Galactic Science

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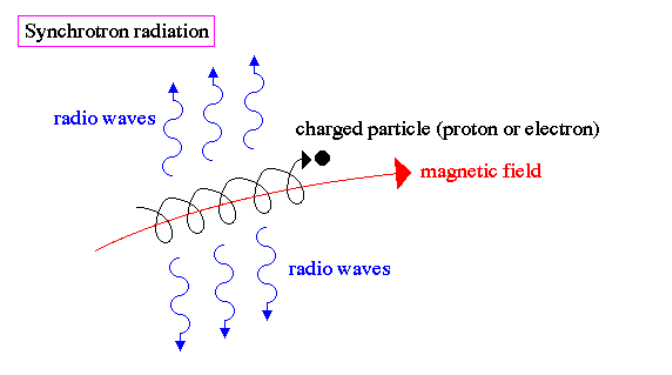
Outline

- Radio Emission: what can we learn?
  - Thermal and non-thermal continuum emission
  - Spectral line radiation
  - The radio spectrum & interferometers
- A Radio Tour of the Milky Way
  - Star Birth - Interstellar
  - Stellar Sources
  - Interstellar gas: Ionized & Atomic Clouds
  - Exotic
- An Unusual Place: Galactic Center

Radio Emission Mechanisms

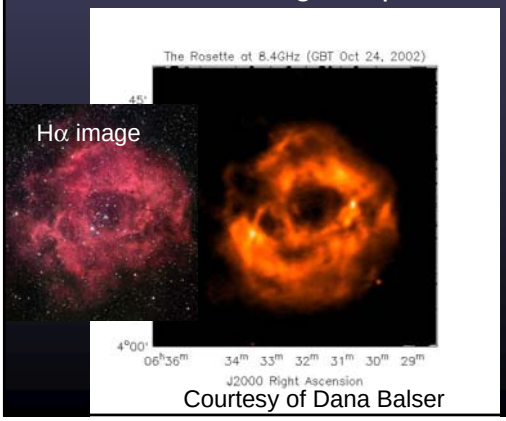
- Synchrotron radiation - continuum
  - Energetic charged particles accelerating along magnetic field lines (non-thermal)



- What can we learn?
  - particle energy
  - strength of magnetic field
  - polarization
  - orientation of magnetic field

Radio Emission Mechanisms

- Thermal emission - continuum
  - Blackbody radiation for objects with T~3-30 K
  - Brehmsstralung "free-free" radiation: charged particles interacting in a plasma at T; e^- accelerated by ion

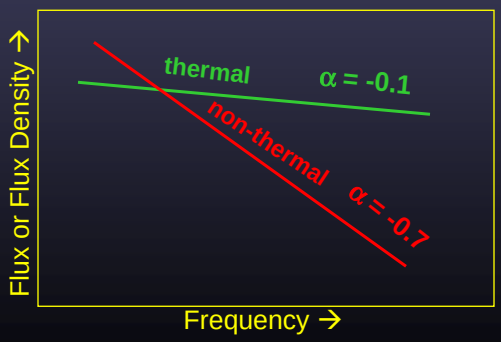


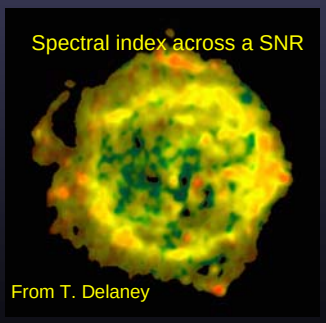
Courtesy of Dana Balser

- What can we learn?
  - mass of ionized gas
  - optical depth
  - density of electrons in plasma

Radio Emission Mechanisms

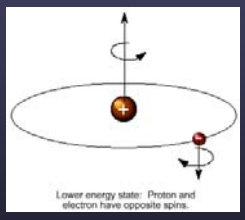
- What we measure from radio continuum
  - Radio flux or flux density at different frequencies
  - Spectral index α, where $S_\nu \sim \nu^\alpha$



