

CAASTRO

ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS

Galactic Centre Annihilation

Lister Staveley-Smith (ICRAR/UWA/CAASTRO)



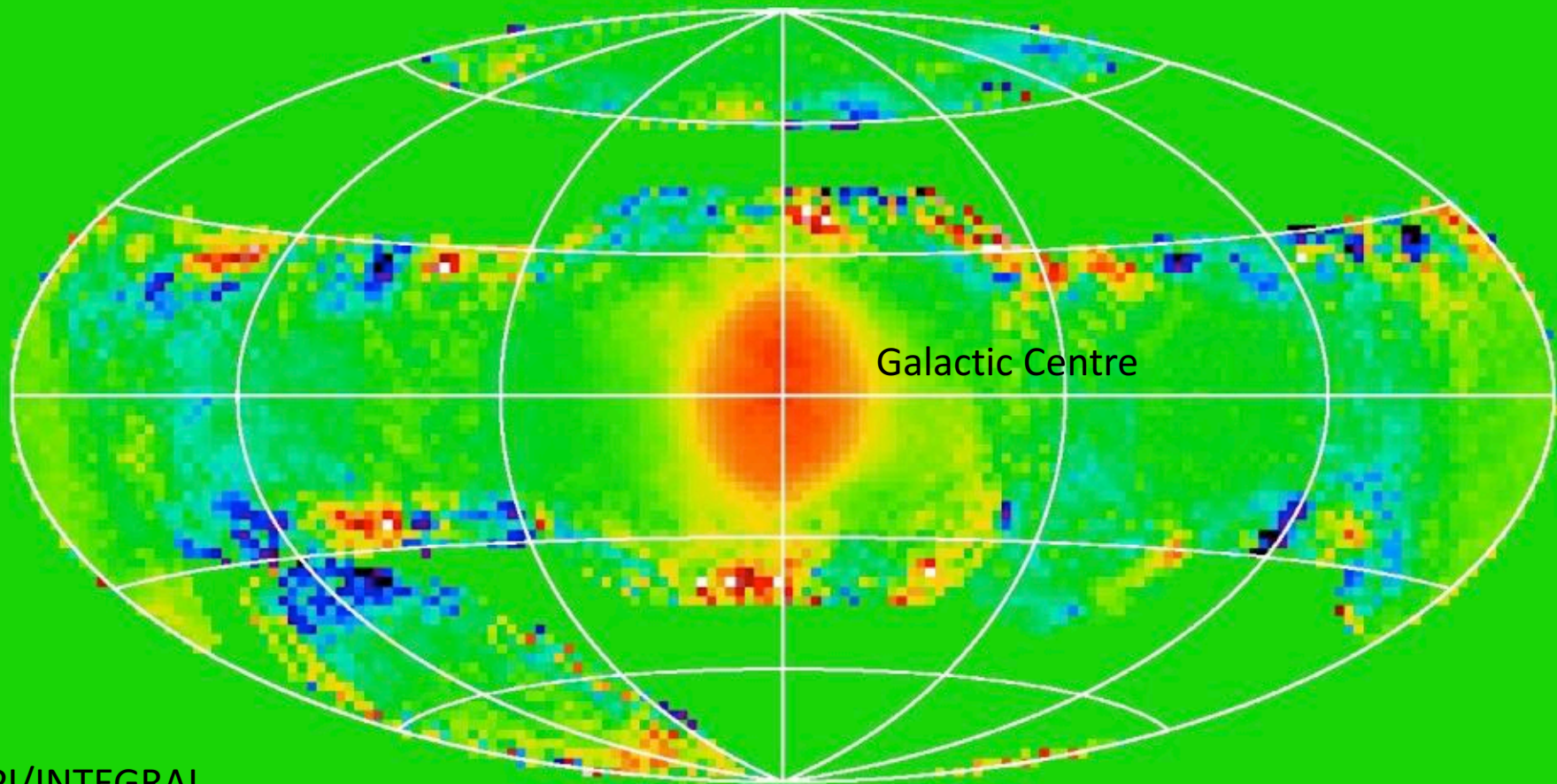
Curtin University



THE UNIVERSITY OF
**WESTERN
AUSTRALIA**

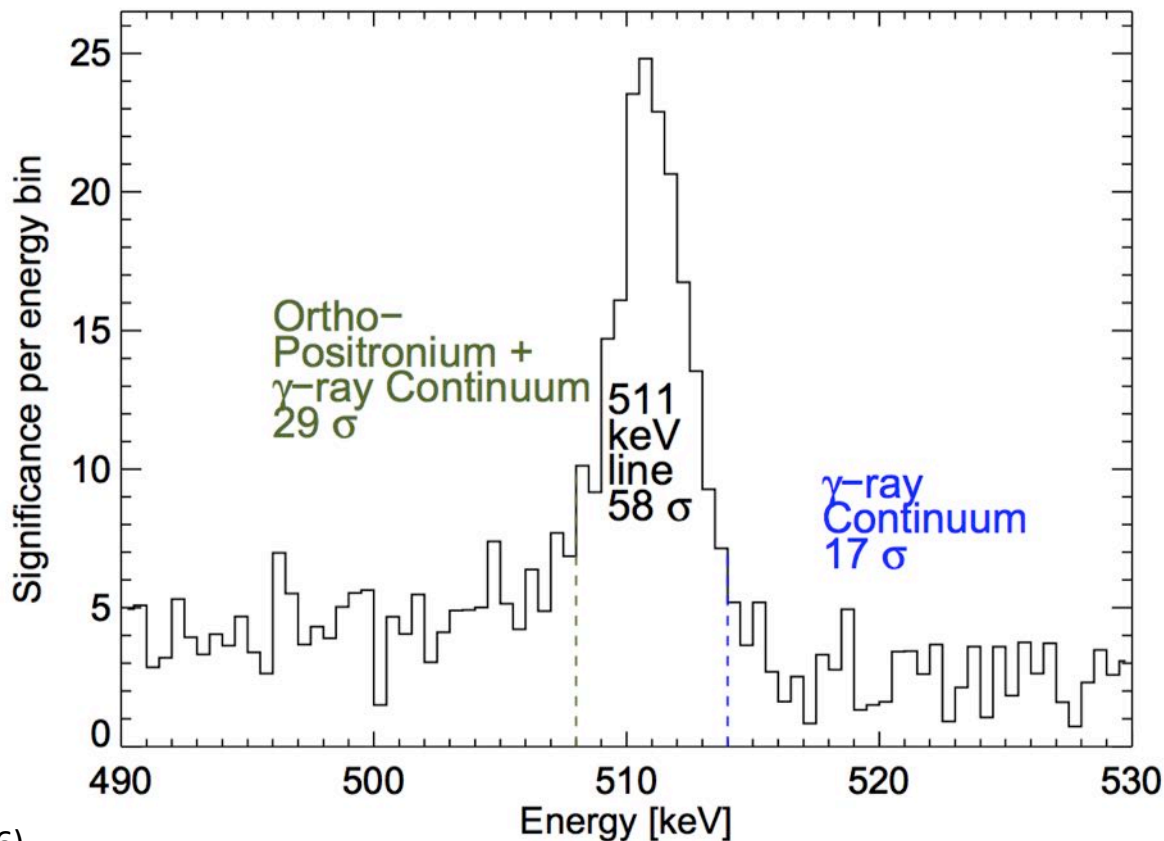


Government of Western Australia
Department of the Premier and Cabinet
Office of Science



SPI/INTEGRAL

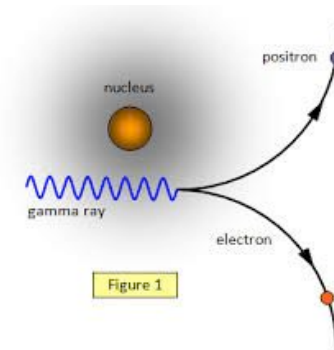
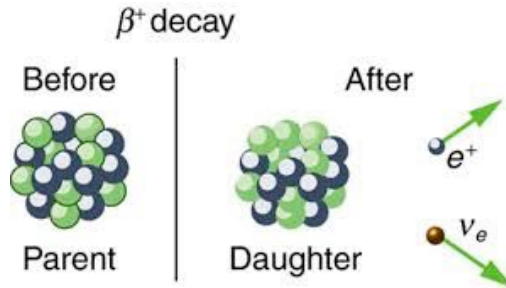
INTEGRAL SPI gamma-ray spectrum



Where do the positrons come from?

