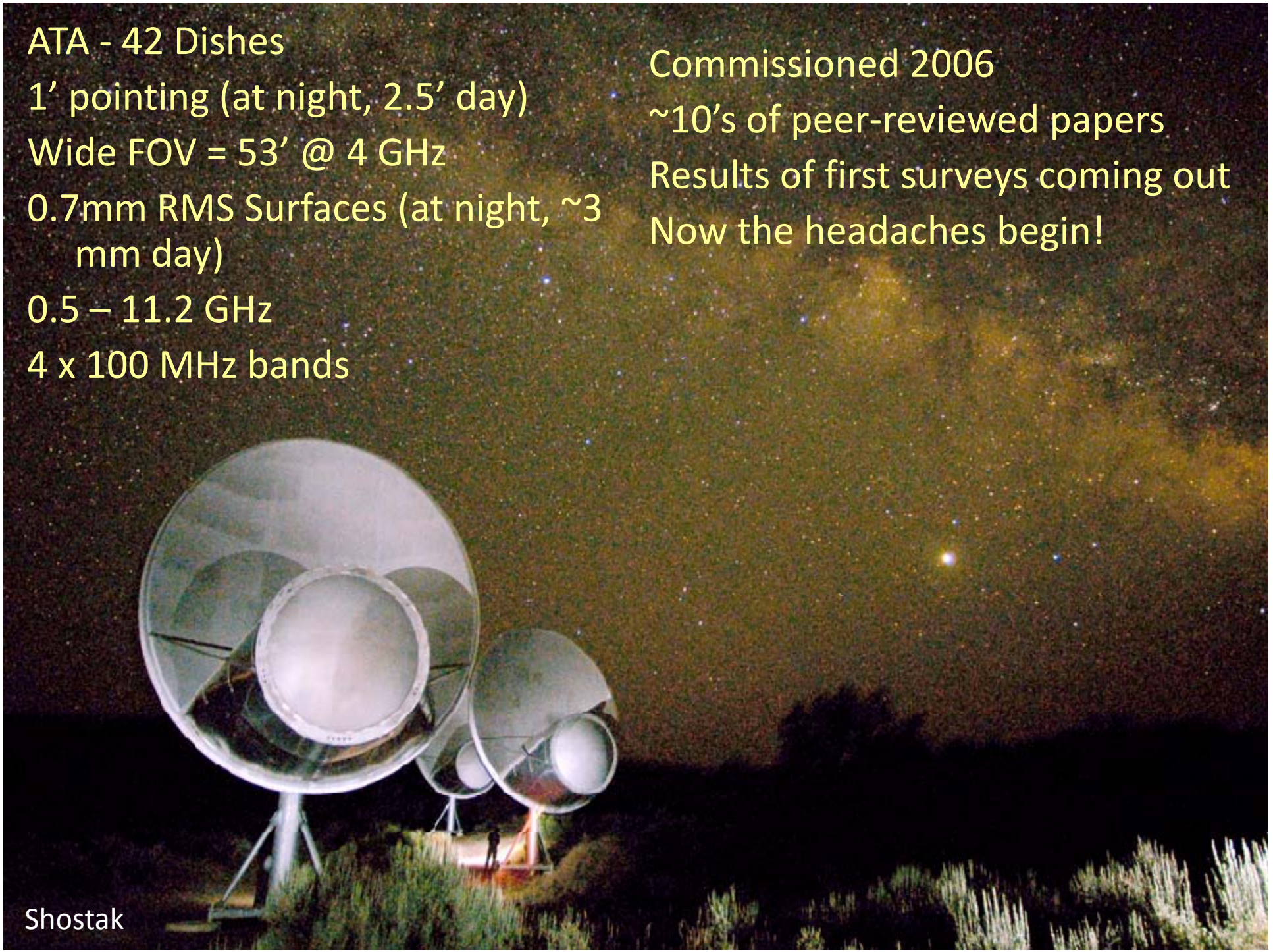
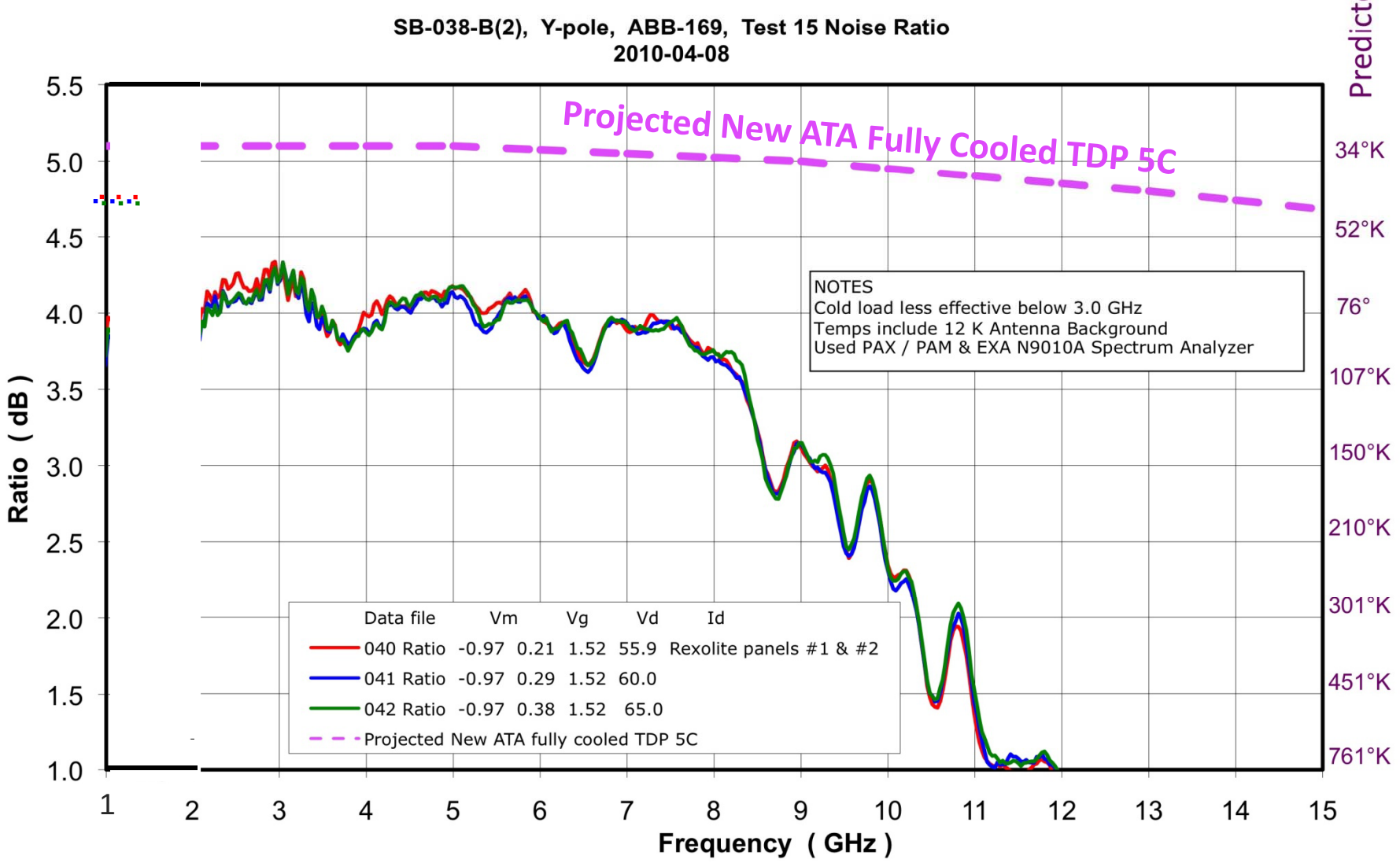
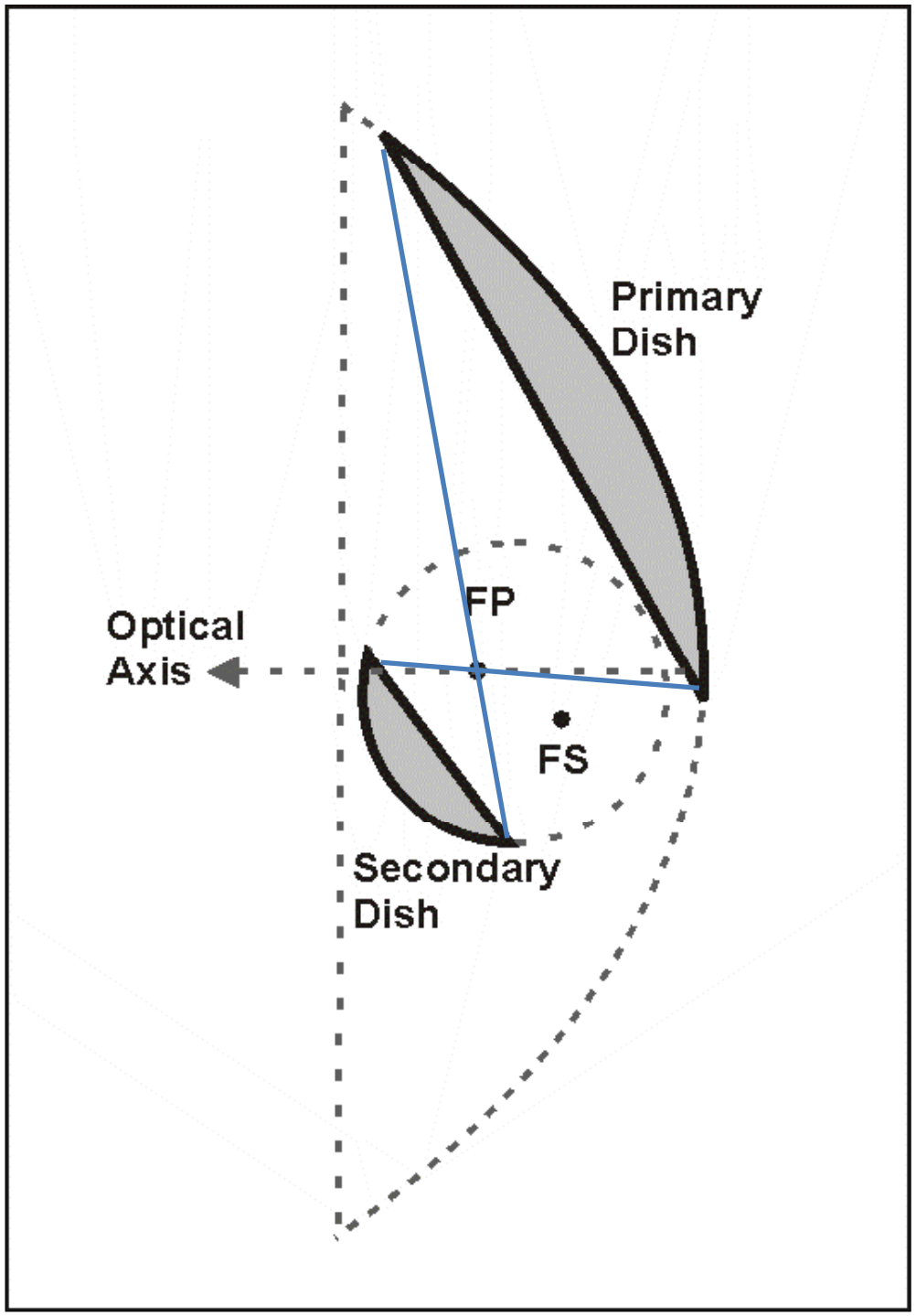
SETI Research, Allen Telescope Array Status and Unsolved Problems

