A NICER Estimation of PSR J0437-4715 Parameters
(Preliminary results!)

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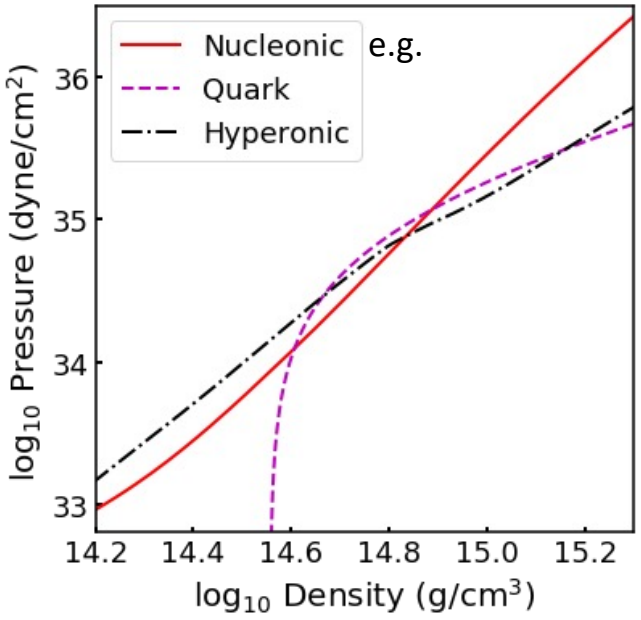
UNIVERSITY OF AMSTERDAM

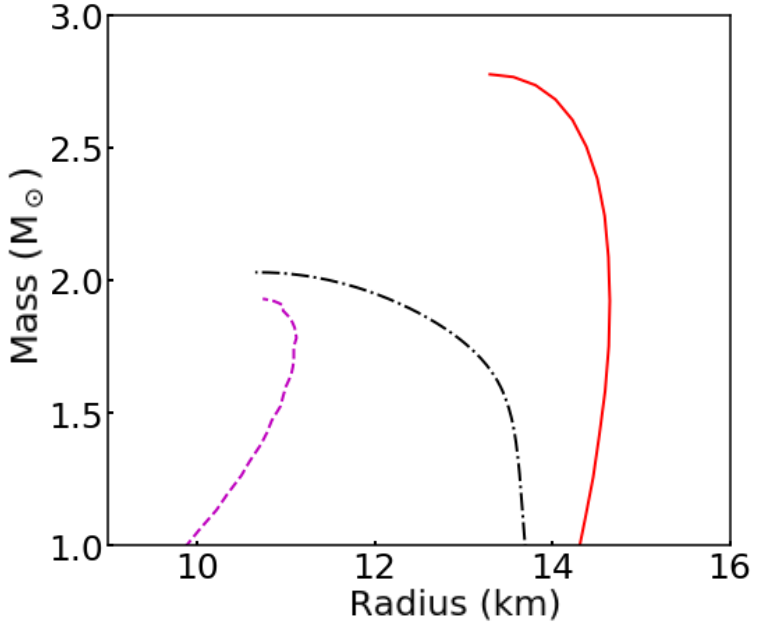
ANTON PANNEKOEK INSTITUTE

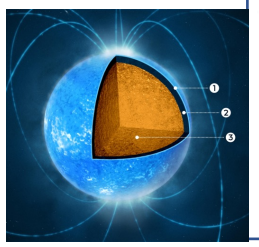
Nuclear Physics ⇔ Spacetime

Equation of state



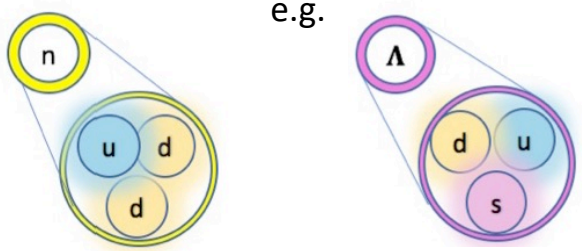
Mass–radius





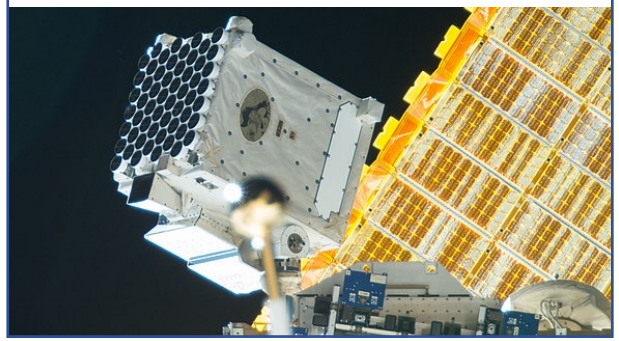
Dense matter physics

e.g.

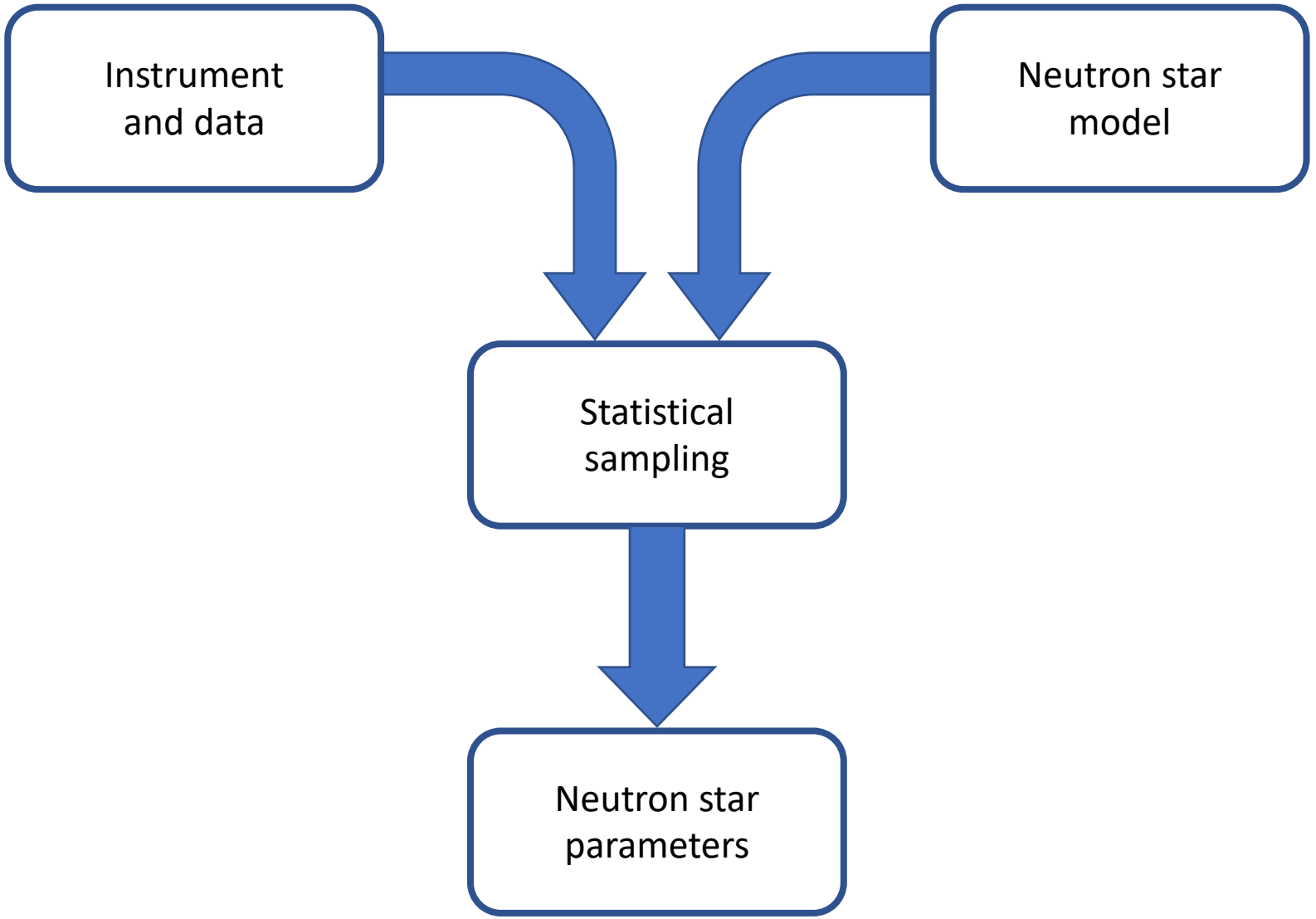


Neutron Hyperon

X-Ray data



X-PSI (github.com/xpsi-group/xpsi)



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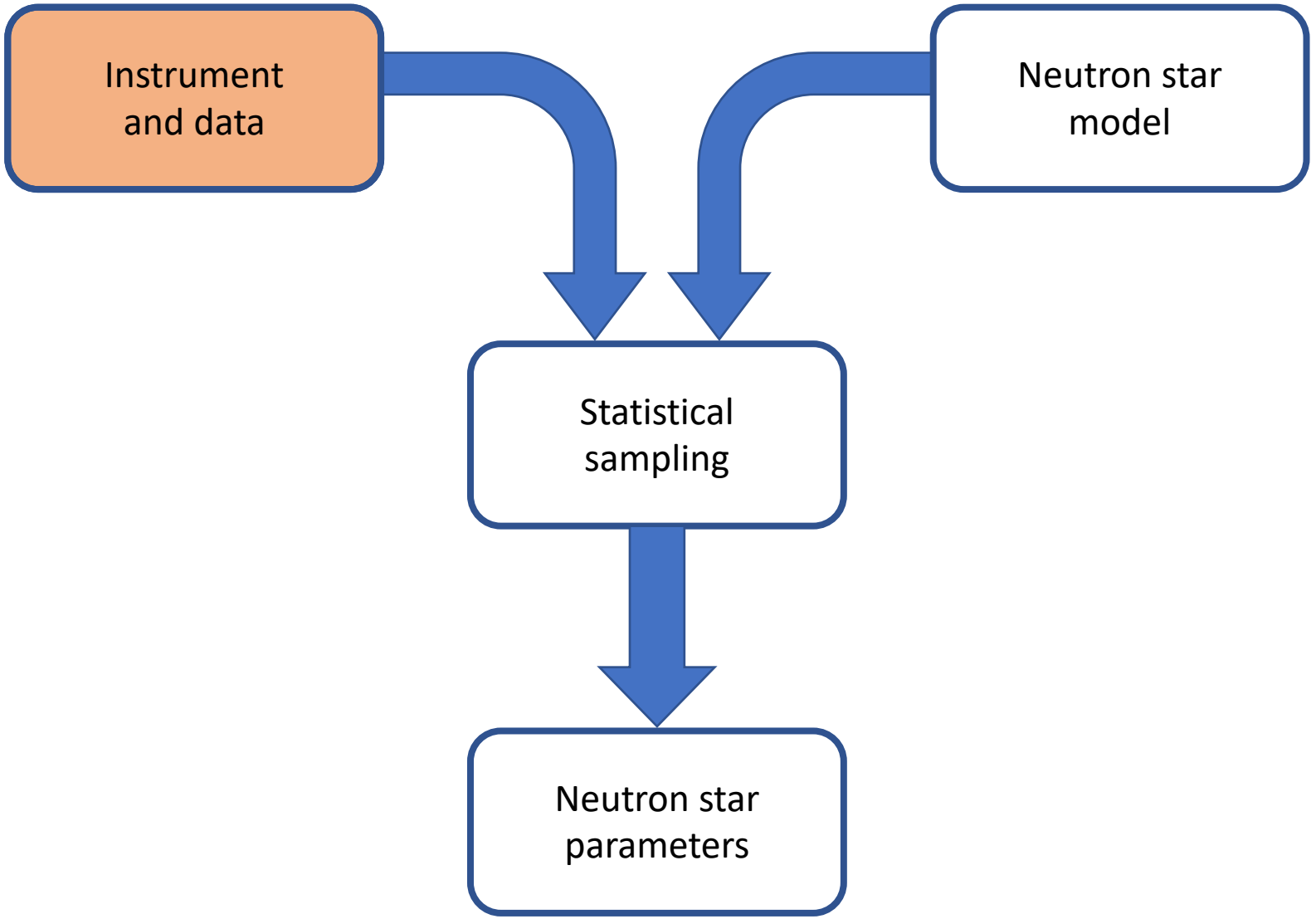
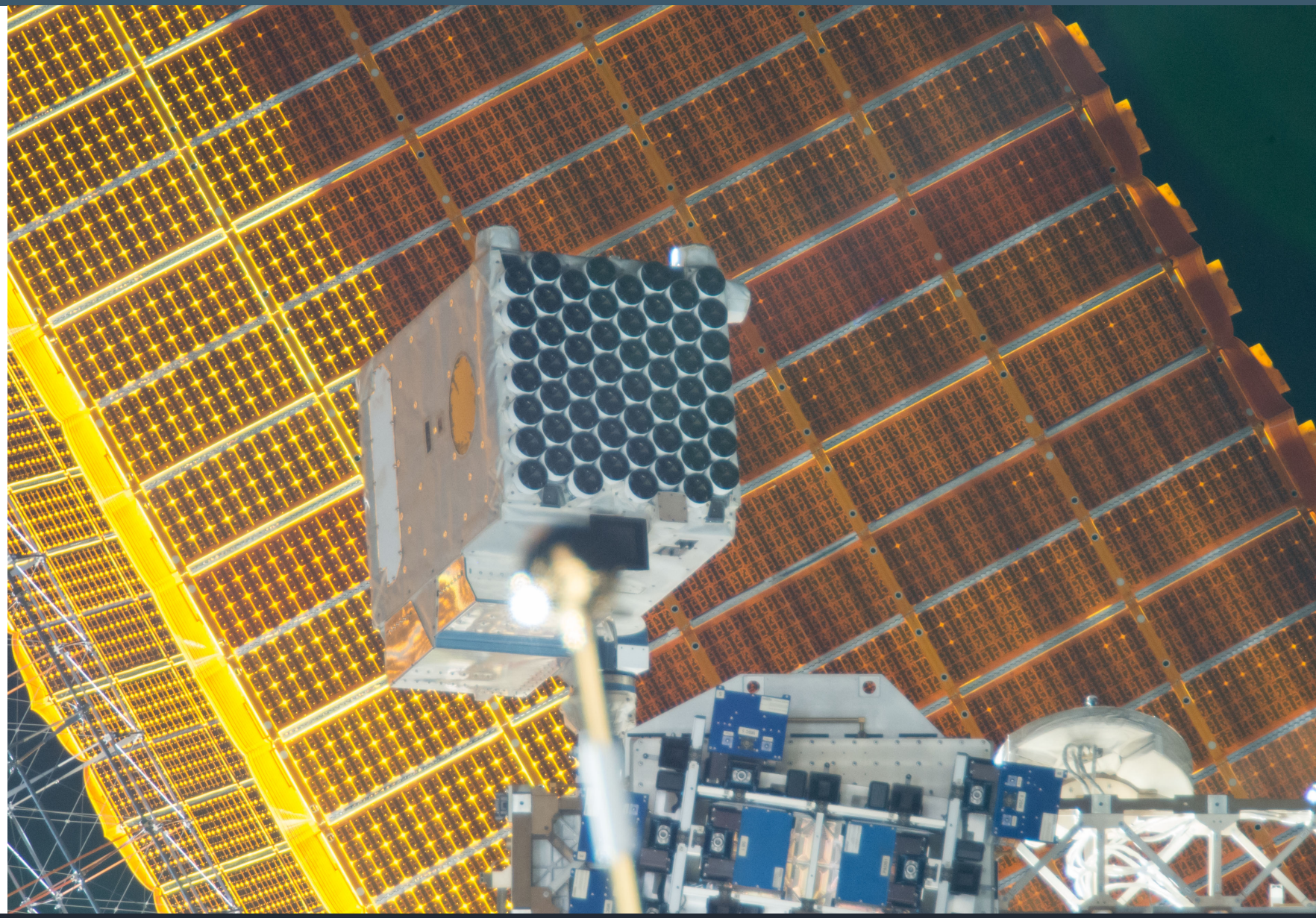


Neutron Star Interior Composition Explorer (NICER)

NICER X-ray Timing:

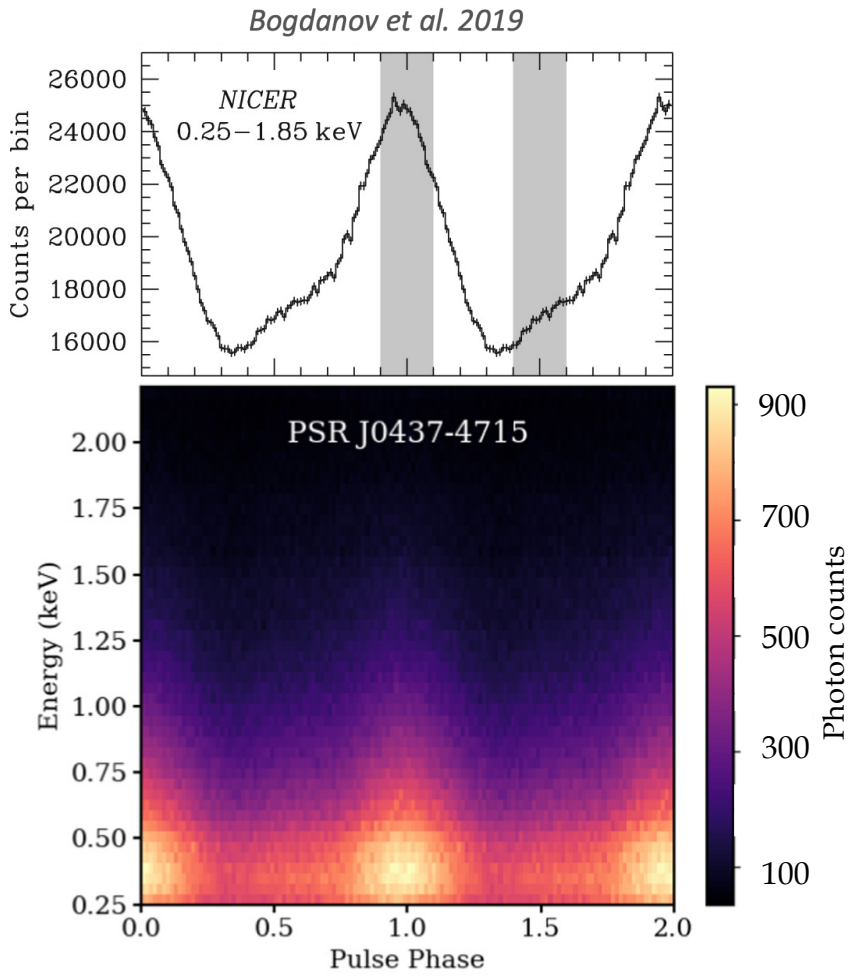
- High sensitivity in soft X-ray band (0.2 – 12 KeV)
- High time and energy resolution

Pulse profile modelling of rotation powered pulsars



NASA's Goddard Space Flight Center

NICER's Primary Target: PSR J0437-4715



- Closest millisecond pulsar
- Brightest NICER source
- Binary system – tight mass and inclination constraints

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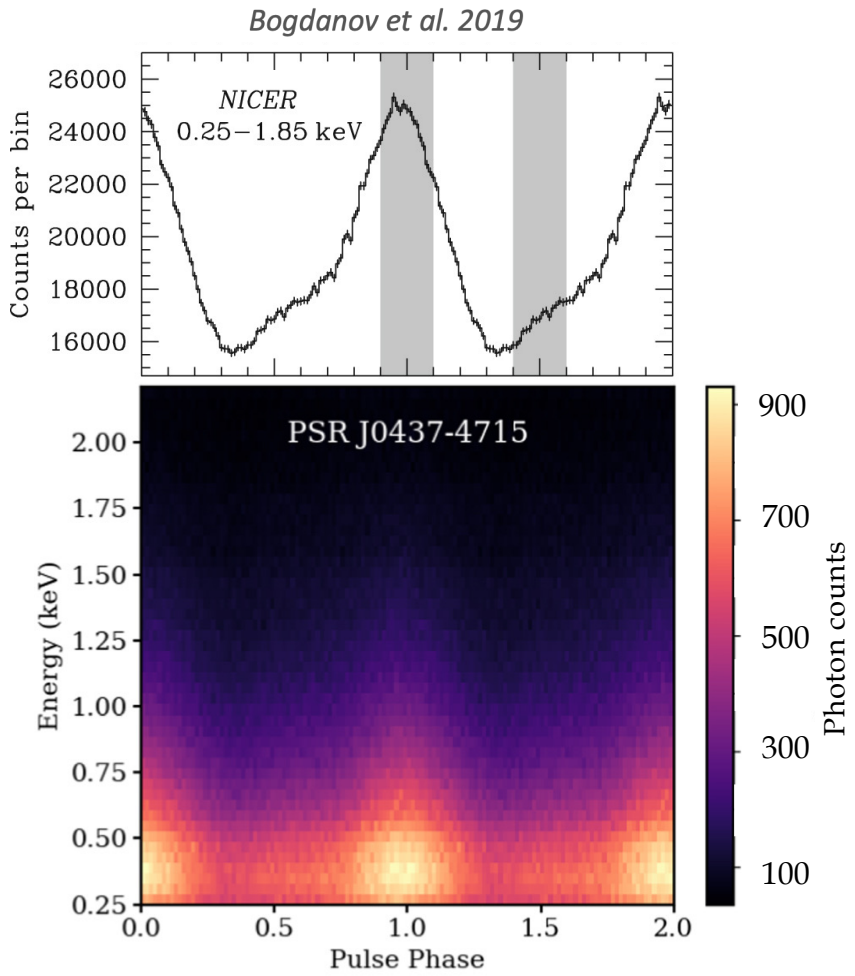

