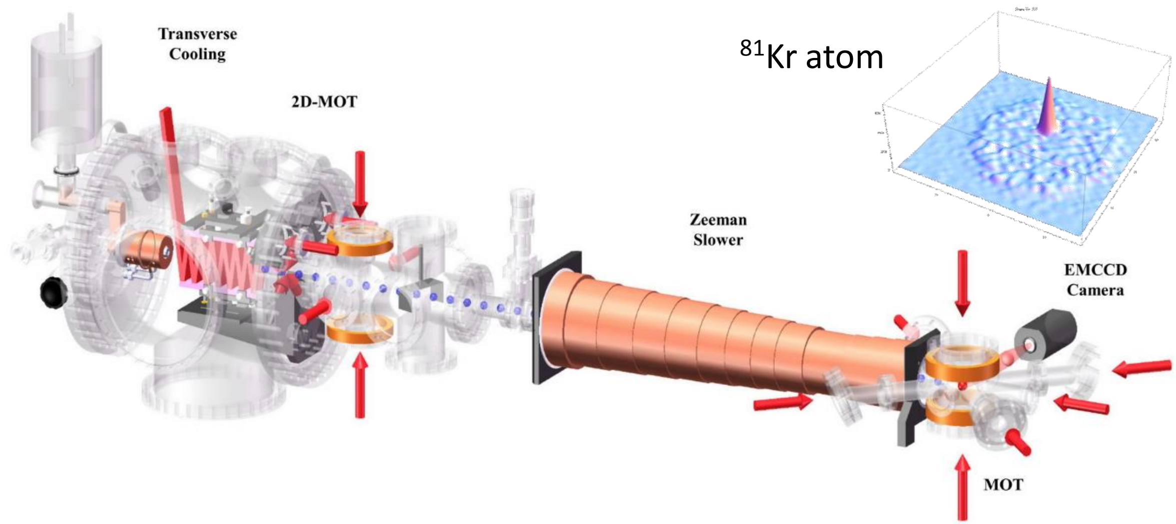
Constraining ice core chronologies with ^{39}Ar and ^{81}Kr

climate.nasa.gov



Florian Ritterbusch[1], Yan-qing Chu[1], Ilaria Crotti[2], Xi-Ze Dong[1], Ji-Qiang Gu[1], Shui-Ming Hu[1], Wei Jiang[1], Amaelle Landais[3], Lili Shao[4], Volodya Lipenkov[5], Zheng-Tian Lu[1], Barbara Stenni[2], Taldice team[6], Lide Tian[4], A-Min Tong[1], Wen-Hao Wang[1], Guo-min Yang[1], and Lei Zhao[1]

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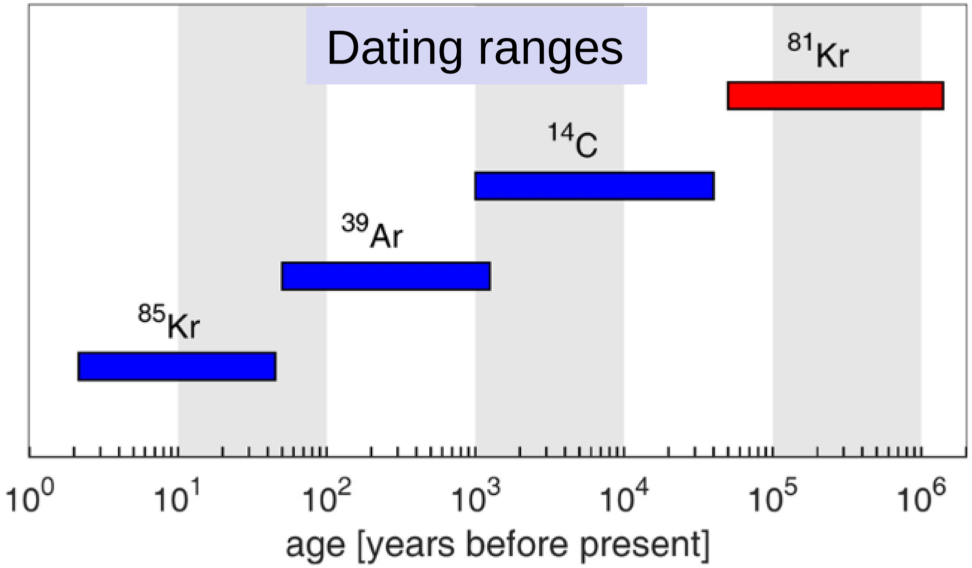
(5) Arctic and Antarctic Research Institute St Petersburg, Russia
(6) www.taldice.org

