Investigation of a Candidate for Cosmic Ray Acceleration

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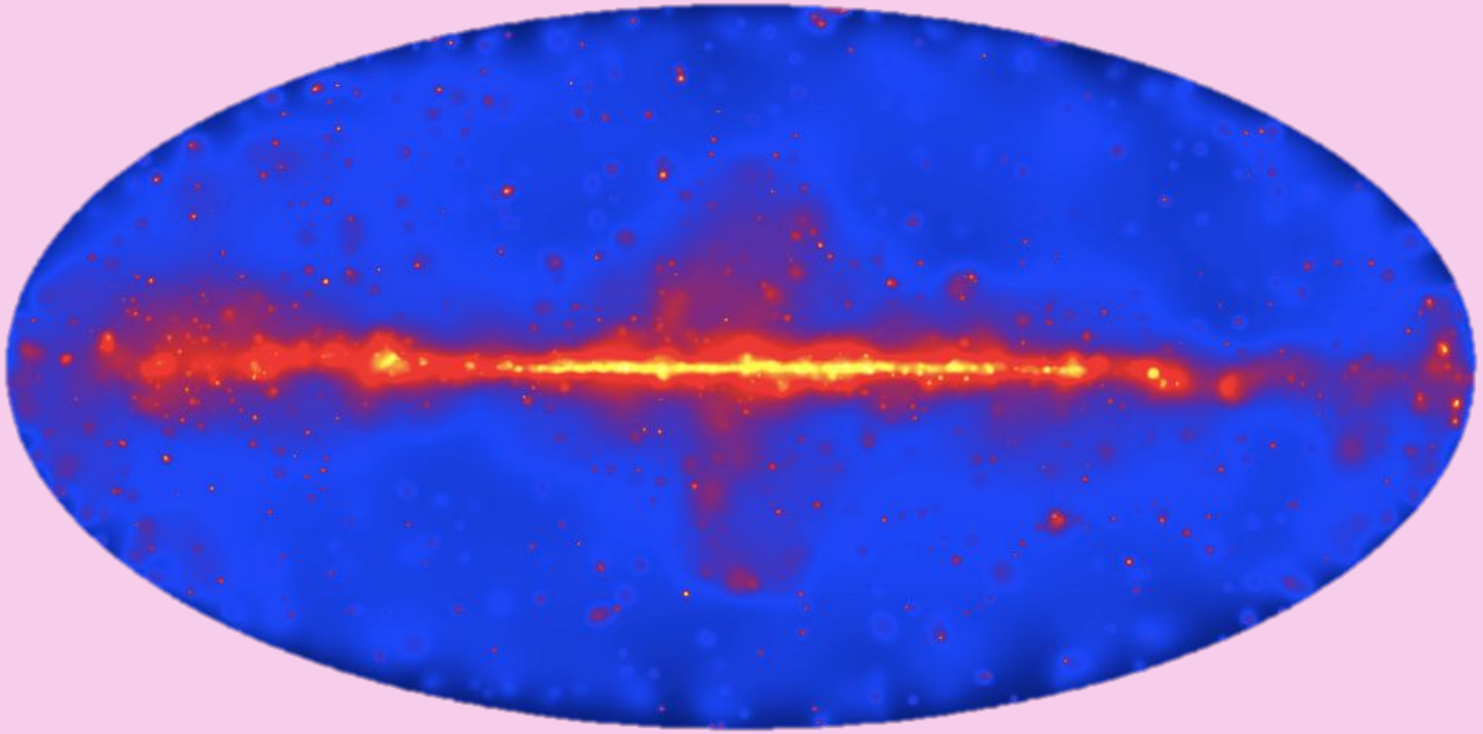
Introduction

Objective

Characterizing a sample of VHE Galactic objects (VHE, E>50GeV) reported in 2016 2FHL catalog to:

- Investigate VHE Galactic objects across EM spectrum & build sample based on multi-wavelength properties
- Understand CR acceleration in the Galaxy



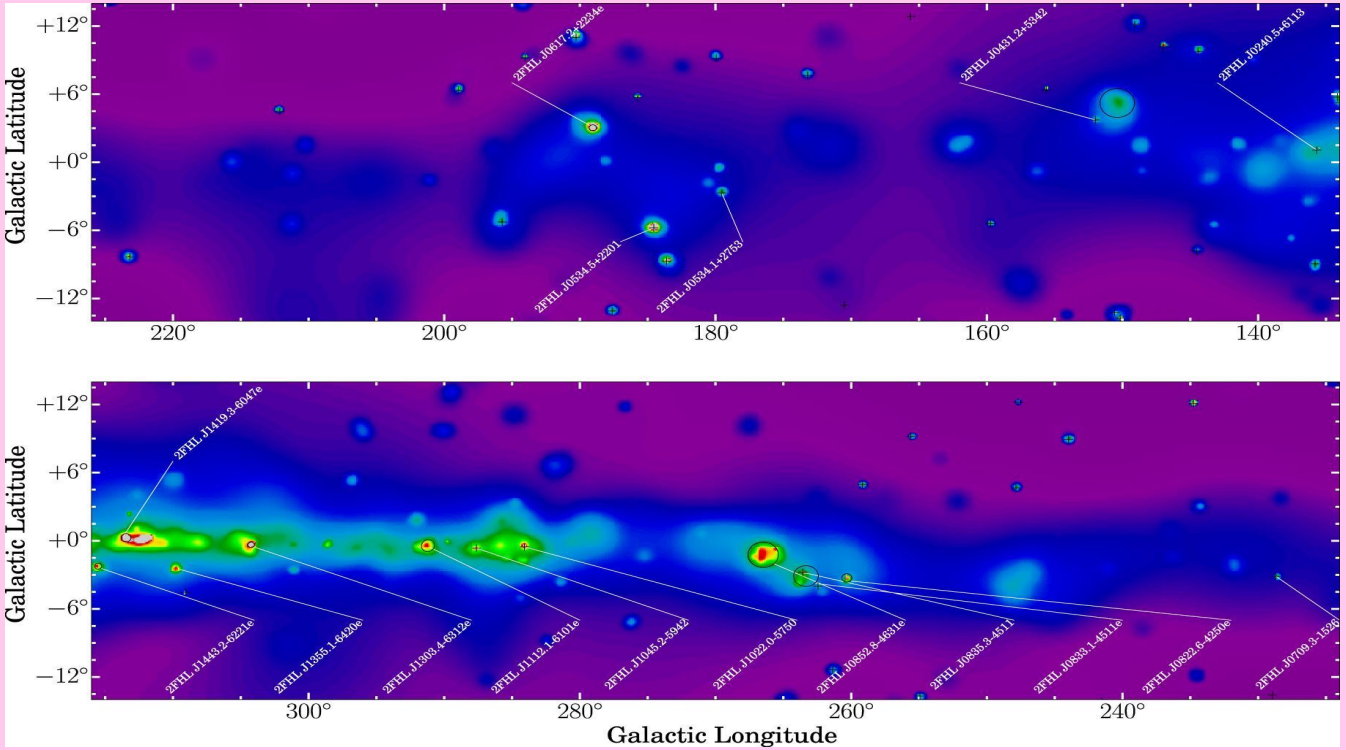
Entire *Fermi* sky from 50GeV-2TeV (Ackermann et al, 2016).

