

HOW ACCELERATOR MASS SPECTROMETRY (AMS) CONTRIBUTED TO THE UNDERSTANDING OF OCEAN CIRCULATION?

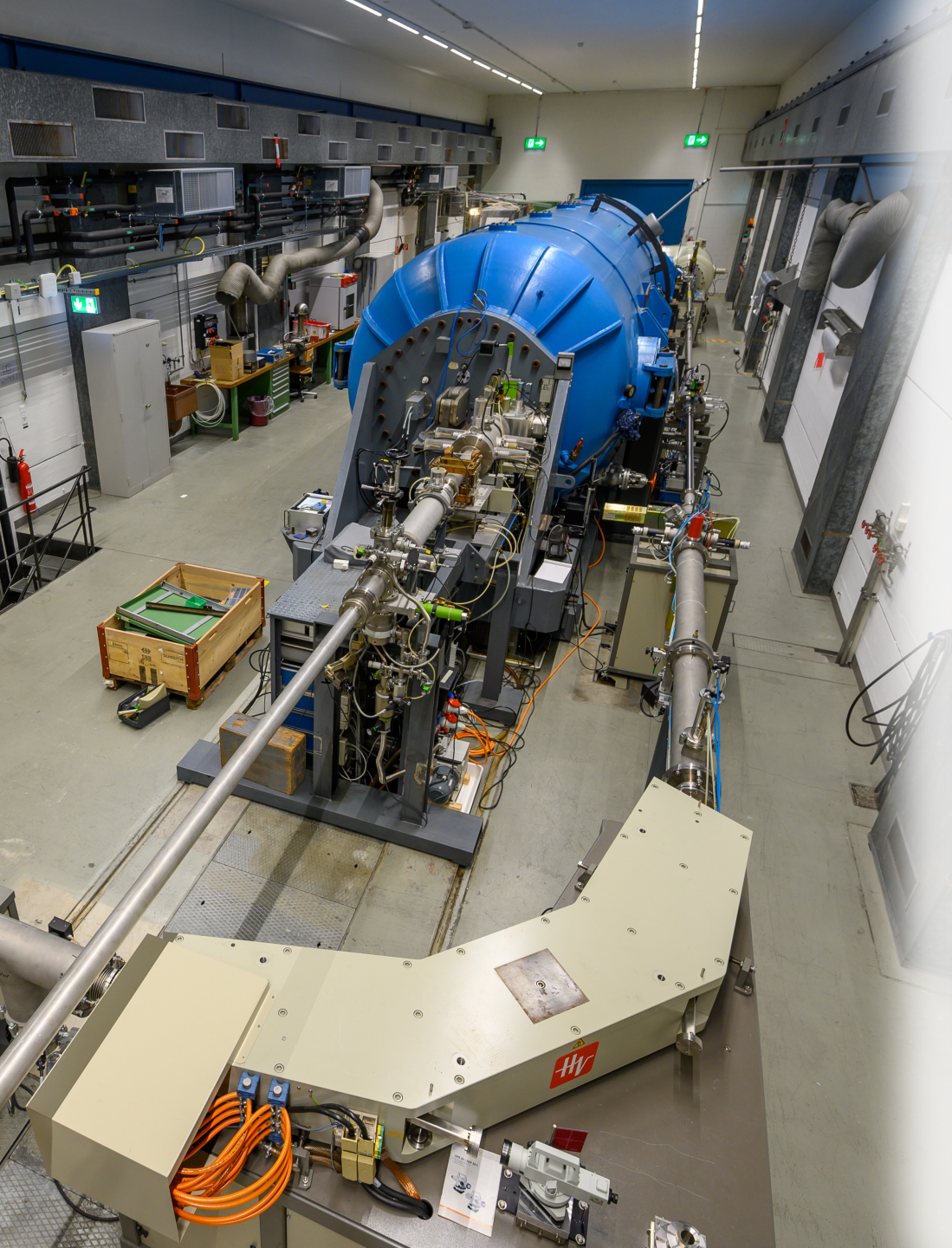
PSI – October 2023

ETH zürich

erc

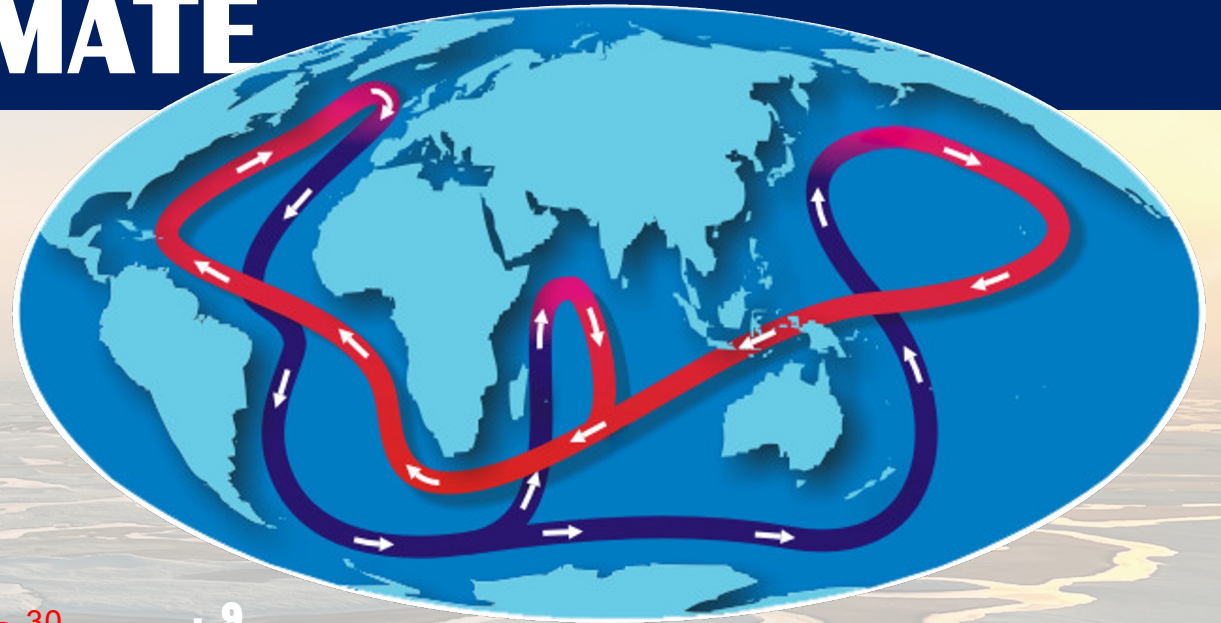
Swiss National
Science Foundation

Núria Casacuberta Arola
Prof. Physical and Tracer Oceanography
D-USYS - ETHZ

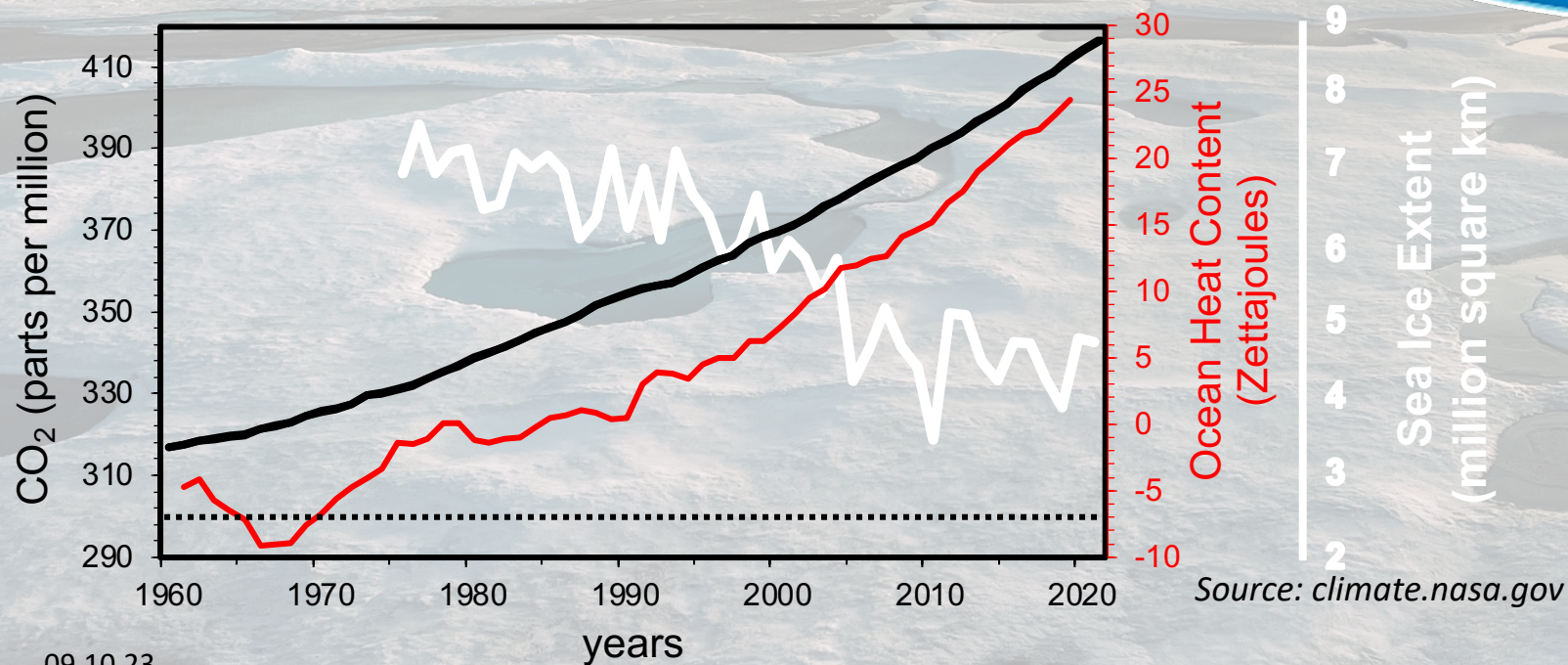


OCEANS REGULATE CLIMATE

... by storing and transporting heat, carbon, nutrients and freshwater all around the world.



The Great Ocean Conveyor Belt. Source: NOAA



OCEANS REGULATE CLIMATE

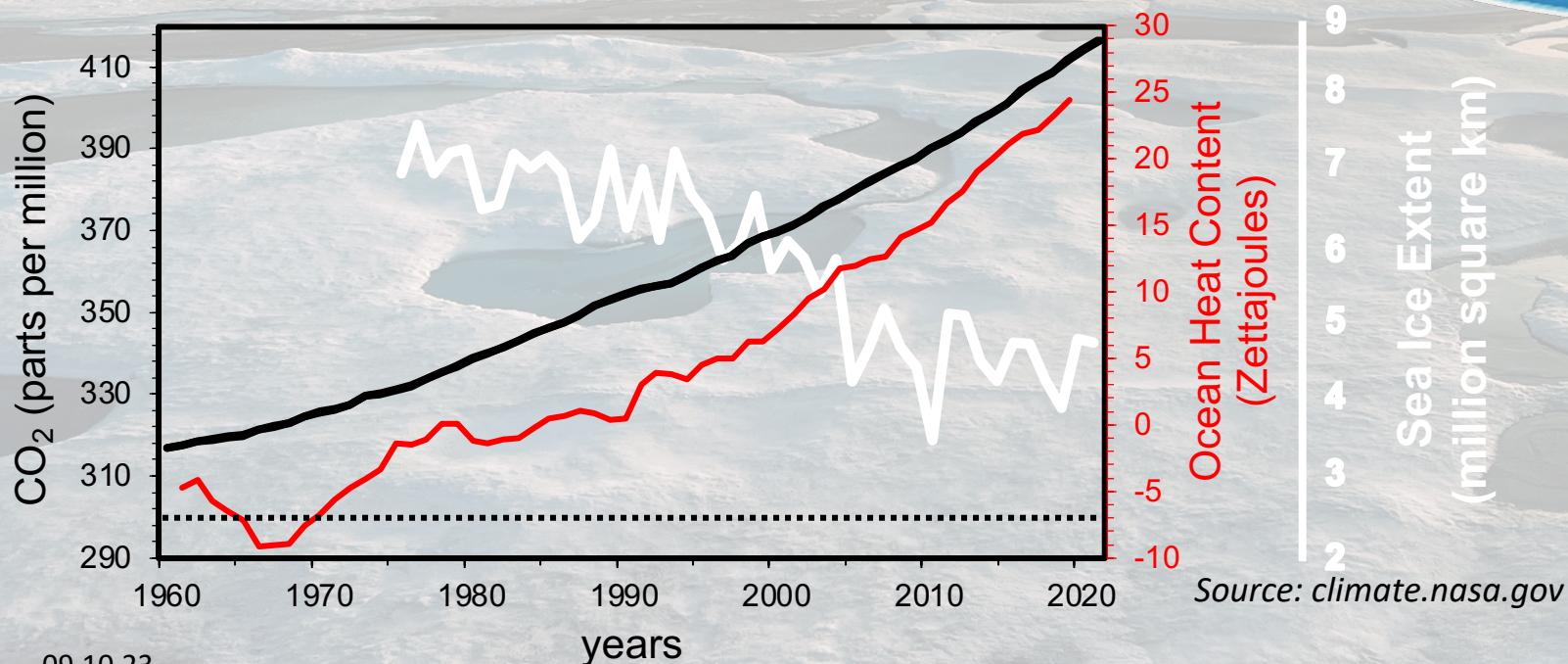
... by storing and transporting heat, carbon, nutrients and freshwater all around the world.