Dating with ^{81}Kr

^{81}Kr is nearly ideal for dating because

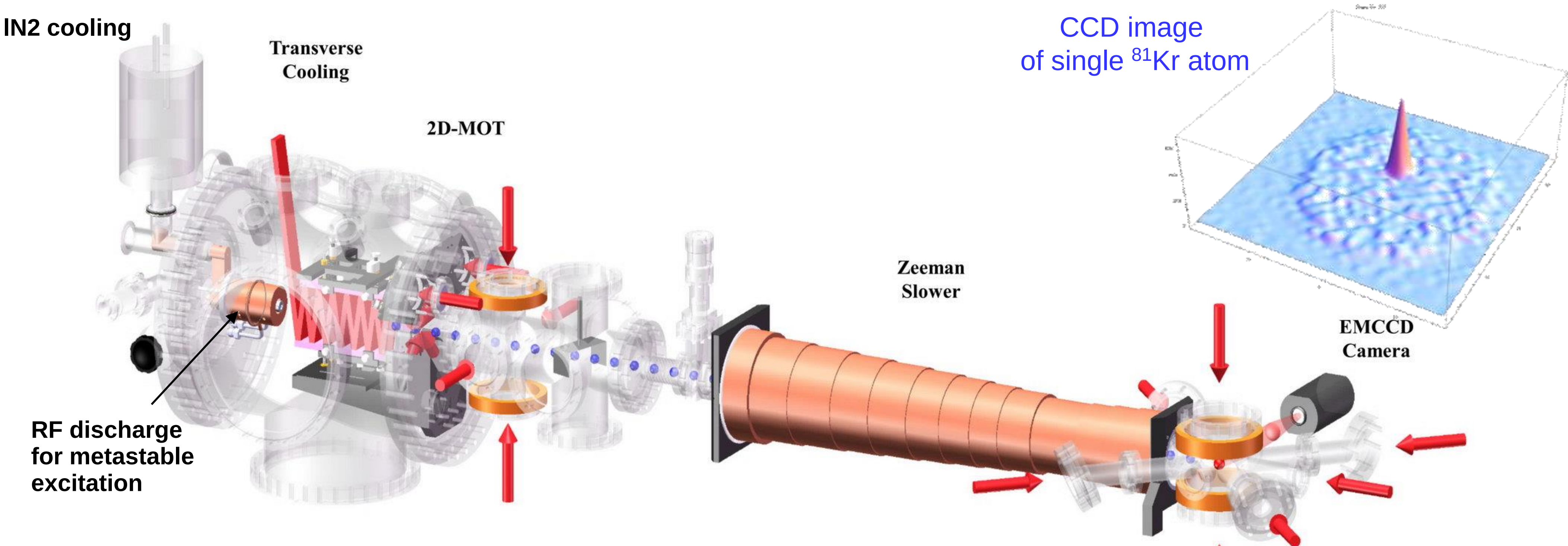
- gas: uniform, stable distribution in the atmosphere
- noble: not altered by chemical processes, simple transport mechanisms
- Cosmogenic origin: ^{81}Kr age correction < 4% over past 1.4 Ma
- Absolute: ^{81}Kr provides absolute, radiometric age
- contamination monitor: modern air entering during sampling or sample processing can be identified with the anthropogenic ^{85}Kr



isotope	halflife	abundance	# of atoms in kg water/ice
^{81}Kr	230 ka	9e-13	1 000
^{14}C	5730 a	1.5e-12	10 000 000
^{39}Ar	269 a	8e-16	8 000
^{85}Kr	11 a	2e-11	30 000

^{81}Kr could not be measured in the past due to its extremely small abundance

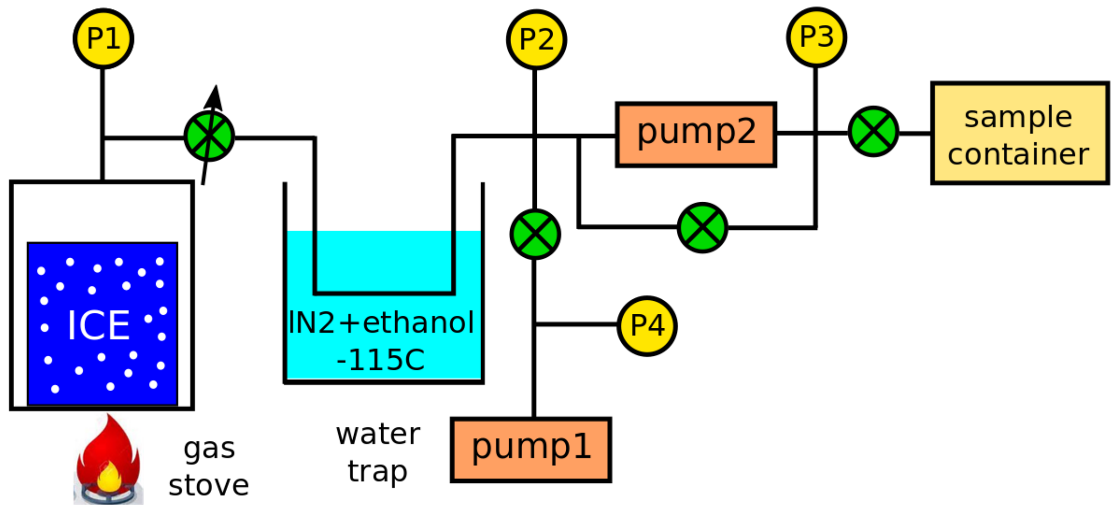
Atom Trap Trace Analysis (ATTA)

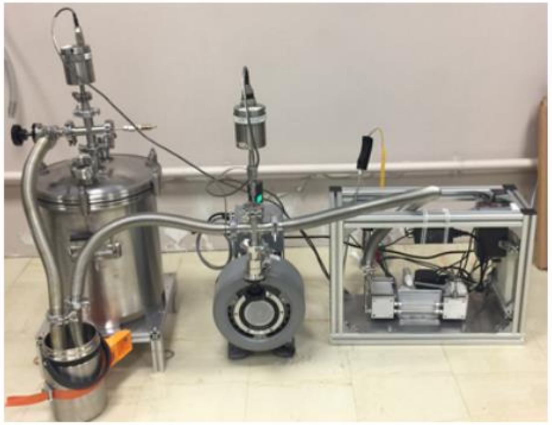


Chen et al. 1999, *Ultrasensitive Isotope Trace Analyses with a Magneto-Optical Trap,* Science 286
Jiang et al. 2012, *An atom counter for measuring ^{81}Kr and ^{85}Kr in environmental samples*, Geochim. Cosmochim. Acta 91
Buizert et al. 2014, *Radiometric ^{81}Kr dating identifies 120,000-year-old ice at Taylor Glacier, Antarctica*, PNAS 111

- the novel laser based detection method Atom Trap Trace Analysis (ATTA) has enabled ^{81}Kr dating
- ATTA has nearly perfect isotope selectivity
- ^{81}Kr is measured relative to ^{83}Kr: $$c_{81} = \frac{(^{81}Kr/^{83}Kr)_{sample}}{(^{81}Kr/^{83}Kr)_{ref}}$$
- ^{81}Kr dating of glacier ice has been demonstrated [Buizert et al, 2014] but large samples (>100kg ice) were necessary at that time
- with our current ATTA system we lowered the sample size down to 0.5-1 µL of krypton, which can be extracted from 5-10 kg of Antarctic ice

