

14 November
2019

GENUS *HOMO* CONQUERS THE WORLD & CIVILIZATION

Homework #7 on WeBWork due Wednesday by 7pm

Astronomy 106 | Fall 2019

1

1



The "Lion Man" figurine from 35,000 – 40,000 years ago; found in Germany.

Genus *Homo* Conquers the World & Civilization

Intelligence and f_i

Evolution of genus *Homo* in Africa

Out of Africa

Victory of *sapiens*, and the consolation prize of *neanderthalensis* and the Denisovans

Primacy of *H. sapiens* and the Upper Paleolithic Age

The Neolithic Age and the Neolithic Revolution

Distribution of plants, animals, and mineral/metal resources

Sumer

f_c

14 November 2019

Astronomy 106 | Fall 2019

2

2

Intelligence & f_i

We are going to stray dangerously close to Making Stuff Up. Drake's original wild guess was $f_i = 0.01$; though much has happened in evolutionary biology since the 1960s, little of it has helped to constrain f_i .

Direct estimate: Count up the number of independent emergences of intelligence and divide by the number of independent tries to get f_i .

- This obviously includes a potentially misleading Earth bias.

What counts as a **robust** emergence of intelligence? This is arguable, but we can probably do no better than to use the criteria we found in our discussion of the evolution of genus *Homo*:

- Independent creation and use of tools
- Independent development of language that involves who-what-where-when concepts at minimum.

14 November 2019

Astronomy 106 | Fall 2019

3

3

Intelligence & f_i

There are other criteria we could use, such as the ability to solve puzzles, run through mazes, or work cooperatively with other animals. But,

- Not many have been widely applied to many kinds of animals
- Some of them are too qualitative, e.g. "cooperation"
- Some are vulnerable to the Clever Hans effect of observer-expectancy: animals achieving results only because the experimenter subtly and inadvertently gives them clues
- In animal-language studies, it is usually difficult to decode utterances into who-what-where-when concepts

Therefore, we will select candidate intelligence detections based on observations of animal interactions rather than human interaction. Also, we discount some wild claims on behalf of deep-sea invertebrates.

14 November 2019

Astronomy 106 | Fall 2019

4

4

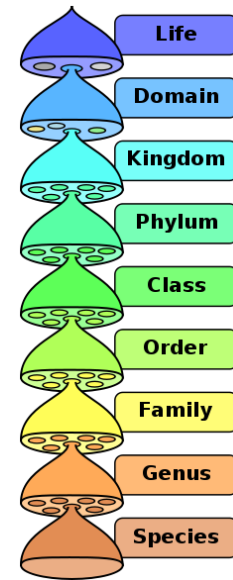
Intelligence & f_i

What counts as an independent try? A "body plan" distinct and different from others at the same phylogenetic rank.

- If all identified intelligences share an ancestor at a given rank – say, phylum or class – we will count this as one robust emergence of intelligence.
- All the others among that rank (including extinct ones) count as independent tries.

The number of categories at each rank increases by about a factor of ten with every step down.

- There have been 5-8 kingdoms, 110 phyla, $\sim 10^3$ classes, 10^4 orders, ..., 10^7 species.



14 November 2019

Astronomy 106 | Fall 2019

5

5

Intelligence genera?

Kingdom	Phylum	Class	Order	Family	Genus	Common name	Language?	Uses tools?	Makes tools?
Animalia	Chordata	Aves	Passeriformes	Corvidae	Corvus	Crow	?	Y	Y
Animalia	Chordata	Mammalia	Proboscidea	Elephantidae	Elphas	Indian elephant	Y	Y	Y
Animalia	Chordata	Mammalia	Carnivora	Mustelidae	Enhydra	Sea otter	N	Y	N
Animalia	Chordata	Mammalia	Primatae	Hominidae	Gorilla	Gorilla	Y	Y	Y
Animalia	Chordata	Mammalia	Primatae	Hominidae	Homo	Human	Y	Y	Y
Animalia	Chordata	Mammalia	Proboscidea	Elephantidae	Loxodonta	African elephant	Y	Y	Y
Animalia	Chordata	Mammalia	Cetacea	Delphinidae	Orcinus	Orca	Y	?	?
Animalia	Chordata	Mammalia	Primatae	Hominidae	Pan	Chimpanzee	Y	Y	Y
Animalia	Chordata	Mammalia	Cetacea	Physeteridae	Physeter	Sperm whale	Y	N	N
Animalia	Chordata	Mammalia	Primatae	Hominidae	Pongo	Orangutan	Y	Y	Y
Animalia	Chordata	Mammalia	Cetacea	Delphinidae	Tursiops	Bottlenose dolphin	Y	Y	Y

14 November 2019

Astronomy 106 | Fall 2019

6

6

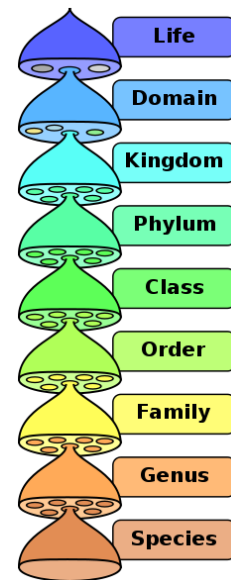
Intelligence & f_i

The seven definite emergences of intelligence belong to four different families and four different orders, but only one class (Mammalia).

- There have been about 1000 classes. This suggests that $f_i = 0.001$.

If crows really do have a language in which individuals exchange who-what-where-when information – or if there are other birds that do and also share the crow's accomplishments in toolmaking – then the intelligence-emergences belong to two classes and only one phylum (Chordata).

- There have been about 100 phyla. This suggests $f_i = 0.01$.



14 November 2019

Astronomy 106 | Fall 2019

7

7

Intelligence & f_i

We are left with some fuzzy constraints:

- f_i seems unlikely to be a hefty fraction of 1.
- Similarly, it seems unlikely to be close to the lower bound of about 10^{-9} (Earth/number of earthlike planets).
- But any value between and far from these can be defended.
- We shall then split the difference (logarithmically) between our two estimates above and take

$$f_i = 0.003$$

- It could be ten times larger; it could be 100-10000 times smaller; no result would really be a surprise.

14 November 2019

Astronomy 106 | Fall 2019

8

8

What do you think is the value of f_i ?

Question!

- A. 0.1
- B. 0.01
- C. 0.001
- D. 0.0001
- E. 0.00001

14 November 2019

Astronomy 106 | Fall 2019

9

9

Genetic diversity of Africa

From *H. erectus* onward, the adaptability and organizational skills permitted by larger brain size – especially tool- and speech-making capabilities – allowed ancient humans to spread past the bounds of their East African homeland.

They had to, for dietary reasons.

- Big herbivores like gorillas and chimps can live (in forests) at population densities of about 1 per km².
- The genus *Homo* line, who preferred meat, could no longer digest leaves and grasses and were not so efficient at hunting yet, could only live at densities **no greater than about 0.1 per km²**.

Competition among the hominids led to

- The more advanced ones forced the less advanced ones to inhospitable places, or
- The more advanced ones either killed or ate the less advanced ones.

They spread throughout the temperate Africa south of the Sahara and the **Sudd**, a huge swamp along the Nile.

