Stanford University

Concurrent Observations of Meteor Head Echo Populations at Multiple High-Power Radar Facilities

Space Environment and Satellite Systems
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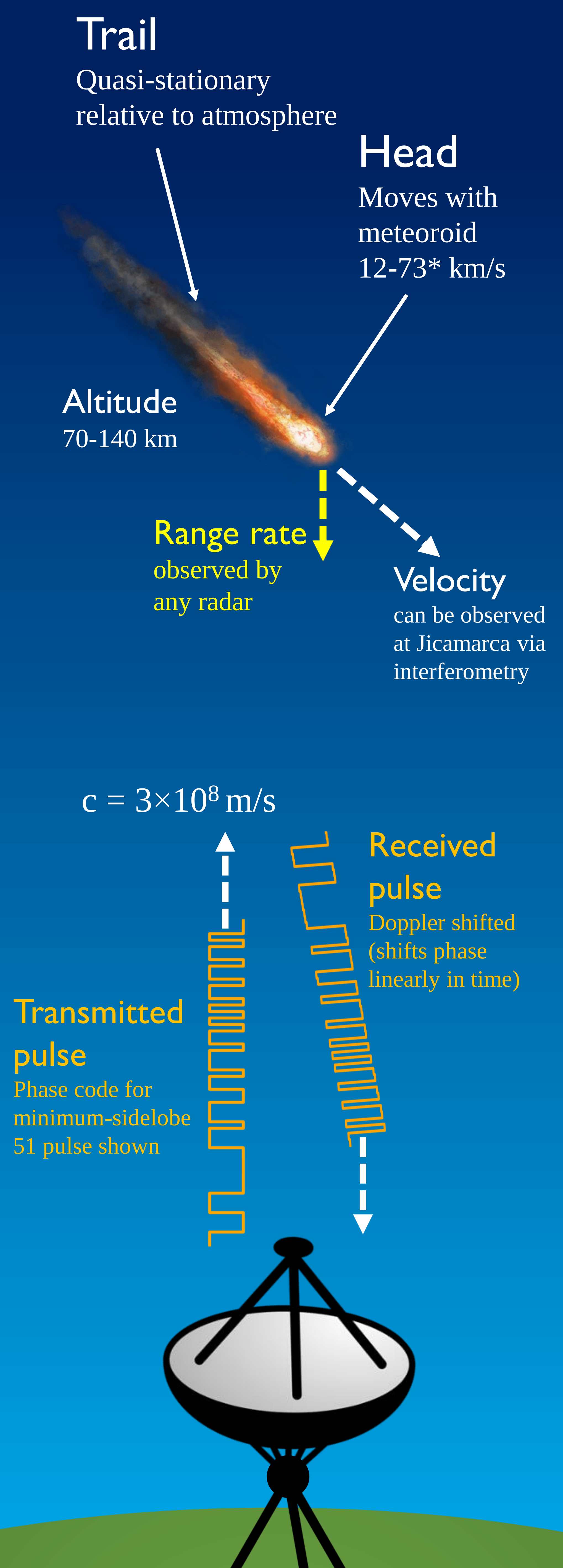
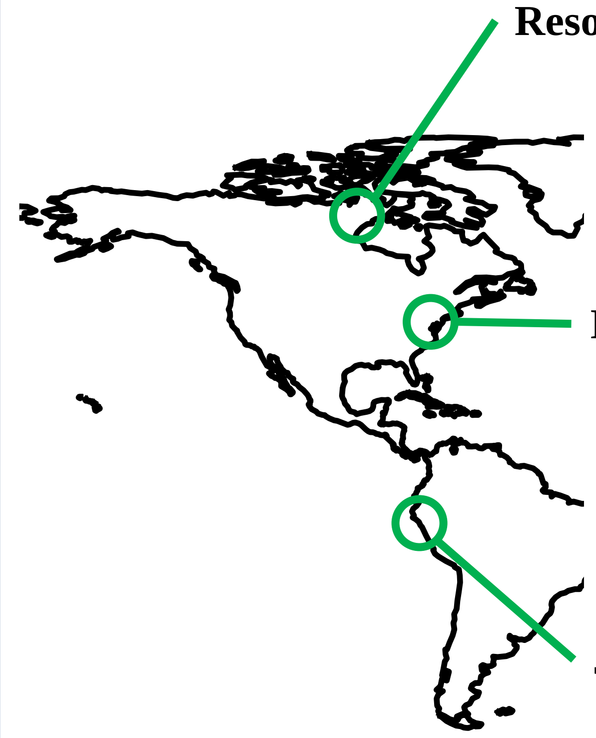


