Resolving LIRG nuclei with VLBI

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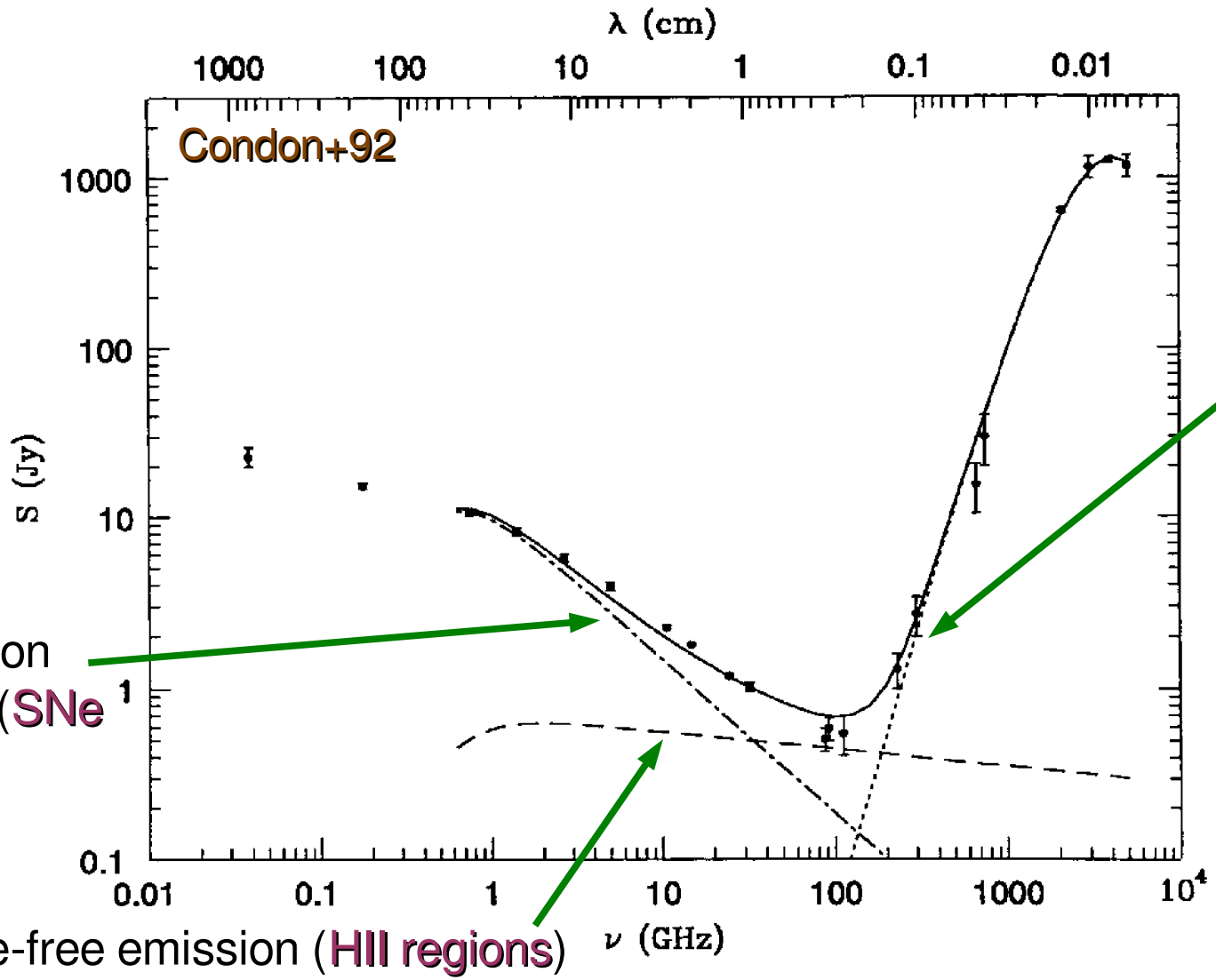
Radio/FIR SED of Star forming galaxies

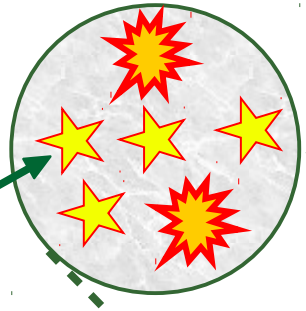


Thermal emission (dust)

Synchrotron emission (SNe & SNRs)

Free-free emission (HII regions)

(U)LIRGs heating mechanism: starburst?



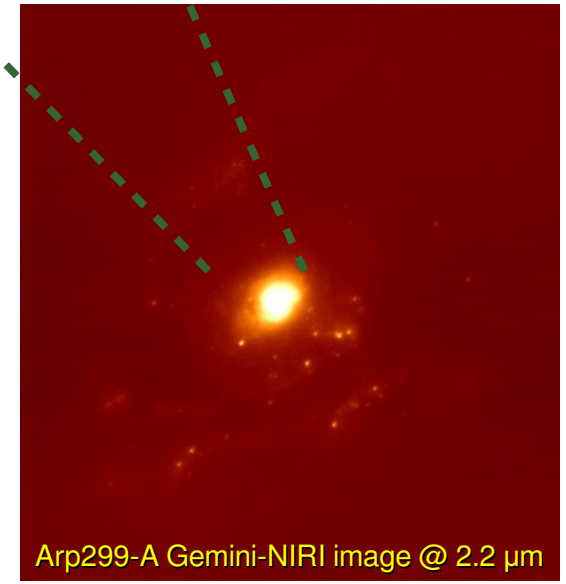
$M > 8M_{\odot}$

$$\left(\frac{\nu_{\mathrm{CCSN}}}{\mathrm{yr}^{-1}}\right) \propto \left[\frac{SFR(M \geqslant 8\mathrm{M}_{\odot})}{\mathrm{M}_{\odot}\,\mathrm{yr}^{-1}}\right] \propto \left(\frac{L_{\mathrm{FIR}}}{\mathrm{L}_{\odot}}\right)$$

Condon et al., 1992

$$\left(\frac{\nu_{\mathrm{CCSN}}}{\mathrm{yr}^{-1}}\right) = 2.7\times10^{-12}\left(\frac{L_{\mathrm{IR}}}{\mathrm{L}_{\odot}}\right)$$

Mattila & Meikle, 2001

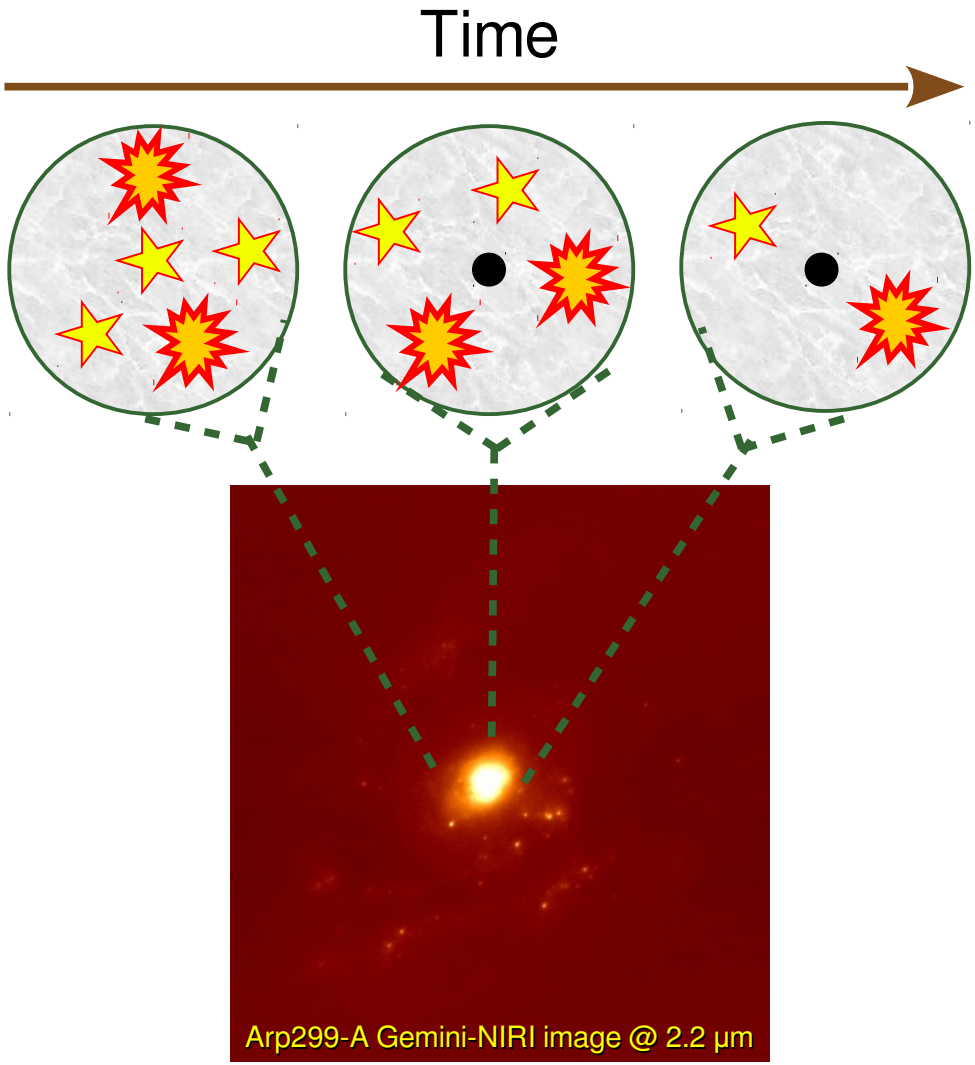


Arp299-A Gemini-NIRI image @ 2.2 μm

(U)LIRGs heating mechanism: starburst and /or AGN?

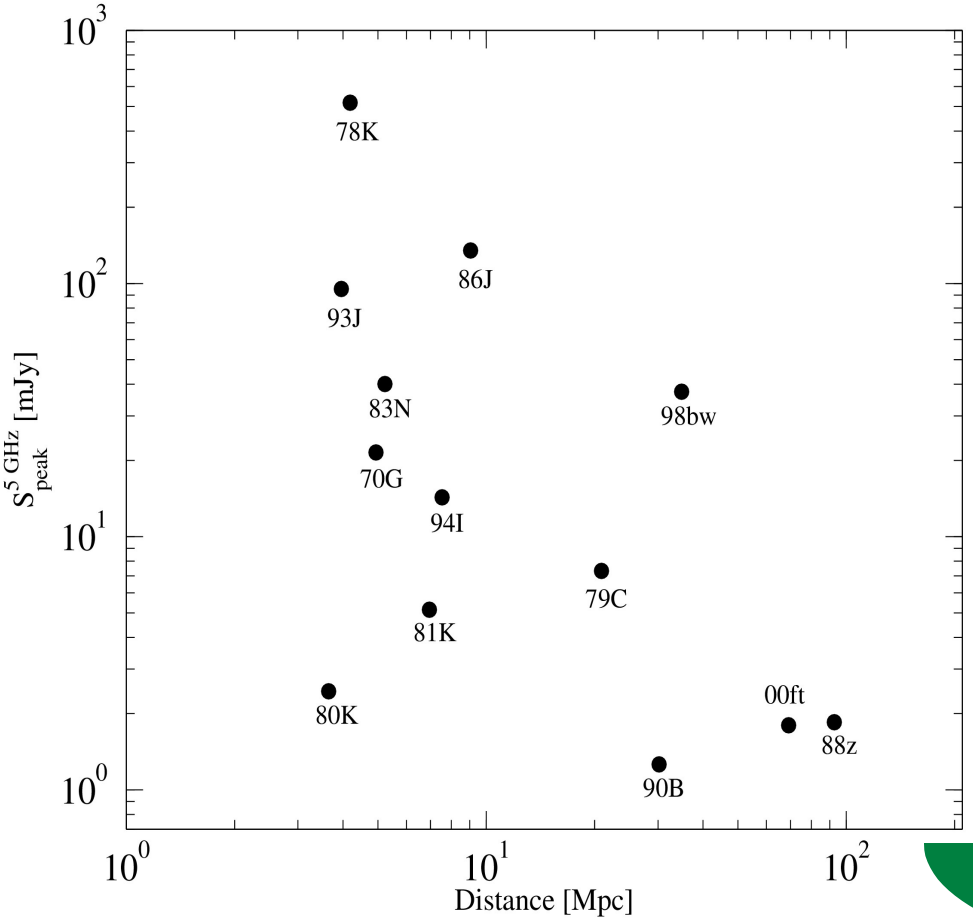
Classification of IR selected galaxies:

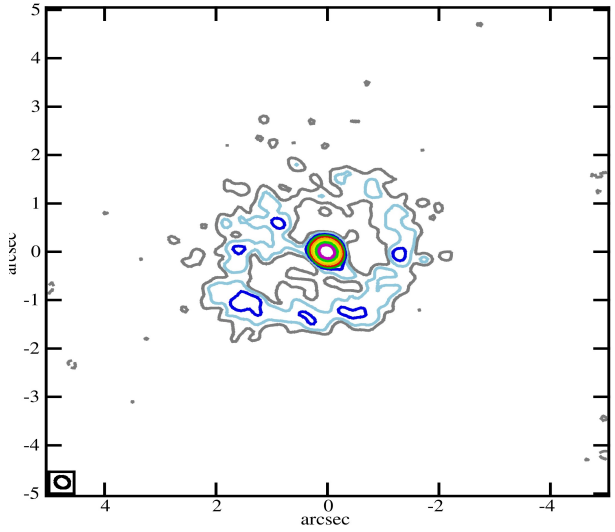
- IR luminosity
- Merger stage



(Yuan et al., 2010)

Observational constraints





High sensitivity!

