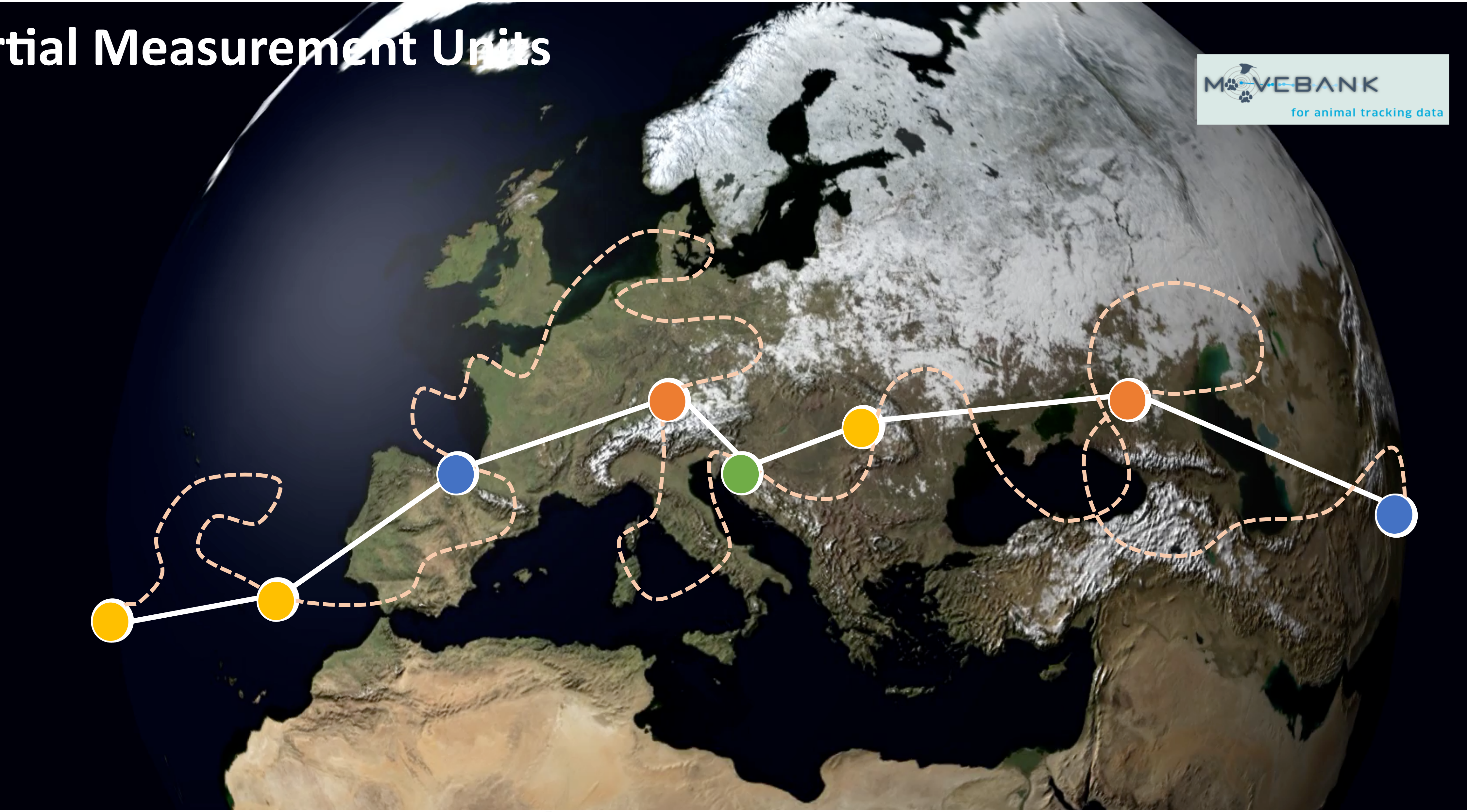
# rtial Measurement Units



MOVEBANK
for animal tracking data

EIGEIST
SHIP DER VOLKSWAGENSTIFTUNG

Move inFormation

MAX PLANCK INSTITUTE
OF ANIMAL BEHAVIOR

Animal-
Environment
Interactions

AniMove

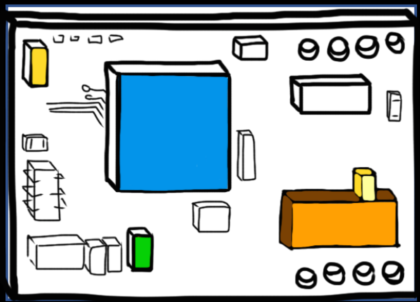

Where is the animal going?
What is the animal doing?
Why is the animal moving?
How is the animal moving?