^{81}Kr dating of ice – sample preparation

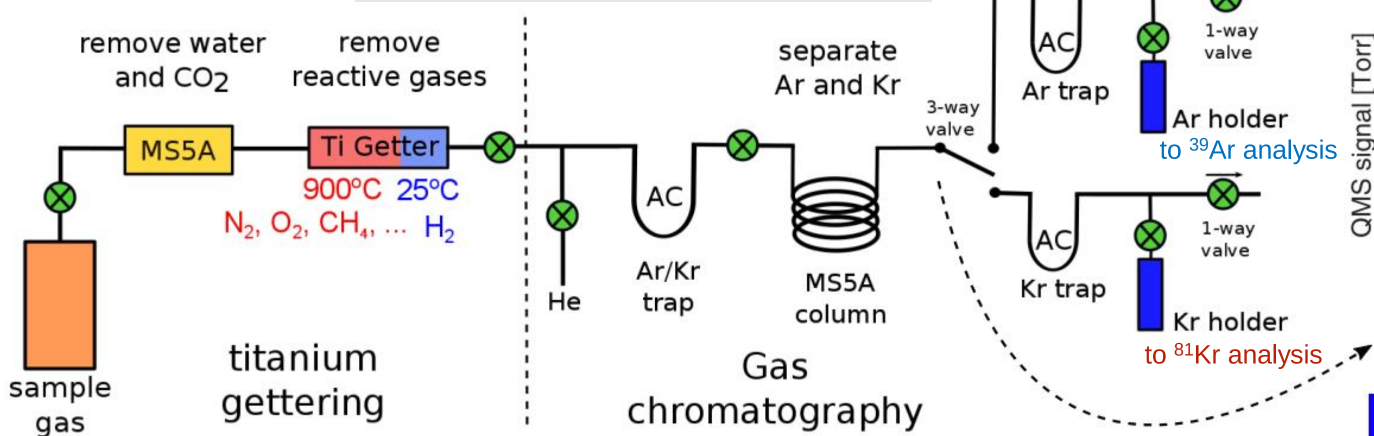


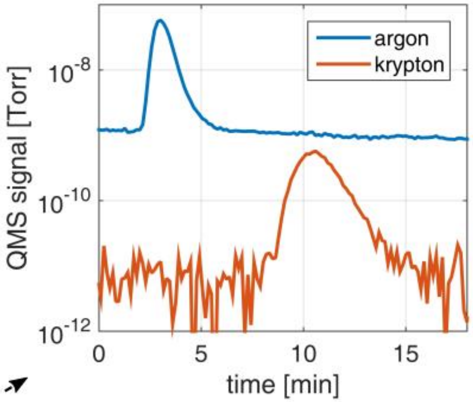


Ice degassing

0.5-1 L air

Dong et al, Anal. Chem. 2019, 91, 21

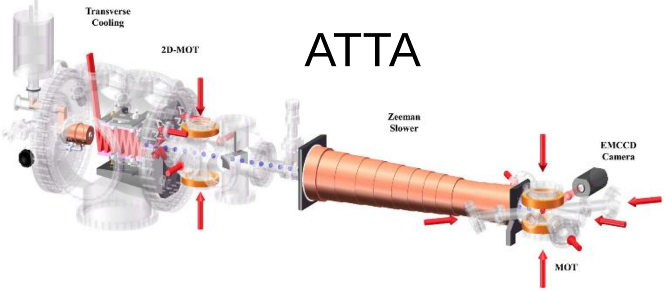




krypton purification

0.5-1 μL krypton

ATTA

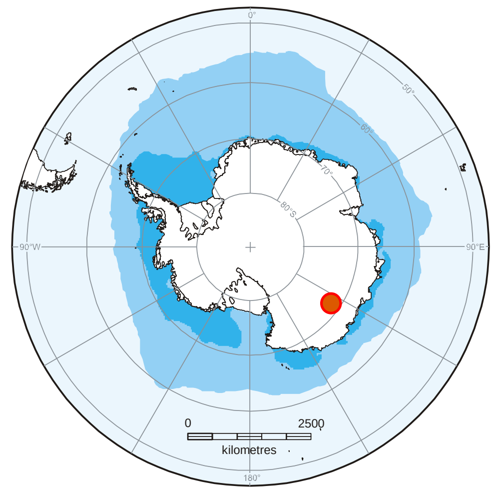


^{81}Kr measurement

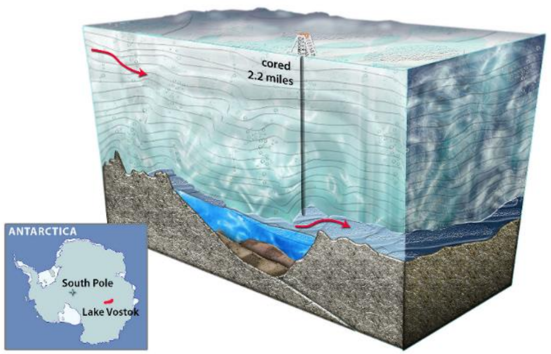
Ice studies with ^{81}Kr

Grove Mountains

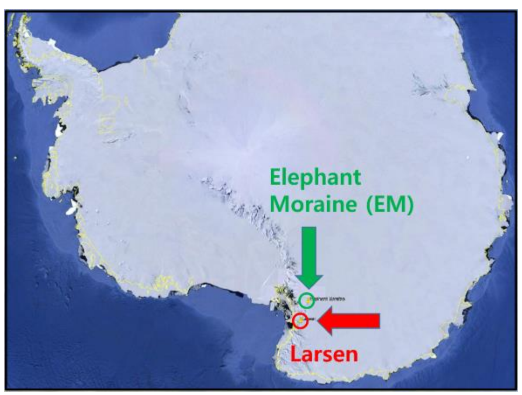
Epica Dome C



VOSTOK station



Larsen and Elephant Moraine



Talos Dome Ice Core

Guliya Ice cap, Tibetan Plateau

Tian et al, 2019, GRL, 46, 6636–6643

^{81}Kr dating of Vostok ice core

- chronology for the disturbed meteoric bottom of the Vostok ice core is difficult
- timescale developed based on linear relation between age and hydrate size
- Use ^{81}Kr as independent check for the hydrate-based timescale
- 1.2 million year old ice revealed at very bottom

