Statistical Physics and Anomalous Dynamics of Foraging

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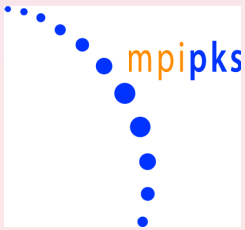
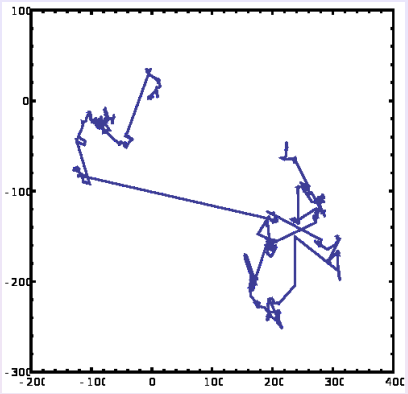
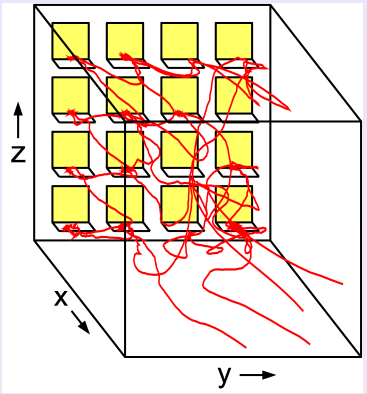
617. WE-Heraeus-Seminar on
Quantifying complex transport with Lévy walks
Physikzentrum Bad Honnef, 25 May 2016



Overview





Theme of this talk:

Can search for food by biological organisms be understood by mathematical modeling?

Two parts:

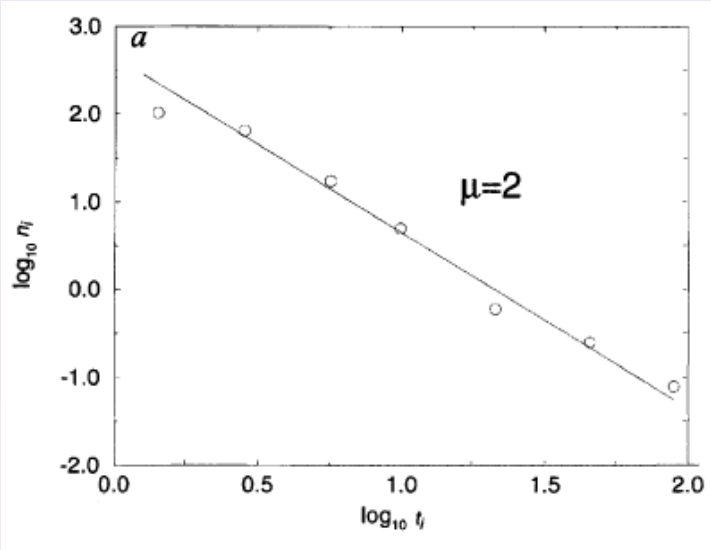
1. Lévy Flight Hypotheses: review and *Advanced Study Group* results
2. Foraging bumblebees: how to analyze biological data in view of stochastic modeling?

Lévy flight search patterns of wandering albatrosses

famous paper by Viswanathan et al., Nature **381**, 413 (1996):

for albatrosses foraging in the South Atlantic the flight times were recorded

the histogram of flight times



was fitted by a Lévy distribution (power law $\sim t^{-\mu}$)

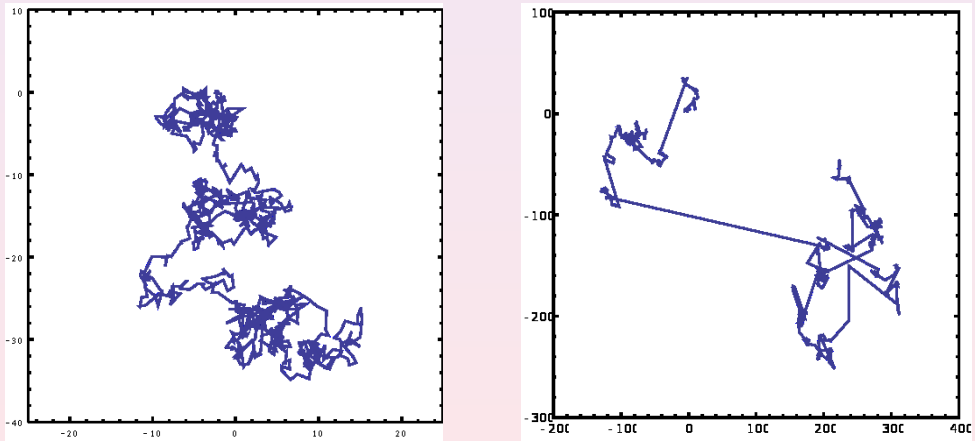
- may be due to the food distribution on the ocean surface being scale invariant: **Lévy Environmental Hypothesis**

