

The Role of Uncertainty in Skyscape Archaeology

Fabio Silva



Today's Talk

- (1) Measurement, uncertainty and its importance
- (2) How to work with full uncertainty
- (3) Iberian passage graves as a case study/application



Structural Alignments

Archaeoastronomers have been primarily interested in alignments between structures and celestial objects such as the sun, moon and stars.

In cases where there is textual or ethnographic evidence that complements the archaeological record, these can support or falsify any observations, hypotheses or speculations regarding celestial alignments.

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In the case of prehistory, however, archaeoastronomer's methodologies have focused on two pillars:

(1) field measurements of orientation

(2) statistical analyses of orientation data for a large numbers of structures

The reasoning is that a statistically significant pattern in orientation (matching a celestial object) can be used to argue for intentionality.



Structural Alignments

Identified patterns can then be used in search of matching topographic and/or celestial objects.

However, and despite strong singular examples (e.g. Stonehenge, Newgrange), very few (strong) patterns have been found using this approach...



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Furthermore, despite the fact that measurements of orientation are the primary form of data used by archaeoastronomers, very little measurement theory has been taken on-board.

As such, I propose to look, first of all, at the theory of measurement





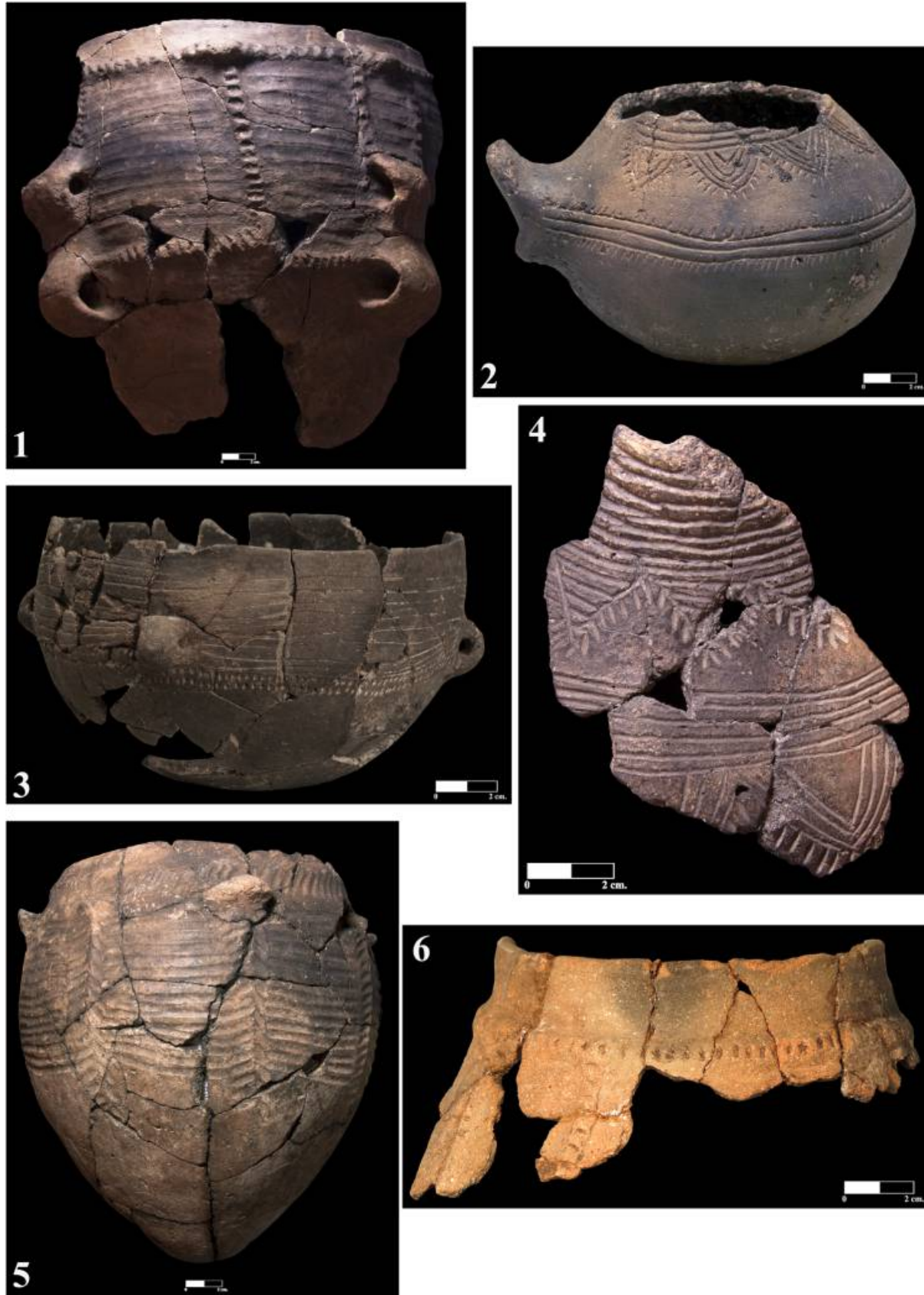
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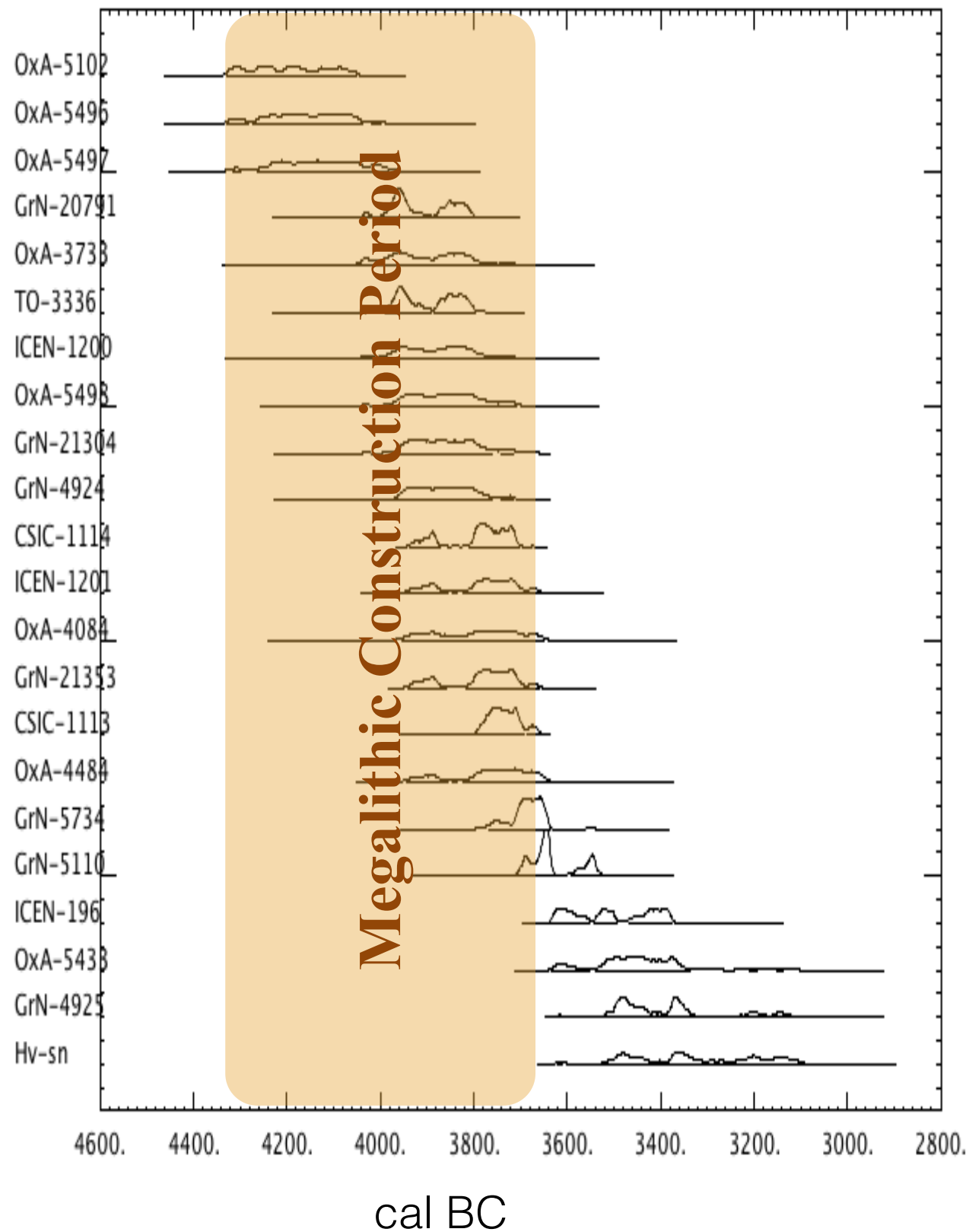
(1) Description

e.g. length of a wall, width of a stone tool or size of a pot

We are interested in the measurement itself.



Early Neolithic Inner Iberia Impressed/Incised-
Channelled pottery



Radiocarbon Calibrated Densities associated with
megalithic sites in Northern Portugal

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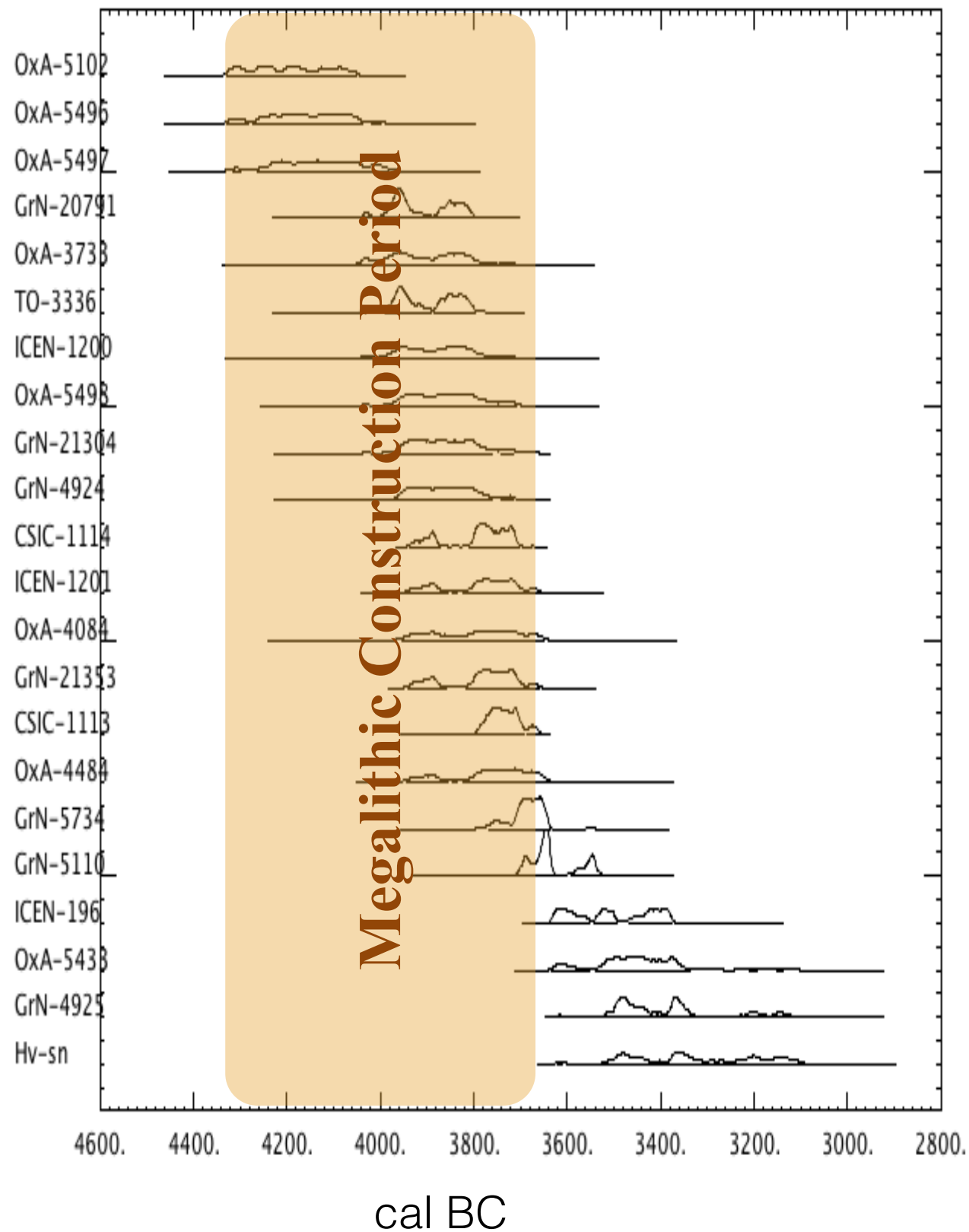
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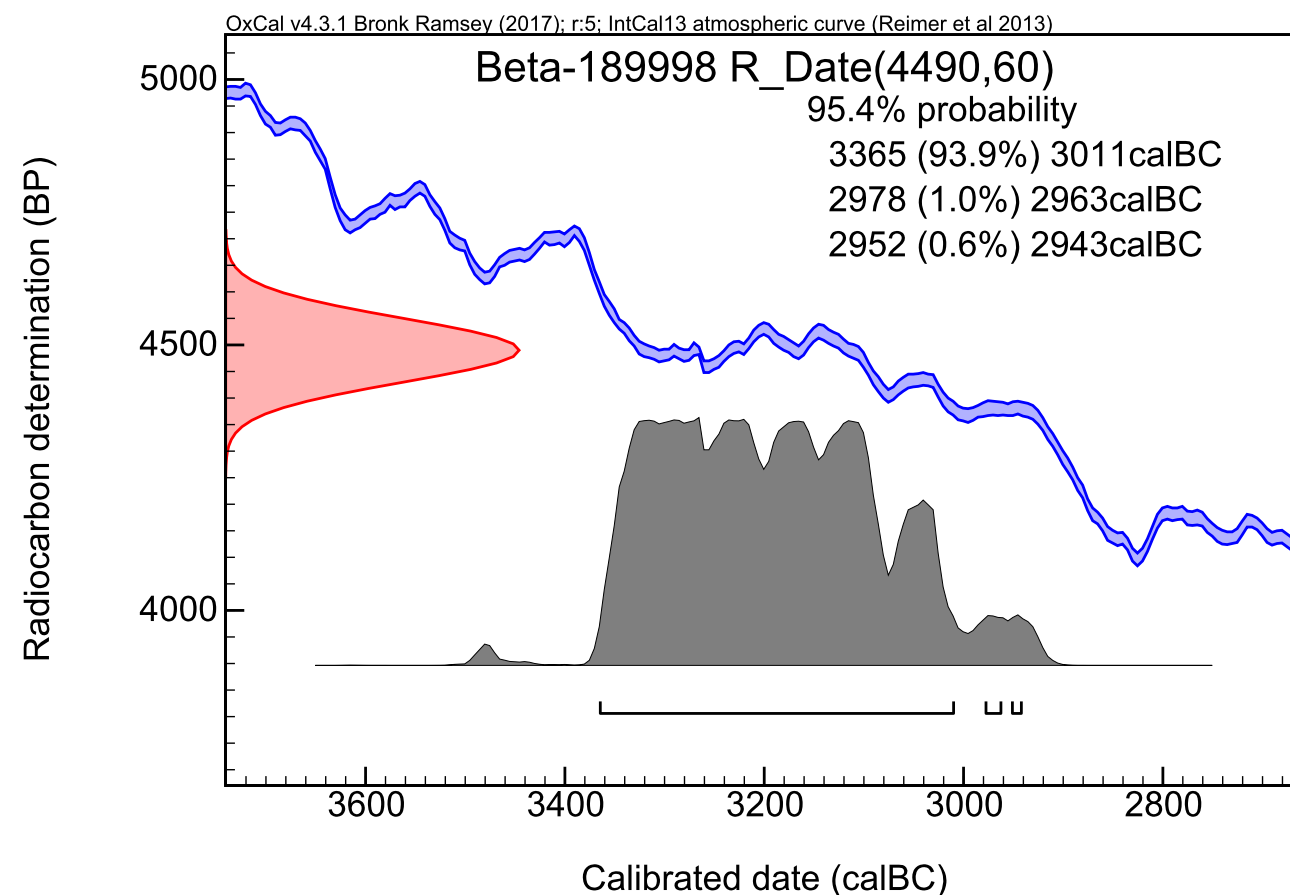
We are not interested in the measurement itself but what we can *infer* from it.

