What we can learn from γ-ray astronomy

Results, Prospects and Limitations

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Introduction

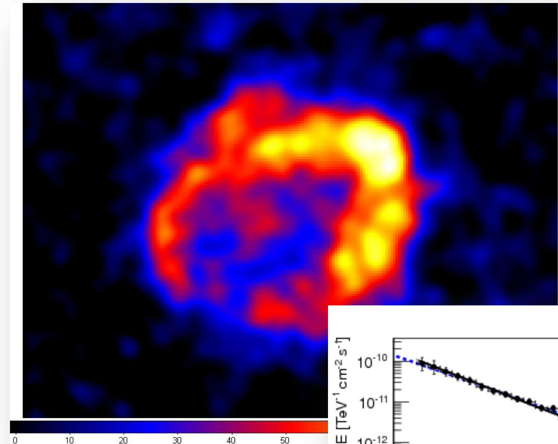
- Composition measurements with Direct Cherenkov (DC) light by IACTs
  - Henrike Fleischhack, Today 09:20
- CR acceleration at Supernova remnants / Galactic CR maximum energy
  - Gwenael Giacinti, Yesterday, 17:30
- Composition models: what to expect from known cosmic accelerators
  - Martin Pohl, Tomorrow, 09:00
- Surely, others will also refer to γ rays

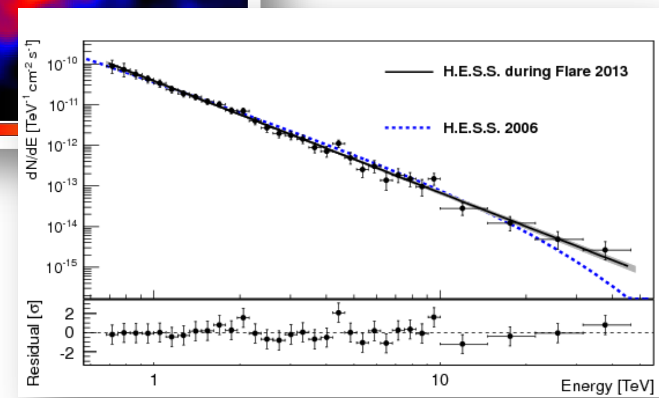
- Here
  - How we can use γ rays to measure CR composition
  - What we can learn from current instruments
  - What are the prospects for CTA?

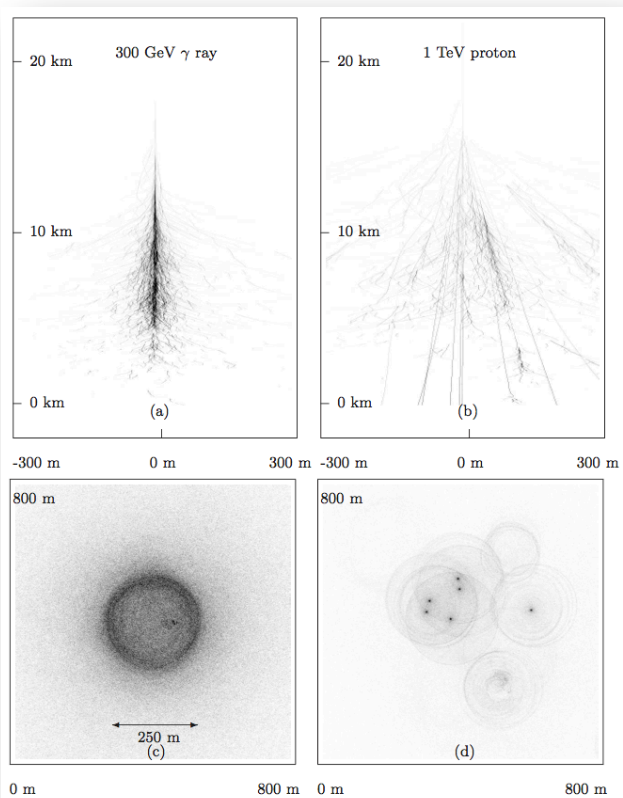
How to use γ rays to infer CR composition

> Use CR-induced air shower

- ‘background’ in γ-ray astronomy
- DC light to infer charge of primary
- study EAS showers directly
- dependent on shower physics models



