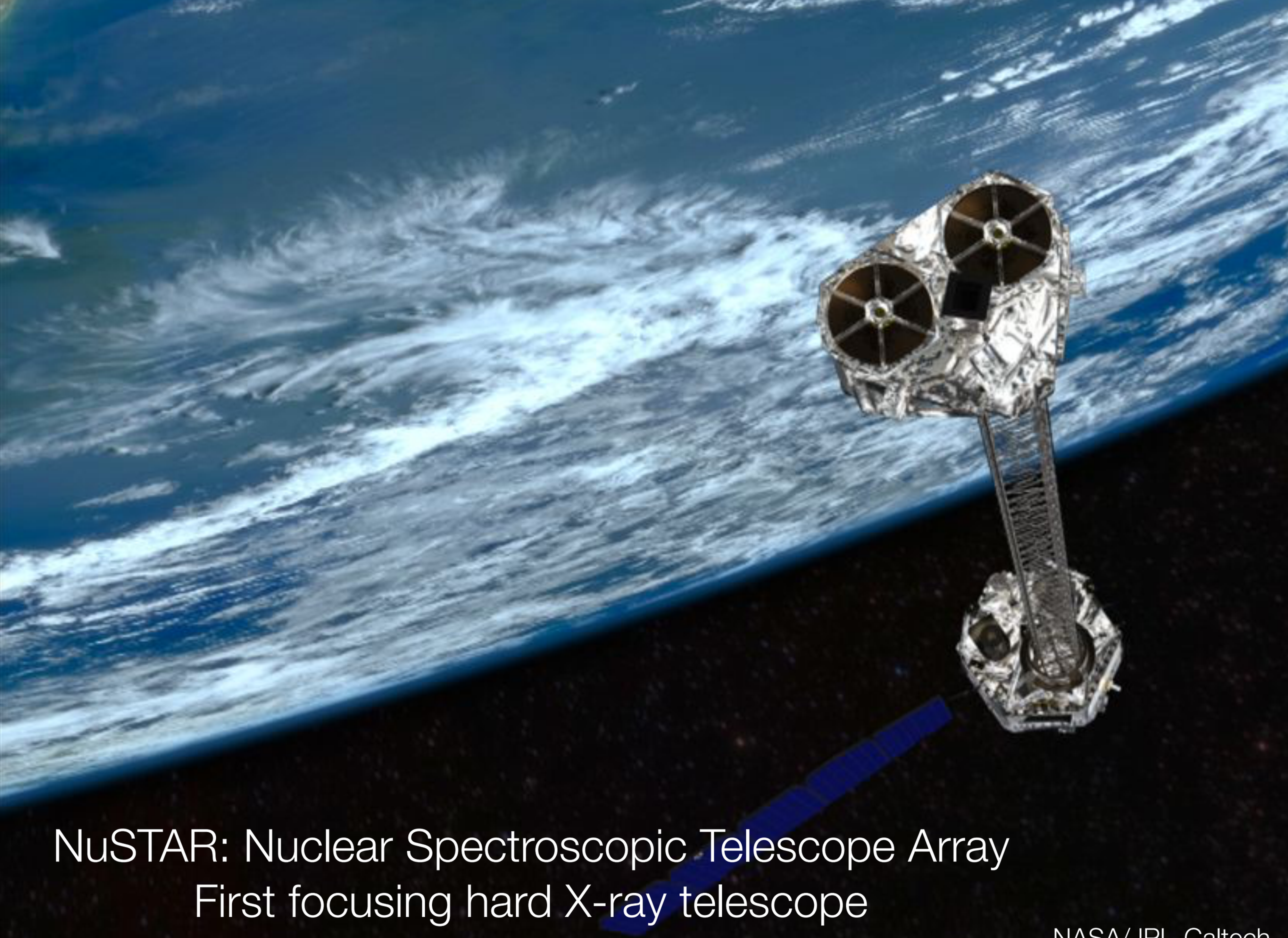
Spectral timing with NuSTAR: Current status and need for timing (cross-)calibration

Matteo Bachetti
(+ Craig Markwardt, Brian Grefenstette, and many more from the NuSTAR team)



NuSTAR: Nuclear Spectroscopic Telescope Array
First focusing hard X-ray telescope

NASA/JPL-Caltech

NuSTAR timing capabilities

- Counting instrument, high timing resolution (10 us) - high timing potential

  - Dead time

- Design absolute accuracy ~ 100 ms

- Achieved the first year ~ 2 ms

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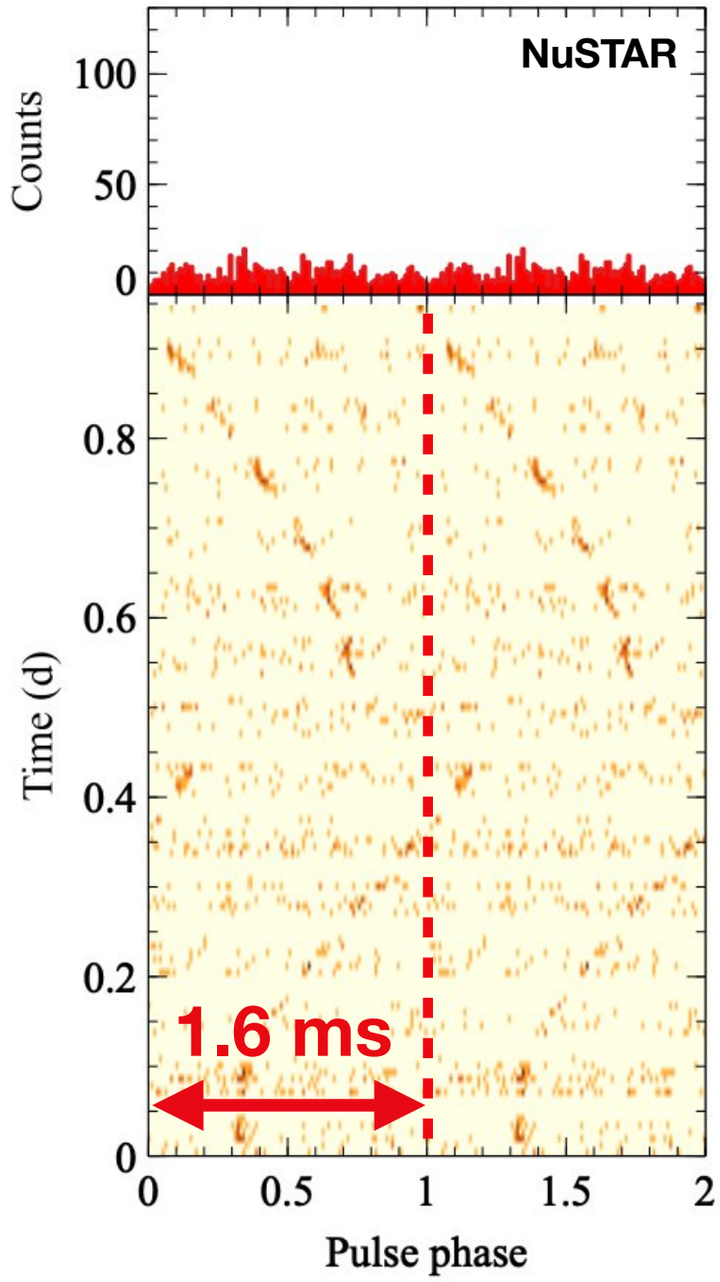

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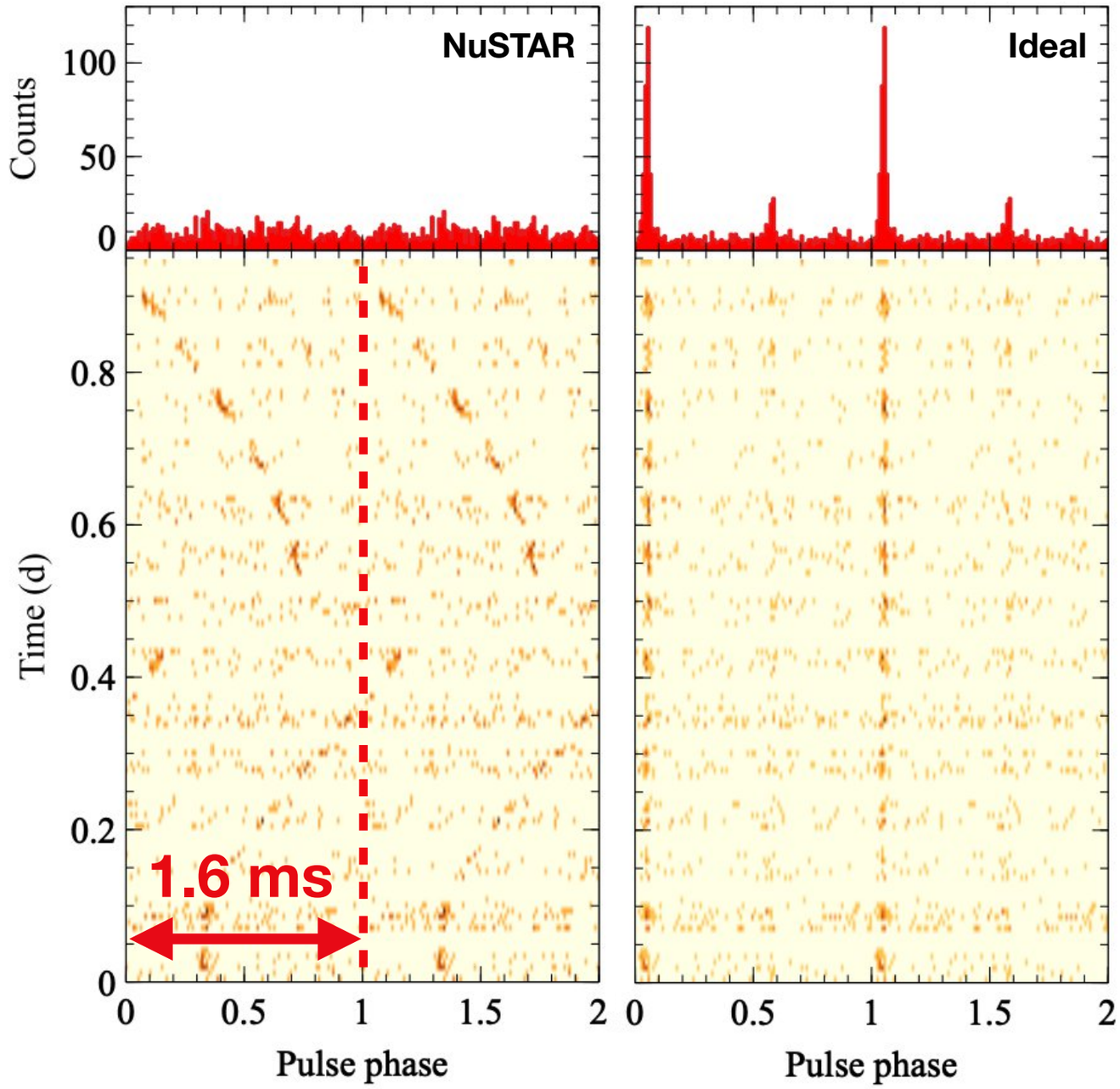
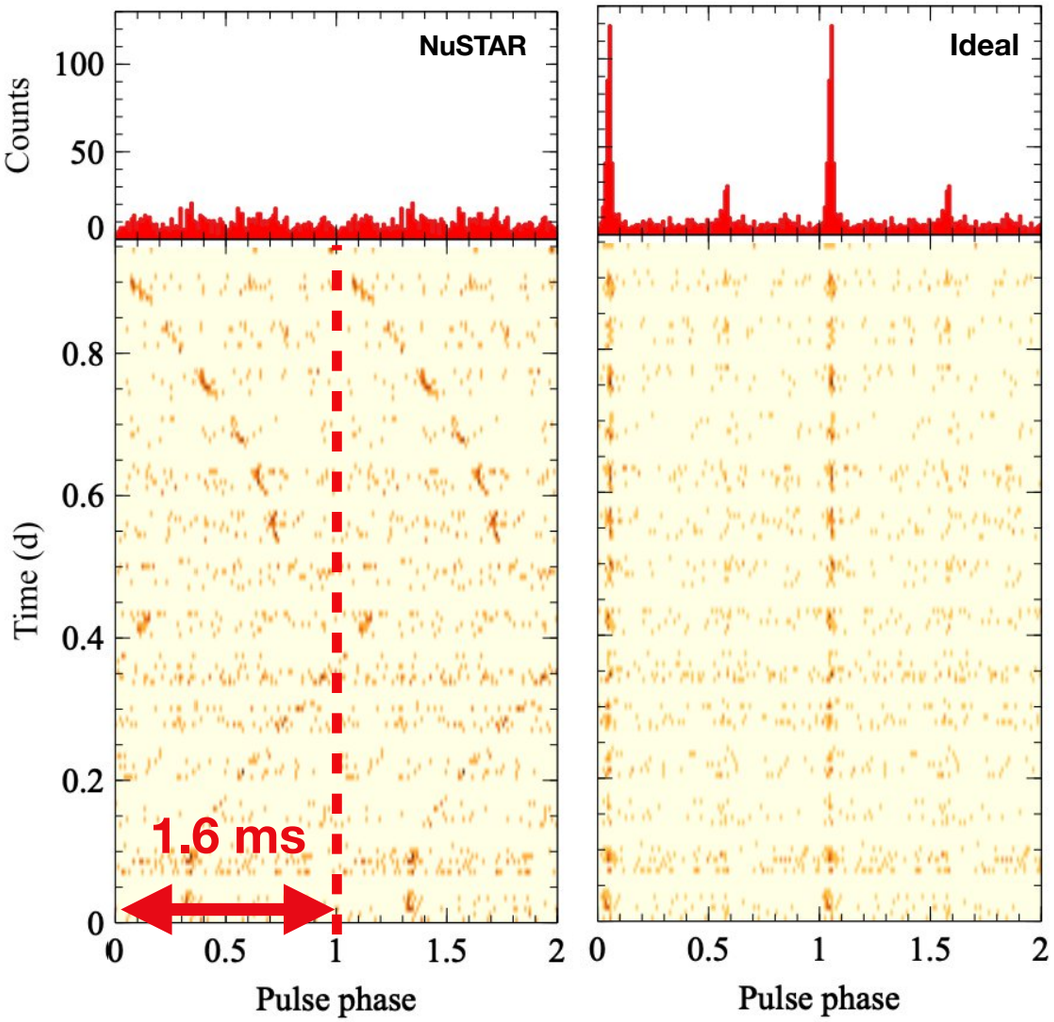
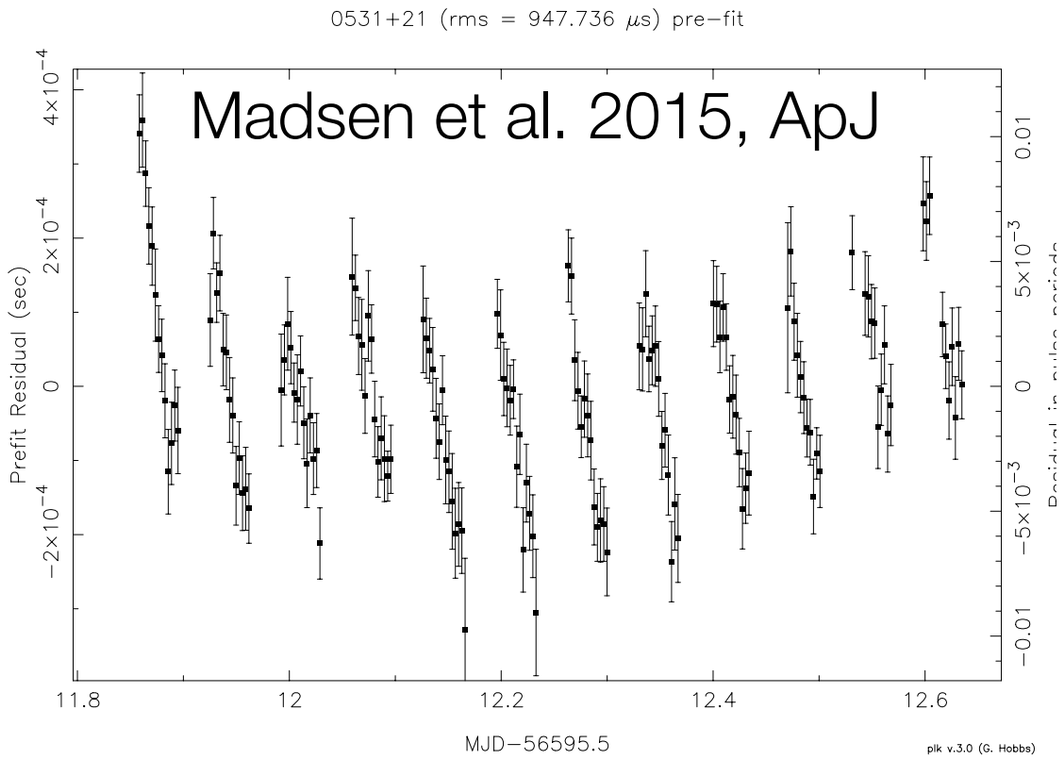


