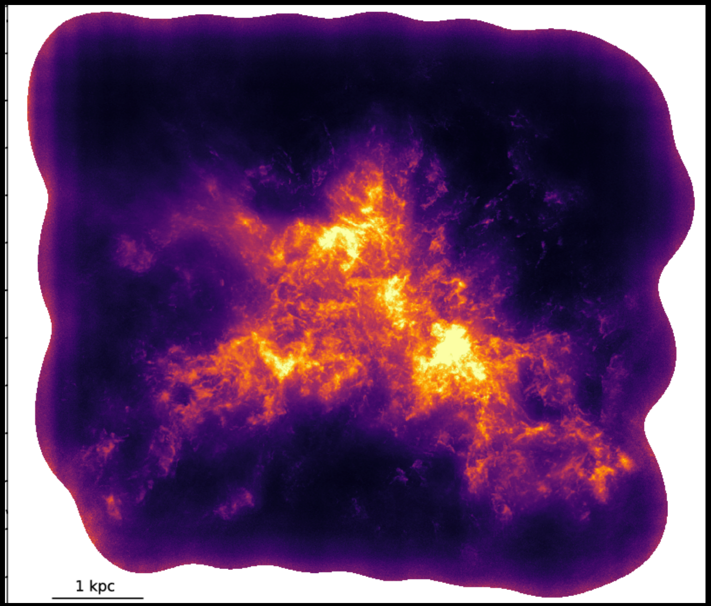
Australian National University



Credit: Pingel et al. 2022

Credit: CSRIO

Pilot Survey Science from the GASKAP-HI Survey

Nickolas Pingel (co-PI)

The Australian National University & University of Wisconsin-Madison

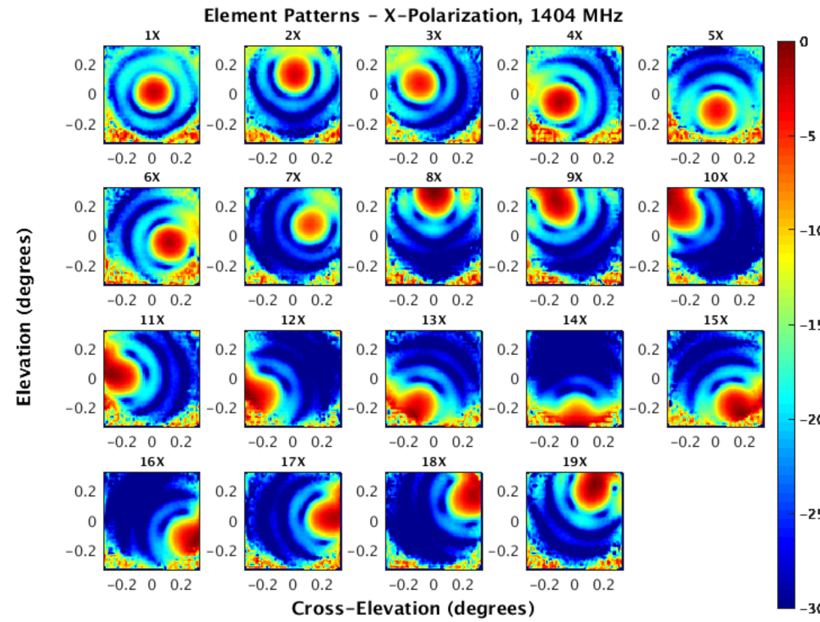
Email: Nickolas.Pingel@anu.edu.au

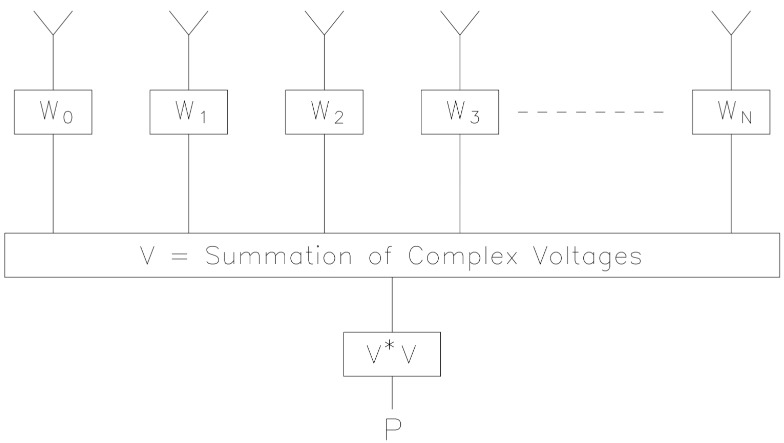
Australian National University

Australian SKA Pathfinder (ASKAP)

Credit: Alex Cherney/CSIRO

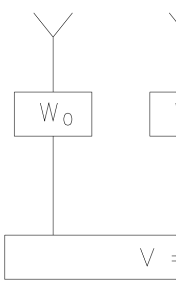
Beamforming

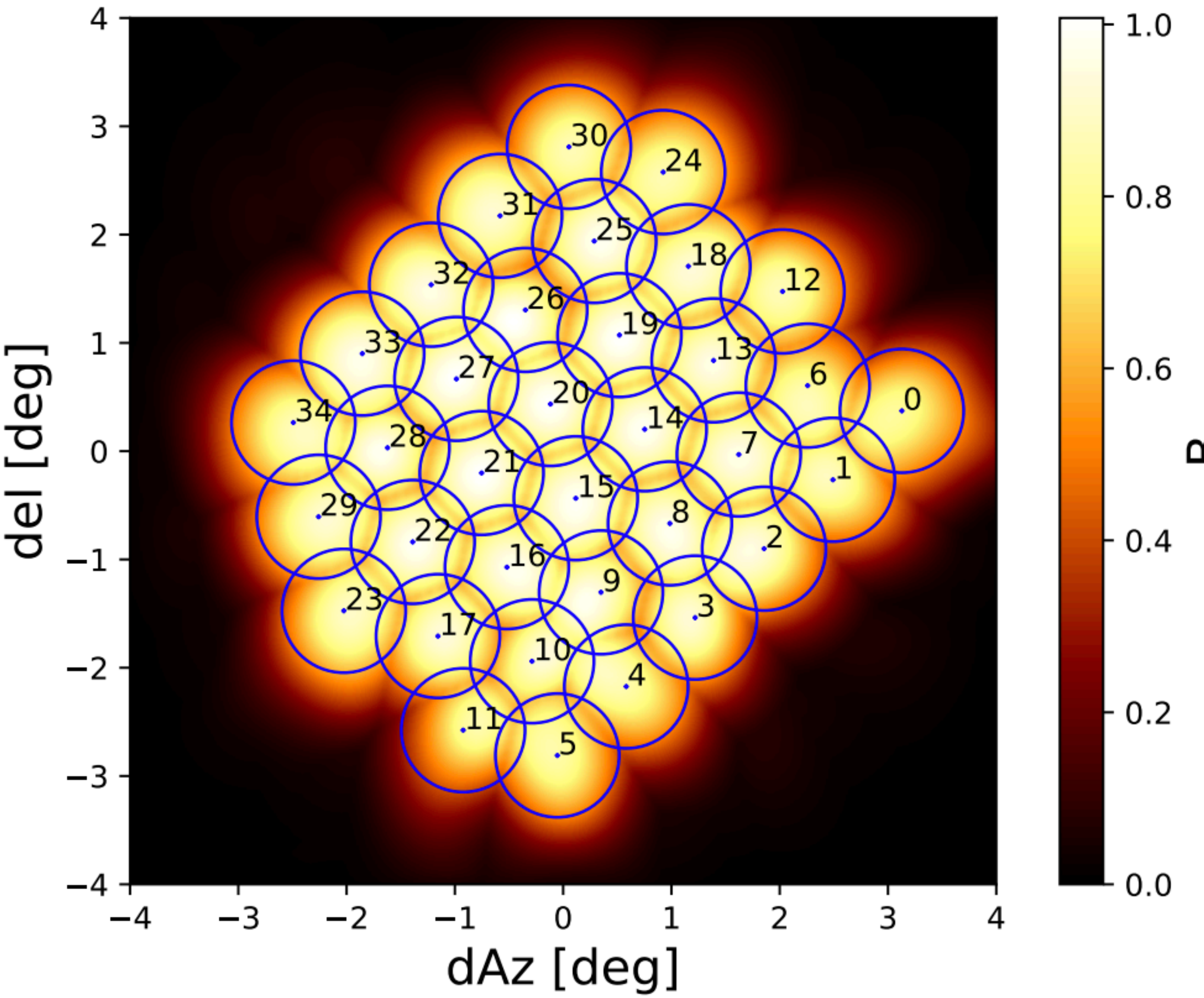


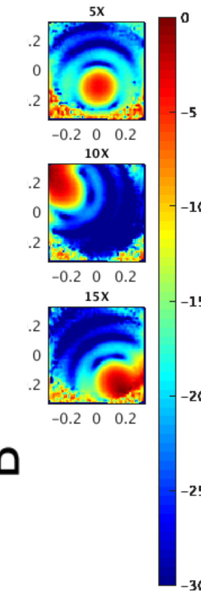


$$V = \sum_{i=0}^{N} W_i v_i$$

Beamforming

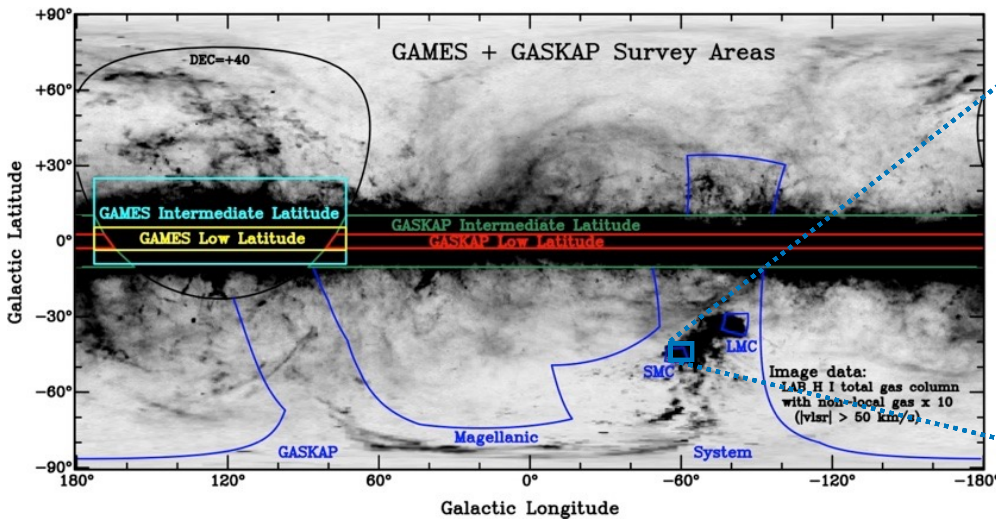




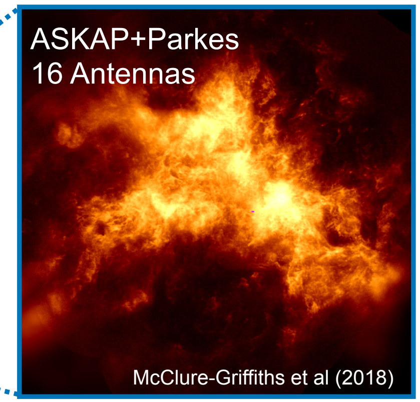


GASKAP: The Galactic ASKAP Survey

Aim: To study the evolution of the Milky Way and Magellanic Clouds through their interstellar gas and star formation



Small Magellanic Cloud



Survey of the Galactic plane and Magellanic System:

HI λ21-cm emission and absorption

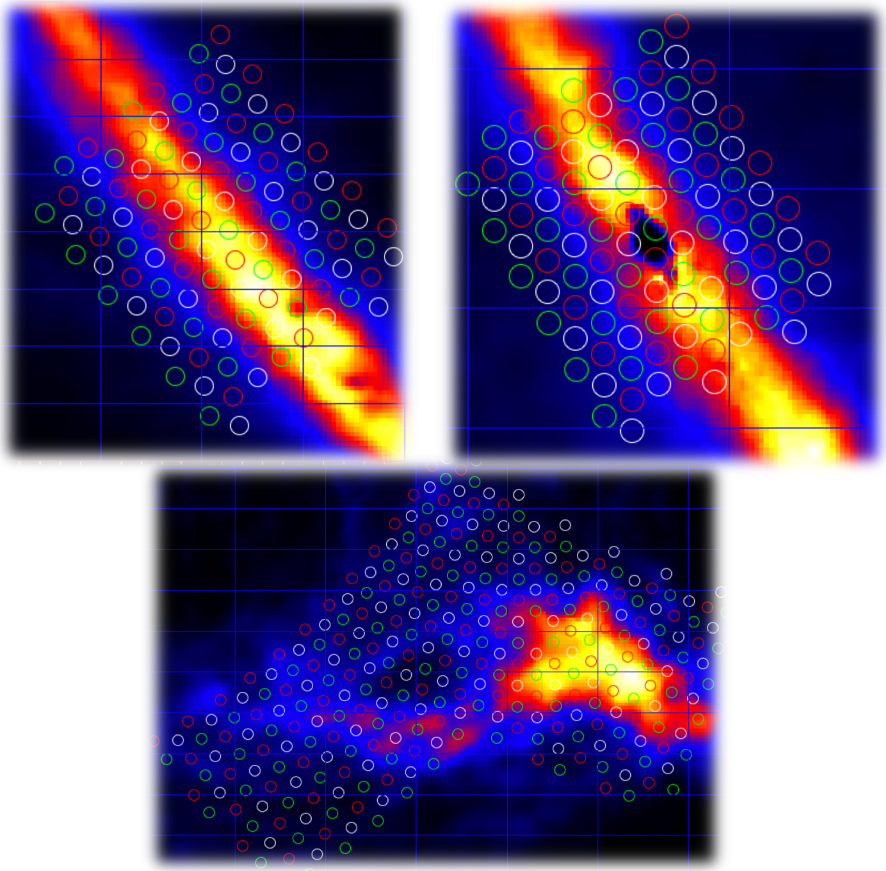
OH λ18-cm diffuse emission and absorption

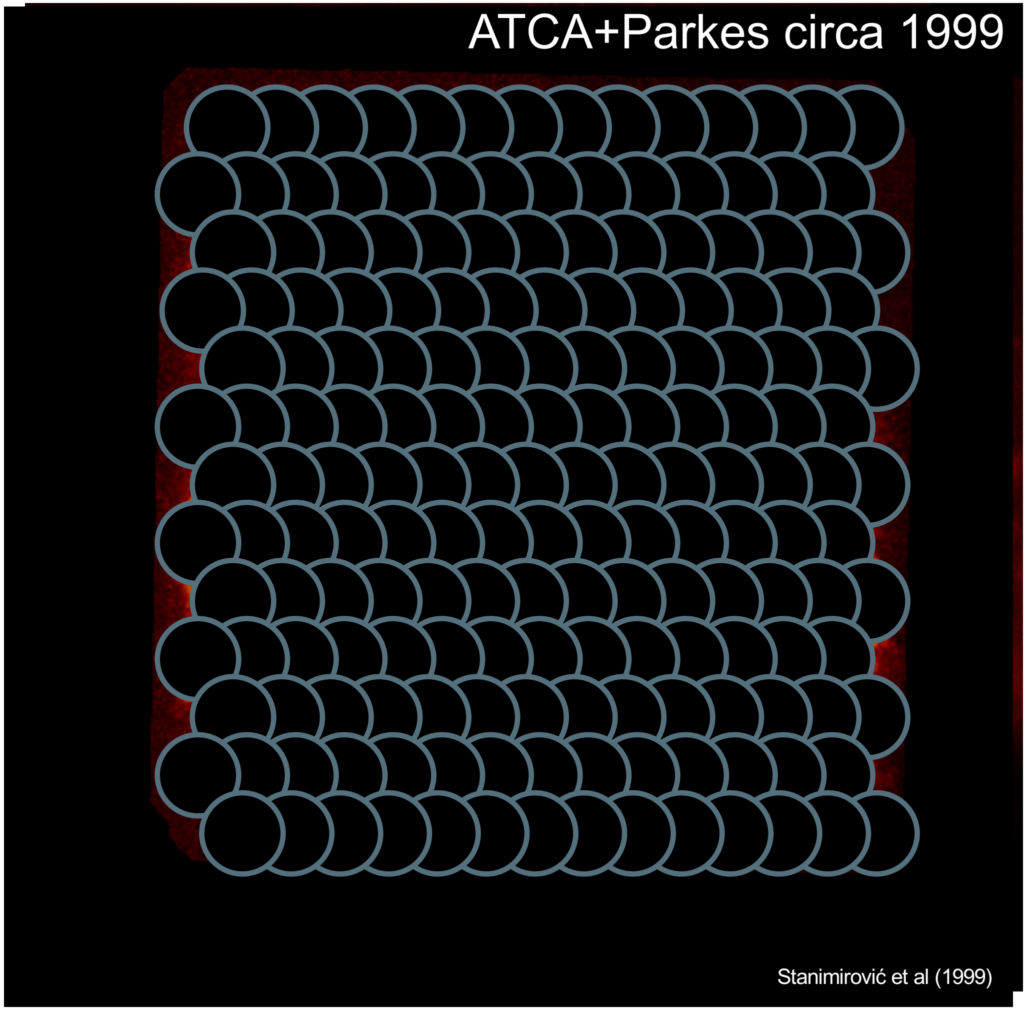
More than order of magnitude more sensitive than previous surveys

GASKAP-HI Pilot Survey Phase I

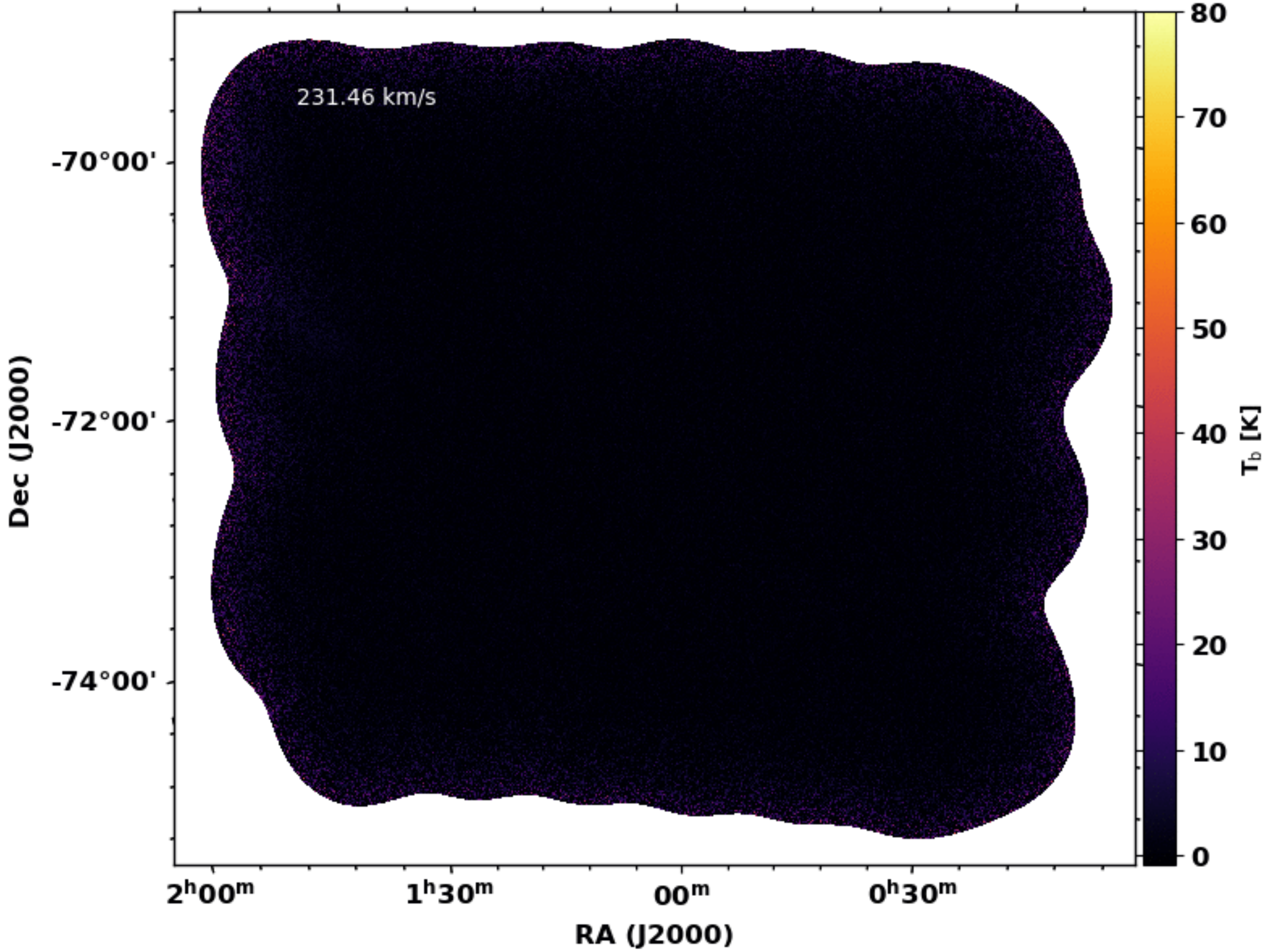
gain experience working with complicated fields and push limits of processing

Field	Obs Time	Expected rms
SMC	20 hr	3.8 mJy
MG - Bridge	10 hr	5.4 mJy
MG - Stream	20 hr	3.8 mJy
Galactic Plane l=339°, b = 0°	16 hr	4.25 mJy
Galactic Center	8 hr	6.0 mJy




ATCA+Parkes circa 1999
Stanimirović et al (1999)

