Supernova factories in the centres of galaxies unveiled by the EVN

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JIVE-ERIC Inaugural Symposium

This work wouldn't have been possible without the contribution of my colleagues. Thanks!

Antxon Alberdi
Marco Bondi
Rubén Herrero-Illana
Antonis Polatidis
Cristina Romero-Cañizales

JIVE-ERIC Inaugural Symposium

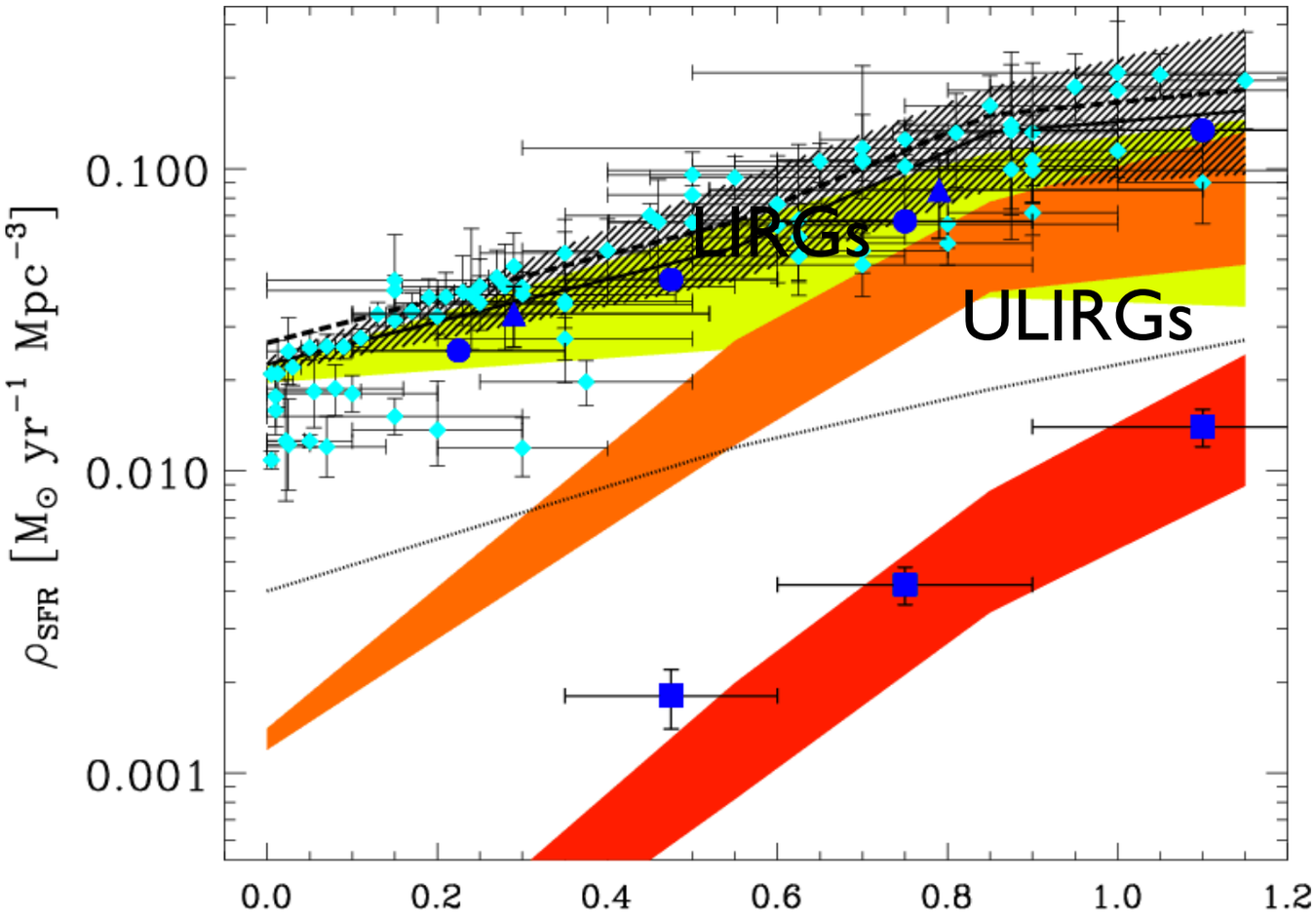
The hidden population of SNe in LIRGs

- Typical SFRs are a few x10-100 M_sun/yr => CCSN rates a few x (0.1-1) SNe/yr

- Significant fraction of the SF at high-z took place in LIRGs/ULIRGs

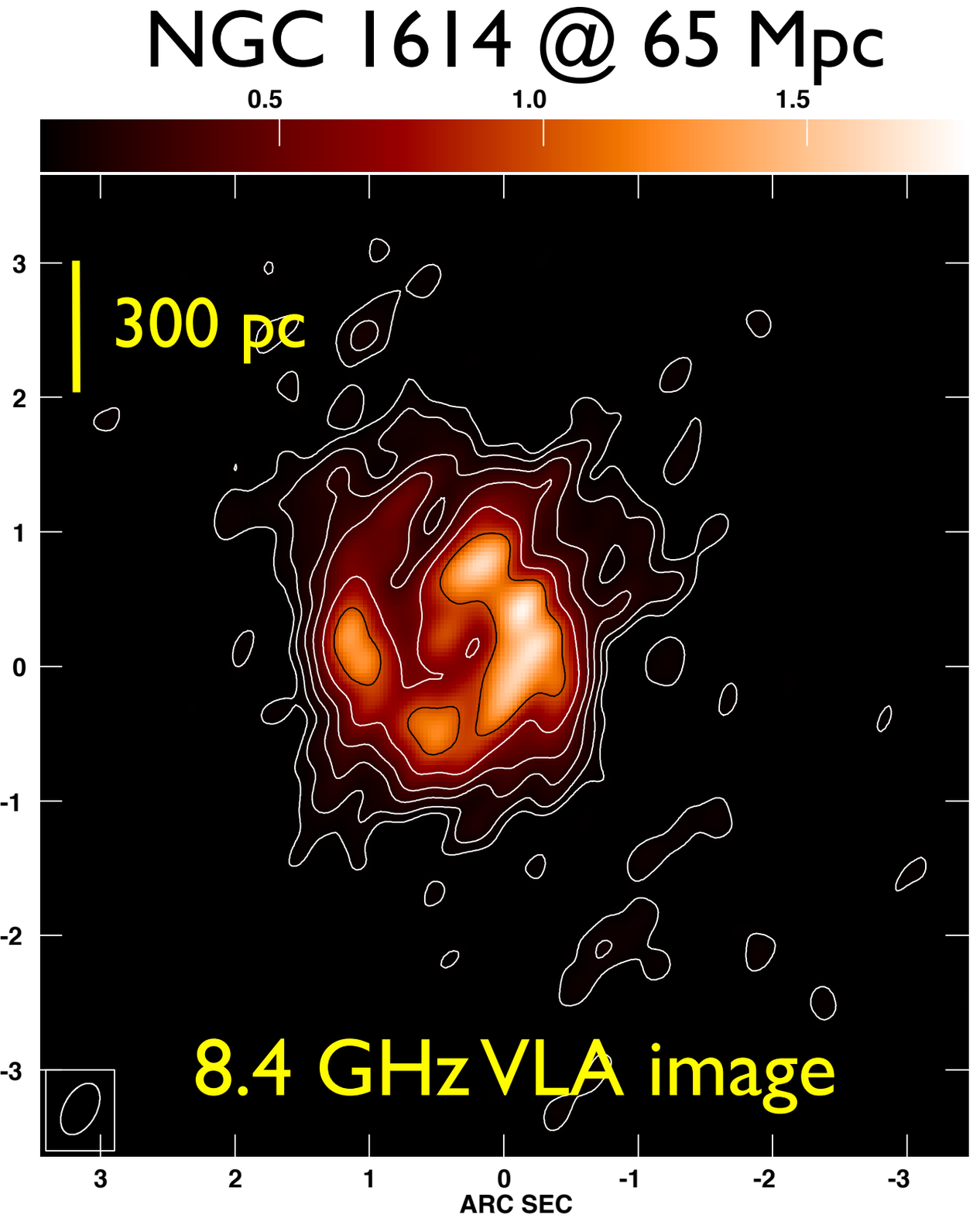
- Detection of SNe crucial for revising CCSN rates both locally and at high-z

SFR density vs. redshift



Magnelli +09, +11

Why do we need the EVN?

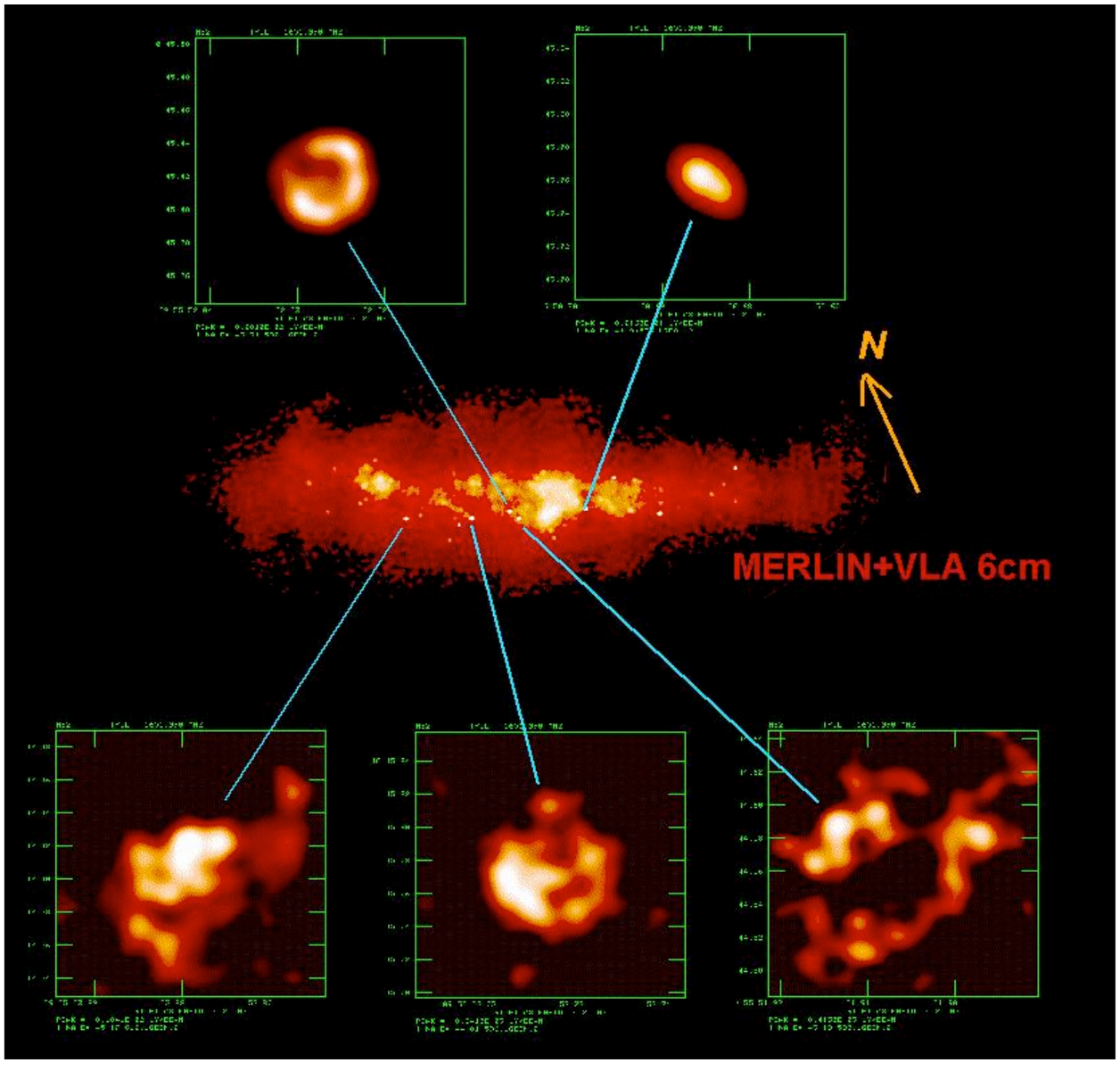


- Compact (<=200 pc), low-surface brightness central radio source
- Extended (>= 1kpc), bright-surface brightness circumnuclear region