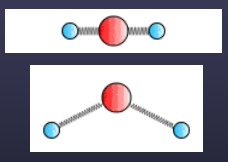


Radio Emission Mechanisms

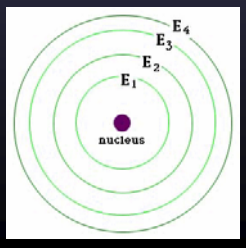
- Spectral line emission
  - Discrete transitions in atoms and molecules



Atomic Hydrogen
"spin-flip" transition
21 cm



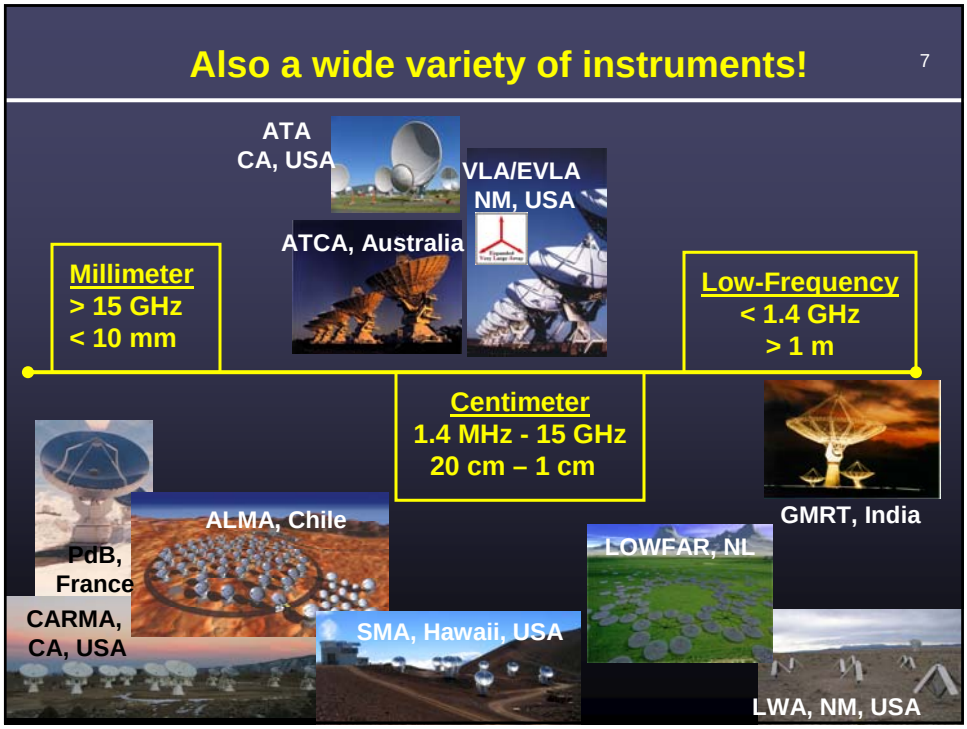
Molecular Lines
CO, CS, H_20, SiO, etc.!



Recombination Lines
outer transitions of H
H166α, H92α, H41α
(1.4, 8.3 GHz, 98 GHz)

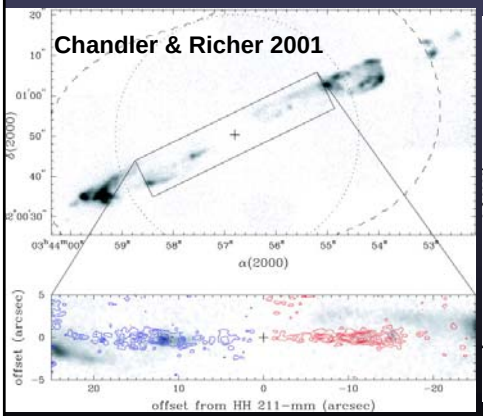
- What can we learn?
  - gas physical conditions (n, T)
  - kinematics (Doppler Effect)

Also a wide variety of instruments!

