# A suspected Dark Lens revealed with the e-EVN

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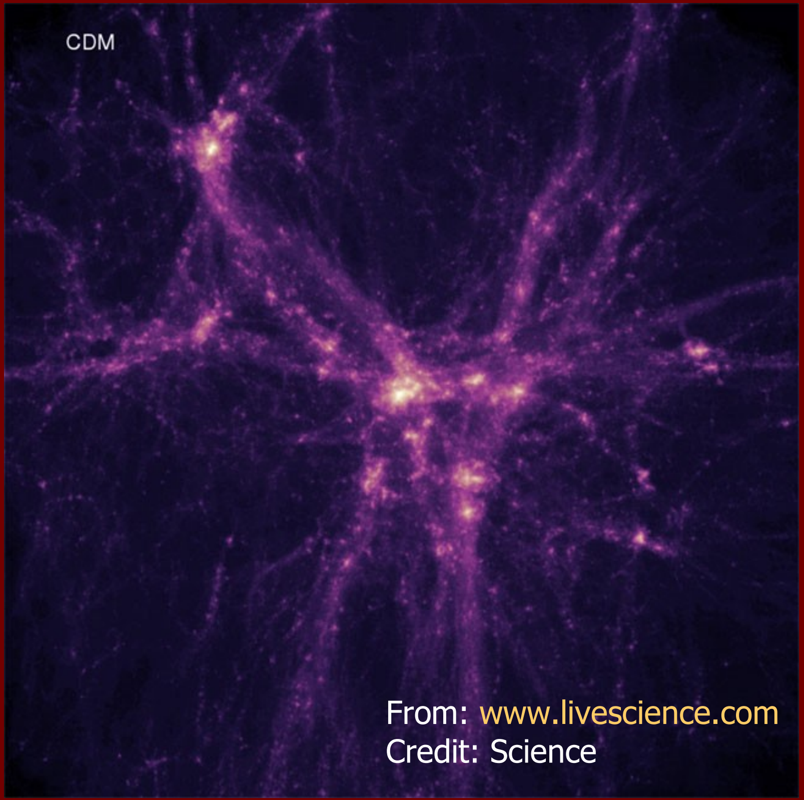
# CDM halos: how to make them visible?

- Galaxies form within massive dark matter halos (CDM)
- Are there halos without associated galaxies? A substantial fraction of the halos may be empty (e.g. *Nagamine et al. 2001, MNRAS 327, L10*)
- These condensations of CDM may reveal themselves by acting as a gravitational lens (*Li & Oostriker 2002, ApJ 566, 652; Wyite, Turner & Spergel 2001, ApJ 555, 504*)




From: www.livescience.com
Credit: Science

# What are the properties of Dark Lenses?

- Properties of DLs were investigated by David Rusin (*2002, ApJ 572, 705 – the introduction follows this paper*)
- Study motivated by a number of quasar pairs observed, with no apparent lensing galaxy (e.g. *Hawkins 1997, A&A 328, L25; Mortlock, Webster & Francis 1999*)
- $O^2R$ pairs (*Kochanek, Falco & Muñoz 1999,ApJ 510, 590*) and those with different spectral line widths are excluded
- Remaining ~10 systems are likely physical pairs based on statistical considerations (*Kochanek et al. 1999*)
- Additional criteria needed to investigate them case by case

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# Dark Lens properties (cont.)

- CDM inner mass profiles predicted to be shallow, $\rho \propto r^{-\alpha}$ :

  $\alpha=1$ (NWF, Navarro et al. 1997, ApJ 490, 493)

  $\alpha=1.5$ (Moore et al. 1999) ; cf. isothermal profile $\alpha=2$
- Cooling may modify the primordial profile, compression…
- To produce primordial DL 1"< $\Delta\theta$ <10" images one requires $M_{vir}>10^{13.5}\ M_{\odot}$ (e.g. Li & Oostriker 2002, Apj 566, 652)
- Rusin (2002) investigated magnification ratios for 2-3 image configurations (3-central image): $r_{ij} \equiv | \mu_i / \mu_j |$
- NFW: ~50% $r_{12}<2$, almost all <5; cf. isothermal only 11% $r_{12}<2$
- Moore: sharper profile, but still tends to produce small $r_{12}$ and relatively bright third image, compared to normal lens galaxies

