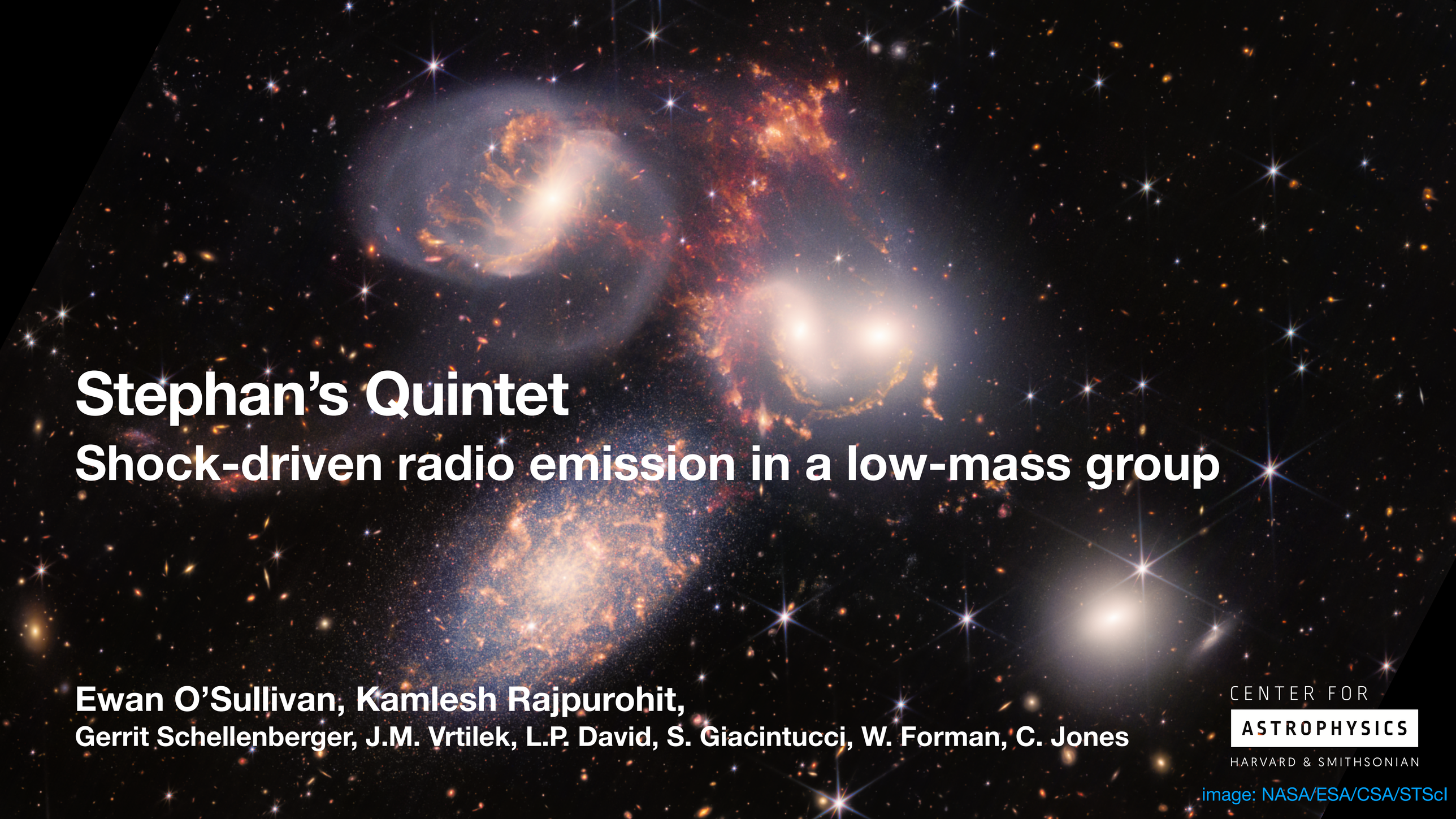

Stephan's Quintet

Shock-driven radio emission in a low-mass group

Ewan O'Sullivan, Kamlesh Rajpurohit,
Gerrit Schellenberger, J.M. Vrtilek, L.P. David, S. Giacintucci, W. Forman, C. Jones

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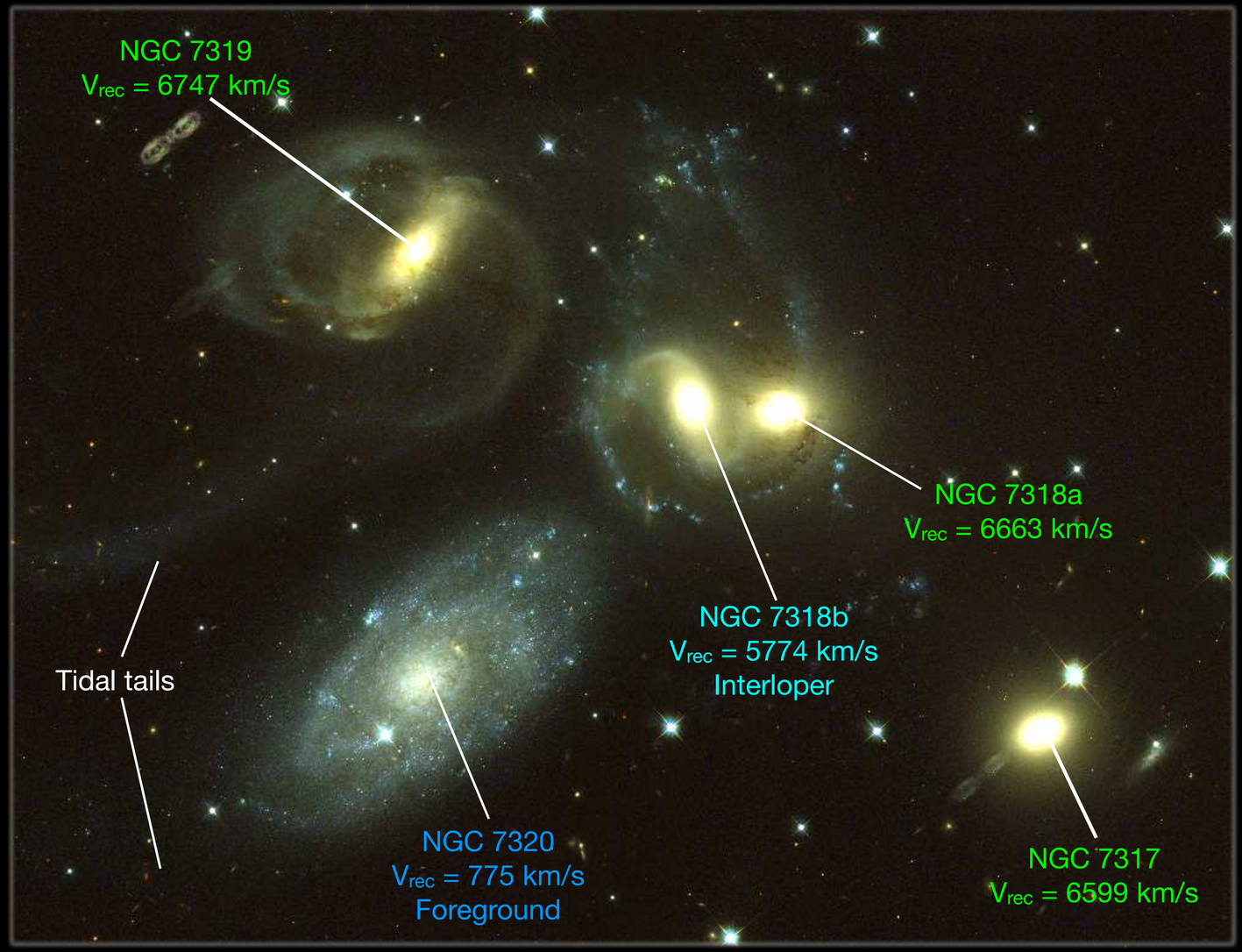
HARVARD & SMITHSONIAN