14 November 2019

Astronomy 106 | Fall 2019

10

10

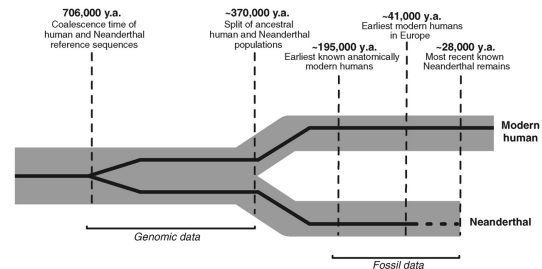
Genetic diversity of Africa

From the viewpoint of the fossil record and relative to the “out of Africa” humans, this “survival of the fittest” addition to ordinary natural selection ensured

- A relatively rapid evolutionary progress toward even more dangerous members of genus *Homo*
- A rapid replacement of previous models

About 370 kyr ago, this evolution appears to have produced two surviving branches of our genus:

- Archaic *Homo*, represented in the African fossil record by *H. rhodesiensis*, and elsewhere by *H. heidelbergensis*, the “Denisovans,” and most numerous by the Neanderthals, *H. neanderthalensis*.
- Modern *Homo*: *H. sapiens*, the species to which we belong.



Noonan et al. (2006)

14 November 2019

Astronomy 106 | Fall 2019

11

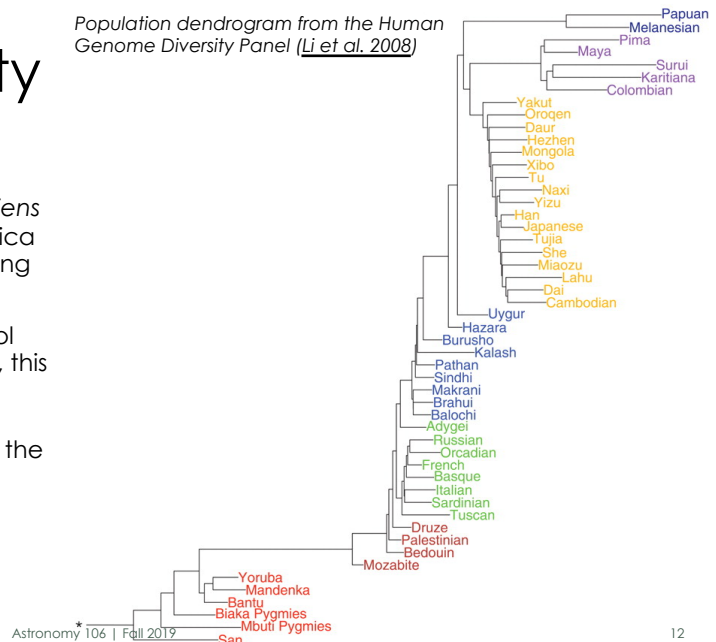
11

Genetic diversity of Africa

By roughly 100,000 years ago, *H. sapiens* had occupied all of sub-Saharan Africa and eliminated its competition, leaving the apes and monkeys to their trees.

Still dominating the human gene pool and having 0.4 Myr of differentiation, this process led to a notable diversity of **races** among African *H. sapiens* that remains the greatest, even now that the species is worldwide.

Population dendrogram from the Human Genome Diversity Panel (Li et al. 2008)



14 November 2019

Astronomy 106 | Fall 2019

12

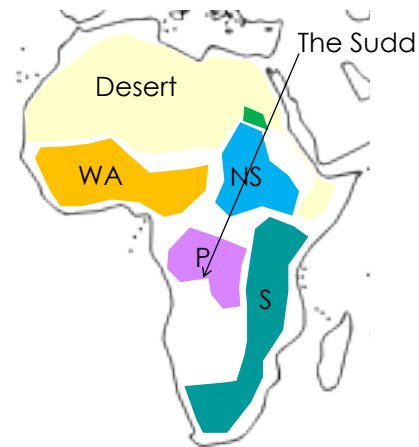
12

Genetic diversity of Africa

The four main branches of African *H. sapiens* are shown to the right, the differences among which are as great as the rest of the world.

- **West Africans** (Niger-Congolese language group)
- **Nilo-Saharans**
- **Pygmys**
- **San** (a.k.a. Khoisan)

All were originally also language groups, though the Pygmys now speak West African (specifically, Bantu) languages.



14 November 2019

Astronomy 106 | Fall 2019

13

13

Out of Africa

There was some leakage from the African gene pool as humans explored for better food sources.

Presumably, the best exit has always been to endure the passage of the Sudd and follow the Nile; this is consistent with the ages of archaic human fossils, which tend to be closer to the Isthmus of Suez the older they are.

There have been at least three escapes: by *H. erectus*, by *H. heidelbergensis*, and by *H. sapiens*. (Probably the Denisovans, too.)

H. erectus escaped sub-Saharan Africa somewhere around 1 Myr ago, rather early in the life of the species. They rapidly spread throughout the temperate regions of North Africa, Europe, and Asia, bringing the Acheulean toolkit along; the exemplars of the **lower Paleolithic age**.

- Thus "Java man" and "Peking man"

14 November 2019

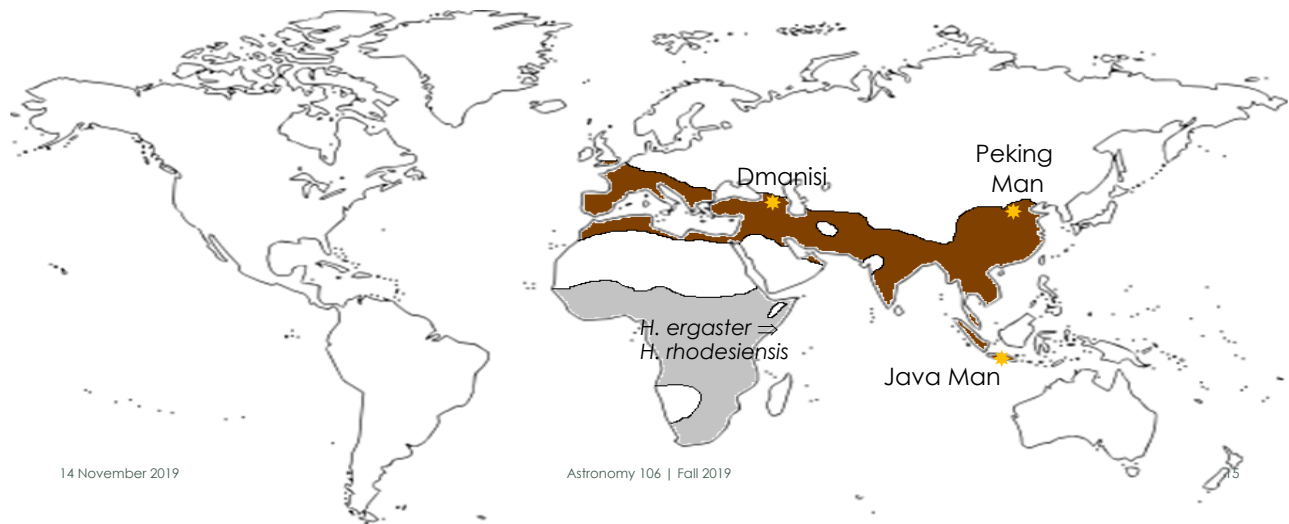
Astronomy 106 | Fall 2019

14

14

Range of *H. erectus*

Ice-age drops in sea level enabled *H. erectus* to walk to Java and Britain.



