WET stars and planets: telescope network observations of mCP stars and planets

Daniel L Holdsworth

with Judith Provencal and the WET collaboration

Asteroseismology

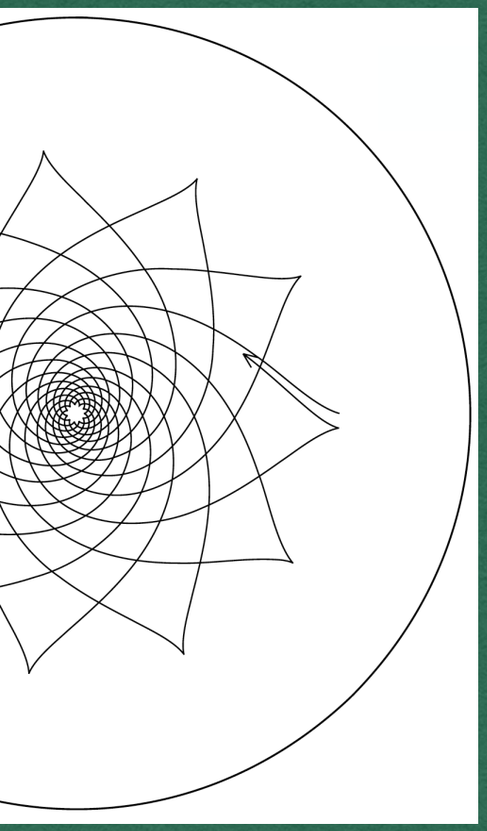
- Study of stellar interiors through global oscillations
- 2 main driving mechanism:

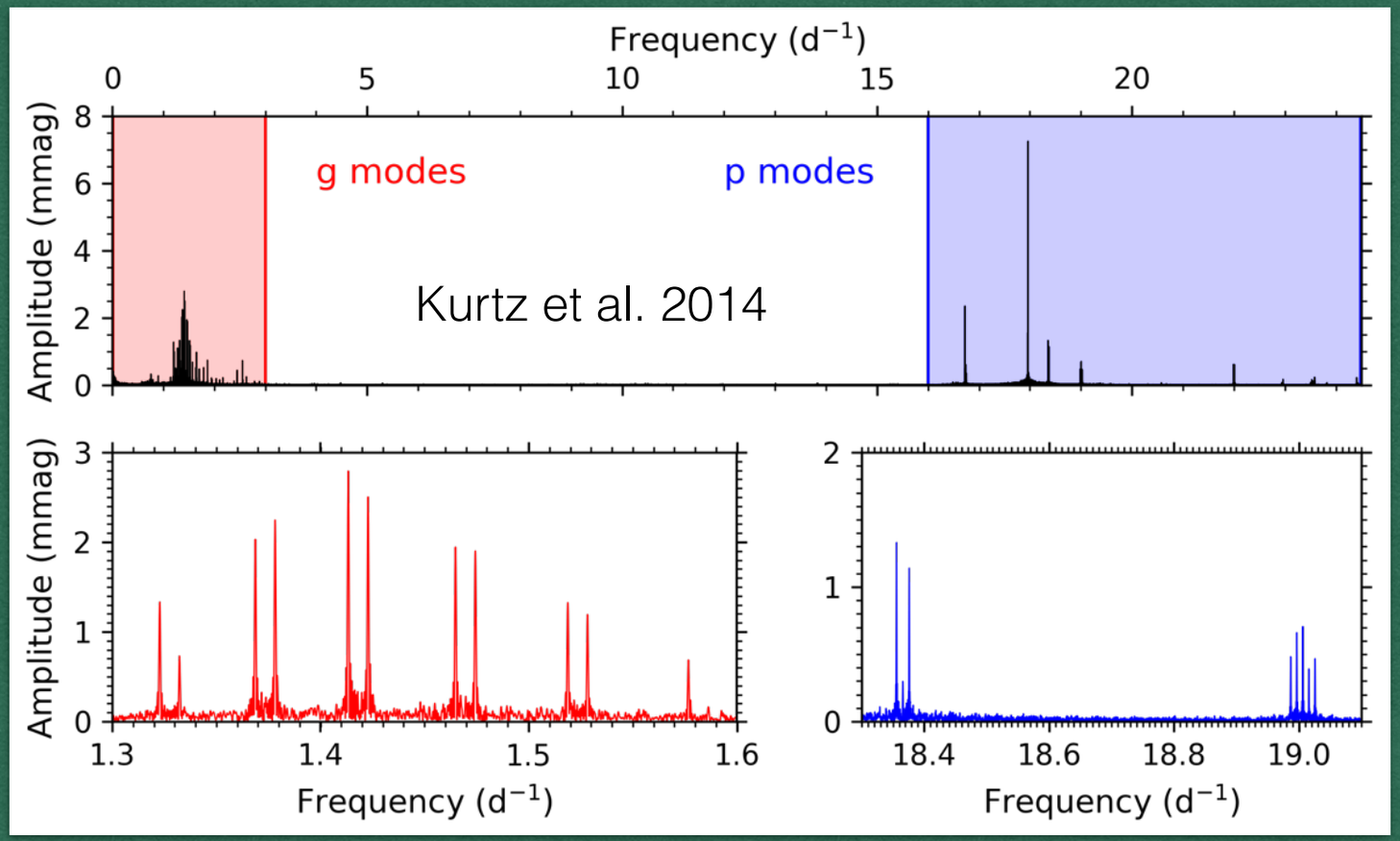
Stochastic Processes	Heat Engine
noise in the outer convection zones lead to global oscillations	Opacity in the H I & He I/II ionisation zones
Short mode lifetimes	Coherent and (normally) long lasting

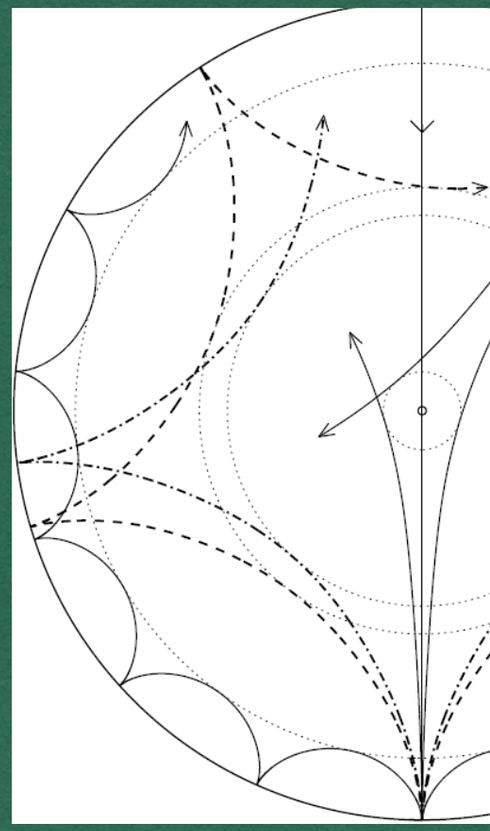
Asteroseismology

Gravity (g) modes

Pressure (p) modes



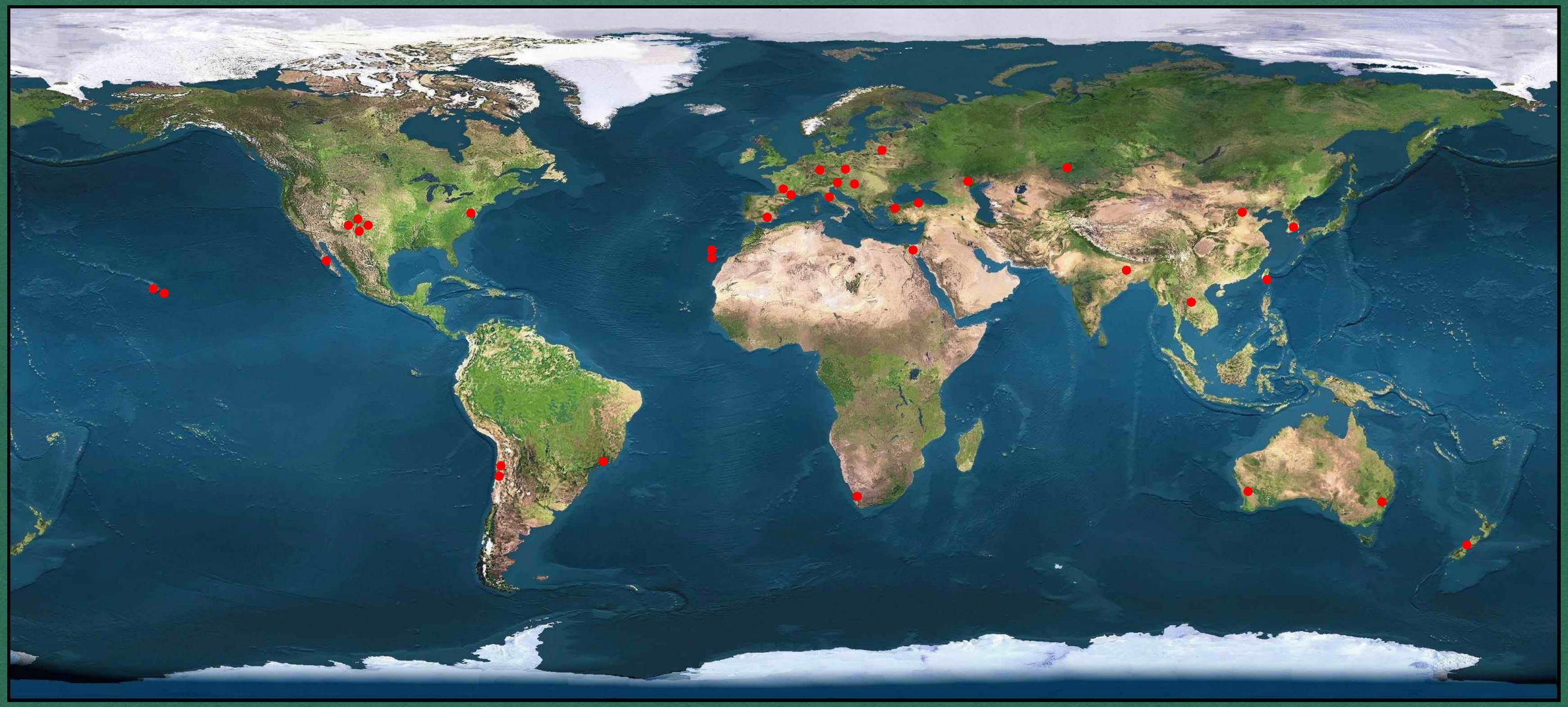




- low frequencies
- probe near-core conditions
- equally spaced in period

- high frequencies
- probe near-surface
- equally spaced infrequency

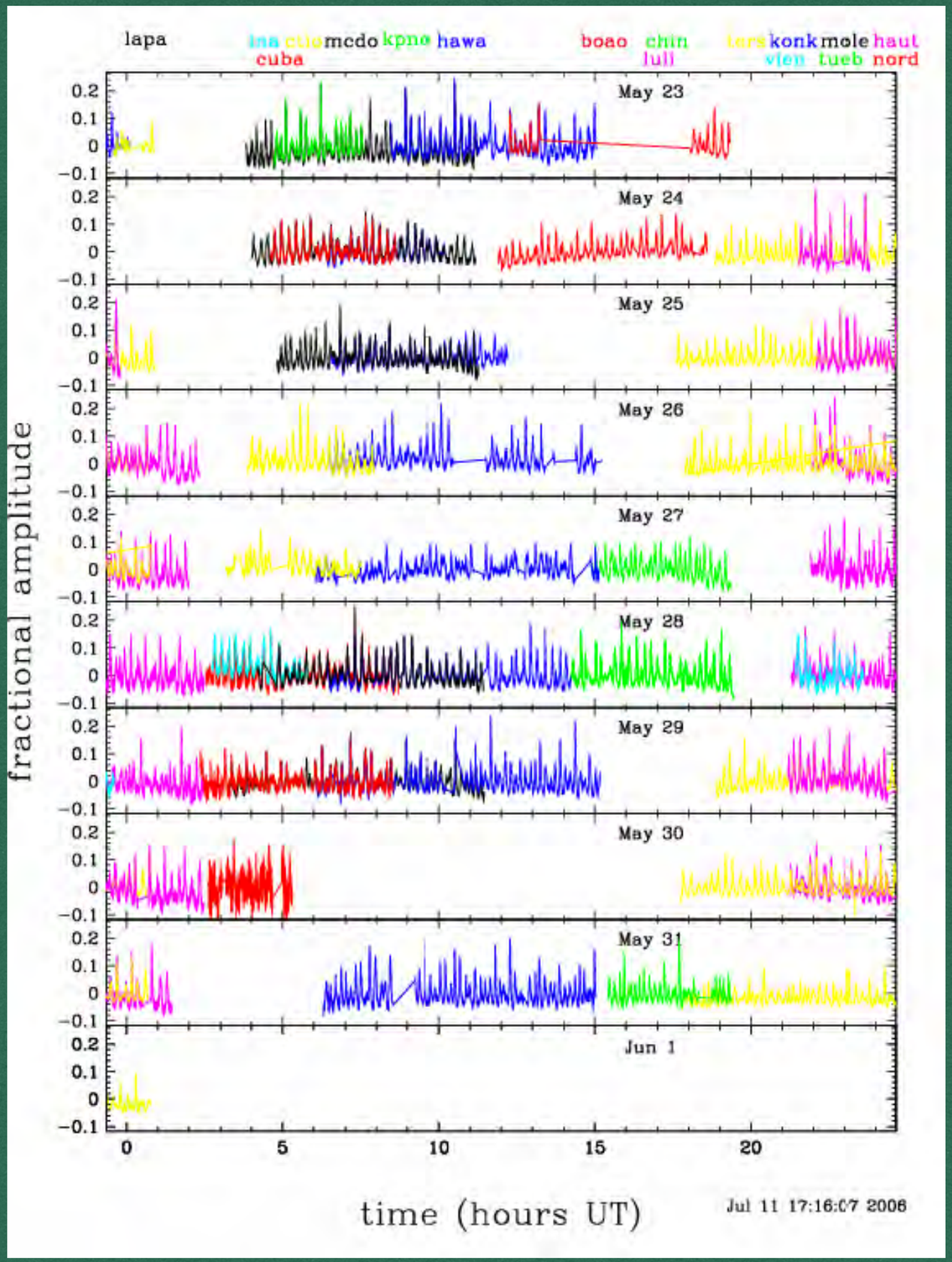
Whole Earth Telescope



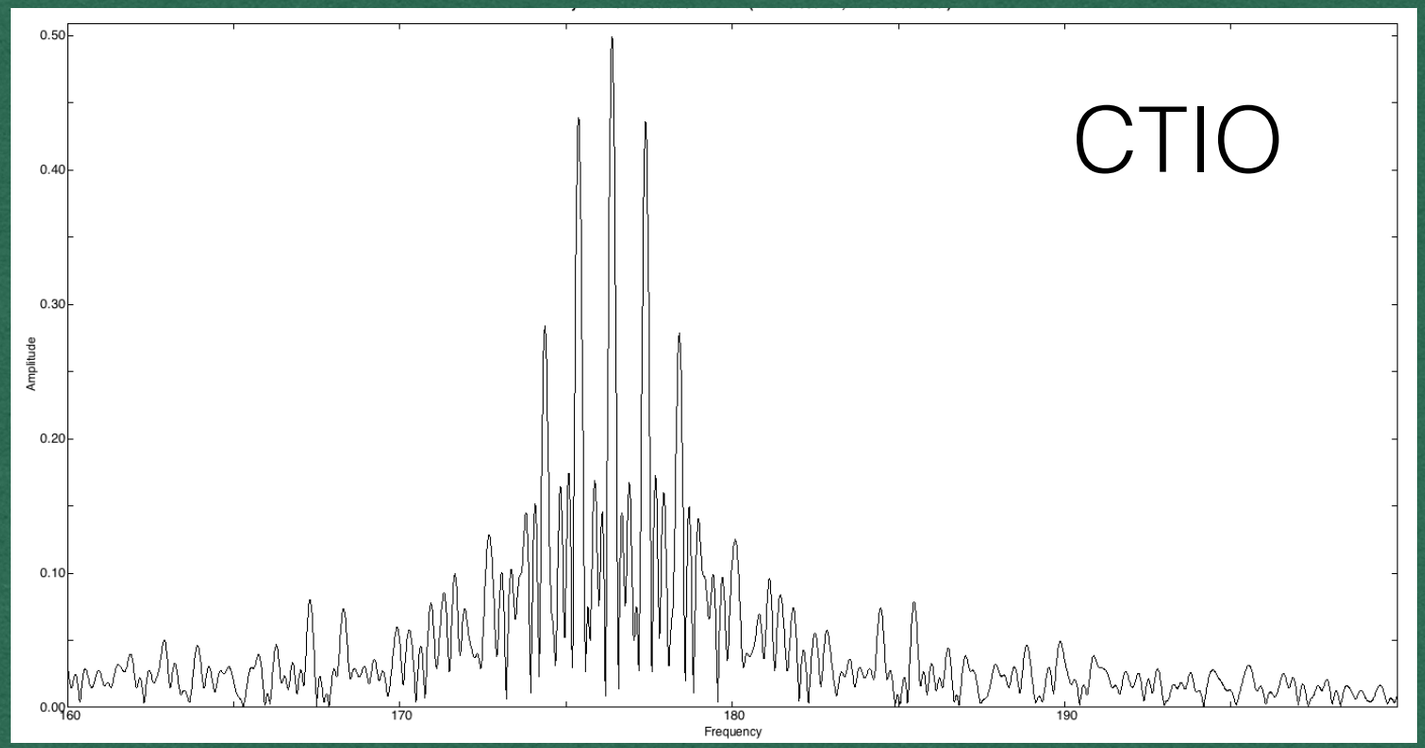
Current Headquarters: Delaware Asteroseismic Research Center (DARC)
Mt. Cuba Astronomical Observatory and the University of Delaware

