How many neutron stars are there in our Galaxy?

Galaxy-wide inference based on a small slice of censored data

Arash Bahramian,

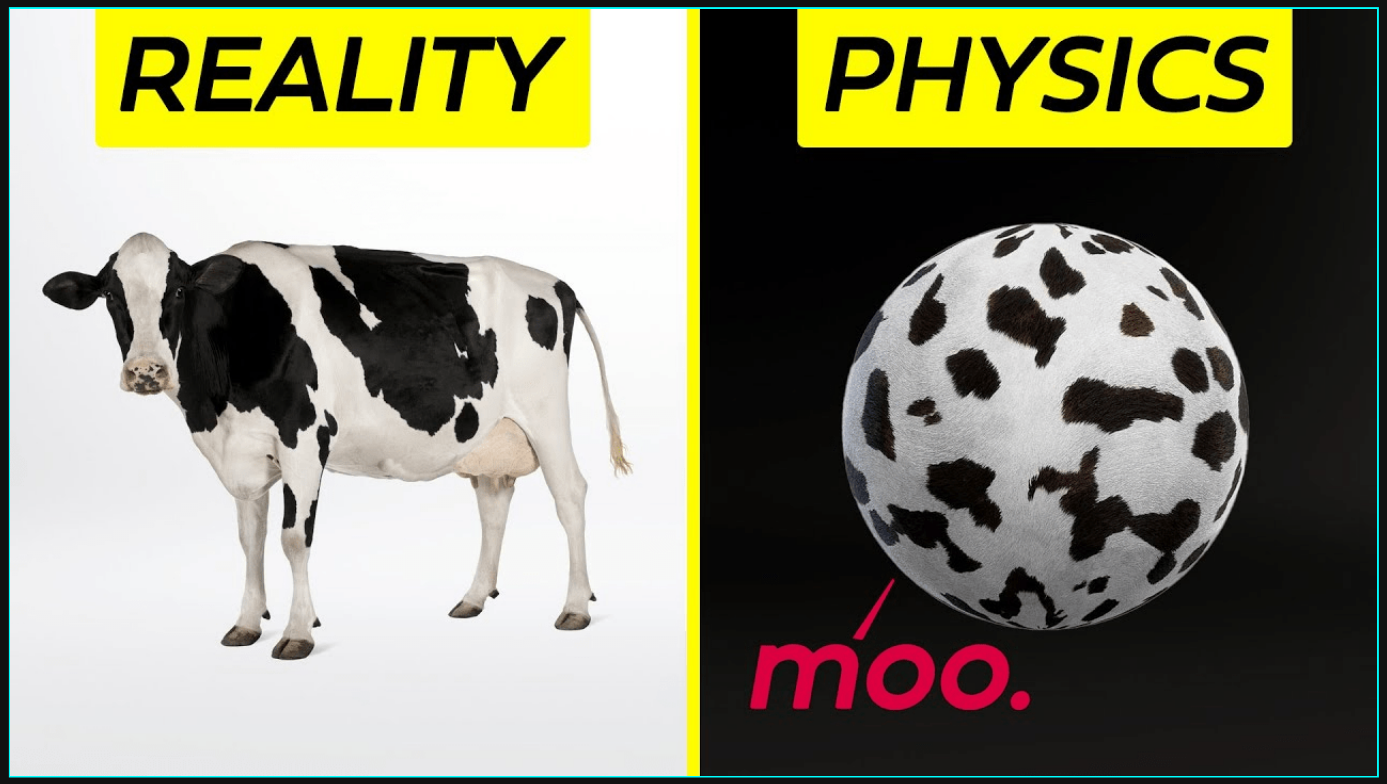
Aloke Phatak, Craig Heinke, Natalie Langford