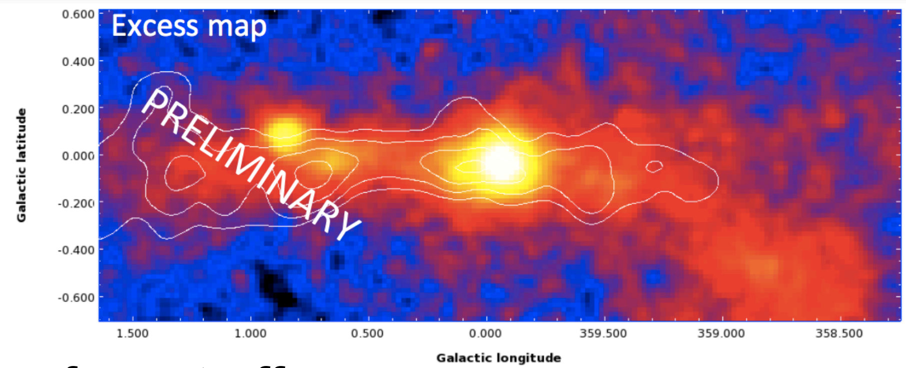




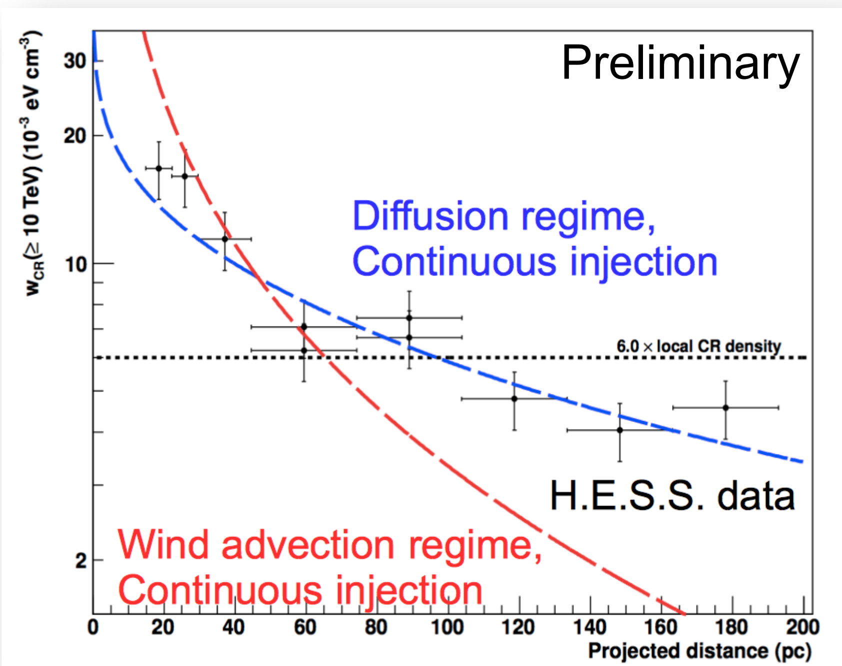
> Indirectly by studying γ-ray sources

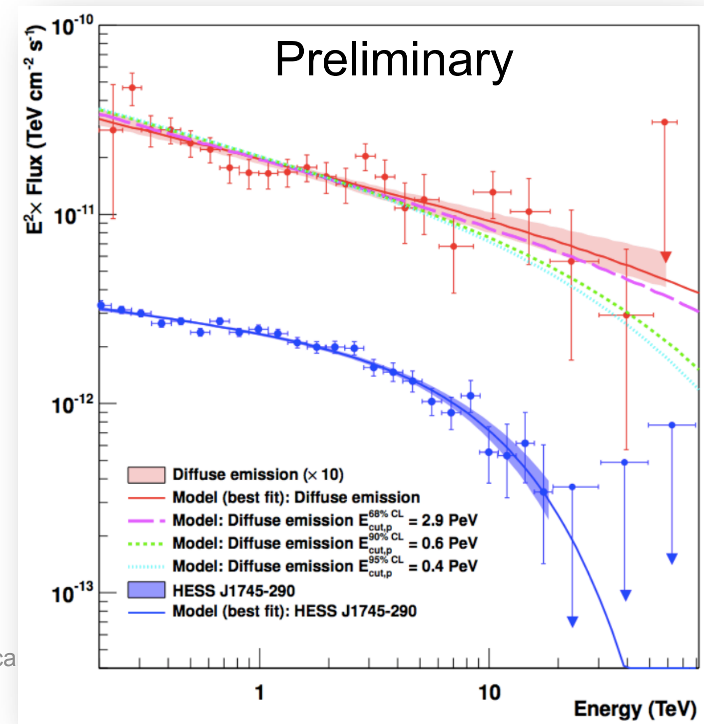
- infer CR properties from γ-ray spectrum (100 TeV γ rays trace 1 PeV CRs)
- from individual sources and populations
- need extra multiwavelength information

Galactic Centre with H.E.S.S.



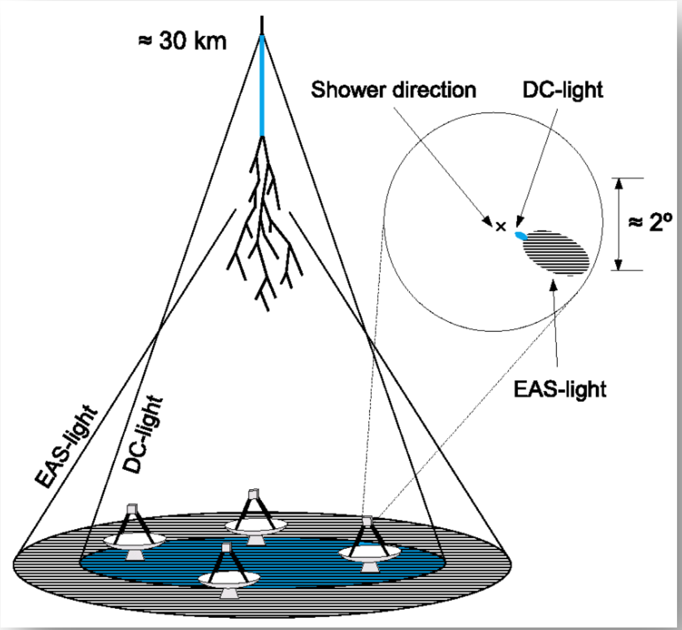
- central source cuts off @ ~10 TeV
- diffuse emission doesn't show indication for cut off
- emission likely due to propagation of protons accelerated in the central source and diffusing away (projected radial distribution matches)
- Parent proton population up to ~1 PeV (2.9 PeV @ 68% CL)

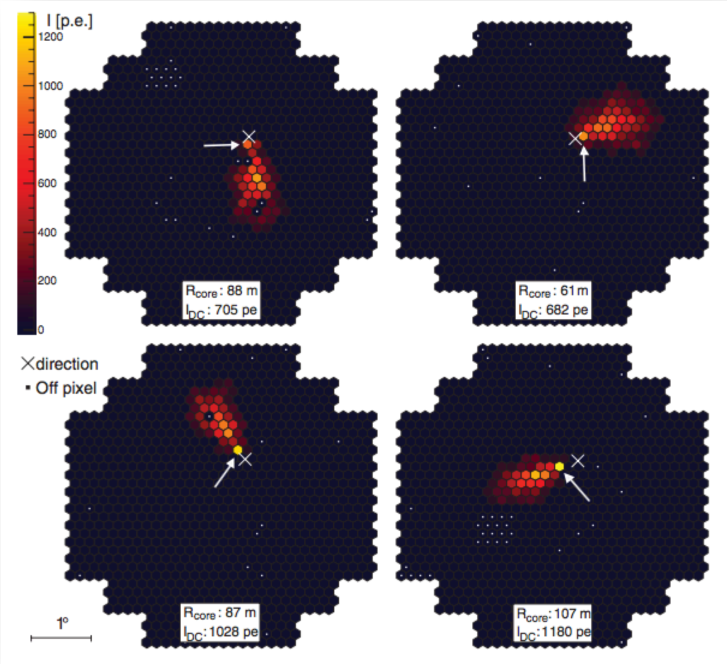


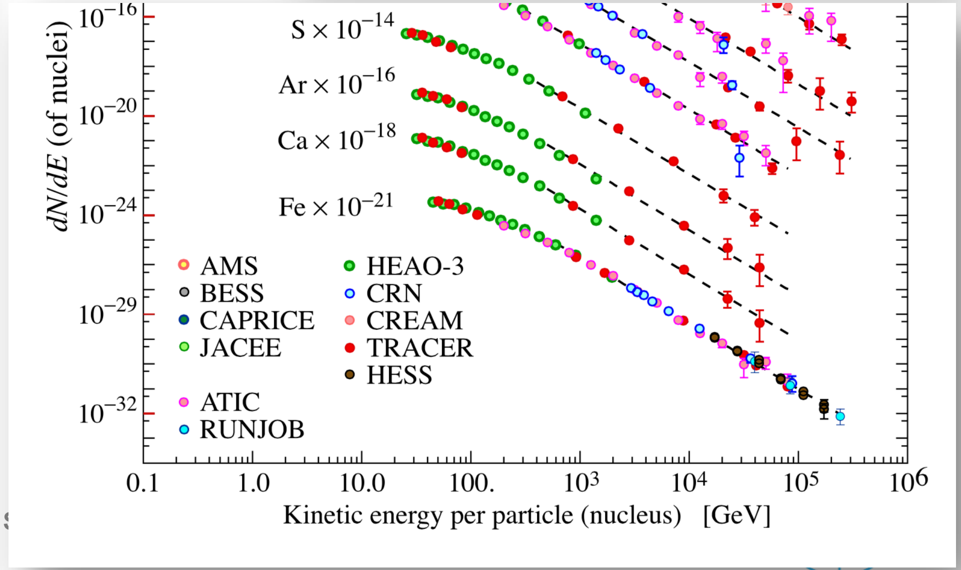


Direct Cherenkov light

- see also Henrike's presentation
  - Nuclei emit DC light and imaged closer to the shower direction in the camera
  - Intensity ∝ $Z^2 \cdot \sin^2(\theta_c)$
  - 10 – 500 TeV range
  - Particle energy from extensive air shower light
  - Charge from DC light



