Finding K2-18 b

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What is K2-18 b?

- "Super Earth" exoplanet in the K2-18 system
- In the news for possibly having molecules that can only be created by living organisms
- Transits K2-18 every 32.9 days
- Other things to know about the K2-18 system:
  - K2-18 b has a sibling! → K2-18 c (non-transiting)
  - K2-18 c orbits closer, with a period of about 9 days

We thought something like this would be interesting to explore because it's such an exciting discovery in the scientific community!

Artist's concept of K2-18 b (NASA)

Question:

Can we detect the transiting exoplanet K2-18 b using the methods we've learned in DATA 275?

How's life? (and its evidence on K2-18 b)

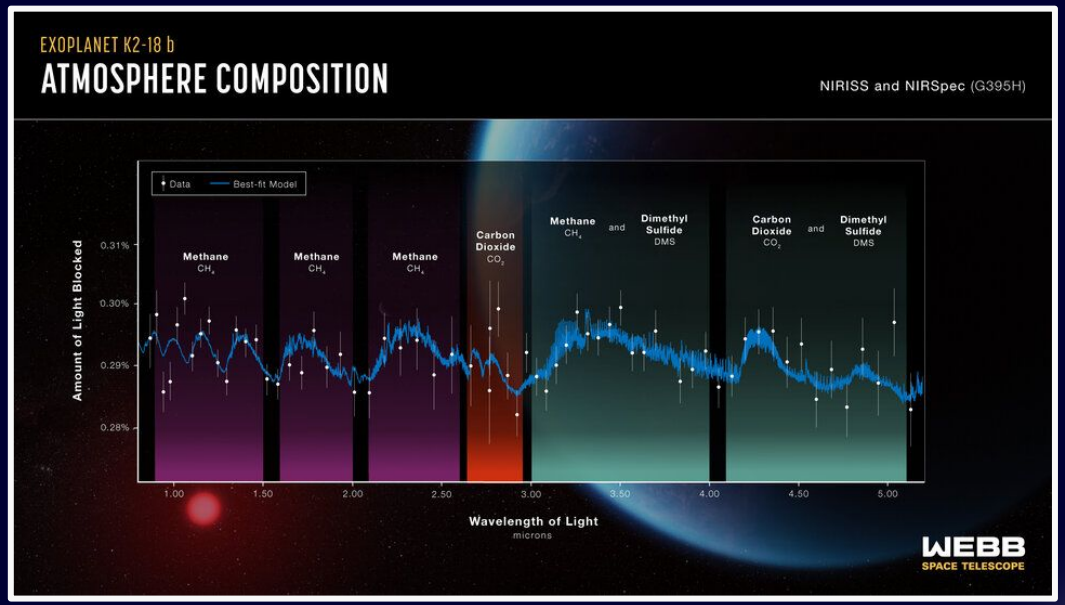
IT'S ALIVE (Franken-style)

- Dimethyl Sulfide (DMS), DMDS, methane and co2 in atmosphere!
- DMS/DMDS unstable
- Potential sign of life

Unfortunately...

- DMS has been produced in lab environments
- Presence of "potential biosignatures", no definite biosignatures

(Madhusudhan et al., 2025)



Atmospheric Composition and Spectra of K2-18 b (ESA)

Data Sources

Not much preprocessing necessary, we just needed to select flux and time columns for our analysis.

K2-18 b

DATA COVERAGE | TESS LIGHT CURVE | TRANSMISSION SPECTRA | RELATED LINKS | JWST VISIBILITY

Period [day] 32.939623 +9.5e-5/-1e-4
Transit Epoch [MJD] 57725.05119 +6.7e-5/-6.8e-5
Transit Duration [hour] 2.682 ±0
Impact Parameter 0.6 ±0.01
ω [°] -5.7 +46.4/-33.8
a [AU] 0.143 +0.006/-0.007
Inclination [°] 89.58
Depth [%] 0.2389
Eccentricity 0.2 ±0.08
a/Rs 69.127

Mission - Instrument	Waveband	Product	Filters	Exposure (sec)	Target	RA	Dec	Start Time	
K2 - Kepler	OPTICAL	timeseries	kepler	7098929	polar201912552	11:30:14.512	+07:35:18.21	2014-05-30 16:09:26	h
HLSP - Kepler	OPTICAL	timeseries	KEPLER	1800	ktwo201912552	11:30:14.512	+07:35:18.21	2014-05-30 15:54:44	K
HLSP - Kepler	OPTICAL	timeseries	KEPLER	1800	ktwo201912552	11:30:14.512	+07:35:18.21	2014-05-30 15:54:44	K
HLSP - Kepler	Optical	timeseries	KEPLER	1800	ktwo201912552	11:30:14.512	+07:35:18.21	2014-06-03 01:40:37	K
HLSP - Photometer	Optical	timeseries	TESS	1800	388804061	11:30:14.434	+07:35:16.19	2021-11-07 00:13:56	T
HLSP - Photometer	Optical	timeseries	TESS	1800	388804061	11:30:14.434	+07:35:16.19	2021-12-03 01:43:55	T