ICRAR

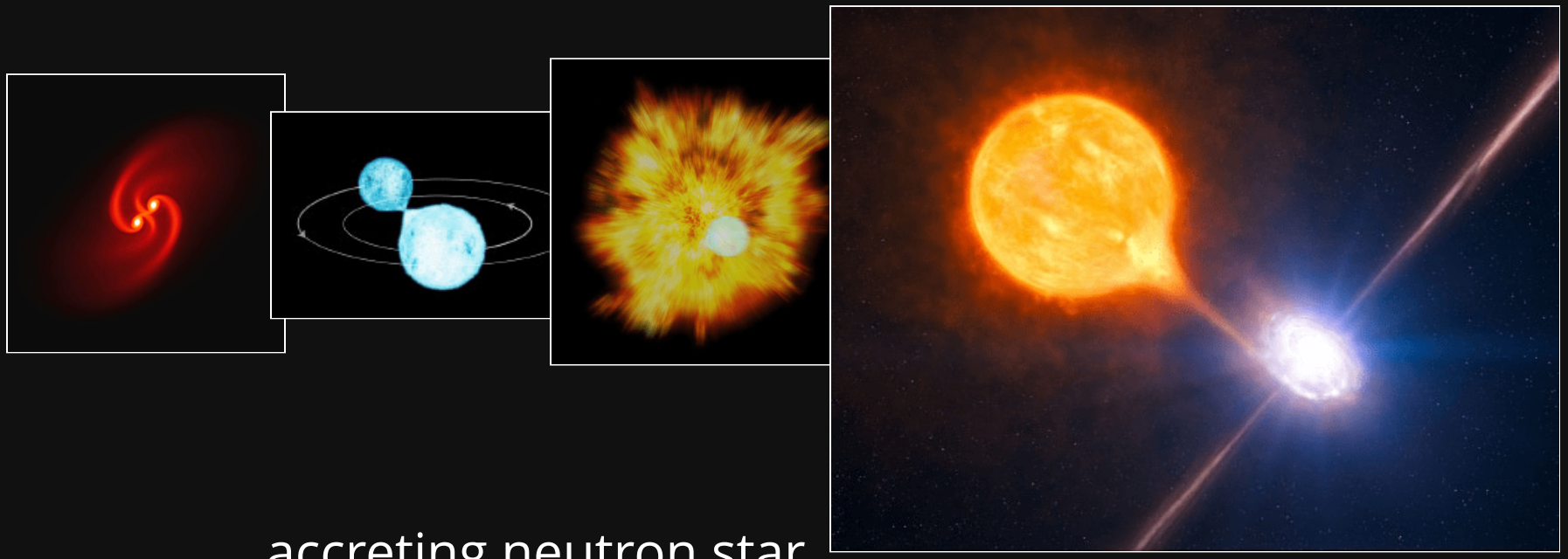
Data Science Transforming Maintenance

Curtin University

Astronomy and Statistics

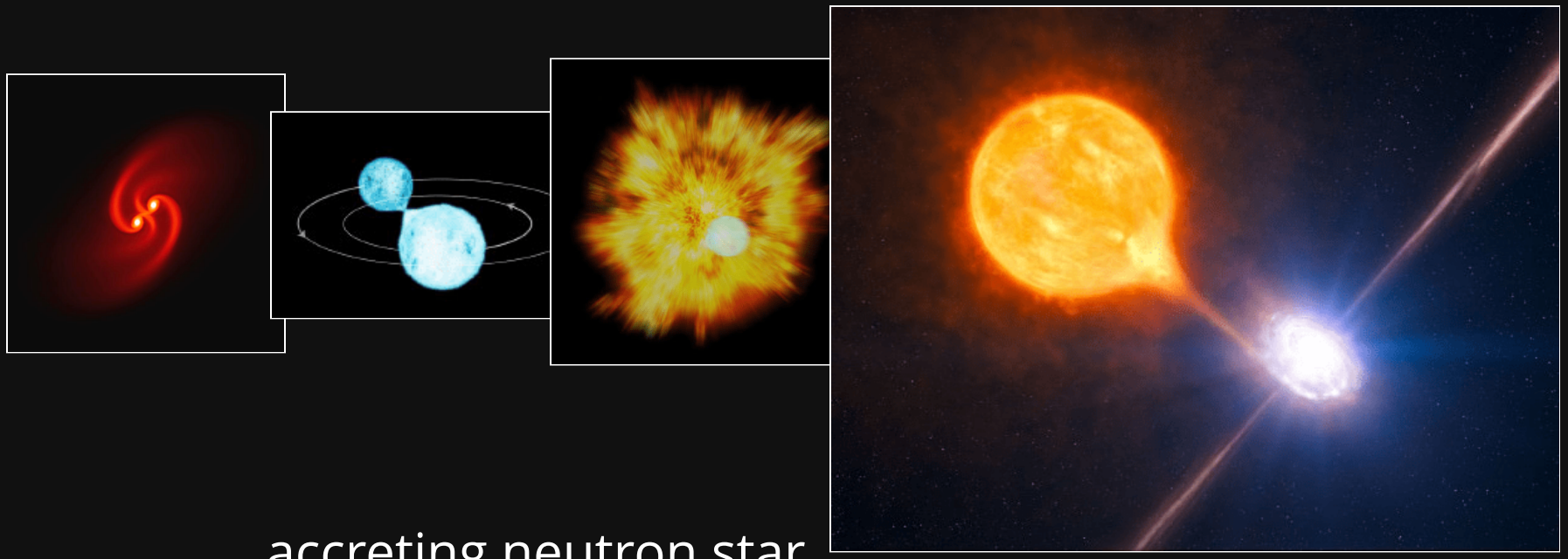


Accreting neutron stars

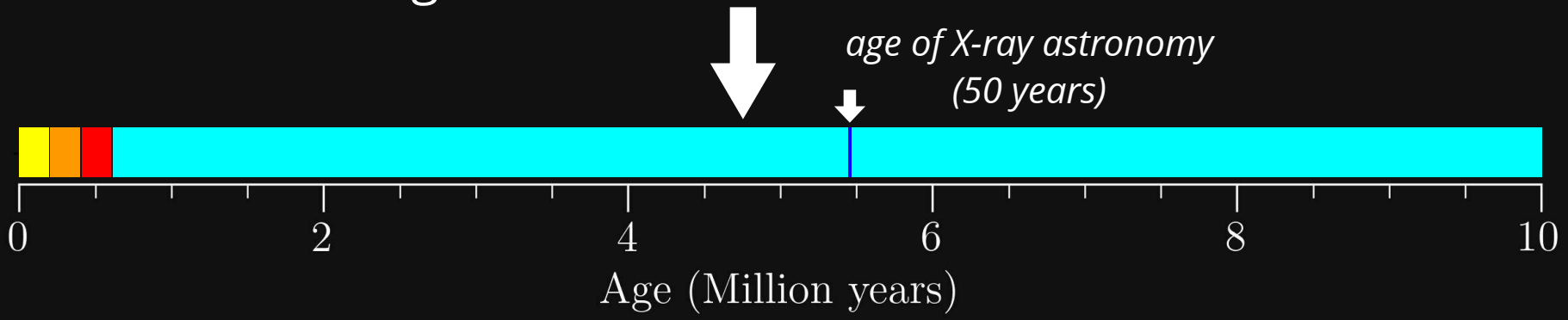


accreting neutron star

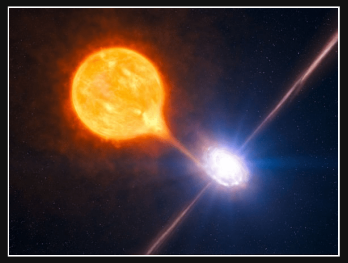
Accreting neutron stars

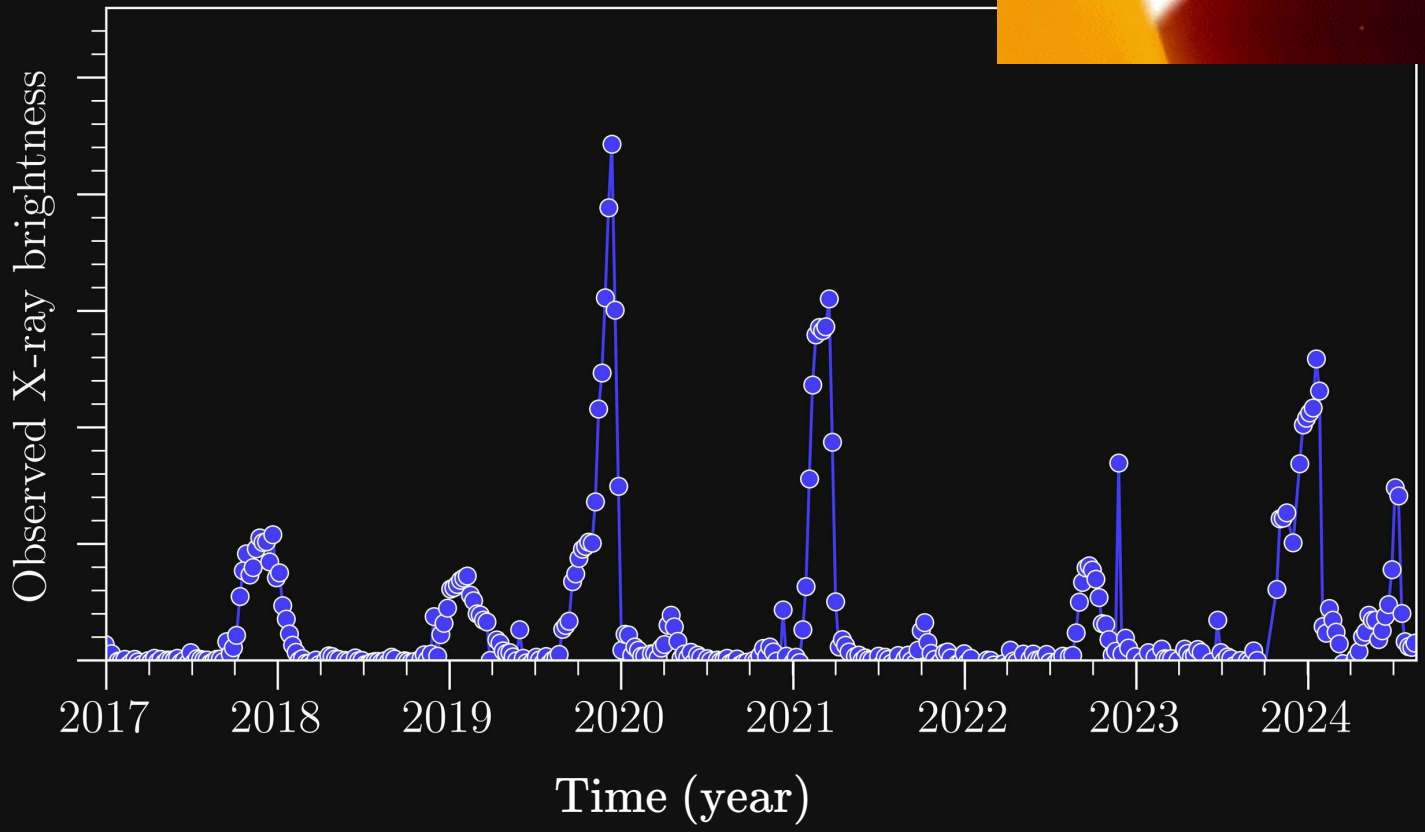


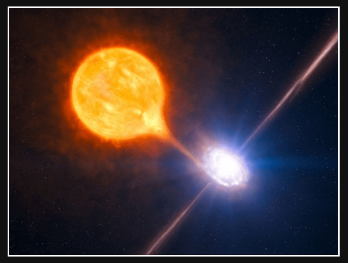
accreting neutron star



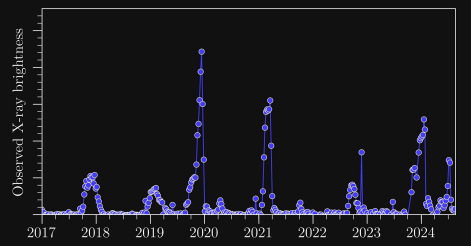
Accreting neutron stars



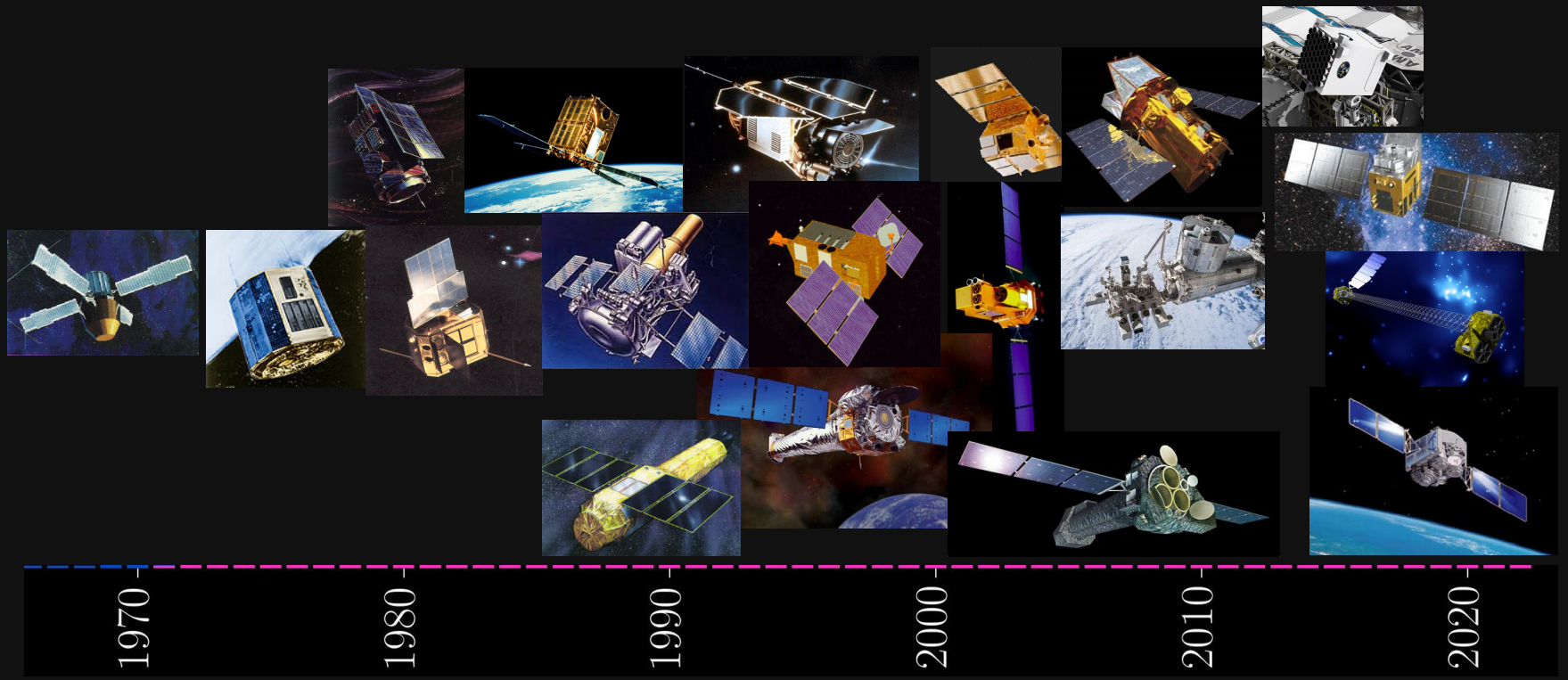




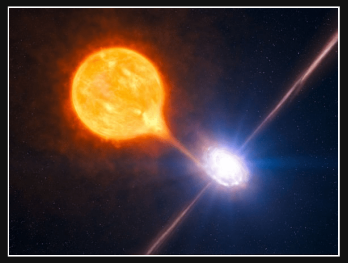
Accreting neutron stars



How we observe and detect them

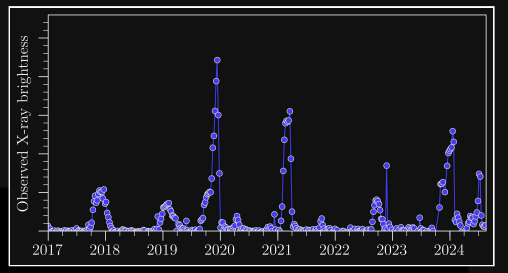


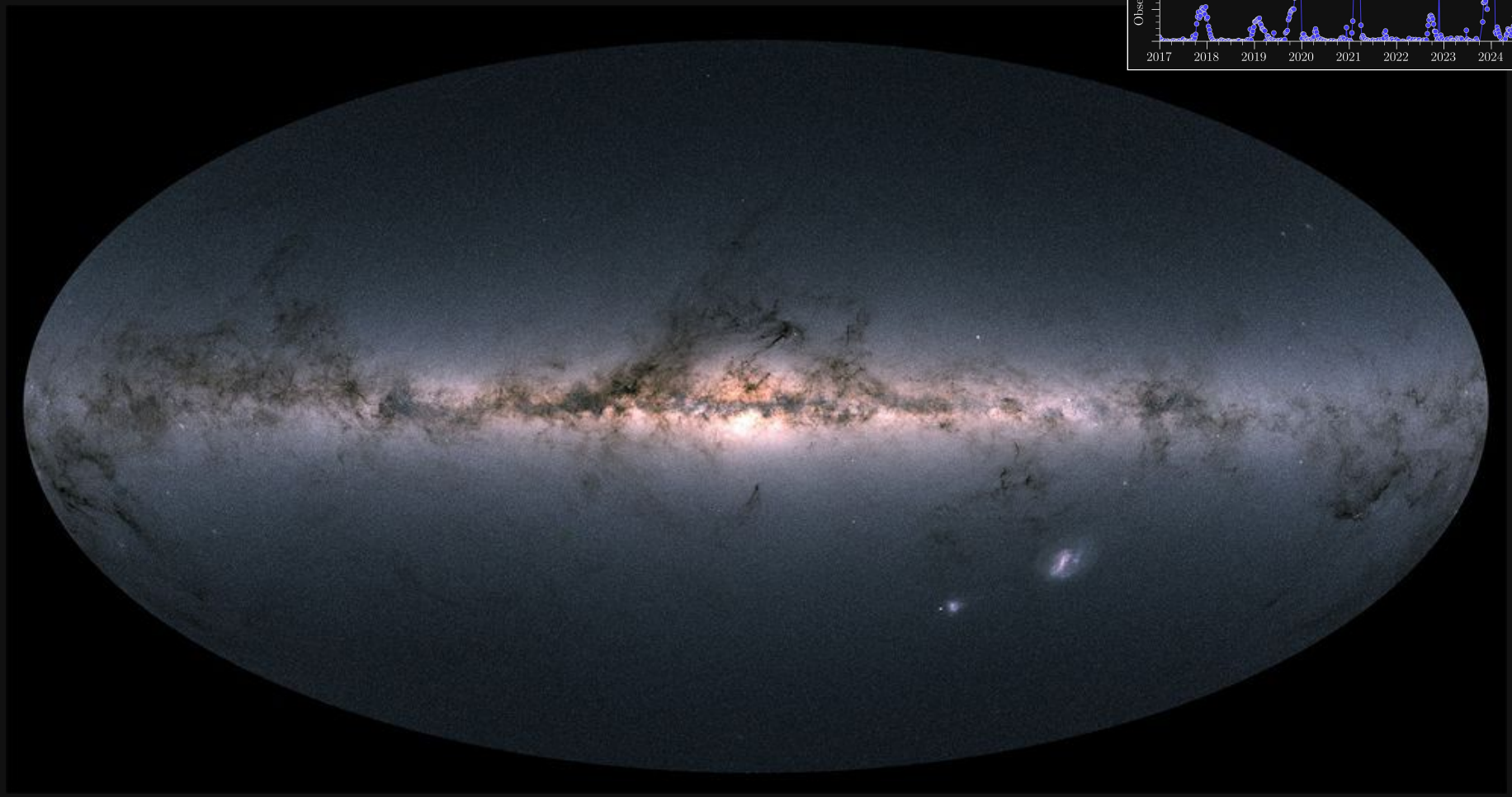
Everything is based on 50 years of observational data,
