EoR Extragalactic Foregrounds

Current Understanding

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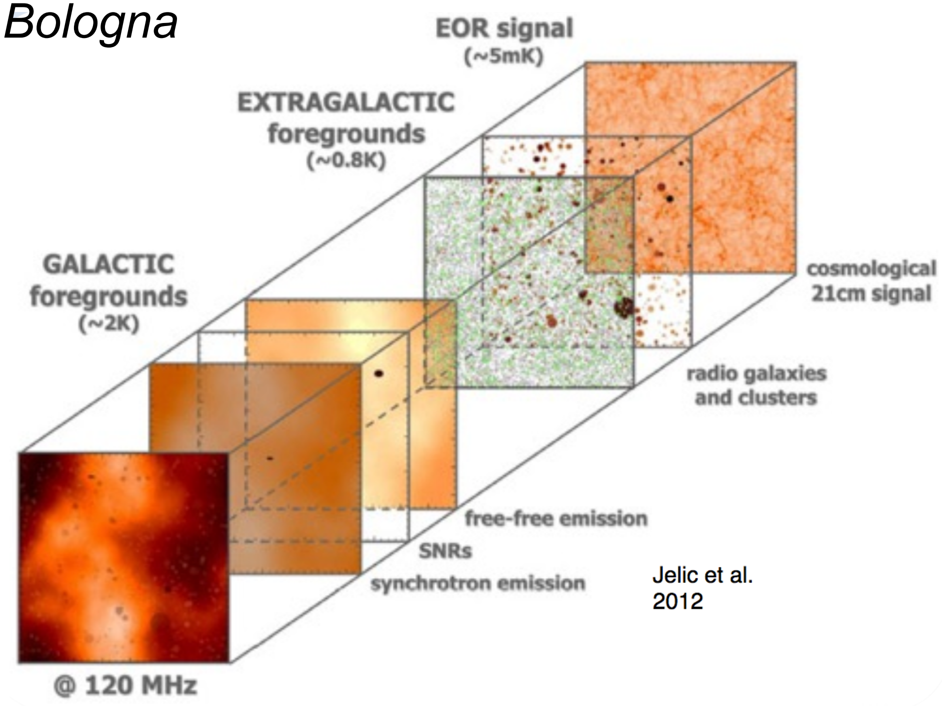


Jelic et al. 2012

This talk has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet]

Low-ν Radio-continuum Surveys

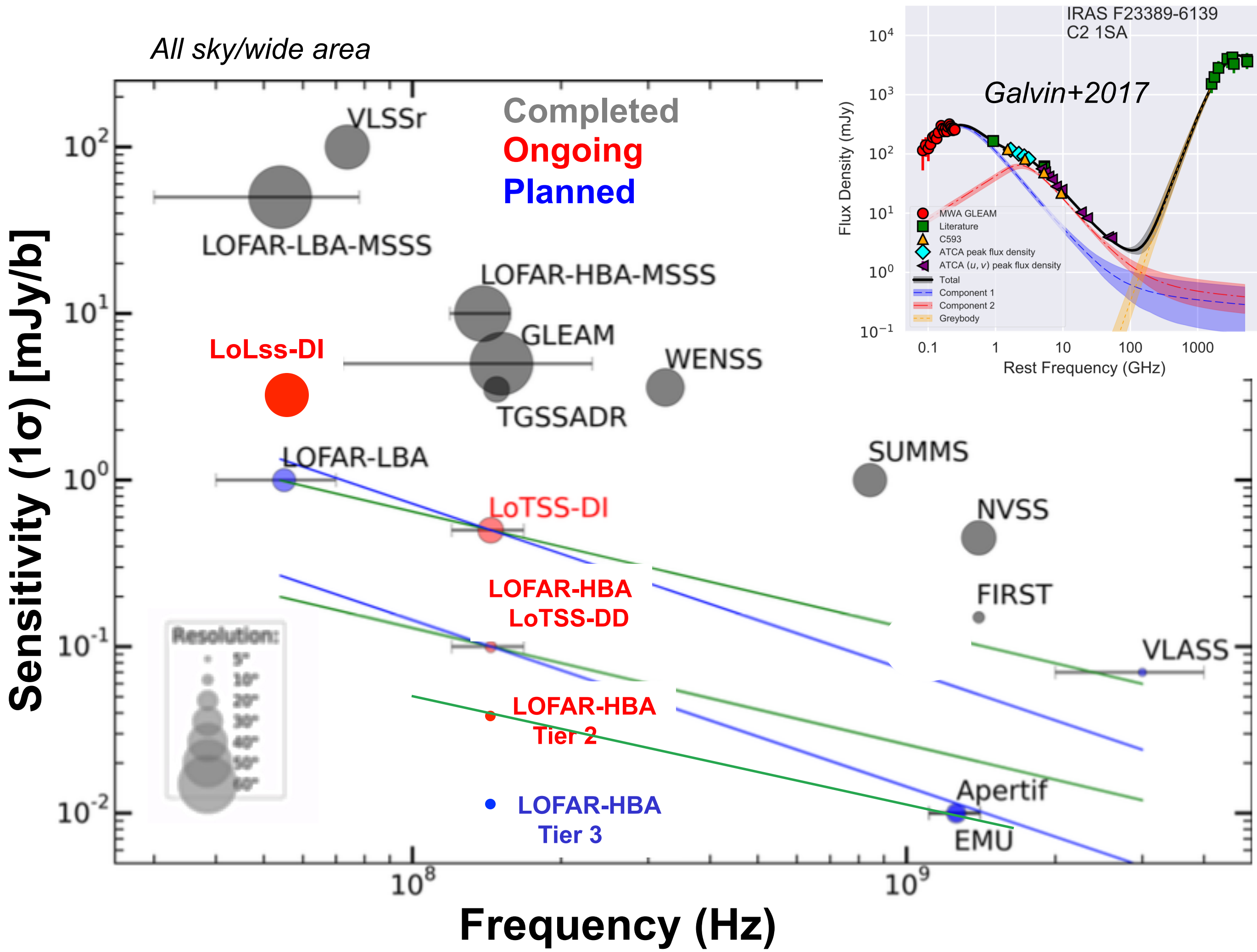
LoTSS-DI
HETDEX Spring field
350 deg2

LoLss
(de Gasperin+ in prep)

LOFAR-HBA Tier 2
25 extra-galactic fields
~25 uJy/b rms
~120-150 hours each

(blank, clusters, nearby galaxies/AGN)

Status blank fields:
H-ATLAS: 10h
Groth-Strip:58h
GOODS-N: 60h
LH: 66h
Bootes: 100h
ELIAS-N: 200h
Tests on Equatorial fields (XMM-LSS)



Adapted from Shimwell+ 2017

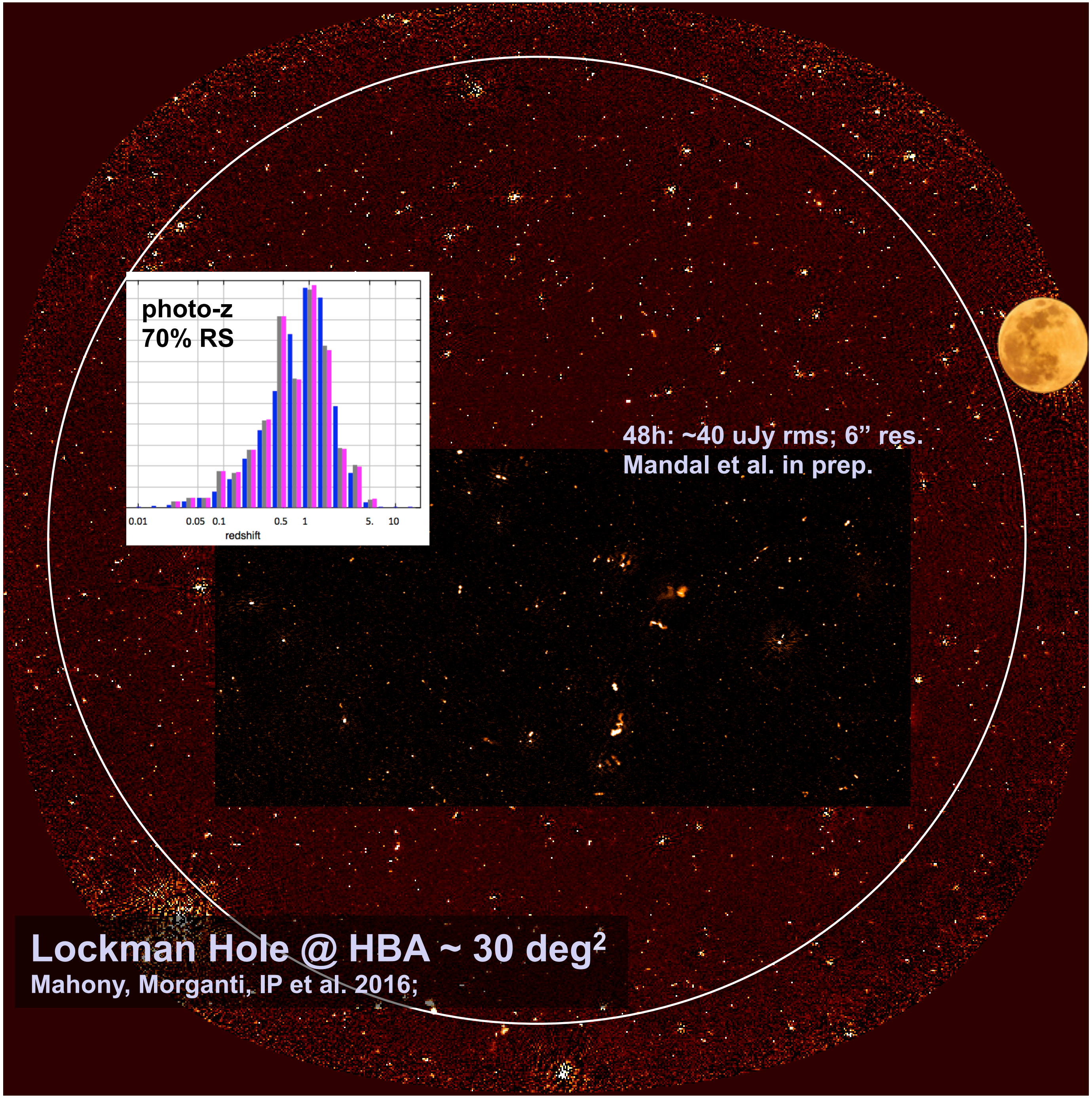
LH @ LOFAR HBA

10h: ~150 uJy rms @ 15"
48h: ~40 uJy rms @ 6"

