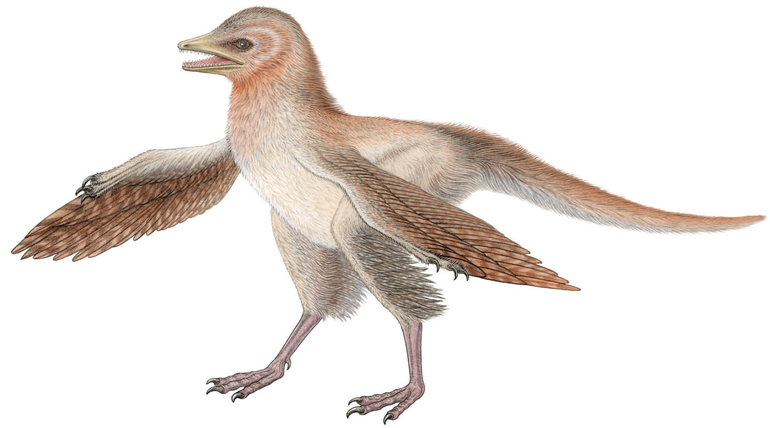
Experimental approaches to understanding the evolution of flight surfaces in dinosaurs: Kurochkin & Bogdanovich (2008) revisited



Gareth Dyke
Ocean and Earth Sciences
University of Southampton, UK

September 2013

Royal BC Museum

University of Southampton

Birds: 10,000 spp.

Descendants of a large and ancient radiation

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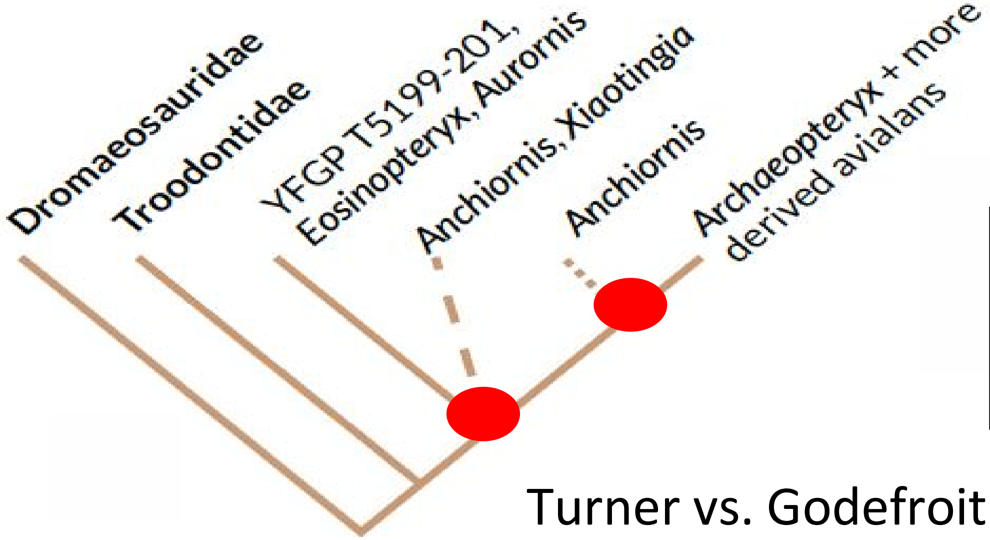
Descendants of a large and ancient radiation

To understand early wing evolution, paravian theropods are key

4/5 winged taxa,
Microraptor/Anchiornis



Turner vs. Godefroit

Context -

Pennycuick (2008), 3 basic achievements required of birds:

(1)Ability to control spatial orientation while being free to move and rotate in 3D, without contact with the ground;

(2)Development of a shape that gives a sufficiently high L/D embodied in a structure that is able to withstand loads of flight;

(3)Development of a source of power that can be used to overcome aerodynamic drag.

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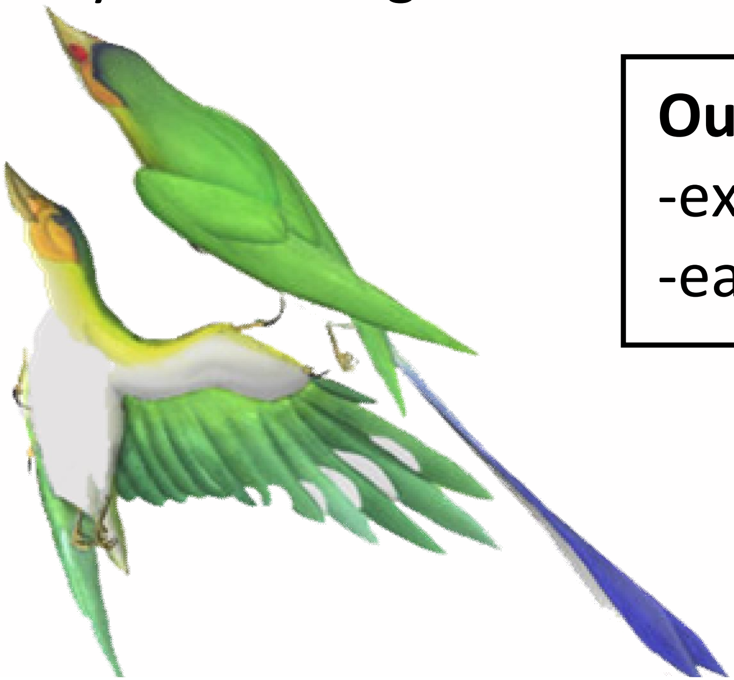
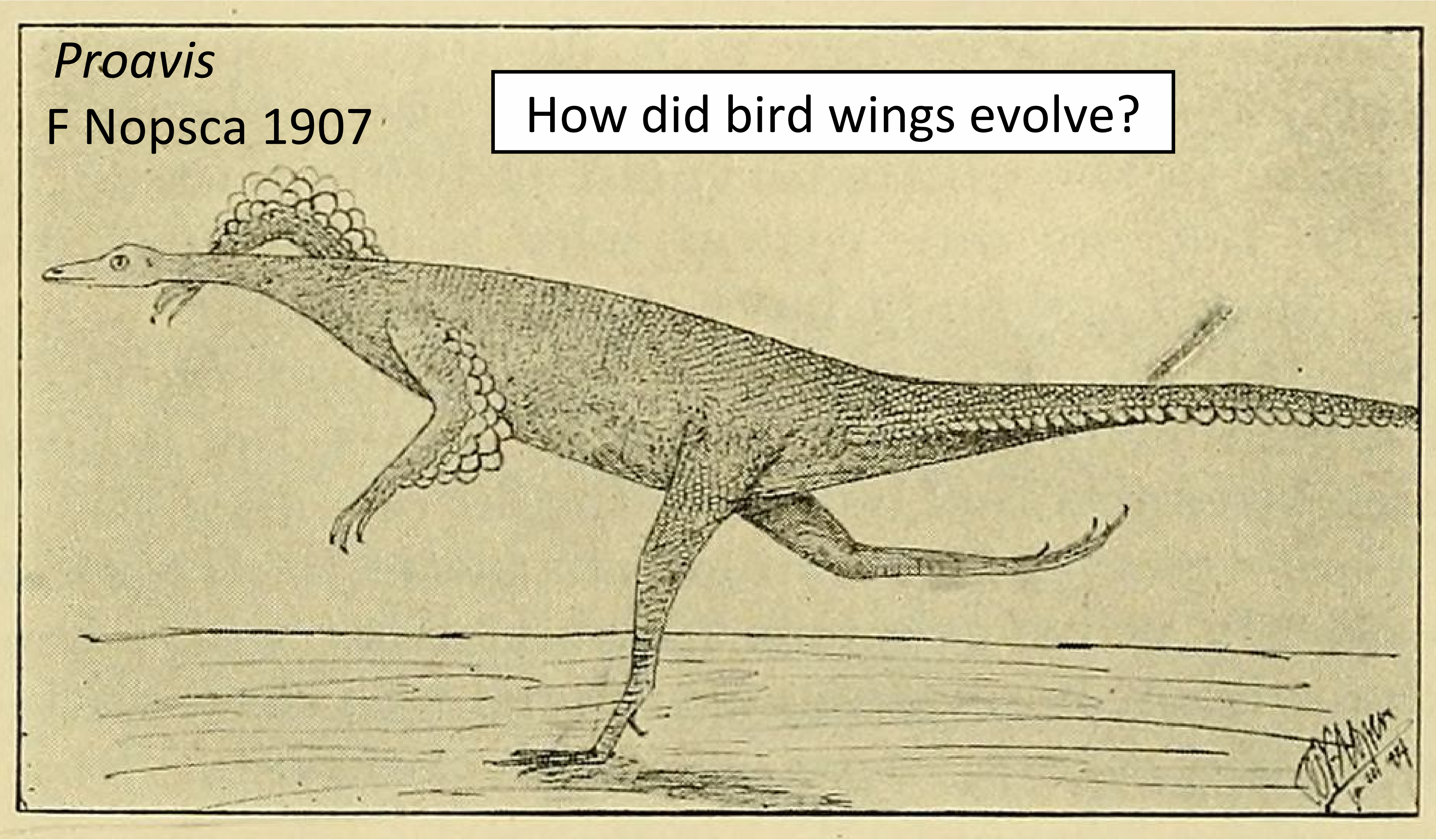


Outline – paravian wings:
-experimental results on *Microraptor**;
-early wing configuration from fossils.