- Higher angular-resolution needed
- Very high-sensitivity need

CCSNe as a direct SFR tracer in (U)LIRGs

M82 at cm wavelengths

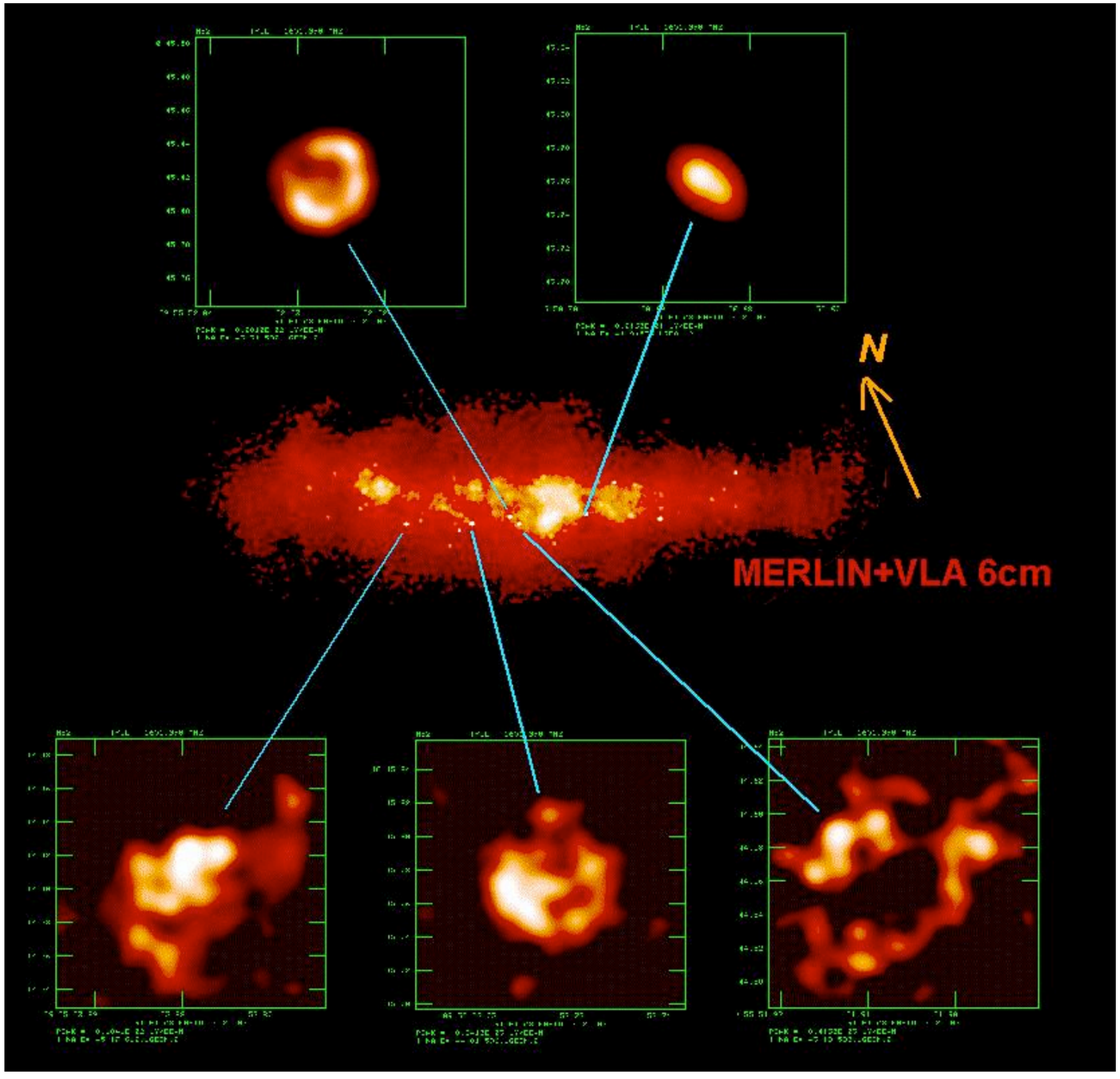


- Stars with M >= 8 Msol yield CCSNe
- Optical searches are deemed to fail due to severe dust extinction.
- Radio emission is free from extinction effects => searches in radio for CCSNe more promising to yield true estimate of CCSN rates.
- CCSNe rate + IMF => direct measurement of current SFR

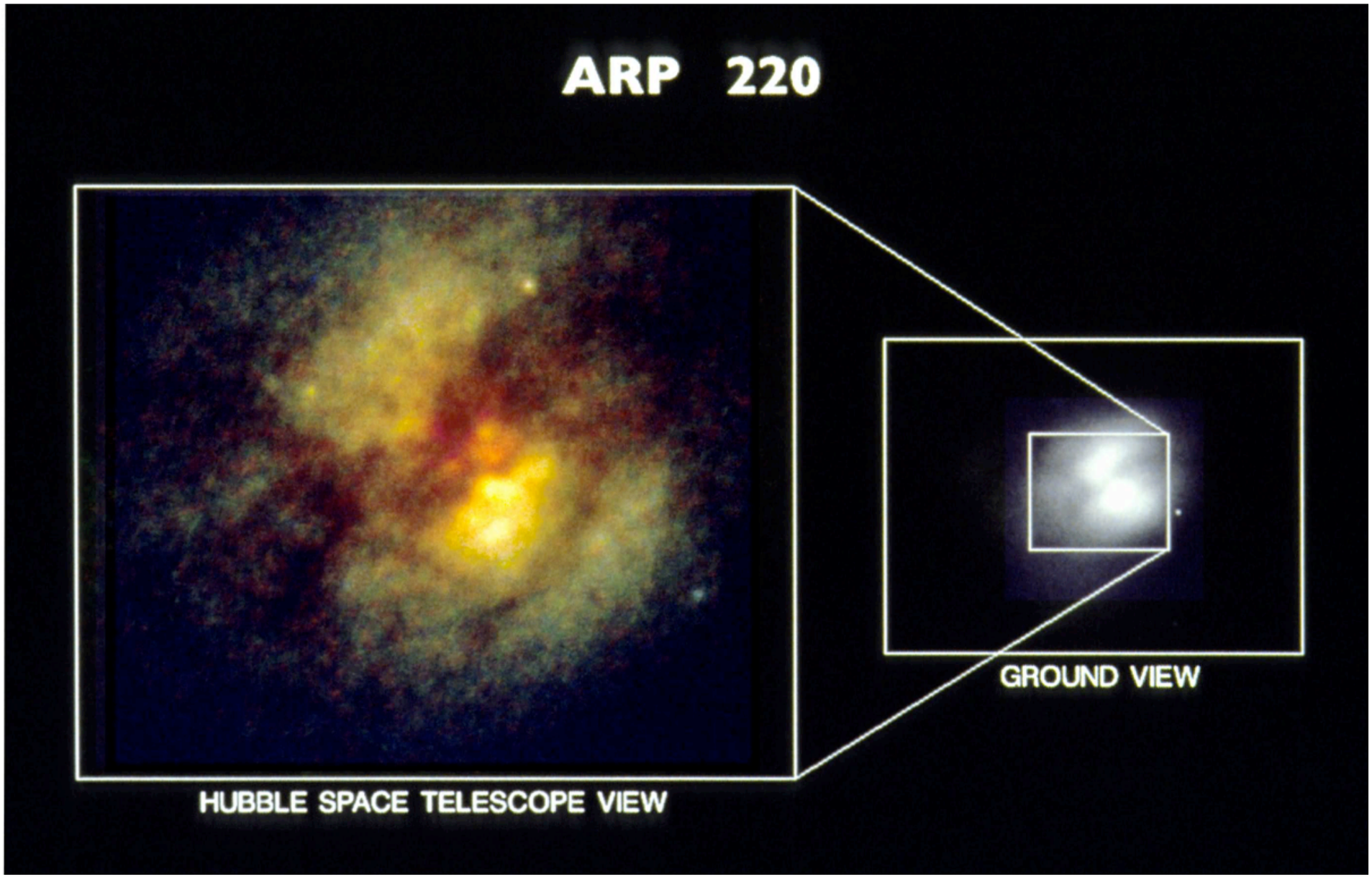
M82 - A Supernova Remnant Lab

- D = 3.5 Mpc
- 1” ~ 17 pc
- $L_{fir} = 5.9 \times 10^{10}\ L_{sol}$
- CCSN rate ~ 2.7×10^{-12} (L_{fir} / L_{sol})(Mattila & Meikle 2001) => SN rate = 0.16 SN/yr
- Radio observations yield SN rate = 0.1 SN/yr (Fenech+ 2008; Beswick+ 2006)

M82 at cm wavelengths

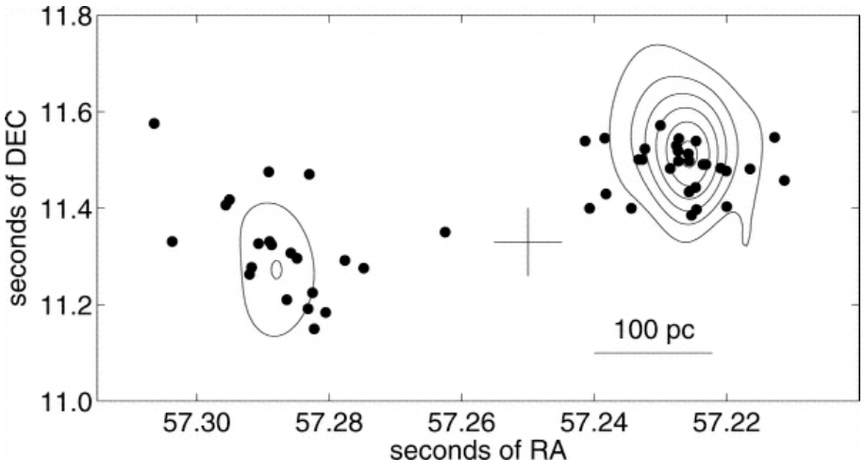


The prototypical ULIRG Arp 220



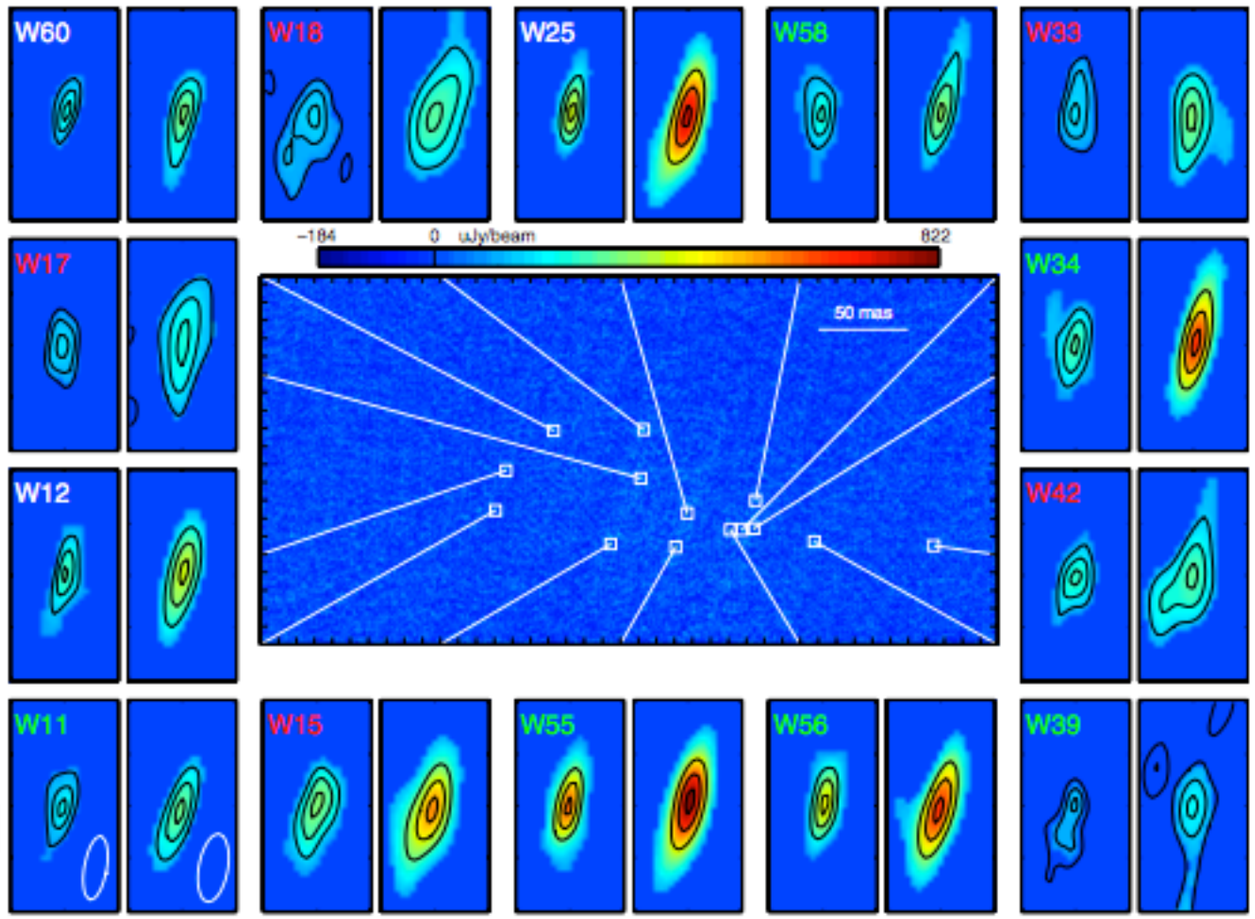
- D = 77 Mpc; 1” ~ 370 pc
- L_{fir} = 1.5 x10^{12} L_{sol} => CCSN Rate = 4 SN/yr