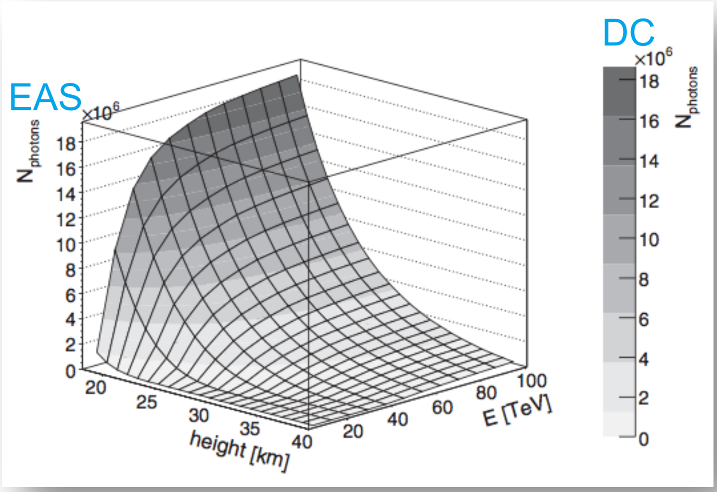




Direct Cherenkov light

Limitations

- minimum energy above which Cherenkov light is emitted → ~10 TeV for iron
- maximum energy below which DC light is still identifiable → DC is ~independent of *E*, EAS increases ~linearly with *E*
- shower interaction model → absolute energy scale
- atmosphere model → light distribution in camera
- reconstruction of shower properties → energy resolution, total number of identified events in images
- identification of proton/helium 'background'

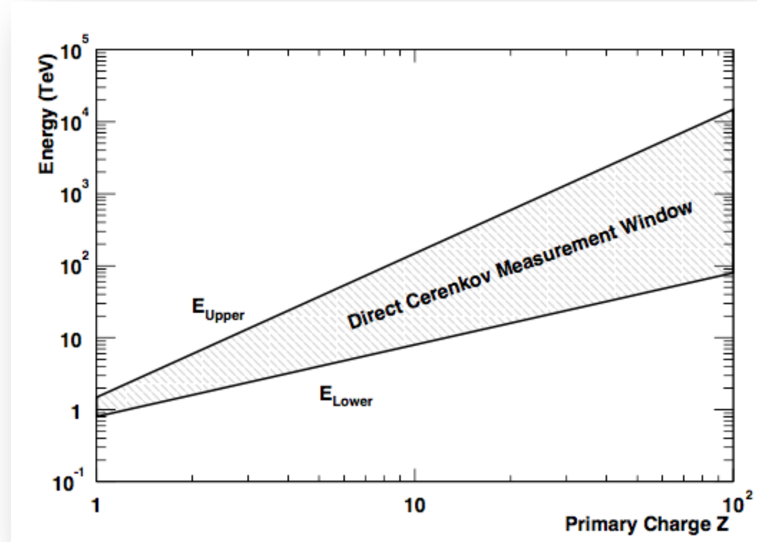


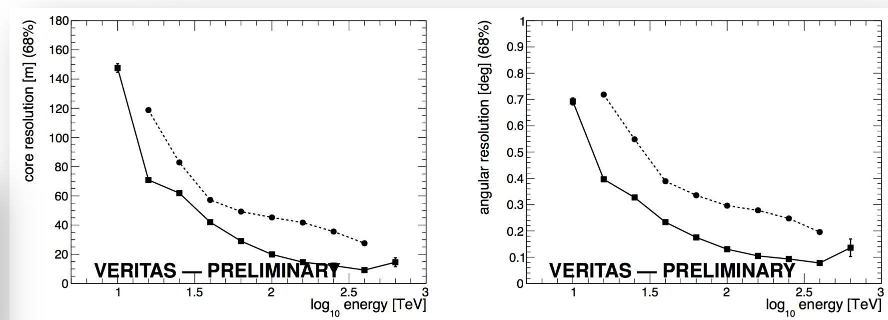
Direct Cherenkov light

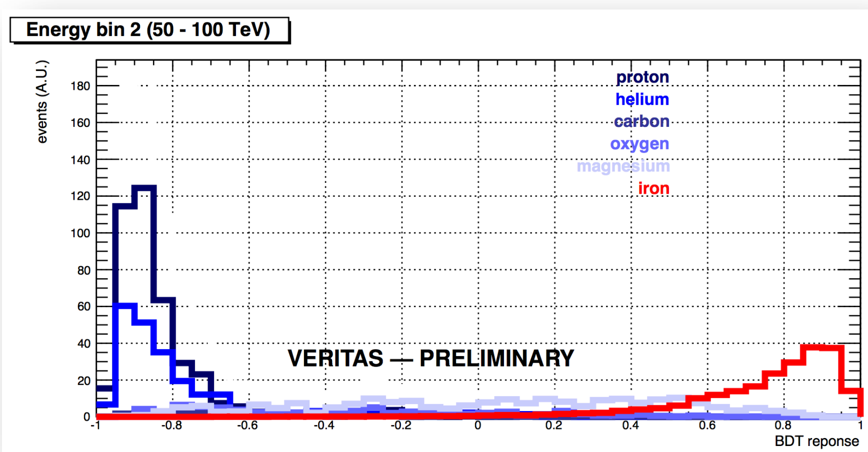
> Limitations

- minimum energy above which Cherenkov light is emitted → nothing we can do about
- maximum energy below which DC light is still identifiable → maybe with CTA, see next slide
- shower interaction model → e.g. LHC, theory
- atmosphere model → monitoring of IACTs
- reconstruction of shower properties → Henrikes talk
- identification of proton/helium ‘background’

→ Henrikes talk (multivariate analyses)