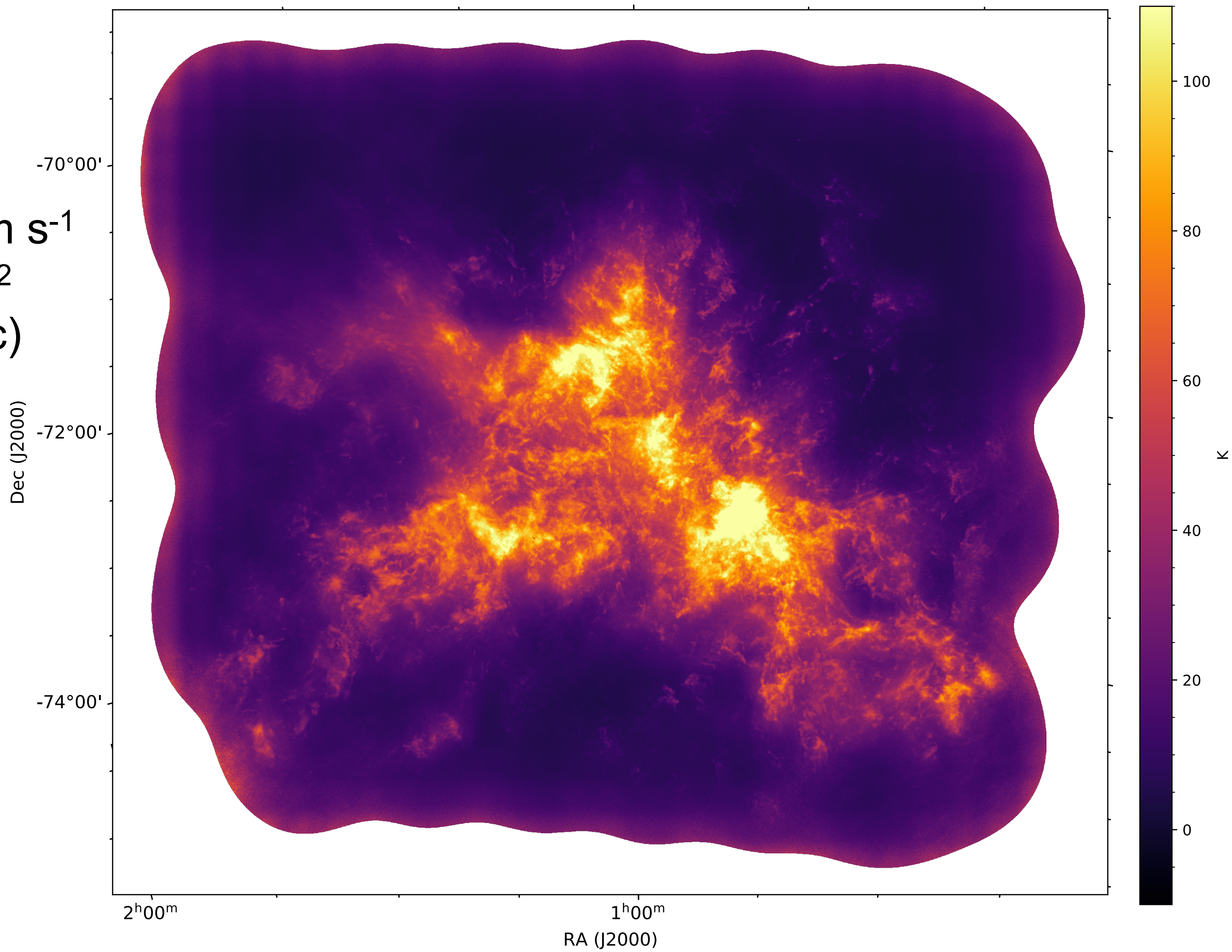
HI Emission in SMC



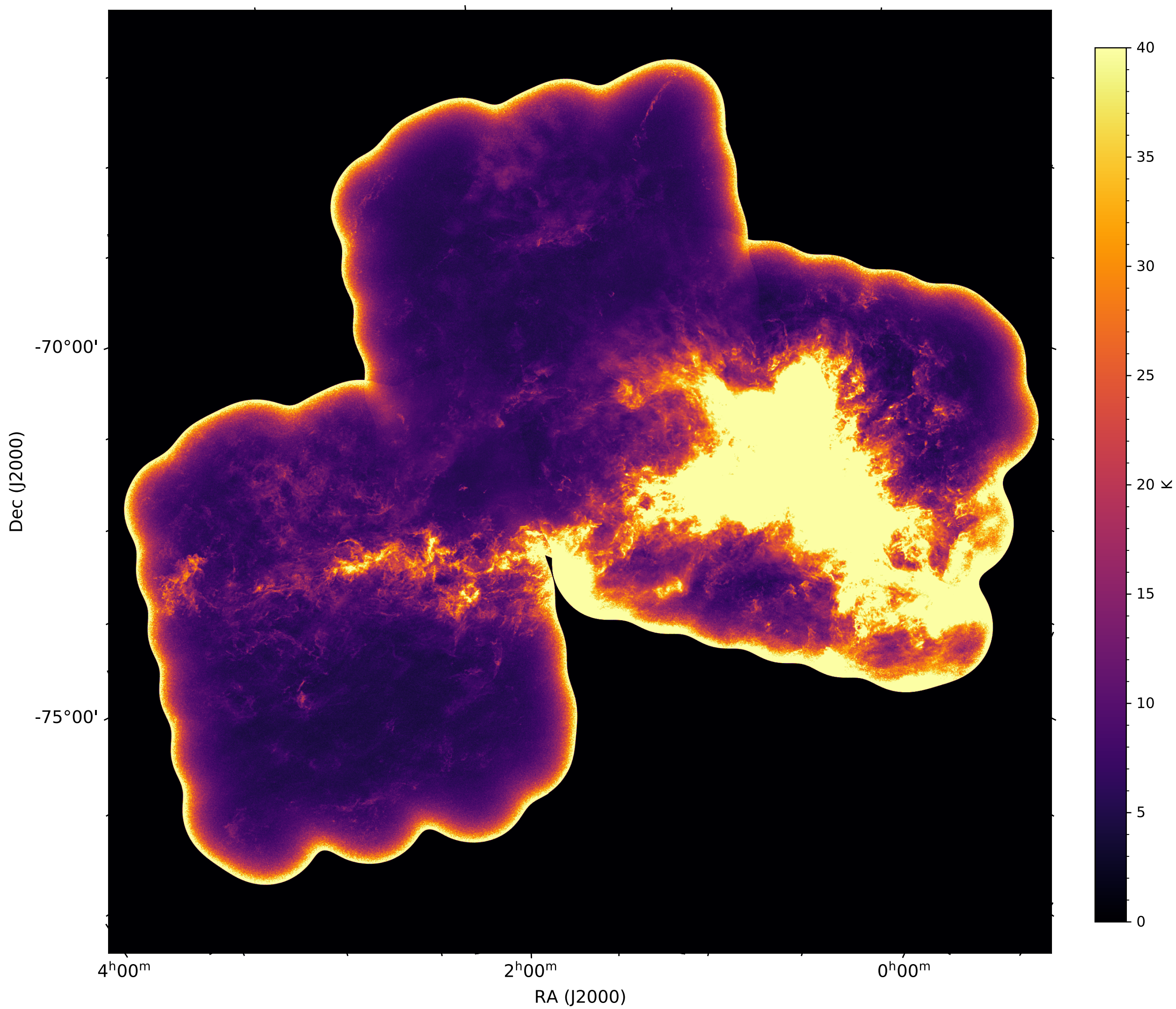
Peak Intensity

Data Properties

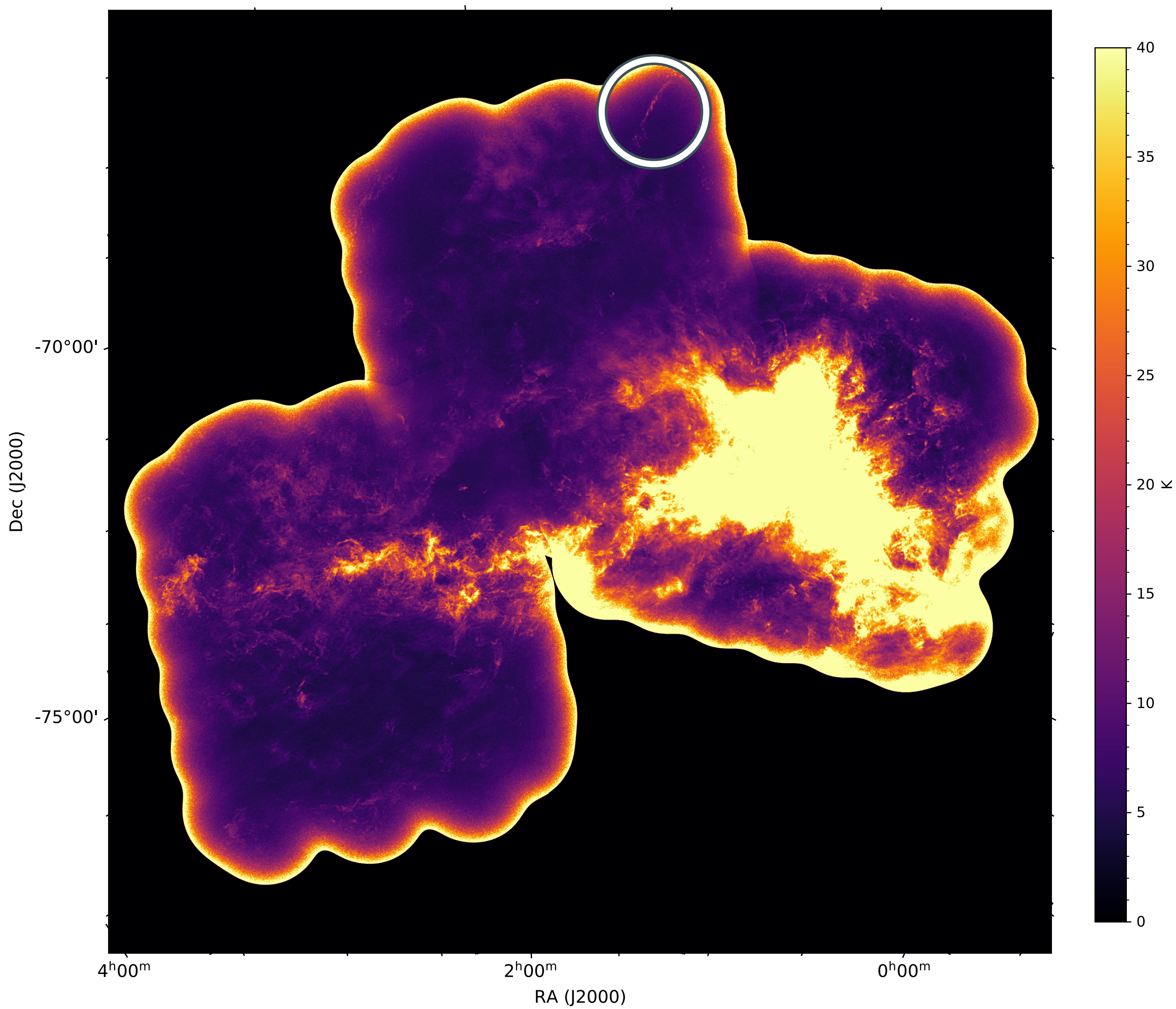
- σ: 1.1 Kper 0.98 km s^{-1}
- $5\sigma_{NHI}$: $4.4x10^{19}$ cm^{-2}
- 30'' resolution (8 pc)



