WHO'S YOUR DADDY?
WHY GPS RULES GNSS

Frank van Diggelen, Broadcom and Stanford Aero-Astro
Stanford PNT, 14 Nov 2013

Thanks for their contributions, edits & comments to:
John Betz, Charlie Abraham, Sergei Podshivalov, Andreas Warloe, Javier de Salas

BIG THEMES

- **The vast majority of GNSS is L1-only, and assisted.**
- **For these receivers, architecture is dominated by *acquisition* sensitivity**
- **GPS C/A code is almost perfectly designed for good acquisition sensitivity**
- **Consumer receivers have rapidly and relentlessly evolved to take advantage of this**
- **And that's why GPS dominates the GNSS landscape, and will do so for years to come**

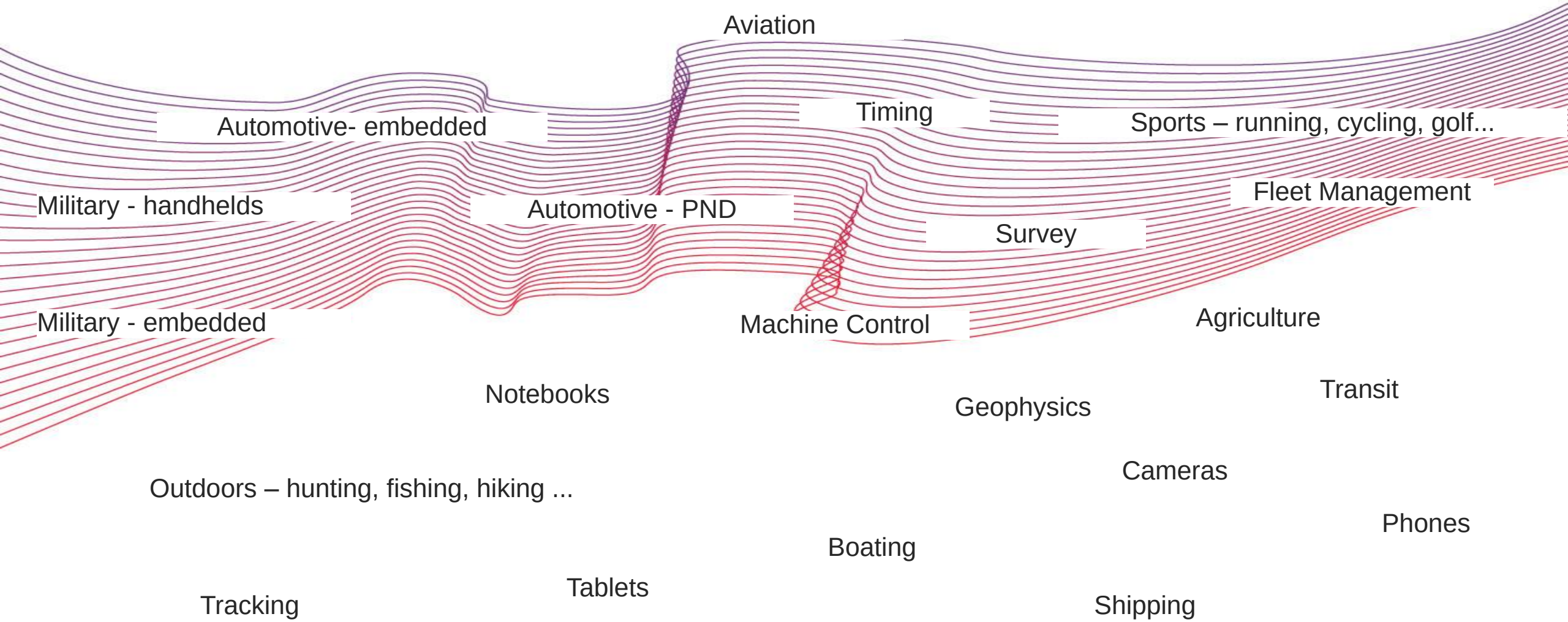
ORGANIZATIONAL OUTLINE

Overview: Cost-benefit analysis of signal processing options for consumer GNSS

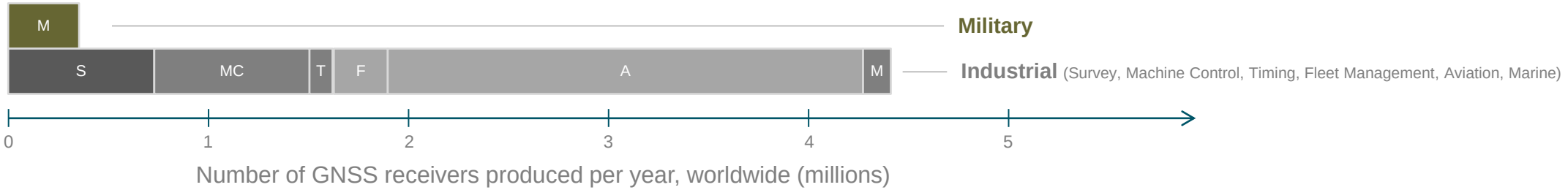
Outline:

- Evolution of GPS receiver architecture to date
  - ⇒ Acquisition speed
  - ⇒ Cost benefit of massive-parallel searches
- Cost constraints for consumer GNSS
- Review of high sensitivity
- Cost-benefit of longer codes
- Cost-benefit of overlay codes and higher data rates
- Why GPS rules GNSS

