ASKAP-FLASH Survey

First Large Absorption Survey in HI using the SKA Pathfinder Telescope

Hyein Yoon on behalf of the FLASH team

Seoul National University / The University of Sydney

ASKAP-FLASH

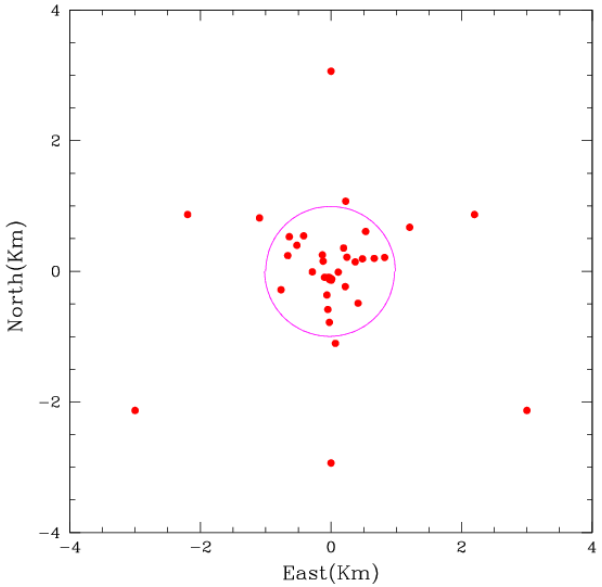


Image credit: CSIRO

ASKAP: Australian SKA Pathfinder Telescope

An SKA-precursor telescope situated at Inyarrimanha Ilgari Bundara, CSIRO's Murchison Radio-astronomy Observatory, in Western Australia





Array configuration
(Gupta et al. 2008)

- 36 dish antennas, D = 12 m
- Frequency (low/mid): 700 – 1800MHz
- **FoV: 6.4 * 6.4 degrees**
- Baseline: 22 m - 6 km
- Processing: ASKAPsoft pipeline
- Pawsey Supercomputing Research Centre
- CASDA archive

ASKAP: Australian SKA Pathfinder Telescope

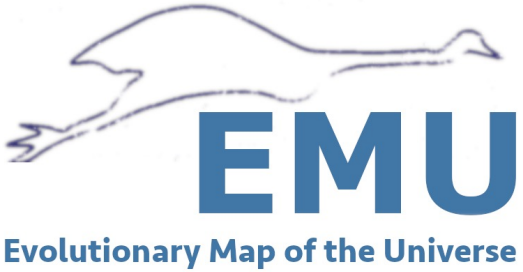
Timeline:

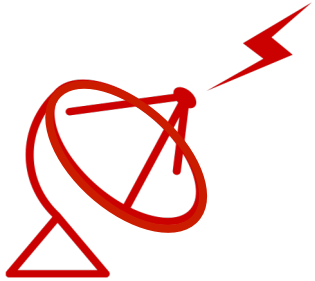
- June 2012: Construction of all 36 ASKAP antennas complete
- July 2013: ASKAP BETA (6 antennas), First science outcomes
- July 2014: Complete 36 antenna array
- Oct 2016: ASKAP Early Science (12 antennas)
- **Aug 2019: Pilot Surveys Phase I 100-hr observations begin (36 antennas)**
- **July 2021: Pilot Surveys Phase II 100-hr observations begin**
- **Nov 2022: Full Surveys commence with one-month trial**
- **2023 – 2028: Five-year Full Survey**

ASKAP Survey Science Projects (75% of ASKAP time)









ASKAP-FLASH









CRAFT: Fast Transient (< 5 sec)

DINGO: Deep HI fields

EMU: Radio continuum all-sky

FLASH: HI absorption all-sky

GASKAP-HI: Galactic HI high resolution
GASKAP-OH: Galactic OH high resolution (MW, Magellanic clouds)

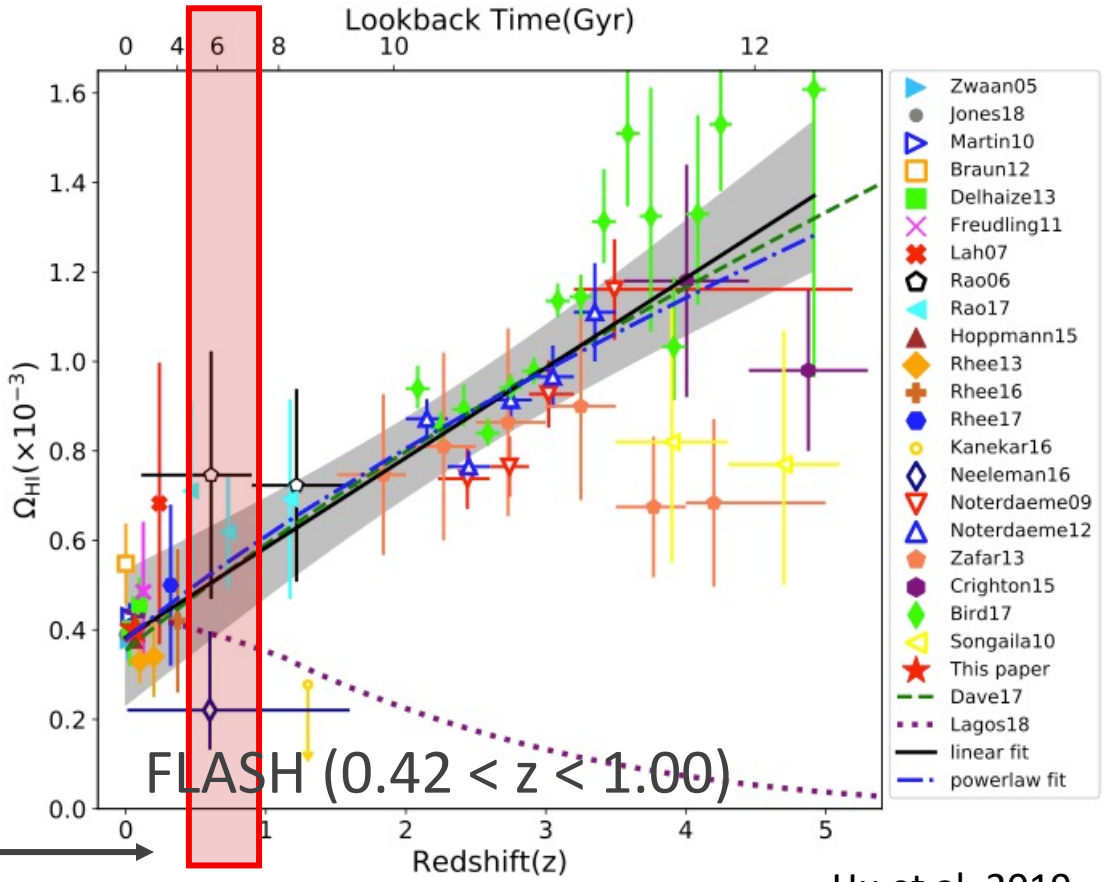
POSSUM: Polarization/magnetic field

VAST: Slow transient (~5 sec)

WALLABY: HI all-sky high resolution

FLASH: Detecting Cold HI Gas from the Distant Universe

- **FLASH: The First Large Absorption Survey in HI**
  - **Wide-field HI 21cm absorption line survey using background radio sources**
  - **First large survey of the HI content of galaxies toward the intermediate z at 0.42 < z < 1.00** (Allison, Sadler et al. 2022, PASA 39, e010)
  - Pilot Survey Phase 1 & 2: data released
    Full Survey: ongoing, observing
- **ASKAP's Strength for FLASH science**
  - **Radio quiet site, free from RFI**
  - Spectra: **288-MHz large bandwidth all at once** – ideal for the large redshift range
  - Continuum: wide field of view phased array feeds (~36 deg^2) – ideal for wide-field survey



Hu et al. 2019

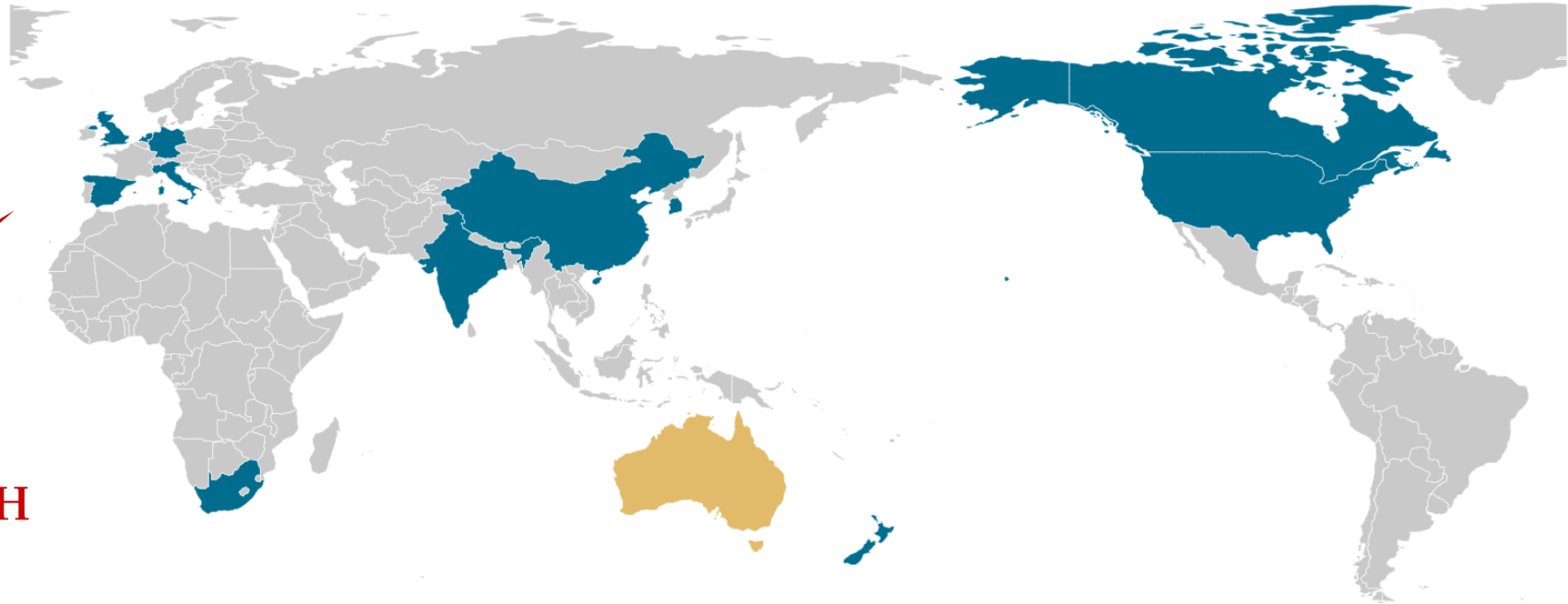
Team FLASH - the First Large Absorption Survey in HI

PI: Elaine Sadler (USyd) and Elizabeth Mahony (CSIRO)

Project Scientist: Hyein Yoon (SNU/USyd)

Executives: James Allison (Previous co-PI; - 2021), Vanessa Moss (CSIRO), Matthew Whiting (CSIRO), Sara Ellison (UVic), Raffaella Morganti (ASTRON), Max Pettini (Cambridge)

Members: Aditya JNHS (USyd), Stephen Curran (VUW), Marcin Glowacki (Curtin), Emily Kerrison (USyd), Renzhi Su (Zhejiang), Simon Weng (USyd) and more (60 members in total, 13 countries)



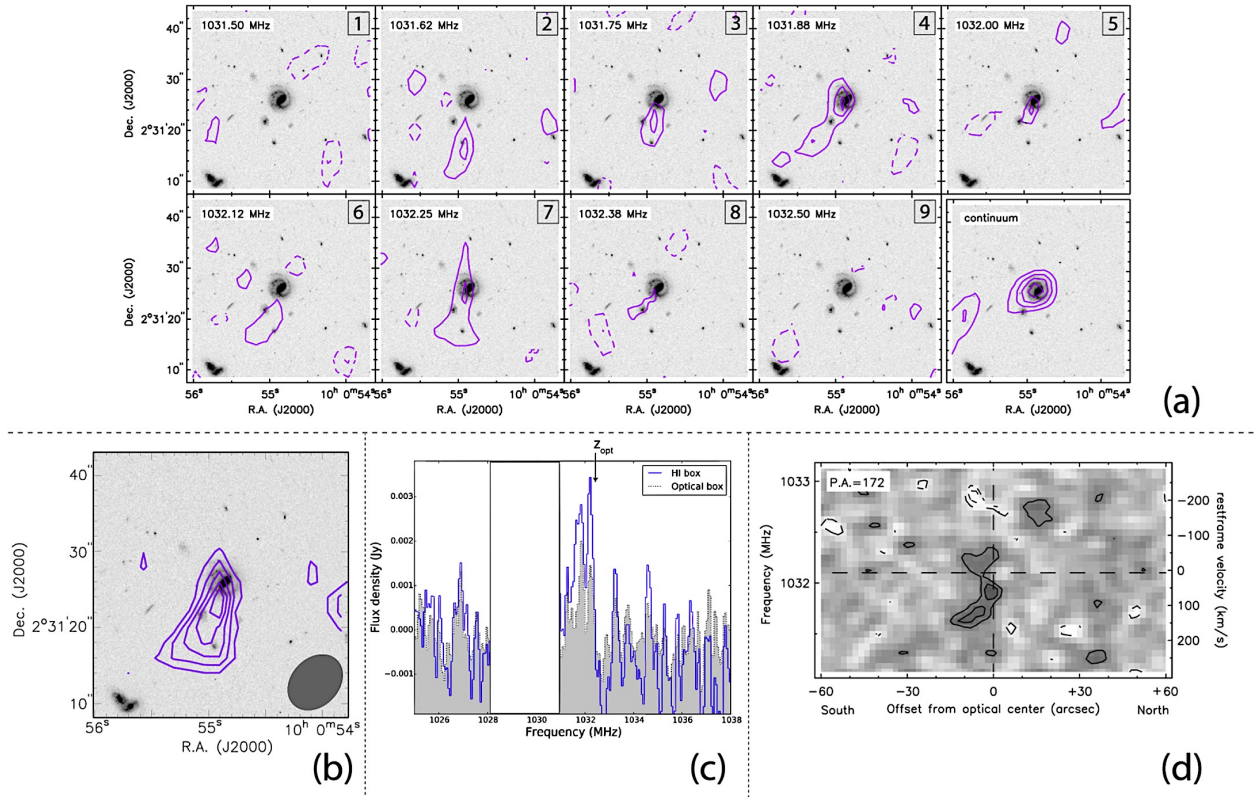
ASKAP-FLASH

Why HI 21-cm Absorption?

