Advances in Wideband SETI and Implications for Radio Telescope Design

Dr Ian S. Morrison

24 October 2011

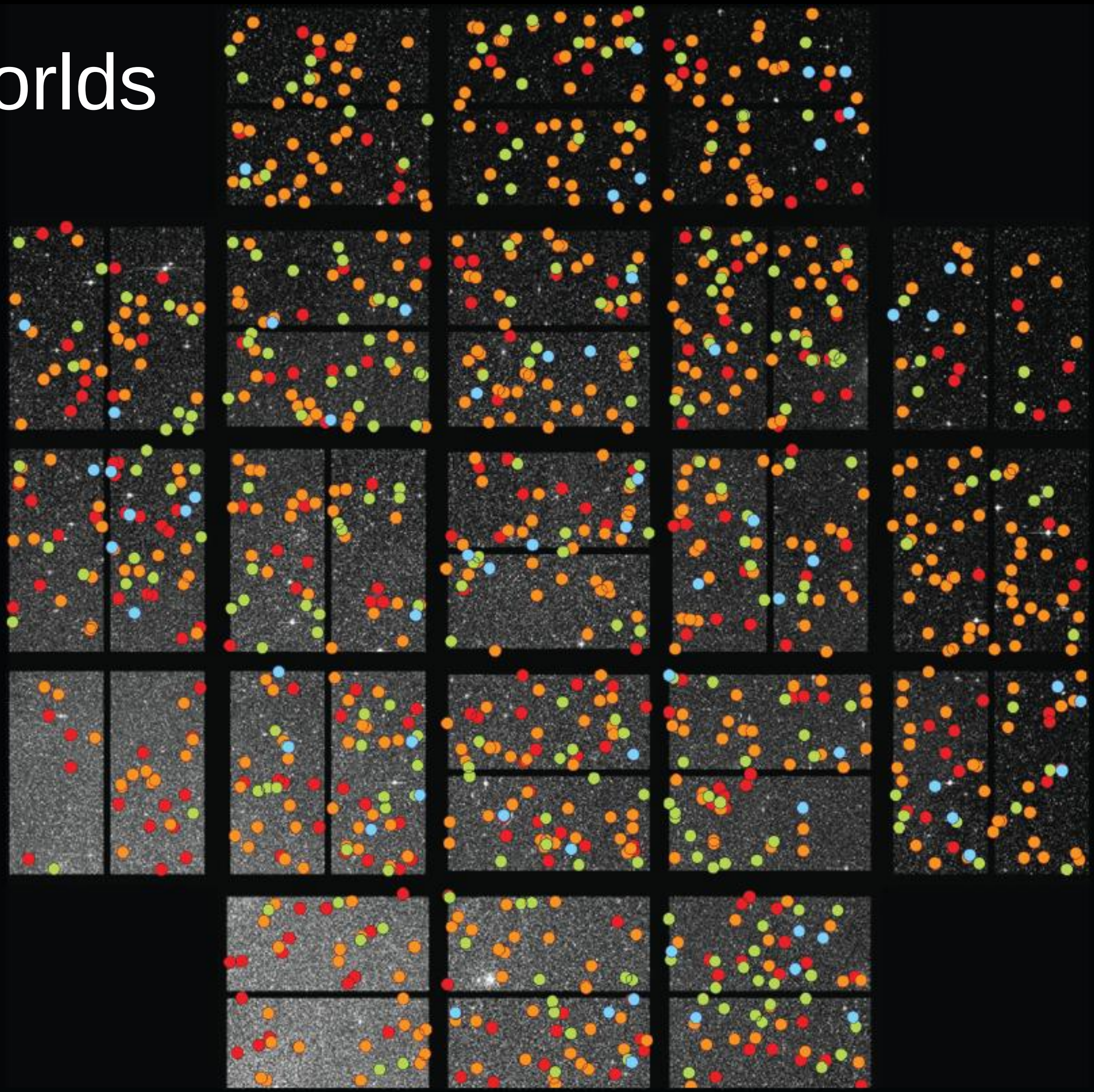
Australian Centre for Astrobiology

UNSW
THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY • AUSTRALIA

Resurgence in SETI

- New generation radio telescopes and anticipation of the SKA
- Emergence of ‘wideband SETI’
- Successes in astrobiology, in particular exo-planet discoveries

1235 Kepler Worlds



68 Earth-size

288 Super-Earth size
1.25 - 2.0 Earth-size

662 Neptune-size
2.0 - 6.0 Earth-size

184 Giant-planet size
6.0 - 22 Earth-size

54 are ‘habitable’