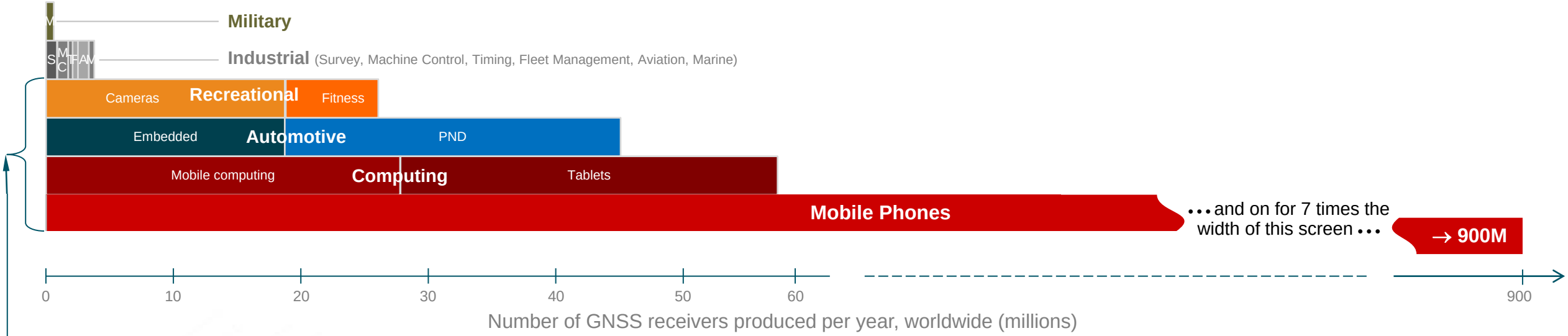
MARKET SEGMENTATION



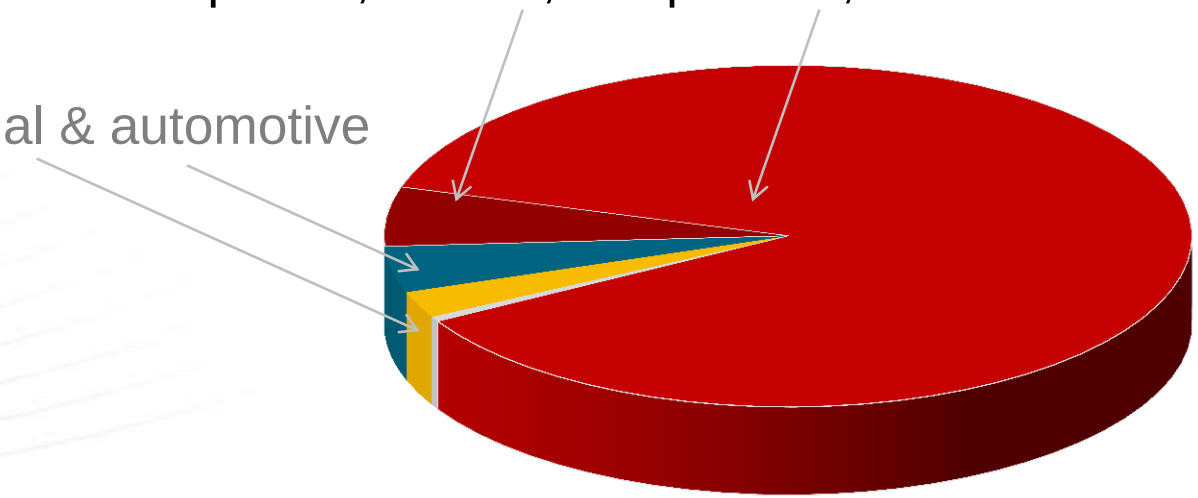
GNSS MARKET SIZE, 2012



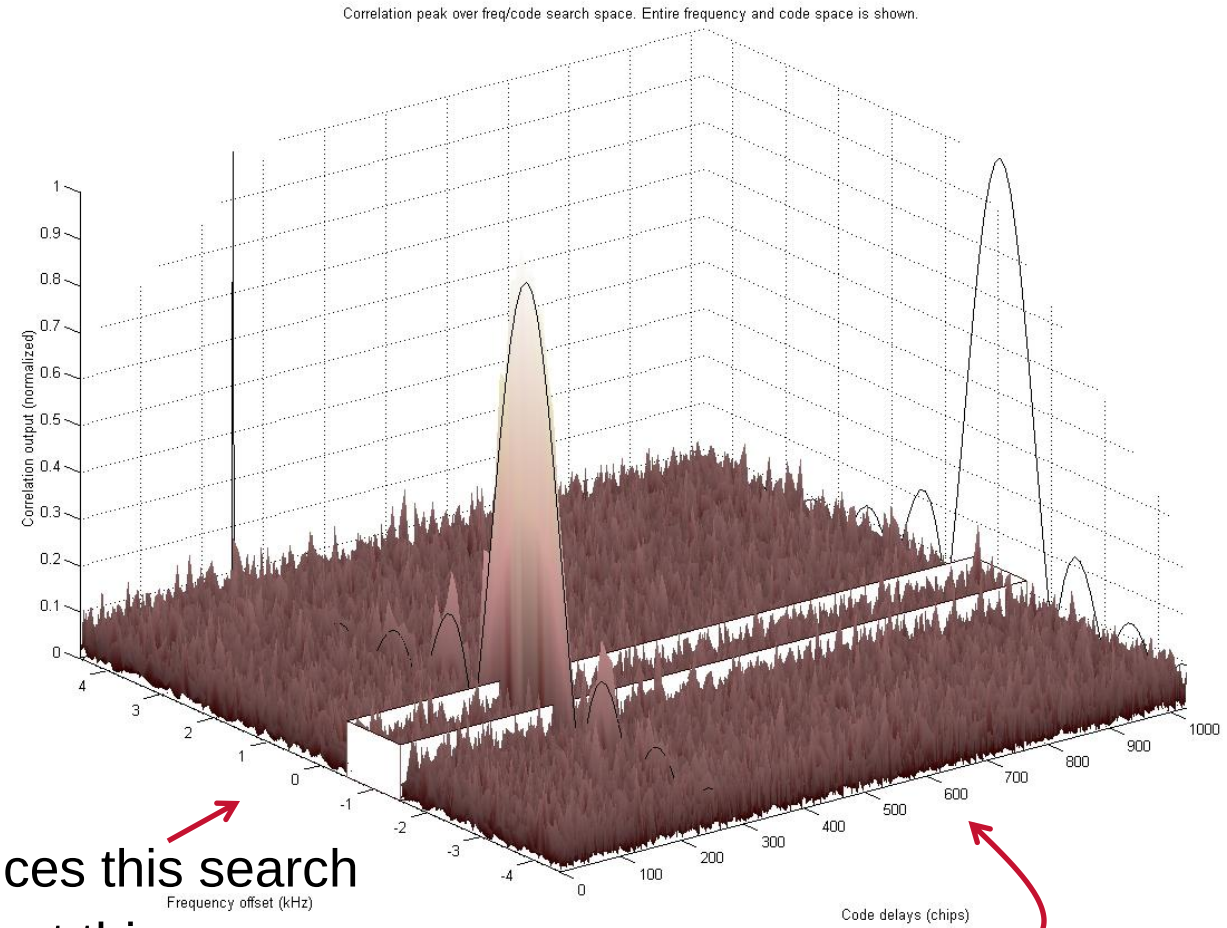
GNSS MARKET SIZE, 2012

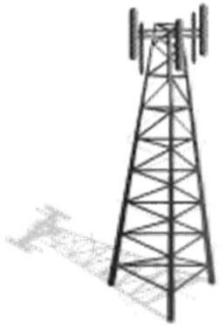


This talk is limited to these market segments: L1-only receivers, Assisted-GNSS;
mostly mobile computers, tablets, cell phones;
