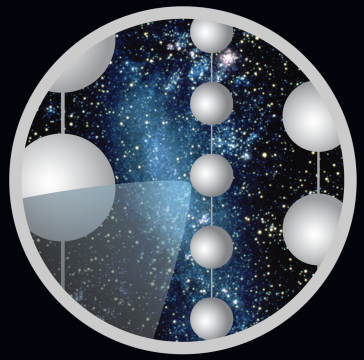


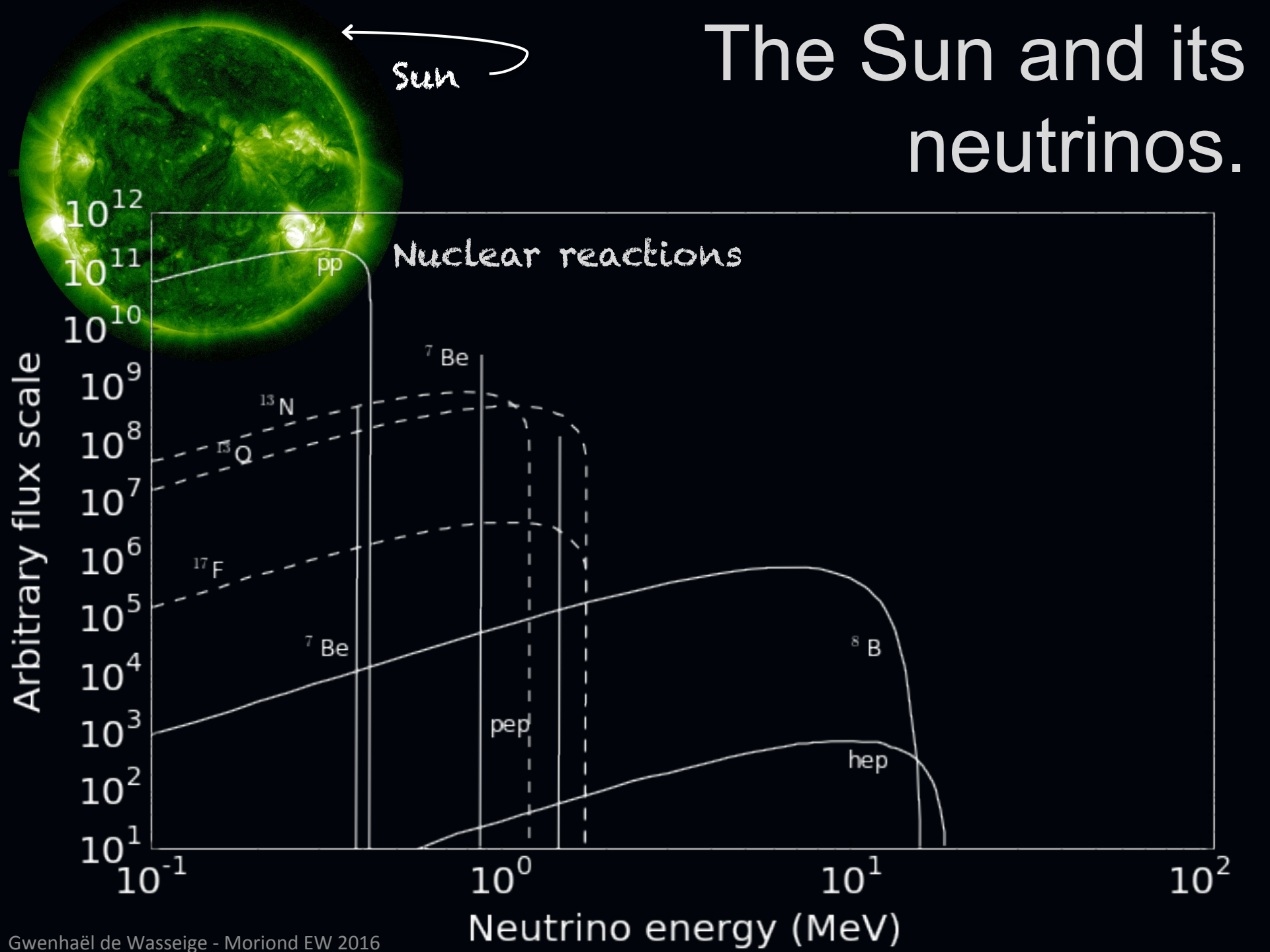
IceCube

On the study of solar flares with neutrino observatories

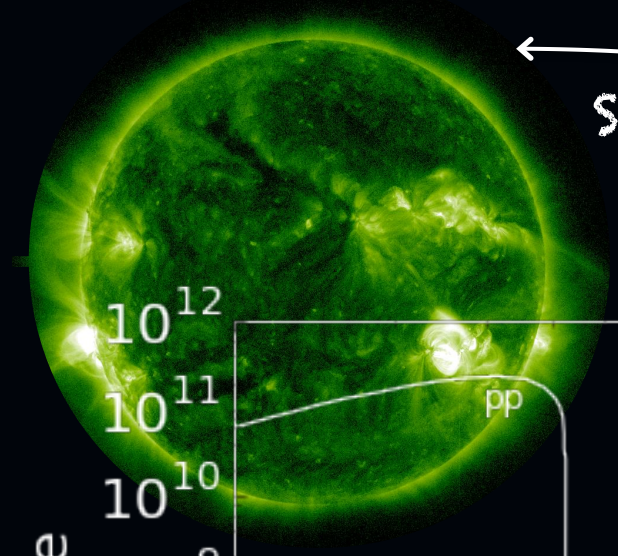
Gwenhaël de Wasseige
for the IceCube Collaboration
https://icecube.wisc.edu

iihe
BRUXELLES BRUSSEL

The Sun and its neutrinos.



The Sun and its solar flare neutrinos.



Where are these flare neutrinos coming from?

$\pi^+ \rightarrow \mu^+ + \nu_\mu$

$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

$\pi^0 \rightarrow 2\ \gamma$

$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$

$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$

What is so exciting about these flare neutrinos ?

