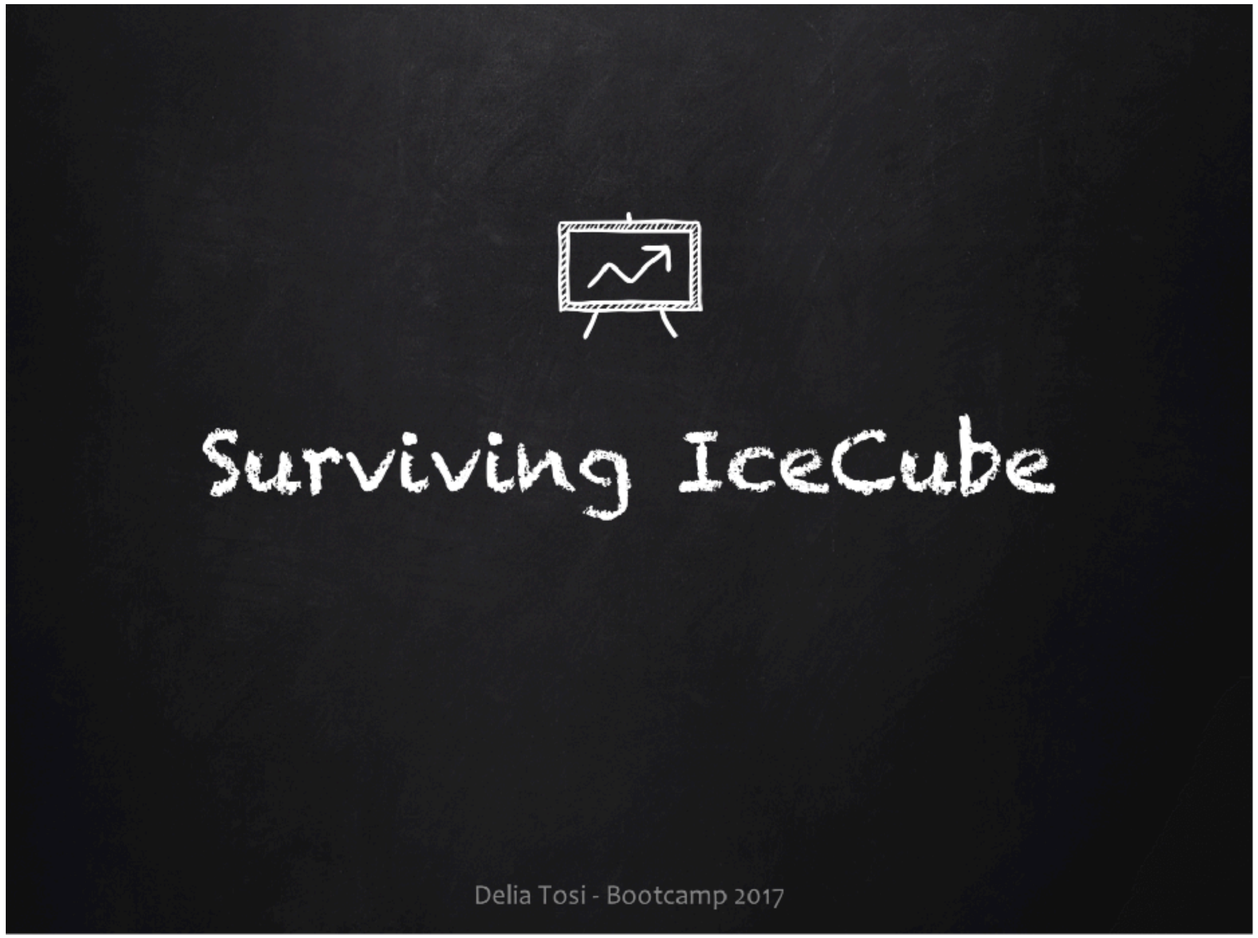
IceCube
as a part of multi-messenger astrophysics community

Presented by Nahee Park

for 2018 Summer Boot Camp

Big recommendation!



Very nice talk given by Delia last year. Strongly recommend to look through it! Recent update on working group organization will be summarized by Sam Fahey on Thursday as he summarizes the scientific topics of the IceCube.

IceCube as a part of multi-messenger astrophysics community

Presented by Nahee Park

for 2018 Summer Boot Camp

IceCube
as a part of multi-messenger astrophysics community

IceCube (1)

as a part of multi-messenger astrophysics community

(1) You heard Francis's talk and will hear for five days. :) (Welcome to the boot camp!)

IceCube (1)
as a part of multi-messenger astrophysics community (2)

(1) You heard Francis's talk and will hear for five days. :) (Welcome to the boot camp!)
(2) Multi-messenger astrophysics?

Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple “messengers”

Multi-messenger Astrophysics

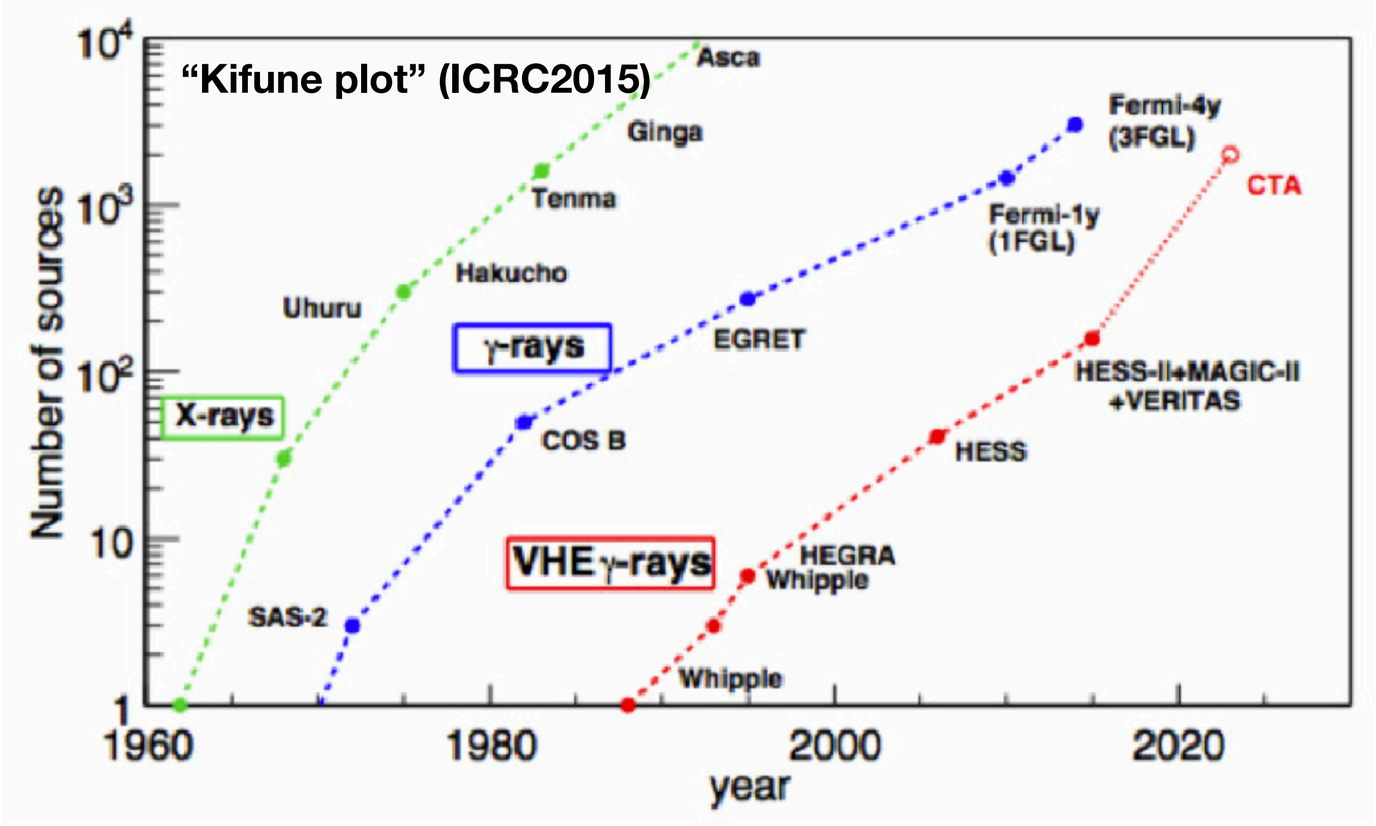
The science of understanding how the Universe works by combining the knowledge gained by multiple “messengers”

- Electromagnetic radiation
- Cosmic-rays
- Gravitational waves
- Neutrinos

Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

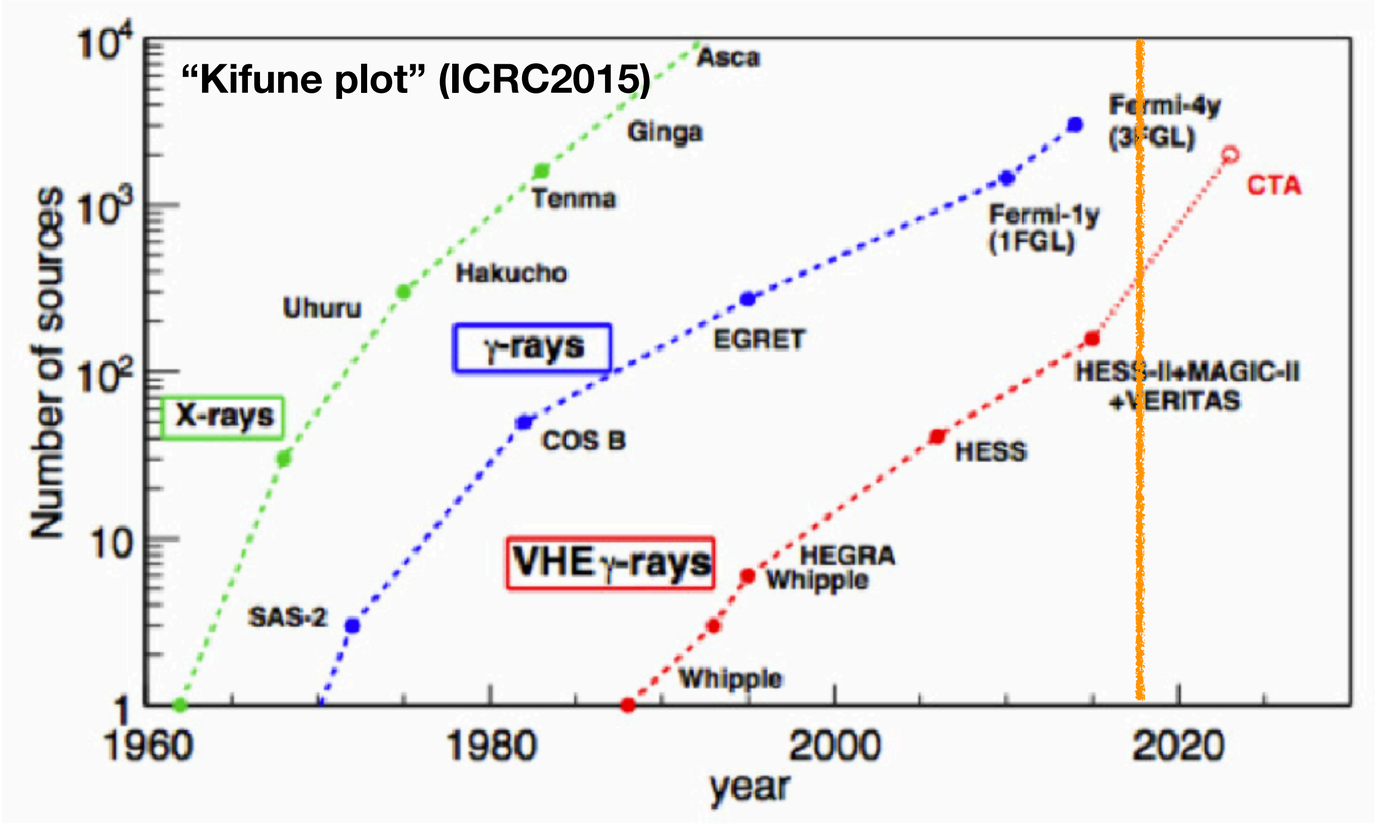
- Electromagnetic radiation
  - ☆ Including traditional observation (radio, optical, UV, X-ray) up to gamma-ray observation
  - ☆ Covers both thermal & non-thermal universe
    - Huge improvement on the sensitivity of gamma-ray (E>30 MeV, > 10 times) in last ~ 10 years
- Cosmic-rays
- Gravitational waves
- Neutrinos
- Cosmic-rays



Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

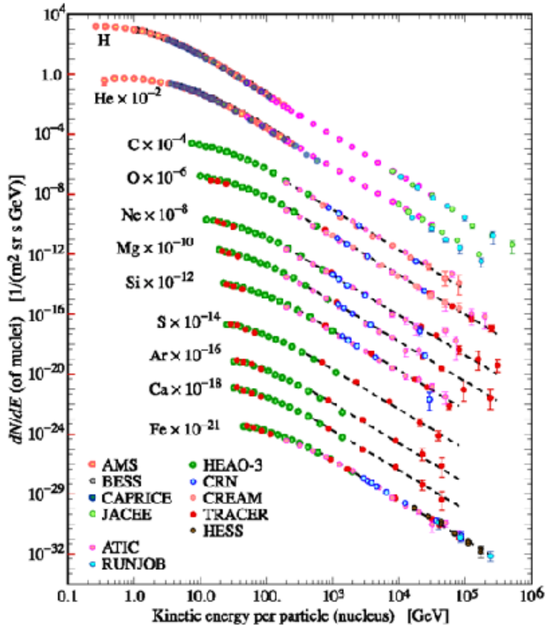
- Electromagnetic radiation
  - ☆ Including traditional observation (radio, optical, UV, X-ray) up to gamma-ray observation
  - ☆ Covers both thermal & non-thermal universe
    - Huge improvement on the sensitivity of gamma-ray (E>30 MeV, > 10 times) in last ~ 10 years
- Cosmic-rays
- Gravitational waves
- Neutrinos
- Cosmic-rays

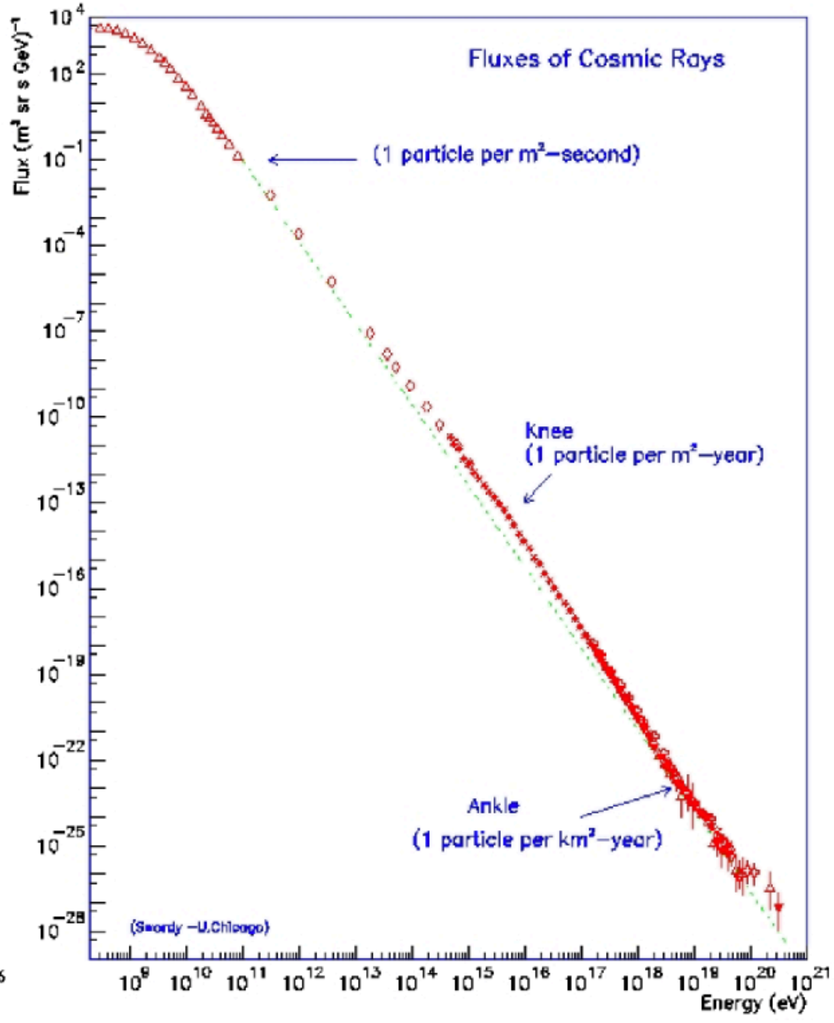


Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Electromagnetic radiation
  - ☆ Including traditional observation (radio, optical, UV, X-ray) up to gamma-ray obse
  - ☆ Covers both thermal & non-thermal universe
    - Huge improvement on the sensitivity of gamma-ray (E>30 MeV, > 10 times) in
- Cosmic-rays
  - ☆ Charged particles originated from outside of the solar system
    - Covers a wide energy range (~GeV (10^9 eV) up to 10^{21} eV)
- Gravitational waves
- Neutrinos

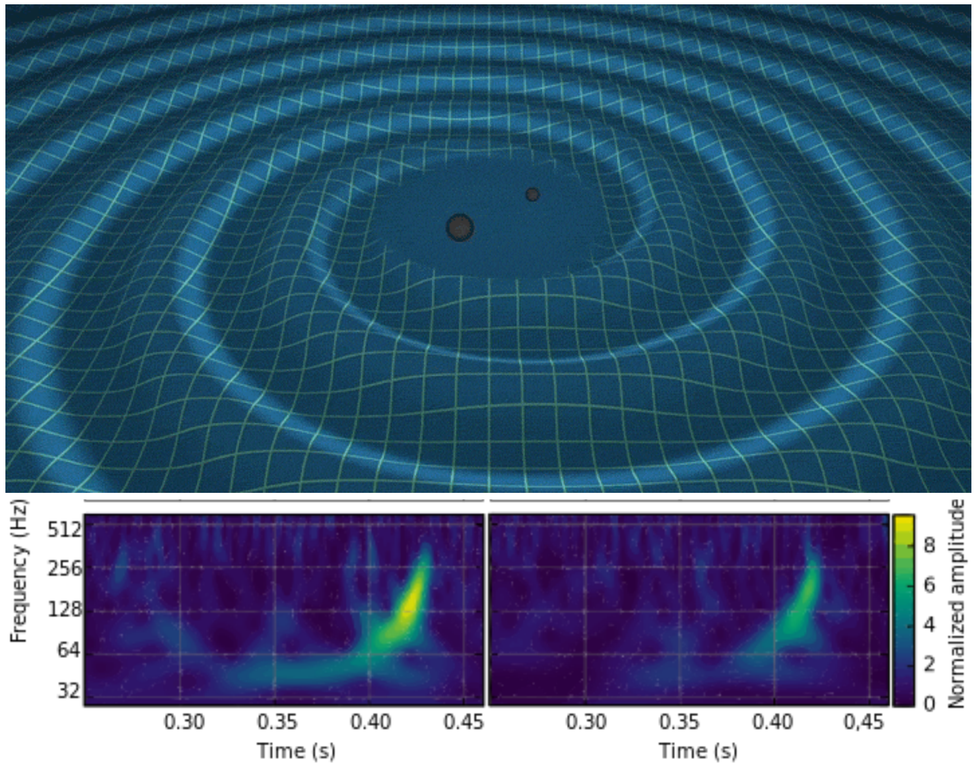




Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Electromagnetic radiation
  - ☆ Including traditional observation (radio, optical, UV, X-ray) up to gamma-ray observation
  - ☆ Covers both thermal & non-thermal universe
    - Huge improvement on the sensitivity of gamma-ray (E>30 MeV, > 10 times) in last ~ 10 years
- Cosmic-rays
  - ☆ Charged particles originated from outside of the solar system
    - Covers a wide energy range (~GeV (10^9 eV) up to 10^{21} eV)
- Gravitational waves
  - ☆ "Ripples" of the fabric of space-time
  - ☆ LICO/Virgo collaboration detect the first gravitational wave in 2015
  - ☆ 6 detections were announced by March 2018
- Neutrinos