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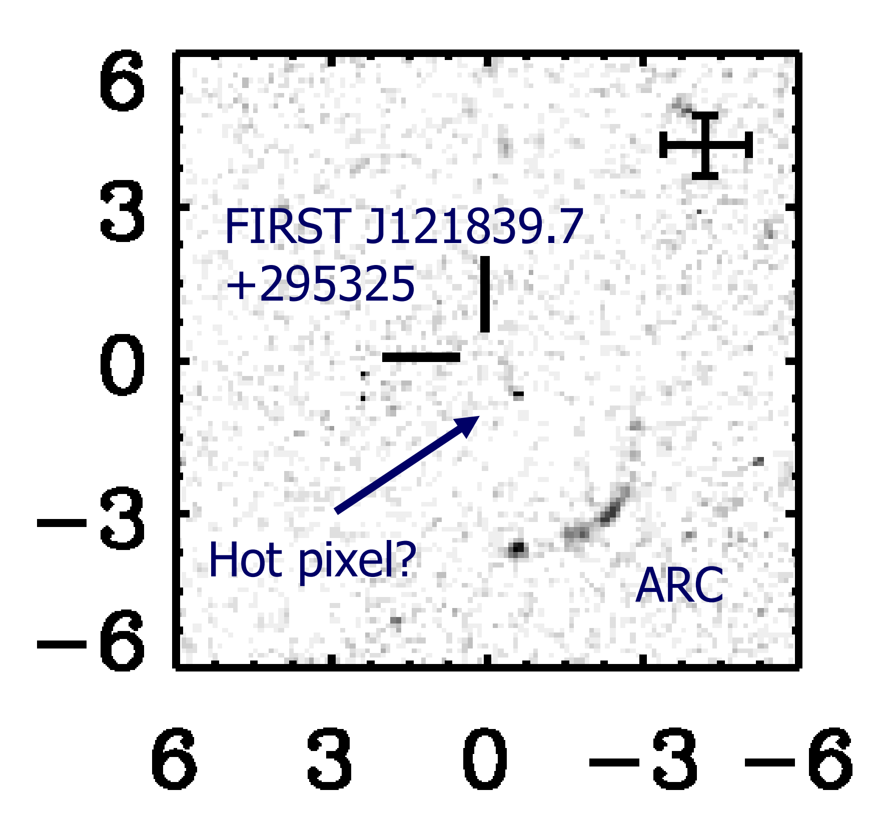
# A Dark Lens candidate

- Russell et al. (2008, ApJS 179, 306)
  Optical arc discovered in HST image -without apparent lensing Galaxy
- Ryan et al. (2008, ApJ 688, 43)
  Nearby FIRST radio source may belong to the lensing object, not seen in the optical image (but note 1$\sigma$ error in registration of positions)
- If the lensing scenario is correct:
  is the lens a heavily obscured galaxy, or an object dominated by dark matter?

HST WFPC2 image



# Radio and optical source properties

- FIRST J1218+2953 33 mJy, deconvolved size <1 arcsec

  129 mJy @330 MHz (WENSS[2]; *de Bruyn et al. 1998*)

  151 mJy @151 MHz (*Hales et al. 2007, MNRAS 382, 1639*)

  284 mJy @ 74 MHz (*Cohen et al. 2004, ApJS 150, 417*) => sp. ind. $\alpha = -0.7$
- Ryan et al. redshift estimates:

  z>0.8 (no optical gx);

  z<1.5 (radio brightness)
- SAO Wide-field IR camera:

  $J_{\mathrm{lim}}$ = 22.0 mag, $H_{\mathrm{lim}}$=20.7 mag

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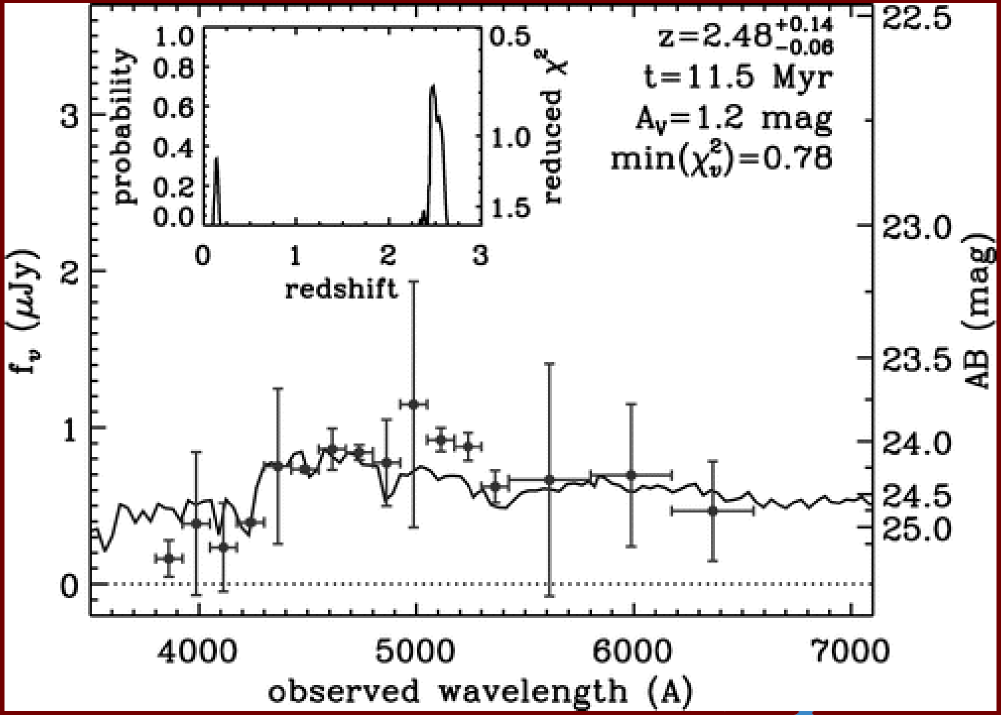
- Optical arc MMT spectroscopy:

  Weak spectral break ~λ4300Å

  Balmer/4000 => z~0.13

  Lyman break => z~2.5; more likely solution

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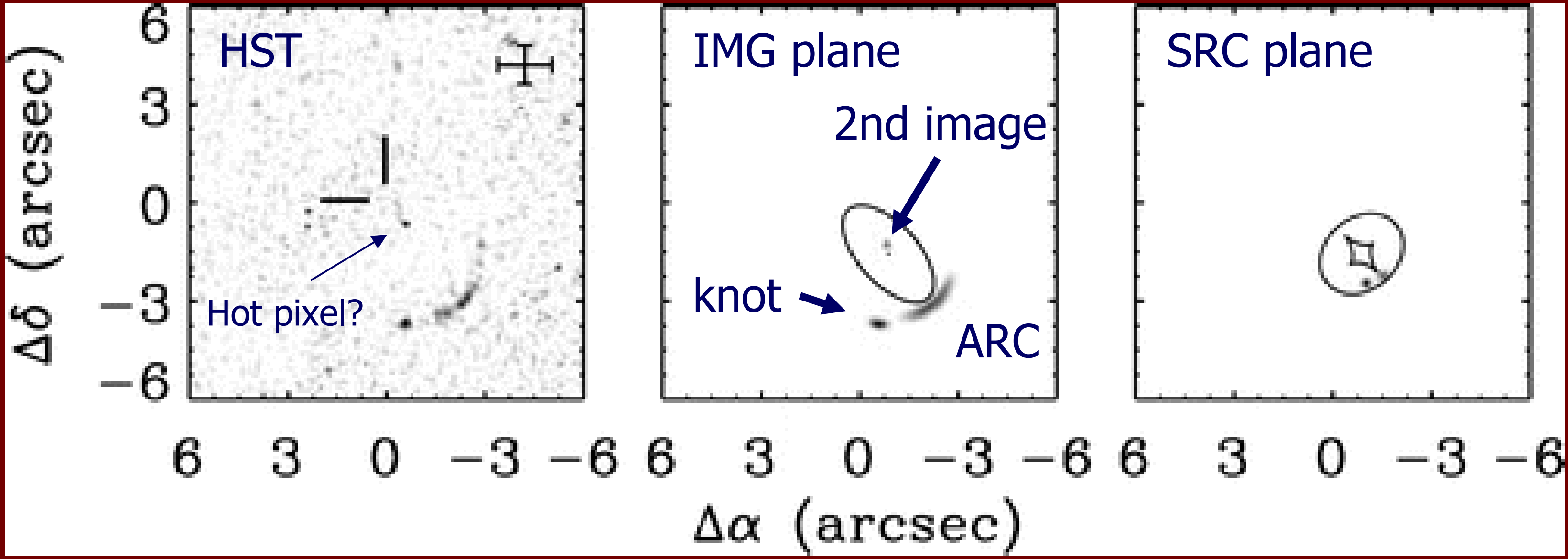
# Ryan et al. Lens Modeling