SETI by Eavesdropping

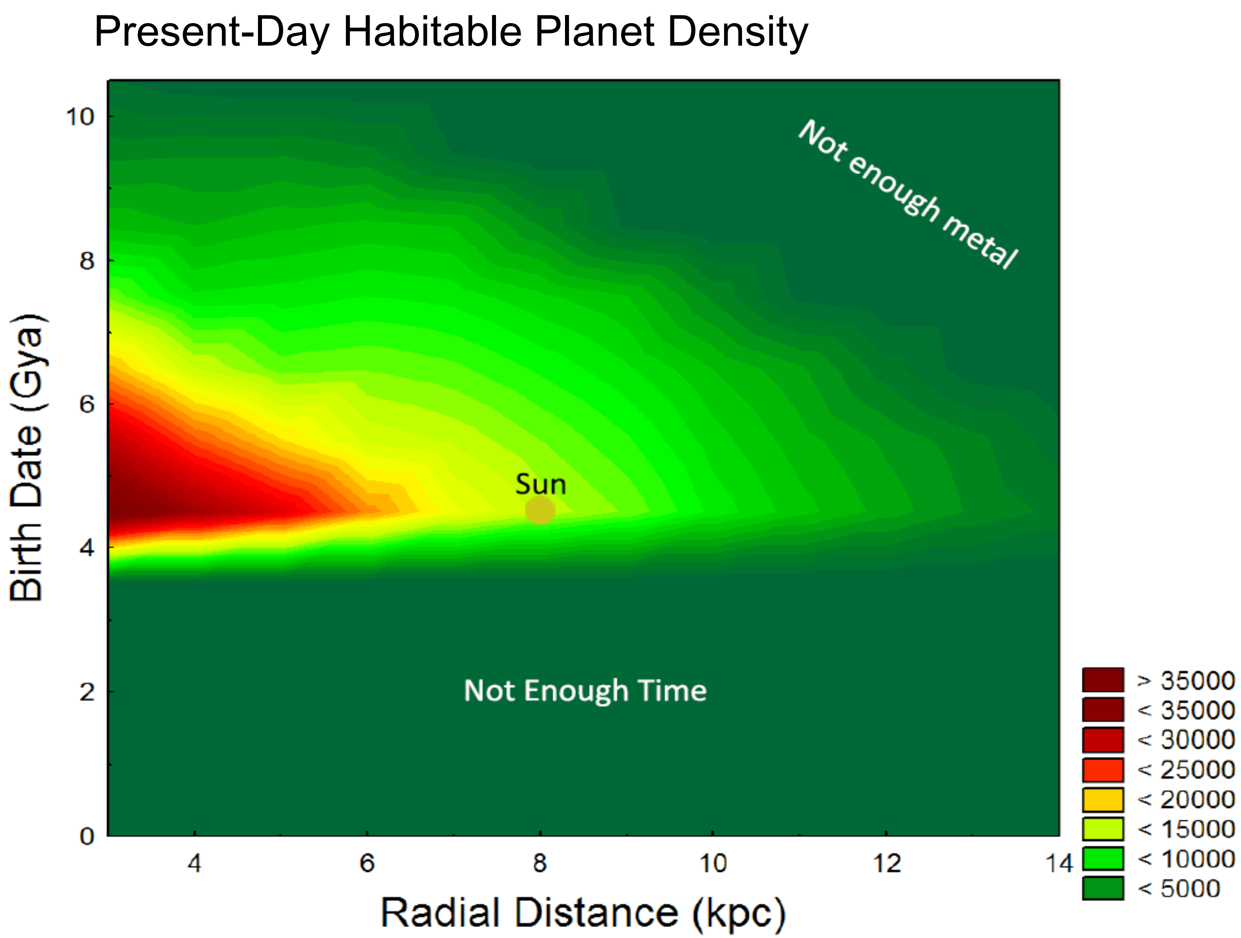
- Expect civilisations to have a short timespan for high power narrowband emissions

  ➔ Emissions tend to become lower power, wider bandwidth and more noise-like as technology advances

- Forgan & Nichol: eavesdropping with the SKA unlikely to succeed beyond 300 ly
  - Assumes pulsed radar: ranges even shorter for wideband communications emissions
  - Few habitable planets within this range

➔ Eavesdropping is **not** a ‘percentage play’