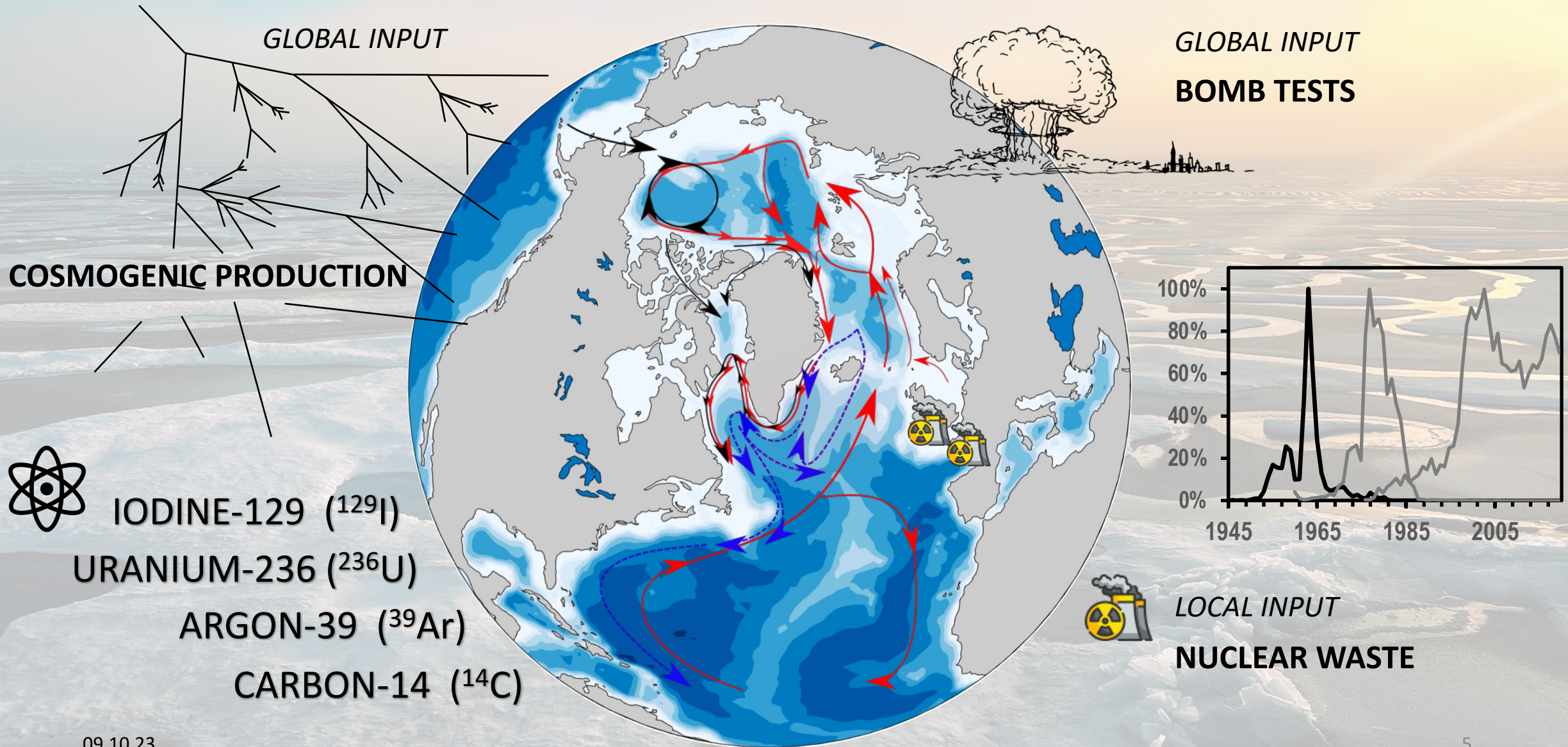
- WHERE? → pathways
- HOW? → mixing
- AGES? → timescales
- Storage of anthropogenic carbon



The Great Ocean Conveyor Belt. Source: NOAA



TRANSIENT TRACERS IN THE OCEAN



LONG-LIVED RADIONUCLIDES



$T_{1/2}$

... in 1L seawater



IODINE-129 (^{129}I)

100% β – (40 keV)
 γ – (29.778 keV)
 γ – (29.458 keV)

15.7×10^6 years

10^{-8} Bq

URANIUM-236 (^{236}U)

100% α – (4.4 MeV)
 γ – (11.2 - 20 keV)

23×10^6 years

10^{-9} Bq

ARGON-39 (^{39}Ar)

100% β – (218.8 keV)

268 years

10^{-7} Bq

CARBON-14 (^{14}C)

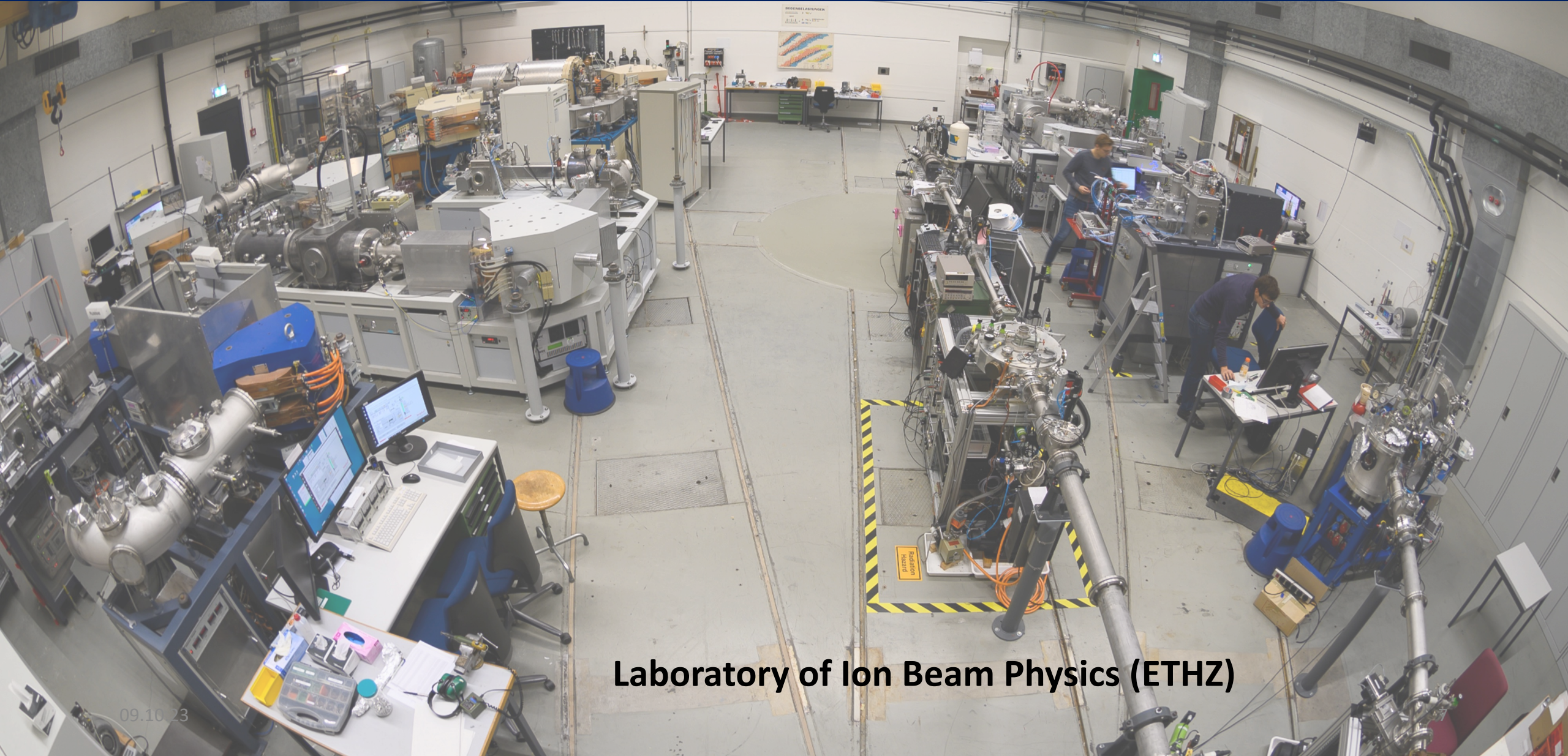
100% β – (49.47 keV)

5730 years

10^{-4} Bq

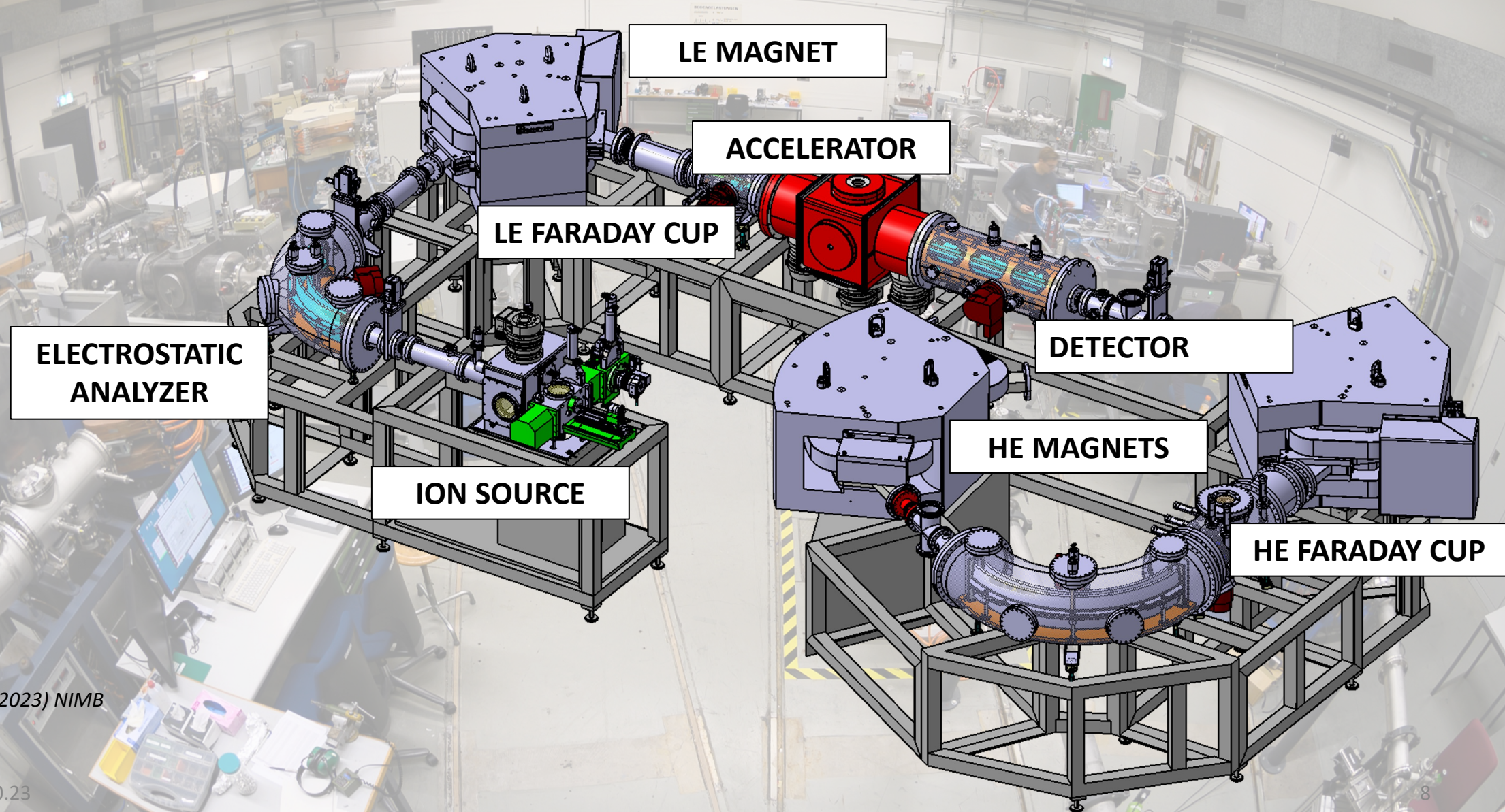
atoms

ACCELERATOR MASS SPECTROMETRY (AMS)



Laboratory of Ion Beam Physics (ETHZ)

MILEA AMS SYSTEM



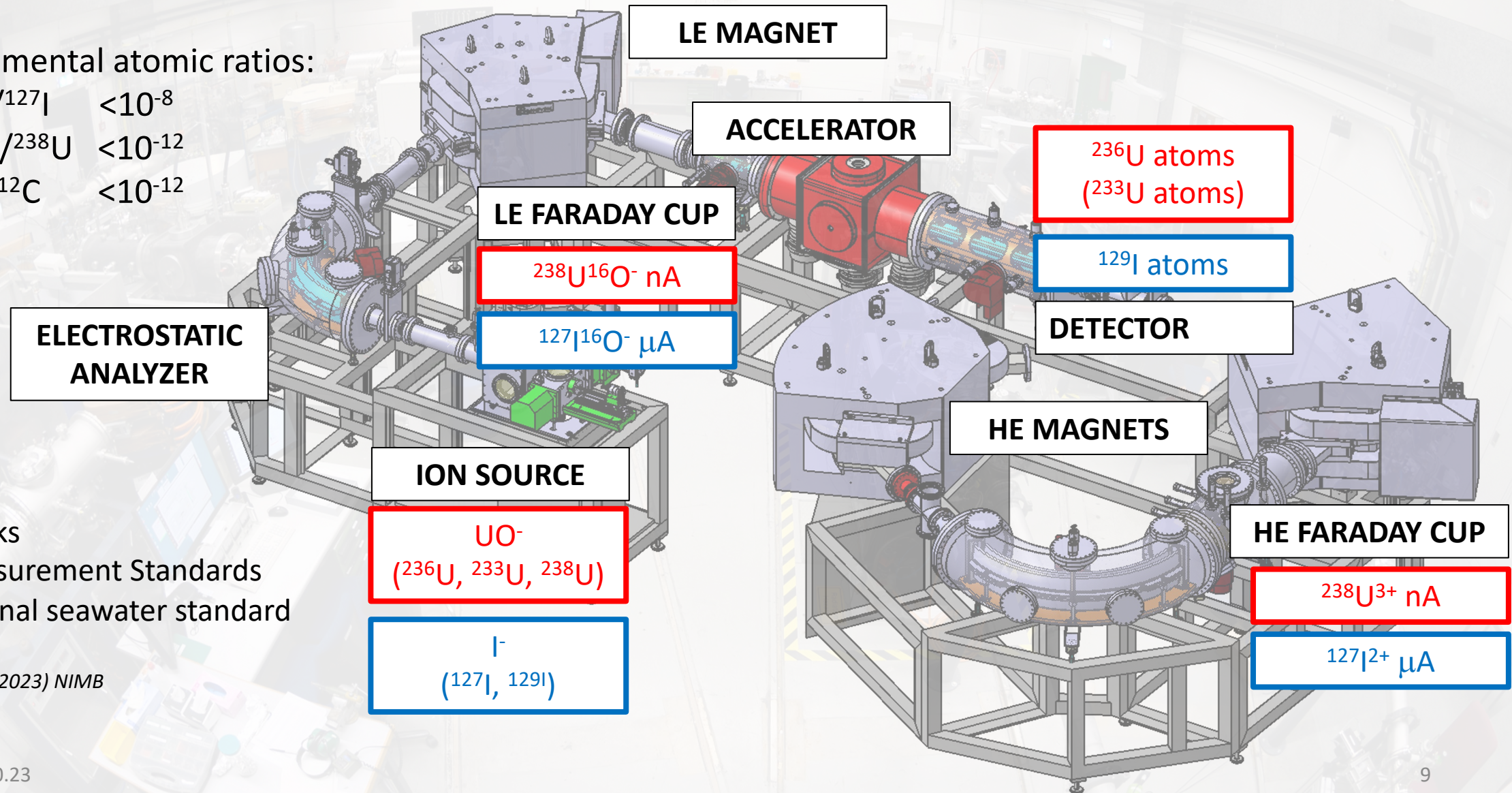
Christl et al. (2023) NIMB

09.10.23

MEASUREMENTS OF ^{129}I AND ^{236}U

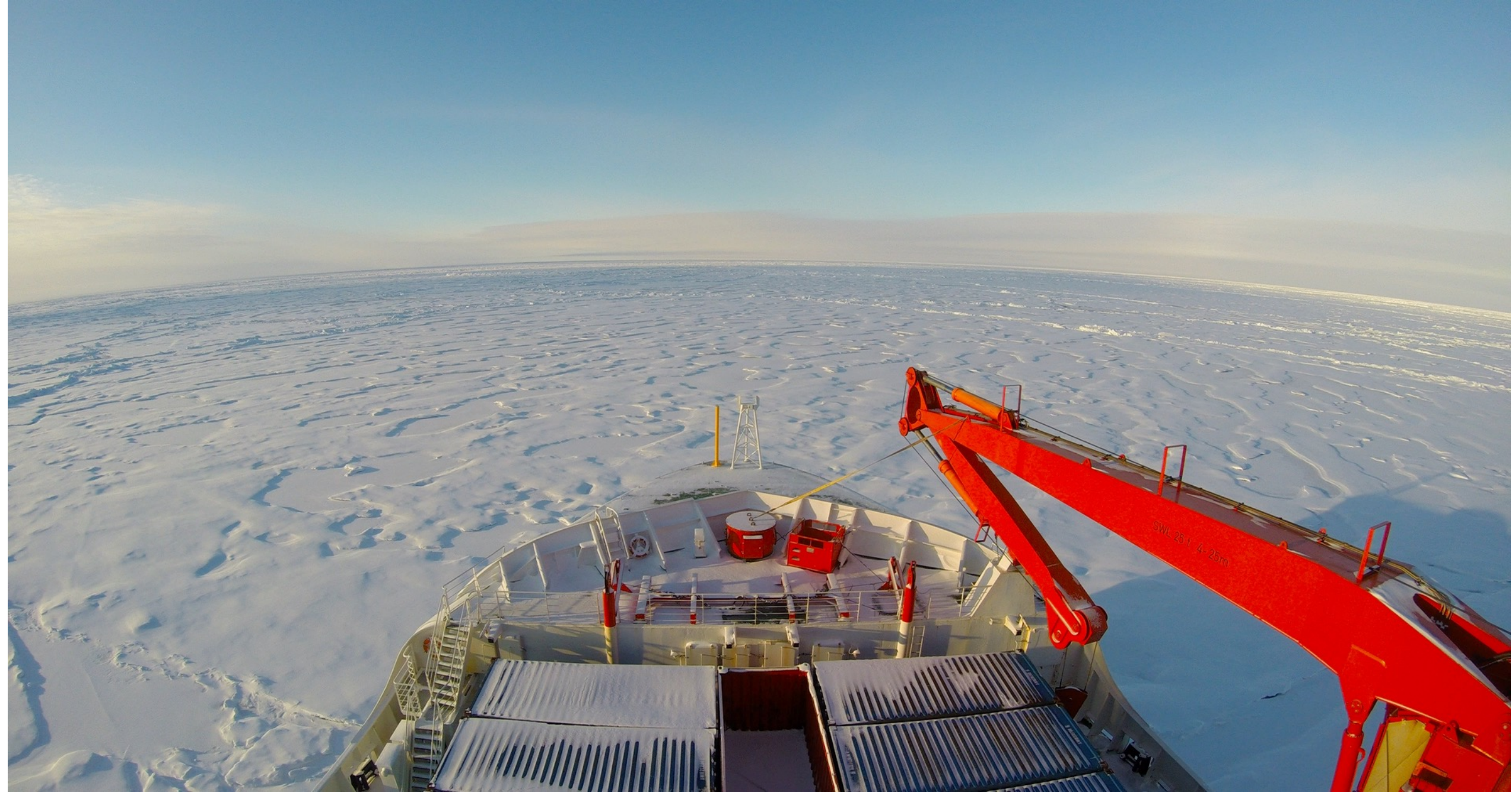
Environmental atomic ratios:

- $^{129}\text{I}/^{127}\text{I} < 10^{-8}$
- $^{236}\text{U}/^{238}\text{U} < 10^{-12}$
- $^{14}\text{C}/^{12}\text{C} < 10^{-12}$

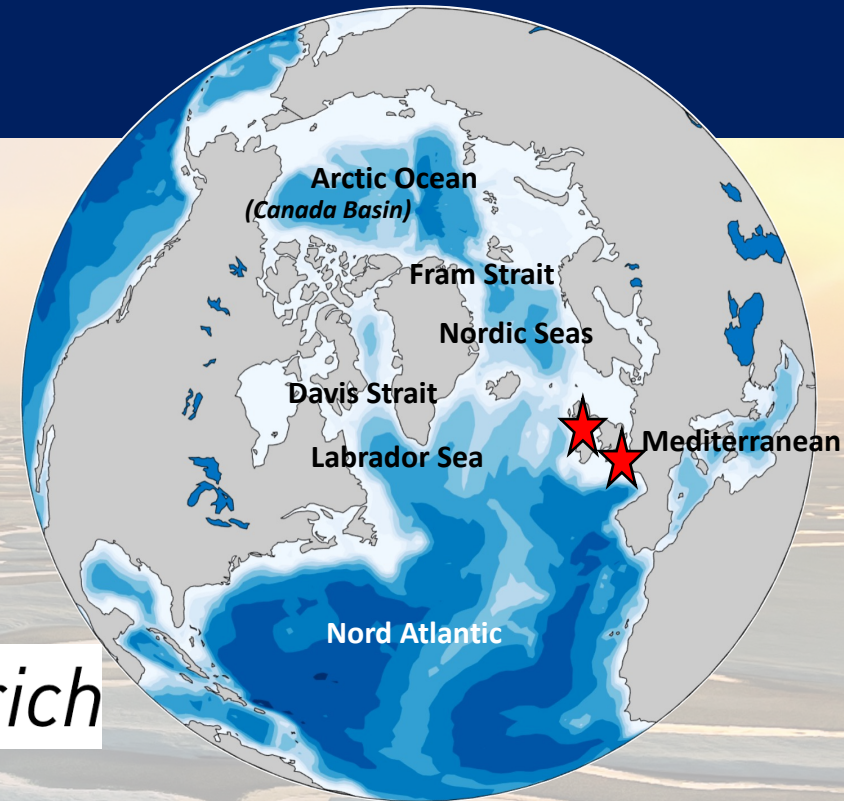


- + Blanks
- + Measurement Standards
- + Internal seawater standard

Christl et al. (2023) NIMB



OCEAN EXPEDITIONS



Schweizerischer Nationalfonds



ETH zürich



2013 - 2019

Central Arctic Ocean (PS94)
Fram Strait (PS100 + NPI)
OVIDE
Barents Sea
Norwegian Coast
Mediterranean Sea
Bermuda
Pacific Ocean

2020

Canada Basin (JOIS) –
Fram Strait
Labrador Sea (AR7W)

2021

Canada Basin (JOIS)
Arctic (Ventilation)
Russian Arctic (ACA)
Fram Strait
North Atlantic (OVIDE)
Iceland (HAFRO)
Nordic Seas (NIOZ)
Bermuda (BATS)

2022

Canada Basin (JOIS)
Fram Strait
Davis Strait
Labrador Sea (AR7W)
Iceland (HAFRO)
Mediterranean Sea
Pacific Ocean
Fukushima

2023

Canada Basin (JOIS)
Fram Strait
Labrador Sea (AR7W)
Faroe Islands
Grand Banks
Fukushima

2024

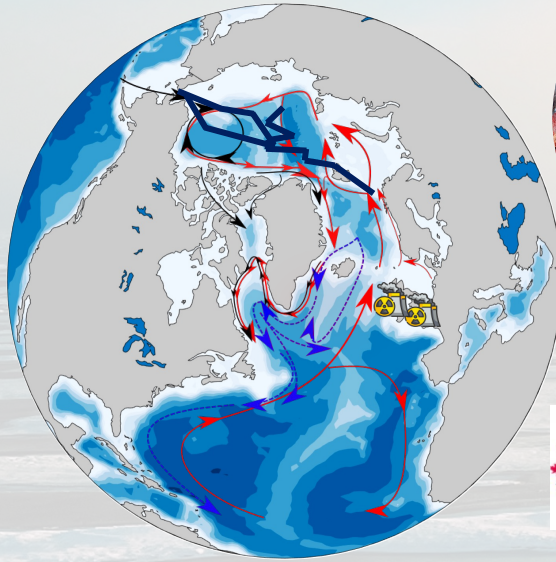
Arctic (ArcWatch)
Canada Basin
Fram Strait
Labrador Sea (AR7W)
Nordic Seas
Fukushima

2025

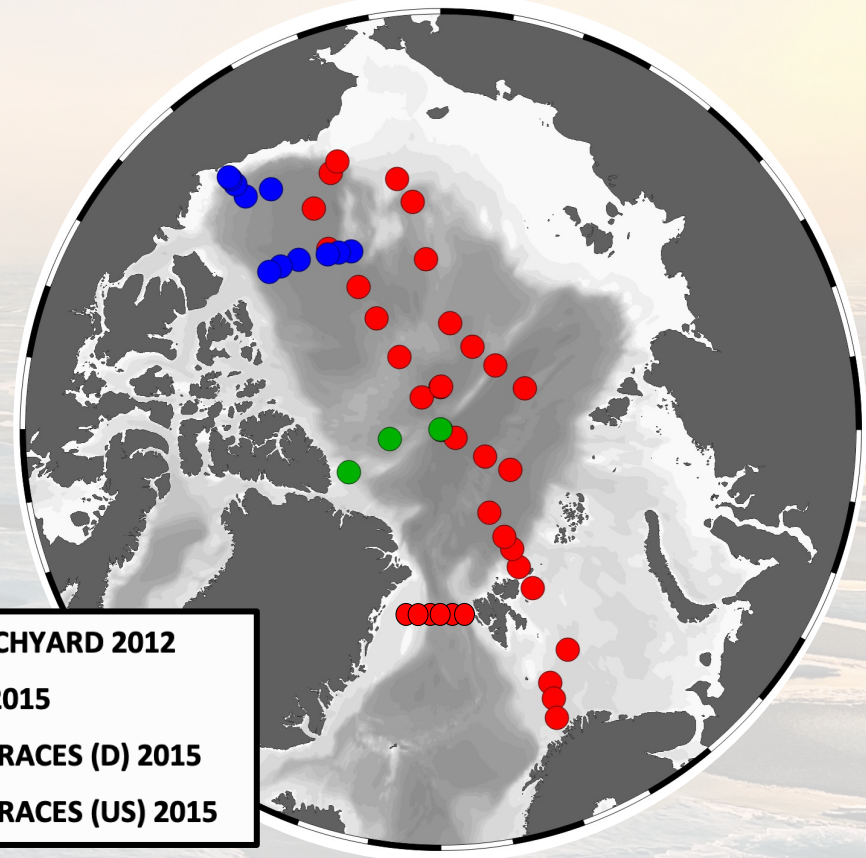
North Greenland (AWI)
...

2026

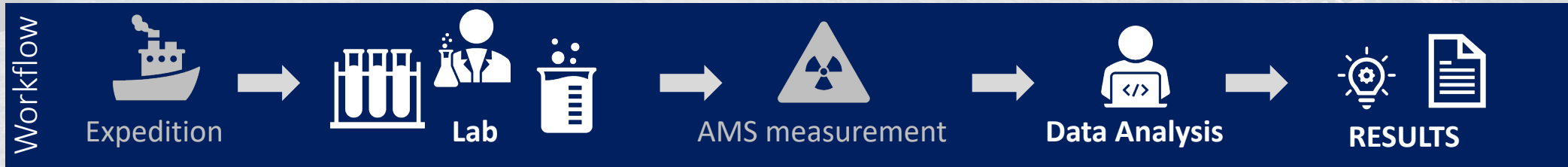
THE FIRST SYNOPTIC ^{129}I AND ^{236}U SAMPLING



Dr. Anne-Marie Wefing
(Postdoc)

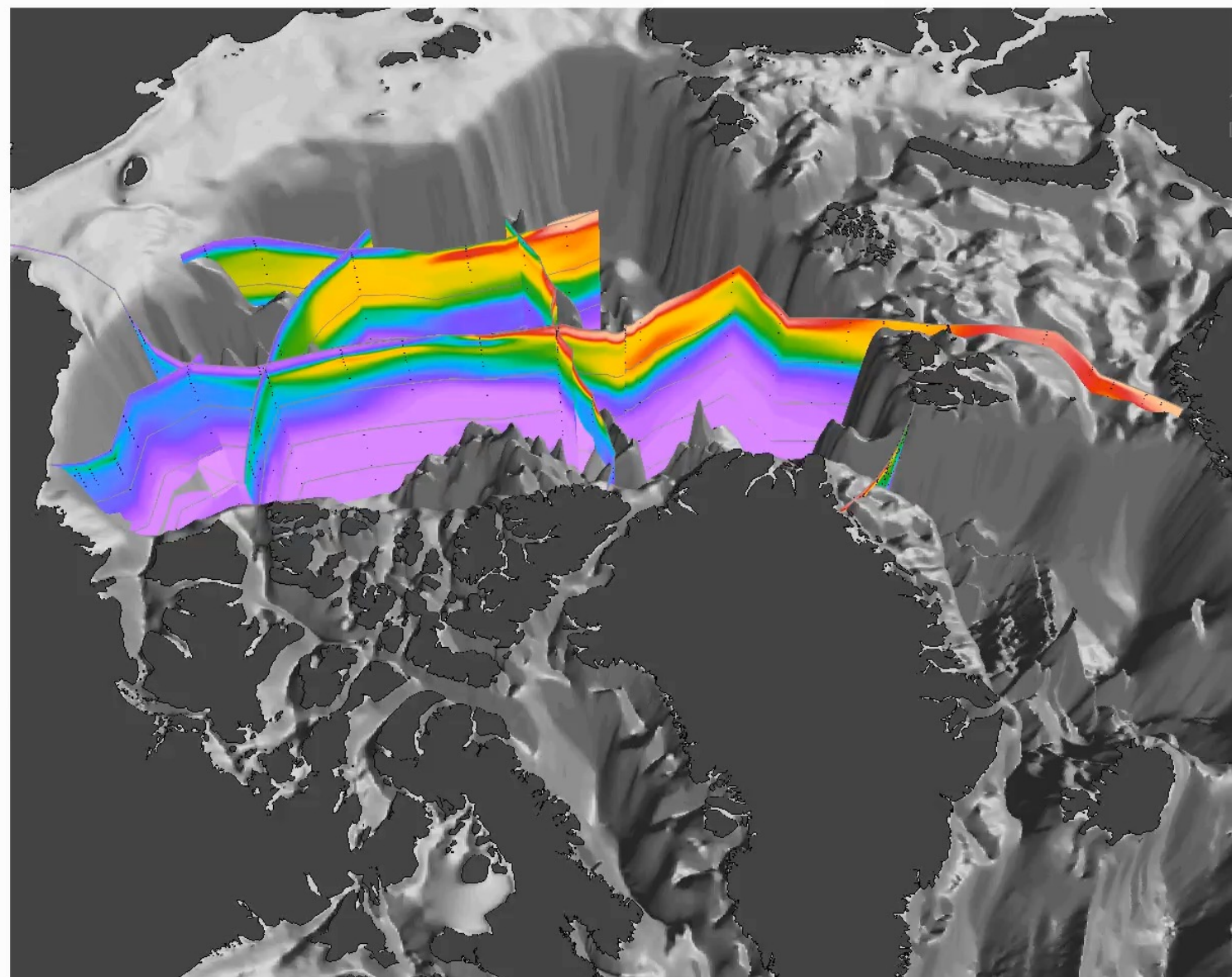
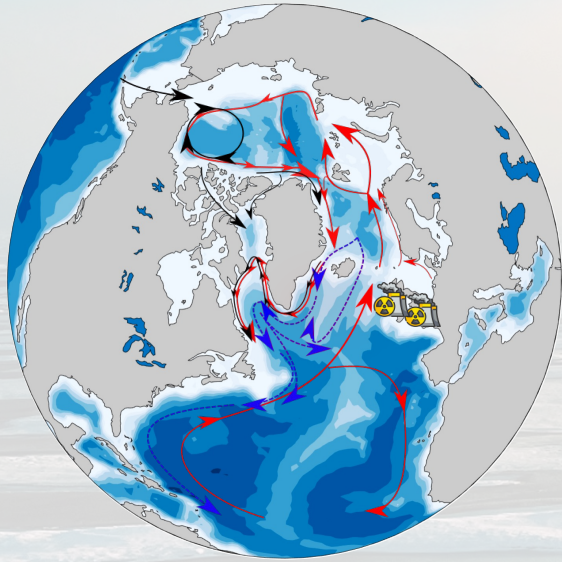


- SWITCHYARD 2012
- JOIS 2015
- GEOTRACES (D) 2015
- GEOTRACES (US) 2015



^{129}I DISTRIBUTION IN 2012-2016

^{129}I (10^7 at/L)