no controlled experiments

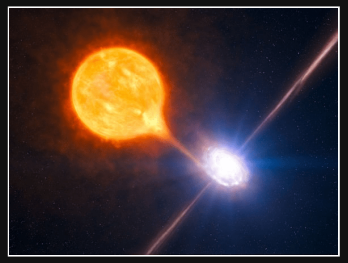


Accreting neutron stars

What fraction of accreting neutron stars have we observed?



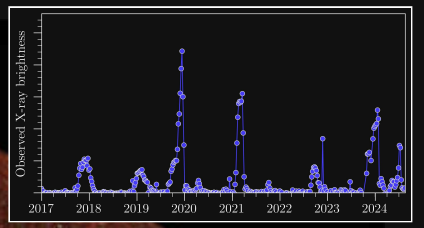


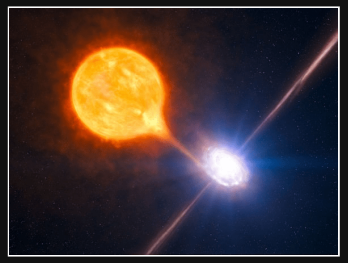


Accreting neutron stars

What fraction of accreting neutron stars have we observed?

If we have stared at our Galaxy for long enough, have we caught them all there?





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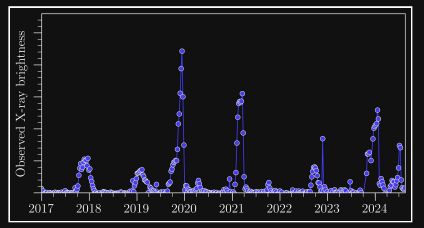
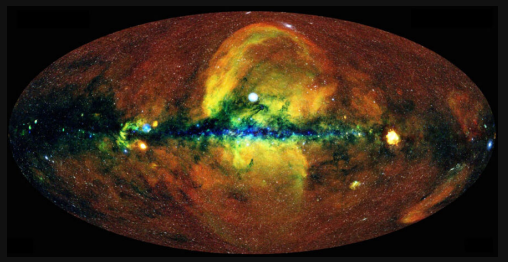


What we have:

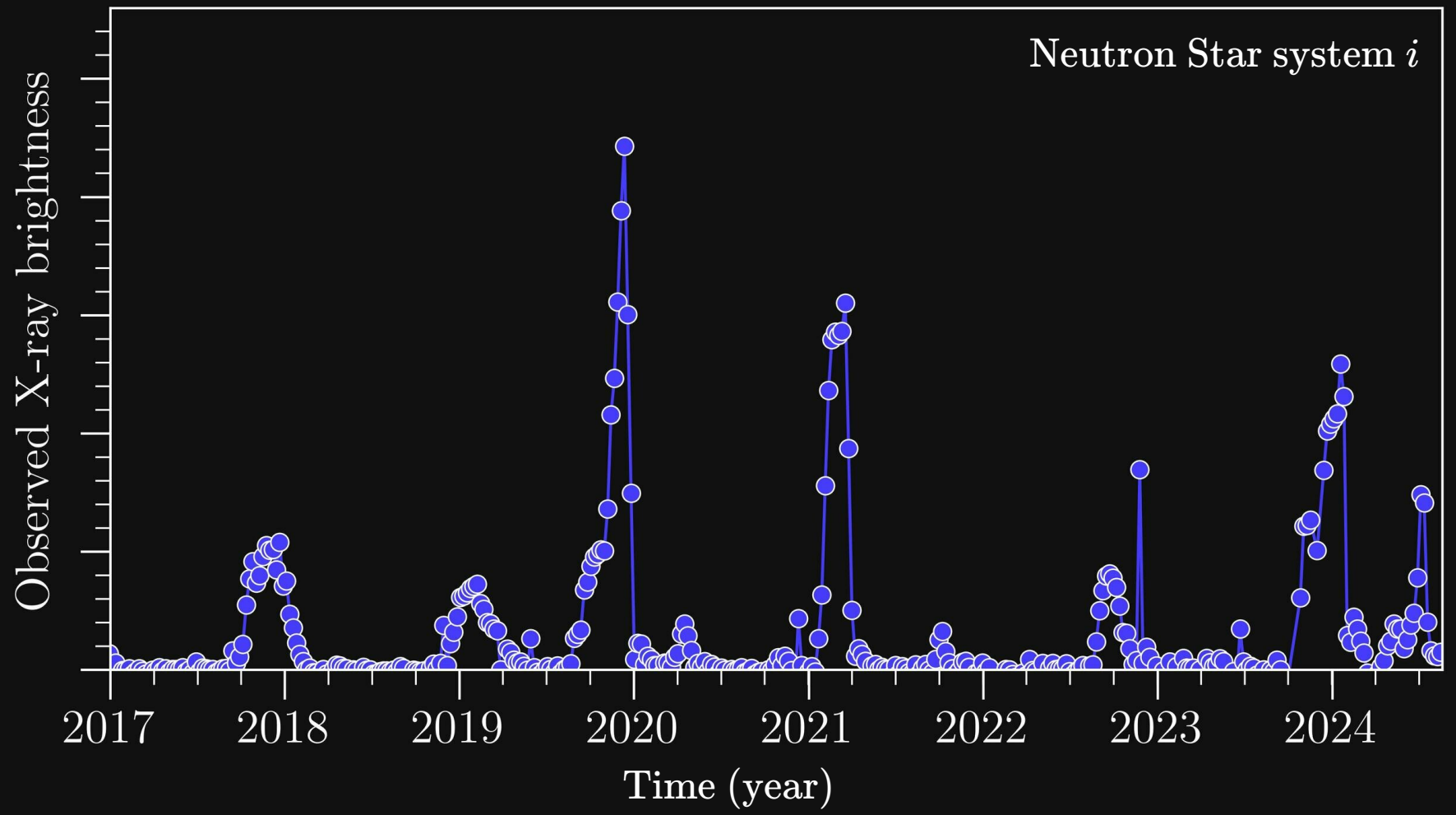
- observed data;
  a tiny slice of time from a long-span time-series



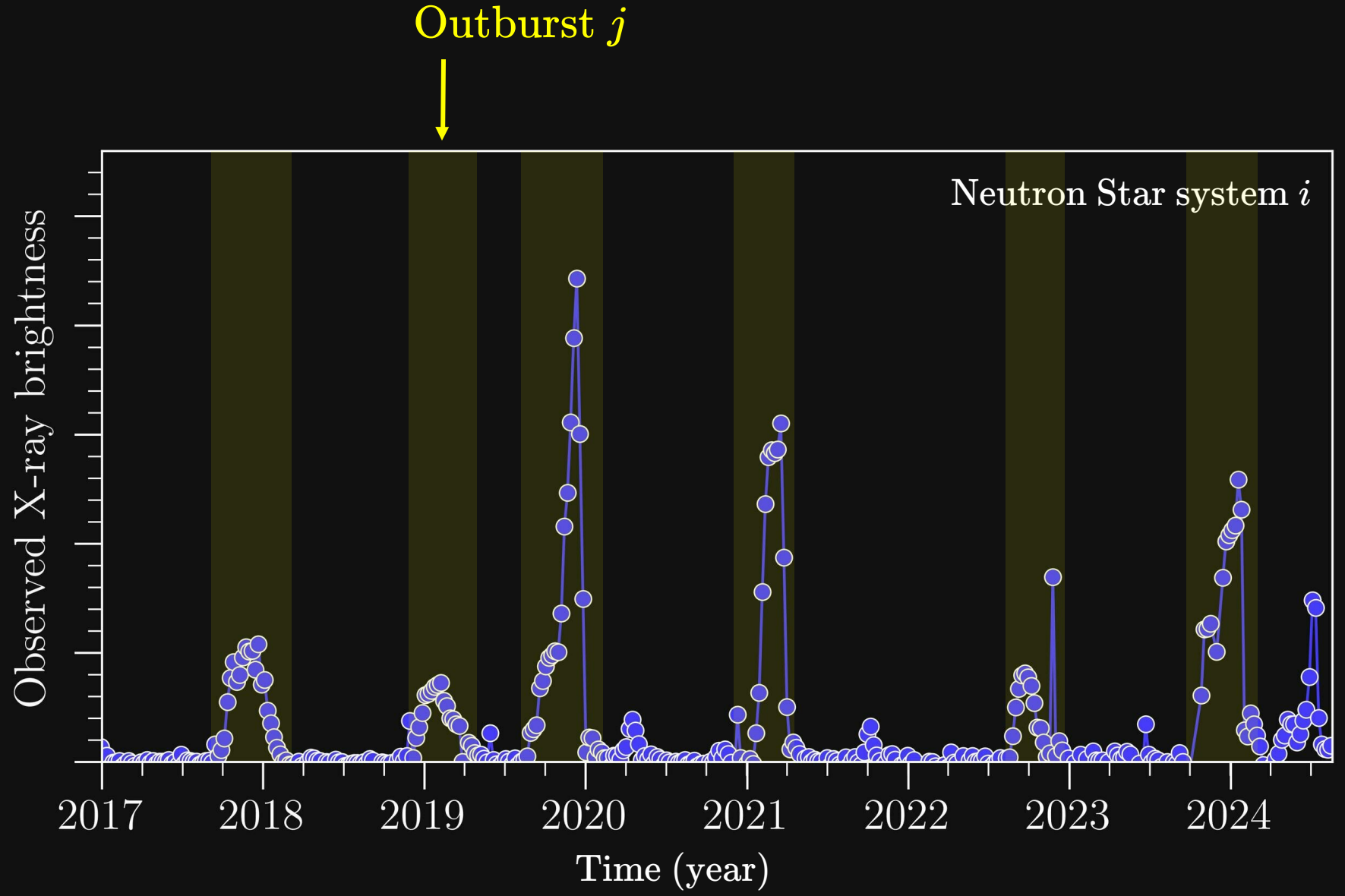
What we are aiming for:

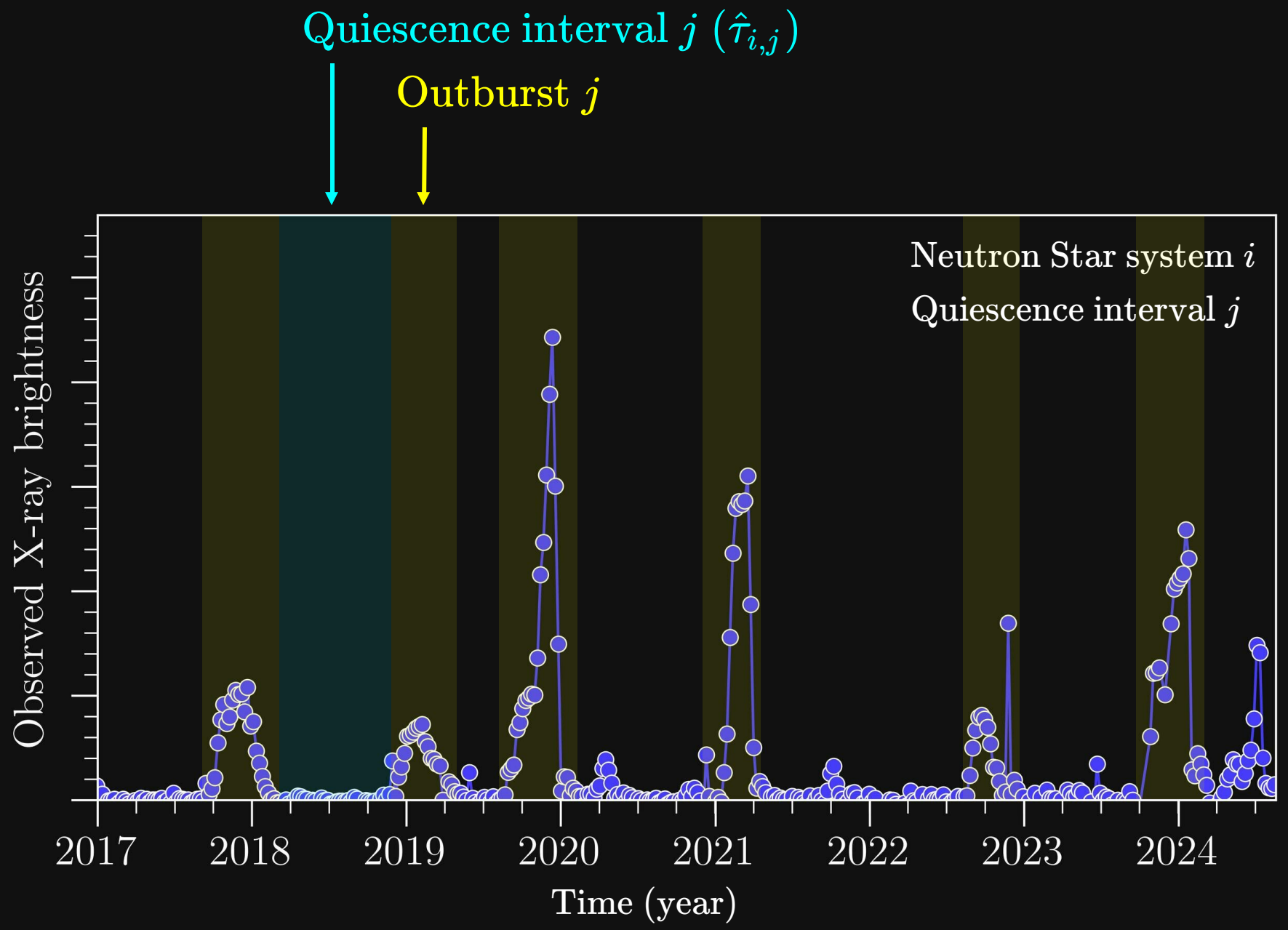
- Building a statistical model to describe accreting neutron stars in our Galaxy

