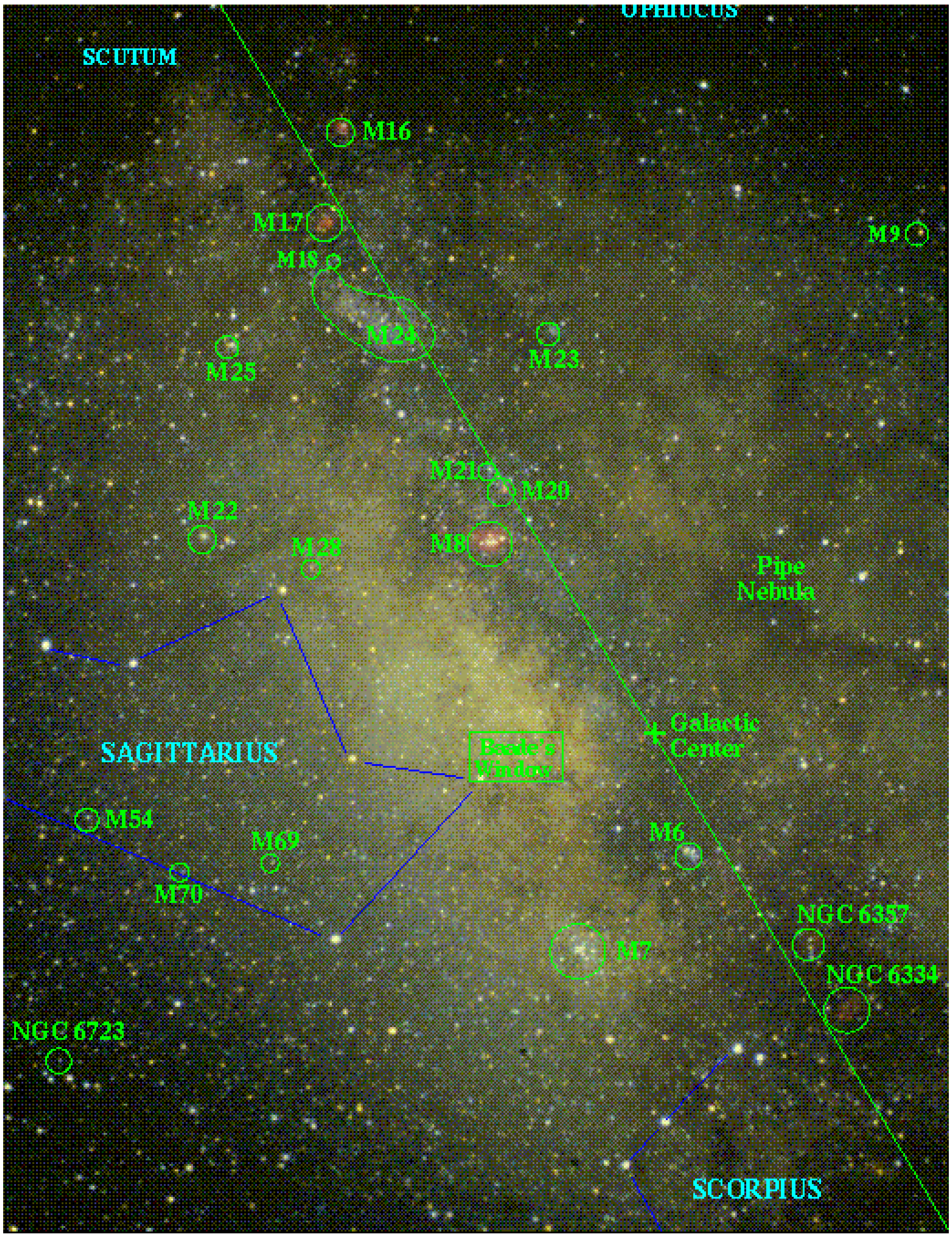
Chapter 8: the center of our galaxy

Ref: Melia & Falcke 2001, ARAA, vol 39, p. 309



Galactic Center: $(a_{GC}, d_{GC}) = (17^h 45.6^m, -28^\circ 56.2')$ in optical (10 x 15 degrees)

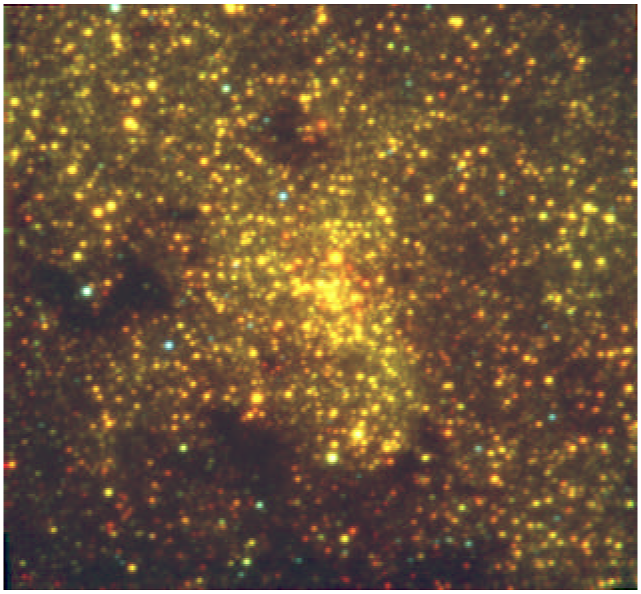
- At distance of only 8 kpc, 1 arcsecond ~ 0.04pc ➔ ideal to study center physics in detail, but difficult due to absorption by dust;

