GCE & M31 gamma-ray emission: a closer look at the MSP interpretation

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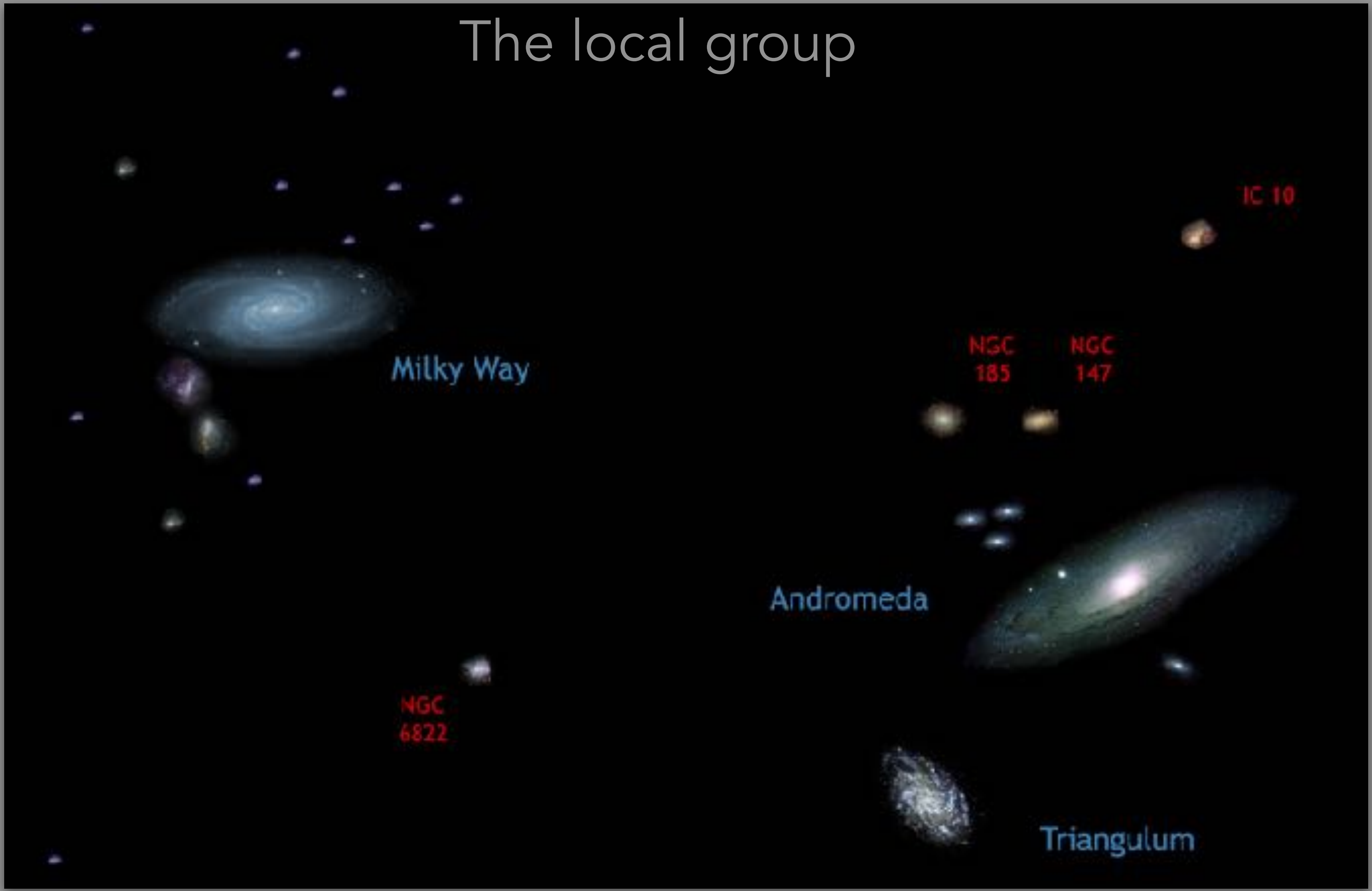
on behalf of the Fermi LAT coll. (***C. Eckner***) and external authors P. Serpico, J. Petrovic and T. Prodanovic

M31?

‘bulkier brother’ of the Milky way:

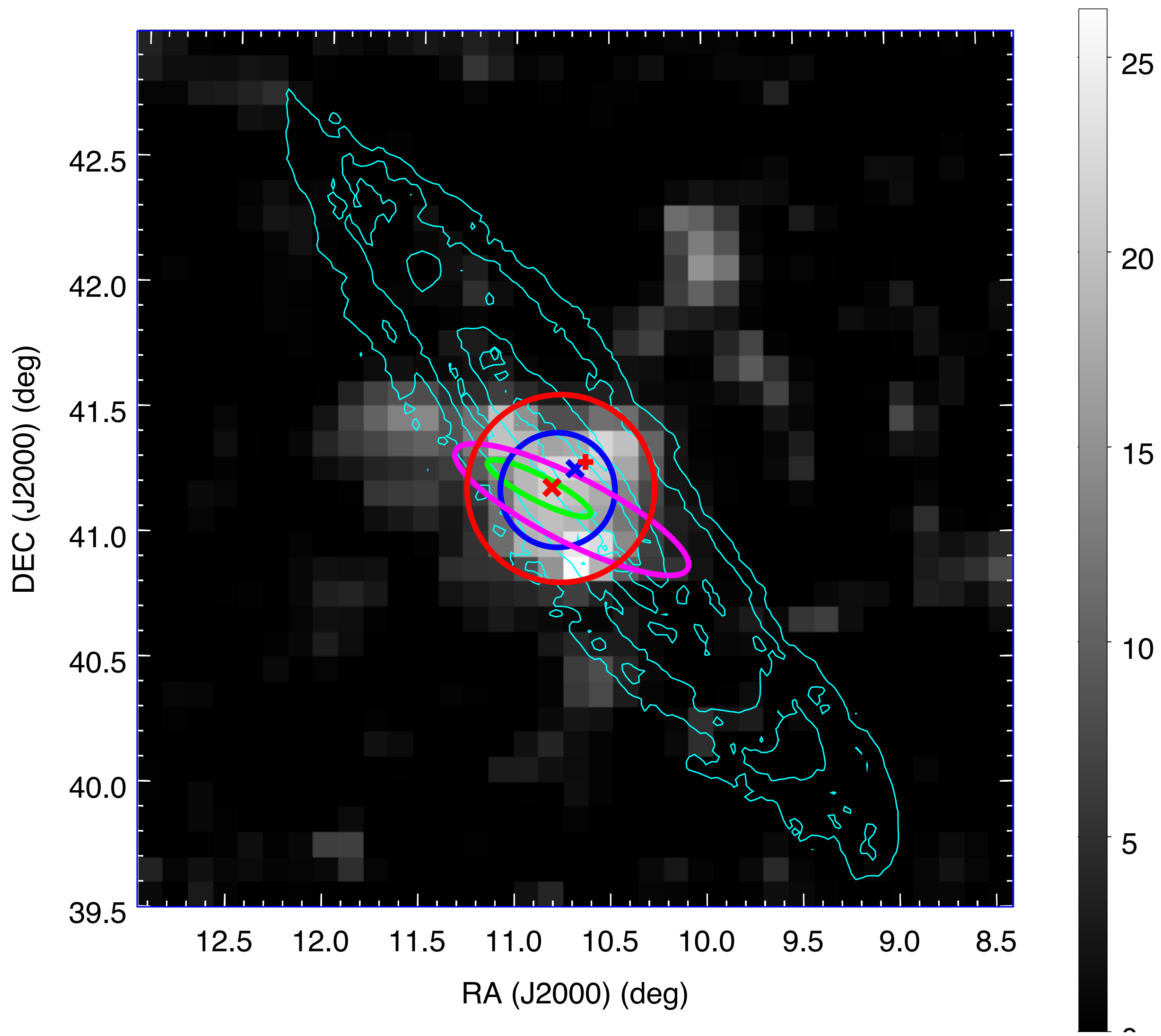
- Large, massive spiral galaxy: 2-3x as big as the Milky Way
- Distance: 780 kpc
- Radial Velocity: -200 km/s -- incoming!



- Bulge mass:
  M31 3-5 10^{10} M⊙ (Tamm+, 1208.5712)
  MW ~0.9 10^{10}M⊙
- few times more globular clusters
- ~2x more massive SMBH

M31 in gamma-rays

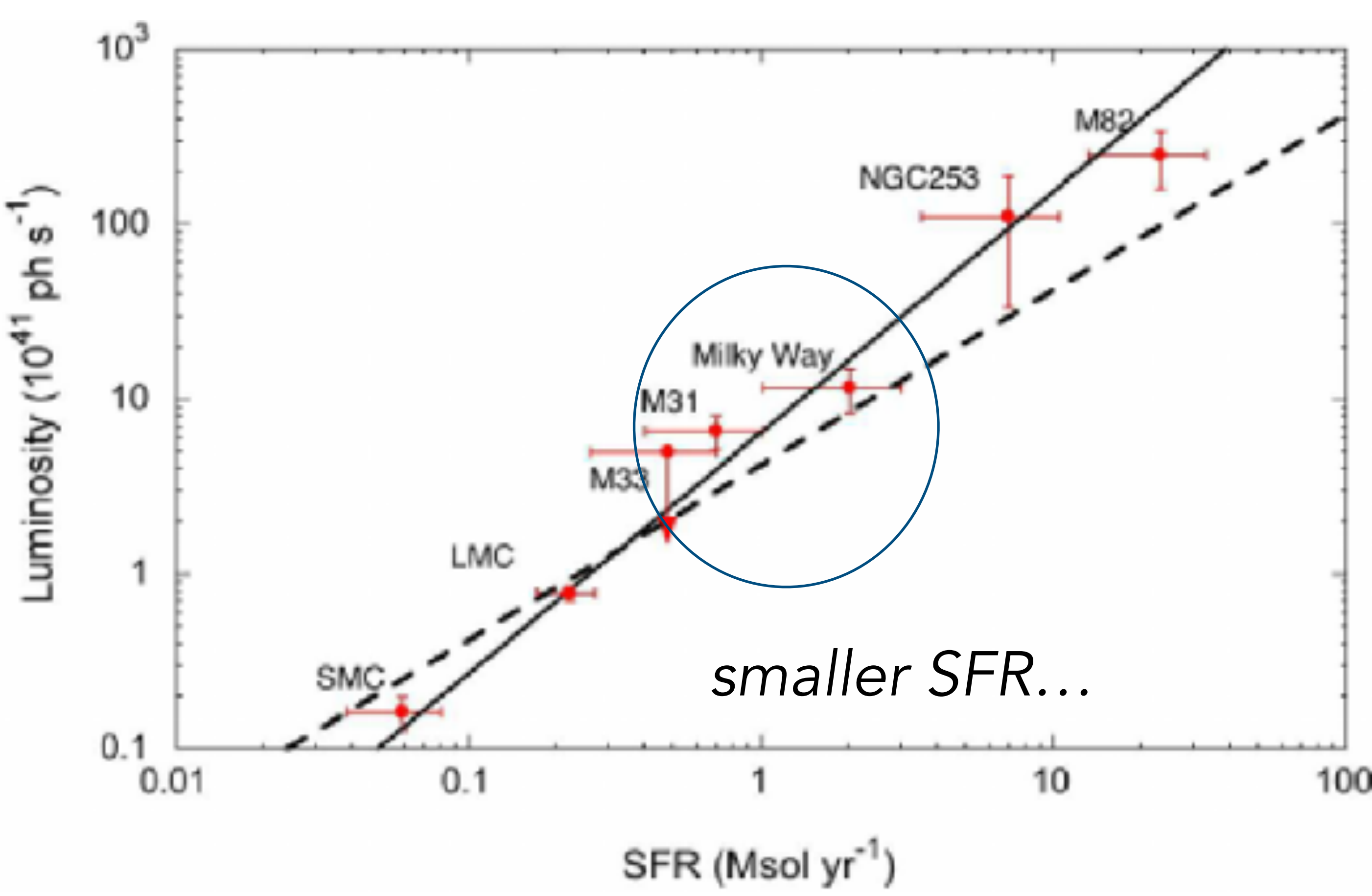
- M31 detected with 5.3σ in two year Fermi LAT data (Abdo+, ApJ (2010))
  → only marginal detection of spatial extension (1.8σ)
- Recently: more detailed analysis with 88 months of Pass 8 SOURCE class events



