Supernova Remnants as PeVatron candidates by CTA observations

Ziwei OU
Supervisors: Tiina Suomijarvi, Jonathan Biteau
Institut de Physique Nucléaire d'Orsay
2018 PHENIICS Fest

Outline of my thesis

- AGN flares simulation (with Jonathan Biteau)

  flare duty cycle simulation for CTA

  already presented in SF2A meeting

- PeVatrons with CTA (with Tiina Suomijarvi)

  SNRs as Pevatron candidates

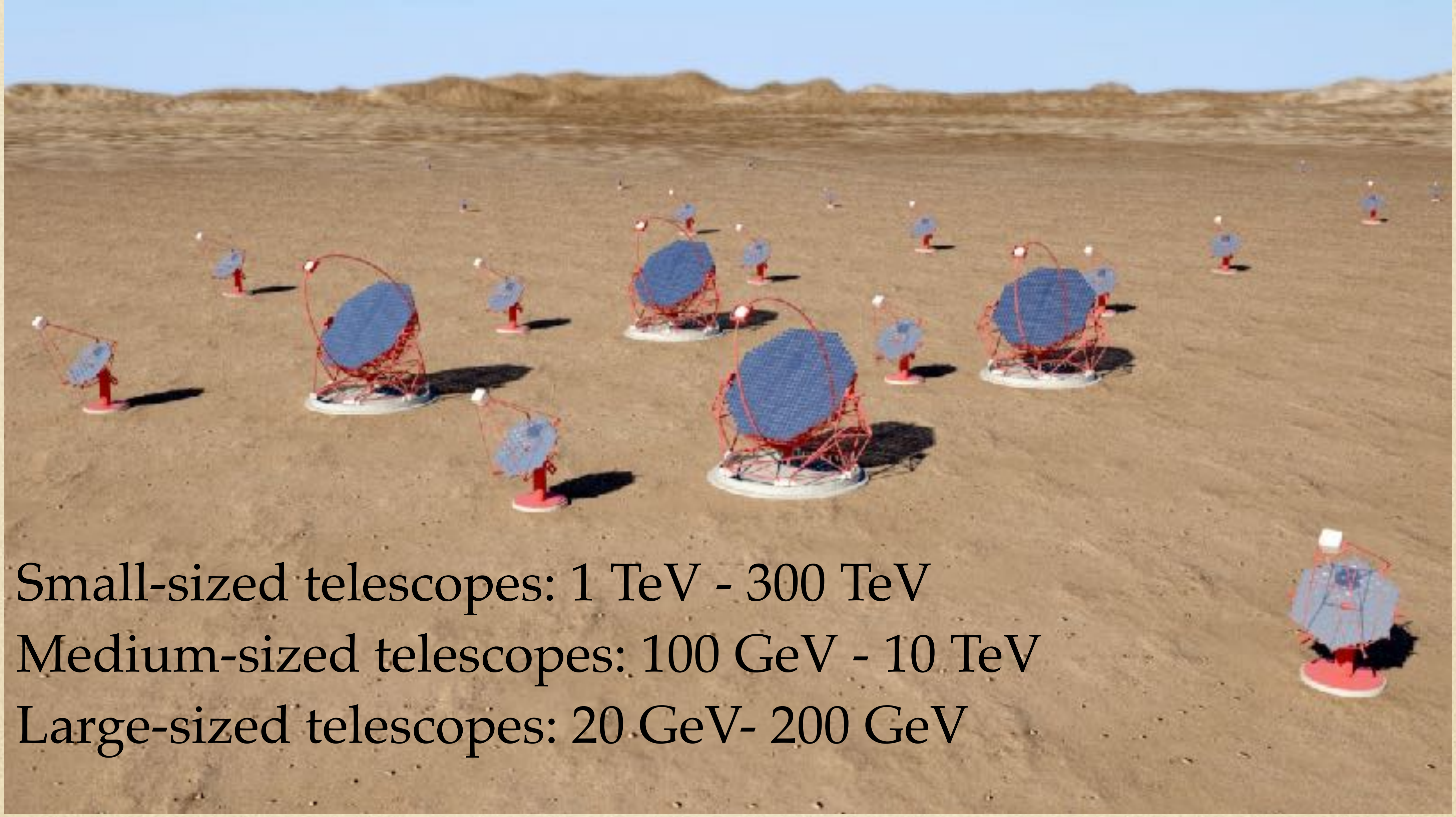
  work in progress, presented in CTA WG meetings

- Analysis of the first CTA data when the first LST in operation (November 2018)?

Outline

- Introduction
  - VHE gamma-ray and CTA observatory
  - PeVatron and proton-proton collision
  - Supernova Remnant
- SNRs spectrum and CTA sensitivities
  - DC-1 data, Prod3b, and ctools
  - our results
- Radiation mechanism for SNRs
  - naima python package
  - our results
- Conclusions