2FHL catalog

- Reported in 2016 (Ackermann et al. 2016)
  - First catalog after Pass 8 event level analysis reconstruction that enabled *Fermi* to probe at energies >50GeV
- Contains ~360 sources detected at energies >50GeV
- Reminder: We want a sample of Galactic objects

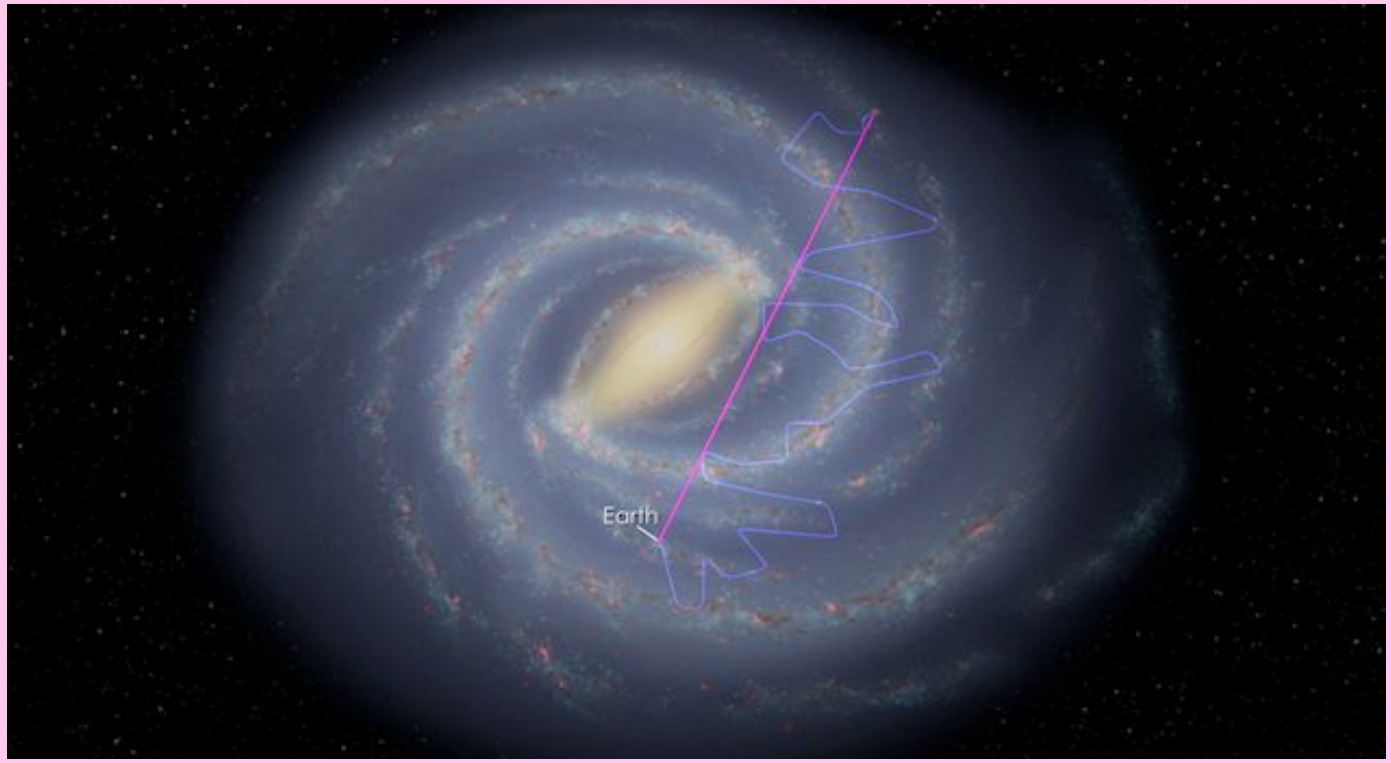
  Criteria 1) Object must be within $|b| < 10°$ from Galactic plane

  Criteria 2) Object must have a γ-ray photon index less than 1.8, $\Gamma_\gamma < 1.8$
- Leaves us with 12 newly detected unidentified sources to identify and characterize
  - Likelihood of extragalactic object in sample: <1



Part of the *Fermi* sky from 50GeV-2TeV with all known 2FHL sources indicated (Ackermann et al, 2016).

PWNe & SNRs: Galactic Accelerators



Cosmic rays (CRs) are charged particles that travel close to the speed of light and are believed to be accelerated in SNR and PWNe.

- Pulsar wind nebulae (PWNe) and supernova remnants (SNRs): these are some of the most powerful sources in our Galaxy
- Thought to generate bulk of Galactic cosmic rays
- Typically emit in the hard γ-ray regime

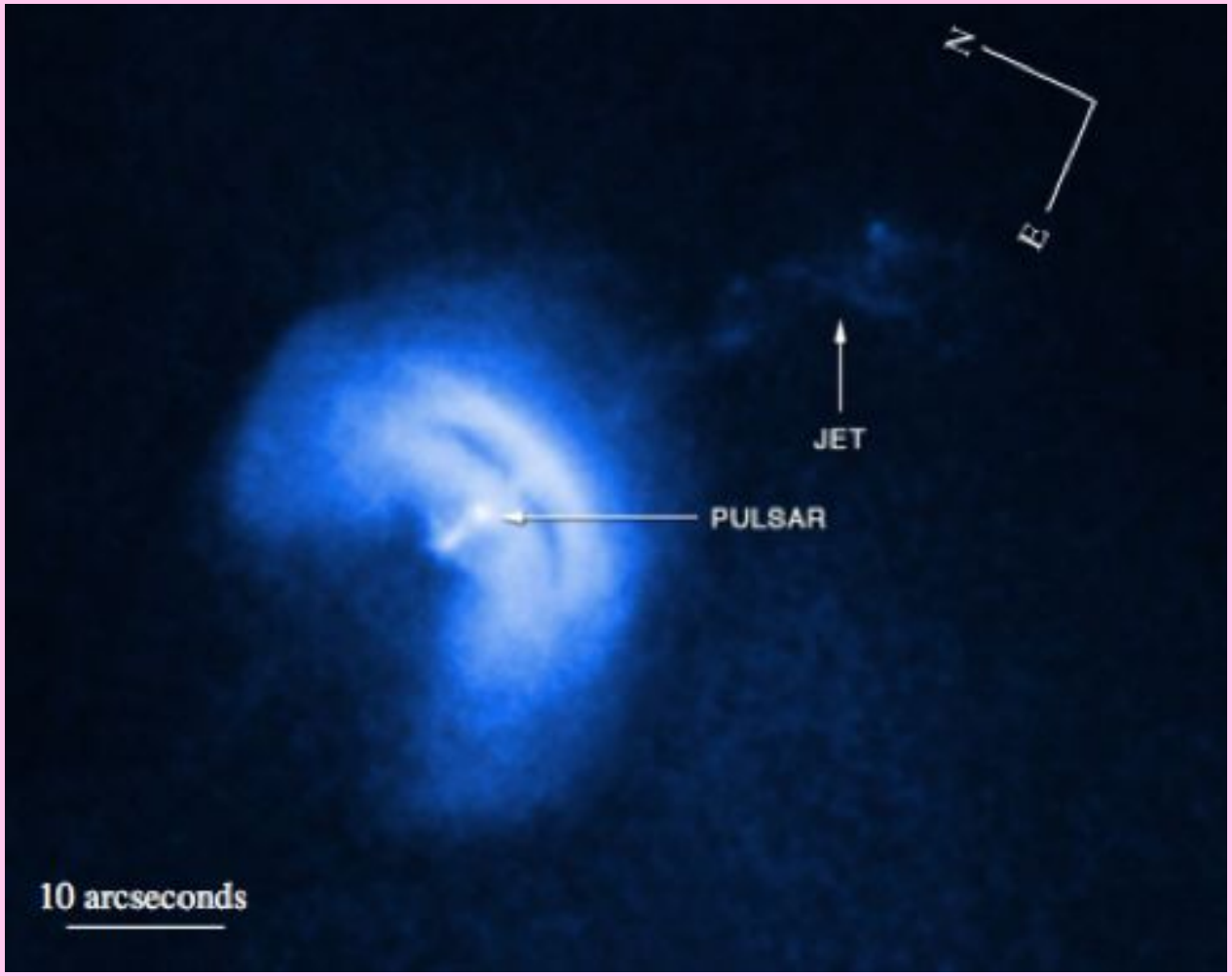
Galactic accelerators responsible for CR production may fall into one of these categories.