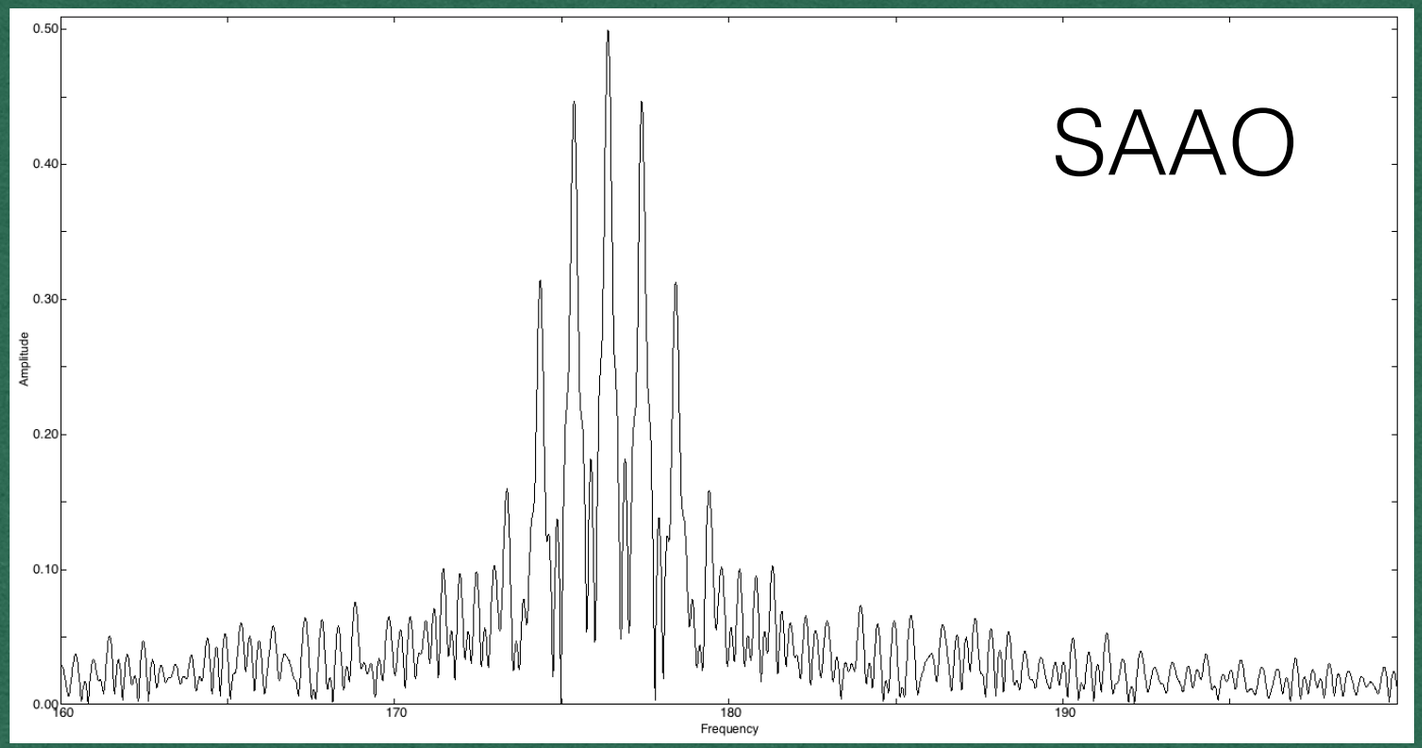
Whole Earth Telescope: the idea

- Founded in 1980 at University of Texas
- Collaborative project to obtain near continuous ground-based observations
- Simplify the window function
- Standardise instrumentation as far as possible
- Primarily set up for pulsating white dwarfs
- 45 observatories have agreed to be involved
- Telescopes range from 0.36-m to 10.4-m

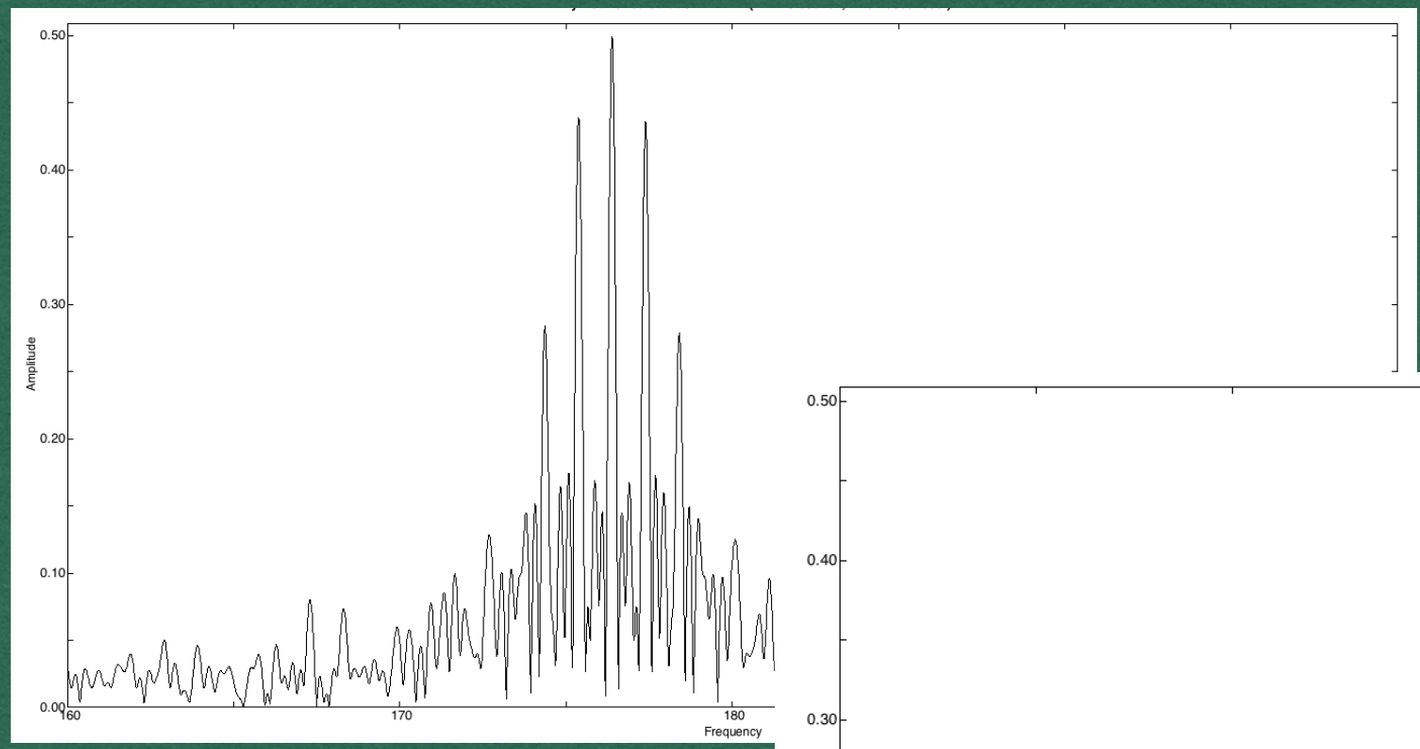


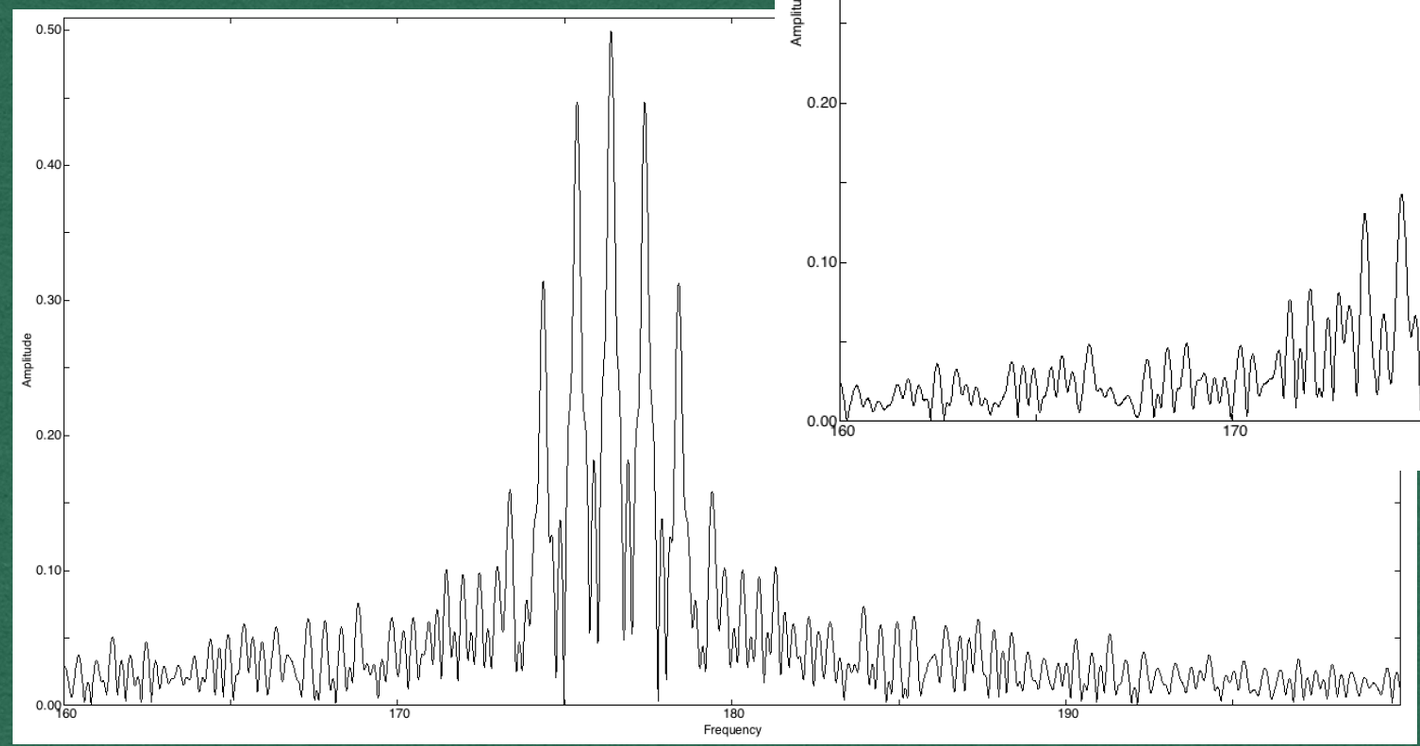
- Telescope time applied for separately
- Predominantly non-robotic
- Send data to headquarters each night
- Reduced/analysed in real-time





Single site Window


Amplitude
Frequency
0.00
0.10
0.20
0.30
0.40
0.50
160
170
180


Amplitude
Frequency
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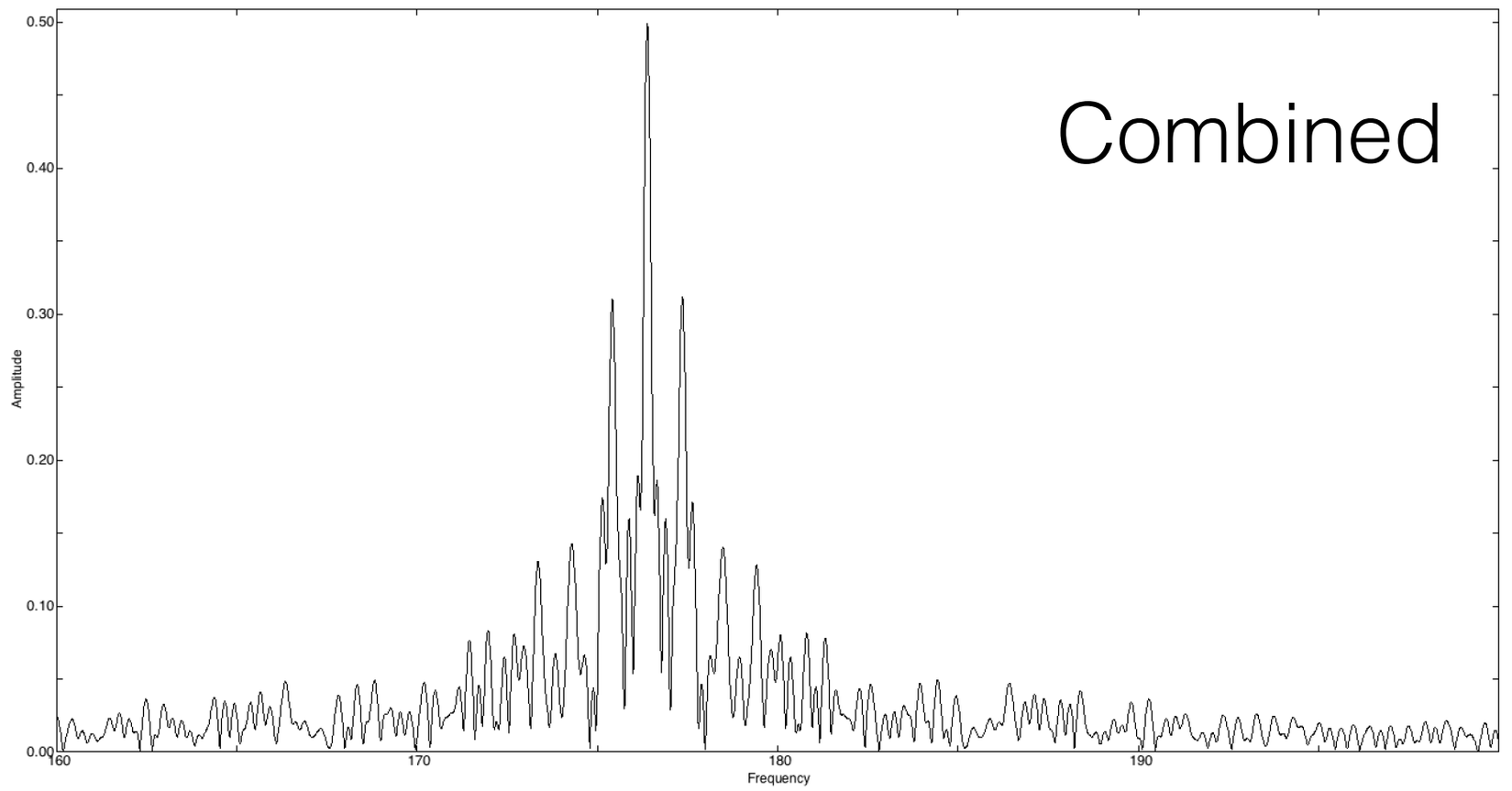
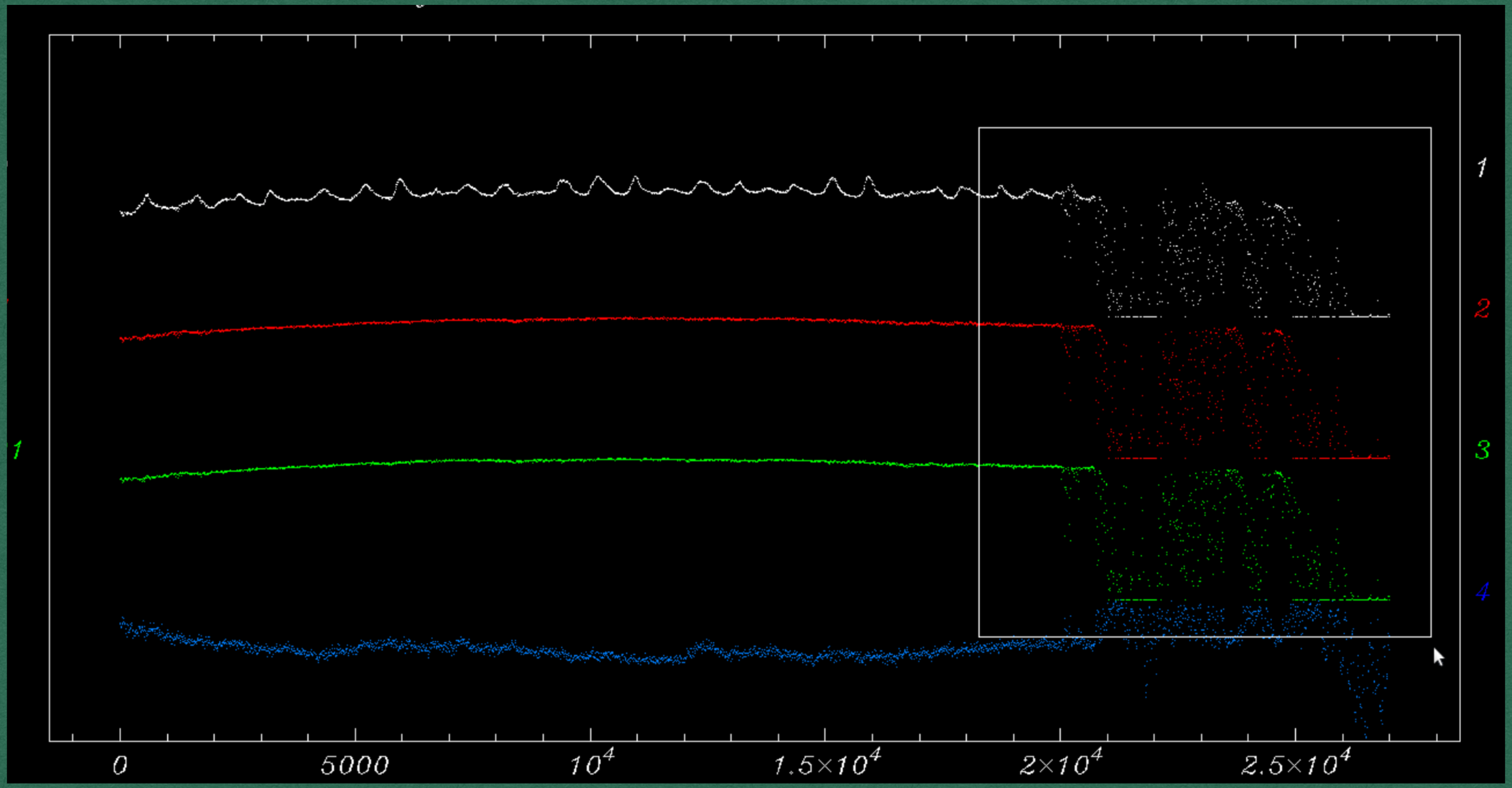

