



Edison Murairi

New York
University Abu
Dhabi

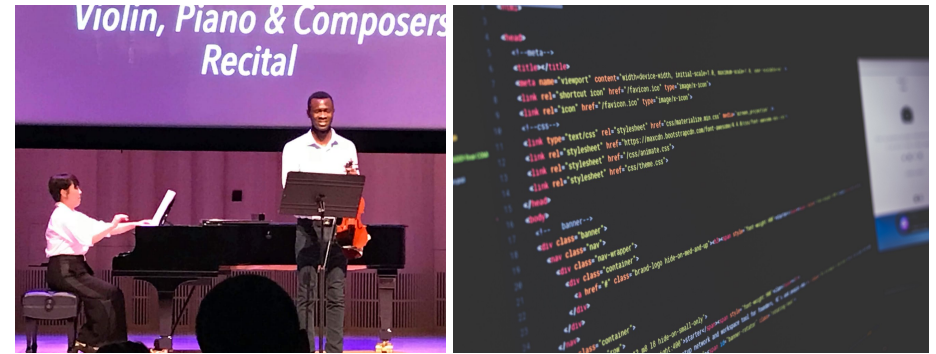
Class of 2020

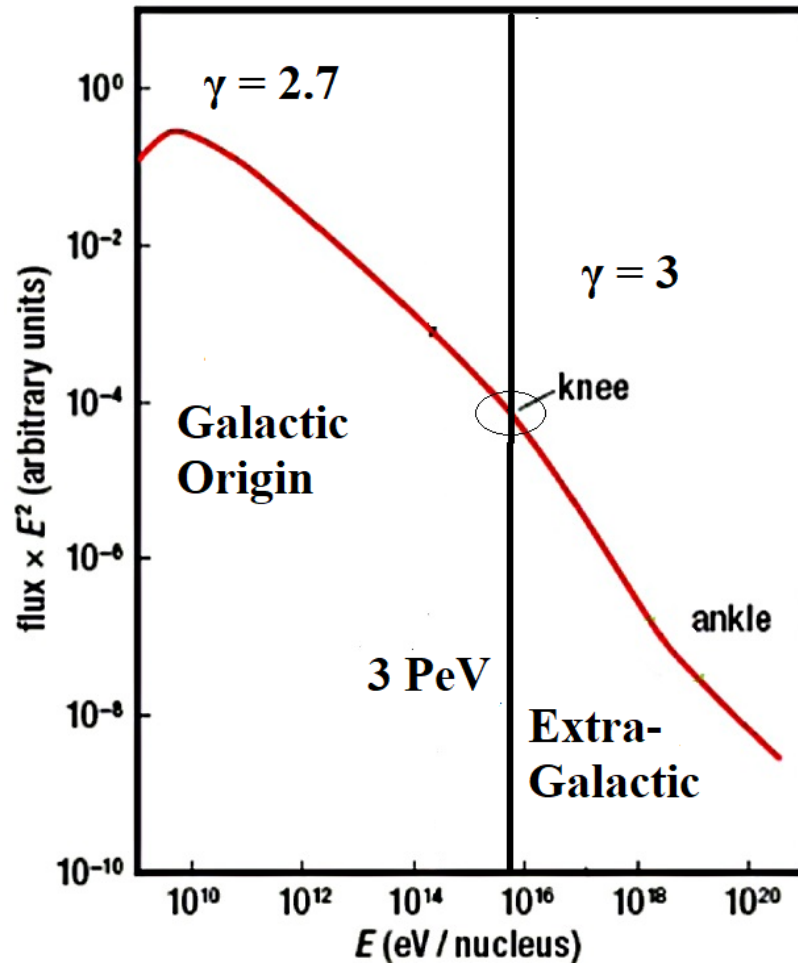
Supervisor:
Jospeh Gelfand

Cosmic Ray Production/Acceleration in SNR

Edison is

- Music Enthusiast
- Amateur Programmer
- Retired Frisbee Player





Back to Real Stuff: Cosmic Rays

- Predominantly charged particles
- From outer Space
- Power Law Spectrum
- Questions:
 - What objects produce them?
 - How?

Figure 1: Alan A Watson, Catching the highest energy cosmic rays, *Astronomy Geo-physics* 50(2009), no. 2, 2.20–2.27

Supernova Remnants?