- HI emission is a powerful tool to measure gas content and study gas interactions directly
- **However, the sensitivity depends on redshifts!**

COSMOS J100054.83+023126.2 at z = 0.376

(CHILES; Fernández et al. 2016)



HI Emission-based Large Surveys

HIPASS (z < 0.042), Parkes

ALFALFA (z < 0.06), Arecibo

EBHIS (z < 0.07), Effelsberg

xGASS (0.01 < z < 0.05), Arecibo

HIGHz (0.09 < z < 0.32), Arecibo

BUDHIES (0.164 < z < 0.224), WSRT

CHILES (z < 0.45), JVLA (1000 hrs)

MIGHTEE-HI (z < 0.58), MeerKAT

Cold-HI (0.74 < z < 1.45), uGMRT

Apertif image survey HI (z < 0.26), WSRT

WALLABY (z < 0.1), ASKAP

DINGO high-z (0.25 < z < 0.4), ASKAP

CRAFTS (z < 0.35), FAST

LADUMA (z < 1.45), MeerKAT (3424 hrs)

Local-targeted: THINGS, VIVA, VLA-ANGST, HALOGAS, MHONGOOSE, HI-RINGS, FEASTS, …

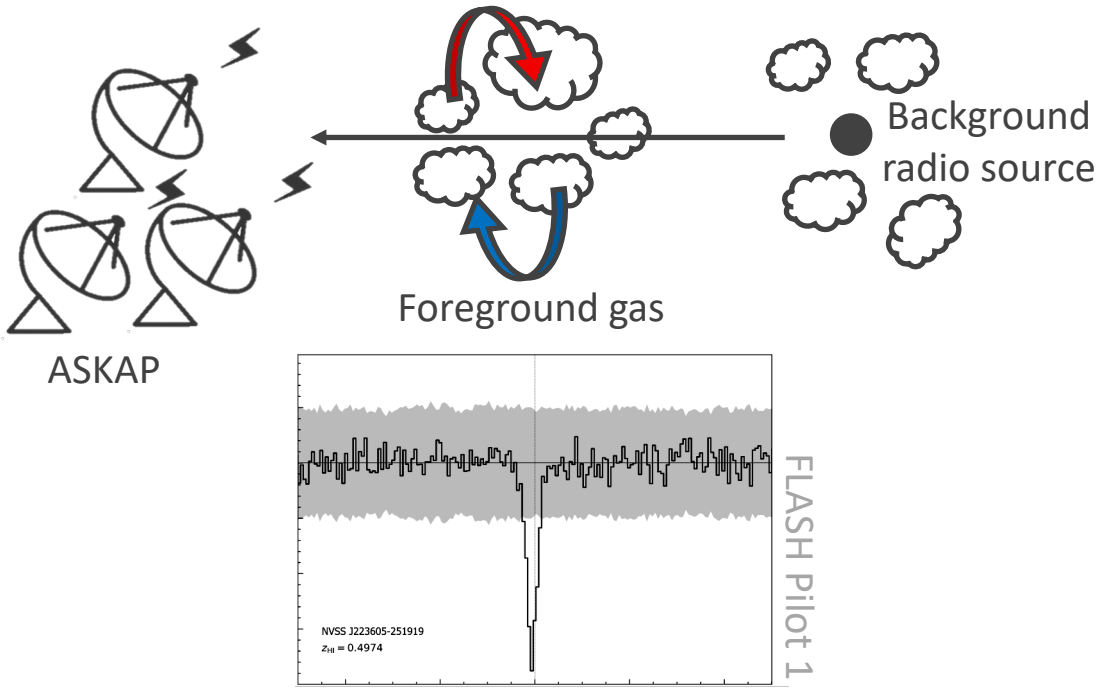
(PI, refs – omitted)

What Can We Learn from HI Absorbers?

Unlike HI emission surveys, sensitivity is independent of redshift!

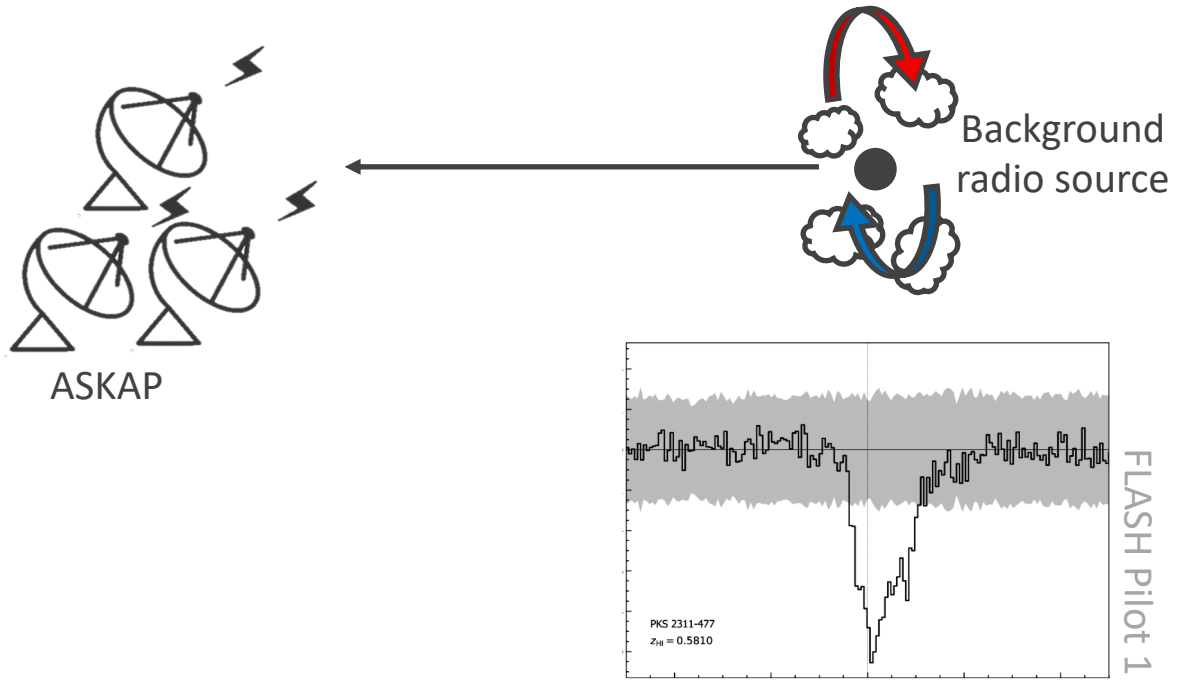
Two different HI absorbers:

Intervening absorbers



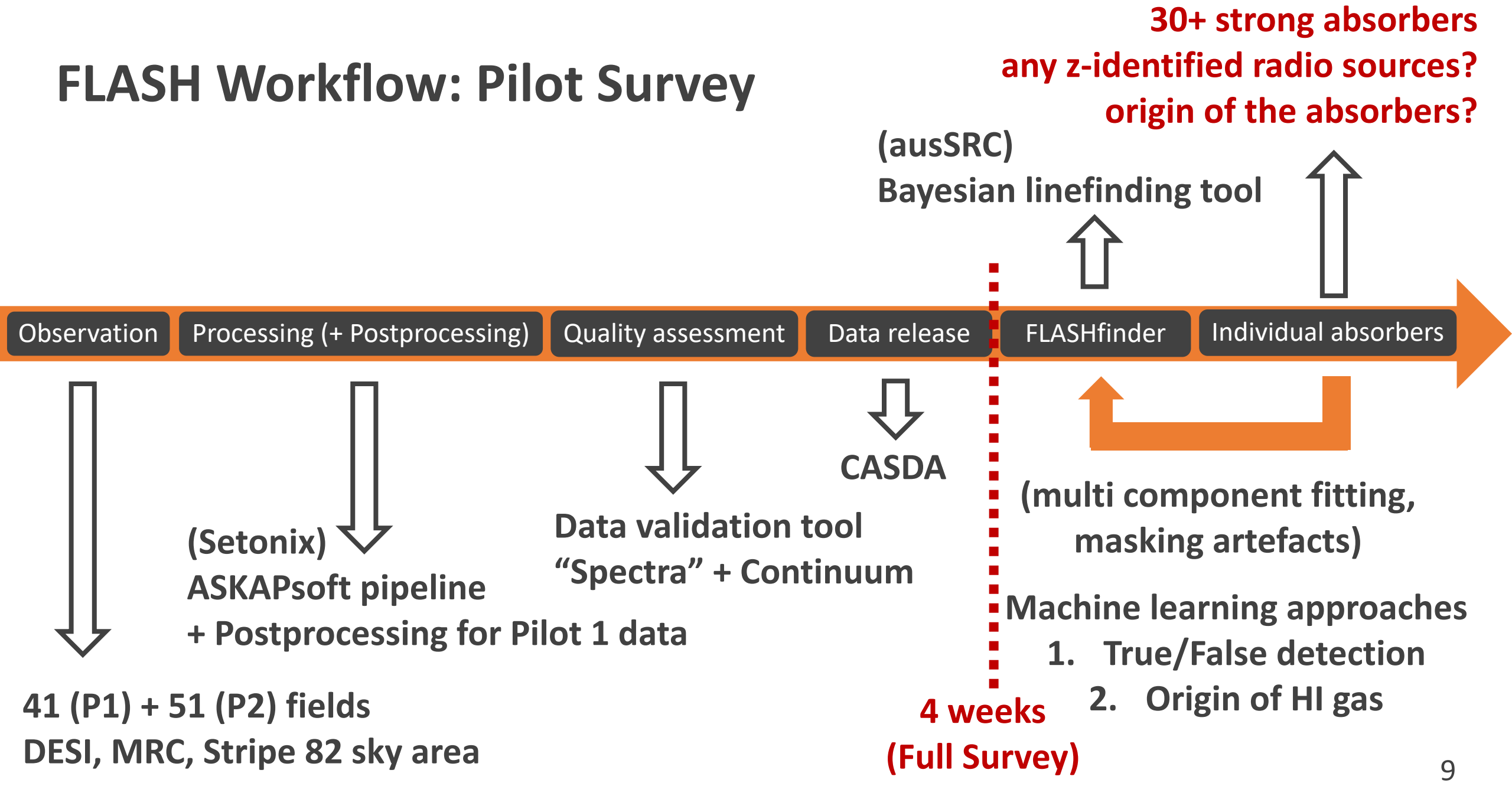
Cosmic evolution of HI gas, galaxy evolution and mass assembly models

