Foreground Mismodeling and the Point Source Explanation of the *Fermi* Galactic Center Excess

Siddharth Mishra-Sharma

Based on:

L.J. Chang, SM, M. Lisanti, M. Buschmann, N.L. Rodd, B.R. Safdi [1908.10874]

M. Buschmann, N.L. Rodd, B.R. Safdi, L. Chang, SM, M. Lisanti, O. Macias [2002.12373]

NYU | Center for Cosmology and Particle Physics

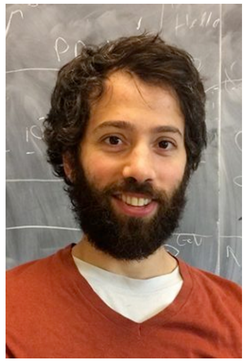
CERN-TH BSM Forum

April 2, 2020

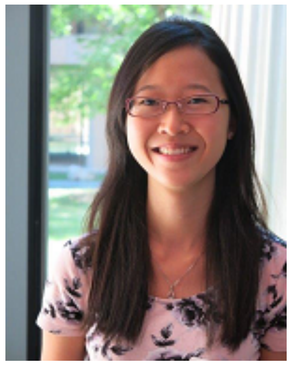
People

Malte Buschmann
(Michigan)

Nick Rodd
(Berkeley/LBNL)



Ben Safdi
(Michigan)



Laura Chang
(Princeton)

Mariangela Lisanti
(Princeton)

Oscar Macias
(Amsterdam/Kavli IPMU)

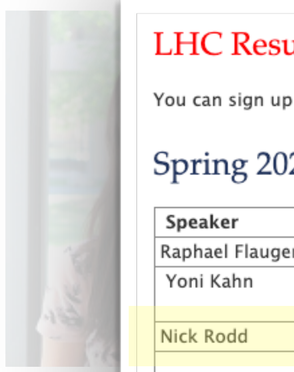
People

#ad

Malte Buschmann
(Michigan)

Nick Rodd
(Berkeley/LBNL)

Ben Safdi
(Michigan)



Laura Chang
(Princeton)

Mariangela Lisanti
(Princeton)

Oscar Macias
(Amsterdam/Kavli IPMU)

LHC Results Forum Talk Schedule

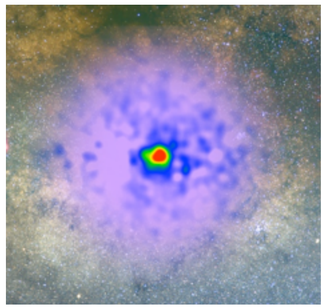
https://sites.google.com/site/lhcresultsforumtalks/

You can sign up to the LHC Results Forum mailing list by clicking here.

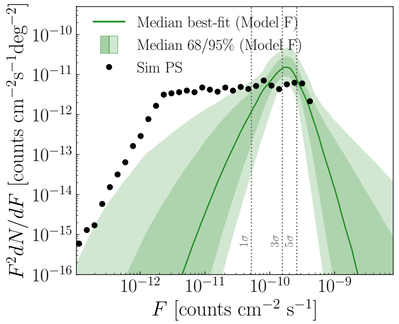
Spring 2020

Speaker	Title	Date	Stream	Slides
Raphael Flauger	On H0	2/28/2020 @4pmET	stream	slides
Yoni Kahn	Converging Excesses in Low-Threshold Direct Detection Experiments	3/13/2020 @4pmET	stream	slides
Nick Rodd	Update on Galactic Center Excess	4/3/2020 @4pmET	stream	slides

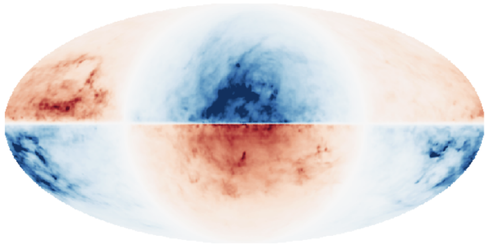
Outline



Galactic Center Excess: Background and Methods

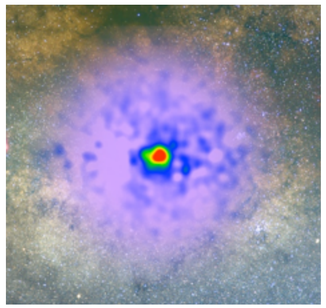


Diffuse mismodeling and lessons from simulation

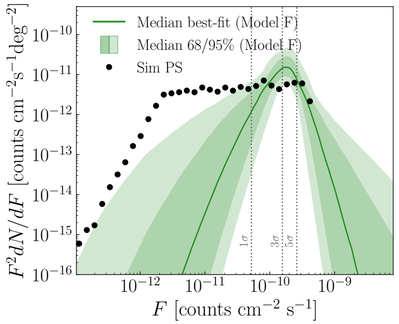


Towards mitigating diffuse mismodeling

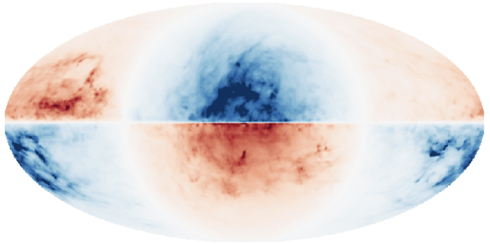
Outline



Galactic Center Excess: Background and Methods



Diffuse mismodeling and lessons from simulation



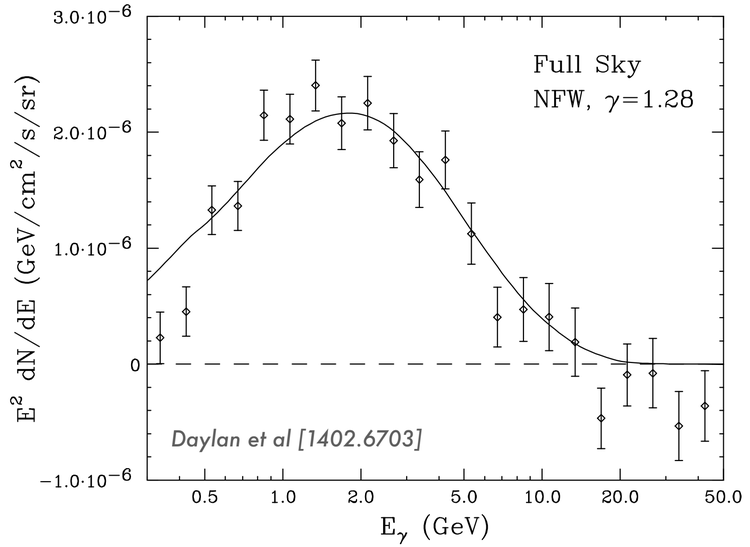
Towards mitigating diffuse mismodeling

The Galactic Center GeV Photon Excess

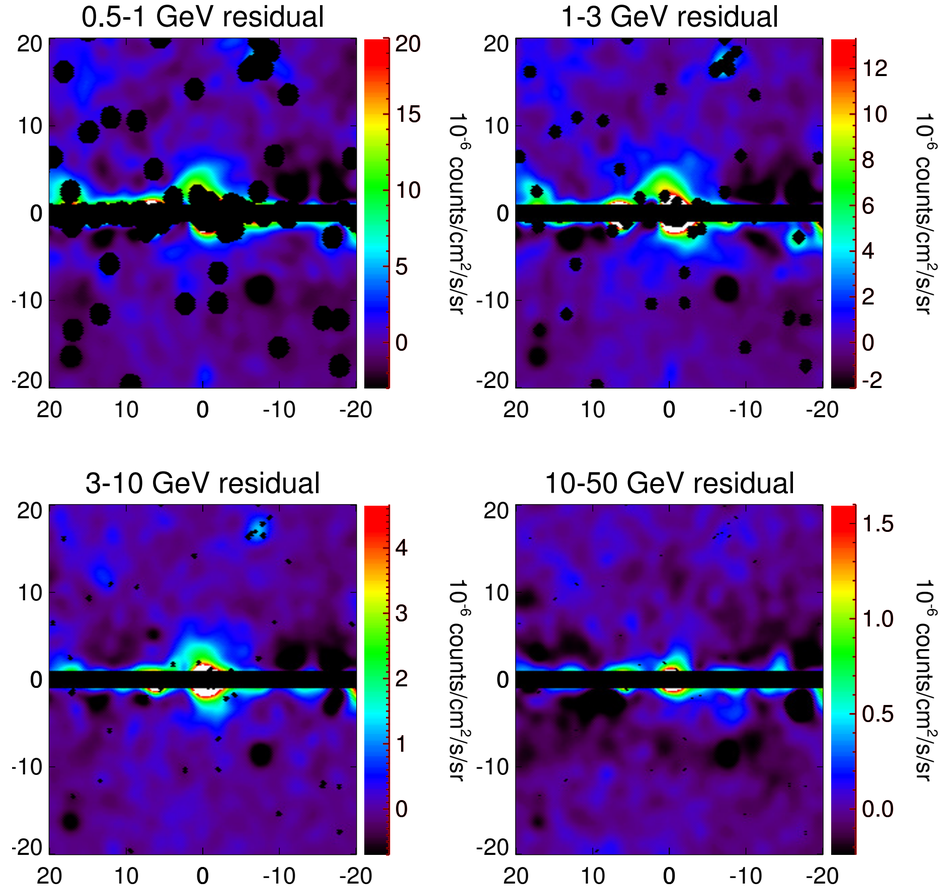
Some facts:

- ~Spherically symmetric gamma-ray excess in the Inner Galaxy
- Extends out 10° from the center of Galaxy
- Constitutes ~10% total flux

Energy spectrum



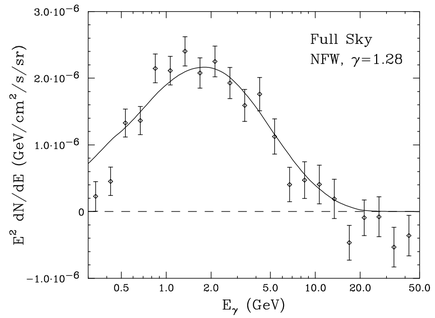
Spatial morphology

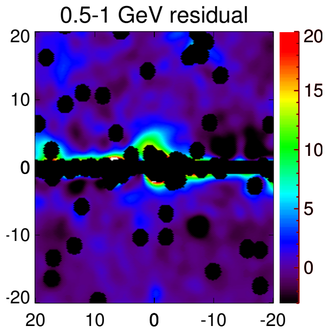


Origin of the GCE

Dark Matter

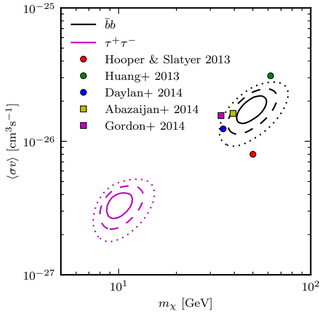
Spectrum and spatial morphology consistent with DM



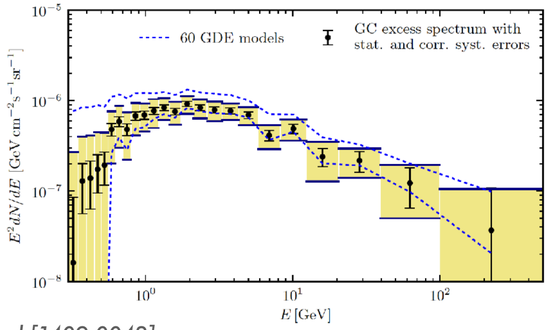


Daylan et al [1402.6703]

Consistent with thermal cross sections



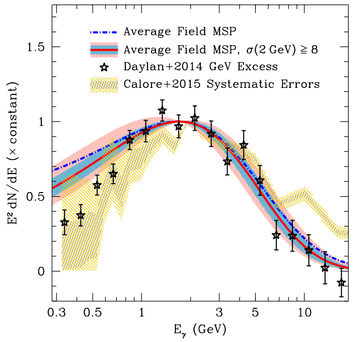
Robust to variation of Galactic diffuse emission



Calore et al [1409.0042]

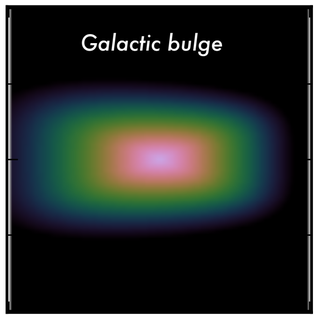
Astrophysics

Spectrum roughly consistent with MSP expectation



Brandt & Kocsis [1507.05616]

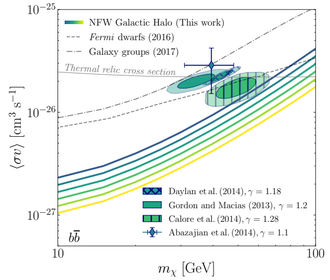
Spatial morphology consistent with stellar distribution



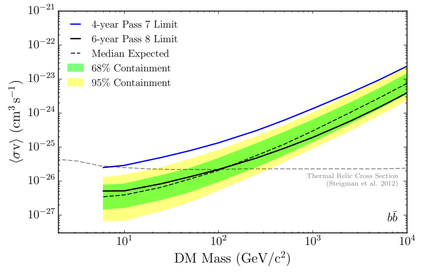
Bartels et al [1711.04778]

+ Macias et al [1611.06644]
Macias et al [1901.03822]

Not seen in other targets

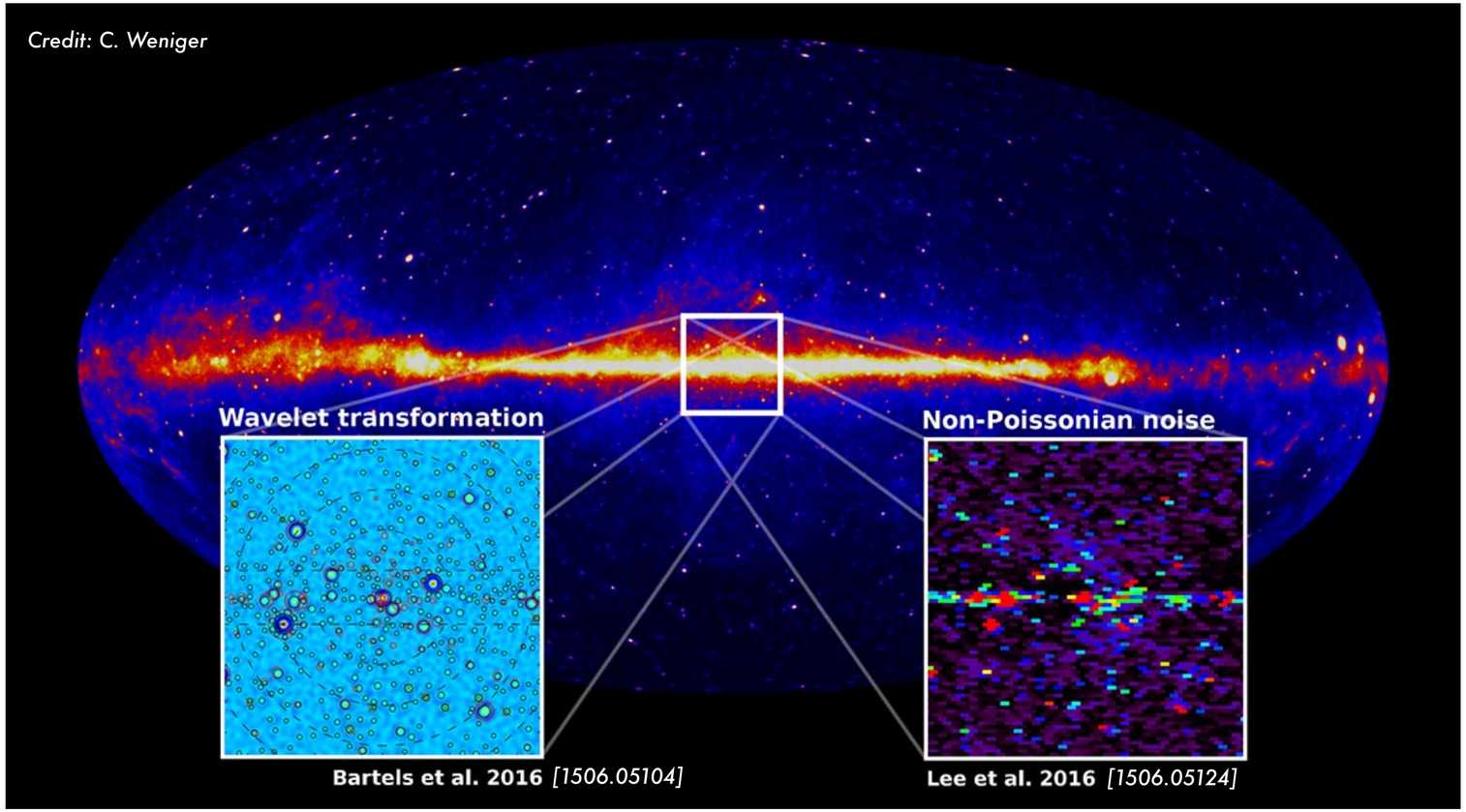


Chang, SM, Lisanti [1804.04132]

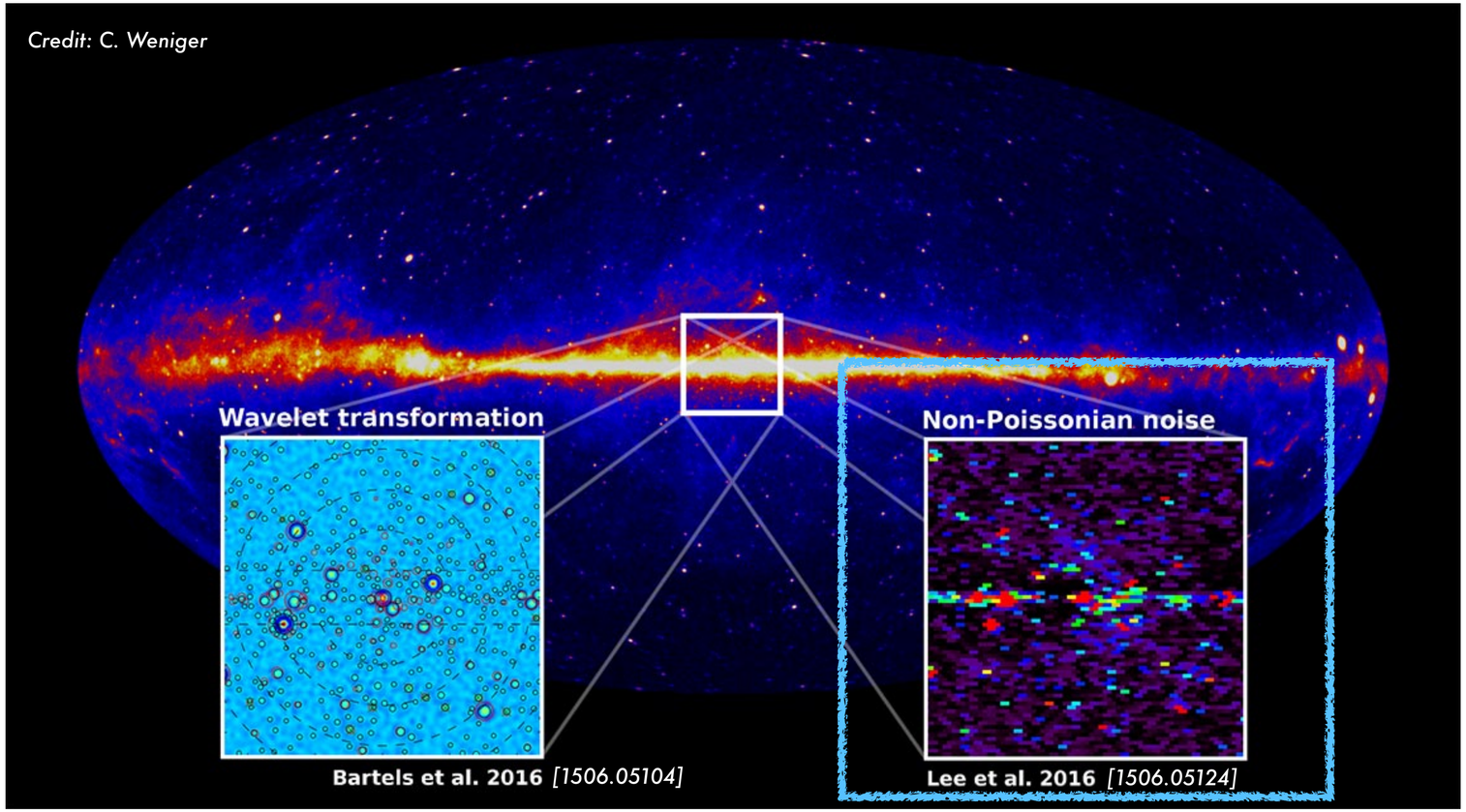


Fermi-LAT Collaboration [1503.02641]

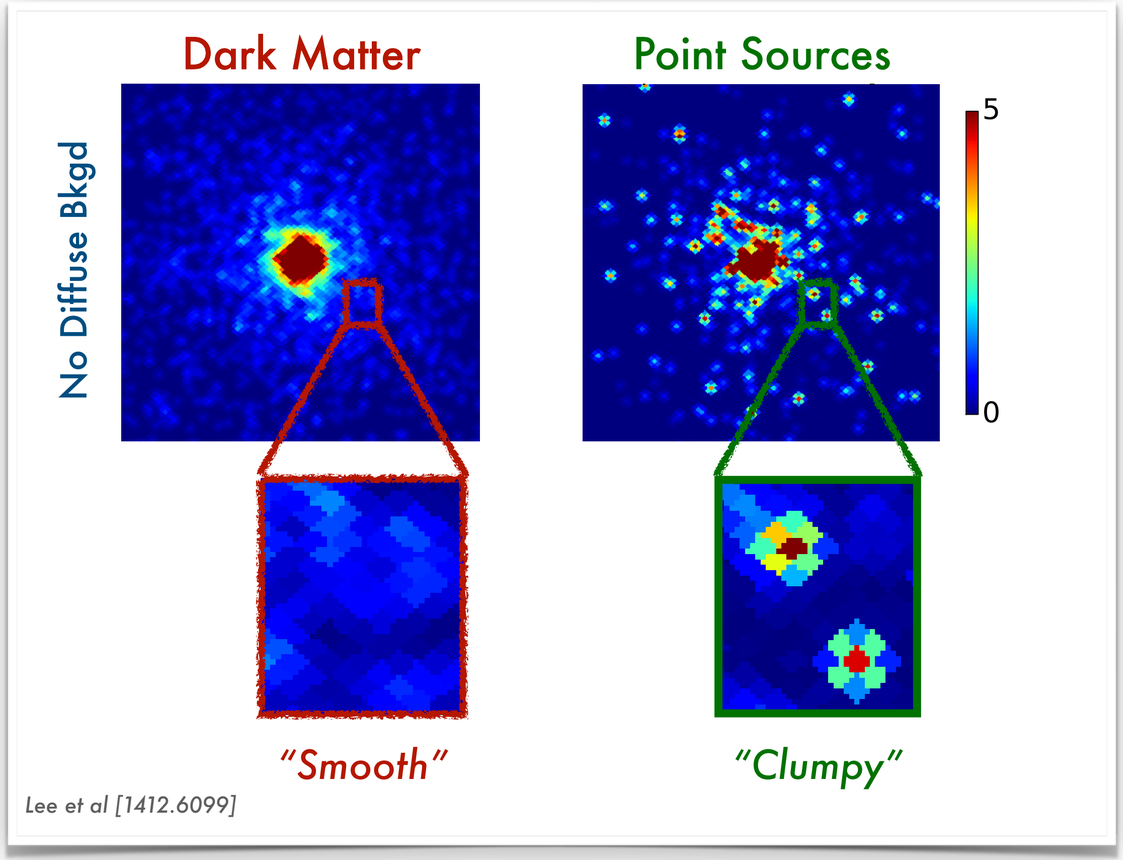
The Status c. 2015: Evidence for Unresolved PSs