- If z~0.13, sources unrelated; if z~2.5, FIRST source may act as lens
- Long arc requires elliptical mass distribution: assumed isothermal profile (thus, normal gx, not DM); `lensmodel` (Keeton 2001)
- Optical knot must be foreground object, or two sources are lensed

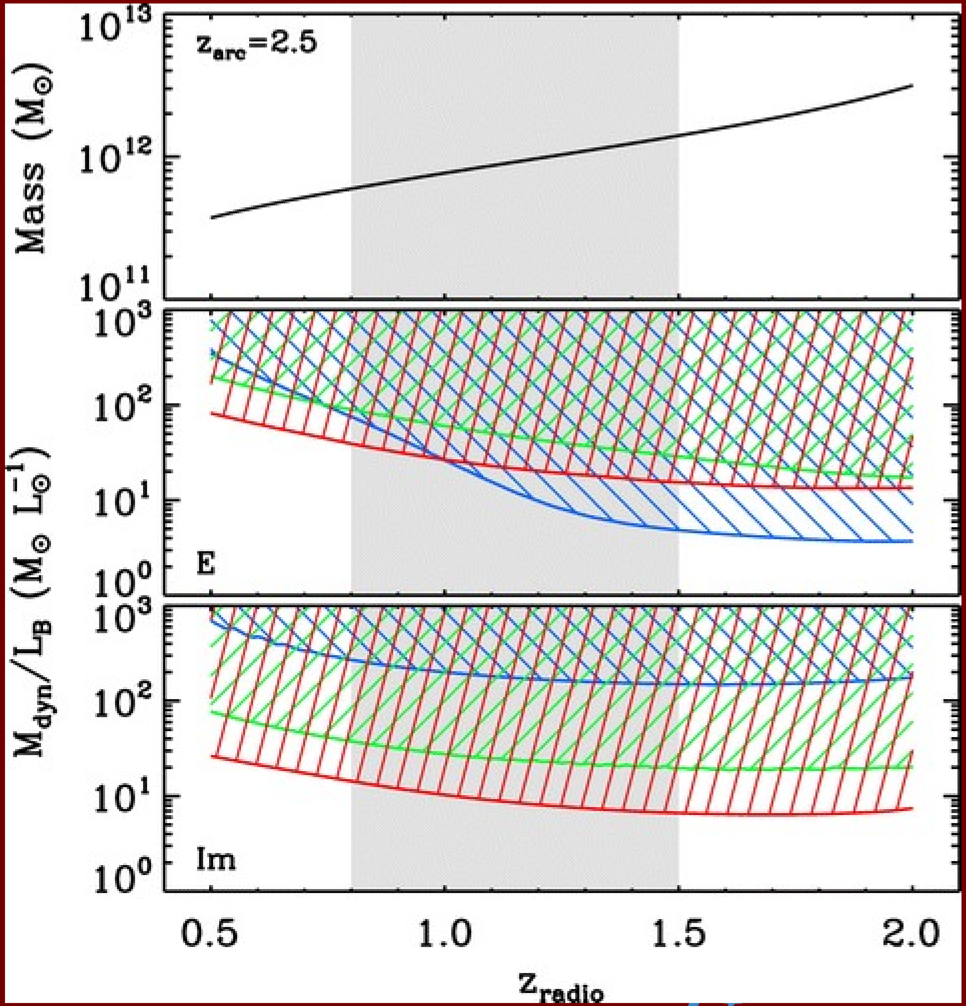



- Arc is a single distorted image in succesful models; variability along the arc must reflect intrinsic brightness varations
- Faint secondary image predicted, close to the “hot pixel”

# Implied masses

- Within the Einstein radius of 1.3 arcsec, the enclosed mass is $\sim 10^{12.5\pm0.5}$ $M_\odot$
- From SWIRC upper limits the dynamical mass to light ratio is $>30\ M_\odot L_\odot^{-1}$
- Assuming modest absorption ($A_V$=1.0 mag)

  it is still $>10\ M_\odot L_\odot^{-1}$ for an early type galaxy –dominated by DM
- Alternatively, if there is an AGN, it can be a dusty, massive, extincted galaxy with $M_\star<10^{10}$ $M_\odot$ and dynamical mass to light ratio $>100\ M_\odot L_\odot^{-1}$