Conventional channels:

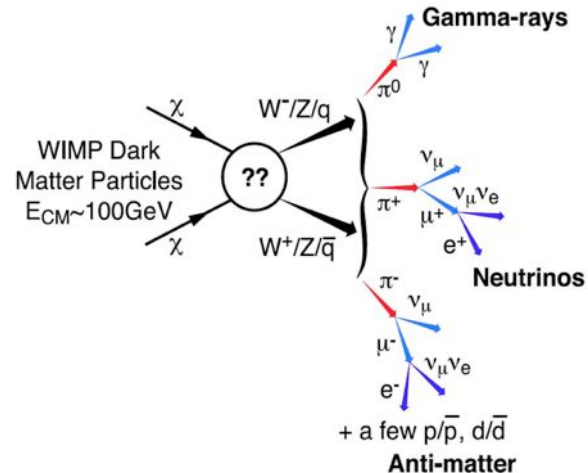
- Black holes/Microquasars (pair production)
- Gamma ray bursts (pair production)
- Neutron stars (curvature radiation)
- Type I supernovae (radioactive decay – ^{56}Ni , ^{44}Ti , ^{26}Al , ^{13}N)
- Cosmic rays



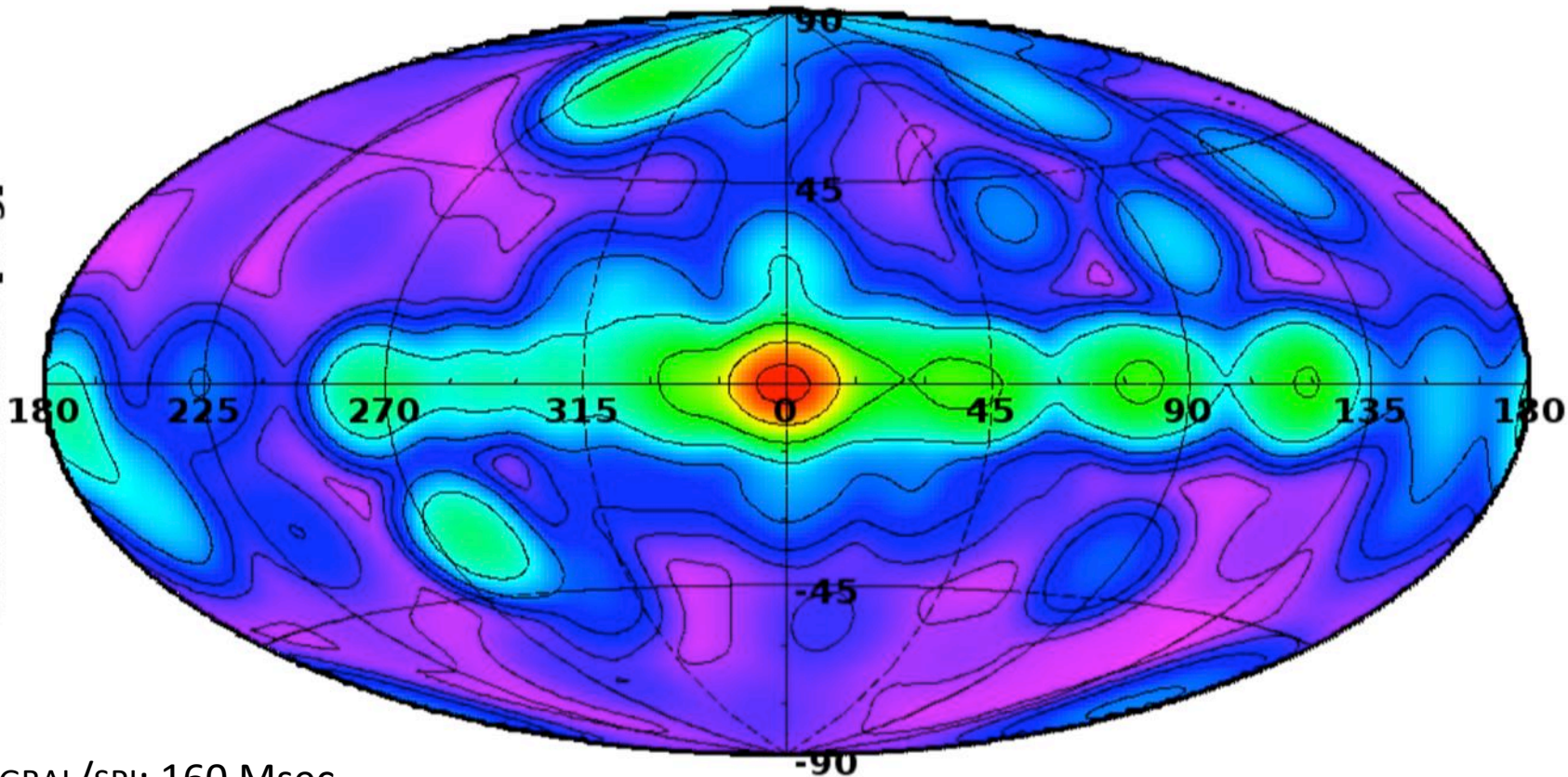
Where do the positrons come from?