*Assumes meteoroid originates from within solar system and does not encounter third-body perturbations

Meteor Experiment

Simultaneous head echo observations at three high-power radar facilities were taken before dawn on October 10th & 11th, 2019.



Resolute Bay Incoherent Scatter Radar (RISR-N)

Carrier frequency:	442.5 MHz
Pulse waveform:	Minimum Sidelobe 51, 1 µs baud
Pulse length:	51 µs
Inter-Pulse Period:	1.4 ms
Beam angle:	26° azimuth, 86° elevation

Millstone Hill Observatory (MHO)

Carrier frequency:	440 MHz
Pulse waveform:	Barker-7, 6 µs baud
Pulse length:	42 µs
Inter-Pulse Period:	2 ms
Beam angle:	270° azimuth, 45° elevation (not zenith-pointing!)

Jicamarca Radio Observatory (JRO)

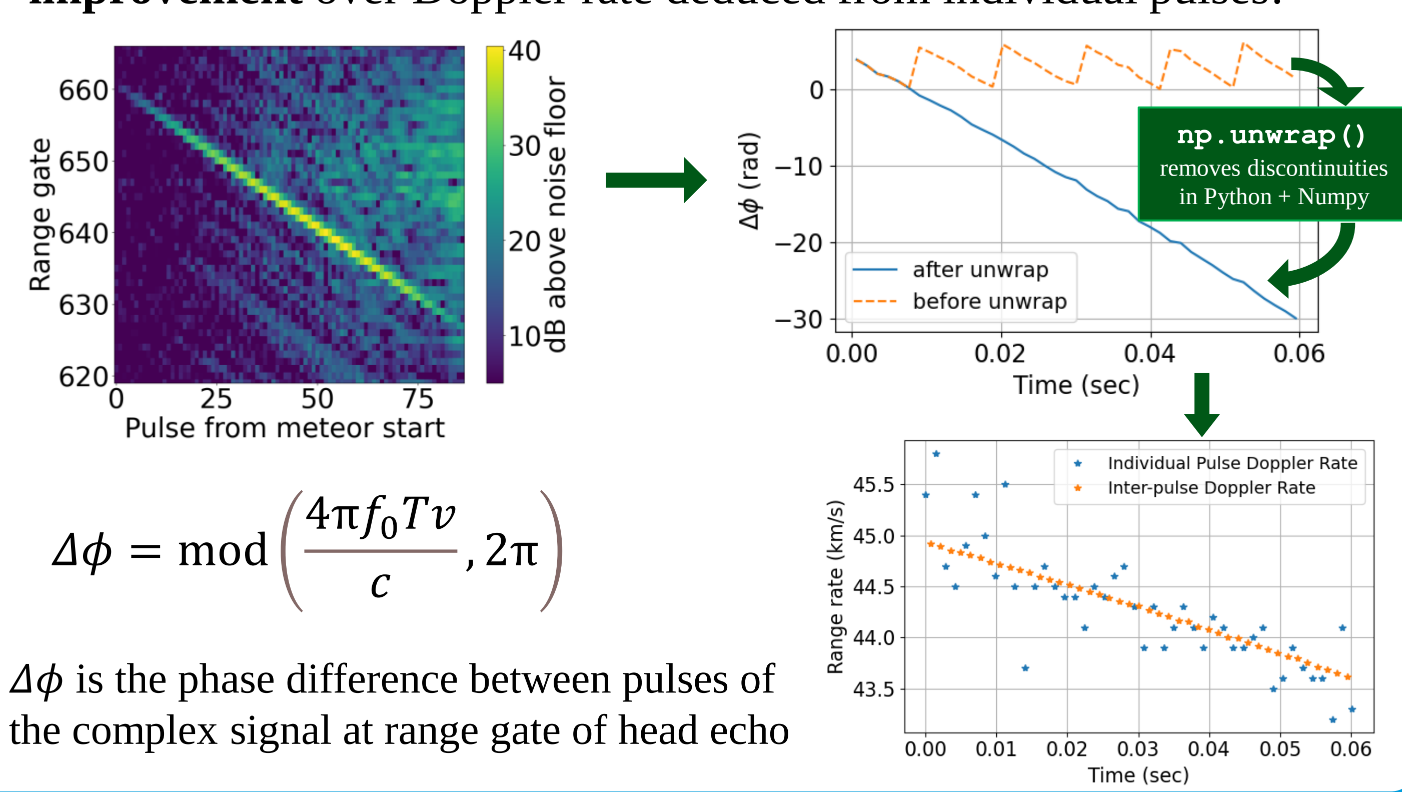
Carrier frequency:	50 MHz
Pulse waveform:	Minimum Sidelobe 51, 1 µs baud
Pulse length:	51 µs
Inter-Pulse Period:	1.25 ms
Beam angle:	90° elevation