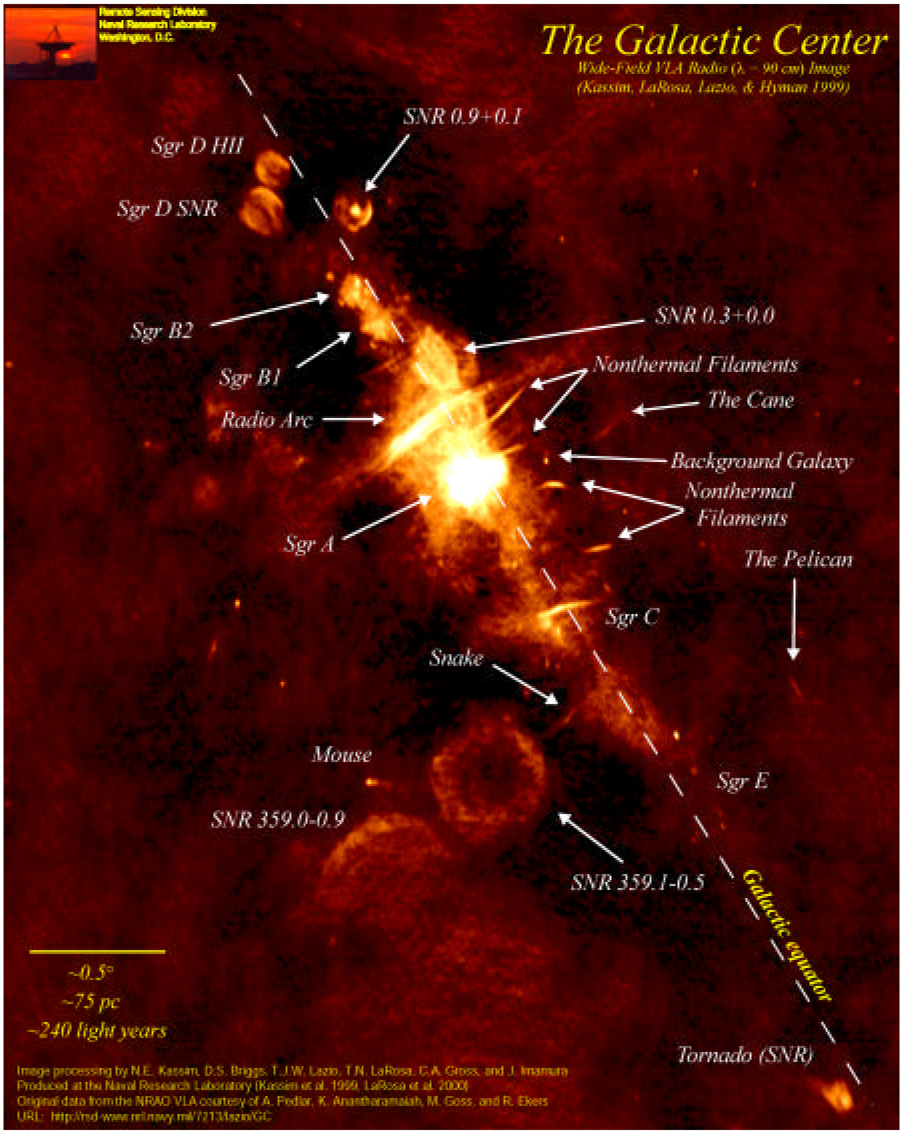
Galactic Center taken in the infrared (1.2-2.2 microns).

The image is 0.5x0.5 degrees (72x72pc) in size (Ian Gatley; NOAO)

The image shows emission from the millions of stars located within the bulge and center of our galaxy. The dark patches are the densest dust clouds which obscure even the infrared light from the stars behind them.

1.7 arcminute (4.1pc) 2.2 micron (JHK) false color image of the Galactic Center (Ohio State Infrared Imager/Spectrometer (OSIRIS); Blum, Selgren, Ramirez, Ohio State U.).