Optimizing the success of random searches

another paper by Viswanathan et al., Nature **401**, 911 (1999):

- question posed about *"best statistical strategy to adapt in order to search efficiently for randomly located objects"*
- random walk model leads to the **hypothesis:**

Lévy flights provide an *optimal search strategy* for *sparse, randomly distributed, immobile, revisitable targets in unbounded domains*



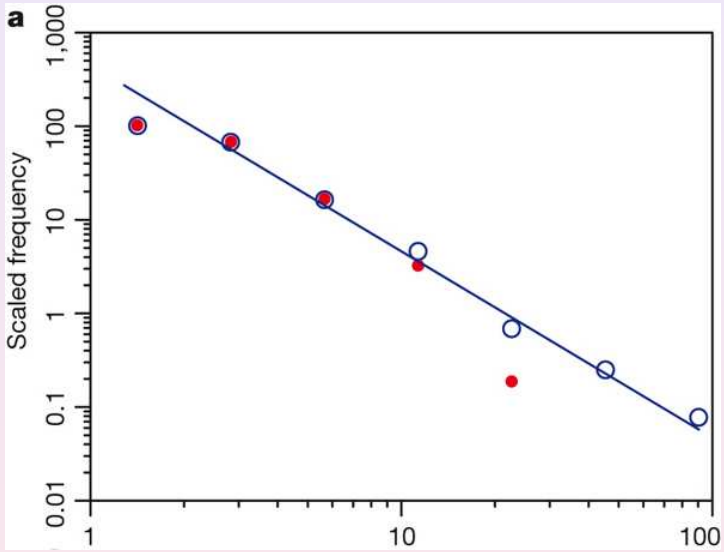
Brownian motion (left) vs. **Lévy flights** (right)

- yields the *second* **Lévy Foraging Hypothesis**

Revisiting Lévy flight search patterns

Edwards et al., Nature **449**, 1044 (2007):

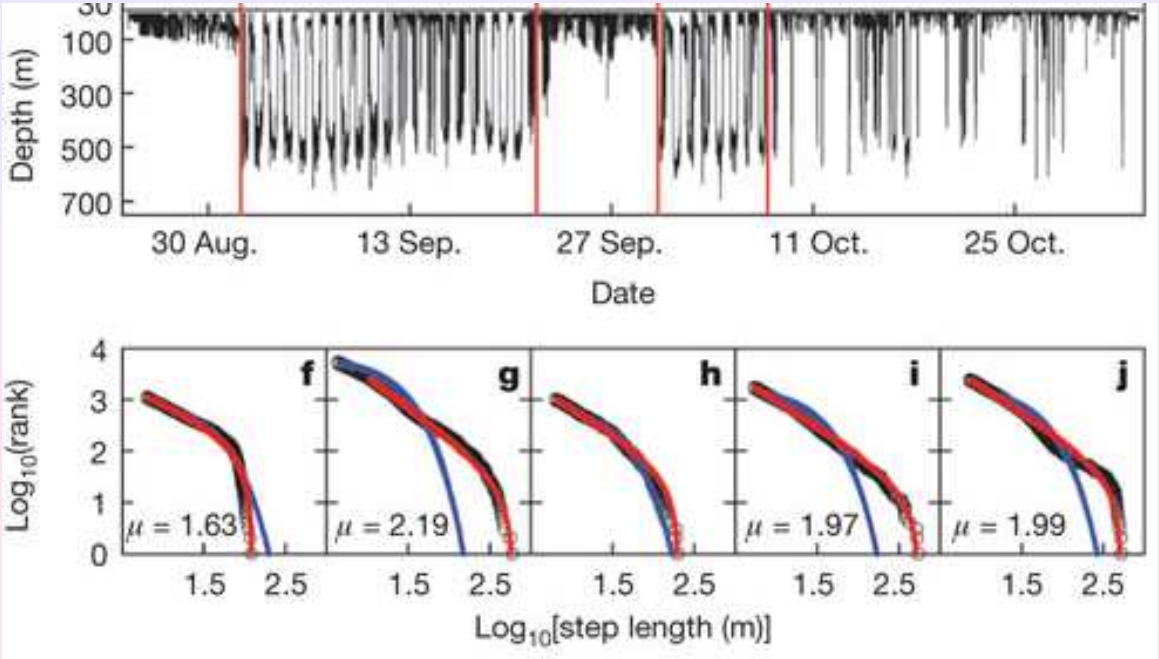
- Viswanathan et al. results revisited by correcting old data (Buchanan, Nature **453**, 714, 2008):