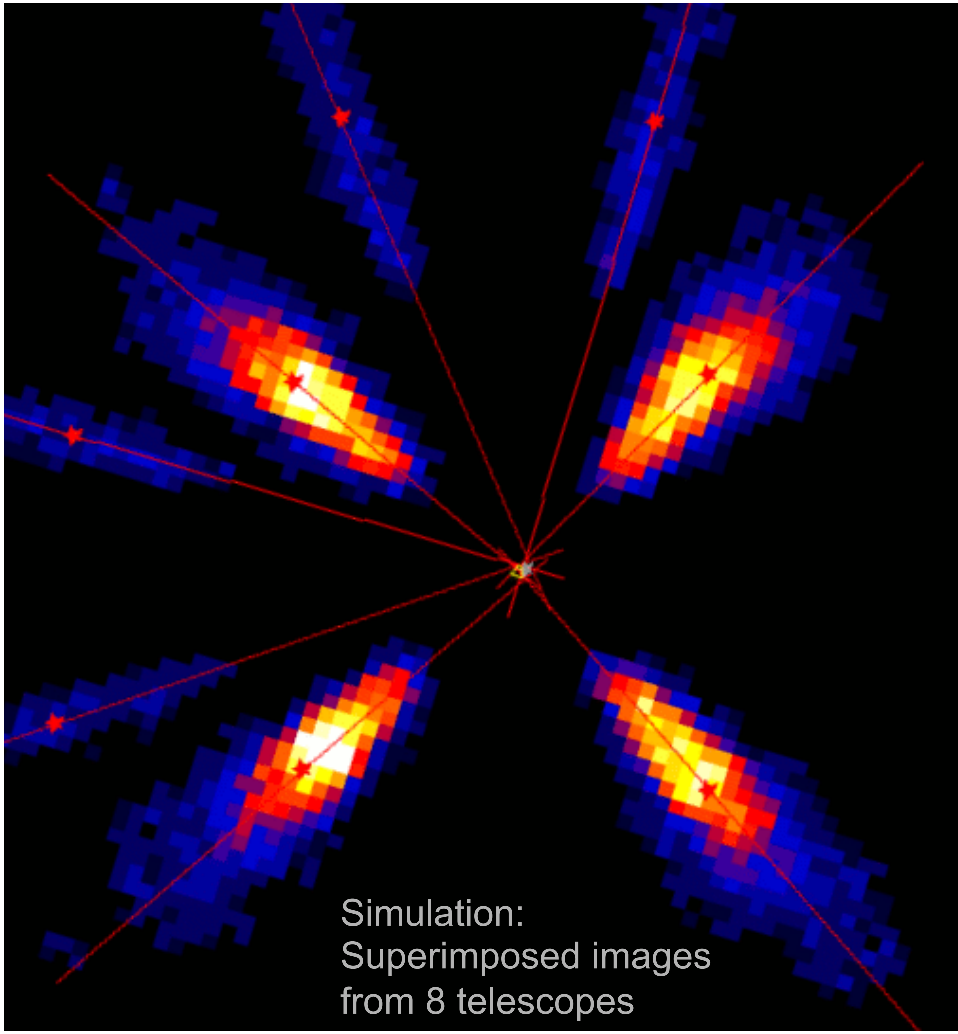






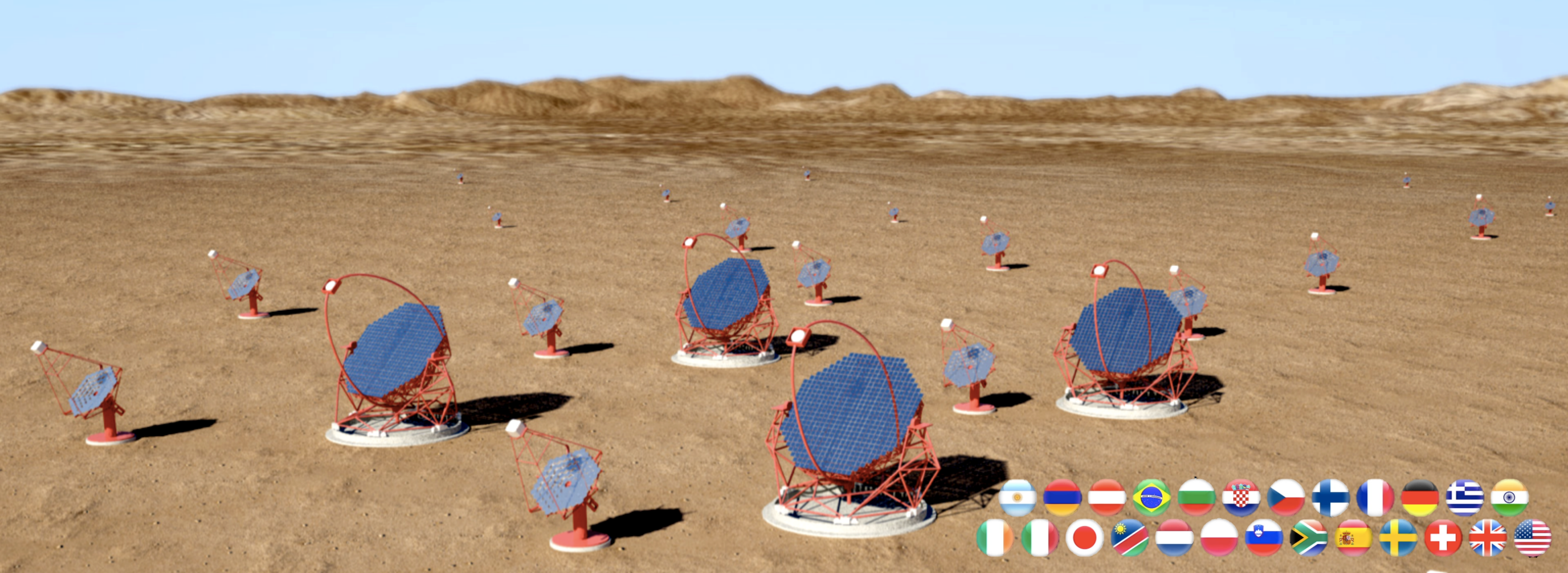
How to do better with IACTs?

- More events
  - More photons = better spectra, images, fainter sources
  - → Larger collection area for γ rays
- Better events
  - More precise measurements of atmospheric cascades and hence primary γ rays and nuclei
  - → Improved angular resolution
  - → Improved background rejection power
- More telescopes!