NuSTAR timing capabilities





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Sanna et al. 2018, A&A

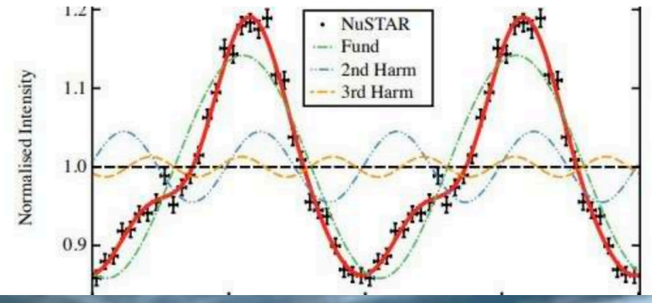
PHYS.ORG Nanotechnology Physics Earth Astronomy & Space Technology

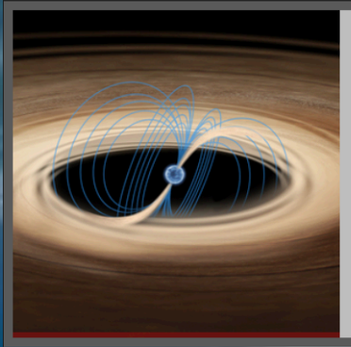
Home » Astronomy & Space » Astronomy » September 12, 2018

New accreting millisecond X-ray pulsar discovered

September 12, 2018 by Tomasz Nowakowski, Phys.org report

G+ Tweet reddit Favorites





NuSTAR Helps Solve 'Rapid Burster' Mystery

News Release • January 31, 2017

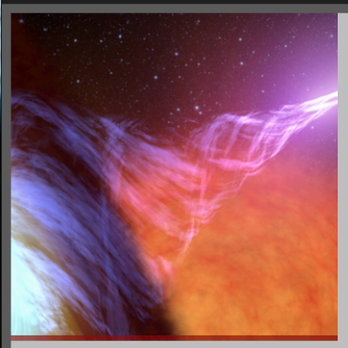
Scientists observing a neutron star in the "Rapid Burster" system may have solved a 40-year-old mystery surrounding its puzzling X-ray bursts.

Learn More →

NASA's NuSTAR Telescope Discovers Shockingly Bright Dead Star

News Release • October 8, 2014

Astronomers have found a pulsating, dead star beaming with the energy of about 10 million suns. This is the brightest pulsar - a dense stellar remnant left over from a supernova explosion - ever recorded. The discovery was made with NASA's Nuclear Spectroscopic Telescope Array, or NuSTAR.