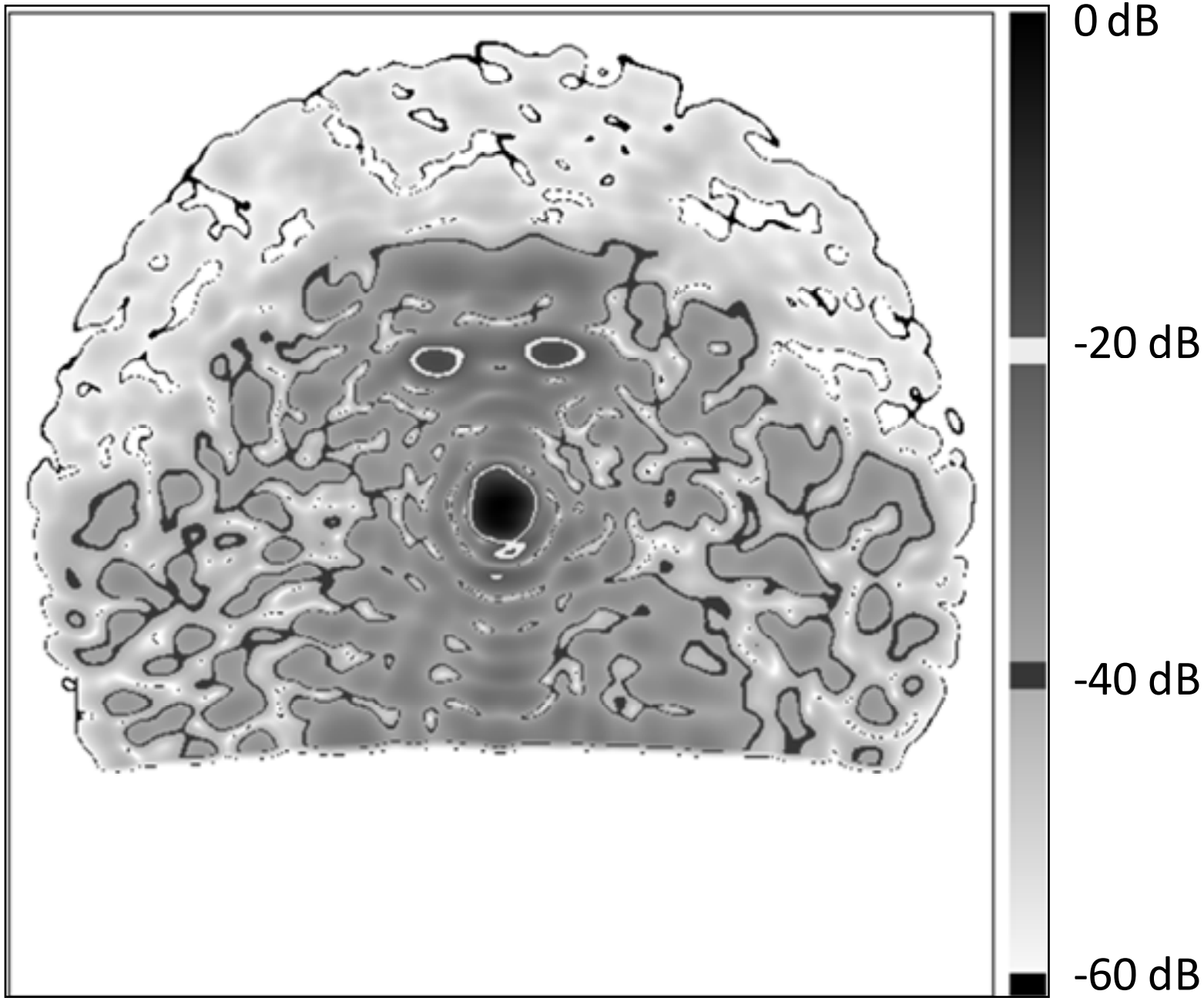
Gerry Harp and ATA Team


ATA - 42 Dishes
1’ pointing (at night, 2.5’ day)
Wide FOV = 53’ @ 4 GHz
0.7mm RMS Surfaces (at night, ~3 mm day)
0.5 – 11.2 GHz
4 x 100 MHz bands
Commissioned 2006
~10’s of peer-reviewed papers
Results of first surveys coming out
Now the headaches begin!
Shostak

