ESO-SKA synergies for extragalactic survey science

Mark Sargent

with: **I. Prandoni** (INAF-IRA)

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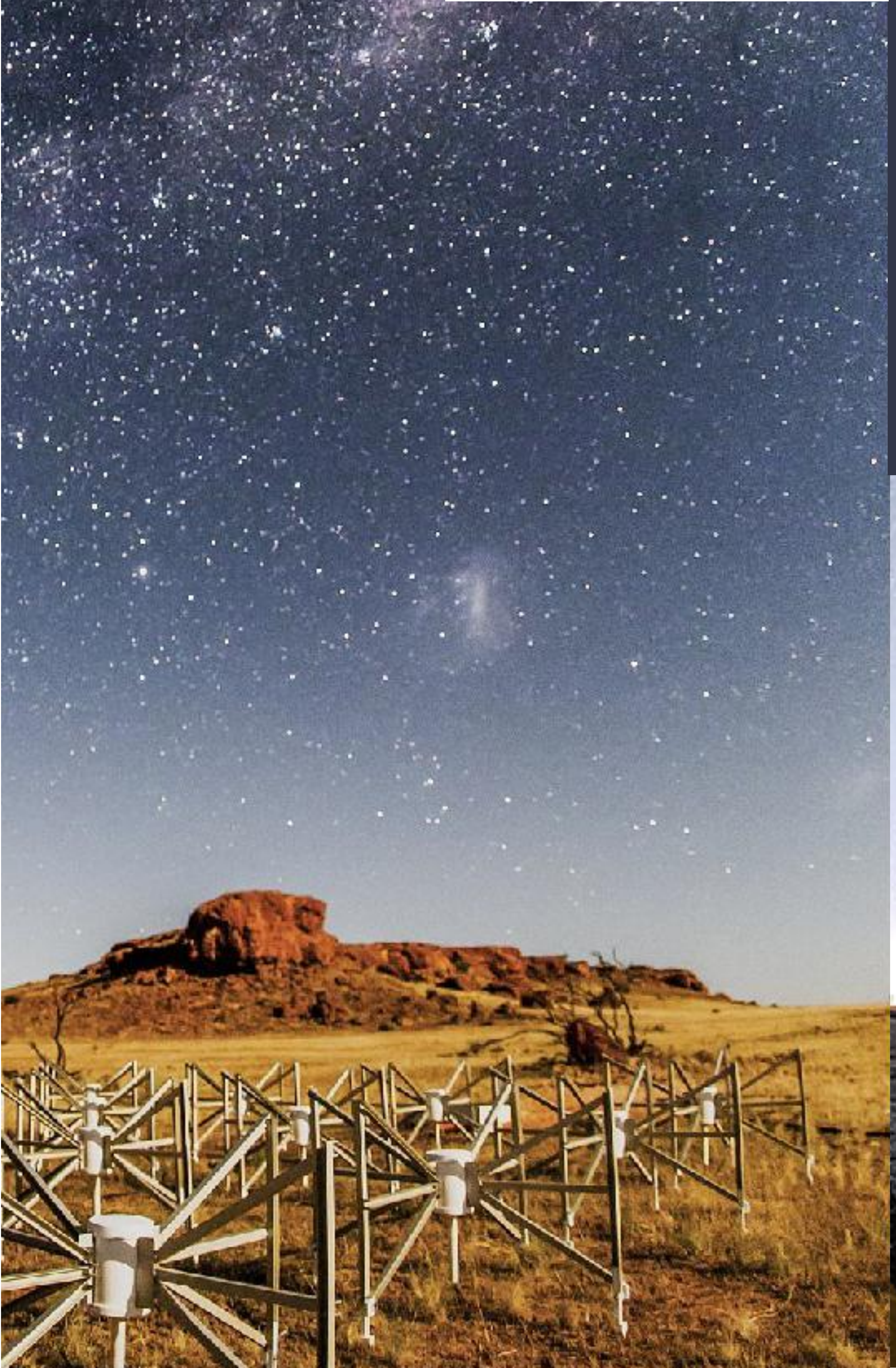
E. Vardoulaki (Tautenburg), and the LOFAR-COMOS team

SKACH winter meeting, Jan. 2024



Credits (left to right): P. Wheeler/ICRAR, M. Claro/ESO, D. Kordan/ESO, SKAO

OUTLINE

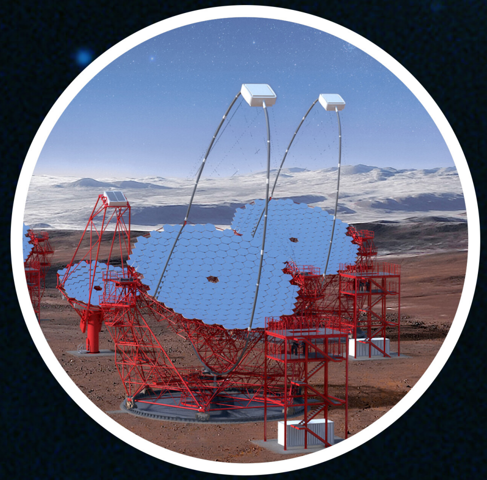
- Introduction:
  - ESO & SKA telescope/instruments and observatory timelines
  - ESO-SKA collaboration agreement
- Some synergistic science cases and recommendations:
  - Environment-dependent galaxy growth
  - Galaxy properties imprinted via gas-feeding from the cosmic web
  - Galaxy-SMBH co-evolution: detailed studies of AGN feedback
  - Long-term prospects with (potential) next-gen ESO facilities
- Conclusions & 2 advertisements

Observational Facilities

Paranal

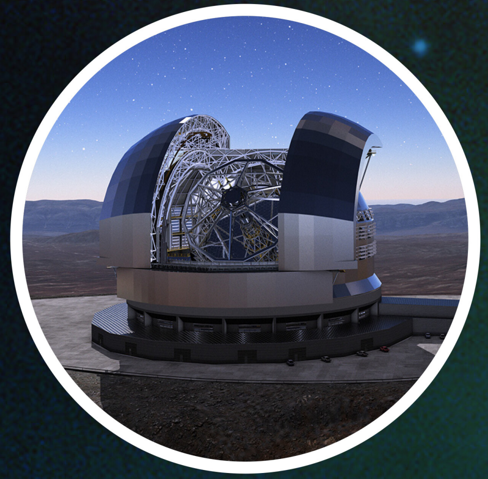
VLT and VLTI

VST and VISTA



CTA Sur*

Armazones



ELT*

La Silla

ESO 3.6-metre telescope and NTT

Chajnantor

ALMA

APEX

*in construction

image credit: ESO

SKA-LOW

THE SKA'S LOW-FREQUENCY TELESCOPE

LOCATION:
AUSTRALIA

FREQUENCY RANGE:
50 MHz–
350 MHz

131,072
ANTENNAS
SPREAD ACROSS **512** STATIONS

MAXIMUM BASELINE:
~65km

SKA-MID

THE SKA'S MID-FREQUENCY TELESCOPE

LOCATION:
SOUTH AFRICA

FREQUENCY RANGE:
350 MHz–
15.4 GHz
WITH A GOAL OF 24 GHz

197 DISHES
(INCLUDING 64 MEERKAT DISHES)

MAXIMUM BASELINE:
150km

image credit: SKAO

ESO-SKA COLLABORATION AGREEMENT

Two intergovernmental organisations dedicated to ground-based astronomy

Signed in July 2023 to collaborate on:

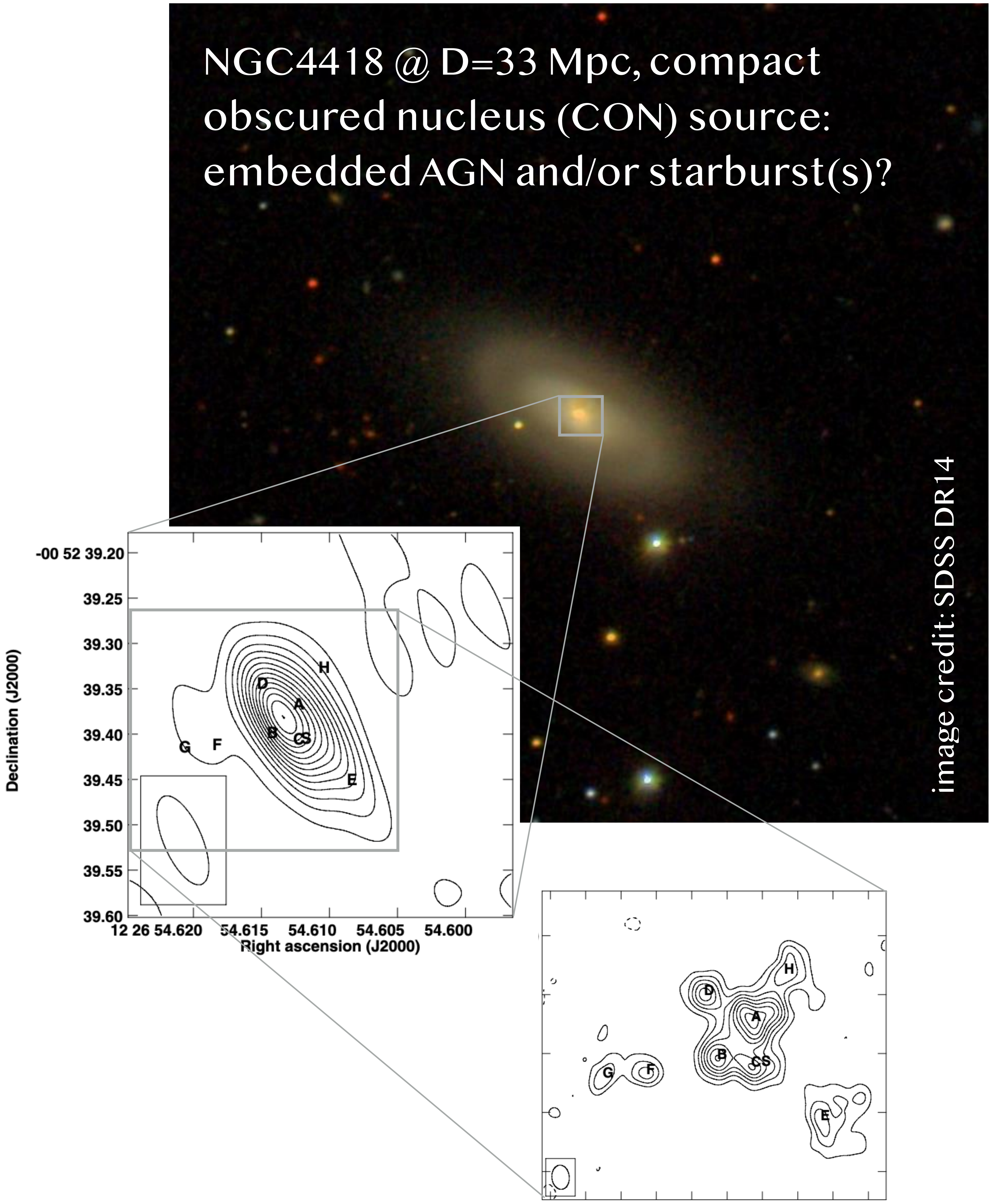
- strategic planning and governance,
- international relations,
- sustainability (e.g., dark & quiet skies), diversity, equity, and inclusion, and
- communication, outreach, and publishing
- joint meetings (e.g., “CS[3] - Coordinated Southern Sky Surveys”)
- Data archives & archival science

