International Centre for Radio Astronomy Research

Axions and Radio Astronomy

Peter Quinn

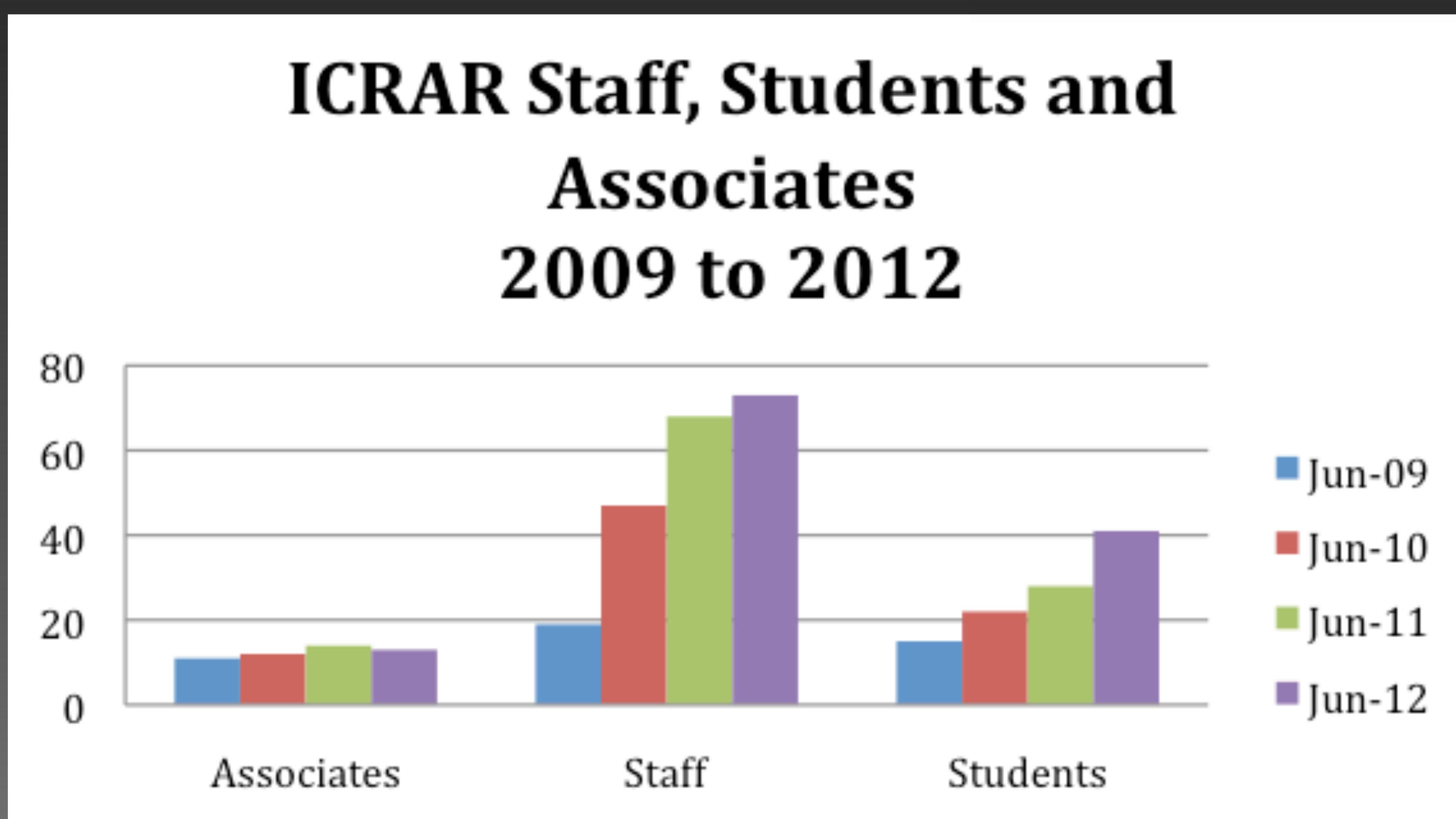
Curtin University

The Government of Western Australia

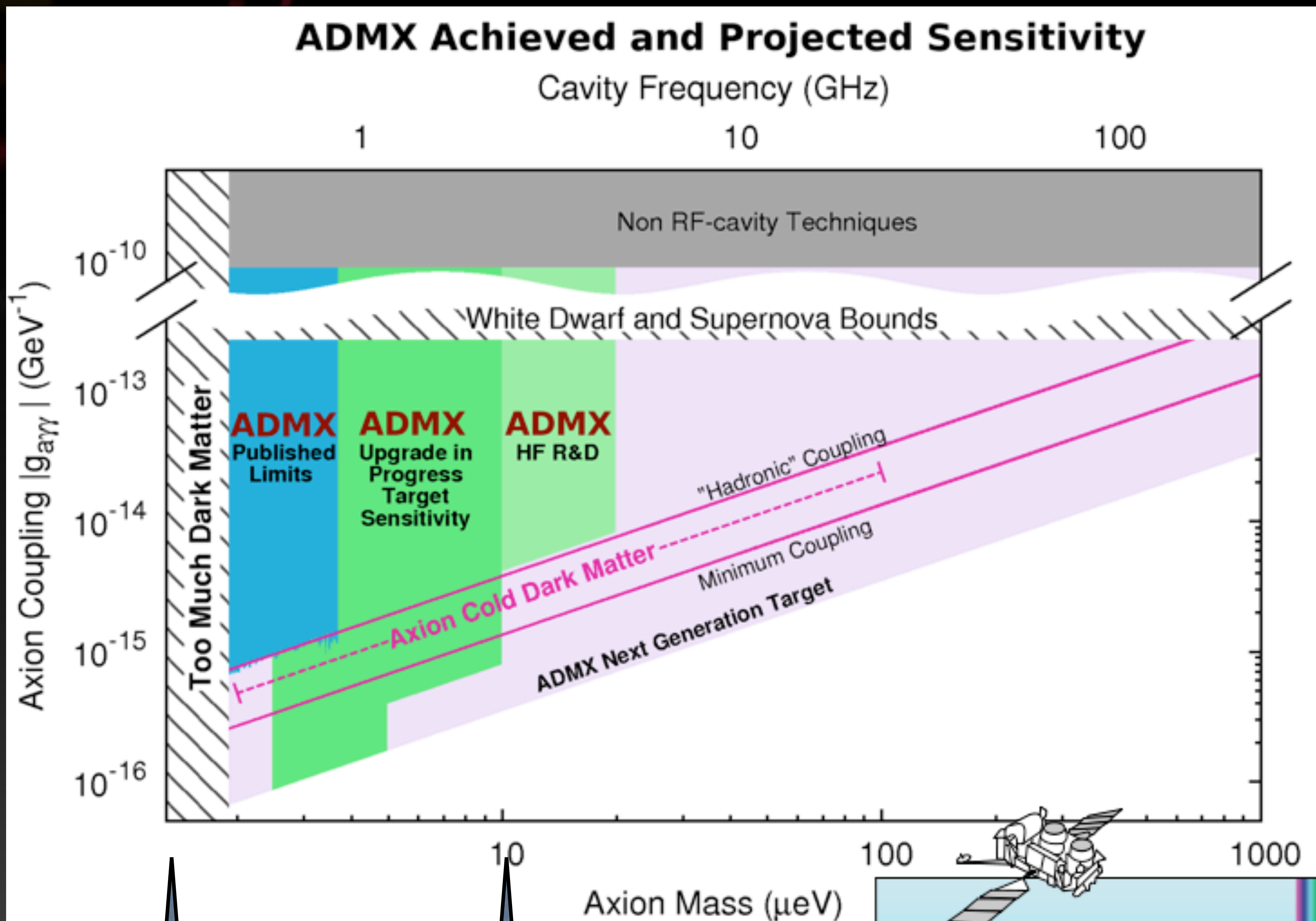
The University of Western Australia
Achieve International Excellence

