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FLNP

DAN Experiment Onboard the Curiosity Rover: Modelling of the Neutron Sensors Response

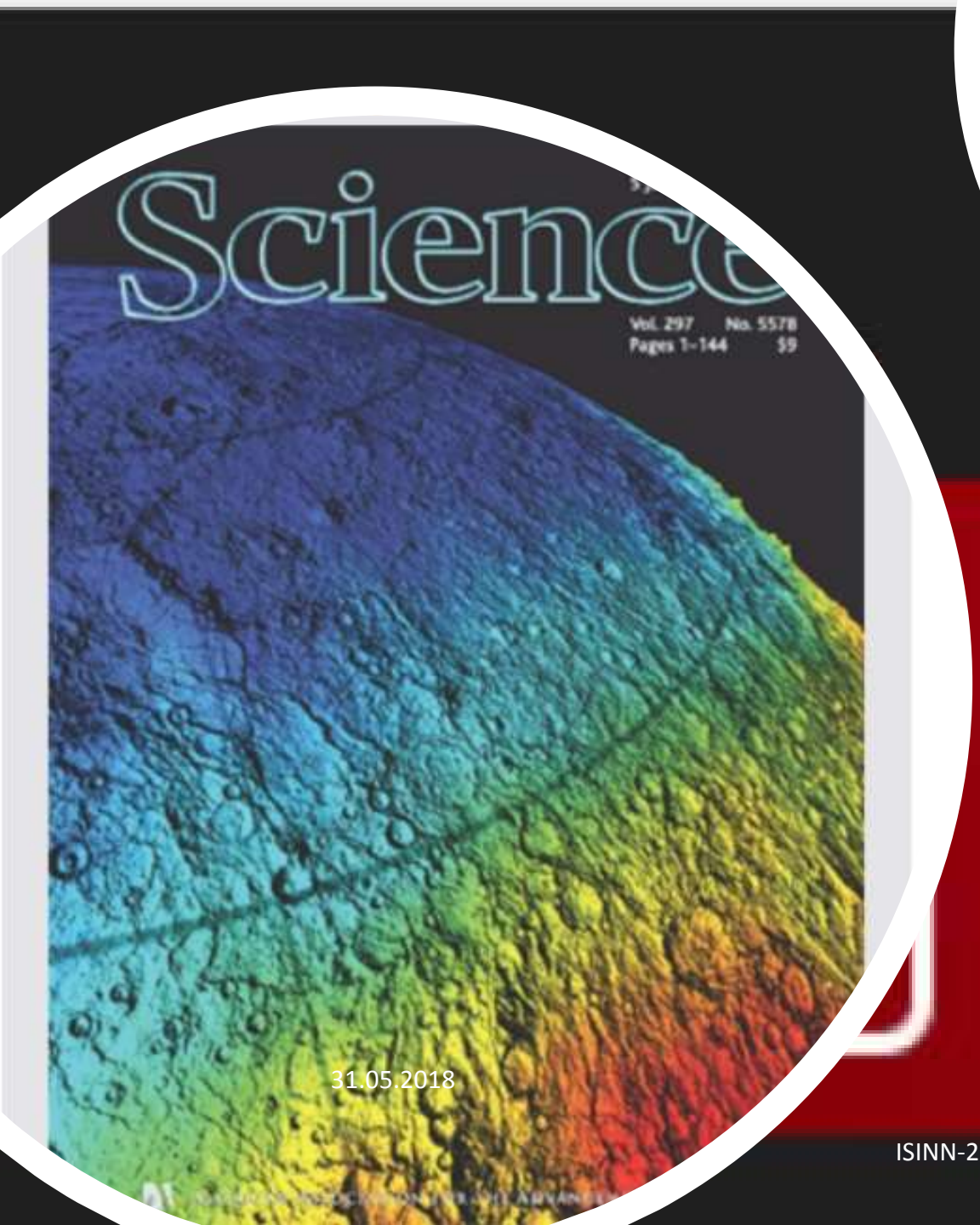
V. Shvetsov, FLNP JINR

ISINN-26, May 28 – June 1, 2018, Xi'an, China

西安交通大学
Xi'an Jiao Tong University

Overview

- Introduction;
- DAN experiment history;
- Martian Soil Modelling Stand at JINR;
- Experiments and Comparison with Martian Data;



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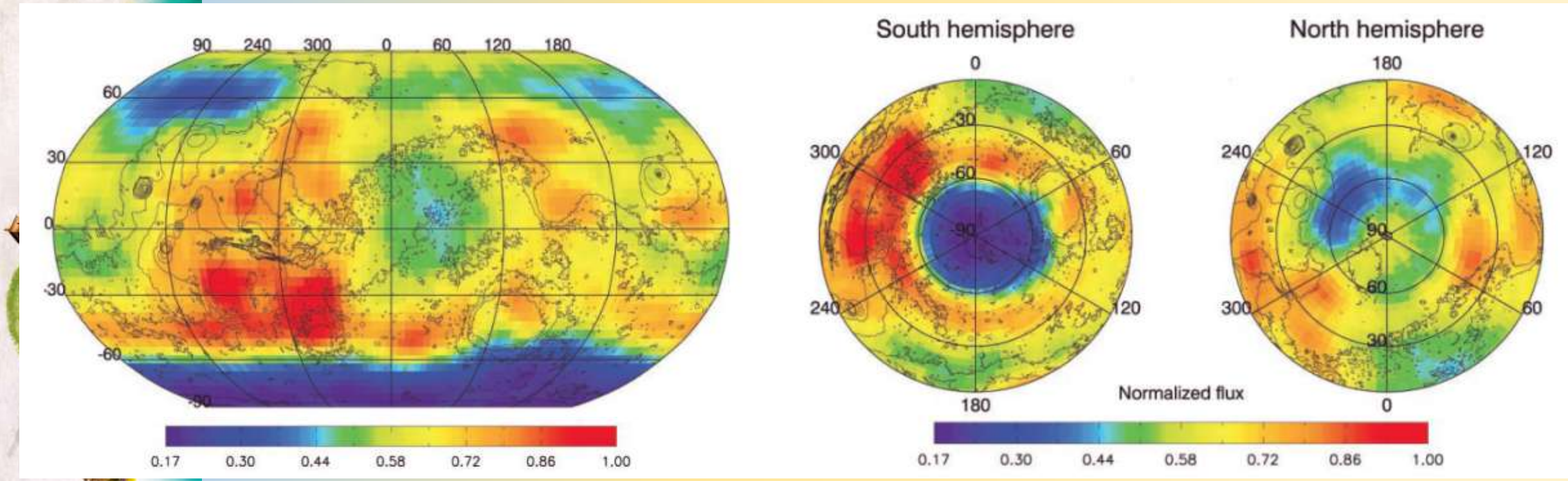

Fig. 1. The initial map of orbital measurements of martian epithermal neutrons by HEND with energies at 0.4 eV to 100 keV for the first 55 days of mapping. Pixels with sizes 4° × 4° are smoothed with the scale of 10°. The size of 4° at the equator corresponds to a linear scale of about 240 km. The contours of MOLA topography (*12*) are shown for comparison. The map is normalized to 1 at the pixel with the highest count rate, 0.26 counts/s in Solis Planum (270°E, 30°S). The minimal statistical significance of any pixel is above 5σ of background fluctuations; minimal time exposure for pixels is 600 s.

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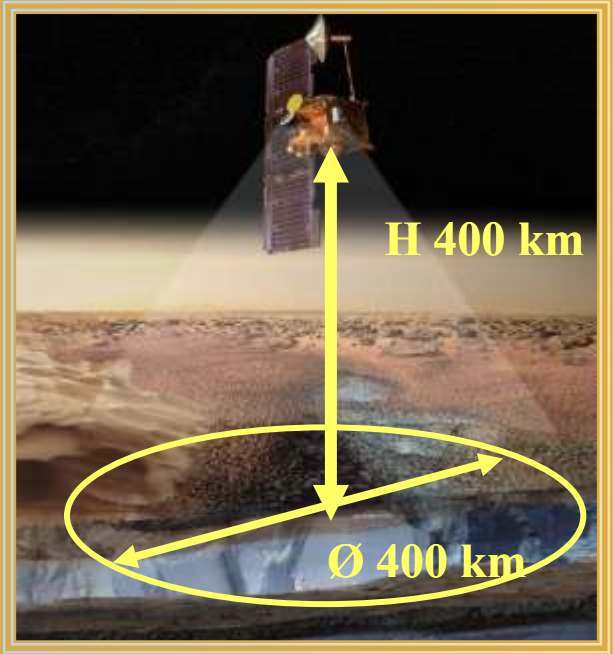
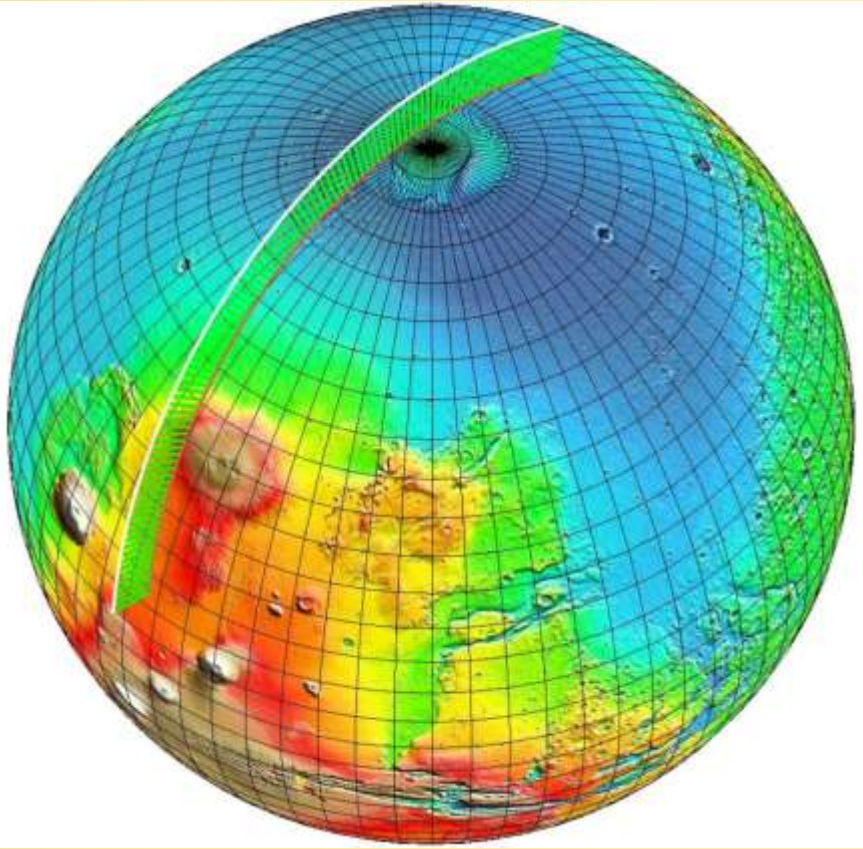
Building the Map
On the surface of planet making a mesh with selected size of pixels. In each pixel independently accumulating counts and exposure time. Selecting a time interval, detector and set of channels to create map.





