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Methods to cope with discrepant data: ^{198}Au half-life evaluation

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When the weighted mean returns reduced χ^2>8 data is considered discrepant

Outline:

- Motivation for ^{198}Au $T_{1/2}$ evaluation
- Statistical approaches to discrepant data
- Predictive power, convergence of techniques
- Conclusions and outlook

Why is ^{198}Au important?

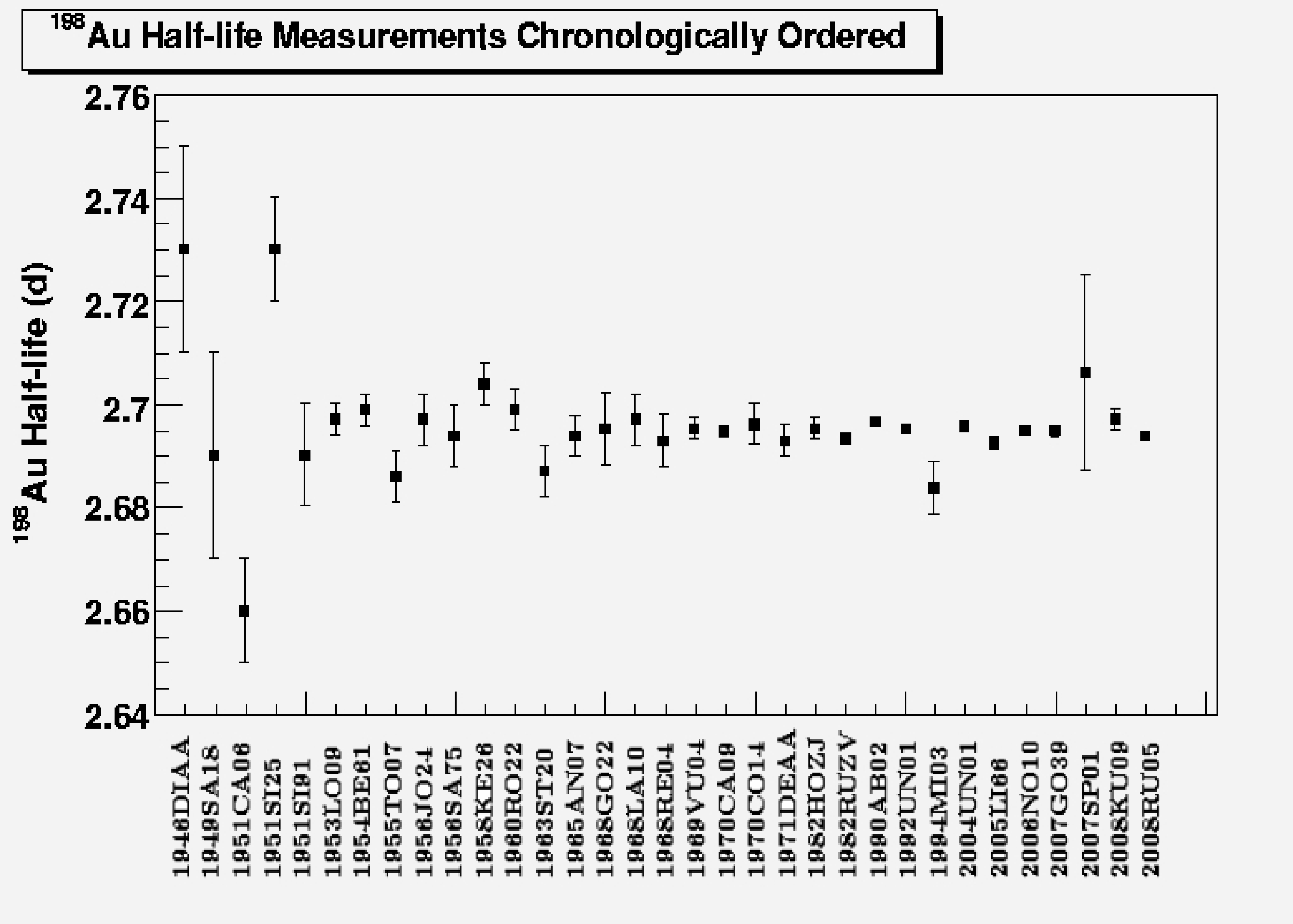
- Medical physics and basic physics research
- Radiation treatment of cancer through gold seed injection (particularly facial cancers)
- "gold" standard for γ-ray energy calibration 411802.05 (17) **eV**
- **Ideal for investigation of recent claims of low-temperature half-life variation**
- **Used to test basic exponential behaviour of radioactive decay law (NIM 2006 A566, 477)**