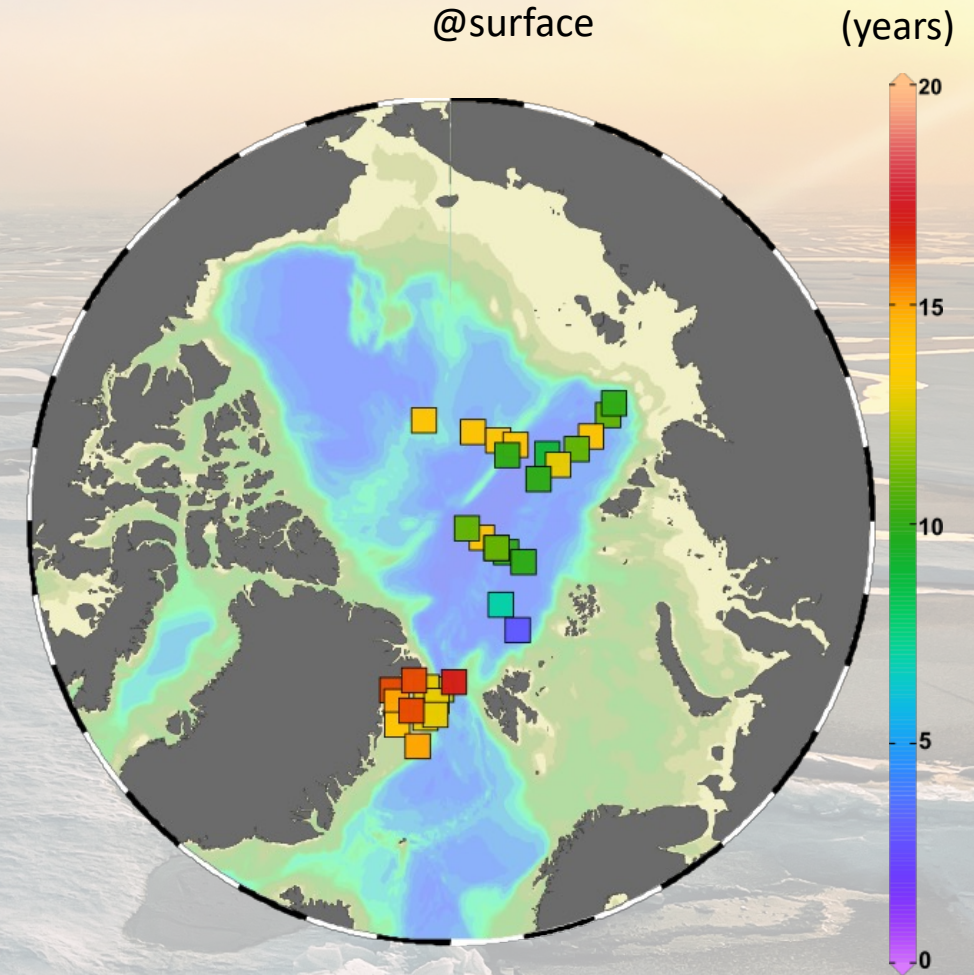
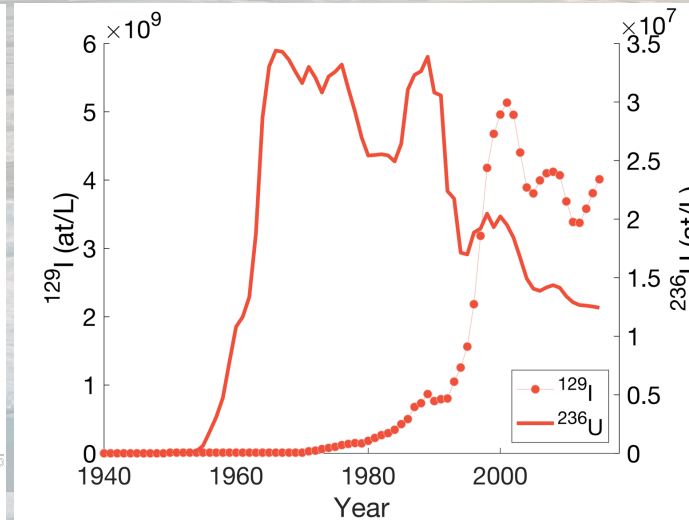
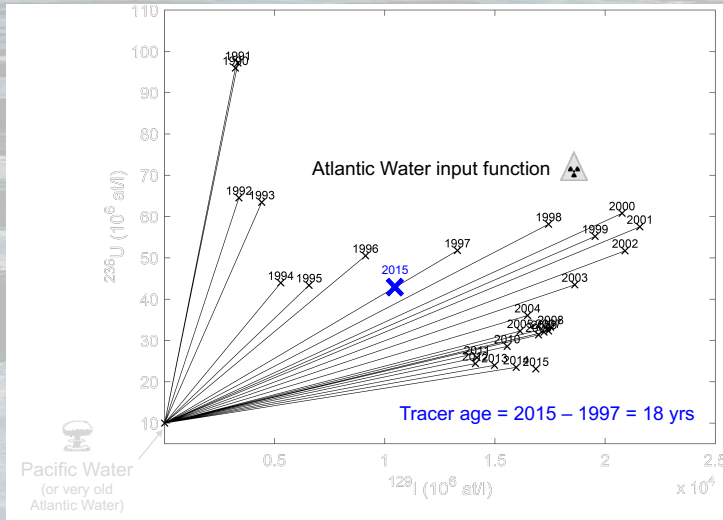
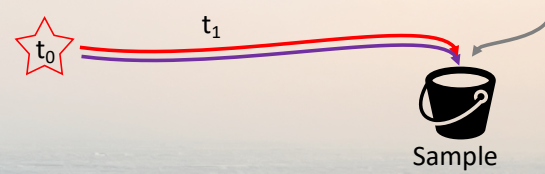


Wefing et al. (2019) JGR
Casacuberta & Smith (2022) ARMS

09.10.23

THE POWER OF COMBINING TWO TRACERS

TRACER AGES

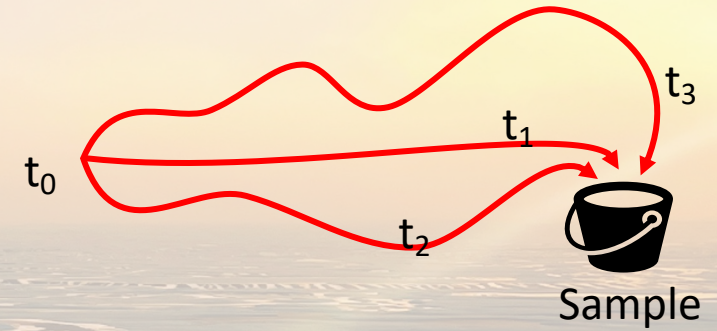


Wefing et al. (2019) JGR
Casacuberta & Smith (2022) ARMS

THE POWER OF COMBINING TWO TRACERS

TRANSIT TIME DISTRIBUTIONS (TTDs)

$$c(r, t) = \int_0^{\infty} c_0(t - t') G(r, t') dt'$$



Inverse Gaussian

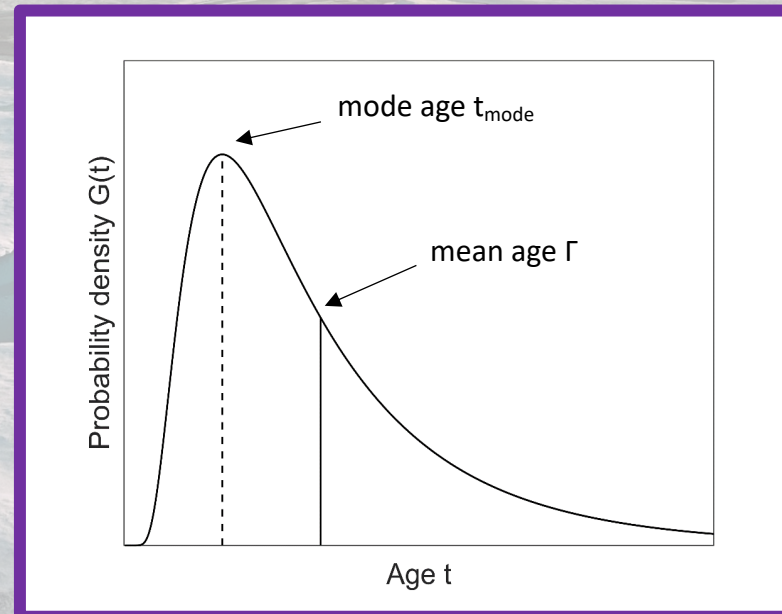
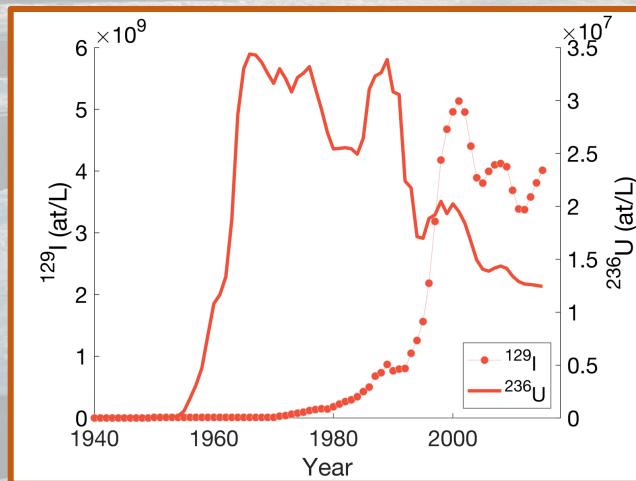
$$G(t) = \sqrt{\frac{\Gamma^3}{4\pi\Delta^2 t^3}} \exp\left(\frac{-\Gamma(t - \Gamma)^2}{4\Delta^2 t}\right)$$

with two parameters:

Γ – Mean age

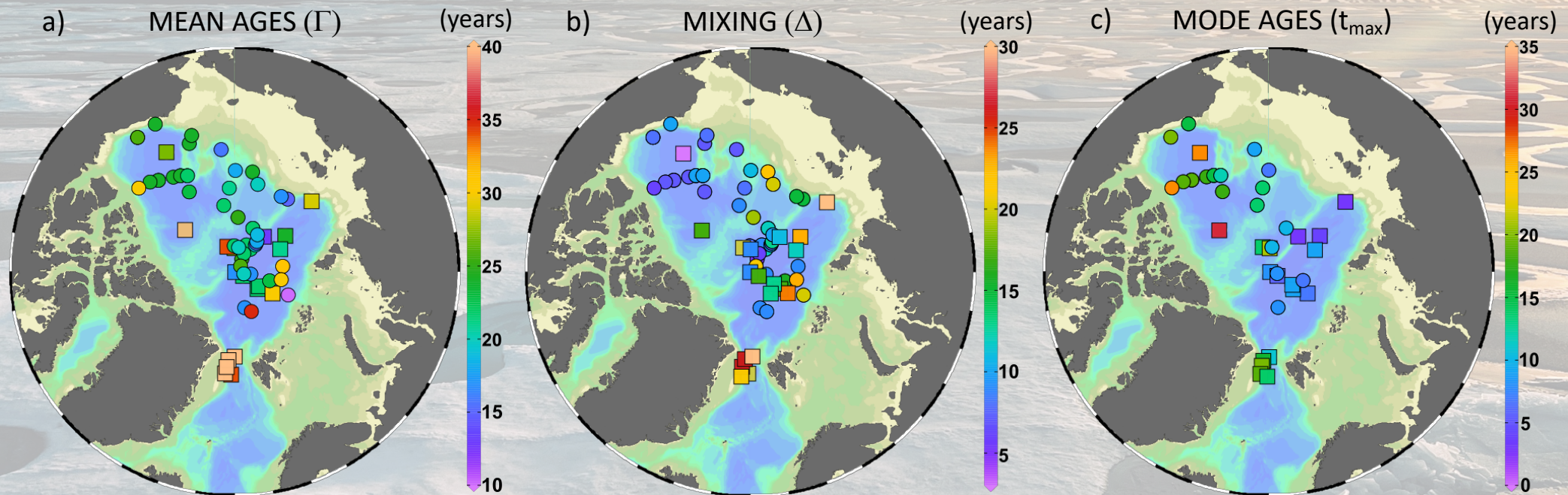
Δ – Width (mixing)

Mode age $t_{\text{mode}} = f(\Gamma, \Delta)$



THE POWER OF COMBINING TWO TRACERS

CIRCULATION TIMES AND MIXING IN THE ATLANTIC LAYER (200 – 800 m)



Wefing et al. (2019) JGR
Casacuberta & Smith (2022) ARMS

FROM TTDs TO ANTHROPOGENIC CARBON (C_{ant})



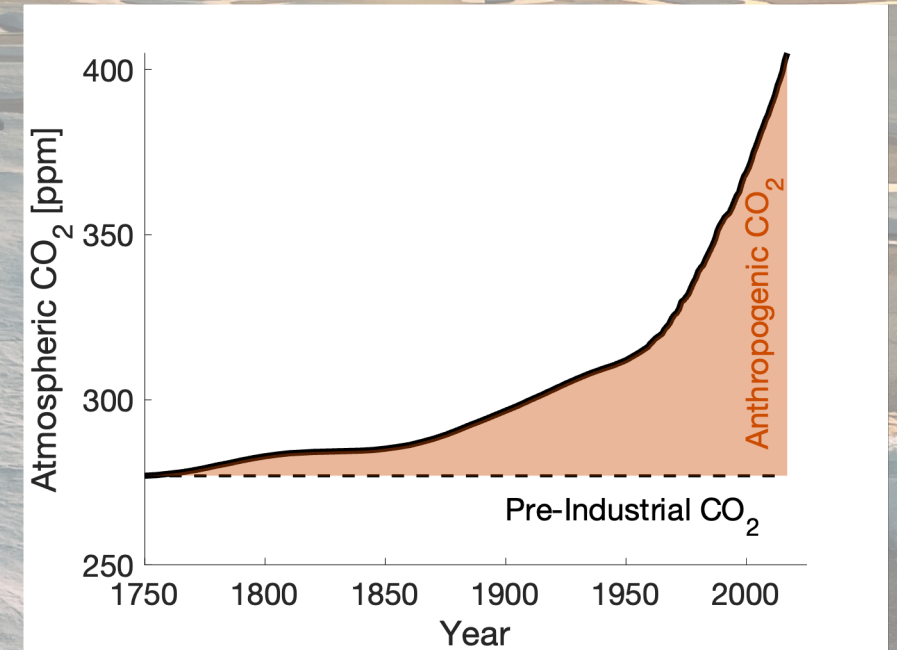
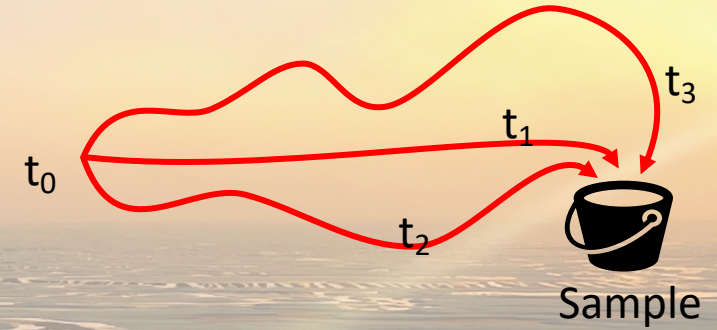
Dr. Anne-Marie Wefing