15

Out of Africa

About 130,000 years ago, near the beginning of the most recent ice age (Weichsel-Wurm), a small band of *H. heidelbergensis* left Africa.

- They seem to have quickly displaced *H. erectus* in Europe, the Near East, and central Asia.
- They flourished by hunting ice-age megafauna, such as mastodons and mammoths, on the treeless tundra south of the ice sheets.
- The natural selection to which their new, cold environment subjected them led to the emergence of a new species, *H. neanderthalensis*, which spread further and supplanted *H. heidelbergensis*.
- Neanderthal remains and the products of their **Mousterian** tool industry comprise the **oldest finds of the Middle Paleolithic Age** in Europe and the Near East.

14 November 2019

Astronomy 106 | Fall 2019

16

16

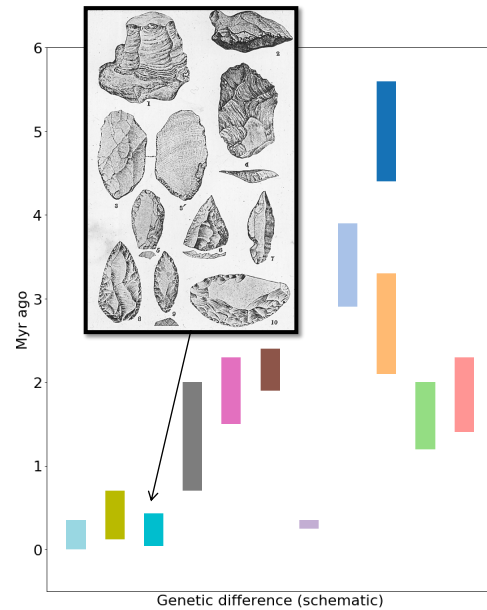
Neanderthal skills

Mousterian tools: made by flaking and included points

Fire, and probably some cooking skills

Clothing, as they could live in cold climates

They also often dug holes in their cave floors which led to *much* confusion due to the mixture of different-age artifacts.



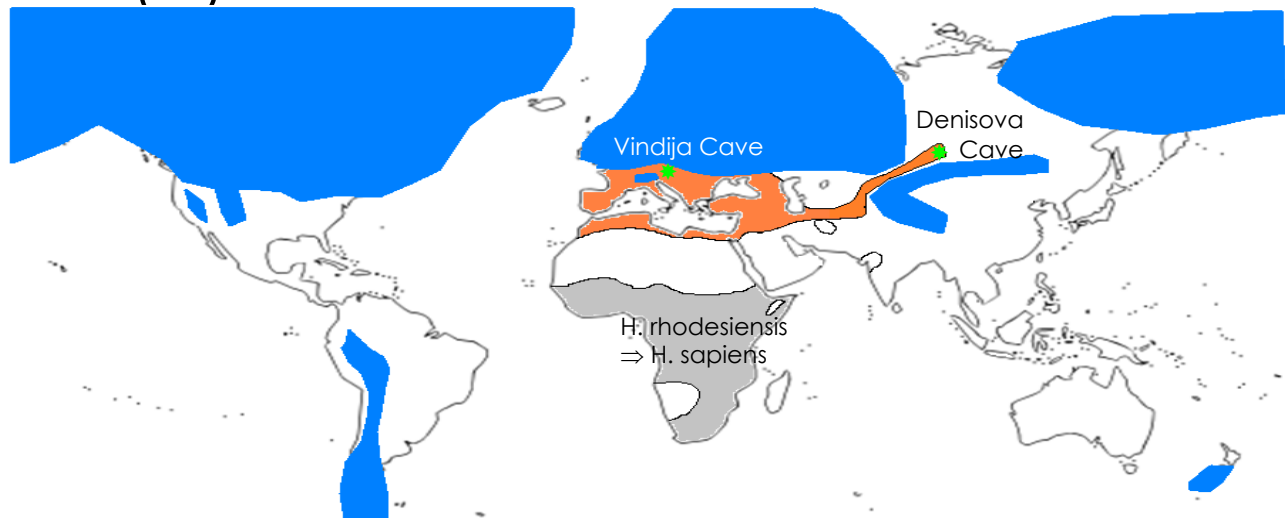
14 November 2019

Astronomy 106 | Fall 2019

17

17

Range of *H. neanderthalensis* and (W) ice sheets



18

Out of Africa

About 80,000 years ago, with the W ice age still in progress, a small group of *H. sapiens* left Africa via the Nile valley. Similar to its predecessors, they began to reproduce, flourish, and expand all over the world.

Also like its predecessors, this group represented a tiny selection of the African gene pool and reproduced very rapidly as it soon took over all the habitats.

Since its numbers grew large so much faster than the time over which *H. sapiens* had evolved, the Out of Africa portion of the species is genetically very homogeneous.

- Norwegians, Chinese, and Australian Aborigines are genetically very similar.
- All are genetically different from all of the remaining African races.

By c. 18 kyr ago, *H. sapiens* had completely replaced their predecessors.

14 November 2019

Astronomy 106 | Fall 2019

19

19

Out of Africa

Though the idea that this takeover took place by violent conquest has been popular (along with suggestions of cannibalism), it has been suggested many times throughout the years that *H. erectus* and *H. neanderthalensis* interbred with *H. sapiens*, and that this replacement was at least partly an assimilation of smaller communities by a larger one.

- *H. sapiens*, with its better tool set and organization, would plausibly have multiplied much faster than the other out-of-Africa communities. It would not have taken long for them to outnumber all others.
- Certainly *H. sapiens* and *H. neanderthalensis* lived side-by-side in Europe and the Middle East for at least 40 kyr.

14 November 2019

Astronomy 106 | Fall 2019

20

20

Out of Africa

The odds would seem to be against this as a means of replacement of *H. erectus*:

- Mitochondrial DNA studies indicate that the maternal lineage of living humans goes back only to about 190-200 kyr ago, thus identifying the epoch of **mitochondrial Eve**.
- Similarly, Y-chromosome studies take the paternal lineage back to the range 60-140 kyr ago: somewhere in there is the epoch of **Y-chromosomal Adam**.
- Neither of these time frames overlaps with *H. erectus*, who was long gone from Africa by this time and might have gone from Eurasia by the time *H. sapiens* left Africa.

14 November 2019

Astronomy 106 | Fall 2019

21

21

Genetics of the *H. sapiens* takeover

But recently, paleogeneticists led by Svante Pääbo retrieved complete genomes for Neanderthal remains found in Vindija Cave, Croatia, and in southern Siberia. These indicate that

- Their gene sequence is distinctively different from all current races of *H. sapiens*.
- **Current Eurasian *H. sapiens* share 1-4% of their coding (non-junk) DNA with the Vindija Neanderthals through maternal or paternal descent.**
- **Current African *H. sapiens* do not share any.**

This is very strong evidence that Neanderthals and modern humans interbred after the latter left Africa.



Pääbo and an old friend

14 November 2019

Astronomy 106 | Fall 2019

22

22

Genetics of the *H. sapiens* takeover

And then there are the Denisovans.