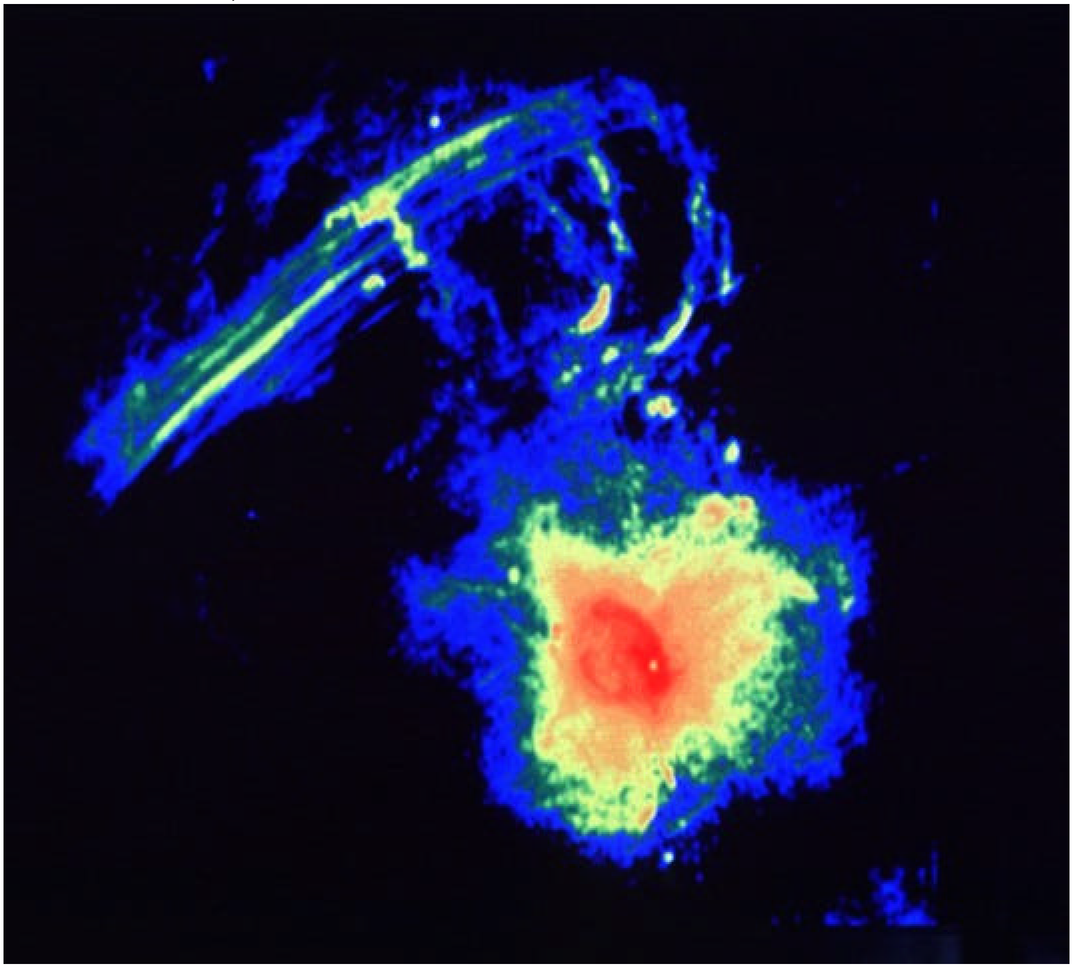


VLA image of center of galaxy ➔ Sgr A* possible $2.6\times10^{6}\ M_{\odot}$ BH

- 6 principal components:
  1. Supermassive BH;
  2. Surrounding cluster of evolved and young stars;
  3. Molecular dusty ring;
  4. Ionized gas streamers;
  5. Diffuse hot gas;
  6. Powerful SN-like remnant;

- Activity in the center can be explained by interaction of these components;

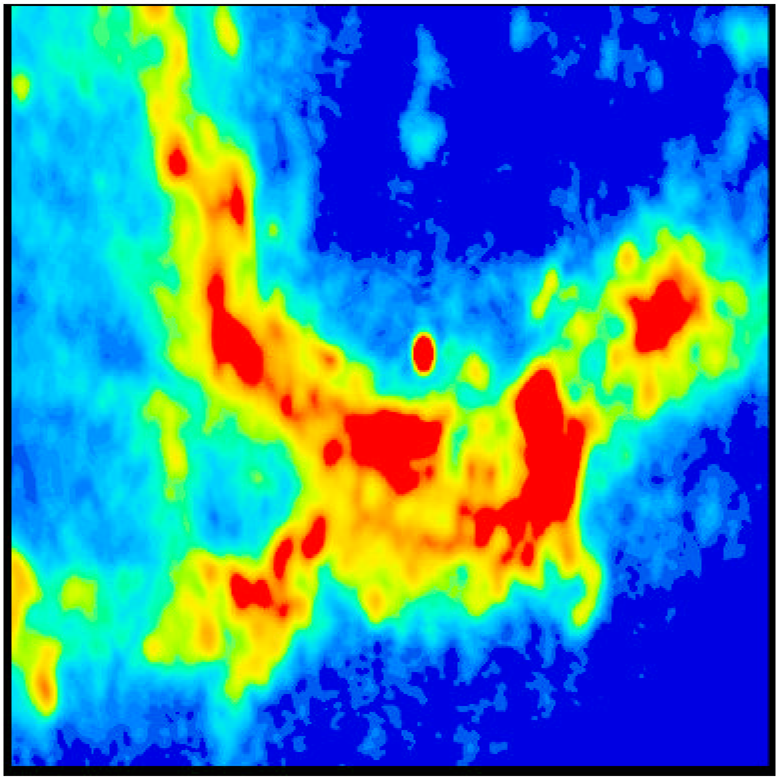
- Dynamical center of MW = Sgr A* = compact non thermal radio source no bigger than 1 AU;



VLA 25 x 25 arcmin (60pc x 60pc) image at 20cm (courtesy of NRAO/AUI: investigators F. Yusef-Zadeh, M.R. Morris, and D.R. Chance1984);

- Filamentary structure near the Galactic Center. The radio continuum observations of Sagittarius A* (Sgr A*) plus the continuum arc in the direction of Galactic Center at 20 cm. The narrow filamentary structures, which make up the continuum arc, have typical widths of 20 arc seconds (< 1 pc). These radio filaments are perpendicular to the galactic plane, parallel to each other, regular, unbroken and homogeneous in their appearance.