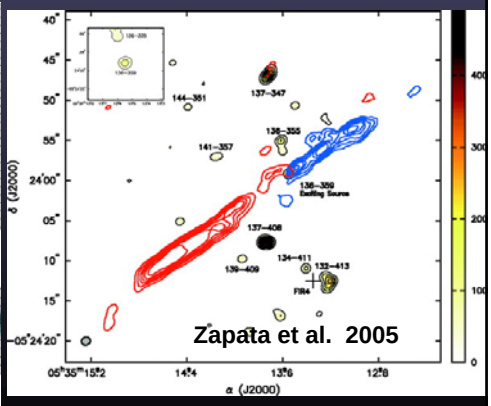


Tour of the Galaxy: Interstellar

- Low Mass Star Formation
  - obscured regions of the Galaxy with high resolution
  - collimated outflows powered by protostar – 10000s AU



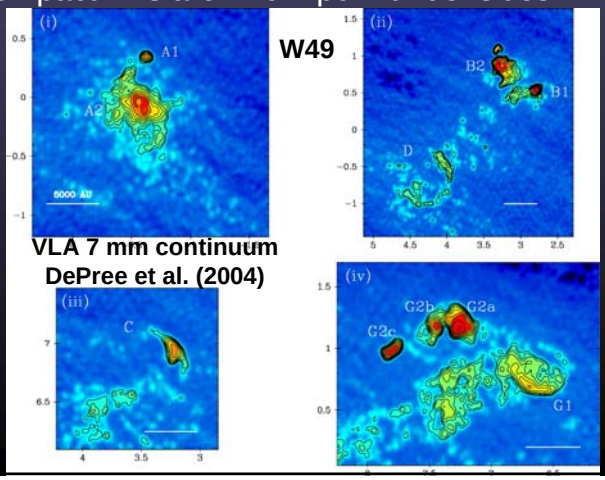
VLA 7mm spectral line (SiO) – 0.5”



SMA 1mm spectral line (CO 2-1) – 1”

Tour of the Galaxy: Interstellar

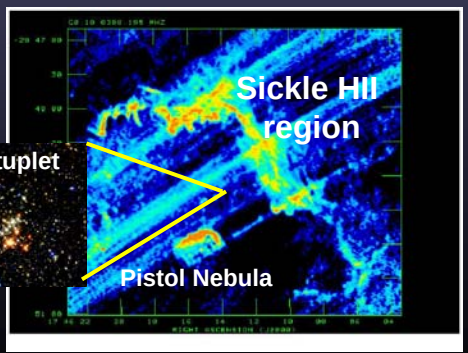
- High Mass Stars in HII Regions
  - high resolution shows objects forming of size ~1000s AU!
  - ultra-compact HIIs are < 0.1 pc with densities n > 10^4 cm^{-3}



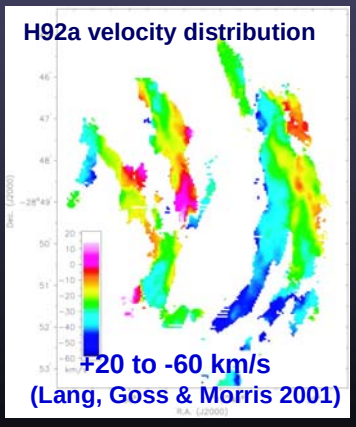
VLA 7 mm continuum
DePree et al. (2004)

Tour of the Galaxy: Interstellar

- HII regions: ionization & kinematics
  - continuum→ Lyman photons = # stars
  - continuum → density, mass of ionized H
  - RRLs → kinematics, physical conditions