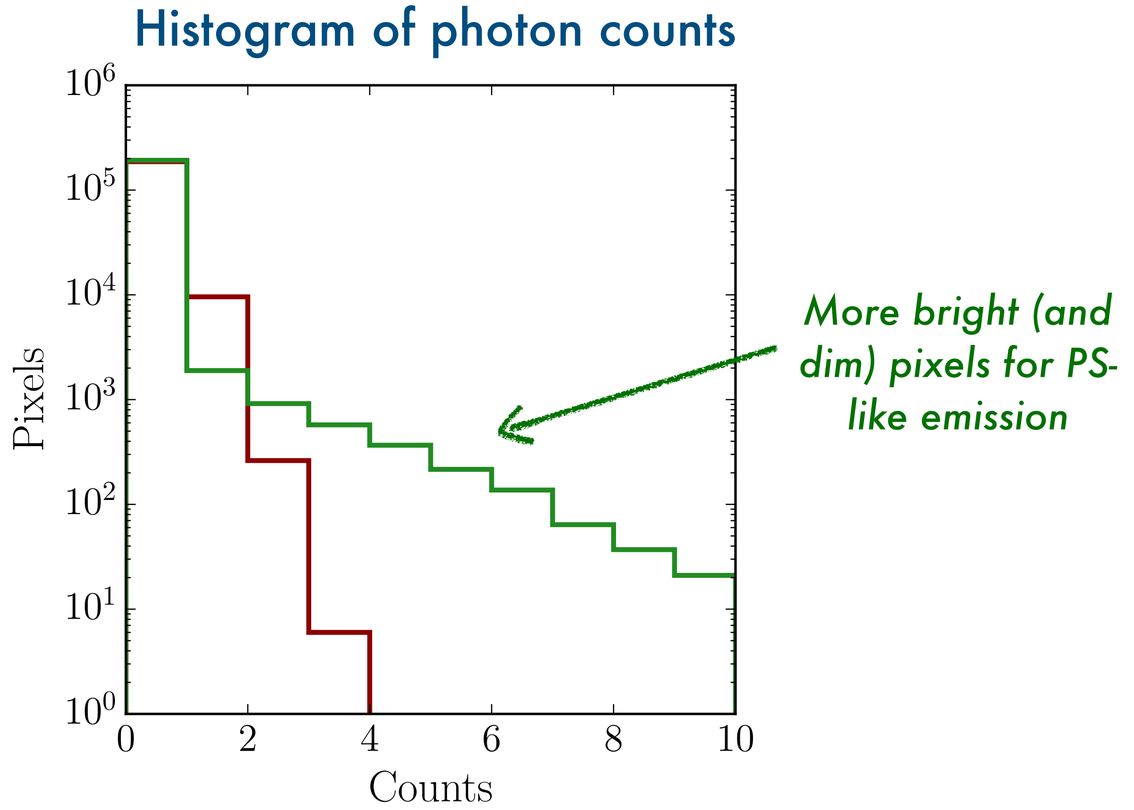


The Status c. 2015: Evidence for Unresolved PSs



Distinguishing PS from DM with photon statistics

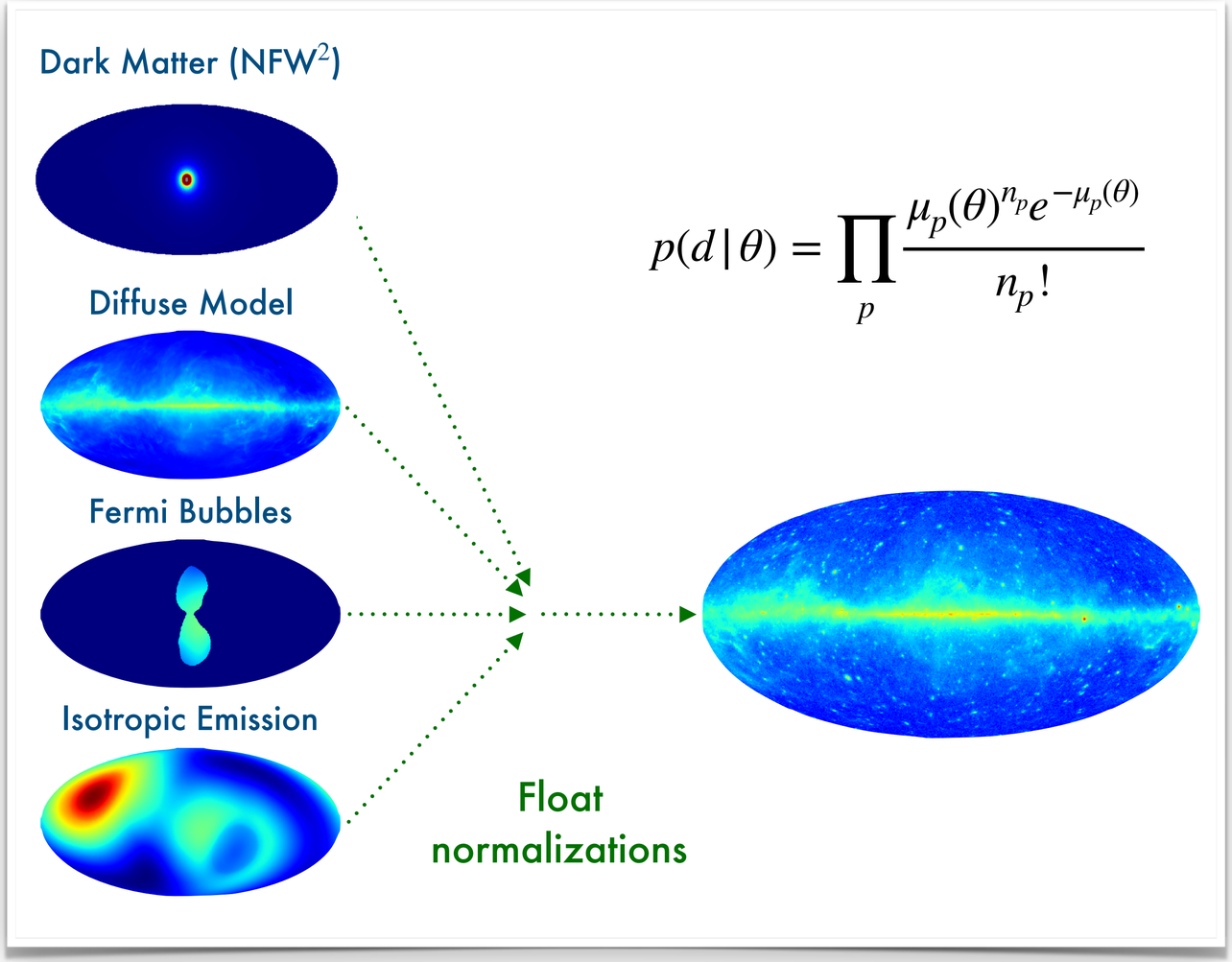




Malyshev & Hogg [1104.0010]

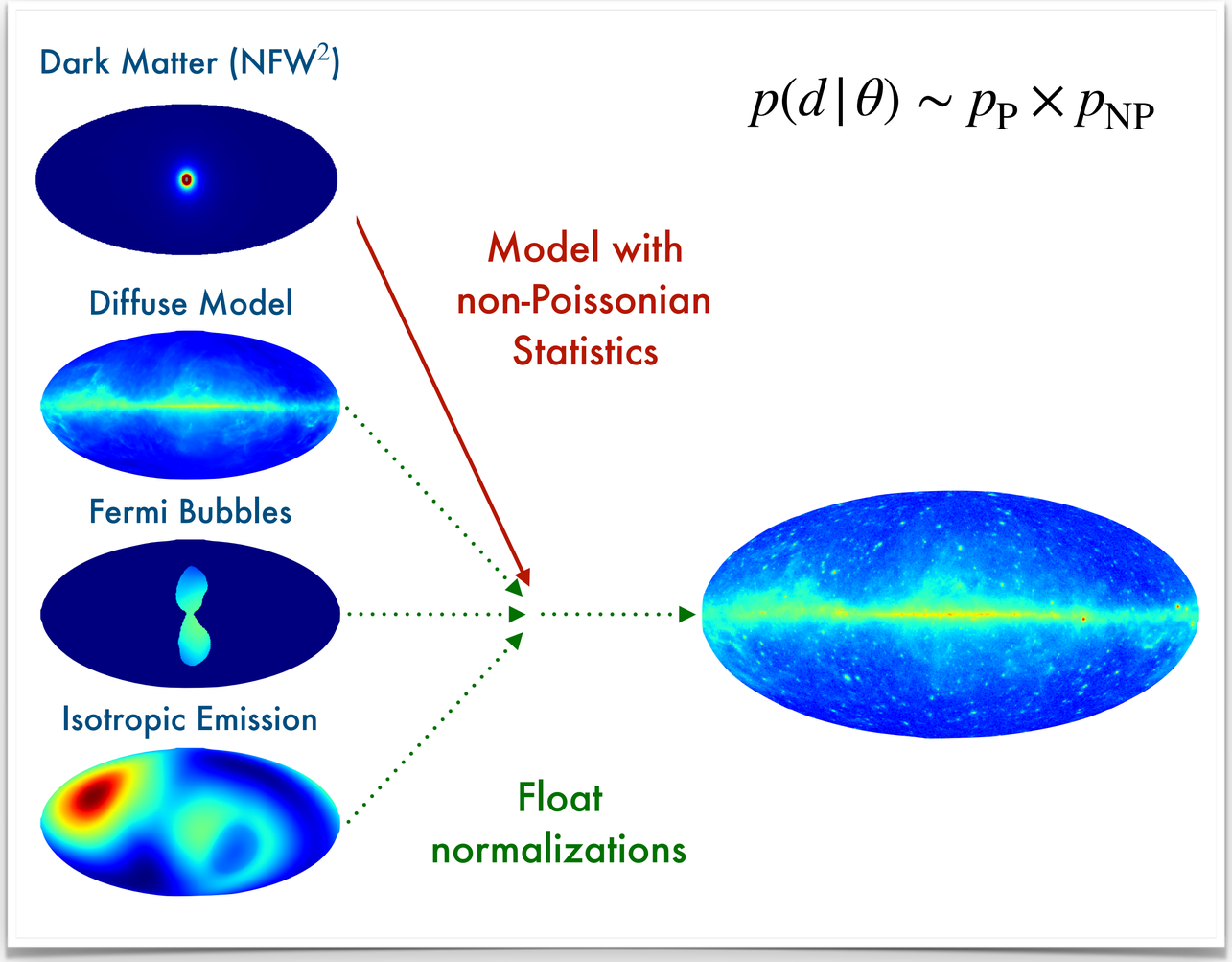
Lee et al [1506.05124]

Poissonian Template Fitting



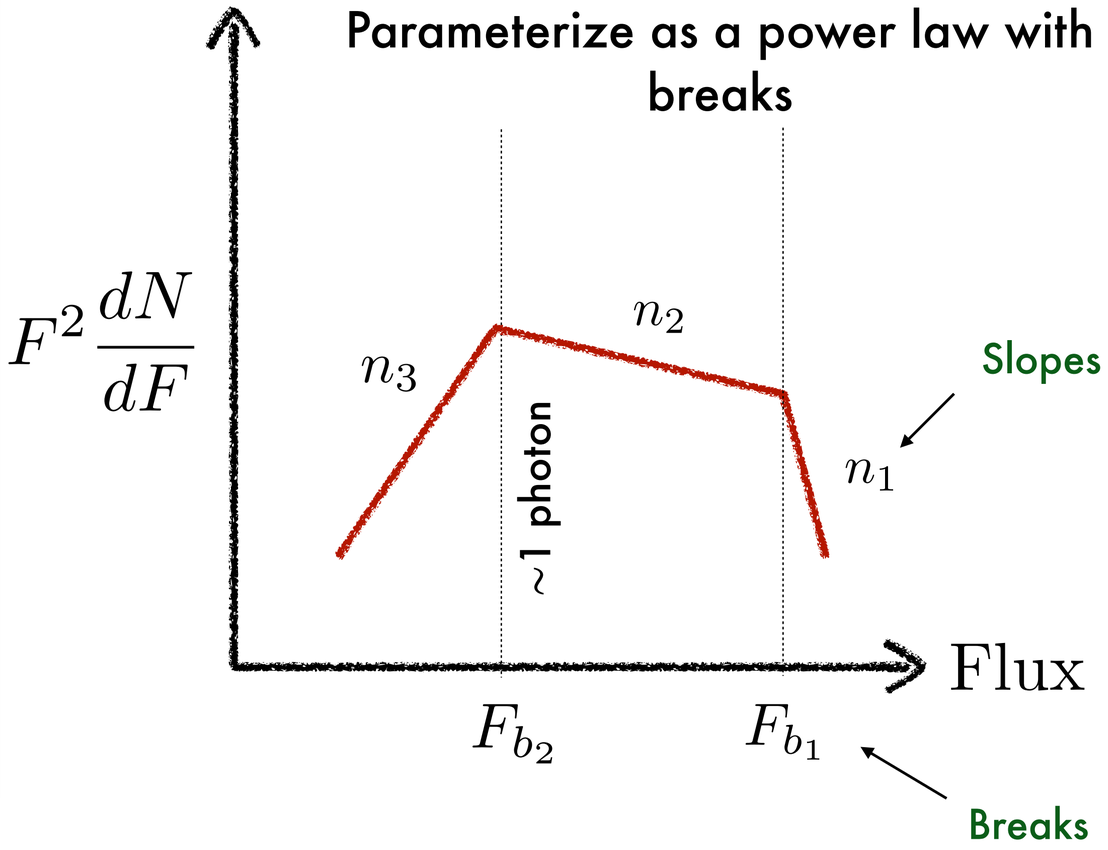
Also point source model and mask (not shown)

Non-Poissonian Template Fitting



Also point source model and mask (not shown)

Source-count distribution gives number of sources in a given pixel with a flux between F and F+dF

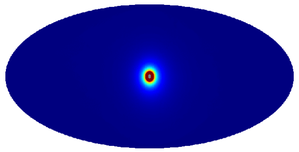


Public NPTF implementation available at https://github.com/bsafdi/NPTFit

Inner Galaxy NPTF Analysis: *Lee et al (2015)*

Goal: to determine which NFW template provides a better fit to the data

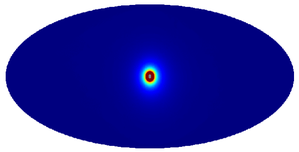
Smooth NFW



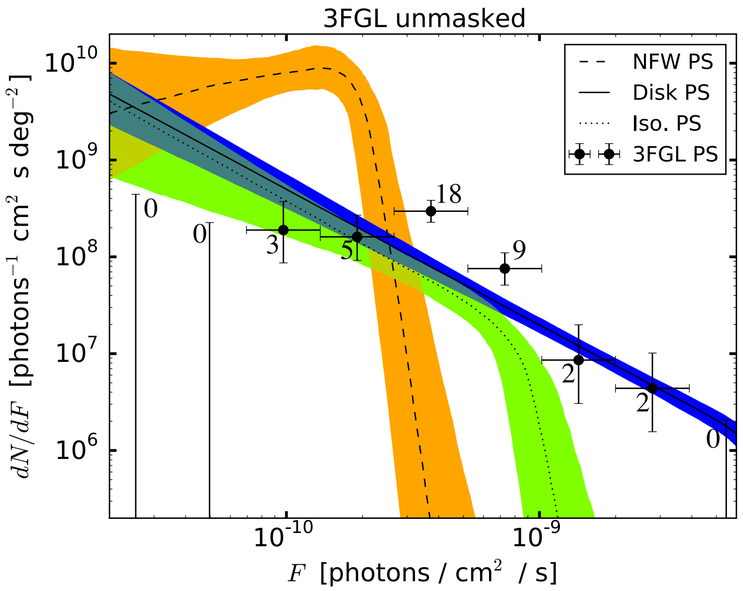
(Poissonian statistics)

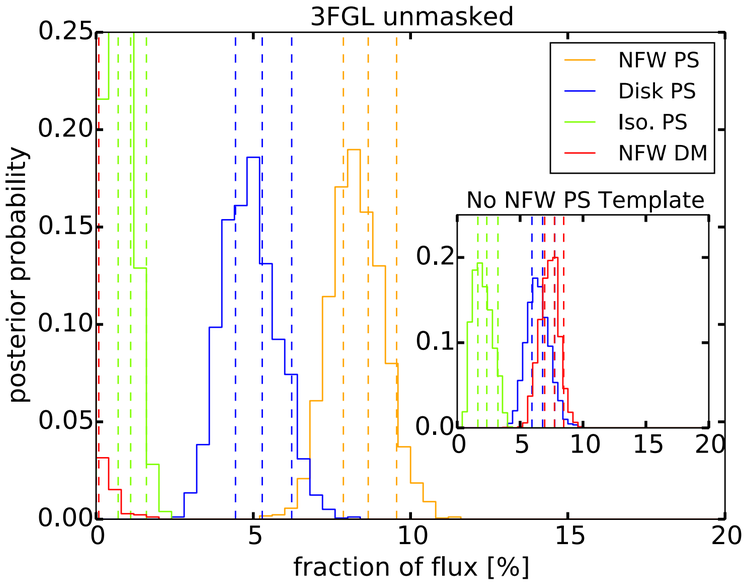
vs

NFW PS



(Non-poissonian statistics)





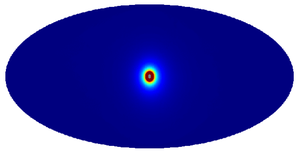
- *Excess flux is entirely accounted for by the NFW PS template*
- *Bayes factor in preference for NFW point sources is ~10^7*

Lee, Lisanti, Safdi, Slatyer, and Xue [1506.05124]

Inner Galaxy NPTF Analysis: *Lee et al (2015)*

Goal: to determine which NFW template provides a better fit to the data

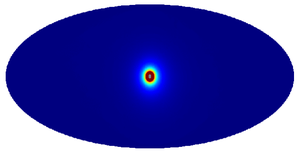
Smooth NFW



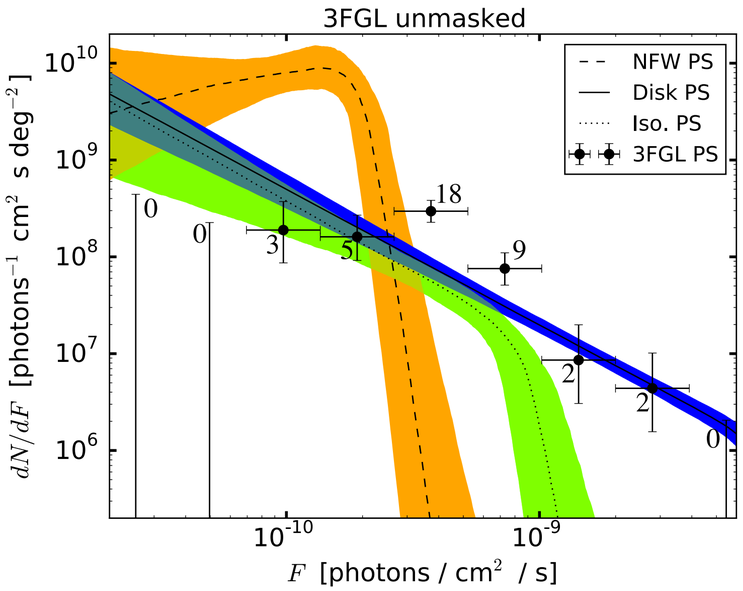
(Poissonian statistics)

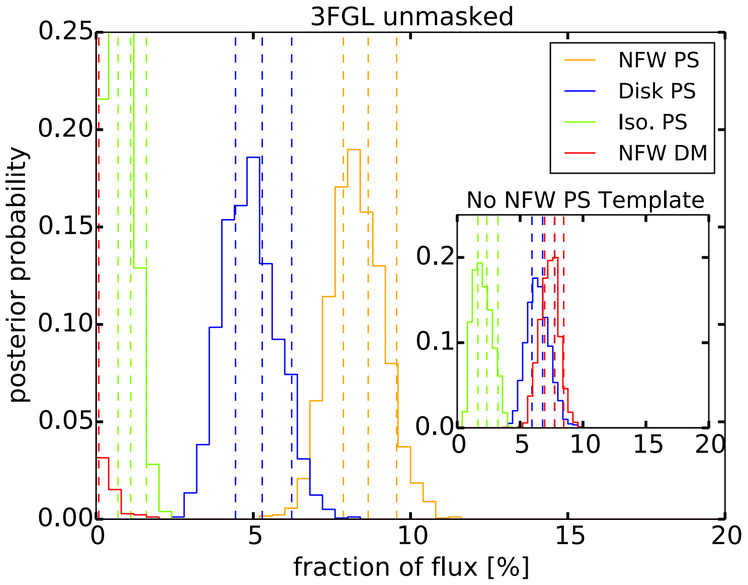
vs

NFW PS



(Non-poissonian statistics)





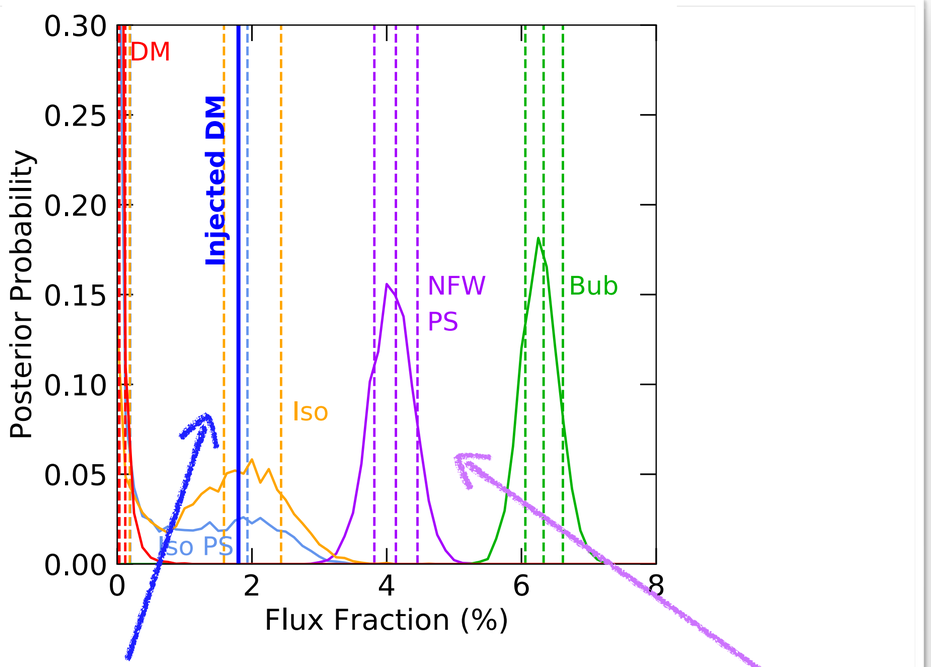
- *Excess flux is entirely accounted for by the NFW PS template*
- *Bayes factor in preference for NFW point sources is ~10^7*

Lee, Lisanti, Safdi, Slatyer, and Xue [1506.05124]

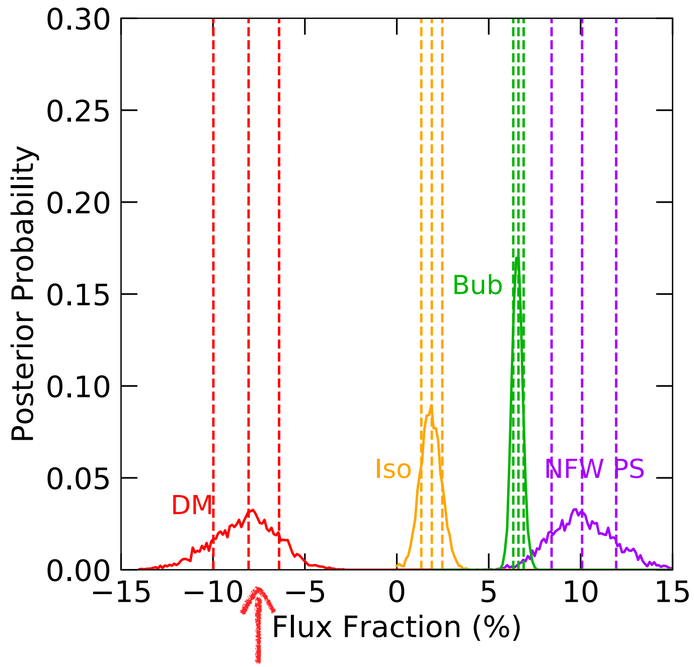
Dark Matter Strikes Back? *Leane & Slatyer (2019)*

Performed a closure test:

Inject a DM signal onto the real data, then try to recover it with the NPTF pipeline



Injected DM flux **gets reconstructed as** *PSs*



DM flux can go negative if allowed to

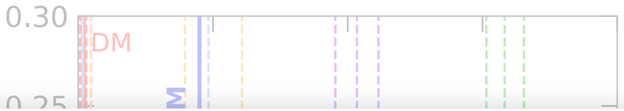
Behaviour attributed to presence of unmodeled PSs or diffuse mismodeling

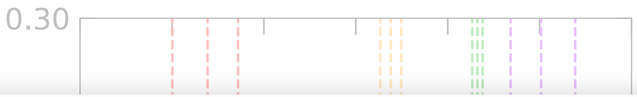
NB: Not an error in the NPTF method!