- On smaller scale 50 x 50 arcsec (2 pc x 2 pc) Sgr A West ➔ image at 2cm show Sgr A* in the center of image and IRS 7 bright central spot to the North;

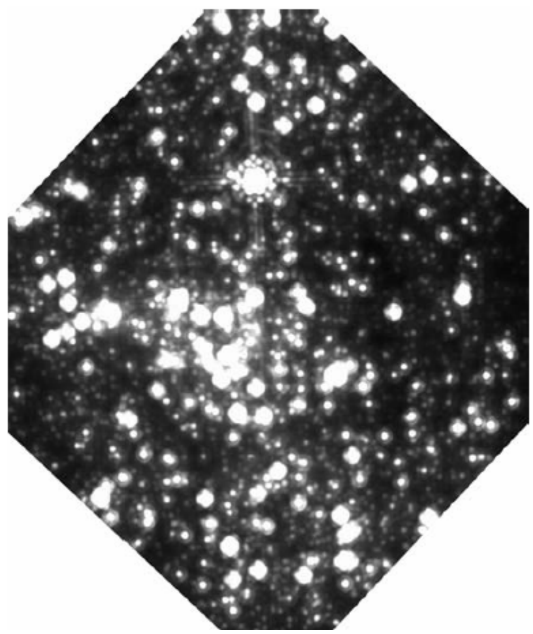


Spectroscopy of gas in mini spiral structures ➔ rotation in clock wise direction at 150 km/s around Sgr A*

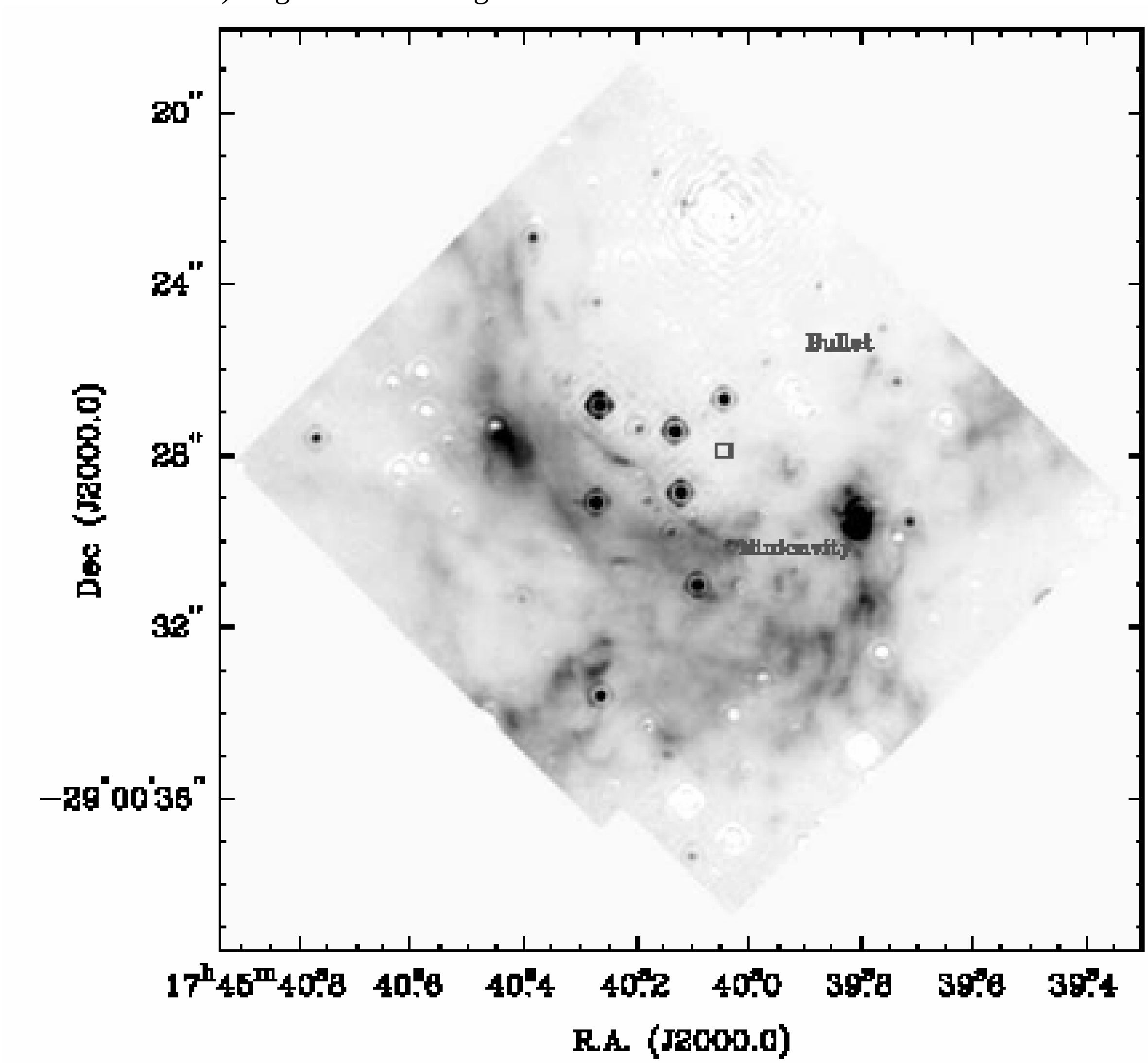
Sgr A West derives is heat from central distribution of bright stars;