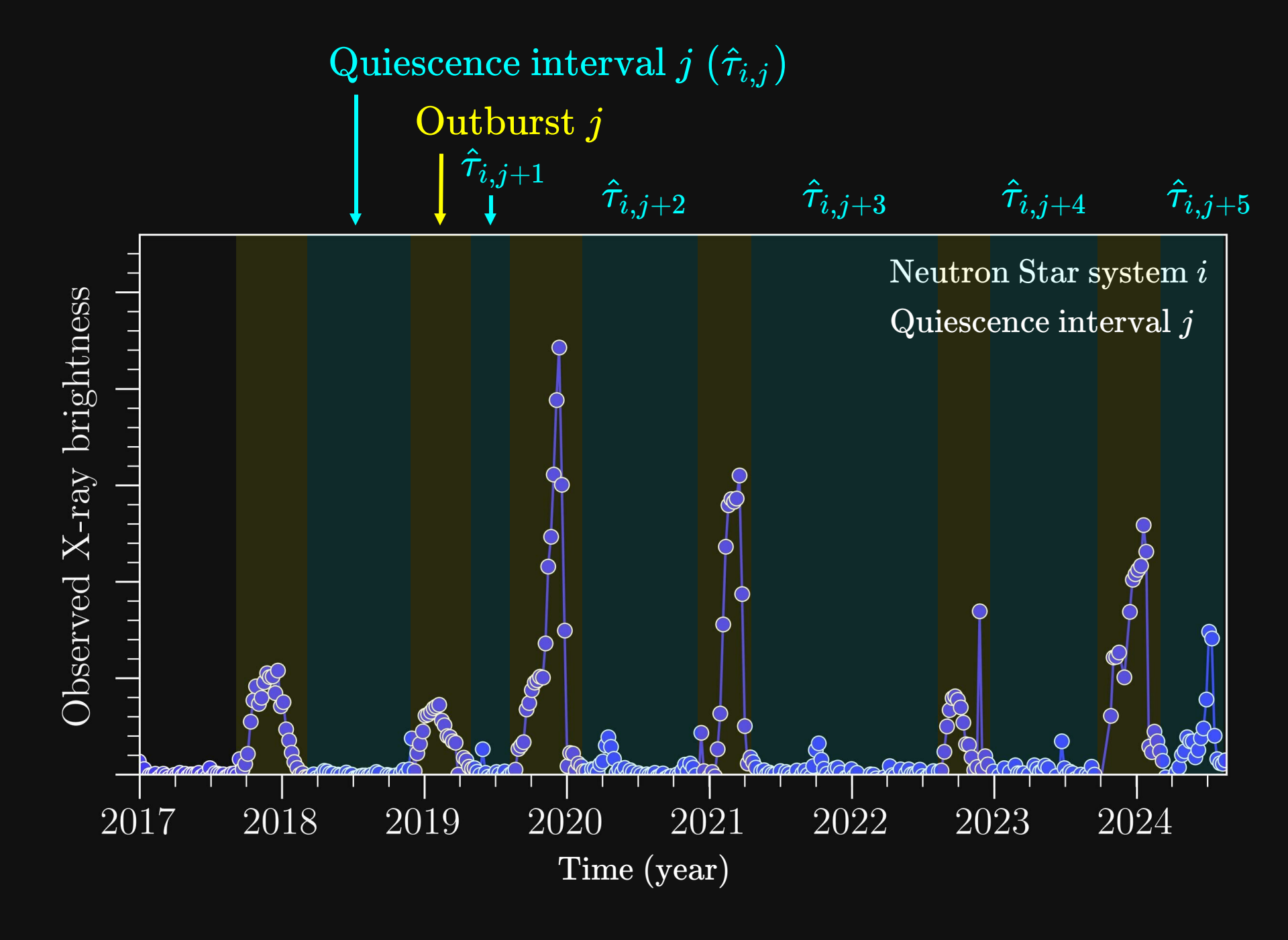
The data

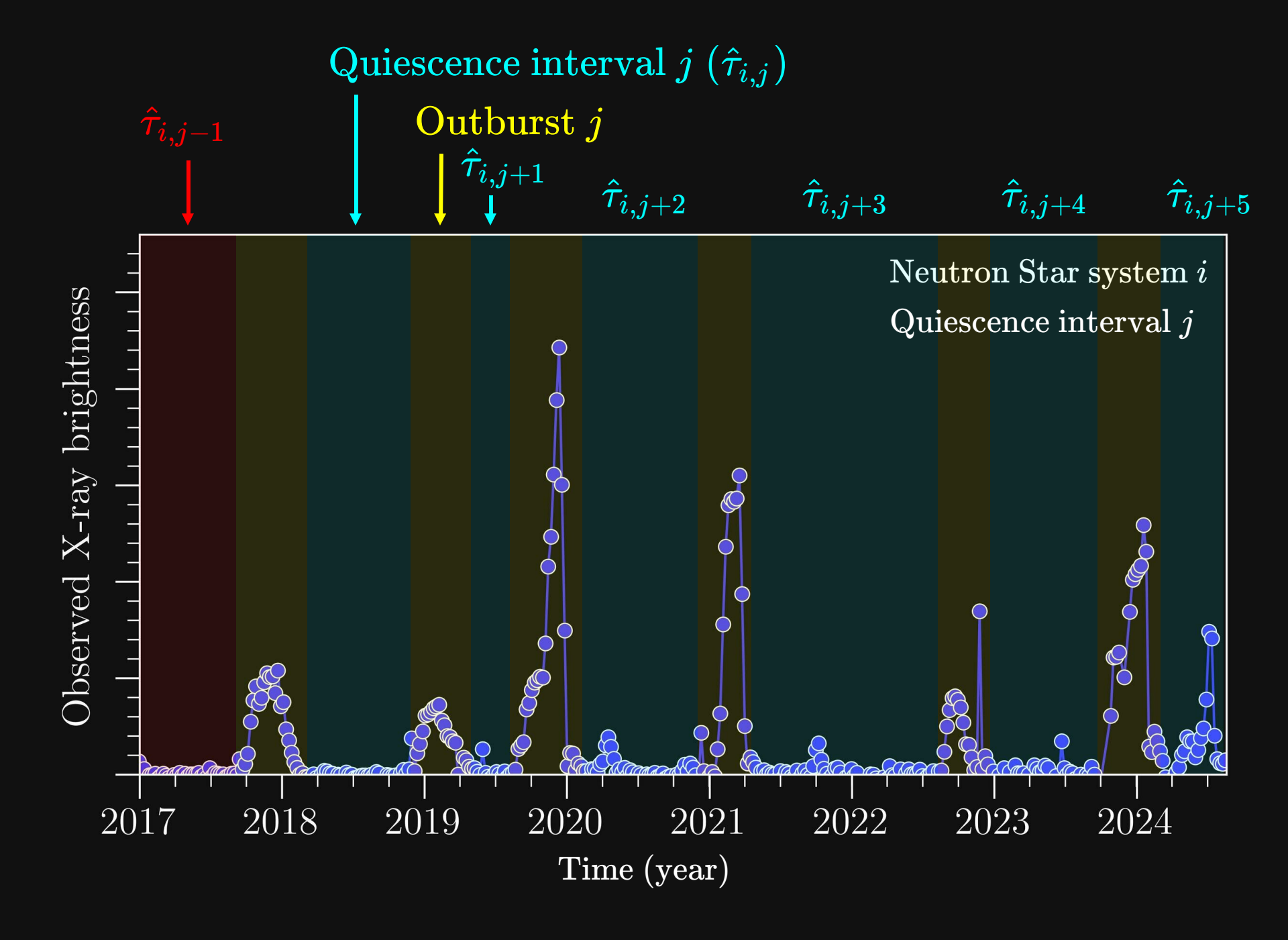

Neutron Star system i
Observed X-ray brightness
2017
2018
2019
2020
2021
2022
2023
2024
Time (year)

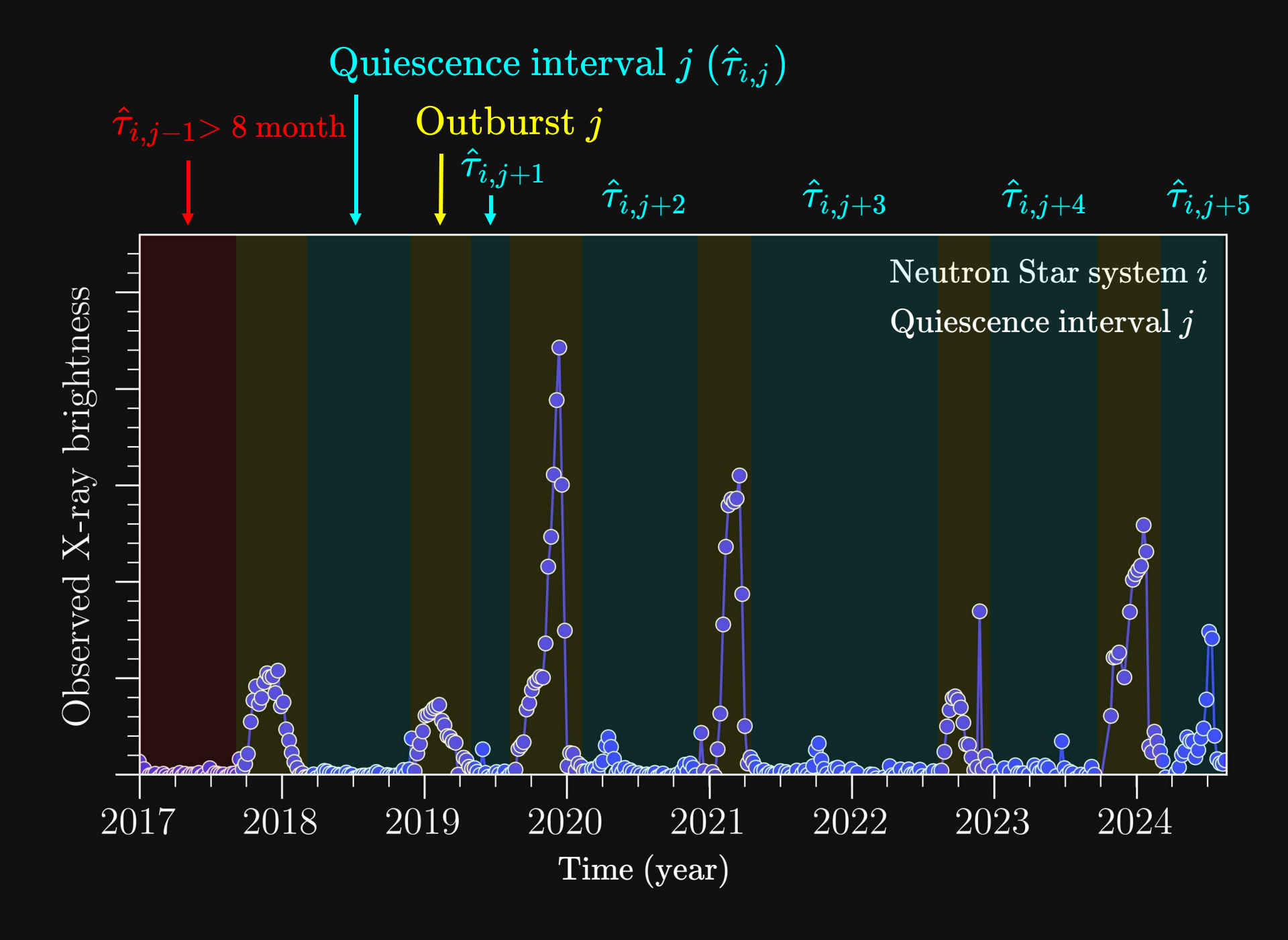
The data


Outburst j
Neutron Star system i
Observed X-ray brightness
2017
2018
2019
2020
2021
2022
2023
2024
Time (year)

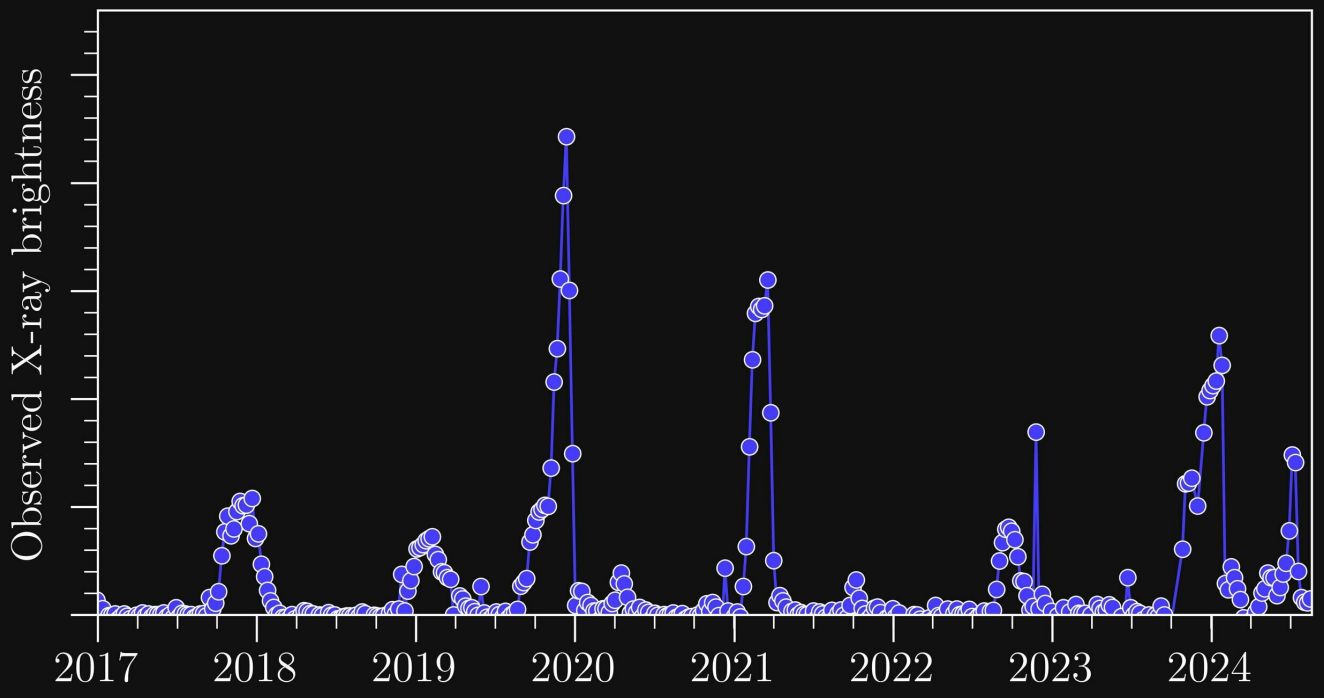

Quiescence interval j ($\hat{\tau}_{i,j}$)
Outburst j
Neutron Star system i
Quiescence interval j
Observed X-ray brightness
2017
2018
2019
2020
2021
2022
2023
2024
Time (year)


Quiescence interval j ($\hat{\tau}_{i,j}$)
Outburst j
$\hat{\tau}_{i,j+1}$
$\hat{\tau}_{i,j+2}$
$\hat{\tau}_{i,j+3}$
$\hat{\tau}_{i,j+4}$
$\hat{\tau}_{i,j+5}$
Neutron Star system i
Quiescence interval j
Observed X-ray brightness
2017
2018
2019
2020
2021
2022
2023
2024
Time (year)

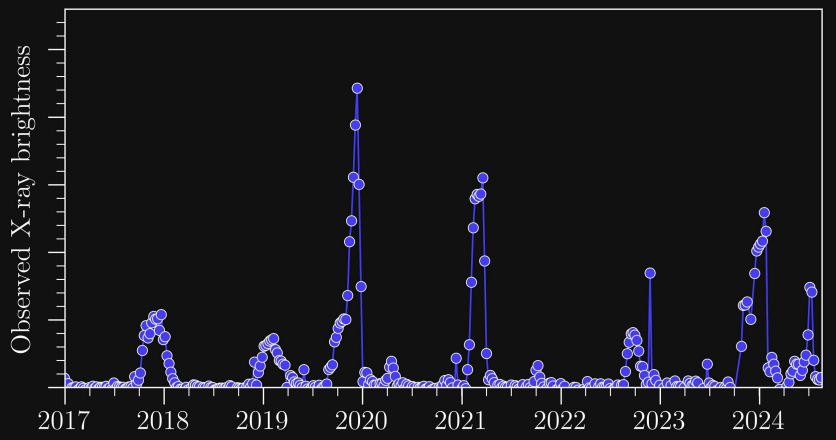

Quiescence interval j ($\hat{\tau}_{i,j}$)
$\hat{\tau}_{i,j-1}$
Outburst j
$\hat{\tau}_{i,j+1}$
$\hat{\tau}_{i,j+2}$
$\hat{\tau}_{i,j+3}$
$\hat{\tau}_{i,j+4}$
$\hat{\tau}_{i,j+5}$
Neutron Star system i
Quiescence interval j
Observed X-ray brightness
2017
2018
2019
2020
2021
2022
2023
2024
Time (year)