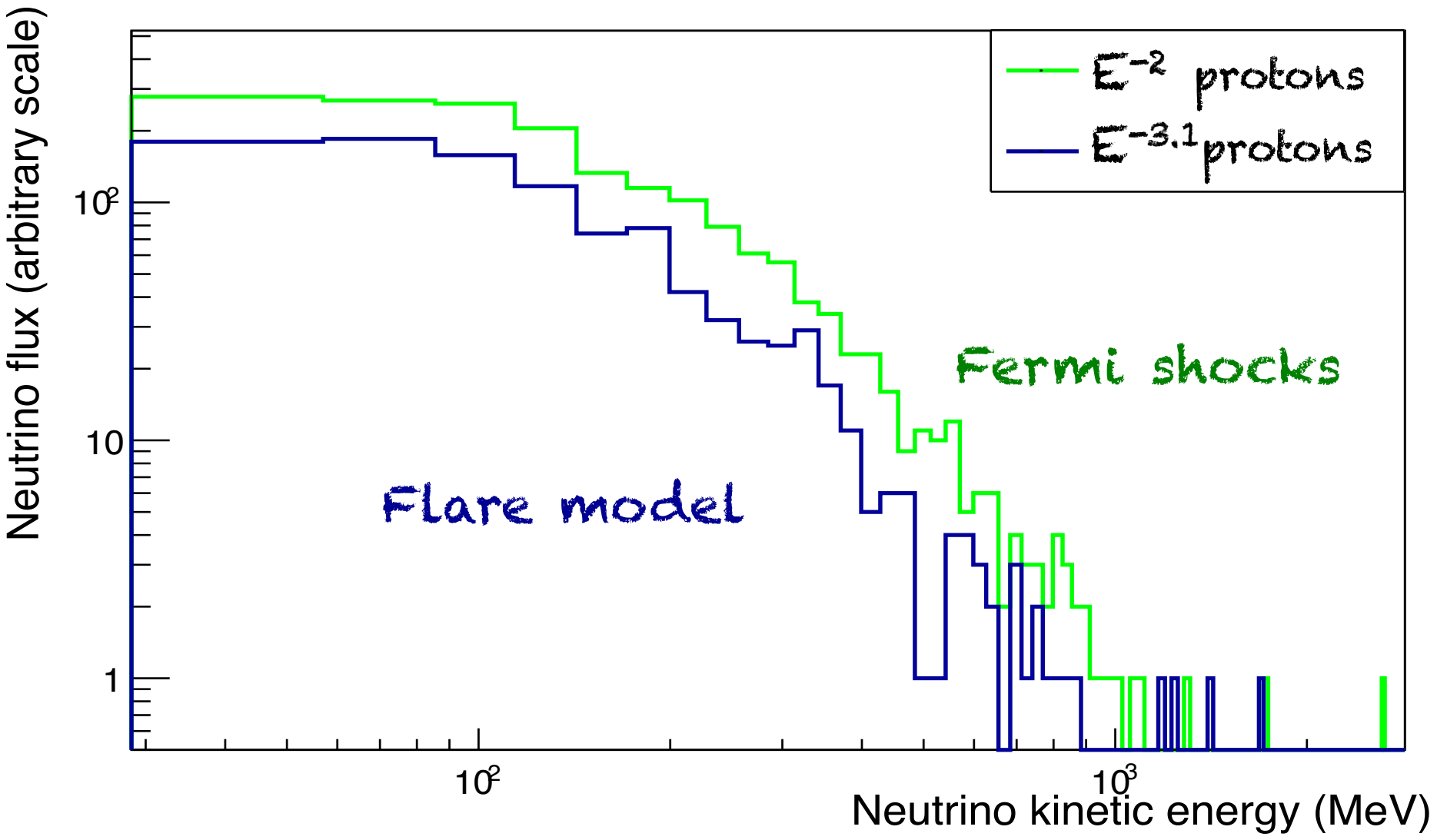
- ν would confirm the **hadronic nature** of solar flares

- ν and γ would give insight into the **acceleration mechanism(s)**

- **Neutrino observatories** could help to constrain current parameters in **solar flare physics**

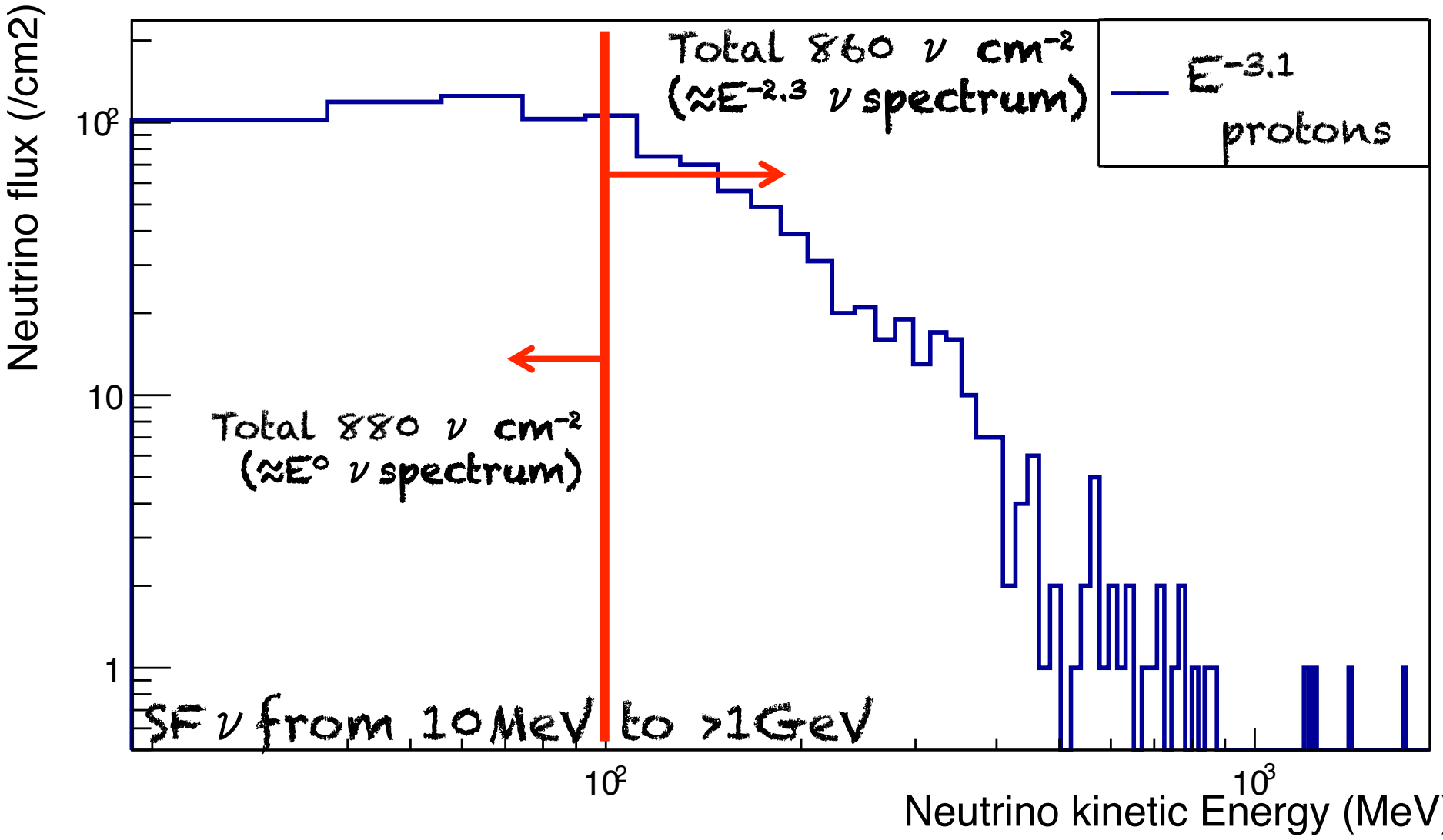
@Sun

What is the spectrum of these flare neutrinos?

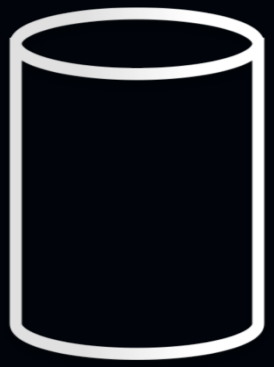


What is the spectrum of these flare neutrinos?

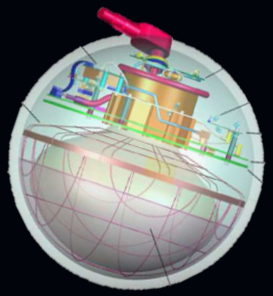
@Earth



What do we need to detect these flare neutrinos?

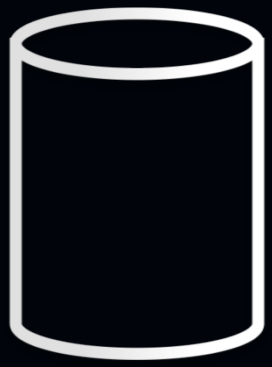


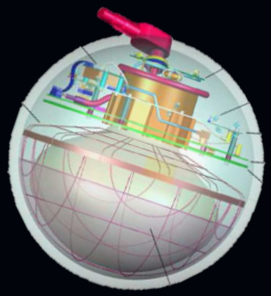
+ Many



+ Many solar flares

What do we need to detect these flare neutrinos?



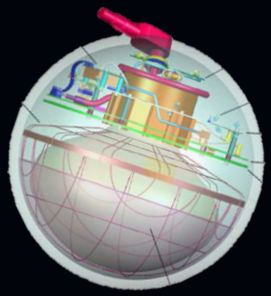
+ Many  + Many solar flares

Homestake excess
-> triggered lots of studies!