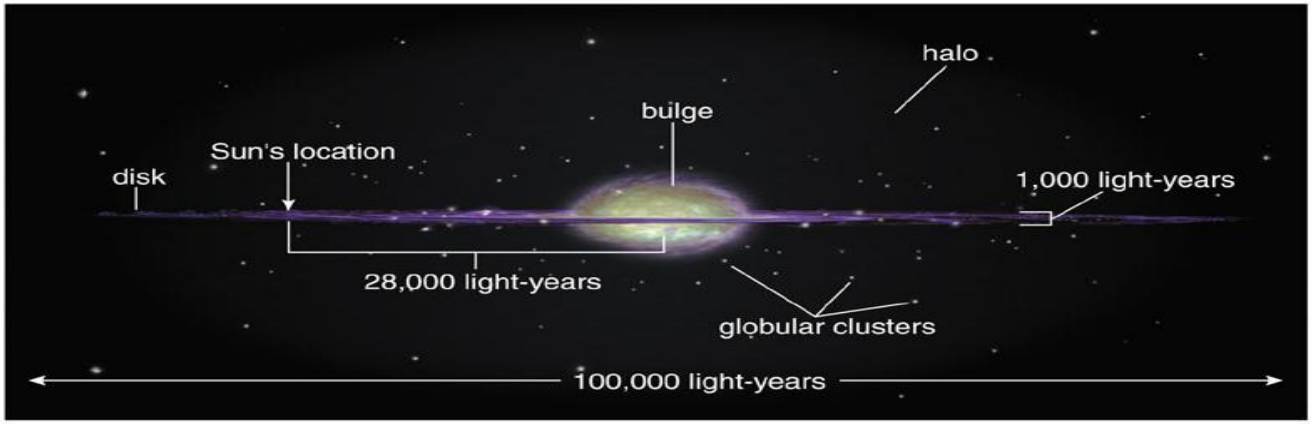
Galactic Habitable Zone



Credit: Gowanlock, Patton & McConnell

Deliberate Beacons

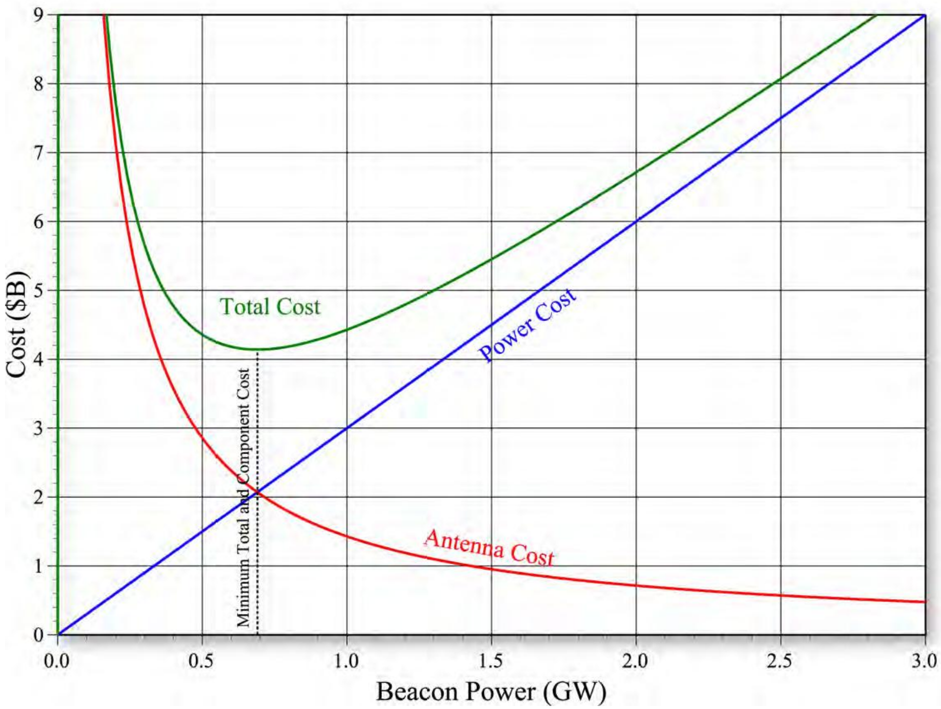
- ~260,000 stars within 250 ly of Earth
- ~10^6 times that in the whole galaxy
- Maximum star density (and habitable planet density) in the central bulge
- Good strategy to search the galactic centre, **but only beacons detectable over such ranges**



→ Chances of detection are orders of magnitude higher if search for **beacons** near the **galactic centre**

Beacons Appear as Transients

- Galactic-scale beacons require **large** EIRPs
- Optimal way to achieve high EIRP is to split cost between antenna and power source (Benford et al)



Credit: James Benford

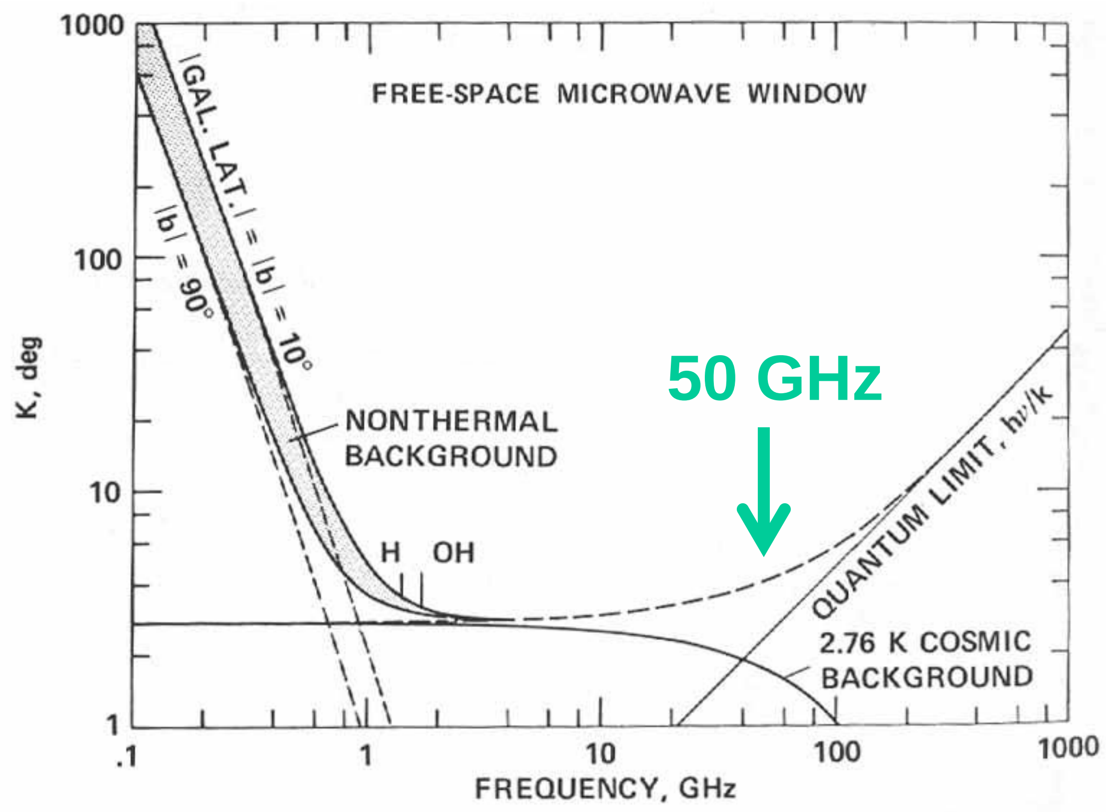
- High-gain antenna ➔ narrow beam
- Beam must scan to illuminate multiple targets (lighthouse analogy)
  - ➔ Finite 'dwell time'
  - ➔ Possibly infrequent 'revisit time'