Dense multi-frequency coverage: 60 MHz – 15 GHz)

All fields:

- **Millions of star forming galaxies and AGN**
- **variety of environments**
- **0<z<6**



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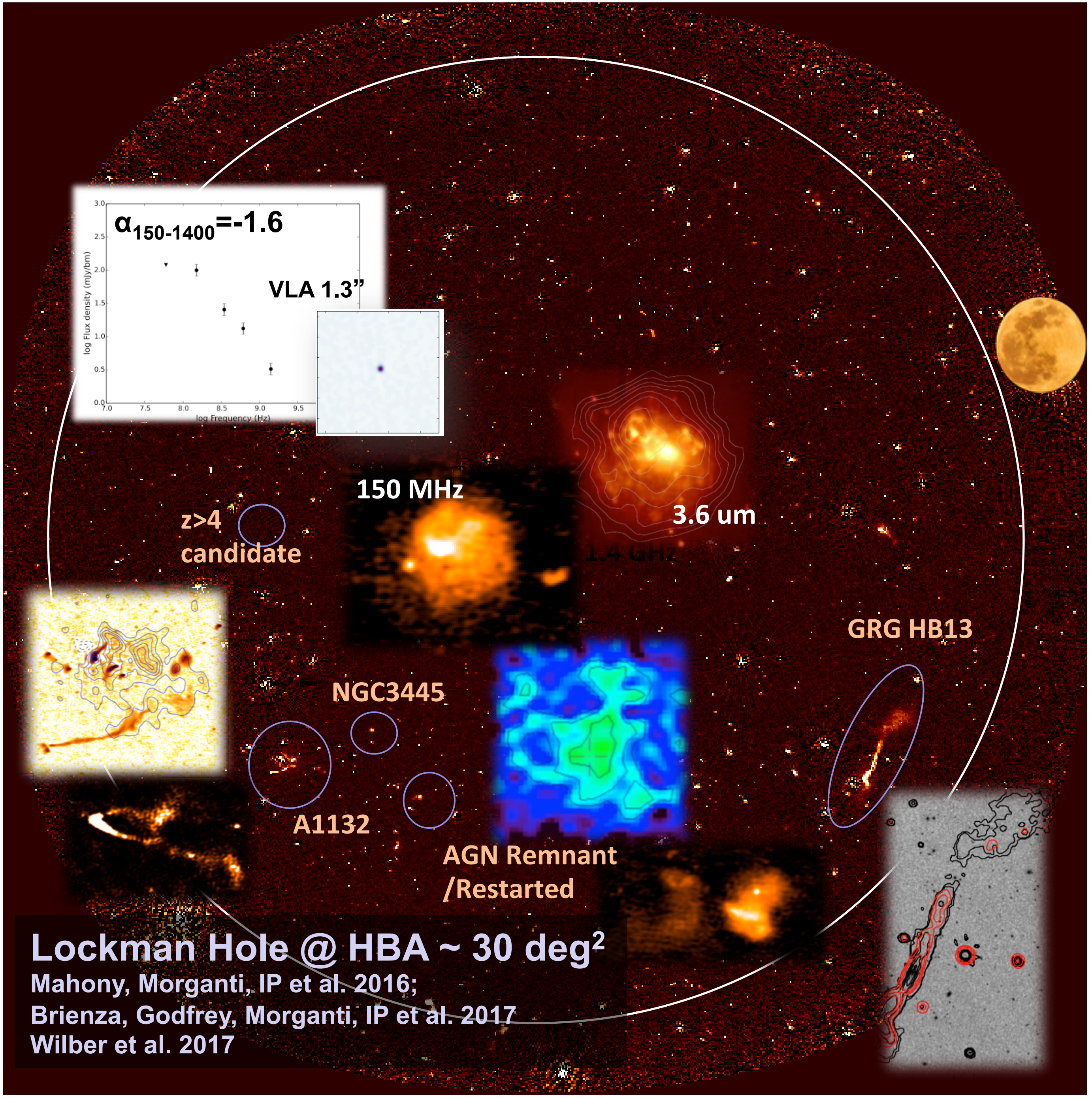
10h: ~150 uJy rms @ 15”
48h: ~40 uJy rms @ 6”

Dense multi-frequency coverage: 60 MHz – 15 GHz)

Rare populations:

- **1 GRG (1.6 Mpc)**
- **1 nearby galaxy**
- **1 Abell clusters**
- **23 AGN remnants/ restarted candidates**
- **100 USS (≤21% *z* > 4 candidates)**
- **13 peaked (incl. MHz-peaked)**

Transversal science



Talk Focus

Extragalactic low-frequency surveys → large variety of sources

- **point & diffuse**
- **Large redshift range ($0<z<6$) → evolution**

Focus on bulk populations: AGN & star forming galaxies (SFG)

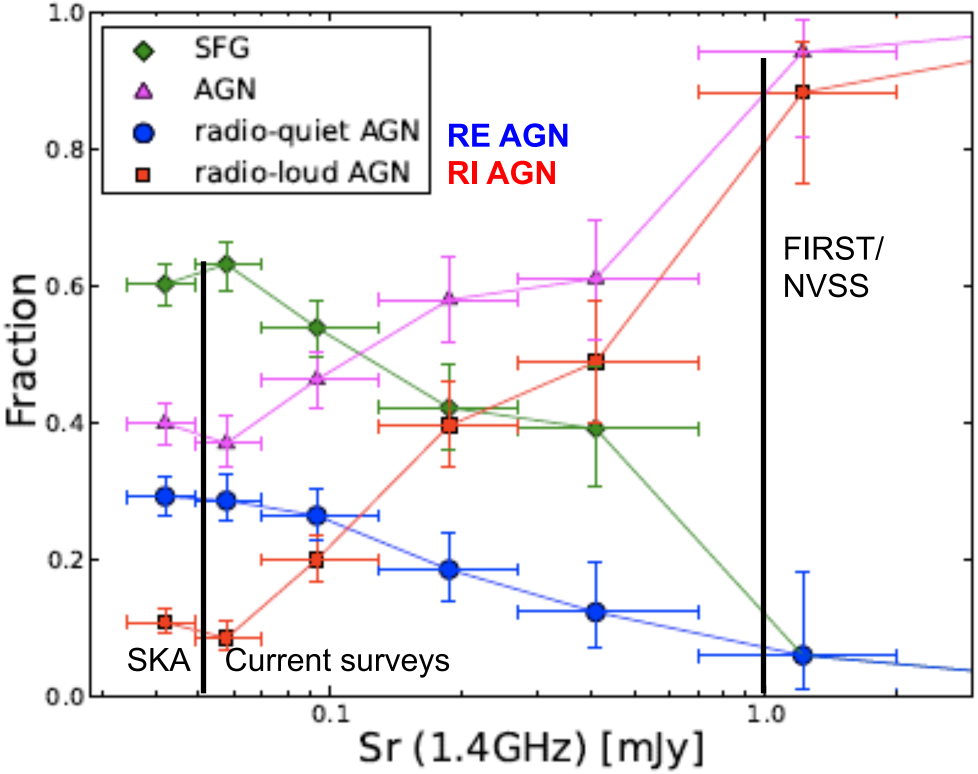
statistical approach (added-value of resolved studies), low frequency

Relevant aspect for foreground radio-continuum statistical modeling:

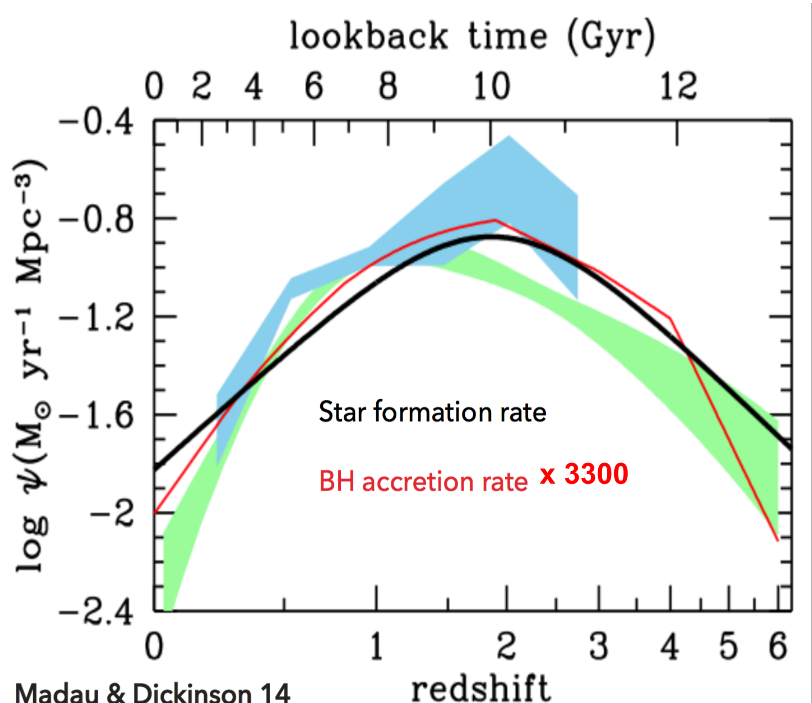
- demography and its evolution
- radio spectra
- clustering properties
- polarization and diffuse extra-galactic emission

Demography: the promise of next-generation RC surveys

ECDFS S>40 uJy (→ 200 uJy @ 150 MHz)
Adapted from Bonzini+2013



- Complete census of SF, AGN activity, up to high-z and down to RQ regime
- Co-evolution and AGN feedback
- not dust extinction/gas obscuration effects