Main parameters of orbit:
Altitude – 400 km;
Orbital period – 2 hours;
Orbit inclination – 93.1^0

Poor spatial resolution.
Pixel size is about 400 km.
Should be about 10-50 km to choose proper place for lander/rover mission

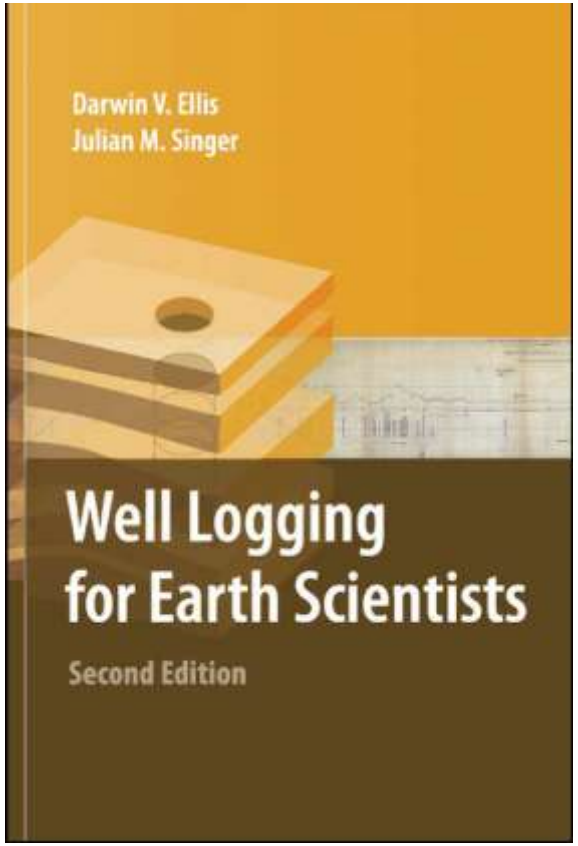
We need neutron detector with collimator on the orbiter

With collimated orbital detector we can choose proper place for landing. Now we need an instrument onboard the rover to seek for water ice under the wheels

Neutron logging

PONTECORVO, B., "Neutron Well Logging," *Oil and Gas Journal*, p. 32, September 11, 1941.

Flerov, G. N., and Alexeyev, F. A. The use of radioactive radiations in prospecting and developing oil deposits in the USSR: World Petroleum Cong., 4th sess., Rome, Proc.. sec. 1, p. 737–746, 1955.



Neutron Logging

Moderation

Inelastic Scattering

Elastic Scattering

Thermalizing

Gamma-rays

Activation

Gamma-rays

Activation

energy, MeV

10^{1} 10^{0} 10^{-1} 10^{-2} 10^{-3} 10^{-4}

10^{0} 10^{1} 10^{2} 10^{3} 10^{4}

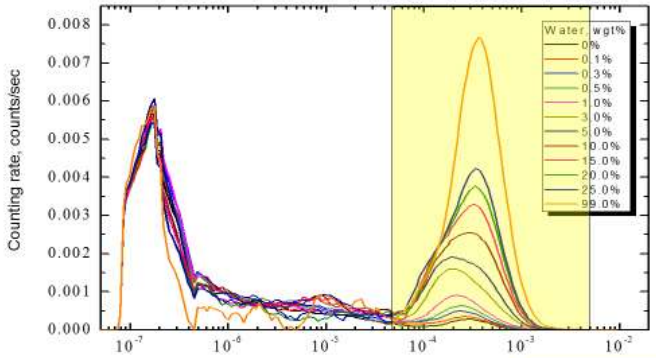
time, μs

2005 -2006: Testing DAN laboratory prototype

Numerical Modeling: Counting rate in case of active regime

Thermal neutrons counting rate obtained as difference between counting rate detected by CTN and CETN

Selection of time interval for analyzes of water amount in soil:



DAN Science Team

Name	Institution	Role in the team
Игорь МИТРОФАНОВ / Igor MITROFANOV (PI)	Институт космических исследований РАН / IKI	Principal Investigator
Максим ЛИТВАК / Maxim LITVAK (DPI and LS)	Институт космических исследований РАН / IKI	DAN leading scientist, physical analysis of DAN data for neutron activation
Антон САНИН / Anton SANIN (Co-I)	Институт космических исследований РАН / IKI	DAN project manager, instrument numerical calibrations
Александр КОЗЫРЕВ / Alexander KOZYREV (Co-I)	Институт космических исследований РАН / IKI	Monitoring and validation of DAN physical performance
Валерий ШВЕЦОВ / Valery SHVETSOV (Co-I)	Объединенный институт ядерных исследований /JINR	DAN physical calibration facilities
Руслан КУЗМИН / Ruslan KUZMIN (Co-I)	ГЕОХИ РАН / Vernadsky Institute	DAN representative in MSL landing site selection process
Давид ГИЛИЧИНСКИЙ / David GILICHINSKY (Co-I)	Институт почвоведения РАН /Institute of soil science	Field tests of DAN analogs, reference library for express data analysis
NASA-related Co-I #1	TBD	DAN express data analysis during operations
NASA-related Co-I #2	TBD	Inter-instrument DAN scientist
NASA-related Co-I #3	TBD	Fast numerical modeling for express data analysis
NASA-related Co-I #4	TBD	Development and delivery of DAN PDS data

