Some new technologies for studying migration

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How can tags help us understand migration?

They can help us learn about a bird's:

Location and its

State

Localization

Classically requires a large number of field workers;

Or a single observer moving around a less-rapidly moving subject.

Most studies of migration need a very large scale of localization.

Recently, more and more animals are being localized by satellite tags;

GPS is revolutionizing localization for large species;

And solar geolocation is proving serviceable for many systems.

What about state?

Location can include altitude and temperature.

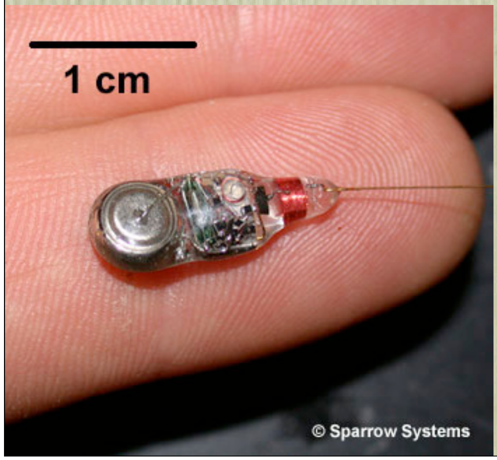
Heart-rate, body temperature or wing-beat frequency have been attainable from custom analog tags.

But we would like to know much more about a migrant's mass, energy consumption, behavior during migration, etc.

Anything else?

40 years of analog wildlife telemetry has been very productive.

Creative packaging and attachments to birds and other wildlife have been developed.
Amazing reductions in size and creative ways of getting state information (heart and wing-beat rate) from an analog signal.
However, there are many other sensors that cannot be so adapted, and all these tags have relatively short life spans.



The cell phone industry has produced a revolution in tiny sensors, processors and memory.

Microprocessors provide the possibility of highly flexible and programmable schedules of transmitting and receiving.

They also provide the possibility of on-board data analysis from a wide array of sensors.

On-board memory provides the potential to store data for later retrieval directly or via an RF transmission.

Once you have digital data on a tag, there are two ways to get it back:

Catch the animal again and download the logged data directly from the tag: ***loggers***.

Use RF signals to get the information back, just getting close to the animal, not having to catch it again: ***transceivers***.

So, why aren't we all using these new tags?

They are not yet available (duh).

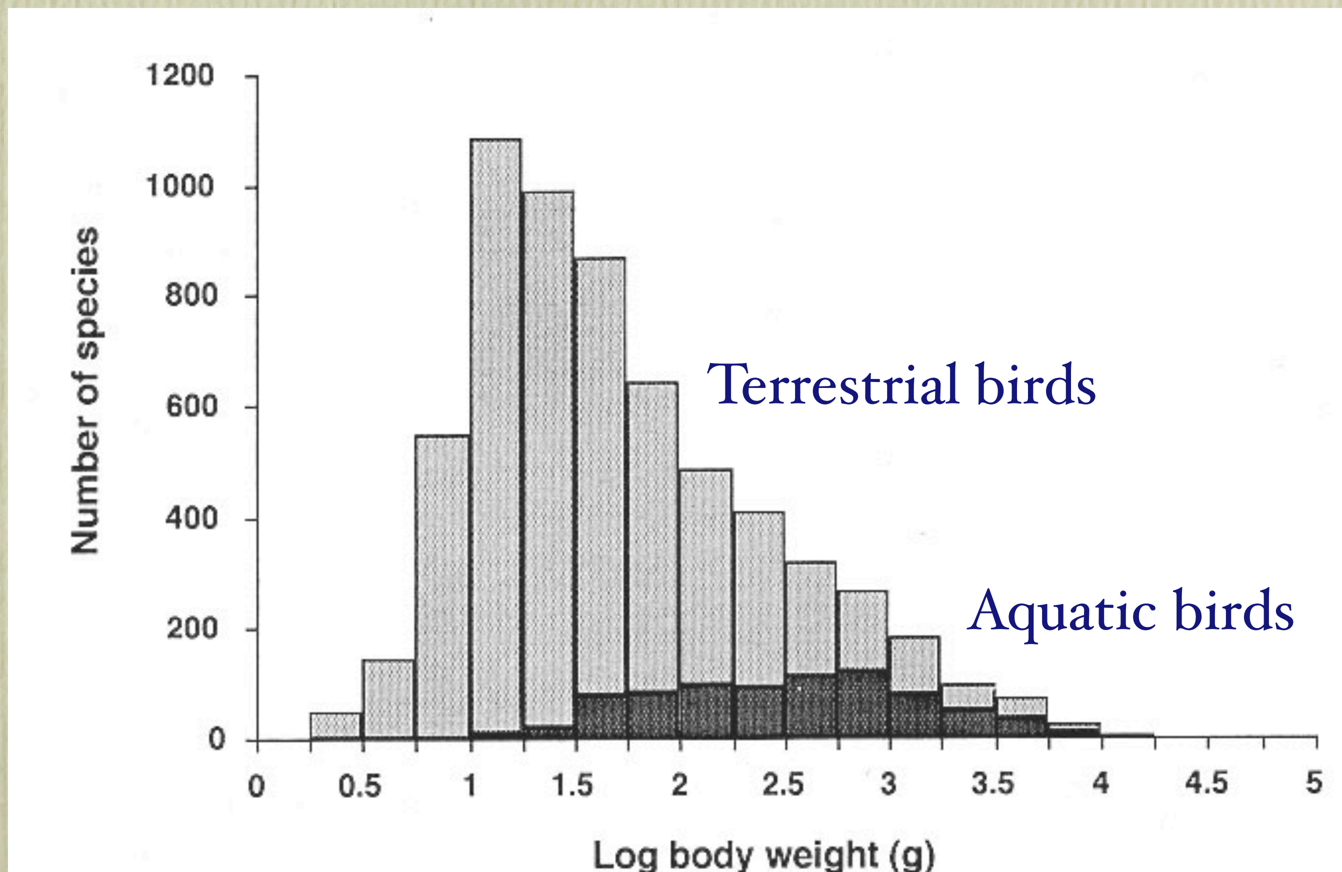
Digital tags require digital receivers.