Motivation for a new evaluation

- A recent paper (2008 PRC 77, 065502) concluded with the remark: "(...) show measurements of the last 40 years with an error less than 0.005 d, so it seems a re-evaluation of the recommended half-life is called for."
- Available evaluations:
- ENSDF+NUBASE: 2.69517(21) d (2001/2003)
- A=198 preprint for ENSDF: 2.9647(3) d (2008)
- Wallet Card: 2.6956(3) d (2005)
- DDEP: 2.6944(8) d (2004 - data up to 1994)

Source	$T_{1/2}$ (d) ($\Delta T_{1/2}$)	Technique (instrument)
1935AM01 *[4]	2.7	
1937MC04 *[8]	2.7	chemical separation
1937PO04 *[9]	2.5	chemical separation
1941SH08 *[10]	2.7	chemical separation
1946DIAA [11]	2.73(2)	(ionization chamber)
1947SE33 *[12]	2.7	β counting (Geiger counter)
1948SA36 *[13]	2.66(1)	β counting (β spectrometer)
1949SA18 [14]	2.69(2)	β counting (β spectrometer)
1949ST17 *[15]	2.7	β and γ counting
1951CA06 [16]	2.66(1)	(Geiger Counter)
1951SI25 [17]	2.73(1)	β counting (liquid counter, β electroscope)
1951SI91 [18]	2.69(1)	Ionization current (ionization chamber, electrometer)
1953LO09 [19]	2.697(3)	(ionization chamber)
1954BE61 [20]	2.699(3)	(ionization chamber)
1955TO07 [21]	2.686(5)	γ timing (2 ionization chambers)
1955TO27 *[22]	2.686 (0.005)	γ timing (2 ionization chambers)
1956JO24 [23]	2.697(5)	γ timing (NaI)
1956SA75 [24]	2.694(6)	(Geiger counter)
1958KE26 [25]	2.704(4)	(Ionization chamber)
1960RO22 [26]	2.699(4)	Calorimetry on gold samples
1963ST30 [27]	2.687(5)	β counting, (β spectrometer)
1965AN07 [28]	2.694(4)	
1968GO22 [29]	2.695(7)	(4π ionization chamber)
1968LA10 [30]	2.697(5)	(ionization chambers, 4π β counters, γ spectrometers)
1968RE04 [31]	2.693(5)	(end window Geiger Muller counters)
1969VU04 [32]	2.695(2)	(4π β-γ coincidence counter)
1970CA09 [33]	2.6946(1)	
1970CO14 [34]	2.696(4)	γ counting (NaI)
1971DEAA [35]	2.693(3)	
1982HOZJ [36]	2.695(2)	
1982RUZV [37]	2.6935(4)	
1990AB02 [38]	2.6966(7)	γ counting (GeLi)
1992UN01 [39]	2.69517(21)	($4\pi\gamma$ ionization chamber)
1994MI03 [40]	2.6837(5)	γ timing (GeLi)
2004UN01 [41]	2.69555(3)	($4\pi\gamma$ ionization chamber)
2005LI66 [42]	2.6924(11)	($4\pi\gamma$ ionization chamber)
2006NO10 [43]	2.6947(6)	γ timing (GeLi)
2007GO39 [44]	2.6949(9)	γ timing (GeLi)
2007SP01 [45]	2.706(19)	γ timing (GeLi)
2008KU09 [47]	2.6971(2)	γ timing (GeLi)
2008RU05 [46]	2.6939(4)	γ timing (2 GeLi 180 geometry accounts for source movement)

Table 1: ^{198}Au half-life data at room temperature from literature with reference. * indicates the value was not considered in the current analysis. Uncertainty in brackets is on last digit(s).