➔ on Earth a beacon will appear as a transient radio source

UNSW THE UNIVERSITY OF NEW SOUTH WALES SYDNEY • AUSTRALIA

Frequency Range

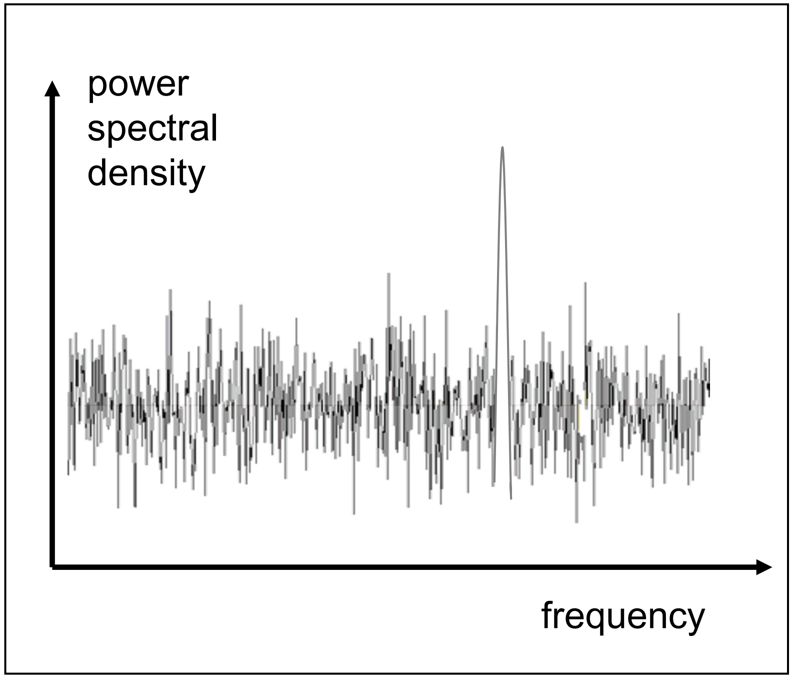
- Higher frequencies favoured for beacons because transmit antenna gain increases with frequency (for given area)



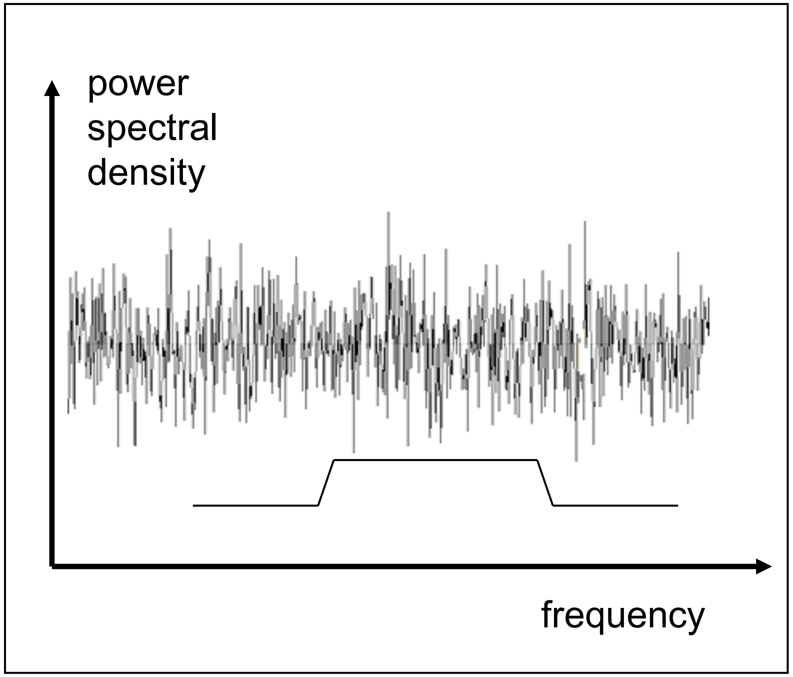
- Terrestrial microwave window: **~1 – 10 GHz**
- Free-space microwave window: **strong case for ~50 GHz**

Credit: NASA (Philip Morrison, John Billingham, John Wolfe)

Narrowband versus Wideband



narrowband



wideband

Narrowband SETI

Why has narrowband been favoured to date?

- Assumed to be easier to generate at high powers
- Signal unaffected by dispersion from the ISM
- Highly sensitive receivers easier to construct

Concerns with narrowband

- Not conclusively of technological origin
- Transmitted power concentrated in narrow bandwidth → jammer
- Low information content (conveys just 1 bit: "you are not alone")
  - If many ETIs & beacons → no incremental value in saying "you are not alone"
- Longer range (galactic scale) increases chance of being detected but high cost to build and operate. Why would ET invest in a beacon and not send information?

