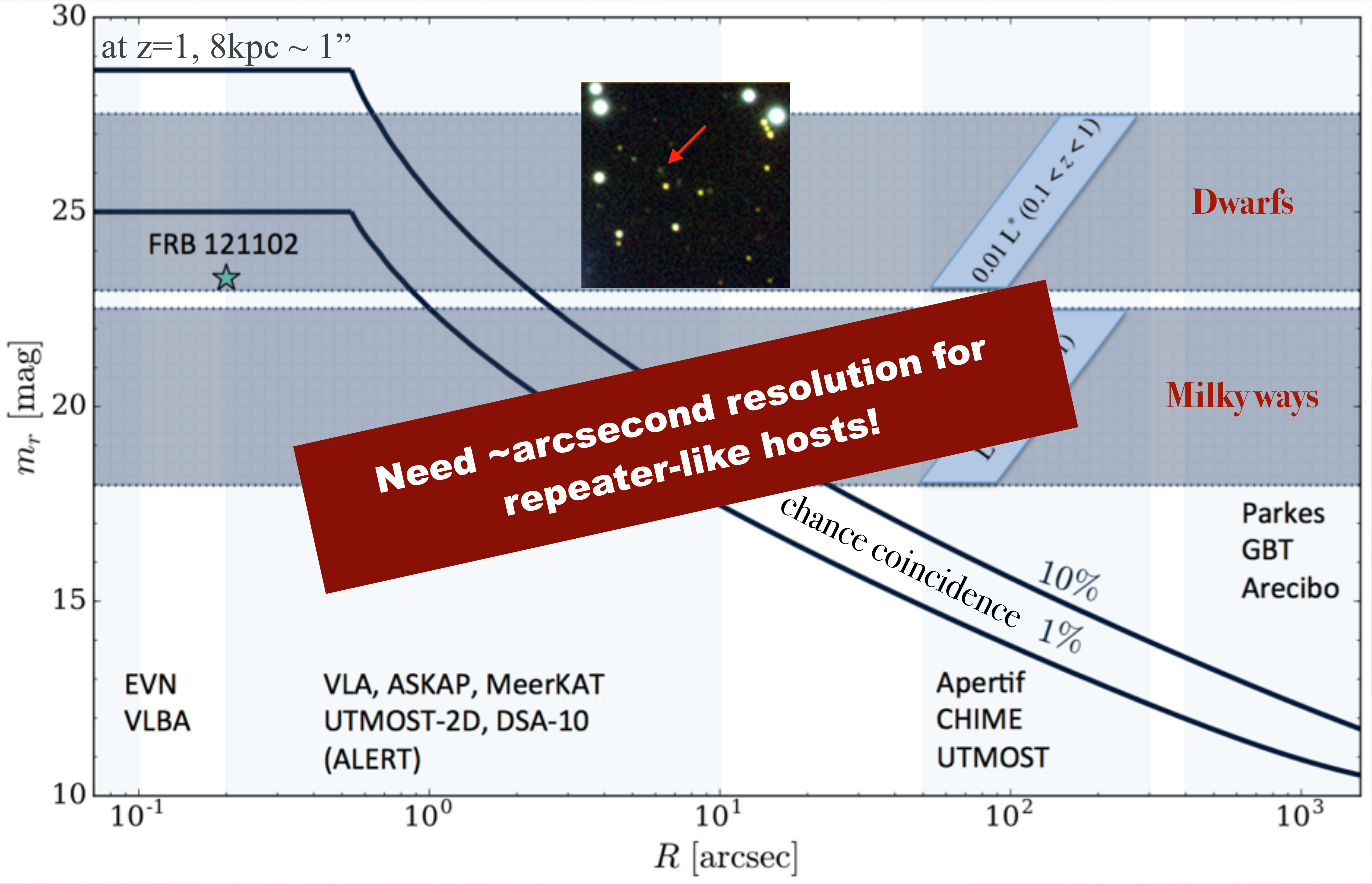
realfast At the

Karl G. Jansky Very Large Array (VLA)

S. Burke-Spolaor
West Virginia University
with Casey Law, Kshitij Aggarwal, Bridget Andersen, Geoffrey Bower, Bryan Butler, Paul Demorest, Joseph Lazio, Michael Rupen

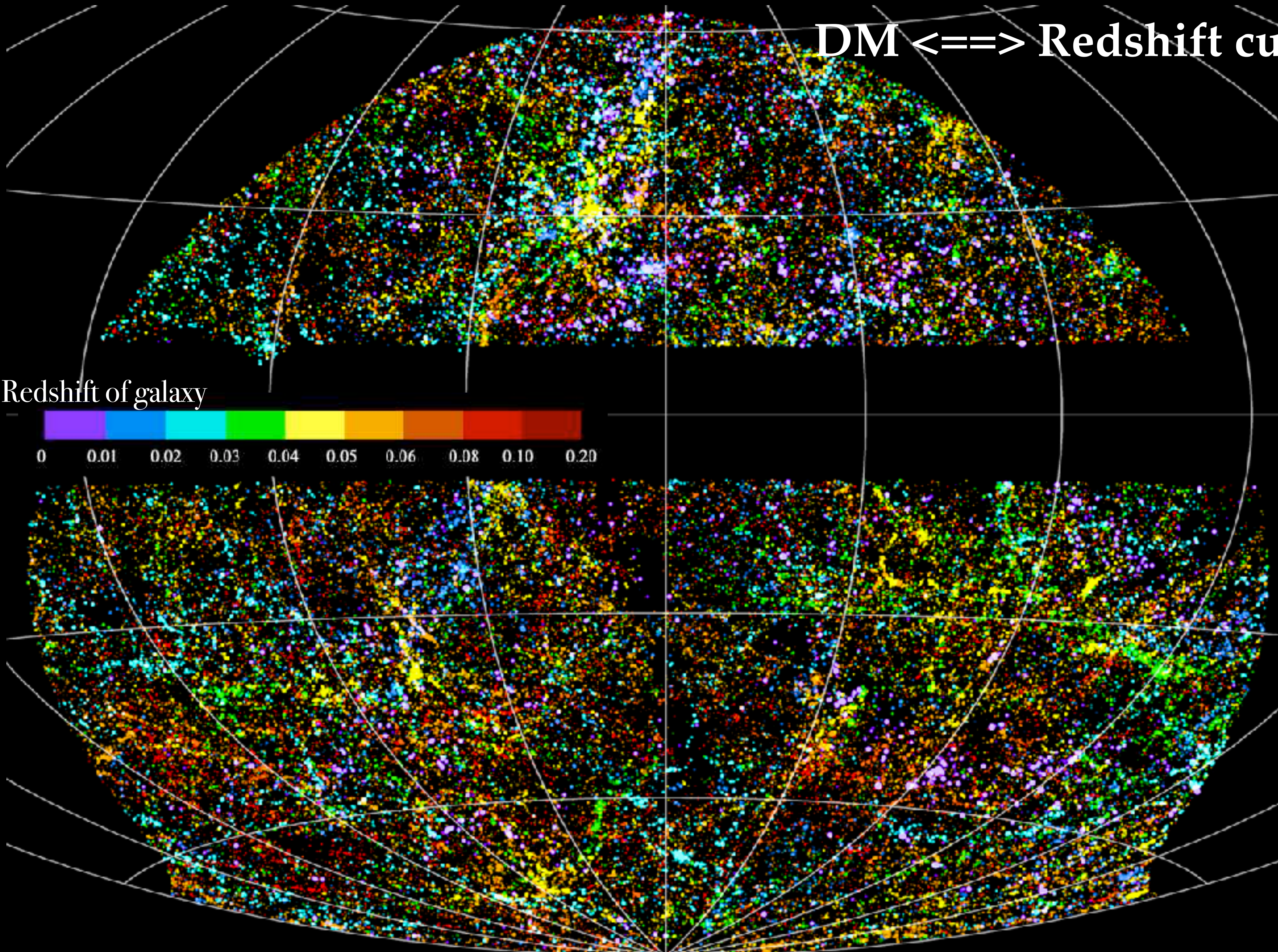
Realfast: **Real**-time **fast** transients on the VLA.

Localization



Eftekhari & Berger (2017)

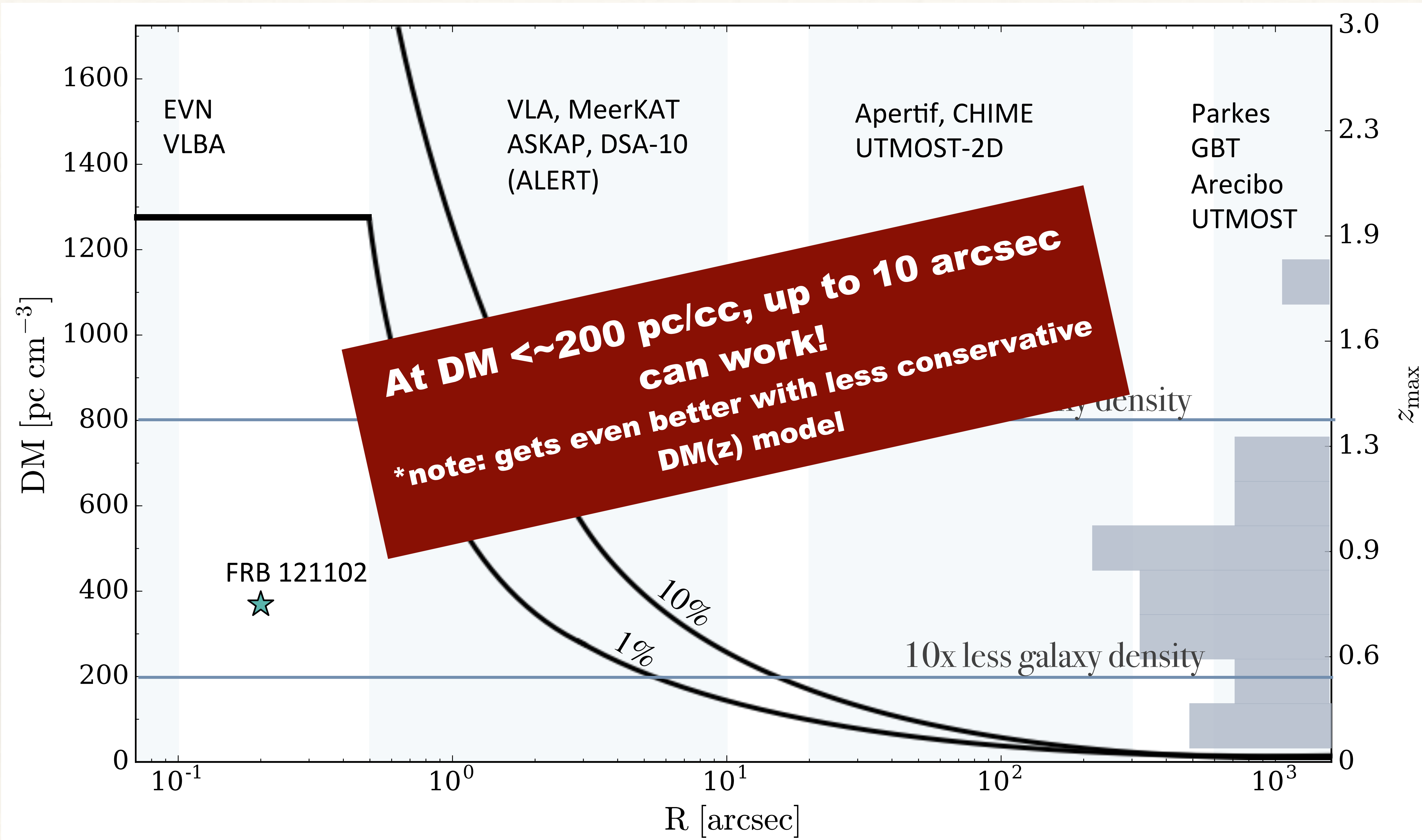
DM <==> Redshift cut



Galaxies in 6dF redshift survey

credit T. Jerrett

Localization



Eftekhari & Berger (2017)

Since last year…

- **2017 "Axes of awesome":**
  - **Sensitivity.**
  - **Localization.**
- **Now add:**
  - **Polarization calibration.**
  - **Voltages for resolving structure.**
  - **Field of view vs. SEFD trade-off: probe FRB evolution**

Our FRB science playing field.