High resolution!

Our modus operandi...

Ryder/Mattila/Kankare/Väisänen/
Randriamanakoto/+

Near-IR AO monitoring of nearby LIRGs

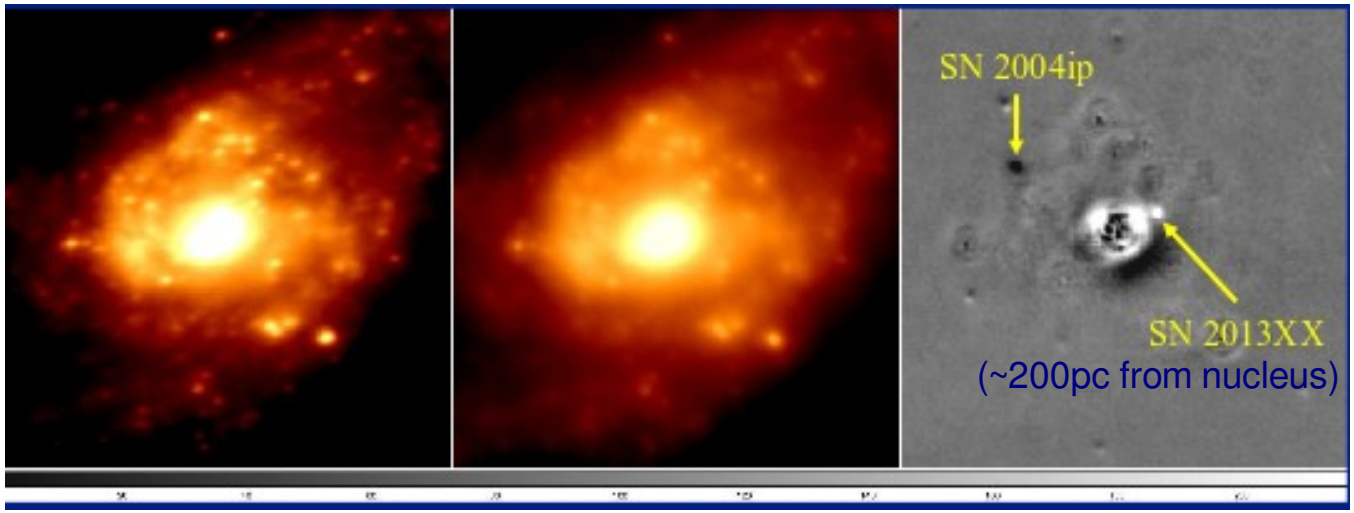
Supernova detection!

Optical/IR follow-up

Triggers radio campaign to detect SN

Pérez-Torres/Alberdi/Beswick/me/+

IRAS 18293-3413



Ryder+14

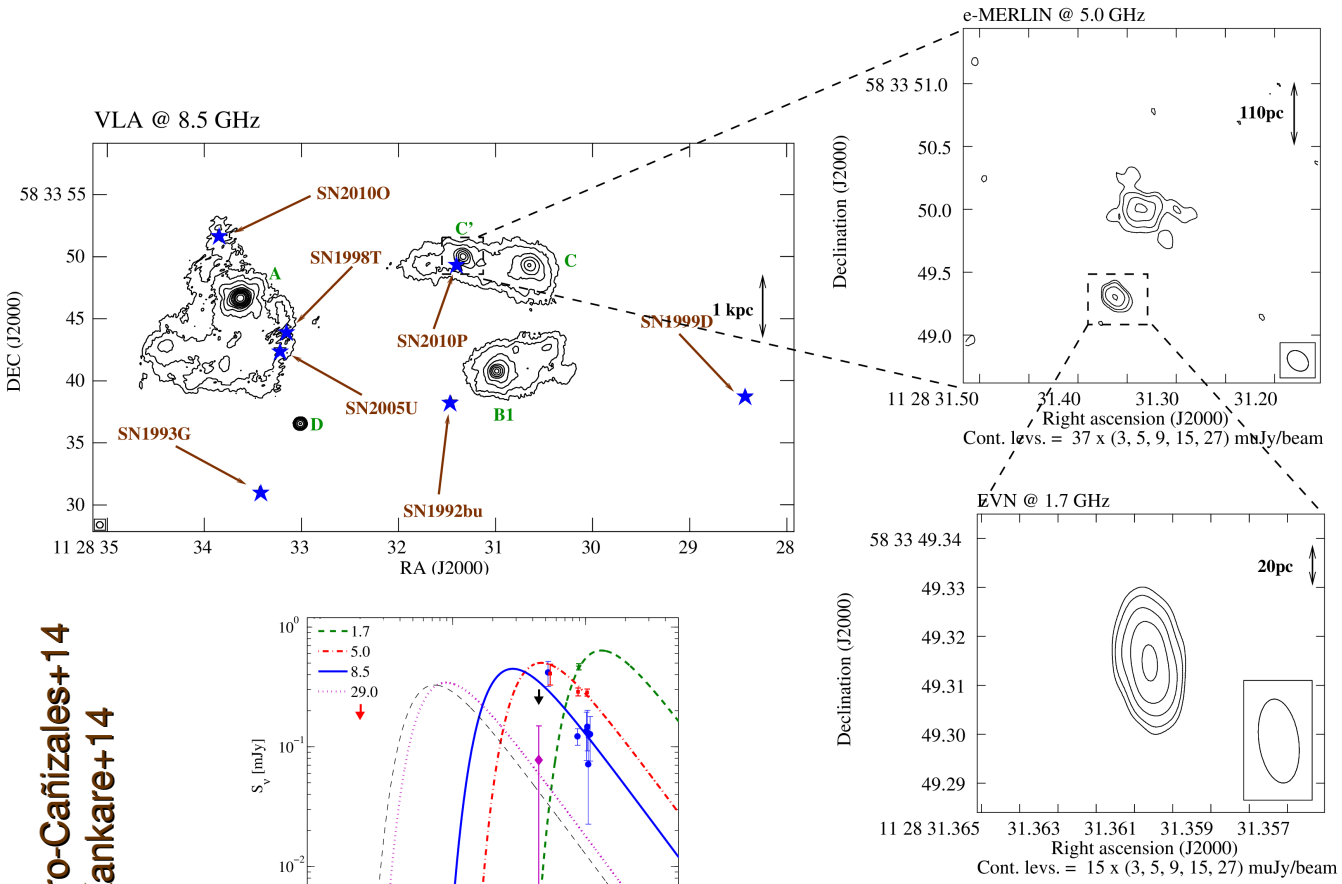
GeMS/GSAOI
Gemini South (2013)

NAOS-CONICA
VLT (2004)

Subtracted image

Radio detection of the supernova?

Yes!



Romero-Cañizales+14 and Kankare+14

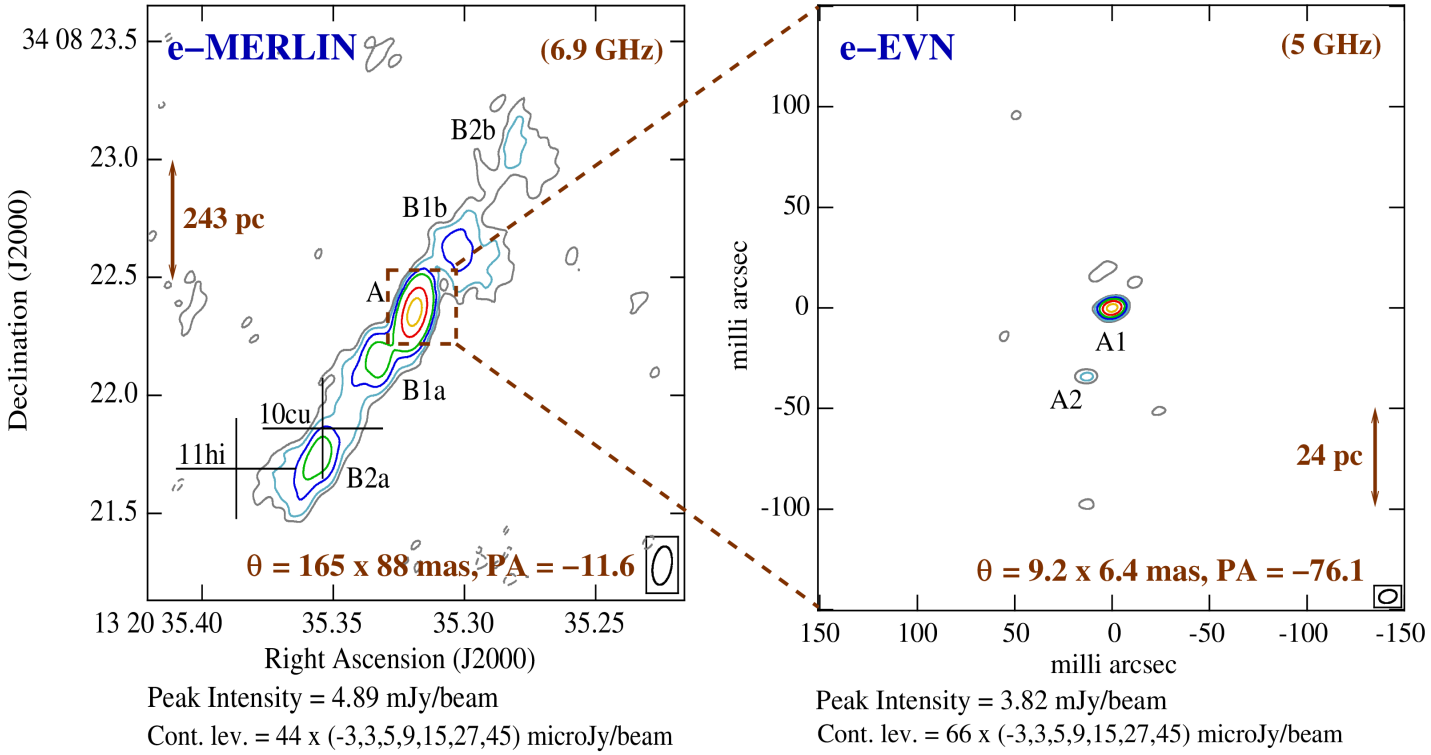
SN 2010P

→ the most distant and most slowly evolving Type IIb radio SN detected to date

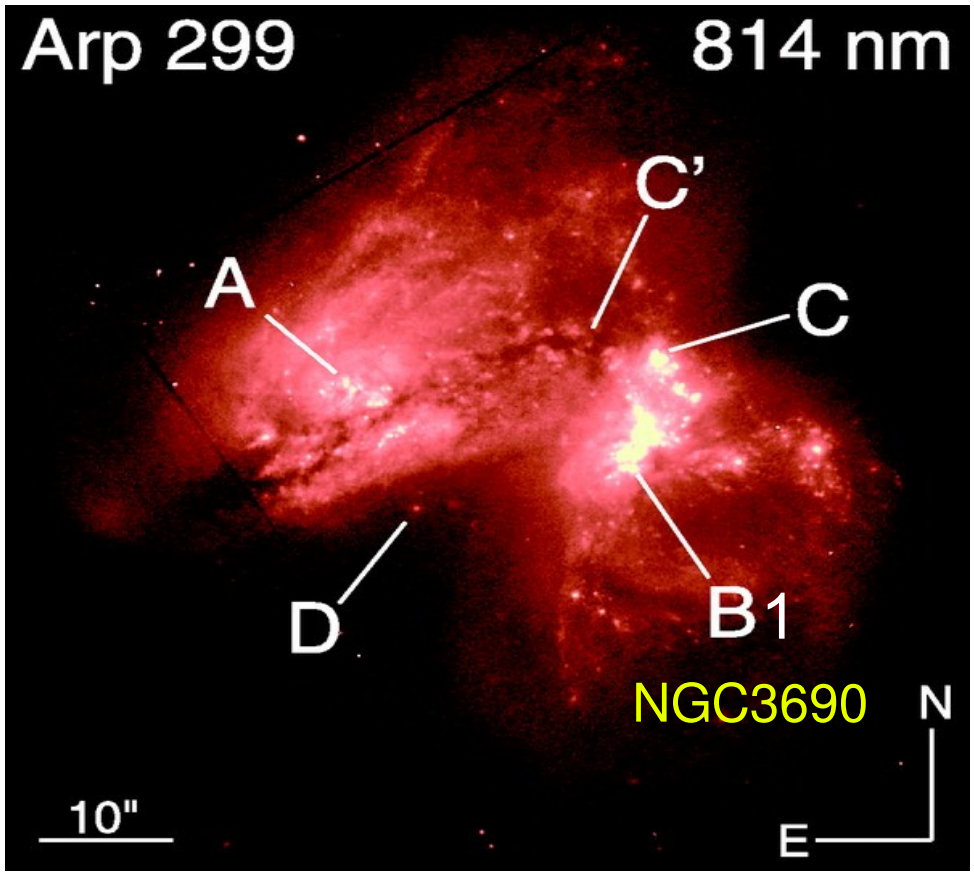
Radio detection of the supernova?