- Closely related to “classical” Neanderthals, though genetically distinct. Maybe a separate thread of African emigration; very thin fossil record, though.
- Fossils from 4 distinct Denisovan individuals have been found in the Denisovan cave.



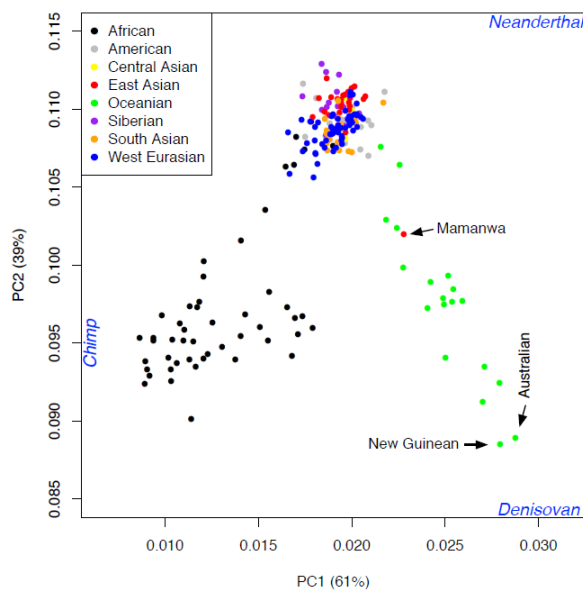
Denisovan cave, location of “X Woman.”

14 November 2019

Astronomy 106 | Fall 2019

23

23



14 November 2019

Astronomy 106 | Fall 2019

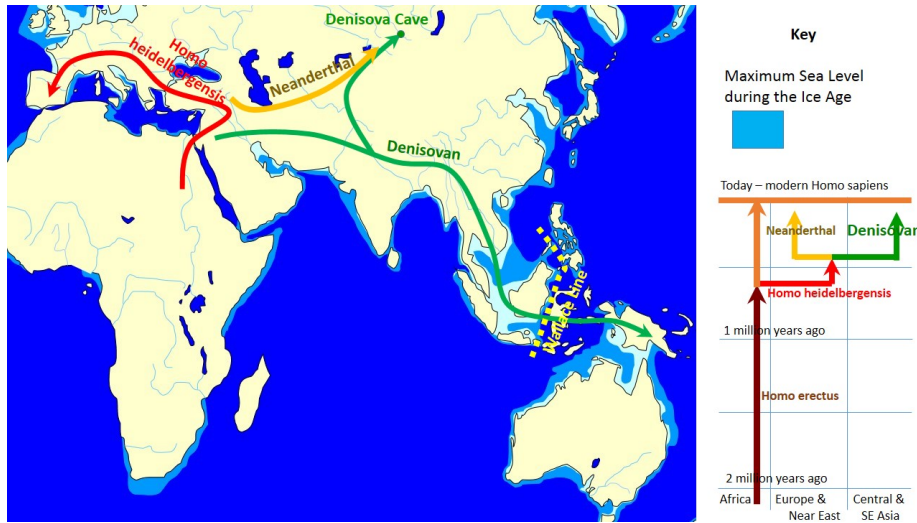
24

Densiovans

4% of the non-junk DNA of **most** present-day Melanesians is descended from Denisovans, evidence of more inbreeding.

Principle component analysis of current populations v. Neanderthals, Denisovans, and chimpanzees ([Qin & Stoneking, 2015](#))

24



14 November 2019

Astronomy 106 | Fall 2019

25

25

Out of Africa, pre-*H. sapiens*

Denisovans and Neanderthals split from *H. sapiens* between 600,000 and 740,000 years ago; they diverged from each other about 200,000 years later.

Which of the following statements applies to you?

- A. I have Neanderthal ancestors but not Denisovan ancestors.
- B. I have Denisovan ancestors but not Neanderthal ancestors.
- C. I have both Denisovan and Neanderthal ancestors.
- D. I have neither Neanderthal nor Denisovan ancestors.

Question!

14 November 2019

Astronomy 106 | Fall 2019

26

26

The Upper Paleolithic age

H. sapiens brought with them many new improvements, for which the remains grace the Eurasian **Upper Paleolithic** Age:

- Even better tools (the Aurignacian industry), including composite structures made of wood or bone and pebbles sharpened to an edge (**microlith** tools). The slightly cruder **Chatelperronian** tools might represent the Neanderthals trying to follow suit, too little and too late.



14 November 2019

Astronomy 106 | Fall 2019

27

27

The Upper Paleolithic age

- New ideas, like
 - Boats: With these, *H. sapiens* colonized New Guinea and Australia about 40,000 years ago – much sooner than the Americas. For that matter, much sooner than Cyprus, Corsica, Sardinia, and even Madagascar, which also require a sea-crossing to reach.
 - (subprimate) animal friends: Dogs begin to appear around the campfires early in the upper paleolithic.



14 November 2019

Astronomy 106 | Fall 2019

28

28

The Upper Paleolithic age

Modern *H. sapiens* have not evolved biologically since about 40,000 years ago. Instead, major developments in the species (mainly the development of civilization) has come in the form of cultural evolution.

Throughout the Paleolithic age, *H. sapiens* operated in a hunter-gatherer society, although campsites (some with storage pits) started making an appearance.



Digital reconstruction of Upper Paleolithic campsite
(García-Díez & Vaquero 2015)

14 November 2019

Astronomy 106 | Fall 2019

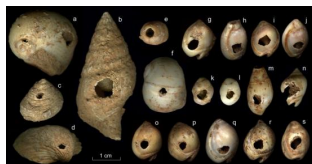
29

29

The Upper Paleolithic age

During the next two "tool" phases, the Solutrean (22 kyr ago) and **Magdalenian** (18 kyr ago) eras, they began to leave the first signs of cultural evolution in the form of representational art.

- Paintings, such as at **Lascaux** (France) and Altamira (Spain)
- Simple jewelry, like the **perforated shells**
- Statuettes, like the Venuses and the "lion man"



14 November 2019

Astronomy 106 | Fall 2019

30

30

The Upper Paleolithic age

By 15,000 yr ago, *H. sapiens* completed their occupation and adaptation to all of the habitable land of Europe, Asia, and Australia, and followed the edges of the ice sheets as they retreated north.

By this time, their multiplication had carried their population far beyond that of Africa.

The adaptation in various climates, and the lack of communication over large distances, led to a differentiation of habits in "culture" and dining during this time.

- The most notable of these is the origin of the basic families of language, since those left the most indelible mark.