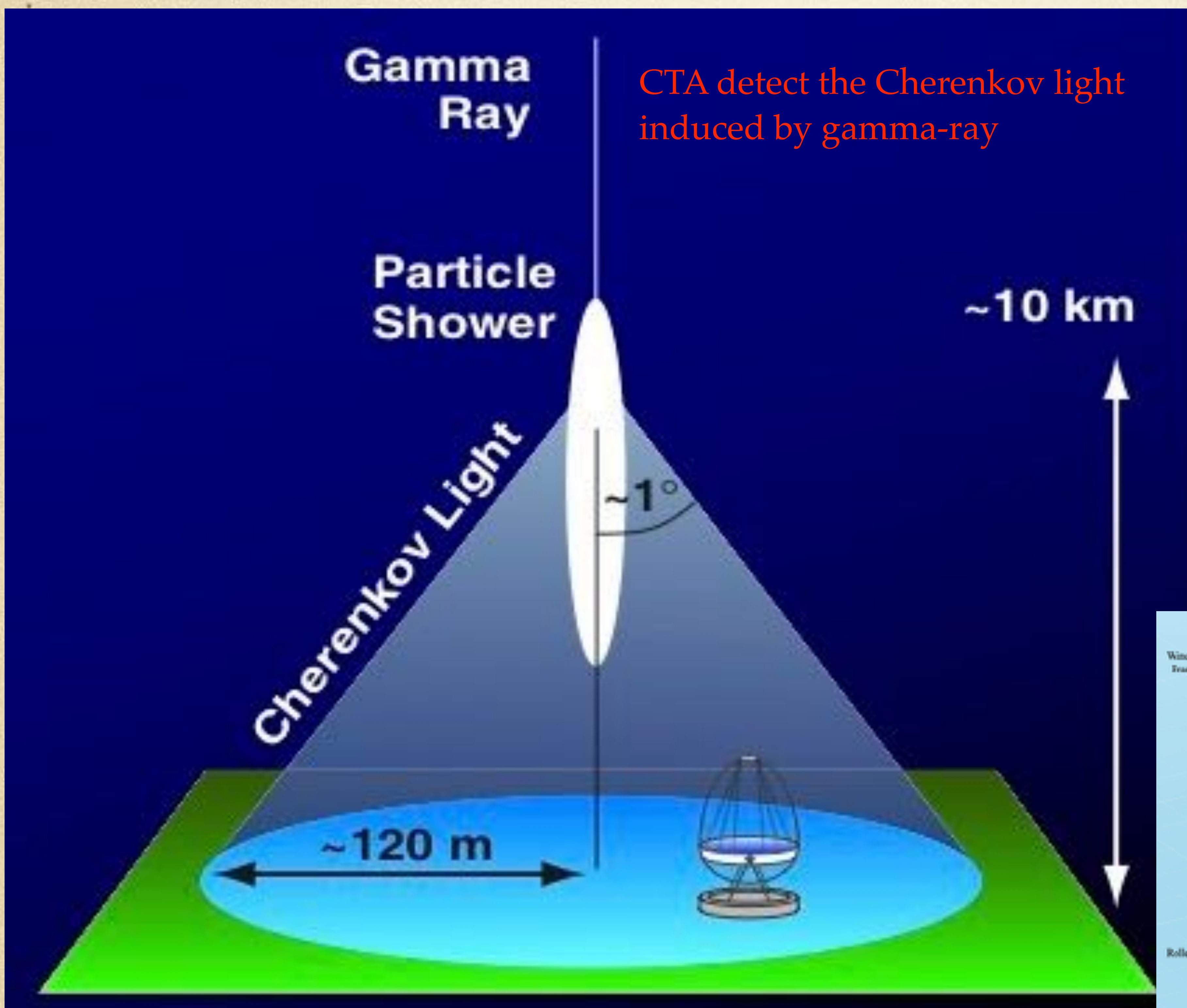
Cherenkov Telescope Array



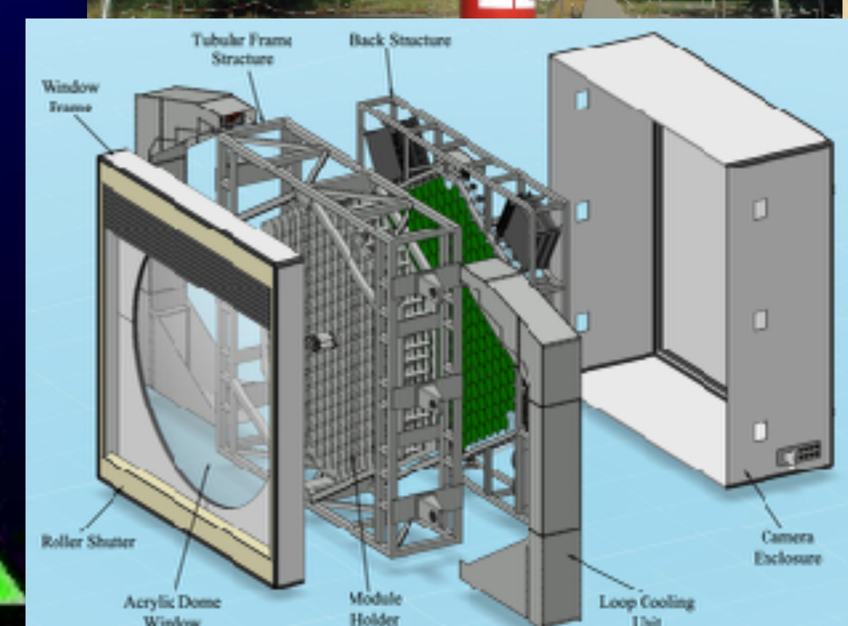
north site: La Palma (Spain)

south site: Paranal (Chile)

