



Sensory Information Systems Program

6 March 2012

Willard Larkin
Program Manager
AFOSR/RSL

Air Force Research Laboratory



Integrity ★ Service ★ Excellence

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2012 AFOSR SPRING REVIEW



PORTFOLIO OVERVIEW

Program manager: Willard Larkin

BRIEF DESCRIPTION OF PORTFOLIO:

- Auditory modeling for acoustic analysis
- Biological polarization optics & vision
- Sensori-motor control of bio- flight & navigation

SUB-AREAS IN PORTFOLIO:

Sensory Information Systems (3003/L)



Program Trends and Strategy:

TOPIC AREA OVERVIEW



Advanced Auditory Modeling:

40%



Scientific Question: How does the auditory brain parse acoustic landscapes, bind sensory inputs, adapt its filters, hear through noise and distortion? Could autonomous listening devices emulate neurology to match or exceed human auditory analysis, e.g., to detect and identify speech targets in noise and reverberation?

Polarization Vision & Optics:

12%



Scientific Question: How do natural photoreceptors detect and how do animal brains interpret polarization information? How is it used for nocturnal navigation or recognition of obscured targets? Can these unique bio-optical systems be emulated?

Sensorimotor Control of Flight & Navigation:

47%



**AFOSR
BioNavigation
Research
Initiative**

Scientific Question: How does neural control make natural, low-Reynolds No. flight autonomous, efficient, and robust? Discover principles of multisensory fusion, distributed sensors and actuators. Develop control laws for emulation in MAVs.

Strategy: Forge useful connections between math and biology



Grantees' Self-Organized Research Workshops (2011)



Neural Oscillations and Speech Perception.

24 May. Hosted by NYU.

Science & Applications for Bio-Inspired Navigation and Control.

23-25 May. Hosted by AFRL/RW.

Bio-Optics and Photoreception.

27-30 June. Hosted by U. Bristol.
Funded by the Rank Prize Foundation

Encoding for Auditory Representations.

22-23 August. Hosted by U. Washington.

Informational Masking & Binaural Hearing.

17-19 Nov. Hosted by Boston U.

Brain Rhythms and Cortical Computation.

18 Nov. Hosted by NYU.

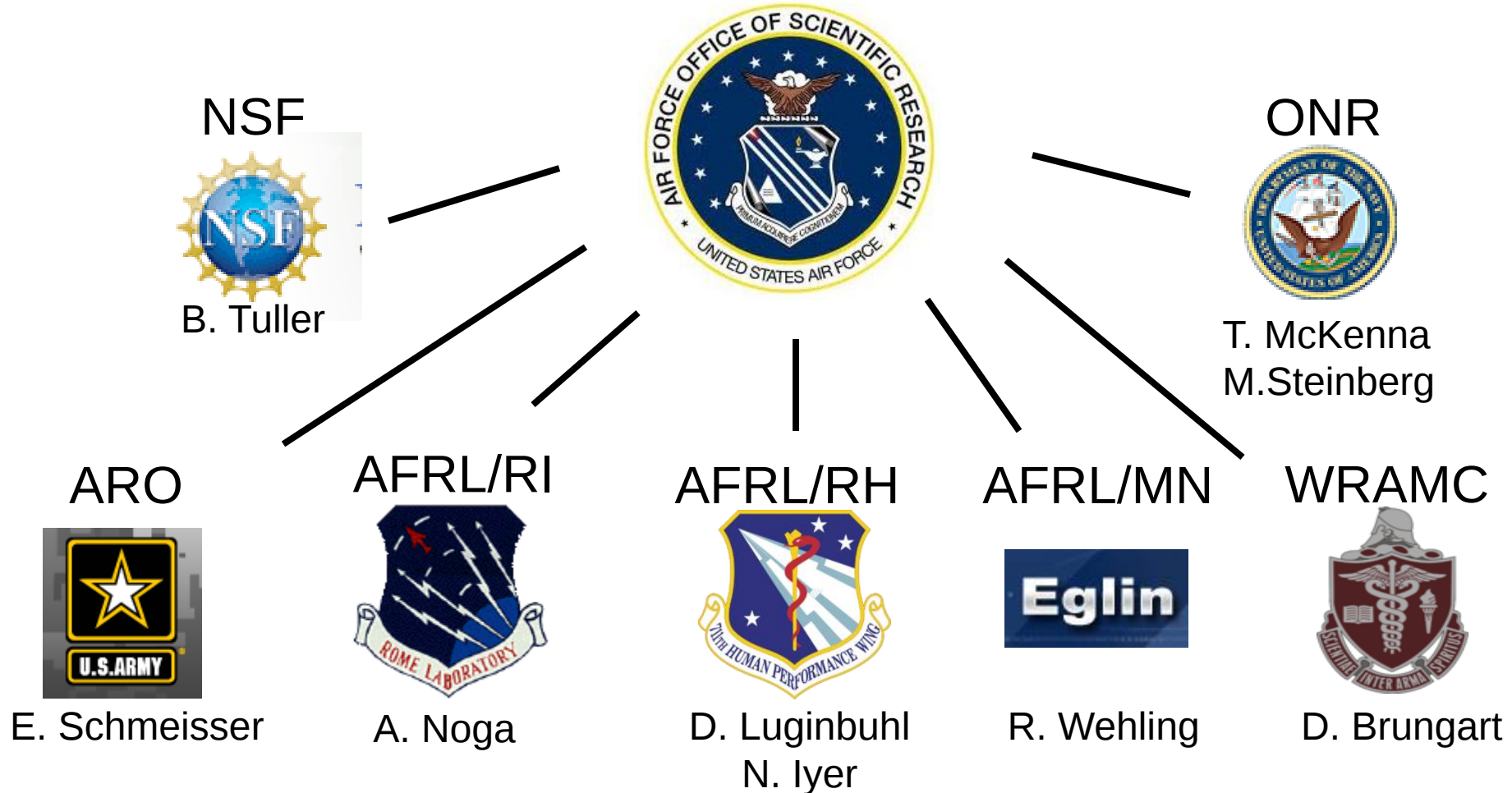
*Convened
by grantees;
No AFOSR
workshop
funding*



Sensory Information Systems Program



Primary Coordination





Sensory Information Systems Program -- People



Dr. Jennifer Talley,
Biology

Dr. Talley (Ph.D. 2010) was recruited from AFOSR-sponsored project at Case Western U. to insect flight lab at AFRL/Eglin



2012
Judith A. Resnik Medal
Dr. Pramod Varshney,
Syracuse U.



Dr. Eric Thompson,
Acoustics

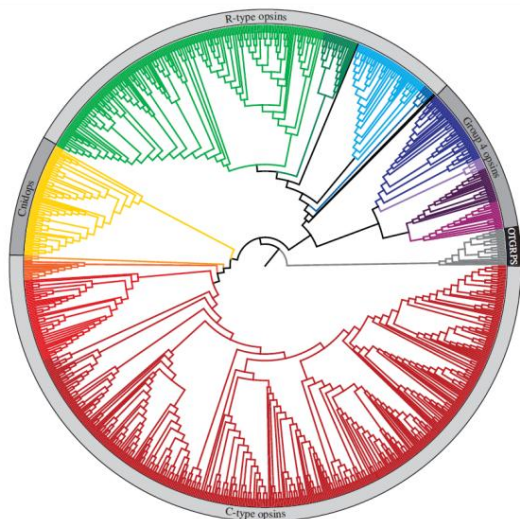
Dr. Thompson (Ph.D. 2009) was recruited from AFOSR-sponsored projects at Boston Univ. to psychoacoustics lab at AFRL/RH