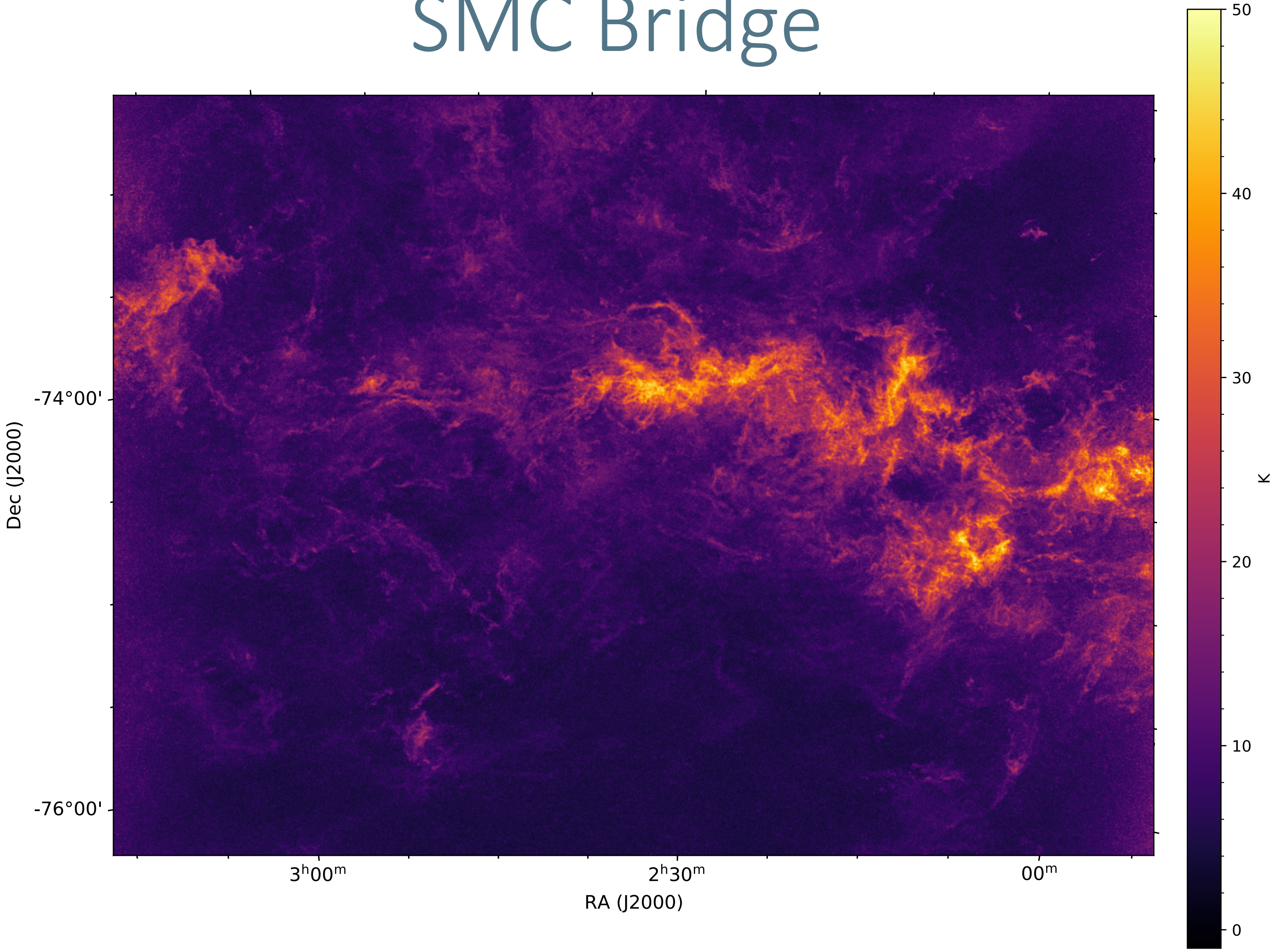
Magellanic Observations



Magellanic Observations



SMC Bridge



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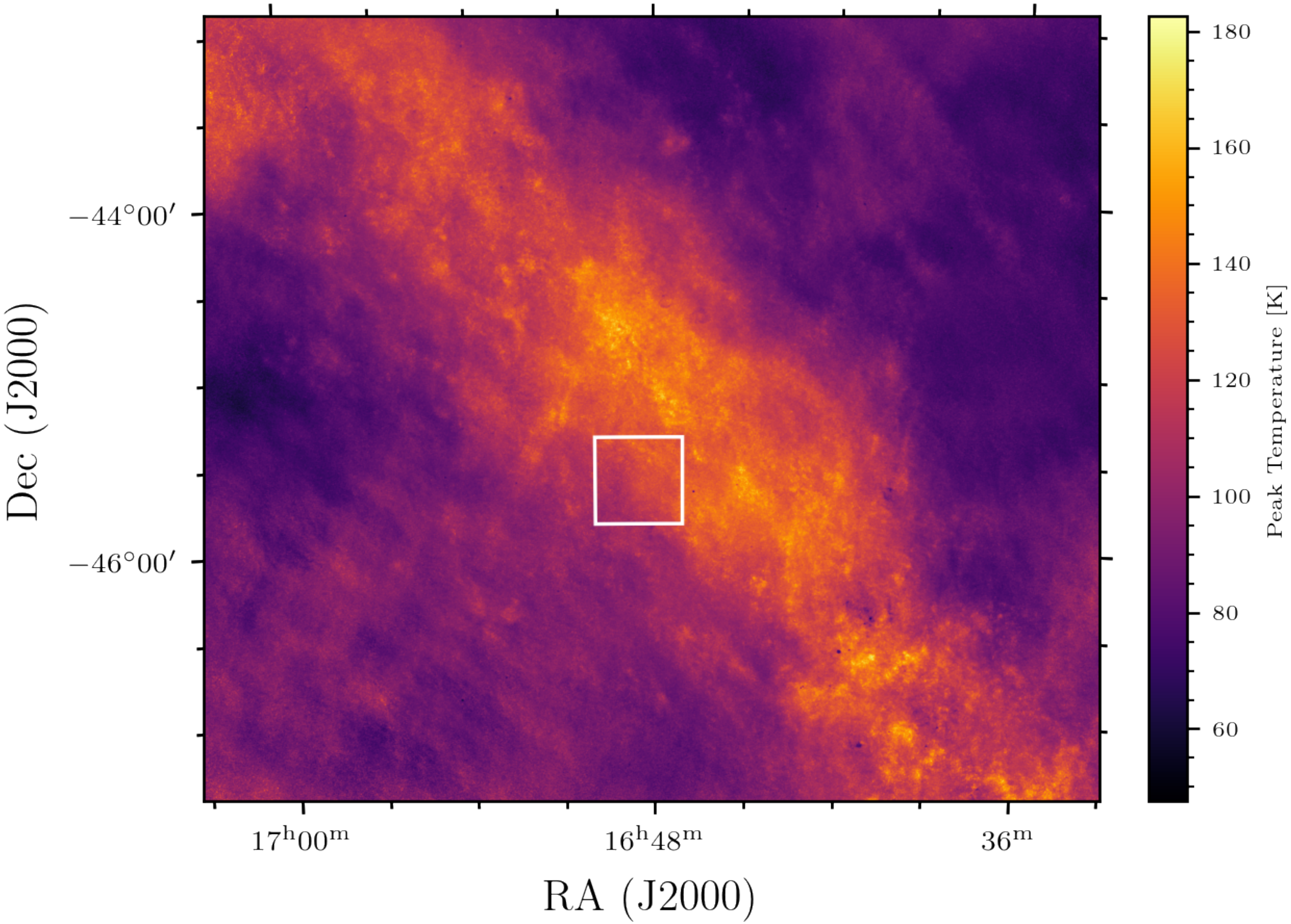
Galactic Plane (*l*=340°)

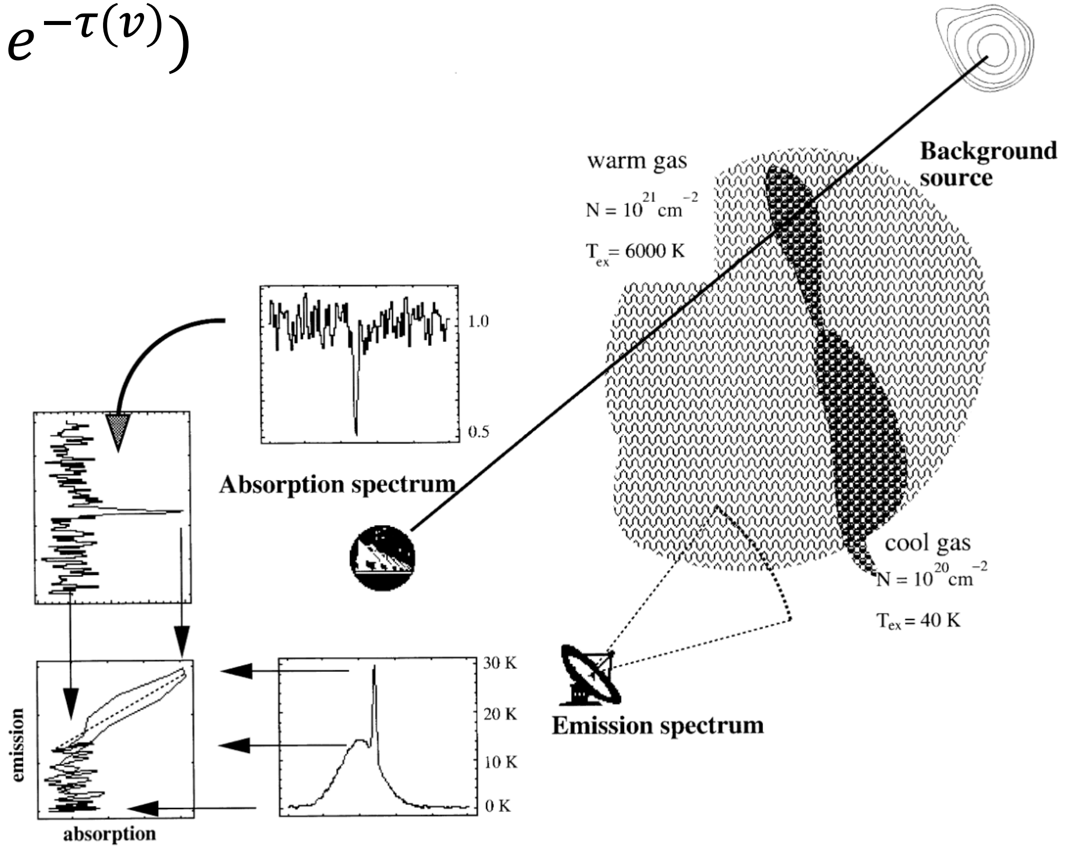


HI Absorption

$$\Delta T_b(v) = T_s - T_0(1 - e^{-\tau(v)})$$

$$T_s = \frac{T_b}{1 - e^{-\tau(v)}}$$

- Find $\boldsymbol{\tau}$ by constructing T_b via nearby reference pointings
- Determine HI column density N_{HI} and T_k



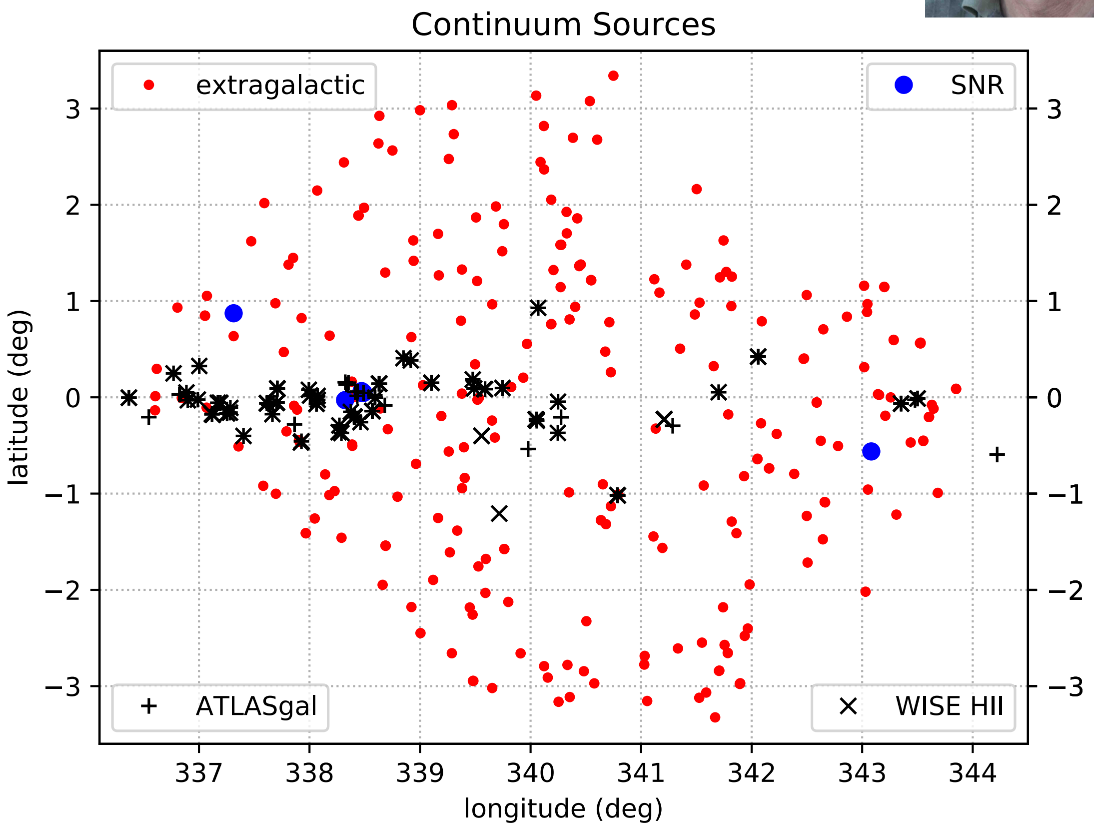
Dickey et al. (2000)