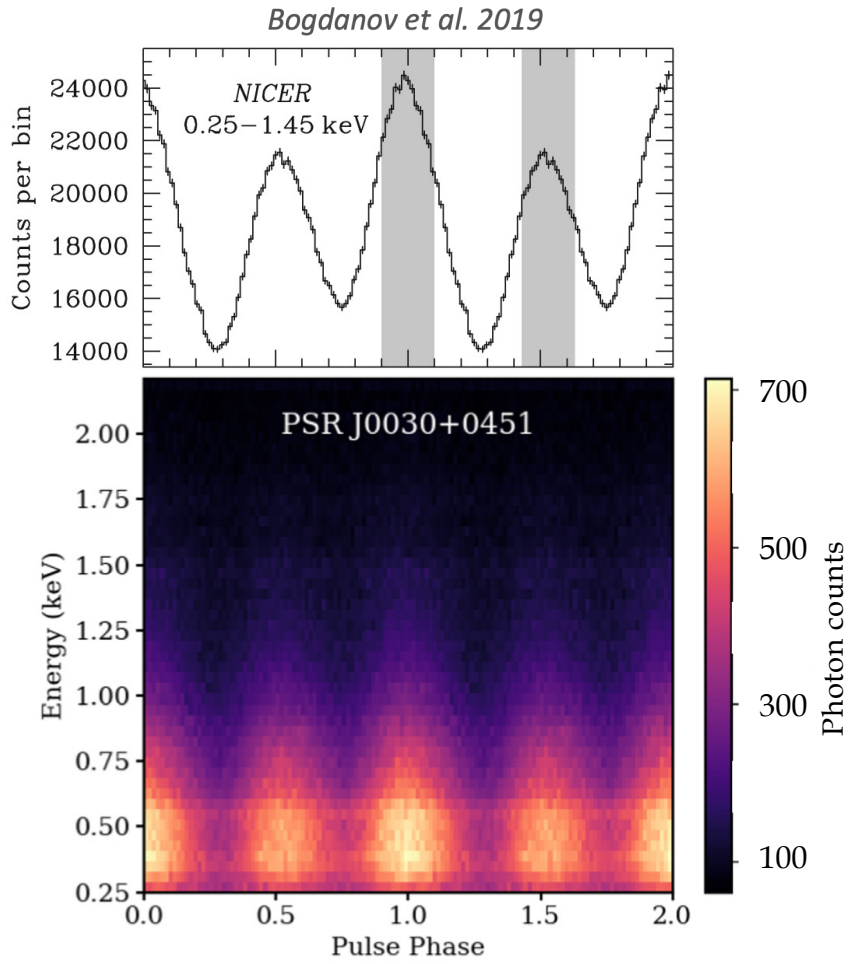

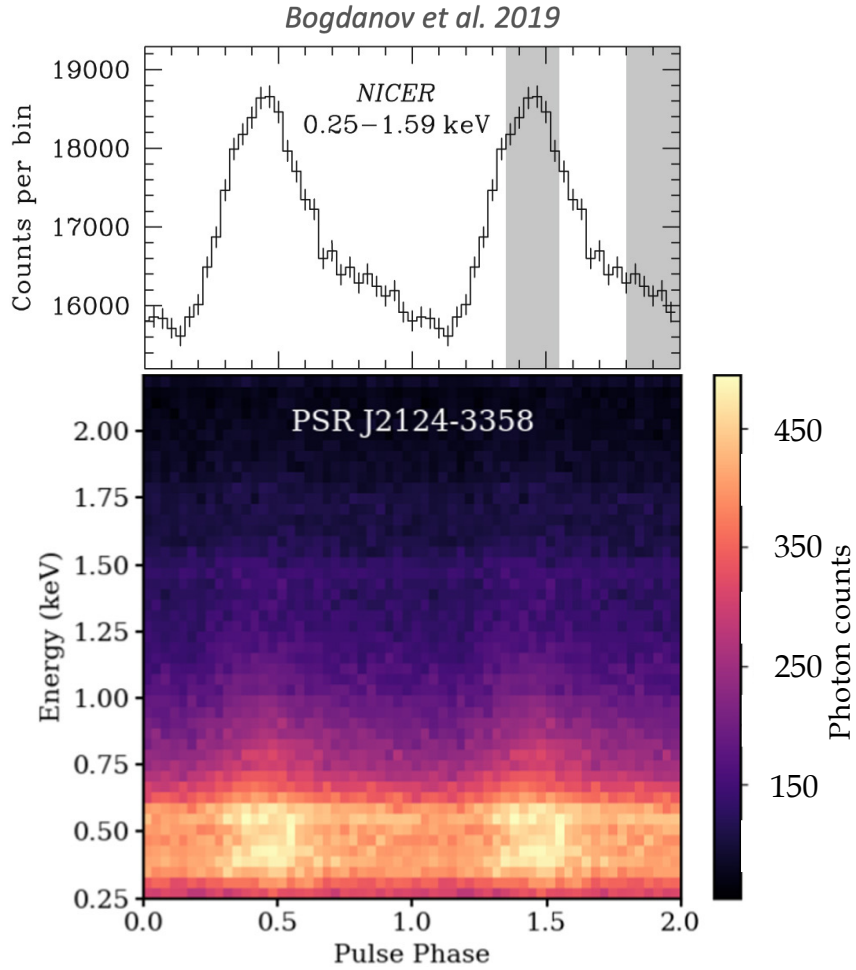

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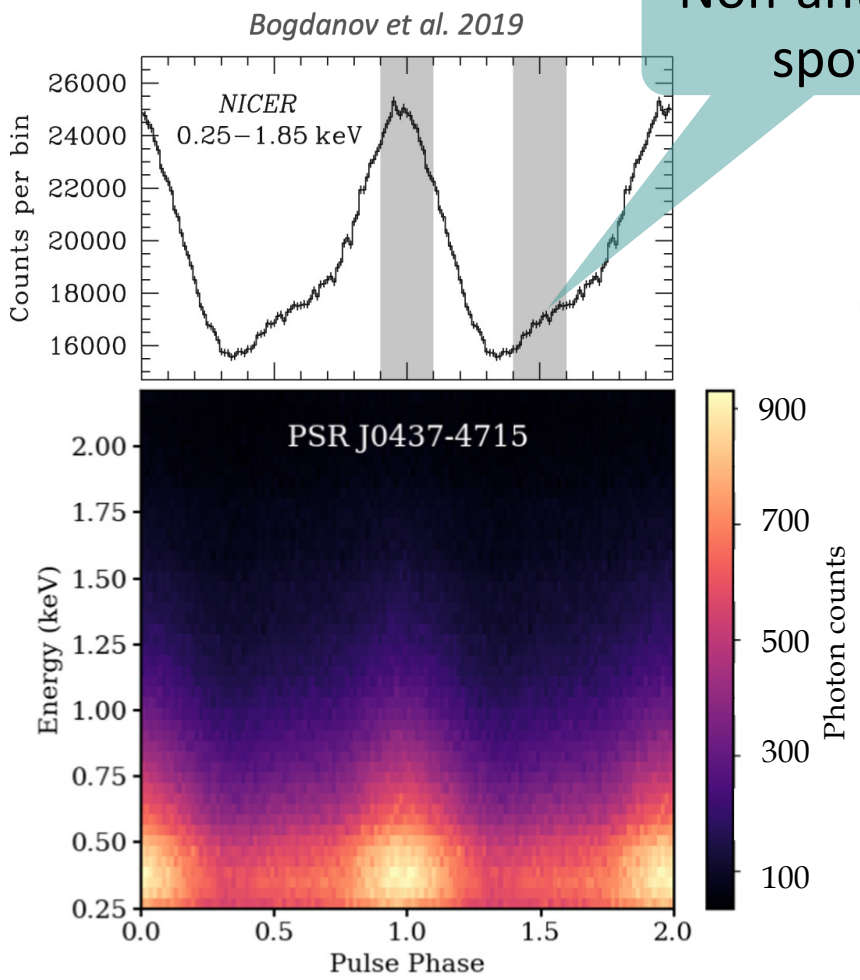
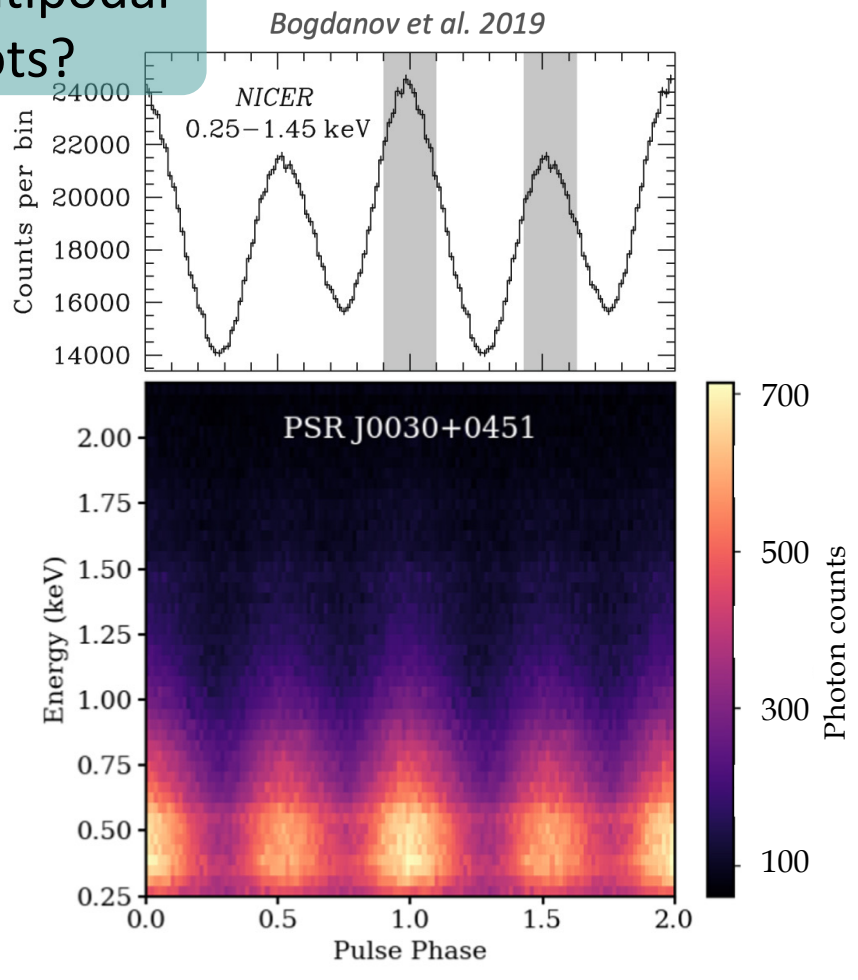
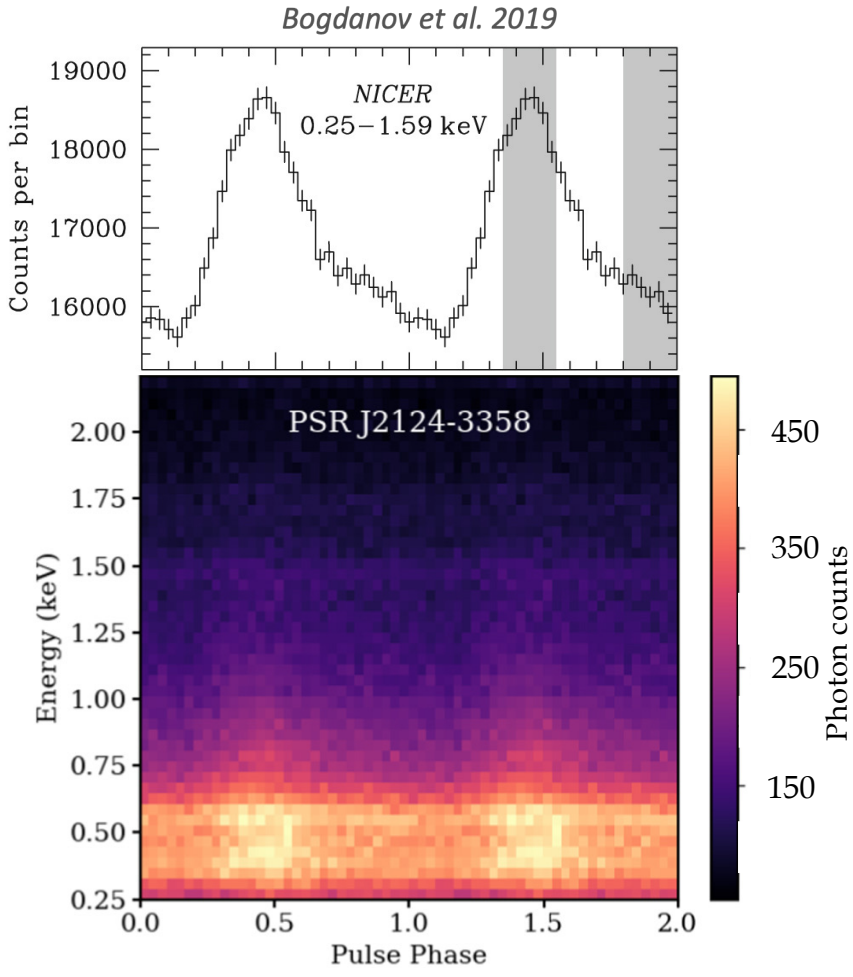
NICER's Primary Target: PSR J0437-4715

Non-antipodal spots?

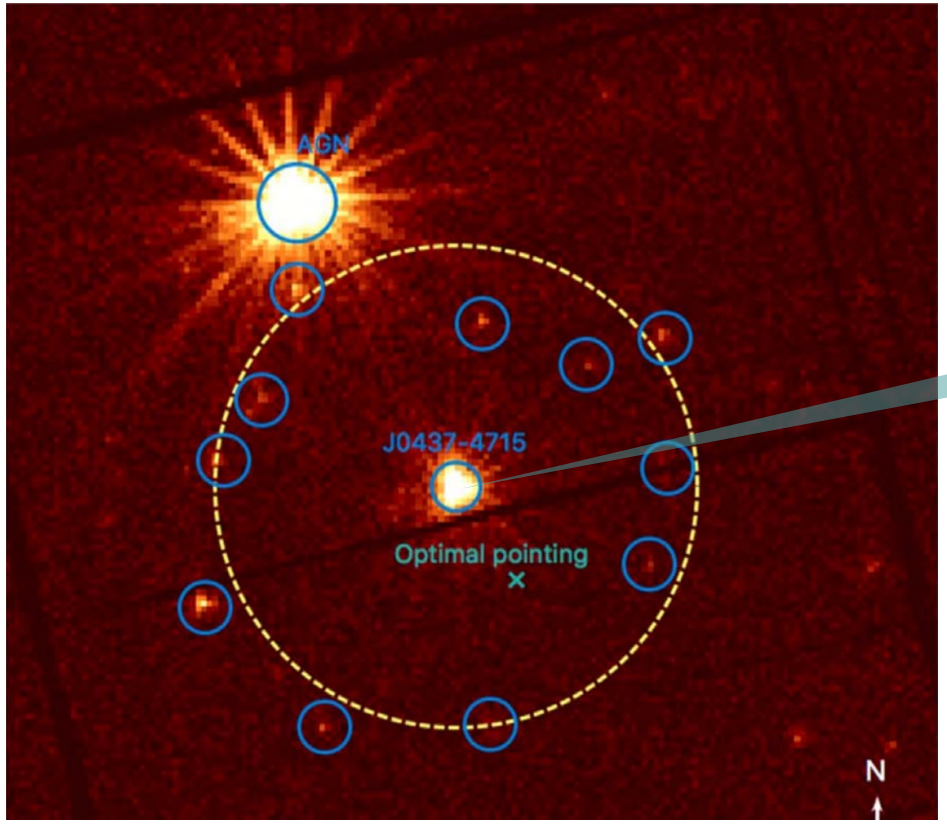






- Best data quality – invites modelling challenges – unexplained features can't be swept off as noise!

PSR J0437-4715: Field-of-View



PSR J0437-4715

Bogdanov et al. 2019

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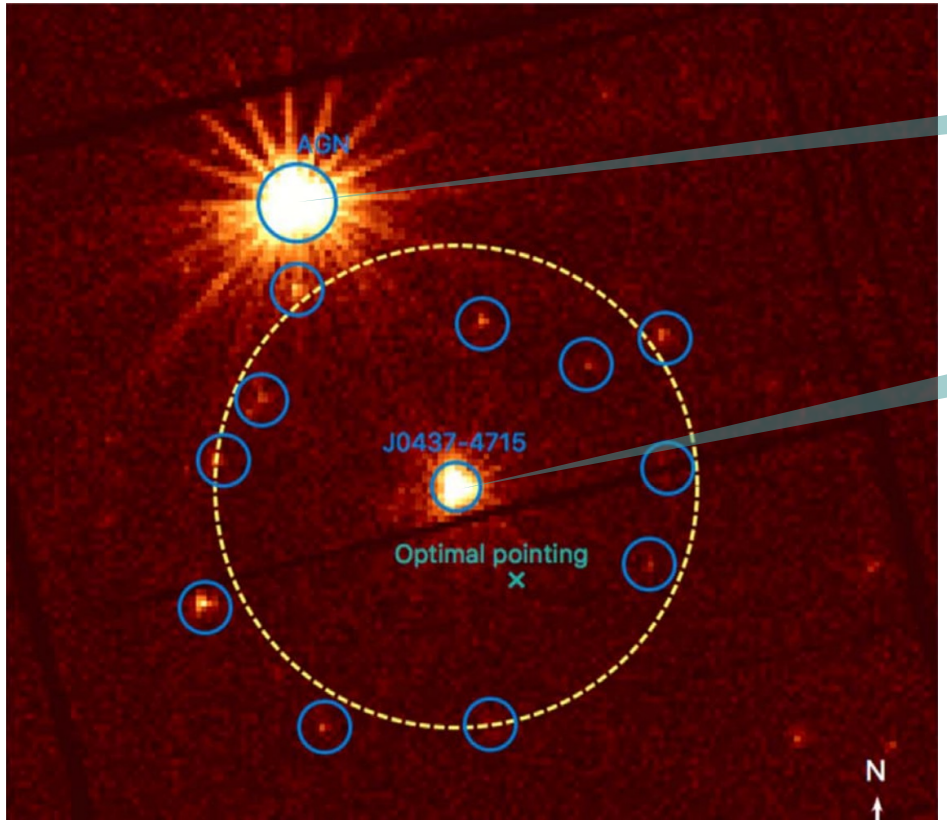

Nearby AGN

PSR J0437-4715

Bogdanov et al. 2019

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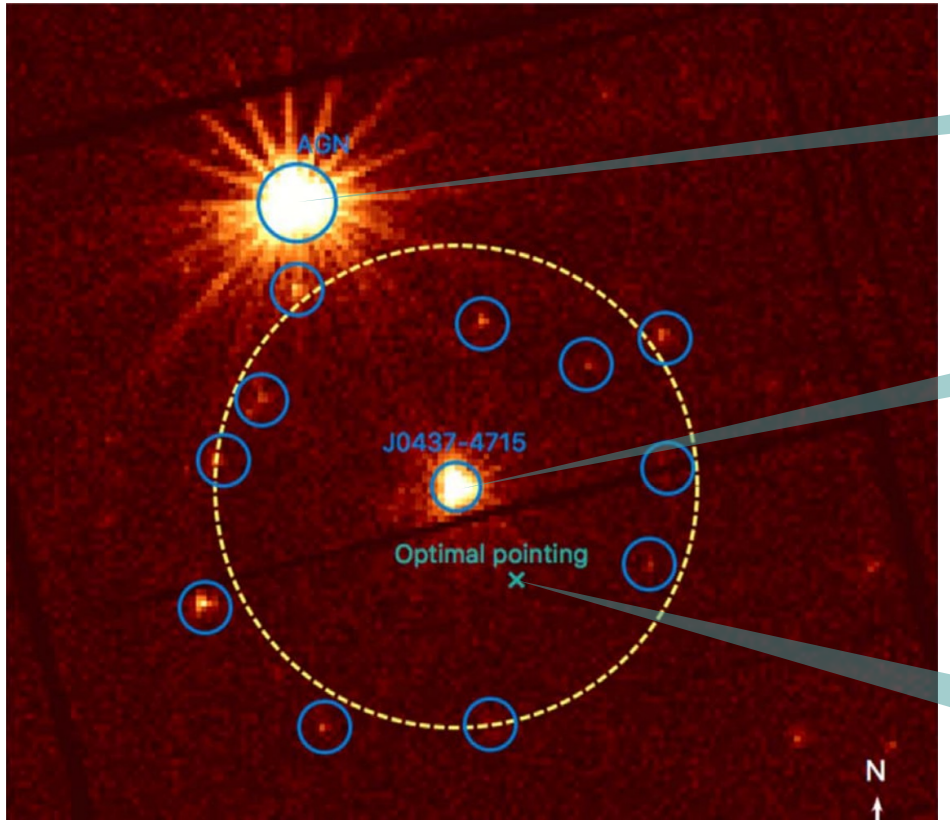