OBSERVATORY LANDSCAPE 2020-2040

New facility/instrument additions and upgrades

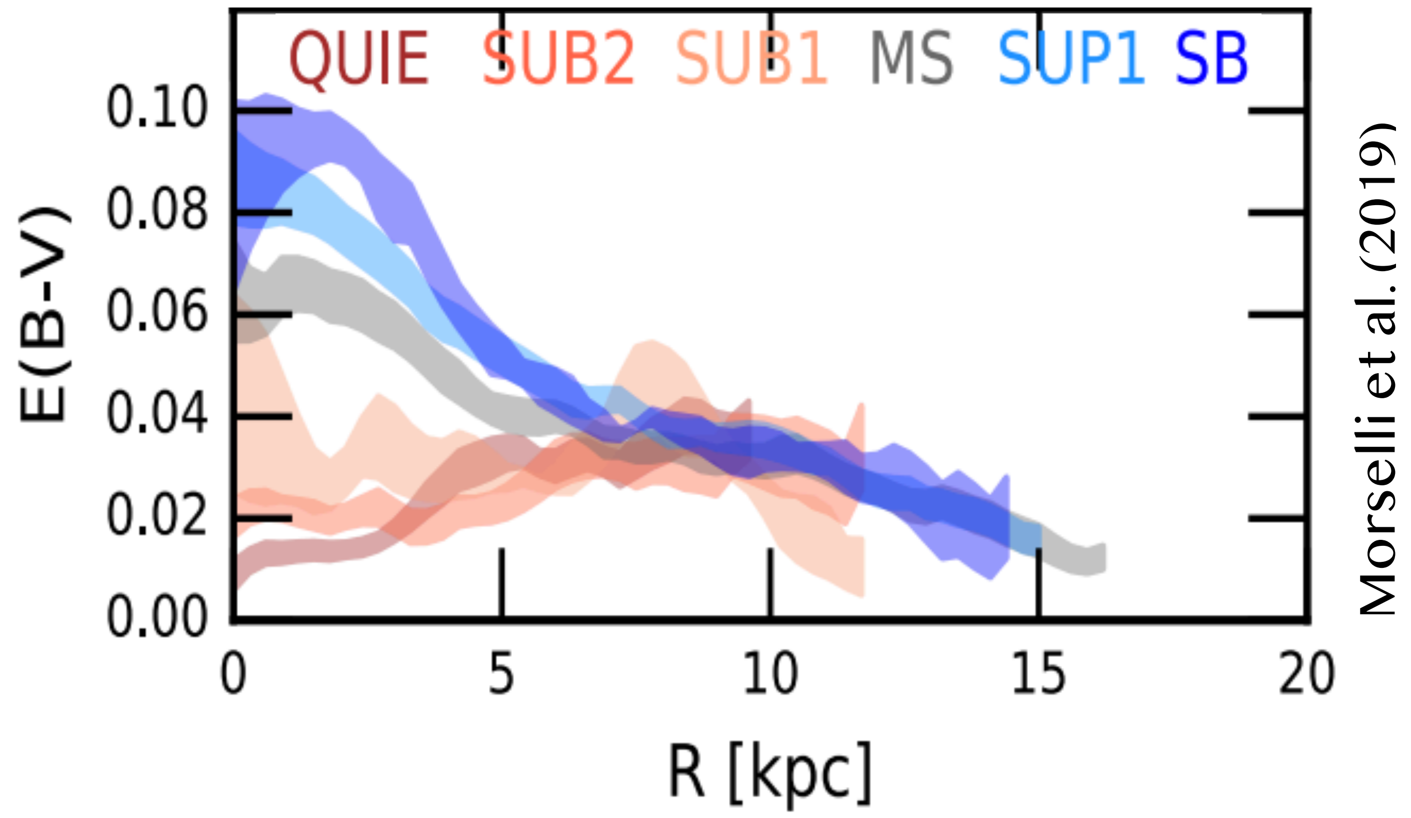
NUCLEAR ACTIVITY IS OFTEN ESP. OBSCURED

Processes in dusty galaxy centres are highly consequential for galaxy evolution

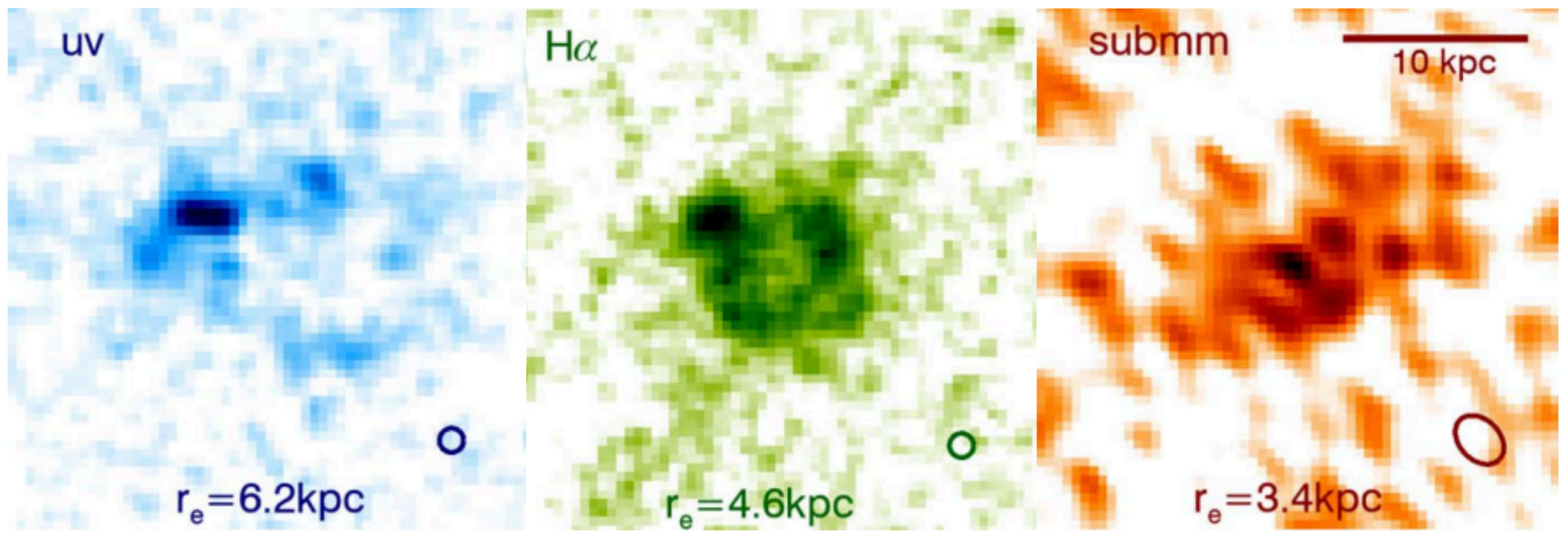


Varenius et al. (2014)

Dust-reddening in active z~1 galaxies is on average strongest in galaxy centres.



Dust-obscured bulge growth in a z~1.3 M31 progenitor:



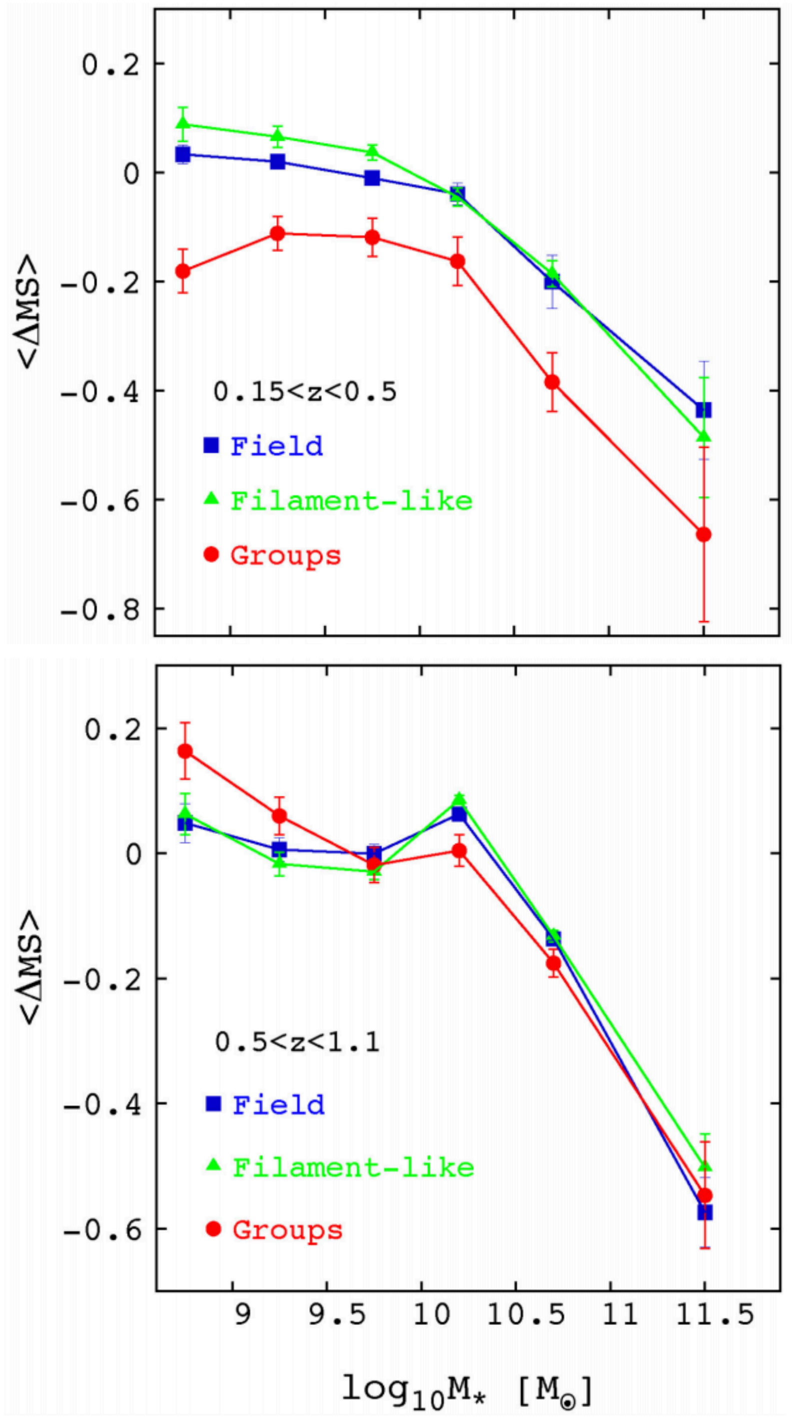
Nelson et al. (2019)

COSMIC (STELLAR) MASS ASSEMBLY

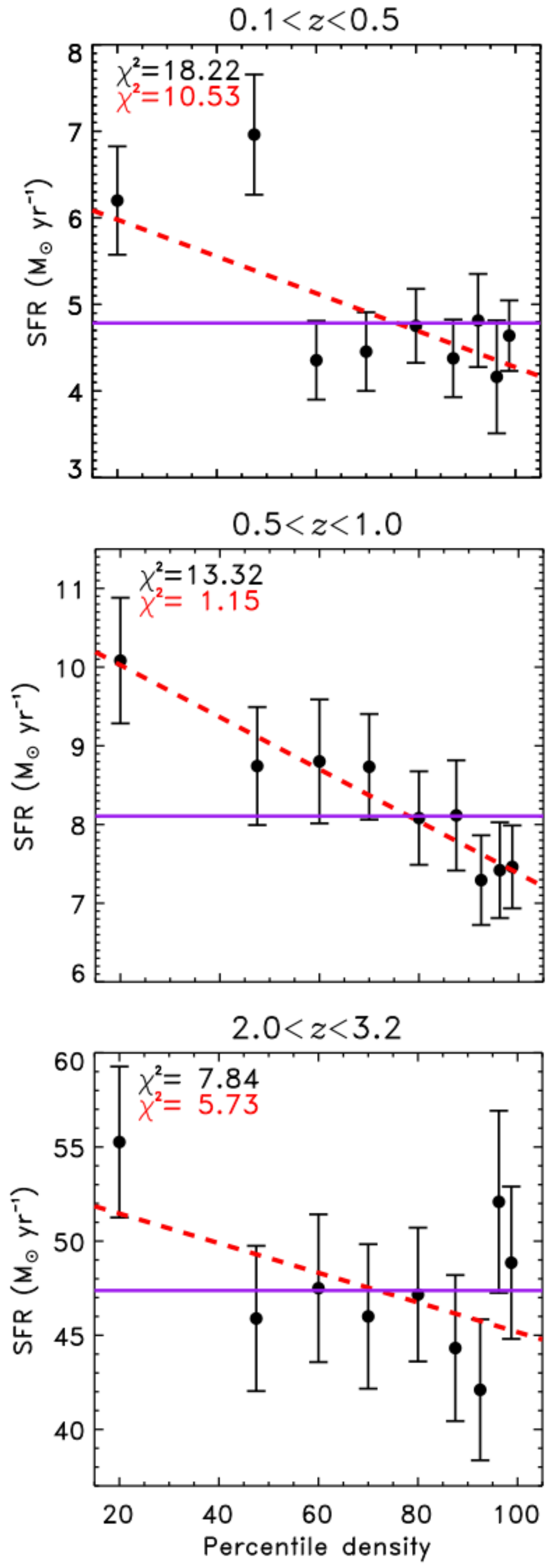
The impact of environment

Example: Different findings re. environment-dependent shape of the galaxy main sequence (MS) in the COSMOS field, depending on details of selection, data used, etc.:

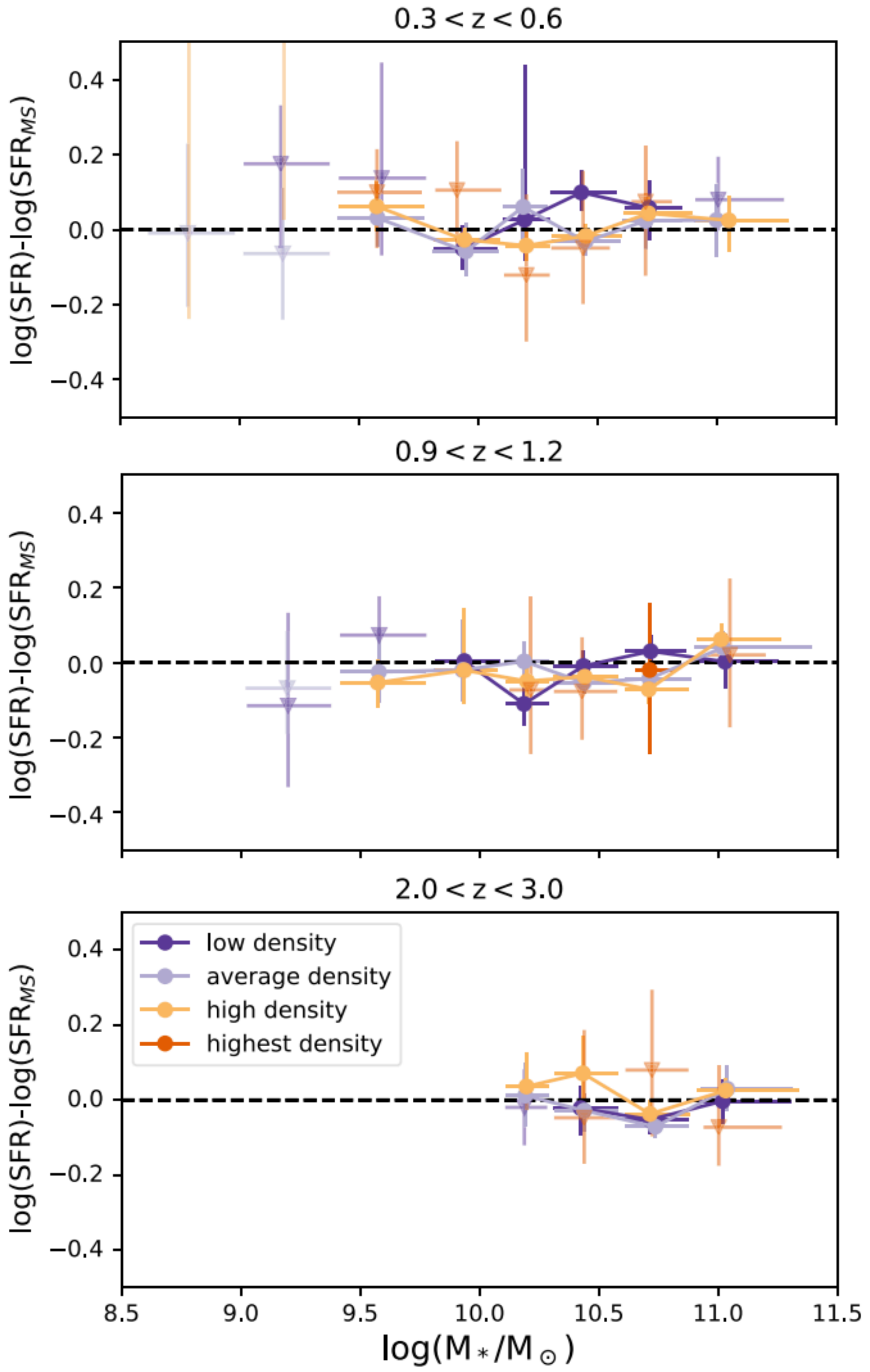
Shape/normalization of MS depends on environment at low redshift (Erfanianfar et al. 2016):



Shape/normalization of MS depends on environment at all redshifts (Duivenvoorden et al. 2016):



Shape/normalization of MS does not depend on environment at any redshift (Leslie et al. 2020):