RECENT HIGHLIGHTS



OPSIN MAP



**New Genomic
Analysis reveals
maximum-likelihood
phylogenetic model
for
Photoreceptor Opsins**



**AFOSR
Polarization Biology
Sub-program
featured in
J. Royal Society
Special Issue**

DR. KEY DISMUKES



**Keynote Speaker for
AFRL – Wright State
Internat. Symposium
on
Aviation Psychology**



Recent Transitions



TO: Navy: Bio-inspired method to classify acoustic sources, e.g., vehicles, humans, marine animals etc., using cortical auditory model. Dr. Sam Pascarelle, Advanced Acoustic Concepts, Inc.

TO: AFRL-- Eglin: Measurements and data on biological wide-field-of-view optical systems to enable 6.2 and 6.3 efforts in vision-based guidance and navigation. D. Stavenga, U. Groningen, N. Strausfeld, U. Arizona, M. Wehling, et al.

TO: Bloedel Hearing Institute: New, patented method to improve auditory coding in cochlear implants. Developed by Dr. Les Atlas, U. Wash. Dr. Jay Rebenstein will develop commercial applications.

TO: AFIT: Techniques in electrophysiology and neuroanatomy for mechanical engineering projects to emulate flapping wing flight. Dr. Mark Willis, Case Western U., Dr. Anthony Palazotto, AFIT

TO: DARPA: System for adaptive, autonomous control of robotic movement, based upon hierarchical neural model of biological control. Roger Quinn & Roy Ritzmann, Case West. U.; G. Pratt, DARPA.



Autonomous Steering: Transition to Army MAST

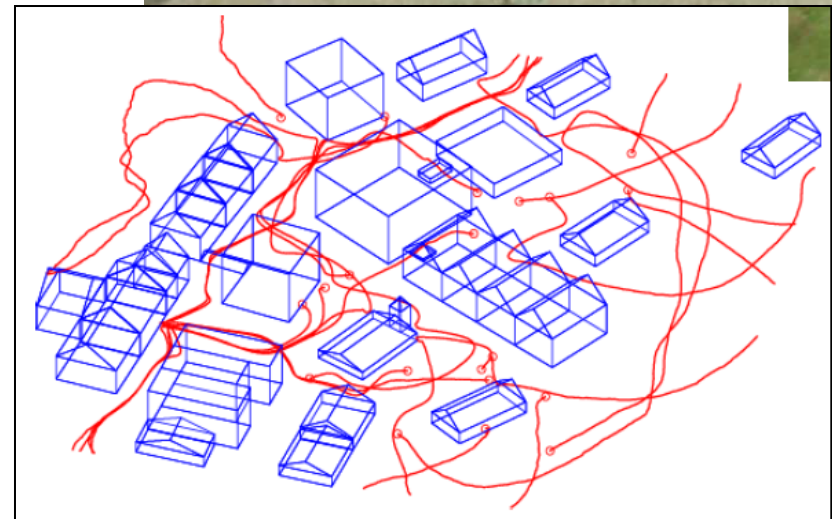


**Quadrotor implements
autonomous 3D navigation using
wide field-of-view optic flow**

Inspiration:

- Insect Compound Eye Research
Eglin AFB 6.1 (M. Wehling, et al.)
- Insect Visual Target Detection Modeling
Tanner Research (P. Shoemaker.)
U. Adelaide (D. O'Carroll)
- Insect Flight Behavior Modeling
U. MD. (J. S. Humbert)

Microautonomous Systems and Technology
<http://www.avl.umd.edu/>





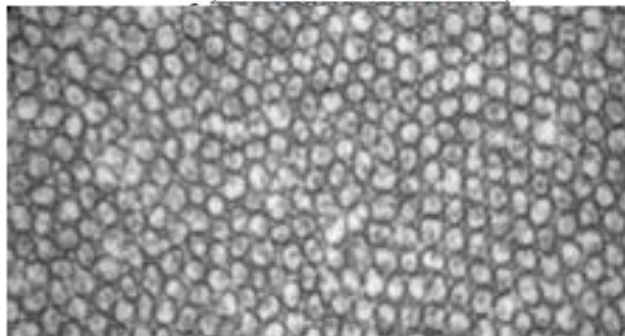
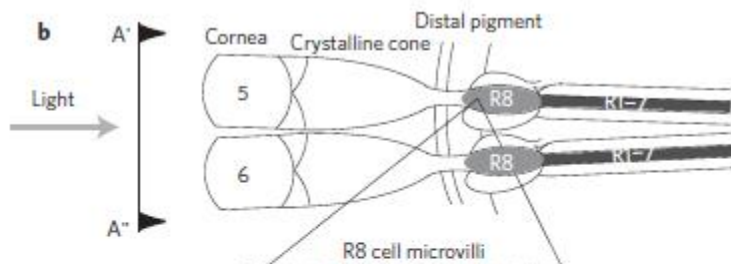
Bio-Emulation Progress

From 6.1 at U. Queensland, U. Bristol, & UMBC



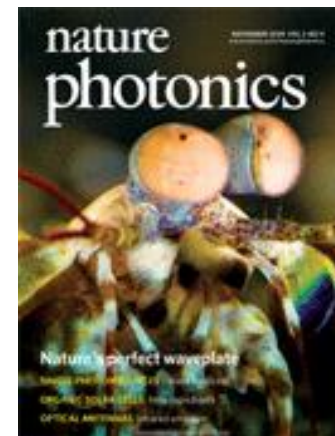
1. Discovery:

Polarization photoreceptor imparts
 λ -invariant 90° phase delay



Honeycomb structure of
photoreceptor's optical
retarder membrane

2. Optical Modeling:



“Nature’s Perfect Waveplate”

Key property:
Intrinsic birefringence of microvilli
elements, in balance with form
birefringence, yields wavelength-
invariant phase delay.