Wideband SETI – benefits & challenges

Benefits

- Conclusively of technological origin
- Robust to noise and interference
- Lower peak power density
- More scope to convey higher information content

Challenges

- Lower peak power density, so simple energy detection unlikely to succeed
- More degrees of freedom in signal structure: harder to find a signal when you don’t know what you’re looking for
- Wideband signals affected in a more complex way by Doppler and ISM degradations (dispersion, scattering), which further complicates discovery

Wideband SETI – misconceptions

- ❑ Wideband signals have too many degrees of freedom
  - ➔ We cannot hope to detect the signal unless we know the signal's structure and key parameters
- ❑ Detection requires redundancy in the signal
  - ➔ There needs to be repetition of waveforms and/or information content

BOTH INCORRECT

Detection of Unknown Wideband Signals

1. Matched Filtering
   - Optimum but impractical without knowledge of signal form
2. Energy Detection
   - Low sensitivity – useful only if signal well above noise
3. Cyclic Spectral Analysis / Peak Regeneration (Gardner)
   - Regenerates discrete spectral lines – may give minor gain
4. Karhunen-Loeve Transform (KLT)
   - More generic than the FT but computationally **very** complex
5. Autocorrelation
   - Generate detectable peaks with modulated and repetitive signals but poor sensitivity with randomly modulated signals
6. Symbol-Wise Autocorrelation (SWAC)
   - Modified autocorrelation approach – more sensitive for randomly modulated signals

Symbol-Wise Autocorrelation (SWAC)

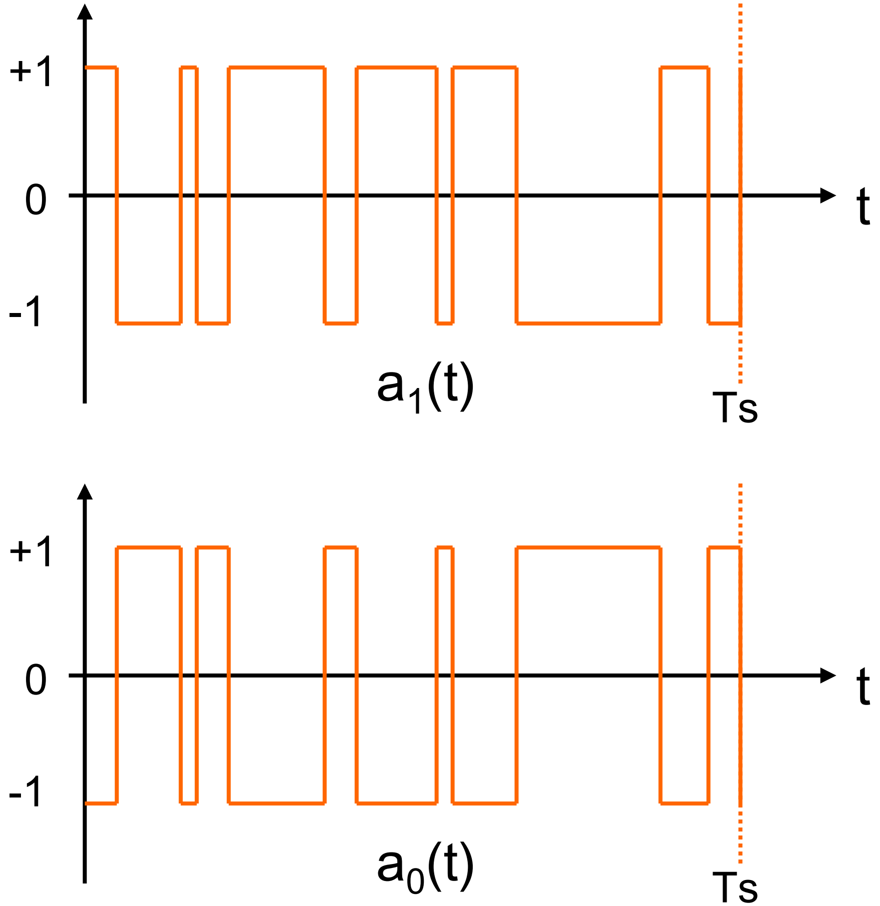
- Correlate M successive adjacent symbol pairs, summing the modulus of each correlation score
- Repeat over a range of assumed symbol periods, looking for a strong peak

$$SWAC(\tau) = \sum_{n=1}^{M} \left| \sum_{k=k_0+(n-1)\tau}^{k_0+n\tau} \left(y_k \cdot \bar{y}_{k+\tau} \right) \right|$$

$$D = \max_{\tau\in[\tau_1,\tau_2],k_0\in[0,\tau]} SWAC(\tau) \qquad \hat{T}_s = \arg\max_{\tau\in[\tau_1,\tau_2],k_0\in[0,\tau]} SWAC(\tau)$$

