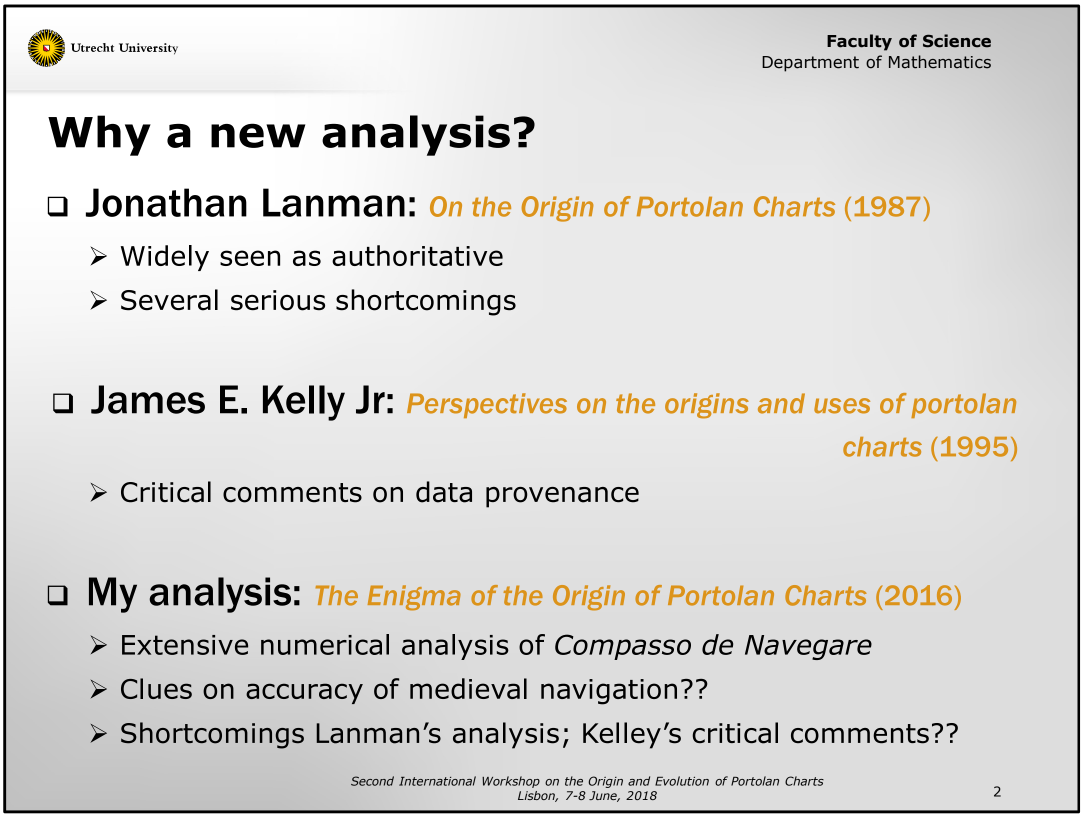
In this presentation I will share with you the results of a numerical analysis of the *Compasso de Navegare*, focusing on questions of data accuracy and the provenance of the data.

(The contents of this presentation is an abbreviated version of Chapter 6 of "The Enigma of Portolan Charts. A Geodetic Analysis of the Hypothesis of a Medieval Origin" by Roel Nicolai, published by Brill, Boston and Leiden).



One might care to ask: why a new analysis?
After all, there is Jonathan Lanman's analysis from 1987, which is widely regarded as authoritative. However, despite its evident merits, Lanman's analysis also suffers from a number of vital shortcomings.

James Kelley wrote on the relationship between portolans and portolan charts and was cautiously critical of the prevailing point of view.

My analysis was published in 2016, although I did most of the work in 2009. My objective was to find out more about medieval navigation capabilities, but I was also intrigued by Kelley's critical comments and the impact of the issues I found in Lanman's work.

James E. Kelley Jr.

- *"Could it be that portolans owe more to portolan charts than vice versa?"*
- **Impossible routes:**
  - Peleio Gavdhos - Majorca runs across Sicily (Rizo portolan - 1490)
  - "Sightings" of reefs beyond visible horizon
- **Percentage "non-standard bearings"**
  - 21% - Compasso de Navegare (1296)
  - 8% - Pietro de Versi (1444)
  - 3% - Rizo portolan (1490)

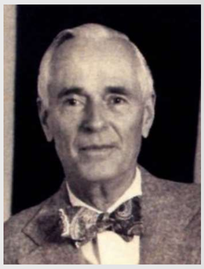
Kelley challenged the consensus view that portolans contain the source data from which portolan charts were constructed, framing his challenge as a question: *"Could it be that portolans owe more to portolan charts than vice versa?"* He drew attention to data inconsistencies such as courses that cut across land; … and reefs that are claimed to be visible on a particular route, while in reality they would be well beyond the horizon. He also stressed that one-fifth of the bearings in the Compasso have a higher resolution than a quarter-wind and noted that the percentage of such bearings drops steeply in later portolans. He suggested they may have been scaled from a chart, but turned out to be too fine-graded to be of any practical use.

Utrecht University

Faculty of Science
Department of Mathematics

Jonathan Lanman

- *"If a chart were the primary source, where would it have come from?"*
- **Mixing up:**
  - plane charting,
  - plane charts
  - Mercator charts
- **Contradictions data ↔ conclusions:**
  - *"remarkable"* or *"surprising"*
- **But: first in-depth study after Kretschmer (1909)!**
- **Dispelled the persistent myth of highly accurate navigation data in portolans**



Dr. Jonathan Lanman

Second International Workshop on the Origin and Evolution of Portolan Charts
Lisbon, 7-8 June, 2018

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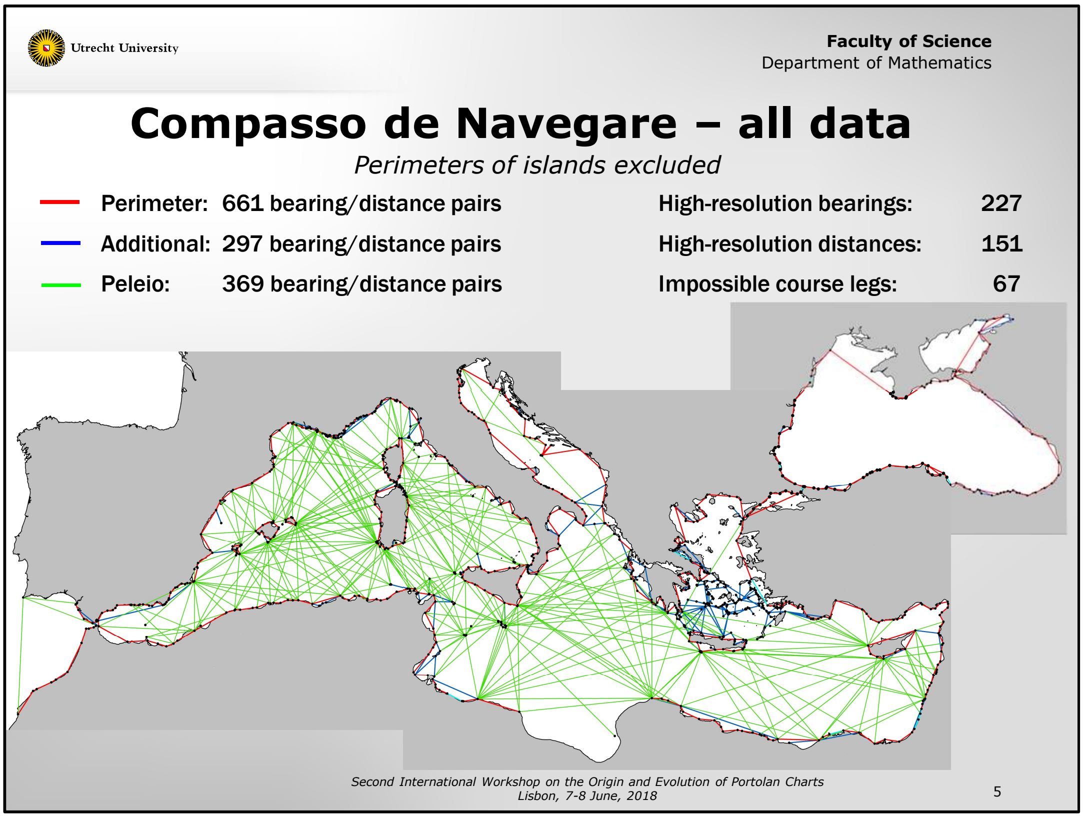
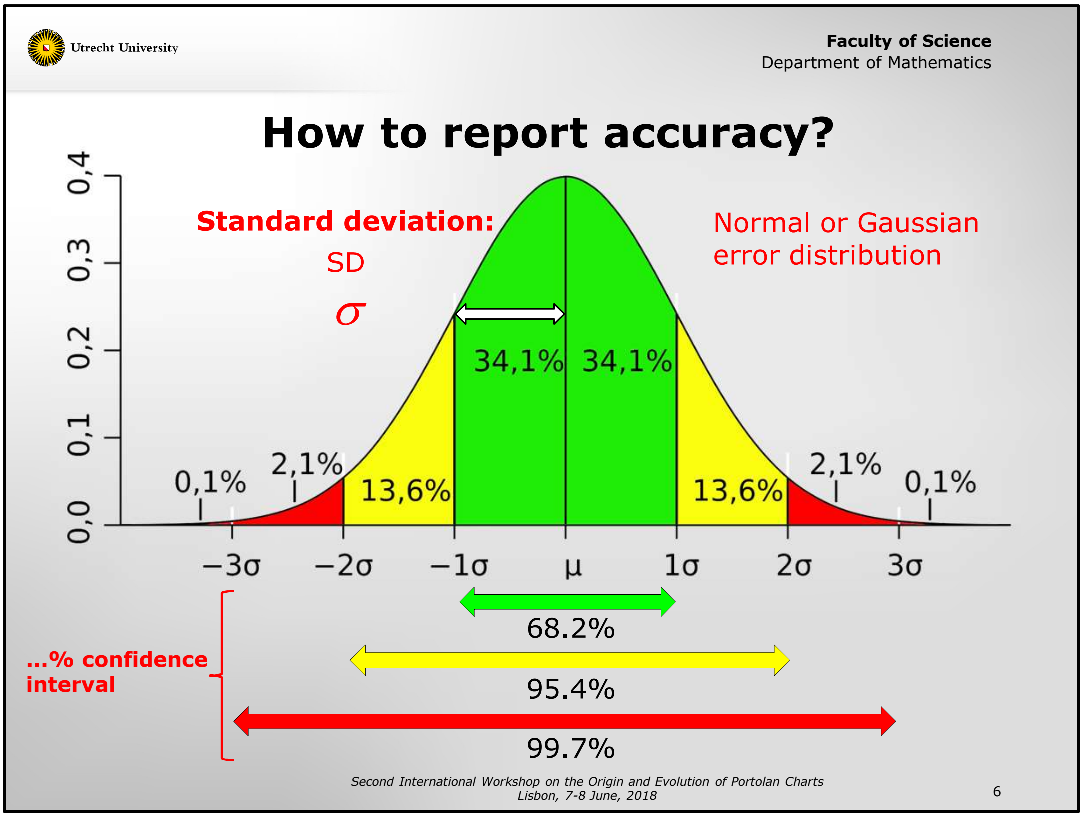
Lanman stated at the beginning of his monograph that his aim was to investigate the relationship between portolans and portolan charts, but adopted an *a priori* position a little later, stating incredulously: *"If a chart were the primary source, where would it have come from?"*
He also mixed up the concepts of plane charting, plane chart and Mercator chart. This may be obvious to a professional geodesist such as me, but Lanman was a medical doctor and lacked formal training in geodesy and cartography.
But that mixing-up led, among other things, to a number of contradictions between his conclusions and the data, which he described as "surprising" or "remarkable" without questioning his premises or methods.