A particular measurement can be used in one or both ways!!

In Archaeology we tend to use measurements in two ways.

For **descriptive purposes** it doesn't matter (much) if a wall is 1m, 1.01m or even 1.1 m wide at any one point. As such we tend not to report (or think about) the measurement's uncertainty.

For **inferential purposes** this is very important. For example, consider the importance of uncertainty in the calibration of radiocarbon dates



Any and all measurements have uncertainty: it is part and parcel of the process of measurement.

This is as true for a compass measurement, as it is for a carpenter measuring the height of a door, or a particle physicist measuring the mass of the Higgs boson!





My argument is that, in Skyscape Archaeology, we are **using measurements of orientation for inference** (we want to infer potential alignment targets).

As such their **uncertainty needs to be taken into account**.

This is common practice in other disciplines, more used to handling quantitative data. E.g.

Taylor, John R. (1997). *An Introduction to Error Analysis: the study of uncertainties in physical measurements*. Sausalito, CA: University Science Books.

Let us use a thought experiment (from Taylor's book) to illustrate the dangers of ignoring uncertainty...

The Importance of Uncertainty

a thought-experiment



Aim: to find out what material the crown is made of

This cannot be measured directly, so it needs to be inferred from a measurable quantity.

Method: to measure the density of the crown.

Hypotheses:

the crown is made of 18-karat gold (density = 15.5 g/cm^3)

the crown is made of a known cheap alloy (density = 13.8 g/cm^3)

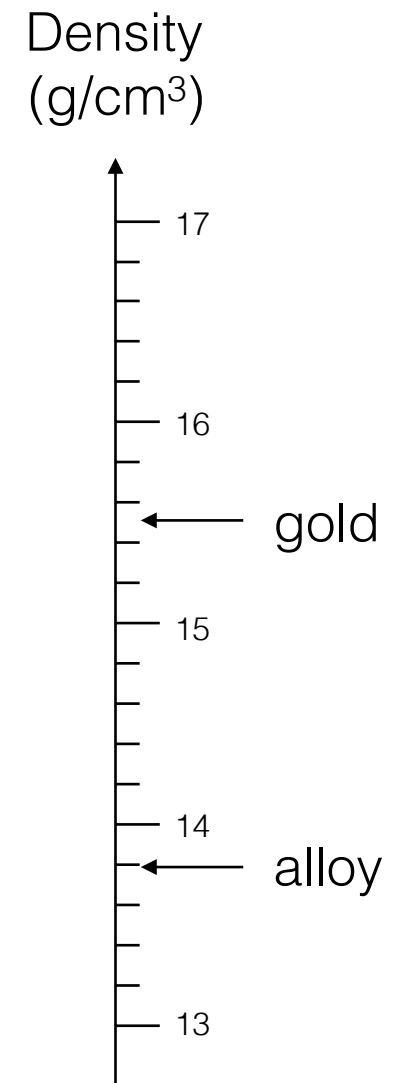
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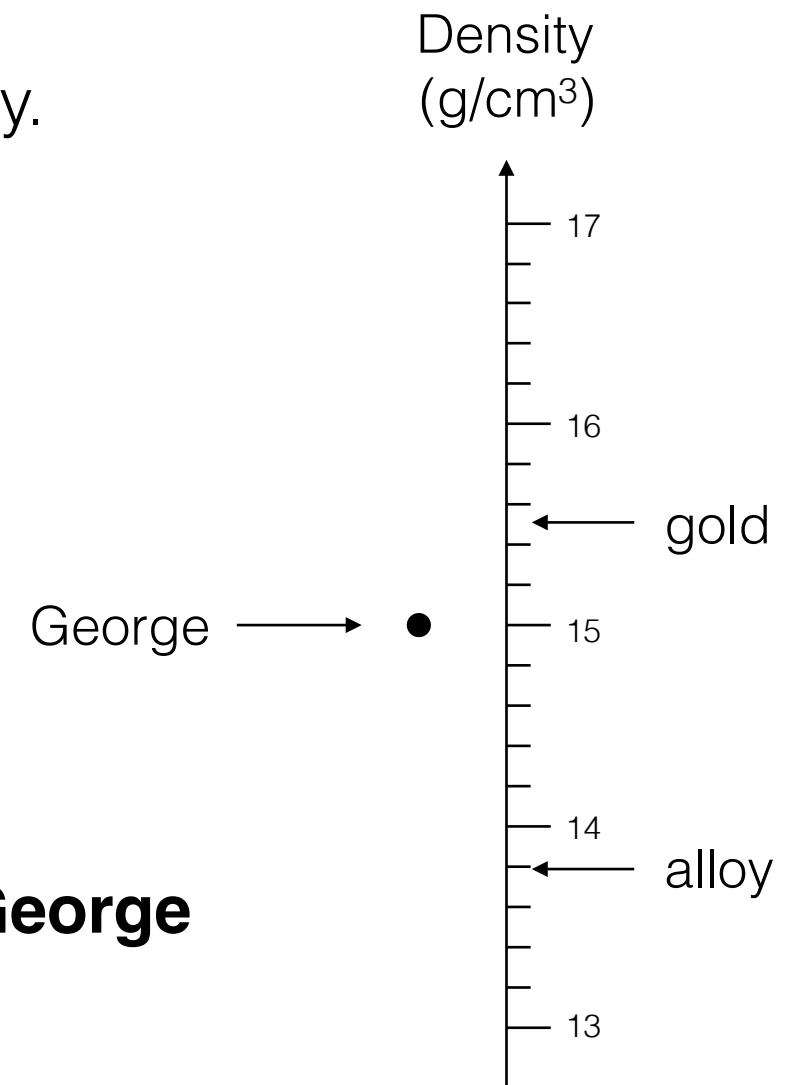
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We invite an expert, George, to measure the crown's density.

George reports it as 15 g/cm³ (no uncertainty was given!)



15 is closer to 15.5 (gold) than to 13.8 (alloy) so George might infer that the crown is made of gold !

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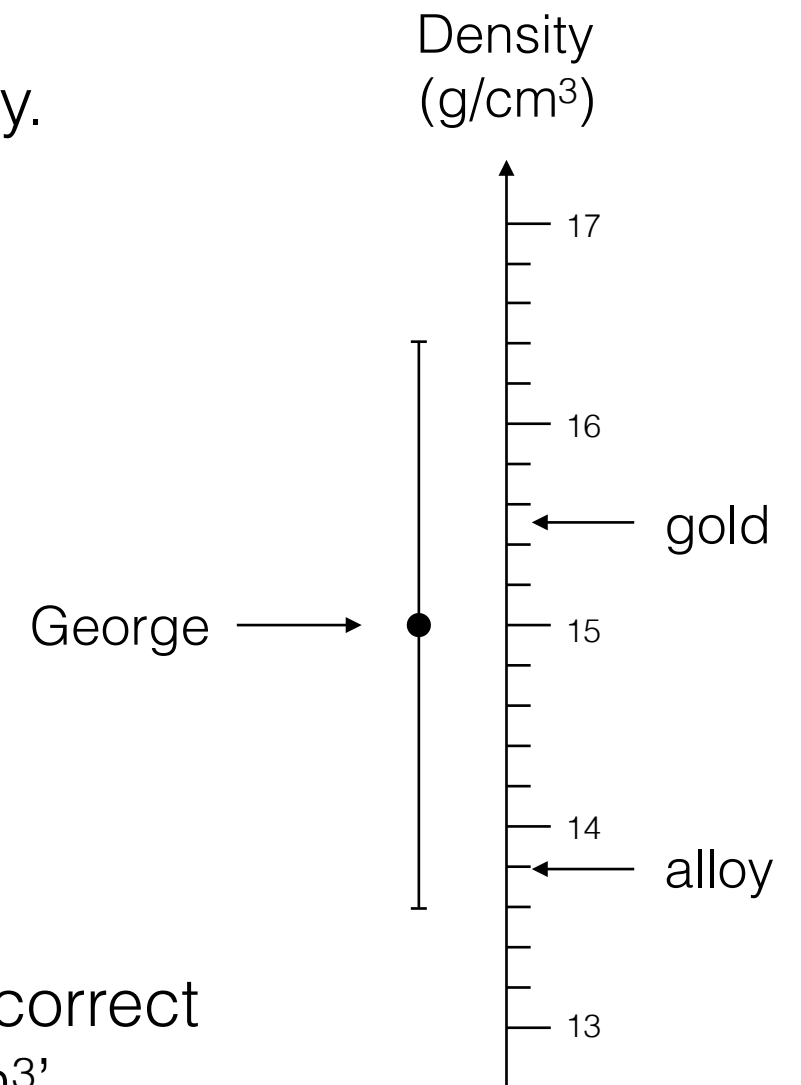
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When pressed about his uncertainty, George says that the correct value 'almost certainly lies between 13.5 and 16.5 gram/cm³'

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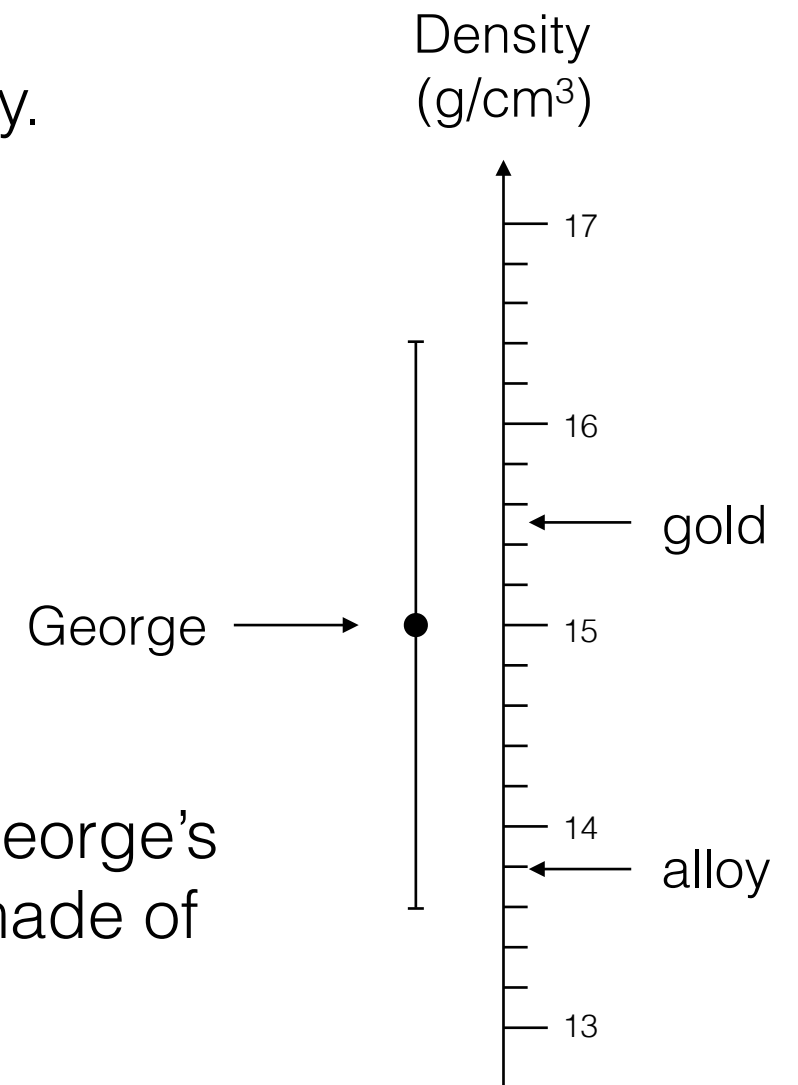
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George reports it as 15 g/cm^3 , and 'almost certainly lies between 13.5 and 16.5 gram/cm³'

When the uncertainty is reported and taken into account, George's method is seen not to be able to tell whether the crown is made of gold or the cheap alloy.