RISK AREA

Physical measurements for DAN FU01calibrations

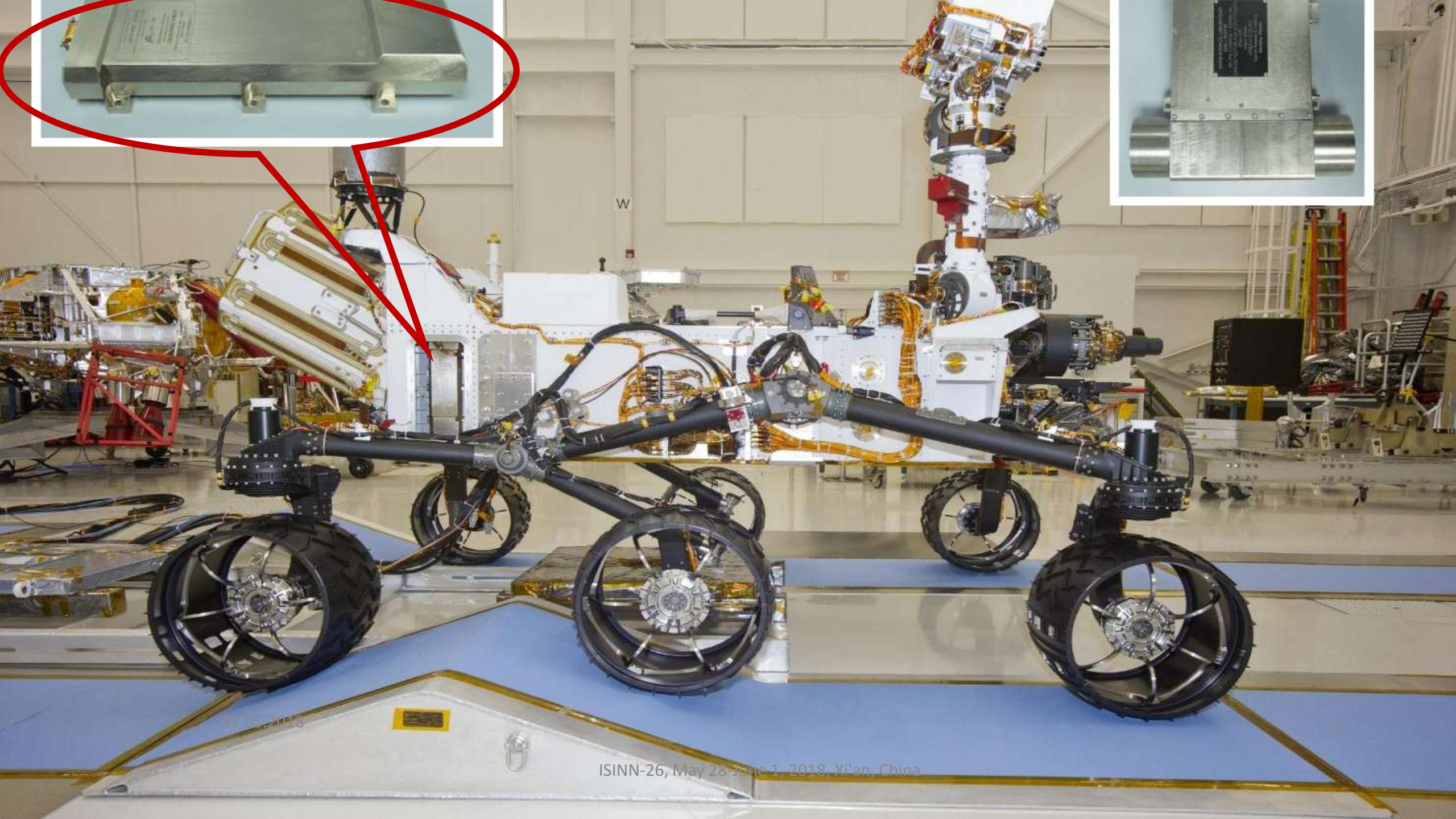
2004 - 2008

DAN: Instrument Delivery Review

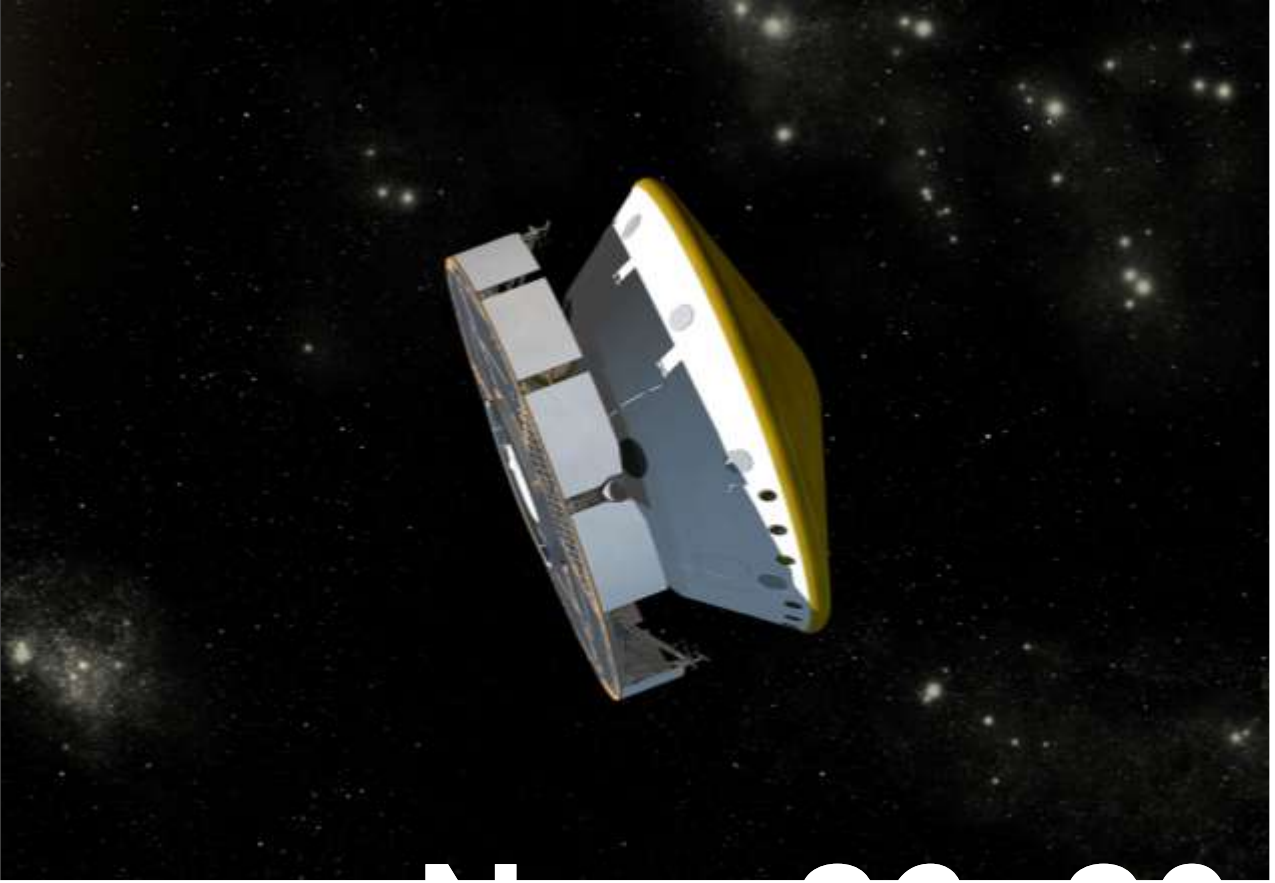
DAN/DE FM-1 characteristics

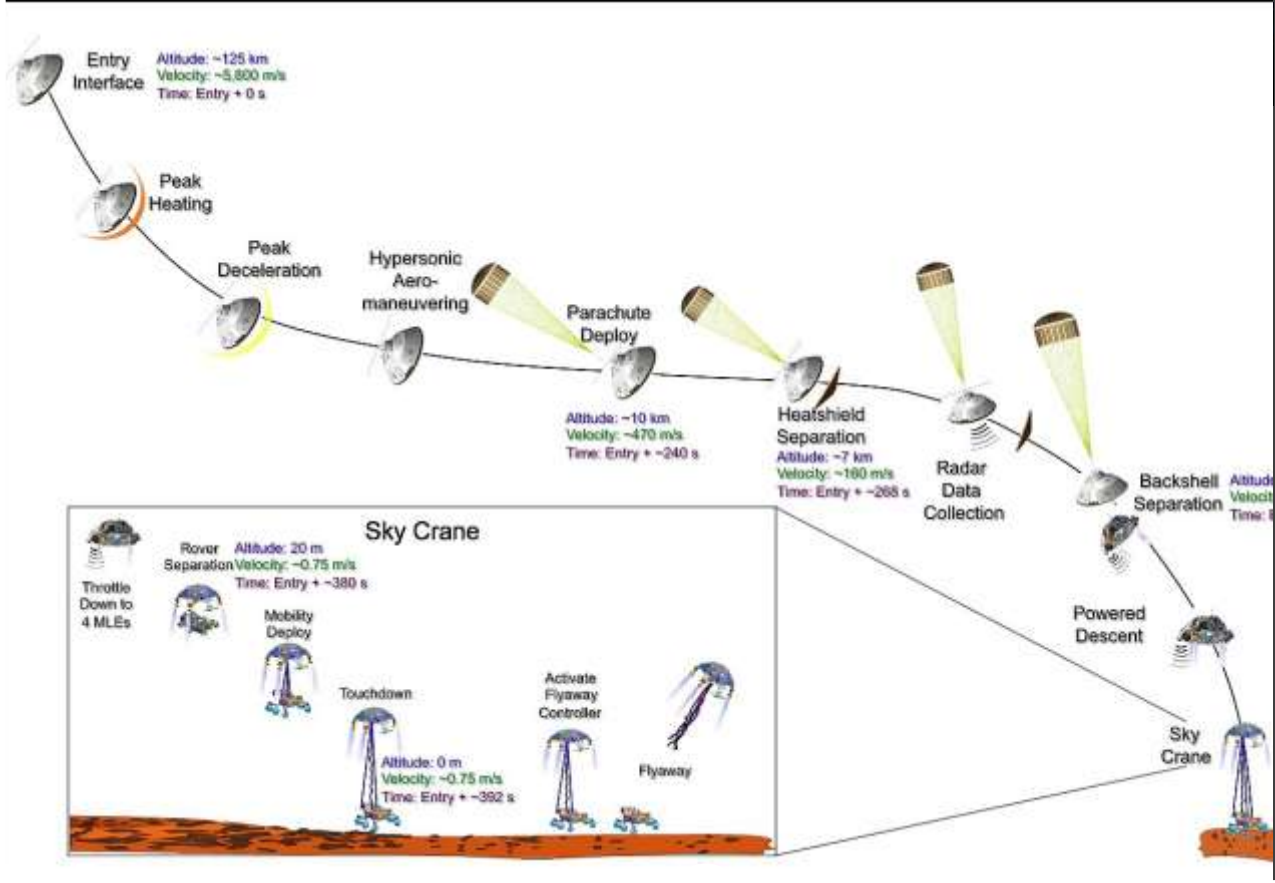
TABLE 1. The main DAN characteristics

Parameter	Value
Max Dimensions	204 x 61 x 211 mm
Mass	1.88 kg
Number of detectors	2 (CTN and CETN)
Neutron energy (detected neutrons)	<0.1 MeV (CTN detector) 0.4 eV – 0.1 MeV (CETN detector)
Number of spectra channels per each detector	16 (linear)
Time scale per each detector	64 (logarithmic)
Duration of Lowest time bin	2 μs
Spatial resolution	<1 m
Max Power in passive mode	< 4.1 W
Max Power at standby mode	< 3.0 W
Warranty	5 years
Operation temperature range	[-40, + 50] °C
Survival temperatures	[- 55, + 70] °C
Input Voltage range (Normal operations)	22 -36 V
Input Voltage range (Surviving)	0 – 40 V
Readiness to operate after switching power on	< 1 sec