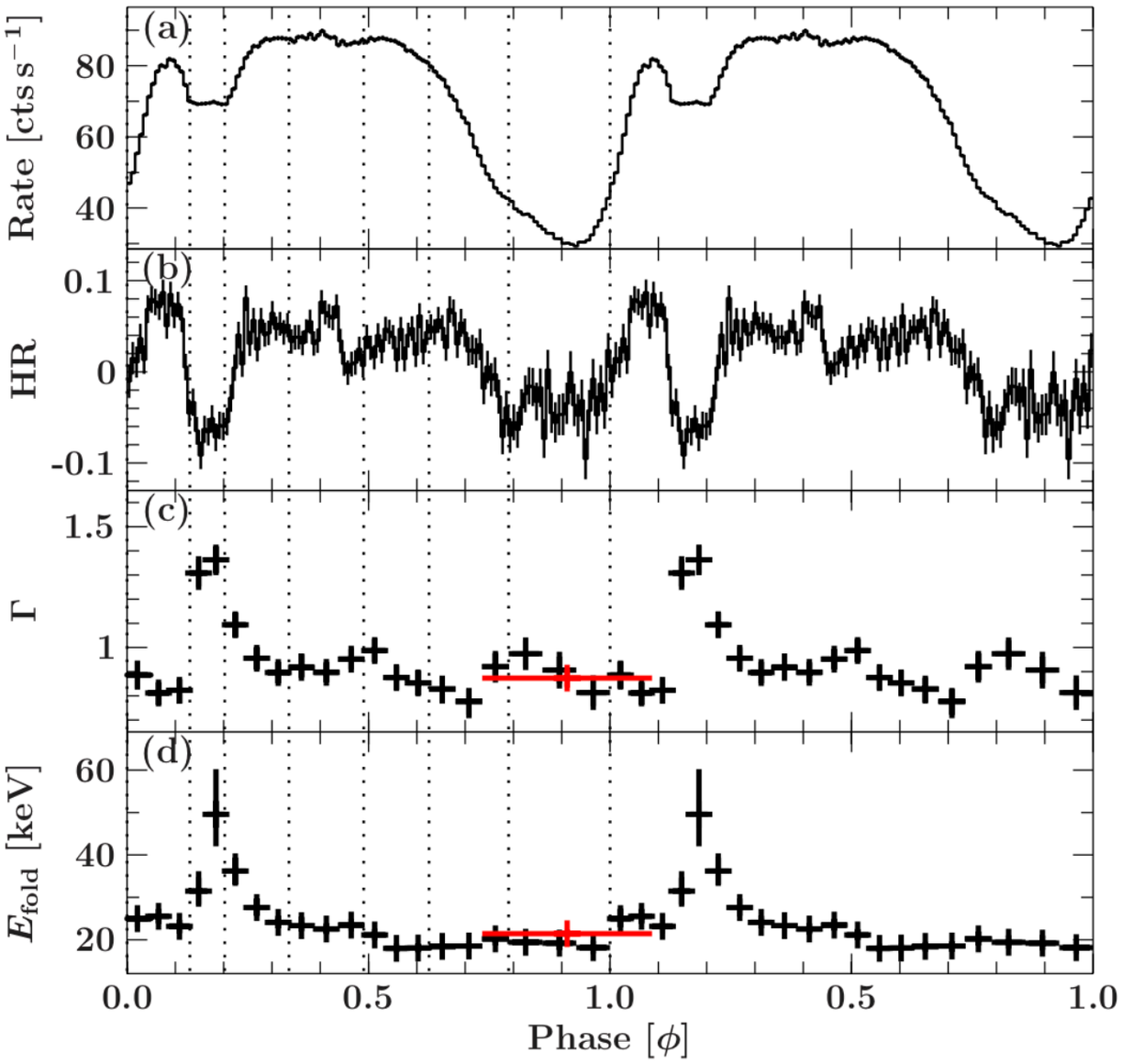
NuSTAR Probes Black Hole Jet Mystery

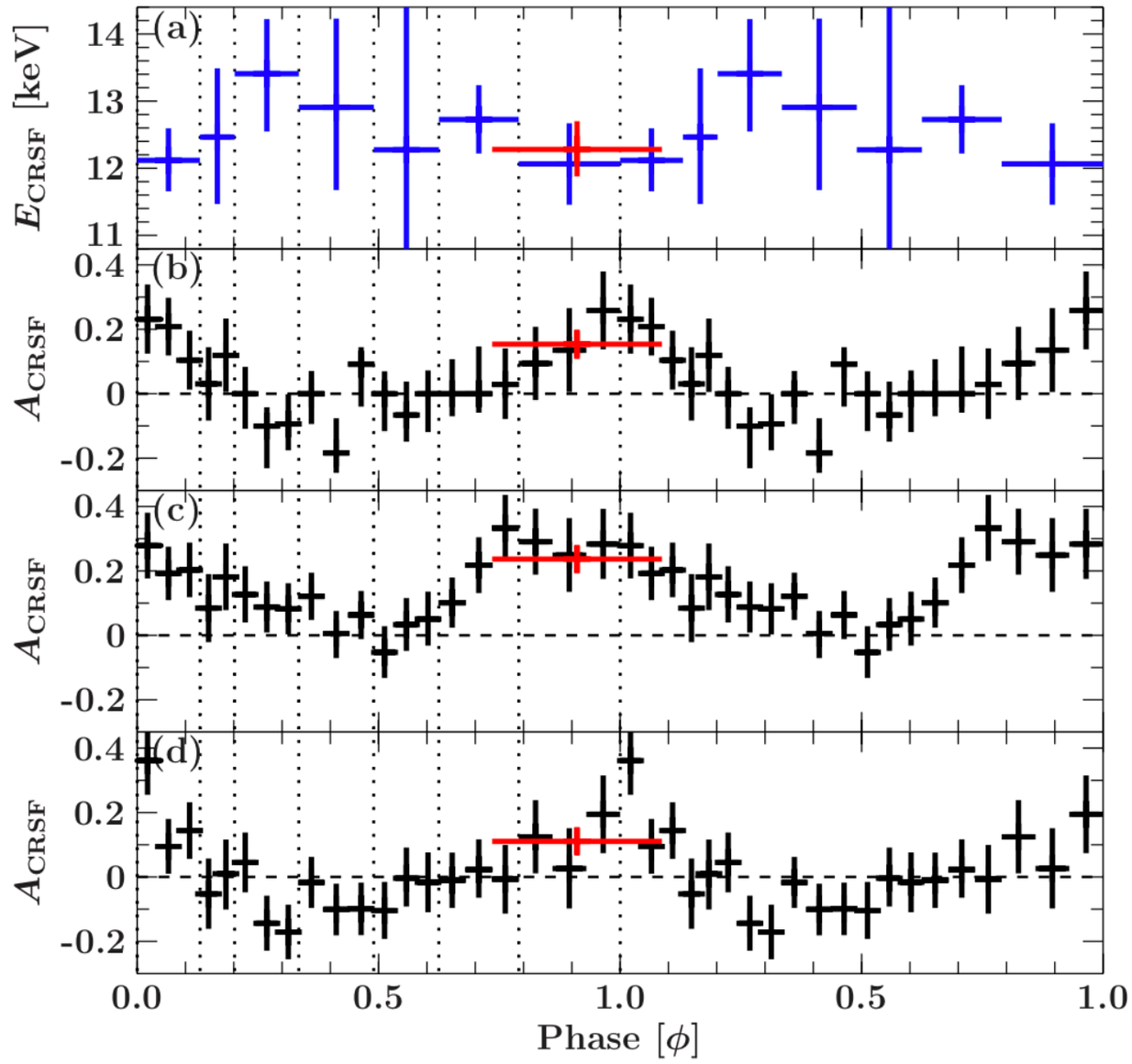
News Release • October 30, 2017

Black holes are famous for being ravenous eaters, but they do not eat everything that falls toward them. A small portion of material gets shot back out in powerful jets of hot gas, called plasma, that can wreak havoc on their surroundings. Along the way, this plasma somehow gets energized enough to strongly radiate light, forming two bright columns along the black hole's axis of rotation. Scientists have long debated where and how this happens in the jet.

NASA/JPL-Caltech

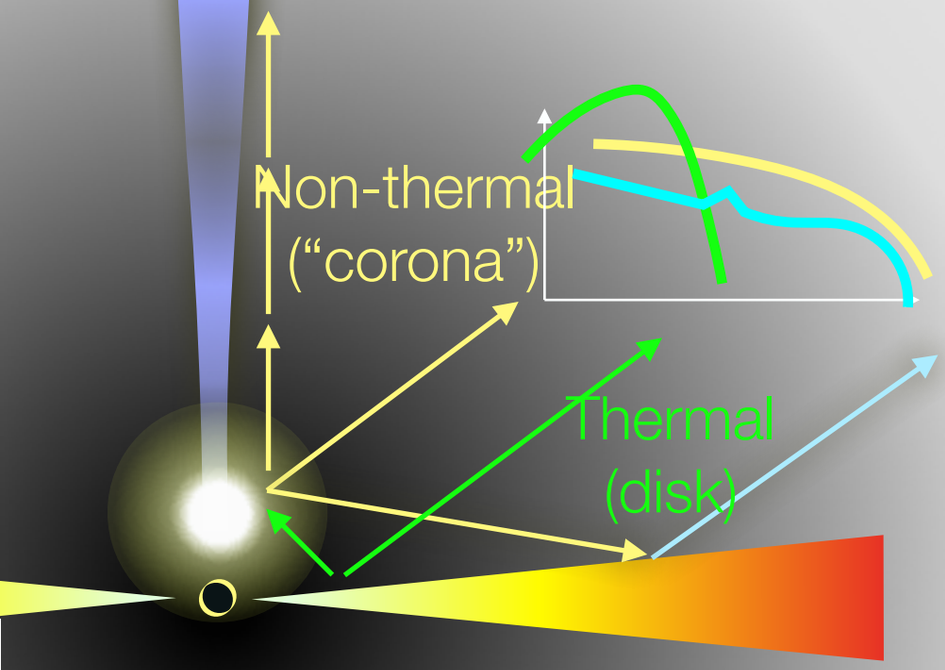
Phase-resolved spectroscopy



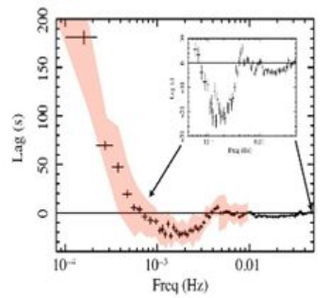


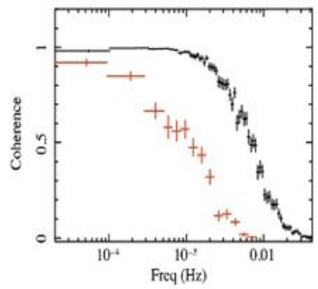
Fürst+14, ApJL, 784, L40

“Spectral timing” etc.



1H0707-495





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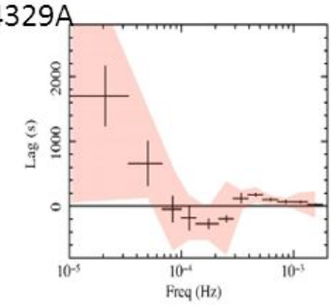
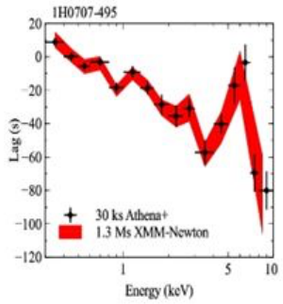
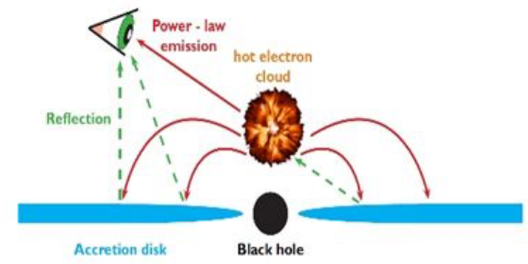
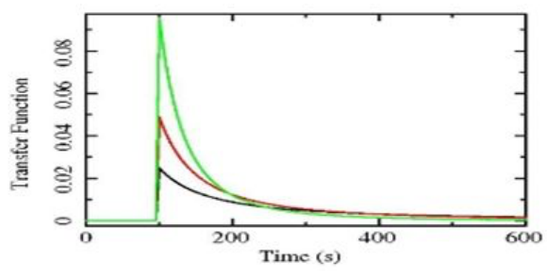


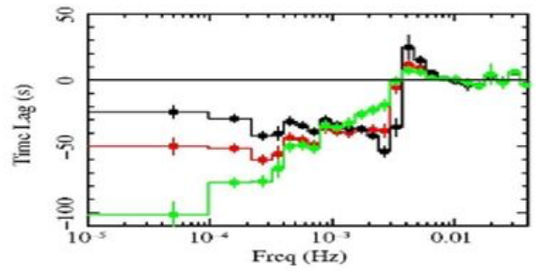


Corona/disk structure of (Reverberation mapping)

Time lag between 1-4keV and 0.3-1keV, Comparison between Athena and XMM





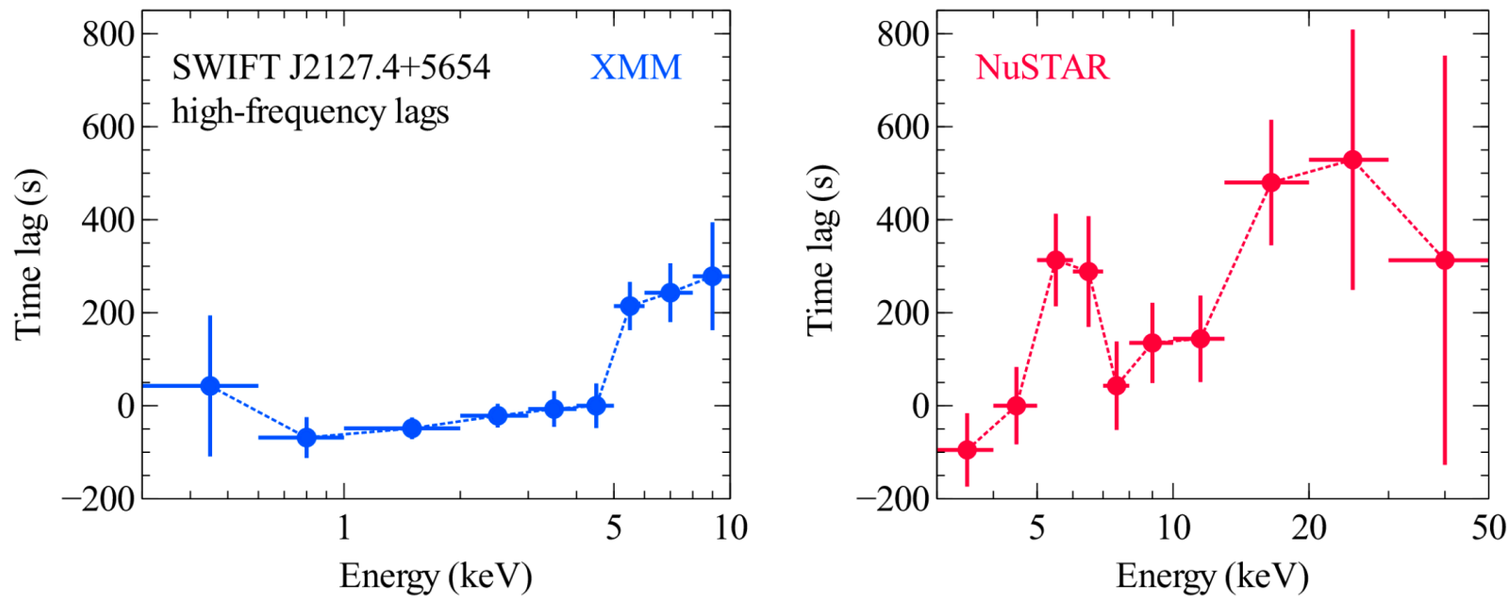


1H0707-495: time lag to probe the transfer structure of corona

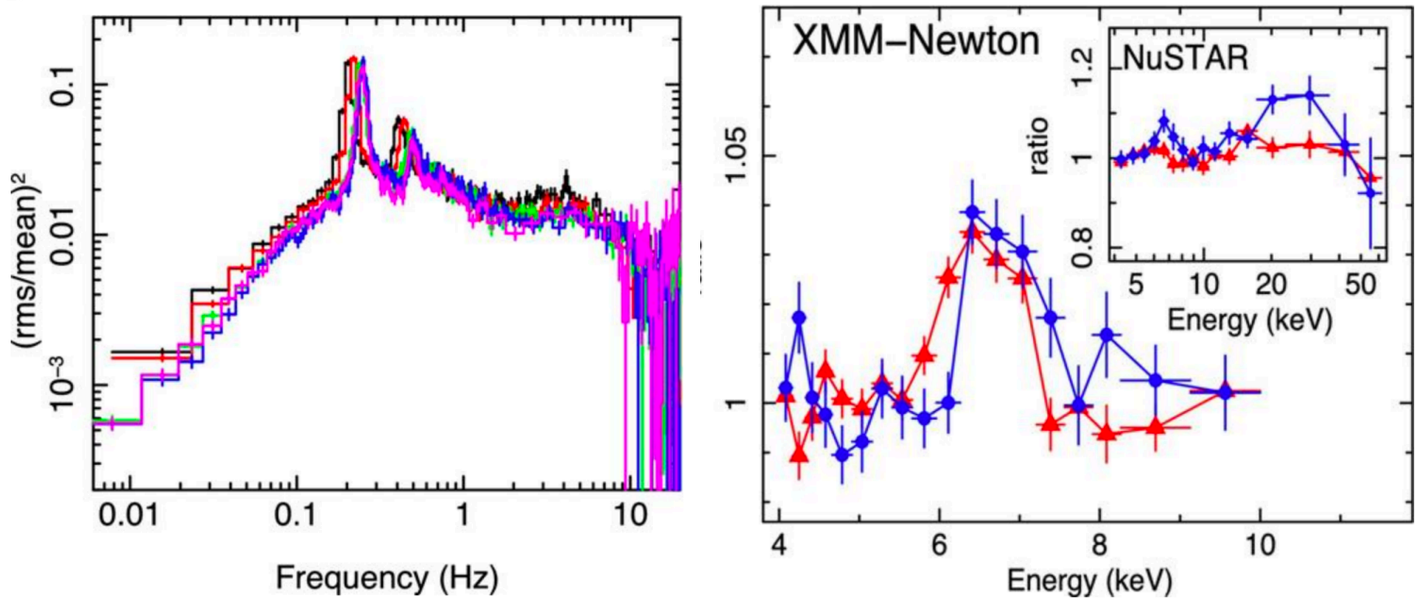
“Spectral timing” etc.