NICMOS image at 1.6 micron of 19 x 19 arcsecond centered on Sgr A*: the brighter star is IRS 7

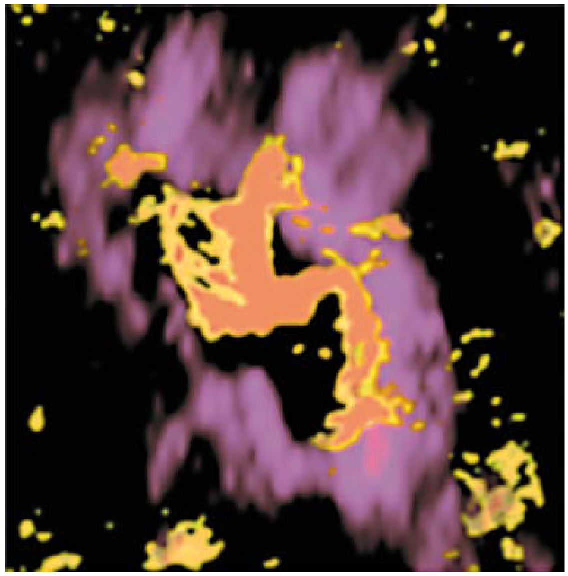
Not clear if stars formed from streamers or are just lying in line of sight;



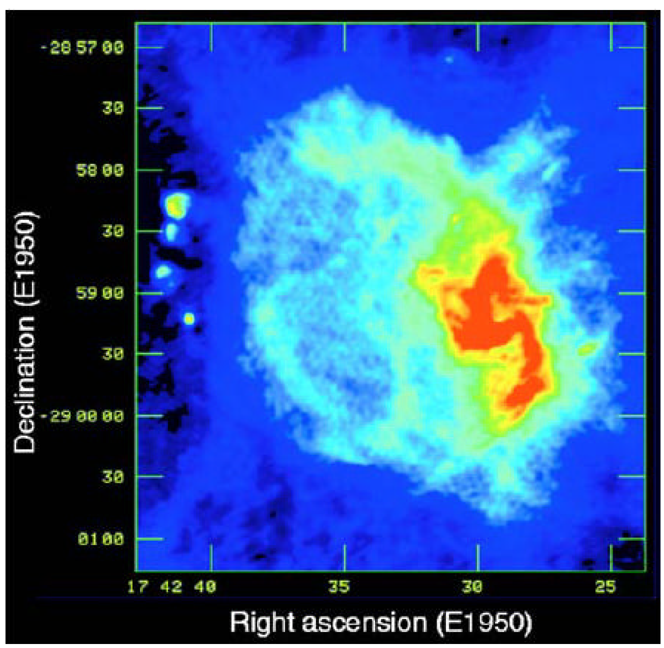
- Other features of Sgr A West (Pa alpha image):
  - o High velocity features = Bullet = 400 – 1200 km/s;
  - o Minicavity: distinct hole in distribution of Radio + Pa alpha emission with 2 arcsecond (0.08 pc) in dimension ➔ effect of stellar wind (unidentified source) or gas flow from Sgr A*?



- On larger scale 1.7 arcmin (4 pc) Sgr A West is thought to lie within a central cavity surrounded by gaseous ring (or disk): image show 1.2 cm radio observation (orange) superimposed on HCN emission (purple);



- Whole Sgr A complex (50 pc x 50 pc) = thermal + non thermal features: Sgr East = possible SN component or low-luminosity AGN – association with 50 km/s molecular cloud suggests energy of order 10^{52} ergs (hypernovae = tidally disrupted stars); Figure shows region 10 x 10 pc (4 x 4 arcmin);



- Sgr A complex associated with diffuse X-ray emission ➔ large temperature and pressure producing hard X-rays suggest unbounded gas – size and sound speed of this feature argue for an age of 50 000 years for the hot plasma bubble;

