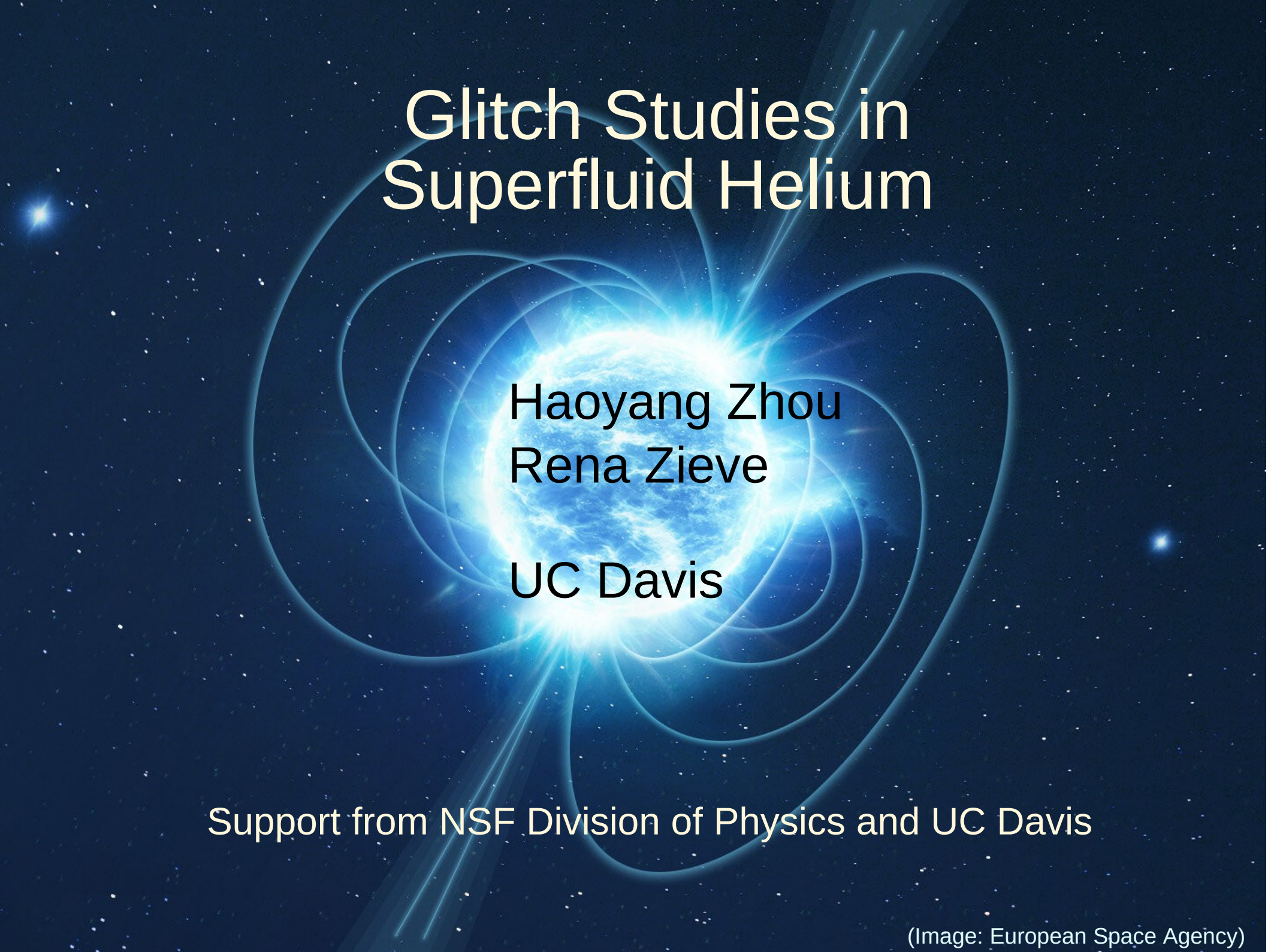
# Glitch Studies in Superfluid Helium

Haoyang Zhou
Rena Zieve

UC Davis

Support from NSF Division of Physics and UC Davis



(Image: European Space Agency)

# Talk Outline

Superfluid helium experimental model

Experimental difficulties

Current data

Where next

Haoyang Zhou

# Superfluid Helium Experiments

Superfluid transition temperature is 2.17 K

Can cool helium to around 1 K with a vacuum pump

- By low-temperature standards, no fancy cryostat needed
- Still need to think about thermal shielding, vacuum feedthroughs

1 K is *not* effectively zero temperature

- Normal fluid fraction 1% near 1.05 K, 5% near 1.31 K
- Different from neutron stars, with negligible normal fluid
- Electron fluid in neutron stars plays role of normal fluid

Vastly different size scales compared to neutron stars

# Superfluid Helium Setup

electromagnet

Nd magnet

Levitation, with Hall probe sensor for feedback loop

Mechanical arm allows lowering and raising probe (e.g., for filling bucket with helium)

