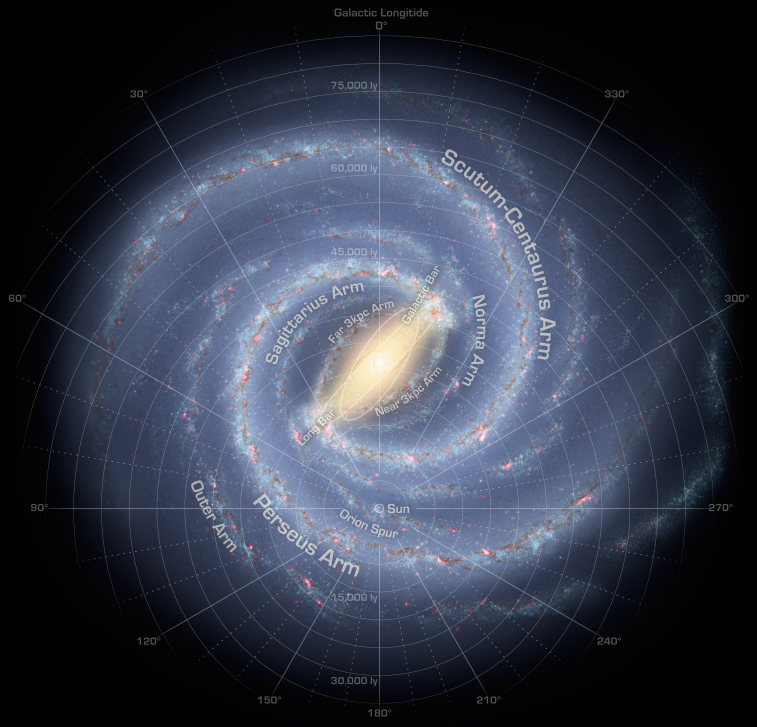
R. Hurt: NASA/JPL-Caltech/SSC



Milky Way structure with Parkes

ATNF User Committee Science Day: Science Drivers for Parkes Receivers

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CSIRO ASTRONOMY AND SPACE SCIENCE
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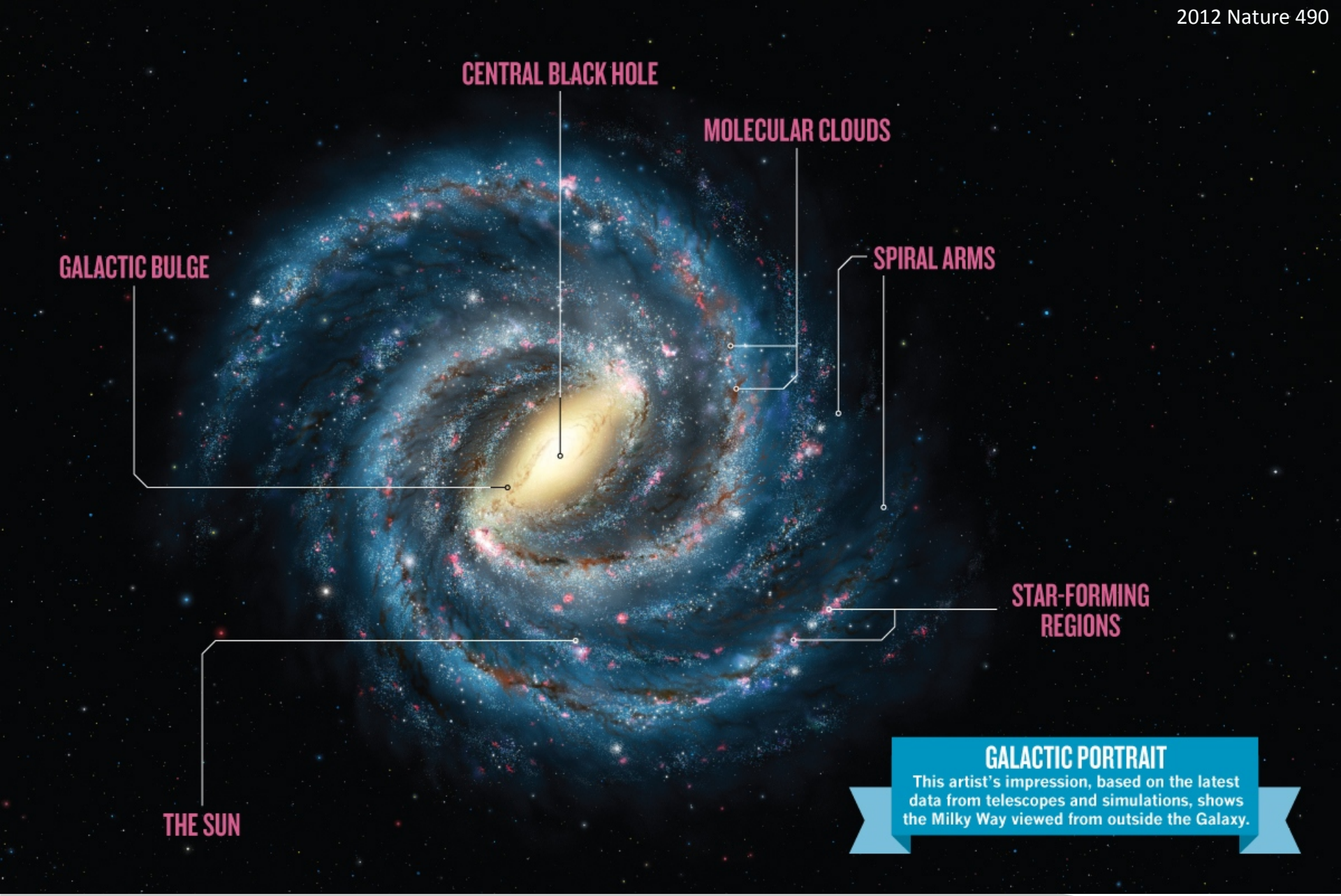
