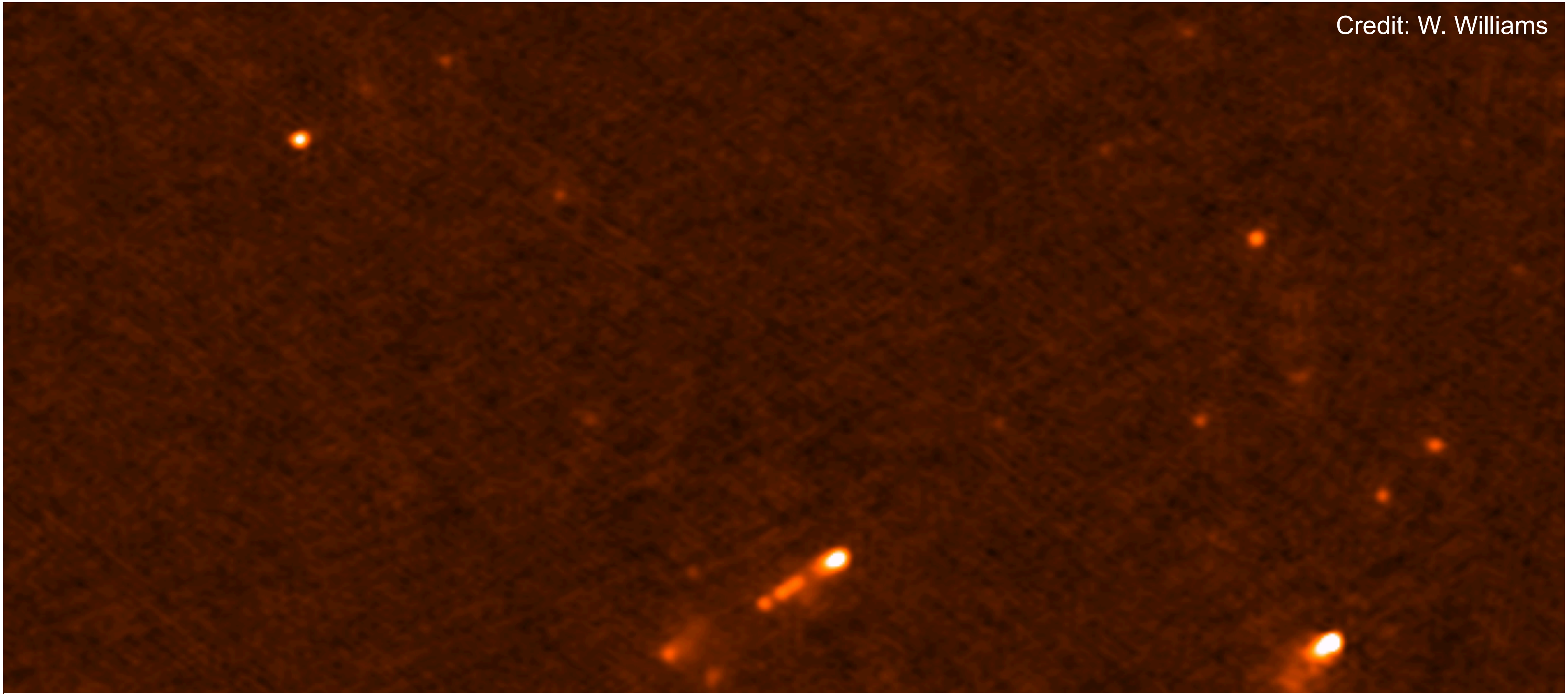
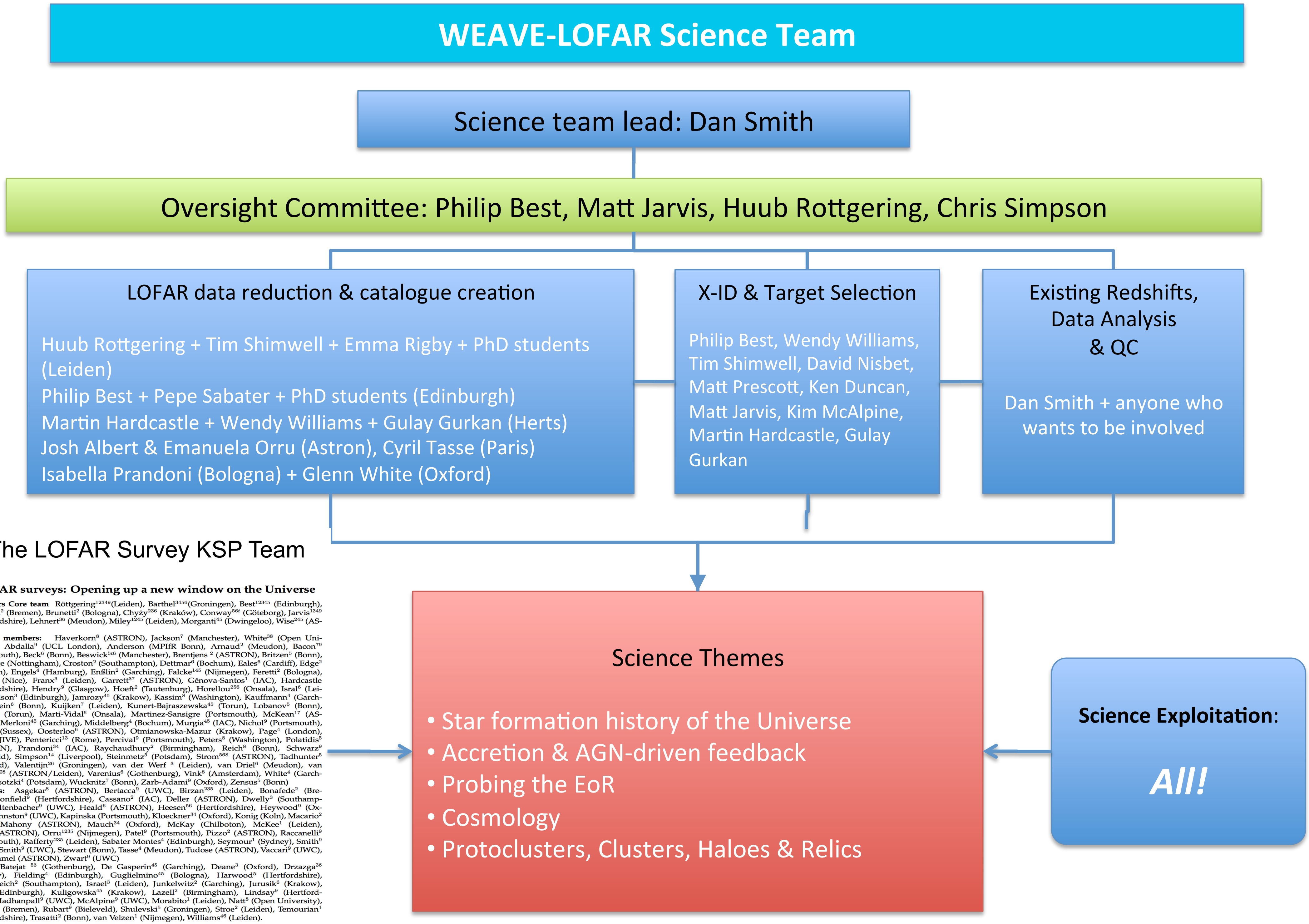


WEAVE-LOFAR

Isabella Prandoni

Based on 1st WEAVE-LOFAR Meeting (March 2016) presentations
(Courtesy Dan Smith – PI of WEAVE-LOFAR Science team)



The LOFAR Survey KSP Team

LOFAR surveys: Opening up a new window on the Universe

Members Core team Röttgering[12349](Leiden), Barthel[3456](Groningen), Best[12345] (Edinburgh), Brüggen[2] (Bremen), Brunetti[2] (Bologna), Chyży[236] (Kraków), Conway[56t] (Göteborg), Jarvis[1349] (Hertfordshire), Lehnert[36] (Meudon), Miley[1245] (Leiden), Morganti[45] (Dwingeloo), Wise[245] (ASTRON)