Vela Supernova Remnant

Optical image of the entire Vela SNR. Red box indicates pulsar position. (adapted from http://chandra.si.edu/photo/2013/vela/)

- Closest composite SNR to Earth (~290pc)
- Resulting from Type II SN ~10,000 years ago

Vela Supernova Remnant



Chandra image of the Vela pulsar and its helical jet caused by the pulsar's precession. (adapted from http://chandra.si.edu/photo/2013/vela/)

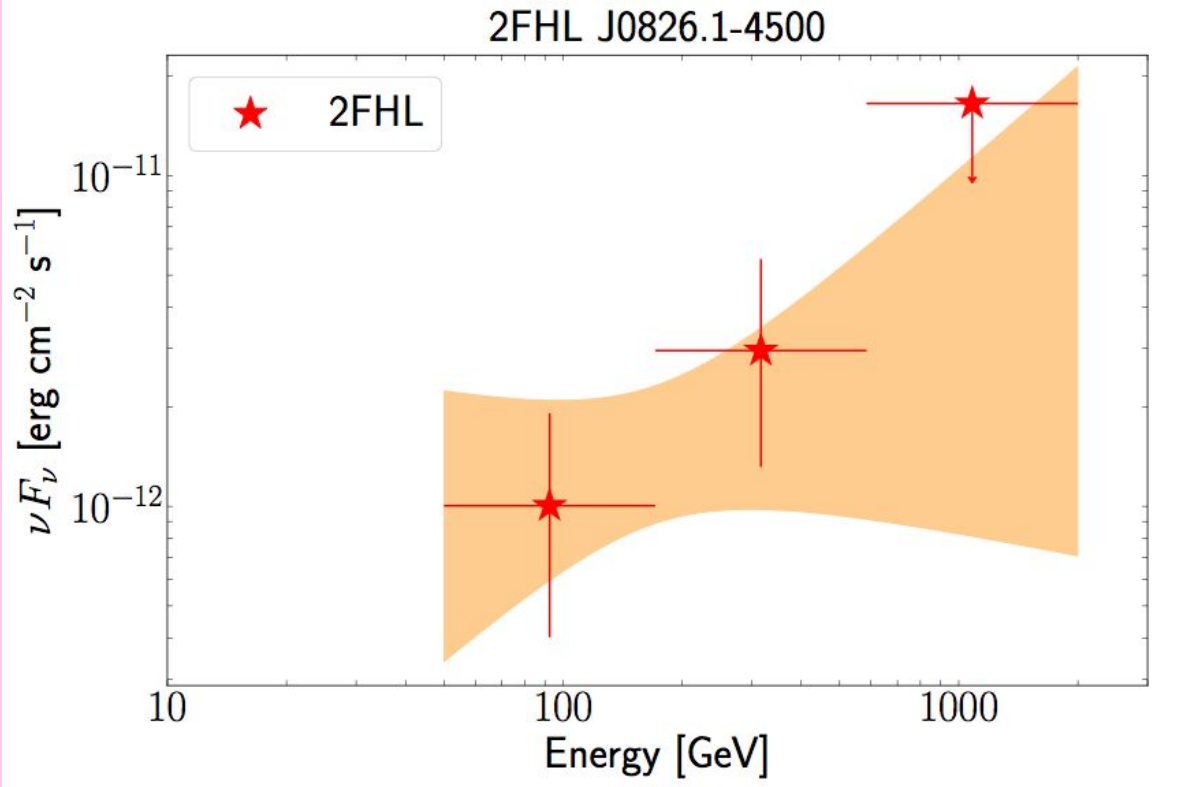
- Closest composite SNR to Earth (~290pc)
- Resulting from Type II SN ~10,000 years ago
- Vela pulsar sits at the central region of SNR fueling an active PWN known as Vela-X
- Asymmetric in appearance:
  - Pulsar and PWN displacement: pulsar proper motion & inhomogeneities in surrounding medium

2FHL J0826.1-4500

2FHL J0826.1-4500: First glimpse

***γ**-rays:*

- First source studied in detail (Eagle et al. 2019)
  - First detected with *Fermi* at E>50GeV