DM annihilation channels:

- Decaying DM (Picciotto & Pospelov 2005)
- Light (MeV) DM direct annihilation (Boehm et al. 2010)
- XDM excitation (Finkbeiner et al. 2007)

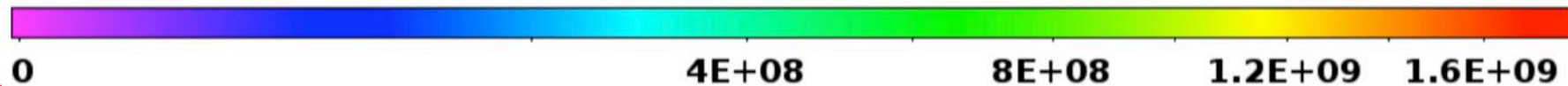


Galactic Latitude [deg]



INTEGRAL/SPI: 160 Msec
(Siegert et al. 2016)

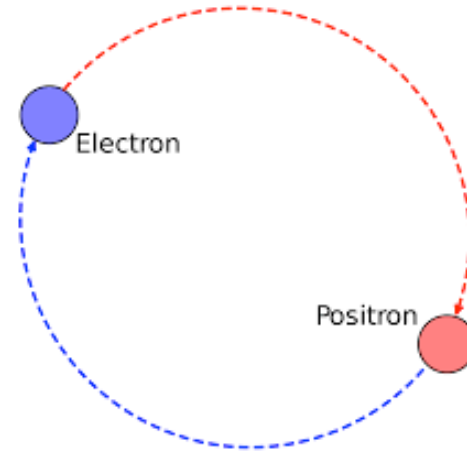
Galactic Longitude [deg]





Positronium (Ps) detection

- Annihilation line
- Hyperfine transition ($\lambda 1.48\text{mm}$)
- Recombination lines





First Ps detection

Evidence for the Formation of Positronium in Gases*

MARTIN DEUTSCH

*Laboratory for Nuclear Science and Engineering, and Department of Physics,
Massachusetts Institute of Technology, Cambridge, Massachusetts*

(Received March 13, 1951)

Phys. Rev. **82**, 455 – Published 1 May 1951

Direct Observation of the Hyperfine Transition of Ground-State Positronium

T. Yamazaki,¹ A. Miyazaki,¹ T. Suehara,¹ T. Namba,¹ S. Asai,¹ T. Kobayashi,¹ H. Saito,² I. Ogawa,³
T. Idehara,³ and S. Sabchevski⁴

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⁴*Bulgarian Academy of Sciences, 72 Tzarigradsko Shose Blvd., 1784 Sofia, Bulgaria*

(Received 5 April 2012; published 20 June 2012)

We report the first direct measurement of the hyperfine transition of the ground state positronium. The hyperfine structure between ortho-positronium and para-positronium is about 203 GHz. We develop a new optical system to accumulate about 10 kW power using a gyrotron, a mode converter, and a Fabry-Pérot cavity. The hyperfine transition has been observed with a significance of 5.4 standard deviations. The transition probability is measured to be $A = 3.1^{+1.6}_{-1.2} \times 10^{-8} \text{ s}^{-1}$ for the first time, which is in good agreement with the theoretical value of $3.37 \times 10^{-8} \text{ s}^{-1}$.