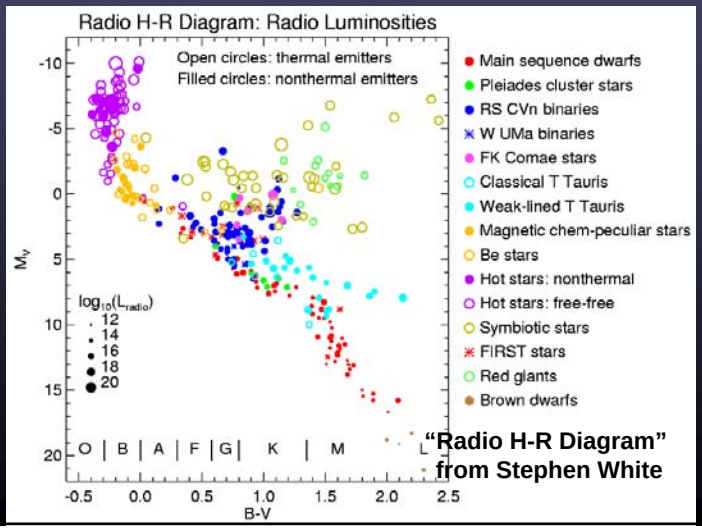
(Lang, Goss & Wood 1997)



(Lang, Goss & Morris 2001)

Tour of the Galaxy: Stellar Sources

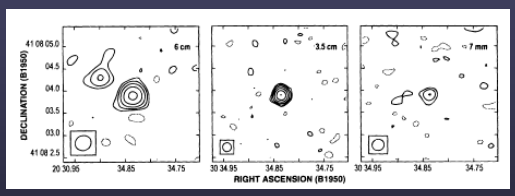
- Stars: Middle Age and Evolving



"Radio H-R Diagram" from Stephen White

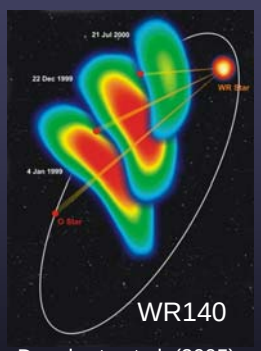
Tour of the Galaxy: Stellar Sources

- Stars: Middle Age and Evolving



CygOB2 #5– stellar wind emission
Contreras et al. (1996)

- Binary system with two O7I stars
- Mass loss ~ 4-5 x 10^{-5} M_o $year^{-1}$



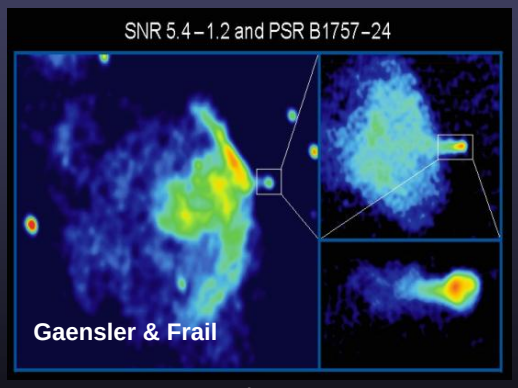
Dougherty et al. (2005)

- WR star and O-star binary
- Nonthermal, varying emission traces wind-wind collision

Tour of the Galaxy: Interstellar

- Supernova Remnants

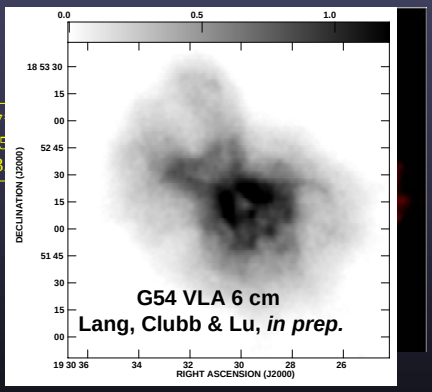
Cassiopeia A SNR
VLA 6 cm image
d = 3 kpc Cassiopeia