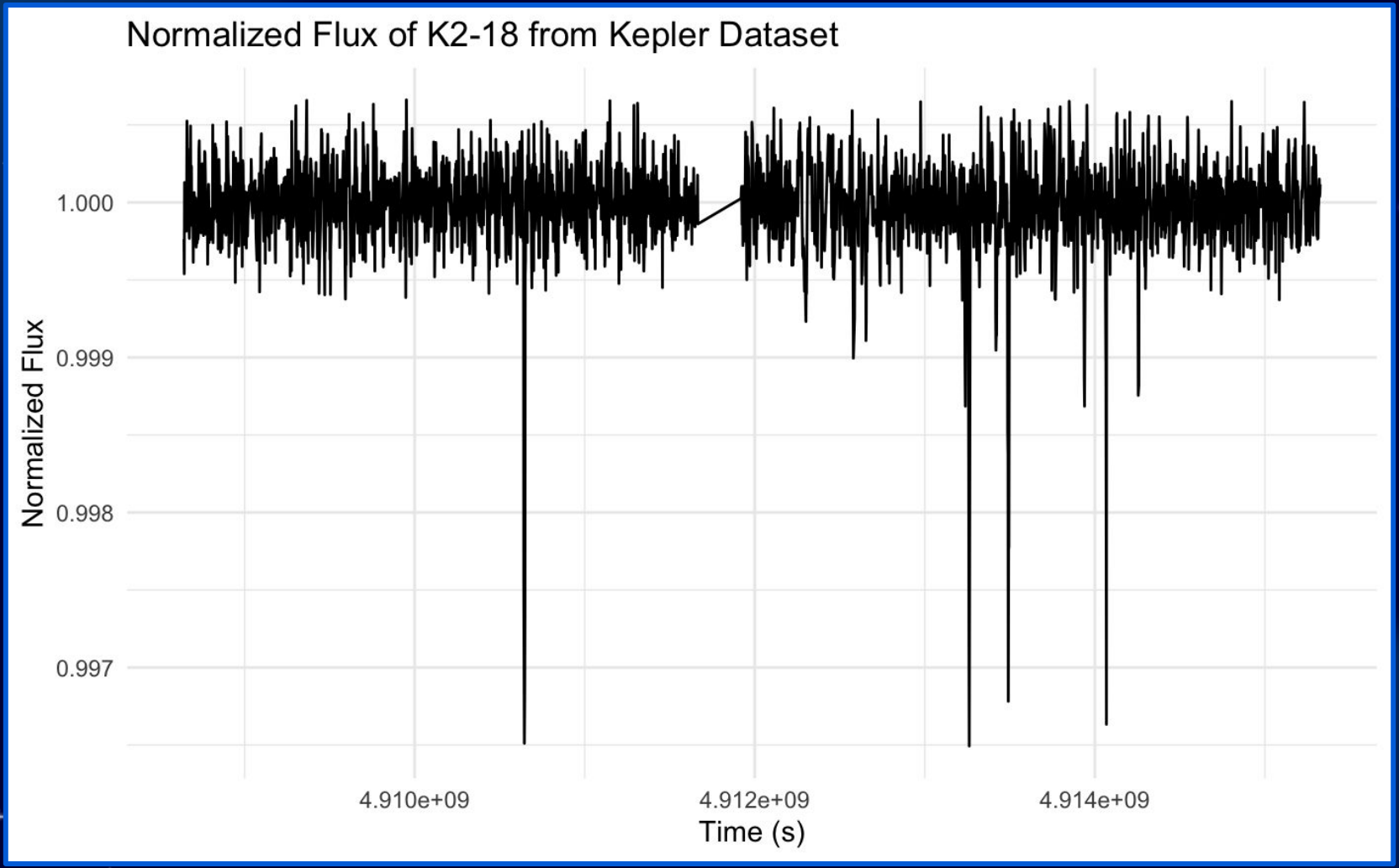
Exo.MAST's datasets on K2-18 b

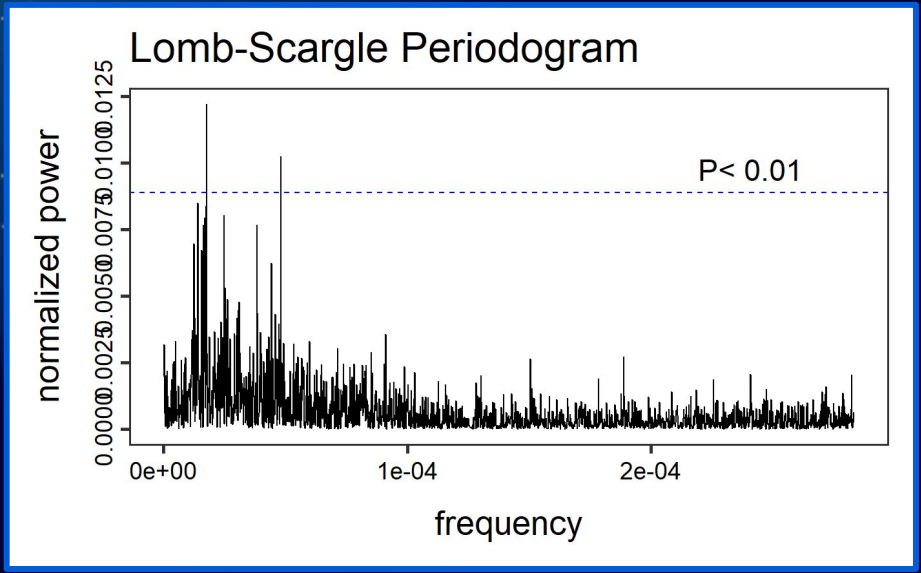
The Original Dataset

- Optical flux data from the Kepler mission
- Observation period of about 82.2 days (2 transits)
- Came as a FITS file, but we read it into R using `readFrameFromFITS()`
- Time units unlabeled but presumed to be days
    - Difference of 0.02 days matched Kepler's 30-minute observation intervals (Hawkes, 2019)
    - Used `mutate()` to add a new column with time converted to seconds

FILTIME	FILFLUX	FILFLUXERROR
56813.00	0.9997632	7.036958e-05
56813.02	0.9995396	7.035285e-05
56813.04	1.0001284	7.037049e-05
56813.06	1.0000919	7.036662e-05
56813.08	0.9999084	7.036106e-05
56813.12	1.0000675	7.036496e-05
56813.14	1.0001211	7.036987e-05
56813.16	0.9998148	7.036277e-05
56813.18	0.9999844	7.036405e-05
56813.20	1.0005249	7.038241e-05
56813.22	0.9999657	7.036210e-05

First few rows of the dataset


Normalized Flux of K2-18 from Kepler Dataset
Normalized Flux
1.000
0.999
0.998
0.997
4.910e+09
4.912e+09
4.914e+09
Time (s)



Original Lomb-Scargle

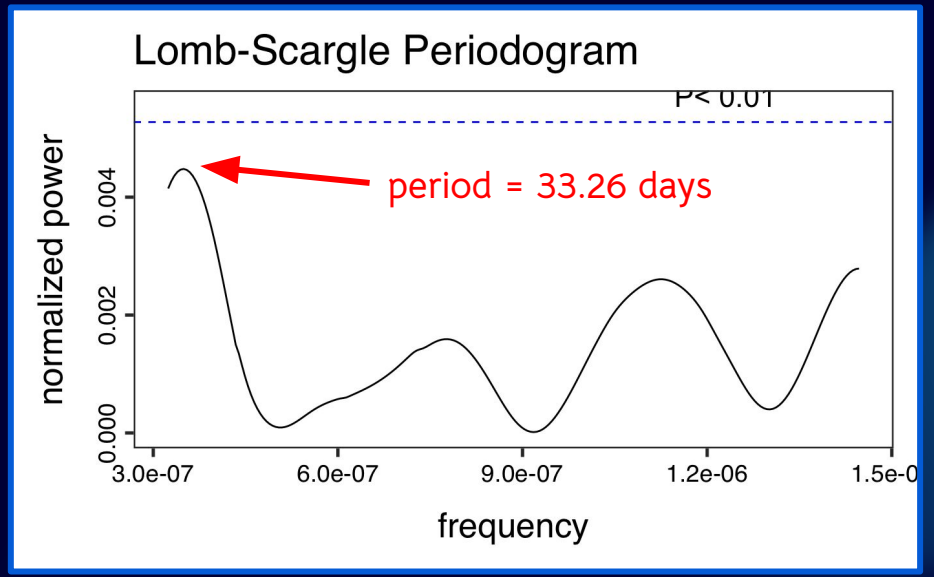
min period = 2 * median period
max period = total exposure time