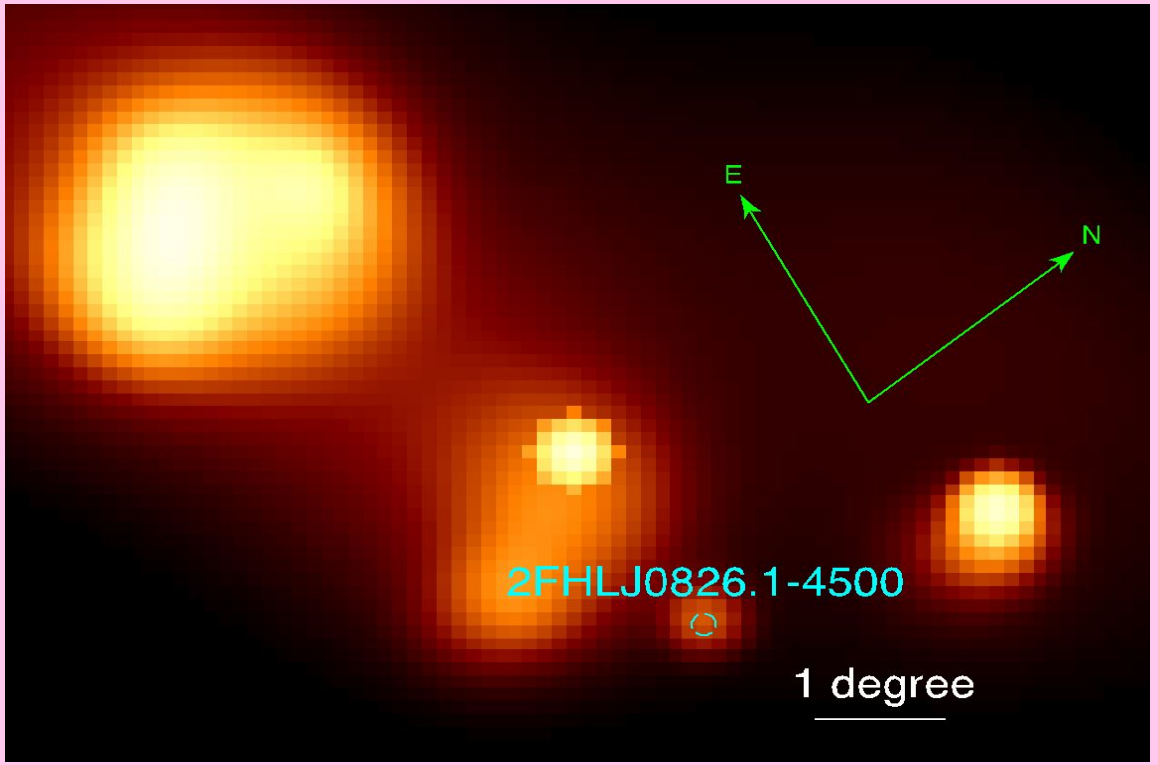


Gamma-ray spectrum from 2FHL catalog. Source not detected below 50GeV.

2FHL J0826.1-4500: First glimpse

γ-rays:

- First source studied in detail (Eagle et al, 2019)
  - First detected with *Fermi* at E>50GeV
  - In the gamma-ray: shows no evidence of extended emission; no structure/shape is apparent

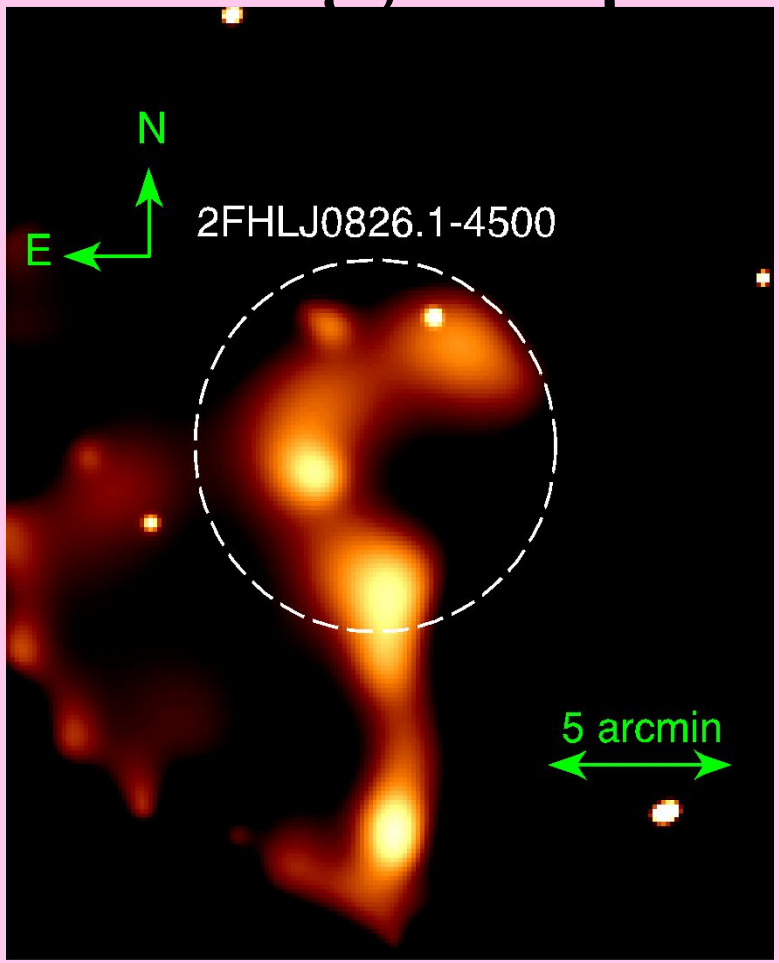


Close up view of 2FHL region that lies within the Vela complex seen here.

2FHL J0826.1-4500: Second glimpse

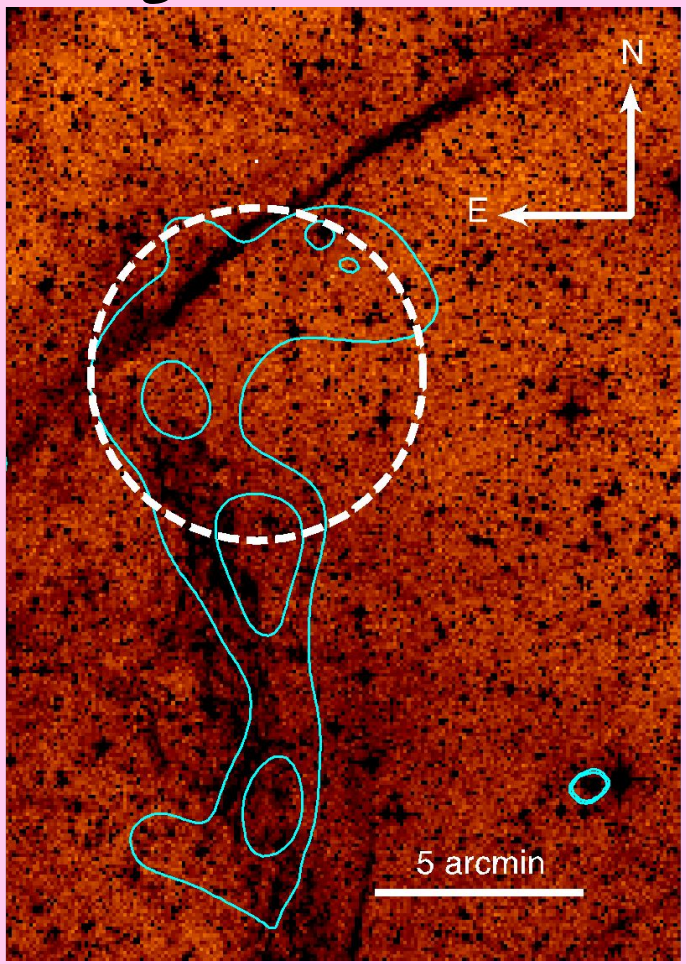
X-rays:

- Followed up in the soft X-rays (0.5-2keV) with XMM-*Newton*
  - Soft, diffuse, and faint X-ray emission present!
  - Thermal in origin



Smoothed, MOS2 0.5–2keV image of the region around 2FHL J0826.1−4500.