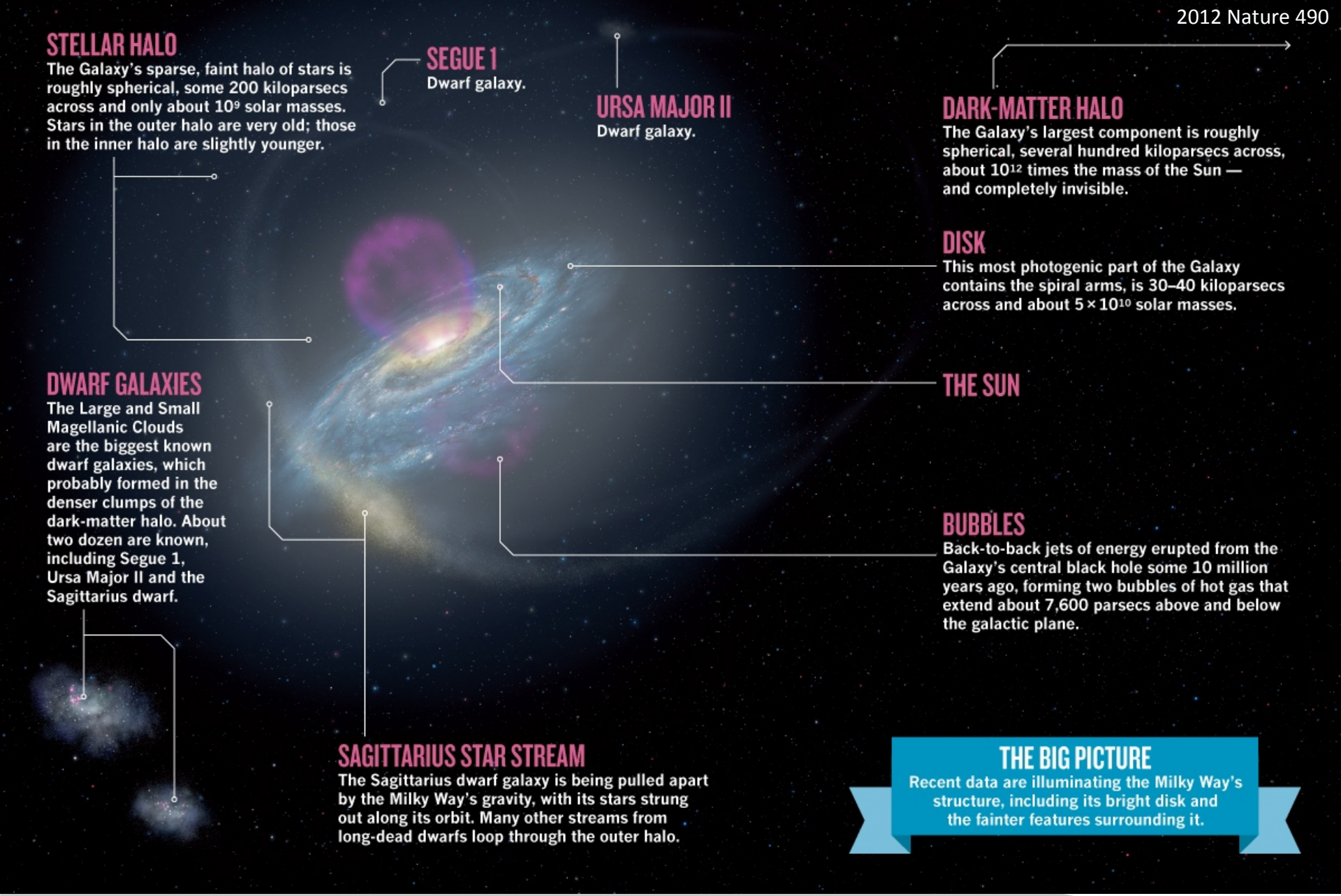
Section 1:
The Milky Way Structure

What (we think) we know


CENTRAL BLACK HOLE
MOLECULAR CLOUDS
GALACTIC BULGE
SPIRAL ARMS
STAR-FORMING REGIONS
THE SUN
GALACTIC PORTRAIT
This artist's impression, based on the latest data from telescopes and simulations, shows the Milky Way viewed from outside the Galaxy.