The RSN factory in Arp 220



Parra +2007

5.0 GHz Global VLBI obs-ns of Arp 220



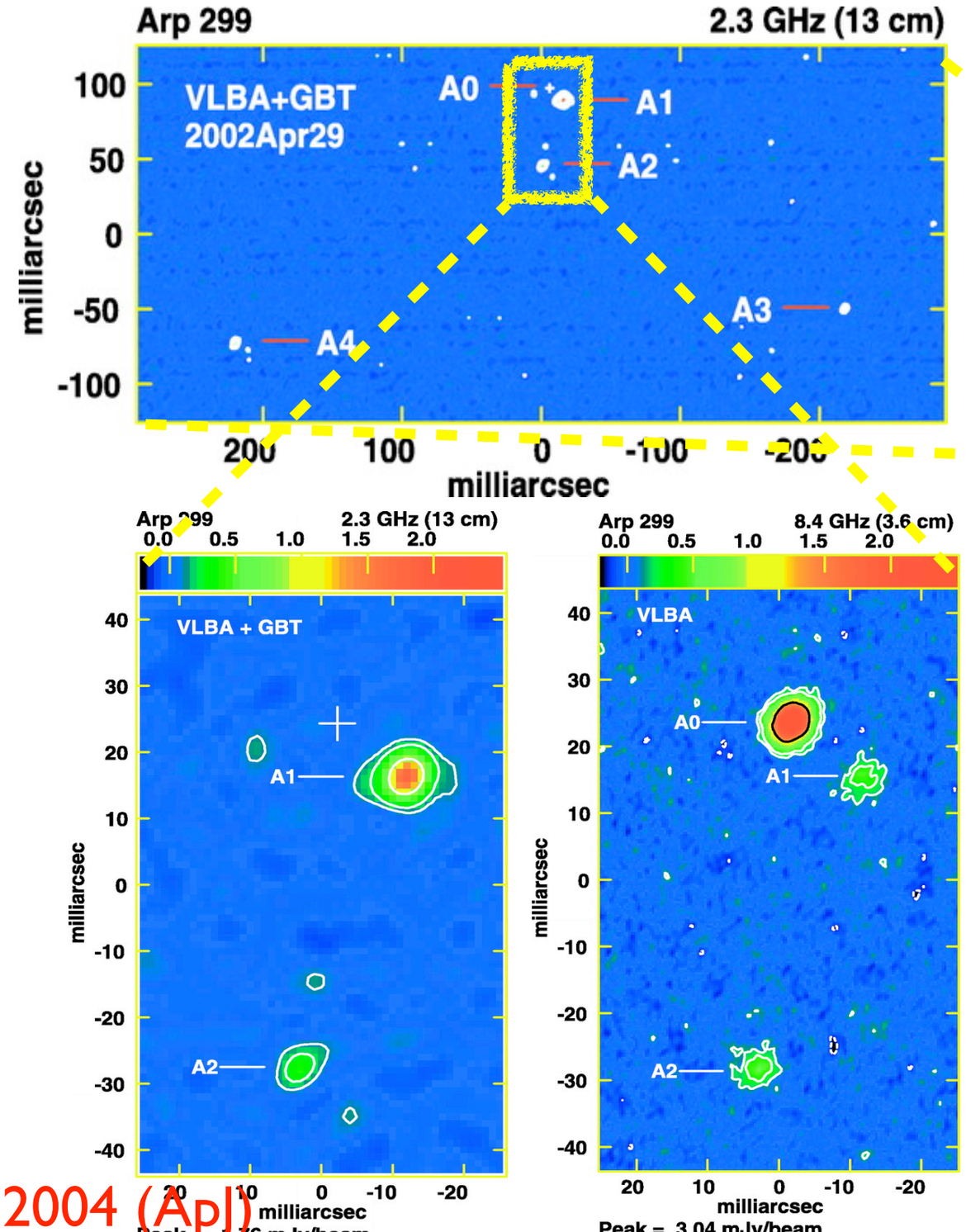
Batejat+2011

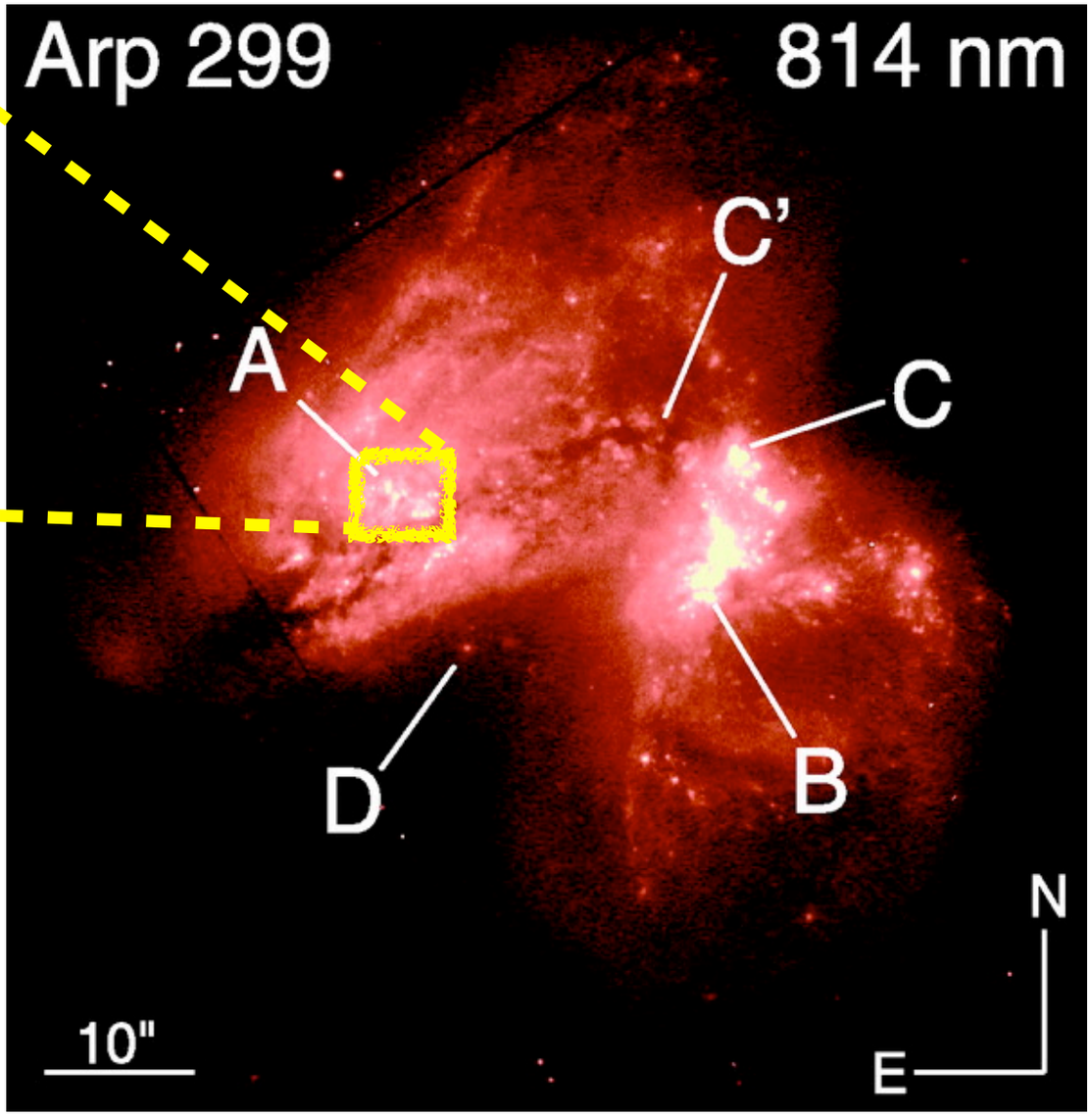
- Large numbers of SNe and SNRs detected.
- All Radio SNe are very bright => Type IIn SNe => very massive progenitors
- Radio SN rate = 4 +/- 2 RSN/yr = Expected total CCSN rate!!

Large number of bright, Type IIn-like SNe => Top-heavy IMF!?

High-angular observations of Arp 299A

- D = 45 Mpc; 1” ~ 220 pc
- L_{fir} = 3 x10^{11} L_{sol} => CCSN Rate ~ 1 SN/yr



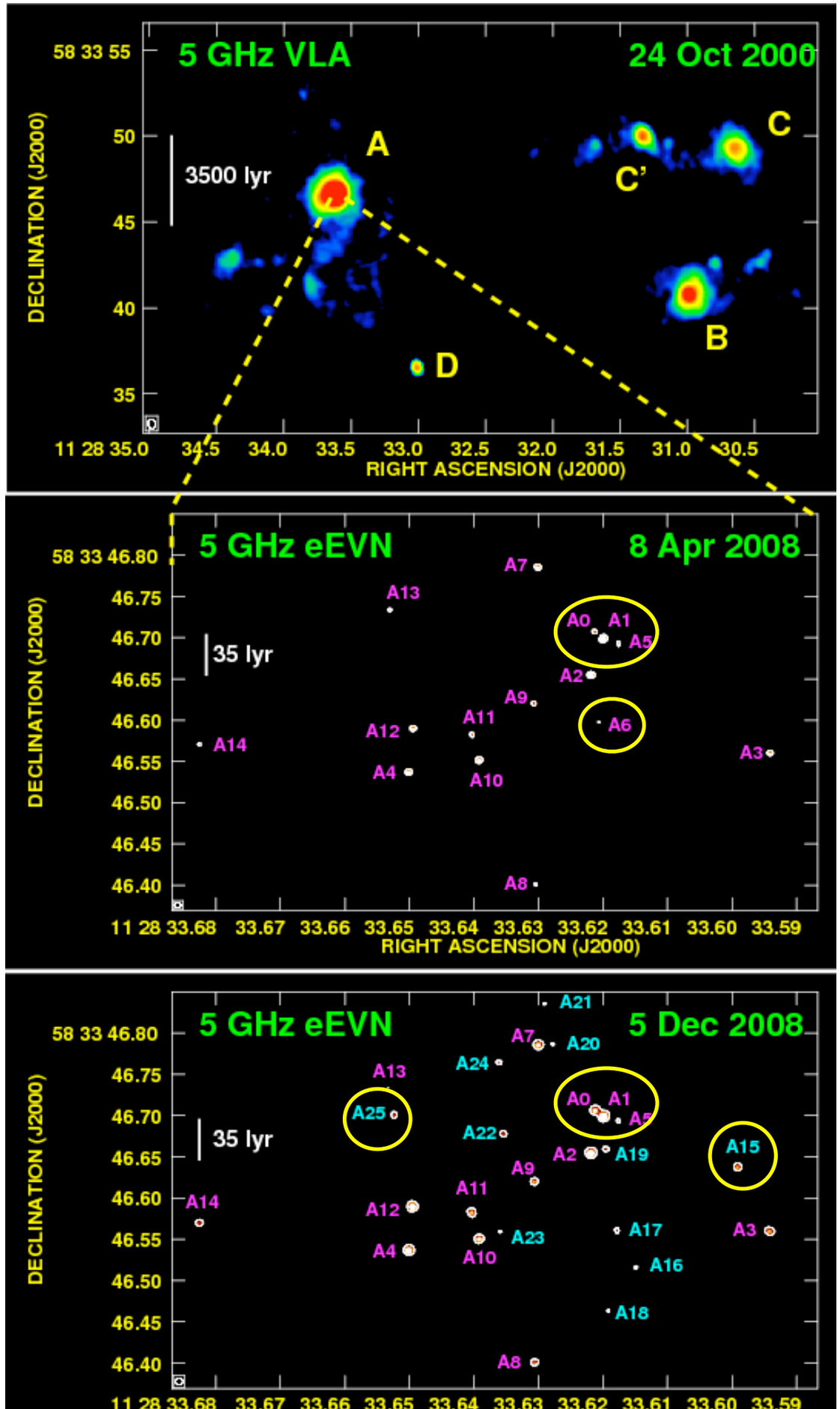


- Discovery of a recent, very bright RSN (A0; L(4cm) = 1.1 x 10 ^{28} erg/s/Hz)

Neff+2004 (ApJ)

An extremely prolific SN factory in Arp 299-A revealed with the eEVN

- ★ SNe and/or SNRs, likely embedded in SSCs.
- ★ Evidence of recent RSNe (A0, A15 and A25), plus a possible microquasar (A6).
- ★ These three RSN are relatively young, slowly evolving, long-lasting SNe.
- ★ Moderate to high radio emission levels (typical of Type II SNe)



Pérez-Torres et al. (Letters to A&A, 2009)

High-angular radio as a tool to pinpoint AGNs... and individual SNe/SNRs.