PHOTOMETRY & SPECTROSCOPY IN SKA FIELDS

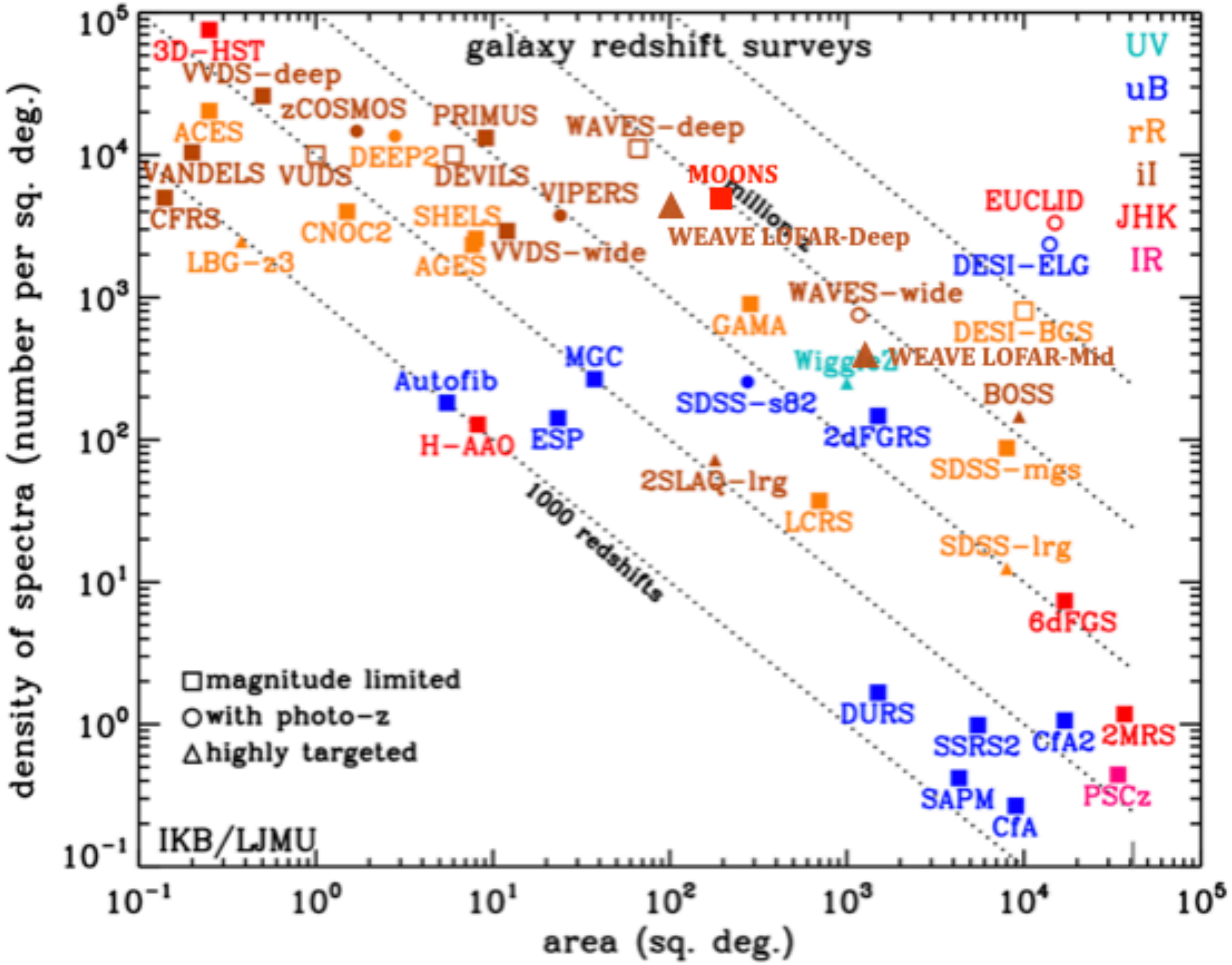
Spectroscopy: redshifts, activity diagnostics, environment & physical properties

Optical/near-IR spectroscopy provides:

- redshifts & environment characterisation
- AGN-SF separation (BPT or MEx)
- physical properties (metallicity, stellar pop. properties, SFR, …)

SKA1 surveys must aim for overlap with optical and near-IR MOS surveys (e.g., 4MOST, MOONS, DESI, …), with the ideal pairings depending on depth/source density and wavelength range covered.

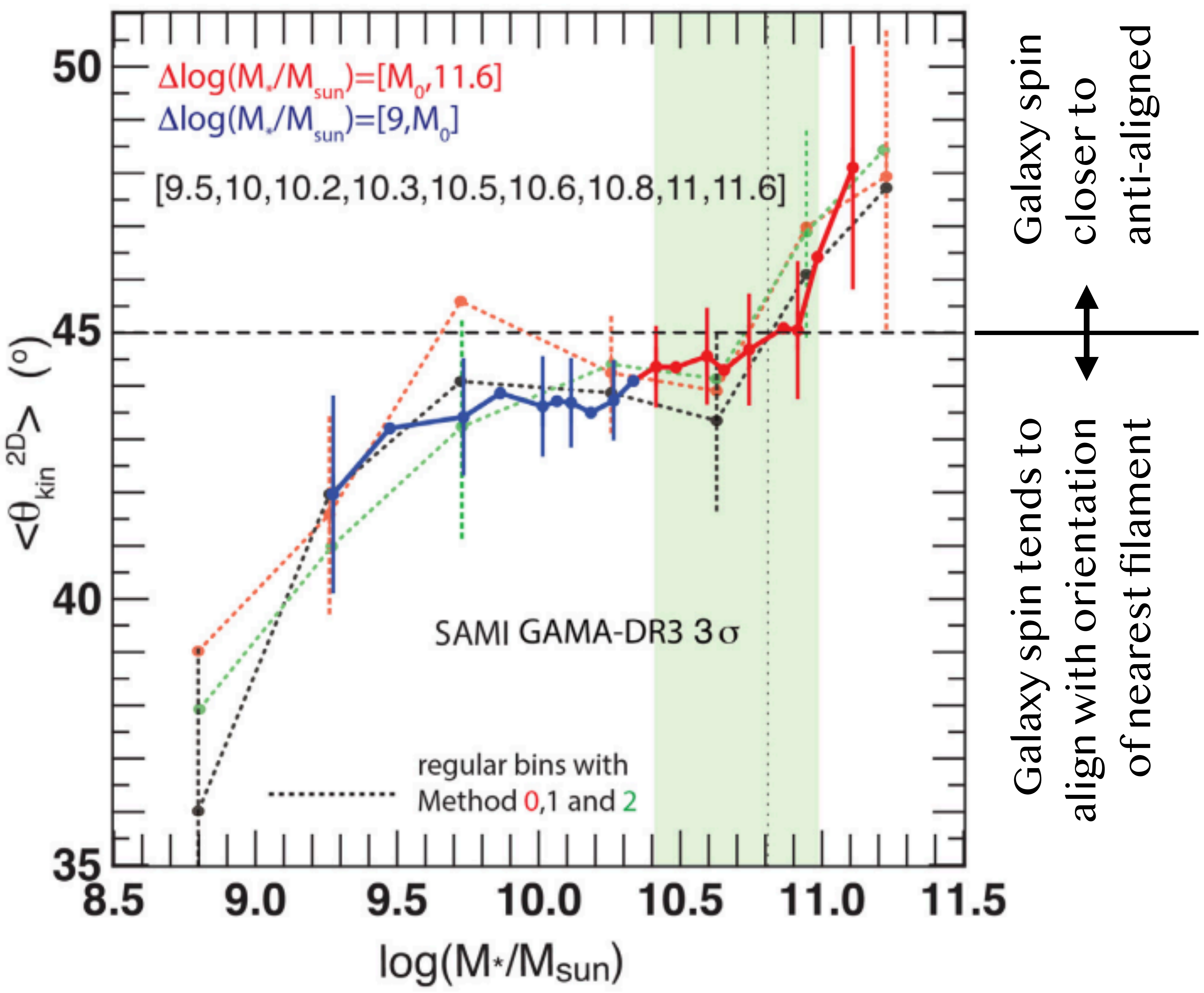
Also: far-IR and sub-mm spectroscopy - e.g. C+ or CO - with ALMA, AtLAST, …



adopted from I. Baldry (w/ a few modifications)

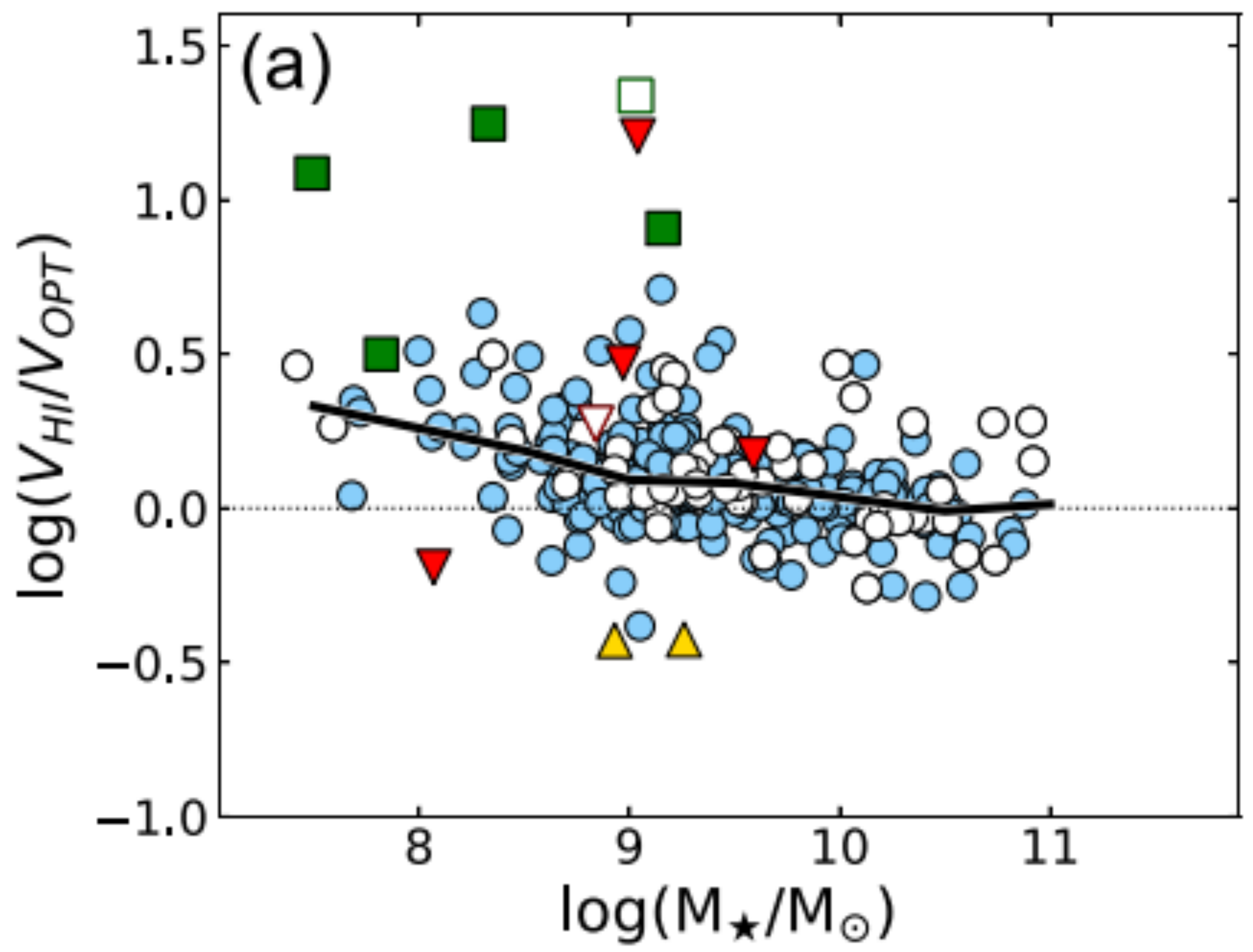
GALAXY EVOLUTION WITHIN THE COSMIC WEB SINCE $z \sim 1$

Do galaxies preserve the imprint of gas feeding from the web? How best to uncover links in a multiphase ISM?



Welker et al. (2020)

Interpreted as the result of spin randomisation during mergers that "build" high-mass galaxies, but: multi-phase gas and stellar tracers can have different kinematics…



Catinella et al. (2023)

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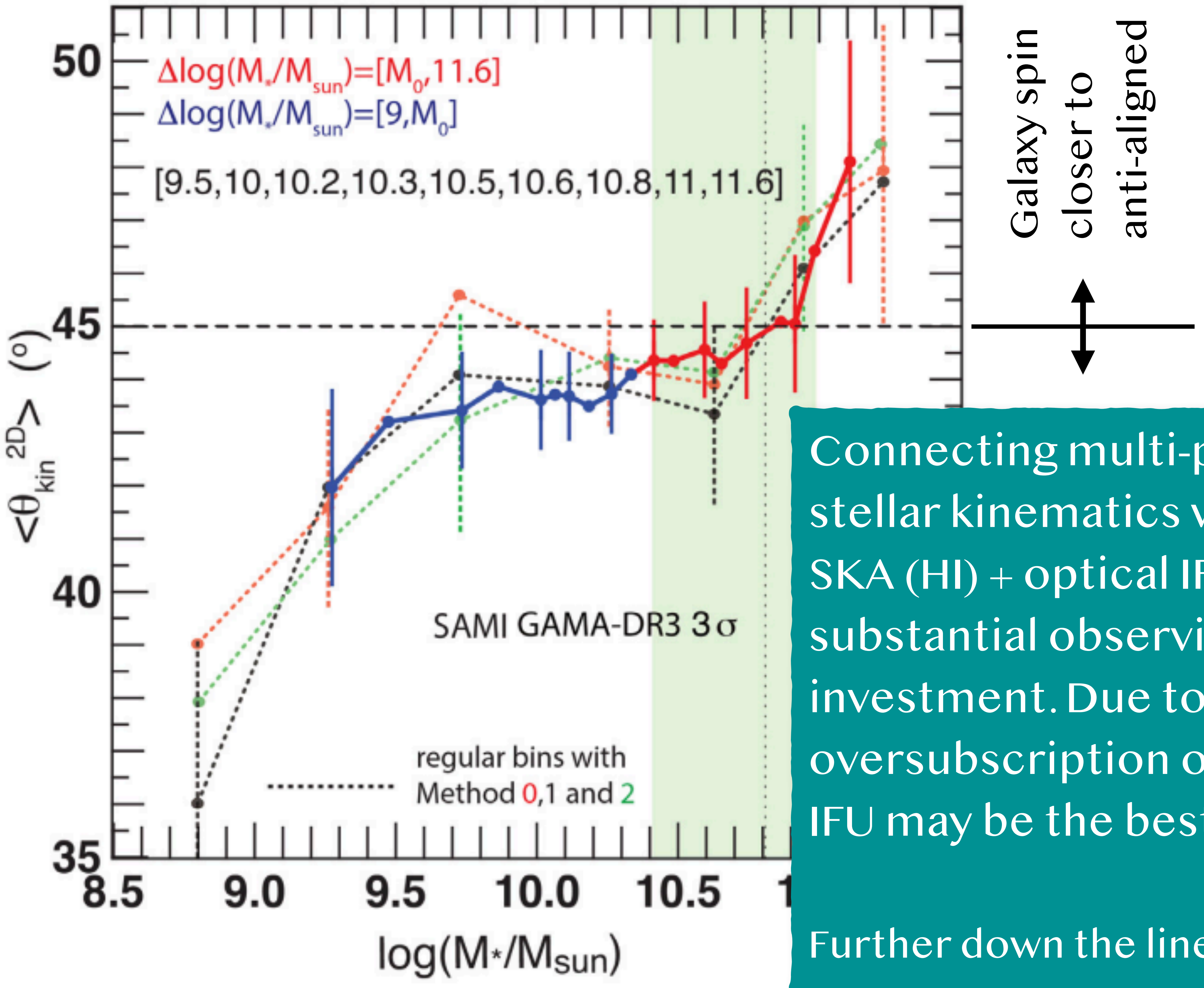