Associated absorbers



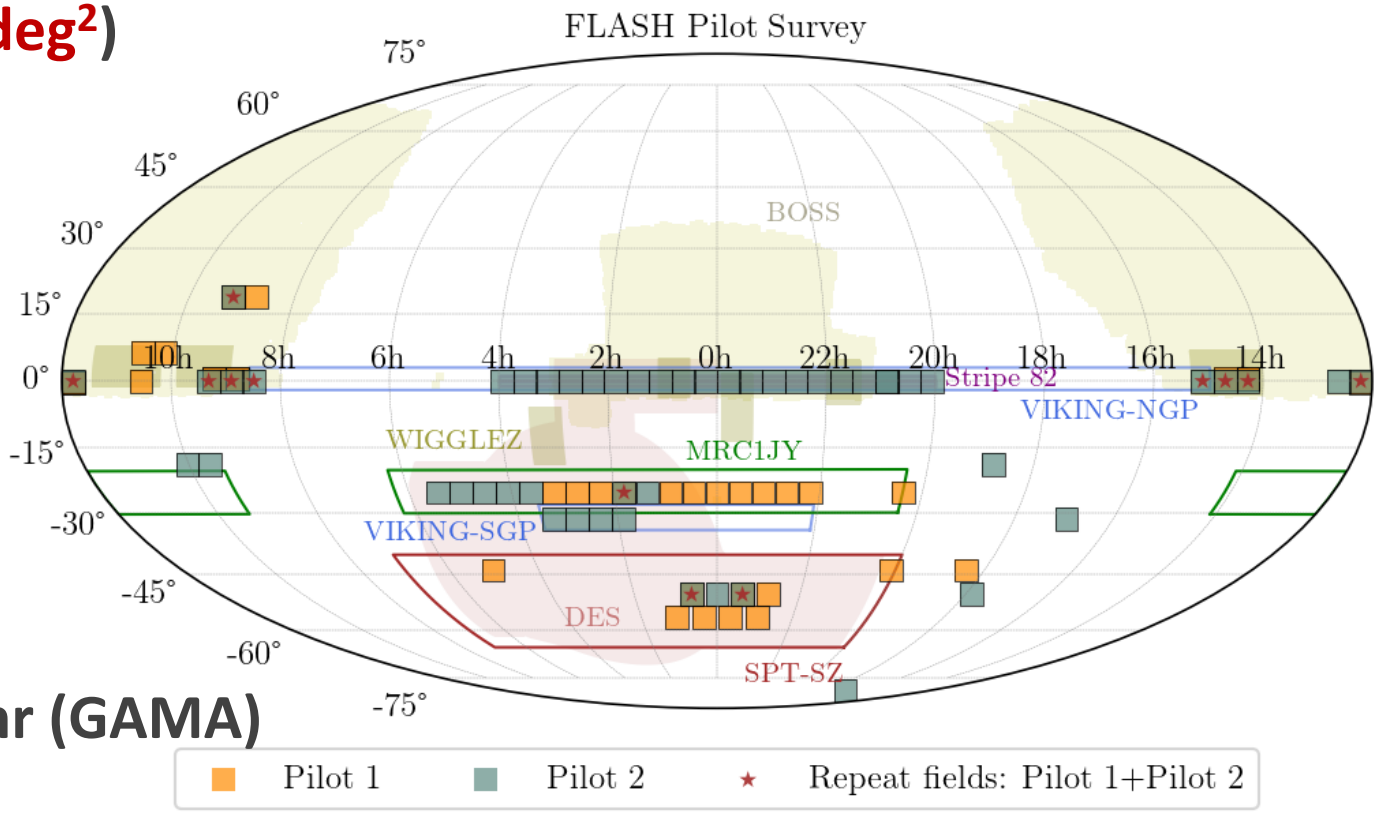
AGN fueling and feedback processes in powerful radio galaxies

FLASH Workflow: Pilot Survey



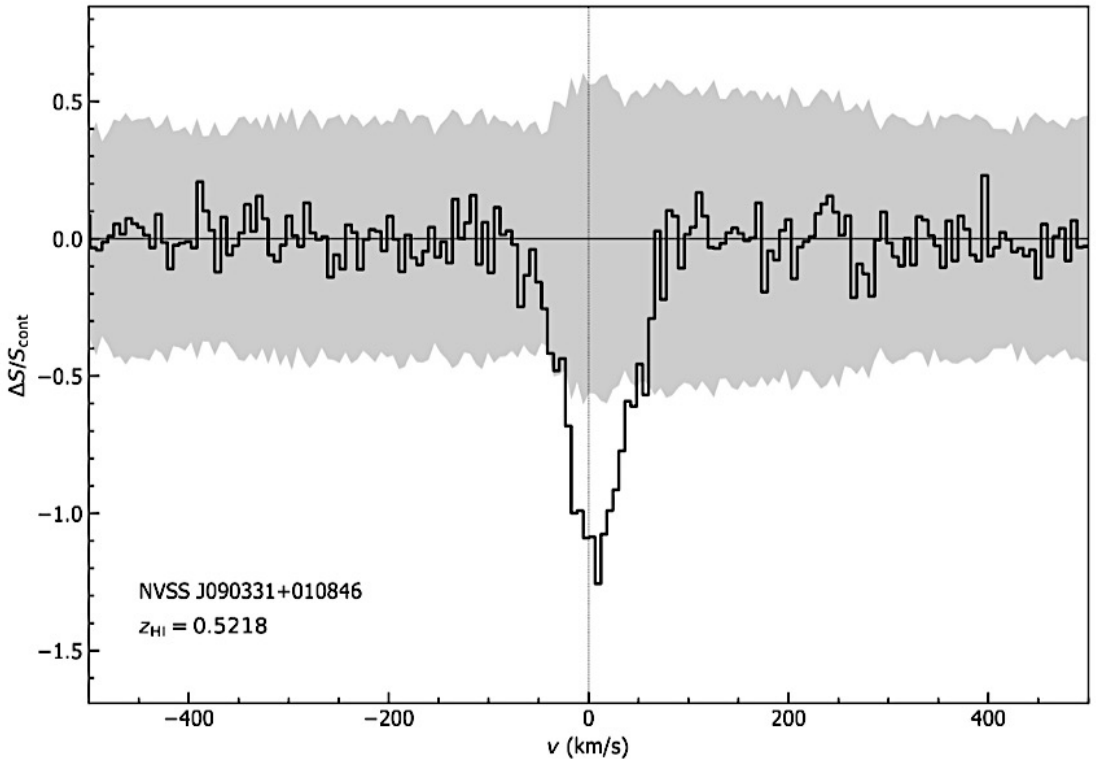
FLASH Pilot Survey Phase 1 and 2

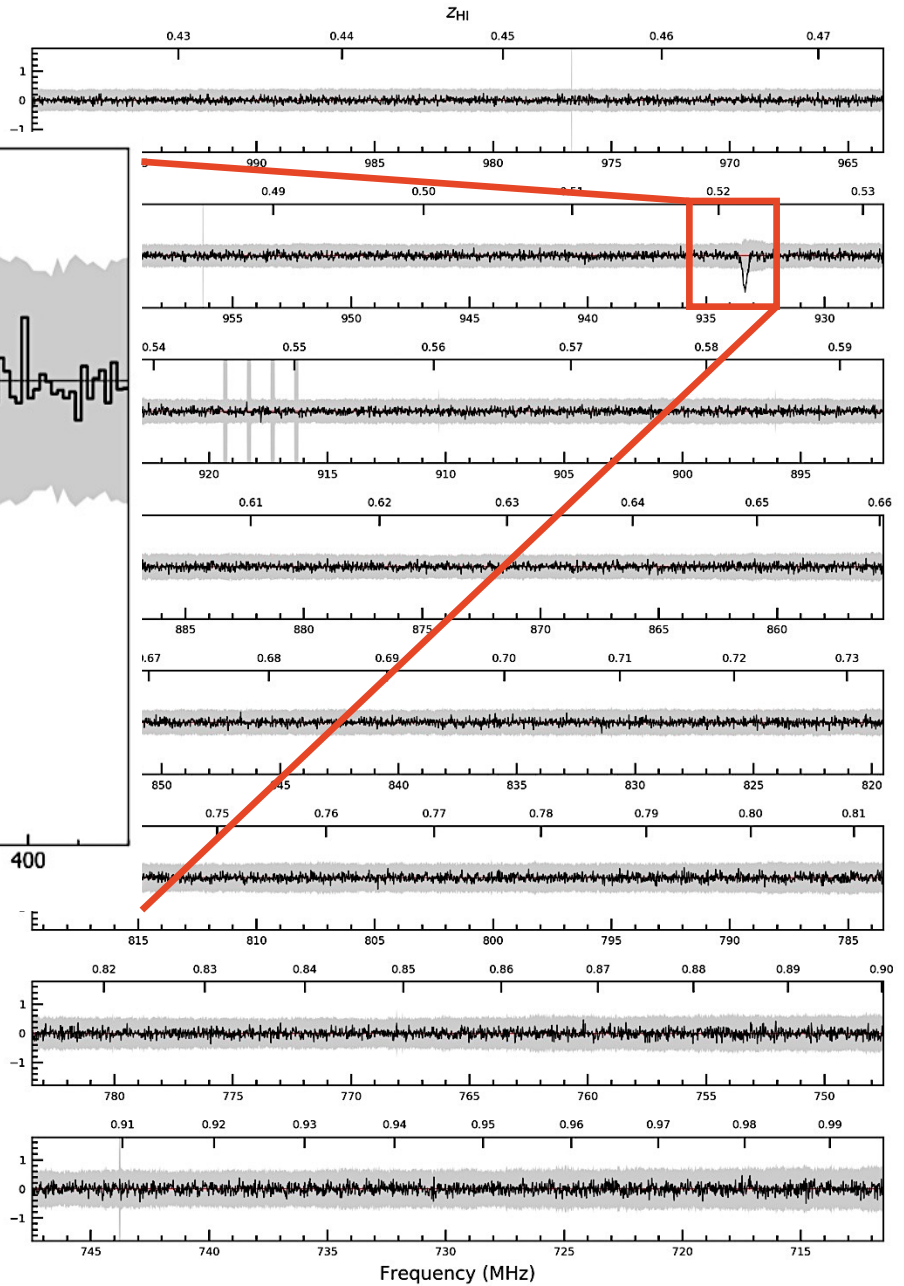
- Pilot Phase 1 and 2 observations have been completed successfully (Dec 2019 - Aug 2022)
- Footprint: 41 (P1) + 51 (P2) (~ 3000 deg^2)
- Frequency range: 711.5 - 999.5 MHz
  (centre: 856 MHz)
- Redshift range: 0.42 < z < 1.00
- Declination range: ~ +18 to -80 deg.
- Field of view: ~ 6.4 x 6.4 deg^2
- Integration time: 2 hr (standard), 6 hr (GAMA)



Yoon et al. in prep

Data Products - Spectra





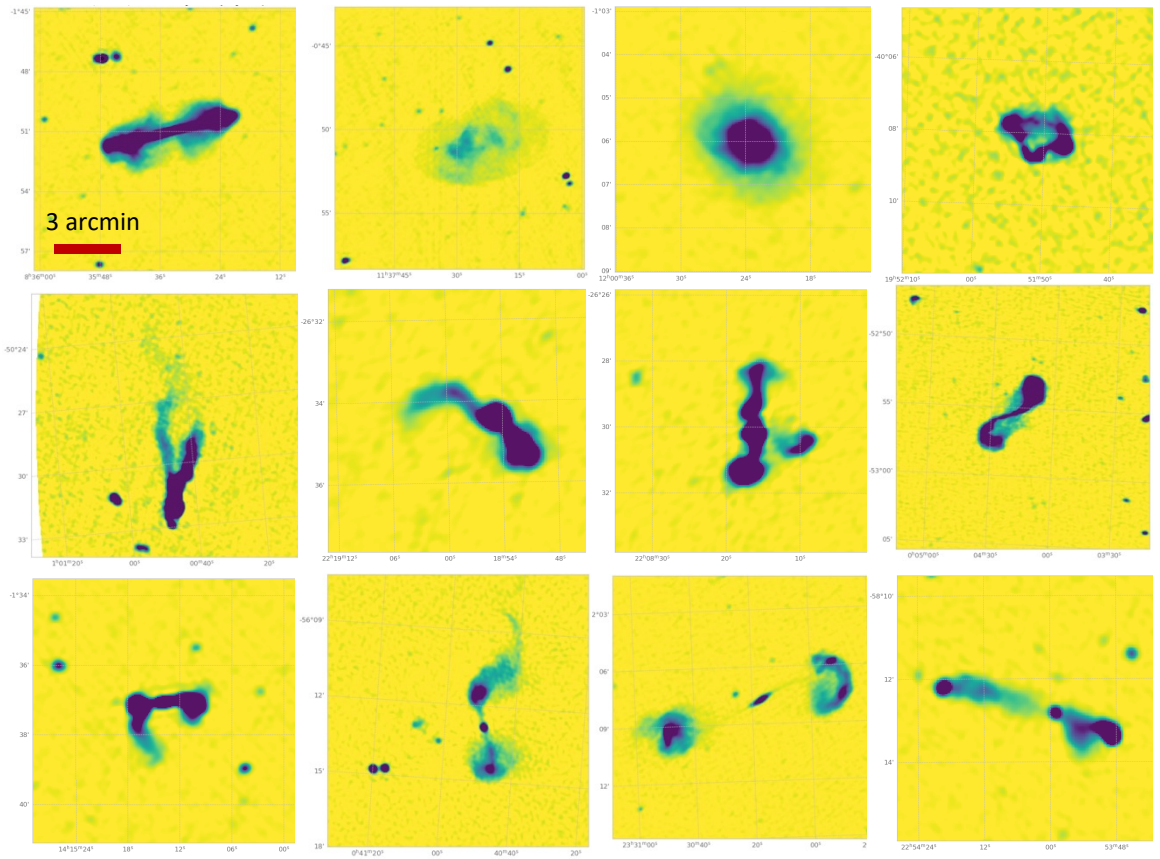
Spectra:

288 MHz band

Chan res = 18.5 kHz

Exp noise = 3.2 – 5.1 mjy/b

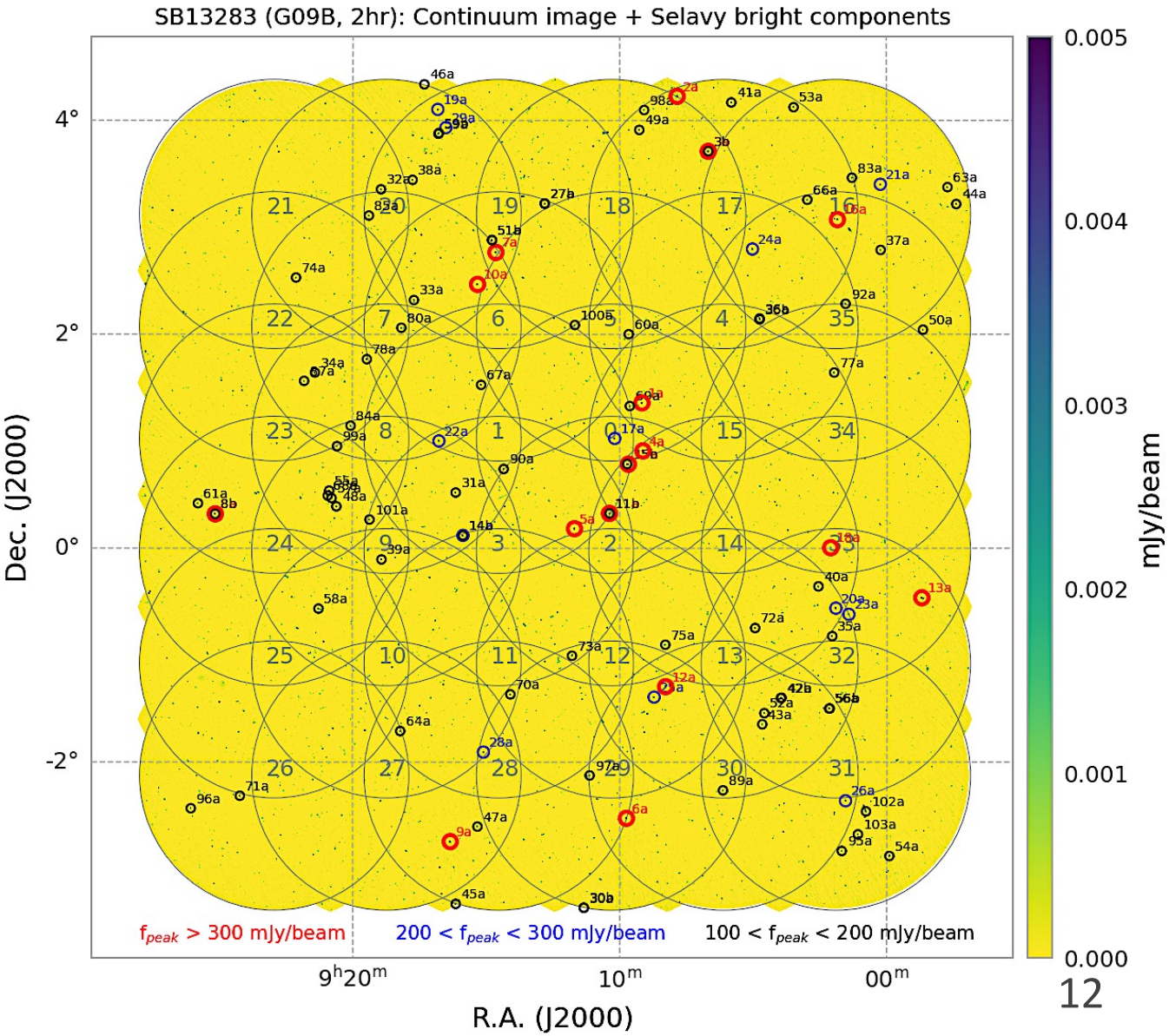
Data Products - Continuum



Continuum:

~ 36 deg^2 wide-field (f ~ 856 MHz, 2-hr)

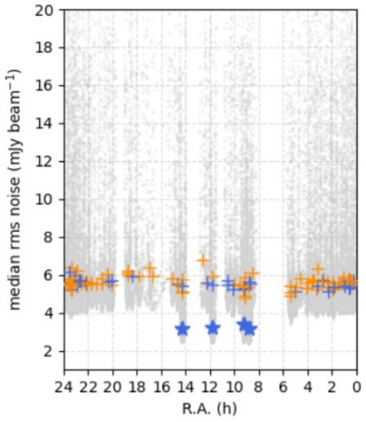
mostly unresolved by the 12-15 ASKAP PSF

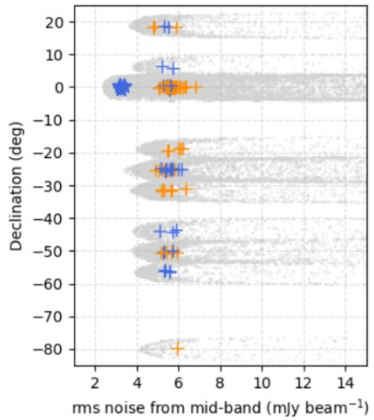


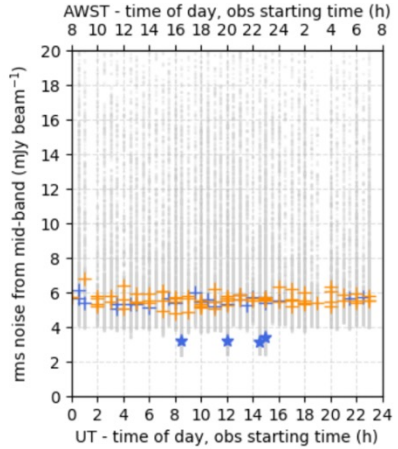
Data Quality

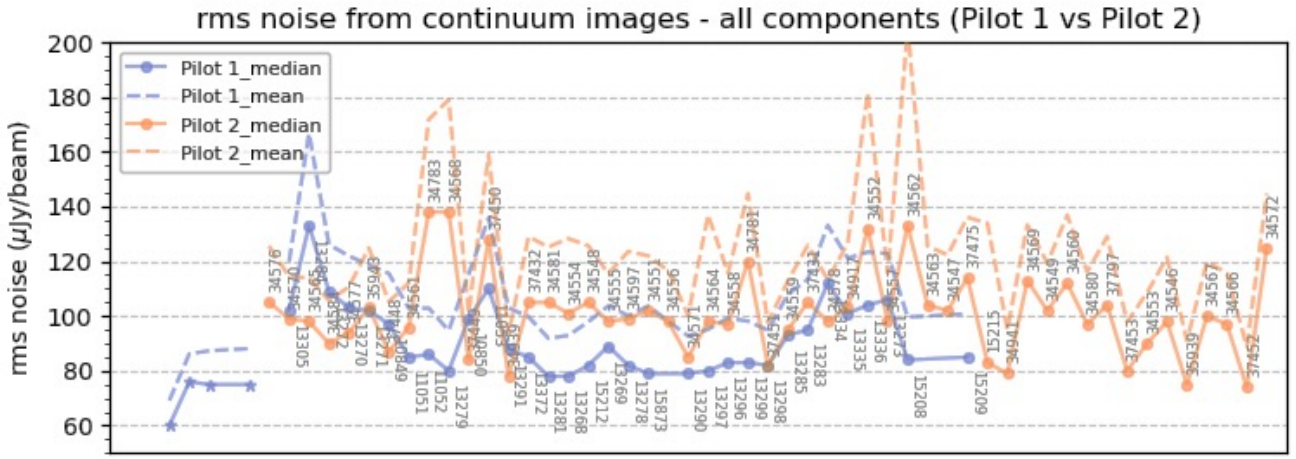
Uniform rms noise level in Pilot 1 & 2:

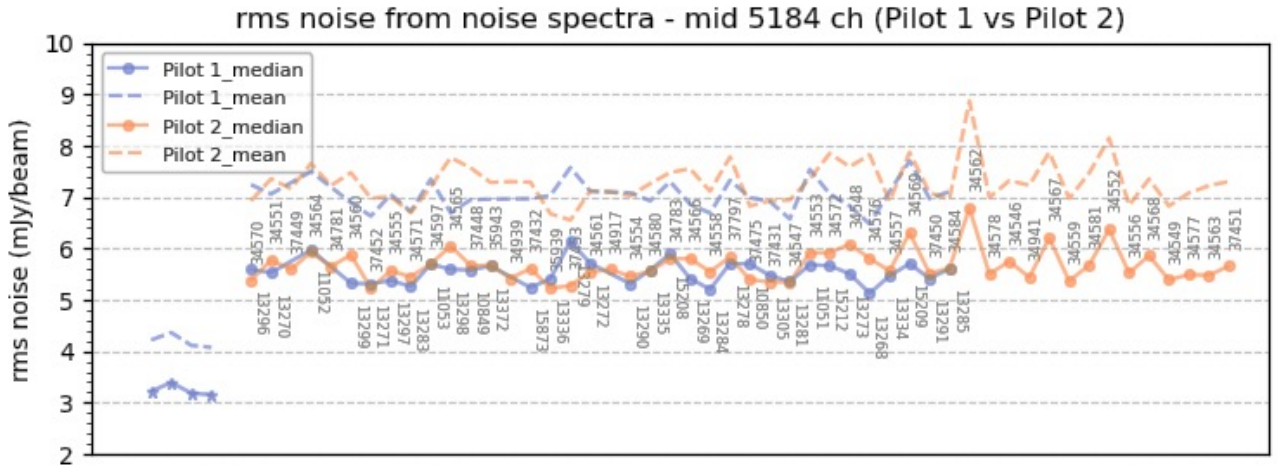
- across the entire spectral band,
- in the continuum images (d < 3.2 deg),
- with different RA/DEC/obs time









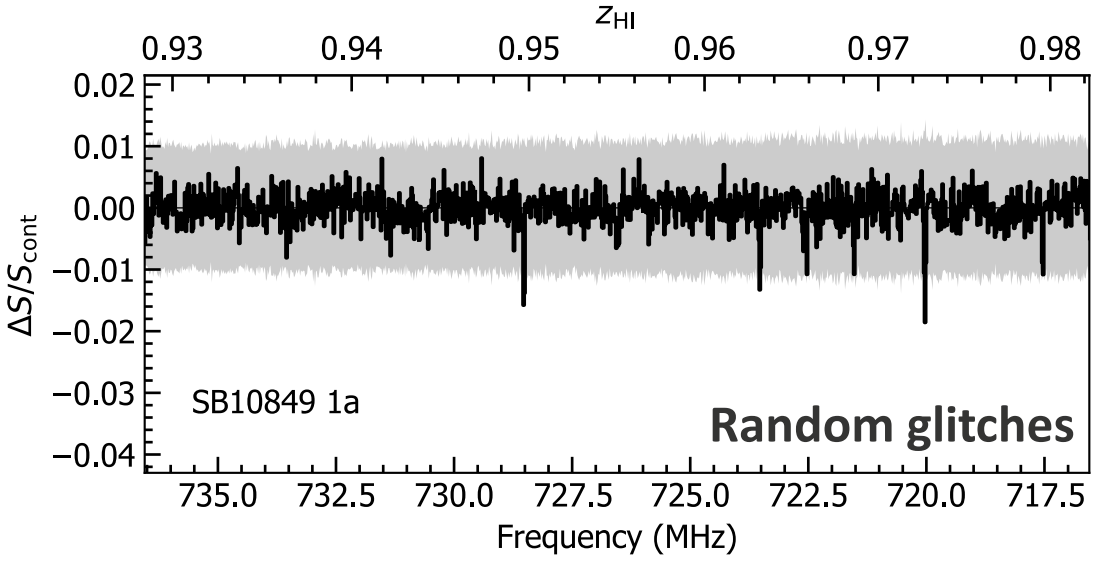


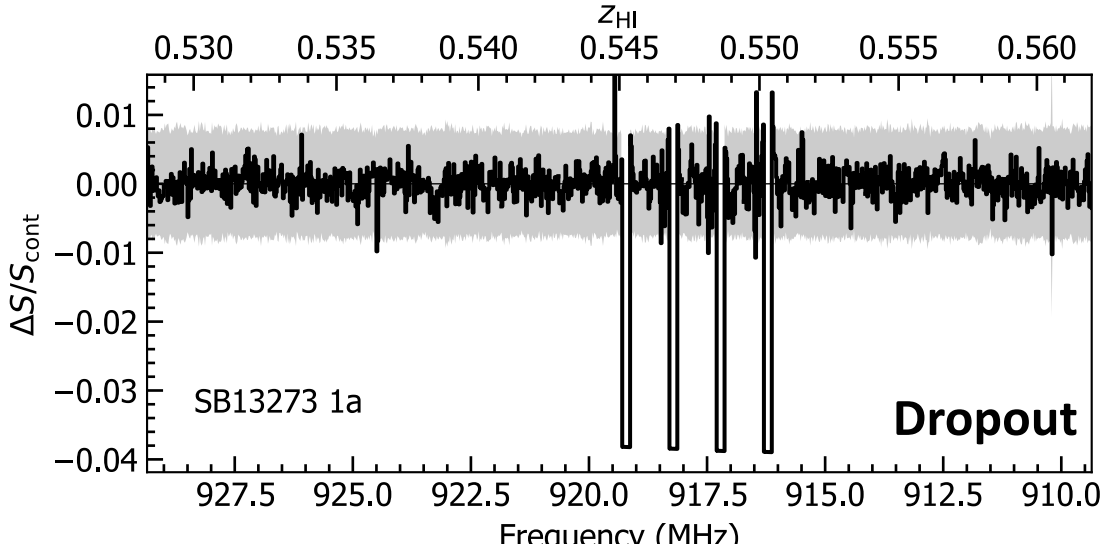
- **Continuum:**
  rms ~ 80 - 100 μJy/beam (2-hr, Phase 1)
  rms ~ 90 - 120 μJy/beam (2-hr, Phase 2)
  rms ~ 75 μJy/beam (6-hr)