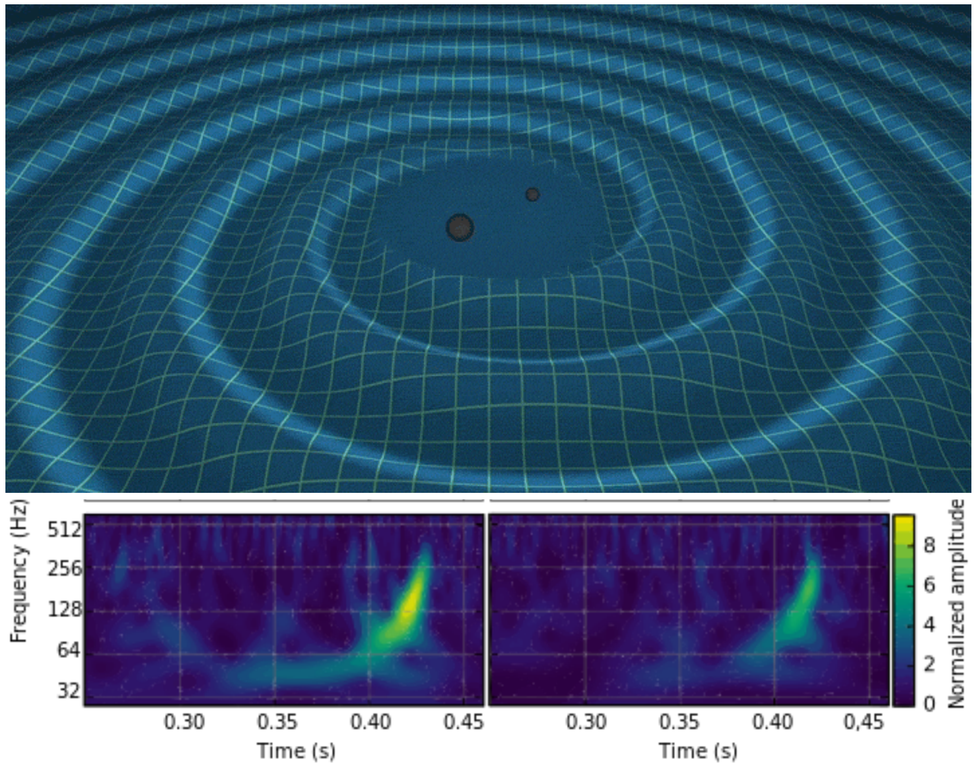


GW150914 by LIGO/Virgo

Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Electromagnetic radiation
  - ☆ Including traditional observation (radio, optical, UV, X-ray) up to gamma-ray observation
  - ☆ Covers both thermal & non-thermal universe
    - Huge improvement on the sensitivity of gamma-ray (E>30 MeV, > 10 times) in last ~ 10 years
- Cosmic-rays
  - ☆ Charged particles originated from outside of the solar system
    - Covers a wide energy range (~GeV (10^9 eV) up to 10^{21} eV)
- Gravitational waves
  - ☆ "Ripples" of the fabric of space-time
  - ☆ LICO/Virgo collaboration detect the first gravitational wave in 2015
  - ☆ 6 detections were announced by March 2018
- Neutrinos

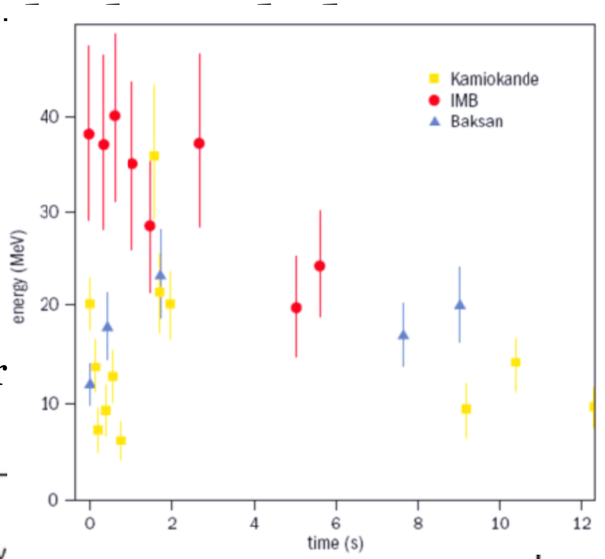


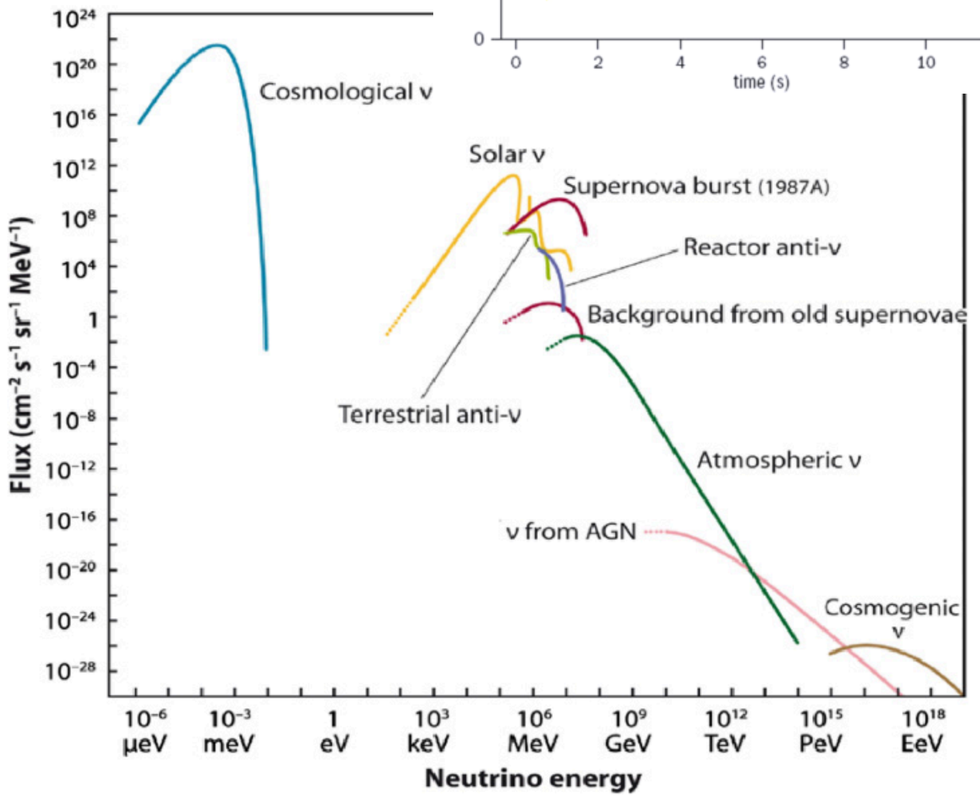
GW150914 by LIGO/Virgo

Multi-messenger Astrophysics

The science of understanding how the Universe works by combining gained by multiple "messengers"

- Electromagnetic radiation
  - ☆ Including traditional observation (radio, optical, UV, X-ray) up to gamma-ray observation
  - ☆ Covers both thermal & non-thermal universe
    - Huge improvement on the sensitivity of gamma-ray (E>30 MeV, > 10 times) in last ~ 10 year
- Cosmic-rays
  - ☆ Charged particles originated from outside of the solar system
    - Covers a wide energy range (~GeV (10^9 eV) up to 10^{21} eV)
- Gravitational waves
  - ☆ "Ripples" of the fabric of space-time
  - ☆ LICO/Virgo collaboration detect the first gravitational wave in 2016
  - ☆ 6 detections were announced by March 2018
- Neutrinos
  - ☆ 1987 SN 1987A events is one of the first famous multi-messenger astrophysics case (optical-MeV neutrino)
  - ☆ IceCube collaboration sends out public announcement for EHE neutrino candidate events from 2016