Motivations

- Determine meteor decelerations more accurately, and estimate said accuracy
  - Previous work calculates decelerations but does not quantify accuracy[1]
- Directly compare head echo populations between facilities without diurnal, seasonal, or space weather observation biases
  - Assess effect of radar instrument parameters and beam direction
- Future: Infer lower thermospheric neutral densities via meteor properties including deceleration, and understand latitudinal coupling

Phase Differencing Technique

Considering phase difference between pulses of matched filter head echo signal yields **order-of-magnitude range rate accuracy improvement** over Doppler rate deduced from individual pulses! [2]



$$\Delta\phi = \mathrm{mod}\left(\frac{4\pi f_0 T v}{c}, 2\pi\right)$$

$\Delta\phi$ is the phase difference between pulses of the complex signal at range gate of head echo

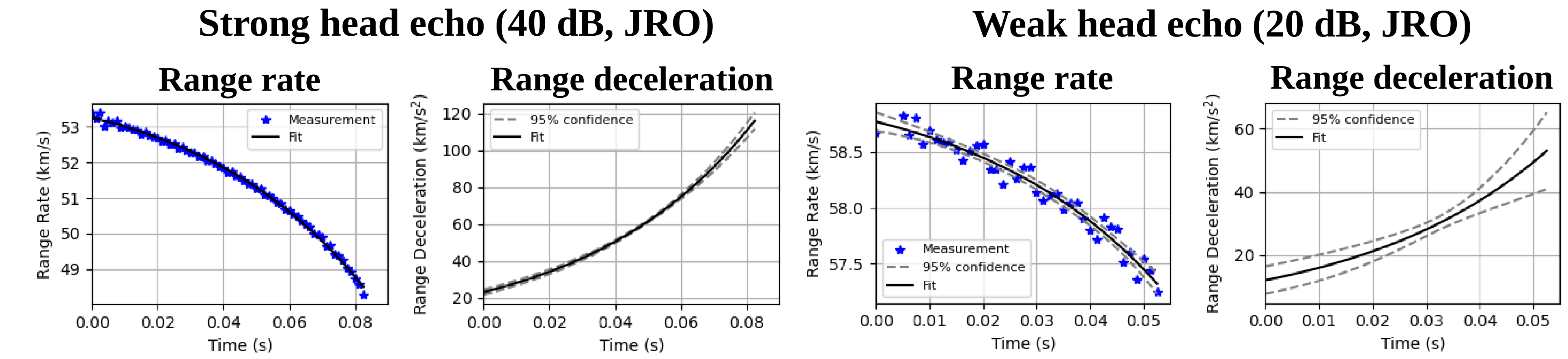
Quantifying Deceleration

Range rate profiles via phase differencing still too noisy for finite-differencing. Therefore, derivative of range rate exponential fit gives us range deceleration. Covariance transform used to determine 95% confidence intervals of deceleration:

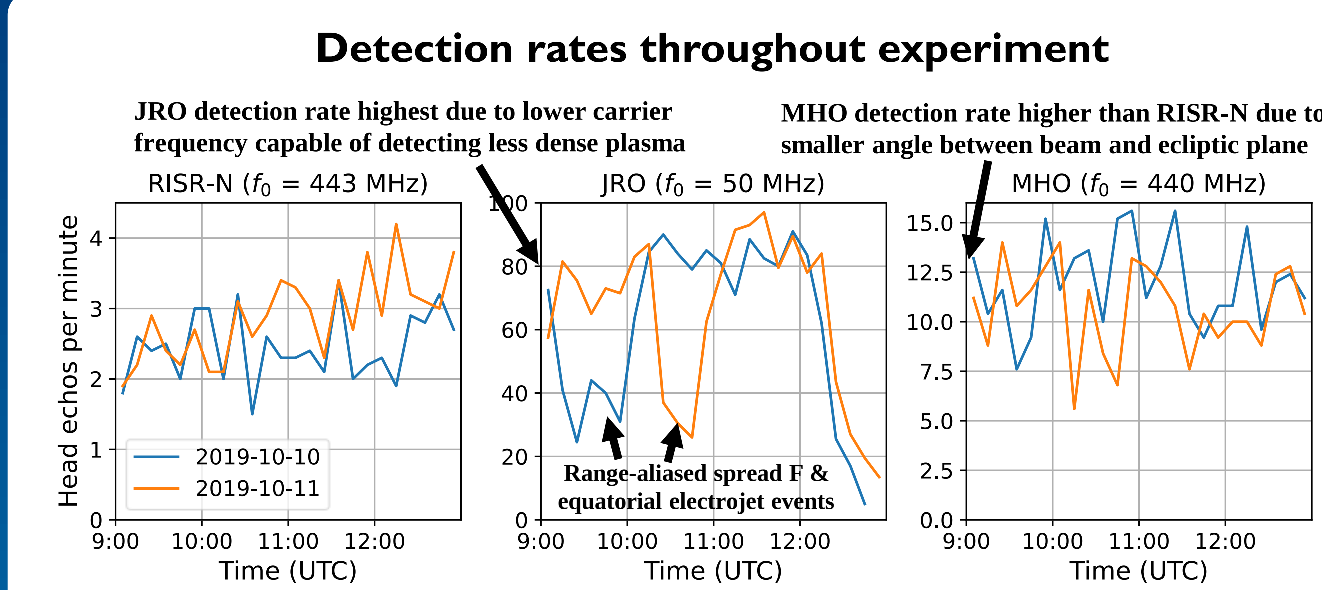
$$v_{fit} = a + be^{\lambda t}$$

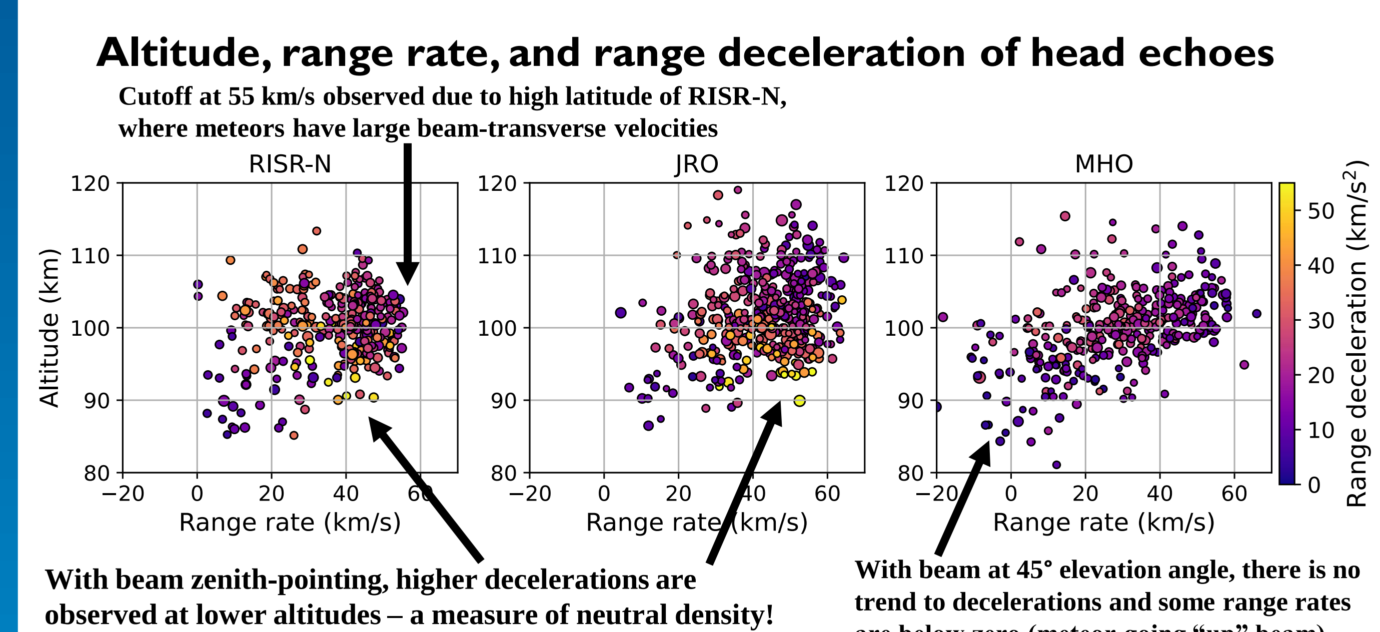
$$\sigma_{v_r}^2 = J_1 \Sigma J_1^T \qquad J_1 = \left[\frac{\partial v_{fit}}{\partial a}, \frac{\partial v_{fit}}{\partial b}, \frac{\partial v_{fit}}{\partial \lambda}\right]$$

Σ is the covariance matrix for parameters a, b, and λ from curve fit



Results & Population Analysis





Detection rates are consistent with previous experiments.[3][4][5] They remain relatively constant throughout duration except at JRO where clutter sometimes obscures head echoes.

We do not measure decelerations above 60 km/s^2, unlike a previous comparative study where many 100-1000 km/s^2 head echoes are observed at the Poker Flat and Sondrestrom radars.[1] We expect similar observations between Poker Flat and RISR-N (both AMISR facilities), so further investigation is necessary. Could be a discrepancy in measurement method or radar detectability.

Conclusions and Future Work

- Facility latitude and beam pointing direction are significant factors for head echo detectability
- Ability of phase-differencing technique to improve range rate/deceleration measurement accuracy for phase-coded pulses is demonstrated (±1 km/s^2 for range deceleration of strong head echoes)
- We do not observe high-deceleration meteors, unlike previous experiments
  - Likely a measurement or detectability discrepancy; future work will investigate further
- When beam is zenith-pointing, head echo range decelerations are sensitive to neutral atmosphere
  - Beam-transverse meteor velocity component remains unknown; future work will estimate it (RISR-N) or use available interferometric measurements (JRO)
  - Technique by Li et al.[6] will be modified to estimate neutral density profile at each facility

References

[1] Mathews et al., 2007 (previous head echo study)
[2] Loveland et al, 2011 (phase differencing to calculate range rate)
[3] Chau and Woodman, 2004 (detection rates at JRO)
[4] Sparks et al. (detection rates at an AMISR facility)
[5] Erickson et al., 2001 (detection rates at MHO)
[6] Li et al., 2016 (neutral density estimation)

Acknowledgements

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