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

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

VLA 20 cm
Lang et al. (1999)

Sickle & Pistol H II regions

Arched Filaments H II Regions

Sgr A complex

25’~60 pc
Radio: Ionization & Kinematics of Arches region

- Arches cluster can ionize edge of cloud
- $N_{\text{Lyc}}$ (cluster) $\sim 4 \times 10^{51}$ ph. s$^{-1}$
- $N_{\text{Lyc}}$ (radio cont.) $\sim 3 \times 10^{50}$ ph. s$^{-1}$
- Arches cluster could be $\sim 20$ 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: $V_{\text{gas}} = +20$ to $-60$ km/s
  $V_{\text{stars}} = +95$ km/s (Figer et al. 2002)

H92$\alpha$ line
CS(2-1) line
(Lang, Goss & Morris 2001)

VLA H92$\alpha$ velocity distribution
(Lang, Goss & Morris 2001)
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
  $\sim 3 - 17 \times 10^{-5} \, M_\odot \, yr^{-1}$
  (no clumping corrections)

combination of 1999 (Lang et al. 2001b) and 2002 observations
• Arches cluster is one of brightest X-ray sources in the GC region
X-ray: Point like Sources in the Arches

• 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 $T \sim 0.7 \text{ keV}$ and $T \sim 5 \text{ keV}$

• $L_x (0.5-8.0 \text{ keV}) \sim 1-2 \times 10^{35} \text{ erg/s}$

• 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

• $L_x (0.5-8.0 \text{ keV}) \sim 5 \times 10^{35} \text{ erg/s}$ 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

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

- greyscale: CS (2-1) IRAM contours; 6.4 keV Chandra crosses: Arches cluster stars

CS (2-1) OVRO ~8” x 4”
Xraydio: Other GC sources of both X-ray & Radio

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

➢ is our Galactic Center unique?
  - identify and compare similar structures, interplay in nearby galaxies

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

MSX Mid-IR 25 µm

Sgr B2

Radio Arc Region