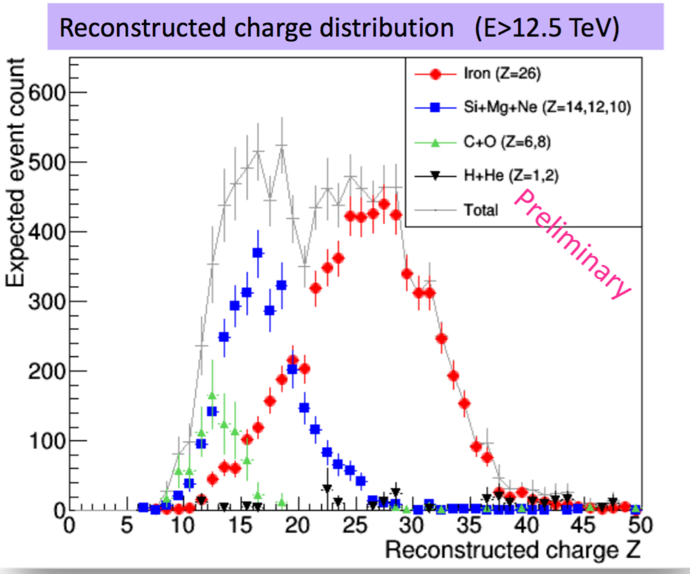
The Cherenkov Telescope array

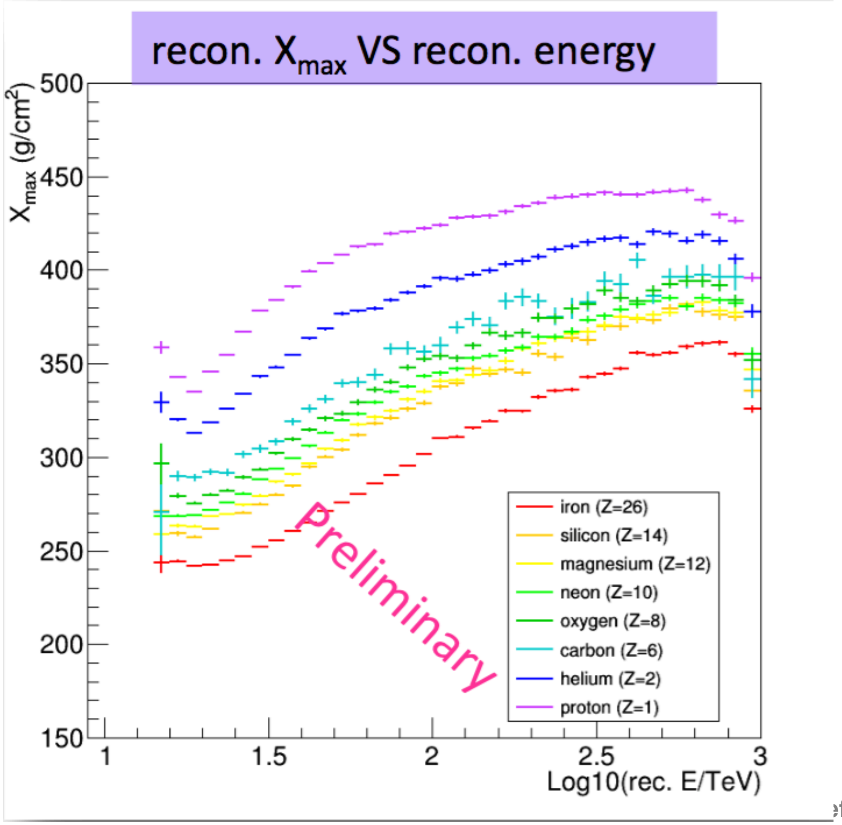
- A huge improvement in all aspects of performance
  - A factor ~10 in sensitivity, much wider energy coverage, much better resolution, field-of-view, full sky
- A user facility / proposal-driven observatory
  - With two sites with a total of >100 telescopes
- A 32 nation ~€300M project
- Non-γ-ray physics is part of key science program



Prospects for CTA – DC light

- Simulations (Michiho Ohishi, et al., ICRR Tokyo)
  - 50-hour observation
  - DC light study for H, He, C, O, Ne, Mg, Si, Fe

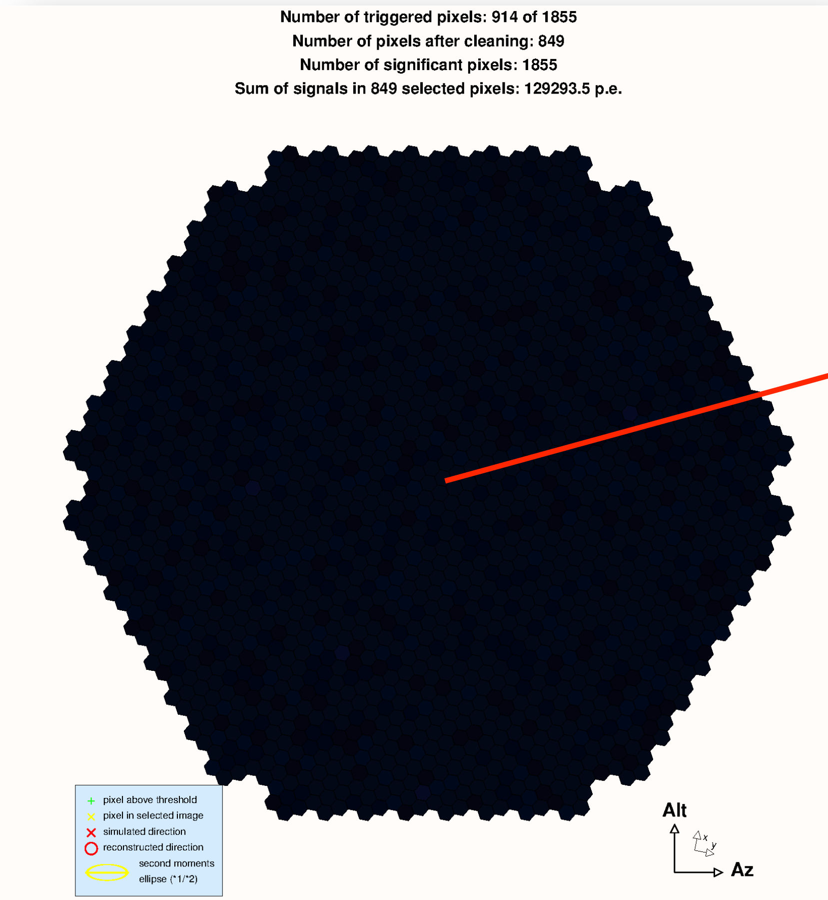




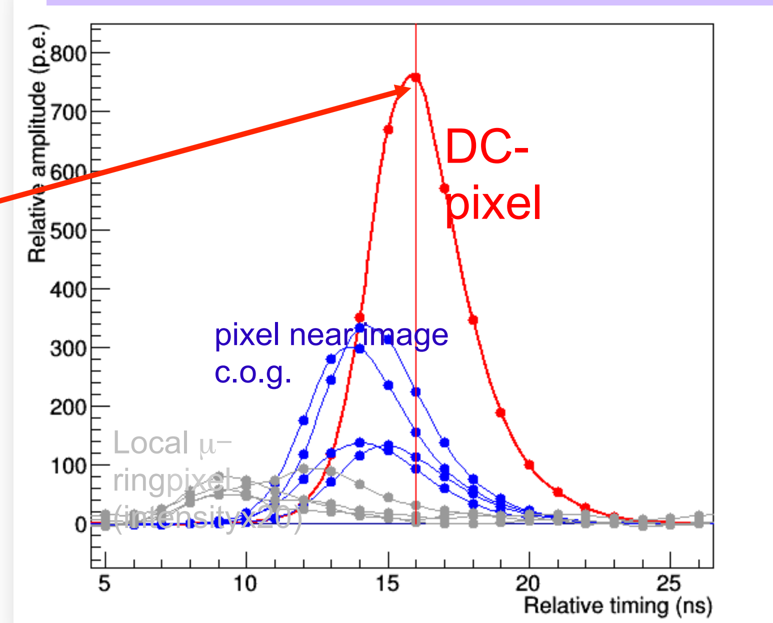
- Shower maximum
  - collision cross section ∝ $\sim A^{2/3}$
  - could use this relation, but again depends on shower model
  - spread is actually larger than error bars shown

