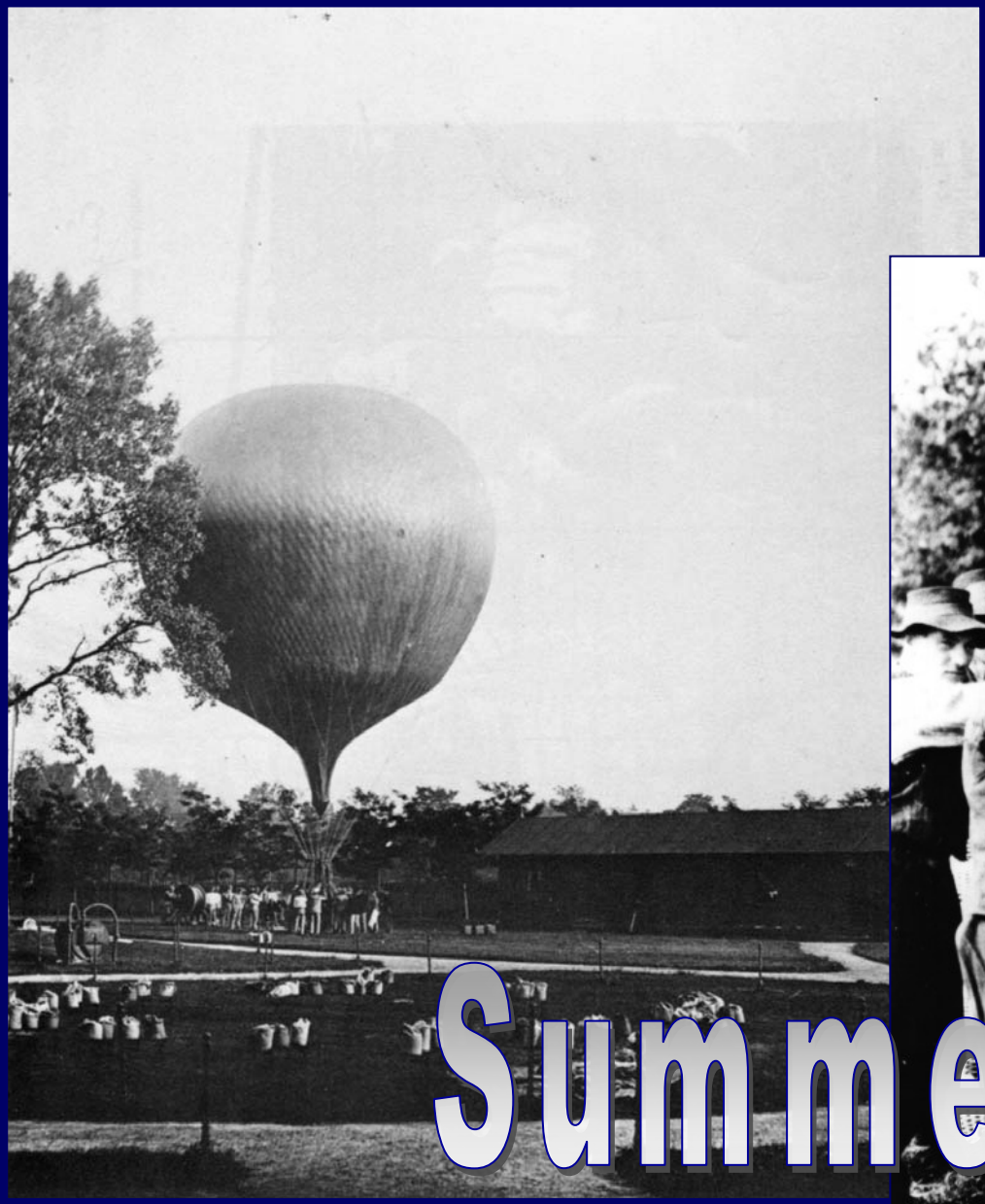
IceCube

Neutrino Astronomy at the South Pole

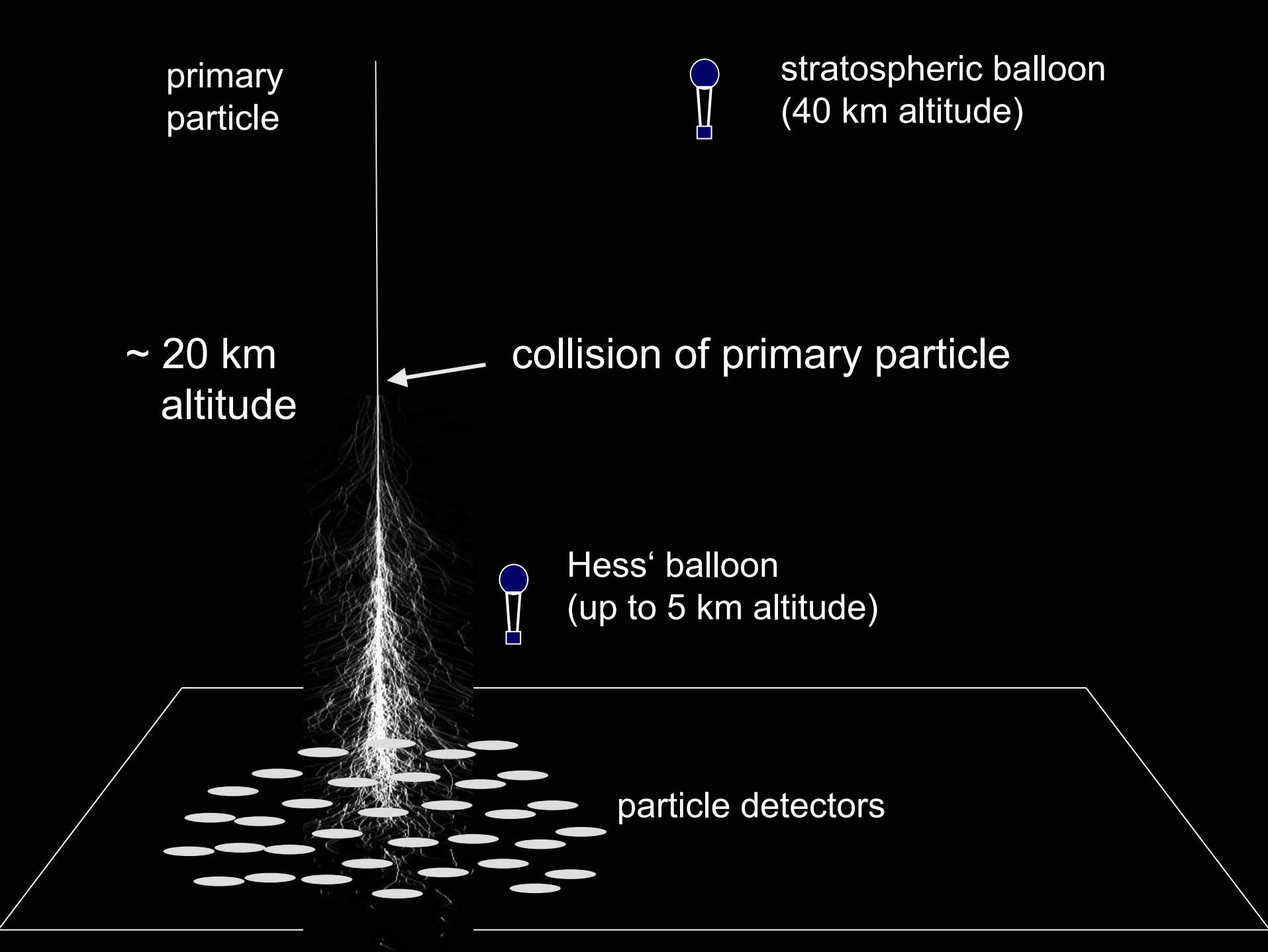
C. Spiering

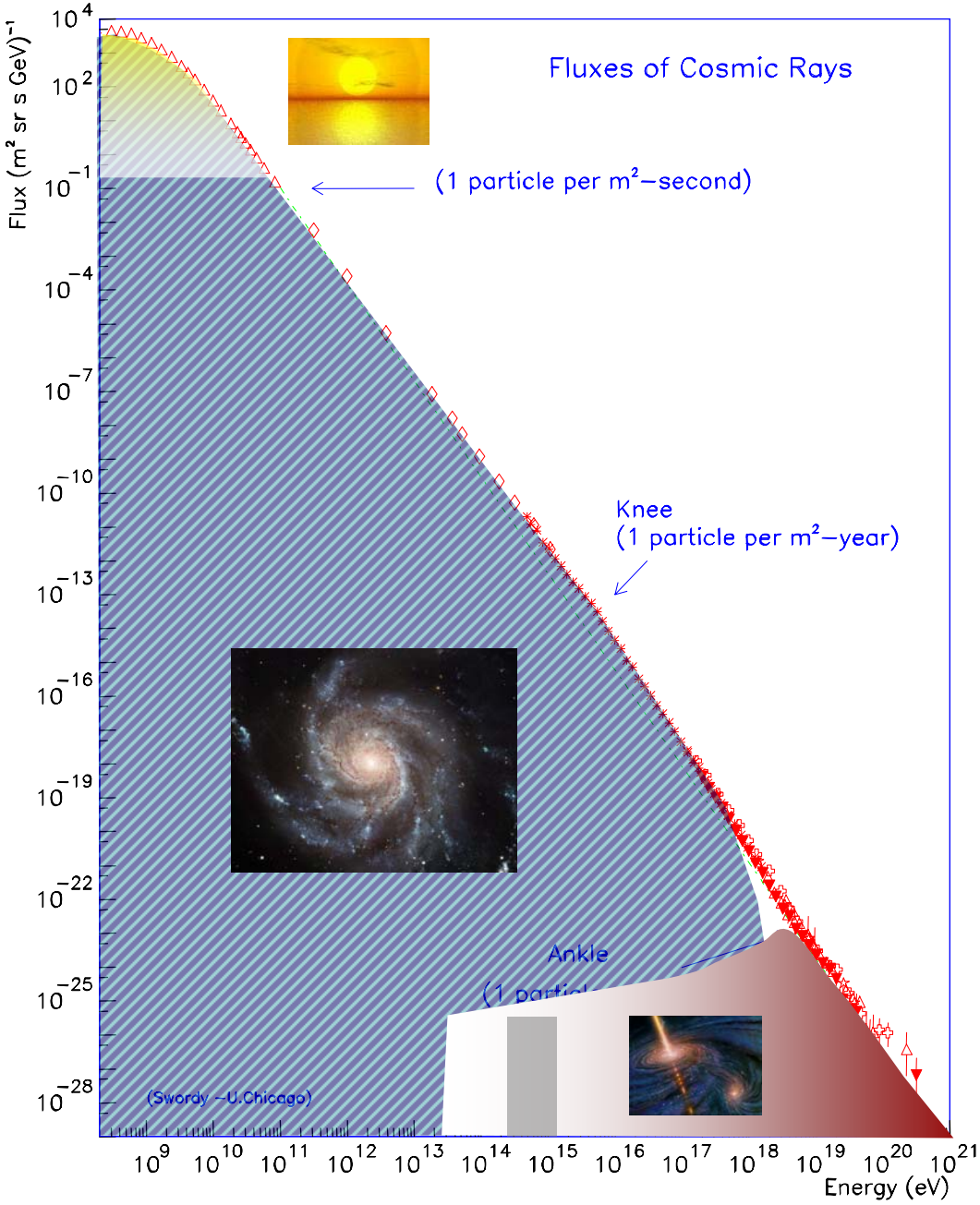
Freiburg, 15.12. 2008

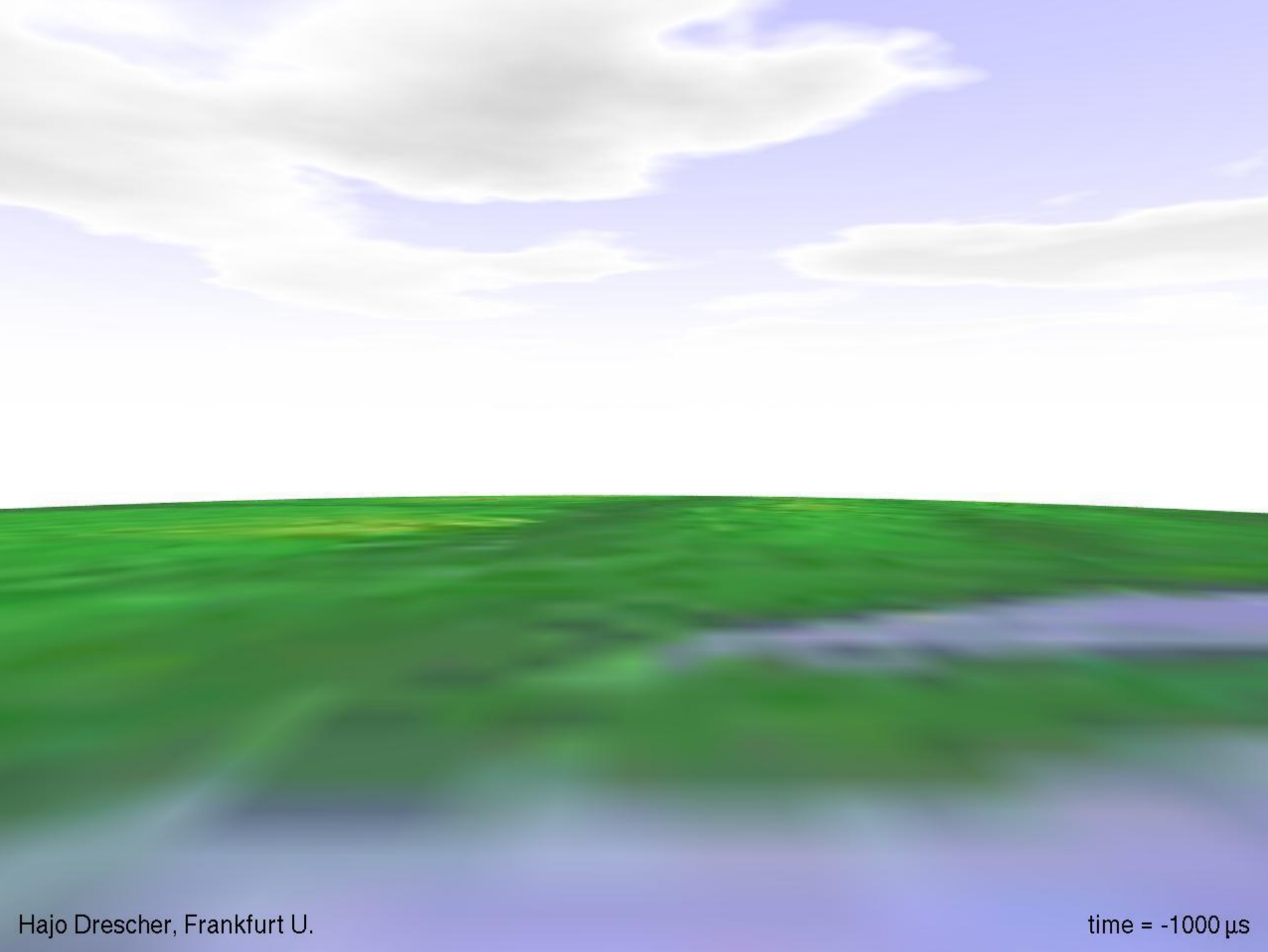
Victor Hess
1912

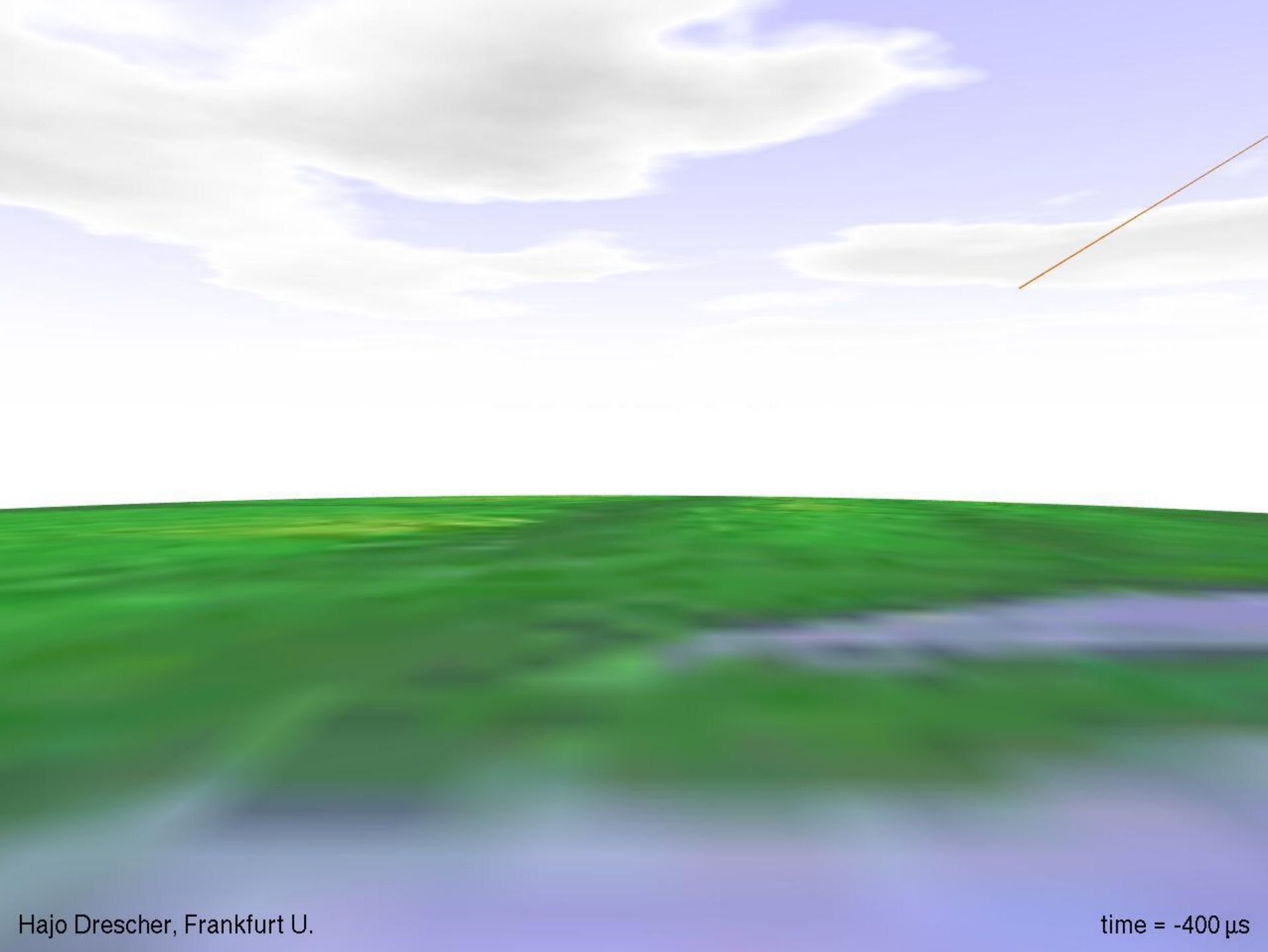


Summer 1912


primary particle
stratospheric balloon (40 km altitude)
~ 20 km altitude
collision of primary particle
Hess‘ balloon (up to 5 km altitude)
particle detectors


Fluxes of Cosmic Rays
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(Swordy – U.Chicago)
Flux (m² sr s GeV)⁻¹
Energy (eV)