image: NASA/ESA/CSA/STScI

Stephan's Quintet

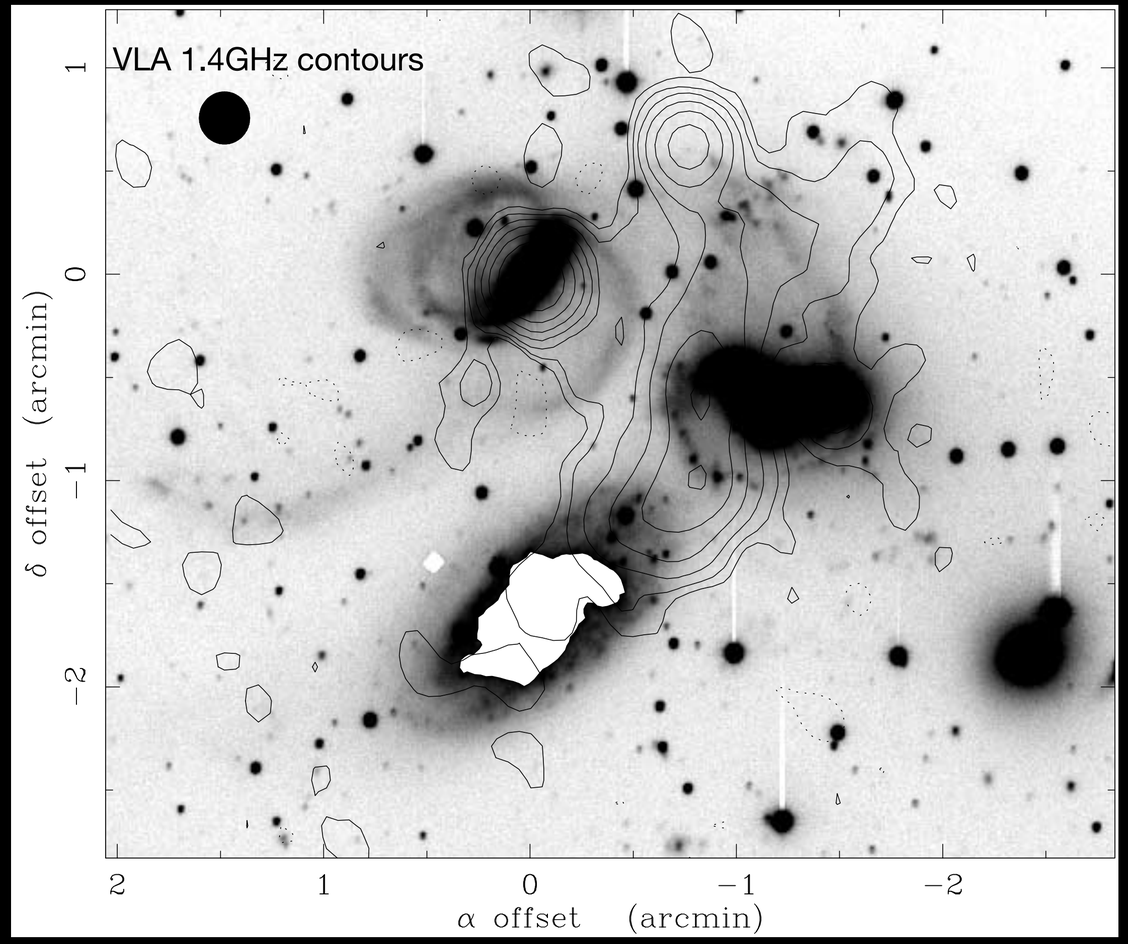
Low-mass, compact galaxy group

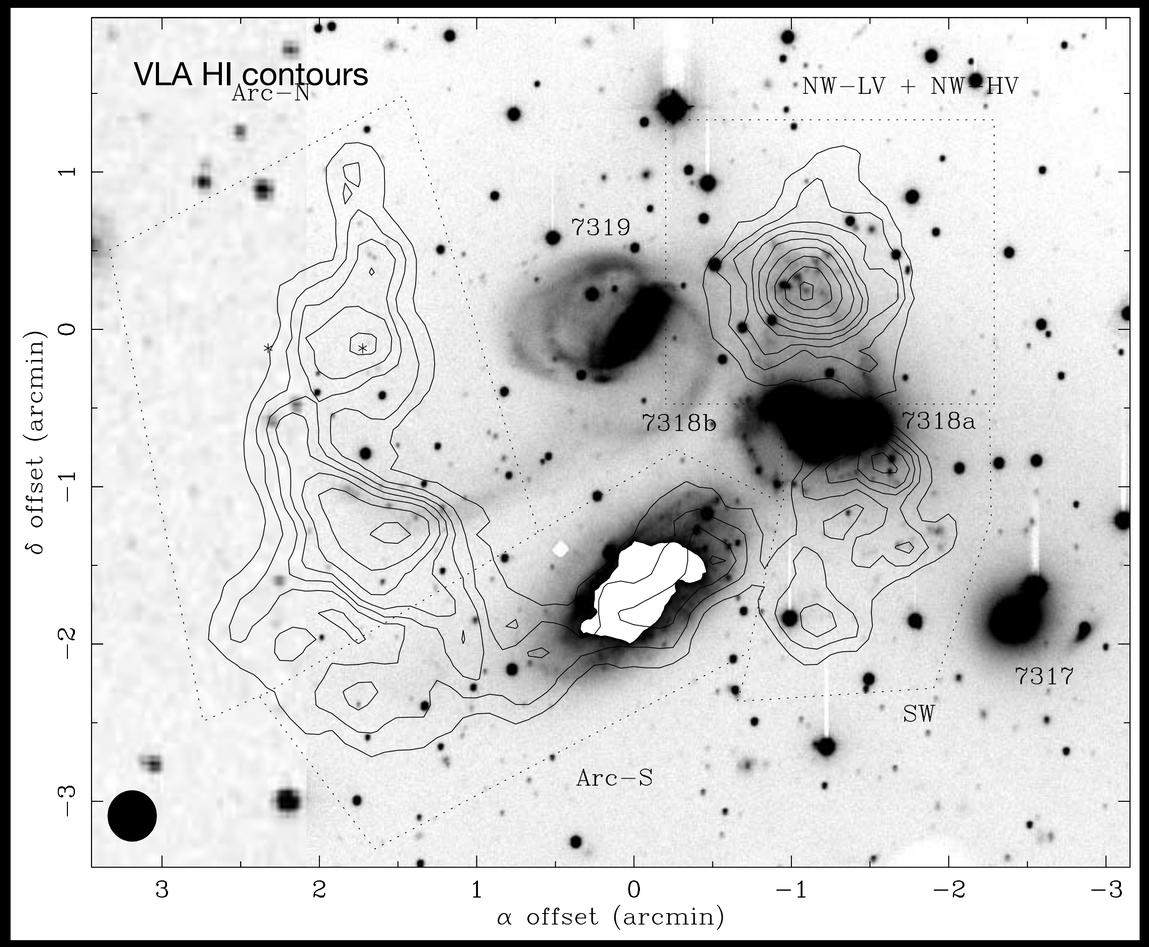
- Poster child for galaxy interactions and collisions
- NGC 7320 is foreground dwarf
- NGC 7318b has ~900 km/s velocity relative to other group members
- Group distance 94 Mpc, diameter ~4' / ~110 kpc