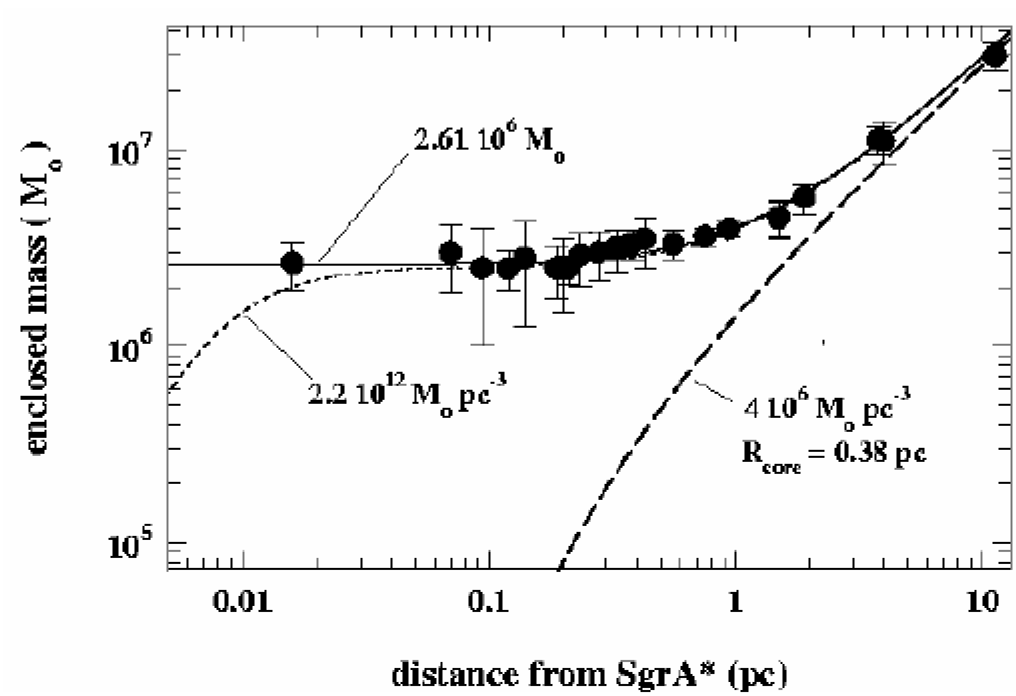
- On scale of hundreds of parsecs: several synchrotron-emitting filamentary structures roughly perpendicular to Galactic plane ➔ possibly magnetic field lines lit up by relativistic electrons;

Sgr A* as a BH:

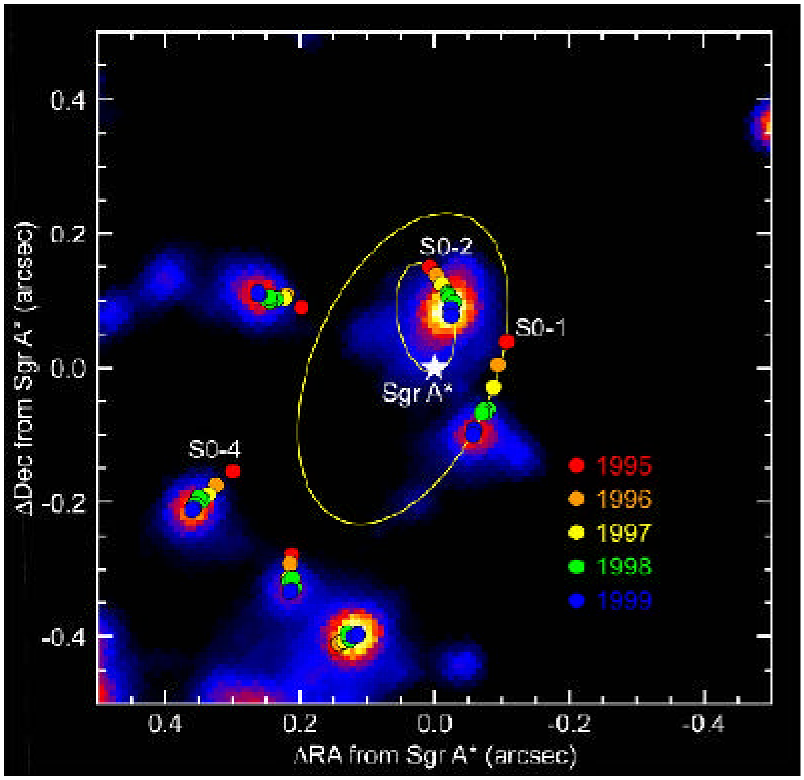
- Lynden-Bell & Rees 1971 ➔ from model of quasar, speculate existence of massive BH in our galaxy observable in radio;

- Balick and Brown 1974 ➔ compact radio source detected near center ➔ Sgr A* (Brown 1982);

- Confirmation with VLA that Sgr A* lies near dynamical center (1980 – 1981) + detected radio variability (1982);



- Genzel & Towns 1987: diagram showing enclosed mass vs distance from Sgr A* ➔ different mass models (core radius – sum of core radius + point mass and core radius + dark cluster) suggest point like object of mass ~ 3×10^6 $M_\odot$ reside in center;



Ghez et al. 2000: detection of the first signs of acceleration of the motion of stars ➔ dynamical center coincides with Sgr A* to within 50 mas;