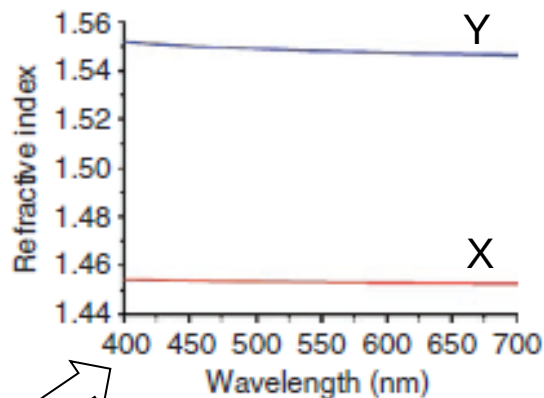
3. Emulation →



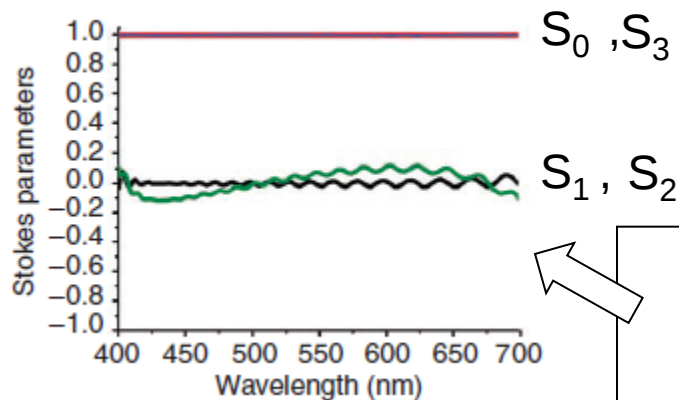
Nano-Rod Deposition Recipe Emulates Biological Achromatic Phase Retarder



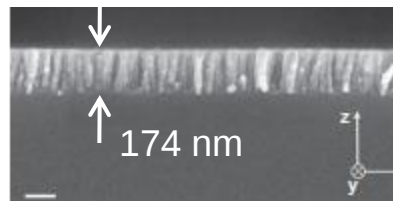
Deposition Angles Alternate
in Ta_2O_5 Nano-rod Layers



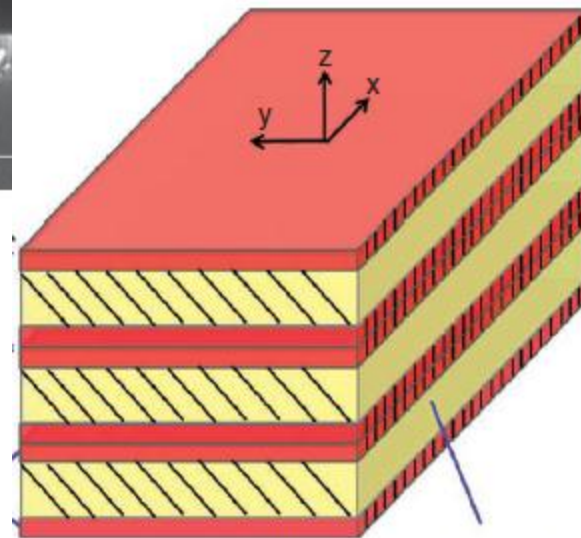
Nano-rod array
exhibits birefringence



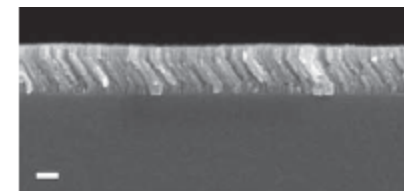
All 4 Stokes
parameters remain
nearly constant in a
multi-layer structure



Upright nanorods
(red layers)



Tilted nanorods
(yellow layers)



Yi-Jun Jen, Nature Comm. 21 June 2011



Auditory Modeling for Acoustic Analysis – Extramural Grants



- **L. Atlas** (U. Washington):
New approach to modulation representation and filtering.
- **E. Bleszynski** (Monopole Research):
Math model of bone- & tissue-conducted sound
- **M. Elhilali** (Johns Hopkins U.):
Cortical model for acoustic scene segregation
- **O. Ghitza** (Boston U.):
Theory of speech parsing via brain rhythms
- **W. Hartmann** (Mich. State U.):
Sound localization
- **G. Kidd** (Boston U.):
Informational masking & speech segregation
- **R. Kumaresan & P. Cariani** (U. Rhode Is. & Harvard):
Spectro-temporal codes for auditory signal representation
- **D. Wang** (Ohio State U.):
Computational auditory scene analysis

***Mathematical and
Psychoacoustic
Research to
Understand & Emulate
the Human Listener's
Auditory Capabilities
and to Enhance these
Capabilities where
Possible.***

**4 NEW TECHNICAL
ADVANCES**





Pointillistic Speech Coding

G. Kidd, Boston Univ., 2011

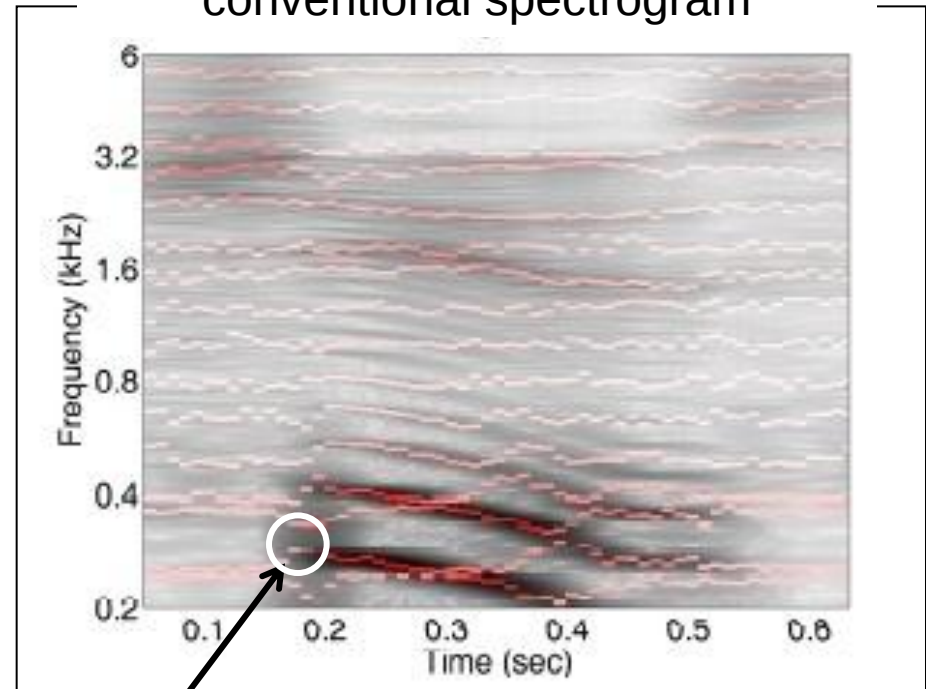


New Technique Isolates Informational & Energetic Masking

Background:

- What listeners can hear in real, multisource acoustic environments is more constrained by informational masking, than by direct, energetic interference of one sound by another.
- AFOSR seeks techniques to study & suppress informational masking.
- Sparse pointillistic coding leaves speech remarkably intelligible, eliminates energy overlaps, isolates effects of informational “cross-talk.”
- Briefed to AFRL/RI in Dec. 2011.

A sparse, pointillistic rendition of the word “SHOES,” overlaid on the conventional spectrogram



Each time/frequency slice of speech has been replaced with a matching cosine fragment.

Red color scales the intensity.