Regular members: Haverkorn[8] (ASTRON), Jackson[7] (Manchester), White[38] (Open University), Abdalla[9] (UCL London), Anderson (MPIfR Bonn), Arnaud[2] (Meudon), Bacon[79] (Portsmouth), Beck[6] (Bonn), Beswick[5t6] (Manchester), Brentjens [2] (ASTRON), Britzen[5] (Bonn), Conselice (Nottingham), Croston[2] (Southampton), Dettmar[6] (Bochum), Eales[6] (Cardiff), Edge[2] (Durham), Engels[4] (Hamburg), Enßlin[2] (Garching), Falcke[145] (Nijmegen), Feretti[2] (Bologna), Ferrari[2] (Nice), Franx[3] (Leiden), Garrett[37] (ASTRON), Génova-Santos[1] (IAC), Hardcastle (Hertfordshire), Hendry[9] (Glasgow), Hoeft[2] (Tautenburg), Horellou[256] (Onsala), Isral[6] (Leiden), Ivison[3] (Edinburgh), Jamrozy[45] (Krakow), Kassim[8] (Washington), Kauffmann[4] (Garching), Klein[6] (Bonn), Kuijken[7] (Leiden), Kunert-Bajraszewska[45] (Torun), Lobanov[5] (Bonn), Marecki (Torun), Marti-Vidal[6] (Onsala), Martinez-Sansigre (Portsmouth), McKean[17] (ASTRON), Merloni[45] (Garching), Middelberg[4] (Bochum), Murgia[45] (IAC), Nichol[9] (Portsmouth), Oliver[3] (Sussex), Oosterloo[6] (ASTRON), Otmianowska-Mazur (Krakow), Page[4] (London), Paragi (JIVE), Pentericci[13] (Rome), Percival[9] (Portsmouth), Peters[8] (Washington), Polatidis[5] (ASTRON), Prandoni[34] (IAC), Raychaudhury[2] (Birmingham), Reich[8] (Bonn), Schwarz[9] (Bieleveld), Simpson[14] (Liverpool), Steinmetz[5] (Potsdam), Strom[568] (ASTRON), Tadhunter[5] (Sheffield), Valentijn[26] (Groningen), van der Werf [3] (Leiden), van Driel[6] (Meudon), van Weeren[128] (ASTRON/Leiden), Varenius[6] (Gothenburg), Vink[8] (Amsterdam), White[4] (Garching), Wisotzki[4] (Potsdam), Wucknitz[7] (Bonn), Zarb-Adami[9] (Oxford), Zensus[5] (Bonn)

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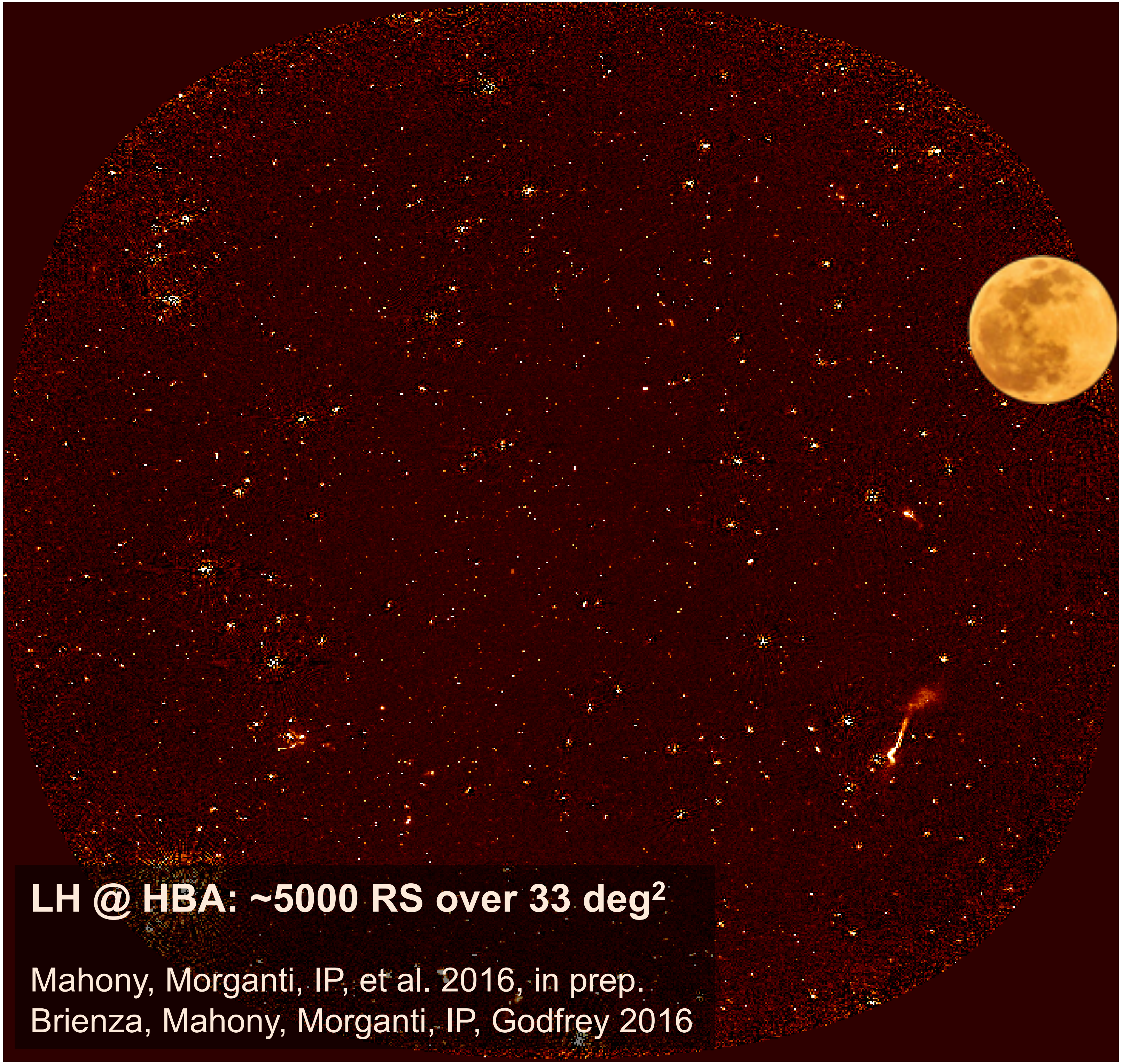
International LOFAR Telescope (ILT)

- **47 operational stations completed**
- **38 NL stations, 9 international stations**
- **3 new stations coming in Poland**

Why LOFAR Surveys?

- Large FoV:
  >30 deg2 @ HBA
- Sensitivity:
  10h @ HBA
  →100 uJy rms
  [EMU: 10 uJy @1.4 GHz]
- Resolution:
  NL → 5" @ HBA
  ILT → 0.5" @ HBA
  [~100 pc scale @z~0
  few kpc scale @ z>1]
- New spectral window (+ Surface Brightness)
  → low-E e^- population