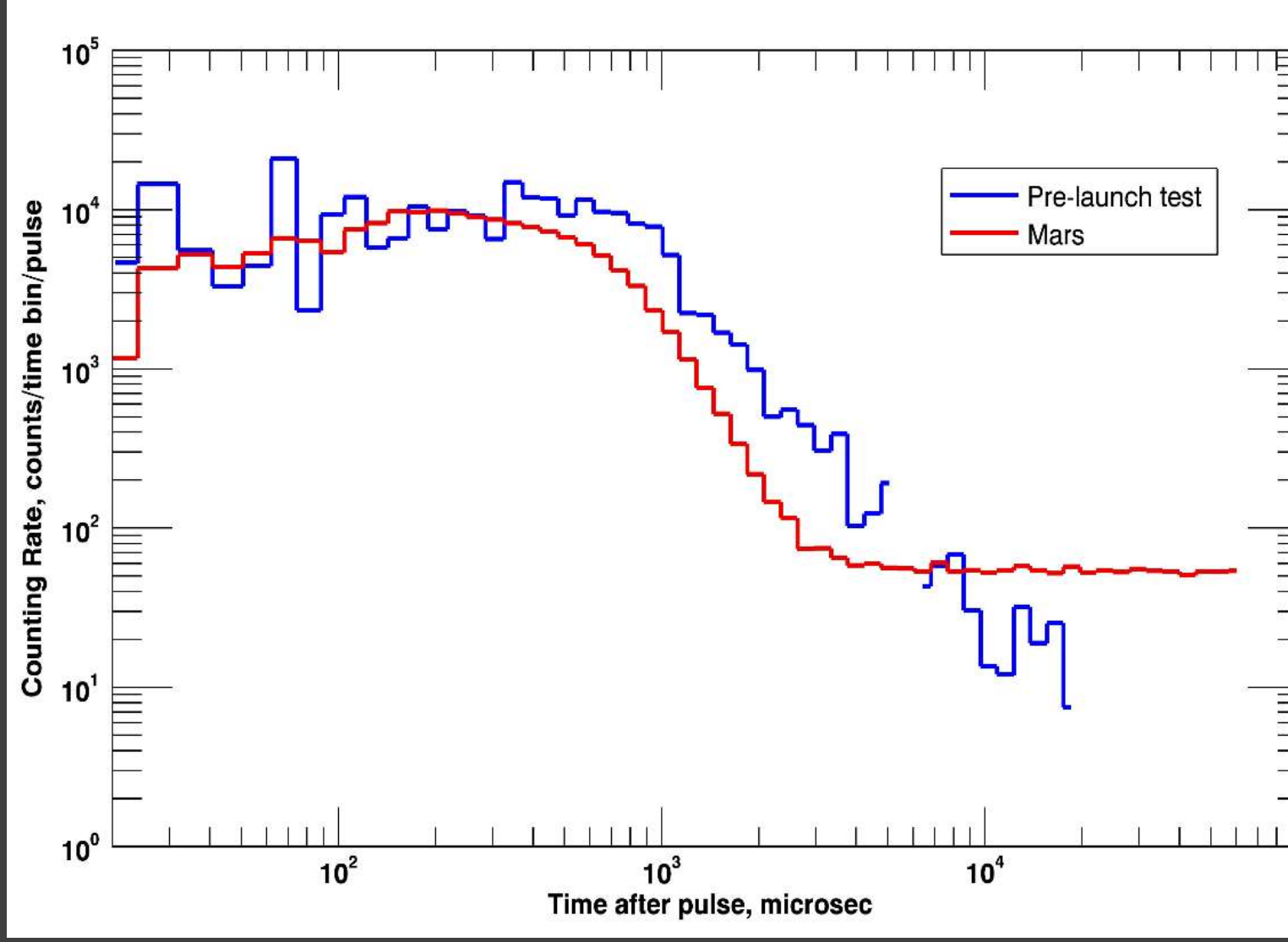


7:02 a.m. PST, Nov. 26, 2011





Nov. 26, 2011 - Aug. 6, 2012



Aug. 2012, Mars, Gale Crater

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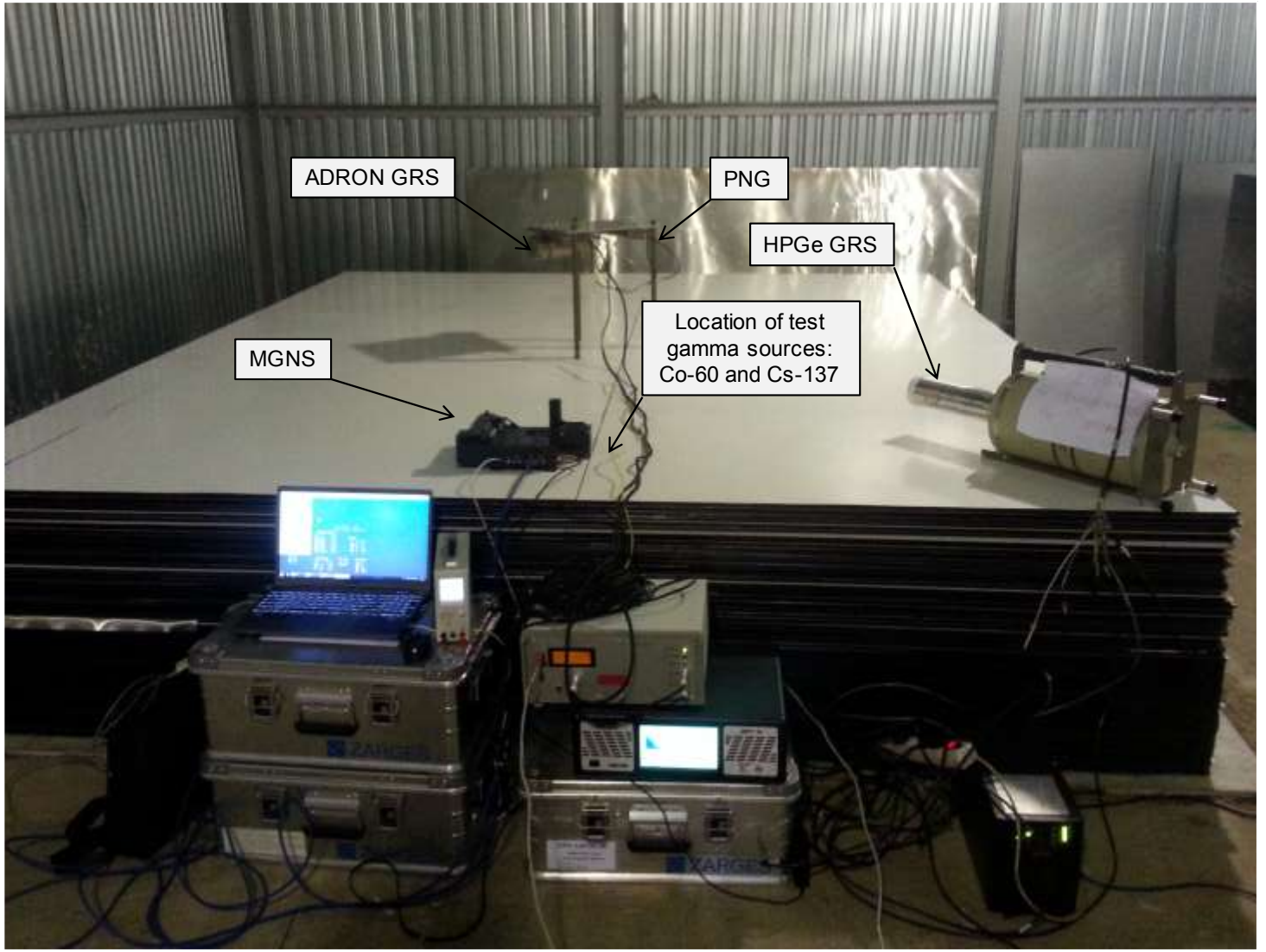
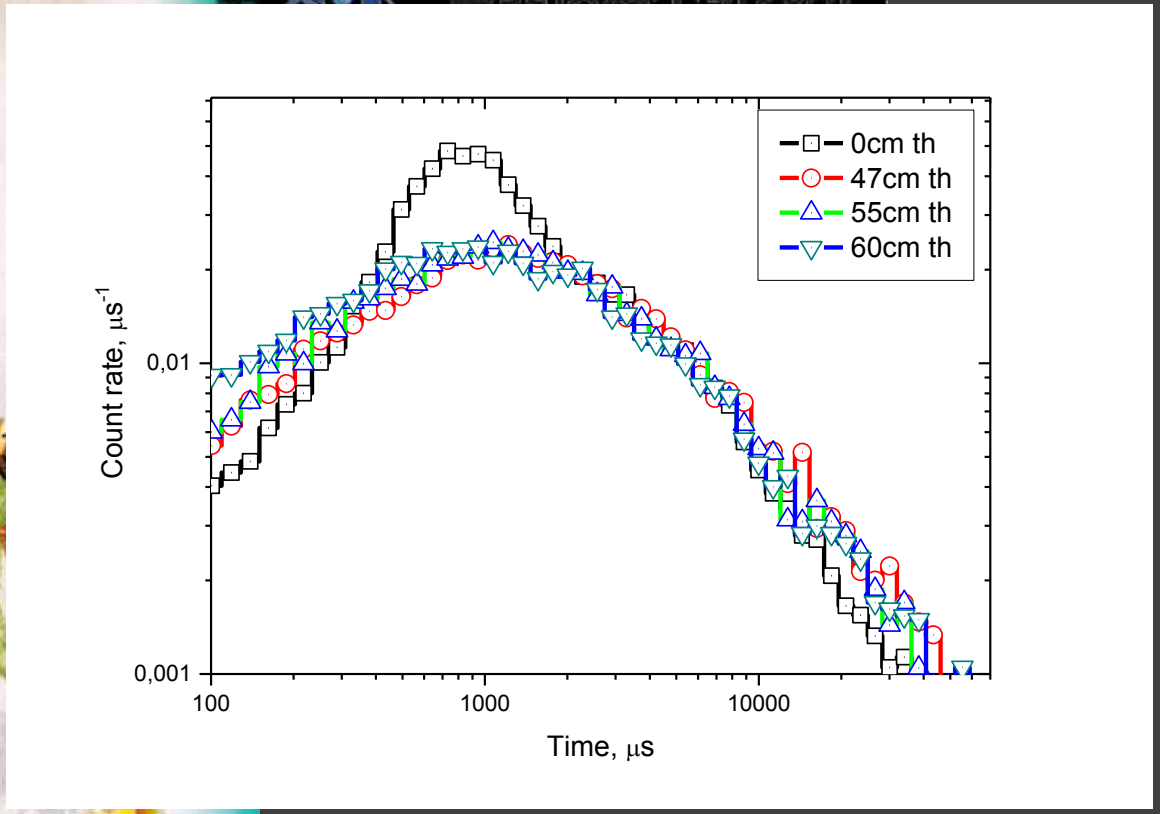
Table 1
Element
the tests

Eleme Oxide
SiO_2
Na_2O
MgO
Al_2O_3
K_2O
CaO
Fe_2O_3
Sr^b
Ba^b
Zr^b

Material	Layer thickness, mm
PVC	0,7
Al	1
Glass	10
Fe	1
Glass	10
Al	1
Glass	10
PVC	0,7
Fe	1
Glass	10
Al	1
Glass	10
PVC	0,7
Fe	1
Glass	10
Al	1
Glass	10
Fe	1
Glass	10
PVC	0.7
Al	1
Glass	10
Fe	1
Glass	10



