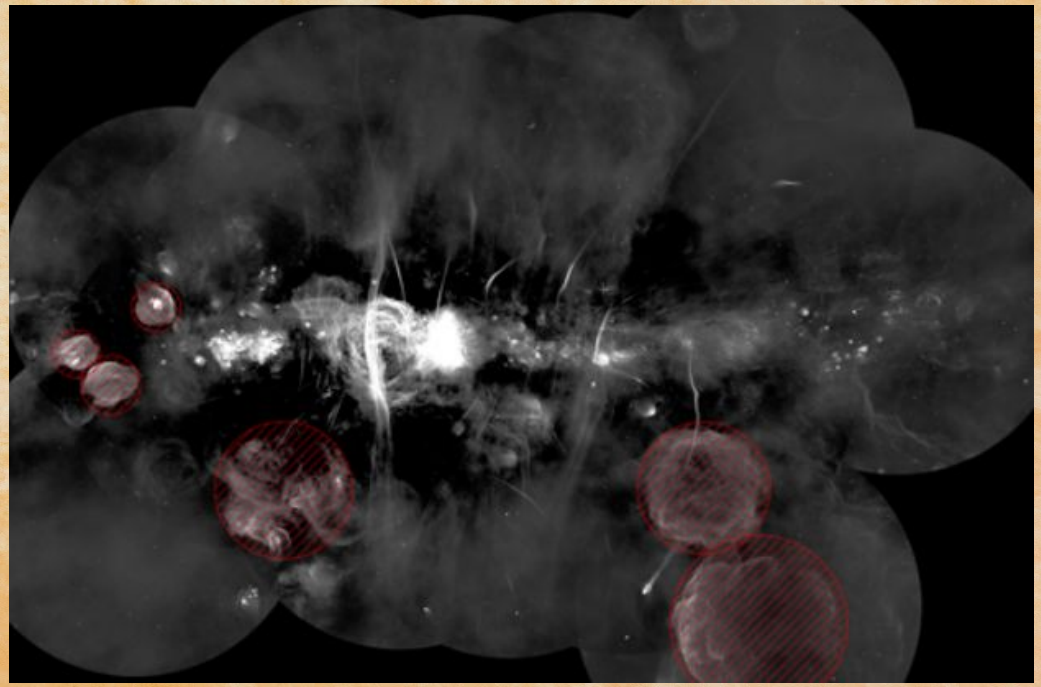
Galactic Filaments Brought to Life by Relativistic Electrons

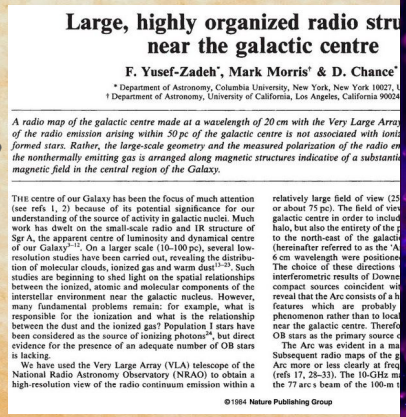
Filaments emanating from the center of the Milky Way were recently mapped. The red circles are molecular clouds and supernova remnants



Link to YouTube Video | Link to Blog Post | Link to Research Paper

Vast Filaments of Gas and Dust Fill the Galactic Center

- Magnetized filaments were first discovered in 1984 using the Very Large Array in New Mexico
- They fill the Galactic Center and Central Molecular Zone
- The filaments are tubes of gas and dust hundreds of light years long
- Dark Molecular Clouds block the galactic center from visible and UV light, so observations need to be made in X-Ray, IR, and Radio spectra



Large, highly organized radio stru
near the galactic centre

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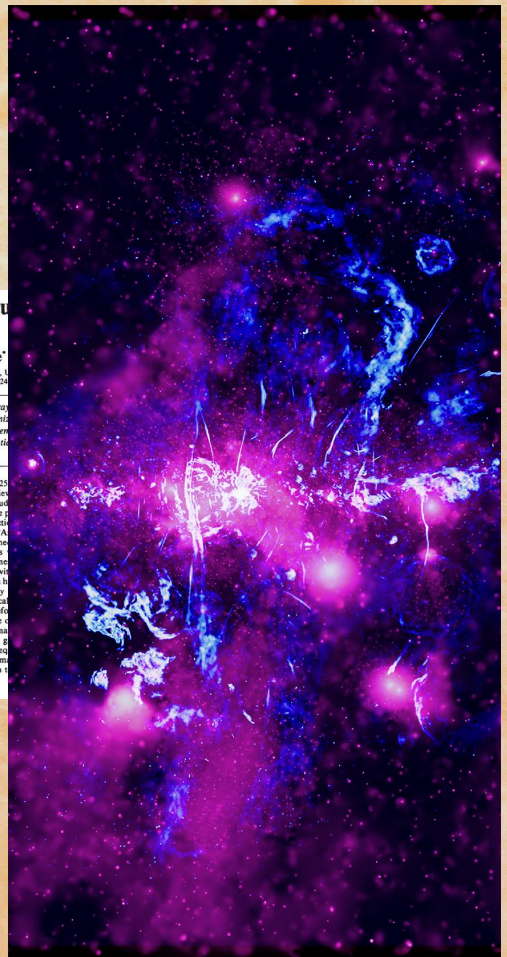
A radio map of the galactic centre made at a wavelength of 20 cm with the Very Large Array of the radio emission arising within 50 pc of the galactic centre is not associated with ioniz formed stars. Rather, the large-scale geometry and the measured polarization of the radio em the nonthermally emitting gas is arranged along magnetic structures indicative of a substanti magnetic field in the central region of the Galaxy.

