Multi-Wavelength Correlations, Observational Biases, and AGN as Possible Particle Accelerators

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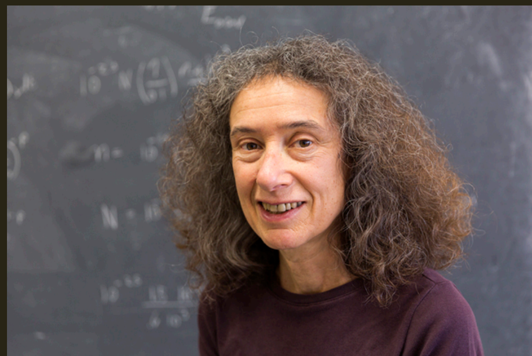
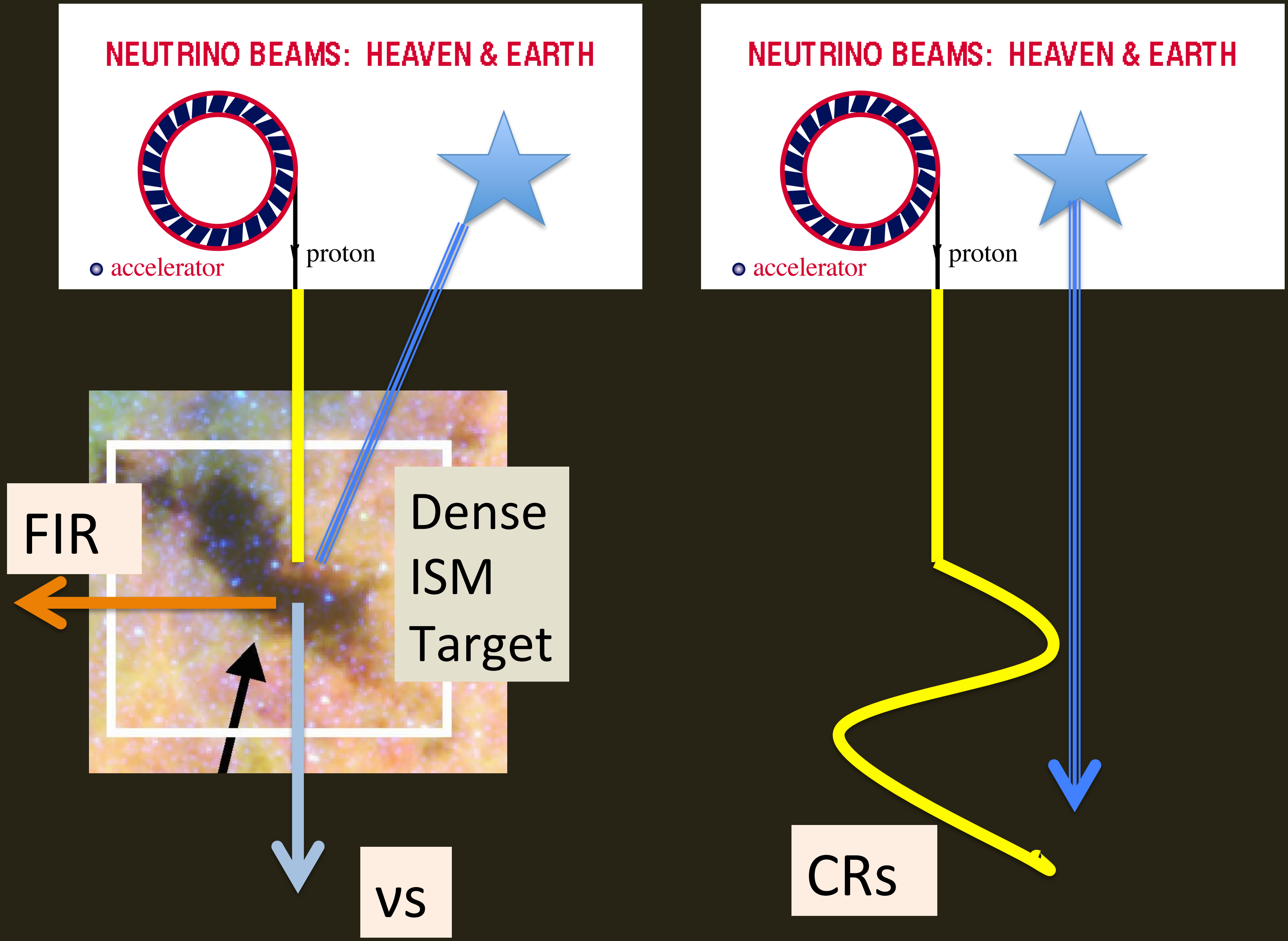


Ellen Zweibel-UW-Madison

Susanne Aalto
Chalmers University

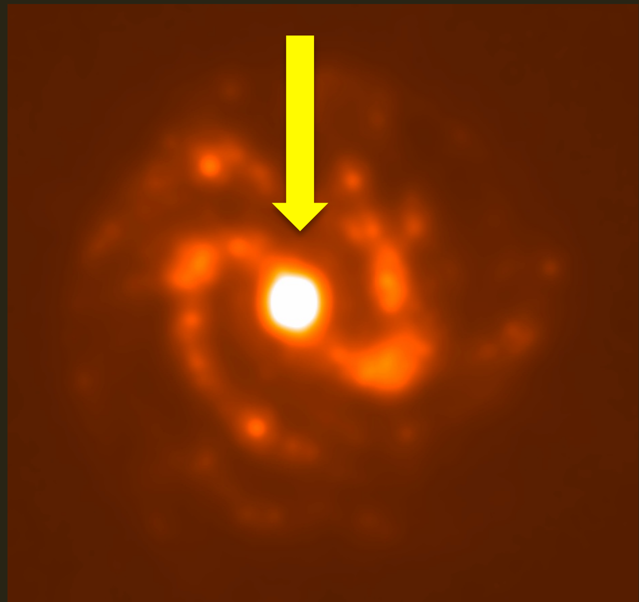
WIPAC
Wisconsin IceCube
Particle Astrophysics Center