Prospects for CTA – DC light

- Timing
  - arrival time of DC light delayed to EAS light
  - CTA cameras will provide timing info
  - could reach up to 1 PeV energies (currently 200 TeV)



PMT signal profile of each component (LST case)



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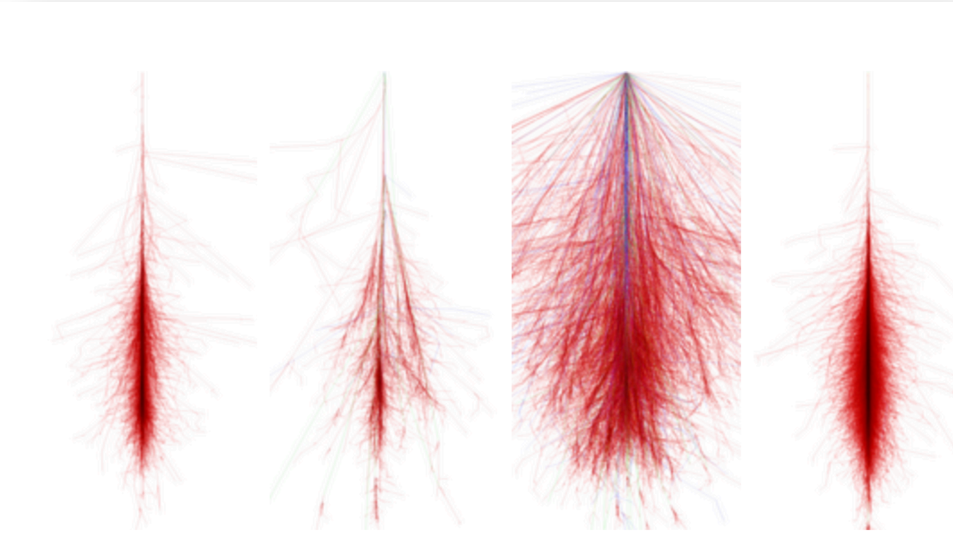
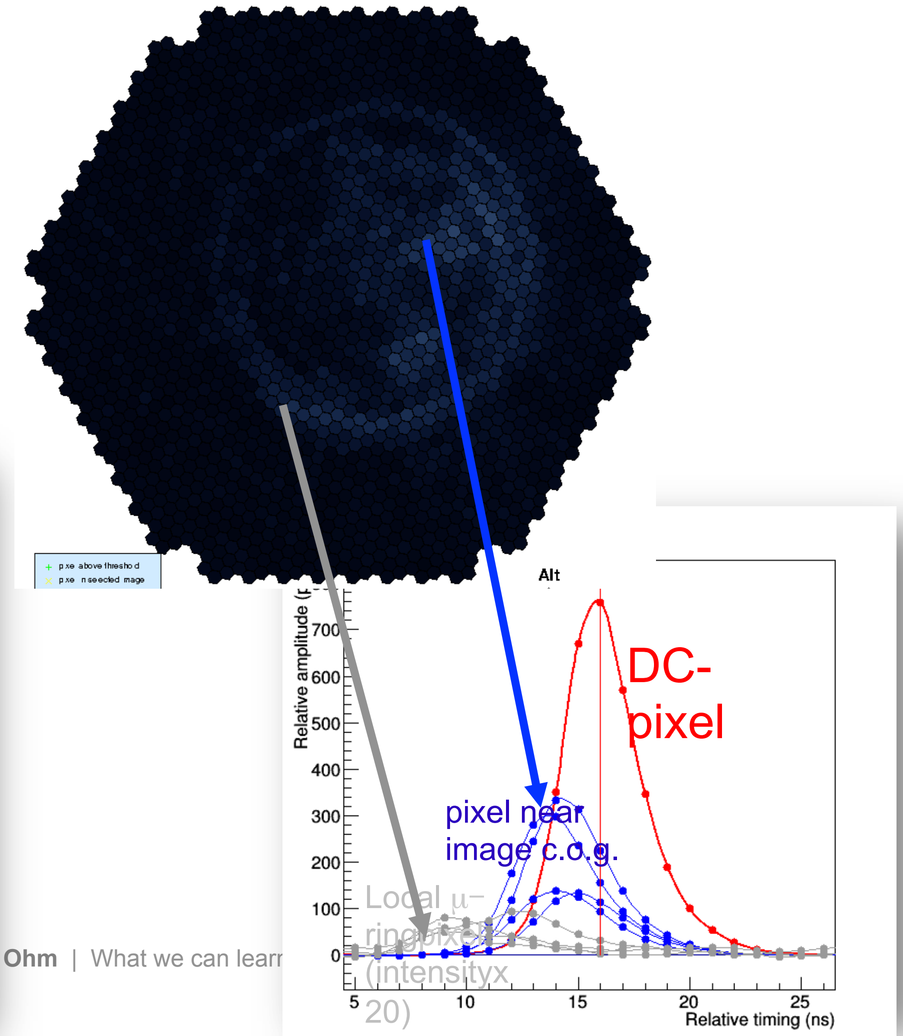
Prospects for CTA – hadron showers

- DC light is a good way but has its limitations
- EAS itself carries plenty of information (especially if seen with many IACTs)
- Probe interaction models
  - compare rates
  - compare shower shapes
  - compare muon content

  → more or less unexplored territory



Photon shower   Proton shower   Iron shower   Muon shower

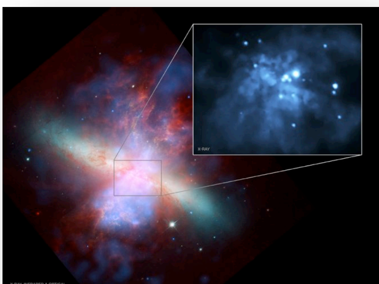
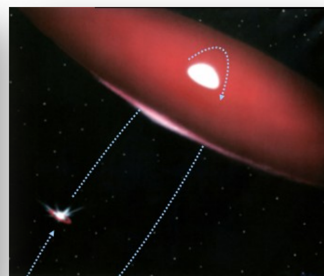
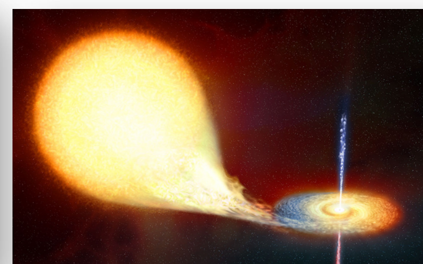


