SYNERGY with High-Energy

Gamma-rays (CTA)
X-rays (including ATHENA)

Message: R+HE => a golden age!

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Future of Canadian Radio Astronomy
Montreal, Sep. 13-14 (2017)
Happy 85!
An exciting future with big facilities

Synergy of HEA with multi-wavelength facilities
Multi-wavelength Emission Processes (non-thermal)

Energy flux ($\nu F_\nu$)

Synchrotron radiation

hadronic

p-p interaction and $\pi^0$ decay

leptonic

Inverse Compton scattering

Multi-wavelength, spatially resolved spectroscopy, is key!

ICS

Emissary Photons

Electron

Magnetic Field Line

ICS

$e^-$

$e^-$

$\nu \rightarrow \nu'$$\nu' > \nu$

PION DECAY
The origin of HE cosmic rays
A century old puzzle!

R-X-γ synergy

GeV-TeV electrons but how about the protons?
Hadronic gamma-rays

2013 Breakthrough in Science: Conclusive evidence for cosmic ray (proton) acceleration in some radio-bright SNRs (a Fermi legacy)

the hadronic scenario also affects the low-freq. radio spectrum
Blooming VHE gamma-ray astronomy

-Galactic Plane: Mostly SNRs and PWNe
-lots of unidentified sources
(need matching angular resolution to R/X)

TeVCat: tevcat.uchicago.ca
SNRcat: http://www.physics.umanitoba.ca/snr/SNRcat
Gamma Catching up
(thanks to the Imaging Atmospheric Cherenkov Telescopes: IACTs)

“kifune” plot; Credit: S. Funk
The next ‘big’ gamma-ray mission: Cherenkov Telescope Array (CTA)

- Theme 1: Understanding the Origin and Role of Relativistic Cosmic Particles
- Theme 2: Probing Extreme Environments
  - including search for FRBs counterparts
- Theme 3: Exploring Frontiers in Physics

“Science with CTA”
(to be soon published)
The next ‘big’ gamma-ray mission: Cherenkov Telescope Array (CTA)

• Theme 1: Understanding the Origin and Role of Relativistic Cosmic Particles
• Theme 2: Probing Extreme Environments
• Theme 3: Exploring Frontiers in Physics

an order of magnitude improvement in angular resolution and sensitivity! spatially resolved spec. in a wider gamma-ray band!

Science with CTA

closely related to SKA/SKA pathfinders science! (discussed by many at this meeting)

an open observatory!

“Science with CTA” (to be soon published)
CTA Key Science Projects

- Galactic Centre
- Galactic Plane Survey
- LMC Survey
- Extragalactic Survey
- Transients
- Cosmic Ray PeVatrons
- Star Forming Regions
- Active Galactic Nuclei
- Clusters of Galaxies

“A Galactic PeVatron?”


“Science with CTA”
(to be soon published)
The Electromagnetic Spectrum
A golden era in **X-ray astronomy**

- **Hitomi** (briefly), (Fermi, SWIFT), **ASTROSAT**, NICER, HXMT

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*Image of a diagram showing the electromagnetic spectrum with emphasis on X-ray astronomy.*

- **Chandra & XMM-Newton**: 0.1 - 10 keV, largest effective area at 1 keV
- **NuSTAR**: 3 - 79 keV, ~18” effective area
- **Hitomi**: ~0.5” effective area

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*Note: The diagram illustrates the relative sizes and effective areas of various X-ray satellites and their capabilities in different energy ranges.*
Future X-ray Telescopes

- **X-ray surveys** (eROSITA coming up: 2018)
- **X-ray polarimetry** (IXPE~2020+, eXTP, XIPE?)
- **High-resolution X-ray spectroscopy** (Hitomi=>XARM~2021......Arcus.....Athena~2028)
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NS Diversity on the Period-B diagram
Synergy between X and R science: population studies

adapted from Harding 2013

See Vicky Kaspi's talk
Future X-ray Telescopes

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PWN: Different population? R-X-gamma synergy

Non thermal X-rays

Radio

Ma+16

R polarization

Reynoso+13

X: synchrotron
Synchrotron:

Non-thermal X-rays

R-X-gamma synergy

How is B amplified?

Is B ordered/disordered?

Connection to Galactic B

(e.g., R. Kothes+; J. West+16, 17)

See Jo-anne Brown’s talk

R polarization

Ma+16

X-ray polarization: a new window into B!

Reynoso+13

Radio

Non thermal X-rays

Prong
Future X-ray Telescopes

- **X-ray surveys** (eROSITA coming up)

- **X-ray polarimetry** (IXPE, XIPE, eXTP)

- **High-resolution (a few eV) X-ray spectroscopy** (Hitomi (2016) => XARM~2021 ..... Arcus .... Athena~2028)

![CCD spectrum](image)

- Perseus cluster
  
  Hitomi collaboration 2016, Nature
Why should a radio astronomer care about high-resolution X-ray spectroscopy?

- Line diagnostics => accurate measurement of thermal, Doppler, turbulent velocities (dynamics, evolution, energy budget)
- relevant to a whole range of astrophysical radio sources (galactic and extragalactic)
ATHENA (2028-) science drivers

The Hot Universe: How does the ordinary matter assemble into the large-scale structures that we see today?

The Energetic Universe: How do black holes grow and influence the Universe?

synergy with SKA science drivers:

- Galaxy evolution, cosmology: “How do galaxies evolve? What is dark energy?”
- Probing the cosmic dawn: “How were the first black holes and stars formed?”
An exciting future with big facilities

Synergy of HEA with multi-wavelength (radio) and multi-messenger (NEXT TALK) facilities
Extra Slides
Involvement in the next flagship high-energy astrophysics (HEA) mission was ranked as the highest medium-scale space opportunity in LRP2010. This recommendation recognized the general importance of probing matter both in its most common state (hot gas in galaxy clusters) and in its most extreme – and hence often most physically revealing – conditions. Such investigations include extremes of gravity (black holes), density, magnetic field (neutron stars), temperature (supernova remnants), and speed (jets, gamma-ray bursts).
LRP 2010, MTR2016, CSA HEA Topical Team

The selection of IXO …(now called ATHENA)….reflected the growing number of Canadian astronomers working in these fields, and the importance of multi-wavelength astronomy.

Building upon the ASTRO-H mission and successful contribution of the Canadian ASTRO-H Metrology System (CAMS), Athena is a natural aspiration for involvement for the HEA community, and associated technology development, in Canada.

May 2017