Amplitude
Frequency
0.00
0.10
0.20
0.30
0.40
0.50
160
170
180
190

Combined

Data Processing

- In-house data reduction: MAESTRO + WQED
- Standard CCD reductions; flat-field, bias, dark corrections
- Aperture photometry performed with IRAF

Data Processing



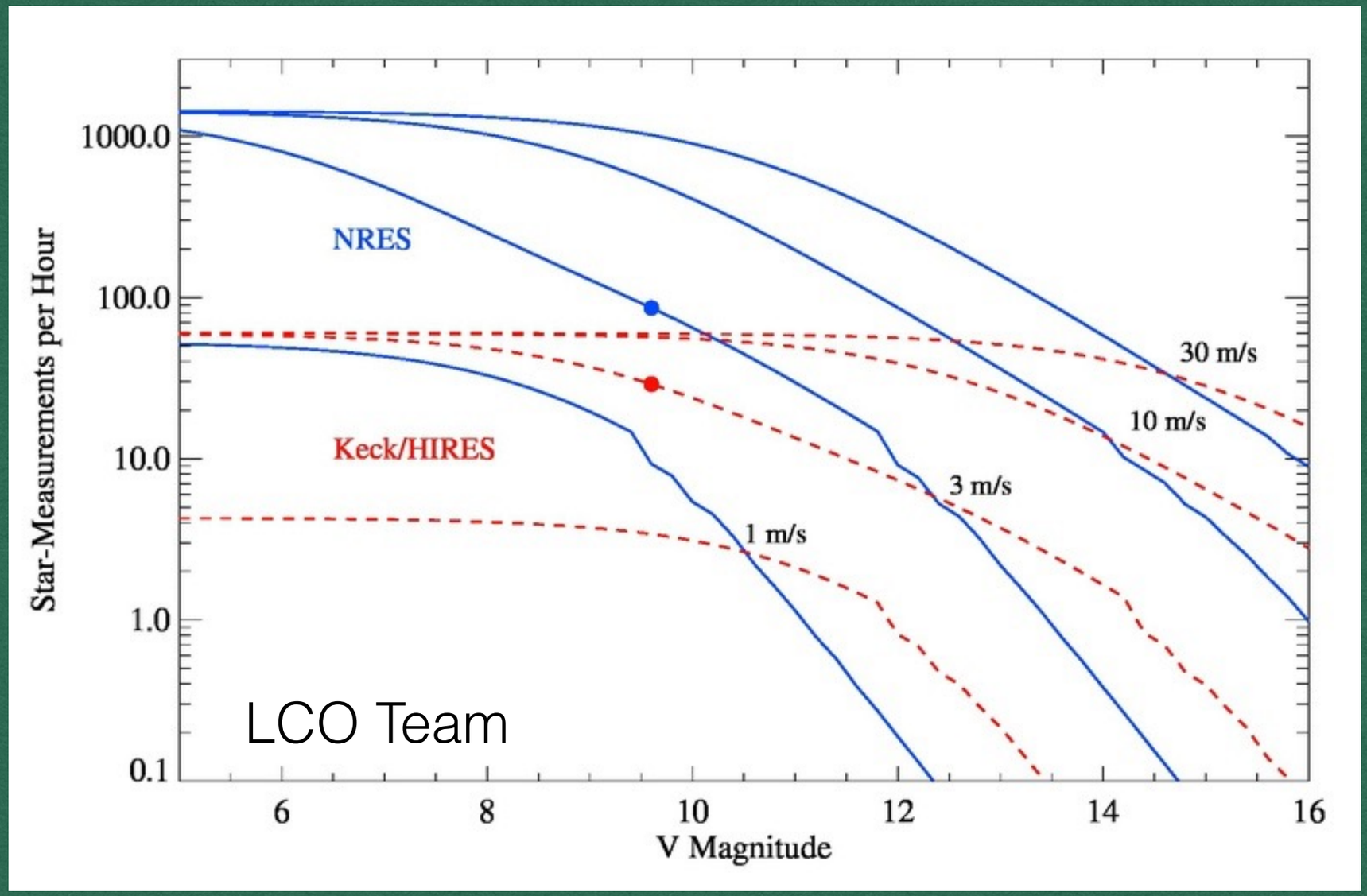
Data Processing

- In-house data reduction: MAESTRO + WQED
- Standard CCD reductions; flat-field, bias, dark corrections
- Aperture photometry performed with IRAF
- Differential photometry and primary extinction correction

- Processing means data are not sensitive to long periods (>~2 hrs)

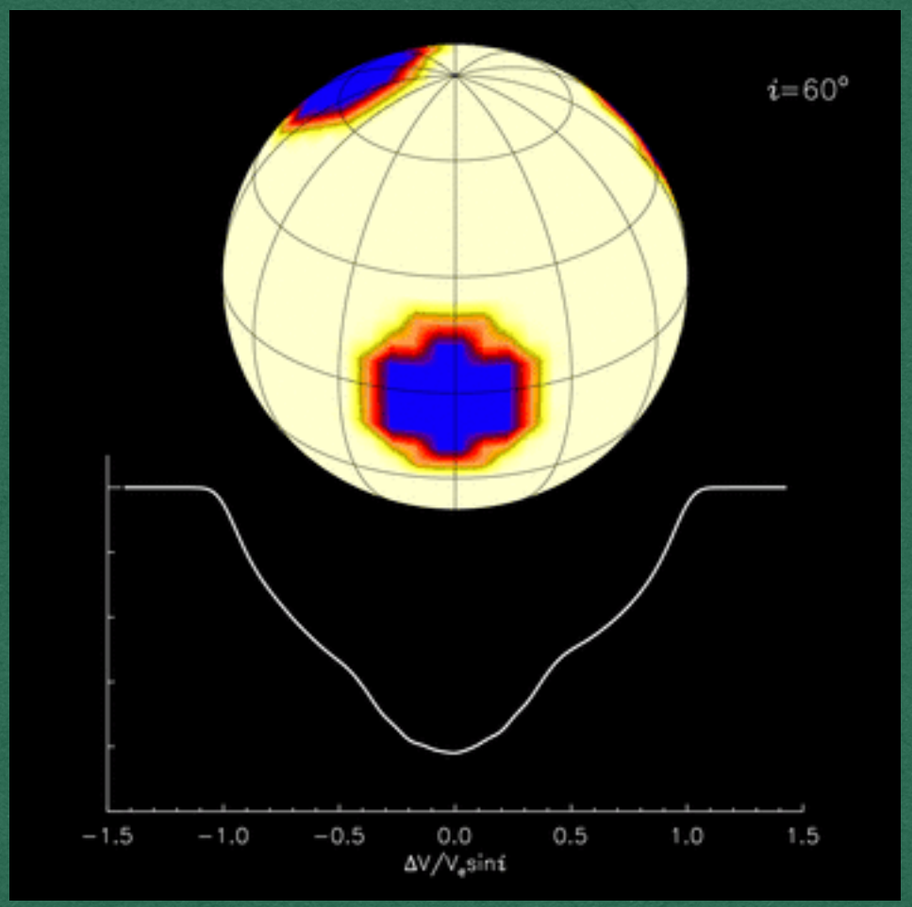
LCO Spectroscopy

- Network of Robotic Echelle Spectrographs
- 6 identical units R~53,000

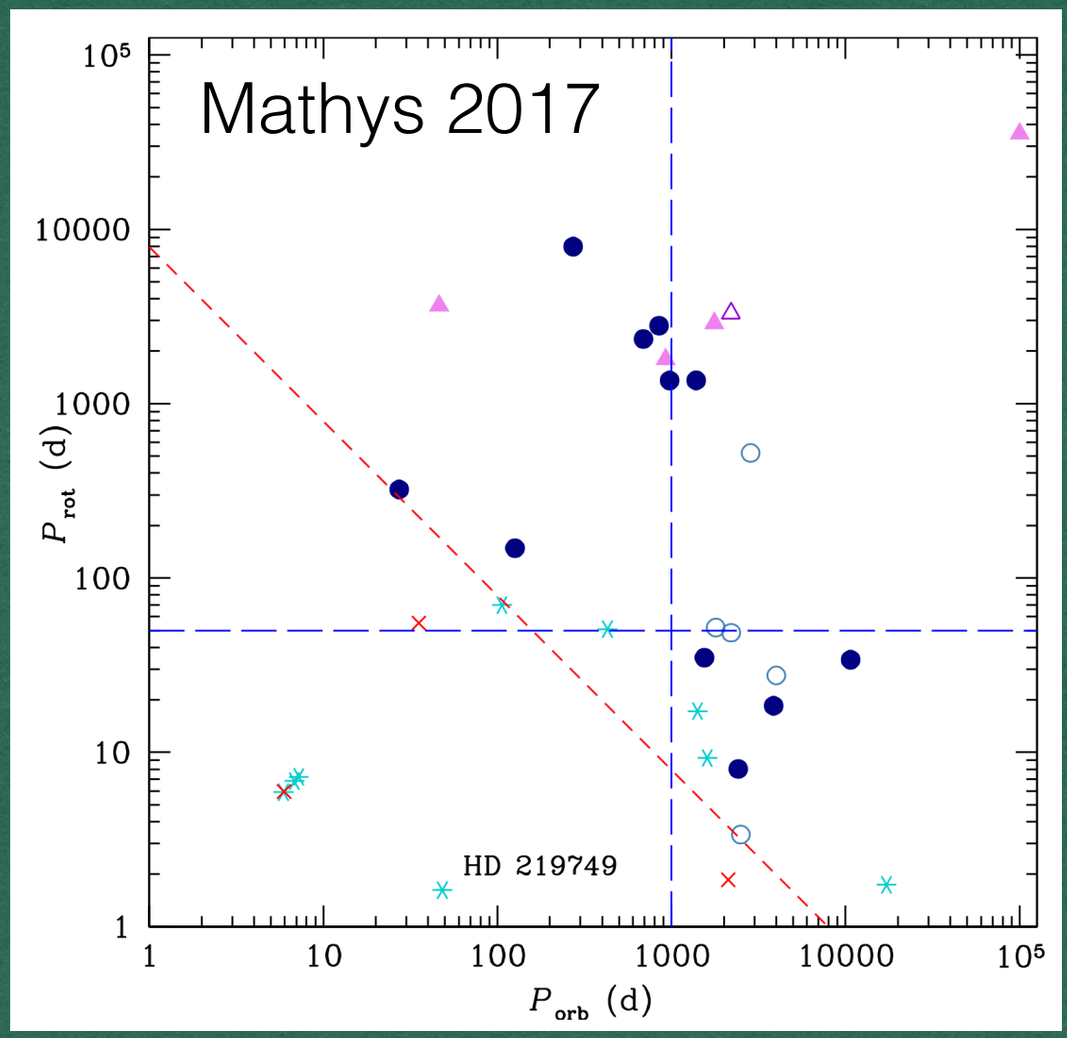


Magnetic Chemically Peculiar Stars

- A & B type stars
- Slow rotators
- Strong, large-scale magnetic fields
- Chemical Spots