- Other argument (Backer 1996): an heavy object in dynamical equilibrium with surrounding clusters of stars will move slowly ➔ no random proper motion detectable:
  - VLA (Backer & Sramek 1999) + VLBA (Reid et al. 1999) results consistent with rotation of the Sun = 220 km/s ➔ after removal of galactic rotation upper limit on proper motion of Sgr A* is +/- 15 km/s;

- Lower limit on mass:
  - In vincinity of Sgr A* stellar motion reach 1000 km/s or more;
  - Assuming no central point mass and equipartition of momentum between fastest stars $(m_* v_*)$ and Sgr A* ($M_{SgrA*} v_{SgrA*}$) yields:

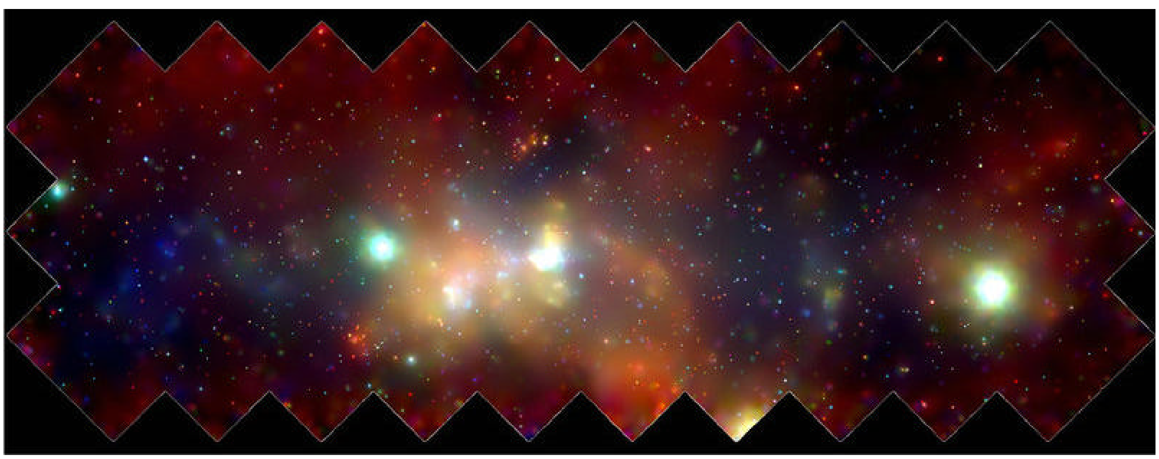
$$M_{SgrA*} \geq 1000 M_\odot \left(\frac{m_*}{10 M_\odot}\right)\left(\frac{v_*}{1500 km/s}\right)\left(\frac{v_{SgrA*}}{15 km/s}\right)^{-1}$$

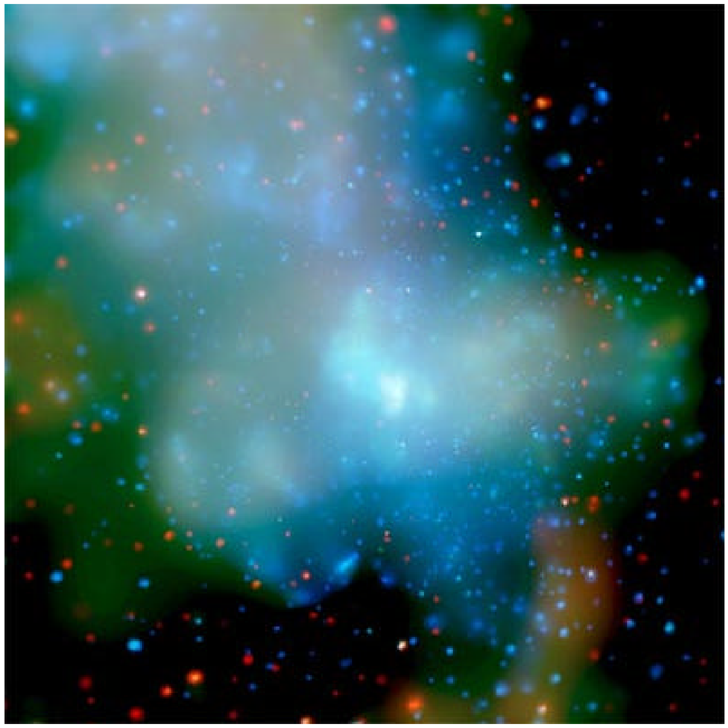
  - Rules out pulsar or neutron star;

- BH sizes:
  - Characteristic size = Schwarzschild radius: $r_s \equiv 2GM/c^2 \sim 7.7\times10^{11} cm$; at 8kpc this yields ~ 6.4 micron arcsecond;
  - Upper limit ~ 1 AU ➔ brightness temperature greater than 10^{10} K;
  - Minimum size ~ 0.1 AU ➔ brightness temperature greater than 5×10^{11} K;
  - Range of typical AGN radio cores that shine below Compton limit;

- Great question: is Sgr A* consistent with other AGNs?
  - Galactic center rich in gas and some much be funneled into the BH, but transformation of kinetic + gravitational energy in radiation seems low ➔ sub-Eddington object.