Motor to drive rotation

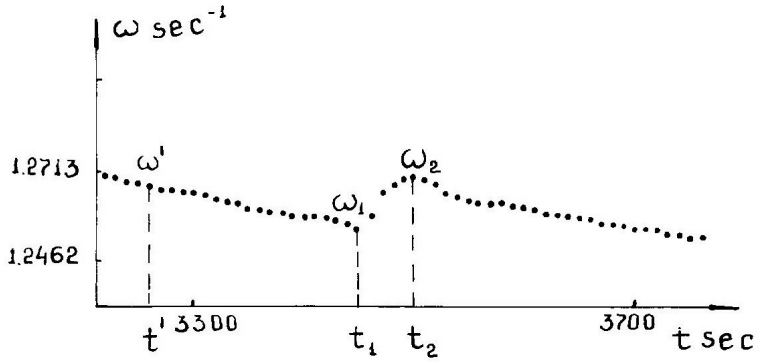
Optic fiber

Slotted disk

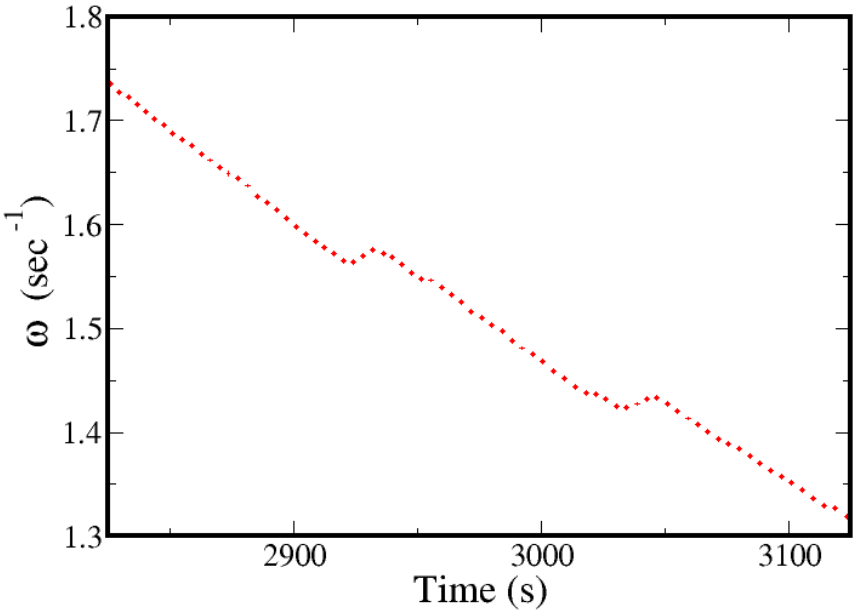
Angular velocity measurement. Light reflects off alternating wedges, so light/dark pattern gives the speed

Helium bucket

# Helium glitches, then and now

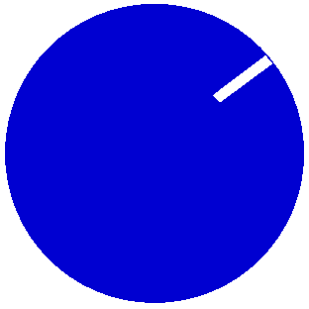



Tsakadze & Tsakadze, JLTP 39 1979
& several other articles

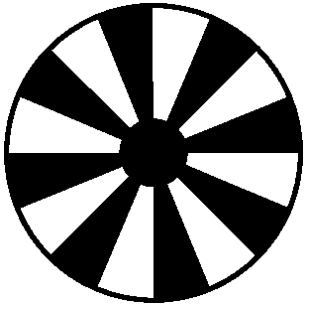



Similarities: time in run (almost 1 hour after rotating)
angular velocity in same range
rise time of glitch
amplitude of glitch
measurement point spacing in time

WHY???



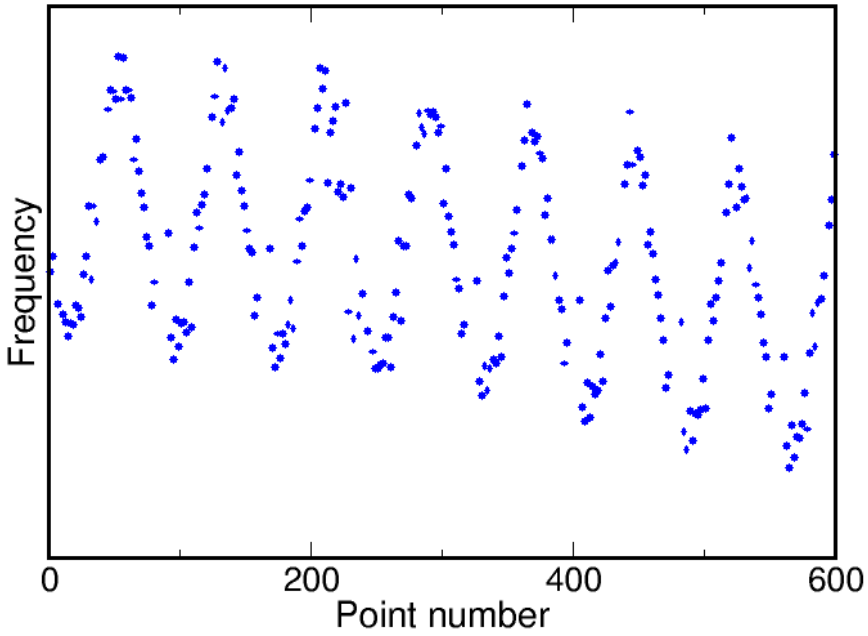
single reflecting
strip



Many reflecting teeth
(actually 40, not just 8)

# Period-matching Oscillation

- Angular velocity varies during a revolution
- One reason: Nd-based magnet for levitation; moment has small horizontal component
- Horizontal field in room, ~0.3 G, gives torque on moment
- For this mechanism, amplitude goes as $1/\omega$