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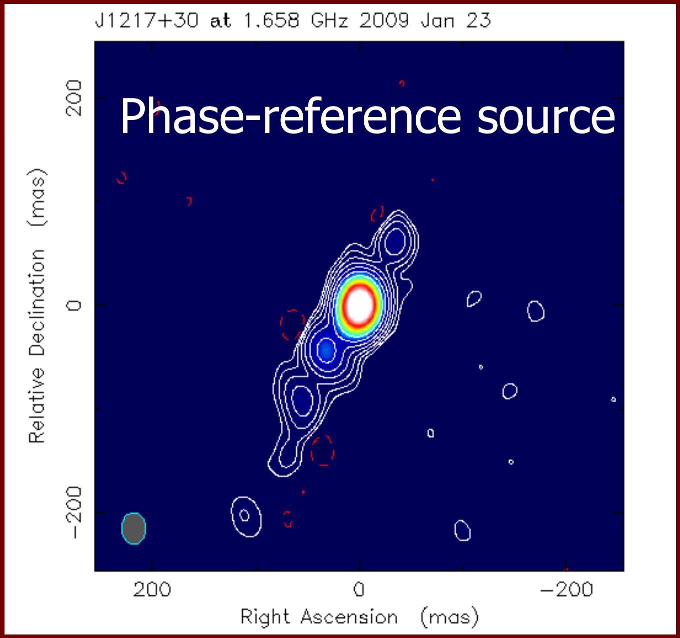
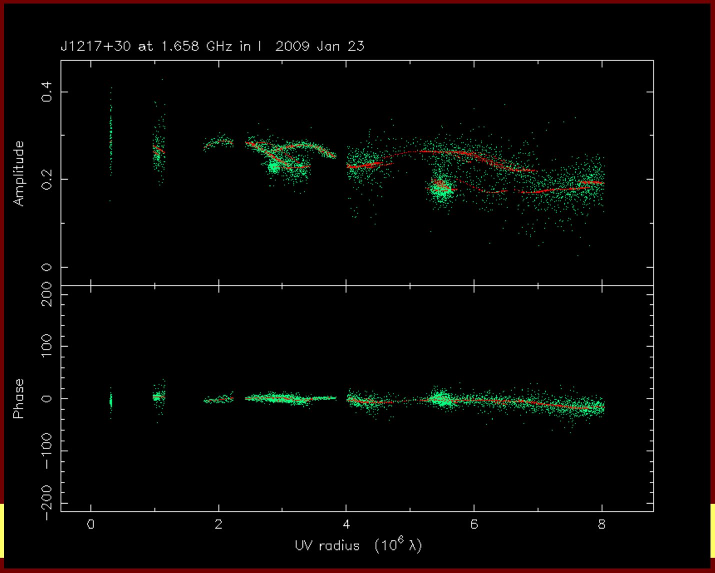
# The hunt for an AGN (S. Frey et al.)

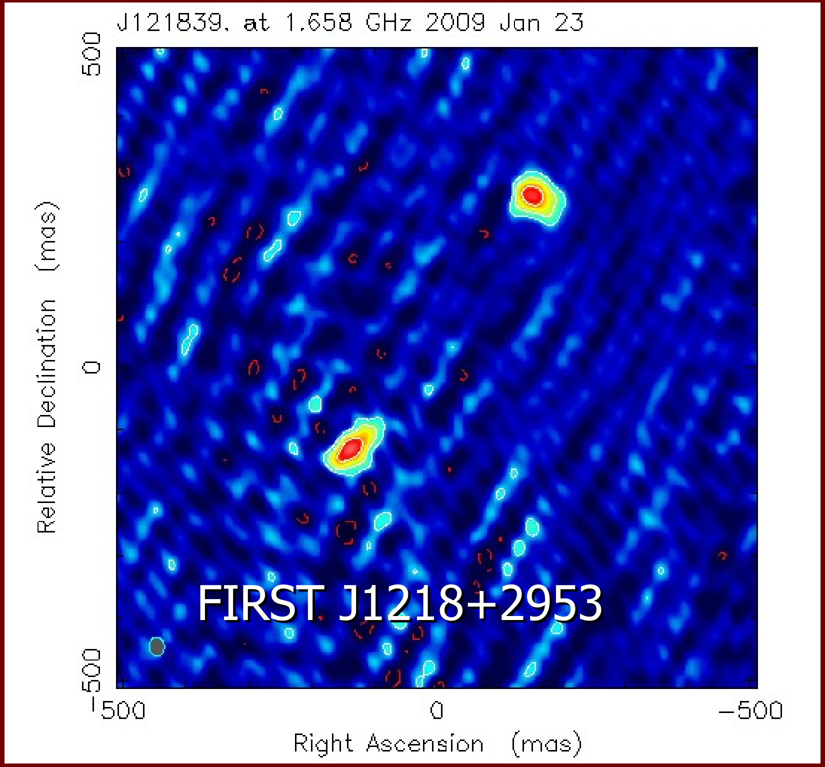
- Short e-EVN request: is FIRST J1218+2953 compact on milliarcsecond (mas) scales?
- 2009 Jan. 23, 1.6 GHz@512Mbps, 2-bit sampling, dual-pol for two hours with the array of Jb2, Cm+Kn from Merlin, Mc, On, Tr, Wb (Ef could not join)
- Phase-referenced to J1217+3007, 0.28 deg. away, in 1:30 – 3:30 min. cycles on calibrator and target