Two basic outcomes from cosmic ray accelerators

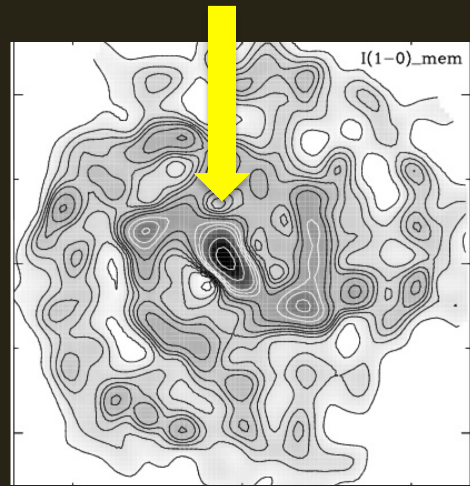


Central Molecule Zone (CMZ): Spiral Galaxy M83

Stellar Surface Density



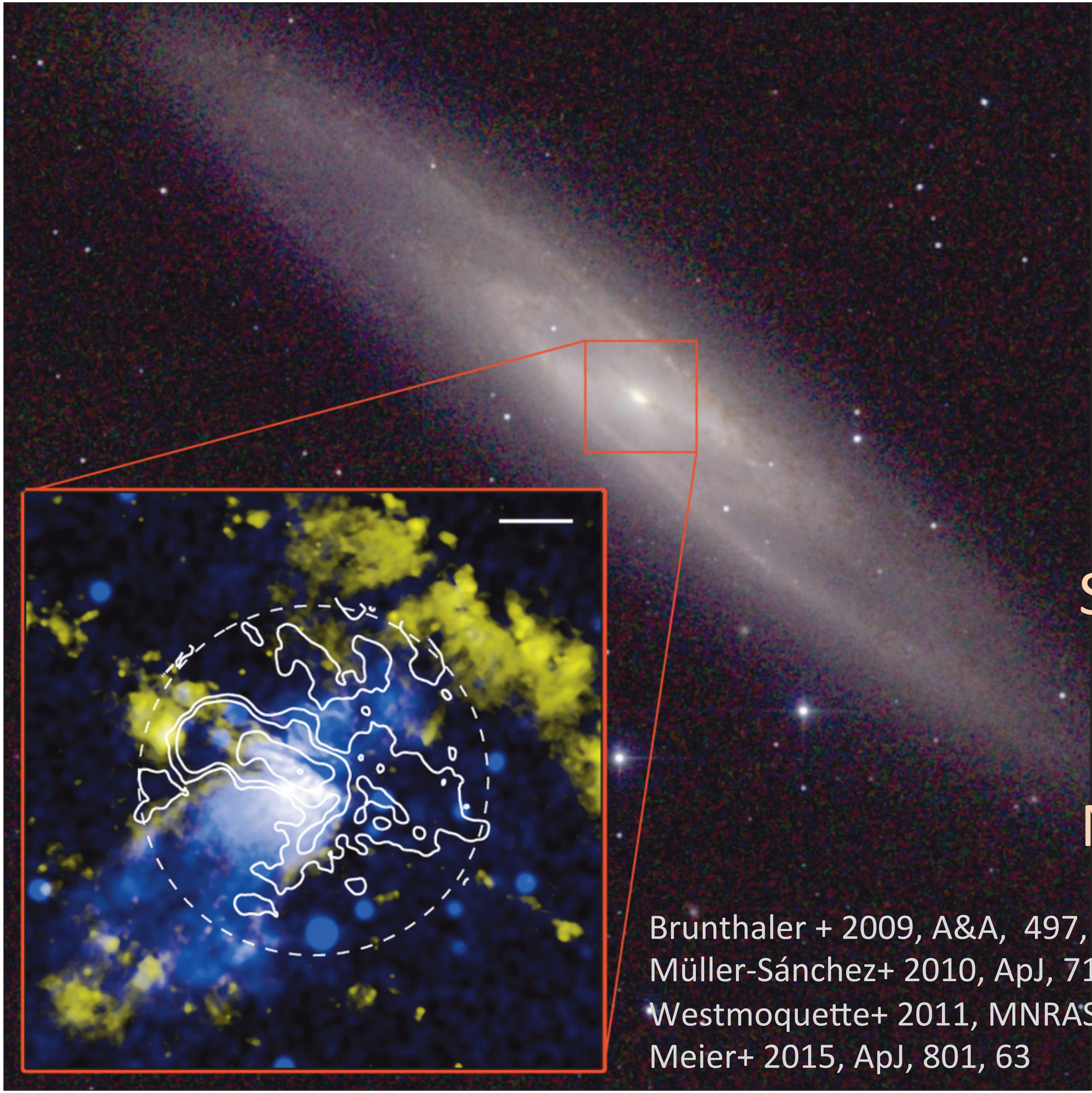
Star Formation Rate Surface Density



Molecular Gas Surface Density

CMZs: R<0.5 kpc; peak gas & star formation rate density
Combine Supernova Accelerators & Targets

E.g., Crocker+2011, MNRAS, 413, 763; Gallagher+ 2014, IAU, 103, 61; Kruijssen+ 2014, MNRAS, 440,3370;

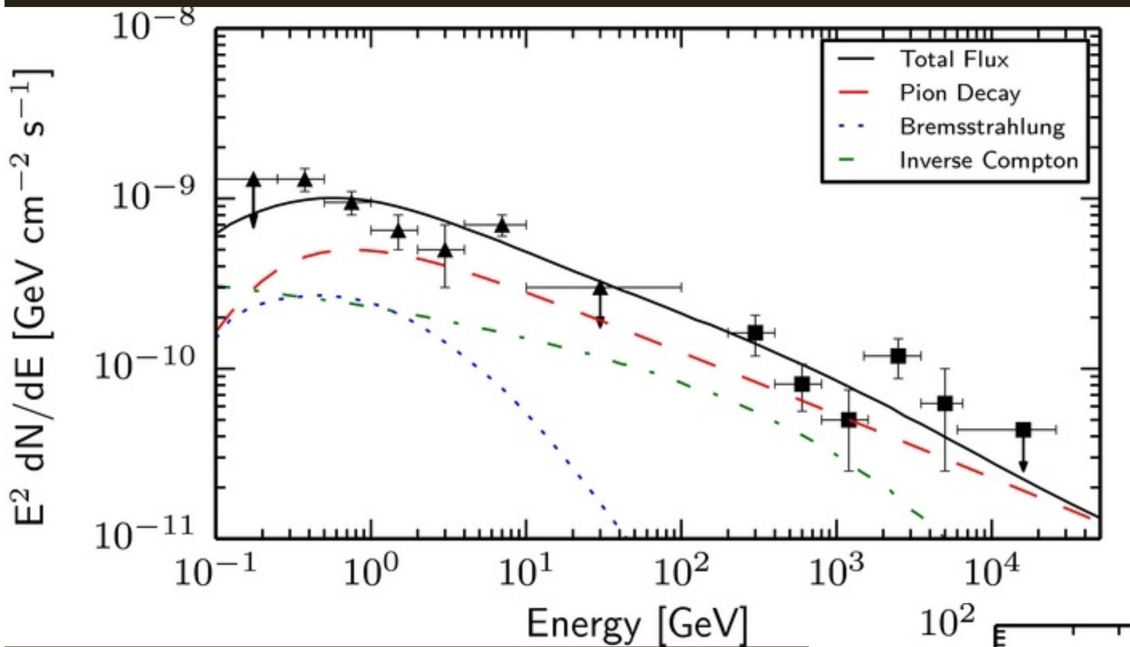


NGC 253
Giant SBc
spiral

CMZ
Starburst →
Maximum
Stellar Energy
Density &
Gas-Rich +
Nuclear Wind

Brunthaler + 2009, A&A, 497, 103;
Müller-Sánchez+ 2010, ApJ, 716, 1166
Westmoquette+ 2011, MNRAS,414, 3719
Meier+ 2015, ApJ, 801, 63

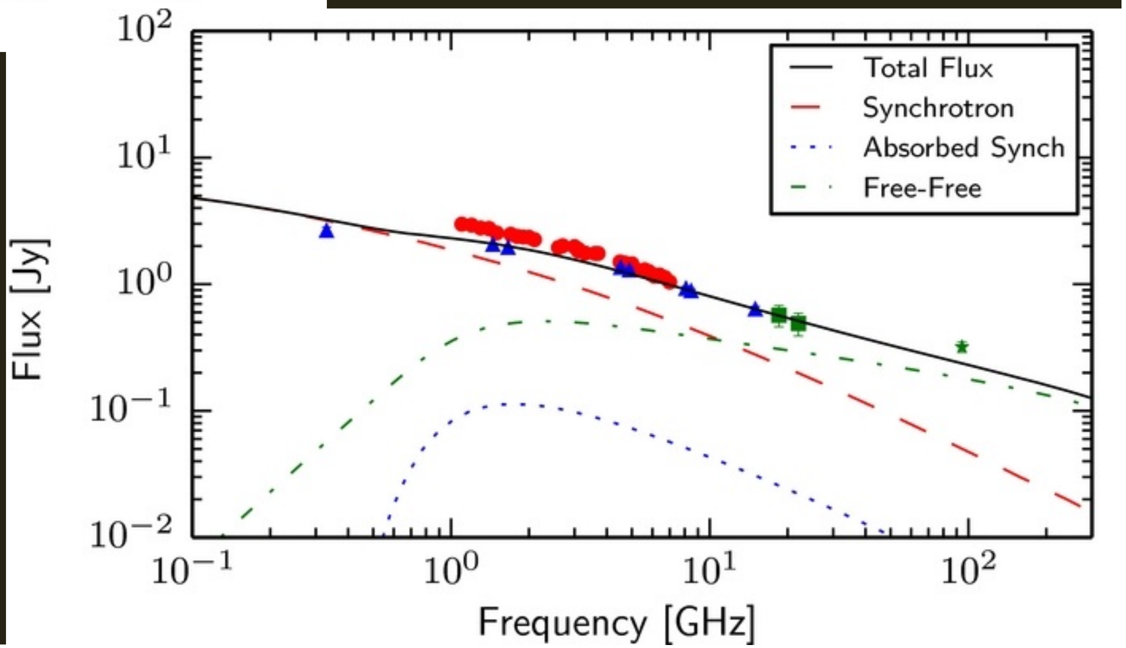
NGC253 CMZ YEGZ Supernova Models Cosmic Ray Accelerator MODEL RESULTS: γ-ray & Radio SEDs