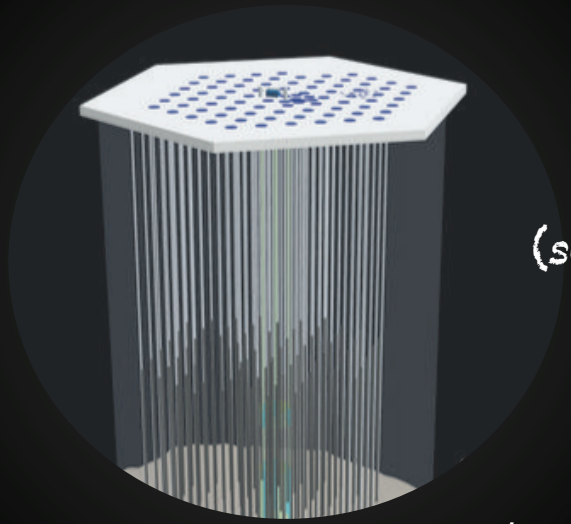
Davis, Subramanian, Bahcall, Bazilevskaya, Ramaty, Murphy, Hirata et al., LSD, Kamiokande, Lingenfelter, SNO, ... (lower part of the spectrum)

What do we need to detect these flare neutrinos?

+ Many



+ ~~Many solar flares~~

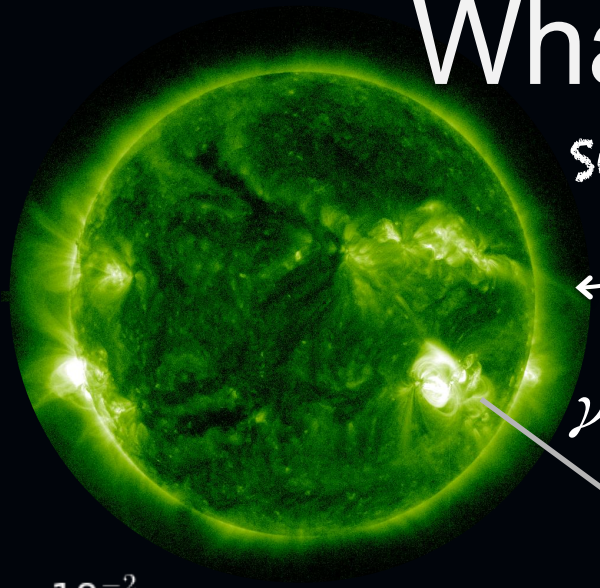


IceCube
(see J. Auffenberg's talk)

Pion solar flares!

(higher part of the spectrum)

What do we call pion-flares?