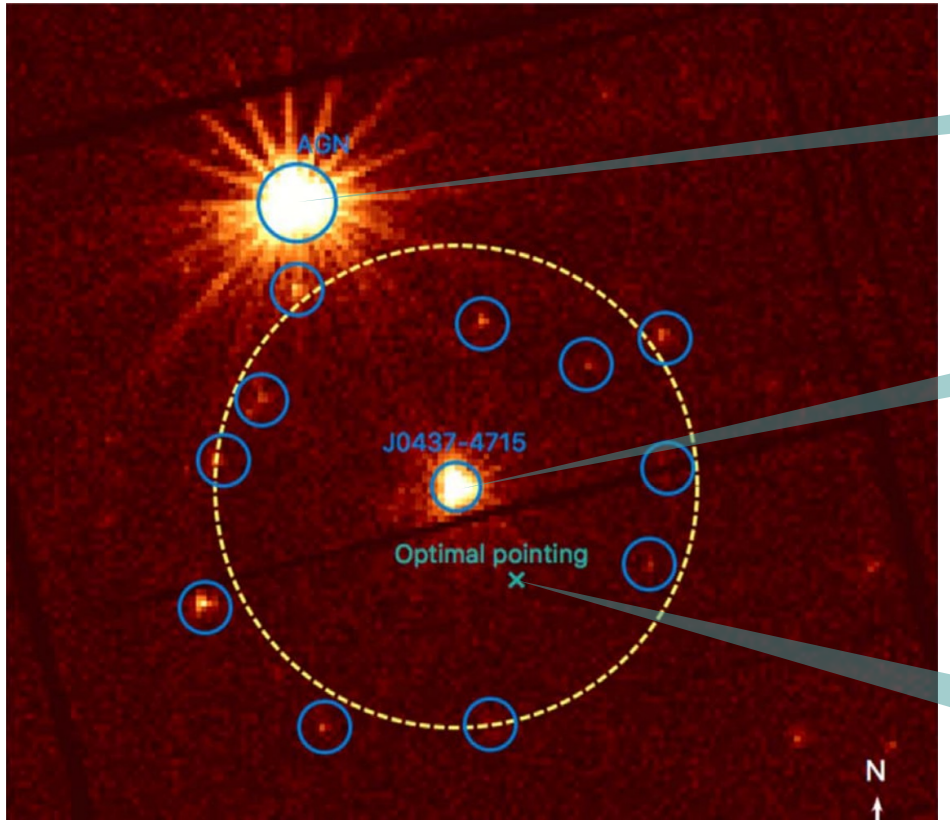
Nearby AGN

PSR J0437-4715

Instrument offset pointing

Bogdanov et al. 2019

PSR J0437-4715: Response Scaling



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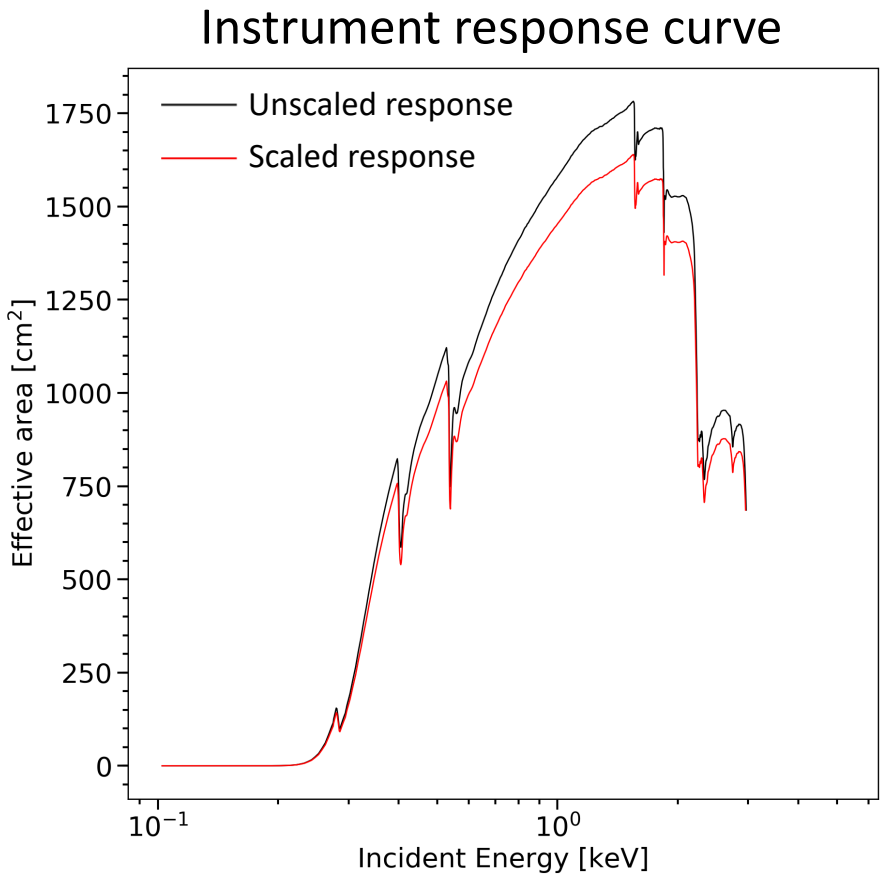

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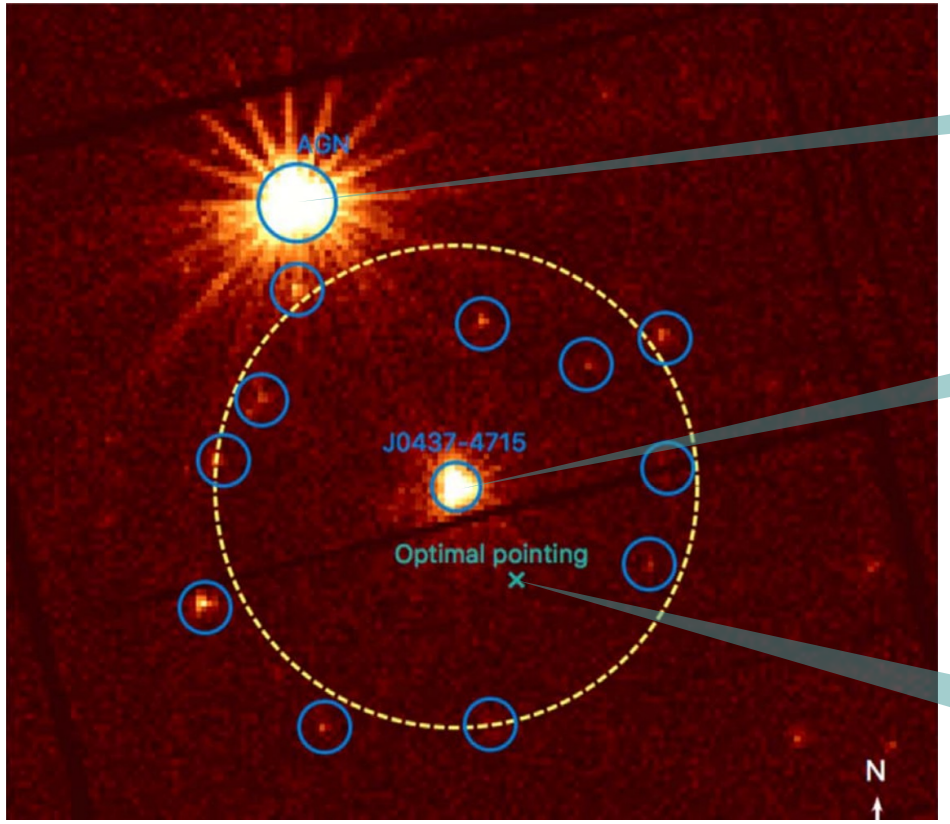

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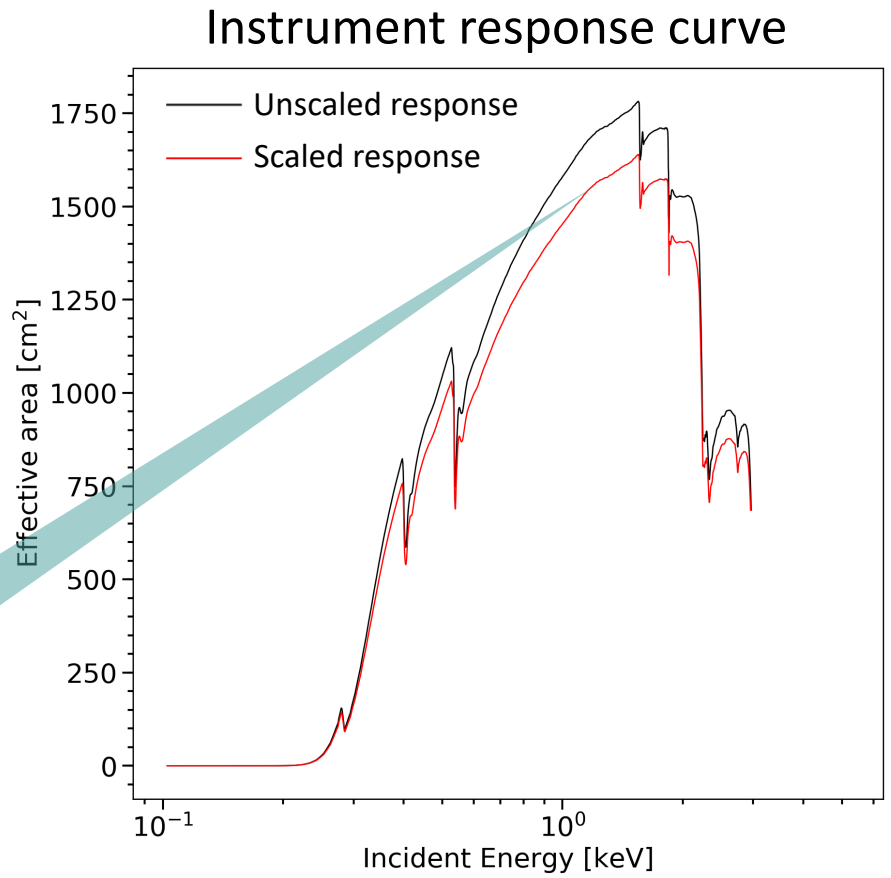
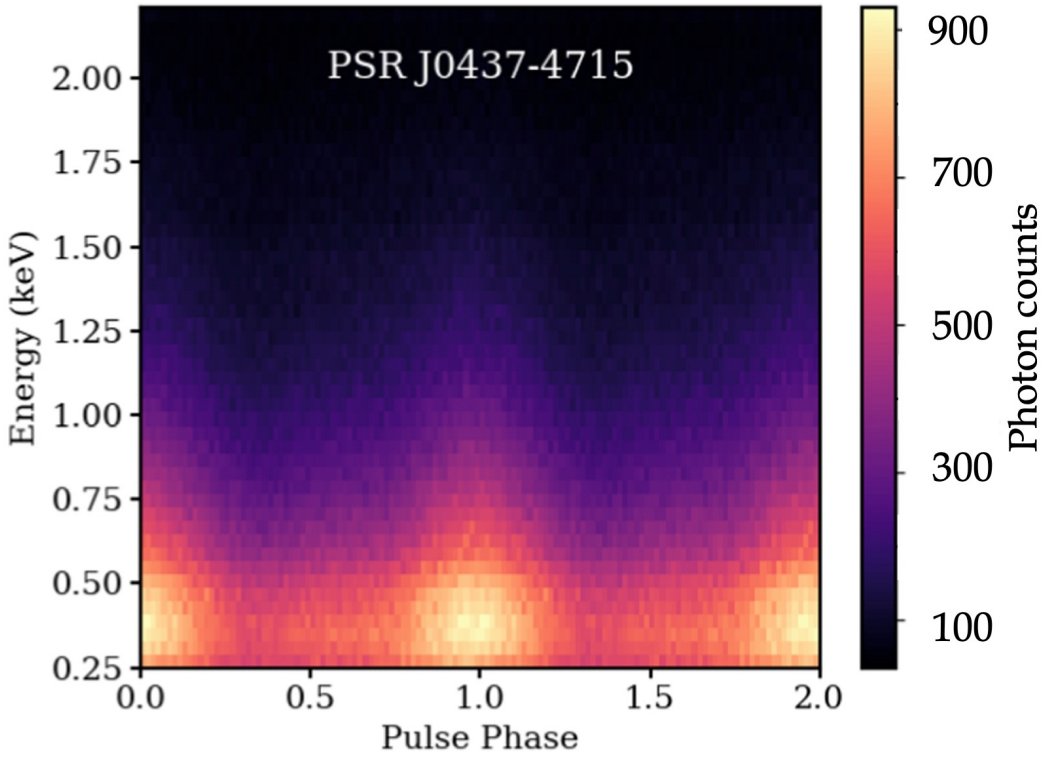


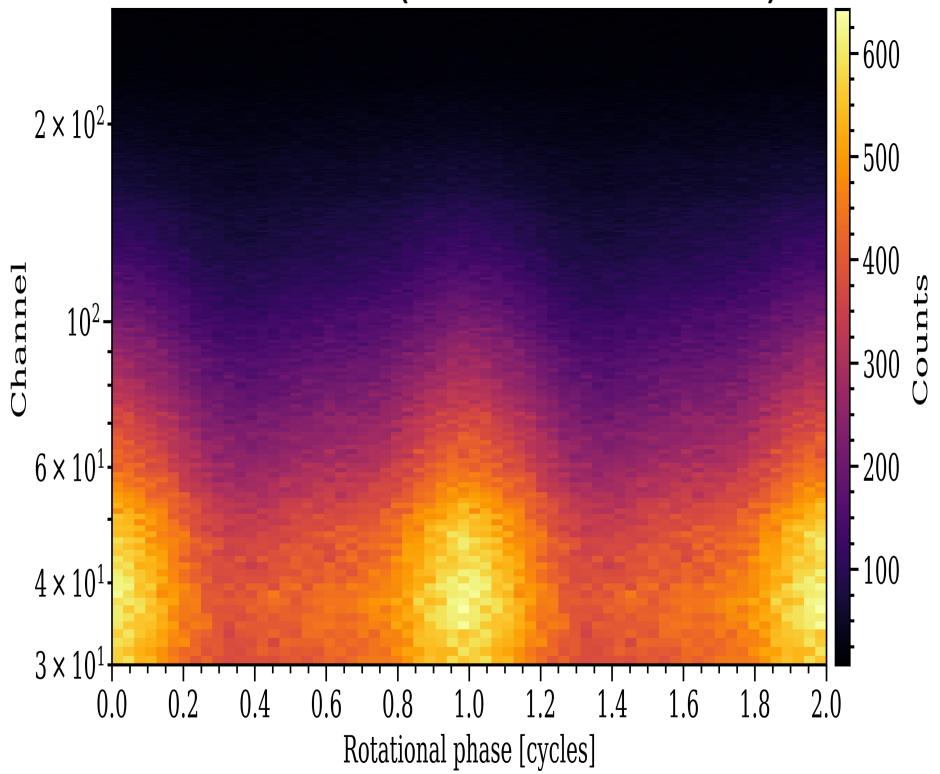
PSR J0437-4715: 3C50 Data Set & BKG

Bogdanov et al. 2019



- Observed between 6 Jul 2017 – 12 Mar 2019
- 951 ks of observation

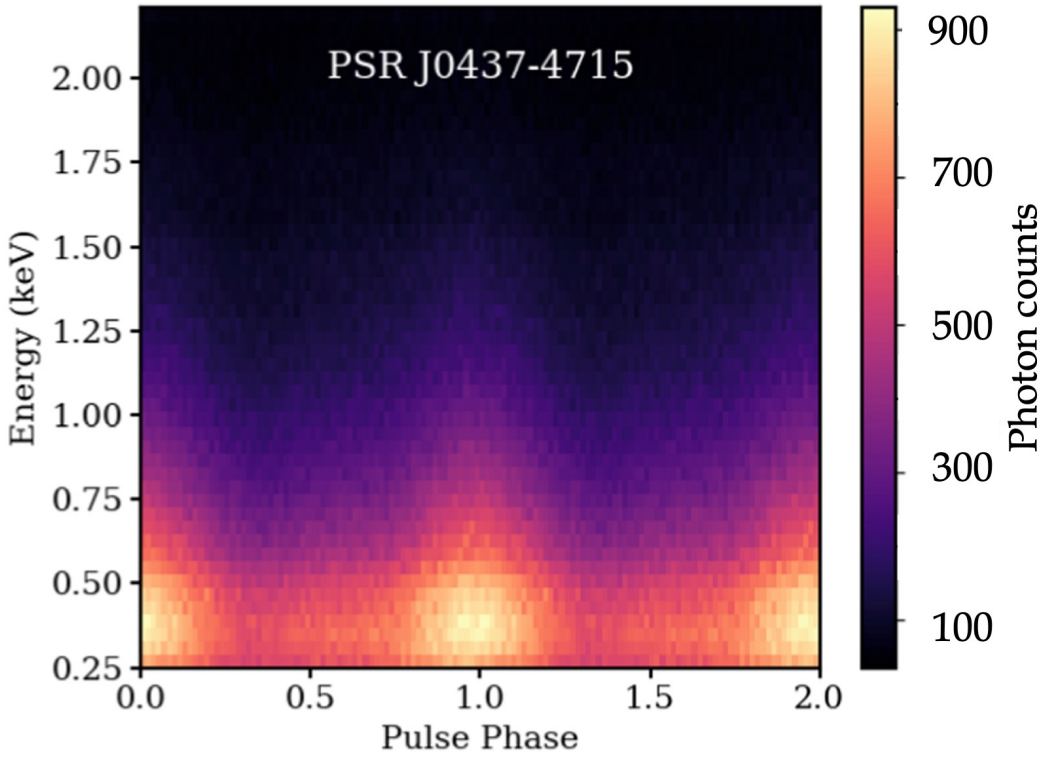
3C50 data set (Remillard et al. 2022)



- Observed between 20 Jul 2017 – 11 Oct 2021
- 1.3 Ms of observation

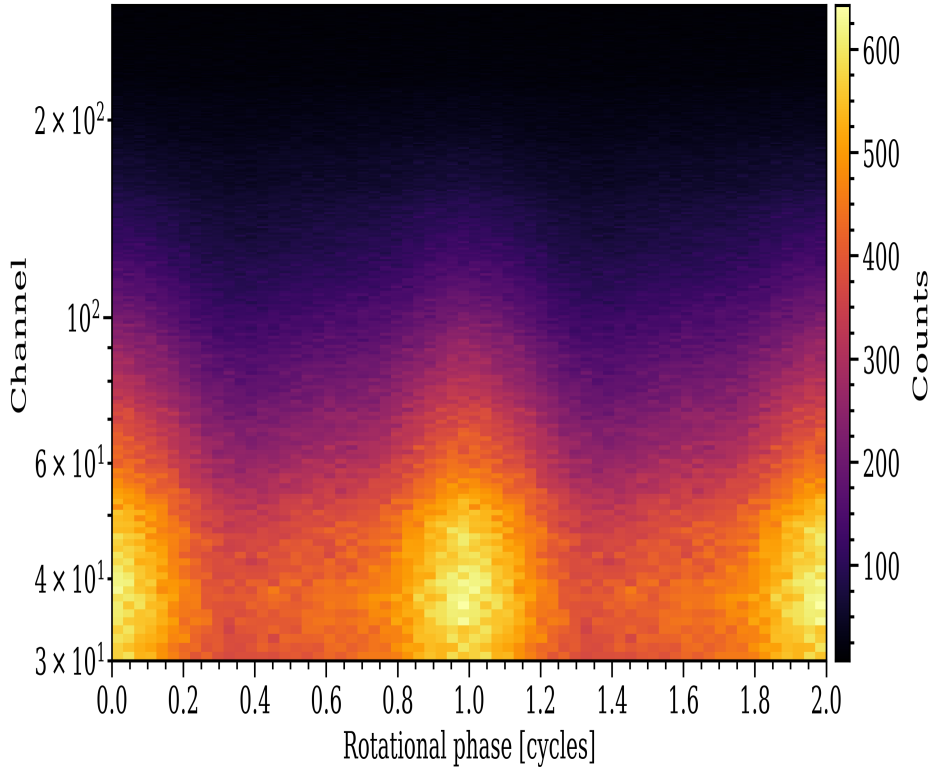
PSR J0437-4715: 3C50 Data Set & BKG

Bogdanov et al. 2019



- Observed between 6 Jul 2017 – 12 Mar 2019
- 951 ks of observation
- No BKG constraint

3C50 data set (Remillard et al. 2022)



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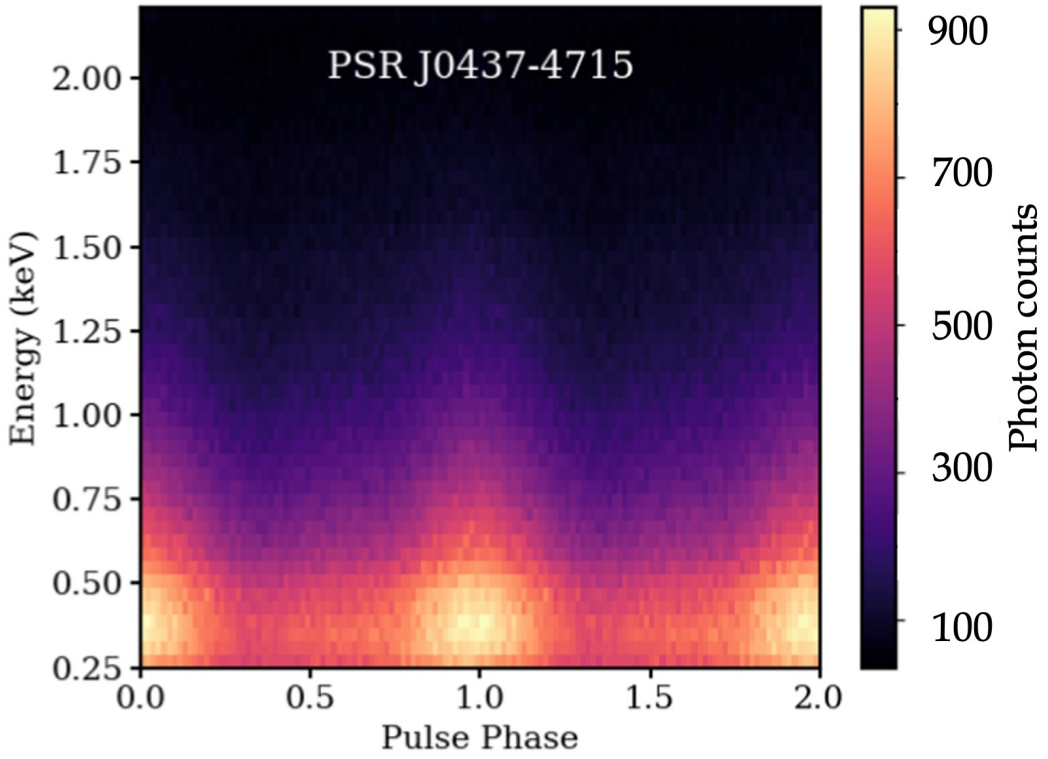
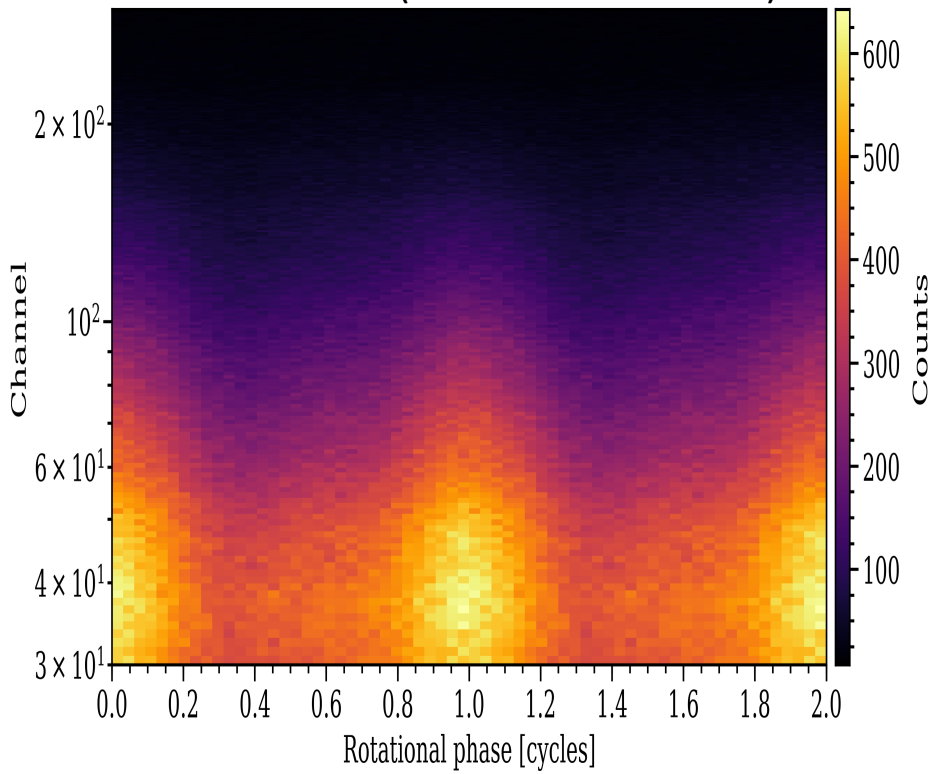