- kT ~ 0.6 - 0.8 keV
  Lx ~ 2-4 x10^{41} erg/s



Stephan's Quintet: the shock ridge

Williams et al. 2002



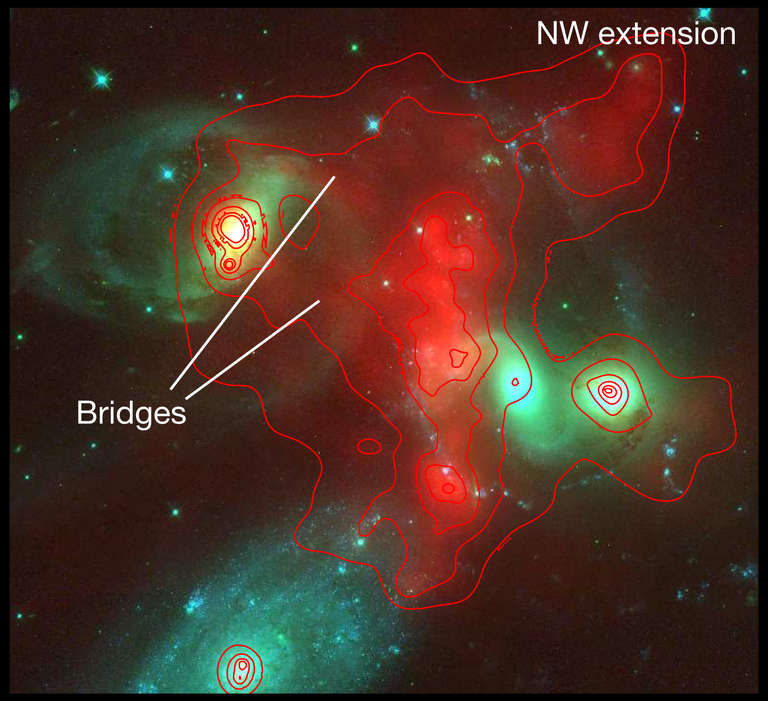


Early radio observations revealed a N-S ridge of continuum emission, HI mainly outside galaxies

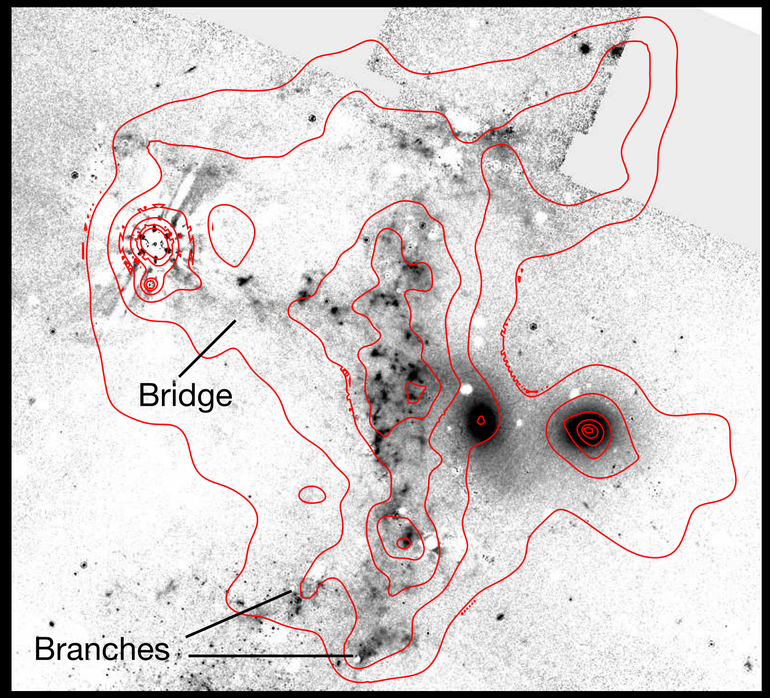
➜ **tidally-stripped gas shocked by collision with NGC 7318b?**