THE centre of our Galaxy has been the focus of much attention (see refs 1, 2) because of its potential significance for our understanding of the source of activity in galactic nuclei. Much work has dwelt on the small-scale radio and IR structure of Sgr A, the apparent centre of luminosity and dynamical centre of our Galaxy[3–12]. On a larger scale (10–100 pc), several low-resolution studies have been carried out, revealing the distribution of molecular clouds, ionized gas and warm dust[13–27]. Such studies are beginning to shed light on the spatial relationships between the ionized, atomic and molecular components of the interstellar environment near the galactic nucleus. However, many fundamental problems remain: for example, what is responsible for the ionization and what is the relationship between the dust and the ionized gas? Population I stars have been considered as the source of ionizing photons[28], but direct evidence for the presence of an adequate number of OB stars is lacking.

We have used the Very Large Array (VLA) telescope of the National Radio Astronomy Observatory (NRAO) to obtain a high-resolution view of the radio continuum emission within a relatively large field of view (25 or about 75 pc). The field of vie galactic centre in order to includ halo, but also the entirety of the to the north-east of the galacti (hereinafter referred to as the 'A 6 cm wavelength were positione The choice of these directions interferometric results of Downe compact sources coincident wi reveal that the Arc consists of a h features which are probably phenomenon rather than to local near the galactic centre. Therefo OB stars as the primary source The Arc was evident in a ma Subsequent radio maps of the g Arc more or less clearly at frequ (refs 17, 28–33). The 10-GHz m the 77 arc s beam of the 100-m t



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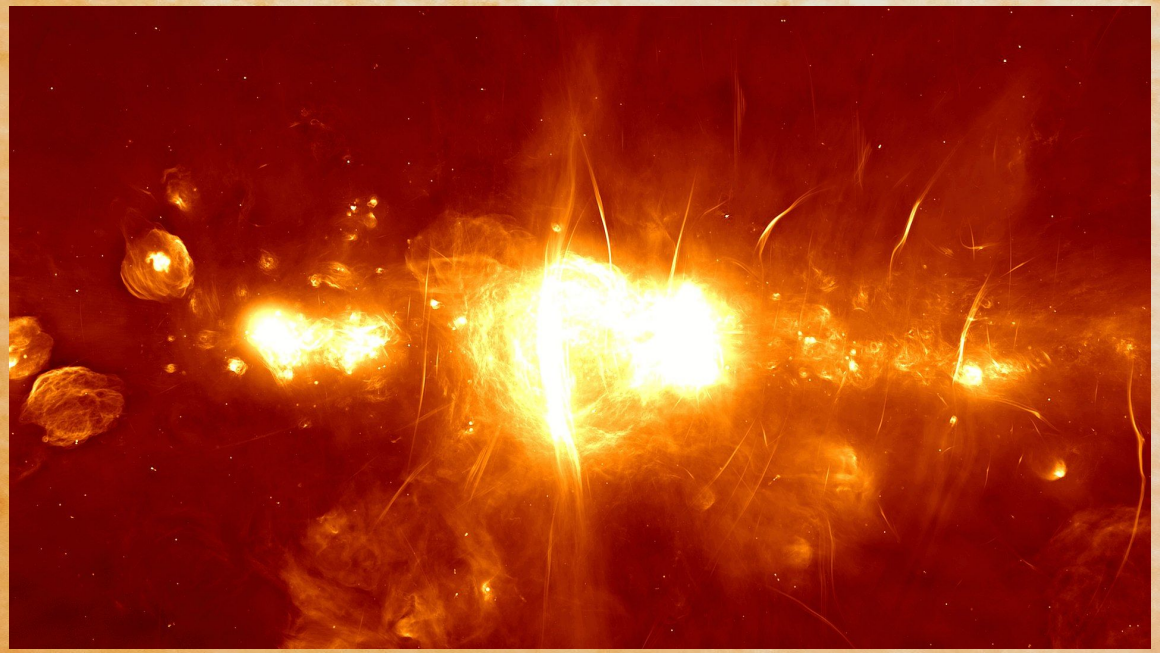
A Diverse Population of Filaments

The first observations found bright, long filaments. Modern observations have found a larger population of short, relatively cool filaments. They're lit by synchrotron emissions powered by fast electrons travelling at relativistic speeds within them.