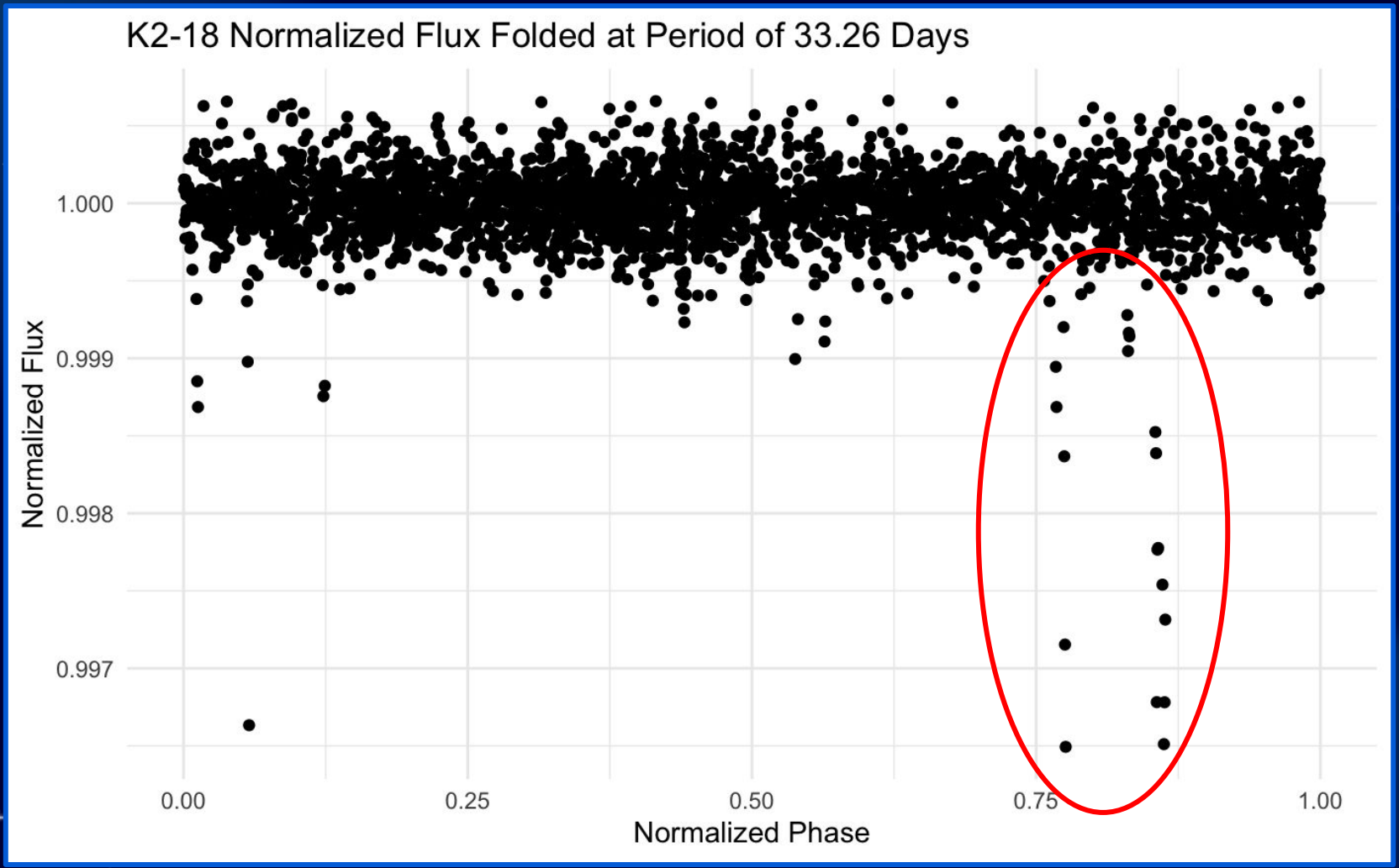
Overtaken by very small frequencies
→ periods too big for what we're looking for