Nevertheless Lanman was <u>not</u> afraid to dirty his hands and take an in-depth look at portolan data and he <u>did</u> succeed in dispelling the – until then – persistent myth that portolans contain highly accurate navigation data.
There are a number of important differences between Lanman's analysis and mine: Lanman limited his analysis to data samples; I identified all points and analysed all data. I also tested two options: that the Compasso data was observed and that it was scaled off.



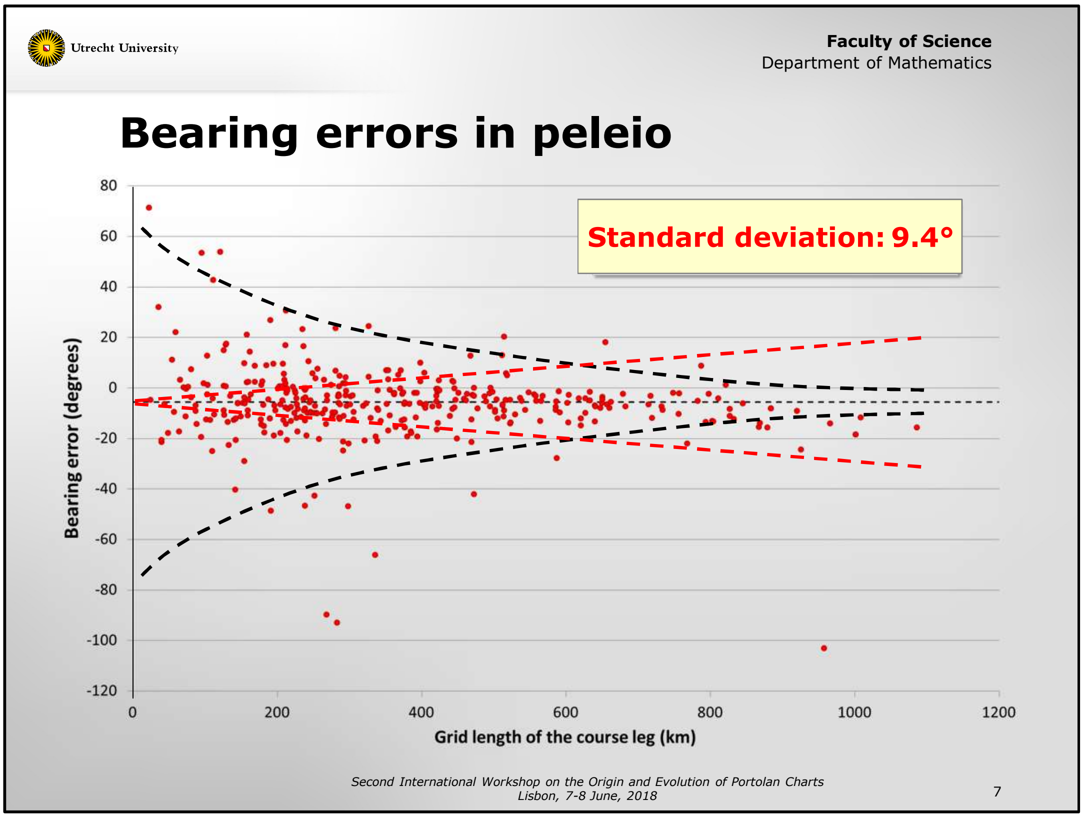
This map visualizes all Compasso data. The *peleio,* long-distance, open-sea routes, are shown in green, and the coastal routes in red. Blue lines represent additional coastal routes for example between the Aegean islands. The text above the map summarizes the amount I analyzed.
I treated the peleio and the coastal data as two separate datasets; Lanman also did this.
I also analysed the high-resolution data Kelley mentioned, but this is not a separate category of data; any high-resolution bearing or distance is also part of either the coastal dataset or the peleio.



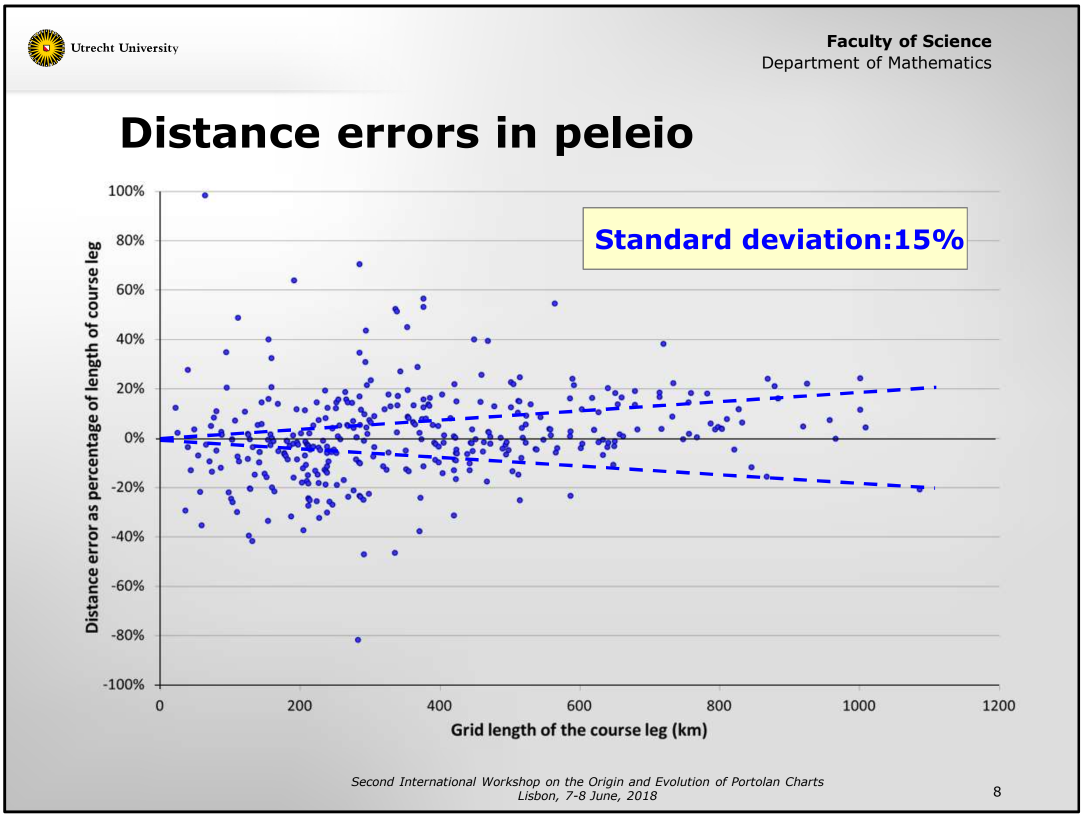
The word 'standard deviation' will be used frequently in this presentation. A brief reminder of what that is, is therefore appropriate. Most measurement data we encounter obey the Normal or Gaussian error distribution. I assume everyone is at least somewhat familiar with it. The **standard deviation** is the distance from the middle of the curve, the theoretical mean value, to the flex point. It is designated by the letters SD or the Greek letter sigma.