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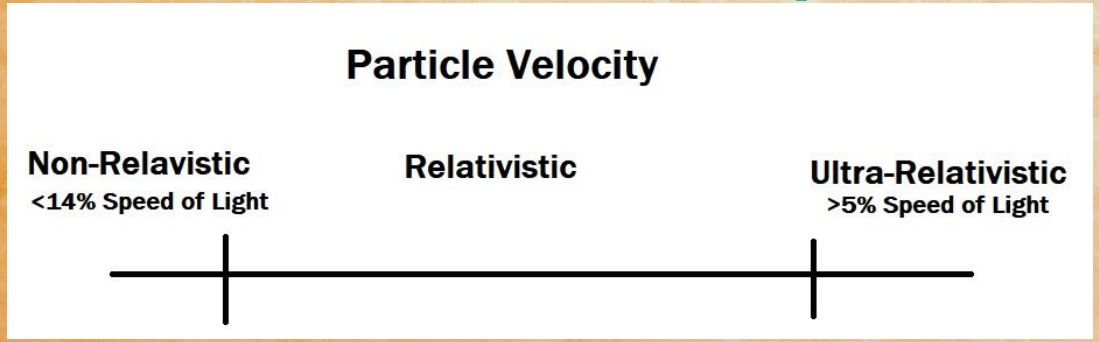
What Are Relativistic Electrons?

- Electrons are liberated from atoms and accelerated to high speed when they're struck by high-energy gamma or x-rays, or heated in accretion discs
- Relativistic speeds are defined by how accurately we can measure time, and how it's changed by velocity
- Faster moving objects experience time as slower than it appears to outside observers (us)
- A 1% difference in the experience of time between object and observer is significant, and it occurs at 14% of the speed of light. Beyond 95% of the speed of light, a particle's mass becomes insignificant compared to its momentum. This is called Ultra-relativistic speed.



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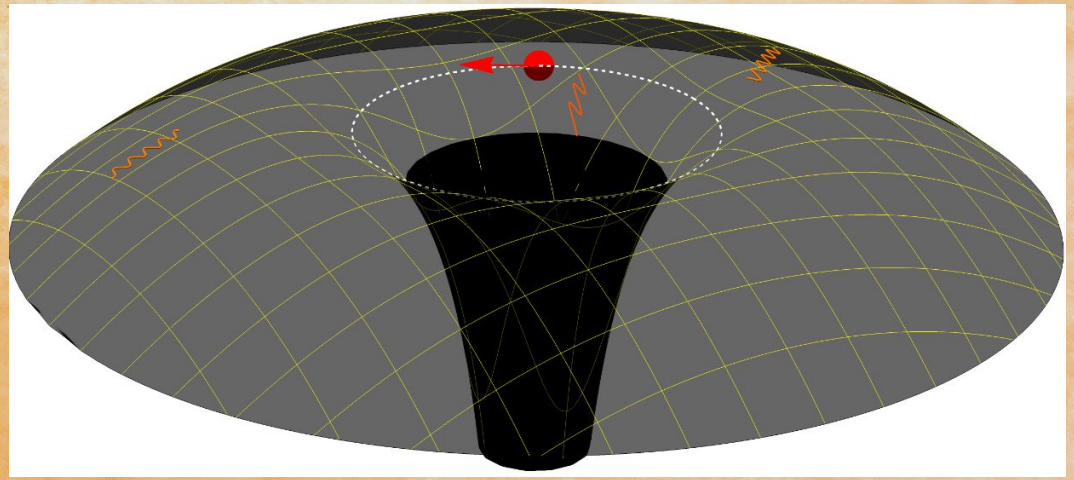
Synchrotron Emissions

- When relativistic electrons cross magnetic fields they change speed or direction, which results in a change in the electron's energy. Some of the change is emitted as photons of light.
- The type of light depends on the initial velocity and the change in velocity, and ranges from radio waves to X-rays.



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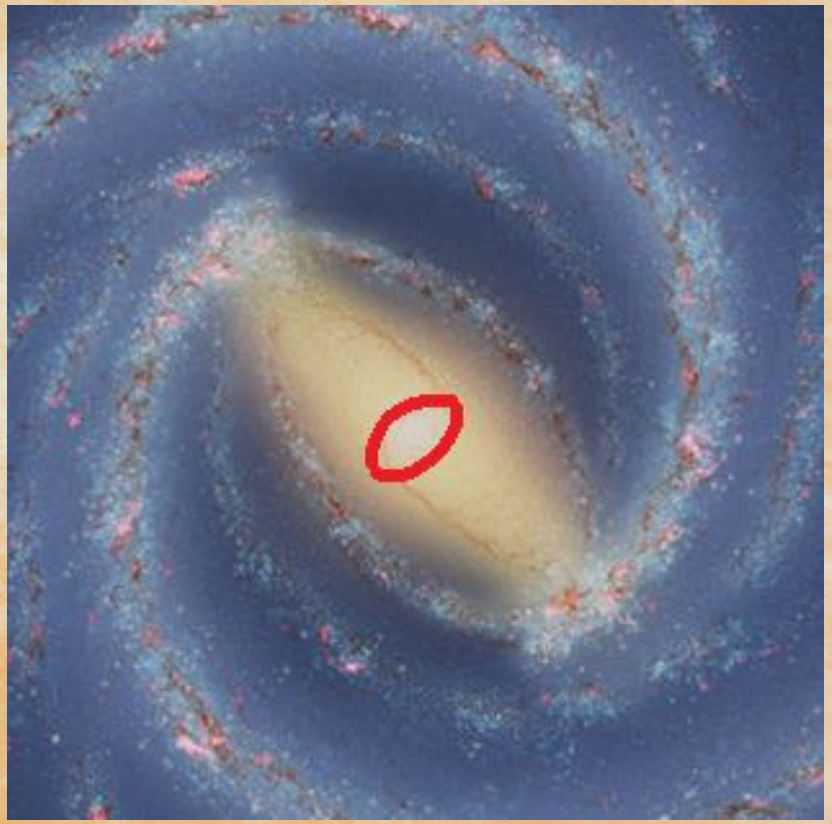
The Central Molecular Zone