Australian National University

HI Absorption in Galactic Plane

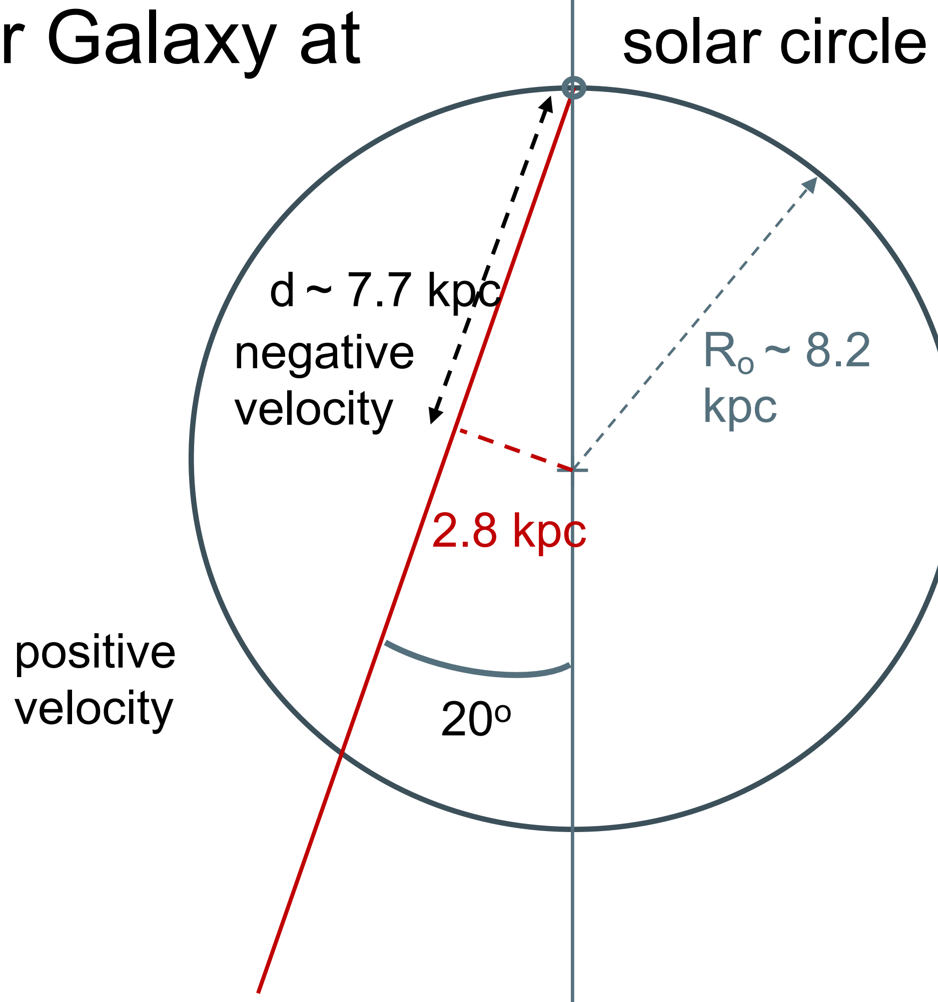
- Work led by John Dickey (U-Tas)
- 20 hours on l=340 deg
- Result:

108 Galactic
238 Extragalactic



Dickey et al. 2022

Kinematic distances in the inner Galaxy at ℓ =340^{o} :



Australian National University

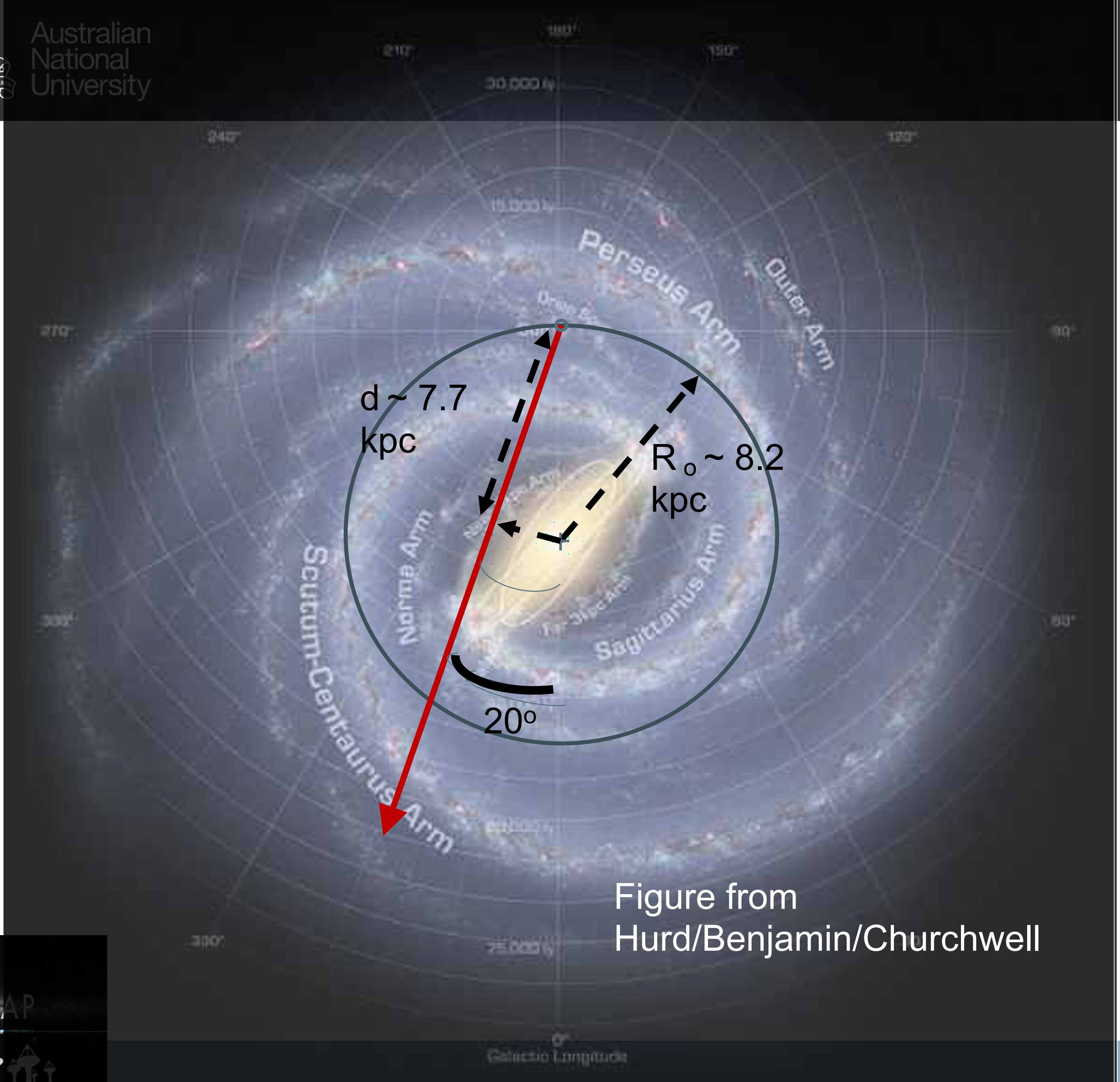
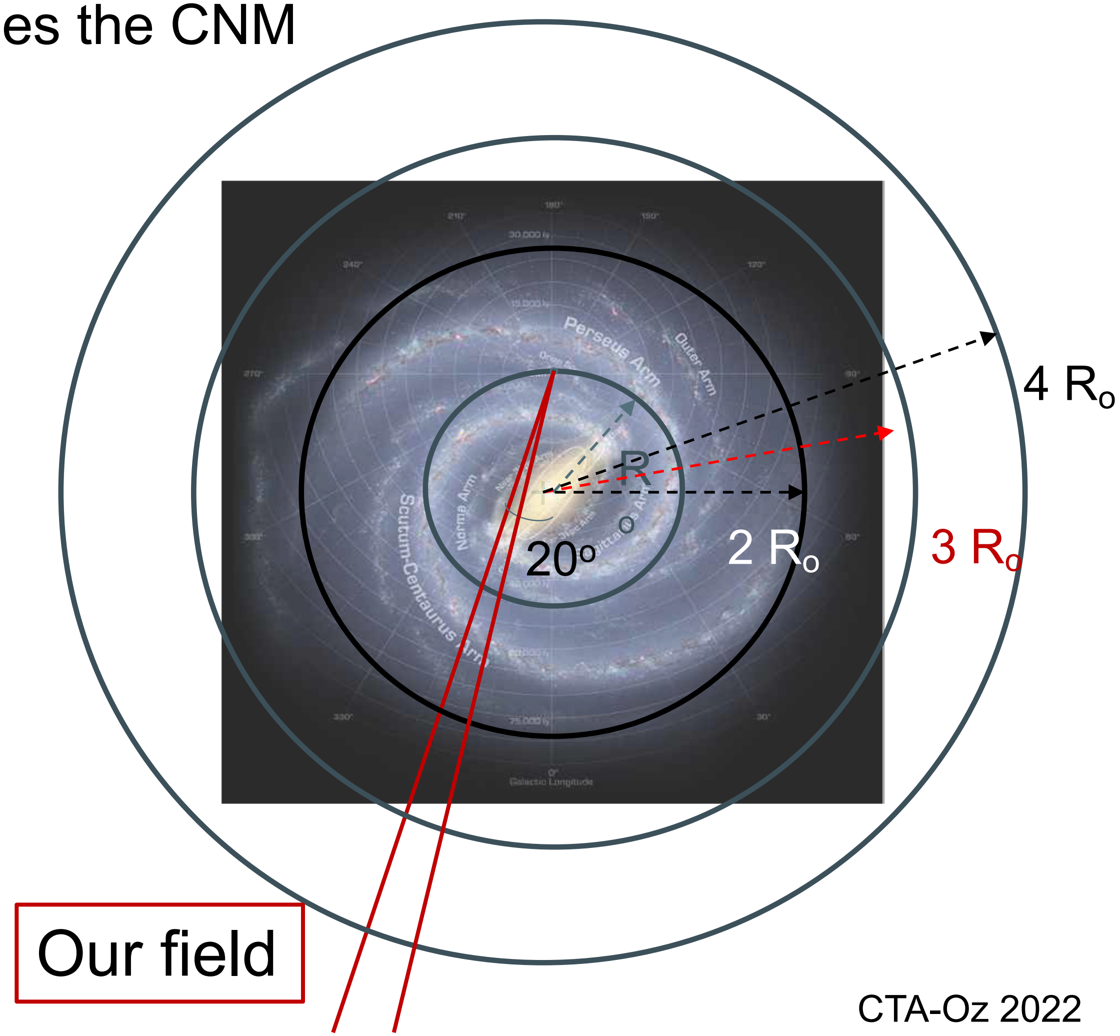


Figure from Hurd/Benjamin/Churchwell

GASKAP

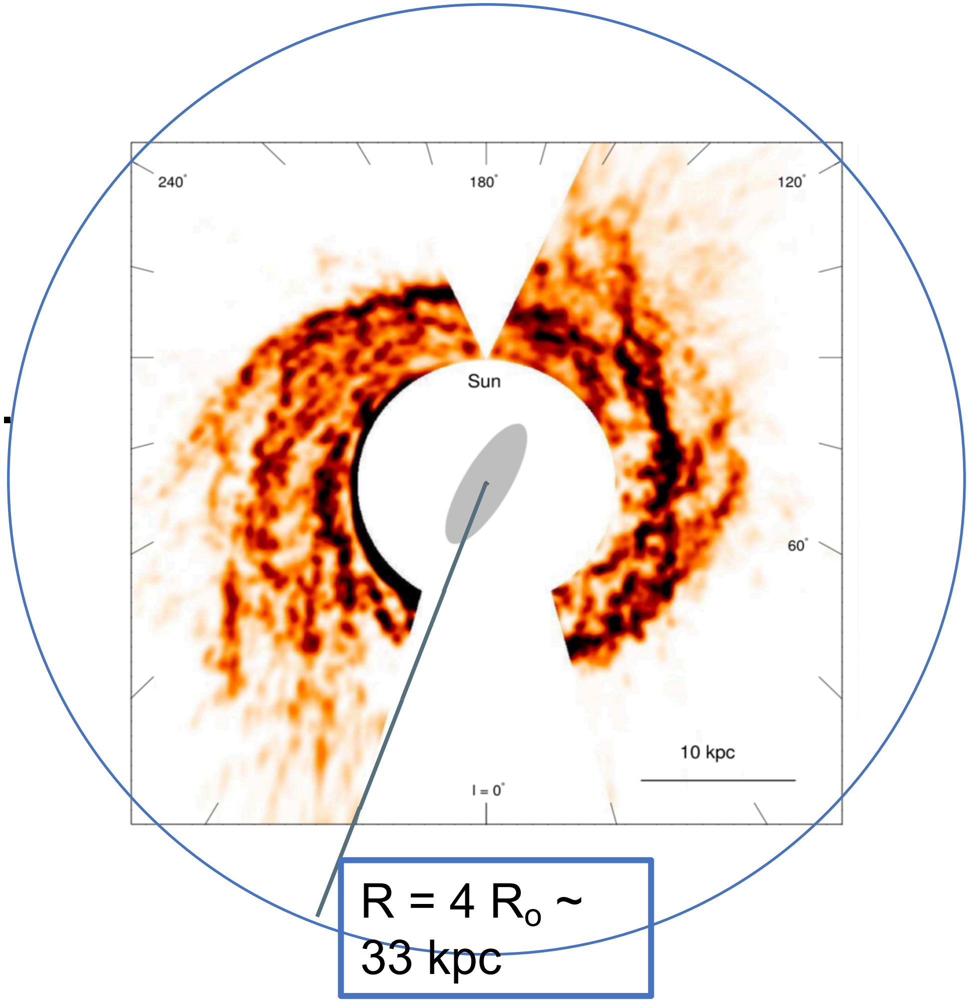
How far out does the CNM go?