Transaural Synthesis: A New Technical Advance in Auditory Measurement

W. Hartmann, MSU.



Scientific Challenge:

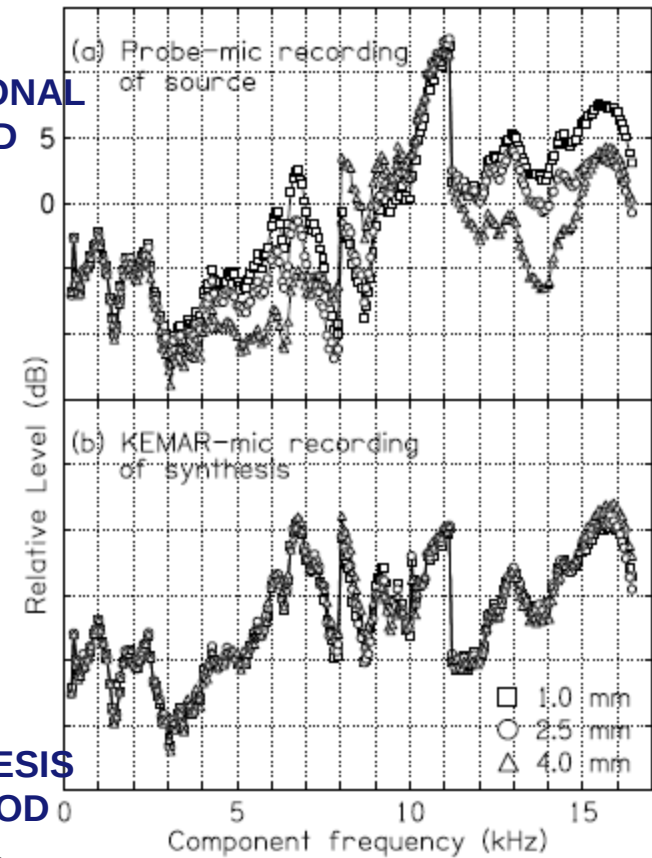
How does binaural hearing disclose the locus of sound in real 3D environments?

Transaural Synthesis Method:

- Eliminates inter-aural crosstalk, compares localization judgments with precisely known acoustic parameters in the ear canals.
- Tests auditory theory by manipulating Interaural phase and amplitude, comparing real sounds with “virtual” sounds.
- Tests in real rooms & environments, with varied reverberation – no headphones.
- Self-compensates for probe-tube positions, enables precise reproducibility.

NOISE SPECTRUM MEASUREMENTS IN EAR CANAL

CONVENTIONAL METHOD



SYNTHESIS METHOD



Acoustic Source Separation:

Recovering Multiple Speech Signals from a Single Channel



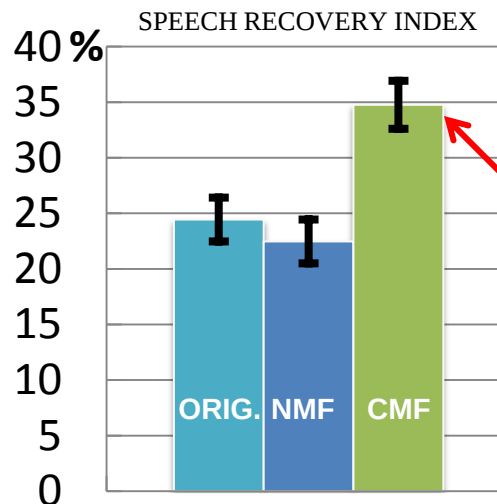
Research Challenge:

Devise a factorization method to:

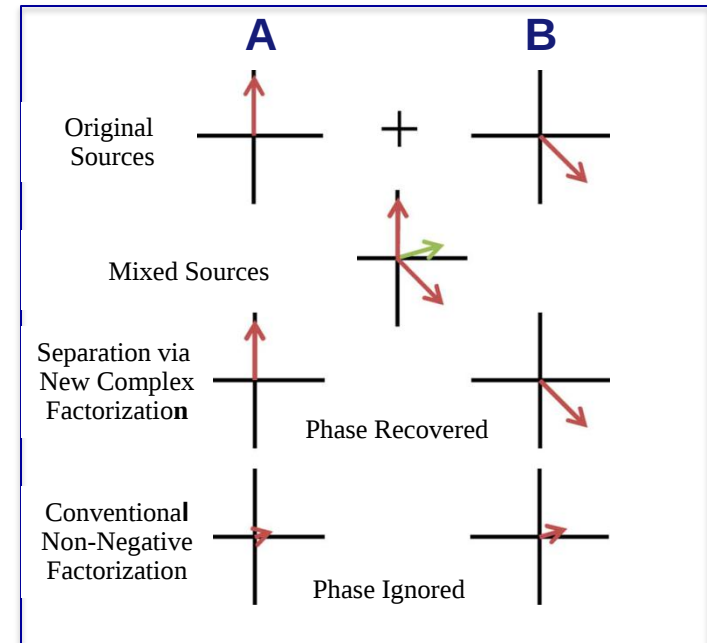
- Recover both magnitude and phase for each speech component superimposed in a single channel
- Avoid trial-and-error basis selection.



Brian King
U. Washington
Ph.D. Candidate
&
RH Summer Student



Why Phase Matters:



New Complex Matrix Factorization method solves superposition and phase problems, eliminates ad hoc basis selection, & Improves speech recognition scores



How do Human Listeners Sort Overlapping Speech Information ?