Measured and Expected Feed/Receiver Performance + 15 GHz Upgrade

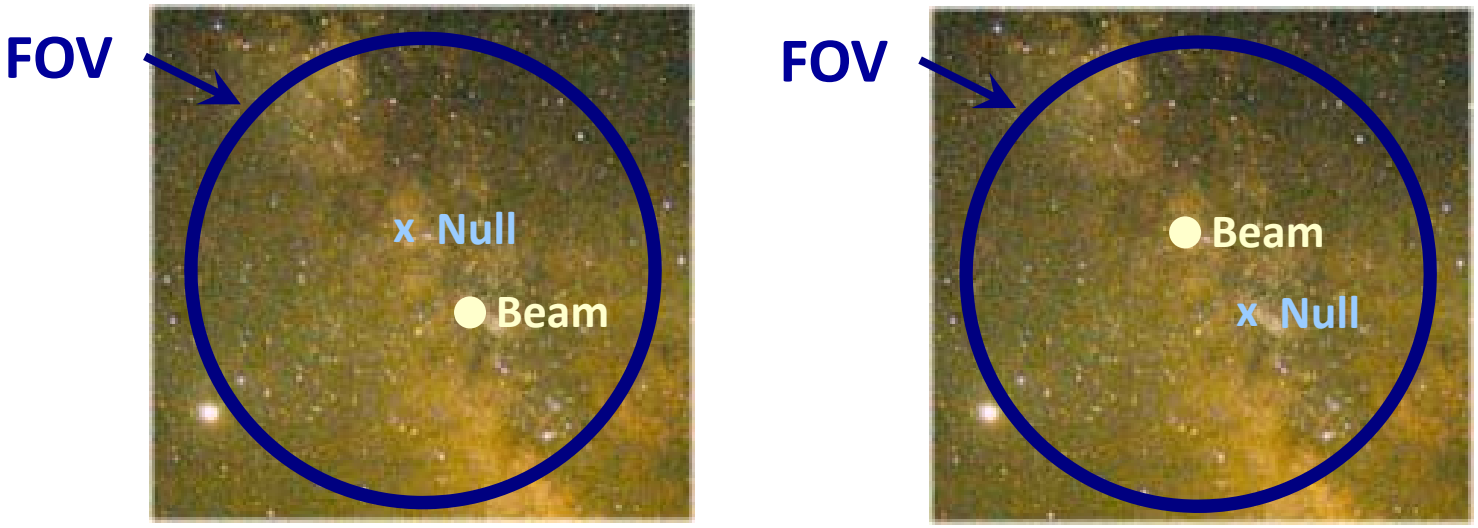



Primary
Dish
FP
Optical
Axis
FS
Secondary
Dish


0 dB
-20 dB
-40 dB
-60 dB

Multiple BF + Nulling

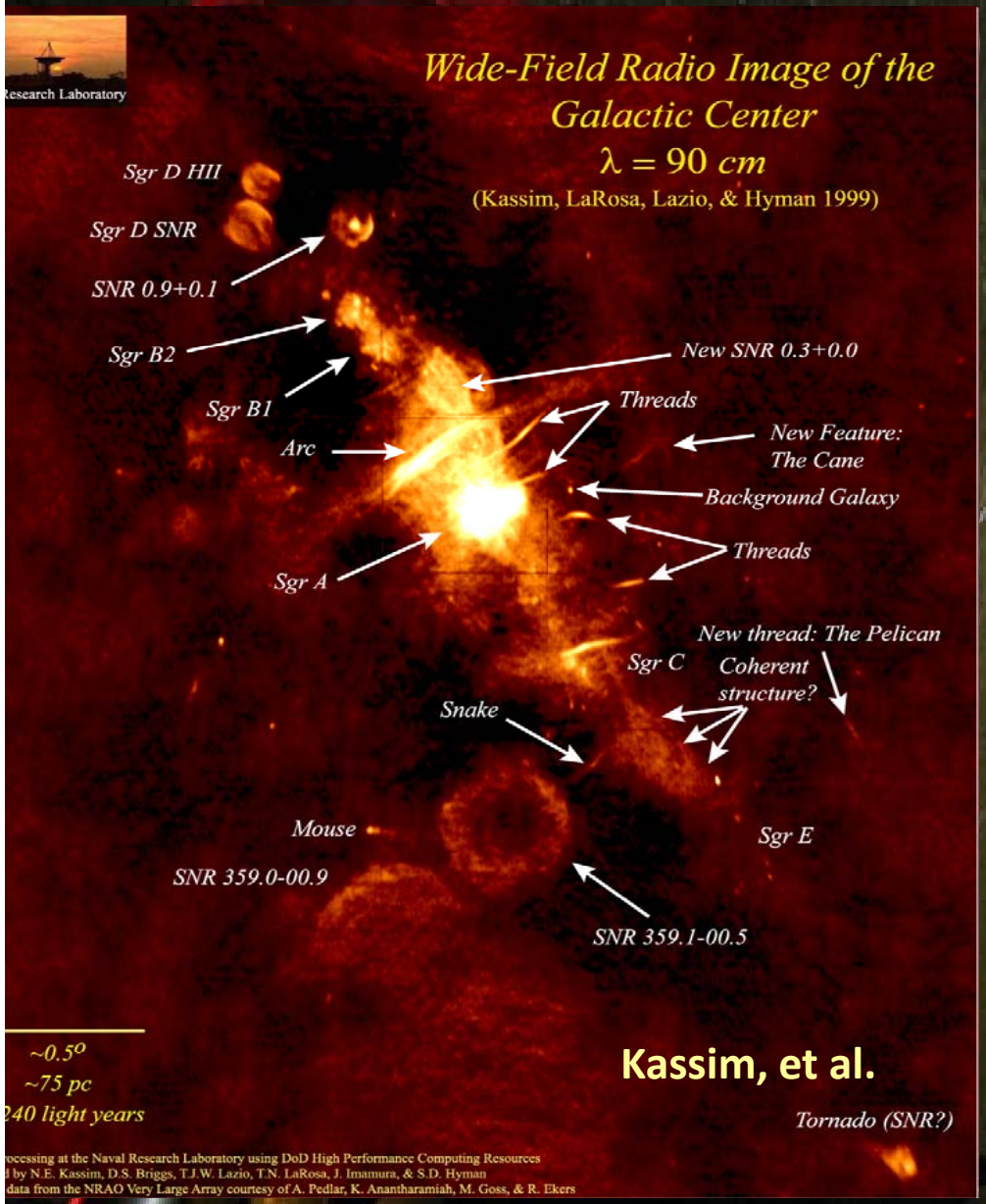
- Simultaneously measure signal at one point (beam 1) while excluding signal from that direction in beam 2, beam 3, etc.



- Anticoincidence rejects signals that appear in both beams (must be RFI)

Ongoing Searches at ATA

Galactic Center Survey: Sky survey of 20 square degrees near the galactic center.

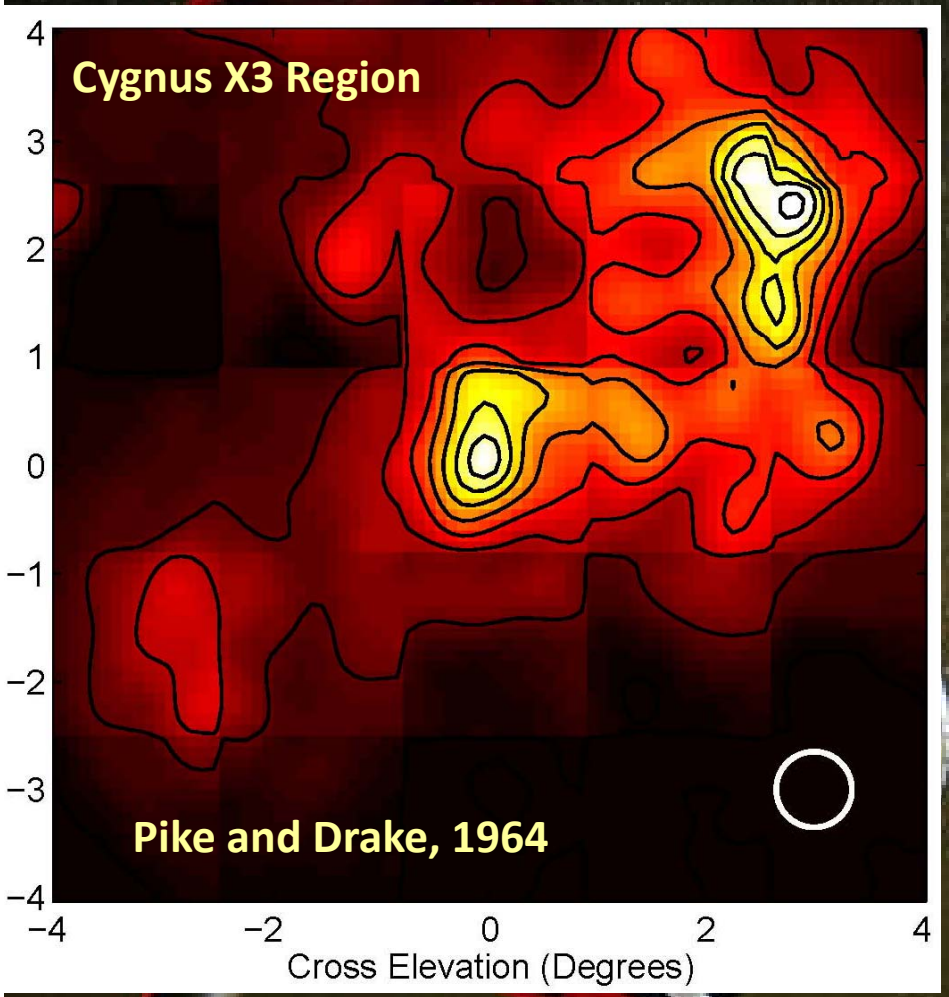


Gal. Center = 26000 LY. Survey detects transmitters with 20,000 x EIRP (transmitted power) of Arecibo planetary radar at the galactic center.

Ongoing SETI at ATA

Galactic Center Survey: Sky survey of 20 square degrees near the galactic center.

Cygnus X-3 Survey: Sky survey of 4 sq. deg. near Cygnus. Includes the x-ray binary star Cygnus X-3.