CTA-Oz 2022

Bright 21-cm emission decreases exponentially for R > ~12 kpc.

HI surface density from Koo et al. 2017



In general the observed radial velocity, V_r, vs Galactocentric radius, R, is

$$V_r \;=\; R_\odot \left[\Omega(R) \;-\; \Omega_\odot\right] \sin\left(\ell\right)\;\cos\left(b\right)$$

For a flat rotation curve, $\Omega(R)/\Omega_\odot = R_\odot/R$ so

$$V_r \;=\; V_\odot \left[\frac{R_\odot}{R} \;-\; 1\right] \sin\left(\ell\right)\;\cos\left(b\right)$$

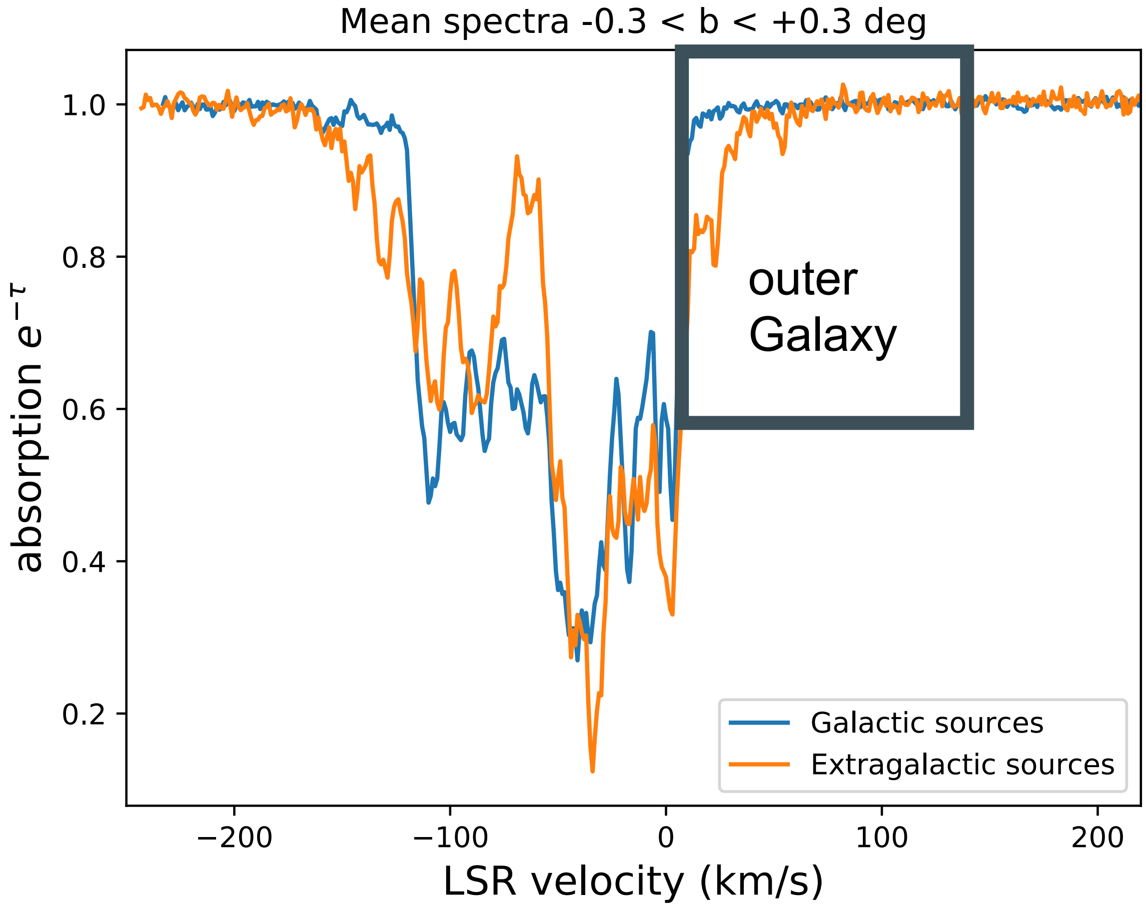
For $\cos\left(b\right) \simeq 1$:

$$\frac{V_r}{V_\odot\;\sin\left(\ell\right)} \;=\; \left[\frac{R_\odot}{R} \;-\; 1\right]$$

For $V_\odot = 240$ km/s and $\ell = 340^o$
$\sin\left(\ell\right) = -0.34$ and $V_\odot\;\sin\left(\ell\right) = -82.1$ km s^{-1} so:

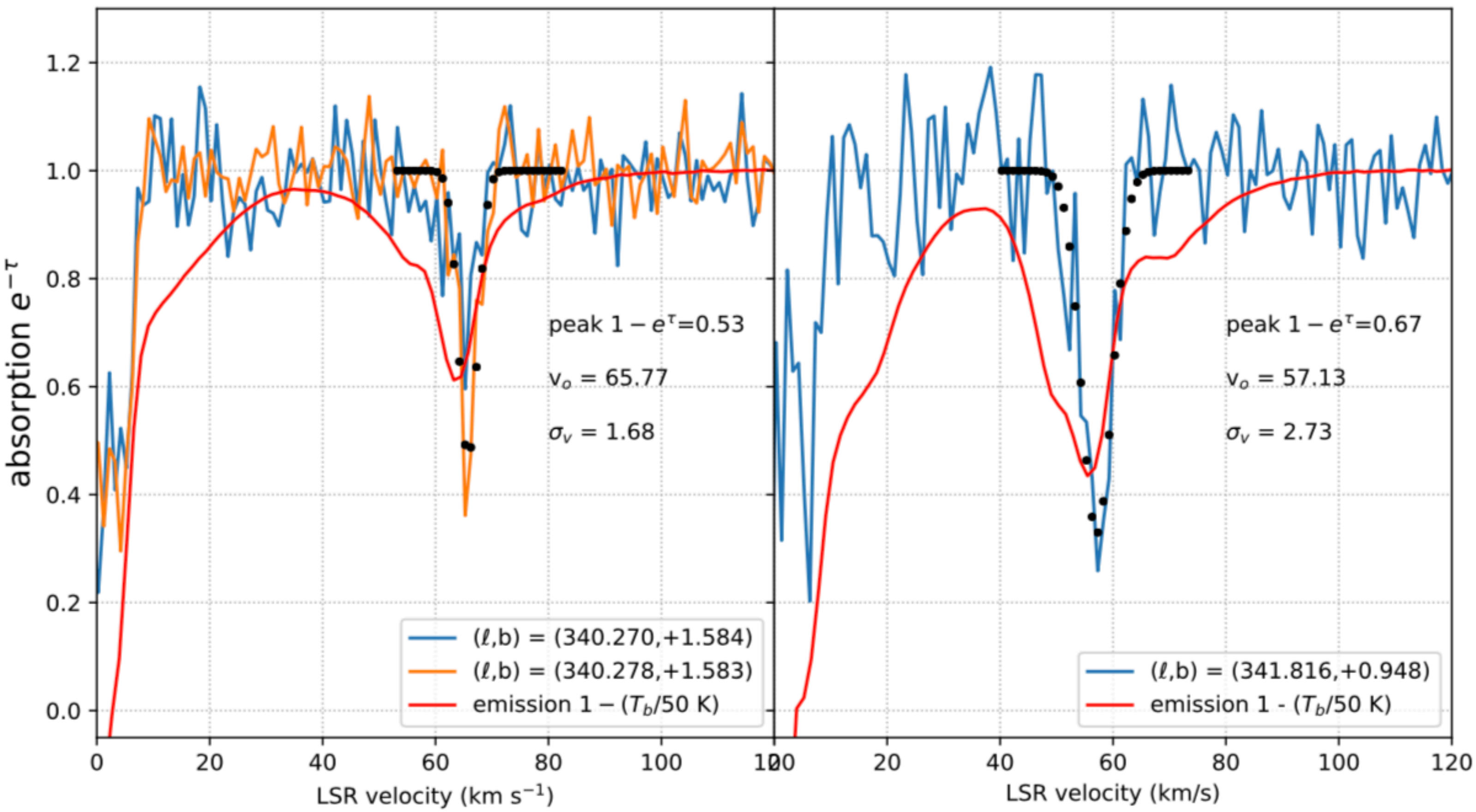
$$\frac{V_r}{82.1\text{ km s}^{-1}} \;=\; 1 \;-\; \frac{R_\odot}{R}$$