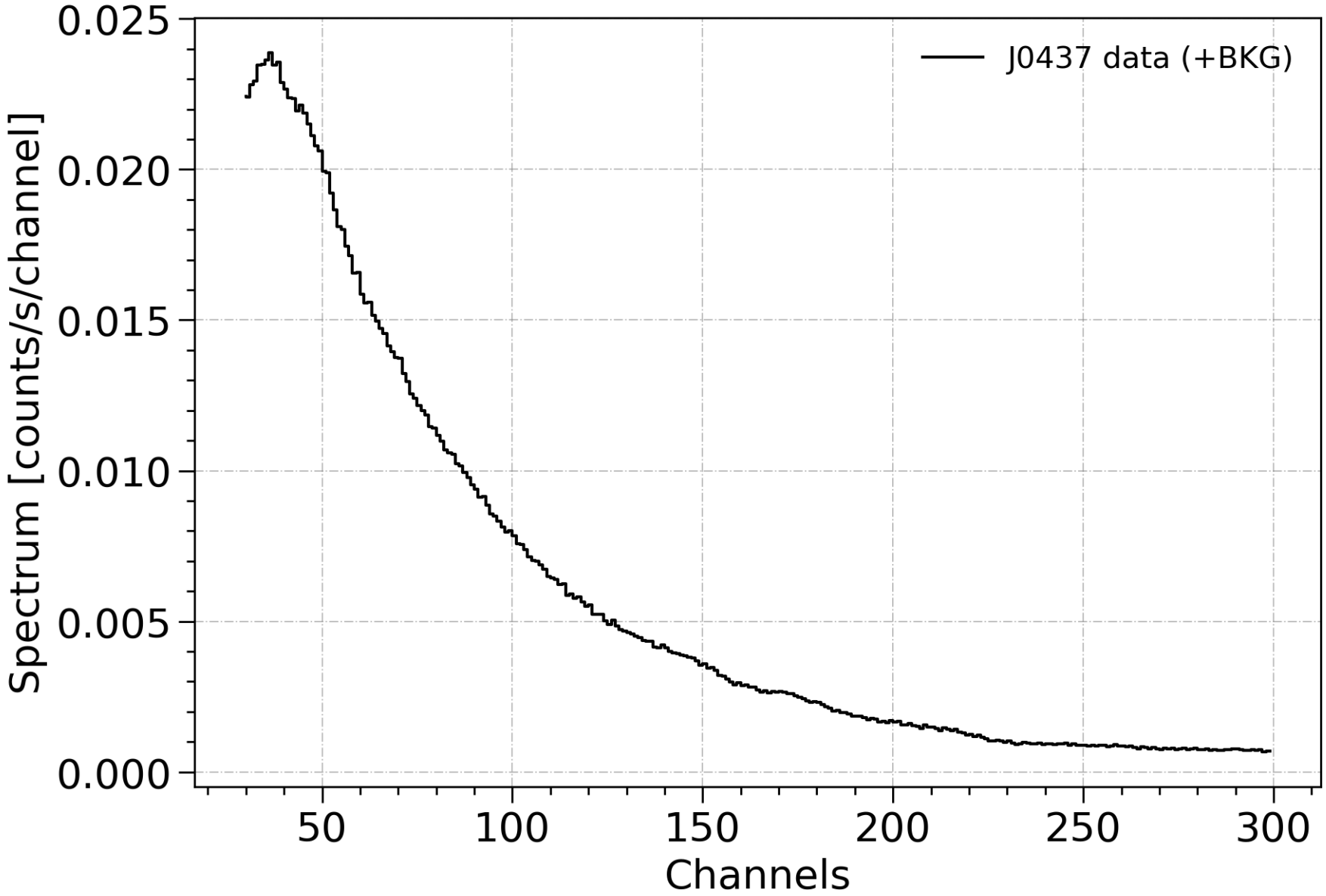
- Observed between 6 Jul 2017 – 12 Mar 2019
- 951 ks of observation
- No BKG constraint
- Noisier data
- ObsID: 0060010101 -> 2060010405

3C50 data set (Remillard et al. 2022)



- Observed between 20 Jul 2017 – 11 Oct 2021
- 1.3 Ms of observation
- Provides instrument BKG estimate
- Cleaner data (some loss of source counts)
- ObsID: 1060010104 -> 4060010638

PSR J0437-4715: 3C50 Data Set & BKG



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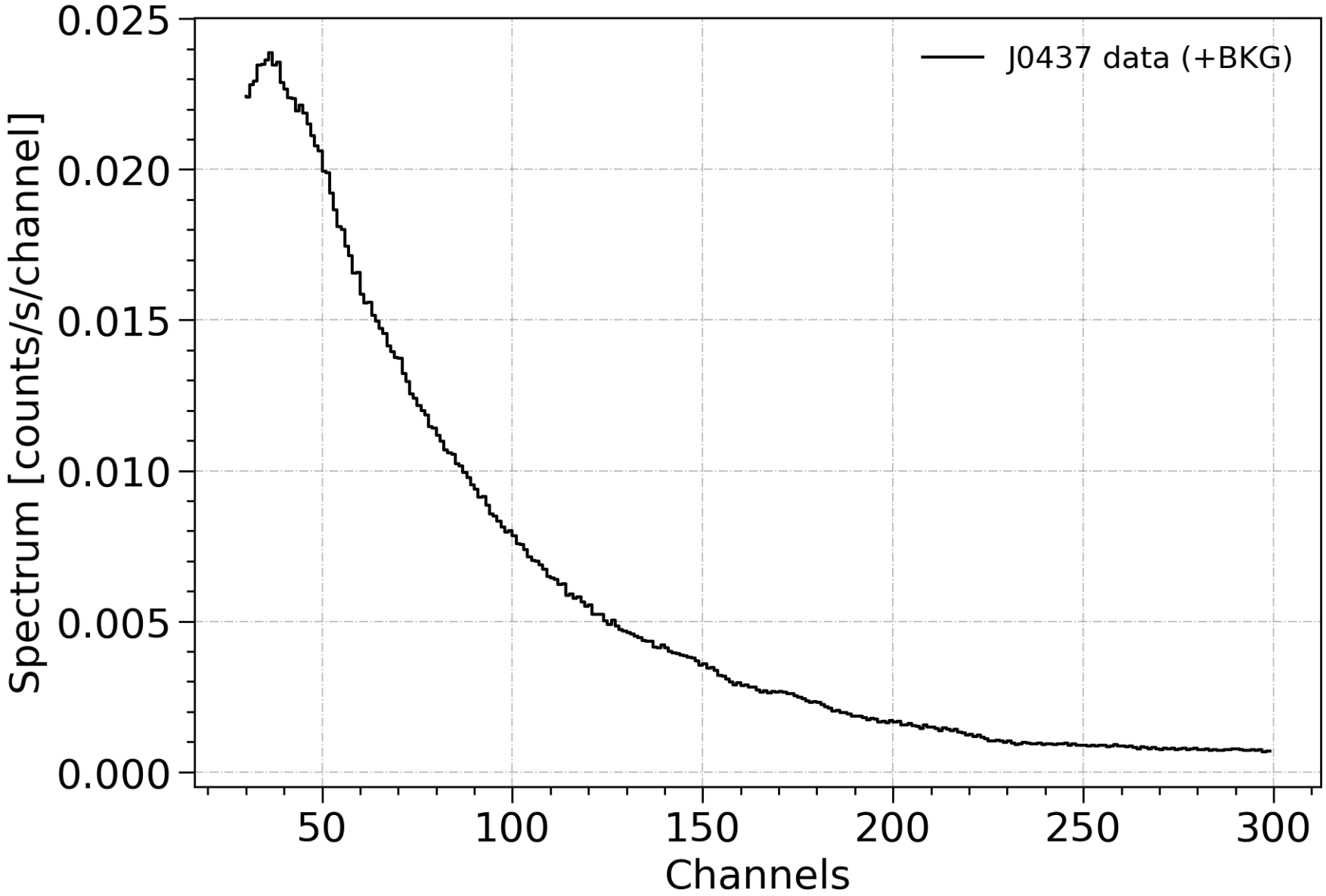

BKG parameters
(1 per channel)

Marginalised when
calculating likelihood

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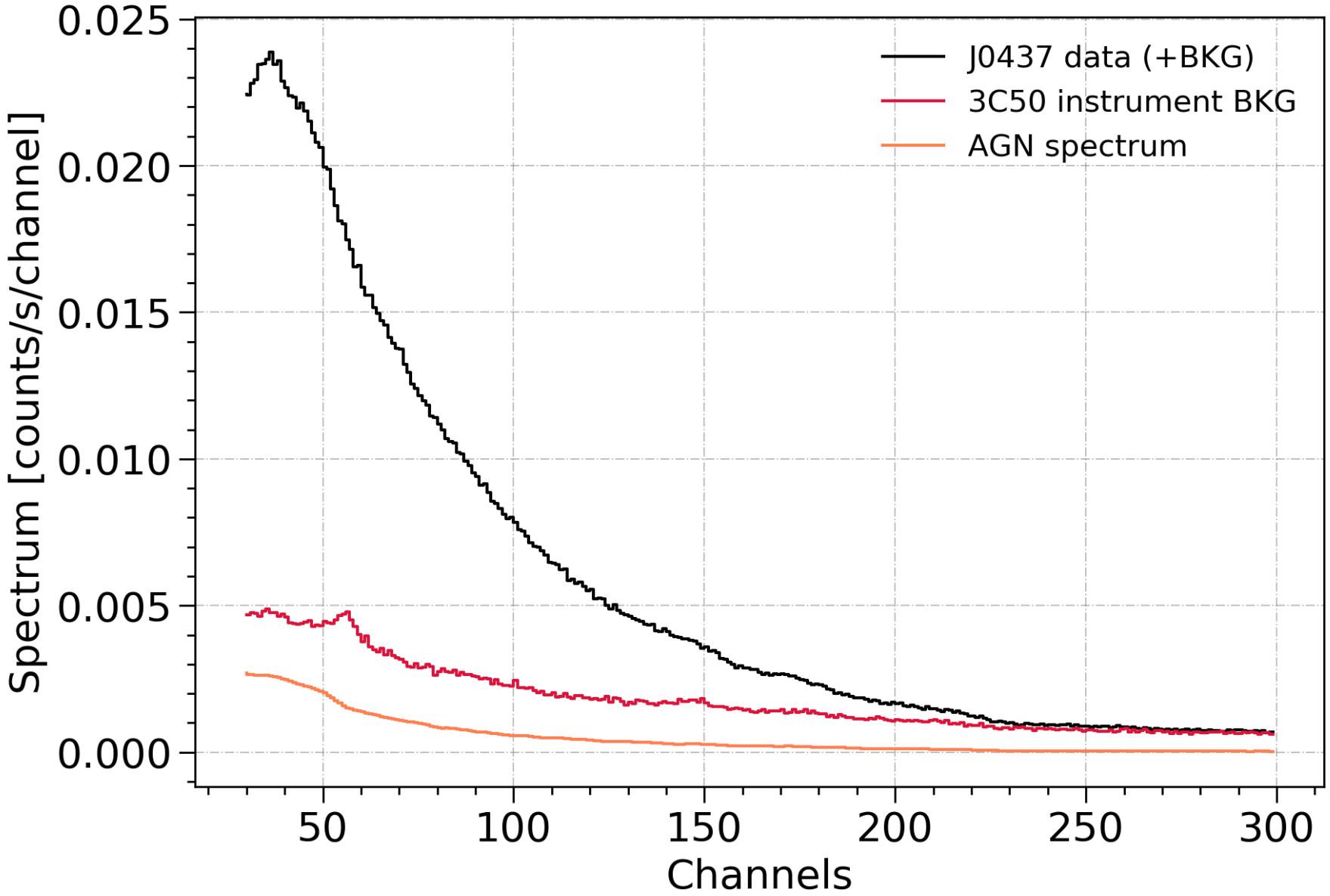

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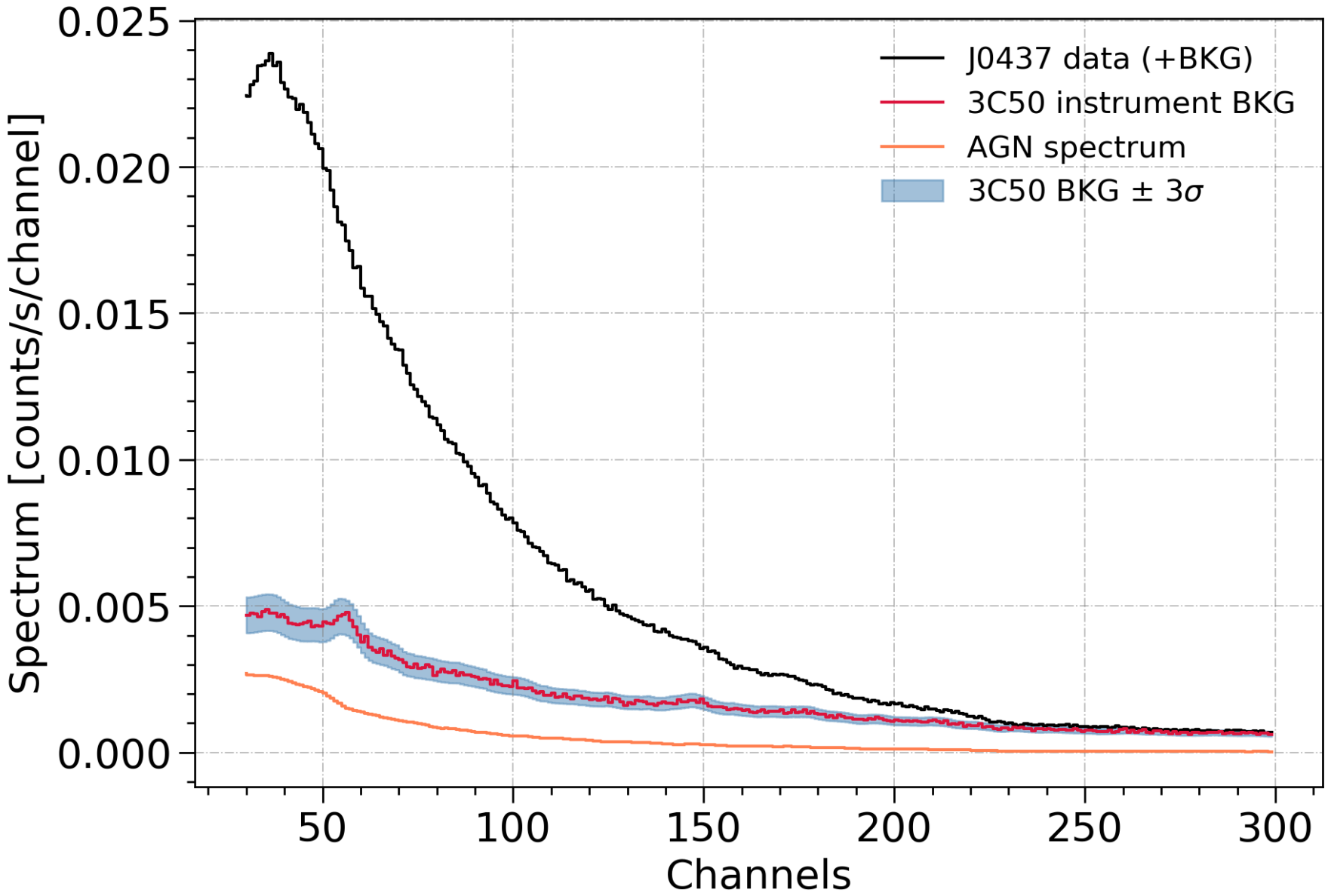

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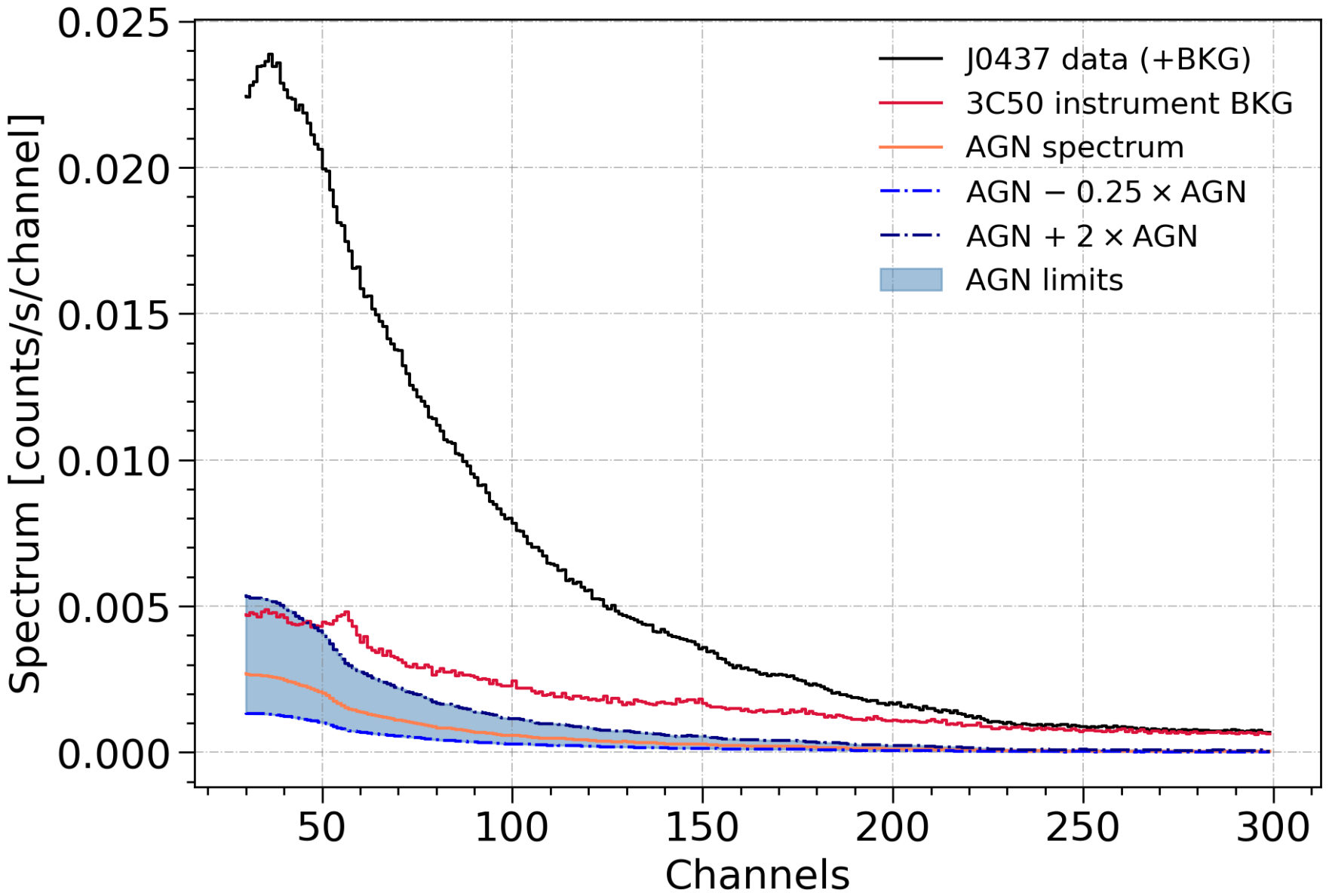