Hajo Drescher, Frankfurt U.
time = -1000 µs


Hajo Drescher, Frankfurt U.
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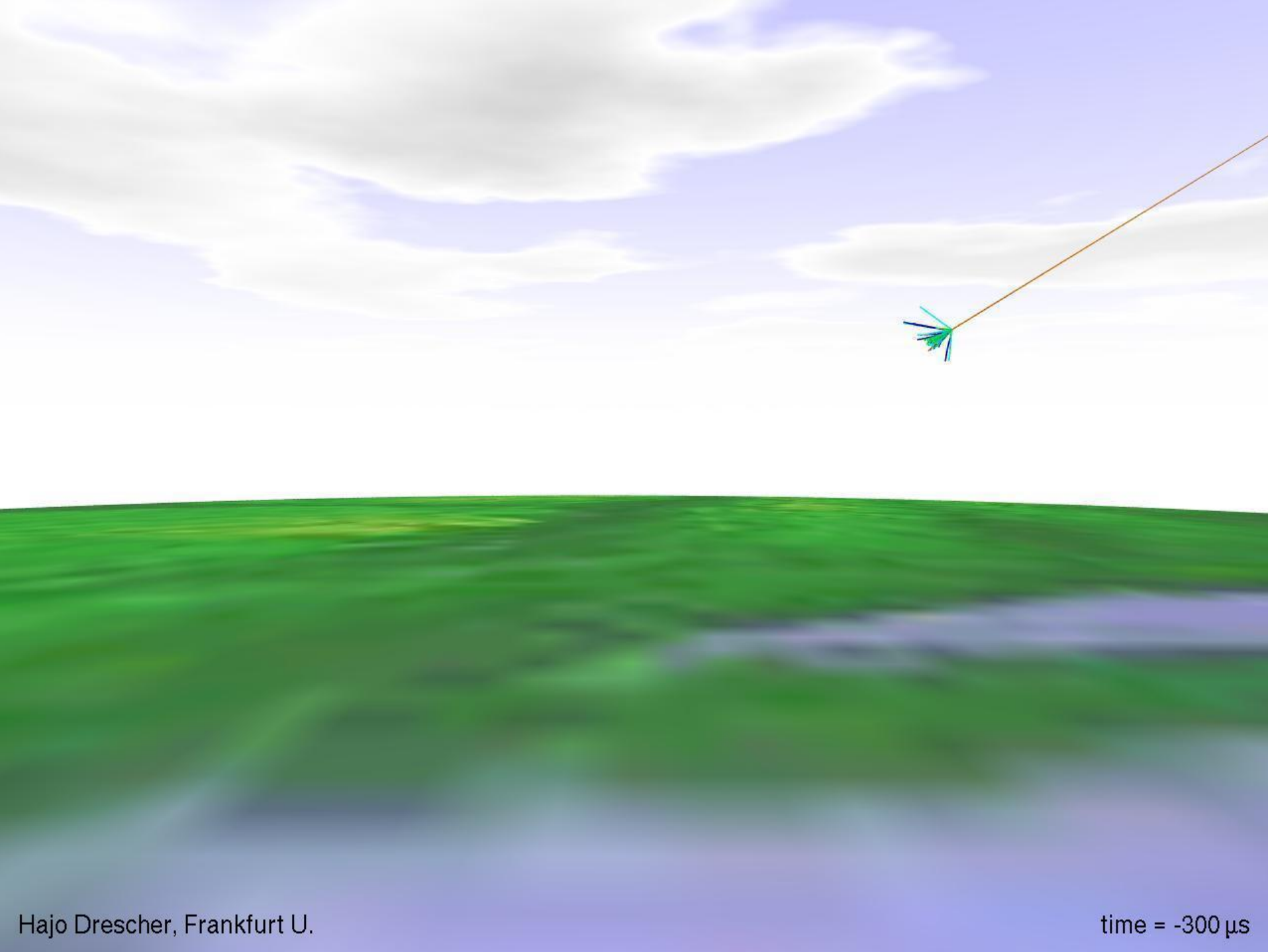
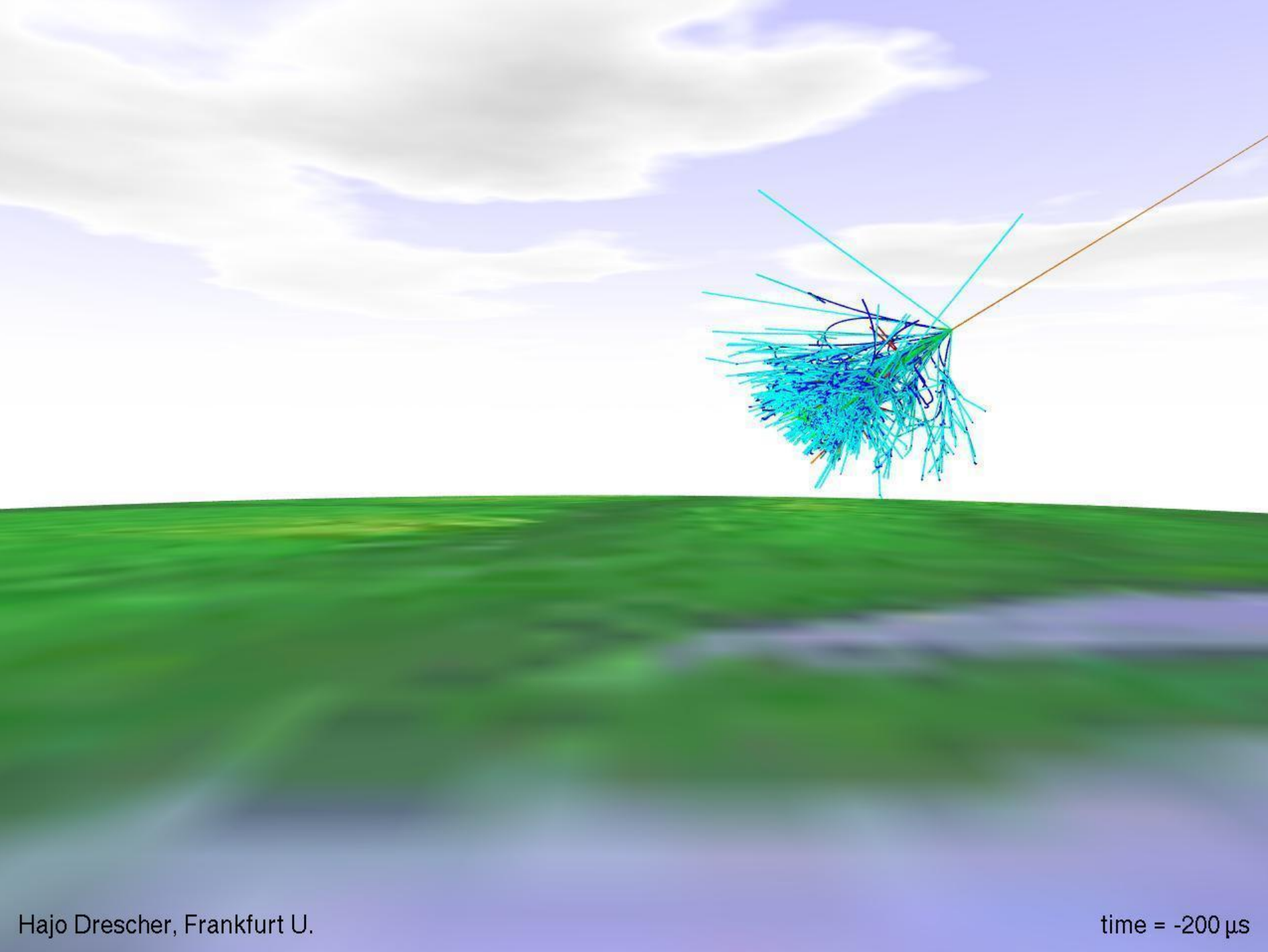
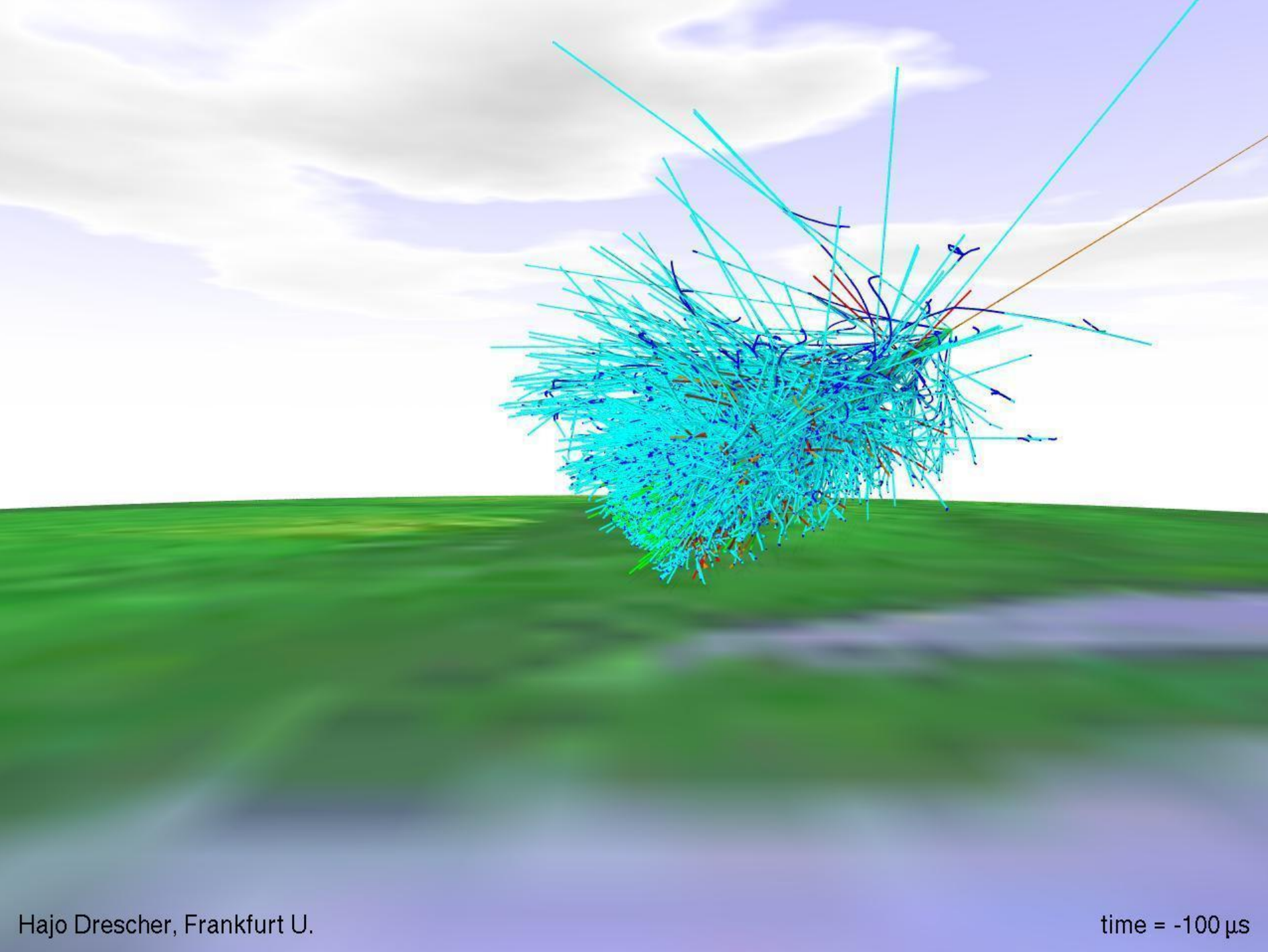
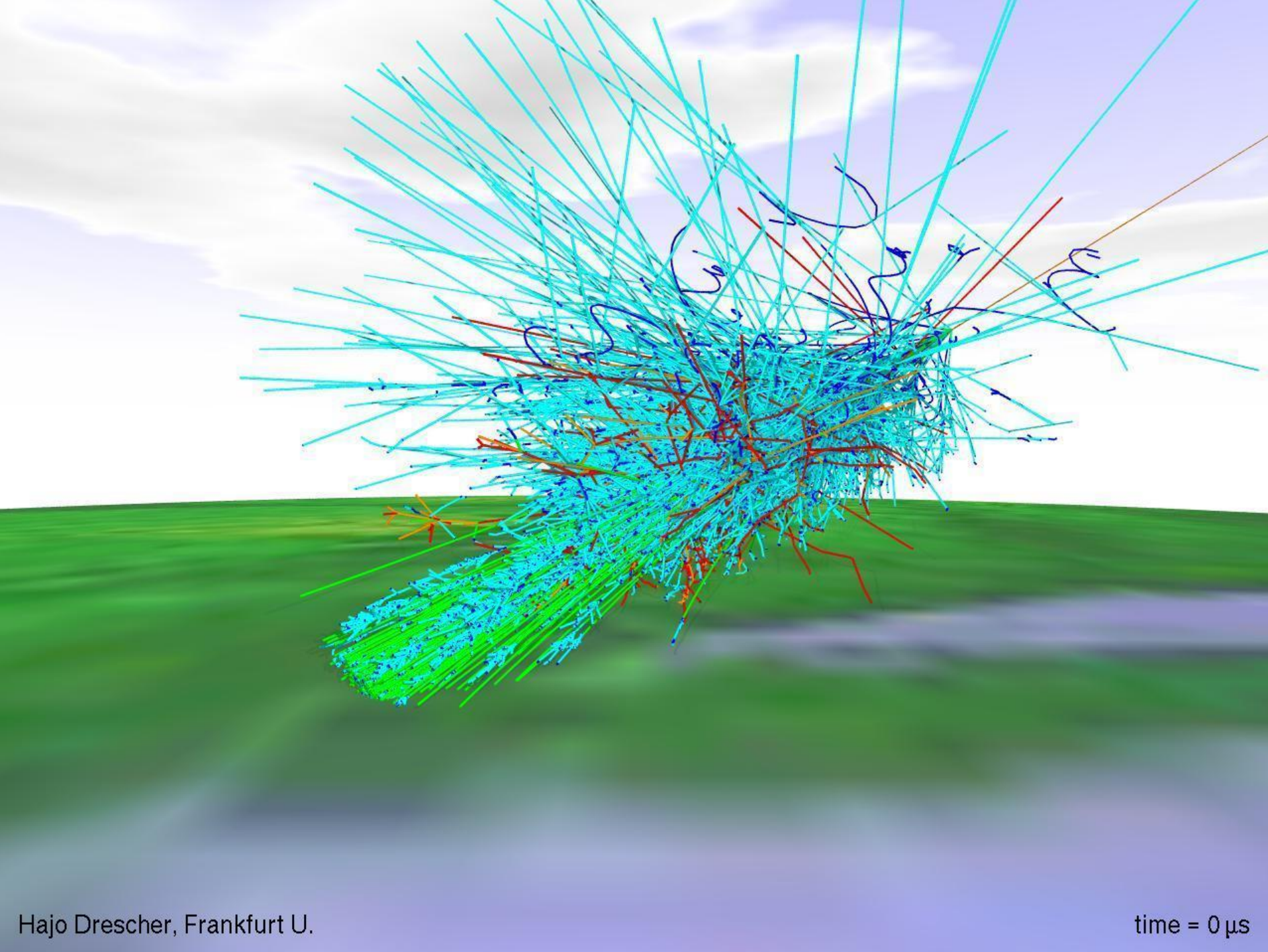
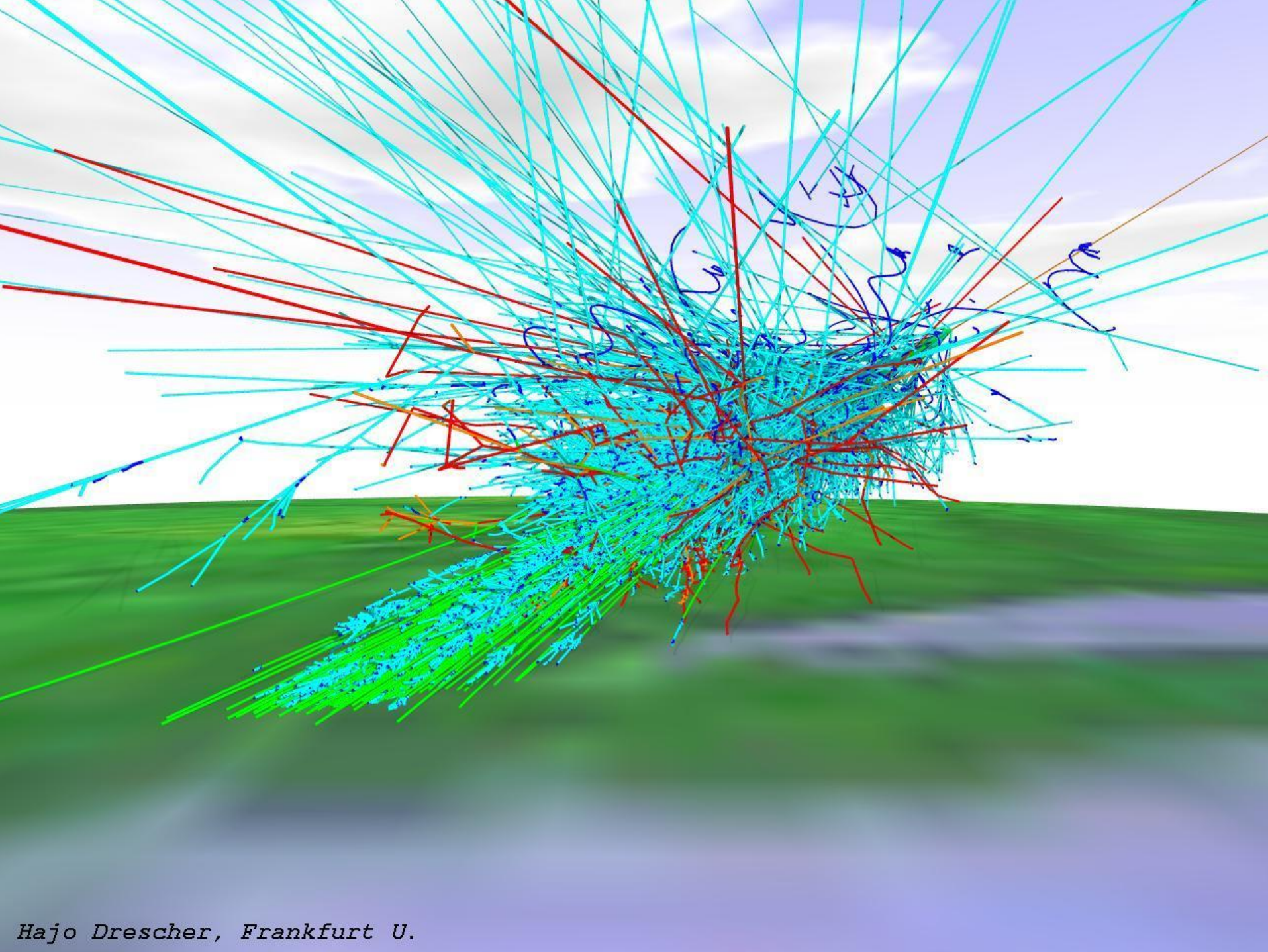
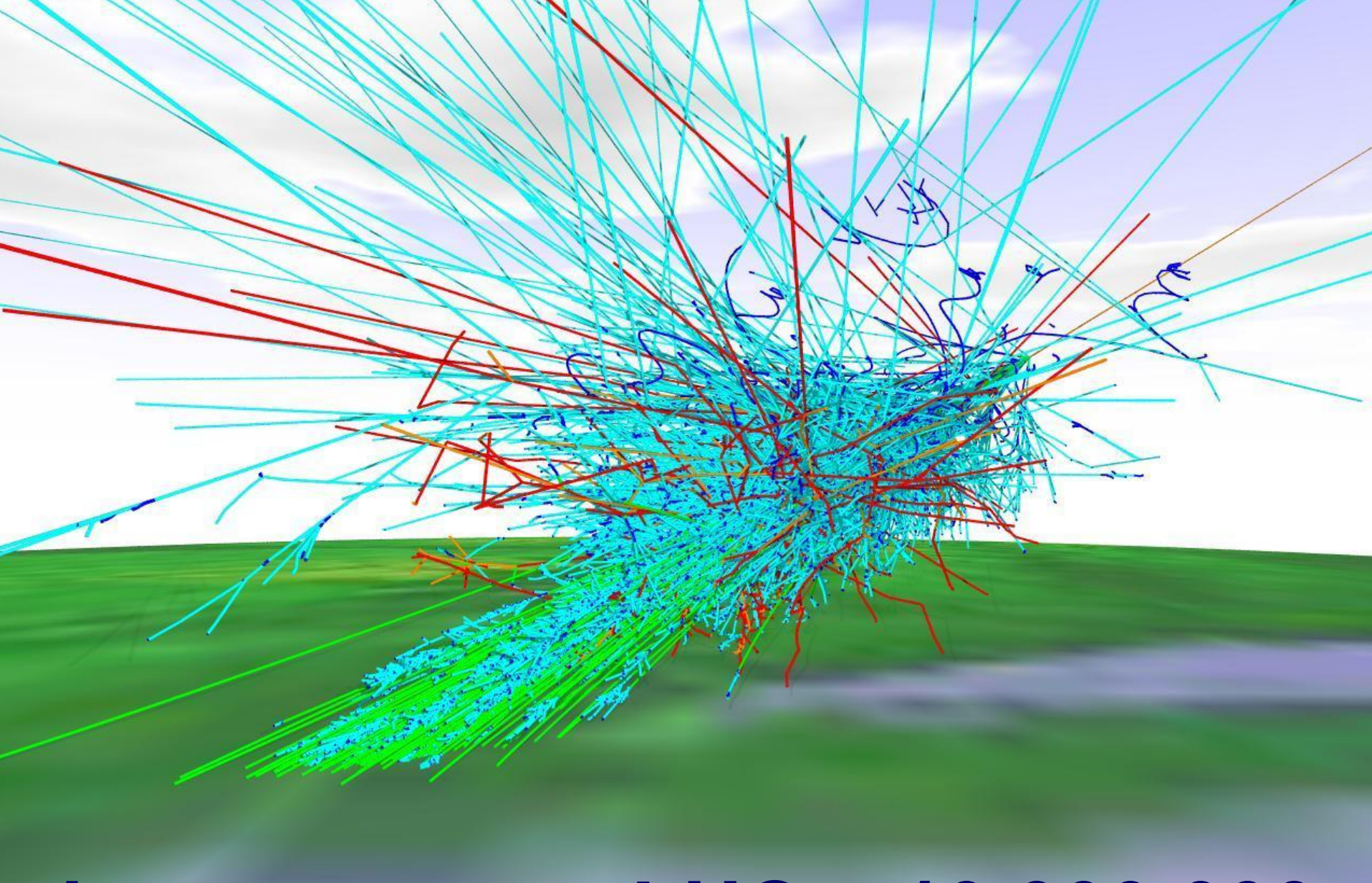

Hajo Drescher, Frankfurt U.
time = -300 µs


Hajo Drescher, Frankfurt U.
time = -200 µs


Hajo Drescher, Frankfurt U.
time = -100 µs


Hajo Drescher, Frankfurt U.
time = 0 µs


Hajo Drescher, Frankfurt U.



beam energy: LHC × 10 000 000

Hajo Drescher, Frankfurt U.

Prominent Source Candidates

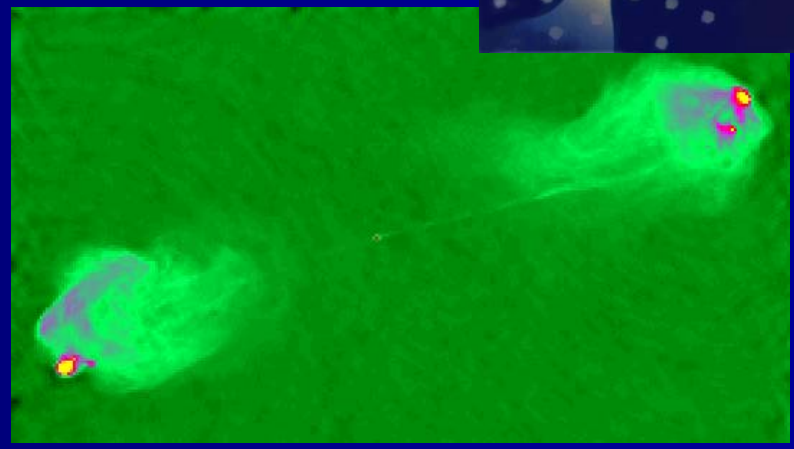
Galactic

SNR

Microquasars
Young SN shells
Pulsars

Extra-Galactic

AGN

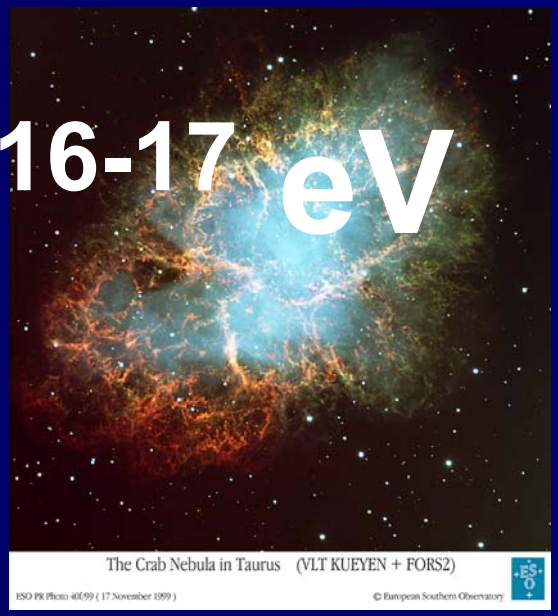


Starburst Galaxies
Galaxy Clusters
GRB

Prominent Source Candidates

Galactic

$10^{16\text{-}17}$ eV

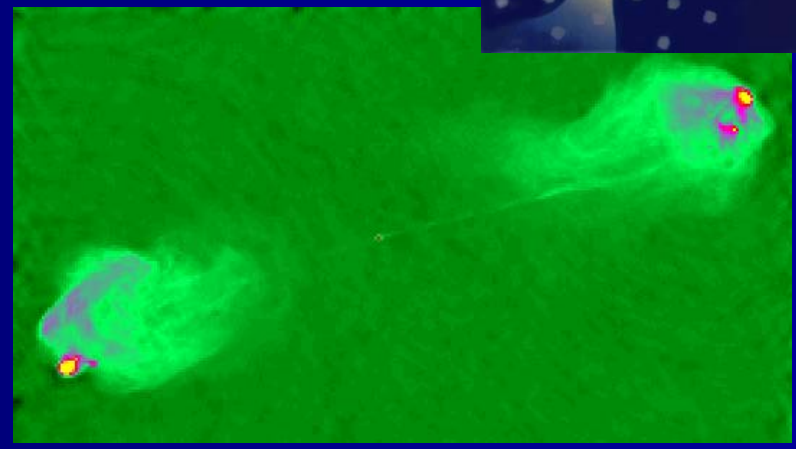


SNR

Microquasars
Young SN shells
Pulsars

Extra-Galactic

AGN



Starburst Galaxies
Galaxy Clusters
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Prominent Source Candidates

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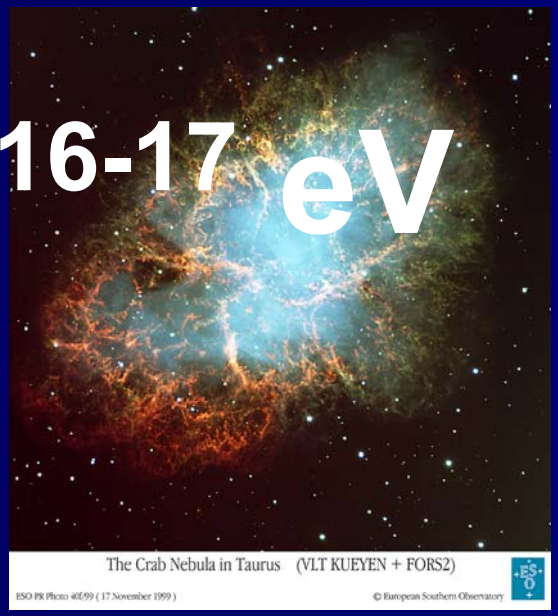
$10^{16\text{-}17}$ eV



SNR

Microquasars
Young SN shells
Pulsars

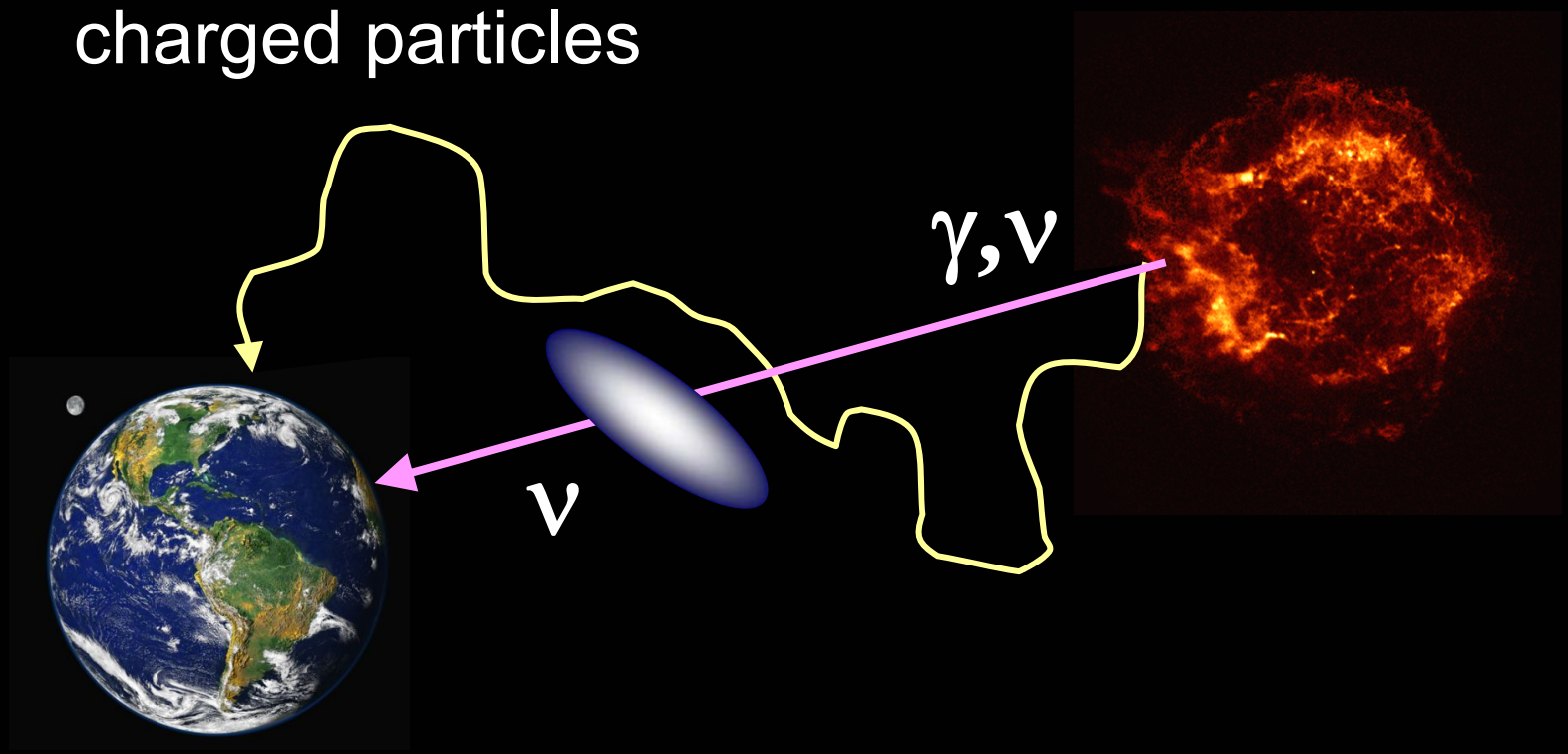
Extra-Galactic

AGN

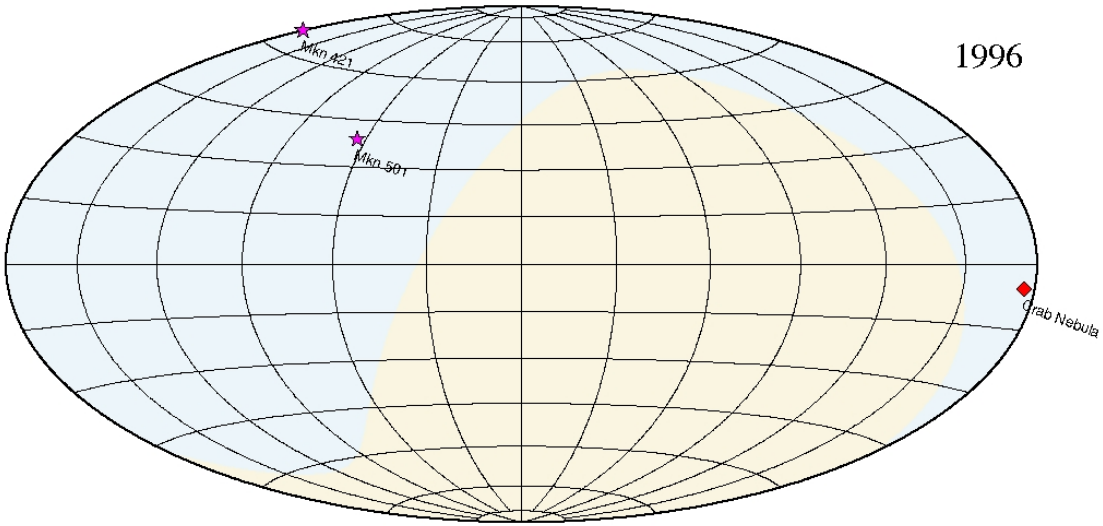
$10^{20\text{-}21}$ eV

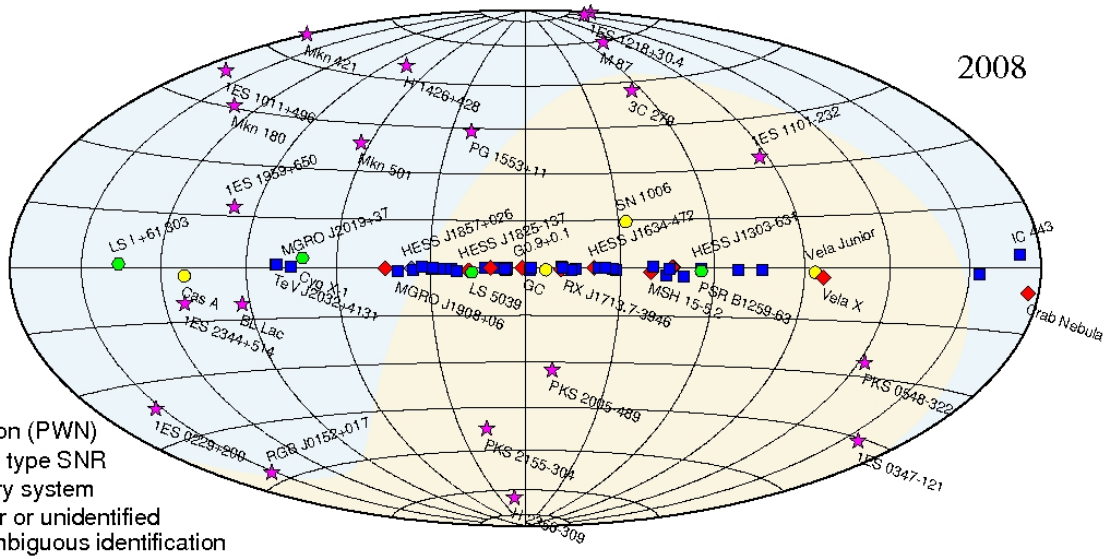
Starburst Galaxies
Galaxy Clusters
GRB

Charged cosmic rays vs. gamma-rays and neutrinos



The sky in TeV gamma rays





1996:

3 sources

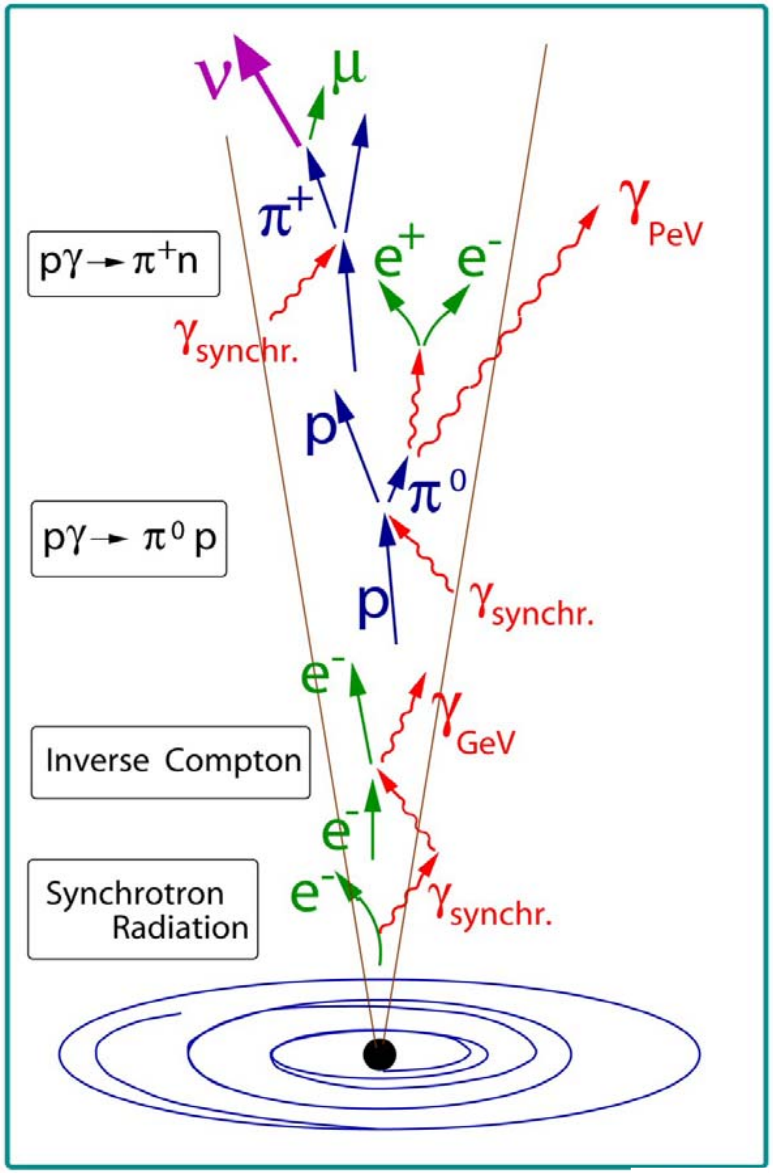
2008:

~75 sources

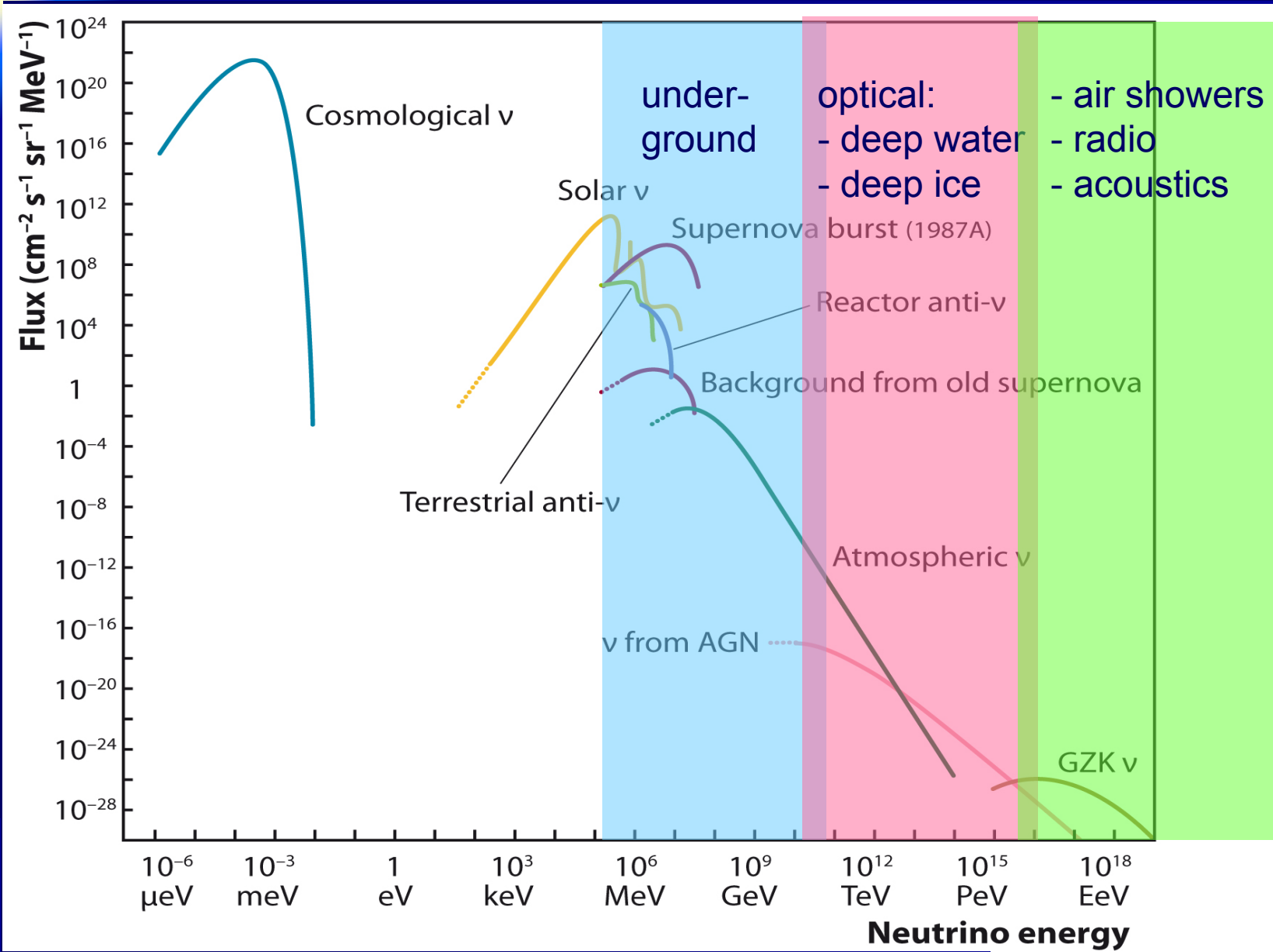
Background colours indicating northern / southern sky