The Mid-Pleistocene Transition and the Vostok Oldest Ice Challenge

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[2]Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

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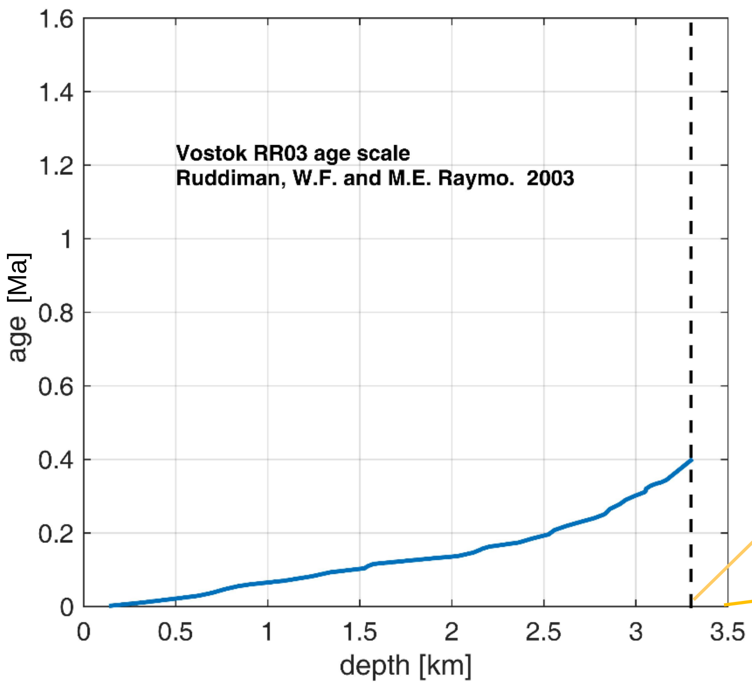
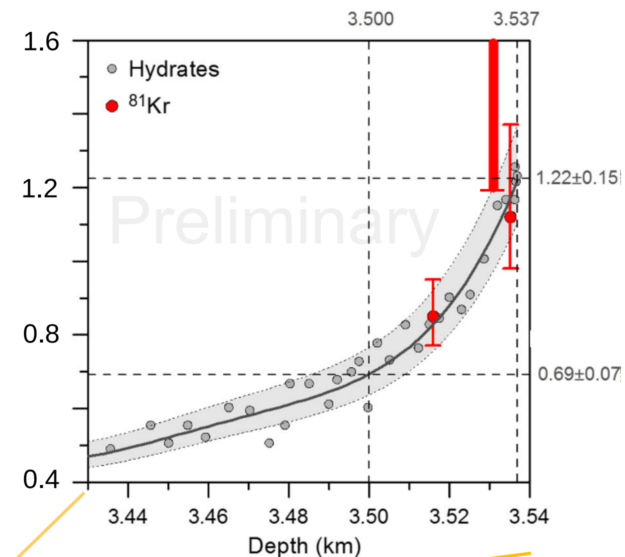
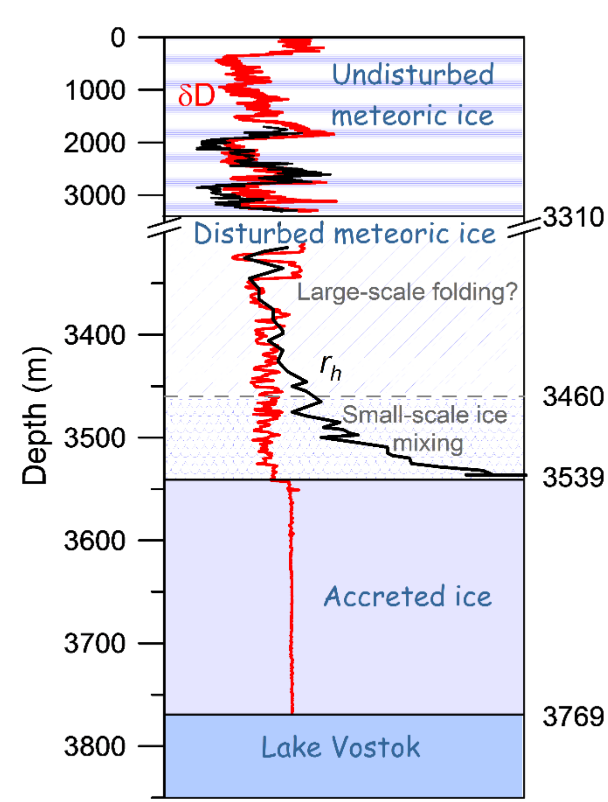


