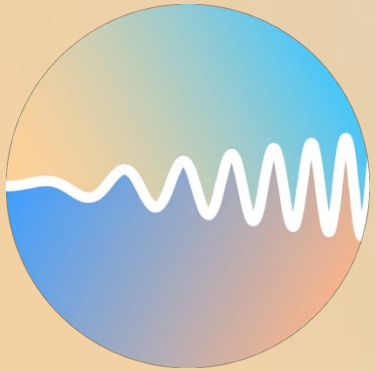

CHRONOBIOLOGY & HEALTH

TRANSLATIONAL SENSORY & CIRCADIAN NEUROSCIENCE

TUMCREATE

Open and reproducible analysis of light exposure and visual experience data

Dr. Johannes Zauner

MeLi Dos
Metrology for wearable light loggers and optical radiation dosimeters

EUROPEAN PARTNERSHIP

Co-funded by the European Union

METROLOGY PARTNERSHIP

EURAMET

Or: How to get from…

…this…

```
datetime,Temperature,Activity Index, Photopic lux,Melanopic EDI, L-Cone EDI, M-Cone EDI, S-Cone EDI, Rhodopic EDI, 380,385,390,395,400,405,410,415,420,425,430,435,440,4
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```
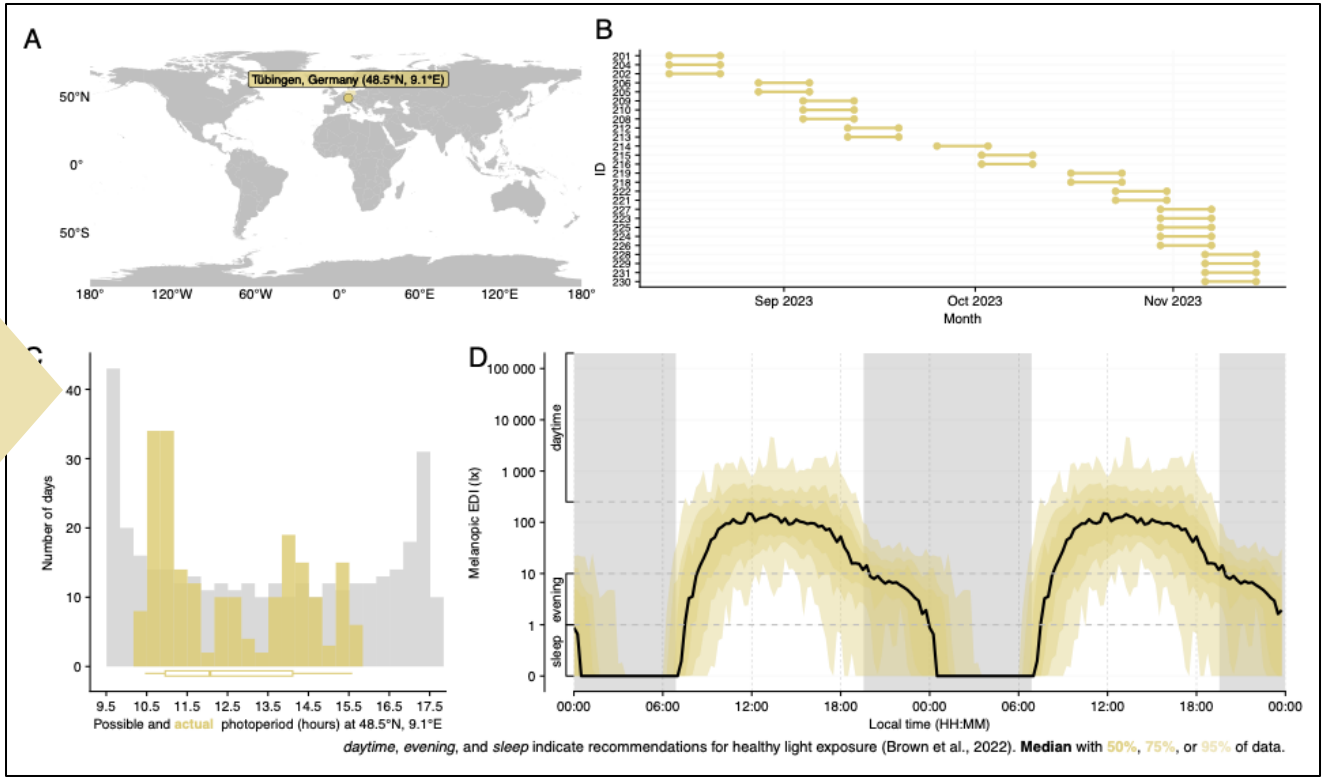

…to this



Funding Statement

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

METROLOGY PARTNERSHIP | EURAMET

The project (22NRM05 MeLiDos) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

wellcome

LightLogR's development is supported by the Wellcome Trust (www.wellcome.org), 226787/2/22/Z.

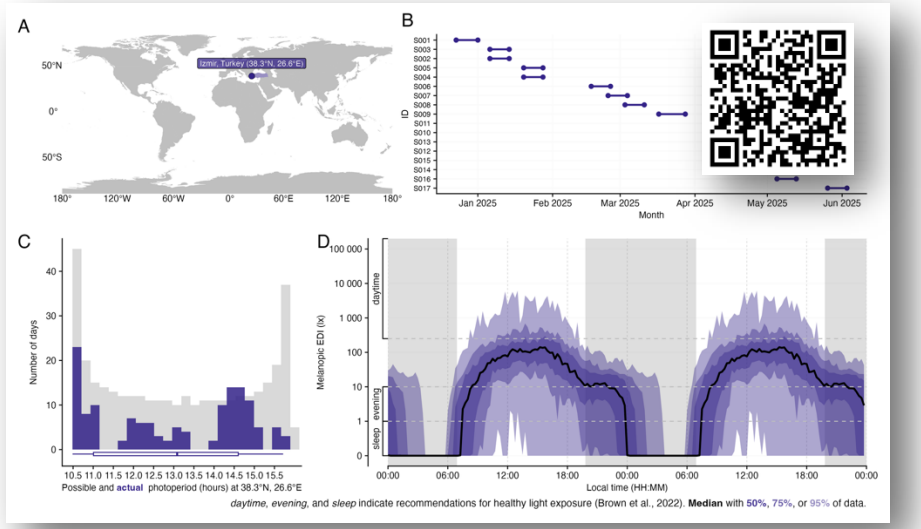
GLEE
GLOBAL LIGHT EXPOSURE ENGINE

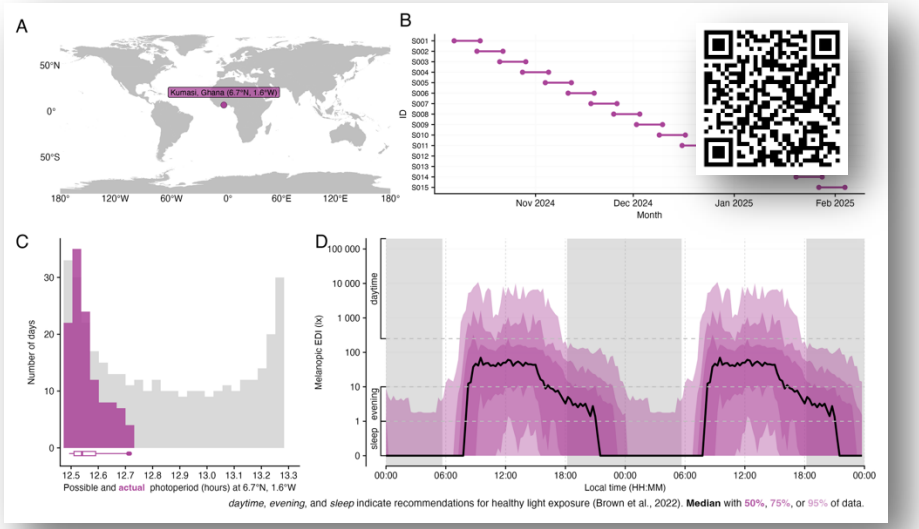
LightLogR's development is supported by the GLEE project (Global Light Exposure Engine, www.visualdiet.org) funded by Reality Labs Research.

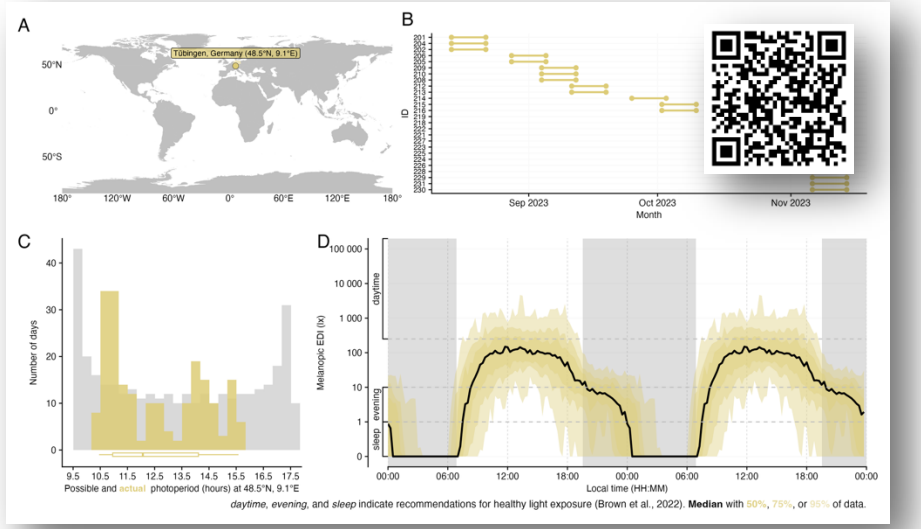
Many research questions can only be tackled if data is openly available: Share anonymous research data to create the maximum impact!

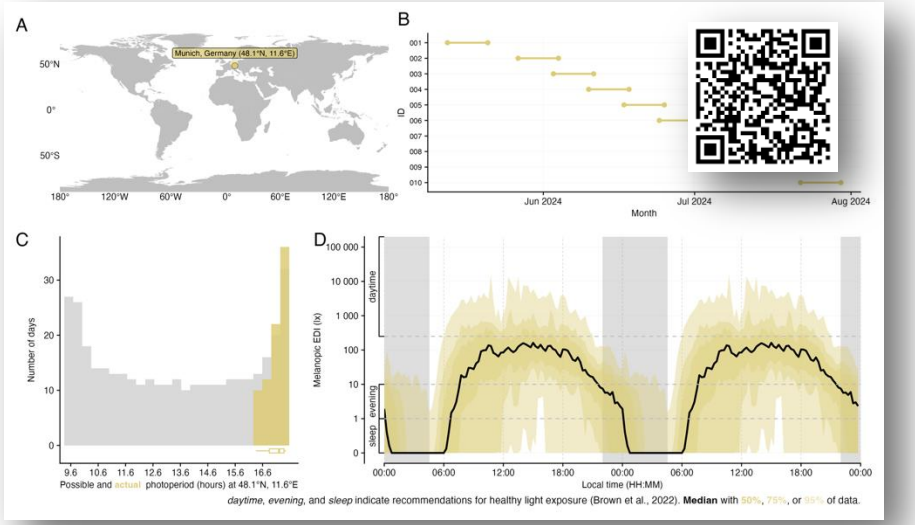
„Among articles stating that data was available upon request, only 17% shared data upon request.“

Hussey, Ian (2025)
Data is not available upon request
Meta-Psychology DOI: 10.15626/mp.2023.4008









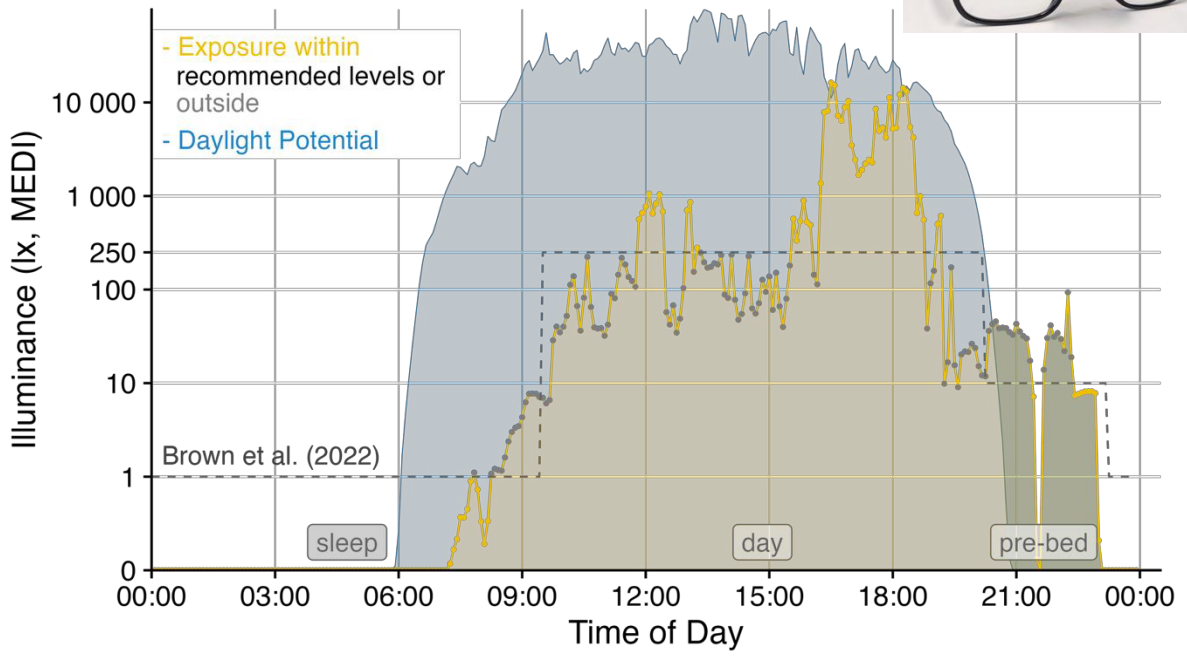
TRANSLATIONAL SENSORY & CIRCADIAN NEUROSCIENCE UNIT
TUMCREATE

Laboratory experiments with fixed light settings are great for mechanistic insights, but real-world light exposure patterns are essential going forward

Stationary measurements: ⟷ Wearable data:

α-opic equivalent daylight (D65) illuminance[3]

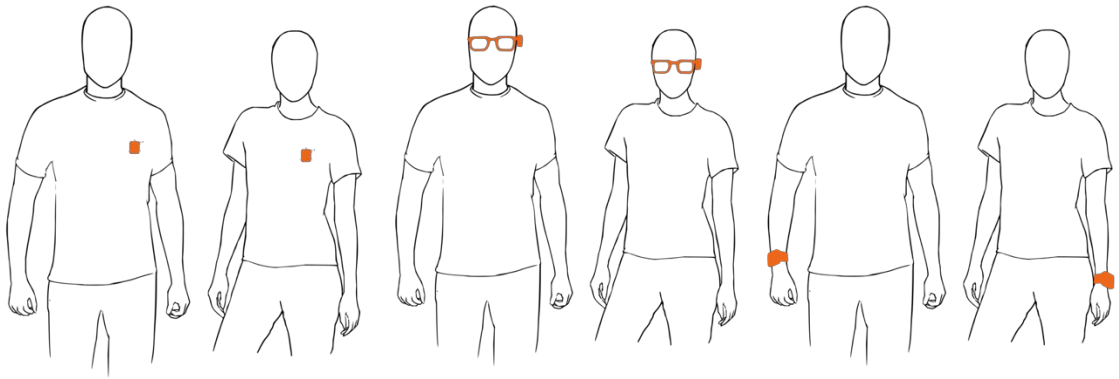
	Scene 1
Melanopsin (MEDI; lux)	241



Spot Measurements (few datapoints, per setting) ⟷ Time Series (MB/GB of data, per participant)

Wearable light logging as a methodology lacks standard approaches, thus compromising the comparability of research from different laboratories

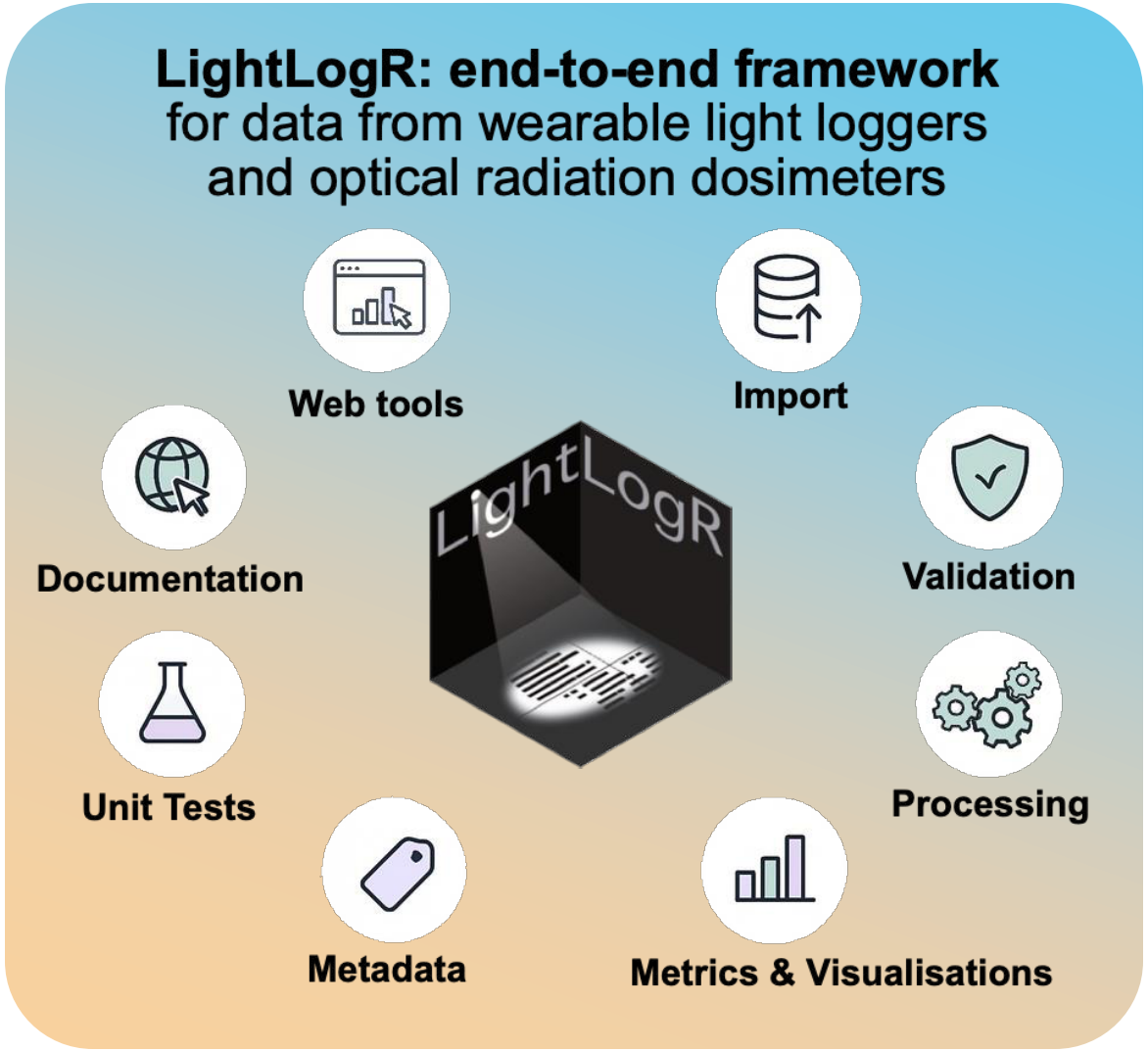
- 50+ wearable devices on the market / in scientific use
- No common set of output quantities / units
- No or very limited metadata
- No standard output format (file format)
- Time stamp / Time zone mess
- Dealing with gaps in the data
- A metaverse of metrics for light exposure



Illustrations: Max Dobberkau (MPI for Biological Cybernetics)

>> Solving these topics on a by-lab level is wasted research time!

LightLogR is a one-stop-shop for dealing with data from wearable devices