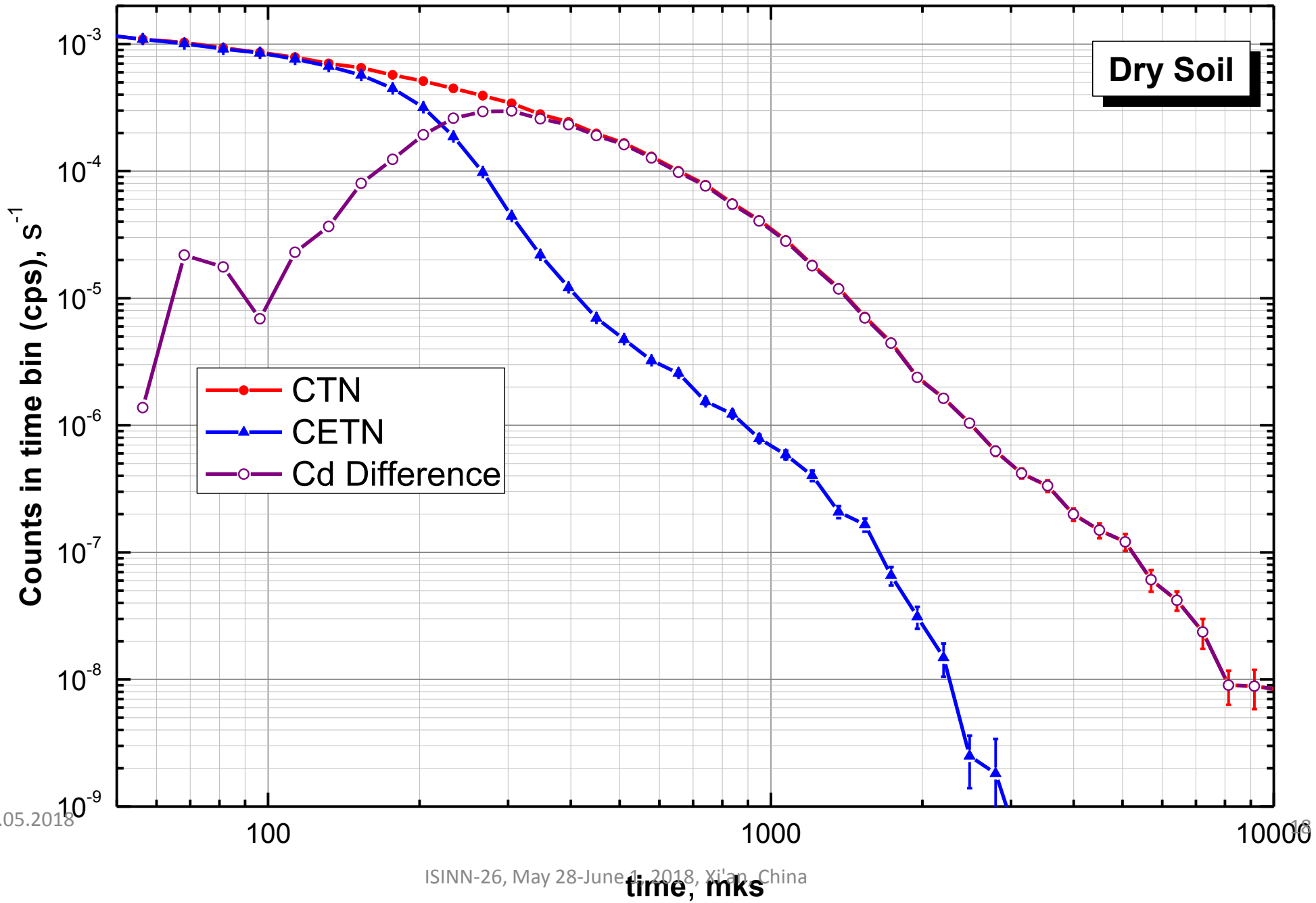
22,7

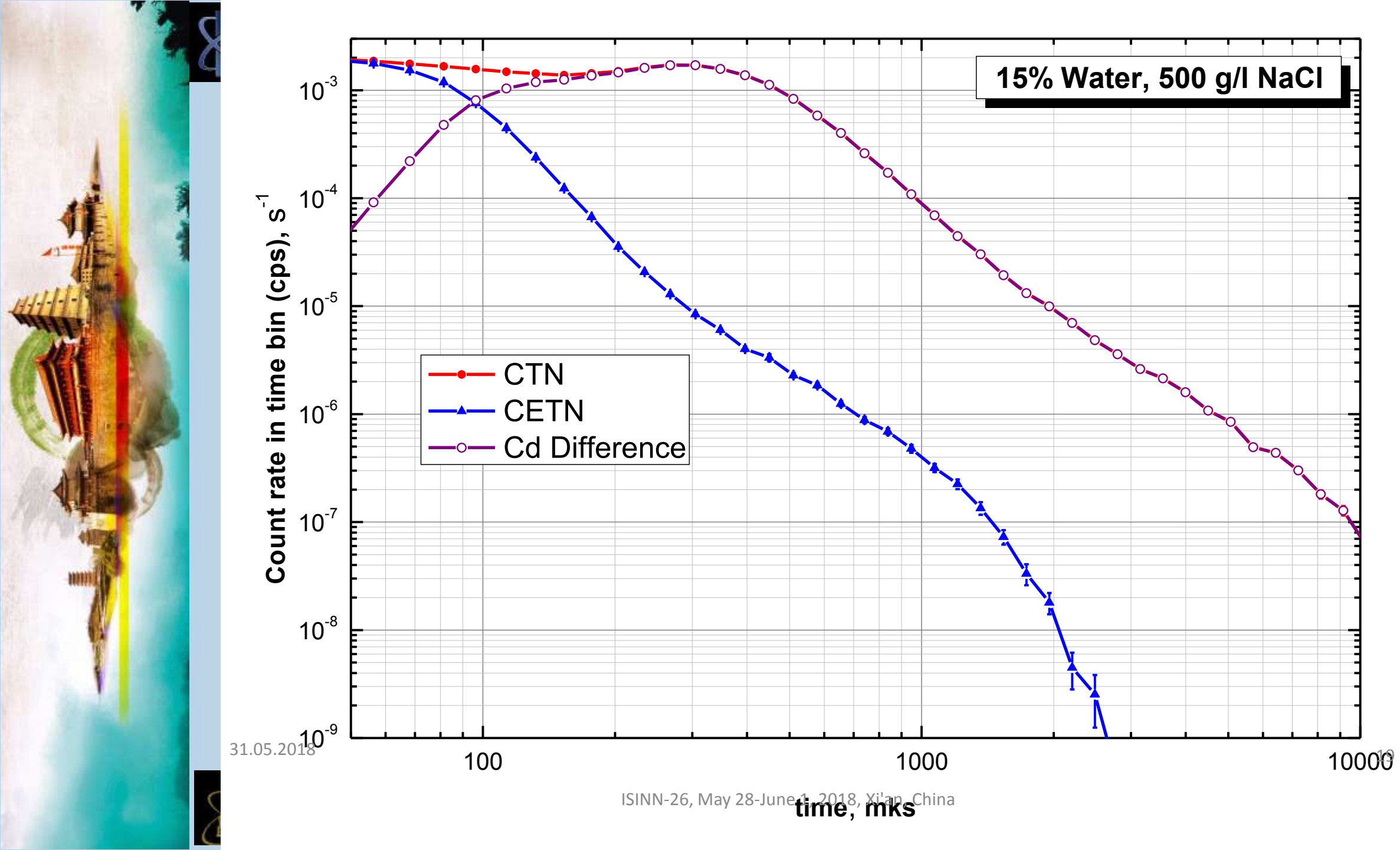


DAN FU2 at the Martian Soil Model

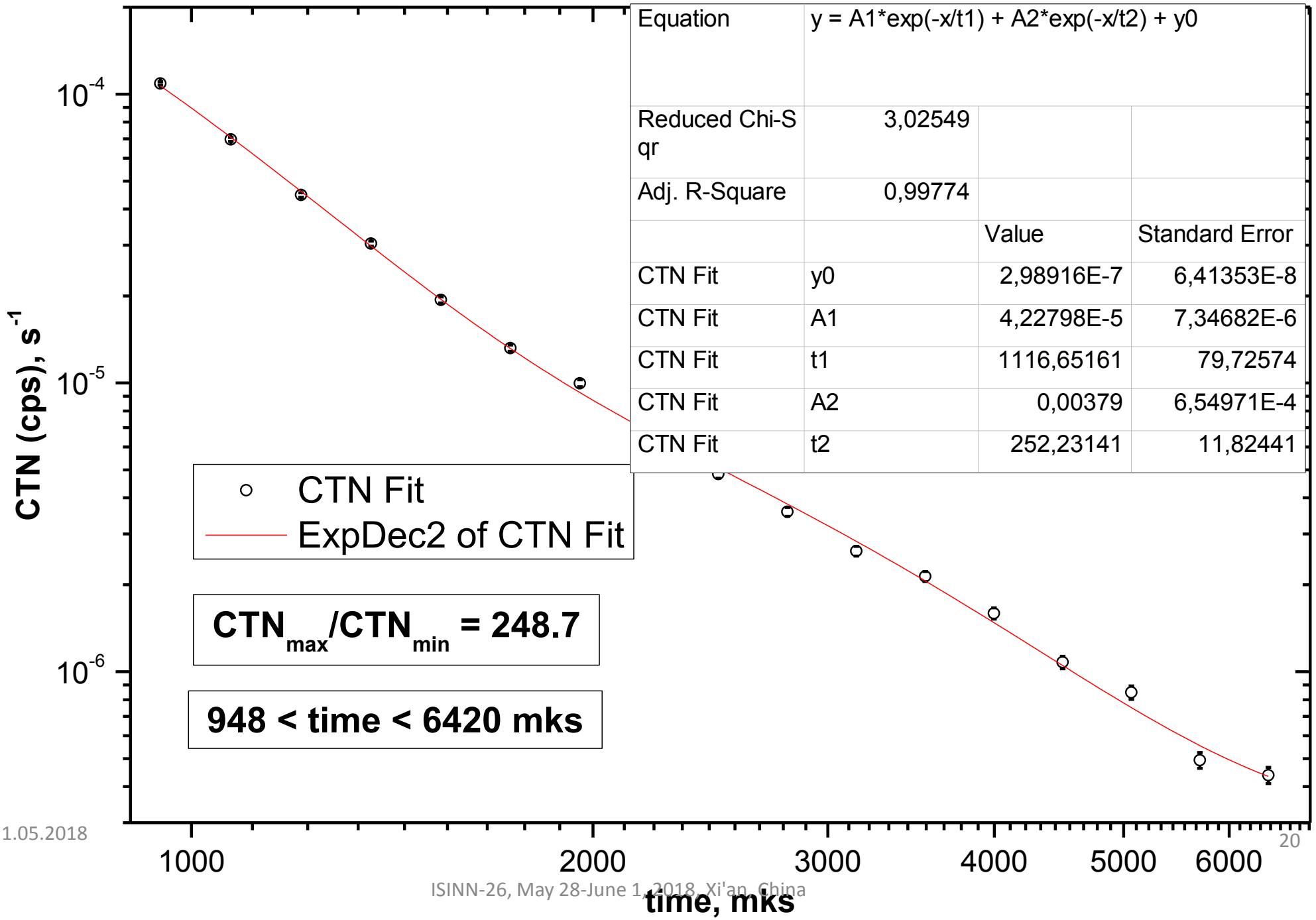
DAN CTN and CETN Sensors Response Modelling

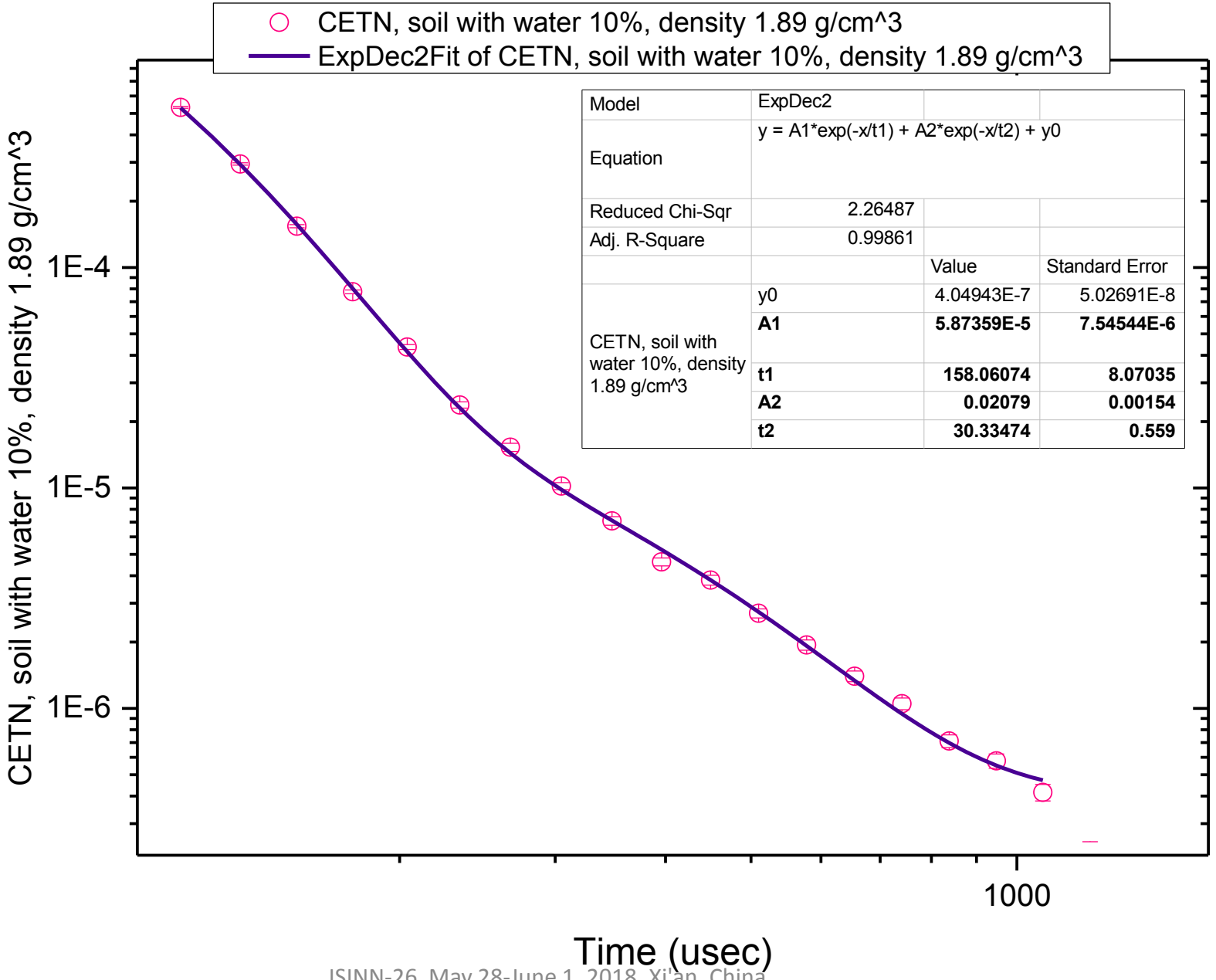
- Variation of the water ice content from the dry soil to 15% weight;
- Variation of the salinity from 0 to 500 g/l;
- Extracted parameters – die away constants;