Madau & Dickinson 14

Demography: the promise of next-generation RC surveys

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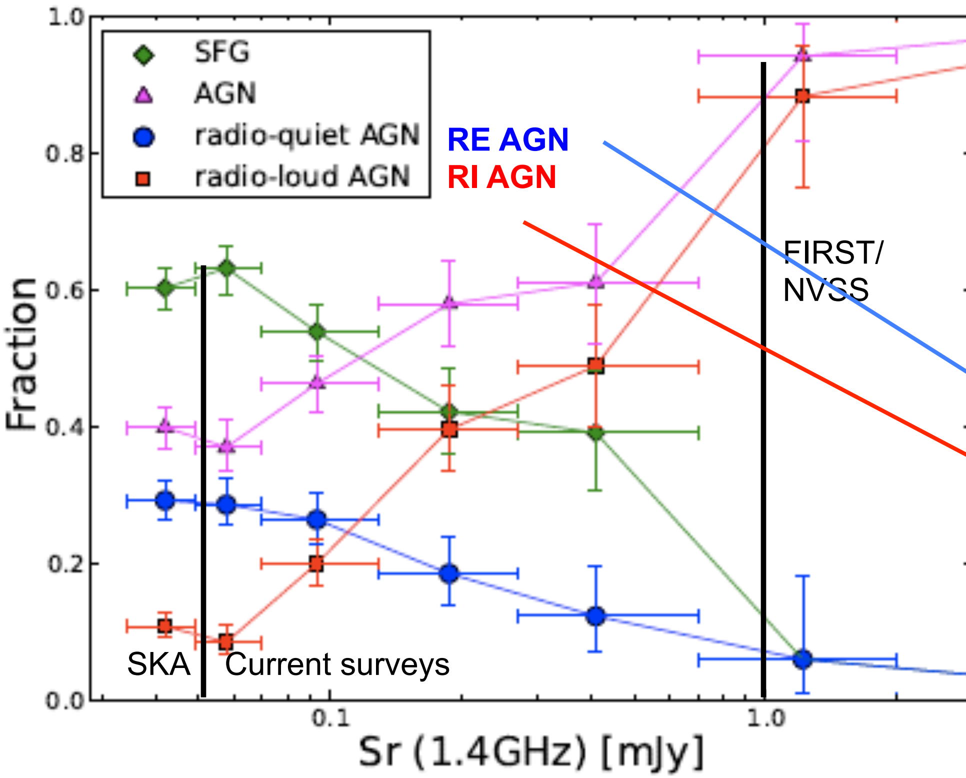
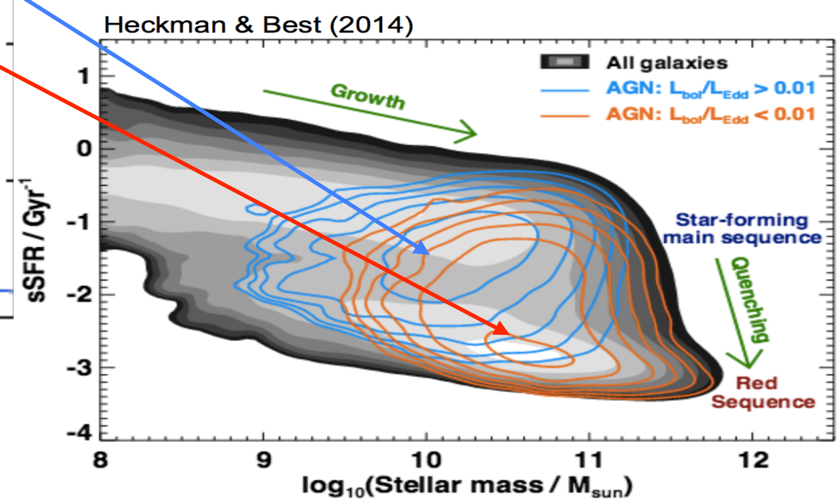


- Complete census of SF, AGN activity, up to high-z and down to RQ regime
- Co-evolution and AGN feedback
- not dust extinction/gas obscuration effects
- Role of AGN feedback



Disclaimer
Panchromatic Approach is Key!

- **Source redshifts**: spectra + multi-band photometry
- **AGN/SFG & RL/RQ AGN separation**

  mid/far IR colors (WISE+Herschel) + X-ray (eROSITA, Athena)
- **AGN accretion physics**: HEG (Seyfert/Q LEG (Liners, ETS)

  X-ray (Athena), High S/N optica (BPT diagnostic, TAIPAN, GA VE..)
- **Host galaxy properties** (m , sSFR, bulge prominence, etc.)
- **Environment**: LSS from o R surveys (LSST, Euclid..)
- **Role of gas:** HI + ALMA
- **Resolved physics at high-z:** High-res opt/NIR from space (HST, JWST, Euclid, ELT) + SKA-MID/VLBI

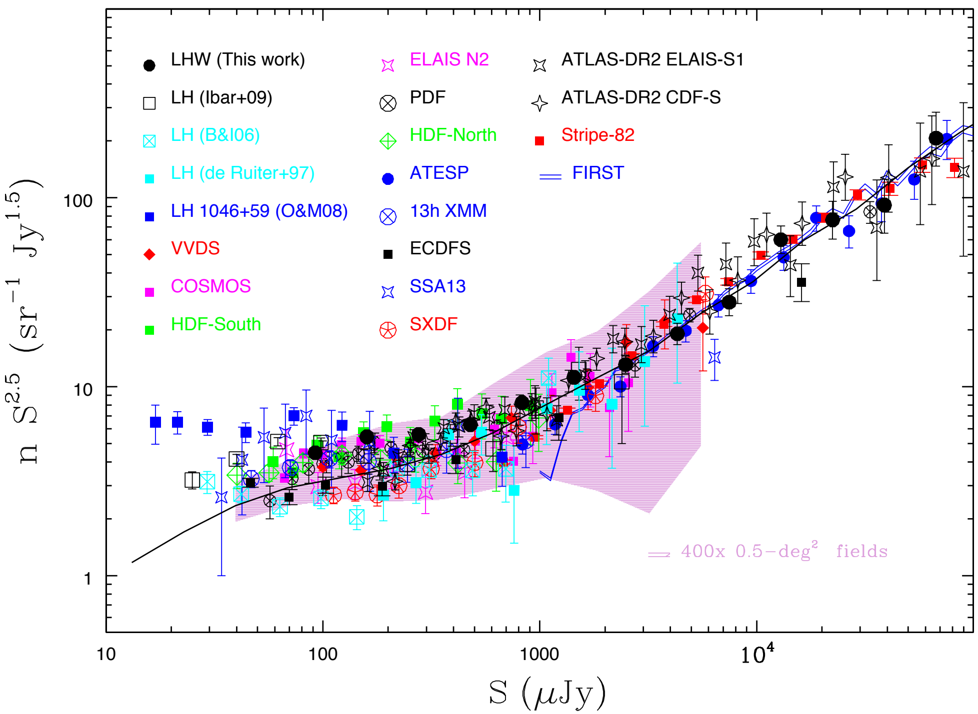
see Matt Jarvis Review

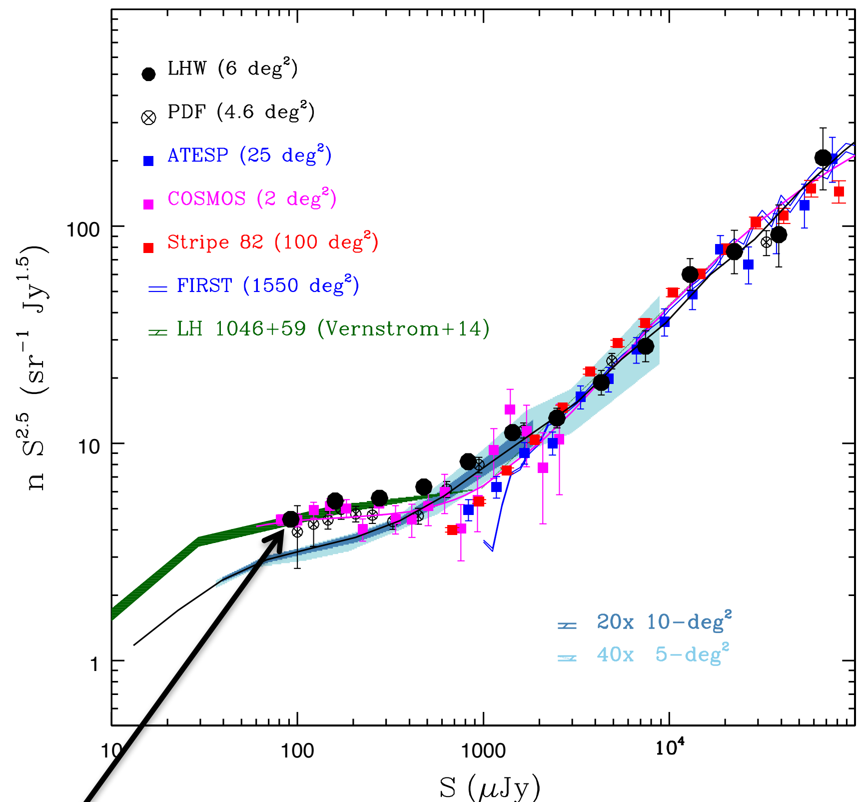
ti-band Information - 2020

	vatory Survey Name	Area (deg^2)	Wavelength Bands	Limiting Mag. or flux[a]	Data Release Date
	ALL*WISE*[a]	42,195	3.4, 4.6, 12, 22 μm	70 μJy	2013
y	PanSTARRS[b]	31k	g, r, i, z, y	$r < 24.0$	2020[b]
-sky	LSST[c]	20k	u, g, r, i, z, y	$r < 27.5$	2020
All-sky	VISTA-VHS[d]	20	Y, J, H, K	$K < 20.0$	2011+
All-sky	*eROSITA*[e]	$\sim$ 42k	$0.5 - 10$ keV	$\sim 10^{-14}$ erg cm^{-2}s^{-1}	2018
All-sky	*EUCLID*[f]	15k	$0.55 - 2.0\,\mu$m+spec.	$YJH < 24$	2020+
All-sky	TAIPAN[g]	20k	$0.37 - 0.87\,\mu$m spec.	$R < 17.5$	2015
All-sky	4MOST[h]	15-20k	$0.39 - 1.05\,\mu$m spec.	$r < 22$	2019+
All-sky	MOONS[i]	15k	$0.8 - 1.8\,\mu$m spec.	(TBD)	2019+
Wide	H-ATLAS[j]	570	$70 - 500\,\mu$m	$S_{250\mu m} > 44.5$ mJy	2015
Wide	DES[k]	5000	g, r, i, z, y	$r < 25$	2017
Wide	VISTA-Viking[d]	1500	Y, J, H, K_s	$K_s < 21.2$	2012
Wide	VST-ATLAS[d]	4500	u', g', r', i', z'	$r' < 22.2$	2016
Wide	VST-KIDS[d]	1500	u', g', r', i'	$r' < 24.2$	2016
Wide	PanSTARRS Deep[b]	1200	$0.5 - 0.8$, g, r, i, z, y	$g < 27.0$	2020
Deep	SCUBA2[l]	1/6	450/850 μm	$S_{850\mu m} > 3.5$ mJy	????
Deep	HerMES[m]	1...270	$70 - 500\,\mu$m	$S_{250\mu m} > 3.8...64$ mJy	2016
Deep	SERVS[n]	18	3.4, 4.6 μm	$\sim 2\,\mu$Jy	2013
Deep	VISTA-VIDEO[d]	12	Z, J, H, K_s	$K_s < 23.5$	2016
Deep	LSST (deep drilling)[o]	38.4	(some of) u, g, r, i, z, y	$r < 30$	2020
Deep	UltraVISTA[d]	0.73	Y, J, H, K_s, NB	$K_s < 25.6$	2016
Deep	DES[k]				

