The Galactic Center Excess & 511 keV Bulge Emission

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*in Collaboration with Francesca Calore, Emma Storm & Christoph Weniger
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Part 1: GCE

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Speckled gamma-ray emission from inner Galaxy points to a new source population

Wavelet transformation

Bartels et al. 2016

Non-Poissonian noise

Lee et al. 2016
Part 1: GCE

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Also: M. di Mauro
This session
Part 1: GCE

That's why I'm in this session =)

Speckled gamma-ray emission from inner Galaxy points to a new source population

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Also: M. di Mauro
This session
GCE features

Calore, Cholis & Weniger (2014)  
Calore, Cholis, McCabe & Weniger (2015)
SkyFact
SkyFact
SkyFact

Advantages

- Hybrid between image reconstruction & template fitting

Foreground/Background Templates

- Inverse-Compton
- Gas (π0) emission
- IGRB
- 3FGL
- Fermi Bubbles
GCE Analysis

1) Fixed Templates
GCE Analysis

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Bartels+ in prep.

cNFW
GCE Analysis

1) Fixed Templates

- cNFW
- Einasto

Bartels+ in prep.
GCE Analysis

1) Fixed Templates

- cNFW
- Einasto
- 511 keV
  - Siegert+ 2015

Bartels+ in prep.
GCE Analysis

1) Fixed Templates

- **cNFW**
  - Dwek+ 1995; Cao+ 2013

- **Einasto**

- **511 keV**
  - Siegert+ 2015

**Boxy bulge**

Superpositions of these

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GCE Analysis

1) Fixed Templates

- cNFW
- Einasto
- 511 keV
  - Siegert+ 2015

Superpositions of these

- Boxy bulge
  - Dwek+ 1995; Cao+ 2013
- Nuclear bulge
  - Launhardt+ 2002

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GCE Analysis

1) Fixed Templates

- cNFW
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- Boxy bulge: Dwek+ 1995; Cao+ 2013
- Nuclear bulge: Launhardt+ 2002
- X-shape: Ness & Lang 2016

Superpositions of these
GCE Analysis

1) Fixed Templates

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- 511 keV
  - Siegert+ 2015

- Boxy bulge
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  - Ness & Lang 2016

Superpositions of these

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GCE Analysis

2) Fixed spectrum
GCE Analysis

2) Fixed spectrum

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GCE Analysis

2) Fixed spectrum

Bulge

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GCE Analysis

2) Fixed spectrum

Bulge + NB

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GCE Analysis

2) Fixed spectrum

Bulge + NB + X

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GCE vs. Stellar Mass

$1.9 \times 10^{27} \text{ erg s}^{-1} \text{ M}_\odot^{-1}$

- Nuclear bulge
- Boxy bulge
- Disk
- M31

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Surprising?

Radius [deg] vs. GCE intensity, $E^2 dN/dE$ [GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$]

- **Einasto**
- **NFW, $\gamma = 1.26$**
- **511 keV (Siegert+ 2015)**
- **Boxy bulge + nuclear bulge**
- **Calore+ 2014**

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Surprising?

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Conclusions part 1

1. The GCE from skyfact is more oblate wrt previous analyses

2. It traces stellar mass in the inner galaxy! MSPs?
Part 2: GCE & 511 keV

- 511 keV: positron annihilation
- Morphology appears similar to that of the GCE

Knoedler+ 2005, INTEGRAL SPI
Population synthesis

1. Thermonuclear SNe (Crocker+ 2016)

2. Low Mass X-ray binaries (LMXBs)
   - MSP progenitors
   - Positrons from jets of accreting BHs (Guessoum+ 2005; Bandyopadhyay+ 2008)
   - 511 keV observed in microquasar jet! (Siegert+ 2016)
Population synthesis

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ultracompact X-ray binaries in the Bulge
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van Haaften+ 2013 model the population of UCXBs in the Bulge.
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  - $2 \times 10^5$ NS-UCXBs in the Bulge
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- $2 \times 10^5$ NS-UCXBs in the Bulge
- $10^4$ isolated MSPs $\Rightarrow$ GCE
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ultracompact X-ray binaries in the Bulge

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We:
- Assume BH:NS = 1:10
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We:

- Assume BH:NS = 1:10
- Model BH-UCXB population as a function of \( \dot{M} \)
  (van Haaften+ 2012)
ultracompact X-ray binaries in the Bulge

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- We:
  - Assume BH:NS = 1:10
  - Model BH-UCXB population as a function of $\dot{M}$
    (van Haaften+ 2012)
  - Calculate Power in BH jets (NSs have too weak jets!!)
Takeaway recipe
Takeaway recipe

star-formation rate

PDF, Star-formation rate

0.8
0.6
0.4
0.2
0.0

0
-2
-4
-6
-8
-10
-12
T[Gyr]
Takeaway recipe

star-formation rate

Delay Time

adapted from van Haaften+ 2013
Takeaway recipe

star-formation rate

PDF: Star-formation rate

\[ \dot{M} \propto \left( \frac{T_{\text{age}}}{1 \text{yr}} \right)^{-\frac{14}{11}} \]

Delay Time

UCXB Evolution

adapted from van Haaften+ 2013

\[ \text{Delay Time} \]

\[ \text{# of systems starting RLOF [Myr]} \]

\[ \text{Delay time since ZAMS [Gyr]} \]
Takeaway recipe

star-formation rate

\[
\text{PDF, Star-formation rate}
\]

Delay Time

\[
\text{adapted from van Haaften+ 2013}
\]

UCXB Evolution

\[
\dot{M} \propto \left( \frac{T_{\text{age}}}{1 \text{ yr}} \right)^{-\frac{14}{11}}
\]

=}

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Takeaway recipe

star-formation rate

Delay Time

UCXB Evolution

\[ \dot{M} \propto \left( \frac{T_{\text{age}}}{1 \text{ yr}} \right)^{-\frac{14}{11}} \]

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Jet kinetic power & positrons

\[ L_J \propto \dot{M} \propto \begin{cases} \frac{L_X^{0.5}}{} & \text{(BH)} \\ L_X & \text{(NS)} \end{cases} \]

Fender+ (2003)

\[ \dot{N}_{e^+} = \frac{L_J}{2\Gamma \langle \gamma \rangle m_e c^2} \]

Heinz & Sunyaev (2002)
Jet kinetic power & positrons

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L_X \text{ (NS)} \end{cases} \]

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Heinz & Sunyaev (2002)

We assume a cold, pair dominated jet
Jet kinetic power & positrons

\[ \frac{L_J}{J} = \dot{M} \left( L_{X,0.5} \times (BH) \right) \]

\[ \dot{N}_{e^+} + \dot{N}_{\text{ne}} = \frac{L_J}{J} \]

We assume a cold, pair dominated jet.

Heinz & Sunyaev (2002)

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Fender+ (2003)

Cumulative positron yield

\[ N_{e^+} (\geq L_X) \]

- BH-UCXBs
- NS-UCXBs
- Observed

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Conclusions part 2

- Evolutionary channel of Millisecond pulsars through LMXBs can explain both the 511 keV and GCE signals from the Bulge!
Conclusion

- The GCE appears to trace stellar mass!
- We find a correspondence with the Bulge + nuclear bulge
- 511 keV and GCE could be related through population synthesis
THANK YOU :)}
Central region ($|b| < 15^\circ$ and $|\ell| < 15^\circ$)

- freeFS
- freeFS_FT
- freeFS_FS
- freeFS+_GeV
- freeFS-_GeV
- NFW100
- NFW126
- Einasto
- BulgeGC
- RCGBulge
- RCGBulgeNB
- RCGBulgeNB_X

Backup: Spectra

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Backup: spectra 2

Central region (|b| < 15° and |ℓ| < 15°)

- IGRB
- Bubbles
- ExtSrc
- ICS
- X
- NB
- RCG
- Gas ring I
- Gas ring II
- Gas ring III
- Data

σ

E [GeV]

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Backup: X-shape

\[ 1.9 \times 10^{27} \text{ erg}\, s^{-1} \, M_\odot^{-1} \]

- Nuclear bulge
- Boxy bulge
- X-shape
- Disk
- M31

Bartels+ in prep.
OTHER COMPONENTS

NFW

BULGE

Richard Bartels (GRAPPA, Amsterdam)

TeVPA 2017, Columbus (OH), USA
OTHER COMPONENTS

NFW

BULGE

Bartels+ in prep.