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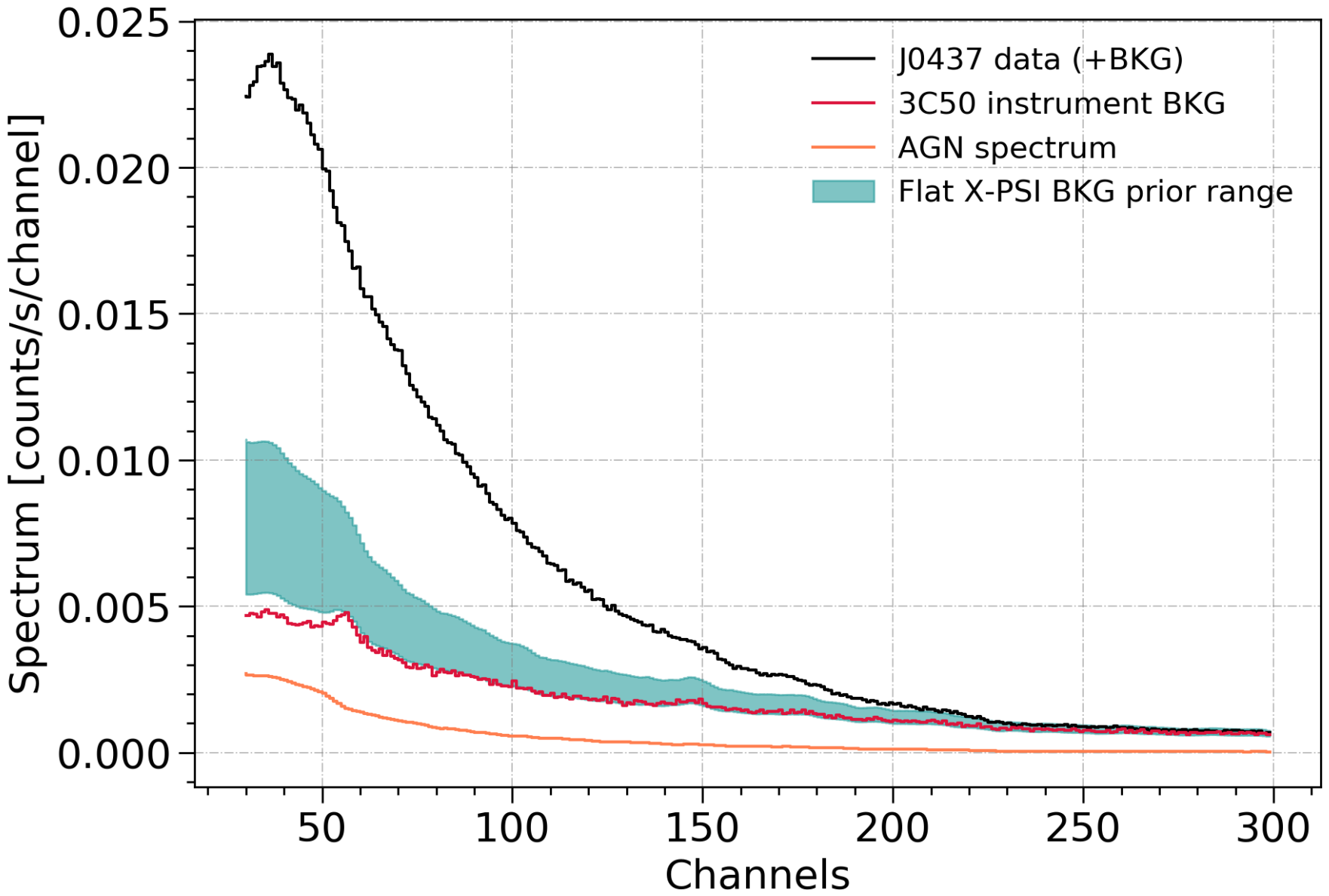

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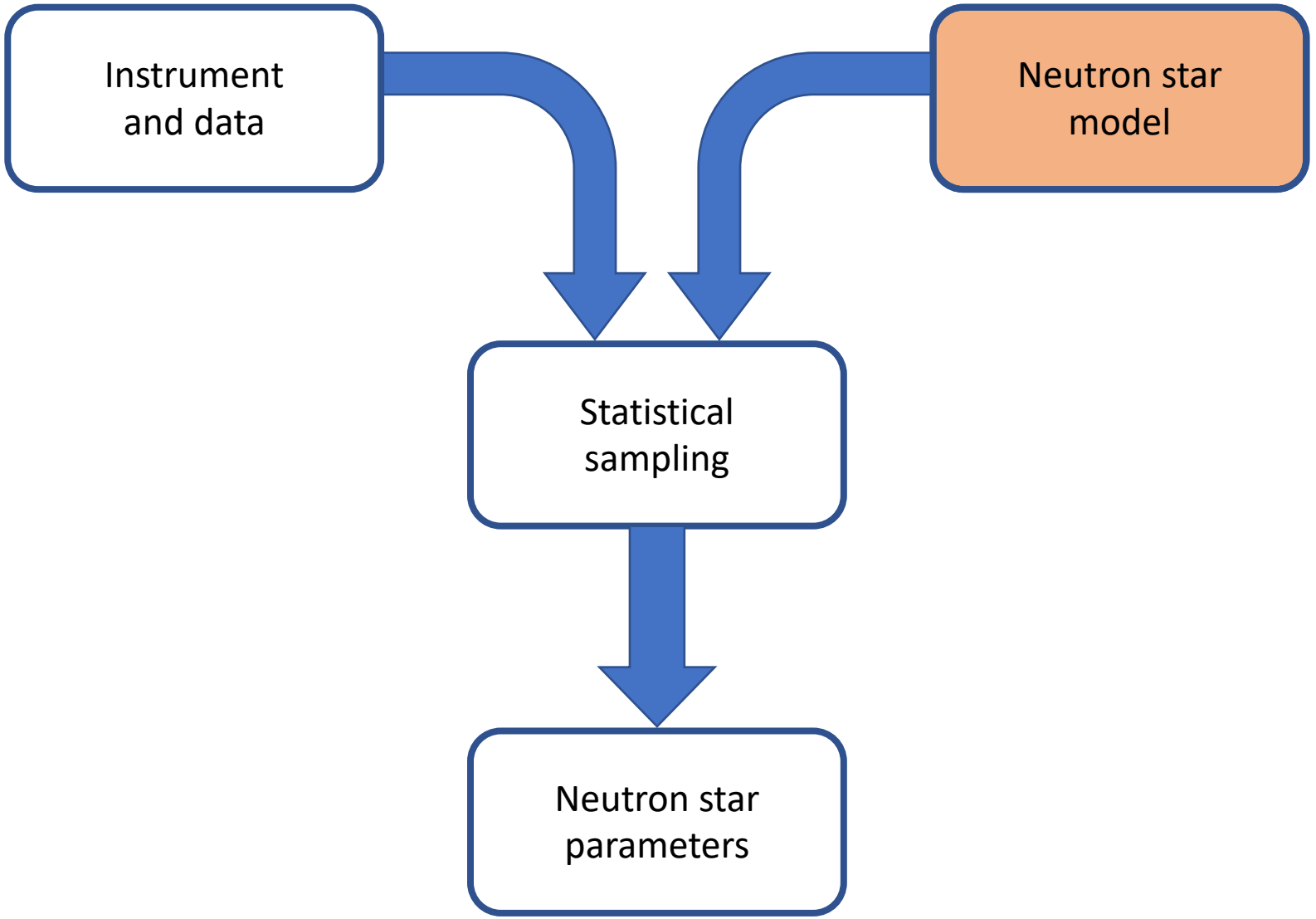

Modelling: Relativistic Ray Tracing

- Oblate Schwarzschild + Doppler approximation (Morsink et al. 2007)

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    - i = 137.506 ± 0.016 degrees
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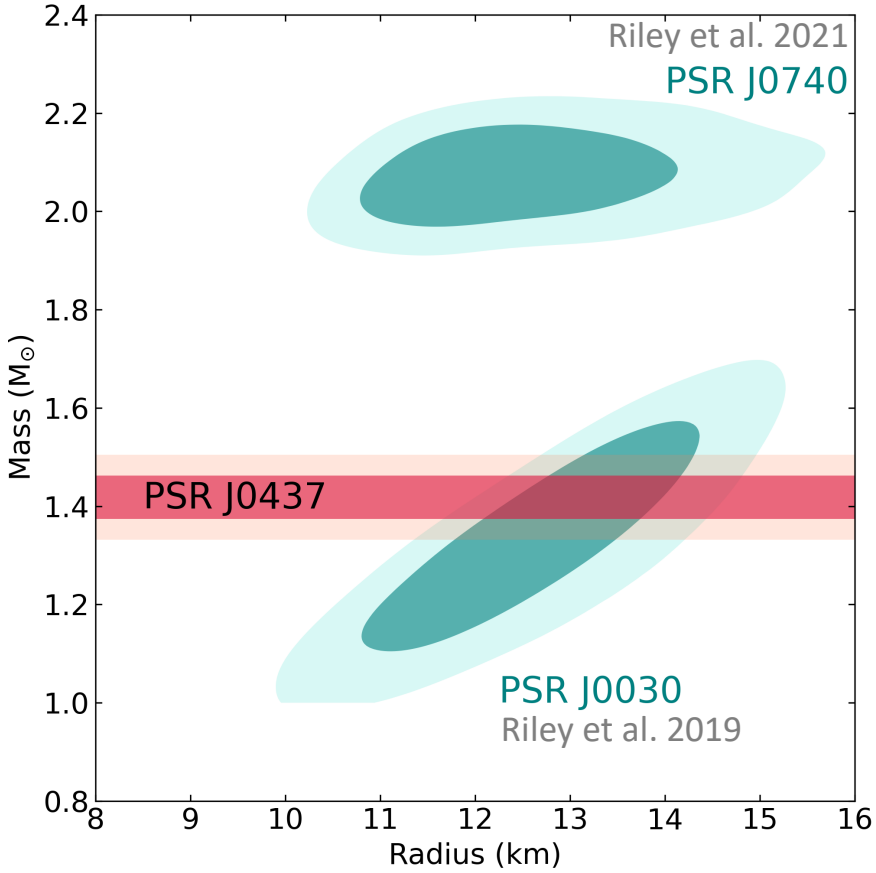
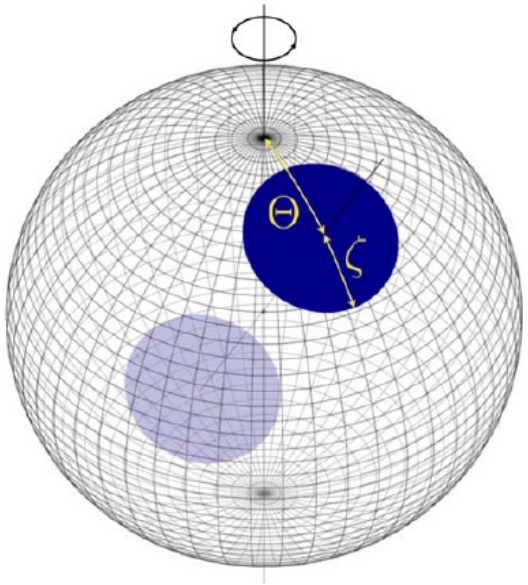


Modelling: Hot Spots

Riley et al. 2019



Single-temperature

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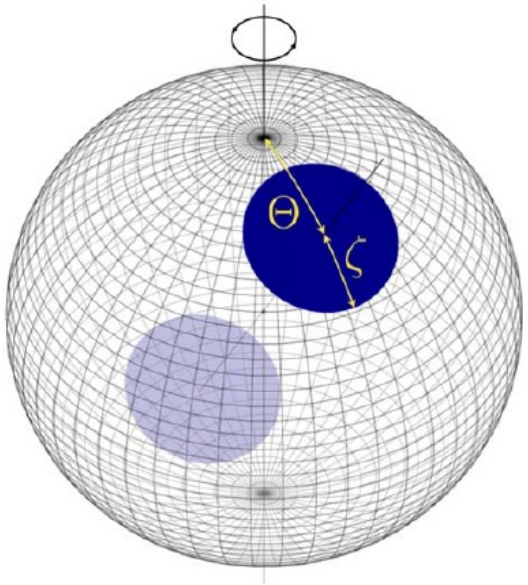

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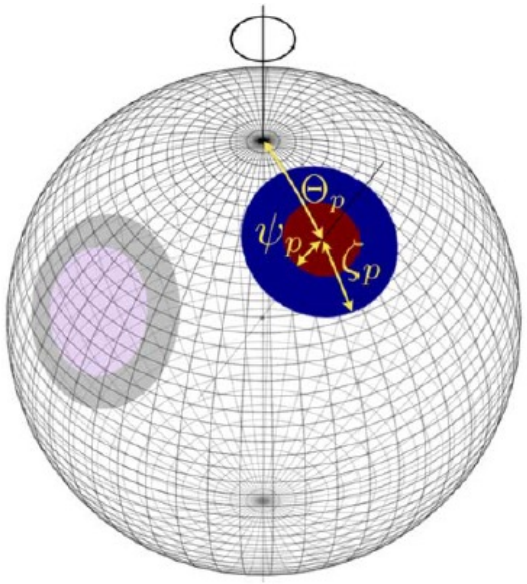

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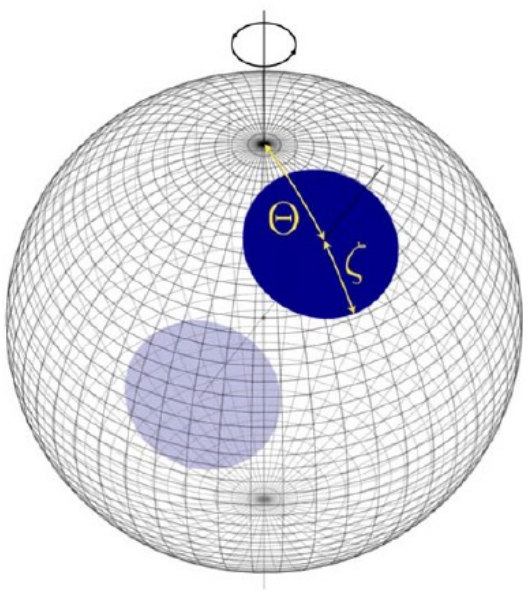

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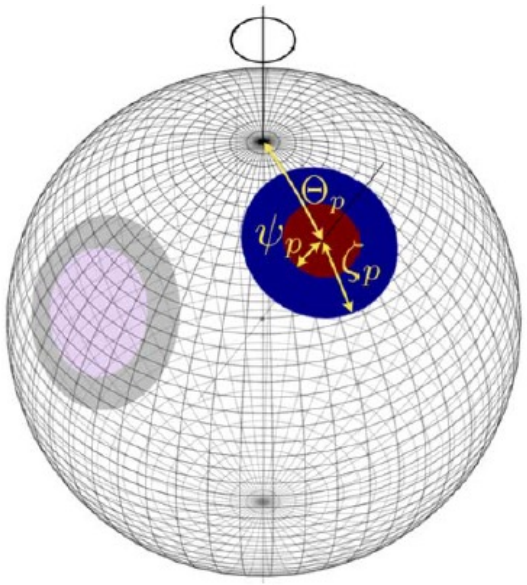

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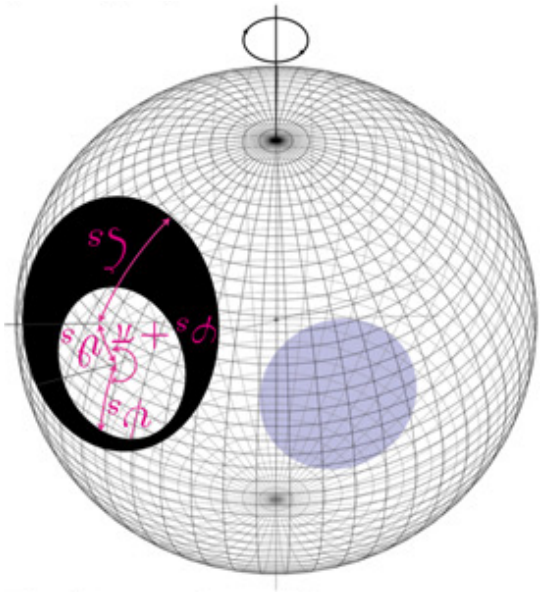

Ring

Modelling: Hot Spots

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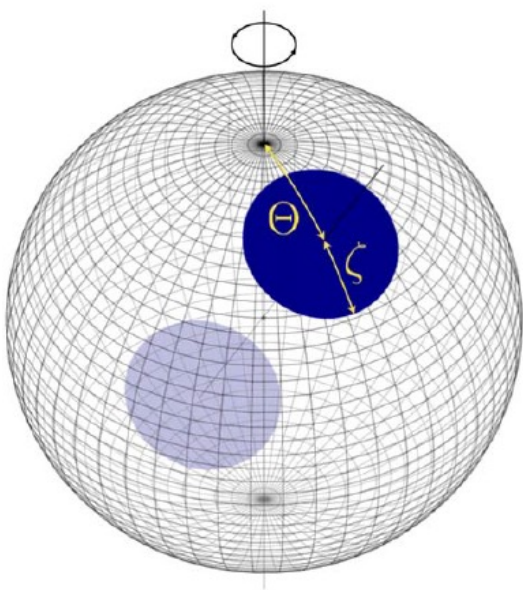
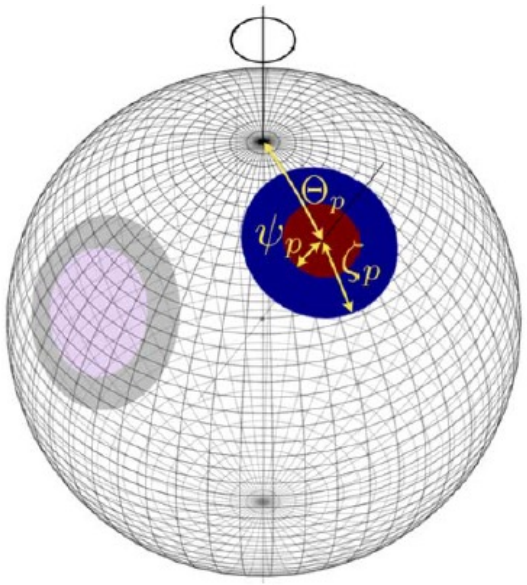


Single-temperature



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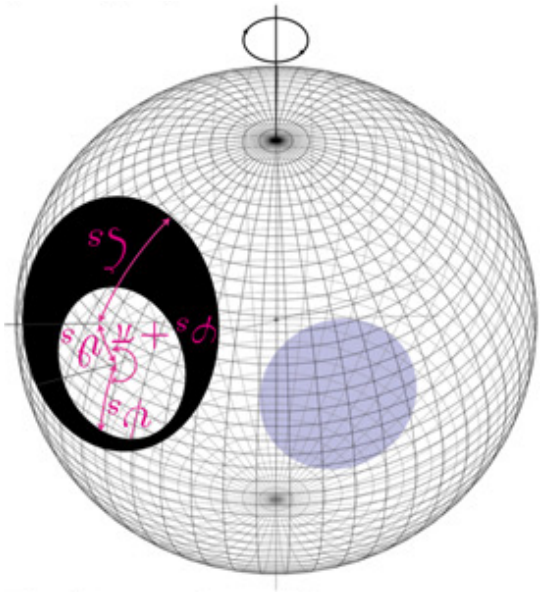
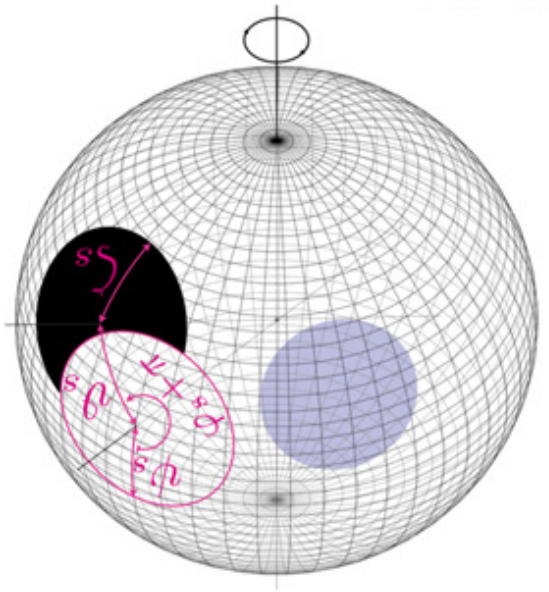


Ring



Crescent

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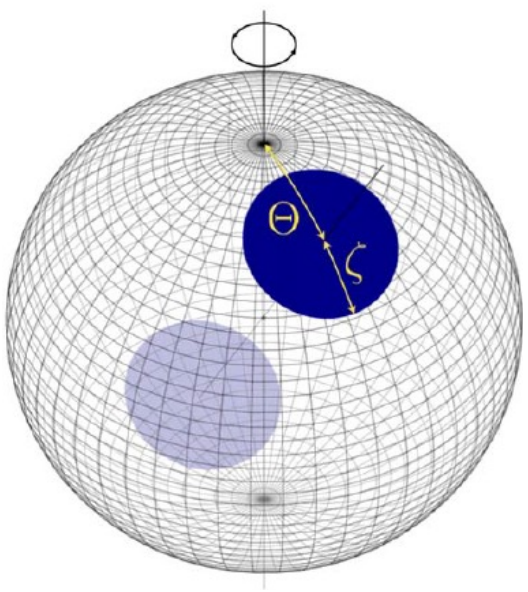
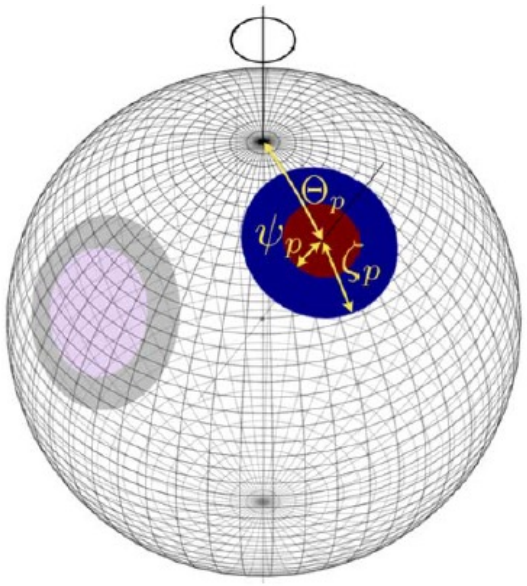
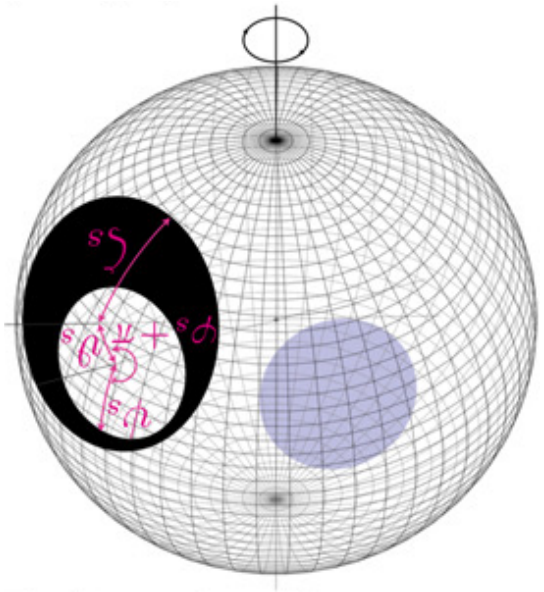