Phase-resolved spectra
Time lags vs Energy
rms vs Energy
Covariance spectrum
QPO phase-resolved spectroscopy
(…)

Often need multi-instrument observations

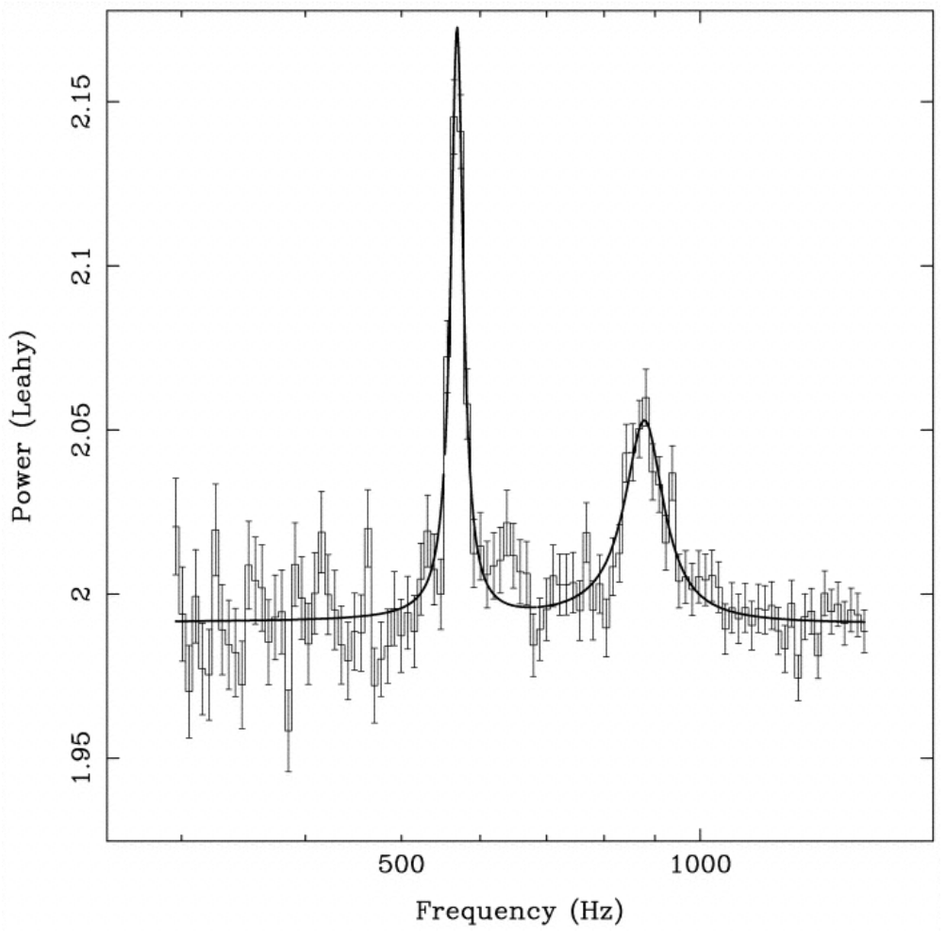


Kara et al. 2015



Ingram et al. 2016

Going to kHz QPOs?



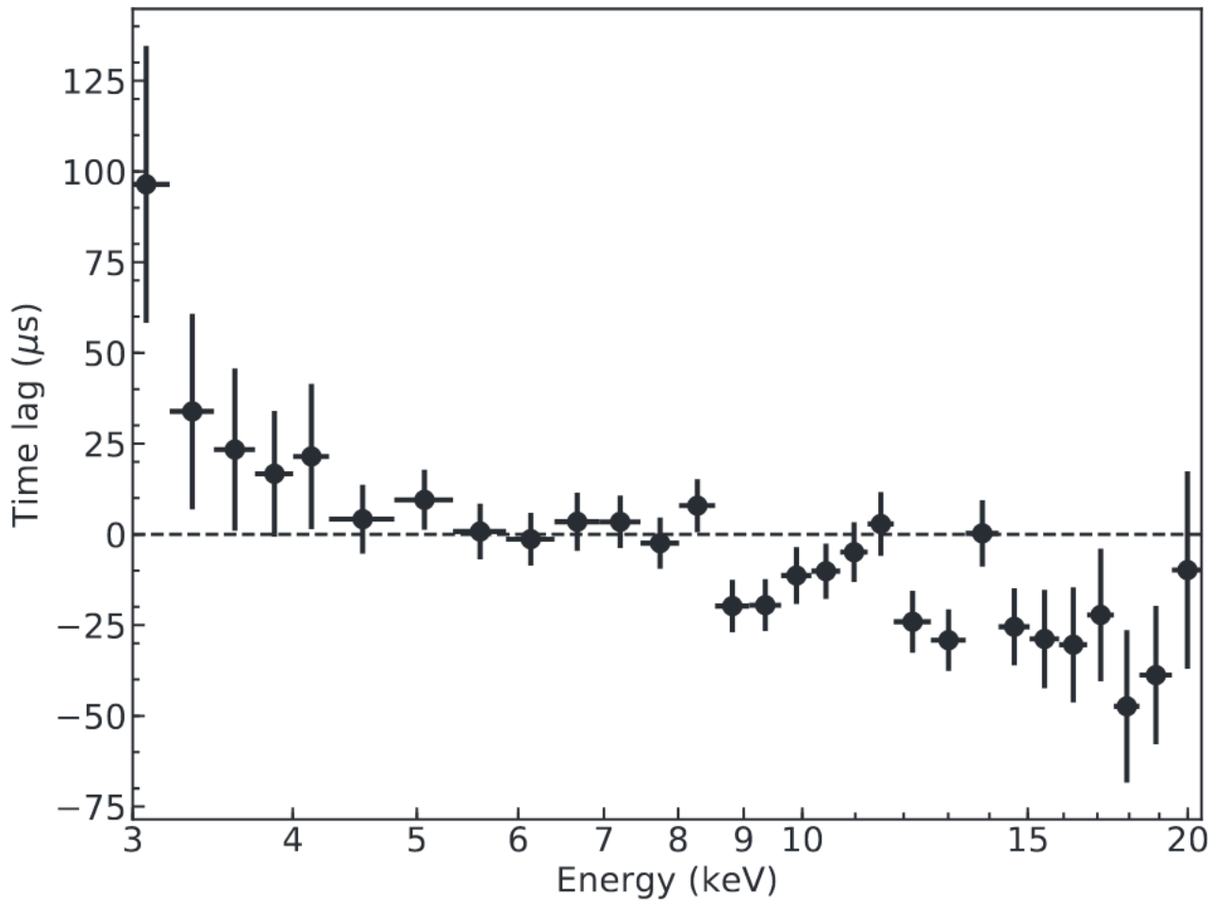


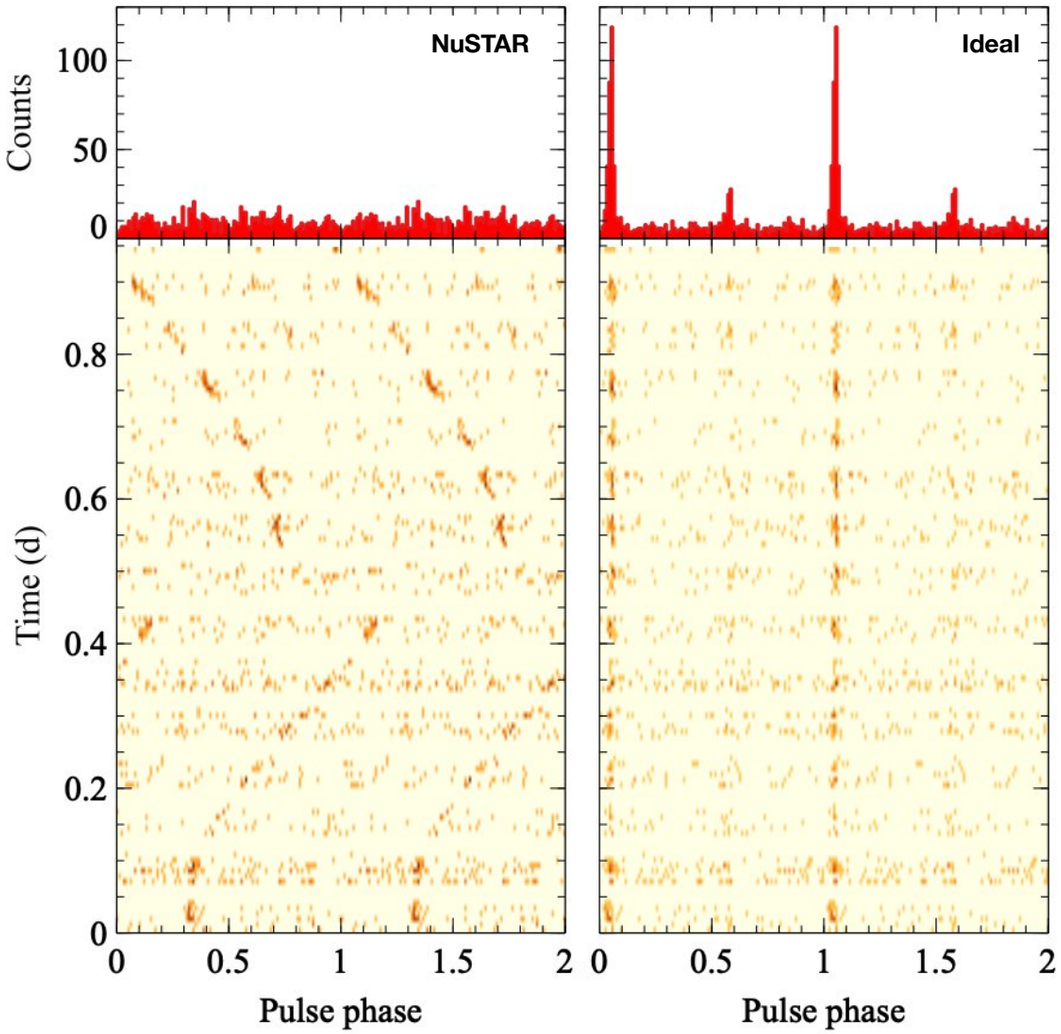
Figure 4.4: Lag-energy spectrum over the frequency range 825–845 Hz, computed from the shifted, averaged cross spectrum. A positive sign indicates that the variation in that energy channel arrived after the variation in the broad reference band.

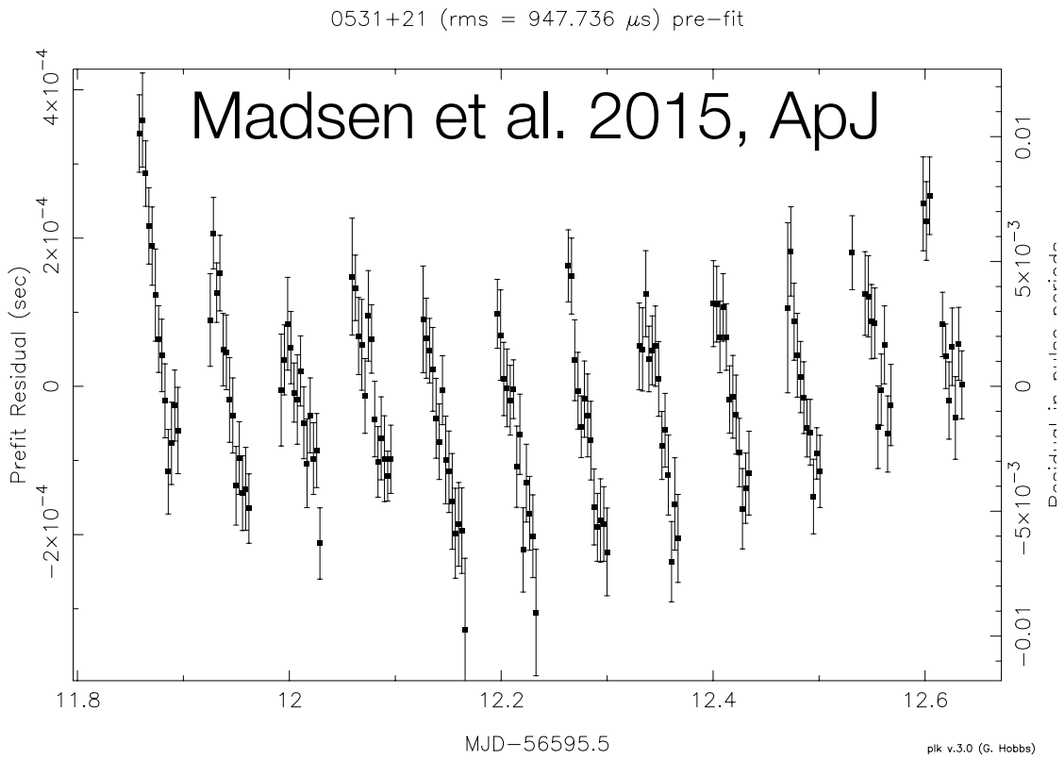
Méndez et al. 1998

Stevens et al. 2018

Need clock stability ~ us, and cross-instrument synch on same level

What is happening?



