The Impact of the Galactic Center Arches Cluster: Radio & X-ray Observations

GC region (Sagittarius) is obscured by ~30 visual magnitudes of extinction – no optical, UV; we rely on *near-IR, radio and X-ray observations*

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Outline

- Arches Cluster: *Radio* results

  - Ionization and kinematics of dense molecular clouds
  - Detections of individual stellar winds in the cluster

- Arches Cluster: *X-ray* results

  - Arches cluster is one of the brightest sources in the GC
  *- Point-like X-ray sources and diffuse emission features**

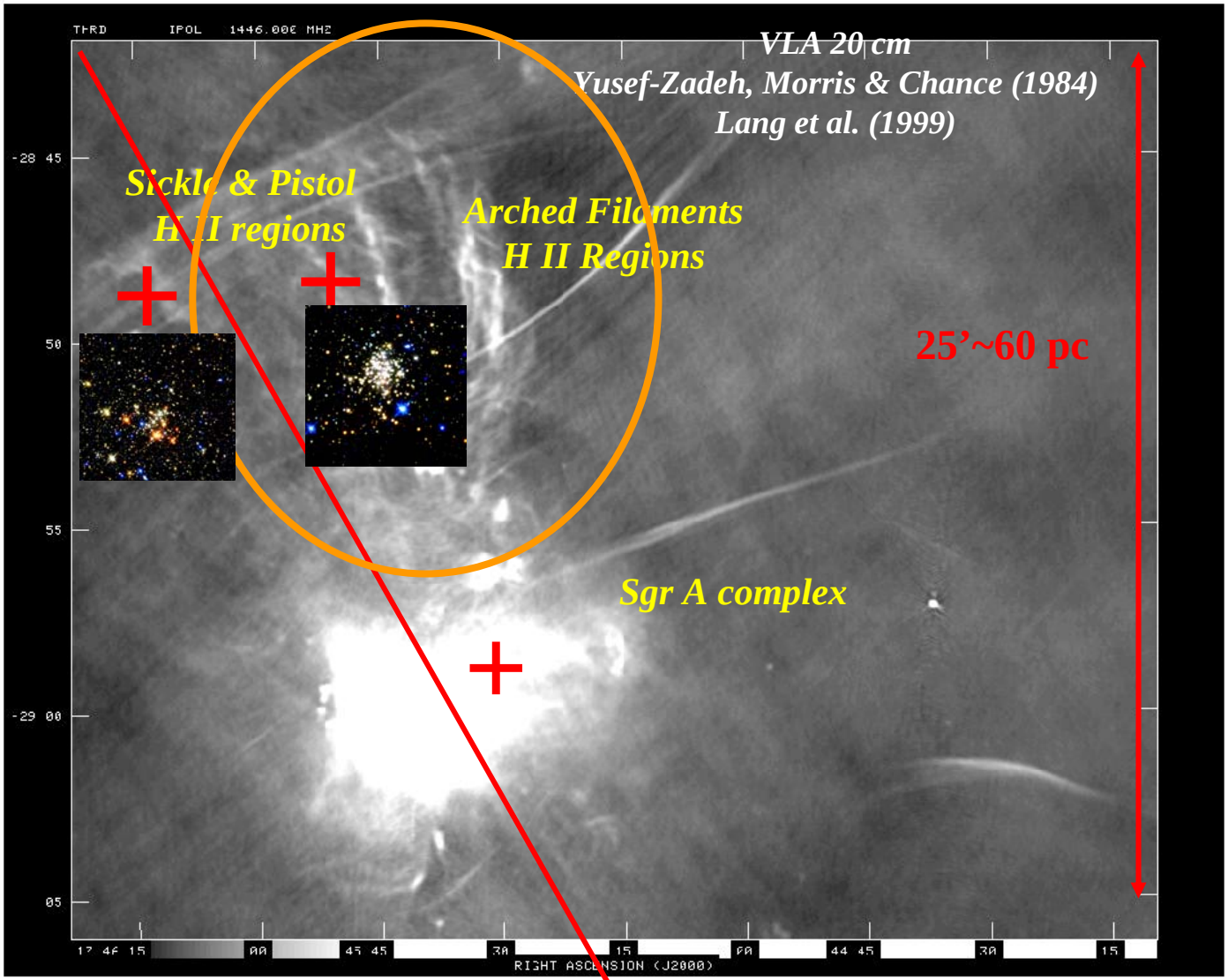
- Arches Cluster: *Xraydio* results

  - Nonthermal diffuse radio emission
  - Nonthermal point-like radio emission
  - Nature of the diffuse 6.4 keV emission

- Galactic Center: *Xraydio* results

  - several nonthermal radio and X-ray features (SNR? NTFs?)
  - diffuse 6.4 keV emission/molecular gas in GC: Casey Law poster

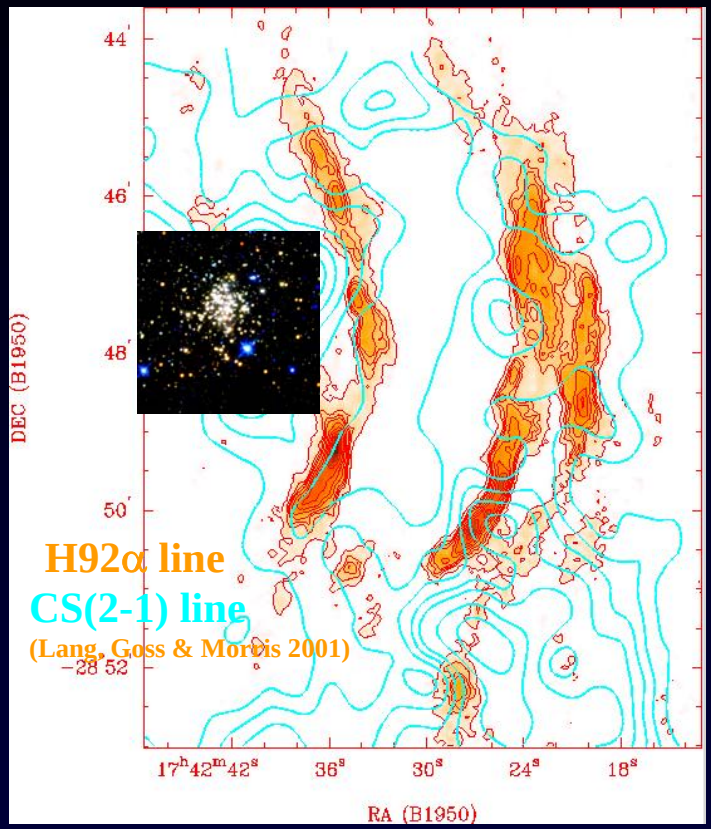
Arches Region: best example of interplay between GC components