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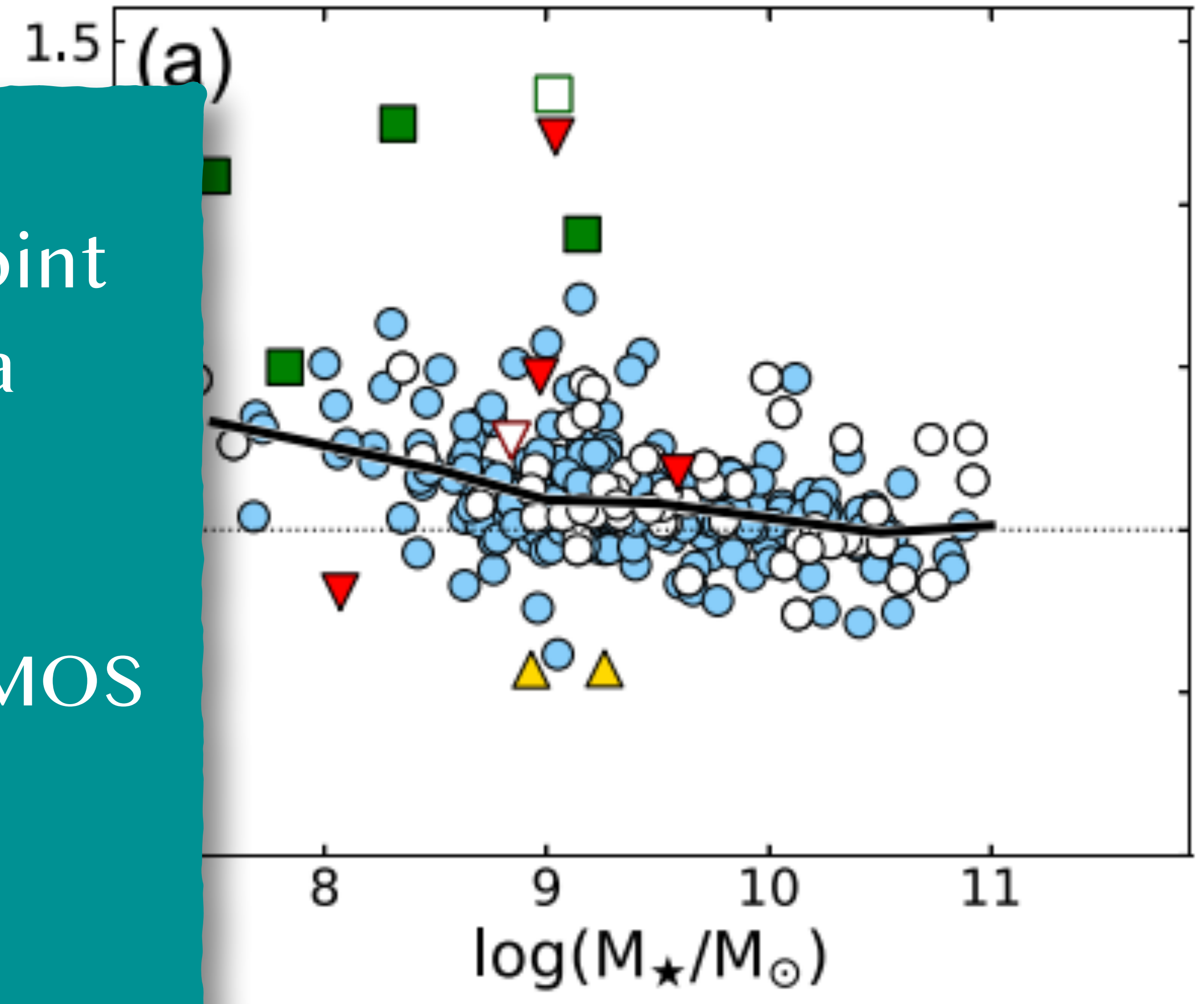


Catinella et al. (2023)

Connecting multi-phase gas and stellar kinematics will require a joint SKA (HI) + optical IFU effort with a substantial observing time investment. Due to the high oversubscription of MUSE, the KMOS IFU may be the best choice.

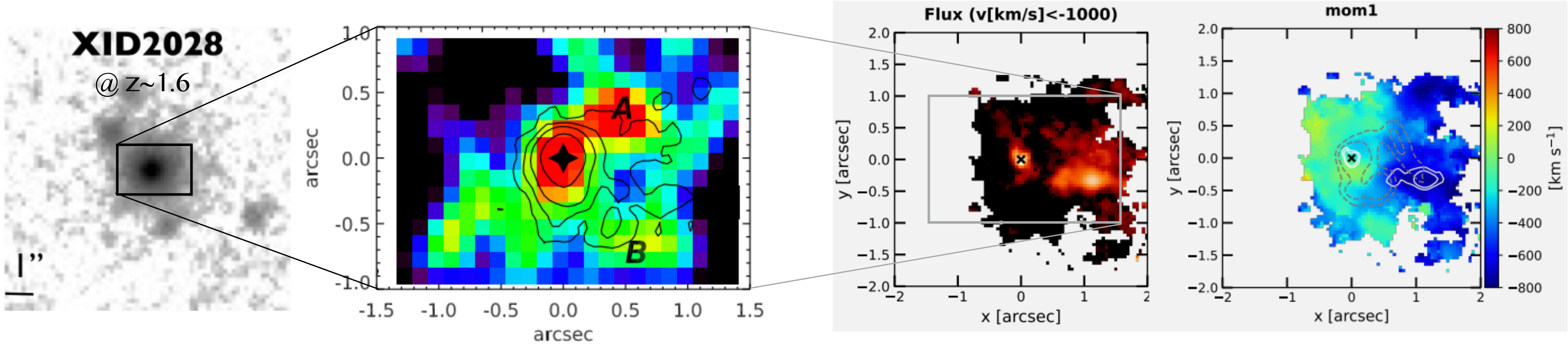
Further down the line: WST…?

GALAXY - SMBH CO-EVOLUTION STUDIES

Feedback astrophysics & galaxy structural evolution at high resolution

Positive and negative feedback (via bubble & outflows) in an obscured quasar at cosmic noon:

Perna et al. (2015), Cresci et al. (2023)

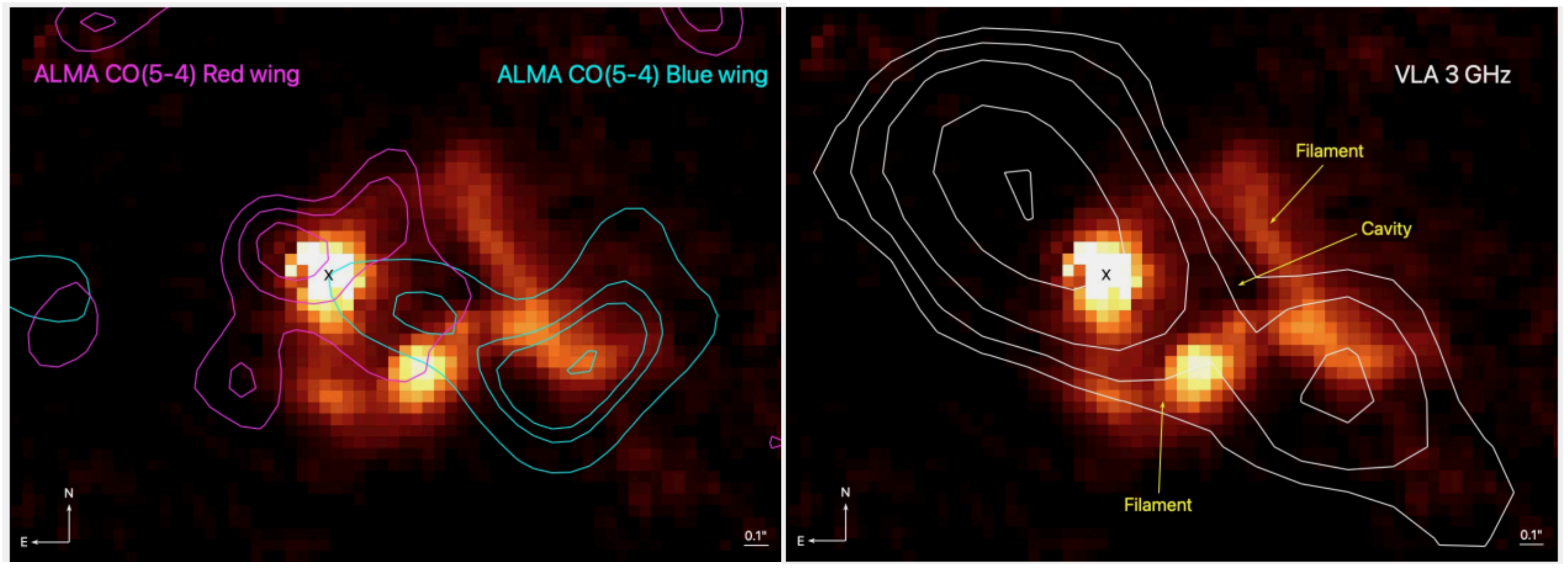


H-band

Hα (SINFONI) + UV (HST)

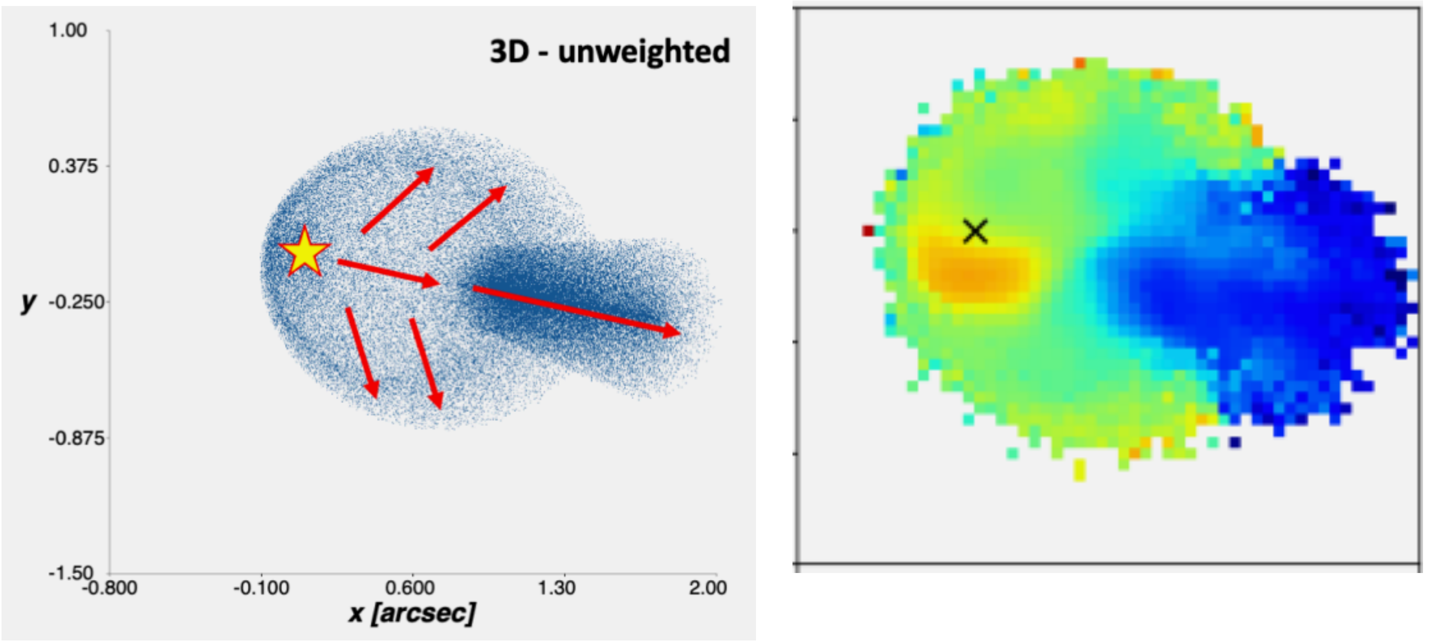
JWST/NIRSpec [OIII]

Cresci et al. (2023)



[OIII] + CO[5-4] (ALMA)