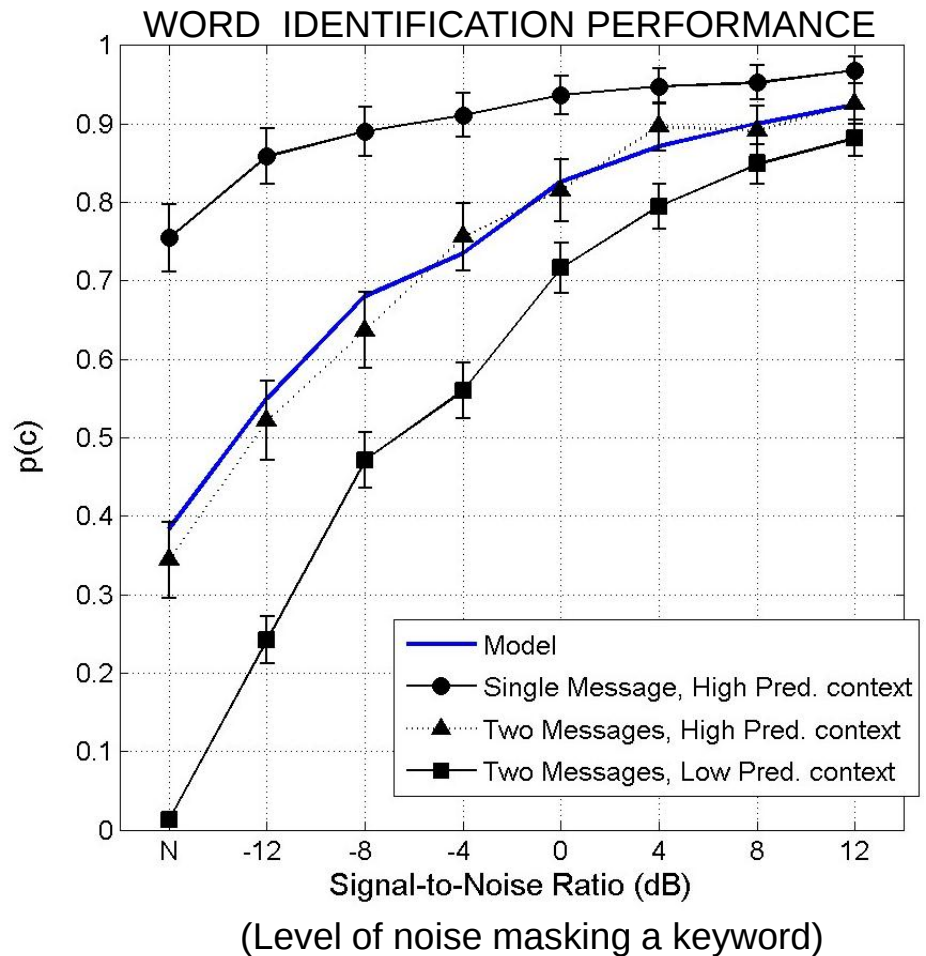


Scientific Question:

When each ear receives a distinct message, can the auditory brain extract key information from both?

Surprising Result:

Manipulation of word predictability in dichotic listening strongly supports a model of attention-switching, rejects hypothesis of divided attention.



N. Iyer, B. Simpson, Principal Investigators, 711 th HPW/AFRL/RHCB Battlespace Acoustics



Coherent Modulation Analysis:

Dr. Les Atlas, University of Washington



Mathematical challenge:

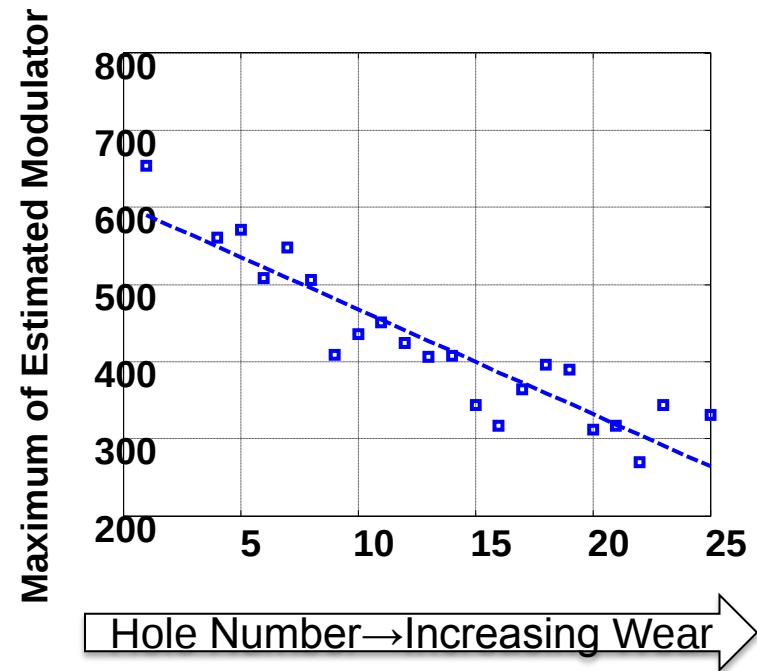
Estimate and separate the linear time-invariant and frequency-invariant components of an acoustic source.

Approach:

Theory of Complex Modulation Filtering, devised by Prof. Les Atlas (originally for analysis of speech signals.)

Unexpected Application:

A simple, one-microphone set-up detects hole quality while drilling in airframe composite material.





Sensori-motor Control of Natural Flight and Navigation

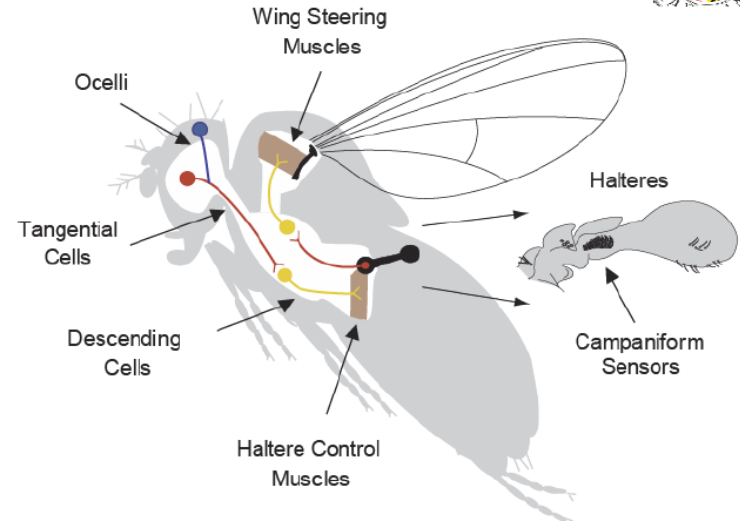


Fundamental Question:

What underlying principles drive biology's design of actuation and sensing architectures?

Motivating Observations from Insect Research :

- Sensors are “noisy,” redundant, distributed in non-orthogonal coordinates.
- Inputs fuse across modalities prior to activating flight muscles.
- No conventional distinctions between estimate/control or inner/outer loop
- Sensors differ radically in bandwidth & temporal response, e.g., vision lags mechanoreception.



Insect Lab, Eglin AFB
Dr. Jennifer Talley



Sensori-motor Control of Natural Flight and Navigation



▲ = AFOSR BIO-NAVIGATION FUNDING INITIATIVE

▲ T. Daniel (U. Washington):
Wing mechanosensor functions.

J. Evers (AFRL/RW):
Natural 3D flight dynamics

M. Frye (UCLA):
Higher-order motion detection

S. Humbert (U. Maryland):
Modeling sensorimotor control

H. Krapp (Imp. College London):
Neural basis of visual steering

P. Krishnaprasad (U. MD):
Modeling formation flight control

▲ S. Reppert (U. Mass):
Clock-compensated navigation

R. Ritzmann (Case Western):
Adaptive locomotion control

R. Olberg (Union College):
Dragonfly flight to target capture

S. Sane (Tata Institute):
Insect multisensory integration

P. Shoemaker (Tanner Res.):
Visual detection of small targets

▲ S. Sterbing (U. MD):
Wing sensors in bat flight control

G. Taylor (Oxford):
Raptor pursuit strategies in 3D

▲ E. Warrant (Lund U.):
Nocturnal navigation

M. Wehling (AFRL/RW):
Neural analysis of optic flow.

▲ M. Willis (Case Western):
Visual / olfactory target tracking



International and 6.2 Coordination



U.K.



G. Taylor



H. Krapp



J. Niven

AFRL-DSTL Working Group
Biologically-Motivated Micro-Air-Vehicles

“STATE OF THE ART REVIEW”

Georgia Tech
15-18 June, 2010



Organizers: M. Wehling, AFRL. P. Biggins, Dstl
30 Participants from UK, US, Industry, Academia, & Gov.