but also
recreational & automotive



SIGNAL PROCESSING BACKGROUND

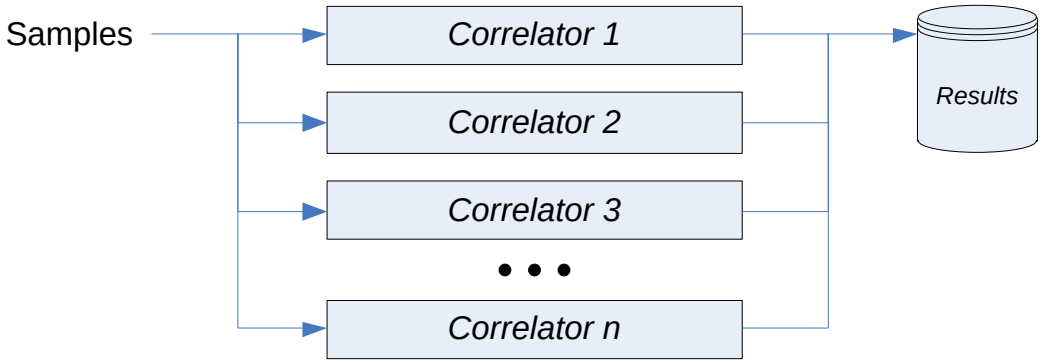




A-GPS reduces this search

But usually not this one

THE GOOD OLD DAYS

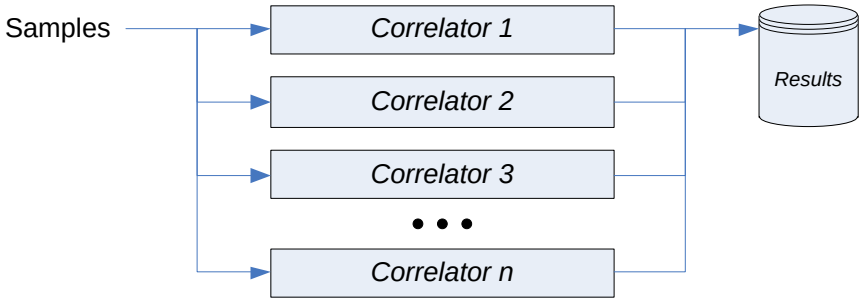


Gen 1

Early Processing Engine ca. 1993

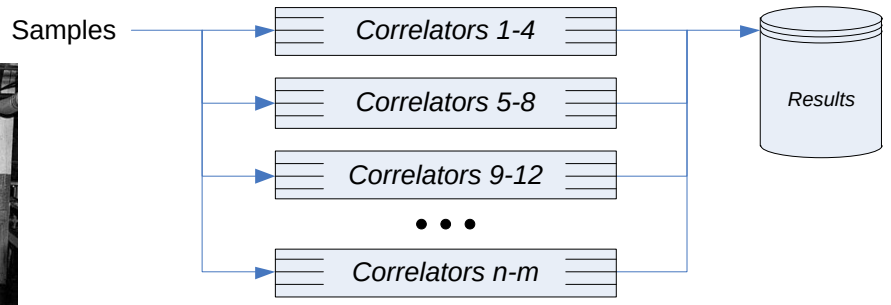
"Back when a correlator was a correlator"