```
install.packages(„LightLogR“)  # R >= v 4.3
library(LightLogR)
```

What to keep in mind

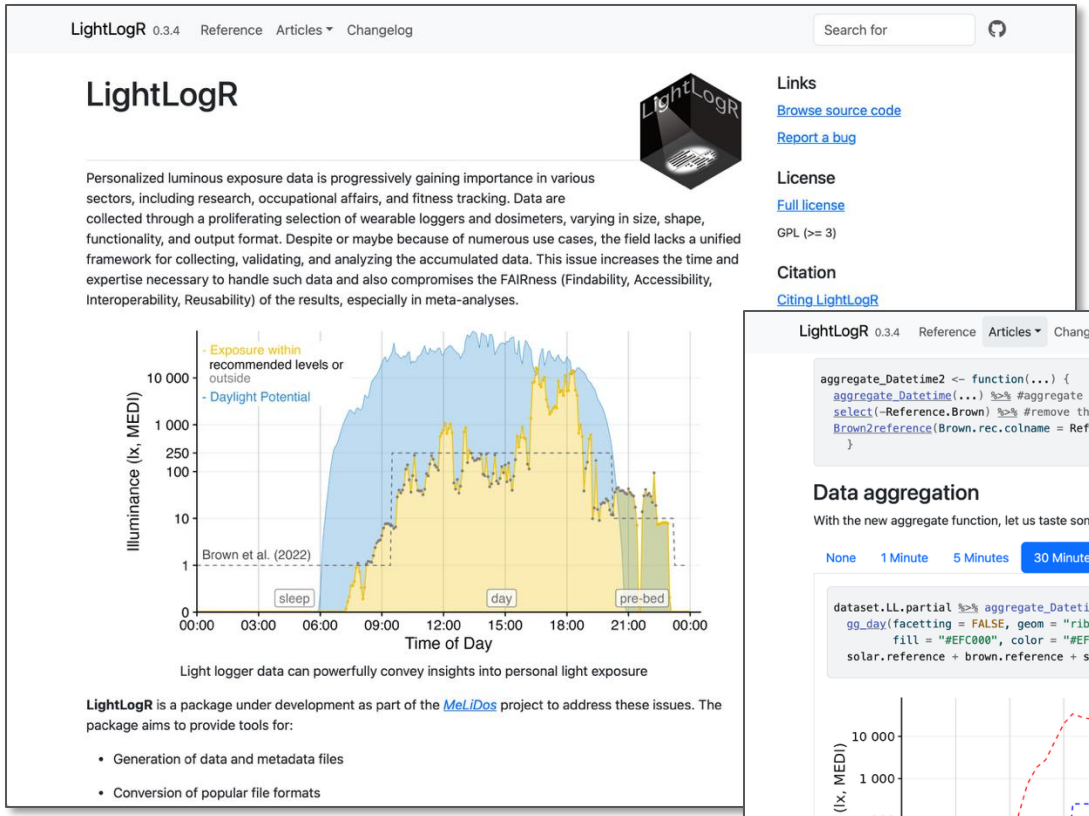
LightLogR is…

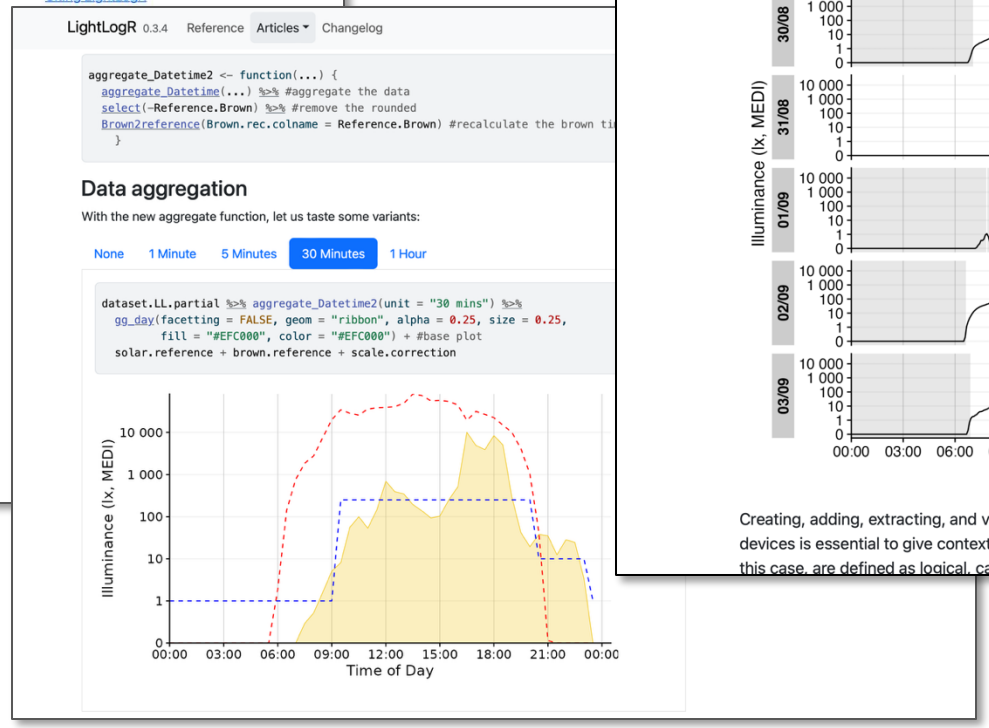
- a feature-rich analysis package for R statistical software, developed for time-series data from wearables
- a framework to prepare and transform data for formal analysis
- deterministic
- purposefully diverse about inputs and outputs (e.g., metrics)
- opinionated
- complaining whenever it can

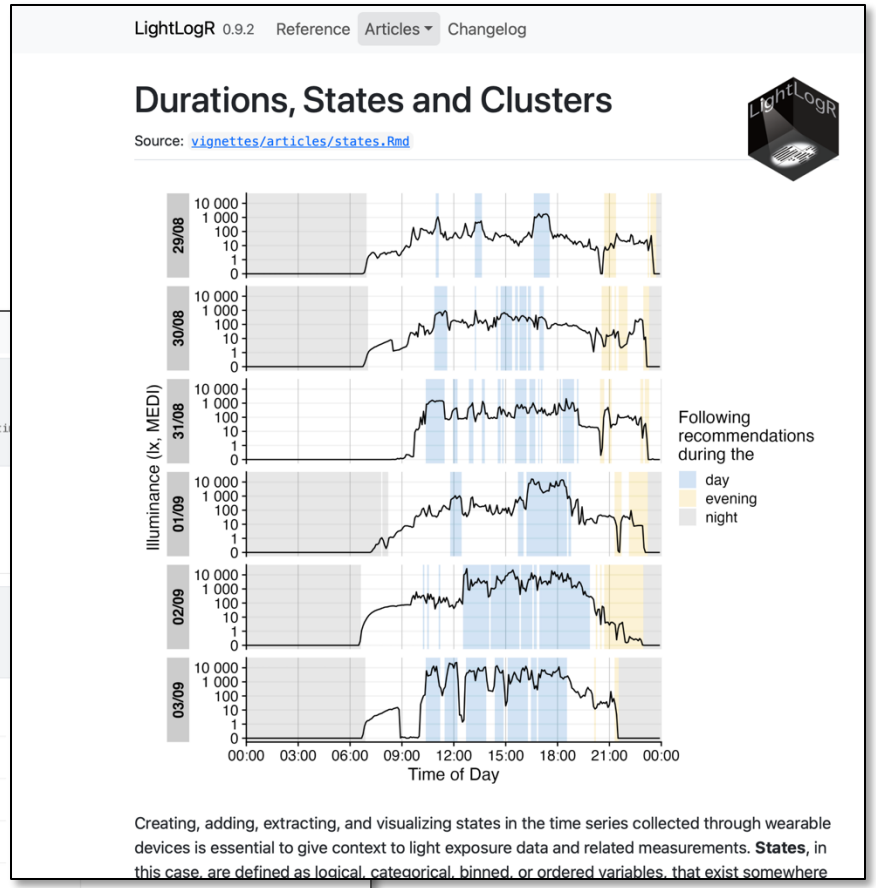
… and is <u>not</u>

- feature complete
- a statistical method for inference
- probabilistic
- a substitute to good study design and data collection (garbage in – garbage out)
- a replacement for a theoretical basis on the topics, or critical thinking
- without danger to calculate absolute nonsense
- an imputation tool to guess missing data

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

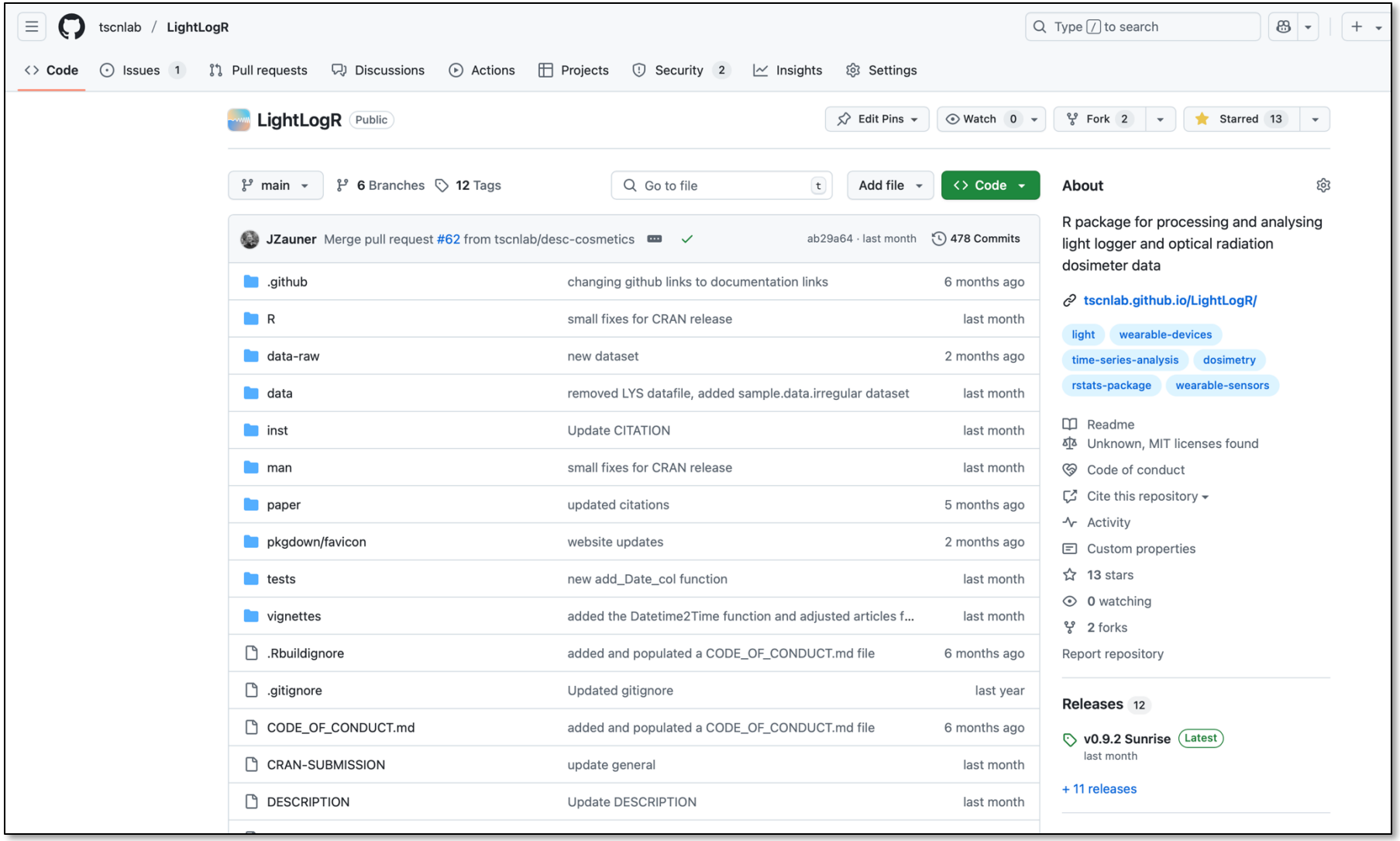






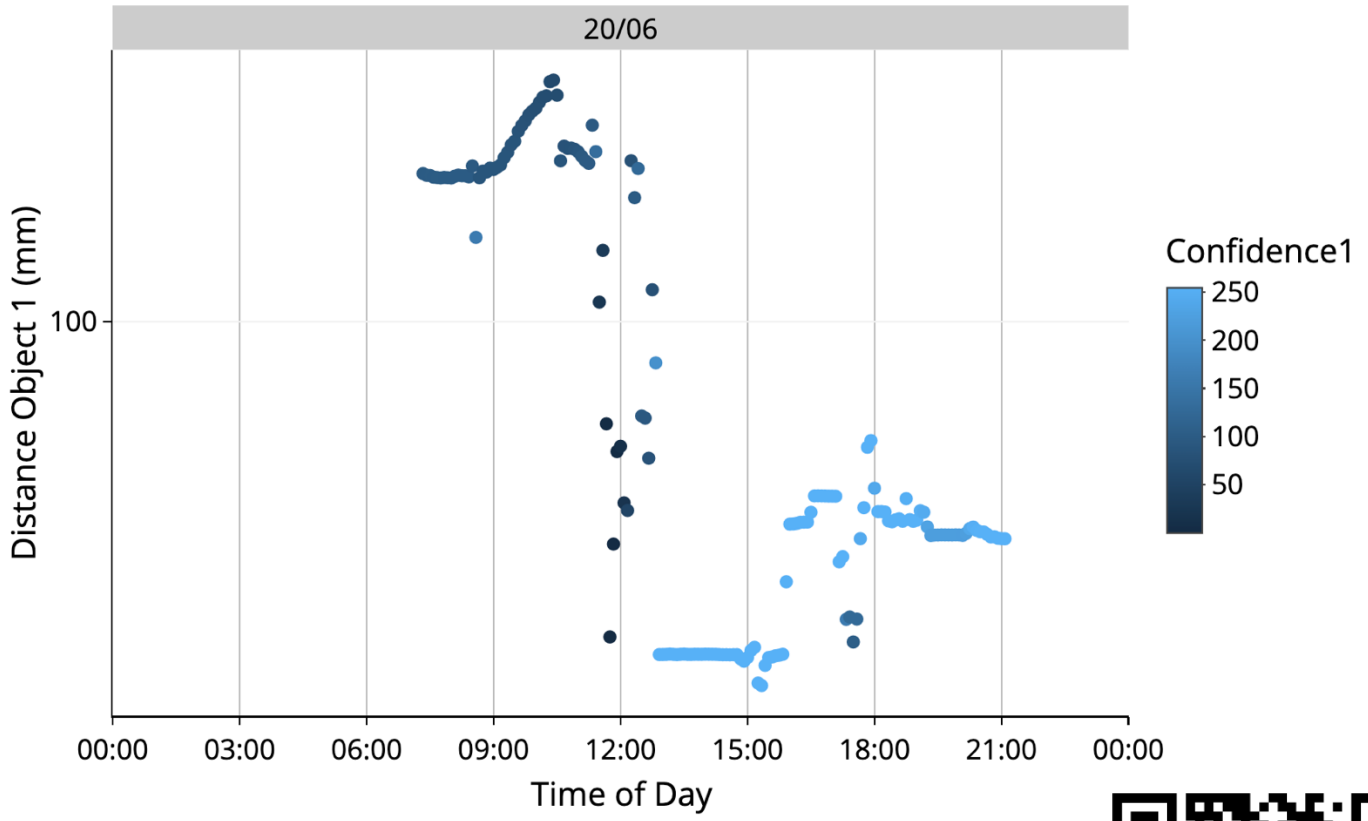
LightLogR is developed as a community-driven open-source project with a permissive license, continuous integration, and continuous deployment

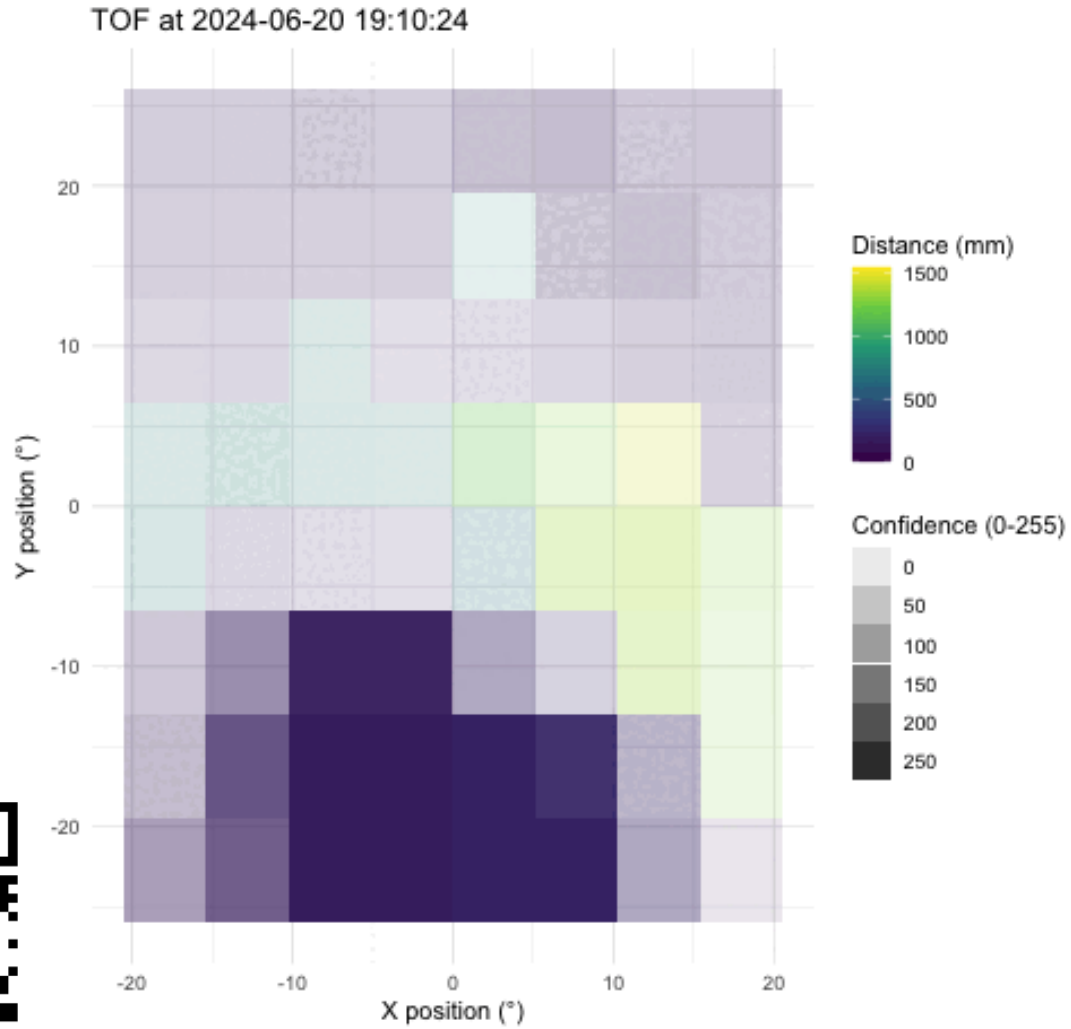
- Hosted on GitHub
- Open Source
- MIT Licence
- Inclusive development
- Issue tracking
- Continuous Integration
- **888 Unit tests** (07/2025) secure stable functionality



https://github.com/tscnlab/LightLogR

LightLogR also works with other modalities of visual experience, such as distance and spectrum





Tutorial on distance, light, and spectrum:
https://tscnlab.github.io/ZaunerEtAl_JVis_2025/

TRANSLATIONAL SENSORY & CIRCADIAN NEUROSCIENCE UNIT

LightLogR: Software for accessible and reproducible import, processing, visualization, and metrics of personal light exposure data

Johannes Zauner

Steffen Hartmeyer

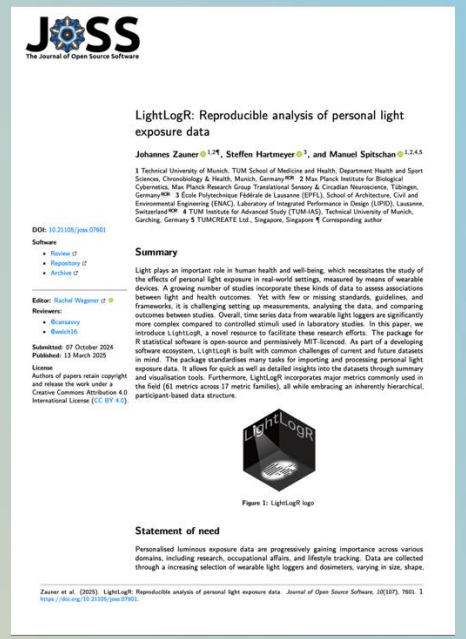
Manuel Spitschan

Join our LightLogR mailing list!
https://lists.lrz.de/mailman/listinfo/lightlogr-users

Software & Documentation

tscnlab.github.io/LightLogR/

Paper



LightLogR: Reproducible analysis of personal light exposure data

Johannes Zauner, Steffen Hartmeyer, and Manuel Spitschan

Summary

Statement of need

DOI: 10.21105/joss.07601

johannes.zauner@tum.de

JZauner

You can live-test **LightLogR** on this page

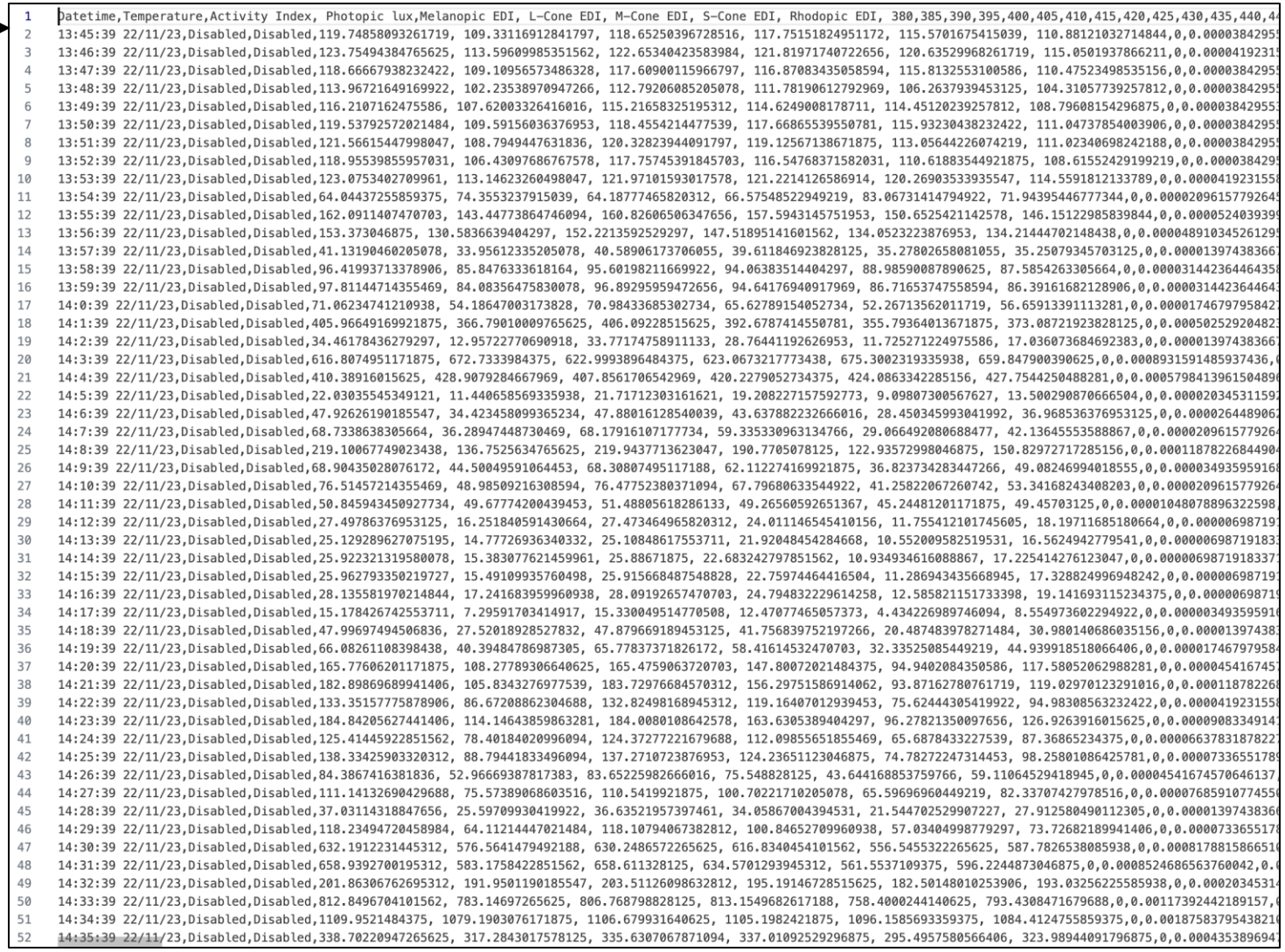
https://tscnlab.github.io/LightLogR_webinar/

Some function showcases

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

At present, these are the devices we support in LightLogR:

- Actiwatch Spectrum
- ActLumus
- ActTrust
- Circadian Eye
- Clouclip
- DeLux
- GENEActiv with GGIR
- Kronowise
- LiDo
- LightWatcher
- LIMO
- LYS
- MotionWatch8
- nanoLambda
- OcuWEAR
- Speccy
- SpectraWear
- VEET



TRANSLATIONAL SENSORY & CIRCADIAN NEUROSCIENCE UNIT

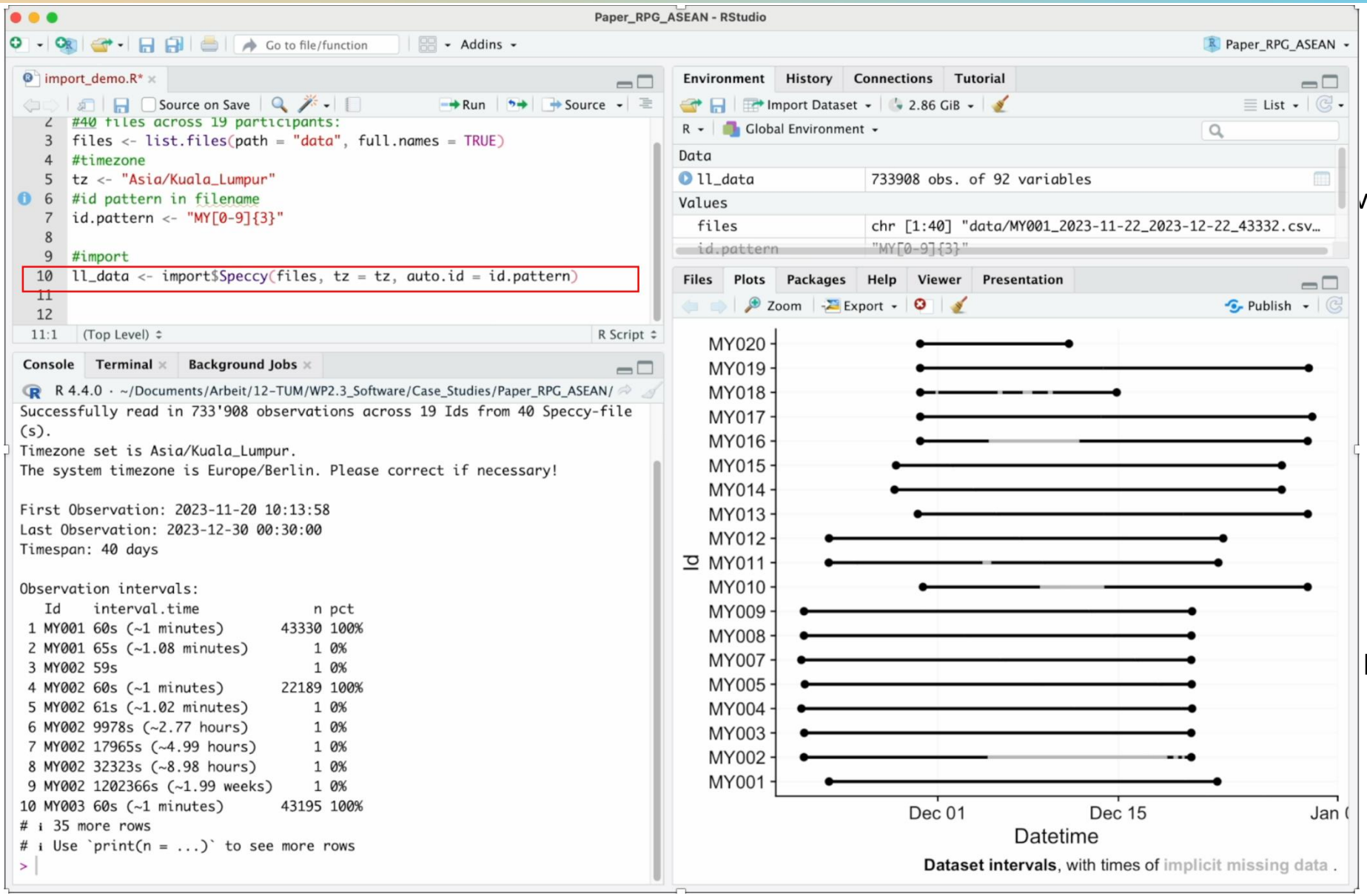
LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

script

variables

console

plots

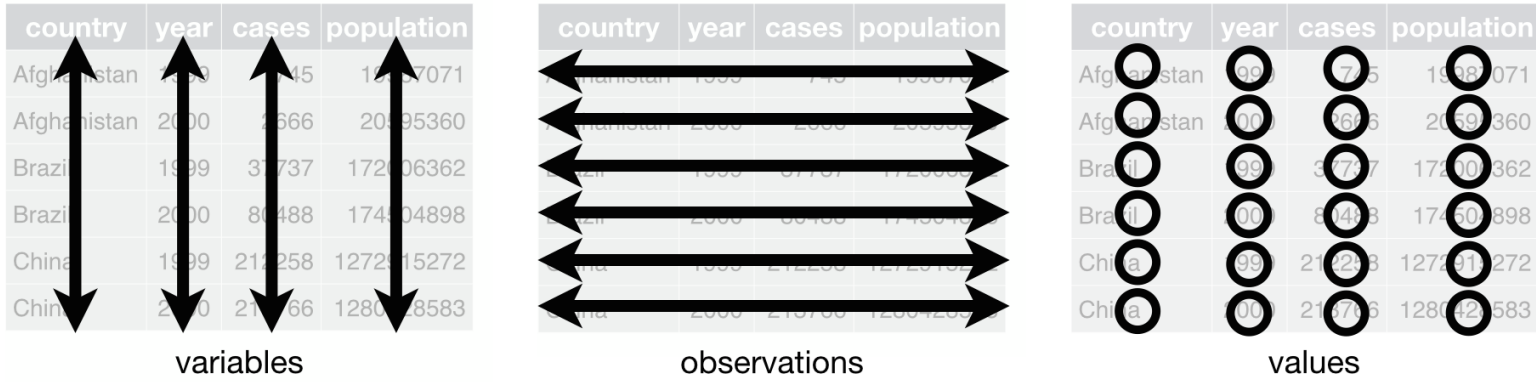


LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> has_gaps()          # shows whether the dataset has gaps
```

```
has_gaps(data) # equal to above
```