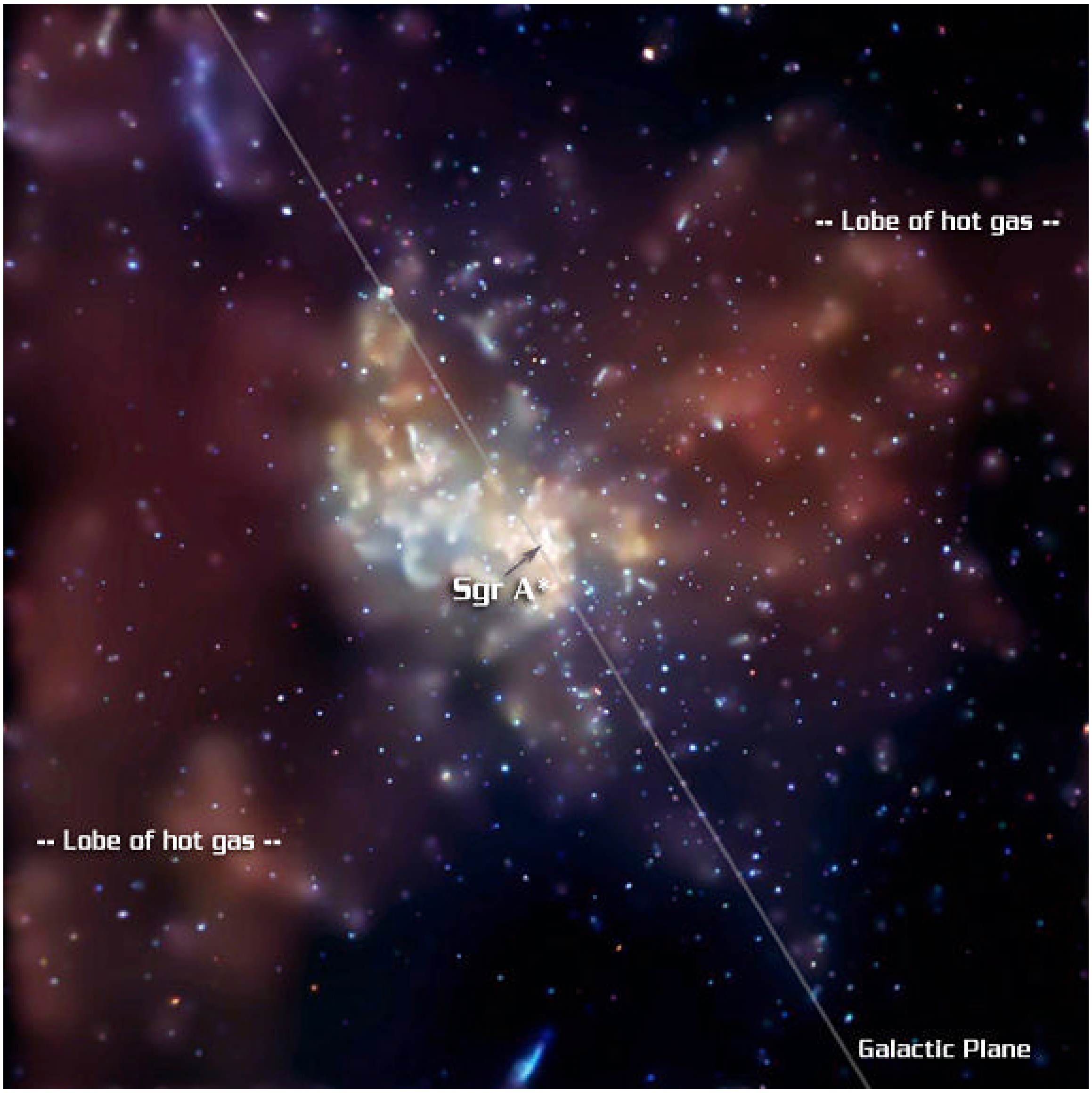
- This 400 by 900 light-year (123 x 276 pc or 51 x 115 arcmin) mosaic of several Chandra images of the central region of our Milky Way galaxy reveals hundreds of white dwarf stars, neutron stars, and black holes bathed in an incandescent fog of multimillion-degree gas. The supermassive black hole at the center of the Galaxy is located inside the bright white patch in the center of the image. The colors indicate X-ray energy bands - red (low), green (medium), and blue (high).





This image was produced by combining a dozen Chandra observations made of a 130 light year (40 pc or 17 arcmin) region in the center of the Milky Way. The colors represent low (red), medium (green) and high (blue) energy X-rays (Credit: NASA/CXC/UCLA/MIT/M.Muno et al.)

- The contributions from 2,357 point-like X-ray sources due to neutron stars, black holes, white dwarfs, foreground stars, and background galaxies was removed, an irregular, diffuse glow from a 10-million-degree Celsius gas cloud, embedded in a glow of higher-energy X-rays with a spectrum characteristic of 100-million-degree gas.


-- Lobe of hot gas --
Sgr A*
-- Lobe of hot gas --
Galactic Plane

Star formation in the center of our galaxy

- Contrary to expectation, the center of our galaxy may have been the site of continuous star formation at very low rate (0.02 solar mass per year; Figer et al. 2004, 601, 319);