Dark Matter Strikes Back? *Leane & Slatyer (2019)*

Performed a closure test:

Inject a DM signal onto the real data, then try to recover it with the NPTF pipeline





Issues related to mismodeling were discussed in *Lee et al (2015)*

for the NFW PSs changes. In particular, the source-count function for NFW PSs is shifted to lower flux, potentially suggesting that some of the near-threshold sources could either be more disk-like in morphology or associated with mis-modeling the diffuse background. However, the preference for NFW PSs remains high, with the model including NFW PSs preferred over that without by a Bayes factor $\sim 10^4$. Unlike the previous analysis that used a truncated

The results of Leane & Slatyer (2019) suggest that these systematics deserve further scrutiny

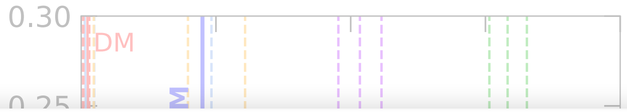
Behaviour attributed to presence of unmodeled PSs or diffuse mismodeling

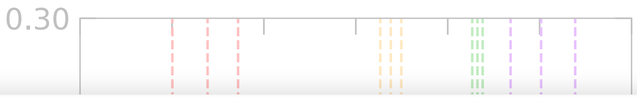
NB: Not an error in the NPTF method!

Dark Matter Strikes Back? *Leane & Slatyer (2019)*

Performed a closure test:

Inject a DM signal onto the real data, then try to recover it with the NPTF pipeline





Issues related to mismodeling were discussed in *Lee et al (2015)*

for the NFW PSs changes. In particular, the source-count function for NFW PSs is shifted to lower flux, potentially suggesting that some of the near-threshold sources could either be more disk-like in morphology or associated with mis-modeling the diffuse background. However, the preference for NFW PSs remains high, with the model including NFW PSs preferred over that without by a Bayes factor $\sim 10^4$. Unlike the previous analysis that used a truncated

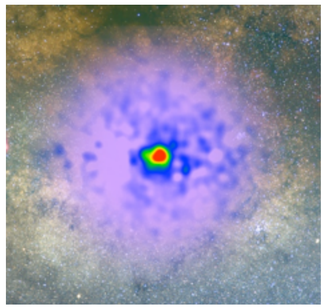
The results of Leane & Slatyer (2019) suggest that these systematics deserve further scrutiny

<u>Goal:</u> to understand and mitigate systematic issues associated with the NPTF in the Galactic Center

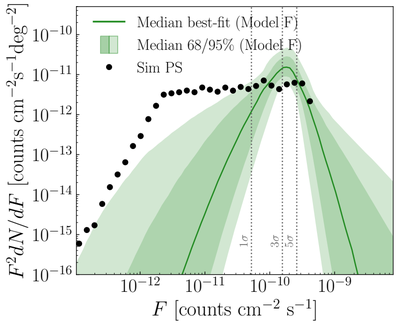
Behaviour attributed to presence of unmodeled PSs or diffuse mismodeling

NB: Not an error in the NPTF method!

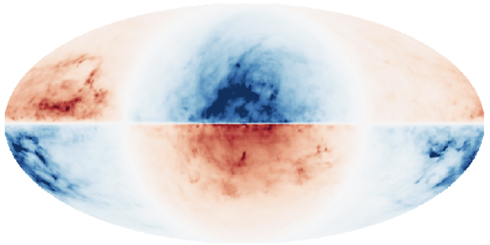
Outline



Galactic Center Excess: Background and Methods

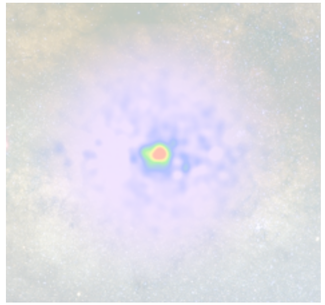


Diffuse mismodeling and some lessons from simulations

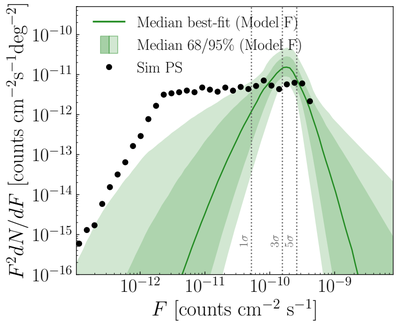


Towards mitigating diffuse mismodeling

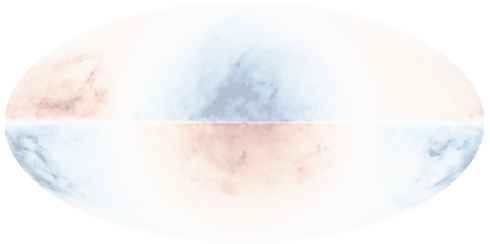
Outline



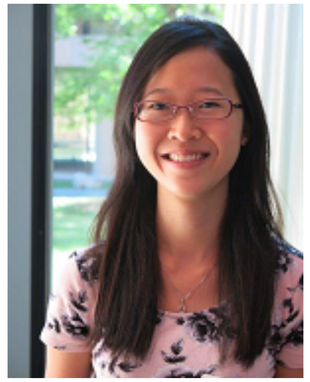
Galactic Center Excess: Background and Methods



Diffuse mismodeling and some lessons from simulations



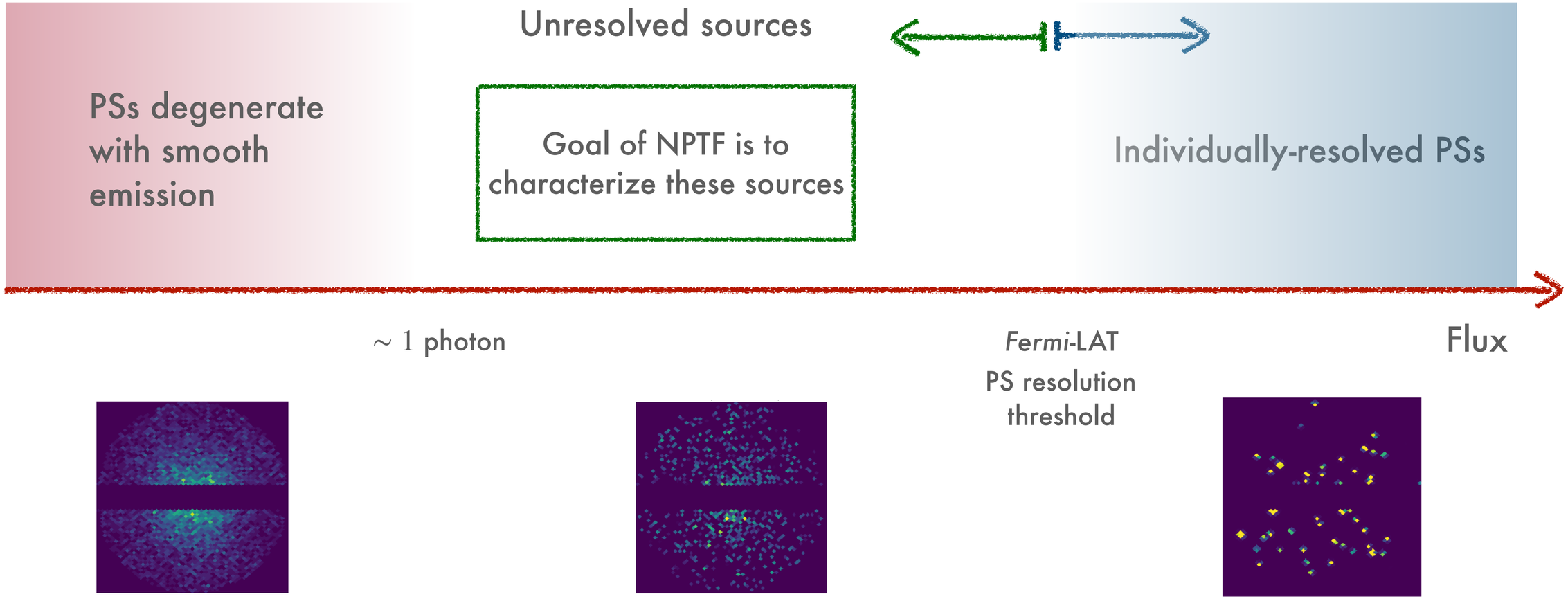
Towards mitigating diffuse mismodeling



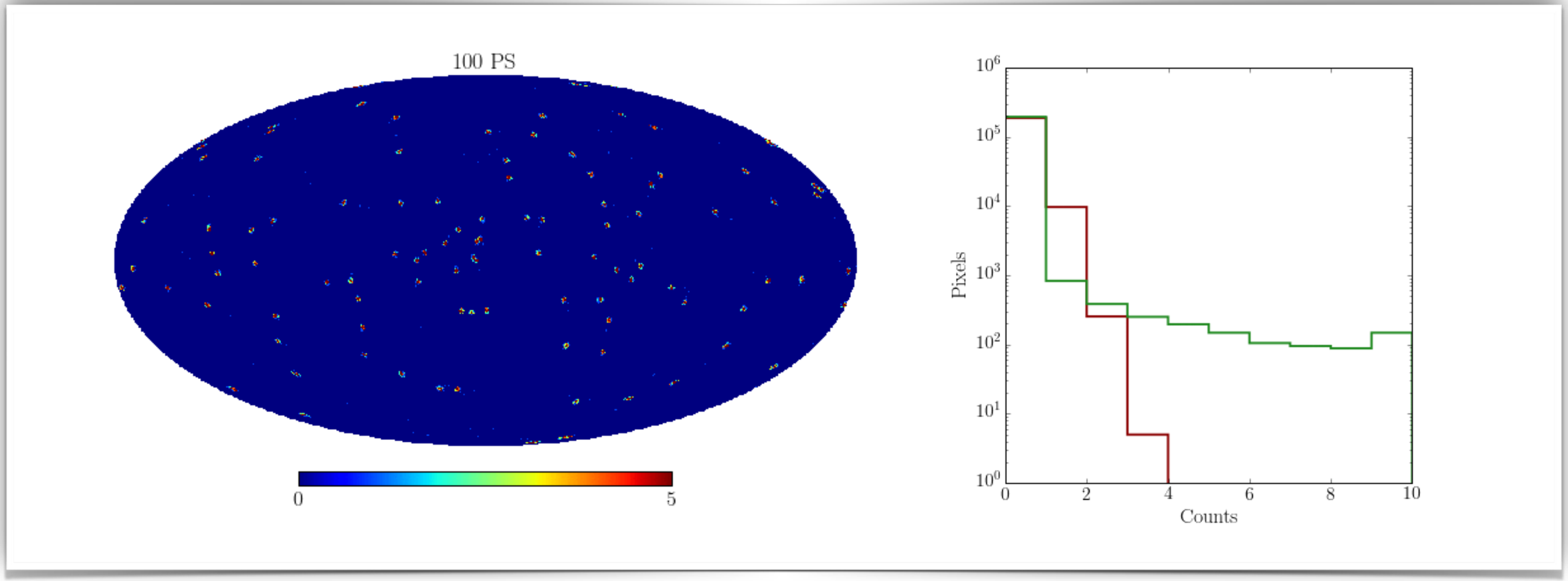
Dissecting the NPTF

What is the method sensitive to?

Slides inspiration from Laura Chang



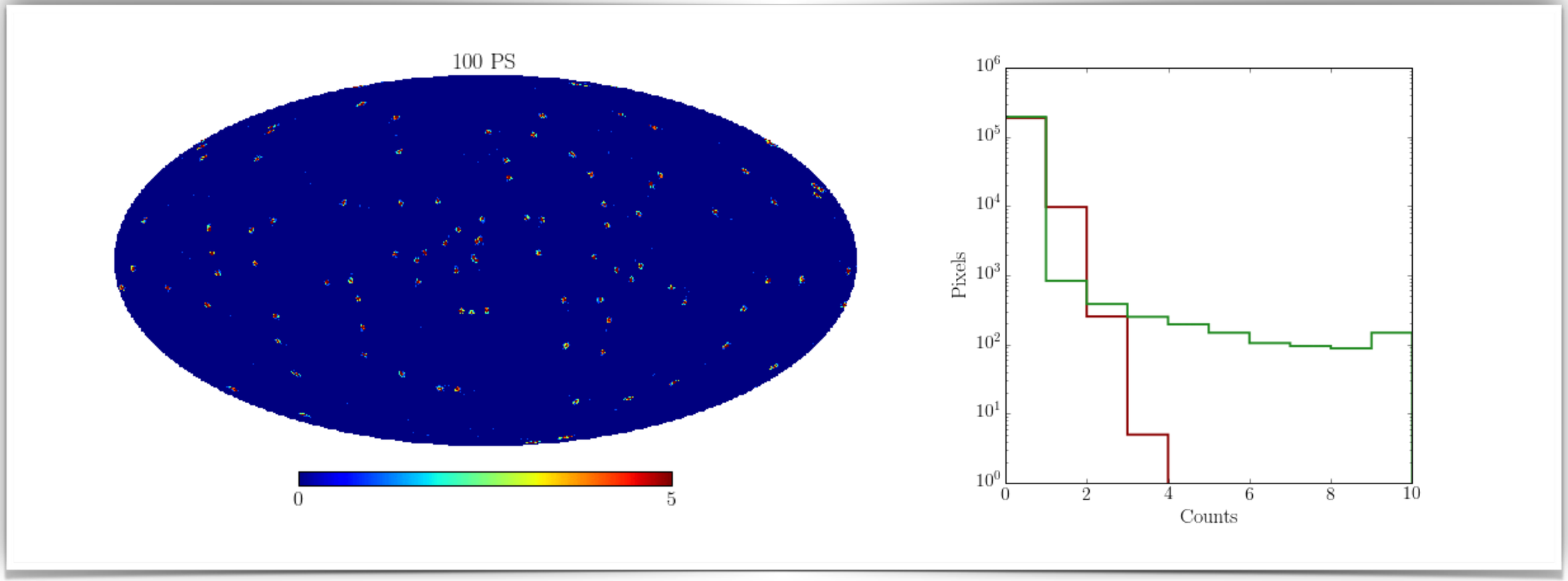
Degeneracy between dim PSs and smooth emission



We can never exclude the PS hypothesis—but we might be able to see evidence for a PS population*

*But we may call it into question by inferring a flux distribution inconsistent with astrophysical expectation

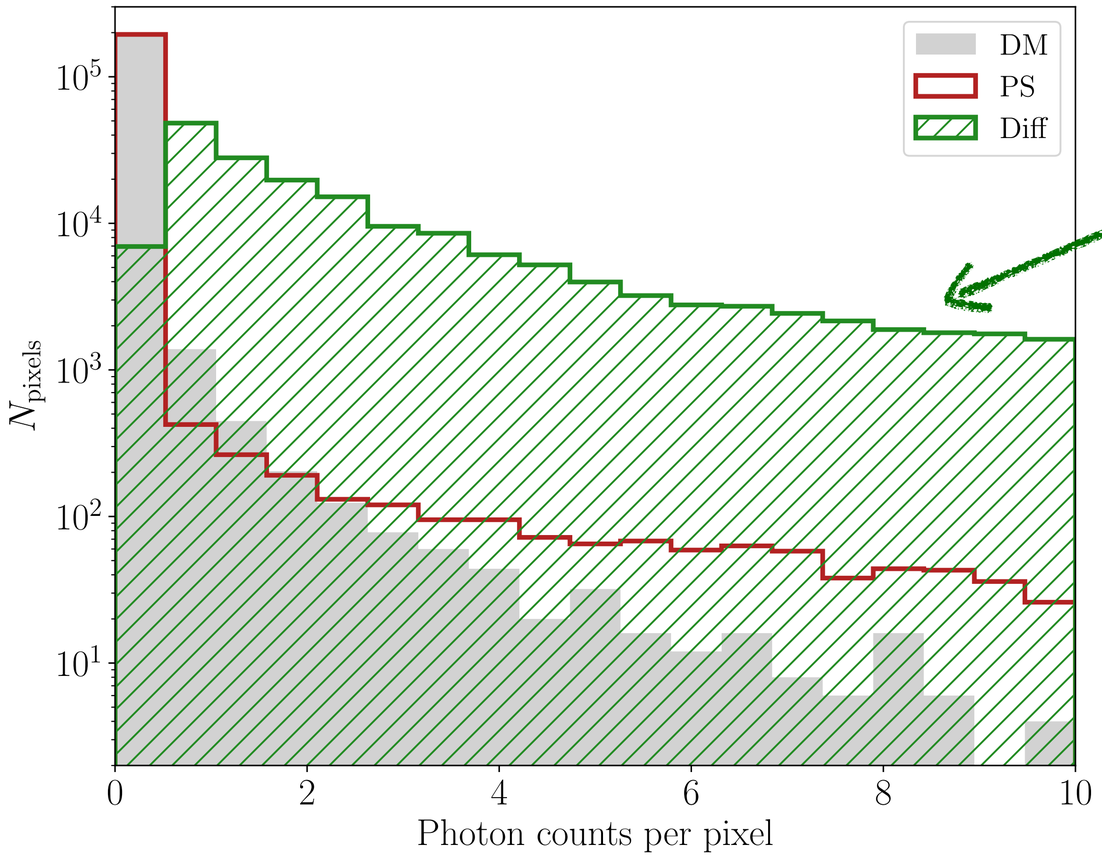
Degeneracy between dim PSs and smooth emission



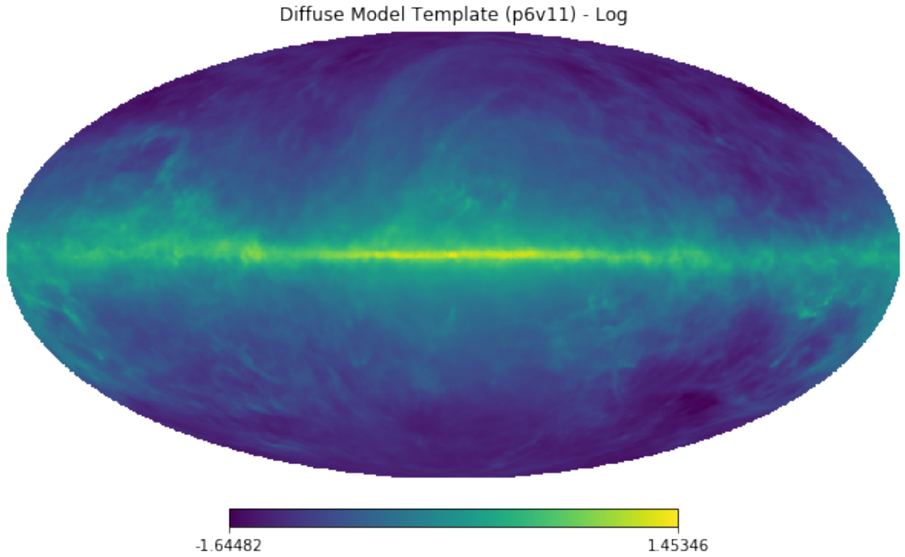
We can never exclude the PS hypothesis—but we might be able to see evidence for a PS population*

*But we may call it into question by inferring a flux distribution inconsistent with astrophysical expectation

So far so good. What about Galactic foregrounds?