Prandoni & Seymour 2015

Evolution: the quest for new models



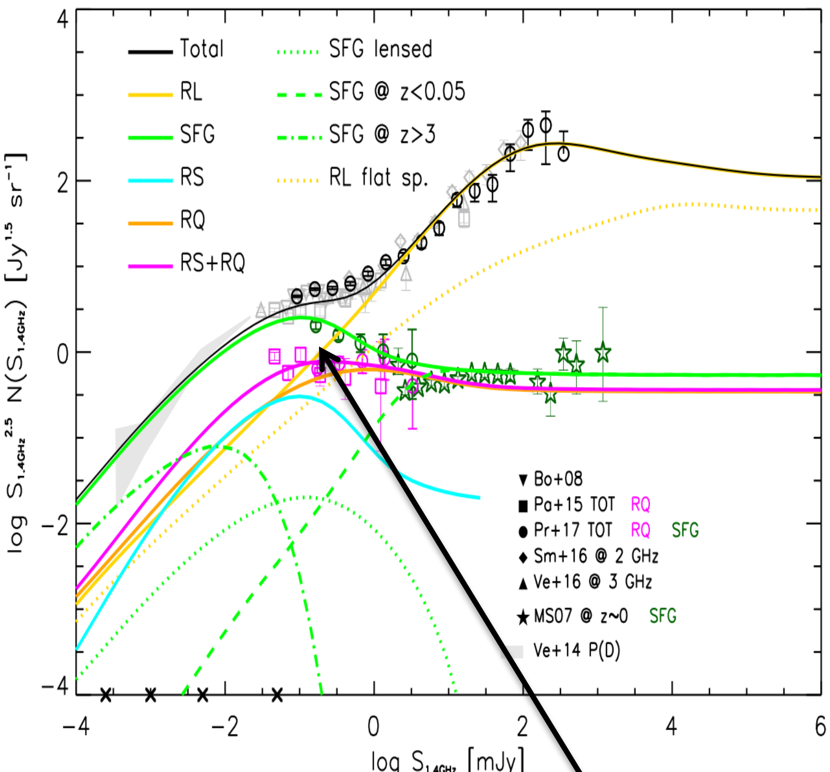


Guglielmino+2012
Prandoni+2017

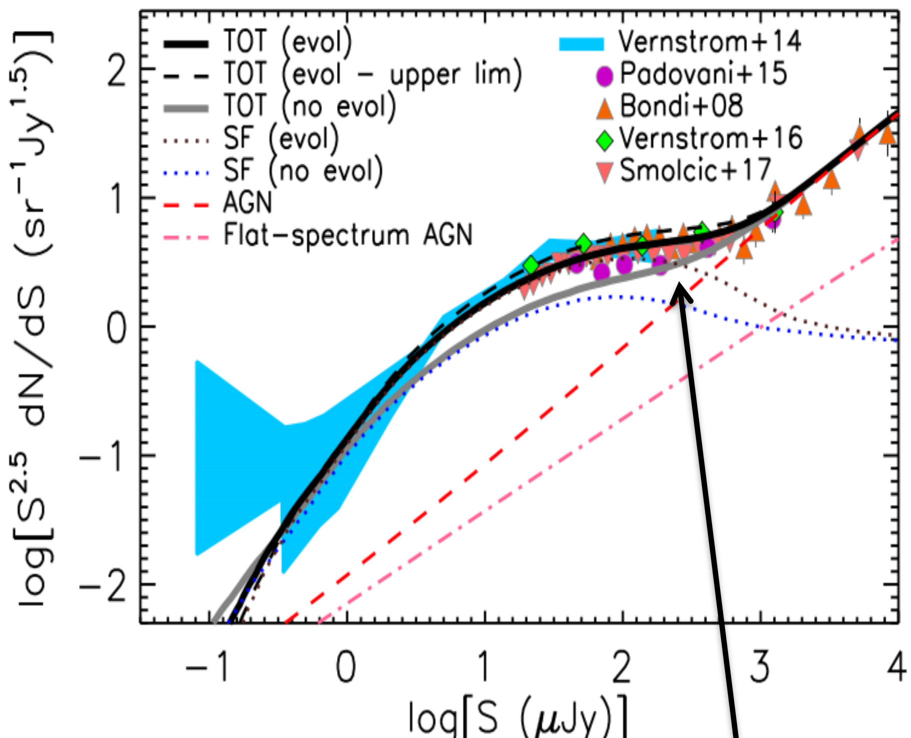
1.4 GHz Large fields point toward an excess wrt S3-SEX models at S<400 uJy

Evolution: the quest for new models

Mancuso, Lapi, IP+2017



Bonato+ 2017

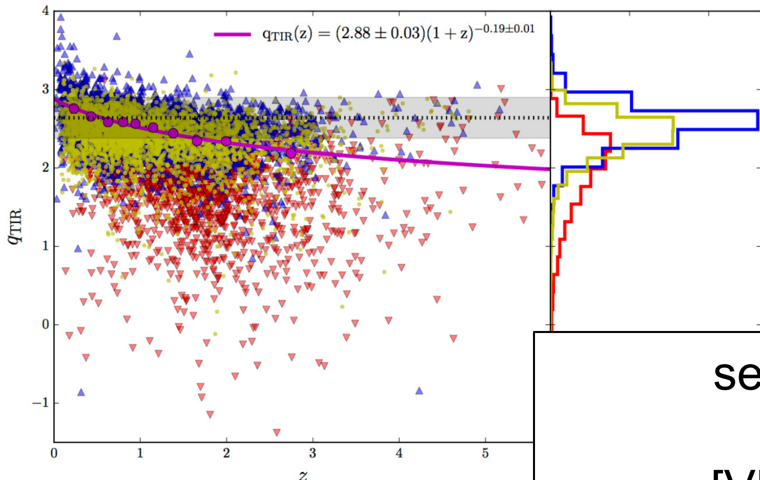


3 component modeling: high-z heavily dust-obscured SB population

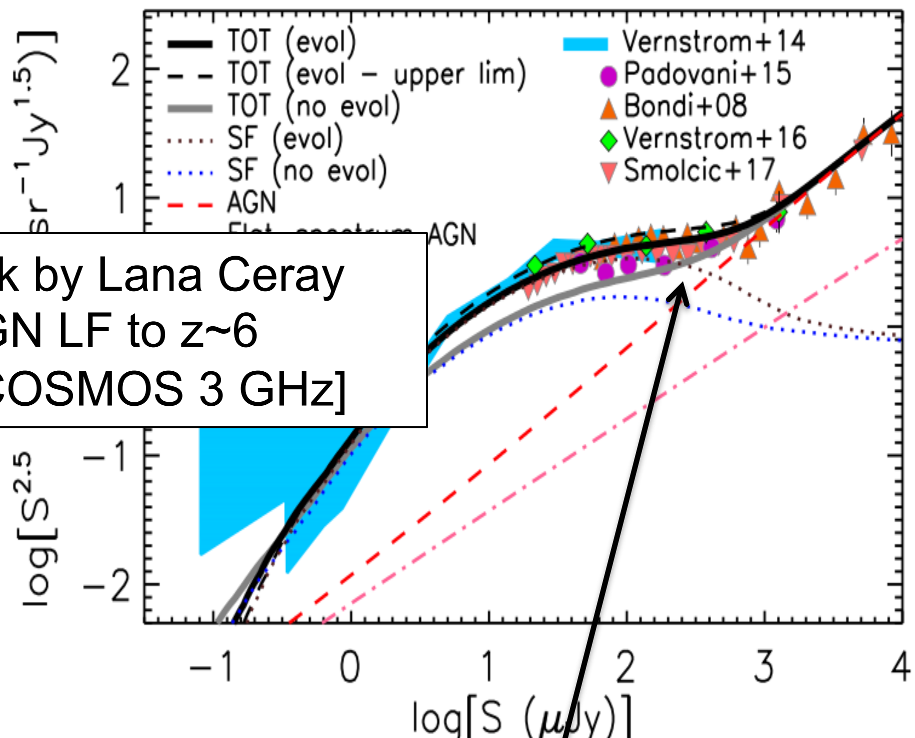
2 component modeling: mild L_{synch}/SFR evolution $(1+z)^a$; a<~1.1

Evolution: the quest for new models

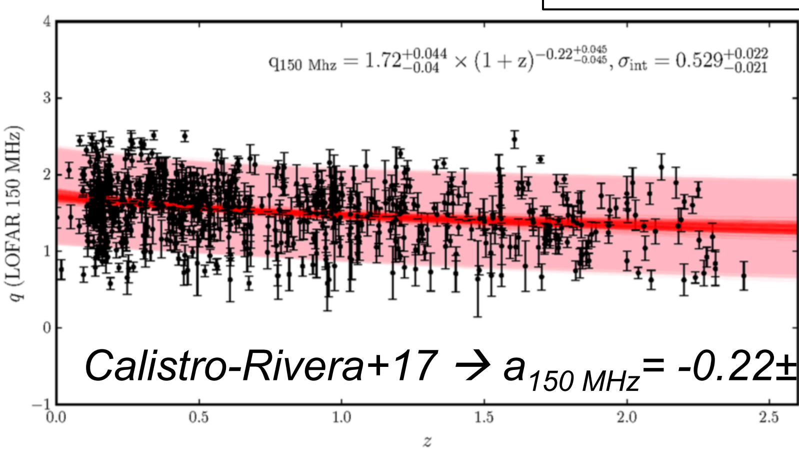
Delhaize+ 2017 → $a_{1.4GHz}$= -0.19±0.01



Bonato+ 2017



see talk by Lana Ceray
AGN LF to z~6
[VLA-COSMOS 3 GHz]



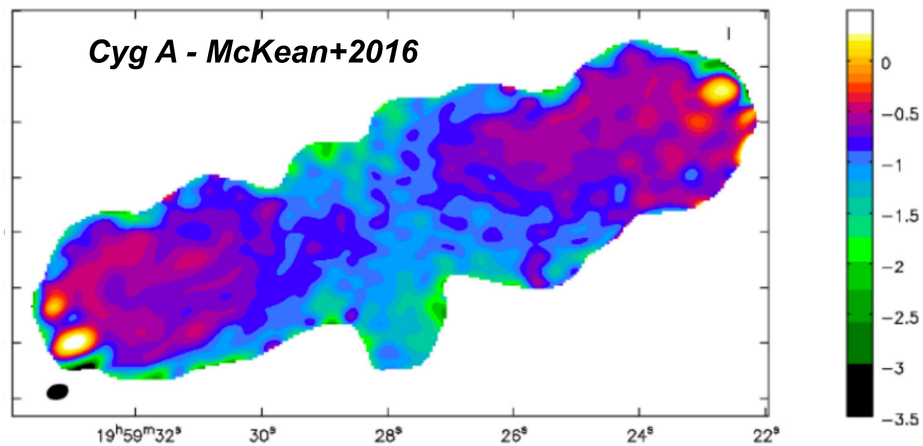
Calistro-Rivera+17 → $a_{150\ MHz}$= -0.22±0.045