STELLAR HALO
The Galaxy's sparse, faint halo of stars is roughly spherical, some 200 kiloparsecs across and only about 10^9 solar masses. Stars in the outer halo are very old; those in the inner halo are slightly younger.
SEGUE 1
Dwarf galaxy.
URSA MAJOR II
Dwarf galaxy.
DARK-MATTER HALO
The Galaxy's largest component is roughly spherical, several hundred kiloparsecs across, about 10^{12} times the mass of the Sun — and completely invisible.
DISK
This most photogenic part of the Galaxy contains the spiral arms, is 30–40 kiloparsecs across and about 5×10^{10} solar masses.
THE SUN
DWARF GALAXIES
The Large and Small Magellanic Clouds are the biggest known dwarf galaxies, which probably formed in the denser clumps of the dark-matter halo. About two dozen are known, including Segue 1, Ursa Major II and the Sagittarius dwarf.
BUBBLES
Back-to-back jets of energy erupted from the Galaxy's central black hole some 10 million years ago, forming two bubbles of hot gas that extend about 7,600 parsecs above and below the galactic plane.
SAGITTARIUS STAR STREAM
The Sagittarius dwarf galaxy is being pulled apart by the Milky Way's gravity, with its stars strung out along its orbit. Many other streams from long-dead dwarfs loop through the outer halo.
THE BIG PICTURE
Recent data are illuminating the Milky Way's structure, including its bright disk and the fainter features surrounding it.

The Milky Way Structure

Physical structure, kinematics & magnetic field

- Galactic centre: Central molecular Zone, tilted inner disk, large amount of star forming material, but little star formation.
- A long (3-4 kpc) bar and a short (1-2 kpc) bar (that are possibly part of the same structure).
- The 3-kpc arms (at least near and far side arms, most likely continuous elliptical structure).
- Four spiral arms: two major (Perseus & Crux-Scutum/Scutum-Centaurus) and two minor (Sagittarius and Norma).
- Solar distance/distance to Galactic centre is 8.4 kpc, from black hole orbiting stars & maser astrometry (c.f. IAU value 8.5 kpc).
- Circular rotation is probably more like ~240 km/s (c.f. IAU value of 220).
- A large-scale magnetic field exists, as traced by rotation measures.
- Magellanic interaction exists, related to outer Galaxy structure.

Section 2:
The past role of Parkes

What has Parkes contributed to our understanding

The past role of Parkes

What have Parkes observations contributed: data sets

- **Galactic HI emission (for rotation curves, longitude-velocity plots)**
  - F. Kerr ++ 1970s; Knapp 1972; Strong et al. 1982; Southern Galactic Plane Survey; GASS.
- **Galactic HI absorption (for kinematic distances, near/far ambiguities)**
  - Radhakrishnan, Goss ++ 1970s & 80s; Caswell ++ 1970s; Jones & Dickey 2012.
- **Formaldehyde absorption (for kinematic distances, near/far ambiguities)**
  - Goss et al. 1980.
- **Continuum (HII regions) plus radio recombination lines (for kinematic distances)**
  - McGee & Gardner 1969; Mezger et al. 1970; Haynes et al. 1978,79; Caswell & Haynes 80s & 90s.
- **Pulsars (for distances and magnetic field measurements)**
  - too many to list (see the online database & other talks!).
- **Masers (for distances and magnetic field measurements)**
  - Caswell ++ 80s,90s,00s; Ellingsen 90s; te Lintel Hekkert et al. 90s; Chapman 90s; Methanol Multibeam (plus followup).
- **Magellanic System (evidence for interaction)**
  - McGee & Milton 1966; Matthewson et al. 1970s & 80s; Putman et al. 2003; Stanimirovic et al. 2004, 09; Dickey et al. 2001; Kim et al. 2003; Brüns et al. 2005; GASS; HIPASS.