FRB params:

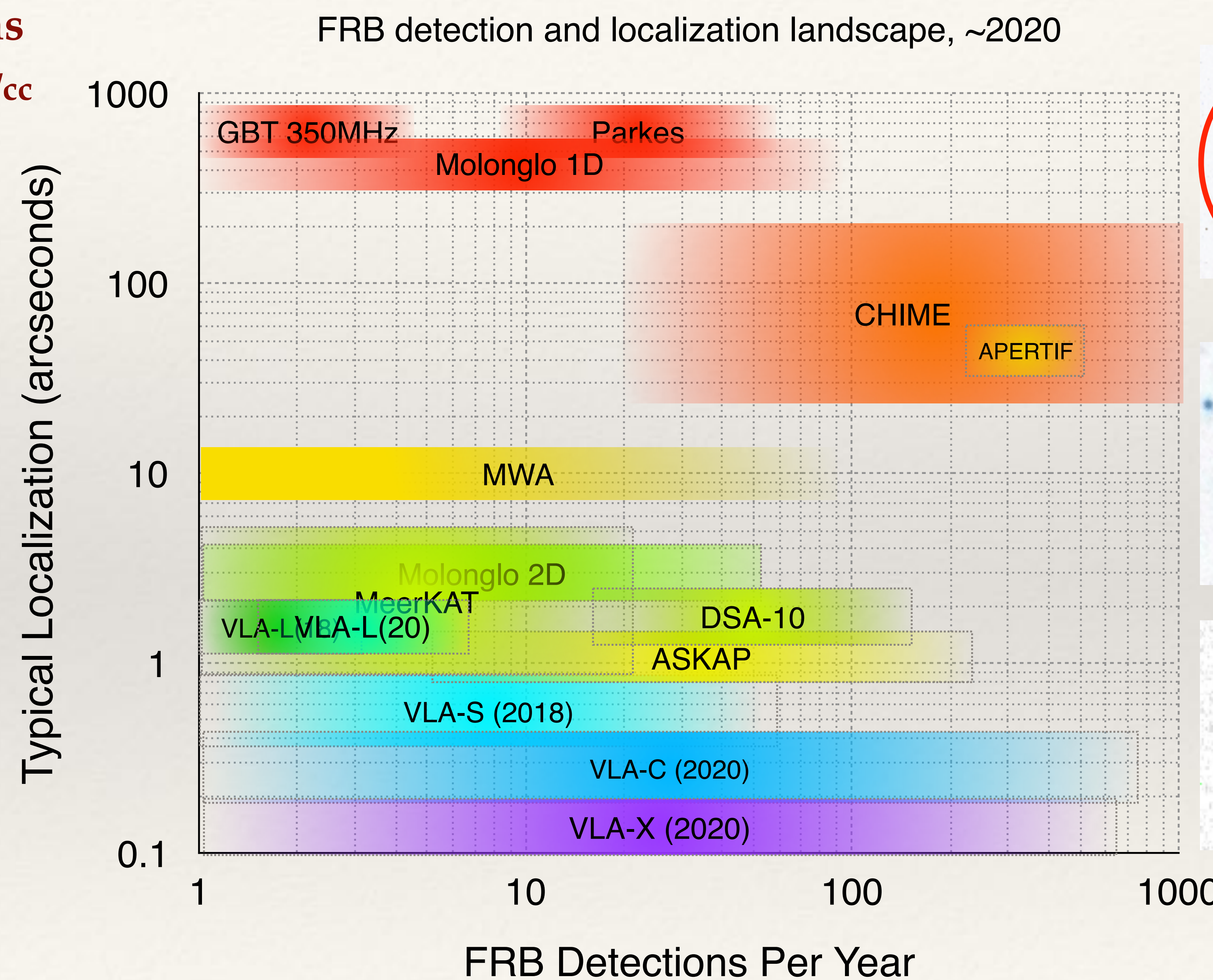
$100\text{us} < w_{int} < 3\text{ms}$

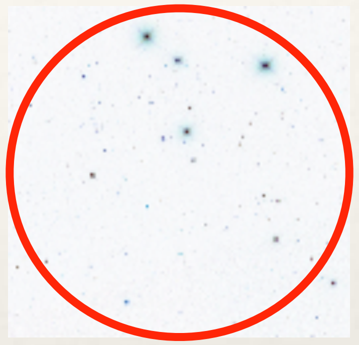
$0 < \tau_{scat}\ (1\text{GHz}) < 3\text{ms}$

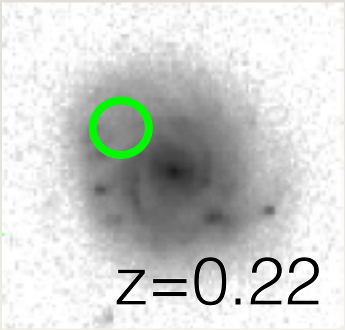
$\langle DM_x \rangle = 400\text{-}800\ \text{pc/cc}$

$-1.5 < \gamma < -0.5$

$-1.0 < \alpha < 2.0$







Our FRB science playing field.

FRB params:

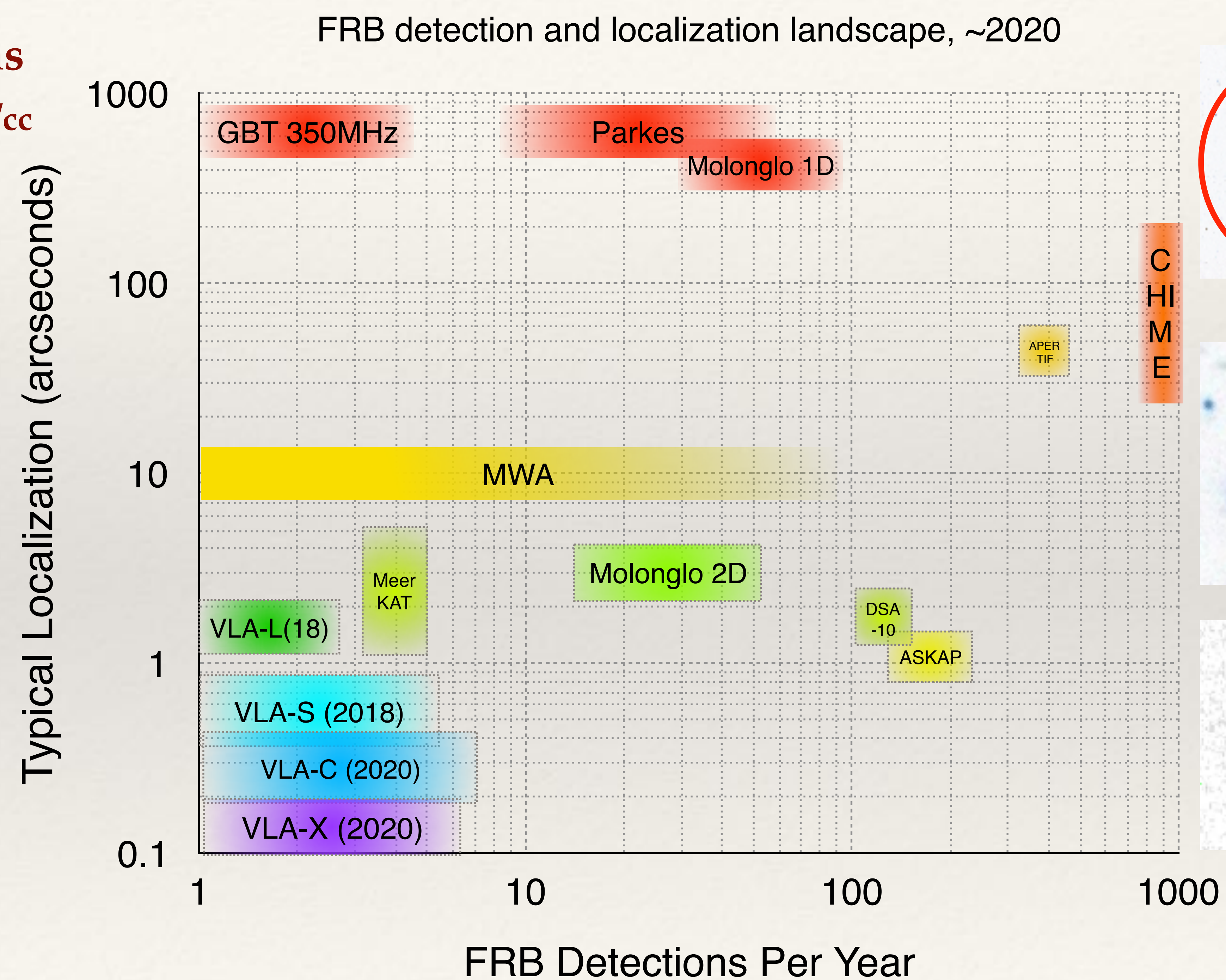
100us < w_{int} < 3ms

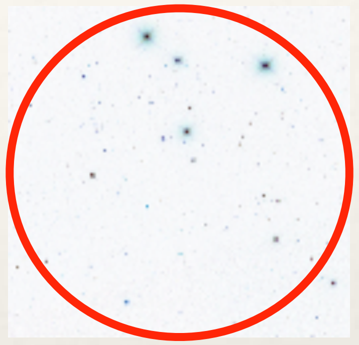
0 < τ_{scat} (1GHz) < 3ms

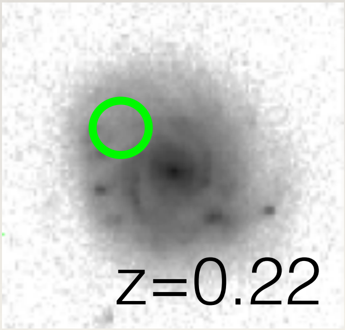
<DM_x> = 400-800 pc/cc

-1.0 < α < 2.0

γ = -0.5







Our FRB science playing field.

FRB params:

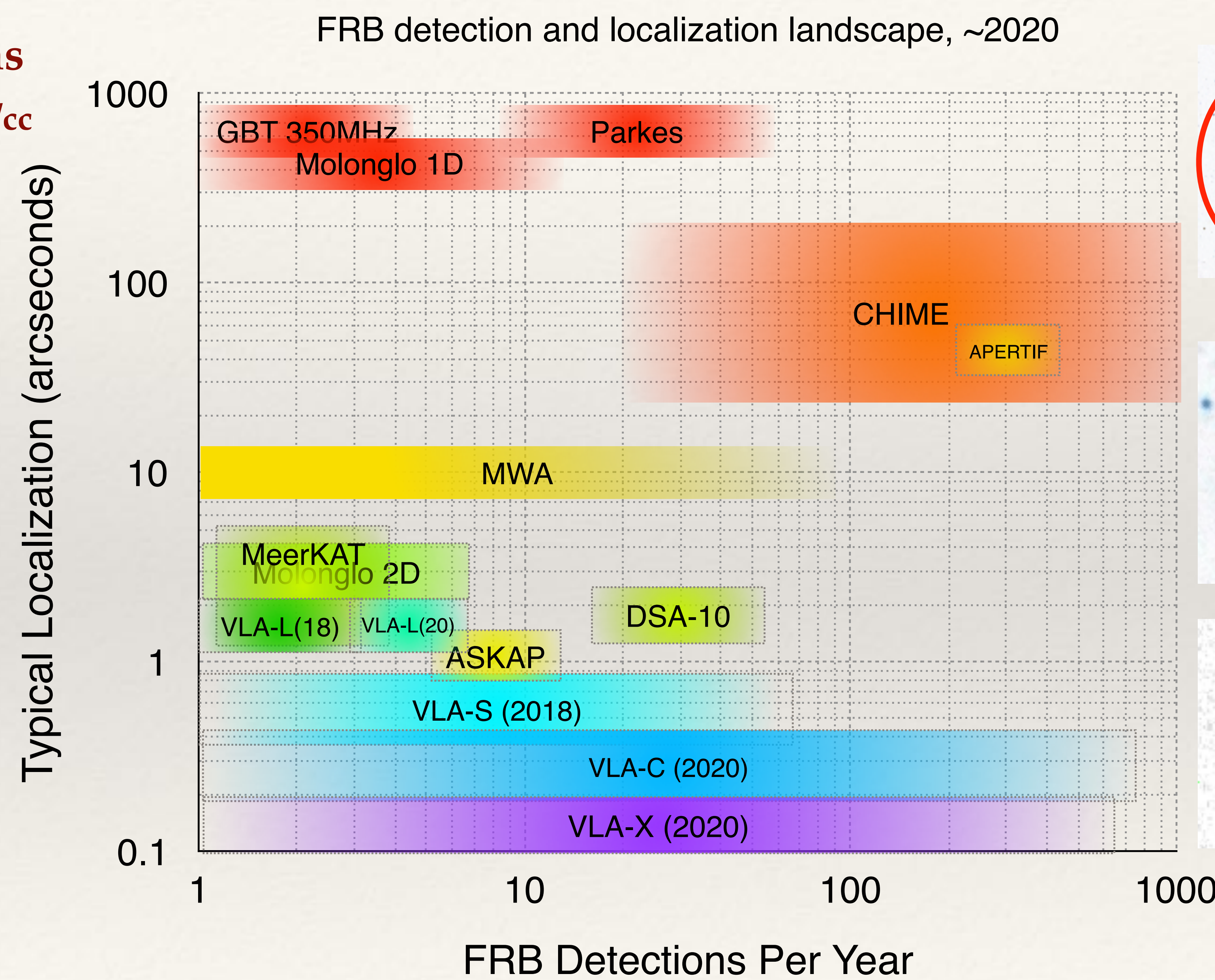
$100us < w_{int} < 3ms$

$0 < \tau_{scat}$ (1GHz) $< 3ms$

$<DM_x> = 400\text{-}800$ pc/cc

$-1.0 < \alpha < 2.0$

$\gamma = -1.5$



Our FRB science playing field.