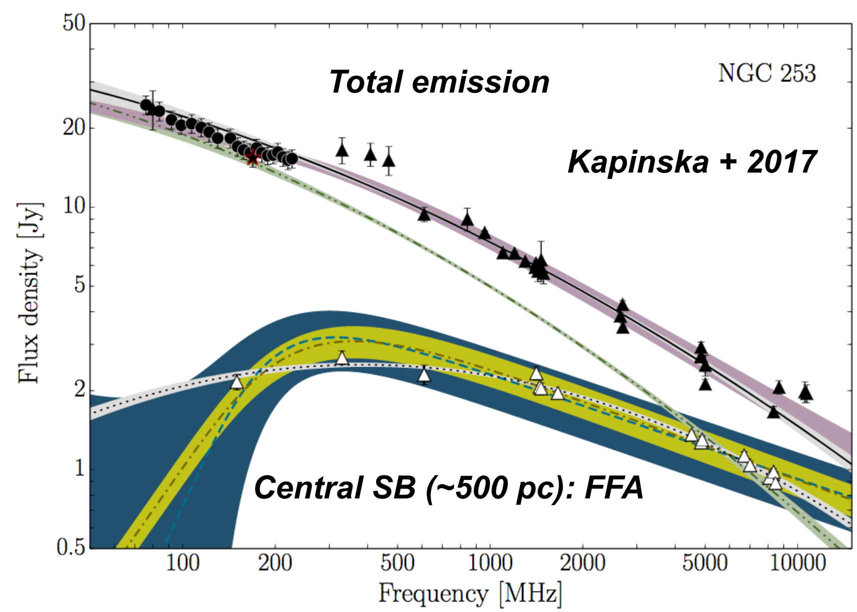
2 component modeling:
mild L_{synch}/SFR evolution
$q \sim (1+z)^a$; a<~1.1

Resolved Radio spectra and radio SED

Detailed radio SED of single objects → inform statistical studies

- synchrotron: steep or ultra-steep spectrum
  - low ν → low E e^- / aged e^- populations
  - high ν → high E e^- / e^- close to acceleration sites
- free free: flatter spectrum
- absorption (ff or synchrotron):
  turnovers



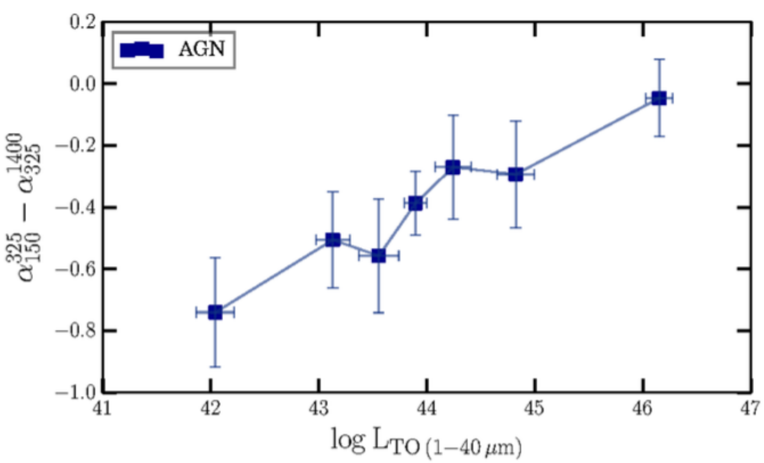


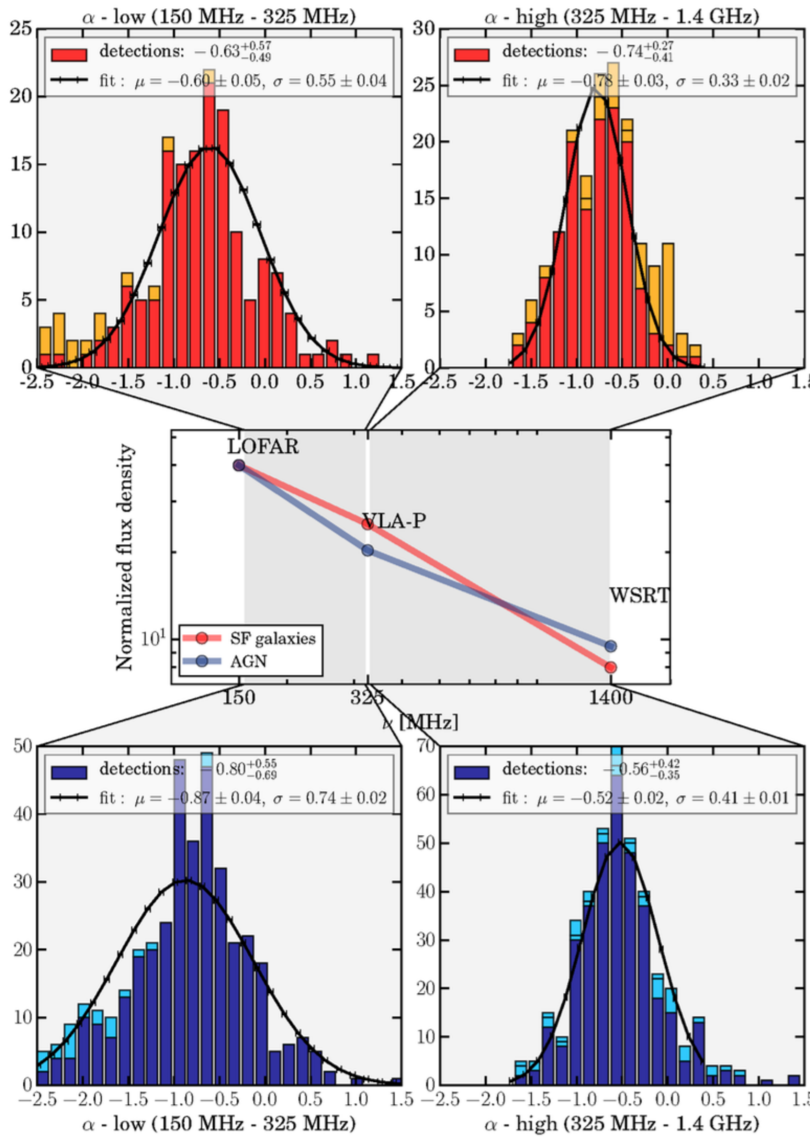
Radio spectra: Statistical studies

Calistro-Rivera+2017
Bootes field

- AGN vs SFG
  - SFG flatten at <300 MHz
  - AGN steepen at <300 MHz (extended)
  - AGN flatter than SFG at >300 MHz (core)
  - no redshift/SFR evolution
  - curvature → 0 for high L AGN

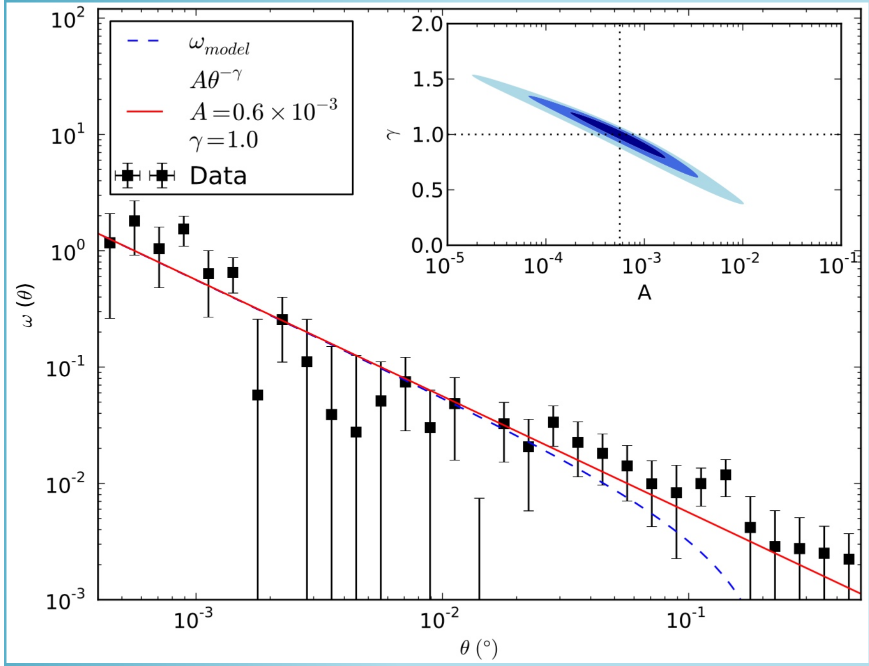
  (hot spots; Jenkins & McEllin 1977)



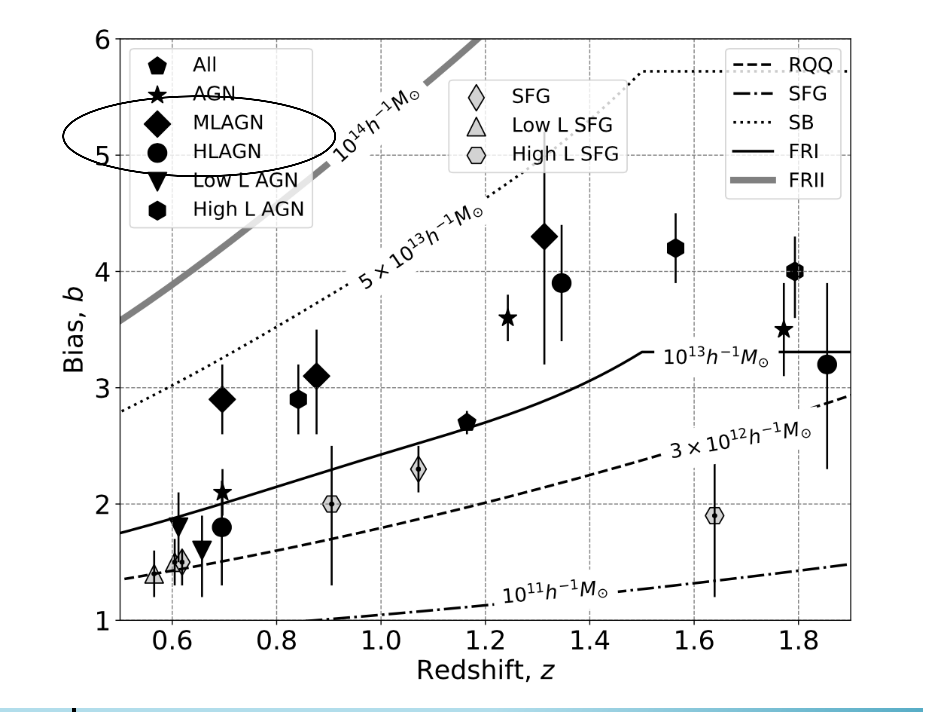


Radio sources and the link to DM haloes

Hale et al. submitted



TPCF from JVLA-COSMOS



Comparison with S3 models (Wilman+08)