The inference based on a qualitative assessment of the 'best-estimate' alone can lead to the wrong inference!

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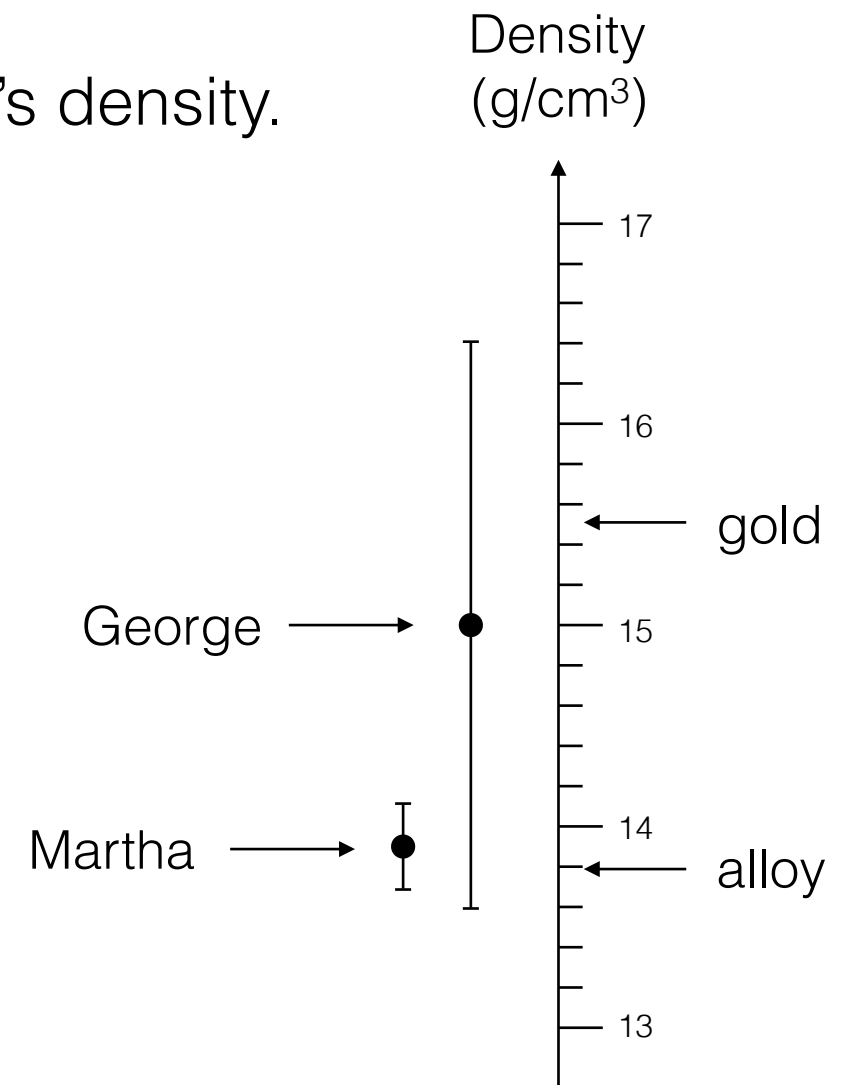
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We invite a second expert, Martha, to measure the crown's density.

Martha reports it as $13.9 \pm 0.2 \text{ g/cm}^3$
(much narrower uncertainty of 0.2 g/cm^3 either way)



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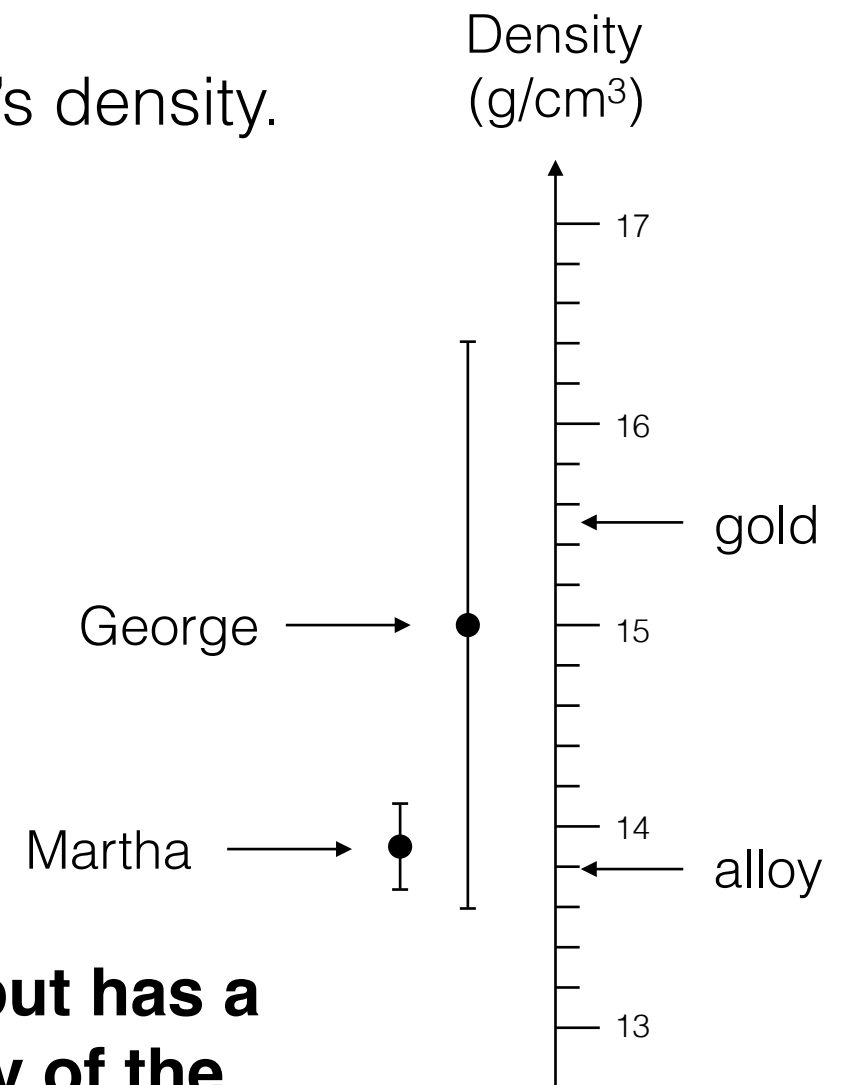
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Martha's measurement is compatible with George's, but has a much smaller uncertainty that excludes the possibility of the crown being made of 18-karat gold!

Conclusion: the crown is made of a cheaper alloy!

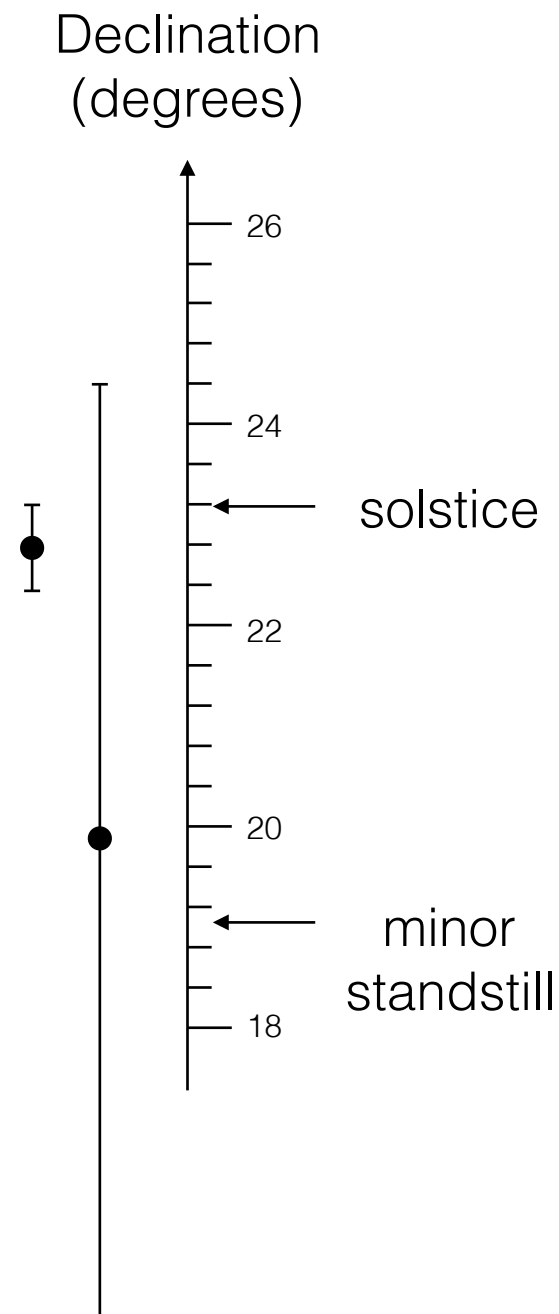
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The Importance of Uncertainty

This thought experiment isn't much different from what we do in Archaeoastronomy.

If we don't take uncertainty into account we might be inferring the wrong celestial targets for our structural alignments.



Uncertainty

Minimum uncertainty is given by the precision of the instrument.
E.g. a measurement with a compass with 1° precision cannot have uncertainty below 1° .

All sources of uncertainty need to be considered.

A carefully thought-through survey methodology, with calibrated instruments, can take care of most, **but never all**, sources of uncertainty.

The question one must ask is how much uncertainty is left?