*Dyke et al. *Nature Comms*. (2013)

The BIG question really is Pennycuick's (2) and (3):



This is related to an even more famous debate: 'ground up' or 'trees down'?

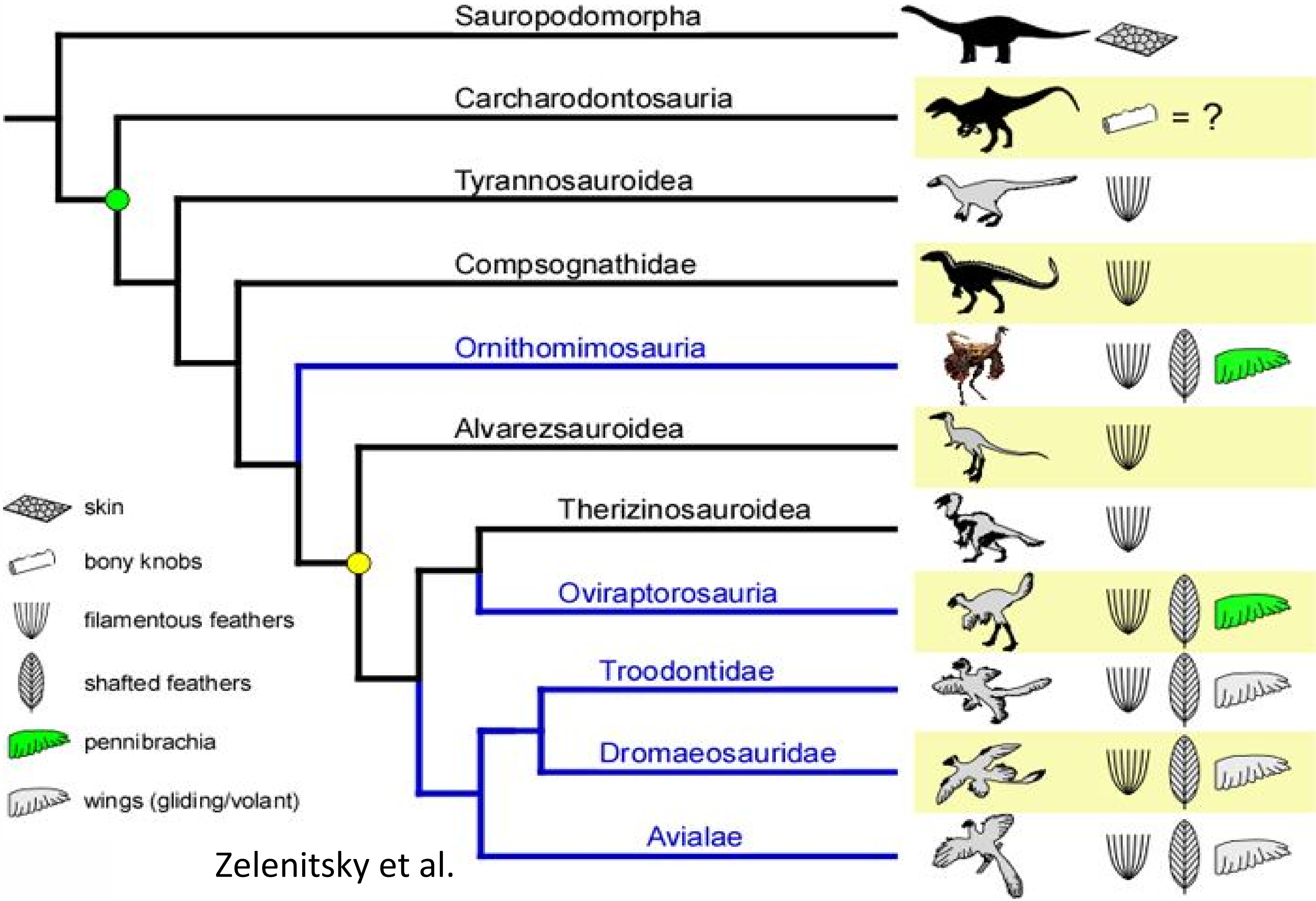
Reconstructing the flight ability of fossil animals

FIG. 7. TETRAPTERYX STAGE IN THE ANCESTRY OF BIRDS

The drawing is based on characters present in Archaeopteryx, and in the young of living birds

Zoologica Vol. II, No. 2. Frontispiece

Context - what we know about feather evolution in dinosaurs?



Zelenitsky et al.

Aerodynamic performance of the feathered dinosaur *Microraptor*

FIG. 7. TETRAPTERYX STAGE IN THE ANCESTRY OF BIRDS

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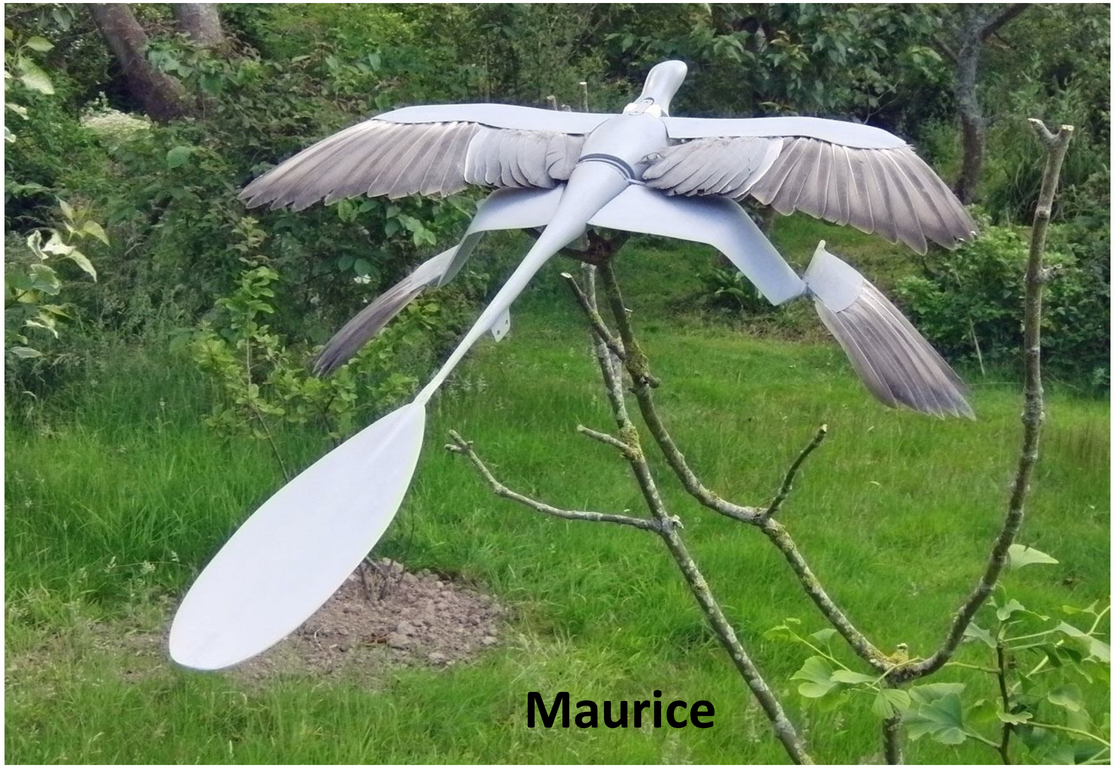
Zoologica Vol. II, No. 2. Frontispiece