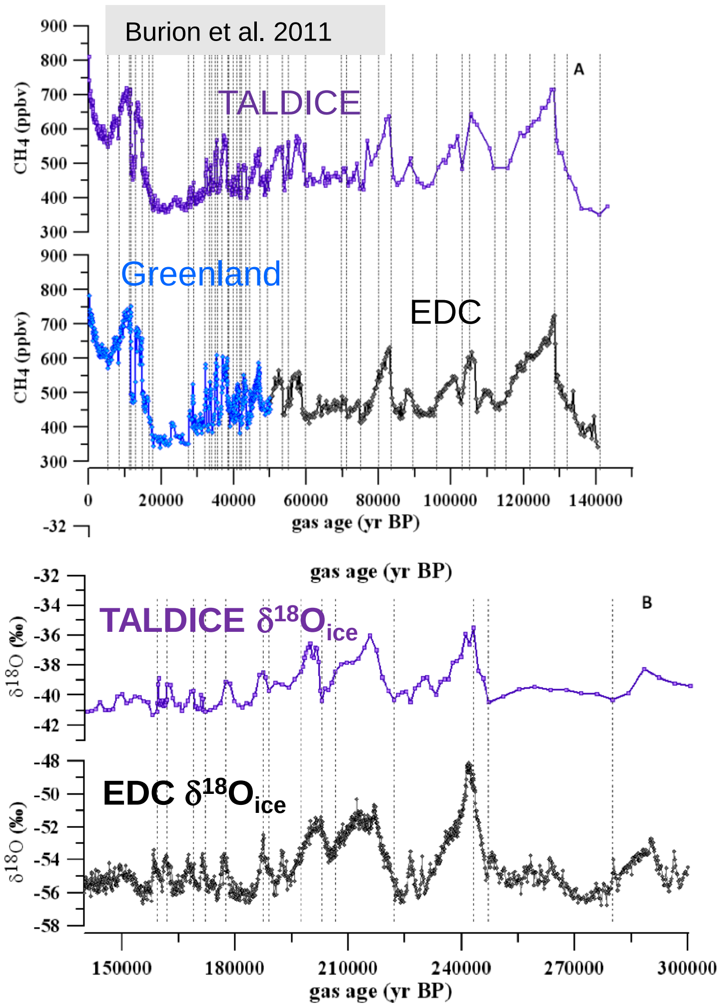


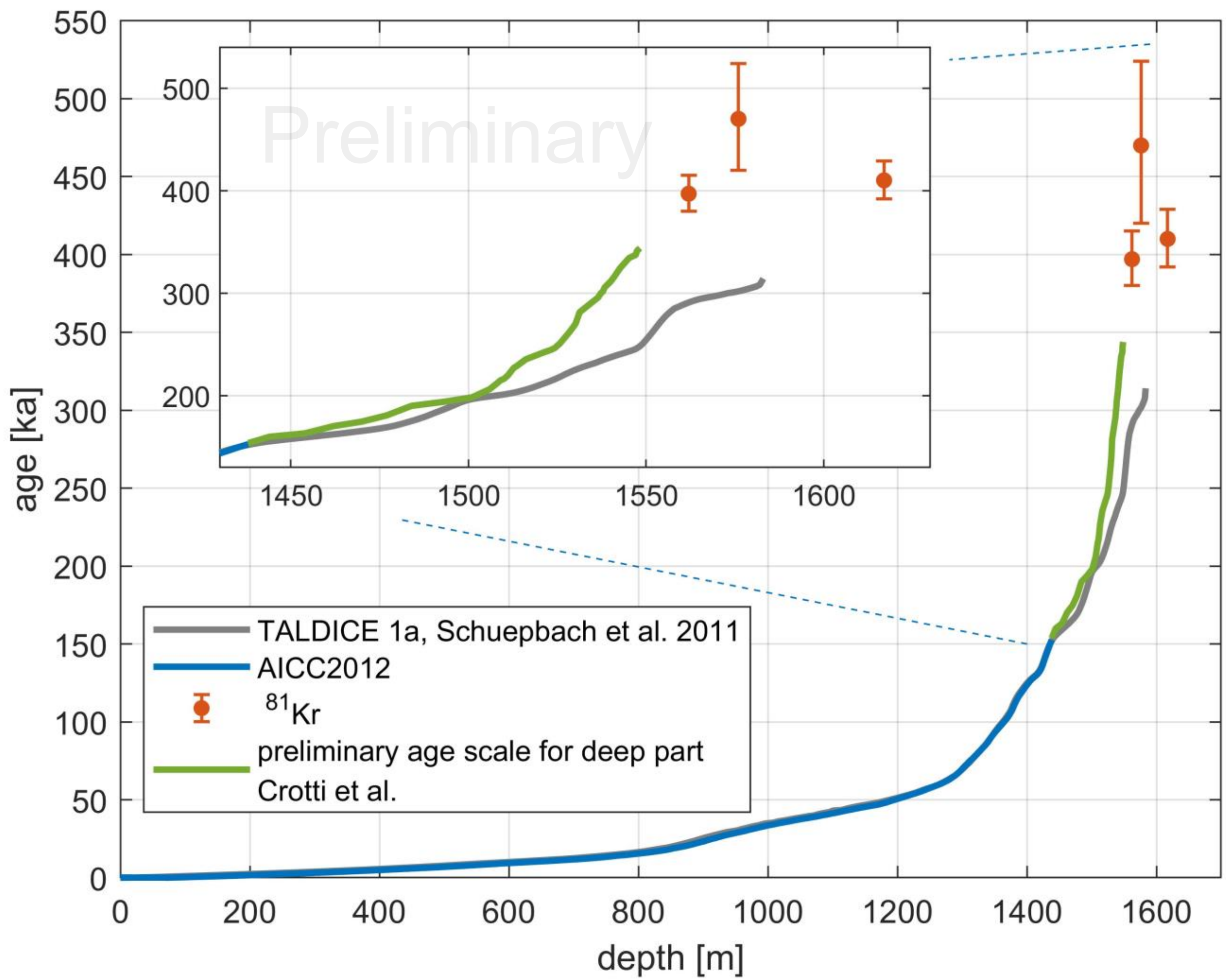


This shows, no significant contamination with modern air, which has ^{85}Kr=75 dpm/cc

Sample depth m	Ice kg	Air mL	Kr μL	^{85}Kr activity dpm/cc	^{81}Kr abundance pmKr	^{81}Kr age ka
3510.5 – 3511.5 3520.0 – 3521.5	6.9	590	0.6	< 0.5	$7.8^{+1.8}_{-1.8}$	850^{+100}_{-80}
3529.0 – 3532.5	7	600	0.6	< 1.1	< 2.5	> 1200
3533.5 – 3537.0	6.9	590	0.6	< 1.7	$3.3^{+1.6}_{-1.8}$	1120^{+250}_{-140}