Dr. Lorenza Raimondi

$$c(r, t) = \int_0^{\infty} c_0(t - t') G(r, t') dt'$$

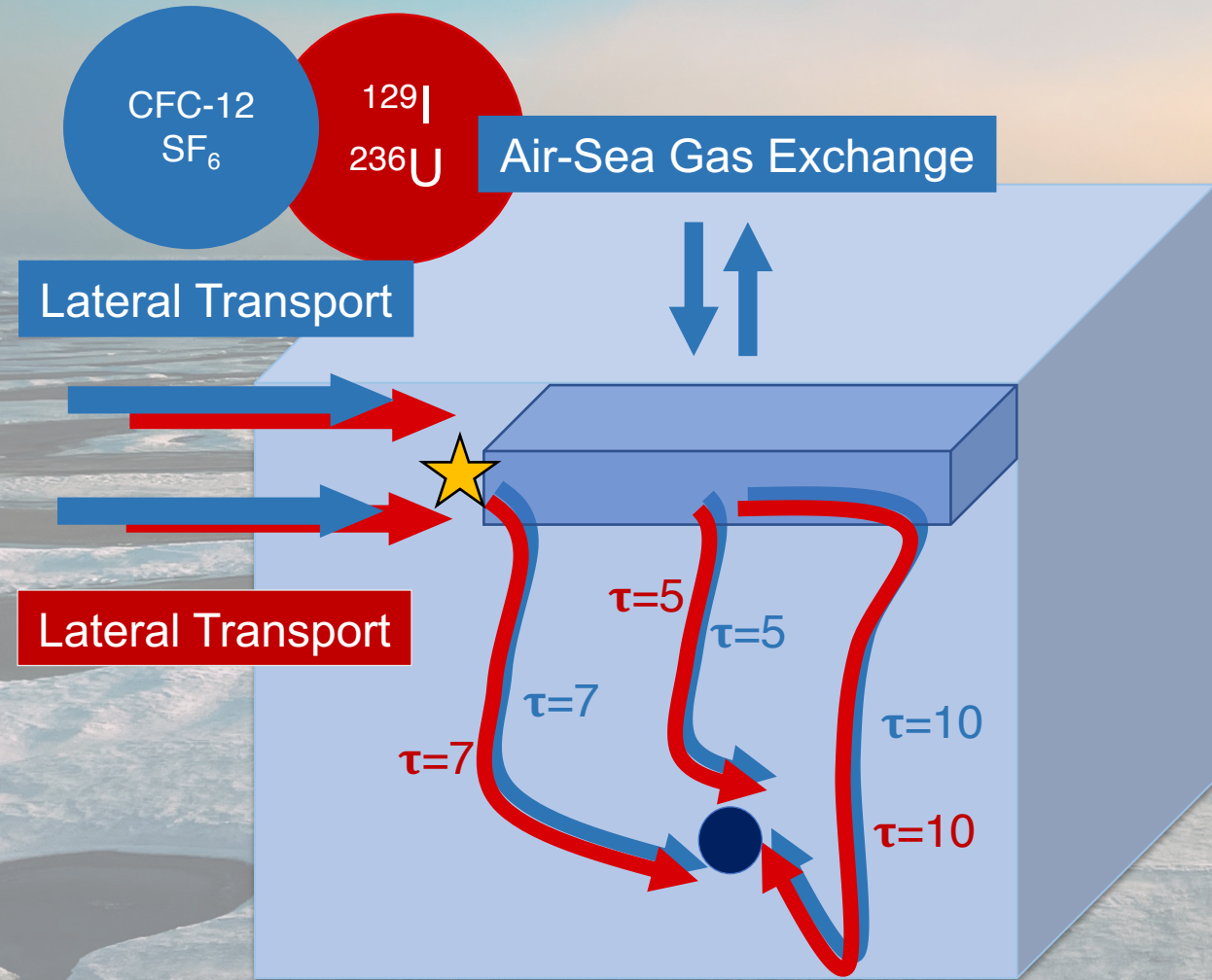
Γ, Δ

$$C_{ant}(r, t) = \int_0^{\infty} \frac{C_{ant(0)}(t - t') G(r, t') dt'}{}$$

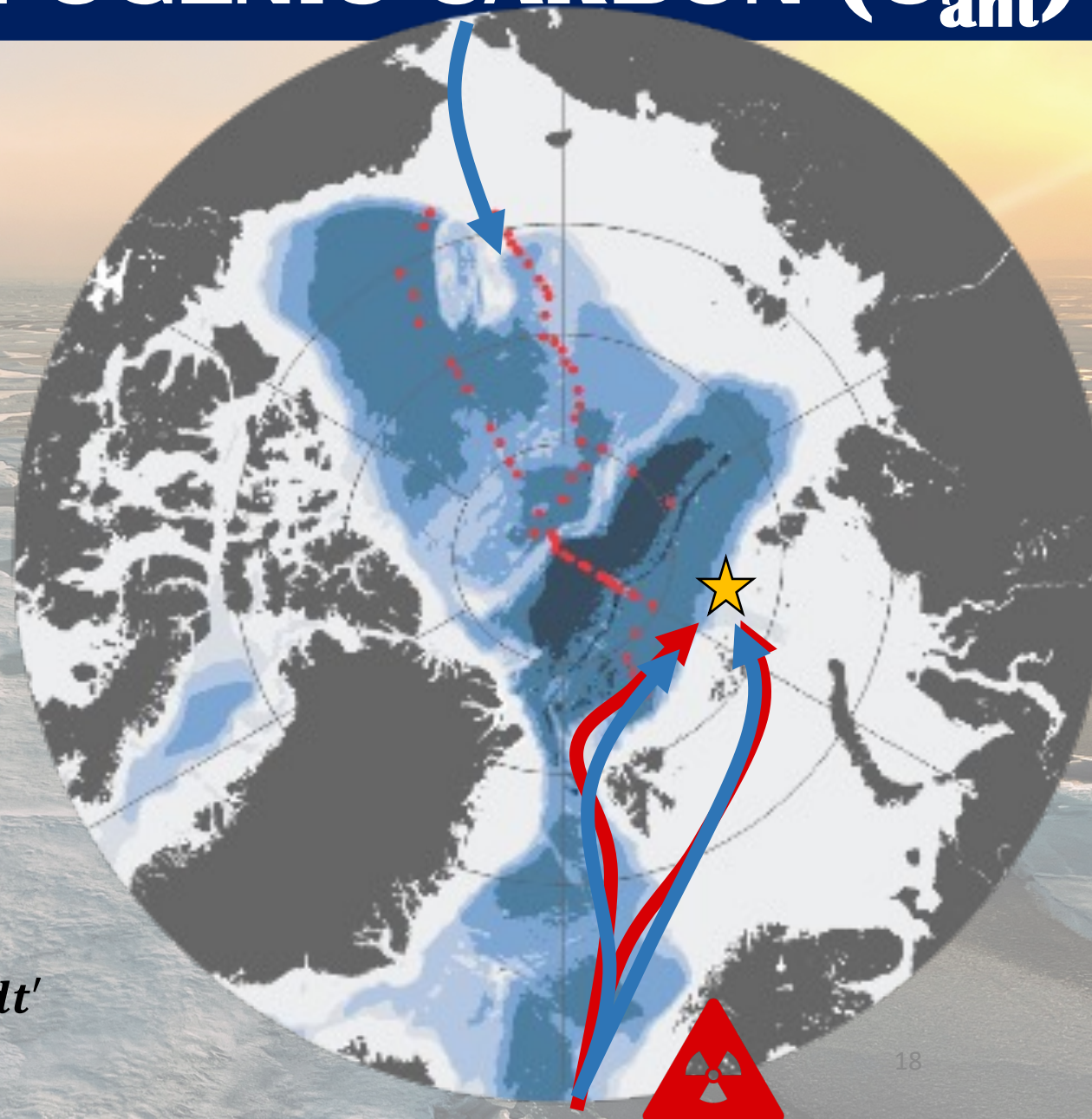


Raimondi, Wefing and Casacuberta (submitted) JGR

FROM TTDs TO ANTHROPOGENIC CARBON (C_{ant})

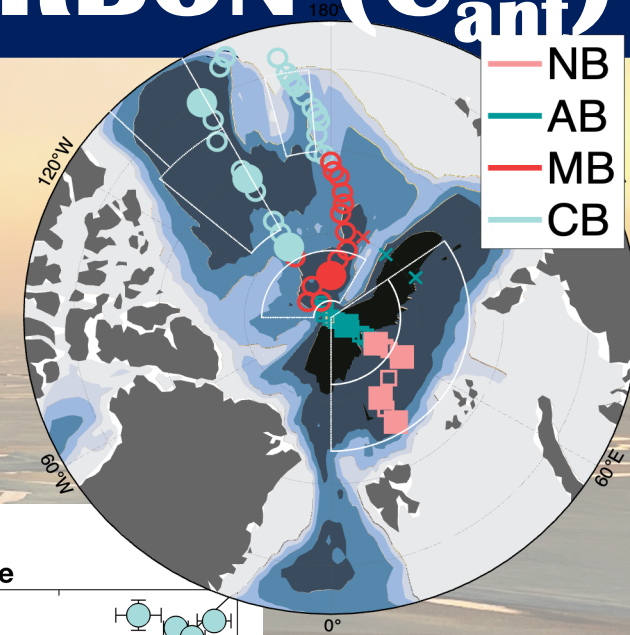


$$c(r, t) = \int_0^{\infty} c_0(t - t') \cdot G(r, t') dt'$$

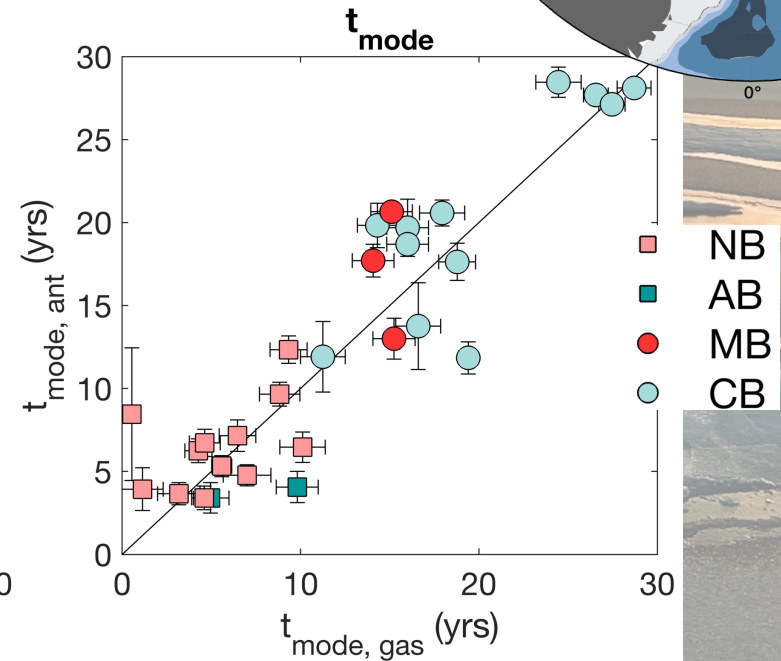
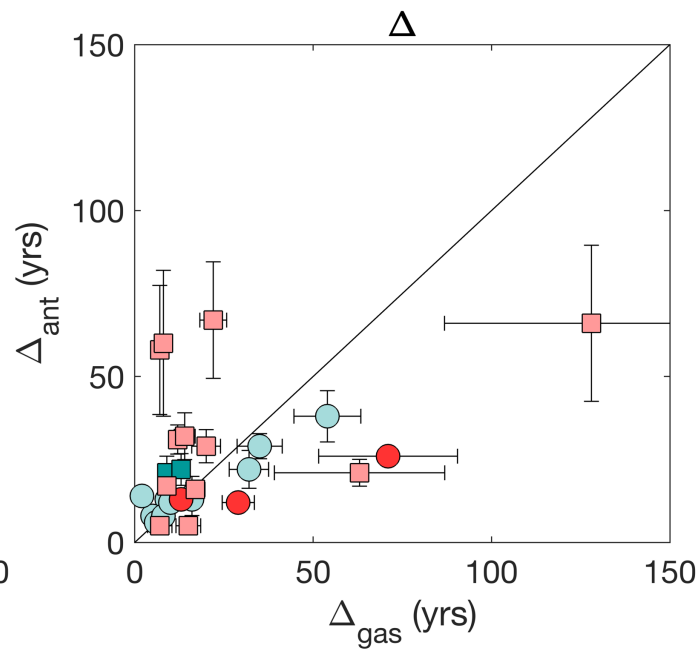
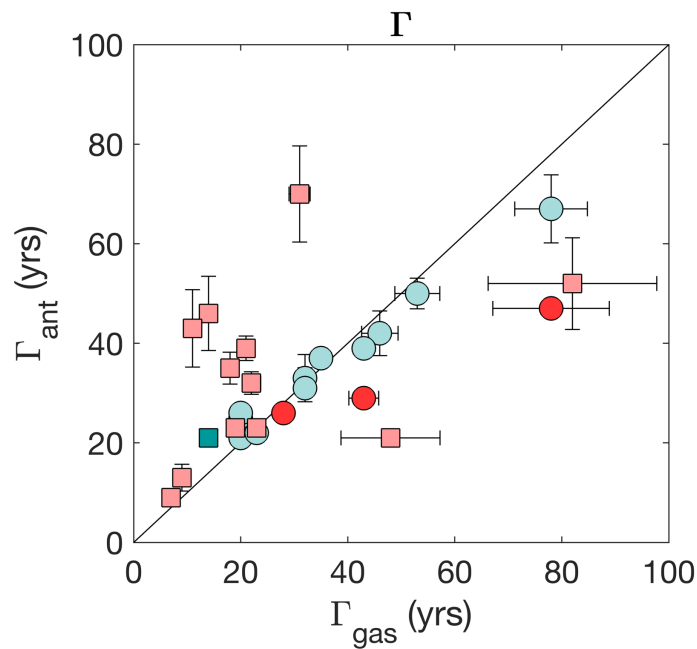


FROM TTDs TO ANTHROPOGENIC CARBON (C_{ant})

- Most of results fall on the 1:1 line
- Most Difference are observed in the NB
- T-mode is a better representation of the circulation



Radionuclides

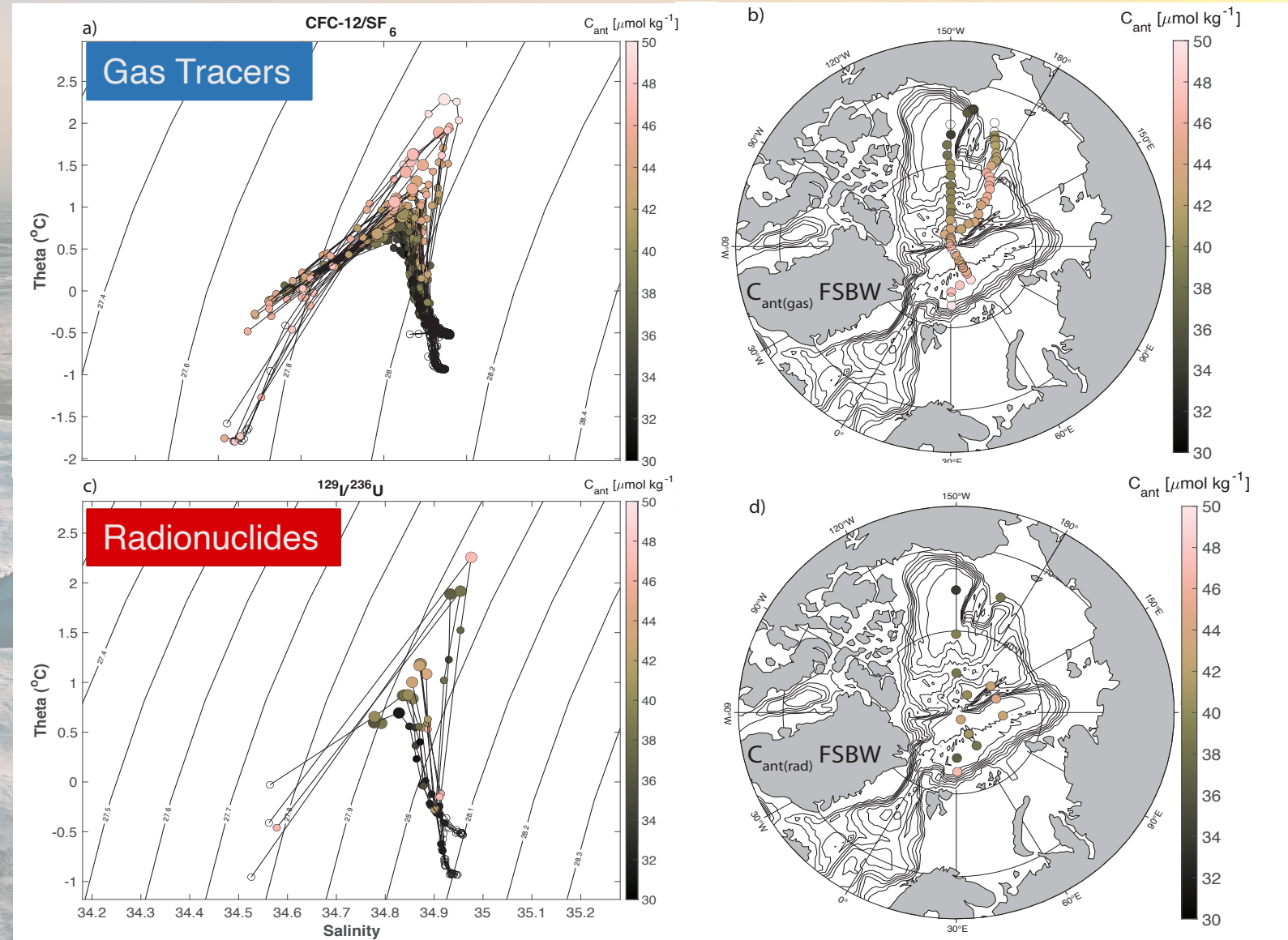


Gas Tracers

FROM TTDs TO ANTHROPOGENIC CARBON (C_{ant})