Ackermann+, ApJ 836 (2017)

Features:

— emission does not correlate with gas maps



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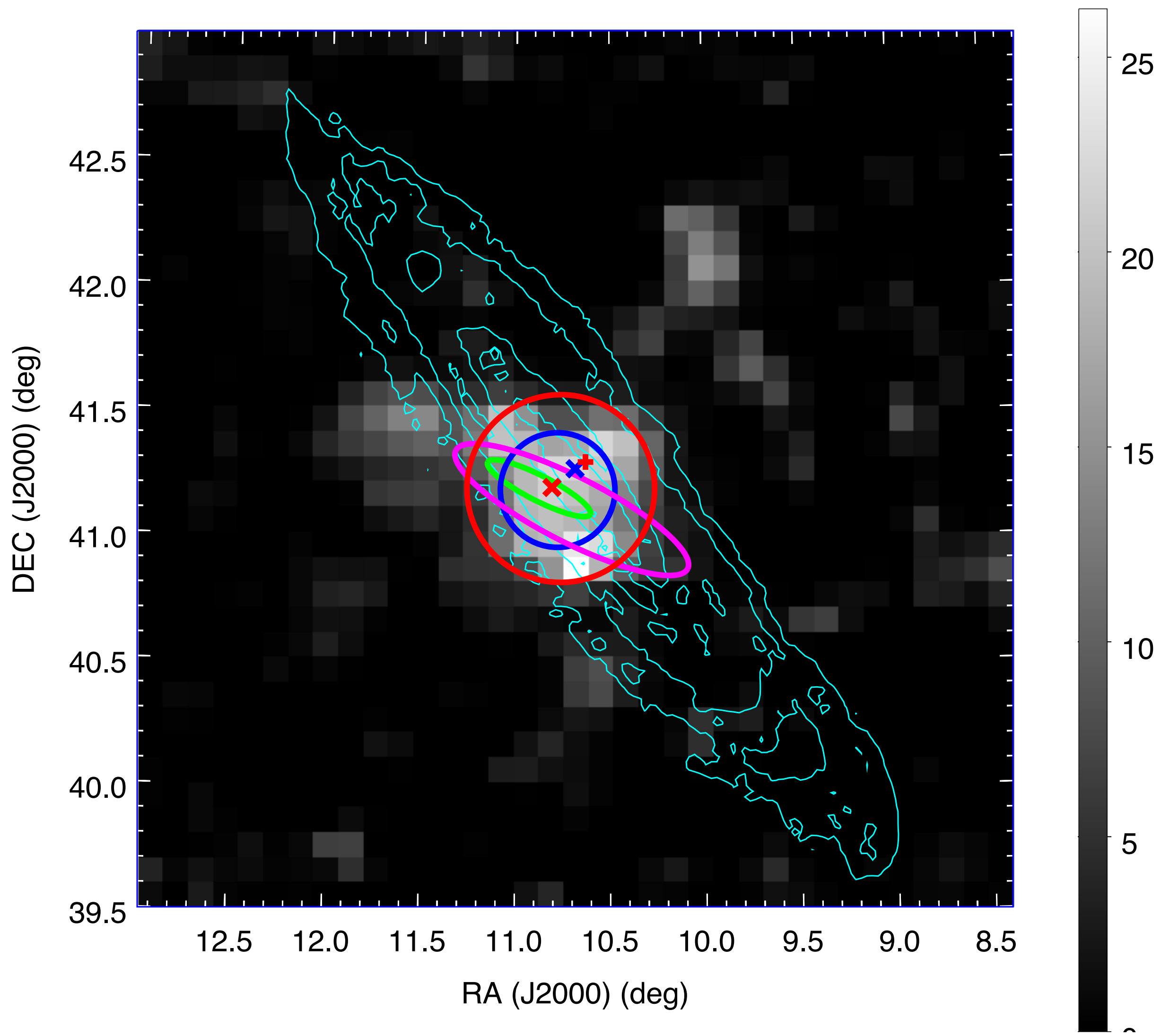

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Features:

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— **emission templates**:

- uniform disk, r~0.38±0.05° (~5 kpc)
- Gaussian, σ~0.23±0.08° (~3.5 kpc)

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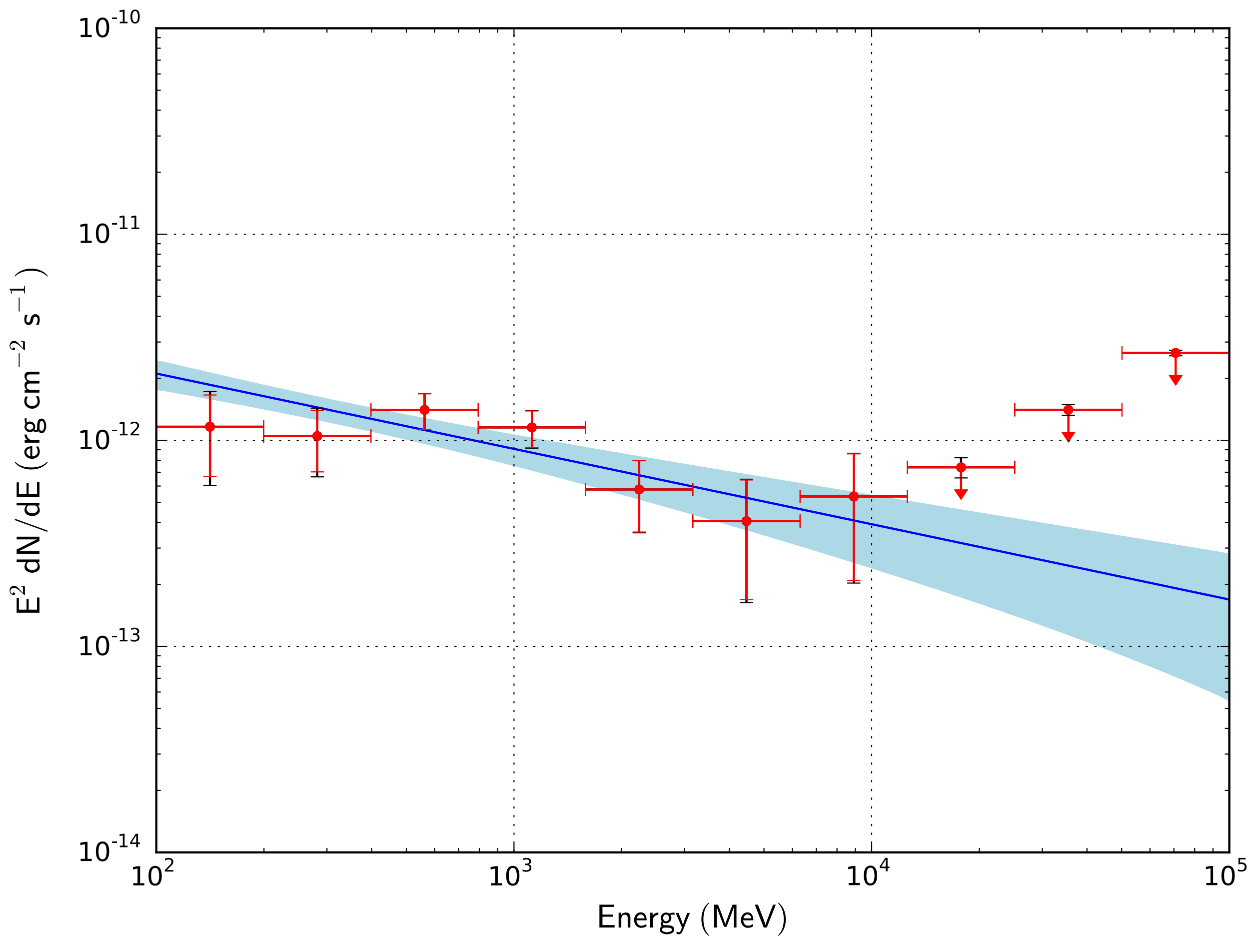