- The Central Molecular Zone is an extremely hot, dense, active star forming part of the Milky Way
- Comprises an elliptical region about 1900 LY across
- Dust and gas are drawn by gravity along the Galactic Bars toward the Galactic Center
- Radiation from the Galactic Center and Central Molecular Zone pushes material outward into the Galactic Halo
- Filaments originate from these dynamics



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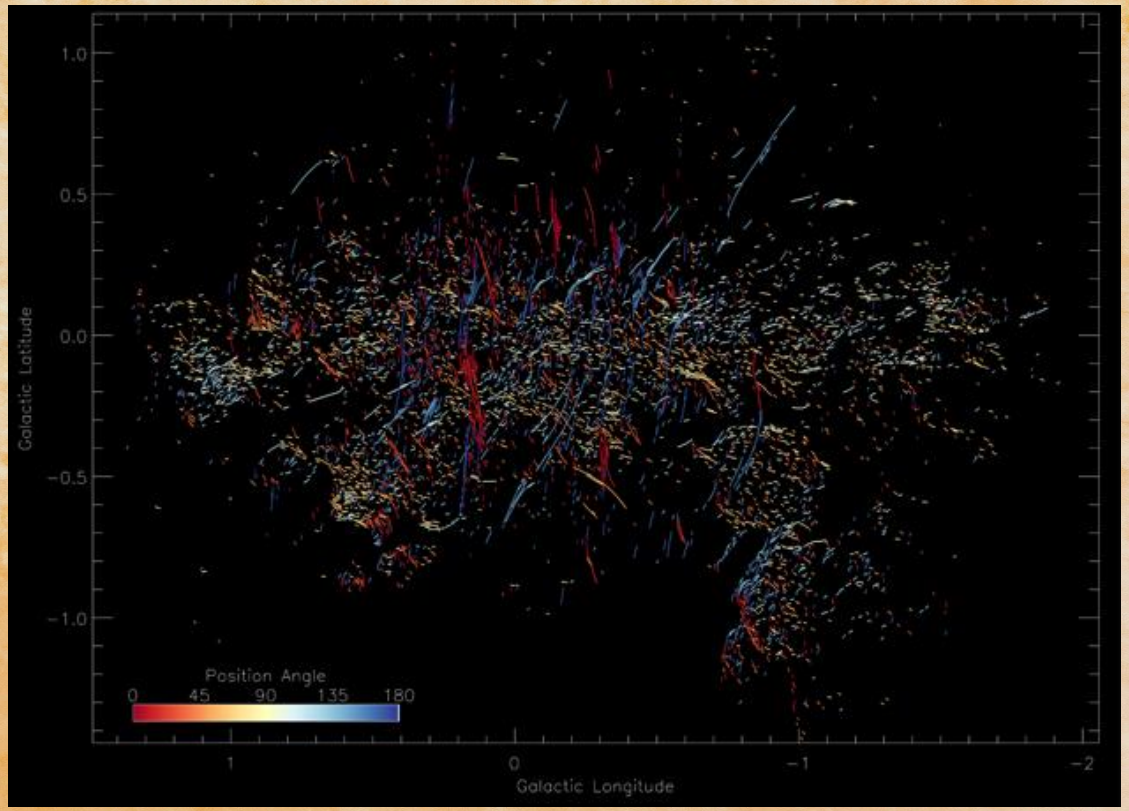
Filaments Can Be Long and Short

- First observations only revealed long, bright filaments
- Modern observations have found both short and long populations
- Gaussian smoothing is used to eliminate noise from the GC and CMZ
- The image on the right is the most exhaustive map produced. Color coding indicates the position angle relative to galactic up