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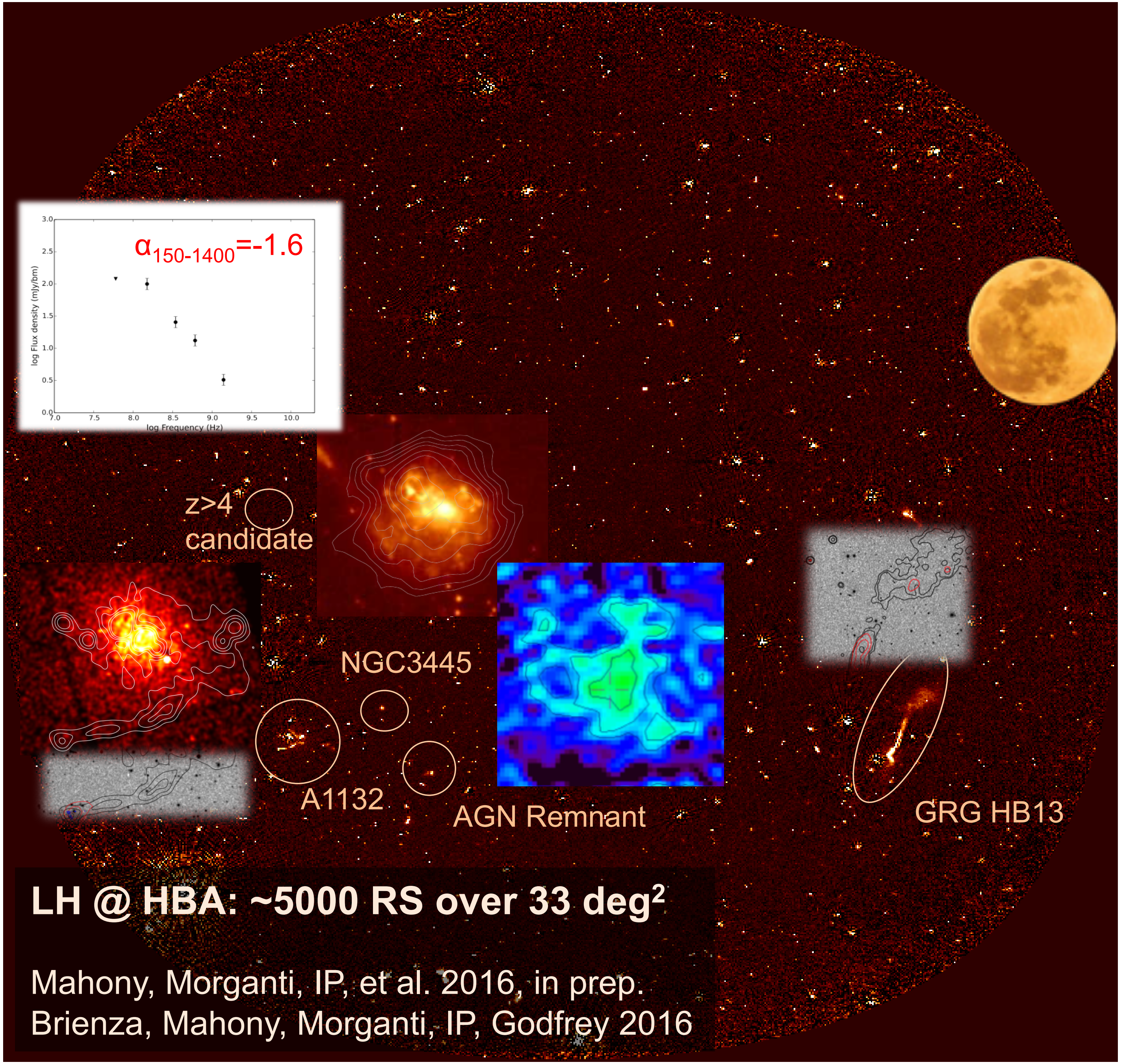


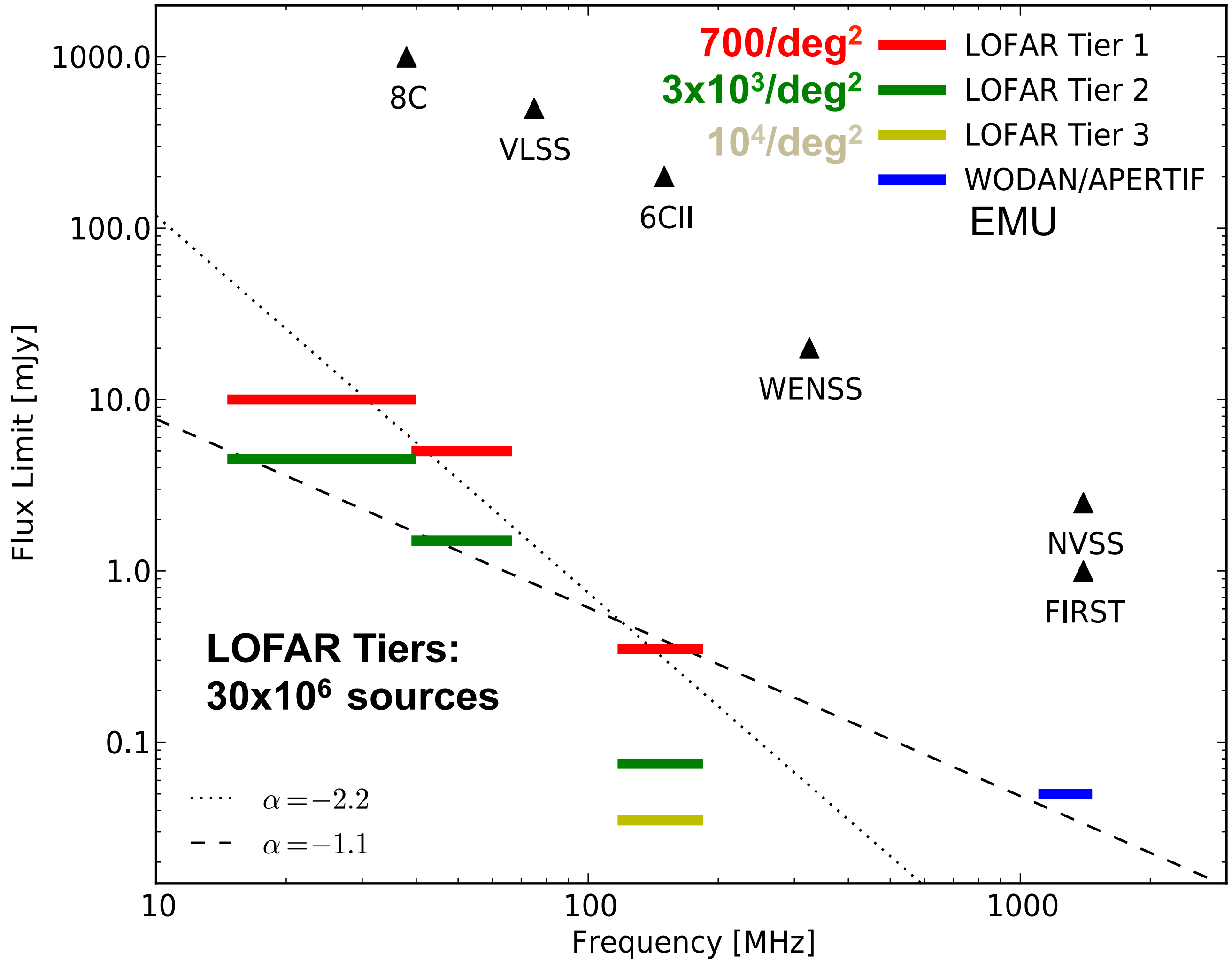
LOFAR Survey KSP – Tiered Strategy

- **Tier 1: All Sky (2π sr) @ LBA & HBA; ~ 100 uJy/b rms @HBA; ~10x @ LBA**
  Science Drivers*: Rare populations; Galaxy/Local Universe; Cosmology; EoR*

- **Tier 2: 25 fields @ HBA & LBA**
  (clusters, nearby gals/AGN, blank)
  ~25 uJy/b rms @ HBA
  10x @ LBA
  Science Drivers*:*
  Detailed physics; SF/AGN ev.