observations of CTA



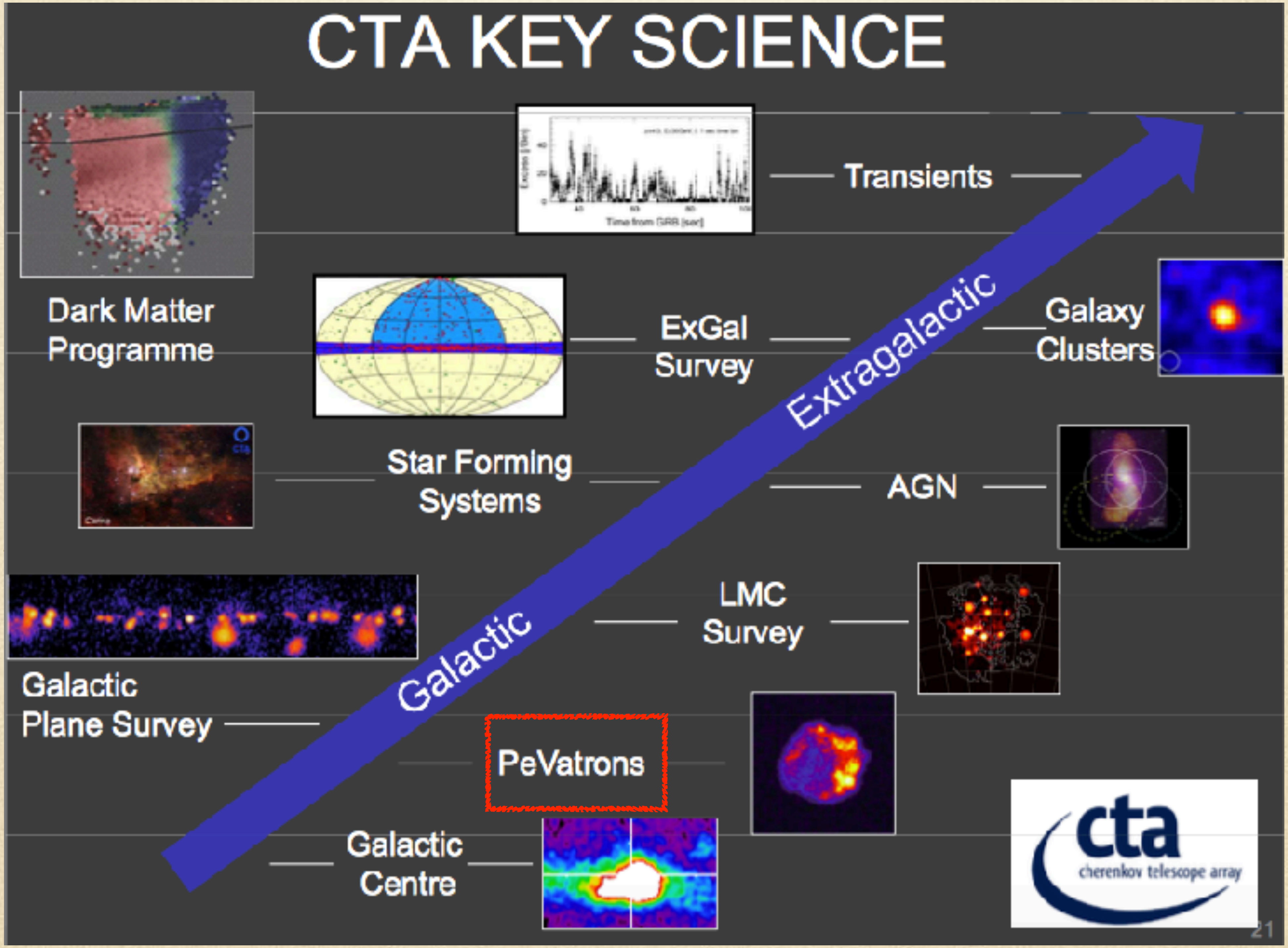

MST prototype in DESY



CTA is under construction

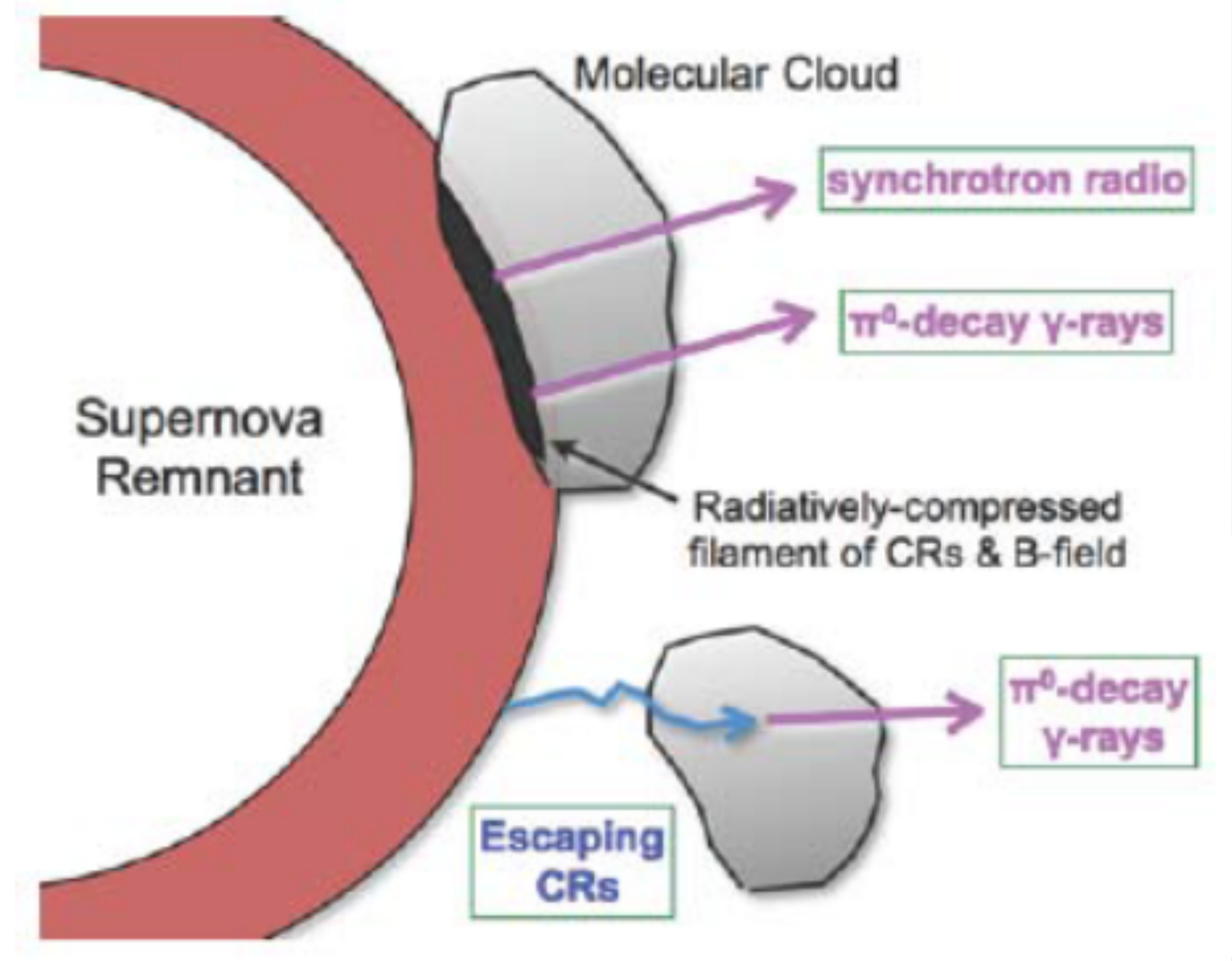
La Palma site

CTA: Cosmic-ray PeVatron as a Key Science Project



from R. Ong (2015)

proton-proton collision induces pion decay



For accelerated protons, hadronic interactions with ambient matter produce neutral pion, decaying into two γ-ray photons

$$\pi^0 \rightarrow \gamma_1 + \gamma_2,$$

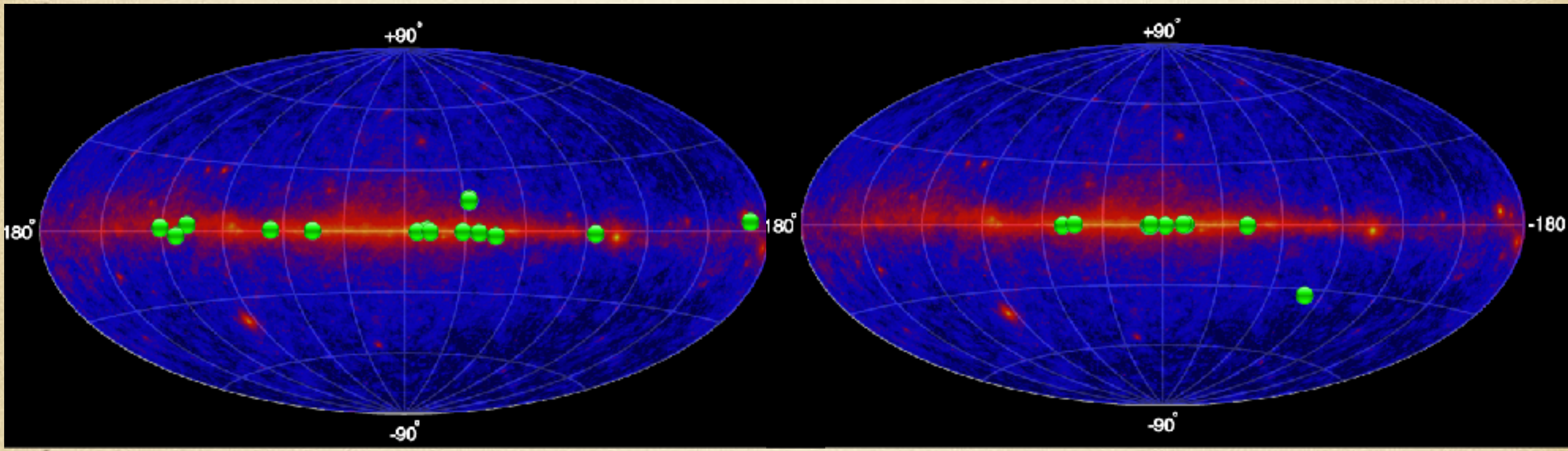
$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu,$$