# How can we resolve behaviour remotely?

e recording by Hannah Williams

Penguin recording by Rory

# nertial Measurement Unit



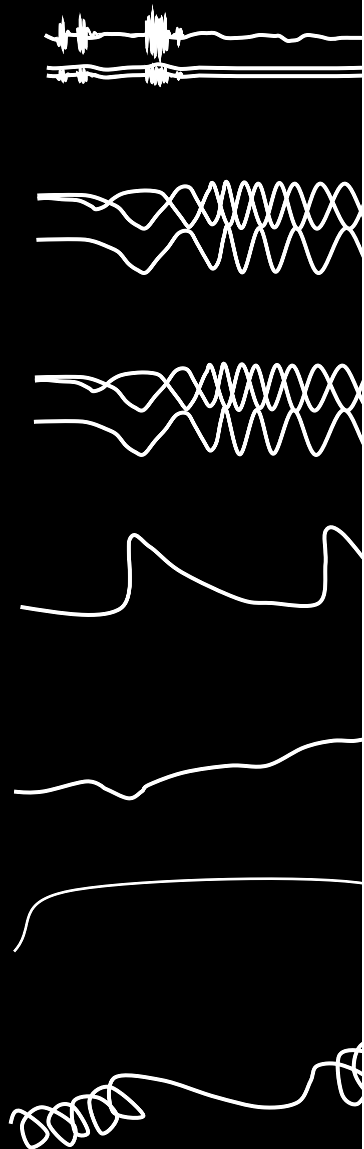

Accelerometry
Magnetometry
Gyroscope

Pressure

Temperature

Light

GPS



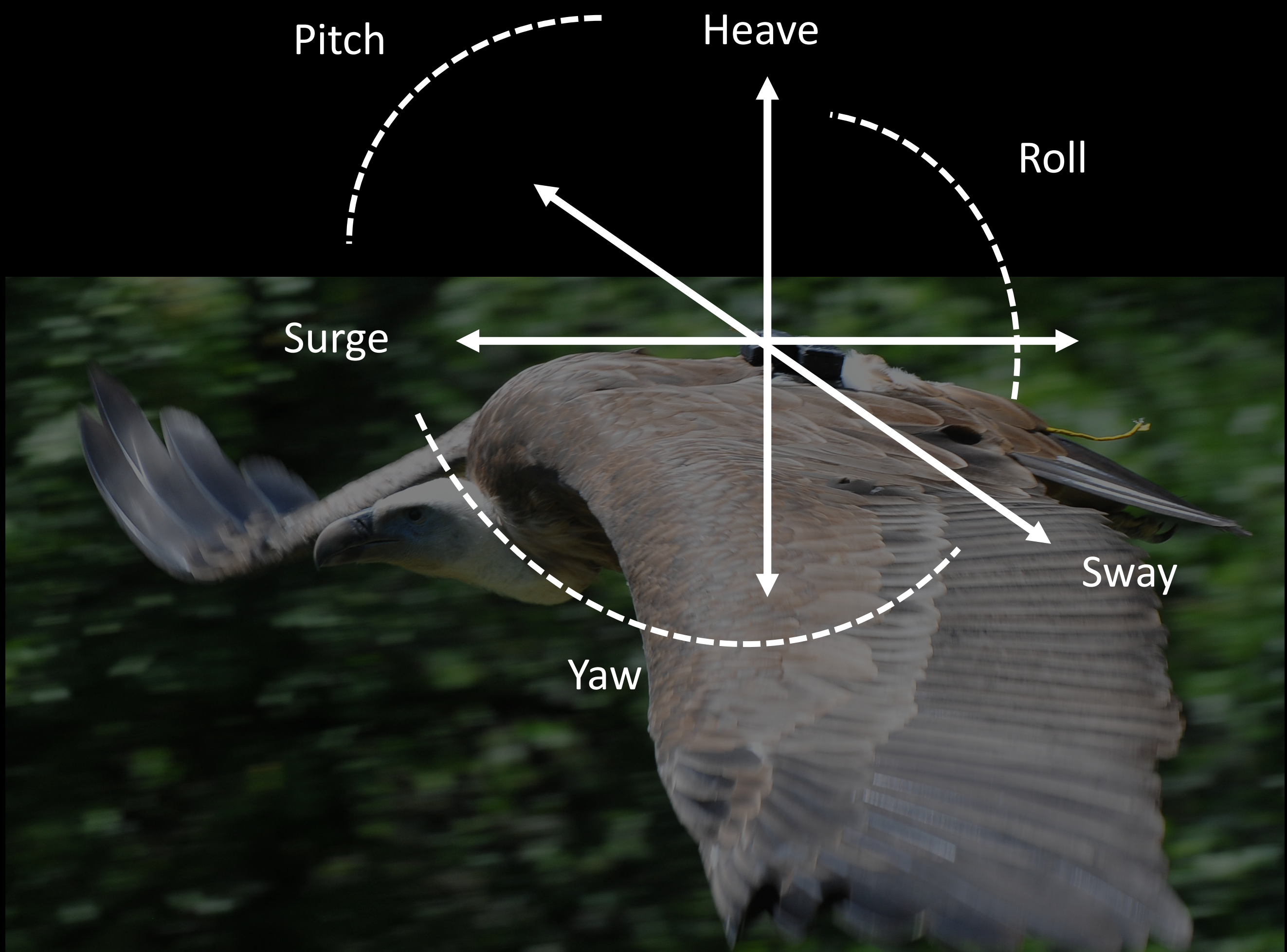
## nertial Measurement Unit

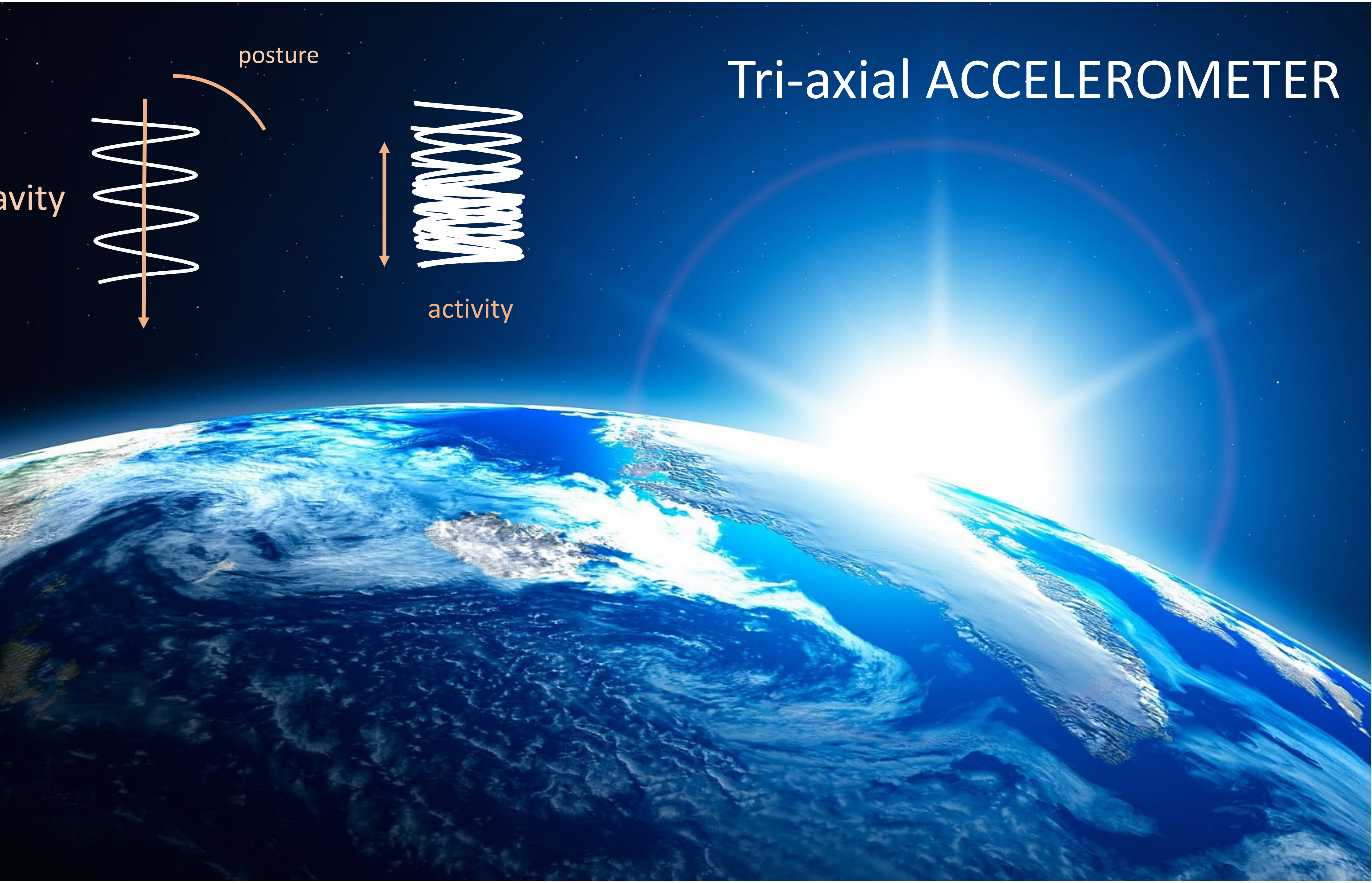
- My aim here is to tell you what these sensors are sensitive too and think about their use in your to extend any GPS or position-based study and for your future projects
- Crucial questions of how best to match the most appropriate sensors and sensor combinations to specific biological questions
- how to analyse rich set of high-frequency multivariate bio-logging data

https://github.com/trichl/WildFiOpenSource

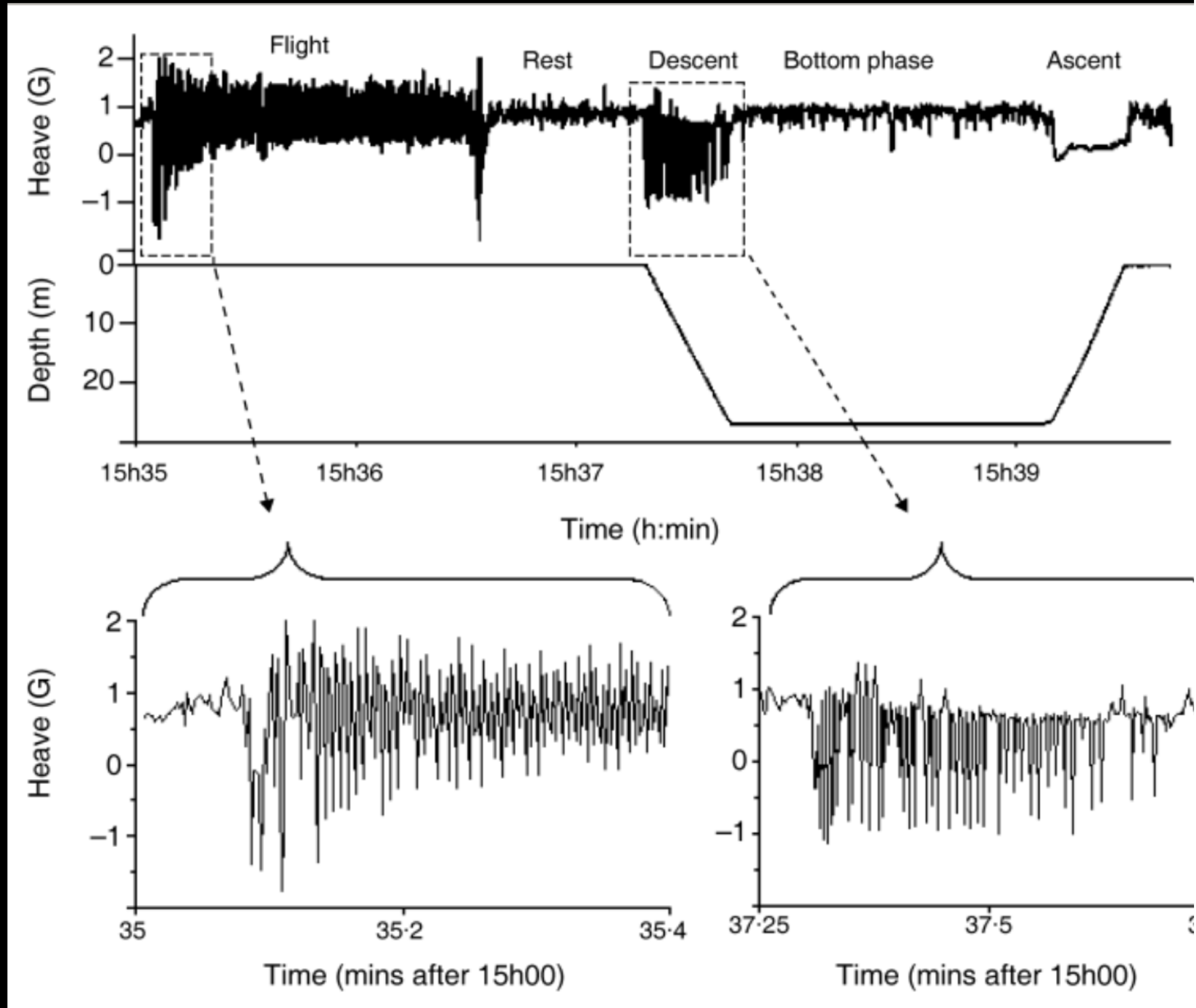
https://github.com/Richard61
/Dead-reckoning-animal-movements-in-R