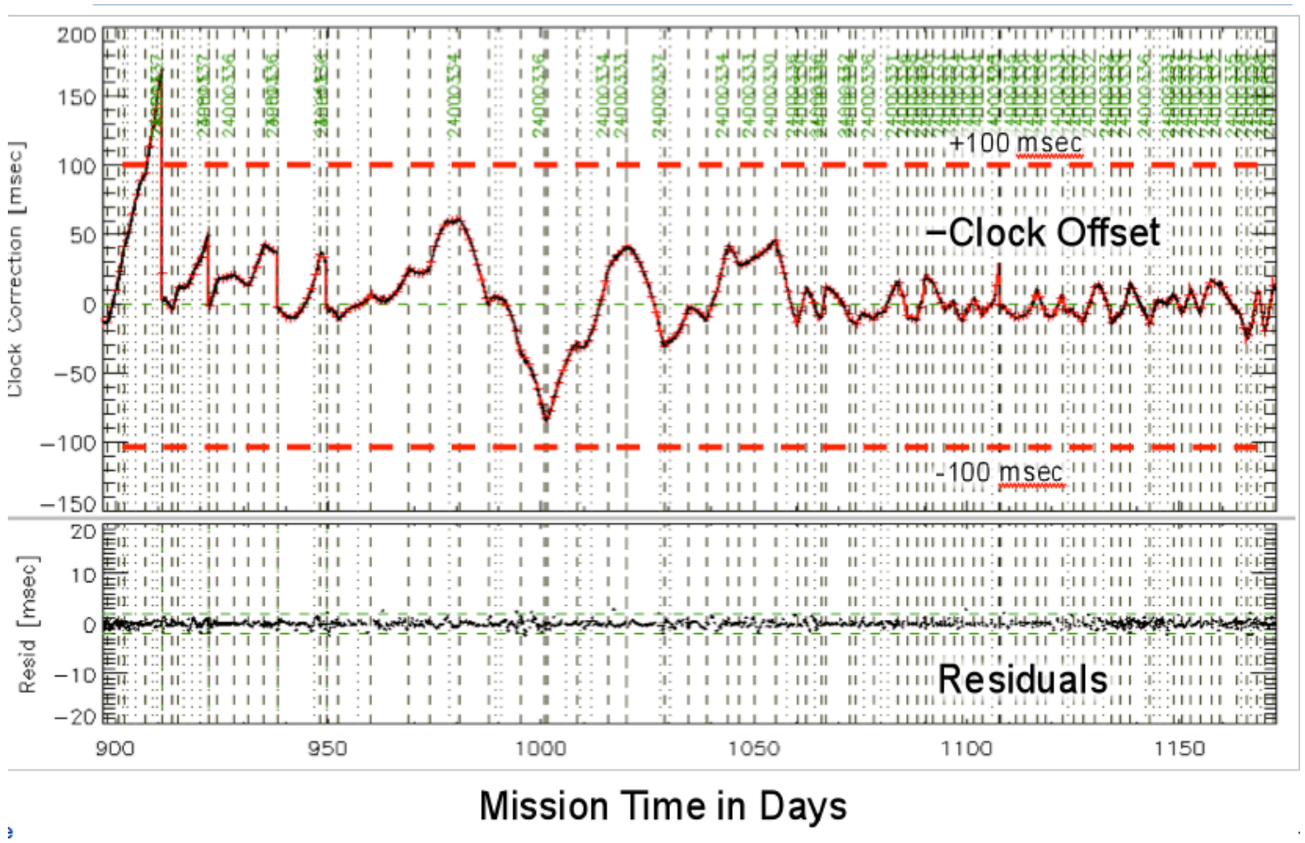


The analysis of the *NuSTAR* pulse phase residuals revealed the presence of a large spin-up derivative (2.6×10^{-10} Hz/s) and an oscillation close to twice the satellite orbital period. We sug-

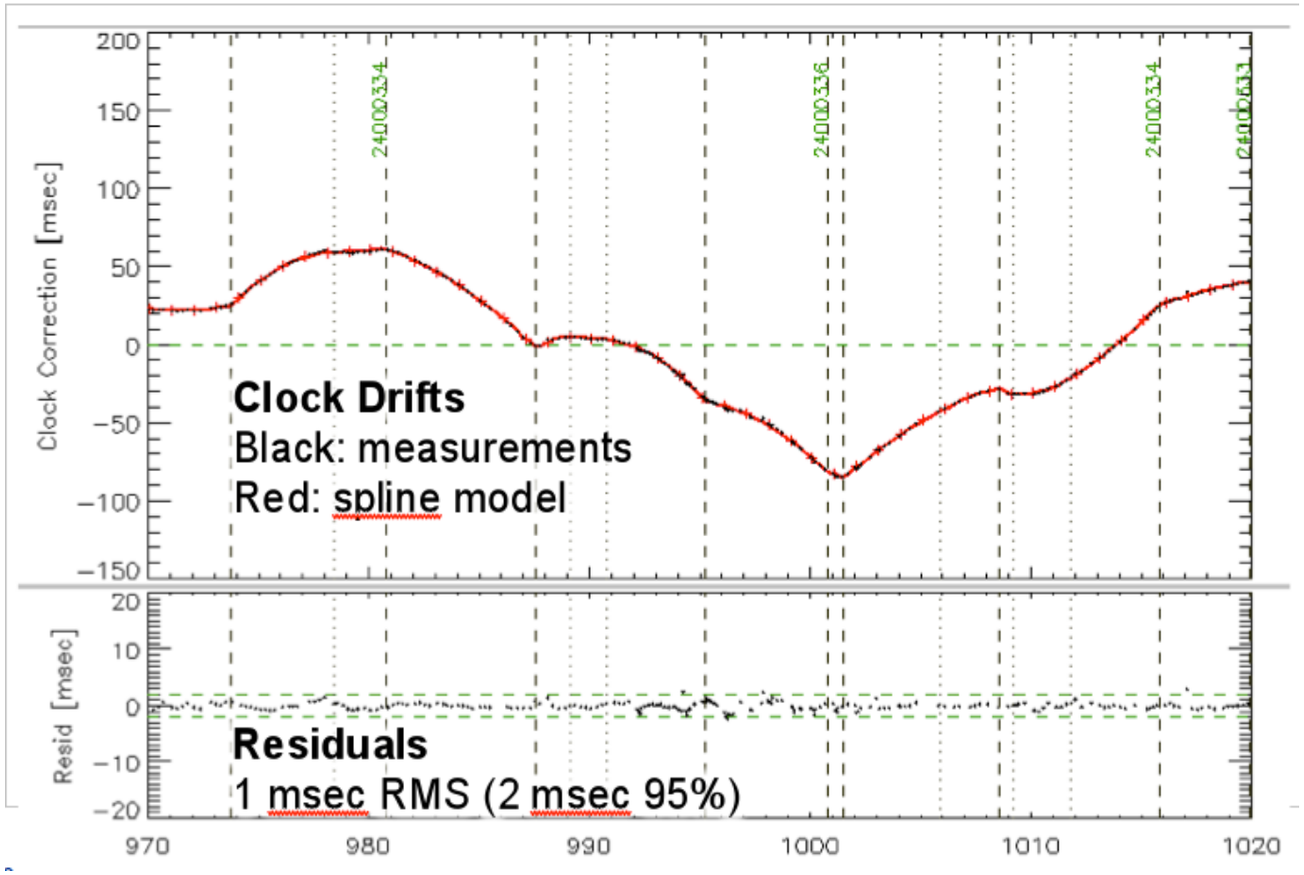
Sanna et al. 2018, A&A

Drifting…

- The spacecraft oscillator drifts (and with it the clock). ->Only (a-priori) unmodeled effect.

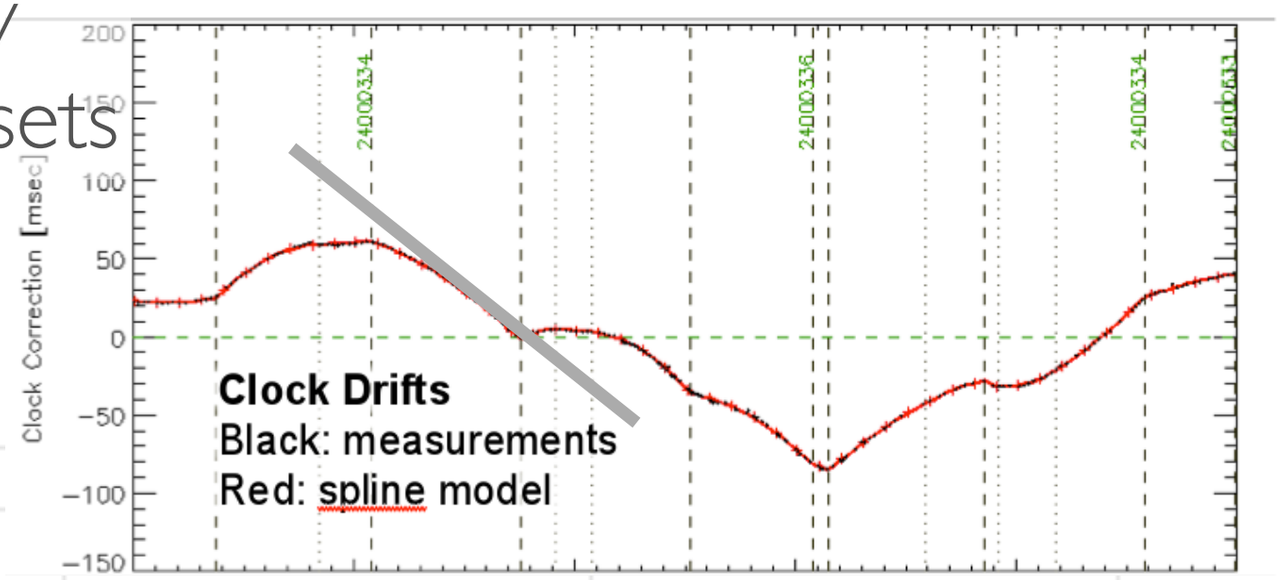


- Frequency is adjusted on a regular basis
- Measured at every ground pass
- Modeled with a spline in between -> clock file used with barycorr.