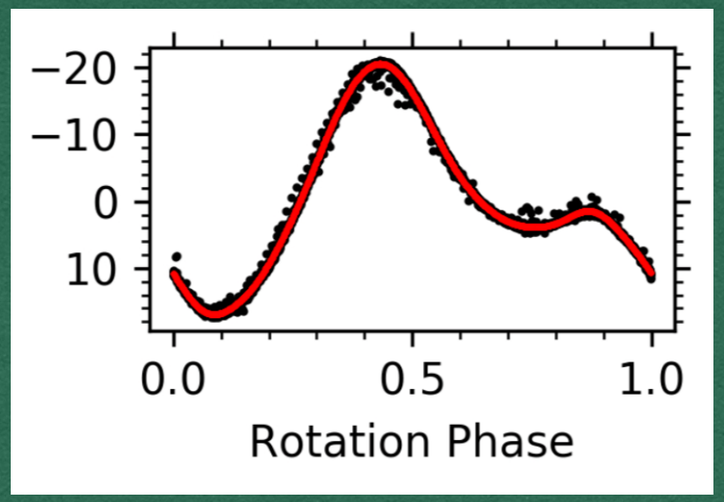
O. Kochukhov

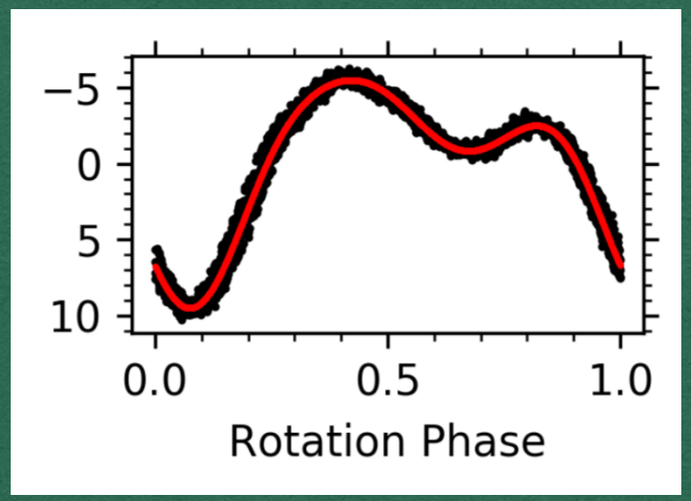


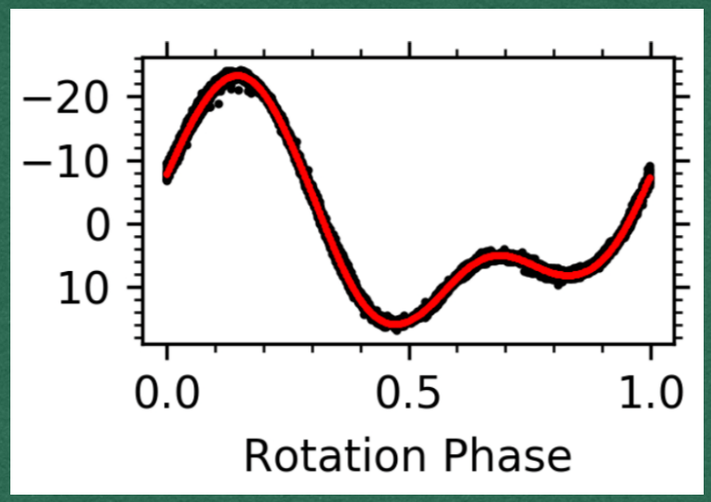
Few short-period binaries

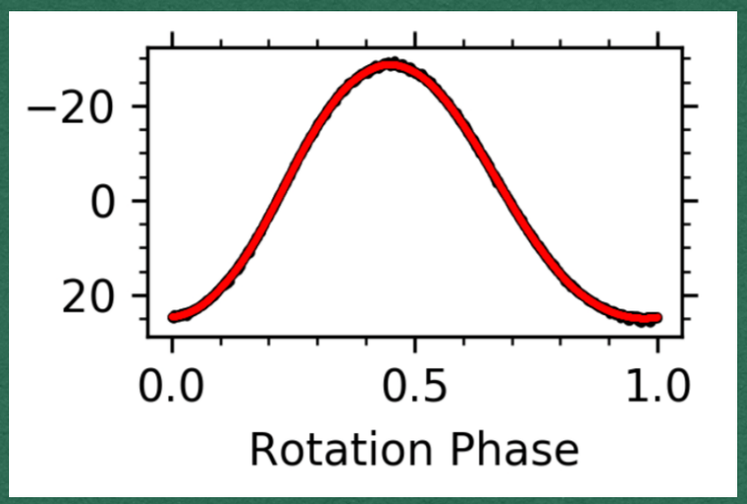
Magnetic Chemically Peculiar Stars

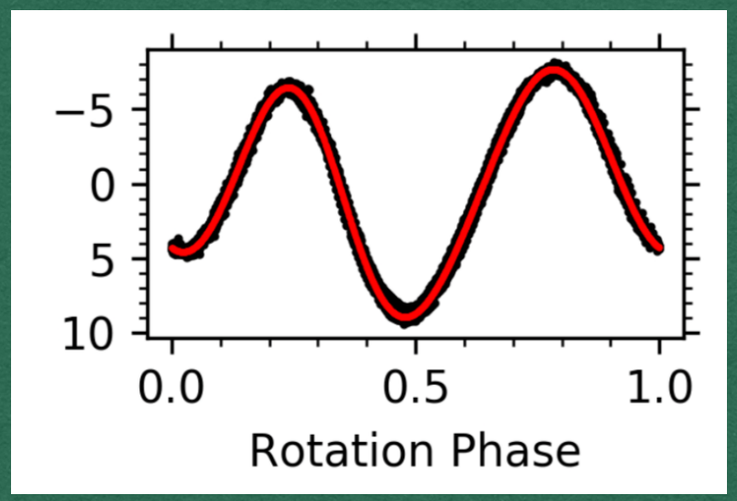
Rotation

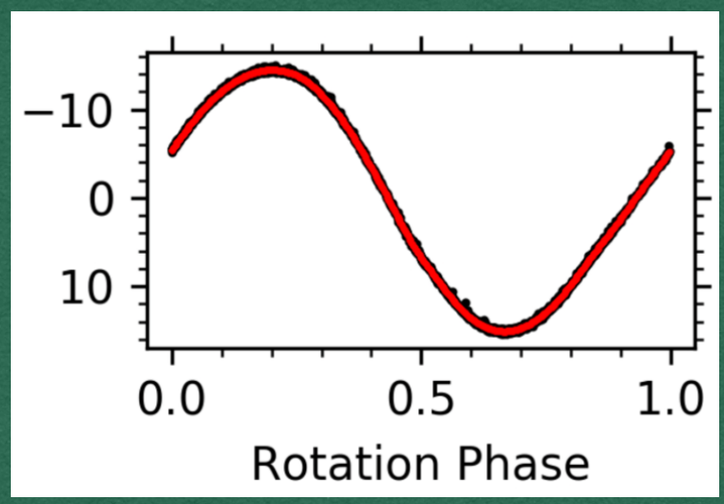








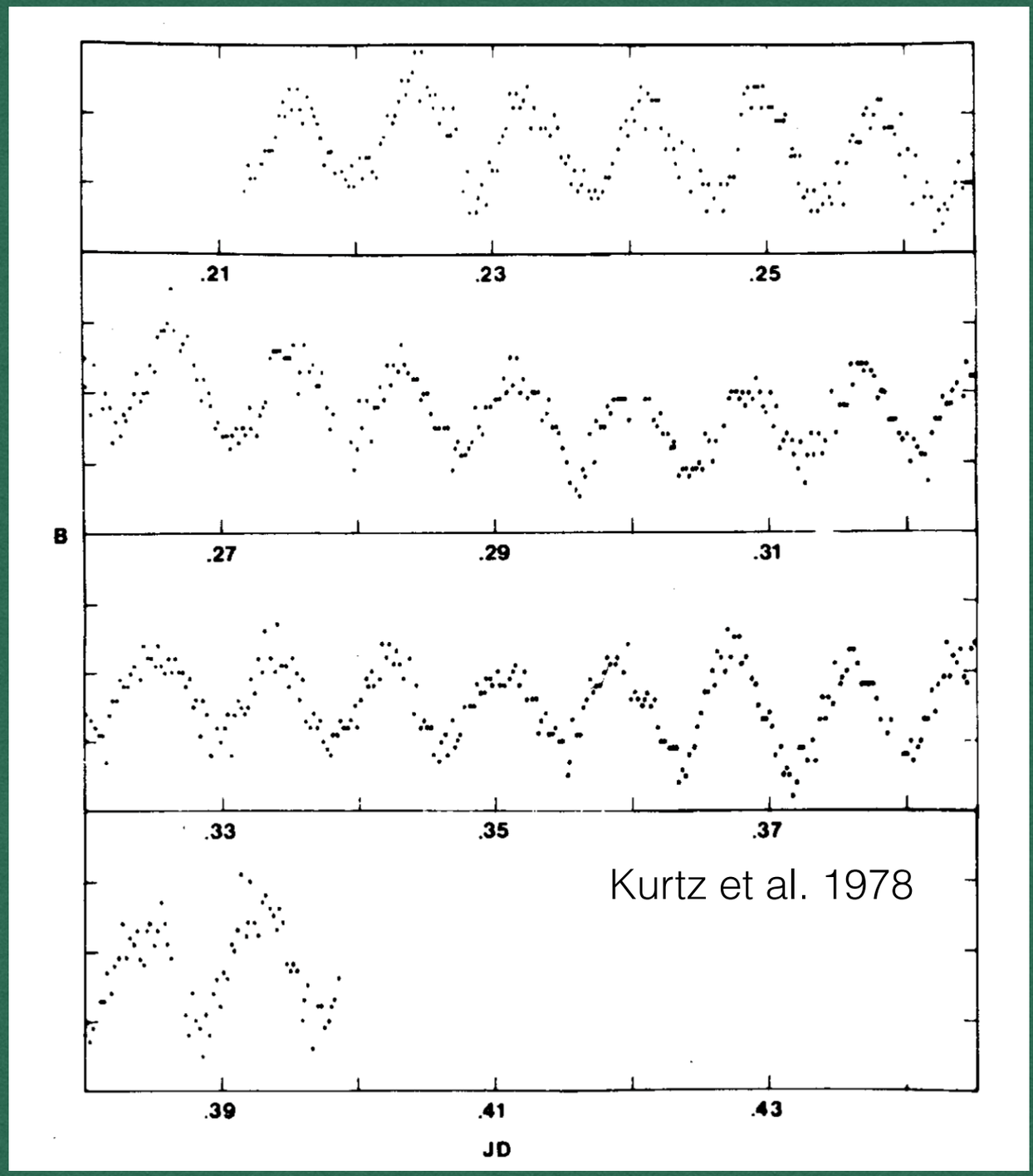




Bowman et al.
2018

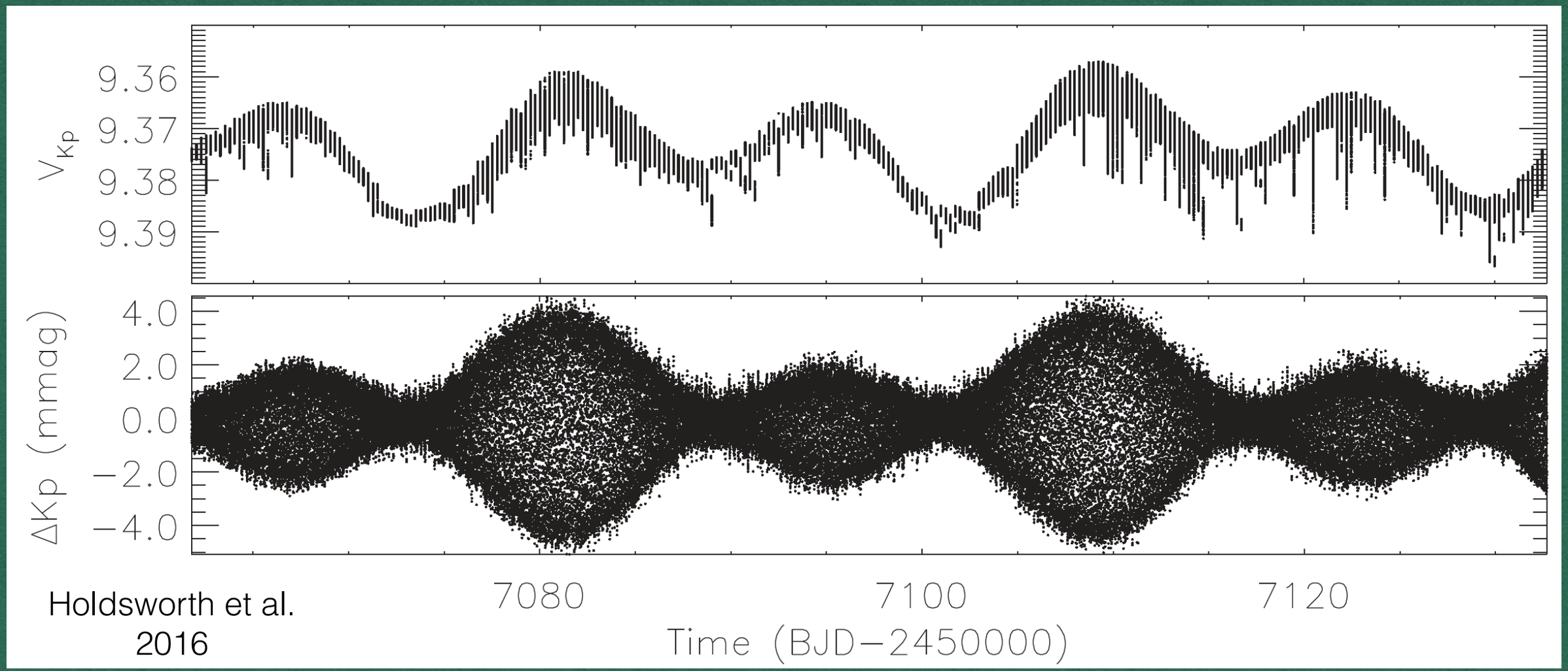
Pulsations in mCP Stars

- Discovered in late 1970s with the 0.5-m SAAO telescope
- High overtone
- Low degree $\ell \leq 3$
- Coupled with the magnetic field
- Pulsation axis (almost) aligned with magnetic axis
- roAp stars