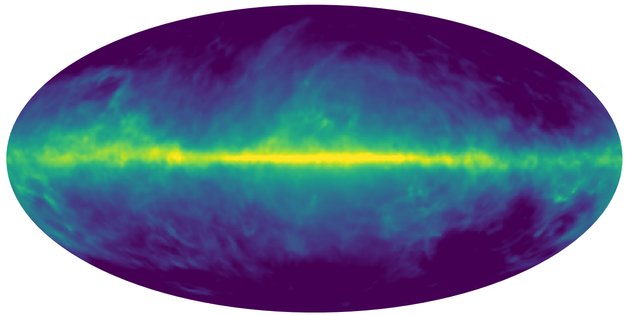
Diffuse foregrounds make up most of the observed emission in the Galactic Center



Much harder problem in the presence of diffuse emission from the Milky Way

Modeling Galactic foregrounds

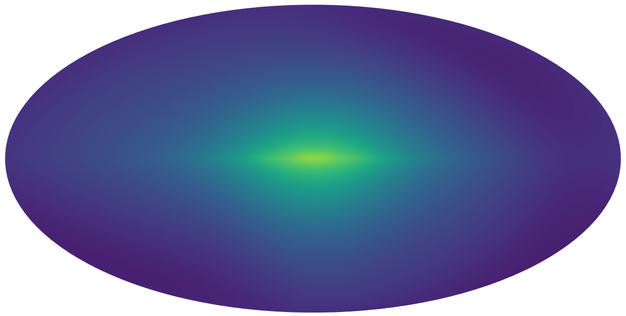
Galactic foreground model

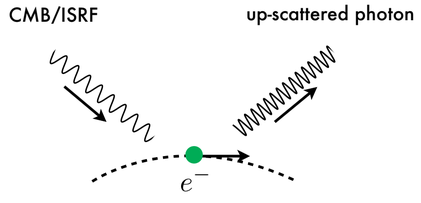


=

Inverse Compton

Traces electron source populations

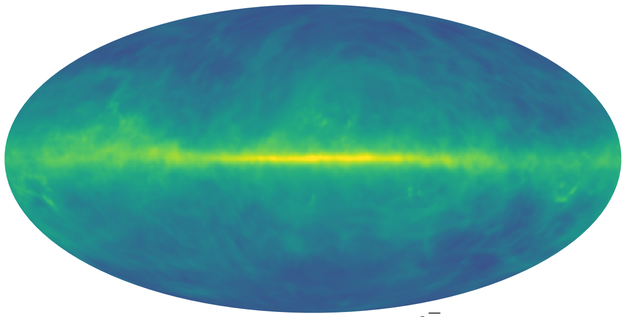


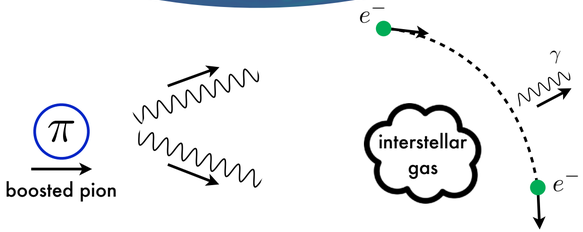


+

π^0 + Bremsstrahlung

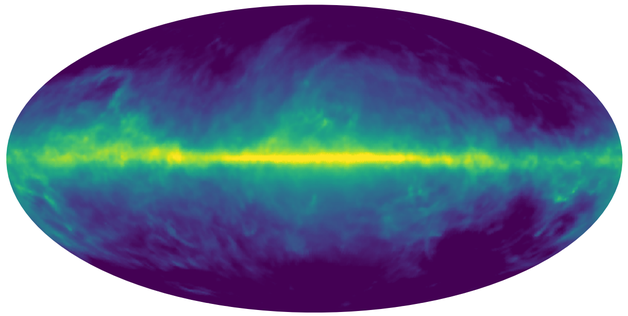
Traces gas/dust distribution





Modeling Galactic foregrounds

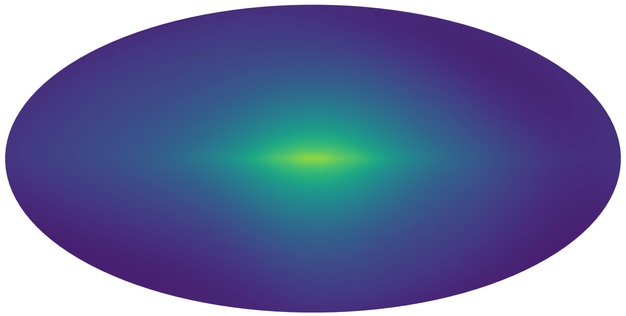
Galactic foreground model

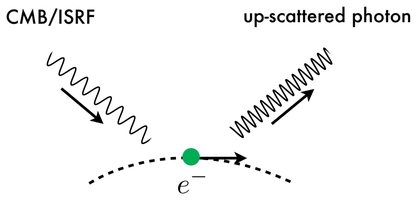


=

Inverse Compton

Traces electron source populations

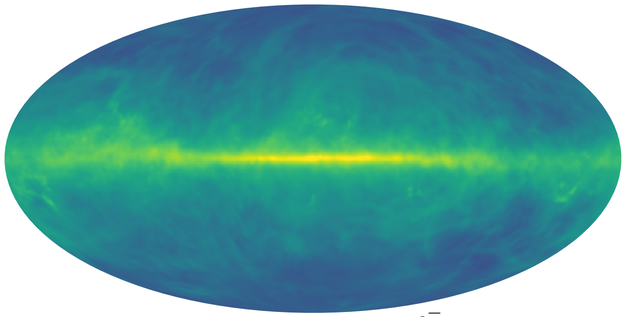


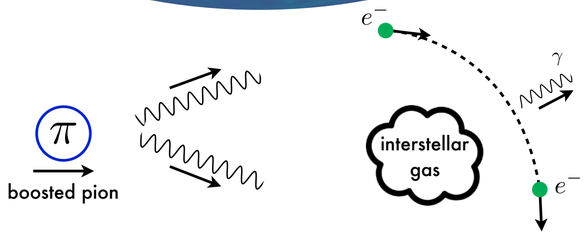


+

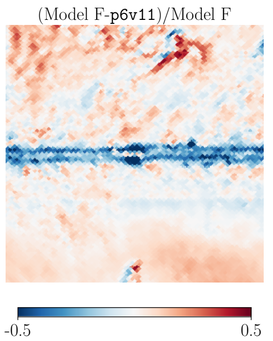
π^0 + Bremsstrahlung

Traces gas/dust distribution





How well can we model foregrounds?



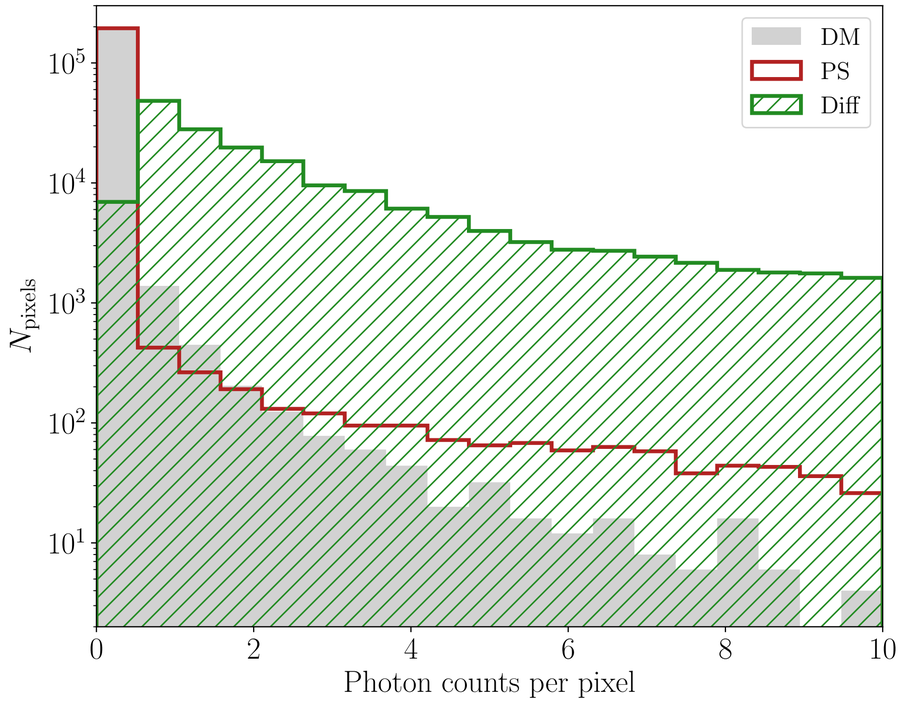
Not very well.

Key question

Given the

1. Degeneracy between dim PSs and dark matter, and
2. Imperfect knowledge of Galactic diffuse foregrounds

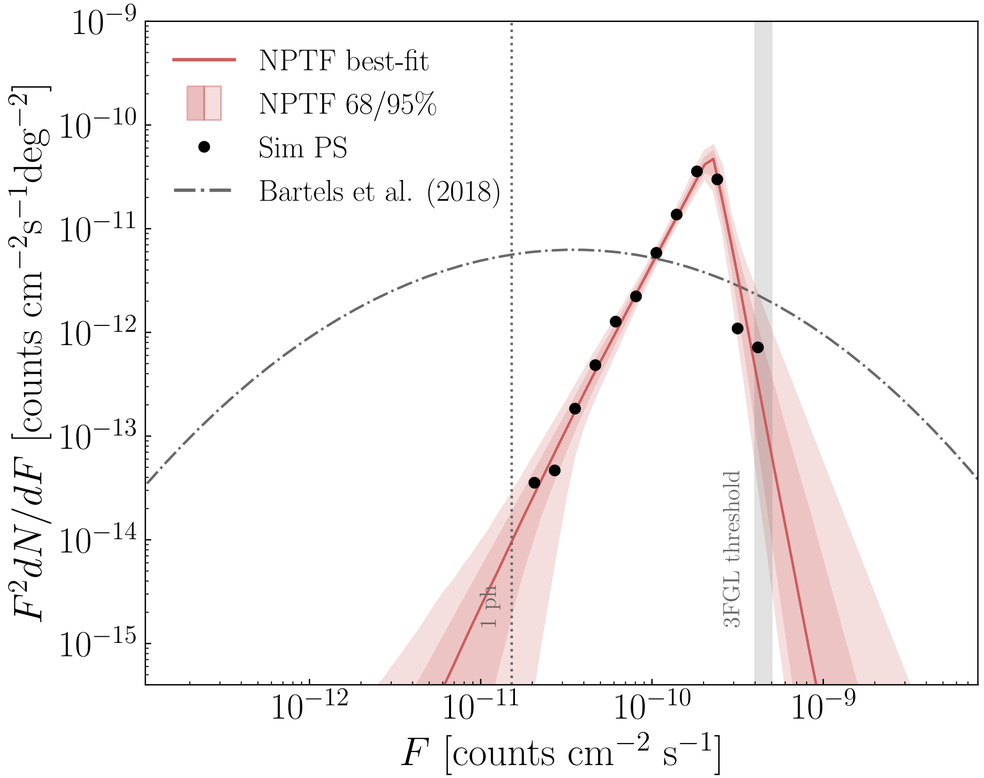
How well can we recover evidence of a sub-threshold PS population?

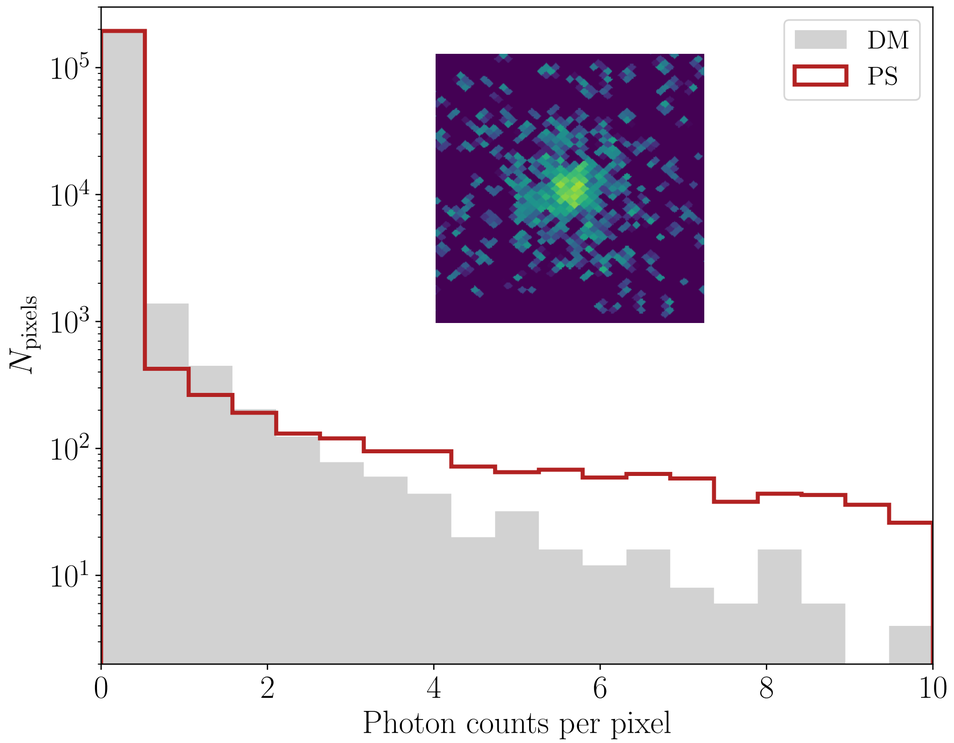


Explore this question with simulations

Consider two "extreme" PS flux distributions

"Hard" flux distribution, most PSs just below detection threshold

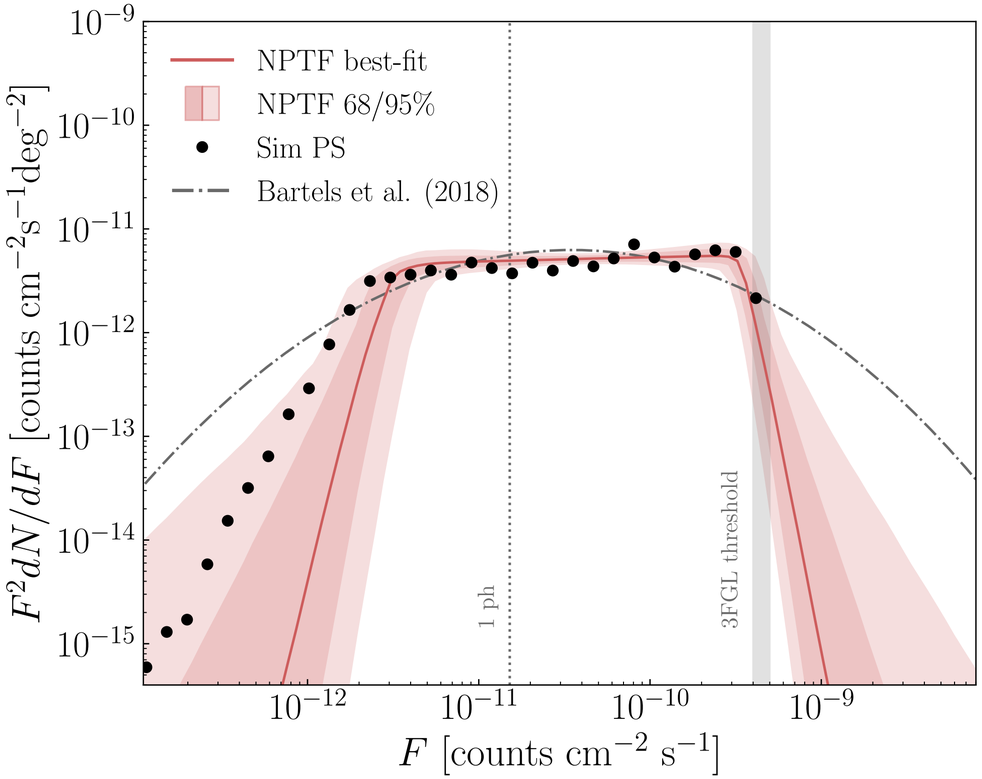


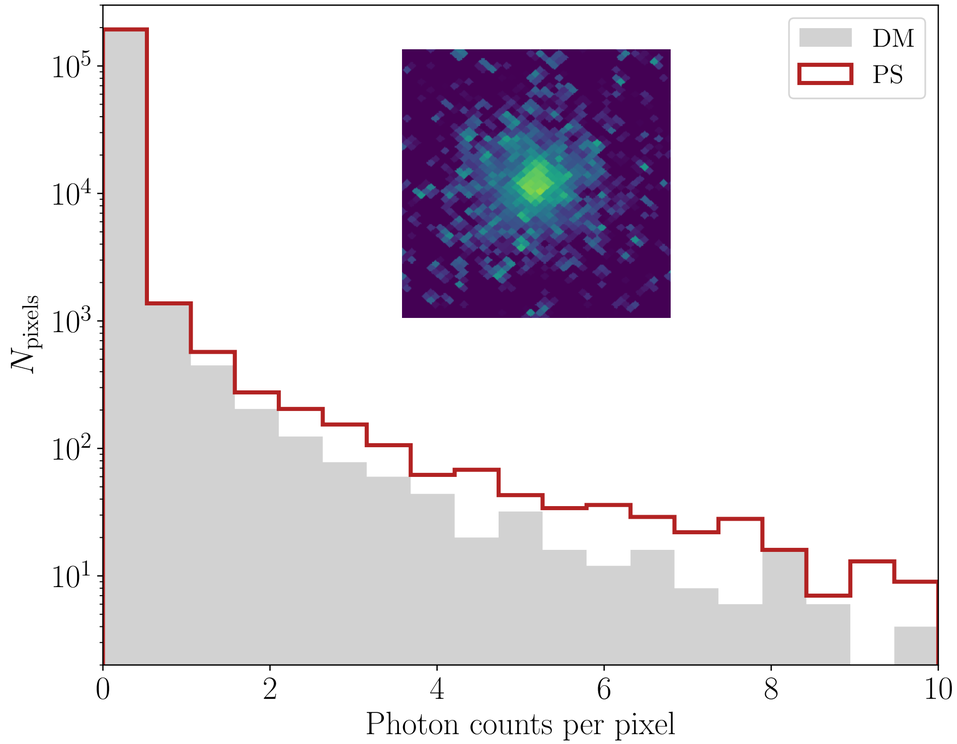


Representative of distribution inferred in *Lee et al (2015)*

Consider two "extreme" PS flux distributions

"Soft" flux distribution, larger number of dim PSs

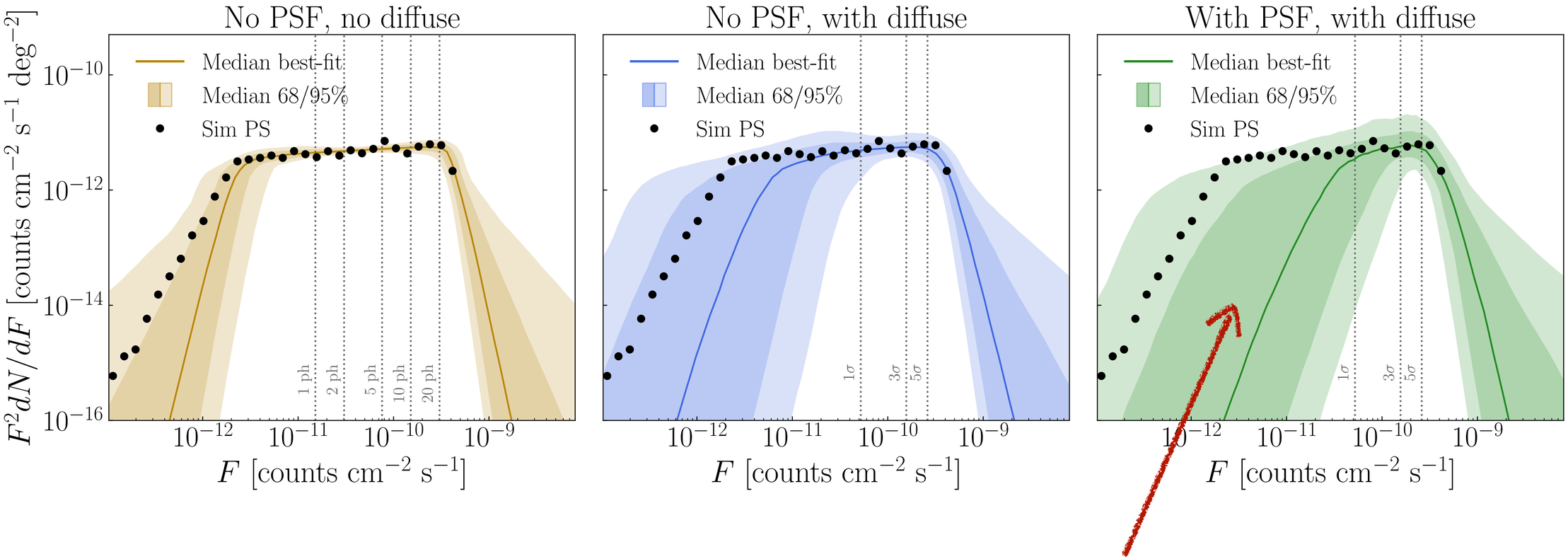




Representative of expectations for MSP flux. *Use as benchmark.*

Point source recovery: adding more knobs

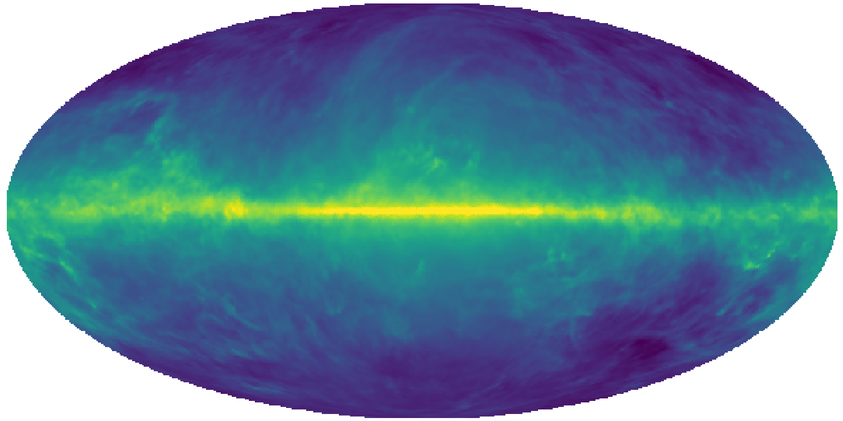
Just PSs *Add PSF* *Add diffuse*



Sub-1σ point sources cannot be reliably characterized

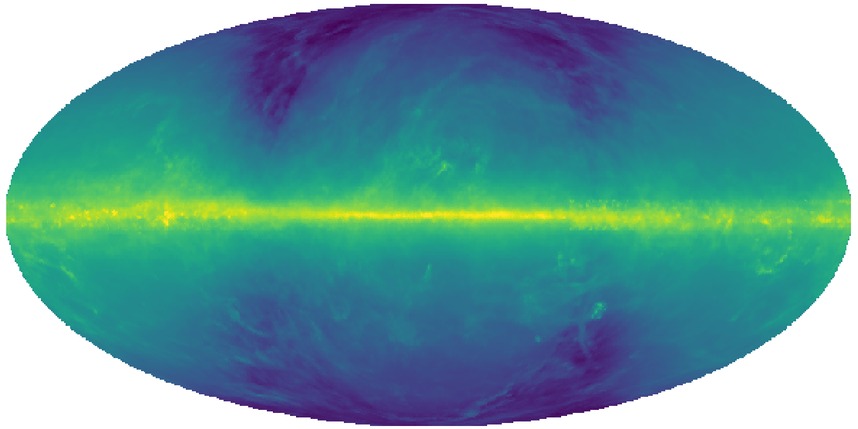
Testing the effect of foreground mismodeling