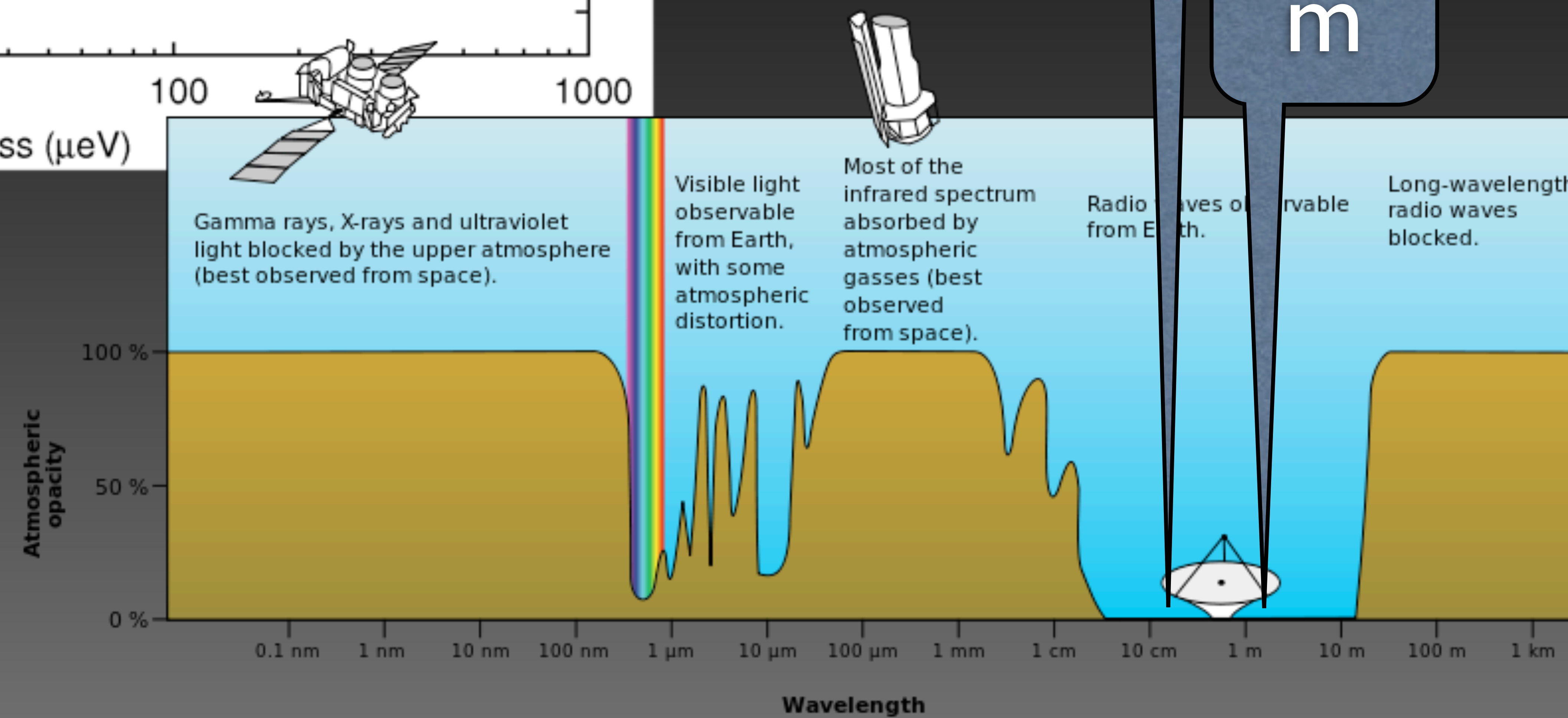
ICRAR

ICRAR launched September 1 2009 as an $115M joint venture of The University of Western Australia and Curtin University in Perth, WA



Axions and Radio Astronomy





200 MHz

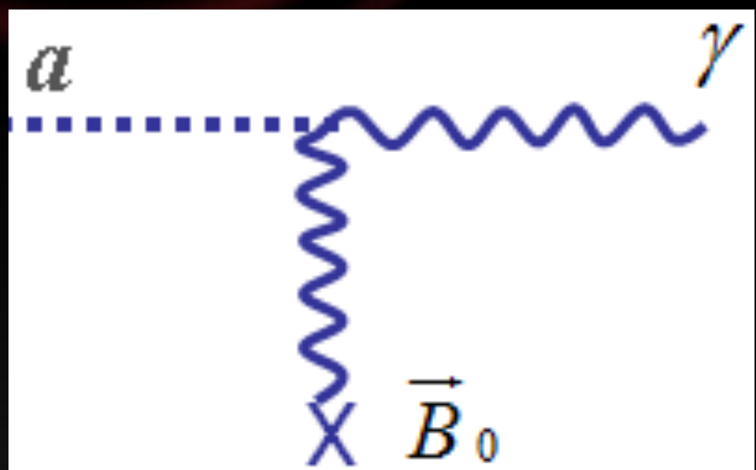
2 GHz

15 cm

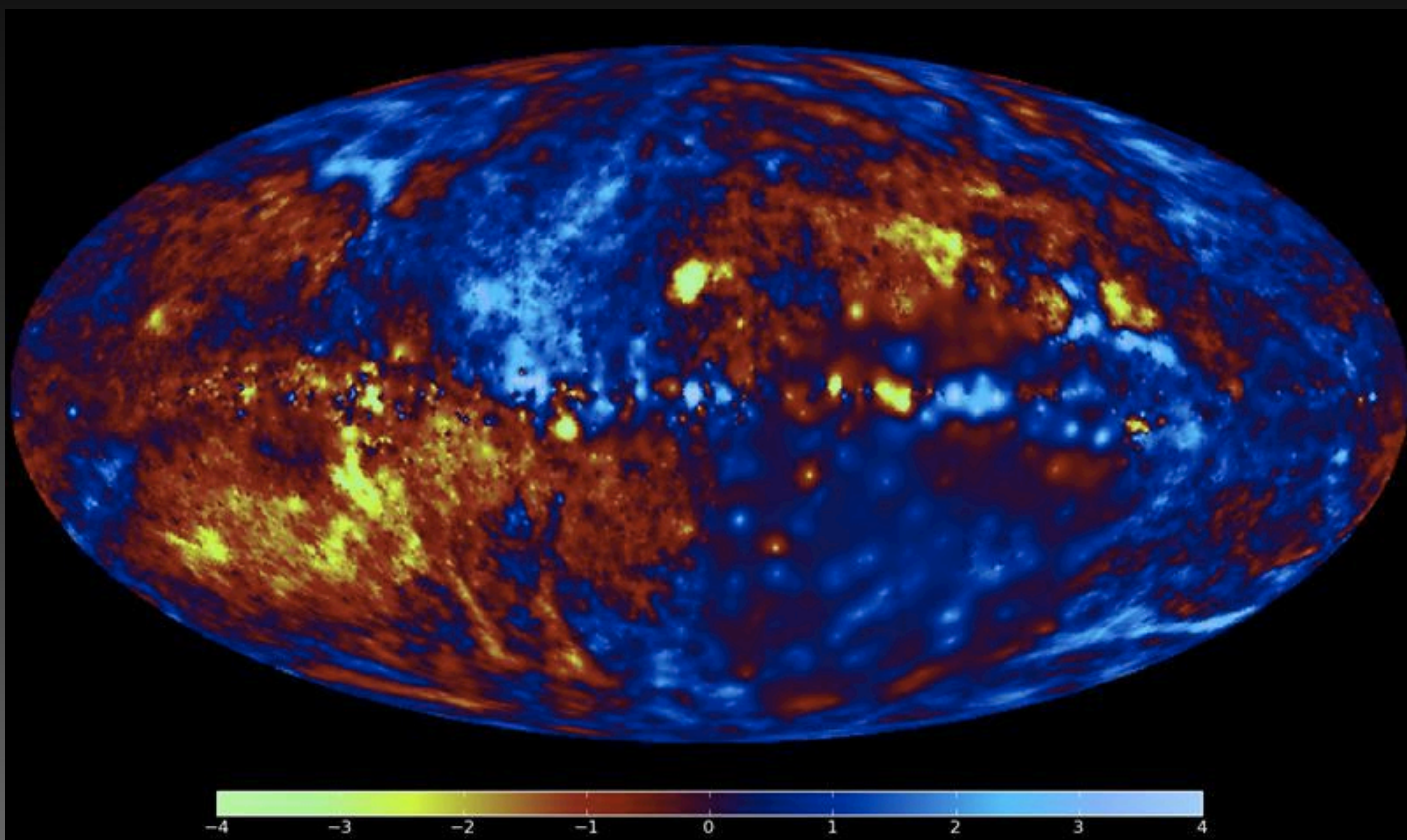
1.5 m

Broad Band - low Field - large Volume

Sivikie 1983



$$\frac{\textit{number of photons}}{\textit{time}} = \frac{\rho_{DM,avg}}{10gcm^{-23}}\left[\frac{1.6}{10^6 s}\right]\left[\frac{Volume}{1cm^3}\right]\left[\frac{B_{avg}}{10^4 G}\right]^2$$