No...

SNe 2010cu & 2011hi
were not detected, however, high-resolution radio observations revealed an AGN candidate plus a starburst



Romero-Cañizales+12 and Kankare+12



HST -**WFPC2** 814nm image (Neff et al., 2004)

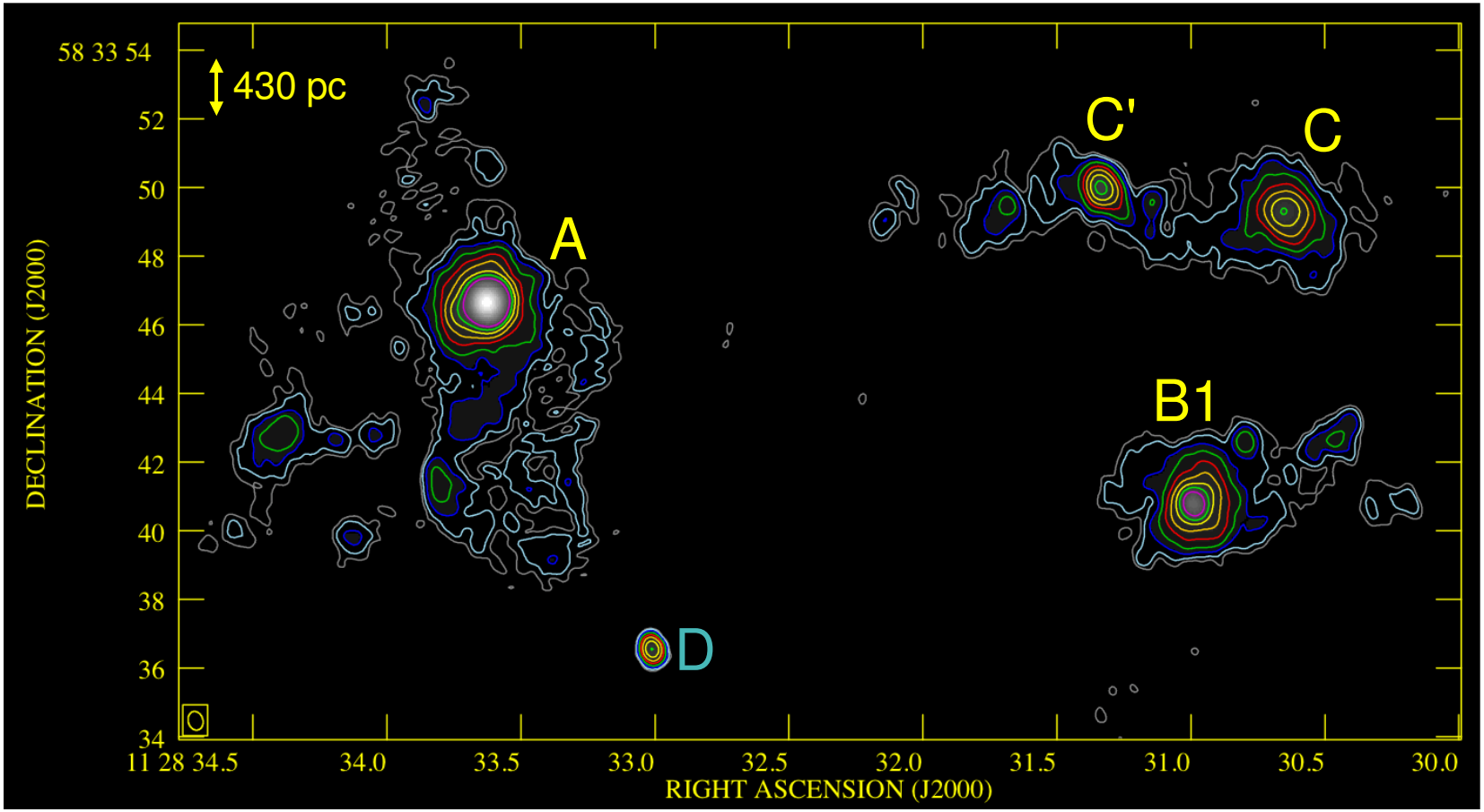
Early stage merger

- D ~ 45 Mpc ⇒ 1 mas ~ 0.2 pc
- L_{IR} ~ 6.7 x 10^{11} $L_{\odot}$

  ~ 40% in A ⇒ $\nu_{CCSN} \approx 0.7\,\mathrm{yr}^{-1}$

  ~ 20% in B1 ⇒ $\nu_{CCSN} \approx 0.4\,\mathrm{yr}^{-1}$

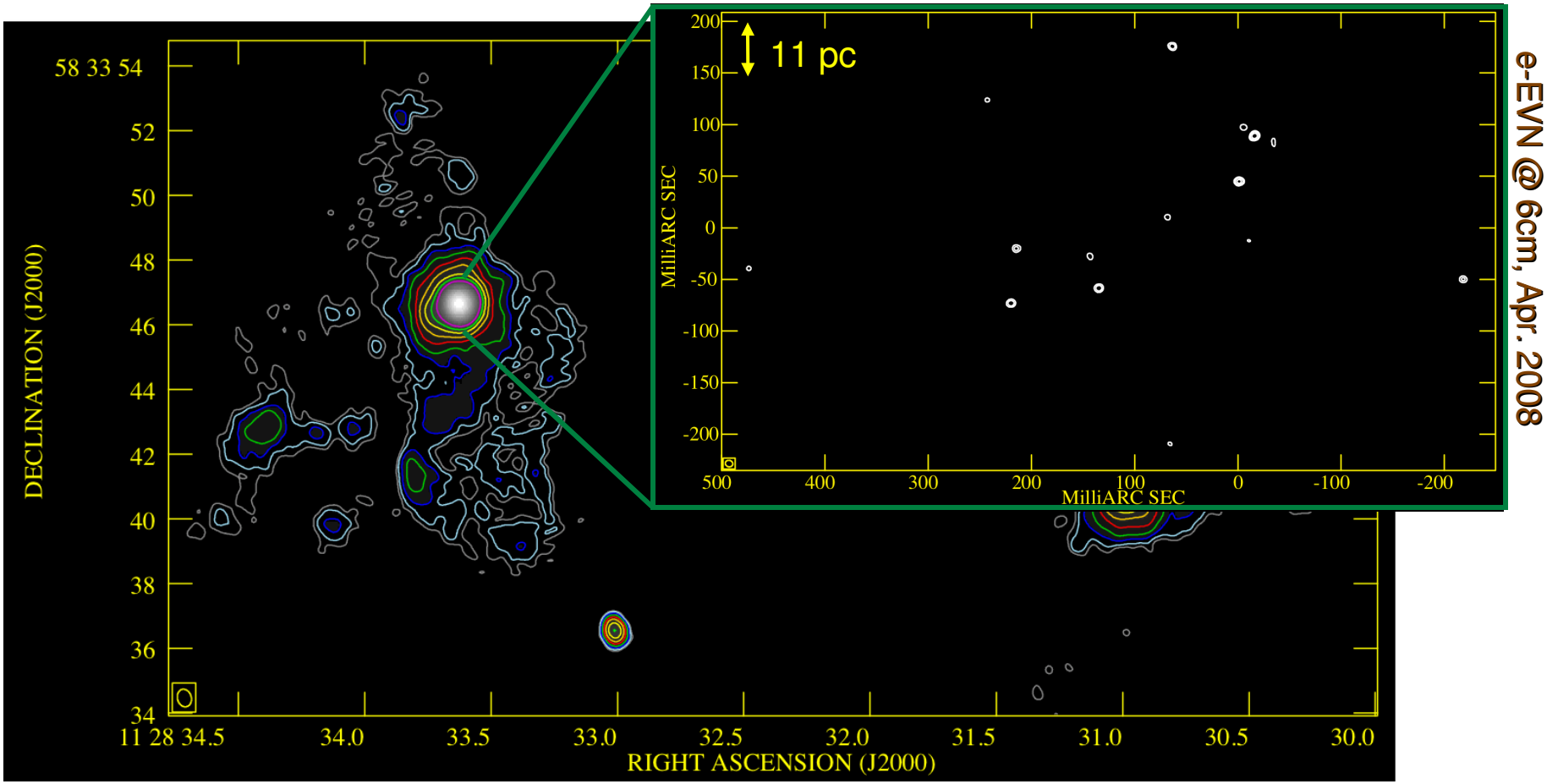
Arp299: its radio emission



VLA observations (6cm = 5 GHz, Oct 2000)