Create simulation (including PS or DM) with one diffuse model



`p6v11`

Run NPTF pipeline with different diffuse model



Model F

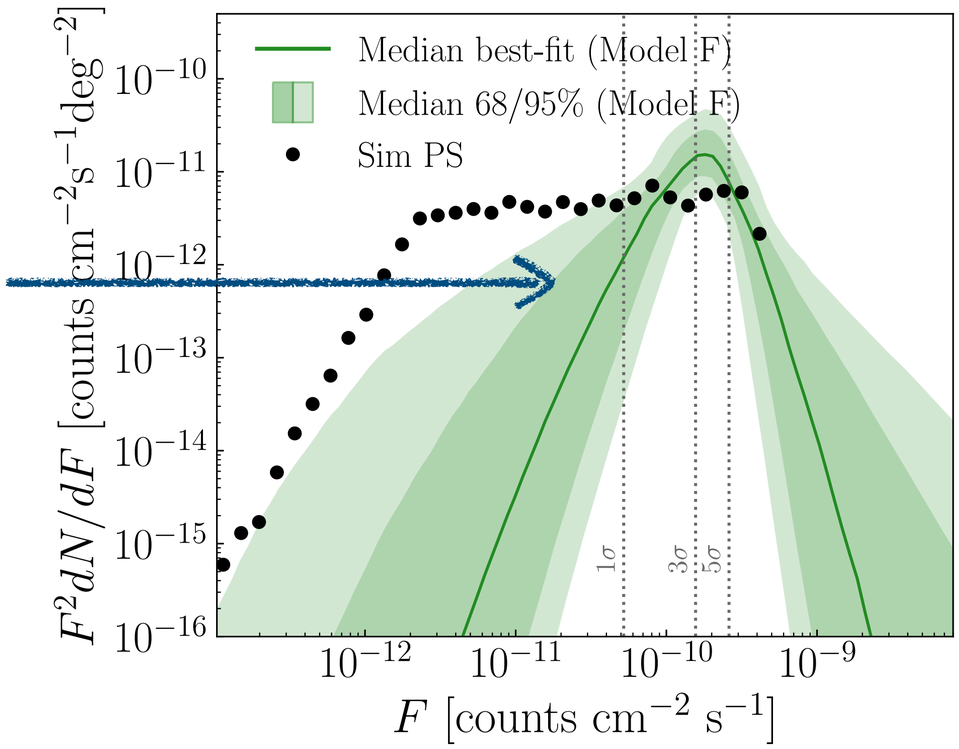
Explore whether significance of PS hypothesis consistent with truth

PS recovery with foreground mismodeling

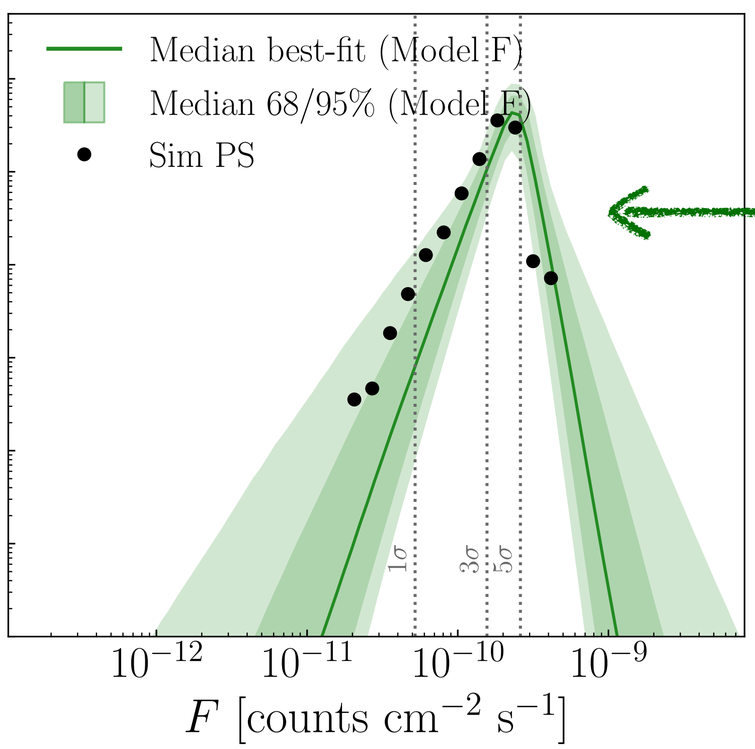
Recovered PS distribution shows deviations from truth

Similar to distribution seen in real data.

"Soft" flux distribution



"Hard" flux distribution

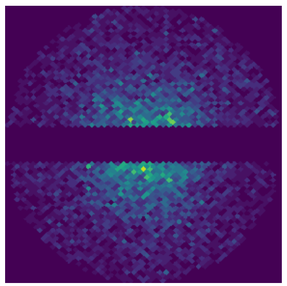


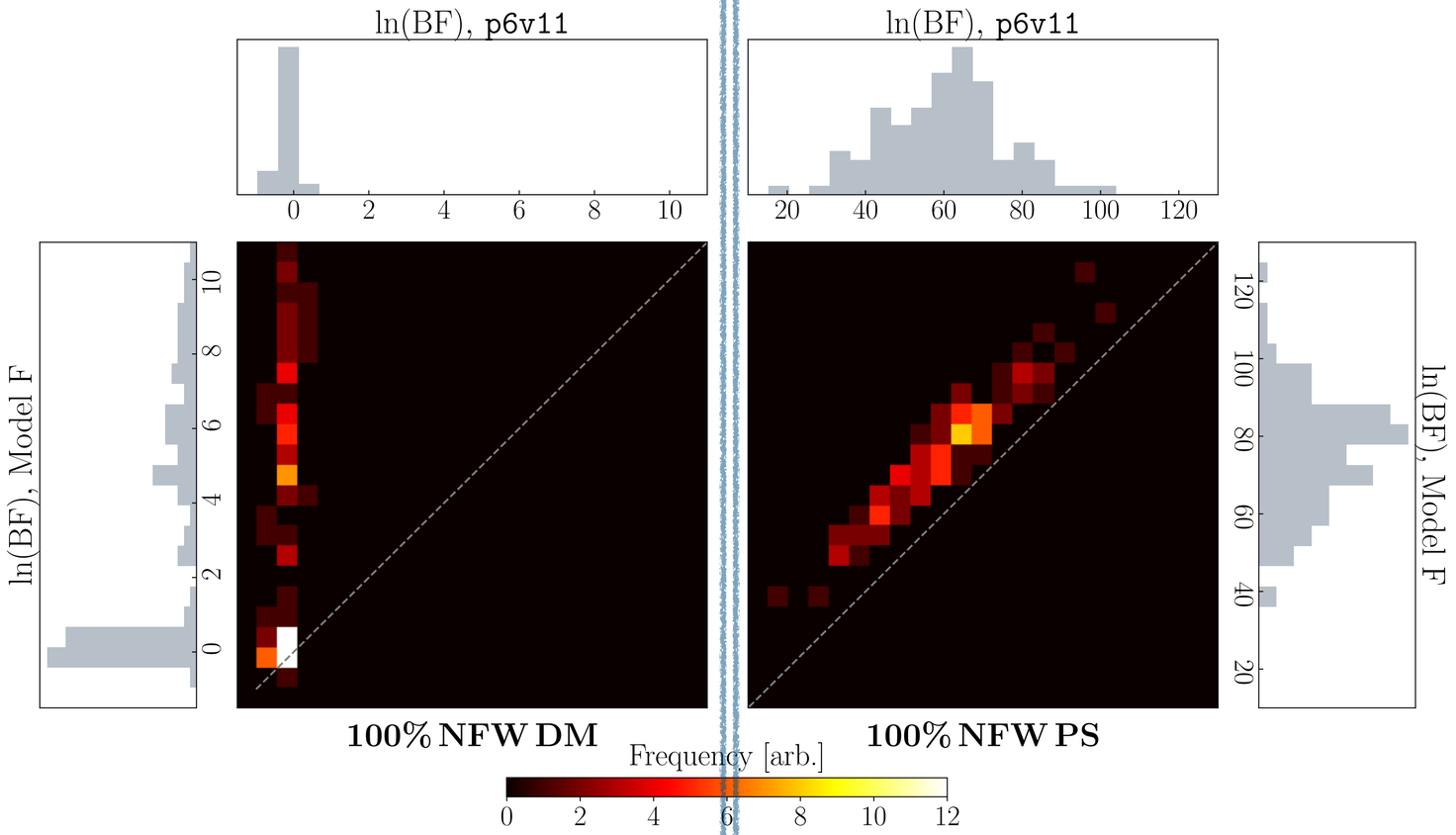
PSs well-characterized even with foreground mismodeling

Suggestive of diffuse mismodeling effects in real data

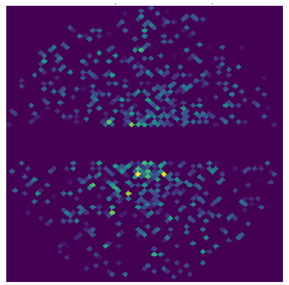
Testing the PS hypothesis

Simulate GCE with DM





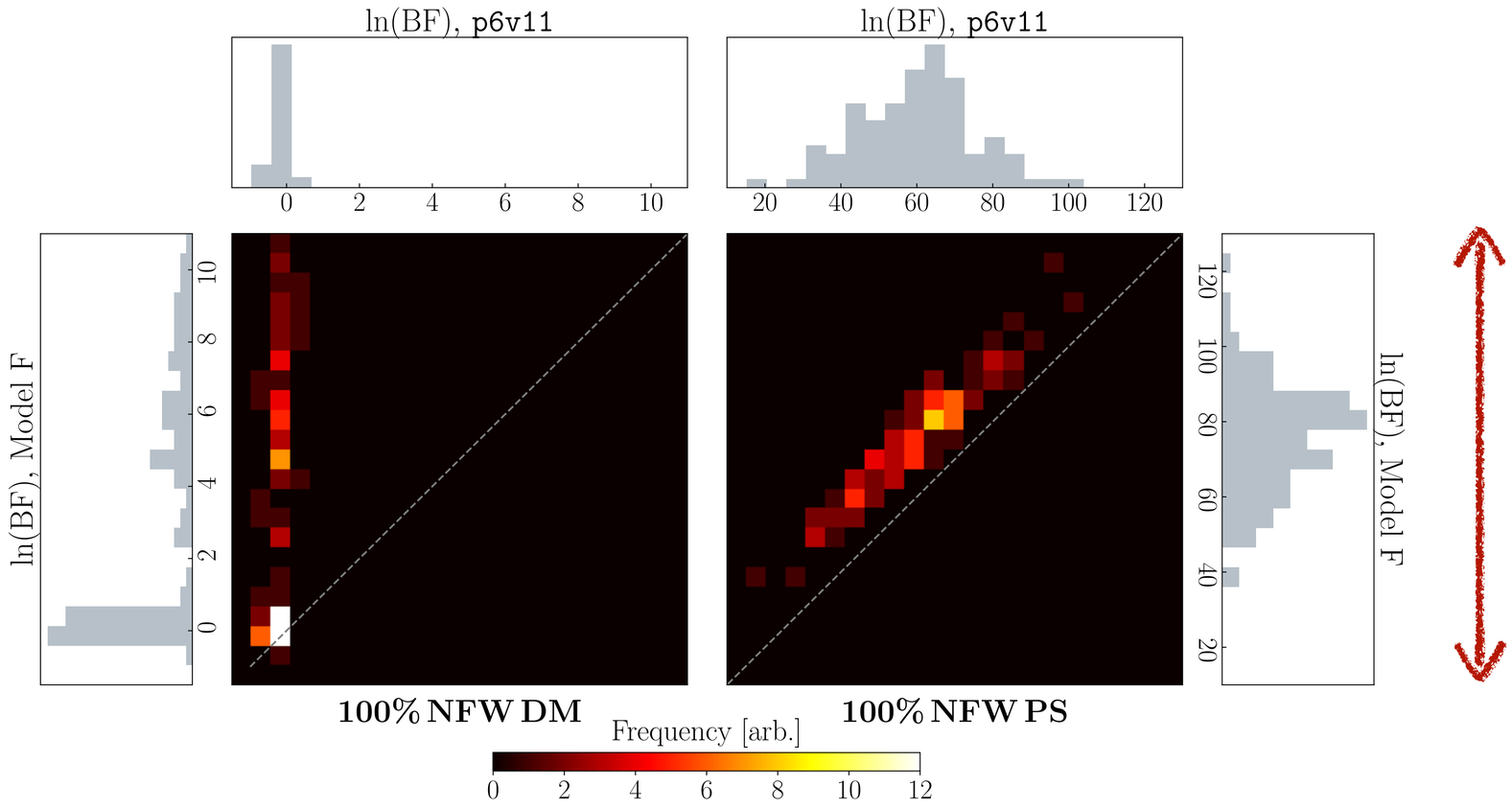
Simulate GCE with PS



Testing the PS hypothesis

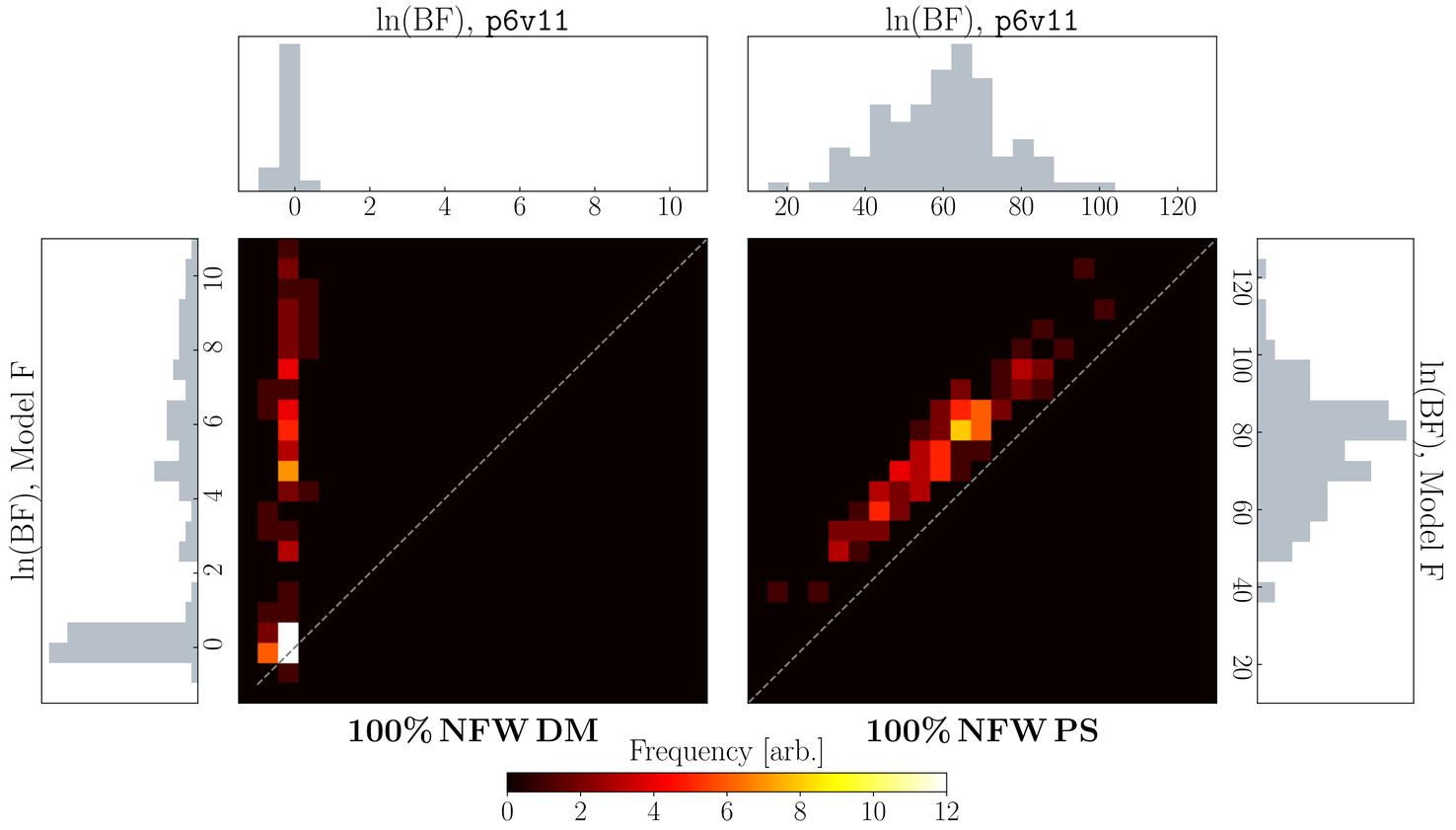
Using truth diffuse model

Using incorrect diffuse model



Testing the PS hypothesis

High-variance residuals can lead to spurious evidence for PSs

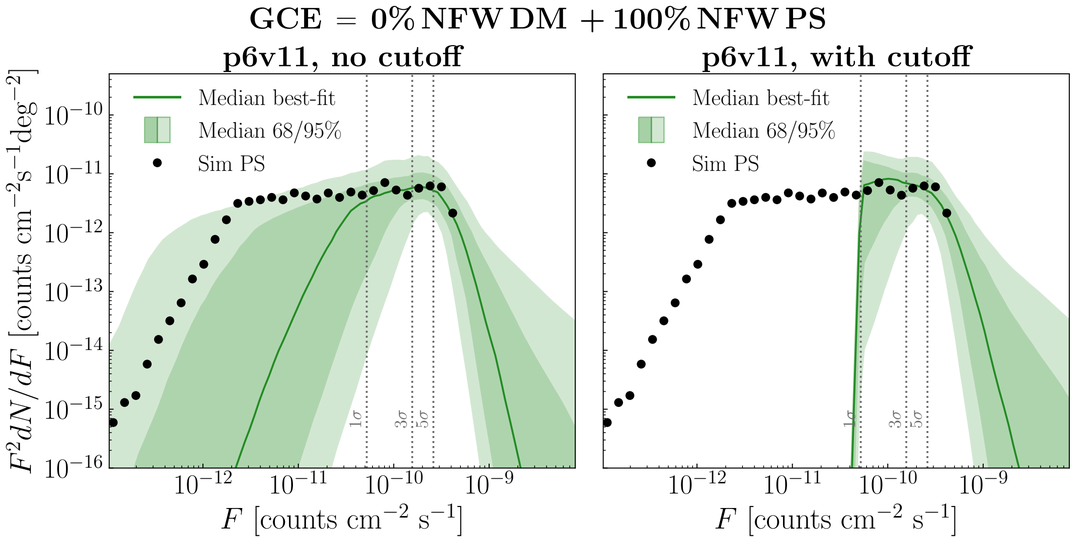


Evidence for PSs generally robust when they are present

Key takeaways

Degeneracy between dim PSs and dark matter can bias inference

One solution: *cut off flux distribution below 1-σ PS detection threshold*

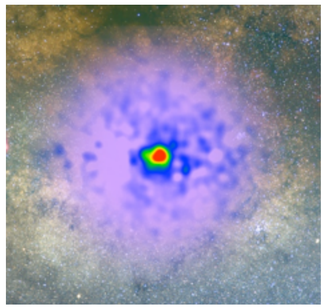


Mismodeling of Galactic diffuse foregrounds can lead to spurious point sources

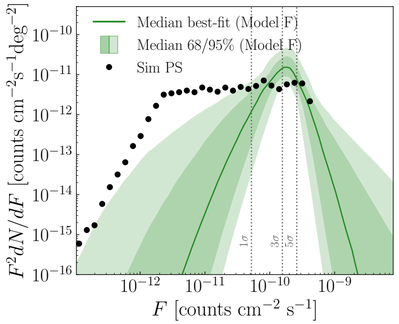
Much harder problem!

Next: possibilities for mitigating diffuse mismodeling

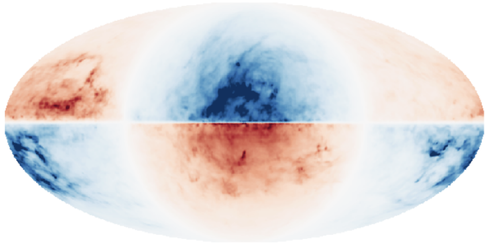
Outline



Galactic Center Excess: Background and Methods

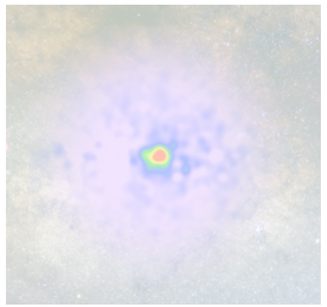


Diffuse mismodeling and lessons from simulation

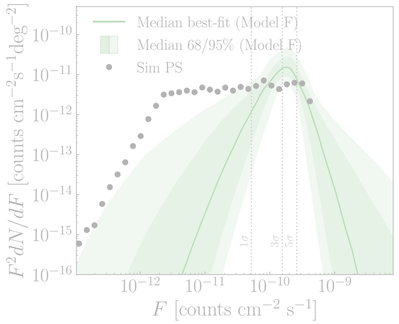


Towards mitigating diffuse mismodeling

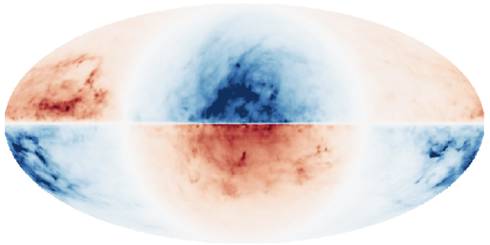
Outline



Galactic Center Excess: Background and Methods



Diffuse mismodeling and lessons from simulation



Towards mitigating diffuse mismodeling

Epistemic classification

Inspired by Josh Ruderman and Don Rumsfeld

Known knowns *Things we know we know*	***Unknown knowns*** *Things we think we know but we don't know*
Known unknowns *Things we know we don't know*	***Unknown unknowns*** *Things we don't know we don't know*

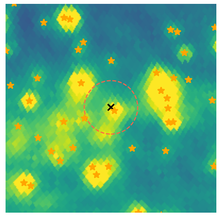
Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Inspired by Josh Ruderman and Don Rumsfeld

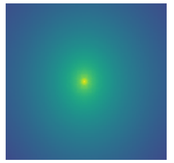
Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*



Unknown knowns

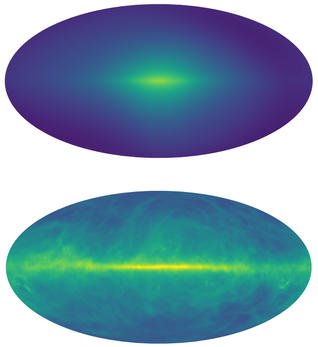
- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*



Known unknowns

Galactic diffuse emission

- *On large scales*
- *On small scales*



Unknown unknowns

Unknown point source populations

?

Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Inspired by Josh Ruderman and Don Rumsfeld

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

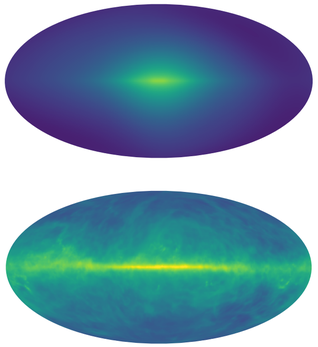
Unknown knowns

- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*

Known unknowns

Galactic diffuse emission

- *On large scales*
- *On small scales*



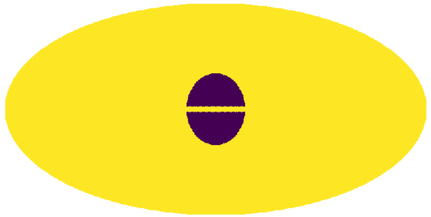
Unknown unknowns

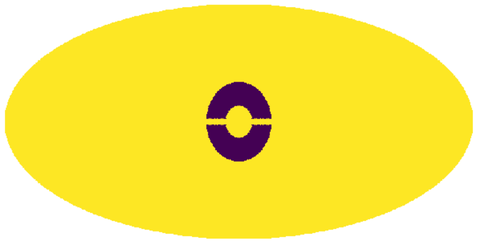
Unknown point source populations

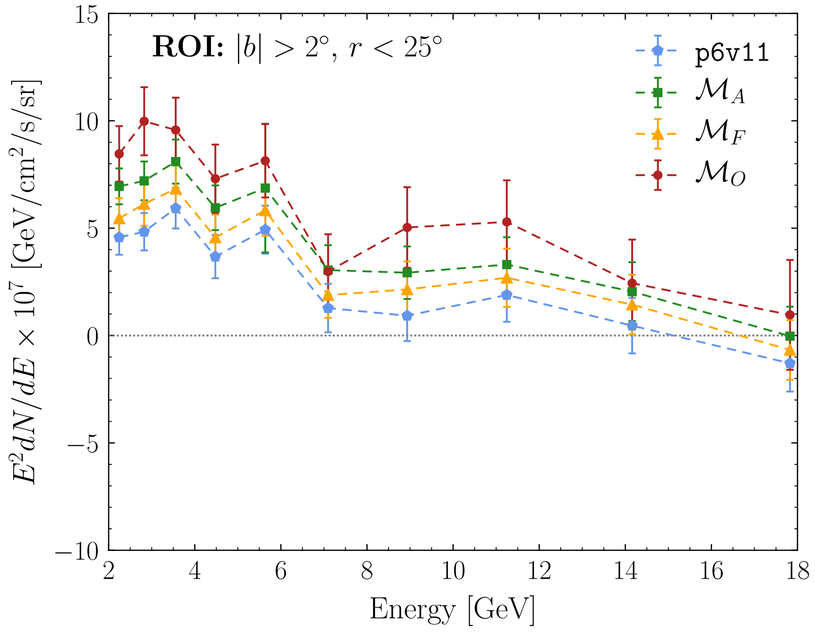
?

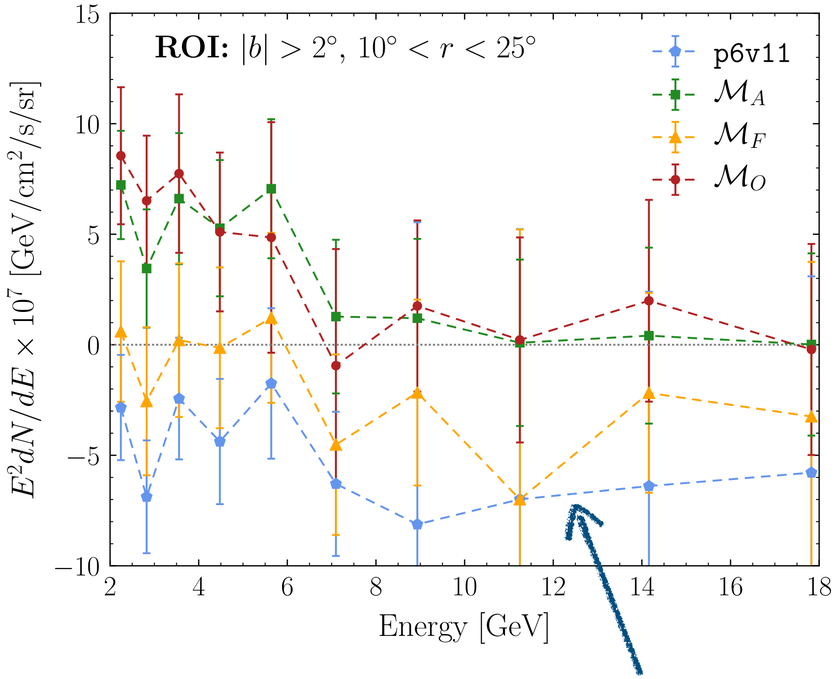
Some diffuse models are better than others

A Poissonian example: the GCE spectrum









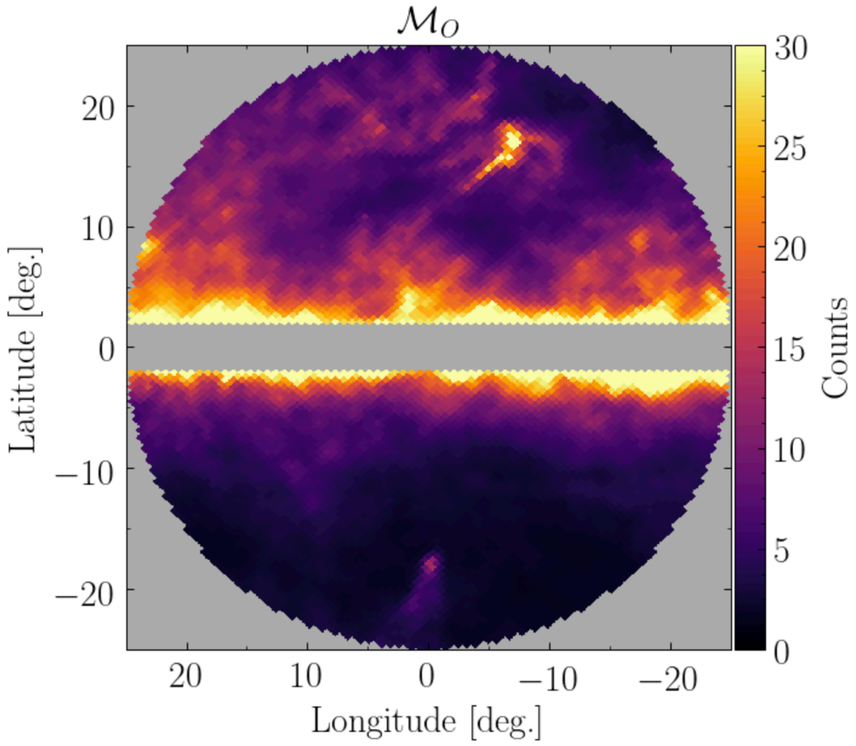
Oversubtraction evident in some diffuse models

p6v11 *model widely used in previous studies*

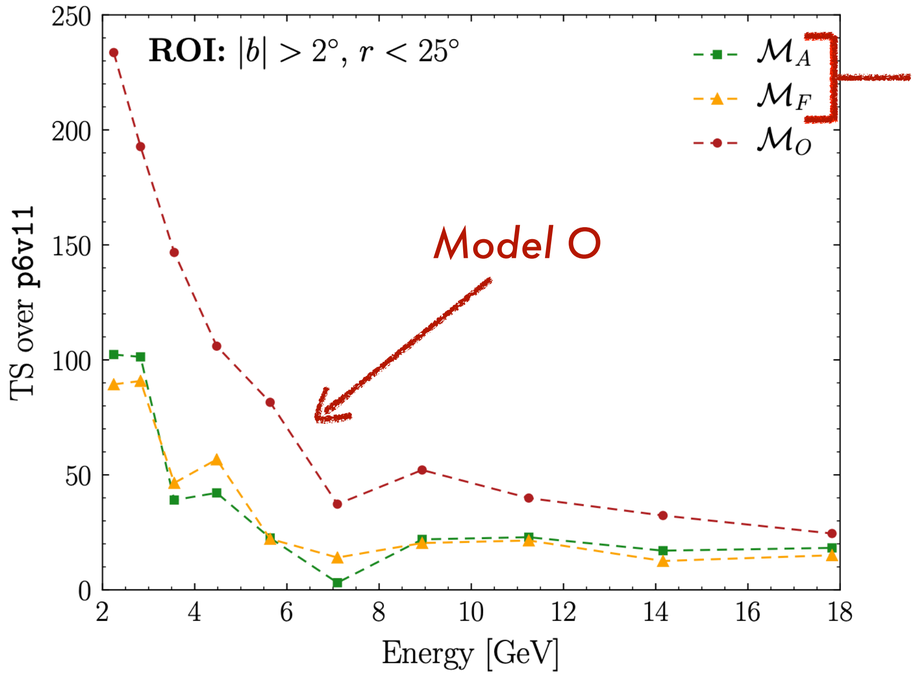
Towards a better diffuse model

Oscar Macias

Diffuse "Model O"



TS improvement over previous models



Models previous considered in Lee et al (2015) and Leane & Slatyer (2019)

- *Updated gas tracers*
- *3D radiation field for IC*
- *Components fit in several Galactocentric rings*

Available at https://github.com/nickrodd/FermiDiffuse-ModelO

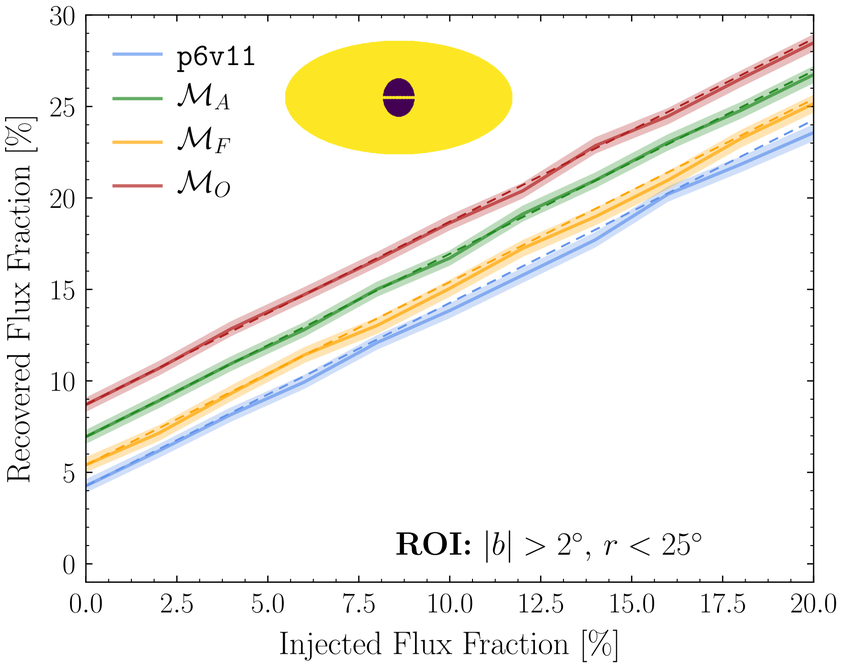
Macias et al [1901.03822]
Macias et al [1611.06644]

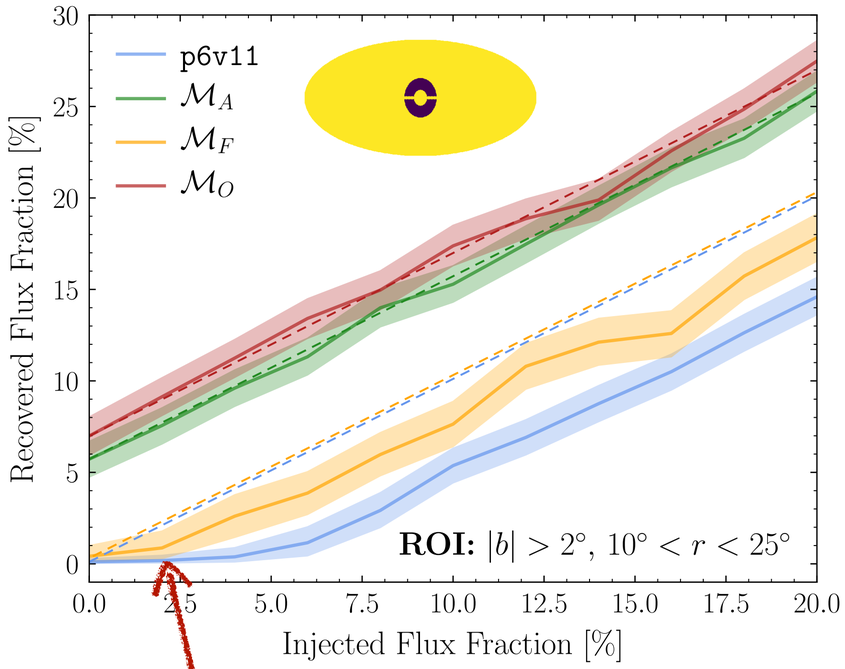
Some diffuse models are better than others

A Poissonian example: signal injection on data

A different way of seeing the same thing: injected DM onto the data and try to recover it

GCE flux inconsistent among models



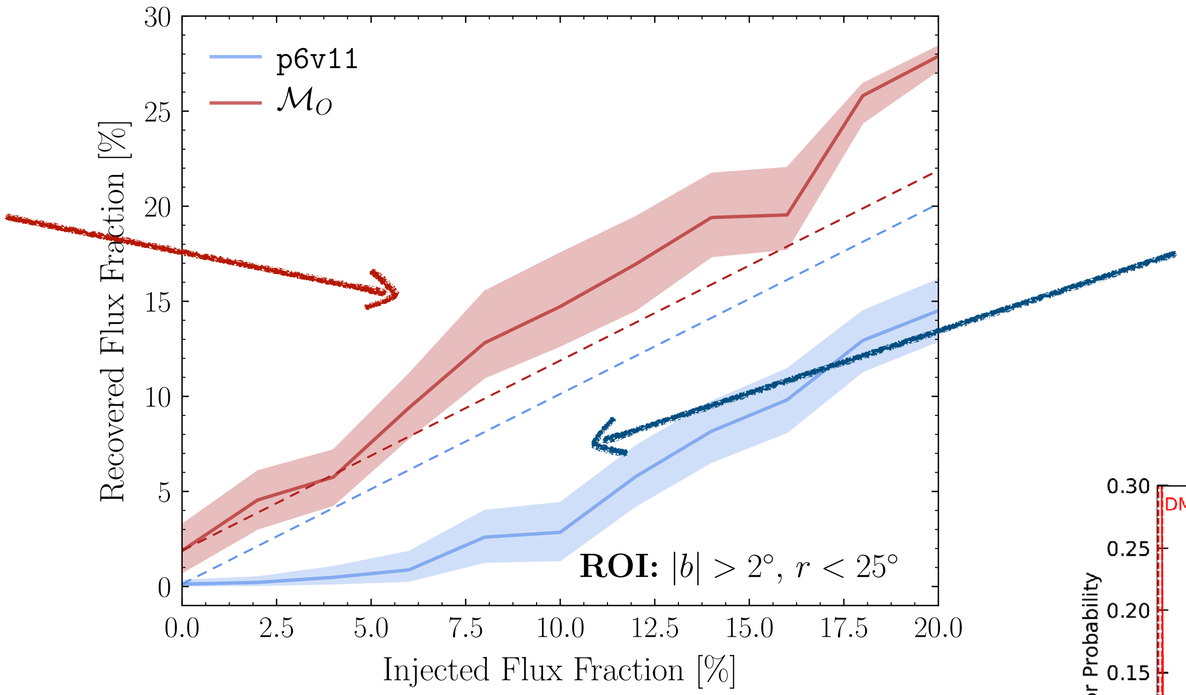


Oversubtraction evident in some diffuse models

Some diffuse models are better than others

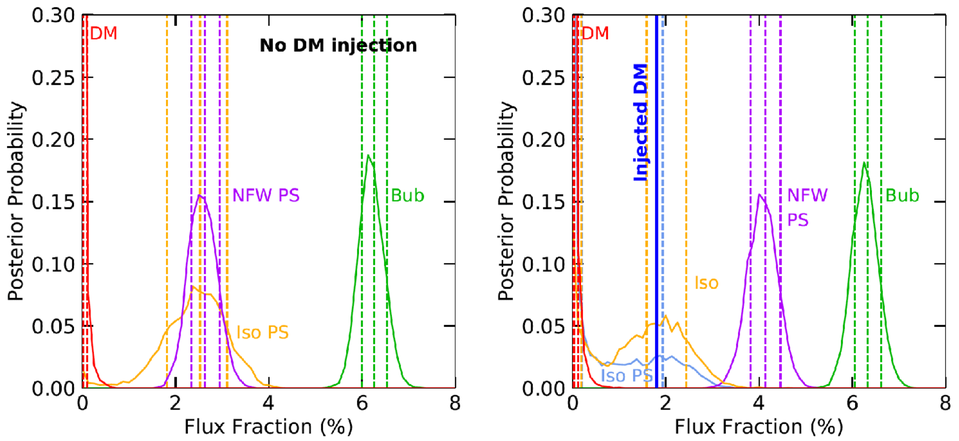
A non-Poissonian example: signal injection on data

Signal injection better-behaved when using diffuse Model O



Large oversubtraction observed for the `p6v11` diffuse model, as pointed out by Leane & Slatyer

Injected DM signal cannot be reliably recovered



Leane & Slatyer [1904.08430]

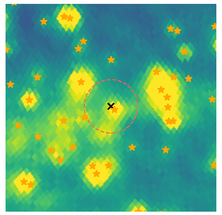
Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Inspired by Josh Ruderman and Don Rumsfeld

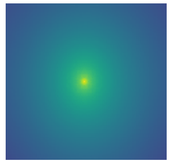
Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*



Unknown knowns

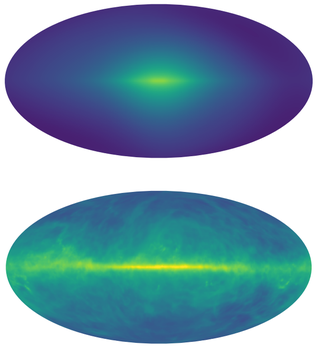
- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*



Known unknowns

Galactic diffuse emission

- *On large scales*
- *On small scales*



Unknown unknowns

Unknown point source populations

?

Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Inspired by Josh Ruderman and Don Rumsfeld

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

Unknown knowns

- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*

Known unknowns

Galactic diffuse emission

- *On large scales*
- *On small scales*

Unknown unknowns

Unknown point source populations

?

Mitigating diffuse mismodeling

Giving the background model more freedom

Less freedom ⟷ *More freedom*

Less conservative

More information about signal

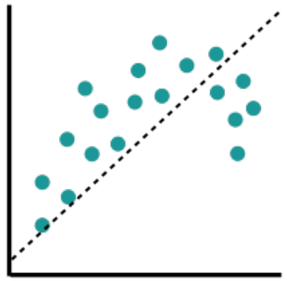
Contingent on background model

More conservative

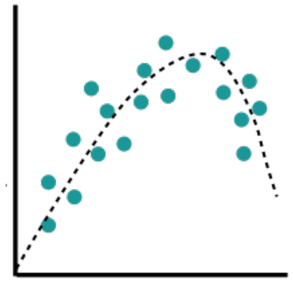
Less extractable information about signal

"Background model-independent"

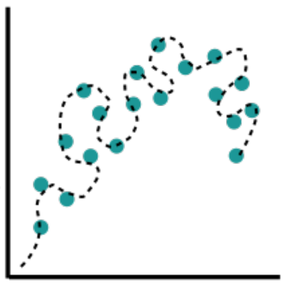
Underfit



Balanced

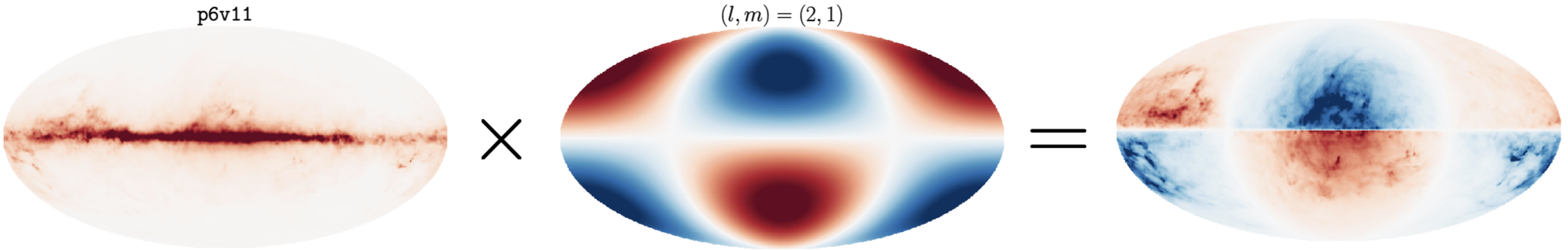


Overfit



(Large-scale) Harmonic marginalization

Extract large-scale harmonic components of diffuse model



$$T_p^{\rm harm} \propto \hat{A}_{\rm diff} T_p^{\rm diff} + \sum_{\ell,m} \hat{A}_{\ell,m} Y_p^{\ell,m} T_p^{\rm diff}$$

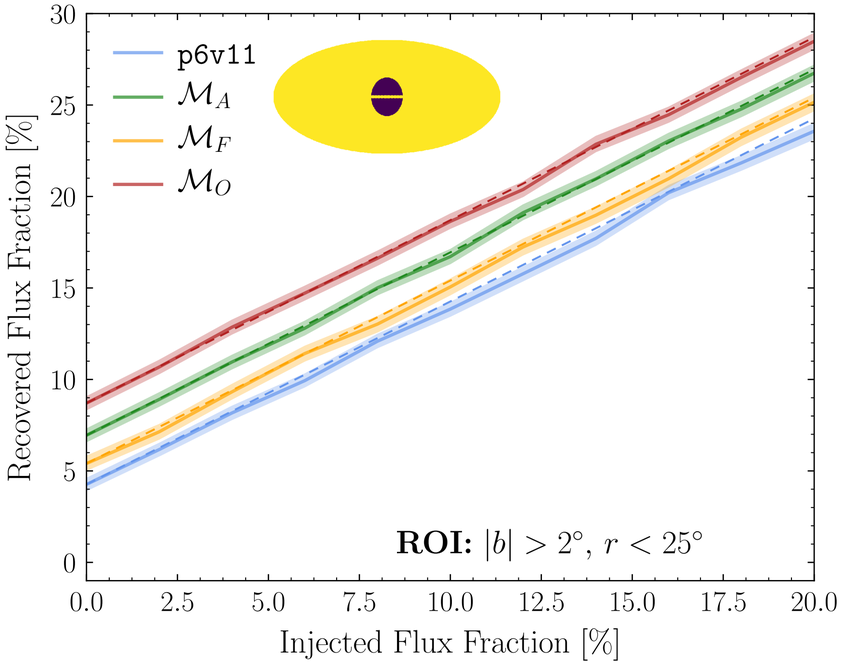
Base model *Modulation of large scales*

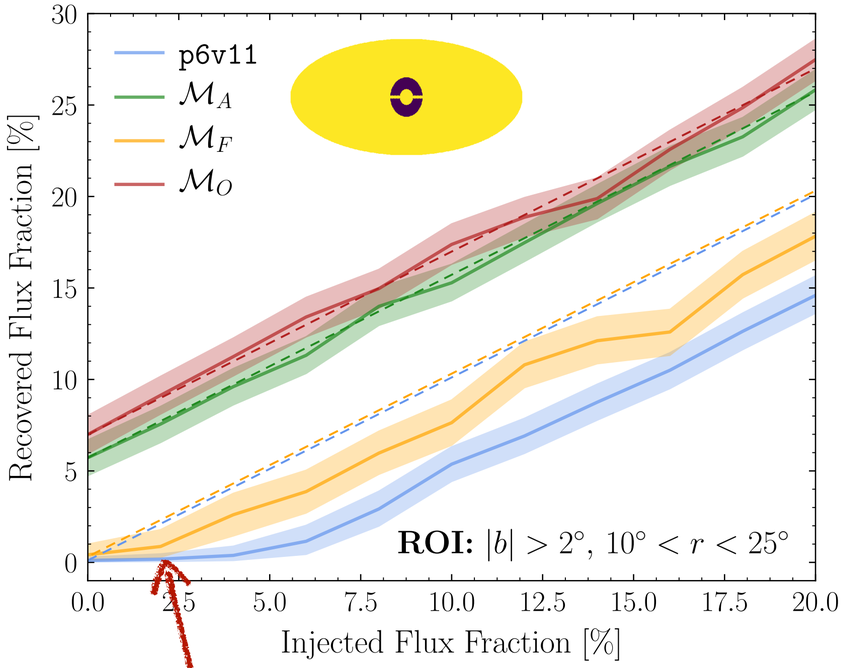
Give each large-scale component an independent degree of freedom

Coming back to signal injection...