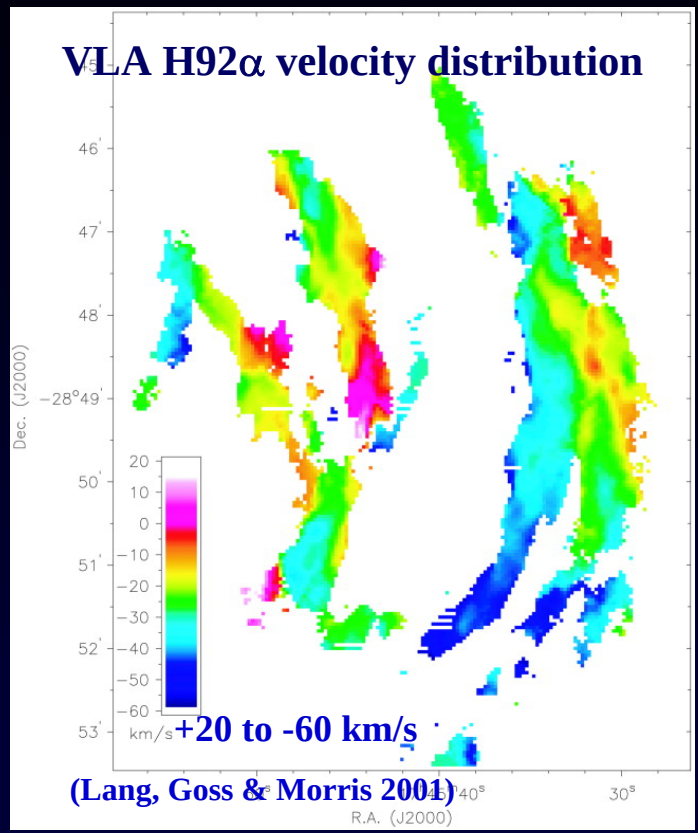


- GCs are known to have dense concentrations of
  - massive stars
  - molecular clouds
  - ionized gas
  - magnetic fields
  - hot ISM
  - SMBH

- the *interplay* between these components which gives rise to
  ENERGETIC
  EPISODIC
  activities

Radio: Ionization & Kinematics of Arches region





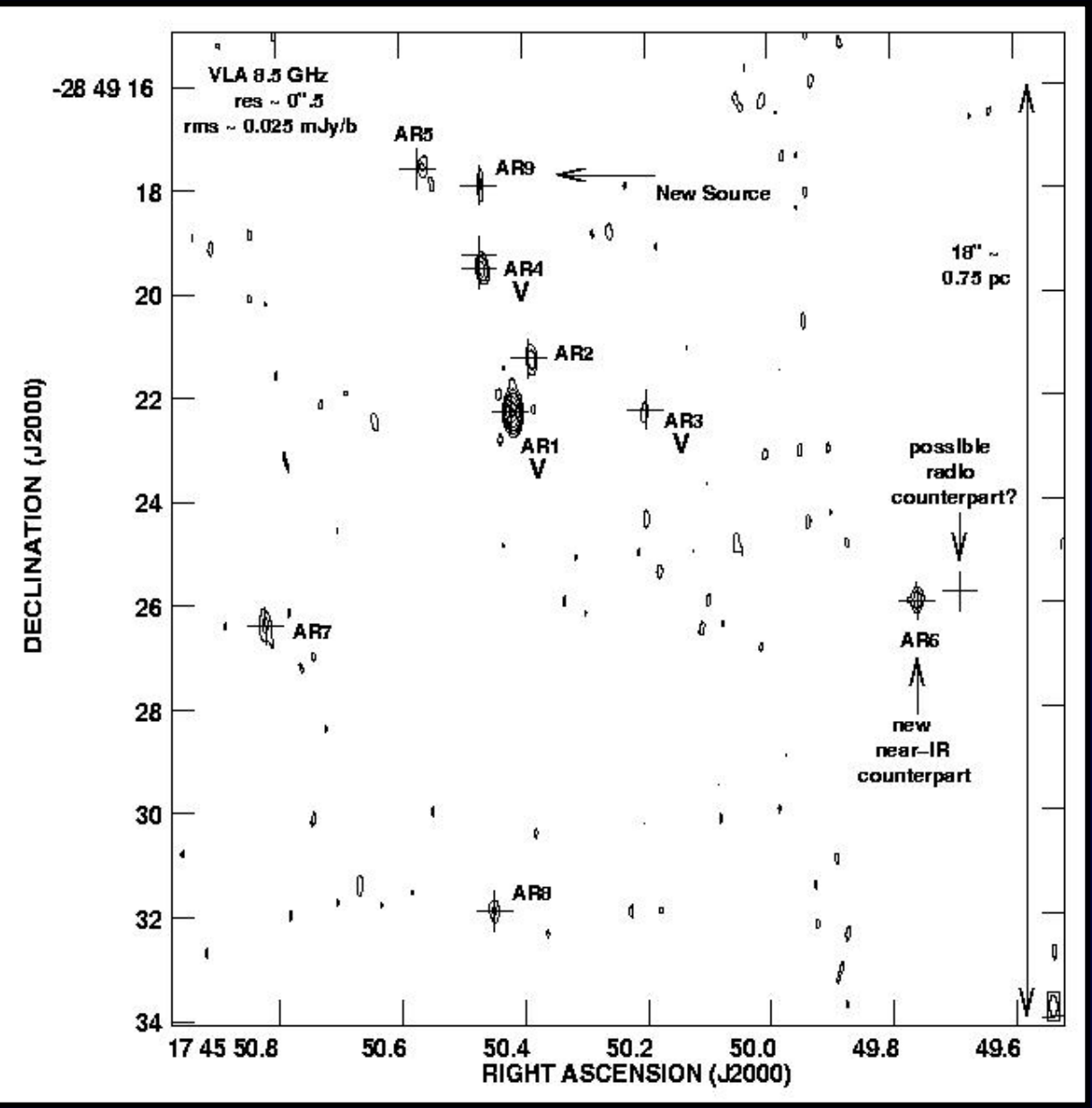
- Arches cluster can ionize edge of cloud
- N_{Lyc}(cluster) ~ 4×10^{51} ph. s^{-1}
- N_{Lyc} (radio cont.) ~ 3×10^{50} ph. s^{-1}
- Arches cluster could be ~20 pc away from molecular cloud

- molecular cloud on peculiar orbit around GC
- cluster not likely to have been born from this particular cloud = passerby
- large velocity difference between them:

Vgas = +20 to -60 km/s

Vstars = +95 km/s *(Figer et al. 2002)*

Radio: Stellar Winds in the Arches Cluster



- 9 sources detected at 4.9, 8.3, 22, 43 GHz

  $\alpha \sim +0.3$ to $+0.9$

  $\alpha \sim -0.7$ (AR6)