Presentations:

[https://livelink.ebs.afrl.af.mil/livelink/lisapi.dll?func=ll&objId=24091294
&objAction=browse&viewType=1](https://livelink.ebs.afrl.af.mil/livelink/lisapi.dll?func=ll&objId=24091294&objAction=browse&viewType=1)

U.S.



M. Willis



S. Humbert



T. Daniel



Span of Natural Flier Research: A Few Program Participants



Vertebrates



Hawks & Falcons



Echolocating Bats

Invertebrates



Megalopta genalis
(Nocturnal Bee)



Bombus terrestris



Dragonfly



Hawkmoth



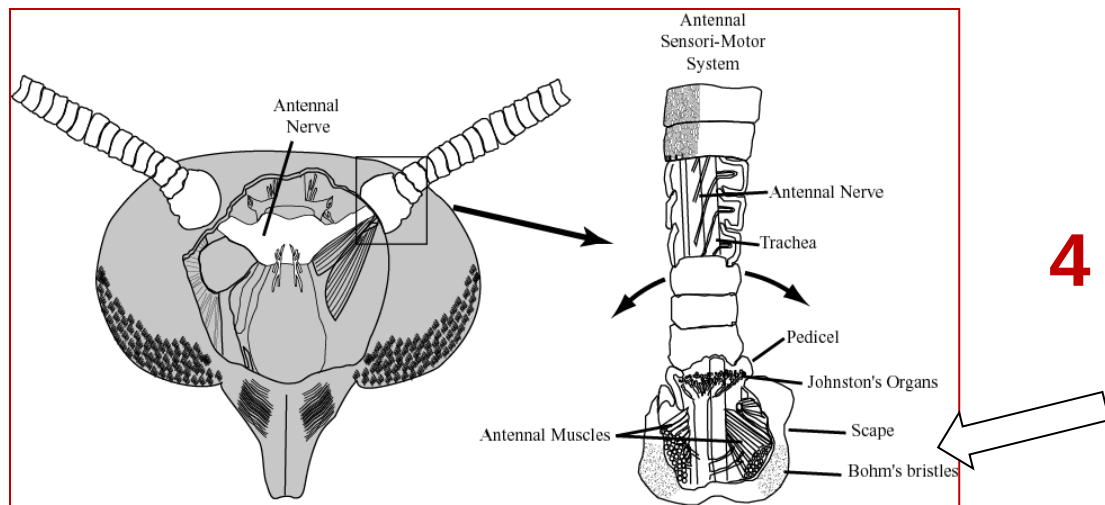
Antennae in Flight Control

Dr. Sanjay Sane, Tata Institute, Bangalore, India



Hawkmoth, *Daphnis nerii*

- 1 Precise control of antennae position is critical for aerial flight maneuvers
- 2 Control system is closed-loop, with sensory latency of 15 msec.
- 3 Antennae integrate mechanosensory & photoreceptor inputs

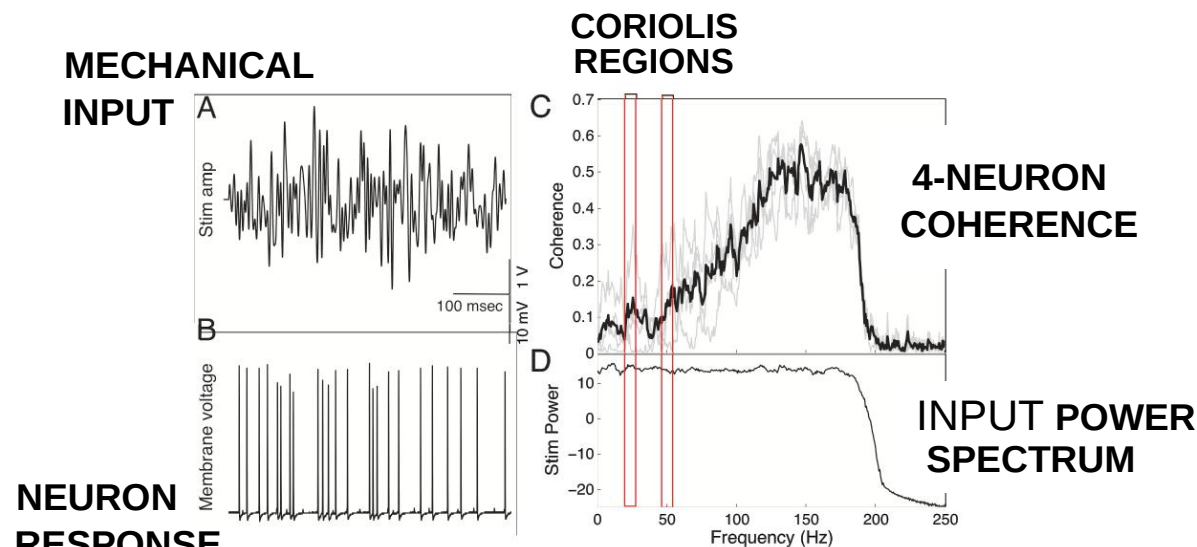


- 4 Antennae position in flight is governed by Bohm's bristles only at pedicel.



Wings are Sensory Receptors

- - - A New Research Effort



Wing Campaniform Neurons Respond to Mechanical Forces



Hawkmoth, *Manduca sexta*

Hypothesis:

Wings not only drive flight, but also detect inertial moments.
- - - strain receptors modulate wing shape and position.

T. Daniel (biology) and K. Morgensen (Aeronautics) U. Washington.



The Mode Sensing Hypothesis for Biological Flight Control



Proposed by 3 AFOSR scientists:

Theory:

Biological sensors and actuators compose a suite of “matched filters,” tuned to salient patterns (“modes”) of self-motion – organized to combine multiple inputs into actuation signals encoded in modal coordinates.



S. Humbert

MARYLAND



H. Krapp

IMPERIAL
COLLEGE
LONDON



G. Taylor

OXFORD

H.G. Krapp, G. K. Taylor, and J.S Humbert (in press) “The Mode-Sensing Hypothesis: Matching Sensors, Actuators and Flight Dynamics.”