H
0.3G

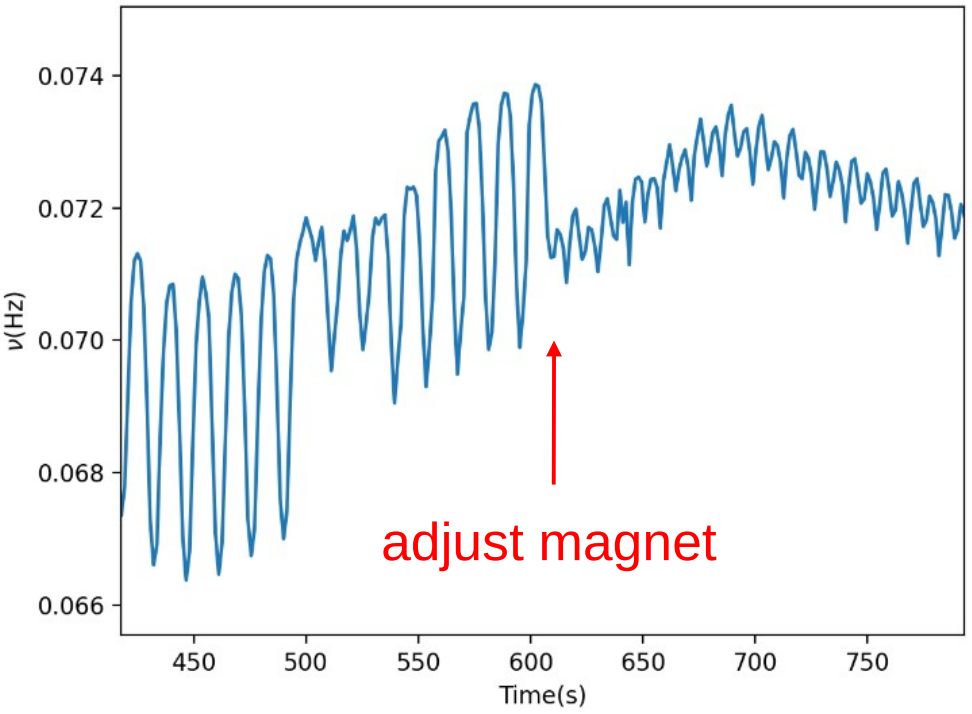
Slows while moving away

Preferred orientation

Speeds up while moving towards

$$\tau = \mu B \cos\theta \approx \mu B \cos 2\pi\bar{\nu}t \qquad \nu = \frac{1}{I}\int \tau dt = \frac{\mu B}{2\pi\bar{\nu}I}\sin 2\pi\bar{\nu}t$$

# Half-period Oscillation




On canceling ambient field, get oscillation at *twice* the rotation frequency

From magnetic (magnetizable) materials near probe

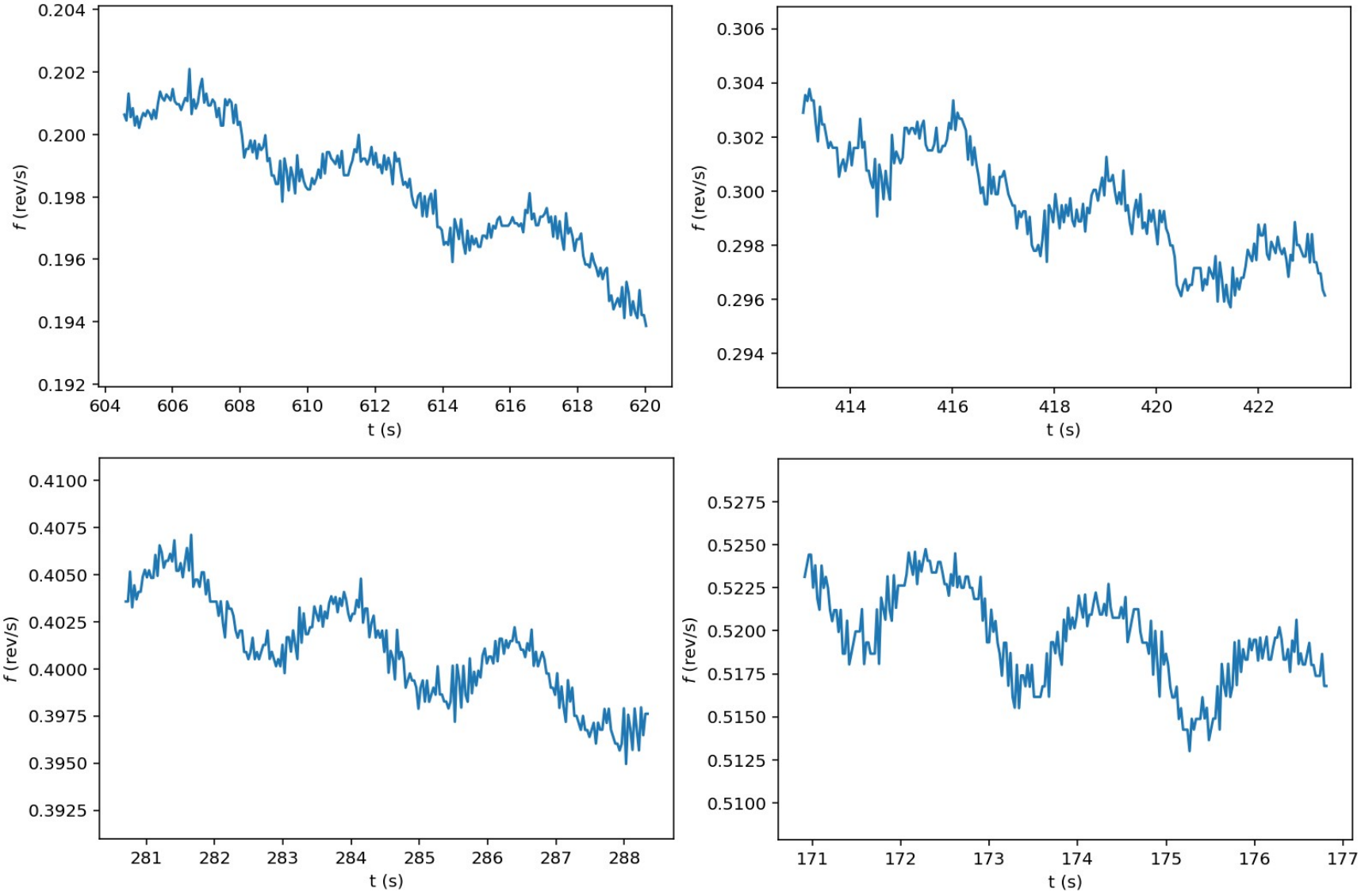
Again, expect amplitude to go as $1/\omega$