Sun

γ >100 MeV

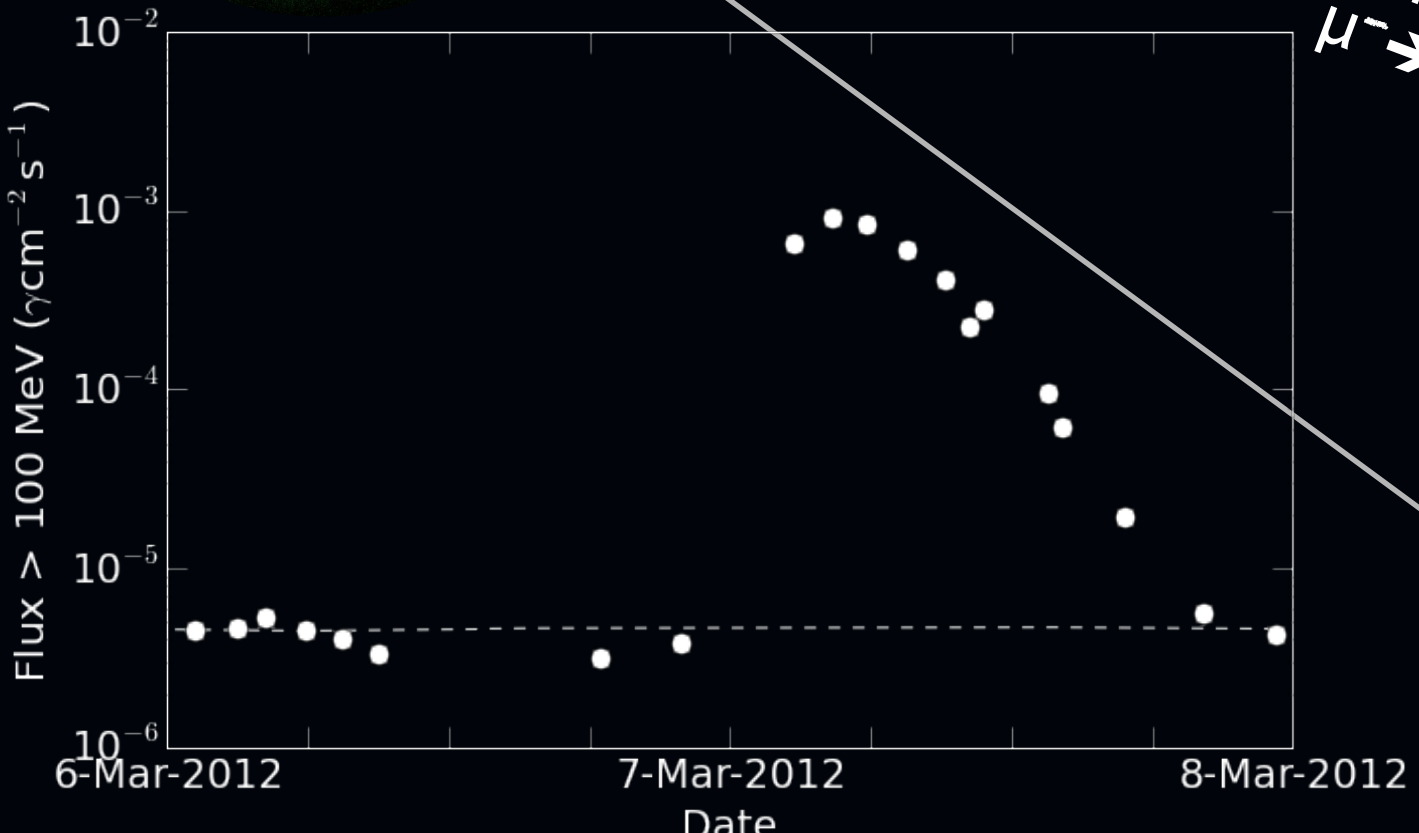
$\pi^+ \rightarrow \mu^+ + \nu_\mu$

$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

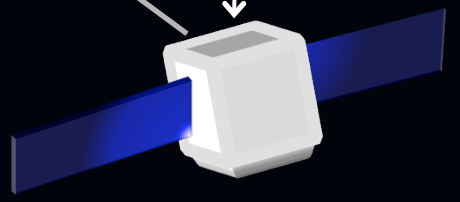
$\pi^0 \rightarrow 2\gamma$

$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$

$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$

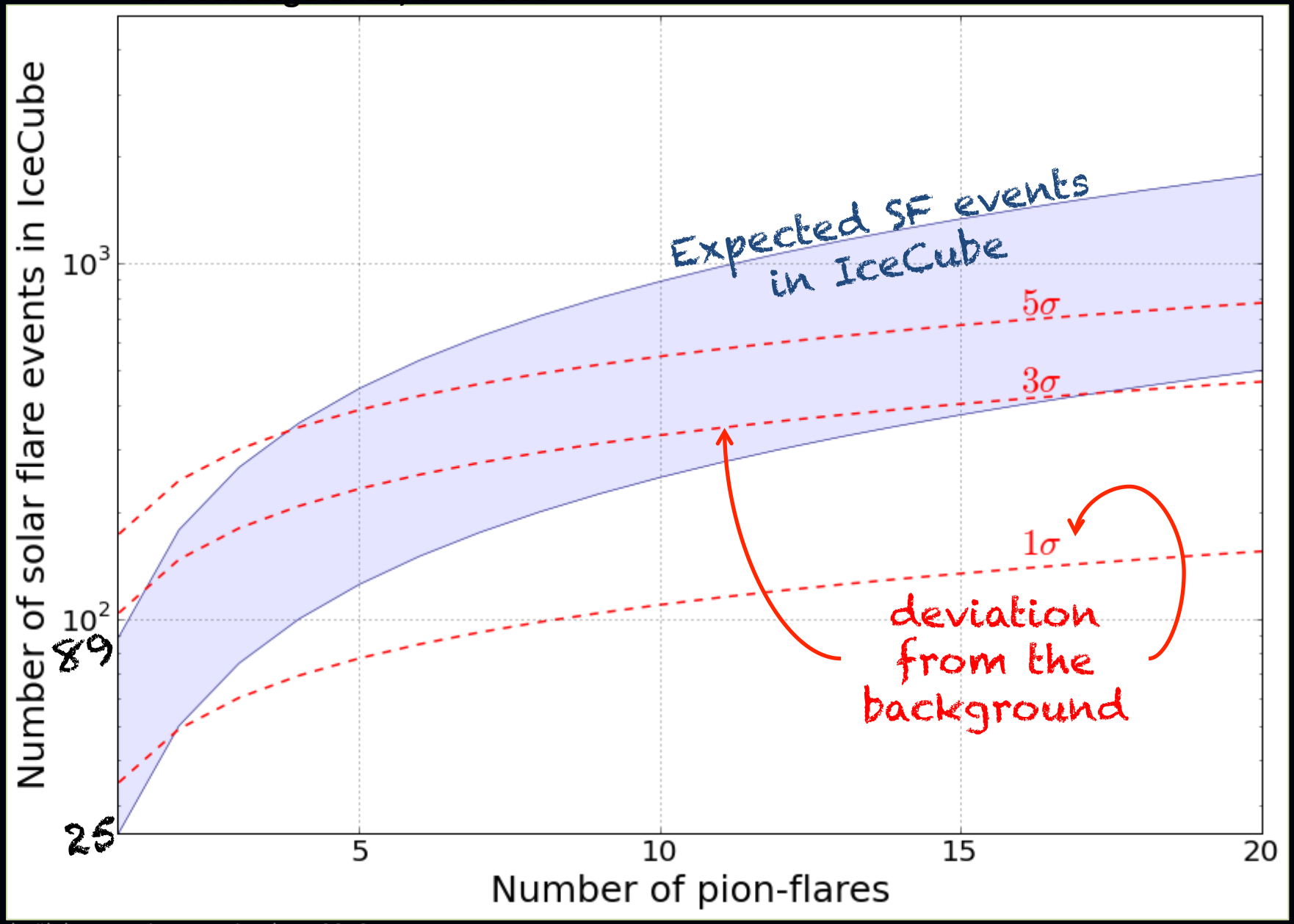


Fermi-LAT



Can IceCube detect solar flare events?

de Wasseige et al., 34th ICRC



Check-list:

- ✓ Simulation of neutrino production in solar flares
- ✓ Feasibility study for the current IceCube detector
- ✓ Development of an alert system (SFNews) for pion-flares

On-going:

- Extraction of <1GeV physics hits from IceCube data
- Find (hopefully) solar flare neutrinos with IceCube

and characterize their spectrum

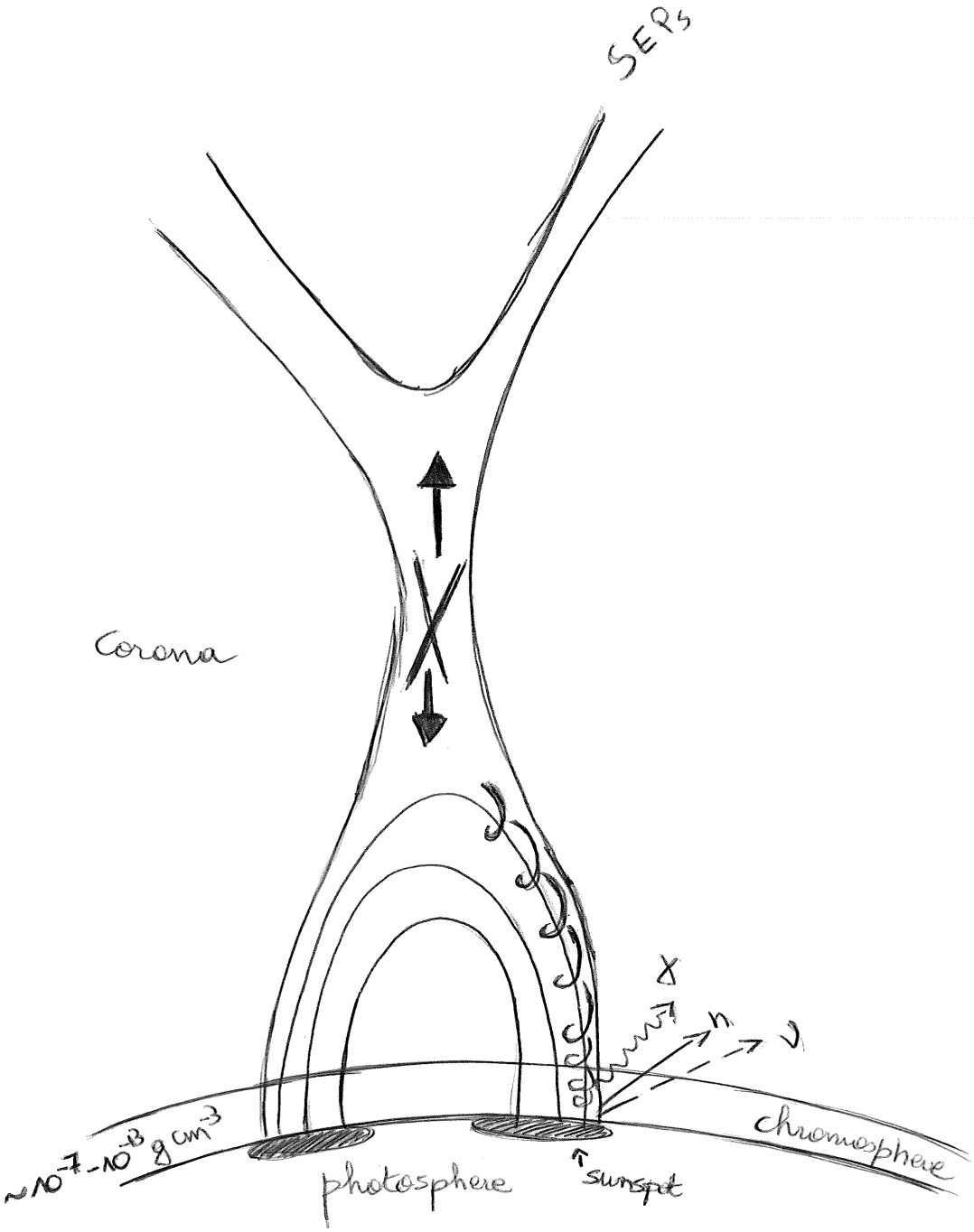
- Characterize solar flare physics

Take-home messages:

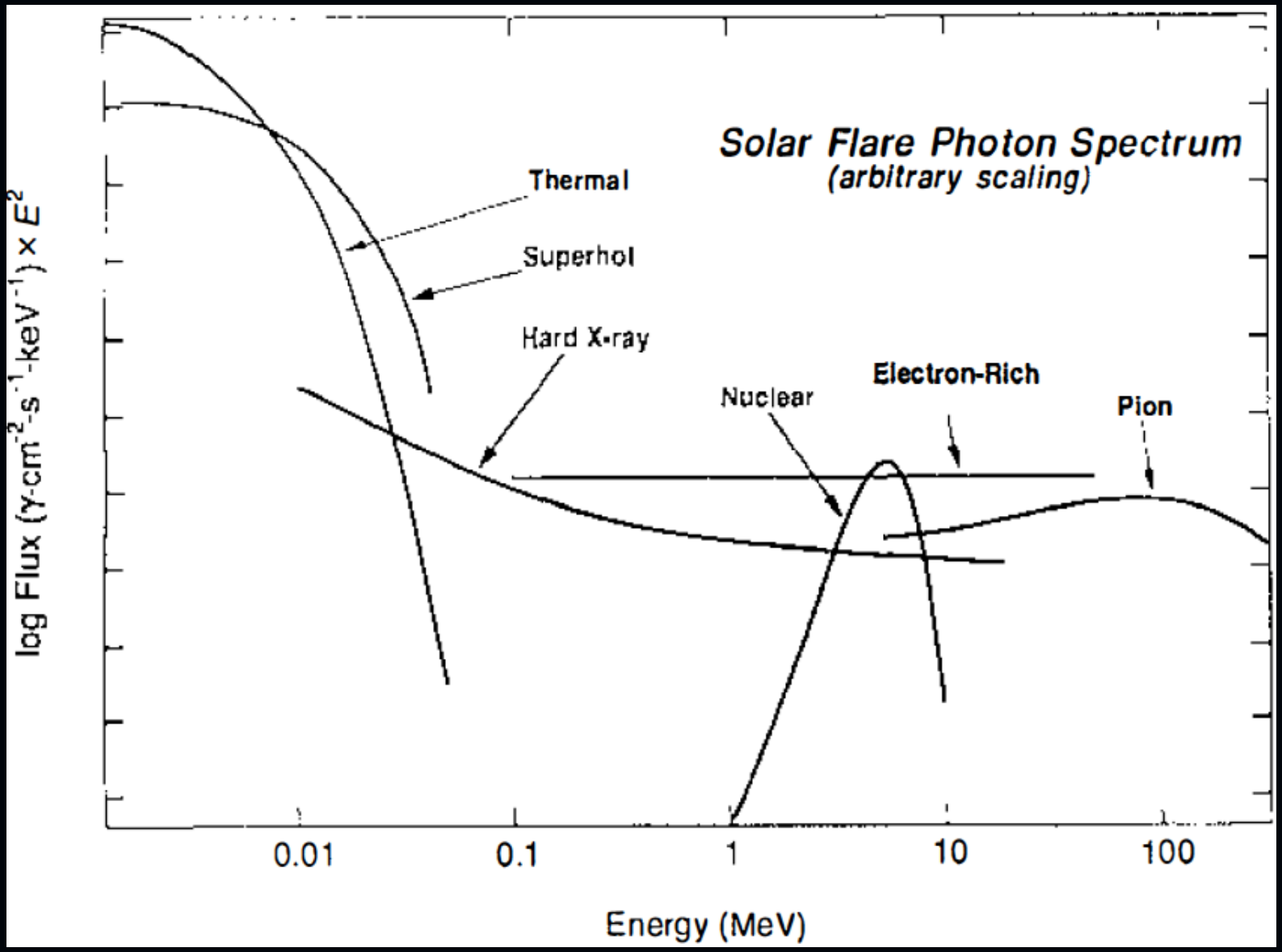
- Solar flare neutrinos of high interest
  (probe hadronic nature, acceleration mechanism)
- New promising solar flare selection (π flares)
- Bigger detector (IceCube)
- Many reasons to stay tuned!

Want to know more?
arXiv:1505.05837 [astro-ph.HE]
arXiv:1512.00204 [astro-.-ph.HE]

Thanks!


SERs
Corona
X
h
ν
~10⁻⁷-10⁻⁸ g cm⁻³
photosphere
sunspot
chromosphere

X/γ-ray solar flare spectrum



Hudson et al.

The simulation

Interior

ρ = Galactic

R = 696 10^3 km

Corona

ρ = 1.6 10^{-18} g cm^{-3}

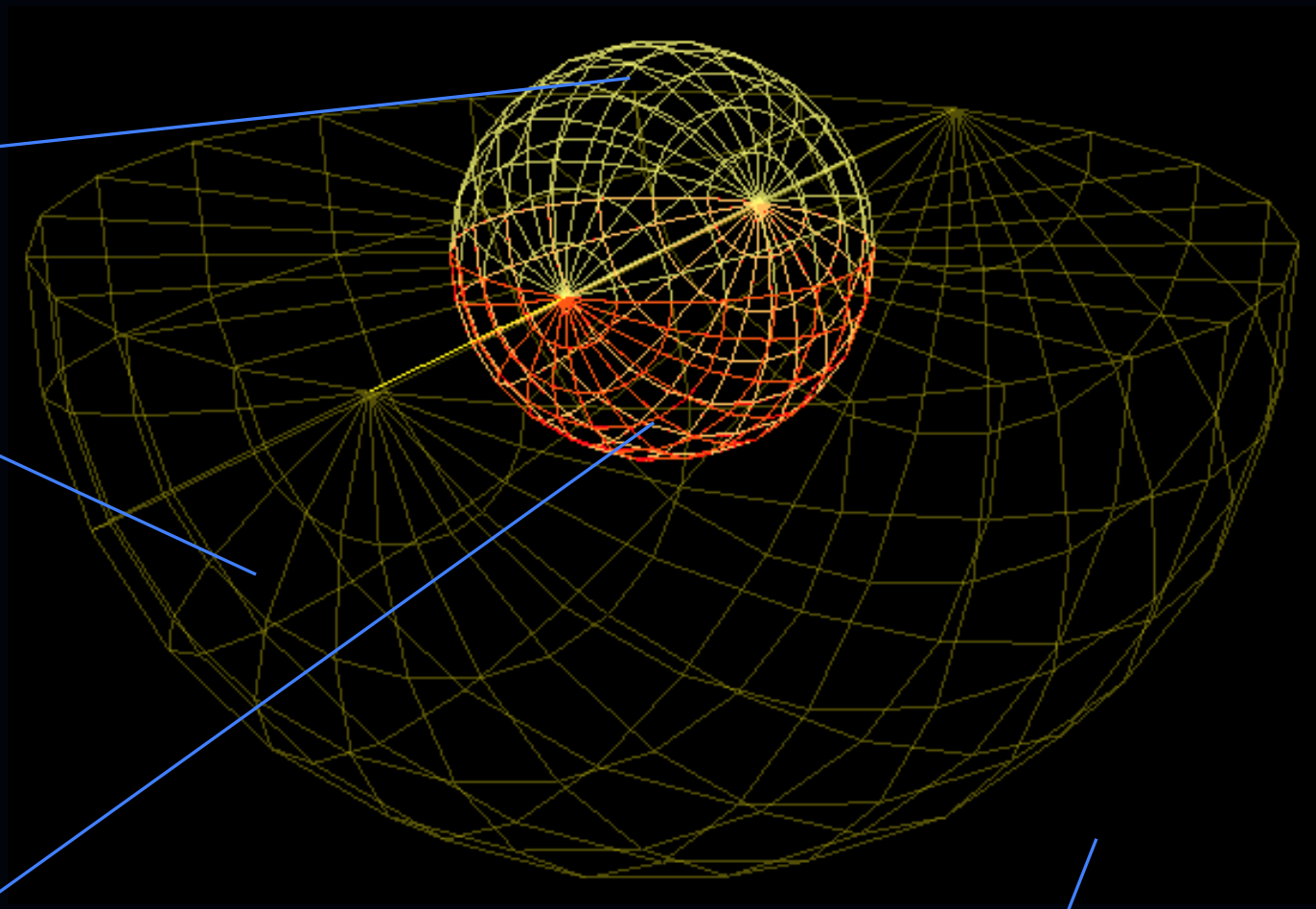
R = 2088 10^3 km

Photosphere + Chromosphere

+ transition region

"Model of chromospheric flare regions" (for bright flares)