SEARCH ENGINE EVOLUTION

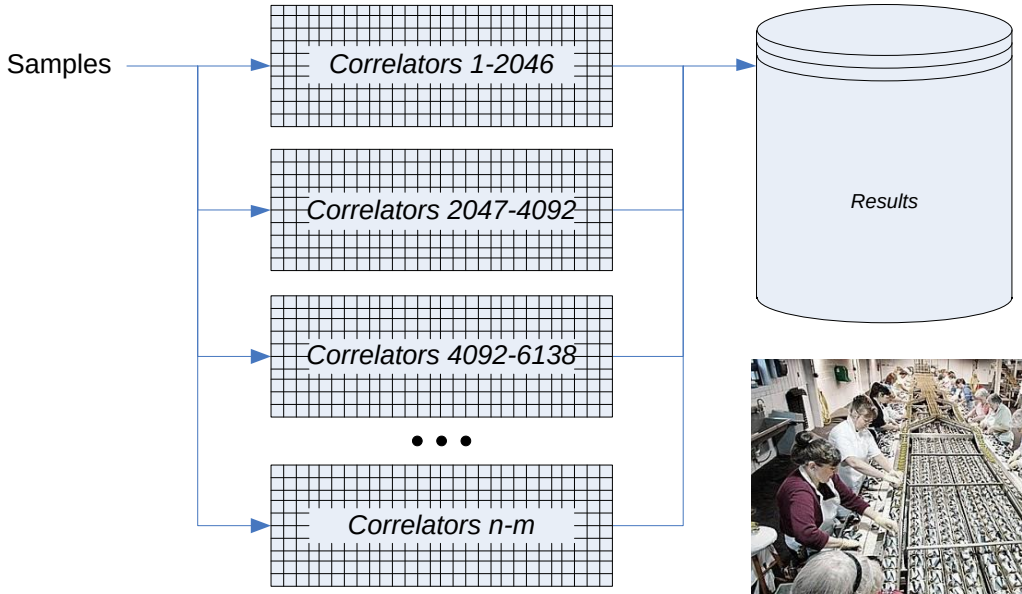


Gen 1

Processing ca. 1993

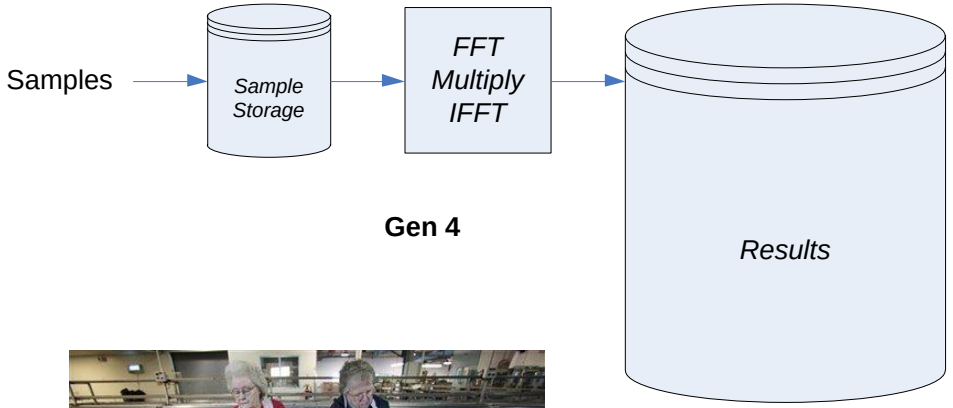


Gen 2



Gen 3

Matched Filter Processing

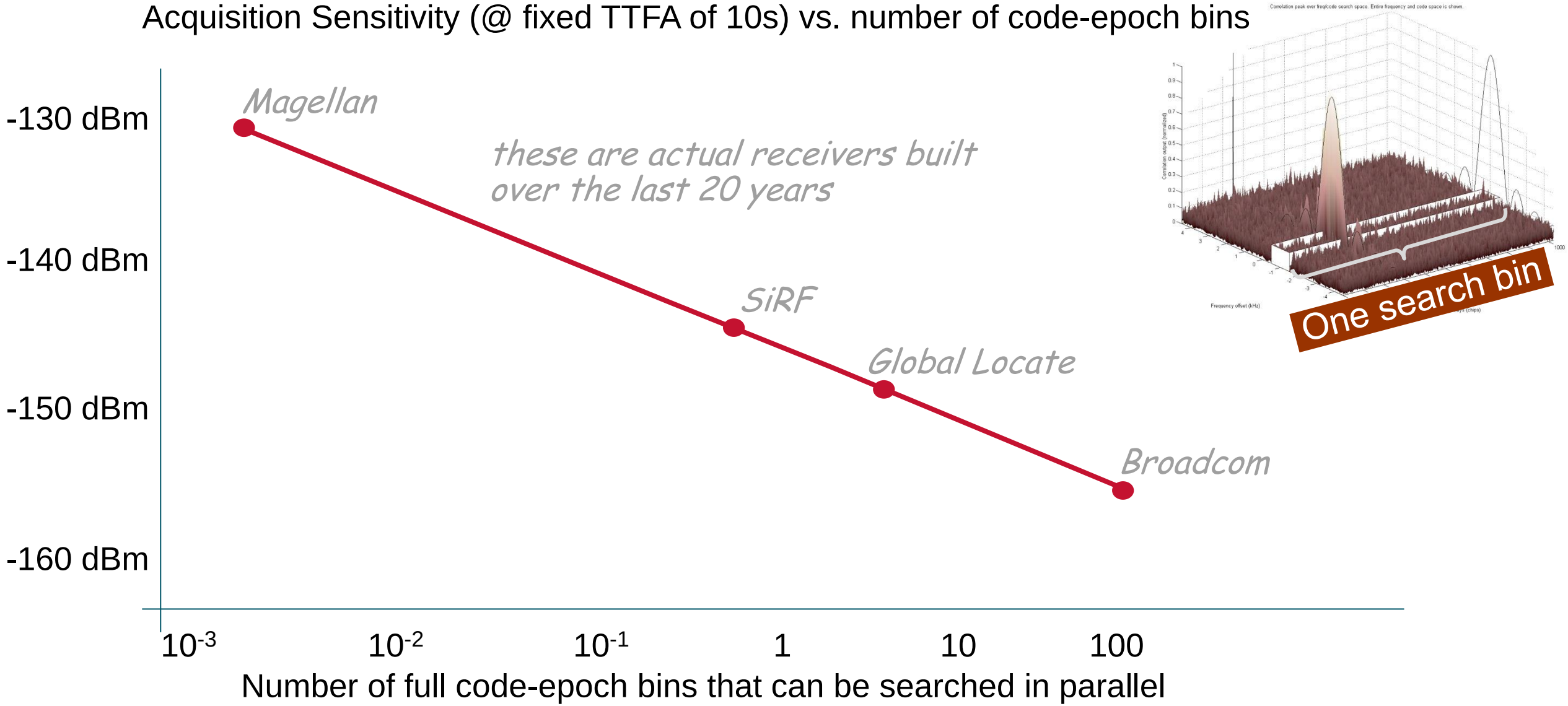


Gen 4

FFT Processing

COST BENEFIT OF ADDING CORRELATORS

Acquisition Sensitivity (@ fixed TTFA of 10s) vs. number of code-epoch bins



 * With A-GPS assistance data: ± 100 ppb frequency, ± 2 s time, ± 3km position, ephemeris

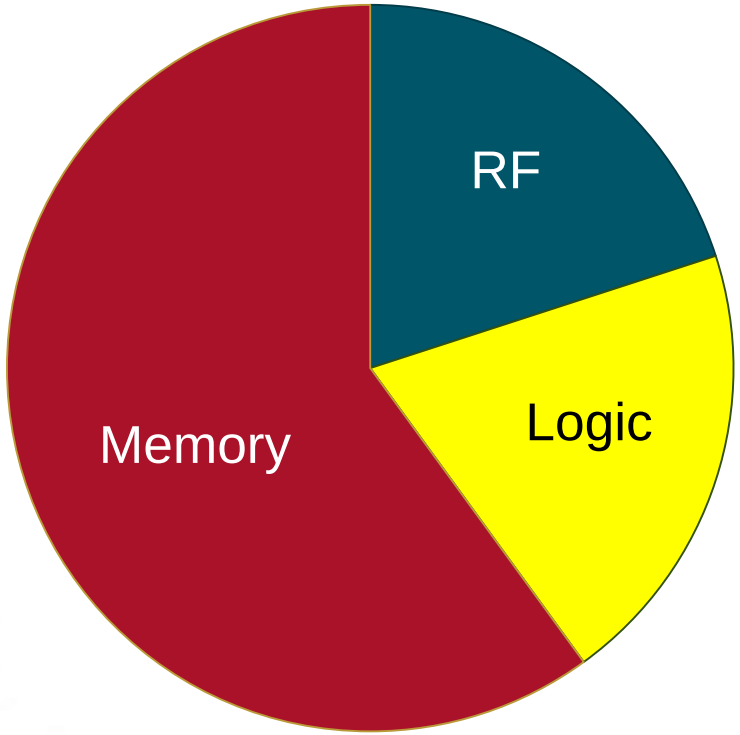
SUMMARY: 1989 TO PRESENT STATE-OF-THE-ART

first handheld consumer GPS

- **Cost-benefit of adding search capability is very good.**

⇒ **most consumer chips support massive parallel searches for all available GPS and GLONASS signals (on L1).**

- **Memory now drives chip size.**
- **The bulk of memory is used for search, mostly for storing code-frequency hypotheses while the signal is integrated.**



COST CONSTRAINTS ARE VERY TIGHT

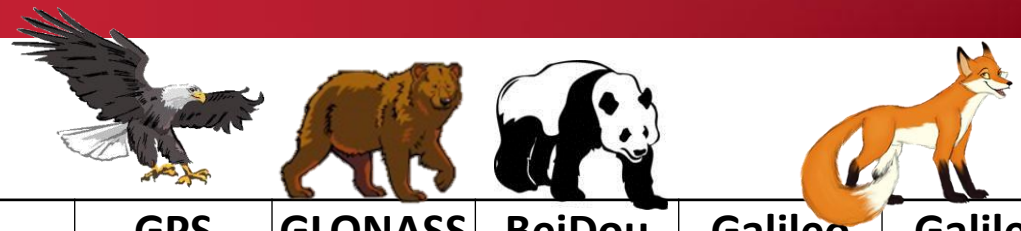
iSuppli estimate of iPhone 4 BOM costs

	SAW Module	Murata	<included in Misc. Costs below>
	Misc. RF Components	PAMs, Modules, Discretes, Passives, etc.	$8.25