Removed what we could, including exterior casing for optic fiber (supposedly non-magnetic, but that was wrong)

Seem to have problematic material in the “vapor shields” built into neck of dewar (which is supposedly aluminum and non-magnetic)

# Period-matching Oscillation #2

After reducing the ambient field, we see this at higher rotation rates:

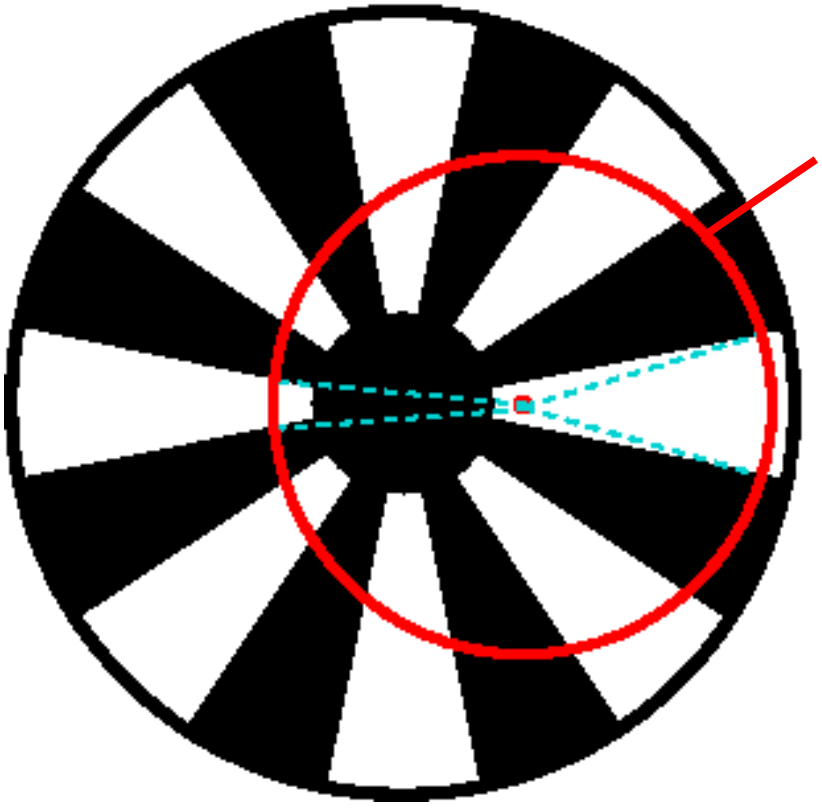



Oscillation amplitude *increases* linearly with frequency.

# Period-matching Oscillation #2

- Comes from measurement disk not being quite centered on the rotation axis

VERY EXAGGERATED PICTURE!!
(real offset << 1 mm)




- Amplitude of this contribution goes as $\omega$
- This is a measurement artifact, NOT a true speed change
- Displacement may be partly from bending of the support rod

# Half-period Oscillation #2

Another geometric effect: slight tilt of disk (from warping of the rod)

Portions above or below the original plane have larger radius under the optic sensor ⟶ longer time interval

Also have shortened time from the tilt

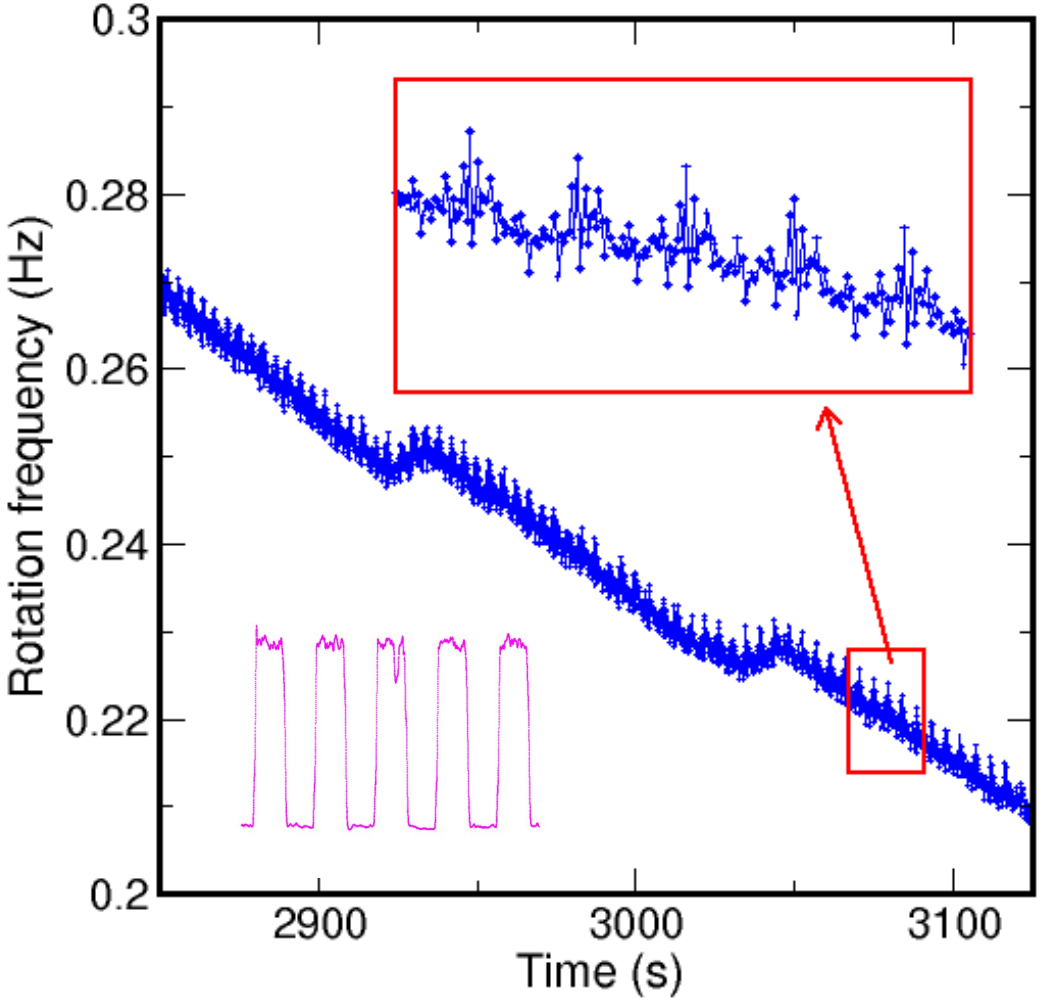
$$\frac{d\psi}{dt} = \frac{\cos\alpha}{\cos^2\alpha\cos^2\theta + \sin^2\theta}$$