[OIII] + JVLA 3 GHz



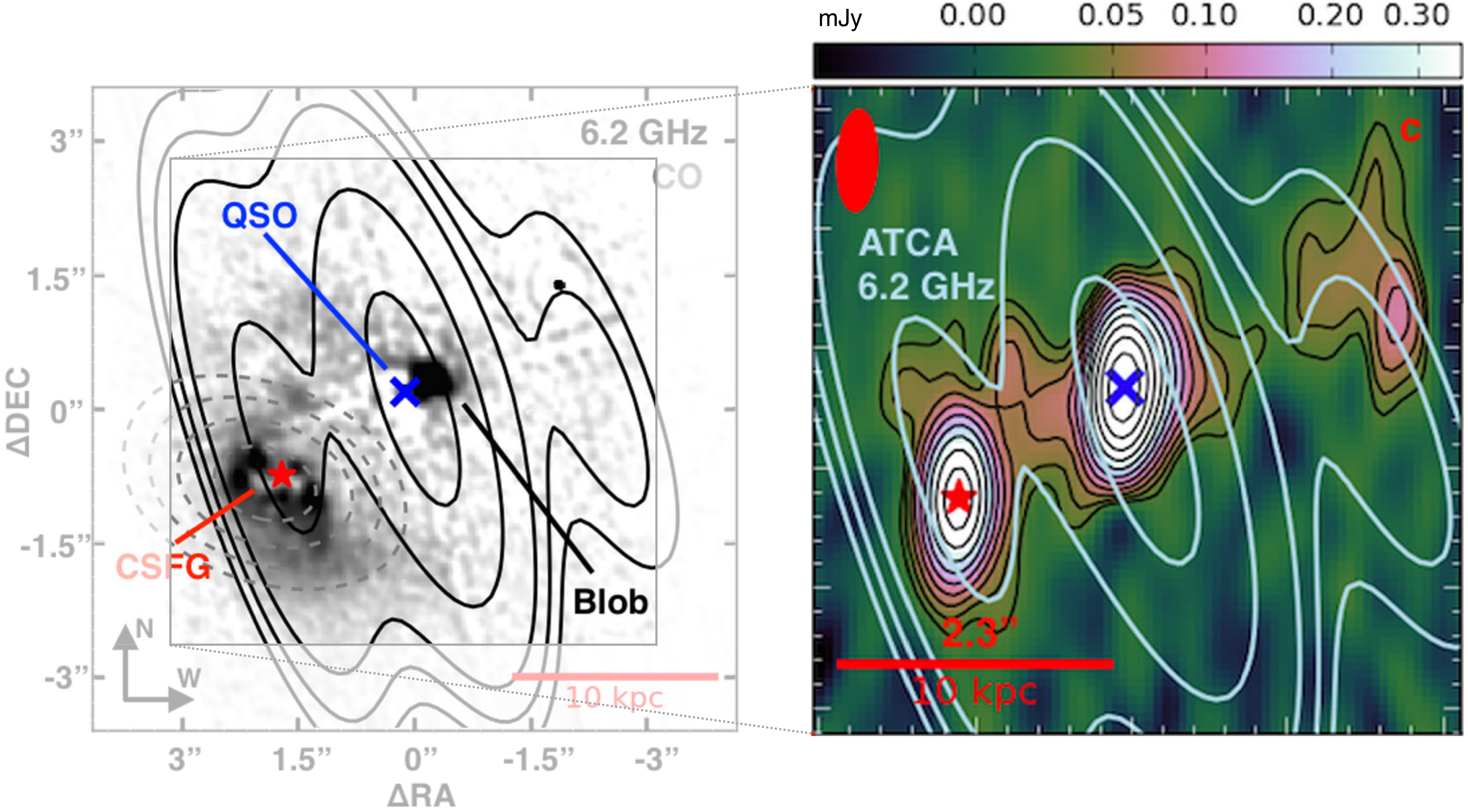
model

Cresci et al. (2023)

High-res and multi-tracer observations are essential for a detailed understanding of the feedback process (here: multi-phase outflow with ~150 M$_\odot$/yr, depletion time of ~30 Myr).

GALAXY - SMBH CO-EVOLUTION STUDIES

Identifying & studying labs for "exotic" feedback constellations



Molnár et al. (2017)

Quick facts on HE0450:

- QSO & starburst (CSFG) pair separated by ~7 kpc
- asymmetrically distributed gas: cold gas in CSFG, blob of AGN-ionized gas beside QSO

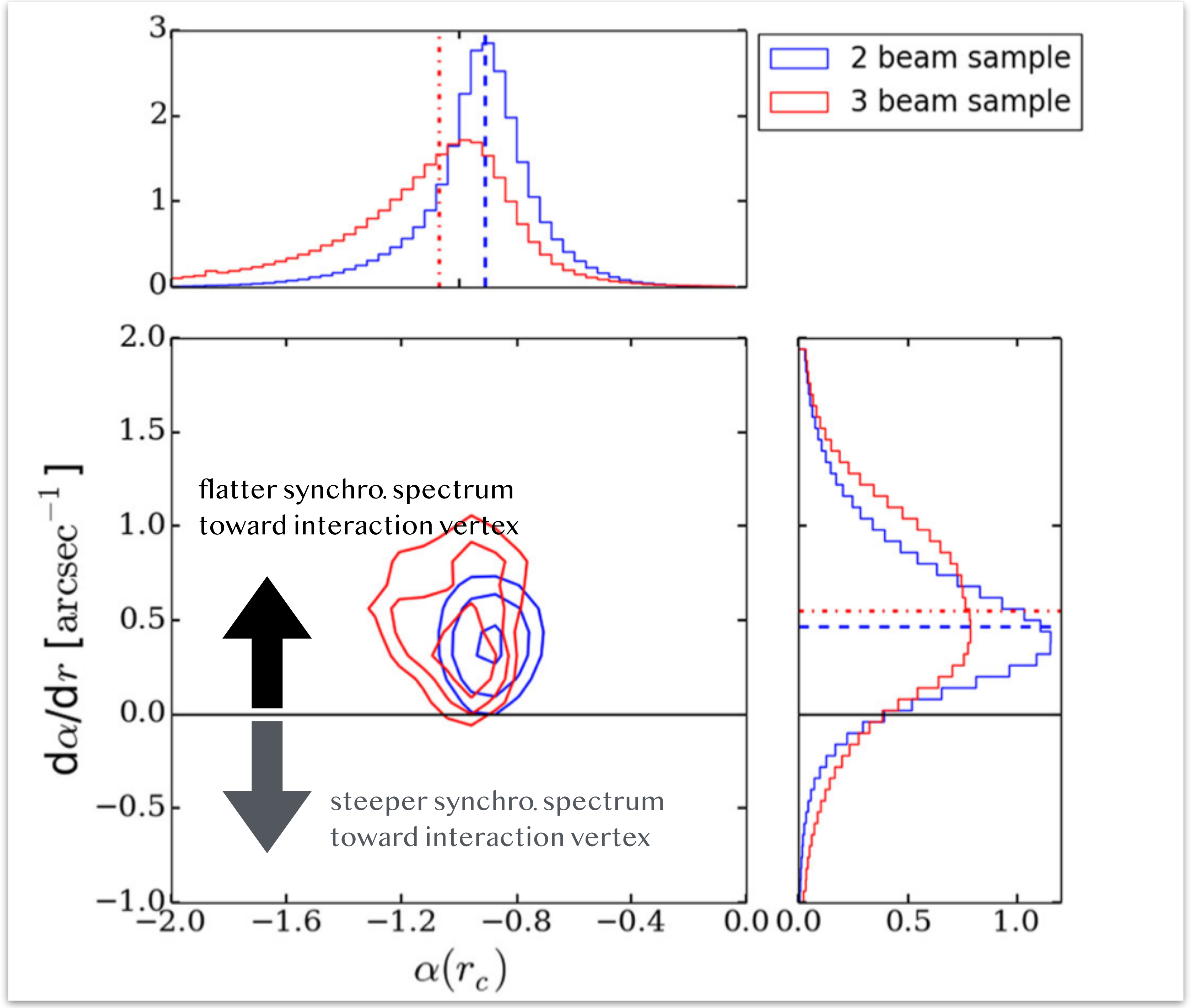
GALAXY - SMBH CO-EVOLUTION STUDIES

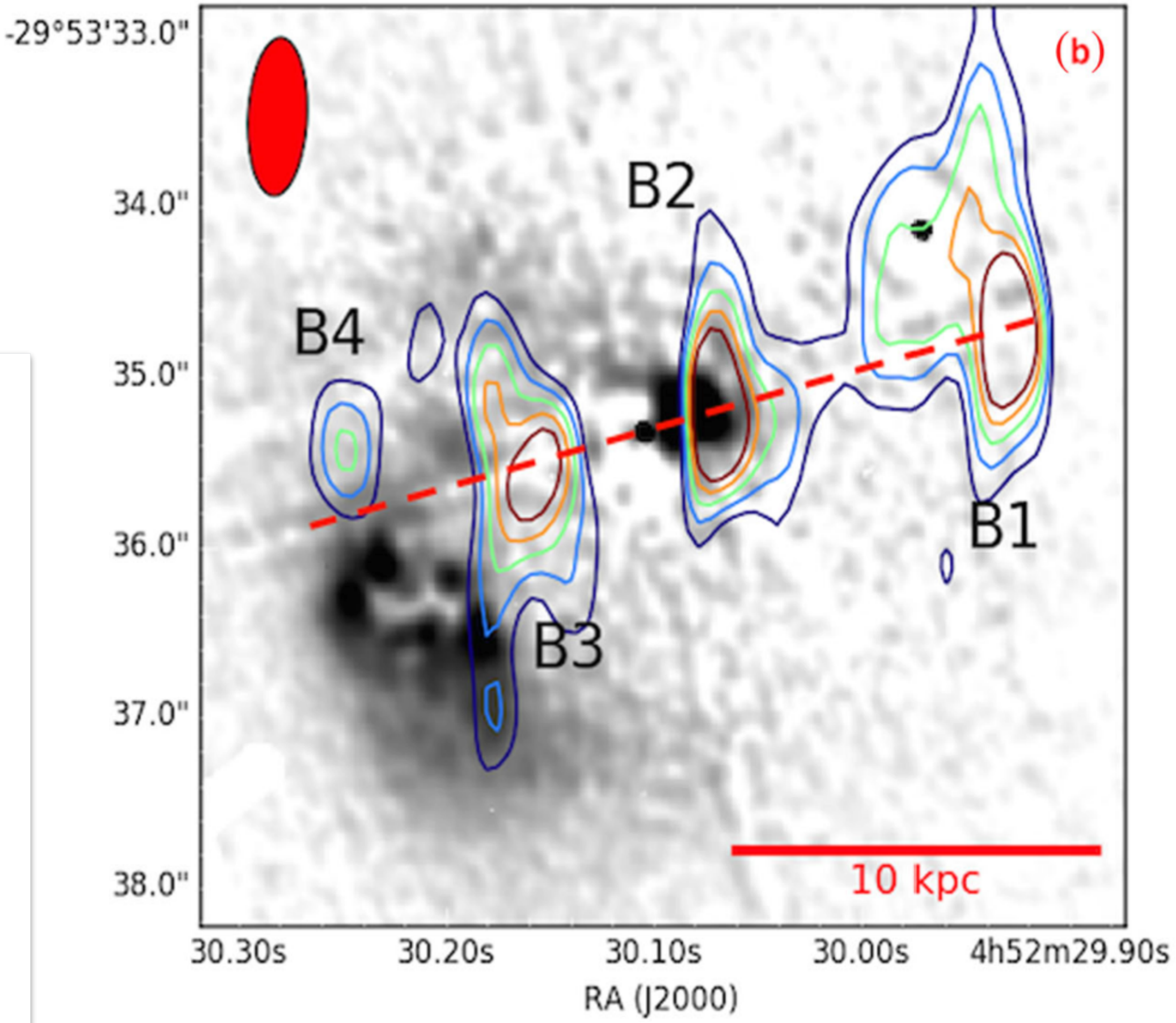
Identifying & studying labs for “exotic” feedback constellations

QSO outflow/jet axis is aligned with northern quadrant…

… and a flatter radio spectral index in this region hints at a younger e- population.

(Caused by jet-ISM interaction? Leads to jet-induced SF)





VLT-VIMOS IFS revealed the presence of shocked gas in the northern half of the companion SFG. (Letawe et al. 2008)