Power Management	Main PM Device	Dialog D1815A 338S0867-A4 Main Pwr Mgmt	$2.03
	Misc. Power Mgmt.	Discretes, Passives, etc.	$1.90
Connectivity	WiFi/BT	Broadcom BCM4329 Module WLAN 02.11a/b/g/n, Bluetooth V2.1+EDR, FM/RDS/RBDS Rcvr	$7.80
	GPS	Broadcom BCM4750	$1.75
	Misc. Connectivity Components	Discretes, Passives, etc.	$0.80
Interface & Sensors	Touchscreen Controller	Texas Instruments 343S0499 (F761586C)	$1.23
	Audio CODEC	Cirrus Logic 343S0589 (CLI1495BO)	$1.15
	E-Compass	AKM AK8975 3-Axis	$0.70
	Accelerometer	ST Micro LIS331DLH 3-Axis	$0.65
	Gyroscope	ST Micro L3G4200D Digital 3-Axis	$2.60
	Misc. Interface & Sensor Components	Discretes, Passives, etc.	$3.80
Display/Camera	Display	3.5" Diag, LTPS LCD, 960x640 Pixels LG (or poss. TMD)	$28.50
	Touch Screen	Capacitive Glass, "Reinforced" Wintek or TPK/Balda	$10.00
	Camera	5MP Auto-Focus	$9.75
	Camera (secondary)	VGA Auto-Focus	$1.00
Battery	Battery	1400mAh	$5.80
Other	Mechanicals	Enclosure, Metals, Plastics, Hardware, etc.	$10.80
	Electro-Mechanicals	PCBs, Acoustics, Connectors, etc.	$14.40
	Misc.	Accessories, Literature, Box Contents	$5.50
TOTAL			$187.51