- + represent near-IR mass-losing sources

(Nagata et al. 95; Cotera et al. 96)

- "V" sources show 10-30% variability between epochs

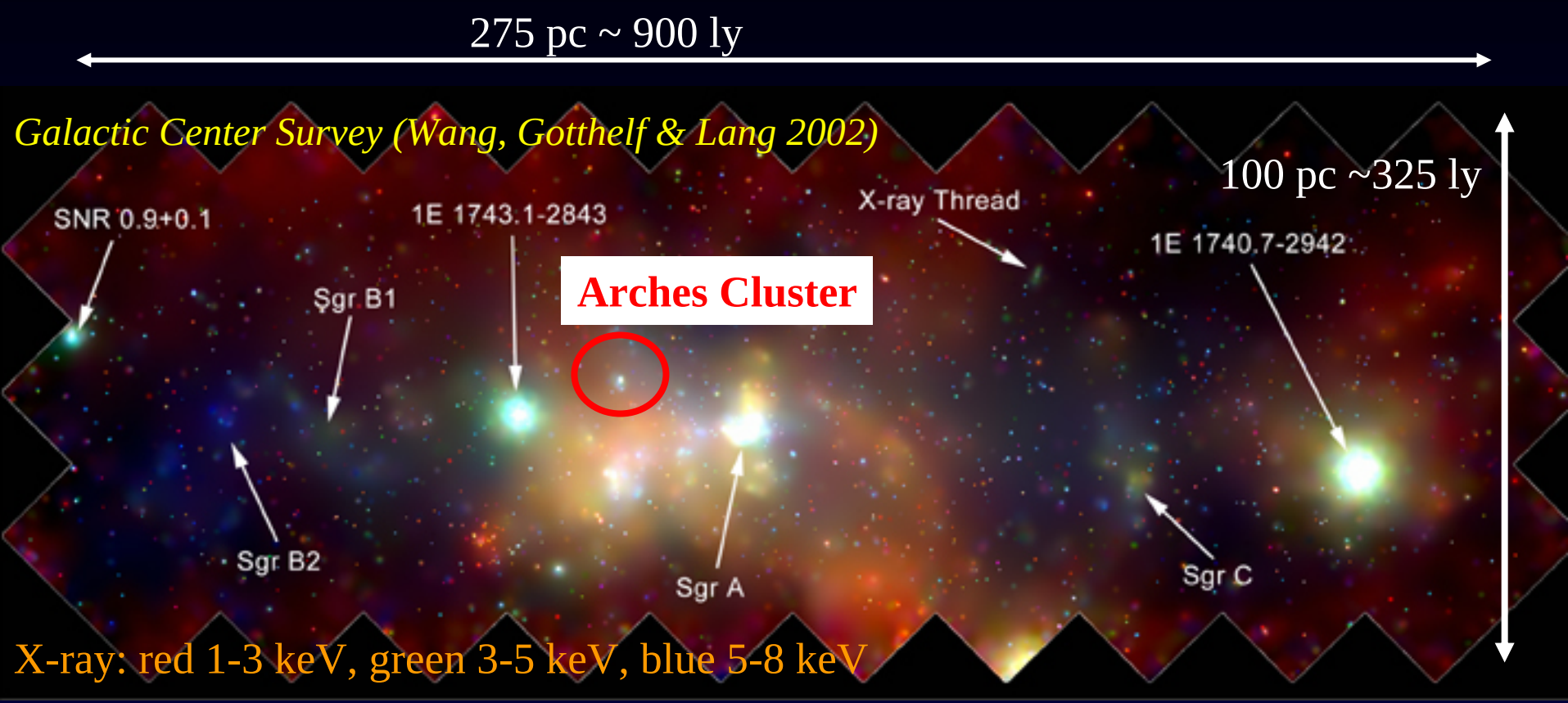
- high mass loss rates

~ 3 – 17 x 10^{-5} M_o yr^{-1}

(no clumping corrections)

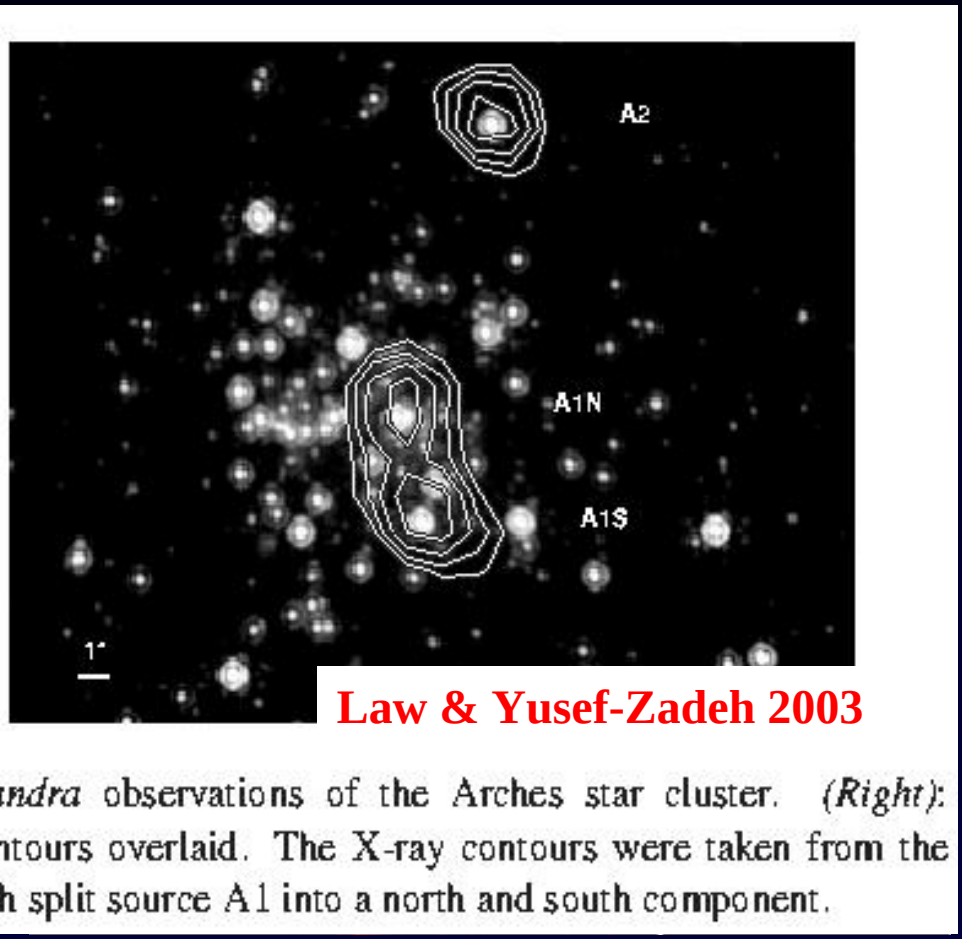
combination of 1999 (Lang et al. 2001b) and 2002 observations