Both tracer pairs show that most of C_{ant} is in the Eurasian Basin in correspondence of the Atlantic branches entering the Arctic Ocean

Raimondi, Wefing and Casacuberta (submitted) JGR



FROM TTDs TO ANTHROPOGENIC CARBON (C_{ant})

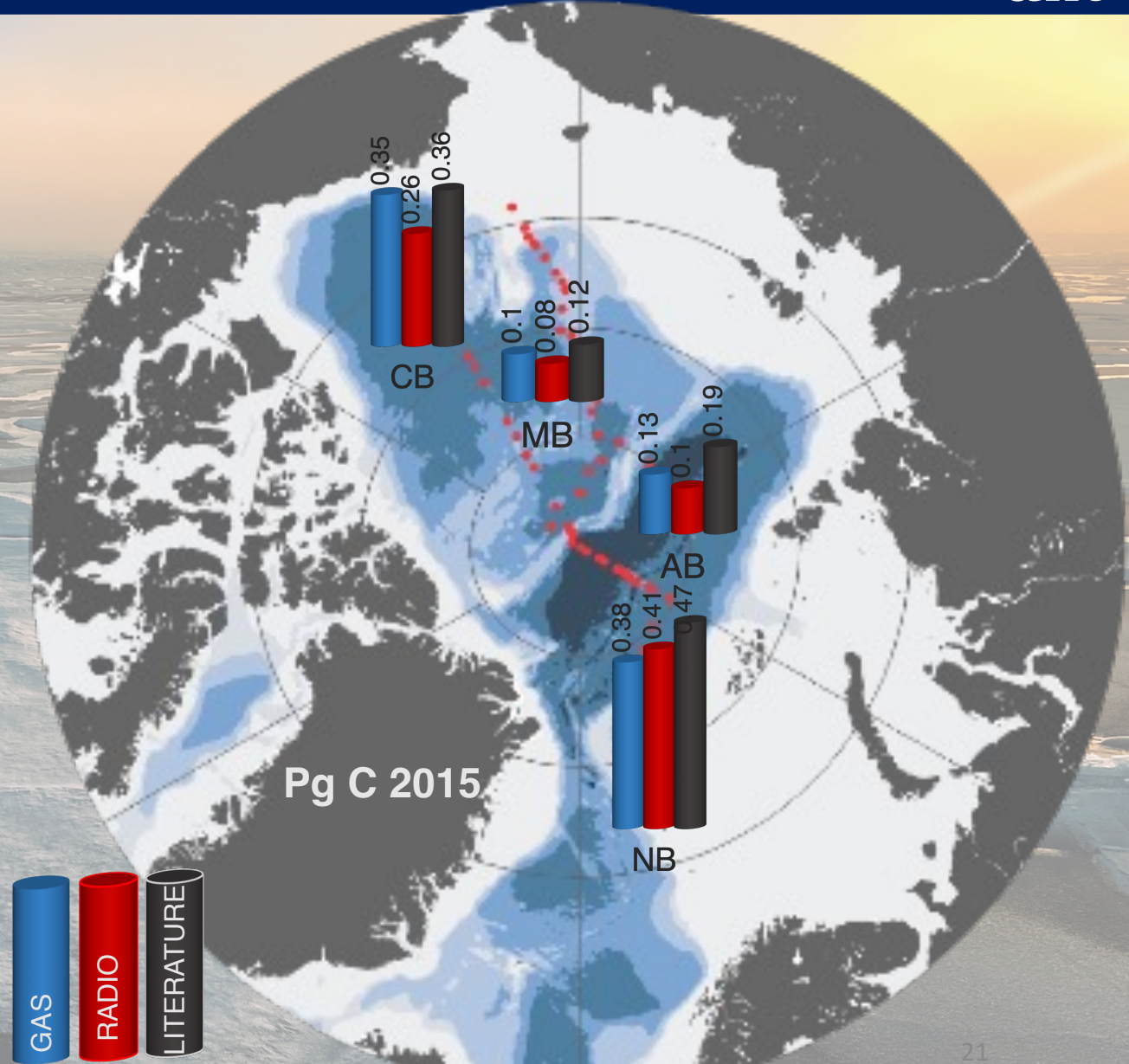
Highest C_{ant} Inventory is found in the Eurasian Basin

High C_{ant} Inventory is also found in the Canada Basin but this is not due to high concentrations but rather larger volume integrated

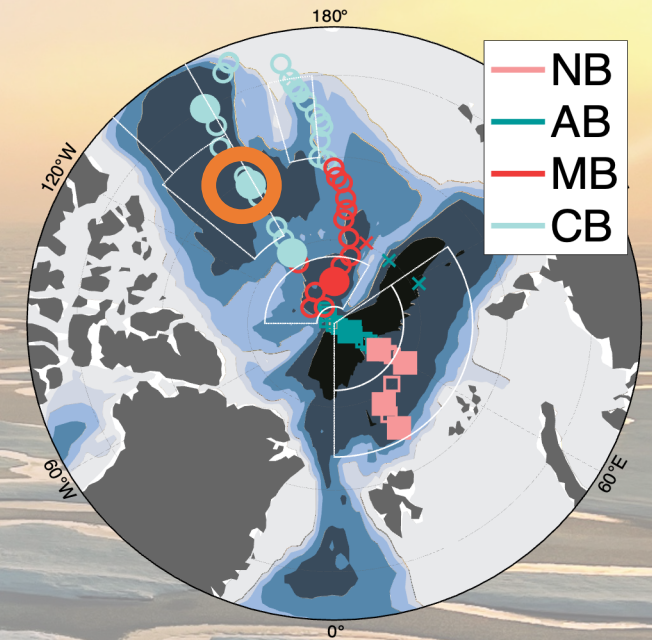
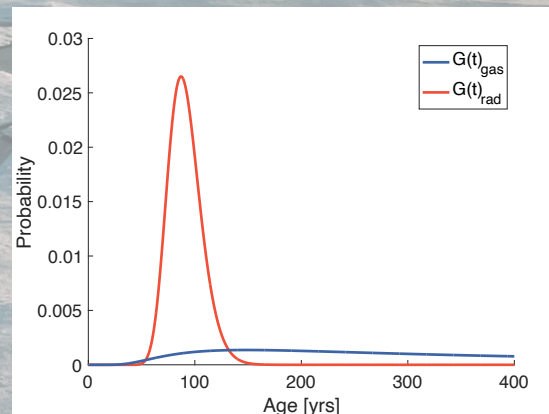
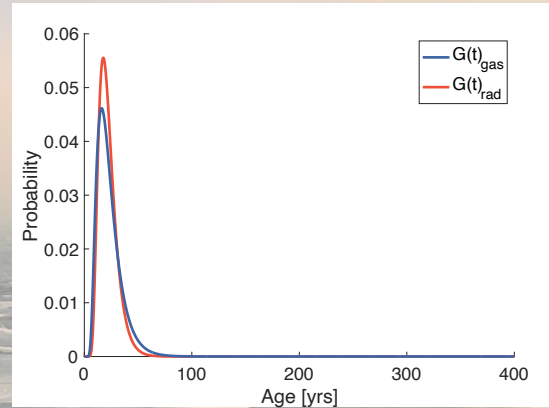
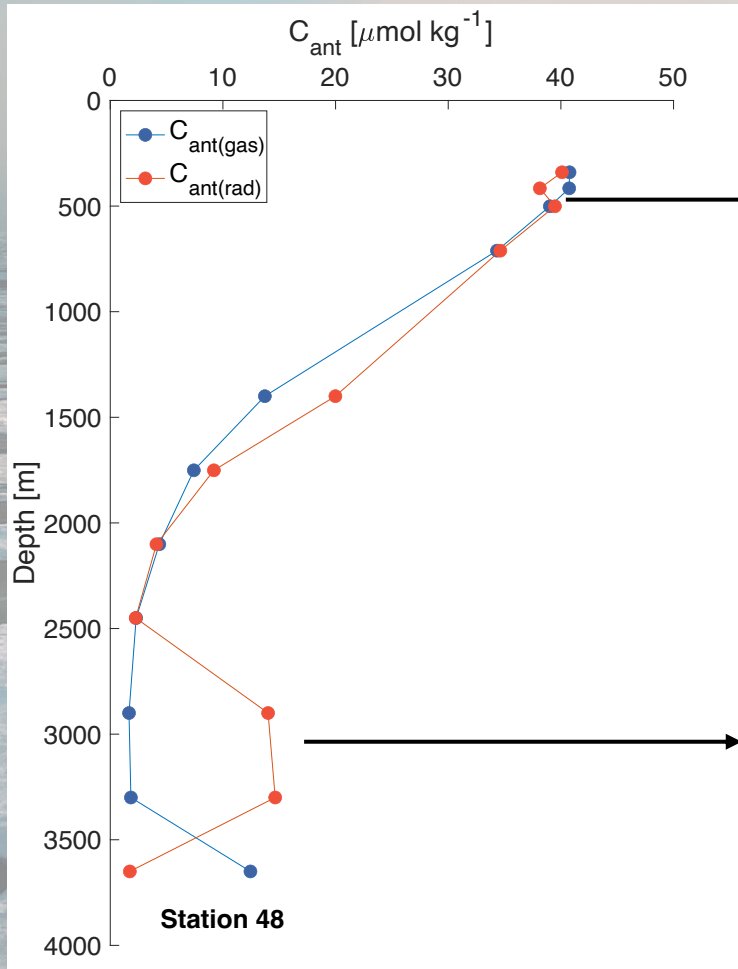
C_{ant} Inventories are lower in the Amundsen and Makarov Basins but they cover a much smaller volume.

These Inventories Do not include estimates below 1500m but still account 60-80% of Inventory

Raimondi, Wefing and Casacuberta (submitted) JGR



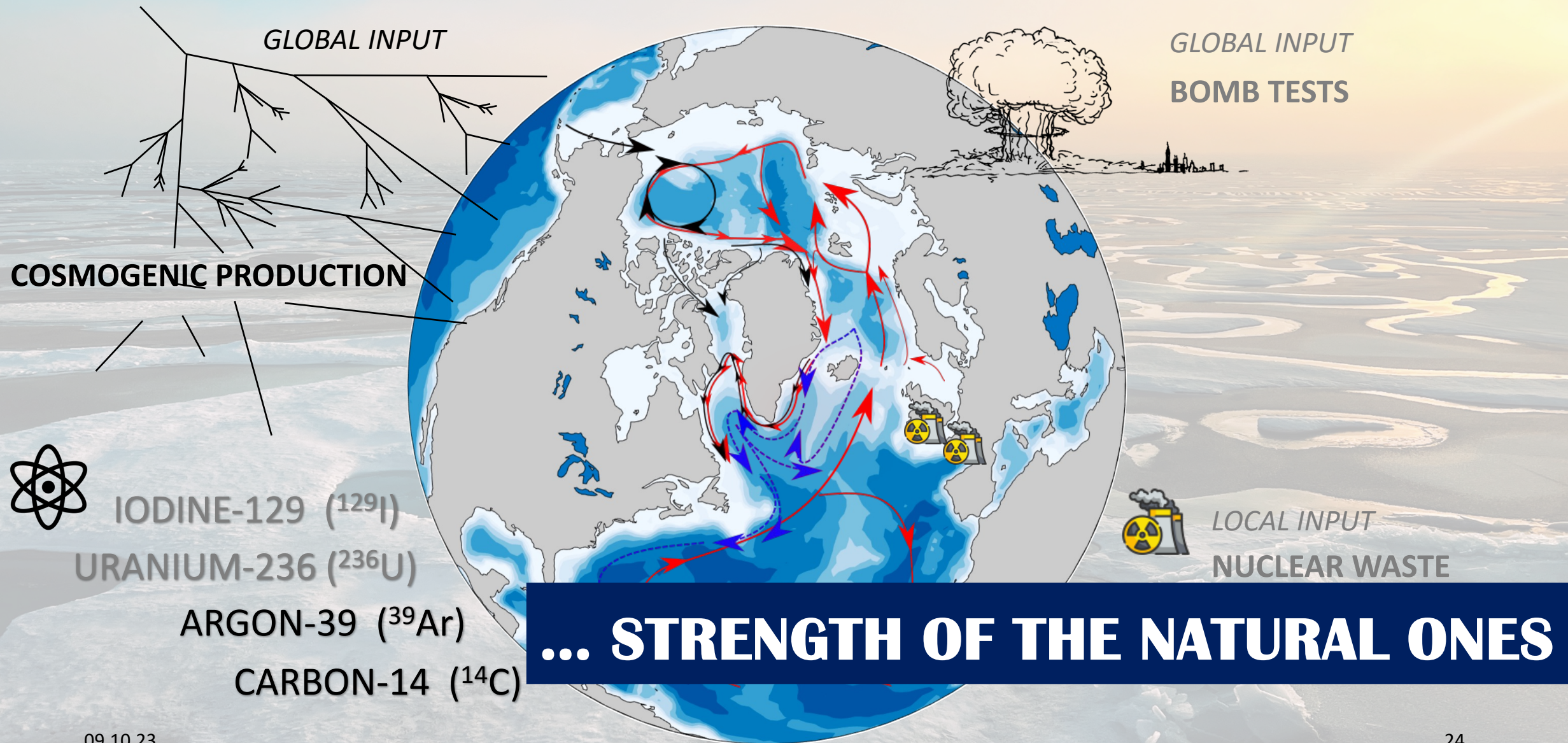
LIMITATIONS OF ANTHROPOGENIC TRACERS



We excluded samples below 1500m depth and calculated inventories only with those samples we could trust the TTD of.

Raimondi, Wefing and Casacuberta (submitted) JGR

LIMITATIONS OF ANTHROPOGENIC TRACERS



^{14}C AND ^{39}Ar TRACERS OF DEEP WATERS?