- VLBI provides precise location of AGN (milliarcsecond resolution).
- Accurate quantification of AGN/SB contribution to total radio emission.
- AGNs show flat, or even inverted spectral index at radio wavelengths

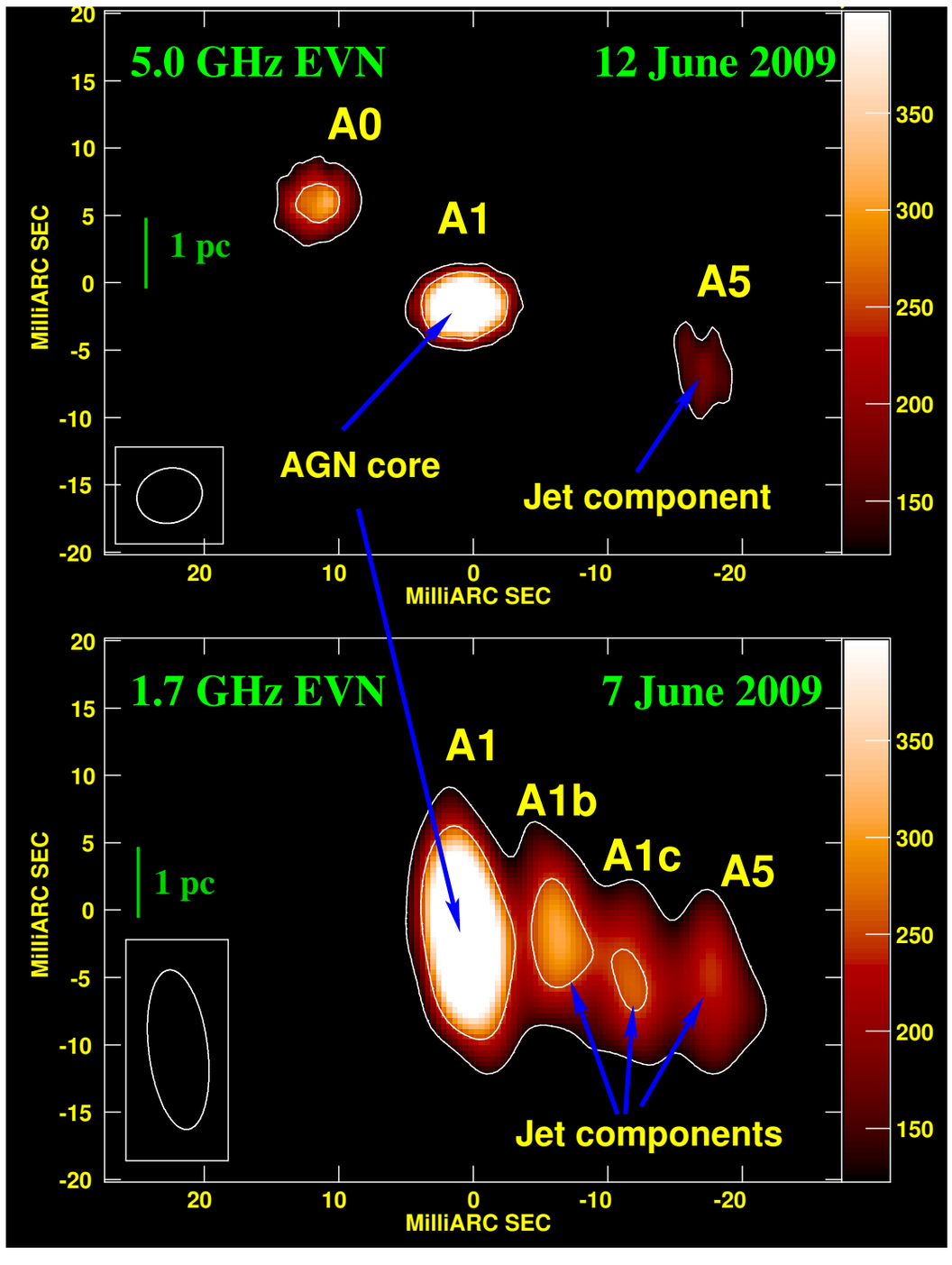
$$S_\nu \propto \nu^\alpha$$

$$\alpha \simeq 0.0\,(\mathrm{flat})$$

$$\alpha > 0.0\,(\mathrm{inverted})$$

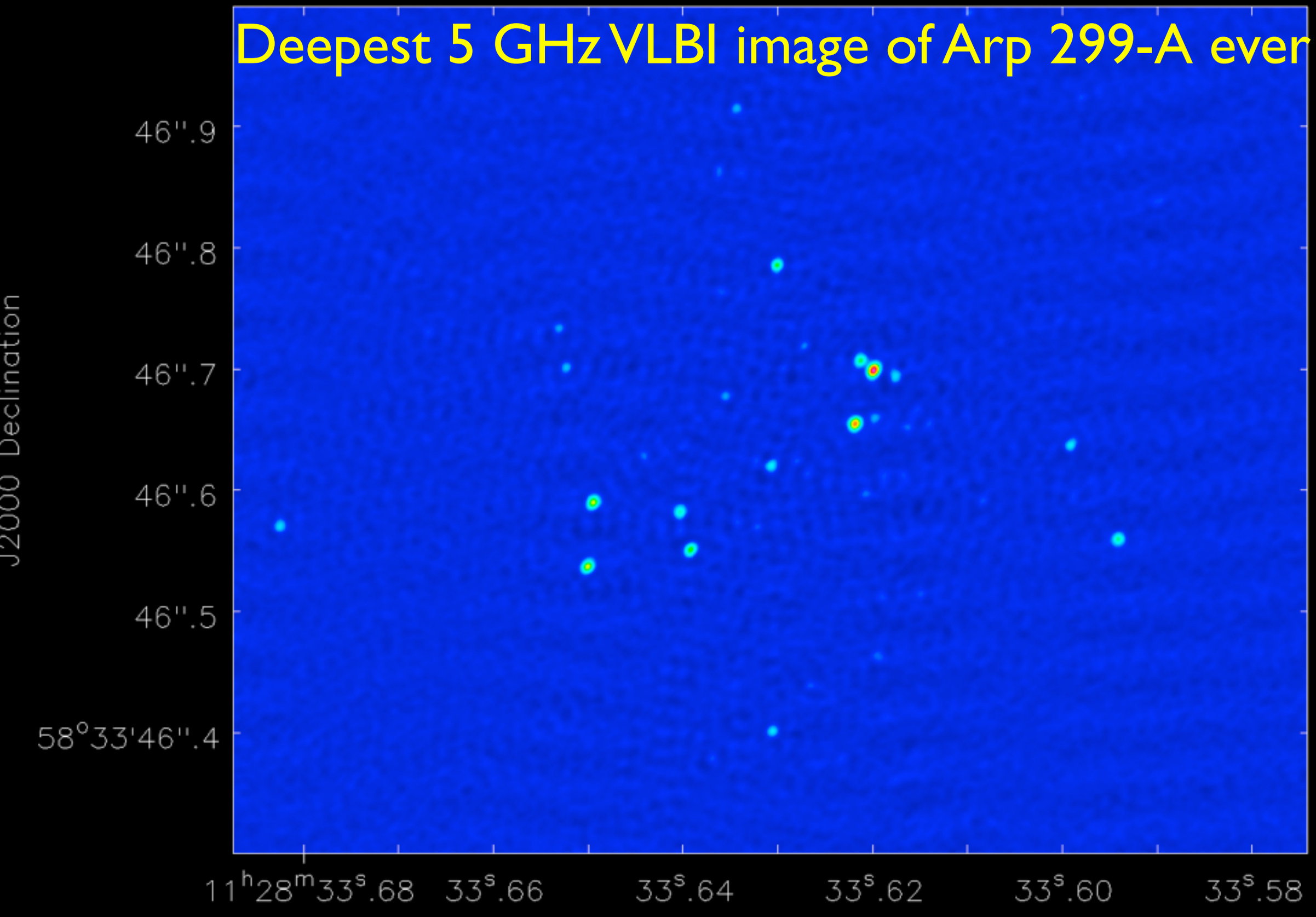
- AGNs show core-jet structure

Arp 299A at cm wavelengths



Pérez-Torres+2010 (Letters to A&A)

Deepest 5 GHz VLBI image of Arp 299-A ever

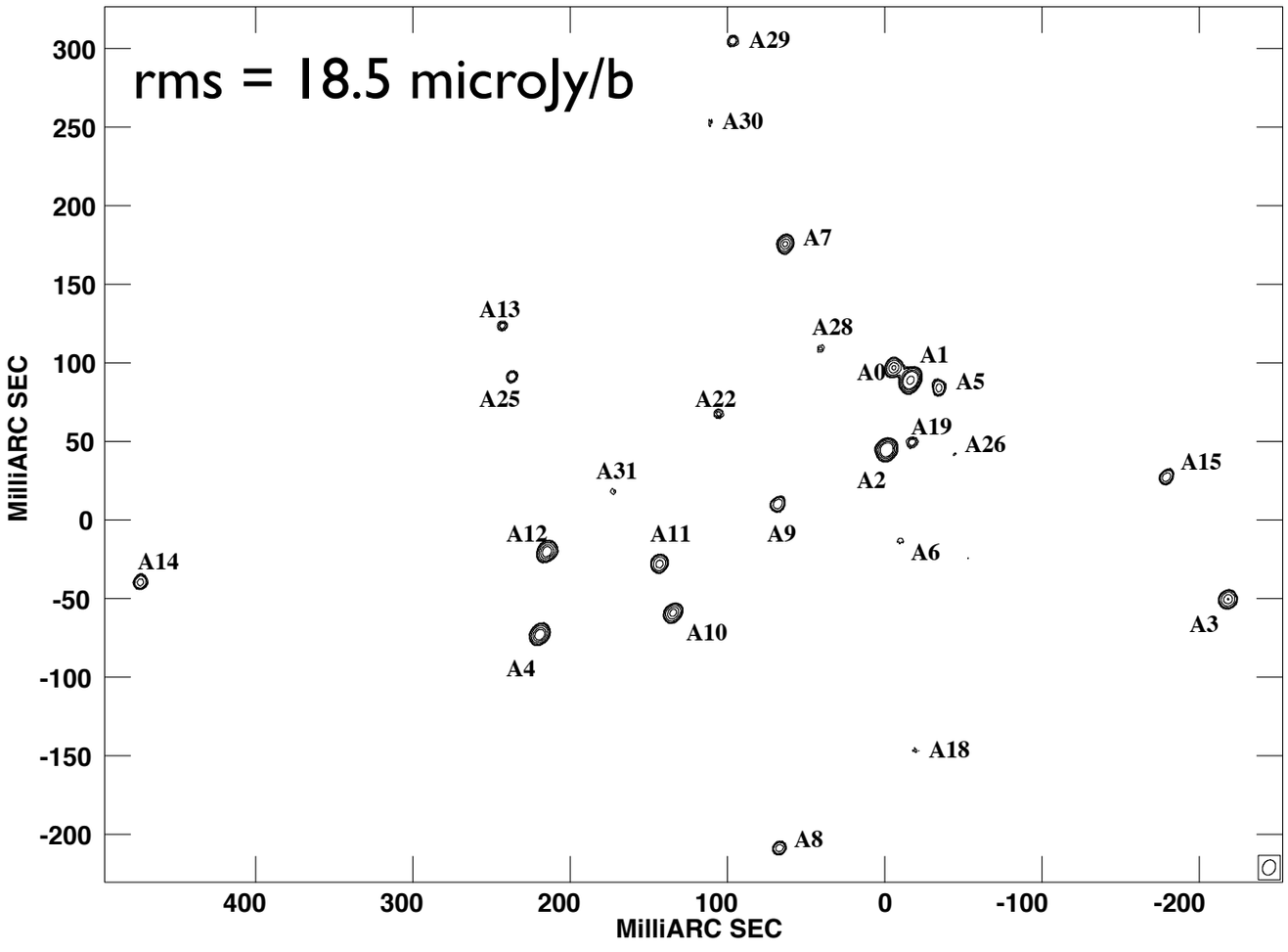


Bondi, Pérez-Torres et al. (A&A, 2012)

The Arp 299-A lab

- 26 sources detected
- 8 new ones
- Mixed population of CCSNe and SNRs
- Evidence for at least 2 recent SNe
- CCSN ~ 0.8 SN/yr
- Taking into account the other 2 SNe that exploded in 2010
  => uncomfortably large CCSN rate for Arp 299-A
  => Top heavy IMF!?

Stacking of the 6-epochs of (e)EVN images
(April 2008 through Nov 2010)



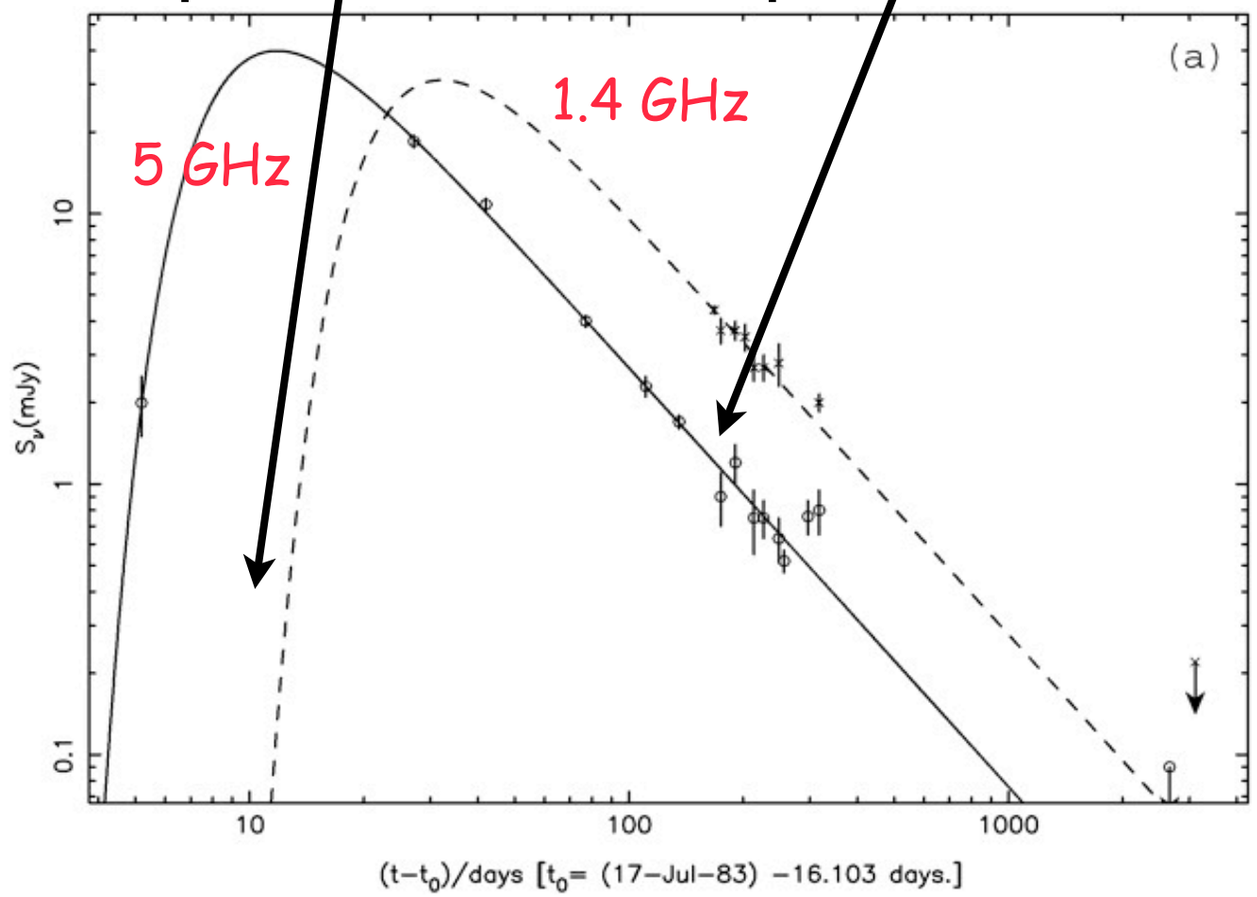
Bondi, Pérez-Torres et al. (A&A, 2012)