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

SNRs as promising PeVatron candidates

- The detection of an SNR with spectrum up to 100 TeV imply that it is a PeVatron, because ~100 TeV photons are produced by ~ PeV protons.
- SNRs are able to satisfy the cosmic-ray energy requirement by converting the kinetic energy into accelerated particle.

γ-ray sky for SNRs



Shell-type SNR

SNR interacting with Molecular Cloud

SNRs are the main source in the gamma-ray sky in our Galaxy

SNR spectrum and CTA sensitivity

DC-1 data, Prod3b IRF and ctools

- Data Challenge one (DC-1): simulated data enable the CTA Consortium Science Working Group to derive science benchmarks for the CTA key sciences project
- DC-1 include Galactic Plane Scan (GPS) as one of the key science projects
- Prod3b Instrumental Response Function: based on Monte Carlo simulation and are released for internal usage
- Ctools: a soft package developed for scientific analysis of CTA data

SNRs spectrum and CTA sensitivities

Low Galactic latitude from TeVCat

HESS J1534-571	15 34 00	-57 06 00	Shell	2015.07		Newly Announced
HESS J1614-518	16 14 19.2	-51 49 12	Shell	2005.03		Default Catalog
RX J1713.7-3946	17 13 33.6	-39 45 36	Shell	2000.02	1 kpc	Default Catalog
CTB 37B	17 13 57.6	-38 12 00	Shell	2006.01	13.2 kpc	Default Catalog
HESS J1731-347	17 32 03	-34 45 18	Shell	2007.07	3.2 kpc	Default Catalog
HESS J1912+101	19 12 49	+10 09 06	Shell	2008.02		Default Catalog
0FGL J1954.4+2838	19 54 27.47	+28 38 54.6	Shell	2009.04	9.2 kpc	Source Candidates
SNR G318.2+00.1	14 57 46	-59 28 00	SNR/Molec. Cloud	2010.12		Newly Announced
CTB 37A	17 14 19	-38 34 00	SNR/Molec. Cloud	2008.11	7.9 kpc	Default Catalog
SNR G349.7+00.2	17 17 57.8	-37 26 39.6	SNR/Molec. Cloud	2013.07	11.5 kpc	Default Catalog
HESS J1745-303	17 45 02.10	-30 22 14.00	SNR/Molec. Cloud	2006.01		Default Catalog
HESS J1800-240C	17 58 51.6	-24 03 07.2	SNR/Molec. Cloud	2008.04	2 kpc	Source Candidates
HESS J1800-240B	18 00 26.4	-24 02 20.4	SNR/Molec. Cloud	2008.04	2 kpc	Default Catalog
W 28	18 01 42.2	-23 20 06.0	SNR/Molec. Cloud	2008.04	2 kpc	Default Catalog
HESS J1800-240A	18 01 57.8	-23 57 43.2	SNR/Molec. Cloud	2008.04	2 kpc	Default Catalog
W 49B	19 11 07.3	09 09 37.0	SNR/Molec. Cloud	2010.12		Default Catalog
W 51	19 22 55.2	+14 11 27.6	SNR/Molec. Cloud	2008.10	4.3 kpc	Default Catalog
SNR G015.4+00.1	18 18 04.8	-15 28 01	Composite SNR	2011.12	4.8 kpc	Default Catalog

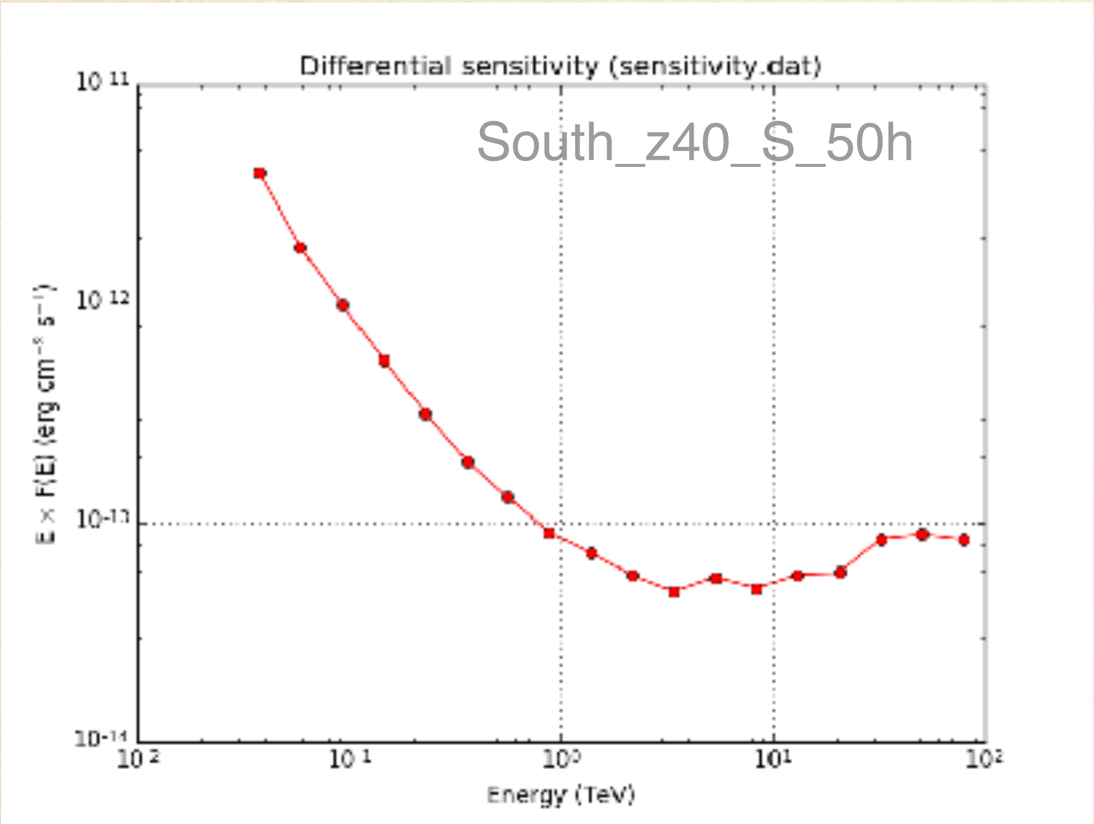
18 candidates for low Galactic latitude SNRs