-> 32 layers (Machado et al, 1979)



ρ_H = 2.31 10^{-7} – 6.97 10^{-13} g cm^{-3}

Width = 1223.5 km

Heliosphere

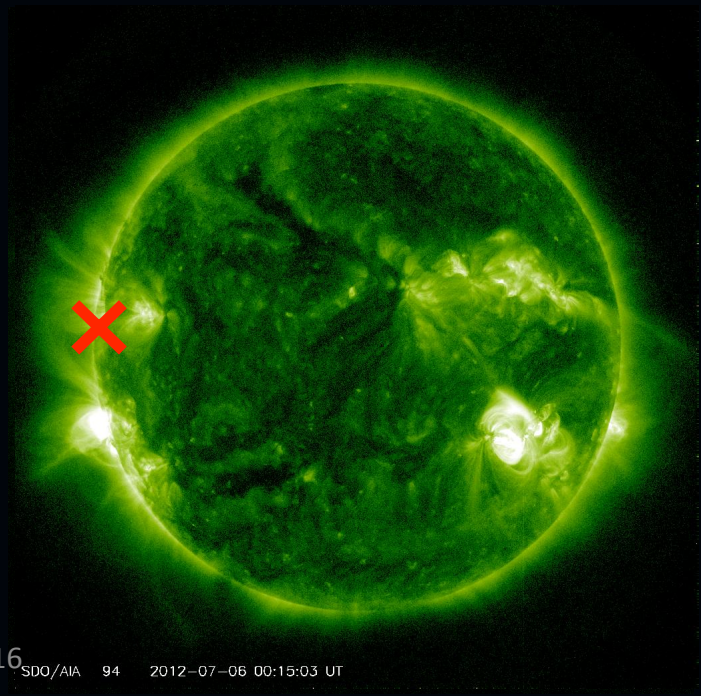
ρ = Galactic

Geant4 simulation

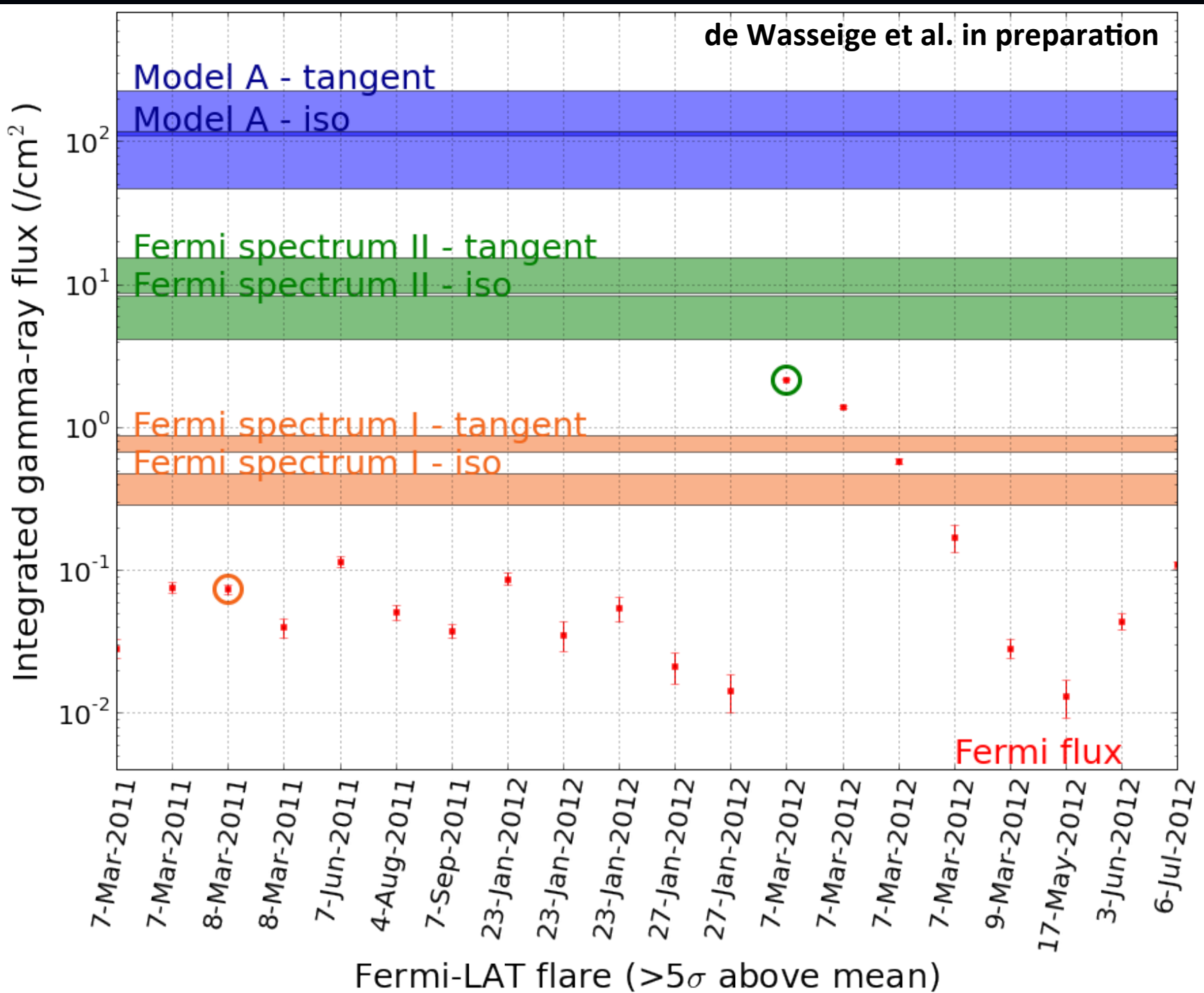
- beam of protons of
  - Model A: $E^{-3.1}$ (E = 30 MeV to 1 GeV) – 2.2×10^{33} p ← June 3, 1982
  - Fermi flare I: $E^{-4.9}$ (E = 30 MeV to 1 GeV) – 3.05×10^{33} p
  - Fermi flare II: $E^{-4.0}$ (E = 30 MeV to 1 GeV) – 2.76×10^{33} p

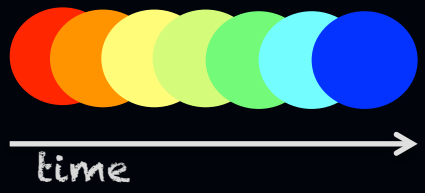
from Fermi observations

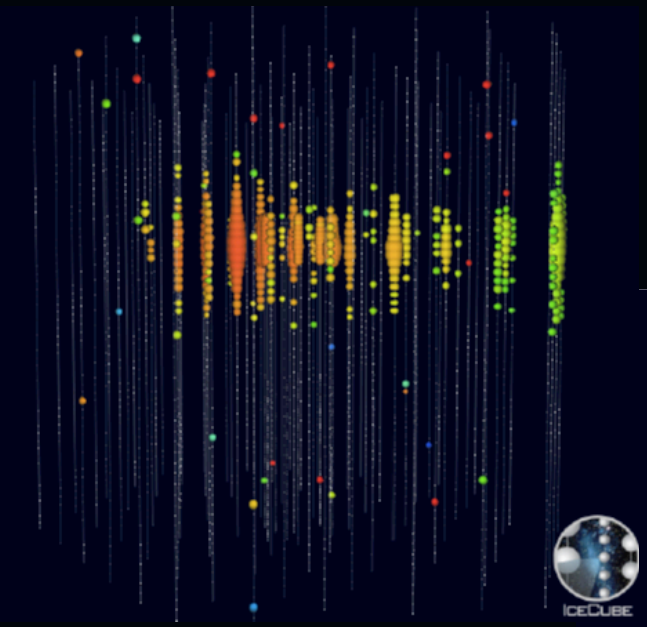
- no magnetic field
- direction: || and $\perp_{iso}$
- composition of the Sun:
  - H:He (9:1)