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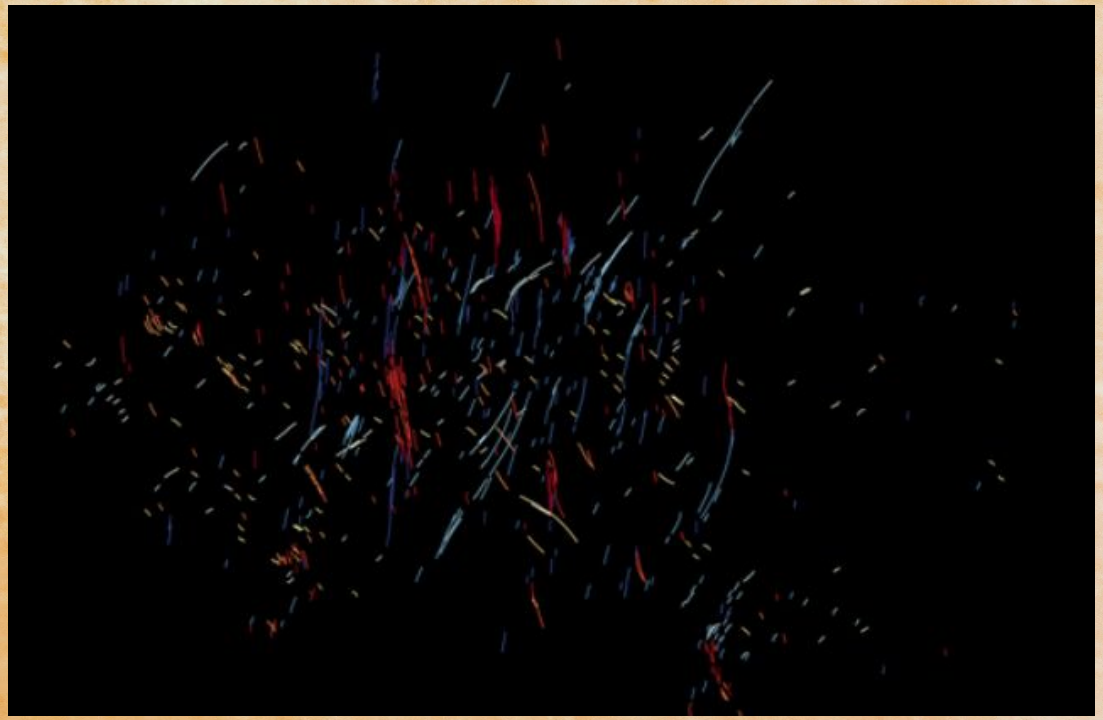
Long Filaments

- Filaments with lengths > 66” are classified as long filaments
- Tend to be more perpendicular to the galactic plane
- More likely to have a variety of emission spectra coming from them



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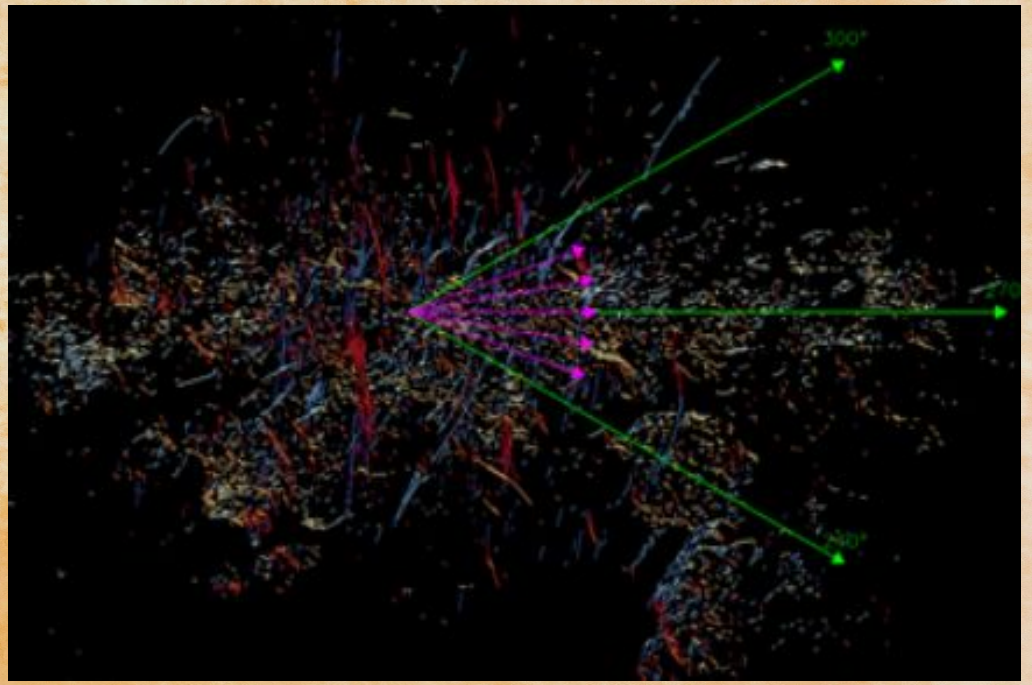
Short Filaments

- The population of short filaments has an apparent length less than 66”
- Shorter filaments have a more uniform distribution of angles relative to the galactic plane
- Shorter filaments have small emission spectra-each filament releases a smaller spectrum of light