Courtesy Matt Jarvis

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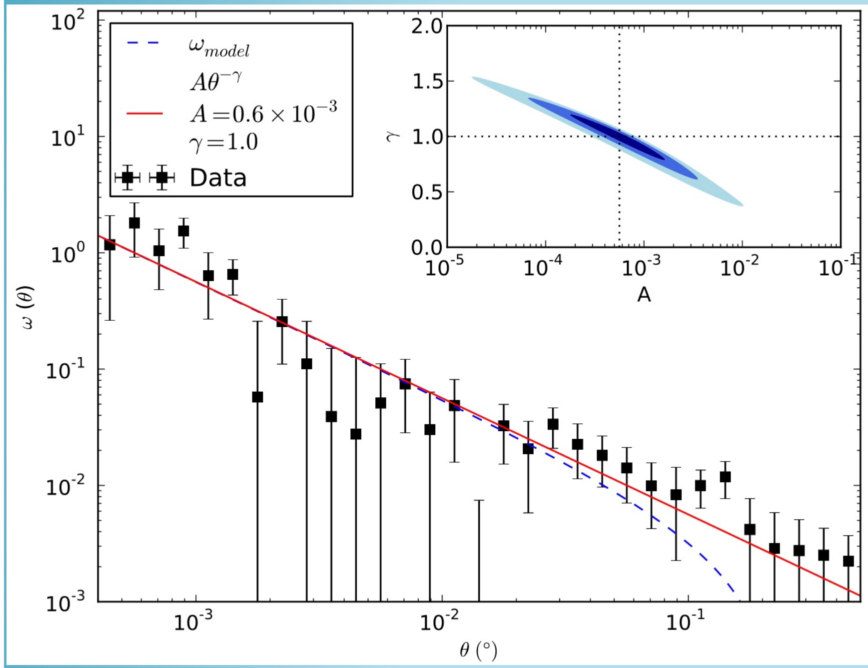

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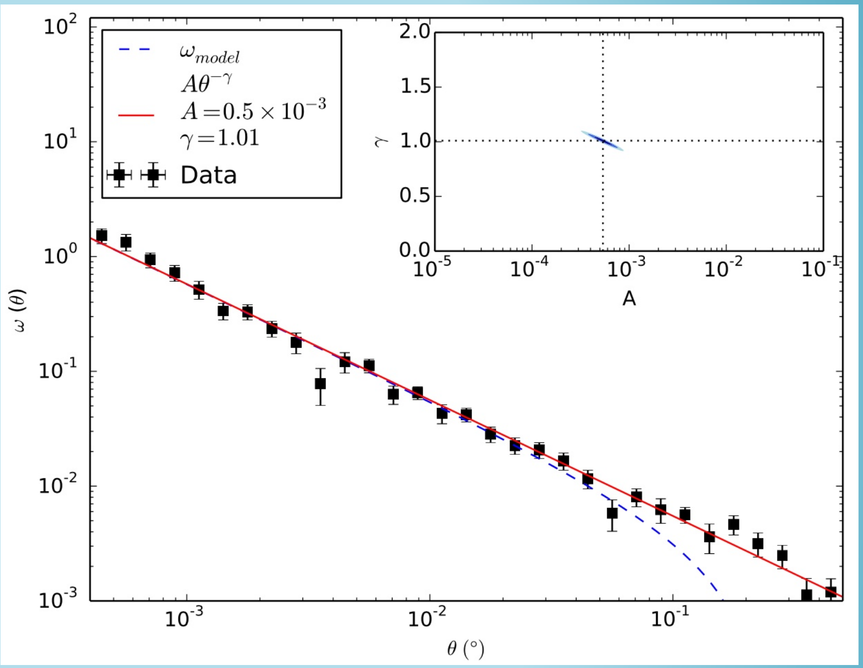


Expected TPCF from MIGHTEE-XMMLSS

but see also LOFAR Tier 2 fields...

Courtesy Matt Jarvis

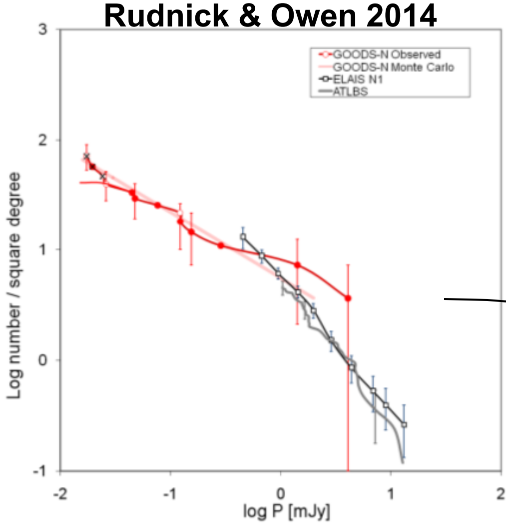
The Magnetized Universe

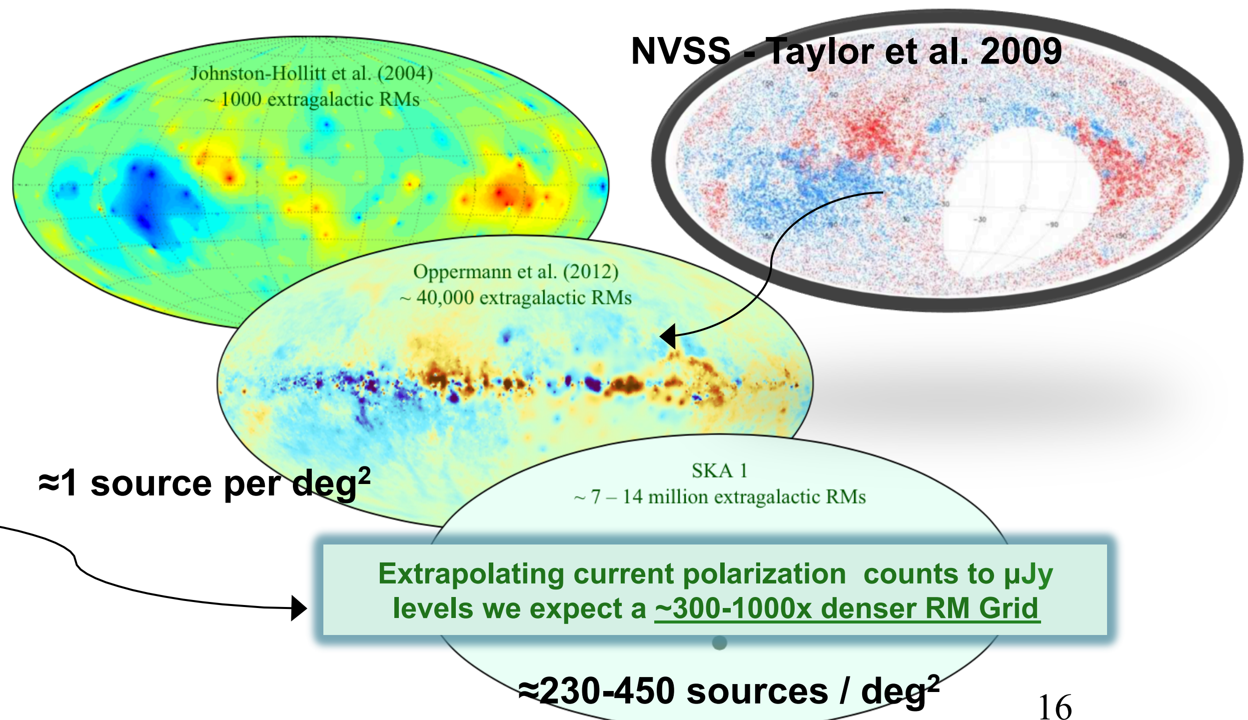
Magnetic fields permeate the Universe, but poorly constrained

- How they grow and propagate (amplification mechanisms, role of CRs)?
- How they affect affect galaxy and cluster evolution?

All-sky RM/pol. surveys provide information on magnetic fields ($B_{||}$ and $B_{\perp}$) for all environments (MW, Galaxies/AGN, Clusters, Cosmic Web**):**