Source: https://r4ds.hadley.nz/data-tidy.html




```
fun3(fun2(fun1(data)))  # equal to below
```

```
data |> fun1() |> fun2() |> fun3()  # %>% is another type of pipe
```

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> has_gaps()          # shows whether the dataset has gaps
```

```
data |> has_irregulars()    # shows whether the dataset has irregular intervals
```

```
data |> gap_finder()        # finds and extracts gaps
```

```
data |> gap_table(MEDI)     # summarizes the dataset per group and overall
```

Summary of available and missing data

Variable: melanopic EDI

	Data					Missing							
	Regular		Irregular	Range	Interval	Gaps				Implicit		Explicit	
	Time	%	n[1,2]	Time	Time	N	ø	Time	%	Time	%	Time	%
Overall	13w 4d 23h 6m 50s	94.0%[3]	0	14w 4d 2h	10	5,900	25m 23s	6d 2h 53m 10s	6.0%[3]	6d 2h 53m 10s	6.0%[3]	0s	0.0%[3]
201	5d 2h 50m 30s	85.3%	0	6d	10s	605	2m 6s	21h 9m 30s	14.7%	21h 9m 30s	14.7%	0s	0.0%
202	5d 21h 19m 40s	98.1%	0	6d	10s	97	1m 39s	2h 40m 20s	1.9%	2h 40m 20s	1.9%	0s	0.0%
204	5d 4h 20m 40s	86.4%	0	6d	10s	605	1m 57s	19h 39m 20s	13.6%	19h 39m 20s	13.6%	0s	0.0%
205	5d 8h 8m	89.0%	0	6d	10s	495	1m 55s	15h 52m	11.0%	15h 52m	11.0%	0s	0.0%

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

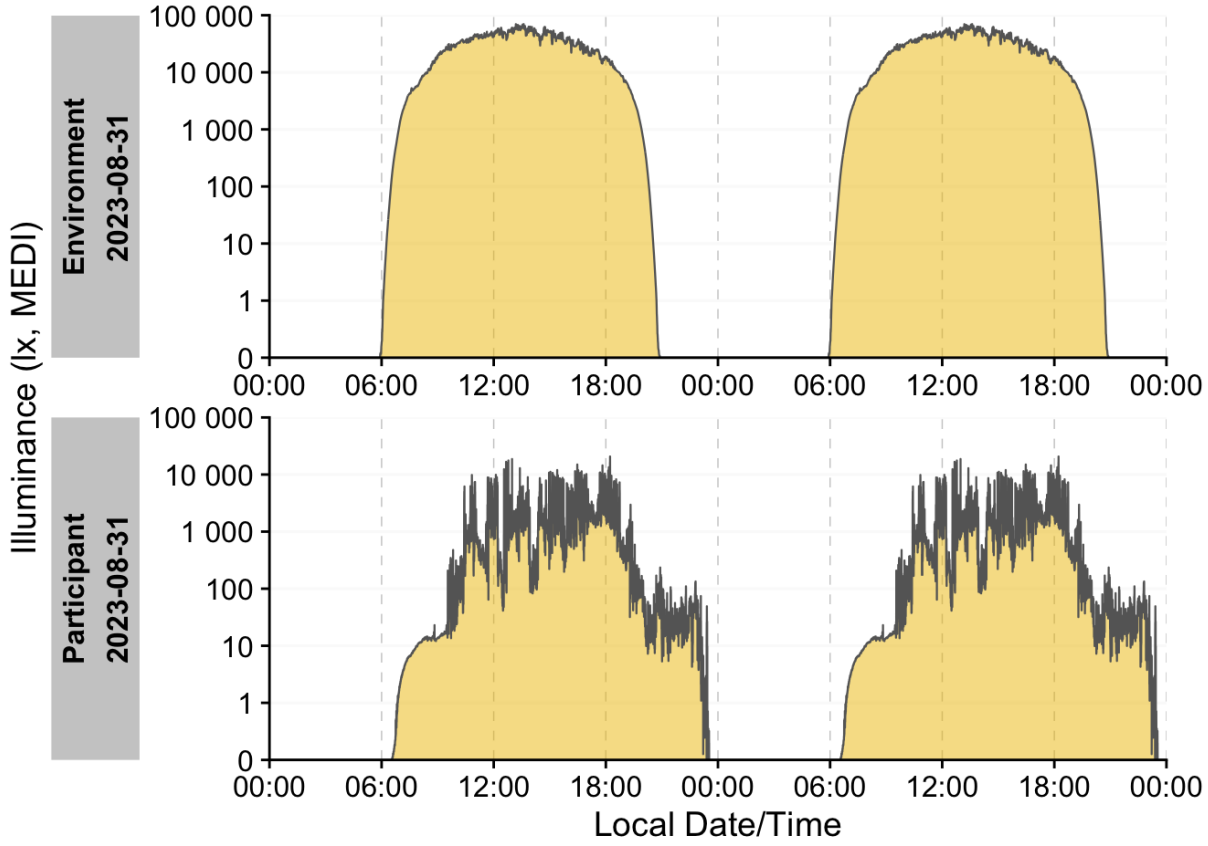
```
data |> gap_handler()          # makes gaps explicit (i.e., into “empty“ observations)
```

```
data |> aggregate_Datetime()   # condense observation intervals into new bins
```

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

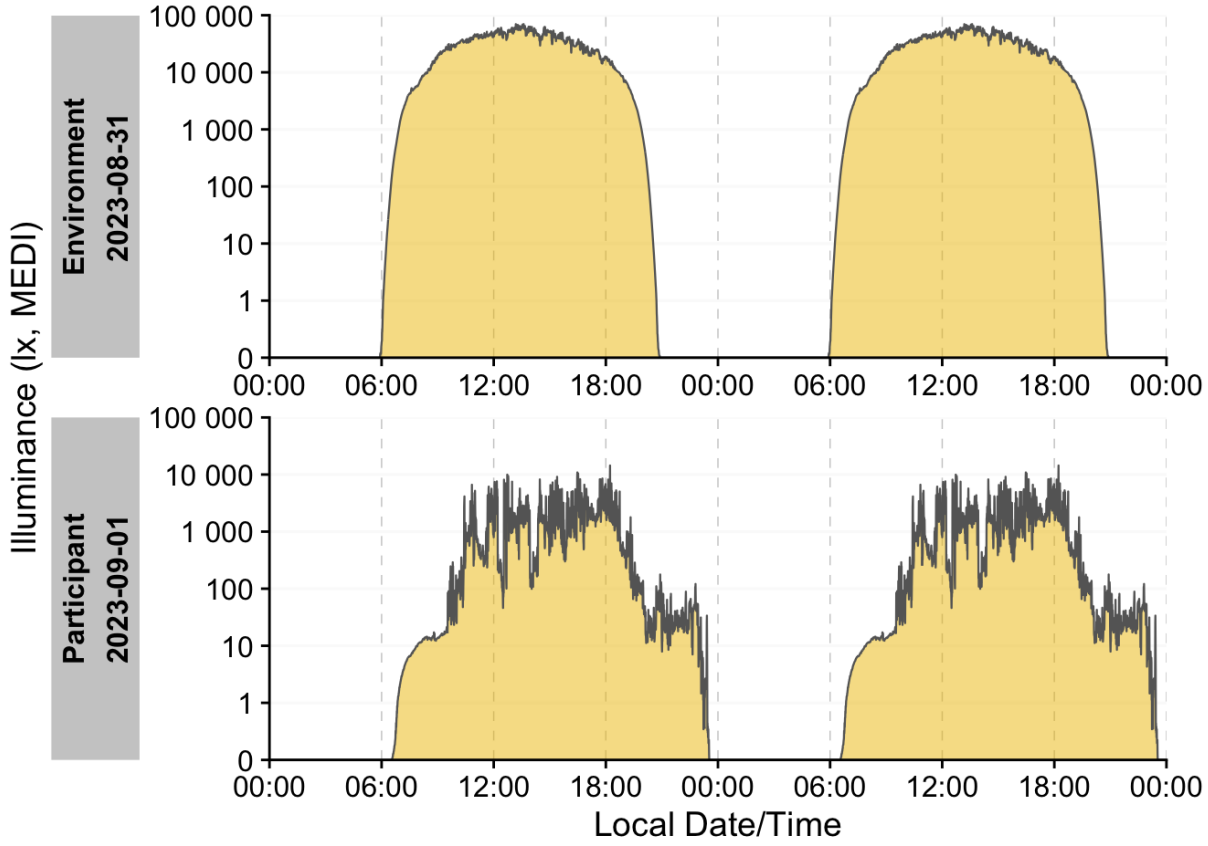
```
data |> aggregate_Datetime(“10 sec“) |>… # condense observation intervals into new bins
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