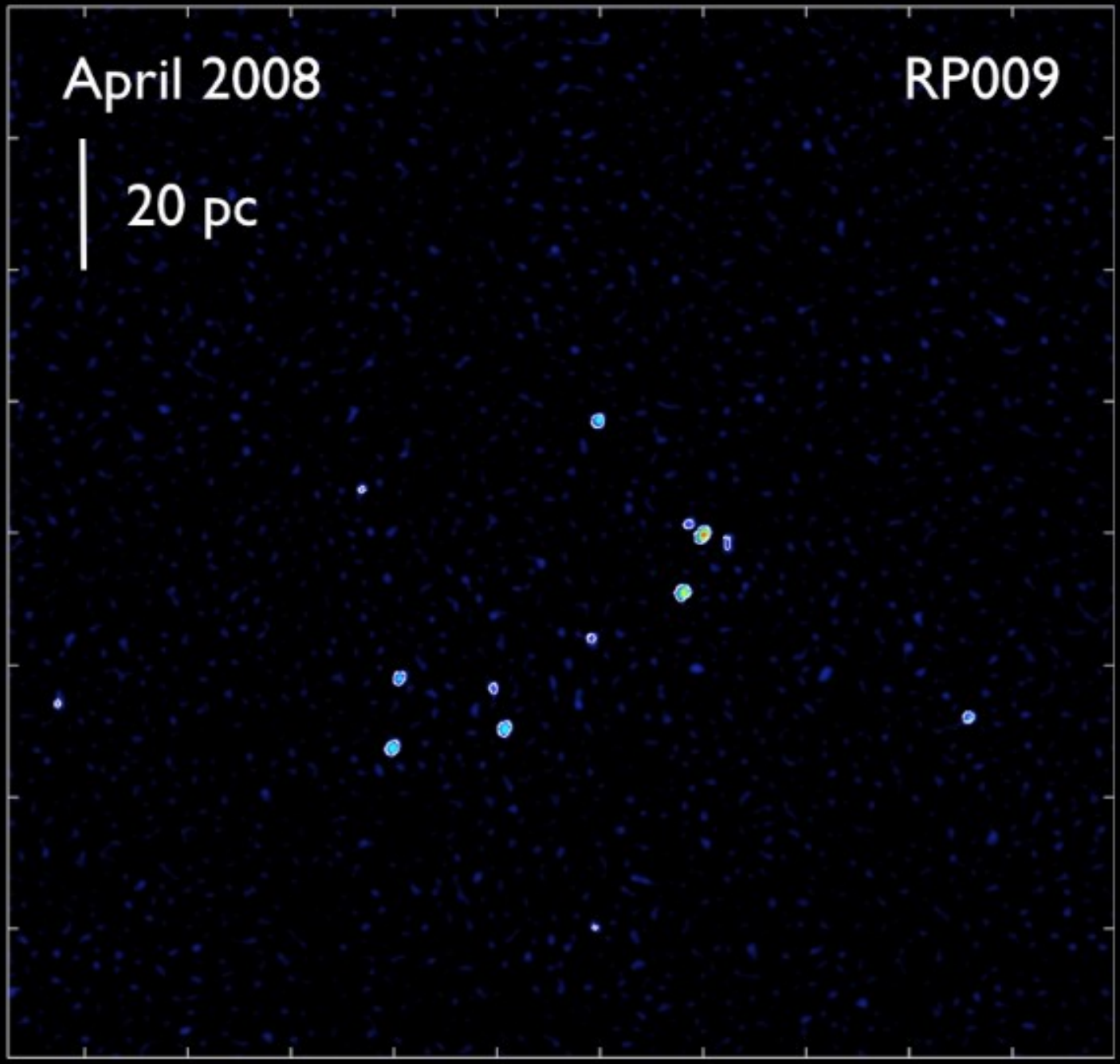
Arp299-A: SN factory

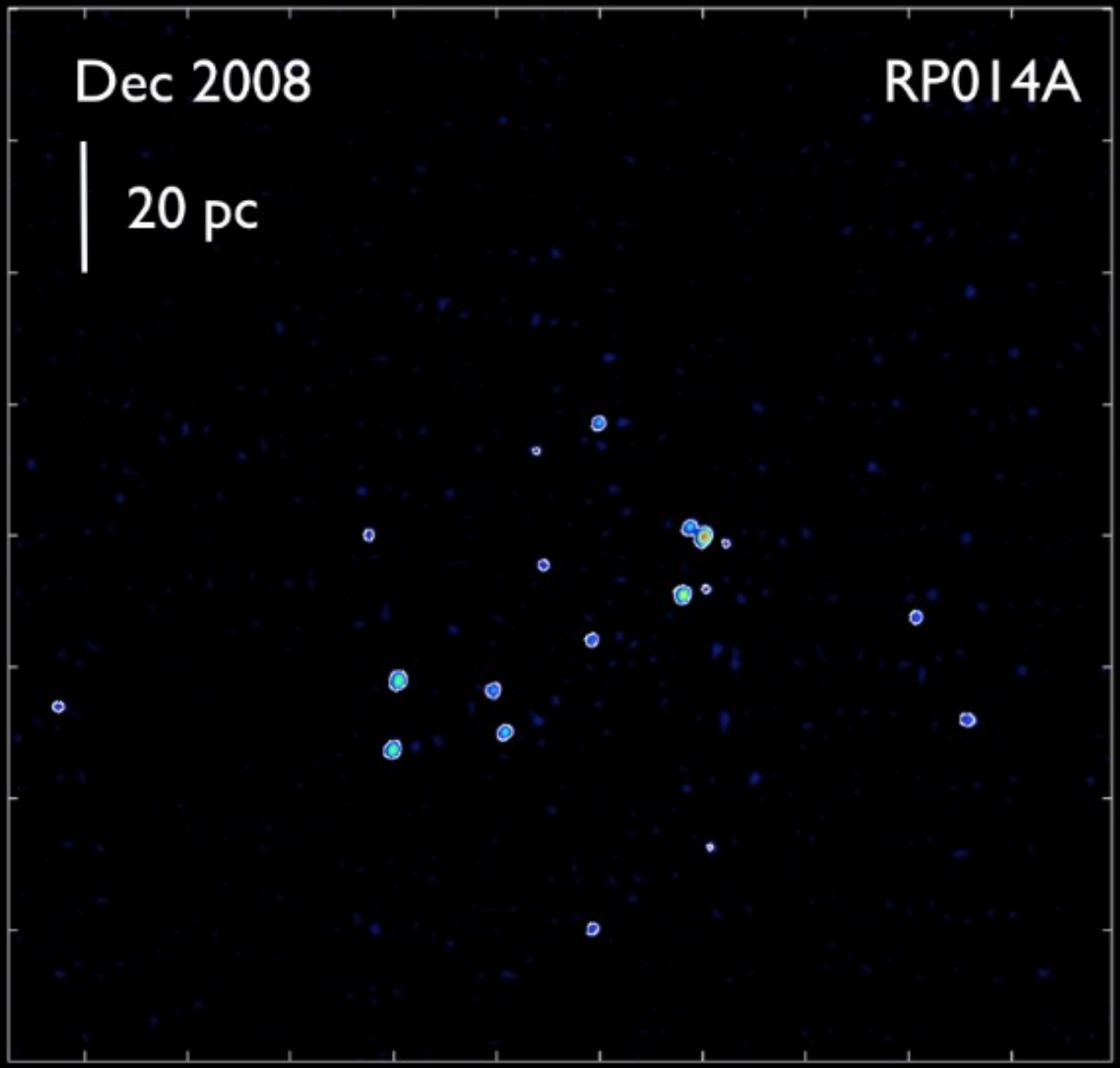
Pérez-Torres+09

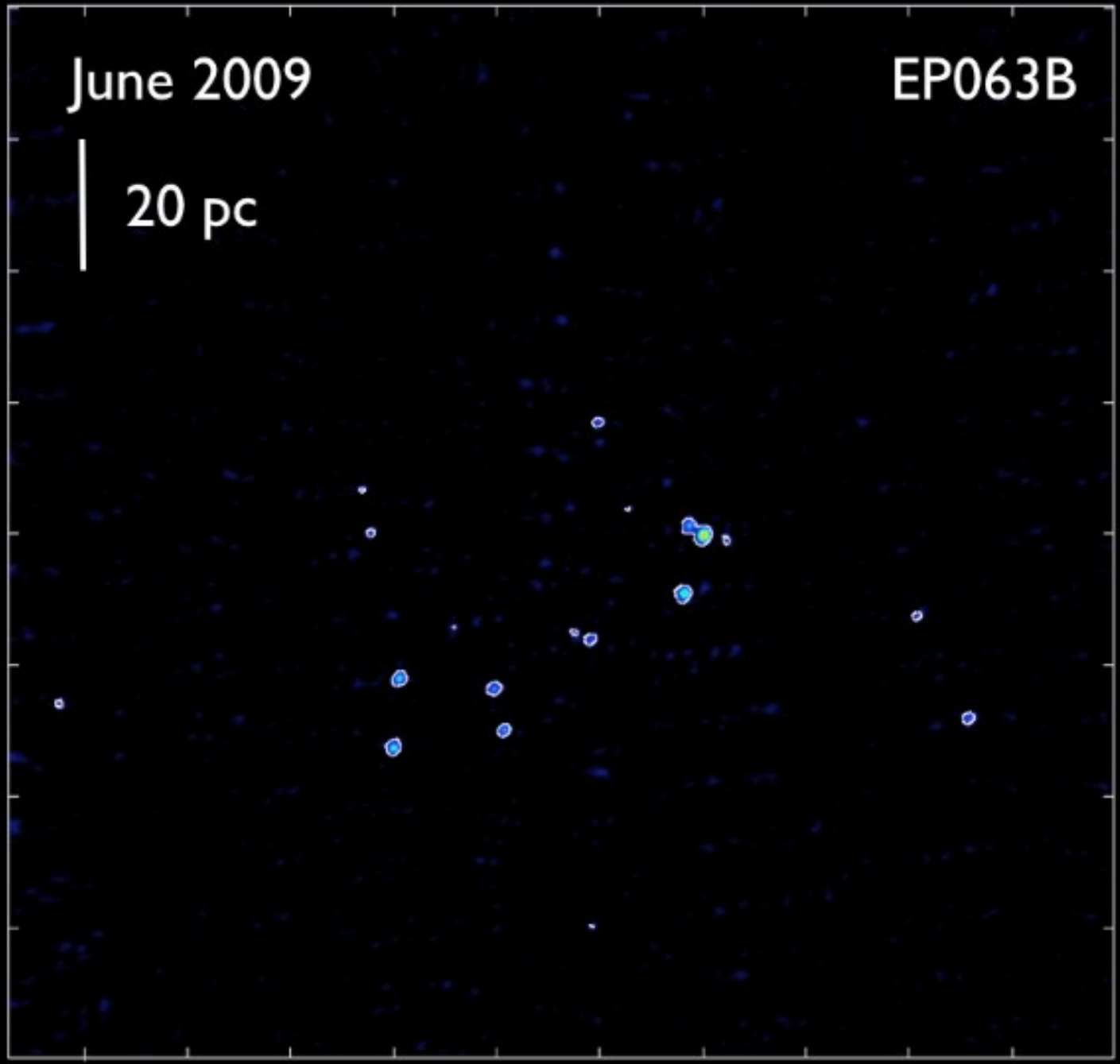


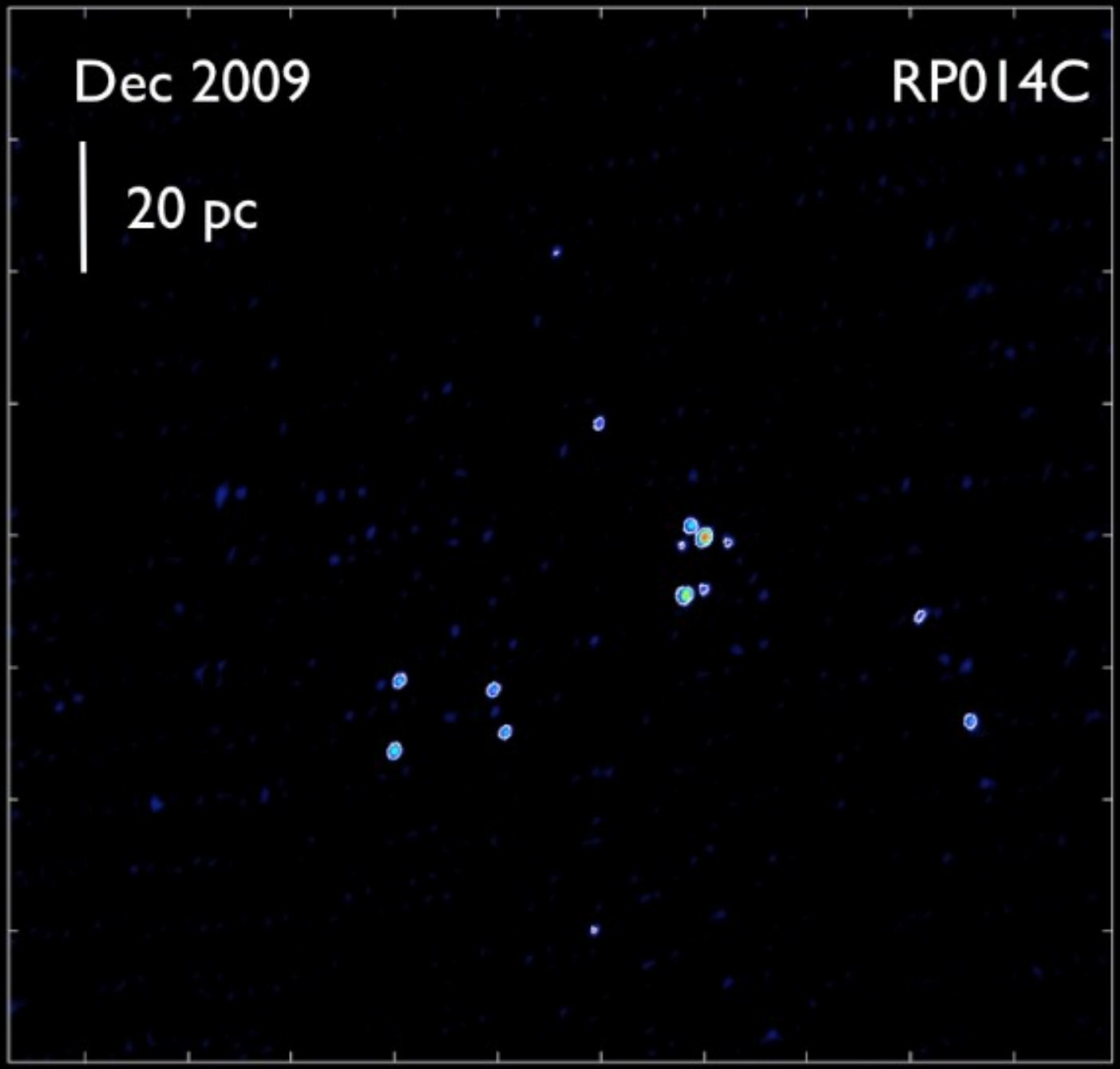
e-EVN @ 6cm, Apr. 2008

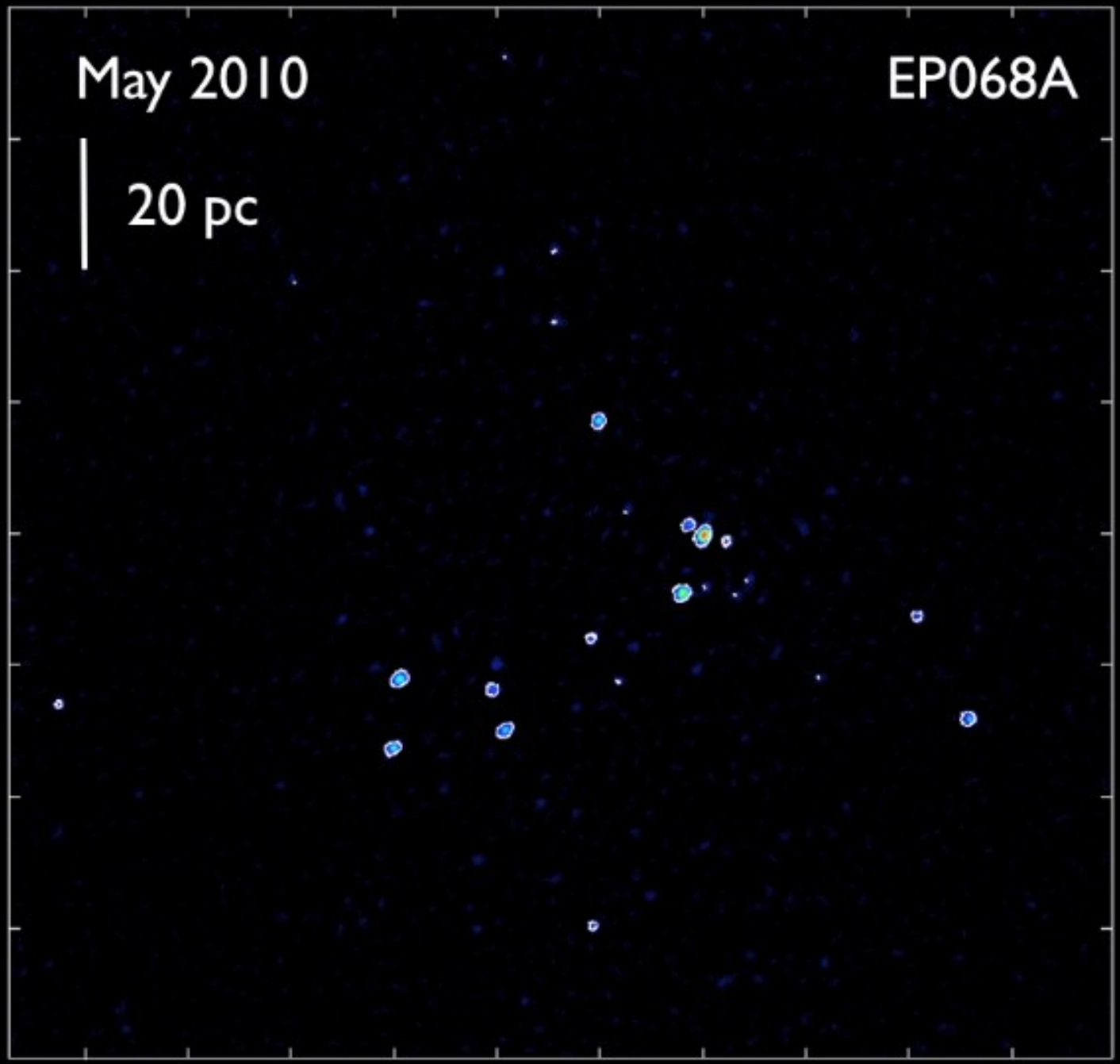
Five of these sources were identified previously with the VLBA by Neff et al., 2004