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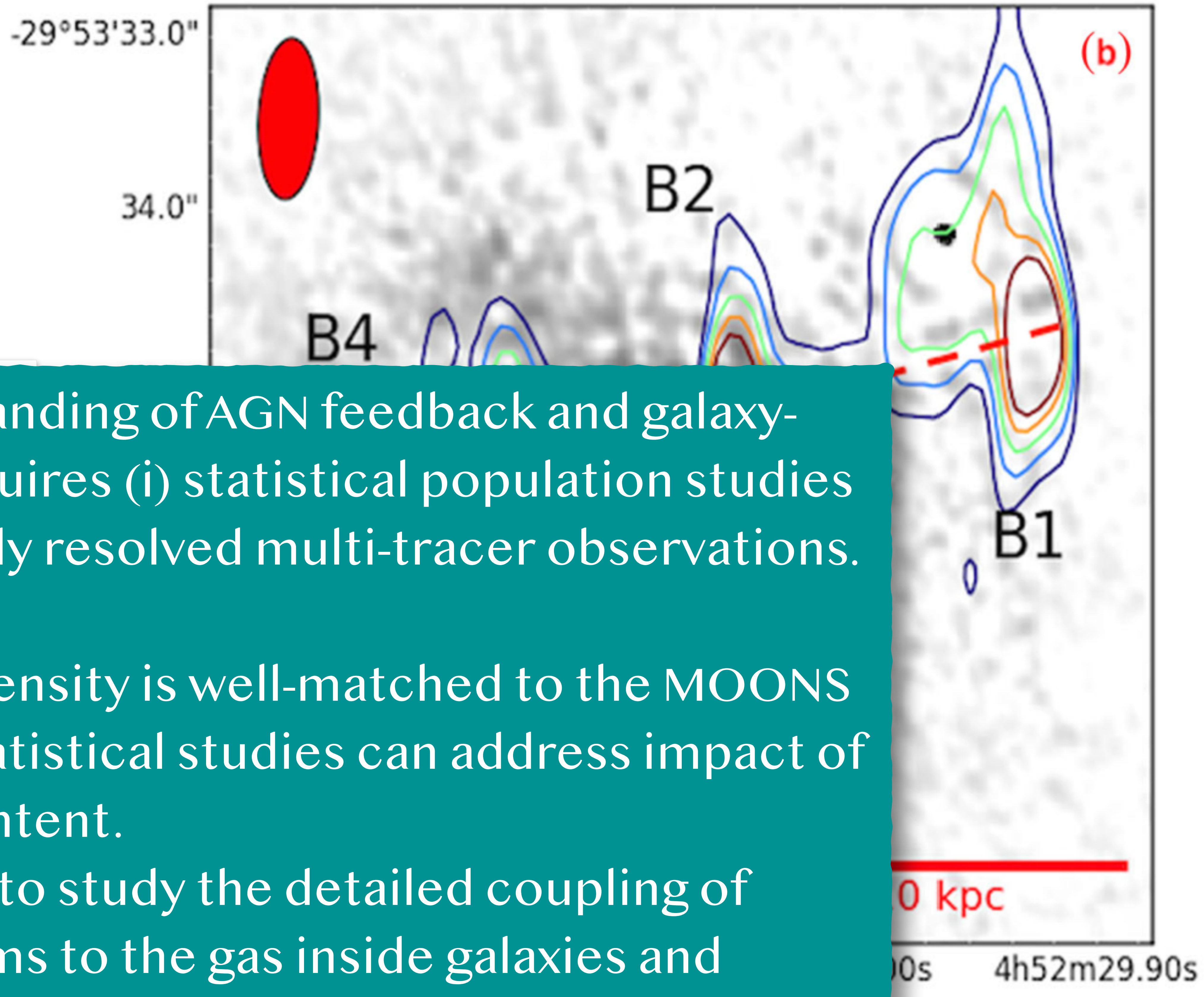
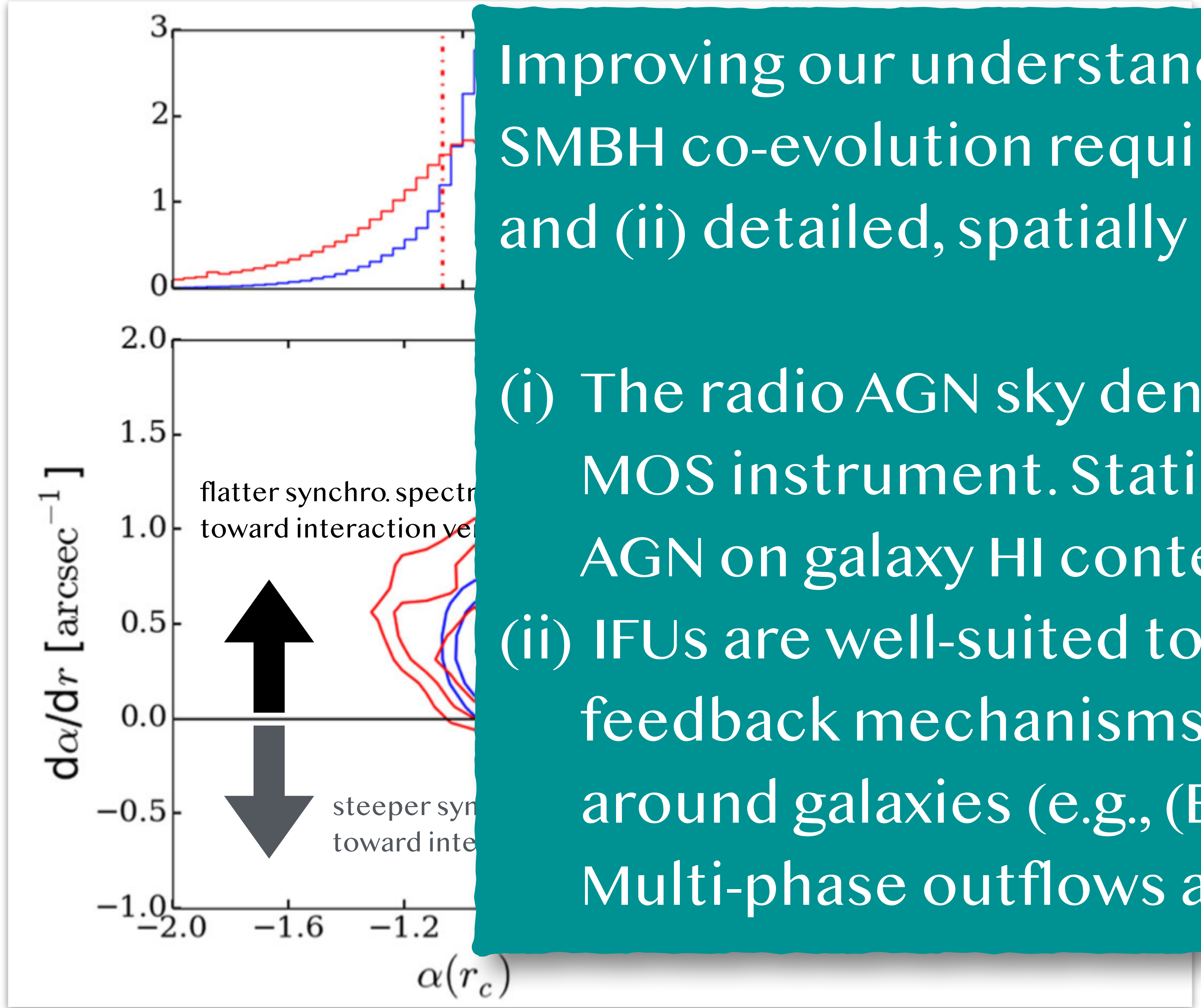




Improving our understanding of AGN feedback and galaxy-SMBH co-evolution requires (i) statistical population studies and (ii) detailed, spatially resolved multi-tracer observations.

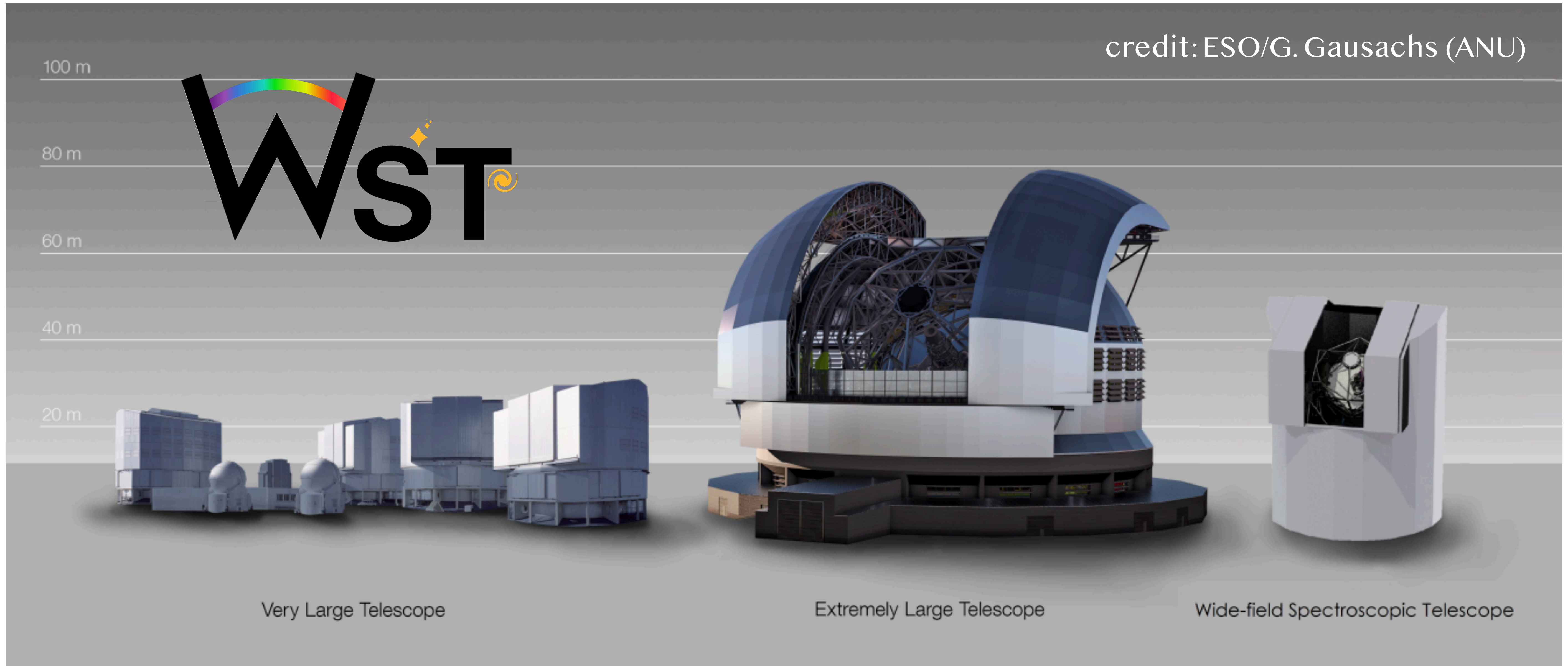
(i) The radio AGN sky density is well-matched to the MOONS MOS instrument. Statistical studies can address impact of AGN on galaxy HI content.

(ii) IFUs are well-suited to study the detailed coupling of feedback mechanisms to the gas inside galaxies and around galaxies (e.g., (Blue)MUSE, ERIS, w/ ELT HARMONI) . Multi-phase outflows also require ALMA follow-up.

…resence of shocked gas in the northern half of the companion SFG. (Letawe et al. 2008)

LONG-TERM FUTURE (MID-2030+)

AtLAST & WST



Wide-field Spectroscopic Telescope

~10 m optical telescope capable of doing simultaneous MOS (~20k objects over 2.5-5 deg^2) and IFU observations (~ 3x3 $arcmin^2$). Possible upgrade to NIR band.

credit: AtLAST consortium

Atacama Larg-Aperture Submillimetre Telescope

50m single-dish sub-mm telescope (35-950 GHz; 10-0.35 mm) for continuum & spectroscopy. Field-of-view ~3 deg^2.

ATLAST-SKA SYNERGIES

Cold gas and dust-obscured galaxy activity through cosmic time

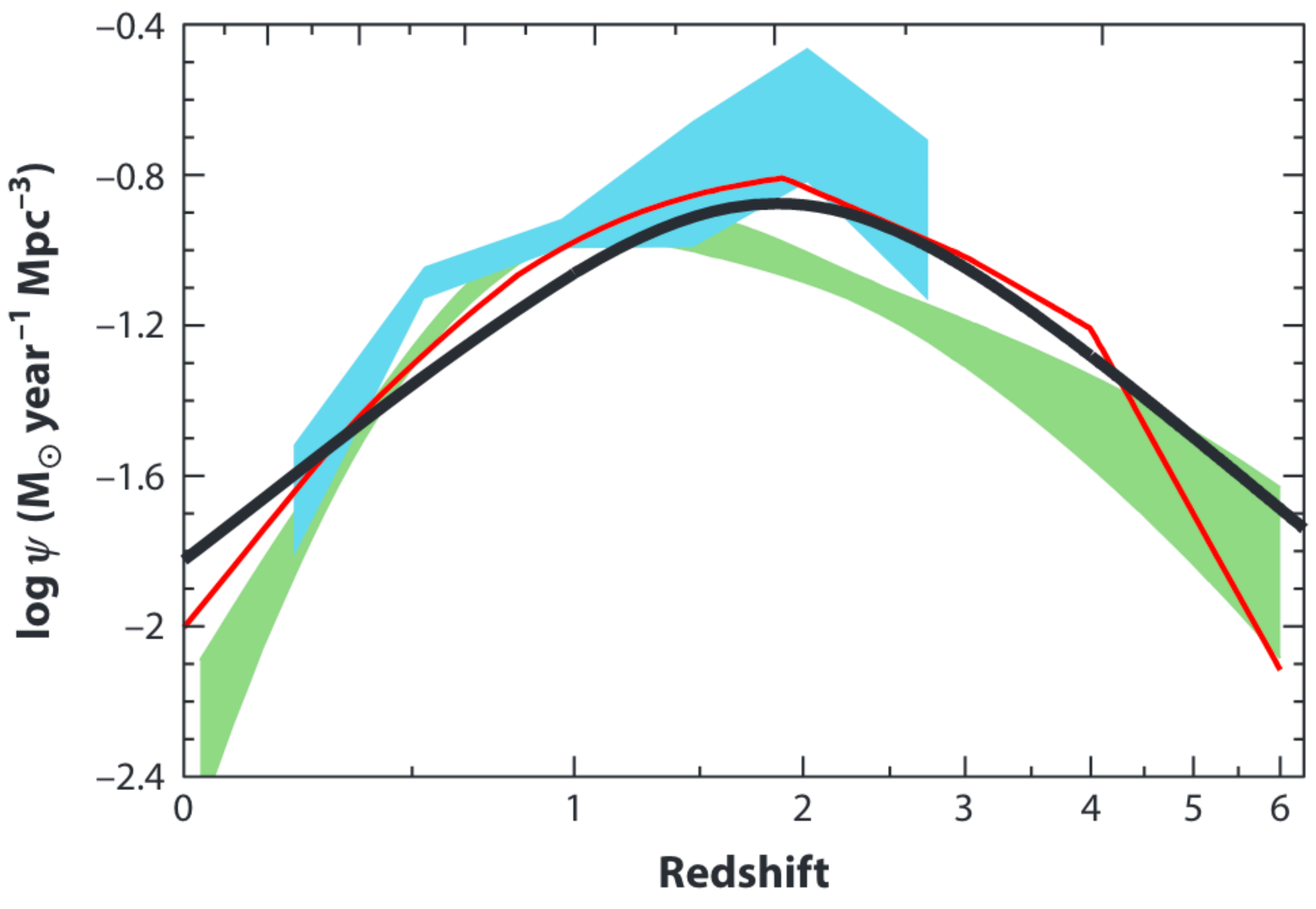
- Sub-mm galaxies in high-z proto-clusters: Feedback (radio-AGN!) and star-formation in future BCG at their formation epoch.
- Total gas budget (atomic + molecular) for HI-detected galaxies in SKA fields.
- Alternative tracers of molecular gas at the highest redshifts: constraints on the SFE of EoR galaxies
- Gas excitation studies for EoR galaxies
- Galaxy SEDs from the synchrotron (100-1000s MHz), over the free-free (10s GHz) and dust-dominated regime (up to ~1 THz)

WST-SKA SYNERGY EXAMPLE

Cosmic evolution of radio-AGN feedback: Contribution of passive vs. active (=star-forming) galaxies

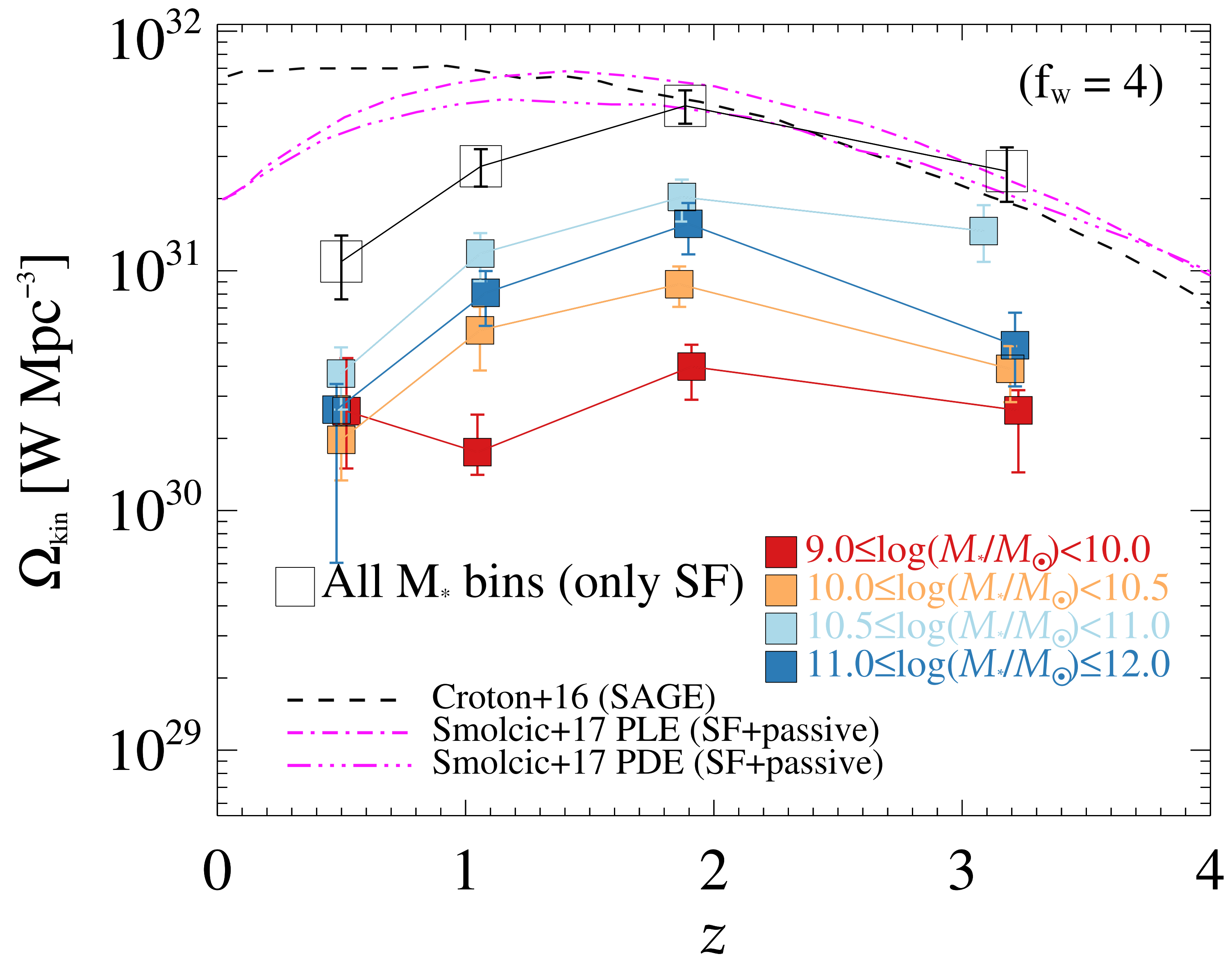
Passive galaxies host the bulk of radio AGN feedback at z < 1, actively SF galaxies do so at z > 1.5.

