓

γ rays produced are most likely due to jets!

Further confirmation will be provided from SED modeling! **(Work in progress)**