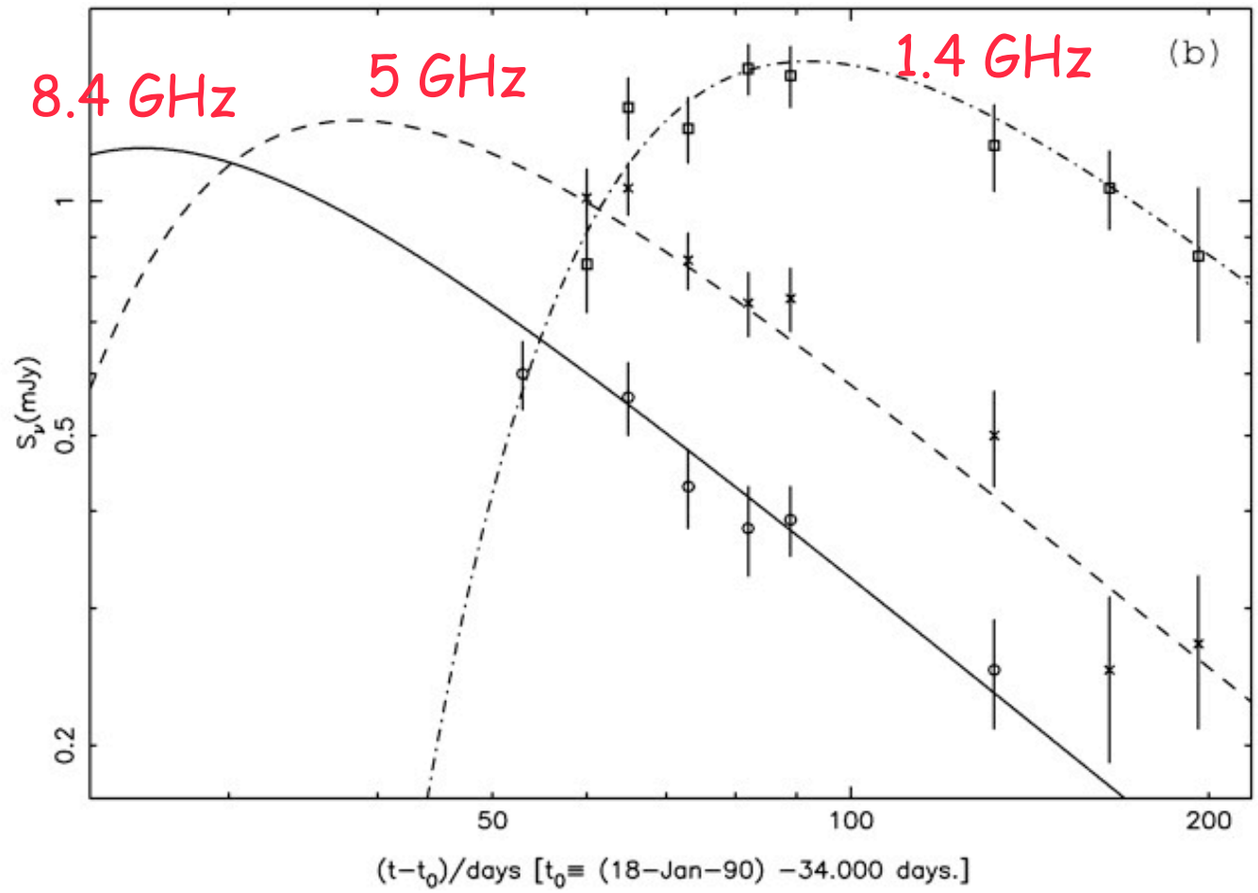
Radio light curves & spectra from SNe

Optically thick phase: alpha >> 0.0

Optically thin phase alpha << 0.0

$$S_\nu \propto \nu^\alpha$$

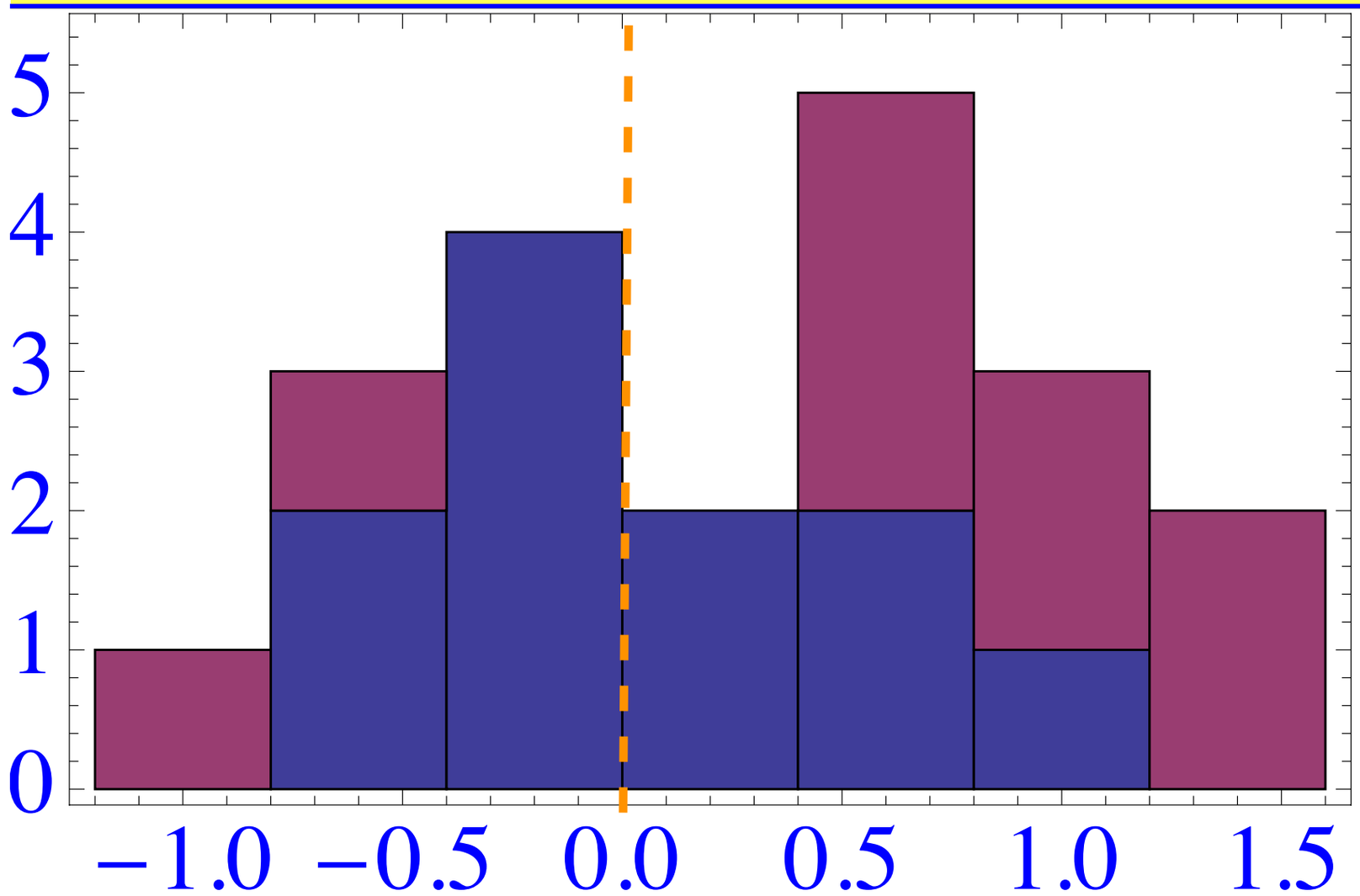




Inverted spectra (alpha >> 0.0) suggest very recently exploded CCSNe.
Steep (alpha << 0.0) suggest RSNe in their optically thin phase.

Source Spectra in Arp 299A

Spectral Index Distribution for Arp 299A

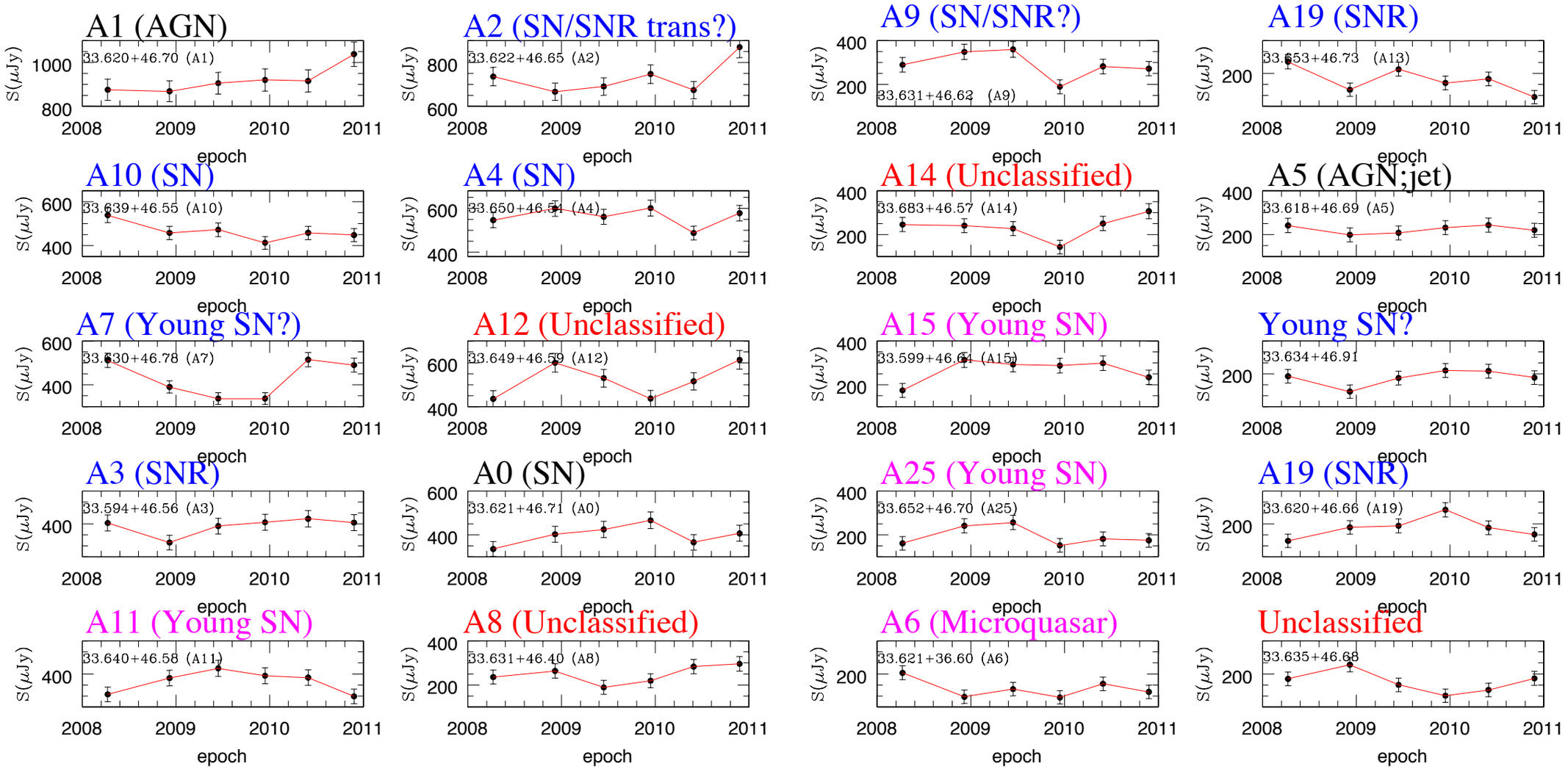


Blue - sources detected at both 1.7 and 5.0 GHz

Magenta - sources detected only at 1.7 GHz (alpha < 0.0), or at 5.0 GHz (alpha > 0.0)

Evidence for RSNe in their optically thick phase (VERY YOUNG), as well as in their opt. thin phase (RELATIVELY YOUNG).