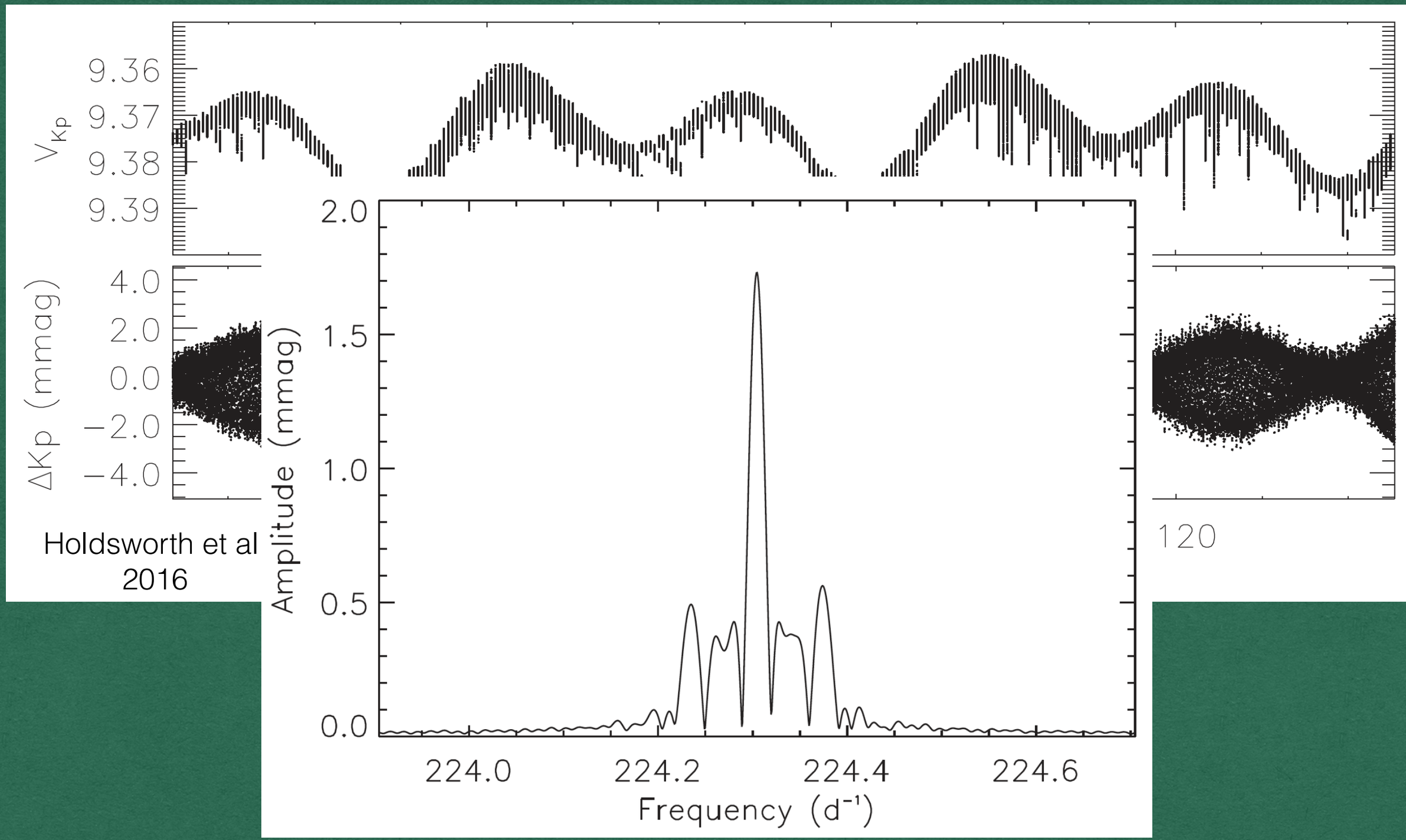
Kurtz et al. 1978

Pulsations in mCP Stars



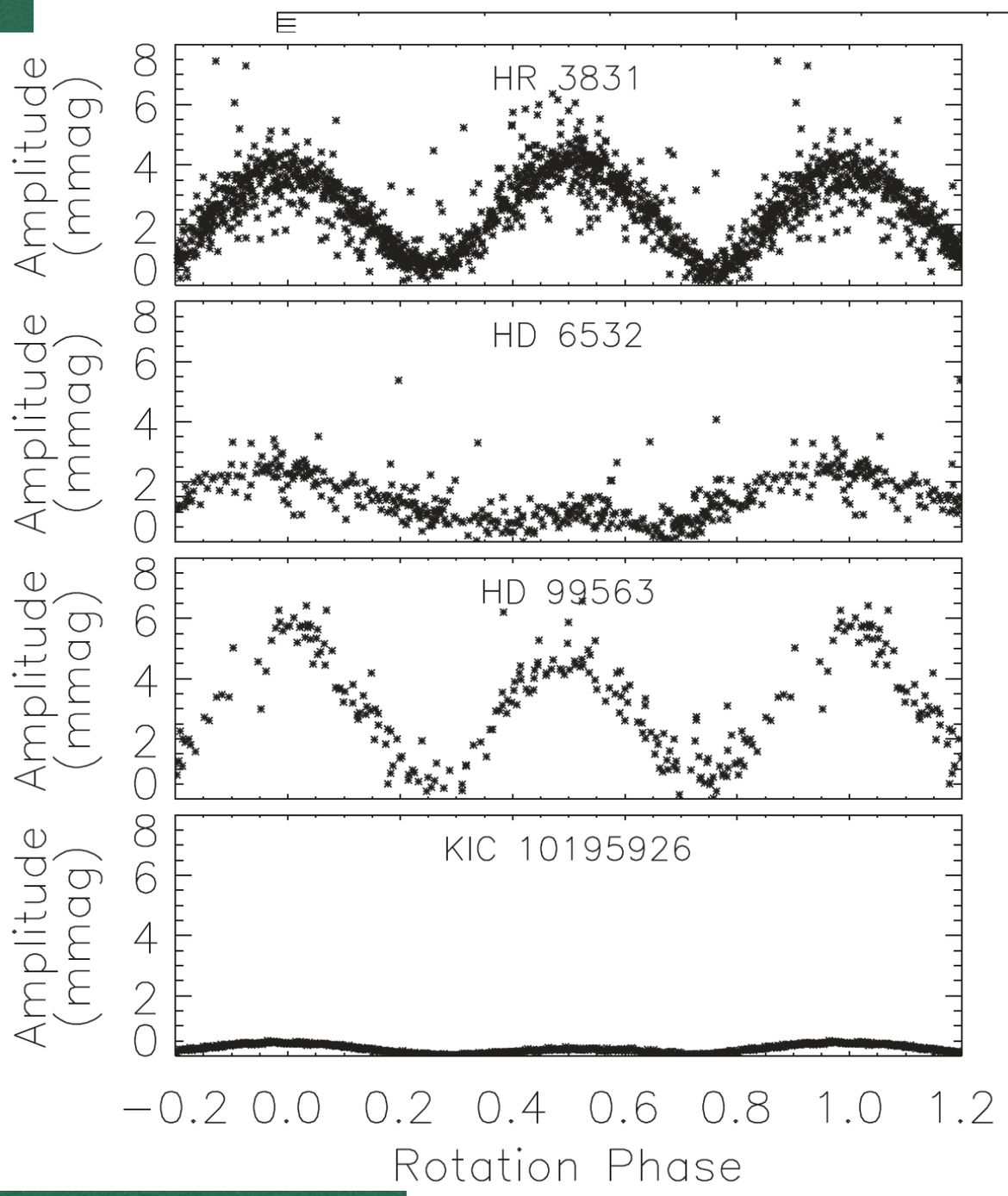
Holdsworth et al. 2016

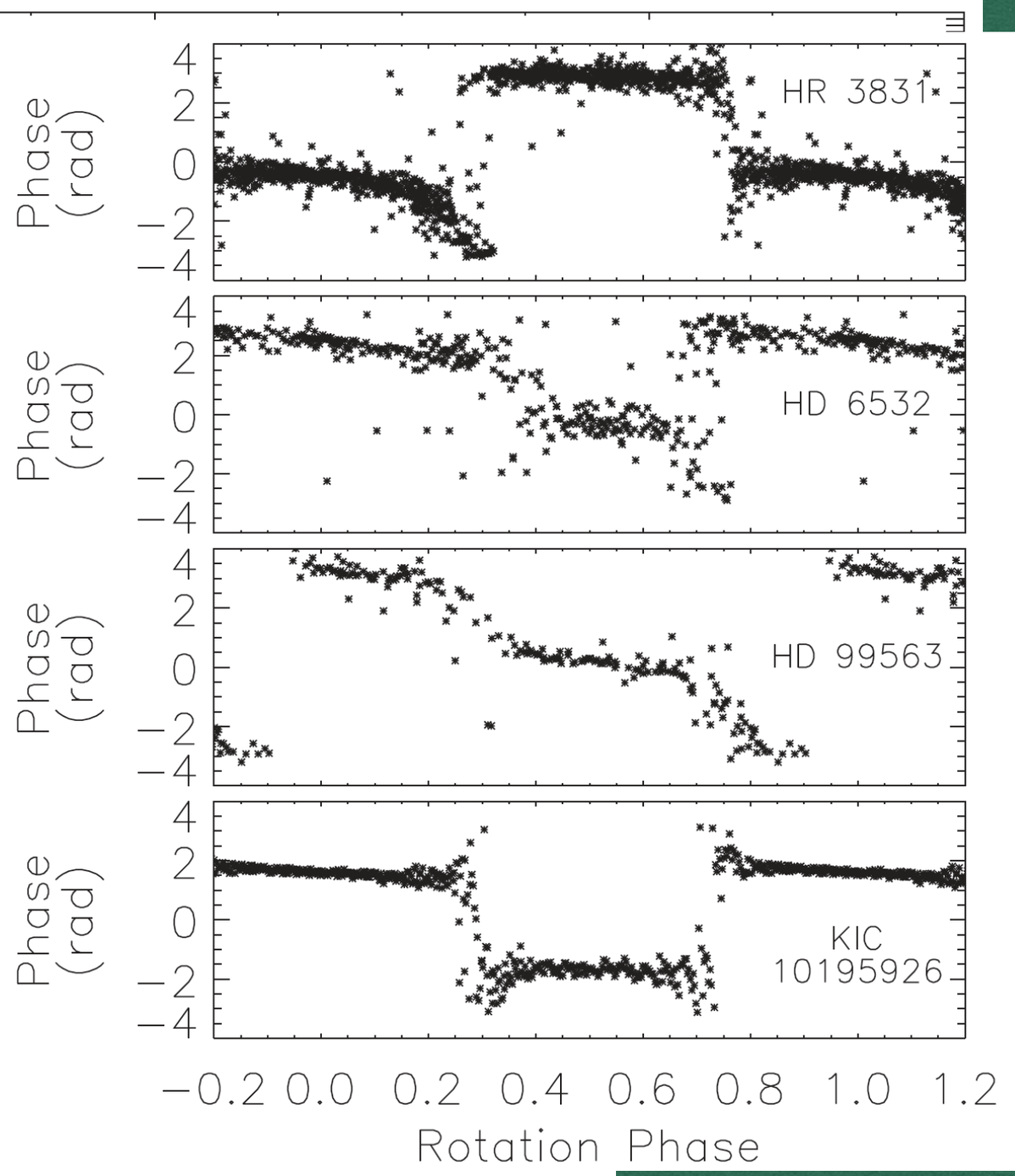
Pulsations in mCP Stars



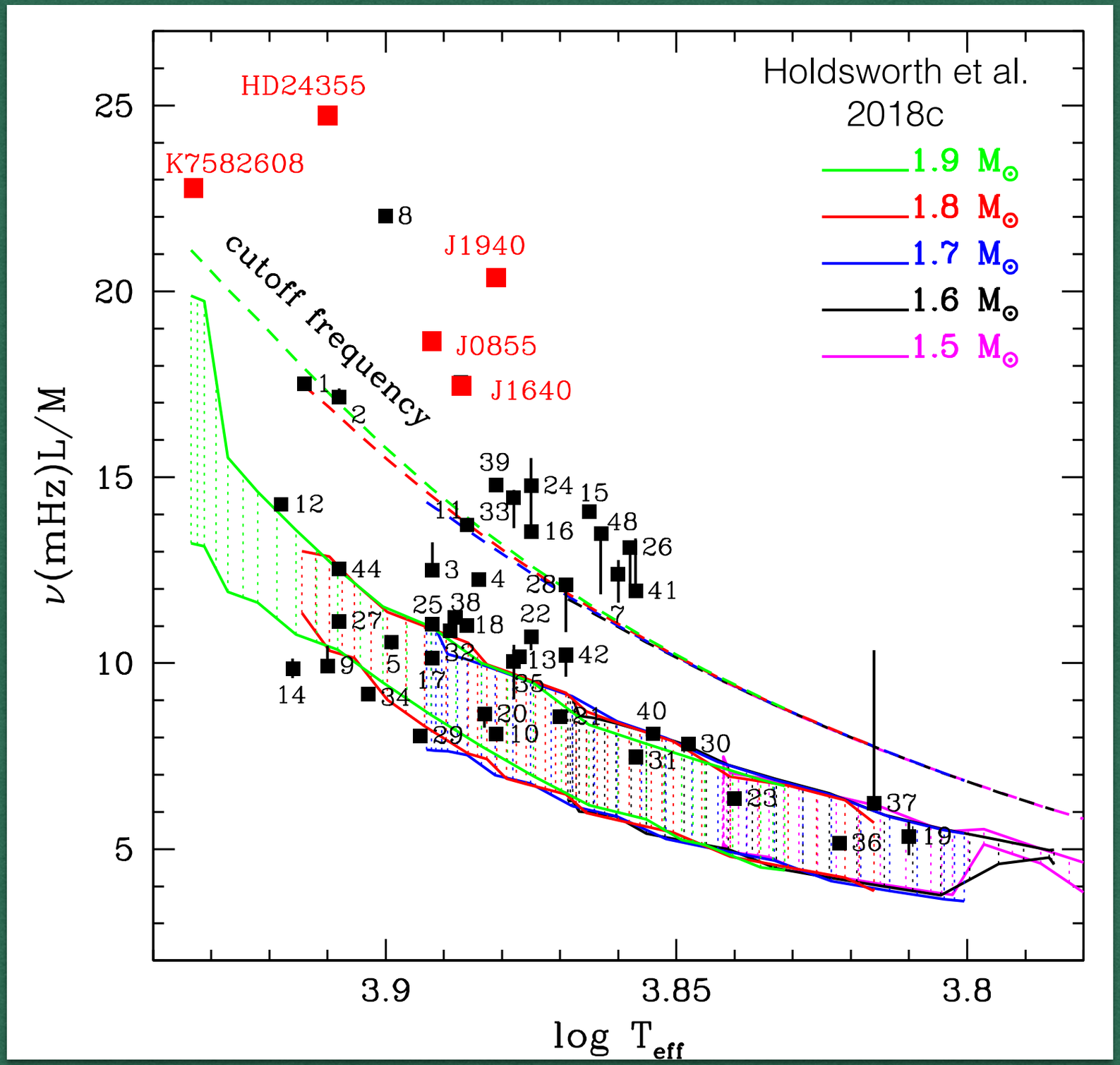
Holdsworth et al 2016

Pulsations in mCP Stars



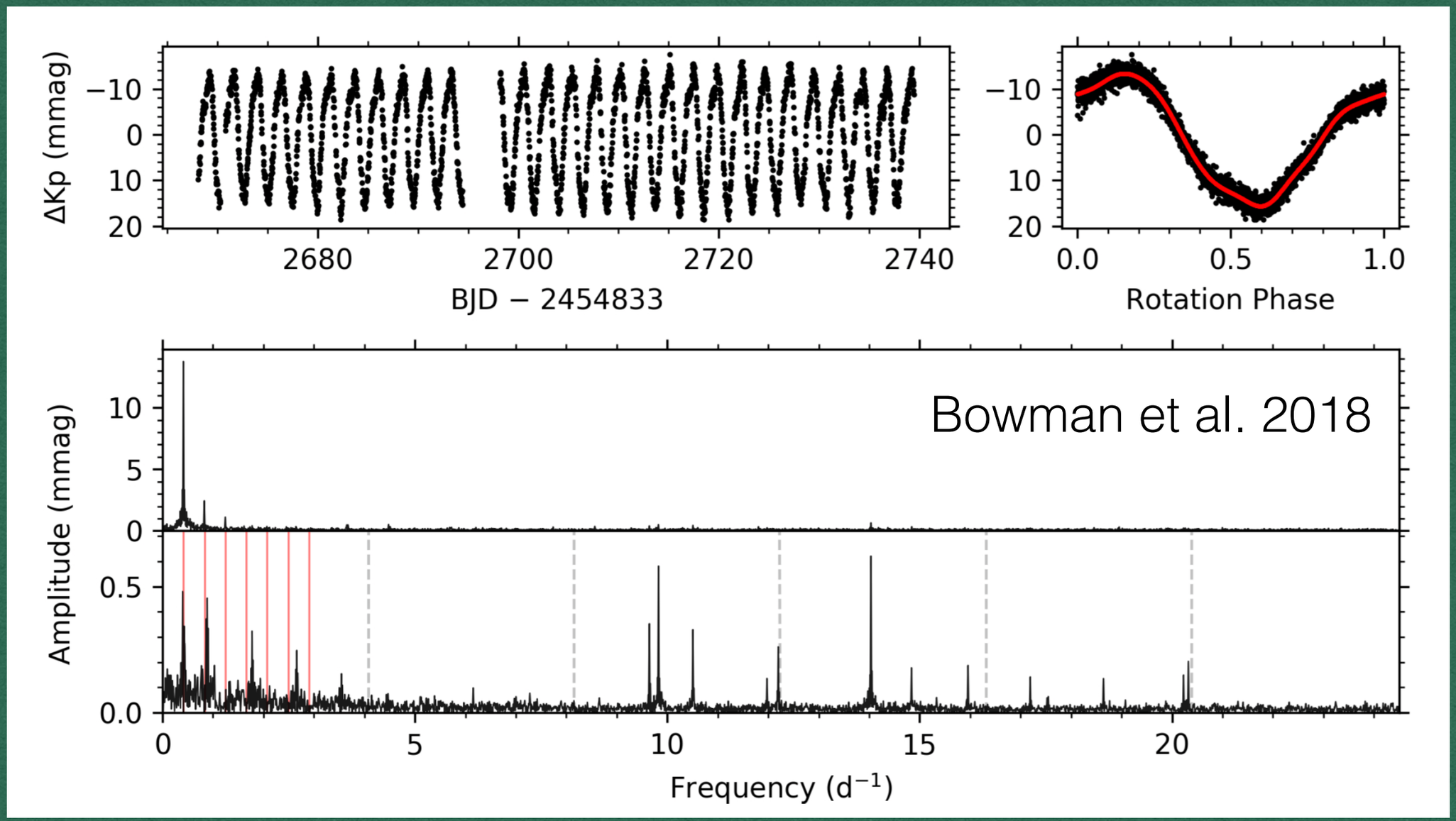


Pulsations in mCP Stars

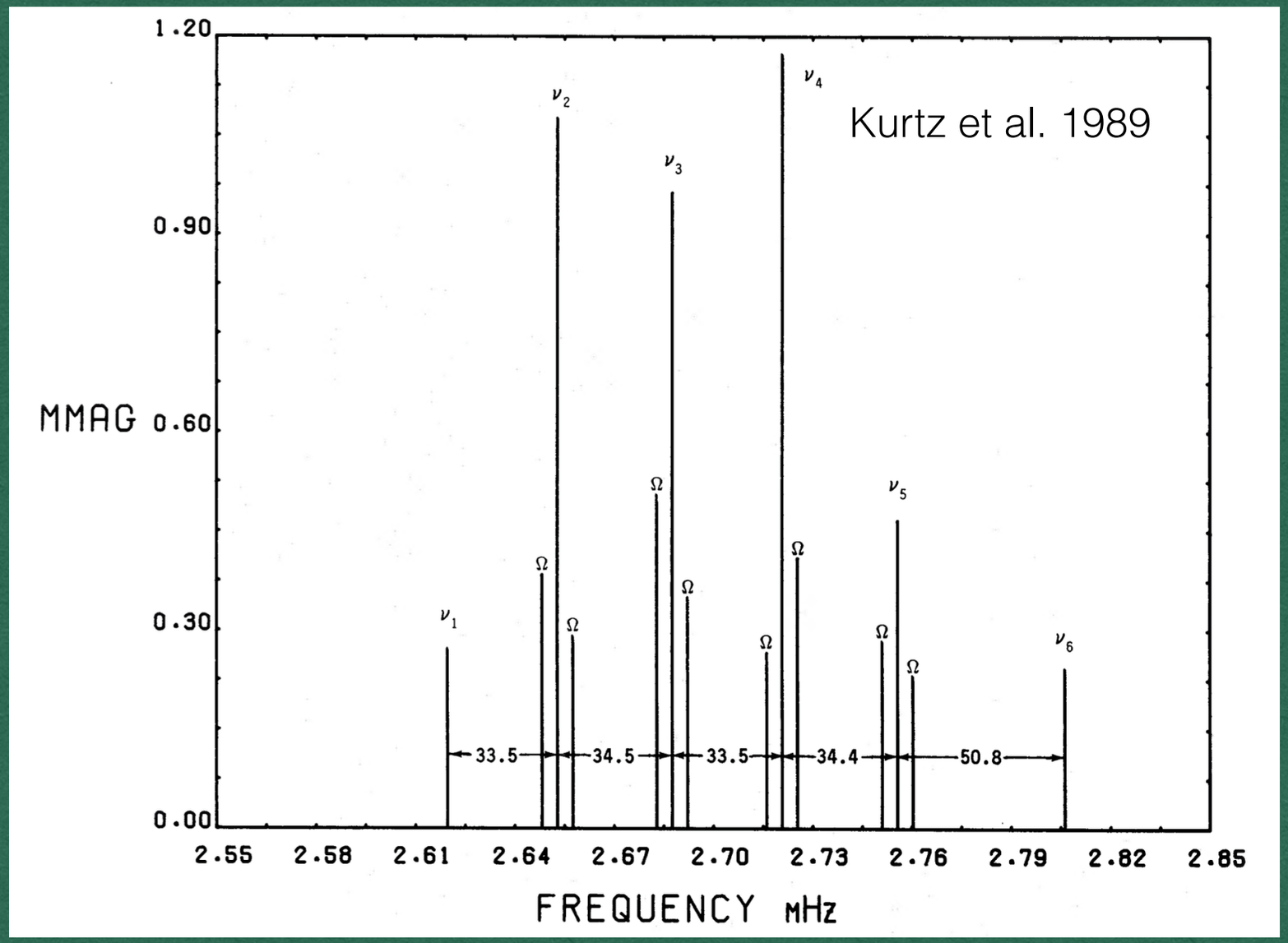


Pulsations in mCP Stars

Low Frequency Pulsations?

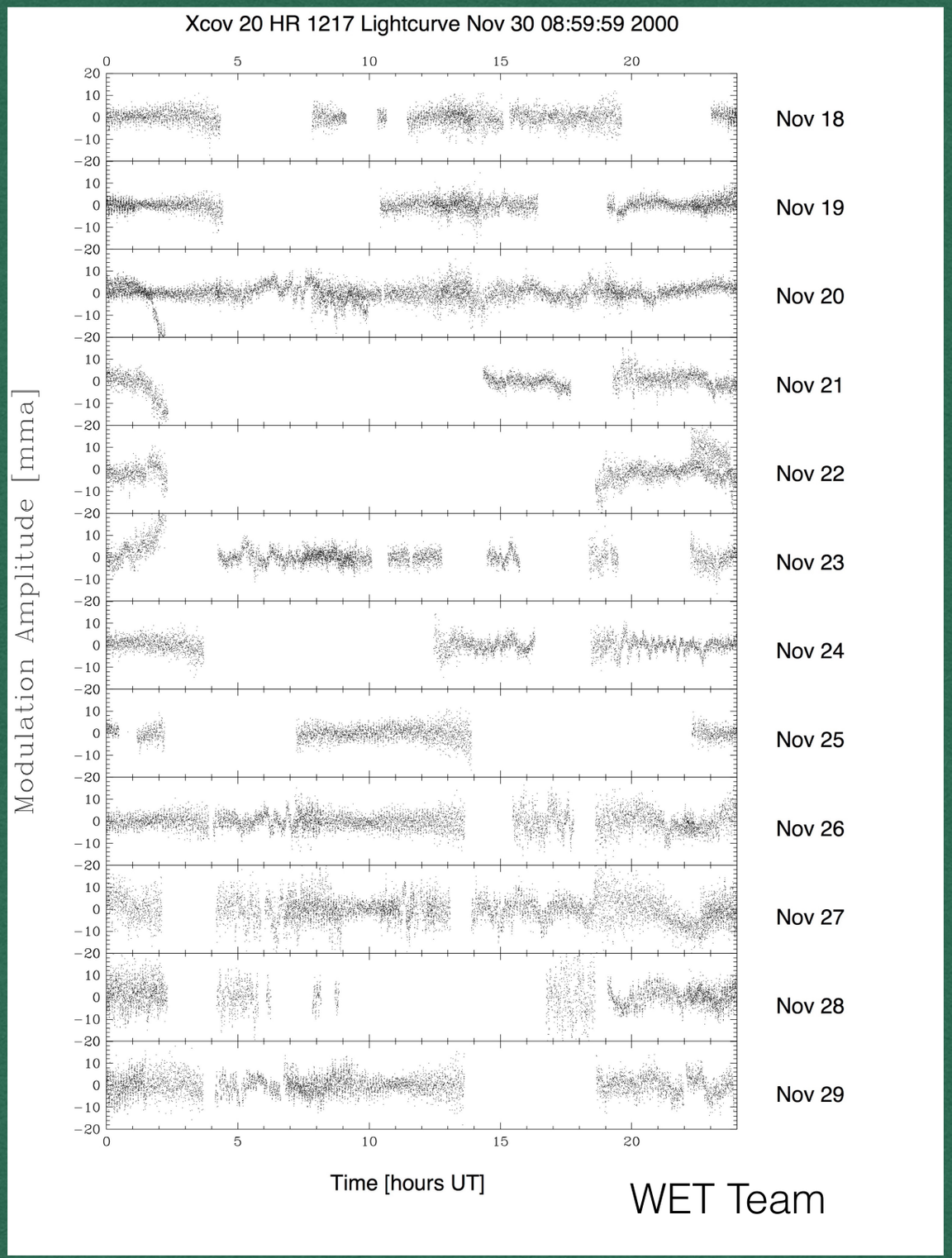


WET Observations of HR 1217
Motivation



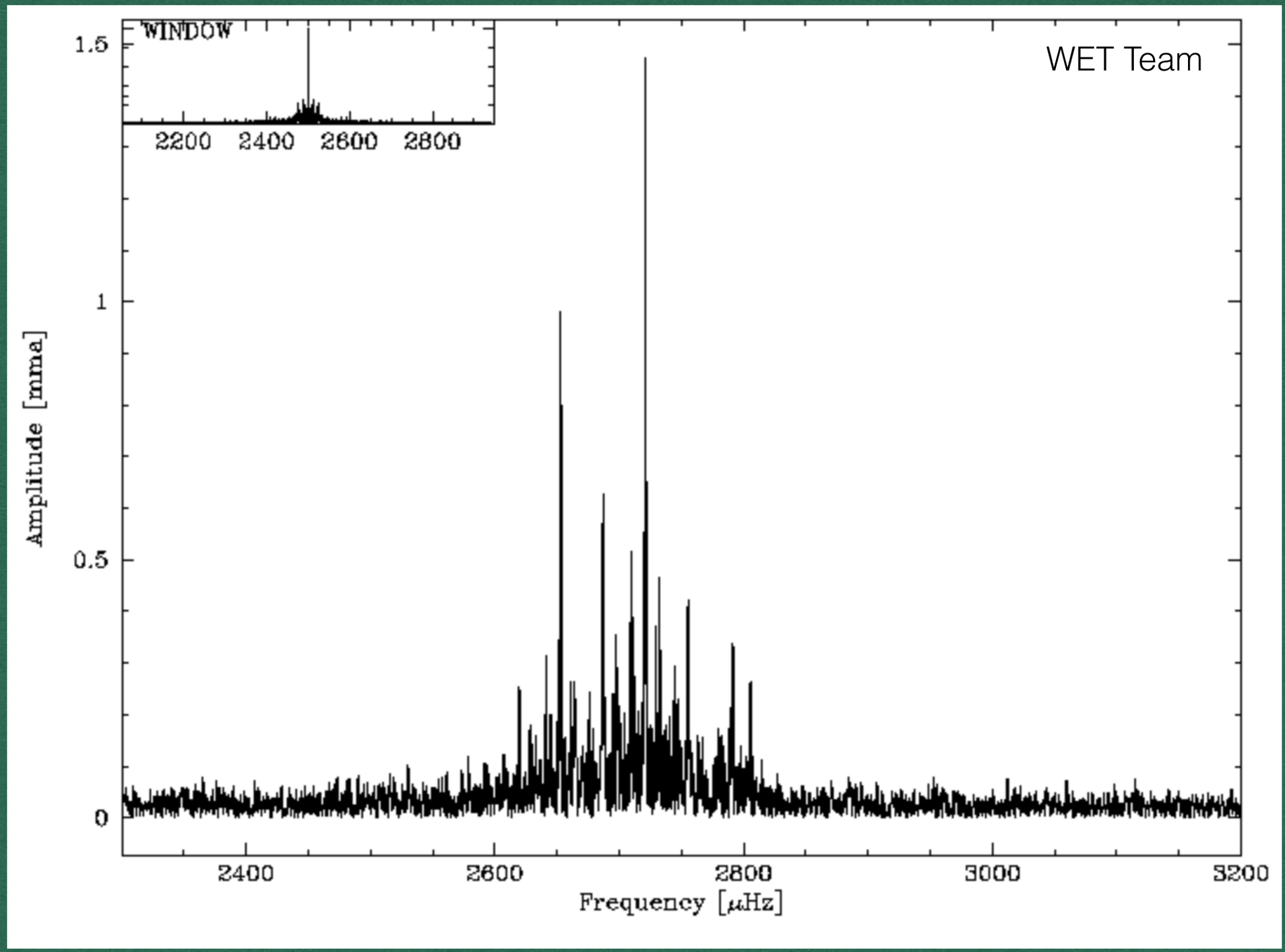
- Alternating odd and even ℓ modes
- Missing mode?
- Cunha 2001 predicted missing mode