First Observation of Resonant Excitation of High- n States in Positronium

K. P. Ziock, R. H. Howell, F. Magnotta, and R. A. Failor

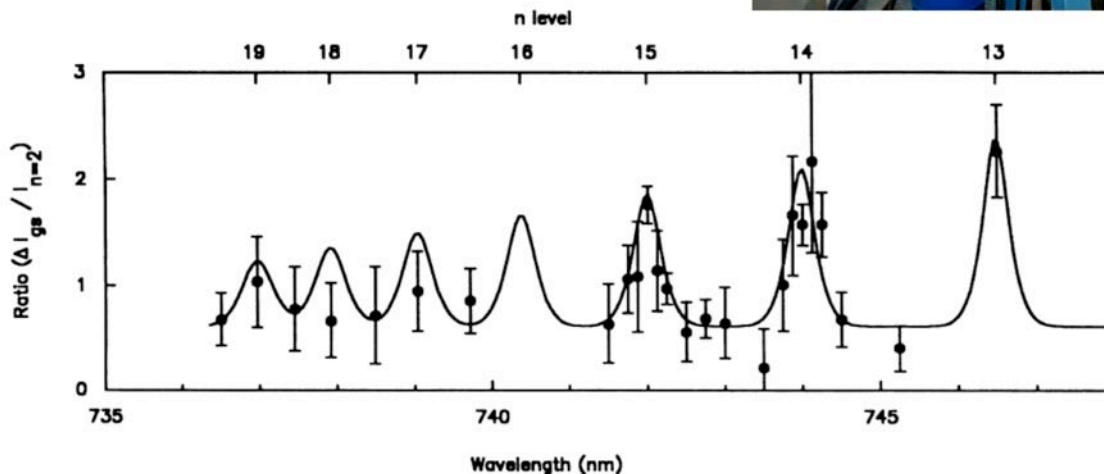
Physics Department, Lawrence Livermore National Laboratory, Livermore, California 94550

K. M. Jones

Williams College, Williamstown, Massachusetts 01267

(Received 30 October 1989)

Positrons obtained from an
electron Linac (pair production)
 $\sim 10^5/\text{pulse}$ (15 ns)
But only one count per pulse!





Recombination lines

Ps Rydberg constant = 0.5 R(Hydrogen)

- Recombination line frequencies = half of hydrogen
- Ps Balmer- α line: $1.3\mu\text{m}$
- Half of transition probability
- Ground state lifetime (para-Ps): 120ps
- Excited states metastable
- Thermal width larger by: $\sqrt{m_p/m_e}$