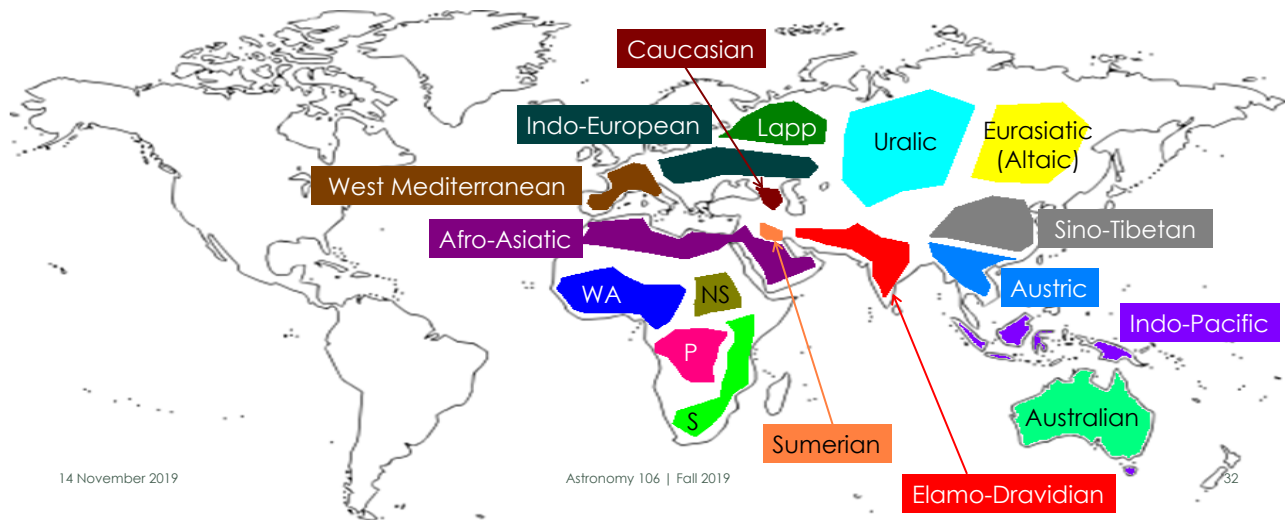
14 November 2019

Astronomy 106 | Fall 2019

31

31

The ethno-linguistic groups, c. 15,000 yr ago



14 November 2019

Astronomy 106 | Fall 2019

32

32

The Neolithic age (new stone age)

By about 10,000 years ago,

- *H. sapiens* had been active in Africa for almost 400,000 years and had built up the four sub-Saharan races that exist today, each originally with its own language group.
- The earliest Eurasian establishments of *H. sapiens* had thousands of generations in which to become accustomed to the resources presented by their homelands, and by then had begun to differentiate into race-like groups as well as language groups, even though large genetic differences had not had time to happen.
- *H. sapiens* had only recently colonized the Americas.

Bands of megafauna-hunters had lived for thousands of years in Beringia, which during the W ice age was dry, non-glaciated grassland; further east was an ice cap.

At about 11,000 years ago, as the W ice age waned, a gap in the ice cap opened up from Alaska through Yukon and Alberta, and the hunters raced through, soon reaching the Great Plains.

14 November 2019

Astronomy 106 | Fall 2019

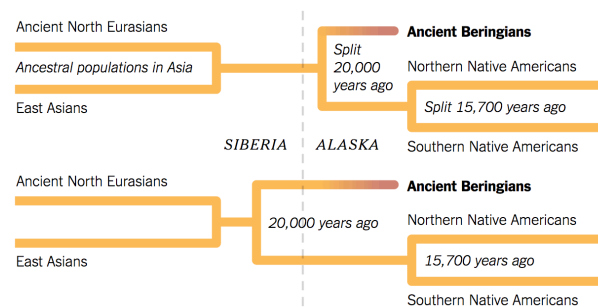
33

33

H. sapien migrates to Americas

That *H. sapien* ventured from Siberia into Alaska to reach the Americas during the end of the last ice age is no mystery – the ocean levels were much lower, enabling relatively easy passage.

There is a genetic difference between Native Americans and an extinct race called the Beringians, remains of which have been found in Alaska. Whether this split occurred before or after crossing remains uncertain.



14 November 2019

Astronomy 106 | Fall 2019

34

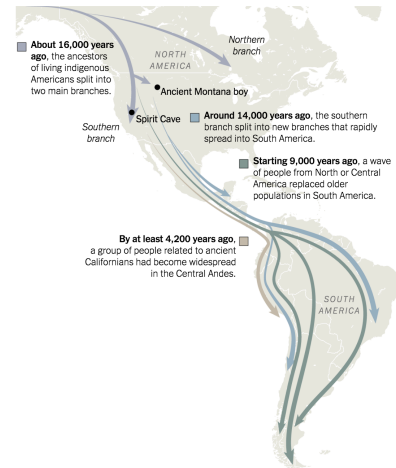
34

H. sapien migrates to Americas

After entering North America, *H. sapien* quickly moved south and expanded into South America.

The genetic differences between ancient remains found in the Spirit Cave and in Chile are incredibly minute, so this expansion was extremely rapid.

Some of the largest differences between the different races in the Americas is a result of different altitudes, not different geographic locations.



14 November 2019

Astronomy 106 | Fall 2019

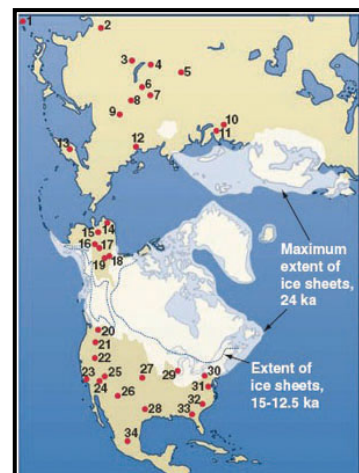
35

35

The Neolithic age (new stone age)

There, they comfortably maintained their upper-Paleolithic lifestyle for a long time, as they finished off all the horses and mammoths. Some continued to move south.

Richer homelands endowed some of the groups with advantages that sped them toward sophistication. Adoption of sophistication moves them out of the Paleolithic Age into the **Neolithic Age**.



CSFA, Texas A&M U.

14 November 2019

Astronomy 106 | Fall 2019

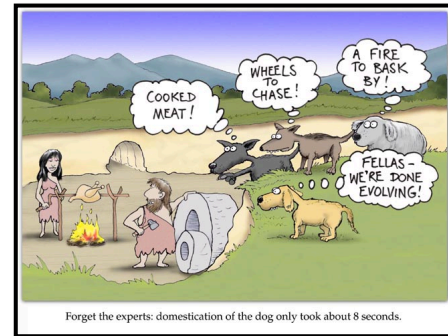
36

36

The Neolithic age (new stone age)

The new features of the Neolithic include:

- Abundant and tasty animals that do not mind living around humans.
- **Domestication**, both to provide food sources more reliable than the hunt, and eventually to provide beasts of burden. Not just taming...
- This is a double-edged sword: more intimate contact with animals meant more crossing over of animal **diseases**. Hinders, but also builds immunity in survivors.
- Digestible, carbohydrate-rich food that can be stored for months without spoilage.
- Domestication here means determining the right seeds for edibility and high productivity, planting, and selecting seeds of the best outcomes for replanting.



14 November 2019

Astronomy 106 | Fall 2019

37

37

The Neolithic age (new stone age)

- Useful minerals: rocks, gems, and eventually metals.
 - Stone tools predominated for a long time, even after the appearance of metal ones.
 - Copper is the first "domesticated" metal: colorful ores, low melting point, easy to cast or hammer.
 - Bronze – a lower-melting point copper alloy – is harder and holds an edge better and is possible to make inadvertently while smelting copper.

The use of metals in tools marks the end of the Neolithic age.



14 November 2019

Astronomy 106 | Fall 2019

38

38

The Neolithic revolution

For those surrounded by relatively rich supplies of animal, vegetable, and mineral resources, it did not take long to realize that to exploit them effectively required a new social order that differed from the tribal structure of hunter-gatherer cultures.