Evolution of cosmic star-formation rate and SMBH accretion rate density:



Madau & Dickinson (2014)

Evolution of cosmic kinetic AGN luminosity density (radio jet-driven AGN feedback):



Delvecchio et al. (2022)

=> WST will detect the D4000 break & absorption lines to z~1.4 for a red cut-off @ 970nm.

Summary & Recommendations I

1. Photometric information for SKA extragalactic fields is likely to be mostly derived from VRO/LSST, Euclid, etc. ESO will contribute essential spectroscopic facilities (but also sub-mm photometry - ALMA or ultimately AtLAST).
2. Important to ensure prompt scientific exploitation of SKA surveys. Avoid long follow-up campaigns; spectroscopy is often the bottleneck.
3. Two time scales for SKA/ESO community synergies: the medium term with new ESO surveys to carry out follow-up of SKA precursor projects, and the longer term where ESO facilities will support SKA survey efforts (and vice versa).
4. Running optical spectroscopy surveys ahead of/in parallel with SKA will ease host galaxy identification and classification process; allow immediate measurements of physical parameters, get information on the wider environment of the radio sources
5. Optical spectroscopy is important complement to HI (different selection function) and allows HI stacking.

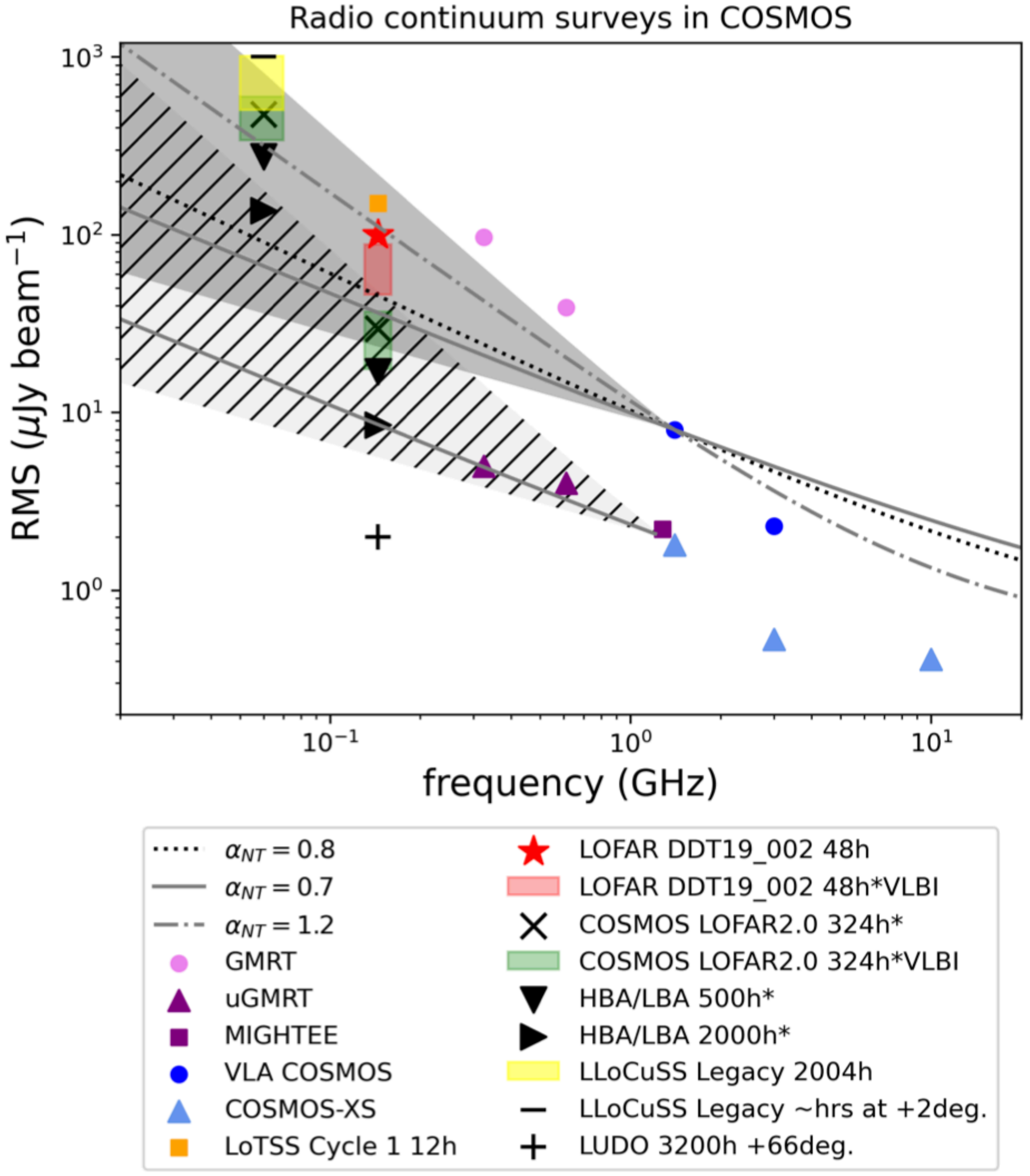
Summary & Recommendations II

6. Time to start thinking about spectroscopic surveys is now. Should aim to start in a couple of years' time.
7. Some ESO instruments may be well placed to play a key role, e.g., KMOS (via public survey call?) or 4MOST (2nd generation surveys).
8. Dedicated spectroscopic facility could strengthen SKA exploitation. Dedicate a VLT UT to surveys (e.g., MUSE, MOONS) or build a dedicated 8-10m class survey telescope like WST.
9. Essential to prepare infrastructure for analysis and interpretation. (Requires co-location of data in some cases - within scope of SRCs?) It is important to build interfaces that allow quantitative scientific analysis (not only high-level visualization).
10. Need to coordinate not just ESO/SKAO but also VRO-LSST, Euclid and other major survey datasets. Community/political efforts needed to ensure coordination (and funding!) of aggregated datasets and archival/analytic infrastructure.

2 ADVERTISEMENTS

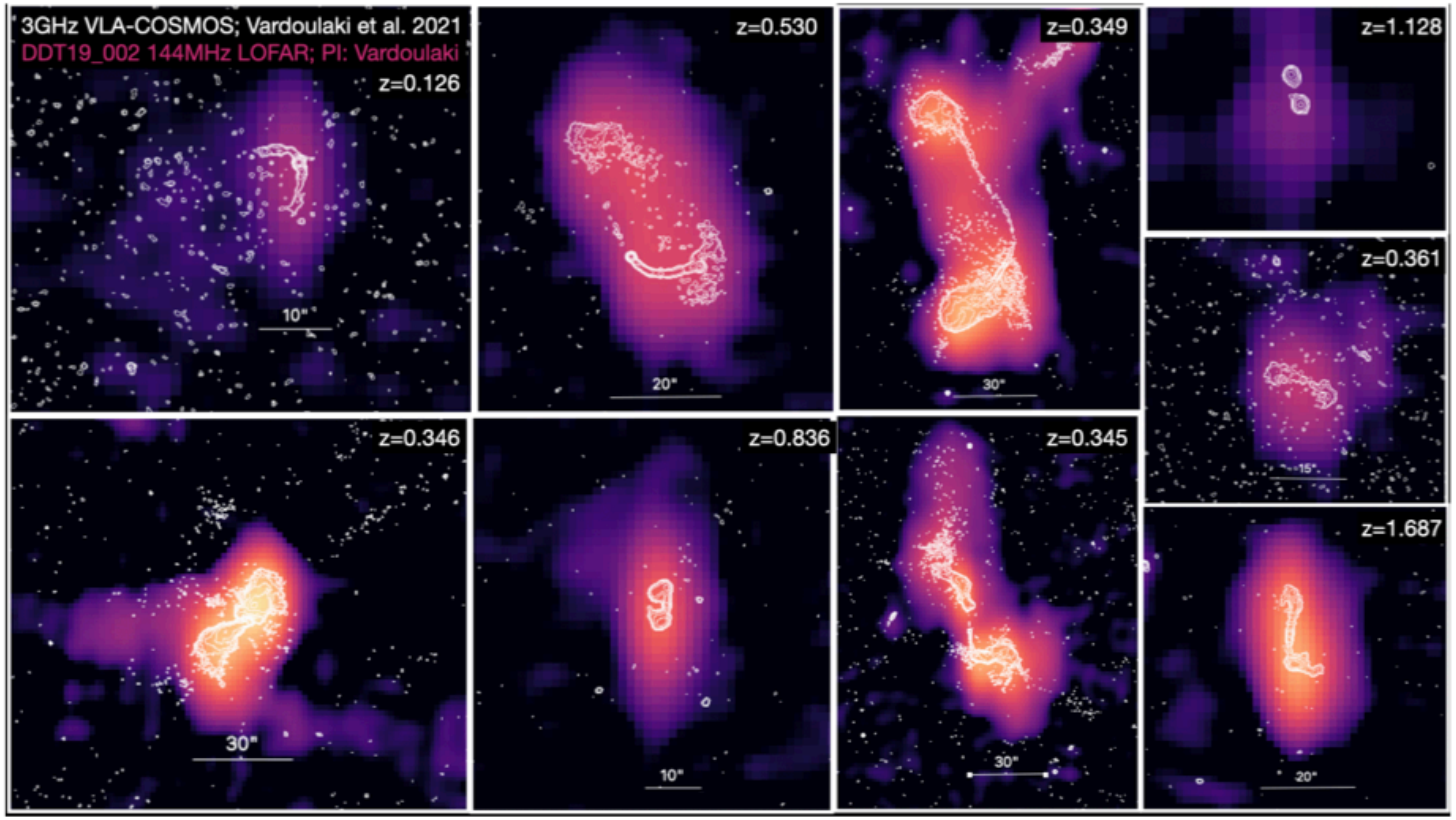
NEW, DEEPER LOFAR DATA FOR THE COSMOS FIELD

Imaging of international baseline data on CSCS



CSCS
Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

Expect: 20x better resolution (new: 0.3”), 2x better sensibility than NL-only image.