- *Microraptor* had 4-5 wings
- Beebe (1914)
- Nature of flight and wing configuration has been much debated

- Stem to the origin of birds (cf. *Archaeopteryx*)

Modelling *Microraptor*



-accurate geometries, joint morphologies and feathering (pigeons and ducks)

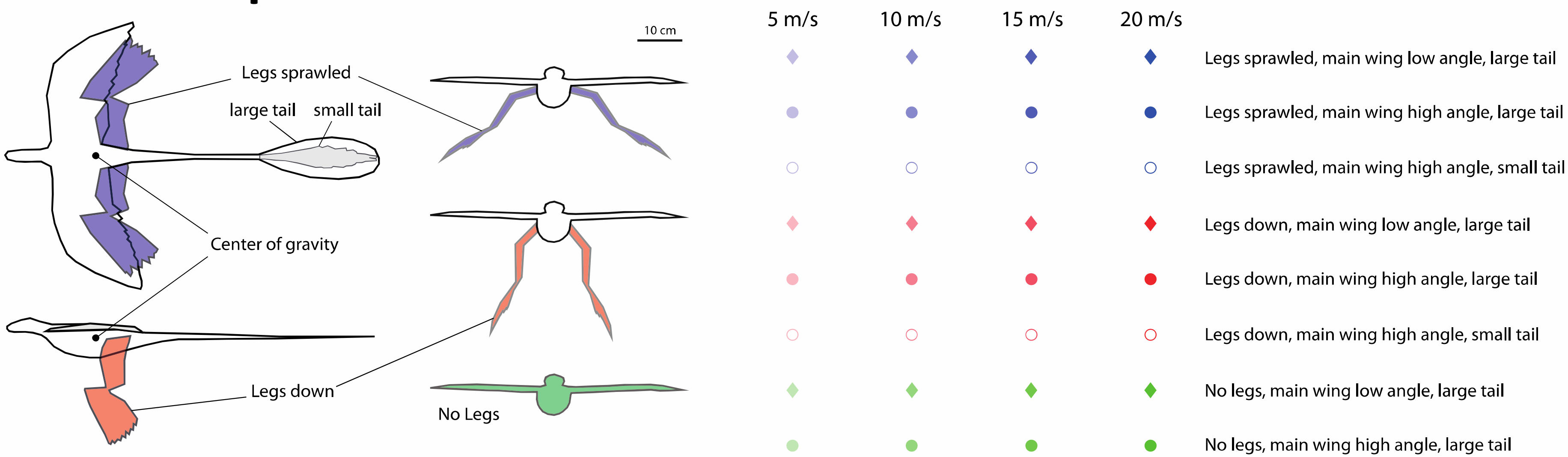
-previous reconstructions based on flat models, or speculation based (more or less) on fossils

Modelling *Microraptor*

-No consensus on likely wing configurations (thus degree of stability and glide performance) has been attained, reflected in a factor of six range of predicted lift-to-drag (L/D) ratios.

-L/D is one fundamental measure of flight performance determining minimum glide angle and thus maximum flight range under steady conditions.

Experimental protocols

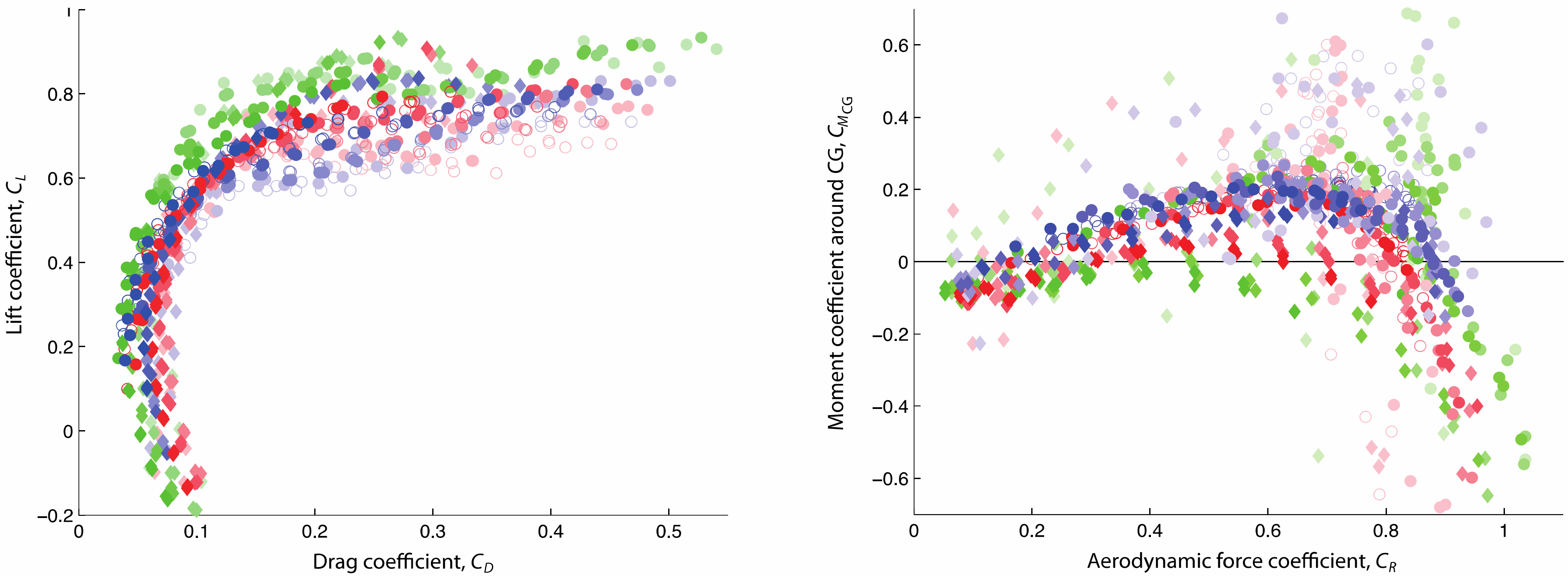


-range of flight velocities and whole animal angles of attack
-8 different configurations (all previously proposed that are anatomically viable
-3 different leg configurations, 3 main wing angles of incidence relative to the body and 3 different tail sizes
-4 different flight velocities (covering the range consistent with those experienced by living gliding and flapping animals): 5 m/sec to 20 m/sec

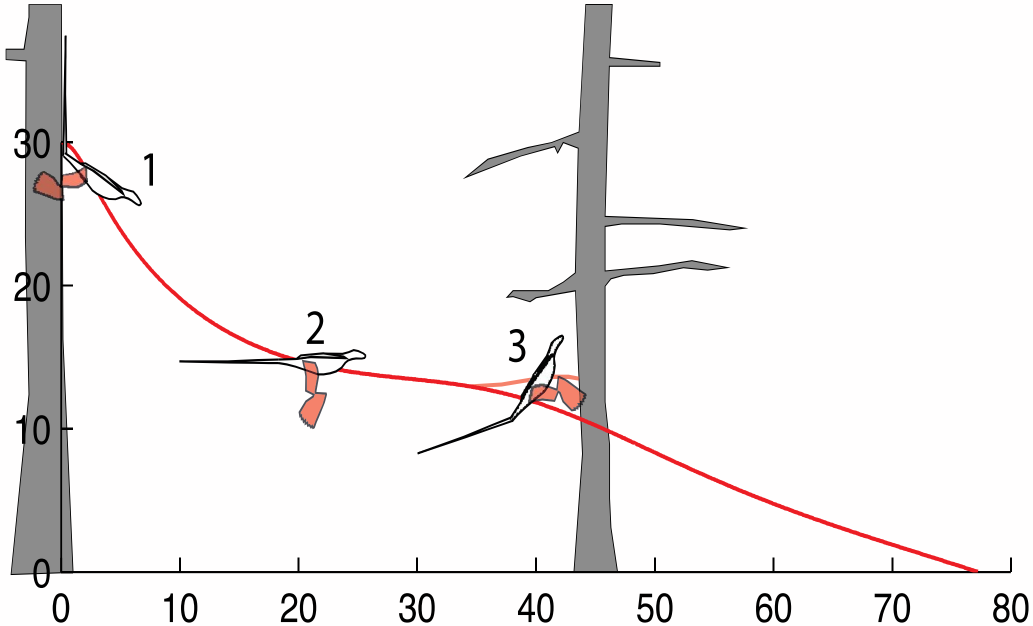
Some experimental results

-L/D glide polars for the model *Microraptor* in different configurations and pitching moment coefficient against aerodynamic force