- Larger bands began to form and to establish fixed residences near tilled fields.
- The increased person-power led to even larger projects, such as the construction of irrigation systems.
- The consistently better-fed populace grew much faster than before.

This is called the **Neolithic revolution** and led straight to **civilization**.

- The revolution happened at different times in different places. To understand why and how, consider the distribution of resources:

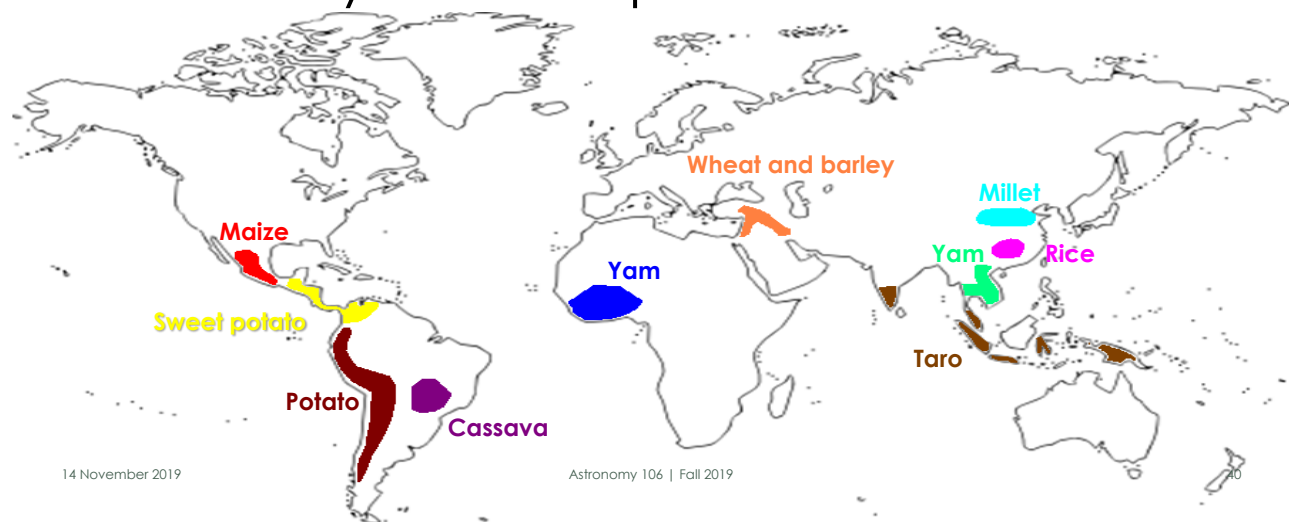
14 November 2019

Astronomy 106 | Fall 2019

39

39

Native ranges of the staple carbohydrate crops



14 November 2019

Astronomy 106 | Fall 2019

40

40

Not all carbohydrate crops are equal

They differ in their other nutrients and their ease of storage.

- Some, like cassava, are very poor in protein.

They differ in resistance to diseases and pests.

Above all, though, they differ in the population they can sustain: simply calories per acre.

Crop	Calories per unit farm area [wheat = 1]
Potato	3.5
Rice	2.8
Sweet potato, yam	2.0
Barley	1.4
Sorghum	1.2
Wheat	1.0
Maize	1.0
Oats	0.8
Millet	0.5