Spectrum Averages



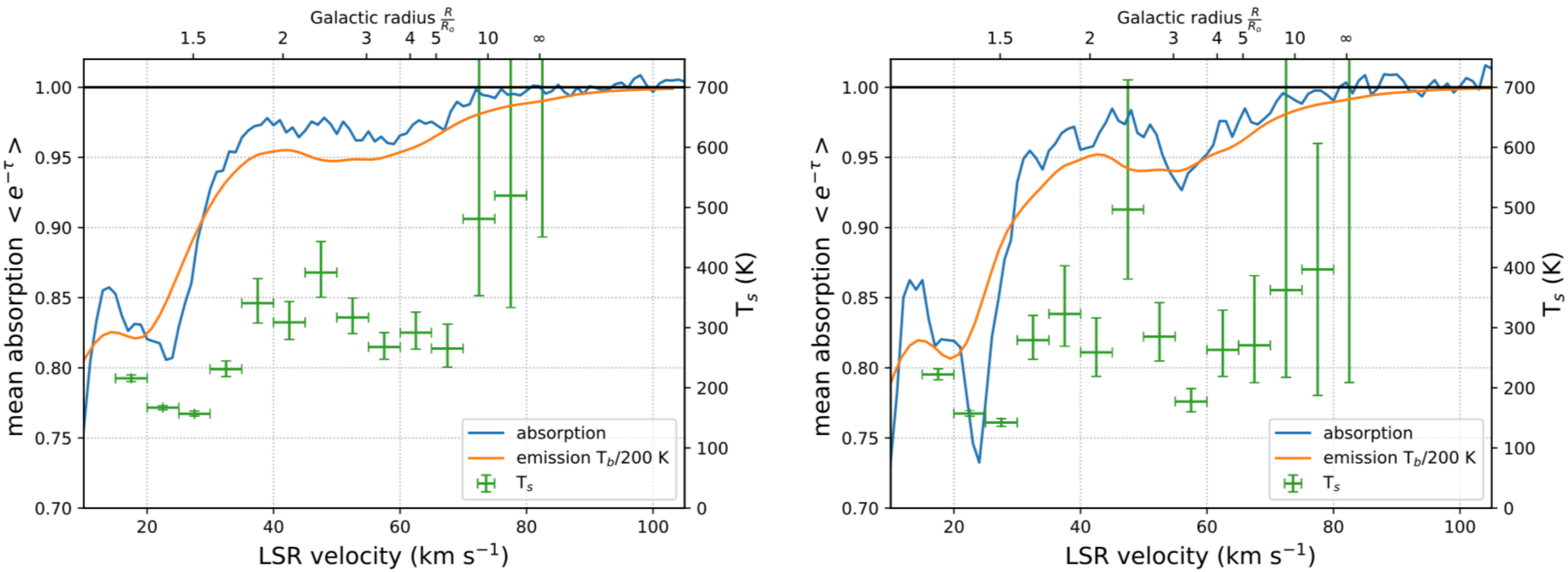
Dickey et al. 2022

Representative Outer Galaxy Absorption



Dickey et al. 2022

Mean Absorption against Extra-galactic Sources



$$T_s = \frac{T_b}{1-e^{-\tau(v)}}$$

T_s is remarkably constant out to ~ 40 kpc

Dickey et al. 2022

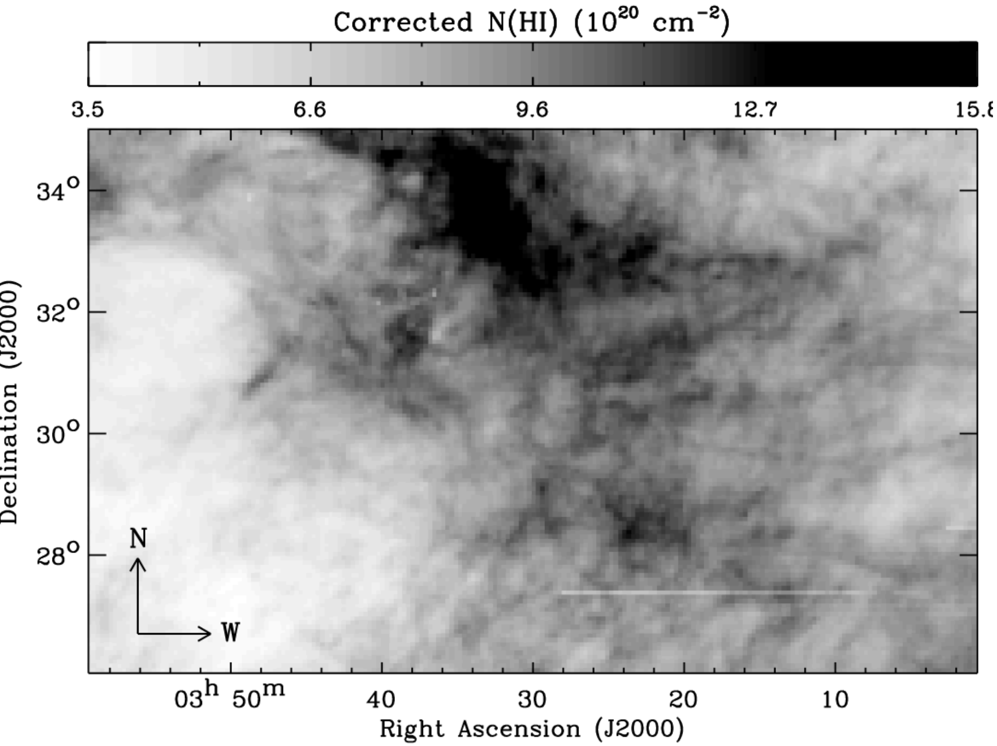
WNM and CNM phases at the edge of the circumgalactic medium

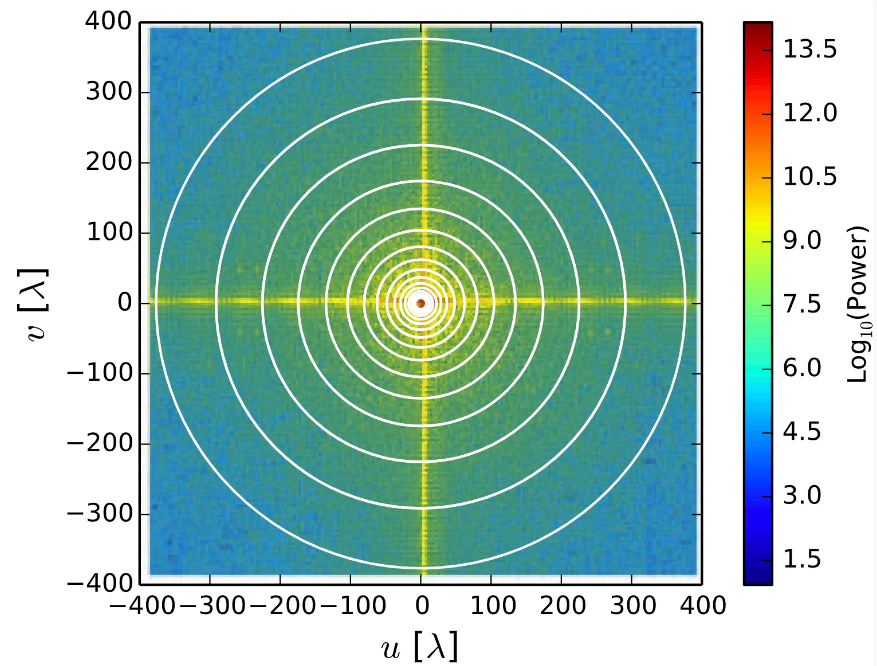
Conditions:

- Clouds have $N_H \sim 10^{20}$ cm^{-3}, $f_{CNM} \sim 0.3$ if $T_{CNM} \sim 100$ K
- gas phase O abundance 0.05 x solar circle (Wenger+ 2019)
- Simulations indicate cold-mode accretion can include both CNM and WNM
  - Banda-Barragan et al. 2020; Nelson et al. 2020; Dutta, Sharma, and Nelson 2021).
- cosmic UV background ionization $\Gamma \sim 6\text{x}10^{-14}$ s^{-1} (Bland-Hawthorn+ 2017)
- radial accretion flow ~2 km s^{-1} at ~ 1 M_o yr^{-1} (Trapp+ 2021)
- HI in the CGM of nearby spirals is observed by GBT
  - See: Pisano 2014; Pingel et al. 2018; Martin et al. 2019; Das et al. 2020; Sardone et al. 2021

Are we seeing Cold Mode Accretion in Action?

Spatial Power Spectrum

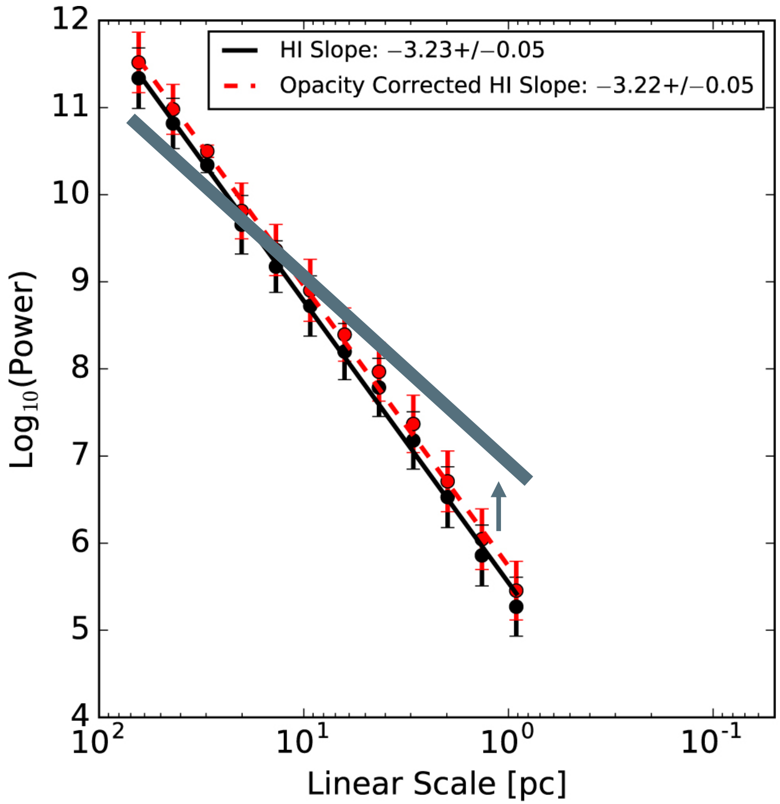




$$P(k) \sim A^{\gamma} \sim \mathcal{F}T[I]\mathcal{F}T[I]^*$$

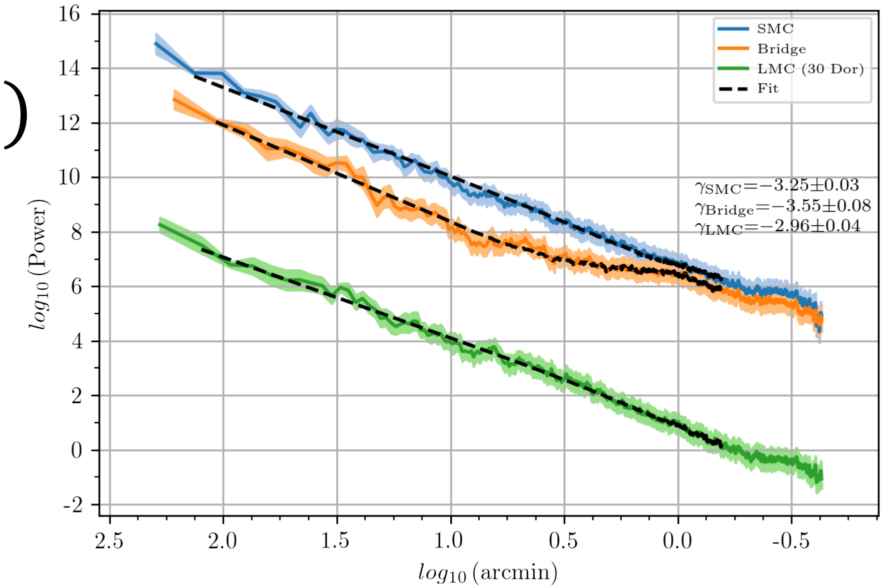
Spatial Power Spectrum

- Provides properties of turbulence
  - Injection and dissipation scale
  - Inertial range
- Slope characterizes turbulent properties
  - Steep
    - Subsonic at small scales and energy injection at larger scales
  - Shallow
    - Supersonic on small scales