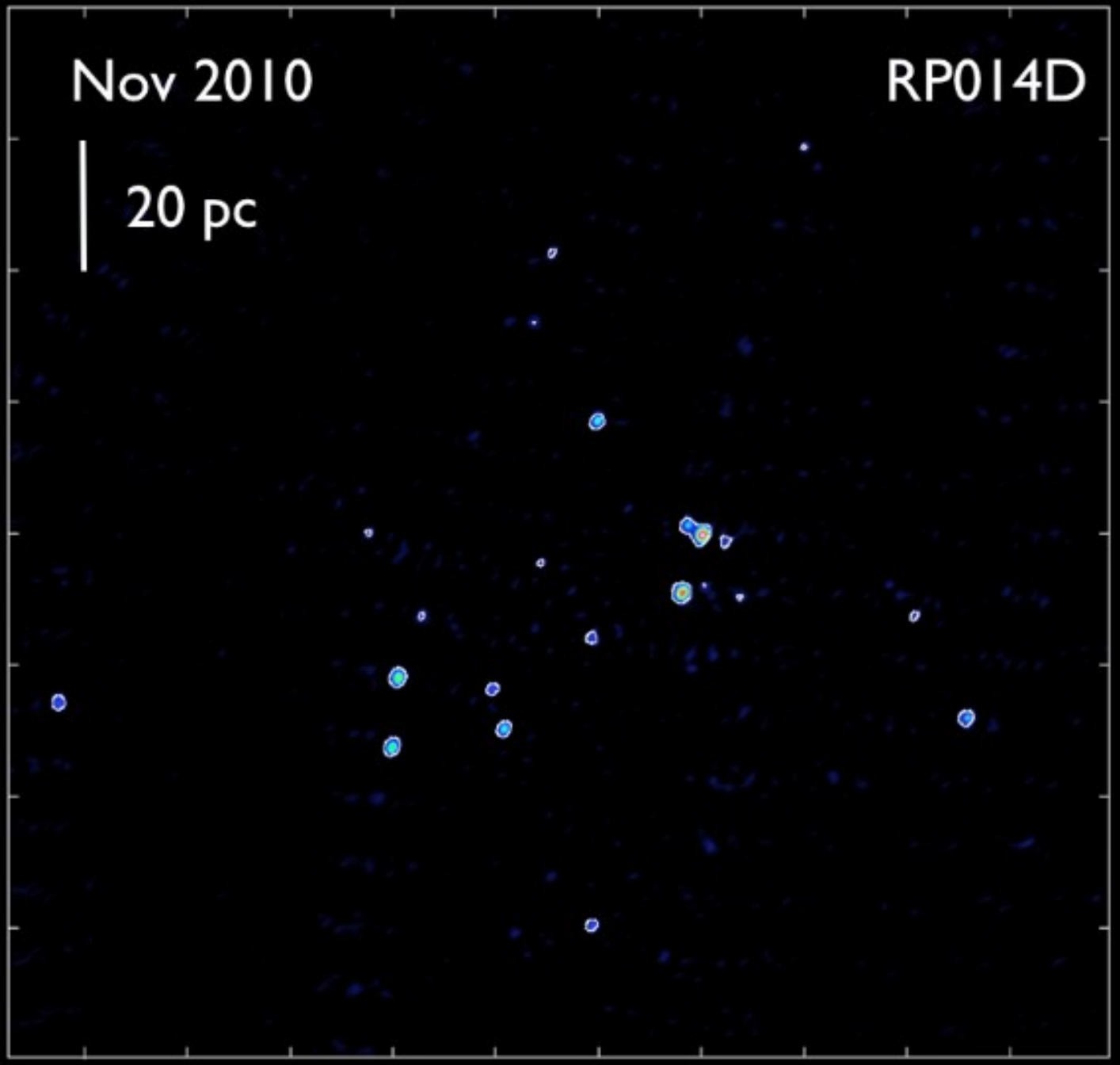

April 2008
RP009
20 pc


Dec 2008
RP014A
20 pc

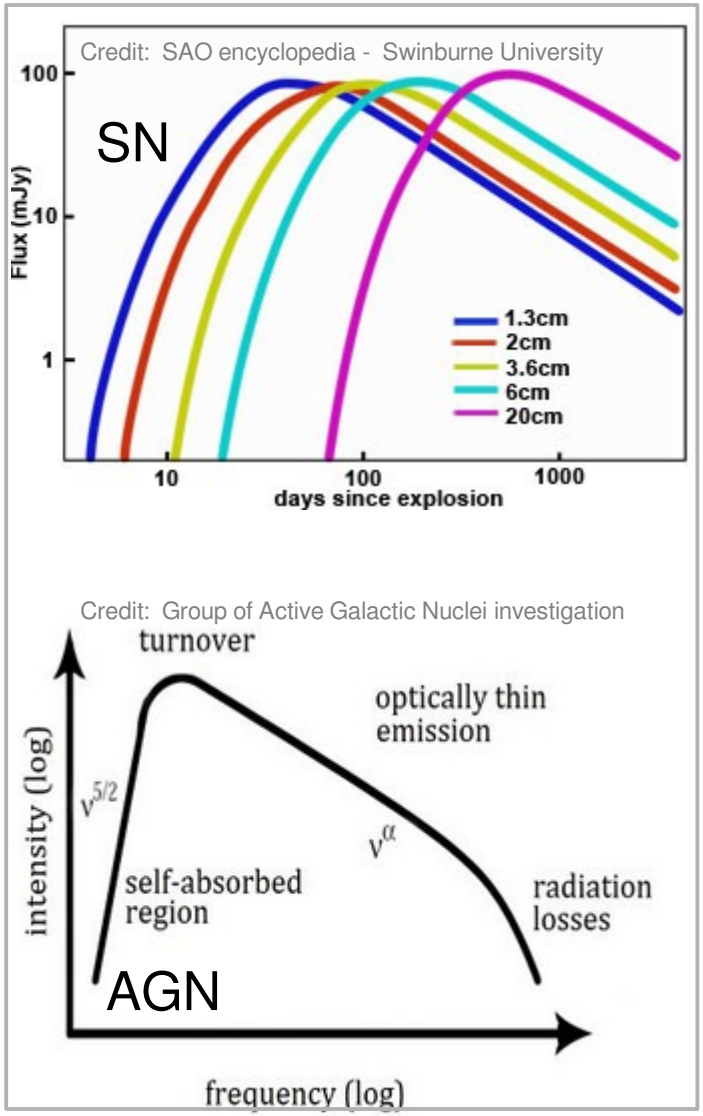

June 2009
EP063B
20 pc


Dec 2009
RP014C
20 pc

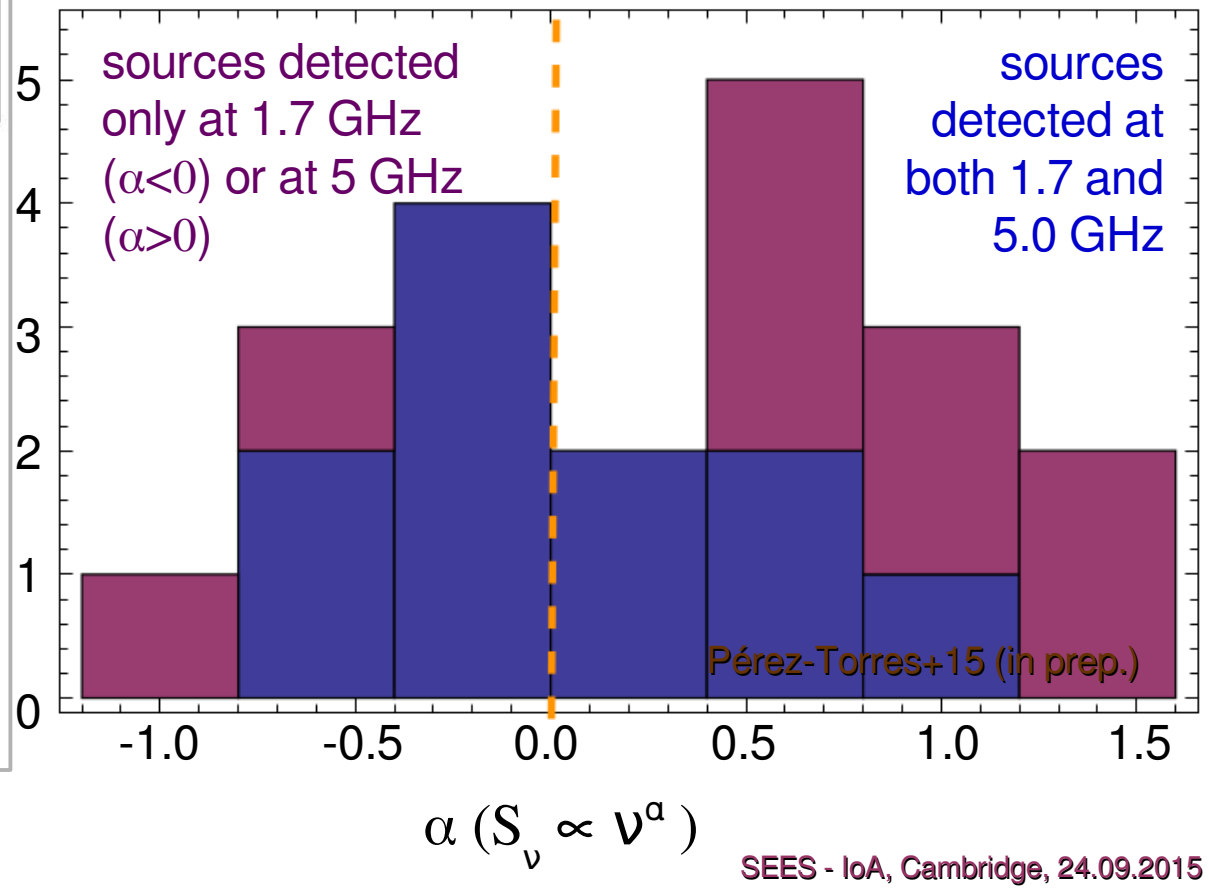

May 2010
EP068A
20 pc


Nov 2010
RP014D
20 pc

Arp299-A: spectral index distribution



Monitoring at two to three different frequencies, roughly every six months to obtain: L_ν, T_B, and the evolution of α and S_ν → help probe the nature of each compact source