2FHL J0826.1-4500: Across the spectrum

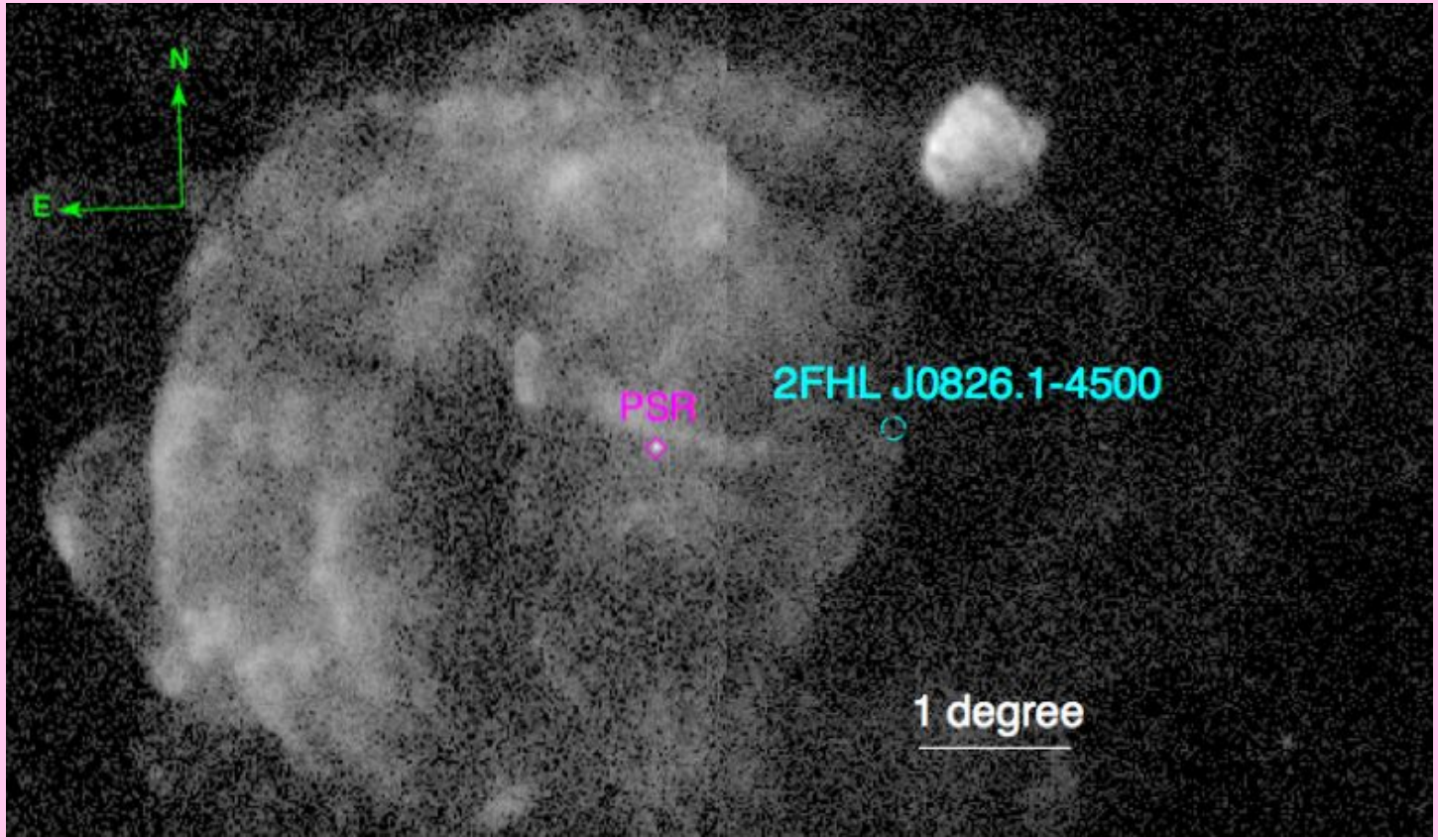


X-ray emission contours overlaid on an H-**α** image of the region of 2FHL J0826.1-4500. The contours are derived from the MOS2 0.5-2keV image and correspond to 1.22×10^{-2} and 1.5×10^{-2} counts.

1. First detected with *Fermi* above 50GeV
2. Peculiar emission observed in soft X-rays from shocked gas (0.5-2keV) with XMM-*Newton*
   - Searched for available data across the electromagnetic spectrum

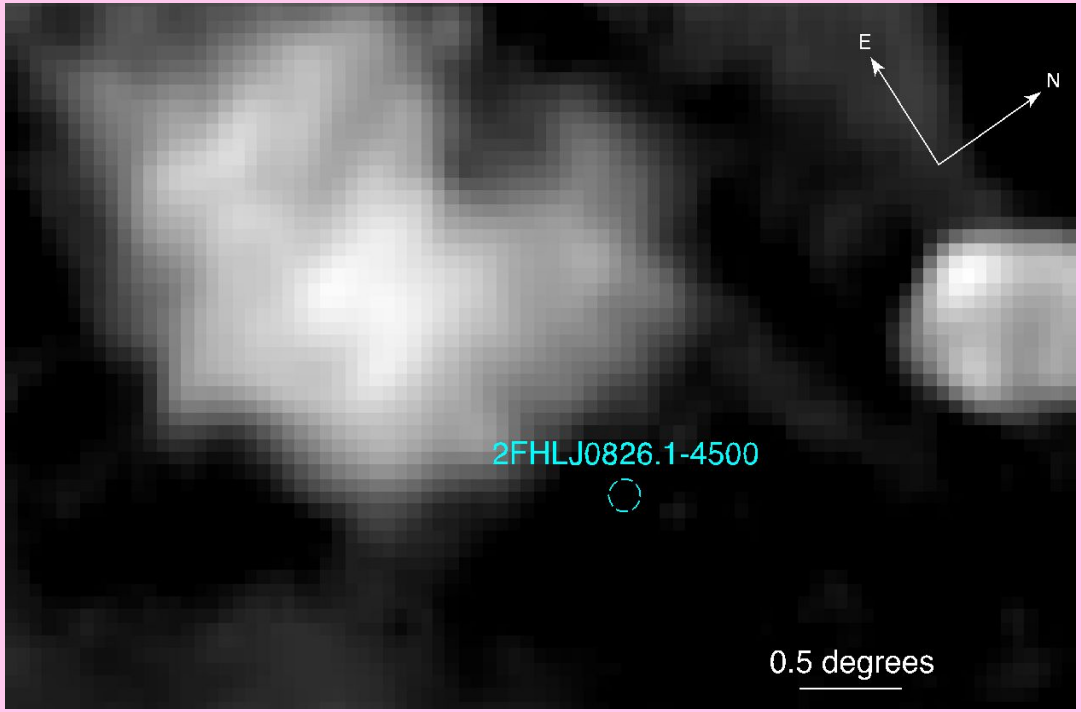
2FHL J0826.1-4500: Across the spectrum

1. First detected with *Fermi* above 50GeV
2. Peculiar emission observed in soft X-rays from shocked gas (0.5-2keV) with XMM-*Newton*
3. Optical filament seen to be spatially and morphologically coincident with X-ray emission
4. ROSAT image shows 2FHL J0826.1-4500 lies on a bright X-ray boundary



ROSAT X-ray image in the 0.5-2.4keV range of the entire Vela SNR.