Biggest problem is mass.

Batteries are still over half the mass of most tags.

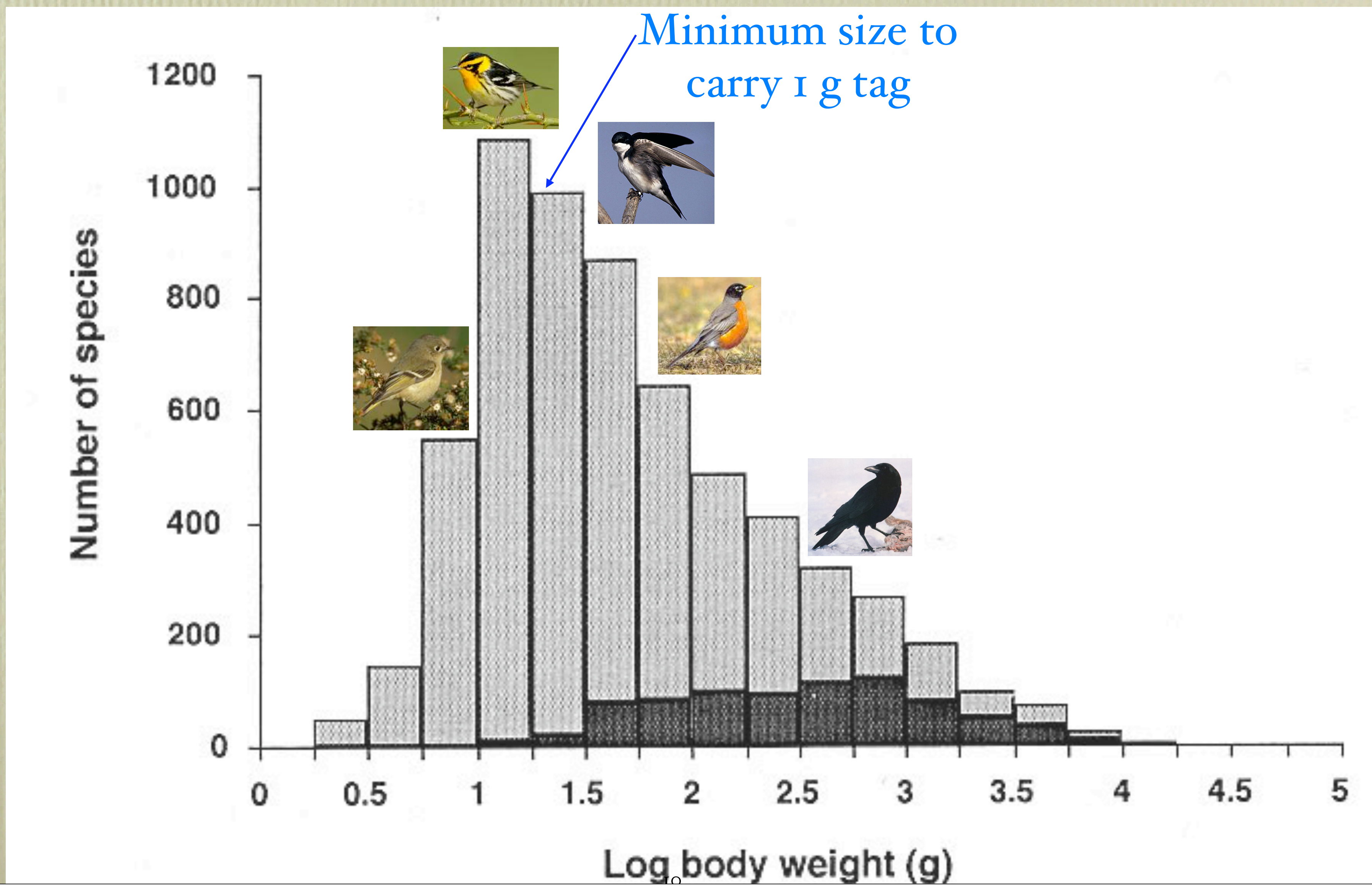
And more functions on a tag require more "real estate" and more energy.

The problem is that birds are small organisms (relative to many other vertebrates), and they can be asked to carry no more than 5% of their lean body weight.



From Gaston, K.J. and T.M. Blackburn. 1995. The frequency distribution of bird body weights: aquatic and terrestrial species. Ibis 137:237-240.

Despite constant pressure for reduction in mass, at Cornell we have settled on trying to achieve a 1 g package.



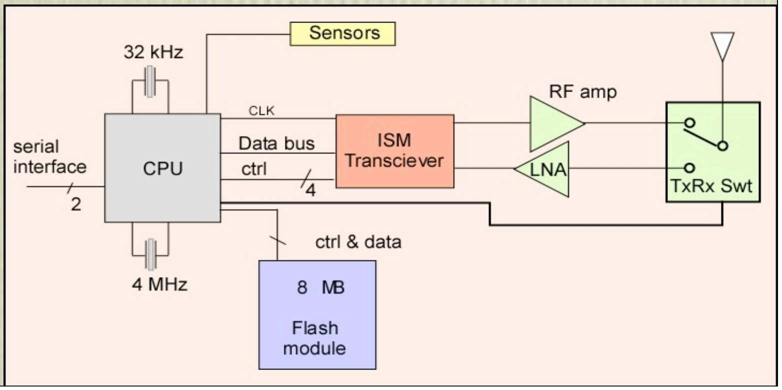
Current RF tag systems being developed at Cornell

Three tag lines, with appropriate receivers:

- Programmable telemetry tag
- Non-RF geolocating logger
- Automatic localization tag

I. Telemetry Transceiver Tag

- Onboard data collection, processing & storage
- On-demand or pre-programmed transmission of data
- Provides core technology (node) for sensor network.