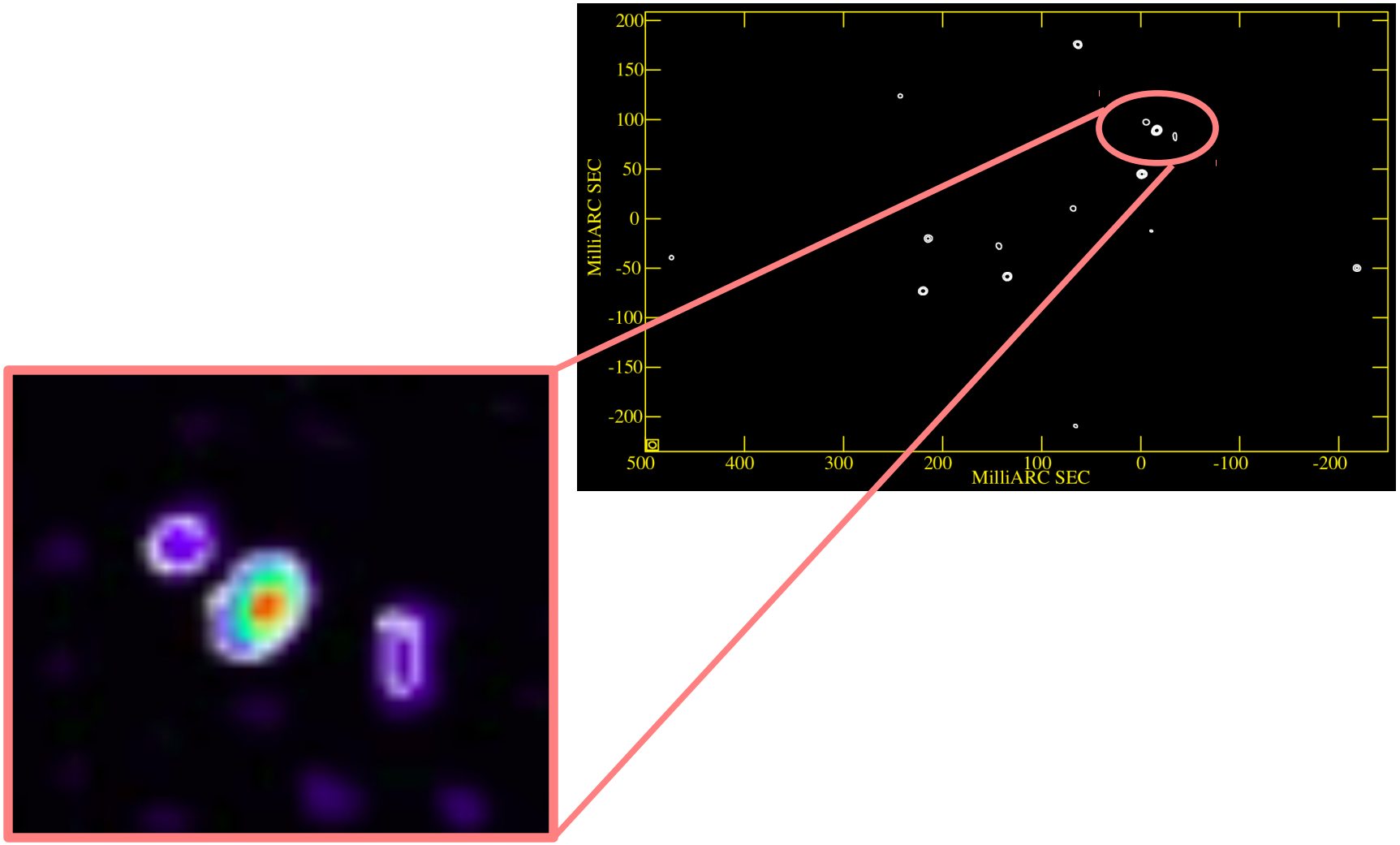


Arp299-A: its constituents

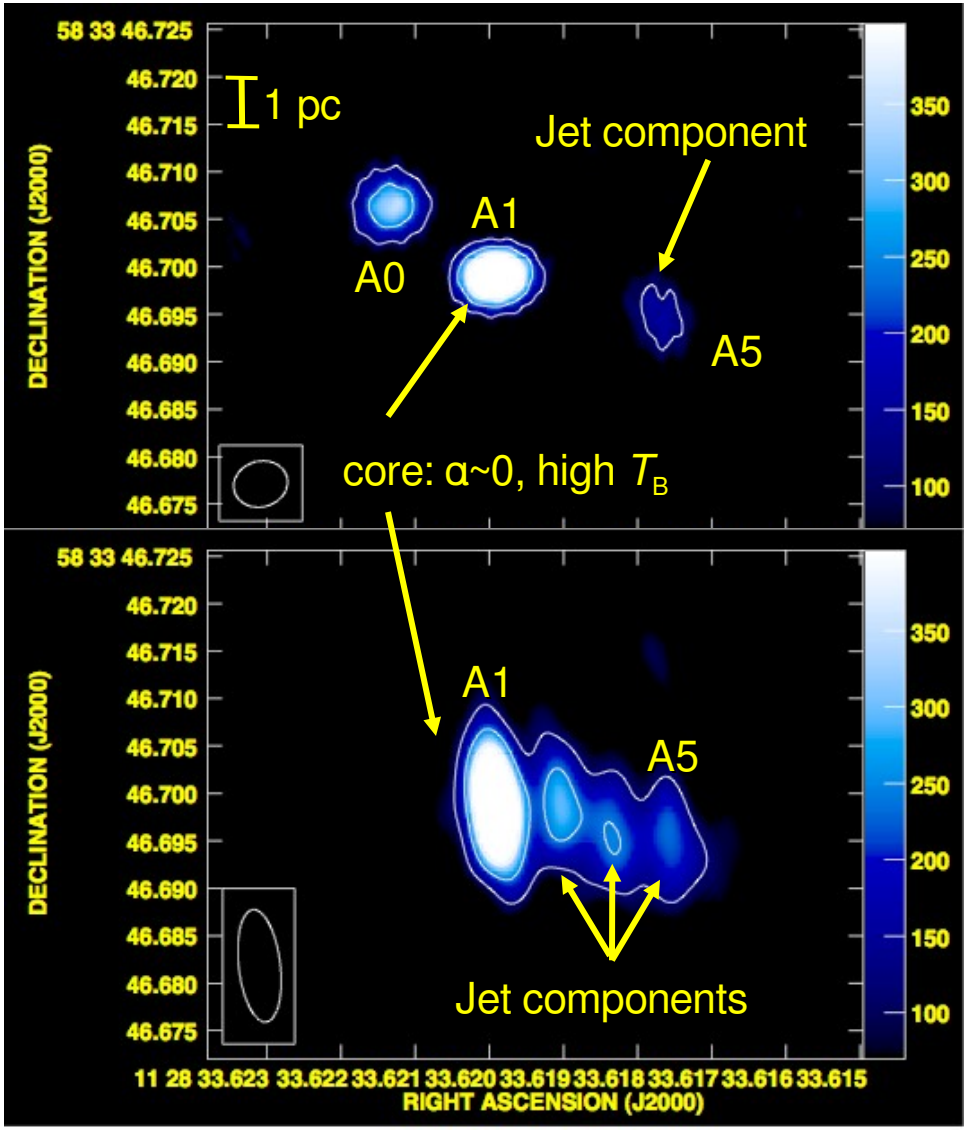
- Rich cluster of compact sources in 150 x 100 pc region
- High $T_B \Rightarrow$ non-thermal origin (SNe and/or SNRs)
- Moderate to high radio emission levels (typical of Type IIb, IIP and IIL SNe): $L_{5GHz} \sim 10^{26}$-10^{27} erg s^{-1} Hz^{-1}
- Evidence for at least two recent radio SN: young, slowly evolving & long-lasting
- $\nu_{nuc} > 0.8$ yr^{-1}
- In a nutshell: this is a very strong starburst, but it is even more than that! ...

Pérez-Torres+09; Bondi, Pérez-Torres+12

Arp299-A: a zoom-in to a very interesting region



Arp299-A: LLAGN and SB coexistence



Discovery of a dusty-buried AGN (Pérez-Torres et al., 2010)

A1-A5 complex

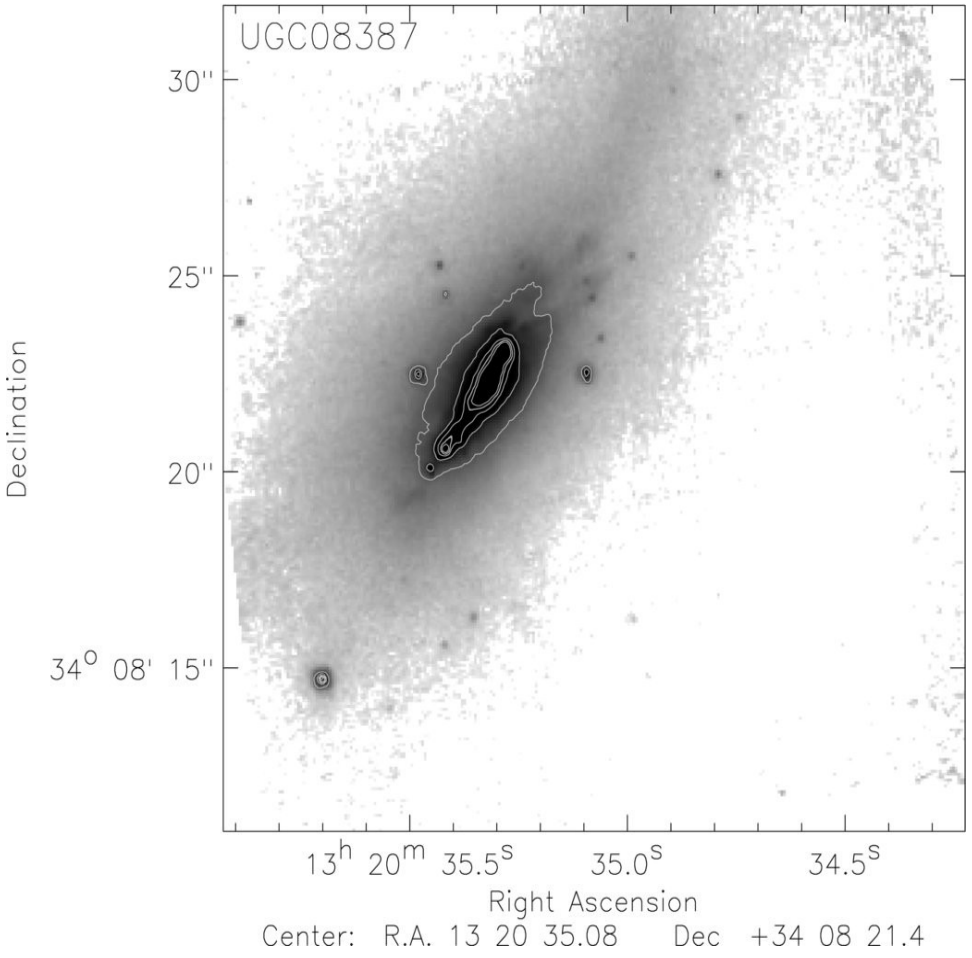
- Core-jet morphology
- $\left(\frac{\nu \times L_\nu}{L_X}\right)_{\nu=5\,\mathrm{GHz}} \sim 10^{-3} \Rightarrow$ LLAGN

A0

- ~~Emission~~ at low freq. owing to a nearby absorber
- RSN 2 pc away from a SMBH

SB & AGN together!!!

IC883



HST -**NICMOS** 1.6 μm image (Haan+11)

Romero-Cañizales +12
Kankare +12

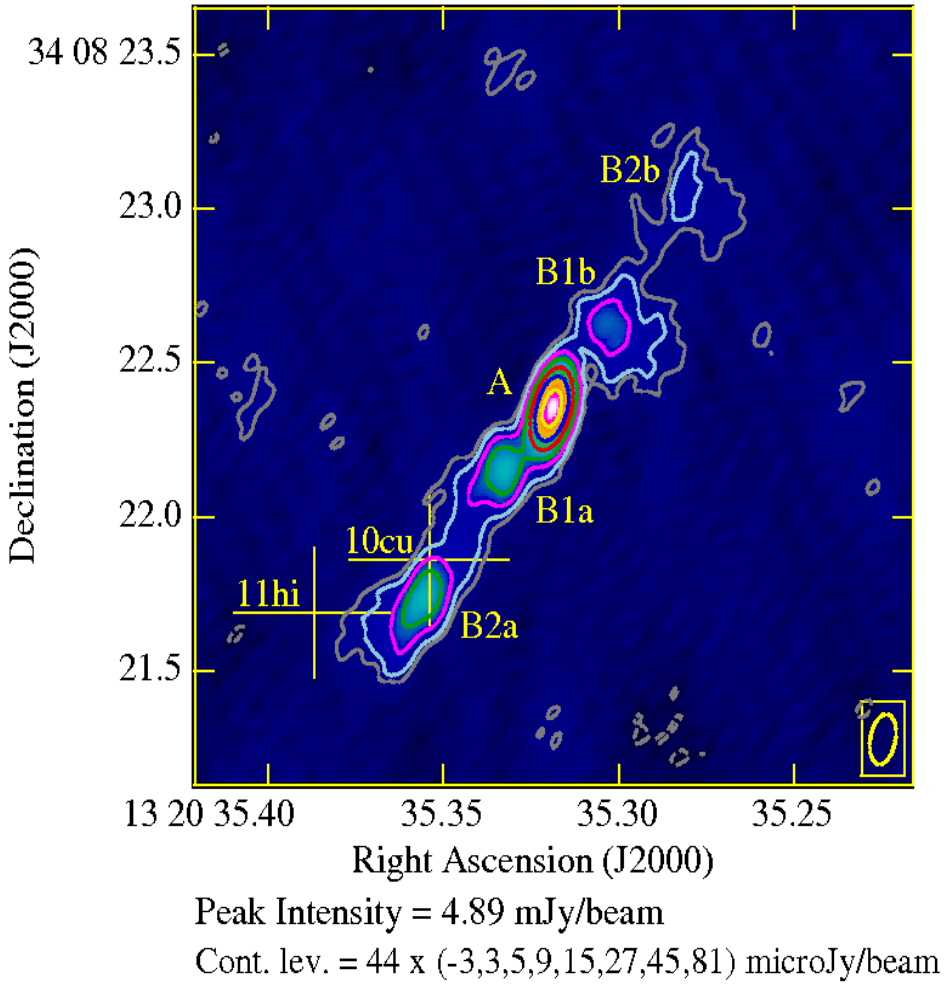
Advanced stage merger (starburst-AGN composite)