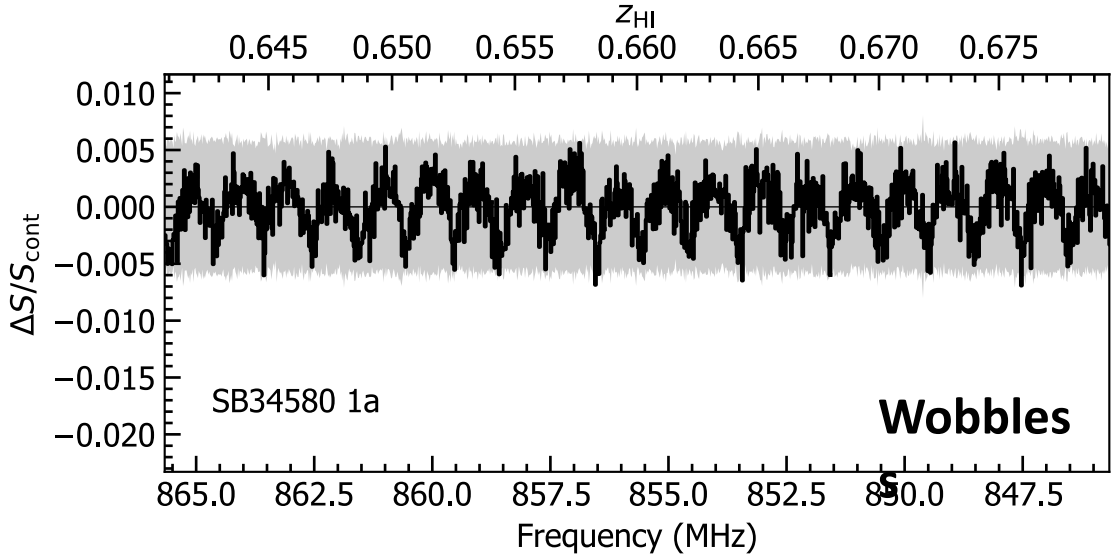
- **Spectra:**
  rms ~ 4.5 mJy per 6 km/s chan (2-hr)
  rms ~ 2.8 mJy per 6 km/s chan (6-hr)

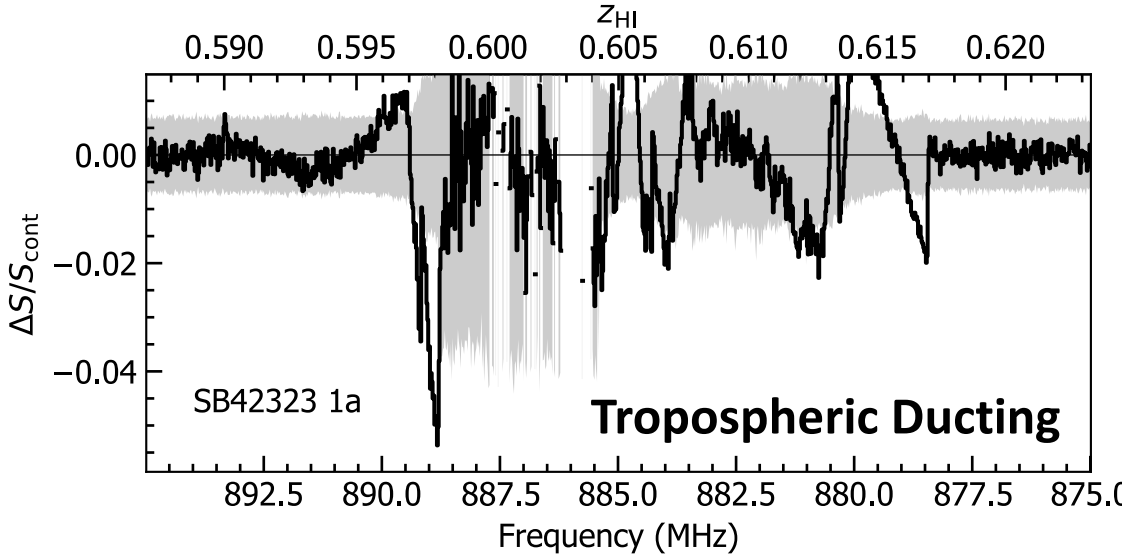
FLASH Pilot Survey data paper 2023, n prep

Data Quality - Challenges Seen from the Pilot data









FLASH Pilot Survey data paper 2023, in prep

Automatically Separate True Detections from the FLASHfinder Outputs

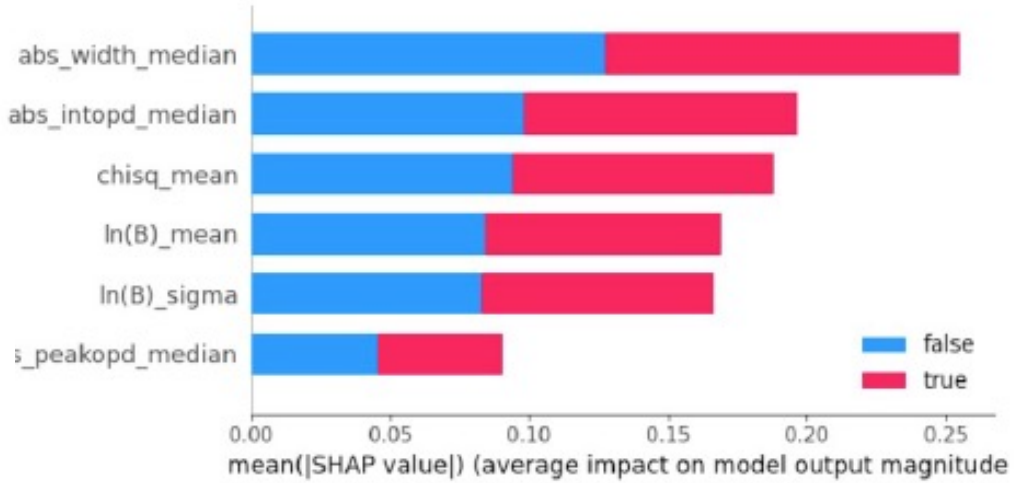
Xiu Liu (CSIRO), Ivy Wong (CSIRO)

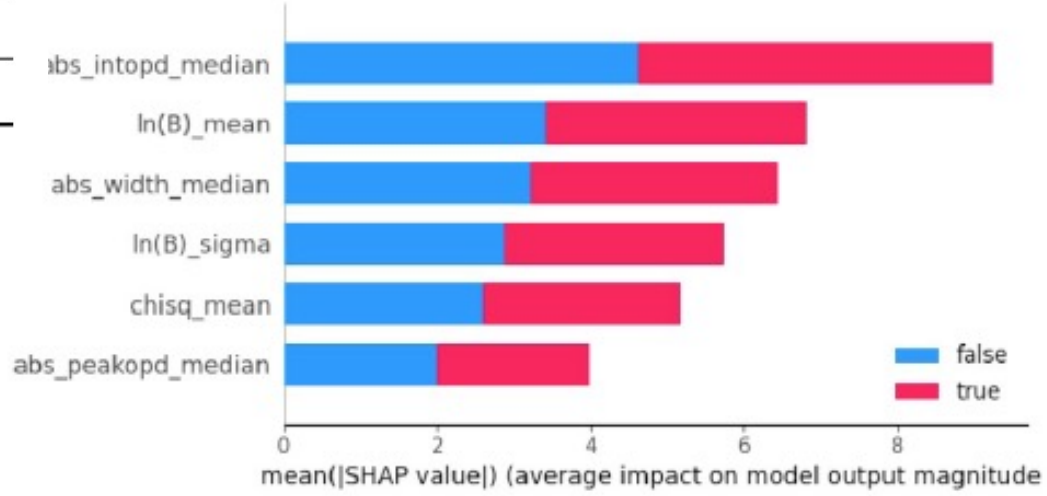
Liu et al. 2023, in prep.

Motivation: FLASHfinder identifies too many bad source candidates (current ratio approx ~100k candidates : ~30 true)

Method: Trained on FLASH Pilot Phase 1 data, making predictions on Pilot phase 2 data

	Logistic Regression	Random Forest	XGBoost
True negative rate	0.624	0.966	0.962
False positive rate	0.376	0.034	0.038
False negative rate	0.101	0.011	0.004
True positive rate	0.899	0.989	0.996
Macro average f1 score	0.76	0.98	0.98





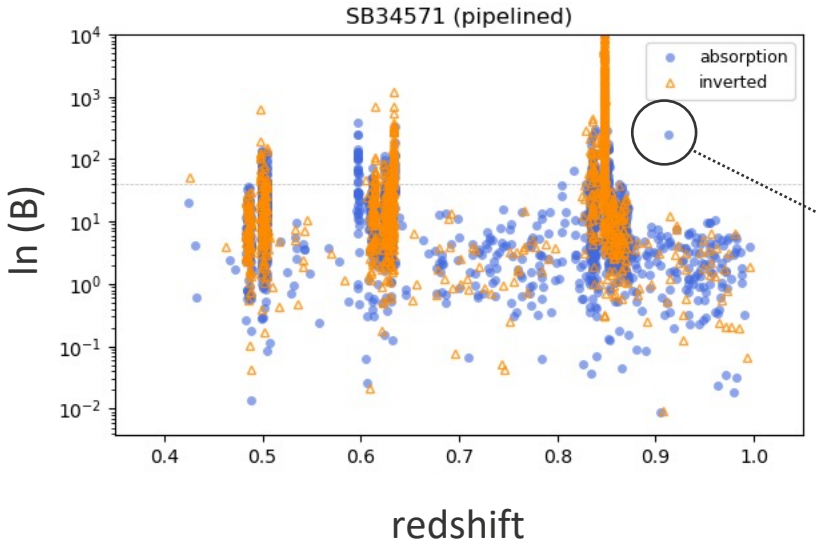
Current results:

1) Simple ML models yielding reasonable results

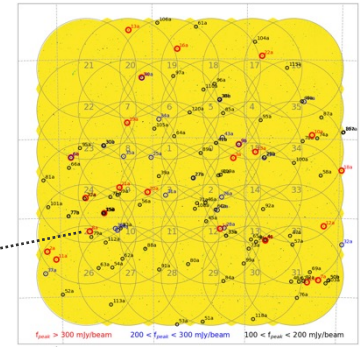
2) ln (B) needs to be used in combination with τint & linewidth for best results

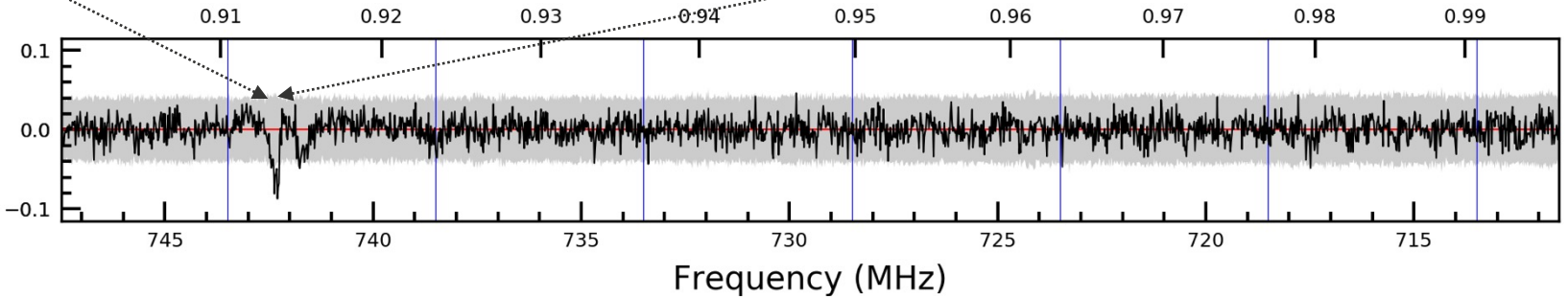
FLASHfinder: Automatic Searching for New Detections

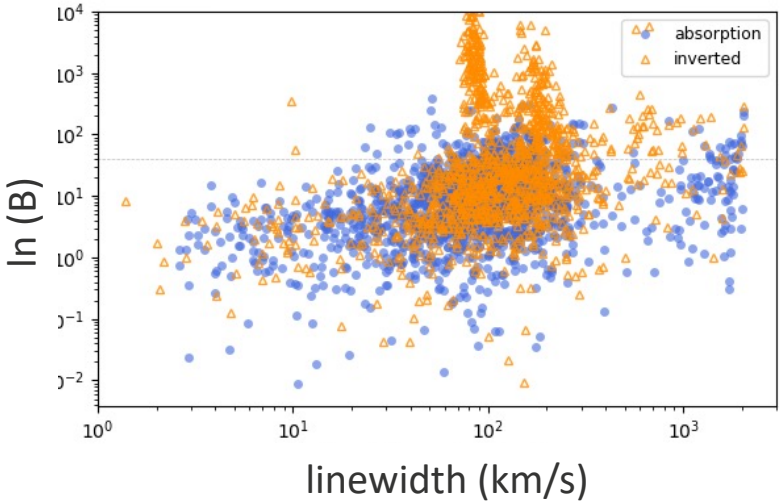
Bayesian approach to the one-dimensional line-finding problem (Allison+ 2012)