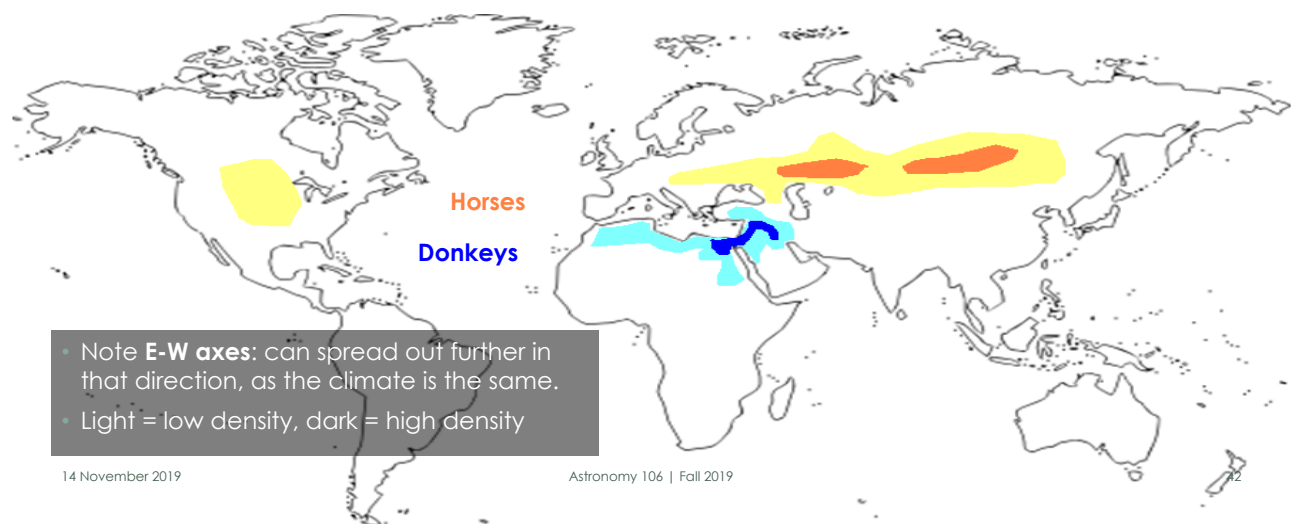
14 November 2019

Astronomy 106 | Fall 2019

41

41

Native ranges of large equines

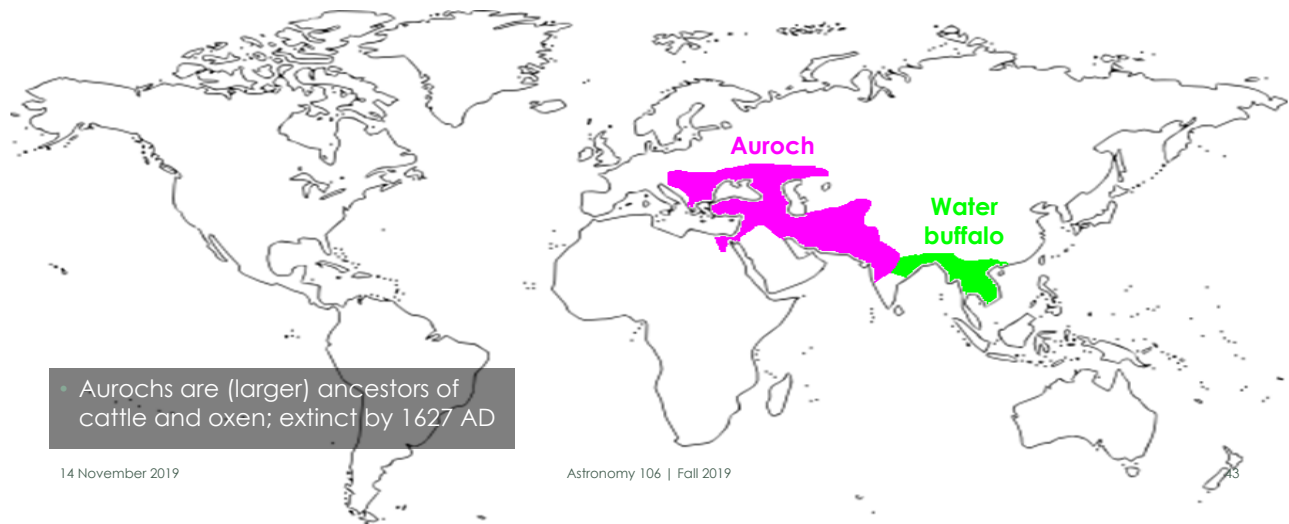


14 November 2019

Astronomy 106 | Fall 2019

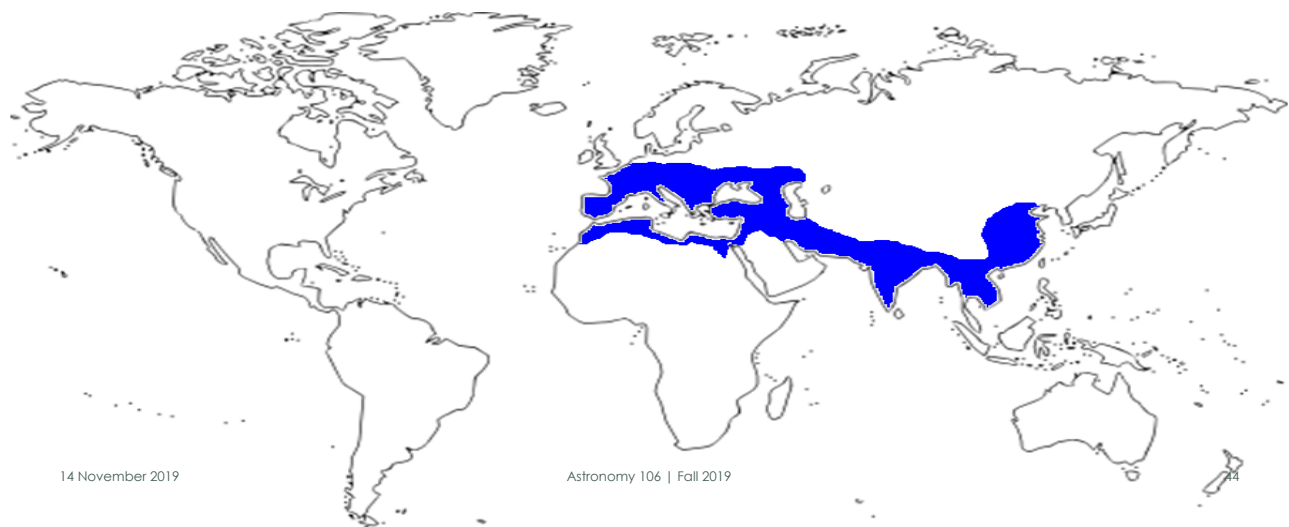
42

Native ranges of large bovines



43

Native range of swine



44

Native range of common (“bezoar”) goats



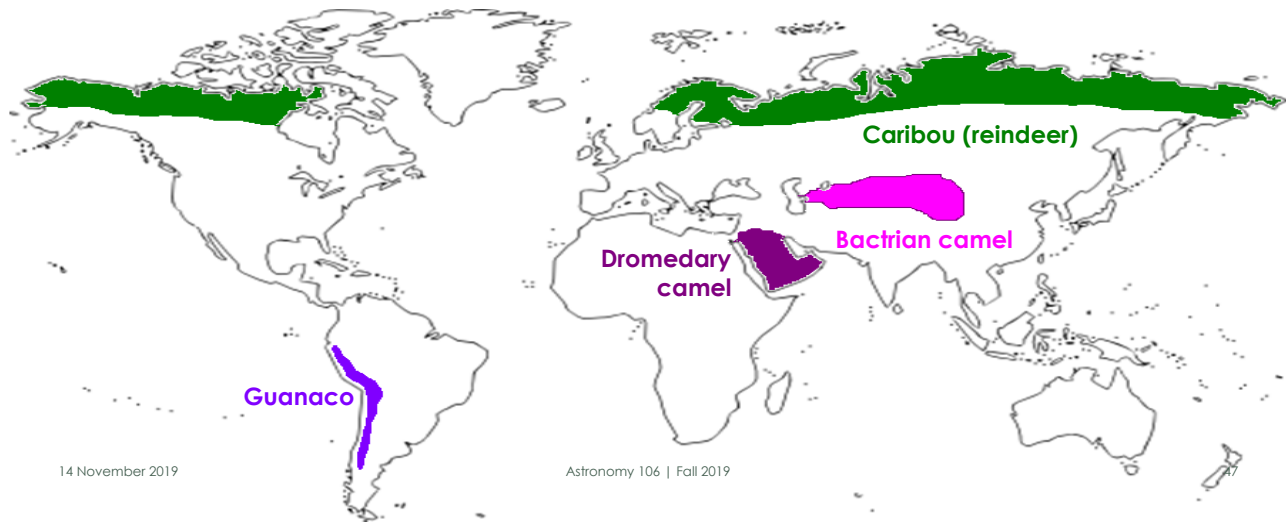
45

Native range of common (“mouflon”) sheep



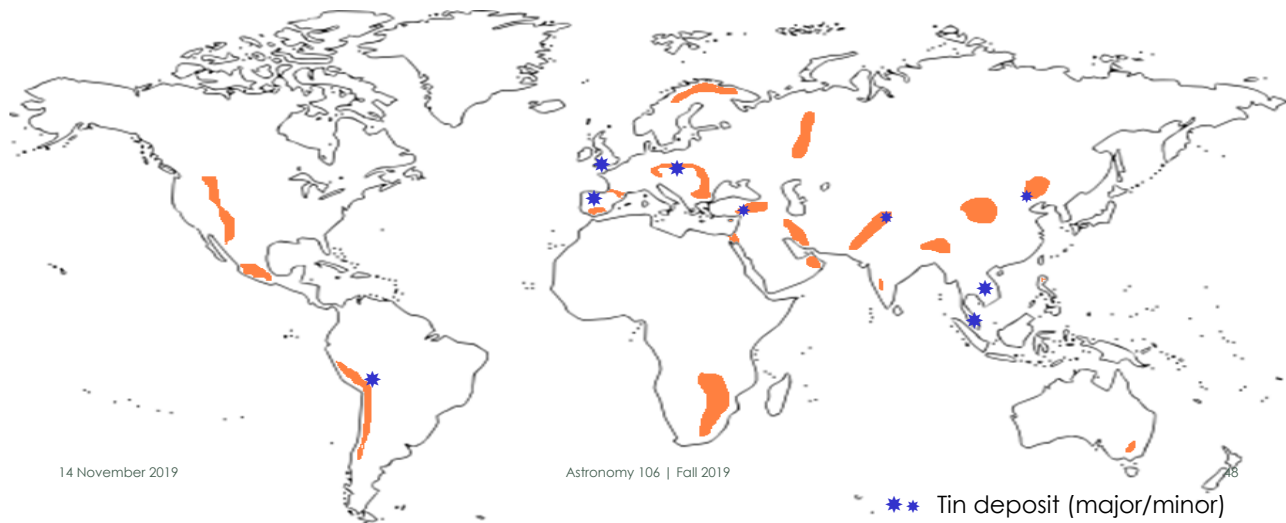
46

Native range of other large mammals



47

Easily-accessible copper and tin



48

Describe the native resources of the continental United States.