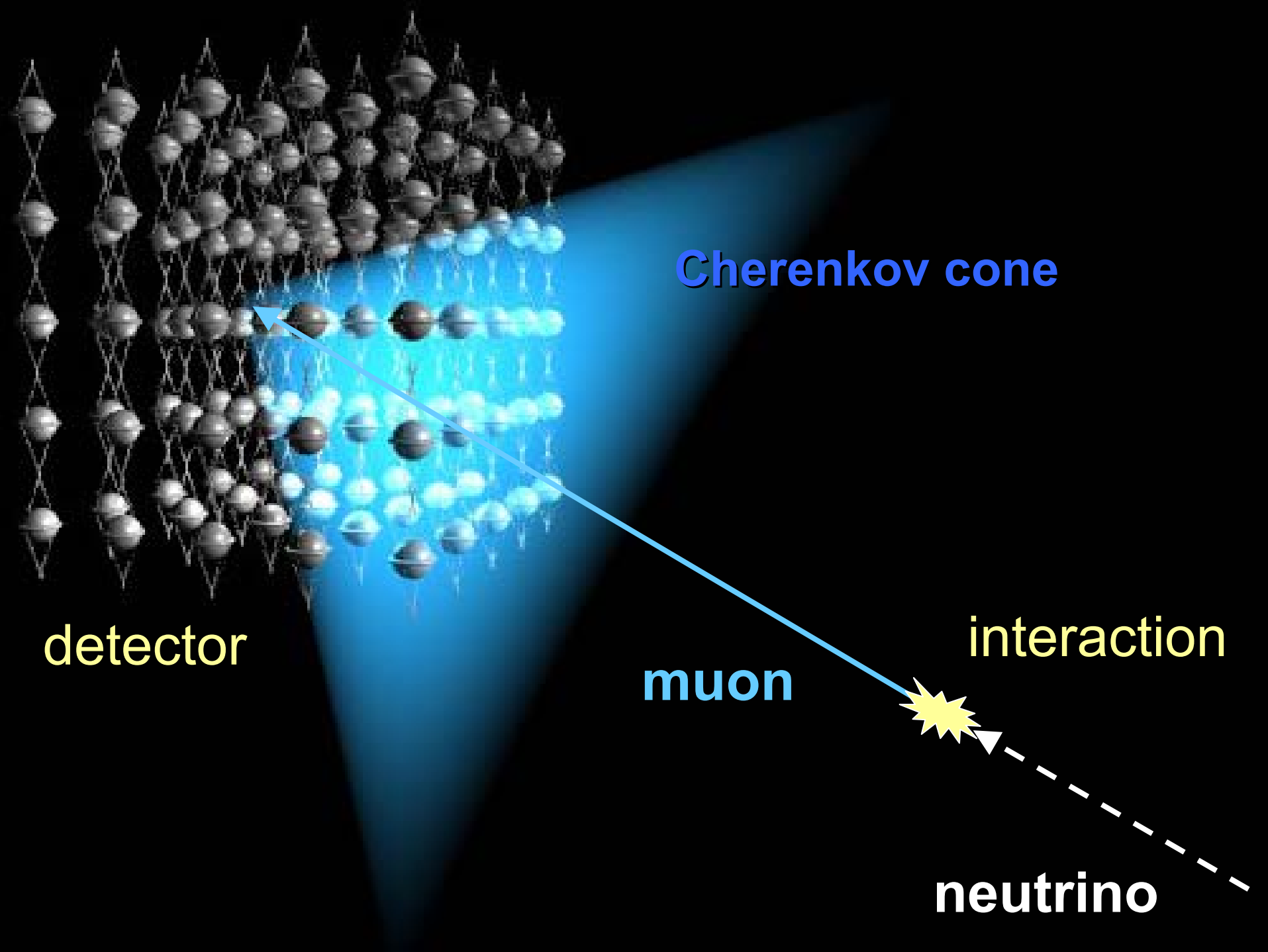
Graphics by Konrad Bernlöhr 2008

Particle Generation in AGN Jets

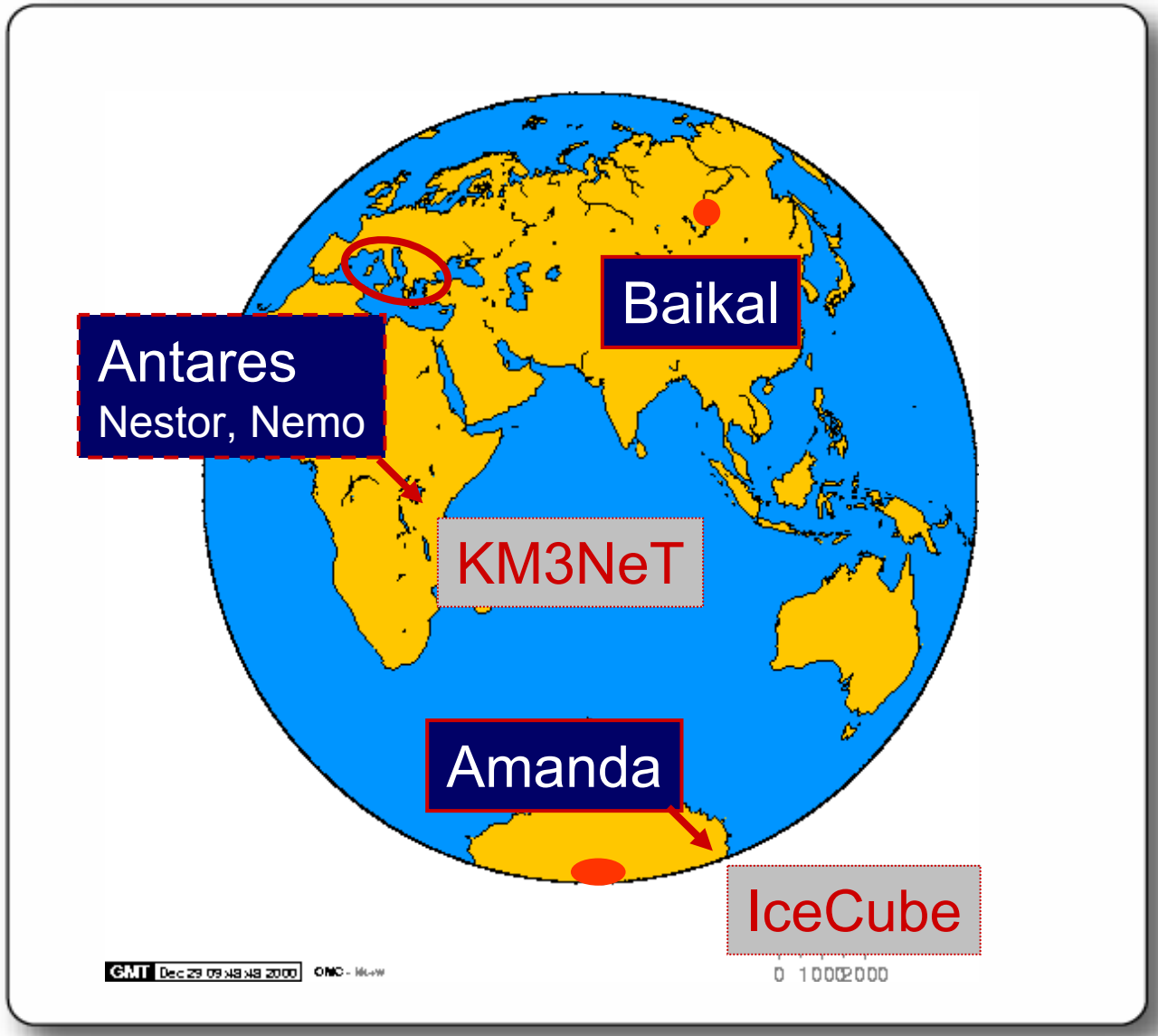


Neutrino fluxes




Cherenkov cone
detector
interaction
muon
neutrino

High energy neutrino telescopes



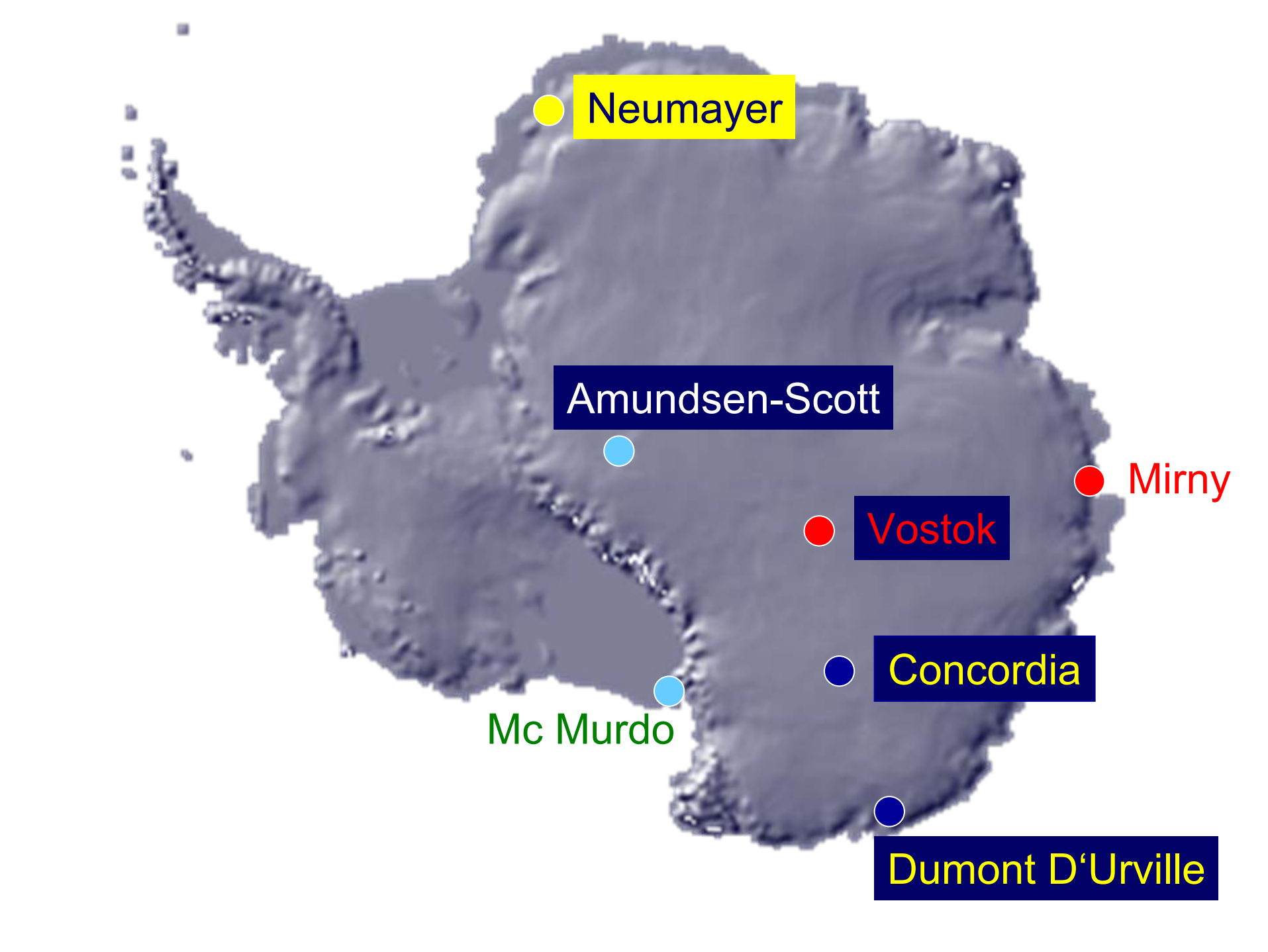

Neumayer
Amundsen-Scott
Mirny
Vostok
Concordia
Mc Murdo
Dumont D‘Urville

PHOTO BY CHARLIE KAMINSKI

SOUTH POLE DEC 2, 2000


Südpol
Astronomie-Sektor
Landebahn
AMANDA
The Dome

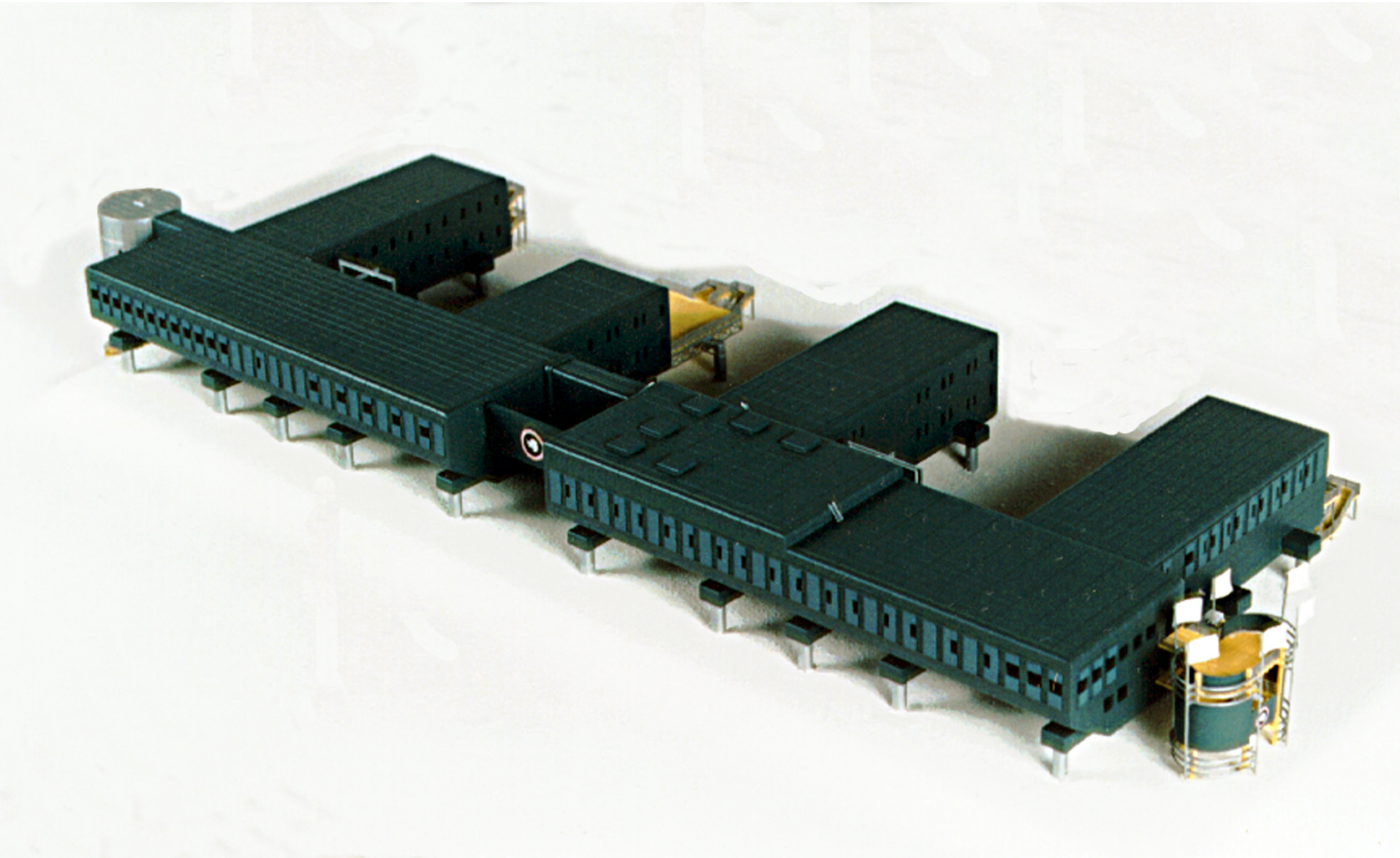
Februar 1957: Die erste Südpolstation

1967 – 74: Neue Südpolstation

Design-Kriterien

15- 20 Jahre Betriebszeit

Maximale Besatzung: 33

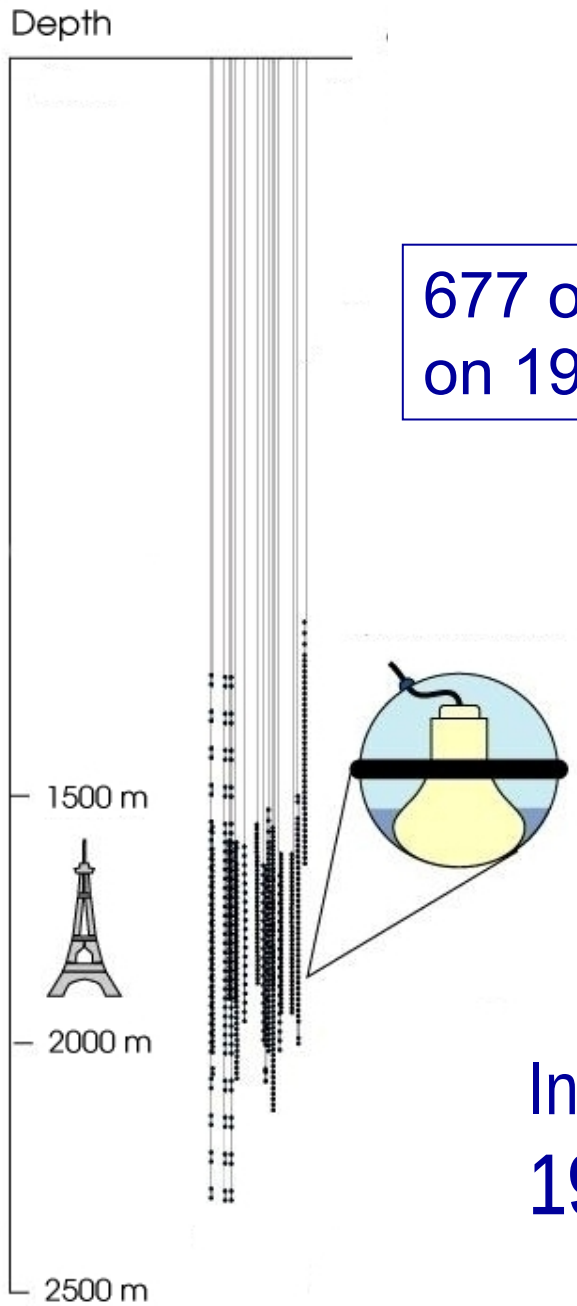



Februar 2000

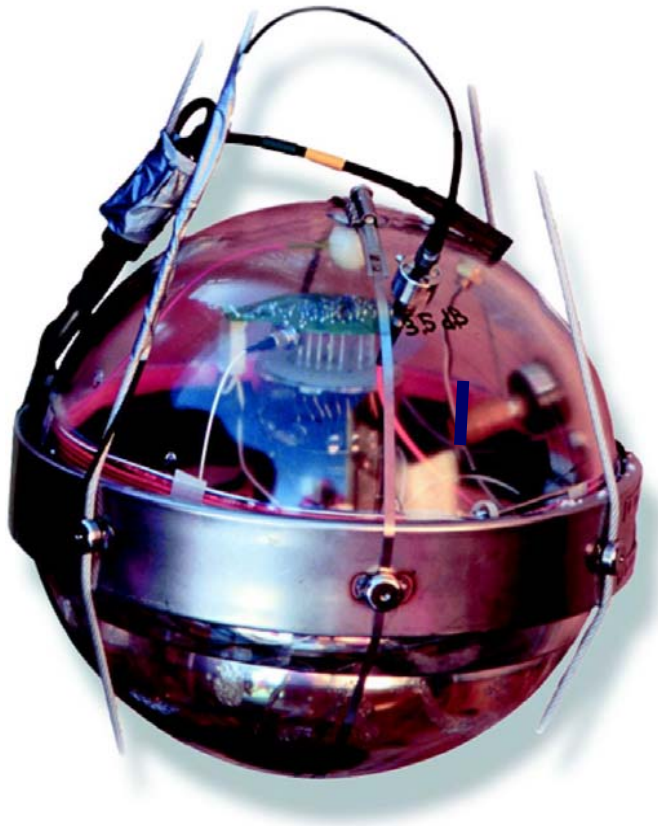

MANTIS

Dezember 2005

AMANDA



677 optical modules
on 19 strings

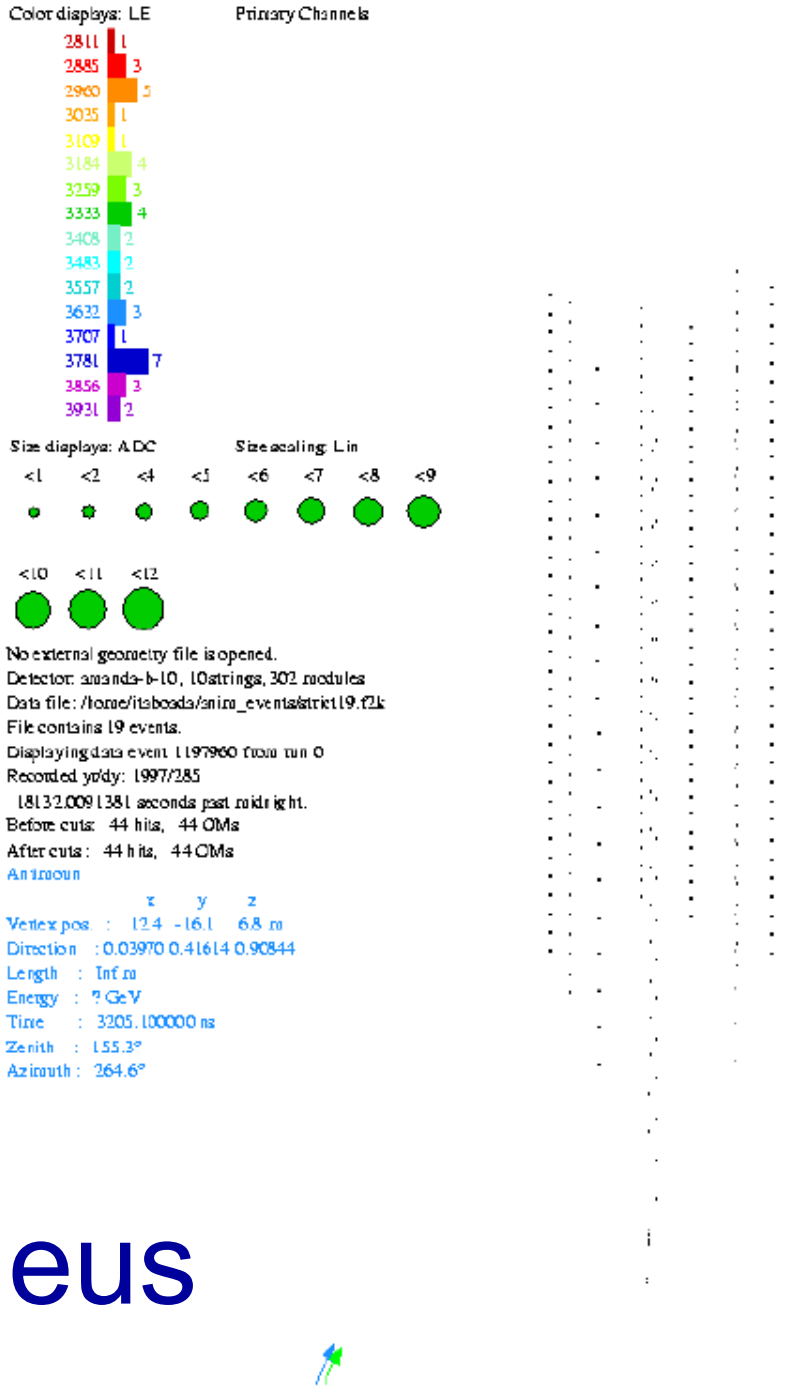


Installation
1996-2000

Hot Water Drilling

2 MW power

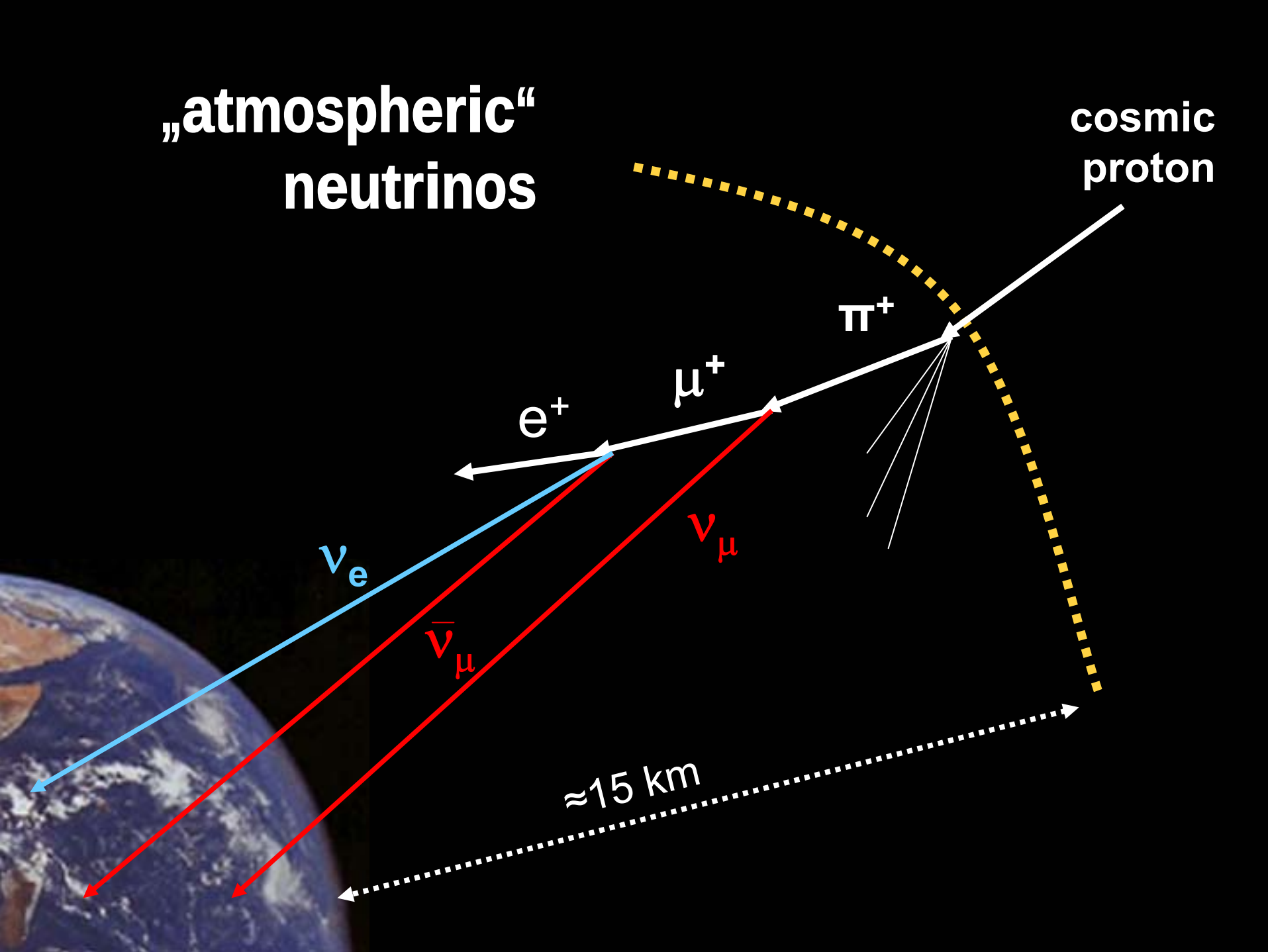
neutrino event in AMANDA



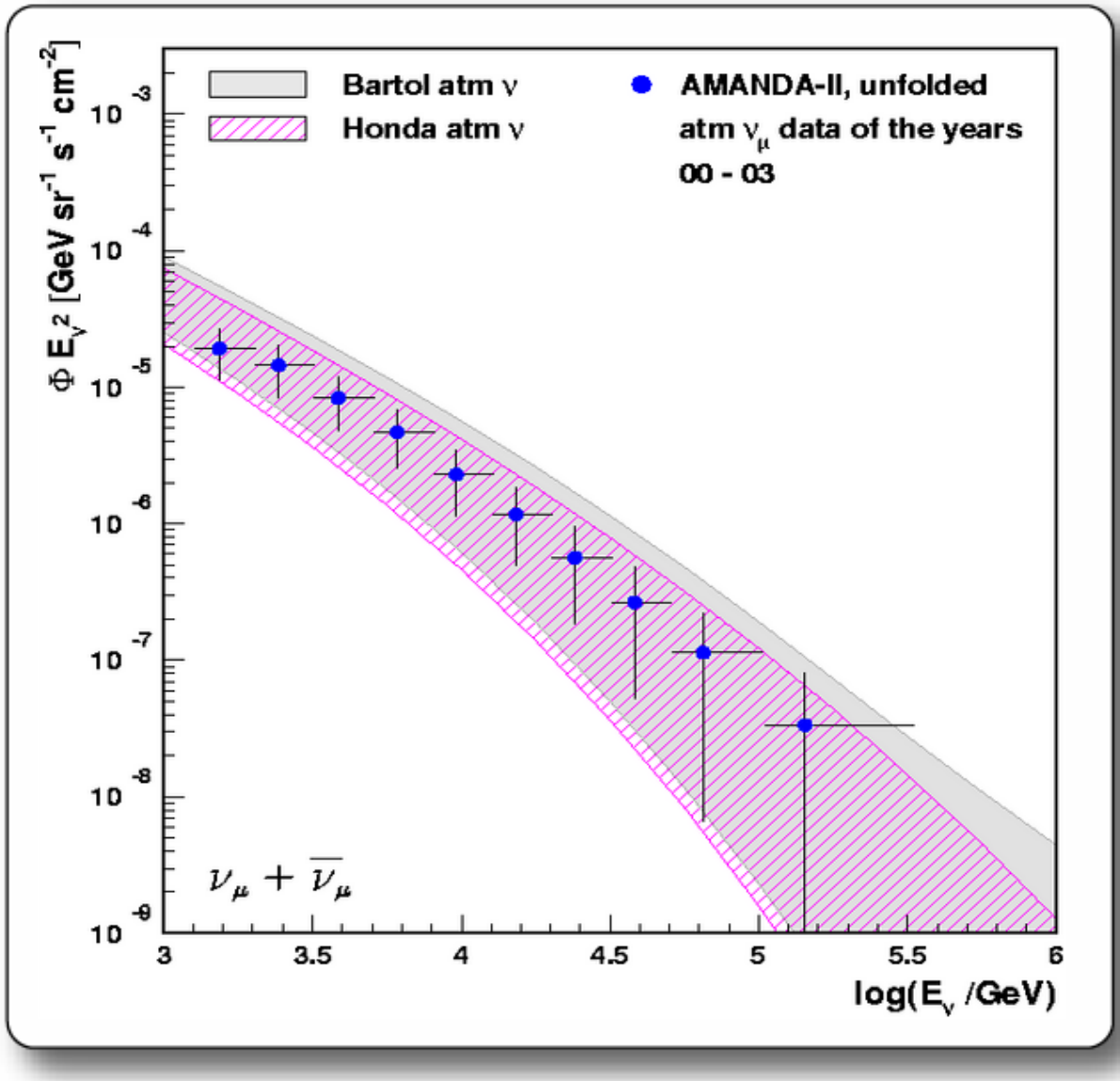
ν + nucleus

$\rightarrow \mu$ + nucleus

„atmospheric“ neutrinos

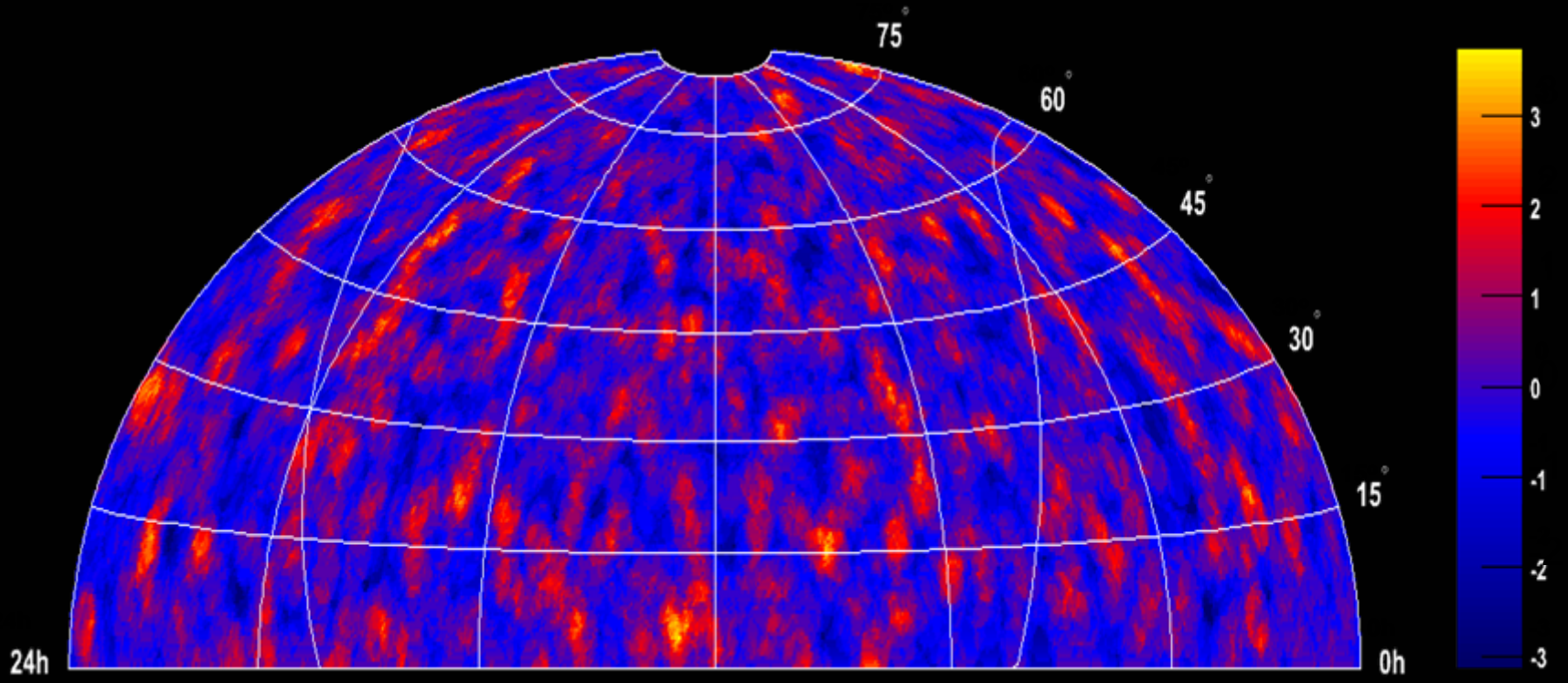


Atmospheric Neutrinos



spectrum measured up to >100 TeV

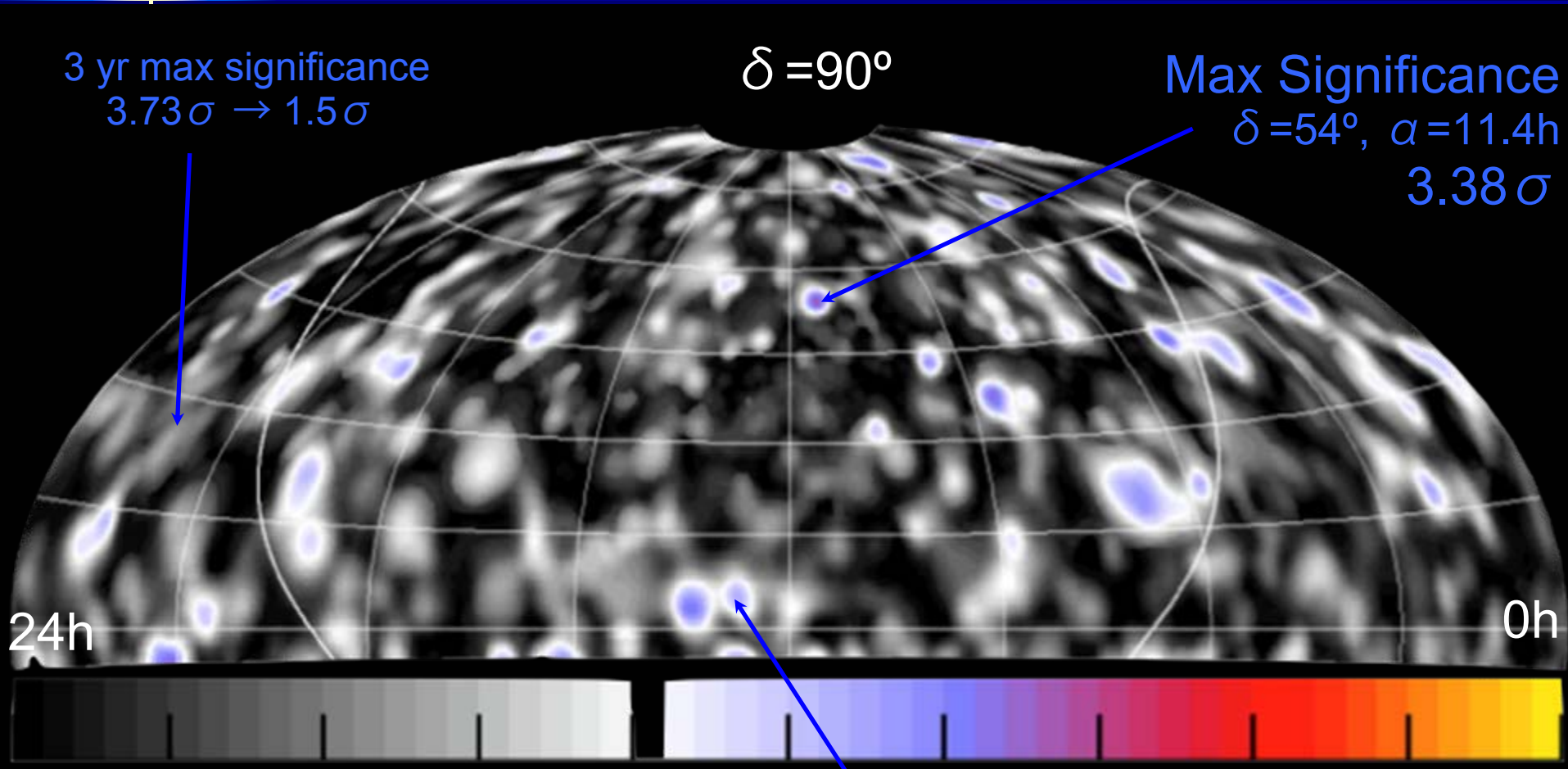
Search for Point Sources



AMANDA-II: 2000-2004 (1001 live days) 4282 ν from Northern hemisphere

No significant excess found

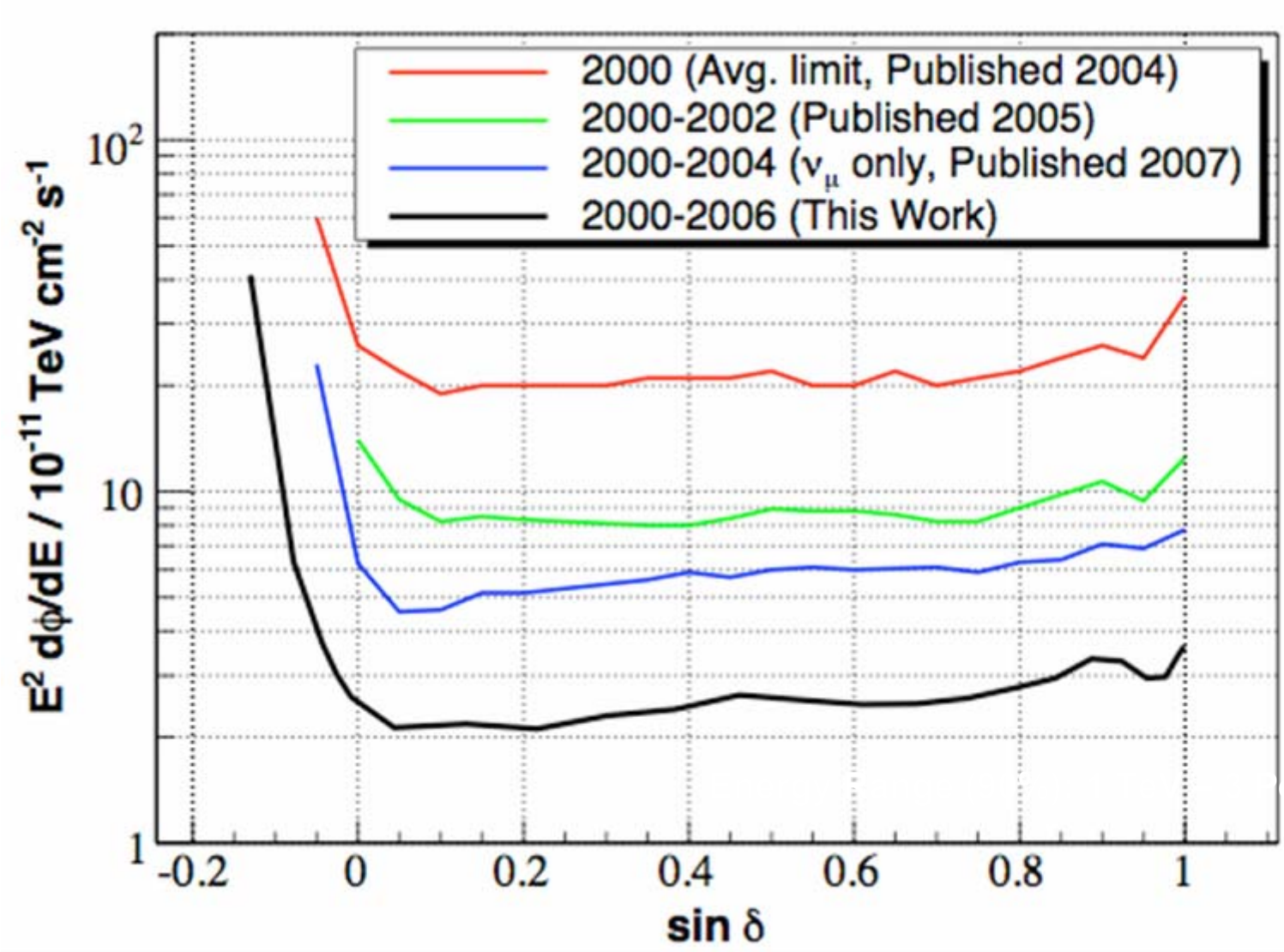
AMANDA final analysis (7 years, 6595 events)



95 of 100 background maps

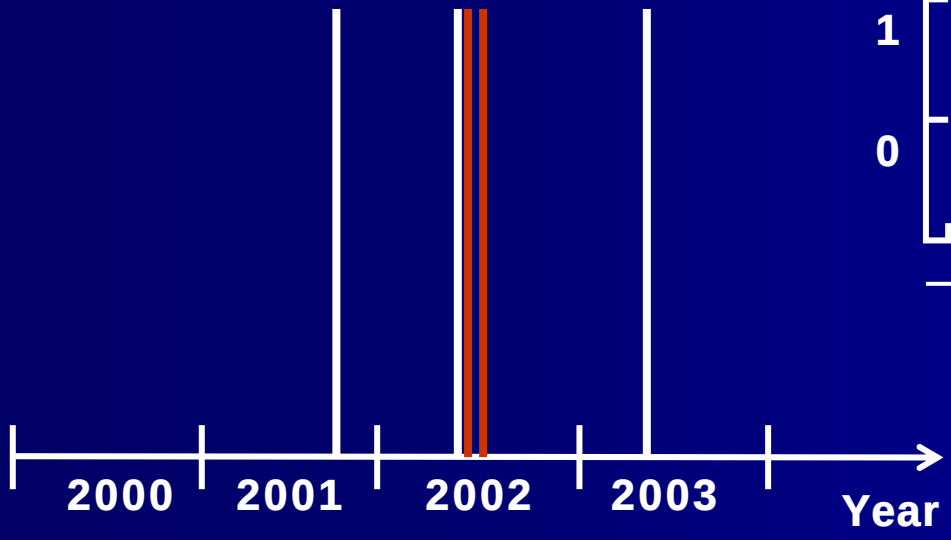
(data randomized in RA) have a point with significance ≥ 3.38 σ

Flux limits for E^{-2} point sources

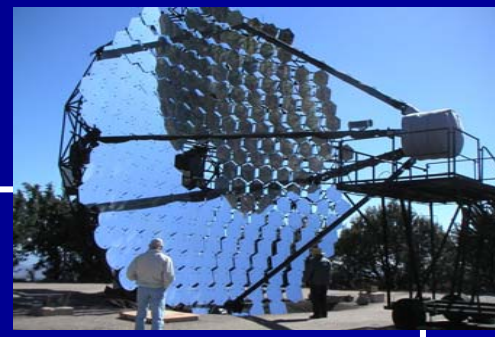


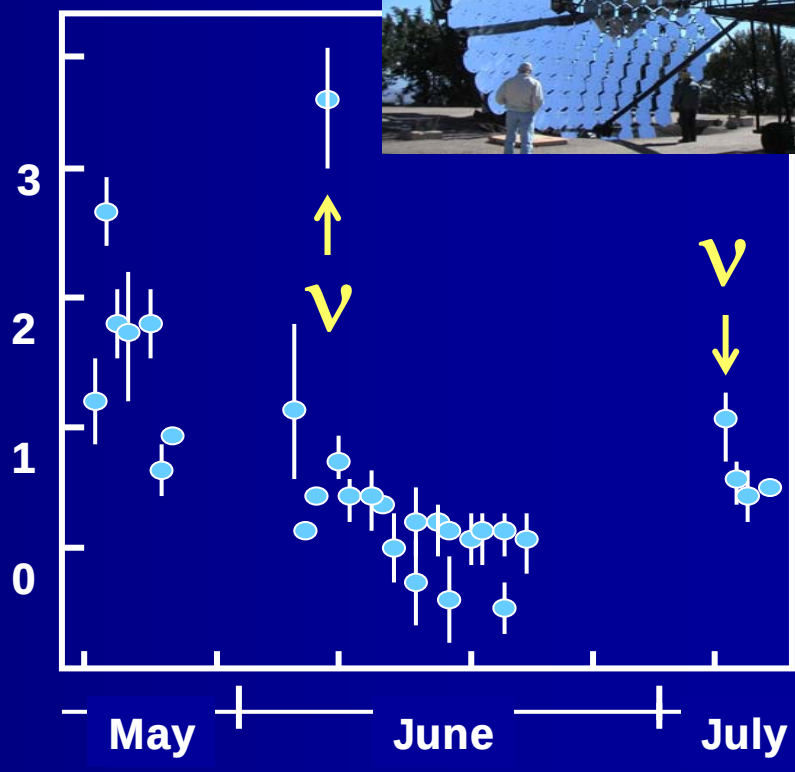
ES 1959+650

Arrival time of neutrinos from the direction of the AGN ES1959+650



WHIPPLE

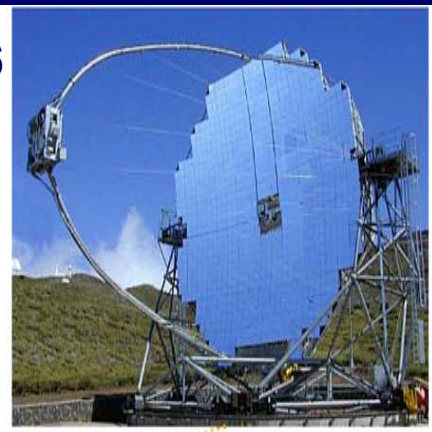




Multi-Messenger Methods

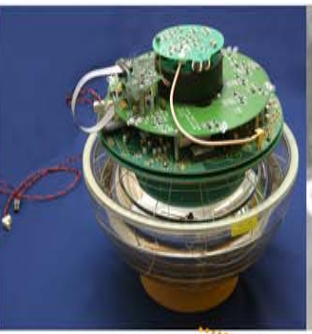
27th September to 27th November 2006
Five alerts sent

Result: 3 observations
No coincidence …



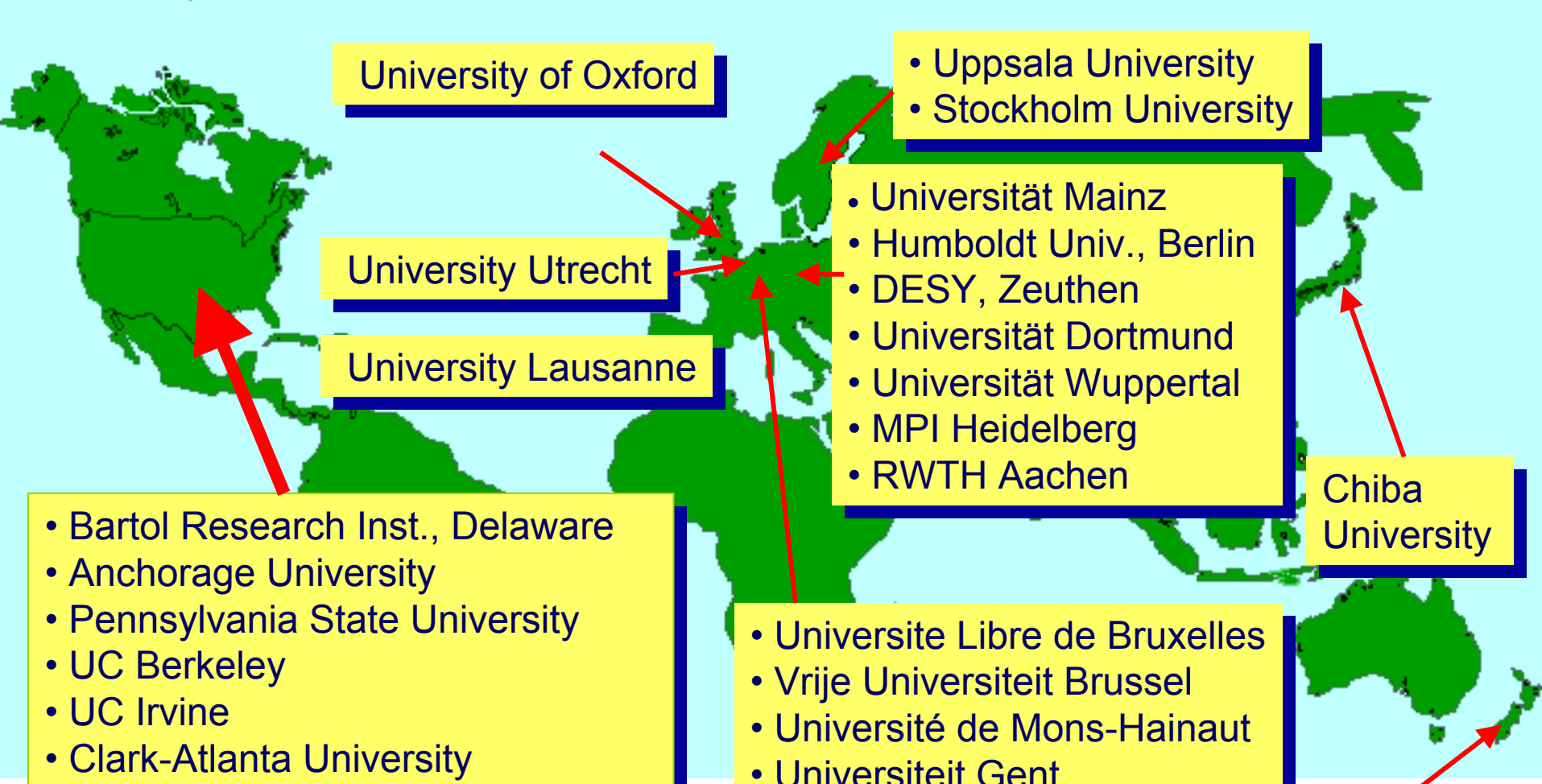
VERITAS
Long-term gamma-ray observations used for light-curves studies

MAGIC
NToO – follow-up **neutrino** alerts plus long term gamma obs.