Milky Way
B: 10^{-6} - 10^{-3} G
V: 10^{68} cm^3

Niels Oppermann, Georg Robbers, Torsten A. Enßlin, MPIA, 2011

Expected MW Axion Signal

PQ+White, UWA undergraduate thesis, 2008

$$B_R^D(r,\phi,z) = D_1(r,\phi,z)D_2(r,\phi,z)\sin(p)$$
$$B_\phi^D(r,\phi,z) = -D_1(r,\phi,z)D_2(r,\phi,z)\cos(p)$$
$$B_z^D(r,\phi,z) = 0$$

$$B_\phi^H = B_0^H \frac{1}{1+\left(\frac{|z|-z_0^H}{z_1^H}\right)^2}\frac{r}{r_0^H}\exp\left(-\frac{r-r_0^H}{r_0^H}\right)$$

$$D_1(r,z) = \begin{cases} B_0\exp\left(-\frac{r-r_\odot}{r_0}-\frac{|z|}{z_0}\right) & r > r_c \\ B_c & r \leq r_c \end{cases}$$

$$\text{ASS+RING:} \quad \begin{cases} +1 & r > 7.5\text{ kpc} \\ -1 & 6\text{ kpc} < r \leq 7.5\text{ kpc} \\ +1 & 5\text{ kpc} < r \leq 6\text{ kpc} \\ -1 & r \leq 5\text{ kpc} \end{cases}$$

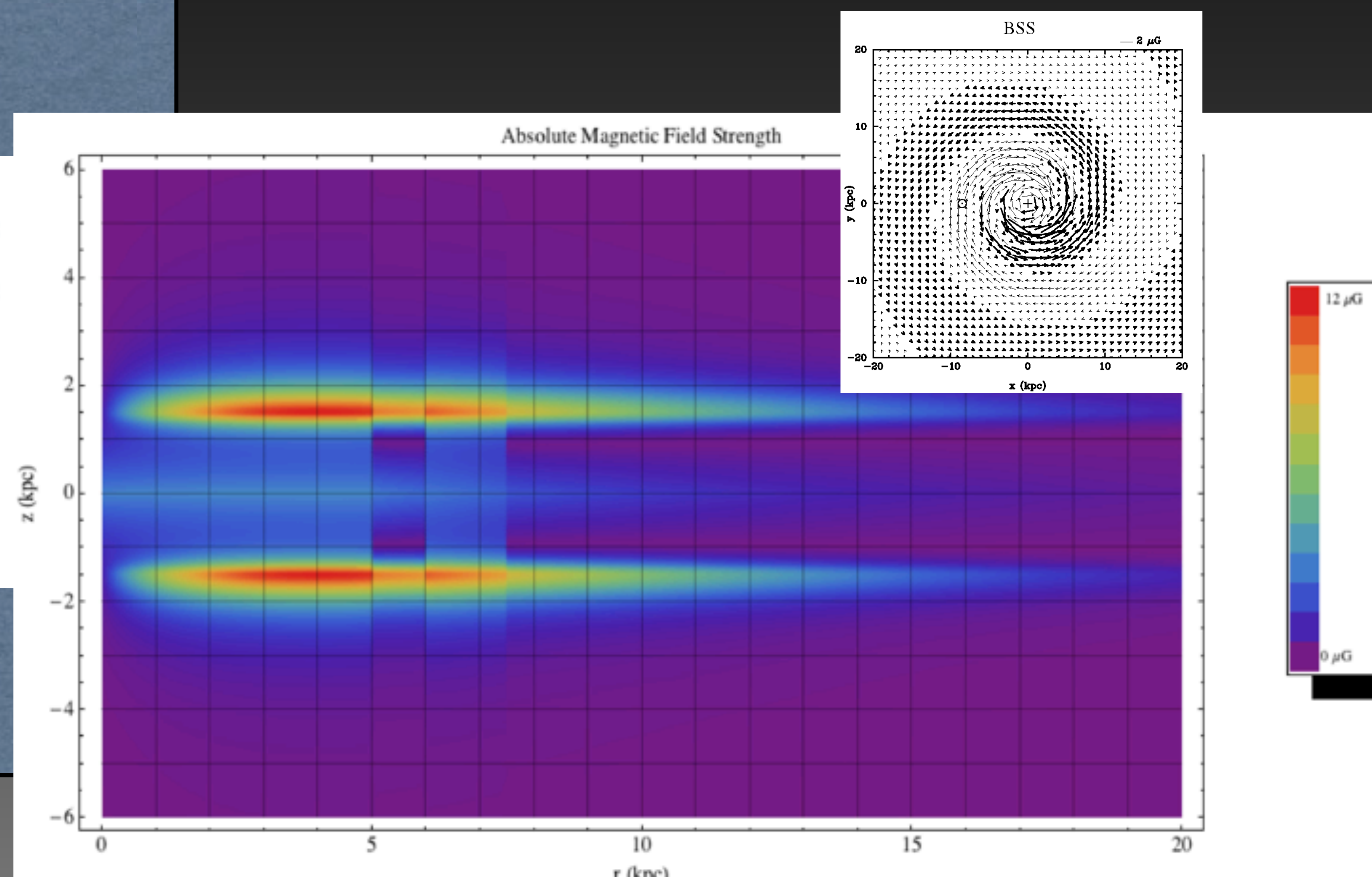
$$\text{BSS:} \quad D_2(r,\phi) = -\cos\left(\phi + \beta\ln\frac{r}{r_b}\right)$$

Sun, Reich, Waelkens & Enßlin (2008)

B model

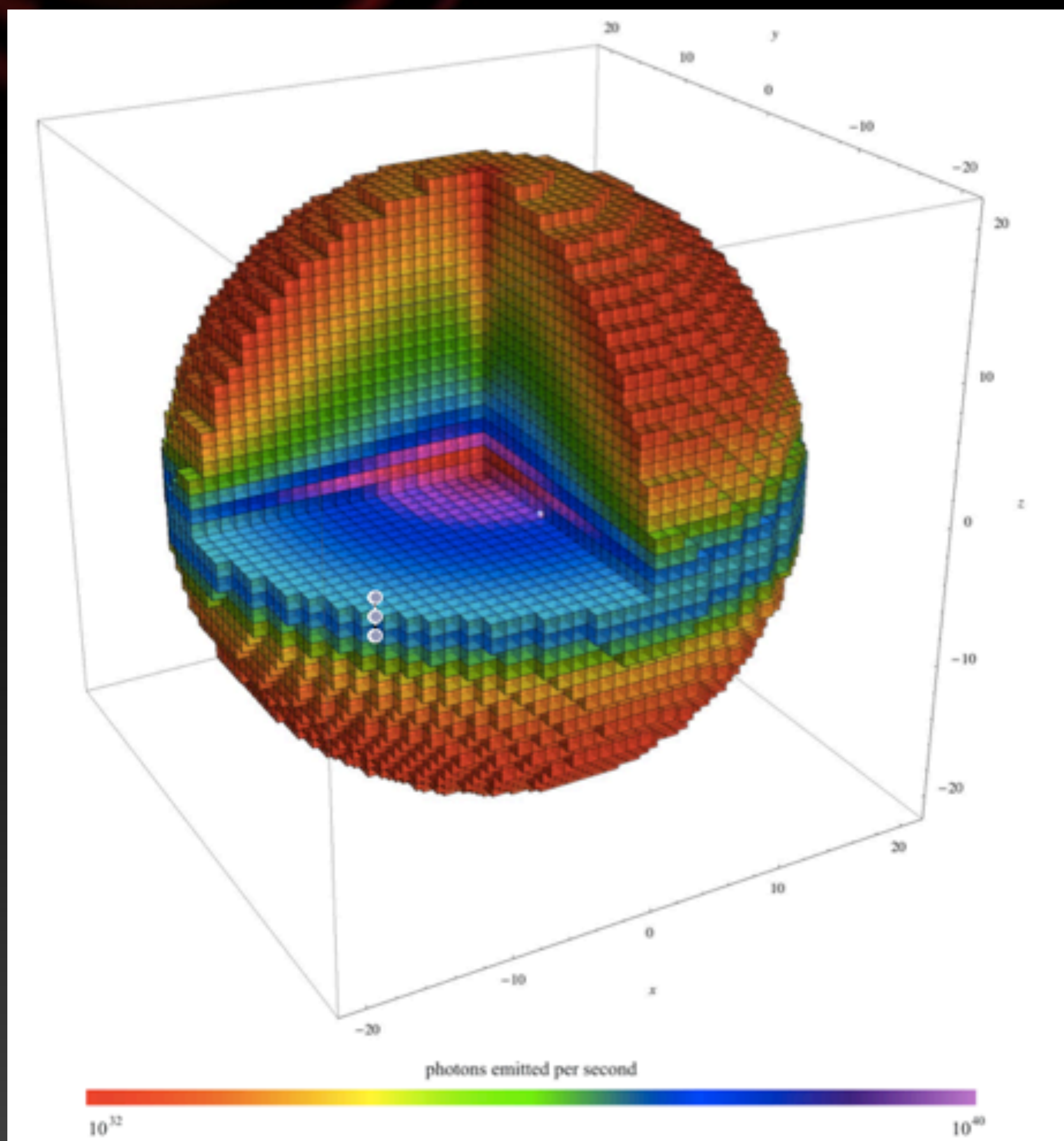
NFW halo: R= 16.7kpc
ρ_0 = 0.347 GeVcm^{-3} = 6.19×10^{-22} kgm^{-3}
Ascasibar et al. (2006)