# nertial Measurement Unit

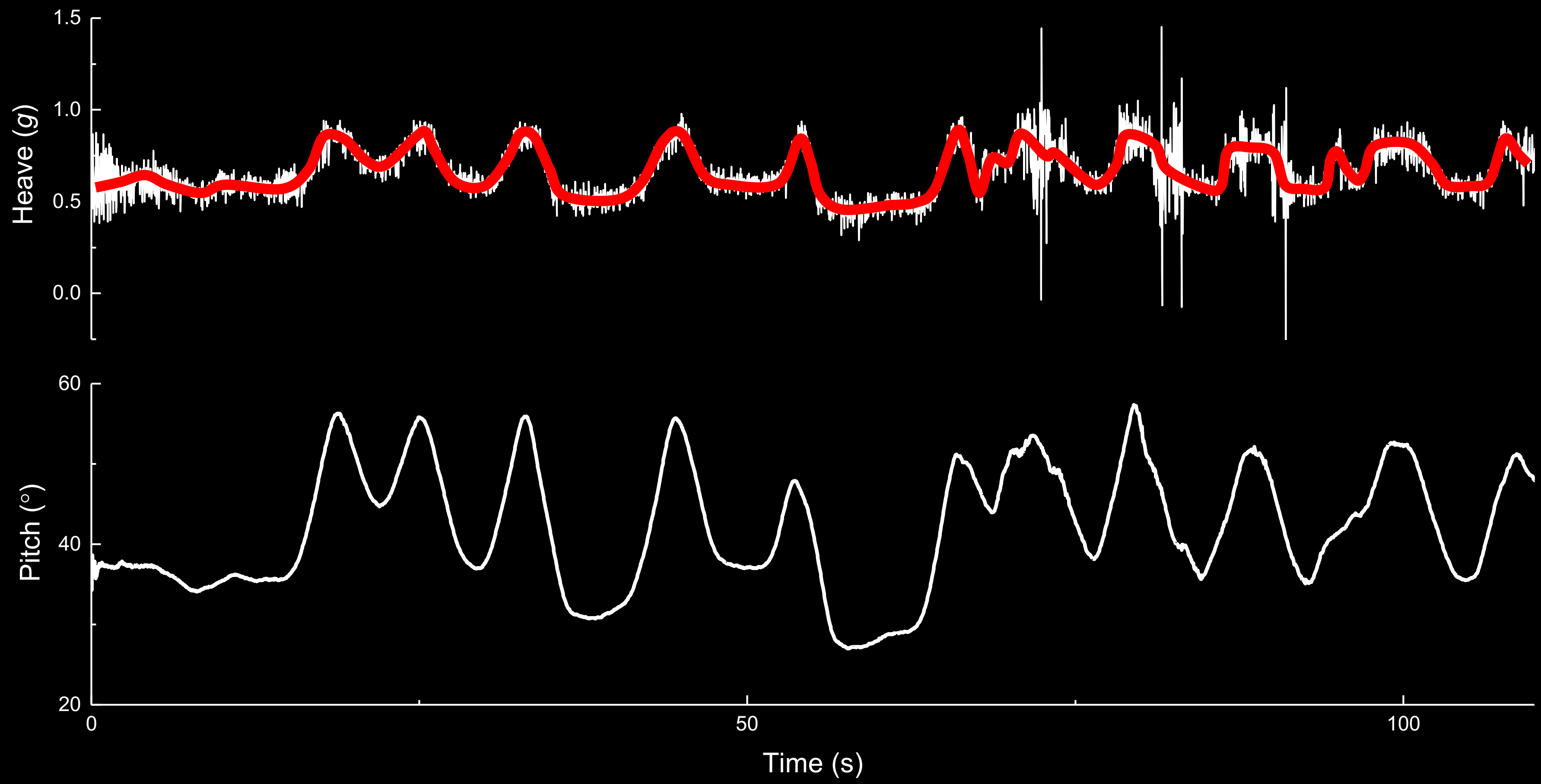


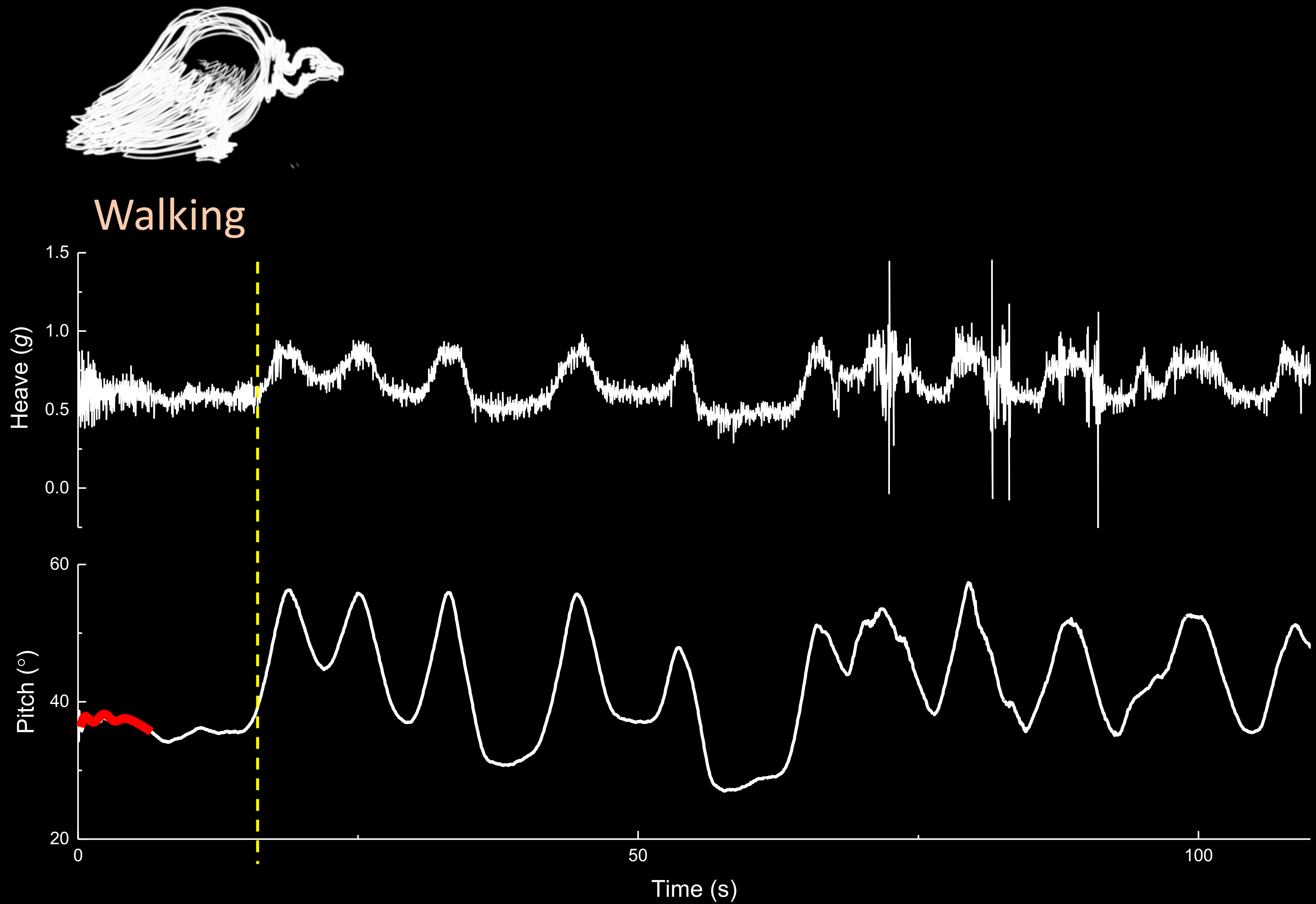

Tri-axial ACCELEROMETER
posture
avity
activity

ive cormorants were fitted with loggers
argest dimensions 65 × 36 × 22 mm
mass 35 g
which recorded triaxial acceleration (0–6 *g*)
at 32 Hz with 22-bit resolution
n a 128 Mb RA memory

