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

Devarshi Choudhury
Nuclear Physics ⇔ Spacetime

Equation of state

- Nucleonic
- Quark
- Hyperonic

Dense matter physics

- Neutron
- Hyperon

Mass–radius

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

Instrument and data

Neutron star model

Statistical sampling

Neutron star parameters
Instrument and data

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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
NICER’s Primary Target: PSR J0437-4715

• Closest millisecond pulsar
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• Binary system – tight mass and inclination constraint
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

Bogdanov et al. 2019

Nearby AGN

PSR J0437-4715

Optimal pointing
PSR J0437-4715: Field-of-View

Nearby AGN

PSR J0437-4715

Instrument offset pointing

Bogdanov et al. 2019
PSR J0437-4715: Response Scaling

Nearby AGN

PSR J0437-4715

Instrument offset pointing

Instrument response curve

- Unscaled response
- Scaled response
PSR J0437-4715: Response Scaling

Instrument response curve

- Nearby AGN
- PSR J0437-4715
- Instrument offset pointing

Bogdanov et al. 2019

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PSR J0437-4715: 3C50 Data Set & BKG

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

- Observed between 20 Jul 2017 – 11 Oct 2021
- 1.3 Ms of observation
PSR J0437-4715: 3C50 Data Set & BKG

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- No BKG constraint

3C50 data set (Remillard et al. 2022)

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- 1.3 Ms of observation
- Provides instrument BKG estimate
PSR J0437-4715: 3C50 Data Set & BKG

- 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
PSR J0437-4715: 3C50 Data Set & BKG

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BKG parameters (1 per channel)

Marginalised when calculating likelihood
Instrument and data \rightarrow Statistical sampling \rightarrow Neutron star parameters

Neutron star model \rightarrow Statistical sampling \rightarrow Neutron star parameters
Modelling: Relativistic Ray Tracing

- Oblate Schwarzschild + Doppler approximation
  (Morsink et al. 2007)
Modelling: Relativistic Ray Tracing

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

• Radio priors from Parkes Pulsar Timing Array
  (PPTA-DR4, Reardon et. al. in prep):
  
  • $M = 1.418 \pm 0.044 \, M_{\odot}$
  • $i = 137.506 \pm 0.016$ degrees
  • $D = 156.98 \pm 0.16$ pc
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Riley et al. 2019

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Modelling: Hot Spots

Riley et al. 2019

Single-temperature
Modelling: Hot Spots

Riley et al. 2019

Single-temperature  
Dual-temperature
Modelling: Hot Spots

- Single-temperature
- Dual-temperature
- Ring

*Riley et al. 2019*
Modelling: Hot Spots

Single-temperature

Dual-temperature

Ring

Crescent

Riley et al. 2019
Modelling: Hot Spots

- Geometrically thin, fully-ionised hydrogen atmosphere using NSX (Ho & Lai 2001)

*See Tuomo’s talk on atmospheres*
Nested sampling using MultiNest (github.com/JohannesBuchner/MultiNest.git)

See Serena’s talk on multimodality

F. Feroz, M.P. Hobson & M. Bridges 2009
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Neutron star parameters
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
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
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
ST-U inferred BKG with lower and upper constraints
ST-U inferred BKG with no constraints

- J0437 data (+BKG)
- 3C50 instrument BKG
- AGN spectrum
- Inferred BKG
- Flat X-PSI BKG prior range
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: ±6% radius constraint
Backup slides