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- uniform disk, r~0.38±0.05° (~5 kpc)
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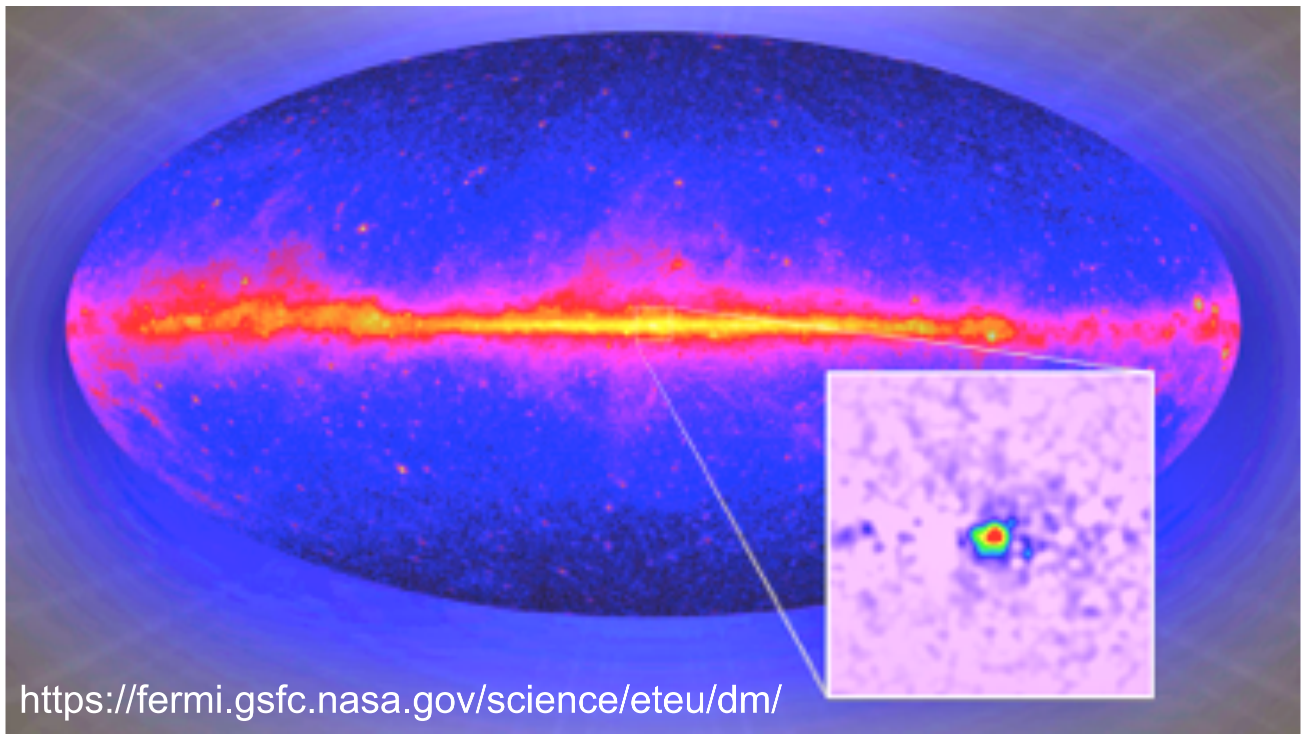
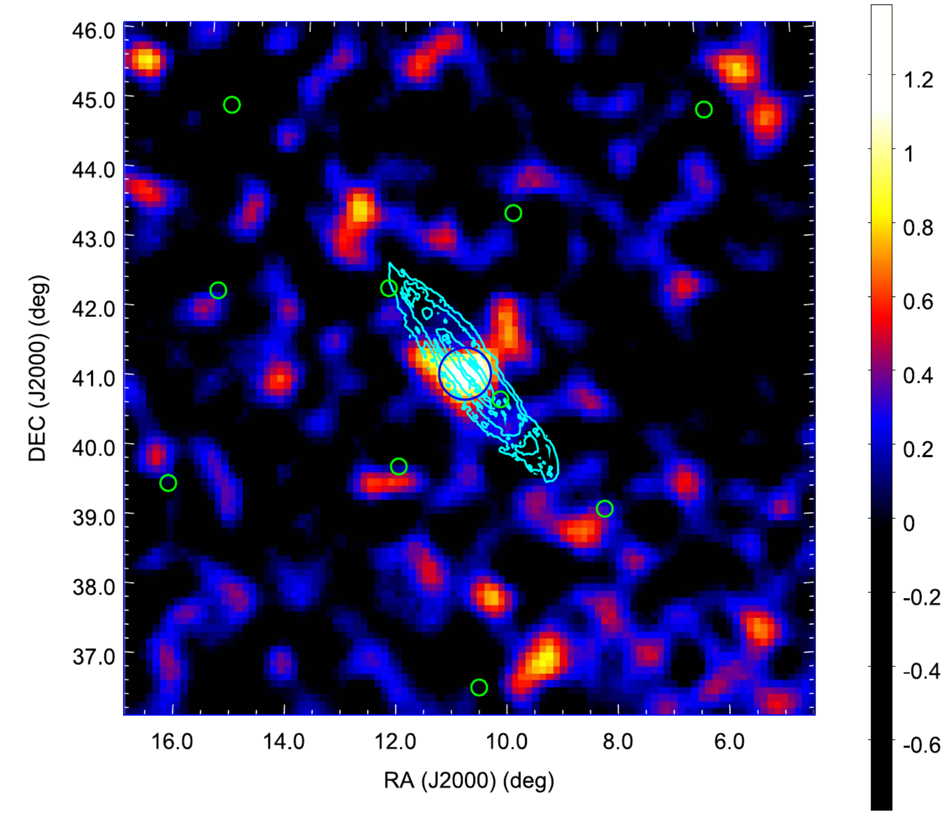
— **spectrum**:

- PL best fit: Γ~2.4 ±0.1
- PLEXP: Γ~2.1 ±0.2, $E_{cut\text{-}off}$ ~5.3 ± 4.9 GeV

GCE vs M31 emission?





Milky Way (MW) Galactic Center Excess ← ? → M31 extended emission

viewed along the plane & dominant GDE — obstructed view on the GCE

$$L^{\rm obs}_{\rm GCE,tot,\ \lesssim 20^\circ} = 2.2^{+1.5}_{-1.9} \times 10^{37} {\rm erg\ s^{-1}}$$

Ackermann+, ApJ 840 (2017)

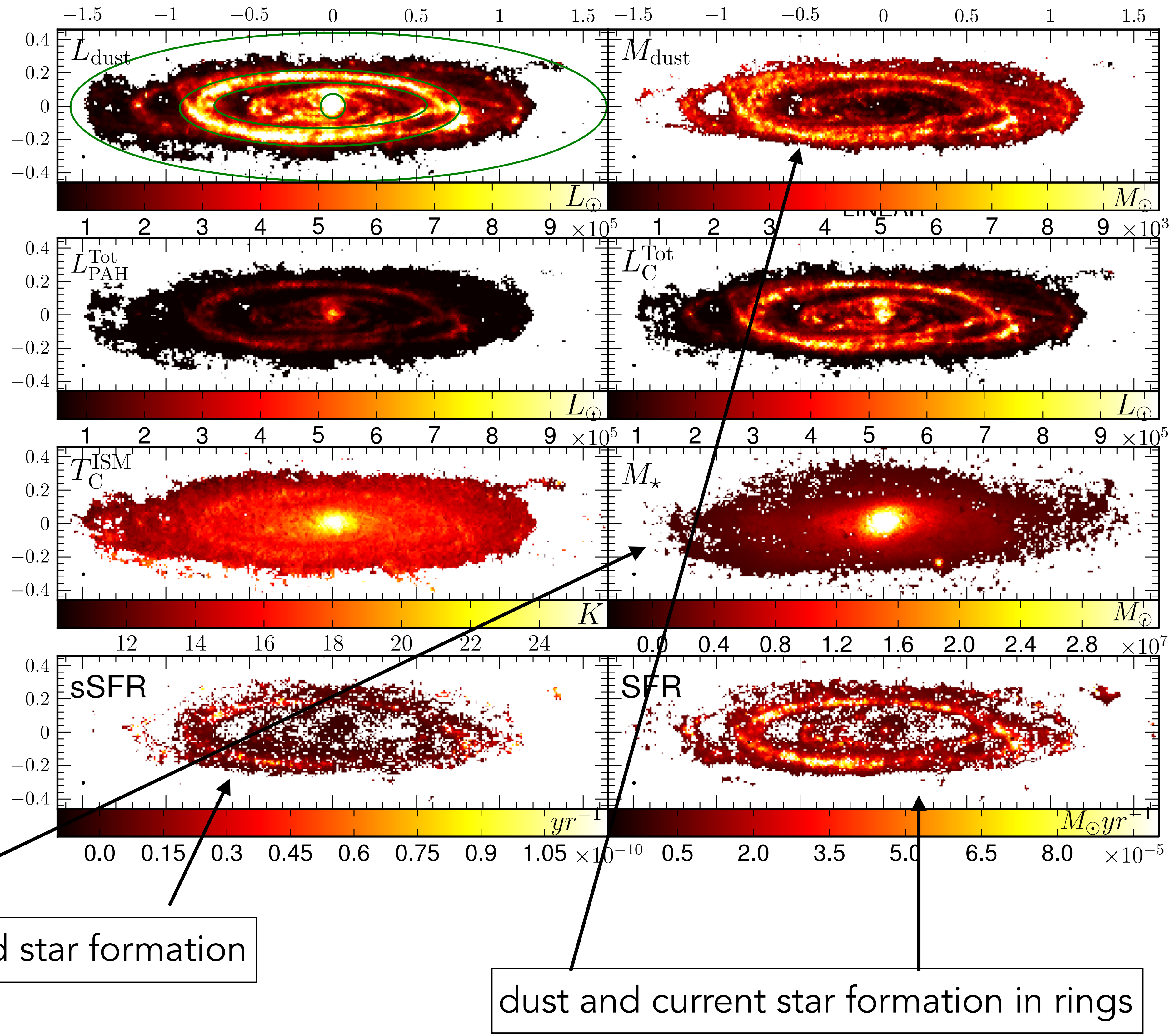
– external viewpoint
– ~10 times lower SFR than in MW, low GDE
– size of the emission region comparable to that of the GCE

$$L^{\rm obs}_{\rm M31\ bulge} = (28. \pm 4.) \times 10^{37} {\rm erg\ s^{-1}}$$

Ackermann+, ApJ 836 (2017)

Motivation for MSP interpretation in M31

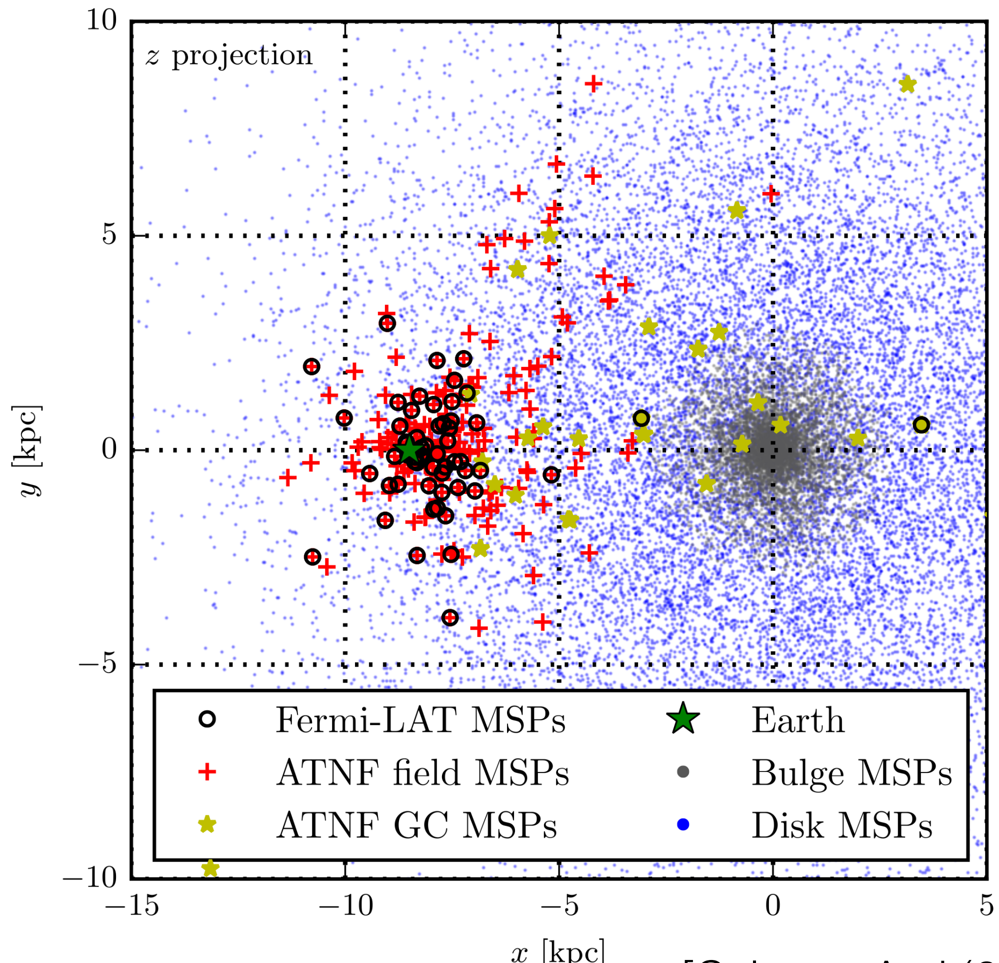
1. **30% of all stellar mass in the bulge** (gamma ray signal tracks M*?)
2. **mostly old stars (>~ 12 Gyrs)**
3. bulge extension of 0.5-1.1 kpc roughly similar to the measured extension (more later)