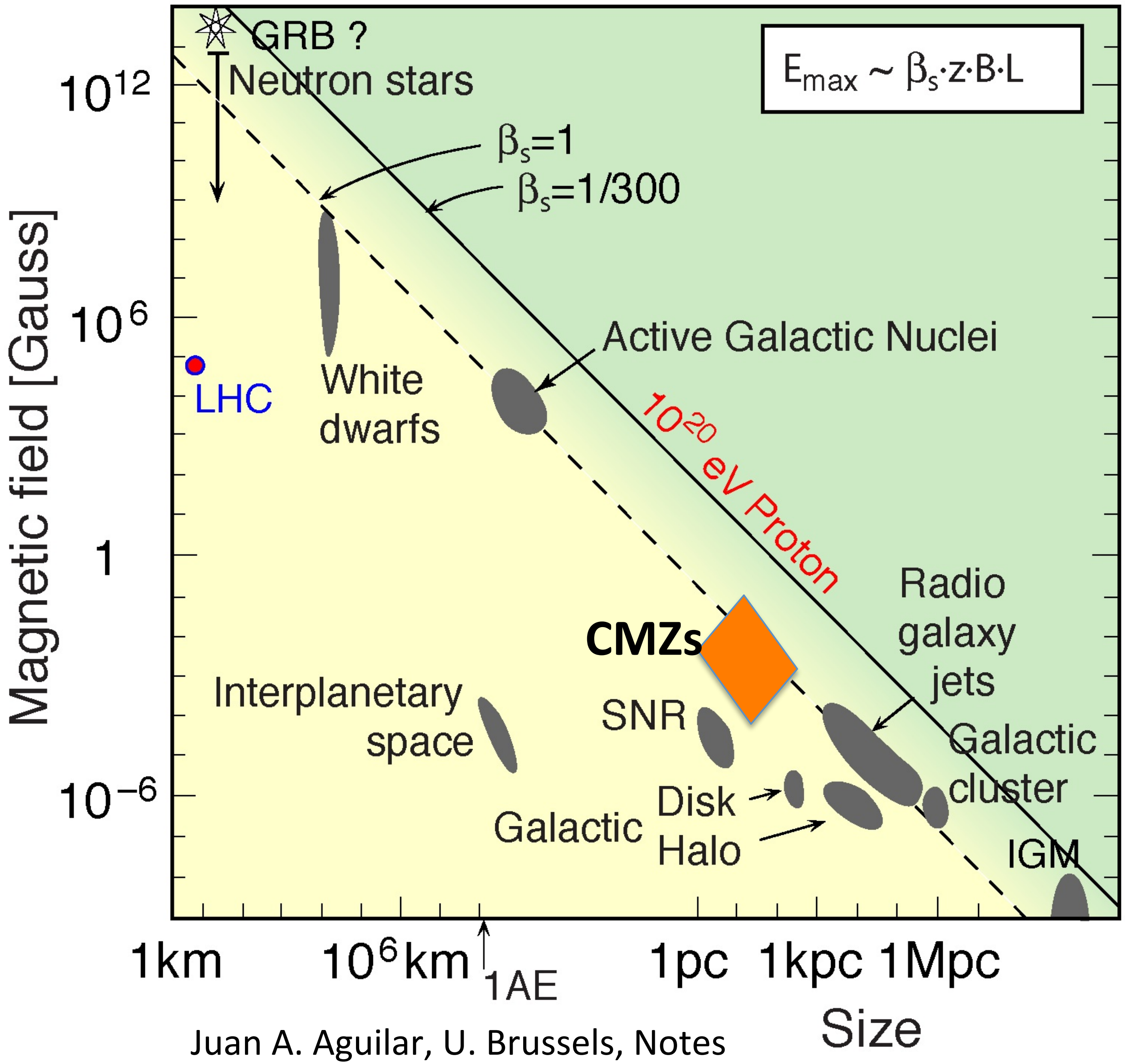


Spectral index p=2.2
Calorimeter factor 0.5-1
B≈300 μG
Undetectable flux of HE neutrinos unless flat spectal component to PeV energies.

Star formation alone unlikely to PeV cosmic rays to produce sufficient high energy cosmic neutrinos in galaxy centers.

Also:Thompson+ 2007, ApJ, 654, 214
Heesen+ 2009, A&A, 494, 563
Paglioni & Abrams 2012, ApJ, 755, 106

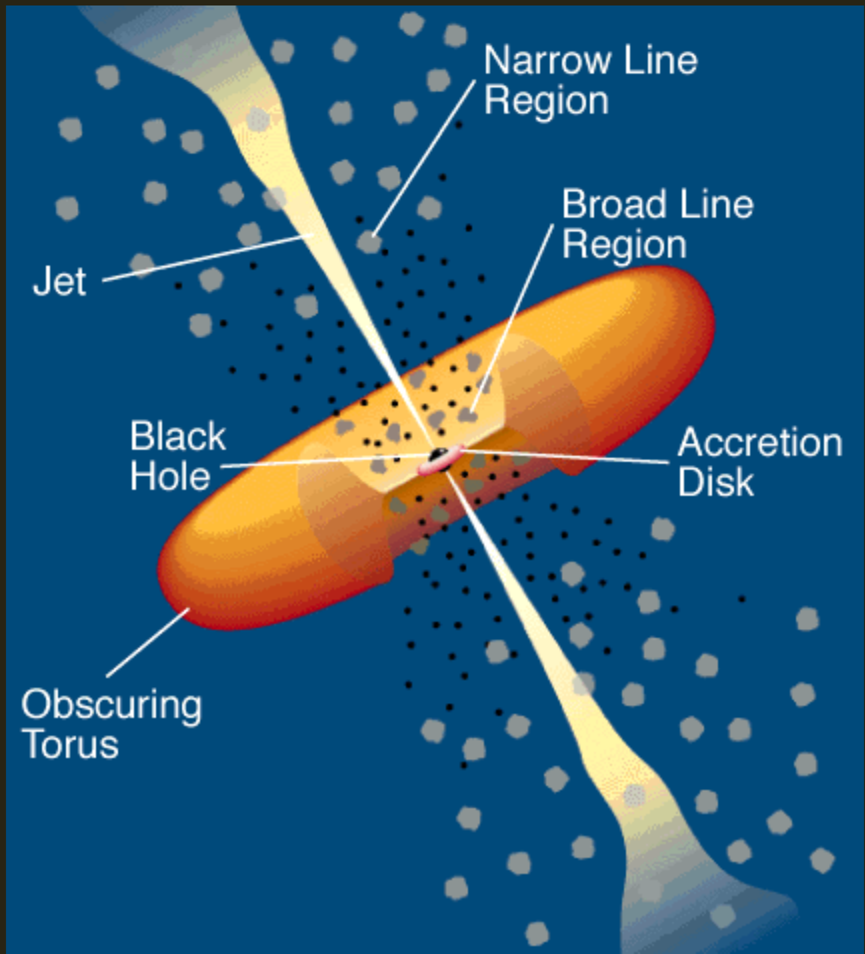




Juan A. Aguilar, U. Brussels, Notes

CMZs
Sizes
&
B-fields
sufficient
for CR
acceleration
To 100s of
PeV

CMZs have R, B, rich in targets…but XStellar AcceleratorsX What Else?