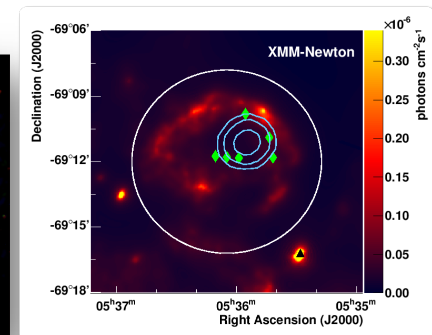
Prospects for CTA – γ-ray sources

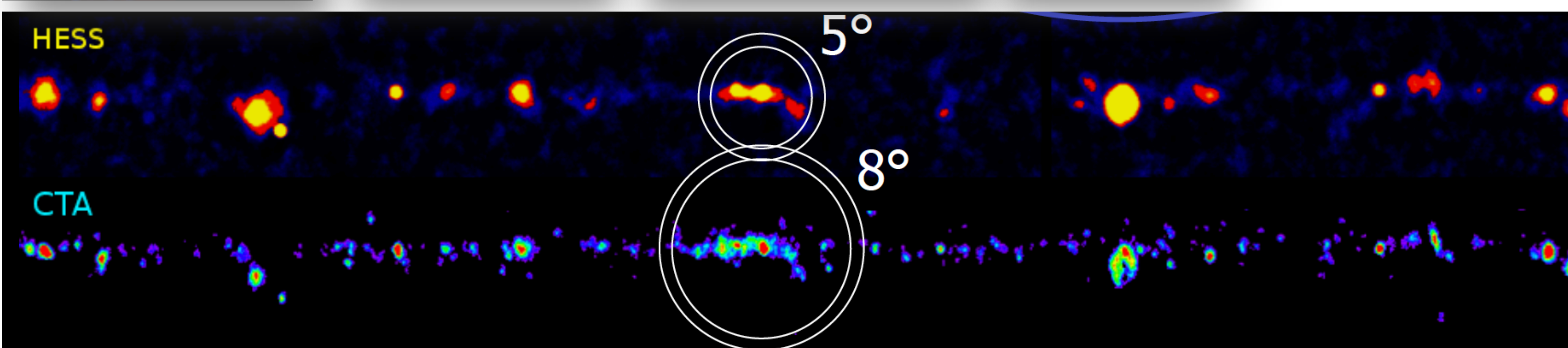
1. Identify cosmic particle accelerators (see Martin Pohls talk tomorrow)
2. Identify hadron accelerators
3. measure composition?

Prospects for CTA – γ-ray sources

1. Identify cosmic particle accelerators (see Martin Pohls talk tomorrow)
   - is straightforward (~100 Galactic sources detected so far)
   - many different source types (now including stellar clusters and superbubbles)
   - will see many more with CTA
   - but what is the underlying emission mechanism?

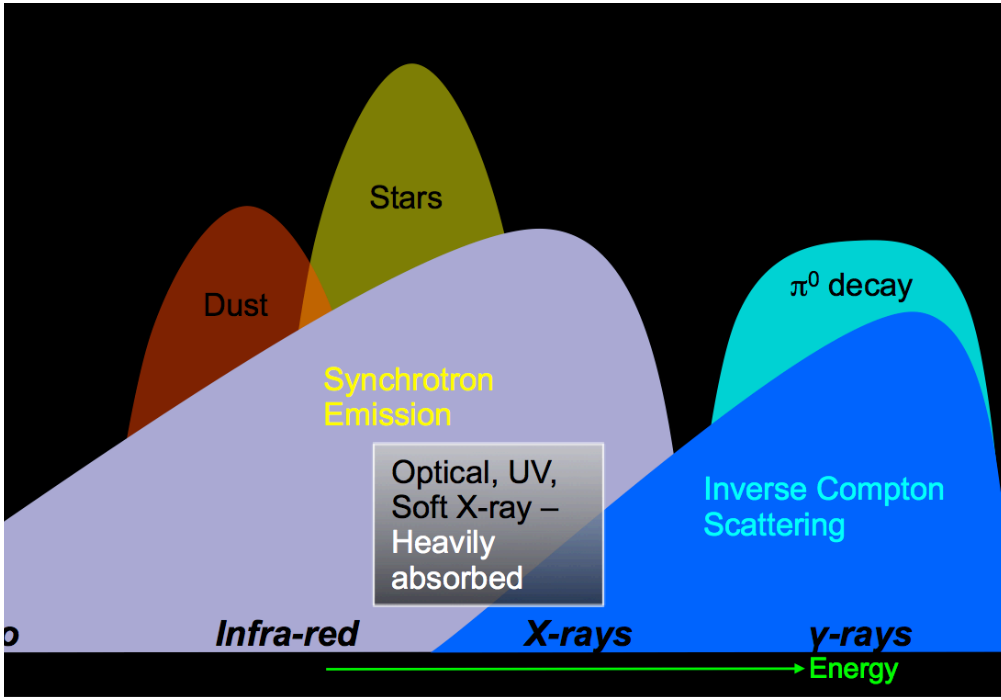




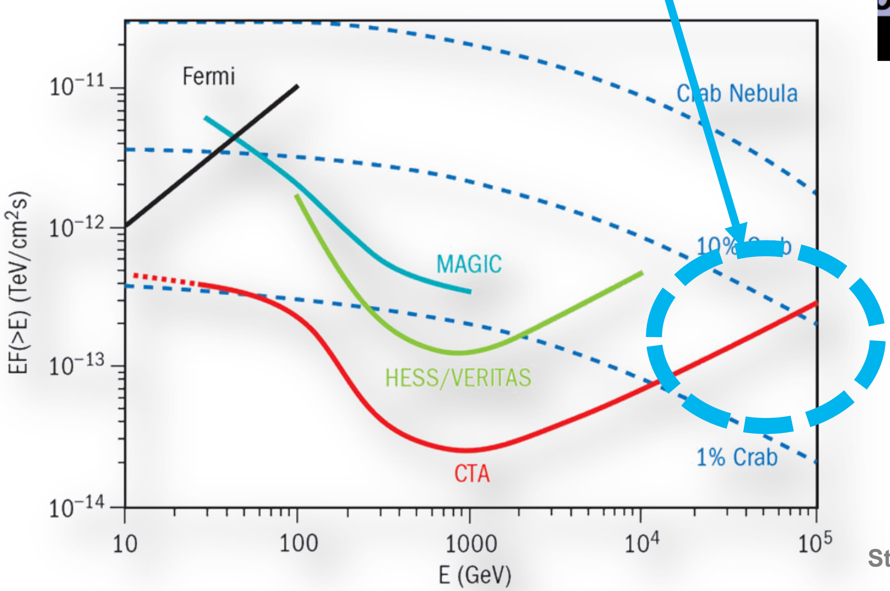




Prospects for CTA – γ-ray sources

2. Identify hadron accelerators
   - only at >50 TeV energies unambiguously possible
   - only one object known to emit at these energies
   - CTA will improve at high energies





- CTA should find a handful of young SNRs emitting at ~100 TeV
- other sources (e.g. stellar clusters?)
- how to measure their composition?