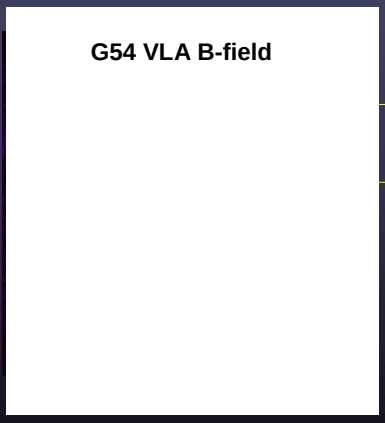


G5.4-1.2 and PSR B1757-24
d = 5 kpc Sagittarius
PSR moving 1,000 miles/sec

Tour of the Galaxy: Interstellar

- Star Death: Pulsar Wind Nebulae



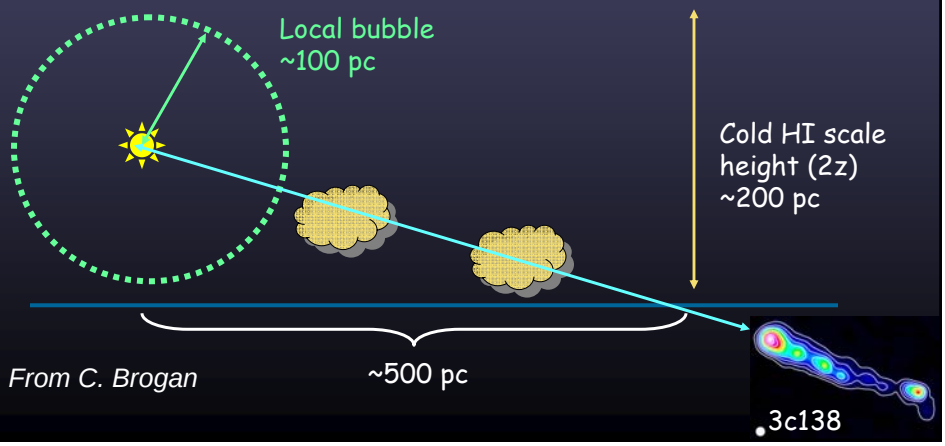


2.5' @
d=2 kpc
~ 1.4 pc

→ radio studies: particle energies, polarization, magnetic field orientation
→ VLA/VLBA pulsar proper motion can be combined with spin-axis orientation (X-ray)
→ Pulsar timing and discovery done with single dish radio telescopes – Parkes, GBT

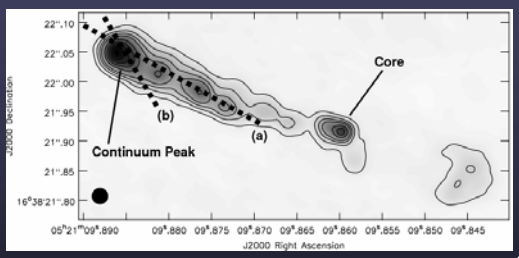
Tour of the Galaxy: Interstellar

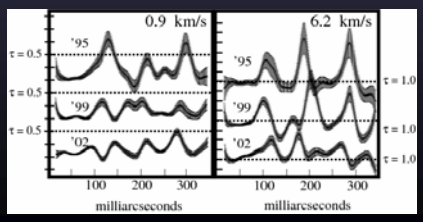
- HI absorption against bright sources
  - Interferometer resolves out Galactic HI emission features, allows the study of small-scale features



Tour of the Galaxy: Interstellar

- HI absorption toward 3c138





VLBA: '95, '99, 2002

Resolution: 20 mas = 10AU at 500 pc

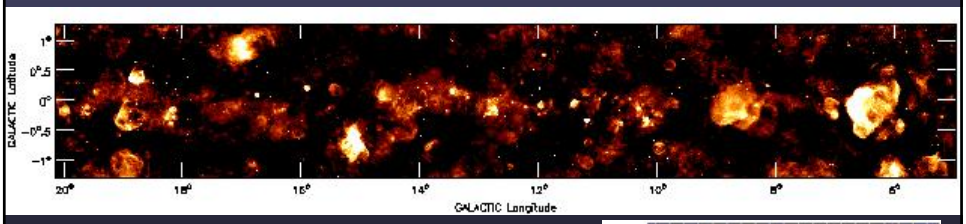
Changes in τ indicate changes in density of Galactic atomic gas