Radial Cone of Short Filaments

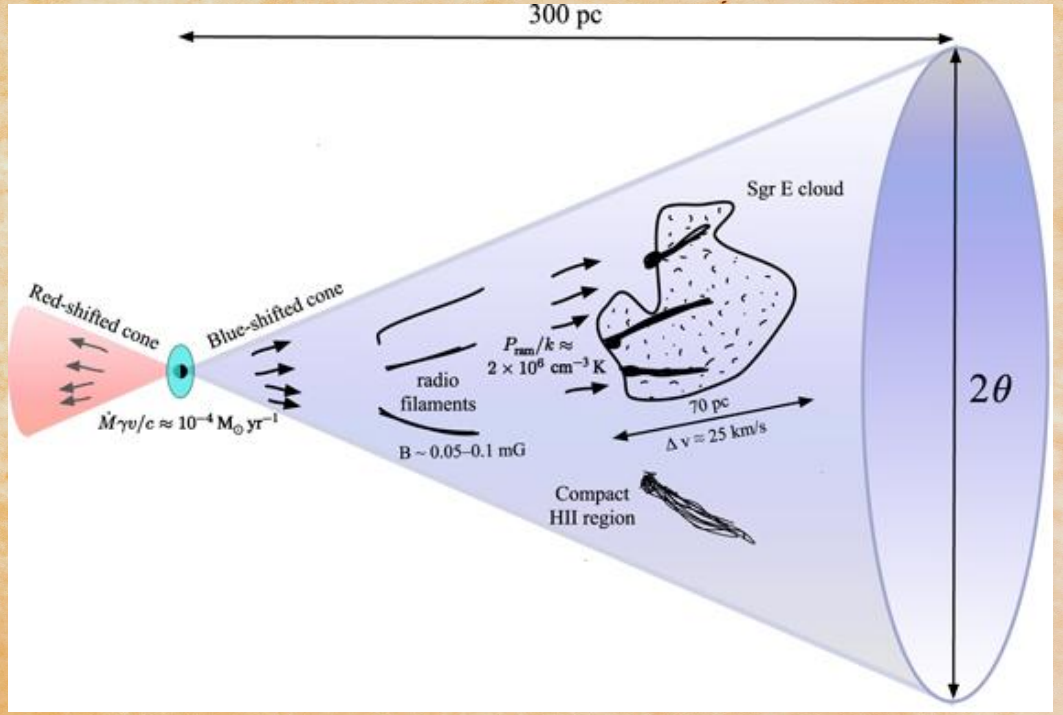
- A subset of short filaments was found in a blue-shifted cone pointing toward quadrant 4
- They point toward the central supermassive black hole, Sgr A*
- The area affected includes the Sagittarius E molecular cloud and several HII regions
- This is evidence of a powerful solar wind or jet emanating from Sgr A*



Hypothesized Model of Conical Outflow

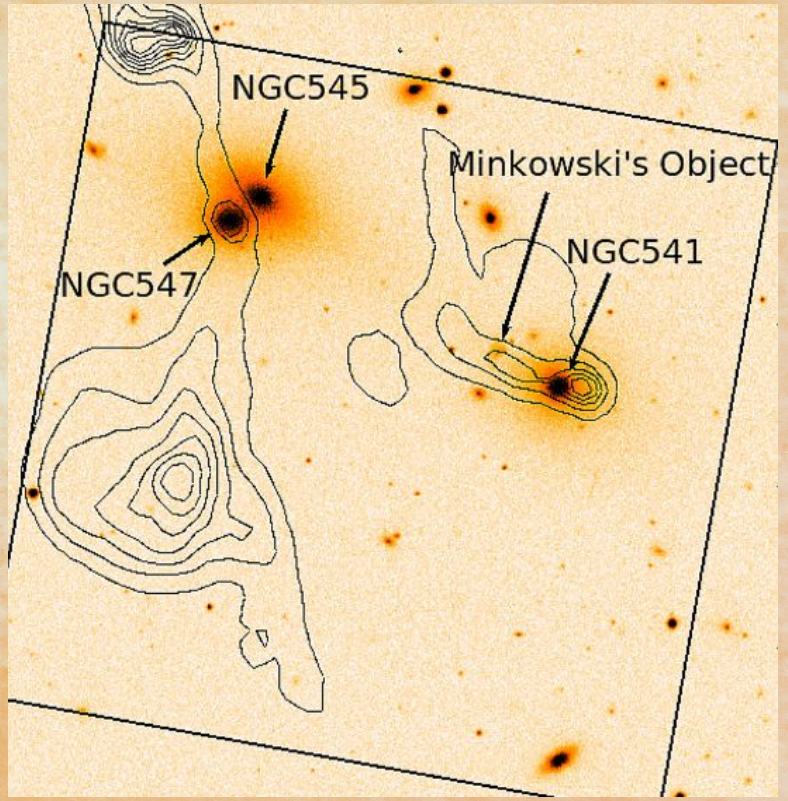
The study's authors proposed a mathematical description of conical outflow for future research. Their initial calculation shows an outflow of material equal to 1/10,000th of a solar mass per year with a maximum age of 6 million years