See also: colliding spiral pairs, e.g., radio bridge in the Taffy galaxies

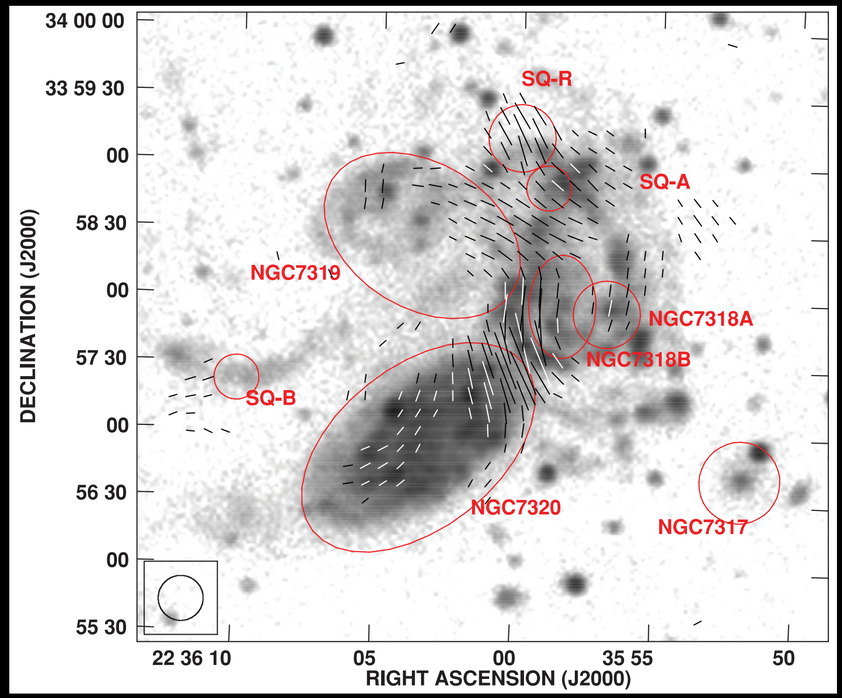
Stephan's Quintet: multiwavelength



Chandra 0.3-2 keV on HST optical



JWST MIRI warm H_2 map, Chandra contours



4.86 GHz pol on GALEX UV (Nikiel-Wroczyski+ 2013)

Exceptional multi-λ coverage: X-ray (*Chandra, XMM*), UV (*HST, GALEX*), IR (*JWST, Spitzer, Herschel*), mm-wave (ALMA, ACA), optical IFUs (WEAVE, SITELLE, GMOS), etc.

- Shock region is highly multiphase (CO, H_2O, H_2, C+, Hα, X-ray, relativistic plasma)
- More complex than simple ridge - bridges to NGC 7319, NW extension, branches at S tip
- Typical polarization fraction ~2% at 4.86 GHz, ~5% in ridge (Nikiel-Wroczynski+ 2013, 2020)

Stephan's Quintet: Questions

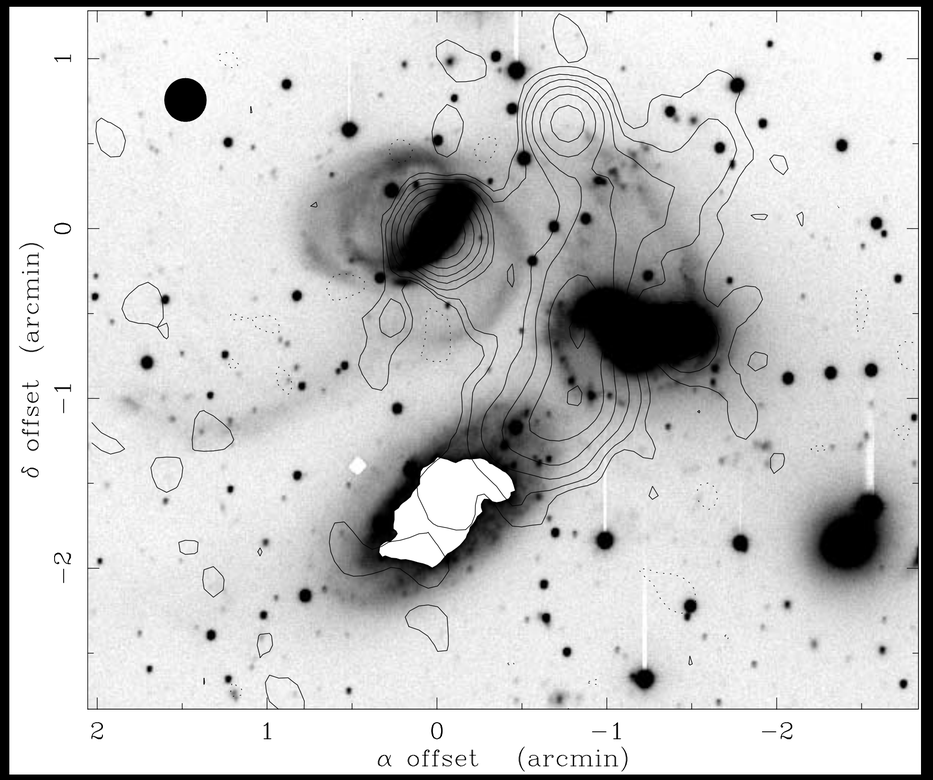
✗ What is the age of the collision?
- youngest star clusters <10 Myr

✗ What is the collision vector?
- Is there a plane-of-sky component?

✗ How was the radio ridge formed?
- Direct collision of HI clouds? collision velocity of 900 km/s is Mach ~25
- DSA from a shock in the X-ray phase? A preshock kT=0.4 keV gives Mach ~2.7
  - Both predict kT ≈ 1.2-1.3 keV, too hot!
  - Shock likely oblique, turbulent line cooling may dominate
- Adiabatic compression? Requires Mach ~3.8 (Arnaudova+ 2024)
  - DSA or compression require survival of relativistic seed electrons from SNae