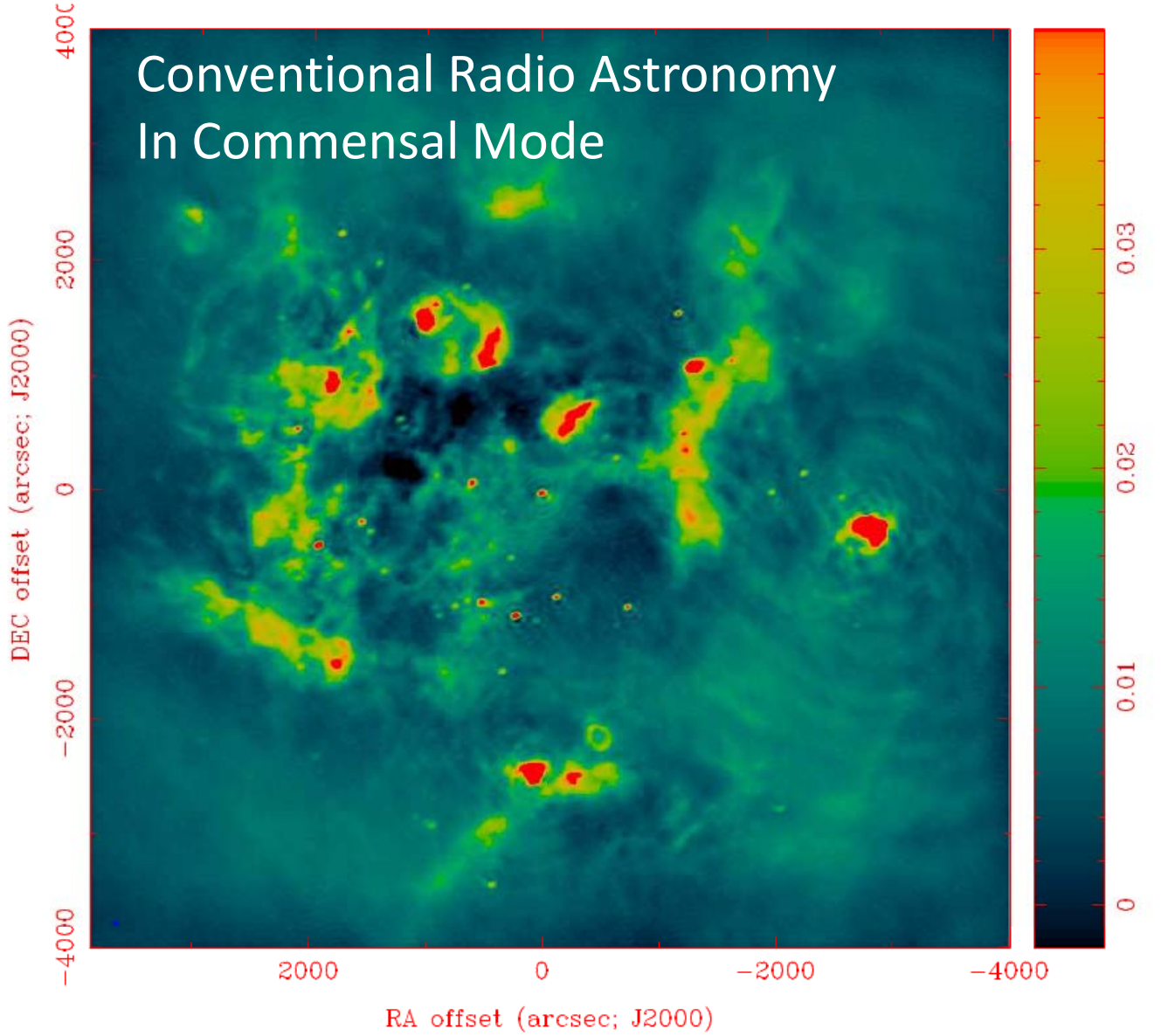


Distance to Cyg X3 is 1.5x distance to GC.

Detects transmitters with 50% of the sensitivity of galactic survey (GC).

Shostak

Conventional Radio Astronomy In Commensal Mode

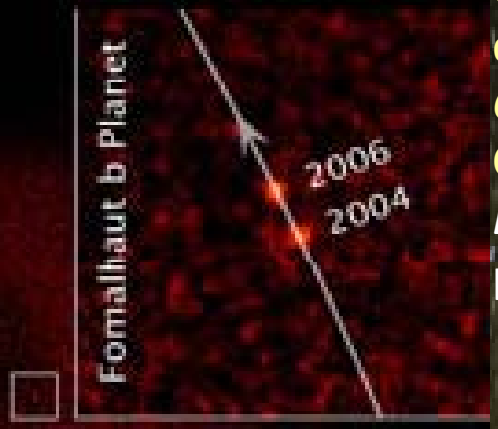


ATA is Designed for Commensal Observing

1 week old

Peter K. G. Williams, Geoff Bower, Peter Backus and the Prelude team ran survey, whilst performing SETI observations.

Ongoing SETI at ATA



Galactic Center Survey: Sky survey of 20 square degrees near the galactic center.

Cygnus X-3 Survey: Sky survey of 4 sq. deg. near Cygnus. Includes the x-ray binary star Cygnus X-3.

Exoplanet Search: Targeted survey, stars with planets in the Waterhole band, ongoing.

Most are between 10-1000 LY.

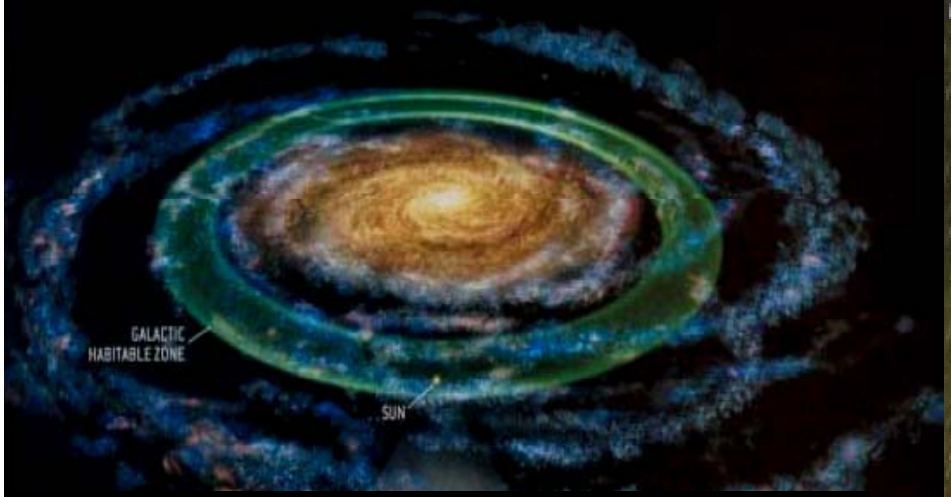
1000 LY ~ 700x sensitivty of GC.

10 LY = 10^4x more improvement.

Kalas, et al.

Ongoing SETI at ATA

Habitable Zone, where astrophysics might permit life.

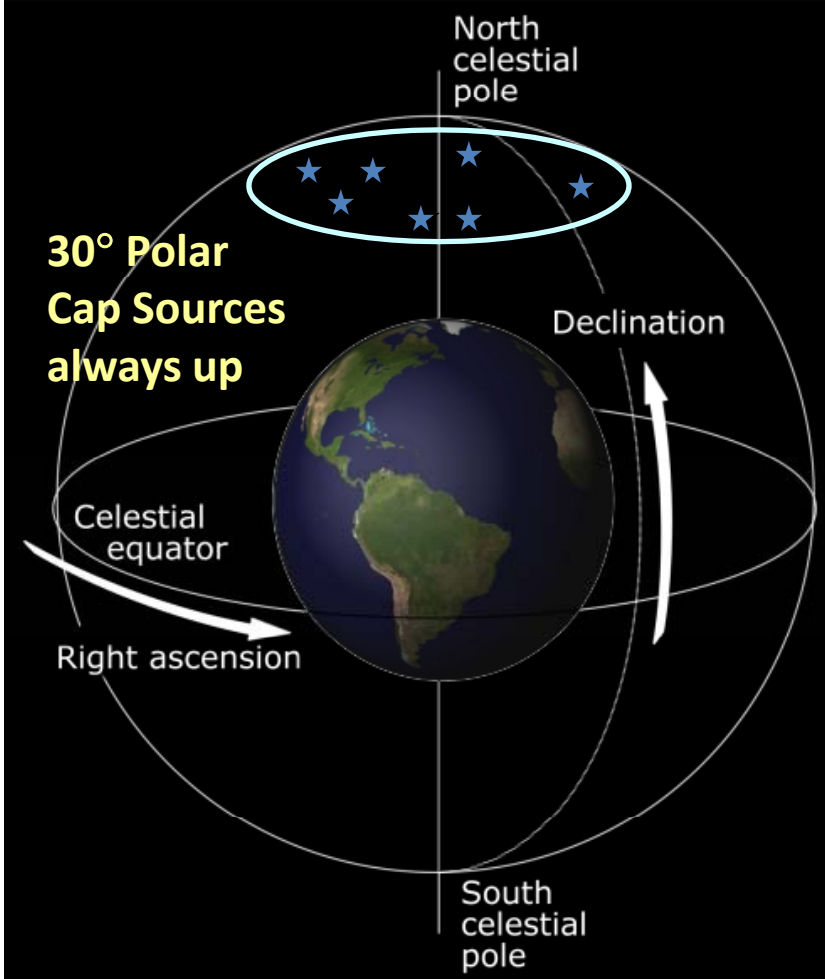


HabCat Catalog: Turnbull and Tarter

Galactic Center Survey: Sky survey of 20 square degrees near the galactic center.
Cygnus X-3 Survey: Sky survey of 4 sq. deg. near Cygnus. Includes the x-ray binary star Cygnus X-3.
Exoplanet Search: Targeted survey, have observed 146 stars with planets in the Waterhole band, ongoing.
Waterhole x2 (2.8-3.4 GHz) HabCat Search: Targeted survey, Turnbull and Tarter compiled list of stars that could be suitable hosts for habitable planets.