Any measurement has a chance of about 68% of deviating less than one standard deviation from the theoretical mean; of about 95% of deviating up to two and 99.7% of being within three times the standard deviation from the theoretical mean.

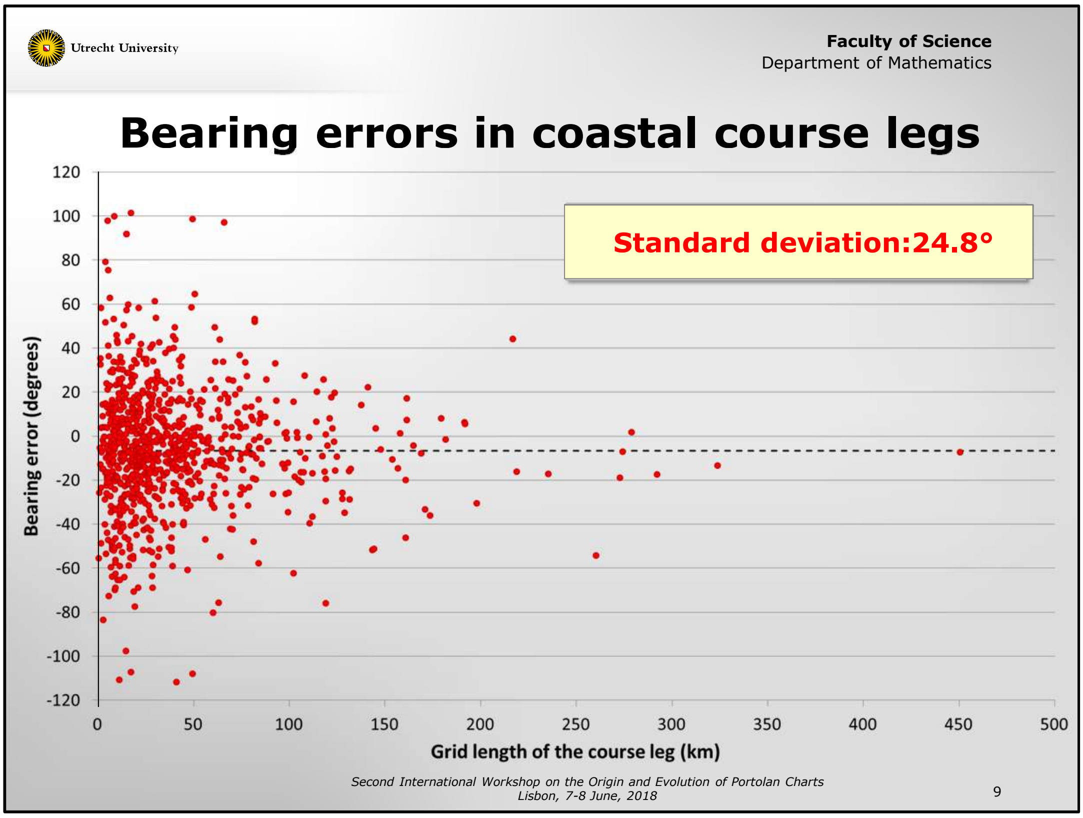
These intervals, with their associated probabilities, are called confidence intervals. They are sometimes used instead of the standard deviation to describe accuracy.



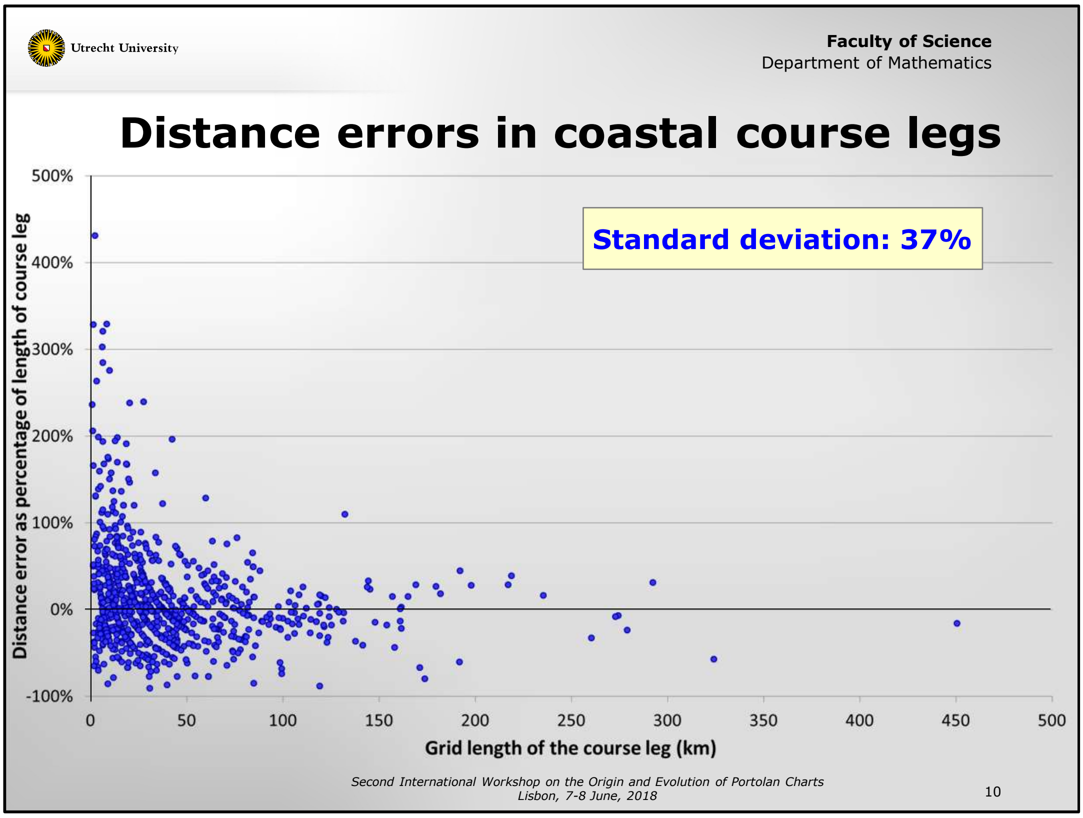
This first graph shows the errors in the bearings of the *peleio*, of which the standard deviation computes as 9.4°. I ordered the errors according to the length of the course leg, because it is to be expected that longer routes tend to have larger errors. Surprisingly, the reverse is the case: in general shorter course legs have larger errors than longer ones. We see the trend indicated by the black dashed lines, while we would expect to see a trend as indicated by the red dashed lines.
These trend lines are only approximate.



The same pattern is visible in the *peleio* distances. The relative error is displayed and its standard deviation is 15%. Larger relative errors are to be expected for longer course legs, as indicated by the dashed cone that grows wider for longer course legs. One might argue that the relative distance error should be about constant because it needs to be multiplied by the length of the course leg anyway to get the distance error proper. However, uncertainties due to variations in wind and current, as well as other factors will be greater on a long route than a on a short one, leading to greater expected relative errors.



The errors in the coastal bearings, which include the inter-island data in the Aegean, exhibit this “short-distance” effect to an even more extreme extent. Their standard deviation is a staggering 25°, but bearings to destinations that might have been visible are misestimated by up to 100°!



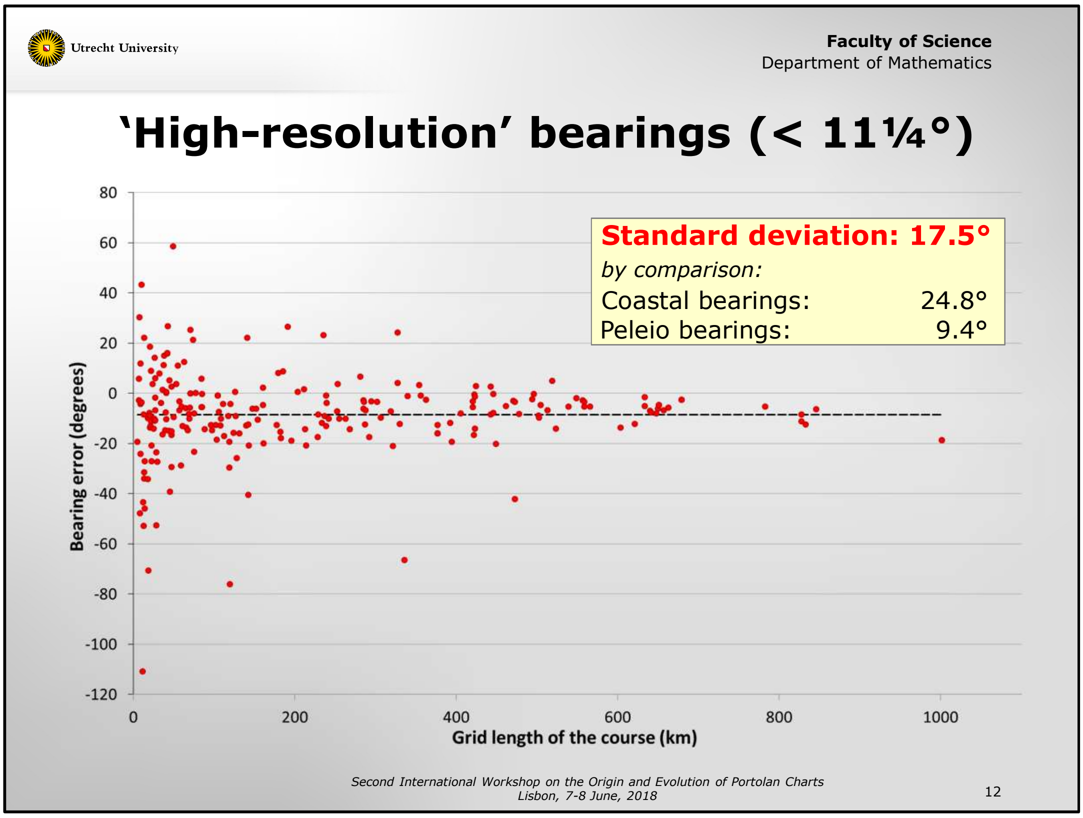
A similar pattern can be seen in the associated distances. Distances to points that would be intervisible in principle are overestimated by hundreds of percent; the most extreme errors are not even shown on this graph. The standard deviation in the coastal distances is as much as 37%.
The curious curvy patterns in the data are artefacts caused by rounding to the nearest multiple of 5 or 10 miles.