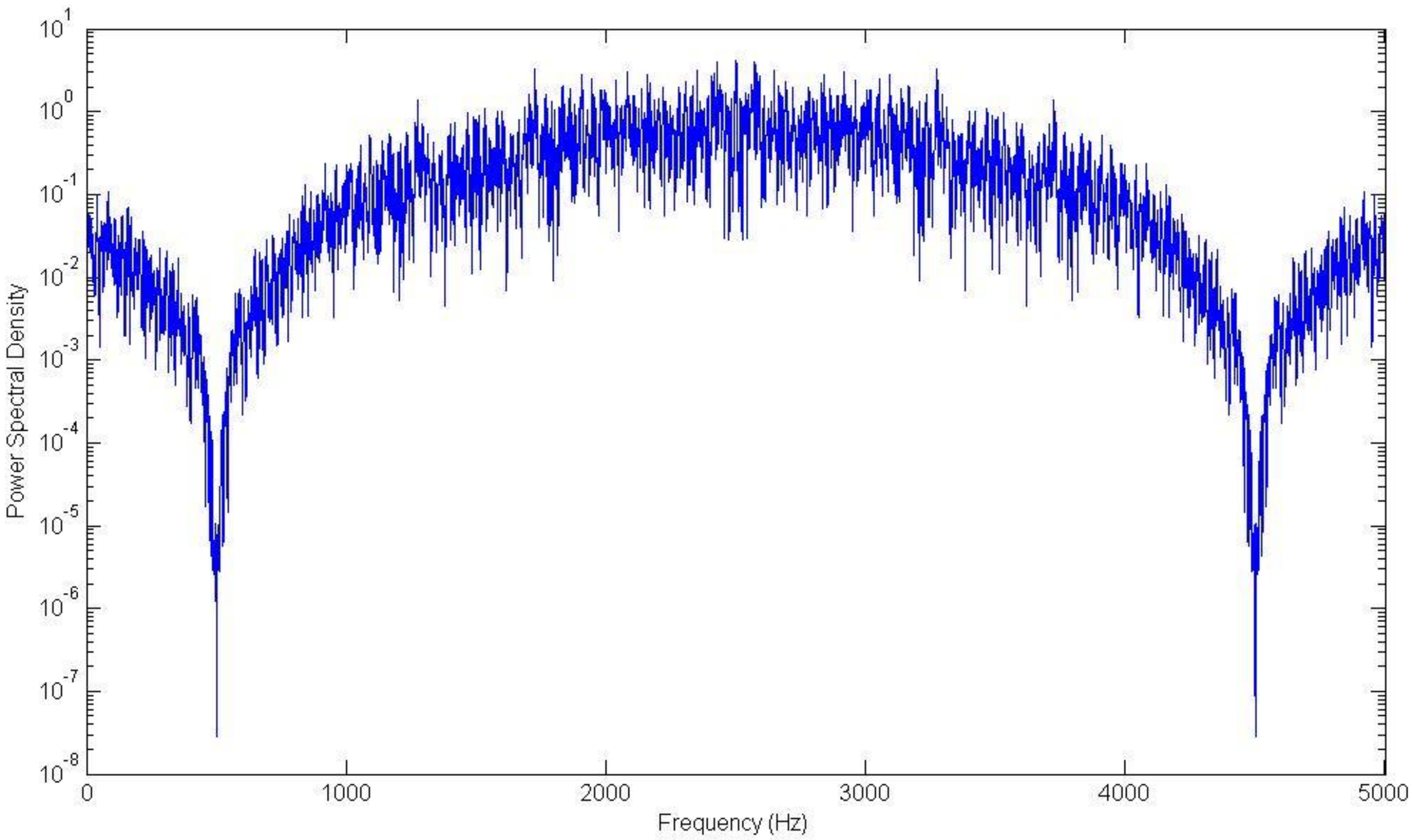
Do NOT need to know centre frequency, bandwidth (symbol/chip rate) or modulation type/alphabet