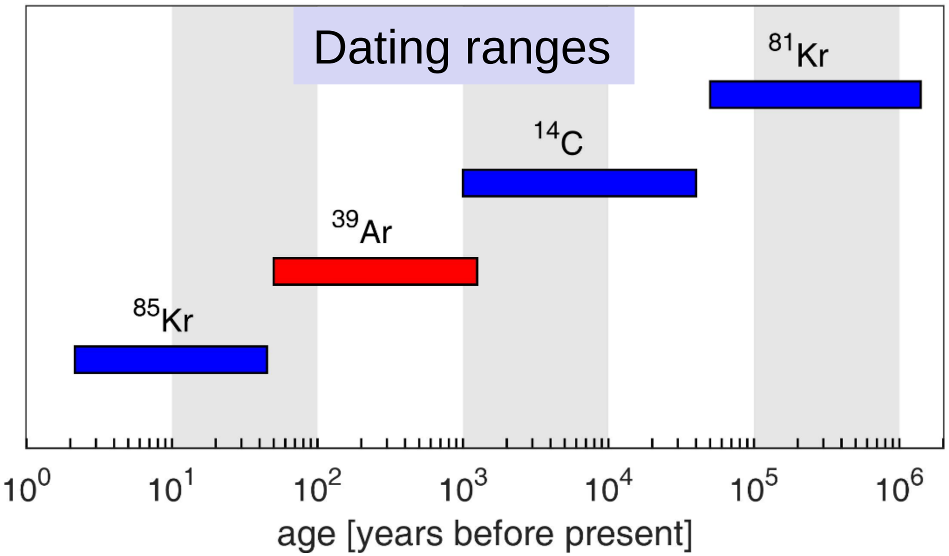
^{81}Kr dating of Talos Dome Ice core





- Initial chronology until 314 ka (1583 m depth) based on stratigraphic matching with Greenland/EDC ice cores (Burion et al. 2011, Schuepbach et al.2011)
- The official chronology AICC2012 was later defined only until 153 ka (1438 m depth) due to disturbed stratigraphy at the bottom (Bazin et al., 2013)
- Check with ^{81}Kr, 3 samples of 5-10 kg ⟶ ^{81}Kr results do not support initial chronology for the bottom
- Use ^{81}Kr and further $\delta^{18}O_{ice}$ and $\delta^{18}O_{atm}$ measurements as constraints to develop a new timescale for the deep part of the core (see presentation Ilaria Crotti et al.)

Dating of ice with ^{39}Ar



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- dating range of ^{39}Ar (50-1500 a) well suited for alpine ice cores
- In the past, ^{39}Ar could only be measured by Low-Level Counting on large samples (>250kg)

  ⟶ ^{39}Ar dating was only feasible for groundwater
- ATTA for ^{39}Ar harder than for ^{81}Kr because relative abundance 1000 times lower

  ⟶ low atom count rate for ^{39}Ar is the main challenge.

ATTA for ^{39}Ar

PRL **106**, 103001 (2011) PHYSICAL REVIEW LETTERS week ending 11 MARCH 2011

^{39}Ar Detection at the 10^{-16} Isotopic Abundance Level with Atom Trap Trace Analysis

W. Jiang,[1] W. Williams,[1] K. Bailey,[1] A. M. Davis,[2,3] S.-M. Hu,[4] Z.-T. Lu,[1,2,5] T. P. O'Connor,[1] R. Purtschert,[6] N. C. Sturchio,[7] Y. R. Sun,[4] and P. Mueller[1]

[1]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*

^{39}Ar count rate ~ 0.2 atoms/ hour

Groundwater dating with Atom Trap Trace Analysis of ^{39}Ar

F. Ritterbusch[1], S. Ebser[1], J. Welte[1], T. Reichel[2], A. Kersting[2], R. Purtschert[3], W. Aeschbach-Hertig[2], and M. K. Oberthaler[1]

[1]Kirchhoff-Institute for Physics, Heidelberg University, Heidelberg, Germany, [2]Institute of Environmental Physics, Heidelberg University, Heidelberg, Germany, [3]Climate and Environmental Physics, University of Bern, Bern, Switzerland

^{39}Ar count rate ~ 4 atoms/ hour

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^{39}Ar dating with small samples provides new key constraints on ocean ventilation

Sven Ebser[1], Arne Kersting[2], Tim Stöven[3], Zhongyi Feng[1], Lisa Ringena[1], Maximilian Schmidt[1,2], Toste Tanhua[3], Werner Aeschbach[2,4] & Markus K. Oberthaler[1]

Dating glacier ice of the last millennium by quantum technology

Zhongyi Feng[a,1], Pascal Bohleber[b,c], Sven Ebser[a], Lisa Ringena[a], Maximilian Schmidt[a,b], Arne Kersting[b], Philip Hopkins[b], Helene Hoffmann[b,d], Andrea Fischer[c], Werner Aeschbach[b,e], and Markus K. Oberthaler[a]

[a]Kirchhoff-Institute for Physics, Heidelberg University, 69120 Heidelberg, Germany; [b]Institute of Environmental Physics, Heidelberg University, 69120

^{39}Ar count rate 5-7 atoms/ hour

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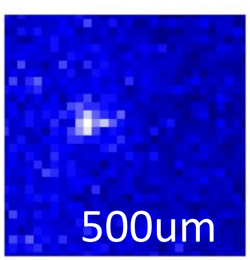
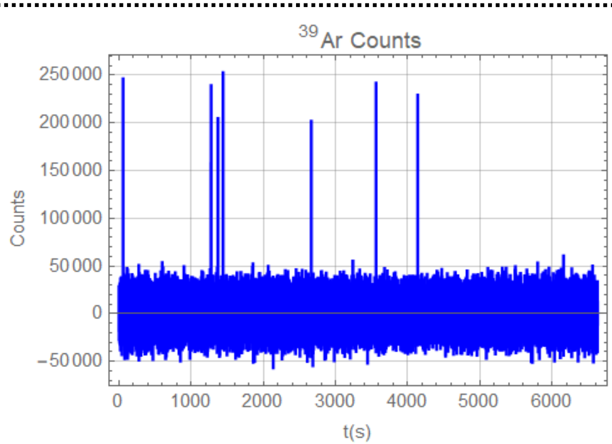
^{39}Ar atom