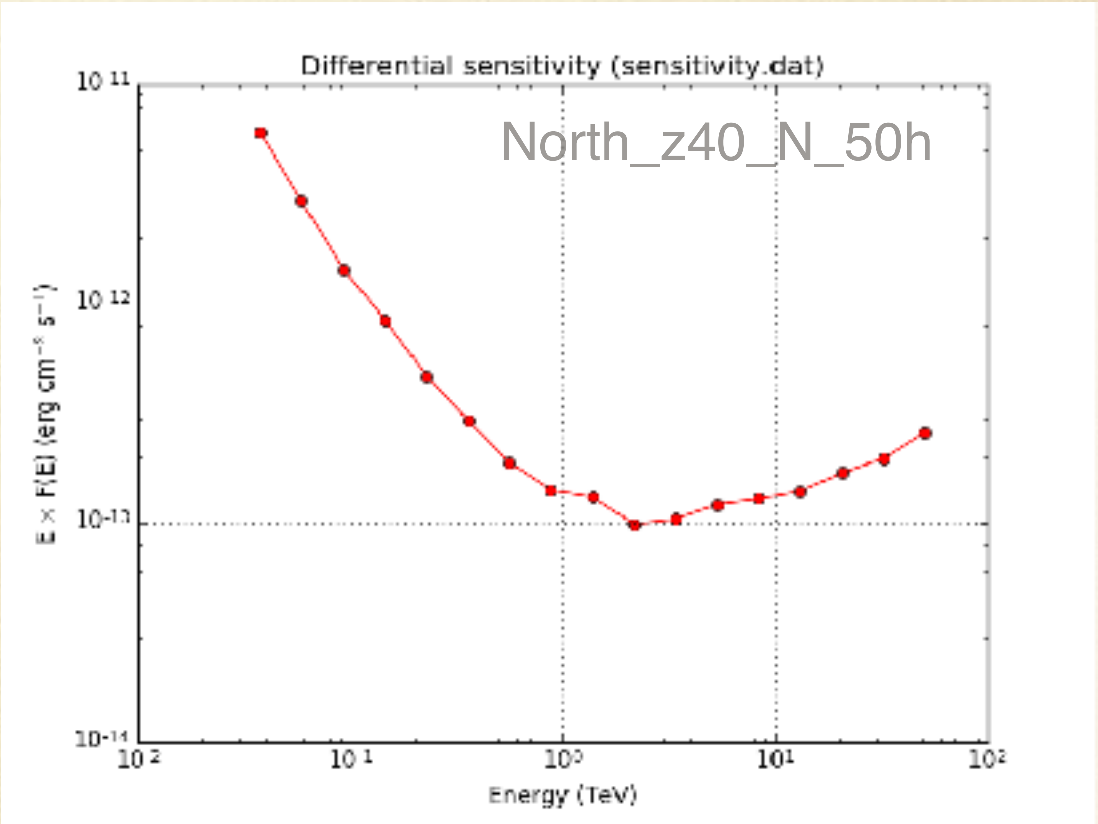
By running the pipeline of ctools, we extract 13 candidates from the DC-1 data

- Shell-type SNR: γ-ray from expanding shell of younger SNR
- SNR interacting with Molecular Cloud: γ-ray from the interaction between older SNR shock and the interstellar medium
- Composite SNR: γ-ray from the SNR and the Pulsar Wind Nebula inside