- **no Lévy flights:** new, more extensive data suggests (gamma distributed) stochastic process
- but claim that **truncated Lévy flights** fit yet new data Humphries et al., PNAS **109**, 7169 (2012)

Lévy Paradigm: Look for power law tails in pdfs

Humphries et al., Nature **465**, 1066 (2010): blue shark data



blue: exponential; red: truncated power law

- ⊖ velocity pdfs extracted, *not* the jump pdfs of Lévy walks
- ⊕ environment explains Lévy vs. Brownian movement
- ⊖ data averaged over day-night cycle, cf. oscillations

Summary: two different Lévy Flight Hypotheses

to be published

Bartumeus, Boyer, Chechkin, Giuggioli, RK, Pitchford, Watkins (2015)

Beyond the Lévy Flight Hypothesis

to be published

Bartumeus, Boyer, Chechkin, Giuggioli, RK, Pitchford, Watkins (2015)

Further work by the Advanced Study Group

1. Taylor-King et al.: approximate derivation of a fractional diffusion equation for short-range correlated Lévy walks in the superdiffusive regime for $t \to \infty$:

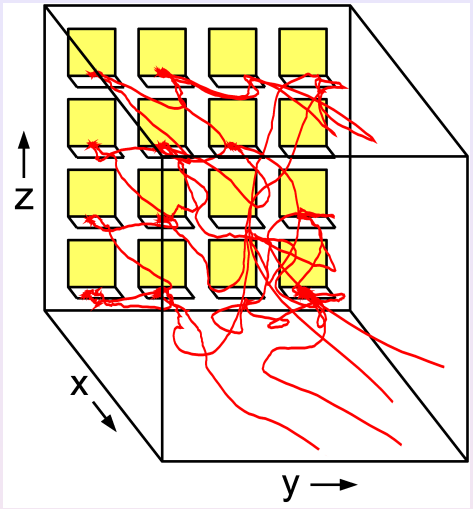
$$\frac{\partial f(x,t)}{\partial t} = K_\alpha \frac{\partial^\alpha f(x,t)}{\partial |x|^\alpha} + K_B \frac{\partial^2 f(x,t)}{\partial x^2}$$

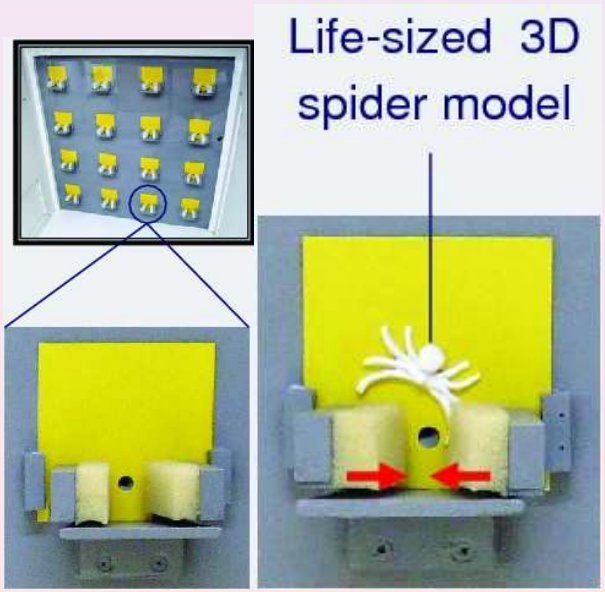
2. Palyulin et al.: search reliability and efficiency assessed for such Lévy-Brownian motion; $\alpha = 1$ not necessarily optimal $\Rightarrow$ **see poster!**