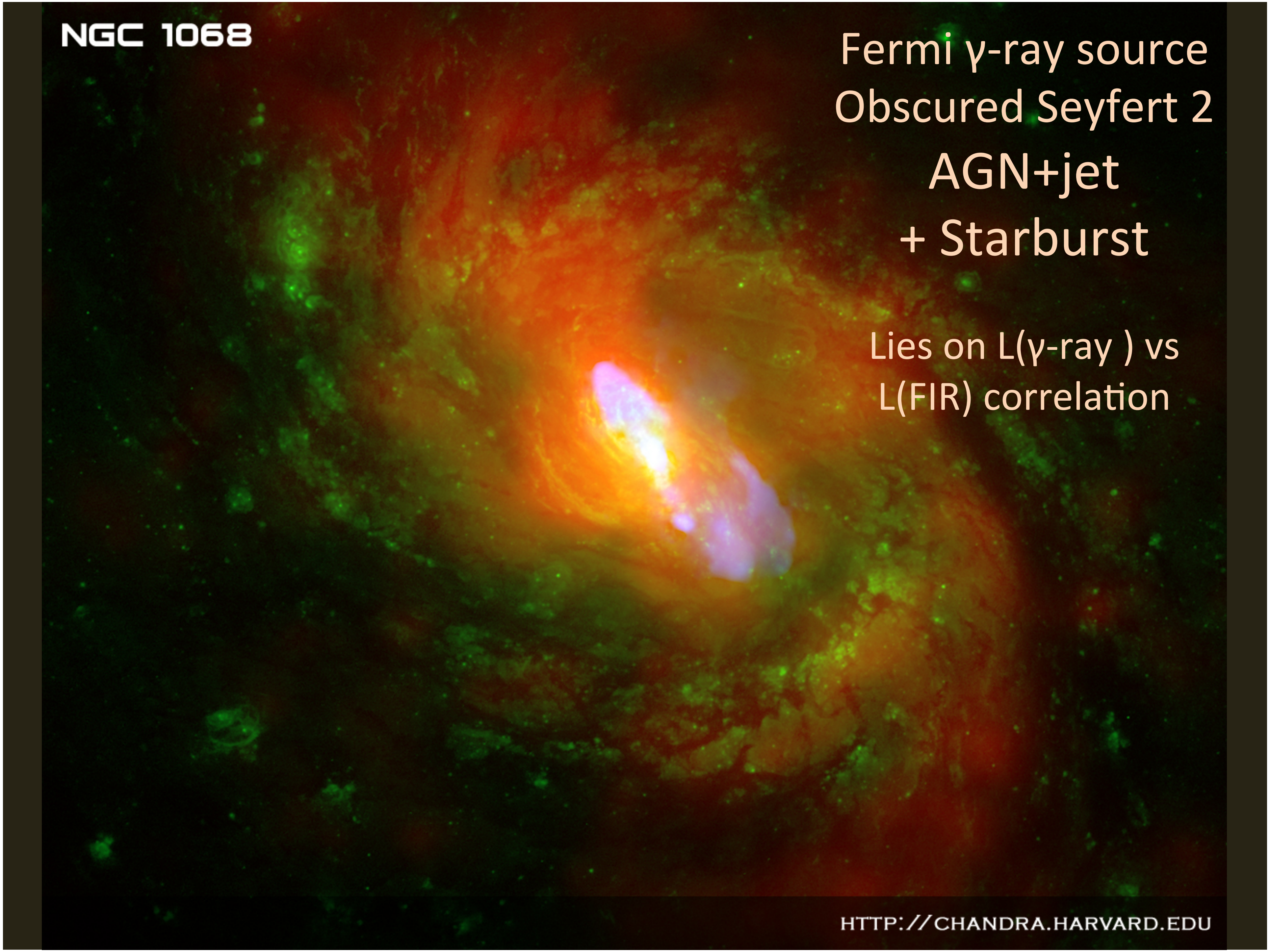
AGN!

Hadrons?

Targets?

Spectrum?

B-fields?


NGC 1068
Fermi γ-ray source
Obscured Seyfert 2
AGN+jet
+ Starburst
Lies on L(γ-ray) vs
L(FIR) correlation
HTTP://CHANDRA.HARVARD.EDU

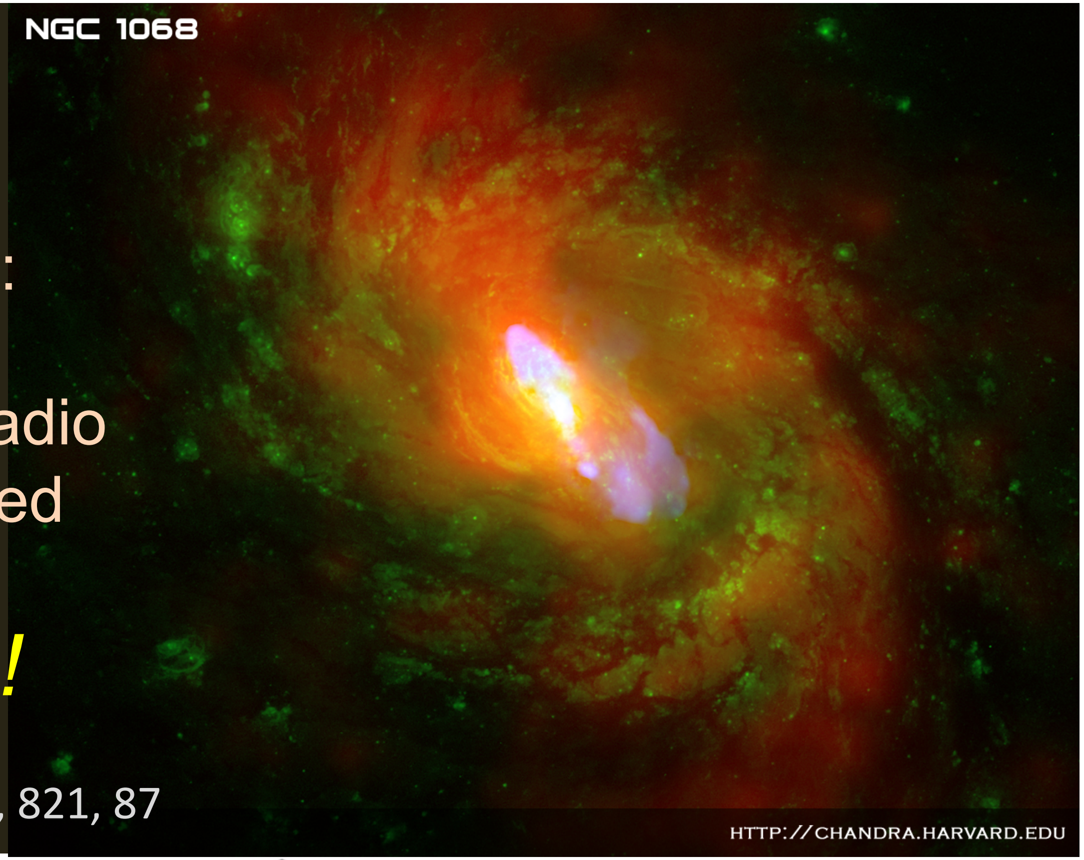
YEGZ SNe model <u>fails</u> for Seyfert 2 galaxy NGC1068:

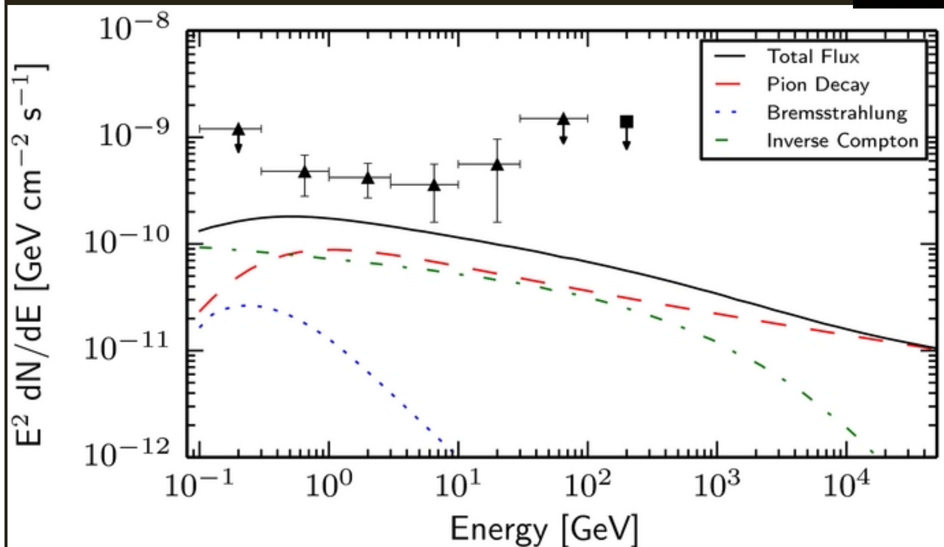
- Y-ray L too high
- Complete mismatch to radio
- Nuclear jet and associated

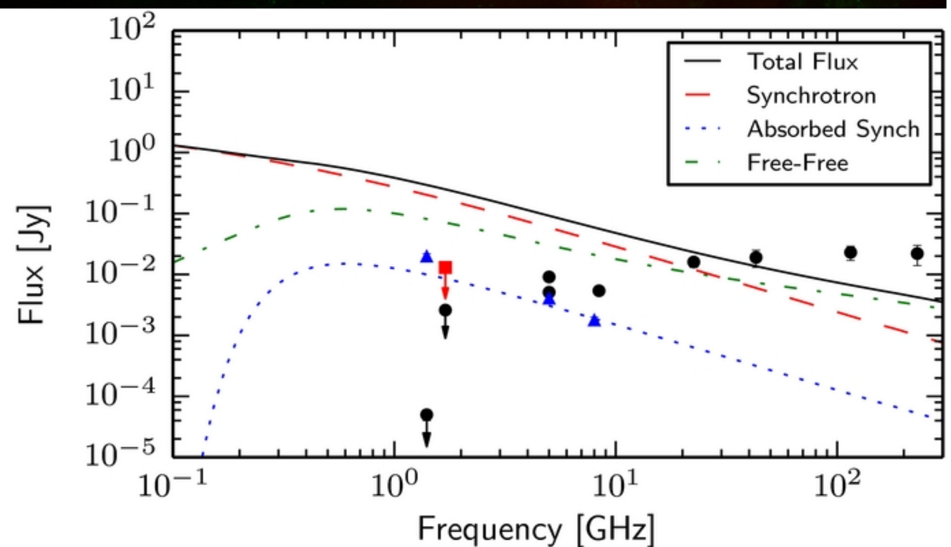
AGN processes!