Chandra X-ray Observations: Arches Cluster



- Arches cluster is one of brightest X-ray sources in the GC region

X-ray: Point like Sources in the Arches



Law & Yusef-Zadeh 2003

ndra observations of the Arches star cluster. *(Right)*: ntours overlaid. The X-ray contours were taken from the h split source A1 into a north and south component.

contours: 1-10 keV emission (Wang, Gotthelf & Lang 2002)
colorscale: NICMOS near-IR image (A.Cotera)

- 3 X-ray point sources in cluster as well as considerable diffuse emission (Yusef-Zadeh et al. 2002)

- point sources fit with two temperature model T ~ 0.7 keV and T~ 5 keV

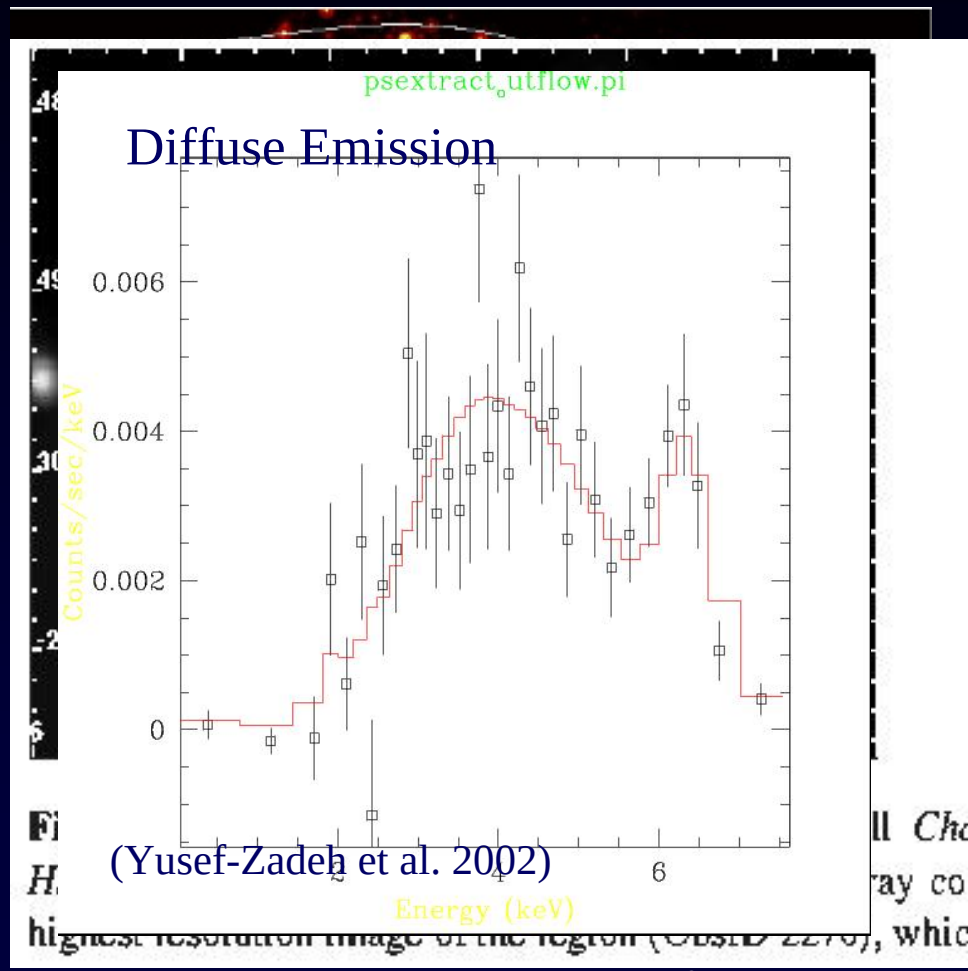
- L_x (0.5-8.0 keV) ~ 1-2 x 10^{35} erg/s

- 2 centrally located X-ray sources are coincident with
  - late type Of/Wolf-Rayet stars
  - radio continuum sources

- **interpretation of X-ray sources:**
  - colliding wind binary sources
  - similar to NGC3603, R136

X-ray: Diffuse X-ray emission in the Arches

- Diffuse X-ray emission prominent in the Arches cluster
- L_x (0.5-8.0 keV) ~ 5 x 10^{35} erg/s for all components of the Arches
- "Cluster wind" – the resulting outflow of shock-heated gas caused by the collisions of 10's of stellar winds
- Canto et al. (2000) predict such a wind and simulations by Raga et al. (2001)
- Interesting feature in the spectrum of the diffuse emission: 6.4 keV line (after point sources are subtracted)
→ more on this shortly



(Yusef-Zadeh et al. 2002)