3. Blackburn et al.: first passage and first arrival problems for Lévy walks studied numerically

Foraging bumblebees: experiment

- tracking of **bumblebee flights** in the lab: foraging in an artificial carpet of **flowers with or without spiders**
- **no test** of the Lévy hypothesis but work inspired by the *paradigm*





safe and **dangerous** flowers

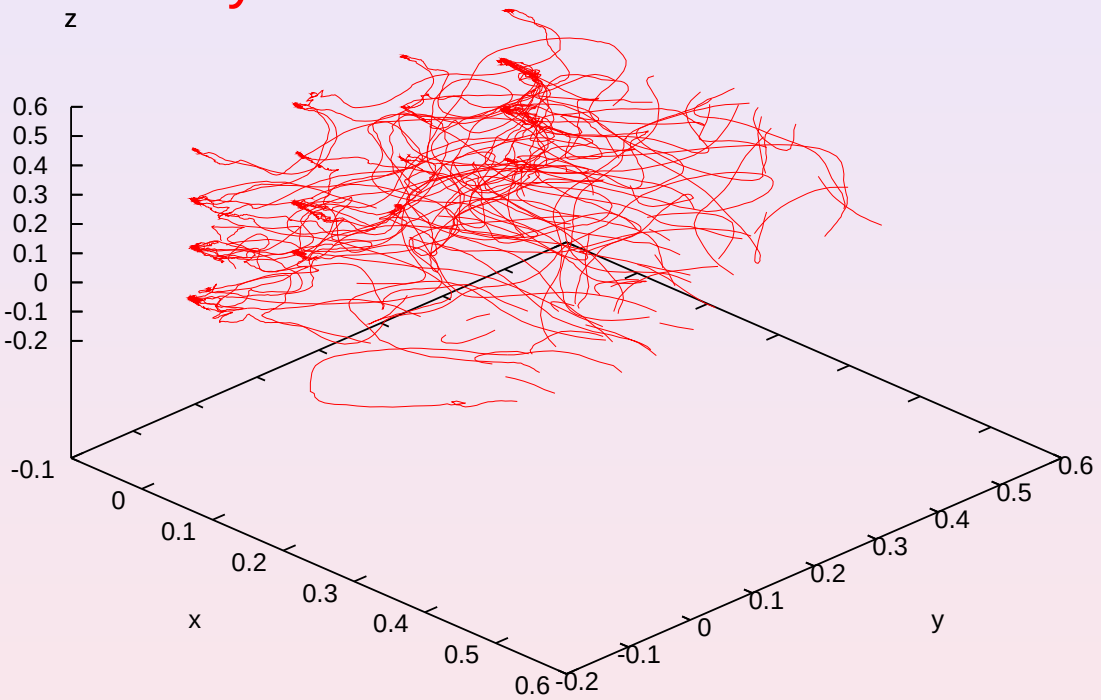
three experimental stages:

1. spider-free foraging
2. foraging under predation risk
3. memory test 1 day later

Ings, Chittka (2008)

Bumblebee experiment: two main questions

1. What type of motion do the bumblebees perform in terms of stochastic dynamics?

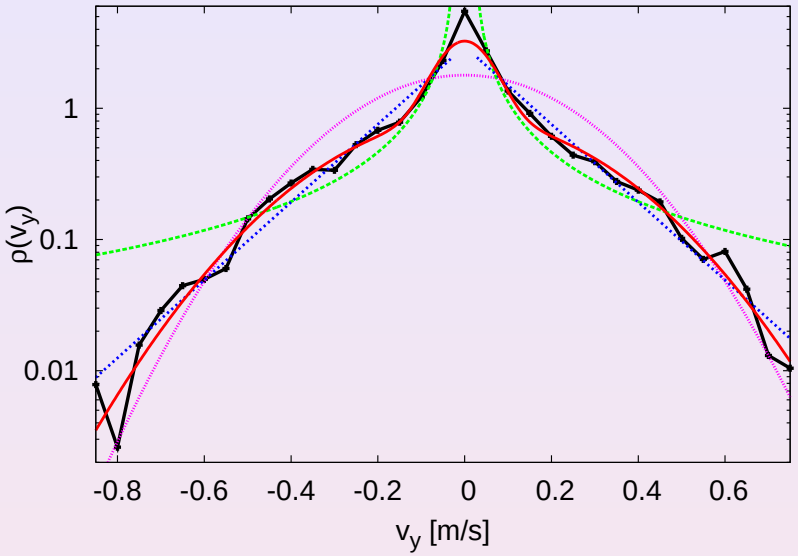


2. Are there changes of the dynamics under variation of the environmental conditions?

Flight velocity distributions

experimental **probability density** (pdf) of bumblebee v_y**-velocities** without spiders (bold black)