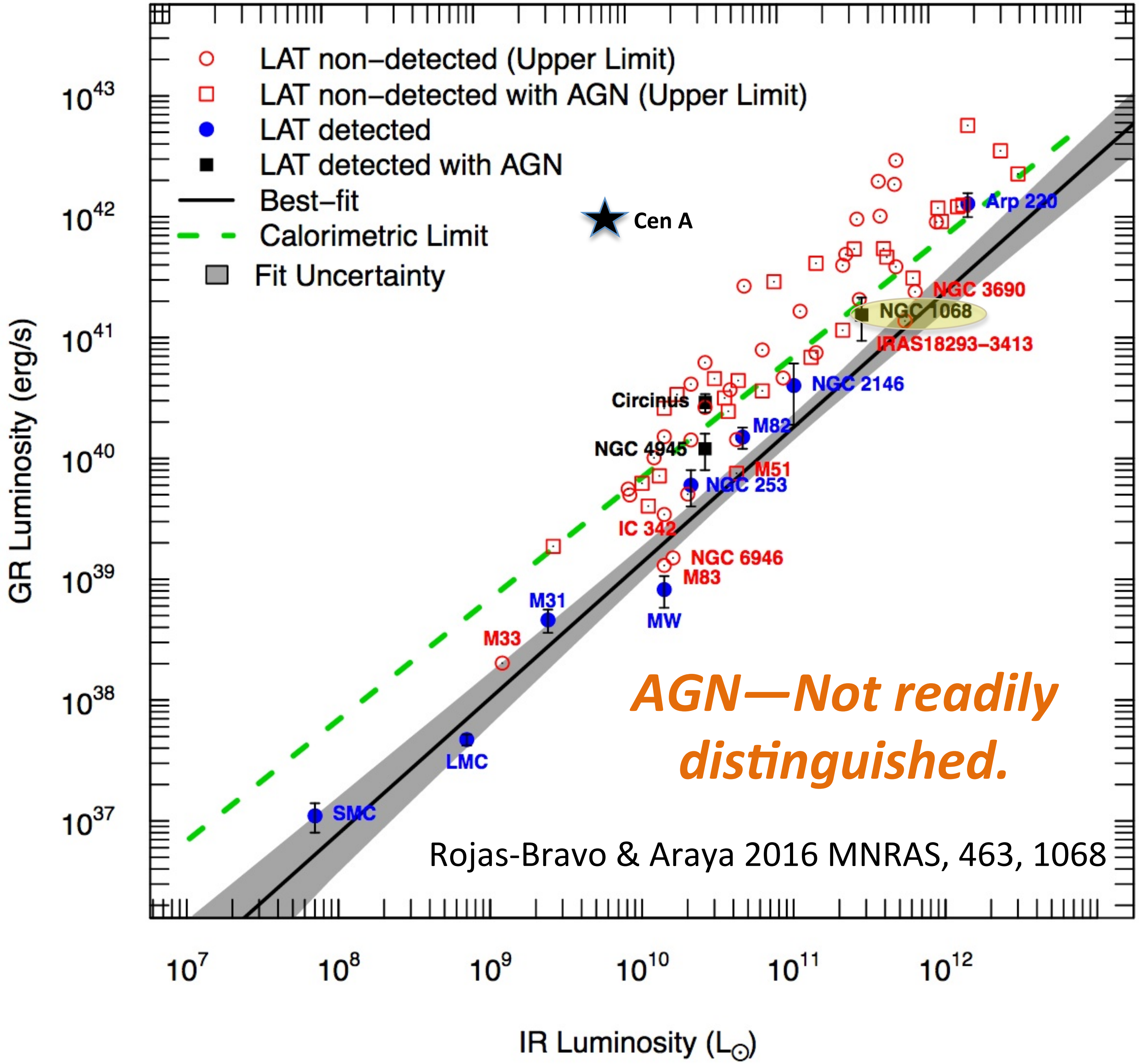
Yoast-Hull+ 2014, ApJ, 780, 137

Also Eichmann & Becker Tjus 2016, ApJ, 821, 87



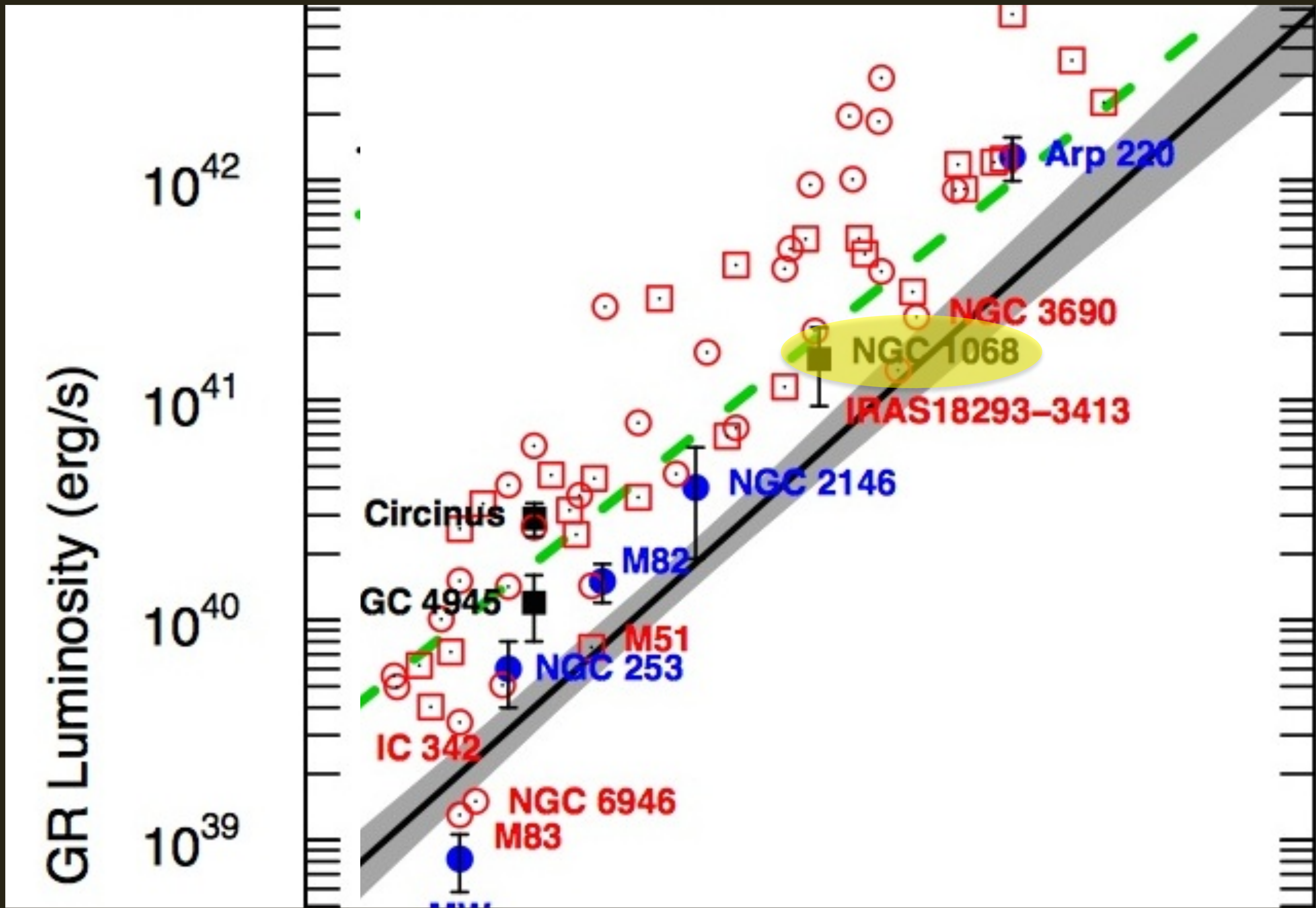






AGN—Not readily distinguished.