-Data show that configurations with a low angle between the main wings and tail had increased glide efficiency at high values of Cr, while altering the size of *Microraptor's* tail made no significant difference to its aerodynamic characteristics



Predictions



-Glide path simulation shows that *Microraptor* would have performed best in shallow glide with its legs held down

-Best performing of all possible configurations is an **anatomically impossible** *Microraptor* without legs (= evolution of hindlimb feathering) (**next best is with legs down**)

-Achieving a high CL was most important for *Microraptor*'s flight (arguments about wing configuration and leg position less critical) **(so wing area is key)**

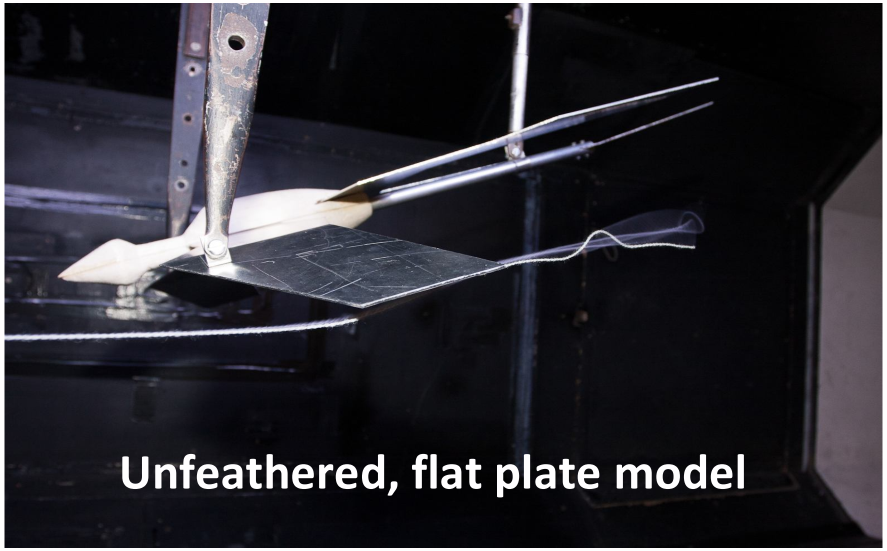
-Differences in gliding leg position only lead to very small differences in performance, a legs down configuration is most likely.

The flight of *Microraptor*

-The most important factor for this theropod was attaining sufficient wing area (**for which derived feathers are unnecessary**); theoretically, all *Microraptor* needed to glide at high CL was an impervious surface

-Comparing feathered and unfeathered models (flat plate experiments) demonstrates that the well-developed asymmetric feathers of *Microraptor* were not necessary to support its high CL (close to stall) flight style

-**Congruent with, and builds on, fossil evidence that shows theropod filamentous integument and symmetric wing feathers first evolved for behaviours other than lift generation**



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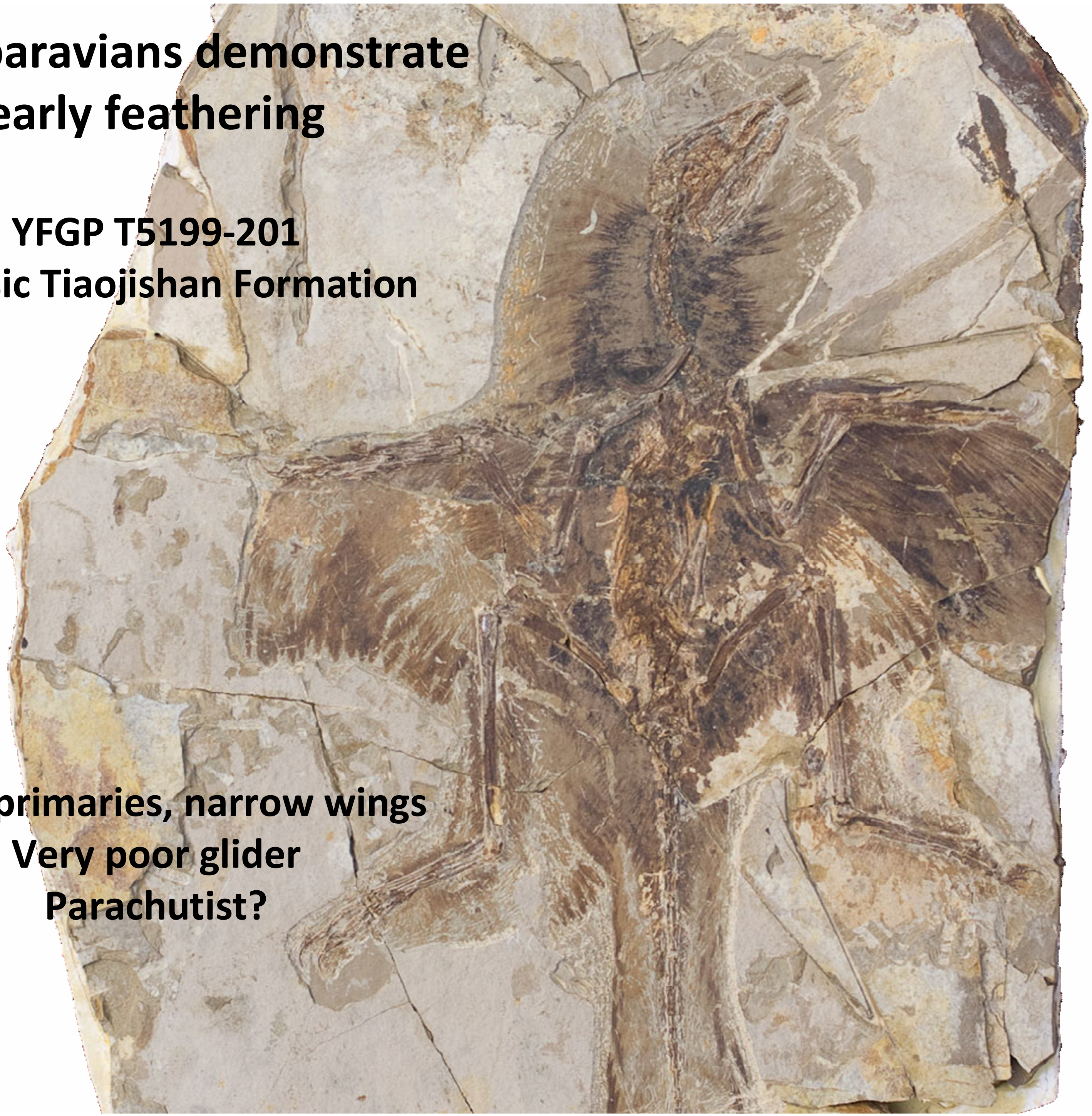
AMNH diorama, photo Roderick Mickens

