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THE COSMIC EVOLUTION OF BL LACERTAE OBJECTS
LUMINOSITY FUNCTION

- Number of sources per bin of luminosity per comoving volume unit (Mpc$^3$)
- It tells us:
  - How the source population formed, evolved, grew
  - Contribution to the gamma-ray background
- A reliable luminosity function of BL Lacs is not derived yet
BL LACERTAE OBJECTS

- Active Galactic Nuclei:
  - Optical Spectrum dominated by the continuum (jet) emission
  - Jet pointing to us
  - Weak disk related emission
  - No emission lines visible
    - no redshift
REDSHIFT ISSUE

- BL Lac samples suffered from redshift completeness problem
- Literature BL Lac Luminosity Functions
  - usually have < 50 objects
  - >30% redshift incompleteness

- How to deal with this problem?
OUR BL LACS SAMPLE

- 211 objects from 1° Fermi AGN catalog (Abdo et al. 2009)
  - ~ 100 with spectroscopic redshift
  - ~ 100 with redshift constrains:
    - Photometric Z (Rau et al. 2012)
    - Photometric Upper Limit (Rau et al. 2012)
    - Spectroscopic Upper Limit (Shaw et al. 2013)
    - Spectroscopic Lower Limit for Intervening system (Shaw et al. 2013)
    - Host galaxy Fitting (Shaw et al. 2013)
  - 206/211 have redshift info

- Largest and most complete BL Lac sample ever!
For each object, derive a probability density function (PDF) of the source redshift combining by:

- All the constrains
- A priori function

The prior would be true distribution $dN/dz$ for all the Fermi BL Lacs if there were no selection effects

- Since we don’t know it we use the luminosity function and then iterate
- Let’s start from a flat a priori distribution
PDF EXAMPLES

Preliminary
RECIPE FOR A LUMINOSITY FUNCTION

1. Produce N(~1000) samples of 206 BLLs
2. For each source draw a random redshift from the source PDF
3. Derive a LF for each sample
4. Average out all the LFs to obtain the final one
5. Use the LF to predict the dN/dz (\textit{\textasciitilde priori})
6. If “predicted dN/dz” is different than \textit{priori} (instep 2), update \textit{priori} and iterate 1-to-6 till convergence
\[ \frac{d^3 N}{dL_\gamma dL dz d\Gamma} = \frac{d^2 N}{dL_\gamma dV} \times \frac{dN}{d\Gamma} \times \frac{dV}{dz} = \Phi(L_\gamma, V(z)) \times \frac{dN}{d\Gamma} \times \frac{dV}{dz} \]

\[ \Phi(L_\gamma, V(z)) = \Phi(L_\gamma, 0) \times e(z, L_\gamma) \]

\[ \Phi(L_\gamma) \propto \left[ \left( \frac{L_\gamma}{L_\gamma^*} \right)^{\gamma_1} + \left( \frac{L_\gamma}{L_\gamma^*} \right)^{\gamma_2} \right]^{-1} \]

\[ e(z, L_\gamma) = \left[ \left( \frac{1+z}{1+z_c(L_\gamma)} \right)^{p_1(L_\gamma)} + \left( \frac{1+z}{1+z_c(L_\gamma)} \right)^{p_2} \right]^{-1} \]
Density of BLLac evolves as \((1+z)^{p_1}\)

\[ p_1 = p_1^* + \tau \cdot (\log L - 46) \]

<table>
<thead>
<tr>
<th>(L_{\gamma} \text{(erg s}^{-1}))</th>
<th>(p_1) Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10^{44})</td>
<td>&lt;0</td>
</tr>
<tr>
<td>(10^{46})</td>
<td>2.1</td>
</tr>
<tr>
<td>(10^{47})</td>
<td>~7</td>
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</tbody>
</table>
LOCAL LF (Z~0)

De-evolved Fermi LF of BL Lacs

1σ uncertainty on best-fit Fermi LFs

LF of Fermi FSRQs (Ajello et al. 2012)
Evolution is positive for high luminosity sources
Evolution is negative for low luminosity sources
Evolution is similar to FSRQ for $L > 10^{46}$
COMPARISON ON DIFFERENT BL LAC CLASSES

LSP+ISP

HSP

Preliminary

14-8-2013 Windows on the Universe  Gasparrini Dario
The increase in the space density of BL Lacs at low $z$ is produced by the negative evolution of HSPs. The rise in number of HSPs coincides with the decline in number of FSRQs.

Possible explanation: HSPs might be end-of-state/starved/recycled FSRQs. Genetic link à la Cavaliere & D’Elia 02, Böttcher & Dermer 02.
FINAL REMARKS

- Largest and most complete sample
- BL Lac class evolution is complex
  - Most luminous evolve strongly
  - Less luminous have negative evolution (mostly HSP)
- The nearby universe \((z\sim0)\) is populated by massive black holes which are starving for gas
- Many outcomes foreseen:
  - BL Lacs might produce a substantial fraction of the Isotropic Gamma-Ray Background \((10-15\%)\)
  - CTA will help finding hundreds of sources
THANK YOU!
\[ \frac{dN}{d\Gamma} = e^{-\frac{(\Gamma - \mu)^2}{2\sigma^2}} \]

\[ z_c(L_{\gamma}) = z_c^* \cdot (L_{\gamma} / 10^{48})^\alpha \]

\[ p1(L_{\gamma}) = p1^* + \tau \times (\log_{10}(L_{\gamma}) - 46) \]
EFFECT OF EBL

Measured Photon Index vs. Log L

- Best-fit to EBL-induced correlation
- Correlation implied by the luminosity function

Preliminary
Luminosity Density [erg s⁻¹ Mpc⁻³]

BL Lac, 1σ uncertainty
FSRQs, 1σ uncertainty (Ajello et al. 2012)

Redshift

DERMER & RAZZAQUE

Fermi 11 month data set
100 MeV = 100 GeV

Cum. Luminosity density [erg Mpc⁻³ yr⁻¹]

BL Lac
Starburst
FR II
FR I
FSRQ

Redshift

0.001
0.01
0.1
1

14-8-2013 Windows on the Universe
Gasparrini Dario
**THE FERMI OBSERVATORY**

- **Satellite gamma-ray telescope**
  - Large Area Telescope (LAT)
    - 20 MeV – > 300 GeV
  - Gamma Burst Monitor (GBM)
    - 8 KeV – 40 MeV

- **Key features**
  - Huge field of view (2.4sr)
    - 20% sky any instant
    - All sky for 30’ every 3h
  - Huge energy range
    - Including unexplored 10-100 GeV range
LARGE AREA TELESCOPE

LAT
- modular - 4x4 array
- 3ton – 650 watts

ANTI-COINCIDENCE (ACD):
- Segmented (89 tiles + 8 ribbons)
- Self-veto @ high energy limited
- 0.9997 detection efficiency

TRACKER/CONVERTER (TKR):
- Si-strip detectors
- ~80 m² of silicon (total)
- W conversion foils
- 1.5 X0 on-axis
- 18XY planes
- ~106 digital elx chains
- Highly granular
- High precision tracking
- Average plane PHA

CALORIMETER (CAL):
- 1536 CsI(Tl) crystals
- 8.6 X0 on-axis
- Large elx dynamic range (2MeV-60GeV per xtal)
- Hodoscopic (8x12)
- Shower profile recon
- Leakage correction
- EM vs HAD separation