Why another telemetry system?

Numerous commercial solutions exist, but...

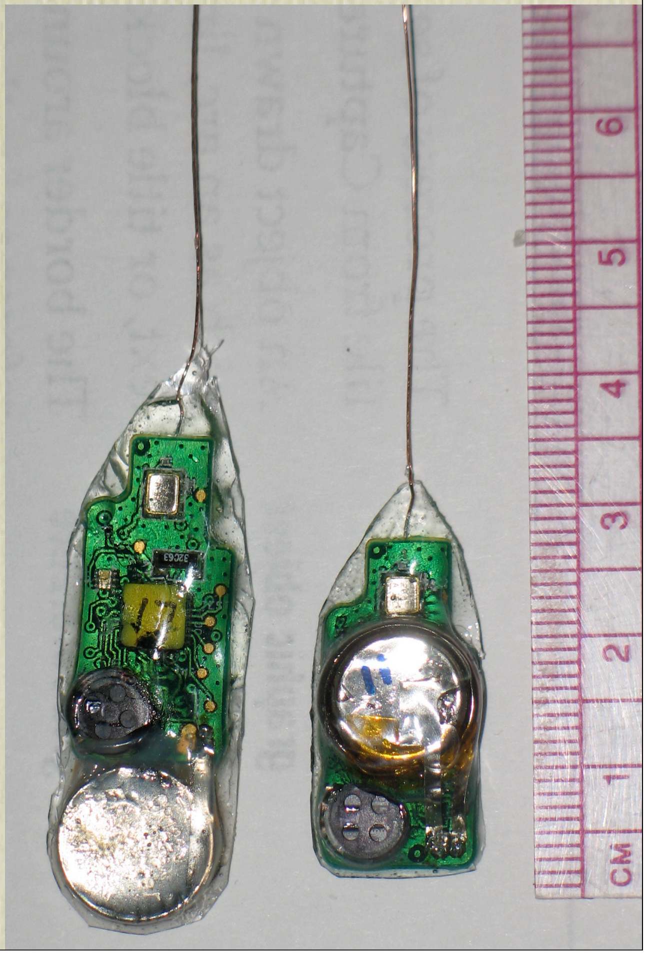
There is currently no way to efficiently track a small, long-range migrant – again, tag mass is the issue.

Efficiently processing, storing light data and retrieving information at a single point via low-power protocol makes this a possibility.

Why not GPS?

We have not yet achieved the mass we are planning for...

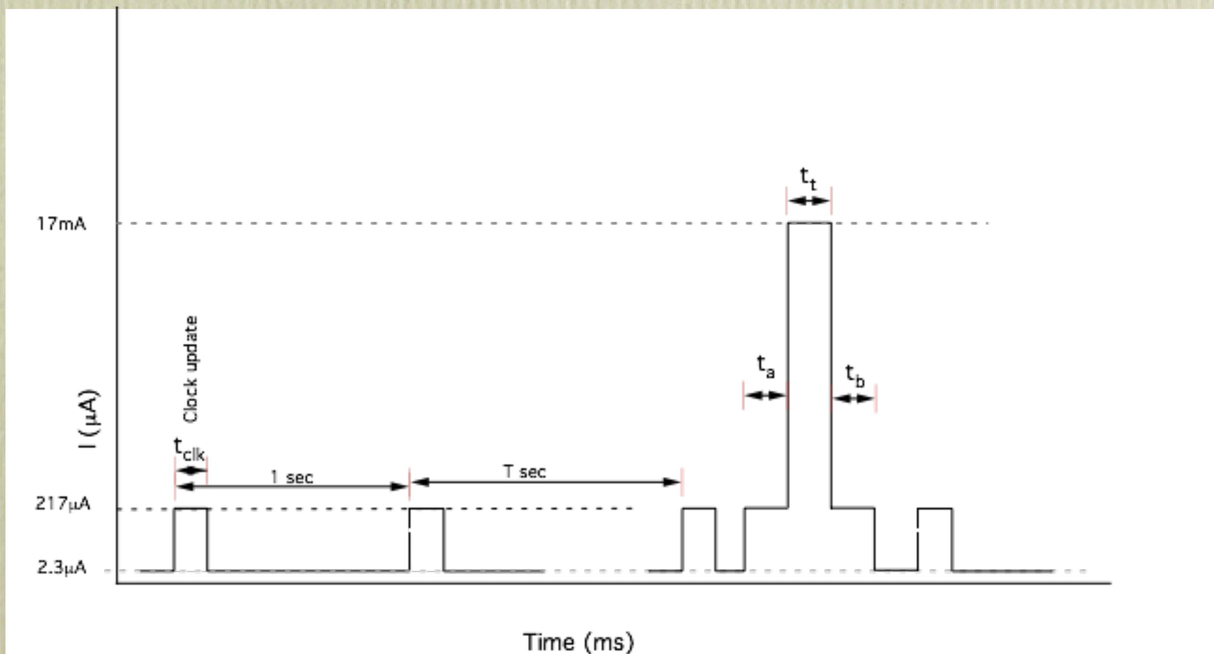
- 3-4 g total weight, depending on potting
- 315 MHz operation
- 5 kB of available storage
- 600 nm peak sensitivity light sensor



Duty-cycling is key to low-energy usage and long tag life

Tag spends most of time in sleep mode, just keeping time with accurate Real-Time Clock.

Scheduled events wake processor up.



Typical energy budget for a 6-month mission

Subsys	I (uA)	T(sec)	E (Joules)	mAh @3V
Stand-by	2.8	1.6E+07	135	12.5
Light Sensing	150	1473	0.663	0.061
Data Transmission	17000	19.2	0.979	0.091
Sync Acquisition	17000	806	41.1	3.80
Totals			177	16.5

Hand-shaking is nearly everything!