- **Tier 3: 5 deep fields @ HBA**
  rms → ~5 uJy/b @ HBA 10^4/deg^2
  Science Drivers*: SF/AGN ev.*

To be completed within next 5 years



Main Science Drivers of LOFAR Survey KSP

I. **Galaxy/AGN co-Evolution:** SF History & Role of AGN Feedback

II. **Formation of Massive Galaxies and Protoclusters:** massive RGs at z>2 as sign-post for proto-clusters

III. **Epoch of Reionization:** IGM through HI abs. studies against z>6 RL-QSO

IV. **RL AGN:** Physics & Duty cycles (new born, mature, dying)

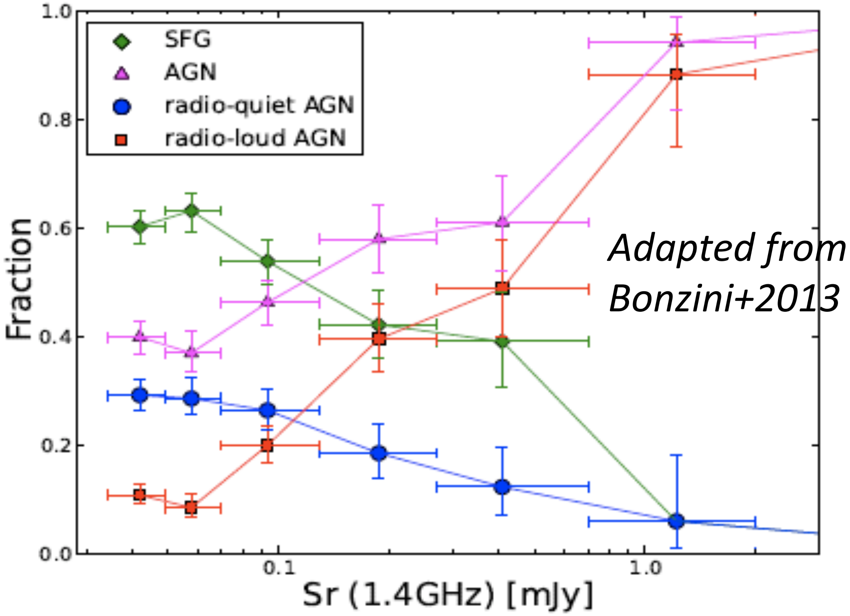
V. **Clusters' dynamics and micro-physics**: Radio Halos & Relics

VI. **Our Galaxy and beyond:** Magnetic Fields, ISM, FIR/Radio Correlation

VII. **Cosmology tests:** clustering, ISW Effect, etc.

VIII....

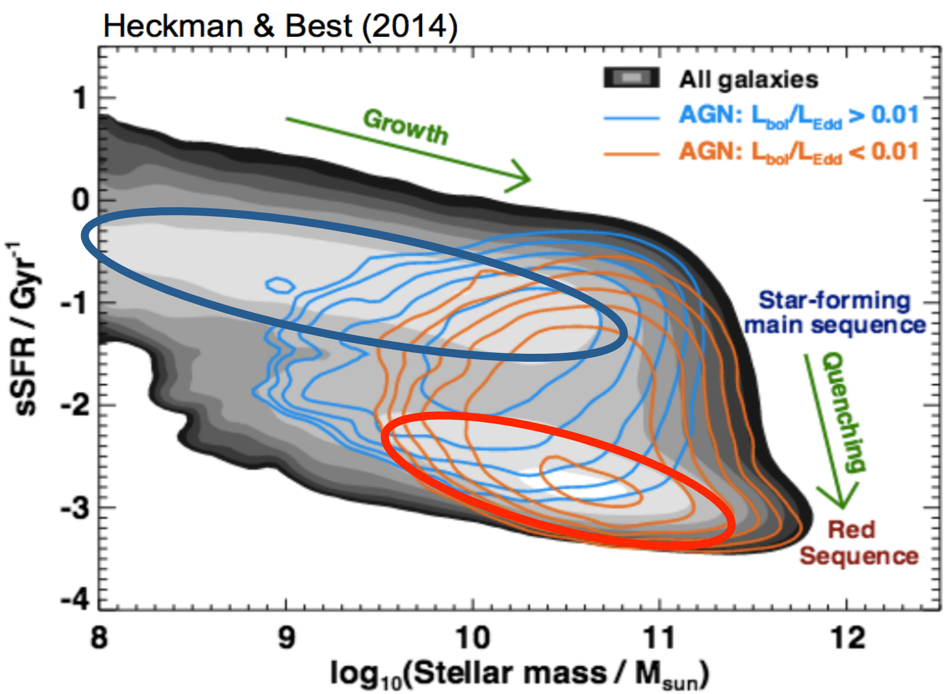
I - Galaxy/AGN co-Evolution:
the promise of deep radio surveys



SFGs & RQ-AGN start to appear at sub-mJy levels in deep radio fields

→ complete view of SF and AGN activity & Feedback to high-z and down to RQ regime

Not affected by dust extinction/gas obscuration



RQ + RL High Excitation Galaxies (HEG)
(L/L_{Edd}>0.01) → **Radiative-Mode Feedback**
→ radiation-driven feedback (winds)
→Truncation mode

RL Low Excitation Galaxies (LEG)
(L/L_{Edd}<0.01) → **Jet-Mode Feedback**
→ jet-driven mechanical feedback
→Maintenance Mode

II – (Massive) Galaxy Formation & Protoclusters:

the promise of deep radio surveys

- **HzRGs unique laboratories for studying massive galaxy and cluster formation + AGN feedback in early Universe**

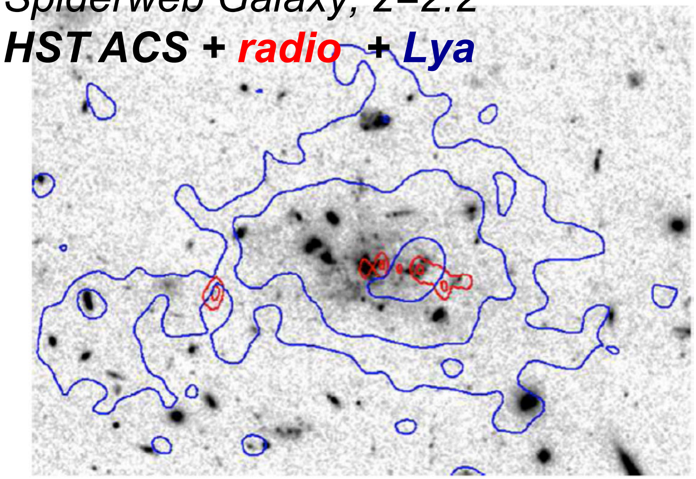
- **Radio-Loudness strong function of stellar mass and environment;**
  ➔ High-z Radio Galaxies (z>2; HzRG) among most massive galaxies in early Universe (HEG, strong Lya Emitters)

- HzRGs clumpy optical morphologies and spectra indicative of extreme SFR + radio-optical alignment
  ➔ **jet-induced star formation may play a more important role at earlier epochs**

- **HzRGs** embedded in giant ionized gas halos and frequently surrounded by galaxy overdensities, e.g. **proto-clusters**
  ➔ likely progenitors of dominant cluster galaxies

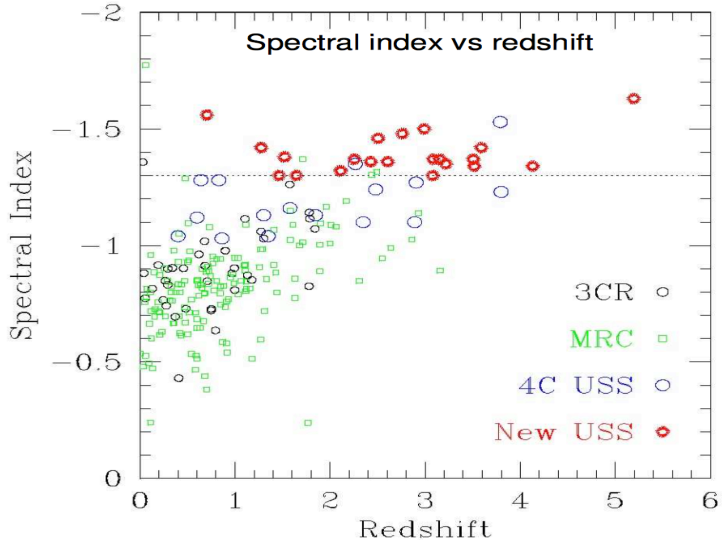
- HzRG can be pre-selected based on their radio spectra [***low frequency crucial]*** ➔ **Ultra-steep Sources (USS)**