**Teardown costs account only for components and do not include other expenses such as manufacturing, software, royalties and licensing fees*

- GPS $1.75
- Touchscreen controller $1.23
- E-Compass $0.70
- Accelerometer $0.65
- Gyroscope $2.60
- …

GNSS: COST OF DIFFERENT CODE LENGTHS



Signal Components	GPS	GLONASS	BeiDou	Galileo	Galileo
				Data	Pilot
Carrier (MHz)	1575.42	1602	1561.098	1575.42	1575.42
PRN (C/A) code length (chips)	1023	511	2046	4096	4096

½ search RAM *2x search RAM* *4x to 8x search RAM* *> 4x to 8x search RAM*

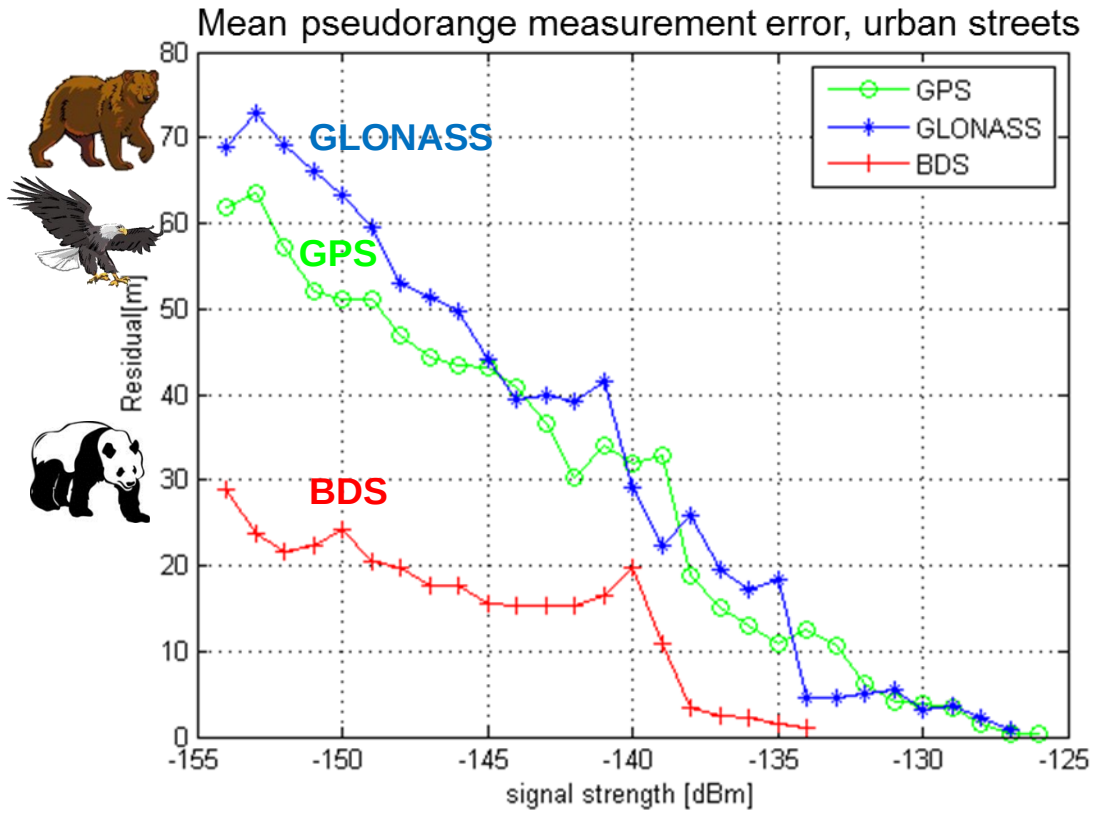
(">" because of overlay code – discussed next)

Benefit of a faster code/BOC is sharper correlation peaks:

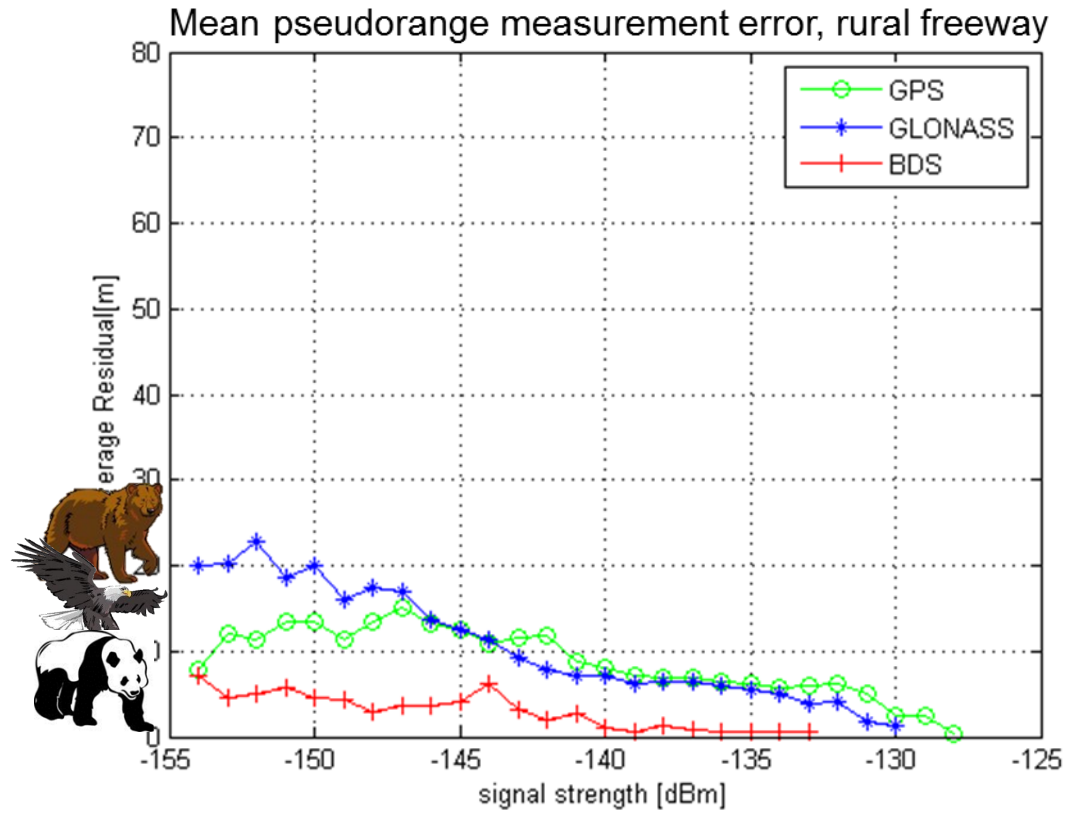
	GPS	GLONASS	BeiDou	Galileo	Galileo
				Data	Pilot
period	1ms	1ms	1ms	4ms	4ms
chip length (approx m)	300m	600m	150m	300m	300m
				BOC	BOC