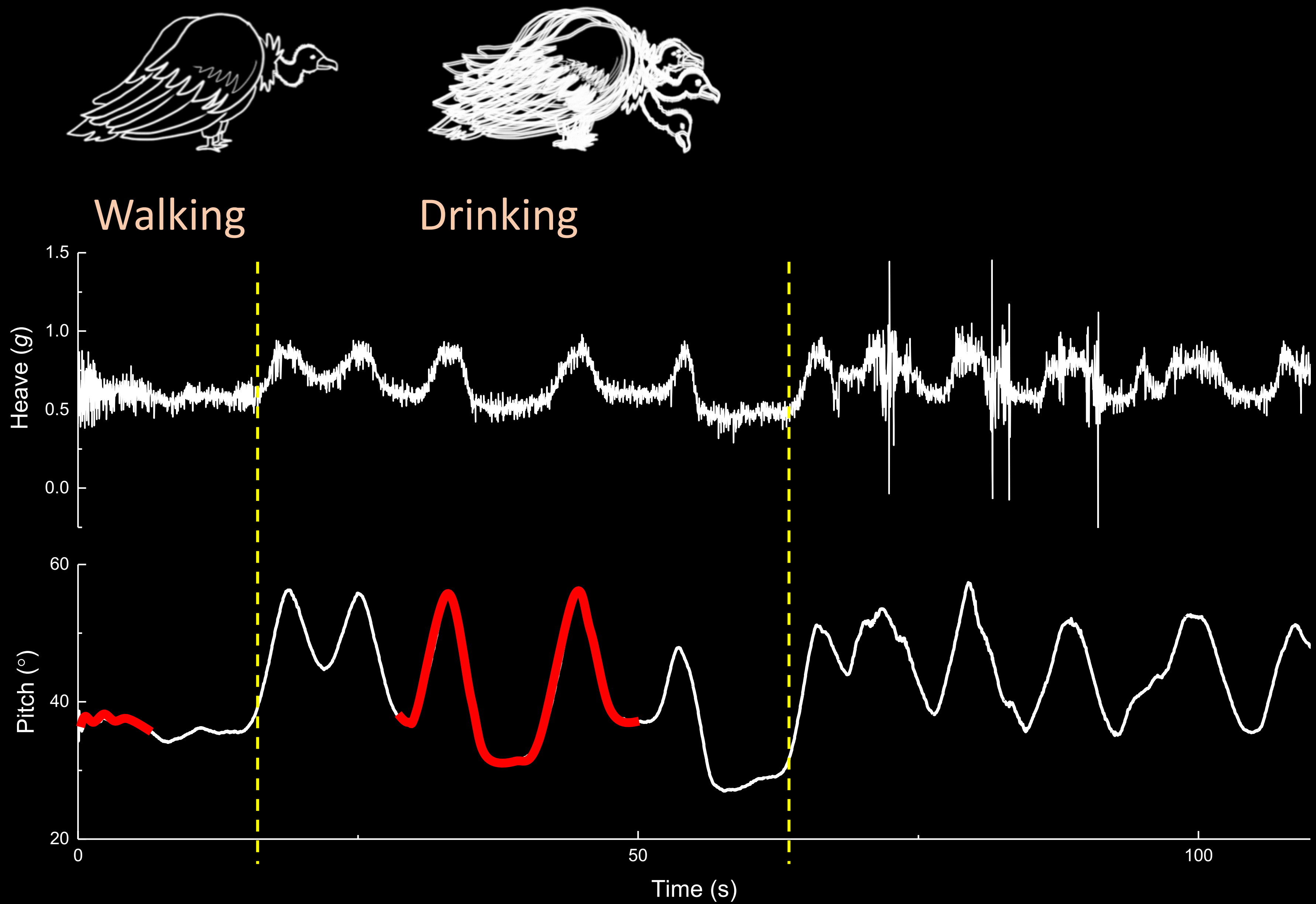



Wilson et al (2006) J

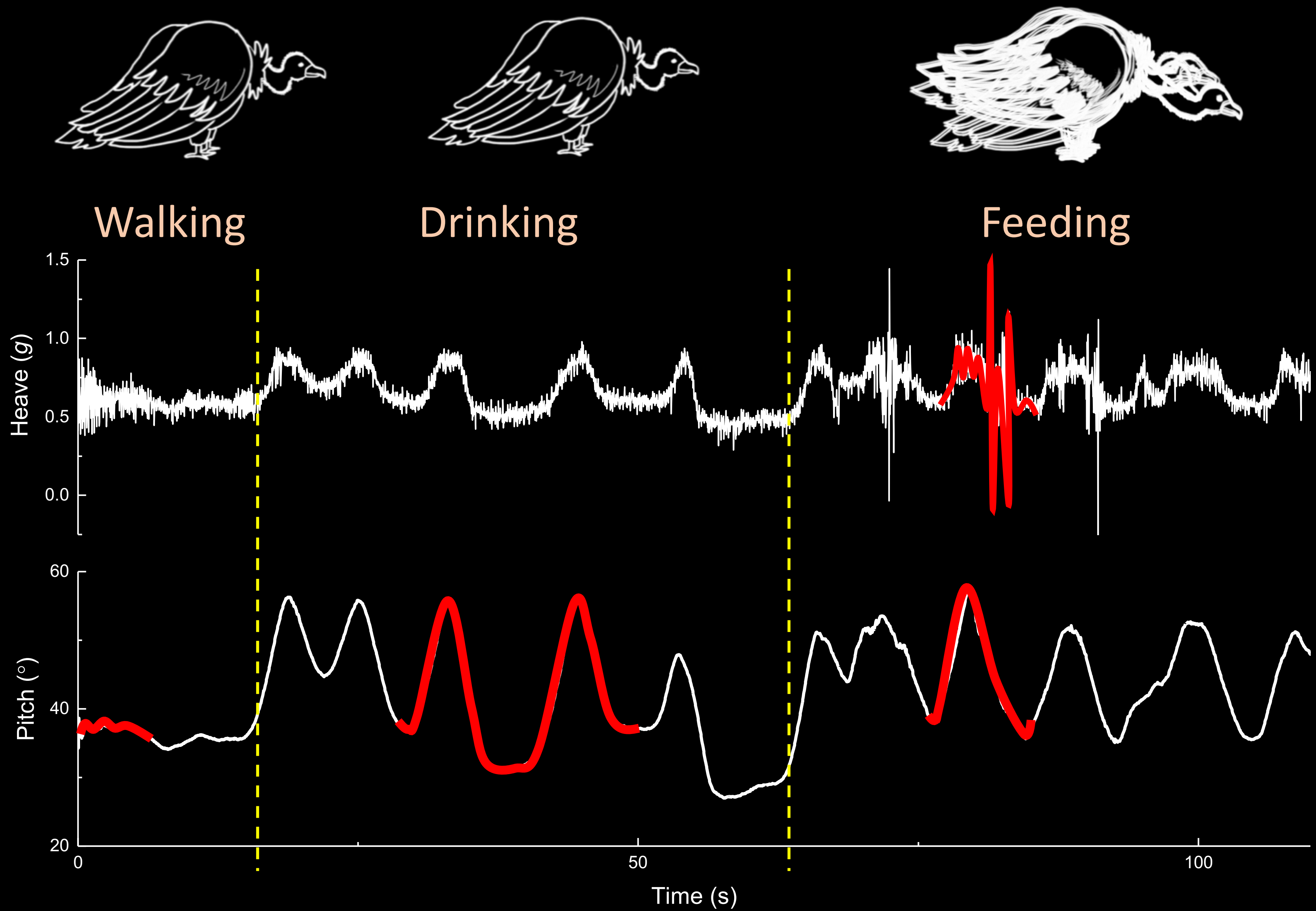

1.5
1.0
0.5
0.0
Heave (g)
60
40
20
Pitch (°)
0
50
100
Time (s)



Walking
1.5
1.0
0.5
0.0
Heave (g)
60
40
20
Pitch (°)
0
50
100
Time (s)



Walking
Drinking
1.5
1.0
0.5
0.0
Heave (g)
60
40
20
Pitch (°)
0
50
100
Time (s)



Walking
Drinking
Feeding
1.5
1.0
0.5
0.0
Heave (g)
60
40
20
Pitch (°)
0
50
100
Time (s)

# How to extract the static and dynamic acceleration components?

- Nyquist or sampling theorem - sampling frequency (temporal or spatial) should be at least twice the fastest frequency of interest
- sensor bit resolution- e.g., 8-bit resolution, meaning the sensor can obtain an absolute resolution given by the maximum resolution range divided by 256.
- Measurement range of the sensor. – e.g., accelerometer which records up to 8 g will miss any data of animals moving more dynamically (e.g., head impacts) default should be at least 16 g for initial studies for terrestrial systems (a lower range may be sufficient for aquatic systems as, due to friction, movement speed may change less fast)
- But highly prescribed, low-frequency sampling may miss serendipitous observations of importance.
- High-frequency recording of raw data (>20 Hz) may be necessary to compute animal posture and DBA
- ‘validated’ in level terrain will produce markedly different acceleration offsets if it normally lives in mountains because body pitch

moothing the data : a running mean ; a Fast-Fourier transformation; a high-pass filter ; a Kalman-filt

# How to extract the static and dynamic acceleration components?

```
quired libraries
tall.packages("zoo") ; install.packages("dplyr")
rary(zoo) ; library(dplyr)

te, currently, scripts are composed of base R syntax, using data frames. Code can be optimized further to become more efficient at computing larger data se
r example, note the time difference between the 'data.frame' and 'data.table' versions of implementing a running mean:
rary(data.table)
<- data.frame(Ax=sample(1:1000,10000000, replace=T),
              Ay=sample(1:1000,10000000, replace=T),
              Az=sample(1:1000,10000000, replace=T))
)
ata.frame / zoo solution
tem.time({
f$Gx = zoo::rollapply(df$Ax, width=w, FUN=mean, align="center", fill="extend")
f$Gy = zoo::rollapply(df$Ay, width=w, FUN=mean, align="center", fill="extend")
f$Gz = zoo::rollapply(df$Az, width=w, FUN=mean, align="center", fill="extend")

ata.table solution
tem.time({
t <- setDT(df)[, c("Gx","Gy", "Gz") := lapply(.SD,function(x) frollmean(x, n = w, align="center", adaptive=F)),
               .SDcols = c("Ax", "Ay", "Az")]

w(dt[40:140,])
```

e use a centre-aligned index (compared to the rolling window of observations), with "extend" to indicate repetition
the leftmost or rightmost non-NA value

## tivity and energy expenditure

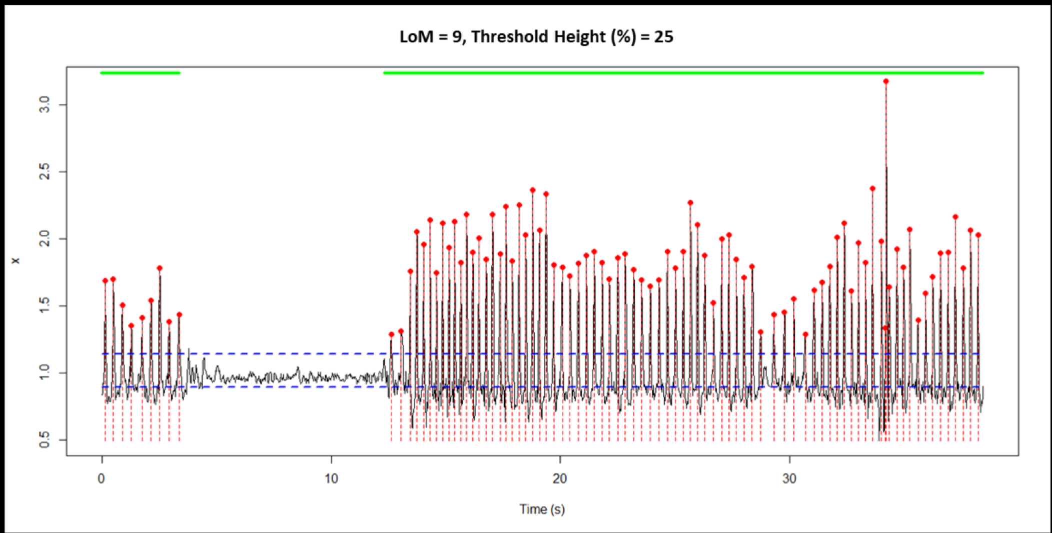
**haviour is manifest by movement so we should 'measure' movement**