Spiderweb Galaxy; z=2.2
HST ACS* + *radio* + *Lya



Pentericci, L., et al, 1997

Miley & de Breuck, 2008



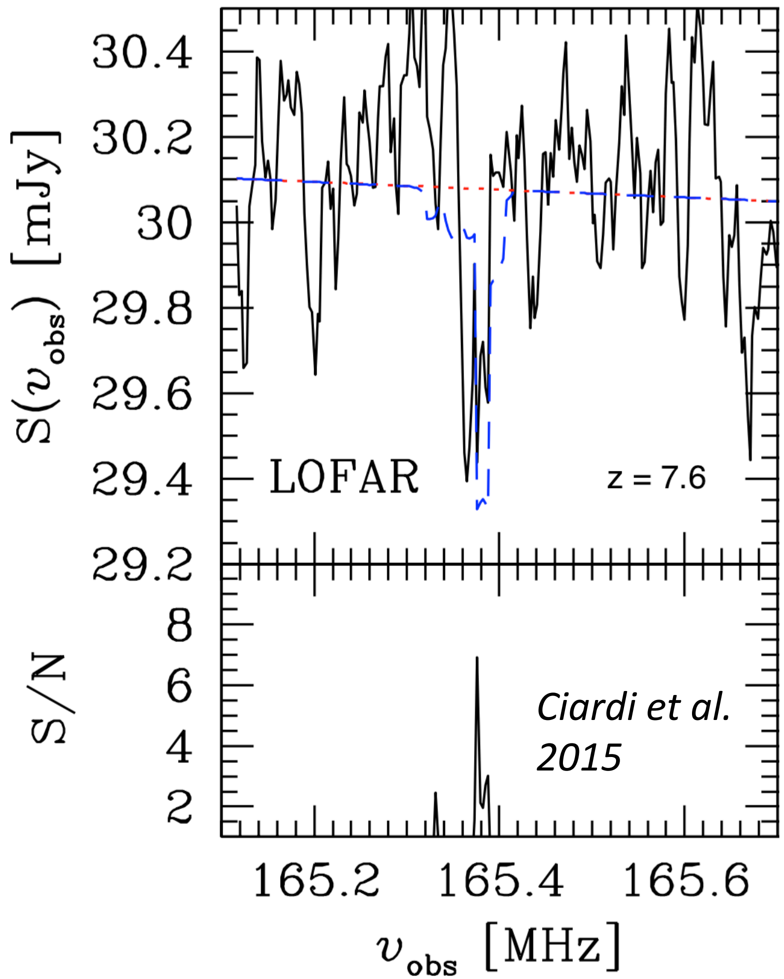
III – Epoch of Reionization:
the promise of deep radio surveys

- **HI optically thin at z>6** [Gunn-Peterson" trough in quasar spectra limited to z<6 because the IGM becomes optically thick to Ly-α photons for neutral fractions > 0.1%]

- **HI absorption against bright radio cores (RL-QSO)→** only tool to probe the cold neutral hydrogen of IGM along source l.o.s. **into EoR**

- **LOFAR radio surveys can detect such features at z>6** [200-1000 hrs integration]

Extremely luminous RL-AGN are rare (~$10^{27\text{-}29}$ W/Hz)
→ **All Sky surveys crucial**



III – Epoch of Reionization:
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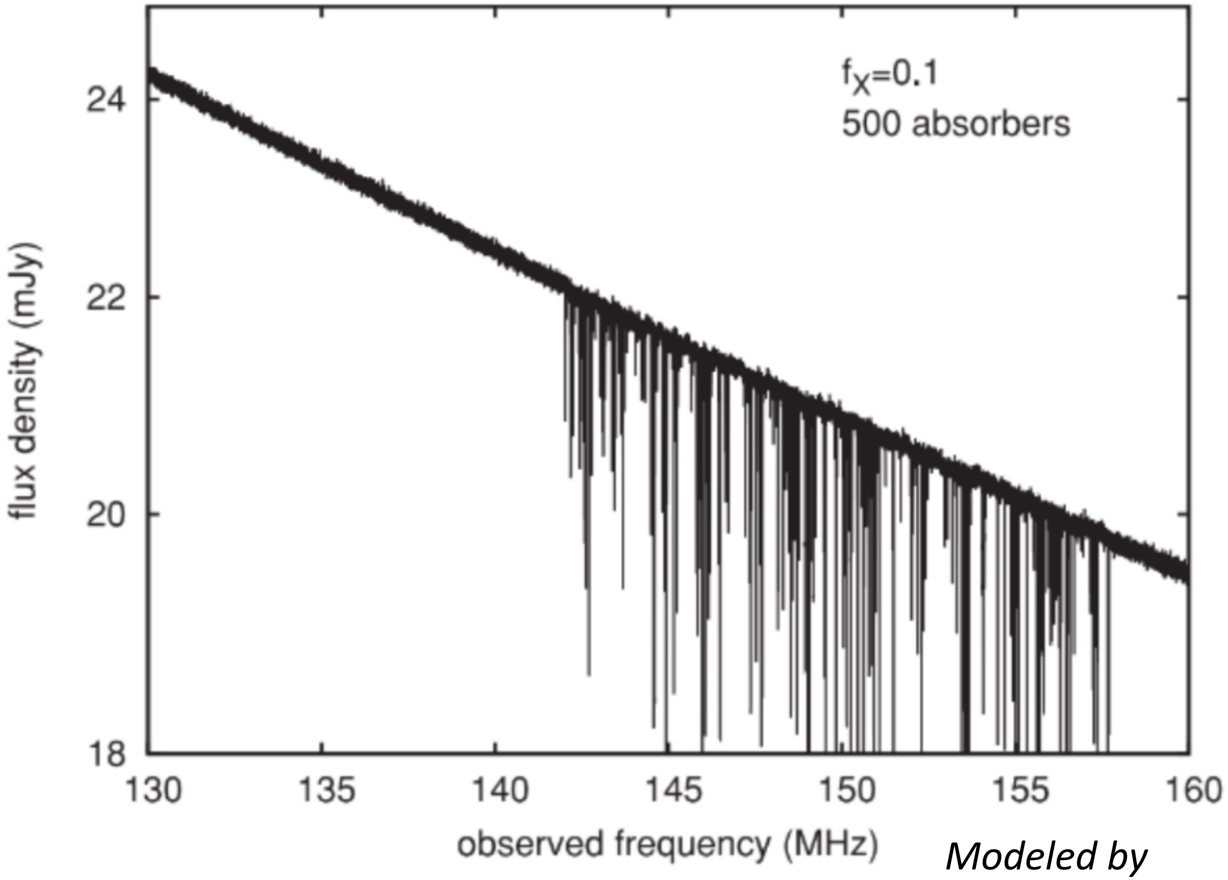
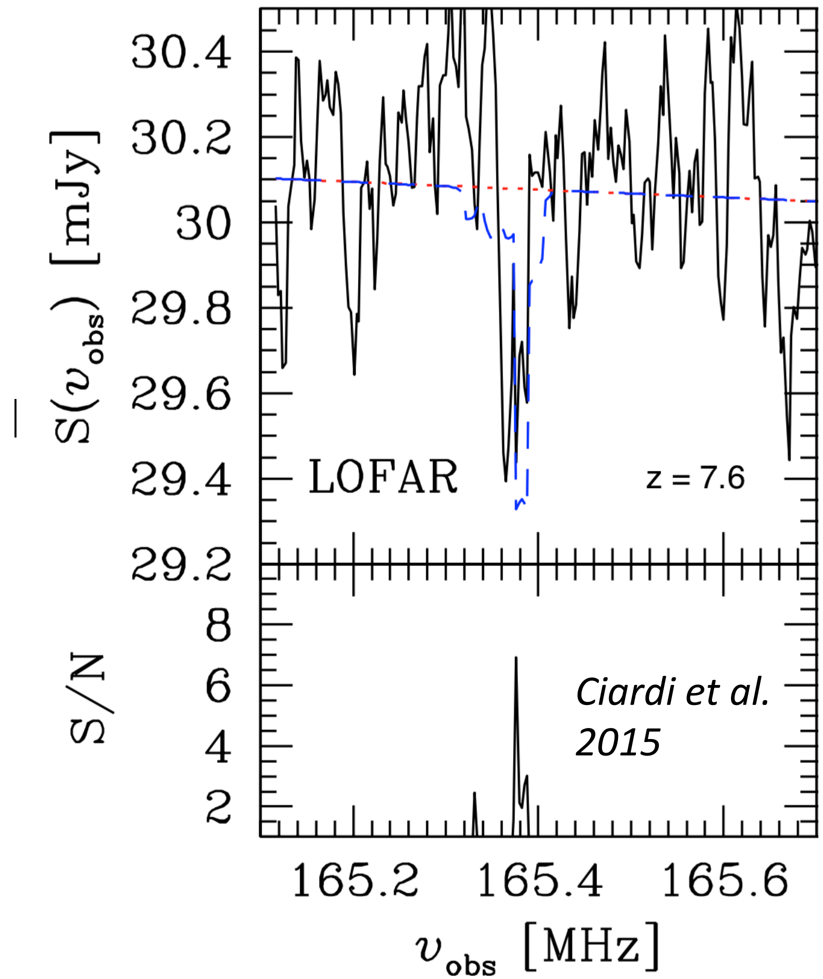