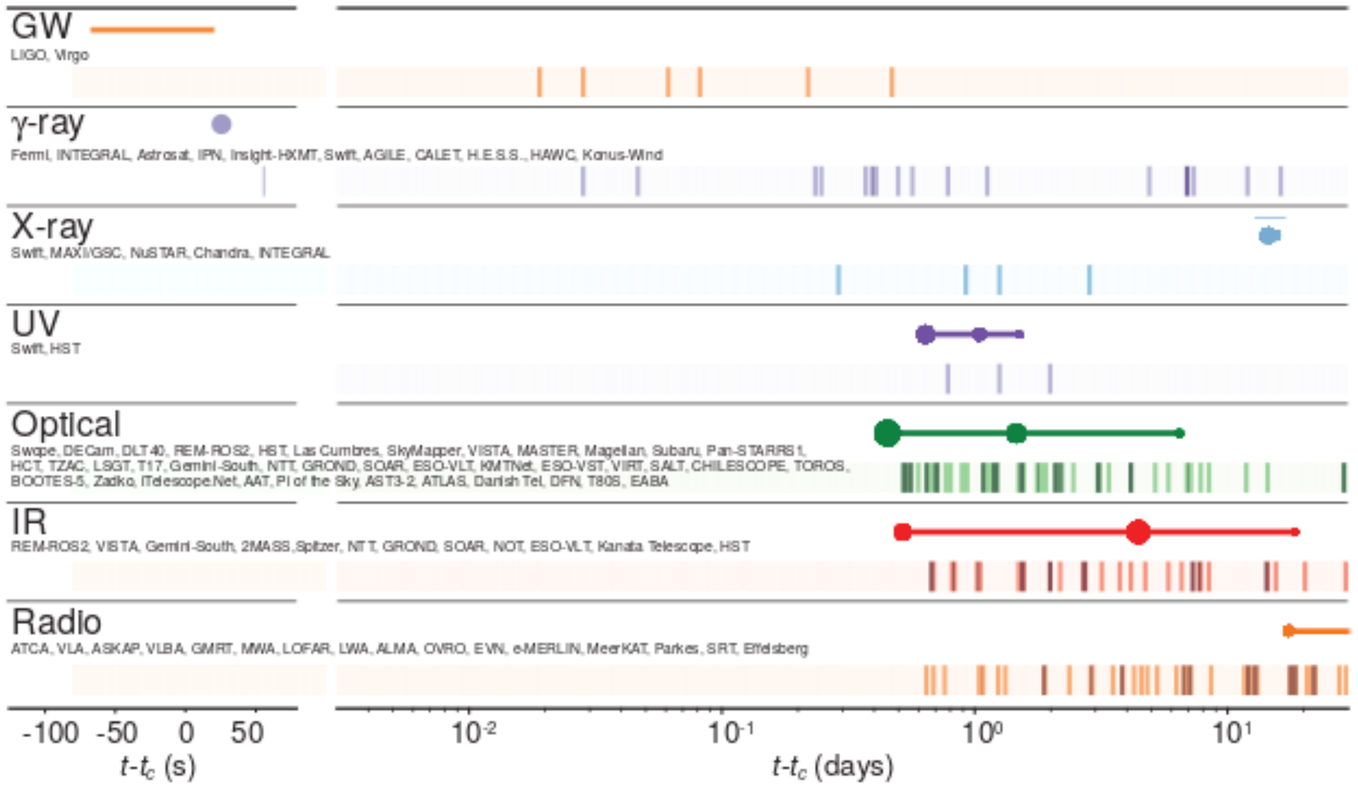


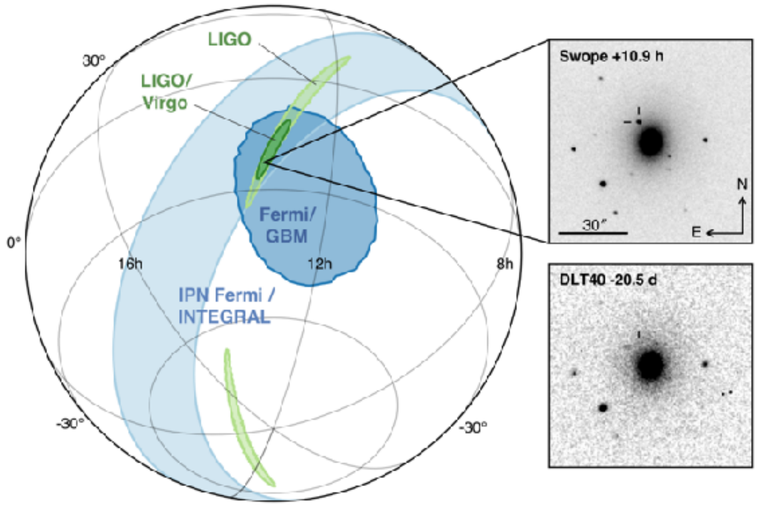


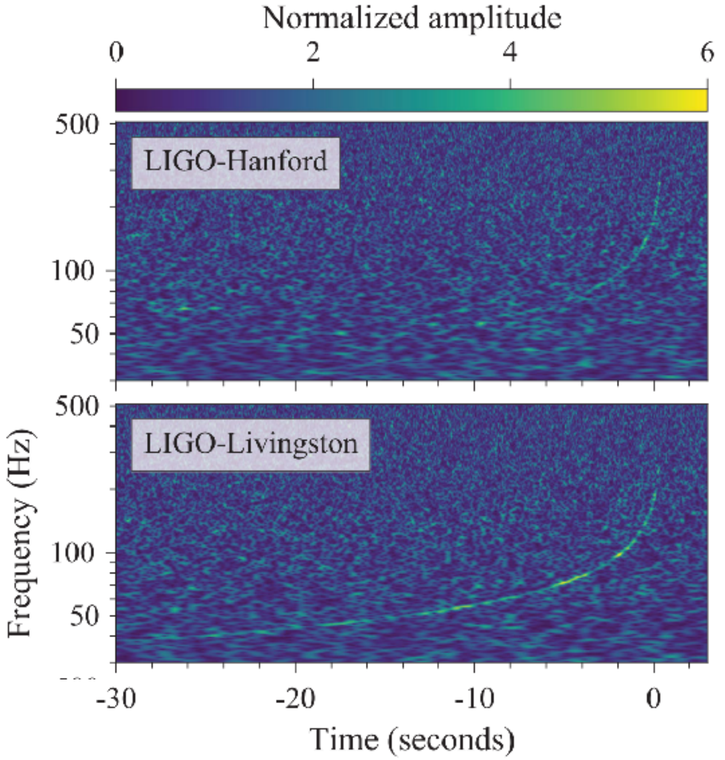
Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- e.g. GW170817 - GRB 170817A event
  - ☆ Neutron star-neutron star merger>>short gamma-ray burst



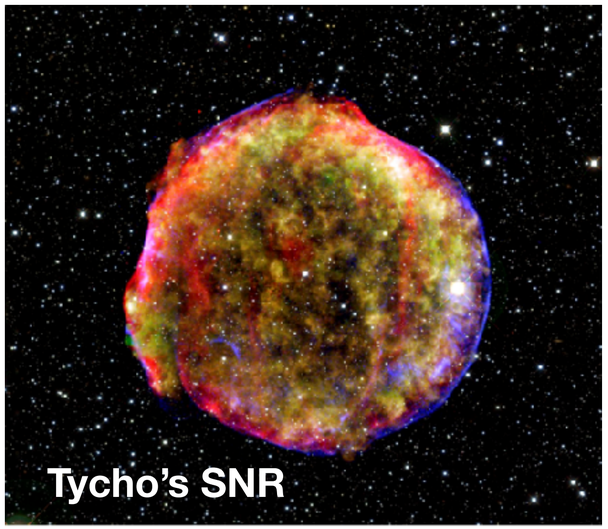




Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple “messengers”

- Cosmic-ray / EM radiation / neutrino observation

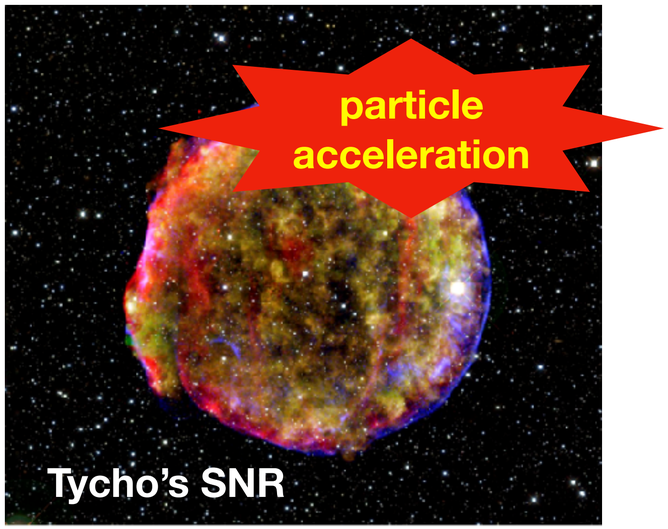


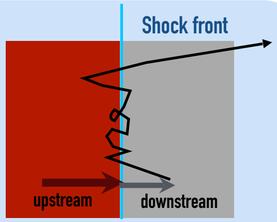
Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Cosmic-ray / EM radiation / neutrino observation

SNRs as CR source
SNR energy : 10^{51} erg
SNR frequency : 2-3/century
With 10% conversion efficiency, can explain CR density (1eV/cm^3)





Diffuse Shock Acceleration

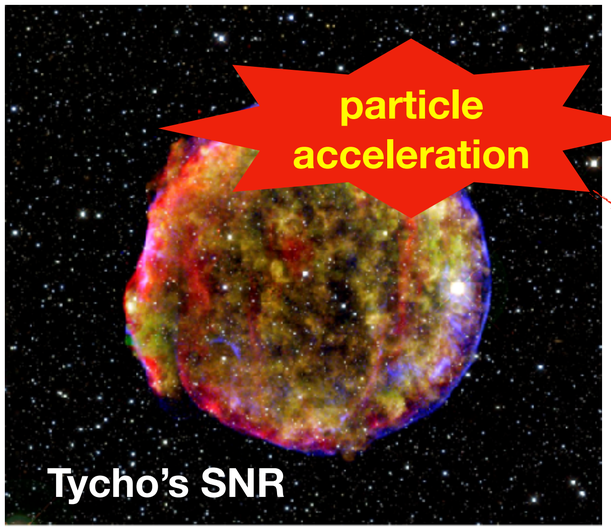
Cosmic-ray

Multi-messenger Astrophysics

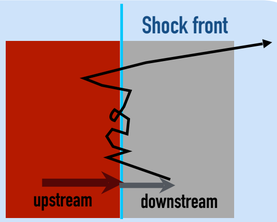
The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Cosmic-ray / EM radiation / neutrino observation

SNRs as CR source
SNR energy : 10^{51} erg
SNR frequency : 2-3/century
With 10% conversion efficiency, can explain CR density (1eV/cm^3)



Cosmic-ray



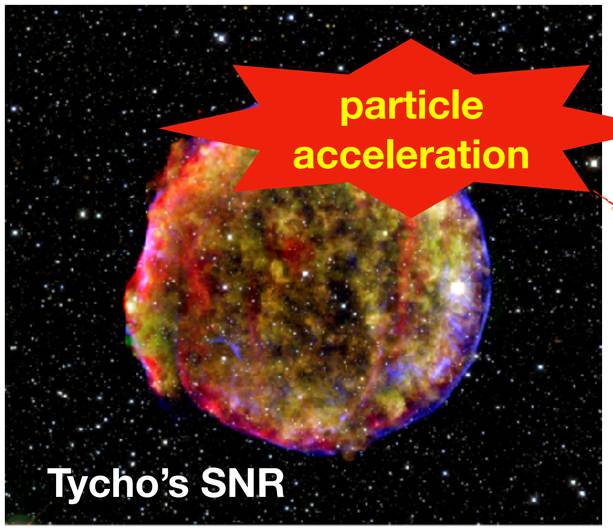
Diffuse Shock Acceleration

Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Cosmic-ray / EM radiation / neutrino observation

SNRs as CR source
SNR energy : 10^{51} erg
SNR frequency : 2-3/century
With 10% conversion efficiency, can explain CR density (1eV/cm^3)

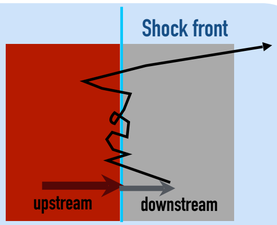


B field

Interaction w/ medium

Interaction w/ photons

Cosmic-ray



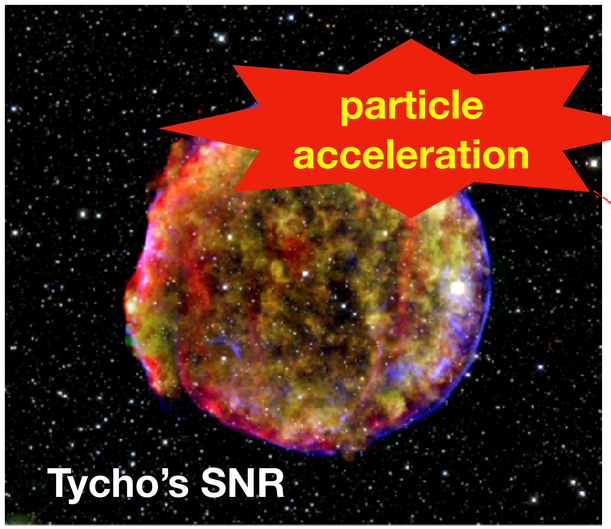
Diffuse Shock Acceleration

Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Cosmic-ray / EM radiation / neutrino observation

SNRs as CR source
SNR energy : 10^{51} erg
SNR frequency : 2-3/century
With 10% conversion efficiency, can explain CR density (1eV/cm^3)



B field

Synchrotron radiation

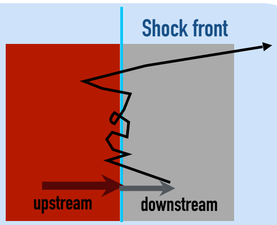
Interaction w/ medium

Thermal

Non-thermal

Interaction w/ photons

Cosmic-ray



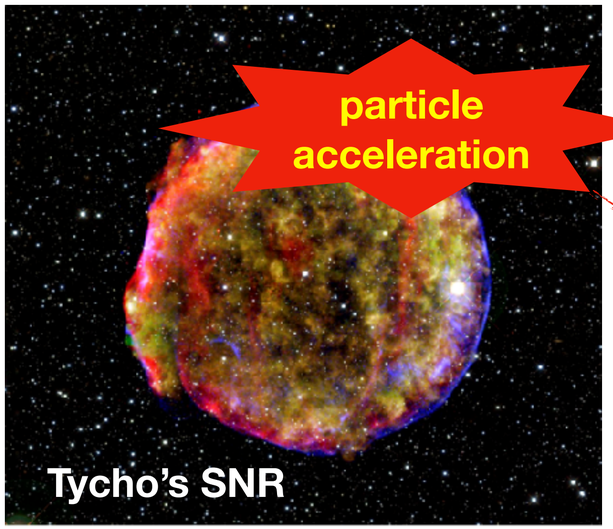
Diffuse Shock Acceleration

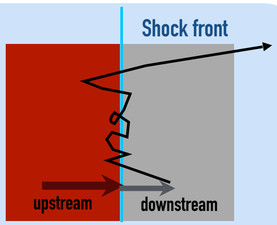
Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Cosmic-ray / EM radiation / neutrino observation