Parkes telescope and MPIPAF



Max-Planck-Institute
Phased Array Receiver

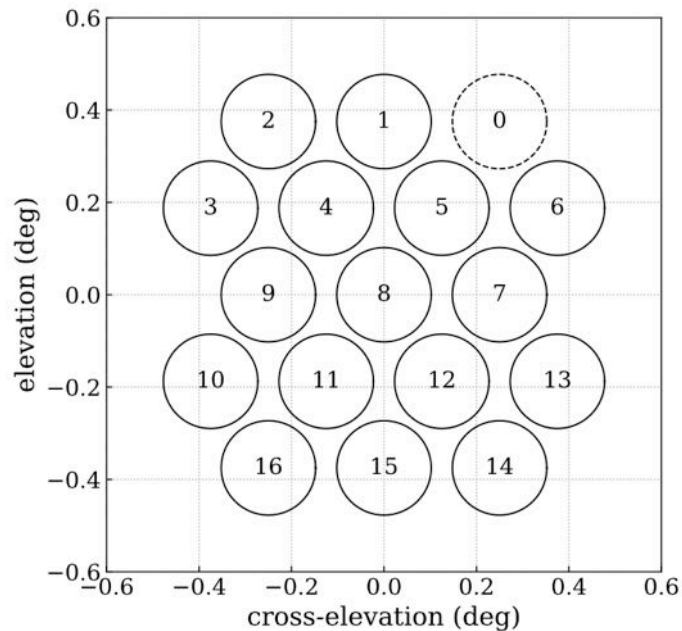


Observations

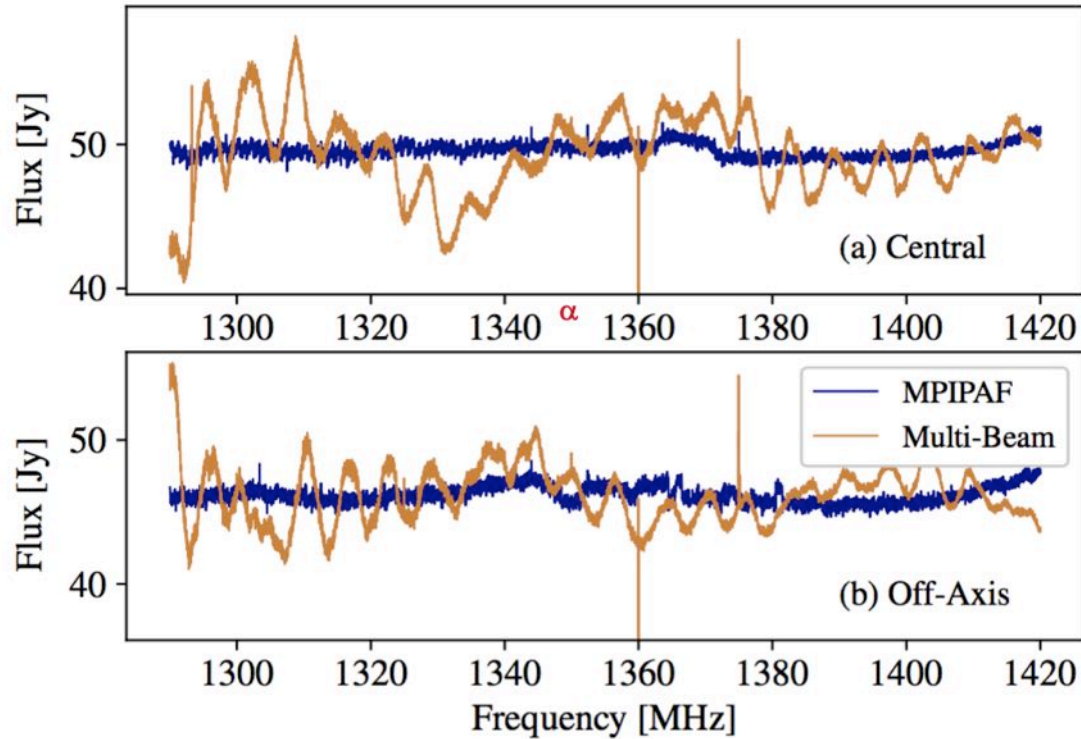
CSIRO Parkes telescope, NSW:

Date: 2016 Sept 1

Integration: 90 sec



MPIPAF: low standing waves



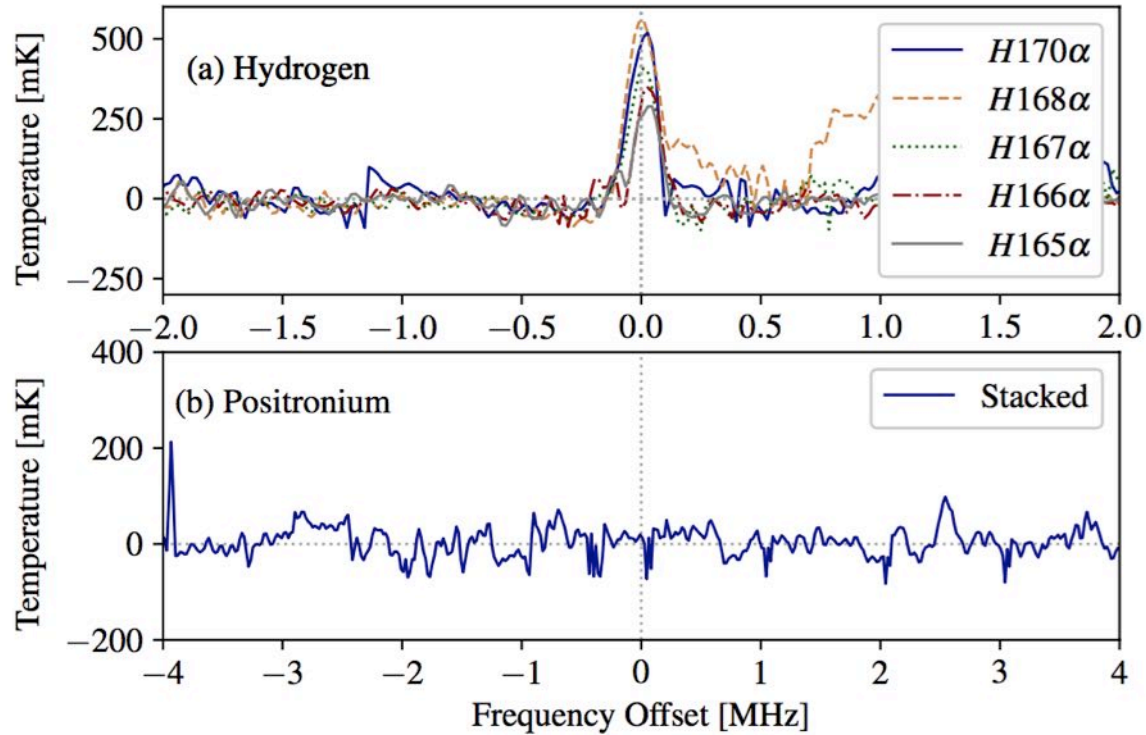


Frequencies

$Hn\alpha$	ν_H [MHz]	$Ps n\alpha$	ν_{Ps} [MHz]
165	1450.58	131	1446.81
166	1424.60	132	1414.29
167	1399.24	133	1382.75
168	1374.48	134	1352.14
169	1350.29	135	1322.42
170	1326.67	136	1293.57
171	1303.60	137	1265.55
172	1281.06	138	1238.33
173	1259.03	139	1211.89
174	1237.51	140	1186.20
175	1216.48	141	1161.23
176	1195.92		
177	1175.82		
178	1156.17		

Table 4 Rydberg numbers (n) and corresponding hydrogen (H) and positronium (Ps) frequencies.

Results



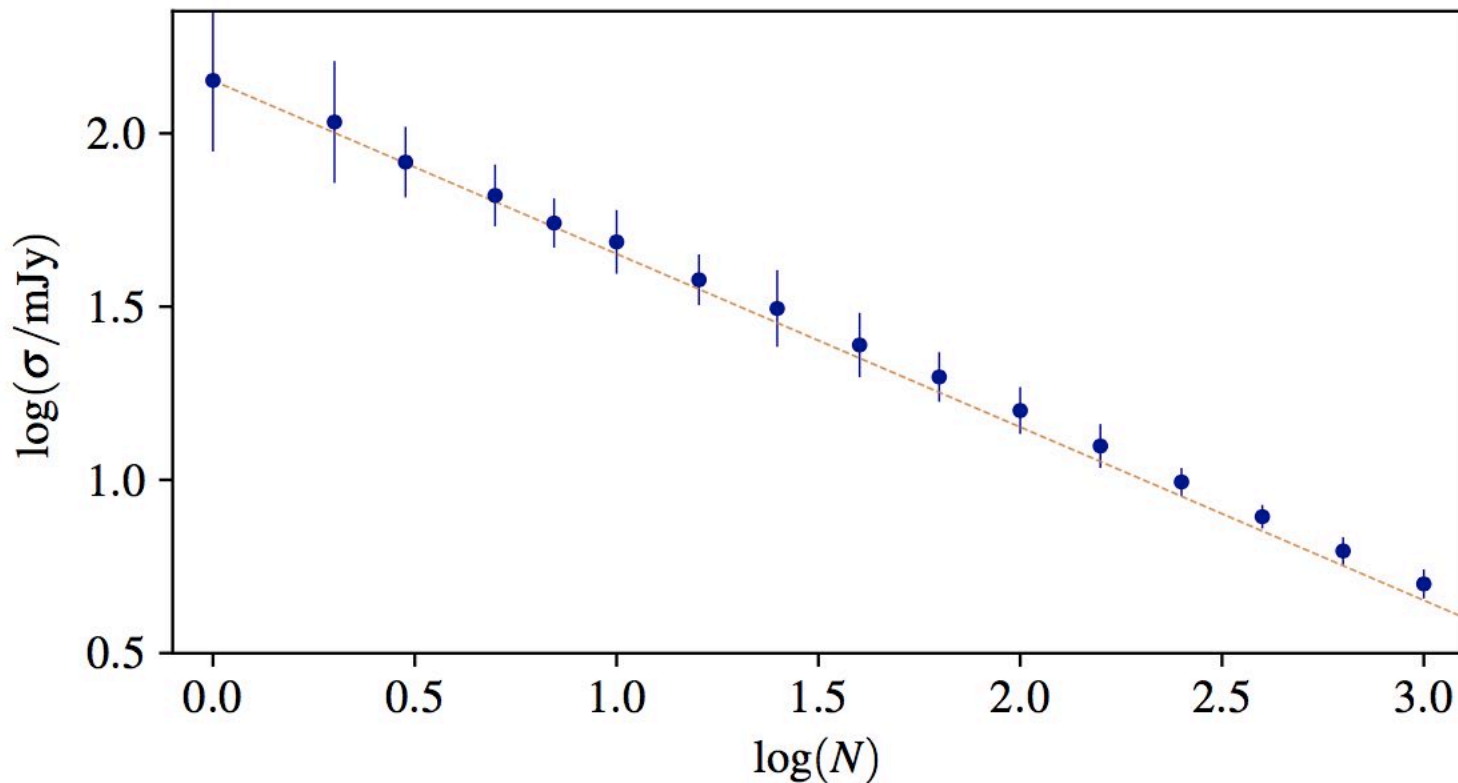


Results

Reynolds et al. (2017):