Zoomed Lomb-Scargle

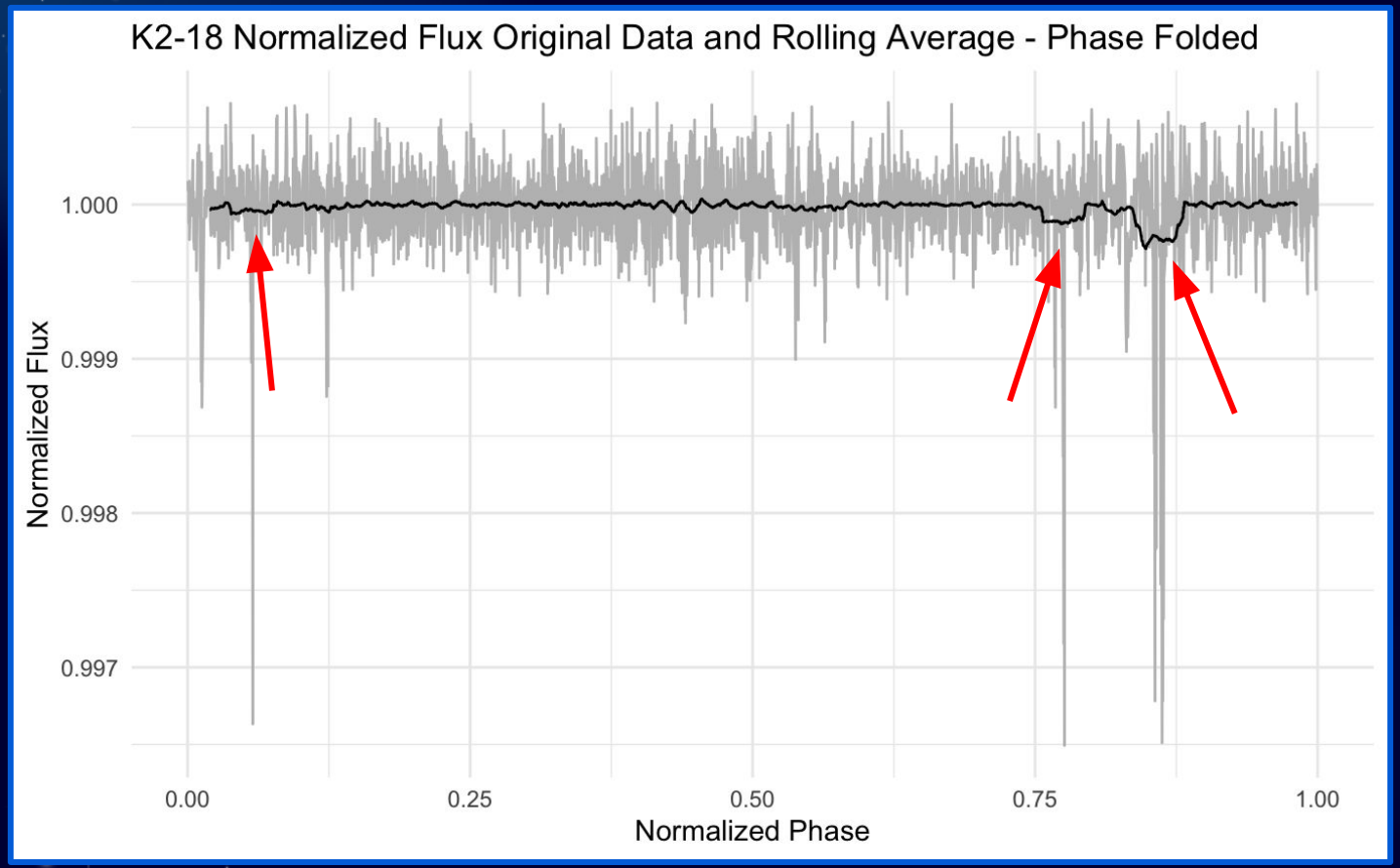
min period = 8 days
max period = 36 days
oversampling factor = 30

Zoomed in to where planets' periods should be + scanned frequencies more thoroughly (oversampled)




K2-18 Normalized Flux Folded at Period of 33.26 Days
Normalized Flux
1.000
0.999
0.998
0.997
0.00
0.25
0.50
0.75
1.00
Normalized Phase

A Breakthrough?!! … Not Quite.

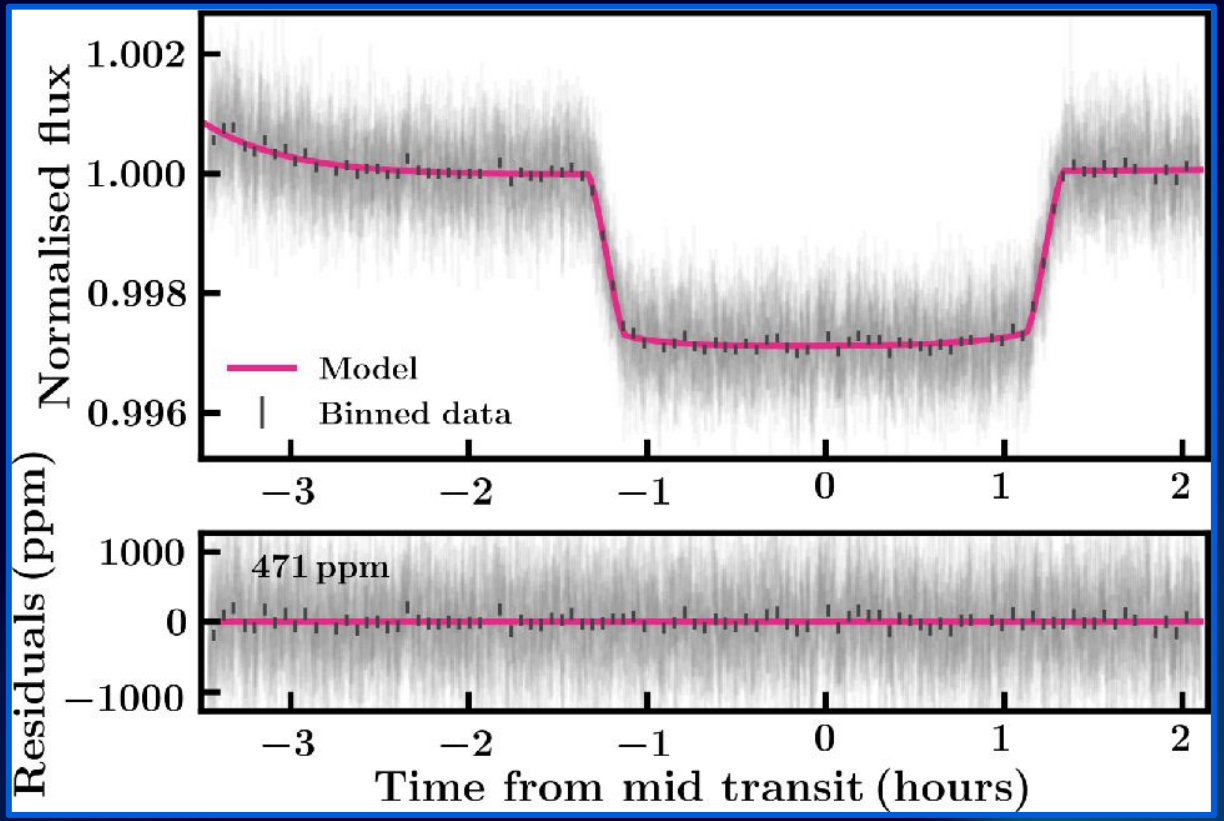


1. If this is folded over a specific period, why does it show multiple transits??

2. Jed said not to get our hopes up

An Actual Transit Plot of K2-18 b

- This is what K2-18 b's transit should look like!
- From a paper we found that used light curve data from JWST to find a transit
- They performed a LOT of correction techniques that were beyond the scope of our skills/this class



(Madhusudhan et al., 2025)

Papers on Transit Identification

Paper on the Atmospheric Composition of K2-18 b (DMS and DMDS Detection)

- This paper contains the transit plot from the previous slide
- Researchers searched for molecular species under a different wavelength range (using JWST).
- They used techniques like MCMC!

Paper on Water Vapor in the Atmosphere of K2-18 b

- Researchers examined 8 transits using Hubble's WFC3 camera
- Data was collected from the same MAST archive that we accessed!
- There was one small difference though...