Poissonian example

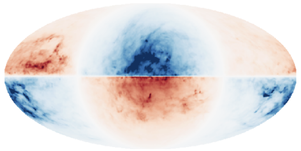
GCE flux inconsistent among models

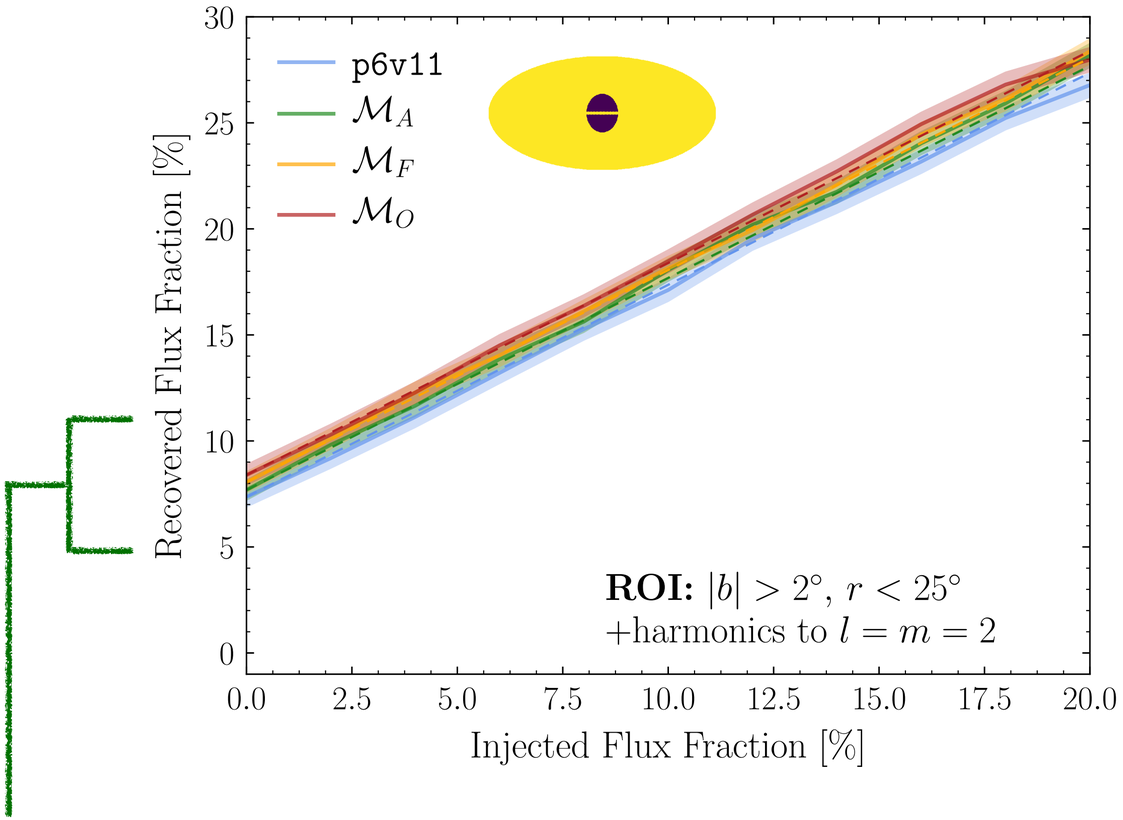


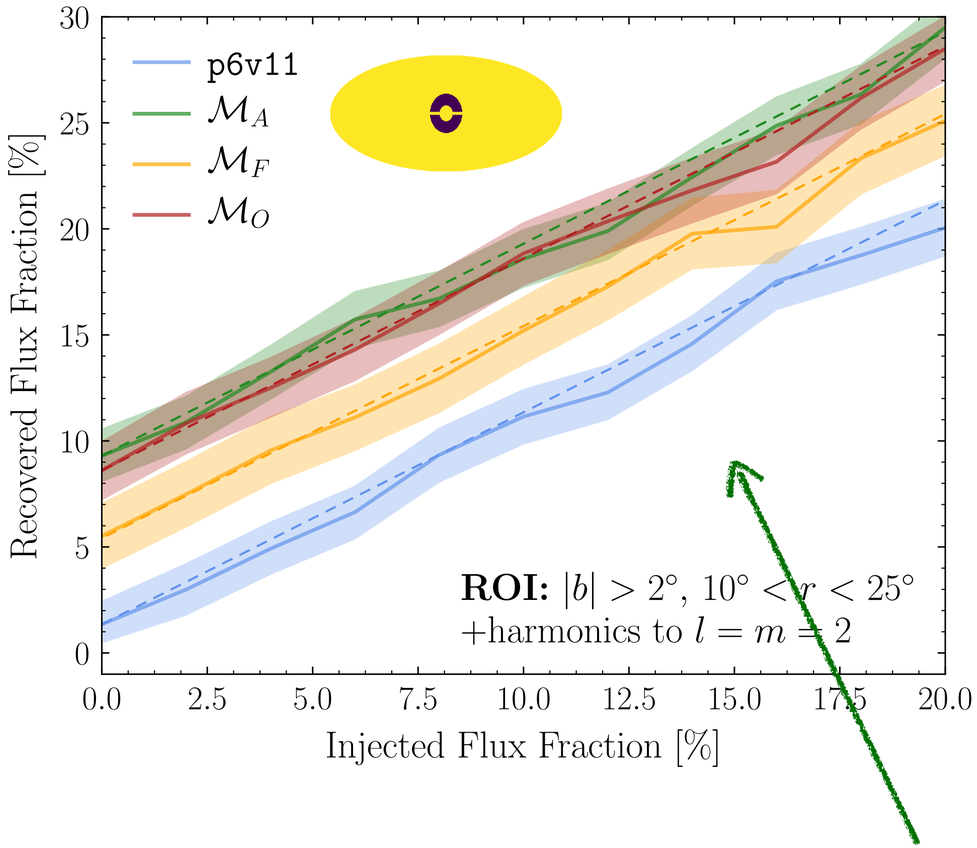


Oversubtraction evident in some diffuse models

Does Harmonic marginalization help?







Consistency between different diffuse models

Successful signal recovery

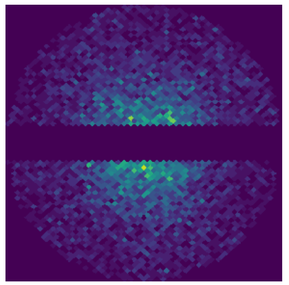
Harmonic marginalization for NPTF

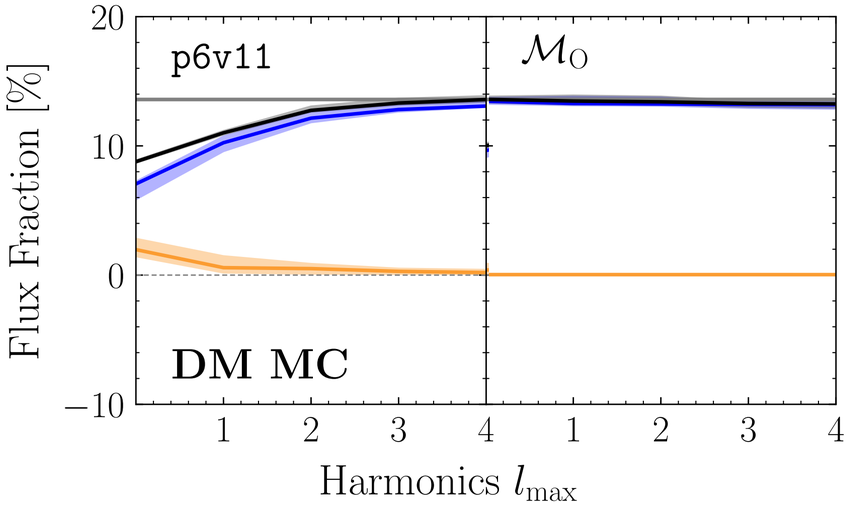
Test with simulations

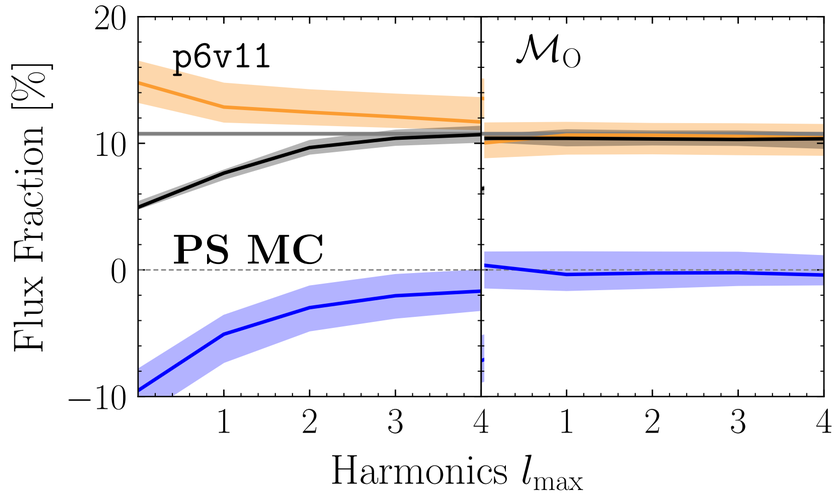
As before,
1. Create simulation with one foreground model (Model O)
2. Analyze with a different diffuse model (p6v11)

DM
PS
Sum
MC truth

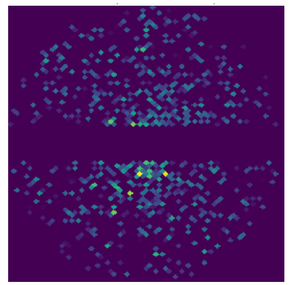
Simulate GCE with DM



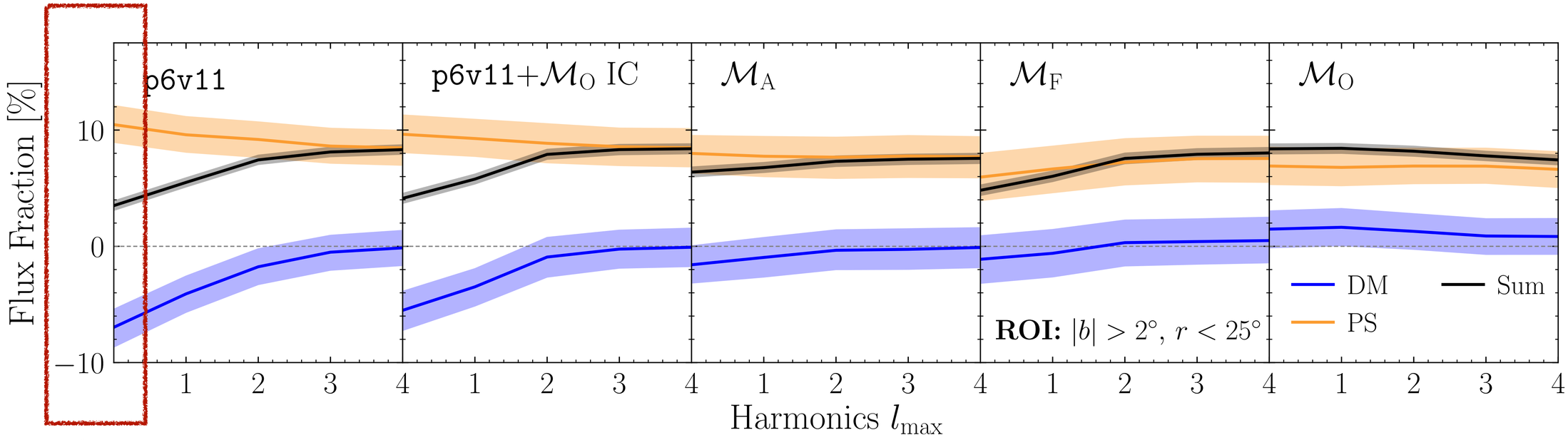




Simulate GCE with PS

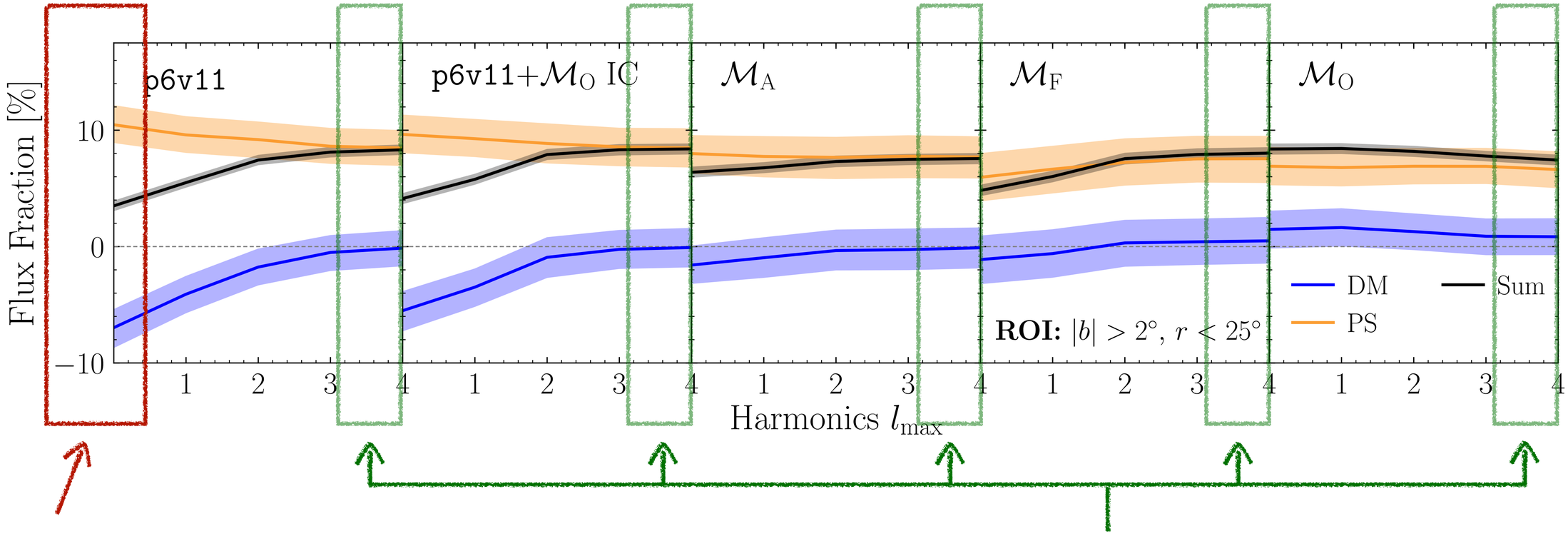


Harmonic marginalization on data



Oversubtraction effect pointed out by Leane & Slatyer

Harmonic marginalization on data

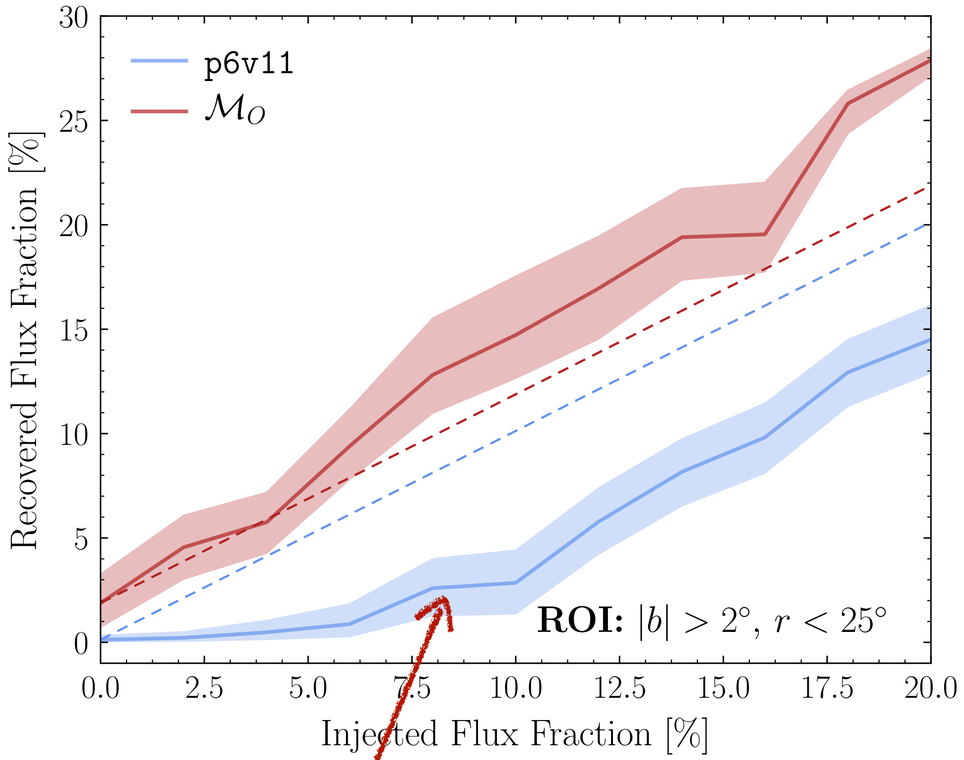


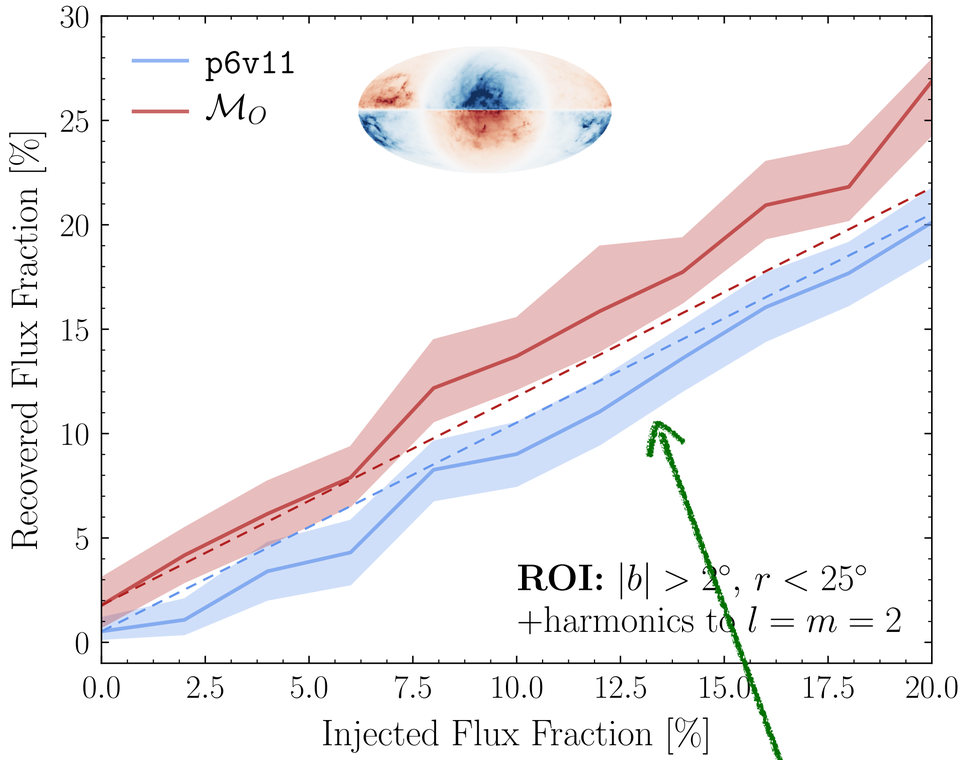
Oversubtraction effect pointed out by Leane & Slatyer

PS/DM inference consistent between diffuse models

Recovered flux fraction consistent with zero

Coming back to signal injection on data...

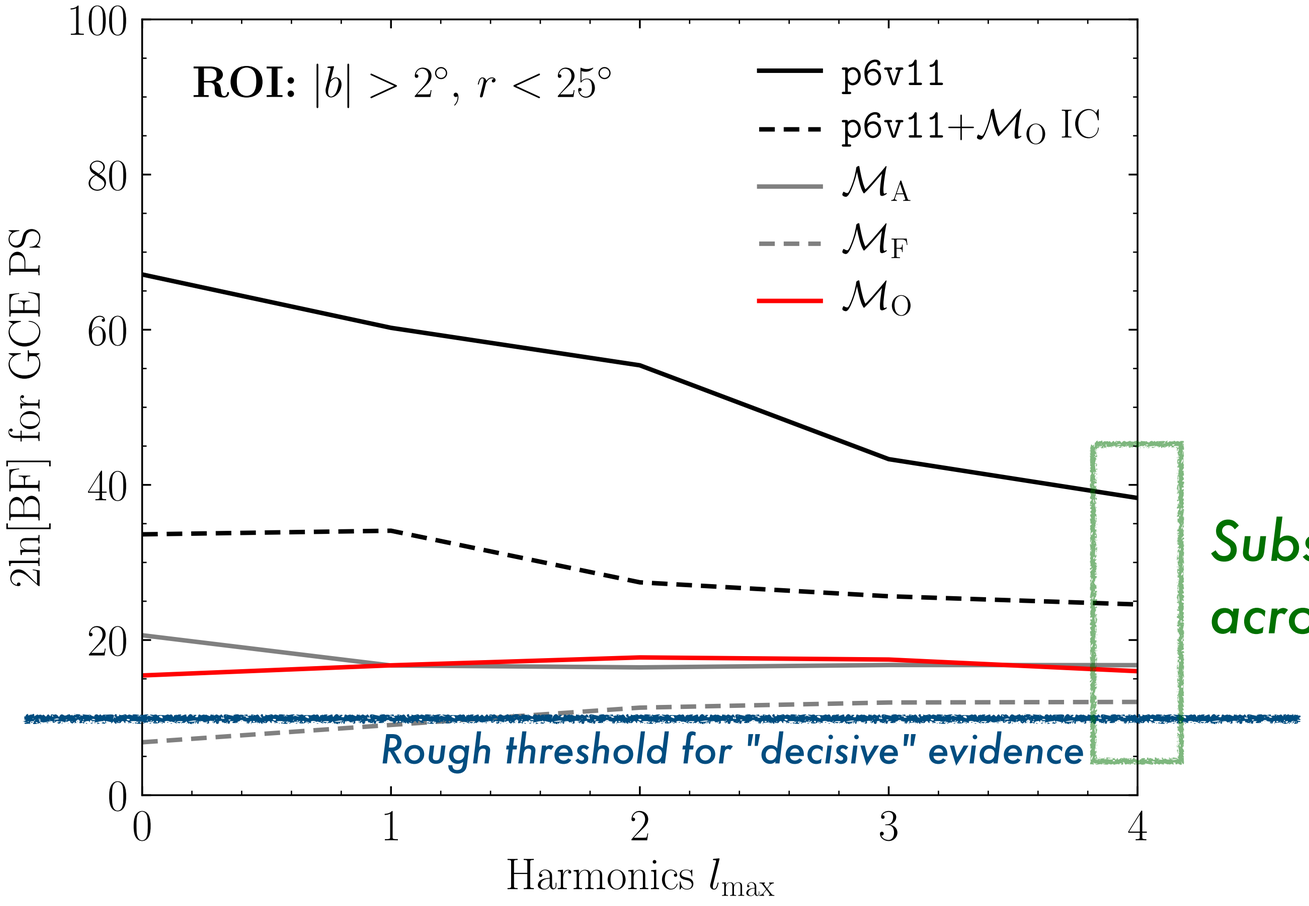




Failure to recover injected signal

Improved behavior of signal injection closure test

Is there a preference for PSs in the data?