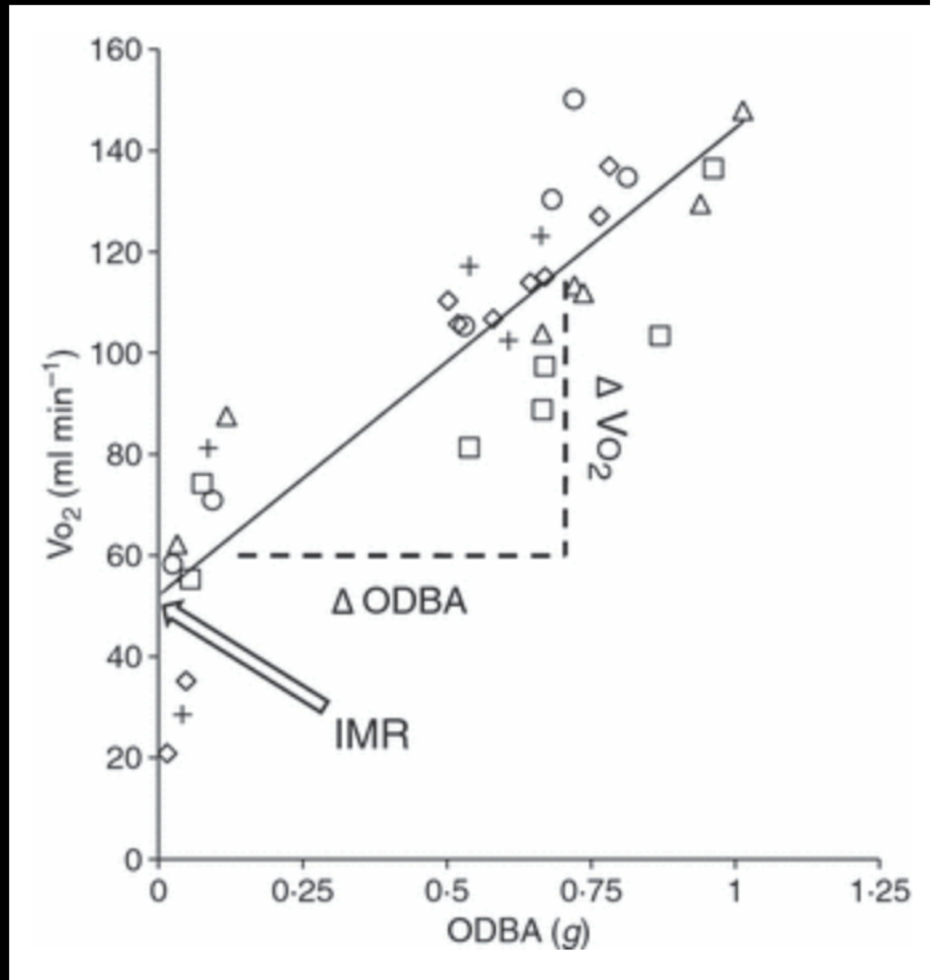
the accelerometry technique has the potential to provide information about how animals partition their use of both time and energy

Energy expenditure is the key link between behaviour and overall fitness e rate at which this mechanical work is conducted (and therefore energy used) is the mechanical power (*P*). The ility of ODBA to act as a proxy for energy expenditure depends, in part, on the link between acceleration oduced by muscular contraction and mechanical power.

**dog.peaks**

ates peaks based on local signal maxima, using a given ing window, with each candidate peak filtered according to ether it surpassed a threshold height




Gleiss et al (2011) MEE

**veACC**

*ACCwave* function uses a FFT (Fast Fourier Transformation) to act the wave of the acceleration data, with a PCA (principal ponents analysis) on the 3 axis to calculate wingbeat uency on the dominant frequency of the burst ynamic body acceleration

## Derivation of DBA – VeDBA and ODBA

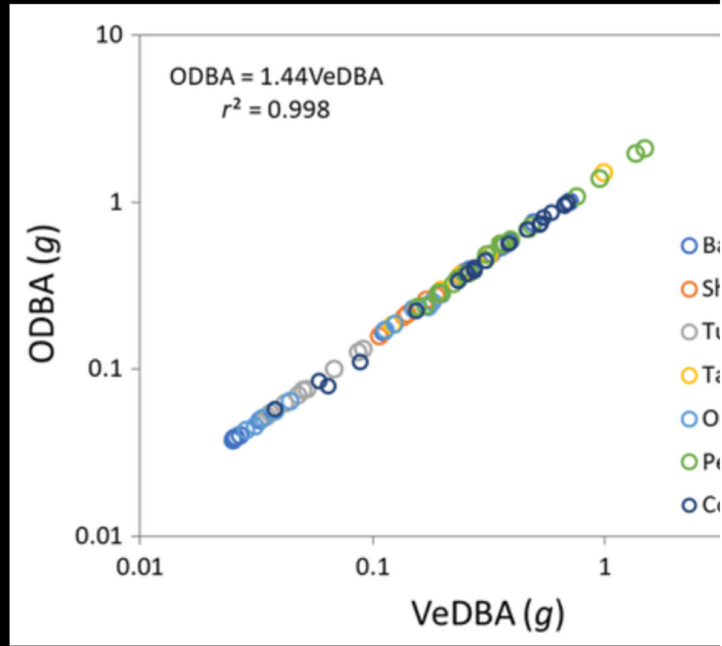
ng removed the Earth's gravitational field from each of the recorded acceleration axes, e should now be summed to provide a measure of DBA. Mathematically, this follows the oach given in Equation 1 where the vectorial sum (Vectorial sum of the Dynamic Body leration, VeDBA) is;

$$\mathrm{VeDBA} = (DAx^2 + DAy^2 + DAz^2)^{0.5} \tag{2}$$

e the "*D*" term refers to the dynamic acceleration stemming from the subtraction of the othed acceleration data from the raw. This expression for DBA has been tested against of oxygen consumption ($\dot{V}O_2$) on numerous occasions across taxa (e.g. Wright, Metcalfe, erington, & Wilson, 2014; Bidder et al., 2017) and found to be a powerful predictor. ever, its formulation is at odds with the first proposition for DBA, that of Overall mic Body Acceleration (ODBA – Wilson et al., 2006) which was simply based on the non- orial sum of the absolute dynamic acceleration values from the three acceleration axes wing;

$$\mathrm{ODBA} = |DAx| + |DAy| + |DAz| \tag{3}$$

Wilson et al (2020) JAE




Wilson et al (202

ynamic body acceleration

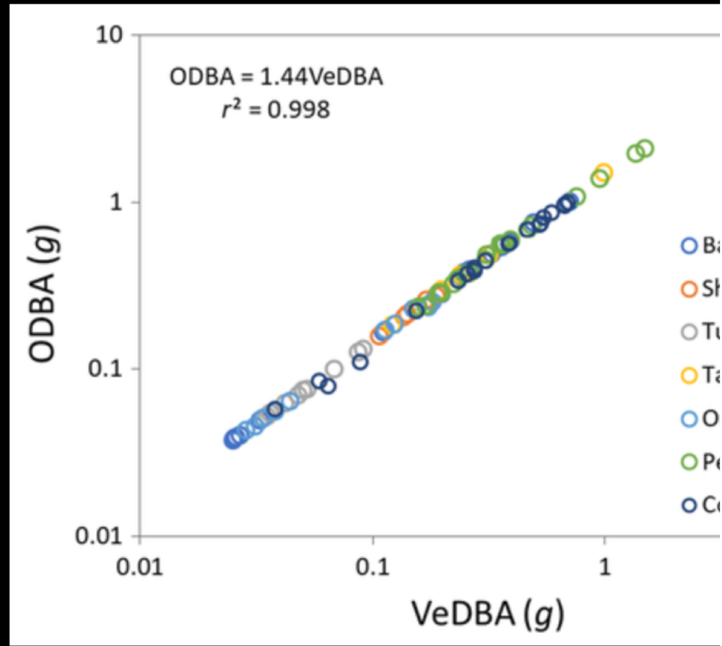
ctorial and additive DBA metrics are proportional to each other.

her can be used as a proxy for energy and summed to estimate total energy pended over a given period, or divided by time to give a proxy for vement-related metabolic power.

BA is statistically marginally better at predicting oxygen consumption

DBA may prove more appropriate when behaviours other than locomotion cur over less predictable orientation planes, & account forerrors associated h device orientation in relation to the plane of muscular contraction

searchers should use the term DBA generally, but be specific about its rivation at the outset. Those requiring the absolute best fit between DBA d $\dot{V}O_2$ may prefer to use ODBA while those seeking to describe animal tion without the energetic component may prefer VeDBA.