The Products Are Images!

- The instrument used for these observations produced images, not time series!
- Paper had instructions on how to deal with this on a linked GitHub page, but we didn't have the time/knowledge to explore it
- It's unfortunate, but at least we know K2-18 b's transit <u>can</u> be identified via public data!

Mission - Instrument	Waveband	Product	Filters	Exposure (sec)	Target
HST - WFC3/IR	INFRARED	image	F130N	1	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552
HST - WFC3/IR	INFRARED	image	G141	103	EPIC201912552

Filtered view of the paper's specified runs in the MAST archive (HST proposals 13665 and 14682)

Transit Roadblocks

Too Few Transits

No one data set we found covered more than two transits. Most data sets only covered 30 minutes.

Unclear Data

Data sets didn't label their time units and didn't map to any identifiable time system.

Data Sources

The data others used to find the transit is somewhere, but sources were questionably cited and hard to track down, or use methods outside the scope of this class.

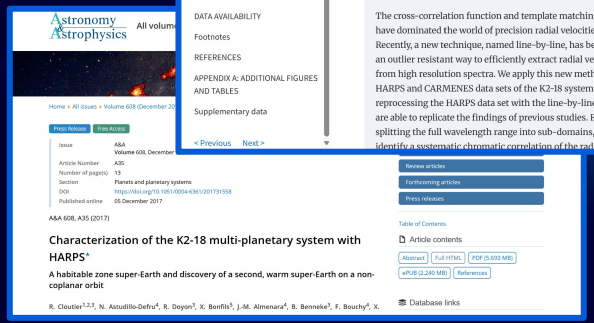
Inconsistent Units

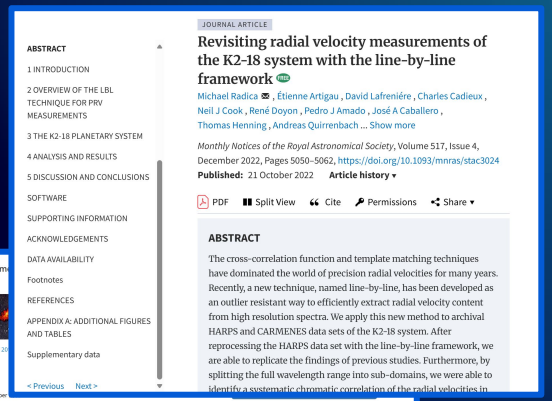
Different data sets used different time and flux units – couldn't combine them to create a data set over a longer time period.

New Question:

If we're unable to identify a transit using flux data, is it possible to at least find K2-18 b's period using radial velocity data?

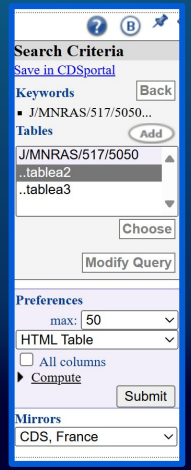
Tracing Data Backwards

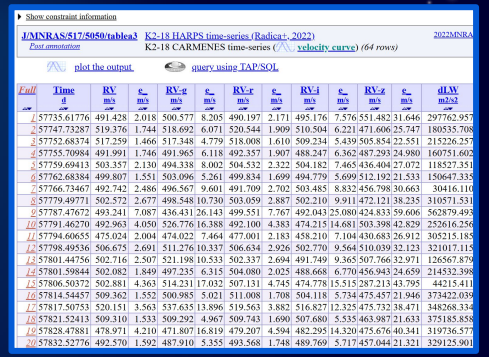


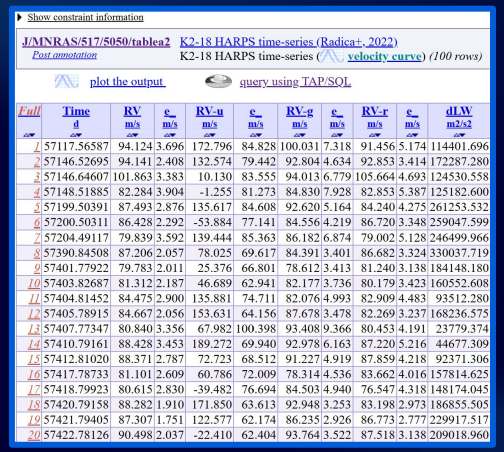


We used data discovered via several scholarly articles that detailed the use of HARPS, or the High-Accuracy Radial velocity Planet Searcher, on the K2-18 system.

One search query later...







2 Radial Velocity time series!

← (We ended up working with this one)

New Data Source

Again, not much preprocessing necessary. This time we just needed to select `Radial Velocity` and `Time` columns for our analysis.