H.E.S.S.
CANGAROO
small overlap in the visible sky

+ optical follow ups, AGILE, GLAST, …


University of Oxford
• Uppsala University
• Stockholm University
• Universität Mainz
• Humboldt Univ., Berlin
• DESY, Zeuthen
• Universität Dortmund
• Universität Wuppertal
• MPI Heidelberg
• RWTH Aachen
University Utrecht
University Lausanne
Chiba University
• Bartol Research Inst., Delaware
• Anchorage University
• Pennsylvania State University
• UC Berkeley
• UC Irvine
• Clark-Atlanta University
• Univ. of Maryland
• University of Wisconsin-Madison
• University of Wisconsin-RiverFalls
• LBNL, Berkeley
• University of Kansas
• Southern Univ., Baton Rouge
• Universite Libre de Bruxelles
• Vrije Universiteit Brussel
• Université de Mons-Hainaut
• Universiteit Gent
Univ. of Canterbury, Christchurch

IceCube


IceCube
AMANDA

2007-2008: 18 strings

2006-2007:
13 strings deployed

IceTop

Air shower detector

80 pairs of ice Cherenkov tanks

Threshold ~ 300 TeV

2005-2006: 8 strings

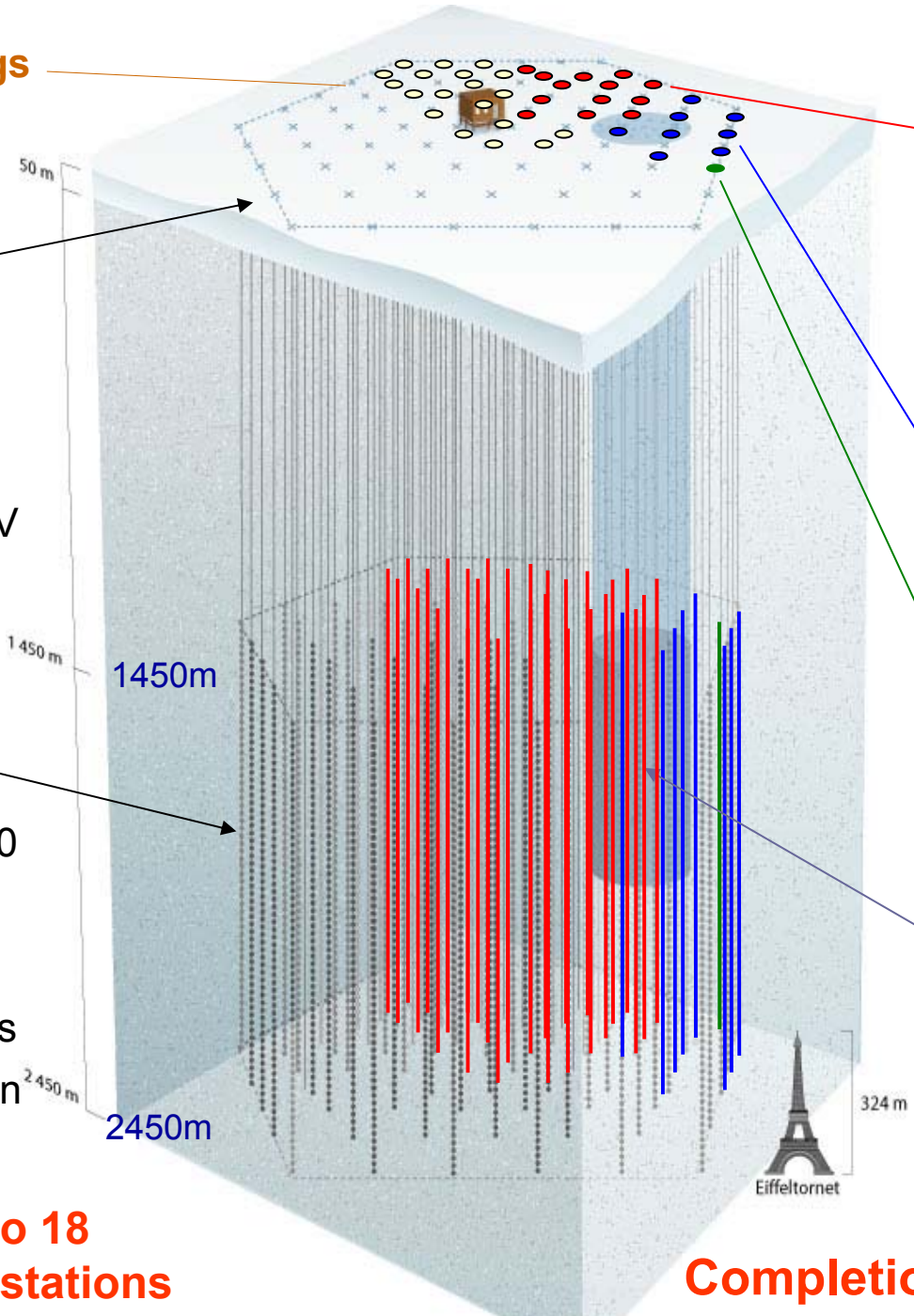
2004-2005 : 1 string

IceCube

Goal of 80 strings of 60 optical modules each

17 m between modules

125 m string separation



AMANDA-II
19 strings
677 modules

2007/08: add 14 to 18 strings and tank stations

Completion by 2011.

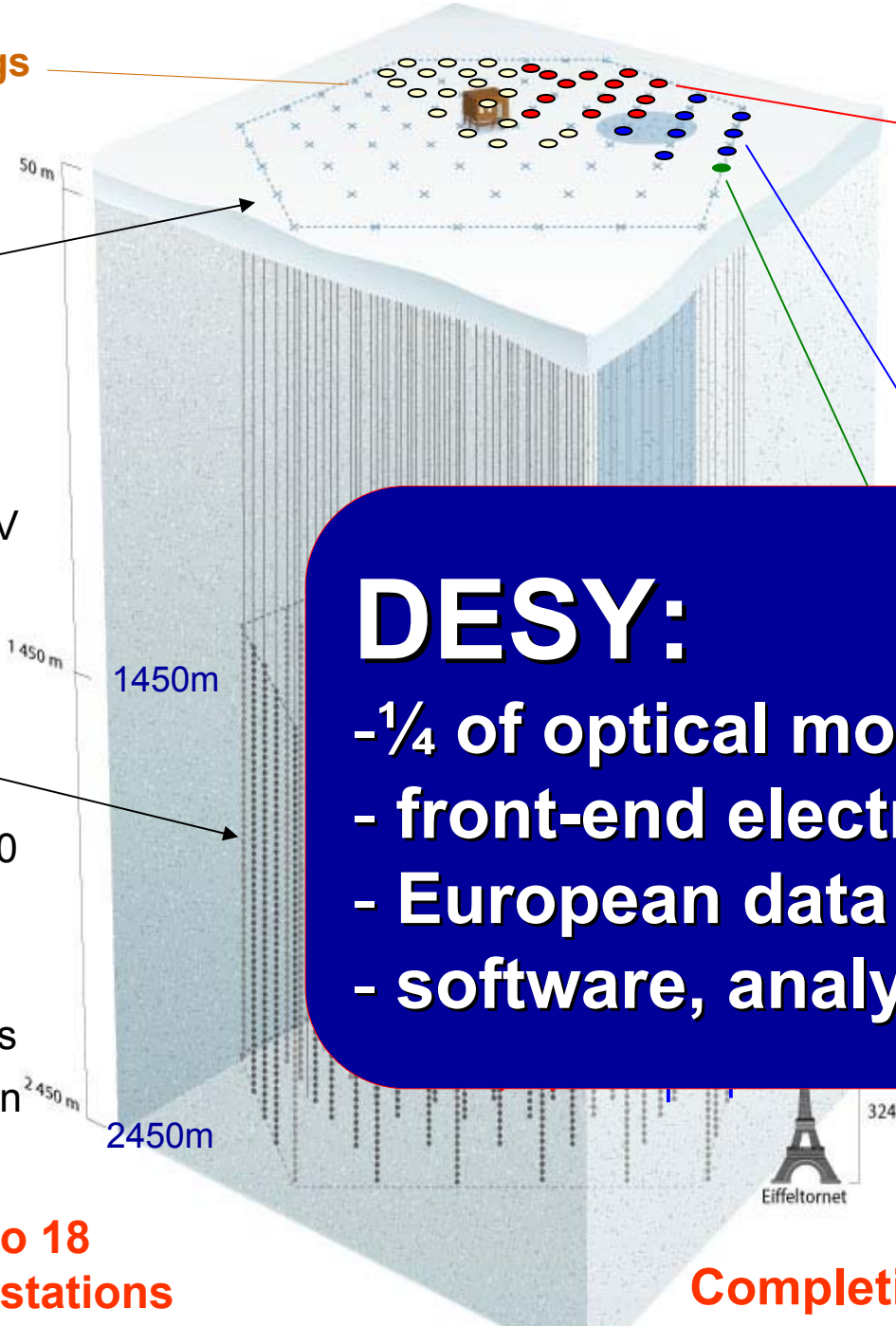
2007-2008: 18 strings

2006-2007:
13 strings deployed

IceTop

Air shower detector
80 pairs of ice
Cherenkov tanks
Threshold ~ 300 TeV

2005-2006: 8 strings



DESY:
-¼ of optical modules
- front-end electronics
- European data center
- software, analysis

IceCube

Goal of 80 strings of 60 optical modules each

17 m between modules
125 m string separation

2007/08: add 14 to 18 strings and tank stations

Completion by 2011.

IceCube

IceTop

Air shower detector

80 pairs of ice Cherenkov tanks

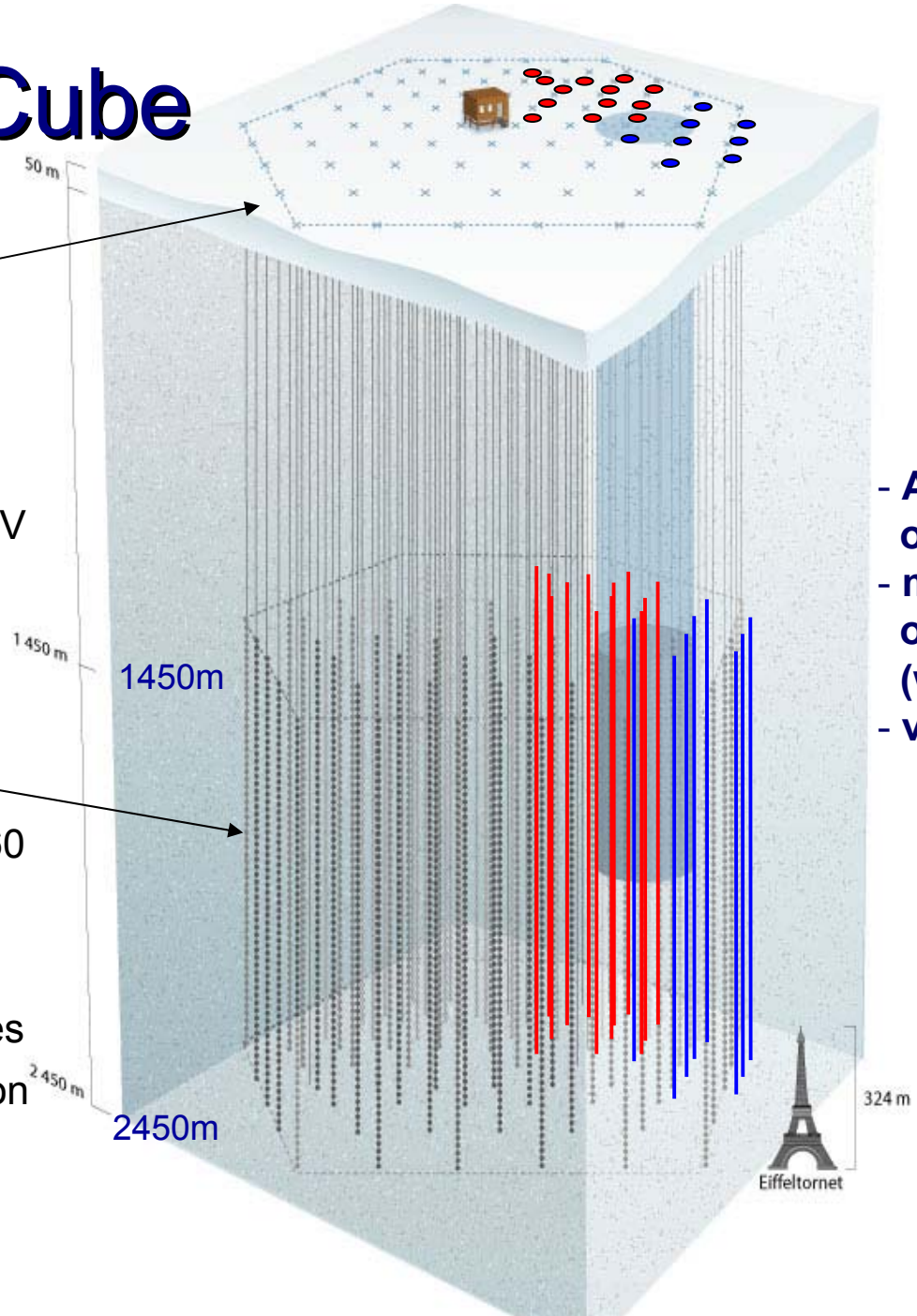
Threshold ~ 300 TeV

InIce

Goal of 80 strings of 60 optical modules each

17 m between modules

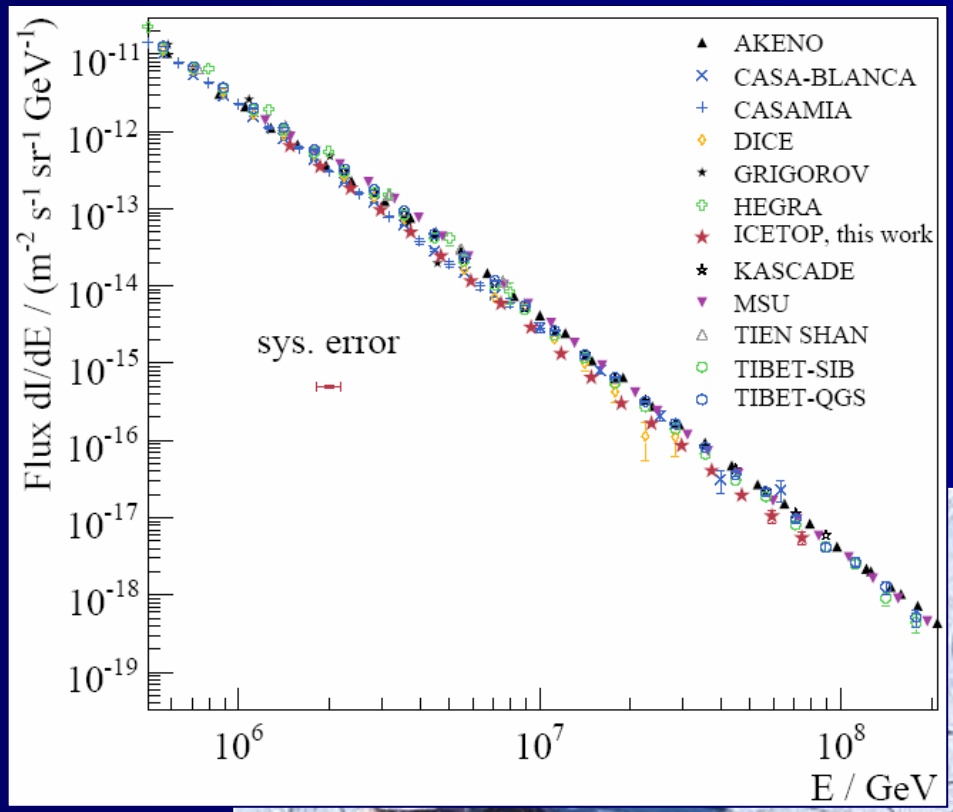
125 m string separation

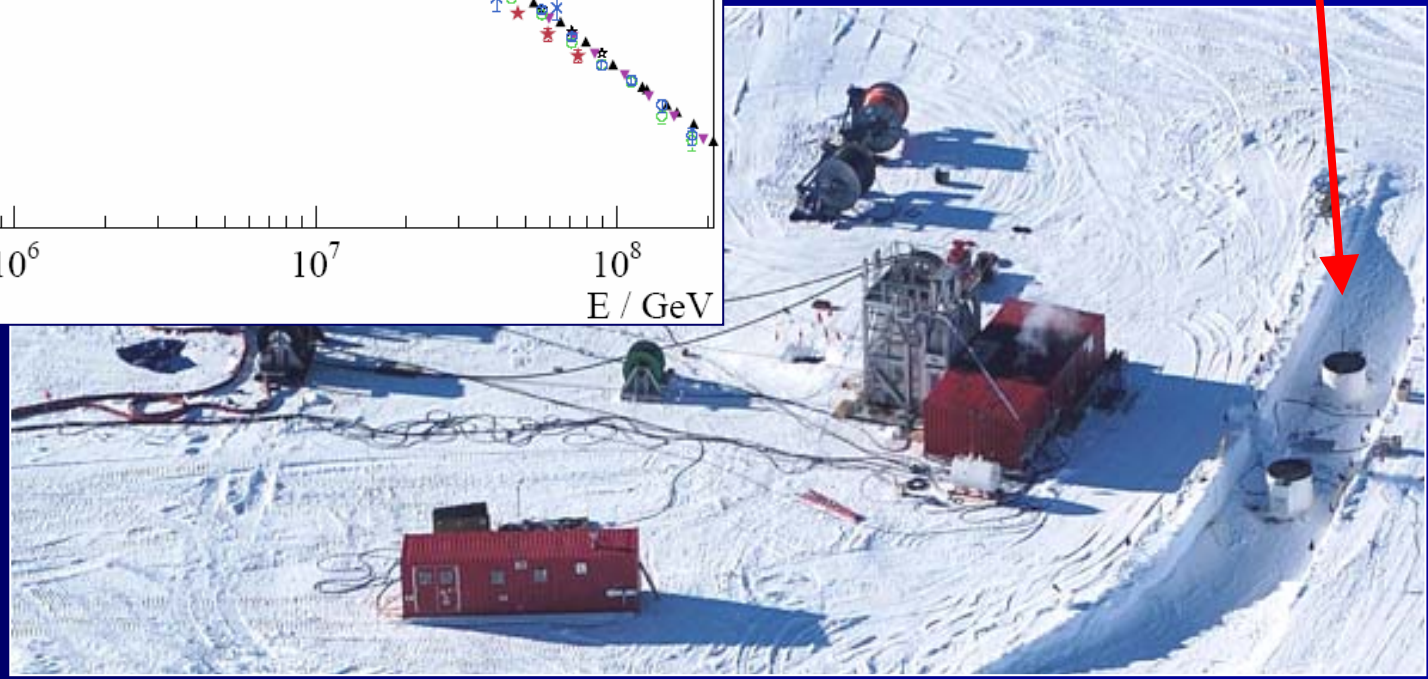


IceTop

- **Angular calibration of IceCube**
- **mass composition of cosmic rays (with IceCube)**
- **veto for IceCube**

IceTop


Flux dI/dE / (m^{-2} s^{-1} sr^{-1} GeV^{-1})
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{6}
10^{7}
10^{8}
E / GeV
sys. error
AKENO
CASA-BLANCA
CASAMIA
DICE
GRIGOROV
HEGRA
ICETOP, this work
KASCADE
MSU
TIEN SHAN
TIBET-SIB
TIBET-QGS