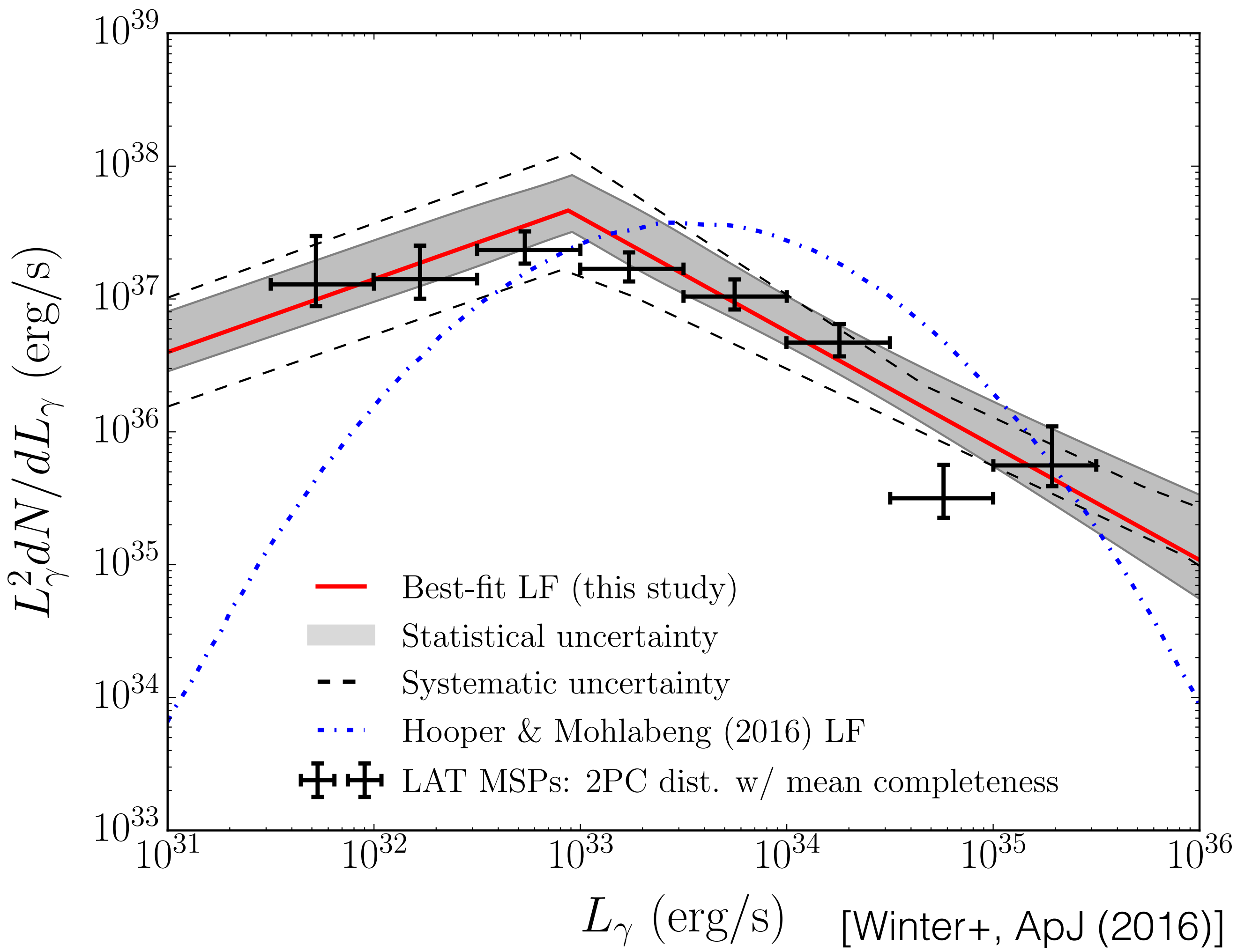
[far IR & sub-mm, Hershel, 1403.4272]

What we learned about MSPs in the MW?

MSP emission observed in
— galactic halo, '**locally**'…



[Calore+, ApJ (2016)]



[Winter+, ApJ (2016)]

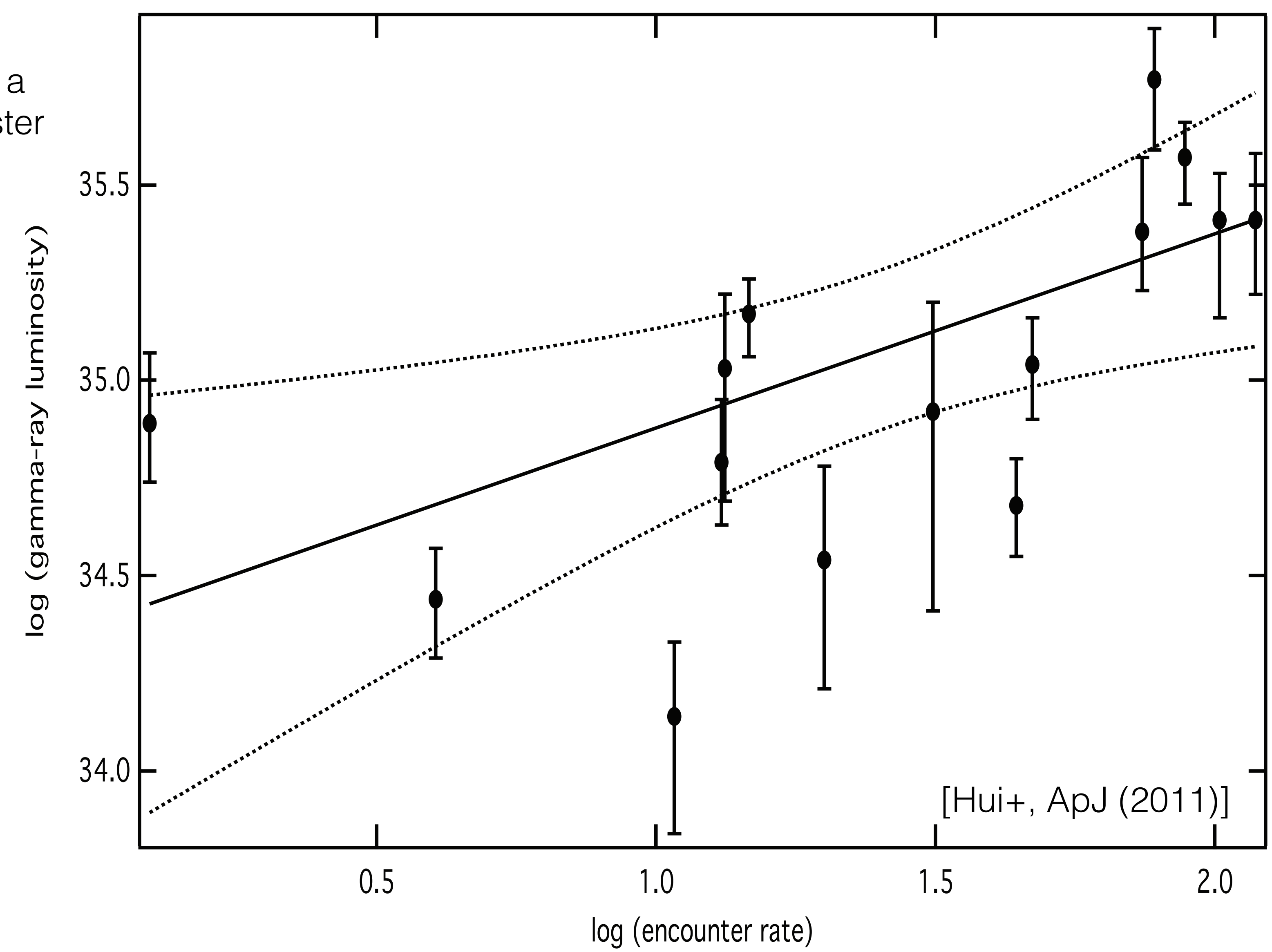
About ~100 MSPs observed to date*, used to derive the **luminosity function**.

*https://confluence.slac.stanford.edu/display/GLAMCOG/Public+List+of+LAT-Detected+Gamma-Ray+Pulsars

What we learned about MSPs in the MW?