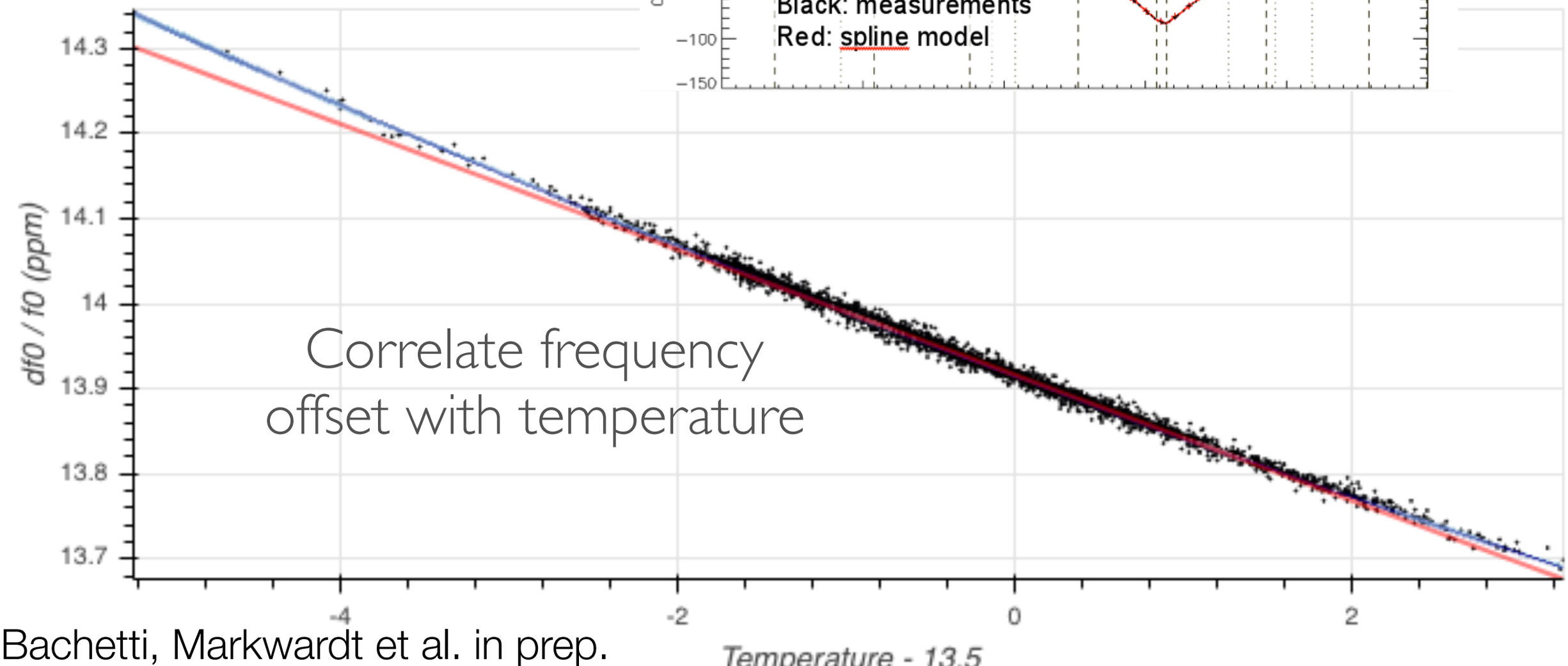


Characterize clock behavior

Measure frequency offsets from clock offsets



Correlate frequency offset with temperature

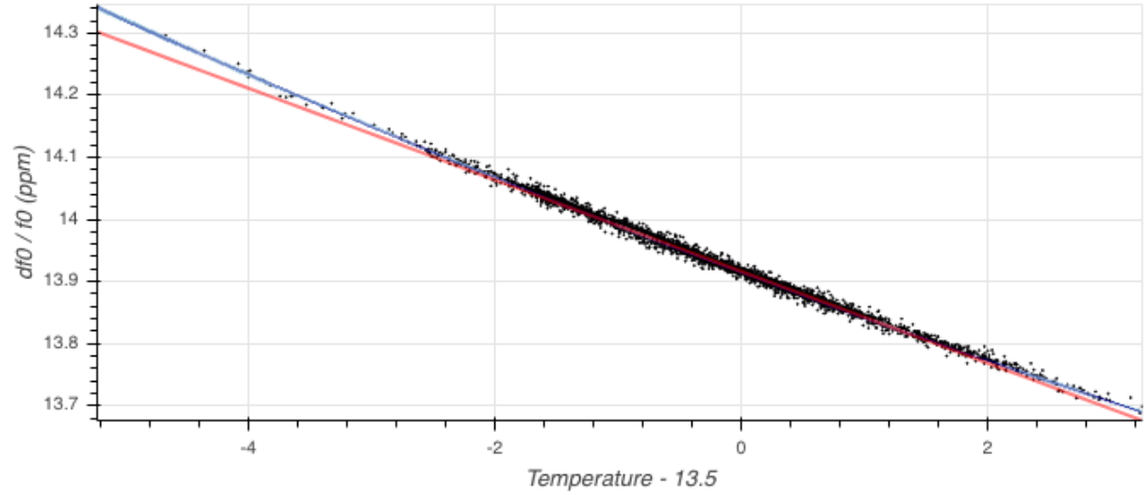


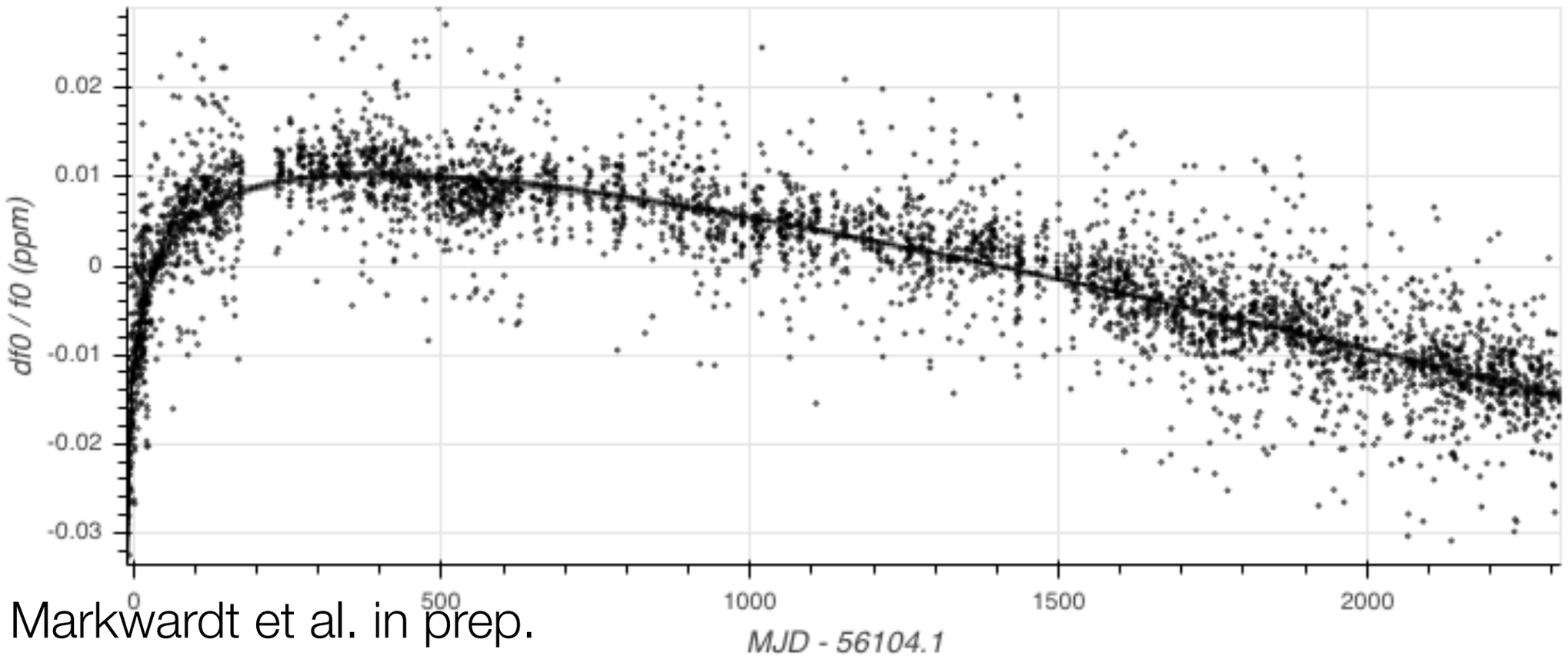
Bachetti, Markwardt et al. in prep.

Characterize clock behavior - II

Correlate frequency offset with temperature

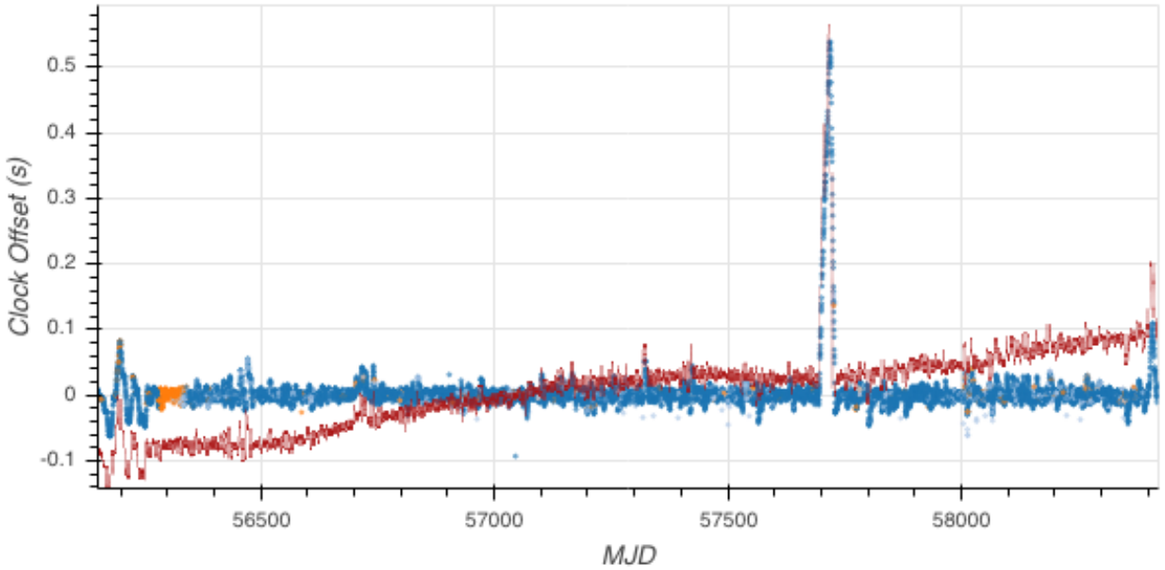
Characterize aging of clock over time





Bachetti, Markwardt et al. in prep.

Characterize clock behavior - III, IV, V, VI, ...



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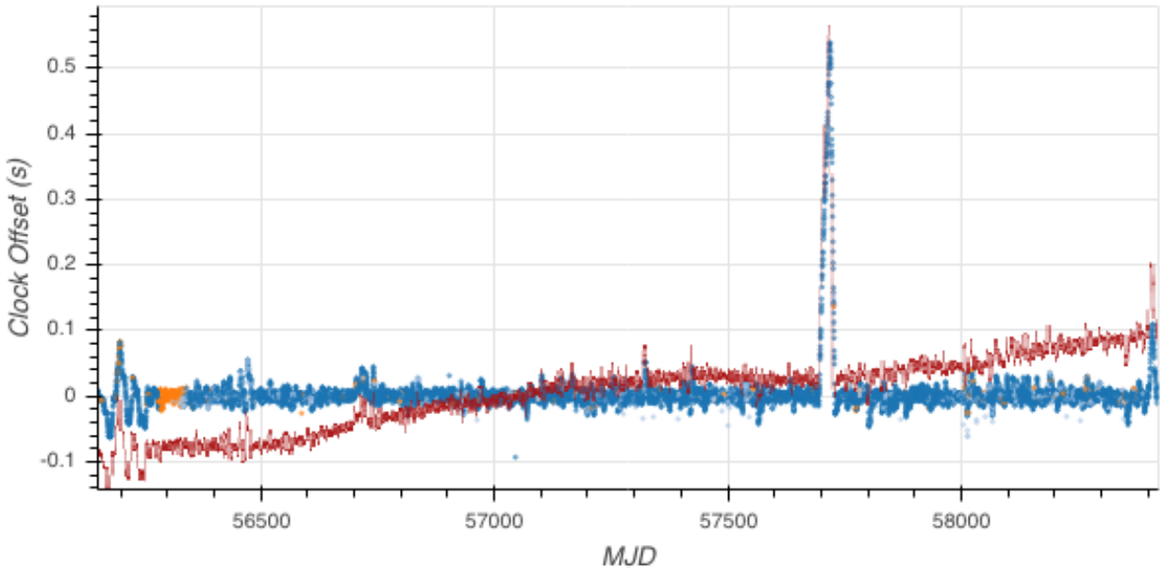