Dry Soil
CTN
CETN
Cd Difference
Counts in time bin (cps), s-1
time, mks
10-3
10-4
10-5
10-6
10-7
10-8
10-9
100
1000
10000

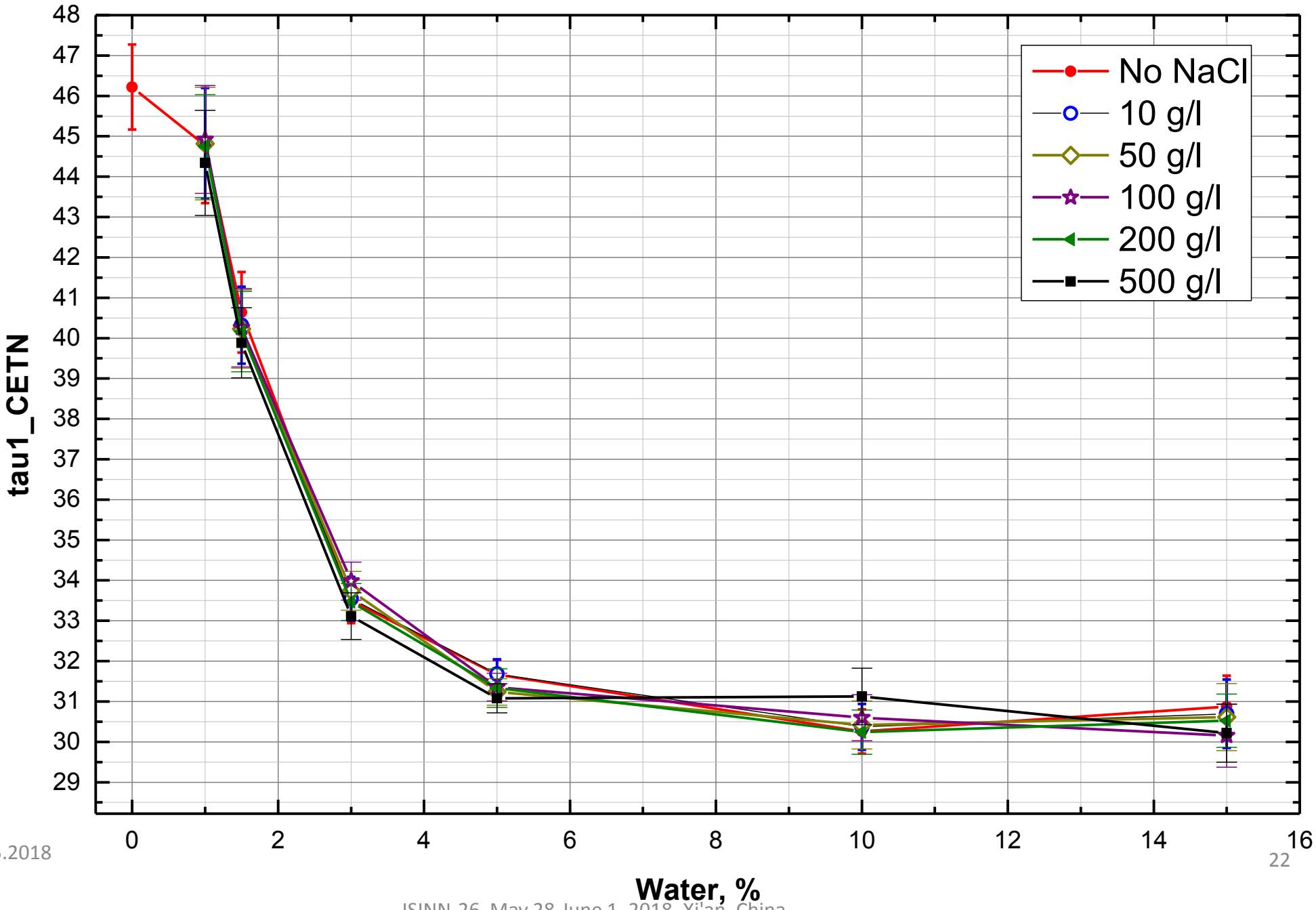

15% Water, 500 g/l NaCl
CTN
CETN
Cd Difference
Count rate in time bin (cps), s-1
time, mks
10-3
10-4
10-5
10-6
10-7
10-8
10-9
100
1000
10000

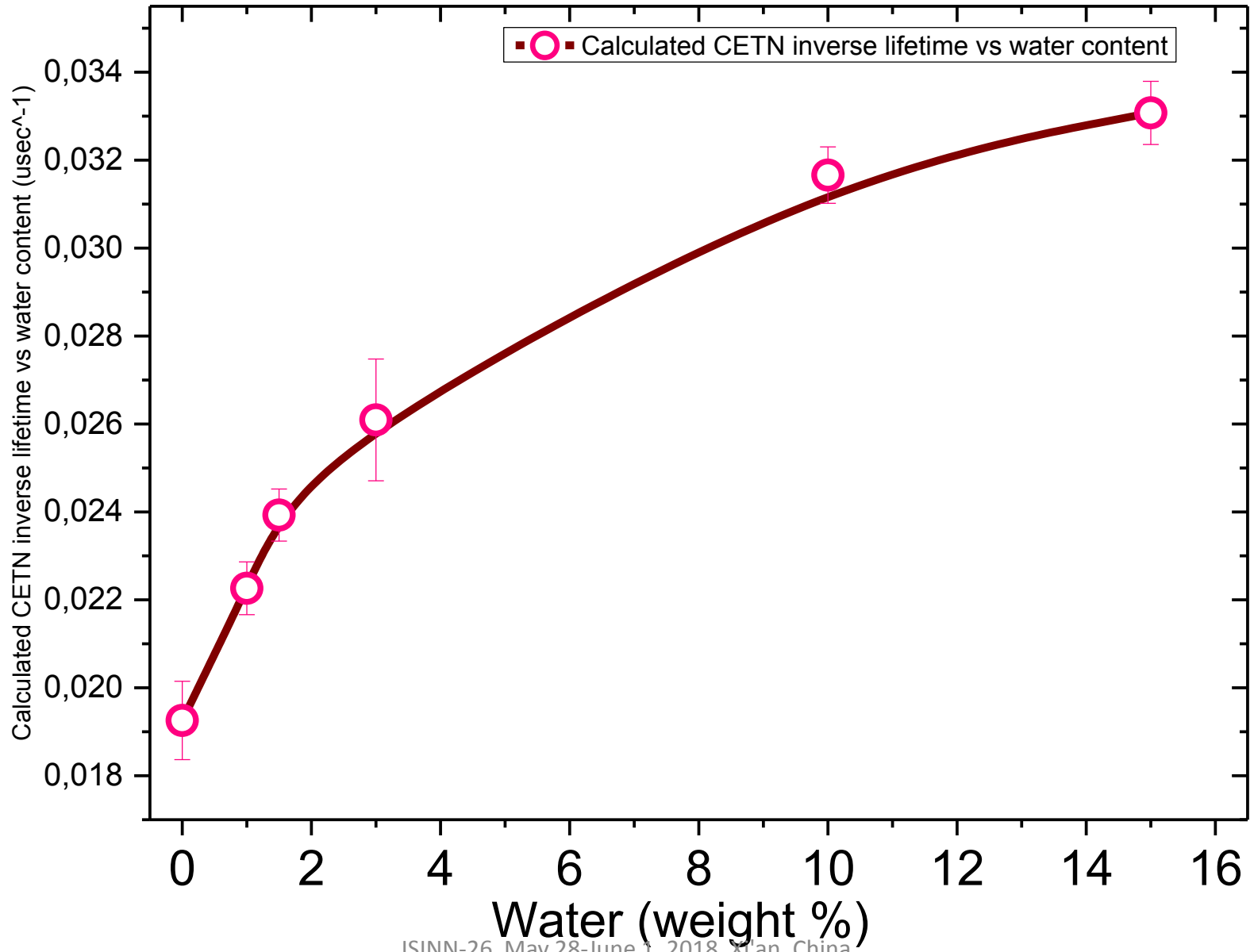
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2) + y0		
Reduced Chi-Sqr	3,02549		
Adj. R-Square	0,99774		
		Value	Standard Error
CTN Fit	y0	2,98916E-7	6,41353E-8
CTN Fit	A1	4,22798E-5	7,34682E-6
CTN Fit	t1	1116,65161	79,72574
CTN Fit	A2	0,00379	6,54971E-4
CTN Fit	t2	252,23141	11,82441