Antipodal spread-spectrum BPSK

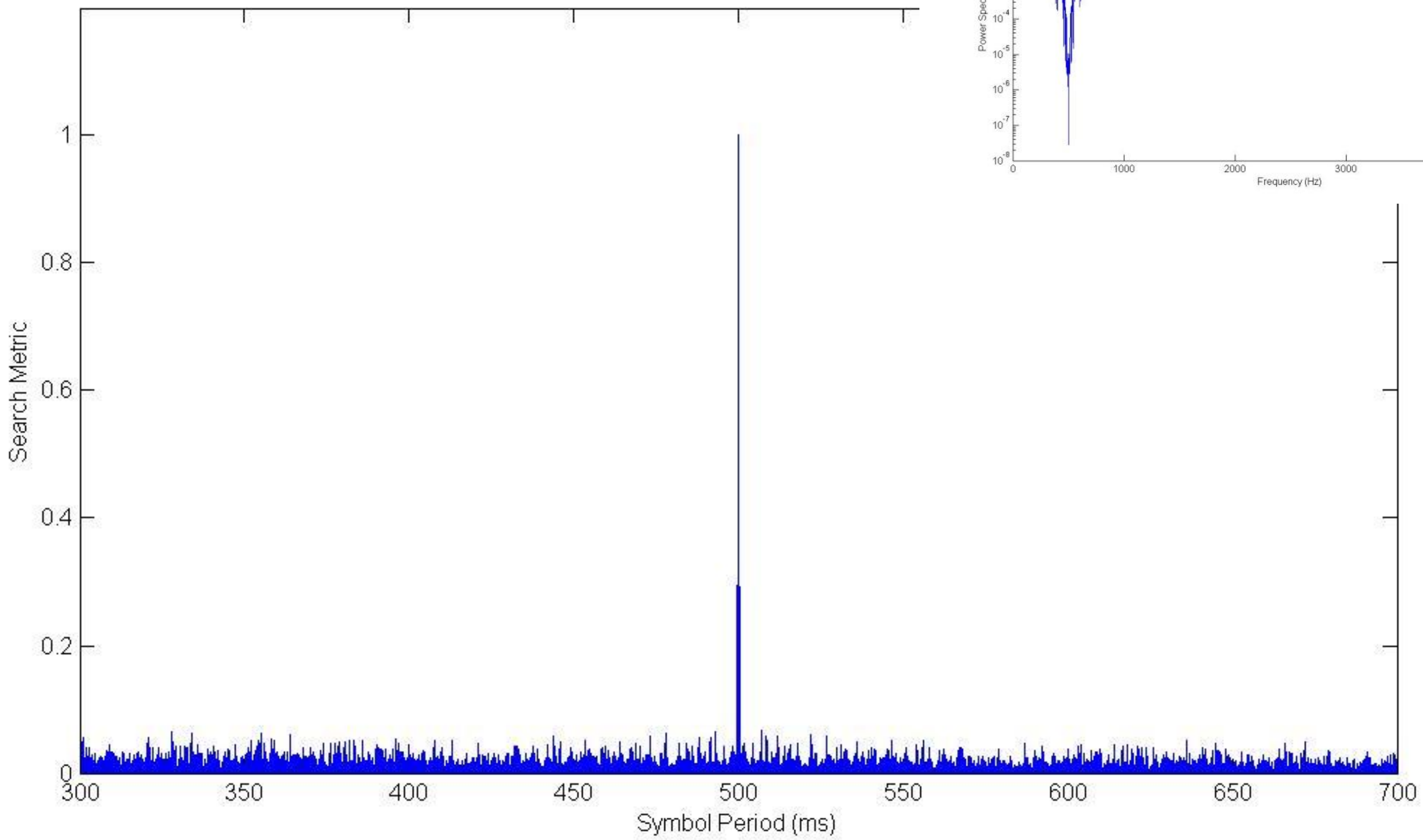


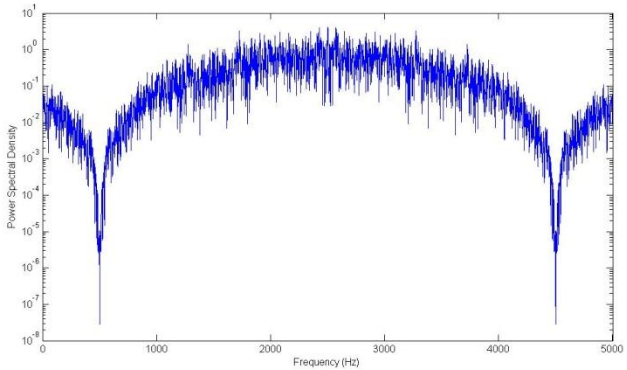
Example – antipodal spread-spectrum BPSK

2 sym/s, 1000 chips/sym BPSK, 50 second burst, no noise



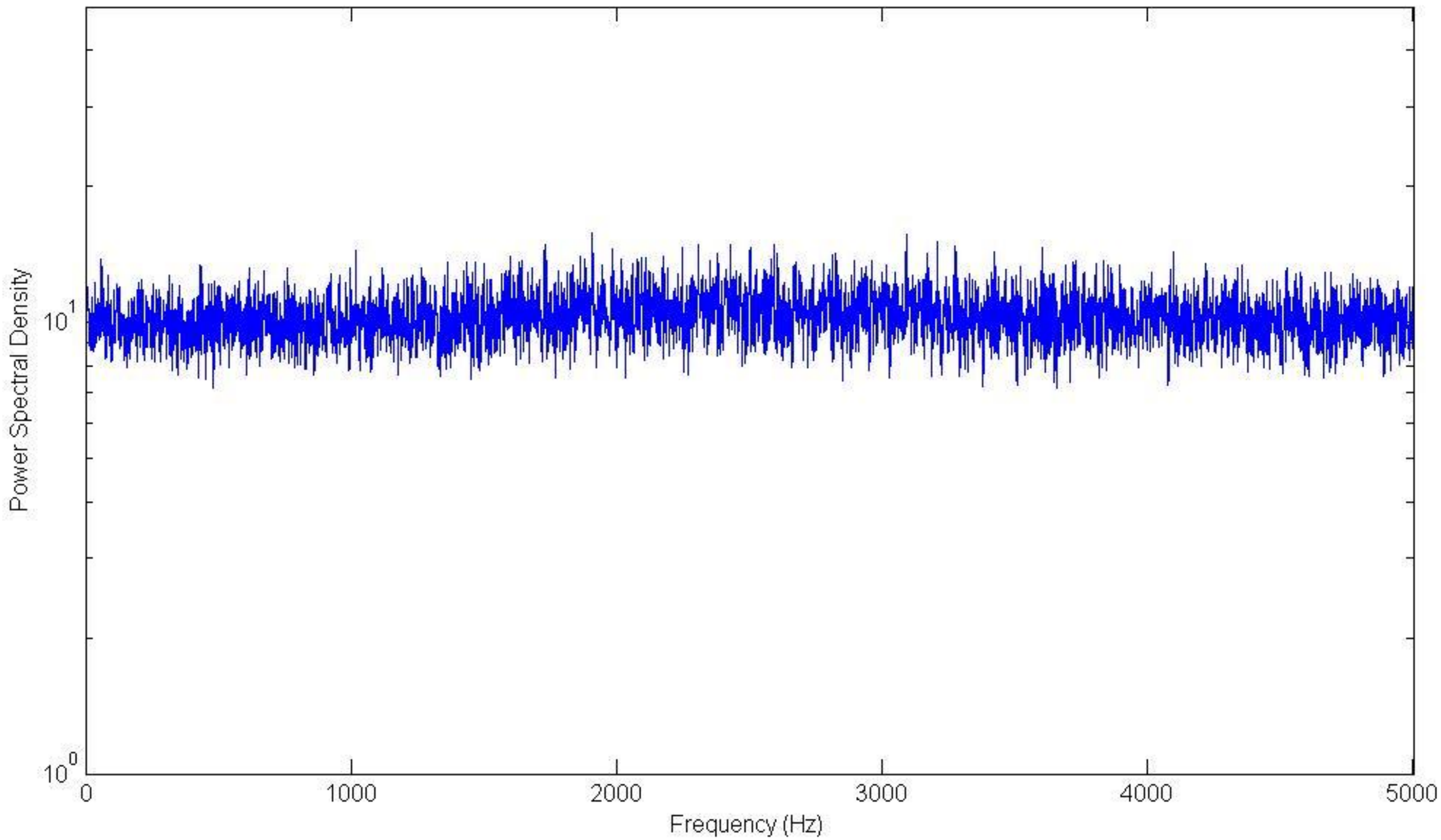
Example – antipodal spread-spectrum BPSK