Typical battery specifications

Part number	Company	Chemistry	V	Capacity (mAh)	E (Joules)	mass (mg)	ED J/mg
BR425	Panasonic	Li	3	25	270	520.5	0.519
CR1216	Renata	Li	3	25	270	659	0.410
CR1025	Renata	Li	3	30	324	600	0.540
CR1025F FV-LF	Renata	Li	3	30	324	800	0.405
PGEB20 1515	FullRiver	LiPo	3.6	10	130	420	0.309
TL4902	Tadiran	Li	3.6	1200	15552	9600	1.62

The base receiver unit

- Same RF chip as used in tag
- Waterproof housing and keypad
- LCD display
- 32 MB of flash
- Serial interface
- Built in GPS
- Fully automated
- Low cost ($500)

Overview – the first implementation: Knot migration

Tags record light data for geolocation during a season.

Inexpensive receiver awaits for the return of the animals and captures the data during a single event transmission.

On the knot

- First attempt was not successful
- Insufficient strain relief, weak antenna
- 2nd attempt had problems with insufficient potting
- Next attempt in a month!

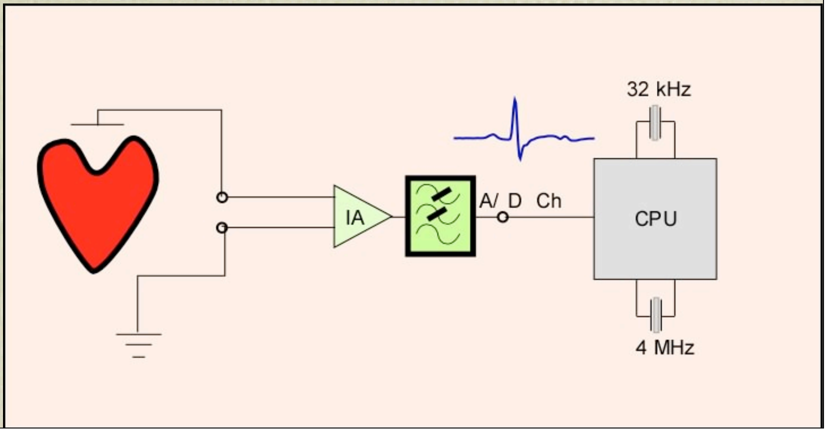
An important lesson from the knot work...

Long-life tags need long-life attachment!

Other possibilities for a smart tag: Heart rate monitor

HR requires relatively large sample rate for ultra-low power system.

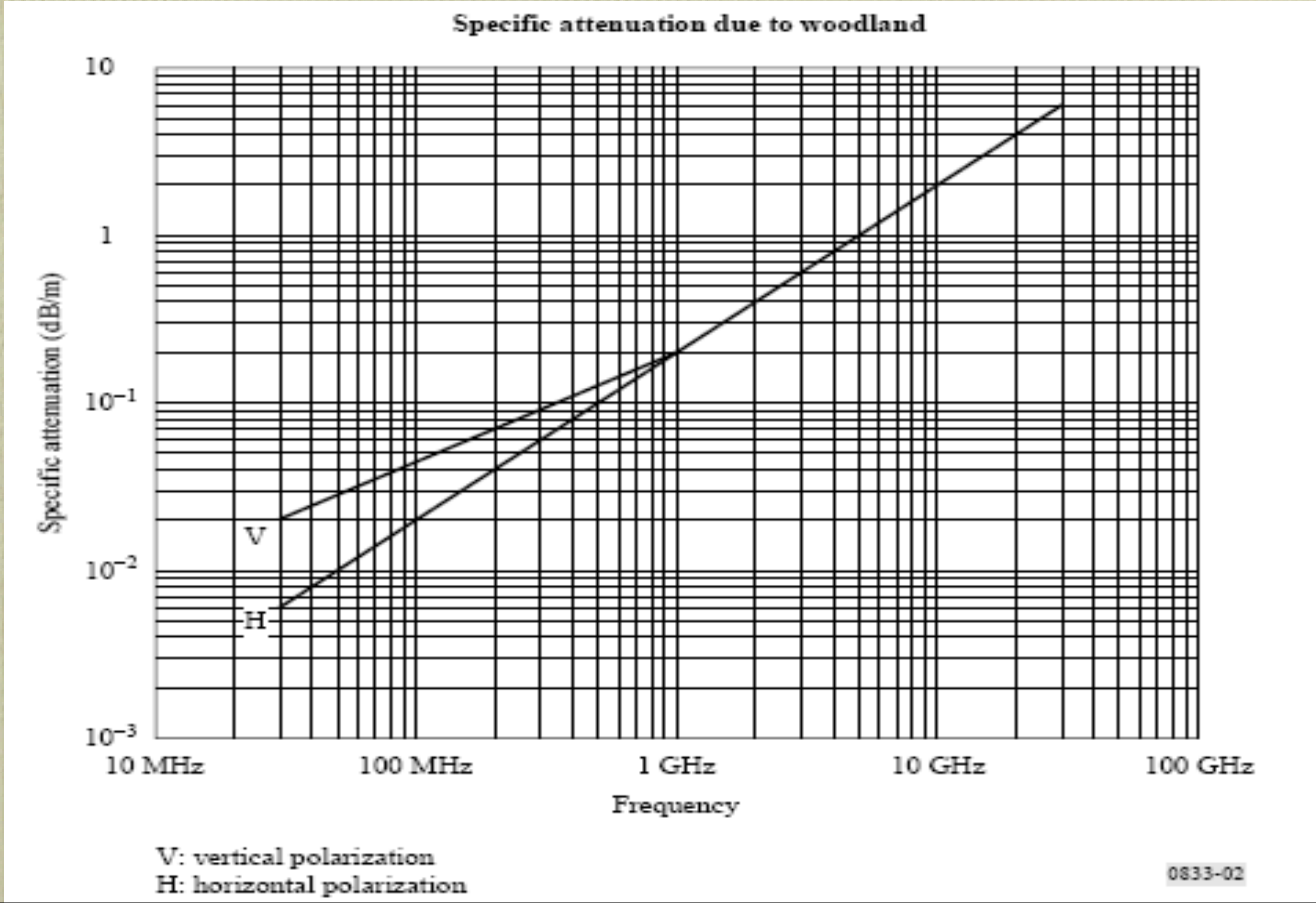
Data reduction via onboard processing enables dramatic reductions in power consumption because writing to memory is energetically expensive