17,000 stars, 4-55000 LY
4 LY – 20,000x better than GC search
55000 LY = 25% sensitvity of GC

Ongoing SETI at ATA



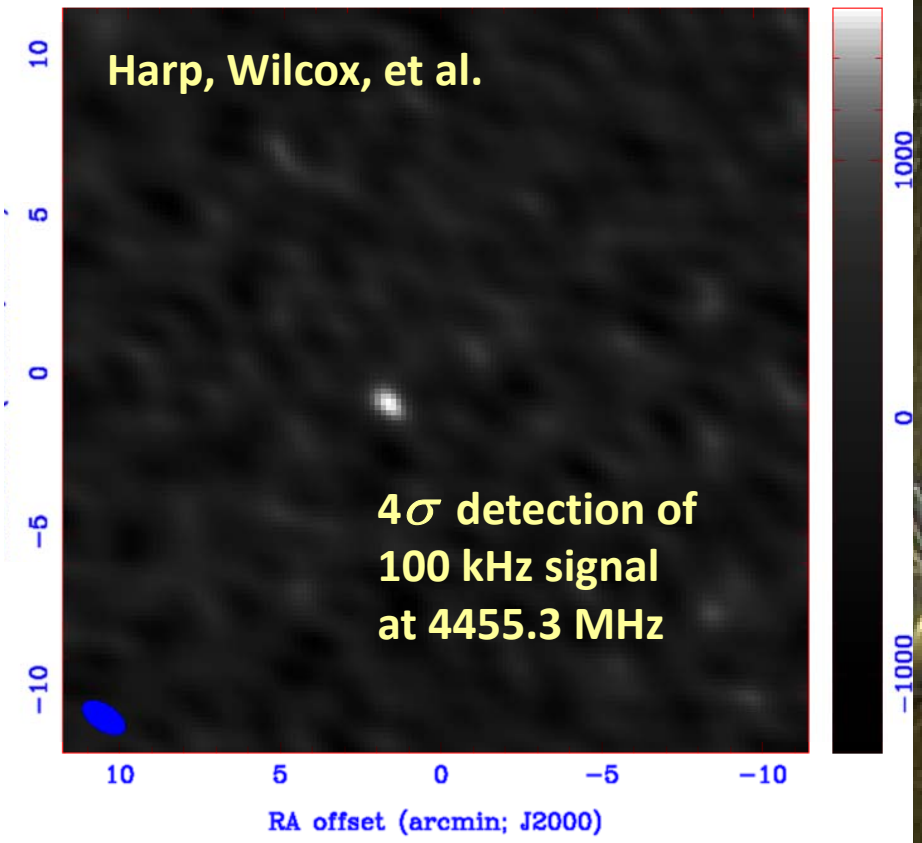
30° Polar Cap Sources always up

Galactic Center Survey: Sky survey of 20 square degrees near the galactic center.
Cygnus X-3 Survey: Sky survey of 4 sq. deg. near Cygnus. Includes the x-ray binary star Cygnus X-3.
Exoplanet Search: Targeted survey, have observed 146 stars with planets in the Waterhole band, ongoing.
HabCat Search: Targeted survey, Turnbull and Tarter compiled list of stars that could be suitable hosts for habitable planets.
PiHI Search 1: Targeted survey, 100 HabCat stars near magic frequency of 4.462 GHz (π times the HI line frequency of 1.421 GHz). Almost virgin frequency territory. After Sagan.

Choose ~100 Habcat stars within 200 LY of earth and in polar cap.
At 100 LY can see a transmitter at ~10x Arecibo radar
DONE!

Harp, Wilcox, et al.

Ongoing SETI at ATA



Galactic Center Survey: Sky survey of 20 square degrees near the galactic center.

Cygnus X-3 Survey: Sky survey of 4 sq. deg. near Cygnus. Includes the x-ray binary star Cygnus X-3.

Exoplanet Search: Targeted survey, have observed 146 stars with planets in the Waterhole band, ongoing.

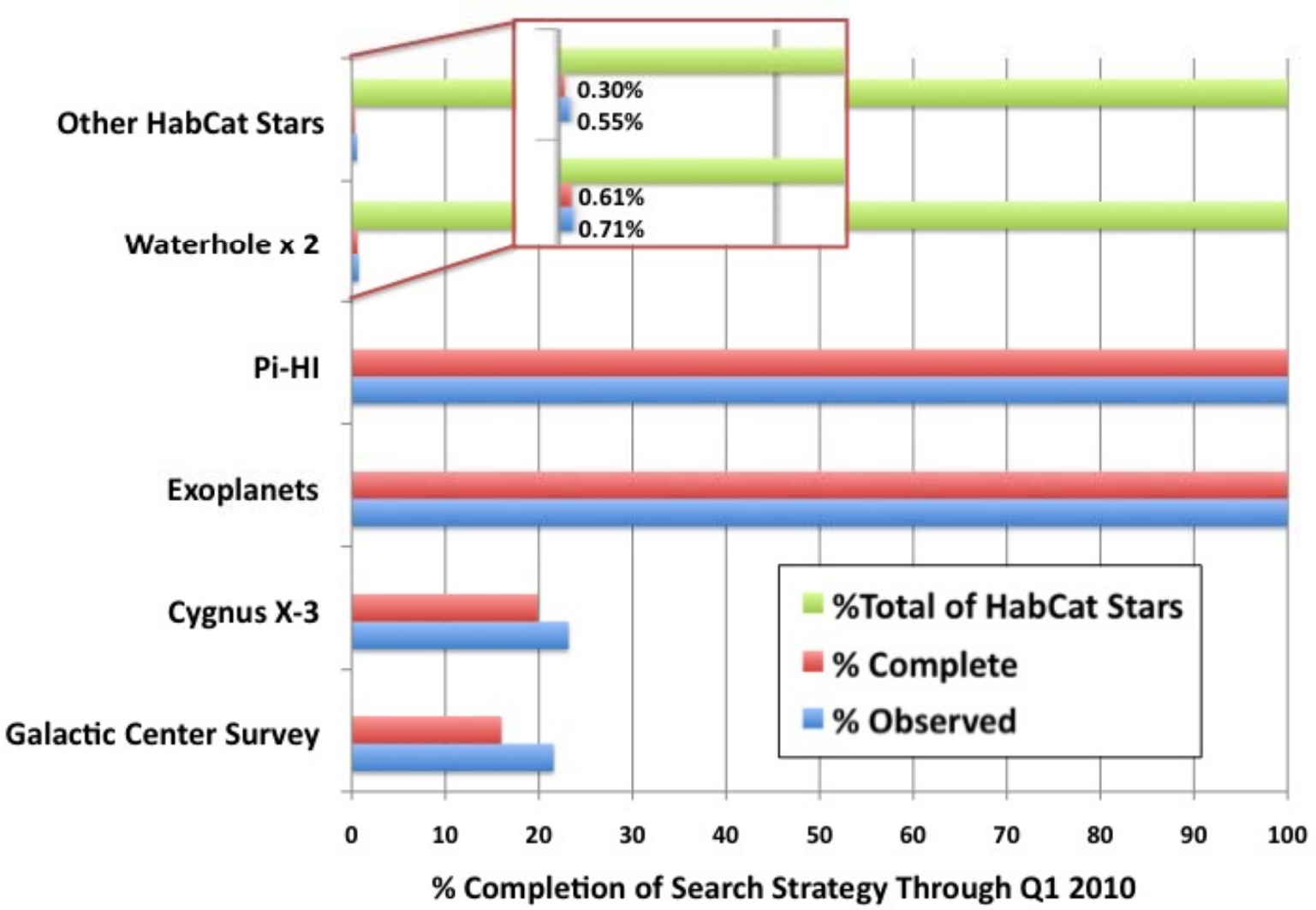
HabCat Search: Targeted survey, Turnbull and Tarter compiled list of stars that could be suitable hosts for habitable planets.

PiHI Search 1: Targeted survey, 100 HabCat stars near magic frequency of 4.462 MHz (π times the HI line frequency of 1.421 GHz). Almost virgin frequency territory. After Sagan.

PiHI Search 2: Sky survey using ATA correlator. Novel scheme runs commensally with targeted survey.

NONE OF THESE INTERESTING SIGNALS WERE PERISTENT.

How Much is Done So Far?

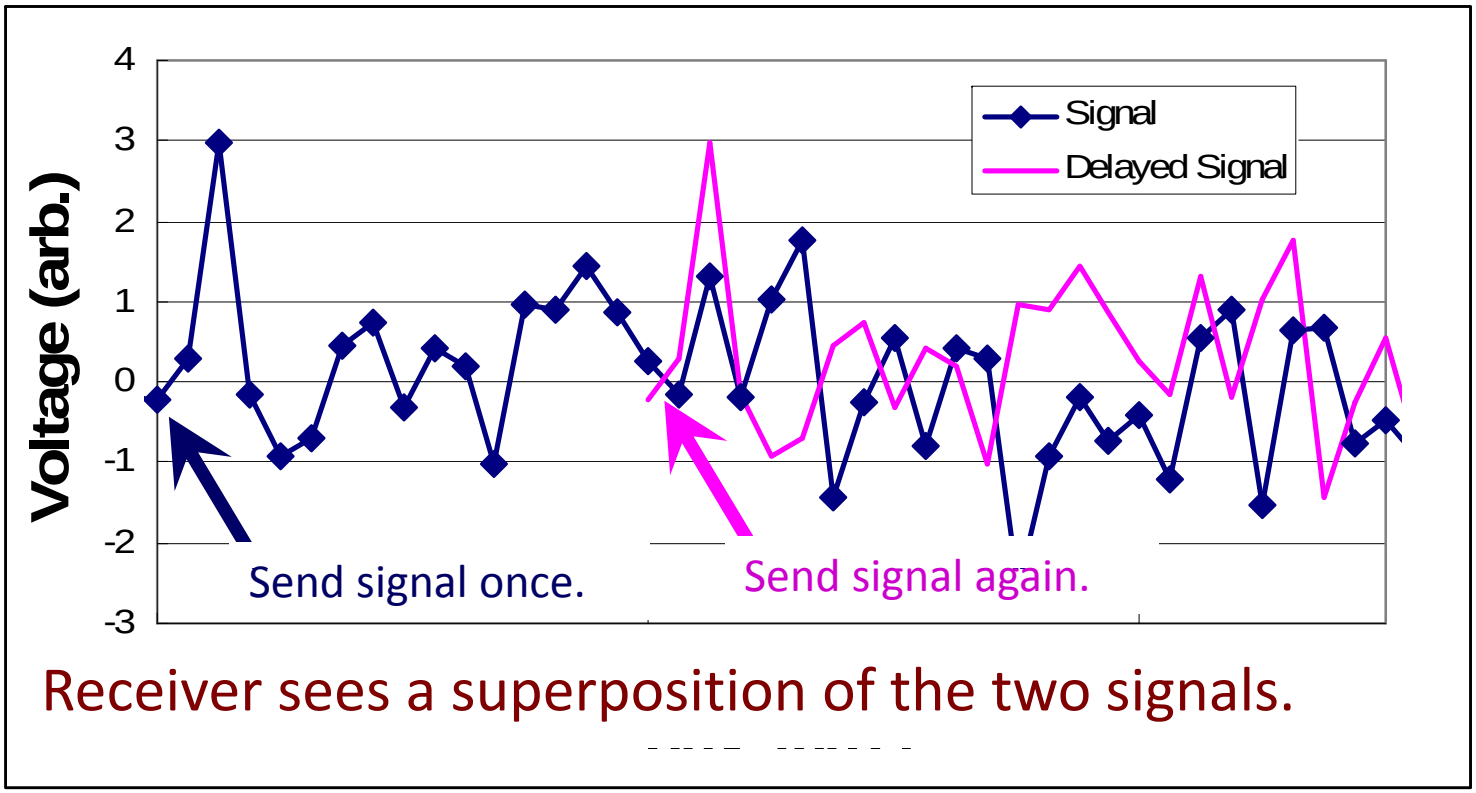


How Do We Know if Signal is Extra-solar in Origin?