Modeled by Mack et al. 2012



EoR 21cm absorption systems : How long it took? How clumpy?

WEAVE LOFAR - MOS

- **WEAVE-LOFAR** will be the **primary source of spectroscopic information for the LOFAR Surveys KSP**

- It will consist of **> 10^6 spectra of radio-selected sources**

- **We are hunting for redshifts**, so the “low”-resolution grating (R=5000, which provides complete wavelength coverage, 3700-9500 A) is essential

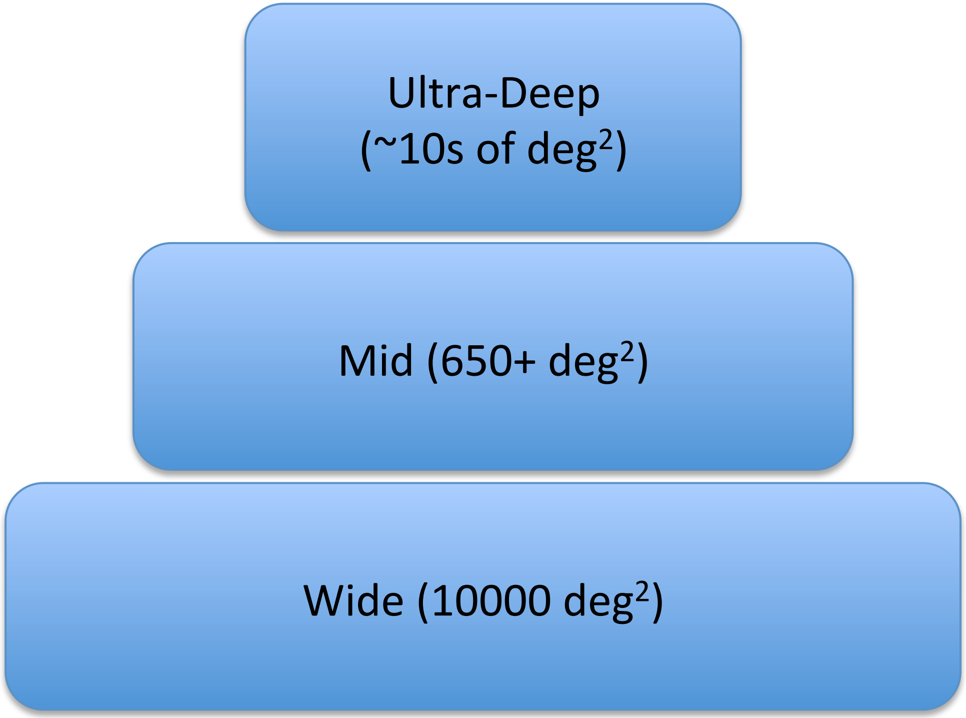
- **High S/N spectroscopy allow robust source classification:**
  - SF vs AGN spectra
  - HEG (Seyfert/QSO) vs LEG (Liners, Early Type)

- Spectroscopy also enables ***a lot* more science**
  - velocity dispersions
  - metallicities
  - virial mass of BHs
  - etc.

WEAVE-LOFAR
Survey Design

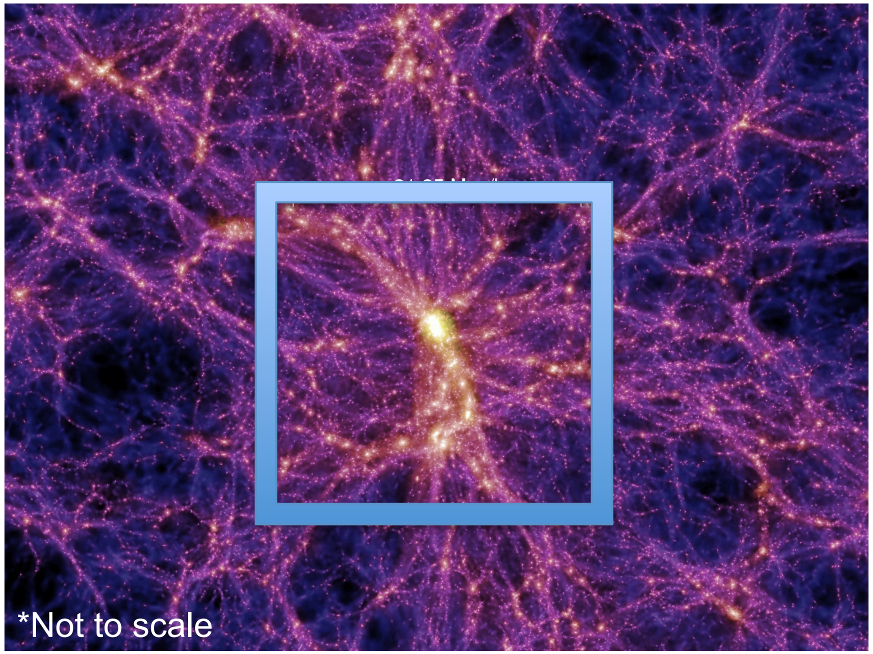
1) **MOS Survey:**

Spectroscopic follow-up of large numbers of LOFAR-selected sources in three tiers, to get *a* complete picture of SF and AGN co-evolution.



2) **IFU Survey:**

Resolved spectroscopy of large samples of proto-clusters and targets with extended haloes to provide detailed studies of the relationship between galaxies/AGN and their environments



1) The Wide
Finding EoR radio galaxies and complete samples of the brightest sources

- **EOR rare population** (we expect 1 z > 6 radio galaxy per 200 deg^2)
- **Good samples of RL-AGN at the bright end of the LF at z > 2,**
- **AGN as tracers of LSS at z < 1**

➔ **Target bright sources, S_{150} > 10 mJy.** Source density is ~160/pointing; target the galactic halo

Essential	Optimal	Ideal
10,000 deg^2	10,000 deg^2	Whole Sky

Essential:
- 1,000 deg^2 complete sampling
- 9,000 deg^2, selecting against SDSS/WISE/PanStarrs targets

Optimal:
- 10,000 deg^2 complete sampling
- 510k Targets; 531k fibre hrs
- **Expect ~50 z>6 RGs**
- **Very large samples of z > 2 AGN**
- **All AGN at z < 1**

Ideal:
- 10^6 spectra
- Best chances of getting to the highest z; better EoR sampling

1) The Wide Tier
The Galactic Halo?