"High-resolution" (Hi-res) data

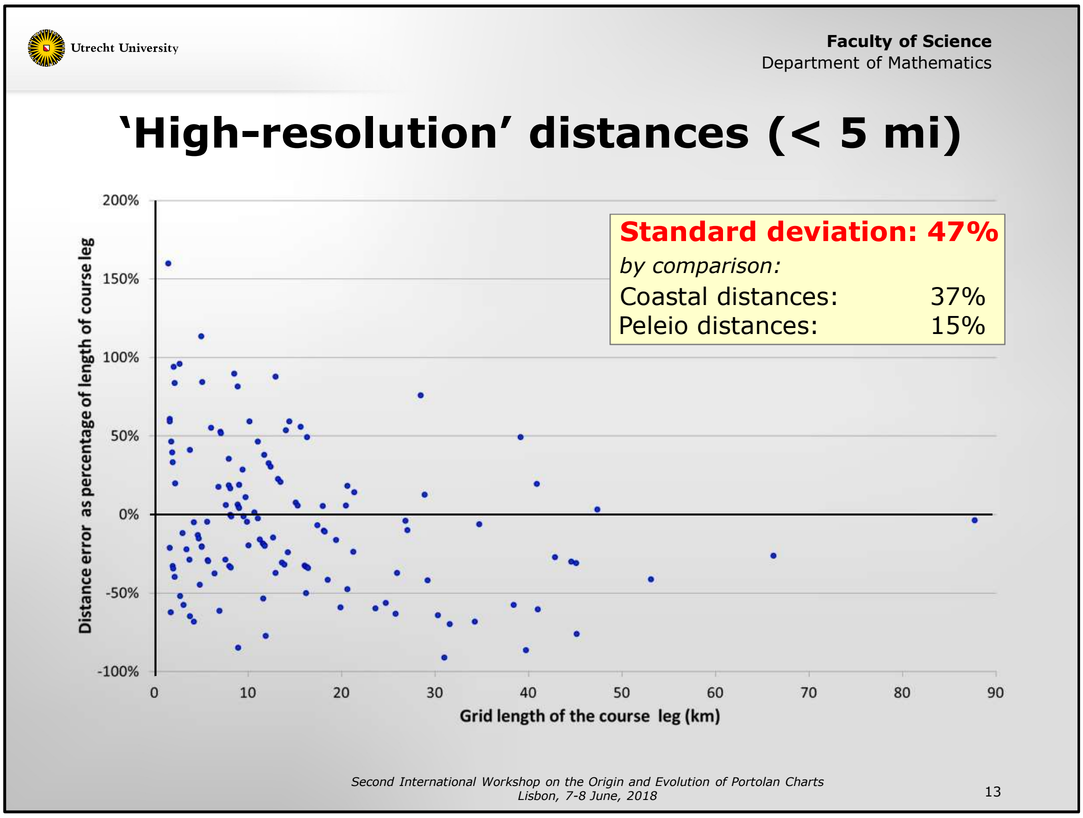
- **Kelley: "*21% of the bearings*"** (sample)
  - Counting all data in the Compasso de Navegare:
    - 17% of routes contain hi-res bearings (227)
    - 11% of routes contain hi-res distances (151)
- **Definition:**
  - Bearings better than multiples of a quarter-wind (= 11¼°)
    - Subdivisions to units of 2.8°
  - Distances better than multiples of 5 portolan miles
- **Do not occur on the same course leg as a rule:**
  - Hi-res bearings 54% in peleio; 46% in coastal routes
  - Hi-res distance mainly in short coastal legs

The extreme errors in short course legs beg the question of what the accuracy is of the high-resolution data, to which Kelley drew attention.
Kelley estimated the high-resolution bearings in the Compasso to occur in 21% of the routes, based on a sample. Counting all data, It turns out to be 17%. Kelley did not estimate the high resolution *distances*, which occur in 11% of the routes.

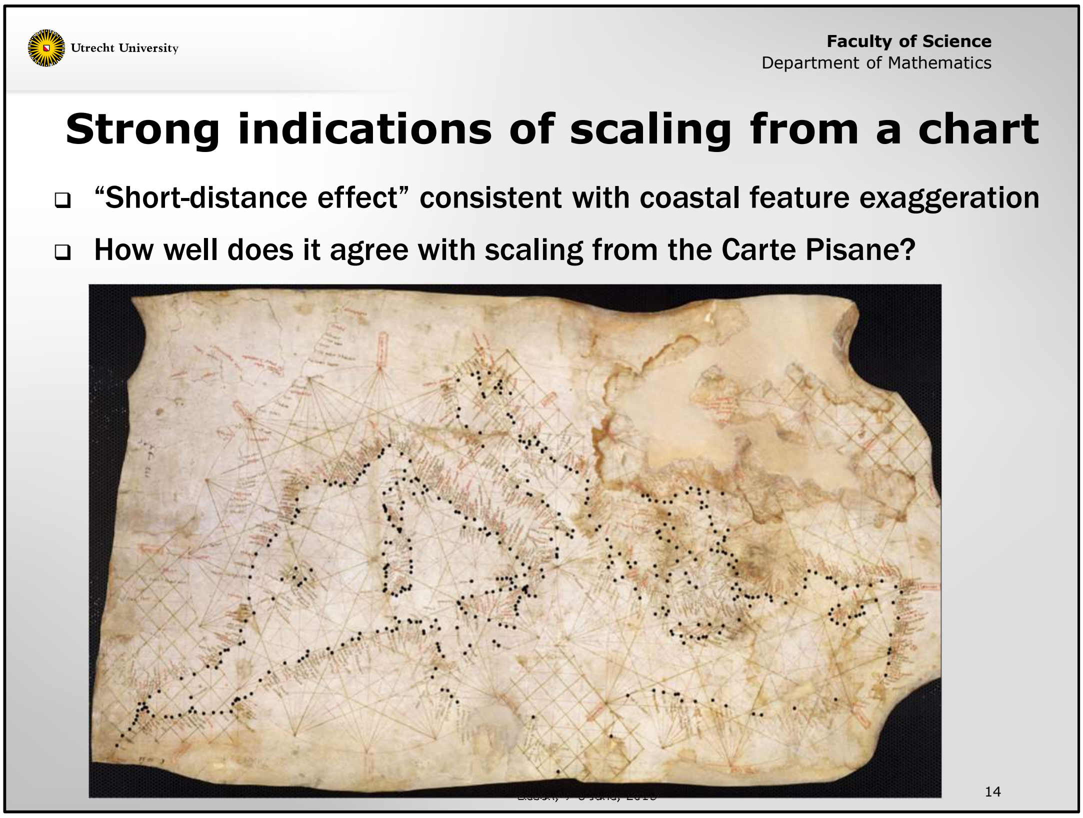
High-resolution bearings in the Compasso are bearings recorded to better than a quarter-wind, in units down to 2.8°.
Distances are classified as "high resolution" when recorded to better than the nearest multiple of 5 miles.
High-resolution bearings and distances do not usually occur together in the same course leg.



However, the high-resolution bearings turn out to be no better than the other bearings. Their standard deviation is 17.5°, which is in-between those of the peleio and the coastal bearings, which is logical, as half of them occur in peleio and the other half in coastal data. However, it <u>is</u> patently clear that the high-resolution bearings do <u>not</u> represent the "better part" of the data.