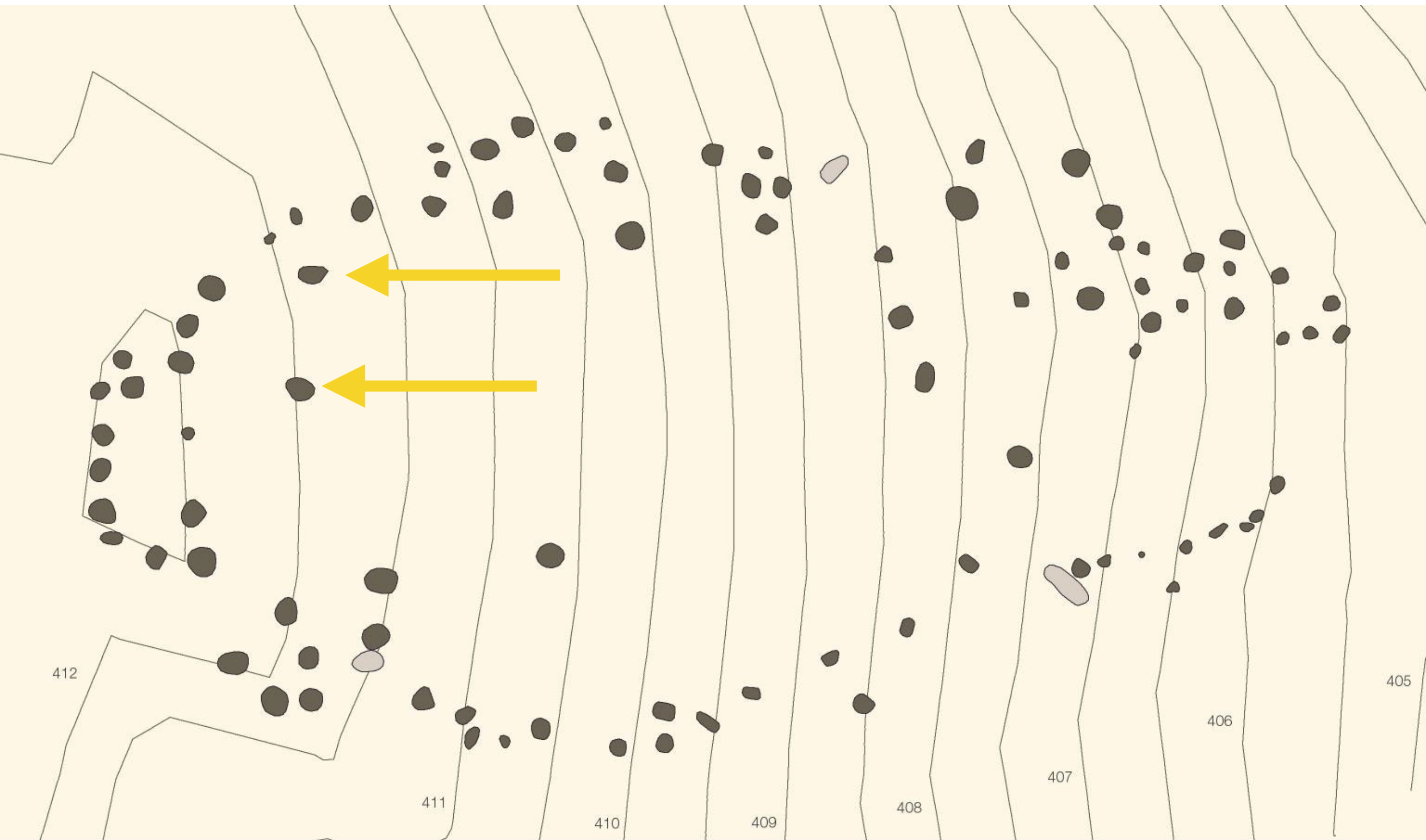


Example

Say that we are measuring the orientation between the two marked stones



Example



Almendres
Recinto megalítico
Concelho de Évora



Menir



Menir
tombado



Curva de nível



omp 1:25000 nº 459

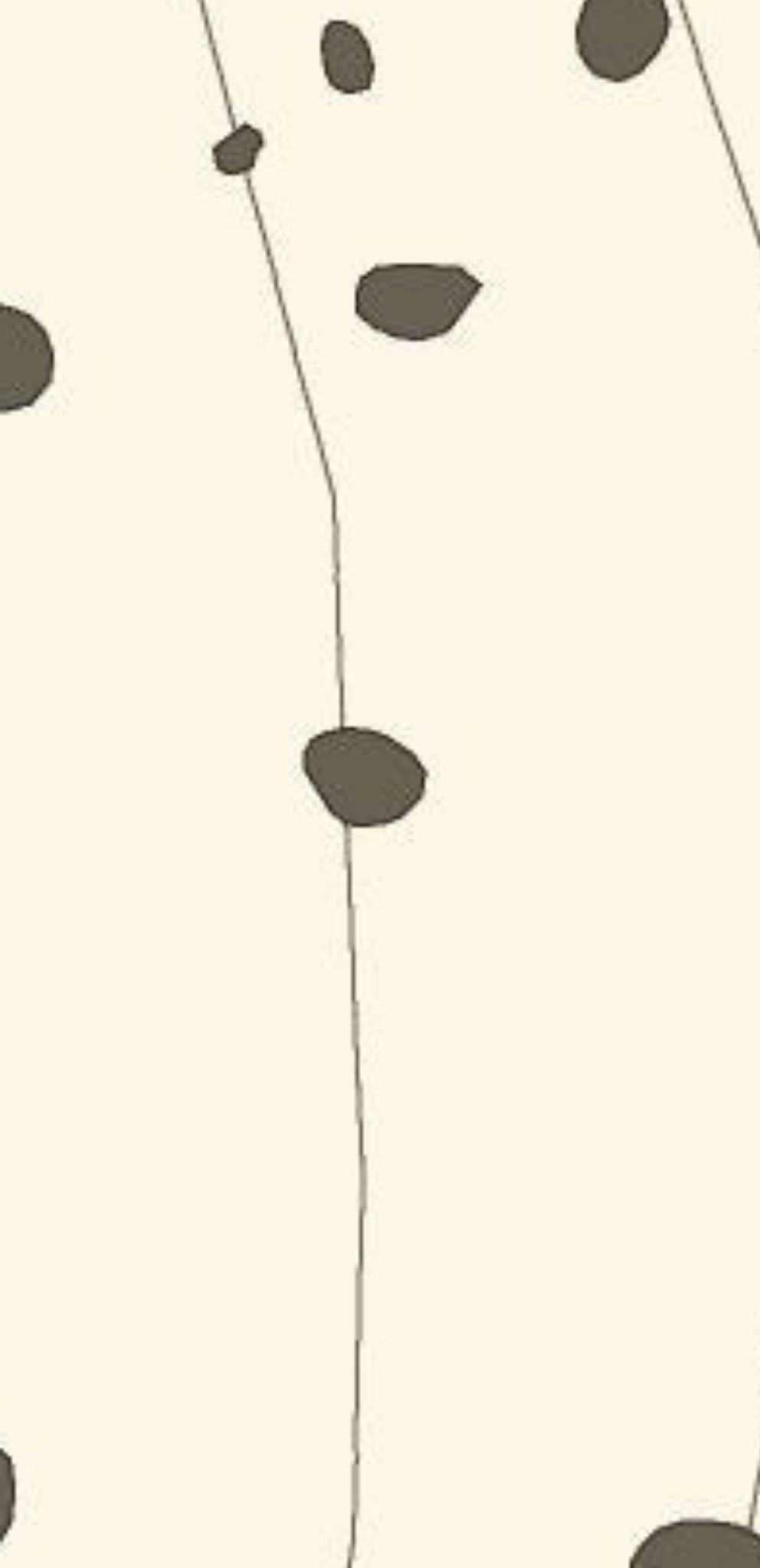
Coordenadas HAYFORD GAUSS Datum Lisboa origem no Ponto Central (metros)
M= 206275 P= 176750



Norte Cartográfico

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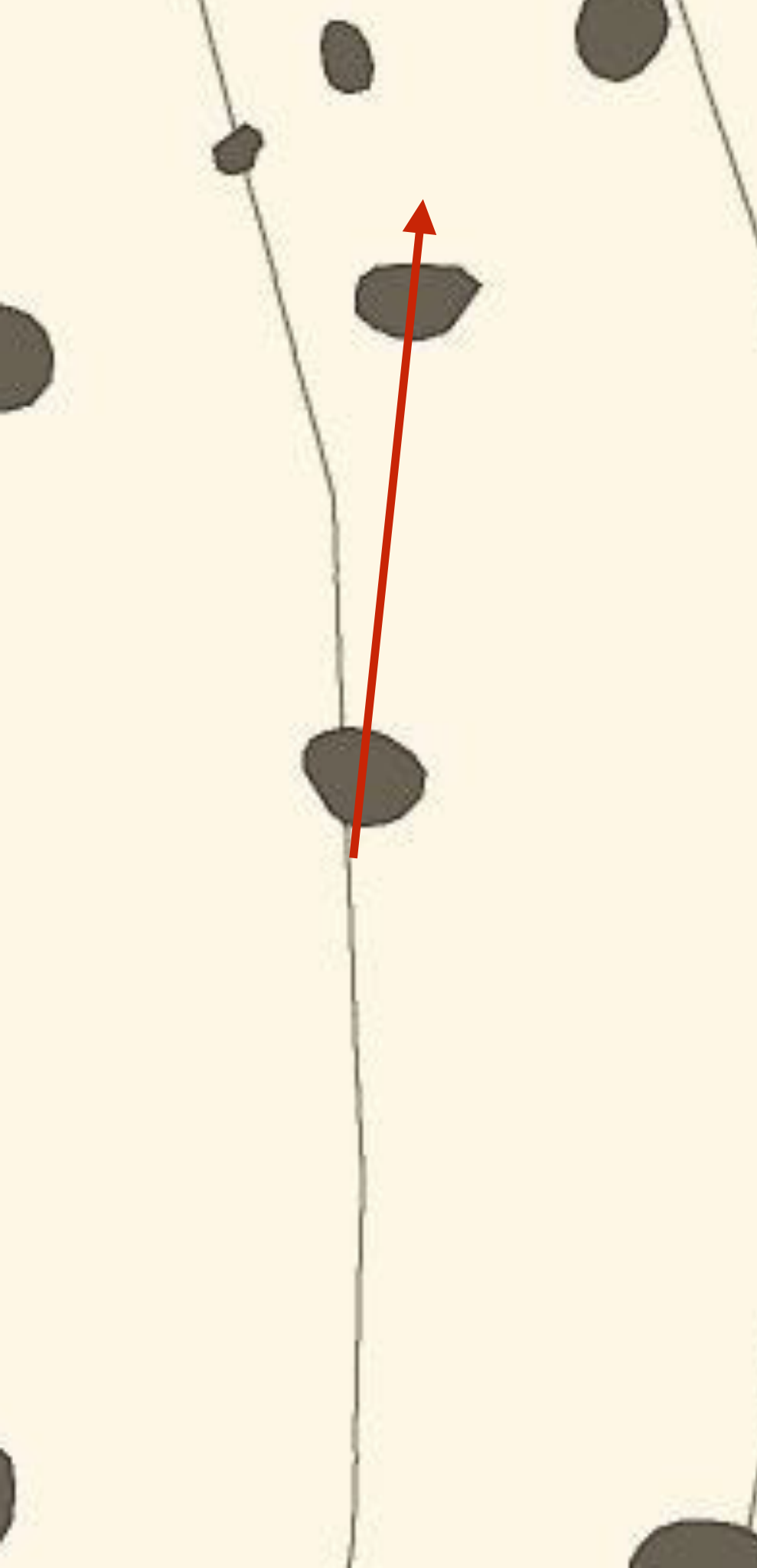
Say that we are measuring the orientation between the two marked stones

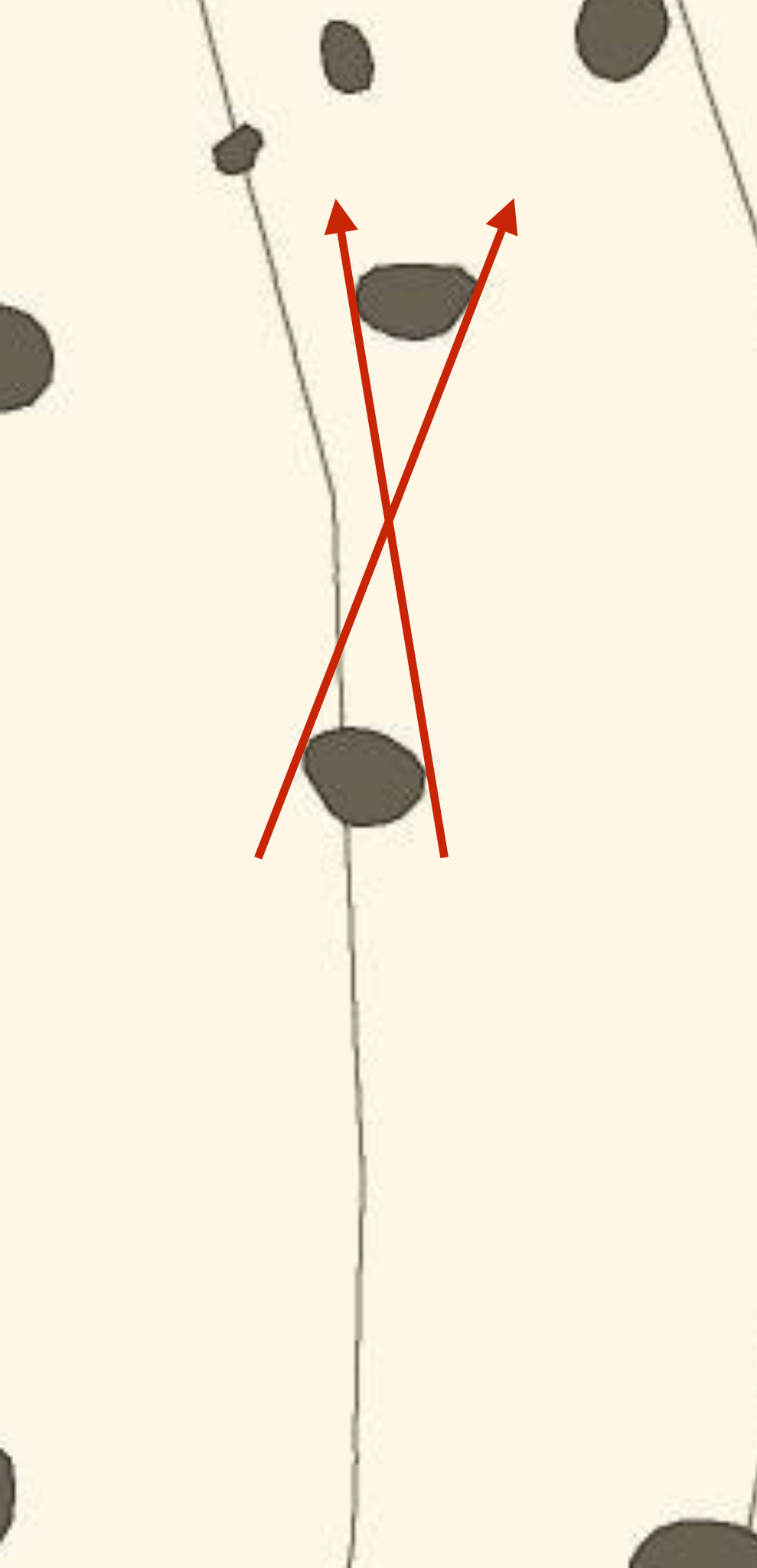
We use a compass with 1° advertised precision to take one measurement

Measurement = 6°

Uncertainty = 1°

Report it as: $6^\circ \pm 1^\circ$





Example

Say that we are measuring the orientation between the two marked stones

We use a compass with 1° advertised precision to take one measurement

The stones have a shape and volume (they are not mathematical points!).

So we should take this into account. Let's say the total range is of 10° : that's 5° each side.

Measurement = 6°

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The stones have a shape and volume (they are not mathematical points!).

So we should take this into account. Let's say the total range is of 10° : that's 5° each side.

Assuming no other sources of uncertainty:

$$6^\circ \pm 6^\circ$$

Meaning that the “true” value can be anywhere between 0° and 12° , a total range of 12° (twice the uncertainty)



Working with Full Uncertainty

(1) It might at first **seem counter-intuitive** to suggest that working with a large uncertainty is better than working with a smaller one...



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The long answer is that we can still look for patterns using likelihood-based statistics, which has been at the core of inferential statistics since R.A. Fisher established it in 1921.



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The long answer is that we can still look for patterns using likelihood-based statistics, which has been at the core of inferential statistics since R.A. Fisher established it in 1921.