Other paravians demonstrate early feathering

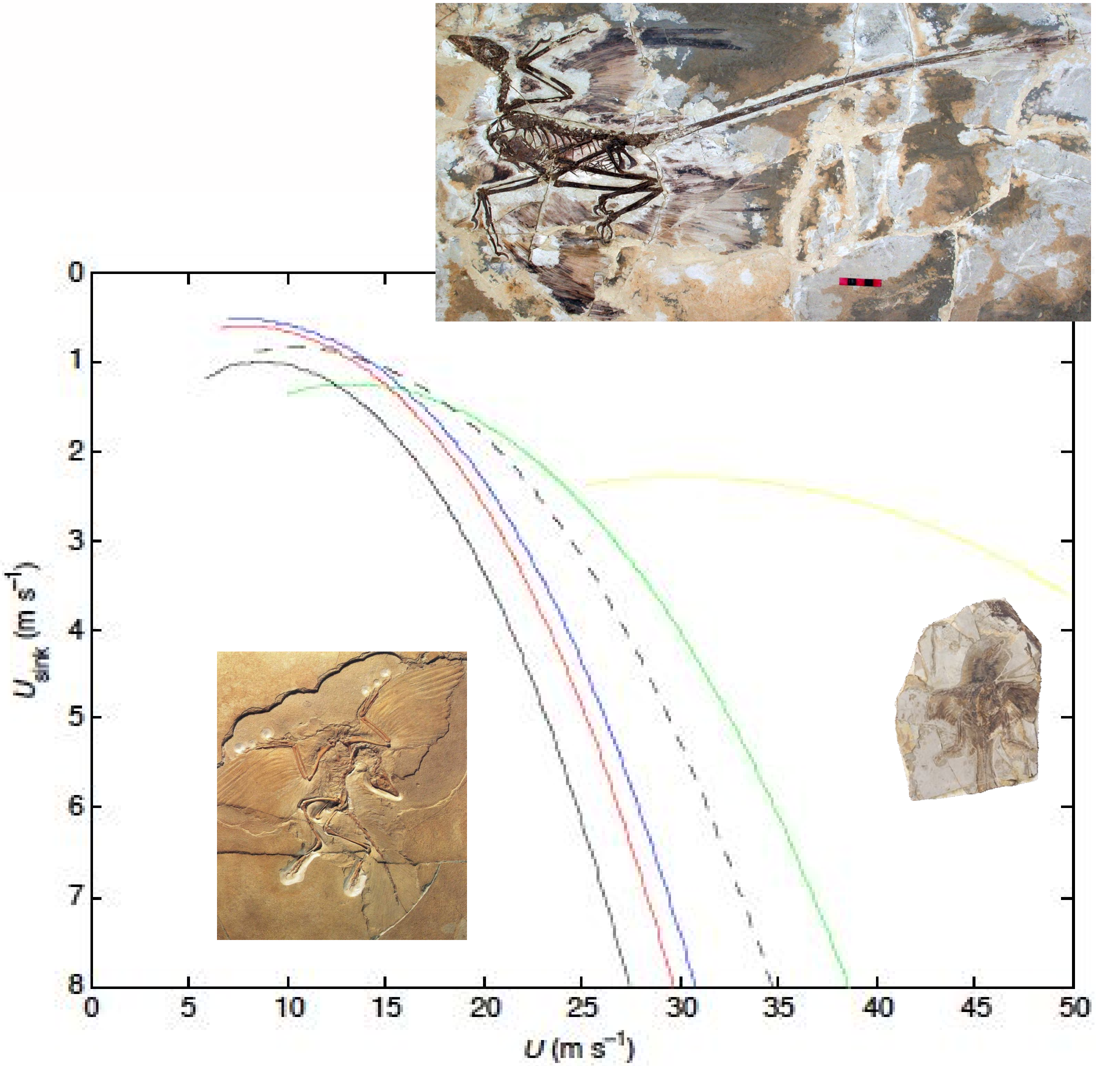
YFGP T5199-201
Jurassic Tiaojishan Formation



Short primaries, narrow wings
Very poor glider
Parachutist?

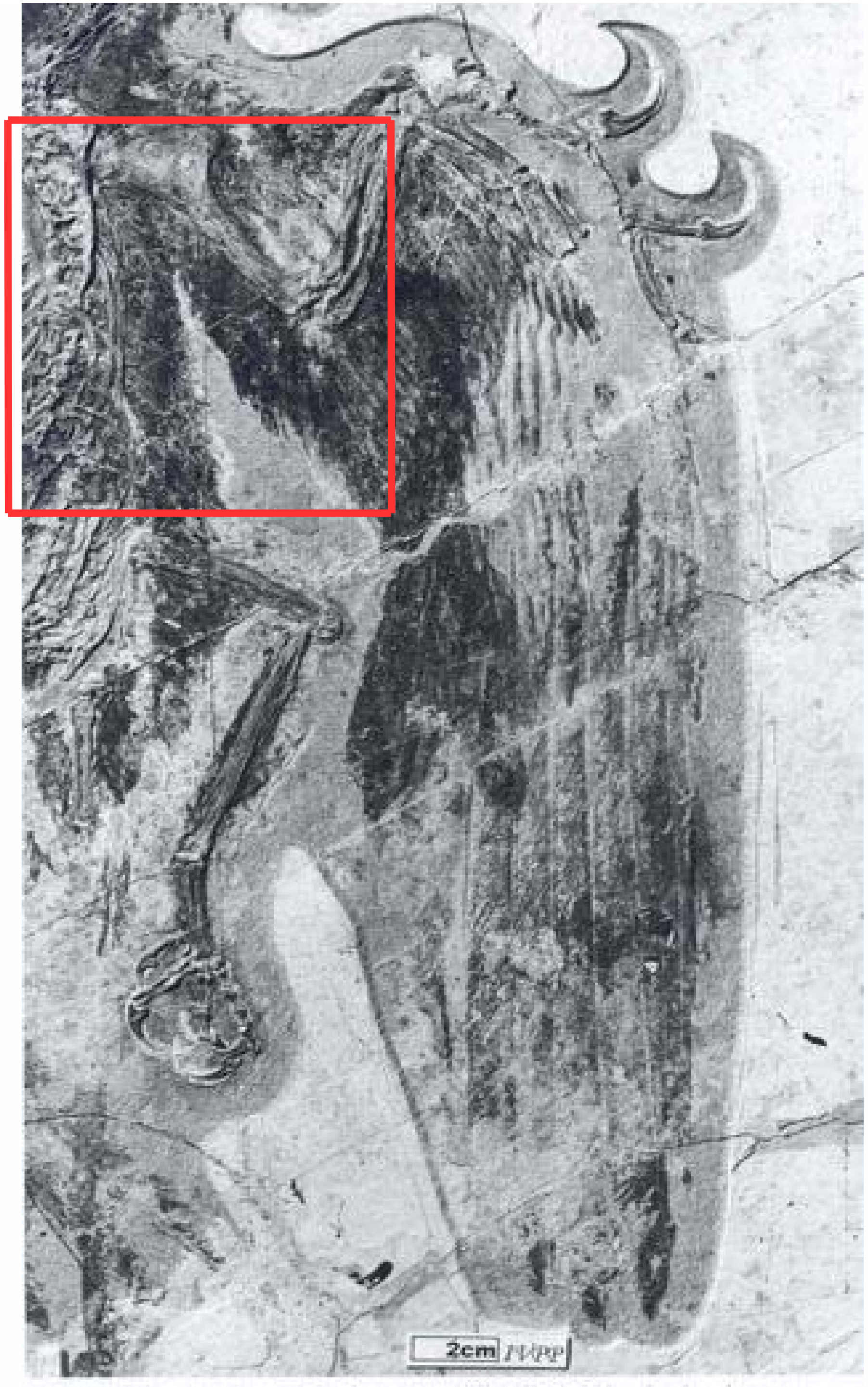
5cm

Early results: Sink speed versus forward velocity



Increasing wing-area (a broad wing) increases the minimum sink speed (reduces glide length): you can glide slower