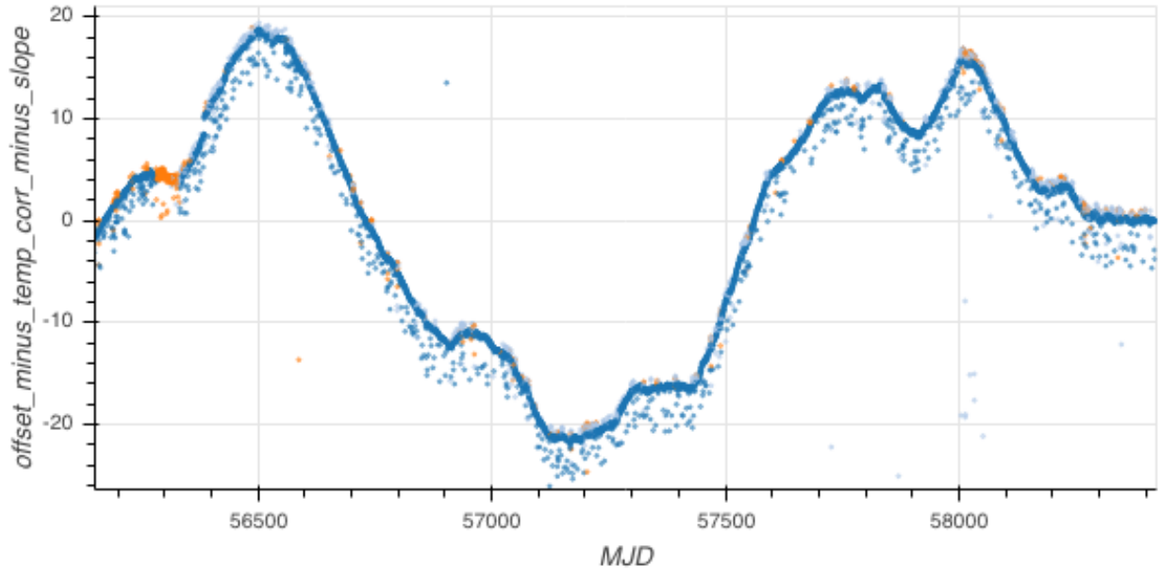

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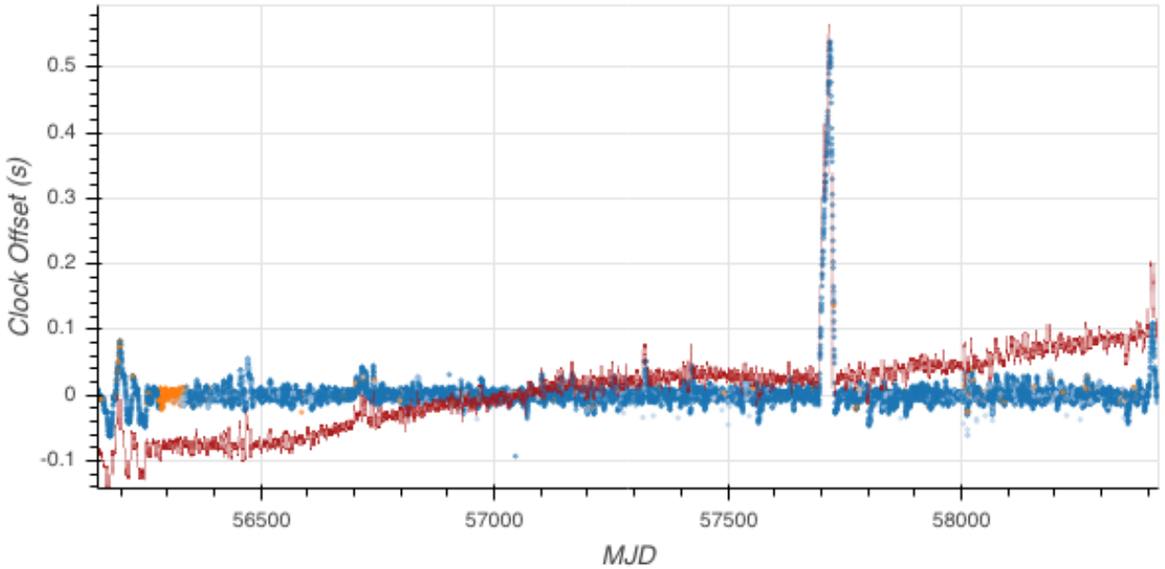

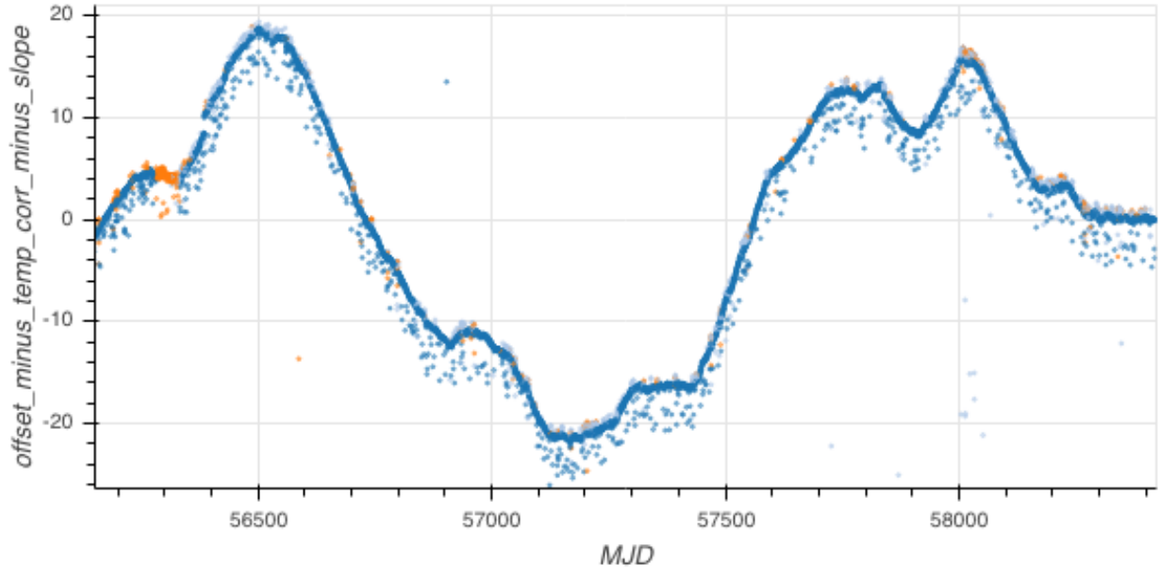

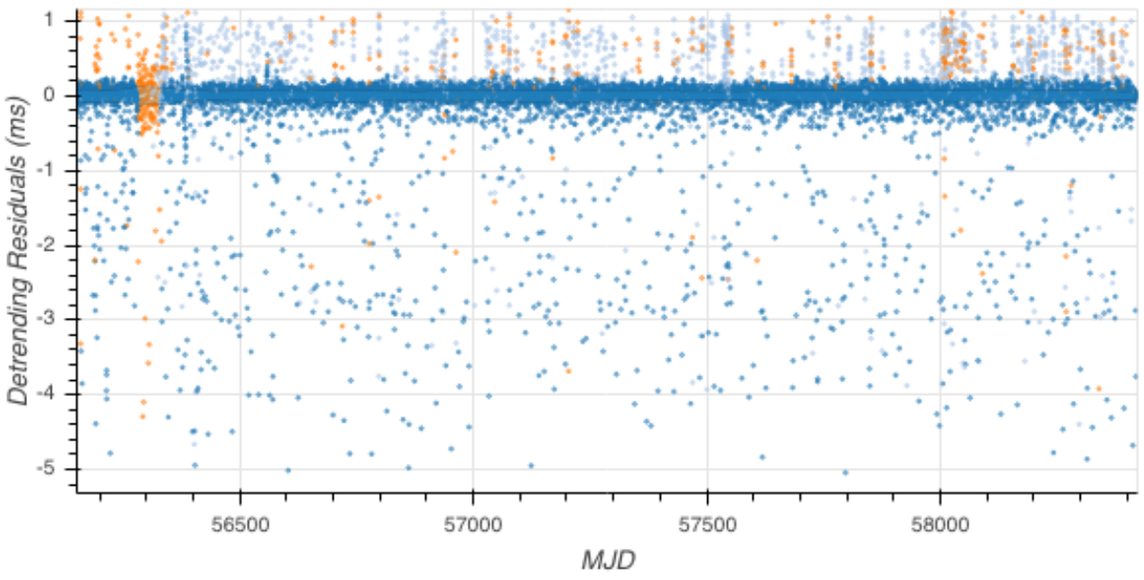

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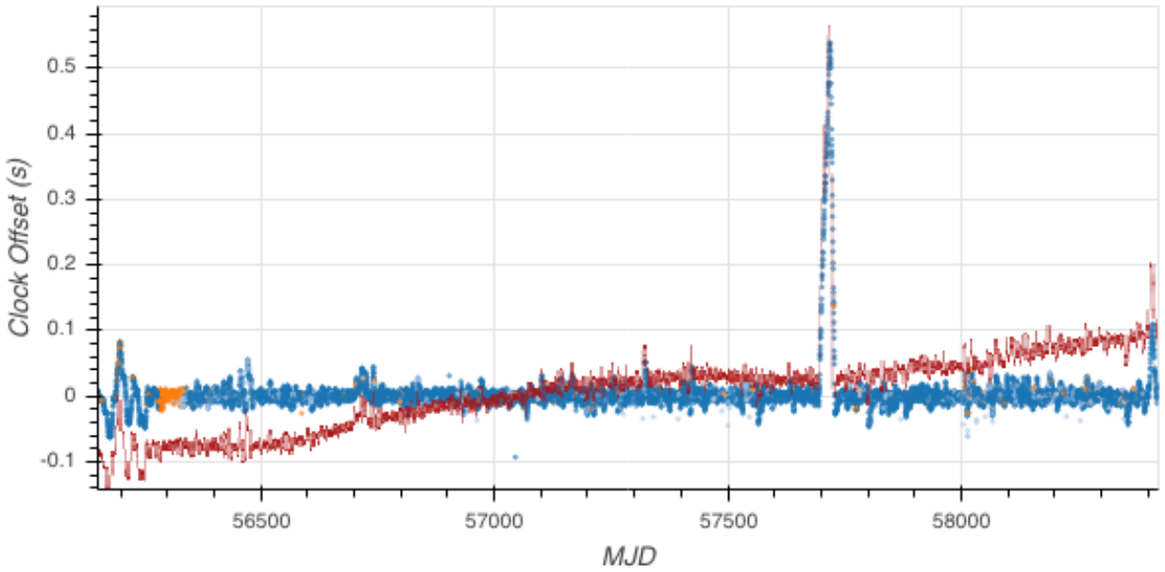