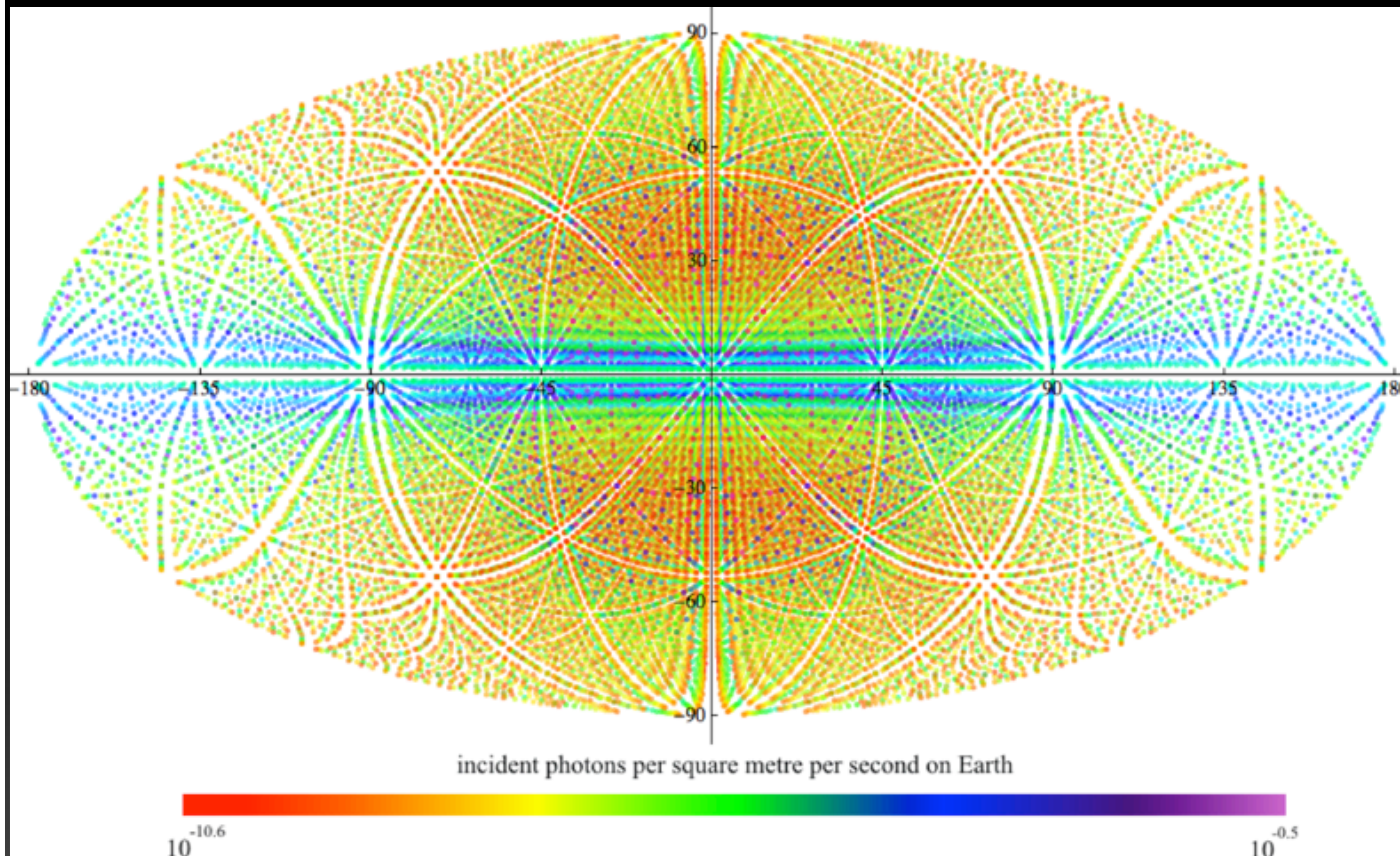
DM model



Sunday, 3 February 13

Axion emission maps





Photon rates on Earth : $10^{-10.6}$ - $10^{-0.5}$ /sec/m^2

Total SKY signal ~ 20 photons/sec/m^2

~ 3x10^{-4} Jy (10^{-26}W/m^2/Hz) (BW=10^6Hz)