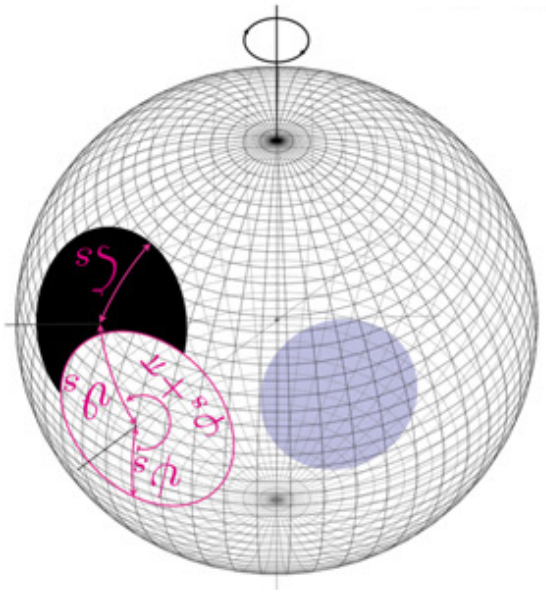
Single-temperature



Dual-temperature



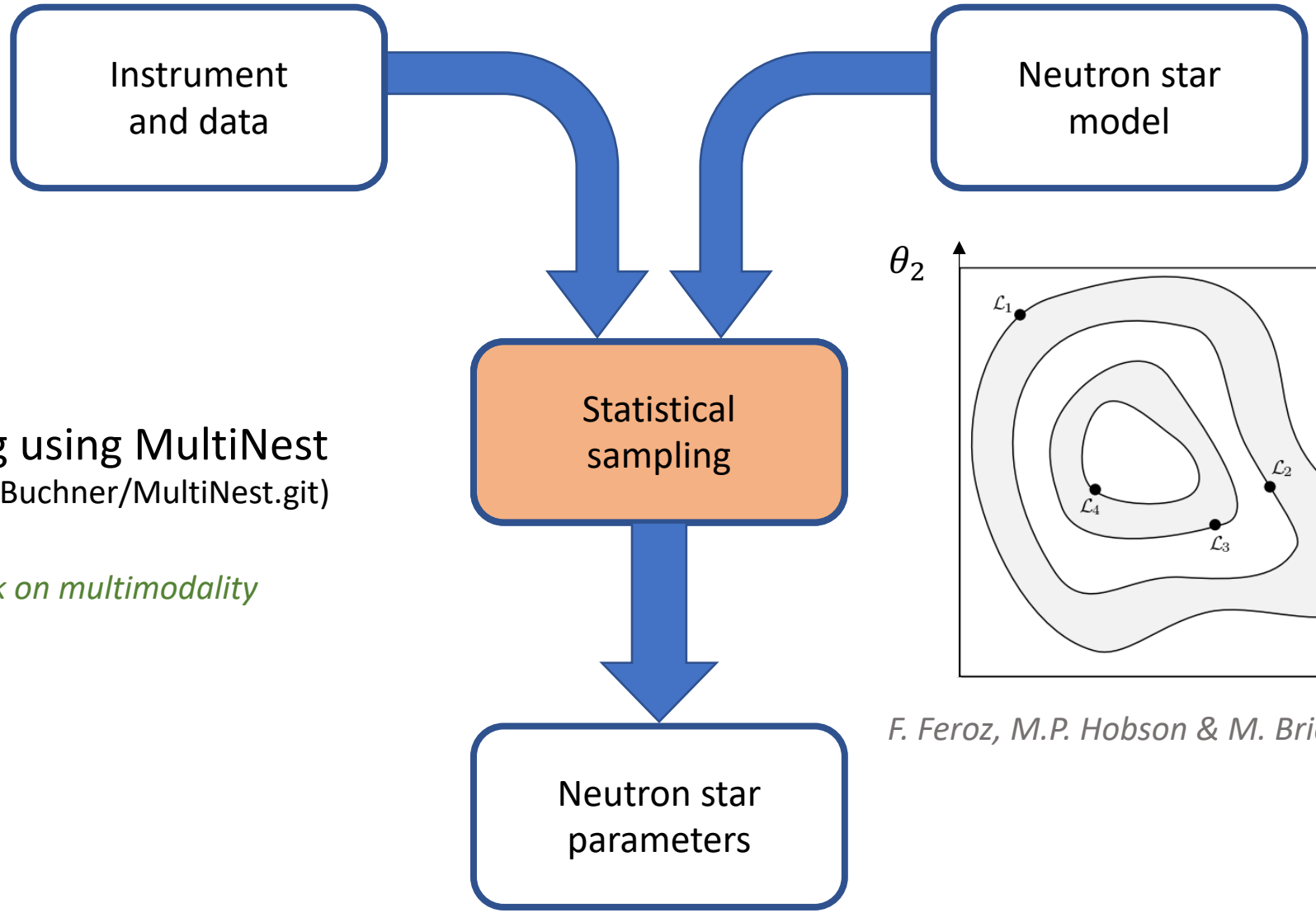
Ring



Crescent

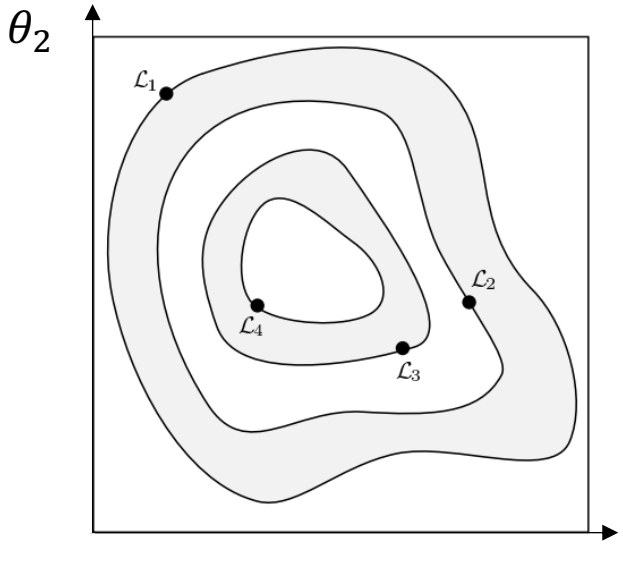
- Geometrically thin, fully-ionised hydrogen atmosphere using NSX (Ho & Lai 2001)
  See Tuomo's talk on atmospheres

X-PSI (github.com/xpsi-group/xpsi)



Nested sampling using MultiNest
(github.com/JohannesBuchner/MultiNest.git)

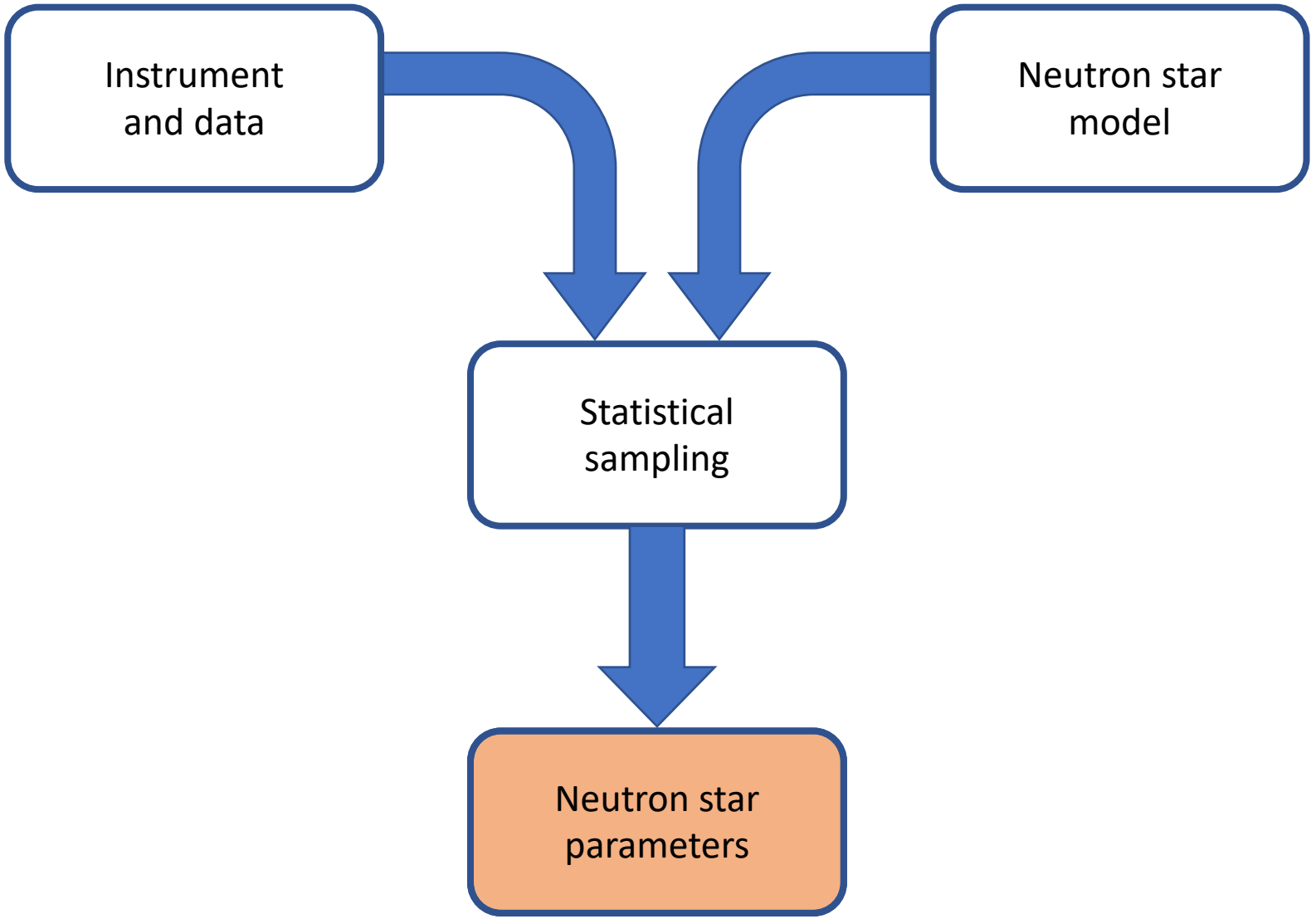
See Serena's talk on multimodality



$\mathcal{L}_1 < \mathcal{L}_2 < \mathcal{L}_3 < \mathcal{L}_4$

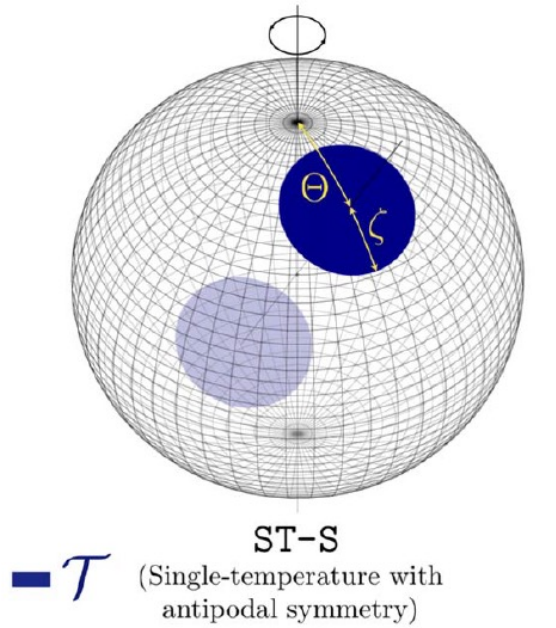
F. Feroz, M.P. Hobson & M. Bridges 2009

X-PSI (github.com/xpsi-group/xpsi)



J0437 Spot Model (ST-S)

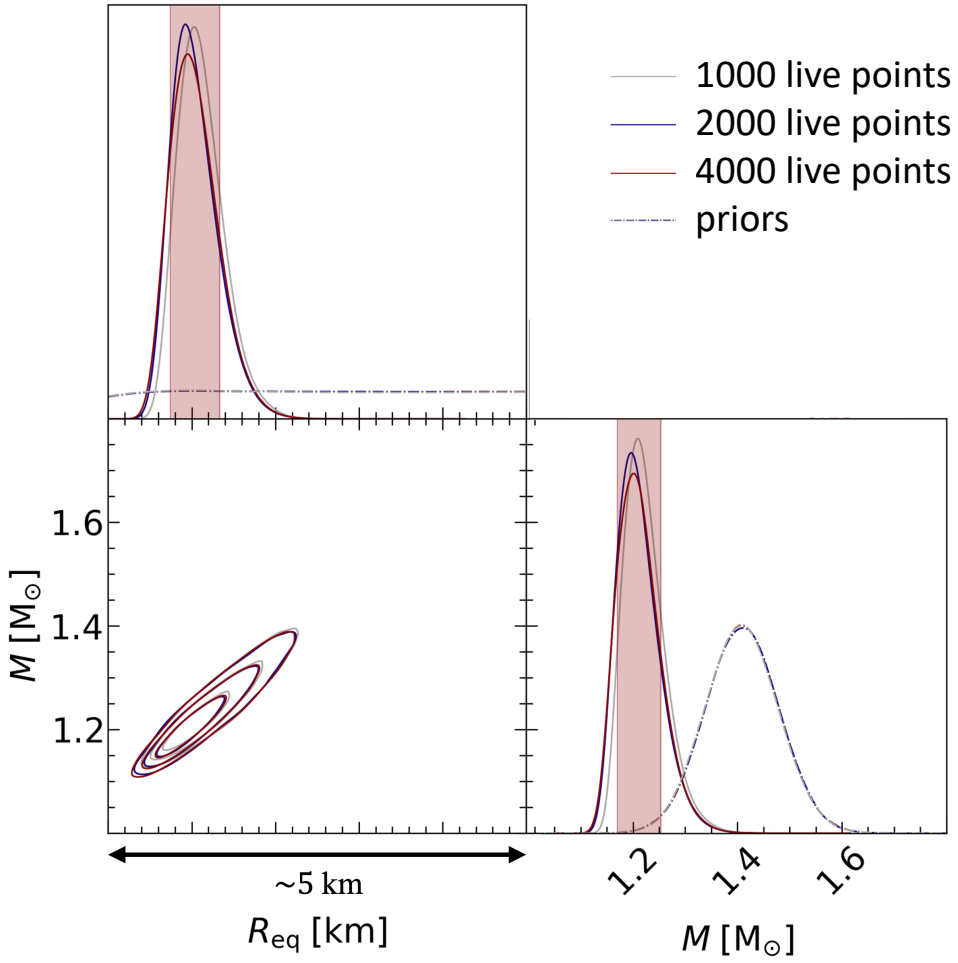
- Spot locations: Antipodal
- Temperature and size: Identical



Riley et al. 2019

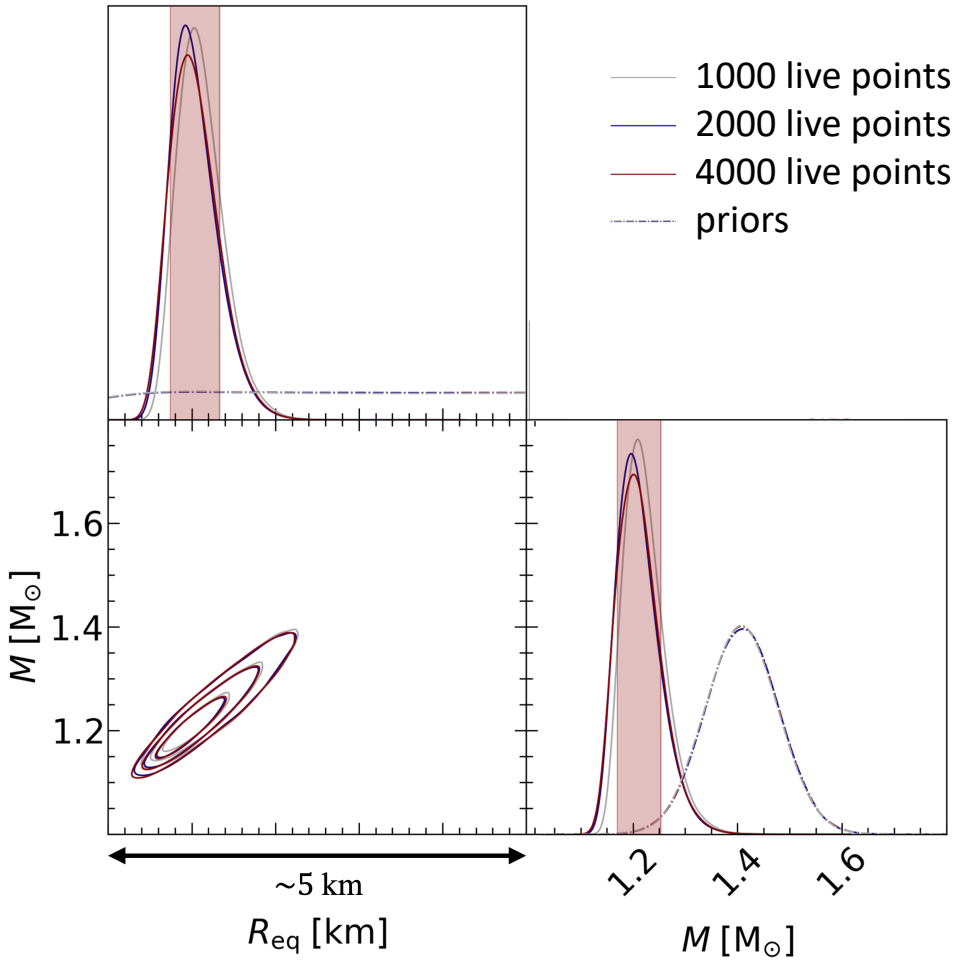
ST-S Results on J0437: Inferred parameters

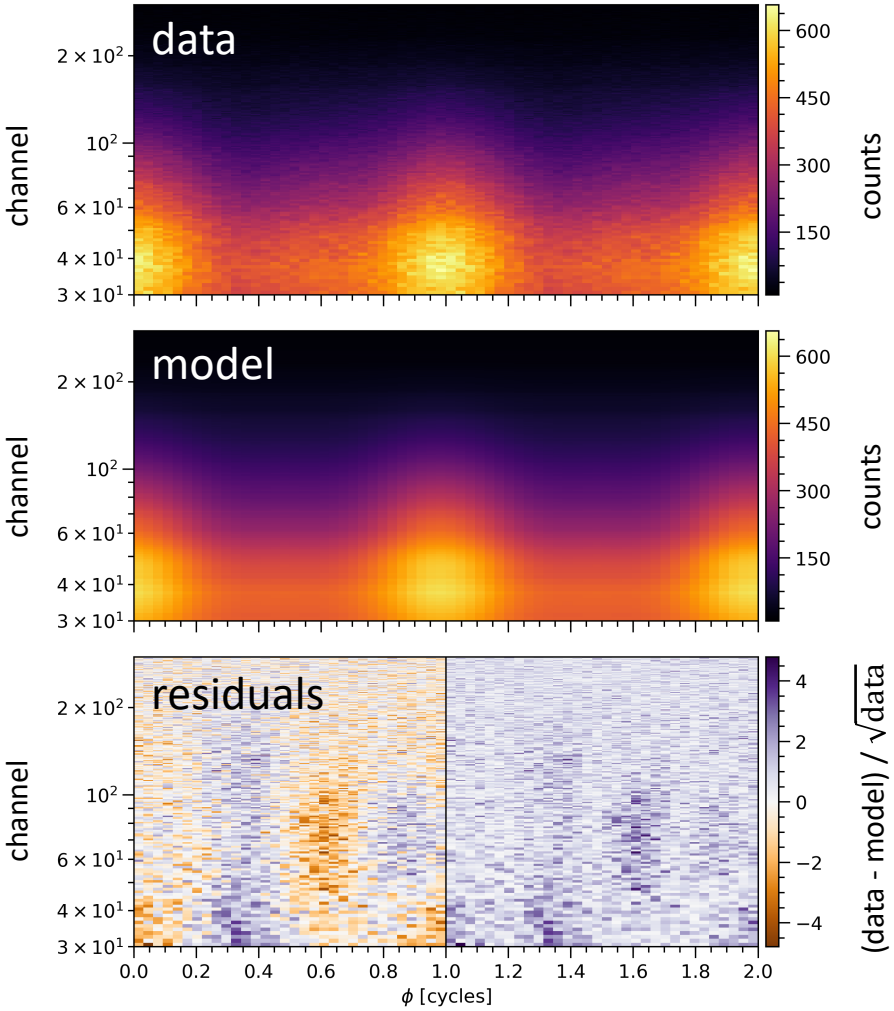
- Tight radius constraint
- Mass not recovered