contours: 1-10 keV emission (Wang, Gotthelf & Lang 2002)
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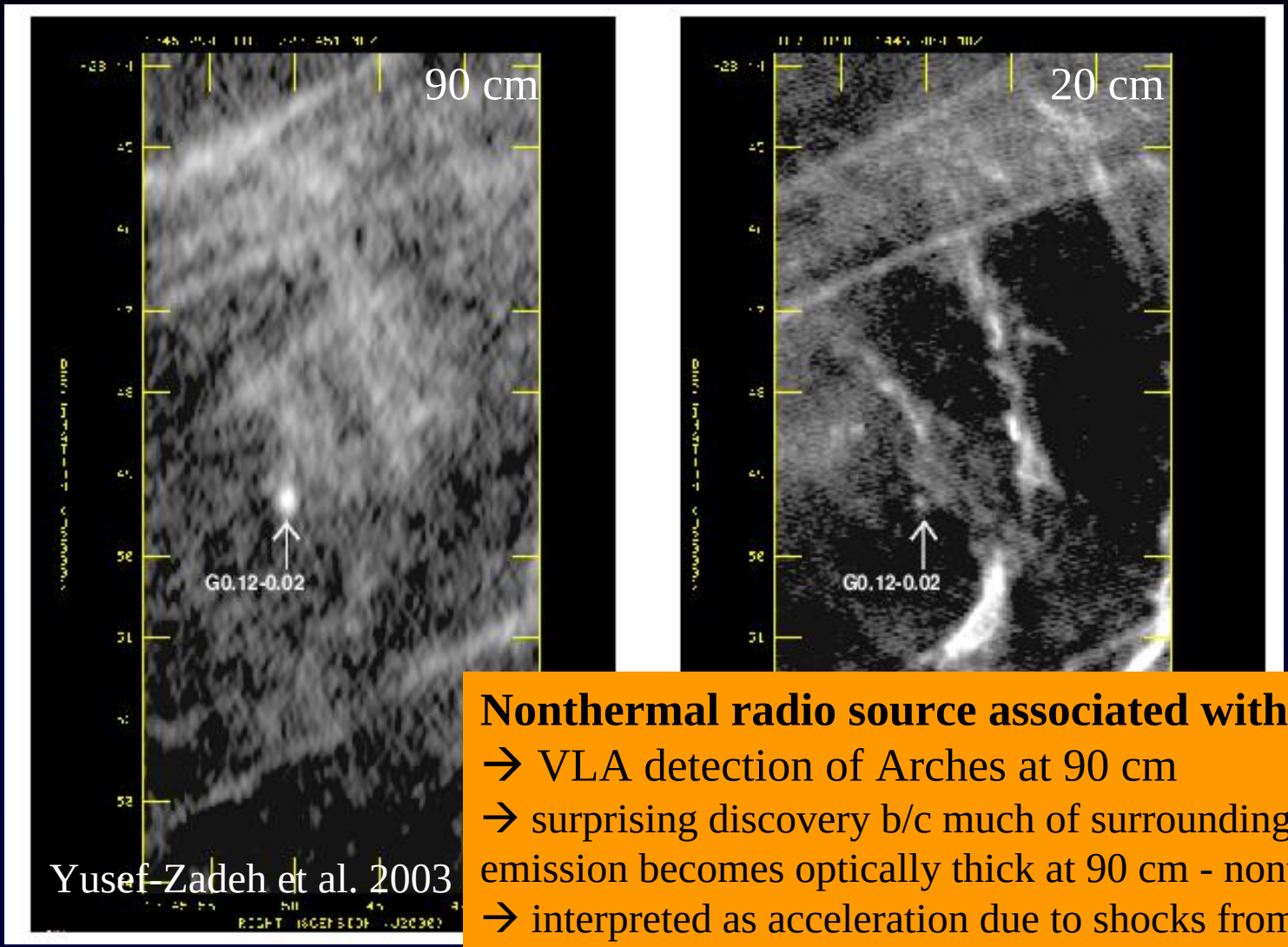
Xraydio: Nonthermal Diffuse Radio Emission



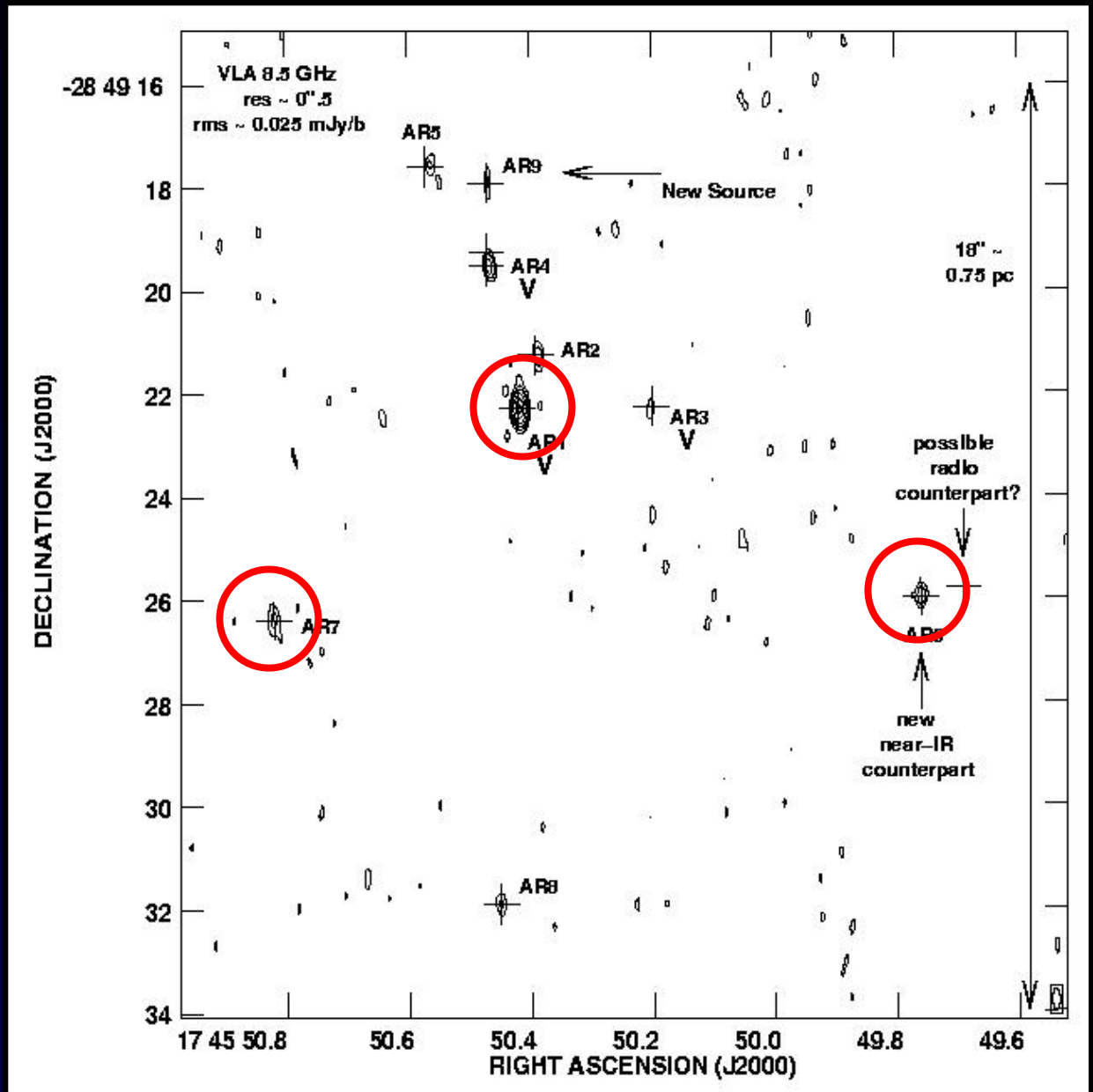
Nonthermal radio source associated with Arches

→ VLA detection of Arches at 90 cm

→ surprising discovery b/c much of surrounding radio emission becomes optically thick at 90 cm - nonthermal

→ interpreted as acceleration due to shocks from wind-wind collisions in the cluster core (outflow)