However, this is quite intuitive (so I won't bore you with statistics to prove my point)

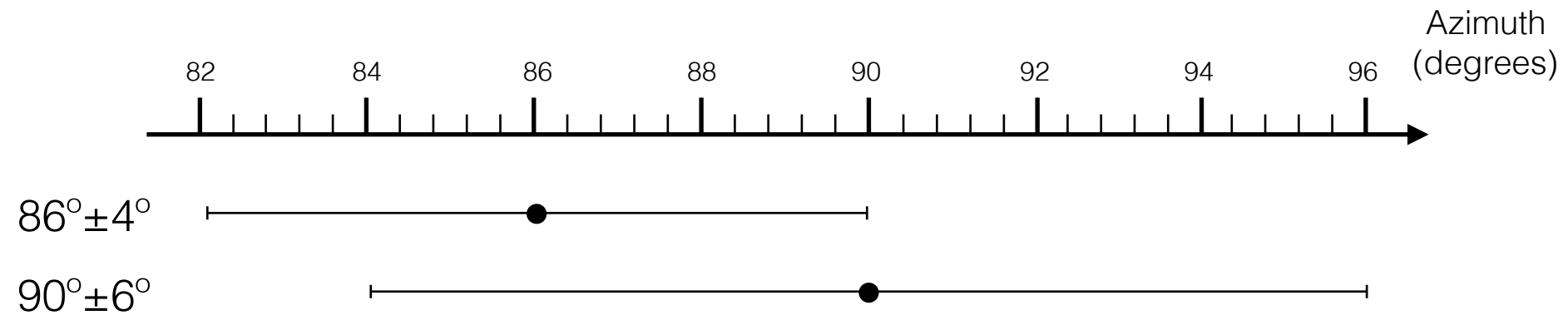
Working with Full Uncertainty

Let's say we have measurements of orientation for two similar structures, with full uncertainty:



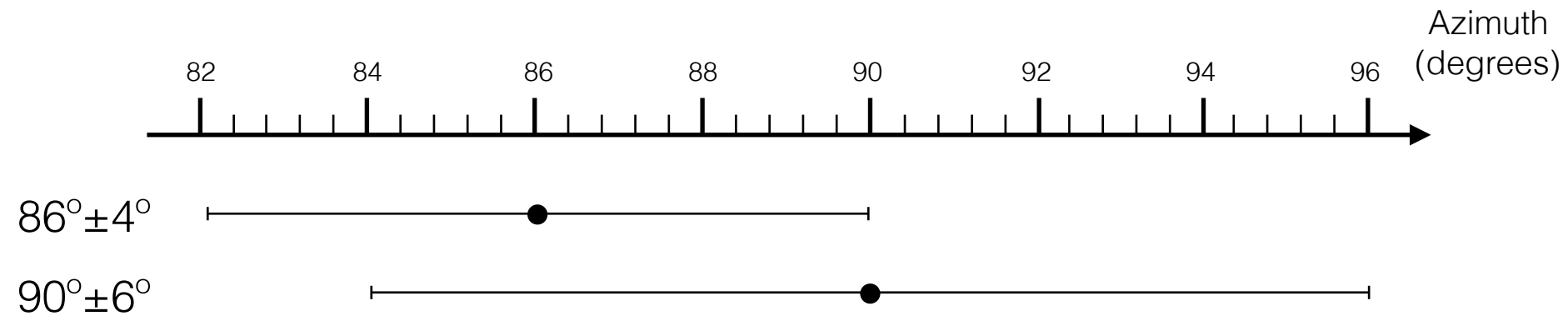
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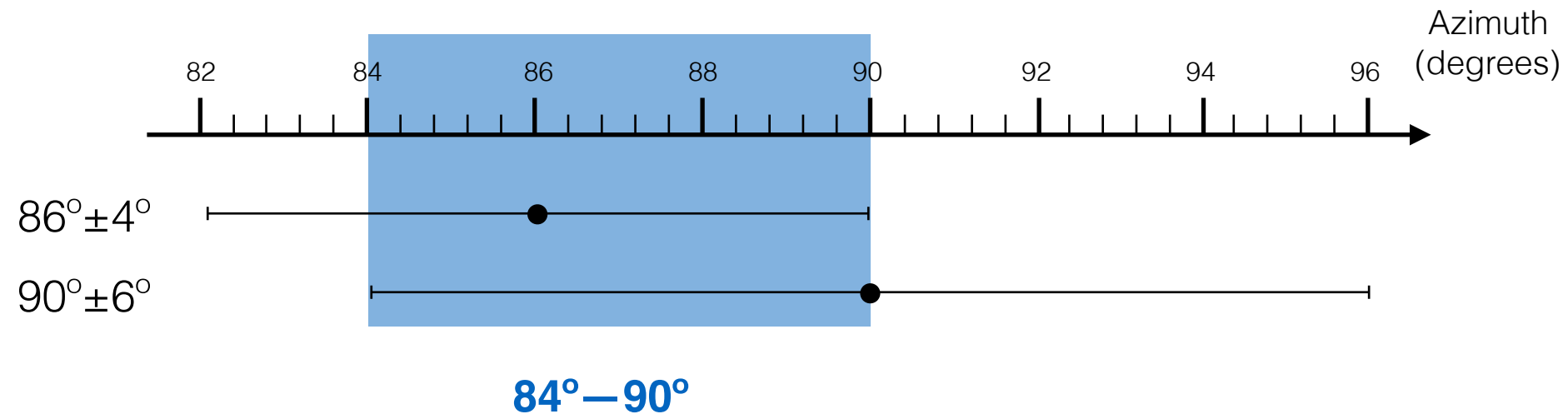
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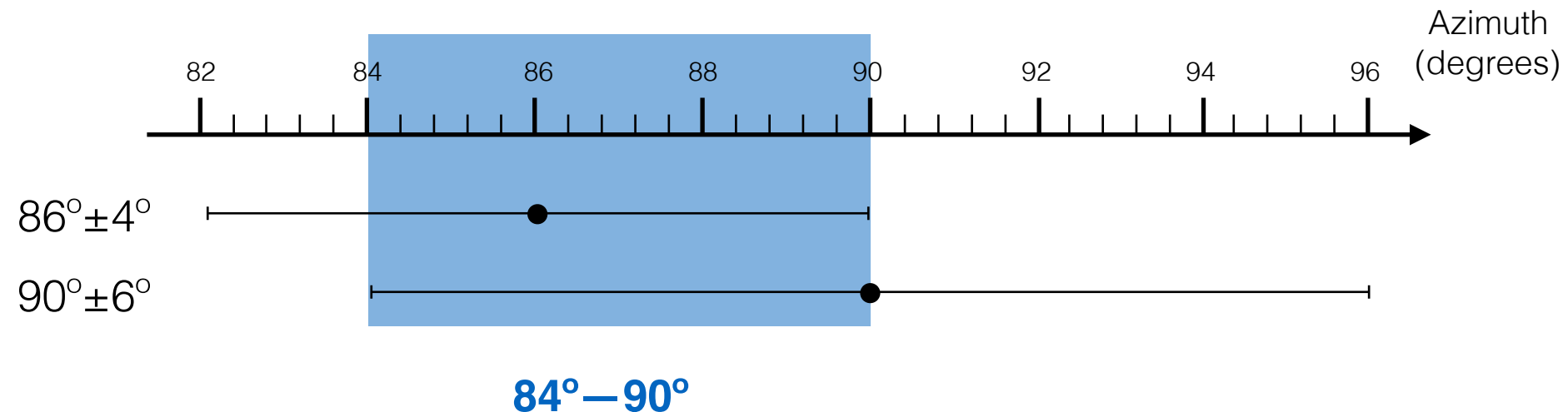
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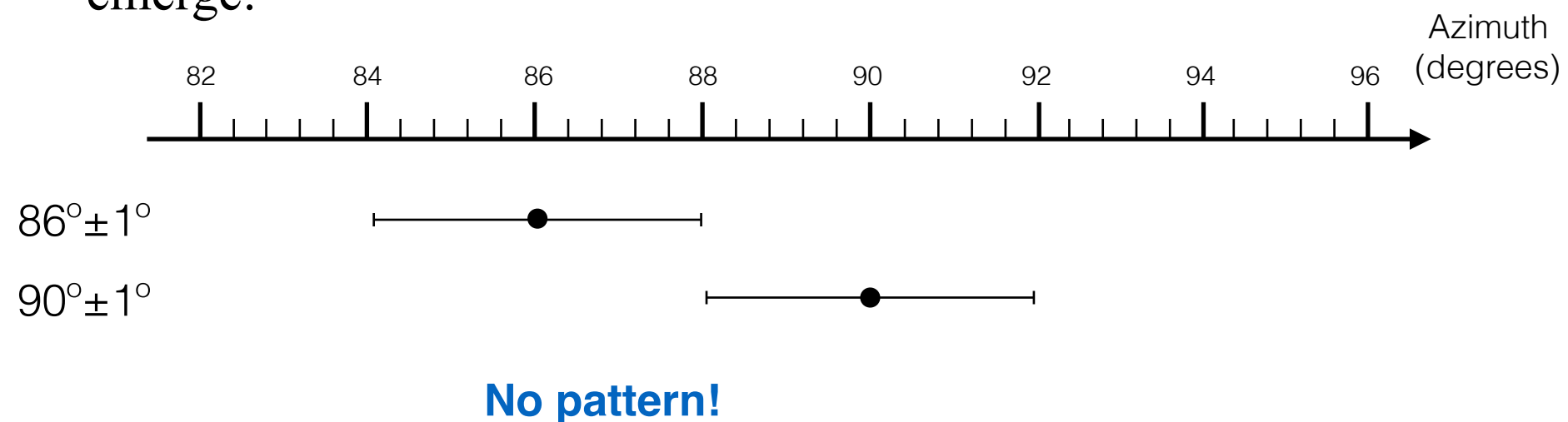
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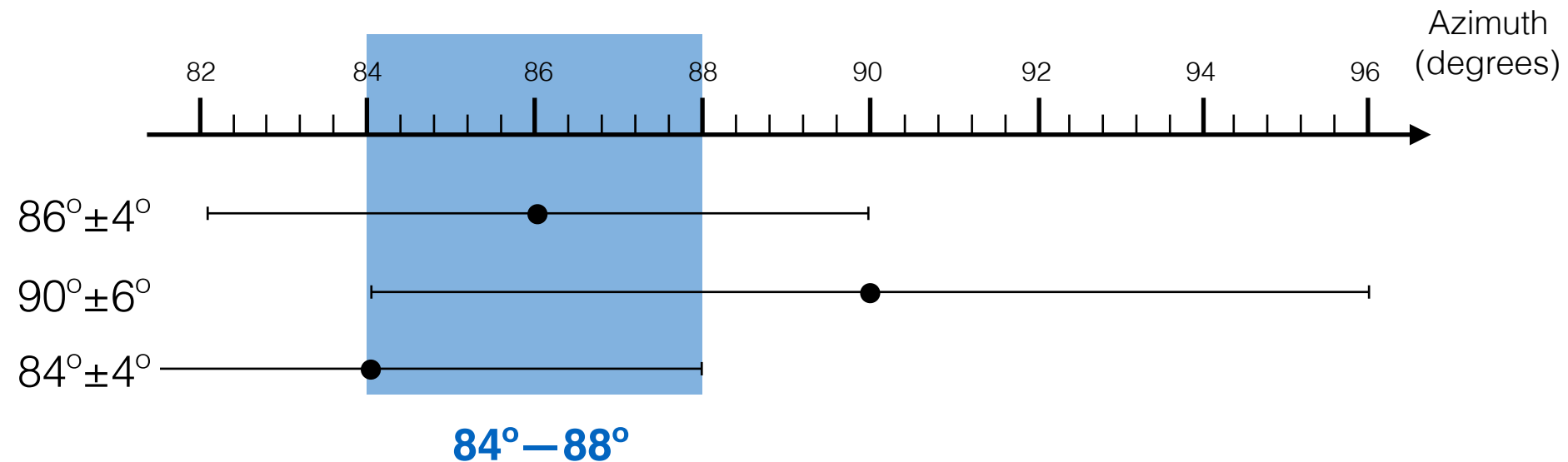
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Note that, if the uncertainty is underestimated a pattern might not emerge:



Working with Full Uncertainty

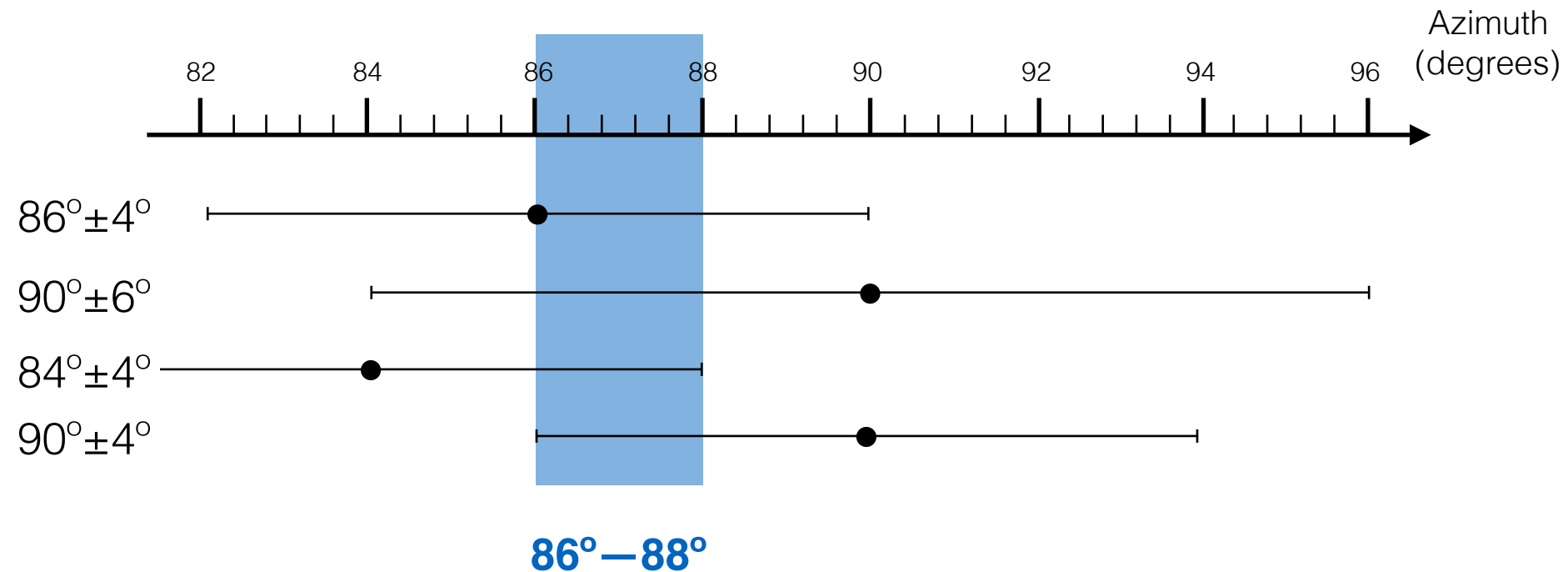
Let's say we have measurements of orientation for **three** similar structures, with full uncertainty:



The larger the number of measured sites, the more we can constrain our inference.