ST-S Results on J0437: Model performance

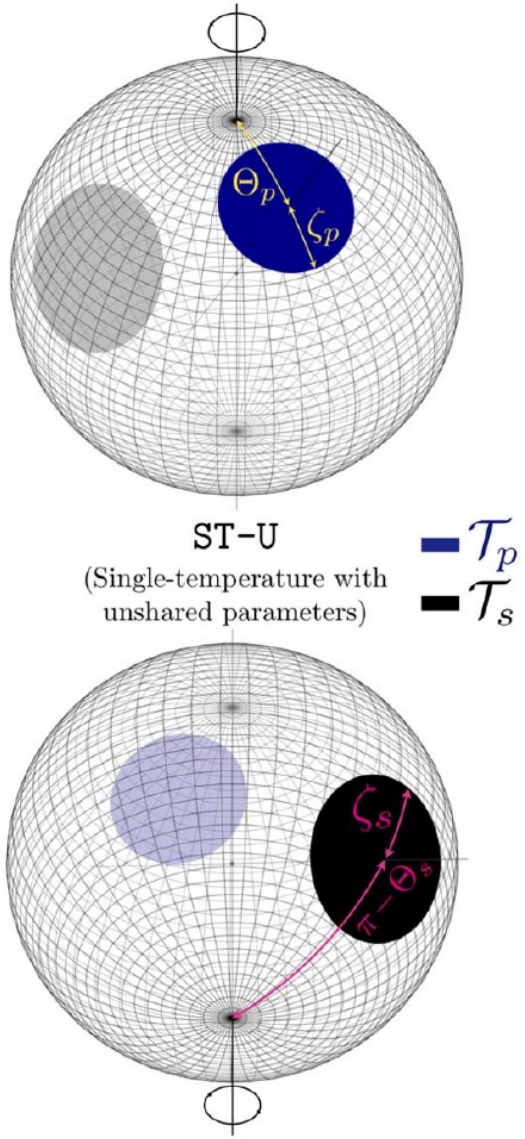
- Tight radius constraint
- Mass not recovered
- Prominent residual structure – can't explain data





J0437 Spot Model (ST-U)

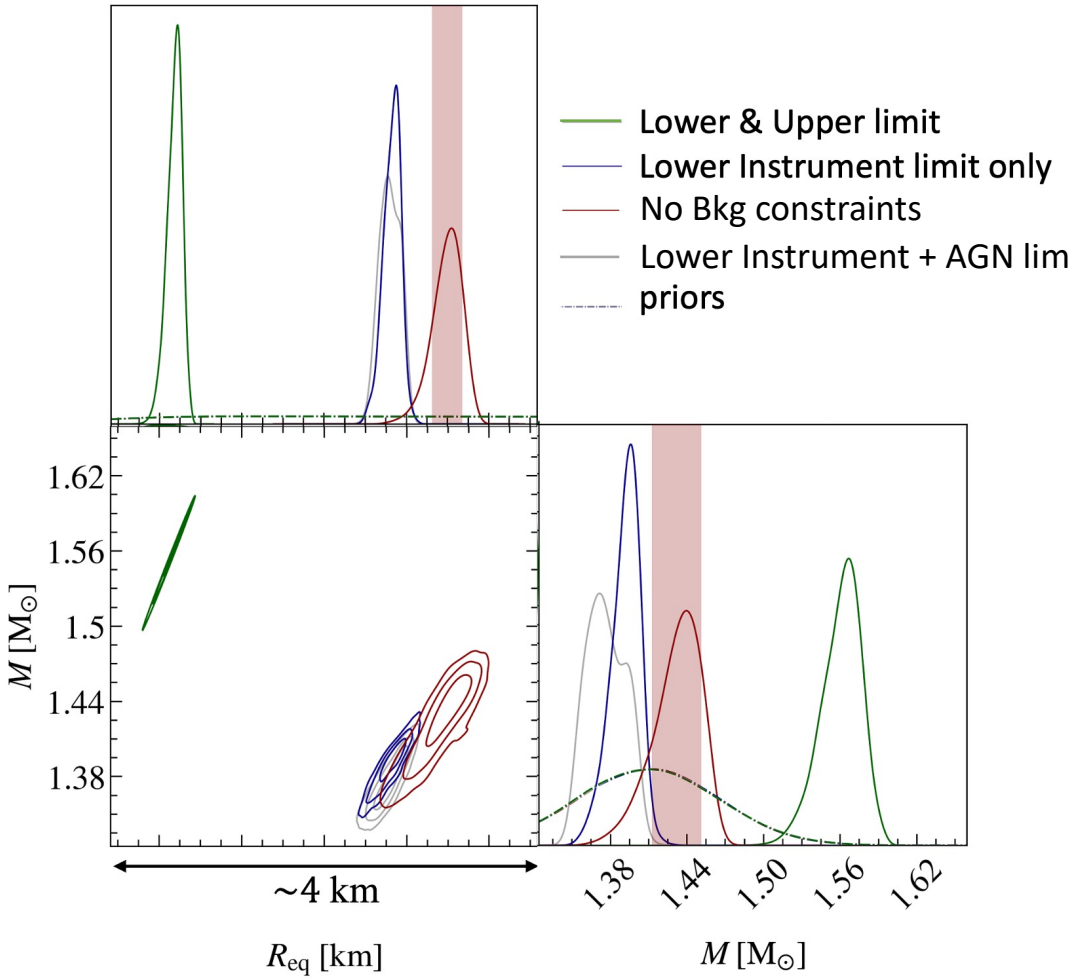
- Spot locations: Independent
- Temperature and size: Non-identical



Riley et al. 2019

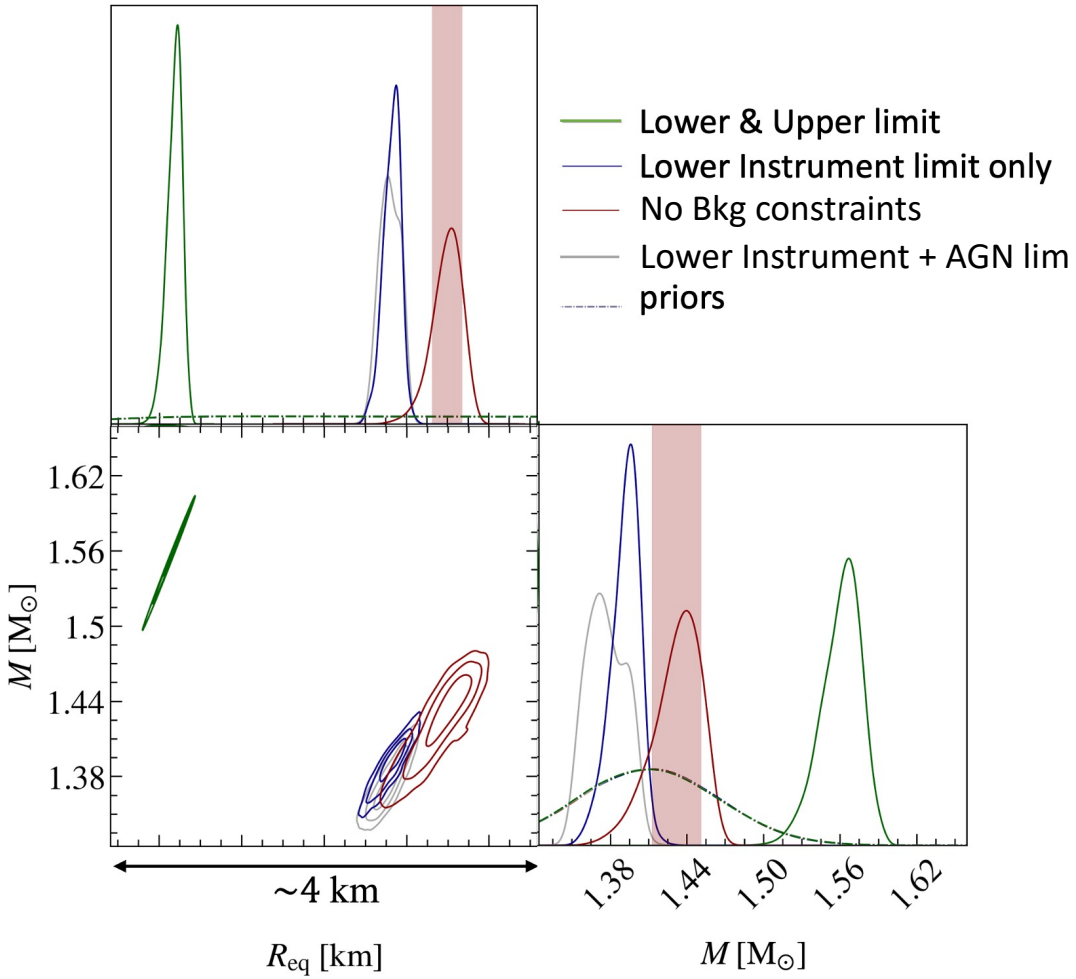
ST-U results on J0437: Inferred parameters

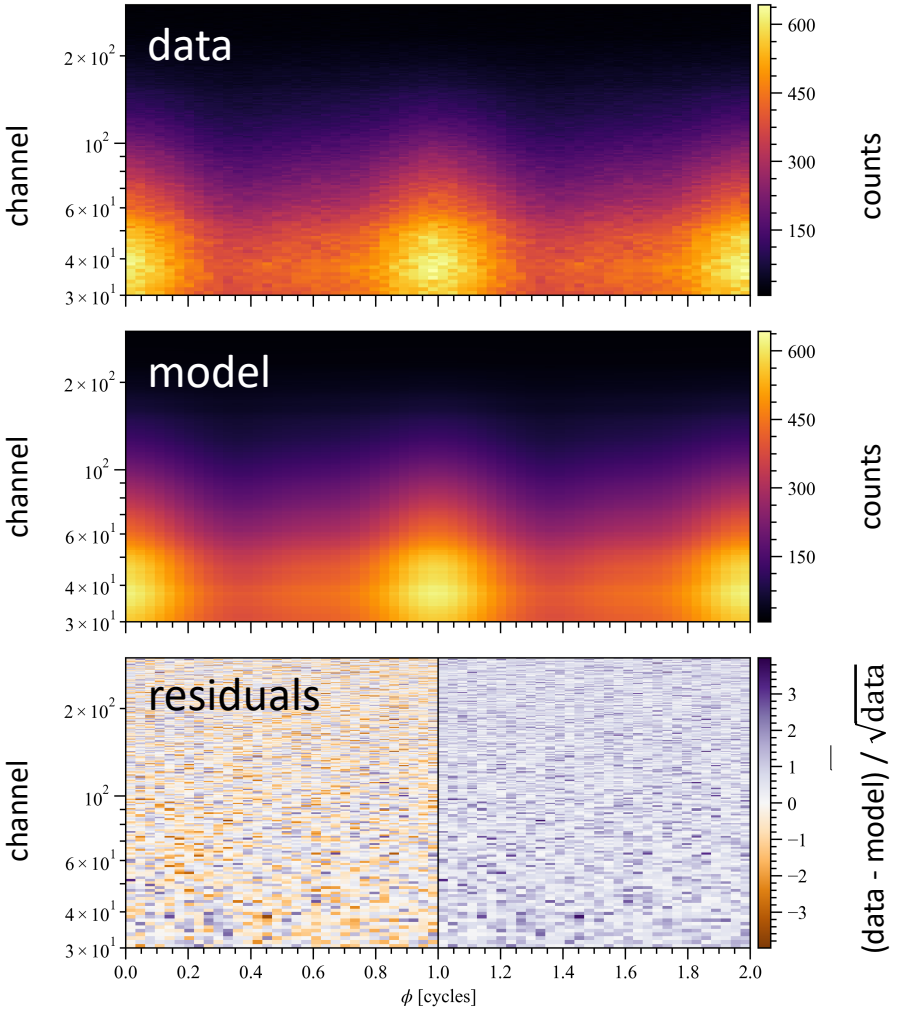
- Mass recovered only in the absence of upper limit



ST-U results on J0437: Free BKG model performance

- Mass recovered only in the absence of upper limit
- Fairly good residuals in the absence of upper limits

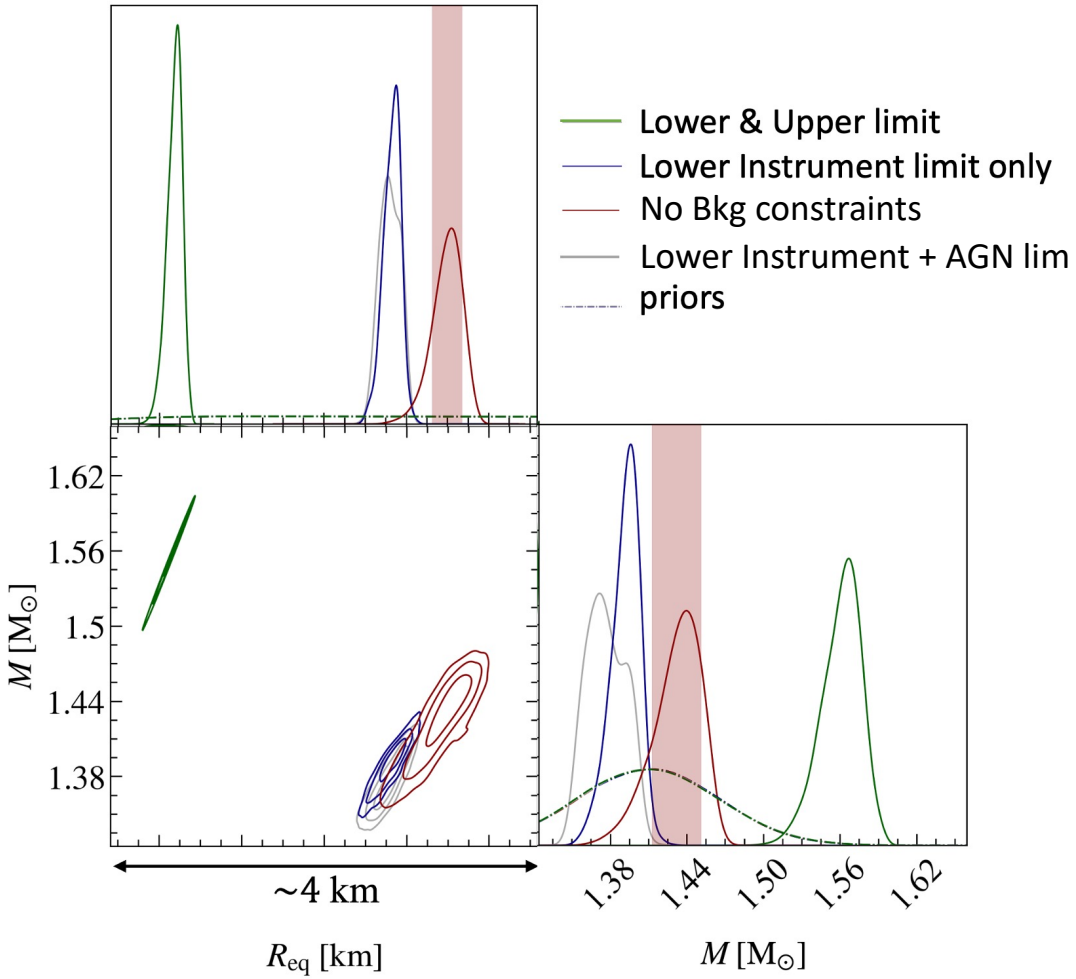


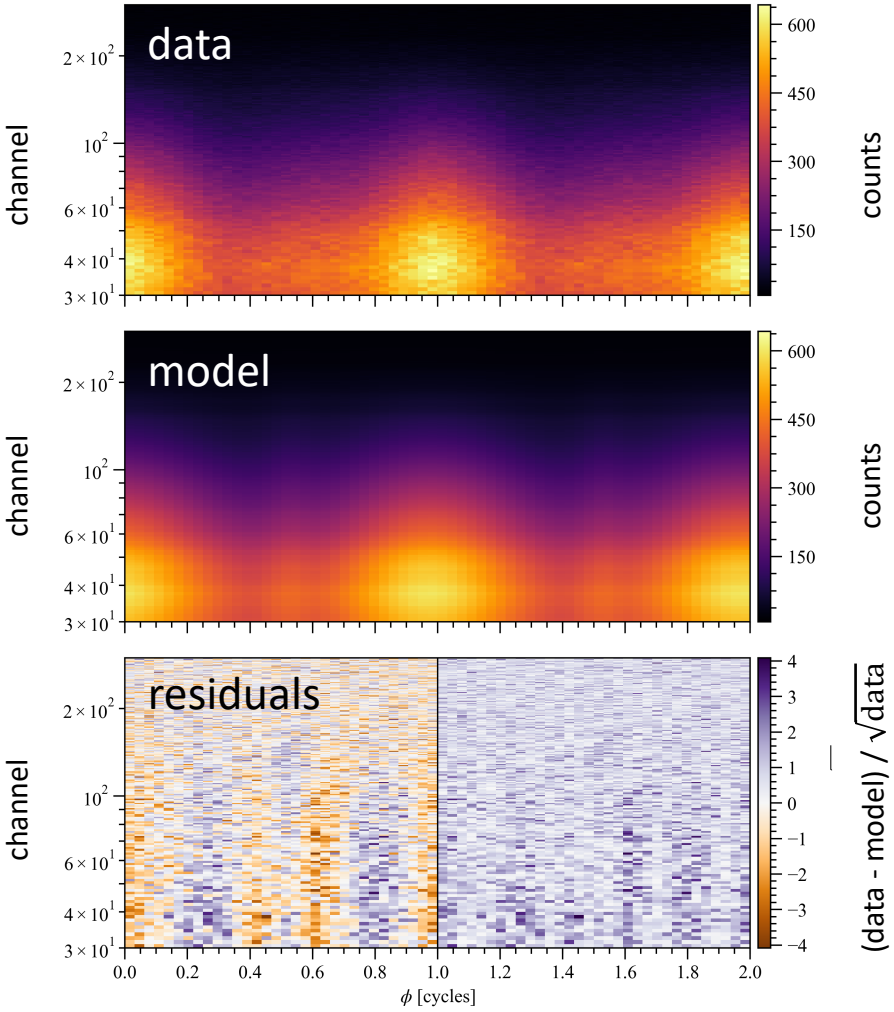


Free BKG model

ST-U Results on J0437: Constrained BKG model performance

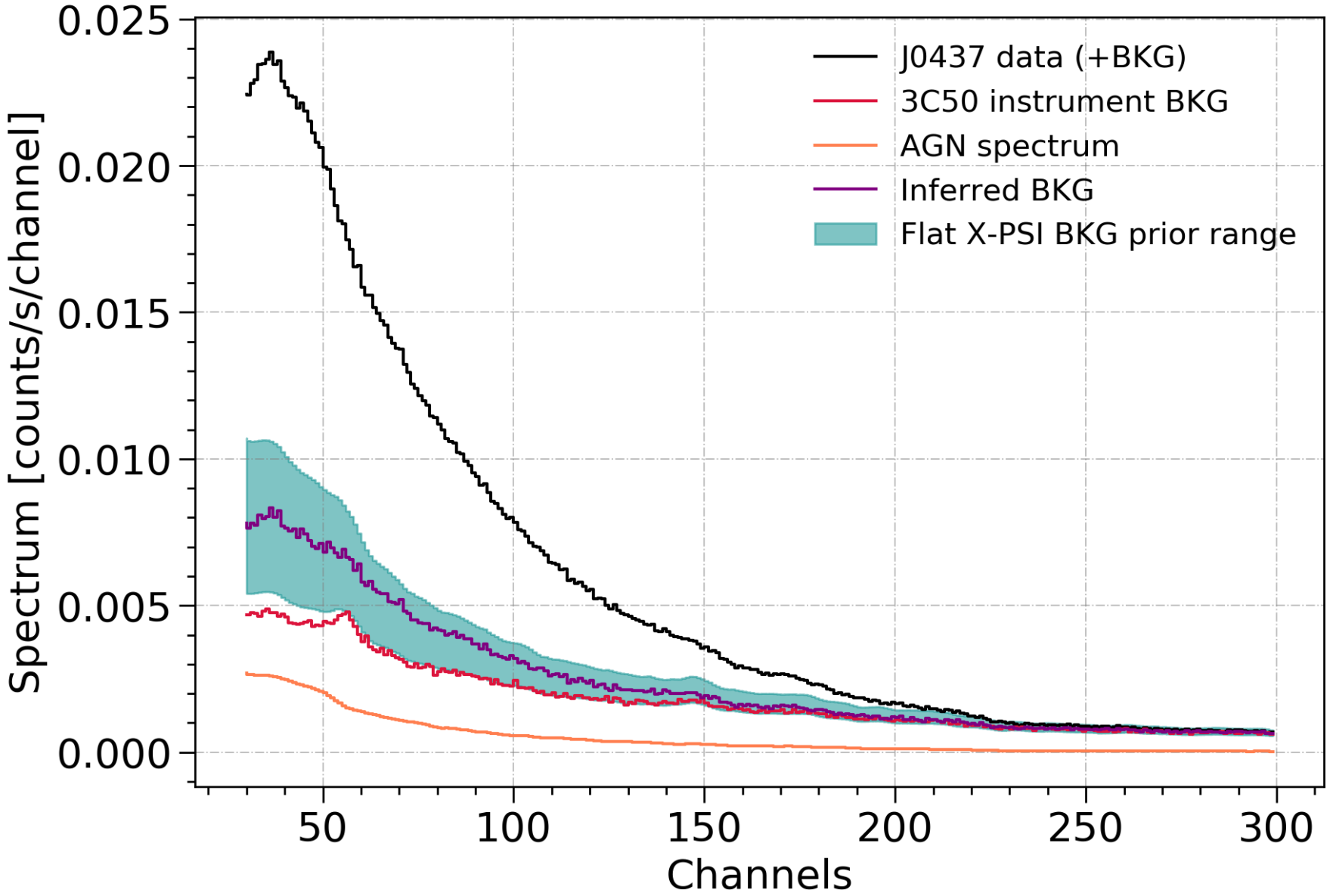
- Mass recovered only in the absence of upper limit
- Fairly good residuals in the absence of upper limits
- Prominent residuals in the presence of upper limits – deficient model