- 3-sigma upper limit $\sim 90\text{mK}$
 - 300x better than VLA limit of Anantharamaiah et al. (1989)
- Recombination rate $< 10^{44} \text{ s}^{-1}$
 - SPI Milky Way rate: $5 \times 10^{43} \text{ s}^{-1}$

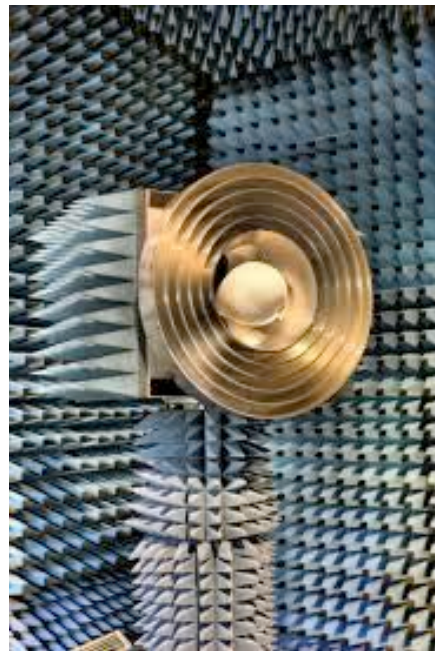
Future prospects



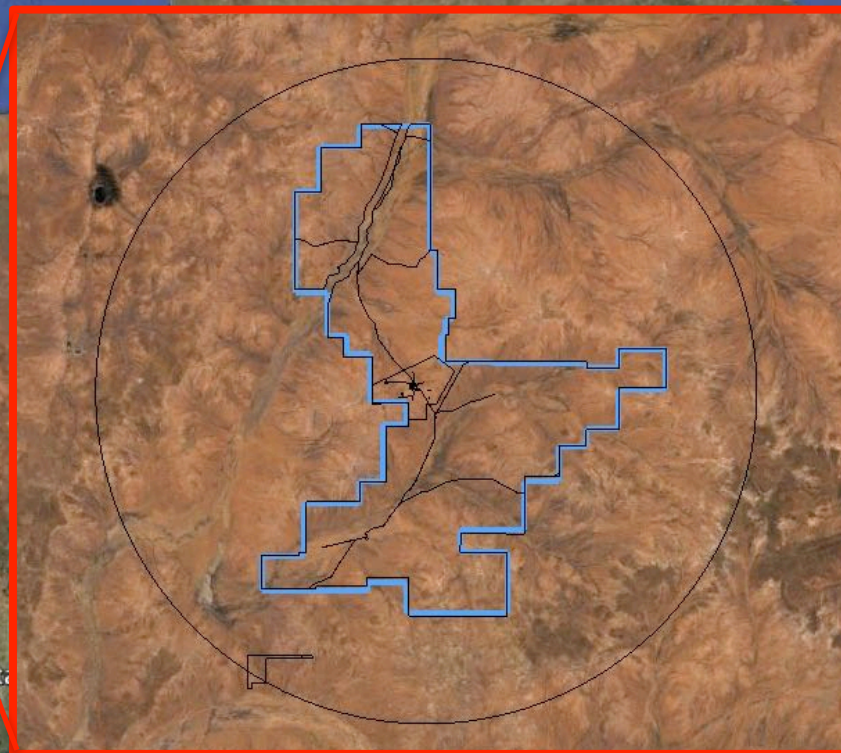


Future prospects

- Parkes Cryogenic Phased Array Feed (0.7-1.8 GHz)
- Parkes Ultra wideband receiver (0.7-4 GHz)
- Australian SKA Pathfinder (0.7-1.8 GHz)
 - Autocorrelations
- Murchison Widefield Array(MWA)
 - Engineering Development Array (EDA)
- SKA



Boolardy Station



1052 km



Murchison Radio-astronomy Observatory

ASKAP



EDA





Summary

- Galactic Centre Ps annihilation line strongly detected at gamma-ray wavelengths
- Source of positrons unknown:
 - ‘Conventional’ channels possible
 - DM-related channels not ruled out
- Detailed imaging, morphology and kinematics will help
- Recombination line measurements in optical hampered by dust extinction
- Parkes radio recombination limits are closing, but still need improving by an order of magnitude
 - Need observations at radio-quiet sites