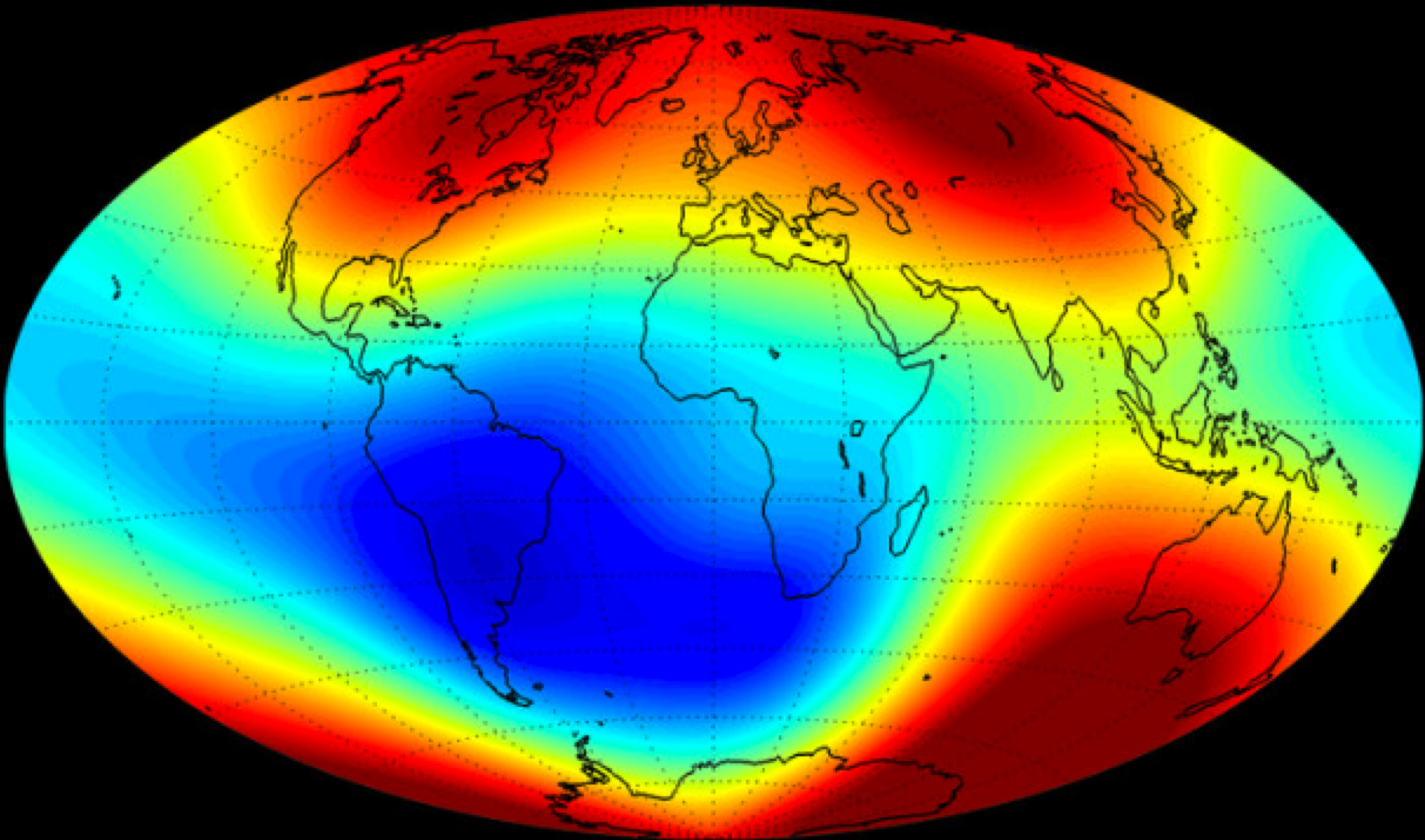

Wilson et al (202

```
) Calculate VeDBA (assuming DBA~speed within Gundog.Tracks is desired. Also post-smooth VeDBA (2 s used here
$VeDBA = sqrt((df$Acc_x - df$Acc_x.sm)^2 + (df$Acc_y - df$Acc_y.sm)^2 + (df$Acc_z - df$Acc_z.sm)^2)
$VeDBA.sm = rollapply(df$VeDBA, width=80, FUN=mean, align="center", fill="extend")
```

# actors affecting DBA metrics

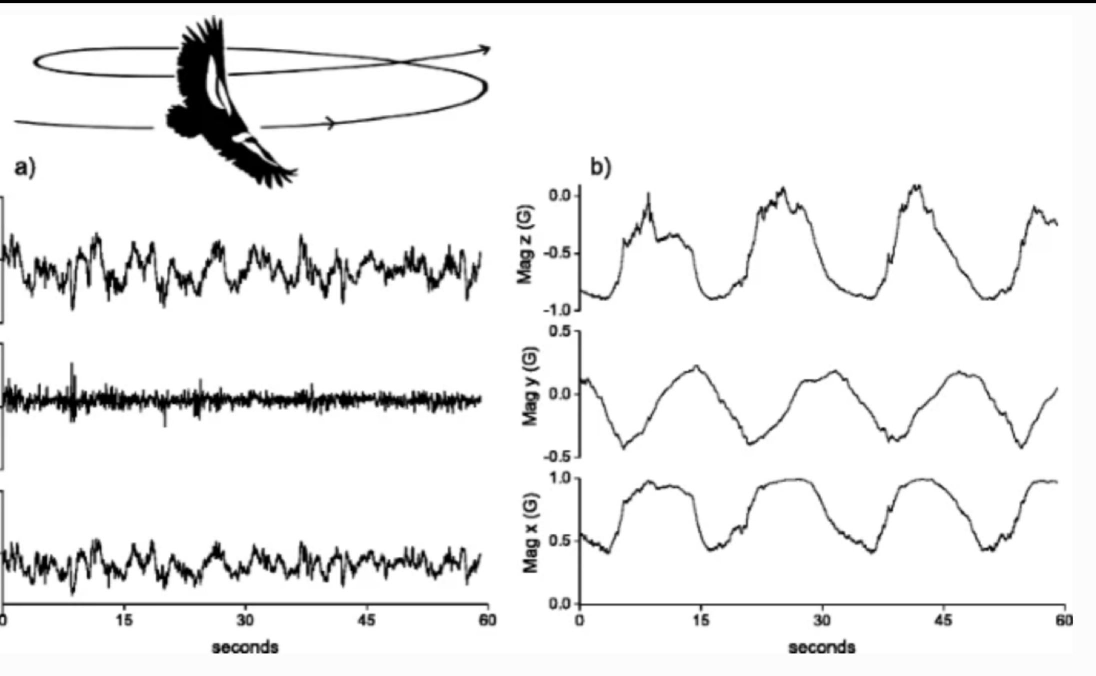
1. Tag position – impossible to orthogonally orientate it in line with main axis of movement to remove angular inadequacies of the ODBA metric
2. Tag stability
3. Environmental DBA
4. Nature of the general relationship between ODBA and $VO_2$
5. Pulling g – where the animal experience increased inertial acceleration in additional to the force of gravity, and the vectorial sum of the smoothed channels may not equal 1
6. negligible DBA signal in slowly moving animals such as many invertebrates and some ectotherms – use rates of change of body pitch, roll or yaw which, although not accelerations, may code for metabolic rate since the animal is still exerting forces to move the body

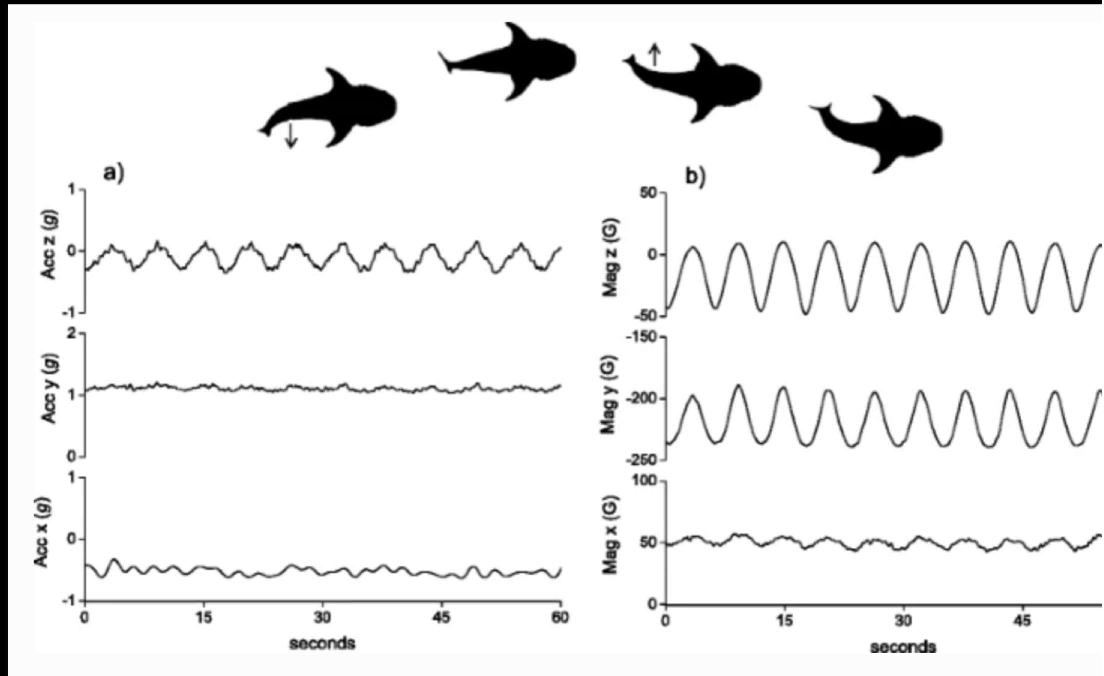
Tri-axial MAGNETOMETER




max.
min.

tri-axial sensors that are capable of recording orientation in relation to the Earth's magnetic field Given this sensitivity, there is great potential for such systems to help elucidate animal behaviour based on angular rotation.