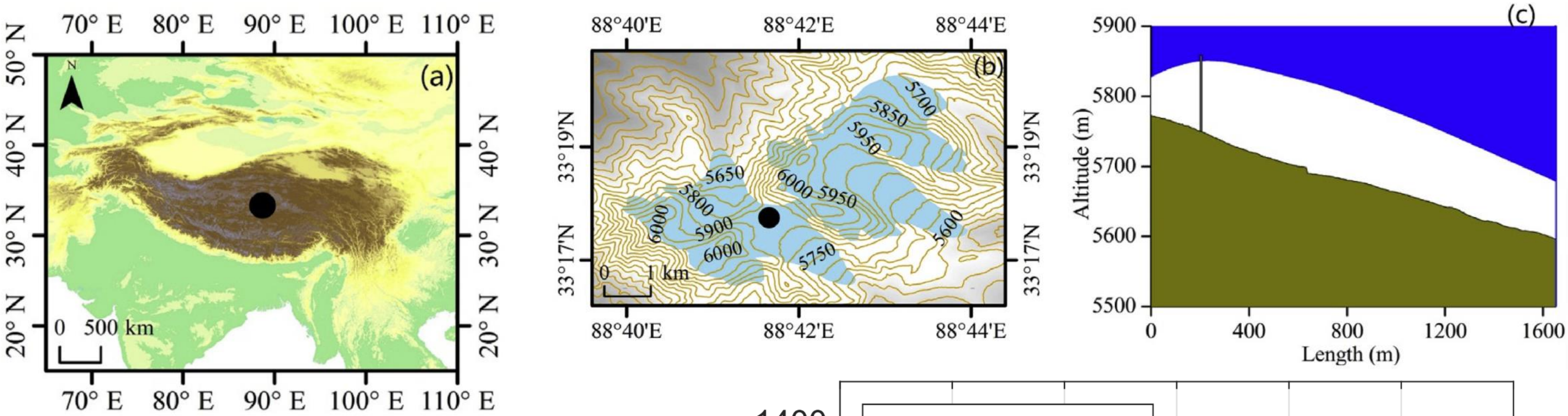


USTC

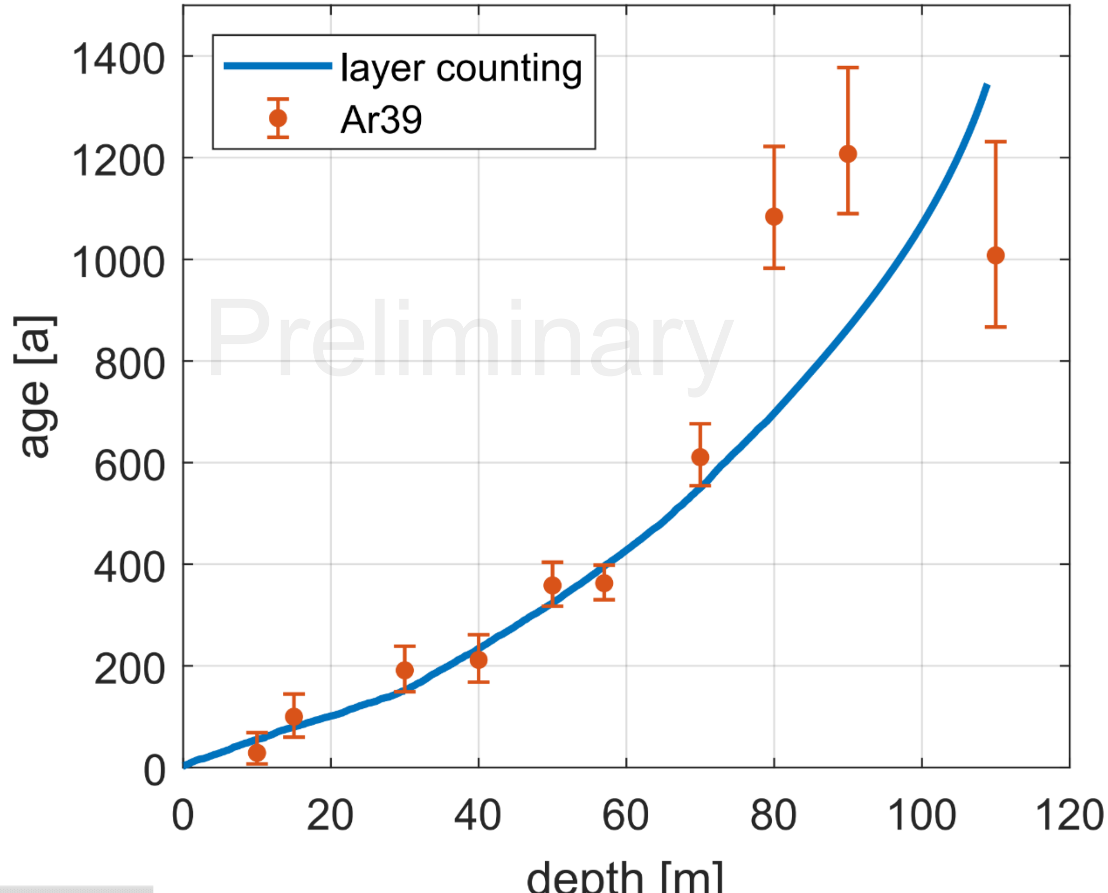
ATTA Setup completed recently

^{39}Ar count rate ~ 10 atoms/ hour

^{39}Ar dating of ice core from central Tibet

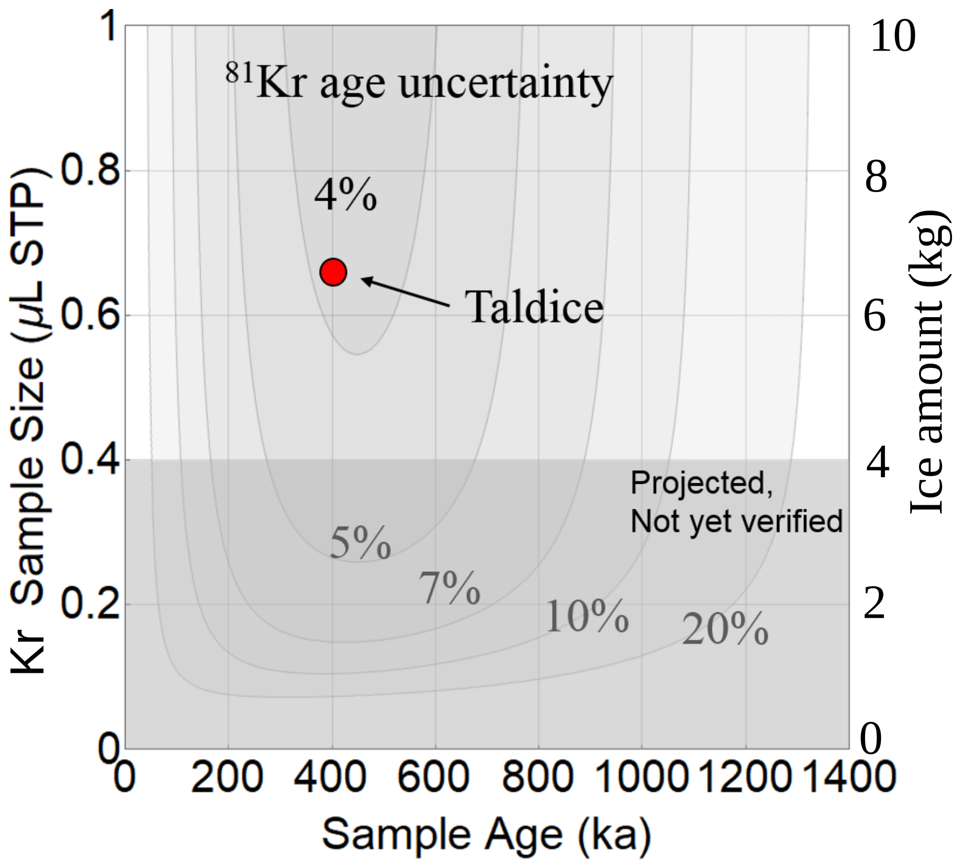


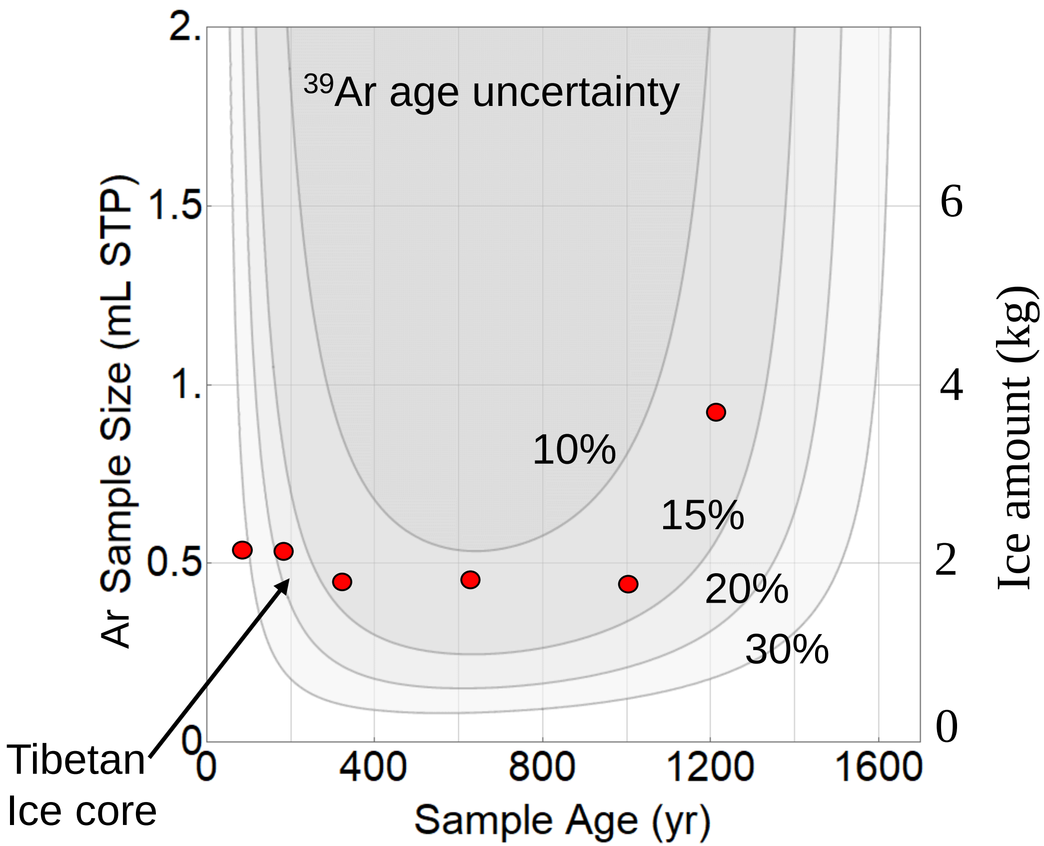
- Chronology based on absolute dating
- (^{3}H, β-activity, ^{137}Cs) and annual layer counting (δ^{18}O, visual, dust)
- Independently check chronology with ^{39}Ar samples of 3-5 kg (air content only ~10 mL/kg)
- measurements in progress to further constrain the bottom part



Lili Shao, et al., Quaternary International, https://doi.org/10.1016/j.quaint.2020.02.030

Summary





- ^{81}Kr dating of 5-10 kg samples from Antarctic ice cores with ATTA
- ^{81}Kr data can be used to constrain continuous timescales, especially where the stratigraphy is disturbed
- an ATTA system for ^{39}Ar analysis on 1-5 kg ice samples has recently been completed at USTC
- an ^{39}Ar profile for an ice core from central Tibet has been obtained to constrain a timescale constructed by layer counting