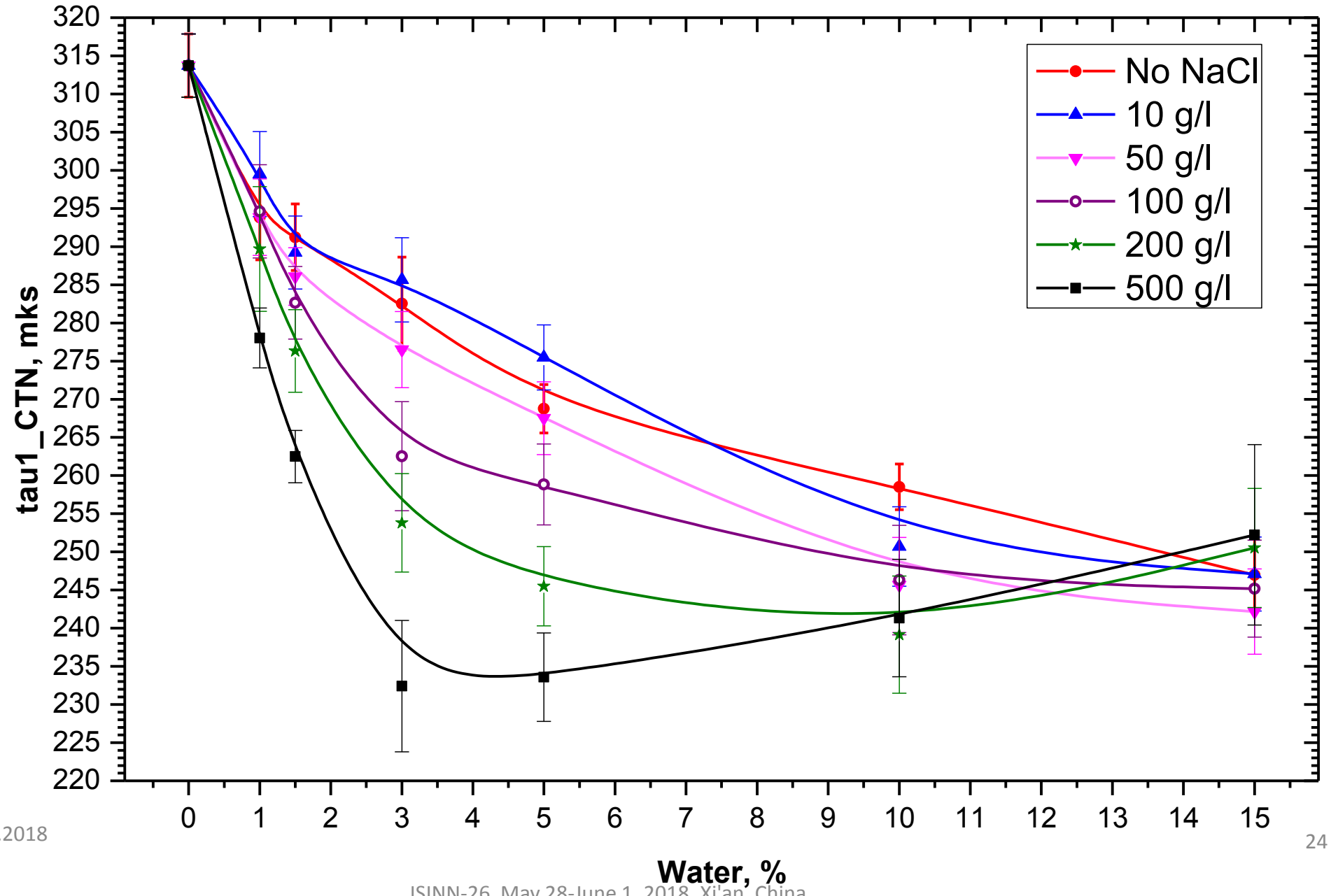


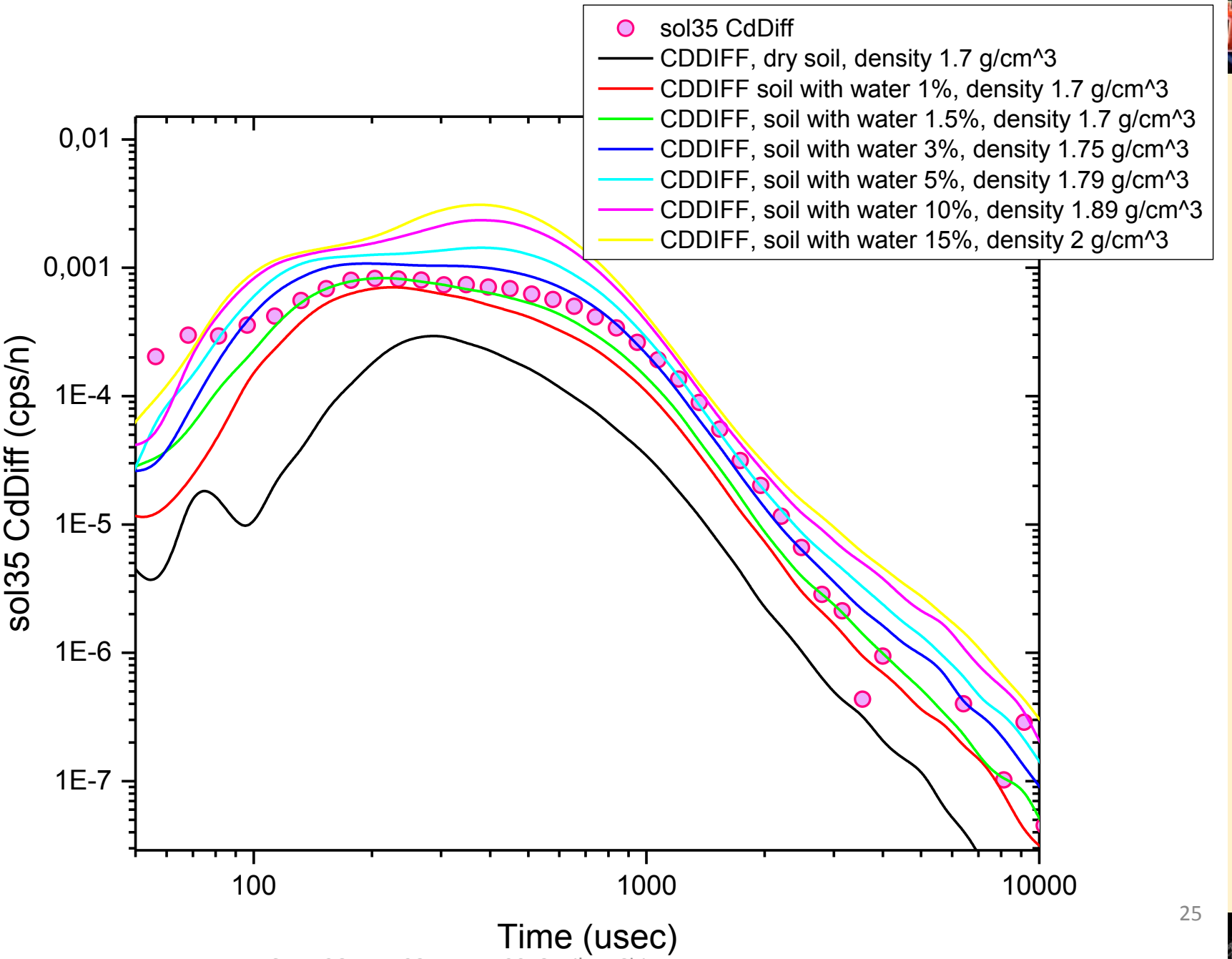


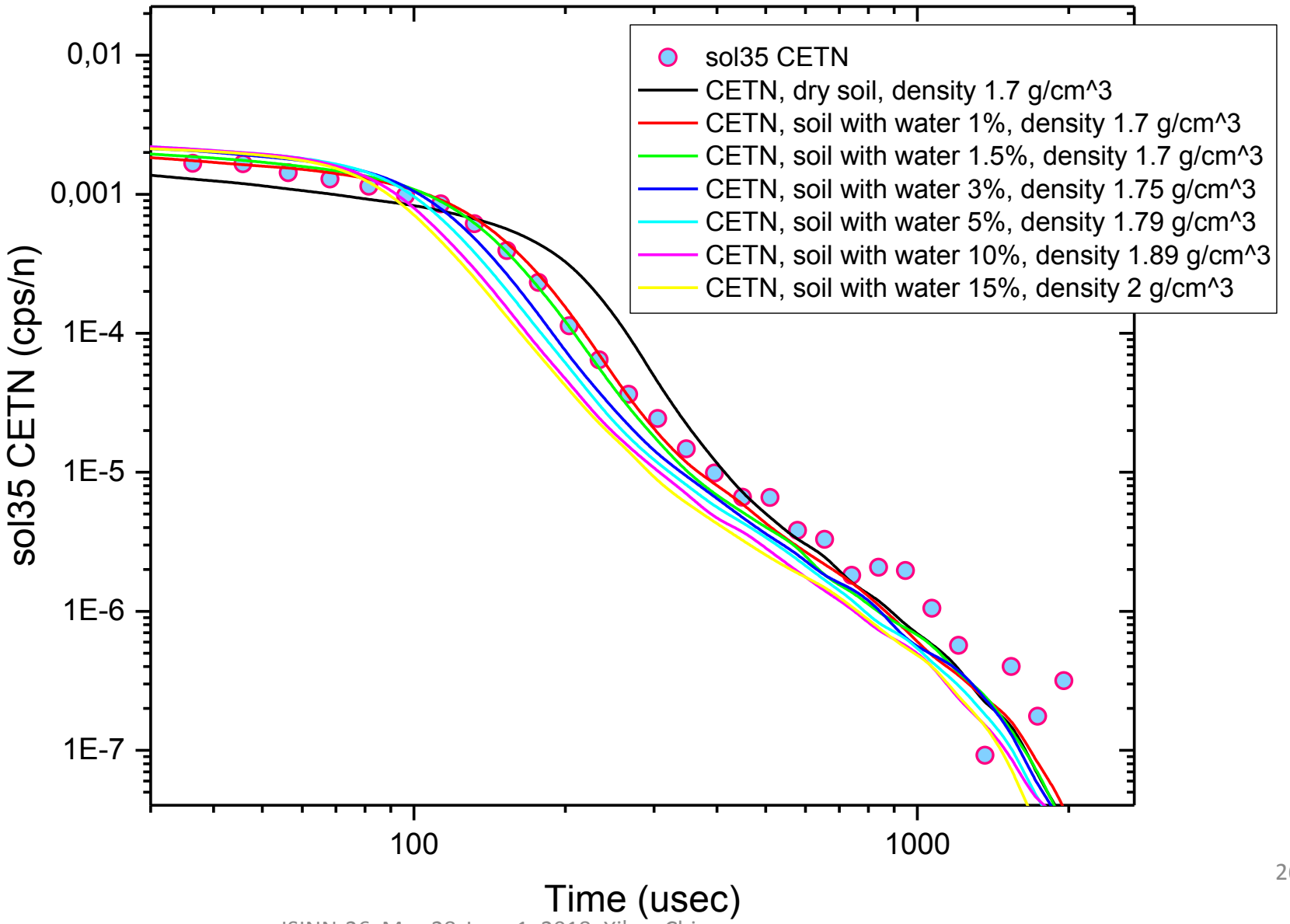
Model	ExpDec2		
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2) + y0		
Reduced Chi-Sqr	2.26487		
Adj. R-Square	0.99861		
		Value	Standard Error
CETN, soil with water 10%, density 1.89 g/cm^3	y0	4.04943E-7	5.02691E-8
	A1	**5.87359E-5**	**7.54544E-6**
	t1	**158.06074**	**8.07035**
	A2	**0.02079**	**0.00154**
	t2	**30.33474**	**0.559**