Rojas-Bravo & Araya 2016 MNRAS, 463, 1068

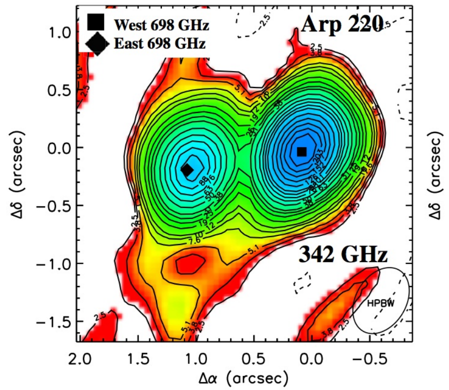


GR Luminosity (erg/s)
10^{42}
10^{41}
10^{40}
10^{39}
Arp 220
NGC 3690
NGC 1068
IRAS18293–3413
NGC 2146
Circinus
M82
GC 4945
M51
NGC 253
IC 342
NGC 6946
M83

Arp 220: Merger

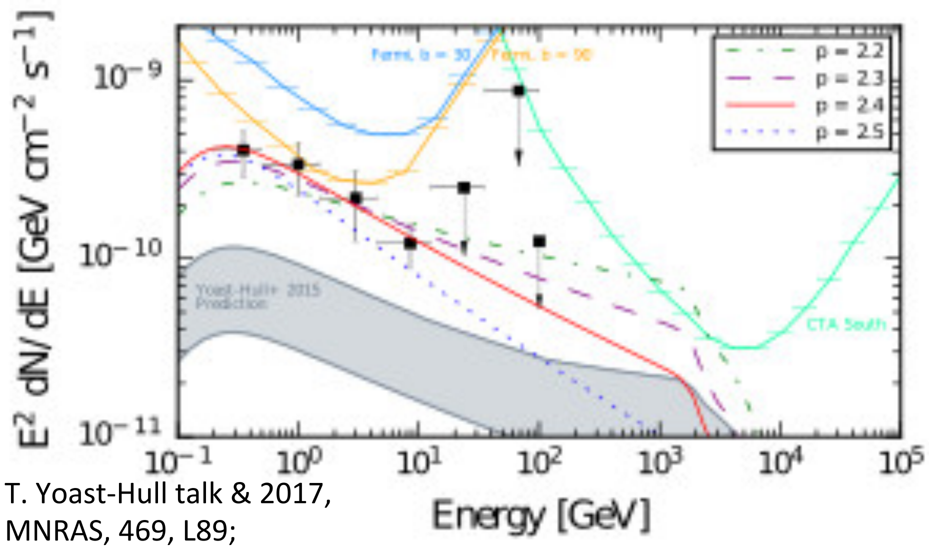
L~1E12 Lsun

Highly obscured nuclei-
opaque HE γ-rays due to
FIR photon field



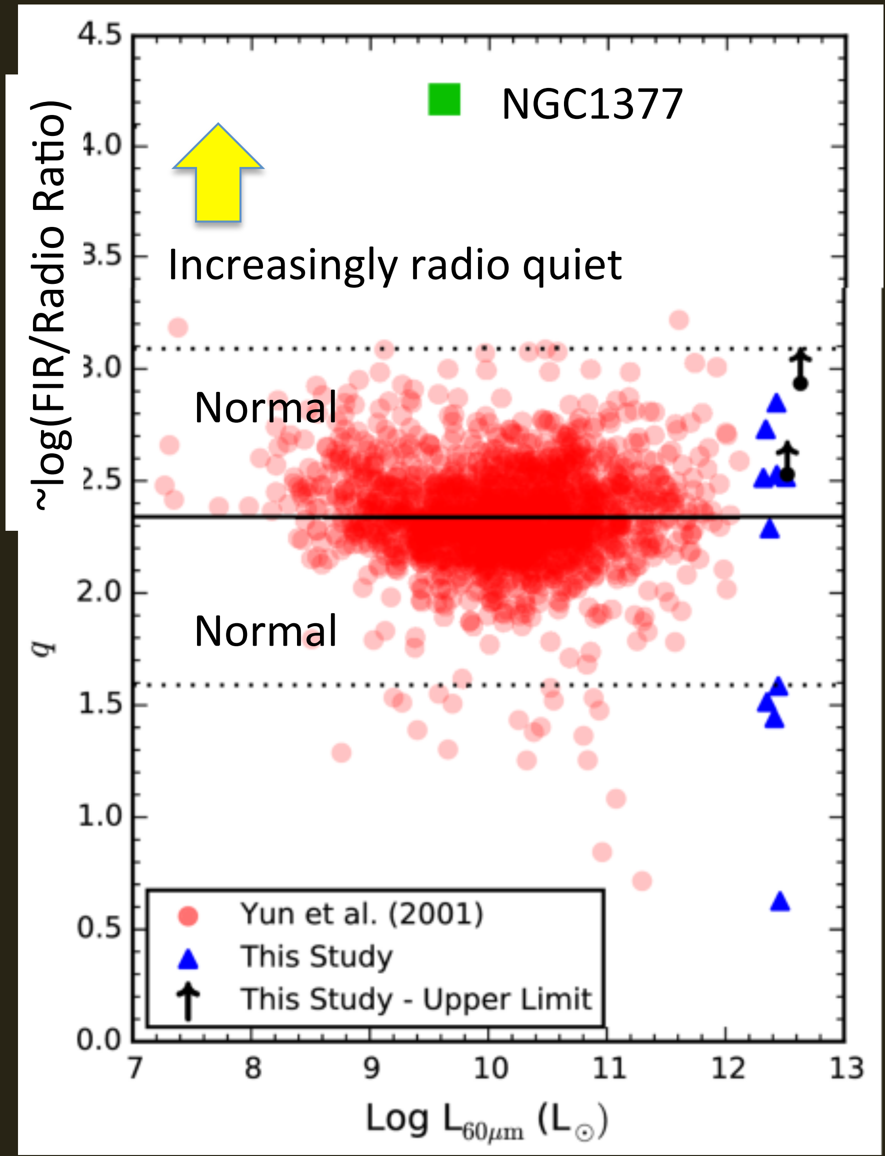
Scoville+ 2017, ApJ, 836, 66

NGC4418: Compact obscured nucleus (CON)



T. Yoast-Hull talk & 2017,
MNRAS, 469, L89;

D-25 Mpc; L(FIR) ~ 5E10 Lsun
Compton thick, no X-rays
Compact molecular core==“target”
Likely buried AGN =“accelerator”?
Example of obscured LL-AGN
See Costagliola+ 2015, AA, 892
Also NuSTAR results; Gorbunov+ 2003,
Aph, 18, 463



Costagliola+ 2016, A&A, 594--VLA

The Hunt for obscured LL AGN:

Radio: Not Always…

The Case of the CON NGC1377

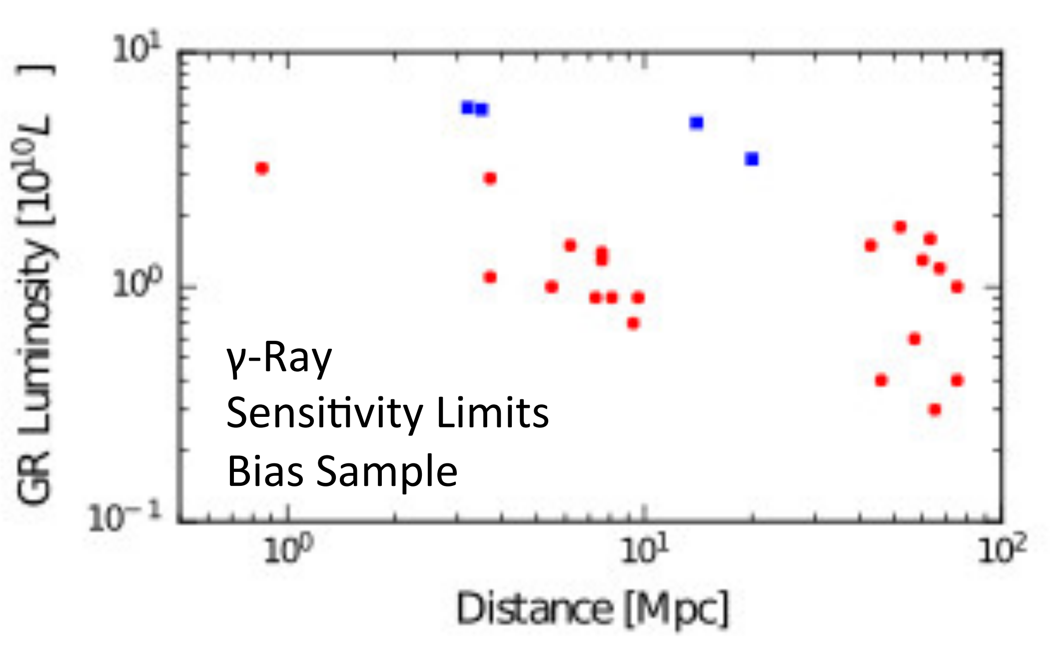
A Buried AGN

Missing in Radio & X-rays

Extreme in a Population of Nearby Sources?

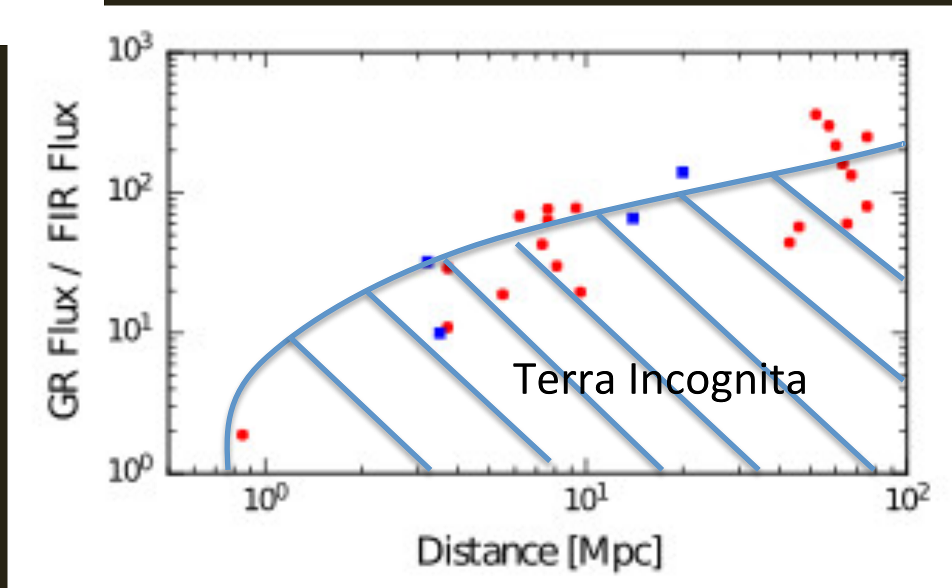
See Maggi+ 2016, PhRvD, 94, j3007

Beware of Inevitable Observational Biases…



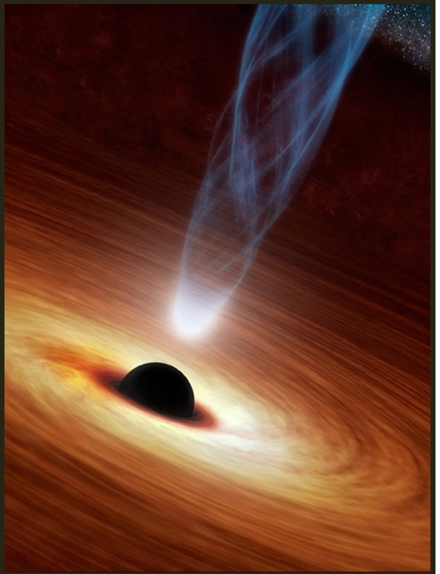
γ-ray sensiitvity much less than FIR and radio → major selection effects in samples

Data from Rojas-Bravo+ 2016, MNRAS, 463, 1068



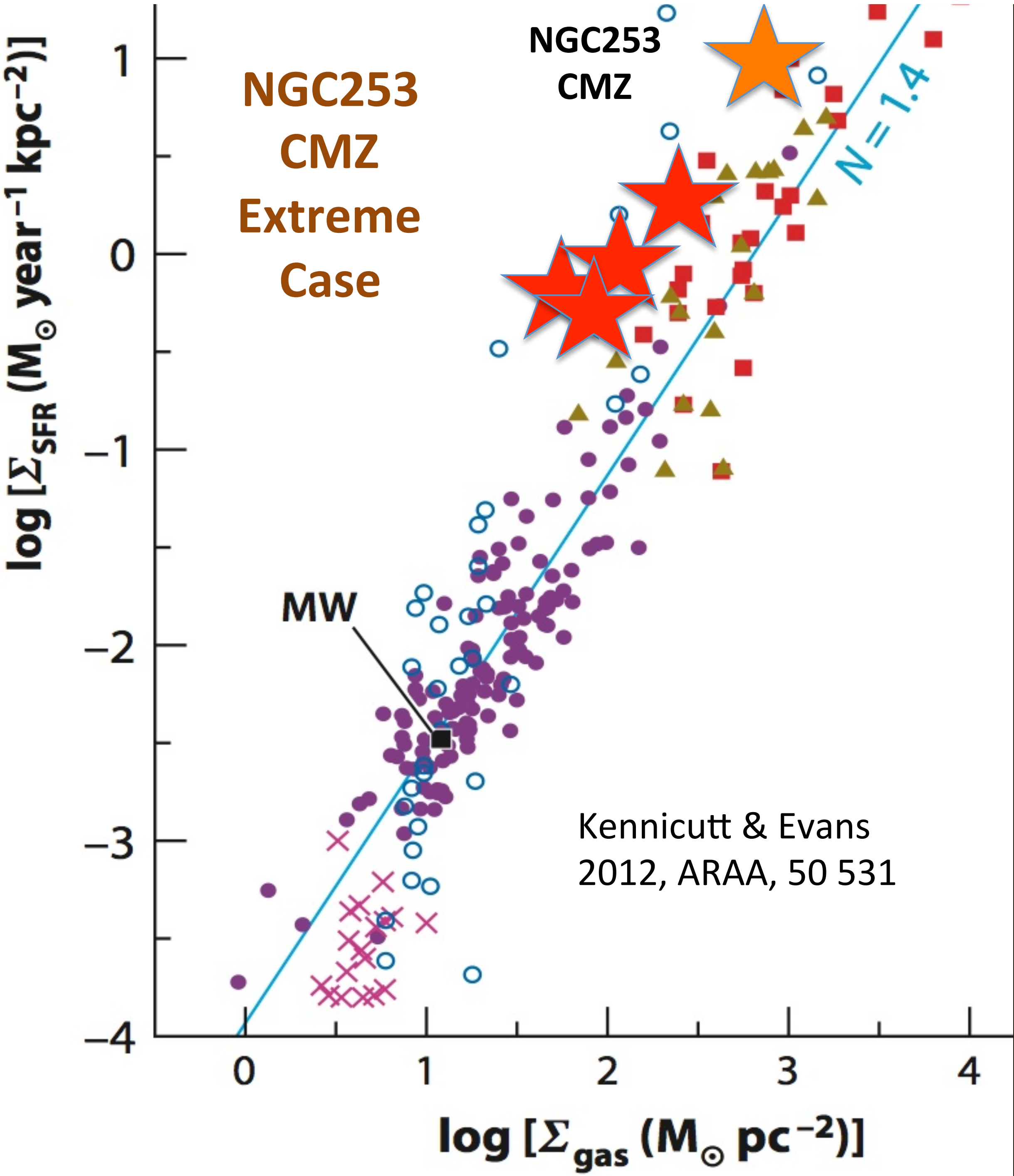
AGN ADVANTAGES

- High energy densities: shocks, magnetic fields
- Ubiquitous SMBH with wide range of activity levels
  - High energy cosmic ray production can be widely distributed in space & time
- Range of obscuration levels by surrounding ISM
  - Low obscuration cases: potential contributors primarily to cosmic ray pool.
  - High obscuration cases—cosmic ray “calorimeters”—potential contributors to high energy cosmic neutrinos.