FRB params:

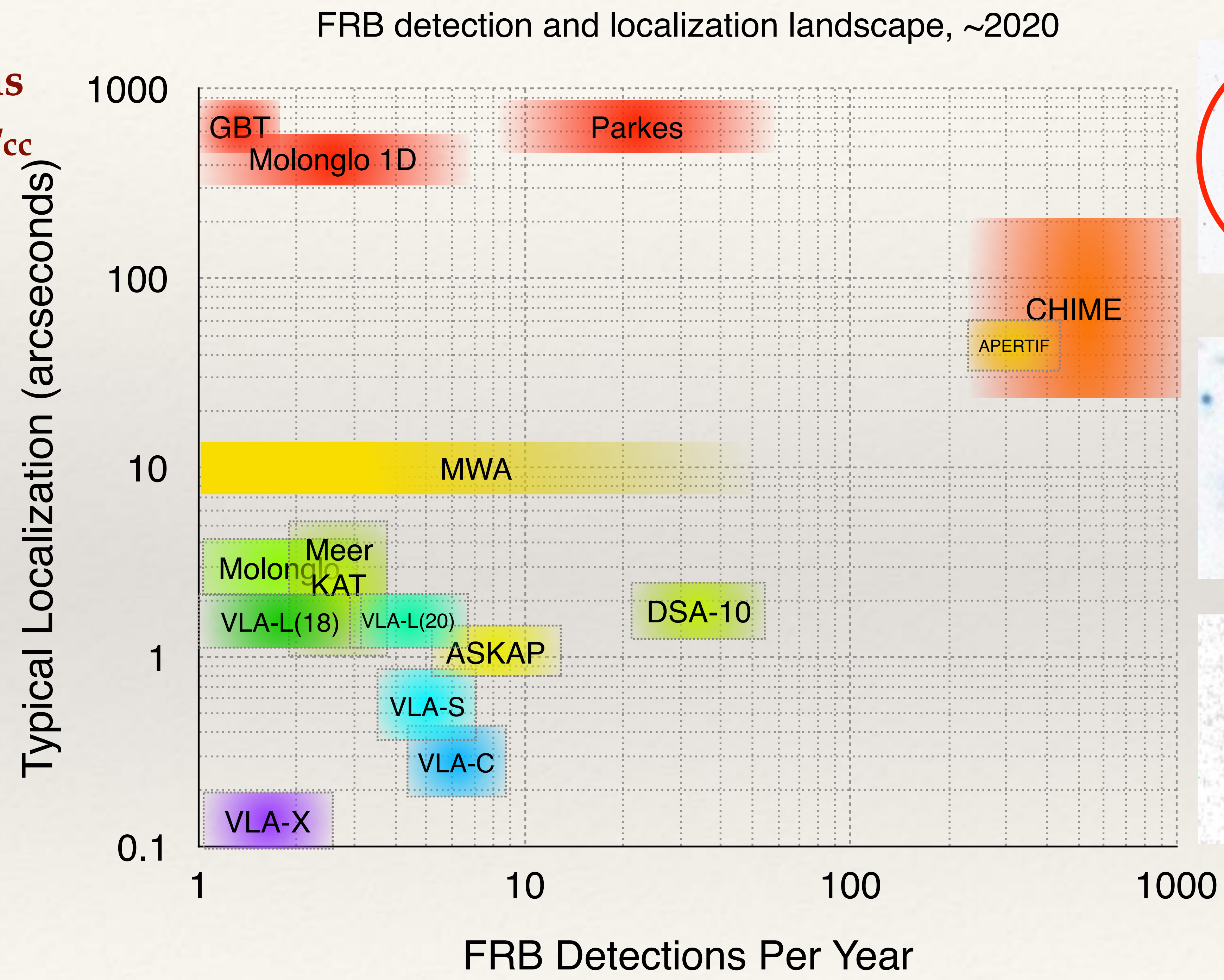
$100us < w_{int} < 3ms$

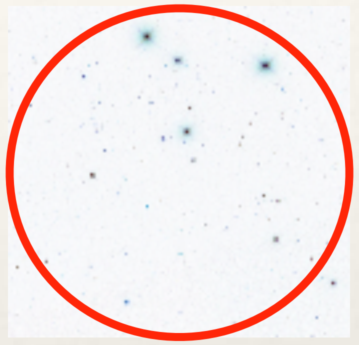
$0 < \tau_{scat}(1GHz) < 3ms$

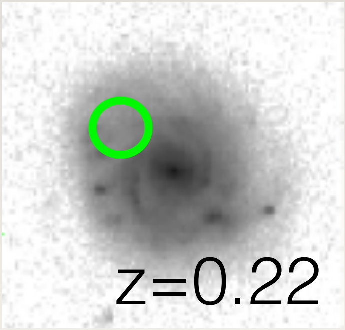
$\langle DM_x \rangle = 400\text{-}800$ pc/cc

$\gamma = -1.5$

$\alpha = 0.0$







Our FRB science playing field.

FRB params:

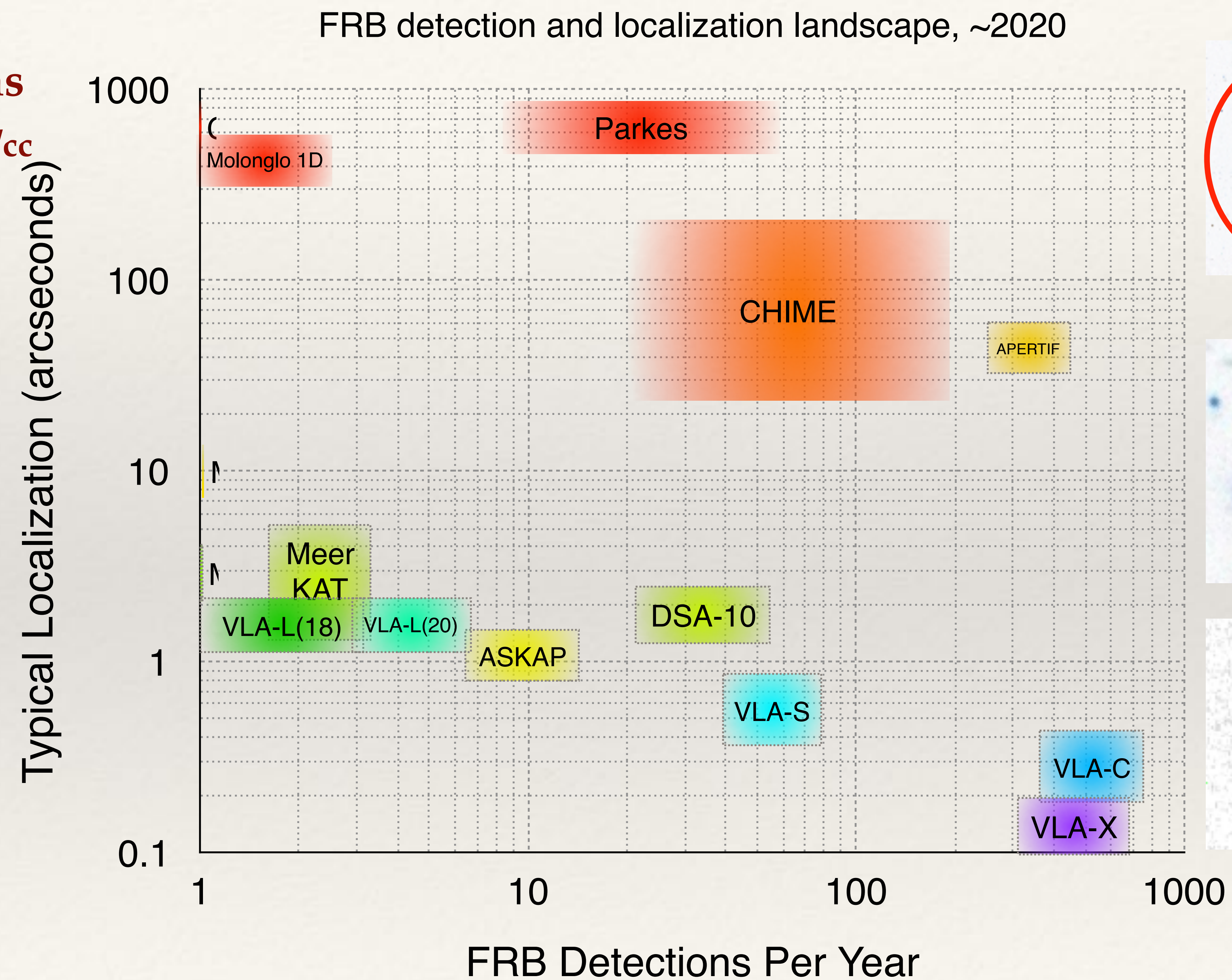
$100us < w_{int} < 3ms$

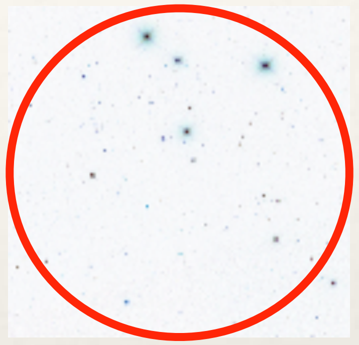
$0 < \tau_{scat}(1GHz) < 3ms$

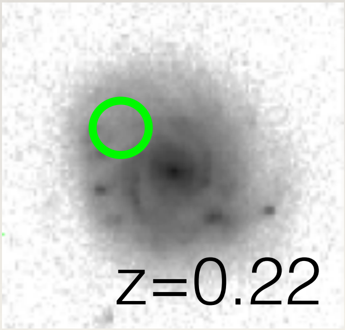
$\langle DM_x \rangle = 400\text{-}800$ pc/cc

$\gamma = -1.5$

$\alpha = +2.0$

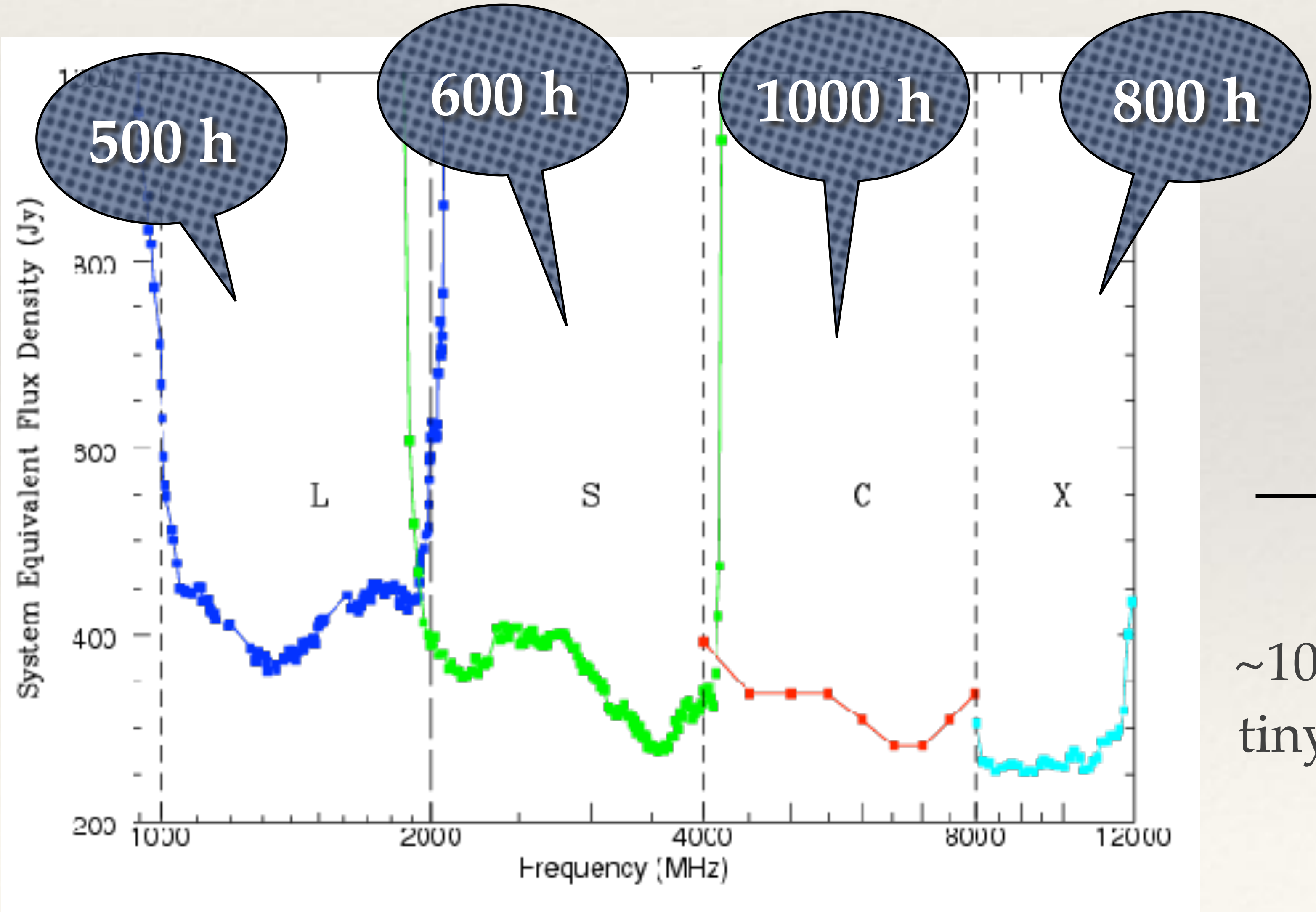






The Very Large Array

Recently upgraded!
Continuous bandwidth coverage!
Super-fancy!