Rudnick & Owen 2014



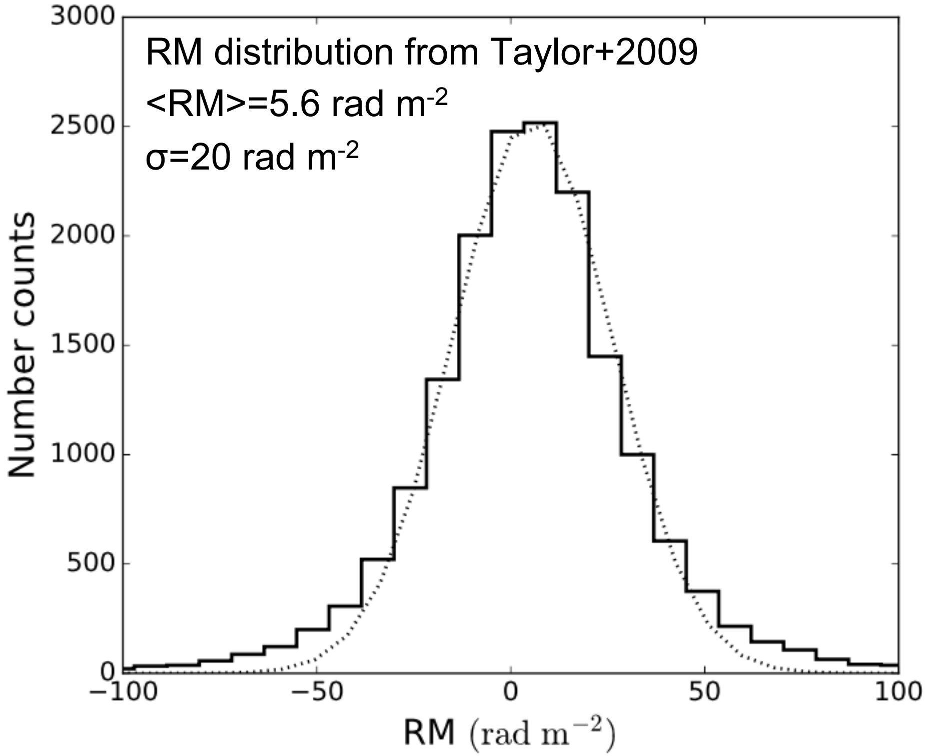


Foreground from point extragalactic sources

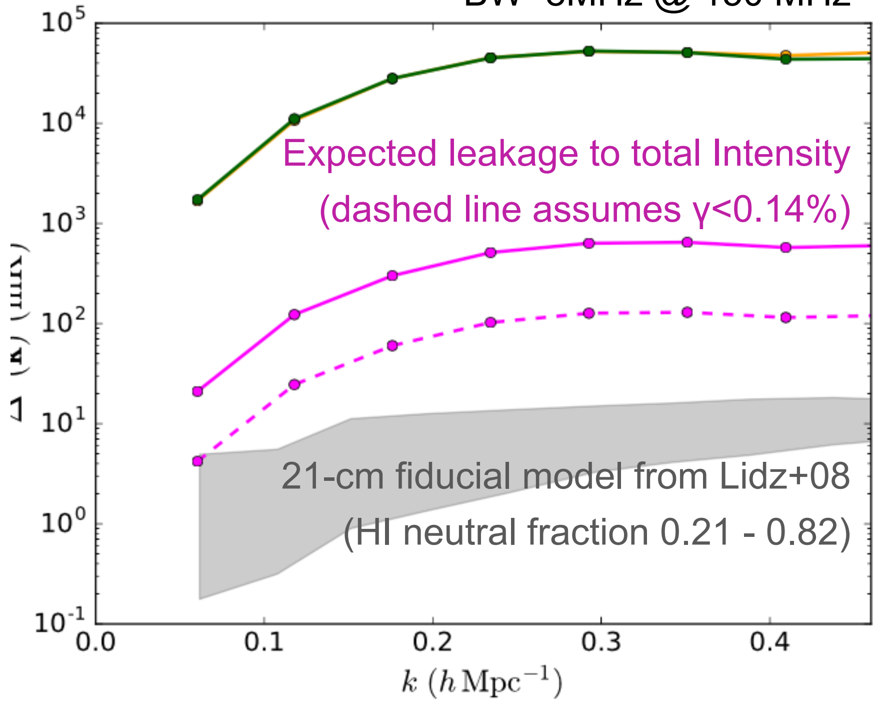
RM distribution from Taylor+2009
<RM>=5.6 rad m^{-2}
σ=20 rad m^{-2}

Source catalogue (Hurley-Walker+14): S>120 mJy @ 150 MHz
Average polarization fraction at 150 MHz: γ< 0.32% (Lenc+2016)

Nunhokee+17



30m baseline
BW=8MHz @ 150 MHz



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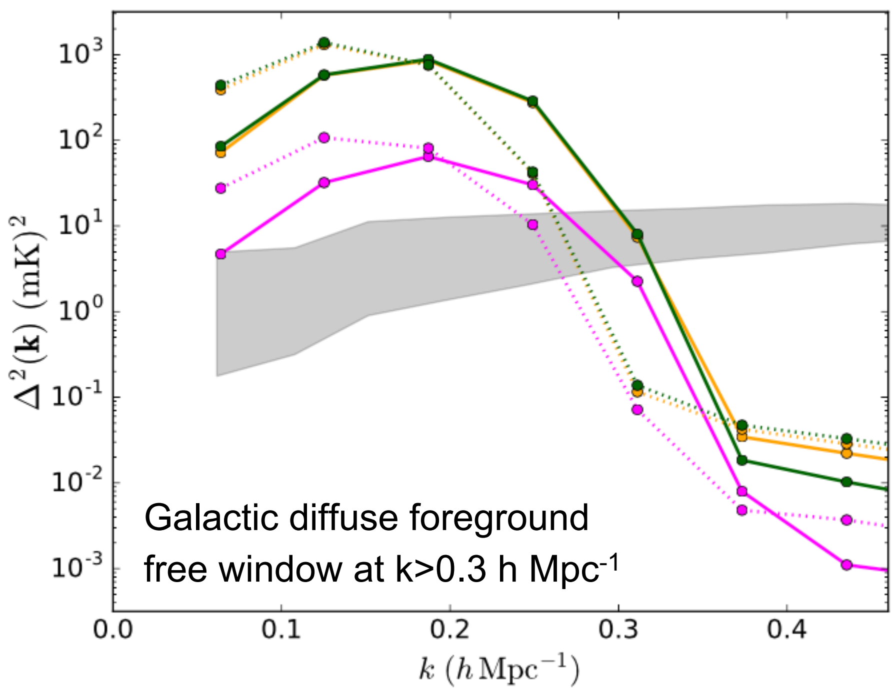

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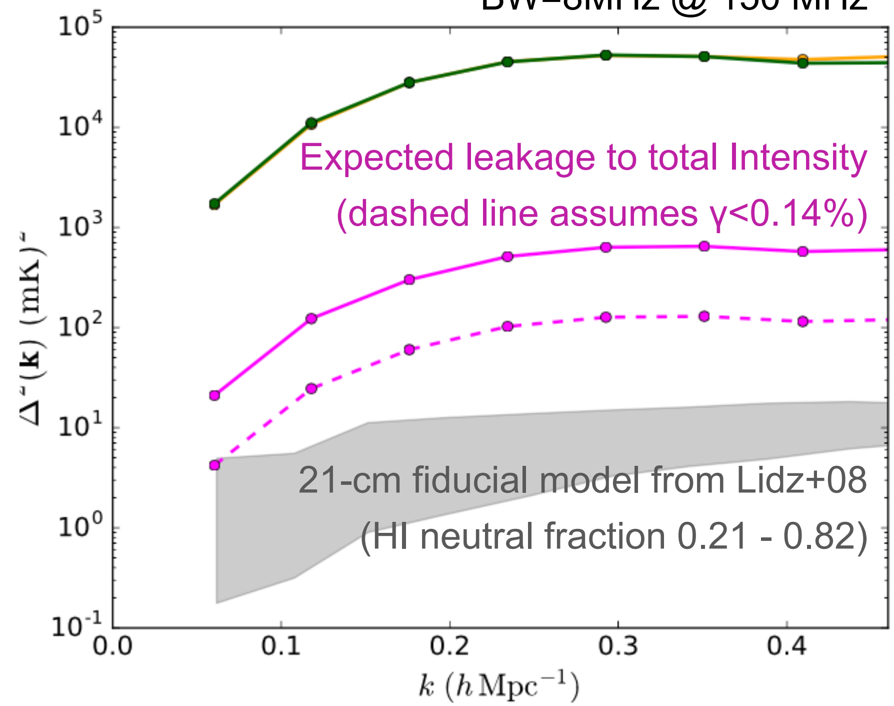
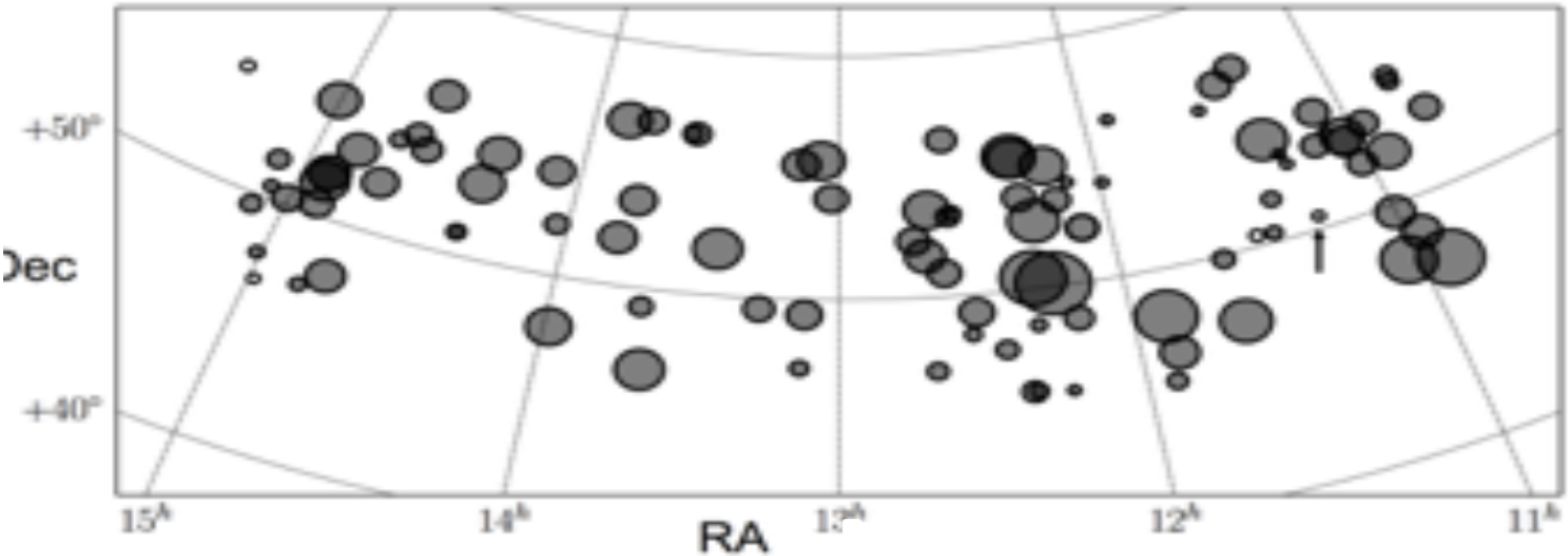


Foreground from point extragalactic sources

LoTSS polarization survey → RM Grid at low frequency

van Eck et al (in prep)