$\alpha$ = tilt angle, $\theta$ = angle on disk, $\psi$ = detected angle

Have not (yet) encountered this particular difficulty

# Other Unwanted Effects

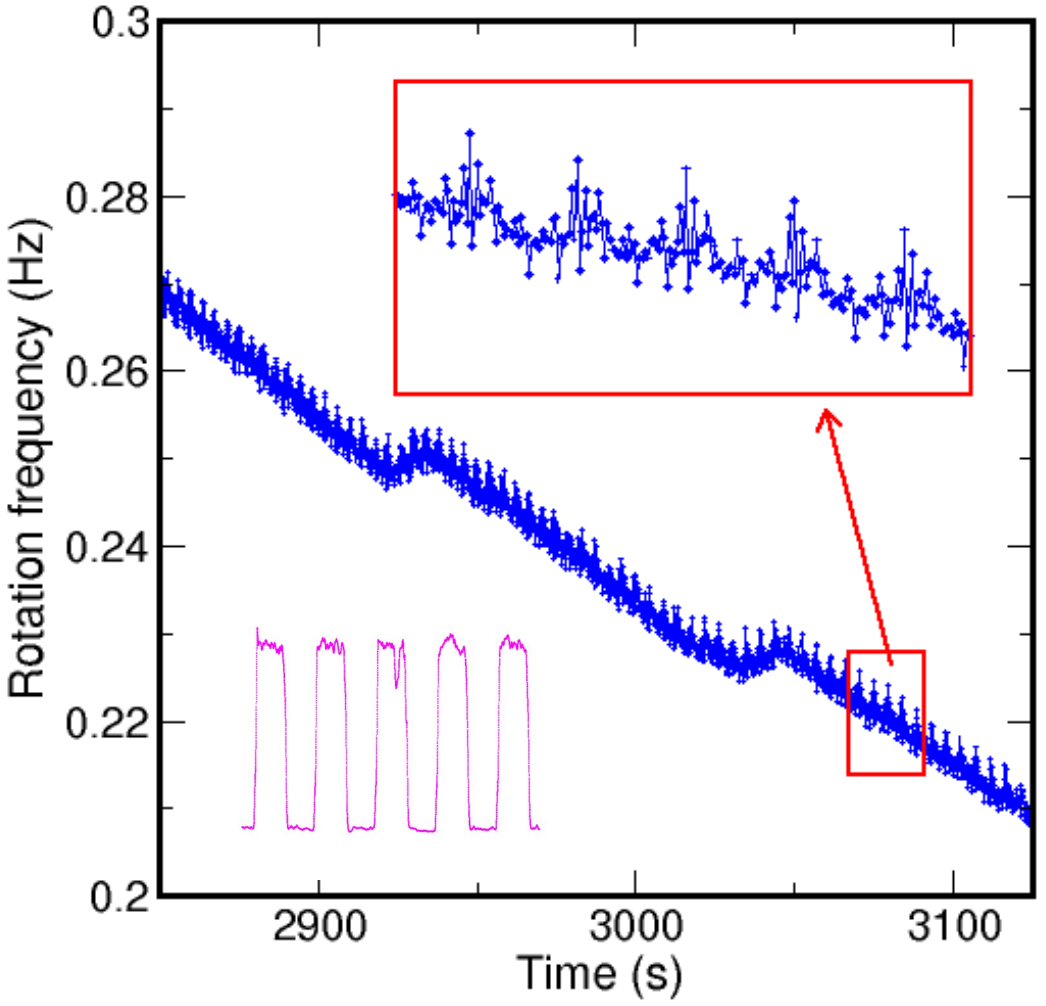
- Magnetic field cancellation is in place
- Complicated periodic features remain from non-identicality of teeth
- Expect linear scaling with rotation speed
- Oscillatory effects make this difficult to subtract off




- Shows only 40 points per revolution; average consecutive points because start vs. end of teeth very asymmetric

# Other Unwanted Effects

- Magnetic field cancellation is in place
- Complicated periodic features remain from non-identicality of teeth
- Expect linear scaling with rotation speed
- Oscillatory effects make this difficult to subtract off




- Shows only 40 points per revolution; average consecutive points because start vs. end of teeth very asymmetric