MSP emission observed in
— galactic halo, ‘**locally**’…
— and cumulative emission in
globular clusters

gamma-ray luminosity of a globular cluster



stellar encounter rate:

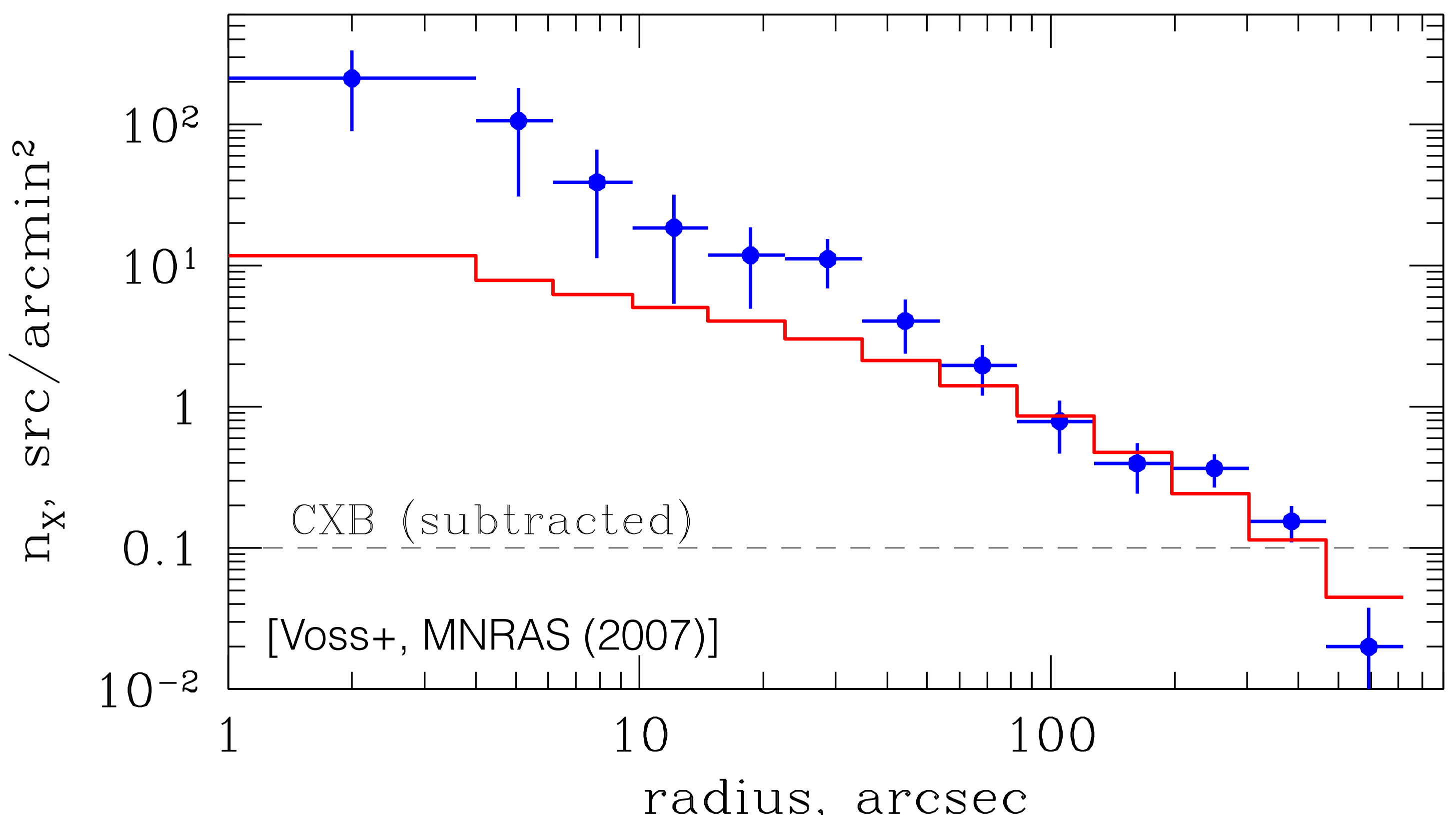
$$\Gamma \sim \int \frac{\rho_*^2}{\sigma} \mathrm{d}V$$

Toy model

Simple ***MSP formation mechanism picture***:
— **primordial** formation (i.e. in Galactic halo), correlates with *total stellar mass**
— **dynamical** (in Globular clusters), correlates with *stellar encounter rate*
densities in Galaxy bulges somewhere in between — possibly both mechanisms at play

* more precisely with OLD stars & does depend on stellar environment and formation history (Ploeg+, 2017)

Note: distribution of LMXBs in M31 follows ρ_* distribution in the outskirts and ρ_*^2 distribution in the inner parts of the bulge



Toy model - in situ formation

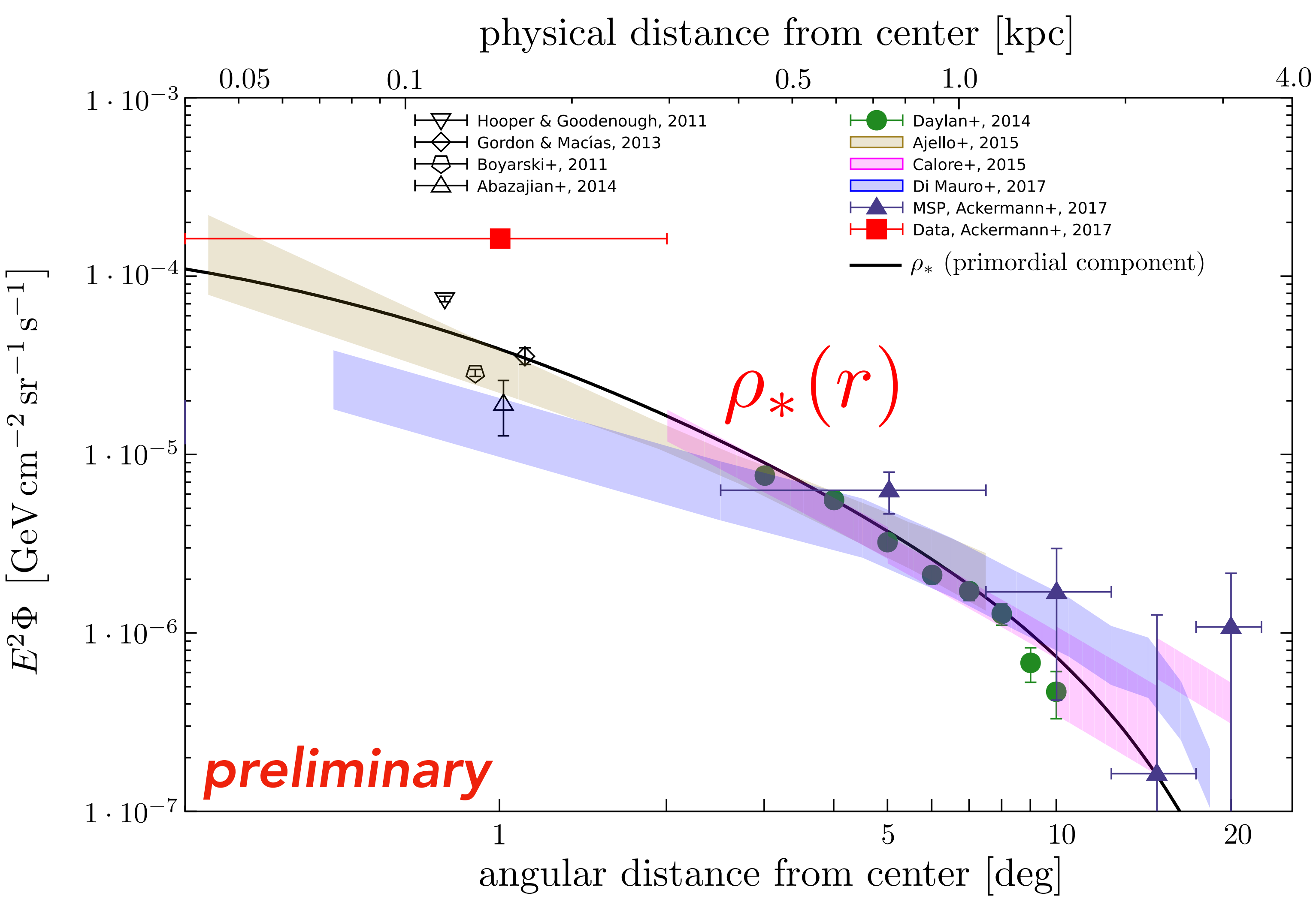
Toy model for MSP emission:

$$n_{\rm MSP}(r) = A \underbrace{\langle \rho_*(r) \rangle_{d_1}}_{\text{"primordial" MSPs}} + B \underbrace{\langle \rho_*^2(r) \rangle_{d_2} / \sigma}_{\text{"dynamically" formed}}$$

Main inputs for our analysis:
– **primordial formation:** use the ***stellar distribution*** & ***MSP luminosity function of field halos*** (already used in Winter+2016 for dSphs)
– **dynamical formation:** use ***gamma ray luminosity vs stellar encounter rate relation*** of globular clusters (Hui+, '11)

→Naive but almost *'parameter free' model*:
– validate it with the Galactic Center Excess features
– check predictions for the M31 extended emission

GCE emission - primordial formation



information about local distribution of MSPs:

$$\langle L_b^{\rm prim} \rangle = \frac{M_b}{M_{MW}} \int_{L_{\rm min}}^{L_{\rm max}} L_\gamma \left(\frac{dN}{dL_\gamma} \right)_{MW} dL_\gamma$$

mass of bulge inside: 2 kpc (~ 16°)

$$L_{\rm MWbulge}^{\rm prim} = 1.7^{+1.5}_{-1.1} \times 10^{37} {\rm ergs}^{-1}$$

from Ackermann+, 2017 (arXiv: 1704.03910):

$$L^{\rm obs}_{\rm GCE,tot,\ \lesssim 20^\circ} = 2.2^{+1.5}_{-1.9} \times 10^{37} {\rm erg\ s}^{-1}$$

$$\rho_{MW,b}(a) = \rho_{0,MW} \frac{e^{-a^2/a_m^2}}{(1 + a/a_0)^{1.8}}$$

[Vanhollebeke+, A&A (2009)]