SNRs spectrum and CTA sensitivities

Results 1: CTA south and north sensitivity curves by using Prod3b IRF



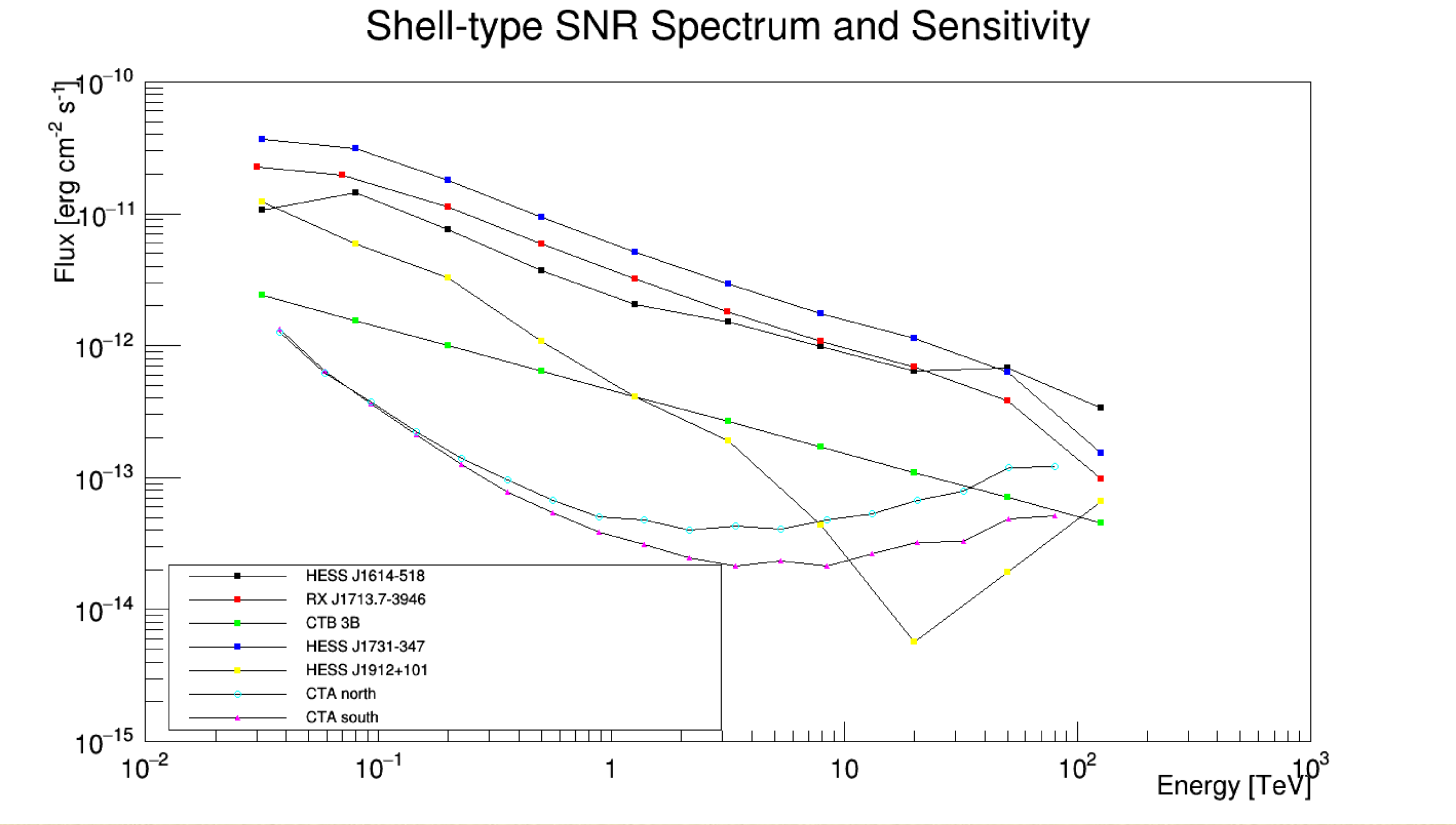


Southern site
40 deg zenith angle
50h observation times

Northern site
40 deg zenith angle
50h observation times

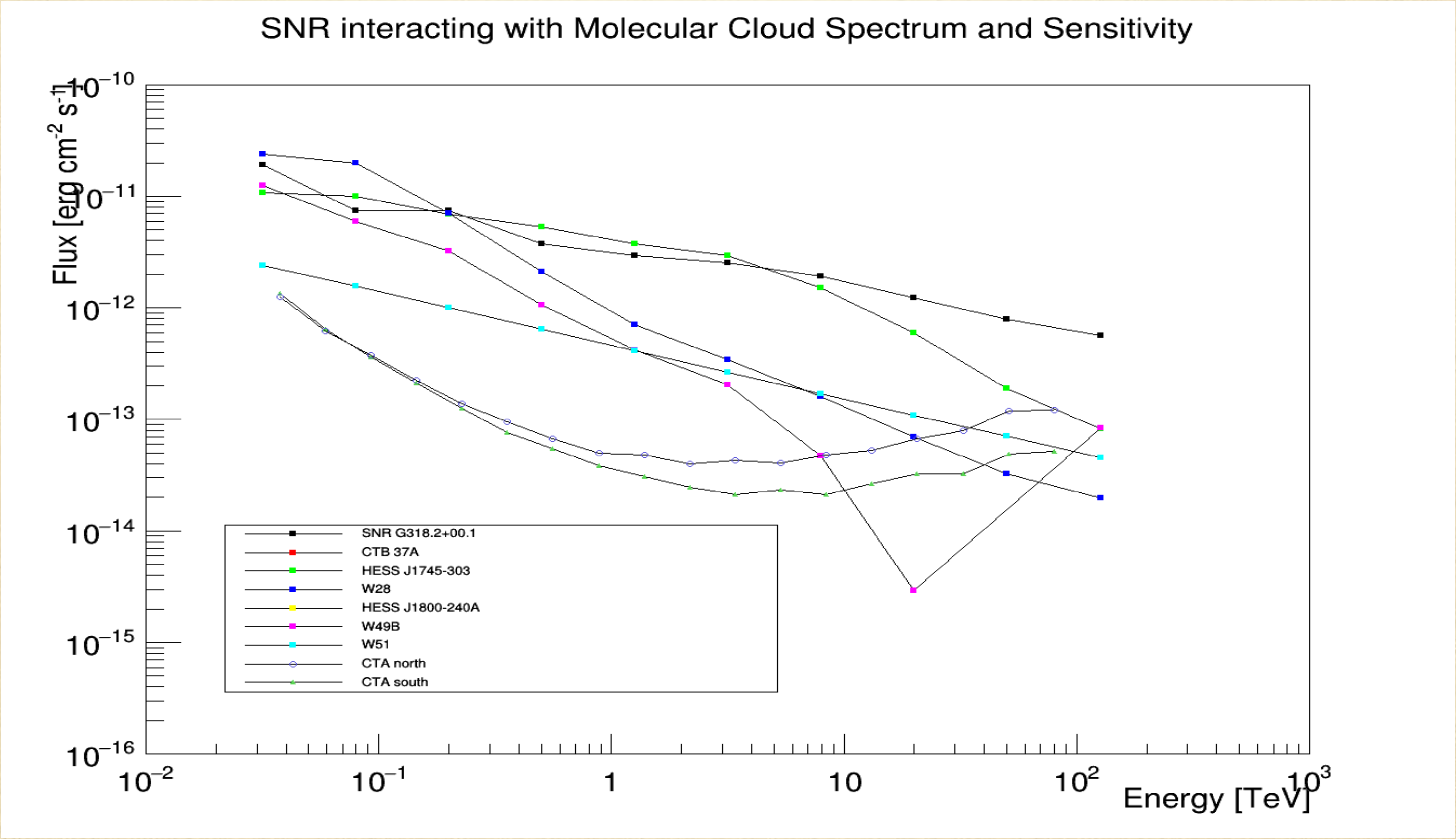
SNRs spectrum and CTA sensitivities

Result2: SNRs DC-1 spectrum and CTA Prod3b sensitivity



SNRs spectrum and CTA sensitivities

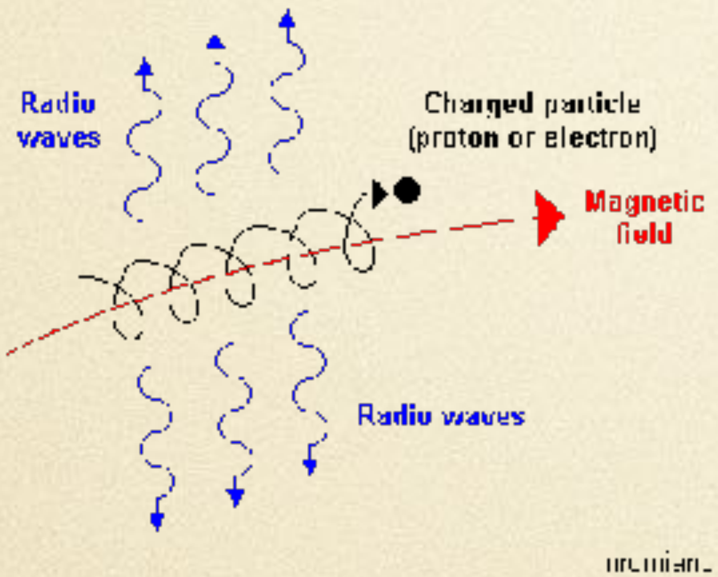
Results2: SNRs DC-1 spectrum and CTA Prod3b sensitivity