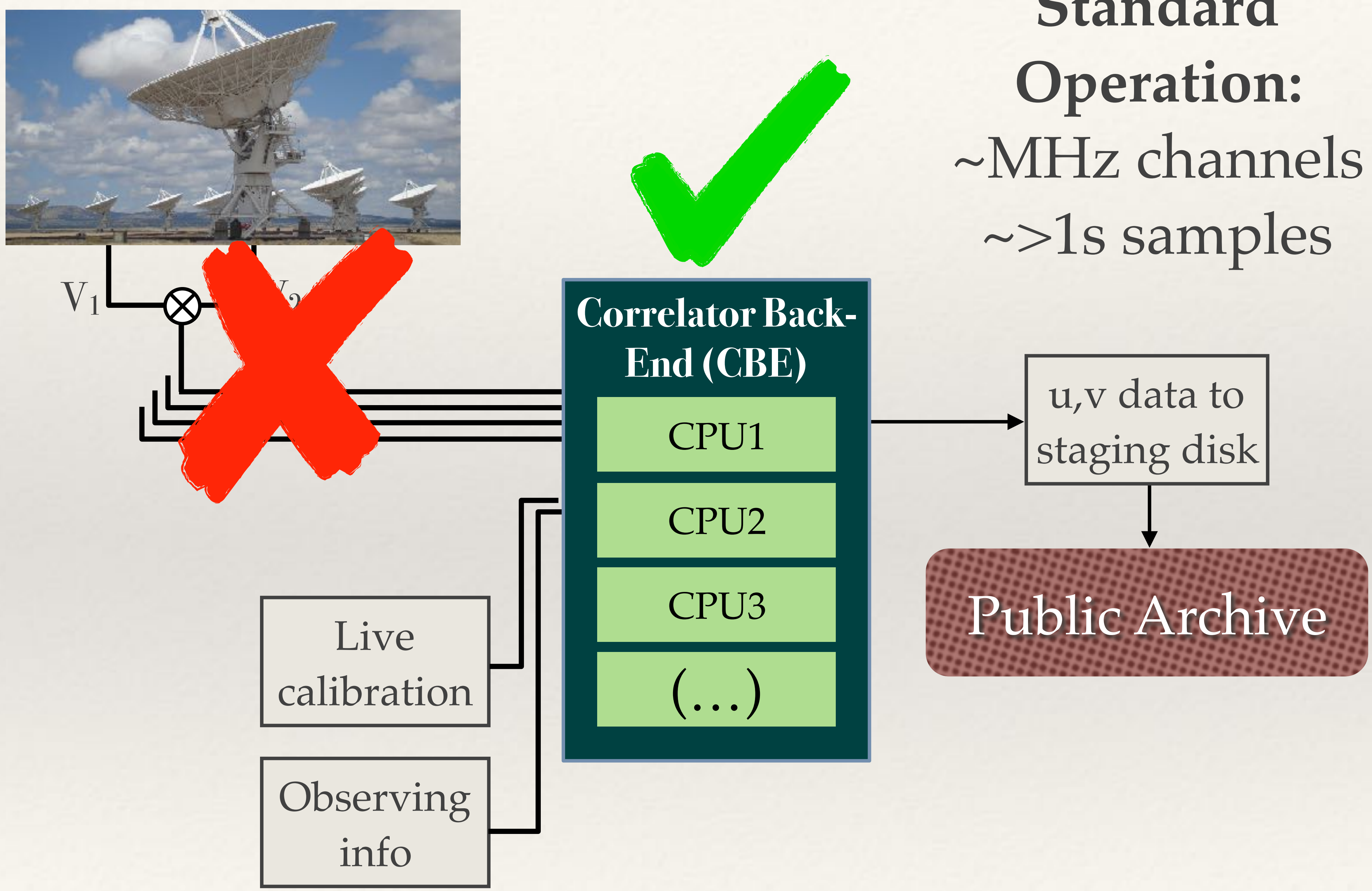


On-target time per year

12-50 GHz: ~1000 h / year but tiny field of view

Signal chain

Standard Operation:
~MHz channels
~>1s samples



realfast prototype

Signal ch

Write speed limit!

L-band (1GHz):
244 MHz bandwidth
(1/4 of available)

S-band (3GHz):
1000 MHz bandwidth
(1/2 of available)

Operation:

f_{center} = 1.5, 3, 6 GHz

256 channels
~5ms samples

C
p

ata

ta

Corr

Processing speed limit:
2-6 h per day of observing to keep up!

ed back
CBE

-sample
,v data on
staging disk

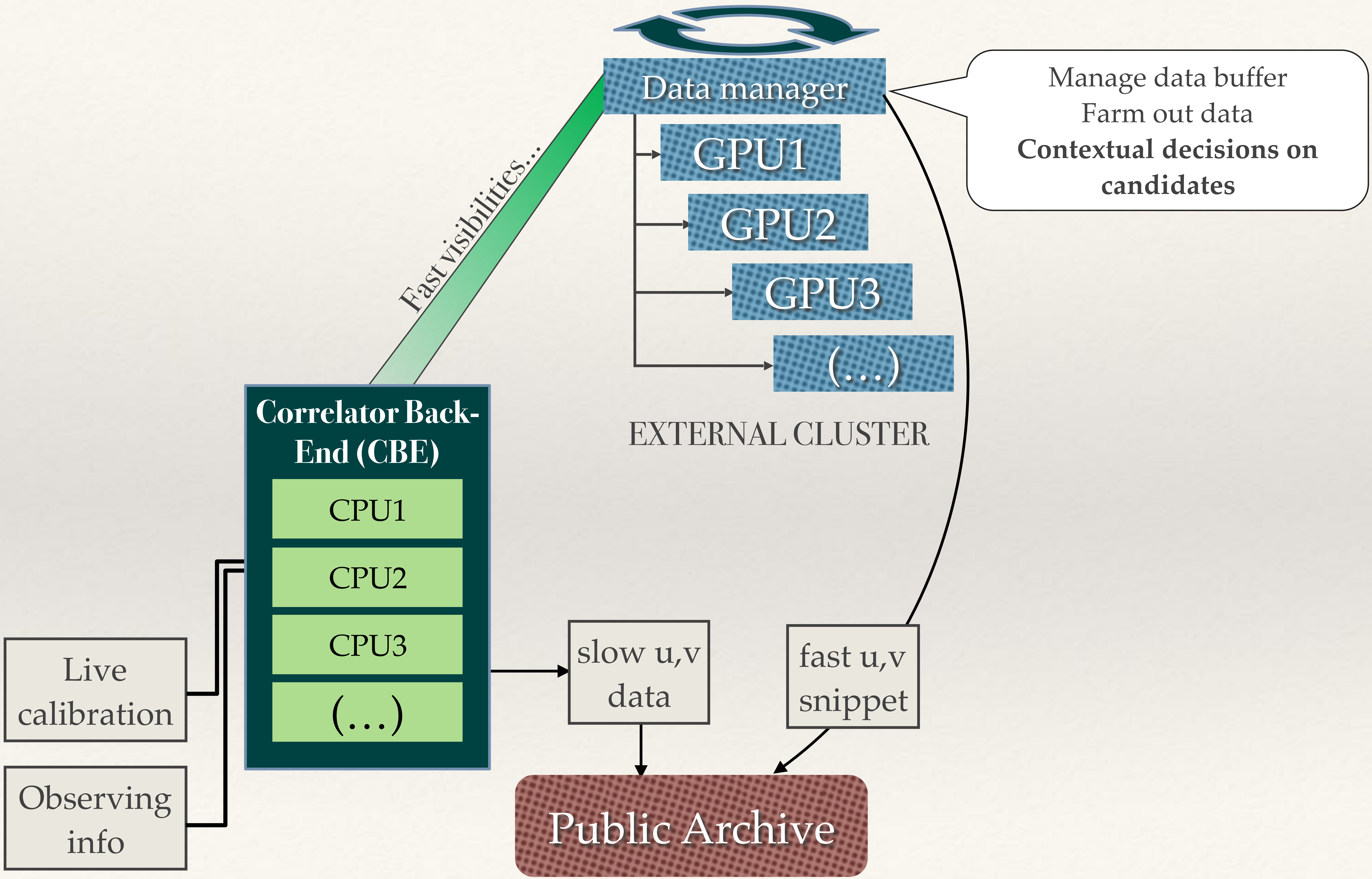
Live calibration

Observing info

Each node:
Flag, calibrate.
Dedisperse the VISIBILITIES.
2D FFT to make IMAGES.
Search image.
Save significant time segments.

Public Archive

Signal chain

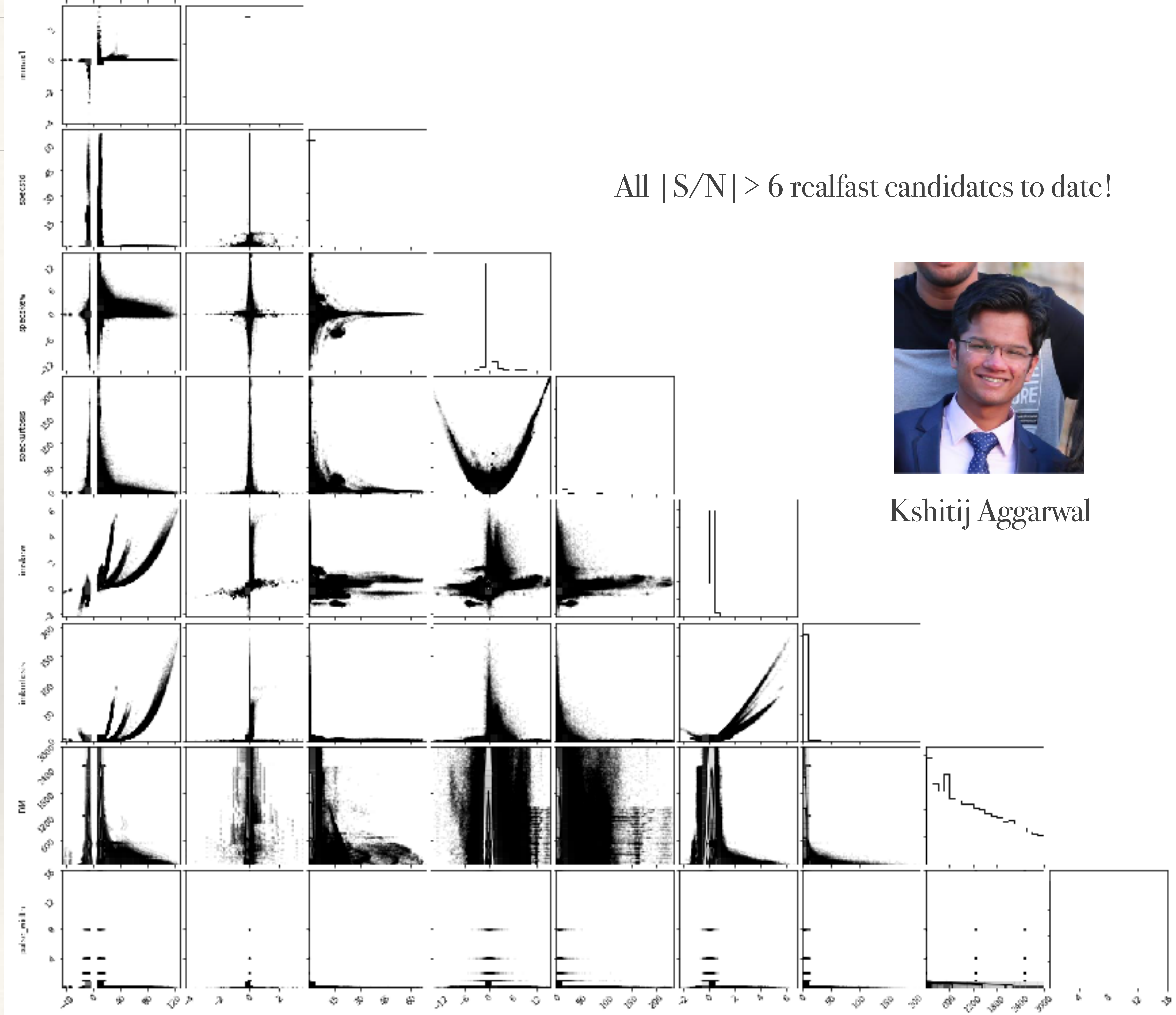


really realfast with commensal observing

- **More time: 150h/year —> ~3000h/year!**
- **More sensitivity: larger bandwidth/shorter sampling**
- **Required:**
  - Changes to VLA CBE pipeline (visibility "spigot").
  - GPU pipeline (currently benchmarking).
  - GPUs and infiniband (Installation in March).
  - Commissioning L, S, C, X; pushing faster.

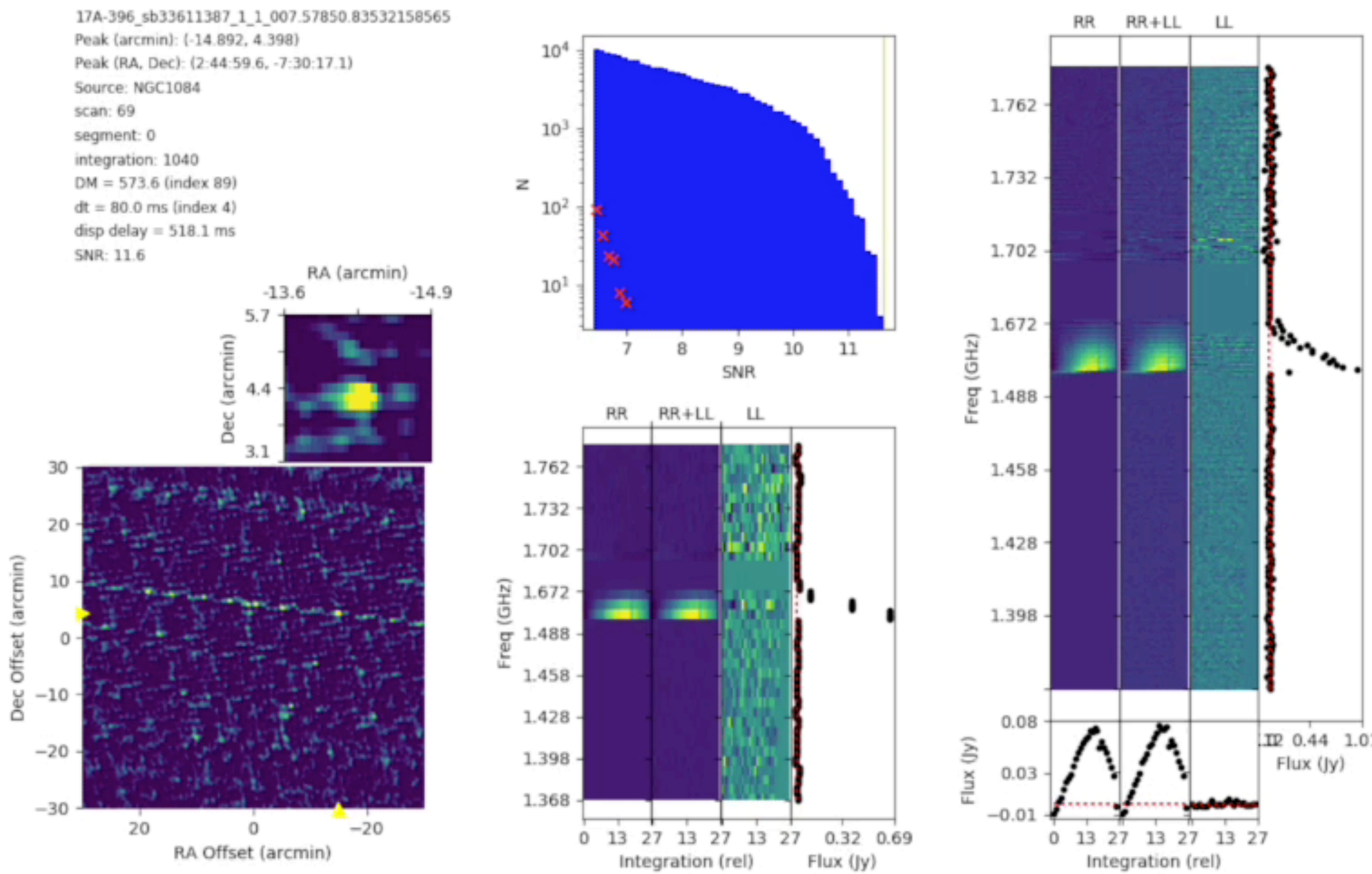
Realfast Perks

- Thousands of hours/year, large frequency range.
- Calibration well-understood.
- Correlation: minimal RFI filtering required!
- Slow sampled data for free.
- Connection to nearby multi-λ facilities (and shared CHIME sky!).
- Instant localization.