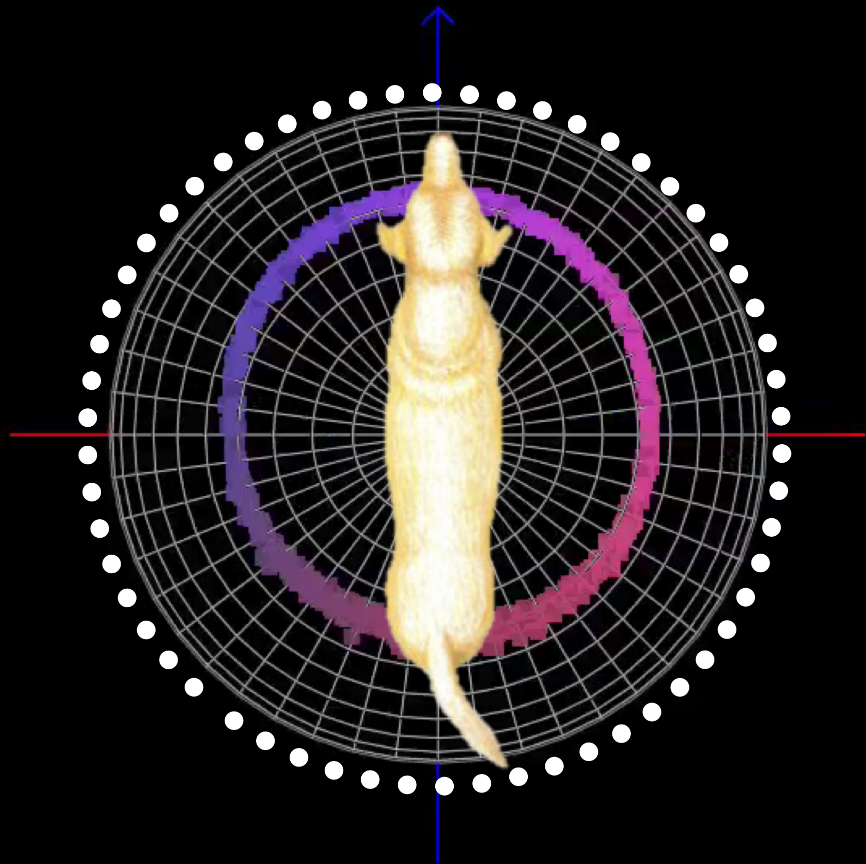




Williams et al (2017) Movement Eco

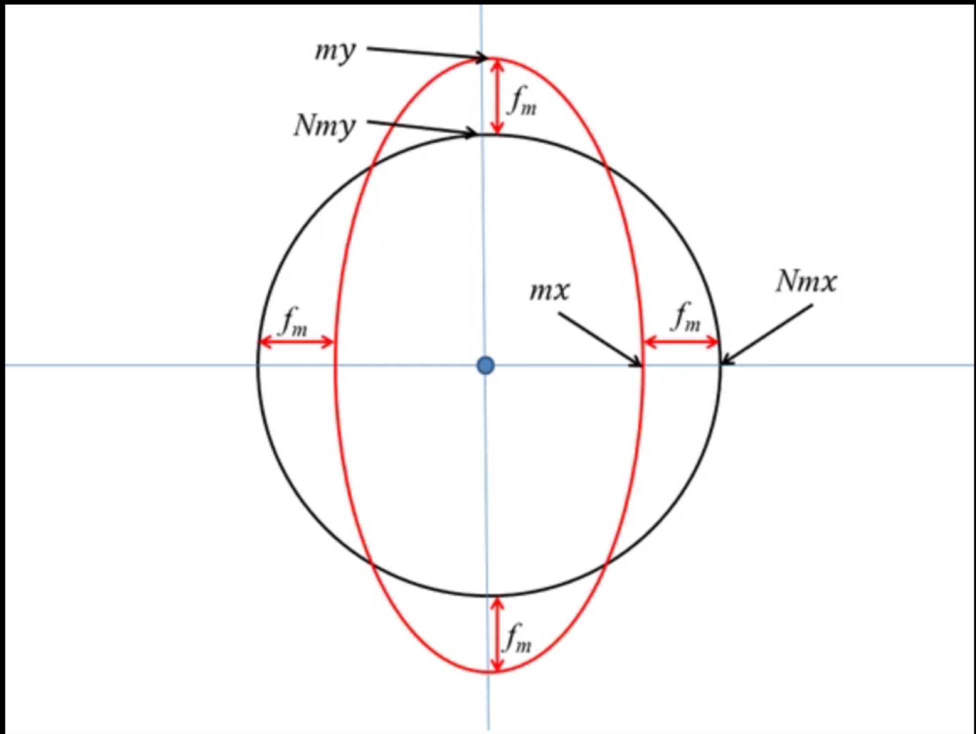
Magnetic field intensity as the frame of reference

Sensitive to directionality and rotation

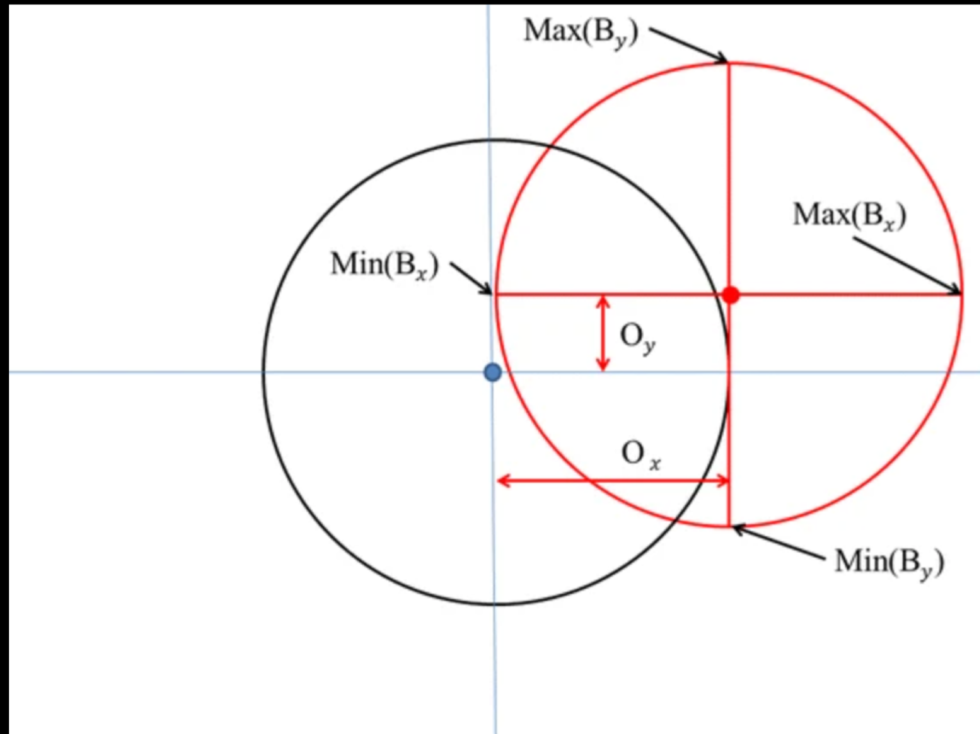
The Normal Operational Plane (NOP) is formed as the animal turns through all headings