SNRs as CR source
SNR energy : 10^{51} erg
SNR frequency : 2-3/century
With 10% conversion efficiency, can explain CR density (1eV/cm^3)





Diffuse Shock Acceleration

B field
Synchrotron radiation
Interaction w/ medium
Thermal
Non-thermal
Interaction w/ photons

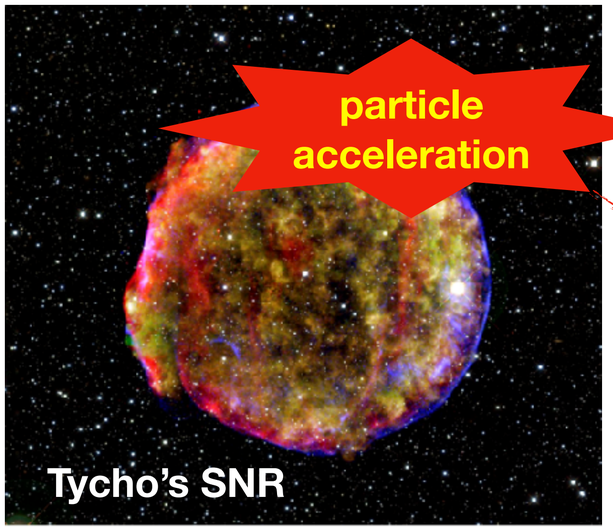
Polarization, Shock morphology comparisons in EM
EM radiation (radio-X-ray)
Cosmic-ray
EM radiation (radio-X-ray)
EM radiation (Radio-gamma-ray)
Neutrino

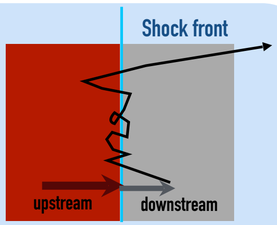
Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Cosmic-ray / EM radiation / neutrino observation

SNRs as CR source
SNR energy : 10^{51} erg
SNR frequency : 2-3/century
With 10% conversion efficiency, can explain CR density (1eV/cm^3)





Diffuse Shock Acceleration

B field
Synchrotron radiation
Interaction w/ medium
Thermal
Non-thermal
Interaction w/ photons

Polarization, Shock morphology comparisons in EM
EM radiation (radio-X-ray)
Cosmic-ray
EM radiation (radio-X-ray)
EM radiation (Radio-gamma-ray)
Neutrino

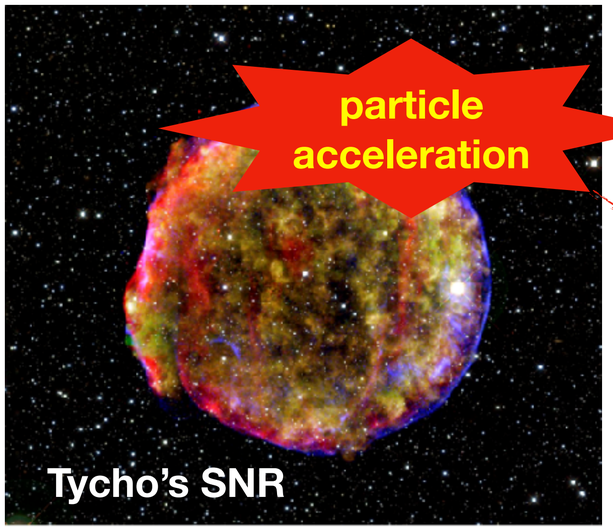
leptonic
leptonic + hadronic

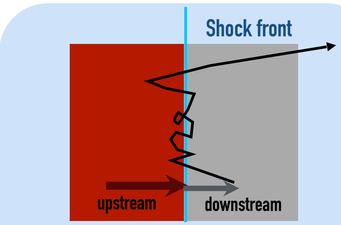
Multi-messenger Astrophysics

The science of understanding how the Universe works by combining the knowledge gained by multiple "messengers"

- Cosmic-ray / EM radiation / neutrino observation

SNRs as CR source
SNR energy : 10^{51} erg
SNR frequency : 2-3/century
With 10% conversion efficiency, can explain CR density (1eV/cm^3)





Diffuse Shock Acceleration

B field
Synchrotron radiation
Interaction w/ medium
Thermal
Non-thermal
Interaction w/ photons

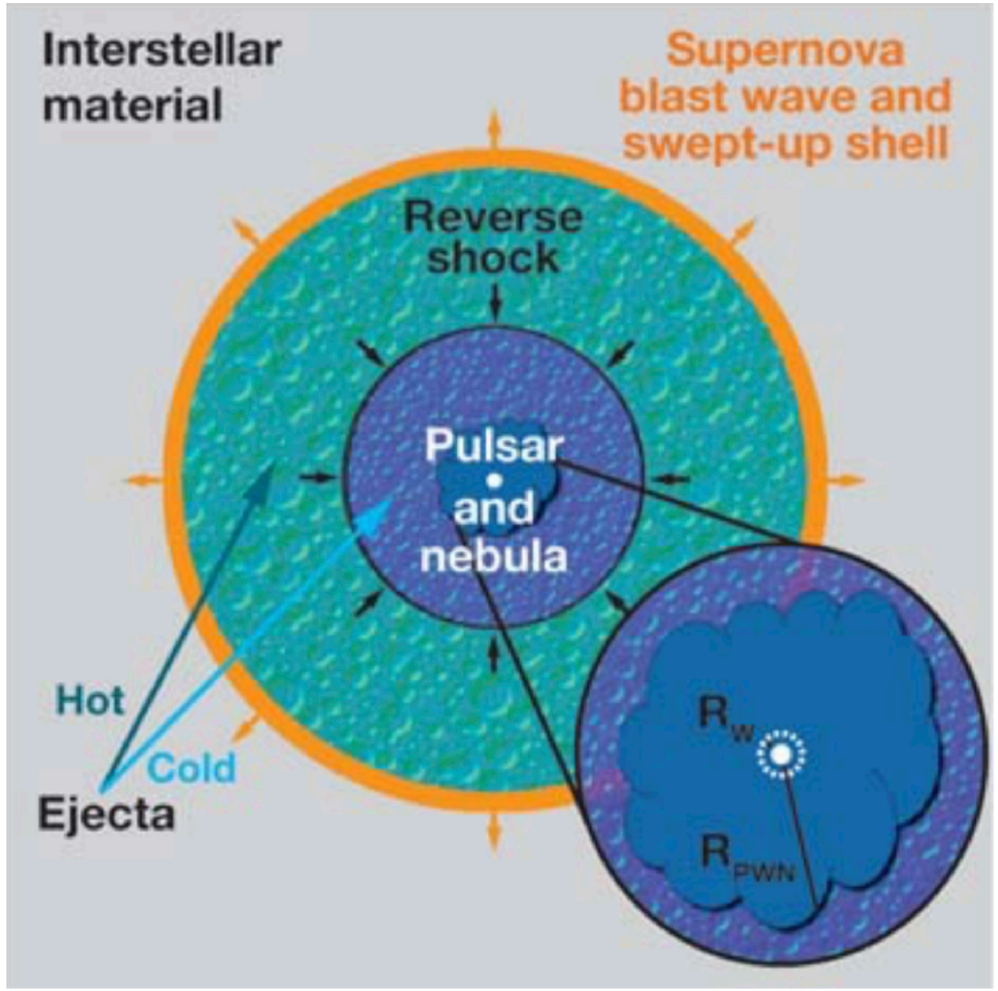
Polarization, Shock morphology comparisons in EM
EM radiation (radio-X-ray)
Cosmic-ray
EM radiation (radio-X-ray)
EM radiation (Radio-gamma-ray)
Neutrino