Challenge from AFOSR:

- Test the theory in neurobiology and flight behavior
- Devise mathematical emulation suitable for MAVs



Each Visual System Cell is Tuned to a Preferred Axis of Rotation

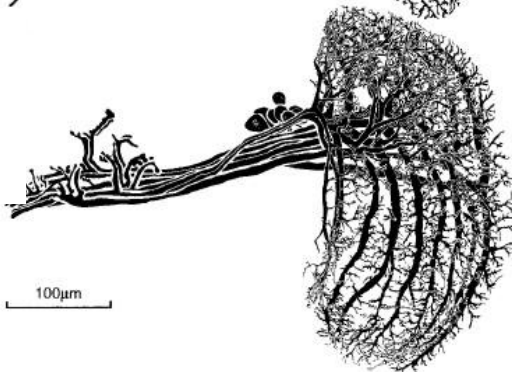


Calliphora vicina
Lobular Plate Tangential Cells
(Compound Eye System)

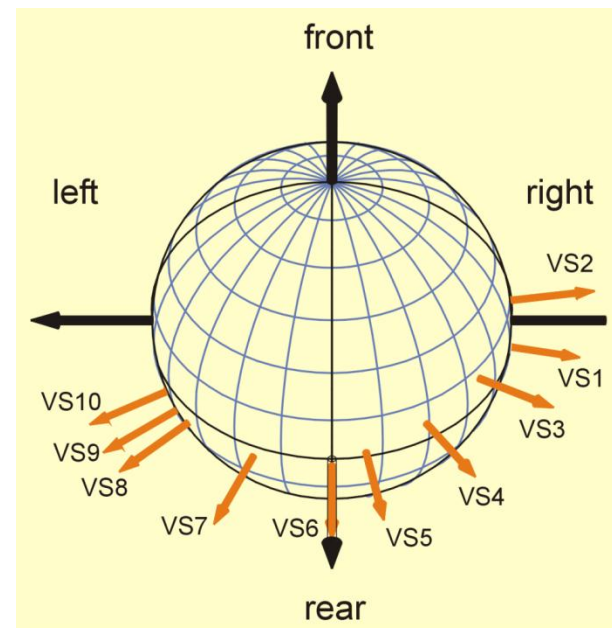
3 HS
cells



10 VS
cells



10 Vertical System Cells



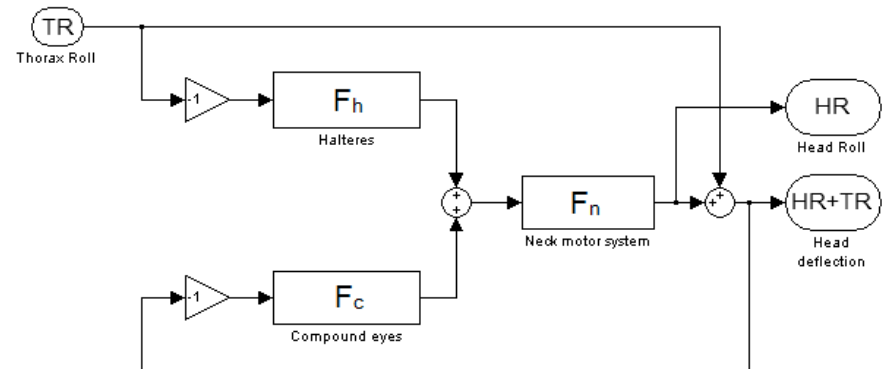
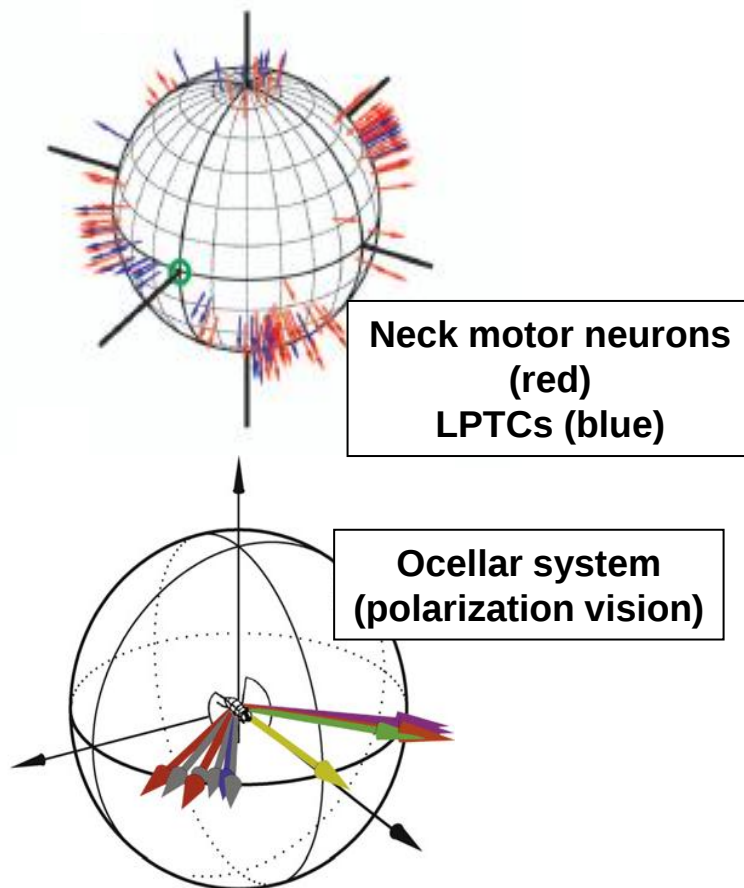
- **Sensory Integration begins by selectively merging these inputs.**
- **The resulting “matched filters” for self-motion are robust and innate.**



Other Motion Sensor Tuning Differs from Compound Eye Tuning



Plots derived from single-unit recordings during controlled rotational stimulation



Theory:

- Short-latency mechanosensors first detect body rotation, then feed forward to induce compensatory head roll via neck motor system ...
- Long-latency visual system acts on residual optic flow feedback from incomplete mechanical compensation.
- Behavioral data fit preliminary model for multimodal sensory integration.



Wing Sensorimotor Activation

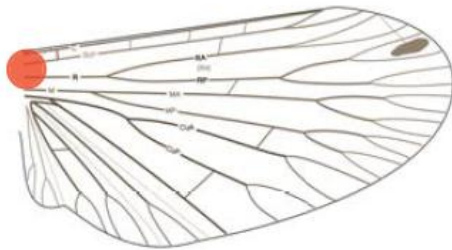
- - A New Program Initiative



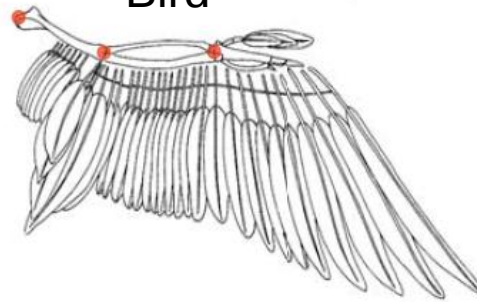
Natural Fliers' Wing Joints

(●) with potential to be controlled during flight

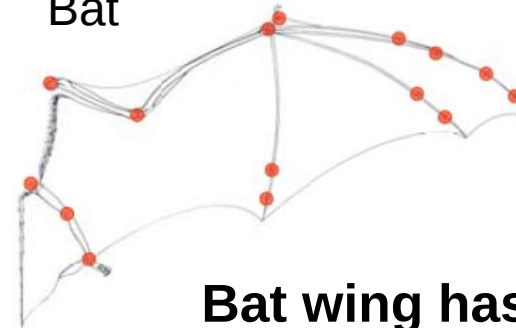
Insect



Bird



Bat



Bat wing has Intrinsic, non-joint muscles



Research Questions:

- Discover joint coordination timing
- Determine functional redundancy
- Do joint muscles control force or position?
- Discover what the intrinsic muscles do.