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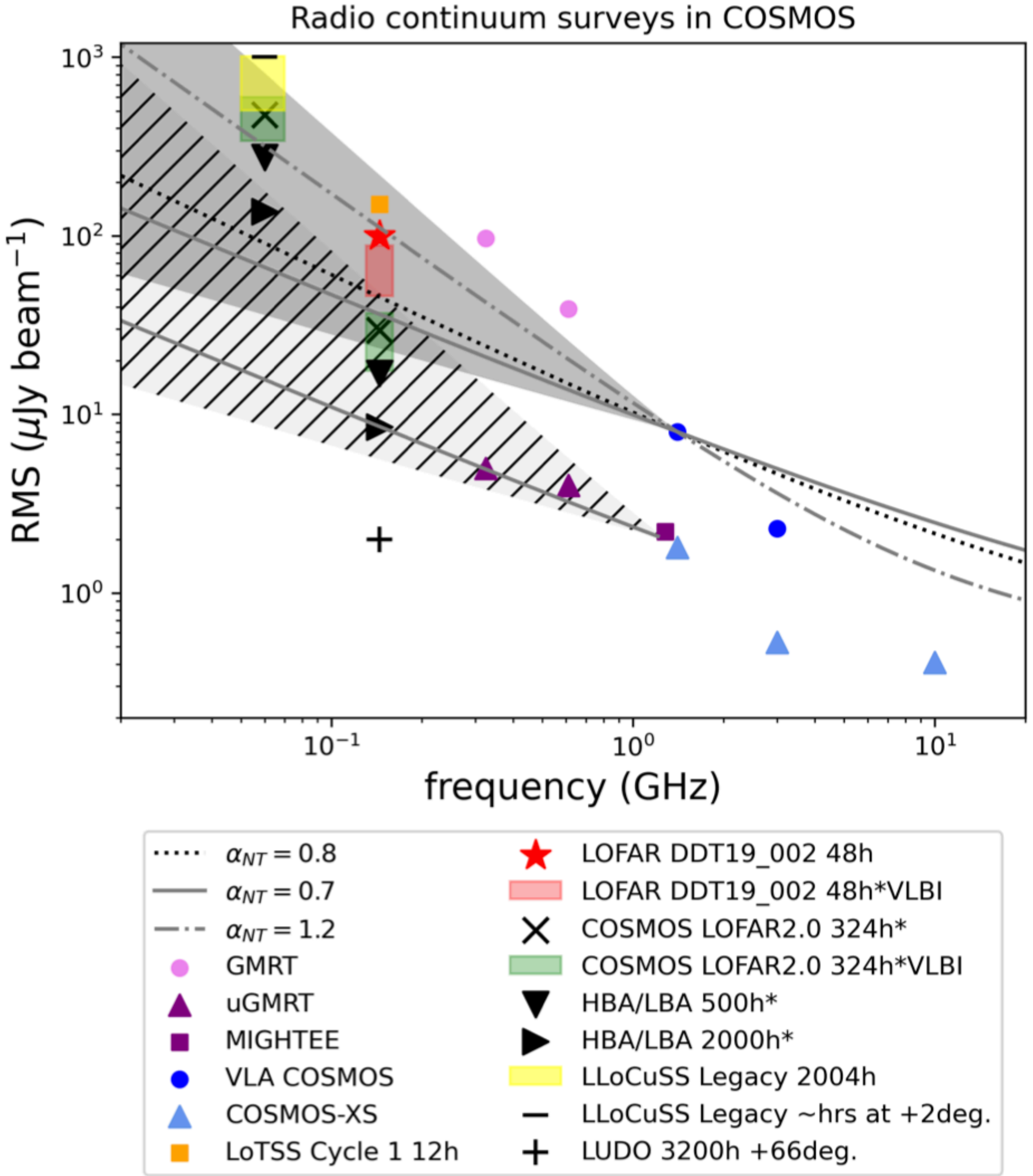
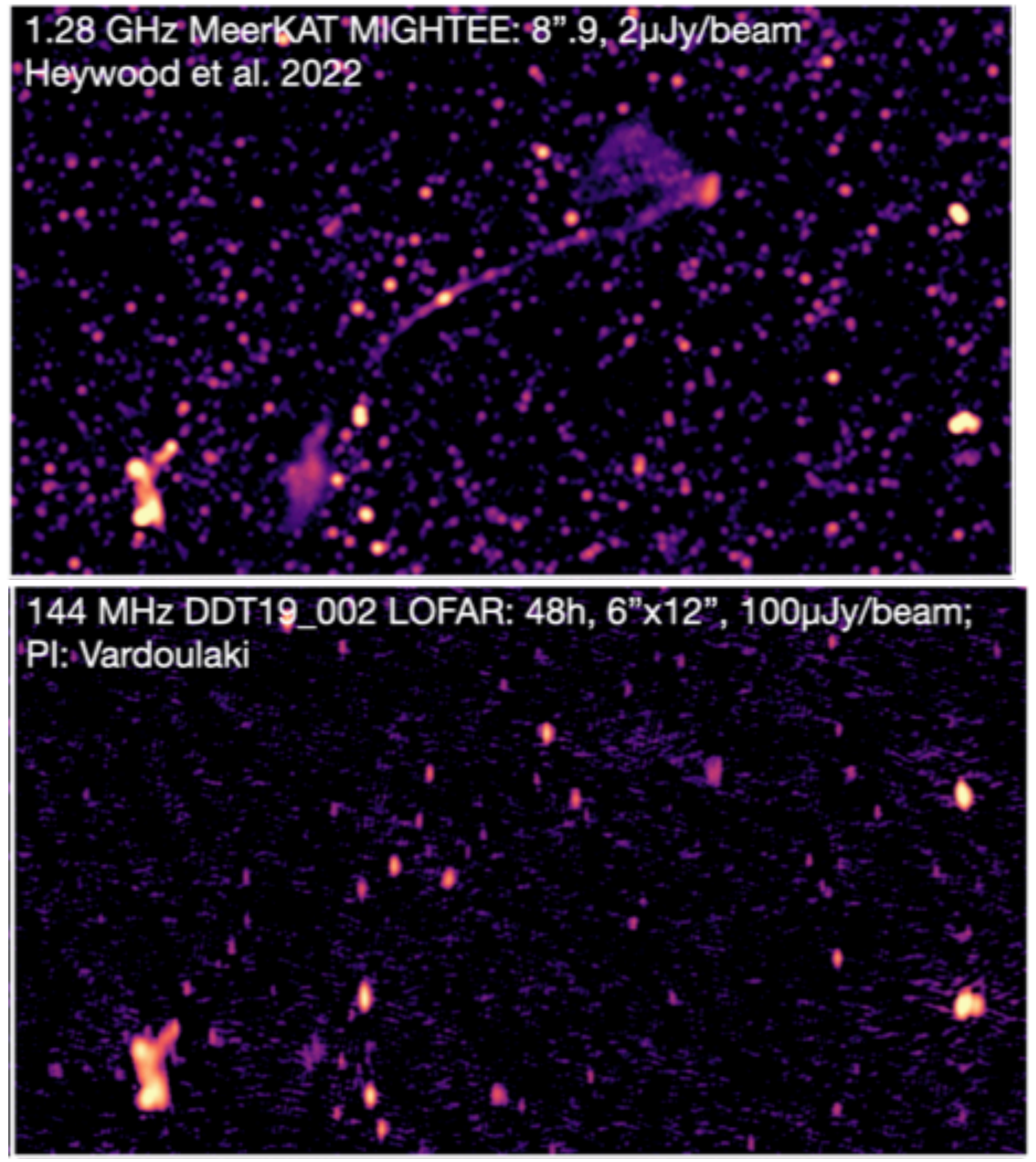
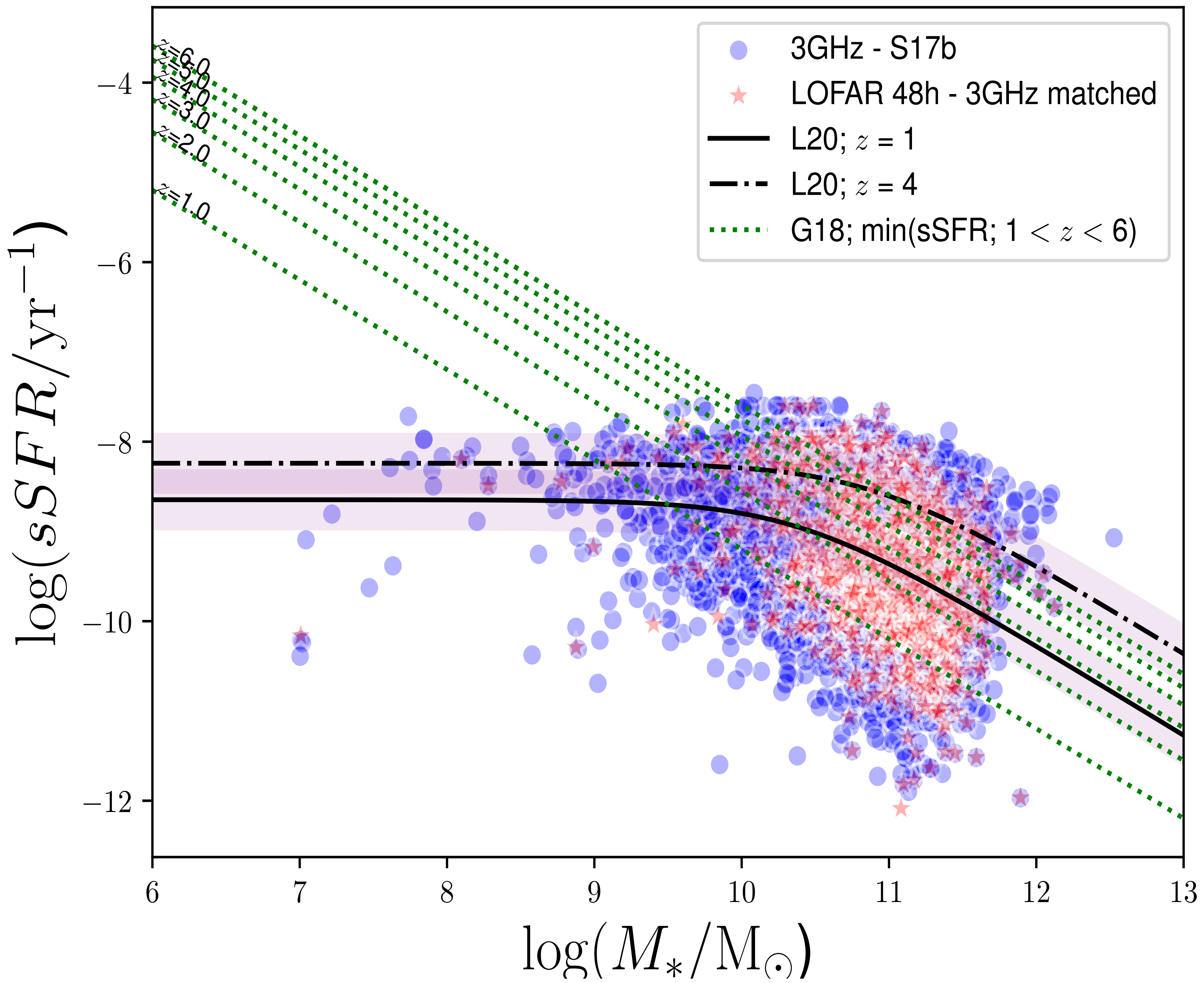


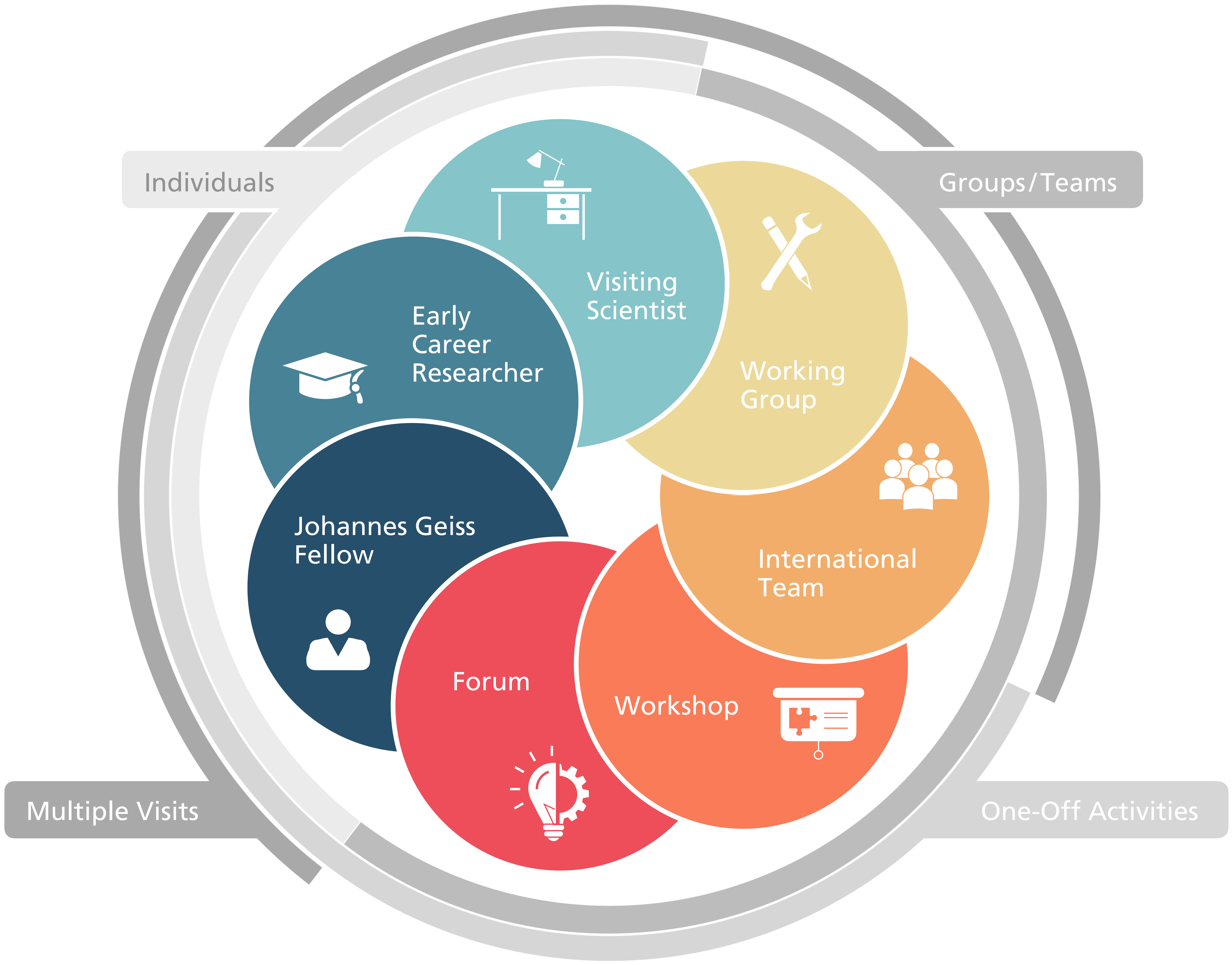




Submitted LOFAR 2.0 LP proposal (PI: E. Vardoulaki) for:

- simultaneous HBA (150 MHz) & LBA (60 MHz) imaging
- 5x deeper imaging than existing 150 MHz data
- coverage approx. depth matched to JVLA-COSMOS 3 GHz

7 Funding Instruments for the Community



INTERNATIONAL SPACE SCIENCE INSTITUTE

2024 Call for International Team projects open

- Tackle your favourite science problem in a group of 8-12 scientists.
  Two to three meetings at ISSI in Bern or Beijing, over ~2 years.

- Funding provided: local expenses of meeting participants (accommodation and a per diem), travel for PI.

- Projects submitted must involve the analysis of space mission data. Can draw on complementary ground-based data and/or theoretical modelling. An inter-disciplinary approach is strongly encouraged.

- Open to all scientists, regardless of nationality or institutional affiliation.

- Deadline March 14, 2024: https://www.issibern.ch/call-for-proposals-2024/


INTERNATIONAL SPACE SCIENCE INSTITUTE
Bern, Switzerland - www.issibern.ch

INTERNATI
SPACE SCIE
INSTITUTE -
BEIJING
Beijing, China - www.issibj.ac.cn

ISSI/ISSI-BJ 2024 Joint Call for Proposals f
International Teams in the Space & Earth Sciences

This call is jointly released by ISSI (International Space Science Institute) in Bern and ISSI Beijing (ISSI-BJ). ISSI & ISSI-BJ organise the same range of activities and share the same Scienc Committee. Applicants can apply for projects hosted by ISSI or ISSI-BJ only, or for joint ISSI/ISSI-BJ projects involving meetings at both sites. All International Team projects are assessed on the same criteria (see Sect. 4), irrespective of the host venue. In preparation for the anonymous peer-review of the science justification section of Team proposals, ISSI expects applicants to fully anonymise their proposals according to our guidelines (esp. when updating resubmissions).

1. Purpose

ISSI and ISSI-BJ invite proposals for International Team projects. International Teams are small groups of scientists conducting space science research by collaborating on data analysis, theory and models. This call is open to all scientists – regardless of nationality or institutional affiliation – who are active in any of the following research fields:

INTERNATIONAL SPACE SCIENCE INSTITUTE