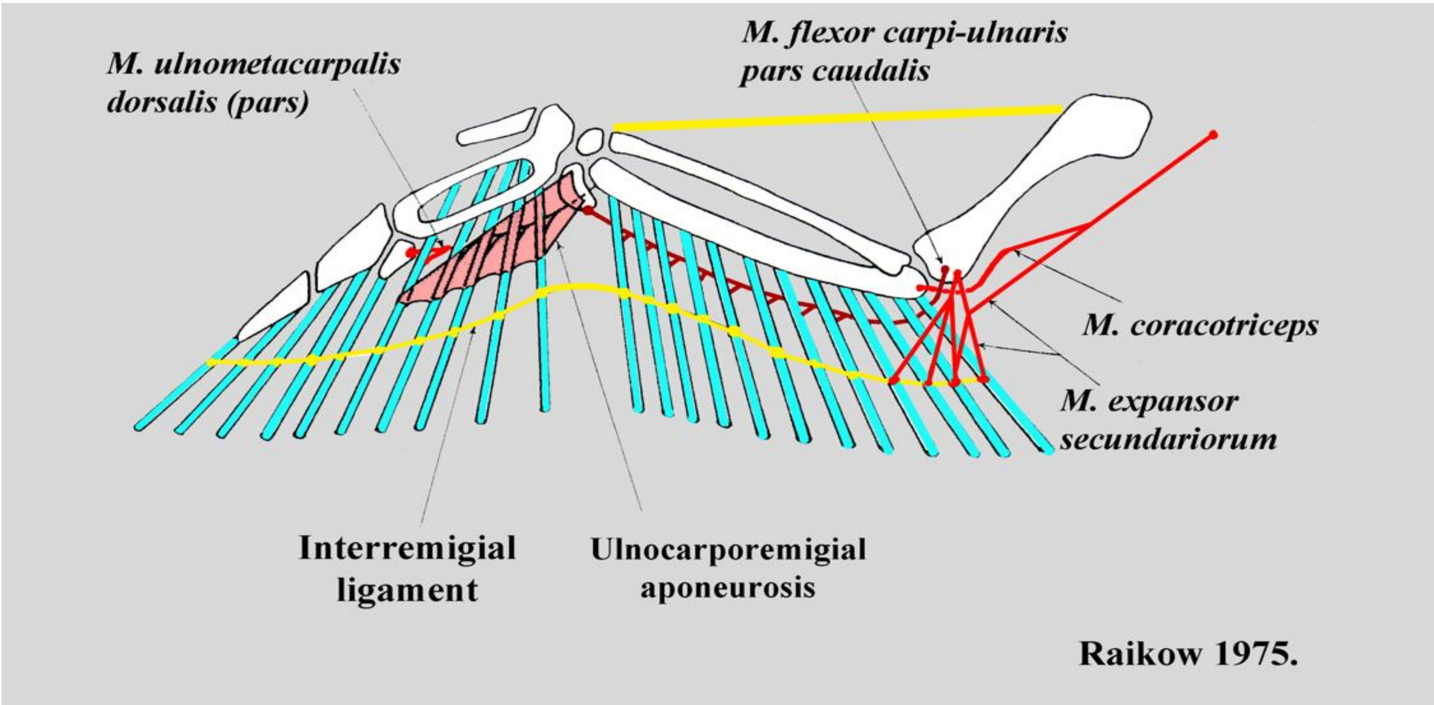
YFGP-T5199-201 also reveals information on feathering