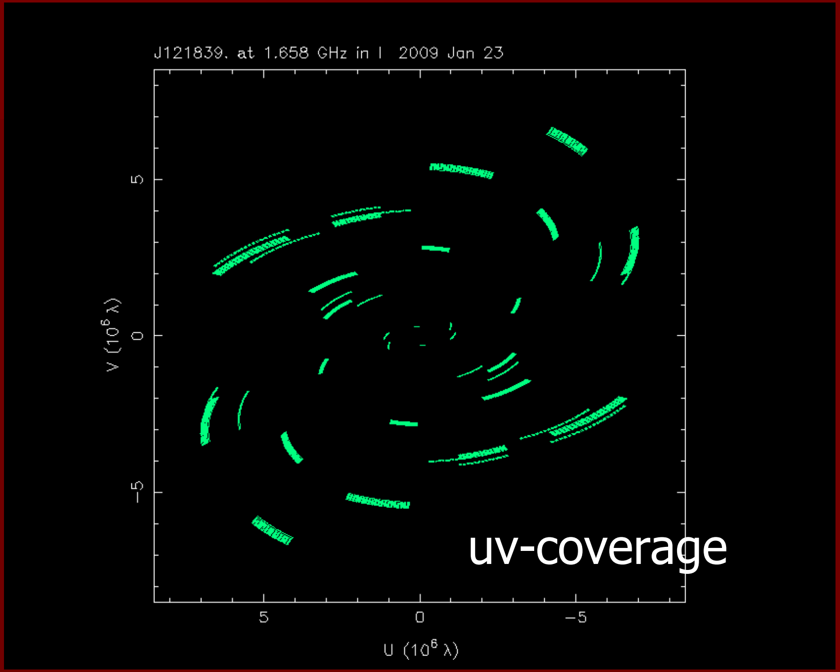


# From just 2 hours of e-EVN data…

- Symmetric structure, spanning ~500 mas
- Several kpc at z~1




- Is this a huge CSO, or a lensed image???
- Note radio source position may be consistent with the lens model centre