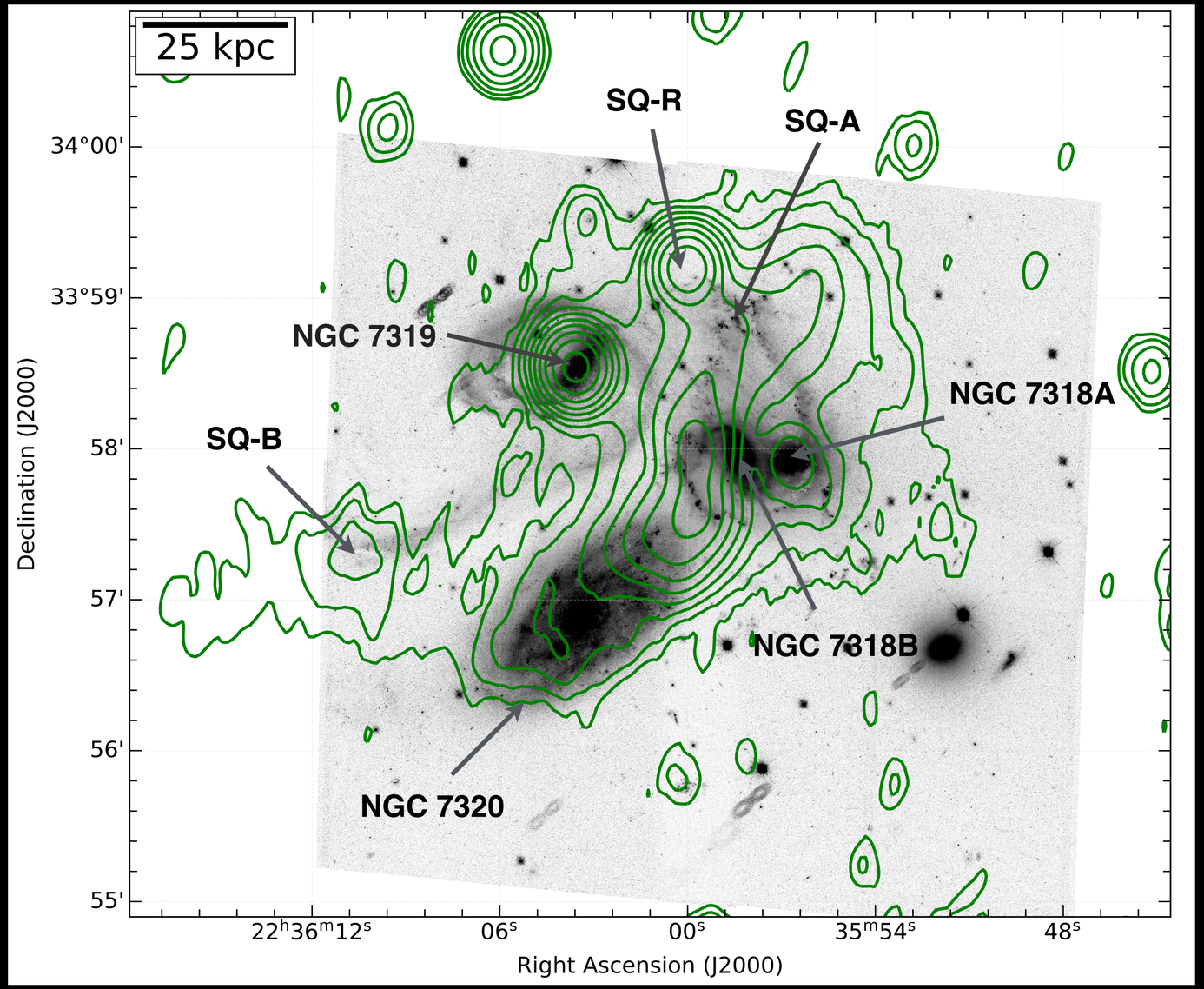
✓ New data: MeerKAT L-band (6 hrs), uGMRT bands 3 & 4 (7 hrs each)
✓ Archival data: LoTSS DR1, JVLA S & C band [obs'd 2020-21, unpublished]

Radio morphology



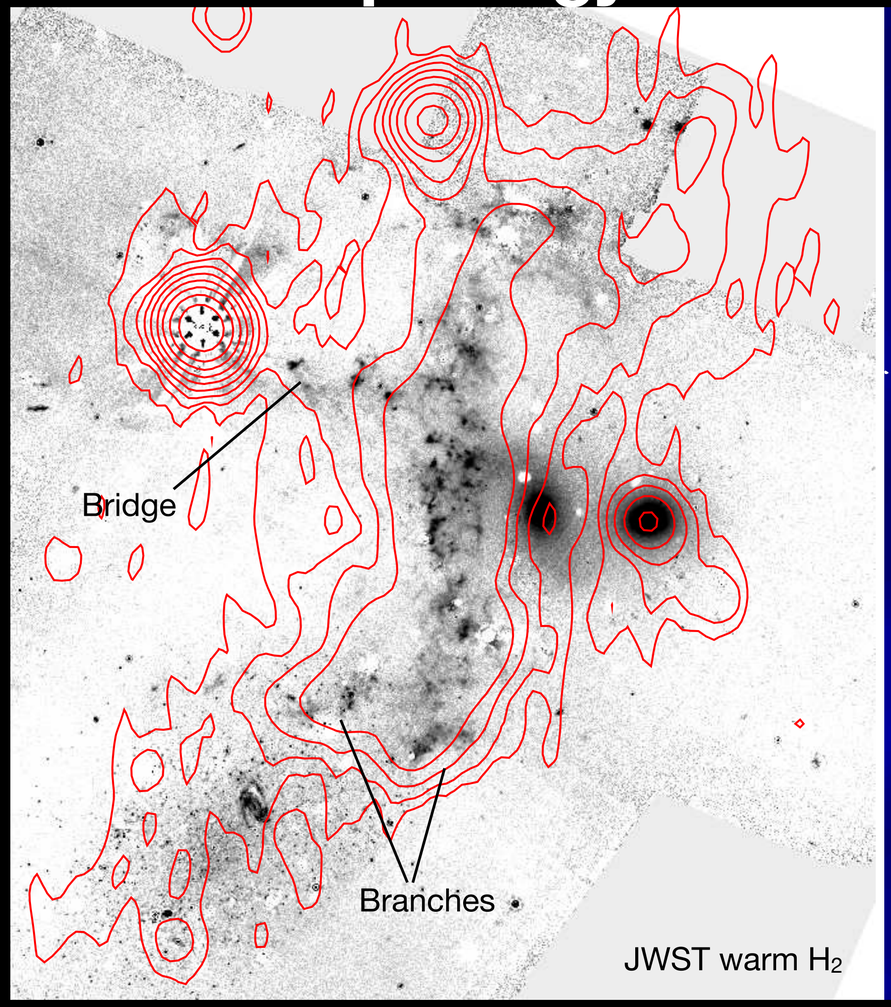
old VLA 1.4 GHz, ~15” HPBW, 100μJy/bm, Williams+ 2002

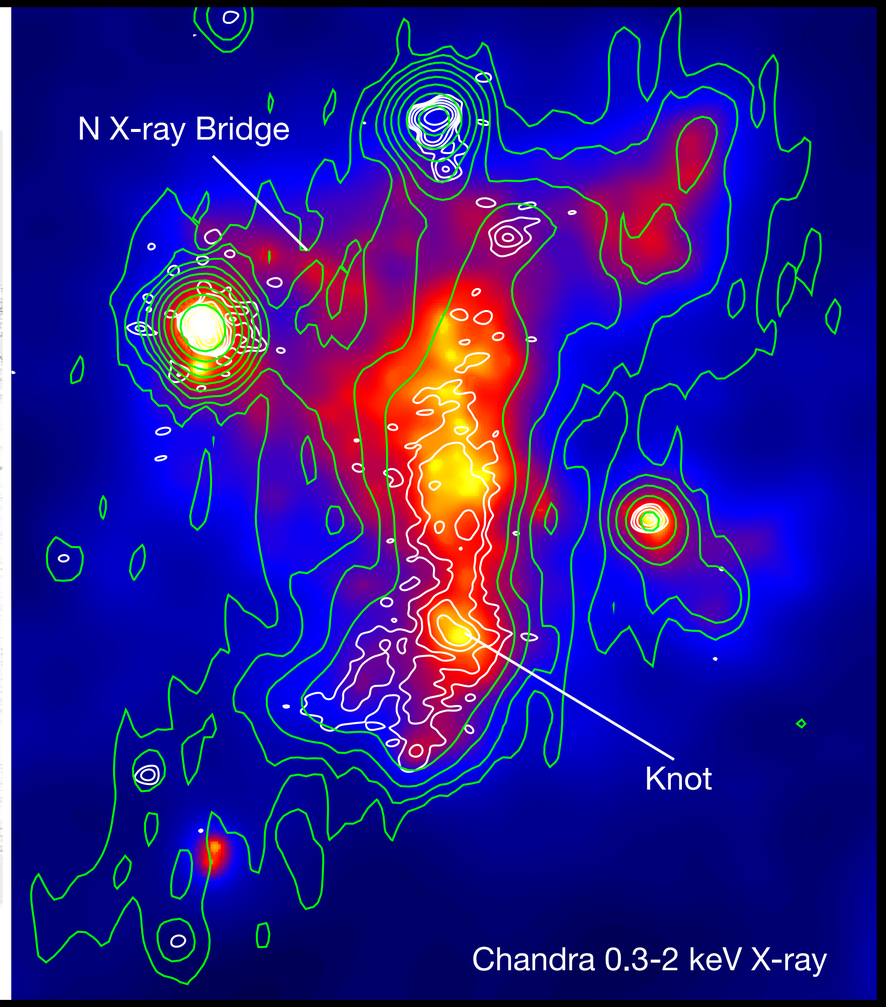
See also structures found by
Nikiel-Wroczynski+ 2013, 2020