Working with Full Uncertainty

Let's say we have measurements of orientation for **four** similar structures, with full uncertainty:



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A Case Study



A Case Study

NW Iberian passage graves

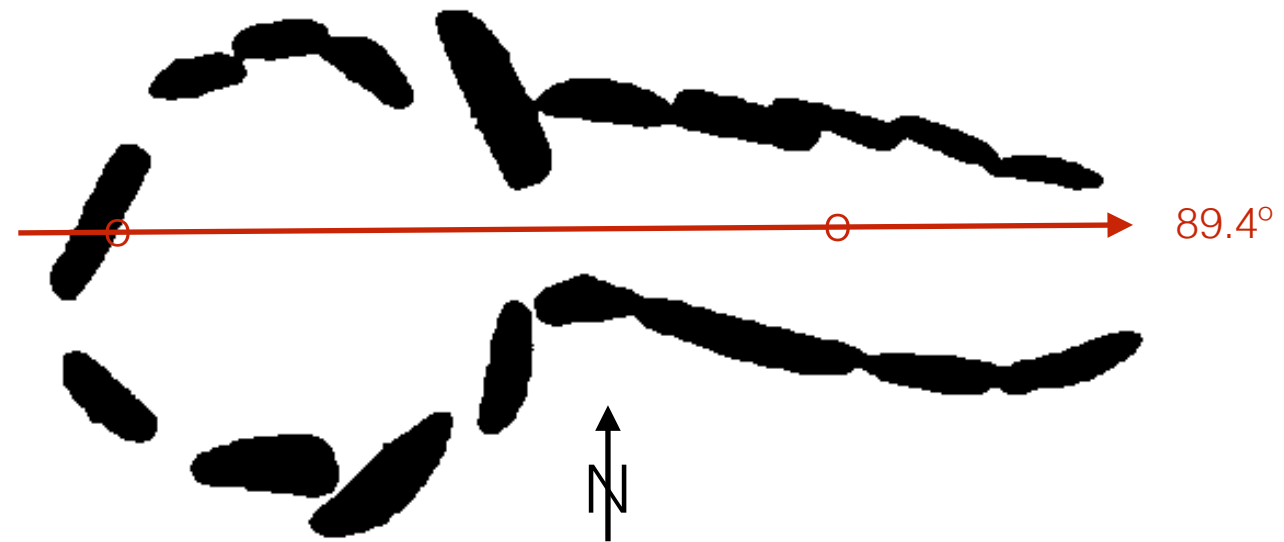
built around 4,300-3,700 cal BC

for more details see Chapter 10 of
*Skyscapes: The Role and Importance of
the Sky in Archaeology*



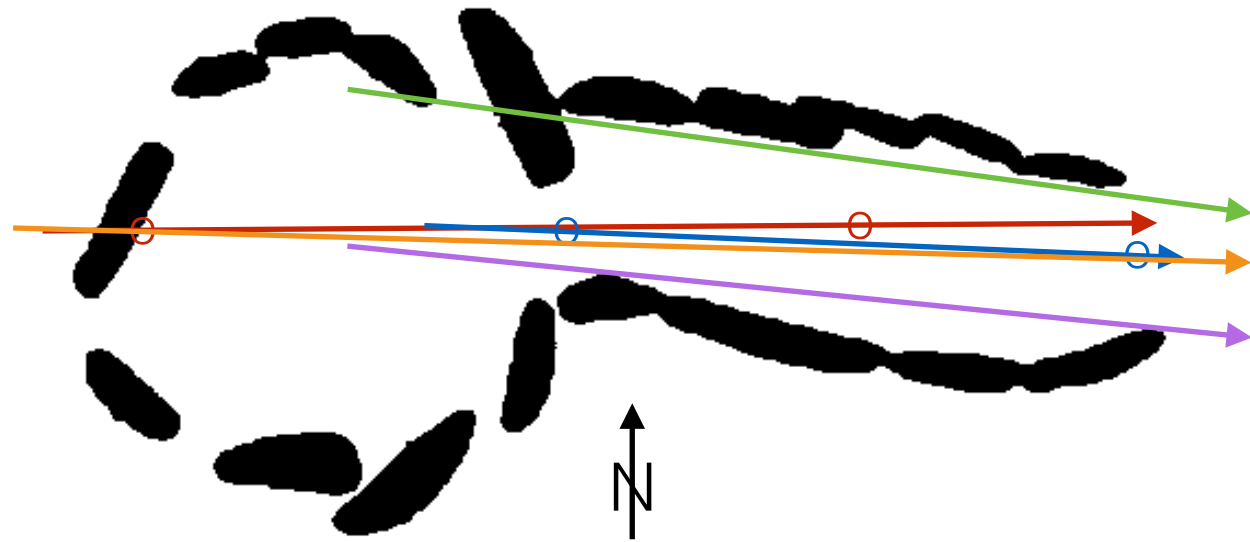
Prior Work

Previous scholars have focused on a 'single' measurement of orientation (below) and mentioned an uncertainty of 2° or 3° , although the latter was never used!



Prior Work

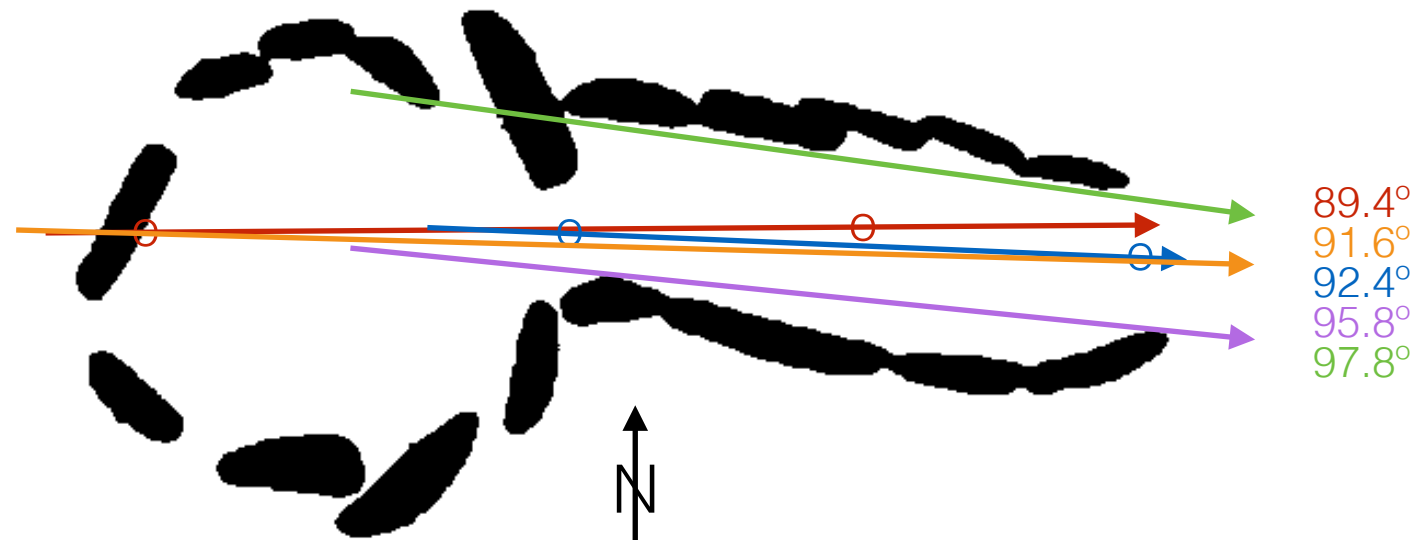
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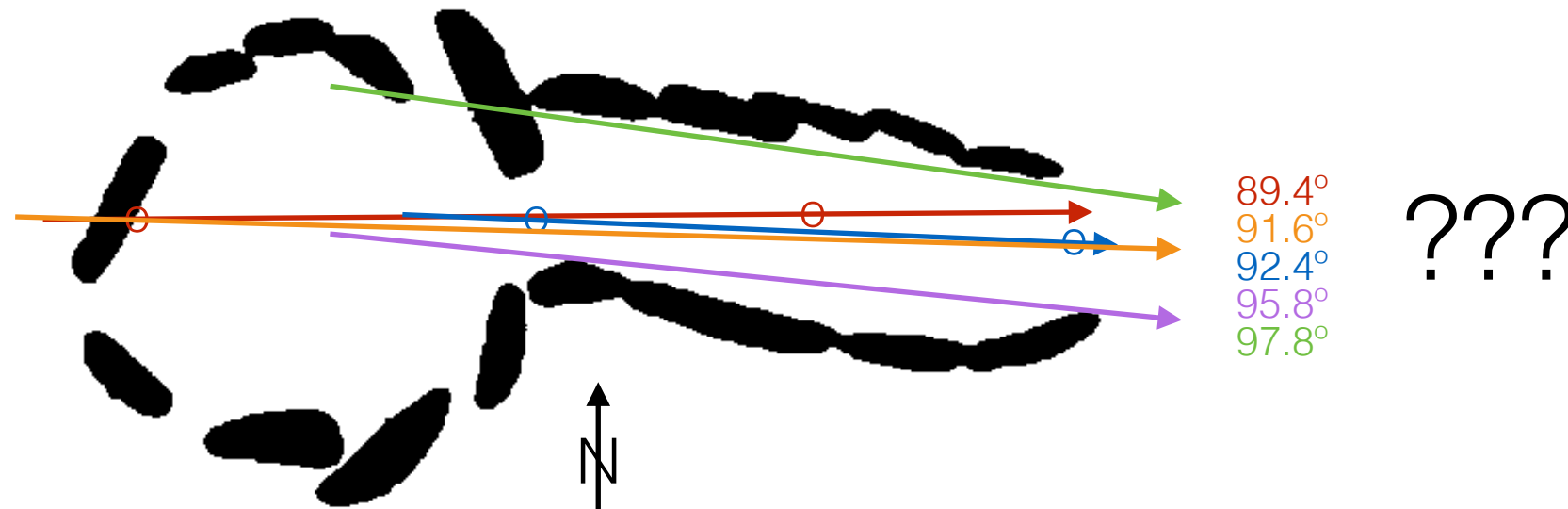


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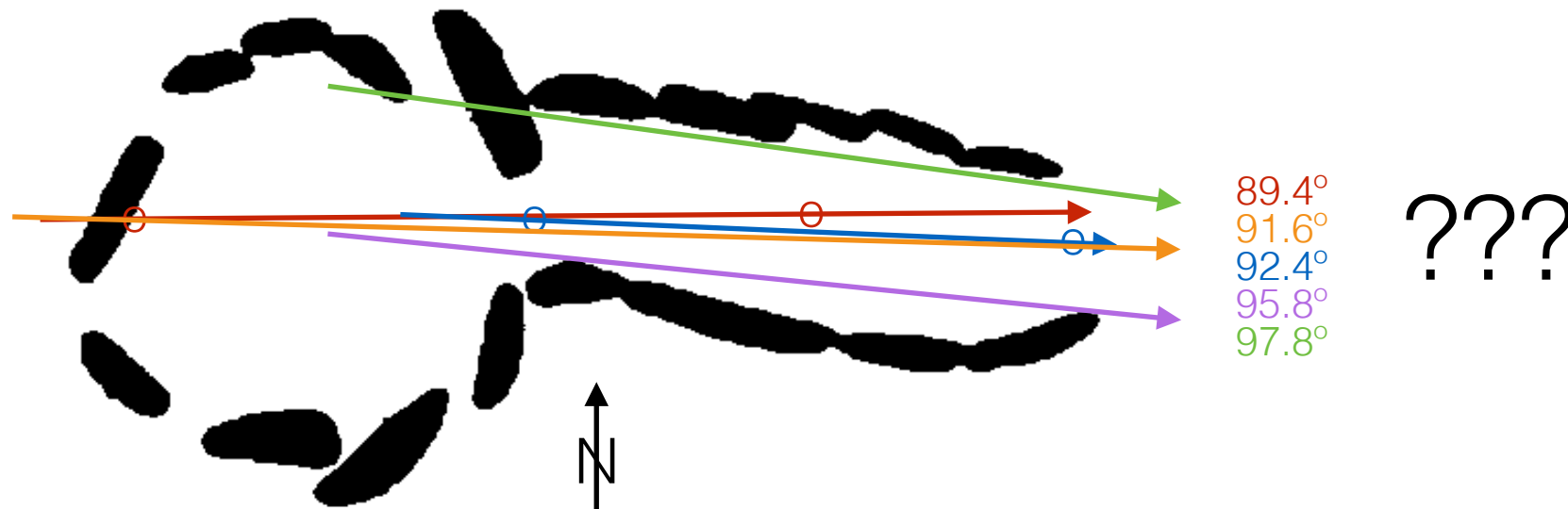
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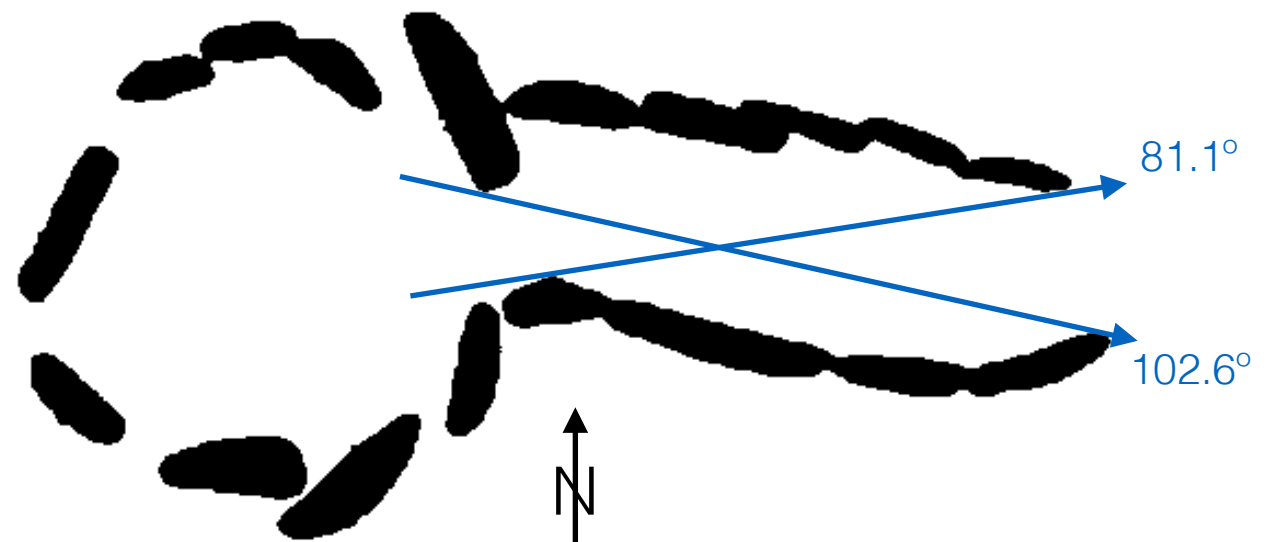
But many such 'single' orientations are possible to measure...