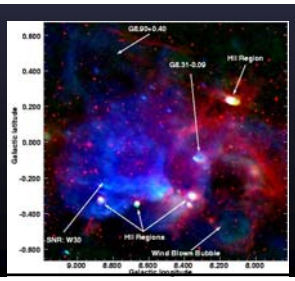
Sizescale of features **~ 25 AU!**

Brogan et al. (2005)

Tour of the Galaxy: Interstellar

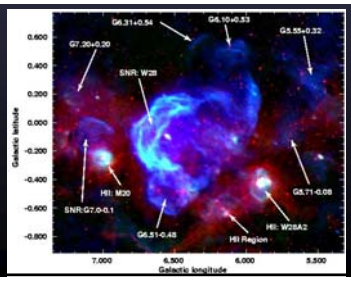
- Low-frequency survey of new SNRs - 90 cm
  - VLA, BCD configurations, resolution ~ 42”; 35 new SNRs





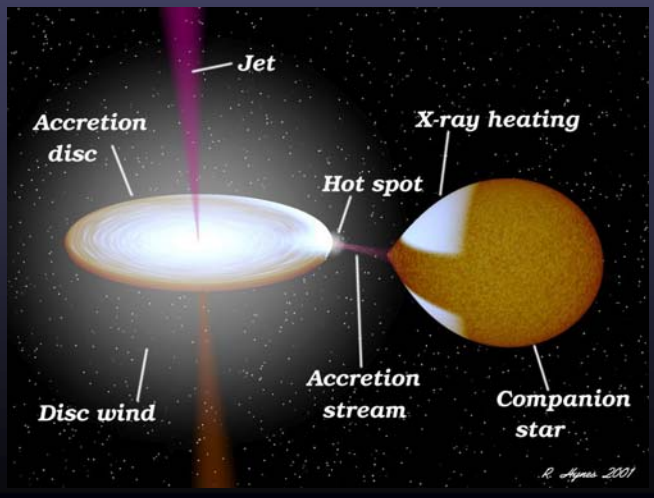
Brogan et al. 2006

Red: 8 μm MSX
Blue: VLA 90 cm
Green: 20 cm
VLA+SGPS



Tour of the Galaxy: Exotic

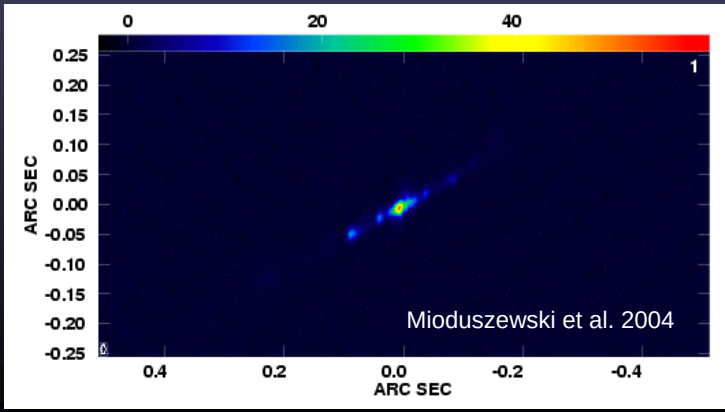
- SS433 – a Galactic Microquasar



Tour of the Galaxy: Exotic

- SS433 – a Galactic Microquasar

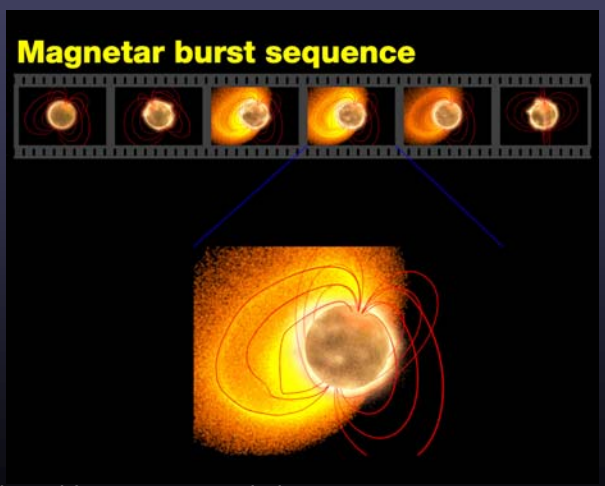
  - 39 2h VLBA observations over 42 days
  - 1.5 GHz, with a resolution along the jet of ~7 milliarcseconds
  ~35 AU at a distance of 5 kpc (i.e., roughly the size of the solar system).