IceCube

IceTop

Air shower detector

80 pairs of ice Cherenkov tanks

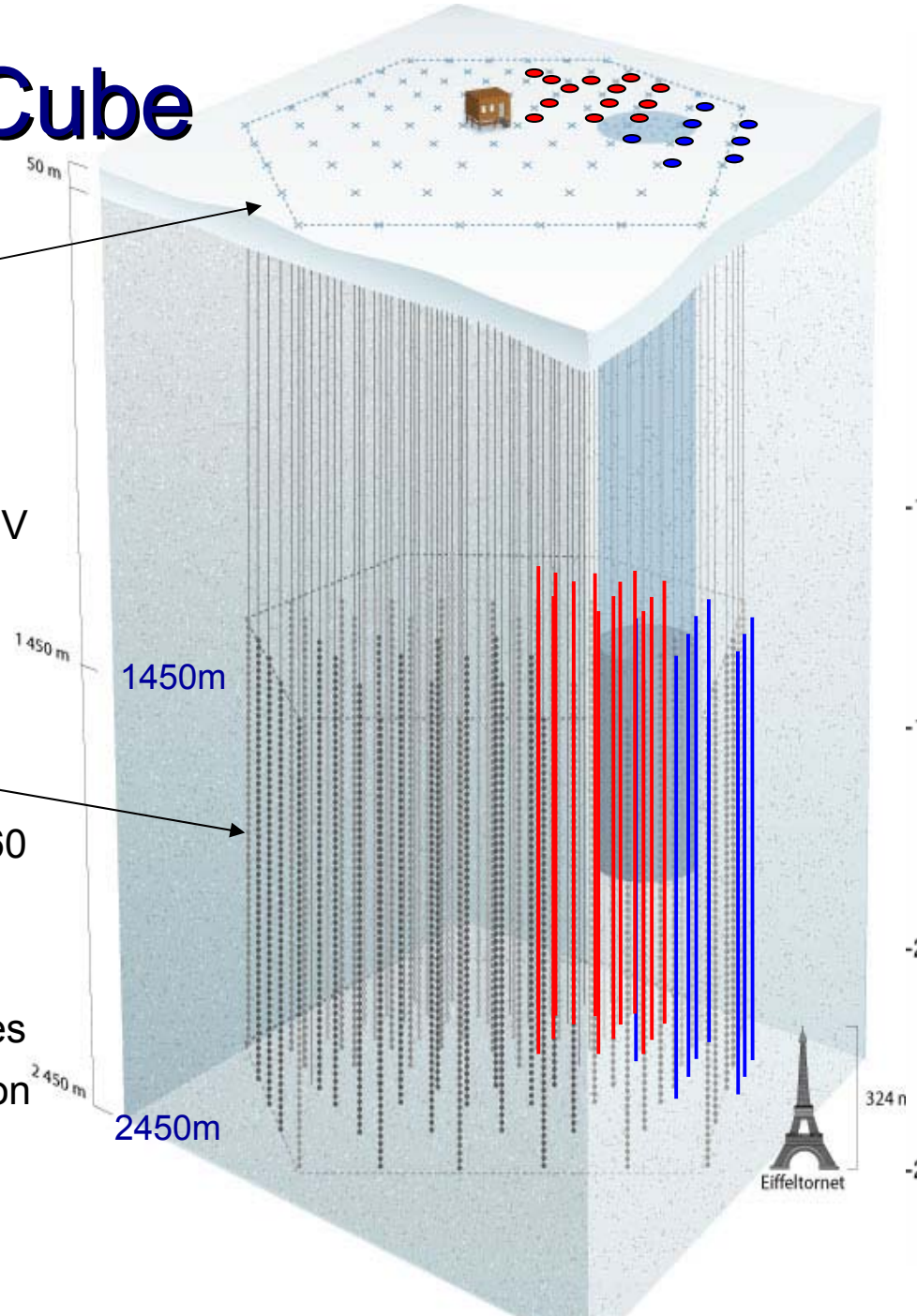
Threshold ~ 300 TeV

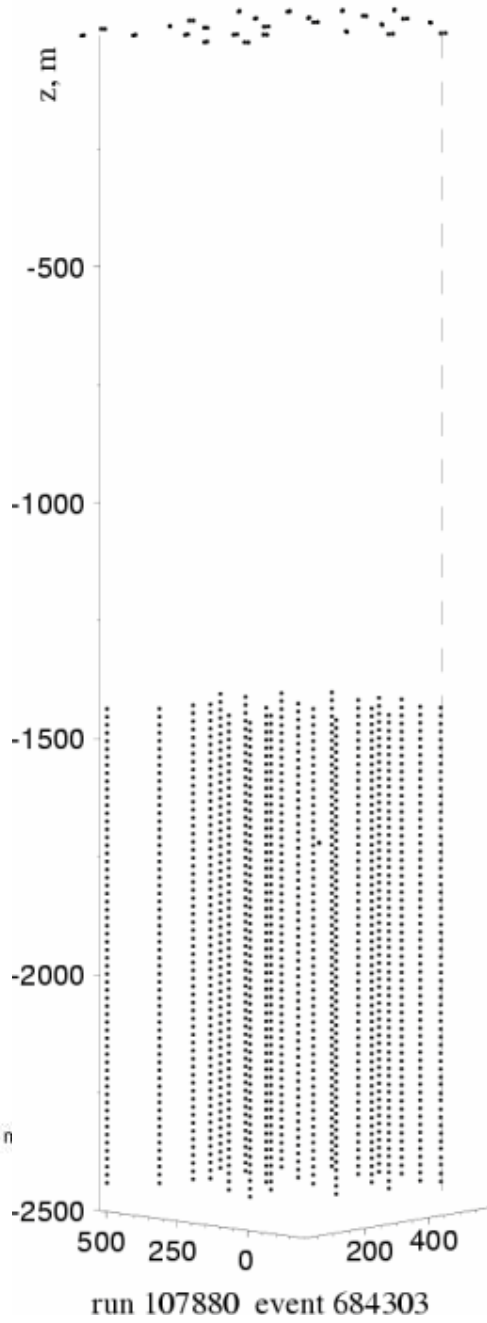
InIce

Goal of 80 strings of 60 optical modules each

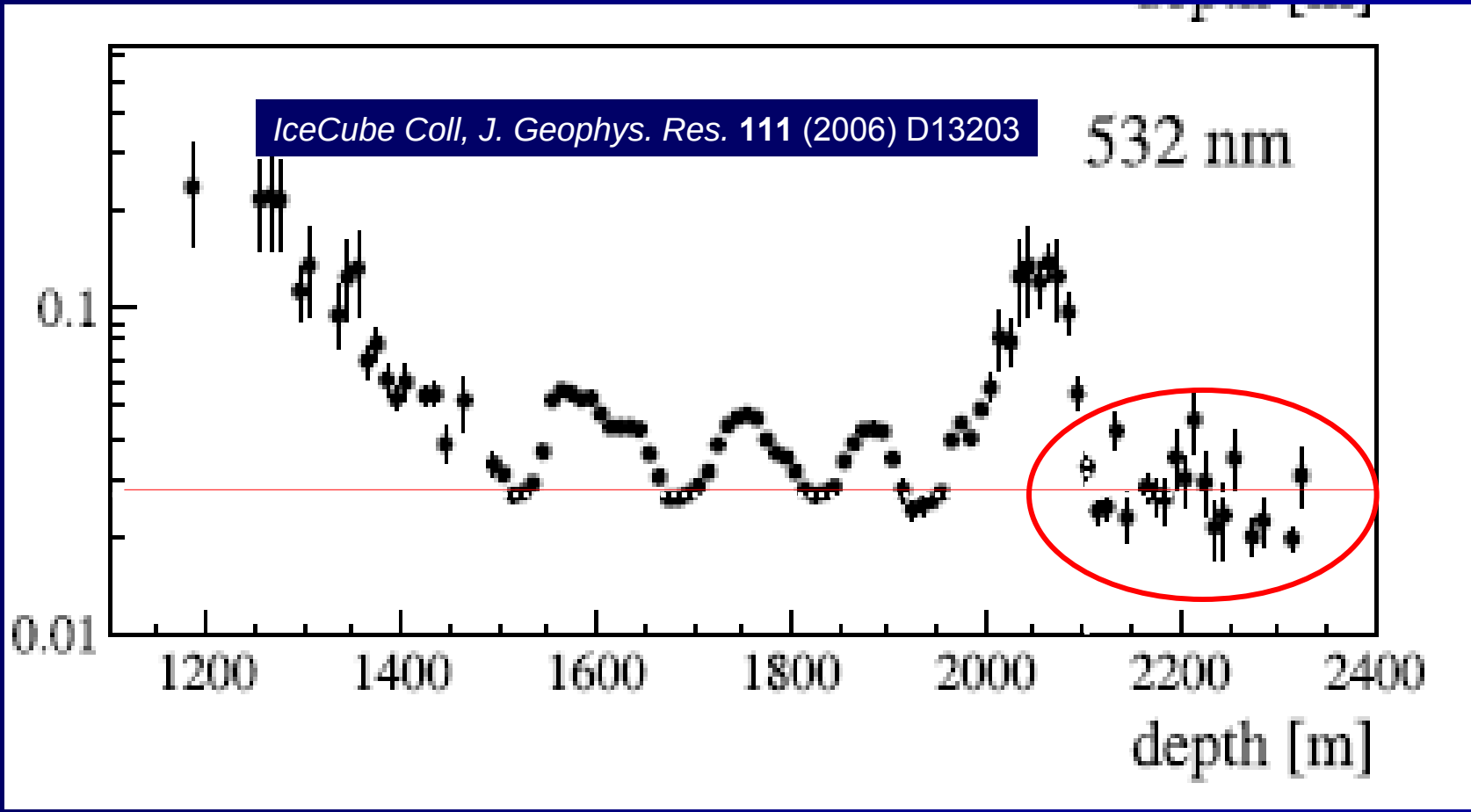
17 m between modules

125 m string separation



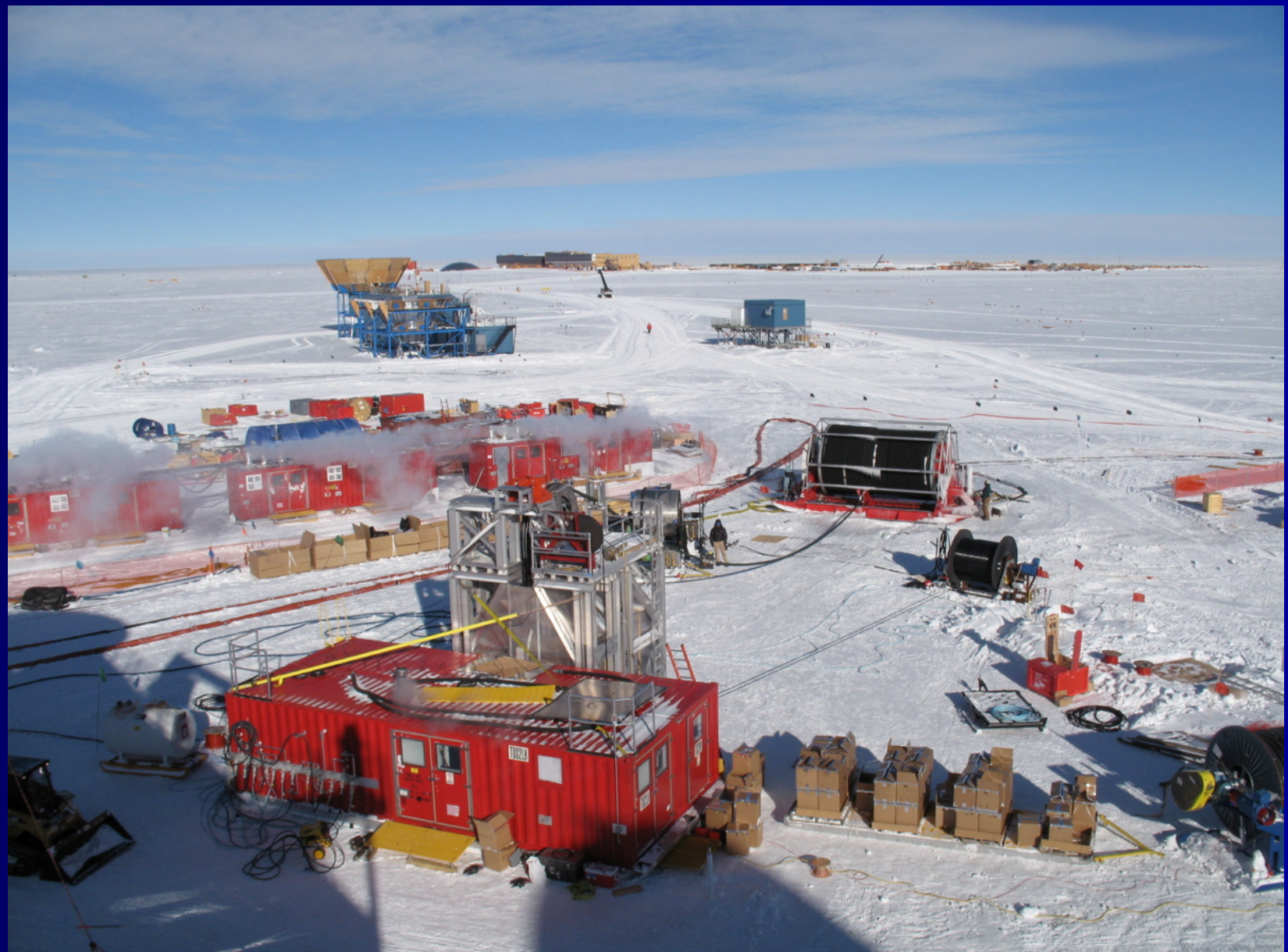


Measured Effective Scattering Coefficient



IceCube Laboratory and Data Center

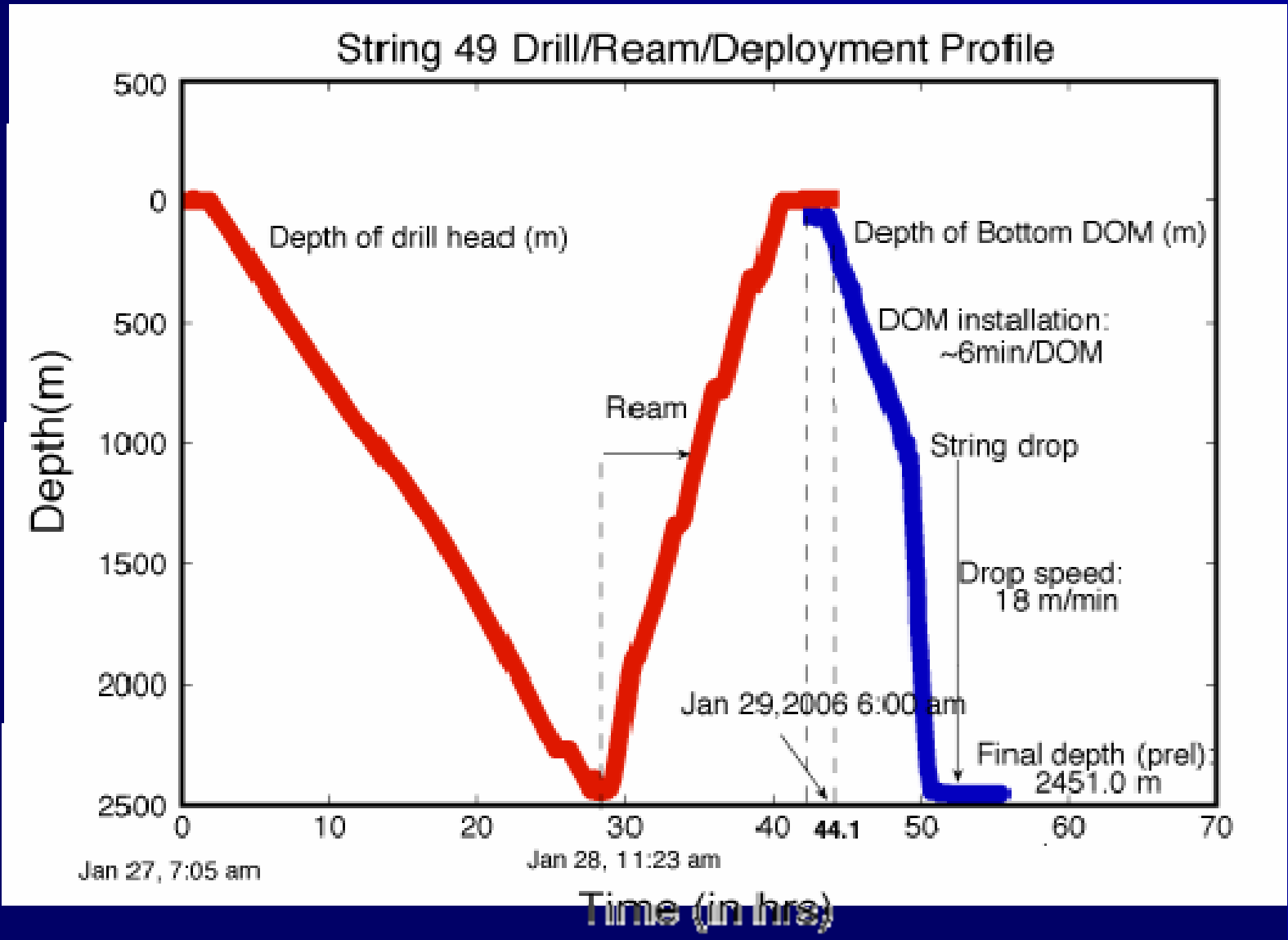
Drill Camp



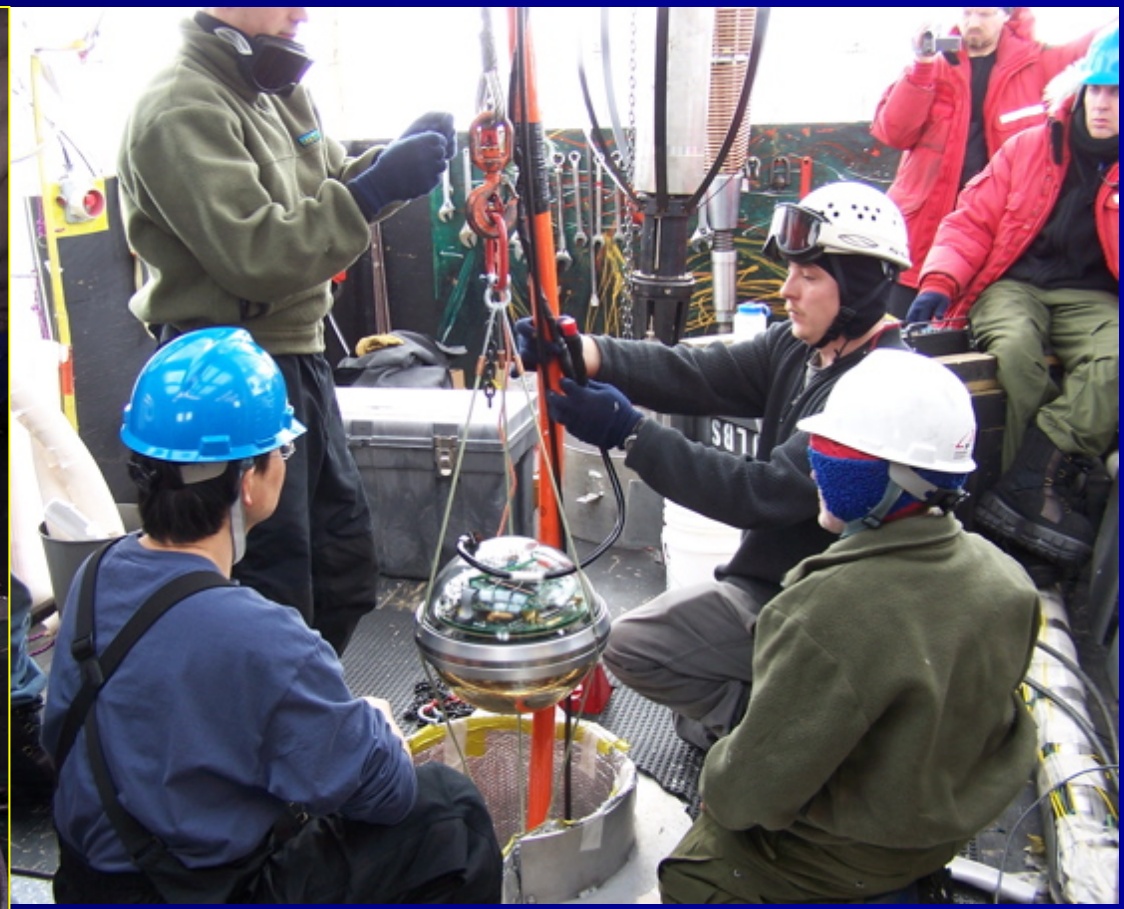
Hot Water Drilling

- 5 MW power
- 16 m³ fuel
  per hole

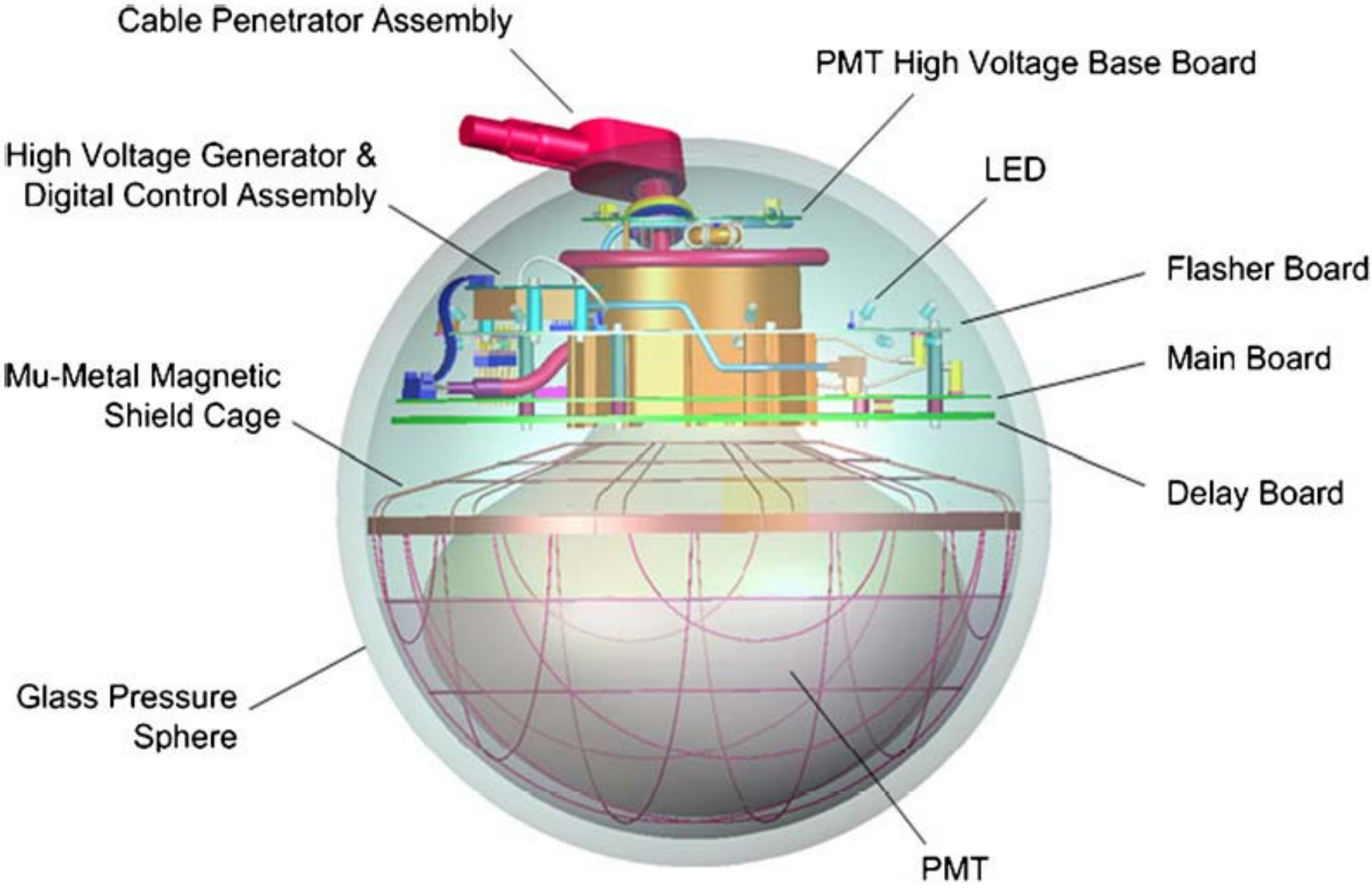
Hot Water Drilling



Deployment

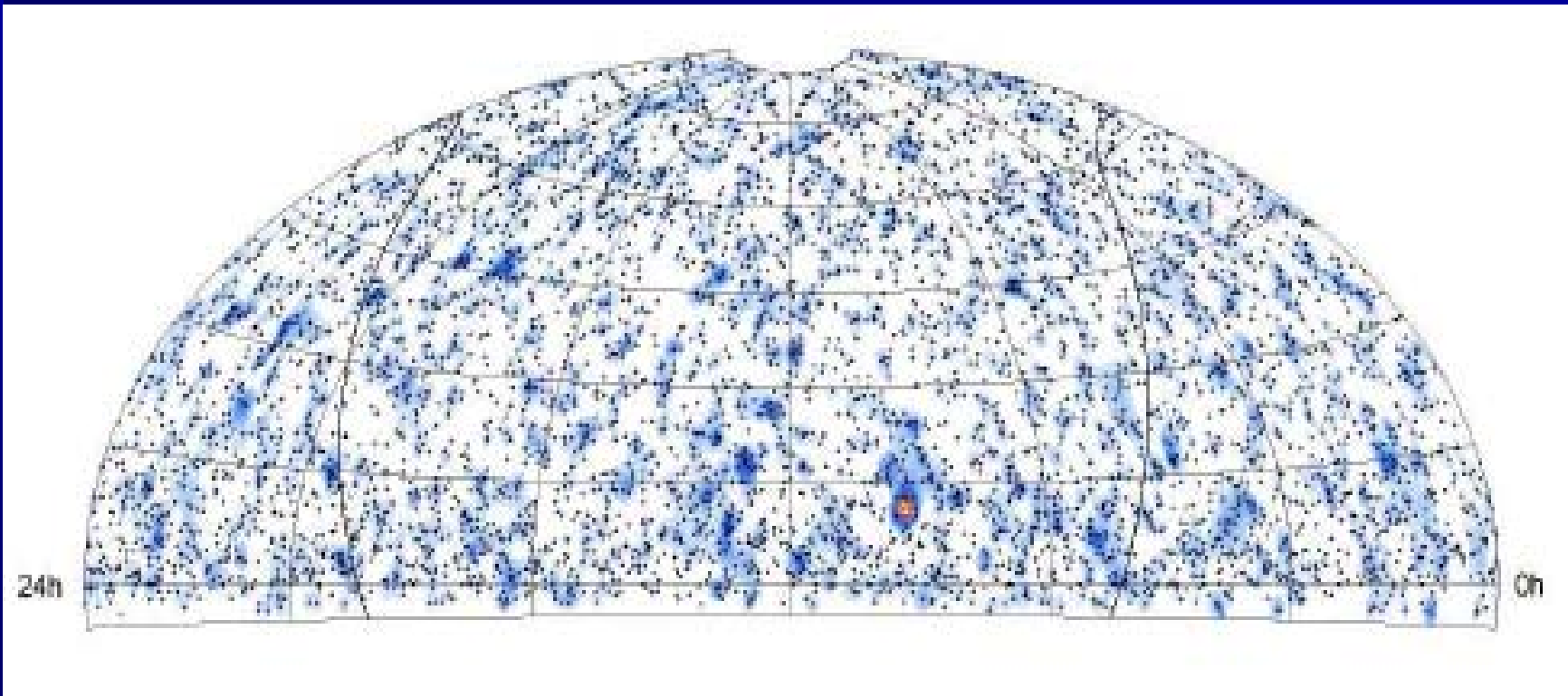


The Digital Optical Modules (DOM)



Search for Point Sources

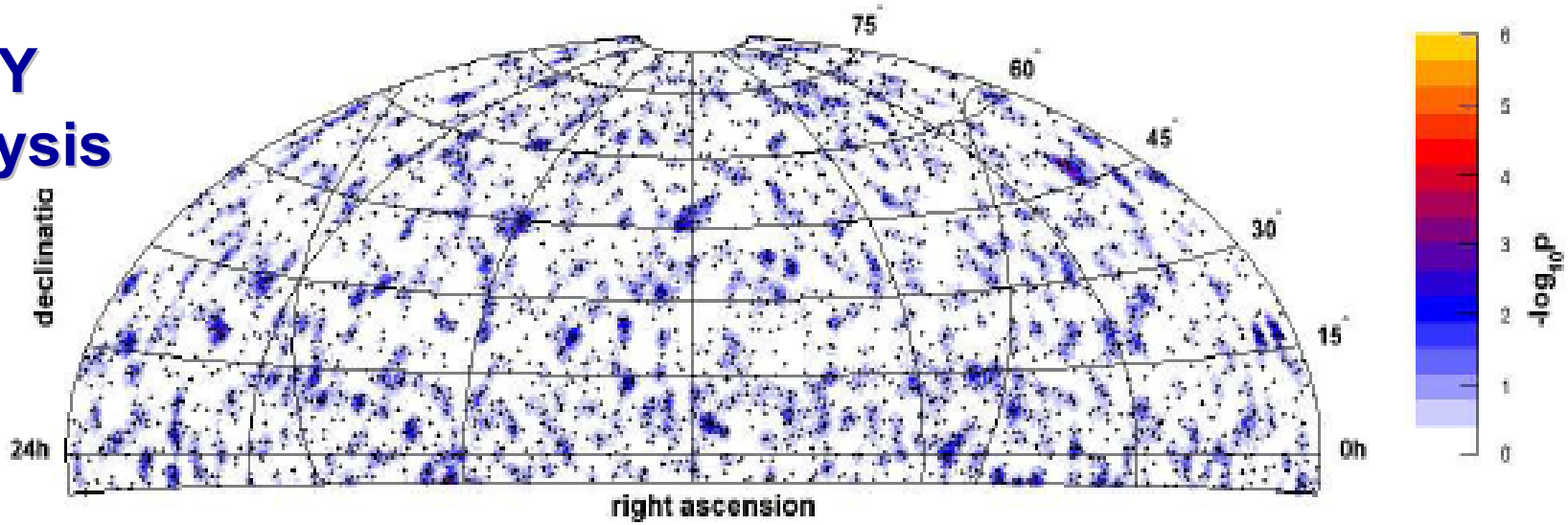
First IceCube skymap, IC-22, 2007 data



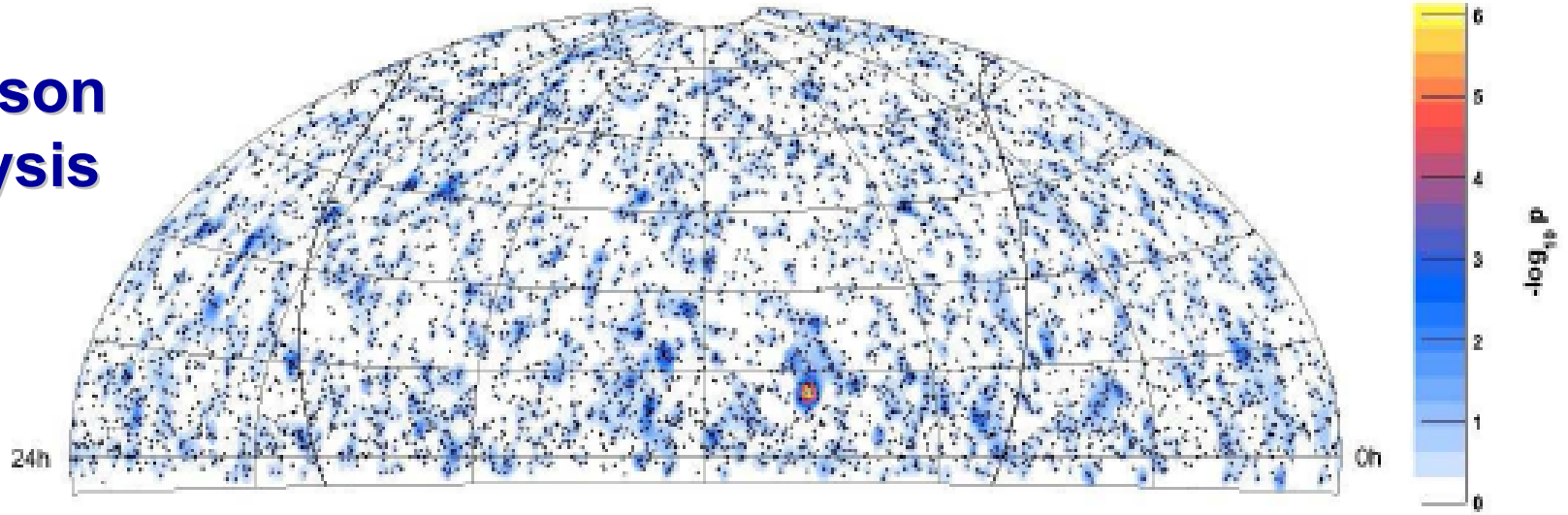
„hot spot“ has 2.4 σ after correction for trial factors
→ Consistent with background

First IceCube skymap, IC-22, 2007 data

DESY analysis

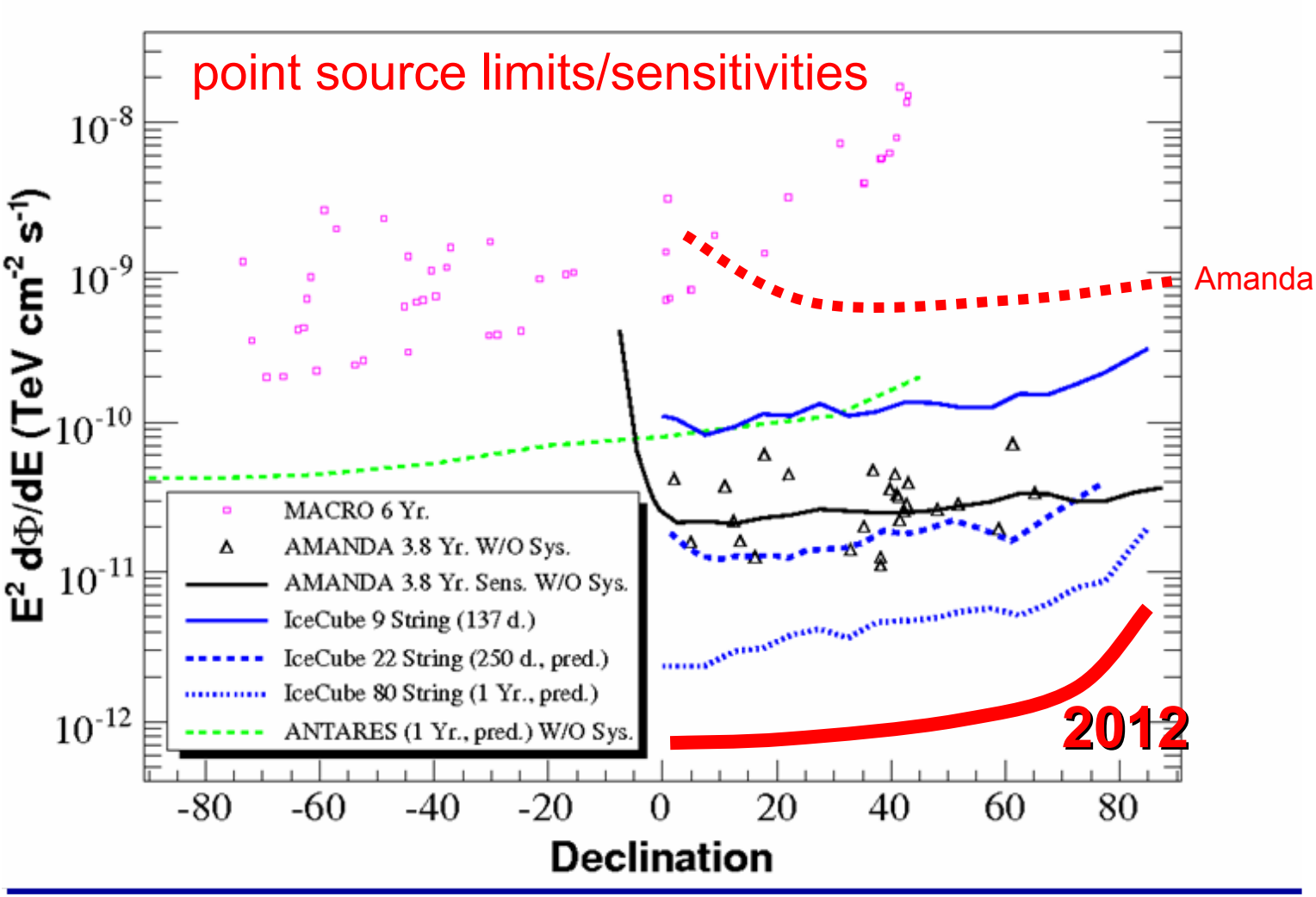


Madison analysis



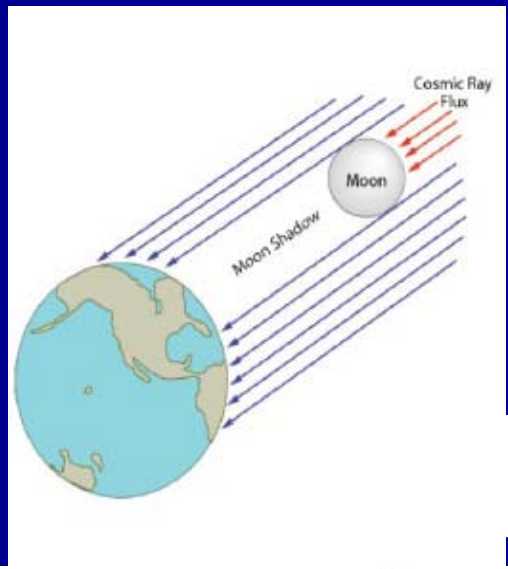
Point sources: the progress

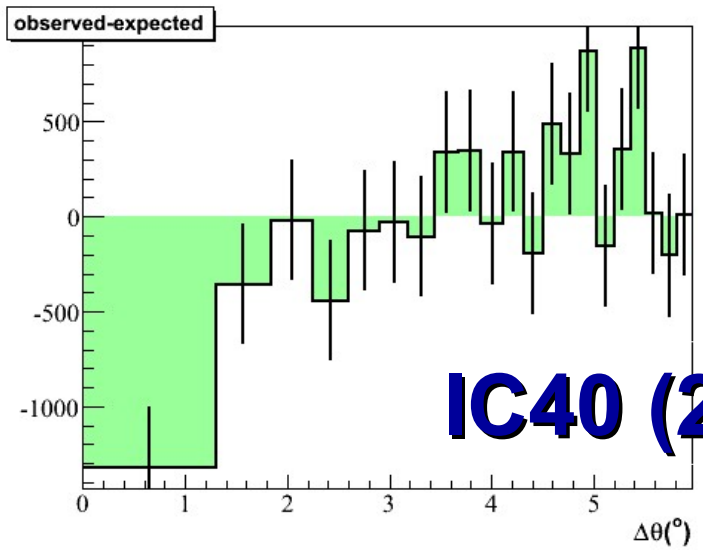
Tremendous progress in sensitivity over last decade



Shadow of the moon (our „first point source“)

- Detect downward muons from cosmic ray interactions
- CRs are shadowed by the moon
- Moon diameter 0.5°
- Seeing the moon shadow proves
  - Absolute pointing about 1° or better
  - Angular resolution about 1°





IC40 (2008)