***Confuciusornis*: a glider?**

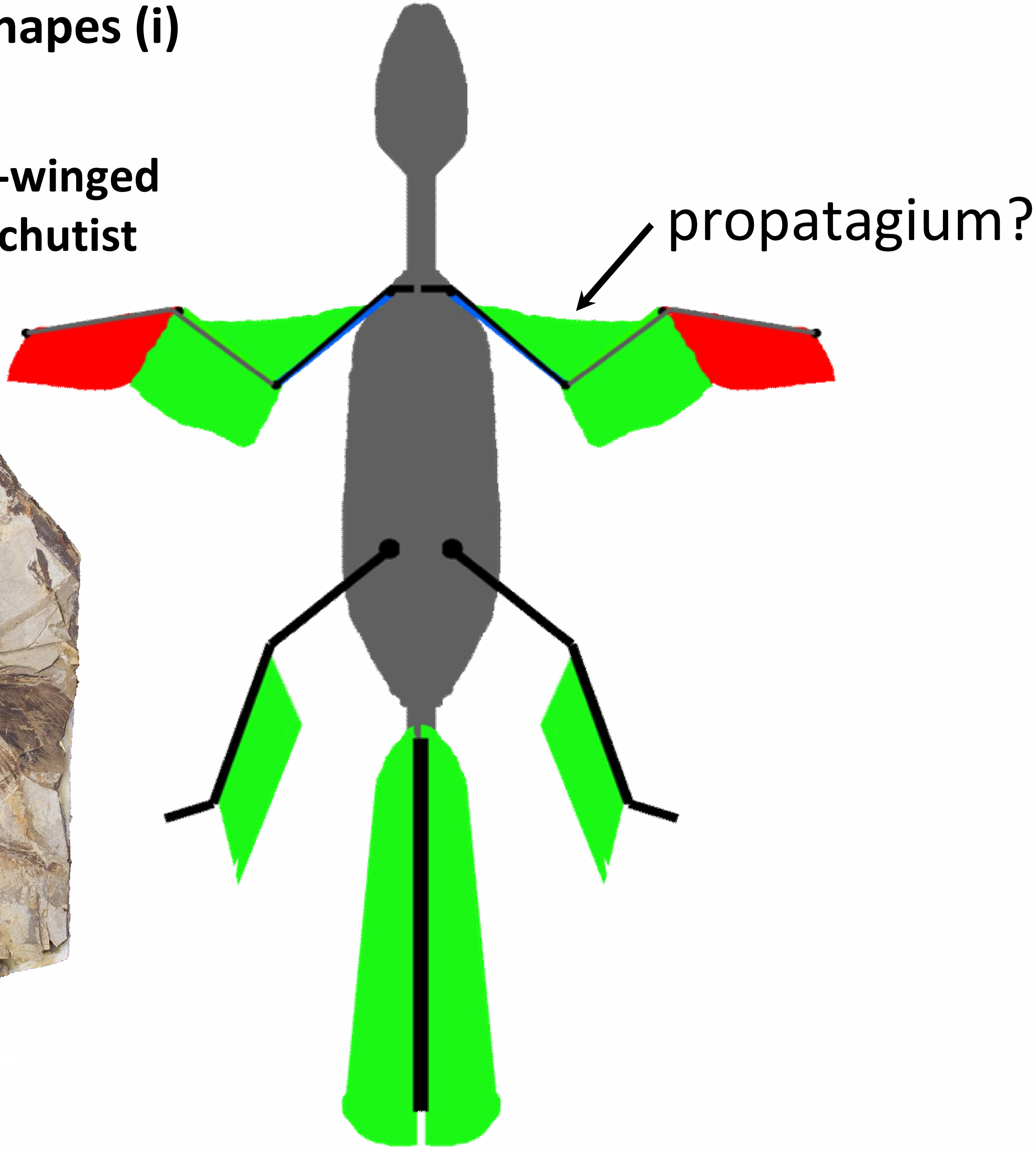

© 2008 Greg Cope


Black-footed Albatross
-elbow marked by coin

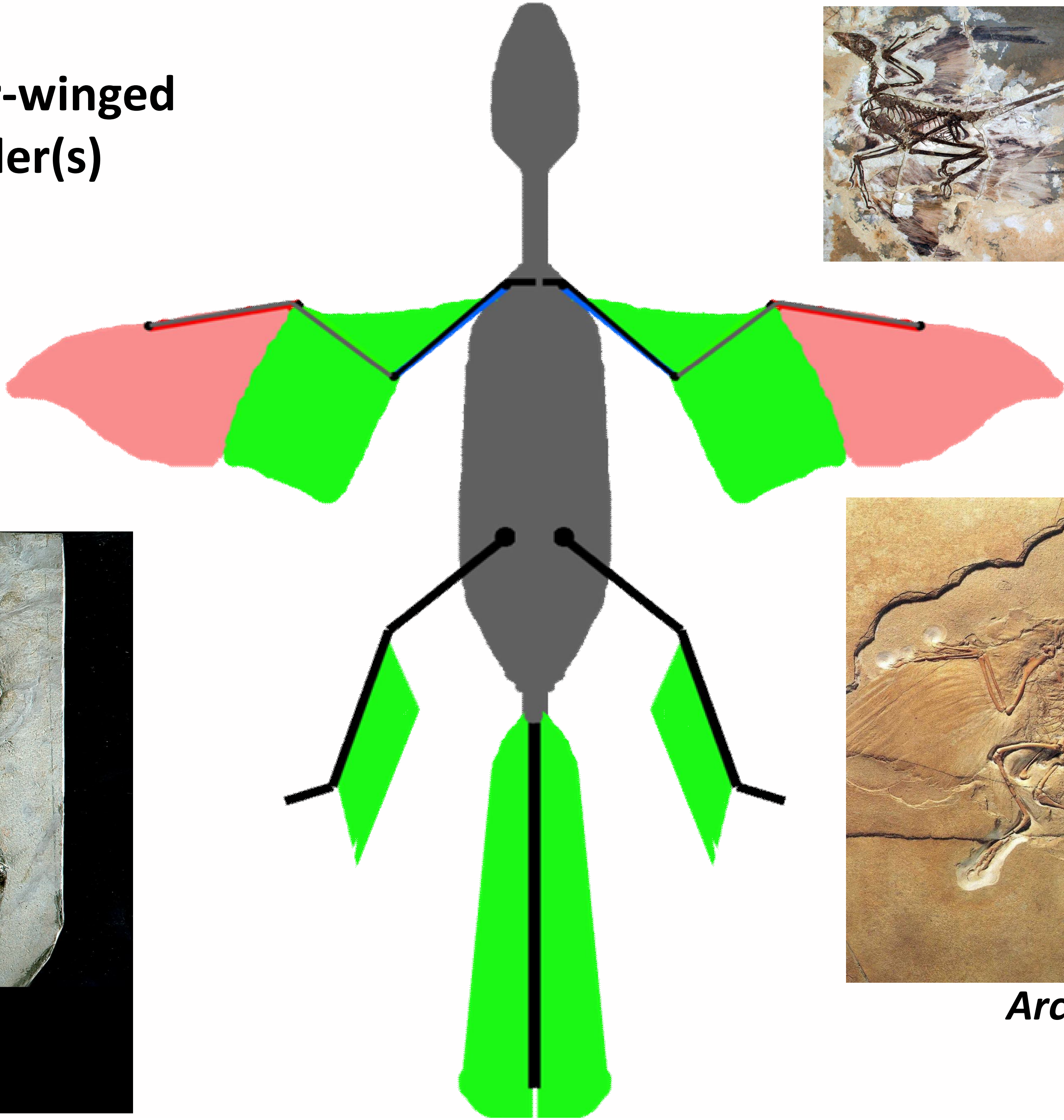

M. ulnometacarpalis
dorsalis (pars)
M. flexor carpi-ulnaris
pars caudalis
M. coracotriceps
M. expansor
secundariorum
Interremigial
ligament
Ulnocarporemigial
aponeurosis
Raikow 1975.

Evolution of wing shapes (i)

Small-winged parachutist

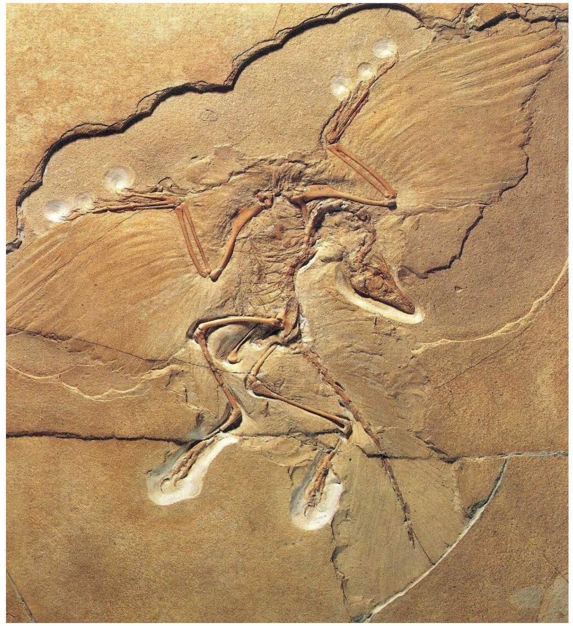


Longer-winged glider(s)



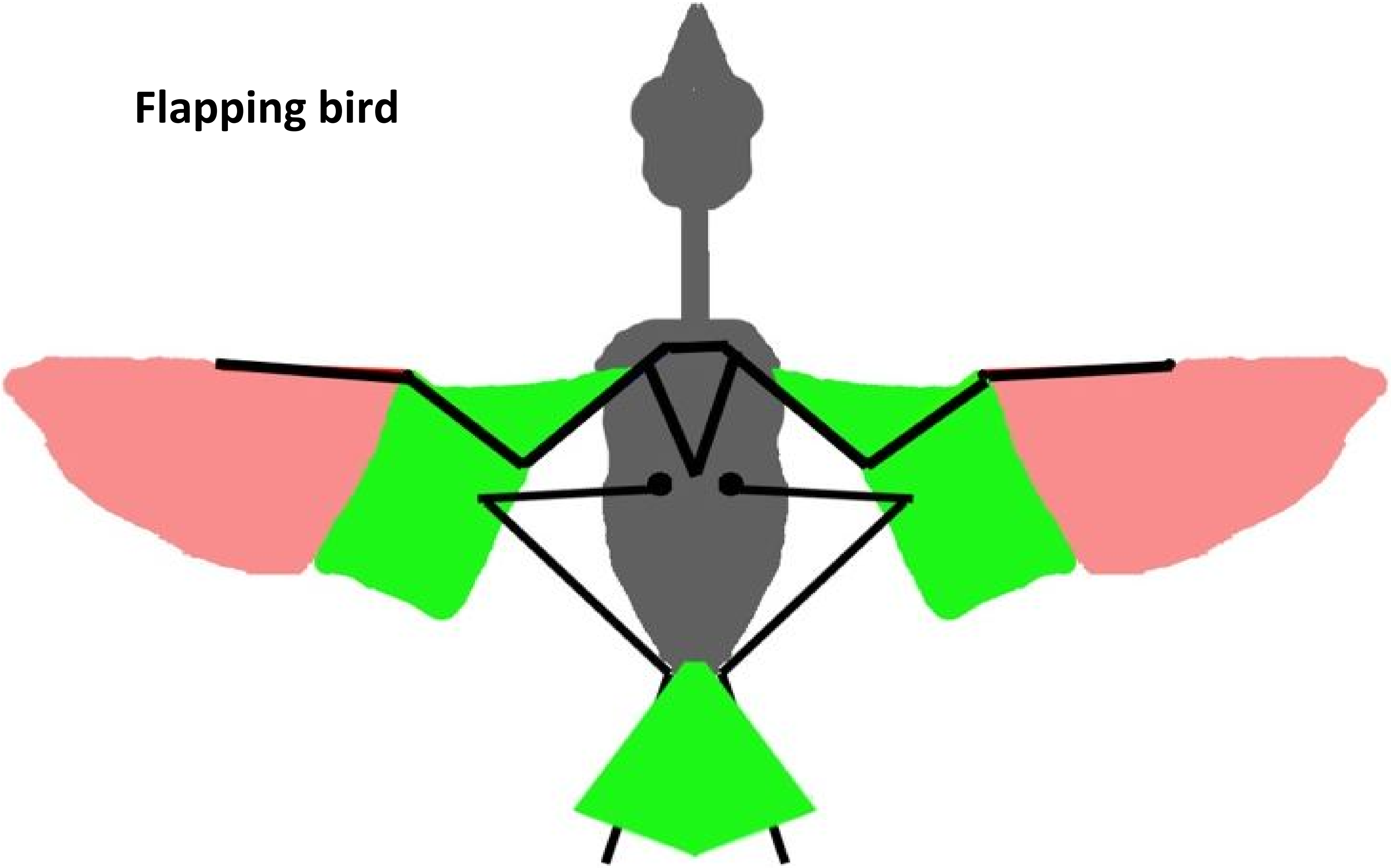
Microraptor

Confuciusornis

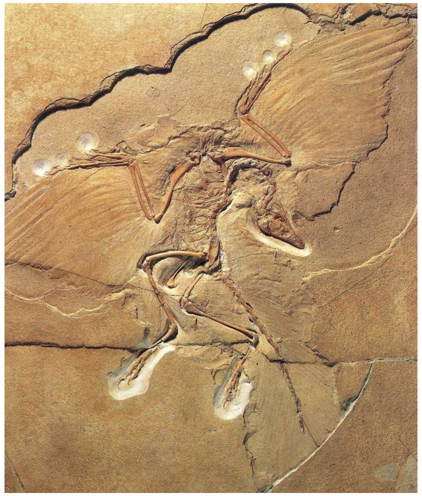


Archaeopteryx

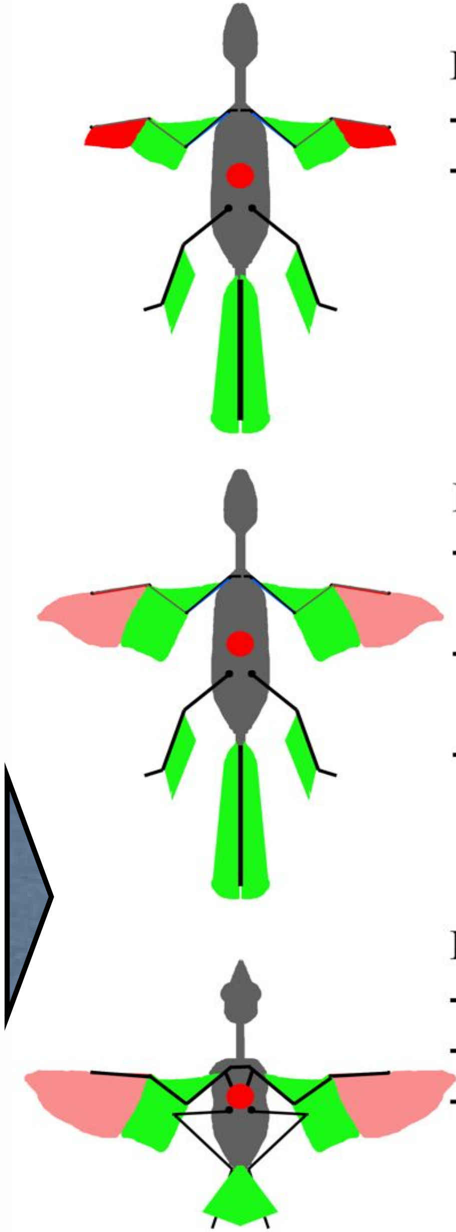
Flapping bird



Evolution of wing shapes (ii)