2 Key RF Design Considerations:

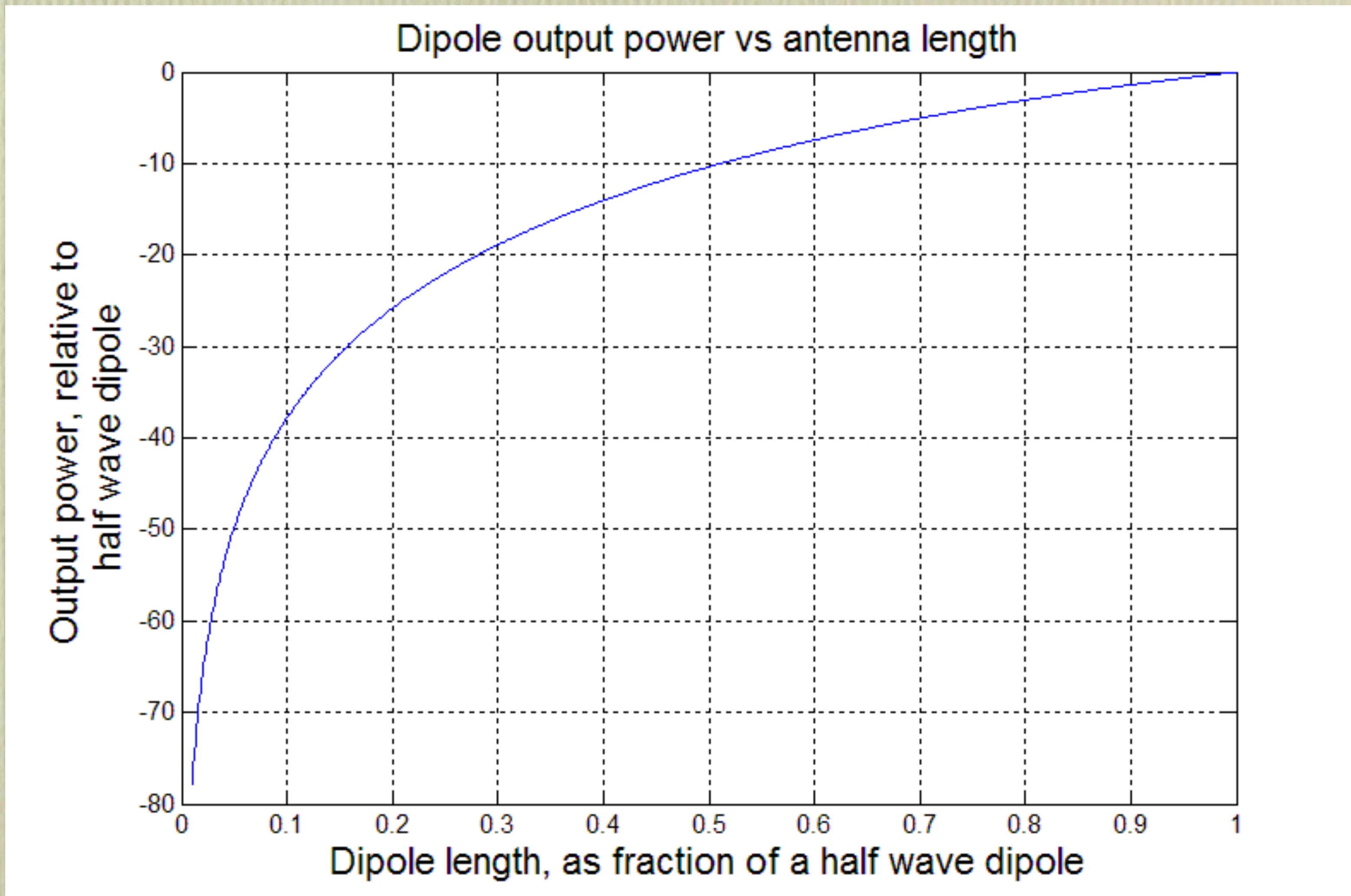
- Operating Frequency band
  - Availability
  - Antenna size and material vs attenuation
- Data rate
  - Slower = better range, but more energy for same output

Foliage attenuation vs. Frequency:
Lower frequency = less attenuation



However, lower frequency comes with a price:

Larger antenna size, or reduced power output for same size



So, a tradeoff in frequency is required. Where is our optimum?

Tradeoff exists in selection of data rate as well:

Lower rate requires more energy per bit, but yields longer range

Specs for CC1101:

Data Rate (kbps)	Sensitivity (dbm)	RX,TX (0 dbm) Current (mA)	Time to send 1KB (msec)	Energy to send 1KB (mJ)
1.2	-111	15.4	6.60E+03	326
38.4	-103	15.2	208	10.3
250	-94	16.5	32	1.58
500	-87	na	16	0.792

Spherical spreading implies 6db loss for each doubling in range.

Slowest rate -> 24db more sensitive than fastest rate.

Slowest rate -> 16x larger range than fastest rate, but at energy cost.

Conclusion: Telemetry transceiver system

Onboard processor allows data processing, scheduling.

Energy demands minimized via scheduling.

Inexpensive base stations allow for affordable, high spatial density arrays.

Flash memory storage allows recovery months or even years after original deployment.

RF data download obviates need for recapture.

II. Geolocation Logger

RF sections of tags add complexity, weight.

The smallest tag possible will not transmit data – it logs it and must be recaptured.

Solar Geolocation

Length of day depends on season and latitude.

Absolute time of midday defines longitude.

This requires an accurate Real-Time Clock on board.

Same algorithm used in telemetery transceiver tag.

Geolocation Loggers

The British Antarctic Survey pioneered solar geolocation and its inclusion in loggers.