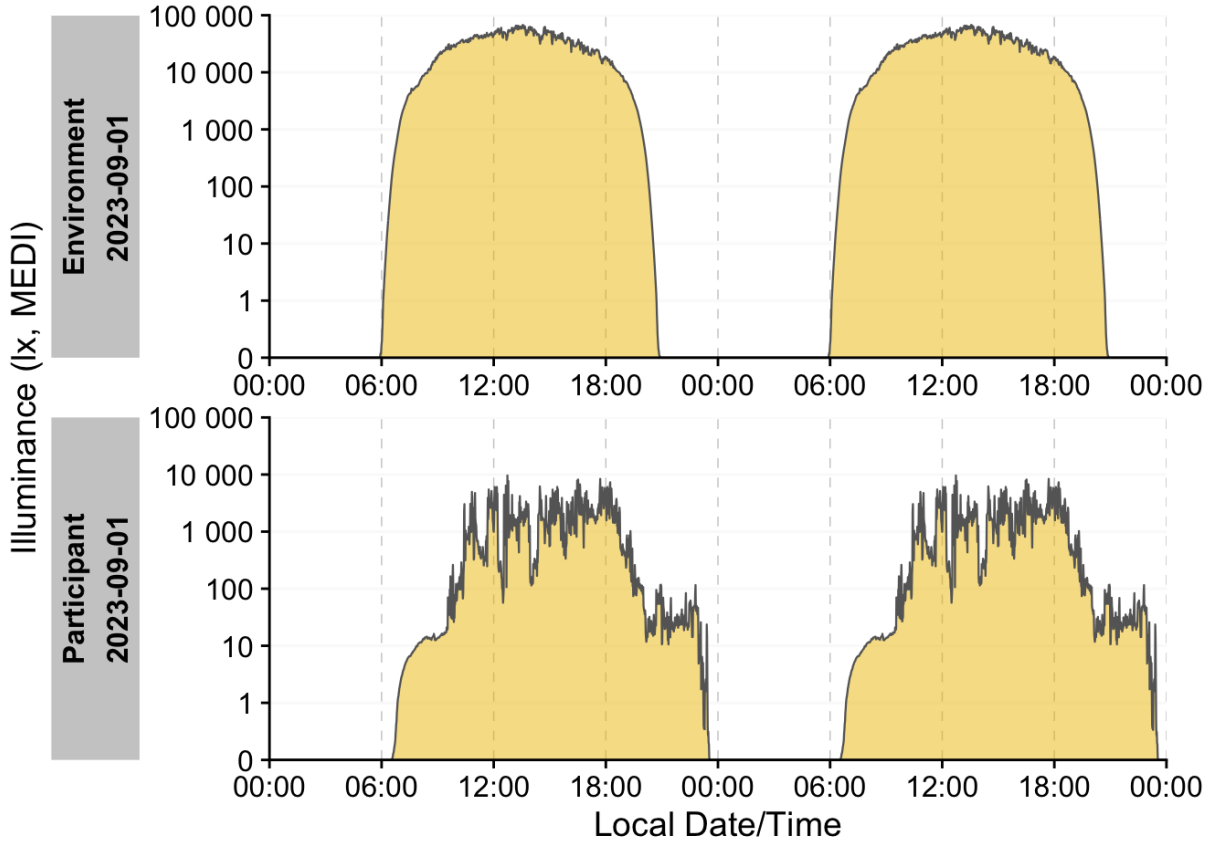
```
data |> aggregate_Datetime(“30 sec“) |>… # condense observation intervals into new bins
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

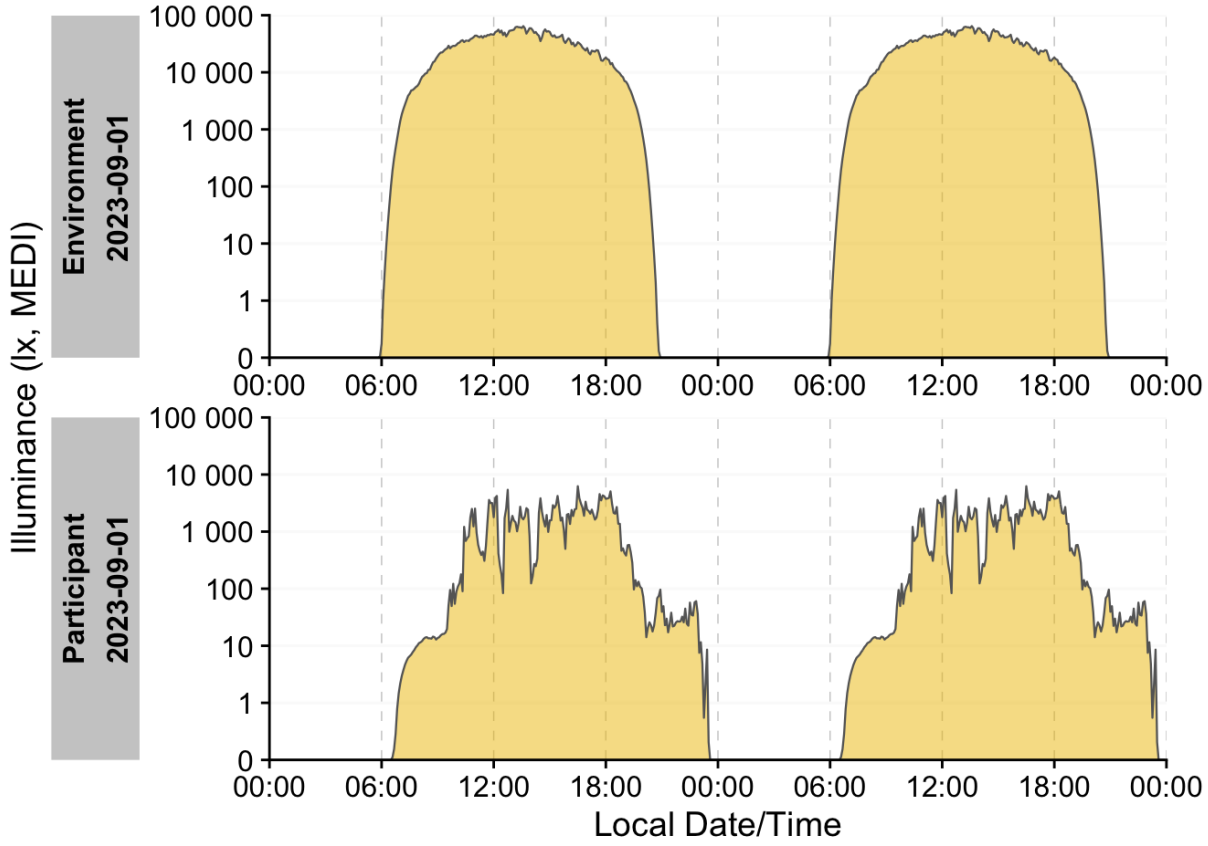
```
data |> aggregate_Datetime(“1 min“) |>…  # condense observation intervals into new bins
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

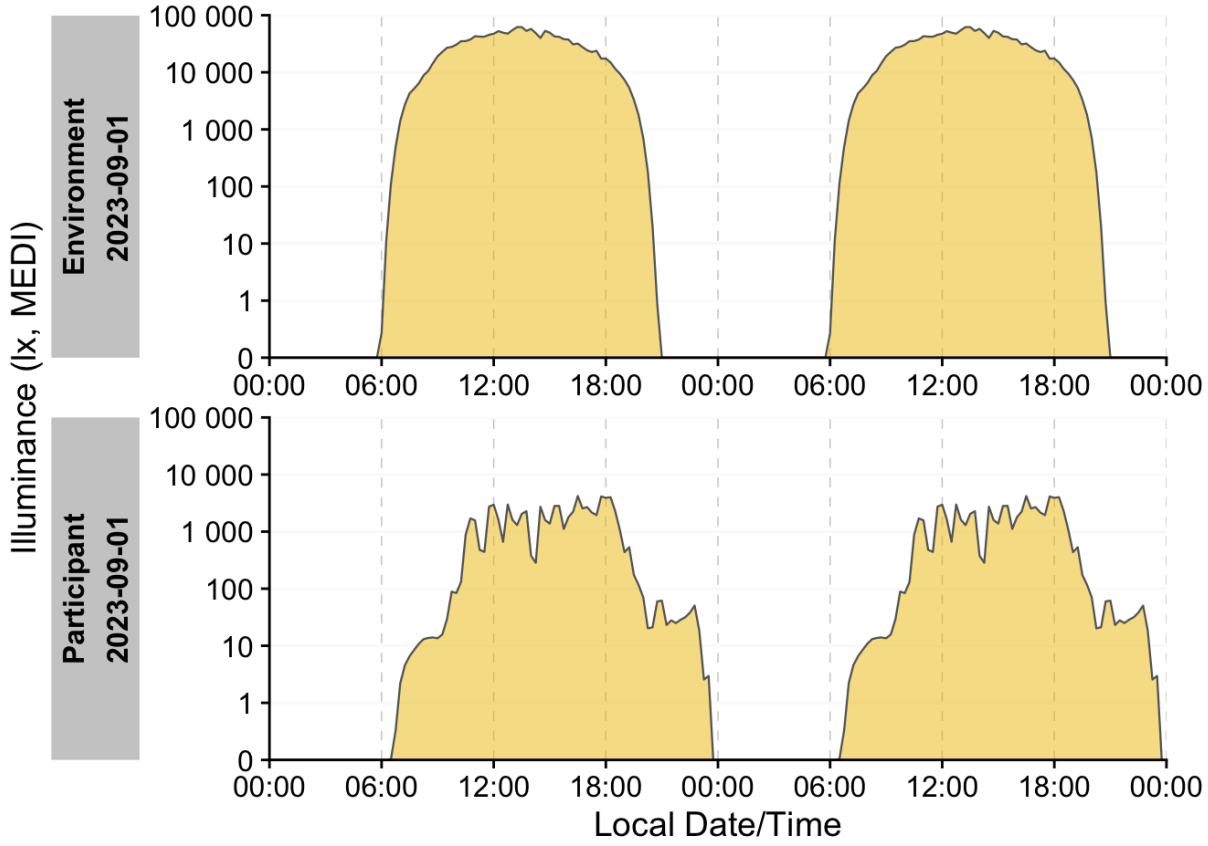
```
data |> aggregate_Datetime(“5 mins“) |>… # condense observation intervals into new bins
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

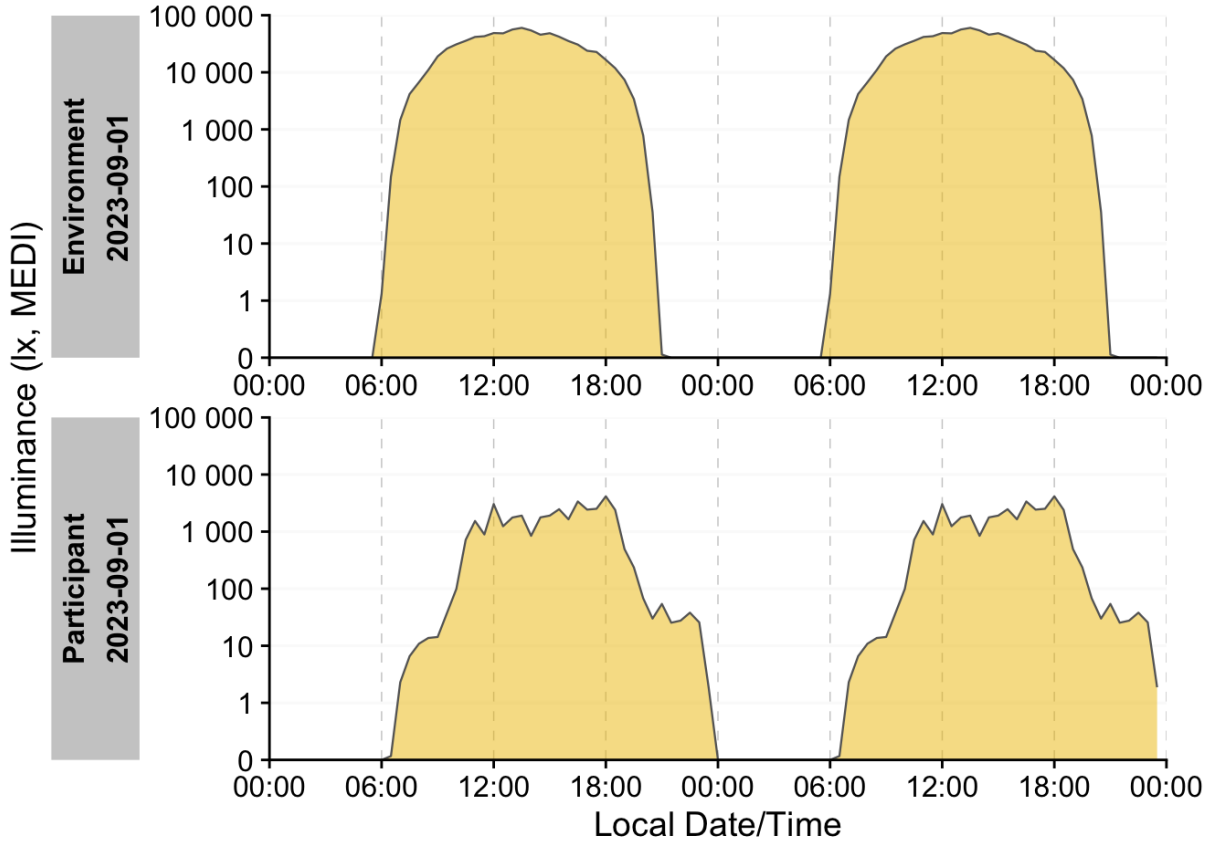
```
data |> aggregate_Datetime(“15 mins“) |>…# condense observation intervals into new bins
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

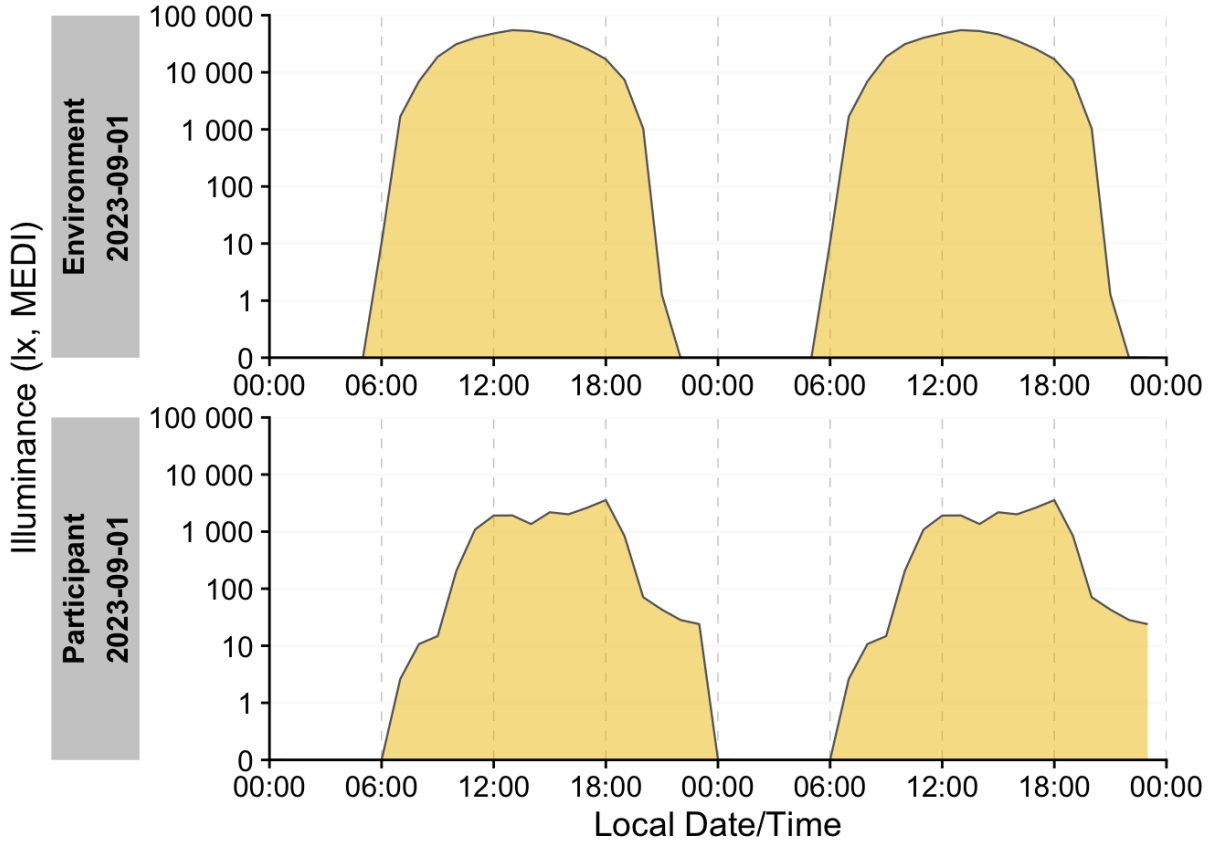
```
data |> aggregate_Datetime(“30 mins“) |>…# condense observation intervals into new bins
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

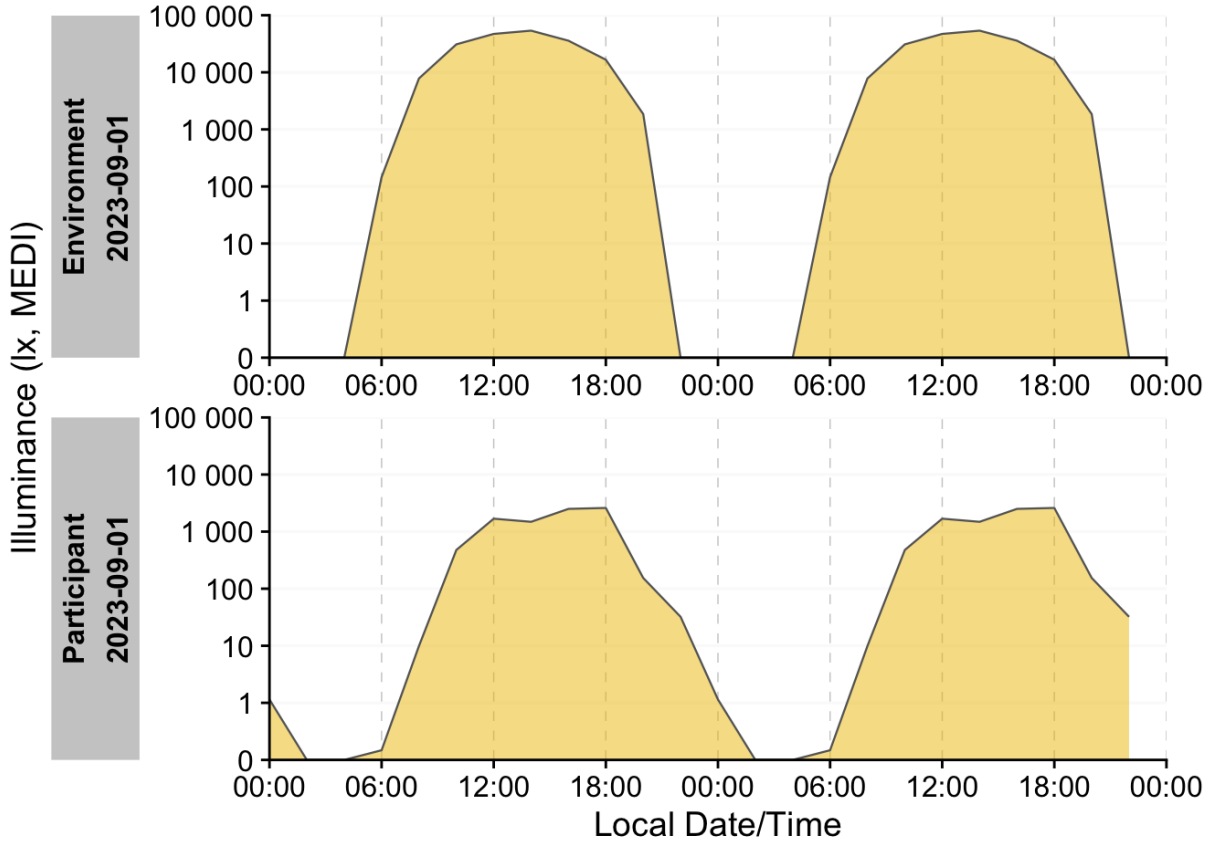
```
data |> aggregate_Datetime(“1 hour“) |>… # condense observation intervals into new bins
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