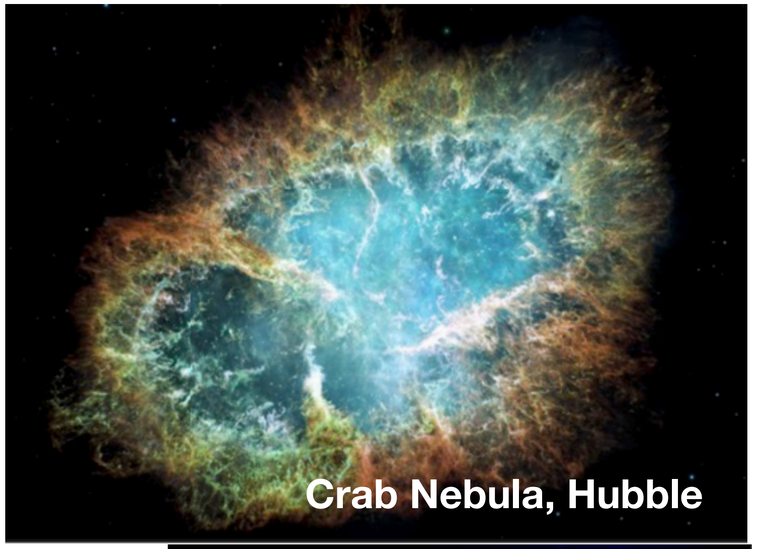
leptonic
leptonic + hadronic
hadronic

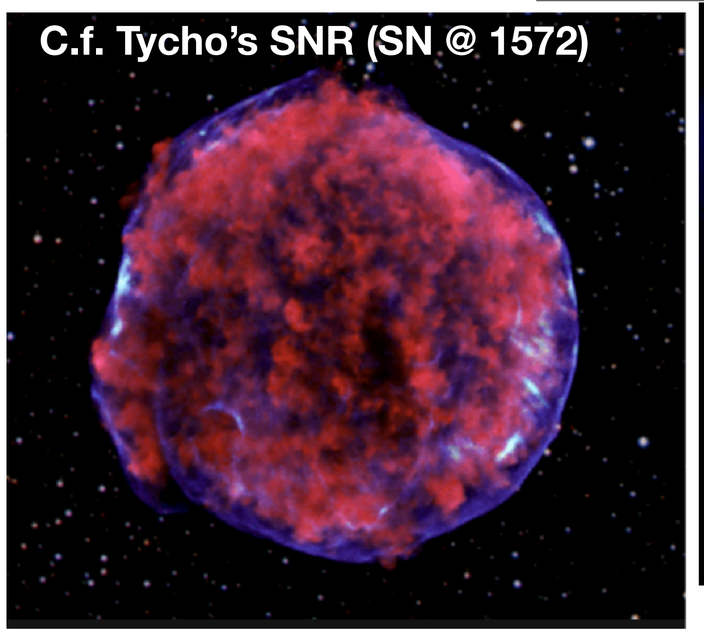
e.g. EM Multiwavelength Observation

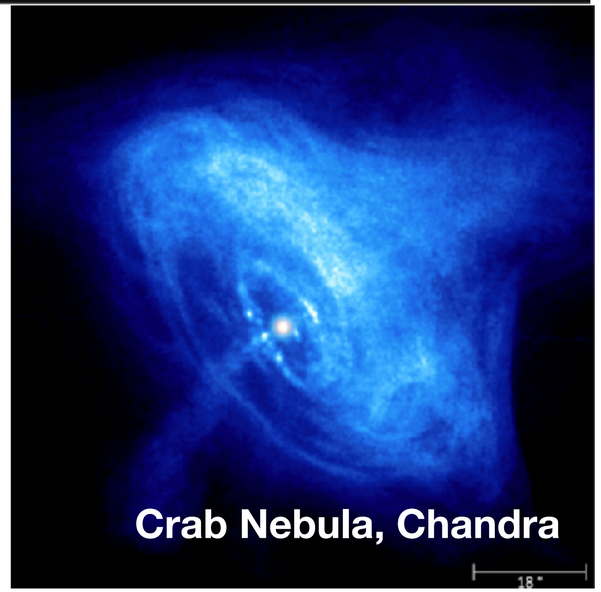
Crab Nebula

- Historic remnant of SN1054 (reported by Chinese & Japanese)
  - ☆ SN 1054 : Type II Supernova — results of explosion of a massive star





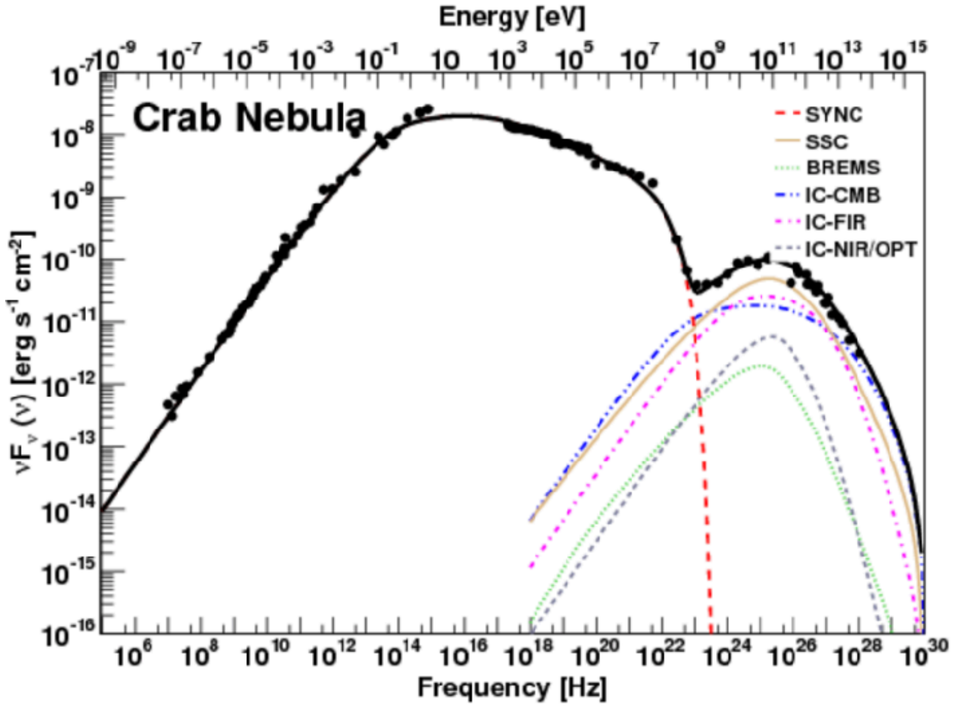


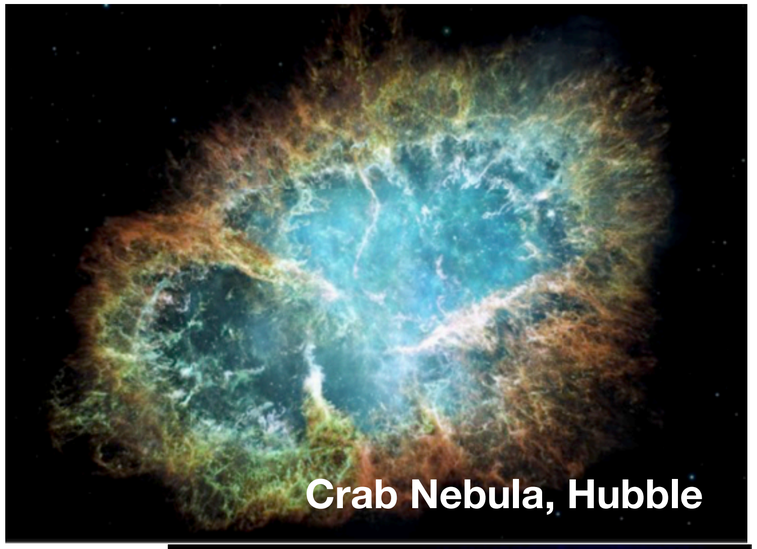


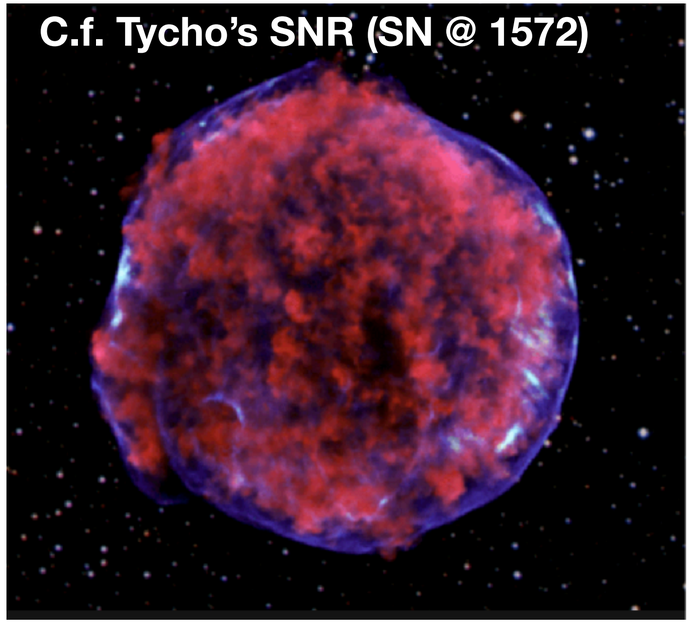
e.g. EM Multiwavelength Observation

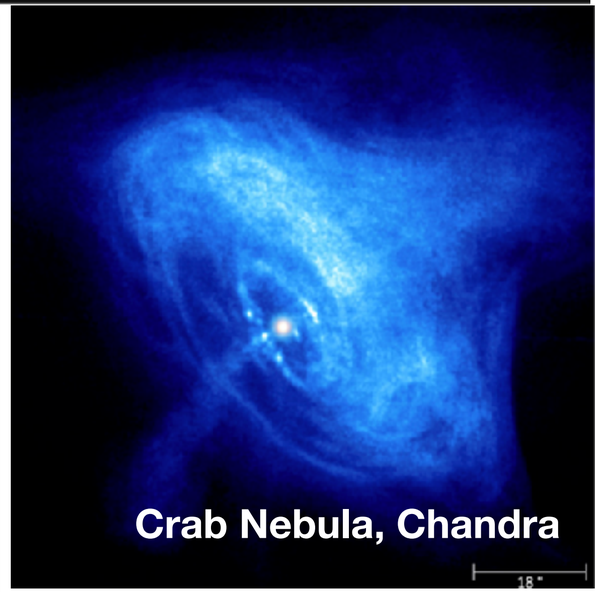
Crab Nebula

- Historic remnant of SN1054 (reported by Chinese & Japanese)
  - ☆ SN 1054 : Type II Supernova — results of explosion of a massive star
- Multiwavelength
  - ☆ Pulsar's pulsing detected in radio, X-ray, and gamma-rays
  - ☆ No detection of SNR shells
  - ☆ GeV gamma-ray flaring episode