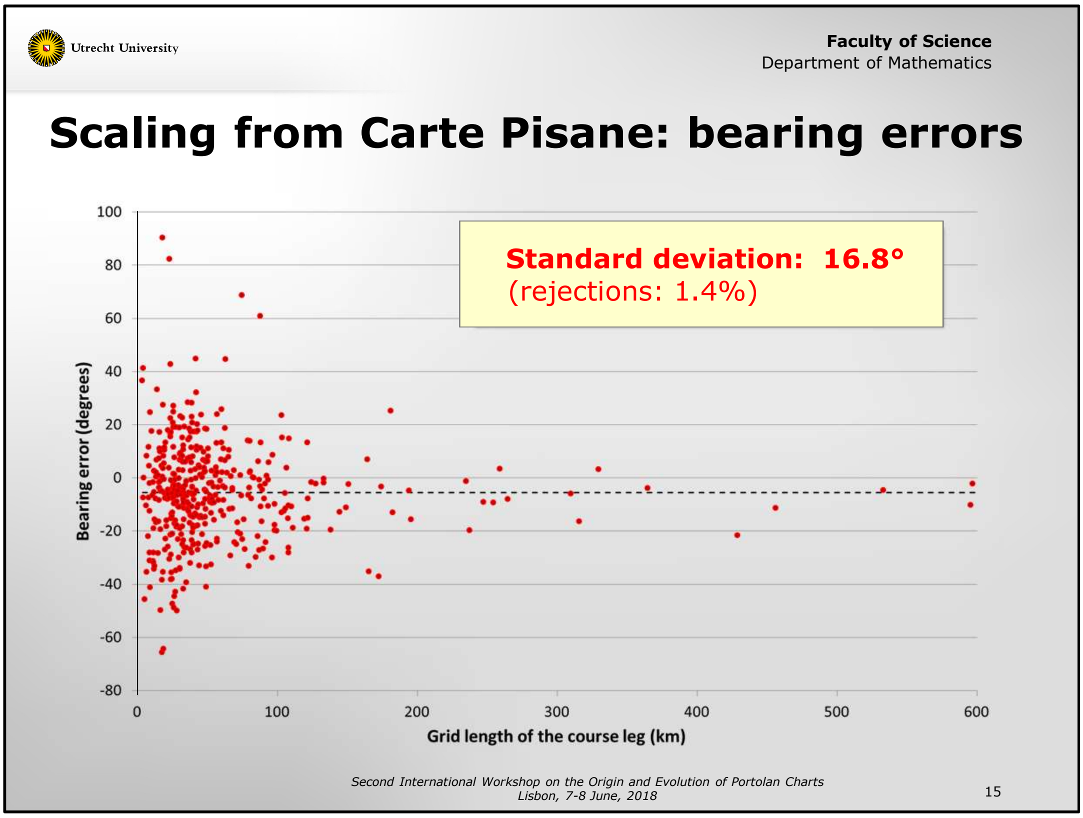


The same "short-distance" effect is visible in the high-resolution distances, which have a standard deviation of 47%; considerably worse than that of the other data, but the high-resolution distances occur mostly in short and very short legs, so that the *relative* error is higher than when the same error occurred in longer course legs. Nevertheless this is much poorer than one might expect.

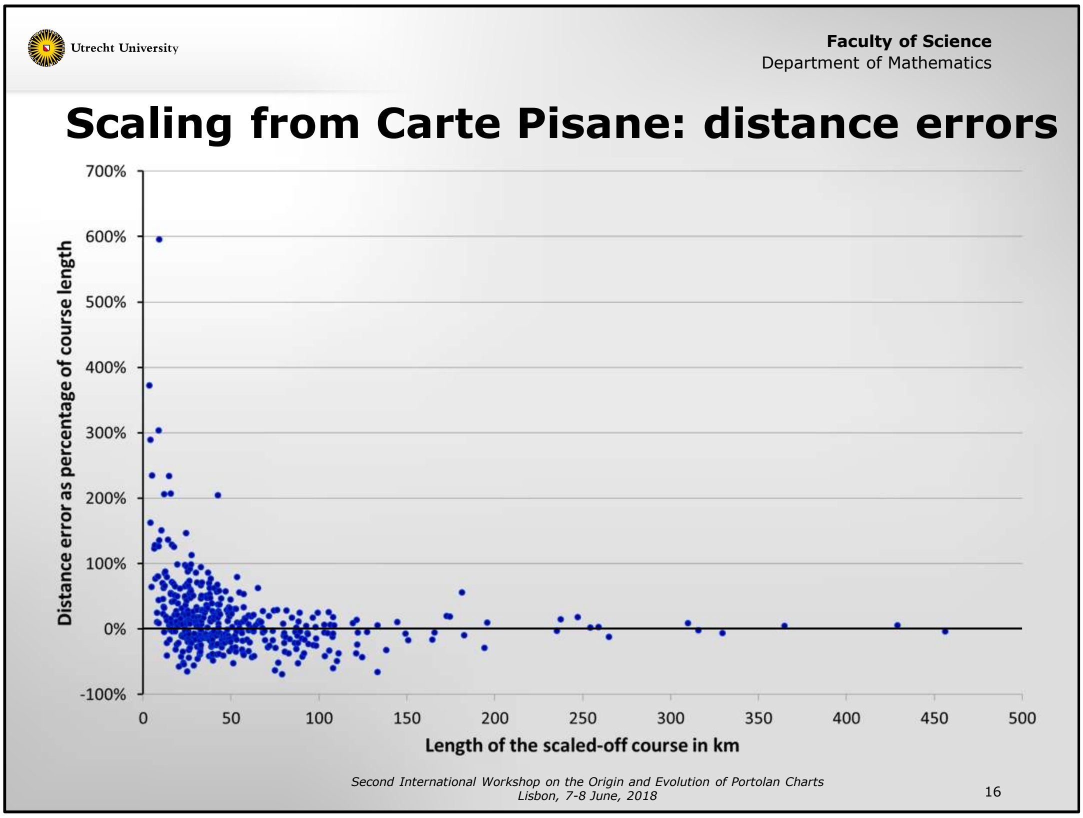


This “short-distance” effect in the error patterns makes no sense at all for observed data: measurement or estimation of both bearing and distance should be more accurate for a short route than for a long one. However, it may make perfect sense for data that was scaled from a portolan chart. In that case it might be explained as resulting from the coastal feature exaggeration and the poor coastal detail of portolan charts, which I presume you are familiar with.

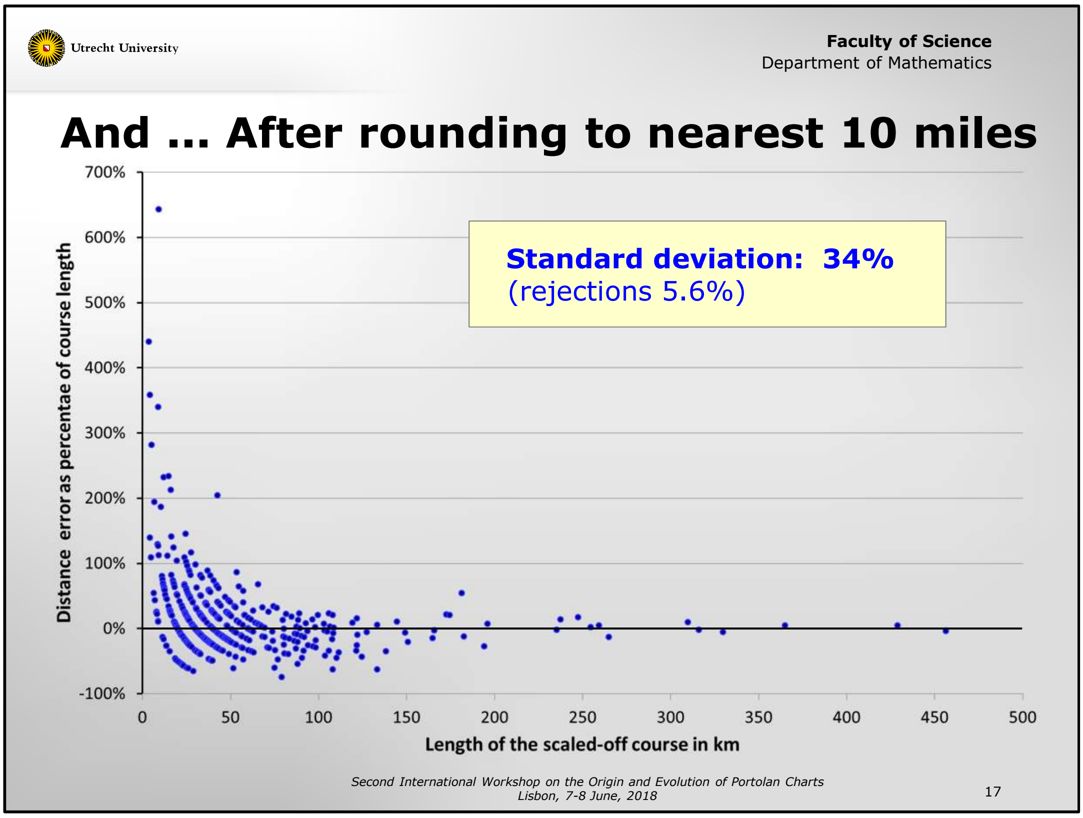
I was initially skeptical that the errors due to scaling from a portolan chart would be as large as we saw, so I decided to put this idea to the test and scale a coastal dataset from the Carte Pisane, which is roughly contemporary with the Compasso de Navegare.
444 identical points were available from my cartometric analysis of this chart and it was therefore trivially simple to “scale off”, that is, compute, distances and bearings between successive points.