Quiescence interval j ($\hat{\tau}_{i,j}$)
$\hat{\tau}_{i,j-1}$ > 8 month
Outburst j
$\hat{\tau}_{i,j+1}$
$\hat{\tau}_{i,j+2}$
$\hat{\tau}_{i,j+3}$
$\hat{\tau}_{i,j+4}$
$\hat{\tau}_{i,j+5}$
Neutron Star system i
Quiescence interval j
Observed X-ray brightness
2017
2018
2019
2020
2021
2022
2023
2024
Time (year)

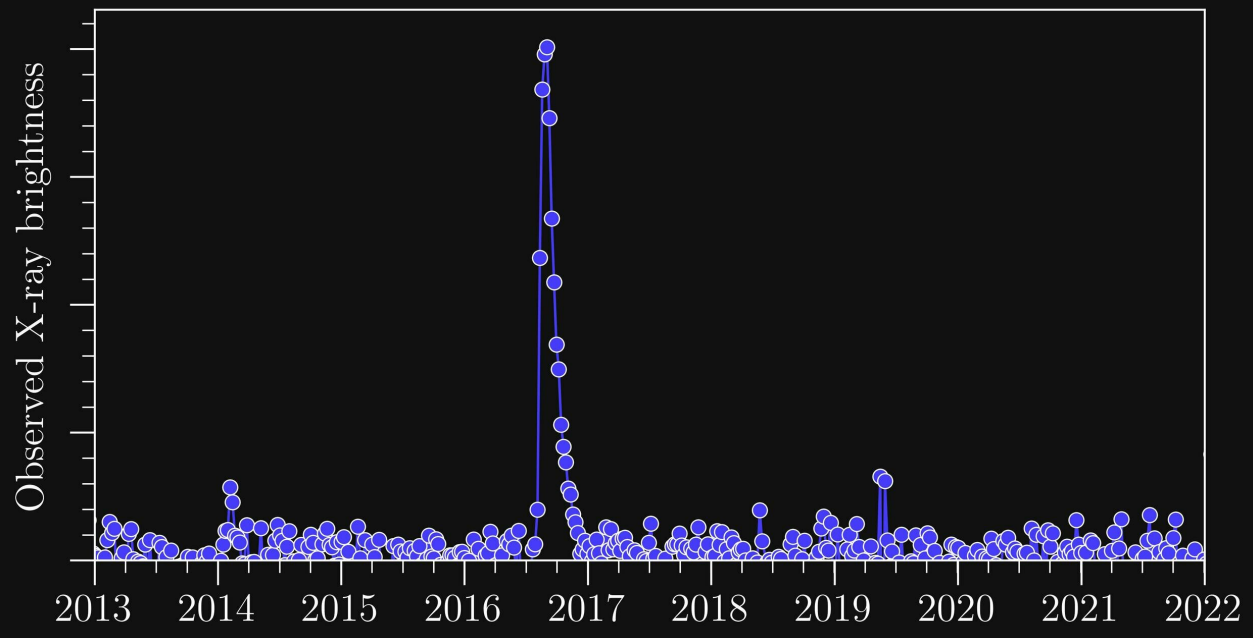
Neutron Star system i $\hat{\tau}_{i,j-1}$ $\hat{\tau}_{i,j}$ $\hat{\tau}_{i,j+1}$ $\hat{\tau}_{i,j+2}$ $\hat{\tau}_{i,j+3}$ $\hat{\tau}_{i,j+4}$ $\hat{\tau}_{i,j+5}$



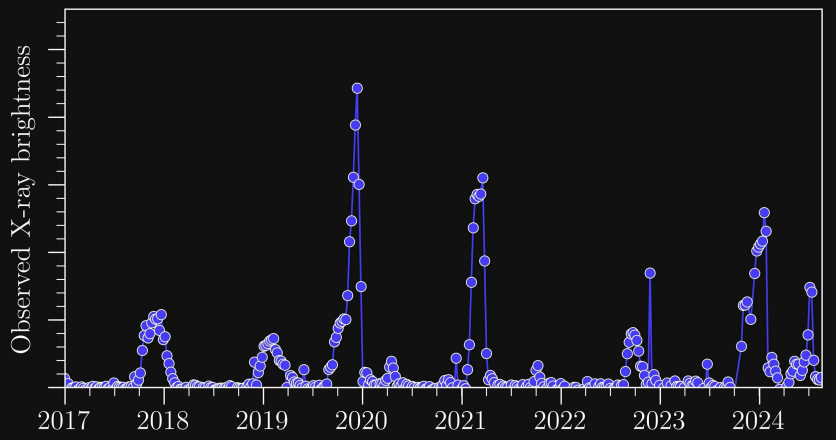
Neutron Star system i $\hat{\tau}_{i,j-1}$ $\hat{\tau}_{i,j}$ $\hat{\tau}_{i,j+1}$ $\hat{\tau}_{i,j+2}$ $\hat{\tau}_{i,j+3}$ $\hat{\tau}_{i,j+4}$ $\hat{\tau}_{i,j+5}$



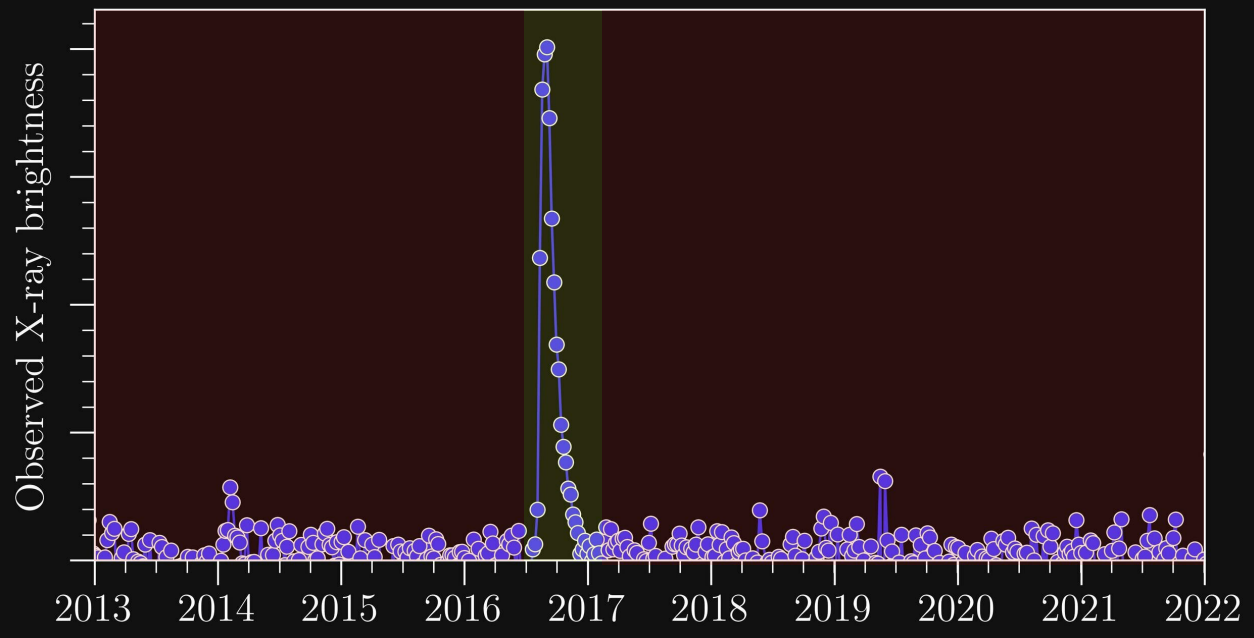
Neutron Star system i'



Neutron Star system i $\hat{\tau}_{i,j-1}$ $\hat{\tau}_{i,j}$ $\hat{\tau}_{i,j+1}$ $\hat{\tau}_{i,j+2}$ $\hat{\tau}_{i,j+3}$ $\hat{\tau}_{i,j+4}$ $\hat{\tau}_{i,j+5}$



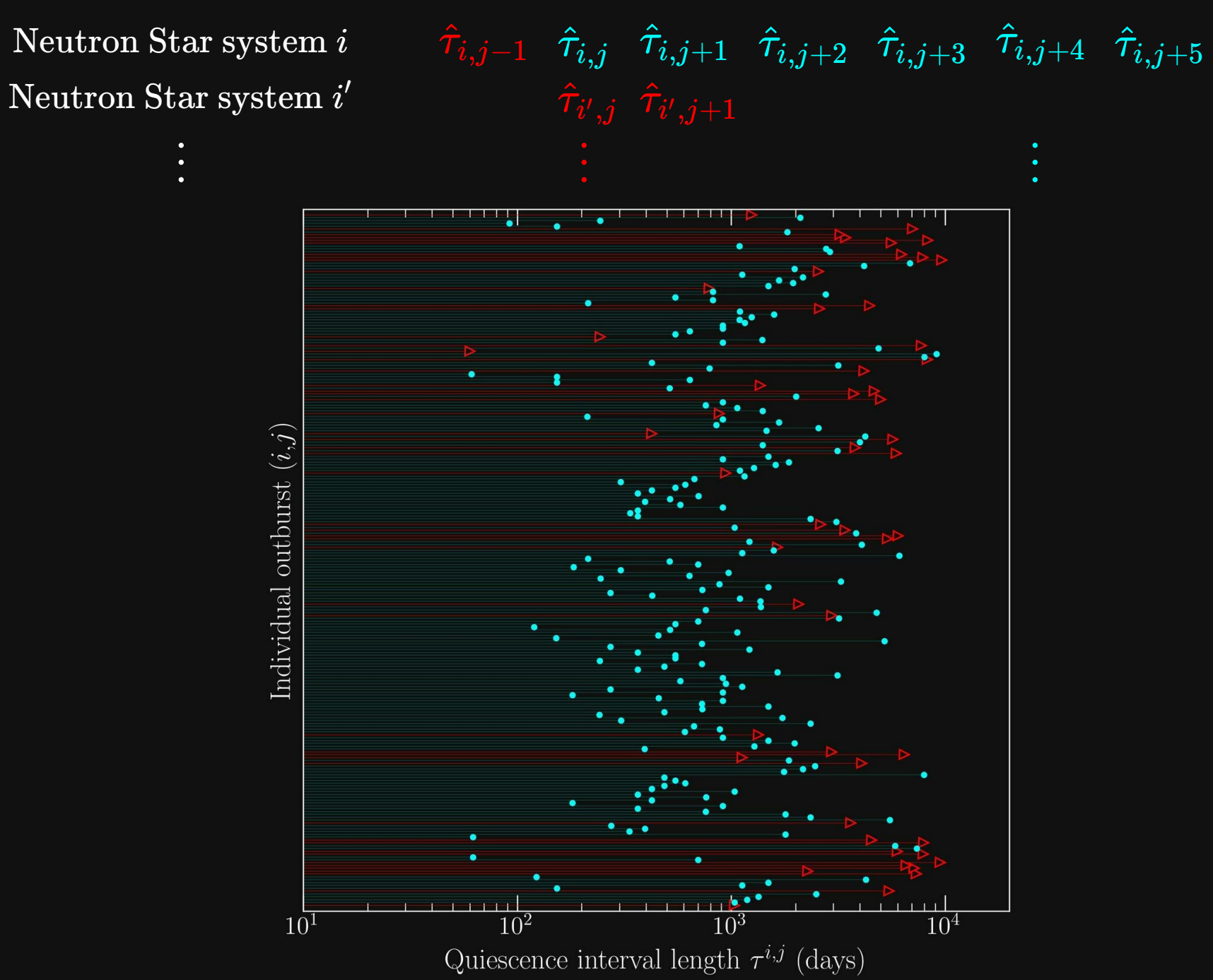
Neutron Star system i' $\hat{\tau}_{i',j}$ $\hat{\tau}_{i',j+1}$