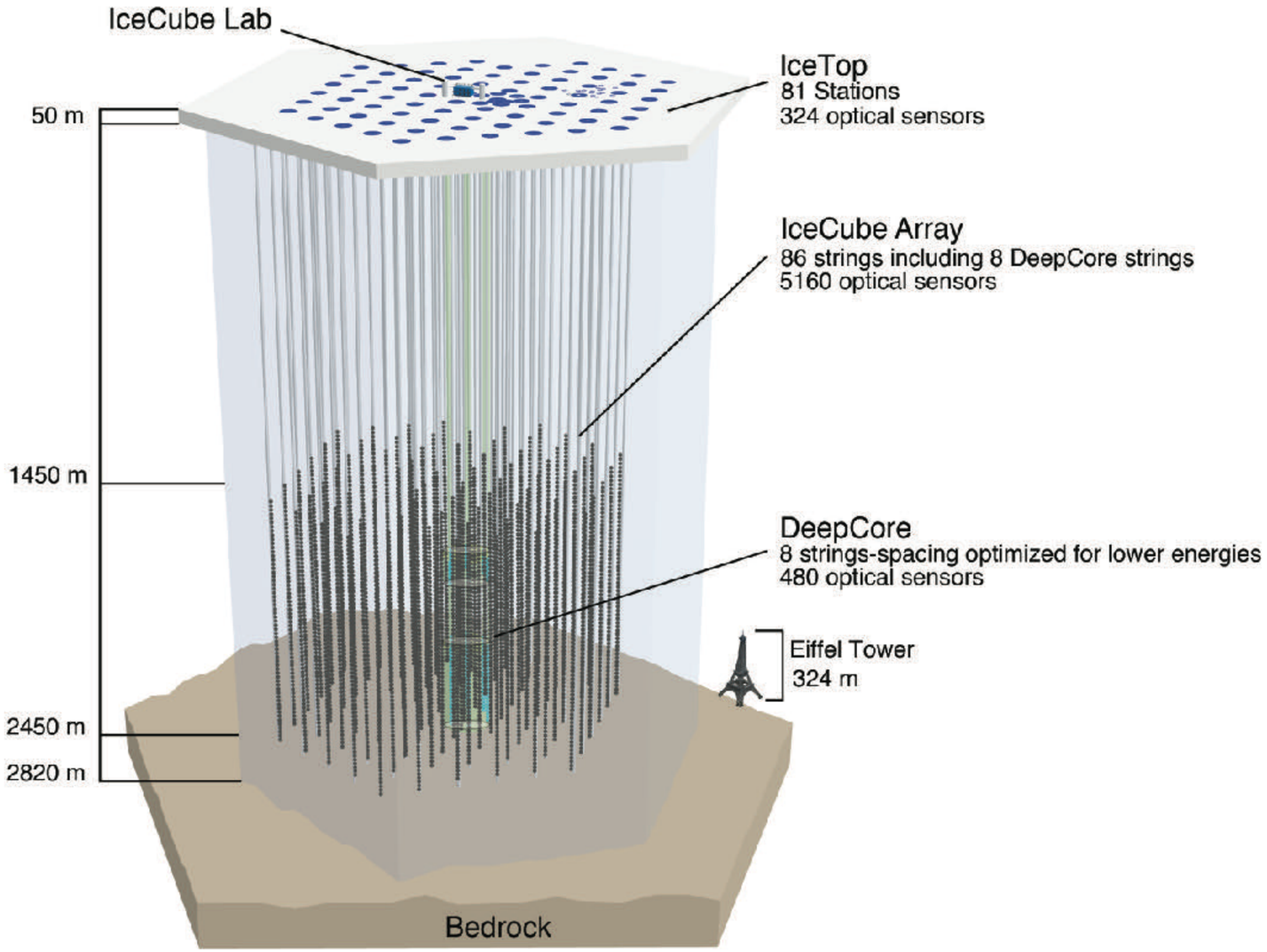






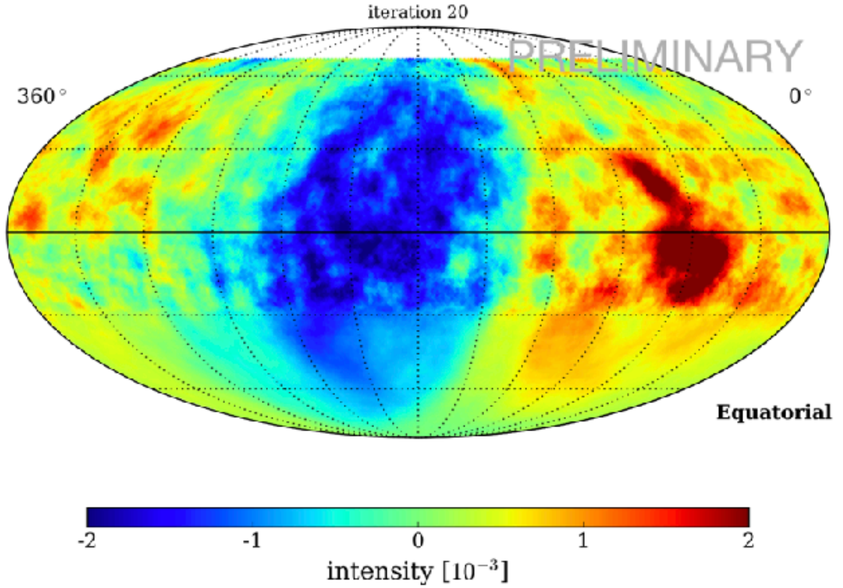


Role of IceCube

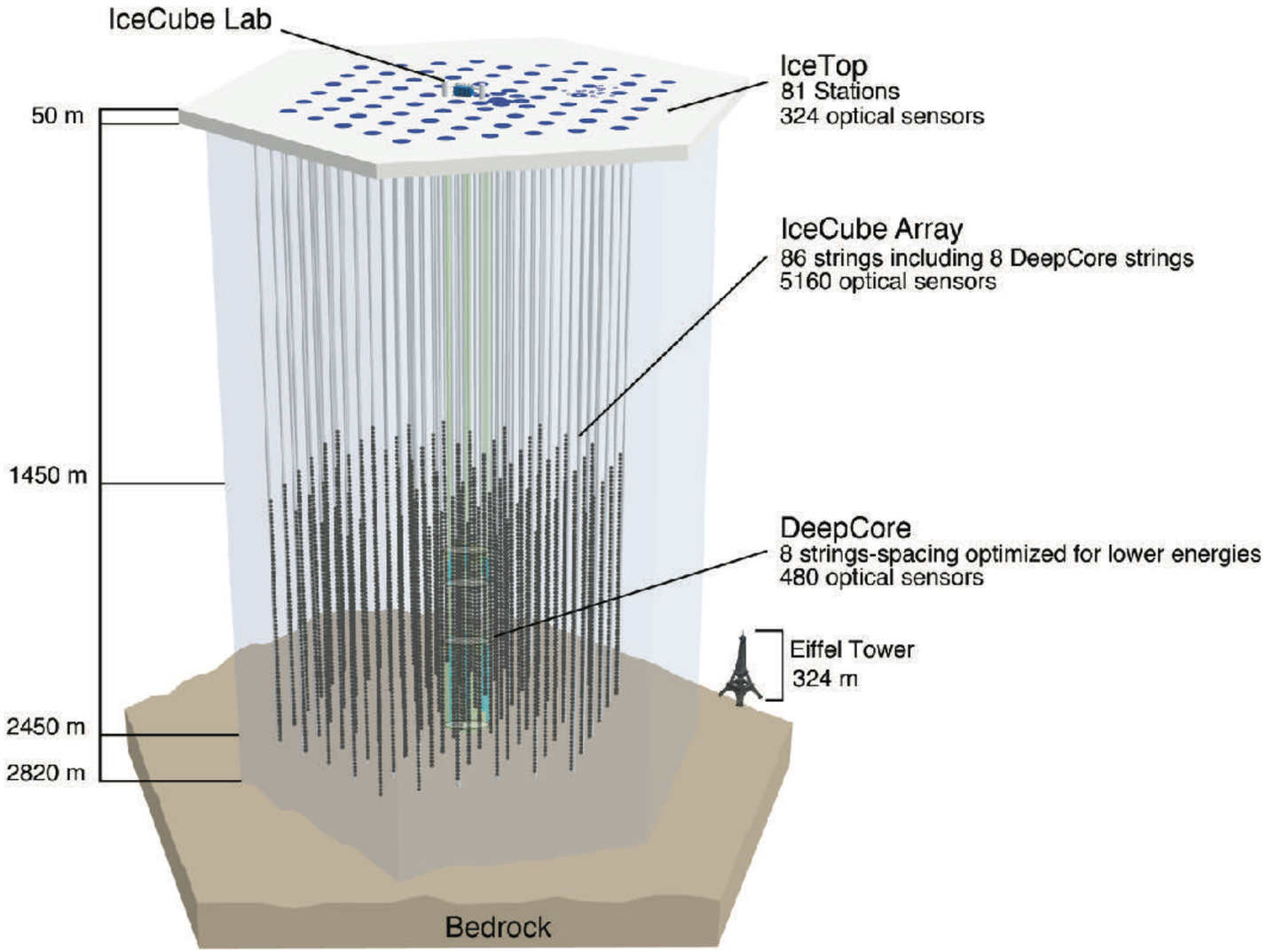


Indirect cosmic-ray measurement

- Spectrum, composition
- Anisotropy



Role of IceCube



Indirect cosmic-ray measurement

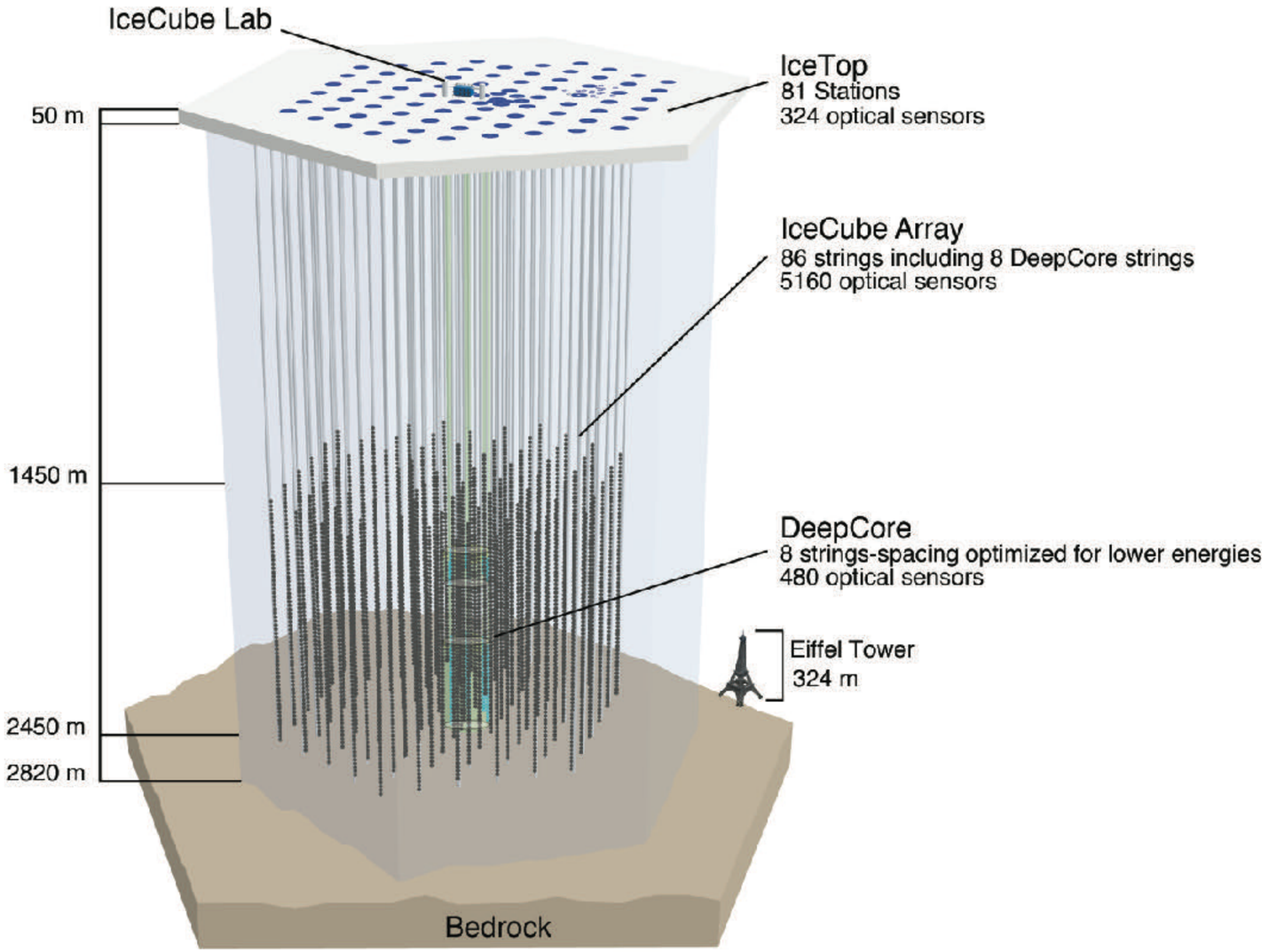
- Spectrum, composition
- Anisotropy

Neutrino measurement

- Astrophysical neutrino transient
  - ☆ Supernova, GRB, AGN flaring?
- Astrophysical steady neutrino sources
  - ☆ Galactic diffuse emission
  - ☆ Galactic hadronic accelerators
  - ☆ Extragalactic hadronic accelerators