^{198}Au Half-life Measurements Chronologically Ordered
^{198}Au Half-life (d)
2.76
2.74
2.72
2.7
2.68
2.66
2.64
1948DIAA
1949SA18
1951CA06
1951SI25
1951SI91
1953LO09
1954BE61
1955TO07
1956JO24
1956SA75
1958KE26
1960RO22
1963ST20
1965AN07
1968GO22
1968LA10
1968RE04
1969VU04
1970CA09
1970CO14
1971DEAA
1982HOZJ
1982RUZV
1990AB02
1992UN01
1994MI03
2004UN01
2005LI66
2006NO10
2007GO39
2007SP01
2008KU09
2008RU05

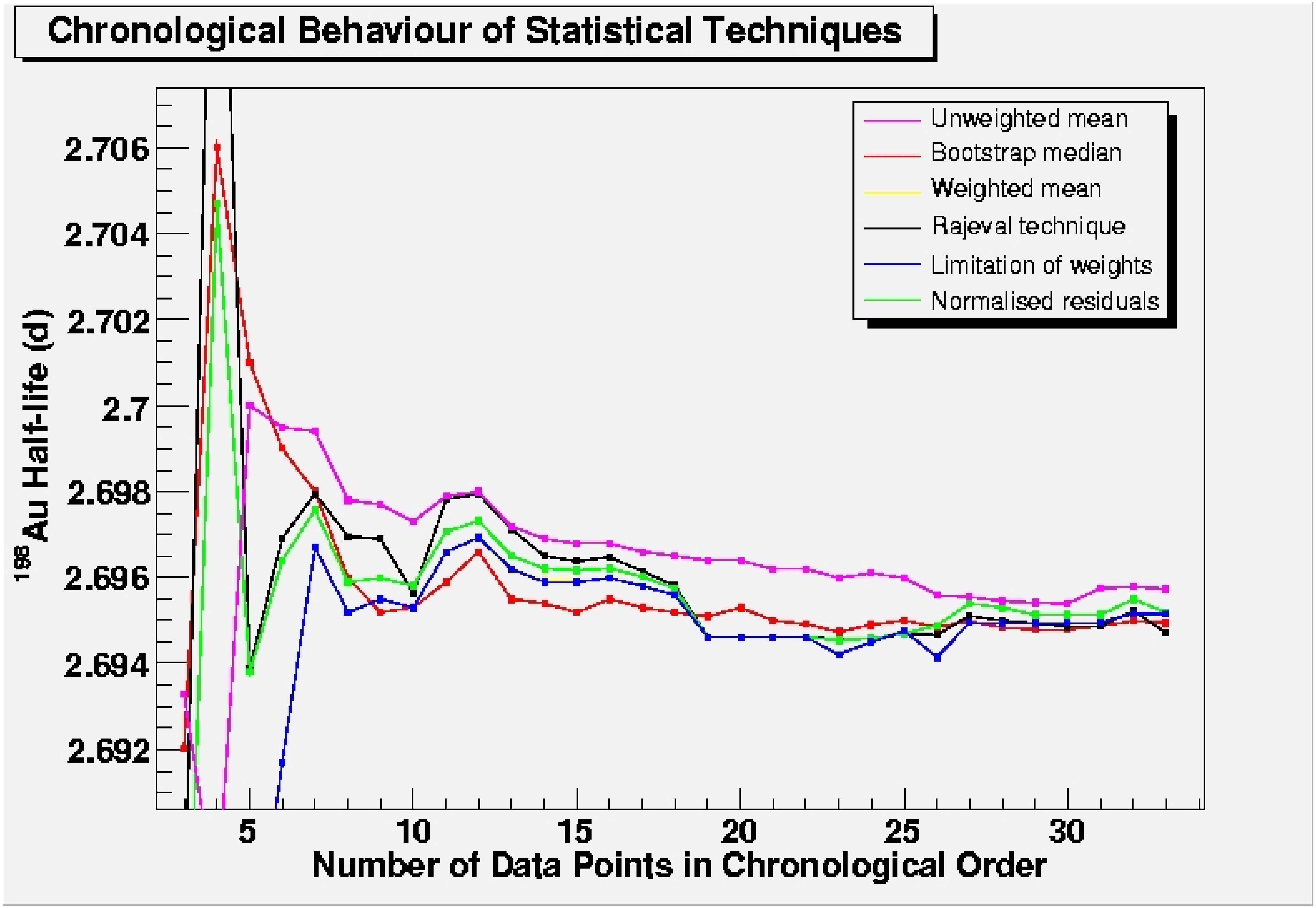
Averaging methods

- Unweighted Mean
- Weighted Mean
- Limitation of Relative Statistical Weights
- Normalised Residuals
- Rajeval Technique
- Bootstrap Median (not a new method, common but not to physics)

- All methods used aside from the Bootstrap median are available courtesy of T.Kibedi from http://www.rsphysse.anu.edu.au/~txk103/