Substantial evidence for PS-like emission across diffuse models considered

Some caveats and future prospects

Epistemic classification of GCE systematics

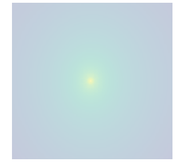
(With a focus on the NPTF. Not comprehensive!)

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

Unknown knowns

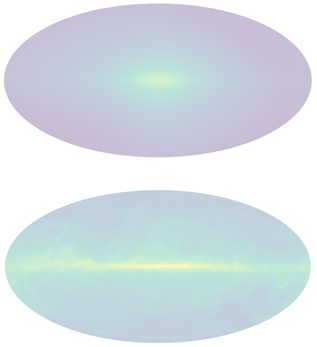
- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*



Known unknowns

Galactic diffuse emission

- *On large scales*
- *On small scales*



Unknown unknowns

Unknown point source populations

?

Epistemic classification of GCE systematics

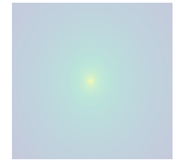
(With a focus on the NPTF. Not comprehensive!)

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

Unknown knowns

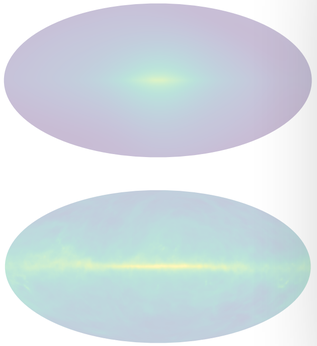
- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*



Known unknowns

Galactic diffuse emission

- *On large scales*
- *On small scales*



Bias due to unmodeled PS populations explored in Leane & Slatyer (2019)

But no evidence for such a population in the data

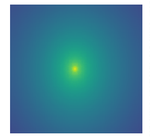
Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

Unknown knowns

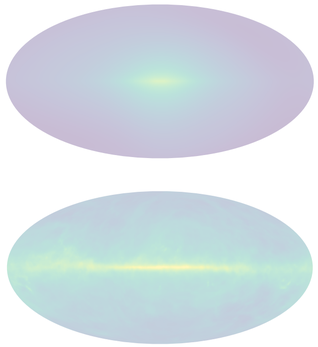


- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*

Known unknowns

Galactic diffuse emission

- *On large scales*
- *On small scales*



Unknown unknowns

Unknown point source populations

?

Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

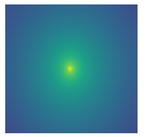
Known unknowns

Galactic diffuse emission

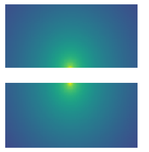
- *On large scales*
- *On small scales*

Unknown unknowns

Assumed NFW signal morphology



Giving signal more freedom (in North vs South) explored in Leane & Slatyer (2020)



?

Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

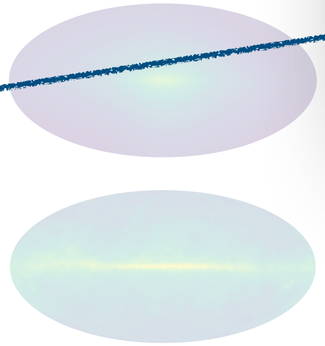
Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

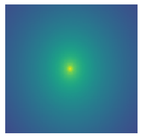
Known unknowns

Galactic diffuse emission

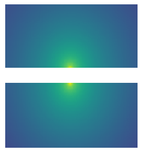
- *On large scales*
- *On small scales*



Assumed NFW signal morphology



Giving signal more freedom (in North vs South) explored in Leane & Slatyer (2020)



Large asymmetry may be further evidence for diffuse mismodeling

?

Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

Known unknowns

Galactic diffuse emission

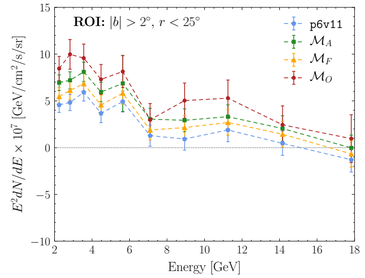
- *On large scales*
- *On small scales*

Possible ways to mitigate

- *Signal-template independent methods*

Reconstruct underlying PS distribution without assuming a template

- *Inclusion of energy binning information*



Work in progress by Buschmann, Rodd, Safdi

Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

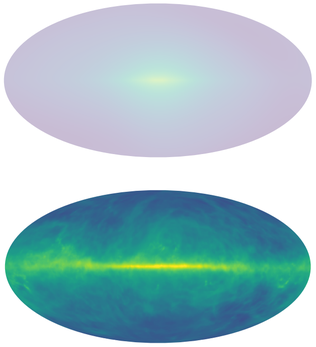
Unknown knowns

- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*

Known unknowns

Galactic diffuse emission

- *On large scales*
- *On small scales*



Unknown unknowns

Unknown point source populations

?

Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

Unknown knowns

- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*

NPTF agnostic to nature of PS-like emission

- *Millisecond pulsars*
- *Multiple PS populations*
- *Small-scale mismodeling of diffuse emission*

Not captured by harmonic marginalization

Unknown unknowns

Unknown point source populations

?

Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

Known knowns

- *Resolved point sources*
- *Detector response (PSF)*
- *Unresolved extragalactic PSs*

Unknown knowns

- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*

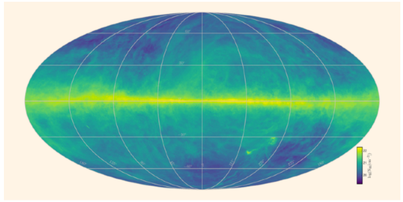
Unknown unknowns

Unknown point source populations

?

Possible ways to mitigate

- *Better/higher-resolution diffuse models*



HI4PI Collaboration

- *(Additional) Data-driven techniques for foreground modeling*

Epistemic classification of GCE systematics

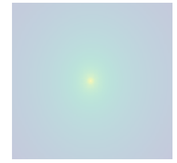
(With a focus on the NPTF. Not comprehensive!)

Known knowns

- Resolved point sources
- Detector response (PSF)
- Unresolved extragalactic PSs

Unknown knowns

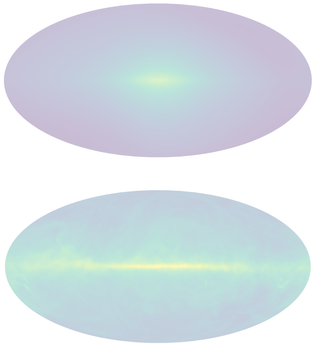
- The morphology of the excess
- Pixel-to-pixel correlations
- Spectral information



Known unknowns

Galactic diffuse emission

- On large scales
- On small scales



Unknown unknowns

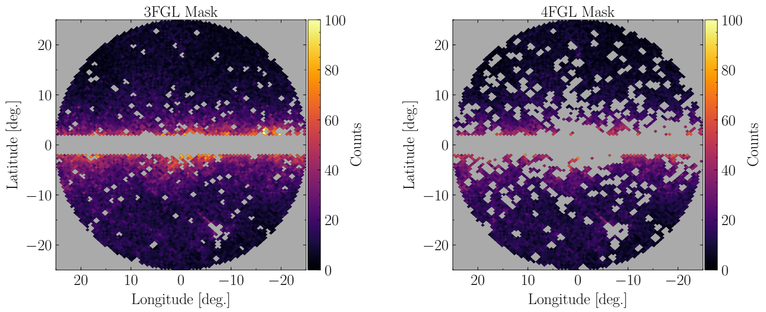
Unknown point source populations

?

Epistemic classification of GCE systematics

(With a focus on the NPTF. Not comprehensive!)

More recent PS catalogs



See GCE wavelets analysis by Zhong et al [1911.12369] using recent 4FGL PS mask

Unknown knowns

- *The morphology of the excess*
- *Pixel-to-pixel correlations*
- *Spectral information*

Known unknowns

Galactic diffuse emission

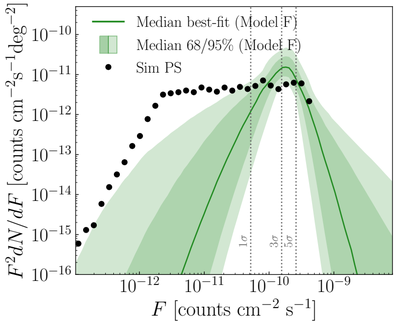
- *On large scales*
- *On small scales*

Unknown unknowns

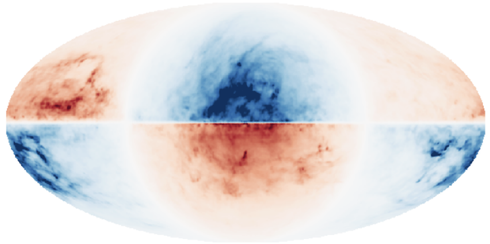
Unknown point source populations

?

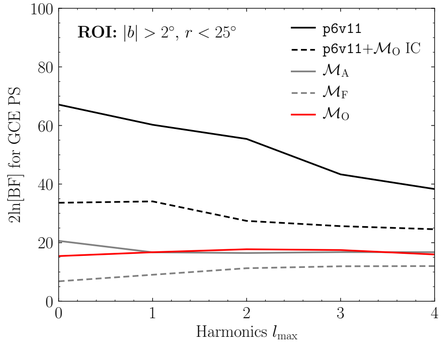
Summary



Degeneracy between dim PSs and smooth emission + diffuse mismodeling can lead to bias PS inference



Better Galactic diffuse models and/or additional diffuse degrees of freedom can mitigate diffuse mismodeling to a large extent



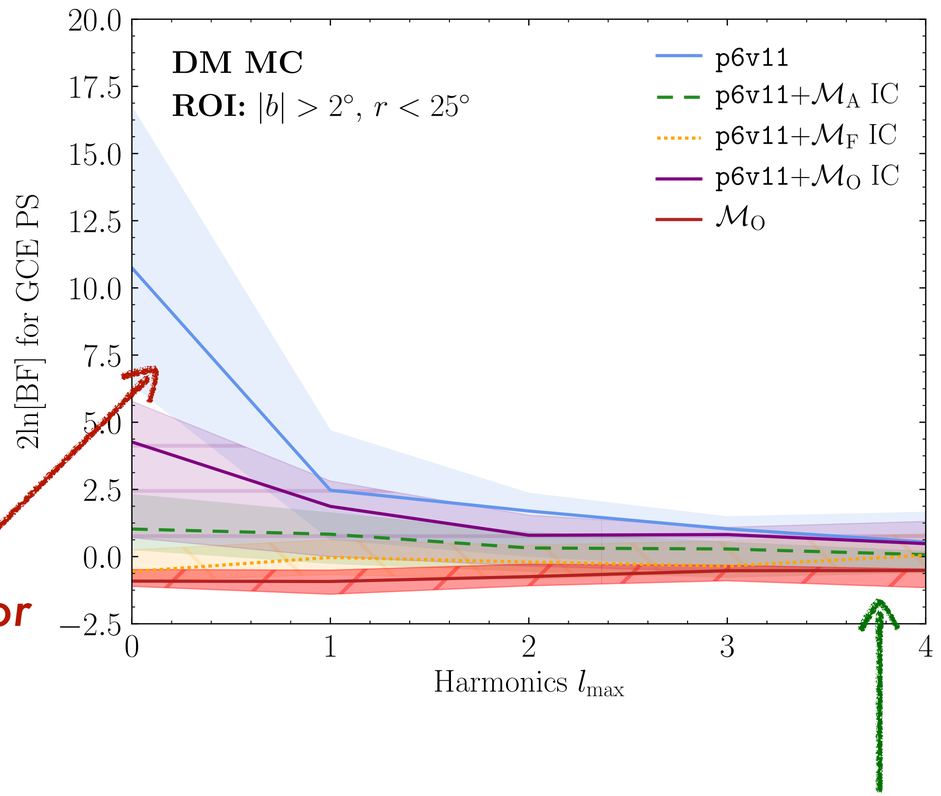
Evidence for PS-like structure in the data robust so far.

More work to be done!

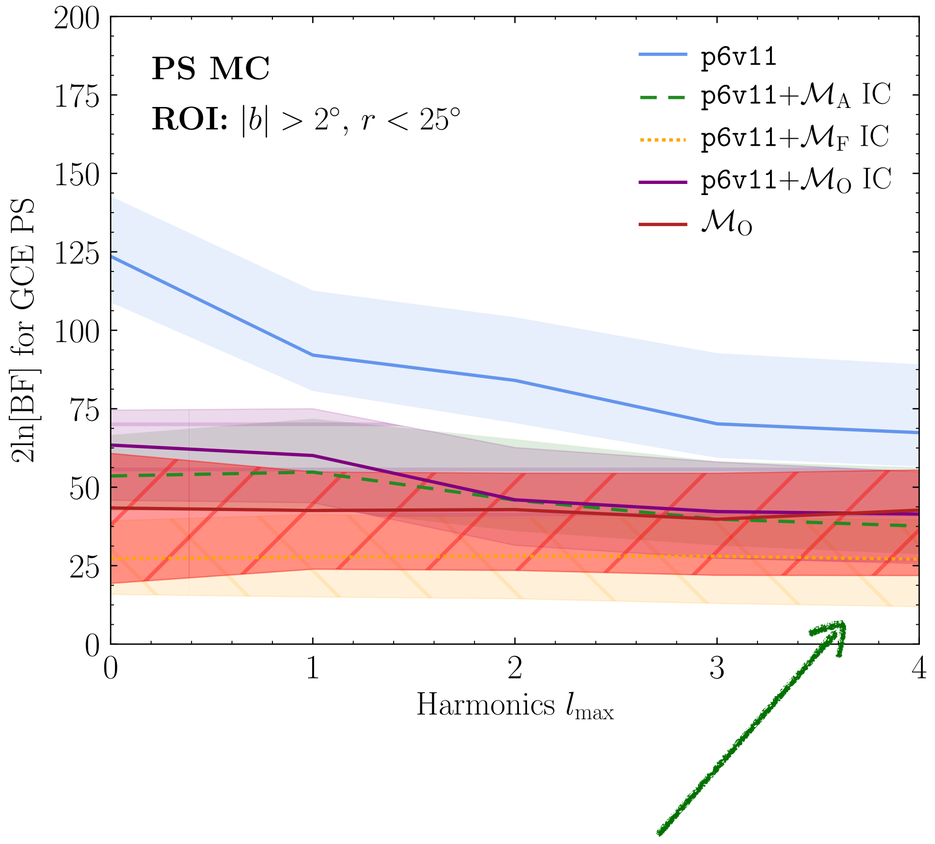
Additional slides

Significance of a PS signal

Test with simulations



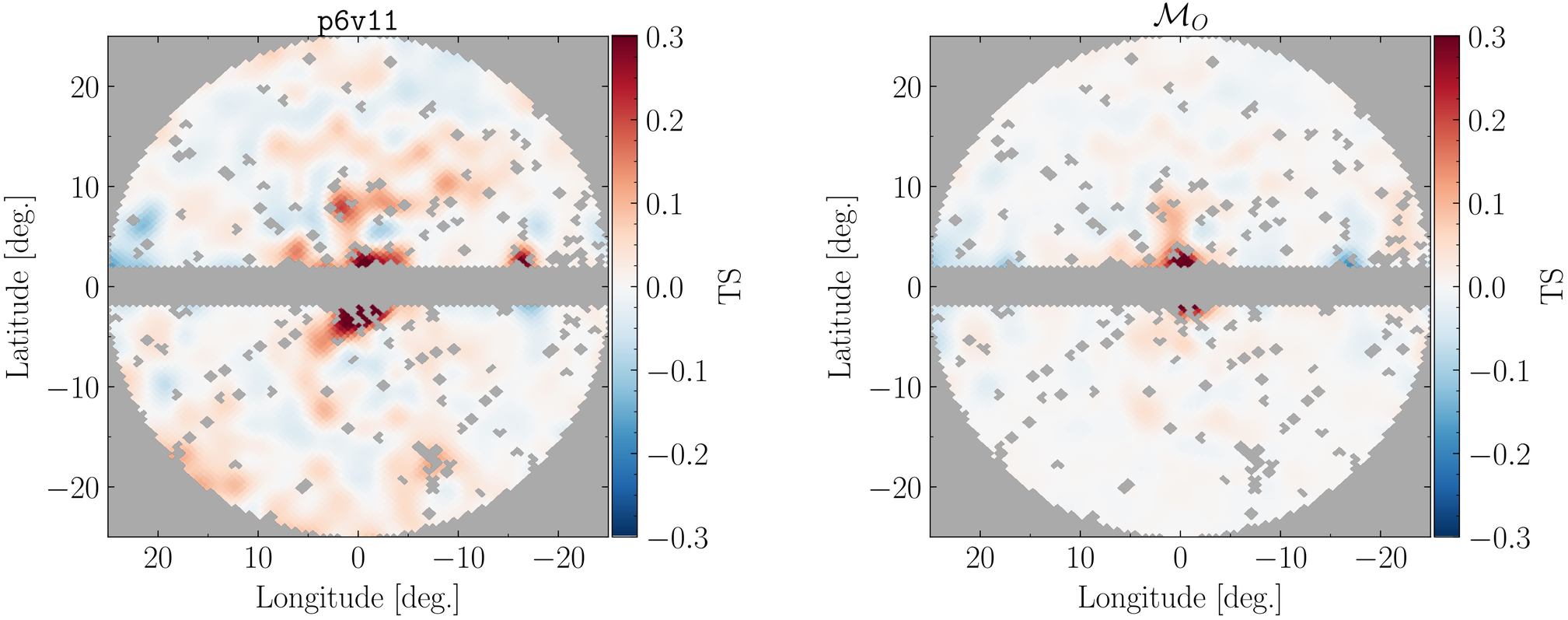
Spurious evidence for PSs



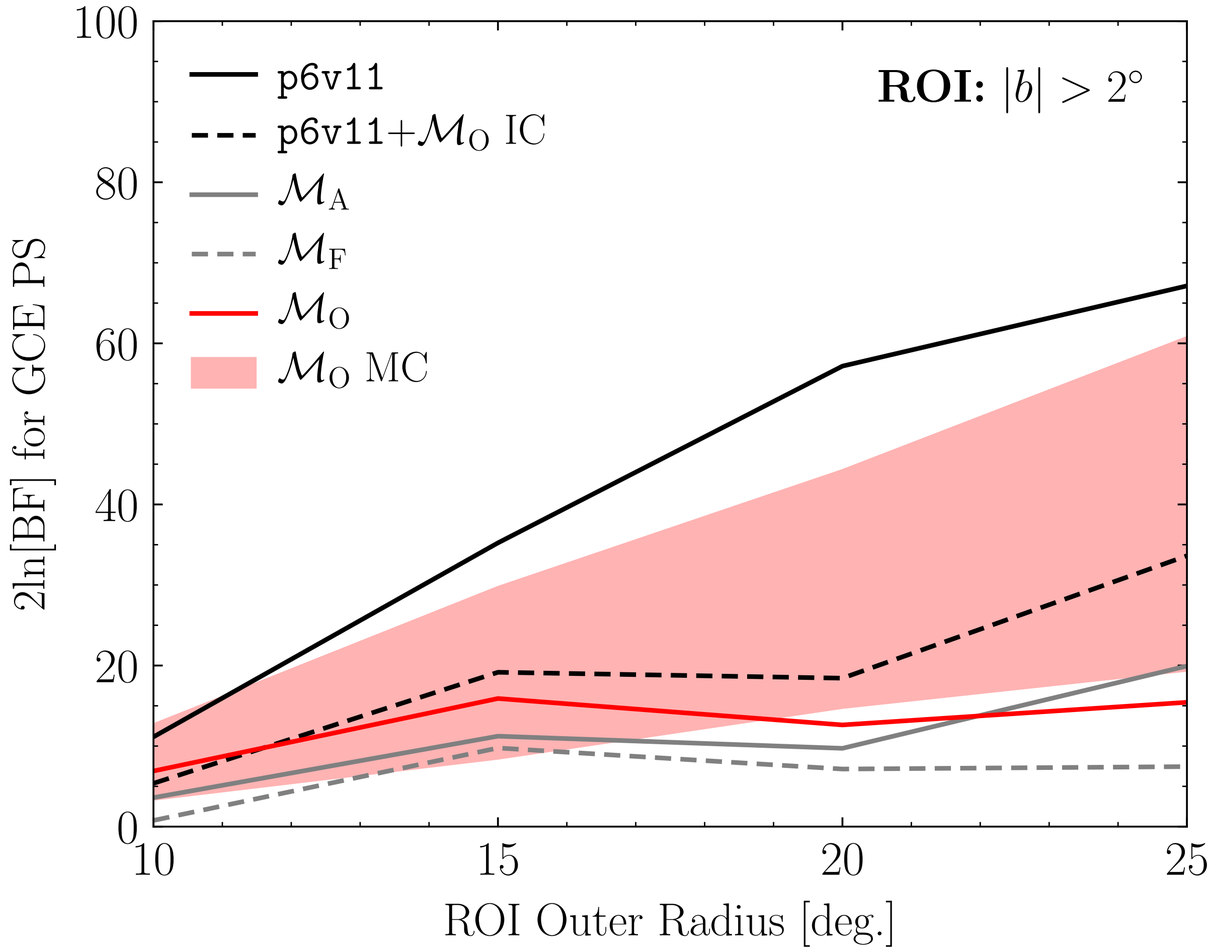
Harmonic marginalization can mitigate mismodeling effects

Some diffuse models are better than others

A non-Poissonian example



NPTF region of interest variations



Diffuse model goodness-of-fit