2FHL J0826.1-4500: Across the spectrum

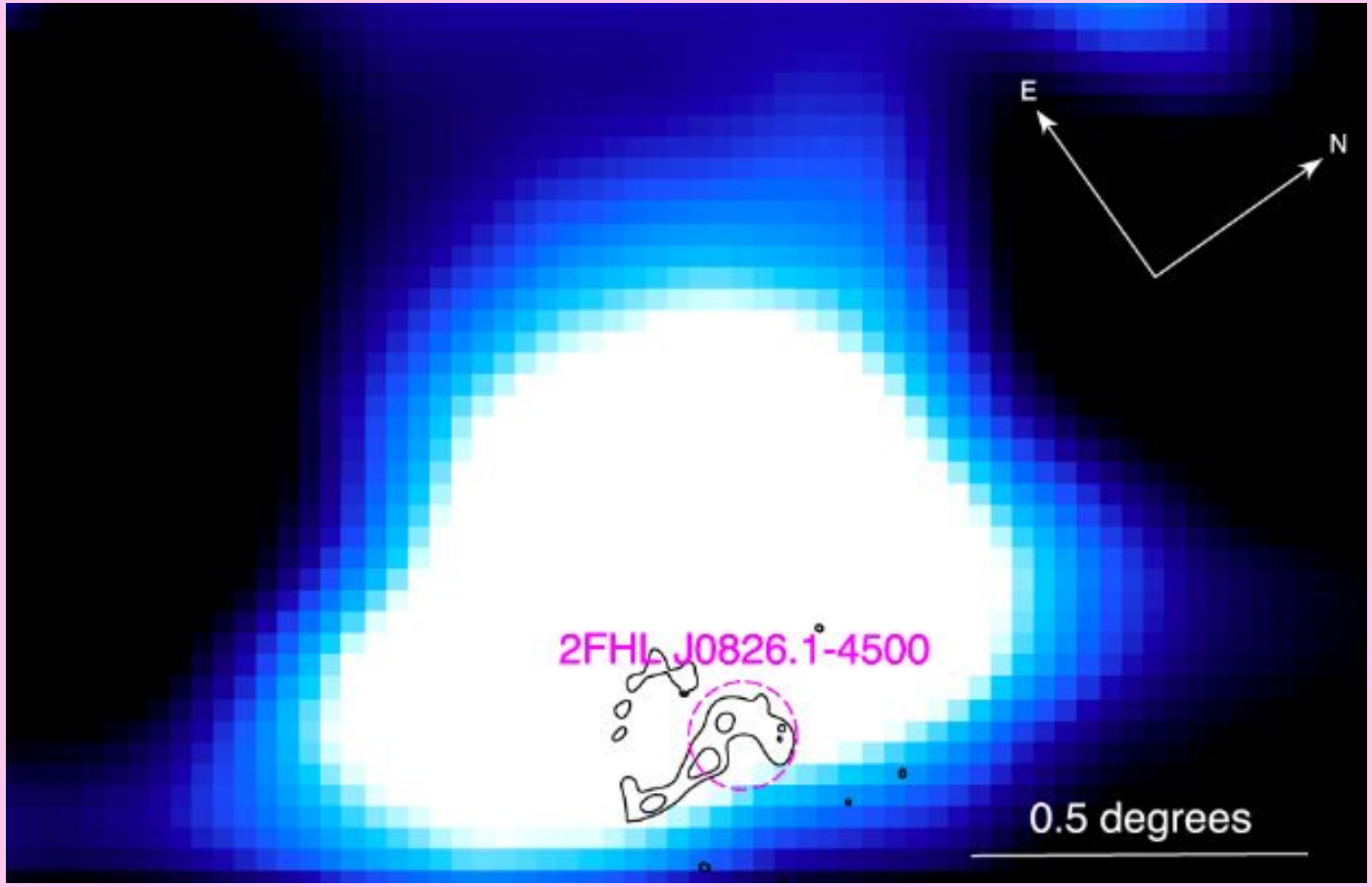


2.4GHz data from the Parkes 64-m radio telescope (Duncan et al 1996).

1. First detected with *Fermi* above 50GeV
2. Peculiar emission observed in soft X-rays from shocked gas (0.5-2keV) with XMM-*Newton*
3. Optical filament spatially and morphologically coincident with X-ray emission
4. ROSAT image shows 2FHL J0826.1-4500 lies on a bright X-ray boundary
5. Found this source lies in cavity of radio emission at 2.4GHz

2FHL J0826.1-4500: Shock-Cloud Interaction

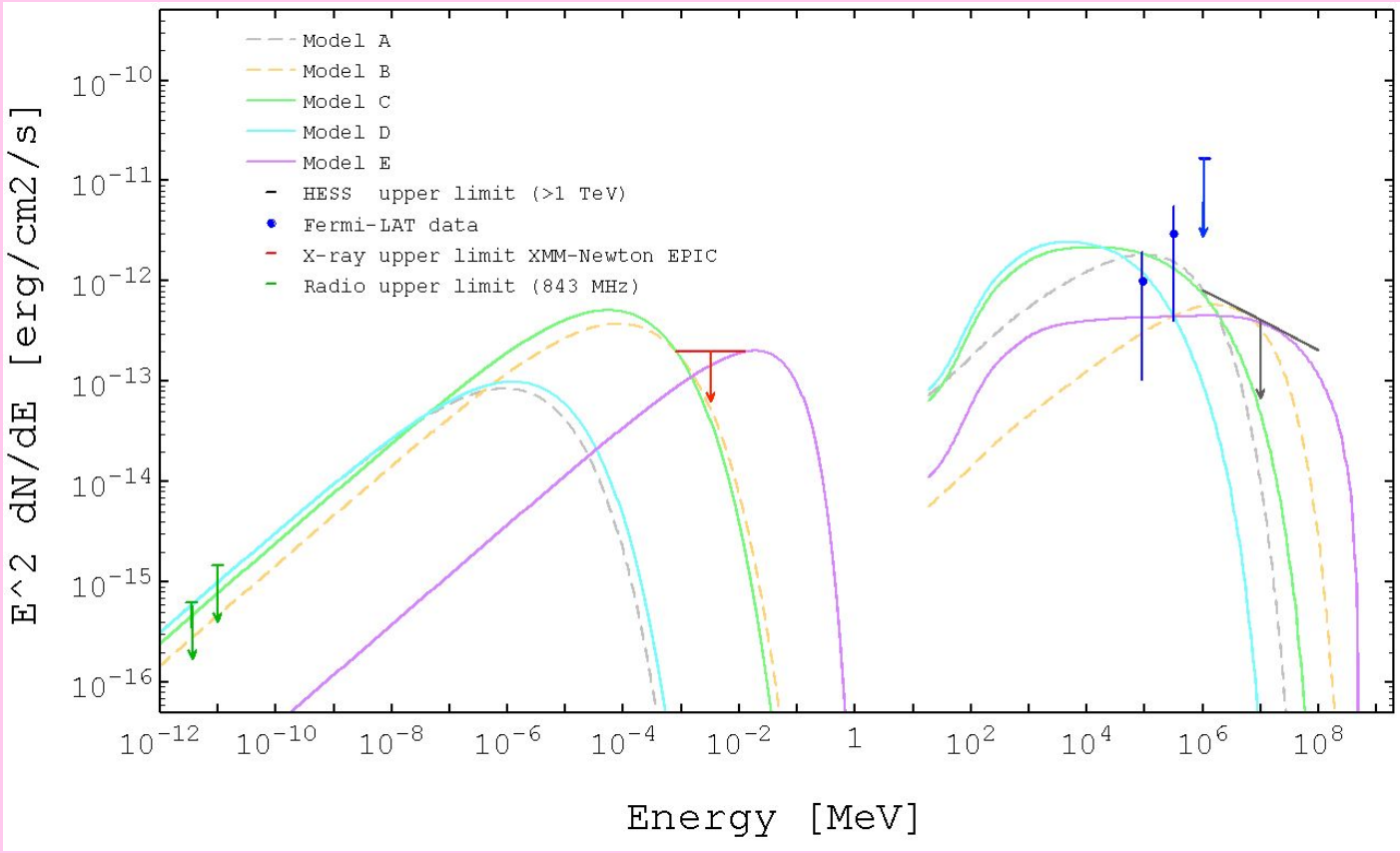
- HI presence was mapped in 1998 in direction of Vela SNR revealing a small HI cloud both spatially and morphologically coincident with the optical filament, X-ray emission, and 2FHL source position.
- Evidence points to γ-rays resulting from the forward shock interacting with a small neutral Hydrogen cloud in this region: potential candidate for CR acceleration