WET Observations of HR 1217

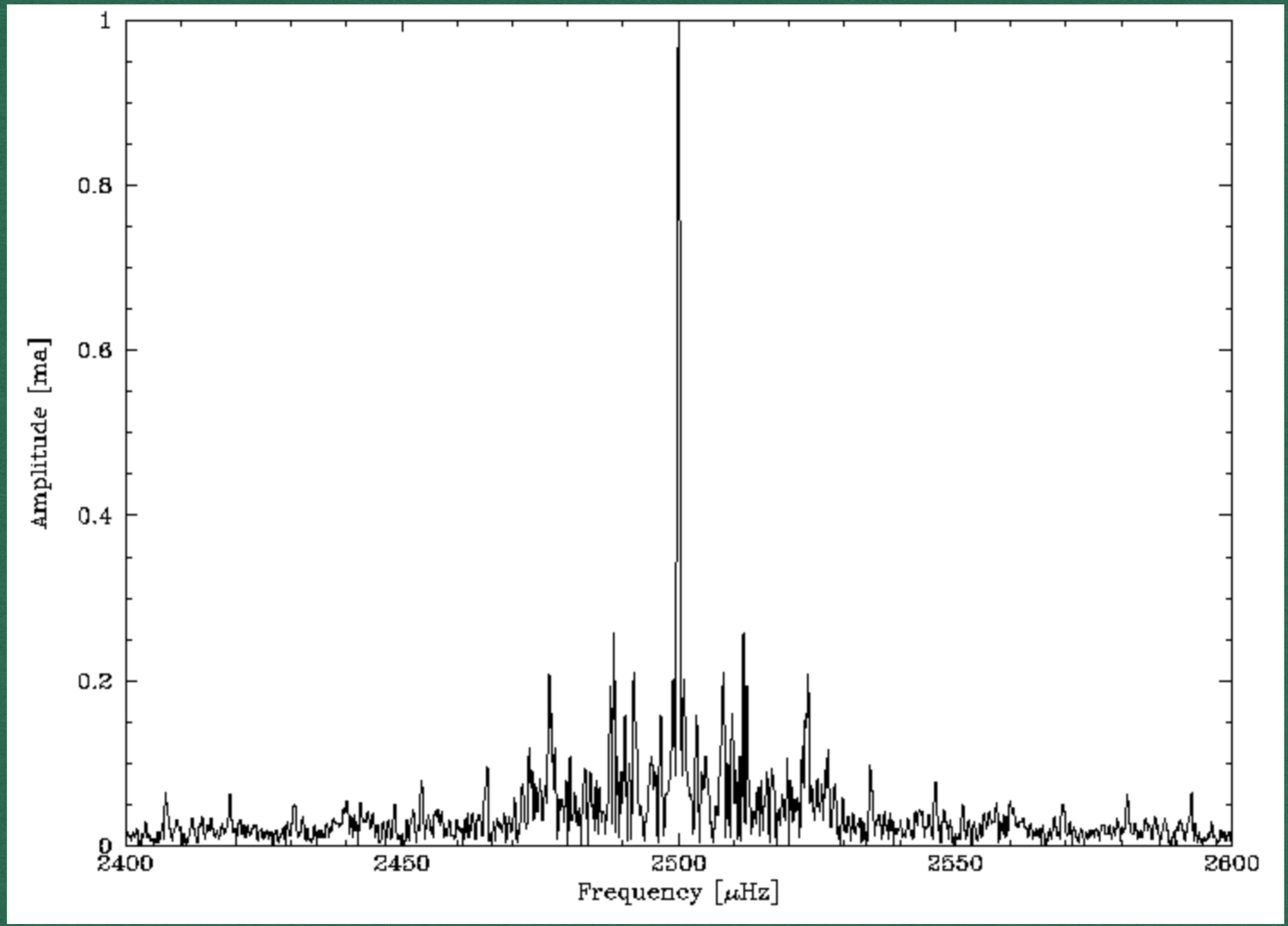


- First ‘real’ campaign on a roAp star
- 35 days of continuous observations
- Duty cycle of 36%
- 14 μm precision on amplitudes ~7x better than single site

WET Observations of HR 1217

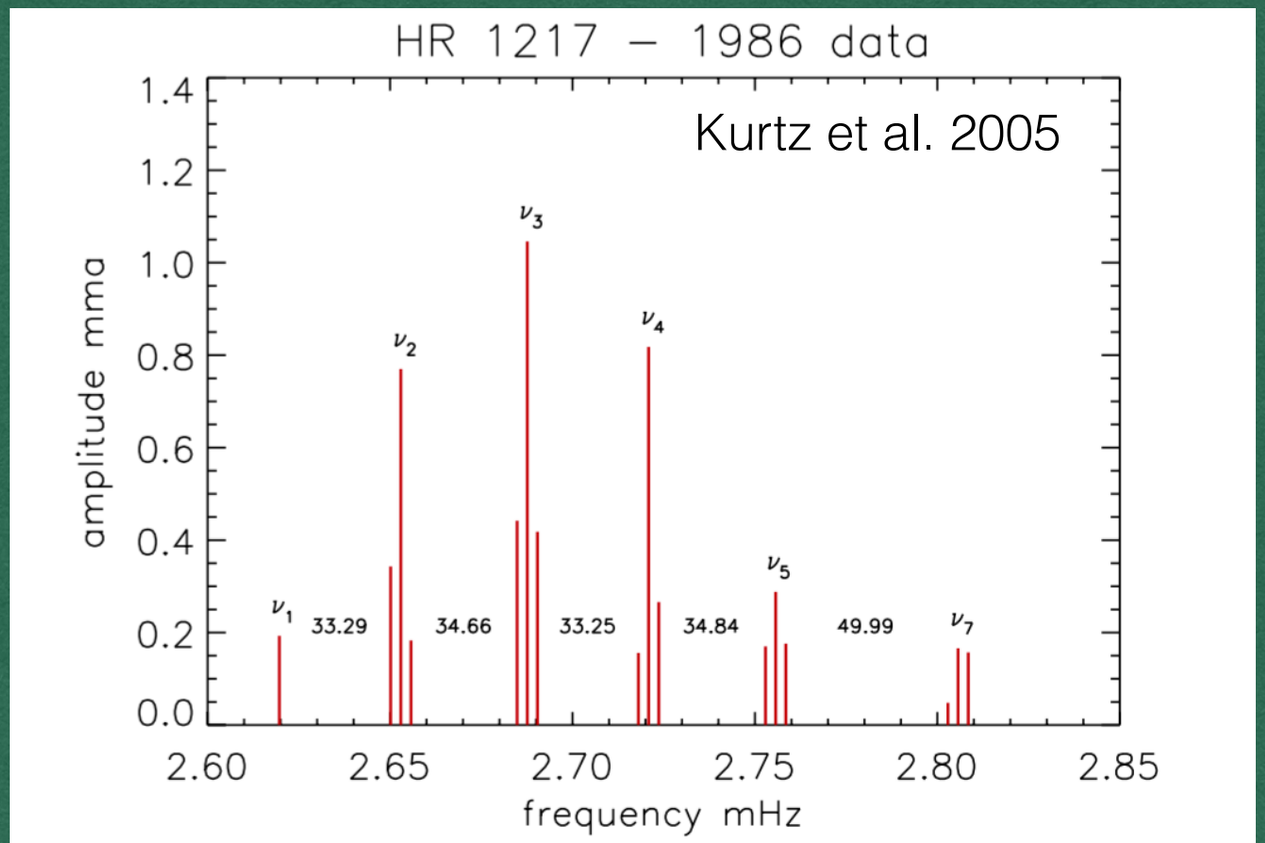


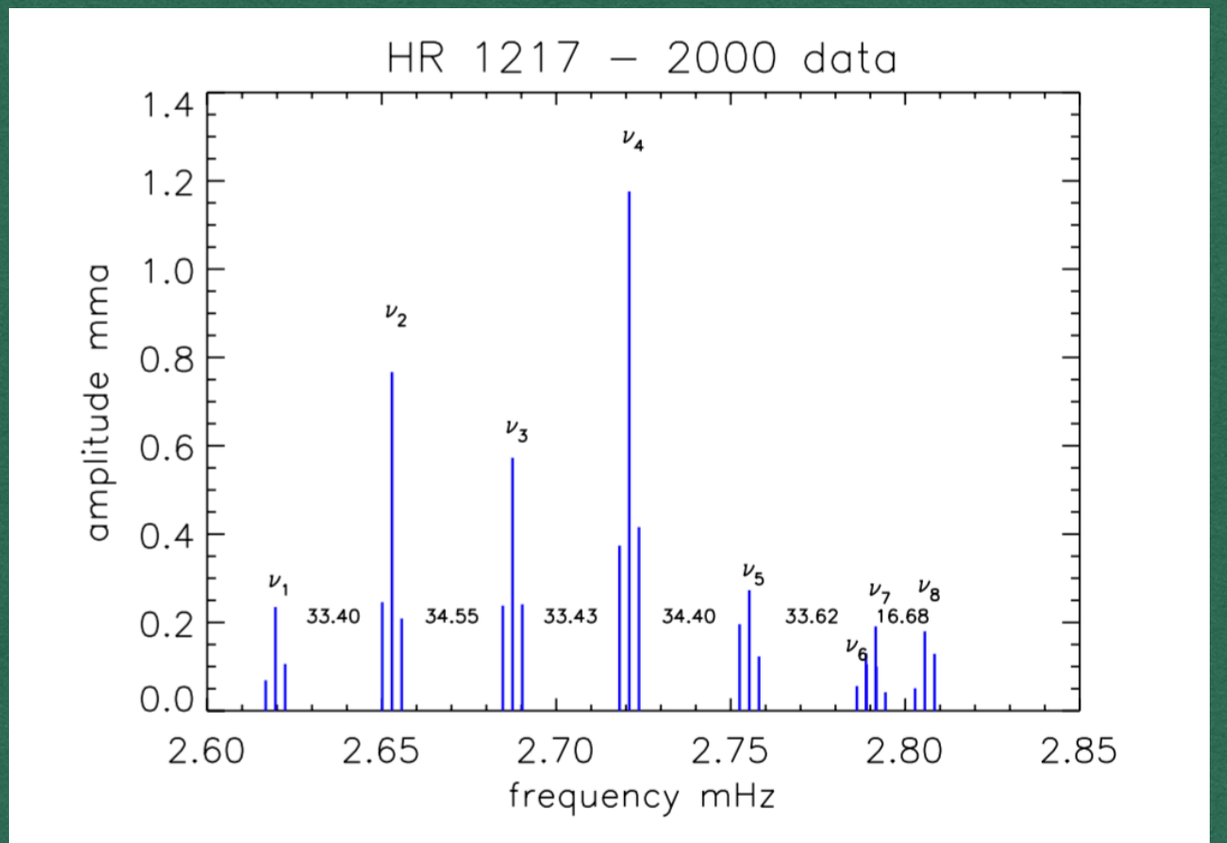
WET Observations of HR 1217



WET Observations of HR 1217

The missing mode

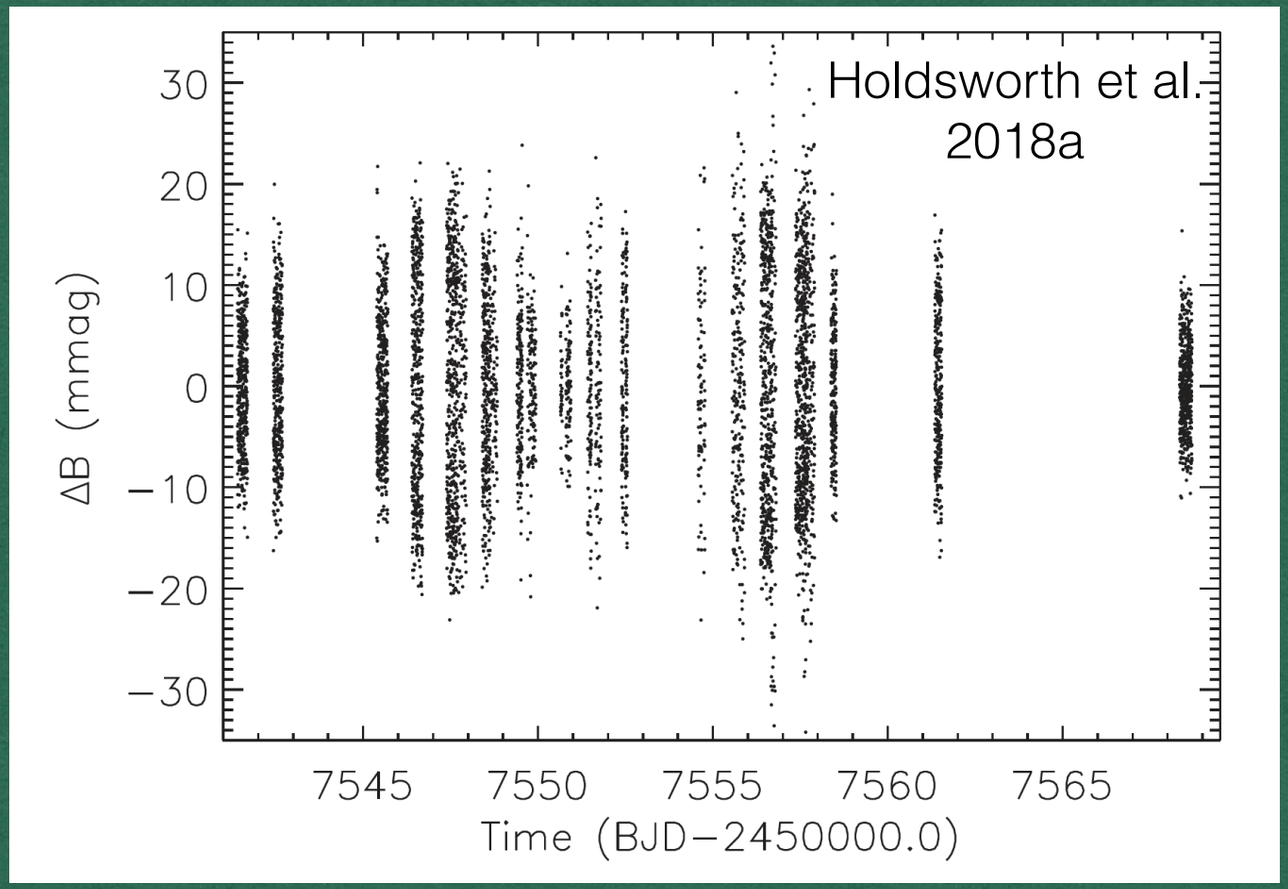




Pushing the limits of ground based observations allows for a more complete asteroseismic model