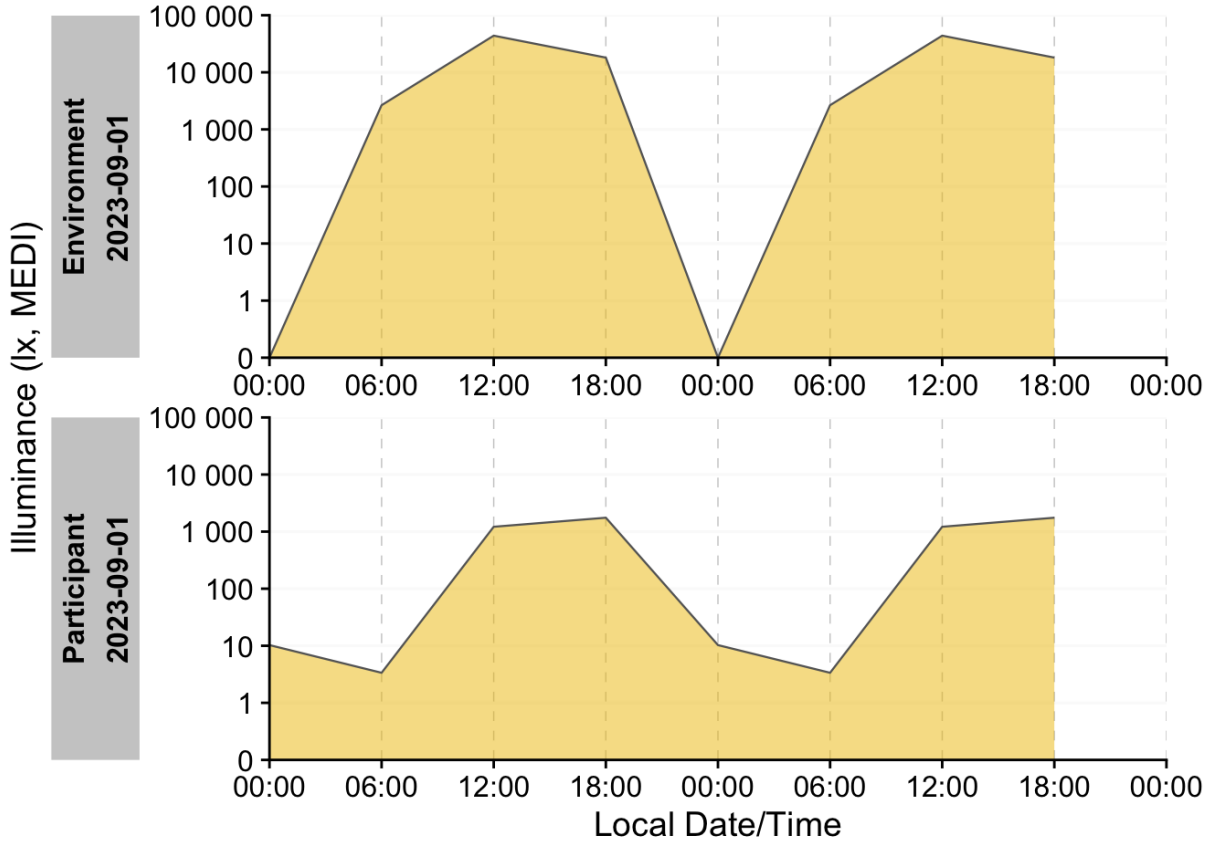
```
data |> aggregate_Datetime(“2 hours“) |>…# condense observation intervals into new bins
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

```
data |> aggregate_Datetime(“6 hours“) |>…# condense observation intervals into new bins
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

```
data |> aggregate_Datetime()             # condense observation intervals into new bins
```

```
data |> add_clusters() / extract_clusters()# find conditions that occur for a set duration
```

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gap_handler()                    # makes gaps explicit (i.e., into “empty“ observations)
```

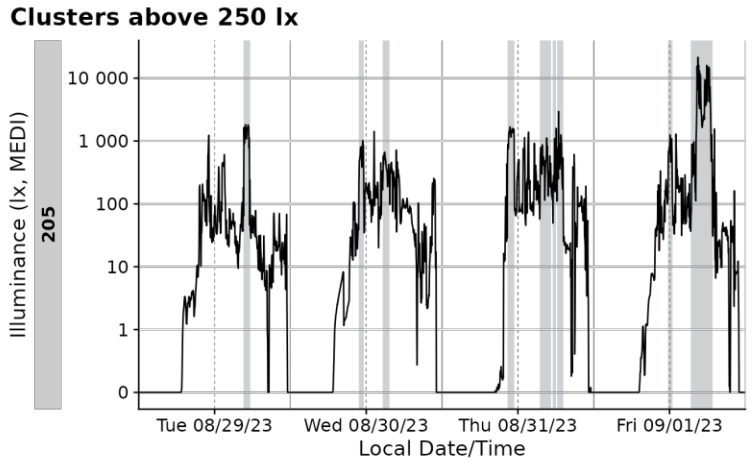
```
data |> aggregate_Datetime()             # condense observation intervals into new bins
```

```
data |>                                  # find conditions that occur for a set duration
  add_clusters(
    MEDI > 250,
    cluster.duration = „30 mins“, duration.type = „min“,
    interruption.duration = „3 mins“, interruption.type = „max“) |> …
```

Clusters of 30 minutes or more above 250 lx

with interruptions of up to 3 minutes

Id	mean_start	mean_end	mean_epoch	mean_duration	total_duration	episodes
205	14:01:48	15:26:23	10s	5074s (~1.41 hours)	96410s (~1.12 days)	19

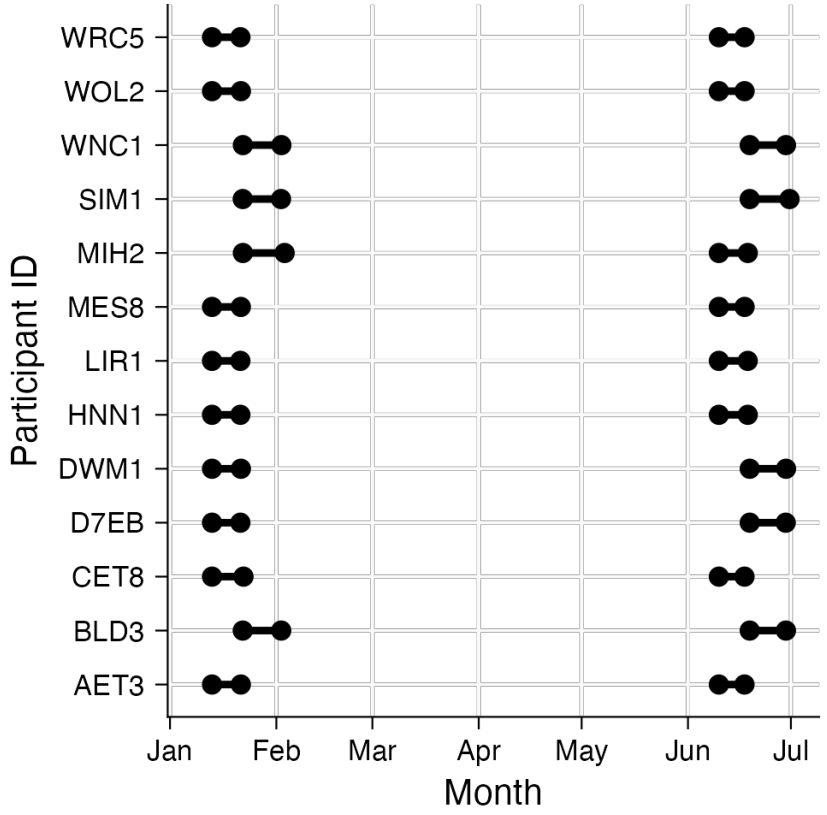


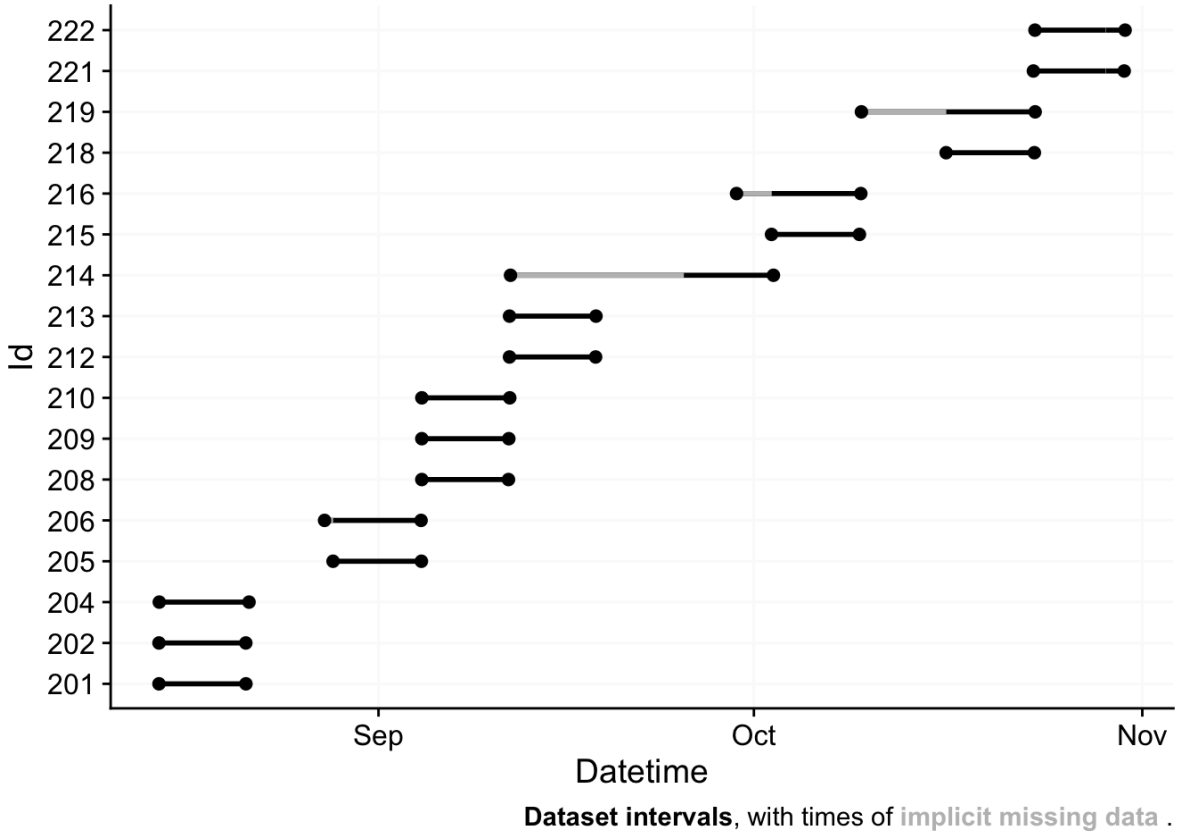
LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> aggregate_Date()                    # condense groups into one day (e.g., average)
data |> remove_partial_data()               # remove groups with too litle data
data |> filter_Datetime() / _Date() / _Time() # trim data based on times or durations
data |> dst_change_handler()                # deal with daylight savings, if the device doesn‘t
data |> add_Date_col() / _Time_col()        # convenience functions for grouping
data |> add_photoperiod(coordinates = c(lat, long))  # add photoperiod information
data |> Brown_rec() / _check() / _cut()     # work with Brown et al. 2022 recommendations
```