Differences in azimuth can ascend to 10° or more!!!

How can we say which line best captures what the prehistoric people had in mind? **We can't!**

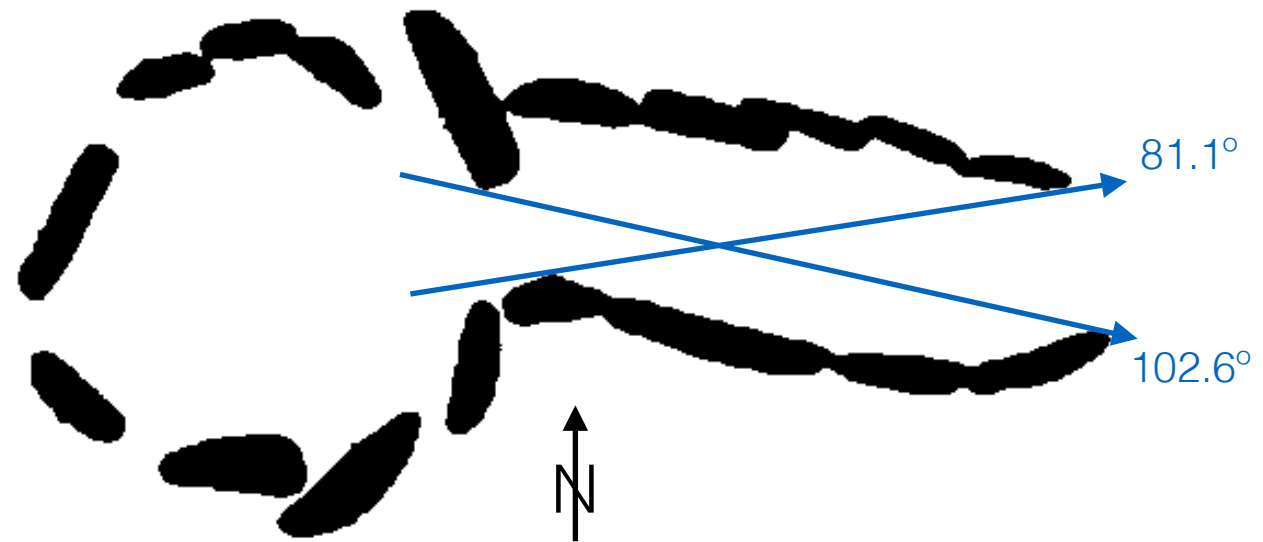
Full Uncertainty

Instead, I've proposed a way to estimate the uncertainty:
by measuring the maximum 'window of visibility'



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There are two reasons for preferring this methodology:

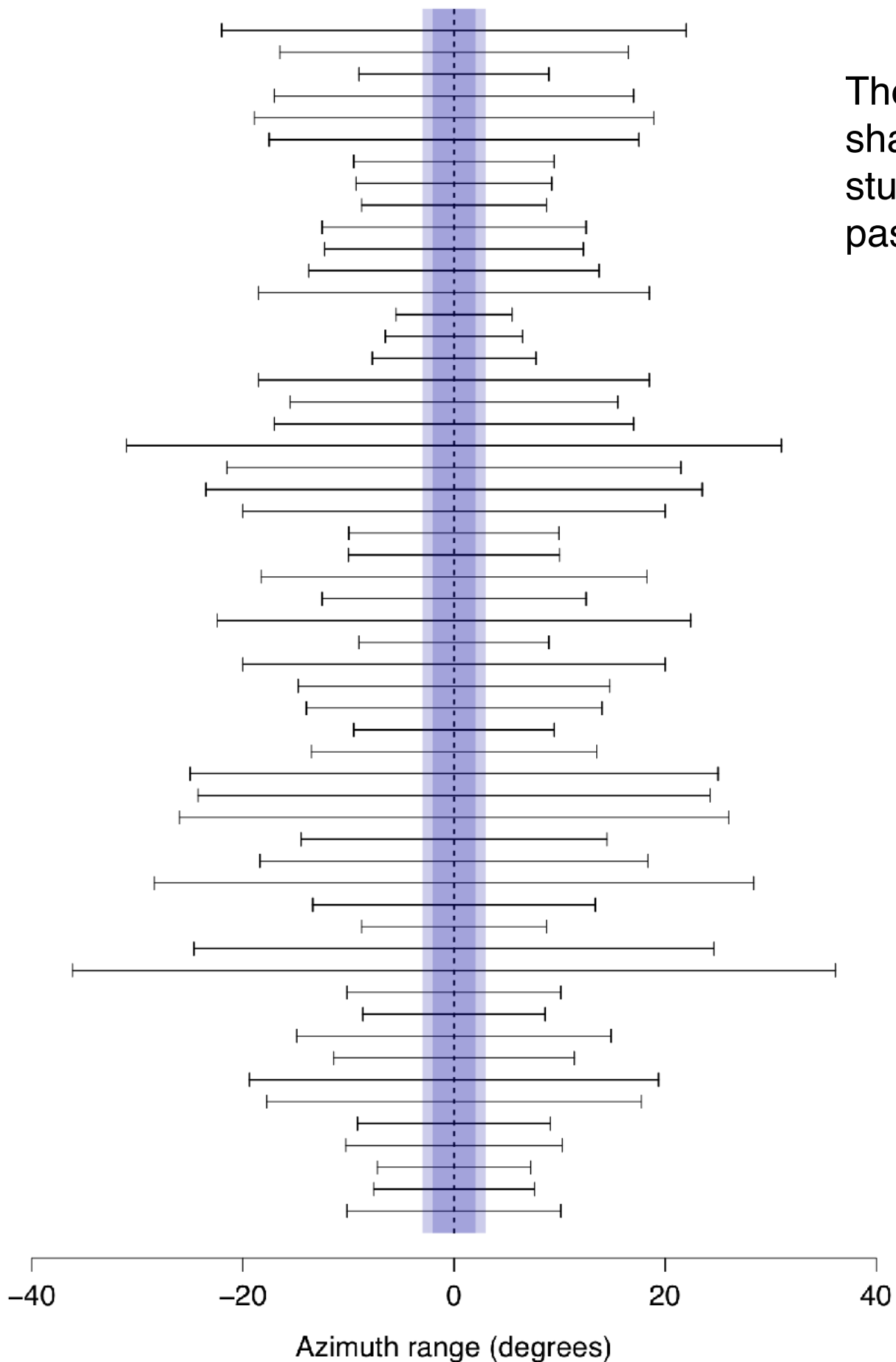
(statistical) : working with maximum uncertainty

(phenomenological) : this window is what is actually experienceable

Hence, both quantitatively and qualitatively we are working with **fewer biases!**

Full Uncertainty

The figure to the left compares the 2° (dark shaded) or 3° (light shaded) uncertainty estimates common in archaeoastronomical studies of passage graves with window measurements for 55 passage graves in Portugal.

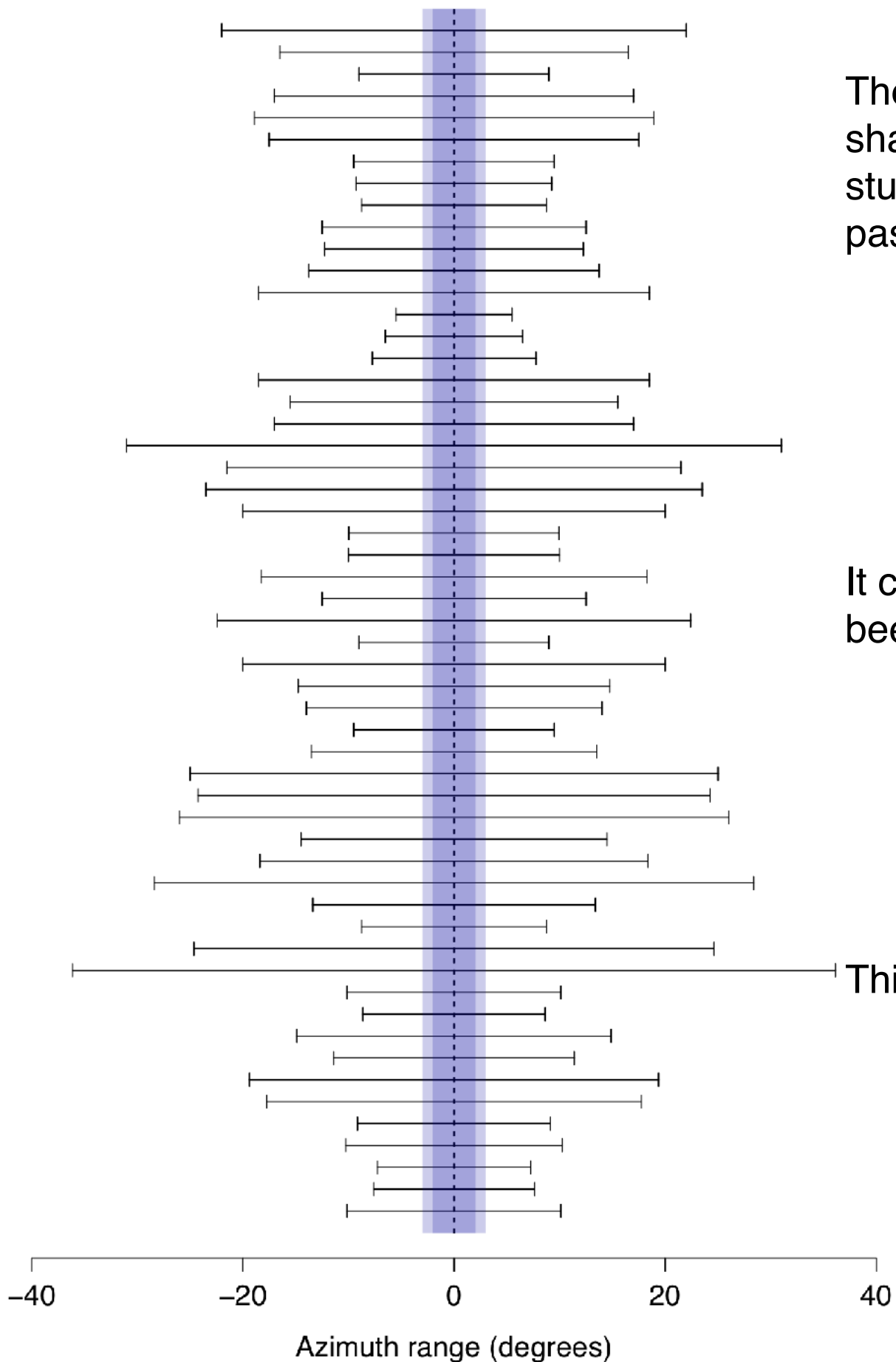


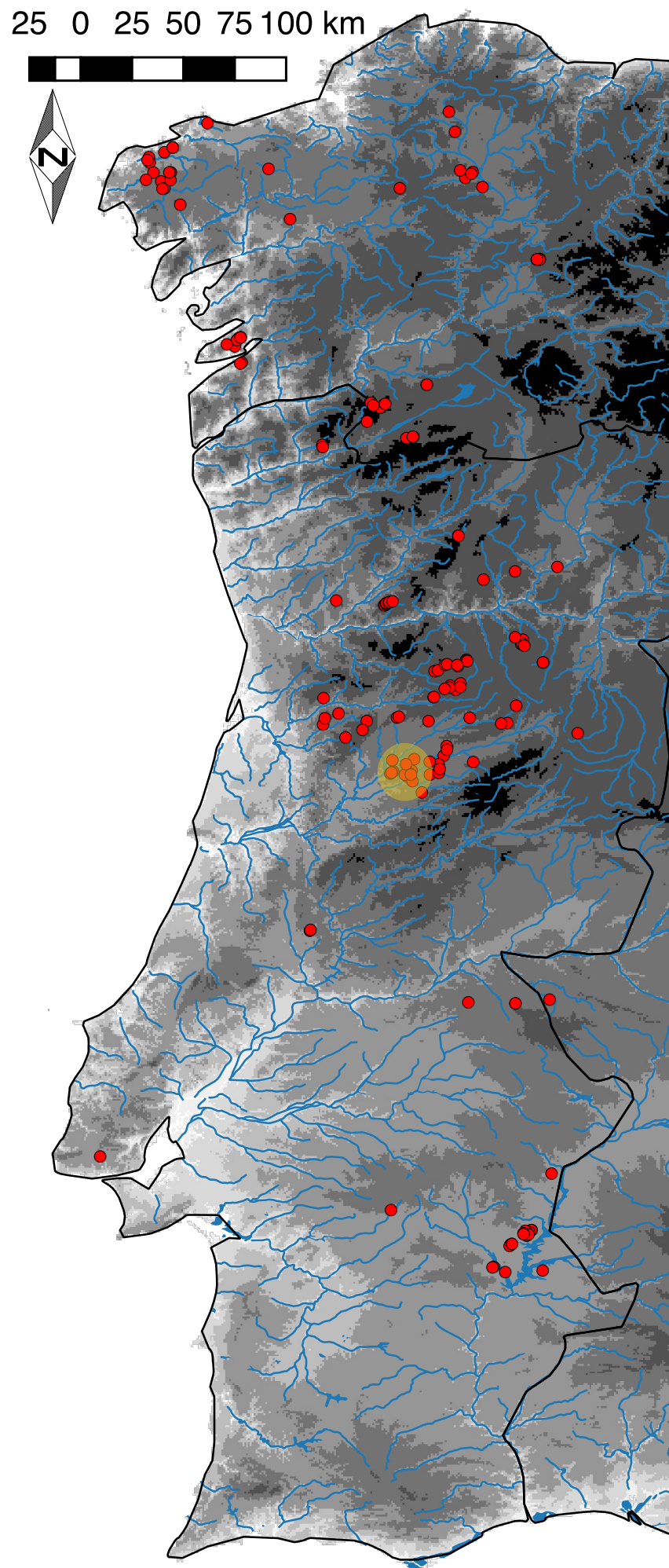
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The figure to the left compares the 2° (dark shaded) or 3° (light shaded) uncertainty estimates common in archaeoastronomical studies of passage graves with window measurements for 55 passage graves in Portugal.