Discovering Bat Wing Musculature Dynamics during Flight

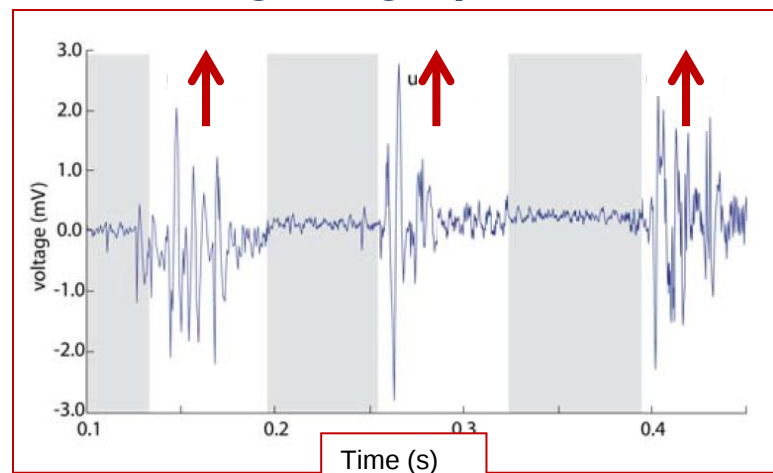


Large bat (1.2kg) in low speed flight has precise control via wing skeletal muscles and wing intramembranous (intrinsic) muscles

Research Techniques:

- Electromyography during flight
- Thermal videography for metabolic load)
- Selective, reversible muscle paralysis
- 3D X-ray mapping of skeletal motion

**Intrinsic Muscles Active only
During Wing Upstroke:**



... A Discovery from AFOSR MURI



SUMMARY:

Transformational Impacts & Opportunities

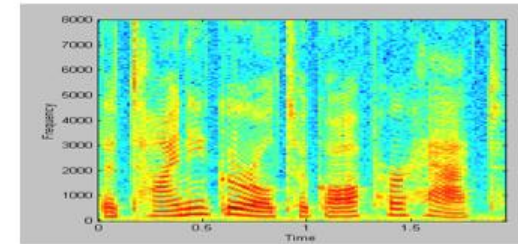


Hearing protection:

- Massive improvements in high-noise attenuation.

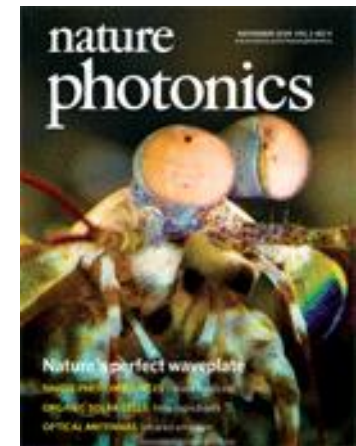
Advanced auditory modeling:

- Mathematics for coherent modulation analysis
- Neural-Inspired analyses to parse acoustic scenes



Optical processing:

- Polarization vision and signaling adapted from biology
- Achromatic 1/4 wave optical retarders
- Emulating compound eye in new optical devices



Autonomous flight control:

- Adaptive airfoils based upon bio-sensory mechanisms
- Steering based upon neural autonomous systems
- Discover sensorimotor basis of formation flight





Questions?



Thank you for your attention.

**Willard Larkin, Program Manager, AFOSR/NL
703-696-7793**

Willard.Larkin@afosr.af.mil



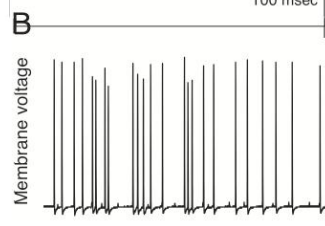
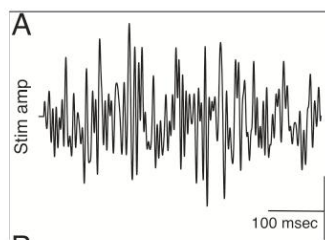
Questions?



Thank you for your attention.

**Willard Larkin, Program Manager, AFOSR/NL
703-696-7793**

Willard.Larkin@afosr.af.mil



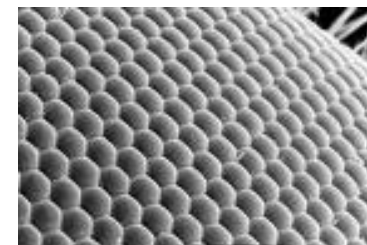


New Lab for Insect Vision
Spectral & Polarization
Electroretinography
AFRL/RWG PI: Martin Wehling



Robber Fly

No Ocelli
Halteres
No VS cells
5-18 HS cells





Dynamics of Bat Wing Musculature

S. Swartz, T. Roberts, Brown Univ., 2011



Large bat (1.2kg) in low speed flight maintains precise control via wing skeletal muscles and wing intramembranous muscles

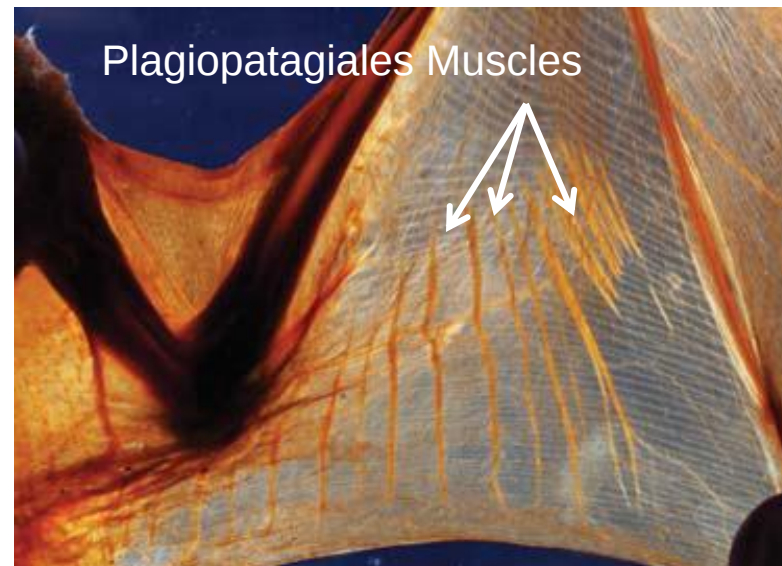
Techniques:

Electromyography during flight

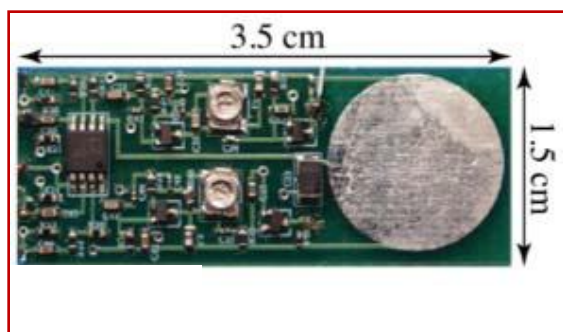
Thermal videography (to measure metabolic load)

Selective, reversible muscle paralysis

3D X-ray mapping of skeletal motion



Muscles active during upstroke:



1.5 gm EMG Telemetry
for in-flight muscle activity