MeerKAT L-band, 15” HPBW, 15μJy/bm, on HST

Radio morphology - correlated structures



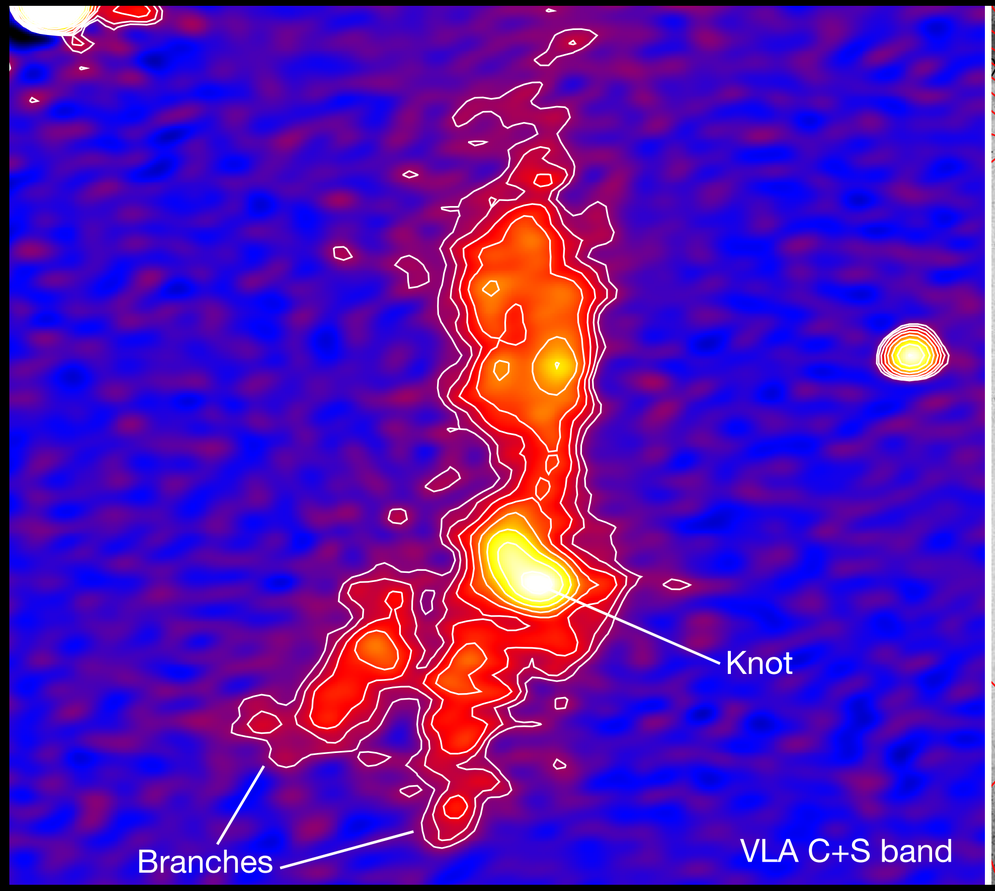


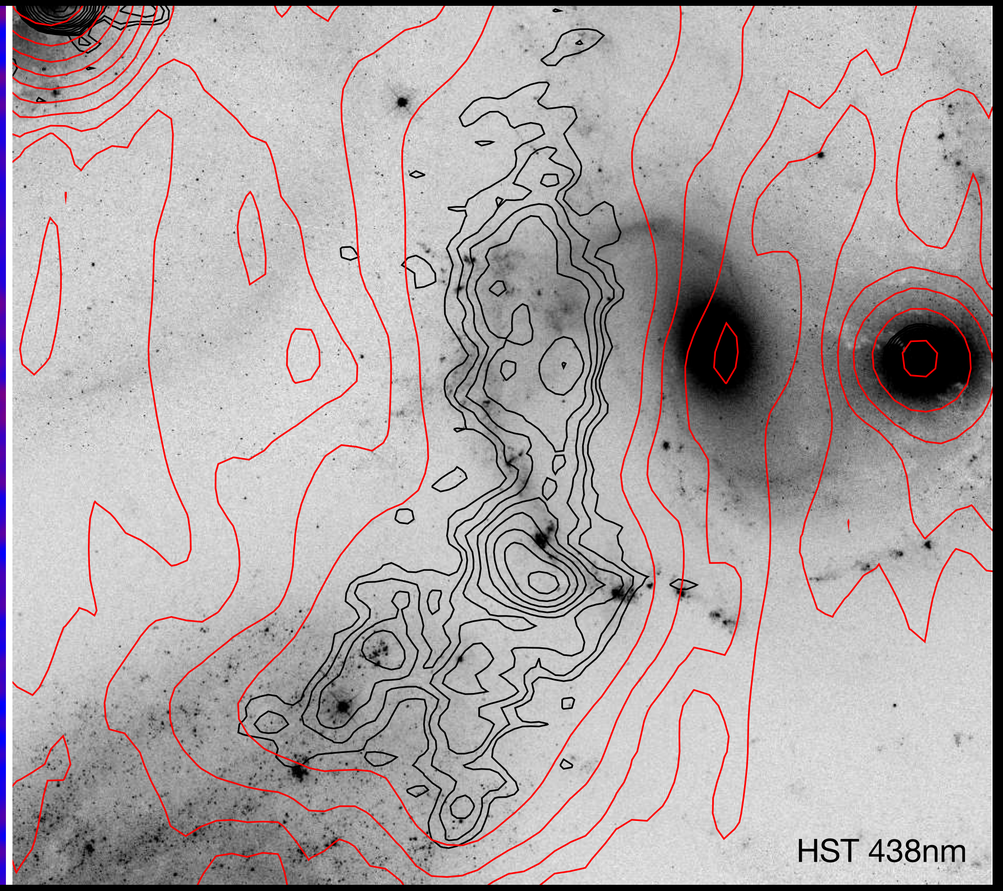
Red / Green contours = MeerKAT L-band
8” HPBW, 12μJy/bm

White contours = VLA C+S-band
3.4”x2.4” HPBW, 8μJy/bm

- On large scale radio ridge correlated with cooler gas (bridge, branches, but not N X-ray bridge)
- X-ray brighter in N ridge, radio in S ridge ➜ influence of SF?