Various of IceCube scientific topic will be summarized by Sam Fahey on Thursday

Role of IceCube

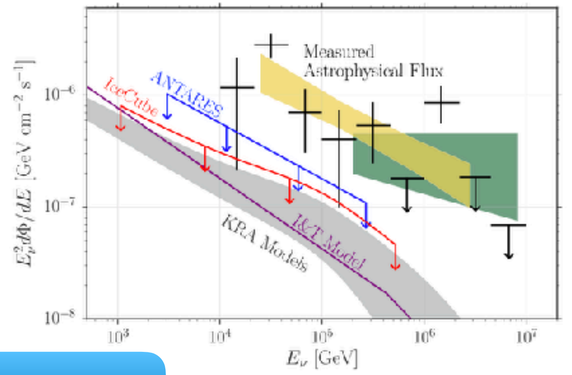


Indirect cosmic-ray measurement

- Spectrum, composition
- Anisotropy

Neutrino measurement

- Astrophysical neutrino transient
  - ☆ Supernova, GRB, AGN flaring?
- Astrophysical steady neutrino sources
  - ☆ Galactic diffuse emission
  - ☆ Galactic hadronic accelerators
  - ☆ Extragalactic hadronic accelerators



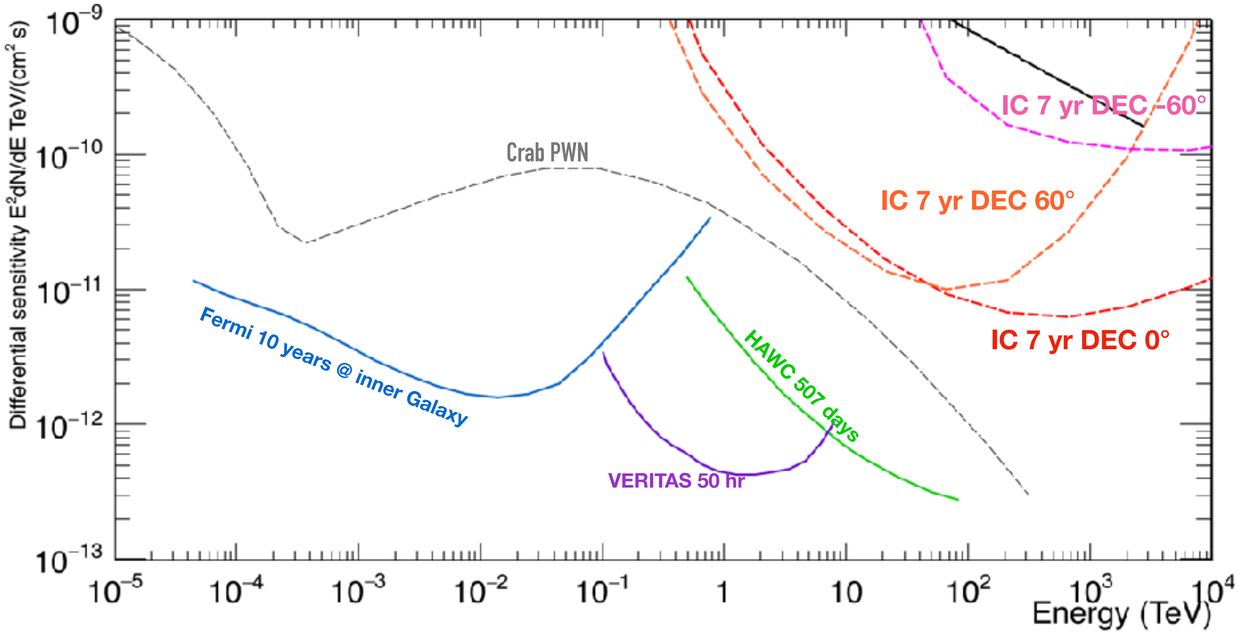
Various of IceCube scientific topic will be summarized by Sam Fahey on Thursday

Neutrino vs. Gamma-ray

Neutrino observation

- Pro
  - ☆ Pure hadronic flux measurement
  - ☆ Can probe deep in the source region & far away
- Con
  - ☆ Mainly due to sensitivity & angular resolution
    - Large amount of background from cosmic-rays

Future of the IceCube will be described by Kael Hanson on Thursday

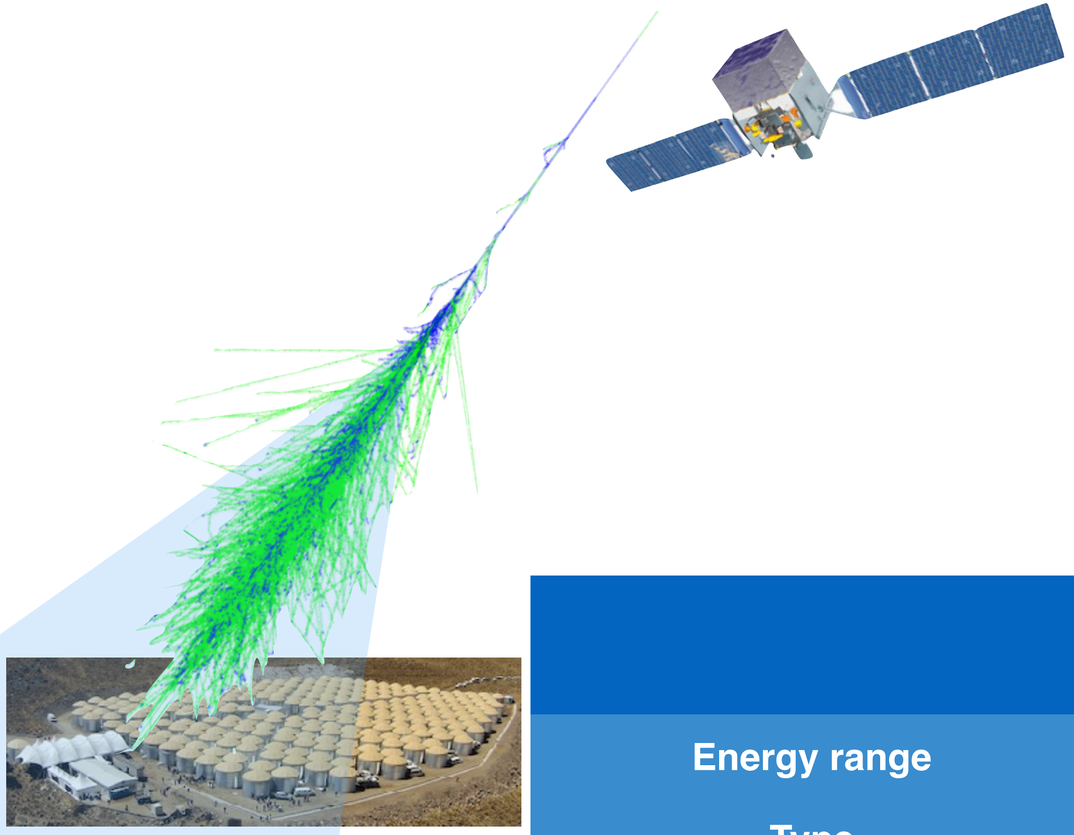


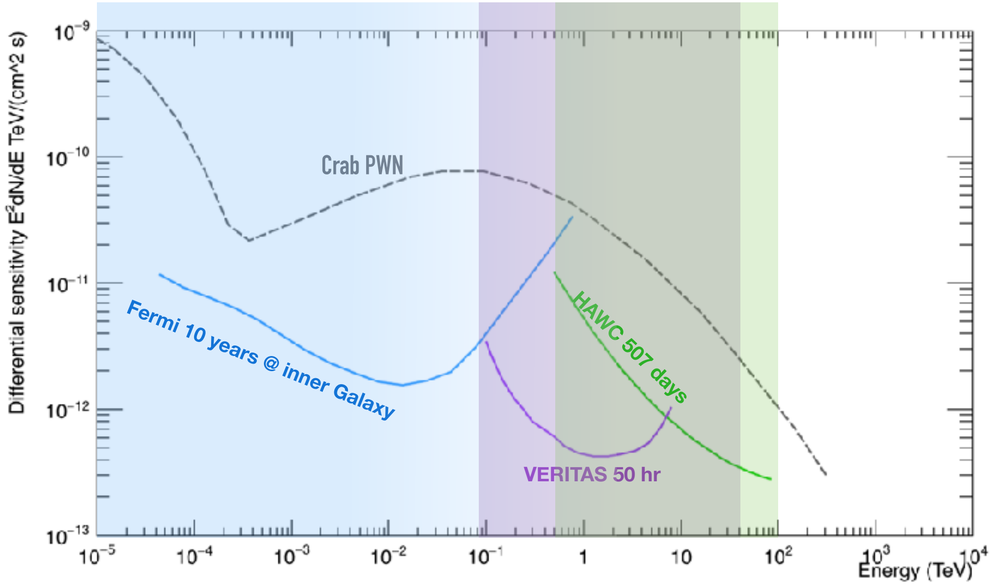
Limitation of gamma-ray observation

- Pro
  - ☆ >200 sources detected for E> 100 GeV
- Con
  - ☆ Confusion between leptonic and hadronic emission
  - ☆ Due to gamma-gamma absorption, gamma-ray cannot escape thick photon field
  - ☆ Due to interaction with extragalactic background light, gamma-ray has energy depended horizon
    - The farthest gamma-ray source detected at z~0.9

Utilize large HE γ-ray window

We currently have instruments covering six orders of energy range in γ-ray observations





	Fermi-LAT (Direct measurement)	VERITAS (IACTs)	HAWC (Air shower array)
Energy range	100 MeV- > 1 TeV	85 GeV - > 30 TeV	100 GeV - 100 TeV
Type	Survey	Pointing (3 degree)	Survey (~2/3 of sky)
Time to detect Crab Nebula (E>100GeV)		~1 min.	~1 day
Duty cycle	~100%	~ 20%	~100%
Effective area	~ 1 m^2	~ 10^5 m^2	~ 10^4 m^2

Multi-messenger Astrophysics

2017 was the year of the multi-messenger astrophysics!

- 2017 August
  - ☆ Triggering of gravitational wave event of GW170817 connected to the discovery of the first electromagnetic counterpart
    - Over 50 facilities world-side followed the event
- 2017 September
  - ☆ Triggering of the extremely-high-energy neutrino events 170922A followed by the flaring episode of a blazar, TXS 0506+056

More will come in very near future!