Target source density”

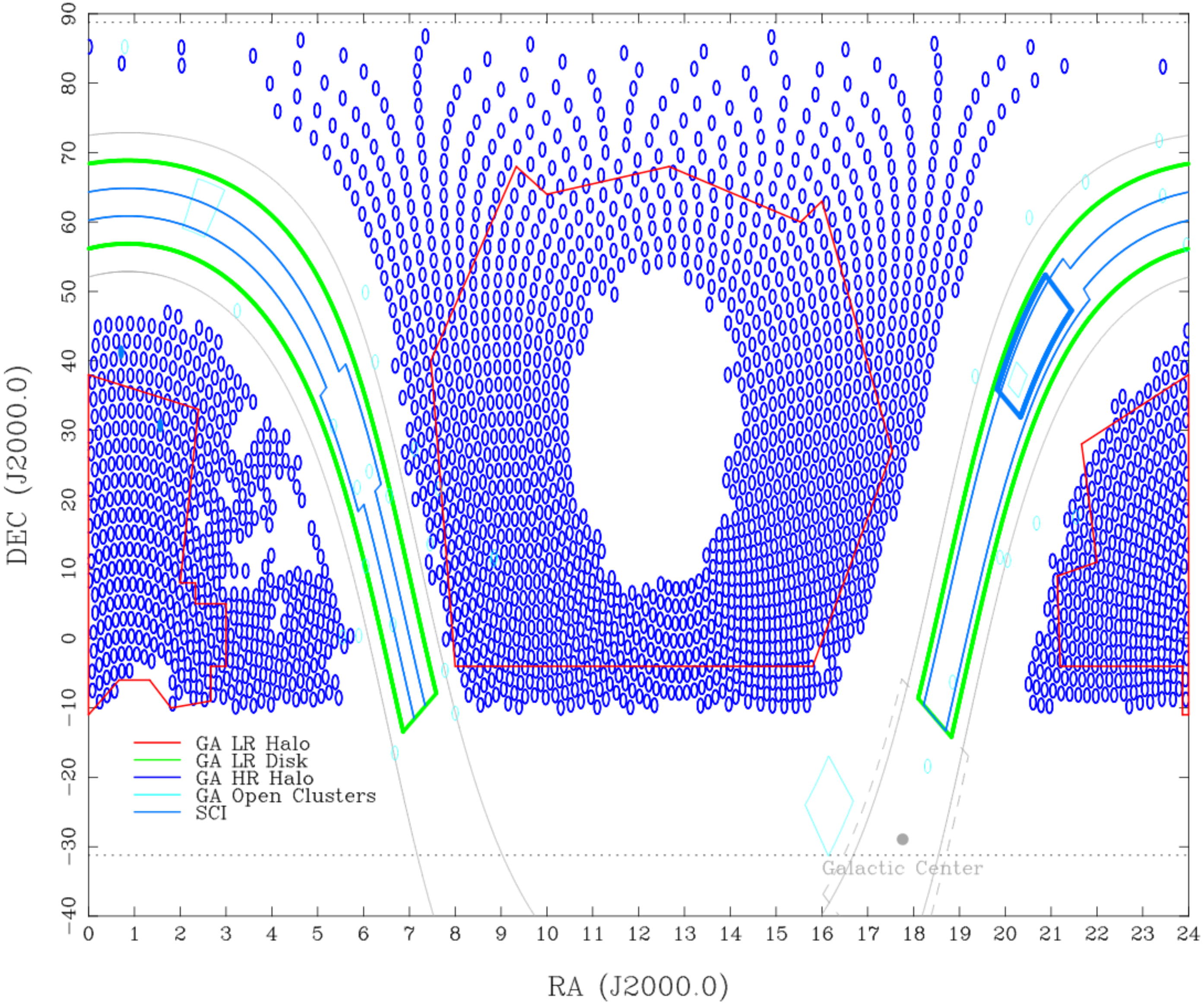
S_{150} = 10mJy

n = 160/field

WEAVE has 960 fibres

Sharing pointings with GA Halo survey, who target primarily Giants (200-550 per tile) plus some MSTO stars

GA Halo survey coverage still being iterated upon, considering going to |b| < 30. Is this an issue for us?



2) The Mid Tier

- **SF and accretion co-evolution at $z < 1.3$ and rare $z > 2$**
- **$S_{150} > 1$ mJy:** Target density is ~1,000 per WEAVE pointing; **ideal; >90% z success at $z < 1$!**
- SFGs are less numerous, so they set the target constraints.

Optimum Scenario **(500hr)**:

- Between **100** (Essential) and **200** (Ideal) SFGs per bin x 5 bins of mass x 10 bins of redshift x 5 bins of environment (**250 bins**)

3) The Deep Tier

- **Low end of AGN RLF and SFRF at both z<1.3 and z>2; physics & ev. of FIR/radio corr.**
- **S_{150} > 100 µJy** will make the best use of the area with multi-wavelength data
- **S_{150} > 300 µJy** more realistic

- **Source density much larger than the WEAVE fibre density** (~1300/deg2 at 300µJy, ~5000/deg2 at 100µJy, according to the S3 simulated skies, corresponding to 4000 and 15000 per pointing) → **need reconfiguration**

- **redshift success rate should be ~70% in 1 hr integrations**

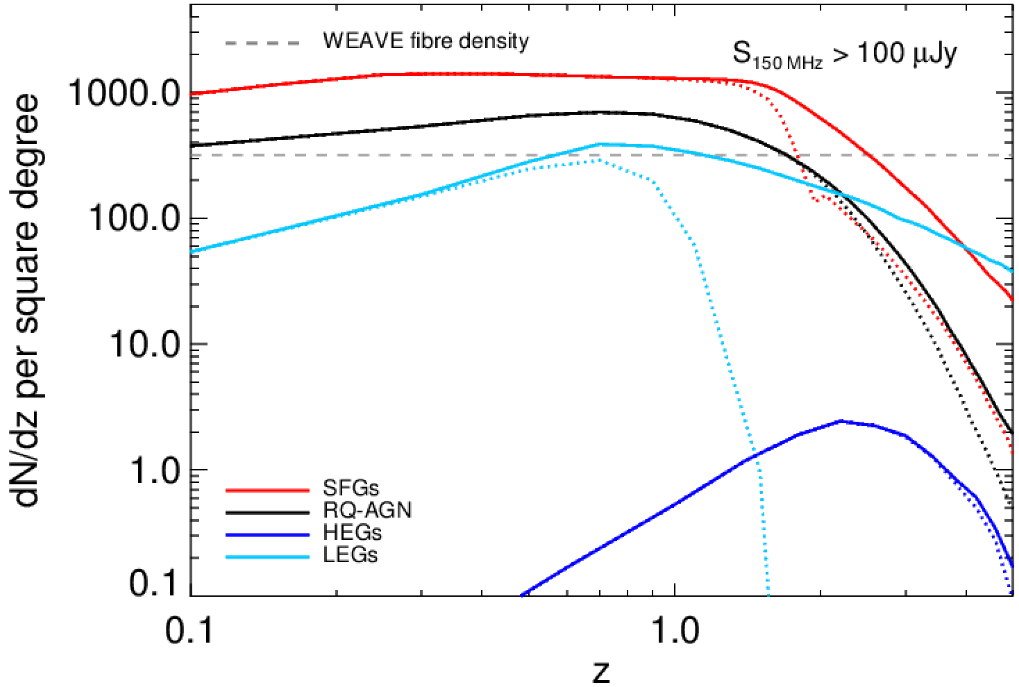
The fields that will have data to this depth are:

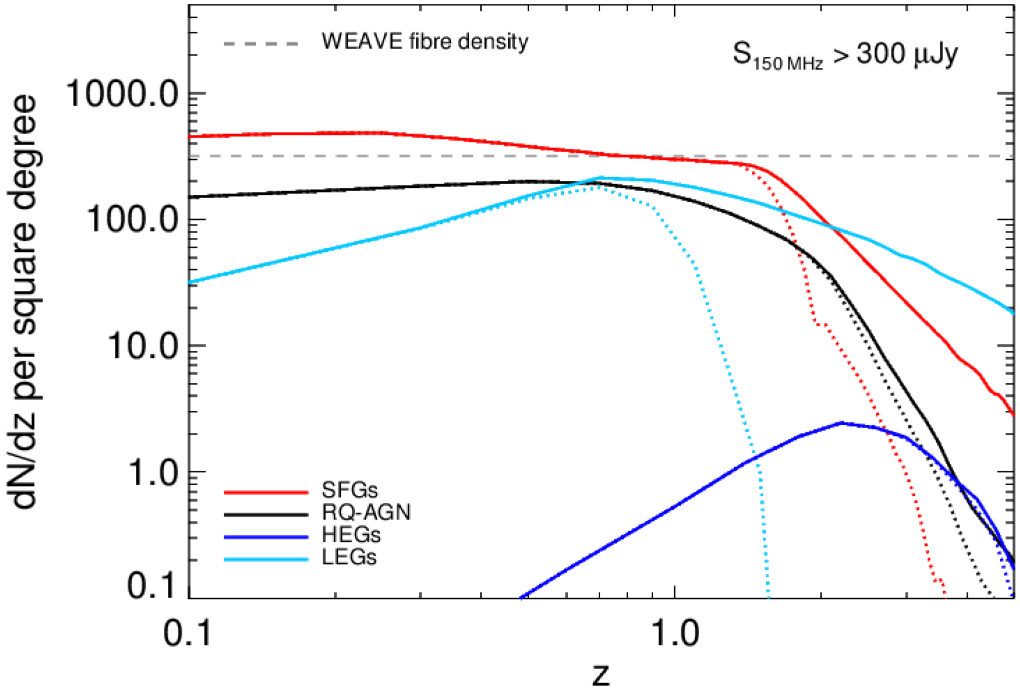
Lockman (1050+57), Böotes (1430+34), ELAIS-N1 (1610+54), NEP (1800+66)

XMM-LSS (0219-05) and COSMOS (1000+02) have the best ancillary data but location means they may not reach the required sensitivity; will target as deep as possible in these fields whilst satisfying the positional accuracy requirements to get sources in the 1.3” fibres.

3) The Deep
What should we expect from the µJy population (~15000/pointing)?

redshift success rate should be ~70% (95% at z < 1) in 1 hr integrations





Optimal Scenario (1000 hrs):

•**100 per bin** x 10 mass bins x 10 redshift bins x 10 environment bins (**1000 bins**)

•**Deeper integrations for "hard" sources**; with 70% z-success in 1 hr, we could re-target the 1/3 of unsuccessful sources for a **further 4 hr each.** Increases the time required by a factor of 2.3.

• **100% redshift success rate at z<1**

Based on SKA Simulated Skies (Wilman et al. 2008, 2010)

IFU Surveys:
- LIFU: Protoclusters
- mIFU: Lya haloes and AGN feedback

- **LIFU**: **5 hr** of observations around **100 Radio Galaxies** (takes 584 hr)
  - Single LIFU field of view is 1.5' x 1.3'
  - **Target the most luminous radio galaxies at 2.0 < z < 2.5 from the MOS WIDE tier**
  - **Expect** to identify upwards of **50 new protoclusters** (i.e. triple the known sample)
  - Expect to reach 4×10^{-18} erg/cm^2/s; **expect ~9 LAEs associated with the RG per field** (derive Lα LF to higher redshift than HETDEX)

- **mIFU**: 600 Targets / 20 multiplex x 5 hrs a pop gives **150hr**
  - 11"x12" close-packed bundles; 20 mIFUs can be positioned simultaneously
  - **Target 400 bright z > 2.3 LAEs** (half RQQs and half SFGs) in a diverse range of environments**,** 5 hr on each

    [12" well matched to study Lα halos around high-z galaxies (extending up to 100 kpc scales)
  - **Plus 200 0.3 < z < 0.7 AGN** to target OIII, OII & Hbeta (AGN feedback in action)

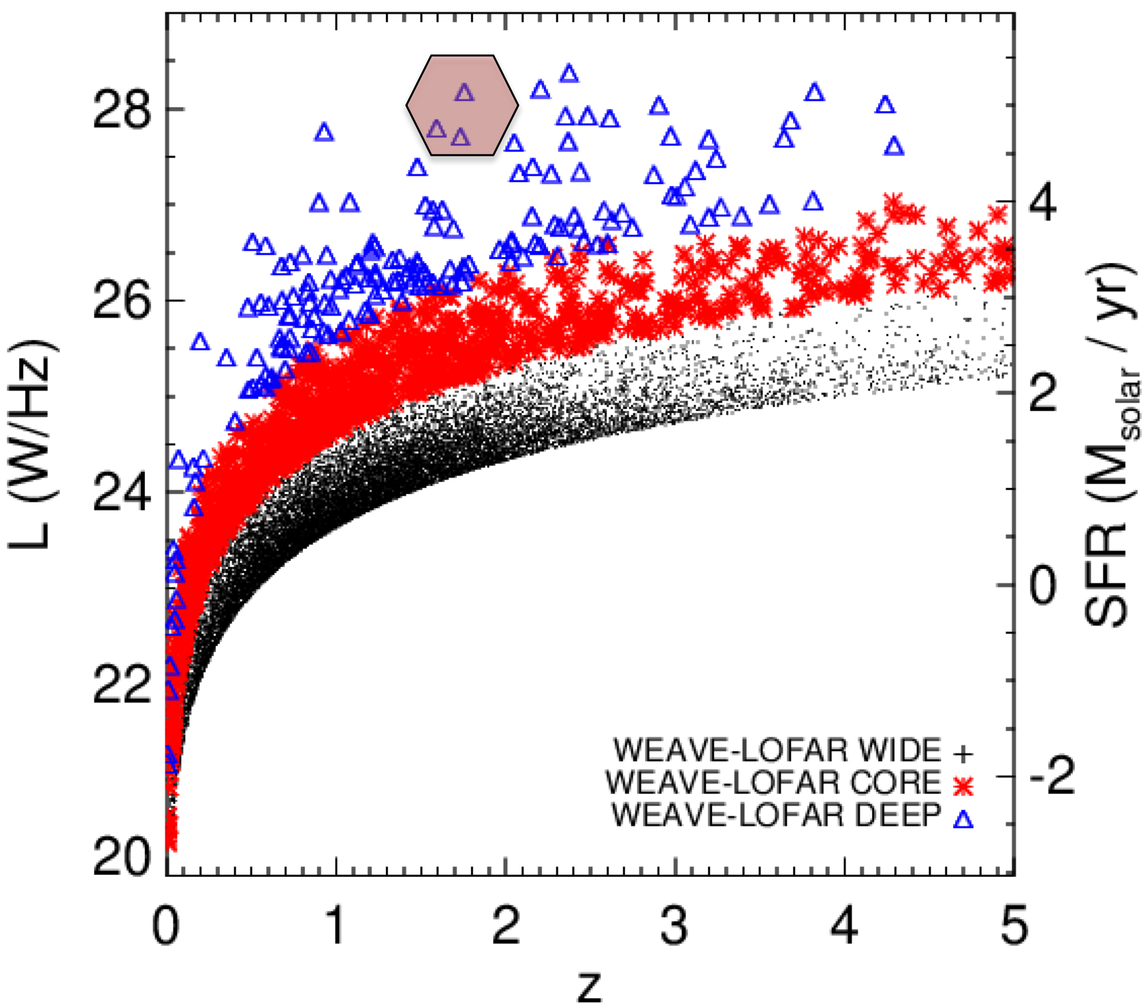
WEAVE-LOFAR
The Bottom Line

- **Panel recommendation:**
  Optimal scenario:
  > 2,051,000 hr + IFU

- **Initial allocation:**
  1,000,000 hr

  Derived taking essential scenarios for all WEAVE surveys and uniformly reducing all to fit in 5 years of survey time

  Does not account for Science review panel recommendations



Thanks very much