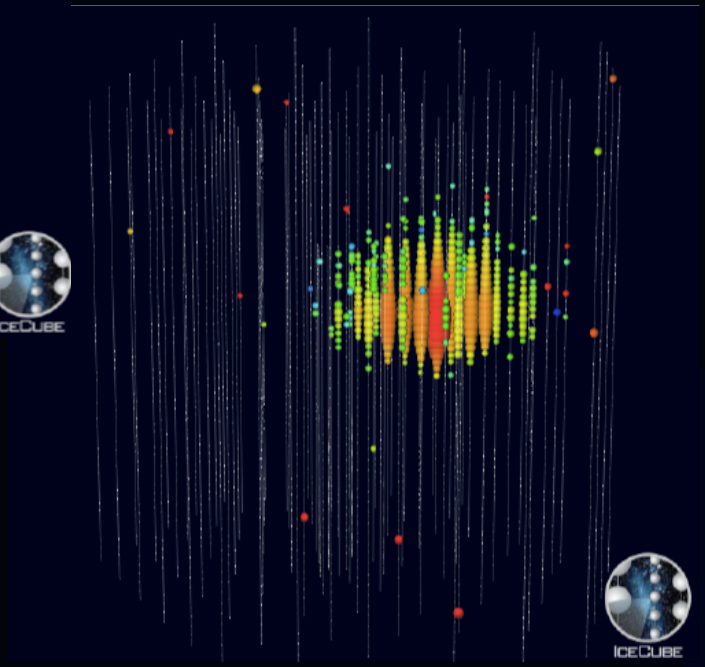
Goal: ν spectrum from a solar flare


de Wasseige et al. in preparation
Model A - tangent
Model A - iso
Fermi spectrum II - tangent
Fermi spectrum II - iso
Fermi spectrum I - tangent
Fermi spectrum I - iso
Fermi flux
Integrated gamma-ray flux (/cm^2)
10^2
10^1
10^0
10^{-1}
10^{-2}
7-Mar-2011
7-Mar-2011
8-Mar-2011
8-Mar-2011
7-Jun-2011
4-Aug-2011
7-Sep-2011
23-Jan-2012
23-Jan-2012
23-Jan-2012
27-Jan-2012
27-Jan-2012
7-Mar-2012
7-Mar-2012
7-Mar-2012
7-Mar-2012
9-Mar-2012
17-May-2012
3-Jun-2012
6-Jul-2012
Fermi-LAT flare (>5σ above mean)