# Phase Info

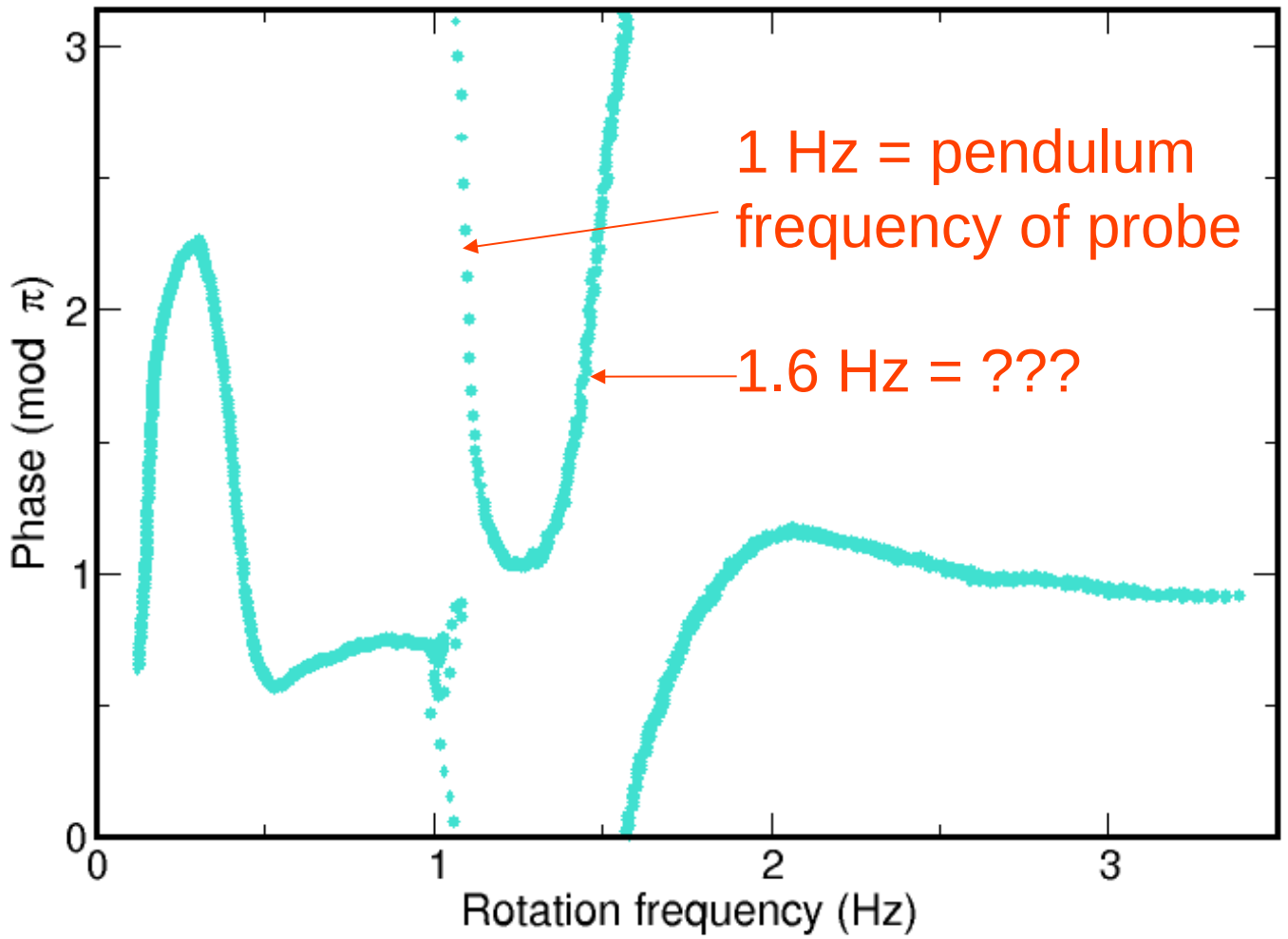
Geometric oscillations should have fixed phase relative to disk, independent of angular velocity

Magnetic oscillations should have fixed phase relative to ambient field (i.e., relative to the room)

- For given run, optics fixed relative to room
- Hence observed tooth patterns also fixed relative to room
- The relationship CAN change between runs.

Two or more sine waves at frequency $\omega$ add to $A\sin(\omega t+\phi)$, with phase depending on the amplitudes of the contributions

# Phase Info




Slowly varying the amplitude of one contribution to oscillations (e.g., by changing current in cancellation coil) modulates phase

May help identify amplitude of each contribution

# Measured Glitches

Examples from 3 slowdowns (under 1.5 total hours of data)

| Glitch size (mHz) | Number of occurrences |
|---|---|
| 1 | 5 |
| 2 | 1 |
| 3 | 3 |
| 4 | 1 |

The table includes just large glitches, where $\nu$ rises by at least 1 mHz. Two of the examples shown here are simply shoulders, where $\nu$ does not increase at all.

Overall: used 241 events from 8 slowdowns for some statistical analysis (less than the astro total, but far more than for any individual star)

# Stuff We've Seen

Several hundred vortices annihilate per glitch ($10^{11}$ in neutron stars)

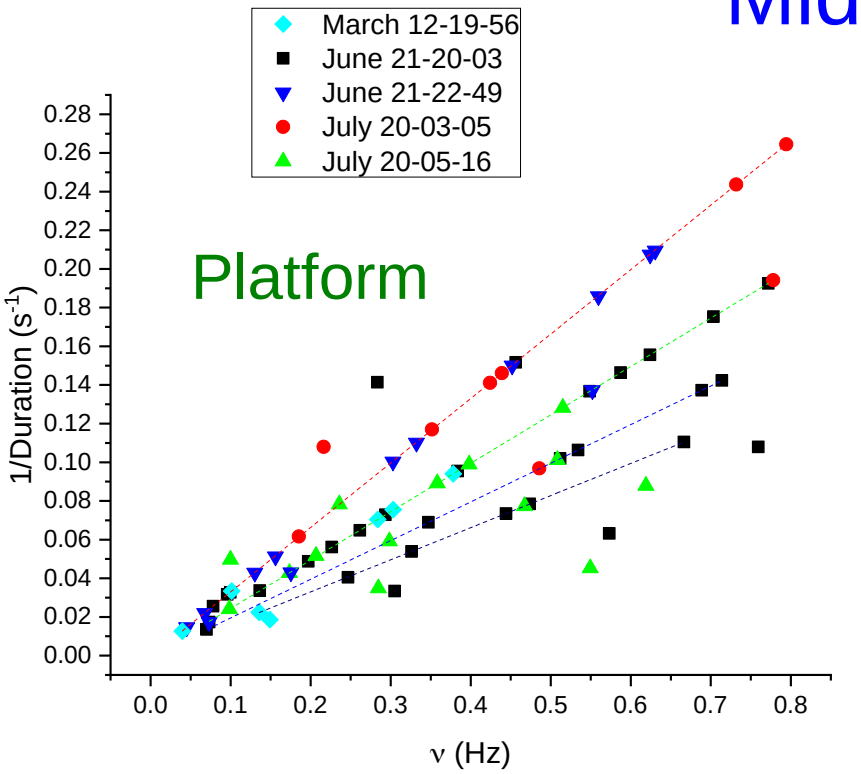
Adding a rough plate midway up the container leads to fewer but larger glitches, probably because vortices pin more strongly