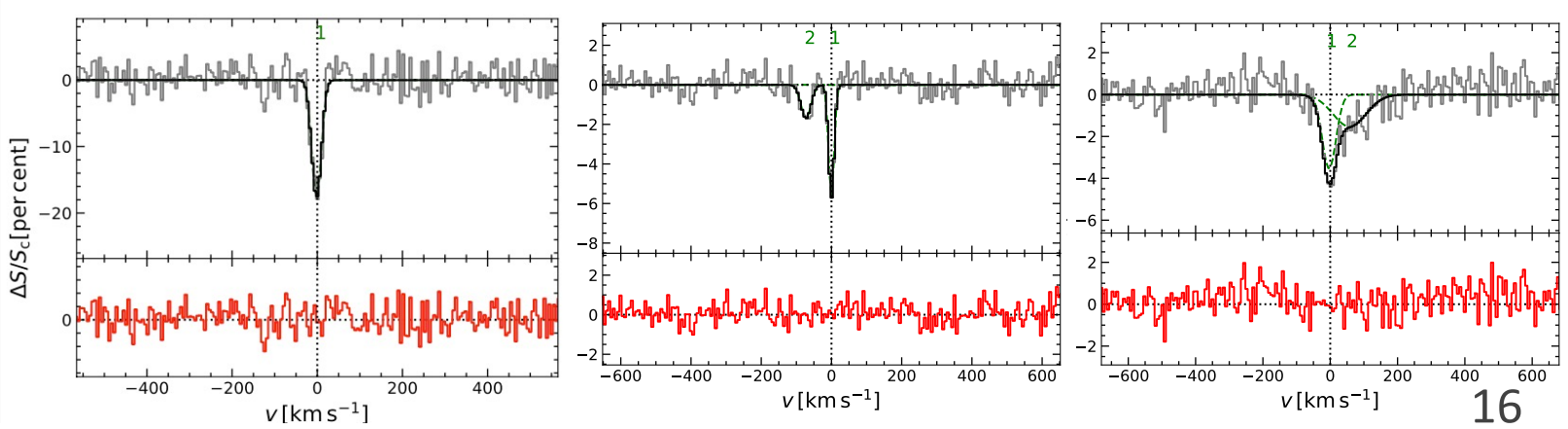


- high Bayes number: identify absorptions
- glitches (correlator errors): masked out

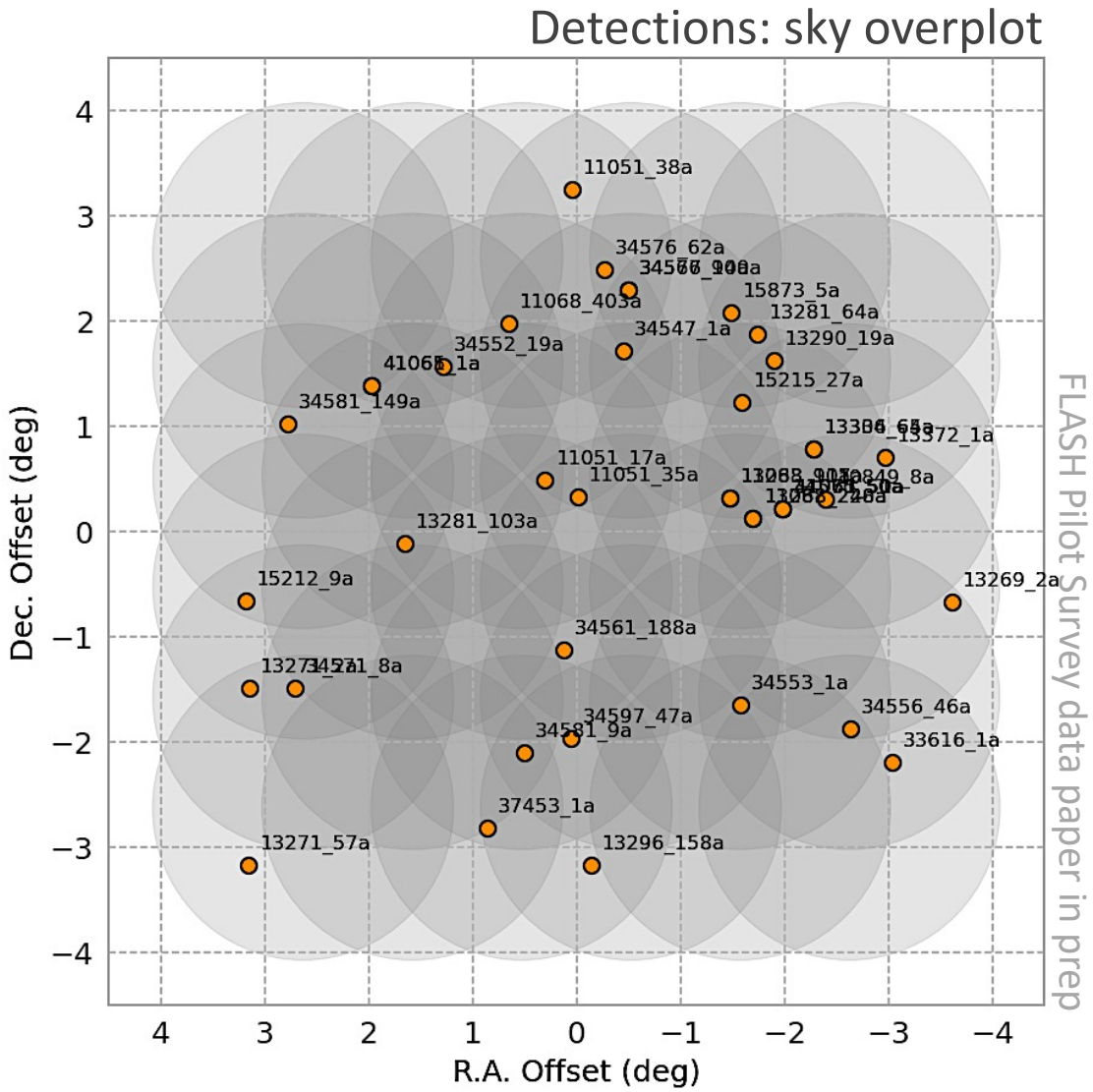


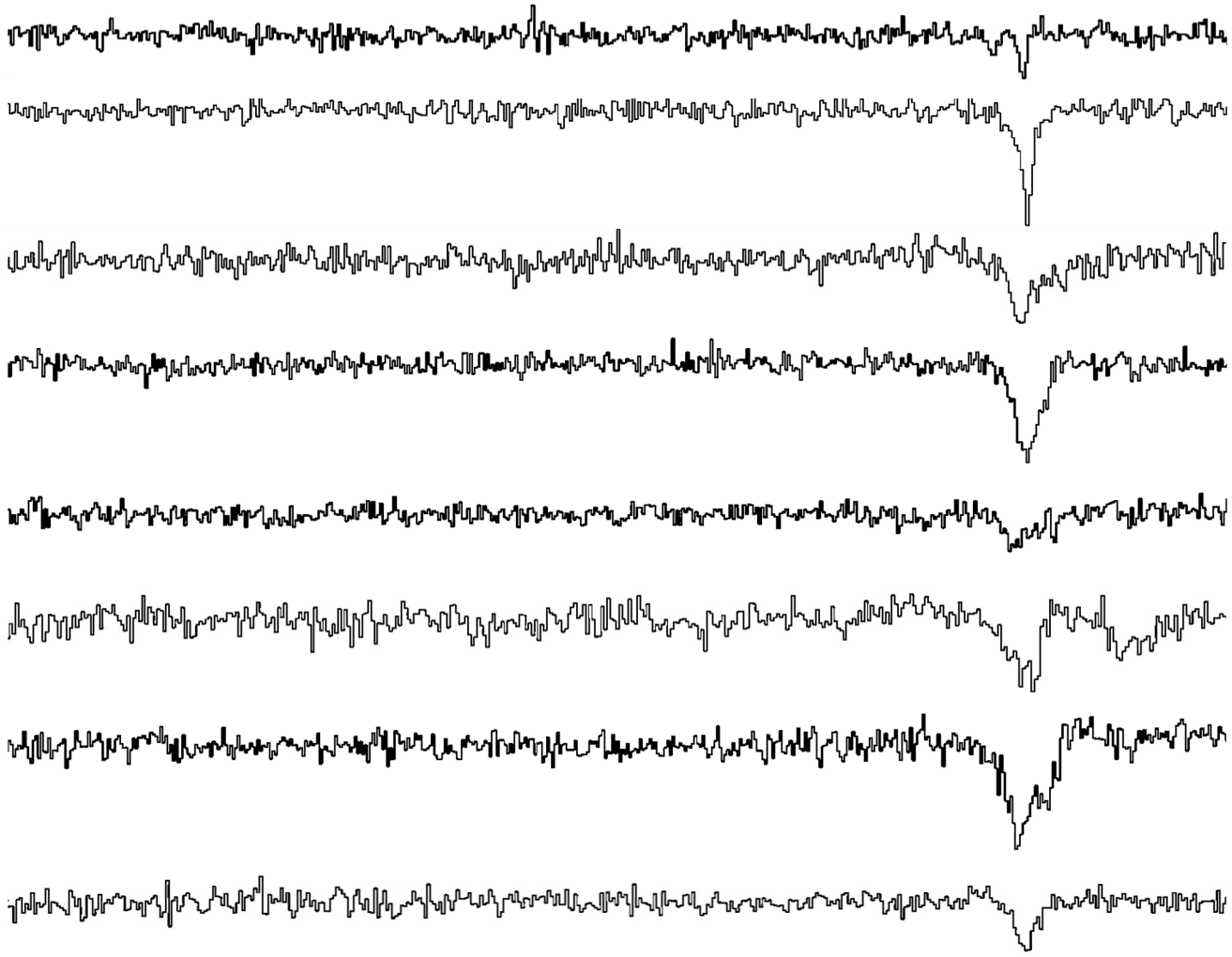






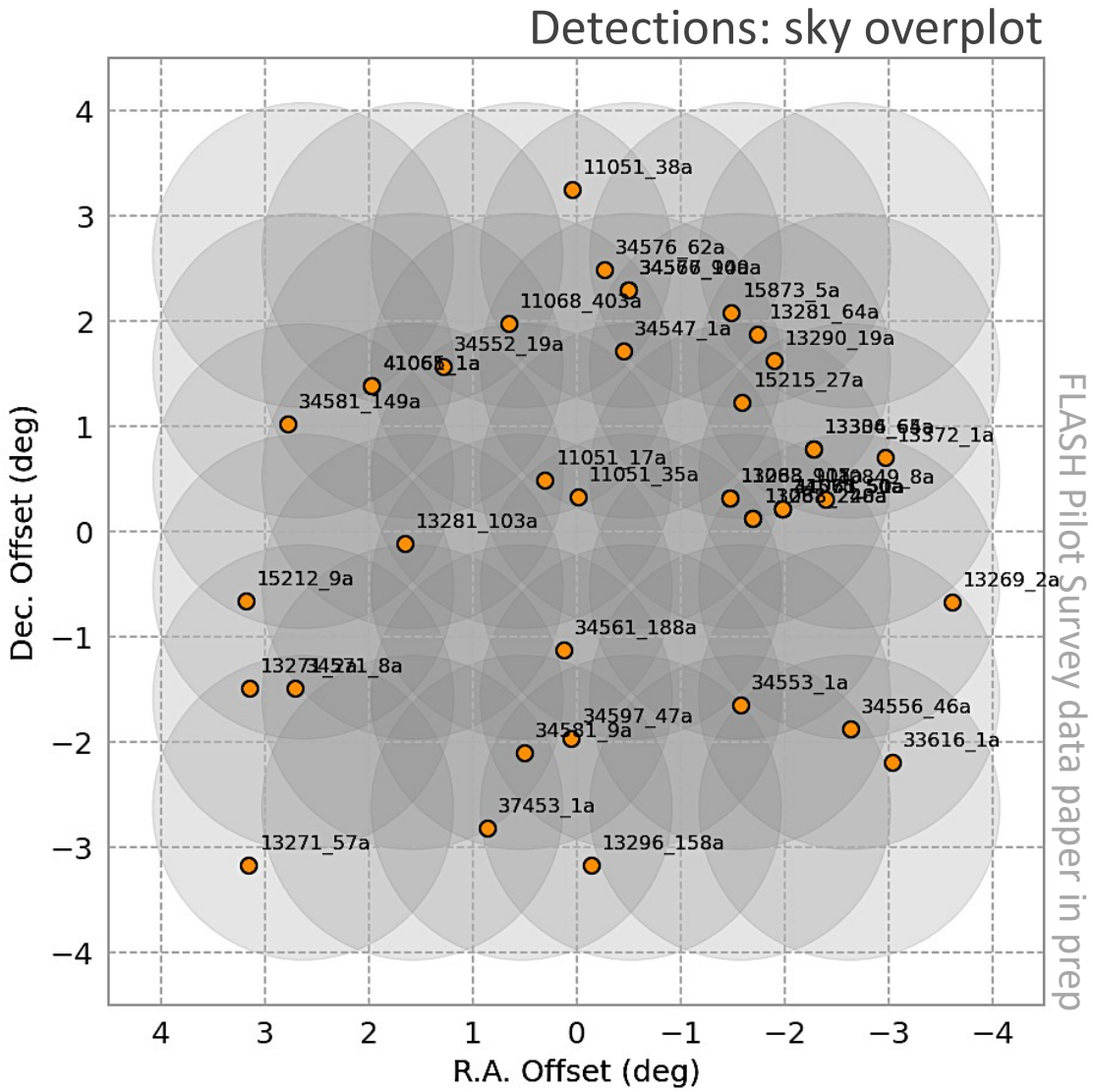
New Detections: HI 21cm absorption lines