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gg_overview()
```

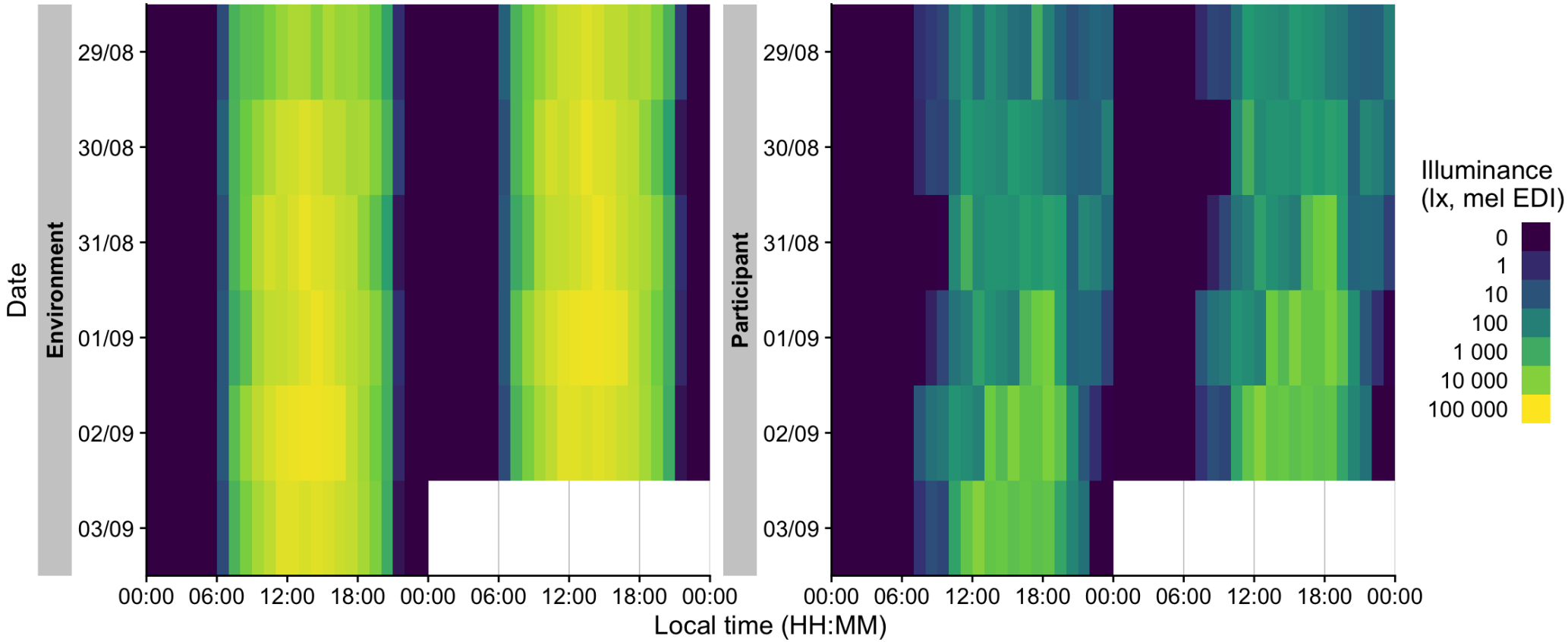




LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

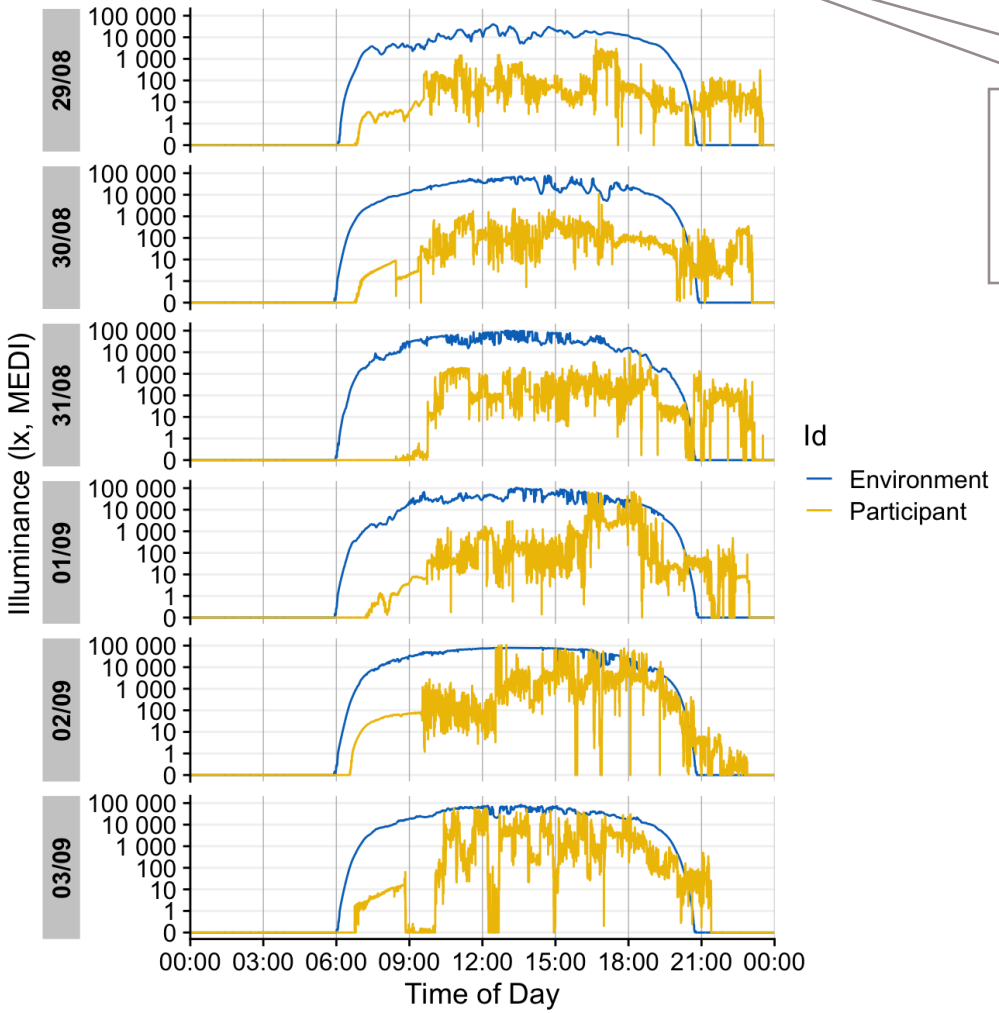
```
data |> gg_heatmap(doubleplot = „next“)
```

Shows the next day to visualize patterns across midnight



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

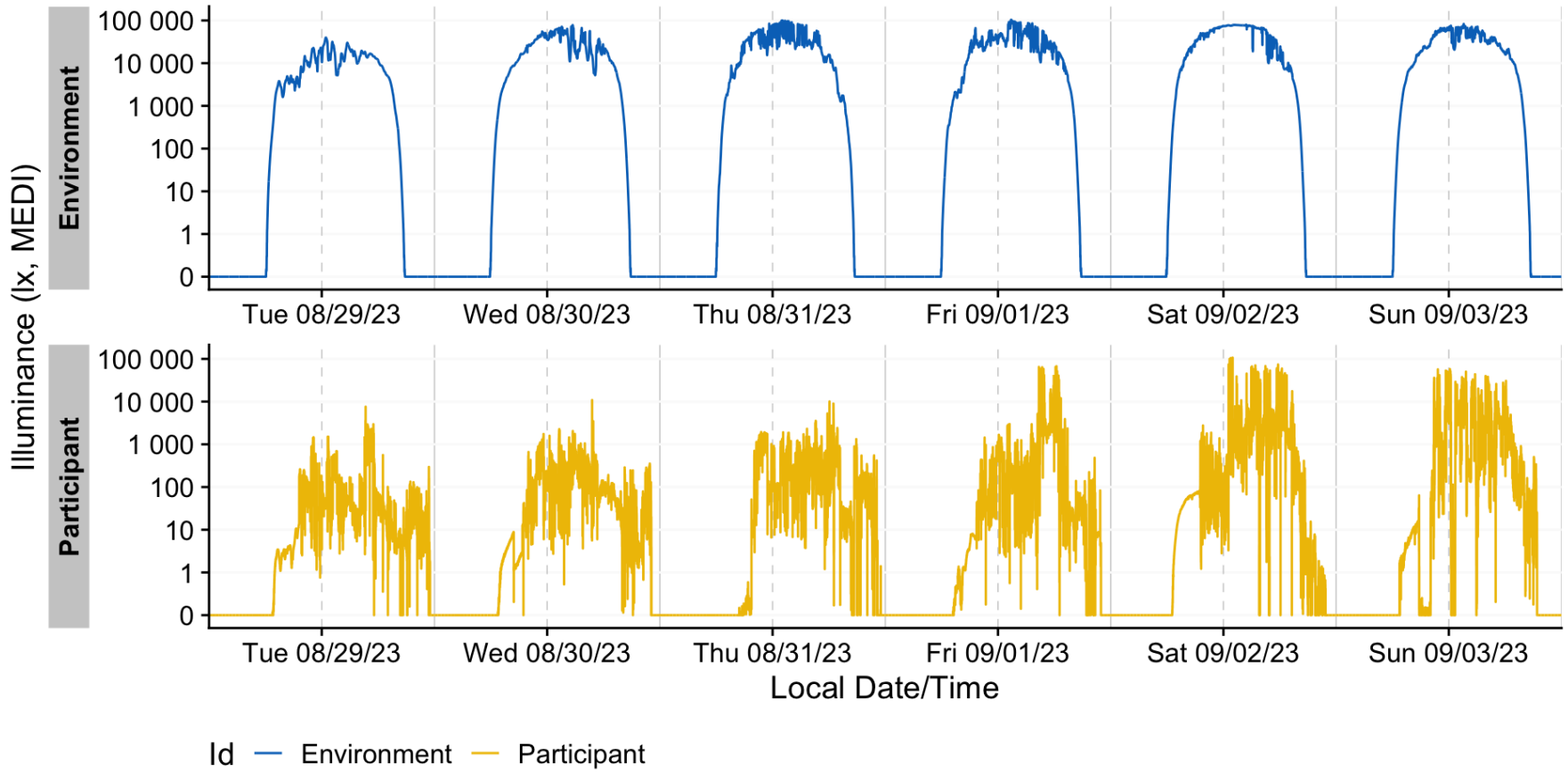
```
data |> gg_day(aes_col = Id)
```



Sets individual colors for every Id

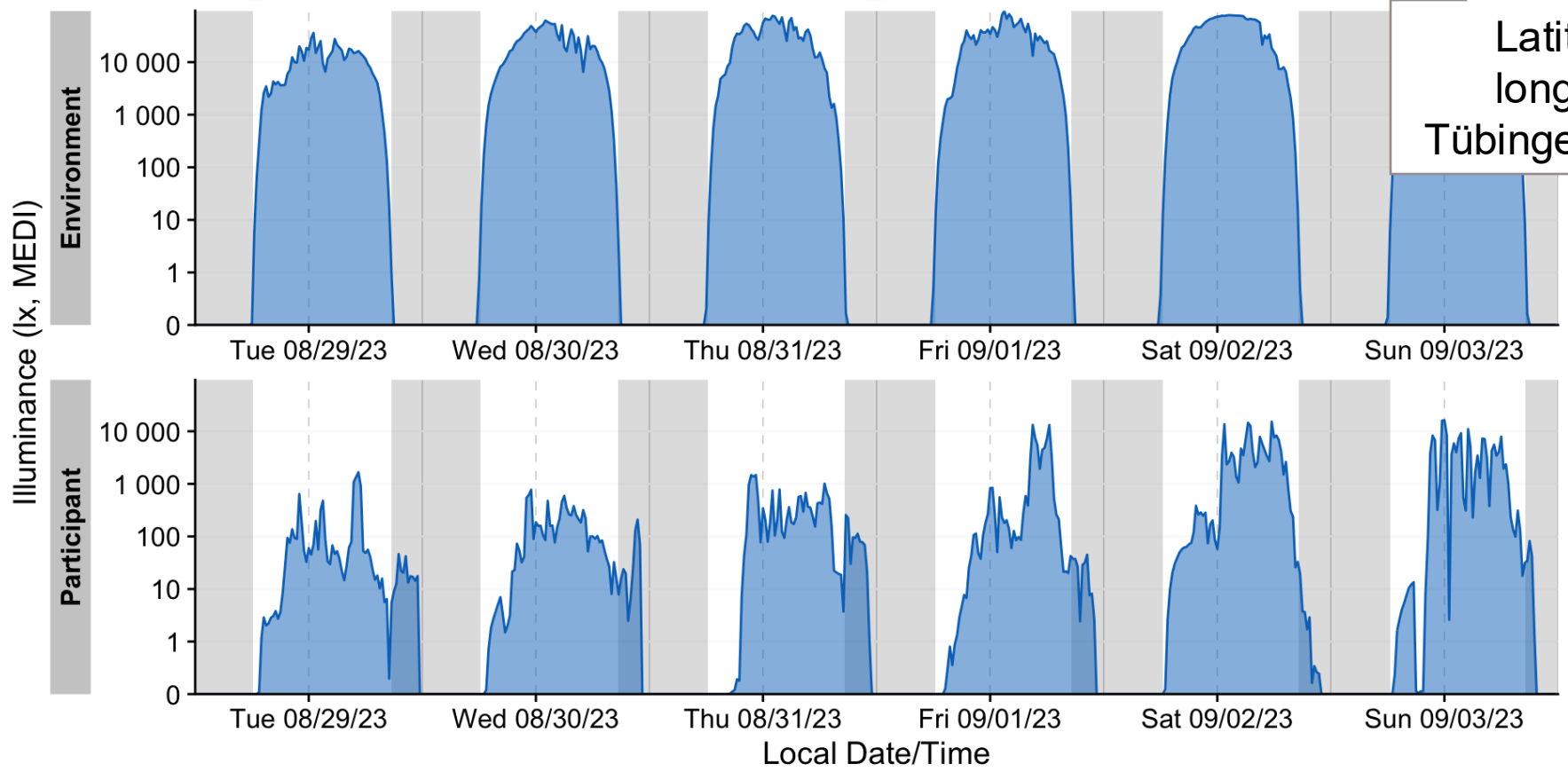
LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gg_days(aes_col = Id)
```



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> gg_days(…) |> gg_photoperiod(coordinates = c(47.5, 9.5))
```

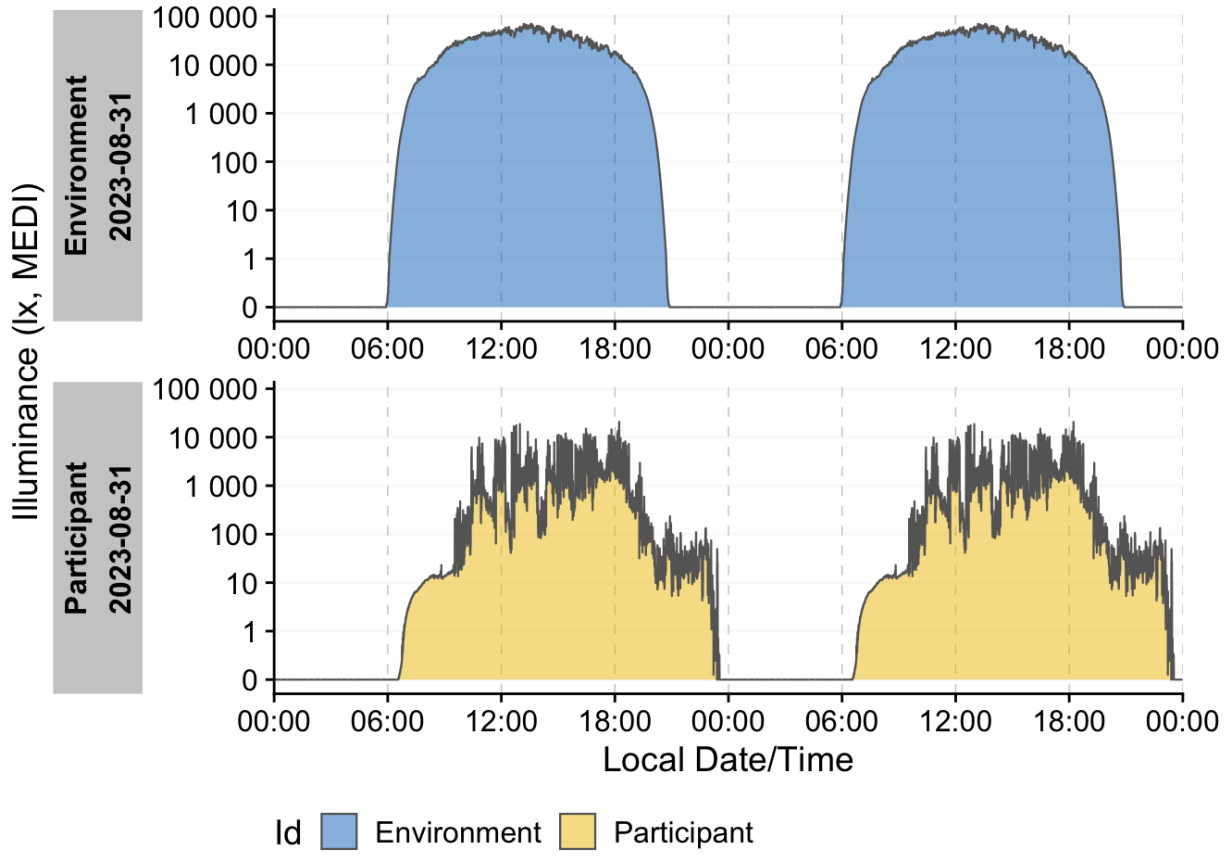


Latitude and longitude for Tübingen, Germany

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> aggregate_Date() |> gg_doubleplot(aes_fill = Id)
```

Condenses data into a single day per group

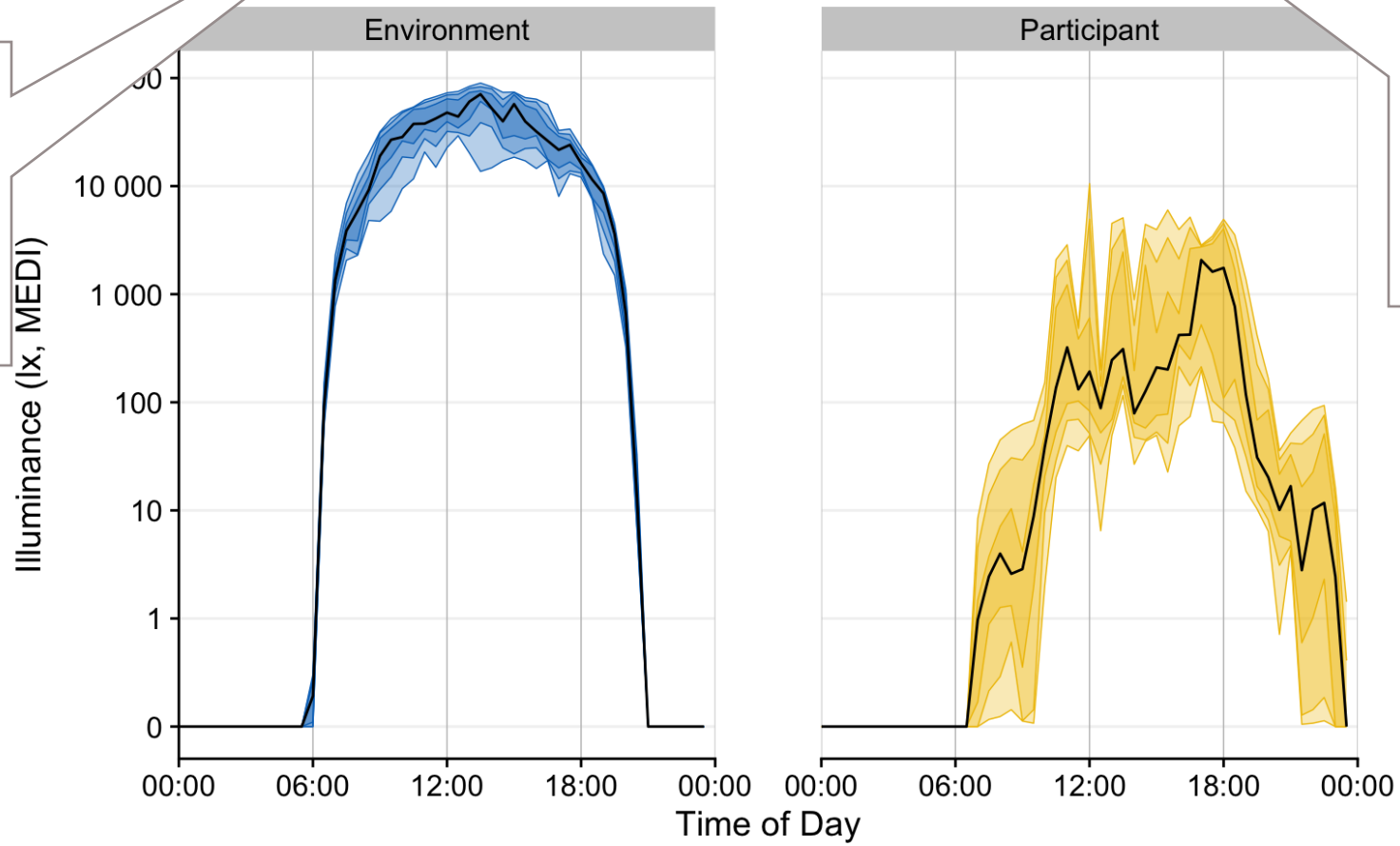


LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> aggregate_Date(…) |> gg_day(…) + geom_ribbon(…)
```

Can calculate any metric for the day. Here: upper + lower bands for 95%, 75%, and 50% of data

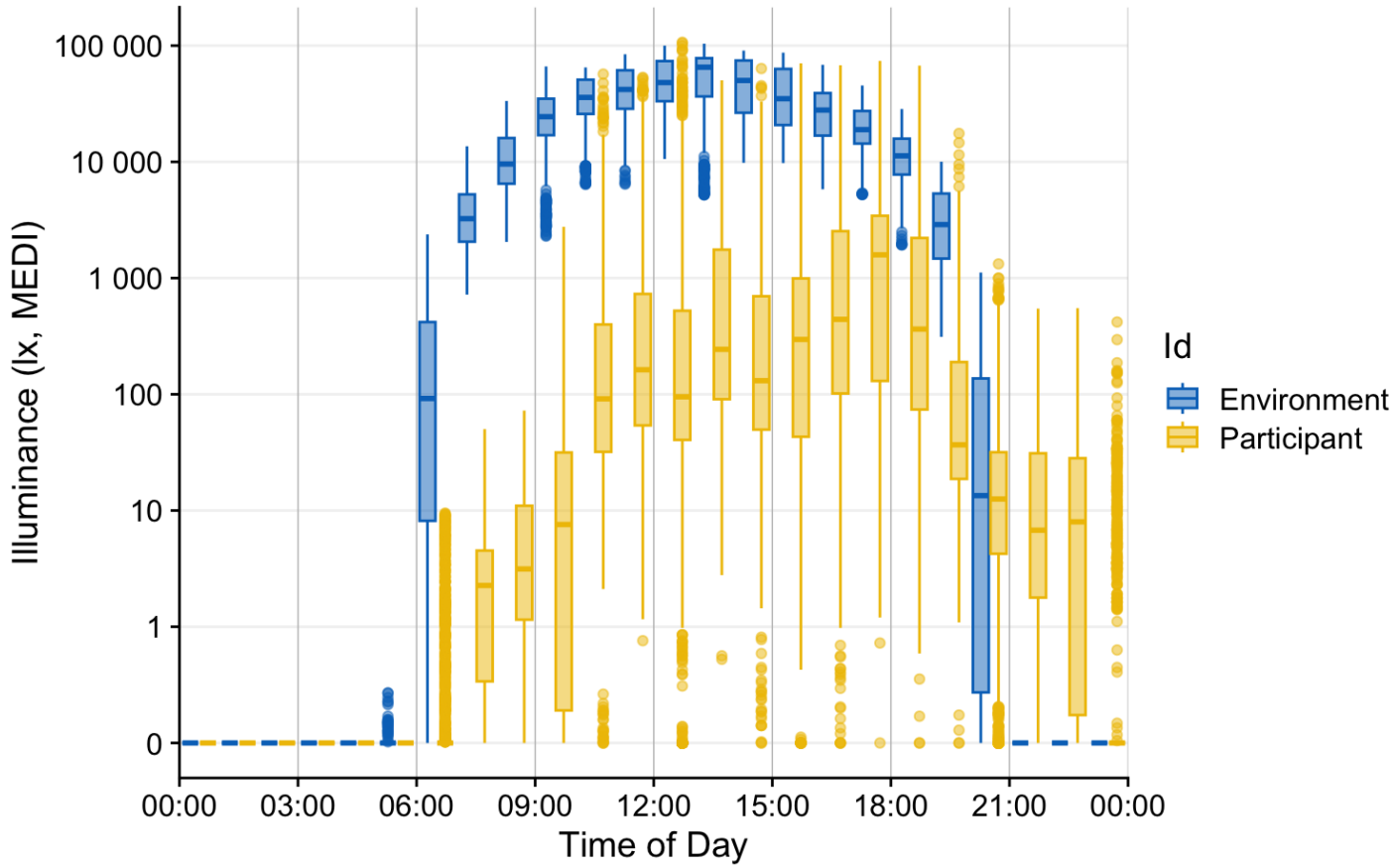
Not a LightLogR function = not a problem -> Interfaces nicely with standard plot library



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> cut_Datetime(unit = „1 hour“) |> gg_day(geom = „boxplot“, …)
```