- Must be noticeably artificial
  - Must contain less than the maximum information content that could be conveyed Redundant!
  - Conventional SETI looks for, essentially, sine waves (the ultimate in redundancy!)
    - This is still a very good idea.
  - Can we design new beacons which embed information, too? Implies wide bandwidth.
- Must be persistent
  - Not their problem, but ours. We can't be sure of direction of signal arrival unless we can make many, many measurements.

Twice Sent Message = Beacon

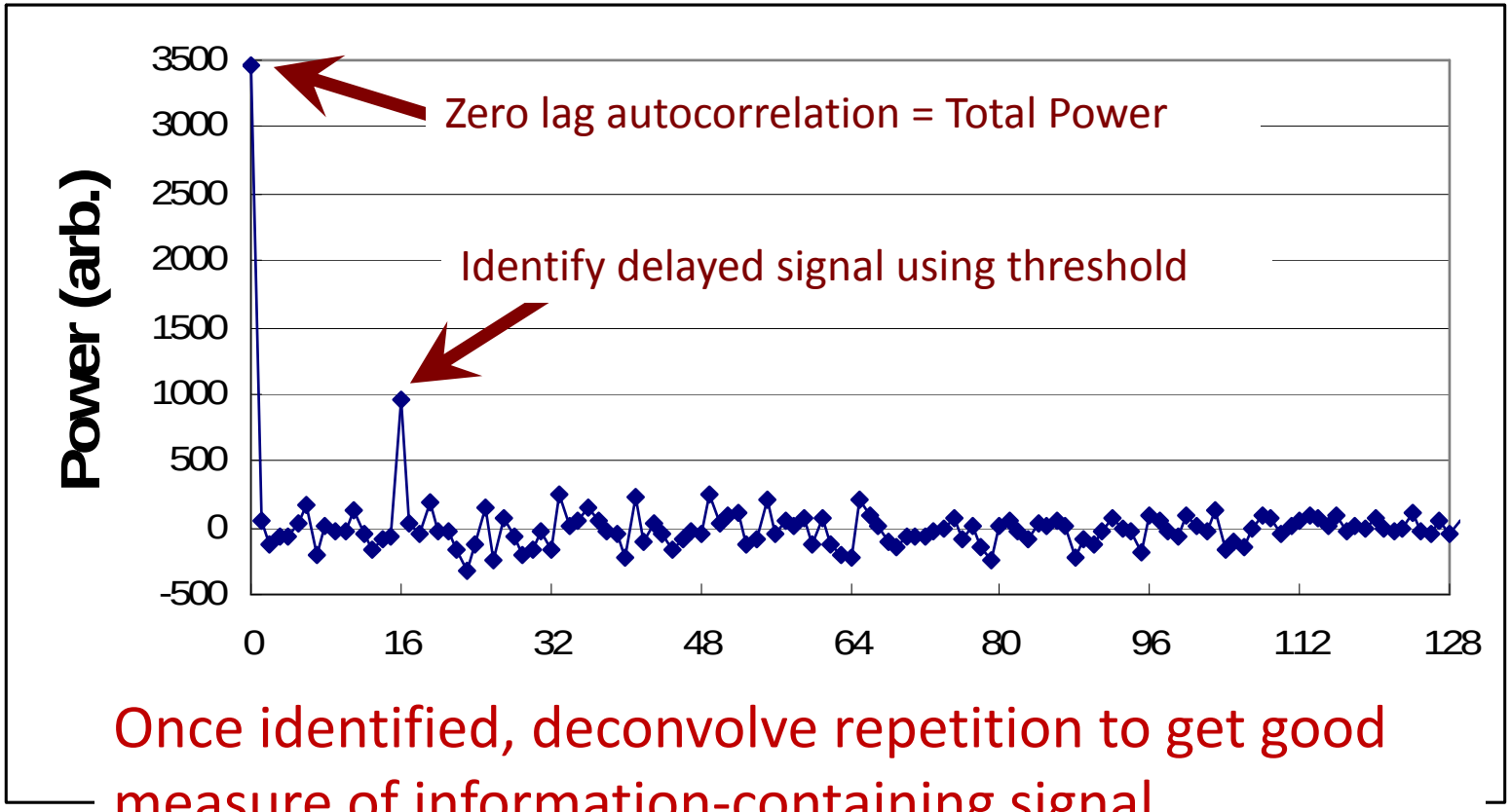
Assume time series contains information, sent multiple times. Here we show most interesting case where N = 2. New & old idea.



Receiver sees a superposition of the two signals.

Autocorrelation Spectroscopy

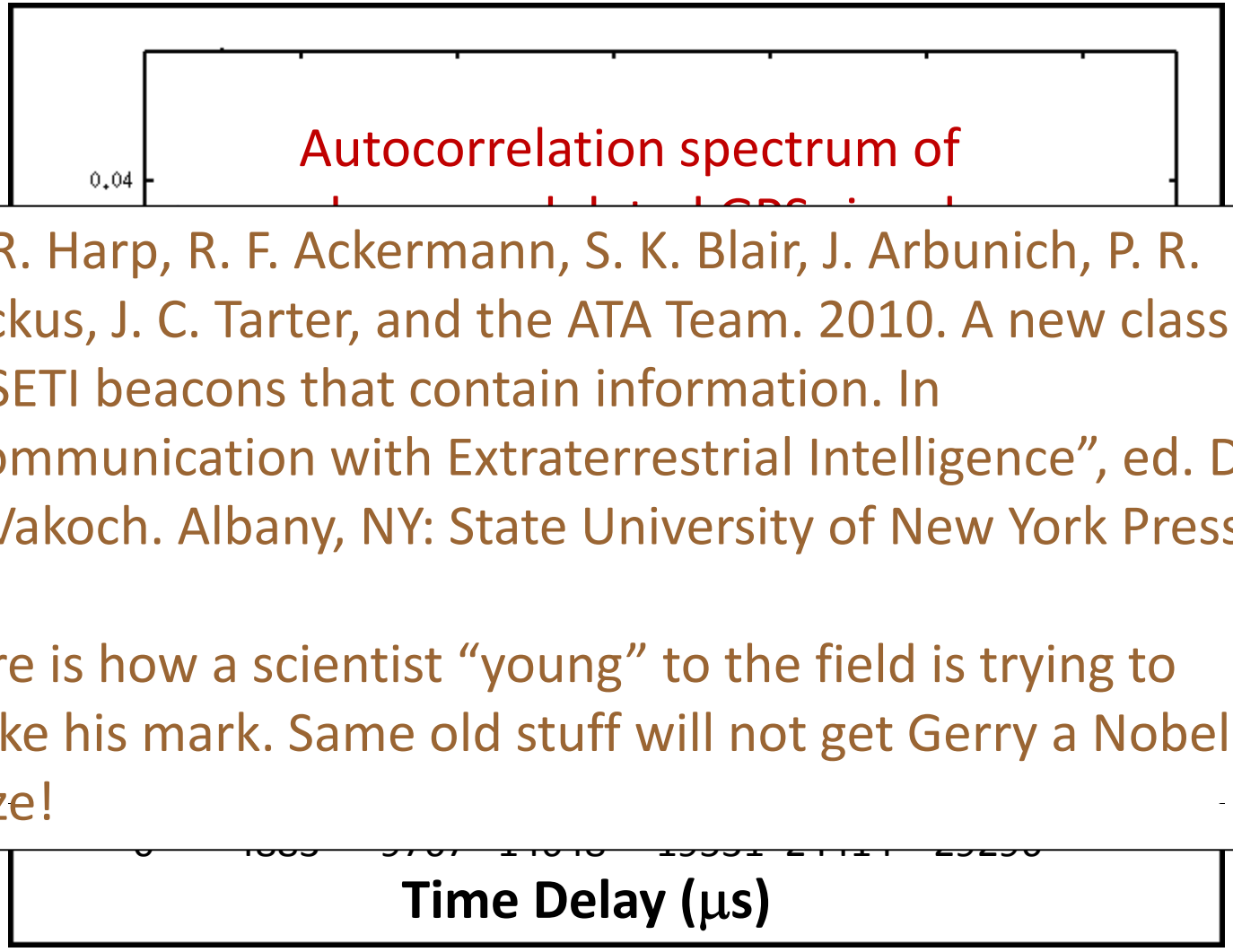
To IDENTIFY the signal, simply compute autocorrelation spectrum (trivial with FFT).