$$P_{\text{ram}} = \frac{\dot{M}\gamma u}{8\pi d^2 \sin^2(\theta/2)}.$$



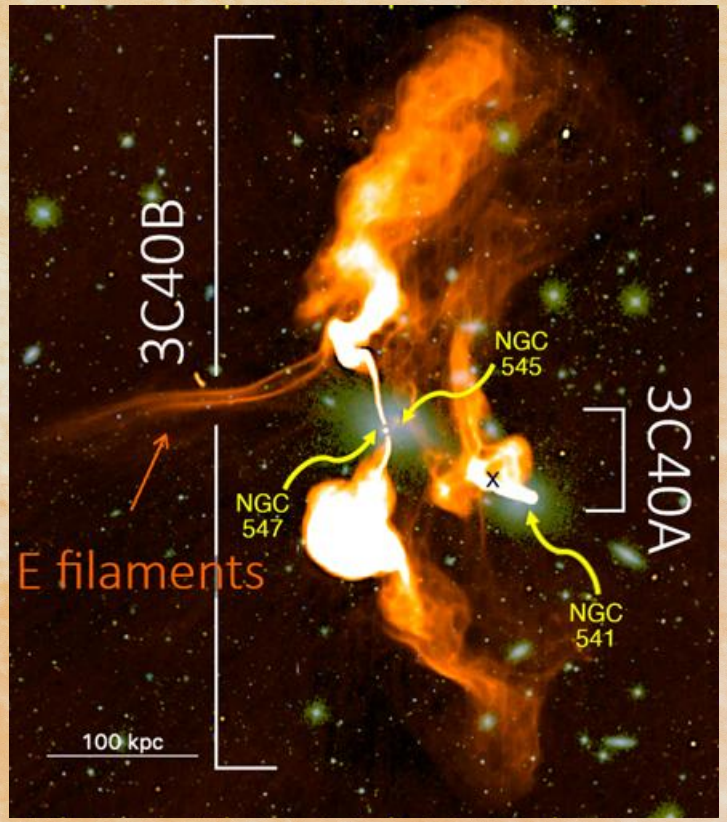
Intra-Cluster Filaments of Cluster A194

- Abell 194 is a small galactic cluster in the Constellation Cetus
- It includes the galaxies NGC-541, -545, -547, radio galaxies 3C40A and 3C40B, and the molecular cloud known as Minkowski's Object
- The cluster's redshift is 0.018, indicating a distance of 250 Million light years

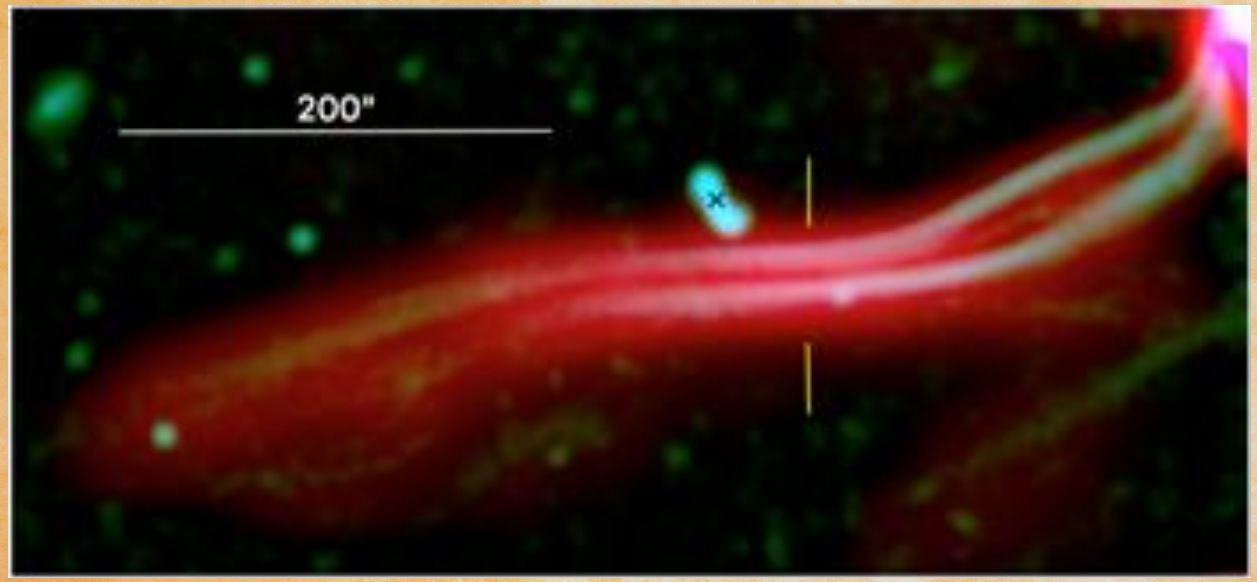


Bubbles Plumes and Filaments

- Gas-Dust structures within the cluster are lit up by synchrotron radiation
- Power sources are radio- and x-ray jets from Active Galactic Nuclei
- Shapes of the structures give insight into the dynamics of filaments, molecular clouds, and shear forces caused by gravitation