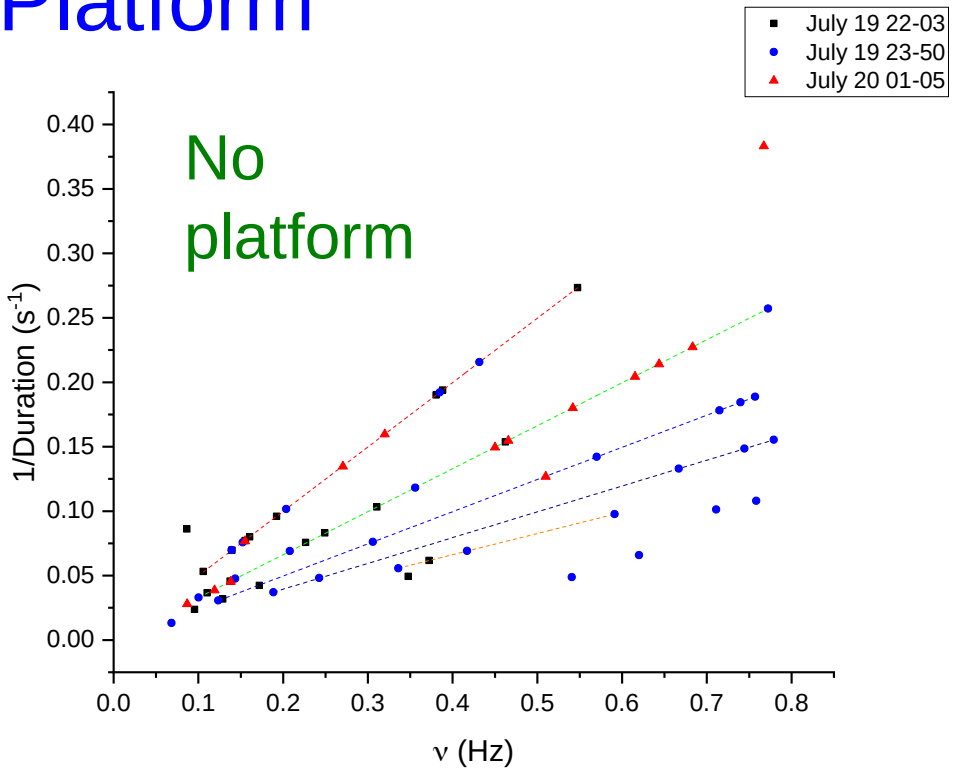
Glitches occur more frequently when deceleration is larger, consistent with relative velocity of interior and exterior increasing faster

Glitches occur more frequently at higher rotation speeds

Cascades of small glitches too close together to be treated as independent. (Rarer in neutron stars, although at least two nearby glitches have been seen.)

# Mid-Cell Platform



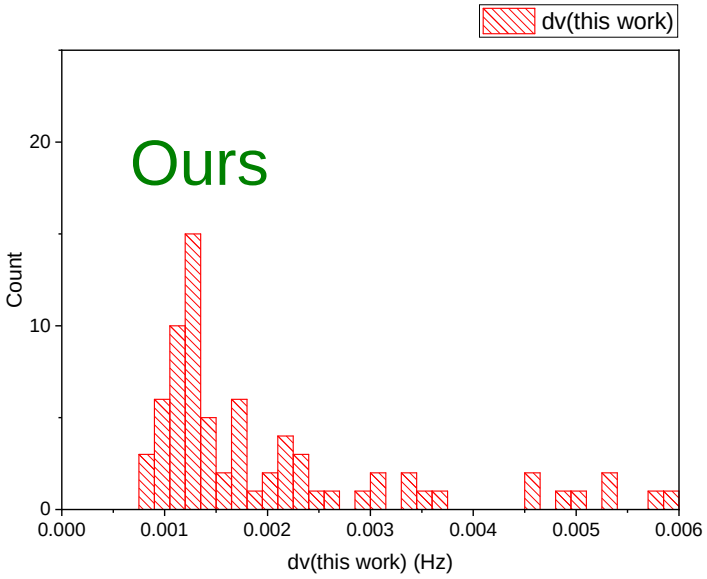



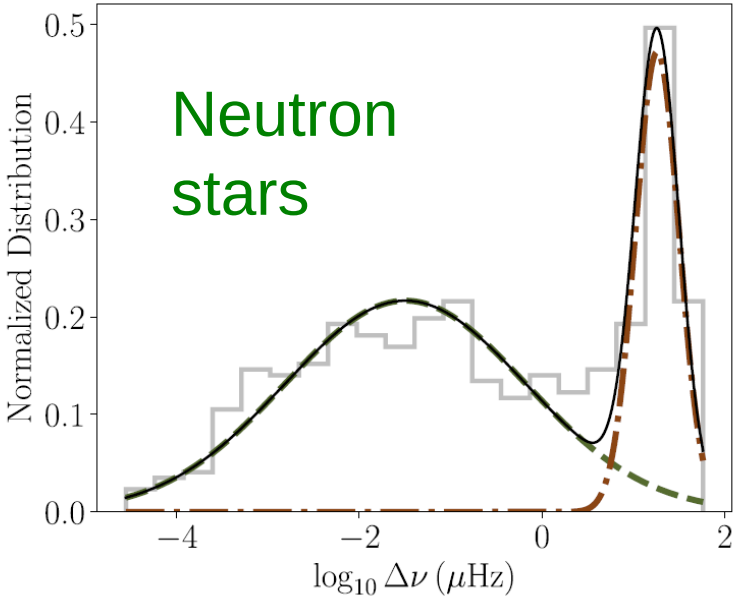

Avalanches at higher speeds have quicker rise time.