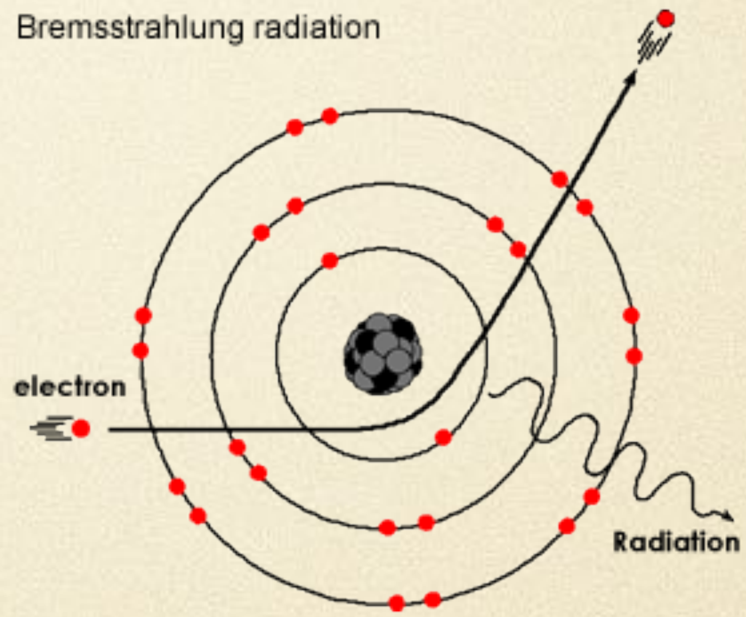


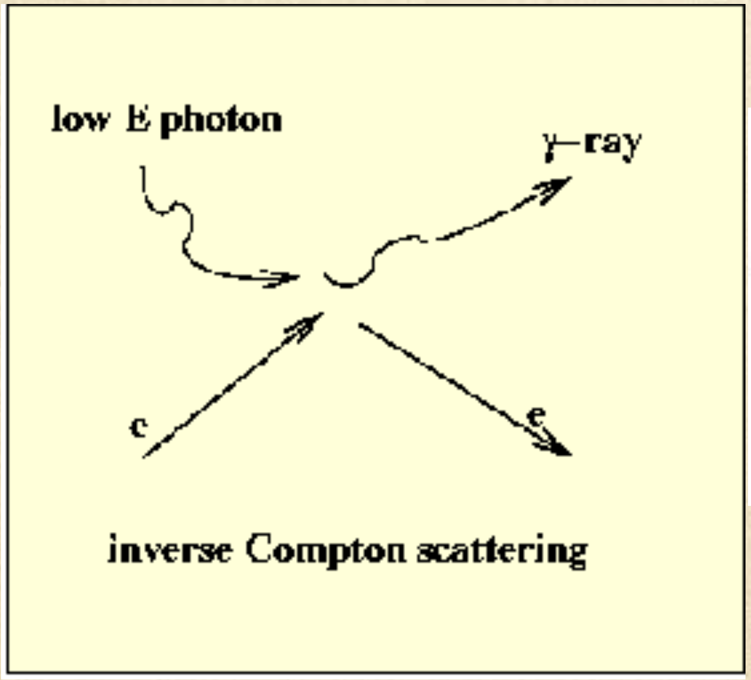
Radiation mechanism for SNRs

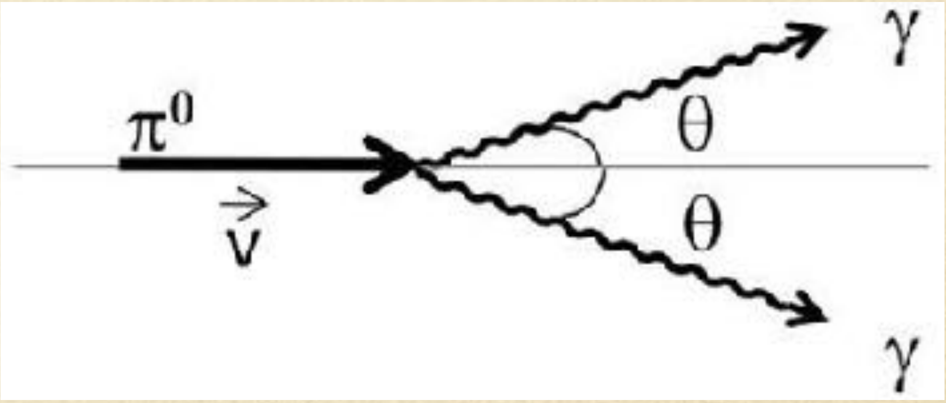
Four main non-thermal radiative mechanisms for producing γ-ray