HI 21cm radio map integrated between 29.7 and 35.3 $km\ s^{-1}$ indicating the location of 2FHL J0826.1−4500 with respect to the HI cloud with blue contours for reference of shock structure and location (Dubner et al. 1998).

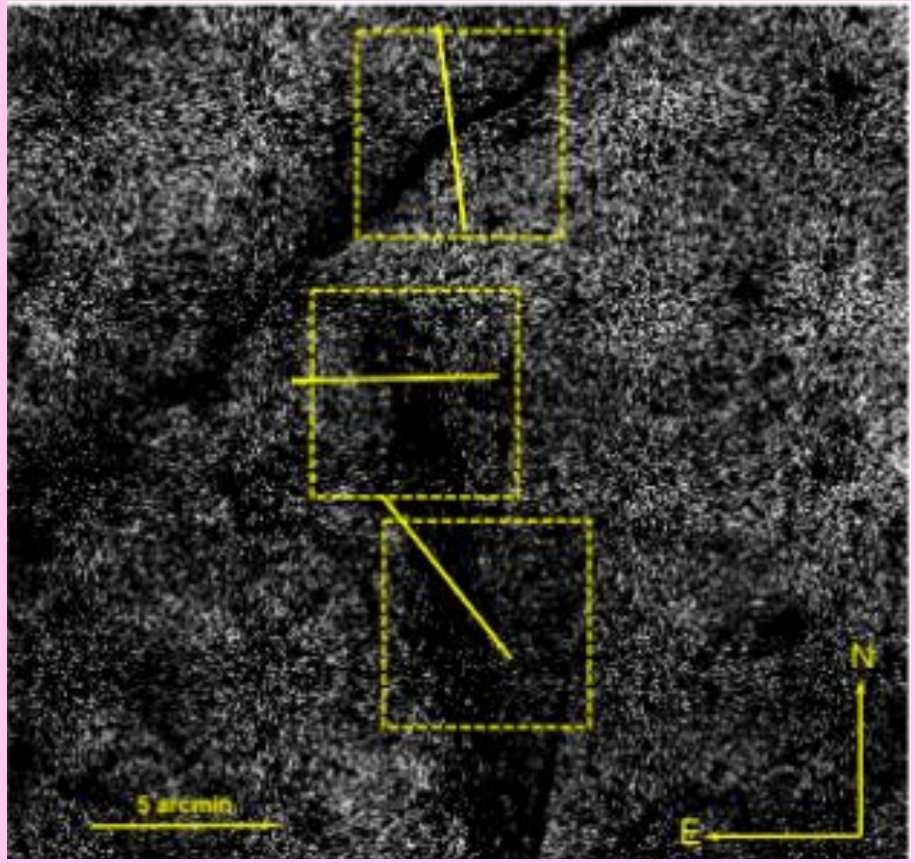
2FHL J0826.1-4500: SED Modeling

- Modeled the spectral energy distribution (SED) from radio to gamma:
  - Can we put constraints on the emission mechanisms? i.e. is it Inverse Compton Scattering? Is it pion decay? Is it non-thermal bremsstrahlung?
  - Type of mechanism points to particle population:
    - Electrons: ICS & non-thermal brem at HE and synchrotron at LE
    - Protons: Pion bump
  - Found either scenario is likely



Spectral energy distribution (SED) for various scenarios: Models A (gray dashed line) and B (yellow dashed line) demonstrate resultant γ-ray spectrum of radiation from relativistic electrons. Models C (solid green), D (solid cyan), and E (solid purple) demonstrate resultant spectrum of radiation from a hadronic population.

2FHL 0826.1-4500: Ongoing



Setup of the planned Gemini-S photometric (boxes) and spectroscopic (slits) observations of three different regions of the H-alpha filament at the location of 2FHL 0826.1-4500.

- Investigate the kinematics of the shock-cloud site i.e. velocity and composition; kinematics will provide indicators to the potential of fresh CRs generated here or if the site is re-accelerating pre-existing CRs
  - Currently reducing incoming data from Gemini-S observation time to study presence of OIII or SII
  - So far, LAT has found mostly CR RE-acceleration sites (Uchiyama et al. 2011)

Summary

1. SNRs & PWNe are promising in their potential for Galactic CR acceleration
2. The Vela SNR may be generating fresh CRs at the western edge of the SNR shell as the forward shock begins to interact with a pre-existing neutral hydrogen cloud
3. Investigation into potential for CR acceleration of 2FHL J0826.1-4500 is ongoing
4. This is just the beginning of understanding the 12 hard, Galactic 2FHL objects that make up our sample so stay tuned ☺