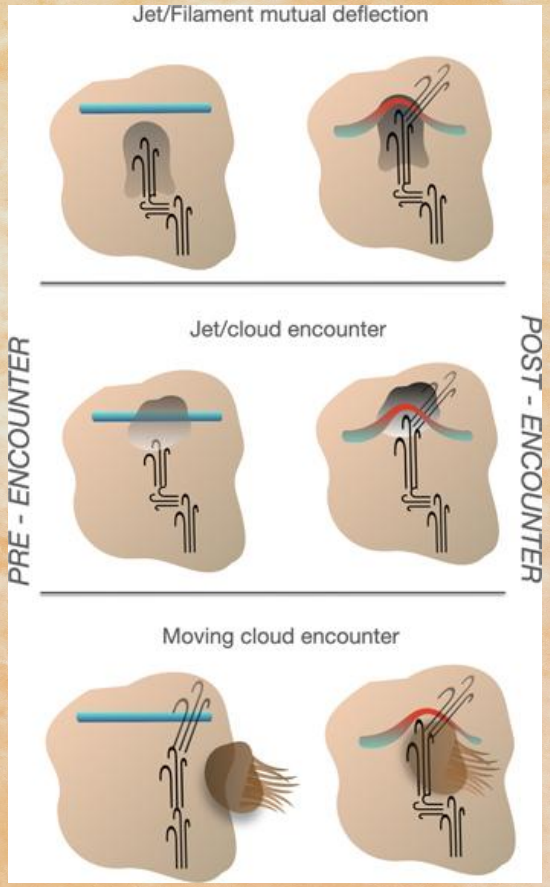
Insights From the E-Filaments



EM and gas outflows from Active Galaxies blow and stretch the filaments. EM strips electrons from their orbitals, magnetizing the gas. The filaments are stretched and ionized. Lengths are determined by the dynamic equilibrium of outflow and magnetic forces.

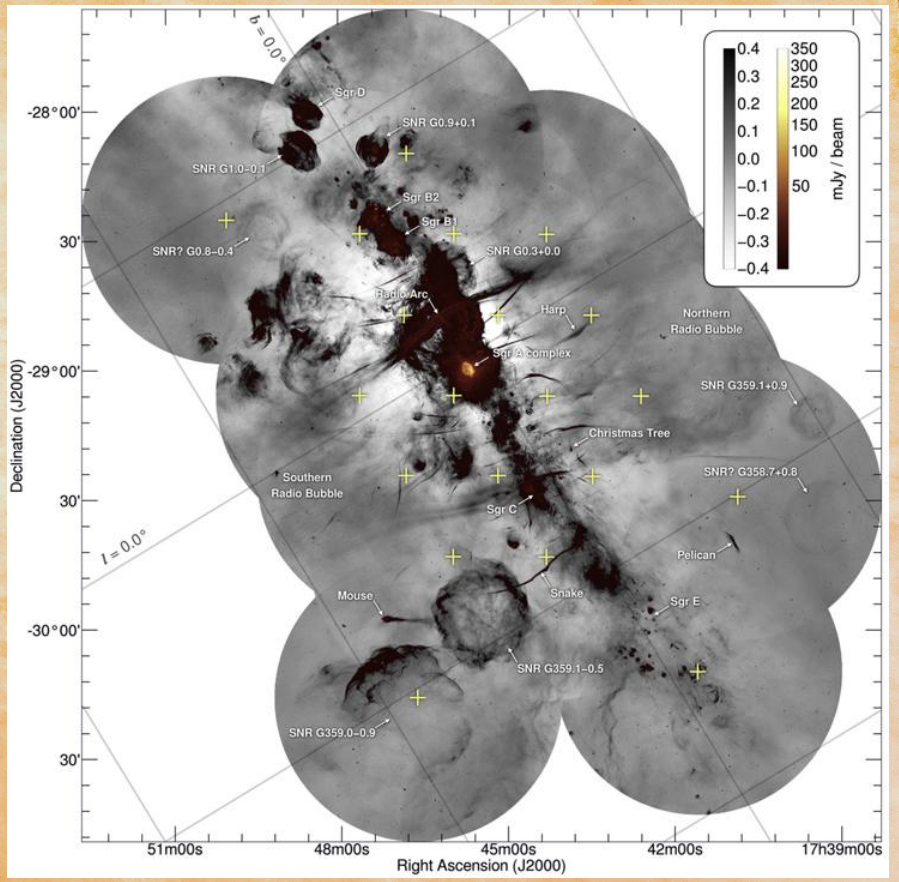
Filaments Shaped by Jets and Clouds

- Molecular clouds and jets interact with filaments, changing their shape and luminosity. At the same time, mass and momentum transfer alters the course of the jet or cloud.
- Cosmic rays interact with filaments through mass transfer and energetic effects. These aren't well studied.
- It's likely that electrons are also accelerated in directions perpendicular to the filaments. This may be the momentum source for the gas cloud distortions of 3C40A and 3C40B.



Insights and Future Areas of Study

- With better telescopes filaments have been found to be ubiquitous throughout the visible universe
- Filaments within and between galaxies appear to have the same origins and dynamics
- Filament lengths, orientations, and shapes are indicators of gas and energy dynamics emanating from Galactic Nuclei
- Synchrotron and Cosmic Ray effects are observable but not well characterized
- Filaments are visible indicators of gas and dust flows in galactic and inter-cluster media



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