- The Bootstrap median code used was courtesy of V. Vanin and O. Helen (2006 NIM A481, 626)
- Bootstrap techniques are classified as computationaly intensive “resampling” techniques but do not take into account experimental uncertainties
- The other techniques are parametric statistics
- Followed the approach of D. McMahon (2004 Appl.Rad.Iso. 60 275) for comparing the various techniques

Predictive Power (Convergence)

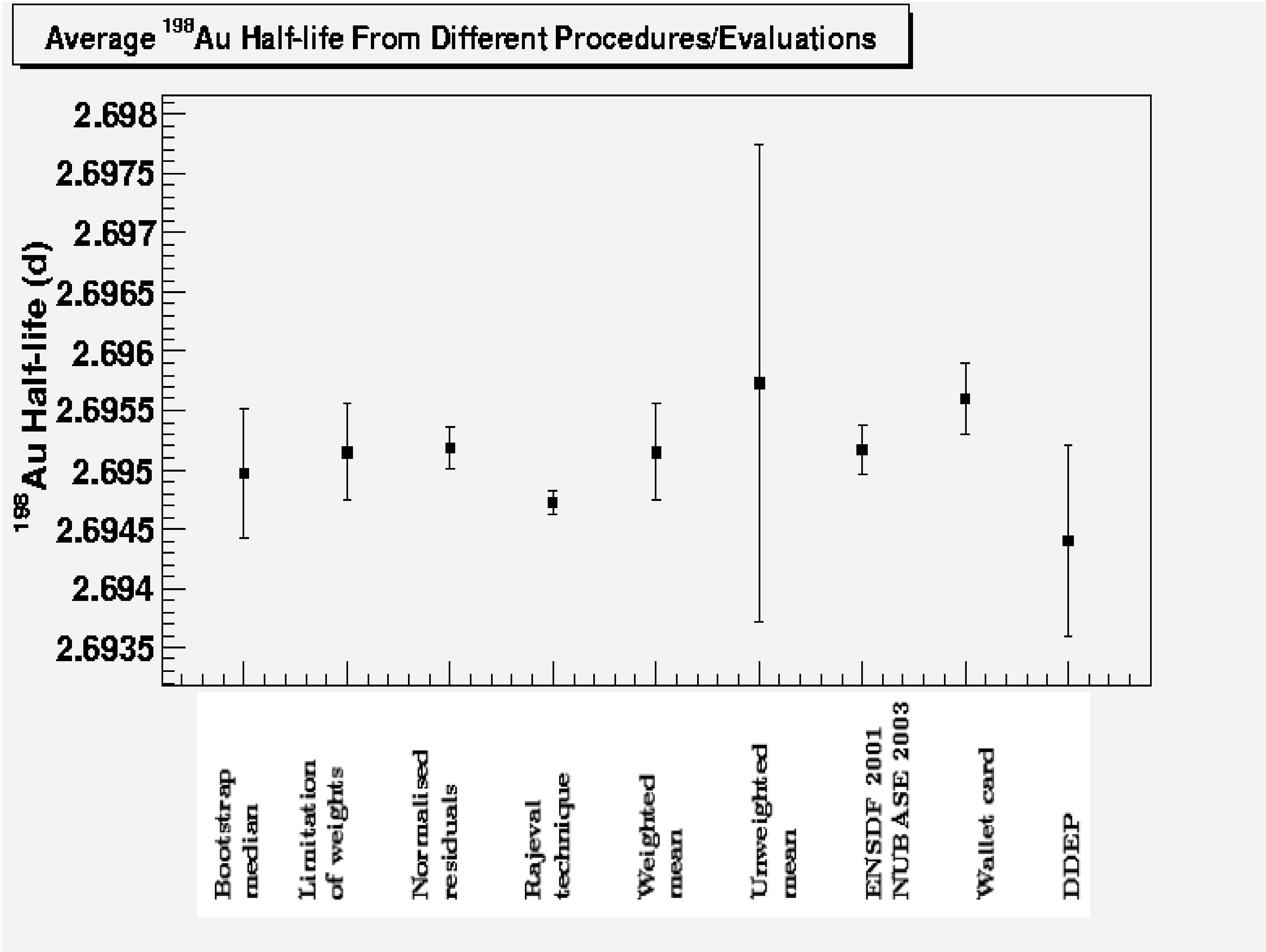
- A priori there's no ideal method for analyzing discrepant convergent data
- Nonetheless, in the act of taking an average over several measurements we desire to have some predictive power – to approach the “true” value as close as possible
- It is the behaviour of a statistical technique in terms of convergence which becomes most important as new data are incorporated