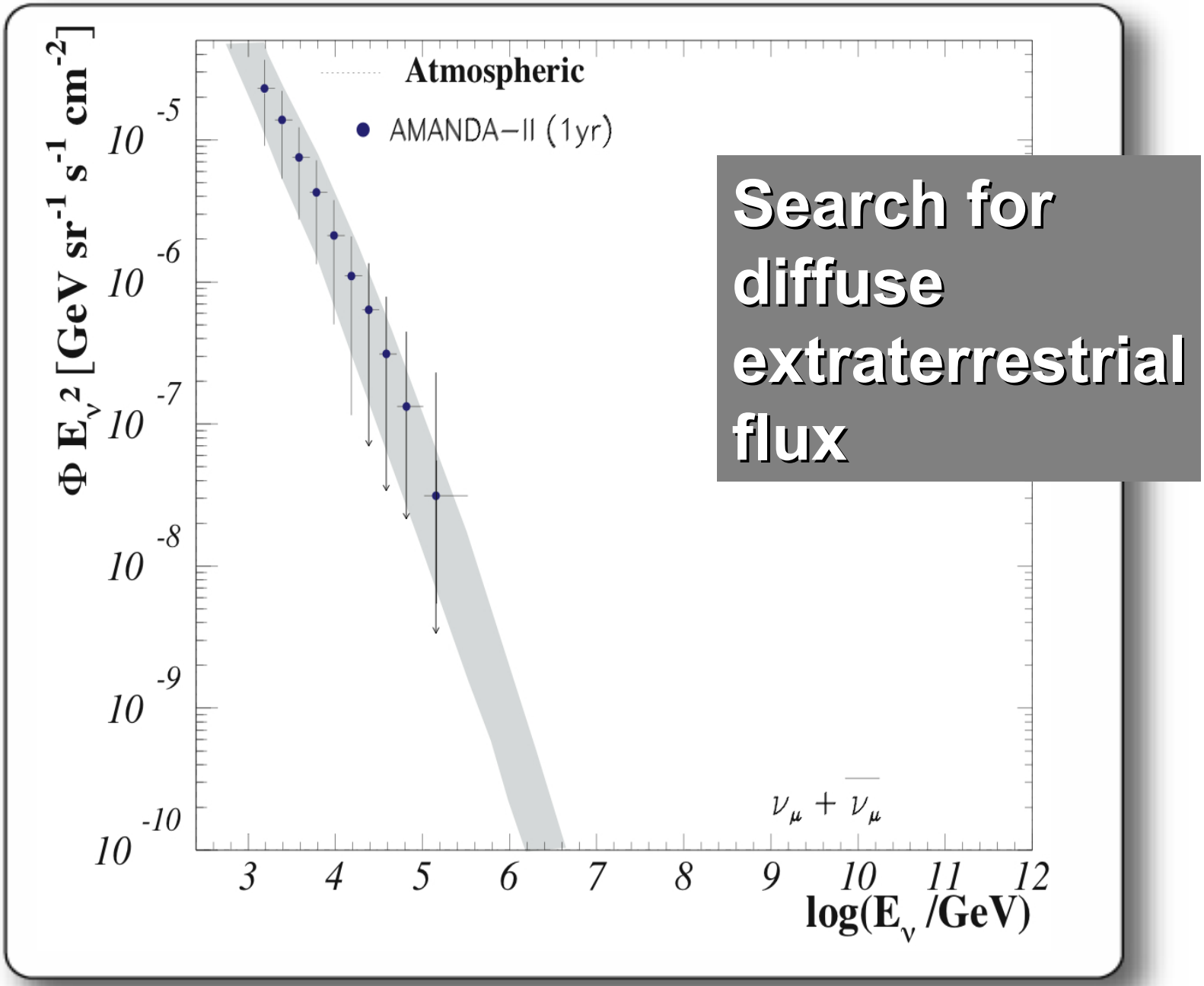
observed: 88202 events

expected: 89522 events

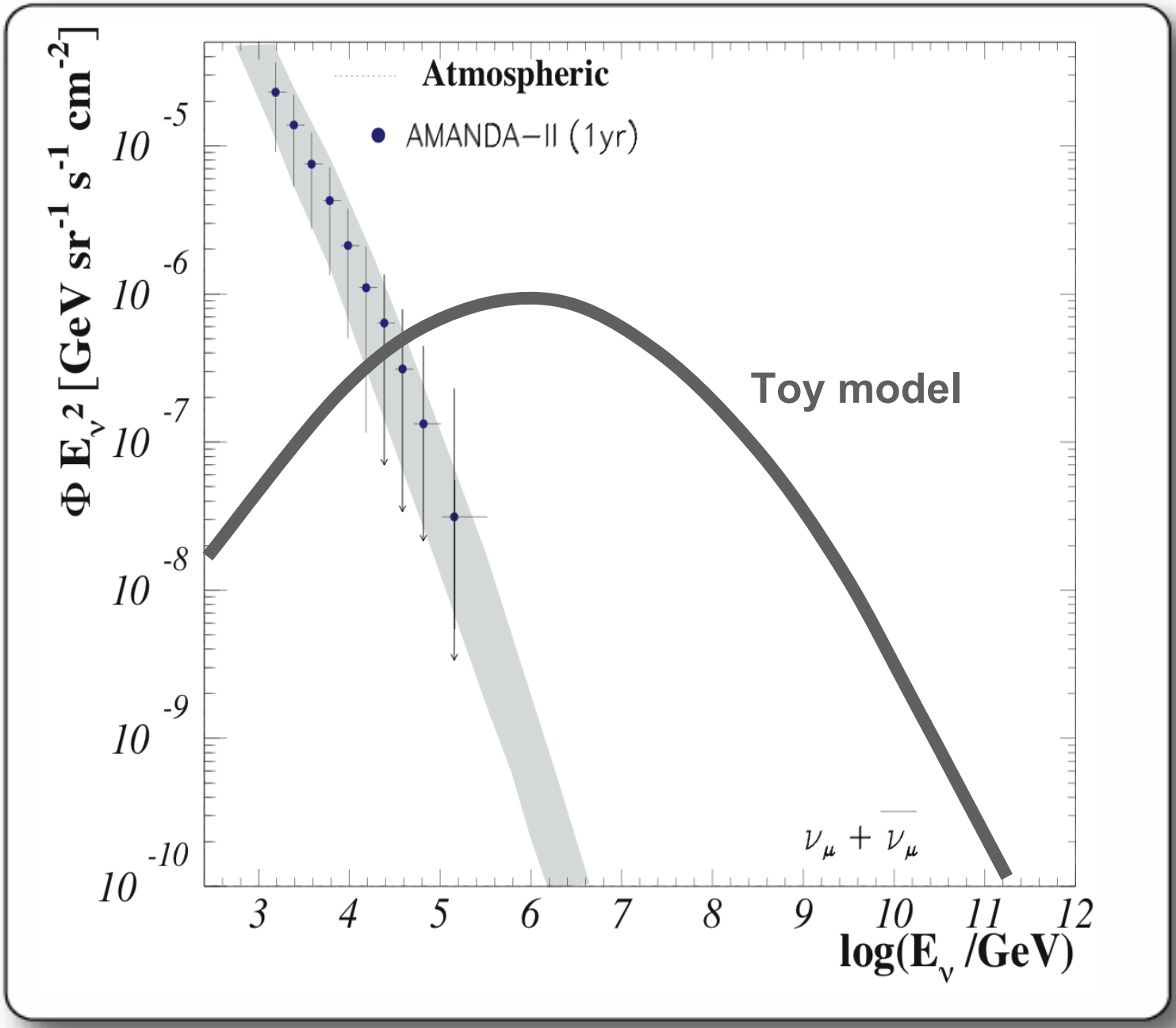
deficit: -1320 events

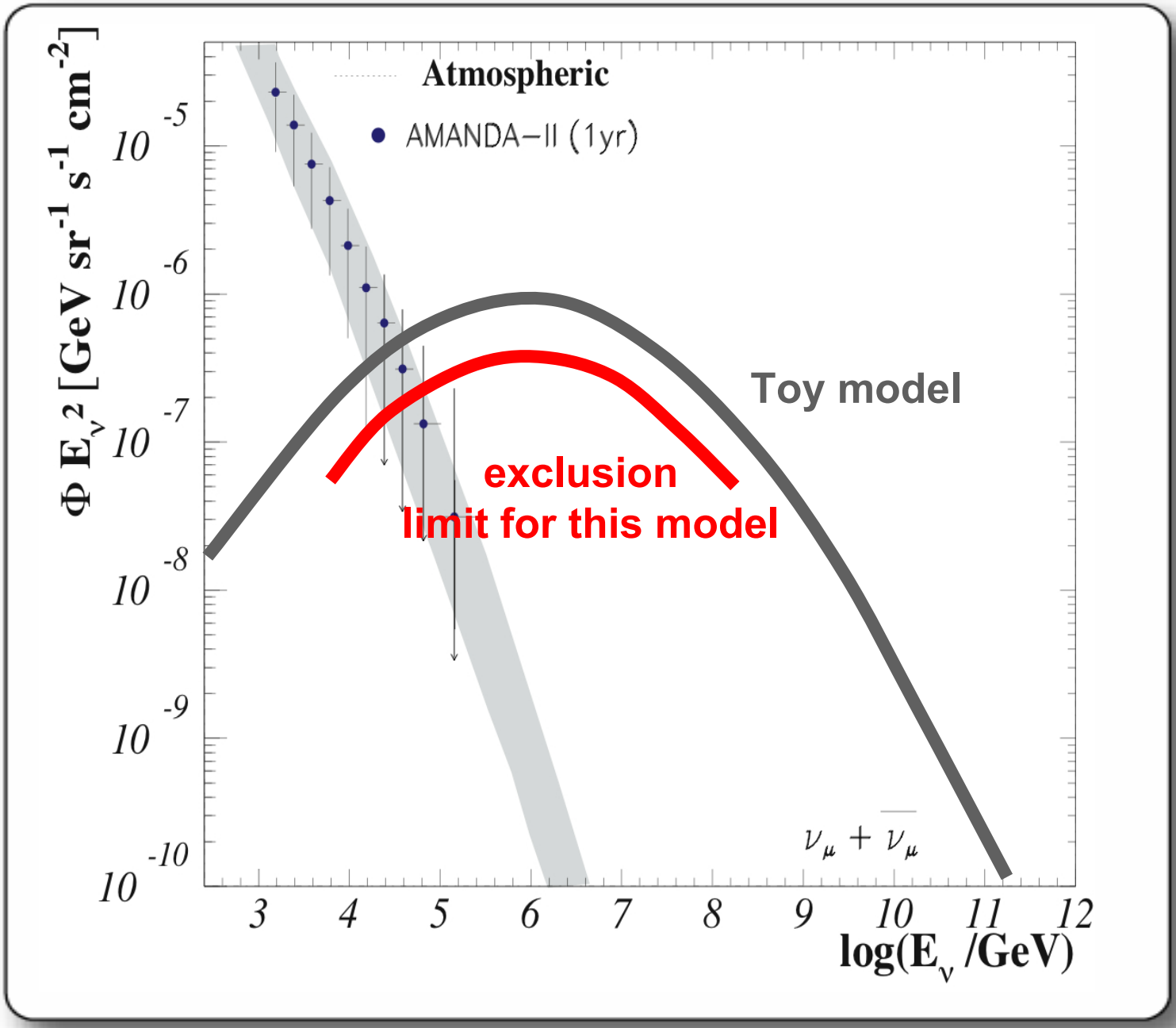
error: 315 events

significance: -4.2 σ

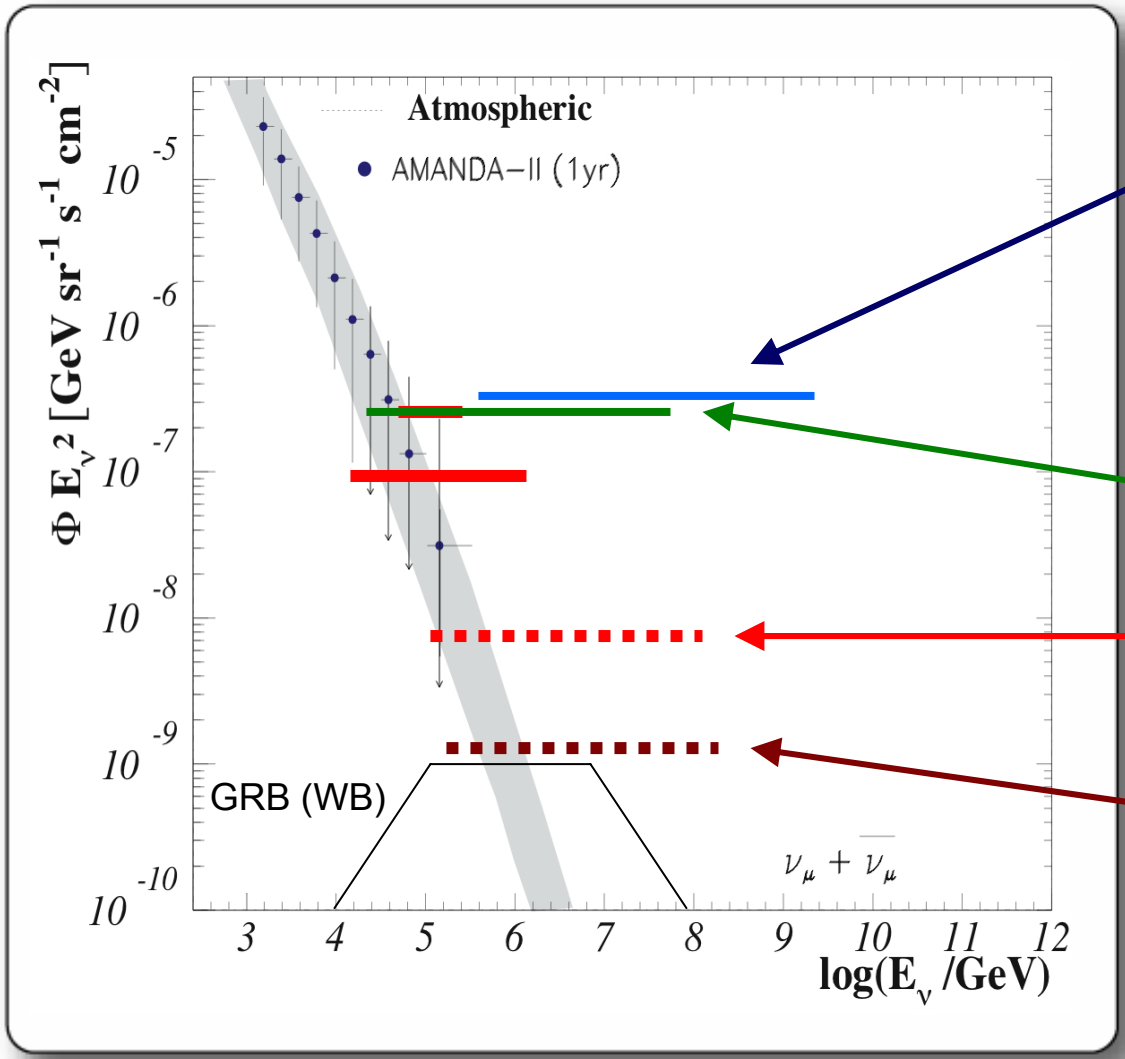


Search for diffuse extraterrestrial flux


Atmospheric
AMANDA–II (1yr)
Toy model
$\nu_\mu + \bar{\nu}_\mu$
ΦE_ν^2 [GeV sr^{-1} s^{-1} cm^{-2}]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
3
4
5
6
7
8
9
10
11
12
log(E_ν /GeV)


Atmospheric
AMANDA–II (1yr)
Toy model
exclusion
limit for this model
$\nu_\mu + \bar{\nu}_\mu$
ΦE_ν^2 [GeV sr^{-1} s^{-1} cm^{-2}]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
3
4
5
6
7
8
9
10
11
12
log(E_ν /GeV)

Limit on diffuse extraterrestrial fluxes



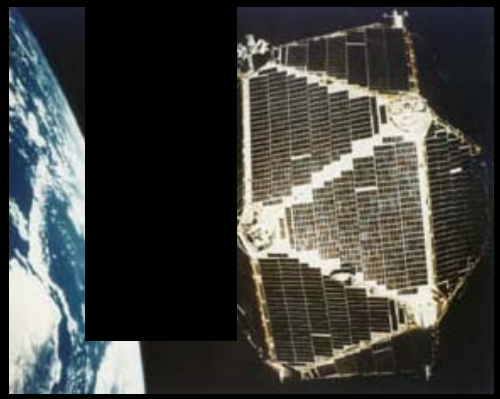
AMANDA HE analysis — *2003*

Baikal — *2006*

IceCube muons, 1 year — *2009*

Icecube, muons & cascades 4 years — *2013*

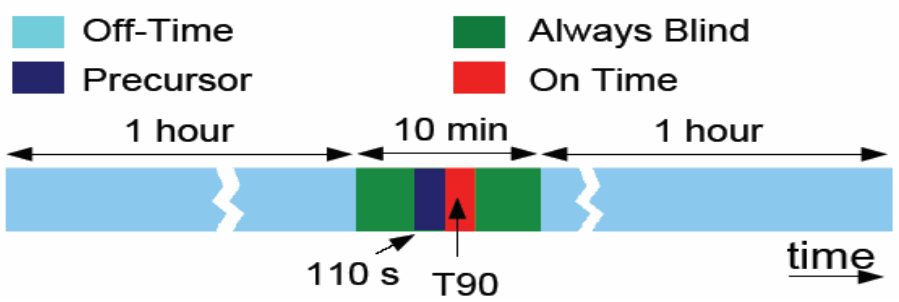
Gamma Ray Bursts



Vela Satellite 1969

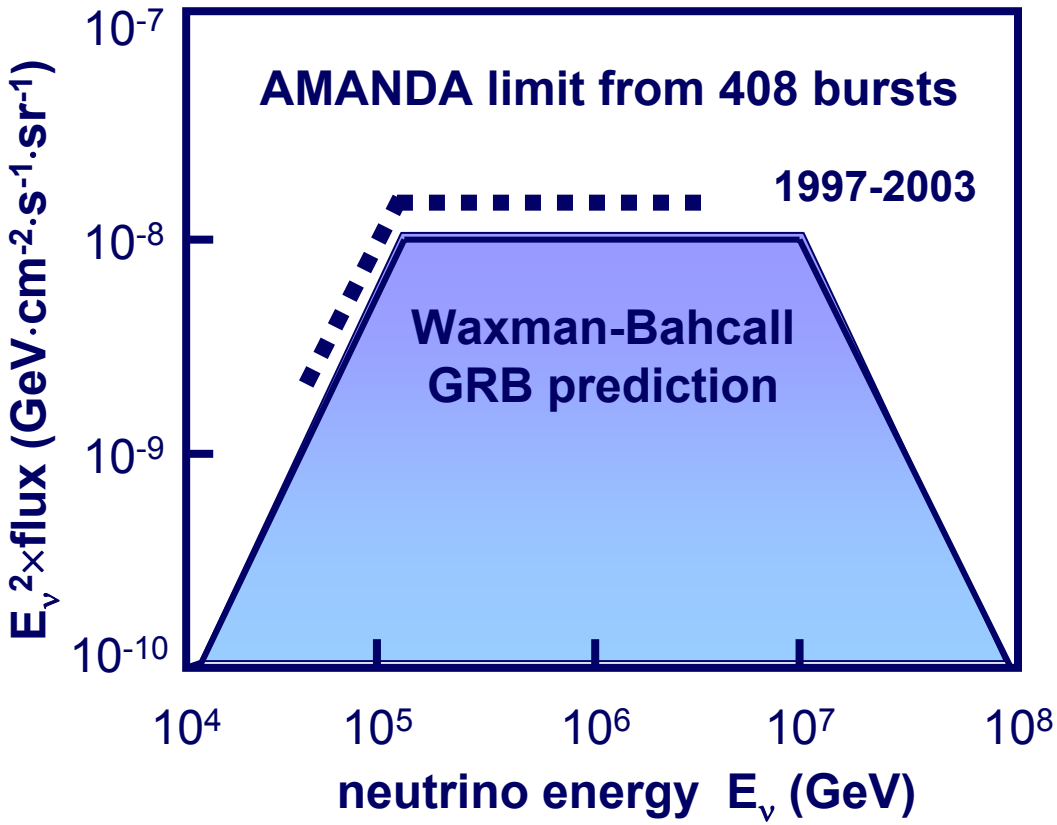
Jet with Γ ~300-1000

Coincidences with GRB



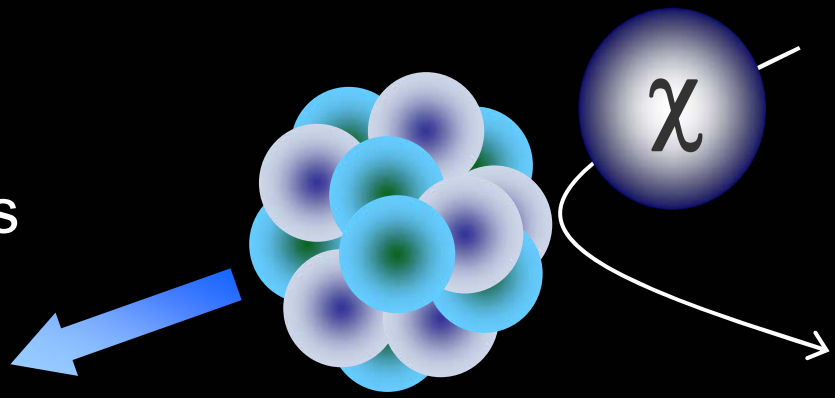
Check for coincidences with BATSE, IPN, SWIFT

- close to WB within < factor 2
- with IceCube: test WB within a few months

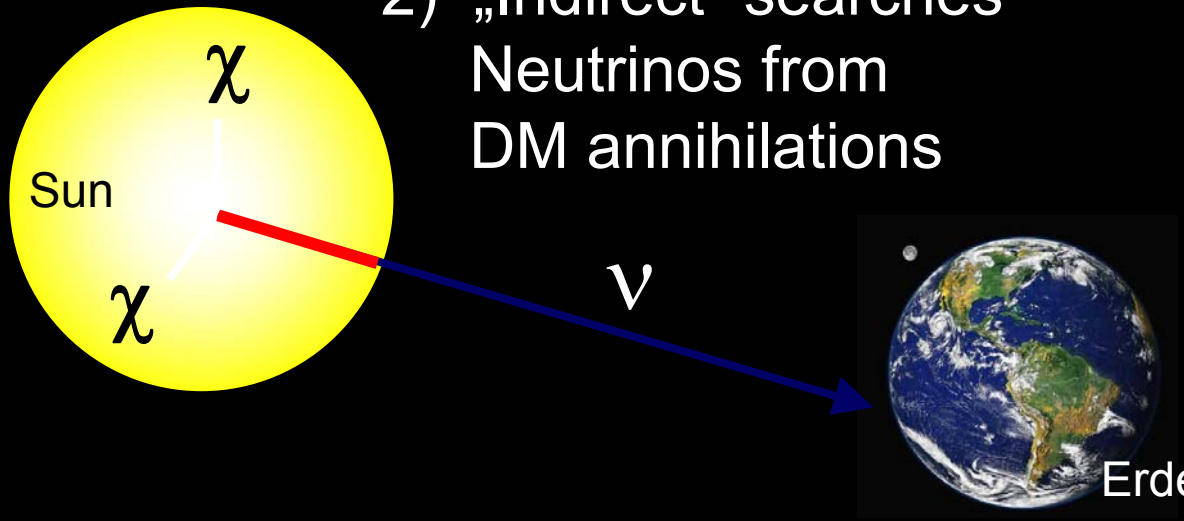


Dark Matter Searches

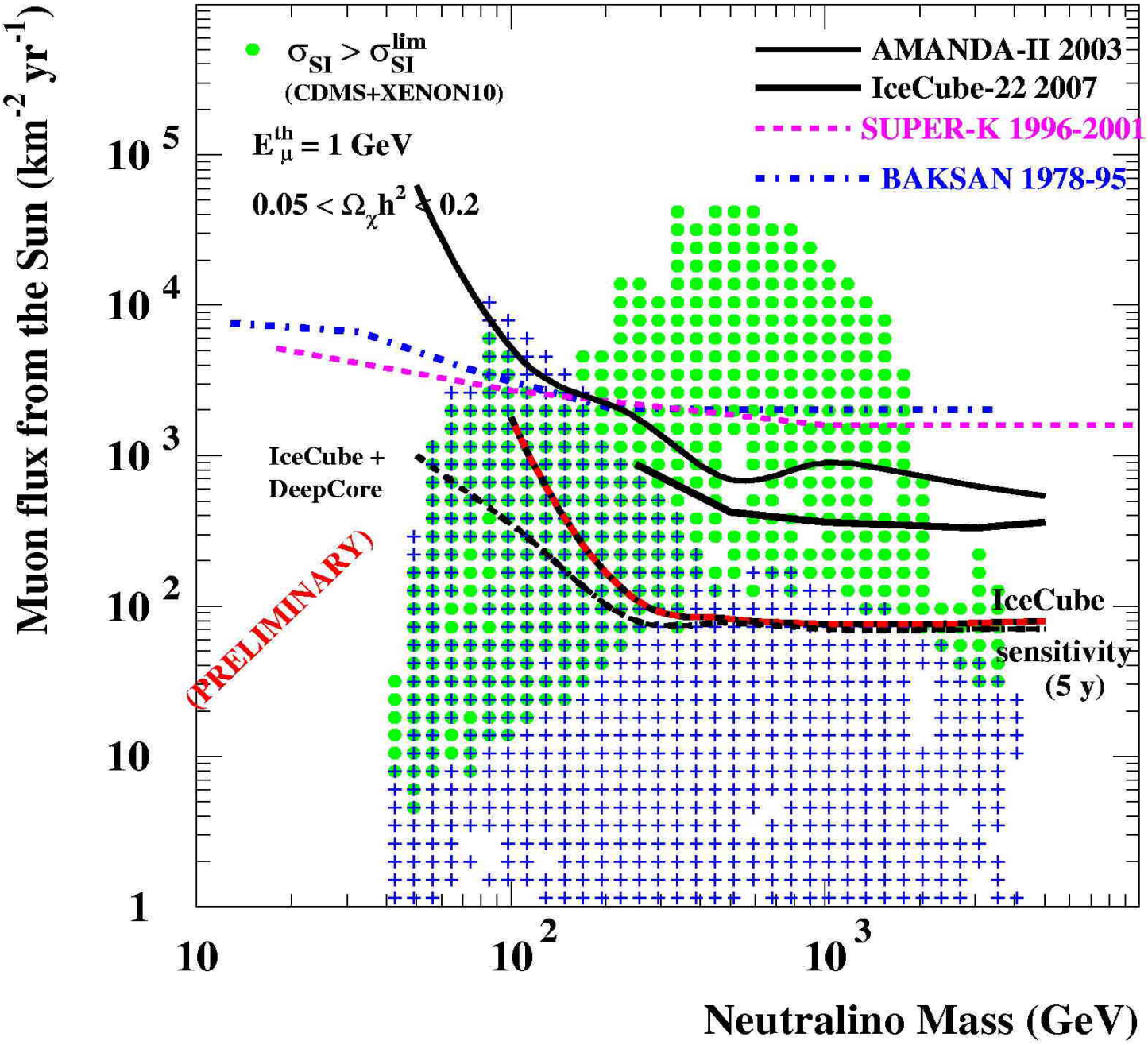
1) „Direct“ search
DM scattering in
underground detectors



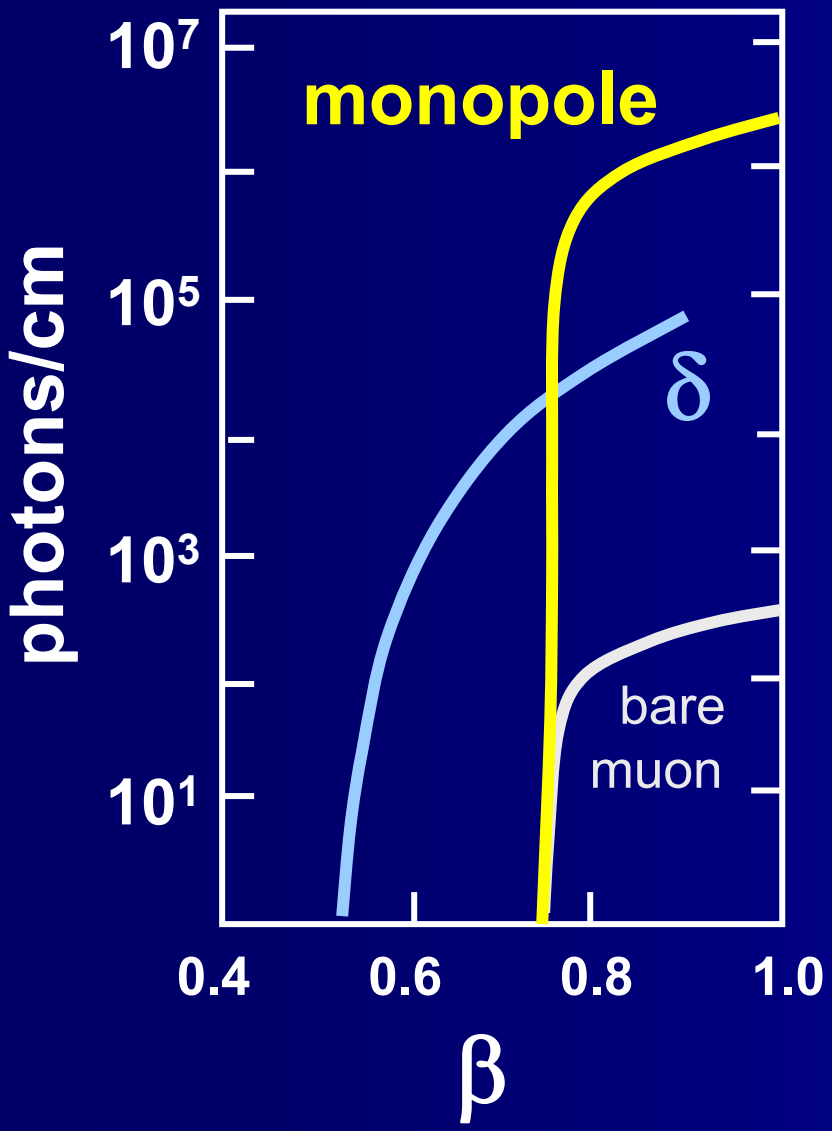
2) „Indirect“ searches
Neutrinos from
DM annihilations