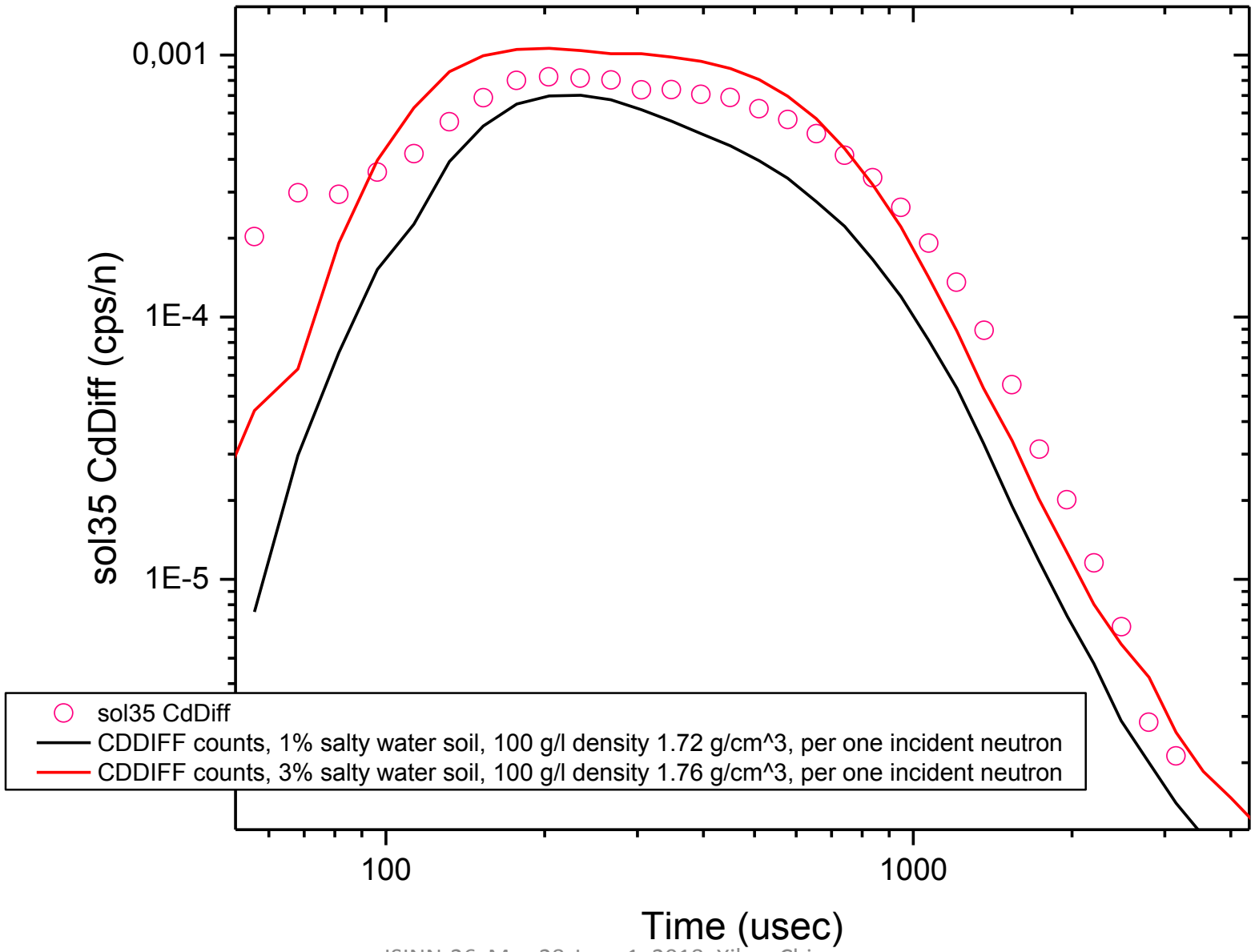

tau1_CETN
Water, %
No NaCl
10 g/l
50 g/l
100 g/l
200 g/l
500 g/l
48
47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
29
0
2
4
6
8
10
12
14
16

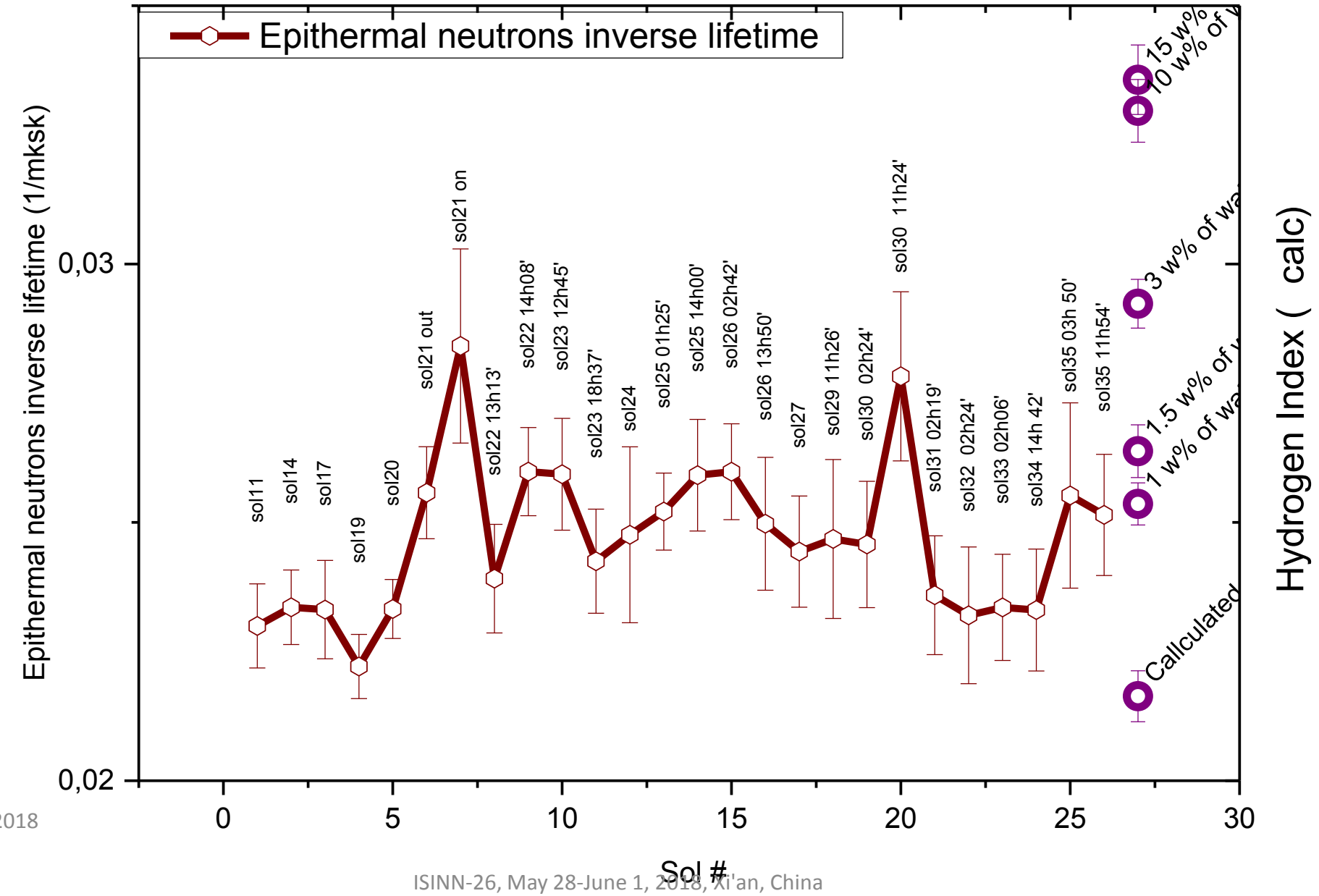

Calculated CETN inverse lifetime vs water content
Calculated CETN inverse lifetime vs water content (usec^-1)
0,034
0,032
0,030
0,028
0,026
0,024
0,022
0,020
0,018
0
2
4
6
8
10
12
14
16
Water (weight %)


tau1_CTN, mks
Water, %
No NaCl
10 g/l
50 g/l
100 g/l
200 g/l
500 g/l
320
315
310
305
300
295
290
285
280
275
270
265
260
255
250
245
240
235
230
225
220
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


sol35 CdDiff
CDDIFF, dry soil, density 1.7 g/cm^3
CDDIFF soil with water 1%, density 1.7 g/cm^3
CDDIFF, soil with water 1.5%, density 1.7 g/cm^3
CDDIFF, soil with water 3%, density 1.75 g/cm^3
CDDIFF, soil with water 5%, density 1.79 g/cm^3
CDDIFF, soil with water 10%, density 1.89 g/cm^3
CDDIFF, soil with water 15%, density 2 g/cm^3
0,01
0,001
1E-4
1E-5
1E-6
1E-7
sol35 CdDiff (cps/n)
100
1000
10000
Time (usec)


sol35 CETN
CETN, dry soil, density 1.7 g/cm^3
CETN, soil with water 1%, density 1.7 g/cm^3
CETN, soil with water 1.5%, density 1.7 g/cm^3
CETN, soil with water 3%, density 1.75 g/cm^3
CETN, soil with water 5%, density 1.79 g/cm^3
CETN, soil with water 10%, density 1.89 g/cm^3
CETN, soil with water 15%, density 2 g/cm^3
sol35 CETN (cps/n)
0,01
0,001
1E-4
1E-5
1E-6
1E-7
100
1000
Time (usec)


0,001
1E-4
1E-5
sol35 CdDiff (cps/n)
100
1000
Time (usec)
sol35 CdDiff
CDDIFF counts, 1% salty water soil, 100 g/l density 1.72 g/cm^3, per one incident neutron
CDDIFF counts, 3% salty water soil, 100 g/l density 1.76 g/cm^3, per one incident neutron


Epithermal neutrons inverse lifetime
Epithermal neutrons inverse lifetime (1/mksk)
0,03
0,02
0
5
10
15
20
25
30
Sol #
sol11
sol14
sol17
sol19
sol20
sol21 out
sol21 on
sol22 13h13'
sol22 14h08'
sol23 12h45'
sol23 18h37'
sol24
sol25 01h25'
sol25 14h00'
sol26 02h42'
sol26 13h50'
sol27
sol29 11h26'
sol30 02h24'
sol30 11h24'
sol31 02h19'
sol32 02h24'
sol33 02h06'
sol34 14h 42'
sol35 03h 50'
sol35 11h54'
15 w%
10 w% of
3 w% of wa
1.5 w% of
1 w% of wa
Callculated
Hydrogen Index (calc)