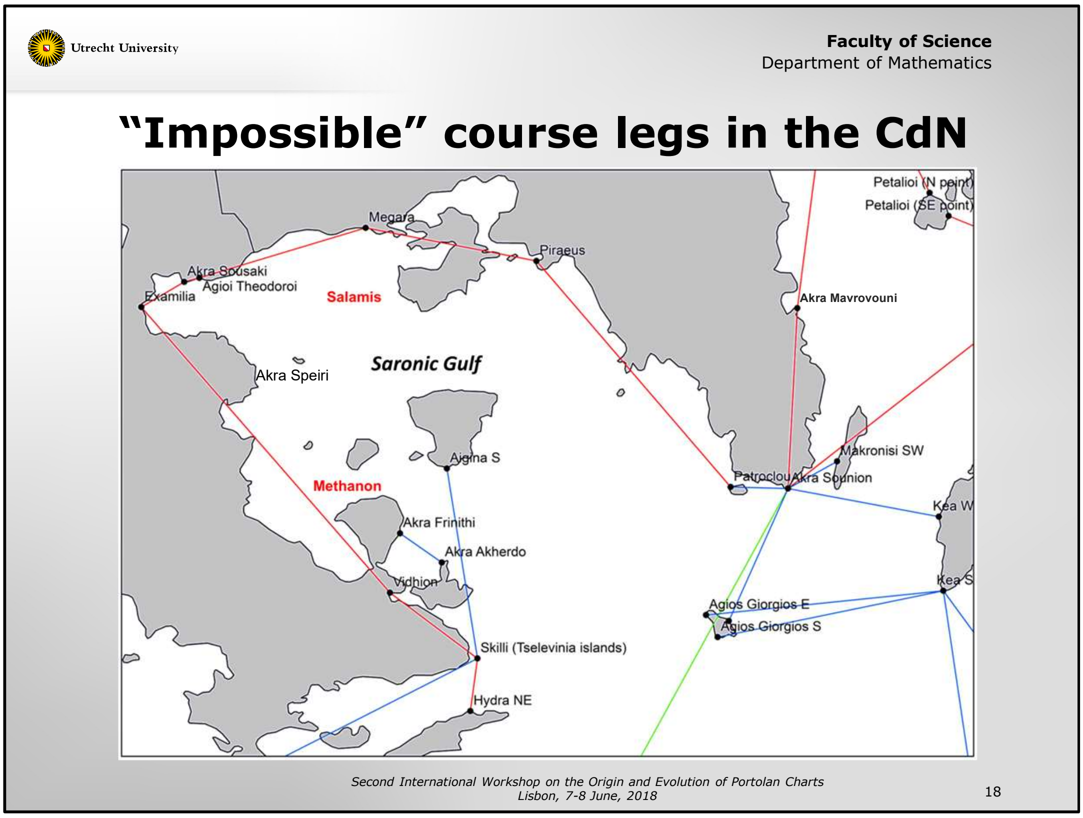
A similar error pattern came out, to my surprise even showing the same magnitude of errors, not only in the bearings, which were rounded to the nearest quarter-wind, but also in the distances …



… shown here before rounding, …



… and here after rounding to the nearest 10 miles. This confirms that the strange curve patterns are caused by rounding.
The analysis results shown so far therefore strongly suggest that the bulk of the data has been scaled off, and that can only be from a from a portolan chart.

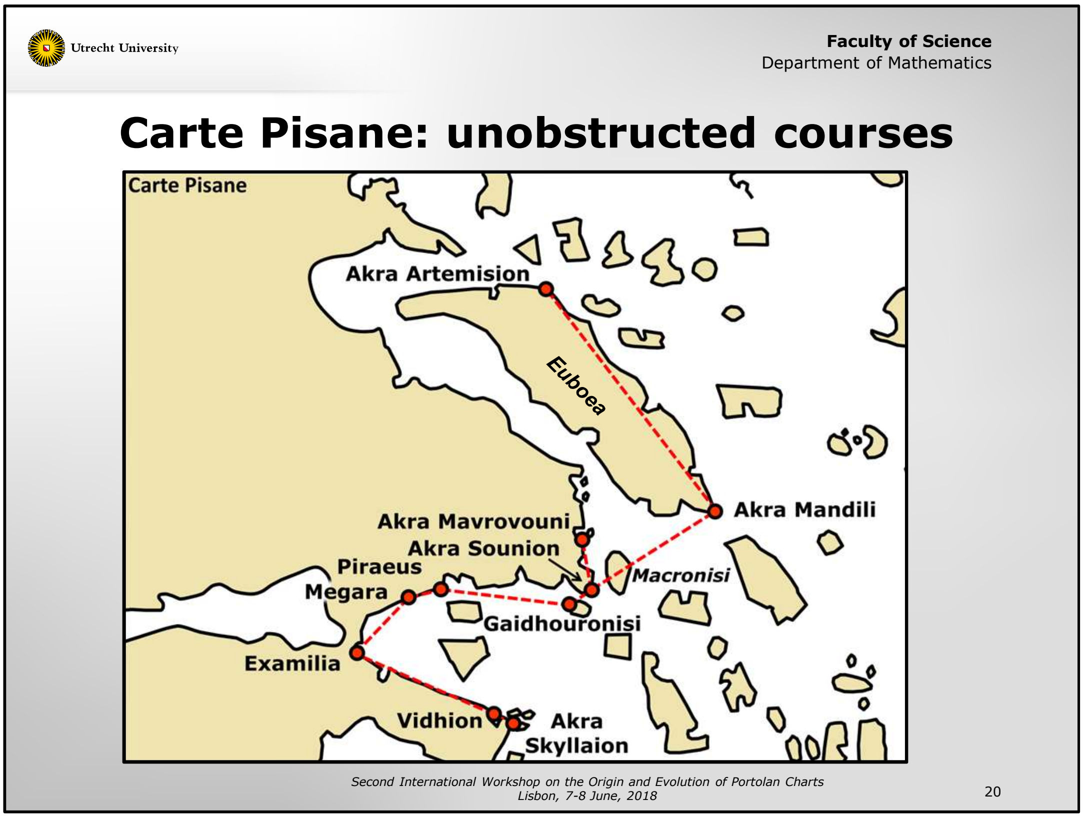


This brings us to James Kelley's claim that numerous course legs in portolans cut across land significantly, suggesting that they may have been scaled off. I found 67 of such course legs in the Compasso. This slide shows a particularly interesting sequence of course legs in the Saronic Gulf near Athens. Going clockwise around the gulf, the first leg from the Tselevinia islands to Vidhion is OK. It may run over land on this map, but a safe distance may have been kept from the coast and a straight course to Vidhion is then feasible. However, that is where trouble begins. The next leg to Examilia cuts across the Methanon peninsula and across the promontory behind Cape Spiri. The route from Megara to Piraeus runs across the island of Salamis. In the east we see one leg that runs entirely over land and one that crosses the island of Macronisi.

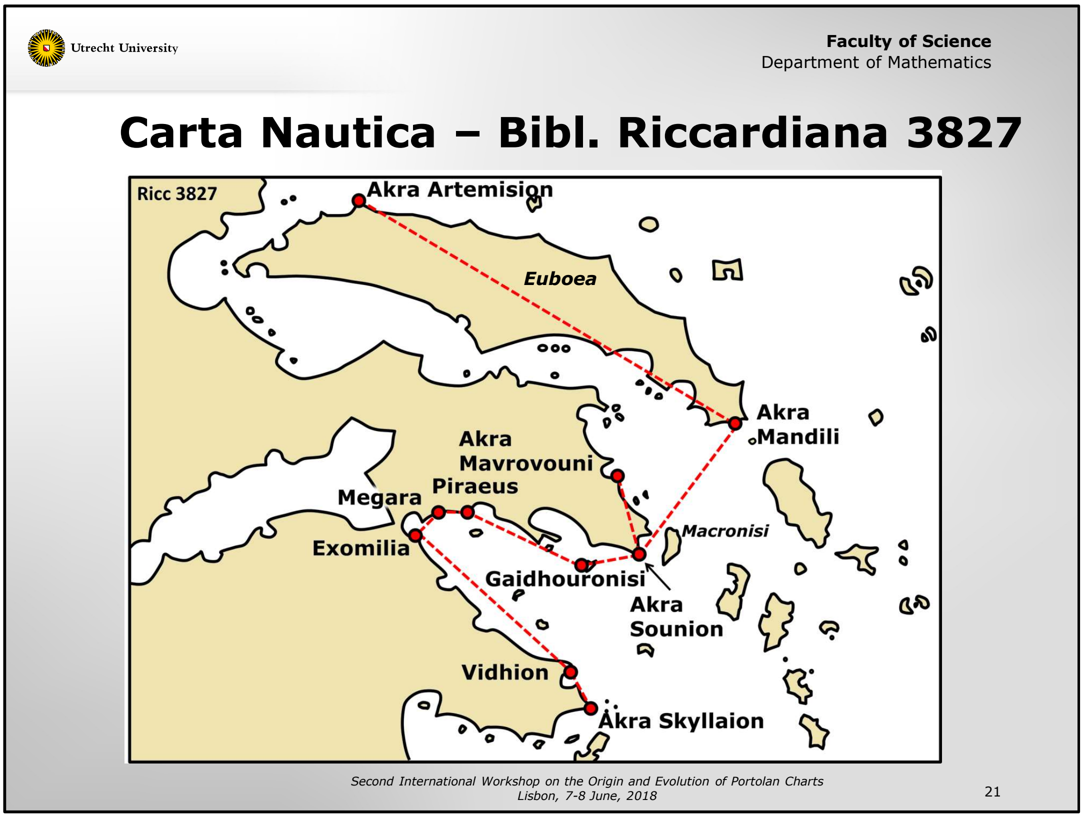
Now what useful information to sailors do such courses convey? Patrick Gautier Dalché suggested they were most likely the result of combining several shorter course legs around the obstruction into a single one. But what is the point of that? If such a course is not visibly impossible, it might be positively dangerous.