Confuciusornis
Sapeornis



Phase 1: Parachutist,
- minimal control
- lift distributed widely

Phase 2: Glider,
- greater lift but still widely distributed
- perhaps some control from primaries
- greater wing span (shallower glide angle)

Phase 3: Flyer.
- controling primaries
-short tail
- centre shifted forward by greater mass of flight muscles, large brain and eyes

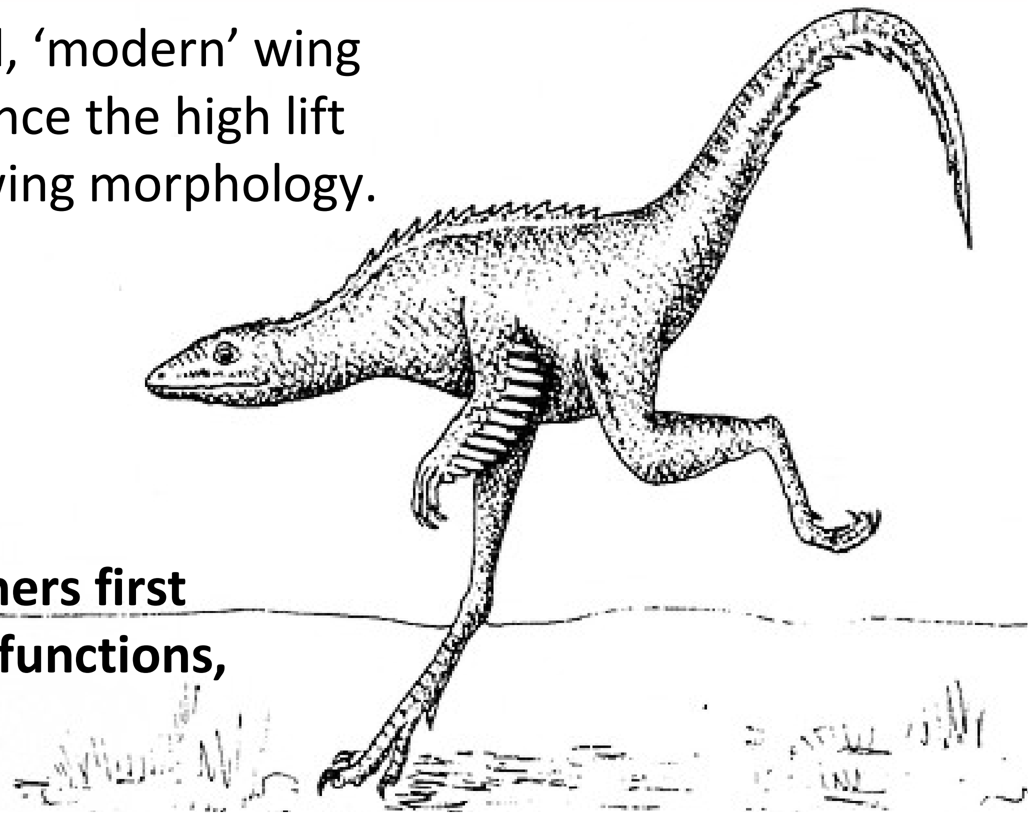
Conclusions

-*Microraptor* was most stable when gliding at high lift coefficients and consequently degraded lift/drag ratios;

-This behaviour had adaptive advantages since sustaining a high lift coefficient at the expense of high drag is the most efficient strategy for gliding from, and between, low elevations;

-Anatomically plausible changes in wing configuration and leg position made little difference to aerodynamic performance;

-*Microraptor* did not require a sophisticated, 'modern' wing morphology to undertake effective glides since the high lift coefficient regime is less dependent upon wing morphology.



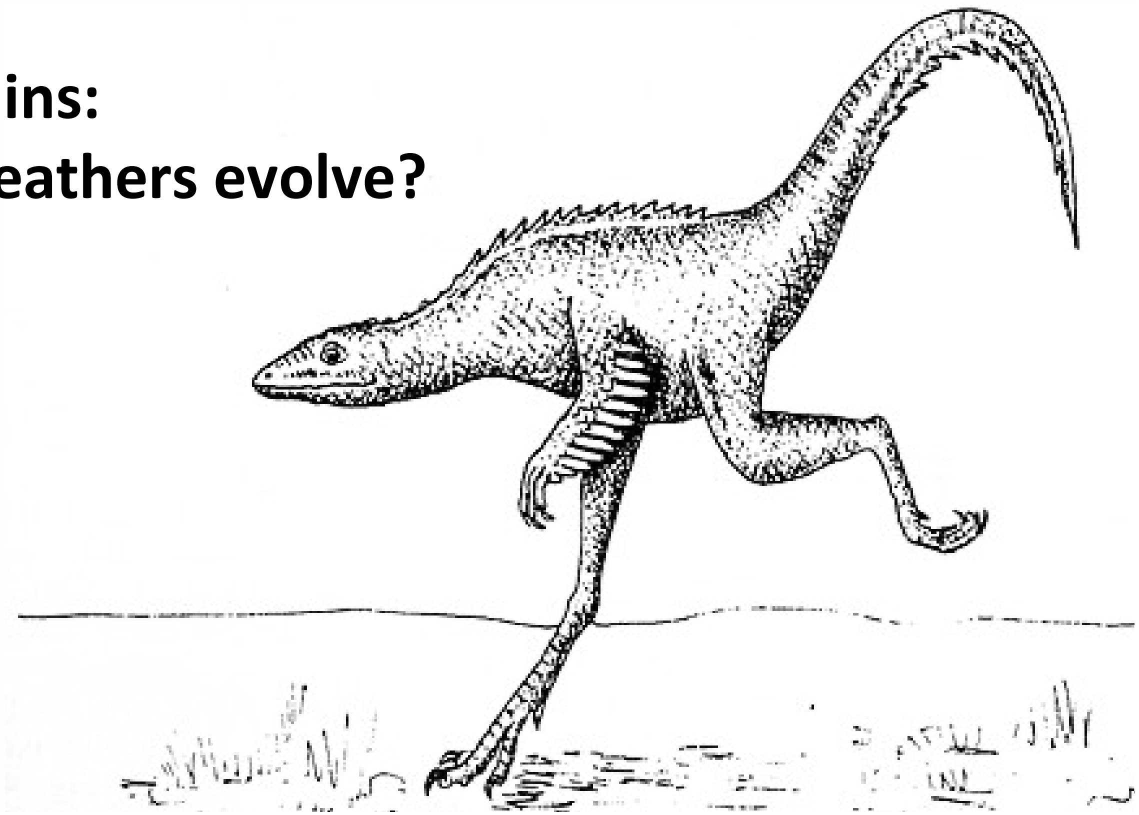
Congruent with the fossil record, and with the hypothesis that symmetric 'flight' feathers first evolved in dinosaurs for non-aerodynamic functions, later adapted to form aerodynamically capable surfaces.

We have also shown

-New fossil evidence for the evolution of wing shape (the primitive condition)

-Hypothetical stages in the evolution of flight surfaces (to be tested by analysis of fossils).

The question remains:
if not for flight, then why did feathers evolve?



If not for flight, then why did feathers evolve?
(one possible mechanism)

‘the sleeping troodontid’

Mei

If not for flight, then why did feathers evolve?
(one possible mechanism)

Gary Kaiser

Acknowledgements

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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