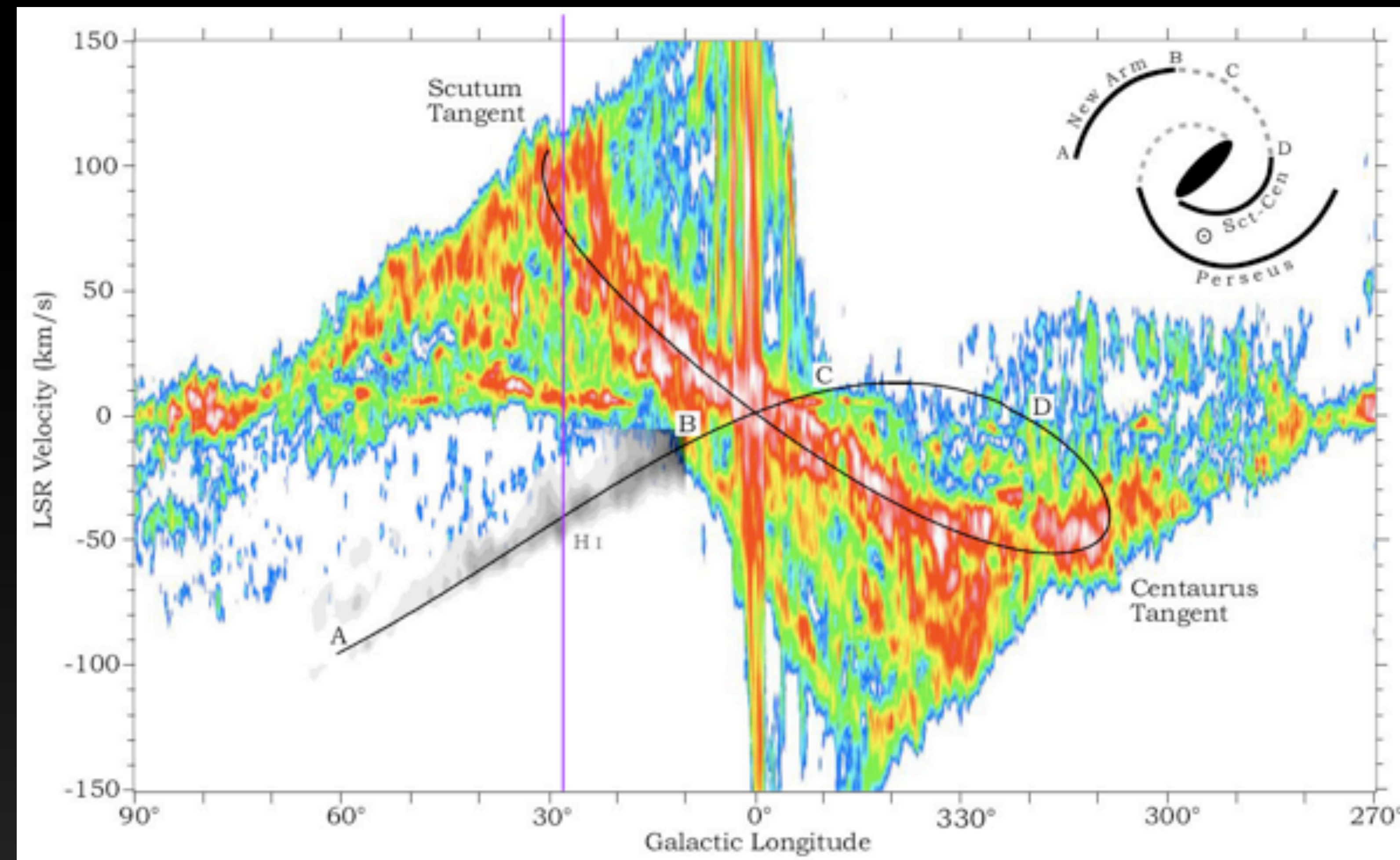
~ 3x10^{-21} W into 1000 m^2

$$P = 4 \cdot 10^{-22}\ \mathrm{W} \left(\frac{V}{200\ \ell}\right) \left(\frac{B_0}{8\ \mathrm{Tesla}}\right)^2 \left(\frac{g_\gamma}{0.97}\right)^2 \cdot \left(\frac{\rho_{\mathrm{a}}}{0.5 \cdot 10^{-24}\ \mathrm{g/cm^3}}\right) C_{nl} \left(\frac{m_{\mathrm{a}}}{1\ \mathrm{GHz}}\right) \left(\frac{\min(Q_{\mathrm{L}}, Q_{\mathrm{a}})}{1 \times 10^5}\right)$$

Dave Tanner

Axion signal features

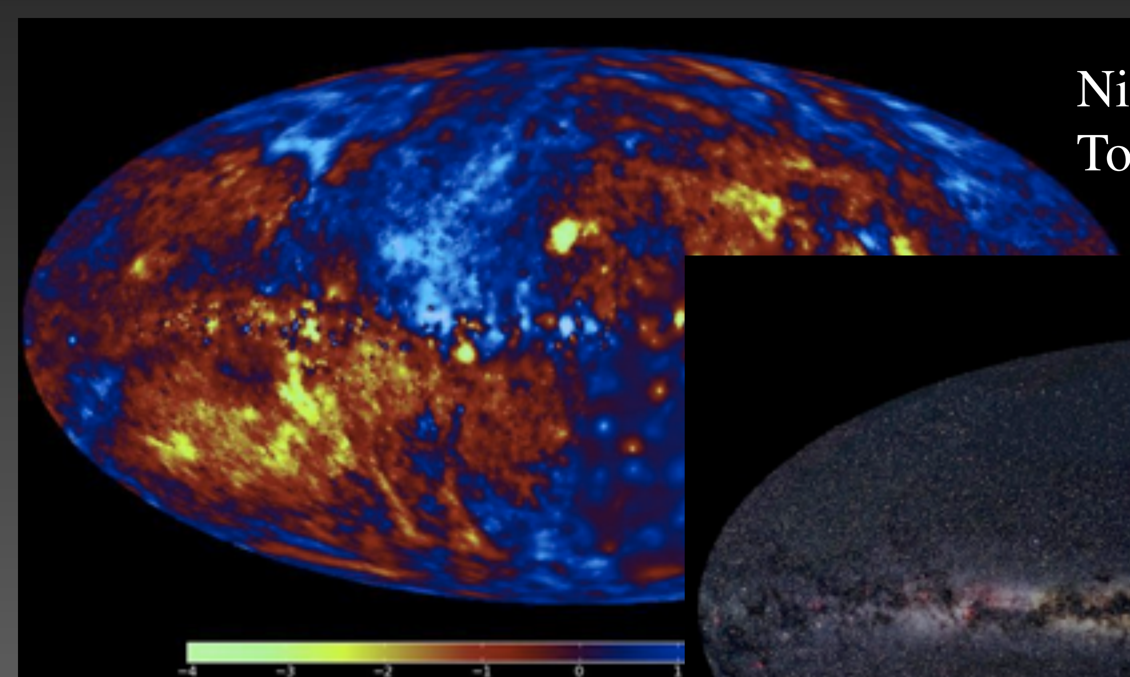
Axion Line
- 300 KM/s + wide
- 200 kHz + @200 MHz
- has MW complex velocity structure folded with NFW density and B structures



MW Hydrogen: Dame, P.M., Thaddeus, P., 2011

Axion Photon Polarization
- should track B field direction

$$\mathcal{L}_{a\gamma\gamma} = g_\gamma a \vec{E} \cdot \vec{B}_0$$



Niels Oppermann, Georg Robbers, Torsten A. Enßlin, MPIA, 2011

Optical image–A. Mellinger/U.Central Michigan; radio image–E. Carretti/CSIRO; radio data–S-PASS team; composition–E. Bresser/CSIRO

Detection challenges

Axion Signal will have an Antenna Temperature of order 1-10 mK - comparable to EoR signal from redshifted HI

Galaxy foreground emission from synchrotron and f-f emission below 1 GHz is 100 - 1000 K