Arp 299A: Source classification and CCSN rate

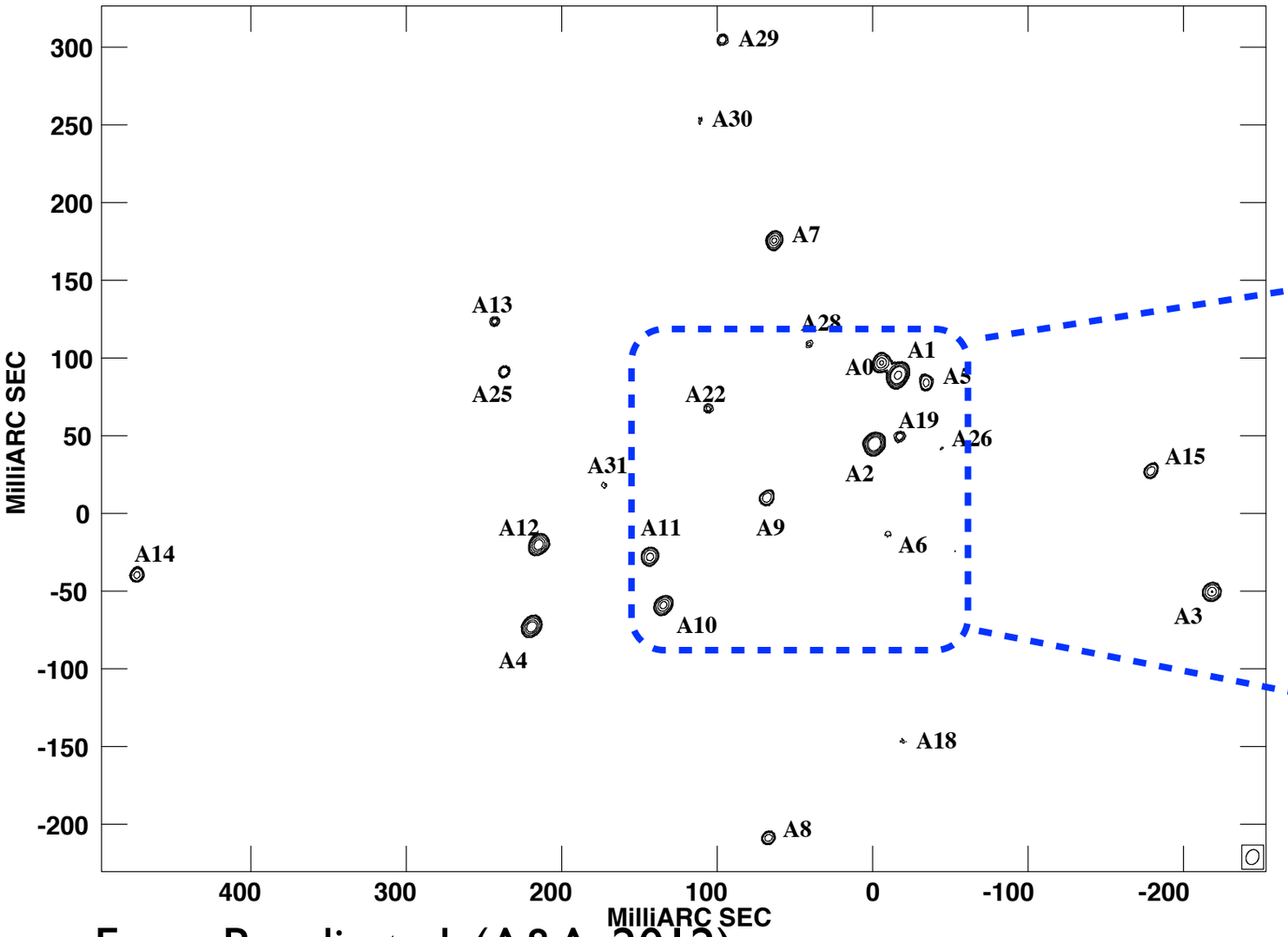


- ~9 SNe
- 5 SNRs
- AGN + jet
- 1 Microquasar (A6)
- 3 unclassified objects

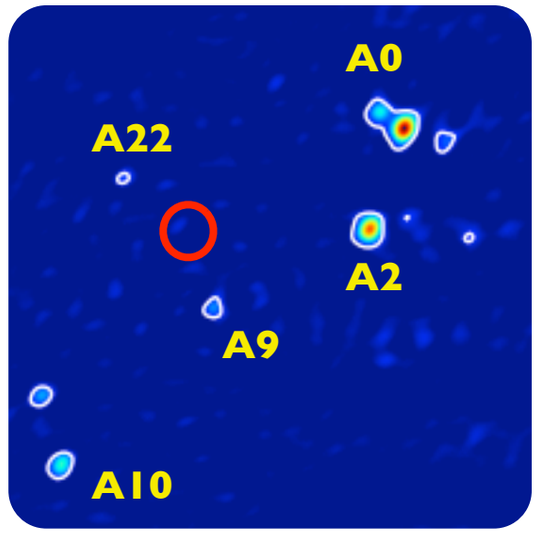
- If t_sn ~ 10 yr => CCSN rate ~ 0.9 SN/yr
- => Top-heavy IMF

The birth of a new core-collapse supernova - ERIC-A SN

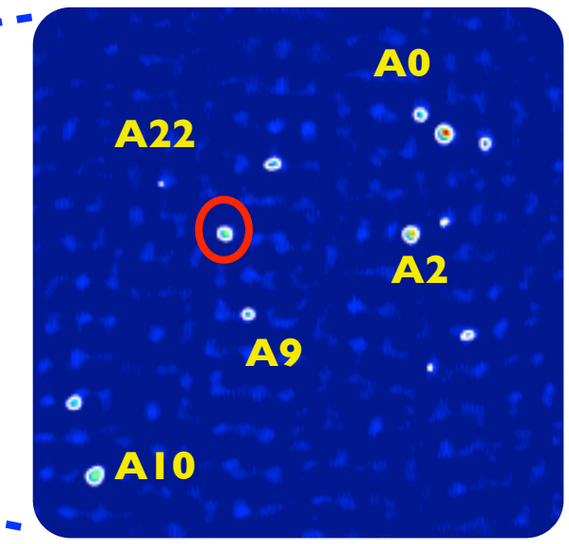
EVN @ 6 cm



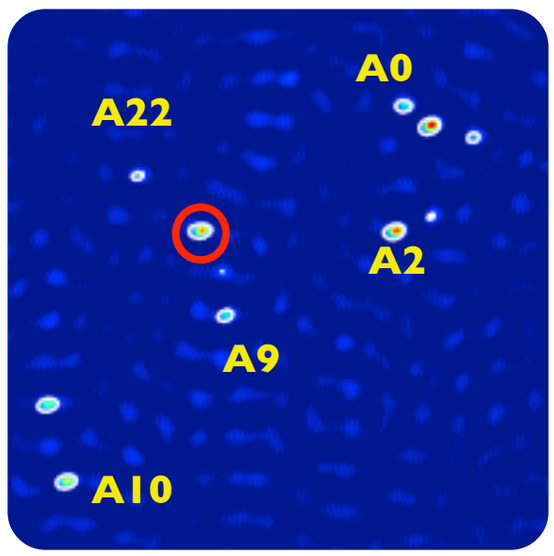
From Bondi et al. (A&A, 2012)



Nov 2010



Jun 2012



Oct 2012

Pérez-Torres et al.
(in preparation)

An extremely prolific SN factory in Arp 299A: The movie

Based on EVN & eEVN obs-ns @ 5 GHz

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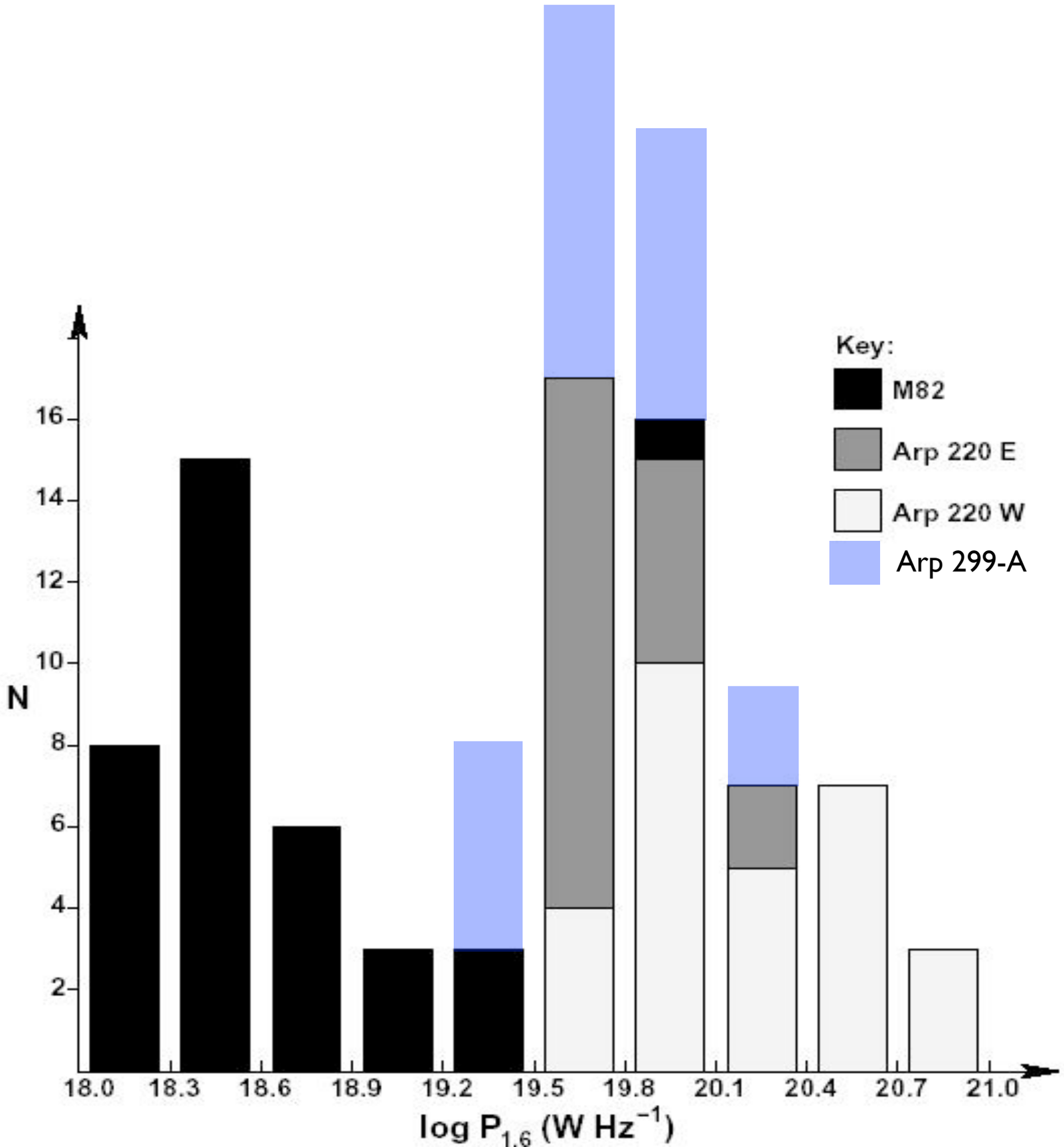
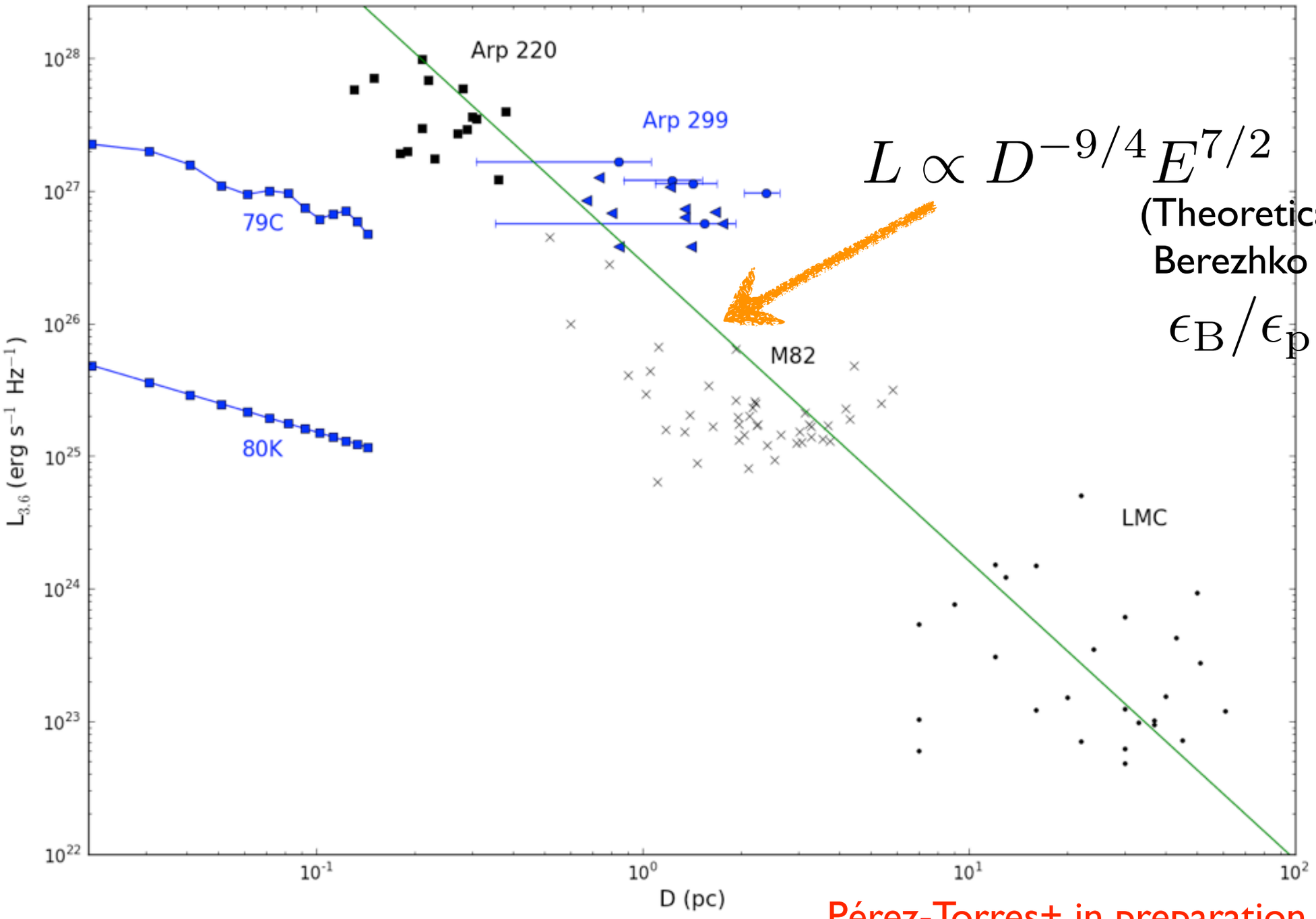
Rubén Herrero-Illana (IAA-CSIC, Granada)
Antxon Alberdi (IAA-CSIC, Granada)
Marco Bondi (IRA-INAF, Bologna)