Once identified, deconvolve repetition to get good measure of information-containing signal.

We Found Artificial Signal!

Proof of principle using ATA + Beamformer + Time capture.



G. R. Harp, R. F. Ackermann, S. K. Blair, J. Arbunich, P. R. Backus, J. C. Tarter, and the ATA Team. 2010. A new class of SETI beacons that contain information. In "Communication with Extraterrestrial Intelligence", ed. D. A. Vakoch. Albany, NY: State University of New York Press.

Here is how a scientist "young" to the field is trying to make his mark. Same old stuff will not get Gerry a Nobel Prize!

ATA is SURVEY Machine

Hexagonal Mosaics at ATA.

20 cm survey
690 deg^2, 12 epoch

Steve Croft, et al.
Ap J **719**
45–58, 2010

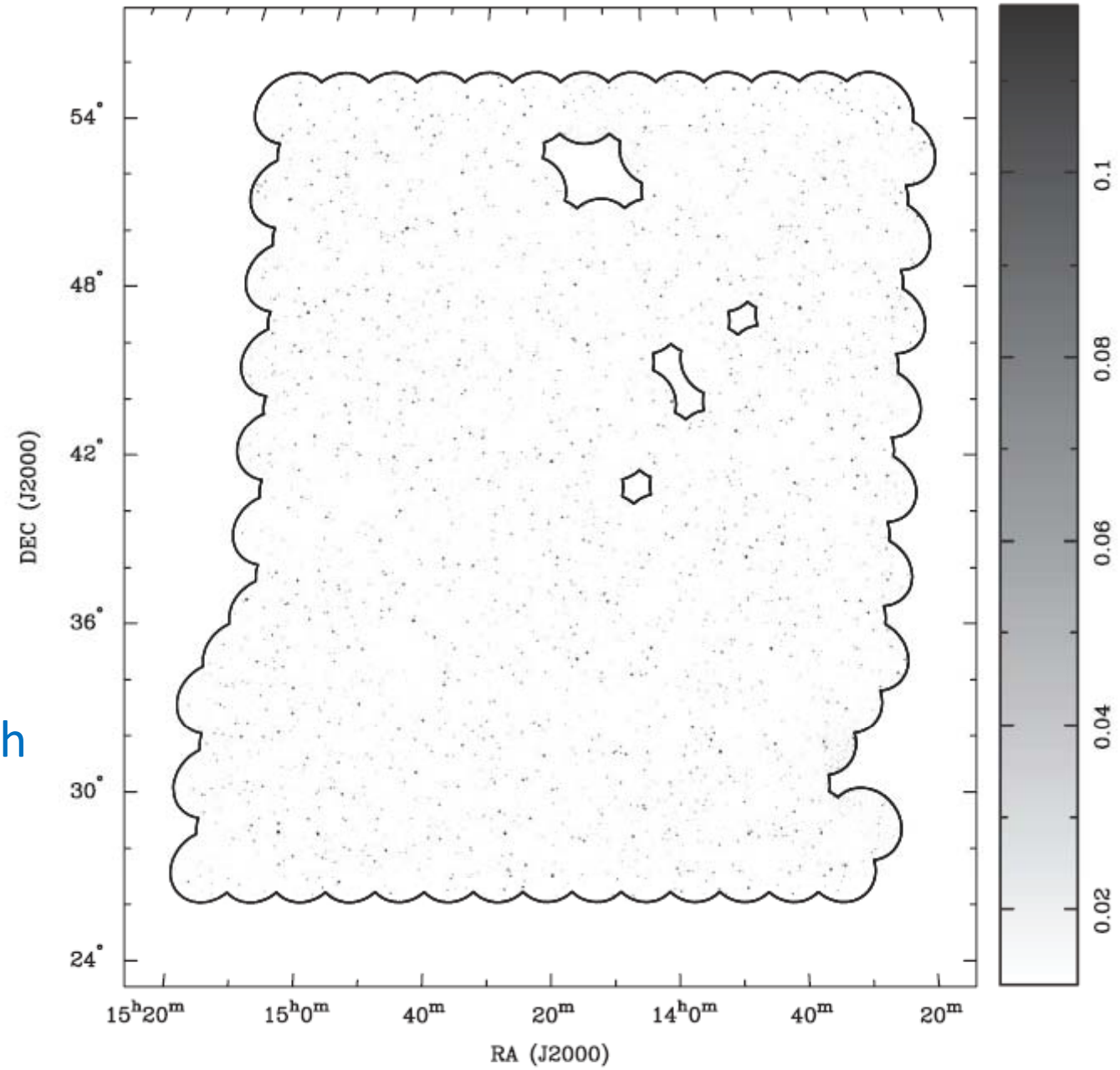
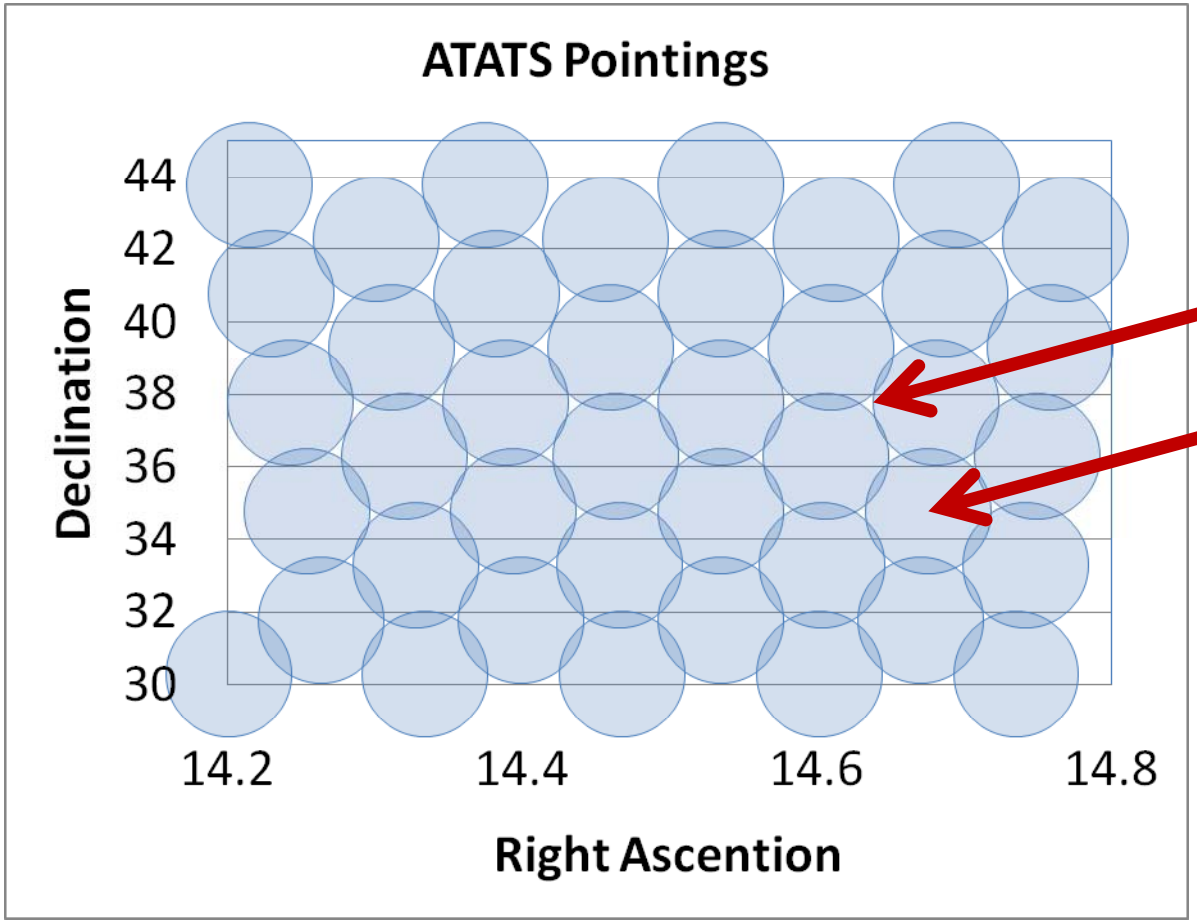


Figure 3. Deep field image, made from a combination of all 12 epochs. The solid line shows the edge of the mosaic—note that some small regions with fewer than nine epochs of good data were not included in the mosaic. The areas near 3C 295 (the large missing region at top center) and 3C 286 (the notch cut into the lower right edge) are notable examples, but there are also a few smaller regions missing, where >4 epochs were unusable due to RFI or some other problem (see Section 4.1). The gray scale runs from 11.82 mJy beam^{-1} (3σ) to 118.2 mJy beam^{-1}(30σ).

Hexagonal Mosaics at the ATA



Suffer low SNR between pointing centers.

Heteroskedasticity (bad).

Solution: More pointings => OTF Mapping

The dread of Primary Beams
(esp. station beams)

- Having flogged this horse for 8 years, I have developed opinions. (^_^)

- I am convinced that even the best case scenarios will introduce PB calibration errors that will limit fidelity much worse than SKA spec.
- And that doesn't even include pointing errors *a la* Sanjay.