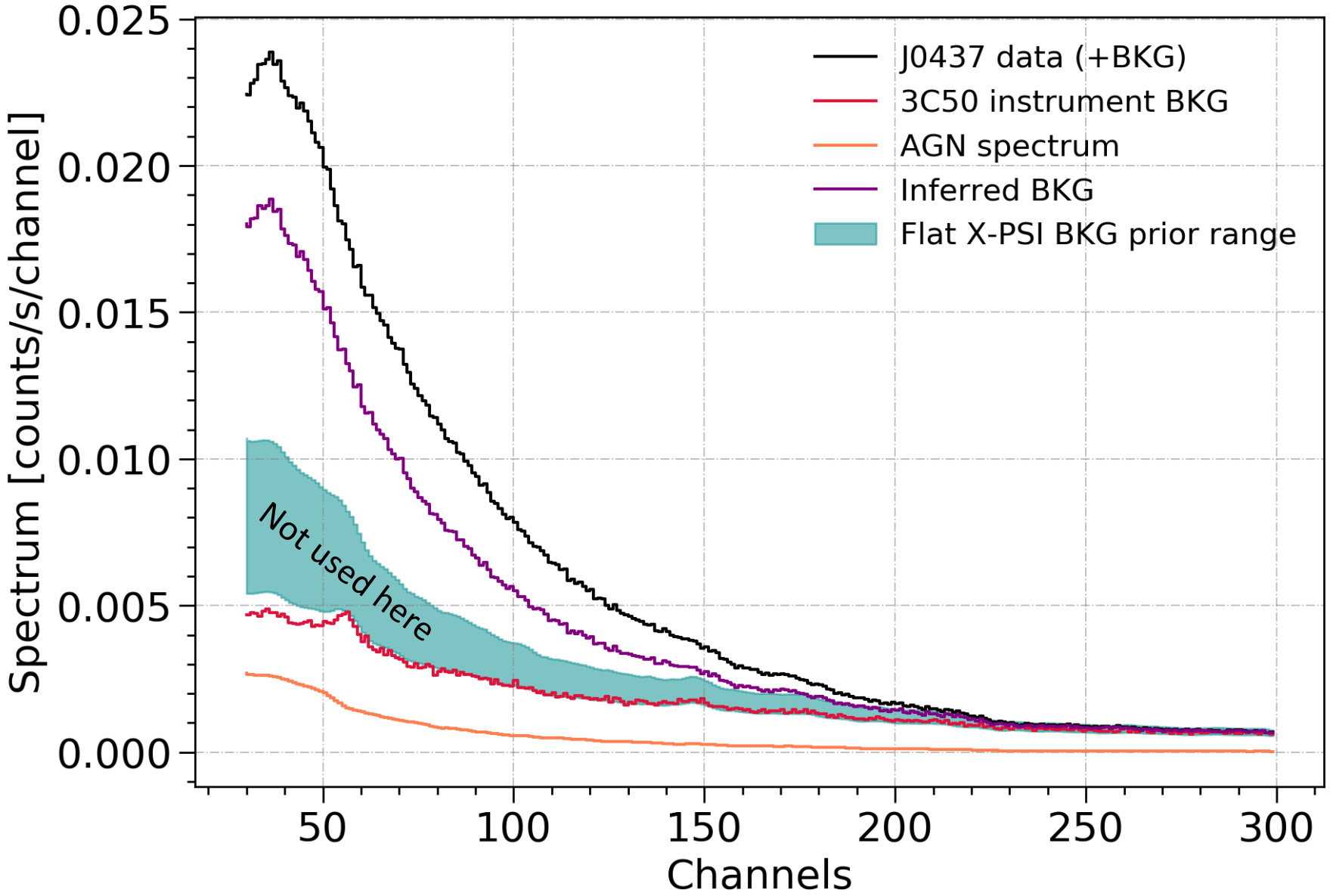


Lower & upper BKG constrainted model

ST-U inferred BKG with lower and upper constraints

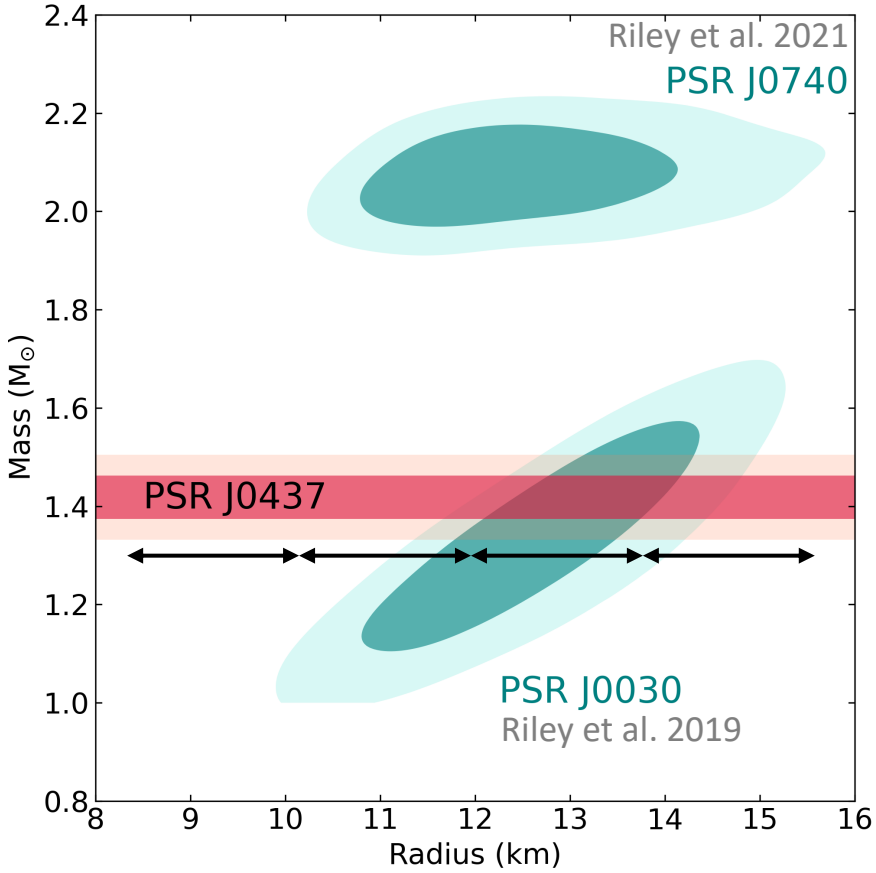


ST-U inferred BKG with no constraints

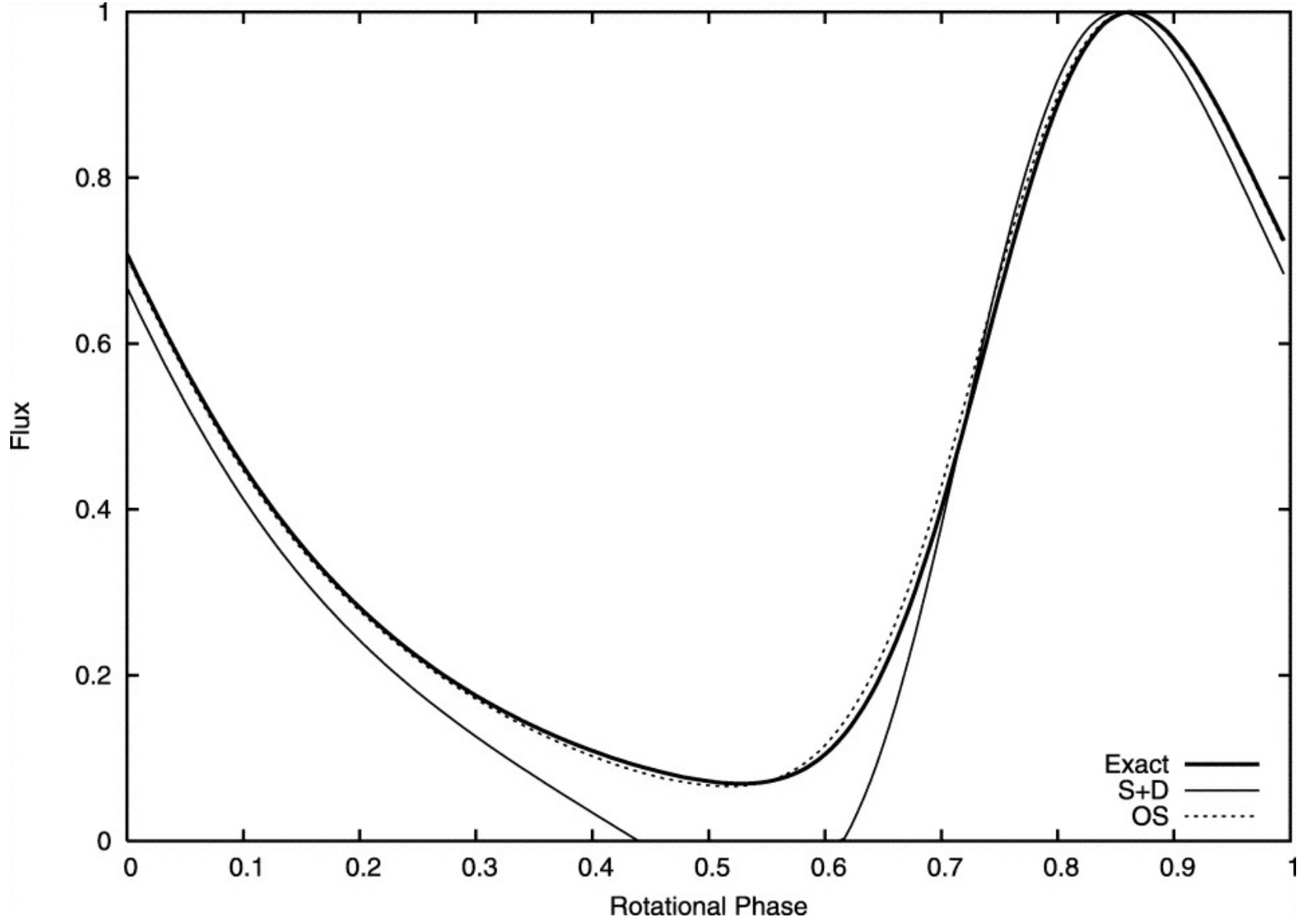


Current Best Models & Radius Constraint Level

- Good news! We have models that work! (Including IM group)
  - Involve more complex geometries
  - Data explained with and without upper BKG constraints
  - Radii consistent for different BKG constraint impositions
  - Better max. likelihood outputs and evidences
- Runs without radio priors tested
  - Radio priors are vital for J0437
- Joint fits with XMM consistent
- Current best model: $\pm 6\%$ radius constraint



Backup slides


Flux
Rotational Phase
Exact
S+D
OS
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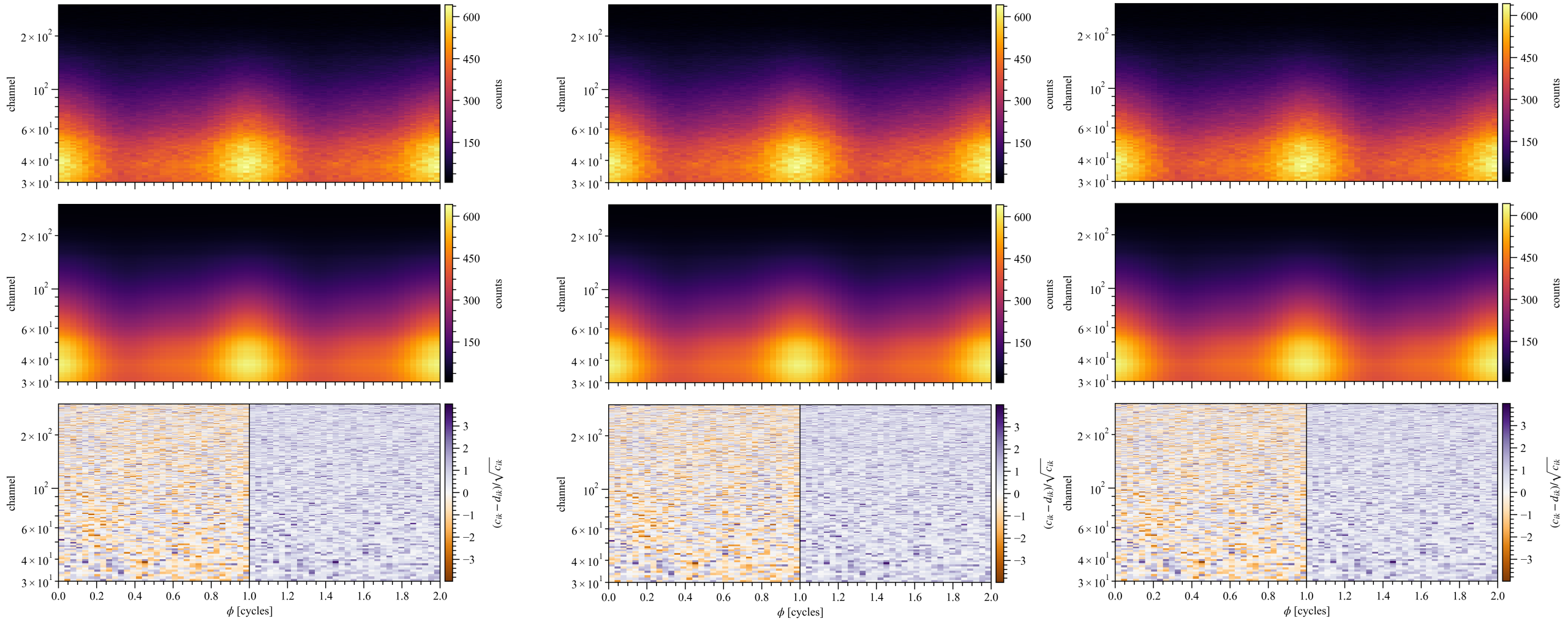
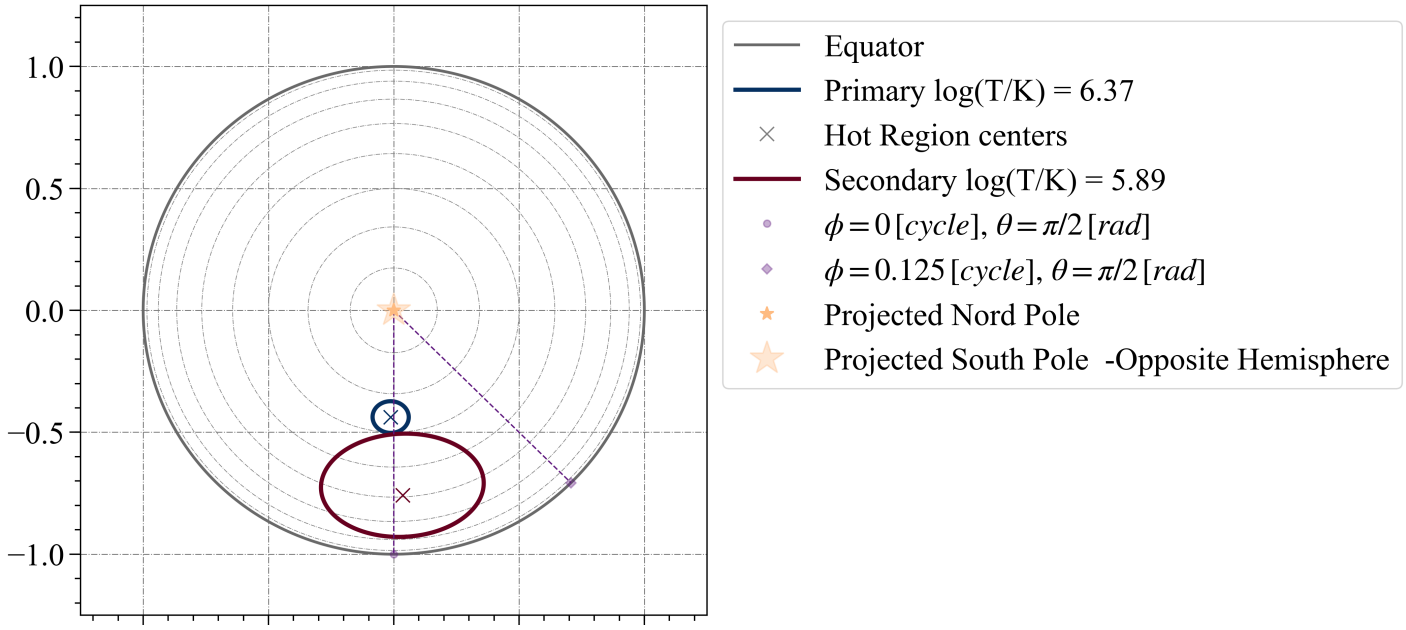
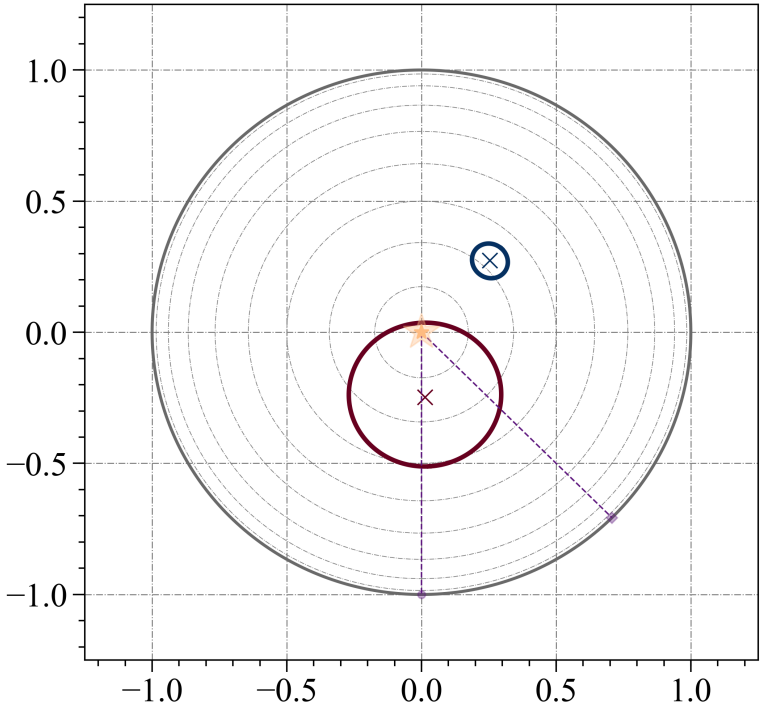
0.2
0.4
0.6
0.8
1
0.1
0.3
0.5
0.7
0.9


channel
counts
ϕ [cycles]
$(c_{ik} - d_{ik})/\sqrt{c_{ik}}$


1.0
0.5
0.0
−0.5
−1.0
Equator
Primary log(T/K) = 6.37
Hot Region centers
Secondary log(T/K) = 5.89
$\phi = 0\,[cycle]$, $\theta = \pi/2\,[rad]$
$\phi = 0.125\,[cycle]$, $\theta = \pi/2\,[rad]$
Projected Nord Pole
Projected South Pole -Opposite Hemisphere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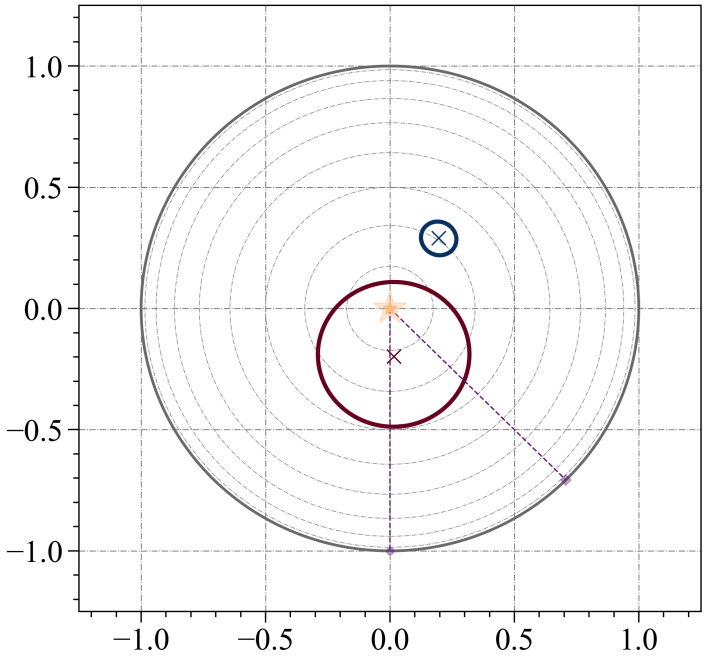
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0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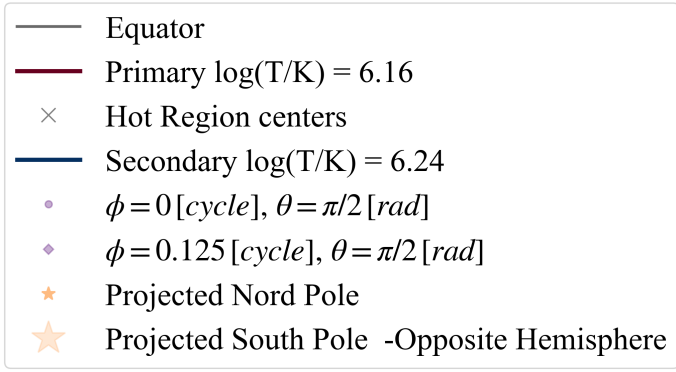
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0


Equator
Primary log(T/K) = 6.16
Hot Region centers
Secondary log(T/K) = 6.24
$\phi = 0\,[cycle]$, $\theta = \pi/2\,[rad]$
$\phi = 0.125\,[cycle]$, $\theta = \pi/2\,[rad]$
Projected Nord Pole
Projected South Pole -Opposite Hemisphere