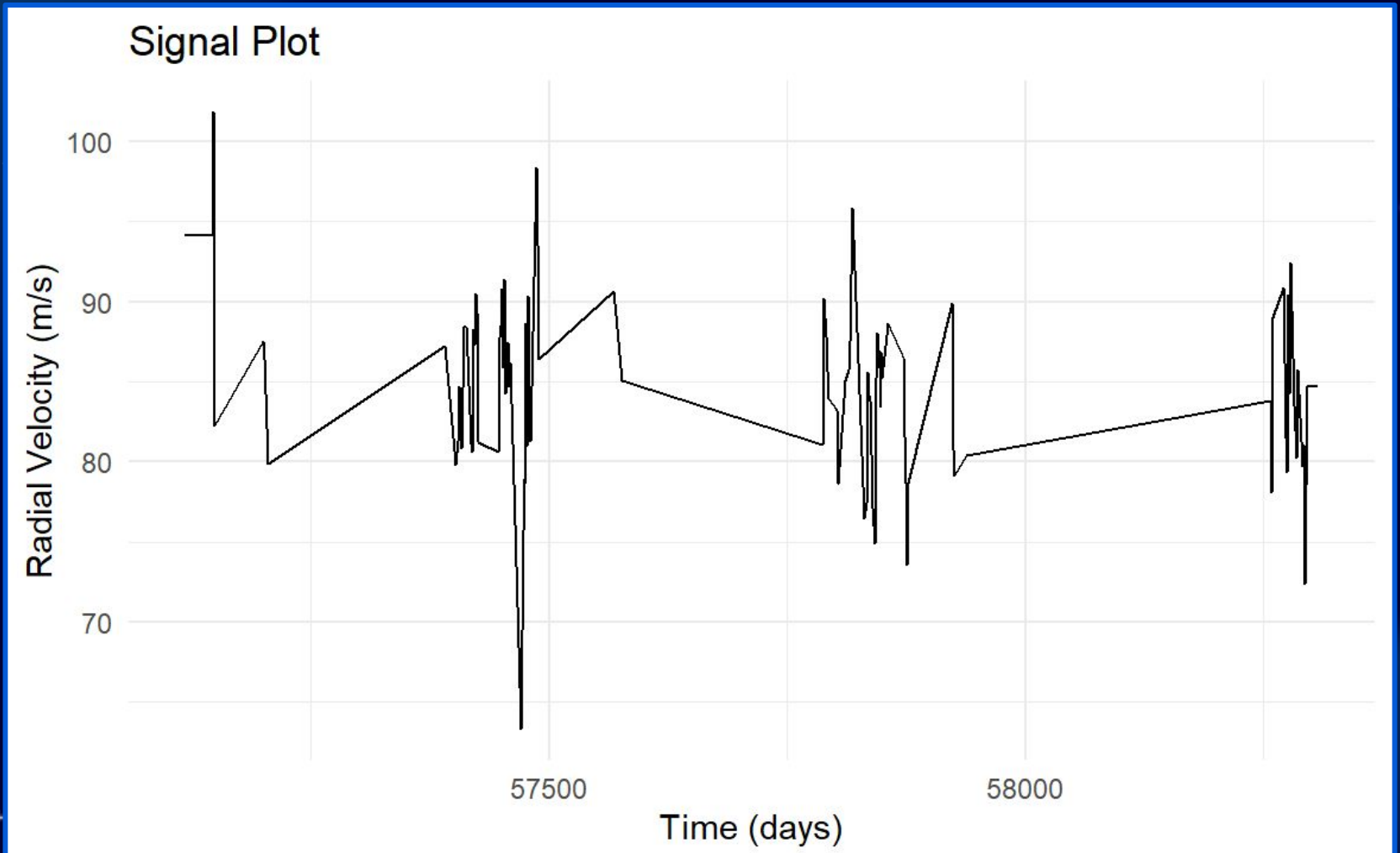
VizieR's data sets on K2-18's Radial Velocity

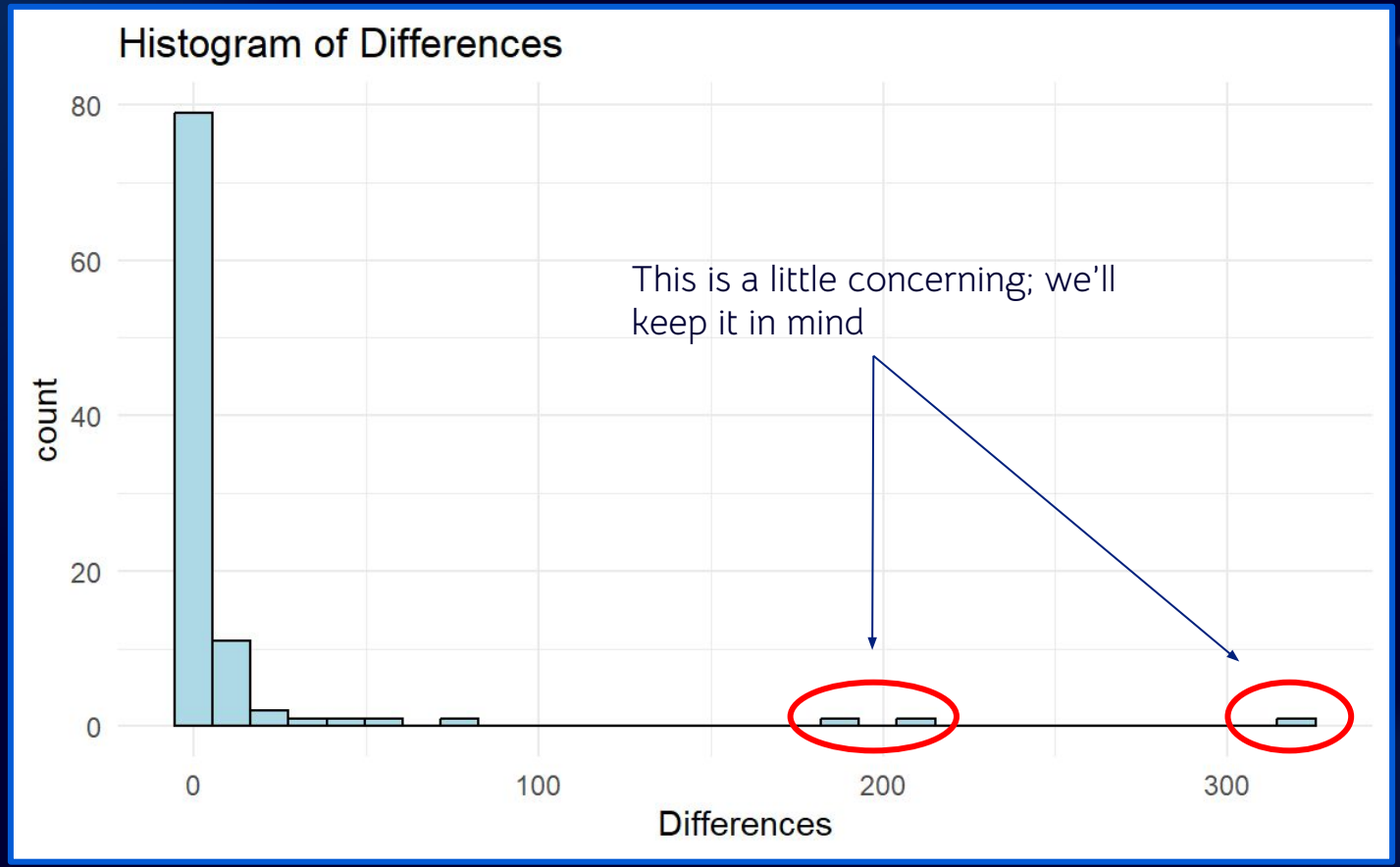
Our dataset – `J/MNRAS/517/5050/tablea2`

- Radial velocity data from ESO's (European Southern Observatory) HARPS
- Observation period of about 1189.91 days, HOWEVER there are only 100 data points (and many gaps in the data)
- The data was downloaded as a txt file, which we read in and reorganized using `fread()`
- `Time` was in days and `Radial Velocity` was in meters per second (able to select necessary variables directly from VizieR)