best fit: mixture of 2 Gaussians, cp. to exponential, power law, single Gaussian

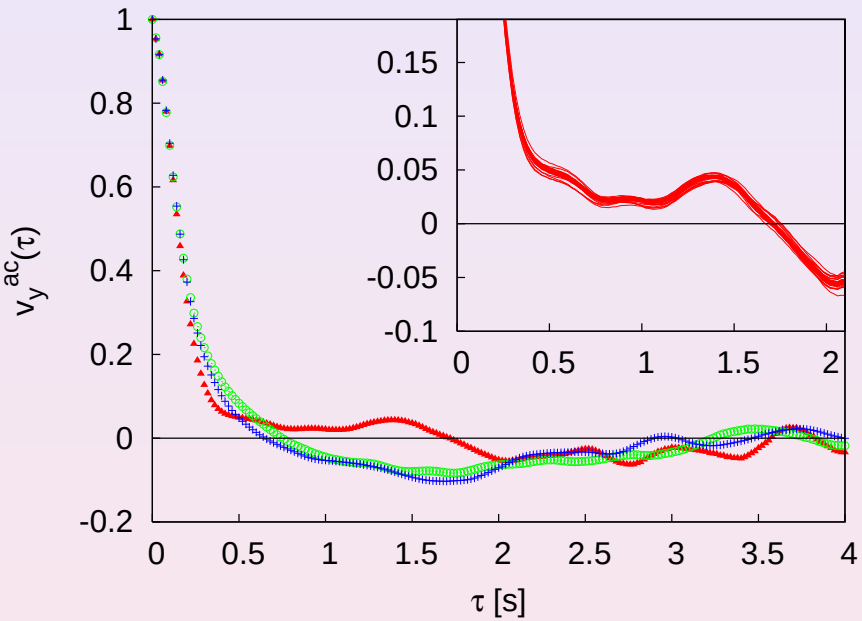


biological explanation: models spatially different flight modes near the flower vs. far away, cf. intermittent dynamics

big surprise: no difference in pdf's between different stages under variation of environmental conditions!

Velocity autocorrelation function || to the wall

$$V_y^{AC}(\tau) = \frac{\langle (v_y(t)-\mu)(v_y(t+\tau)-\mu)\rangle}{\sigma^2}$$



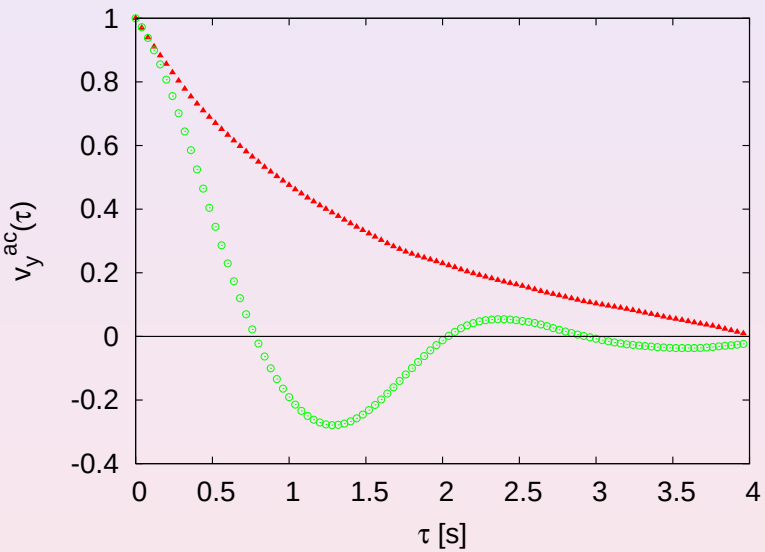
3 stages: spider-free, predation thread, memory test

all changes are in the flight correlations, *not* in the pdfs

model: Langevin equation

$$\frac{dv_y}{dt}(t) = -\eta v_y(t) - \frac{\partial U}{\partial y}(y(t)) + \xi(t)$$

η: friction, ξ: Gauss. white noise



result: velocity correlations with repulsive interaction U bumblebee - spider off / on