Our measurement of rise time is quantized (the lines) by our current time resolution of one point per revolution.

Avalanches without platform stick almost to one line per run. More spread with platform could indicate multiple vortex types.

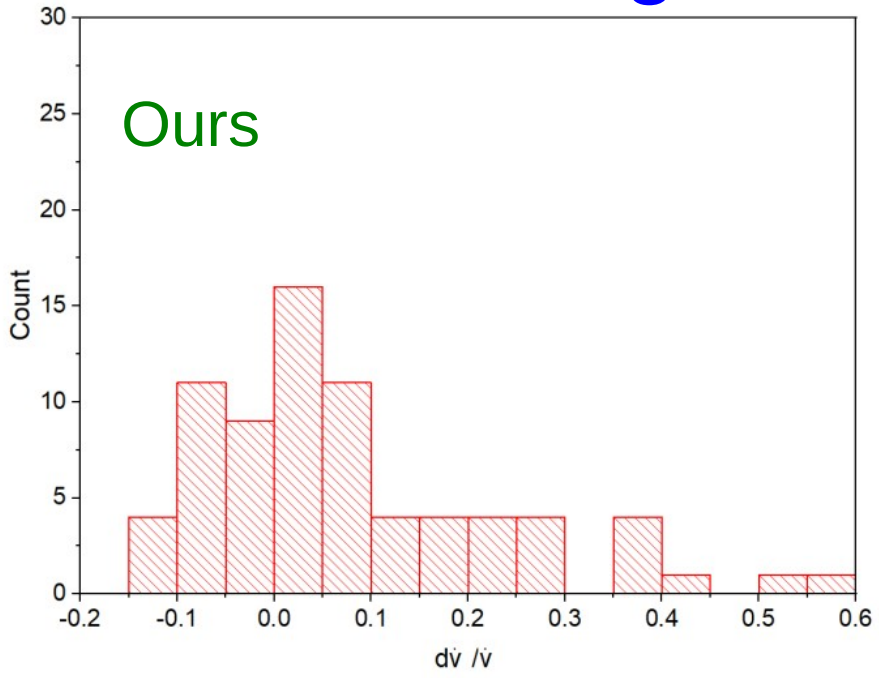
# Glitch Size Distribution

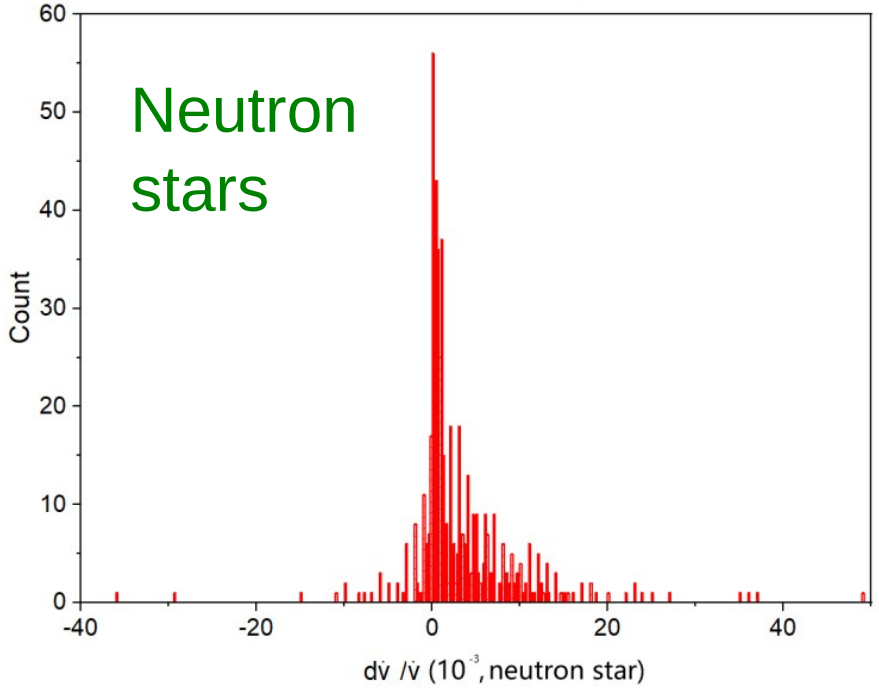



- We find histogram with single peak near 1.25 mHz
- Neutron star distributions display two peaks
- Our much lower speeds and hence vastly smaller numbers of vortices per event may prevent us from seeing the same physics

# Change in slope at glitch




- Change in slope at glitch divided by slope
- Both distributions are centered at a small positive value and cross zero
- Better time resolution may significantly improve our data quality here

# Future Plans

- Improve apparatus to increase duty cycle and eliminate various signal headaches
  - Vacuum can and helium pot, so not pumping on dewar
  - Superconducting levitation: eliminate pendulum and magnetic effects although might make geometric oscillations worse
- Improve signal extraction for better time resolution
- Take more data, explore different parameters (shape, deceleration rate, etc.)

# Conclusions

- **We see glitches in superfluid helium**
- Lots of them (by astronomical standards)
- Likely contains subset of the physics in neutron star glitches
- Better time resolution will help understand glitch duration, cascading glitches, and changes in deceleration from before to after a glitch