Xraydio: Nonthermal Radio Stellar Wind Emission

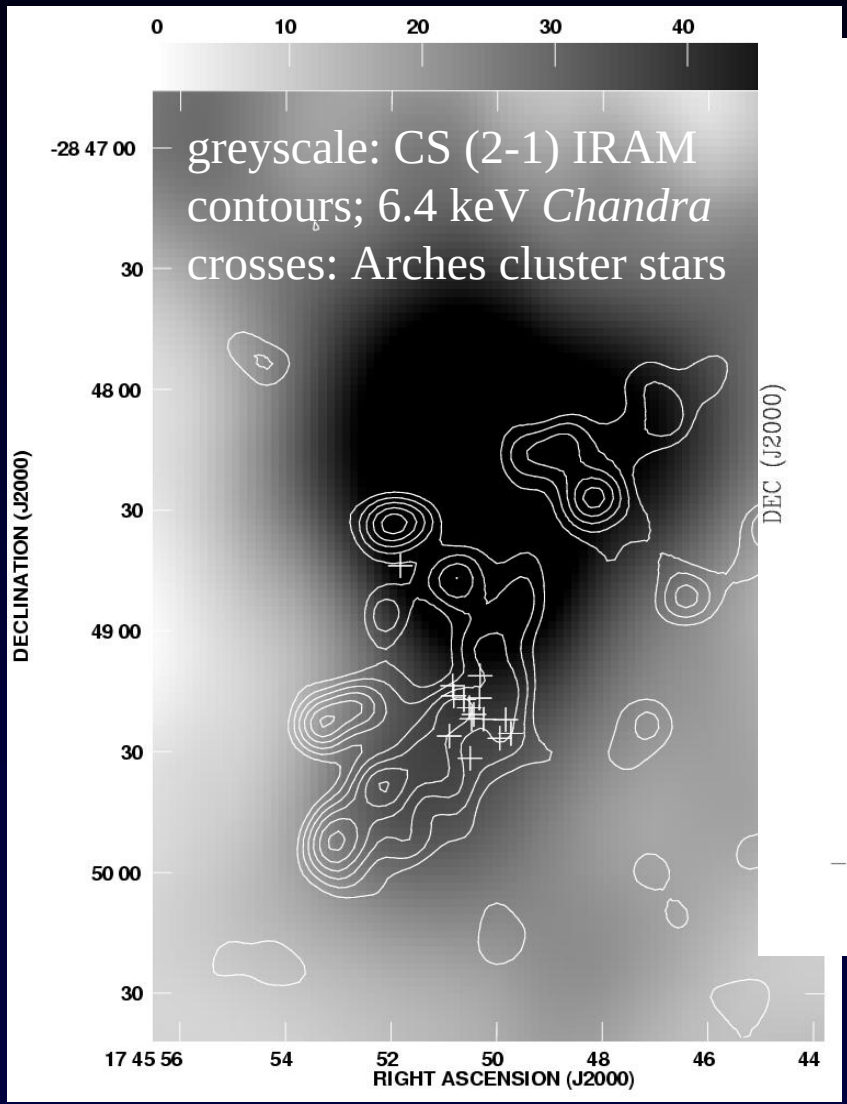


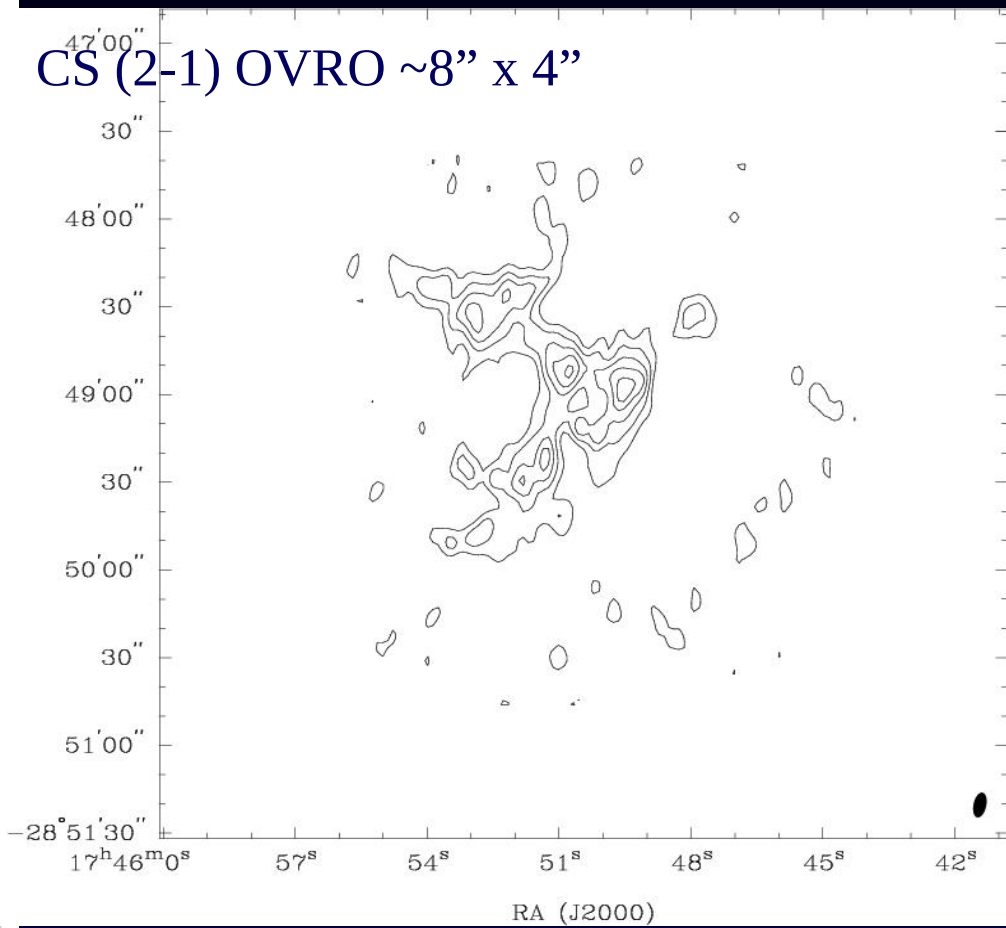
- Several Arches radio wind sources show flattened or nonthermal (NT) spectral index

→ NT wind component
→ 30-60% of winds have NT component (Leitherer et al. 1997
→due to wind-wind collisions in a binary system

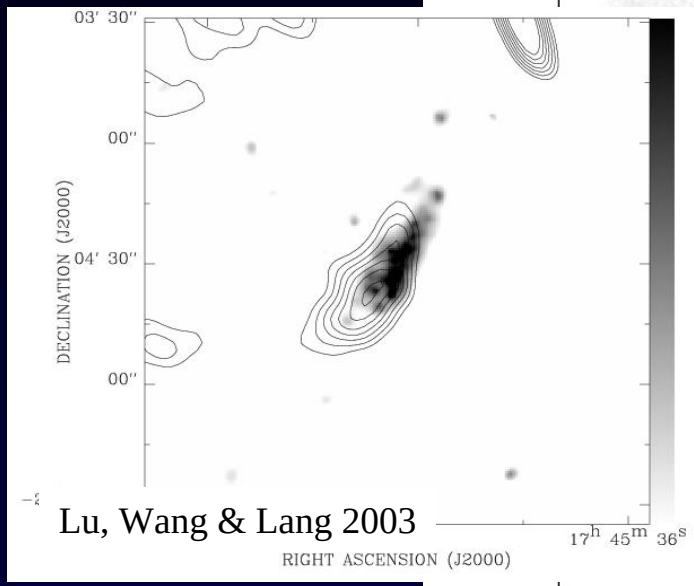
- VLBA radio observations of Arches cluster might show compact NT emission (proposed) & confirm
  - NT component
  - stars are binaries!