Pérez-Torres et al. (2009, A&A Letters)
Pérez-Torres et al. (2010, A&A Letters)
Bondi, Pérez-Torres et al. (2012, A&A)
Pérez-Torres et al. (tbs to A&A)

The Arp 299-A starburst in context - Filling the gap between M82-like and Arp 220-like SBs



Luminosity - size relationship for Arp 299A



Pérez-Torres+ in preparation

- Arp 299-A nicely fills the gap between M82 and Arp 220-like objects

LIRGI: eMERLIN Legacy Project

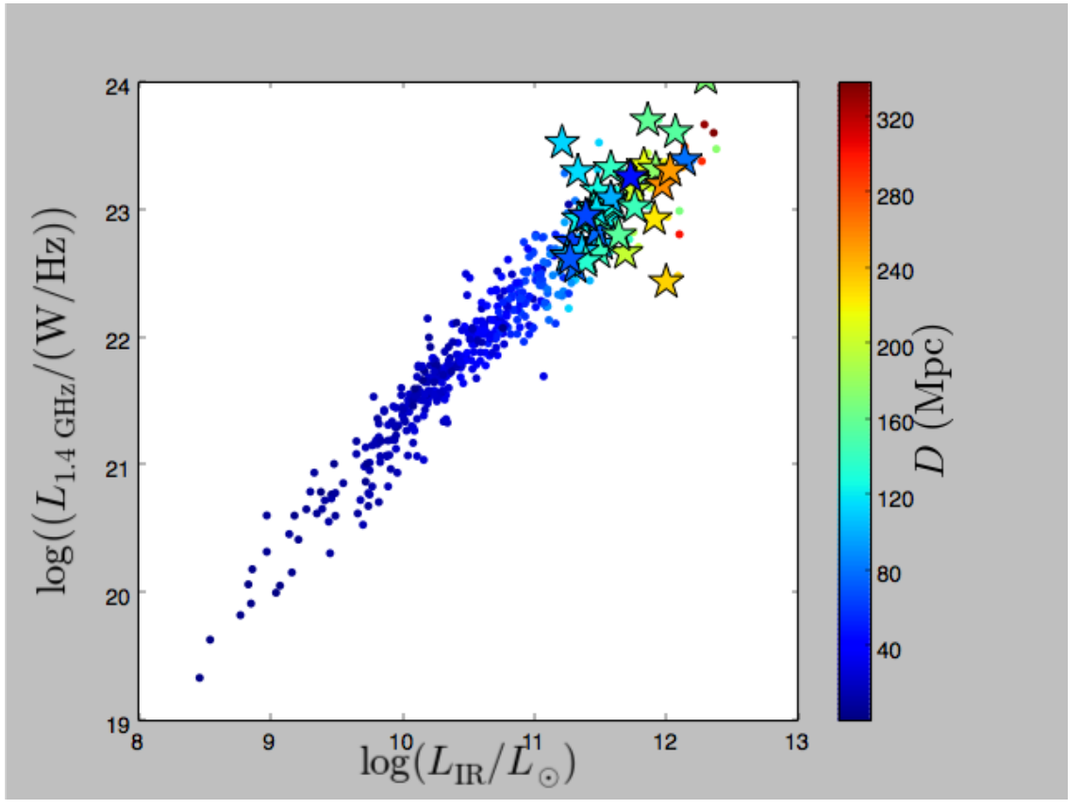
(http://www.lirgi.iaa.es) (PIs: John Conway & Miguel Pérez-Torres)

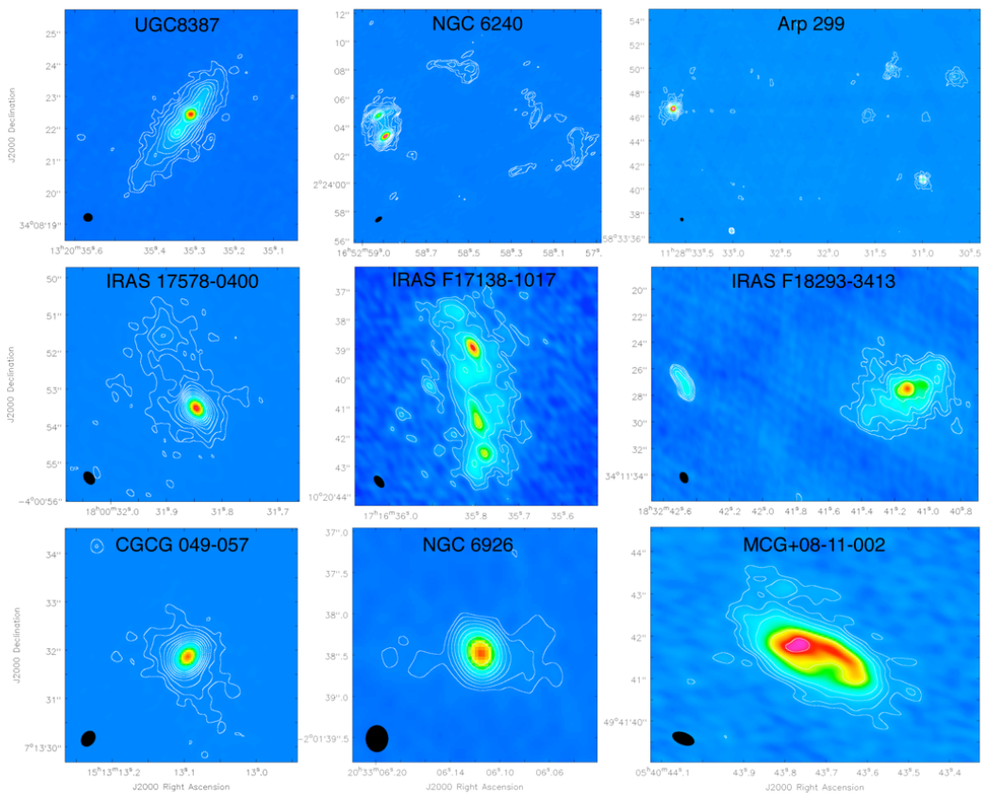
- Legacy survey observations of 42 of the most luminous northern LIRGs selected from IRAS (Sanders+ 2003)

- Sample spans the range of FIR luminosity from the upper end of LIRGs to ULIRGs

- Properties of LIRGI sources similar to SF-gals at high-z.

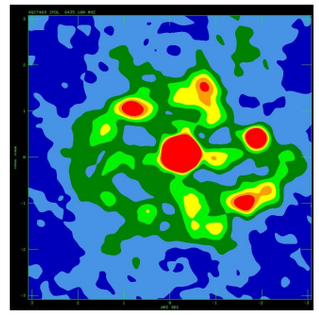
- Complementary to GOALS





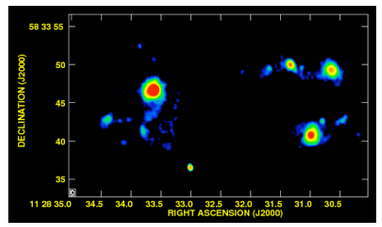
Time

SB-dominated
(Early merger)



NGC 7469

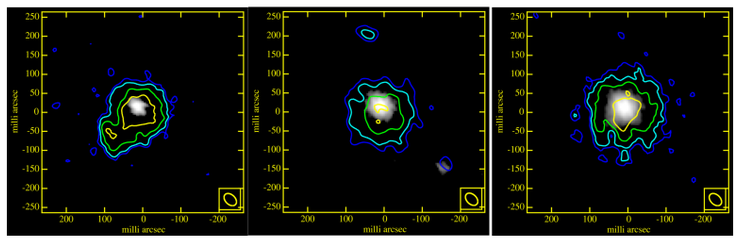
SB+AGN
Intermediate-merger

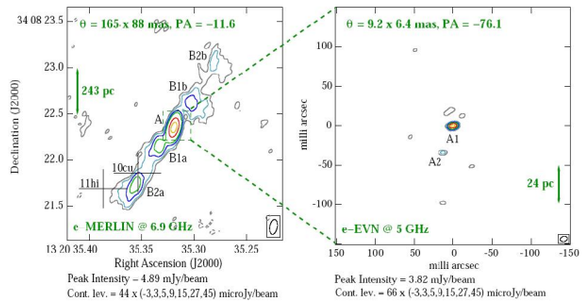


Arp 299

SB ↘ AGN ↗
(Advanced merger)