WET Observations of J1940

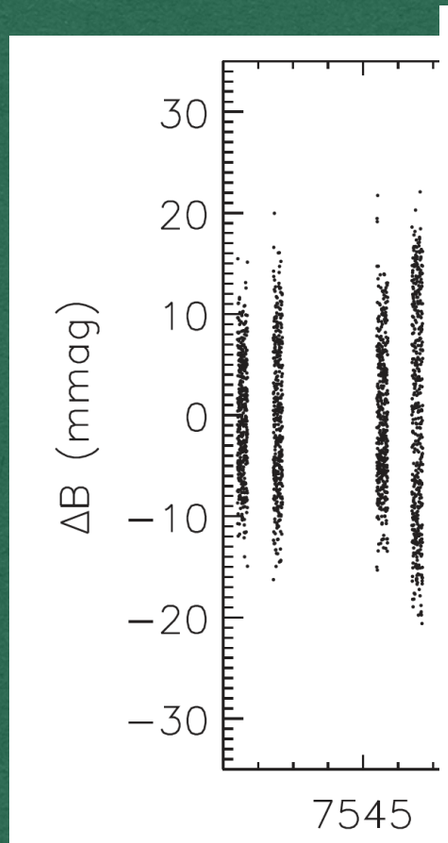
The highest amplitude roAp star

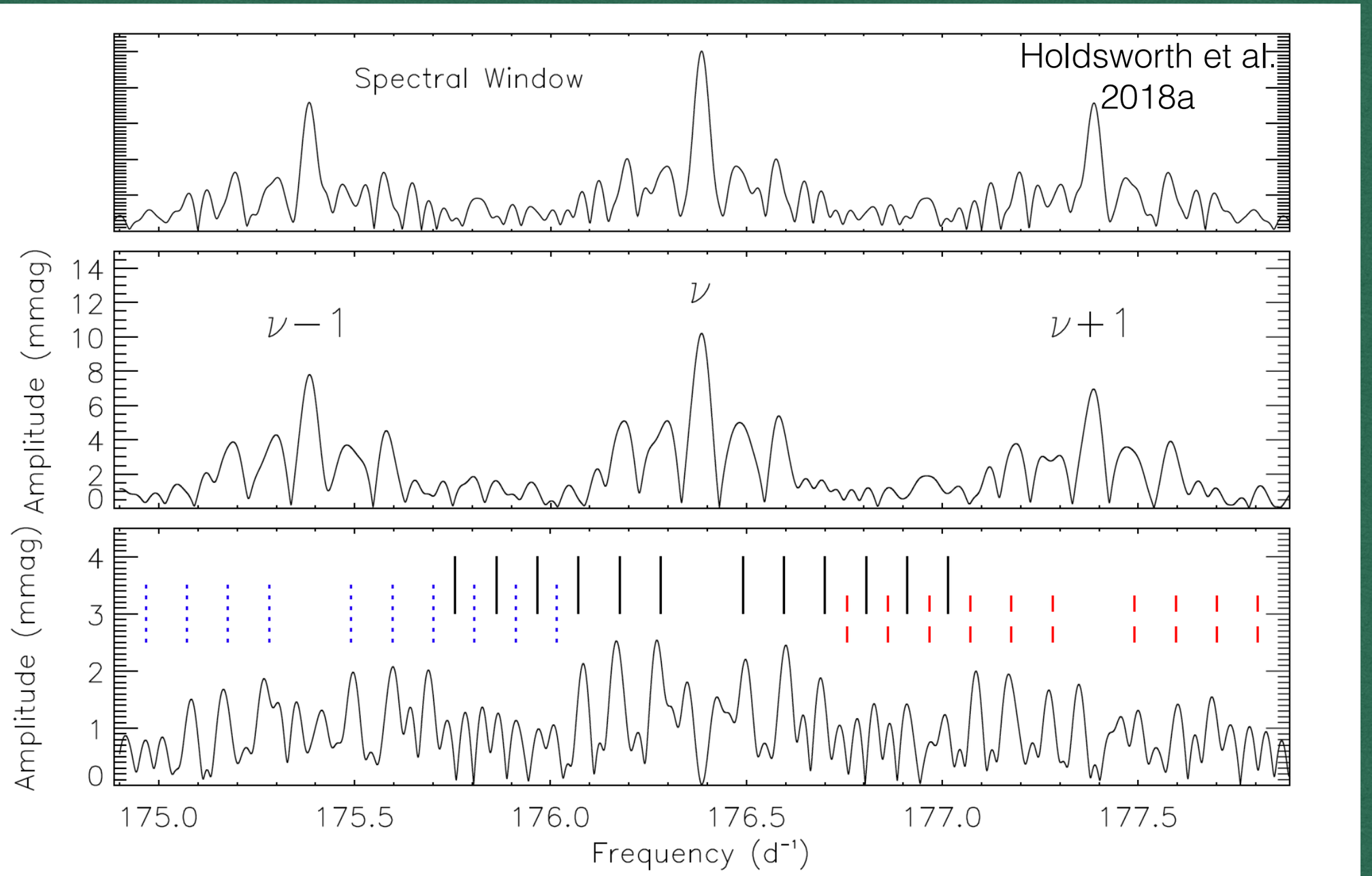


- 2016 campaign
- 21% duty cycle

WET Observations of J1940

The highest amplitude roAp star

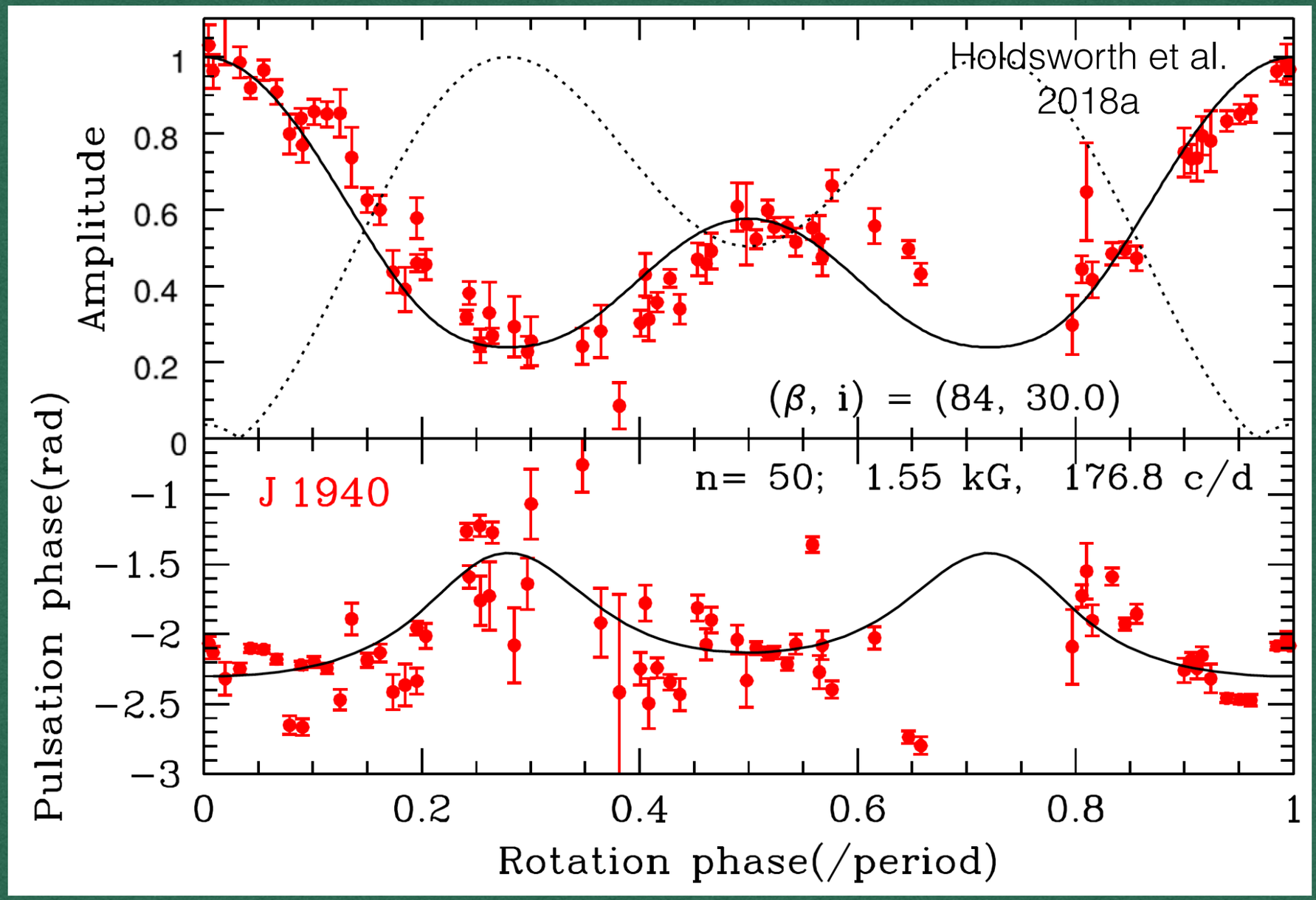




- 2016 ca
- 21% du

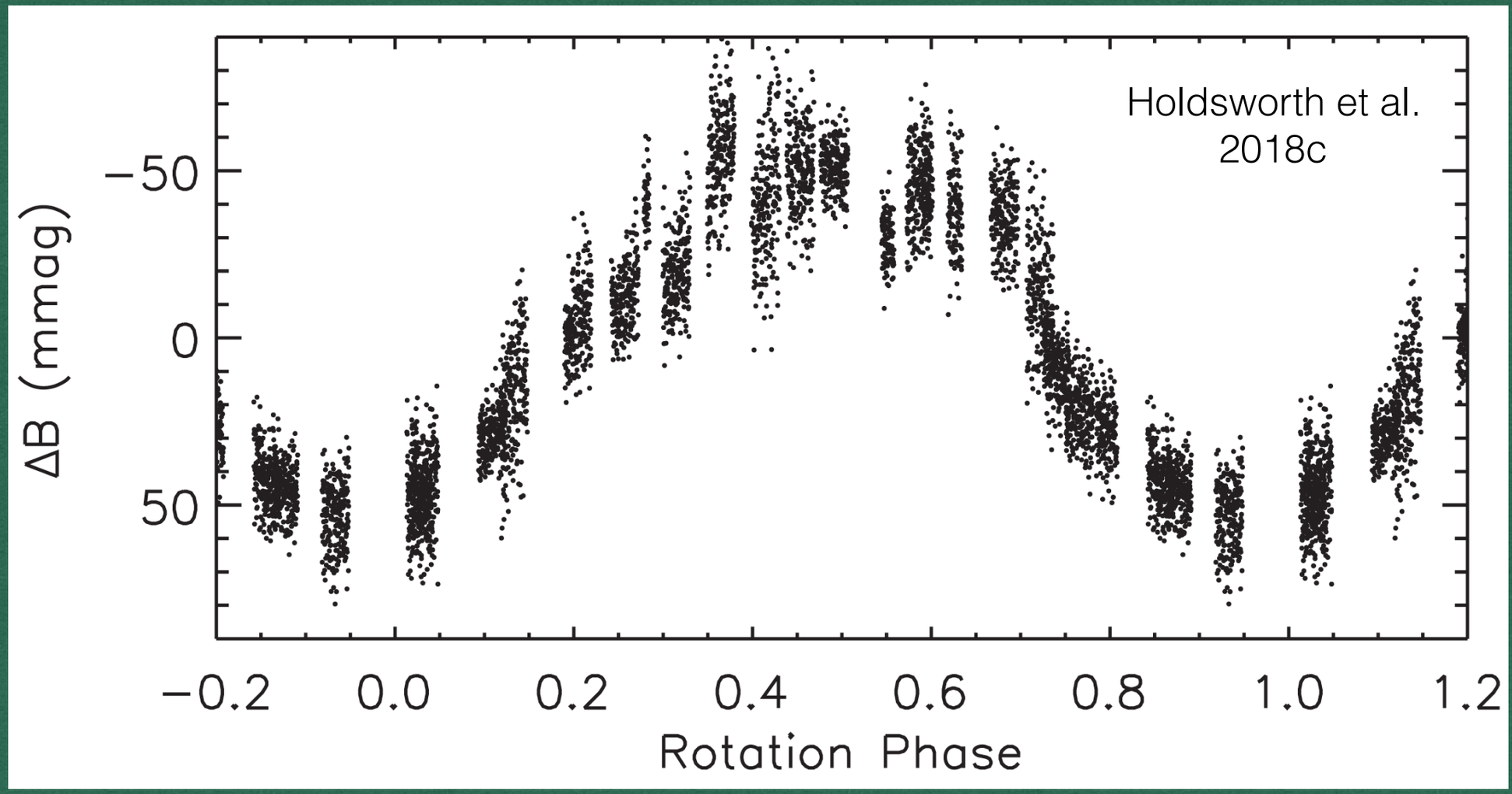
WET Observations of J1940

The highest amplitude roAp star



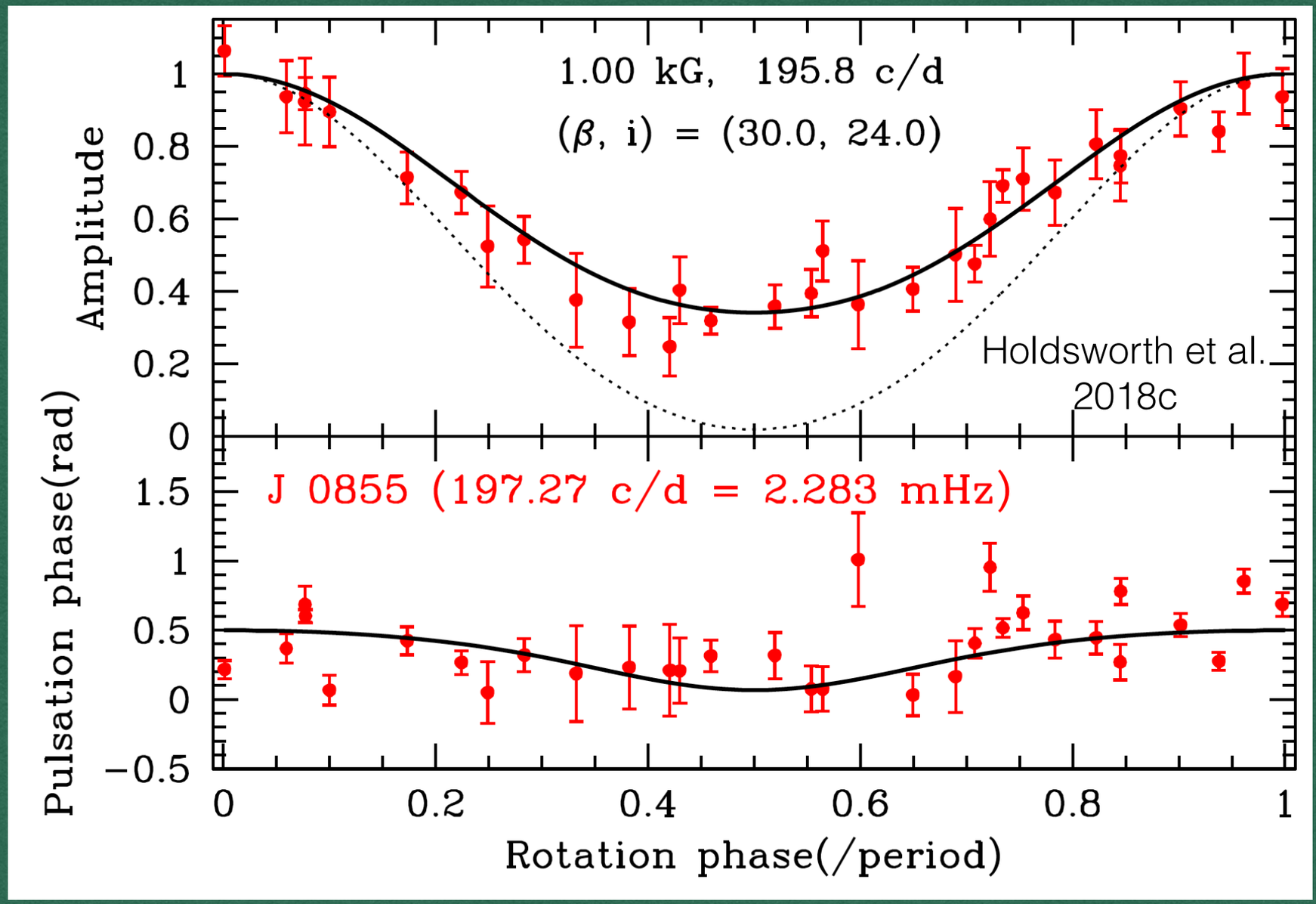
Phase variations suggest song distortion by magnetic field

LCO Observations of J0855



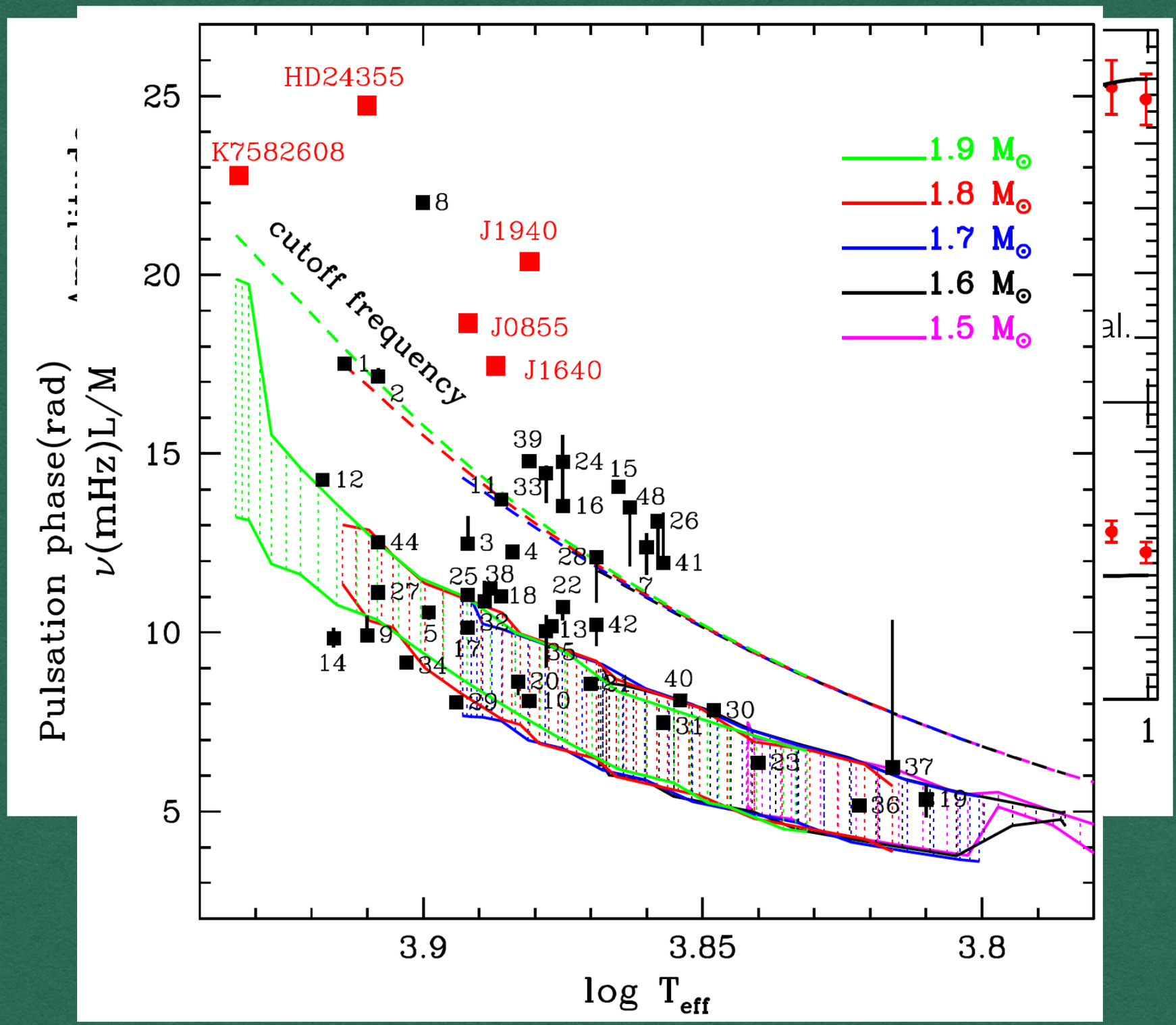
- 60 hr of observations
- Data span 86 days
- More difficult than WET time
- High competition for slots