AGN PROBLEMS For PROGRESS

- Suveys of obscured LL AGN incomplete
- Difficult to distinguish AGN from supernova accelerators from FERMI SEDs.
  - Especially issue in highly obscured AGN
  - Variability?
  - CR energies to >PeV, > AGN IC cutoffs
    - *BUT Galactic SMBH!--HESS*
- Hadronic component of AGN not identified
  - Environmental factors—AGN/ starburst combinations



No dectable neutrino flux from extreme nearby system

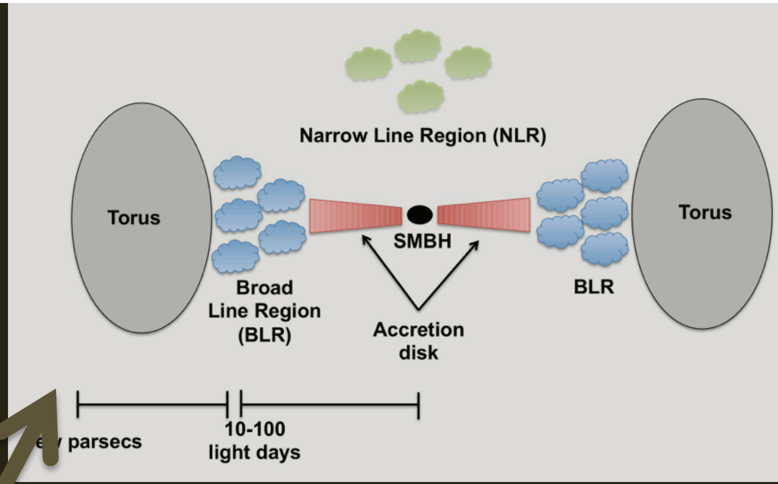
$1/D^2$ MAJOR Influence on fluxes

CMZs host:

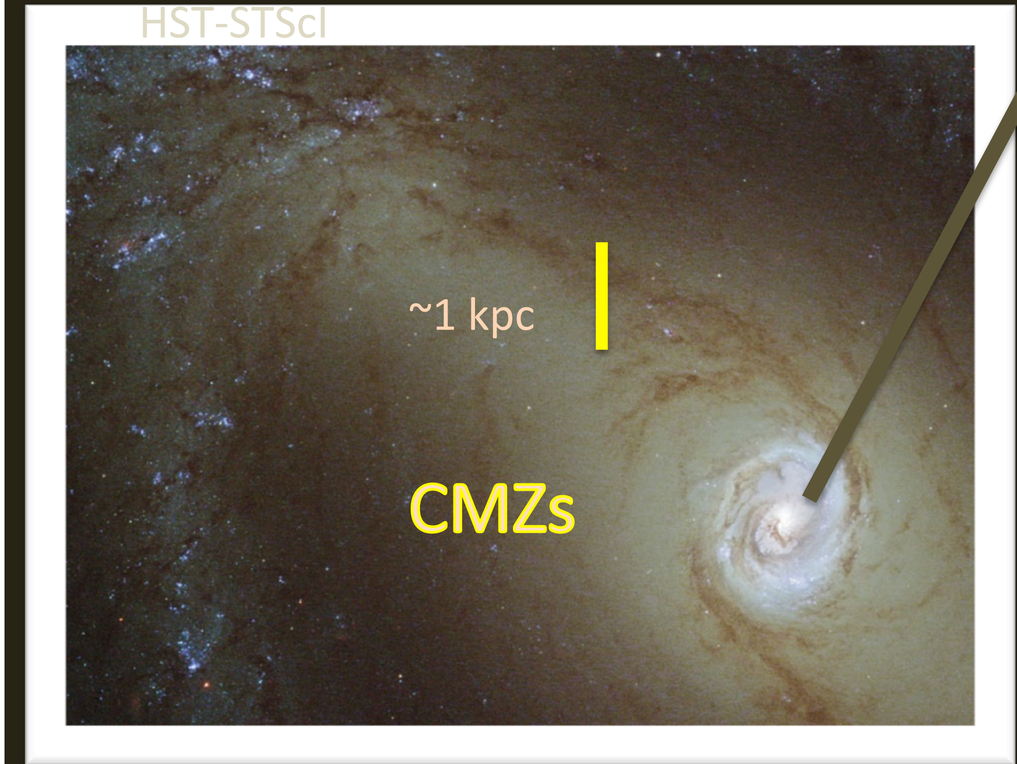
Starbursts

SMBH

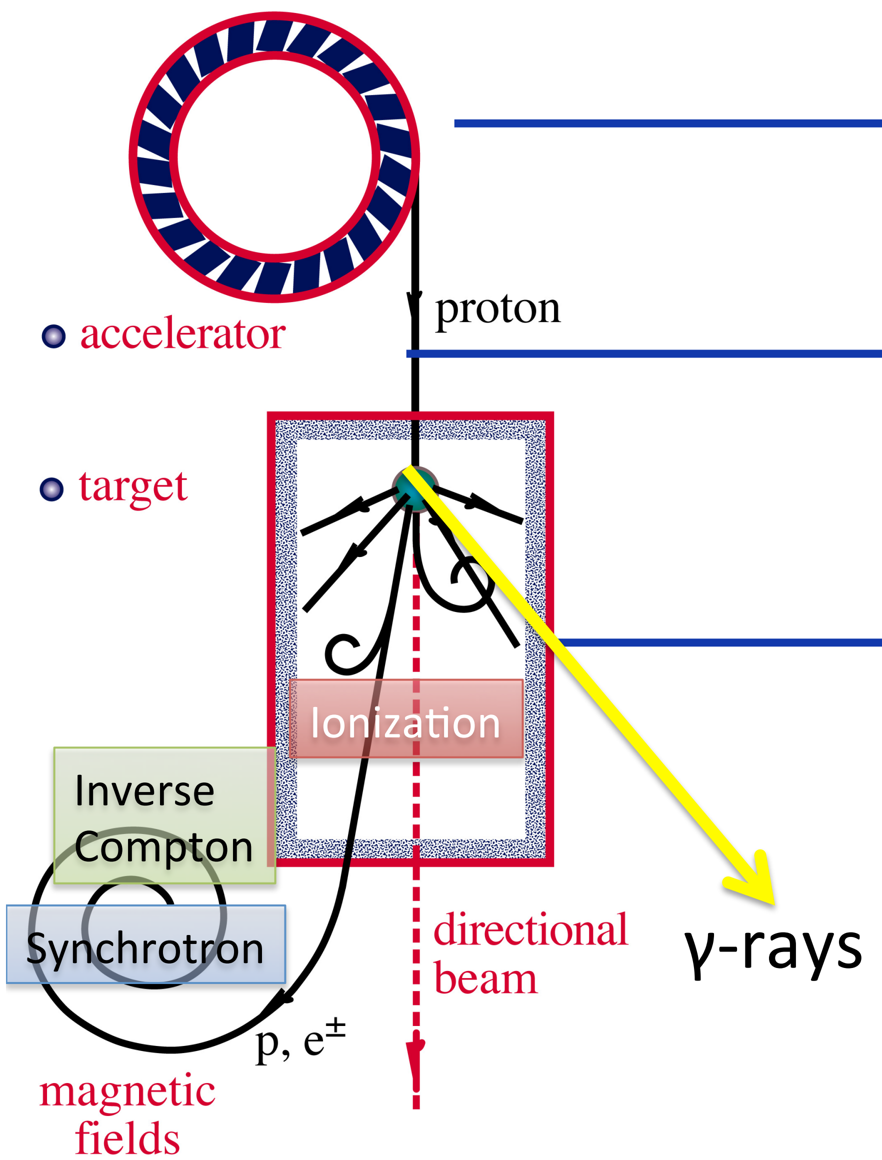
AGN with varying obscuration



C. Ricci U. Geneva



HIGH ENERGY COSMIC RAYS +NEUTRINOS: ACCELERATOR + TARGET



Supernova Remnant OR AGN....

Magnetic Field Confinement

Radiation & Matter

$p + \gamma/p \rightarrow n + \pi^+$

~ cosmic ray + neutrino

$\rightarrow p + \pi^0$

~ cosmic ray + gamma