Xraydio: Correlation between 6.4 keV emission and molecular gas near Arches





Xraydio: Other GC sources of both X-ray & Radio



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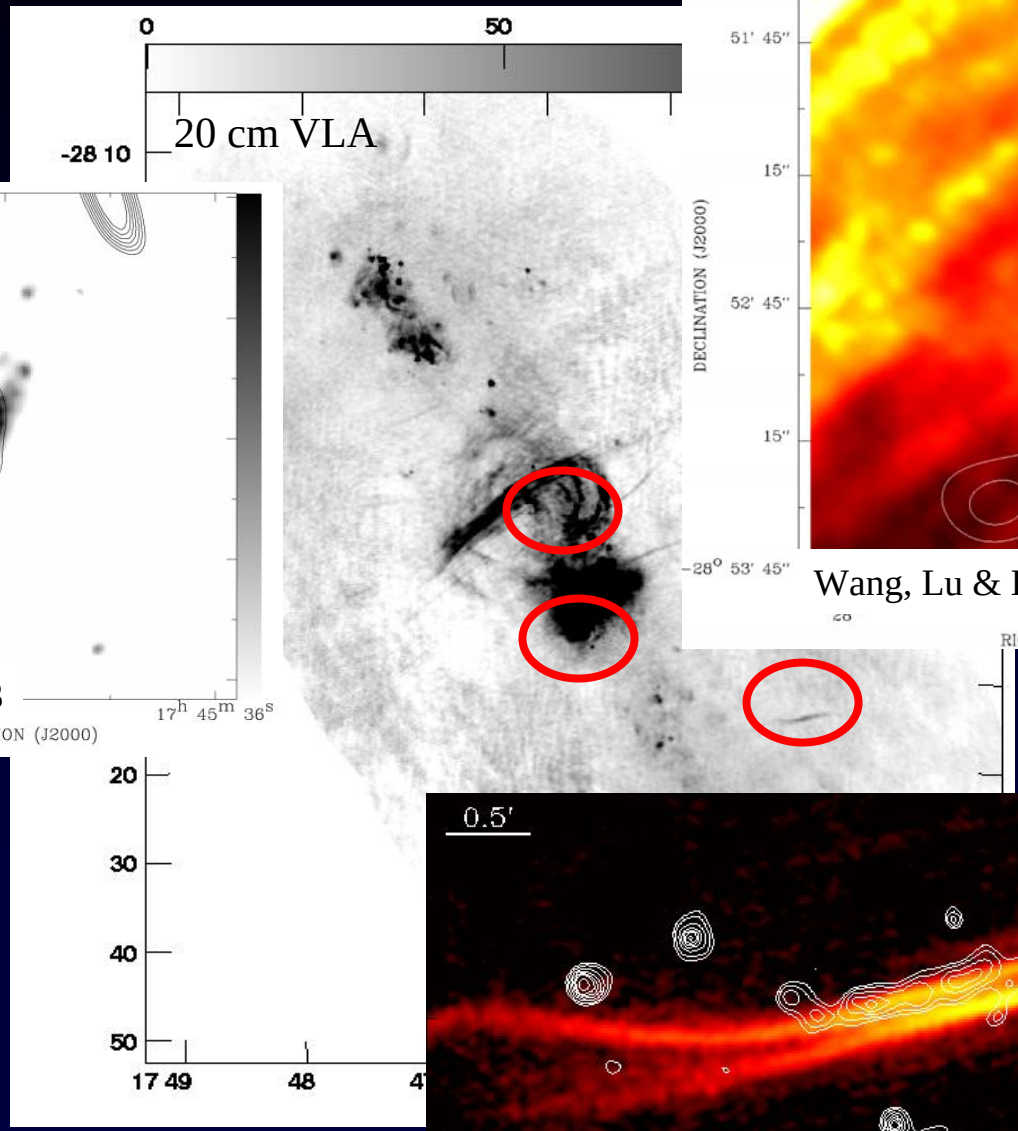
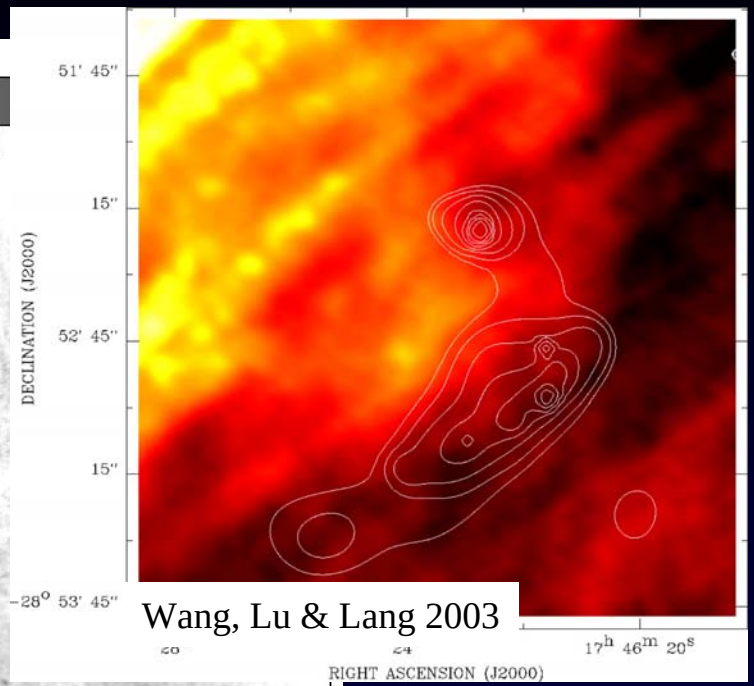
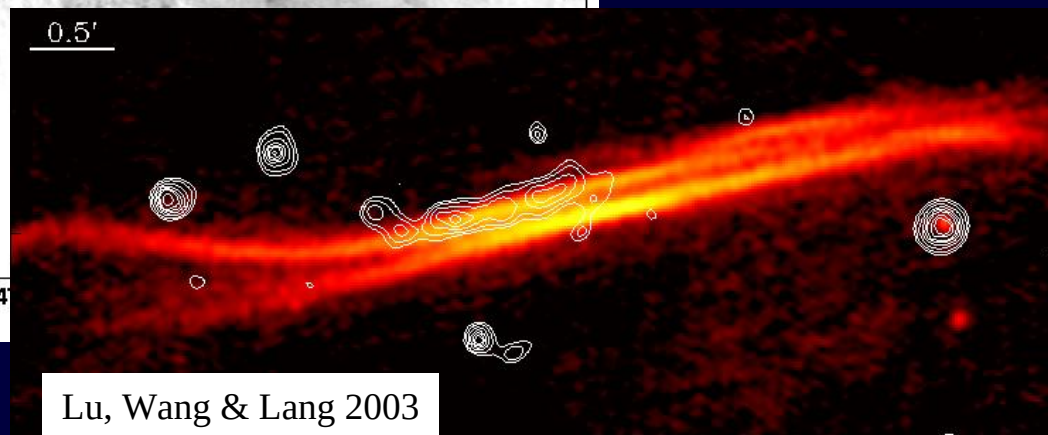