IRAS 23365+3604

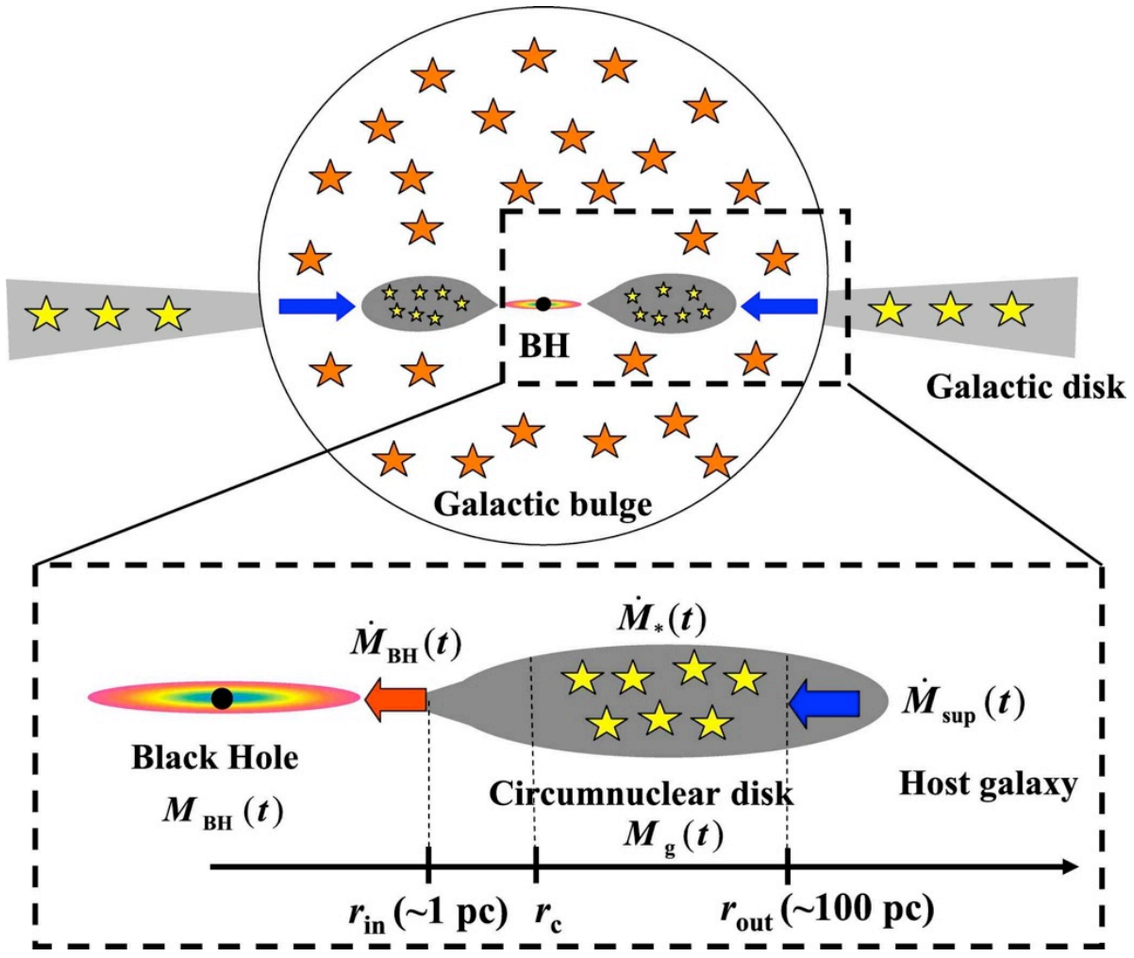




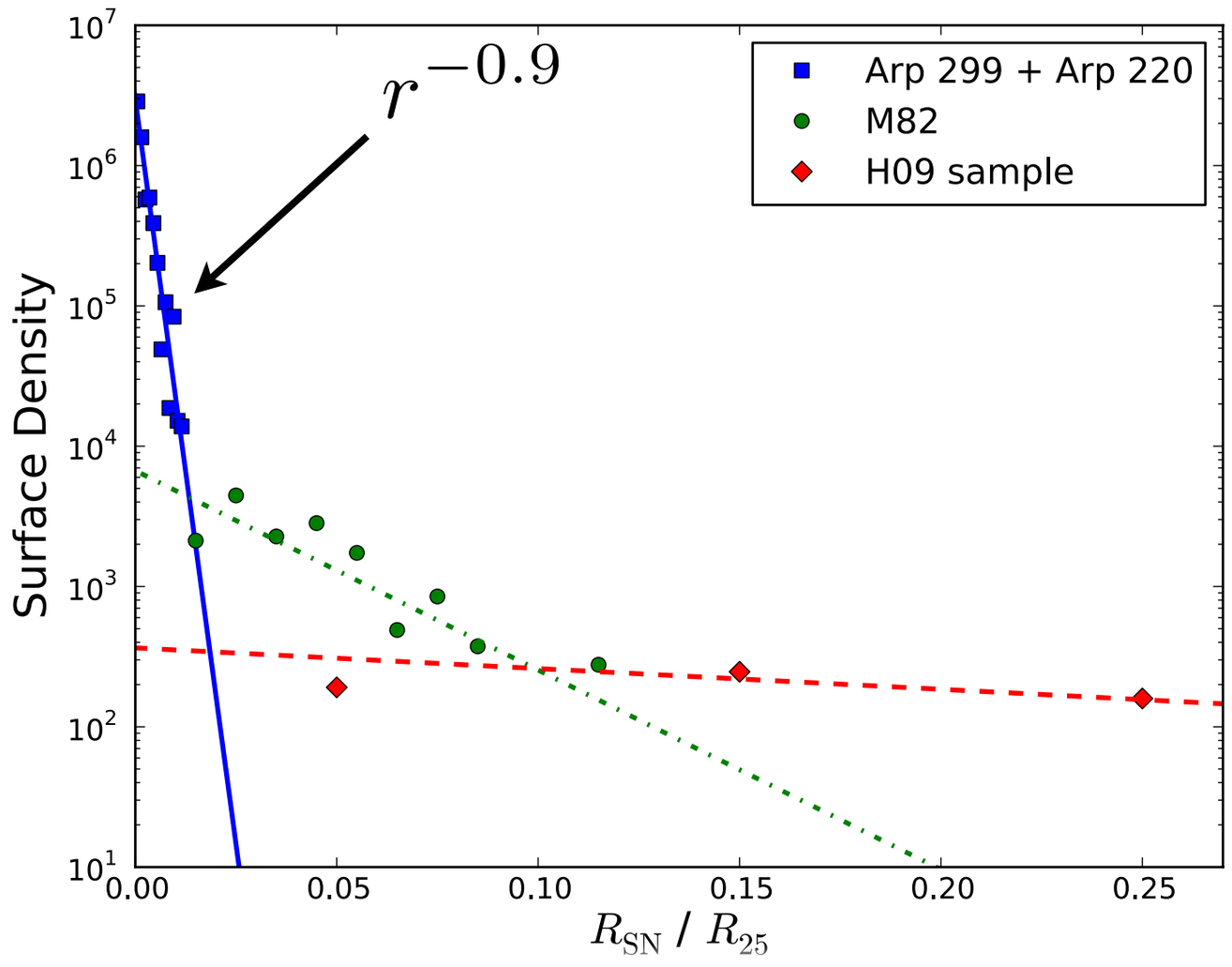
IC883

VLBI observations of local ULIRGs support a (U)LIRG/QSO evolutionary path (Yuan+2010)

Evidence of nuclear disks in starburst galaxies from their radial distribution of SNe



Kawakatu & Wada (2008, ApJ)



Herrero-Illana, Pérez-Torres & Alberdi (2012, Letters to A&A)

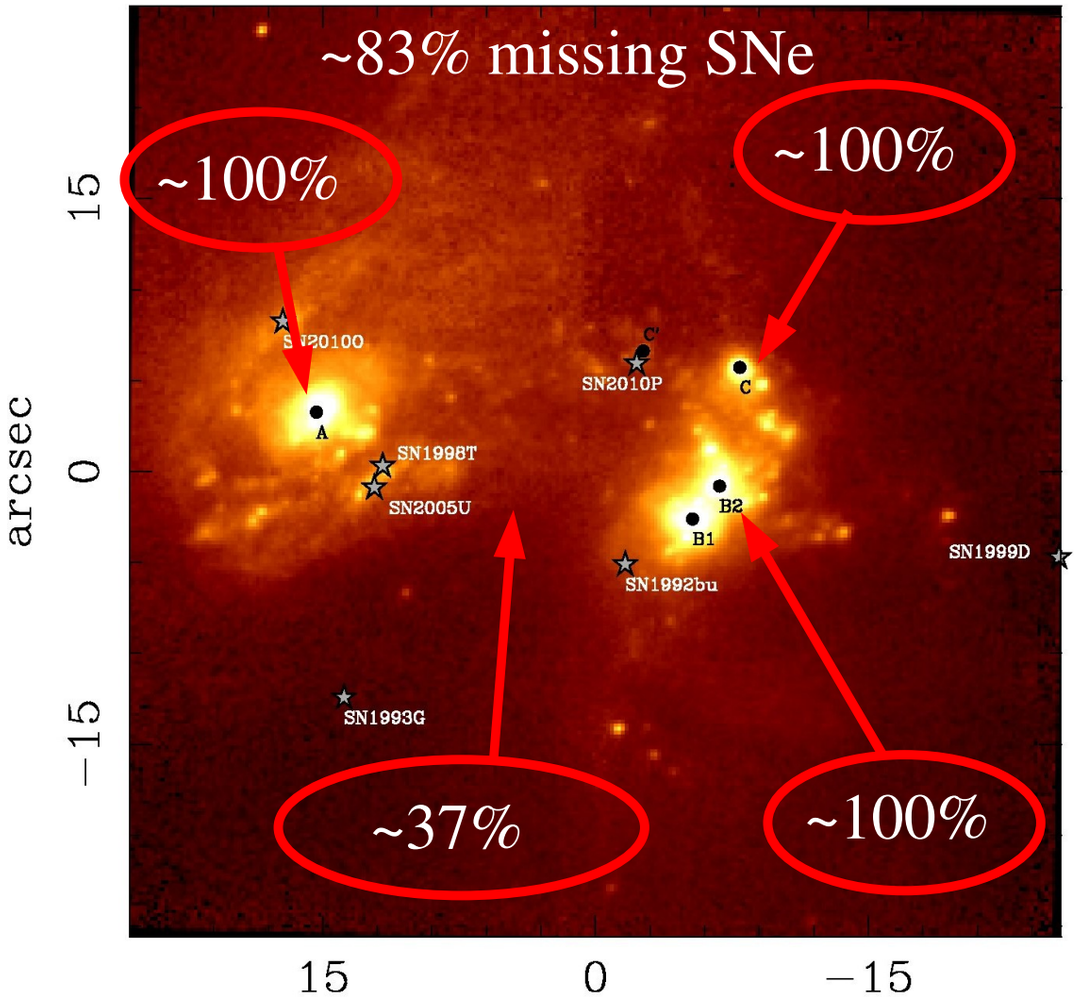
Theory predicted

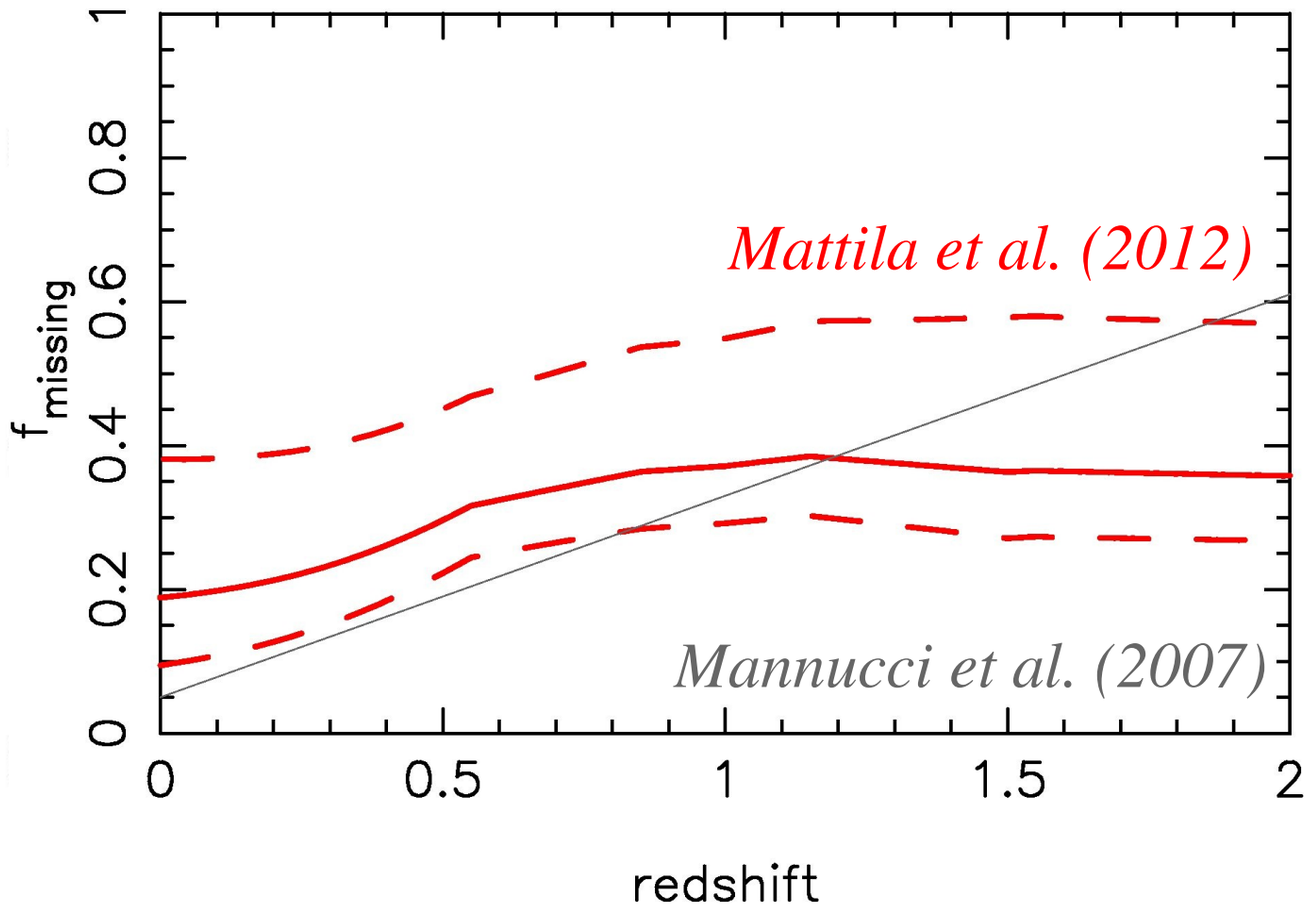
$$\Sigma_{SN} \propto r^{-1}$$

We found

$$\Sigma_{SN} \propto r^{-0.9\pm0.1}$$

Fraction of (optically) missed SNe in Arp 299





Mattila et al. (2012, ApJ)

VLBI observations allow to correct for the missing fraction of CCSNe in LIRGs/ ULIRGs

Arp 299 used as template for correct for missing fraction of SNe accross SF history

Bottom lines

☑ Radio observations at the highest resolution and sensitivity are extremely useful to

(i) discern SBs from AGNs in the innermost regions of (U)LIRGs,
(ii) trace recent SFR activity, and
(iii) unveil the hidden population of CCSN => true CCSN rates

☑ Arp 299-A fills a gap between M82-like and Arp 220-like SBs

☑ They seem to be the best testbed cases for studying in real-time SB factories in the central regions of U/LIRGs, and a VLBI radio monitoring of them must be supported.

☑ VLBI radio searches on large samples needed to get meaningful statistical results.

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