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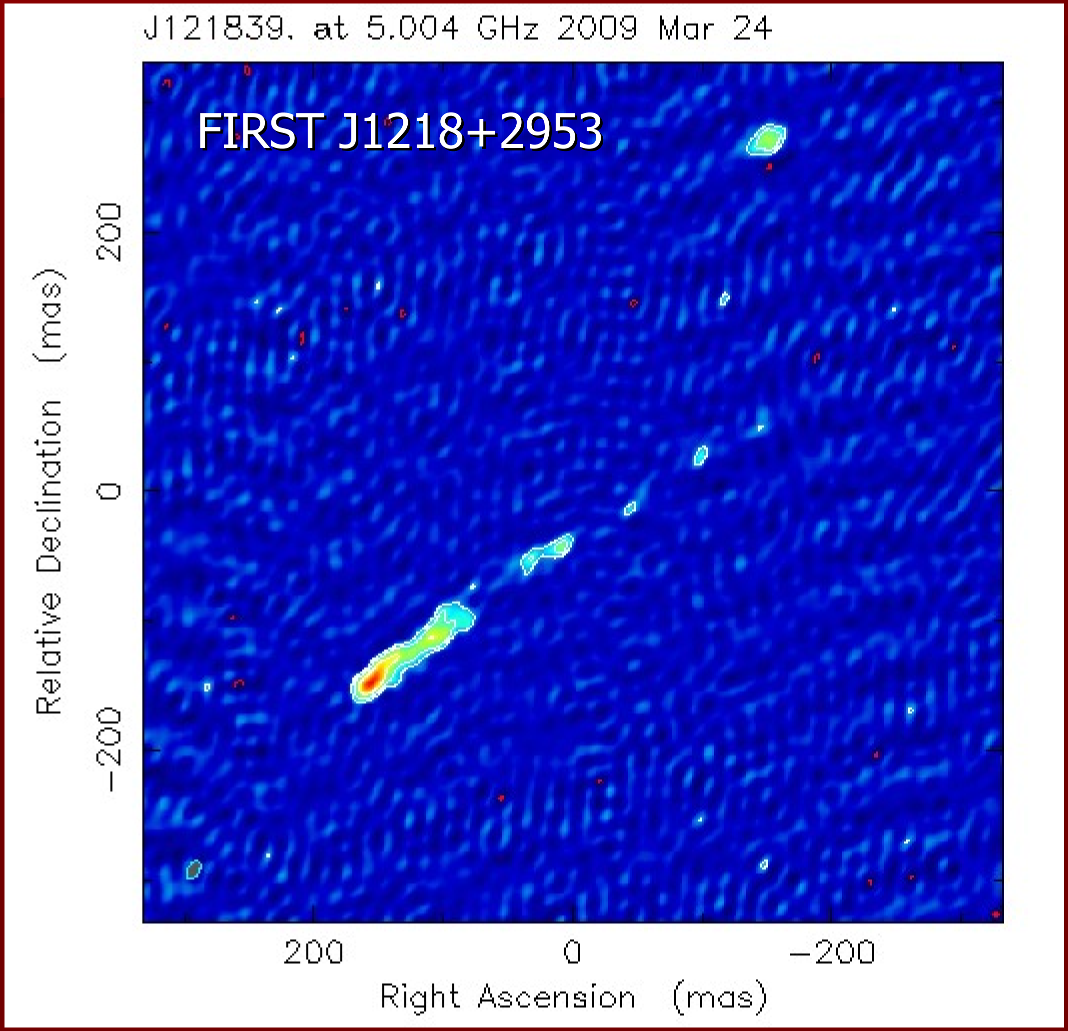
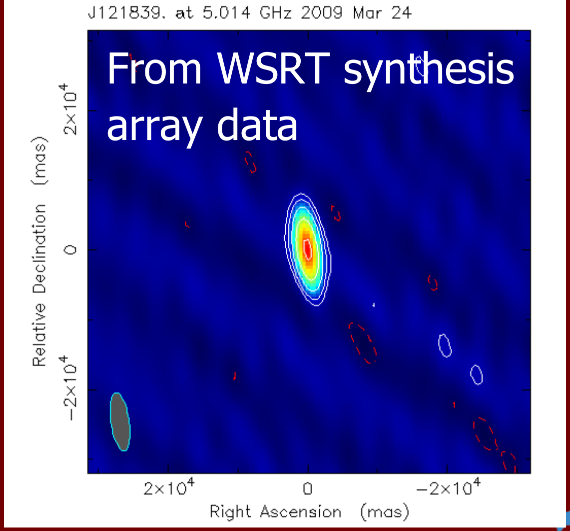
# Follow-up observations

- Proposal for 2009 Feb. 1 deadline: full track e-EVN observations at 5 and 1.6 GHz
- Needs spectral index information, higher resolution, and better sensitivity
- 5 GHz on 2009 Mar. 24-25, 1024 Mbps @Ef, On, Tr, Wb, 512 Mbps @Jb2, Mc, 128 Mbps from Cm&Kn, 8 hours
- 1.6 GHz on 2009 Apr. 21-22, 512 Mbps@Ef, On, Tr, Wb, Jb1, 256 Mbps@Ar (daytime limitation), 128 Mbps Cm&Da, 8 hours
- Same 1:30 – 3:30 min. p-ref cycle as before

# 2009 Mar. 24-25, e-EVN, 5 GHz




- Complex structure, hard to interpret
- Does not look like CSO or core-jet system
- WSRT resolution not enough to resolve the location of the arc