Radio morphology - correlated structures



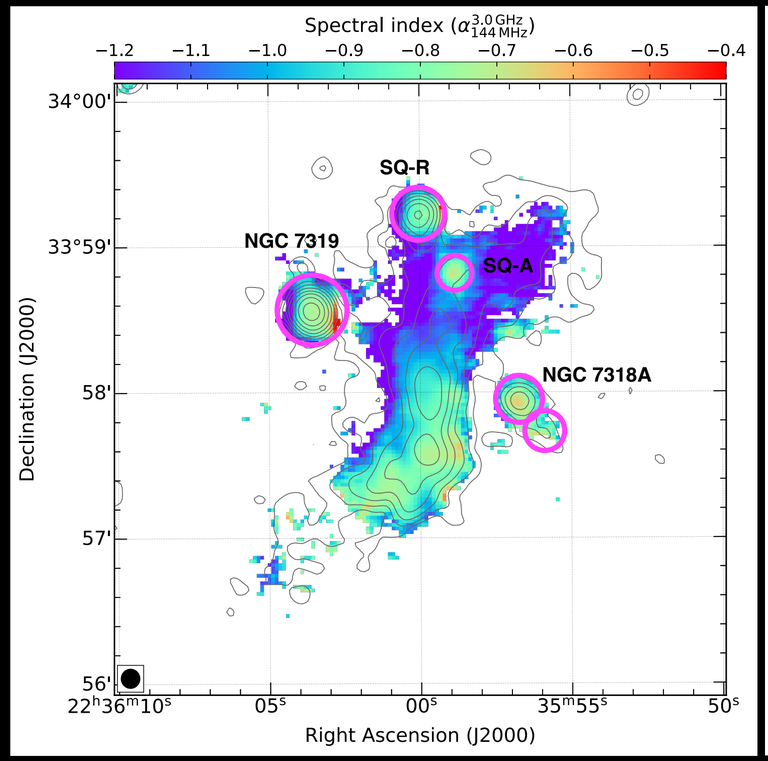


Red contours =
MeerKAT L-band
8” HPBW, 12μJy/bm

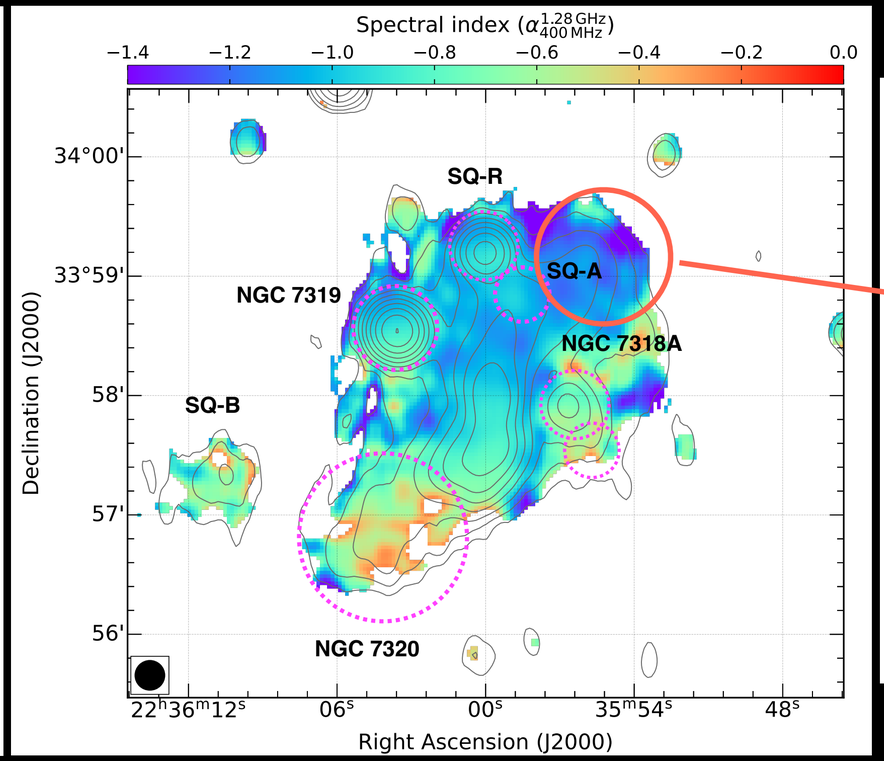
Black / White contours
= VLA C+S-band
3.4”x2.4” HPBW
8μJy/bm

- VLA C+S band traces brightest parts of southern ridge
- Bright knot associated with young star clusters and CO clouds in tidal arm ➜ SF-dominated
- Other radio-bright regions (e.g., branches) not well correlated with SF