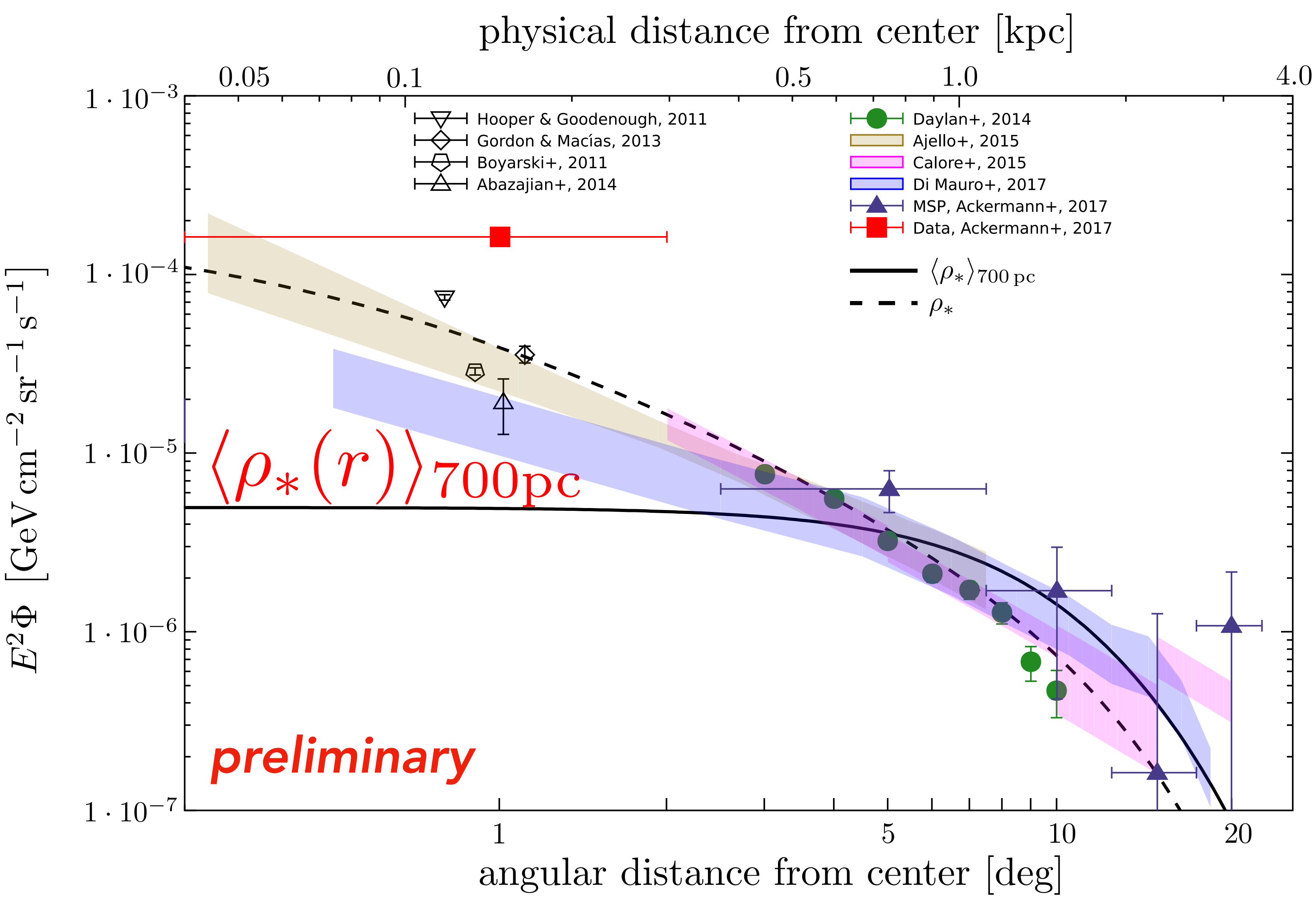
Spherically averaged (as compared to radial profile data)

→ ***good agreement with GCE properties, both in morphology and normalization!***

MSP GCE interpretation: [Bartels+, PRL (2016), Lee+, PRL (2016), Charles+, Gomez-Vargas+, …

GCE emission - primordial formation

MSP migration?



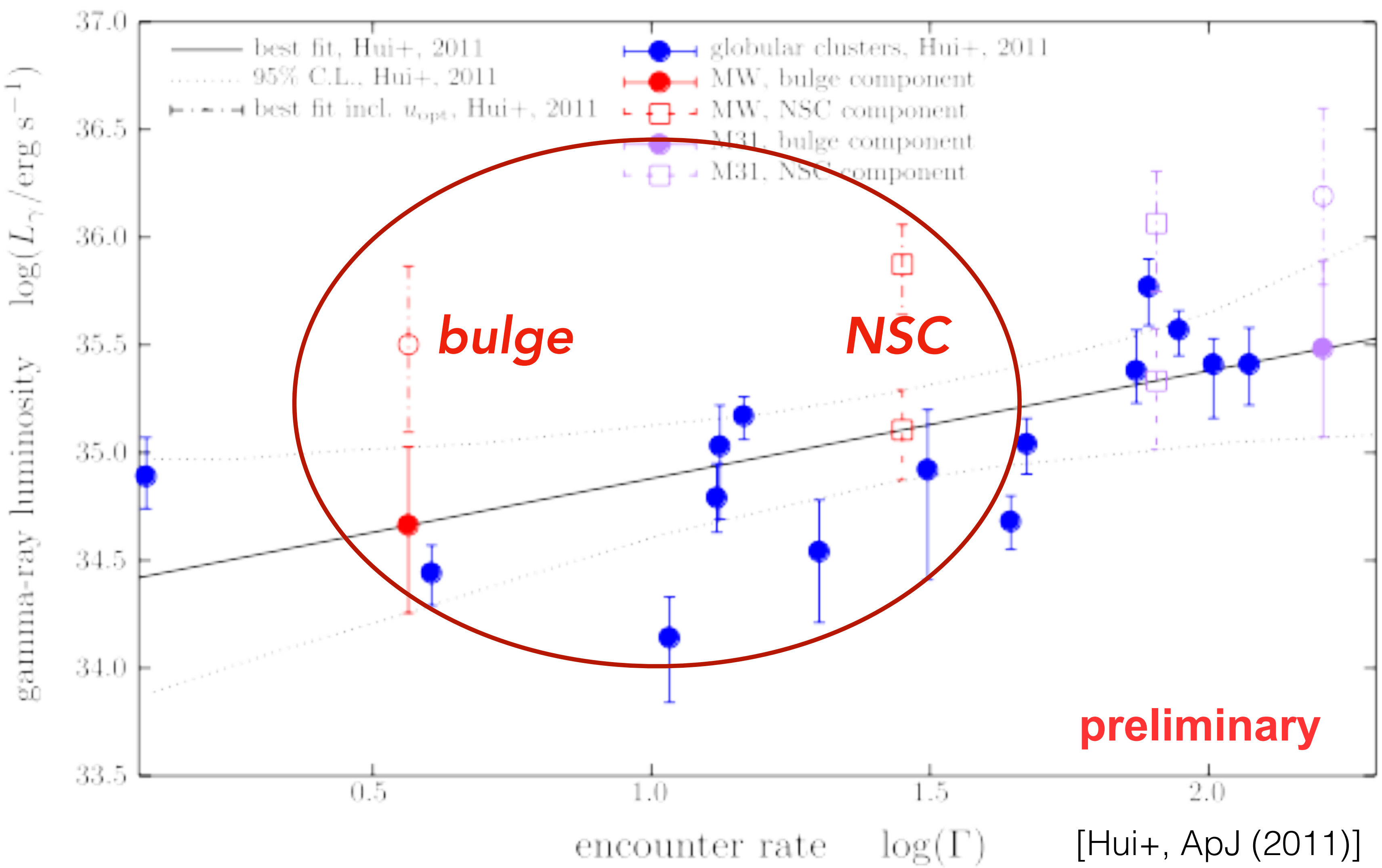
By using a viral theorem, a la Zwicky ;)

and MSP velocities 30-70km/s

→ migration distances 700-900pc

→**agreement within inner 2 deg worsens, when migration taken into account**

GCE emission - dynamical formation



[Hui+, ApJ (2011)]

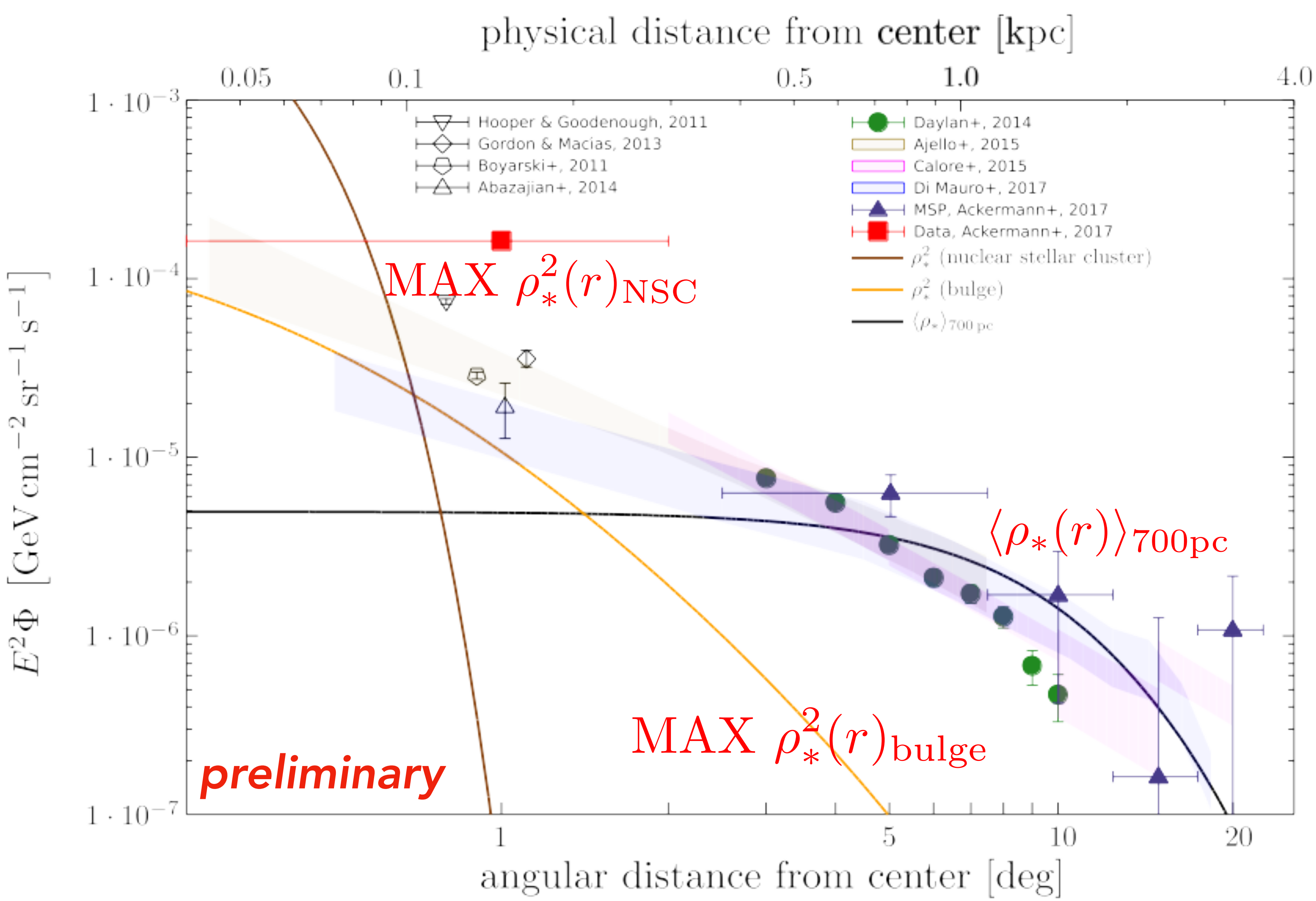
gamma ray luminosity of GlCls correlates with:

— stellar interaction rate $\rho_*^2(r)$

— but also with the low energy photon filed (ISRF)

$$L^{\mathrm{dyn}}_{\mathrm{MWbulge}} \leq 0.05\ L^{\mathrm{prim}}_{\mathrm{MWbulge}}$$