The past role of Parkes

What have Parkes observations contributed: science outcomes

- **Galactic rotation curves**
  - Gunn et al. 1979; Fich et al. 1989; McClure-Griffiths & Dickey 2007.
- **Southern sky spiral arm locations**
  - Caswell et al. 1975; McClure-Griffiths et al. 2004.
- **Galactic centre kinematics**
  - McGee ++ 1960s & 70s; Caswell & Haynes 1982; McClure-Griffiths et al. 2012.
- **Structure and dynamics through maser kinematics and densities**
  - Green et al. 2009; Green et al. 2011.
- **Galactic Structure, Warp/Flare**
  - Kerr 1969; Simonson et al. 1976; McClure-Griffiths et al. 2004.
- **Interaction of Magellanic system with Galaxy (High Velocity Clouds)**
  - Putman et al. 1998; McClure-Griffiths et al. 2008; Diaz & Bekki 2011.
- **Magnetic field structure through rotation measures**
  - Mao et al. 2012; SPASS.

Section 3:
The current and future role of Parkes

What can Parkes contribute to our understanding

The current and future role of Parkes

The questions to be answered (revisiting what we know)

- **Galactic centre: Central molecular Zone, tilted inner disk, large amount of star forming material, but little star formation.**
  - **What is the detailed structure and kinematics of the inner Galaxy and Galactic centre?**
  - **What is going on with the star formation?**
- **A long (3-4 kpc) bar and a short (1-2 kpc) bar (that are possibly part of the same structure).**
  - **Are they part of the same structure?**
  - **How are their kinematics and mass distribution related to the Galaxy's structure**
- **The 3-kpc arms (at least near and far side arms, most likely continuous elliptical structure).**
  - **What is the complete structure? How does it interact with the bar(s) and spiral arms?**

The current and future role of Parkes

The questions to be answered (revisiting what we know)

- Four spiral arms: two major (Perseus & Crux-Scutum/Scutum-Centaurus) and two minor (Sagittarius and Norma).
  - What is the precise (to within a few 10ths of a kpc) location of the spiral arms? What is their curvature, width and extent?
  - What are the full three dimensional kinematics of the spiral arms? and how does the rotation curve vary across the Galaxy (c.f. tangent point determination)?
- Solar distance/distance to Galactic centre is 8.4 kpc (from black hole orbiting stars & maser astrometry).
- Circular rotation is probably more like ~240 km/s (c.f. IAU value of 220).
  - Currently based on Northern Hemisphere maser astrometry, is this a biased estimate or is it Galaxy wide case?
  - How appropriate are circular rotation estimates across the Galaxy?
- A large-scale magnetic field exists (as traced by rotation measures).
  - What is the magnetic field structure within the arms (at any given point)?
- Magellanic interaction exists, related to outer Galaxy structure.
  - Exact nature of interaction and first interaction or previous interaction(s)?

The current and future role of Parkes

Data to be collected: ongoing projects

- **SPLASH – Masers & Inner Galaxy/Galactic centre diffuse hydroxyl – H-OH receiver**
  - **hydroxyl (1.6-1.7GHz) capable PAF would enable more sensitive & faster observing, thus enabling further off plane coverage, and better spectral baselines.**
- **V255 – Maser astrometry – Methanol-6 receiver**
  - **Good methanol maser (6.7-GHz and 12.2-GHz) capable Parkes receiver would provide significant sensitivity boost for Long Baseline Array.**
- **Proposed HII region recombination line study – Mars receiver**
  - **Wide band mid-frequency (4-12.2GHz) receiver would provide both continuum and many lines simultaneously, vastly improving on existing data.**
- **Various pulsar searches – astrometry and rotation measures – see pulsar talks**

The current and future role of Parkes

Data to be collected: future projects

- maser astrometry and pulsar astrometry (keeping Parkes part of LBA).
- continuum (HII regions) plus multiple recombination line measurements, similar to Anderson/Bania northern hemisphere work.
- rotation measures (pulsars).
- maser polarimetry (single dish & part of LBA).
- multi-transition molecular emission data (many lines observed simultaneously), particularly towards Galactic centre.

- (not strictly Galactic structure) multi-transition follow-up of individual regions to address what is the detailed makeup of the Interstellar medium across the Galaxy
  - ➢ (see Alex's & Andrew's talks)

The current and future role of Parkes

Summary

- **Precise structure and kinematics through astrometry – requires availability of appropriate frequencies across multiple epochs throughout the year – keeping Parkes part of LBA and having frequency flexibility.**
- **Structure and kinematics through more objects with kinematic distances – requires multiple recombination line capability (broadband 4-12.2 GHz) and/or other molecular tracers.**
- **Galactic centre progress needs multiple transitions (different tracers) observed simultaneously – to piece together the various components and their kinematics.**

- **All could be addressed through a couple of wideband receivers.**

Don't forget complement of Tidbinbilla with Parkes in LBA (= very sensitive with combined large collecting area) and possible increased availability in coming years.

Thank you

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