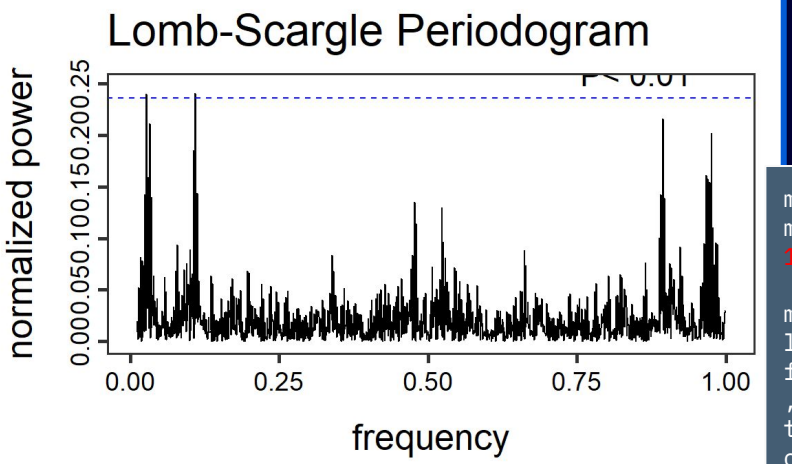
Full	Time d	RV m/s
1	57117.56587	94.124
2	57146.52695	94.141
3	57146.64607	101.863
4	57148.51885	82.284
5	57199.50391	87.493
6	57200.50311	86.428
7	57204.49117	79.839
8	57390.84508	87.206
9	57401.77922	79.783
10	57403.82687	81.312

First few rows of the dataset


Signal Plot
100
90
80
70
Radial Velocity (m/s)
57500
58000
Time (days)

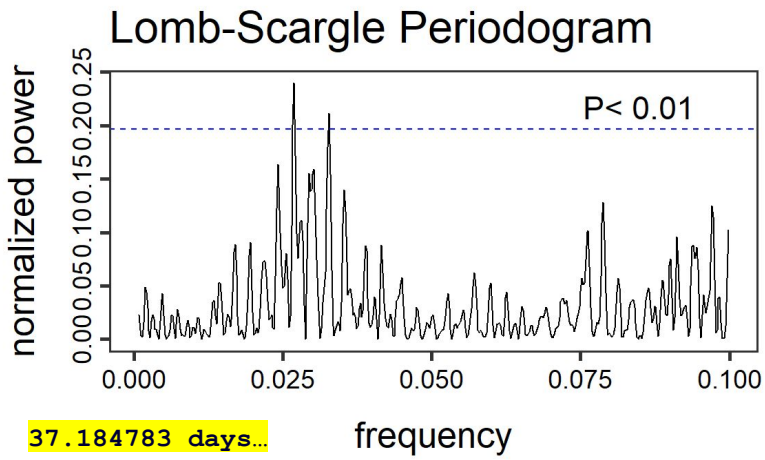


A histogram of the distances between time measurements



To a smaller range...

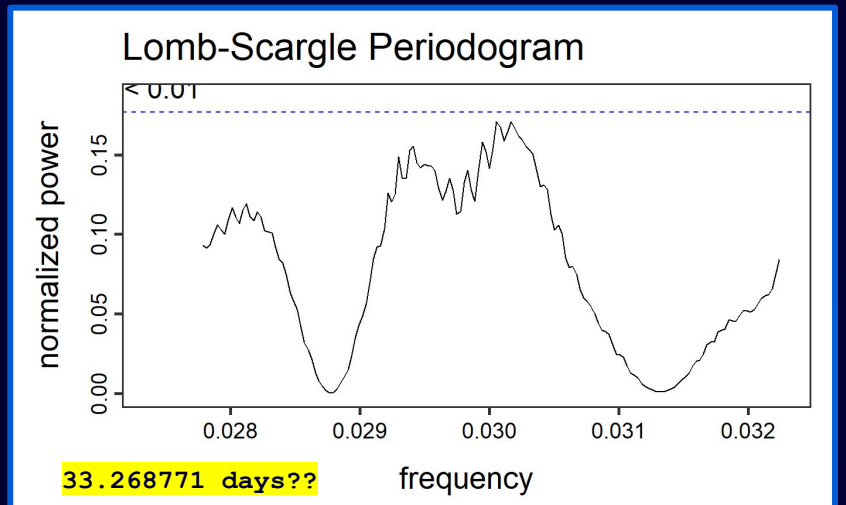
```
min_period = 10
max_period =
10000

model <-
lsp(t2_lomb,
from=1/max_period
,
to=1/min_period,
ofac=4)
```



37.184783 days…

From a larger range...

```
min_period = 1
max_period = 100

model <- lsp(t2_lomb,
from=1/max_period,
to=1/min_period, ofac=1)
```



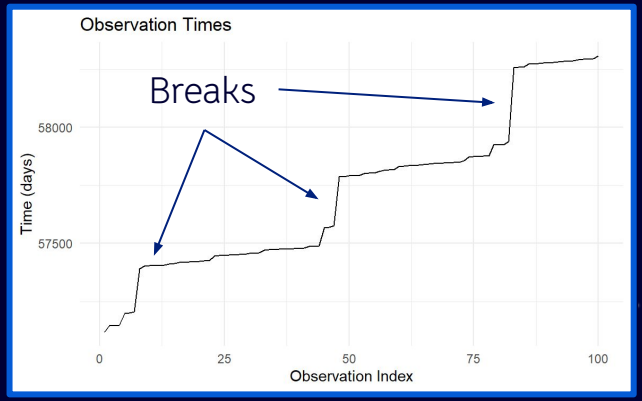
33.268771 days??

To an even smaller one!

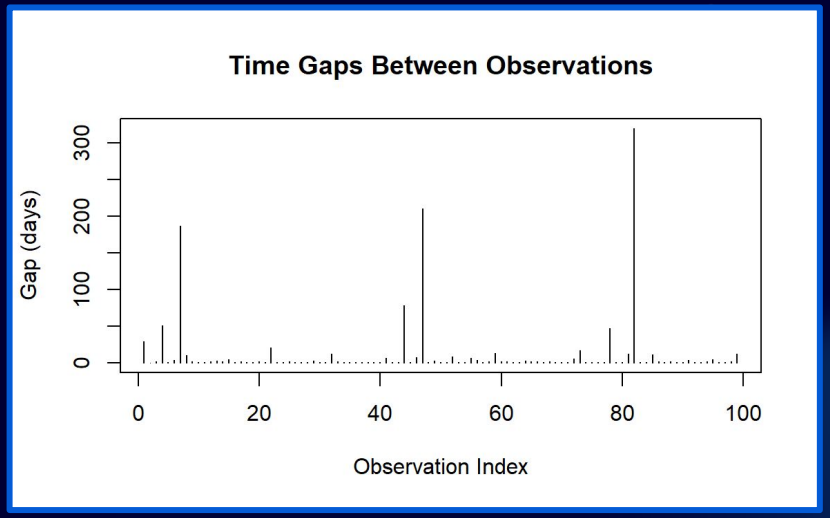
```
min_period = 31
max_period = 36

model <- lsp(t2_lomb,
from=1/max_period,
to=1/min_period, ofac=30)
```

So...What's Wrong?