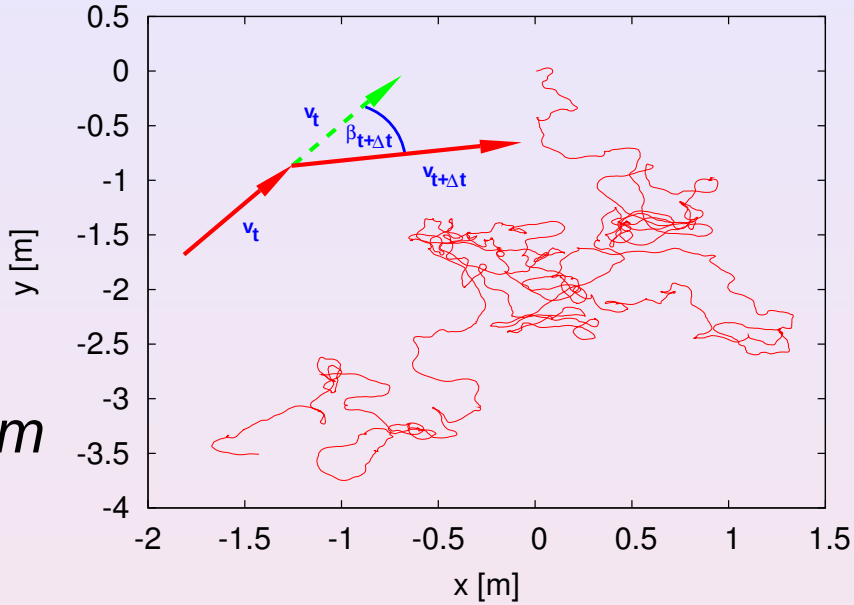
Lenz et al., PRL **108**, 098103 (2012)

Modeling free bumblebee flights

reorientation model:

describe 2d movement in comoving frame by

- speed $v(t) = const.$
- turning angle $\beta(t) = \xi(t)$ as random variable from *non-uniform pdf* modeling persistence

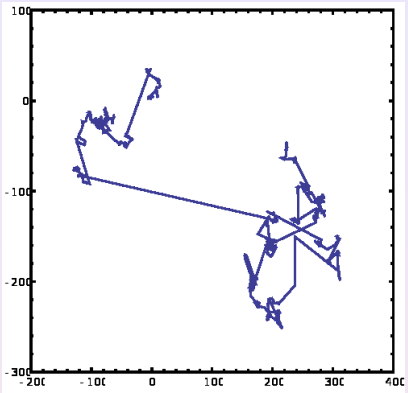


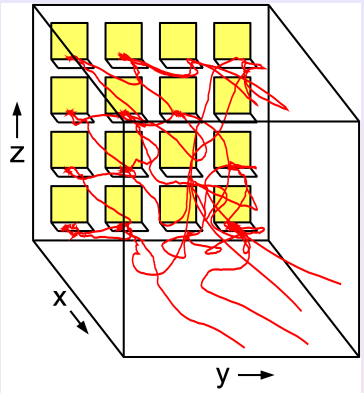
generalized model for bumblebee flights far away from flowers constructed from experimental data:

- $\beta(t) = \xi_v(t)$: power law correlated Gaussian noise
- $\frac{dv}{dt} = g(v(t)) + \psi(t)$: generalized Langevin equation with anti-correlated Gaussian noise

F.Lenz, A.V.Chechkin, RK, PLoS ONE 8, e59036 (2013)

Summary





- Be careful with (power law) paradigms for data analysis.
- Other quantities may contain crucial information about foraging; **example:** bumblebee flights under predation thread.
- **Conclusion of our Advanced Study Group:**
  A more general biological embedding is needed.

Thanks to the Advanced Study Group

Statistical physics and anomalous dynamics of foraging

MPIPKS Dresden, July - December 2015

F.Bartumeus (Blanes, Spain), D.Boyer (UNAM, Mexico), A.V.Chechkin (Kharkov, Ukraine), L.Giuggioli (Bristol, UK), *convenor:* RK (London, UK), J.Pitchford (York, UK)

ASG webpage: http://www.mpipks-dresden.mpg.de/~asg_2015

Literature:

RK, *Extrem gesucht*, Physik Journal 14(12), 22 (2015)

RK, *Search for food of birds, fish and insects*, book chapter (review; preprint, 2016)