- D ~ 100 Mpc ⇒ 1 mas ~ 0.5 pc
- $L_{IR} \sim 4.7 \times 10^{11}\ L_{\odot}$

$$\nu_{CCSN} \approx 1.3\,\mathrm{yr}^{-1}$$

Two SN discoveries in the NIR:
SN 2010cu **(Ryder+10)** &
SN 2011hi **(Kankare+11)**

IC 883: e-MERLIN observations

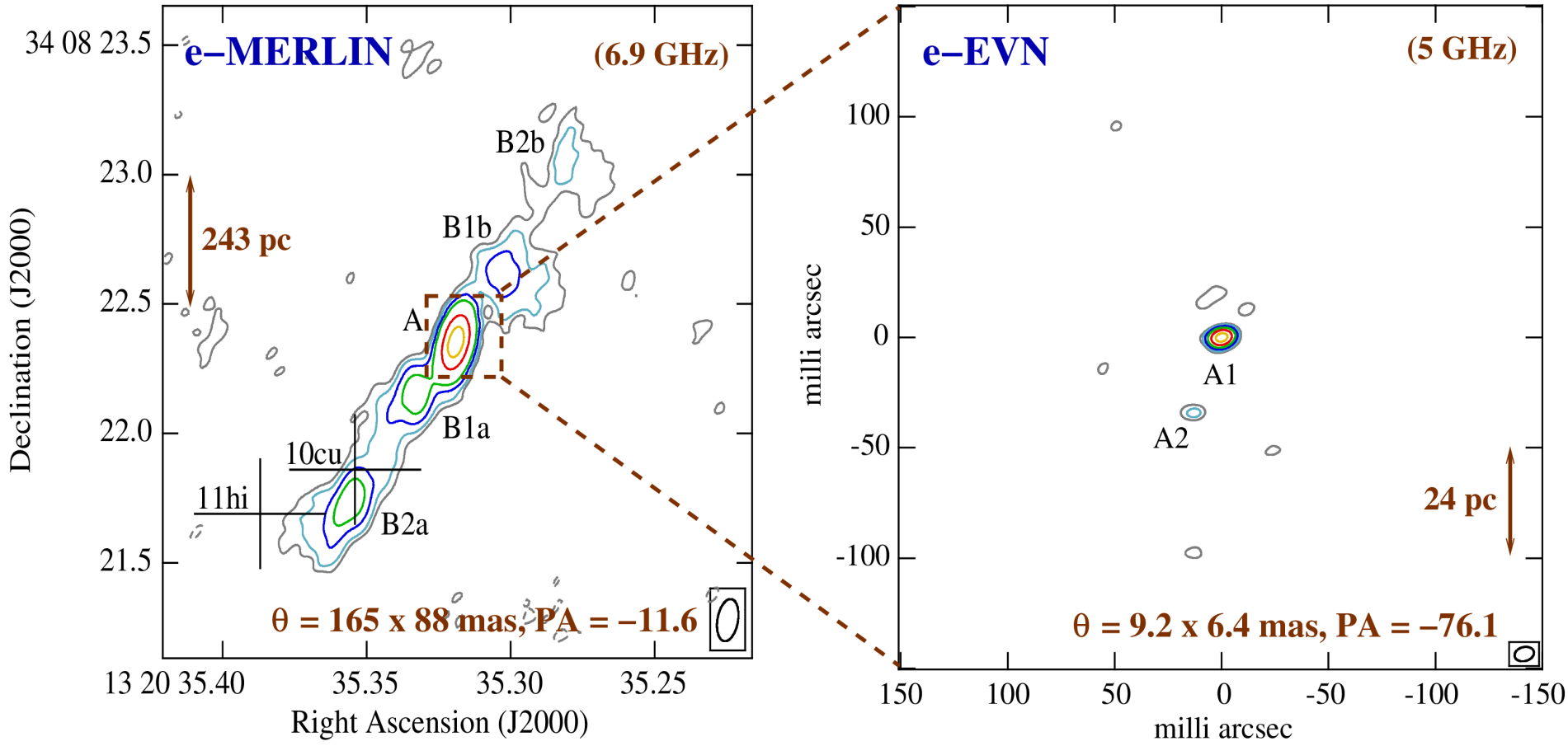


~ 1 kpc structure at 144º

Warped ring

No radio detection 1month after NIR discovery of SN 2011hi (type IIP)

IC 883: e-MERLIN + e-EVN observations



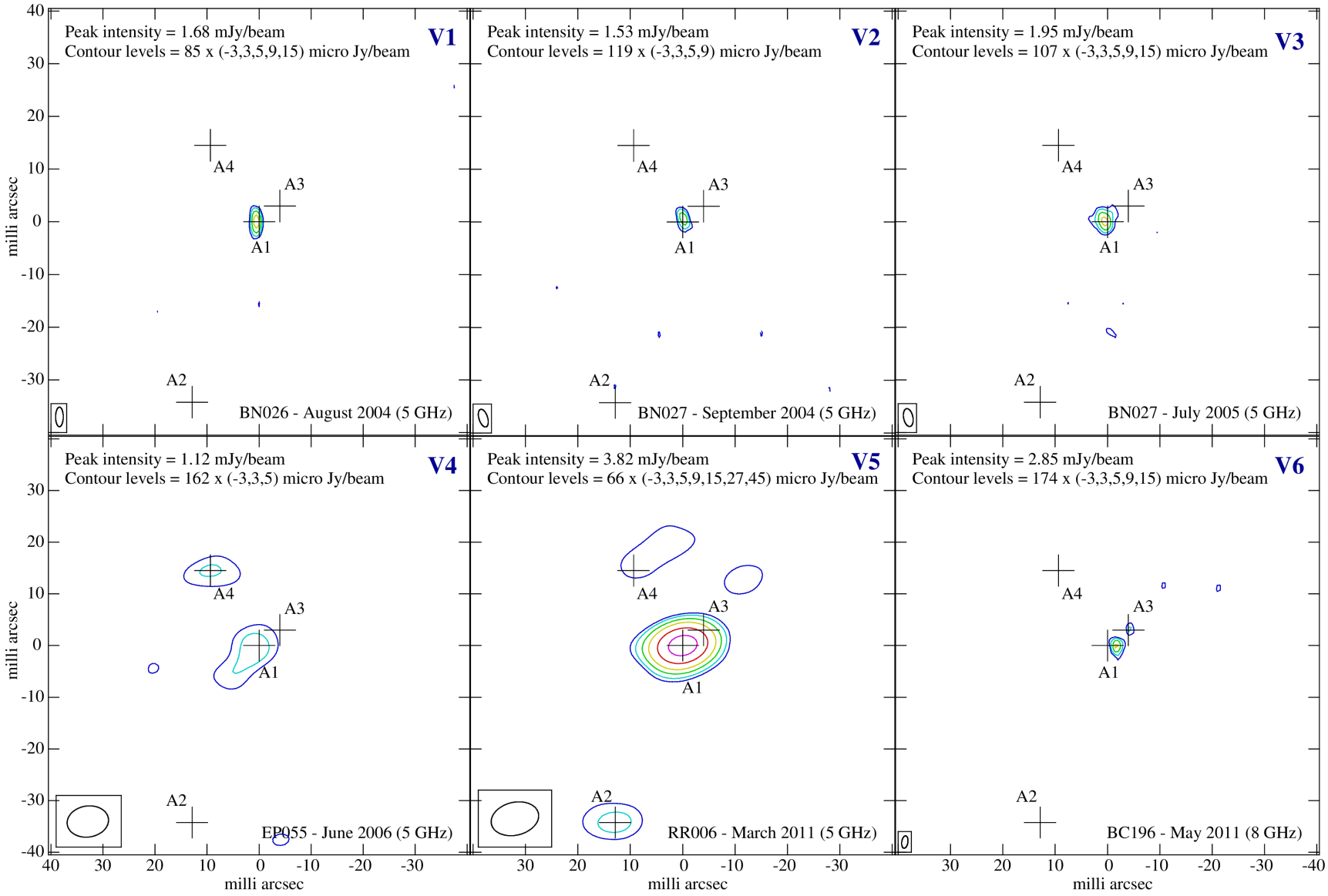
Peak Intensity = 4.89 mJy/beam

Cont. lev. = 44 x (-3,3,5,9,15,27,45) microJy/beam

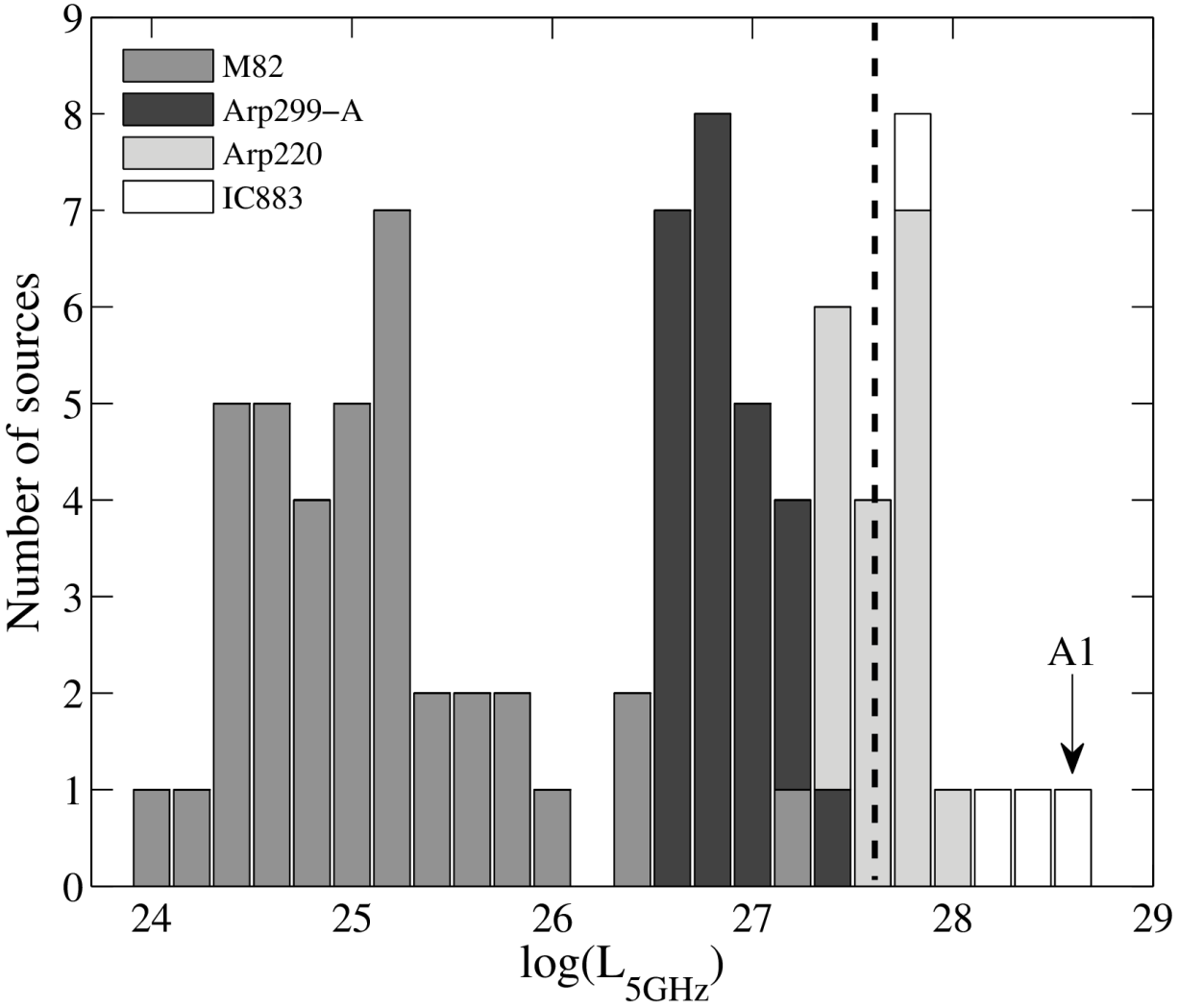
Peak Intensity = 3.82 mJy/beam

Cont. lev. = 66 x (-3,3,5,9,15,27,45) microJy/beam

IC 883: VLBI monitoring



IC 883: compact sources (SNe, SNRs, AGN?)