Neutron Star system i $\hat{\tau}_{i,j-1}$ $\hat{\tau}_{i,j}$ $\hat{\tau}_{i,j+1}$ $\hat{\tau}_{i,j+2}$ $\hat{\tau}_{i,j+3}$ $\hat{\tau}_{i,j+4}$ $\hat{\tau}_{i,j+5}$

Neutron Star system i' $\hat{\tau}_{i',j}$ $\hat{\tau}_{i',j+1}$

$\vdots$ $\vdots$ $\vdots$


Neutron Star system i
Neutron Star system i'
$\hat{\tau}_{i,j-1}$ $\hat{\tau}_{i,j}$ $\hat{\tau}_{i,j+1}$ $\hat{\tau}_{i,j+2}$ $\hat{\tau}_{i,j+3}$ $\hat{\tau}_{i,j+4}$ $\hat{\tau}_{i,j+5}$
$\hat{\tau}_{i',j}$ $\hat{\tau}_{i',j+1}$
Individual outburst (i,j)
10^1
10^2
10^3
10^4
Quiescence interval length $\tau^{i,j}$ (days)

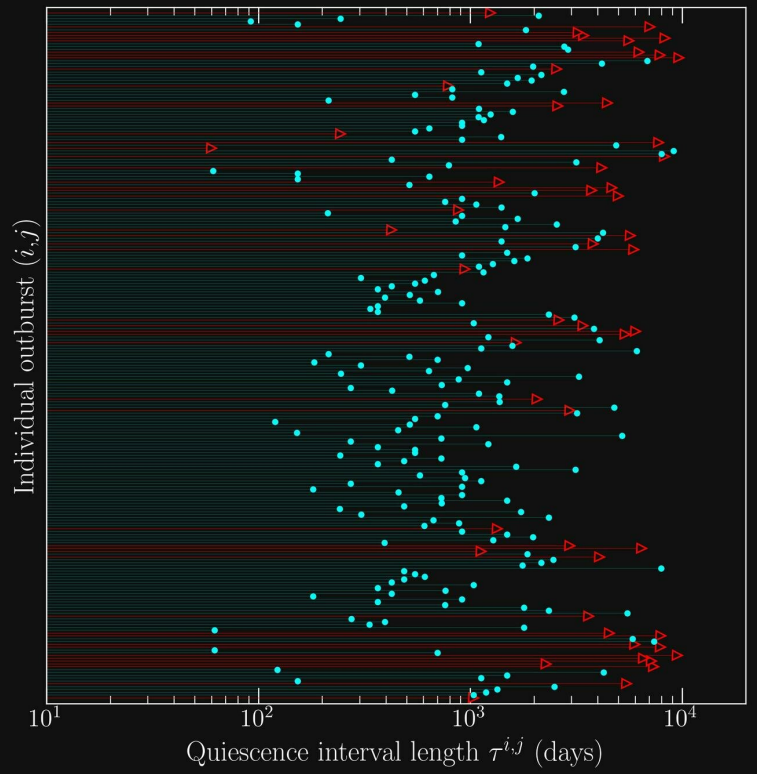
Univariate survival

Neutron Star system i

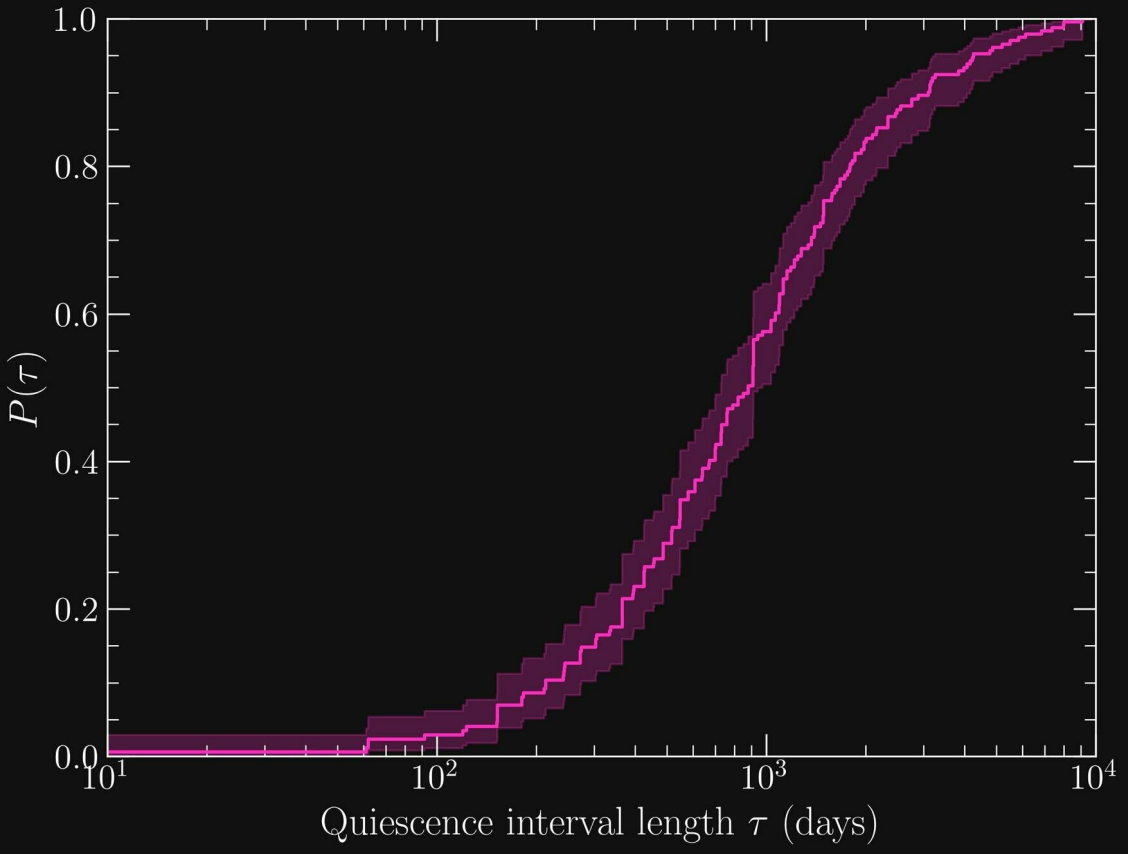
Neutron Star system i'

$\hat{\tau}_{i,j-1}$ $\hat{\tau}_{i,j}$ $\hat{\tau}_{i,j+1}$ $\hat{\tau}_{i,j+2}$ $\hat{\tau}_{i,j+3}$ $\hat{\tau}_{i,j+4}$ $\hat{\tau}_{i,j+5}$

$\hat{\tau}_{i',j}$ $\hat{\tau}_{i',j+1}$



Non-parametric



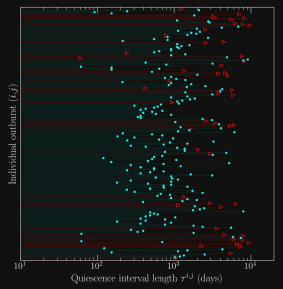
Univariate survival

Neutron Star system i

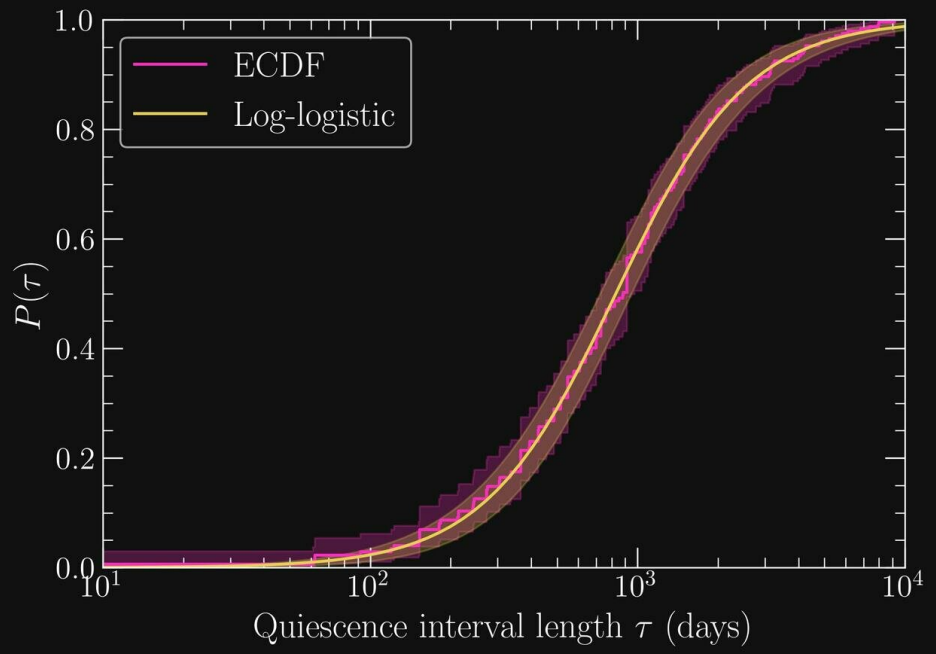
Neutron Star system i'