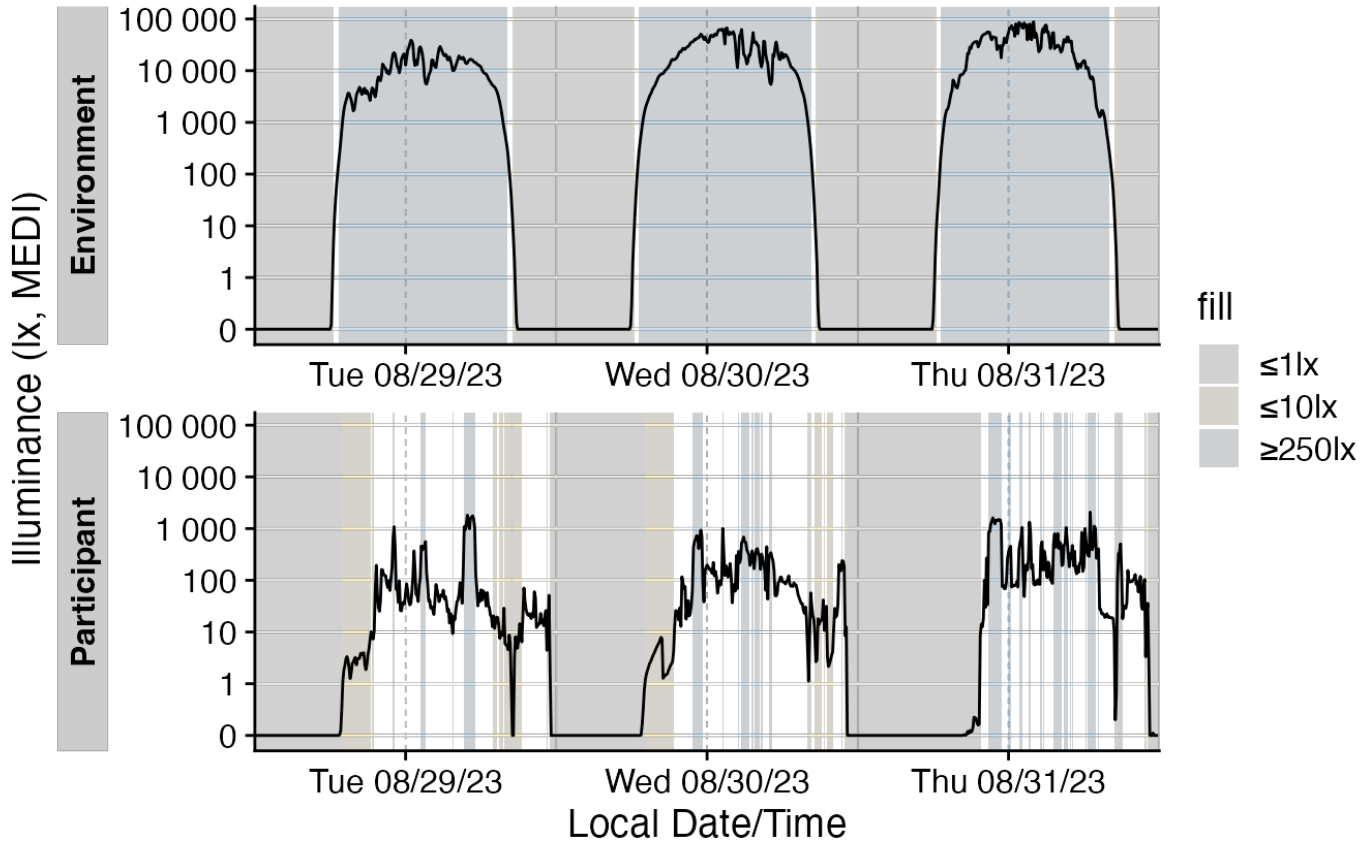
Adds a new column with 1hour sections



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> cut_Brown() |> gg_days() |> gg_state(state, aes_fill = state)
```

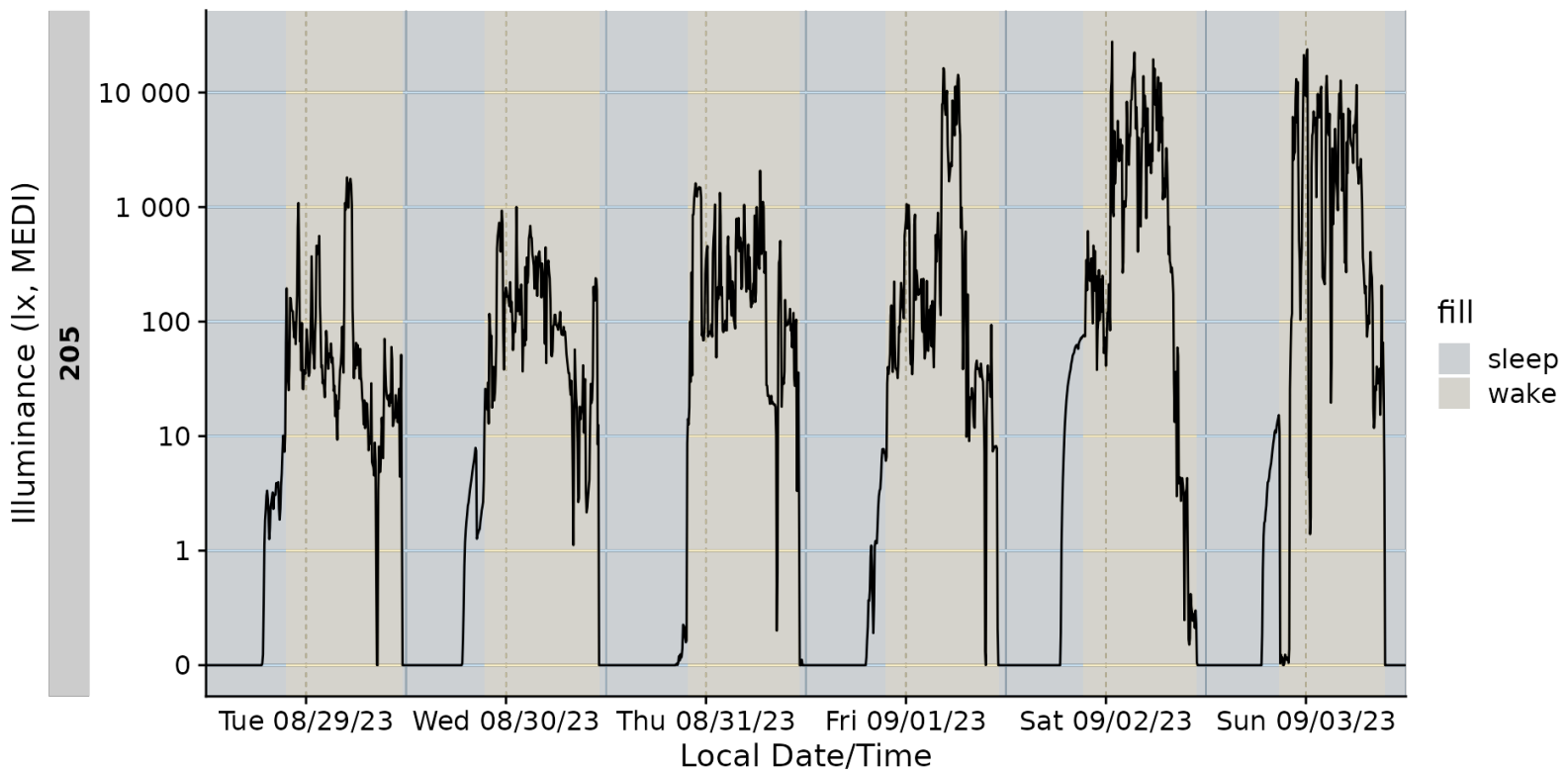
adds a new column `state`



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> add_State(sleep,…) |> gg_days() |> gg_state(state, aes_fill = state)
```

adds a new column indicating sleep-wake times from diary

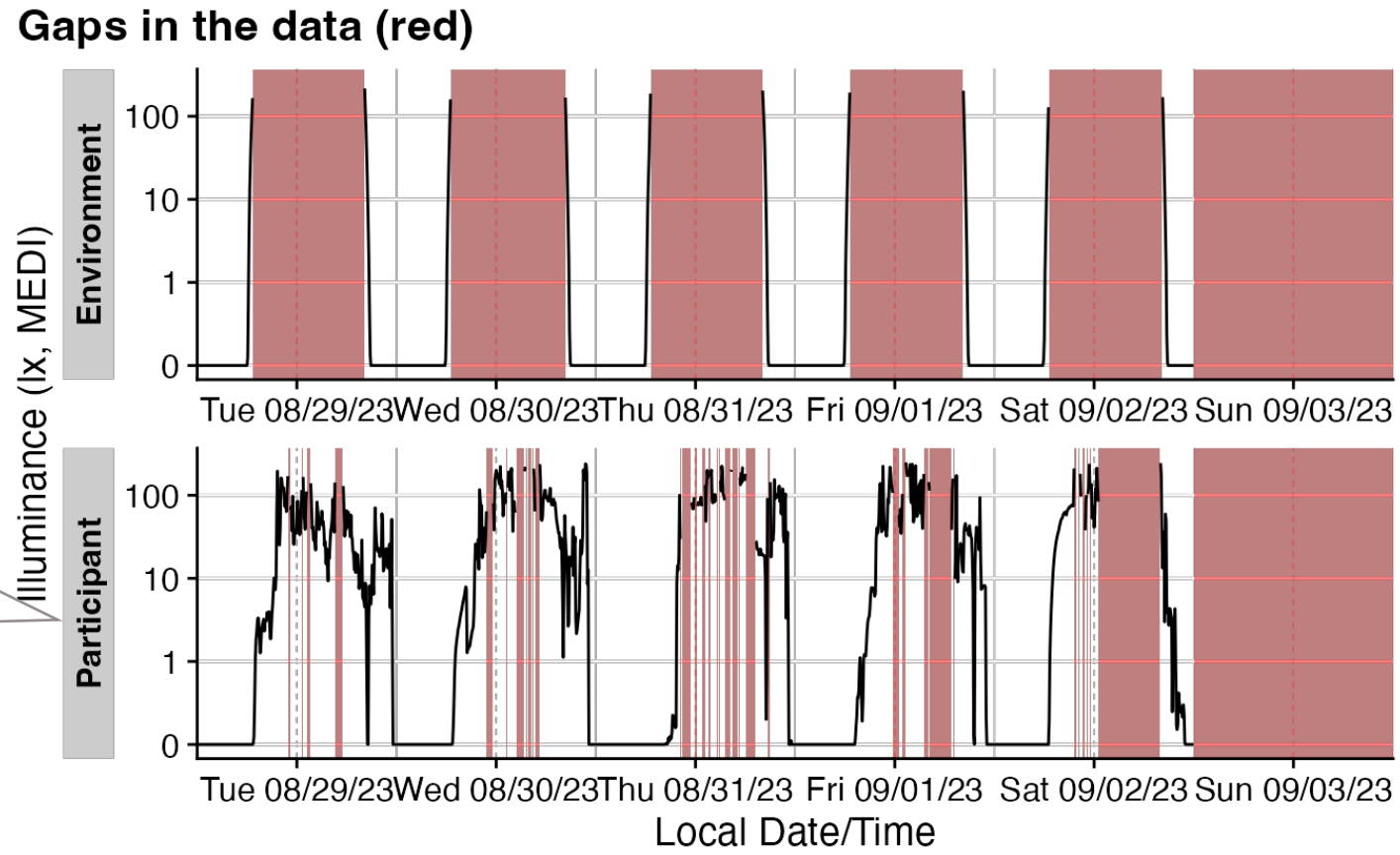


LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |> … |> gg_gaps(MEDI)
```

Throw data above a given threshold away

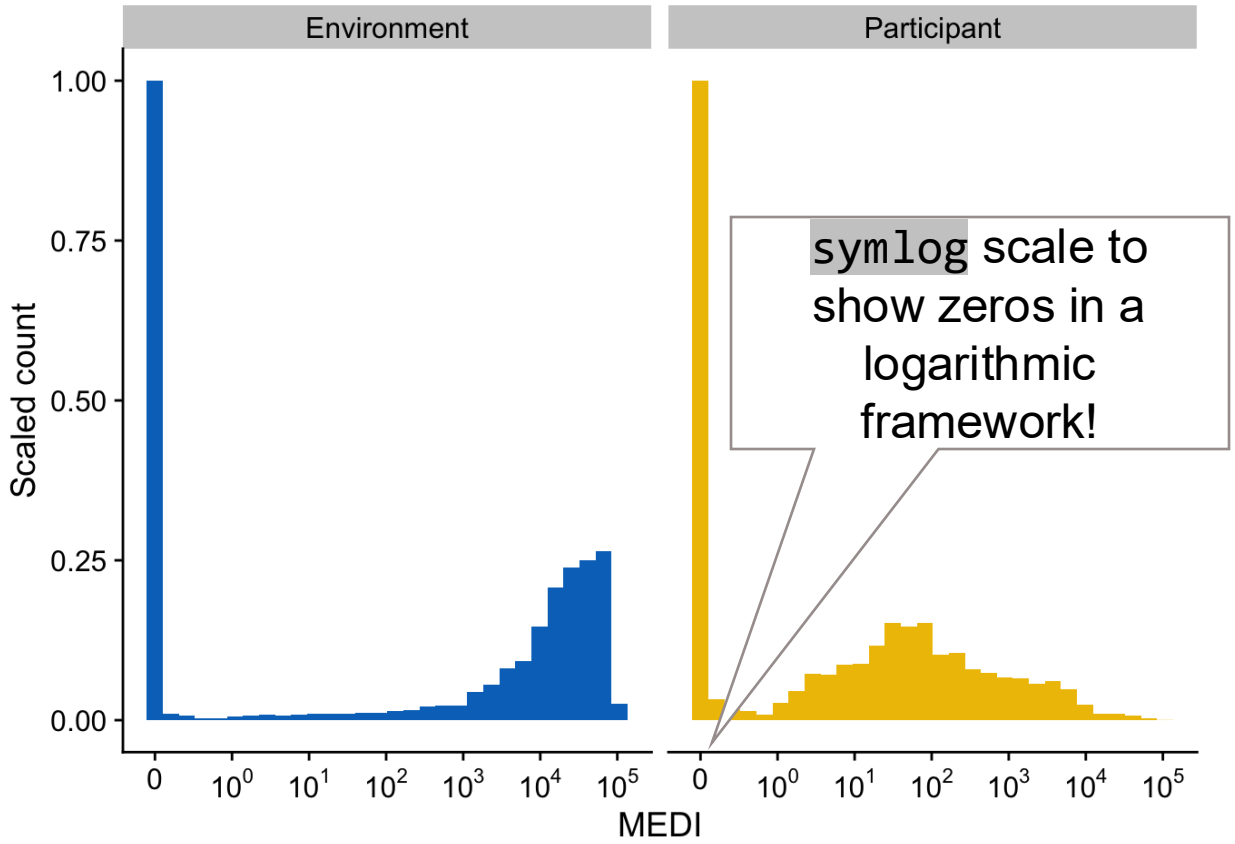
Will only show groups that have gaps



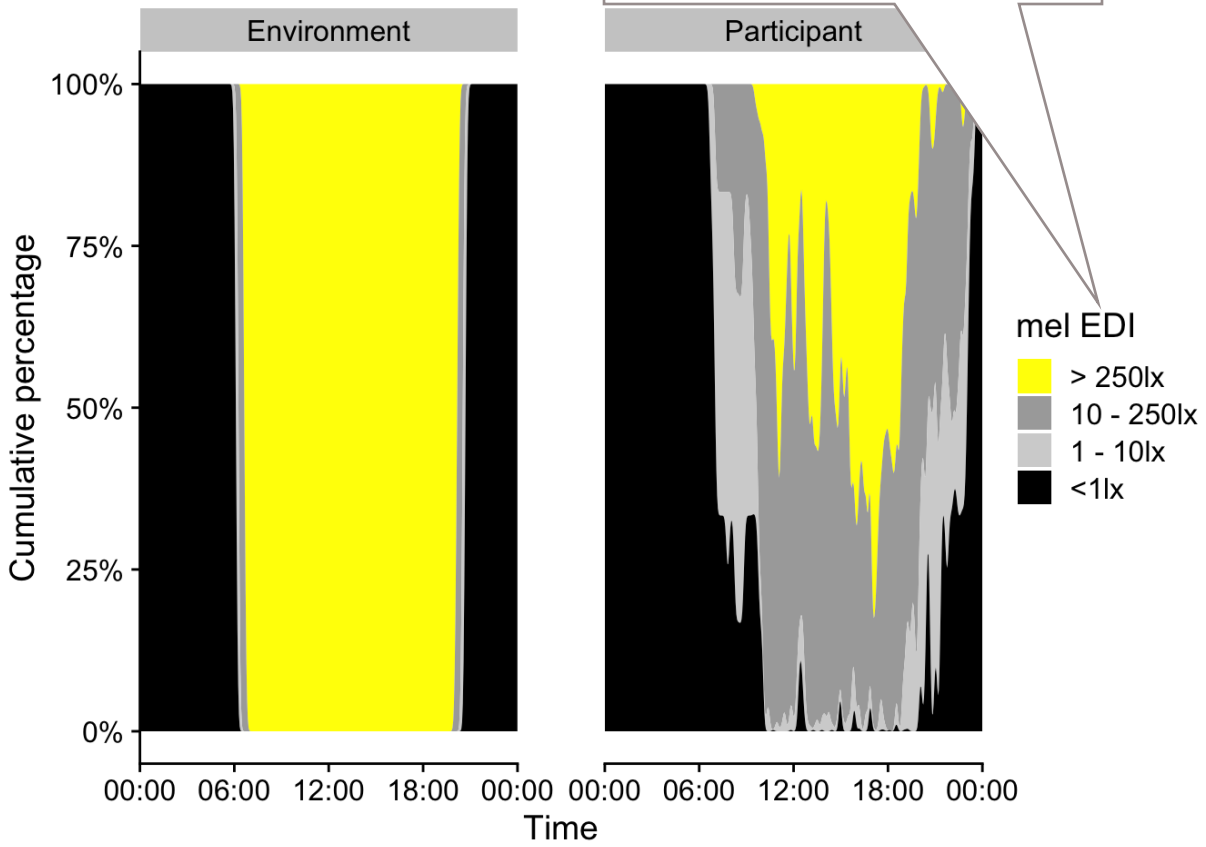
LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

These are standard visualizations that use LightLogRs functionality in parts

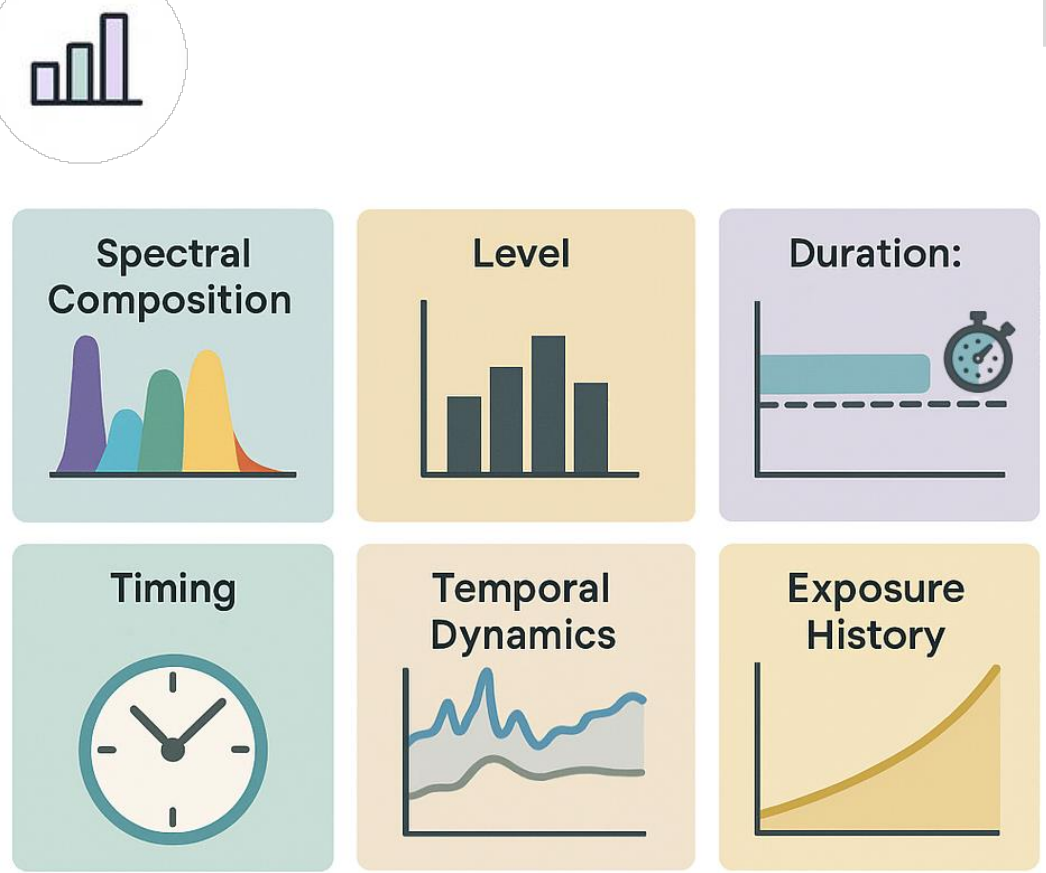
`cut_Brown()` facilitates these and other dividers



`symlog` scale to show zeros in a logarithmic framework!



LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation



Metric Family	Metrics	Note
Barroso	7	
Bright-dark period	4 x 2	bright / dark
Centroid of light exposure	1	
Disparity Index	1	
Dose	1	
Duration above threshold	3	above, below, within
Exponential moving average (EMA)	1	
Frequency crossing threshold	1	
Intradaily Variance (IV)	1	
Interdaily Stability (IS)	1	
Midpoint CE (Cumulative Exposure)	1	
nvRC (Non-visual circadian response)	4	
nvRD (Non-visual direct response)	2	
Period above threshold	3	above, below, within
Pulses above threshold	7 x 3	above, below, within
Threshold for duration	2	above, below
Timing above threshold	3	above, below, within
18 Families	**62 metrics**	

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |>
  add_Date_col(group.by = TRUE, as.wday = TRUE) |>
  summarize(
          duration_above_threshold(MEDI, Datetime, „above“, 250, as.df = TRUE)
          )
```