ARGON-39 (^{39}Ar)

CARBON-14 (^{14}C)

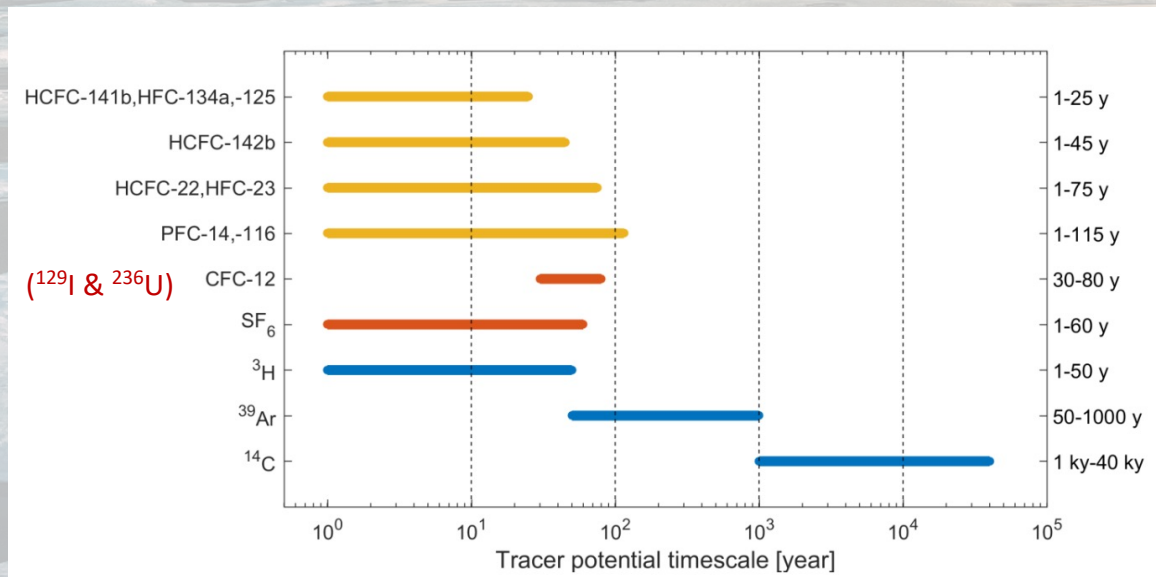
$T_{1/2} = 269$ years

$T_{1/2} = 5730$ years

$^{39}\text{Ar}/\text{Ar} = 10^{-16}$

$^{14}\text{C}/\text{C} = 10^{-12}$

... not a new idea!



Li & Tanhua (2019)

09.10.23



ELSEVIER

Nuclear Instruments and Methods in Physics Research B 172 (2000) 473-478



www.elsevier.nl/locate/nimb

Comparison of ^{39}Ar and ^{14}C ages for waters in the deep ocean

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^a Lamont-Doherty Earth Observatory of Columbia University, 61 Route 9W, P.O. Box 1000, Palisades, NY 10964-8000, USA

^b Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami, FL 33149, USA

Abstract

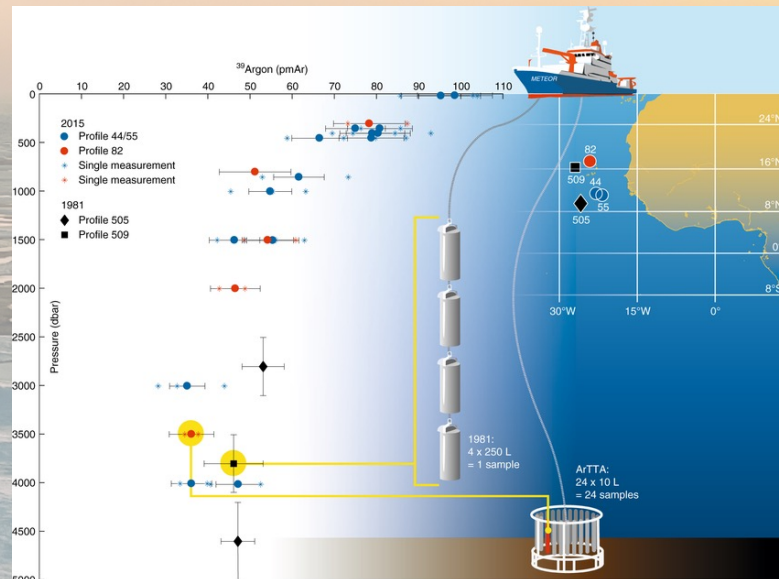
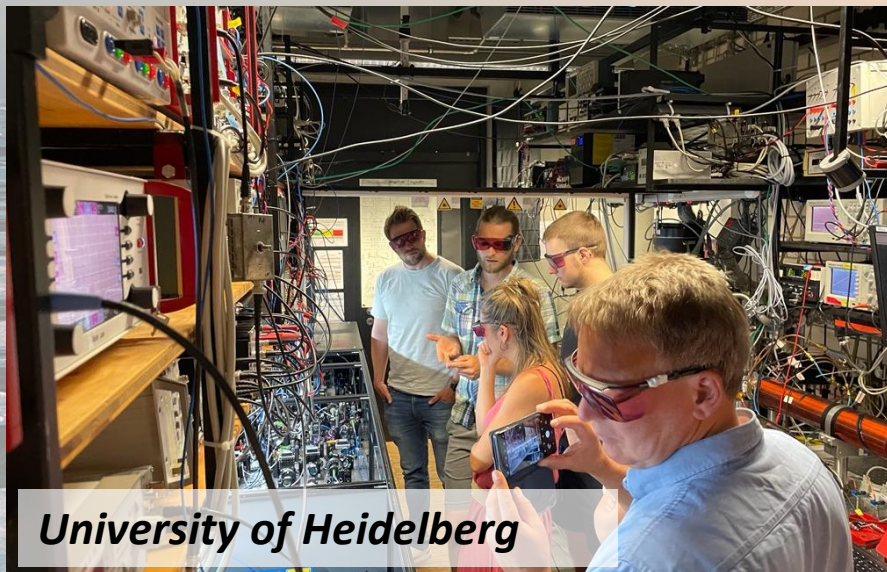
^{39}Ar ages on ocean water samples are consistently younger than ^{14}C ages. The difference is the result of diffusive mixing in the sea which has a greater impact on ages based on short-lived than those based on long-lived radiotracers. It is clear that a more dense survey of ^{39}Ar with higher accuracy measurements would prove of great value in constraining ocean general circulation models. © 2000 Elsevier Science B.V. All rights reserved.

PACS: 92.10.M

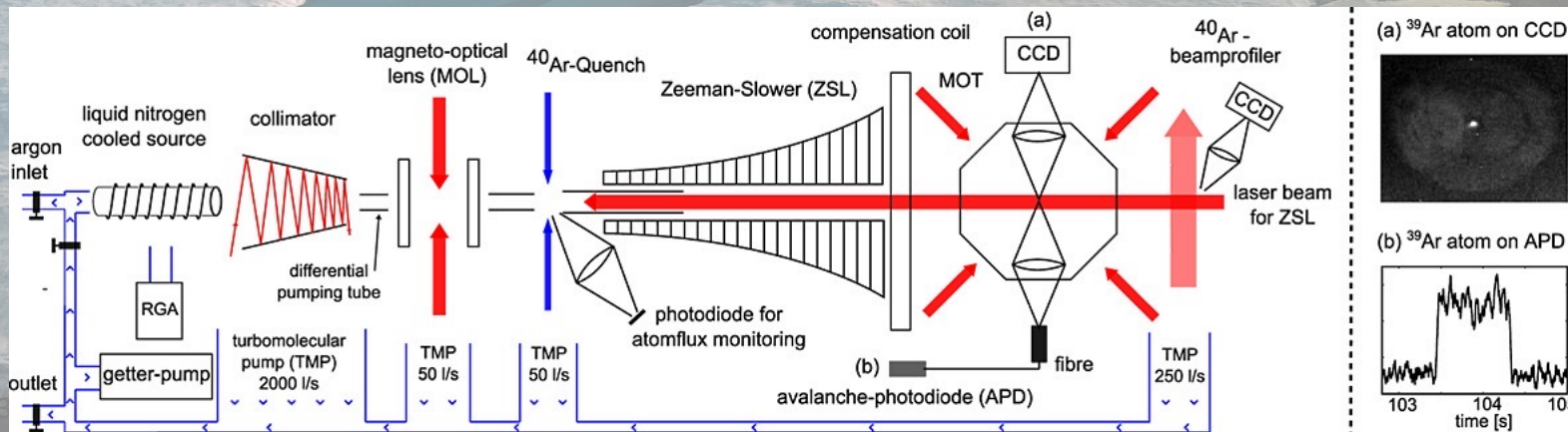
Keywords: Oceans; Thermohaline structure and circulation

ATOM TRAP TRACE ANALYSIS (ATTA)

^{39}Ar CAN NOW BE MEASURED FROM 10L SEAWATER SAMPLES

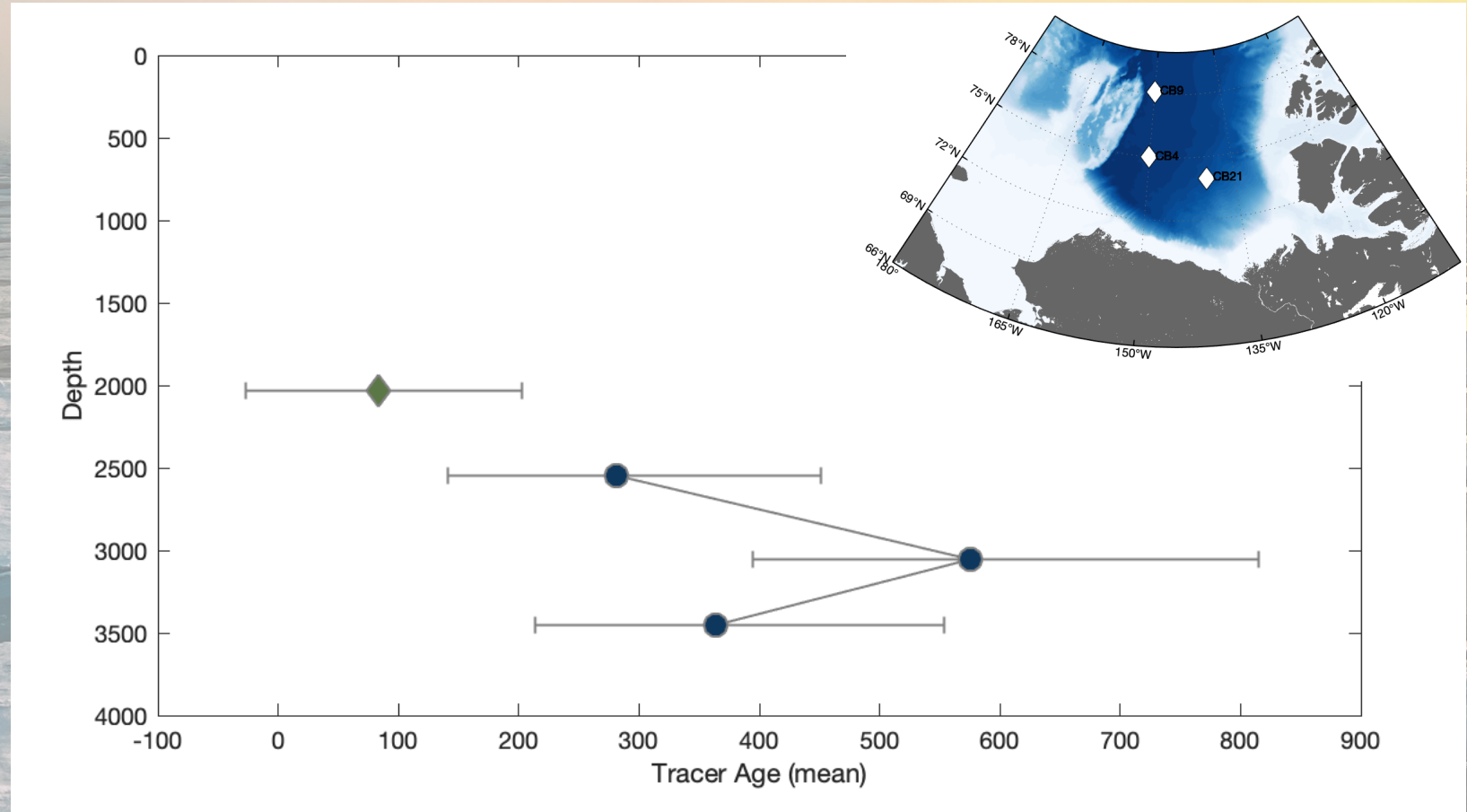
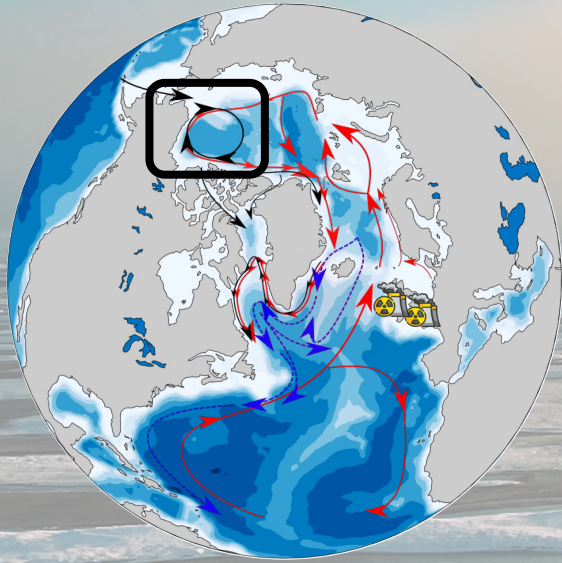


Ebser et al. (2018)



Ritterbusch et al. (2014)

FIRST ^{39}Ar RESULTS FROM CANADA BASIN



WORK IN PROGRESS...