3) produce
DM particles
at LHC


$\sigma_{SI} > \sigma_{SI}^{lim}$
(CDMS+XENON10)
$E_\mu^{th} = 1$ GeV
$0.05 < \Omega_\chi h^2 < 0.2$
AMANDA-II 2003
IceCube-22 2007
SUPER-K 1996-2001
BAKSAN 1978-95
IceCube + DeepCore
(PRELIMINARY)
IceCube sensitivity (5 y)
Muon flux from the Sun (km^{-2} yr^{-1})
Neutralino Mass (GeV)
10^5
10^4
10^3
10^2
10
1
10
10^2
10^3

Relativistic Magnetic Monopoles



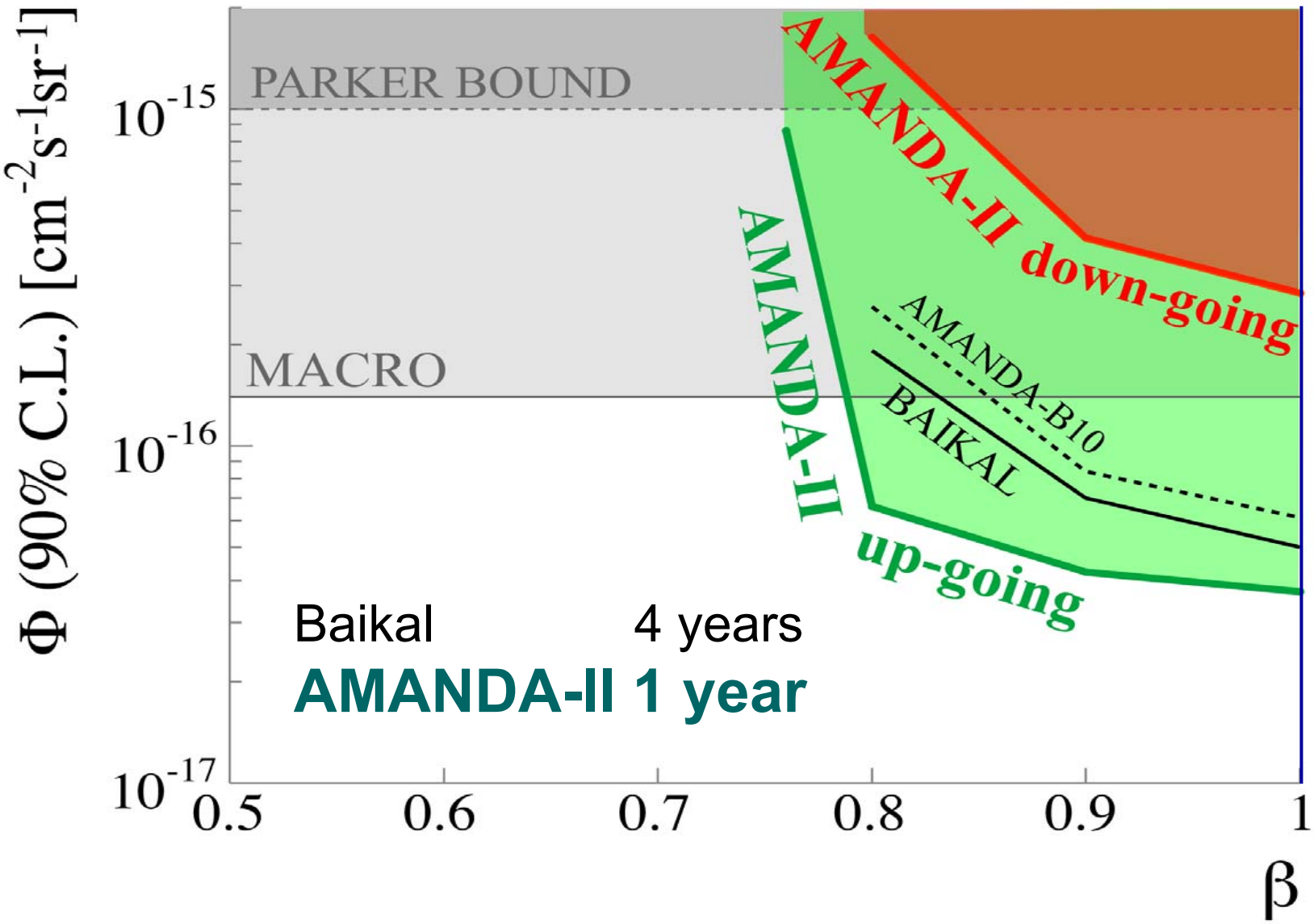
Cherenkov Light $\propto$ $n^2 \cdot (g/e)^2$

n = 1.33

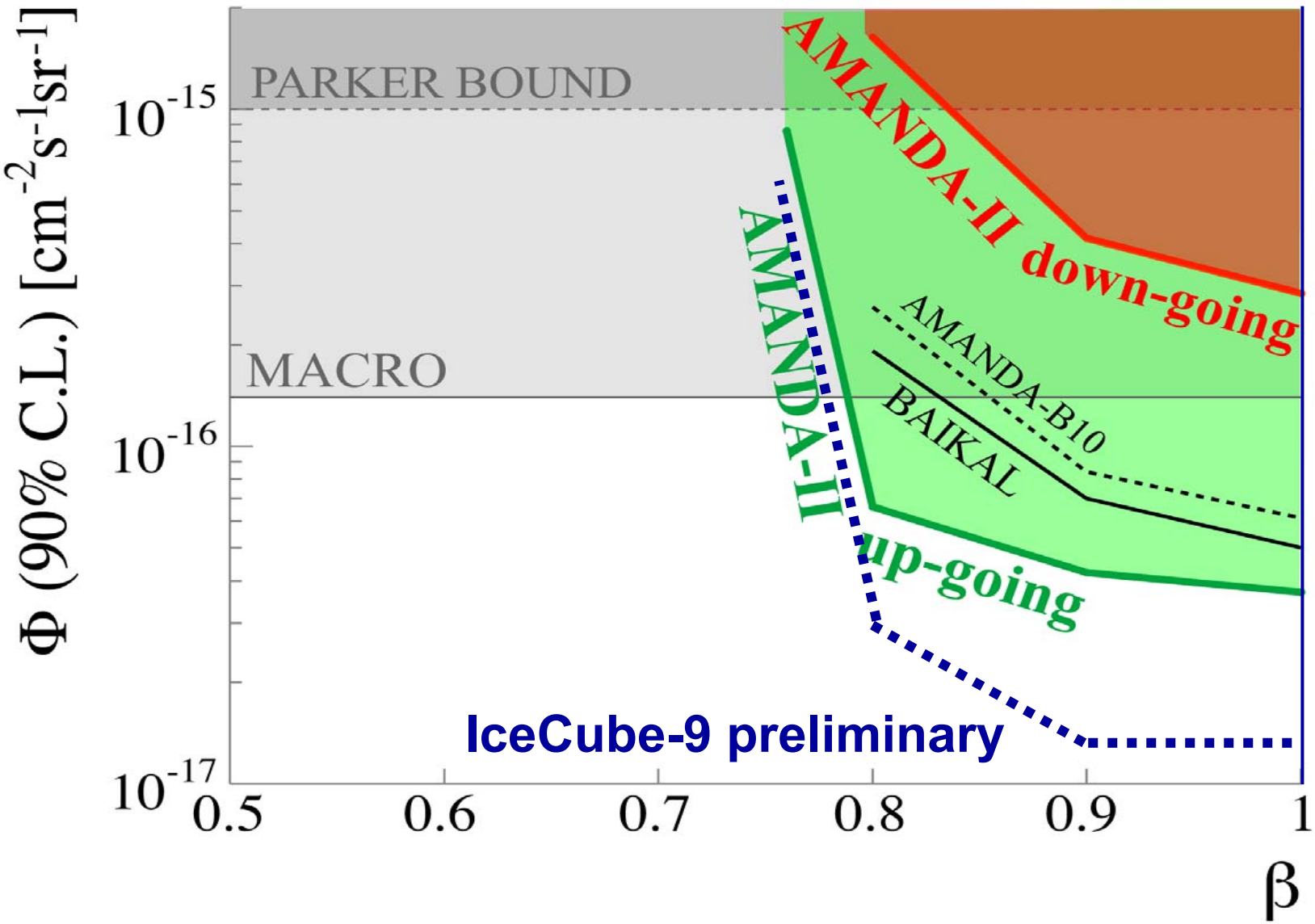
(g/e) = $^{137}/_{2}$

$\approx$ 8300

Relativistic Magnetic Monopoles

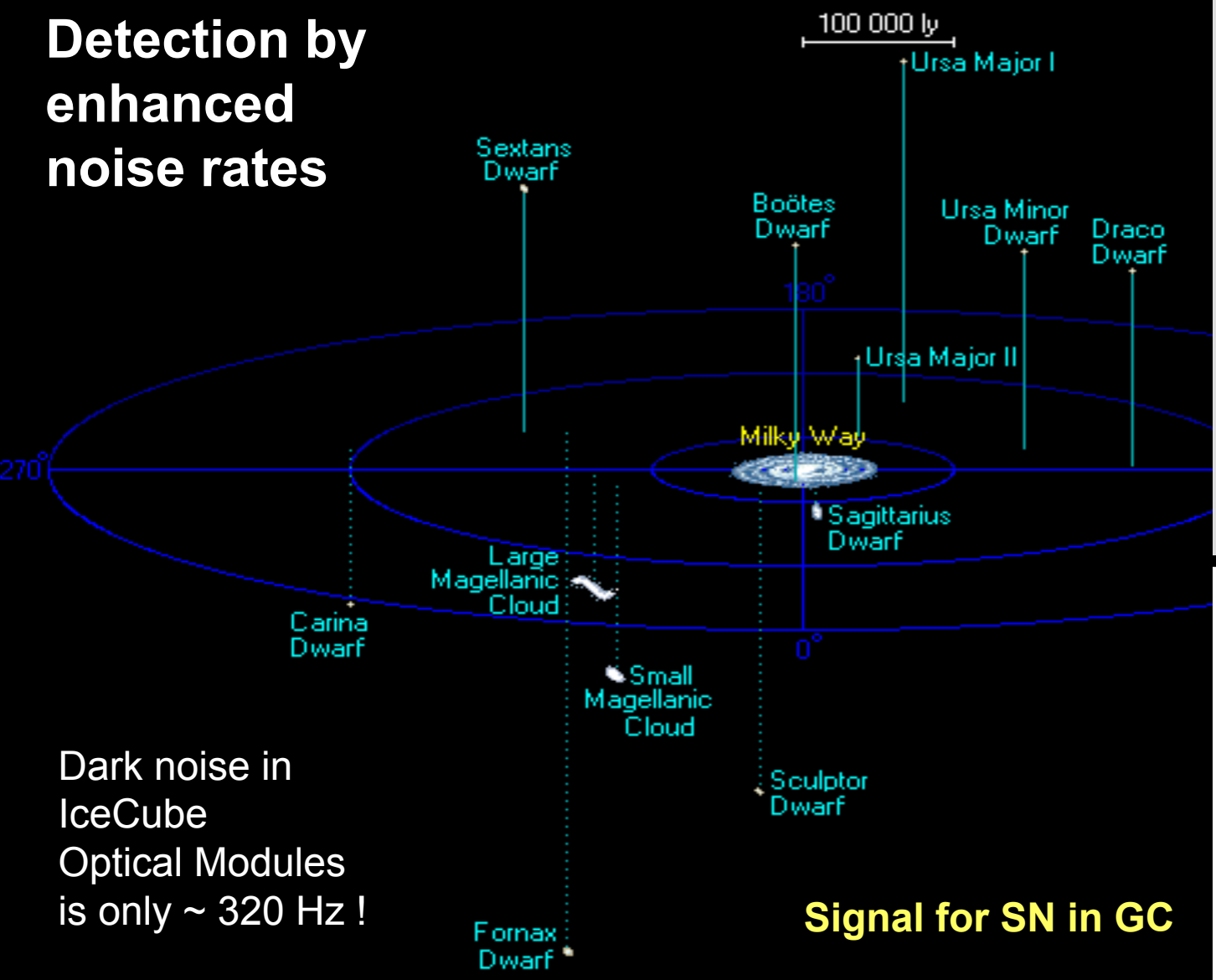


Relativistic Magnetic Monopoles

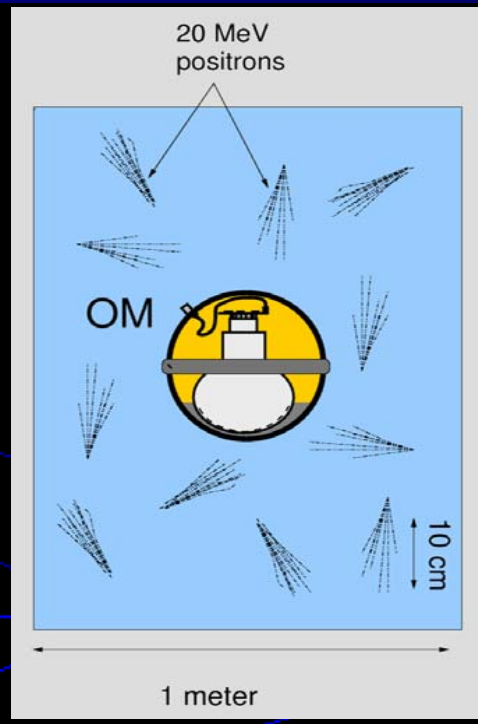


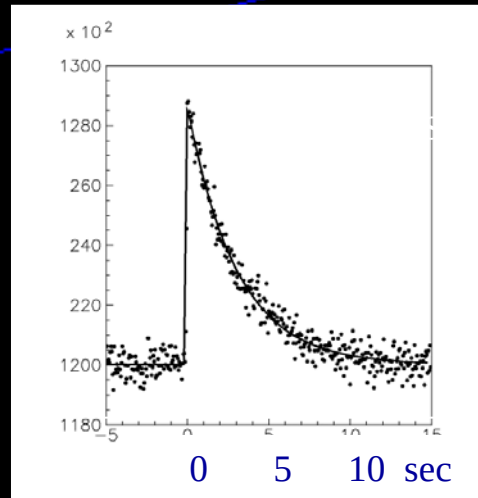
Supernovae in IceCube

Detection by enhanced noise rates



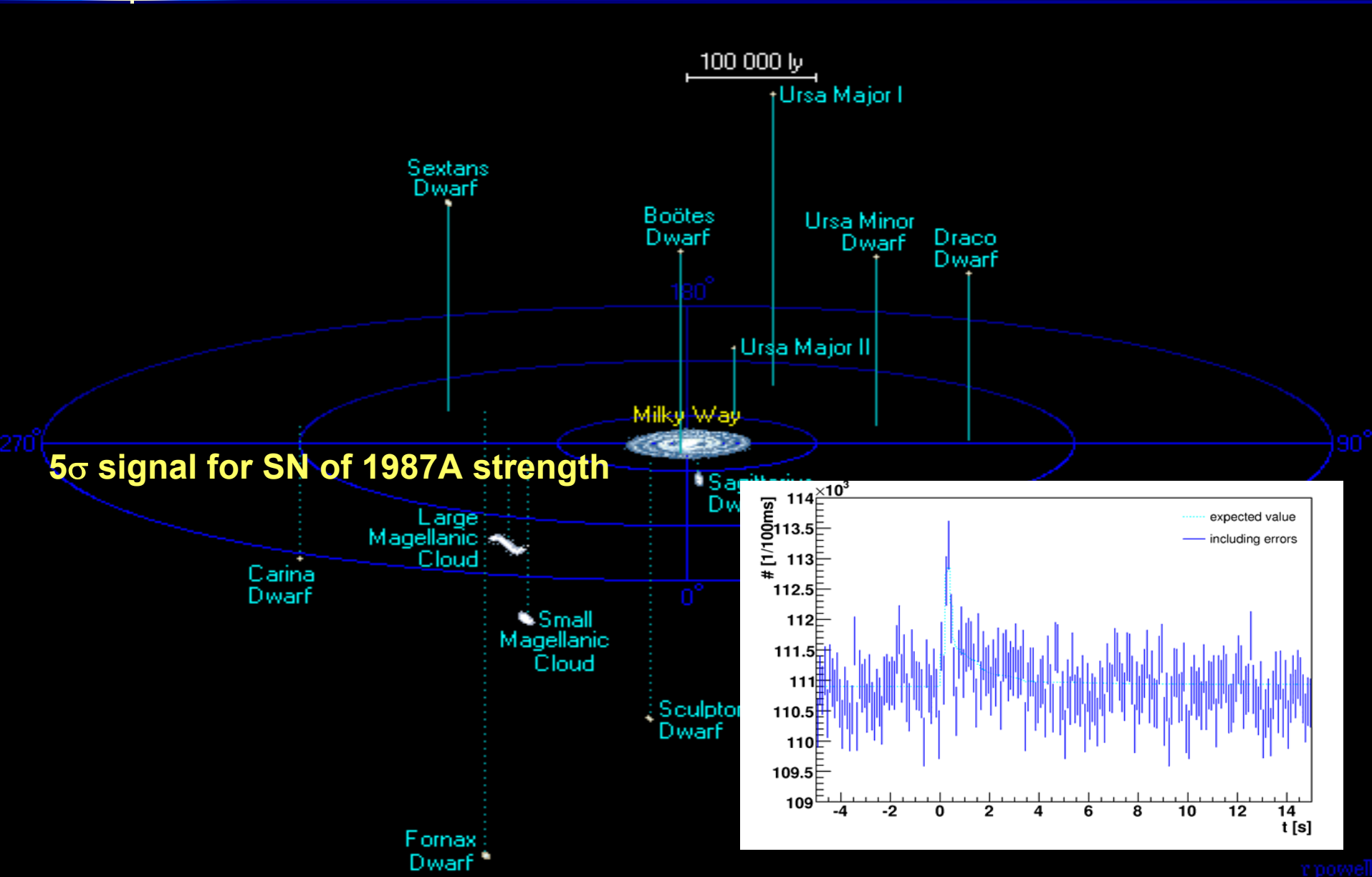
Dark noise in IceCube Optical Modules is only ~ 320 Hz !



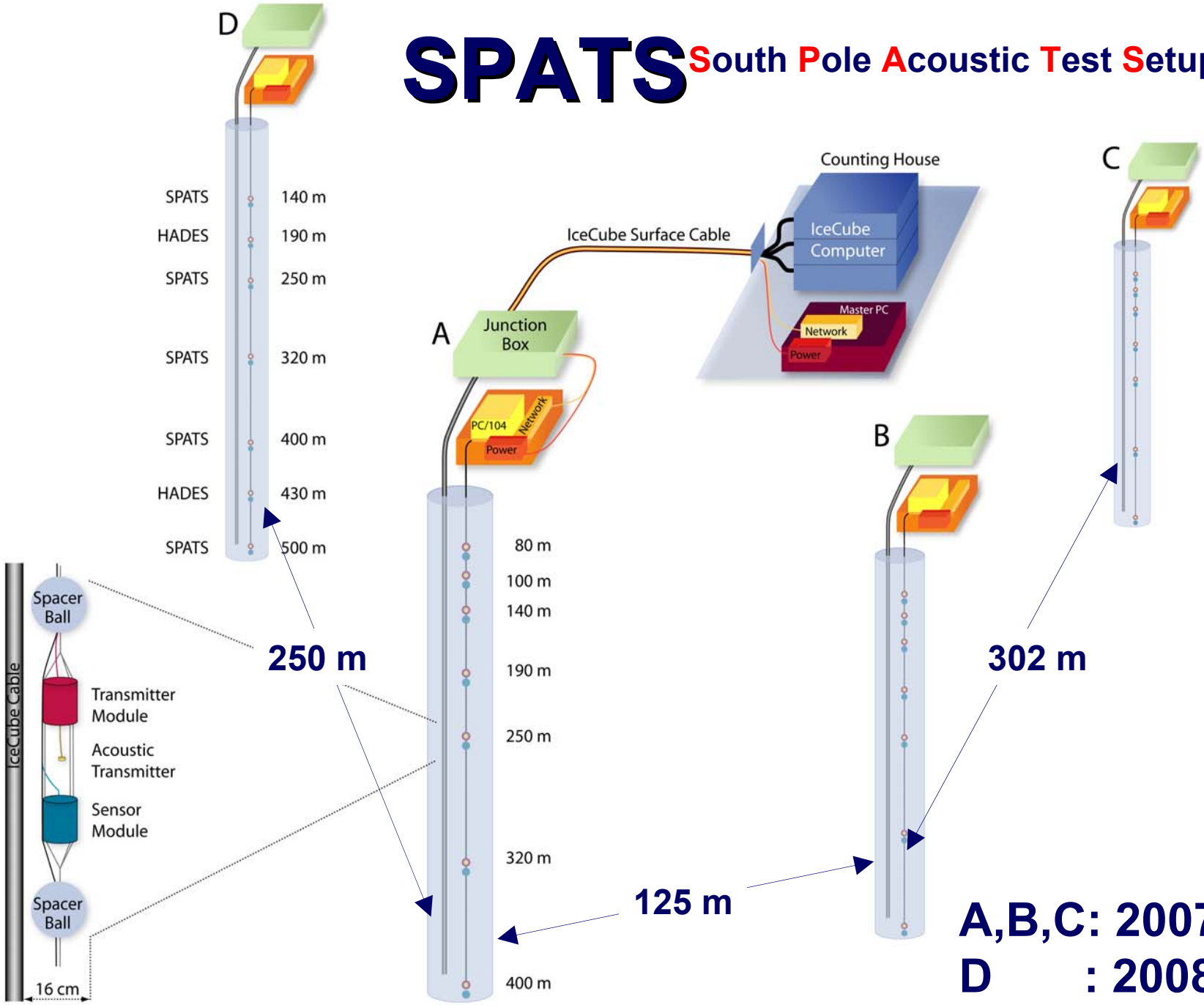


Signal for SN in GC

Supernovae in IceCube



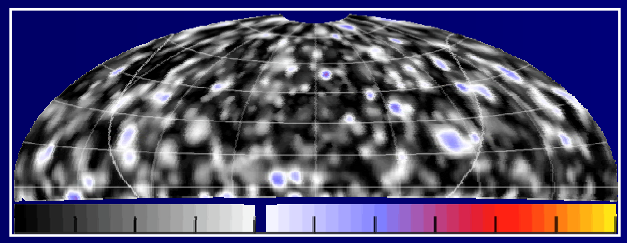
SPATS South Pole Acoustic Test Setup



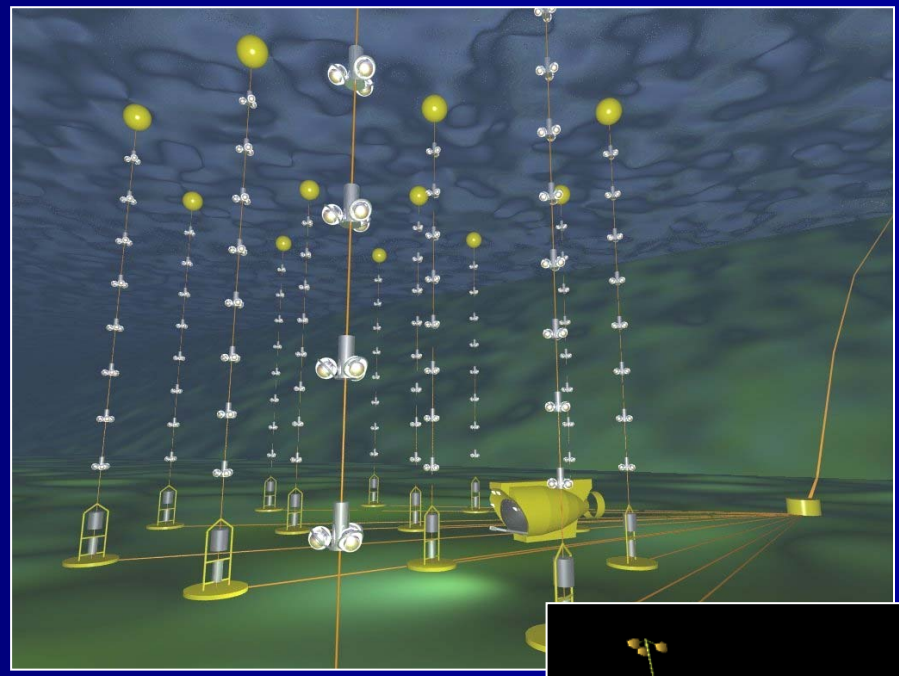
A,B,C: 2007
D : 2008

Summary

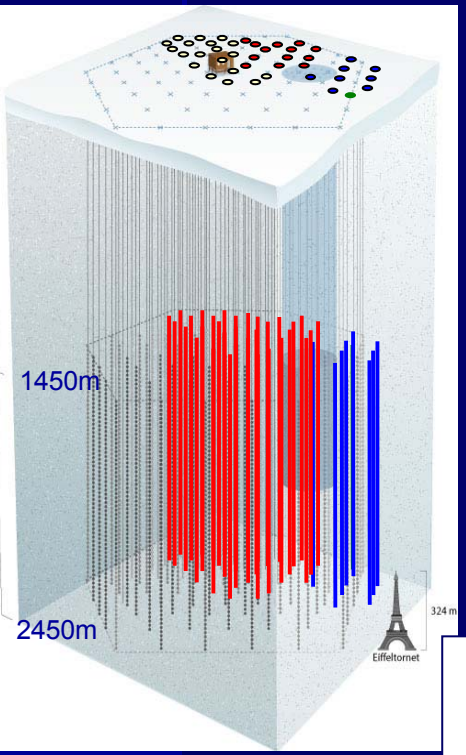
A fantastic year 2008



7 year skymap
AMANDA

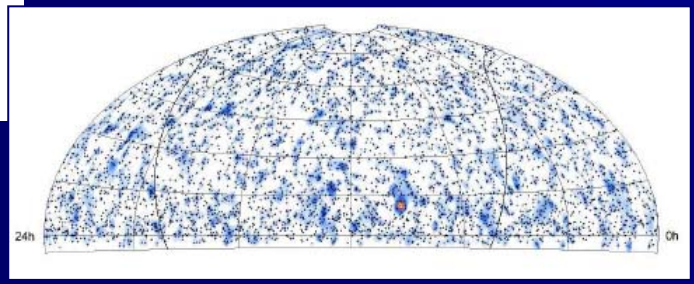


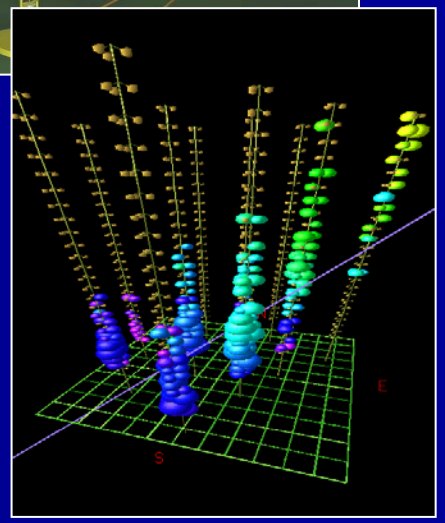
IceCube
50% complete



ANTARES fully
operational

High-statistics sky-map IceCube





High statistics
of neutrinos
in ANTARES

Summary

- no positive detection yet, but already testing realistic bounds
- IceCube reaches 1 $km^3 \times$ year by early 2009
- entering region with fair discovery potential.
  Most interesting period 2009-2013 !
- Coming soon:
  - New record sensitivities for dark matter, magnetic monopoles and other exotica
  - Particle physics with ½ million atm. neutrinos
  - Determination of cosmic ray mass composition with alternative method
- IceCube is ready for the next Supernova