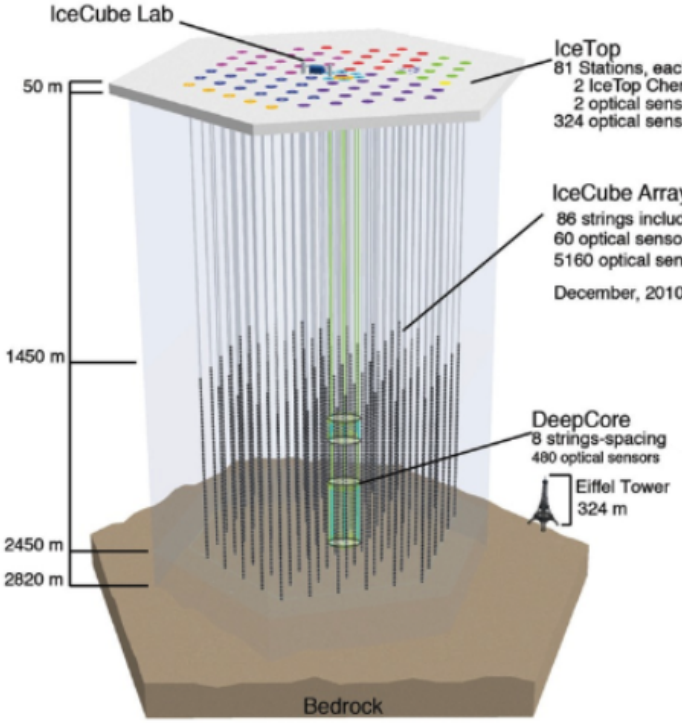
High energy
ν_μ event



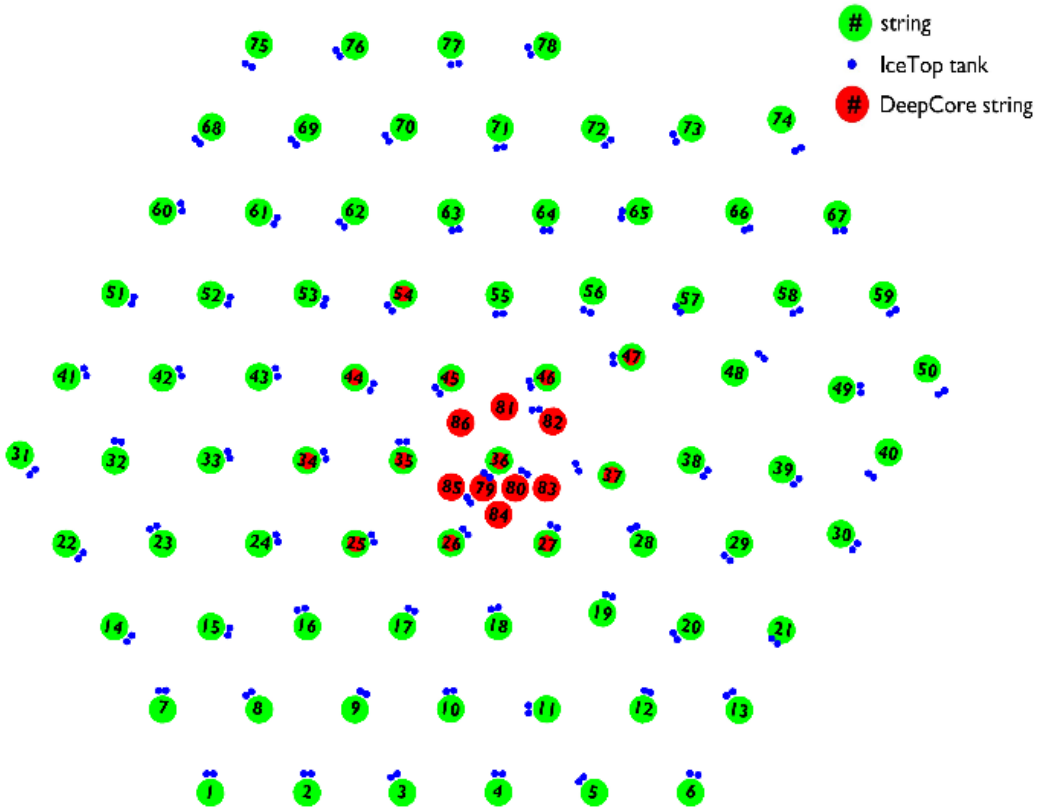
High energy
ν_e/NC event

SIMULATED solar
flare event

IceCube

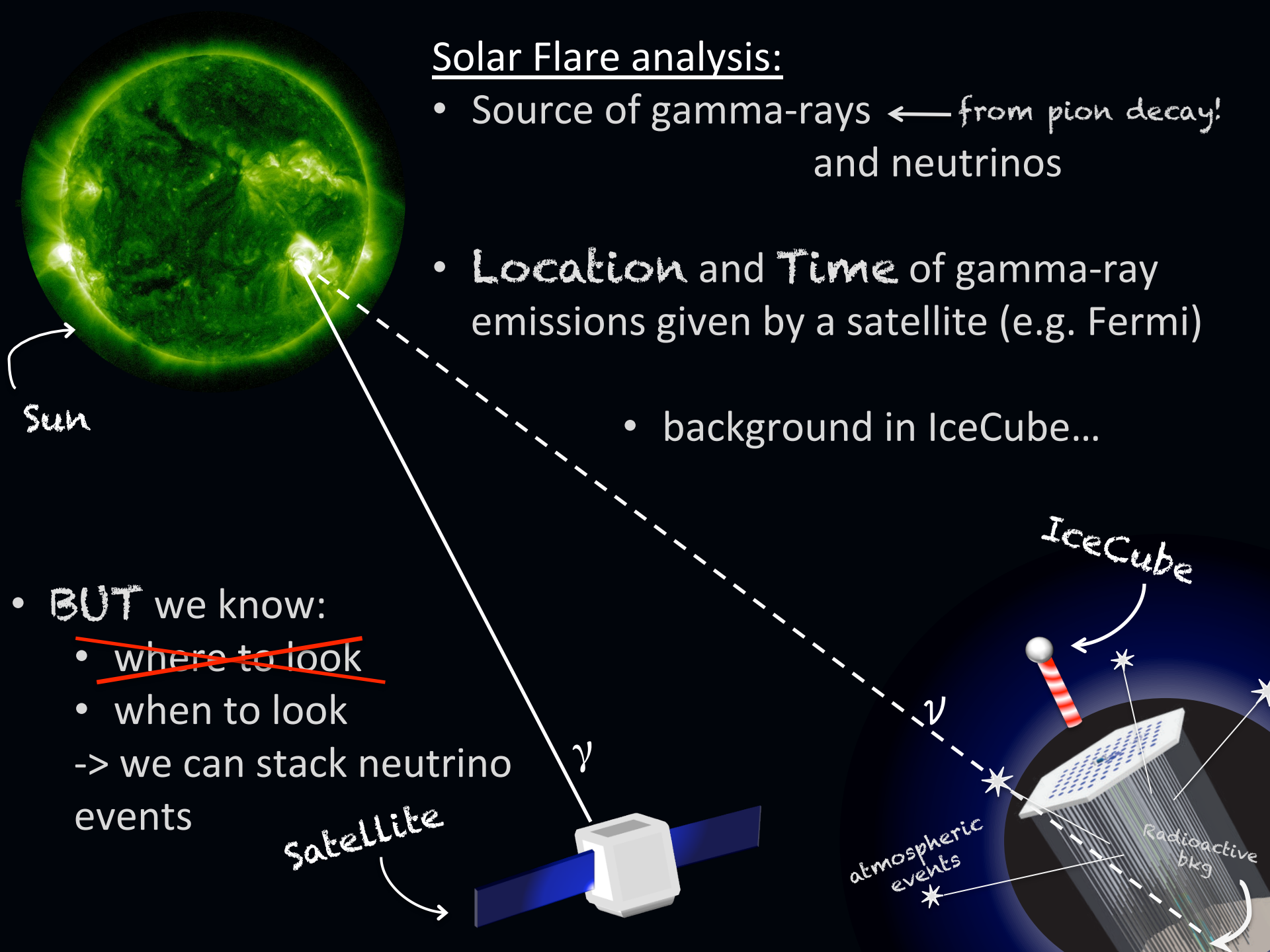


SF ν from 10MeV to >1GeV



+ SNDAQ!!
(Supernova data acquisition system)

= rate monitoring system

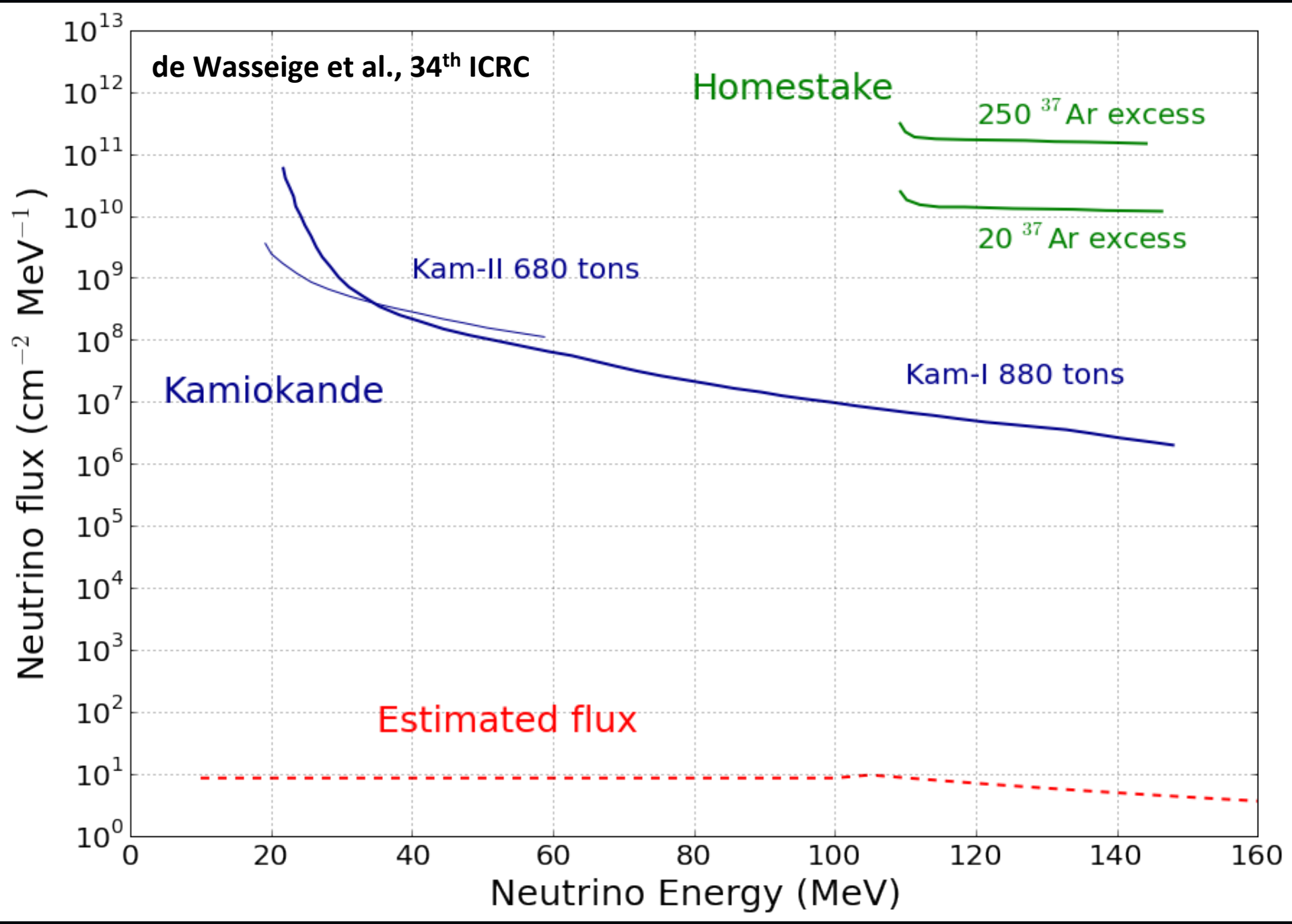

Solar Flare analysis:
• Source of gamma-rays ⟵ from pion decay!
and neutrinos
• Location and Time of gamma-ray emissions given by a satellite (e.g. Fermi)
• background in IceCube…
Sun
• BUT we know:
• where to look
• when to look
-> we can stack neutrino events
γ
ν
Satellite
IceCube
atmospheric events
Radioactive bkg

$$N_{events} = \int dE\, N_A \sigma(E) \rho\, V_{eff}(E) \frac{d\phi(E)}{dE}$$

SFNews alert system

- Re-definition of "an event"
- More hands on the event selection
- Should allow longer integration time

Definitely the BEST way to search for solar flare neutrino events!
(up to now...)


de Wasseige et al., 34th ICRC
Homestake
250 37Ar excess
20 37Ar excess
Kam-II 680 tons
Kamiokande
Kam-I 880 tons
Estimated flux
Neutrino flux (cm−2 MeV−1)
Neutrino Energy (MeV)
10^13
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
0
20
40
60
80
100
120
140
160