Synchrotron



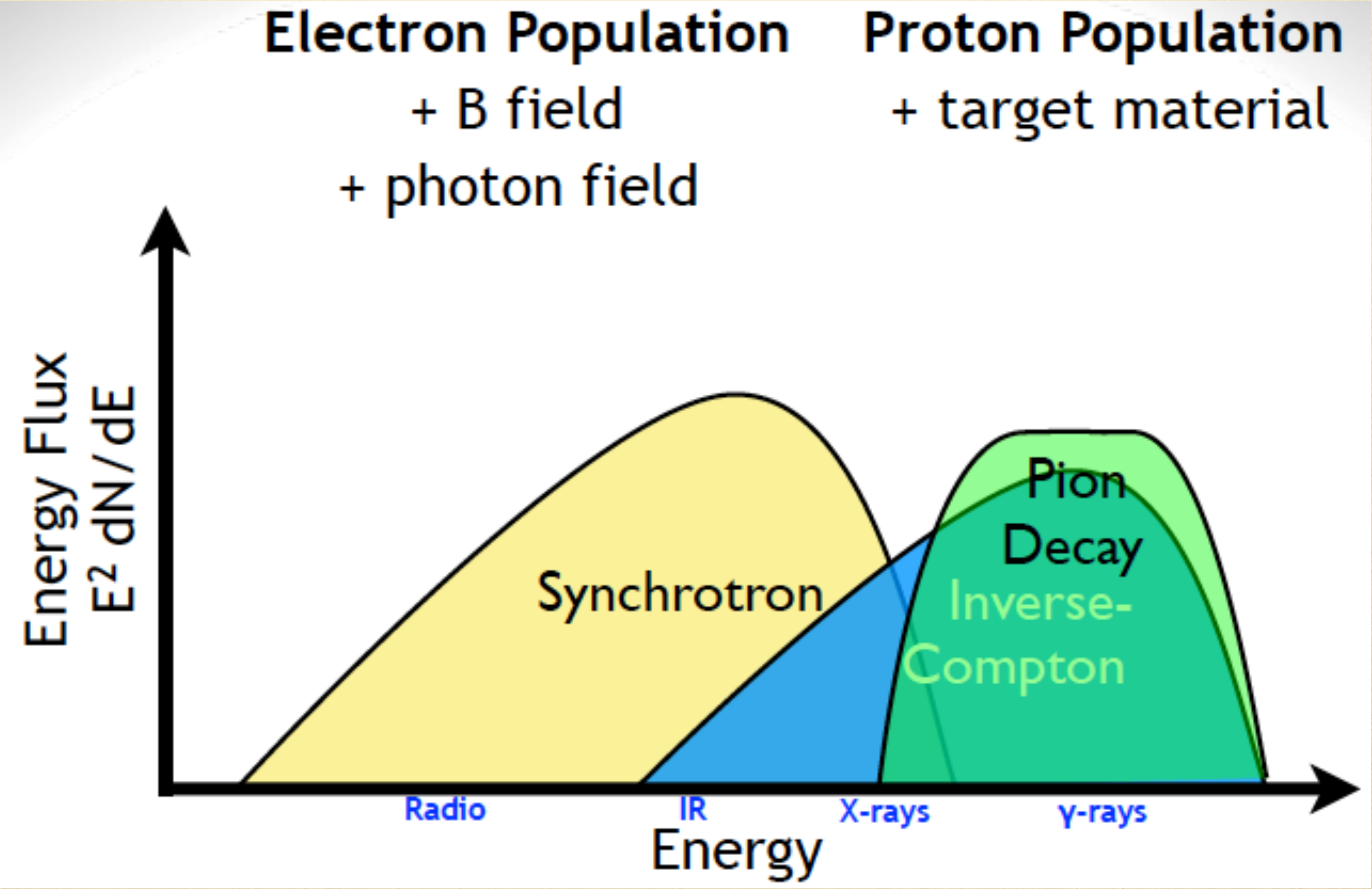






pion-decay

Different radiative model contribute to the SED



Radiation mechanism for SNRs
Naima Python package

- Compute non-thermal radiative model (Inverse Compton, Synchrotron, non-thermal Bremsstrahlung, Pion-decay) from population of electrons or protons

- Take an Exponential Cutoff Power Law as particle distribution function (protons, electrons)

$$f(E) = A(E/E_0)^{-\alpha} \exp(-(E/E_{cutoff})^{\beta})$$

amplitude: 6.64 (electrons), 1.42 (protons)

power Law Index: 2.89 (electrons), 2.13 (protons)

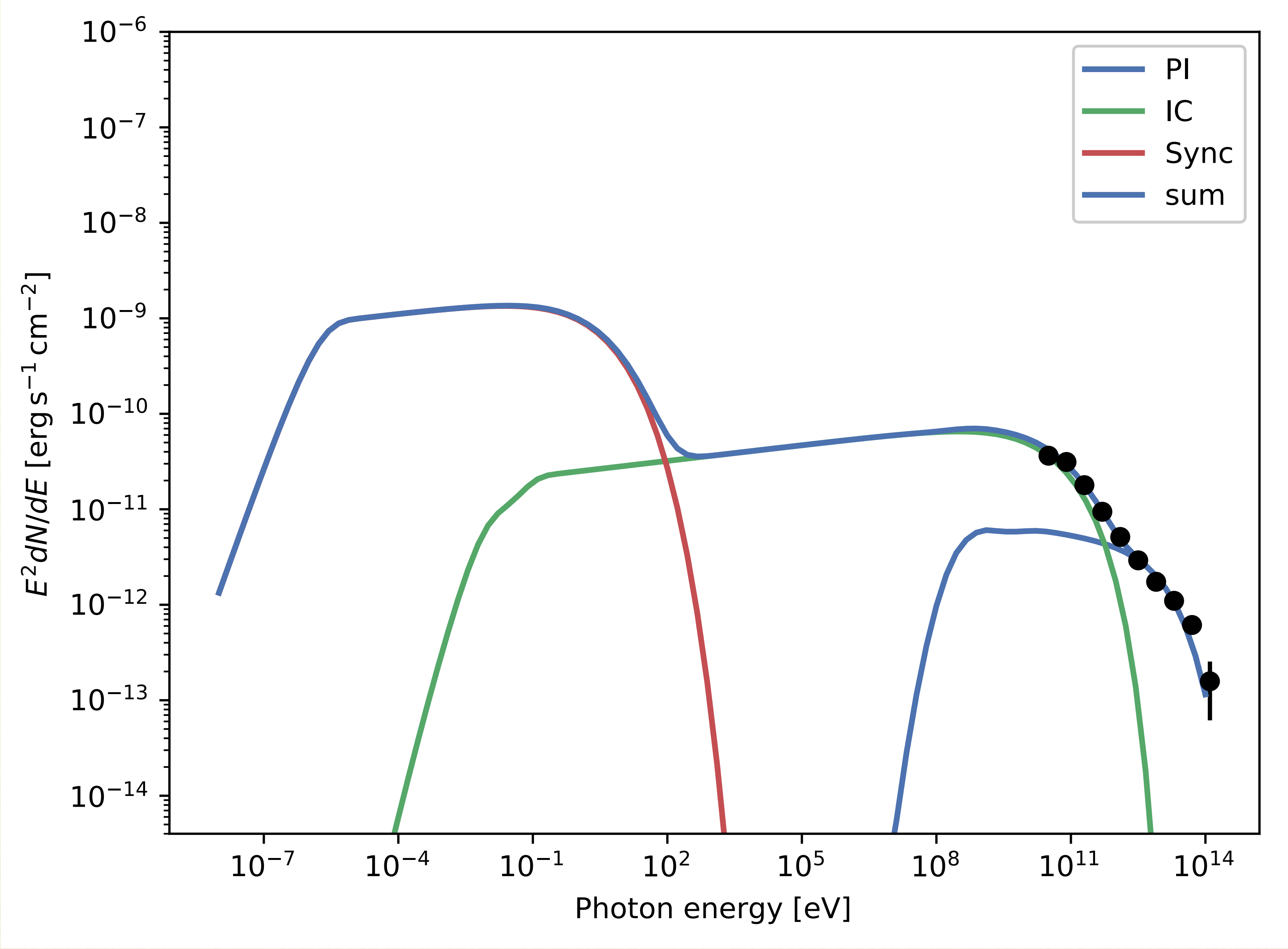
cutoff Energy: 10^3.18 GeV(electrons), 10^5.24 GeV(protons)

magnetic field: B = 23.5 uG is used for this study

proton number density: n = 0.008 cm^-3 is used

Radiation mechanism for SNRs

Results: Examples of radiation mechanism for Shell-type SNRs: RX J1713.7-1946



Conclusions

- For shell-type SNRs, three sources (RX J1713.7-3946 and HESS 1731-347, HESS J1614-518) can be seen by both south and north arrays from 30 GeV to 100 TeV.
- For SNR-MC system, SNR G318.2-00.1 can be seen by both south and north arrays from 30 GeV to 100 TeV.
- For RX J1713.7-3946, bremsstrahlung does not make significant effect to them, and pion decay dominates inverse Compton in the higher energy part of CTA.
- Next steps: add Fermi data; fit the data with model