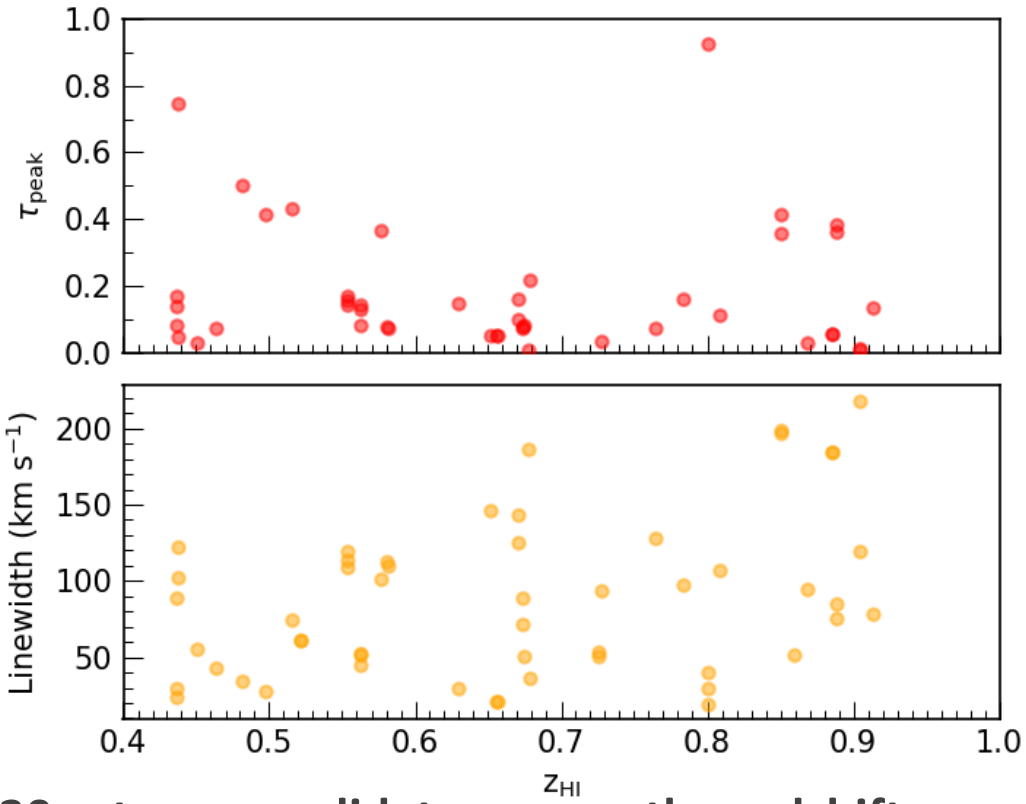




FLASH Pilot Survey data paper in prep

New Detections: HI 21cm absorption lines

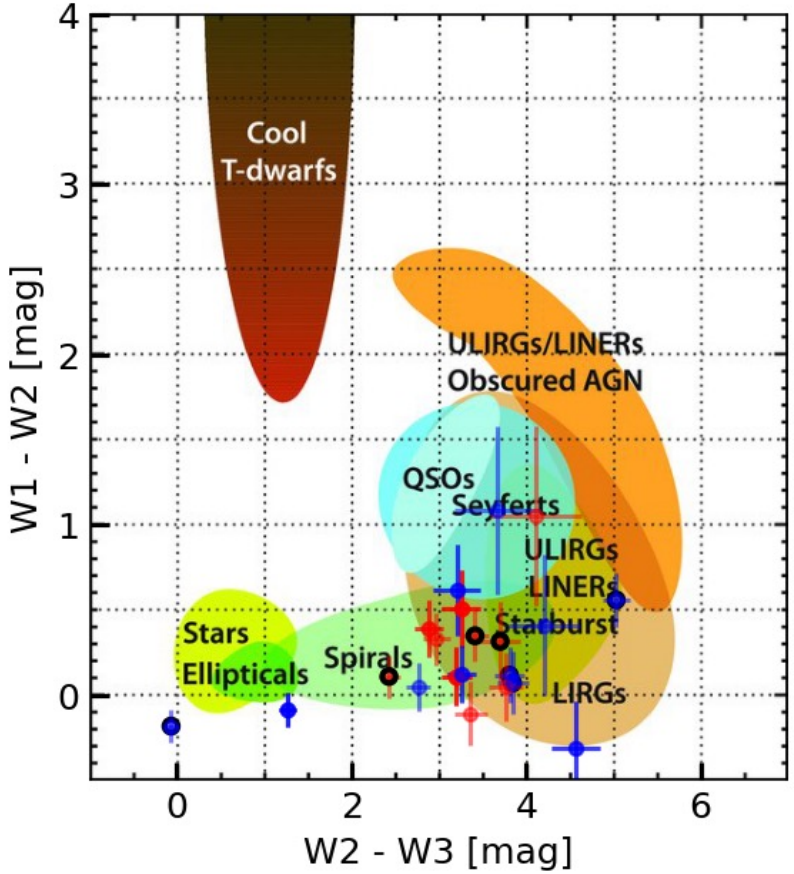




- 30+ strong candidates across the redshift range
- identified by the FLASHfinder (high significance)
- narrow to broad lines (~19 to 218 km/s)
- low to high peak optical depths

Associated vs Intervening Absorbers

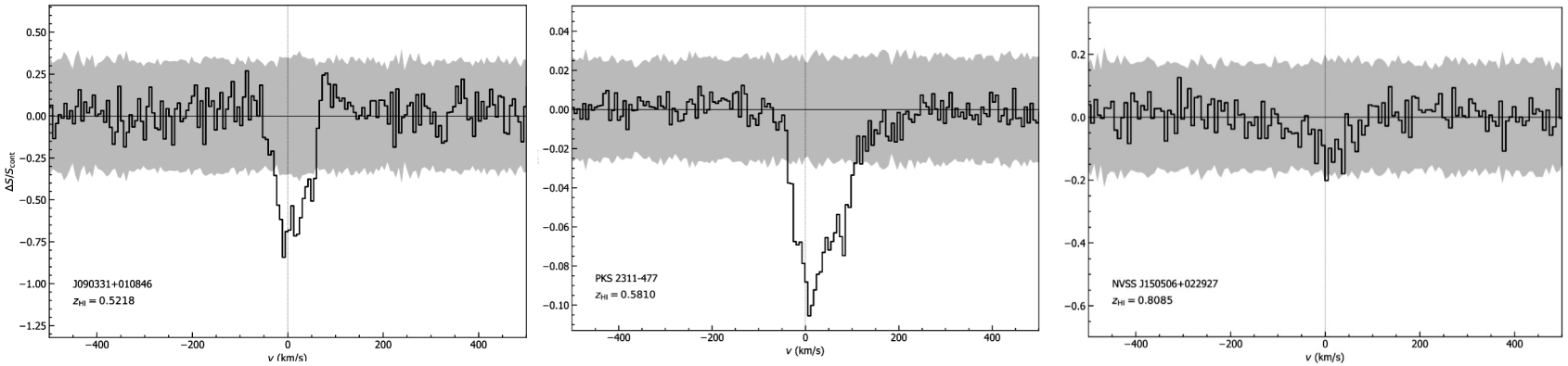
Machine Learning classification of the detected lines (by Stephen Curran)



Yoon et al. in prep

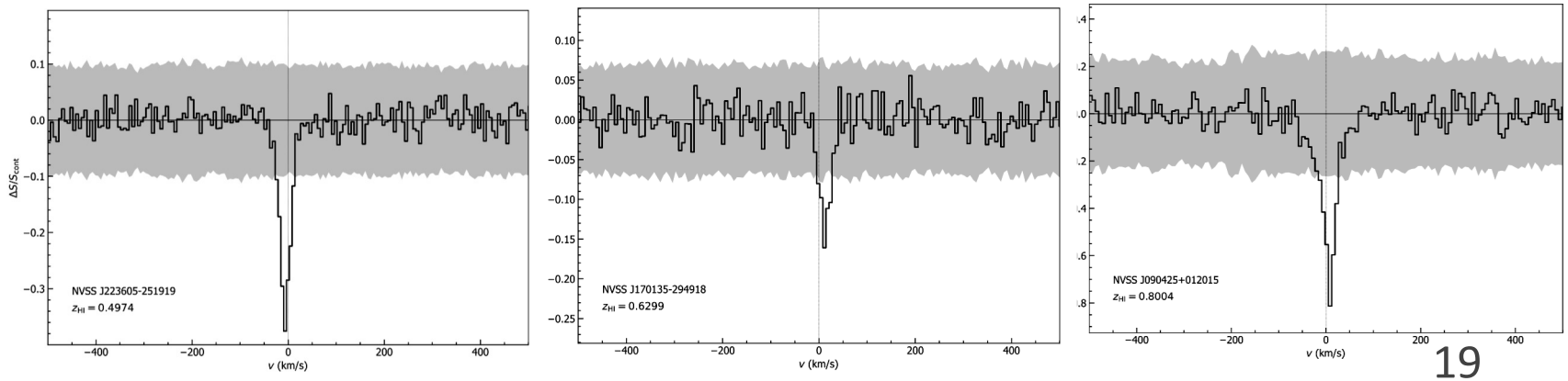
Associated absorbers



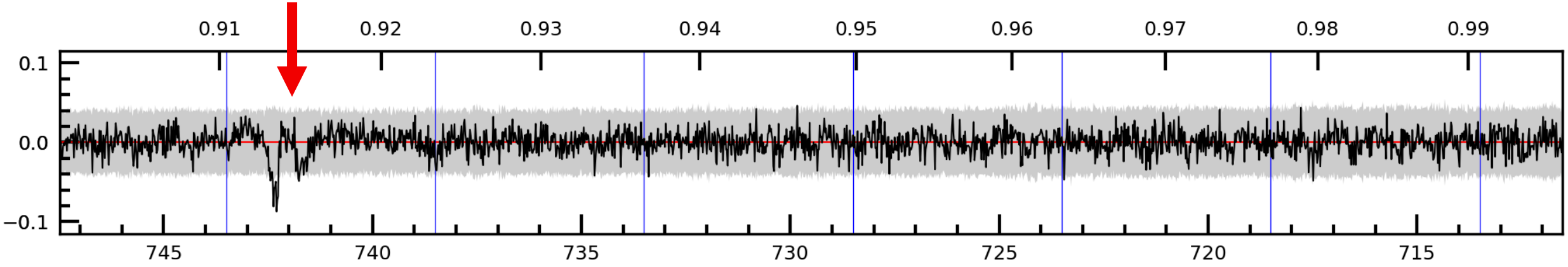


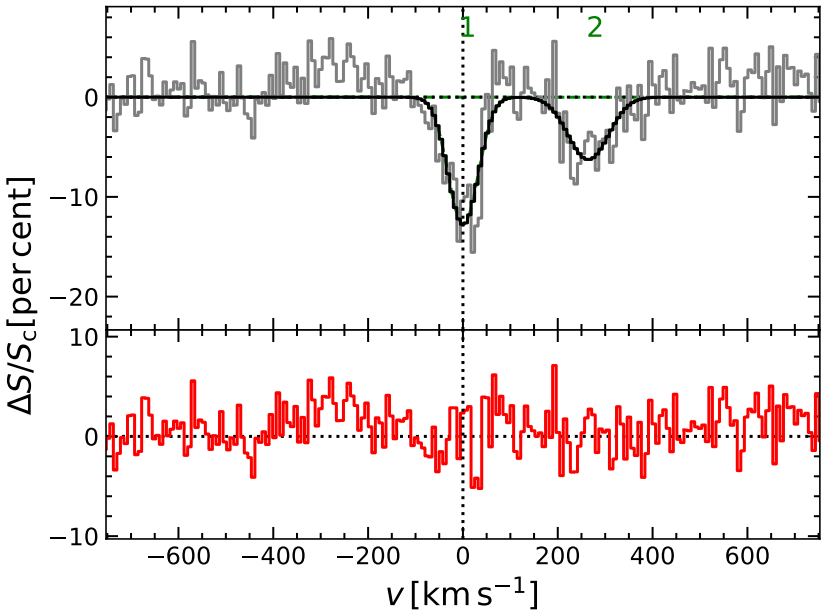
Intervening absorbers

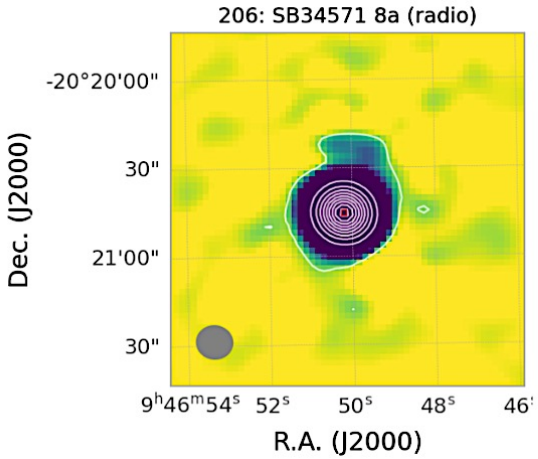


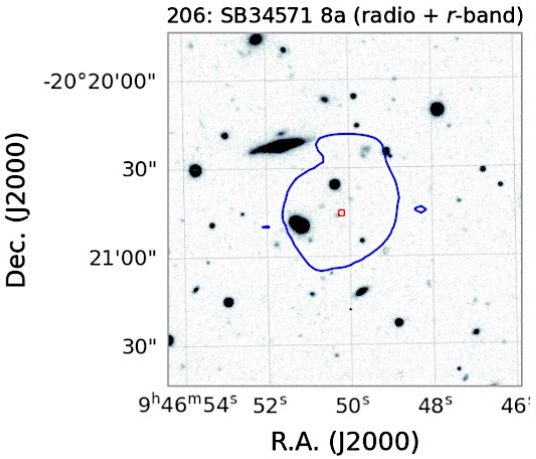


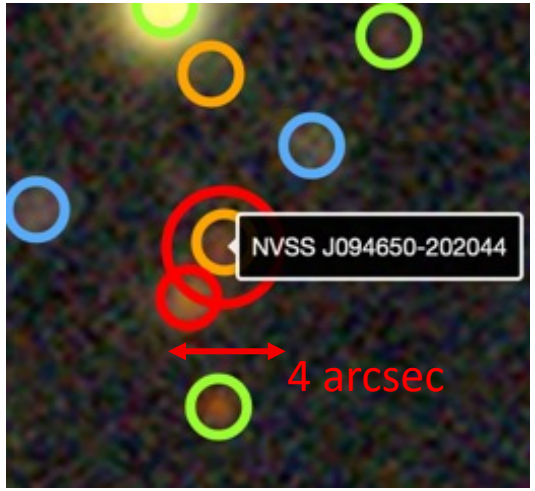
Associated Absorber Candidate: NVSS J094650-20204