- ❑ Shock waves
- ❑ Extremely energetic explosions: $E \sim 10^{51}$ ergs
- ❑ Frequent: 2 – 3 SN every ~ 100 years
- ❑ Requirement:
 - ❑ If mainly supernova remnants produce CR, $\eta_{cr} = 10\%$

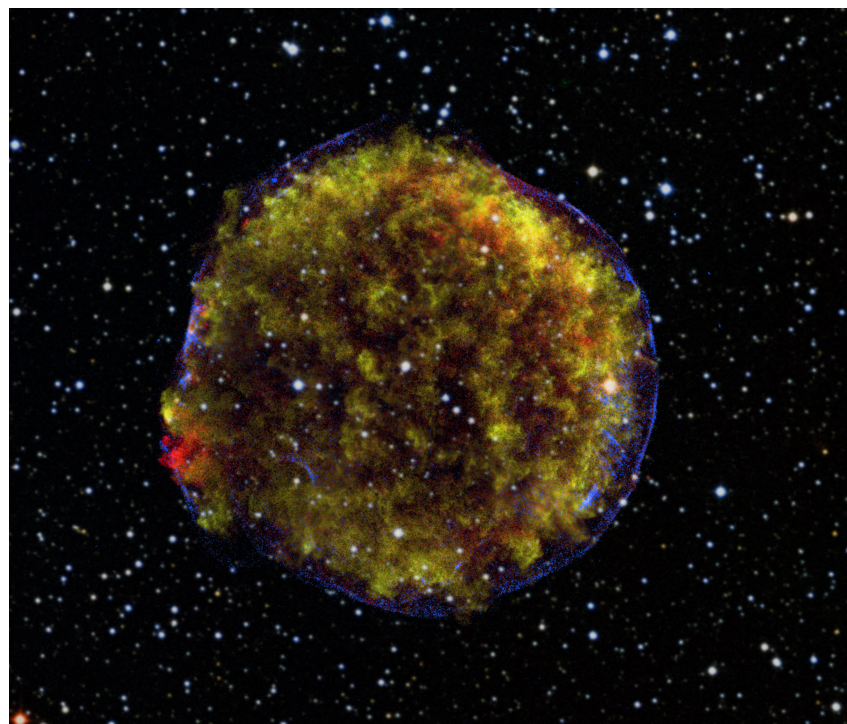


Figure 3: Tycho's Supernova Remnant. Chandra : Spacecraft. <http://chandra.harvard.edu/photo/2016/tycho/>. Accessed 25 November 2018

CR acceleration efficiency of SNRs

Function of:

□ SNR evolution:

□ Shock velocity

□ SNR age, size

□ Surrounding Environment:

□ Magnetic field

□ Density

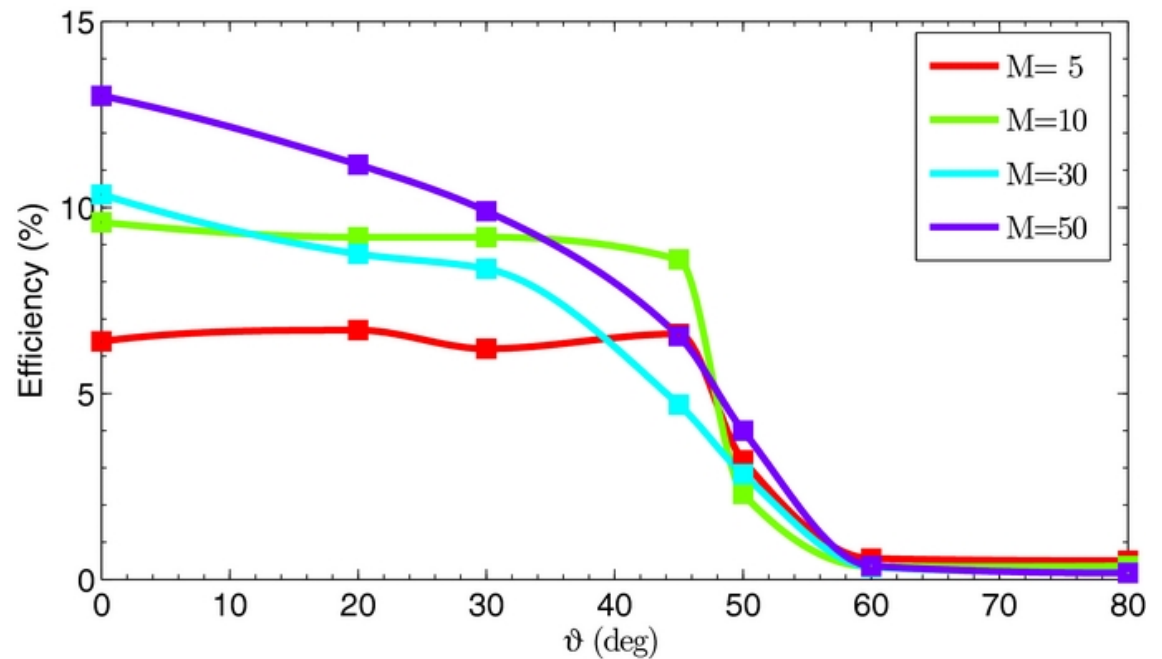
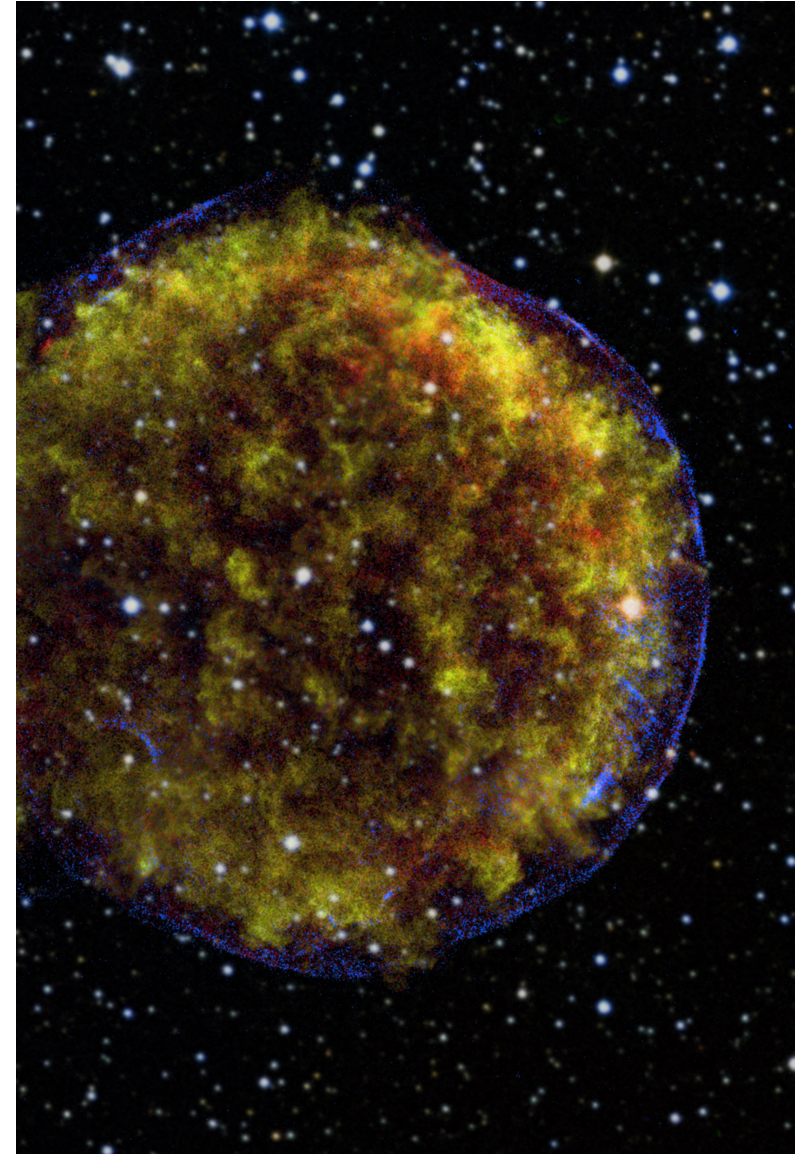