  - Solution 0: Calibrate them. Won't work, time dependent, etc.
  - Solution 1: Calibrate them on the fly. Ouch!
  - Solution 2: Arrange a situation where the primary beams "go away," as in very highly redundant on the fly (OTF) mapping.

- Polarization. PB currently limits ATA in this mode.

Mosaic => On the Fly Mapping

- For large fields, make extremely dense mosaic of pointings (super-Nyquist)
- Keep it moving! No overhead / settling time.
- We (Miriad) need a new paradigm to deal with OTF mapping.
  - Too many pointings! Each pointing doesn't have enough SNR to clean.
  - Talk about this later, too.
  - How does ALMA plan to do it?

Pointing Specs

Parameter	Spec.	Meas. X-pol	Meas. Y-pol
Pointing	3’	1.5’ RMS Night 3’ RMS Day	NA
Squint	No spec.	NA	3.4’ RMS
Dish Surface Accuracy	3mm	0.7mm Night 3mm Day	0.7mm Night 3mm Day
Tracking error budget	12” = 10% synthetic beam width @ 10 GHz	7.2” RMS (encoder step = 6”)	7.2” RMS (encoder step = 6”)

Wide Field Clean

How to clean over wide fields where beam is not constant?

- Shows up both in low-freq's, OTF mapping.
- Simple ideas that may mitigate this effect.
  - Project / Morph in image space to create a more constant beam over image.
  - Clean entire image with "average beam," then restore with a position dependent gaussian+residual beam.
    - Follow with second stage clean on higher SNR facets

High Data Rates

- Long baselines / large field of view (ATA => 3km)
  - Conventional wisdom says we can't dump fast enough.
  - Conventional wisdom rarely leads to Nobel prizes.
  - Archives of overly reduced data are useless.

- Data compression
  - Its time for radio astronomy to meet Mr. Huffman.
  - This relates to long baselines and to data archiving.
  - Ripe for creative research.

Prepare for “New” Astronomy

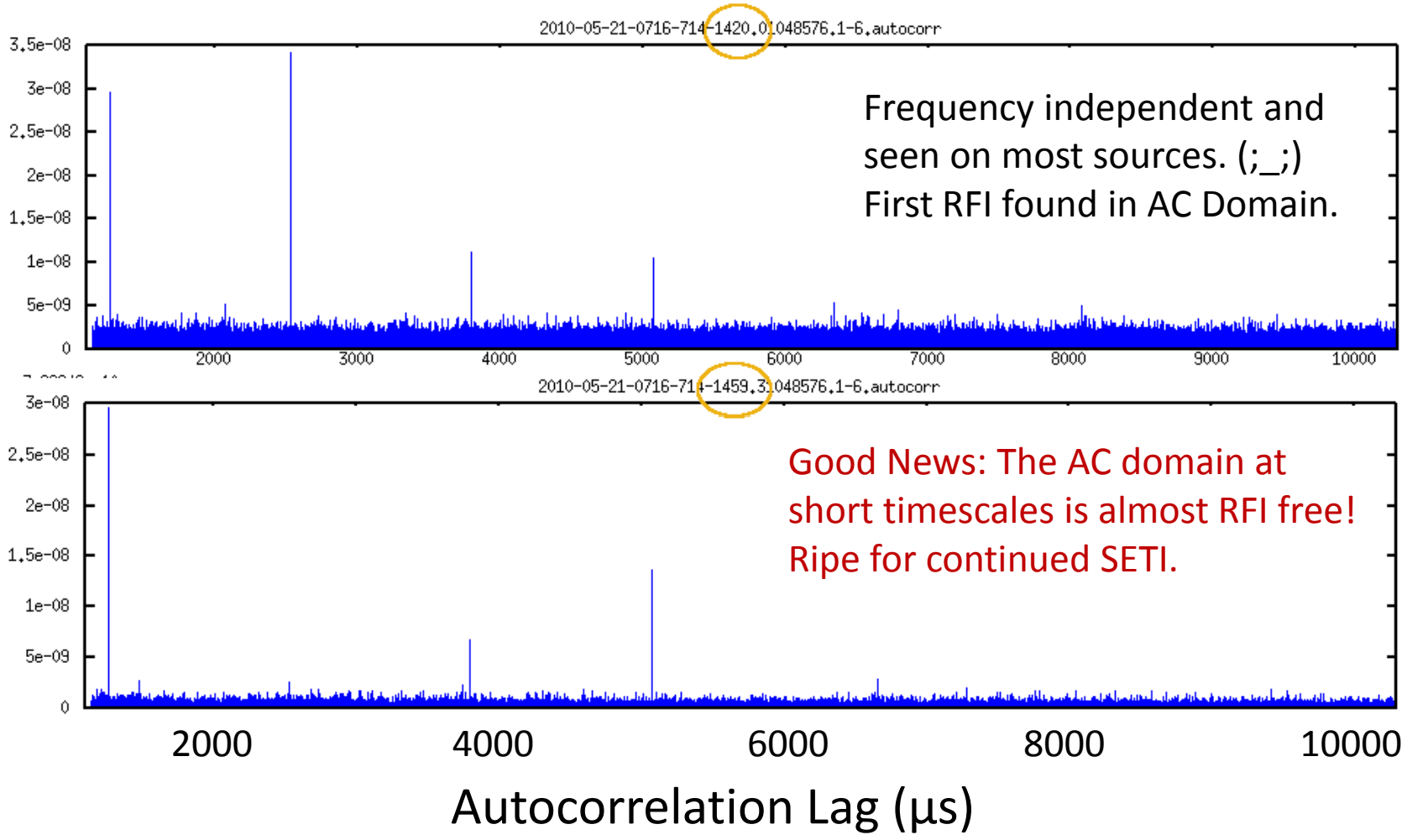
- No ambitious young astronomer is interested in continuing your research, Mr. Bigshot. (^_^);
  - Very simple: Who will get the prize, you or her?
- What are the hot fields?
  - SETI is HOT. No kidding!
    - SETI can be for radio astronomy what Hubble is for optical astronomy. (See funding.)
  - Life away from earth.
    - Molecular spectroscopy in our solar system to spectroscopy in distant galaxies.
    - Planet counting.
    - Habitable zone <> extremophile biology.

Prepare for “New” Astronomy

- Short timescales. Much ATA research.

Extreme Time Domain Astronomy

G.R. Harp, R. F. Ackermann, S. A. Meitzner



Prepare for “New” Astronomy

- Short timescales. Much ATA research.
  - Single pulse transients. GC, Crab, … (RFI makes this hard).
  - Short timescale variable sources. Pulsars, SETI, the unknown[2].
  - These present huge correlator dump/storage problems. Moore's law won't save us here. We need new algorithms and creative solutions.

- Wide bandwidths (Same thing, really.)
  - Spectral index in static domain (infer galaxy type, flat-band => blazars, GHz spectral features, unknown.
  - Dispersed time-variable signals (SETI, Pulsars).
  - More BW = more correlator & more storage
  - Evade RFI

Prepare for “New” Astronomy

- How does a big instrument support single-PI / High Risk science?
  - Remember what it felt like to invent radio interferometry?
    - WYDIA? Or get on a new train before it leaves the station?
  - Some best and brightest do not eat bread & butter. It’s cake or they leave the party!
  - Radio Astronomy needs a few such people.
  - Maybe the answer is…

Prepare for “New” Astronomy

- Data archiving.
  - Not boring! If you save enough data.
  - Optimal is to save the raw data from every antenna.
    - Don't tell me I can't. We’re beginning at ATA.
    - Our biggest future donors are more excited about this than anything else.
    - Not if, but where to start and what is the growth plan.
  - Low entry budget for researchers at smaller / undergraduate universities.

Funding

- US NSF is not going to pay for SKA: decadal review. (;_;)
- Develop private funding -- one place where the SETI Institute is leading the way in Radio Astronomy. Humble as we are! (^_^);;
- Develop collaborations with non-science governmental agencies.
  - Weather
  - Space
  - I know a guy who thinks he can predict earthquakes by looking for disturbances in the ionosphere.

Who is SETI / ATA?

SETI Institute

Ackermann, Rob
Backus, Peter
Barott, Billy
Bradford, Tucker
Davis, Mike
DeBoer, Dave
Dreher, John
Harp, Gerry
Jordan, Jane
Kilsdonk, Tom
Pierson, Tom
Randall, Karen
Ross, John
Tarter, Jill

UCB and HCRO

Backer, Don ♠
Blitz, Leo
Bock, Douglas
Bower, Geoff
Cheng, Calvin
Croft, Steve
Dexter, Matt
Engargiola, Greg
Fields, Ed
Forster, Rick
Gutierrez-Kraybill, Colby
Heiles, Carl
Helfer, Tam
Jorgensen, Susie
Kaufman, Jeff
Keating, Garrett (Karto)
MacMahon, Dave
Milgrome, Oren
Thornton, Doug
Urry, Lynn
Van Leuven, Jori
Vanourtryve, Cassandra
Welch, Jack
Werthimer, Dan
Williams, Peter
Wright, Mel

Minex

Cork, Chris
Fleming, Matt
Vitouchkine, Artyom

Student Interns

Imara, Nia
Chubb, Kelsey
Adair, Aaron
Nadler, Zachary
Pearson, Ruth
Bethany Wilcox
Jack Arbunich
Seth Meitzner