BeiDou and Galileo should be more *accurate*

ERRORS IN MEASURED PSEUDORANGES, PER GNSS



Urban



Rural

GNSS: COST OF DIFFERENT CODE LENGTHS

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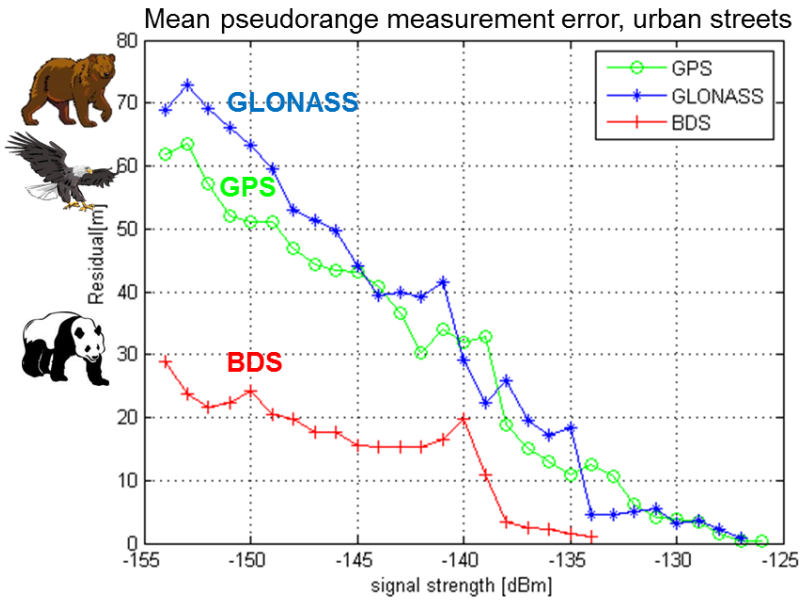
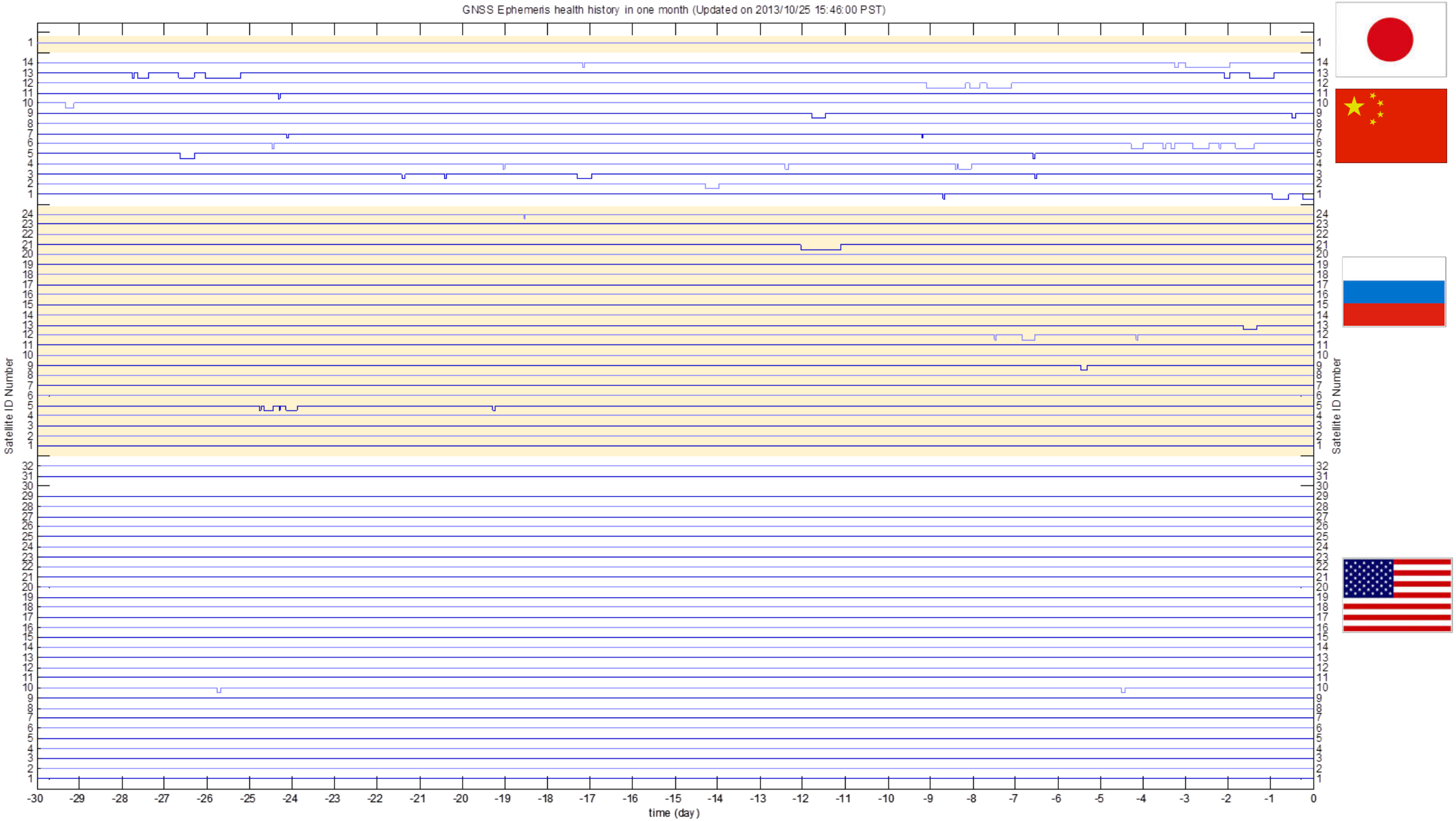