- If the transients are SNe

$\Rightarrow \quad \nu_{nuc} > 0.6\ yr^{-1}$

and $\quad \nu_{tot} > 1.1\ yr^{-1}$

- A1 (e-EVN) and A (e-MERLIN) ⇒ AGN

$$\left(\frac{\nu \times L_\nu}{L_X}\right)_{\nu=5\mathrm{GHz}} \sim 10^{-3} \Rightarrow \text{LLAGN or normal AGN ?}$$

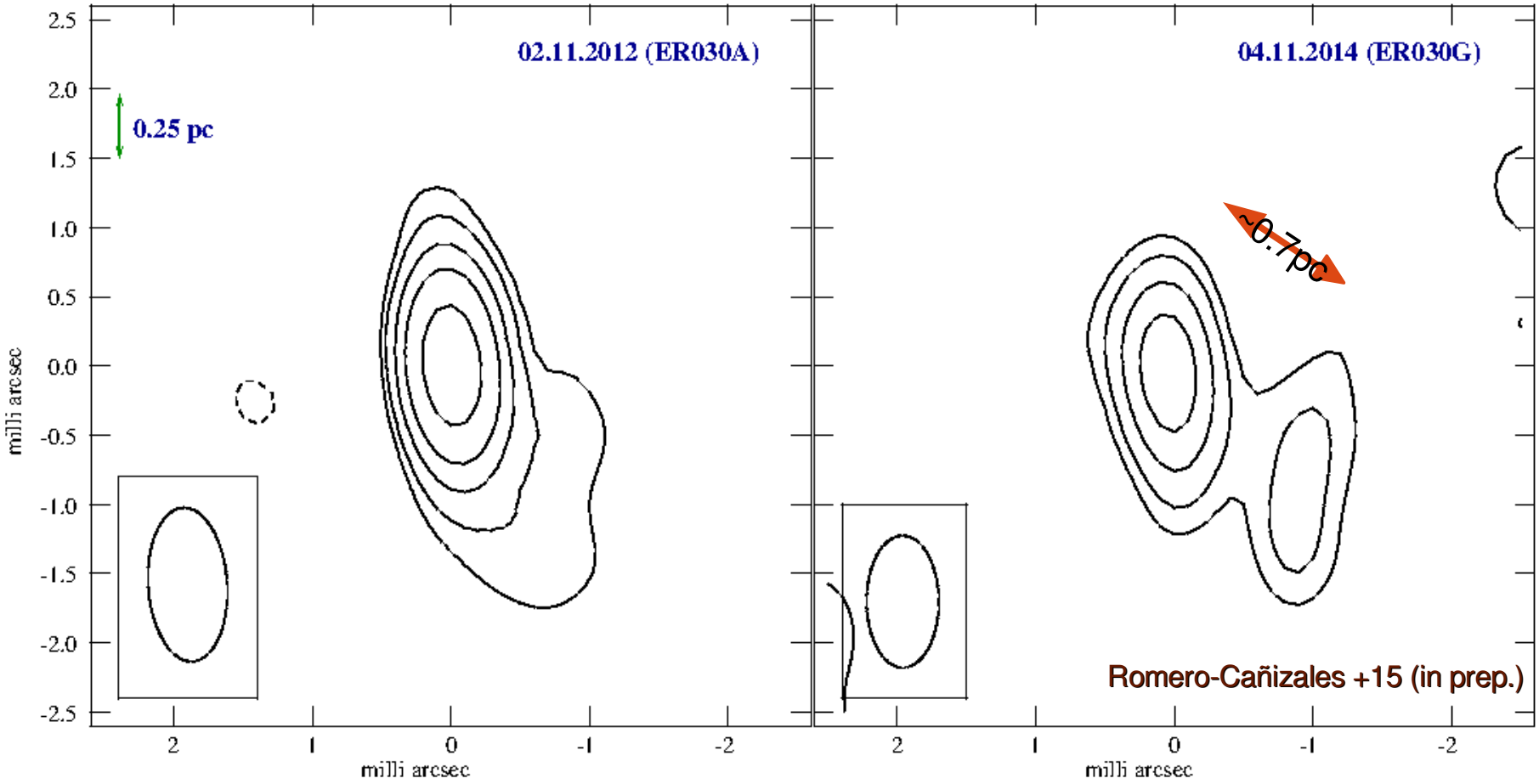
- Non-thermal compact components in a 100 x 100 pc region ⇒ SB activity in the nucleus

AGN & SB together!!!
candidate

Romero-Cañizales +12

IC 883: monitoring

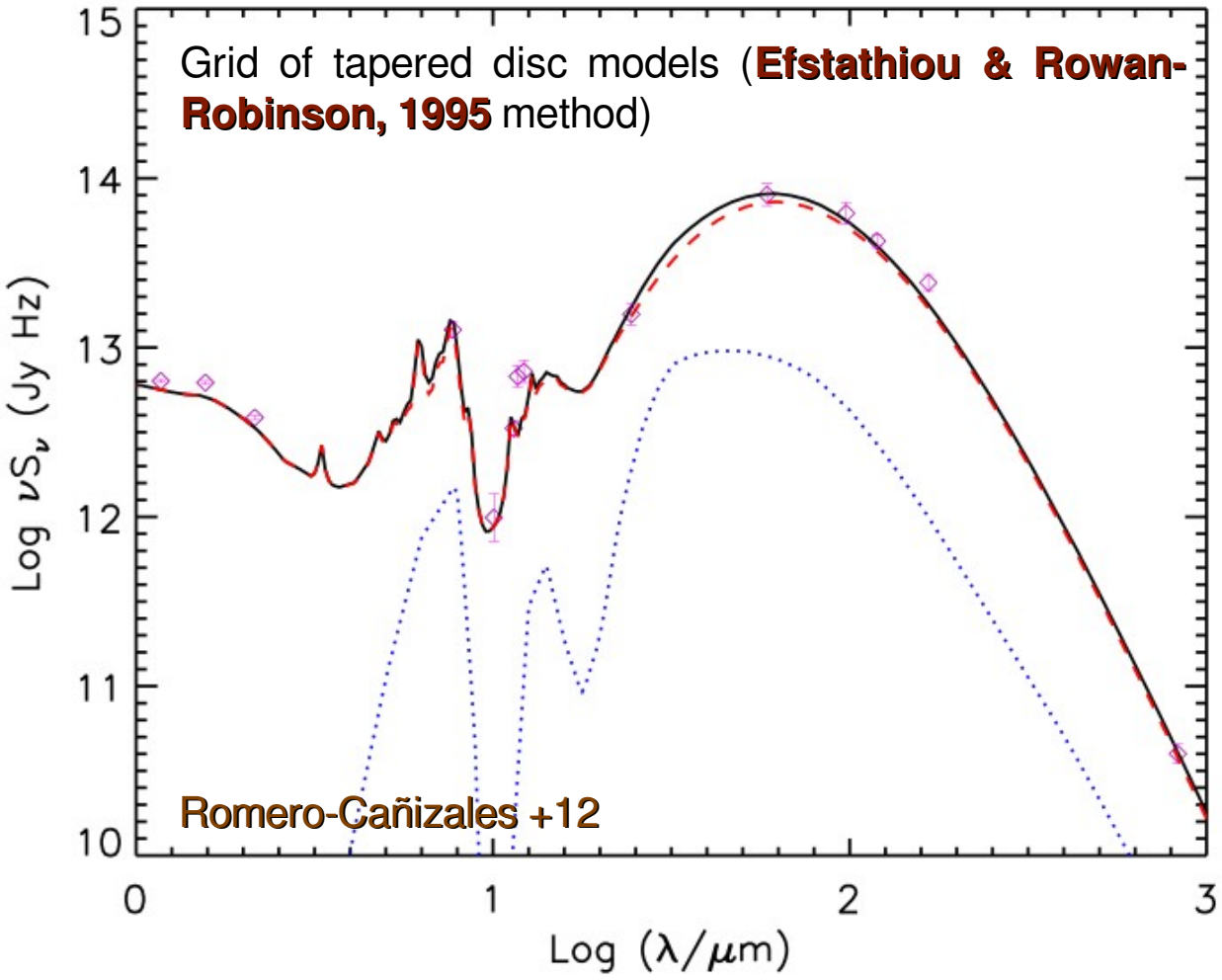
New ejected component at 8.4 GHz: not present in VLBA observations from 15.05.2011 at the same frequency.



⇒ the component has moved at an apparent speed of $0.6\ c < v < 1.1\ c$

The core ($L_{8.4GHz} > 1 \times 10^{28}$ erg s^{-1} Hz^{-1}) has a flat spectrum between 5 and 8.4 GHz, but it is highly absorbed at 1.7 GHz

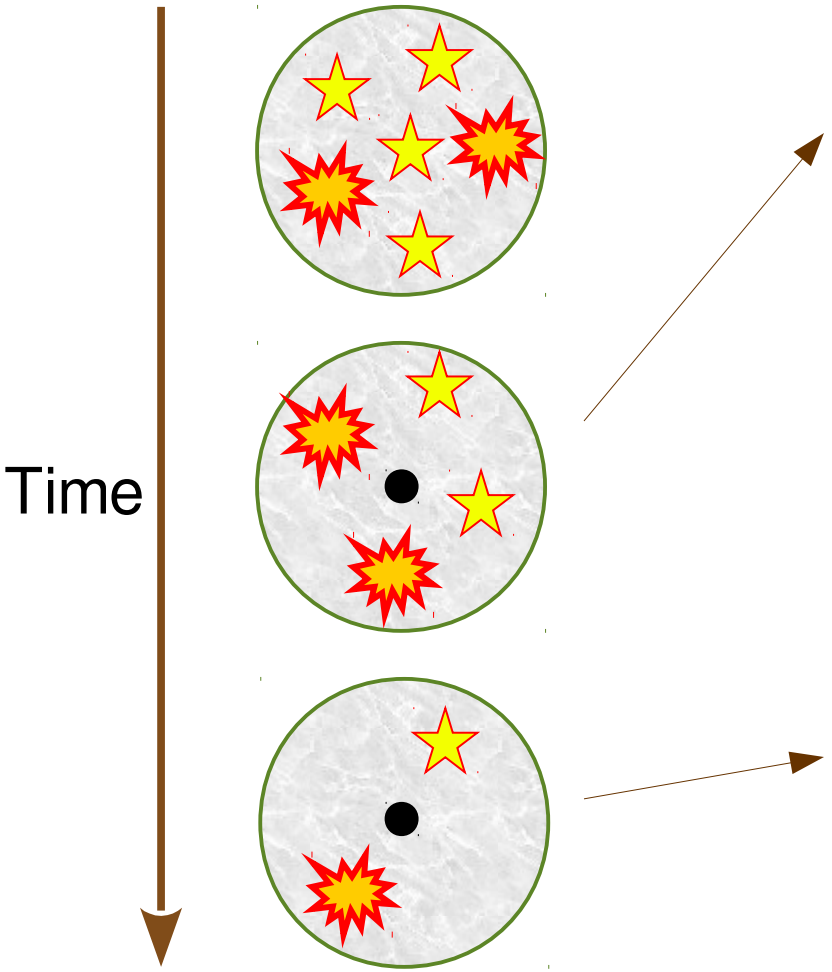
IC 883: IR SED

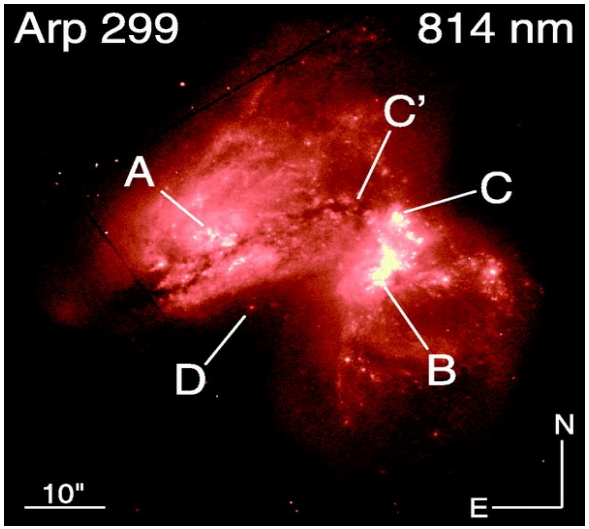


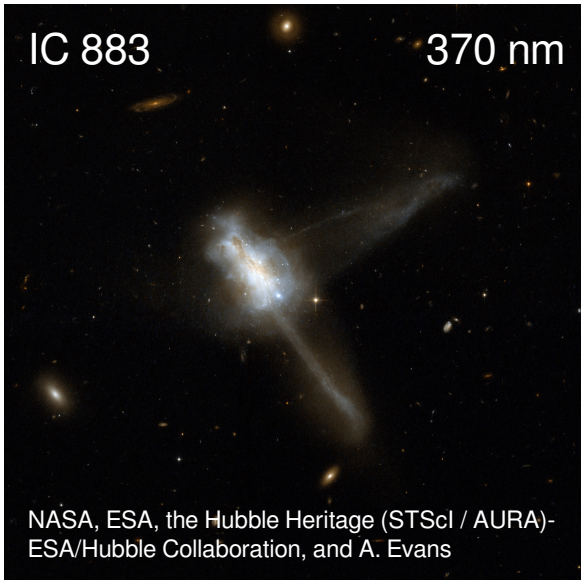
- AGN is not needed (<10% the contribution from the starburst)
- But, it could be 30x than observed
- Still, in X-rays and in radio, the AGN seems to be the dominant source **(Romero-Cañizales+15 in prep.)**

A similar situation holds in other nearby (U)LIRGs **(Ricci+15 in prep.)**

Back to Yuan+10 evolution scenario...







Take away points:

- ✔ Ongoing transient activity (SB + AGN) is found in the innermost nuclear regions of (U)LIRGs → high extinction
- ✔ To see such activity directly and quantify it, high-resolution radio observations are a must!