8-8 *Kraus, RADIO ASTRONOMY, 2nd ed.*

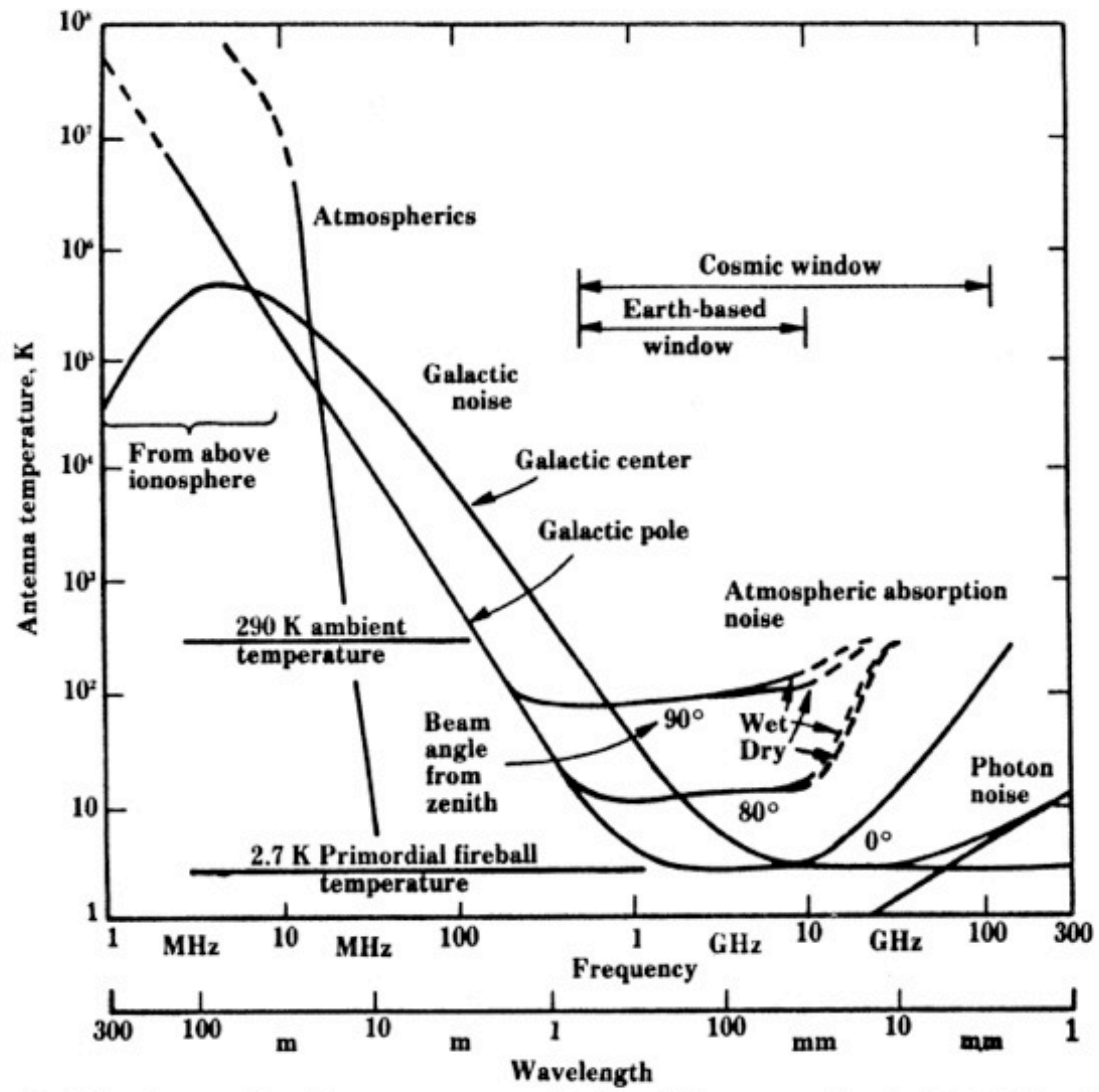


Fig. 8-6. Antenna sky noise temperature as a function of frequency and angle from zenith. A beam angle (HPBW) of less than a few degrees and 100 percent beam efficiency are assumed. (*After Kraus and Ko*, 1957, *cosmic noise between* 10 MHz *and* 1 GHz; *Penzias and Wilson*, 1965, *cosmic noise above* 1 GHz; *Croom*, 1964, *atmospheric noise*; *CCIR*, 1964, *atmospherics*; *and Radio Astronomy Explorer Satellite* RAE-2, *Novaco and Brown, cosmic noise below* 10 MHz.)

Previous Searches

A Radio Telescope Search for Axions

B. D. Blout, E. J. Daw, M. P. Decowski, Paul T. P. Ho, L. J Rosenberg, and D. B. Yu

astro-ph 0006310v1, 2000

Used Haystack Observatory 37m

@ 35.92 GHz - 44.08 GHz

Limits: < 10^{-18}W

This search ruled out axions of mass 298 to 363 μeV with axion-to-two-photon coupling of $g_{a\gamma\gamma} > 1.0 \times 10^{-9}$ GeV^{-1} at 96% confidence

A revolution in radio astronomy capabilities - the SKA

- An 50 fold increase in sensitivity and 200 fold increase in field of view = 10,000 survey speed compared to any existing facility
- 10^6 m^2 from 70 MHz to 10 GHz using multiple receiver technologies - aperture arrays, phased array feeds and single pixel feeds on dishes
- 10 Countries (UK, Australia, NZ, South Africa, Canada, Germany, Netherlands, Italy, Sweden, China)
    - pre-construction 2012 - 2016 - 90MEuro
    - Phase 1 build 2016 - 2019 - 400 MEuro
    - Phase 2 build 2019 - 2024 - 1.2 BEuro
- Concepts: 1990 - 2005 (Hydrogen Array - survey from EoR (z~10) to z=0, 1 Billion object detection)
- Precursors: 2005 - 2016 - ASKAP, MWA and MeerKAT - $470M AUSTRALIA, $200M RSA