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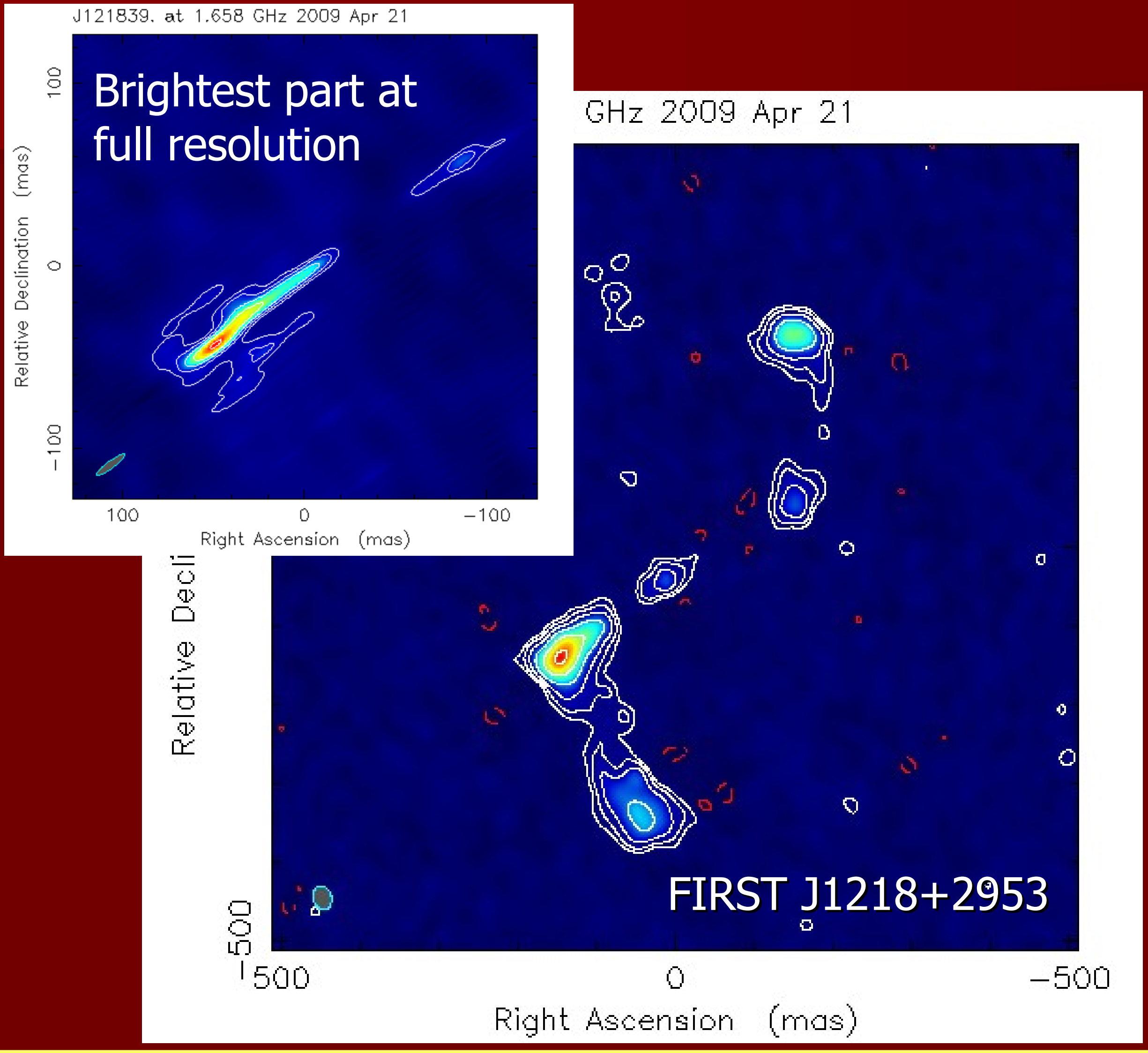
# 2009 Apr. 21-22, e-EVN, 1.6 GHz




- Structure is resolved, but brightest features visible at full resolution, including Arecibo
- Components have steep spectra, and structure indicates CSS/ MSO –type morphology on the tapered map
- Missing some extended flux, but most of the WSRT flux density is recovered with VLBI within 1 arcsecond

# Summary of results

- FIRST J1218+2953 has a very complex strucuture on 10-1000 mas scales
- Being a lensed image is unlikely, because VLBI recovered flux is consistent with what is measured on WSRT scales – radio emission from the arc cannot be significant, in contrast to lens-scenario expectations
- Looks like definite evidence for AGN activity, which must mean that the radio source HAS TO BE in the lens model centre
- If this is indeed a gravitational lens at z~1, the galaxy must be extremely dark, totally extincted (but what is the "hot pixel?")
- Deeper IR limits are required, or redshift determination for the radio source (very sensitive UHF HI observation – SKA?)

# Conclusions

- The very sensitive short spacings of the (e-)EVN are extremely valuable for studying high redshift, MSO-like systems
- WSRT synthesis data together with VLBI provide additional unique information on the sources
- Short turnaround time and more regular sessions with the e-EVN helps PIs considerably to produce VLBI results on timescales comparable to other instruments