Soft iron



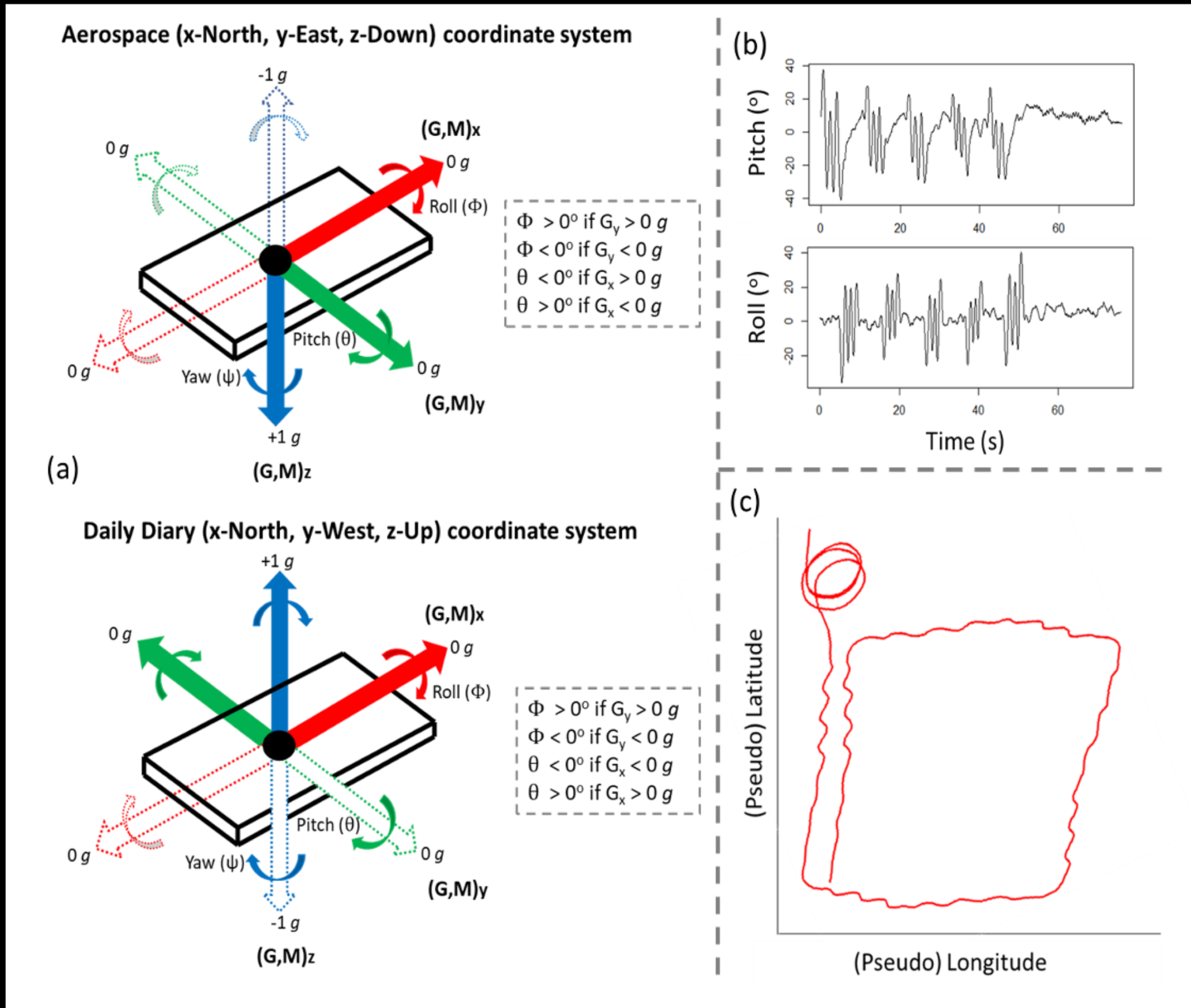

Hard iron



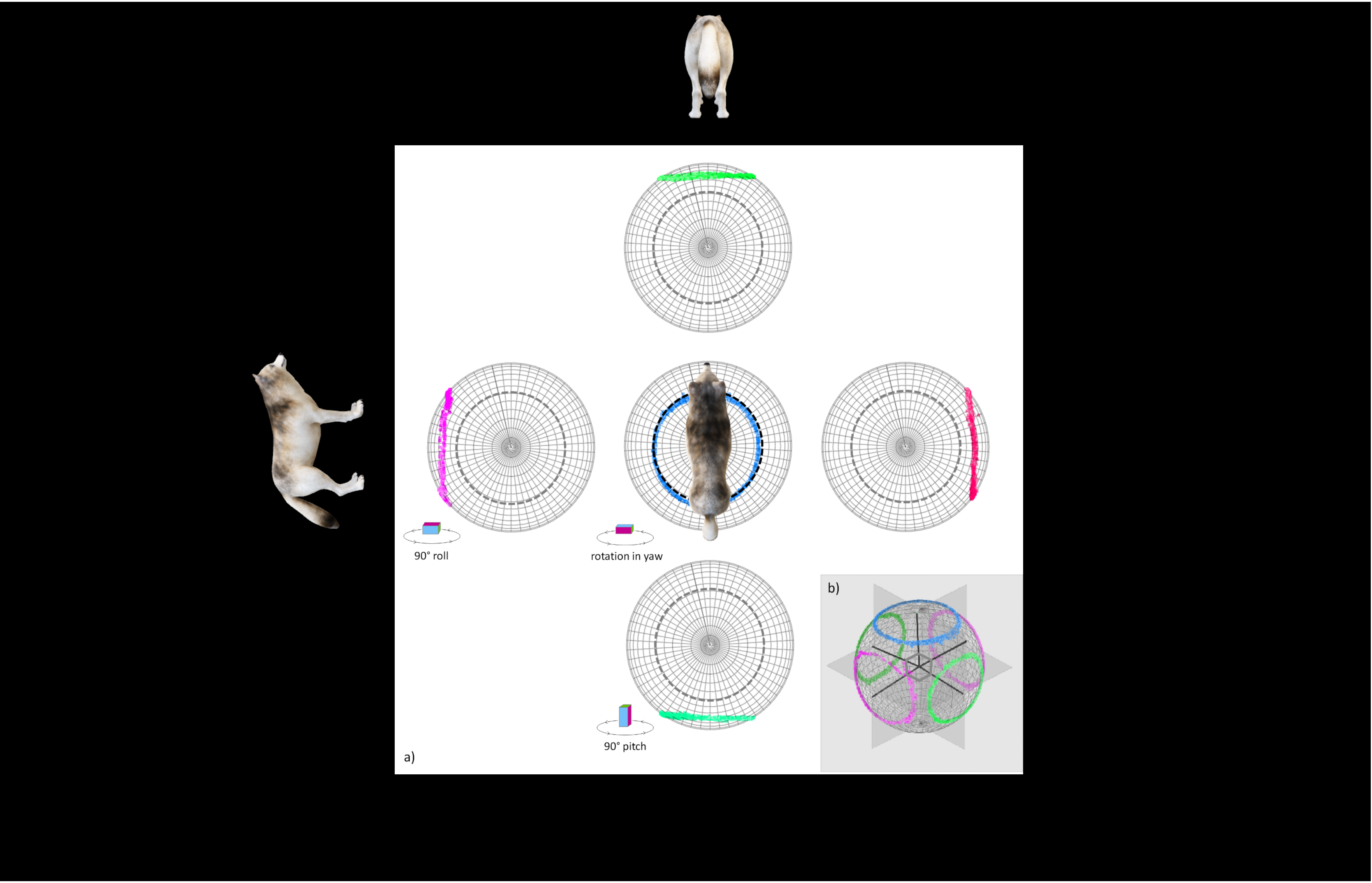

Bidder et al (2015) Movement Ecology

```
Gundog.compass = function(mag.x, mag.y, mag.z, acc.x, acc.y, acc.z, ME,
pitch.offset = 0, roll.offset = 0, yaw.offset = 0, method = 3, plot=TRUE)
```

## lving orientation with magnetic and configuration calibrations

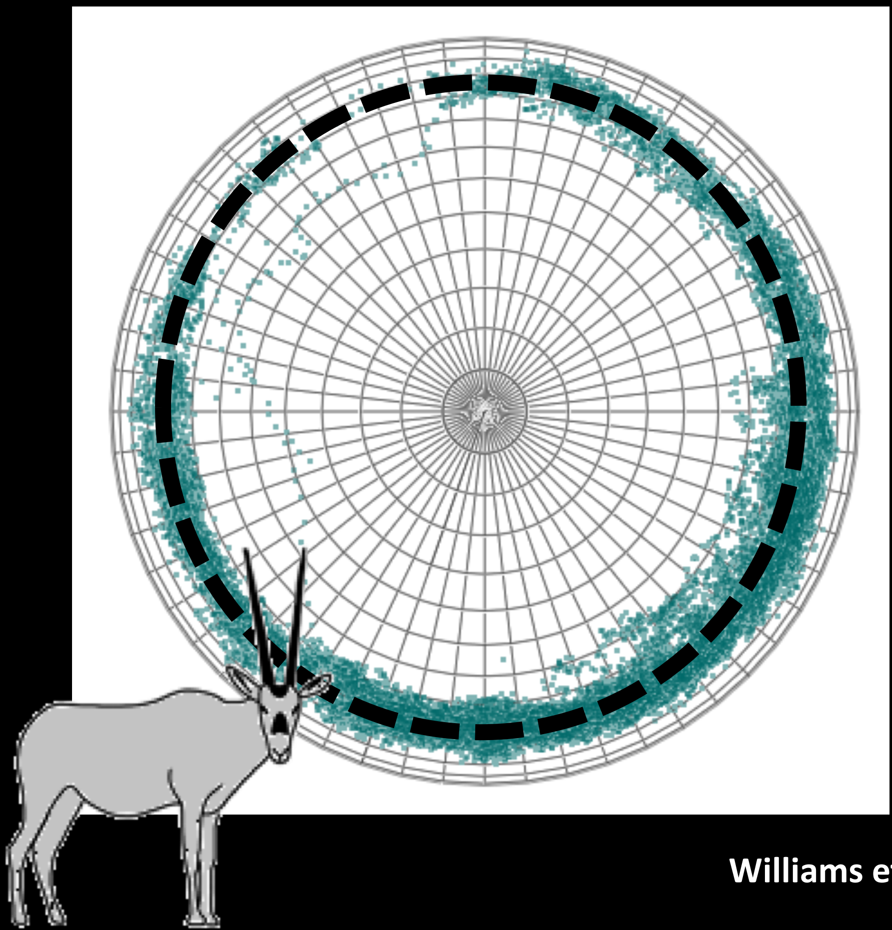


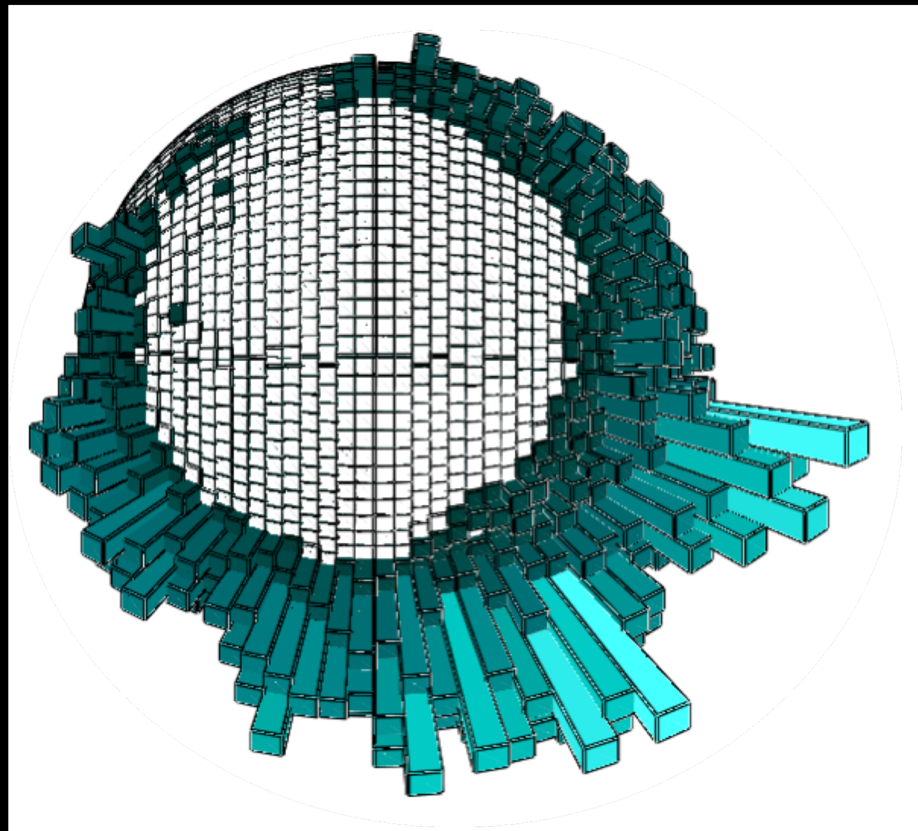

Gunner et al 2021


90° roll
rotation in yaw
90° pitch
a)
b)

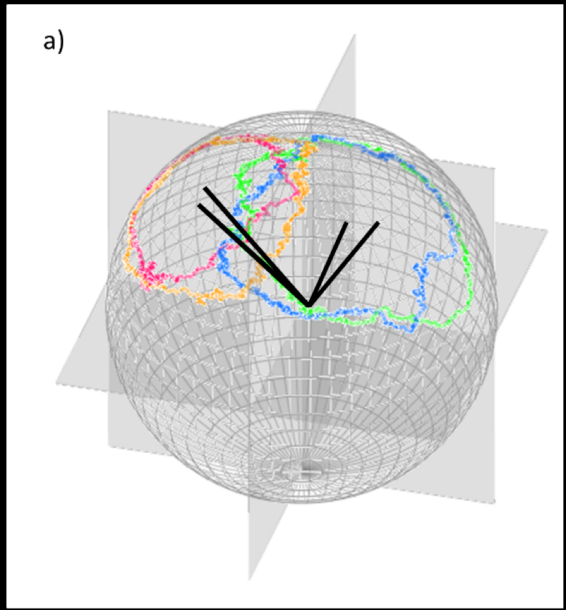
# ormal Operational Plane

Adds directionality to behaviour to examine interactions, vigilance and responsivness





**Williams et al. 2017** Identification of animal movement patterns using tri-axial magnetometry. Movement Ecology




# 'M-prints' to define behaviour!