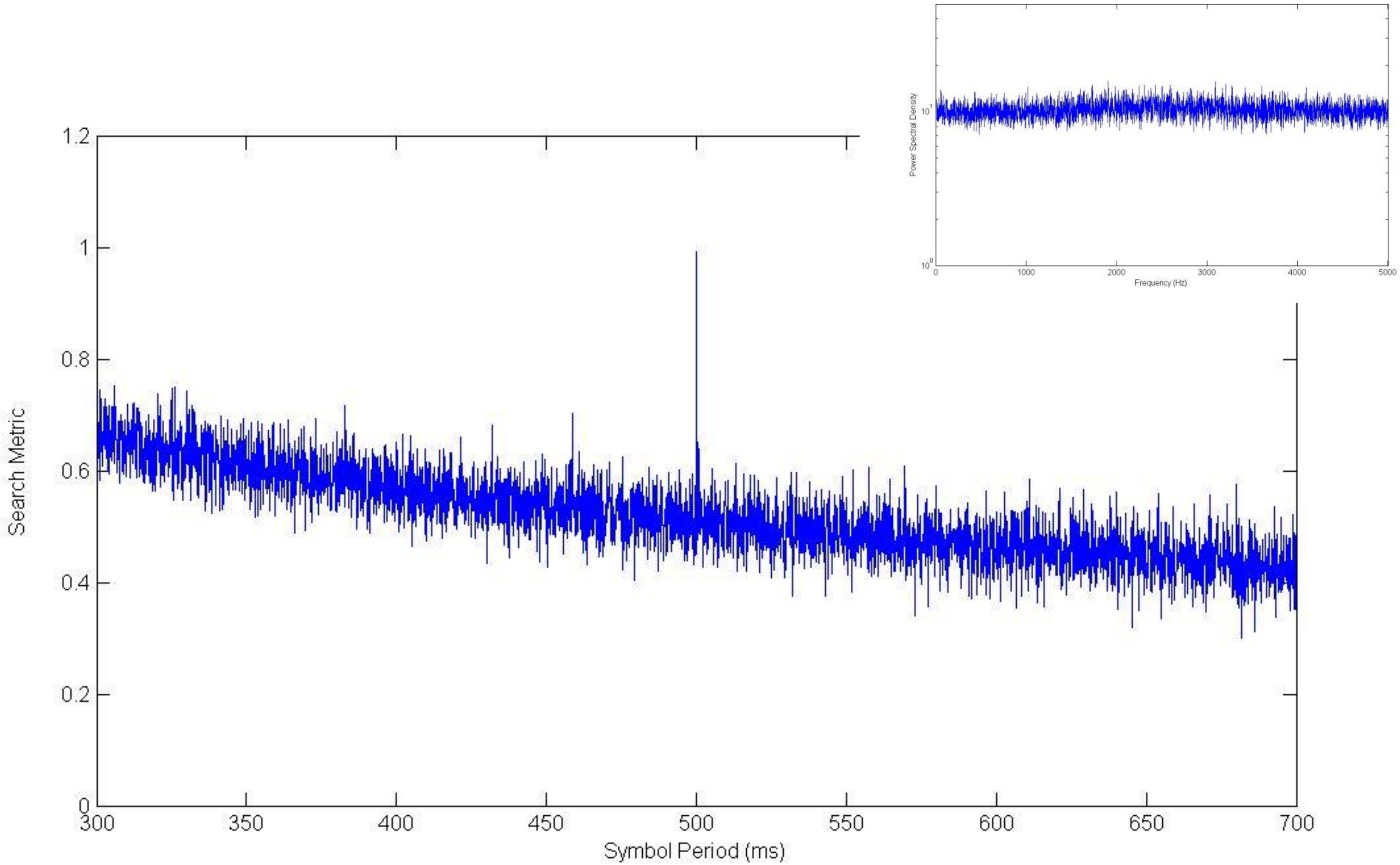


Example – antipodal spread-spectrum BPSK

2 sym/s, 1000 chips/sym BPSK, 50 second burst, -18 dB SNR



Example – antipodal spread-spectrum BPSK



Wideband SETI – telescope design implications

- High-resolution time-domain sampling

  → access to ‘raw’ **complex I/Q samples** of beamformer output

- Sampled bandwidth: **minimum 1 MHz**, preferably **10 to 100 MHz** (selectable across the whole feed bandwidth)

- Sample quantisation: **minimum 8 bits**, preferably **10 bits**

- Logging of samples to file – to support **off-line processing**

Wideband SETI – Experiment Proposal

Project ‘STRAWBALE’:

Search for TRAnsient Wideband Beacons And Long-range Emissions

Working Group Proposal

Current SETI in Australia:

- ❑ **ICRAR**: VLBI SETI (using LBA)
- ❑ **ACA/UNSW**: Wideband SETI / SWAC (using ATA)
- ❑ **UWS**: Optical SETI
- ❑ **Boonah**: amateur optical & radio SETI

New working group to coordinate Australian SETI?

- ❑ Opportunity to take a leading role in the overall planning of SETI for the SKA

Summary

1. Focus on **beacons** emanating from the **galactic centre**
2. Such beacons can be expected to appear as **transients**
3. Such beacons can be expected to be **wideband**
4. Such beacons are more likely to be found at **10 GHz and higher**
5. Design telescope back-ends to support **detection of wideband transients**
6. Australia well-placed to take a leading role in planning **SETI for the SKA**

Questions?