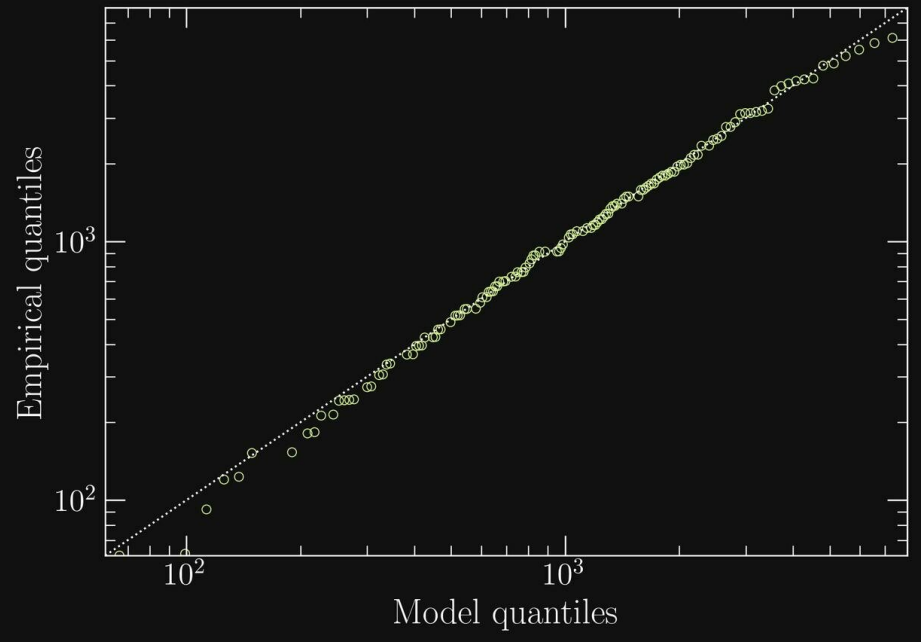
$\hat{\tau}_{i,j-1}$ $\hat{\tau}_{i,j}$ $\hat{\tau}_{i,j+1}$ $\hat{\tau}_{i,j+2}$ $\hat{\tau}_{i,j+3}$ $\hat{\tau}_{i,j+4}$ $\hat{\tau}_{i,j+5}$

$\hat{\tau}_{i',j}$ $\hat{\tau}_{i',j+1}$



Parametric





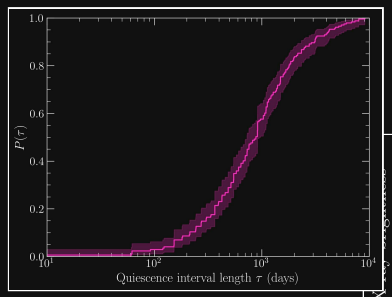
The problem with Univariate survival

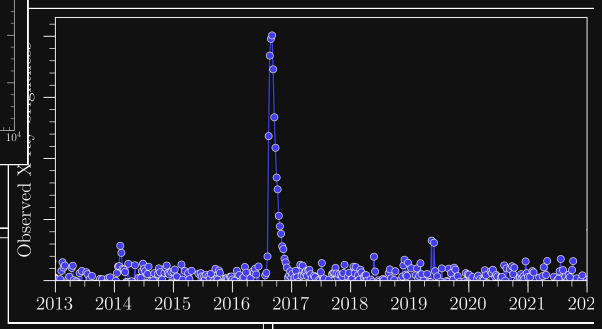
Neutron Star system i

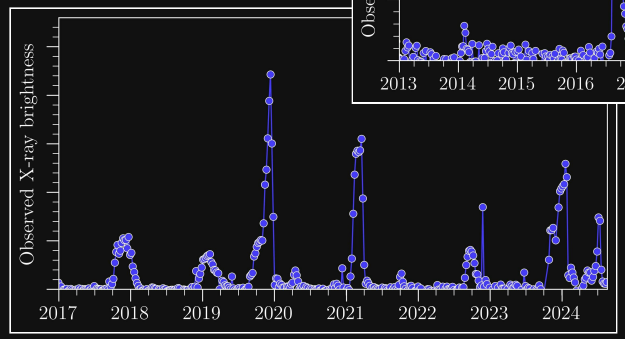
Neutron Star system i'

$\hat{\tau}_{i,j-1}$ $\hat{\tau}_{i,j}$ $\hat{\tau}_{i,j+1}$ $\hat{\tau}_{i,j+2}$ $\hat{\tau}_{i,j+3}$ $\hat{\tau}_{i,j+4}$ $\hat{\tau}_{i,j+5}$

$\hat{\tau}_{i',j}$ $\hat{\tau}_{i',j+1}$

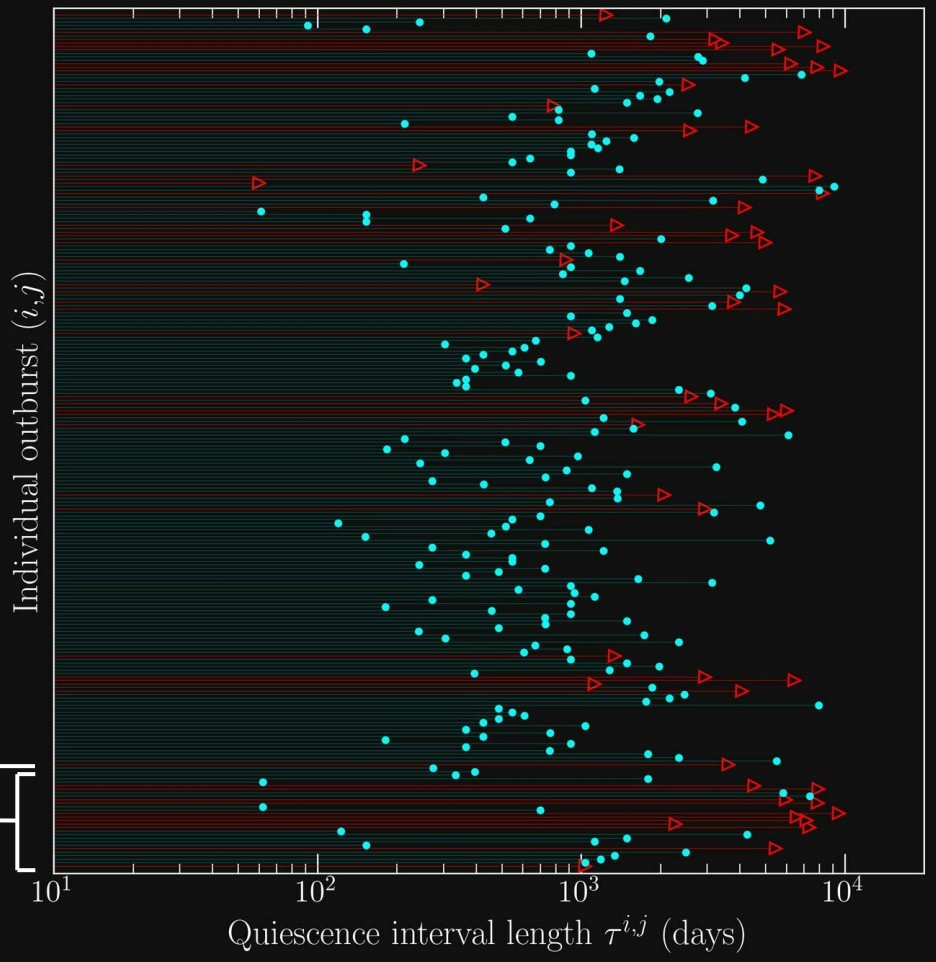






$i = 2, j = 1$

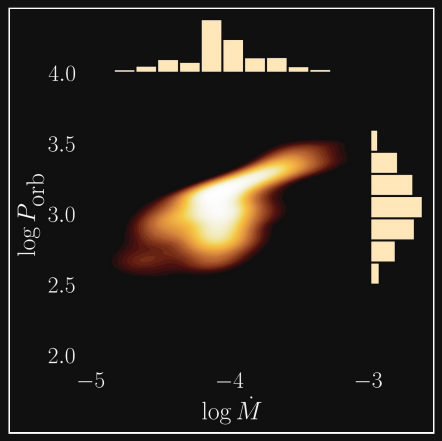
$i = 1, j = 1, \cdots, 15$



A mechanistic approach

Galaxy-wide simulations

COMPAS

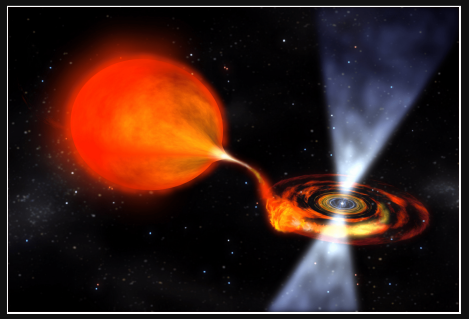


Informative priors

Orbital period and Mass transfer rate

$p(P_{\rm orb}, \dot{M})$

Deterministic



Recurrence time

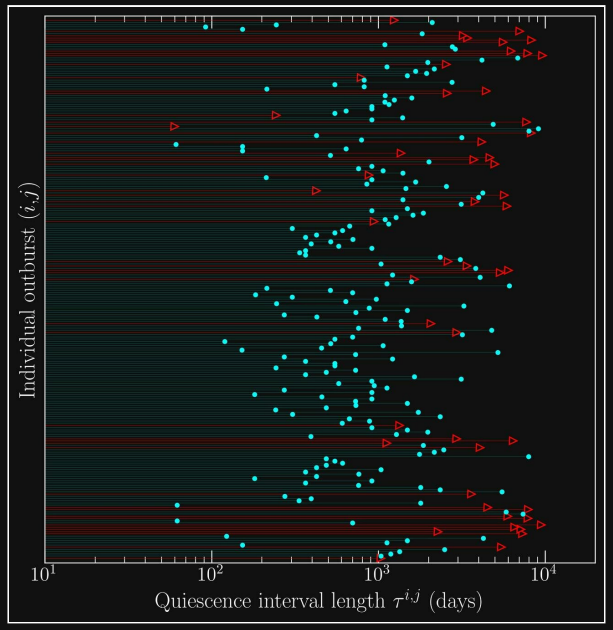
$\tau(P_{\rm orb}, \dot{M})$

Inferred

$\bar{\tau}_i$

Estimated

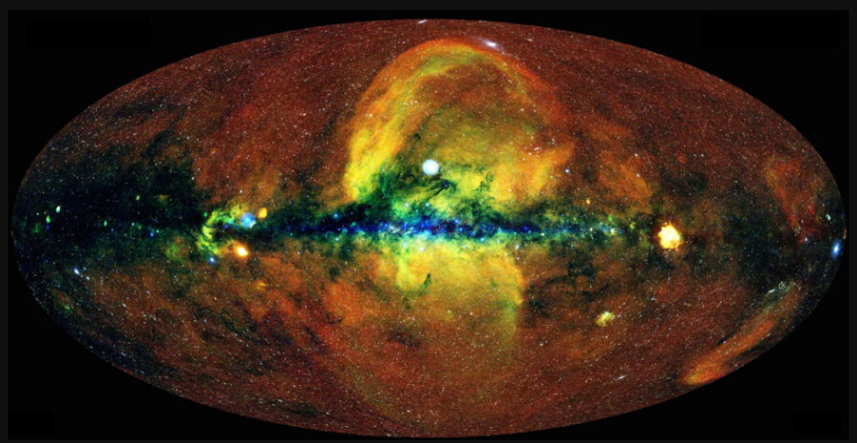
$\hat{\tau}_{i,j}$



Early results and future directions

If we have stared at our Galaxy for long enough,
have we caught all accreting neutron stars there?

Probably missing a significant fraction

Next steps

- Quantifying the fraction of missing systems
- Considering role of formation scenarios
  (i.e., sensitivity to the priors)