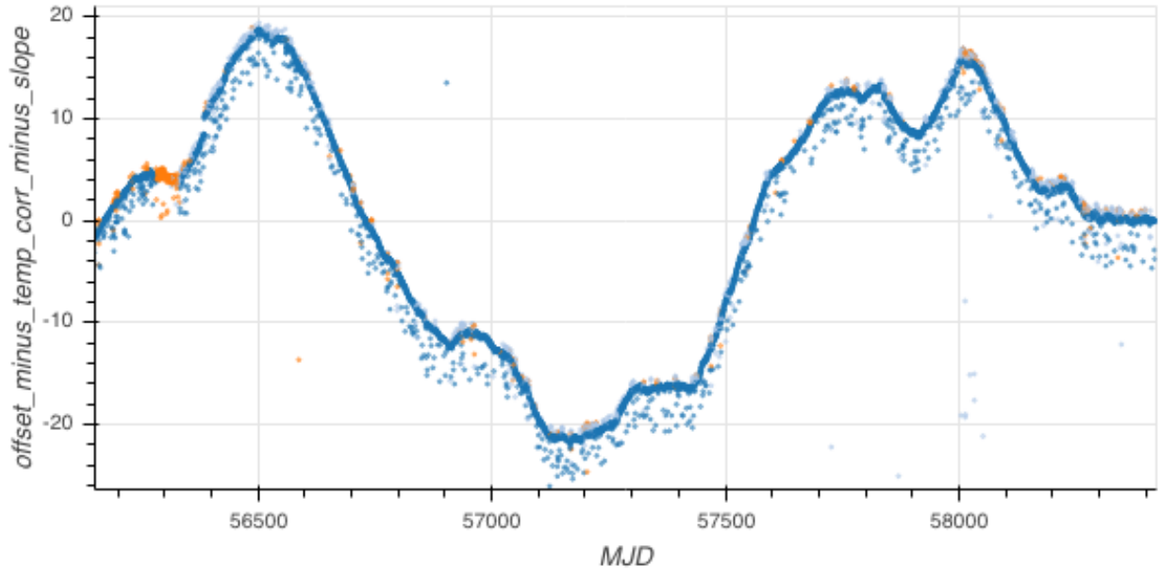

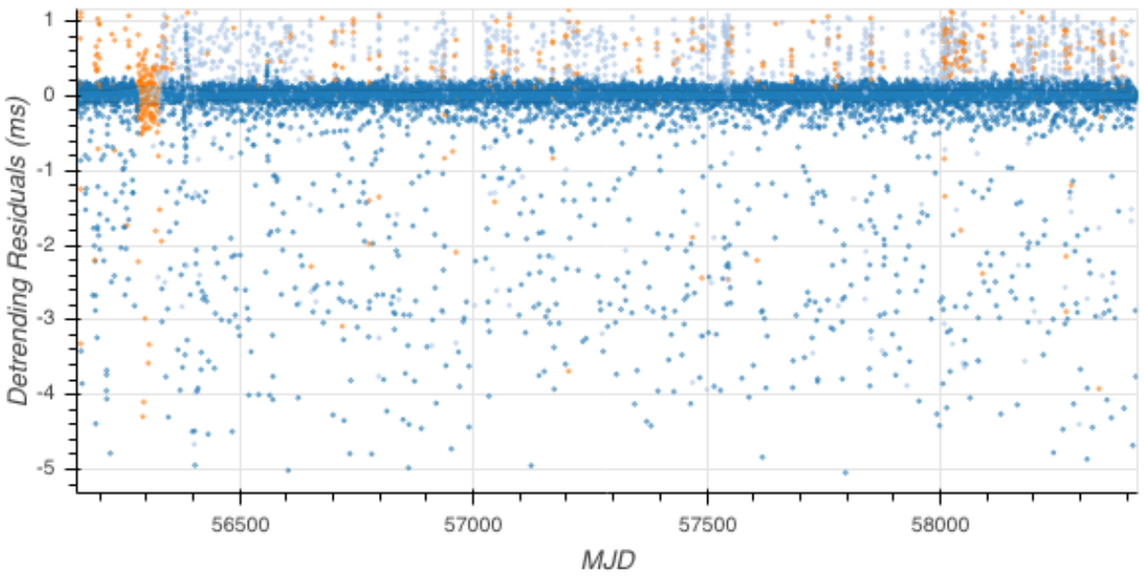

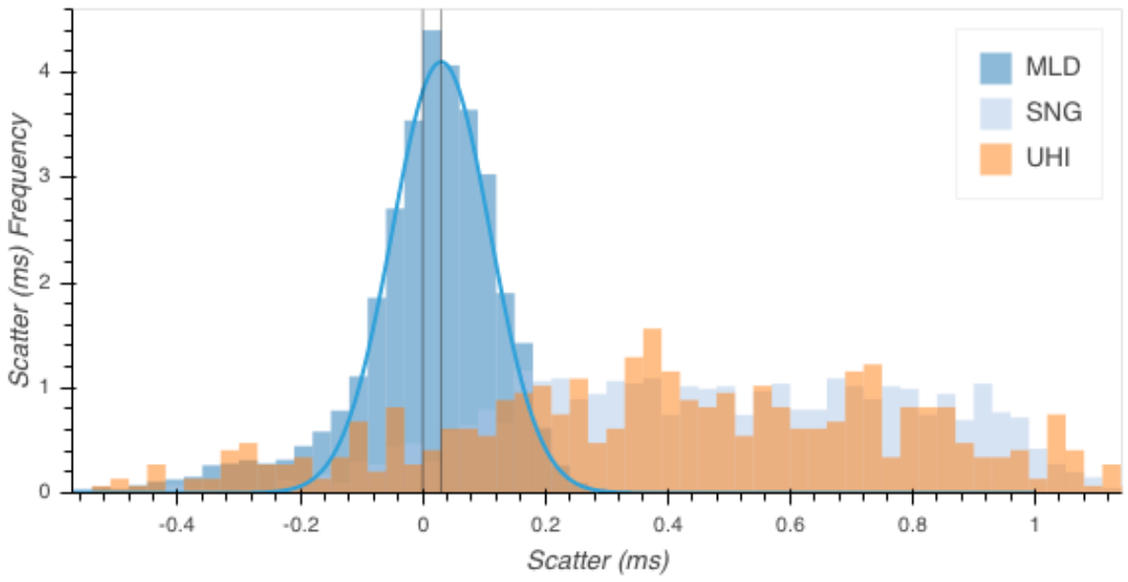

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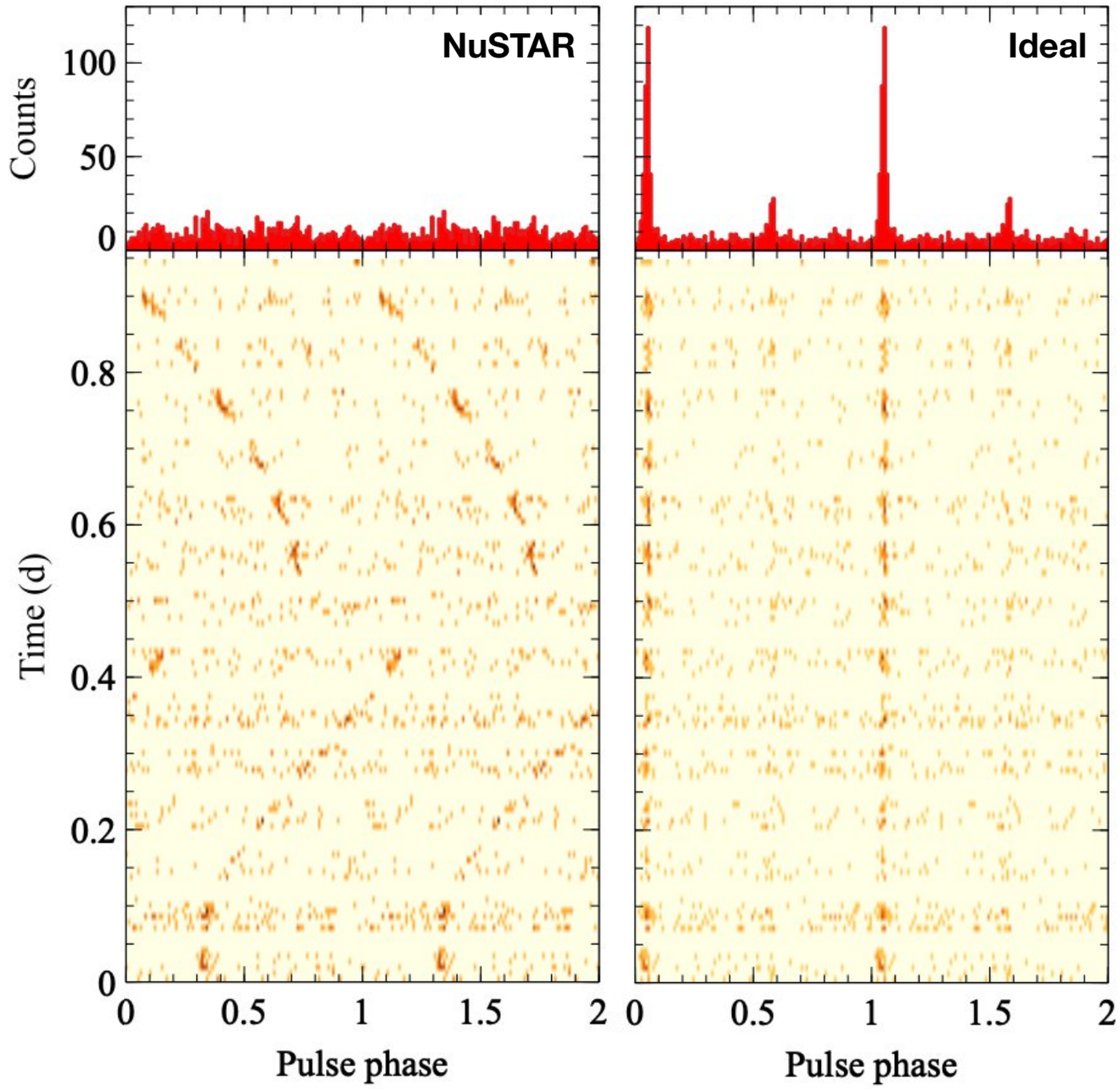
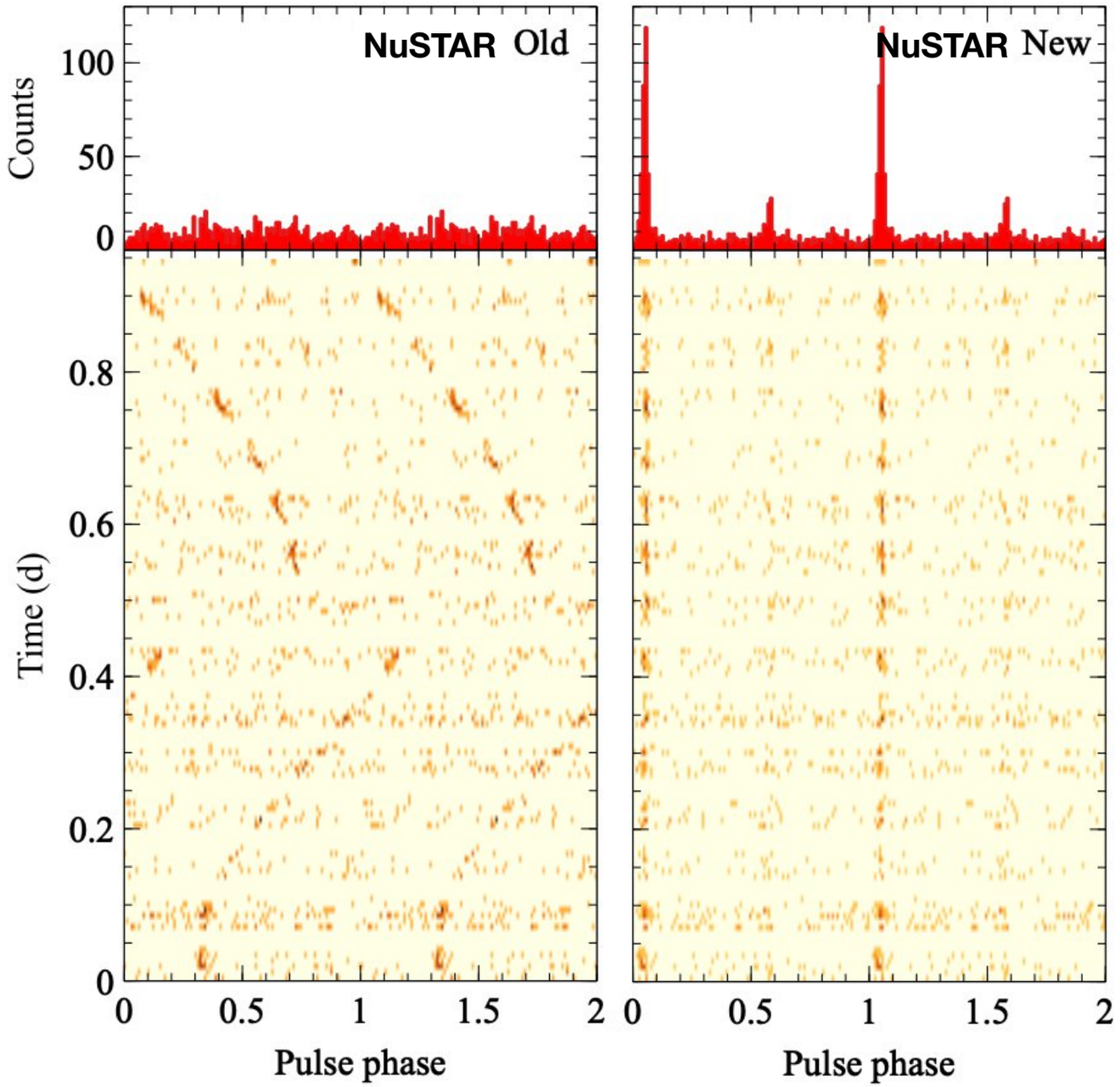
Characterize clock behavior - results



Characterize clock behavior - results

Phaseogram of PSR B1937+21 with NuSTAR, with current clock correction and new clock correction

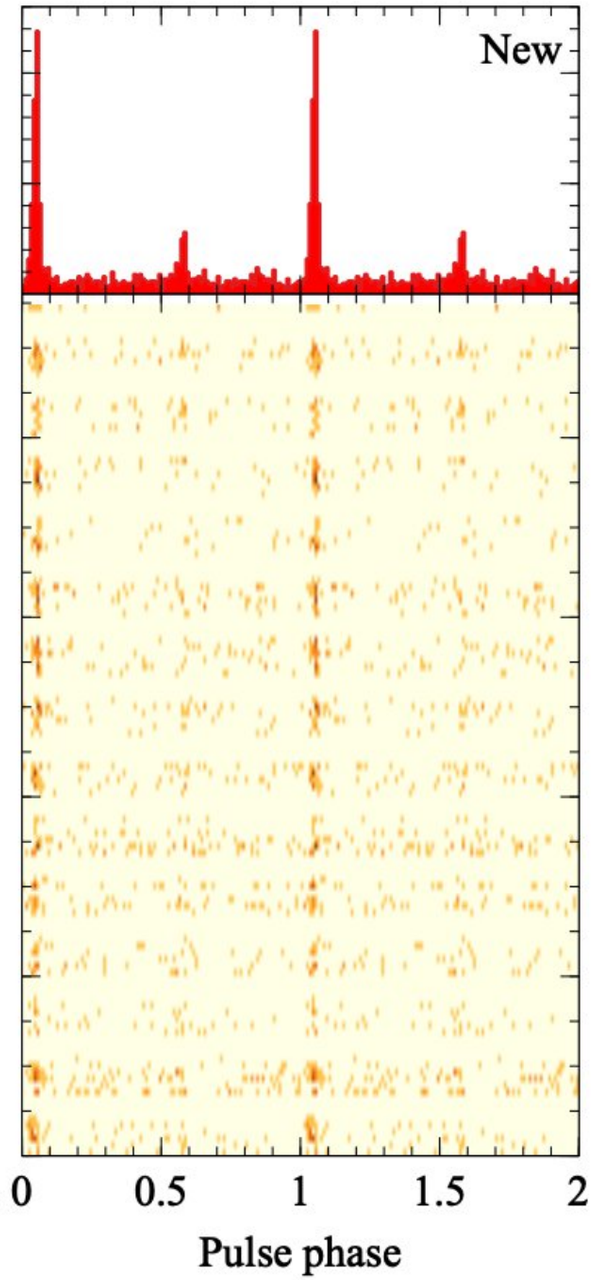
- Millisecond pulsars now feasible with NuSTAR!
- Characterizing the temperature-driven clock drift between ground passes allows for extremely more accurate clock correction



Bachetti, Markwardt et al. in prep.

Bottom line

- NuSTAR now ready for fast timing:
  - 20 us stability over ~1 day
  - 60 us absolute calibration uncertainty?
- Need for cross-calibration tests.



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