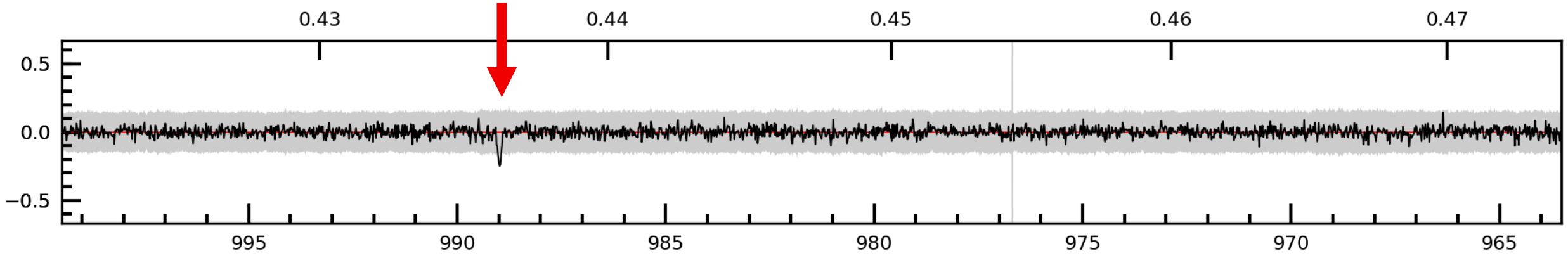


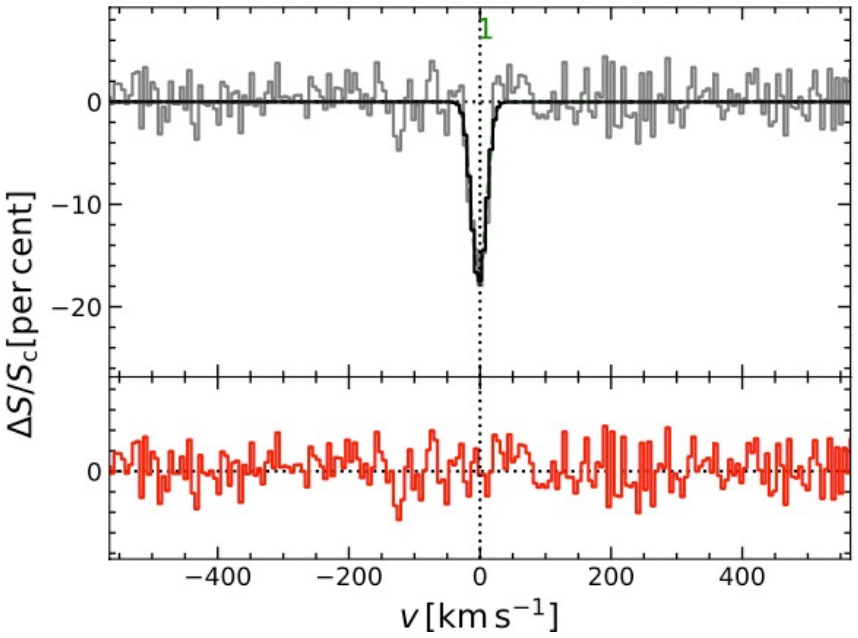


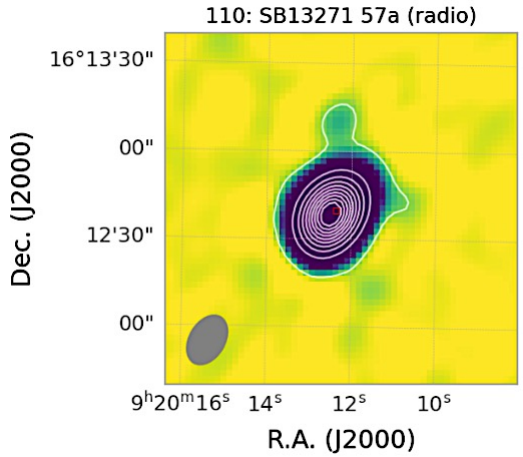
- z ~ 0.9134 (identified by [OII] Brookes et al. 2008)
- F = 550mJy, optical depth = 0.135, Linewidth ~ 78 km/s (left)
- Asymmetric, broad line, multiple components

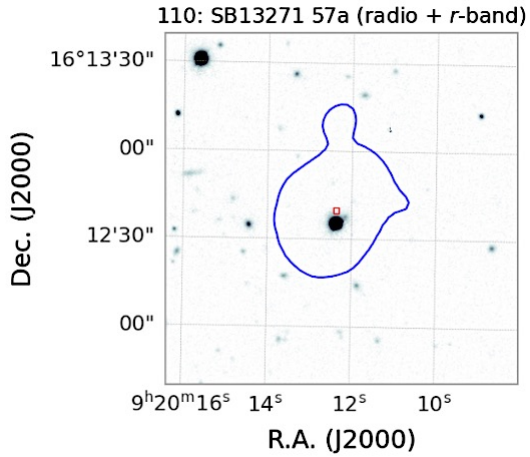
Image: Marcin Glowacki, Elizabeth Mahony

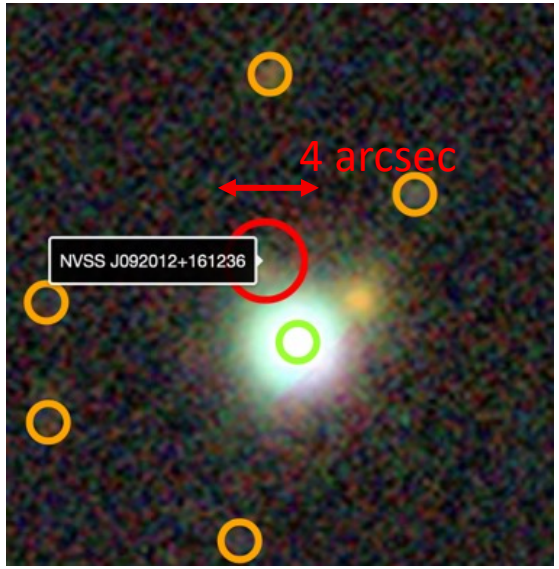
Intervening Absorber Candidate: NVSS J092012+161238











- z ~ 0.4362
- High peak optical depth, 0.38
- Symmetric, narrow line, single Gaussian

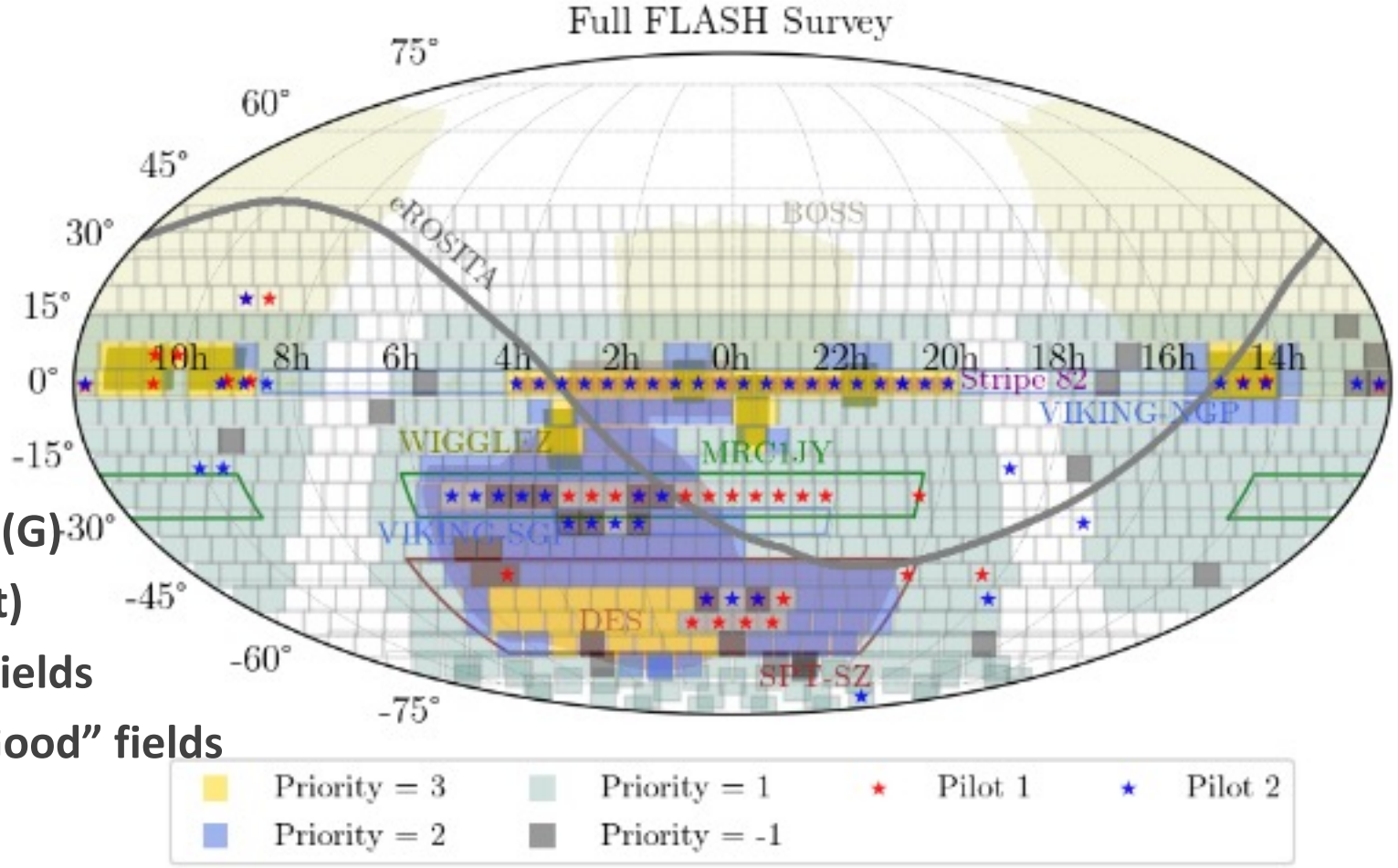
Pilot Survey 1 and 2: Summary and Future Plan

- **Pilot Survey Phase 1 & 2 (~3000 deg^2):**
  - **~30 strong candidates for associated & intervening absorbers**
  - **Spectra: new detections have been found, FLASHfinder tests**
    - associated or intervening HI absorbers (rms 4.5 mJy per channel)
  - **Continuum: high-quality wide field continuum images (36 deg^2, rms = 100 µJy)**
- **Synergy with multi-wavelength observations:**
  - **NTT, Gemini (optical counterpart)**
  - **MeerKAT, GMRT, ATCA (SED, high-resolution spectra)**
  - **KVN, VLBA, LBA, e-MERLIN and more (high-resolution imaging)**

FLASH Full Survey

5 years FLASH Full Survey
(Late 2022 - 2028)

- 600 fields (~25,000 deg^2)
  - Priority 3: Stripe 82, WiggleZ, DES (G)
  - Priority 2: WiggleZ (rest), DES (rest)
  - Priority 1: Rest, Pilot “uncertain” fields
  - Priority -1: Bright sources, Pilot “Good” fields



- Sky: DEC < + 15 deg. |b| > 8.5 deg.
- Total time: 1200 hrs (2 hr/field)
- Redshift range: 0.42 < z < 1.00

As of now:
42 fields (7%) have been released
(600 fields * 600 spectra/field= ~ 360,000 spectra)

CASDA and Guest Science Time

- **Data Products: released on CASDA**
  - **CSIRO ASKAP Data Access Portal (https://data.csiro.au/)**
  - **e.g. code: “109” for the pilot survey 1 & 2, “209” for the full survey**



  - **TOPCAT, astroquery tap**
- **Guest Science Proposals (Due: 15 June, 15 Dec)**
  - **Since 15 Dec 2022**
  - **~10 % of total observing time**