Add weekday information and get outputs for each participant and day

Condense into one row per group

wDay	duration_above_250
201	
Tue	34500s (~9.58 hours)
Wed	32780s (~9.11 hours)
Thu	21820s (~6.06 hours)
Fri	31670s (~8.8 hours)
Sat	15010s (~4.17 hours)
Sun	24400s (~6.78 hours)
202	
Tue	18760s (~5.21 hours)

Provide the measurement variable it has to be calculated for

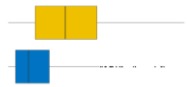
Set the threshold. Default is „above“, but „below“ or „within two thresholds“ is also possible

Automated naming for output column

LightLogR enables reproducible data analysis from many light logger models, including visualizations and metric calculation

```
data |>
  add_Date_col(group.by = TRUE) |>
  summarize(
            duration_above_threshold(MEDI, Datetime, “above“, 250, as.df = TRUE),
            bright_dark_period(MEDI, Datetime, „brightest“, „10 hours“, loop = TRUE),
            …
            )
```

Add as many metrics as needed

	Malaysia			Switzerland				
	Mean	SD	n	Mean	SD	n	Difference M-S	Boxplot
FLiT1000	**38,664**	8,857	413	**35,909**	8,818	489	**2,755**	
FLiT250	**37,192**	9,723	439	**33,204**	9,880	509	**3,988**	
FcT250	**36**	31	490	**67**	44	533	**−31**	
IS	**0.162**	0.0581	19	**0.164**	0.0664	20	**−0.00129**	

Physiologically-relevant light exposure and light behaviour in Switzerland and Malaysia. Anna M Biller, Johannes Zauner, Christian Cajochen, Marisa A Gerle, Vineetha Kalavally, Anas Mohamed, Lukas Rottländer, Ming-Yi Seah, Oliver Stefani, Manuel Spitschan
bioRxiv 2025.01.07.631760; doi: https://doi.org/10.1101/2025.01.07.631760

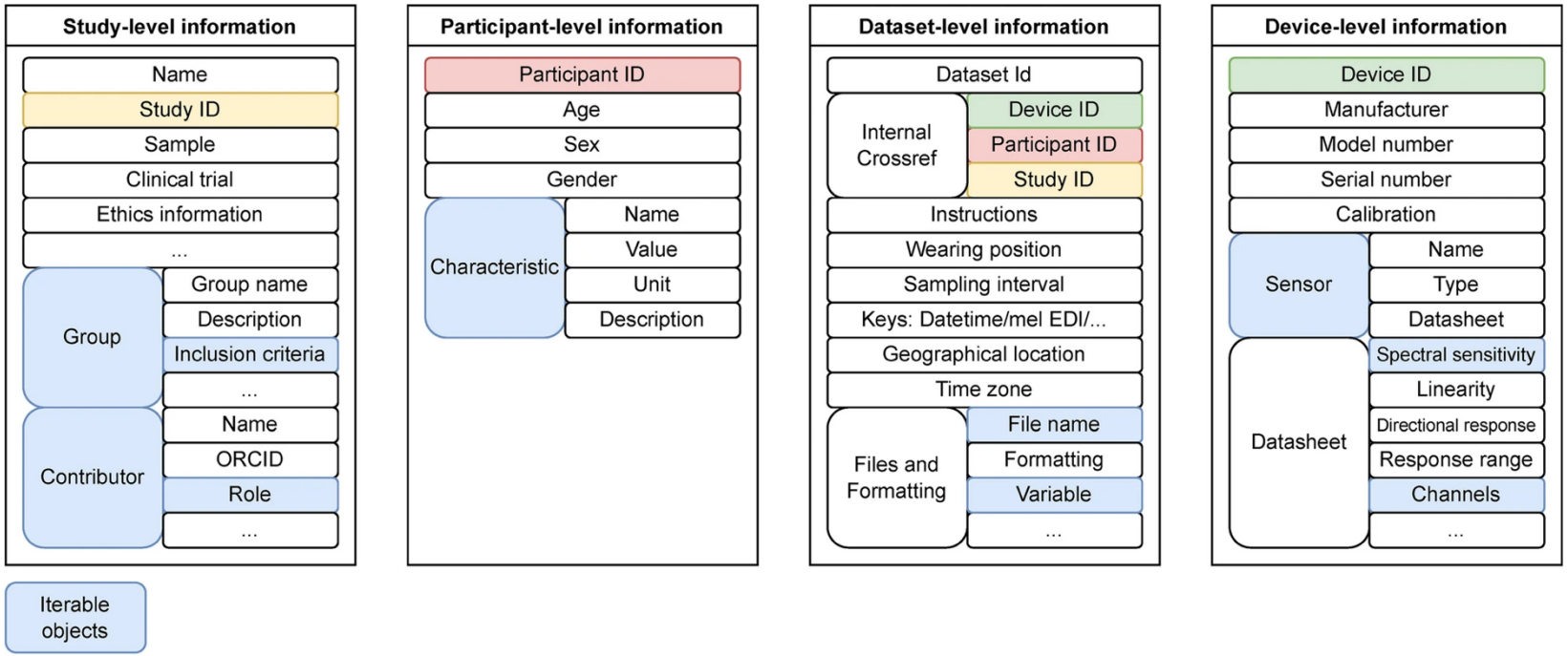
In the near future, LightLogR will be extended to work with rich metadata to support analysis and FAIR data


SOFTWARE Open Access

Metadata recommendations for light logging and dosimetry datasets

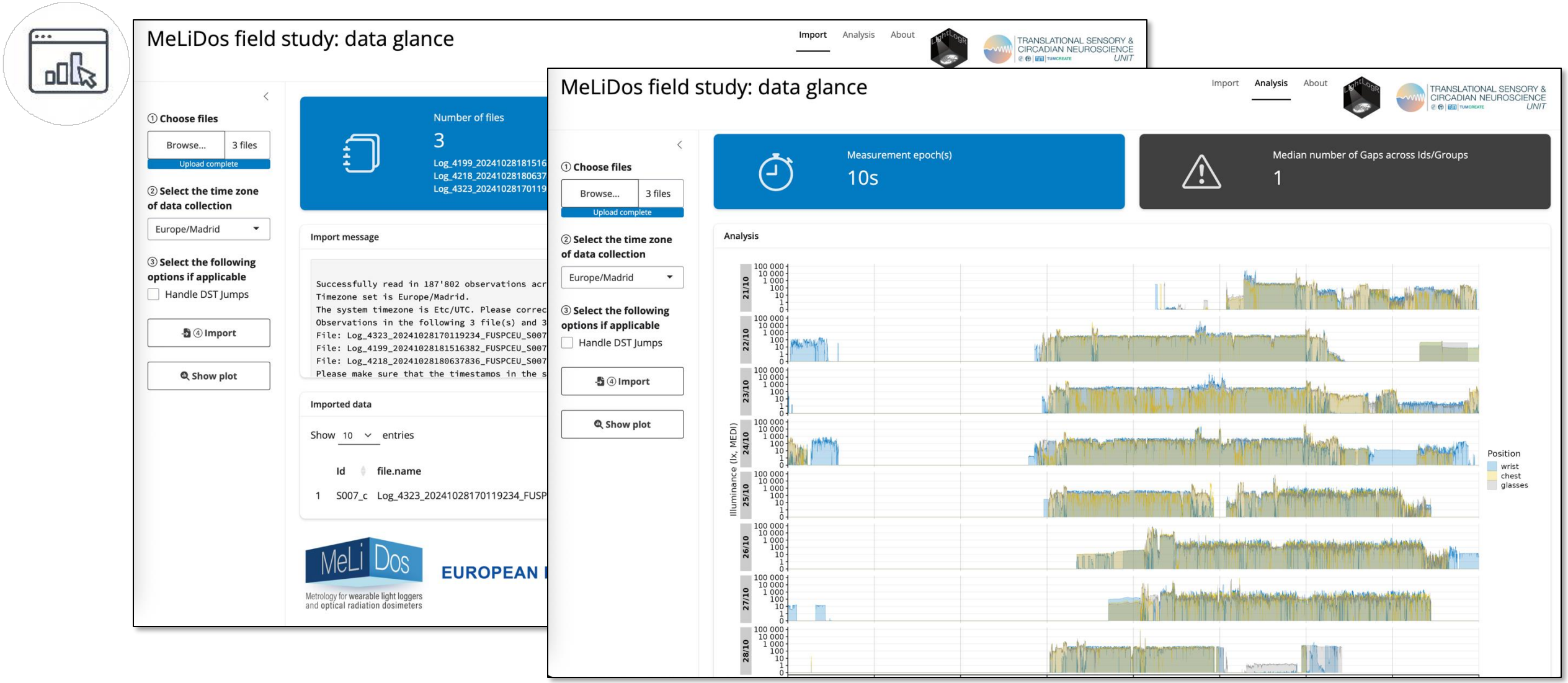
Manuel Spitschan, Grégory Hammad, Christine Blume, Christina Schmidt, Debra J. Skene, Katharina Wulff, Nayantara Santhi, Johannes Zauner and Mirjam Münch

BMC Digit Health 2, 73 (2024). https://doi.org/10.1186/s44247-024-00113-9



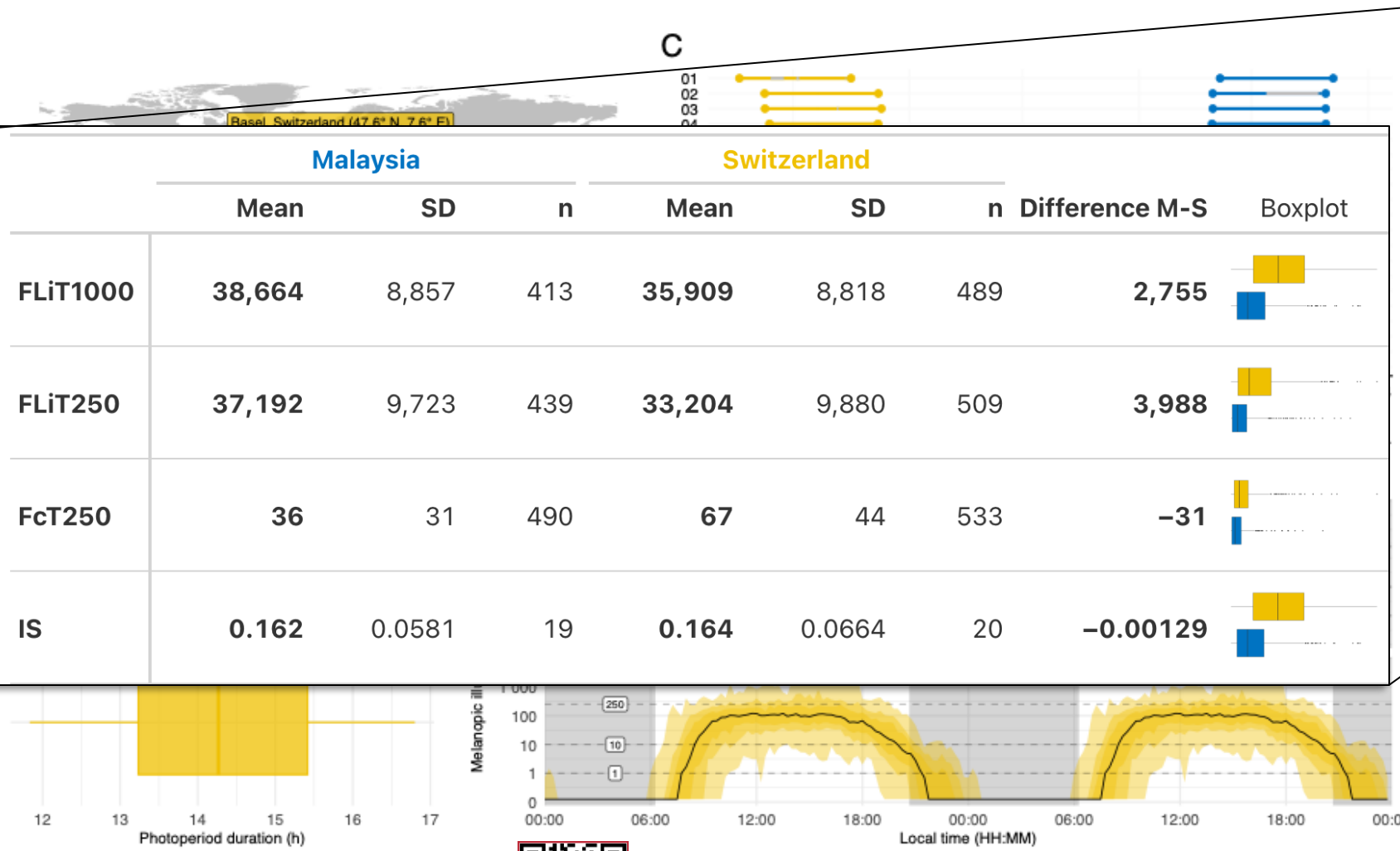
Bubnicki, J. W. et al. (2023). Camtrap DP: an open standard for the FAIR exchange and archiving of camera trap data. *Remote Sensing in Ecology and Conservation*. https://doi.org/10.1002/rse2.374

Developing toolsets to access LightLogRs core functionality without programming are on the way. Data glance as proof-of-concept.



https://tscnlab.shinyapps.io/MeLiDos_Data_Glance/

Example analysis from Biller et al. (2025): LightLogR provides an end-to-end framework for analysis



	Malaysia			Switzerland				
	Mean	SD	n	Mean	SD	n	Difference M-S	Boxplot
FLiT1000	**38,664**	8,857	413	**35,909**	8,818	489	**2,755**	
FLiT250	**37,192**	9,723	439	**33,204**	9,880	509	**3,988**	
FcT250	**36**	31	490	**67**	44	533	**−31**	
IS	**0.162**	0.0581	19	**0.164**	0.0664	20	**−0.00129**	

	Malaysia			Switzerland				
	Mean	SD	n	Mean	SD	n	Difference M-S	Boxplot
FLiT1000	38,664	8,857	413	35,909	8,818	489	2,755	
FLiT250	37,192	9,723	439	33,204	9,880	509	3,988	
FcT250	36	31	490	67	44	533	−31	
IS	0.162	0.0581	19	0.164	0.0664	20	−0.00129	
IV	1.29	0.483	472	1.28	0.504	504	0.00480	
L5m†	−0.781	0.524	490	−0.966	0.183	533	0.185	
L5mde†	0.836	0.785	490	0.971	0.912	533	−0.136	
L5mn†	−0.341	0.897	490	−0.797	0.499	533	0.456	
LE	5,117	7,132	490	18,765	26,249	533	−13,648	
LLiT10	23:18	01:04	493	22:18	01:52	528	01:00	
LLiT250	17:42	02:36	432	19:14	02:10	510	−01:31	
M10m†	2.37	0.578	490	2.87	0.706	533	−0.503	
MEDI†	0.469	1.42	704,123	0.547	1.61	765,617	−0.0788	
MPratio	0.932	0.119	490	0.947	0.103	533	−0.0150	
PAT1000	957	1,360	490	1,692	2,031	533	−736	
SCmelEDI	1.52×10^{-3}	1.36×10^{-4}	490	1.40×10^{-3}	1.19×10^{-4}	533	1.15×10^{-4}	
TAT1000	47m	1h 4m	490	1h 44m	1h 41m	533	−57m	
TAT250	1h 38m	1h 38m	490	3h 28m	2h 20m	533	−1h 50m	
TATd250	1h 36m	1h 36m	490	3h 25m	2h 18m	533	−1h 49m	
TBTe10	2h 32m	1h 5m	490	2h 39m	1h 1m	533	−7m	

† values were log10 transformed

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Summary

- **Personal light exposure** is **deeply related to human health**, both on a principled physiological and an epidemiological level
- The research **field** is **developing rapidly yet is fragmented**
- **Need for common metadata, file formats analysis pipelines, and secondary data!**
- **MeLiDos** and **CIE JTC20** work on **common standards**.
- **LightLogR**, as a common pipeline for analysis – available today and under continuous development!