It clearly demonstrates that in most cases, the uncertainty has been grossly underestimated.

This might be why no significant patterns have been found!





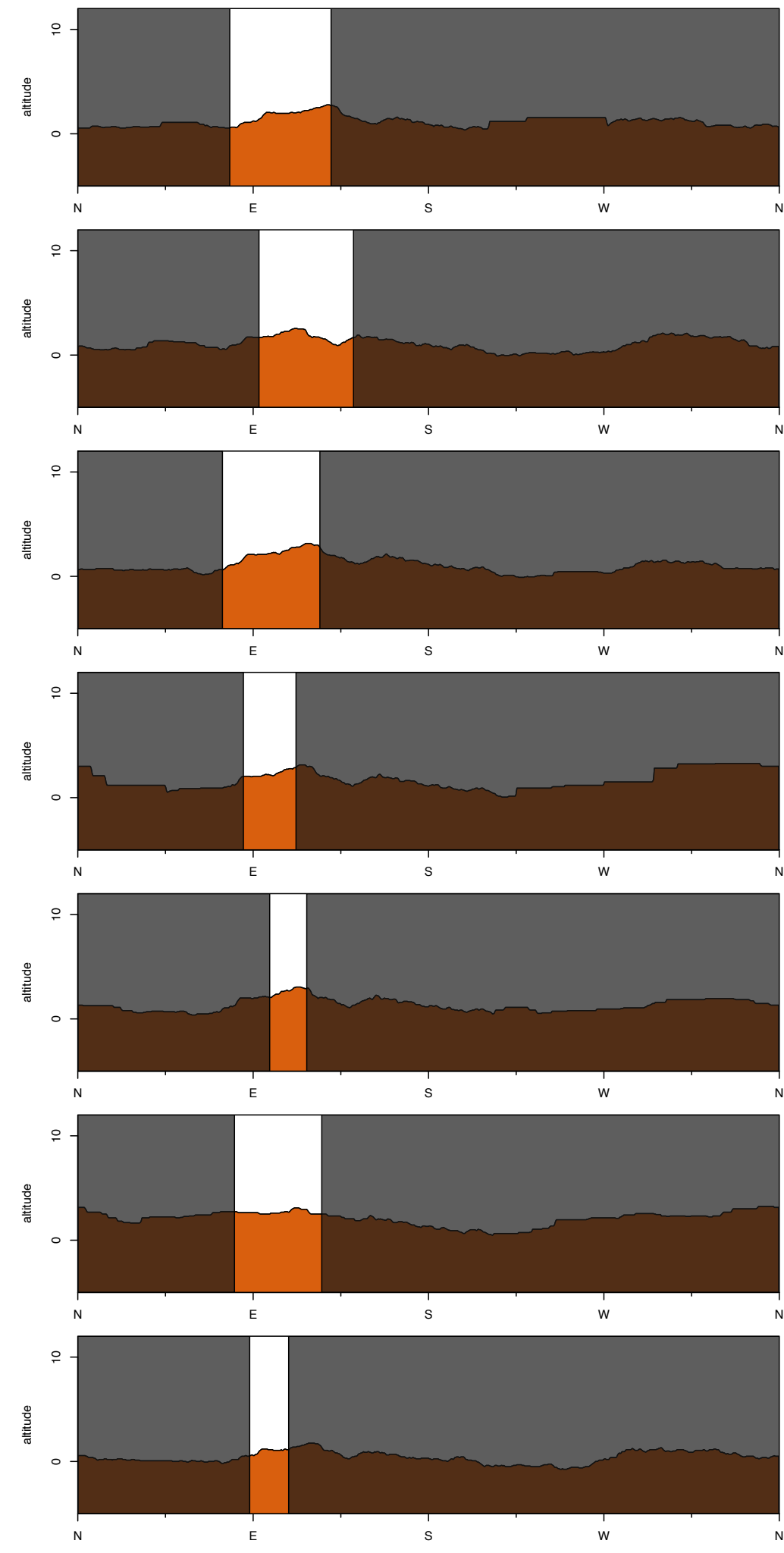
Case Study

Let's look specifically at a cluster of passage graves in the *Upper Mondego* basin, roughly corresponding to the councils of *Carregal do Sal* and *Nelas*

Case Study

Observations:

(1) all 7 structures are oriented towards the same orographic feature



Serra da Estrela

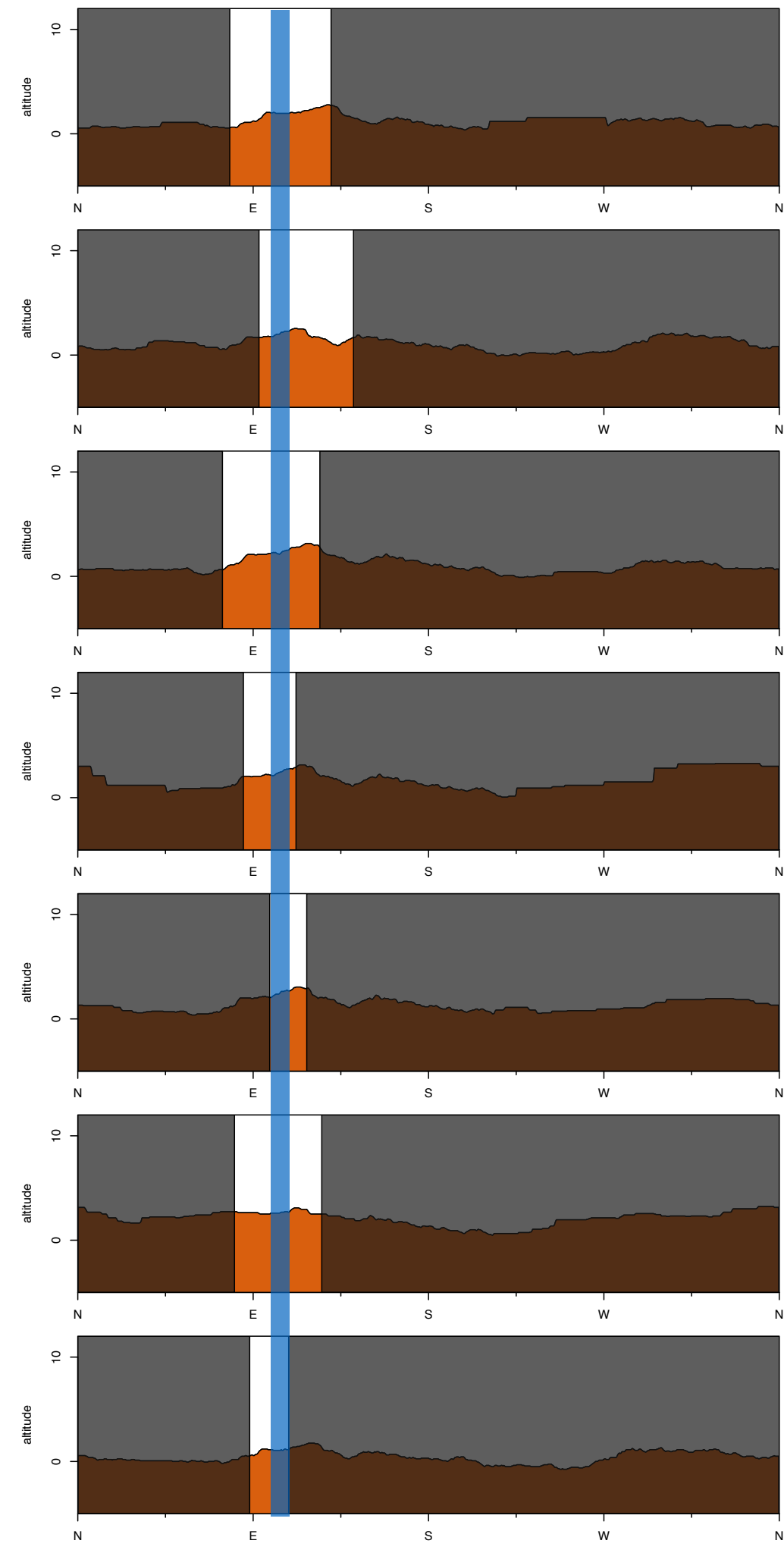
The mountain range where we believe this Neolithic community would have spent their summers.



Results

Observations:

- (1) all 7 structures are oriented towards the same orographic feature
- (2) the windows of all structures overlap in the blue region



Results

Observations:

- (1) all 7 structures are oriented towards the same orographic feature
- (2) the windows of all structures overlap in the blue region
- (3) the pattern (the blue ribbon) matches the rising position of the star Aldebaran in the period 4,300-3,700 cal BC





Aldebaran

E

Heliacal Rising of Aldebaran
c. May 1st 4000 BCE
from Carregal do Sal (Portugal)

Economic Model

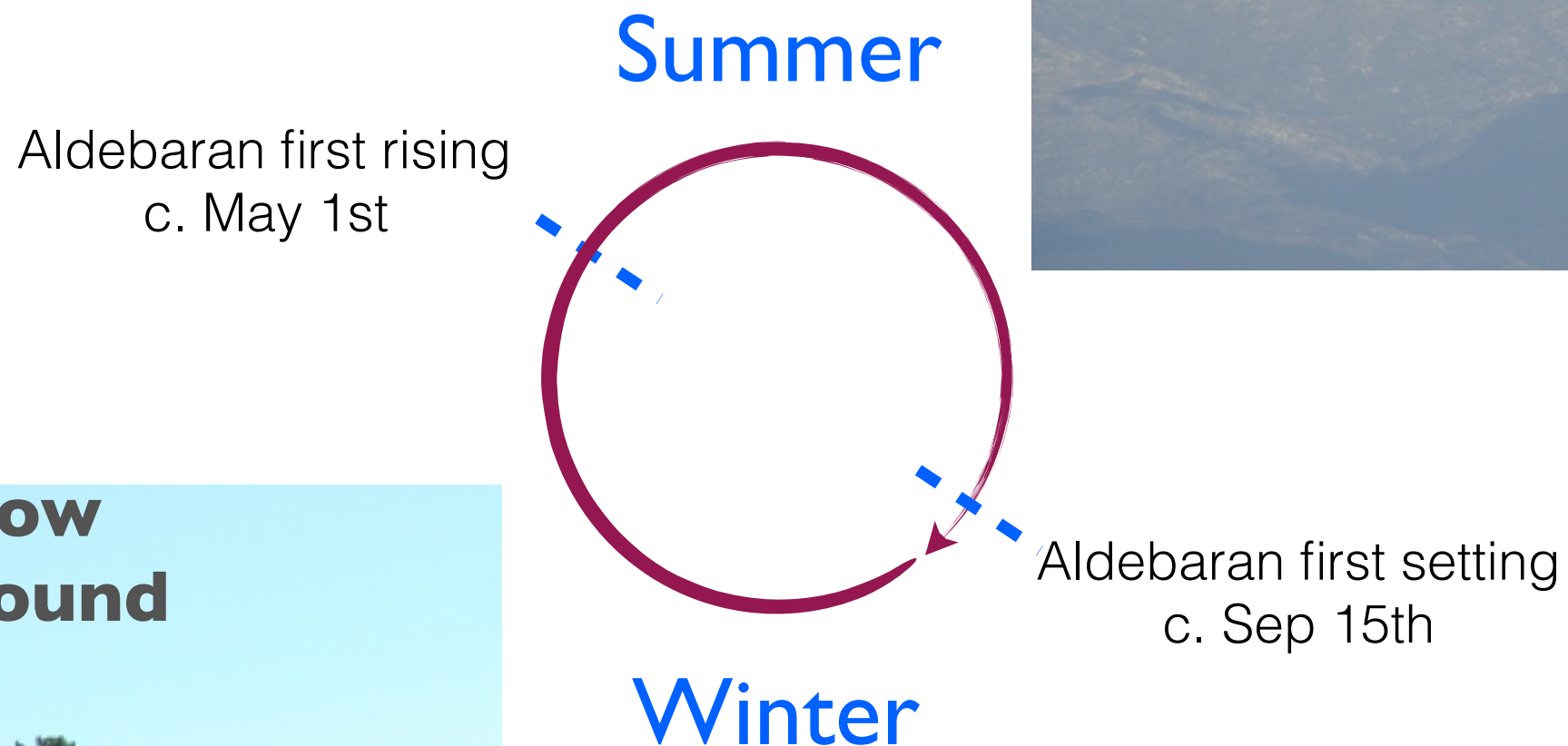
(4) The star Aldebaran provides a good match to the independently derived seasonal economic model for this Neolithic community



**low
ground**



high ground



In Conclusion

- (1) Archaeoastronomy uses measurements of orientation
- (2) All measurements have an associated uncertainty
- (3) Uncertainty is required for an accurate inference
- (4) Estimating, reporting and working with full uncertainty is not only necessary...
- (5) ... but it can also allow for patterns to be identified where no patterns were seen before.





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