LCO Observations of J0855

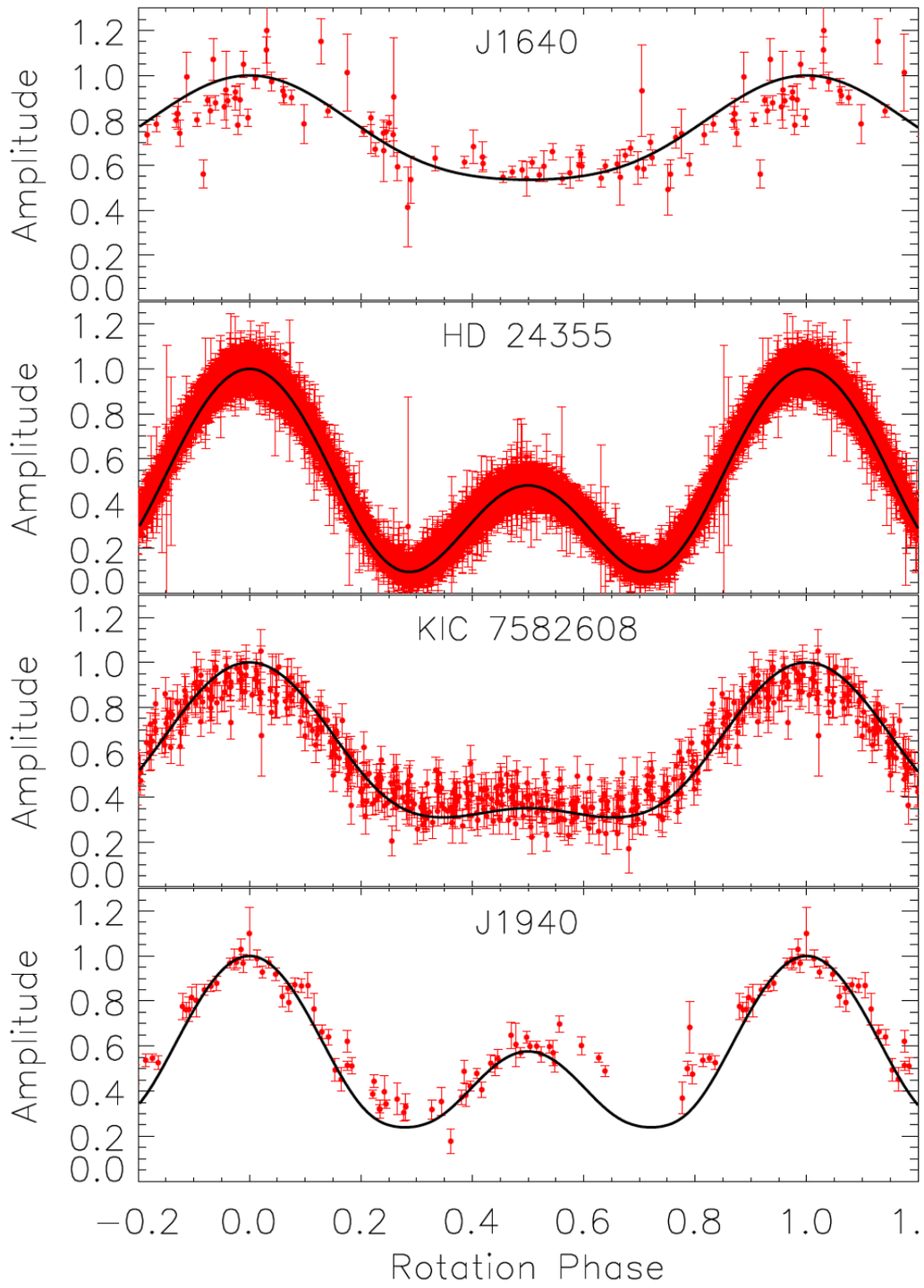


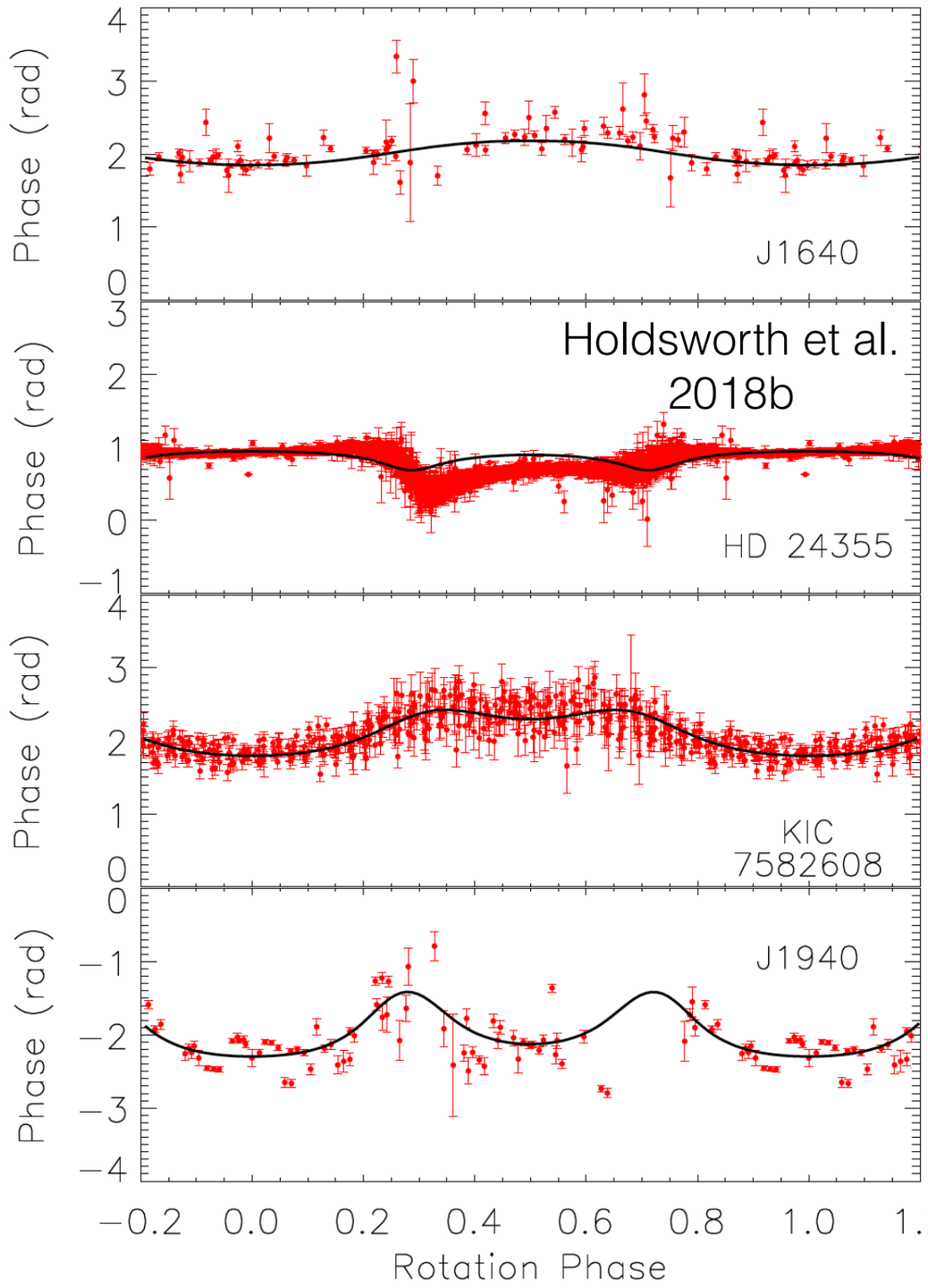
- Again a distorted mode. Why?

LCO Observations of J0855



LCO Observations of J0855





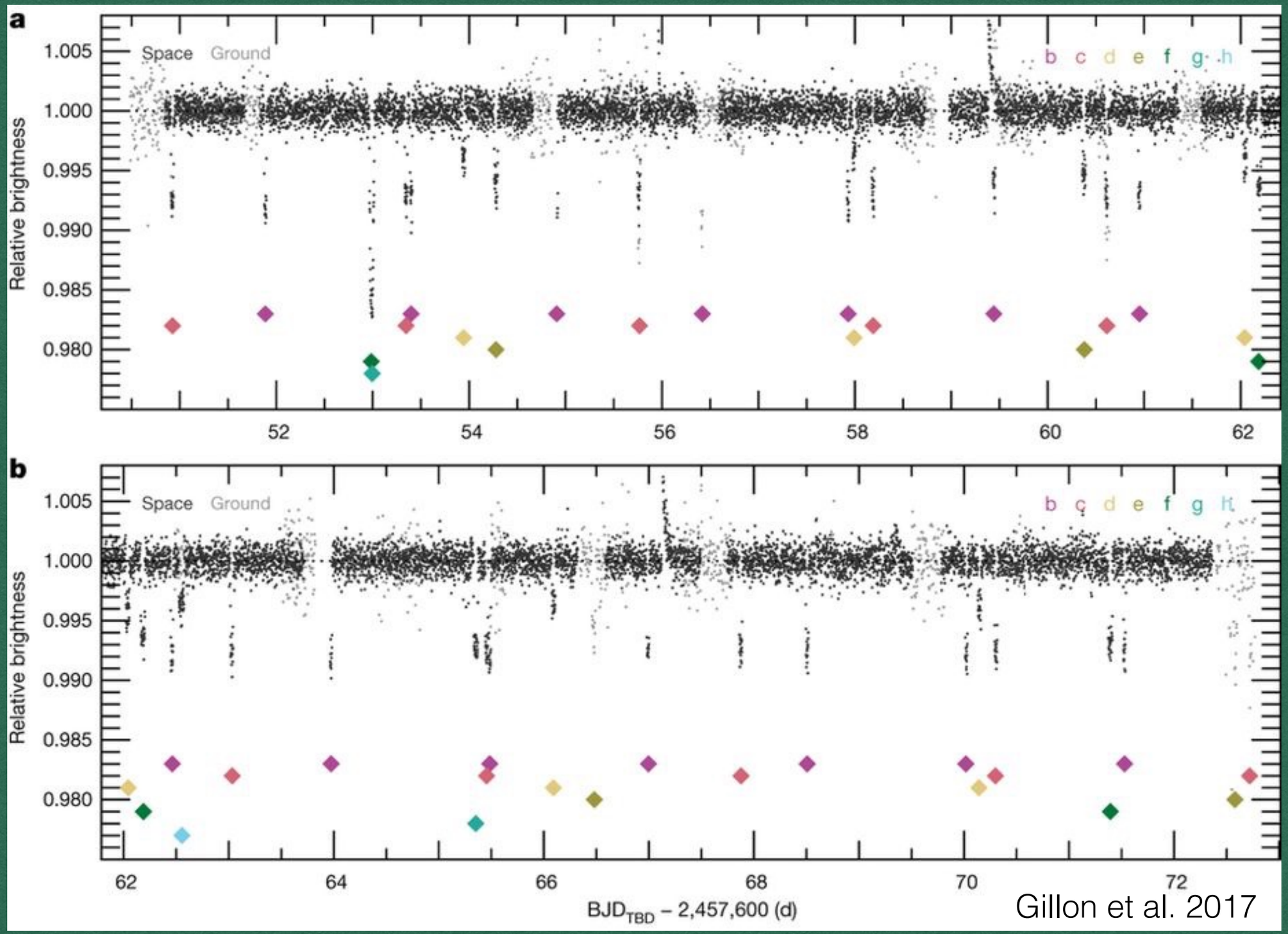
Observations of Exoplanets

Observations of Exoplanets

Facility/instrument	Number of hrs	Year(s)	Number of light curves	Filter/grism	Number of transits
TRAPPIST-South	677.9	2013 2015 2016	214	I+z	b: 13, c: 1, d: 3, e: 5, f: 3, g: 4
Spitzer/IRAC	476.8	2016	30	4.5 μm	b: 16, c: 11, d: 5, e: 2, f: 3, g: 2, h: 1
TRAPPIST-North	206.7	2016	75	I+z	b: 4, c: 3, e: 1
LT/IO:O	50.3	2016	10	z'	b: 1, c: 1, e: 1, f: 1
UKIRT/WFCAM	34.5	2015 2016	9	J	b: 4, c: 3
WHT/ACAM	25.8	2016	4	I	b: 1, c: 1, d: 1
SAAO-1m/SHOC	10.7	2016	5	z'	None
VLT/HAWK-I	6.5	2015	2	NB2090	b: 1, c: 1, e: 1, f: 1
HCT/HFOSC	4.8	2016	1	I	b: 1
HST/WFC3	3.9	2016	1	G141 (1.1-1.7 μm)	b: 1, c: 1

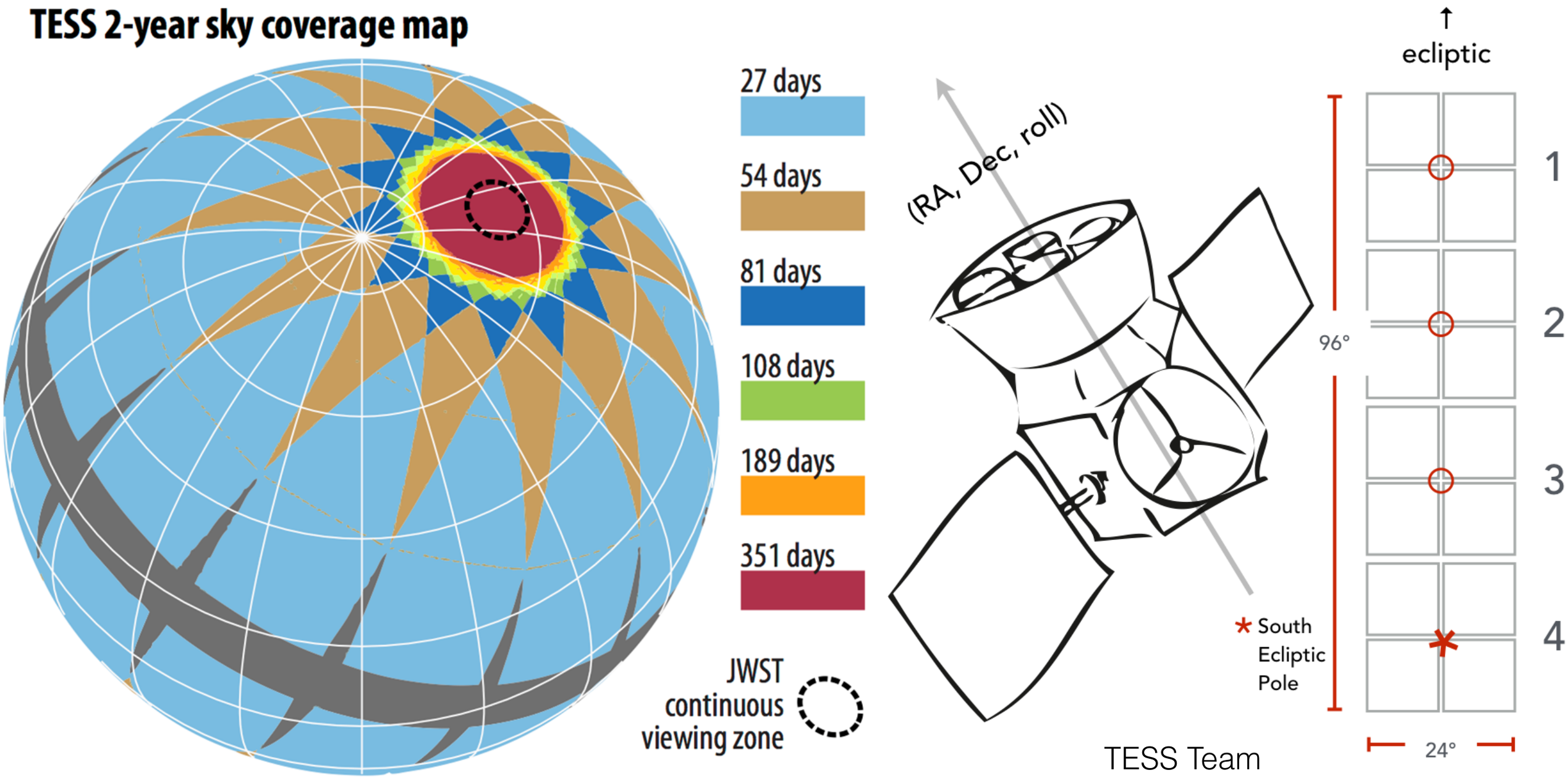
Gillon et al. 2017

Observations of Exoplanets



Gillon et al. 2017

Observations of Exoplanets
TESS



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Thank you for your attention!