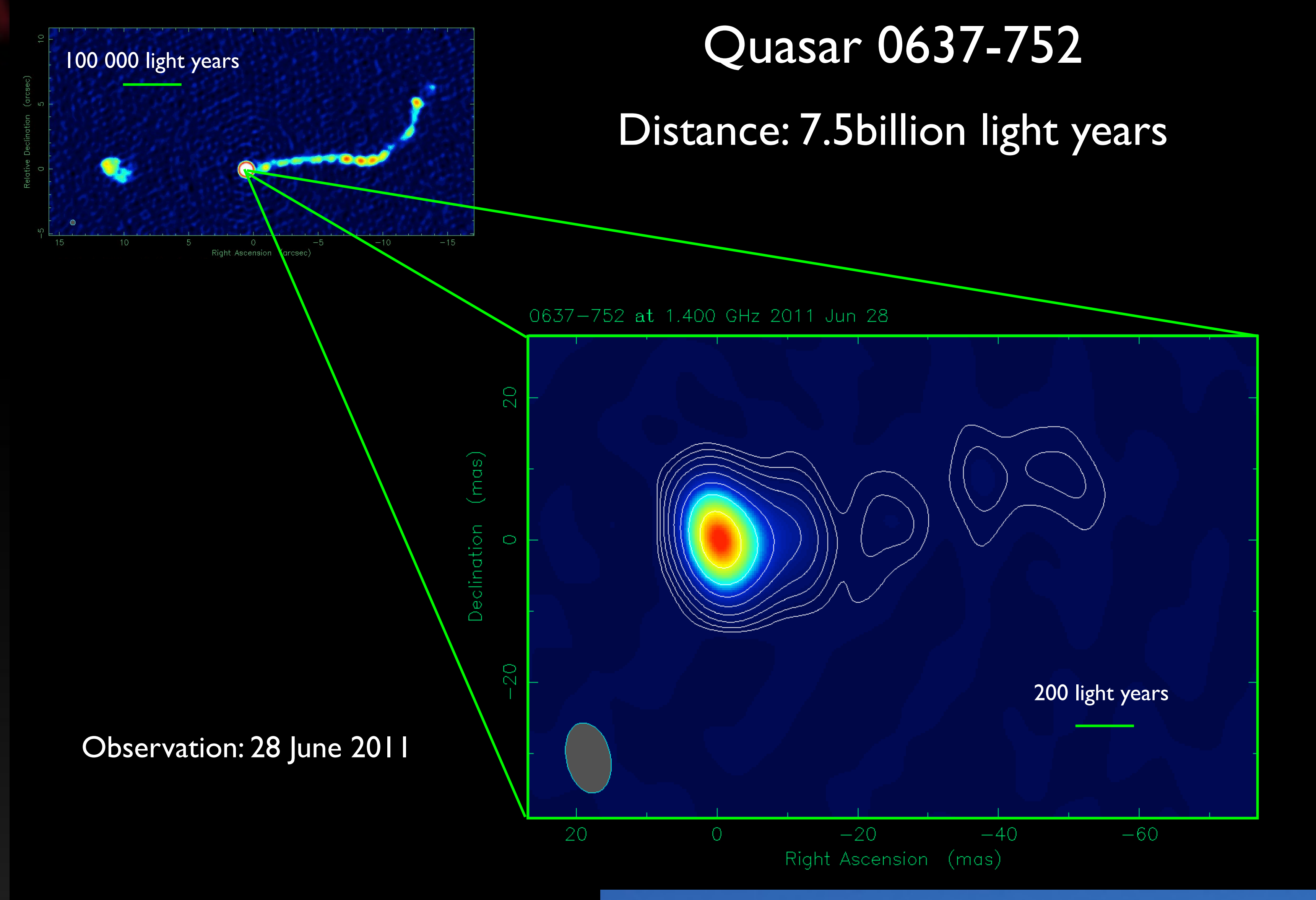
3000+ 15m dishes
baselines ~ 1000 km

~1 million dipoles

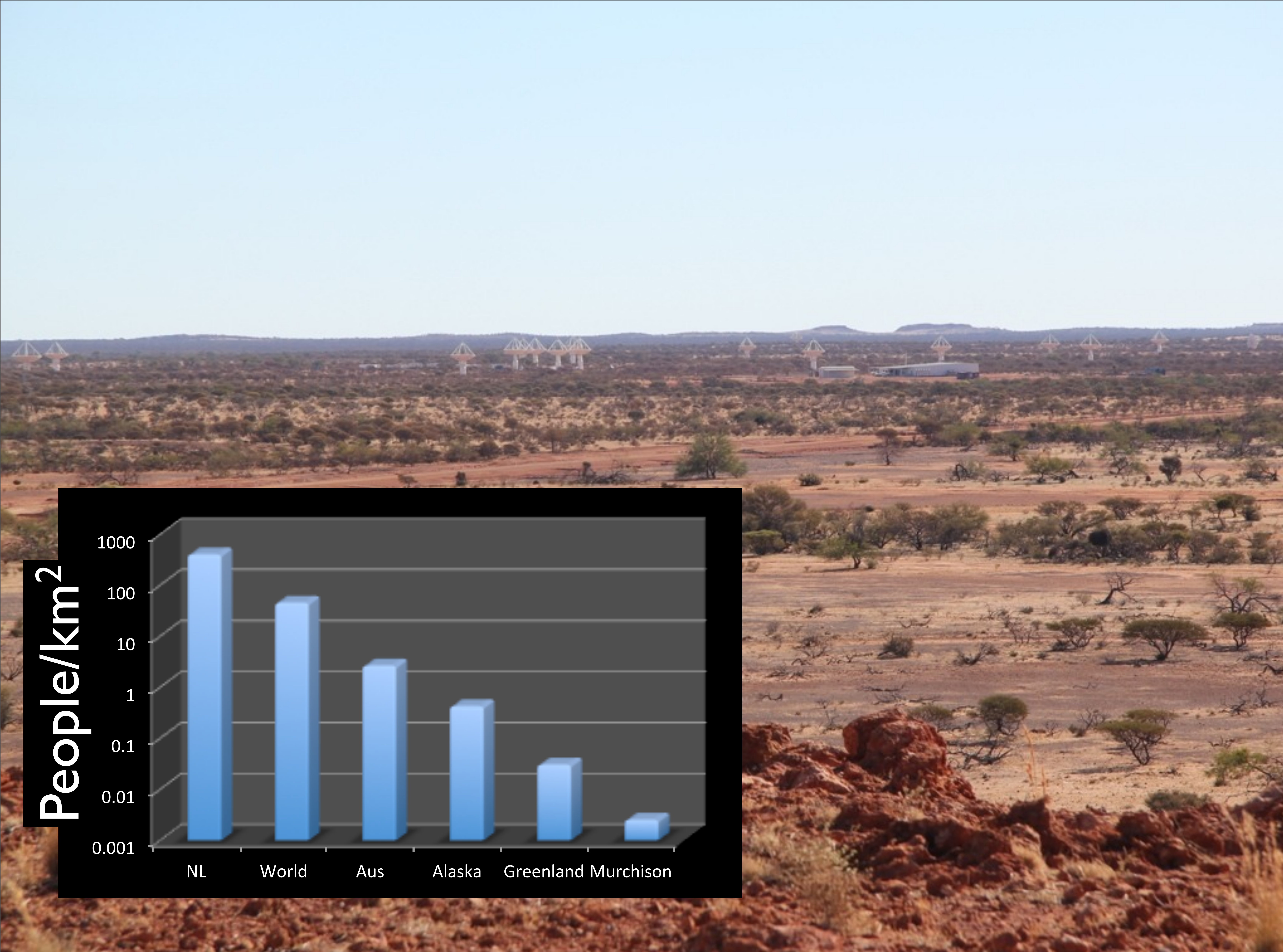
Raw data rate ~ 1Exabyte/day

Sites

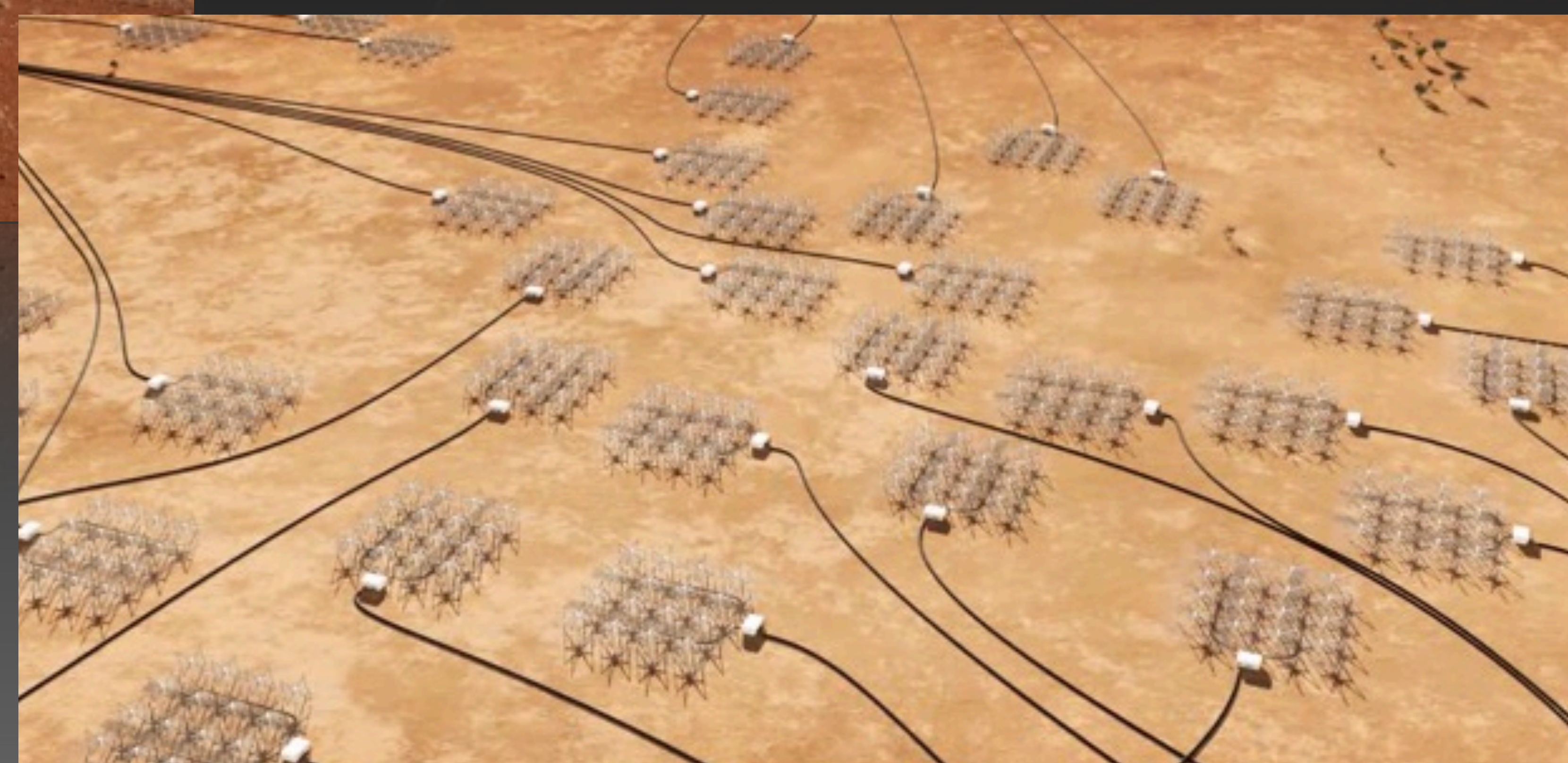
May 25 2012: Both countries to share project