First on large seabirds, and now on a 1.5 g tag being used in songbirds.

Cornell Geolocation Loggers

Present Cornell tag weighs 1 g in total.

Light & temperature logging; 8kB memory

With solar cell should last over a year.

Now improving design for better data acquisition and off-loading.

IV. Future engineering work

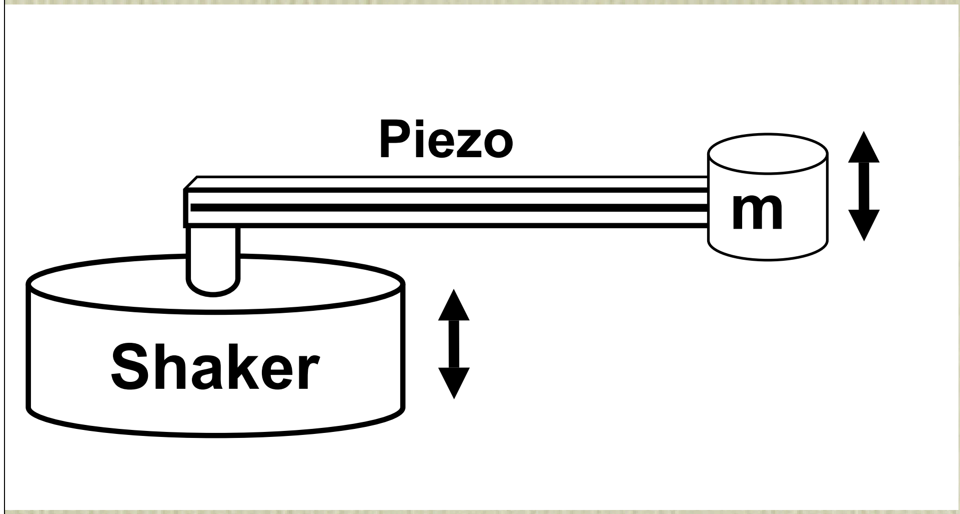
Different frequency choices

Antenna materials & Design

Tag & Base communication protocol improvements

Energy harvesting

Energy harvesting can extend runtime

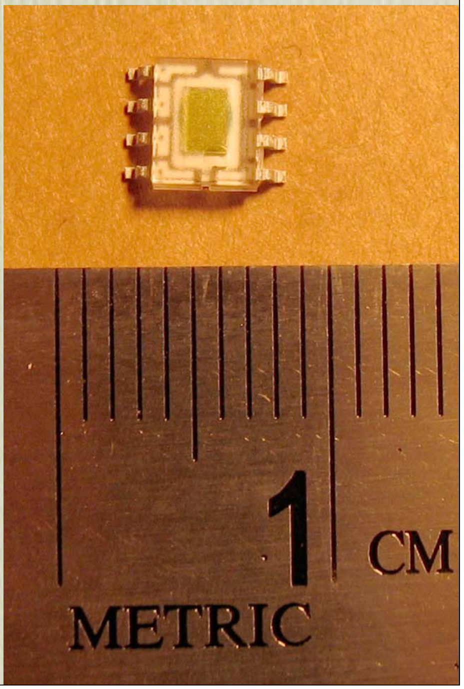


Small piezo bimorph delivers hundreds of microwatts with a reasonable excitation.

Integration, control, conditioning remain challenges.

Small solar cells are an appealing option: 62mg, 4v, 50uA.

Occlusion by feathers is an issue.



We are working with Theunis et al. to develop a real-time localization system for shorebirds in the Wadden Sea.

Imagine what this could do for studies of stop-over and refueling ecology in other stop-over areas...

Another long-term goal is a radio turnstile project.

Every year, billions of migrants fly across southern North America on their way to and from wintering areas in Central and South America.

If these migrants were smart-tagged:

Receivers in their path could down-load a great deal of data in the time it takes to fly into and out of range.

Here, the challenge is not to localize but to maximize distance of detection and data transfer.

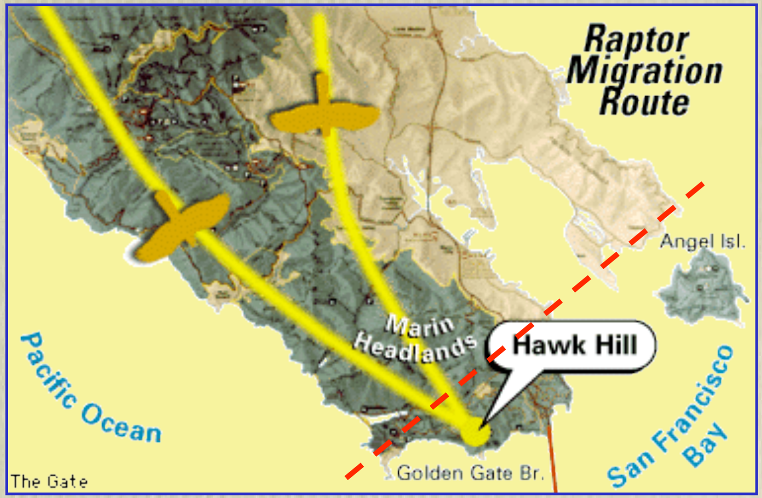
With the solar geo-location transceivers:

We could know the breeding and wintering localities and the migration timing of very large numbers of birds.