"Vestas Wind" wrecked on Cargados Carajos reef (2014)

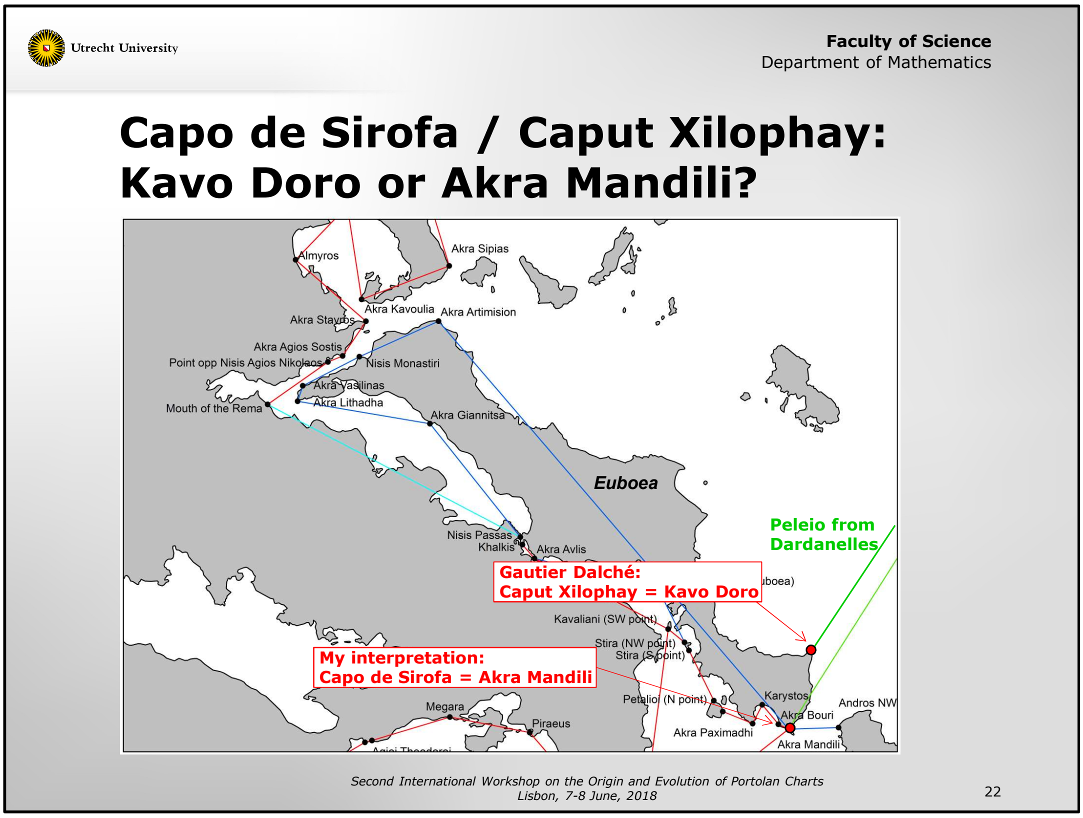
This may happen when a navigator lays a course across a reef instead of around it. This is the Vestas Wind racing yacht in the 2014 Volvo Ocean Race. The location is the middle of the Indian Ocean.
It makes no sense to combine courses if the intention is to publish practical sailing instructions.
However, a rational answer to my question as to <u>why</u> presents itself when the same routes are shown on a portolan chart.



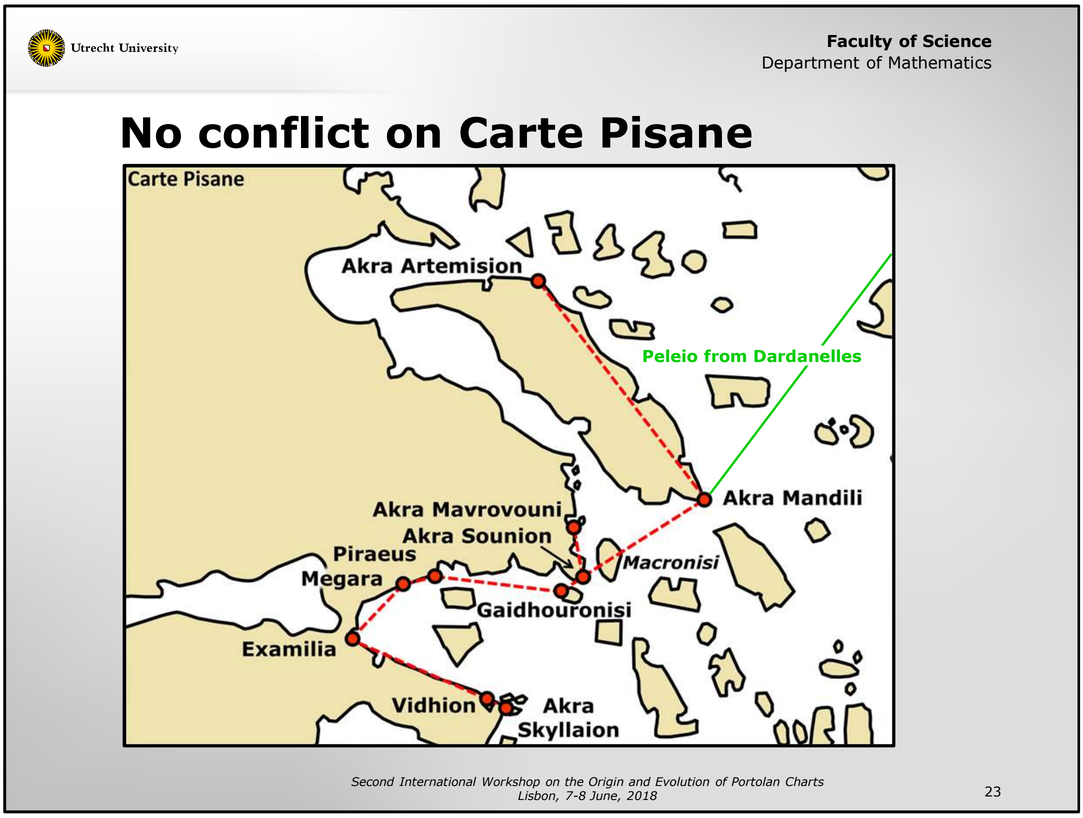
This is a tracing of the same area of the Carte Pisane coastal outlines, showing the same course legs and you will be able to see without difficulty that all routes are unobstructed, except the one across the island of Macronisi.



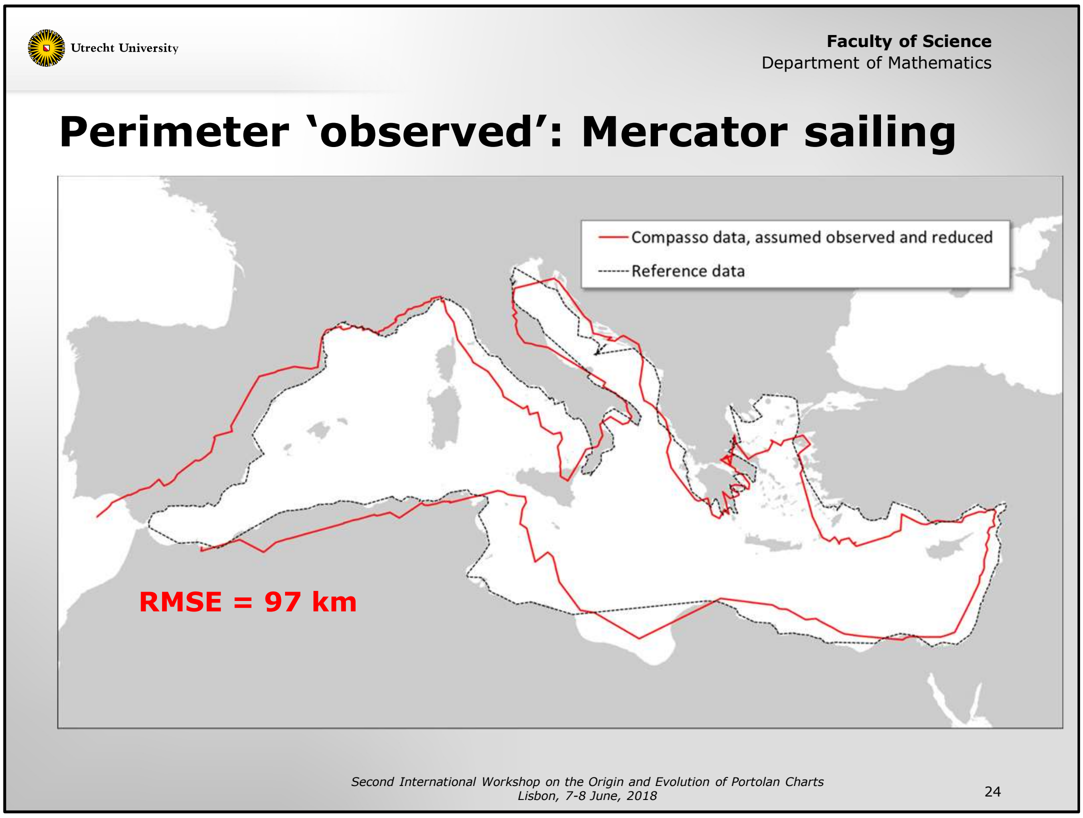
The same holds for the early 14th century chart in the Biblioteca Riccardiana in Florence. Although Macronisi is no longer in the way, now we have a route that runs diagonally across the island of Euboea, known as Negroponte to the Italians in medieval times.