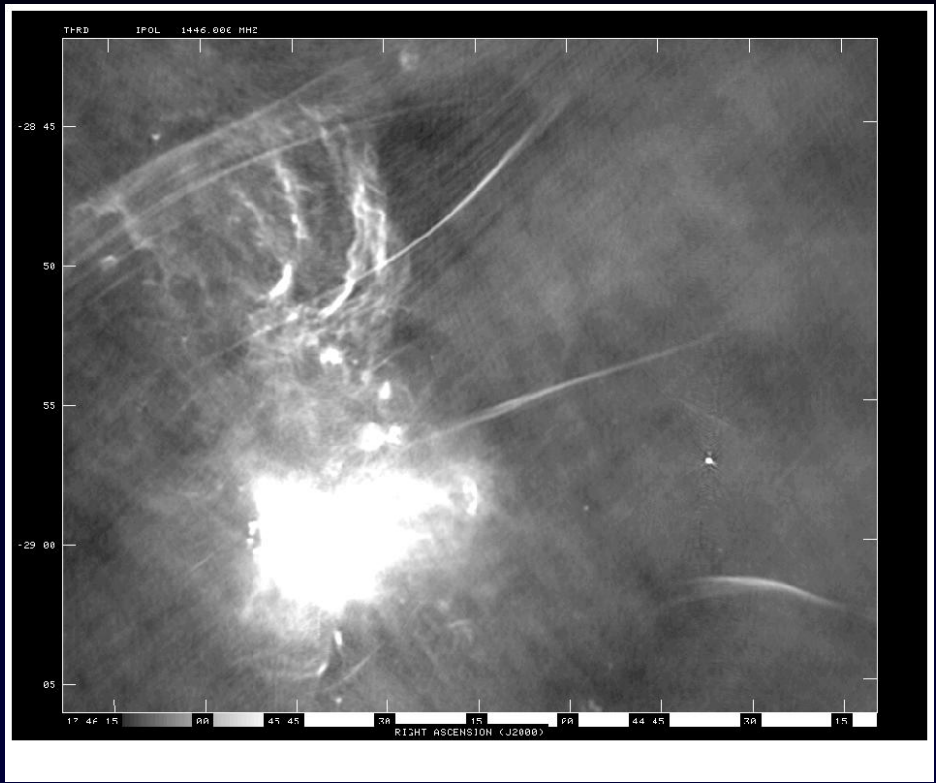


Wang, Lu & Lang 2003



Lu, Wang & Lang 2003

Conclusions



- Arches Cluster

- responsible for ionizing cloud edges

- young stars losing mass at high rates, collisions of winds

- collective expanding: 'cluster wind'

- X-ray sources may illuminate the molecular gas (6.4 keV) near Arches

- The Arches Cluster environment is similar to NGC3603 and 30 Dor

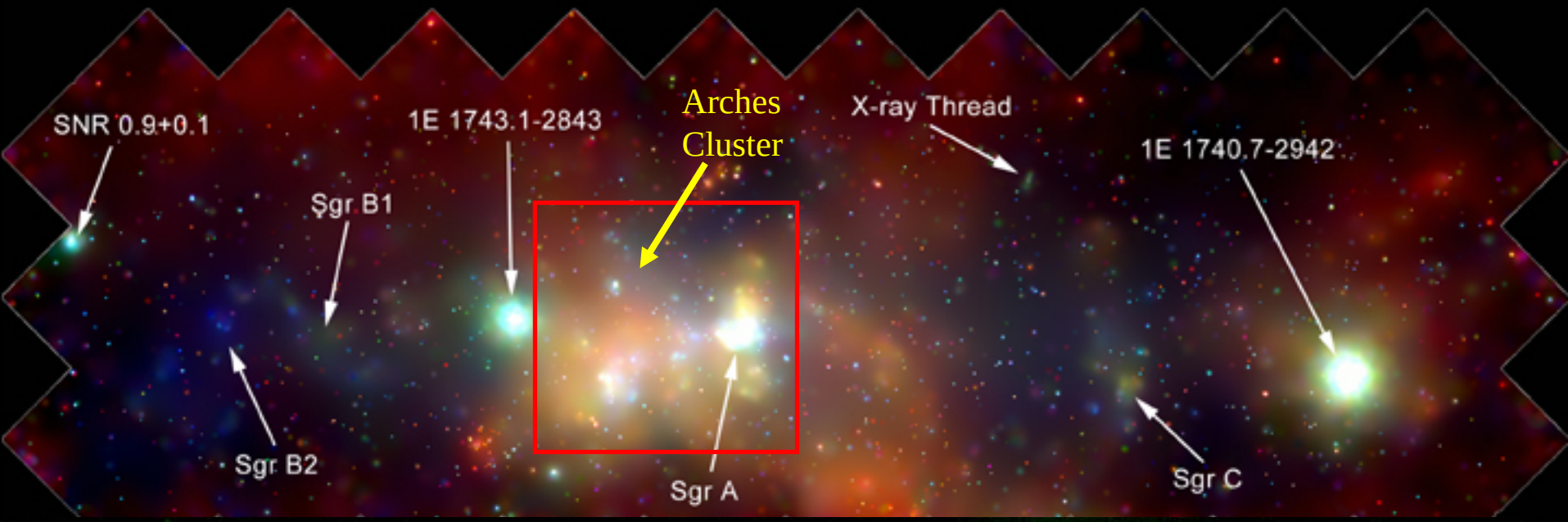
- GC region is much more completely understood by incorporating massive Stars and their influence

- Overall diffuse hot emission in GC (traced by X-rays) likely to arise from massive star activities – SNR, winds

➢ is our Galactic Center unique?

- identify and compare similar structures, interplay in nearby galaxies

Massive star activities driving energetics in the GC



MSX Mid-IR 25 μm

30 pc