GCE emission - primordial + dynamical formation



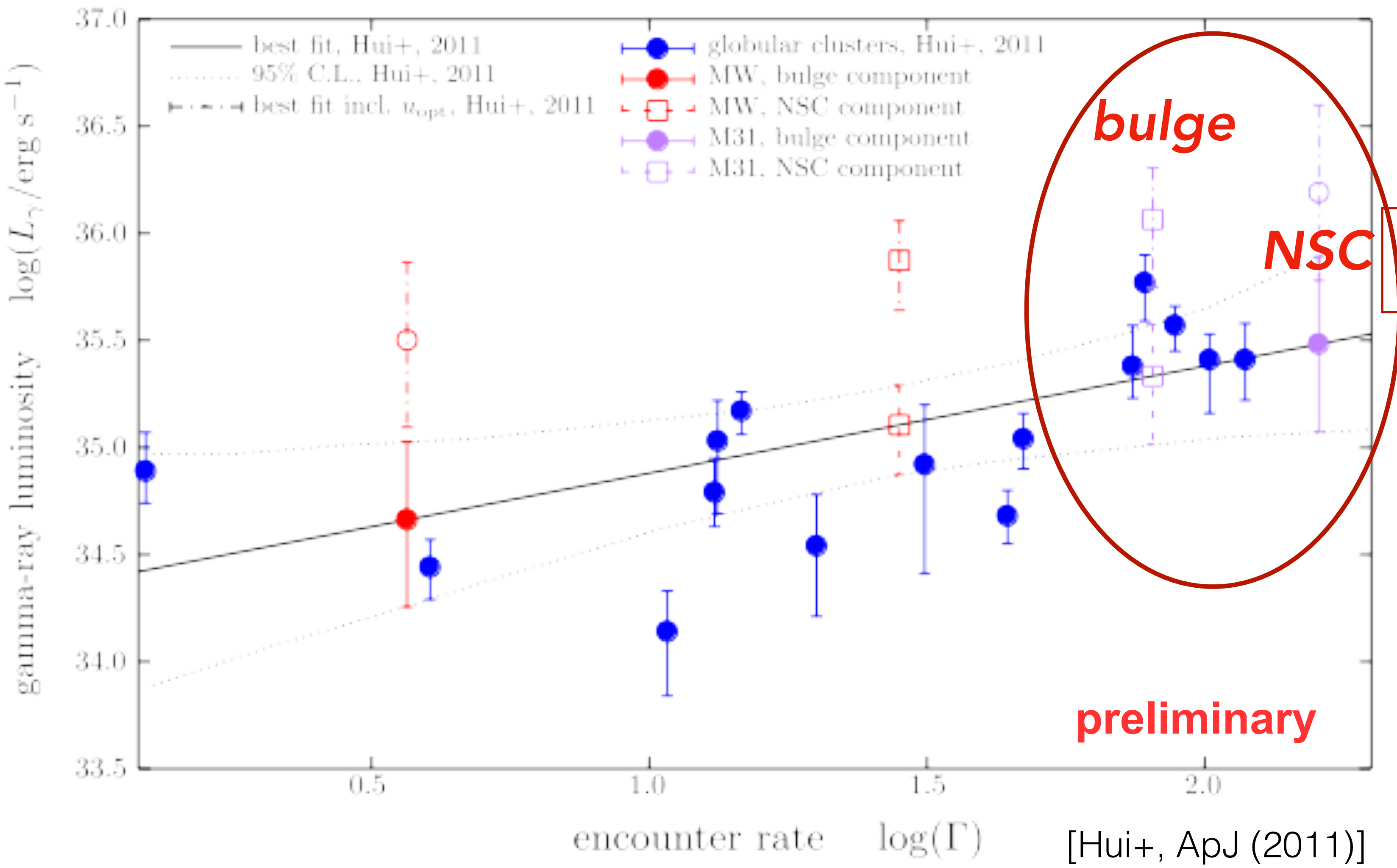
$$L^{\mathrm{obs}}_{\mathrm{GCE,tot},\ \lesssim 20^\circ} = 2.2^{+1.5}_{-1.9} \times 10^{37} \mathrm{erg\ s}^{-1}$$

$$L^{\mathrm{prim}}_{\mathrm{MW\ bulge}} = 2.0^{+3.2}_{-1.3} \times 10^{37}\ \mathrm{erg\,s}^{-1}$$

$$L^{\mathrm{dyn}}_{\mathrm{MWbulge}} \leq 0.05\ L^{\mathrm{prim}}_{\mathrm{MWbulge}}$$

→ ***good agreement with GCE properties, when dynamical formation + MSP migration into account!***

M31 - primordial + dynamical formation



[Hui+, ApJ (2011)]

total luminosity:

$$L^{\rm obs}_{\rm M31\ bulge} = (28. \pm 4.) \times 10^{37} \mathrm{erg\ s^{-1}}$$

$$L^{\rm prim}_{\rm M31\ bulge} = 7.5^{+12.0}_{-5.3} \times 10^{37} \mathrm{erg\ s^{-1}}$$

$$L^{\rm dyn}_{\rm M31NSC} \leq 0.01\ L^{\rm prim}_{\rm M31}$$

→***predicted luminosity under predicts but agrees within ~3σ with the measured emission from M31***

Caveats:

— NSC properties poorly known

— other gamma-ray sources expected to contribute (point sources, SMBH…?)

M31 - primordial + dynamical formation

morphology:

Template	TS	Δ *LogL*
Uniform disk	46	–
Gaussian (MSP PLEC)	46	–
Point Source	37	4.3
$IRAC_{1^\circ}$	41	2.4
$IRAC_{0.7^\circ}$	41	2.5
IRAC	40	2.6

preliminary

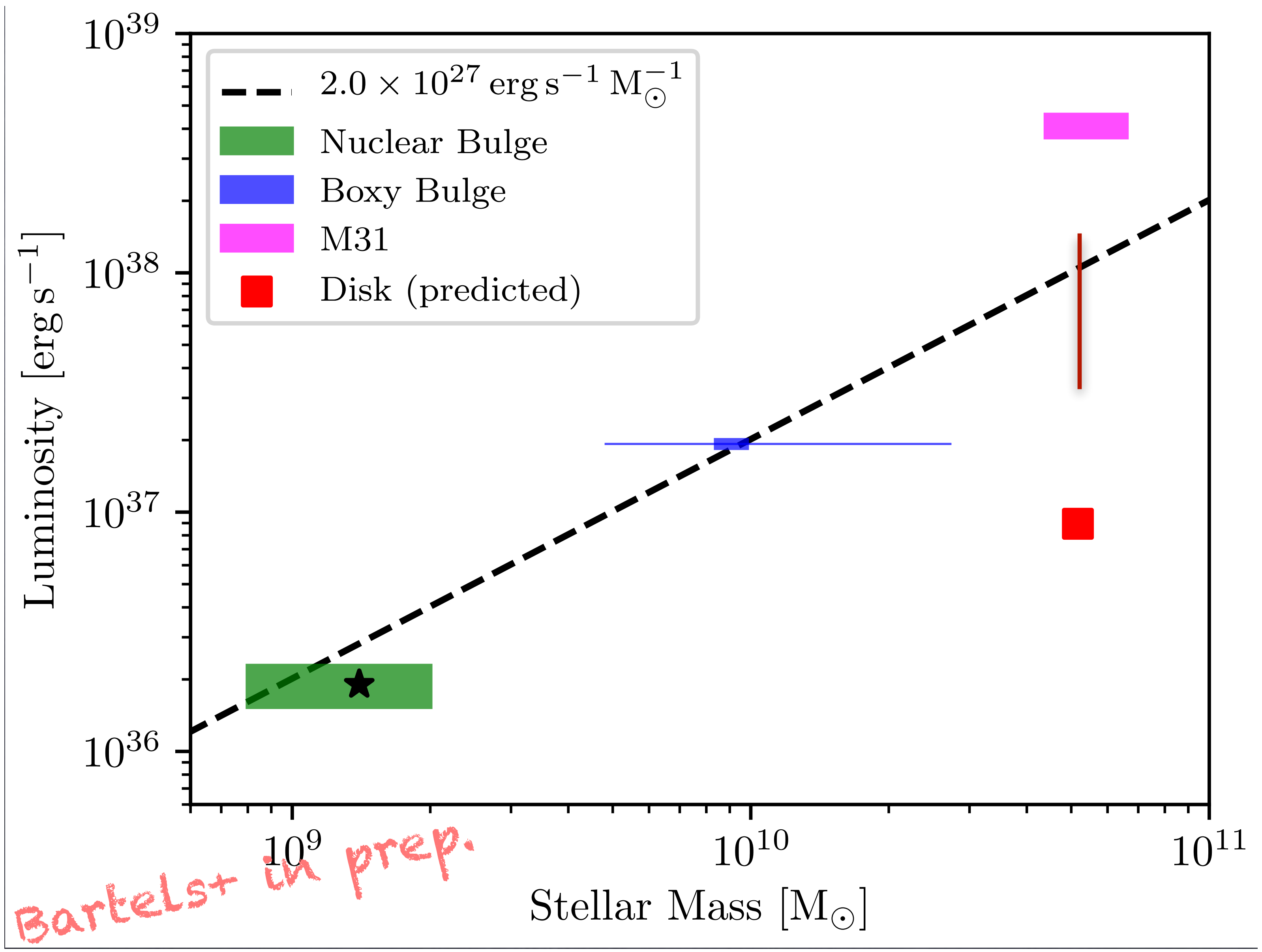
Spitzer/IRAC 587 maps at 3.6 μm template tracing old stars which reside dominantly in the bulge

→***morphology consistent within 3σ with the best fit templates, though the data suggest larger extension***

Note that the disk emission of M31 is predicted to be below the upper limit of non-detection.