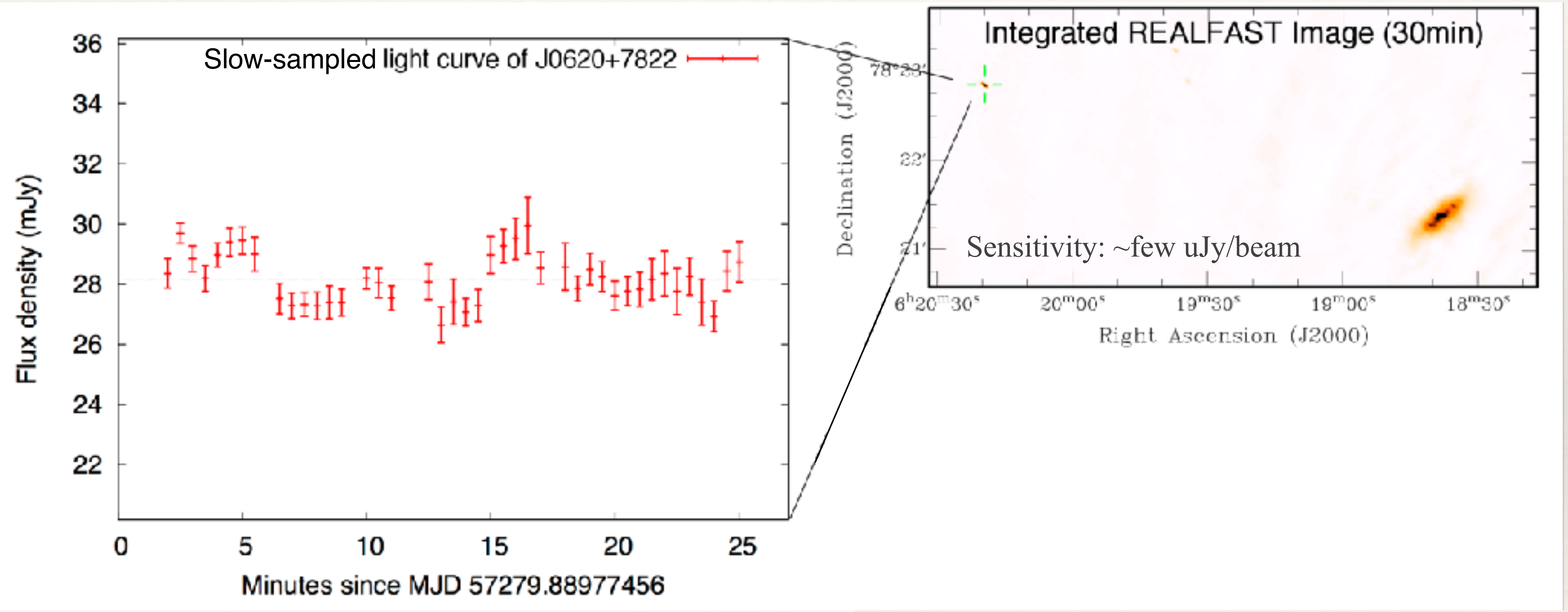
All |S/N| > 6 realfast candidates to date!

Kshitij Aggarwal

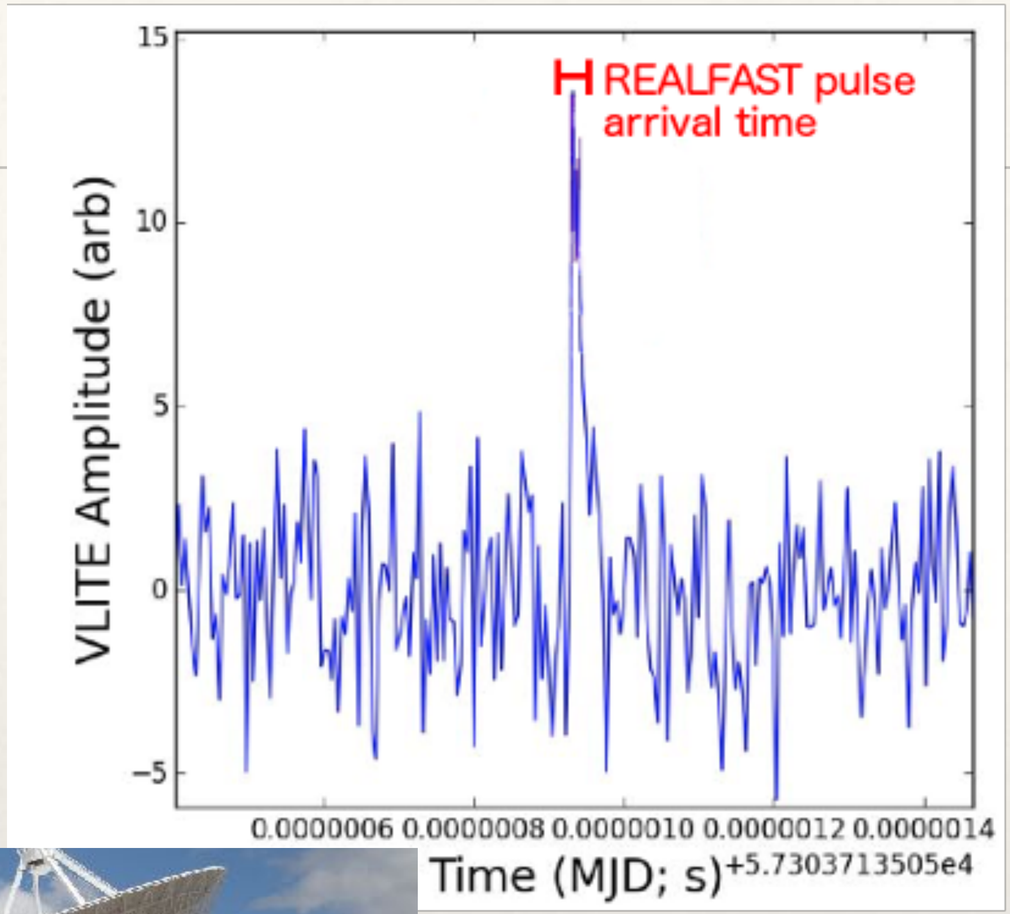


17A-396_sb33611387_1_1_007.57850.83532158565
Peak (arcmin): (-14.892, 4.398)
Peak (RA, Dec): (2:44:59.6, -7:30:17.1)
Source: NGC1084
scan: 69
segment: 0
integration: 1040
DM = 573.6 (index 89)
dt = 80.0 ms (index 4)
disp delay = 518.1 ms
SNR: 11.6
RA (arcmin)
Dec (arcmin)
Dec Offset (arcmin)
RA Offset (arcmin)
N
SNR
RR
RR+LL
LL
Freq (GHz)
Integration (rel)
Flux (Jy)

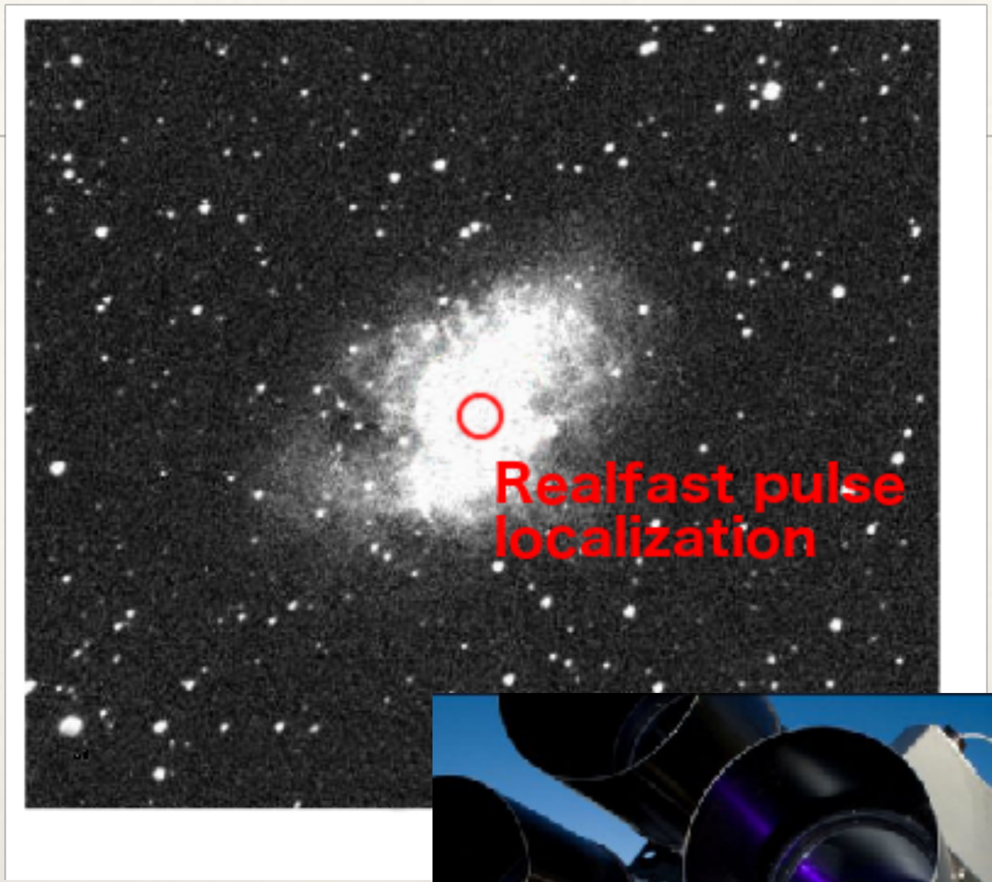
Slow-sampled data for free



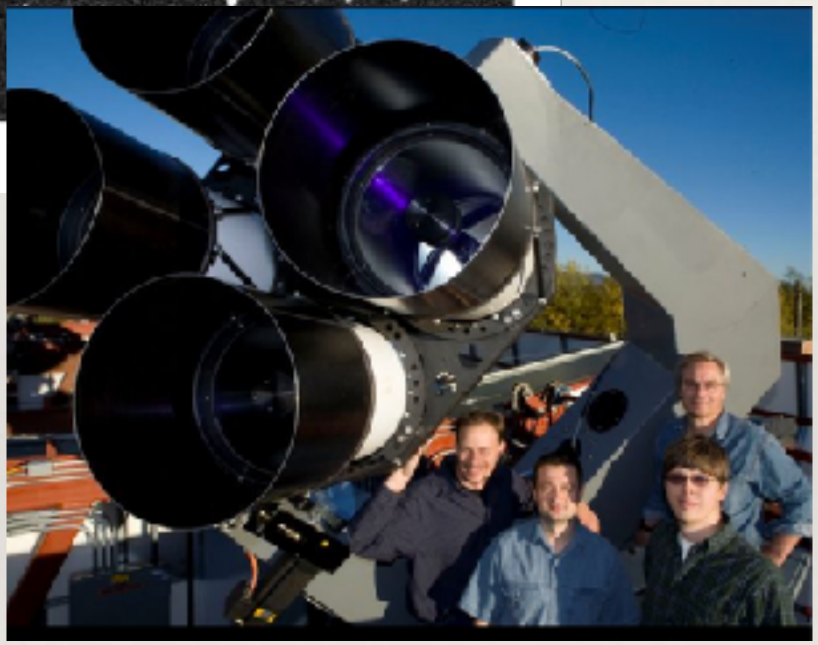
Triggered VLITE (350MHz) Detection



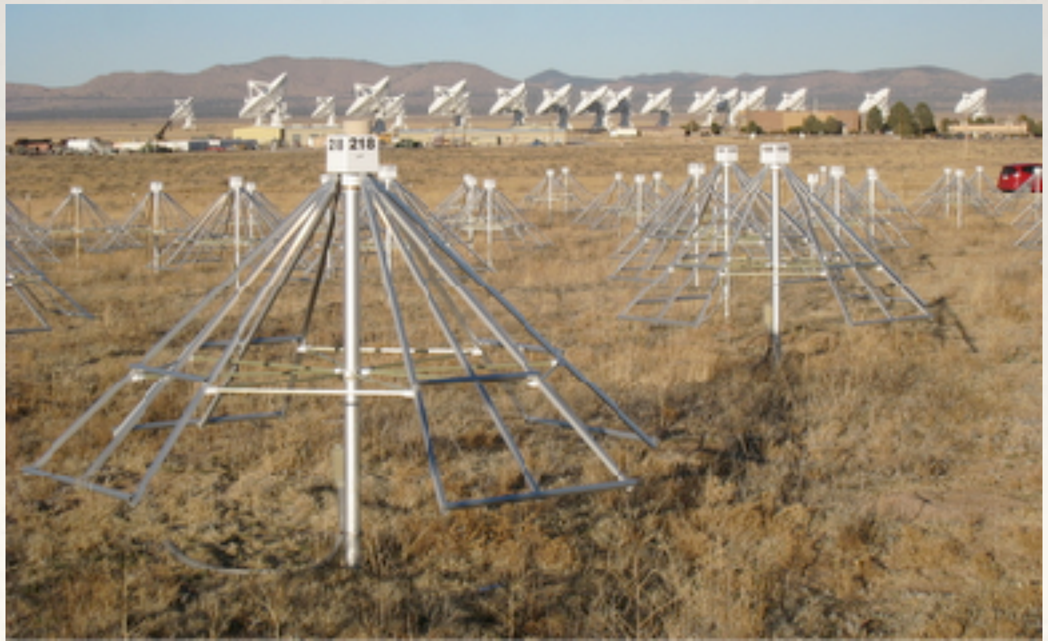
Simultaneous RAPTOR Optical Image



Realfast: 1.5 GHz
VLITE: 350 MHz



Also involved, not shown:

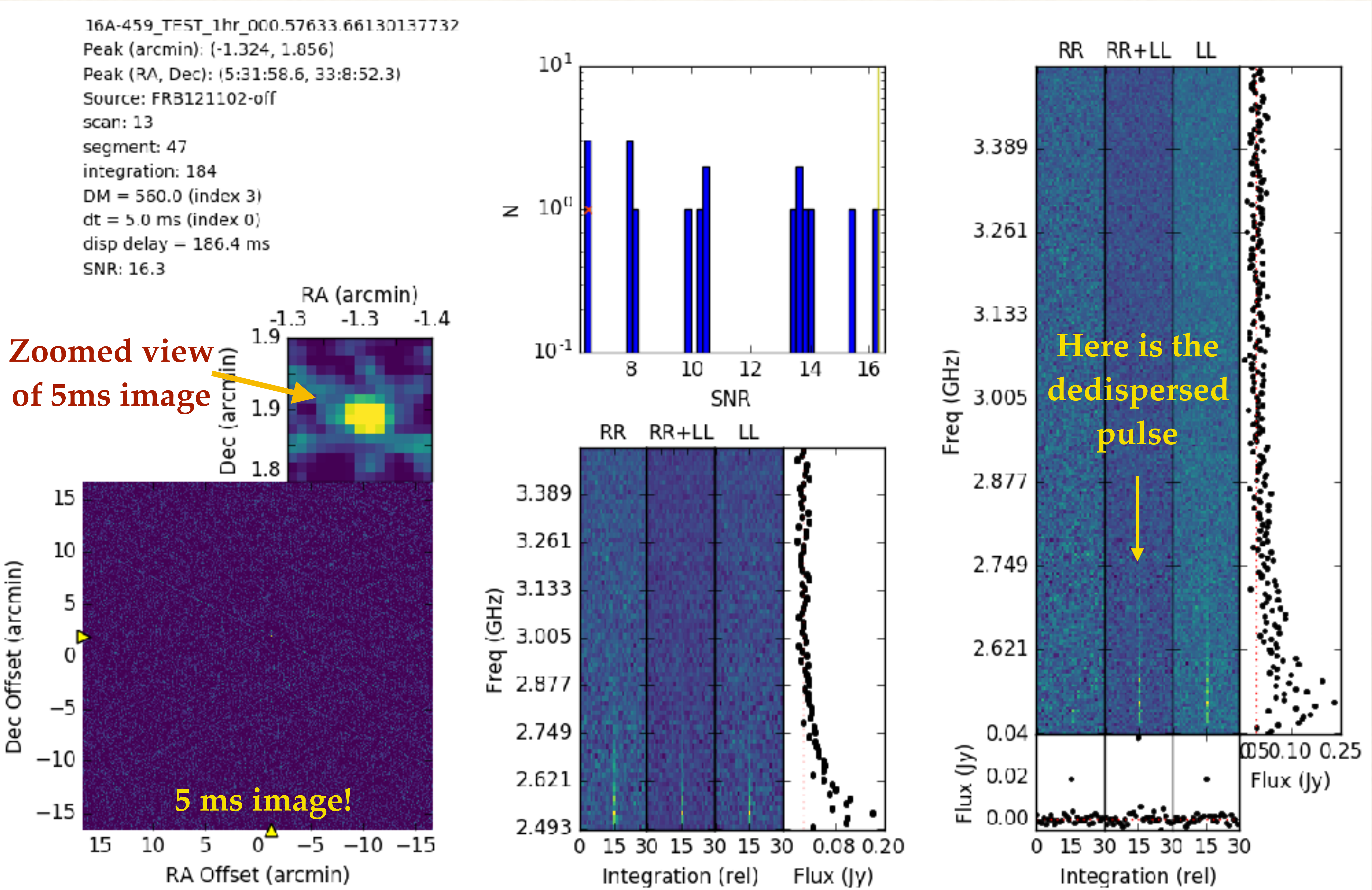


Long Wavelength Array (~100 MHz)

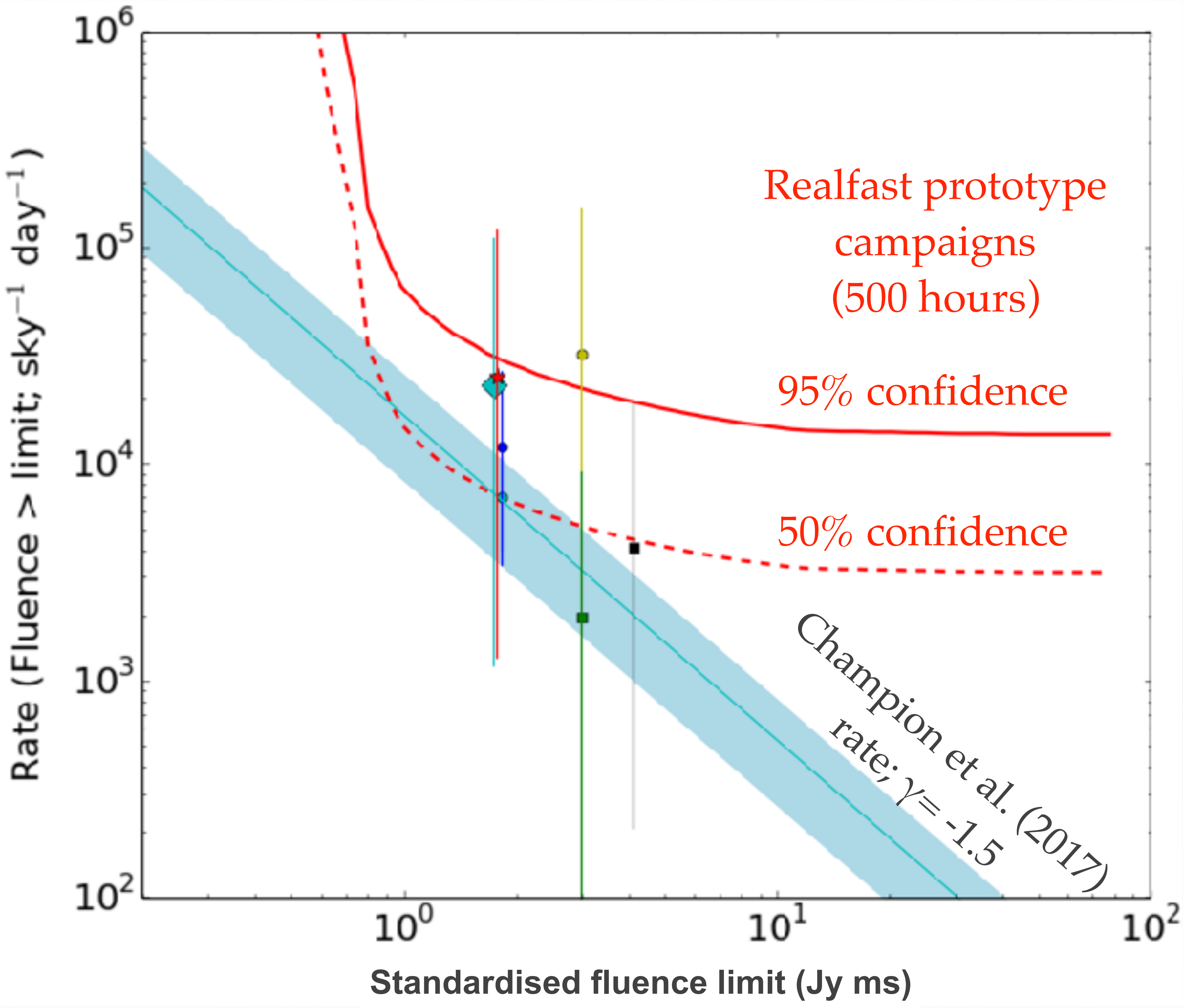
Experiment vs. Facility

- Typical continuum observations:
  - AGN, supermassive and intermediate-mass black holes
  - Star formation
  - HII regions
  - Molecular clouds
  - Pulsar timing (sometimes!)
- Open for targeted proposals!!!

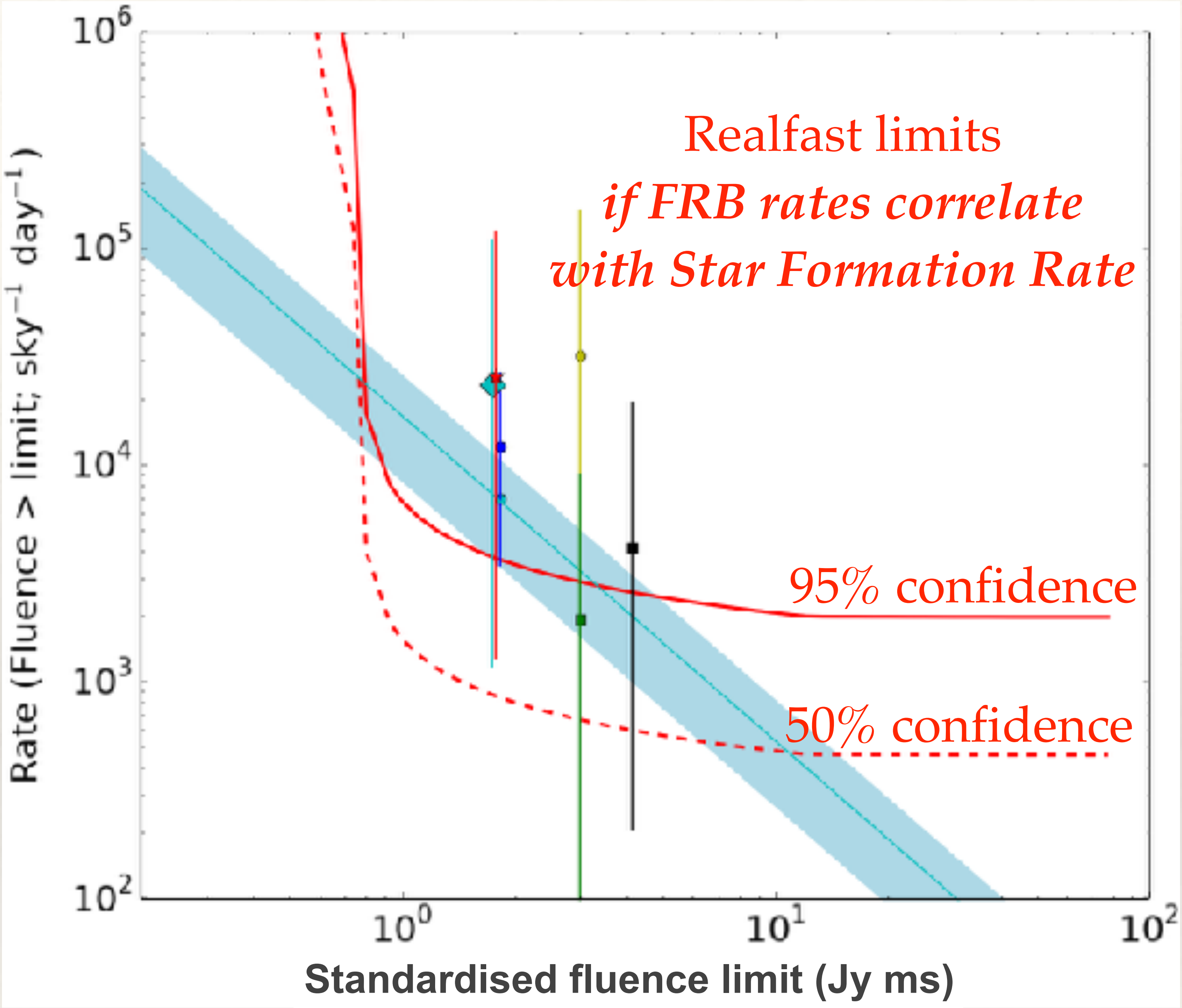
Realfast prototype commissioning, Aug 23 2016



Why haven't we found anything (blind)?



What do non-detections tell us?