- To figure out why we were seeing interference (false signals) in our lomb scargle, we plotted `Time` (in days) against the `Observation Index`, or row
- Three large bursts of observations!
- Confirmed this further by plotting the `Gaps` (in days) against the `Observation Index`
- These gaps in observations could be responsible for our false signals



← A plot of `Time` (in days) by `Observation Index`

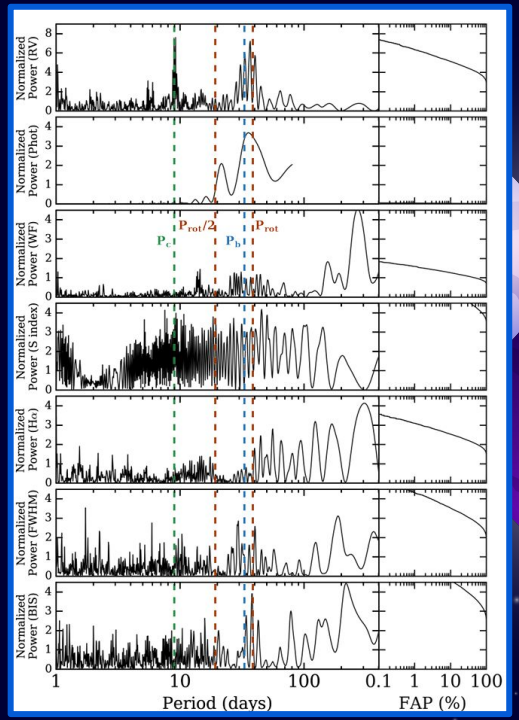


A plot of `Gaps` (in days) by `Observation Index`

A Paper on Radial Velocity Examination

Characterization of the K2-18 multi-planetary system with HARPS

- Used radial velocity data from VizieR to characterize the planet's mass
- Used several methods we learned about in this class, like Lomb-Scargle (see image right) and MCMC
- Analysis really complex → no way we could replicate (or understand) most of it



Cloutier et al., 2017

Conclusions

- Couldn't find the transit of K2-18 b because:
  - Not enough transits in a single data set
  - Required methods outside the scope of the class
  - Exoplanet transits are notoriously difficult to tease out!
- Couldn't find the period of K2-18 b via radial velocity because:
  - Only 100 observations
  - Gaps in the data (3 bursts of observations)
- Found mysterious period of 33.26 days with multiple unrelated methods???
- Real data is quite difficult to work with! Not everything works out, but it was interesting to see how many papers made use of methods we learned about in this class (Lomb-Scargle and MCMC)
- What we would do differently if we had another chance:
  - Choose another exoplanet with a shorter period to attempt transit identification on?

References

Cloutier, R., Astudillo-Defru, N., Dovon, R., Bonfils, X., Almenara, J.-M., Benneke, B., Bouchy, F., Delfosse, X., Ehrenreich, D., Forveille, T., Lovis, C., Mayor, M., Menou, K., Murgas, F., Pepe, F., Rowe, J., Santos, N.C., Udry, S., & Wünsche, A. (2017). Characterization of the K2-18 multi-planetary system with HARPS. *Astronomy and Astrophysics, 608*. https://doi.org/10.1051/0004-6361/201731558

European Southern Observatory. (n.d.). *HARPS*. https://www.eso.org/public/teles-instr/lasilla/36/harps/

The European Space Agency. (2023, November 9). *Webb discovers methane and carbon dioxide in atmosphere of K2-18 b.* https://www.esa.int/Science_Exploration/Space_Science/Webb/Webb_discovers_methane_and_carbon_dioxide_in_atmosphere_of_K2-18_b

Ghosh, P. (2025, April 17). *Scientists find 'strongest evidence yet' of life on distant planet*. BBC. https://www.bbc.com/news/articles/c39jj9vkr34o

Hawkes, A. (2019, February 6). *Kepler's Final Image Shows A Galaxy Full Of Possibilities*. NASA. https://www.nasa.gov/image-article/keplers-final-image-shows-galaxy-full-of-possibilities/

Madhusudhan, N., Constantinou, S., Holmberg, M., Sarkar, S., Piette, A.A.A., & Moses, J.I. New Constraints on DMS and DMDS in the Atmosphere of K2-18 b from JWST MIRI. *The Astrophysical Journal Letters, 983*(2). https://doi.org/10.3847/2041-8213/adc1c8.

References

National Aeronautics and Space Administration. (2024, October 25). *K2-18 c.* NASA Science. https://science.nasa.gov/exoplanet-catalog/k2-18-c/

National Aeronautics and Space Administration. (2025, March 28). *K2-18 b.* NASA Science. https://science.nasa.gov/exoplanet-catalog/k2-18-b/

Neilson Jr., E.H. (n.d.) *Read a single data set from a FITS file into a data frame*. R Documentation. https://search.r-project.org/CRAN/refmans/FITSio/html/readFrameFromFITS.html

Radica, M., Artigau, E., Lafreniére, D., Cadieux, C., Cook, N.J., Doyon, R., Amado, P.J., Caballero, J.A., Henning, T., Quirrenbach, A., Reiners, A., & Ribas, I. (2022). Revisiting radial velocity measurements of the K2-18 system with the line-by-line framework. *Monthly Notices of the Royal Astronomical Society, 517*(4), 5050–5062. https://academic.oup.com/mnras/article/517/4/5050/6767604#379437824

Tsiaras, A., Waldmann, I.P., Tinetti, G., Tennyson, J., & Yurchenko, S.N. (2019). Water vapour in the atmosphere of the habitable-zone eight-Earth-mass planet K2-18 b. *Nature Astronomy, 3*, 1086–1091. https://doi.org/10.1038/s41550-019-0878-9

Data Sources

K2-18 b | Exo.MAST (Transit data)

VizieR (Radial Velocity data)

Thank You!

Any Questions?