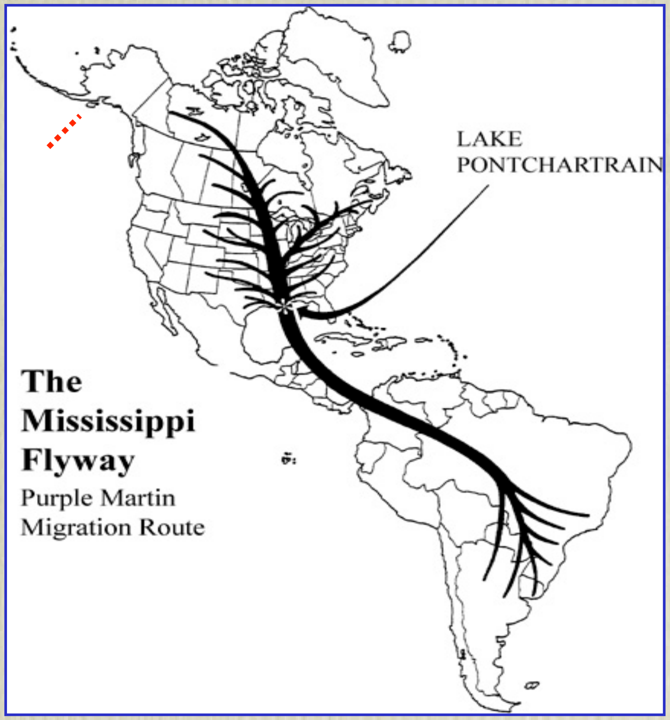
Knowing when, and if, birds checked in would give us unprecedented detail on patterns of mortality.

This would target conservation efforts as never before.

A line of receivers across Marin County, CA, or Cape May, NJ, could intercept very large numbers of coastal migrants.



A line of receivers across Panama could intercept a large number of species crossing to South America.



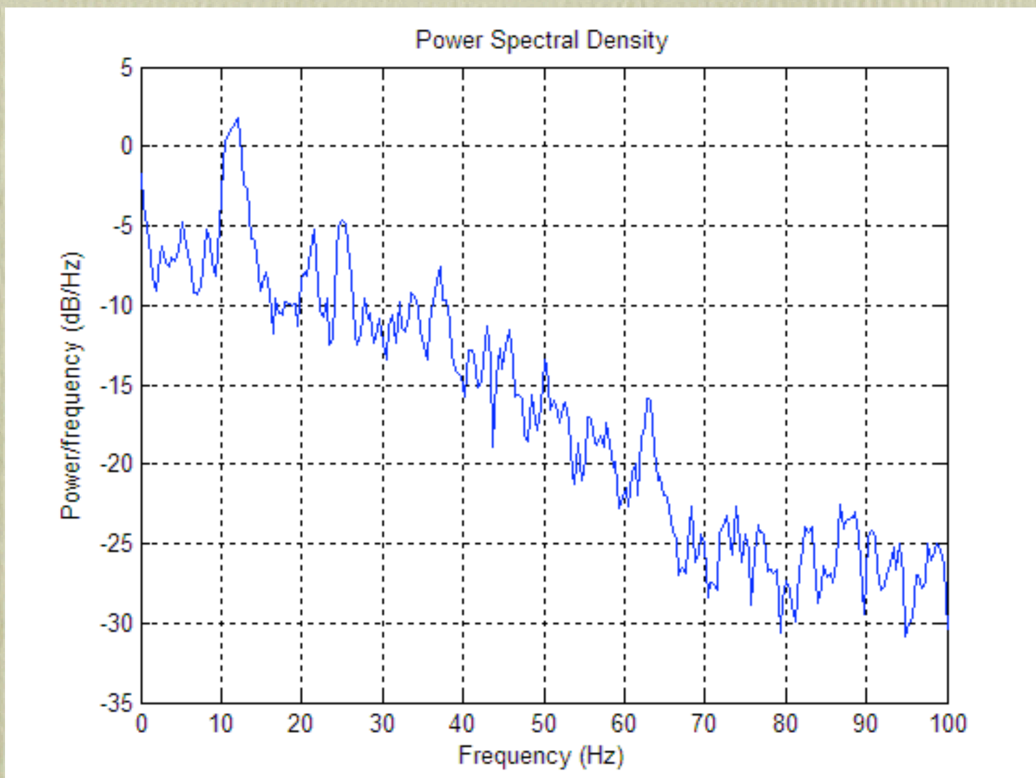
We are likely to start in Veracruz, in an area where diurnal raptor migration is very strong.

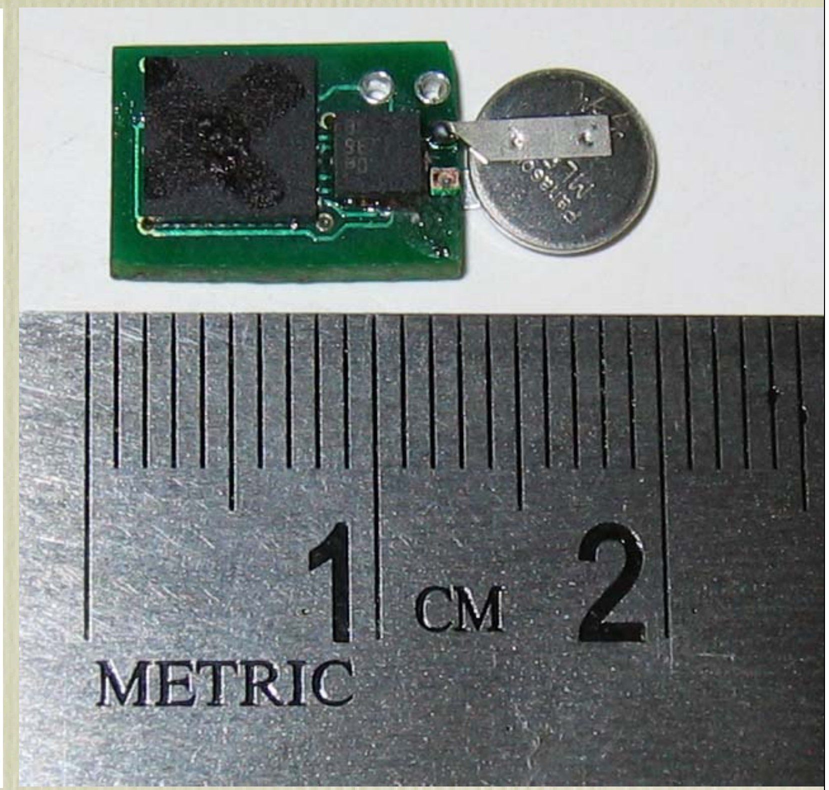
Do you have a strong candidate for your favorite turn-stile site?