Figure 4: Caprioli Spitkovsky 2014 , ApJ , 783, 91

Case 1: Tycho

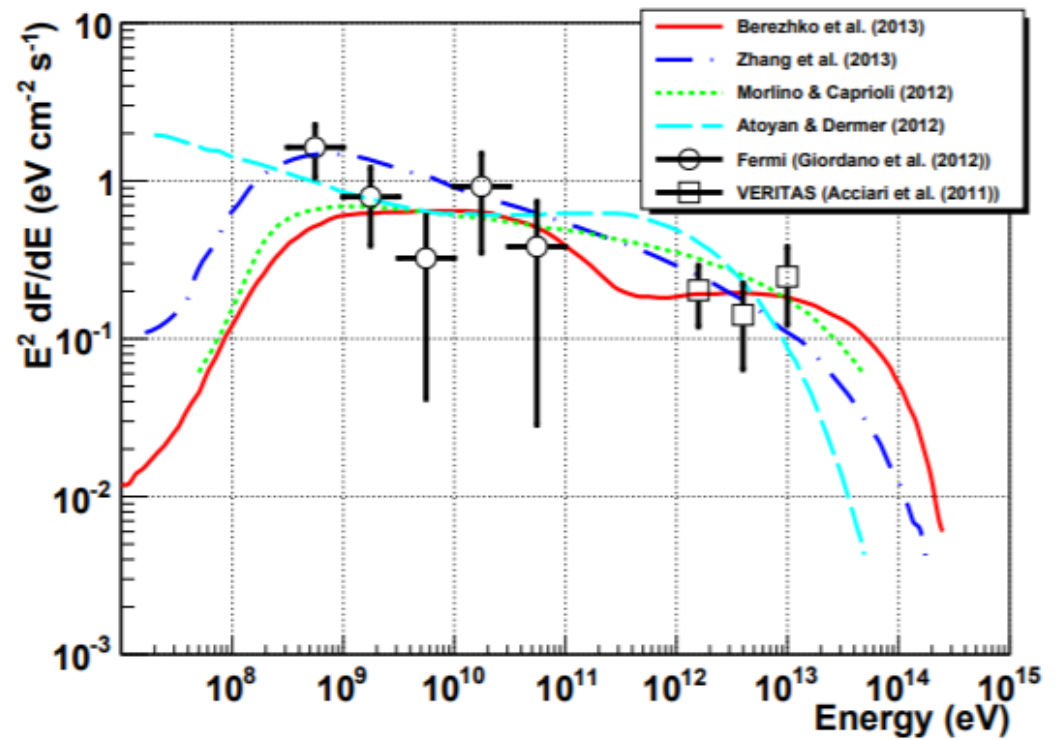
- ❑ Type Ia SNR
- ❑ Shell-like Morphology
- ❑ Chandra: Non-Thermal emission shows evidence of CR acceleration
- ❑ Does it satisfy equation here.sfy the requirement?
 - If γ ray produced:
 - ❑ In Molecular cloud (Blue)
 - ❑ In Clumpy ISM (Red): 1% efficiency
 - ❑ In Homogenous ISM: 12% efficiency (Wohaaaa)

So, Drum Rolllllllllll



Annnnnnd

Not Enough Statistics



<https://arxiv.org/abs/1308.0610>

New York University Abu Dhabi

What to do then?

- Keep on collecting SNR and study their properties

SNR	Age	\bar{n}	ISM	B_{snr}	η_{cr}	K_{ep}	$E_{0,p}$
Cas A	330 yr	30 cm^{-3}	Clumpy	0.5–1 mG	0.005–0.02	0.004–0.02	10–30 TeV
Tycho	440 yr	$\sim 0.3 \text{ cm}^{-3}$	Uniform	200–300 μG	0.06–0.075	0.0016	>470 TeV
IC 443	4,000 yr	$\sim 250 \text{ cm}^{-3}$	Clumpy	10 μG	0.006–0.02	0.01–0.03	100–200 GeV
W44	20,000 yr	$\sim 100 \text{ cm}^{-3}$	Clumpy	40–800 μG	0.03–0.15	0.01–0.05	...
W51C	30,000 yr	10 cm^{-3}	Clumpy	<150 μG	0.16	0.0125	120 TeV
W28	40,000 yr	$\gtrsim 100 \text{ cm}^{-3}$	Clumpy	40–160 μG	0.01–0.03	0.01	...

<https://iopscience.iop.org/article/10.1088/0004-637X/777/2/148/meta>