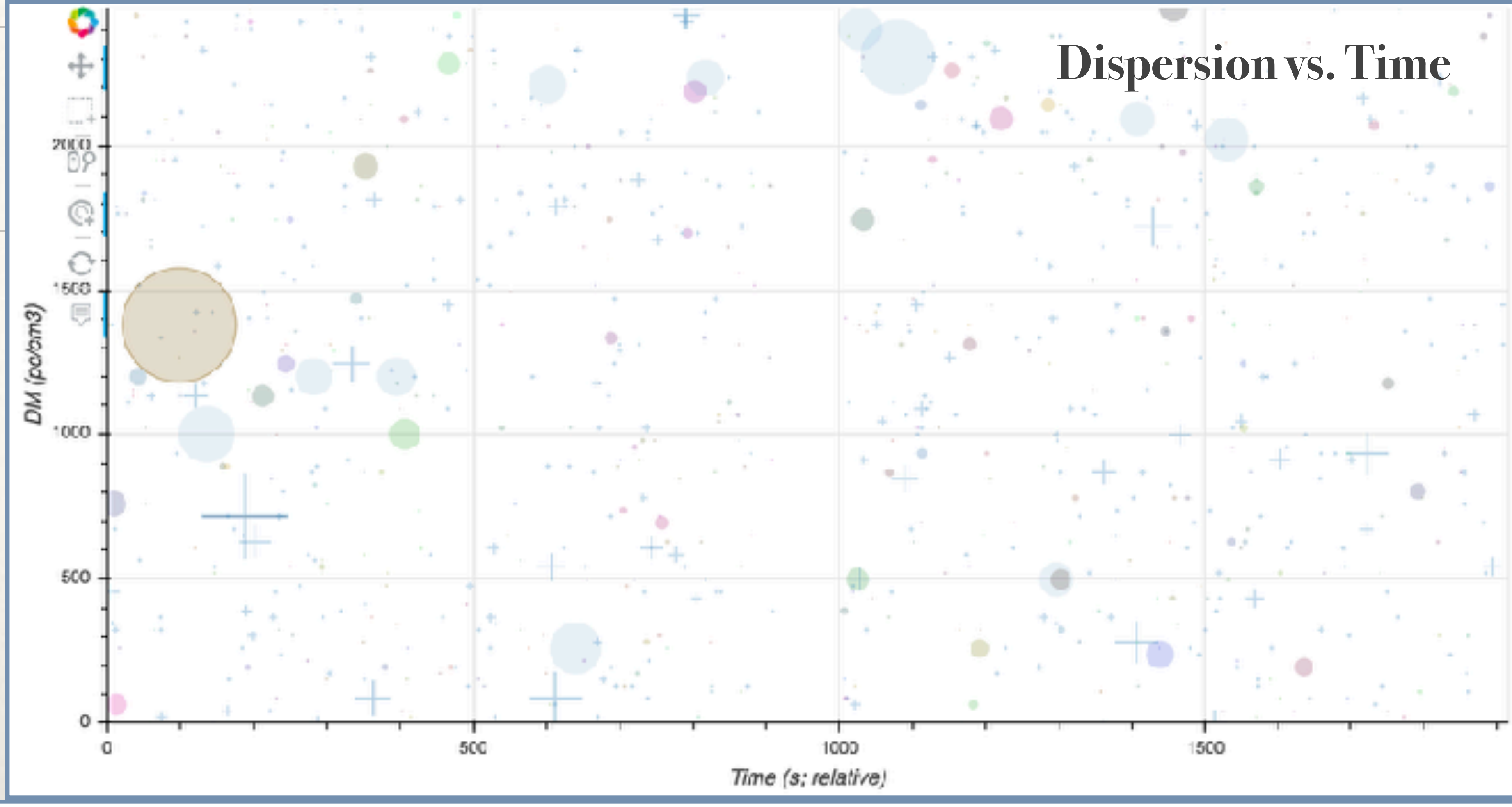


Assumptions:

- Distance limit < 200 Mpc (Wasserman & Cordes 2016)
- Parkes observed large sky areas (Champion et al. 2017)

Pitfall(s)…

(Lessons from a desperate interferometry crew?)


Dispersion vs. Time
DM (pc/cm3)
Time (s; relative)
0
500
1000
1500
2000

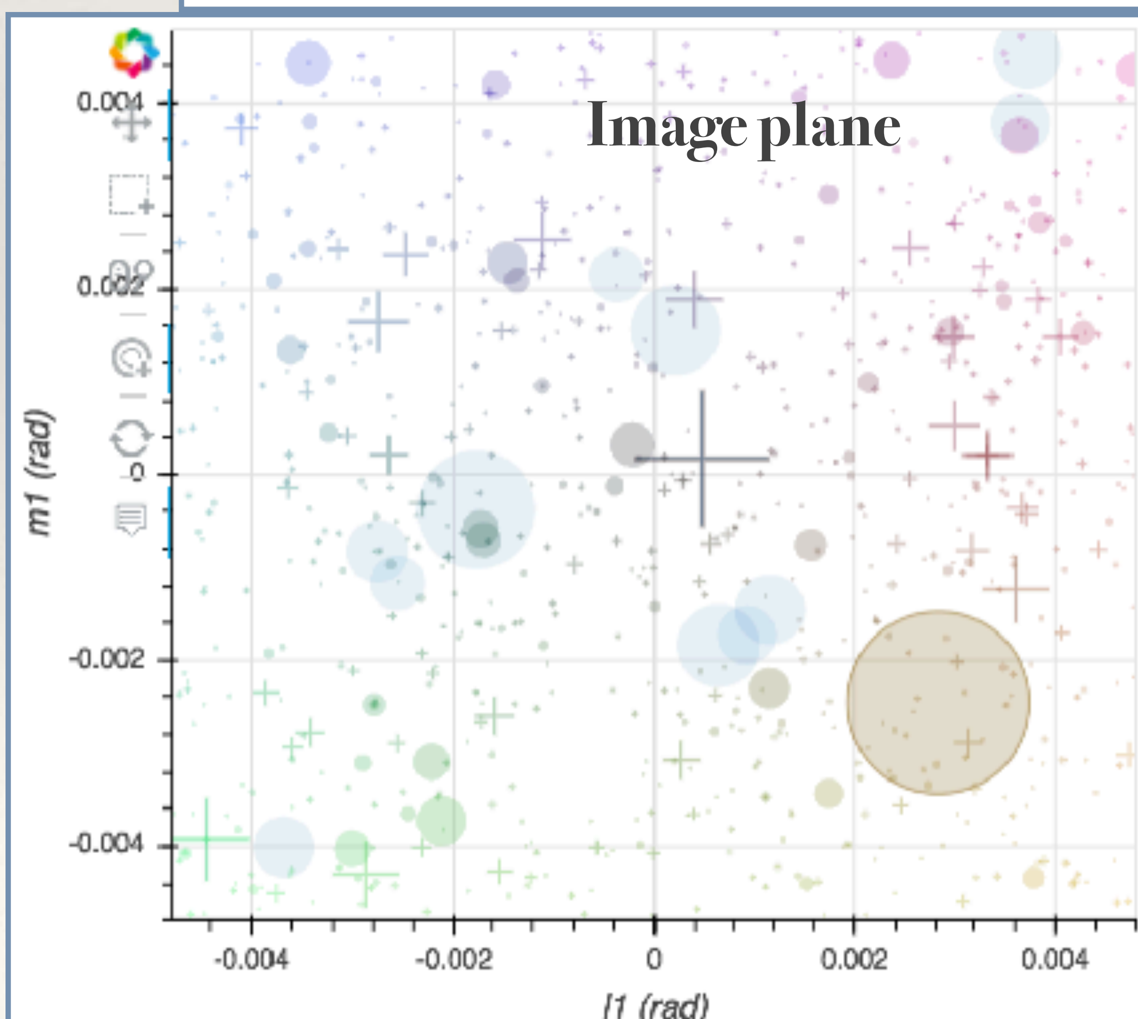


Image plane
m1 (rad)
l1 (rad)
0.004
0.002
0
-0.002
-0.004

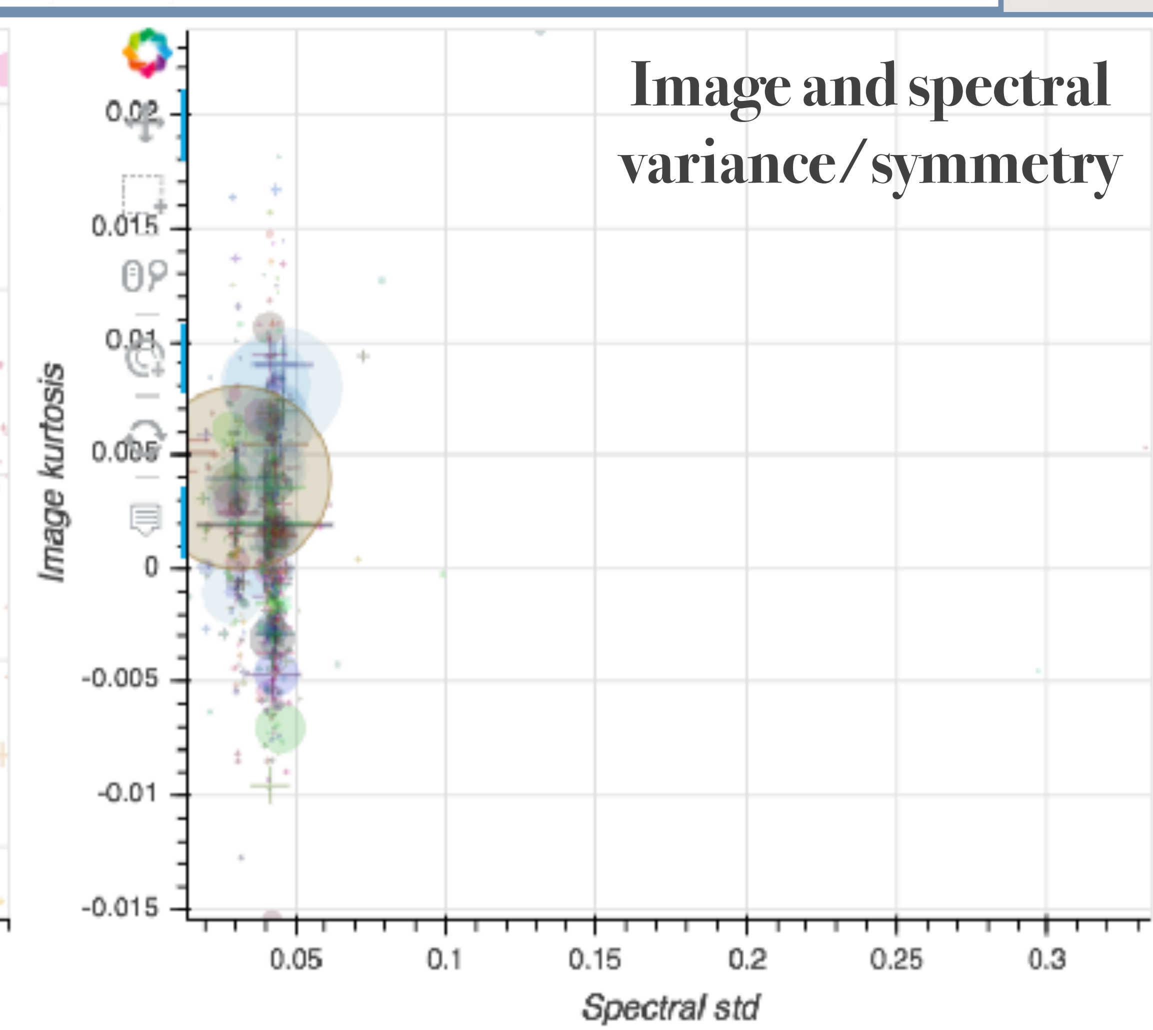
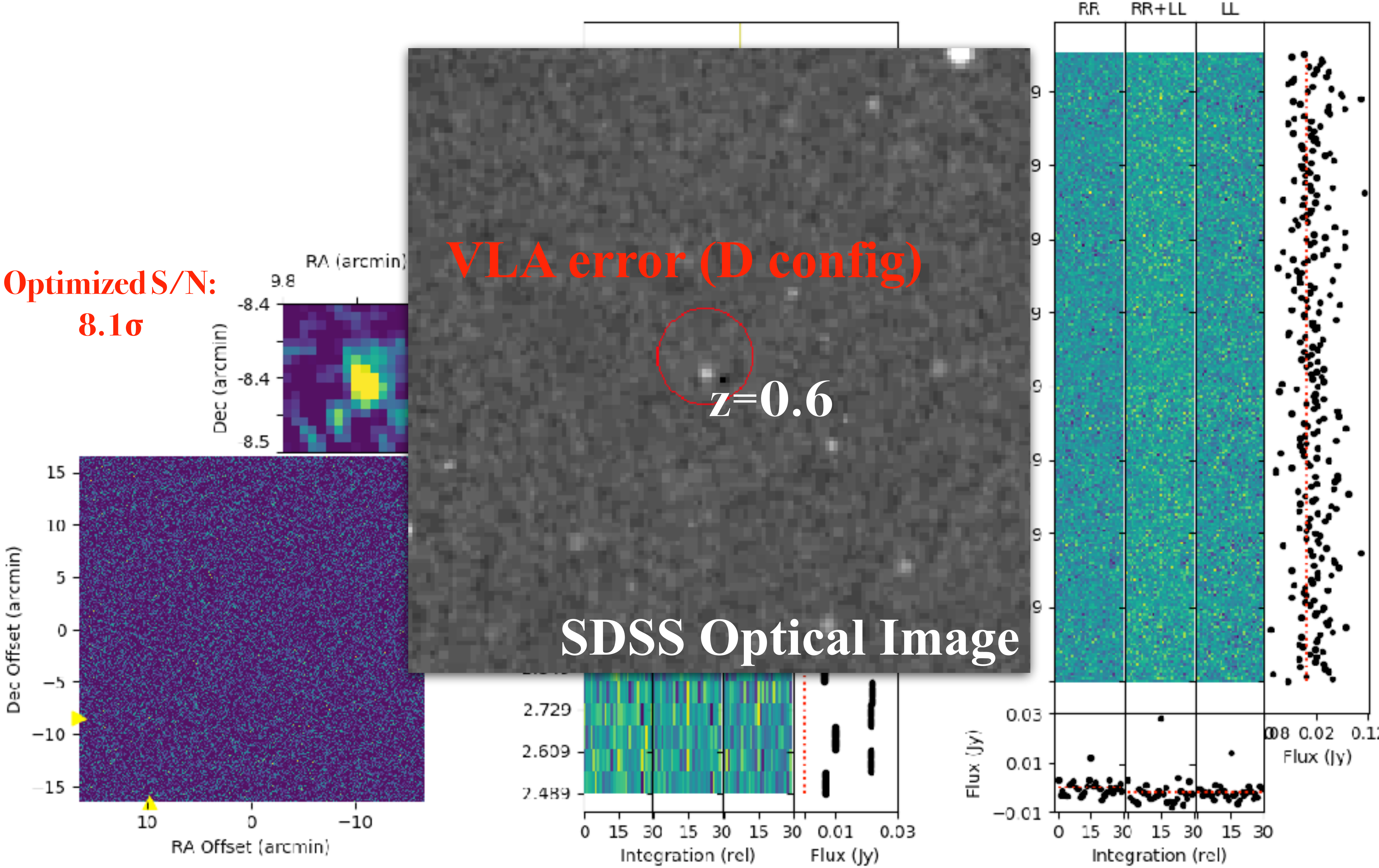
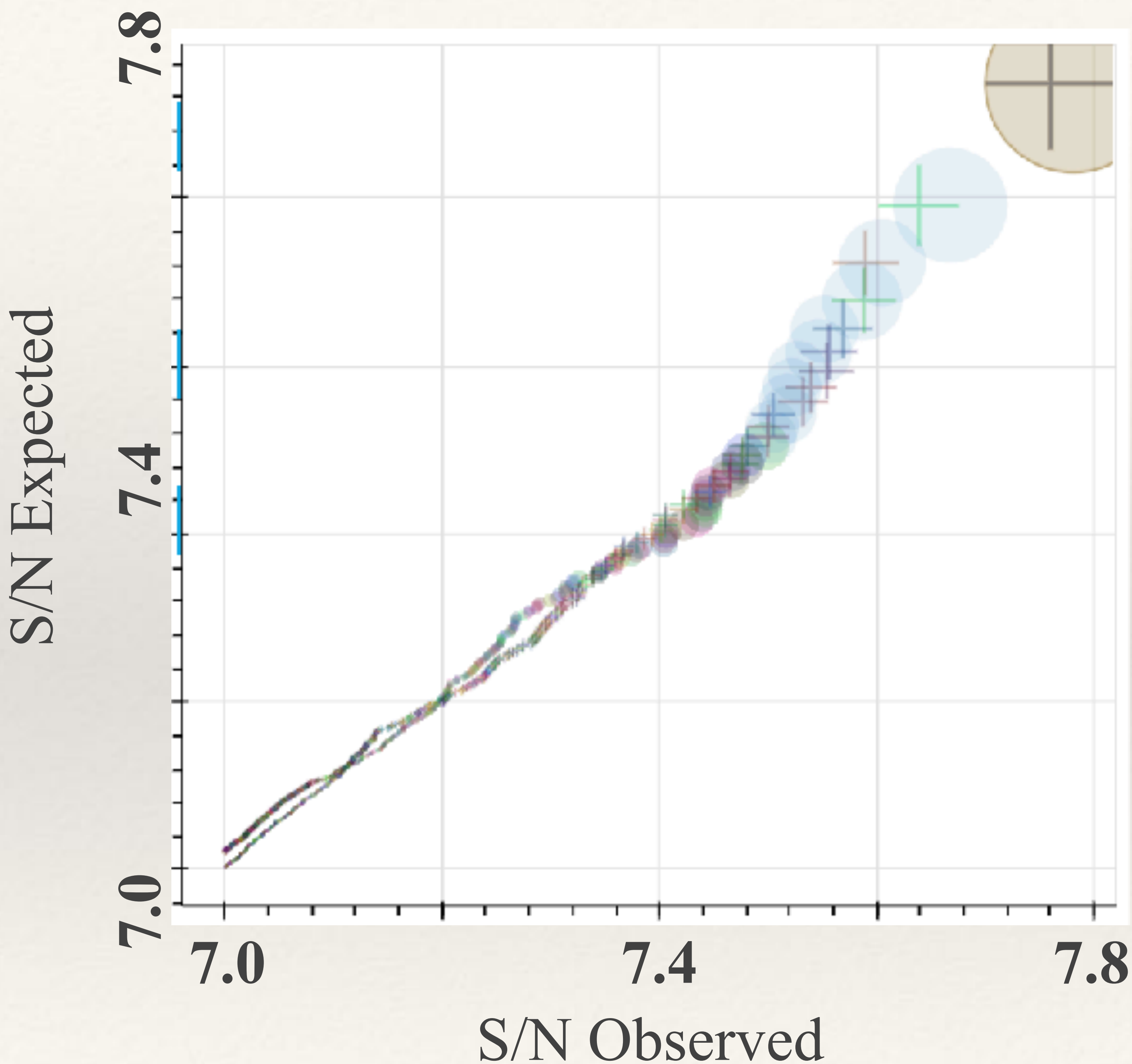