Outlook

— in our toy model GCE properties can be explained with the simple MSP emission model including primordial and dynamical formation of MSPs



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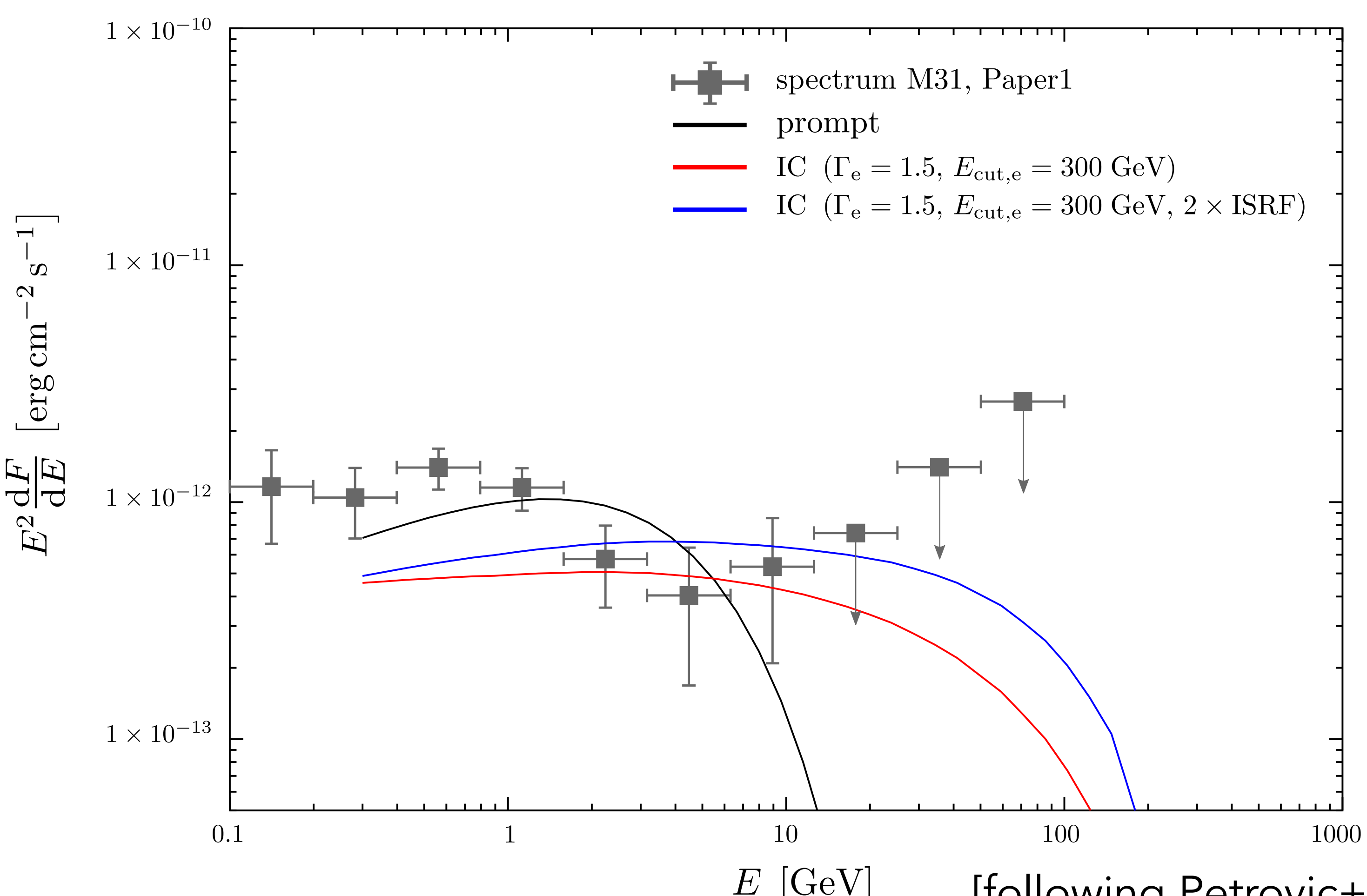
— in our toy model GCE properties can be explained with the simple MSP emission model including primordial and dynamical formation of MSPs

— the models under predict (but is consistent within three sigma) with the M31 measurement

— better angular resolution needed…

— electrons from MSPs? (Venters+, ApJ (2015)) — CTA, Astrogam/AMEGO?



[following Petrovic+, JCAP (2015)]

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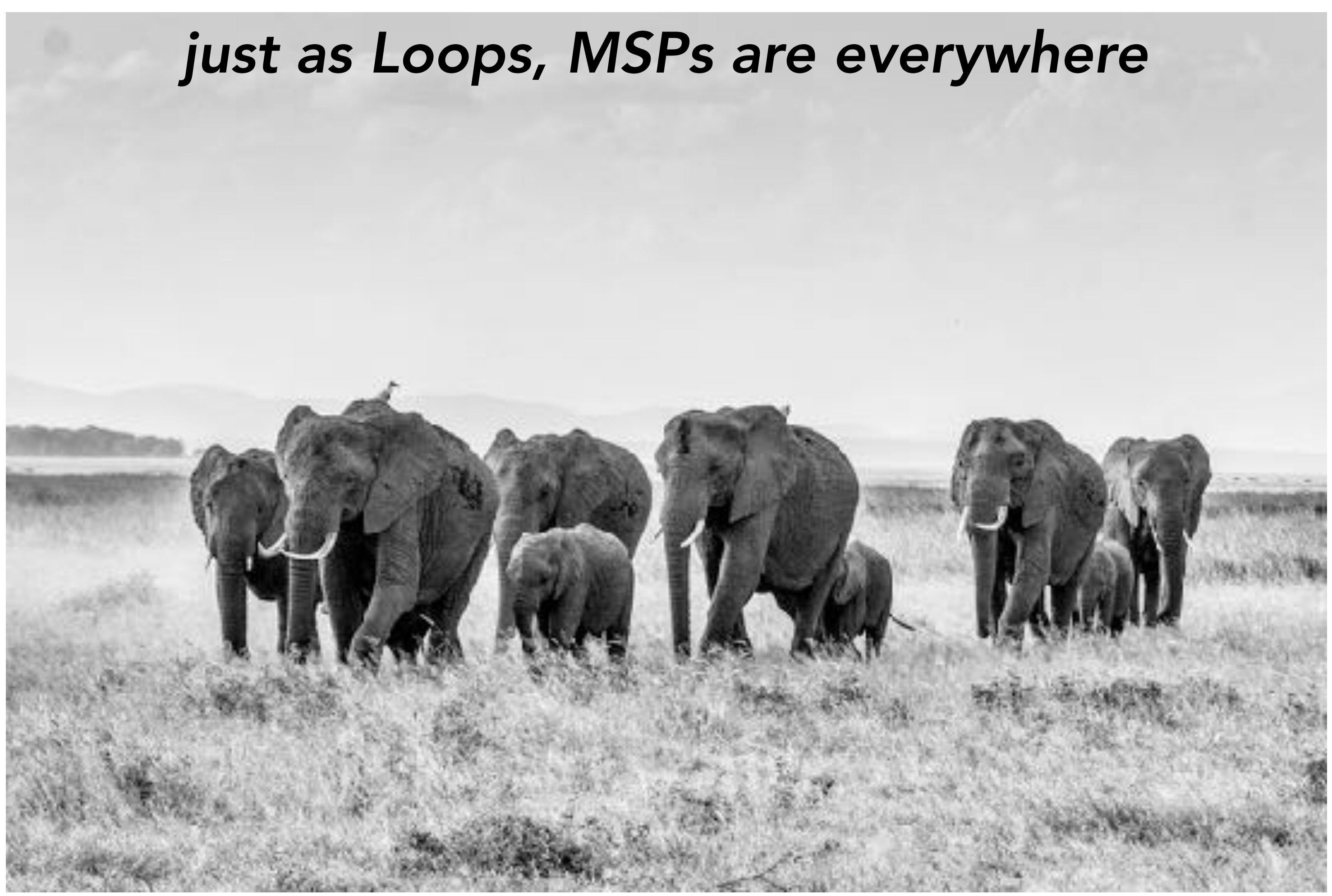
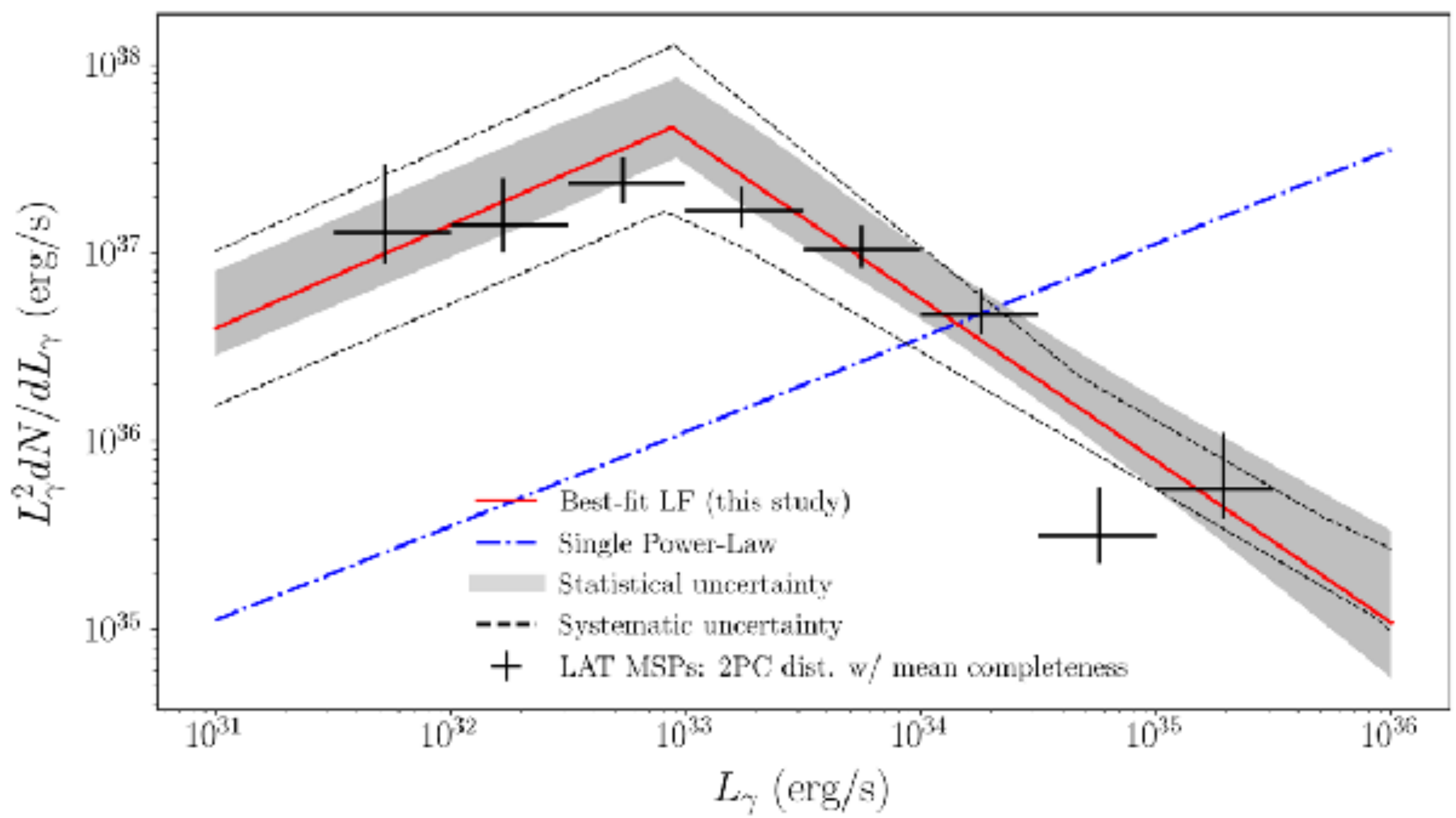


Extra



For MSPs above 10^33 erg/s, ~ 45 +/- 25 MSPs within a 1.5 kpc volume.

About 20 LAT detected MSPs above 10^33 erg/s.