ASKAP
all 36 dishes
on site May


People/km^2
1000
100
10
1
0.1
0.01
0.001
NL
World
Aus
Alaska
Greenland
Murchison

MWA



MWA

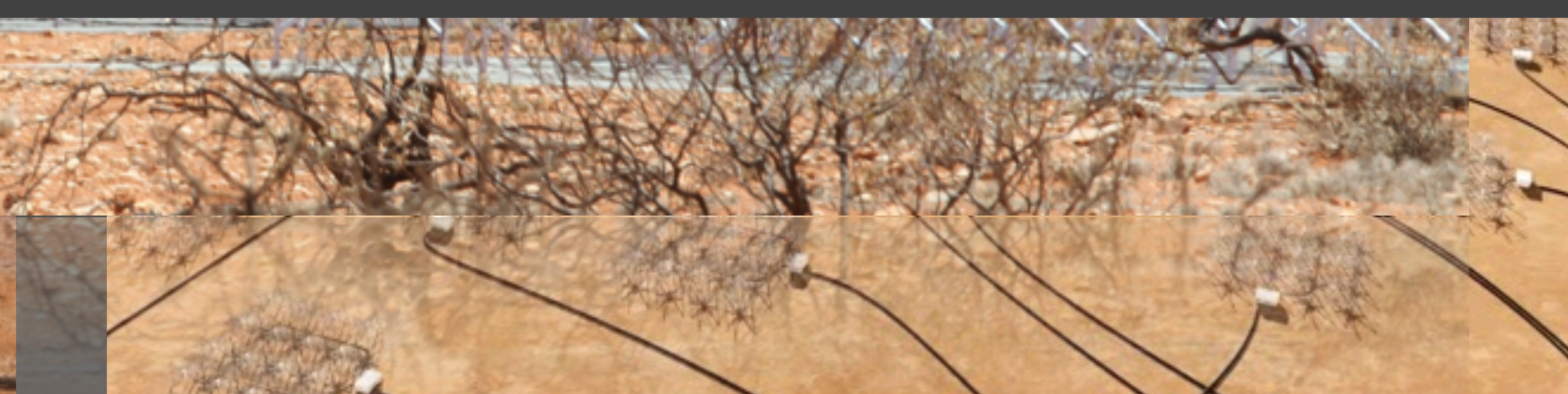
MWA

128 tiles deployed

16 receivers deployed

Infrastructure deployed

Onsite computing deployed,
Including correlator



MWA

128 tiles deployed

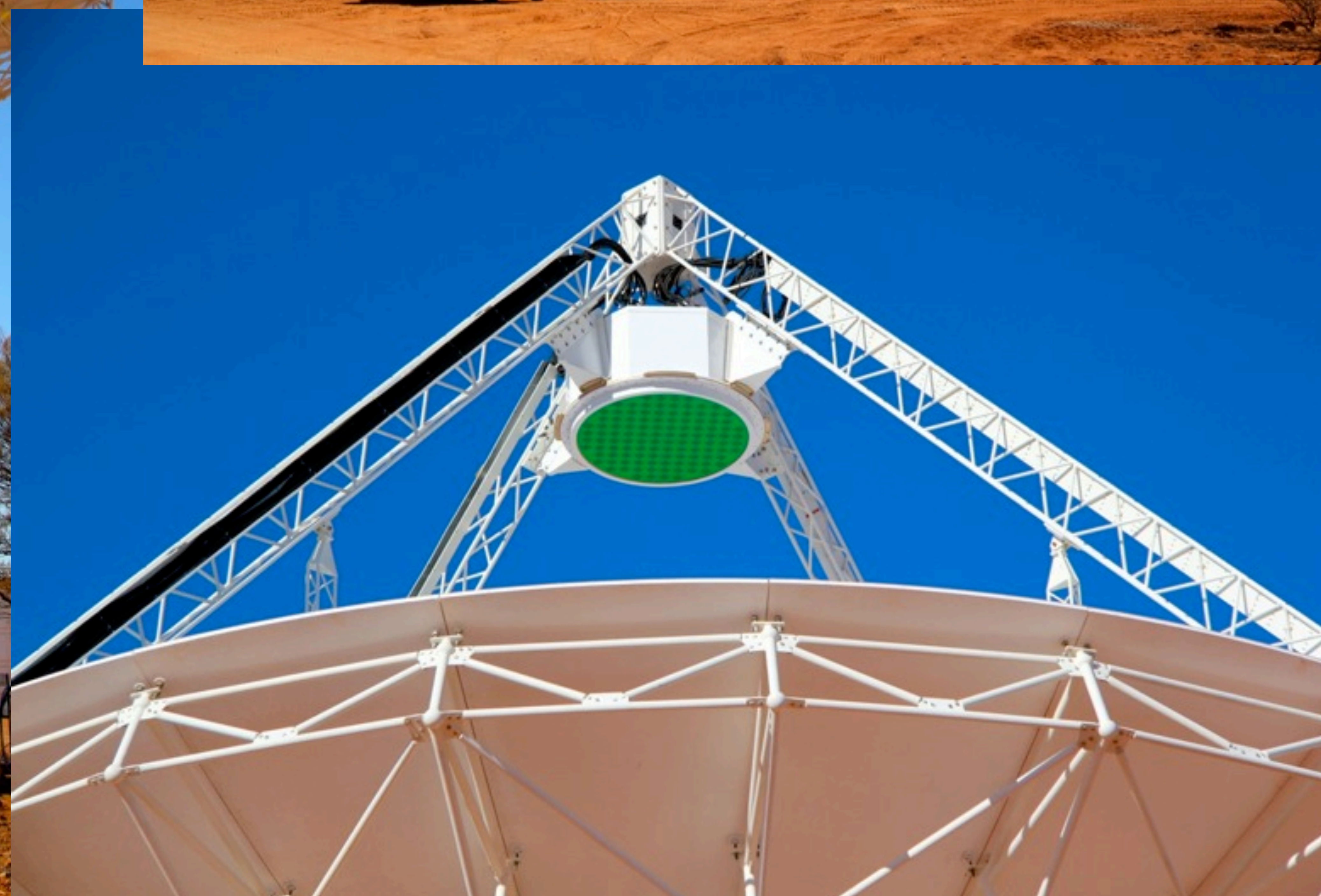
16 receivers deployed

Infrastructure deployed

Onsite computing deployed, Including correlator

MWA Science Operations start July 2013
80MHz - 300 MHz

ASKAP
700MHz - 2 GHz
Operations with 18 dishes mid 2014



$470 million investment

$47M Federal funding Geothermal cooling and PV power

NBN Link G-P, MRO Link, $50M CSIRO/Federal

Pawsey Supercomputer Centre, Perth.

Precursor and SKA Capabilities

Axion sky signal
~ 0.1 mJy
~ 10^6 MWA sec
~ 1 year given
BG

Telescope	Aperture (A) (m^2)	$A/T_{receiver}$	Sensitivity mJy/SQRT(sec) @ BW=1MHz	Total Axion Power received (W)	Axion Antenna Temperature (K)
MWA	10^3	20	100	2.6×10^{-21}	0.2 mK
SKA Phase 1 Low	10^5	1000	1	2.6×10^{-19}	20 mK

Assumed description for SKA1 and SKA2

		SKA1_low	SKA1_mid	SKA2_low	SKA2_mid_dish	SKA2_AIP_AA	AIP_PAF	Comments
Collector type		Sparse AA [1]	15m dish [1]	Sparse AA [1]	15m dish [1]	Dense AA [1]	15m dish+PAF [1]	Offset feed dishes
No. of collectors		280 [3][9]	250 [1]	280 [3][10]	2,500 [11]	280 [3]	2000 [15]	
Frequency range	GHz	0.07 – 0.45 [1]	0.45 – 3.0 [1]	0.07 – 0.45 [2]	0.45 – 10 [11]	0.4 – 1.4 [2]	0.45 – 3.0 [13]	50MHz goal
Max bandwidth	GHz	0.38 [1]	1.5 [8]	0.38 [2]	*Depends on feed*	1.0 [8]	0.3	
Dish feeds: 1.	GHz		0.45 – 0.9 [1]				0.45 – 0.9 [13]	
2.	GHz		0.8 – 1.6 [1]		To be decided		0.8 – 1.6 [13]	
3.	GHz		1.5 – 3.0 [1]				1.5 – 3.0 [13]	
Effective FoV	deg^2		*1GHz:* 1.0 [1]	200 [4]	*1GHz:* 1.0 [1]		*0.5GHz:* 144 deg^2 [13] *1GHz:* 36 deg^2 [13] *2GHz:* 9 deg^2 [13]	15m dish FoV
No. of beams		160 [1]	1		1		36	
Sensitivity: /element	m^2K^{-1}	*131 MHz:* 7.2 [8]	*1-2GHz:* 4.0 [8]	*>90MHz:* 14.3 [8]	4.0 [8]	*<1.2GHz:* 36 [8]	*1-2GHz:* 3.5 [14]	
total sensitivity	m^2K^{-1}	*131MHz:* 1,515 [1] *300 MHz:* 889 [1]	*1-2GHz:* 1,031 [1] *0.45-1GHz:* 773 [1]	*>90MHz:* 4,000 [2]	10,000 [2]	*<1.2GHz:* 10,000 [2] *1.4GHz:* 5,000 [2]		Sensitivity of AA on boresight