Summary

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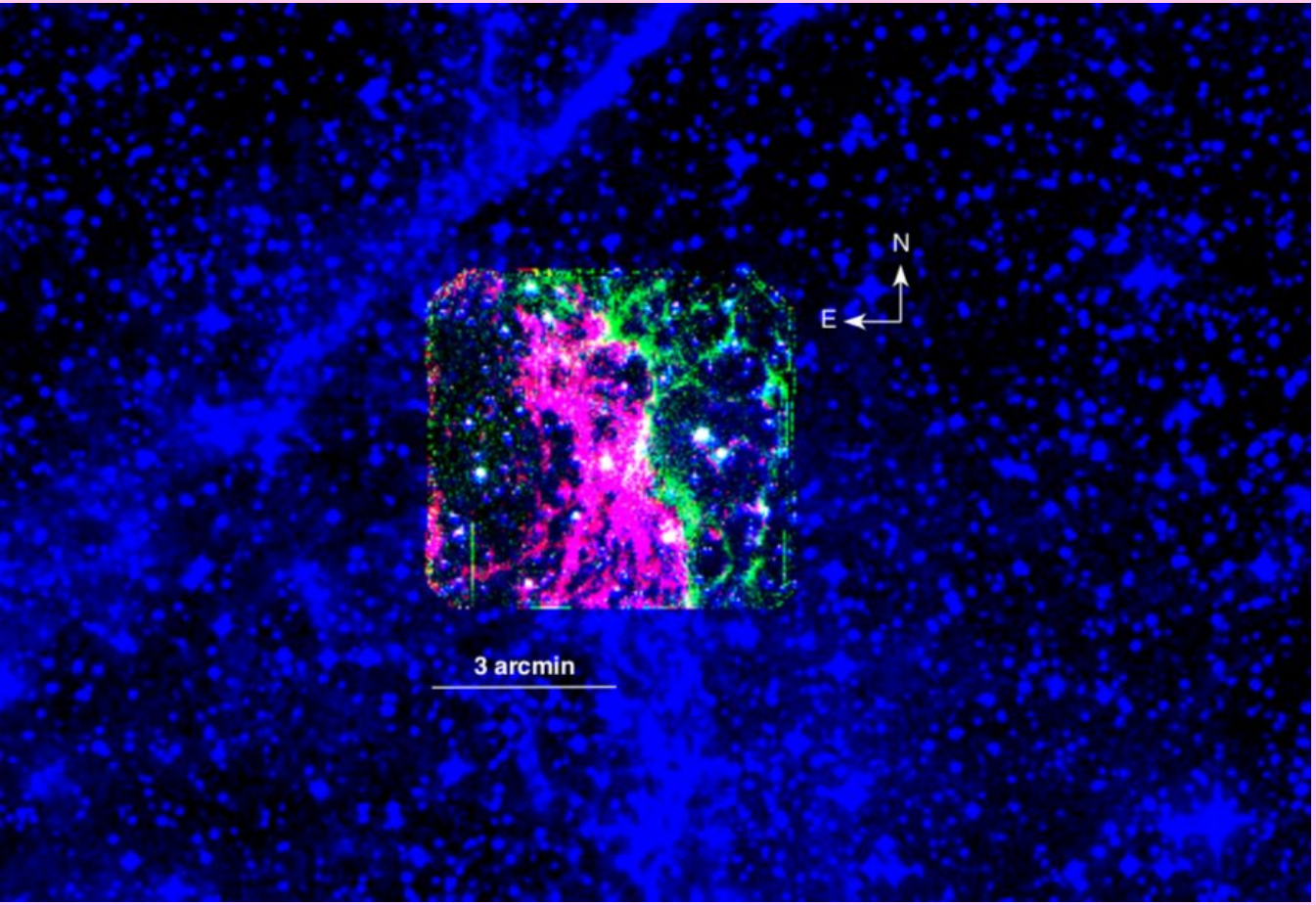
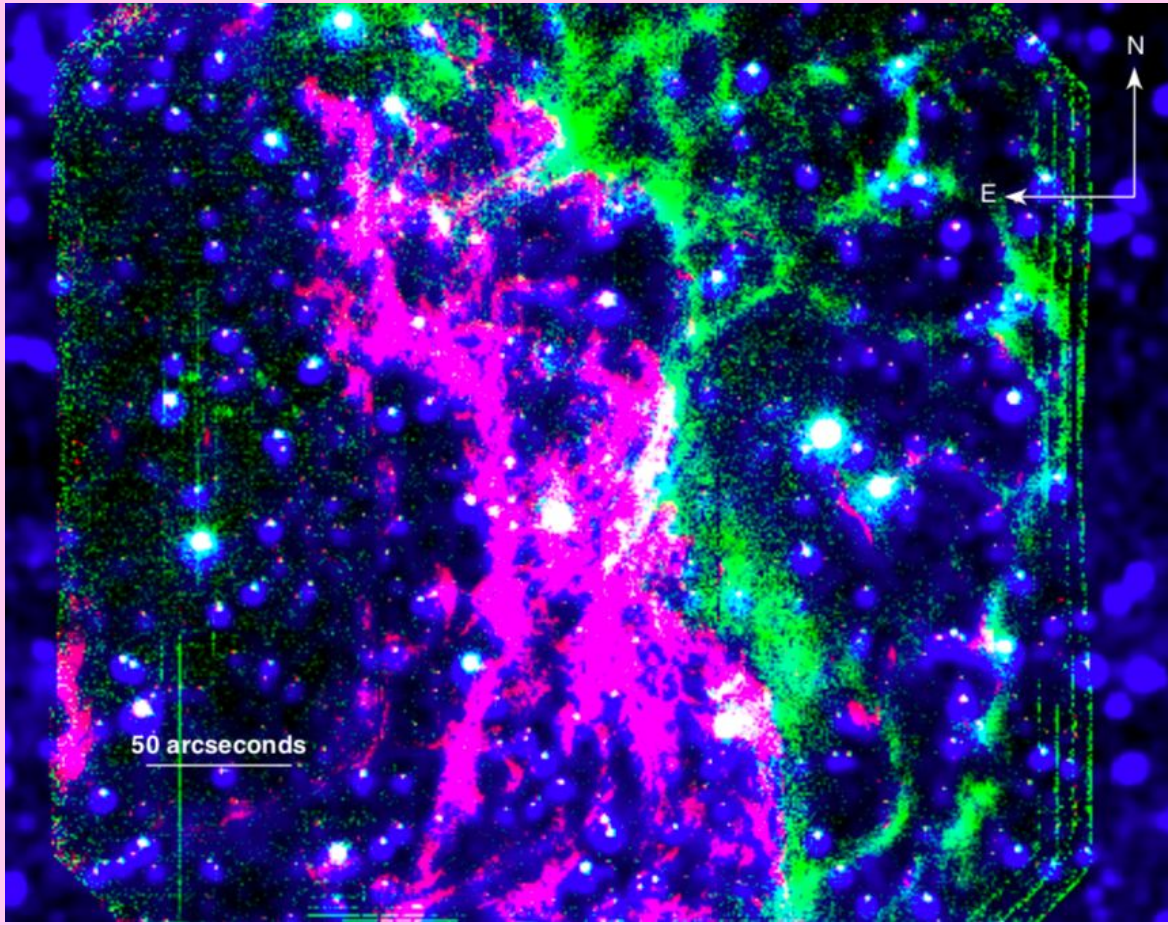
Thank you! Questions?

Preliminary Gemini Results



Zoomed out of the DSS image to emphasize what region we are looking at.



Central region of 2FHL J0826.1-4500 H-alpha filament. Red: SII, green: OIII, and blue is the DSS image.