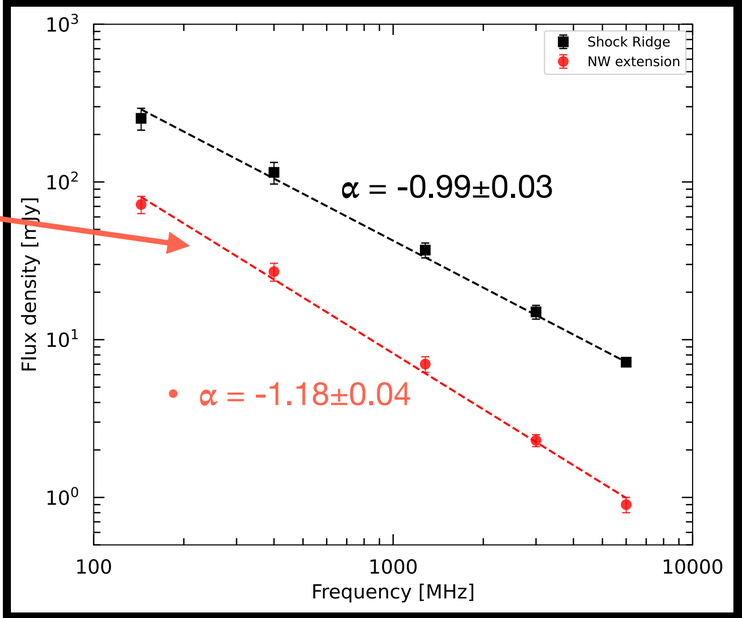
Spectral index



144 MHz - 3 GHz index, 8” HPBW

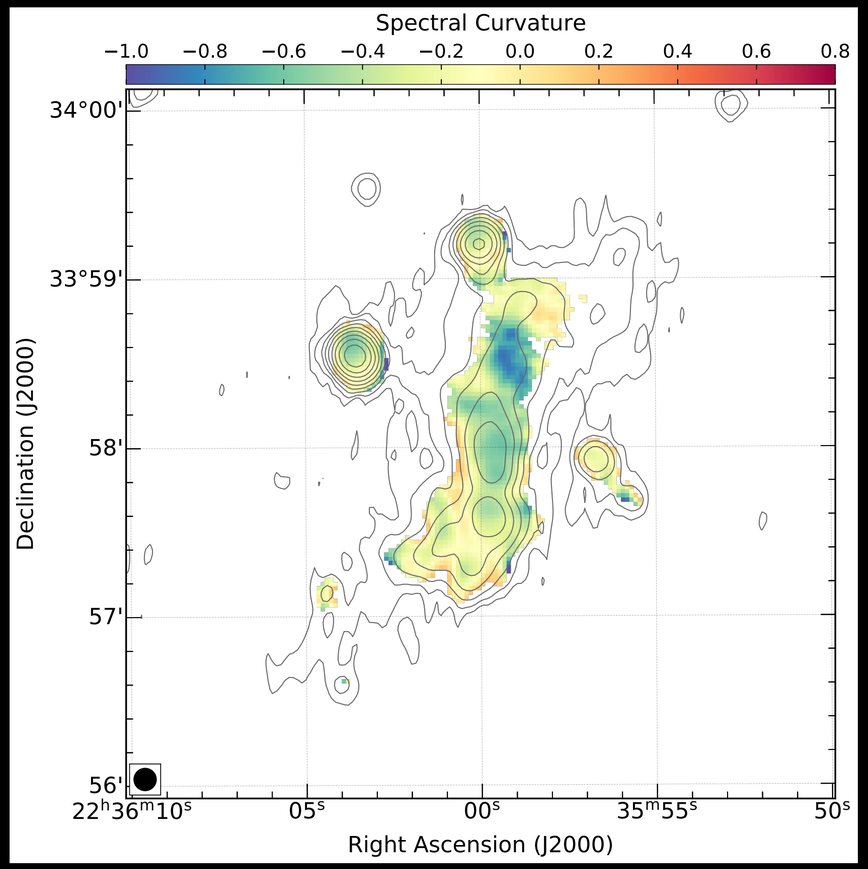


400 MHz - 1.28 GHz index, 15” HPBW

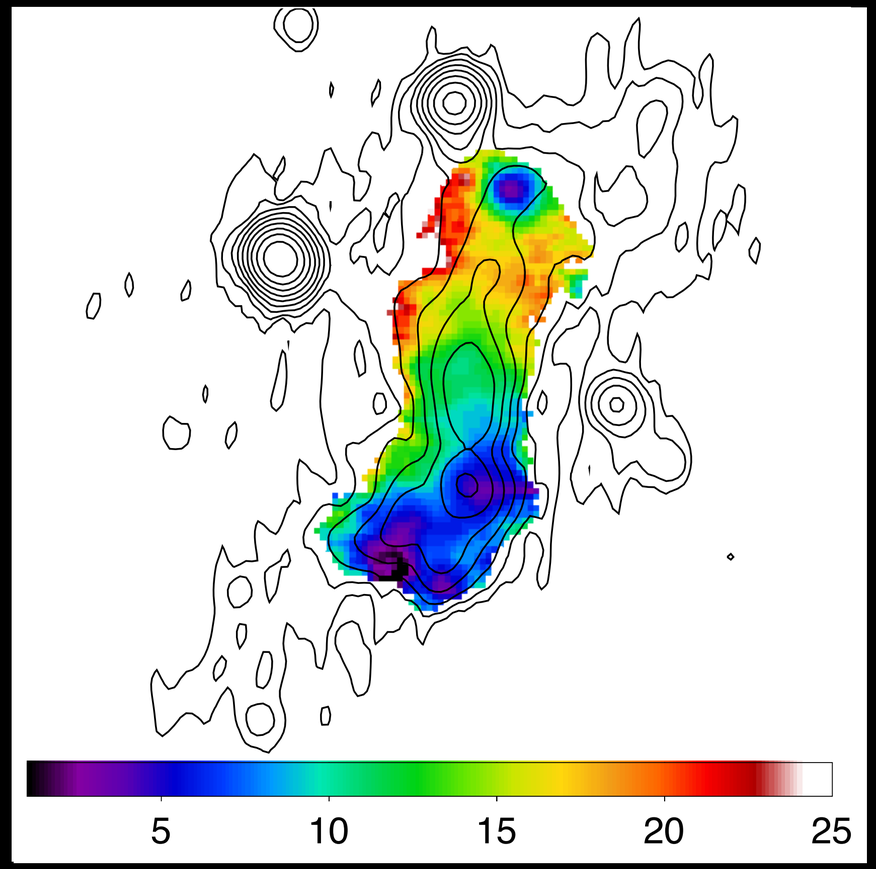


- No spectral index gradient across ridge ➜ interloper vector close to line of sight
  - Bad news: we’re looking through the shock front
  - Good news: 900 km/s V_{rec} offset is a good measure of collision velocity
- Integrated spectral index of steepest emission α = -1.18

Curvature and age



144-400 MHz vs 1.28-6 GHz, 8” HPBW



Radiative age (Myr) assuming α_{inj} = -0.7

- Strongest curvature, oldest ages in N ridge, ~15-20 Myr.
- At 900 km/s, interloper galaxy has since moved ~18 kpc, comparable to width of ridge

What have we learned?

- Radio ridge structures correlated with cooler gas ➜ origin in stripped ISM material
- No spectral index gradient, low polarization fraction ➜ collision vector close to line of sight
  - angle may be as low as 20°
- Spectral curvature suggests interaction age ~15-20 Myr
- Mechanism of radio emission is still unclear
  - Mach ~3.8 shock required by adiabatic compression difficult to reconcile with evidence against plane-of-sky motion
  - DSA may also imply high shock speed: integrated α = -1.18 ➜ Mach ~3.5
    - But we are looking through the shock front, X-ray/radio Mach number disagreement in relics, etc
  - Is survival of relativistic seed electrons from SNae in stripped gas realistic?
  - Strong shock in HI: requires extended cold gas envelope ➜ MeerKAT HI analysis?


Thank you!