Chronological Behaviour of Statistical Techniques
Unweighted mean
Bootstrap median
Weighted mean
Rajeval technique
Limitation of weights
Normalised residuals
2.706
2.704
2.702
2.7
2.698
2.696
2.694
2.692
198Au Half-life (d)
5
10
15
20
25
30
Number of Data Points in Chronological Order

Tabulated Results From the Various Techniques

• Unweighted mean	2.6957(20) d	
• Weighted mean	2.69515(41) d	χ^2=23.5
• Normalised residuals	2.69518(17) d	χ^2=2.5
• Rajeval's	2.694722(92) d	χ^2=2.0
• Bootstrap median	2.69497(55) d	
• Limitation of relative statistical weights	2.69515(41) d	χ^2=23.4



Average ^{198}Au Half-life From Different Procedures/Evaluations
^{198}Au Half-life (d)
2.698
2.6975
2.697
2.6965
2.696
2.6955
2.695
2.6945
2.694
2.6935
Bootstrap median
Limitation of weights
Normalised residuals
Rajeval technique
Weighted mean
Unweighted mean
ENSDF 2001
NUBASE 2003
Wallet card
DDEP

Bootstrap median recomended
$^{198}Au\ T_{1/2} = 2.69497(55)$ d

- The Bootstrap median clearly converges the quickest and additionally has the following desirable traits:
- Not easily affected by outliers
- Not easily thrown off by a single high precision measurement
- Uncertainty is not physically unreasonable considering the measured chemical effect on half-lives ~0.01% (RT may not be meaningful)
- Uncertainty is large enough to cover other methods

The Bootstrap Method

- Bootstrap means it “Re-samples” the data set
- If you have X data points then the bootstrap samples – with replacement - X data N times
- It then applies a statistical function, in our case the median on each sample – quoted uncertainties are not considered
- An unweighted average over all N sample medians is the bootstrap estimate
- The uncertainty given by the method is the unweighted average of the difference between the bootstrap estimate and each sample median

Conclusion

- Recommended ^{198}Au half life 2.69497(55) d based on bootstrap method
- Proposed improvements to bootstrap method to include uncertainties
- Need a good Monte-Carlo
- Ultimately would like to put it together with Avetools so that evaluators and other users have at their disposal all methods