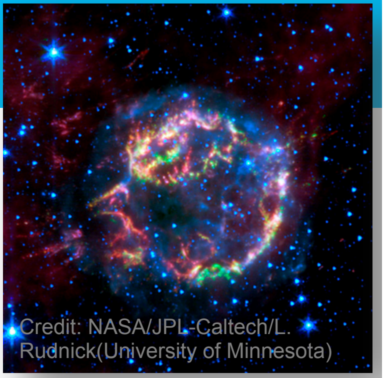
Prospects for CTA – γ-ray sources

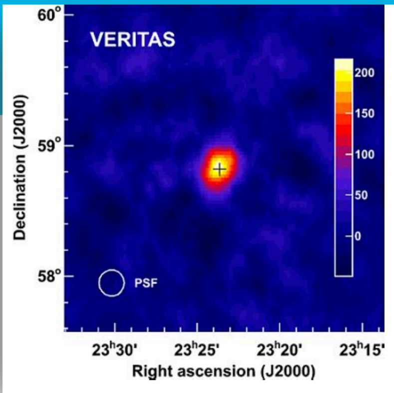
3. measure composition?
   - not clear how with γ rays alone, maybe E_{max}
   - additional input needed

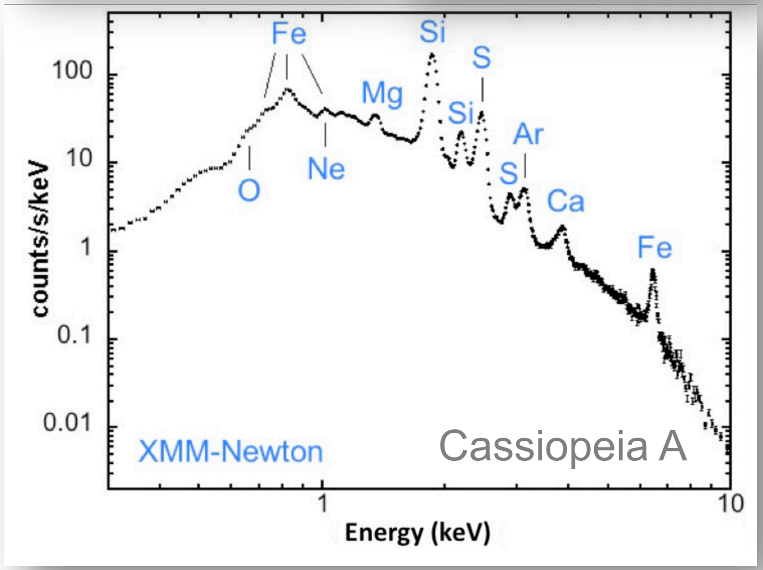
> radio
   - localize acceleration sites
   - provides input to emission modeling

> mm/sub-mm, infrared
   - Environment in which particles are accelerated
   - Ionisation studies from mainly low-energy CRs (but no composition and/or high energies)

> Future optical facilities
   - maybe probe faint line emission from non-radiative shocks → probe injection region?







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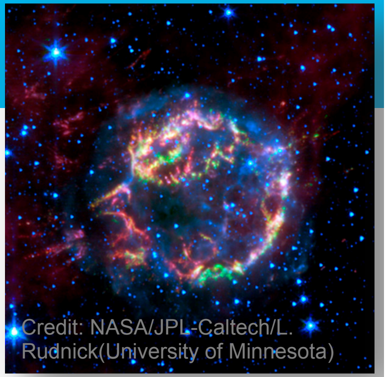
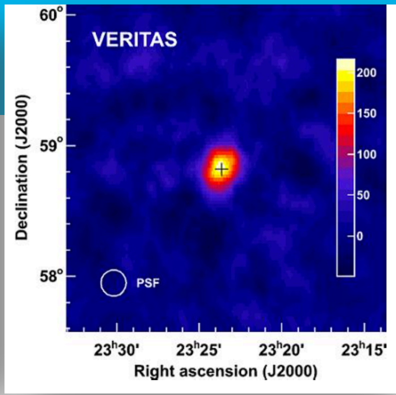
Prospects for CTA – γ-ray sources

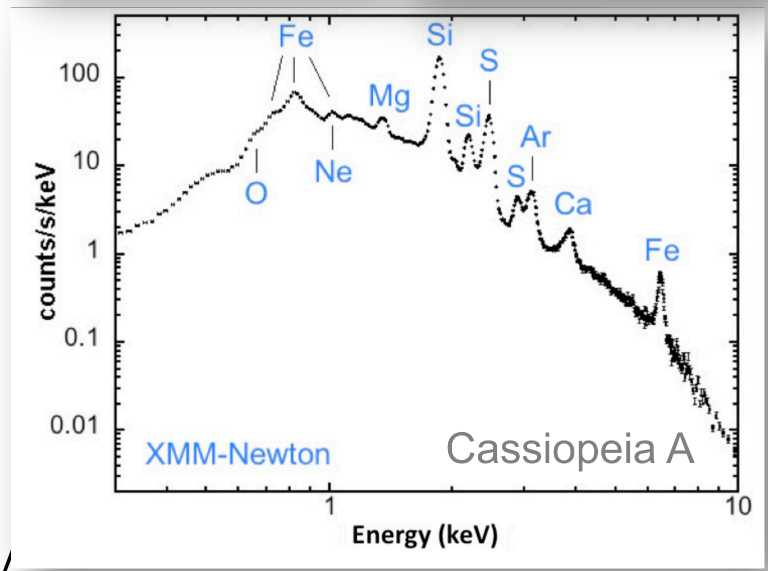




3. measure composition?
   - not clear how with γ rays alone, maybe E_{max}
   - additional input needed

> X-rays
   - spectroscopy to measure composition near accelerators

> Neutrinos
   - point back to their acceleration site
   - unambiguous probe of hadron accelerators
   - Galactic IceCube neutrinos between 0.1 – 1.0 PeV
   - diffuse neutrinos likely beyond reach of CTA



Summary

- Current experiments
  - mainly explored DC light up to ~150 TeV with limited charge resolution
  - indication of the first 'PeVatron' in Galactic Centre
  - large data sets sitting on disk and not fully explored yet

- CTA
  - DC light studies offer potential to probe other elemental groups and reach higher energies
  - CTA will probe entire galaxy → population studies, very high-energy emission from sources other than SNRs
  - Potential to probe interaction models with shower images (e.g. shape, muon content)
  - Multi-wavelength and multi-messenger approach very important

→ Galactic high-energy neutrinos? Counterpart(s) in γ rays?

→ Need to study CRs at their accelerators and at Earth