(ACQUISITION) SENSITIVITY REVIEW

- Sensitivity beyond -140 dBm is achieved with a combination of coherent and non-coherent integration.
- We want the coherent interval as long as possible up to the limits imposed by:
  - Unknown changes in user motion
  - Unknown clock (frequency) drift
  - Unknown bit transitions

Remember, a-priori time assistance is only good to ±2s

- Optimal coherent interval (for acquisition sensitivity) is in the range 20 to 100 ms.

20 ms: all energy lost with unknown velocity change of 19cm /20ms = 34 km/h

100 ms: -3 dB freq bin is ± 3ppb wide, signal will move across bins during non-coherent integration.

EFFECT OF DIFFERENT BIT RATES (SECONDARY CODES AND DATA)

Signal Components	GPS	GLONASS	BeiDou	Galileo	Galileo
				Data	Pilot
2nd code length		2	20		25
period		20ms	20ms		100ms
length (ms)		10ms	1ms		4ms
Data bit rate	20ms	20ms	20ms 2ms GEO	4ms	

Longest coherent interval with bit alignment loss < 2dB. 13ms 7ms 1ms 4ms >4ms

at cost of more memory

Either you lose sensitivity, with the same amount of memory, or you add memory to support different bit transition hypotheses,

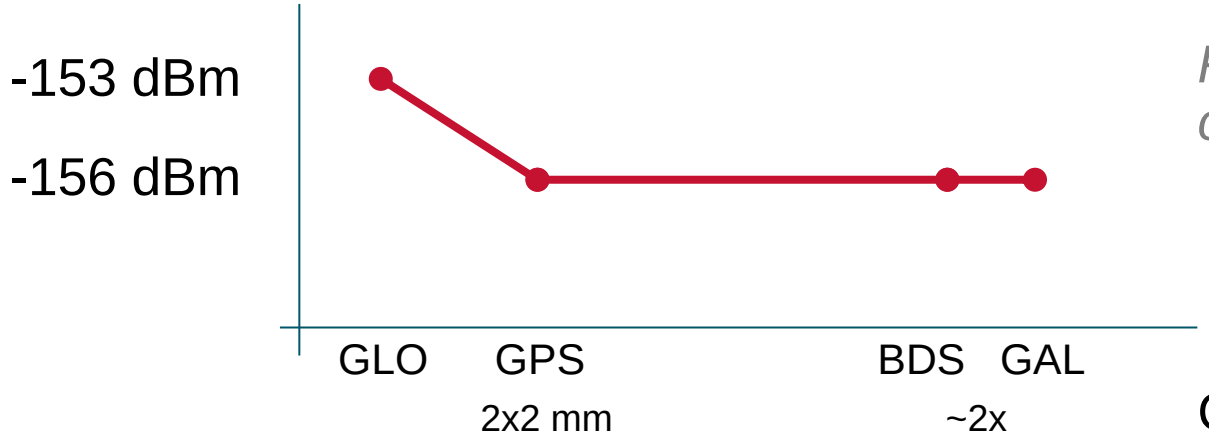
Note the 100ms period, Galileo pilot signal could give significantly greater acquisition sensitivity, but at the cost of much more memory.

COST-BENEFIT OF DIFFERENT CODES, DATA RATES





Signal Components	GPS	GLONASS	BeiDou	Galileo	Galileo	GPS III, L1C
				Data	Pilot	Pilot
Carrier	1575.42	1602	1561.098	1575.42	1575.42	1575.42
PRN (C/A) code length	1023	511	2046	4096	4096	10,230
2nd code length		2	20		25	1800
period		20ms	20ms		100ms	18s
chip length (ms)		10ms	1ms		4ms	10ms
Data bit rate	20ms	20ms	20ms 2ms GEO	4ms		



Relative size of (fictitious) single-constellation chips, and acquisition sensitivity

Chip size (@ 40nm)

SUMMARY

- **Acquisition sensitivity is the feature that drives consumer chip size:**
  - Because of search memory.
- **GPS C/A code gives a near-optimal signal.**
- **Any other single-constellation chip would either be less sensitive or more expensive.**
- **Nice features in future GNSS (e.g. Galileo & GPS III) but years away from full benefit**
- **Therefore, in the next several years we will see cell phones with:**
  - GPS + GLO
  - GPS + BDS
  - GPS + GLO + BDS
  - GPS + GLO + GAL
  - GPS + GLO + BDS + GAL
  - **But few or none without GPS**

Thank you!