BEYOND THE ARCTIC OCEAN

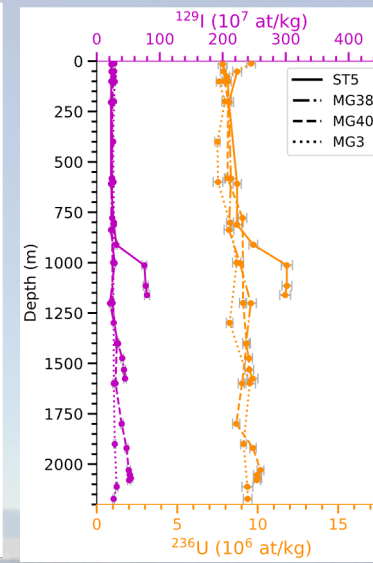
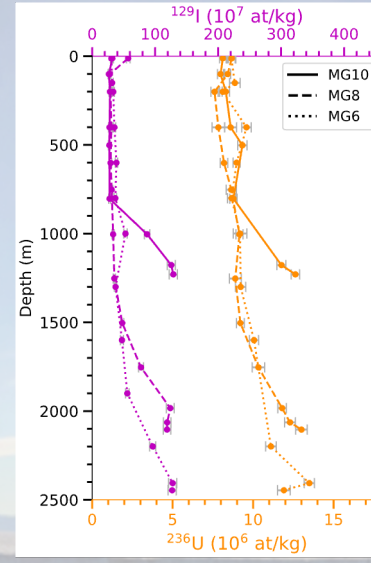
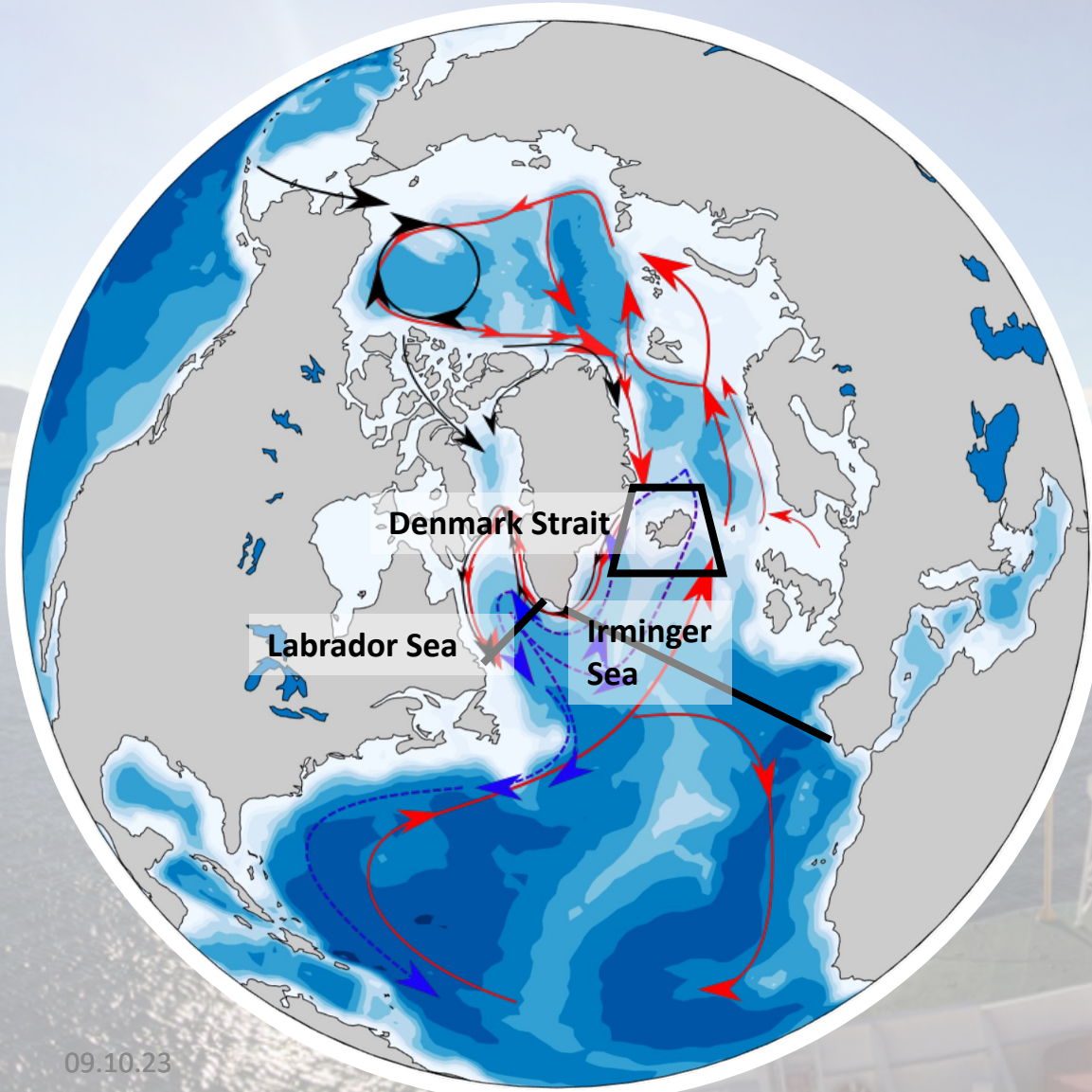
09.10.23

SWL 25 t 4-25m

27



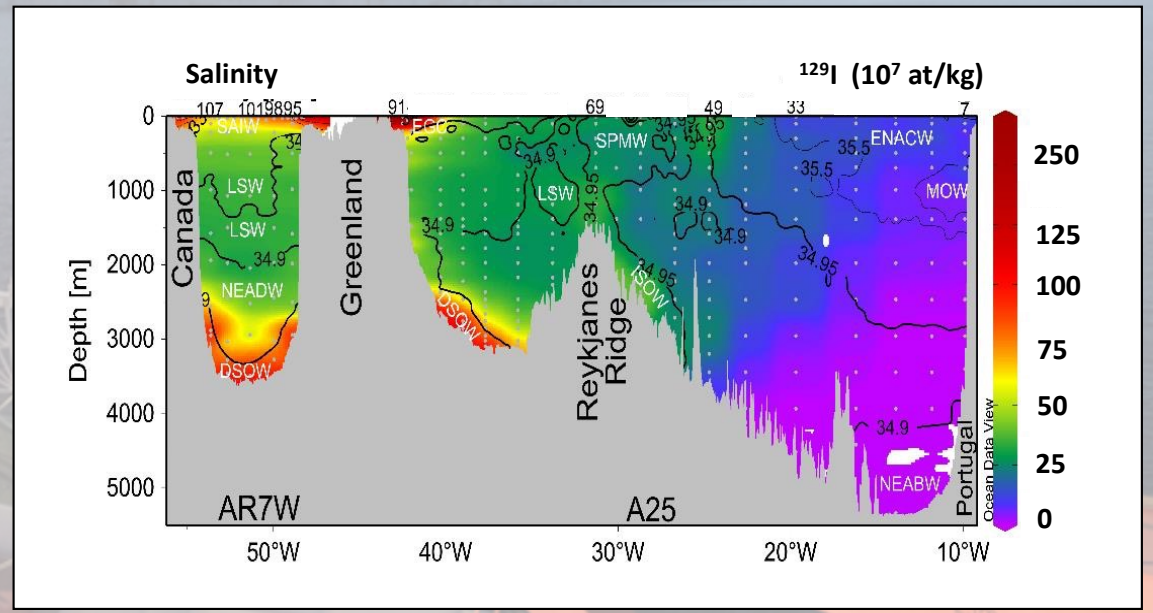
... AND IN THE SUBPOLAR NORTH ATLANTIC



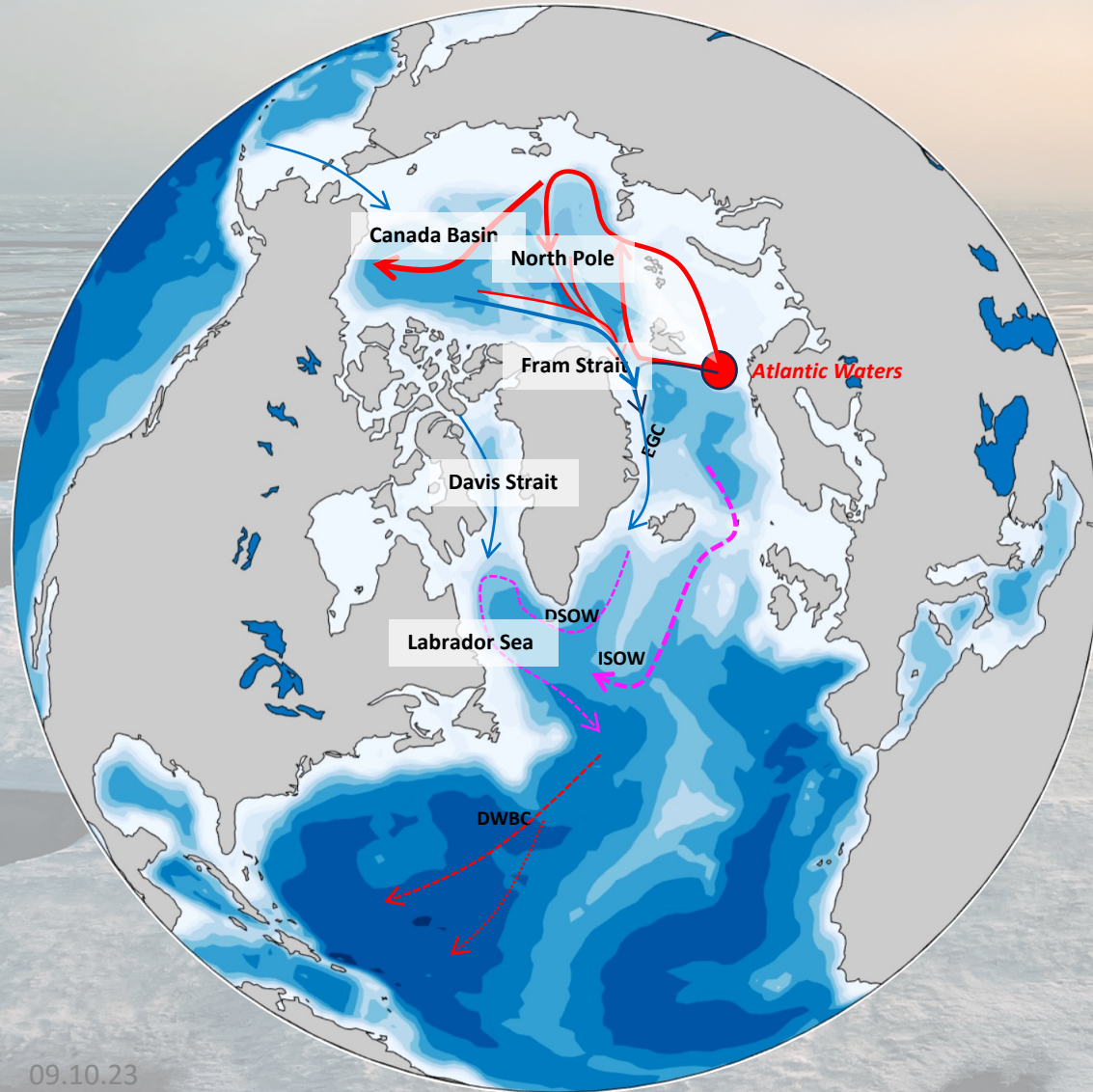
Duncan Dale

Lisa Leist

Leist et al. (in prep.)
Dale et al. (in prep.)



WHAT DID AMS HELP US UNDERSTANDING?



It takes about 10 years for Atlantic Waters to reach the North Pole, more than 25 in the Canada Basin and about 40 to outflow through the Fram Strait.

Atlantic waters in the Arctic Ocean store more than 1 Pg of anthropogenic carbon (C_{ant}).

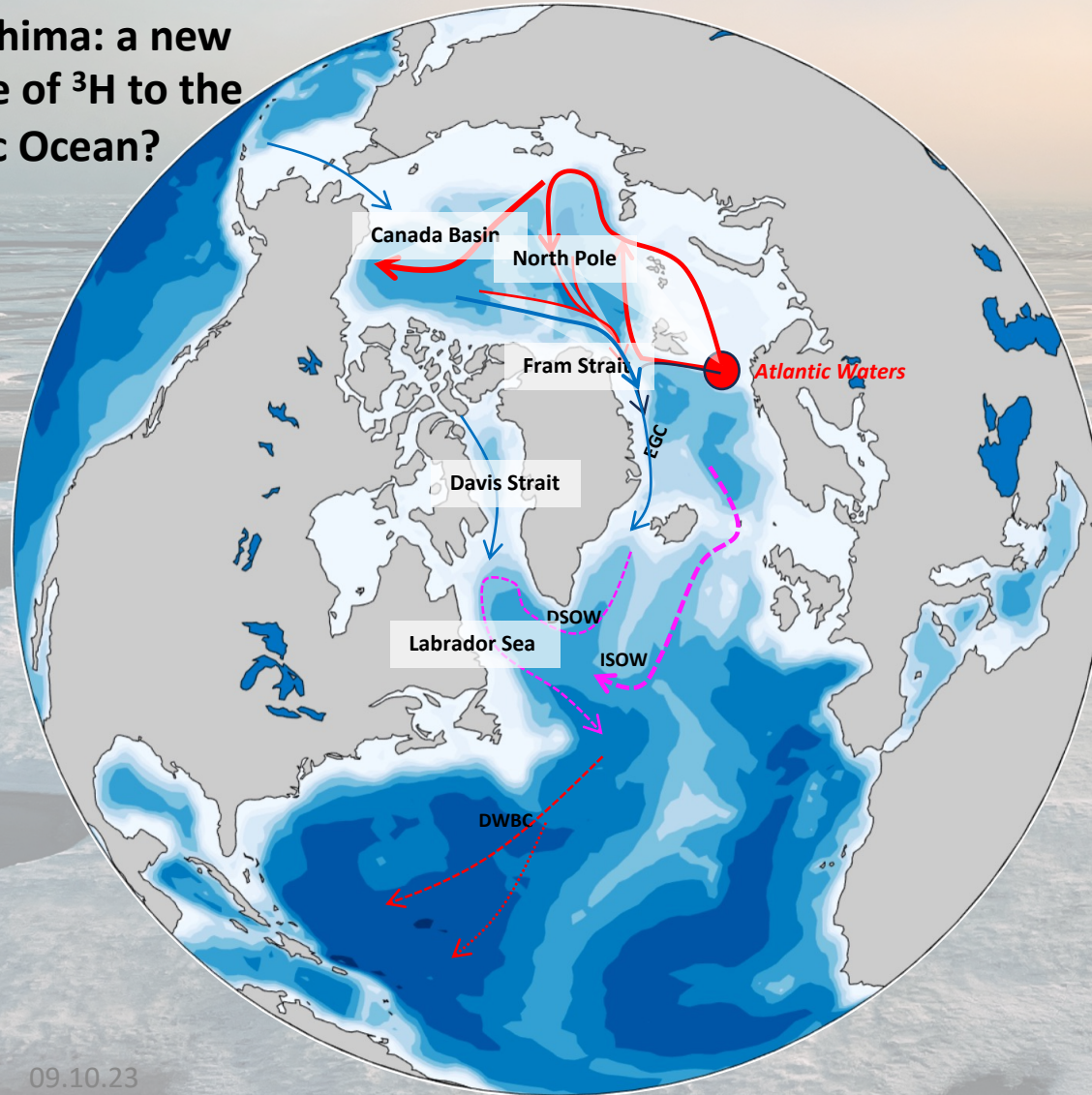
Most of the Atlantic Waters flowing in the Arctic, exit via Fram Strait. An increase of Pacific Waters (fresh) exiting the Fram Strait was observed between 2016 and 2019.

Recirculation of Atlantic Waters in the Fram Strait may contribute to about 50% to the East Greenland Current (EGC).

Denmark Strait Overflow Waters (DSOW) are formed from EGC shelf Waters and are very advective as they are transported from the source region to the Deep Labrador Sea, and beyond.

WHAT ELSE DO WE WANT TO LEARN?

Fukushima: a new source of ^3H to the Pacific Ocean?



What are the temporal changes of Ocean Circulation and what is their relation to Climate Change?

What is the role of the oceans in storing anthropogenic carbon and the rate of change?

NEXT EXPEDITIONS: ... COLLECTING EVIDENCE!!

2023


- Arctic Canada Basin (JOIS 2023)
- Labrador Sea (AR7W 2023)
- Grand Banks
- Fram Strait

2024

- Arctic Canada Basin (JOIS 2024)
- Central Arctic (Arcwatch 2024)
- Davis Strait
- Labrador Sea and Bafin Bay (Amundsen 2024)
- Nordic Seas (UFO 2024)

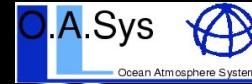
2025

- Arctic Makarov and Nansen Basin (AWI 2025)
- Nordic Seas (UFO 2025)
- Labrador Sea (AR7W 2025)
- ...

 Fisheries and Oceans
Canada
Pêches et Océans
Canada



Imperial College
London



Atmosphere and Ocean
Research Institute
The University of Tokyo



Laboratory of Ion Beam Physics

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Lorenza Raimondi
Lisa Leist
Annabel Payne
Duncan Dale
Marcel Scheiwiller
Habacuc Perez-Triboullier
Kayley Kündig
Bianca Wagenbach

Thank you!