Tour of the Galaxy: Exotic

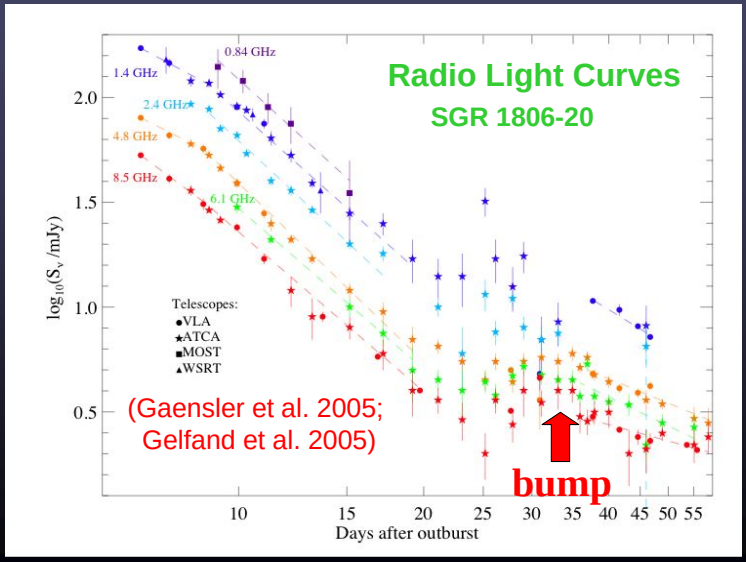
- SGR 1806-20: Magnetar Burst Activity

Soft Gamma-Ray Repeater

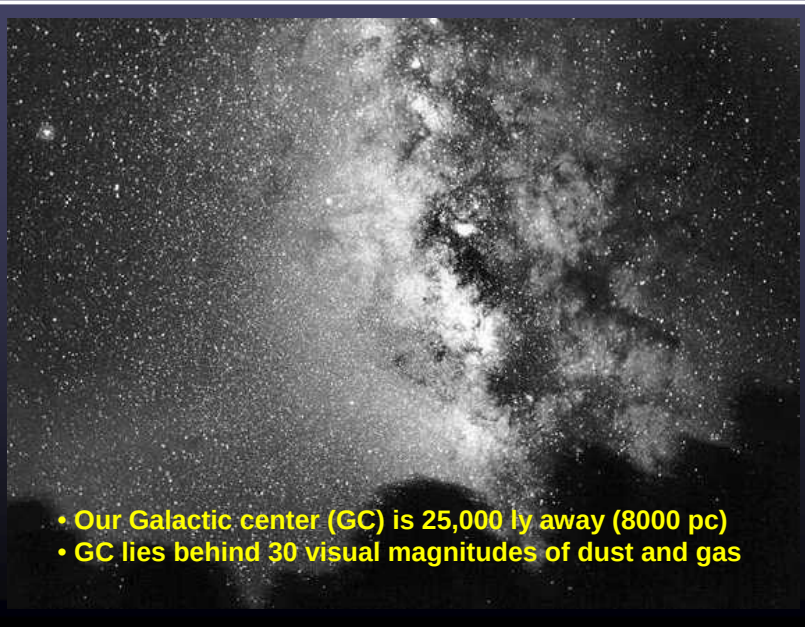


Adapted from Duncan and Thompson 1992

Tour of the Galaxy: Exotic

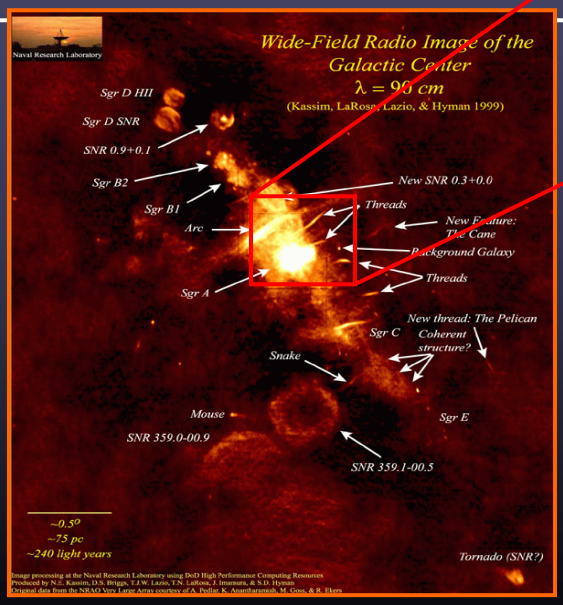


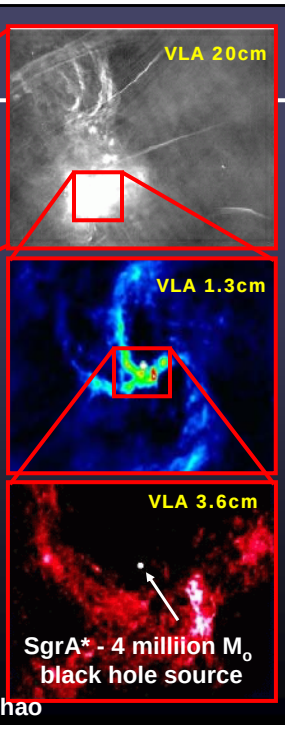
Tour of the Galaxy: The Galactic Center



- Our Galactic center (GC) is 25,000 ly away (8000 pc)
- GC lies behind 30 visual magnitudes of dust and gas

Center of our Galaxy

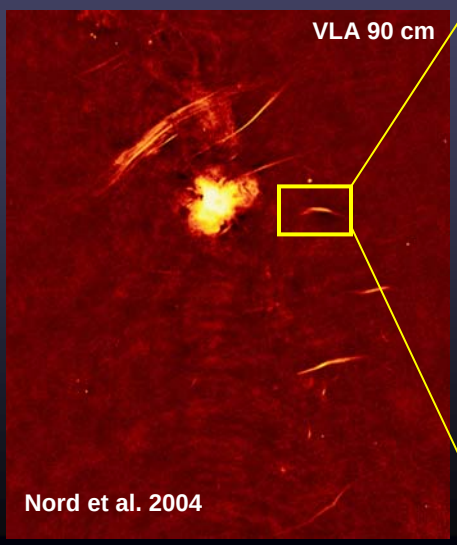