Detecting the Magnetized Cosmic Web

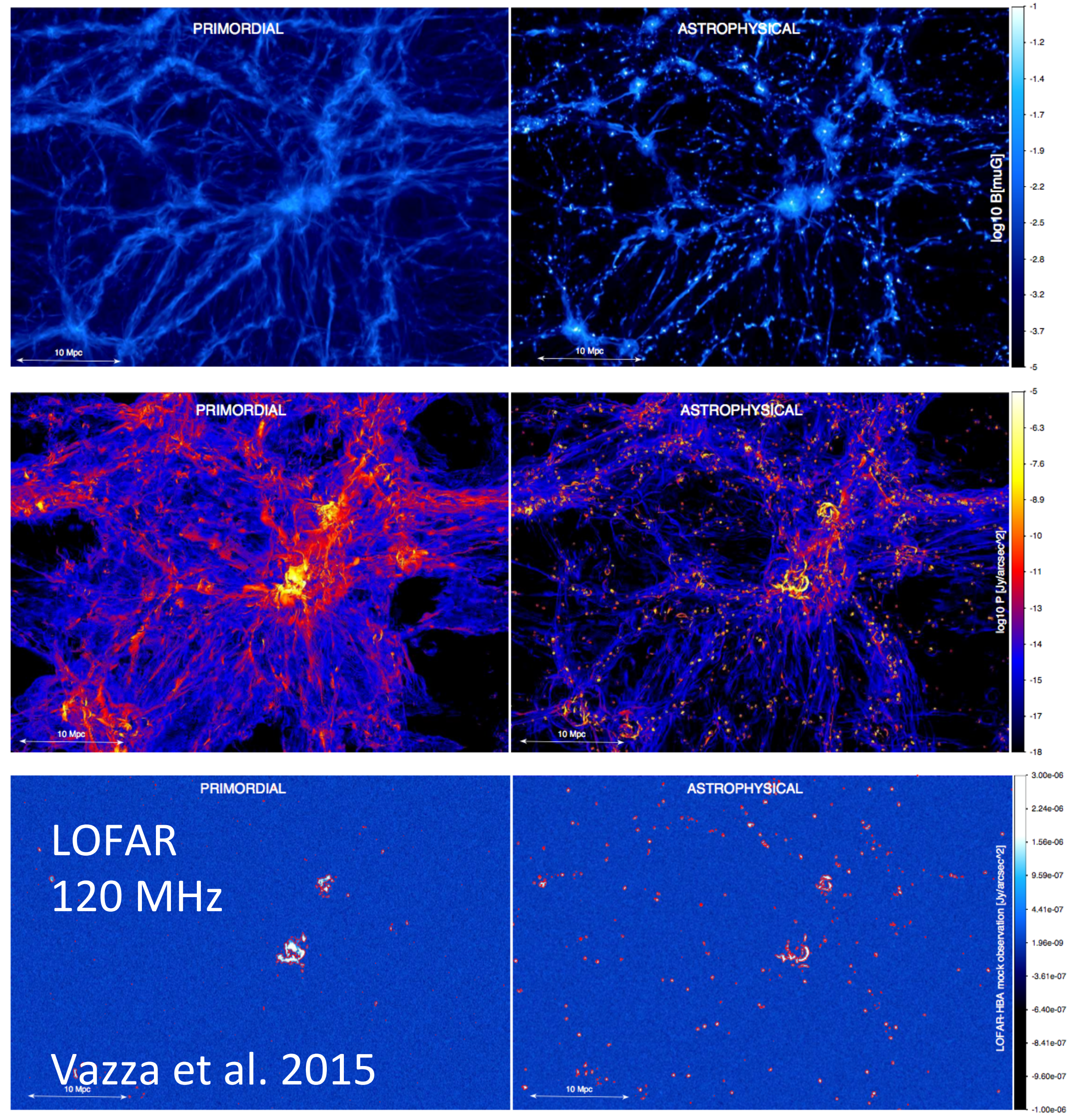
Cosmic Web surrounded by strong accretion (steady) shocks that accelerate particles

Diffuse synchrotron radio emission from shocked WHIM can illuminate the cosmic web

Primordial Scenario:
Turbulent amplification and compression of weak cosmological fields (seed 10^{-9} G)

Astrophysical Scenario:
Magnetization by galactic winds and outflows powered by star formation feedback, SN, AGN (seed 10^{-11} G)

Magnetic fields in filaments should carry memory of the initial field



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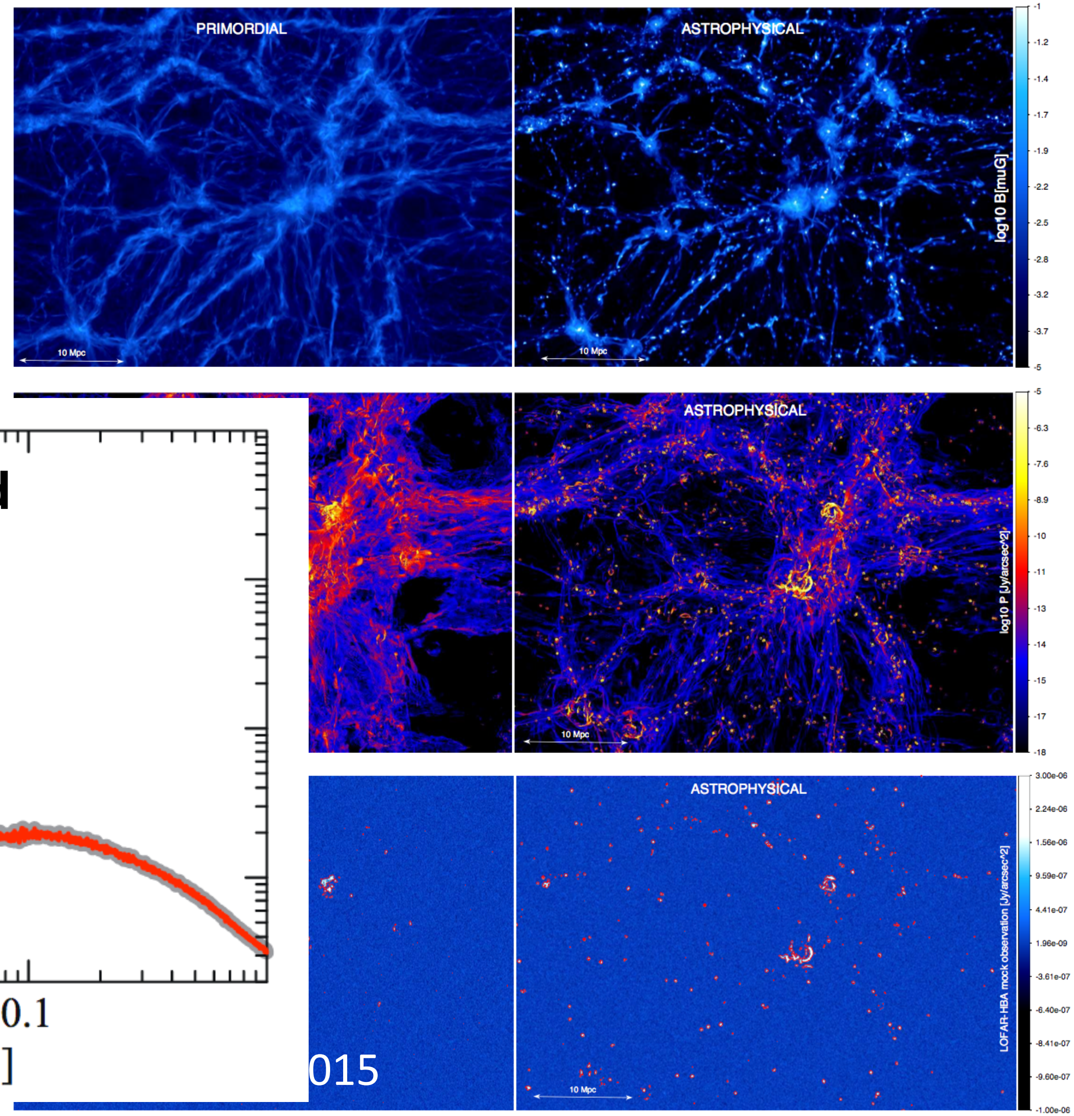

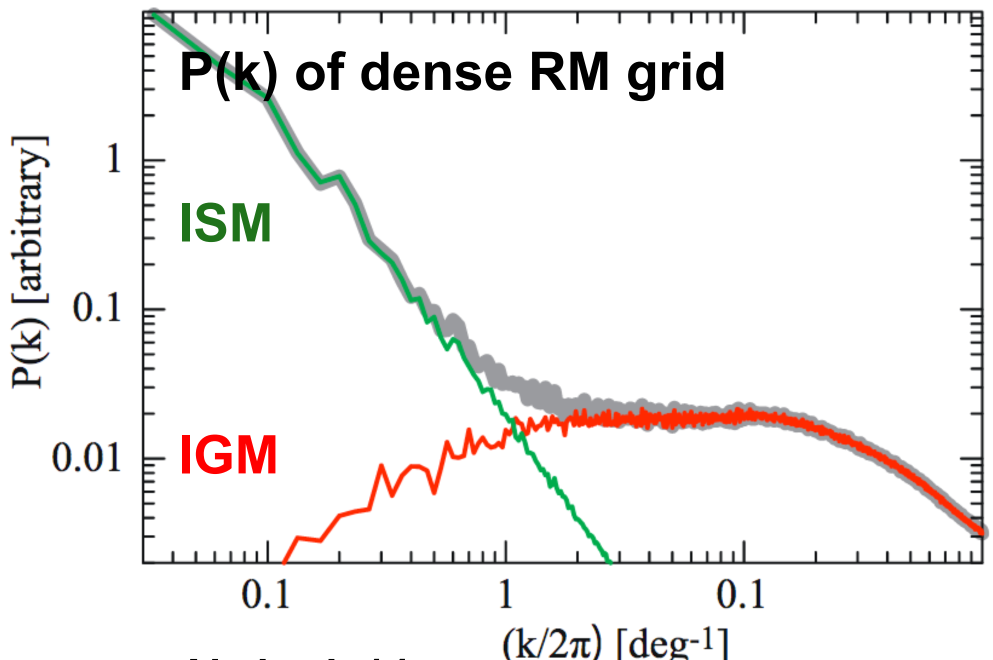

Akahori+14

Summary

Deep RC surveys provide **a valuable dust-extinction/gas-obscuration-free tool to study** thermal and non-thermal emission in galaxies and AGN

– **Low-frequency deep surveys can now compete with cm surveys (non thermal emission) and privide unique information of low E electron populations**

Ongoing surveys are revolutionizing our knowledge of radio source populations:

– faint radio population is **composite**: **SFG**; **RL AGN** (RI AGN; RE AGN)**; RQ AGN** (RE AGN)
  - Origin of radio emission in RQ AGN?
– Evolutionary **models need to be updated** (especially for RQ population: SFG & RQ AGN)
  - Radio/FIR correlation needs to be better understood
– **Clustering** models of radio sources need **to be updated** (both for RI and RE AGN)
– Radio spectra **complex**: not single power law (neither for SFG nor for AGN)
– Point source **polarization foreground potentially important**, need better estimate (ongoing work with LOFAR)
– **Diffuse emission from filaments unconstrained**; next-generation surveys needed

THANKS