This begs the question as to whether my identification of *Capo de Sirofa* in the Compasso as Cape Mandili is correct. My interpretation is based on the series of short course legs along the southern coast of the island of Euboea (Negroponte) and the course leg to Cape Sounion to the southwest (off this map). But Gautier Dalché identifies the corresponding *Caput Xilophay* in the *Liber de existencia* as Kavo Doro, on the basis of a peleio from the Dardanelles. He does flag that the peleio from there to Cape Sounion runs too far across land. Surely one of us must be wrong!

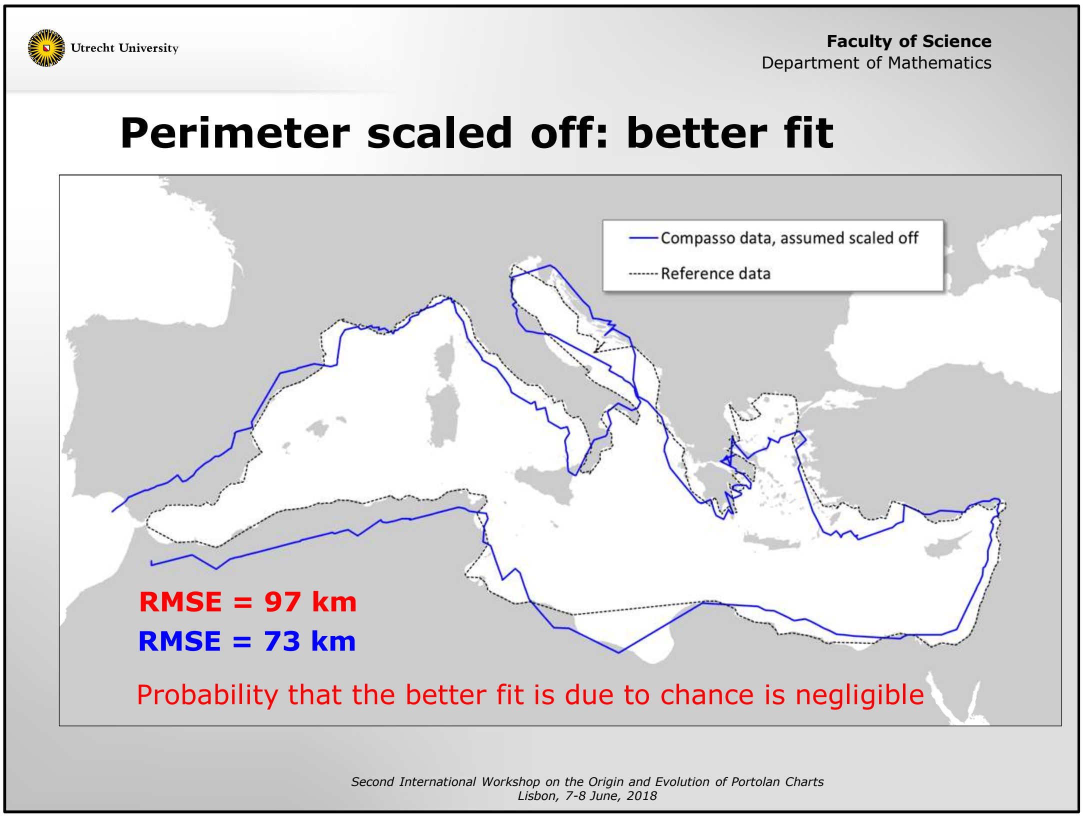


However, neither of us needs to be when these course legs were scaled from a *Carte Pisane*-like portolan chart. All routes to *Capo de Sirofa* are then unobstructed due to the wedge-shaped south-east of Euboea on this chart! Summarising: in addition to the errors in individual bearings and distances, many other features of the *Compasso* suggest that its data was scaled from a portolan chart.

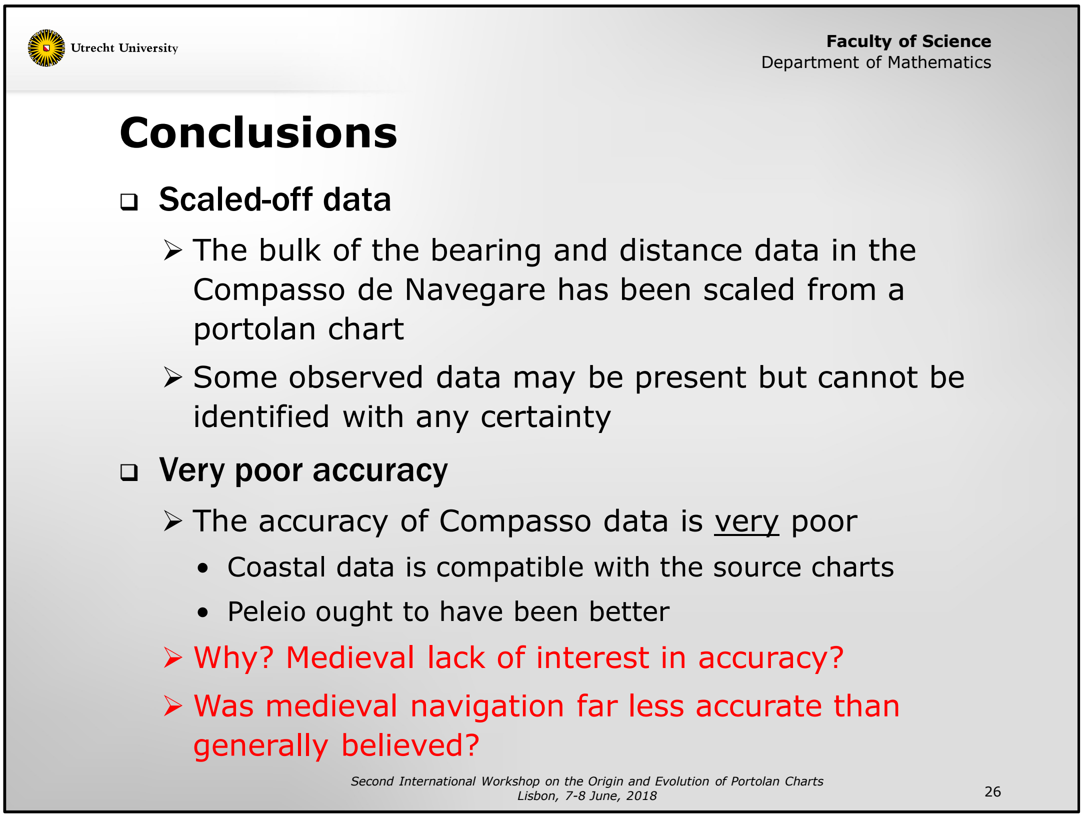


This provisional conclusion is supported by the sequence of courses around the perimeters of the Mediterranean and the Black Sea. Geometrically closed traverses exist for both in the Compasso.

The slide shows the result of plotting the Mediterranean perimeter, assuming that the data was observed. Because this perimeter is plotted on a Mercator map, so-called "Mercator sailing" has to be applied, which means that the distances need to be corrected for the latitude-dependent scale distortion of the Mercator projection. The bearings have to be corrected for magnetic declination, which were computed from a paleomagnetic model (CALS7k.2) for the year 1250. Next the perimeter from the Compasso data was best-fitted, in a least-squares sense, to the Mercator reference perimeter. That enables the degree of fit to be expressed as a Mean Square Error, of which the square root is shown in the bottom-left corner.



A similar evaluation was made assuming that the data was scaled off. In that case the distances require no Mercator scale correction, because they are assumed to originate from a Mercator-like chart. But a correction for variations in chart scale for the western, the central and the eastern Mediterranean is needed. These regional scale differences, which exist on a portolan chart as well as in the Compasso data, are of the order of 10%. The bearings do not need to be corrected for magnetic declination but for chart skew and the relevant values were computed for the three sub-areas from the Compasso data. The Root Mean Square Error for the total perimeter fit can be computed again and the smaller number in blue shows that the scaling-off hypothesis yields the better fit. This difference is statistically significant. That is mainly because the test statistic is computed from a large amount of data.



My conclusions are therefore entirely different from Lanman's, while I am able to confirm Kelley's skepticism:

- the bulk of the data in the Compasso de Navegare has been scaled from what can only be a portolan chart; it may contain some genuine observations too, but those cannot be identified with any degree of certainty.
- the second conclusion is that the data is of a appallingly poor accuracy. For the coastal data that is well explained by the poor coastal detail and feature exaggeration of the source charts, but it doesn't explain why sailors apparently found that adequate. However, peleio could have been scaled-off more accurately. Is this poor accuracy due to the typical medieval lack of interest for accuracy or does it indicate that medieval navigation was not as precise a process as many people believe and was mainly a visual affair with little interest for exact numbers? Or both?

The second conclusion leads to the important question as to what data was used for the construction of the first portolan chart.
If an accurate set of navigation measurements was initially available, why then was it swapped for such an obviously inferior dataset?
I presume my position is known: I concluded on these and other grounds that portolan charts cannot be original medieval creations and therefore I look forward to the discussion this afternoon.
Thank you for your attention.

Thank you for your attention!

Questions?