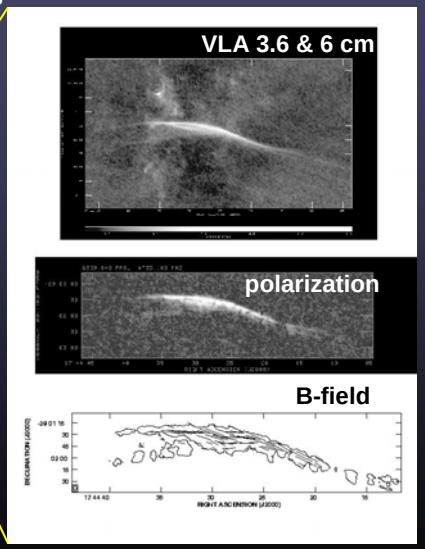


Credits: Lang, Morris, Roberts, Yusef-Zadeh, Goss, Zhao

Tour of the Galaxy: The Galactic Center

- Magnetic Field: Pervasive vs. Local?





Lang & Anantharamaiah, *in prep.*

Summary

- Radio Interferometry: a powerful tool
  - Physical insight into many different processes
  - Spatial scales comparable or better than at other wavelengths: multi-wavelength approach
- A great time for students & interferometry!
  - Amazing science opportunities with new tools