Question!

- A. Rich in resources; even in the beginning, a Land of Opportunity.
- B. Only a few domesticate-able animals, but well endowed besides that.
- C. Better bring your own.

14 November 2019

Astronomy 106 | Fall 2019

49

49

Describe the native resources of Central America.

Question!

- A. Rich in resources; even in the beginning, a Land of Opportunity.
- B. Only a few domesticate-able animals, but well endowed besides that.
- C. Better bring your own.

14 November 2019

Astronomy 106 | Fall 2019

50

50

Luck of the draw

Given these distributions, it is no wonder why civilization became established first in the places that it did.

- **The Fertile Crescent:** good grain resources, great animal resources, room to spread out successfully from the native habitat of the plants, a great fertile plain with big rivers in its midst. Stone and metals a long walk away.
- The Nile and Indus valleys: lacked only the grains at first, better stone and mineral resources than the Fertile Crescent.
 - Adjacent to the Fertile Crescent, so it did not take them long to get wheat and barley.
- The Yellow River plain: not the best of grains or animals but enough of each to get started. Adopted rice rather late from their southern "proto-Austro-Thai" neighbors.



14 November 2019

Astronomy 106 | Fall 2019

51

51

Luck of the draw

And why it lagged in places

- Africa: lots of large mammals, but none of them easy to domesticate; N-S axis, long way between crops and metals
- Europe, north Asia: too far from the good crops
- Americas: Mostly too little time, but having only one large domesticatable mammal and a N-S axis did not help.

Success at mammal husbandry

Continent	Candidates	Domesticated
Eurasia	72	13
Sub-Saharan Africa	51	0
Americas	24	1
Australia	1	0

Candidate: herbivorous or omnivorous mammal, > 100 lb. After Jared Diamond (1997), *Guns, germs, and steel*

14 November 2019

Astronomy 106 | Fall 2019

52

52

The winners: candidates for independent emergences of civilization

Sumer: agriculture and animal husbandry by 8000 years ago, literate by 5500 years ago. All other Eurasian civilizations may have learned the main skills of civilization from Sumer.

Egypt: agriculture by 7000 years ago, literate by 5000 years ago.

"India" (the Punjab and the Indus valley, e.g. Harappa and Mohenjo-Daro): agriculture by 6500 years ago, literate by 4700 years ago. Linked by many busy trade routes with Sumer.

China (Yellow River plain): agriculture by 7000 years ago, literate by 4500 years ago. Written language similar to Sumer's.

Mesoamerica: agriculture by 3200 years ago. Never quite got literate, but invented pictographs 2000 years ago and had complex calendrical inscriptions 1200 years ago. Only civilization guaranteed to be independent of Sumer.

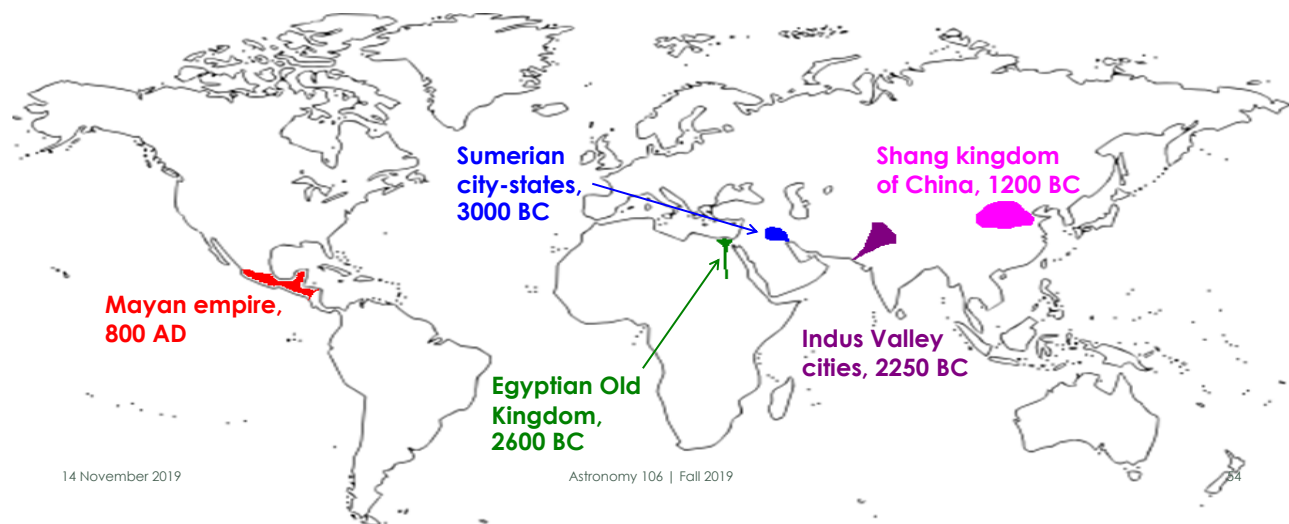
14 November 2019

Astronomy 106 | Fall 2019

53

53

The winners



14 November 2019

Astronomy 106 | Fall 2019

54

54

Some Sumerian inventions

Urban specialization of occupations; thus, leisure	Tanned leather
Writing, both pictographs and script (cuneiform)	Kiln-dried brick masonry
The wheel, both for potters and carts	Hand tools: hammer, chisel, brace, bit, nails
Irrigation (large scale)	Waterproof and sail-powered boats
Copper tools	Glue
Bronze: first arsenic bronze, then tin bronze after trade commenced	Swords and armor
Arithmetic and accounting	Sandals and boots
Astronomically-derived calendar	Beer (long credited to the Egyptians)
	Trade (probably)

14 November 2019

Astronomy 106 | Fall 2019

55

55

Civilization and f_c

By this, we mean technological civilization that, like ours, would develop the capability to communicate with others.

Once intelligence evolved, the production of civilization took much less time (1 Myr) than the evolution of life (600 Myr) or intelligence (3.2 Gyr) did. And from Sumer to us is much shorter (6000 yr).

- **Intelligence does not run out of time to civilize.**

We even had a little bad luck: from the place in which humans evolved, it was difficult to get to the resources required to build civilization.

As most will agree: once a civilization like the classic ones is produced, **evolution of a technological civilization is inevitable.**

14 November 2019

Astronomy 106 | Fall 2019

56

56

Civilization and f_c

Considering the good and bad luck to somewhat offset each other, we may consider the "statistical" answer offered by the Earth:

- Two independent loci of intelligence developed on Earth, both mammals: one land-based (hominids), one ocean-based (cetaceans)
- One of those developed civilization. This suggests $f_c = 0.5$
- The result is quite uncertain – and only barely makes it into the Speculation category – but at least it seems clear that **we would expect f_c to be larger than f_i** , and Earth offers confidence that f_c can be a large fraction.
- Compare to Drake's original guess: $f_c = 0.01$. There are still good arguments for small f_c , but not as many as for small f_i .

14 November 2019

Astronomy 106 | Fall 2019

57

57

Comet
46P/Wirtanen

Alex Cherney (Terrastro,
TWAN)

14 November 2019

Astronomy 106 | Fall 2019

58

58