We believe these systems could produce data of unprecedented quality on the movements and mortality of individual birds.

And such data could revolutionize our understanding of avian movements, both from basic and conservation perspectives.

Once you have a computer on a bird's back, it can be used for all kinds of neat biology!





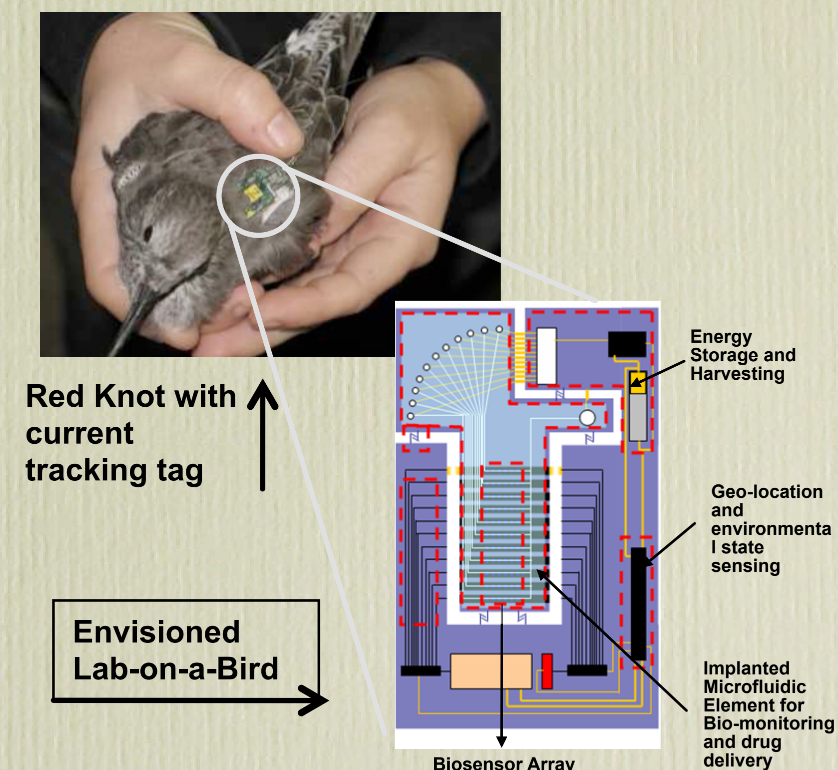
What would you dream about doing with such tags?

And with the development of a "Lab-on-a-Bird" much new biology will be approachable.

Metabolic studies of movement decisions.

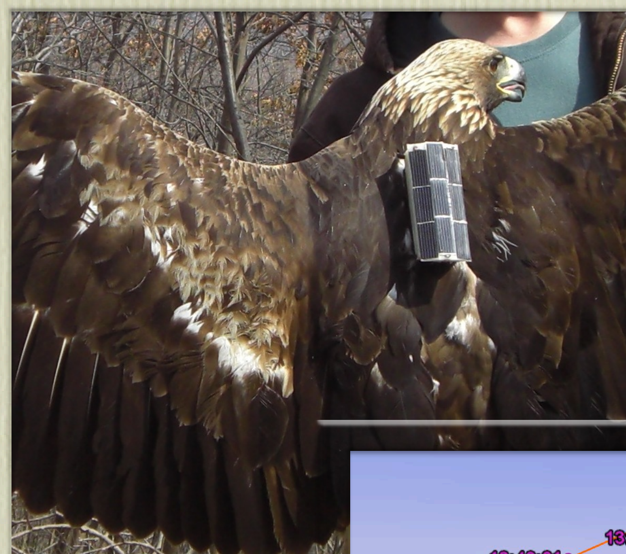
Monitoring of migrating birds as vectors for H5N1, etc.

Remotely controlled administration of hormones...



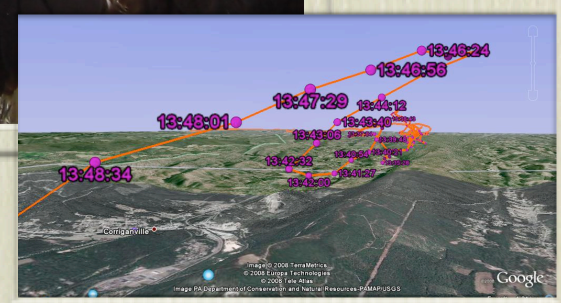
The same micro-processor-controlled platform can be used for a dispersal tag.

Especially with an interrogator transceiver to find the dispersers and call in to tell us where they are.



Mike Lanzone

Powdermill Nature Reserve



Credits

Collaborators:

Chris Clark
Eric Spaulding
Kathy Cortopassi
Ephraim Garcia
Tim Reissman
Jimmy Chang

Funding sources:

Gordon & Betty Moore Foundation

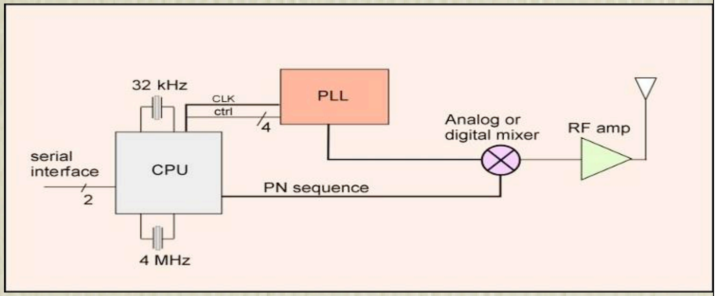
NSF

Private funding

[redacted]

III. Automatic Localization Tag

- Optimized for long-distance detection
- Low power consumption = long life & small size
- Large number of individuals can be tracked simultaneously.



Microcontrollers (uC's) increase tag functionality

CLO is building small, power-efficient uC based tags

uC's Enable:
Flexibility, optimized power usage, data telemetry, data processing, data storage