Image and spectral variance/symmetry
Image kurtosis
Spectral std
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
0.05
0.1
0.15
0.2
0.25
0.3



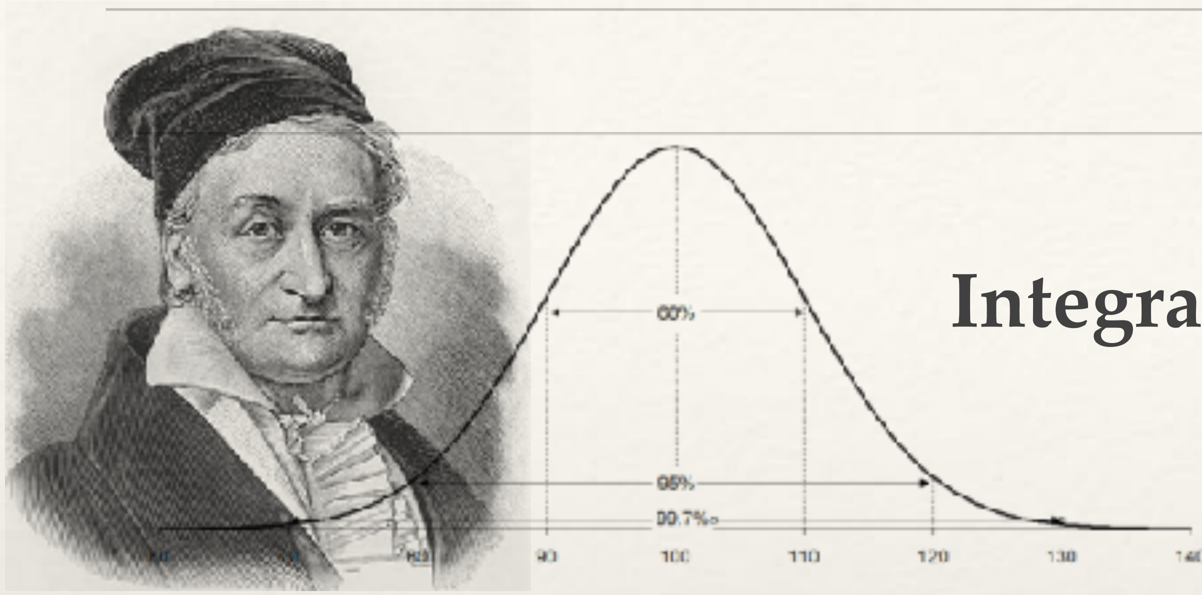
Optimized S/N:
8.1σ
VLA error (D config)
z=0.6
SDSS Optical Image
RA (arcmin)
Dec (arcmin)
Dec Offset (arcmin)
RA Offset (arcmin)
Integration (rel)
Flux (Jy)
RR
RR+LL
LL

“Normal Quantile” Plots



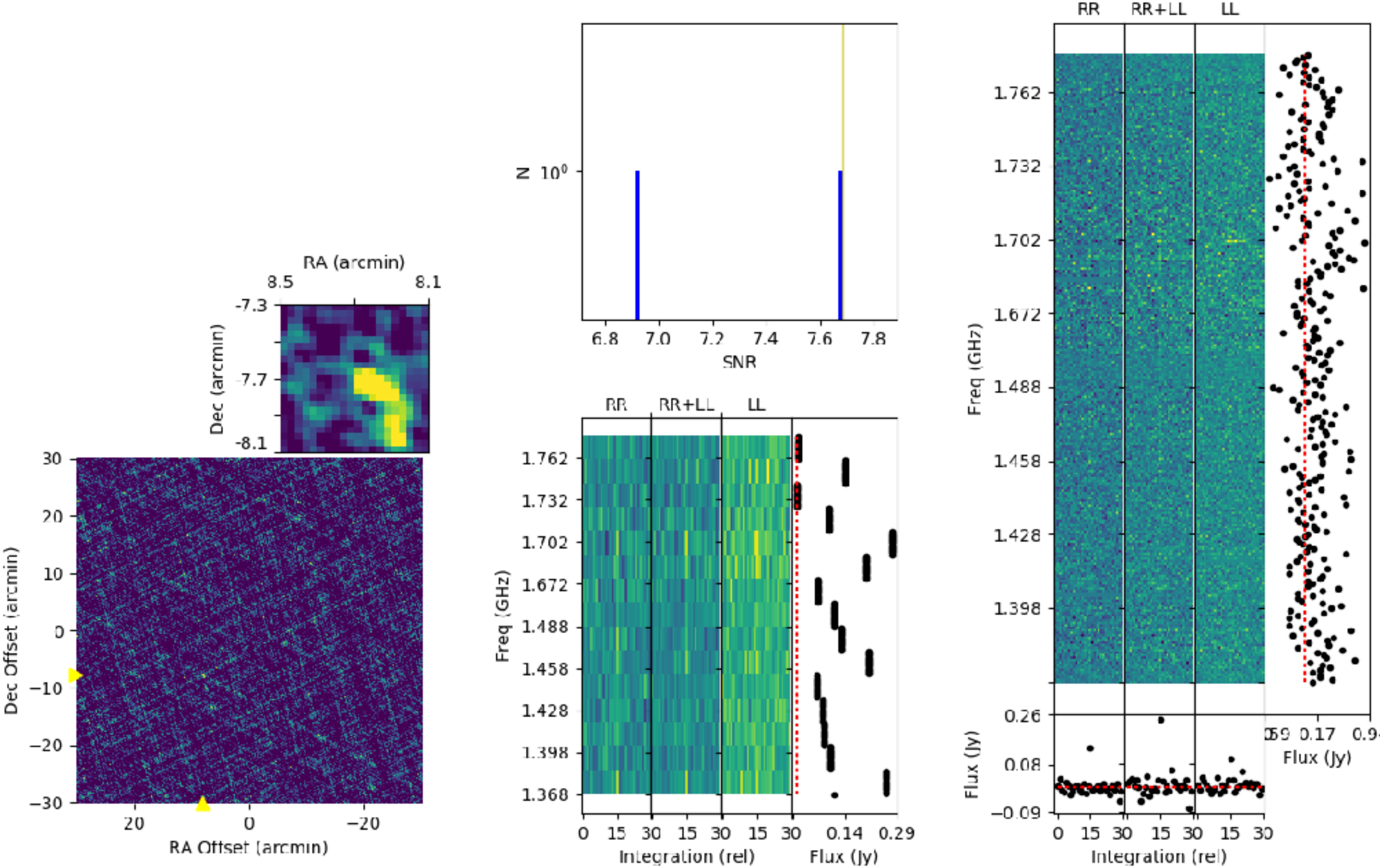
e.g. Law et al. (2015)

Blizzards hide the faintest snowflakes.



Number of samples =
Integration rate x Resample factor x N_{DMs} x N_{pixels}

Experiment	Independent samples per hour	Average time between >8σ *thermal noise* events
Single dish	10^{11}	8000 hours
Realfast D config	10^{14}	8 hours
Realfast A config	$>10^{15}$	20 minutes



RA (arcmin)
8.5
8.1
-7.3
-7.7
-8.1
Dec (arcmin)
30
20
10
0
−10
−20
−30
Dec Offset (arcmin)
20
0
−20
RA Offset (arcmin)
N
10^0
6.8
7.0
7.2
7.4
7.6
7.8
SNR
RR
RR+LL
LL
1.762
1.732
1.702
1.672
1.488
1.458
1.428
1.398
1.368
Freq (GHz)
0
15
30
Integration (rel)
0.14
0.29
Flux (Jy)
RR
RR+LL
LL
1.762
1.732
1.702
1.672
1.488
1.458
1.428
1.398
Freq (GHz)
0.17
0.94
Flux (Jy)
0.26
0.08
−0.09
Flux (Jy)
0
15
30
Integration (rel)

Lessons

- S/N alone is not necessarily a good measure of significance. Where do we draw the line?
- Where is YOUR noise floor?
- Patience…
- (Possibly?) wider FOV would improve bright, rare detections.

Realfast Commensal: The Book

arXiv:1802.03084

REALFAST: REAL-TIME, COMMENSAL FAST TRANSIENT SURVEYS WITH THE VERY LARGE ARRAY

C. J. Law,[1] G. C. Bower,[2] S. Burke-Spolaor,[3,4,5] B. J. Butler,[3] P. Demorest,[3] A. Halle,[1] S. Khudikyan,[6]
T. J. W. Lazio,[6] M. Pokorny,[3] J. Robnett,[3] and M. Rupen[7]

[1] *Department of Astronomy and Radio Astronomy Lab, University of California, Berkeley, CA 94720, USA*
[2] *Academia Sinica Institute of Astronomy and Astrophysics, 645 N. A'ohoku Place, Hilo, HI 96720, USA*
[3] *National Radio Astronomy Observatory, Socorro, NM 87801, USA*
[4] *Department of Physics and Astronomy, West Virginia University, Morgantown, WV 26506, USA*
[5] *Center for Gravitational Waves and Cosmology, West Virginia University, Chestnut Ridge Research Building, Morgantown, WV 26505*
[6] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA*
[7] *National Research Council of Canada, Herzberg Astronomy and Astrophysics, Dominion Radio Astrophysical Observatory, P.O. Box 248, Penticton, BC V2A 6J9, Canada*

(under review at ApJ Supplements)

Ultimate goals

- Commensal.
- Real-time detection.
  DATA RATES, SELF-TRIGGERING, PROMPT EMISSION.
- Localization of every FRB detected.
  - At least 10 by early/mid-2020.
- Public triggers and open data availability.
- (Eventually, hopefully) An open VLA capability supported by NRAO.