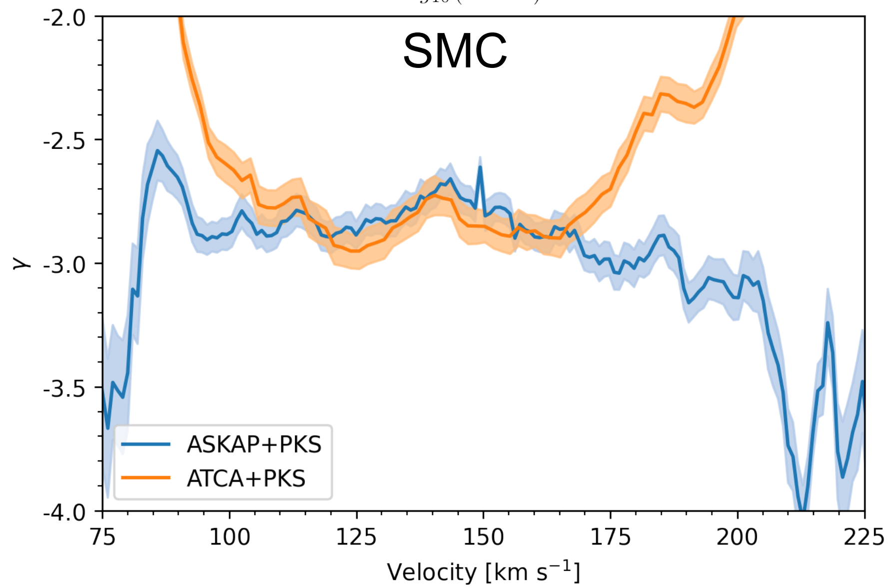


Pingel et al. 2018

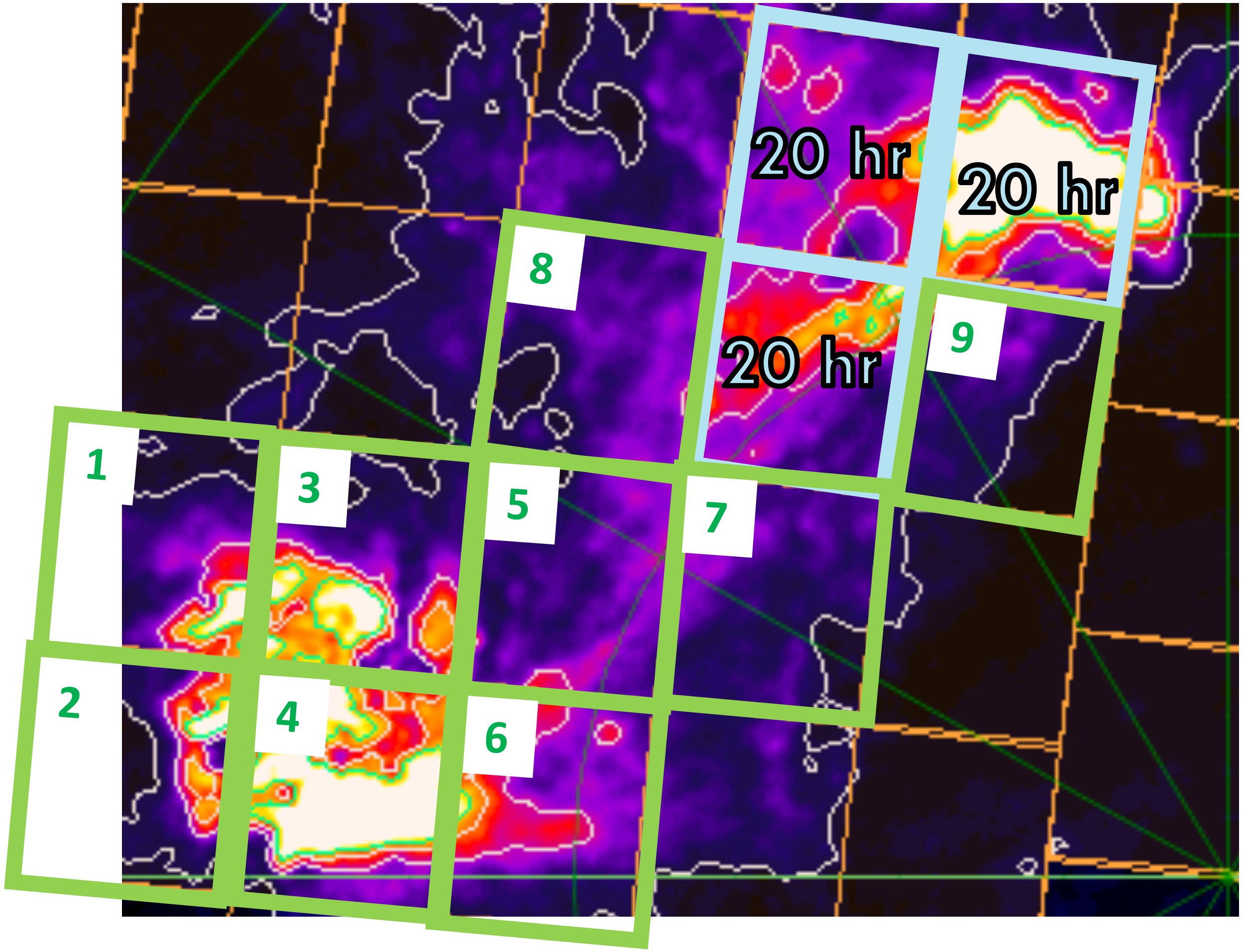
$$P(k) = B(k)A^{-\gamma} + QP_{noise}(k)$$



- Top: Spatial Power Spectrum (SPS) fit to column density images of SMC, Bridge, and LMC
  - Model accounts for beam/noise
  - Each gives distinct slope values, indicating sensitivity to environment (e.g., star formation, large-scale energy injection)
- Bottom: SPS fit to individual spectral channels (SMC)
  - ASKAP/ATCA in excellent agreement
  - Sensitivity of GASKAP data facilitates better characterization of turbulent properties across full spectral range
- power-law nature of ISM extends down to ~10 pc
- Power-law indices in single channels are comparable to dust measurements



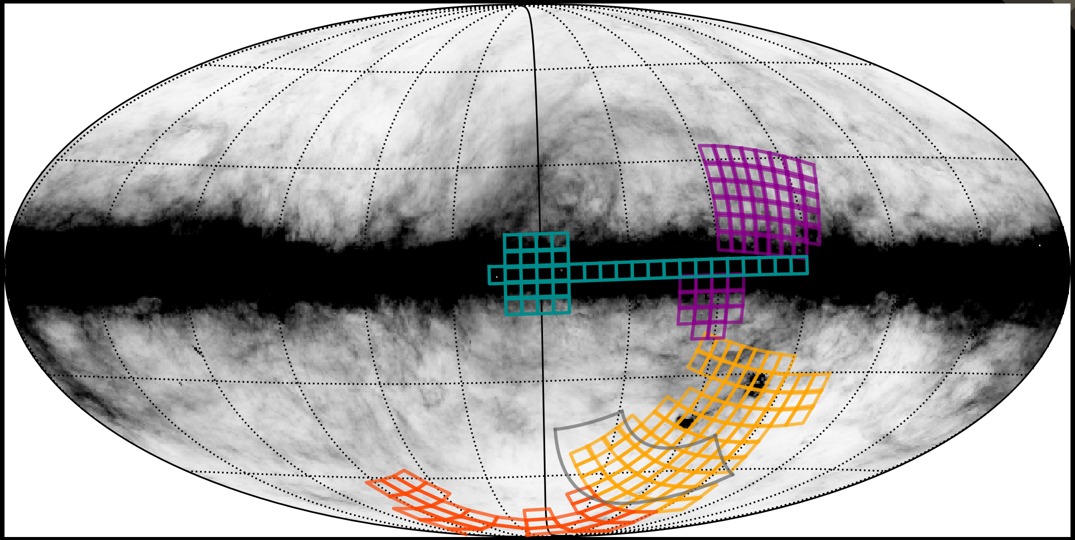
GASKAP-HI Pilot Survey Phase II



+ Test commensality with WALLABY in the Galactic Plane toward Vela

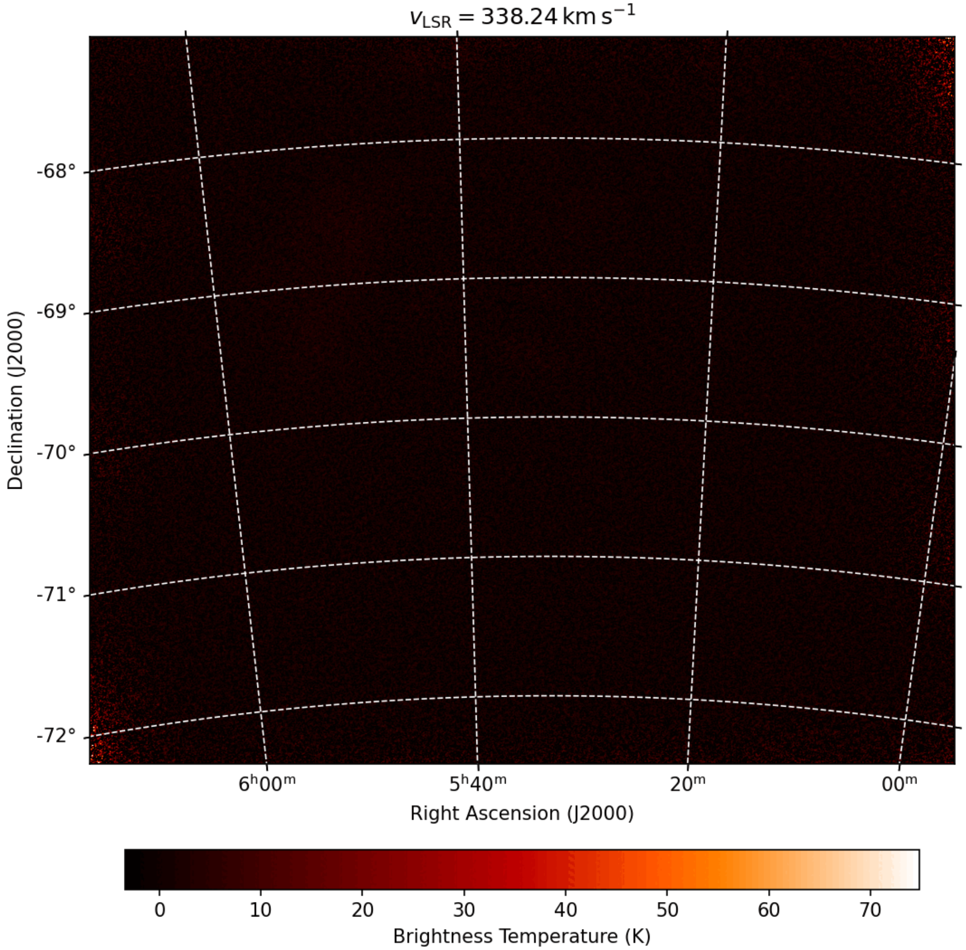
Summary and Future

- Custom pipeline allows us to utilize joint deconvolution
- For the first time, we can study HI on similar physical scales as dust and molecular gas
- Study of emission and absorption in conjunction gives us the complete picture of the multiphase ISM
- *GASKAP will be the next standard for HI (and OH) observations of the Magellanic System and Galaxy for the coming decade*



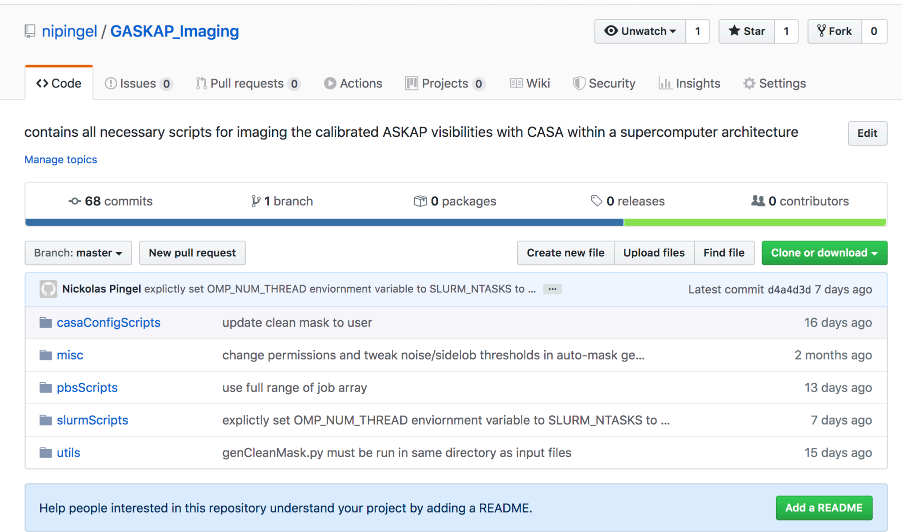
Name	Science Sections	Area (fields)	Time/Field (hours)	Total Time (hours)
Magellanic Clouds + foreground	§3.1.2, 3.1.1, 3.1.3, 3.1.4, 3.3	6	200	1200
Galactic Plane ($270° \leq \ell \leq 17°$)	§3.1.1, 3.1.3, 3.1.4	20	50	1000
Magellanic Stream I + foreground	§3.2, 3.1.4, 3.1.1, 8	84	30	2520
Galactic Centre	§3.3, 3.1.1	16	50	800
Magellanic Leading Arm + foreground	§3.2, 3.1.1, 3.1.4	61	12	732
Magellanic Stream II + foreground	§3.2, 3.1.3, 3.1.4	49	12	588

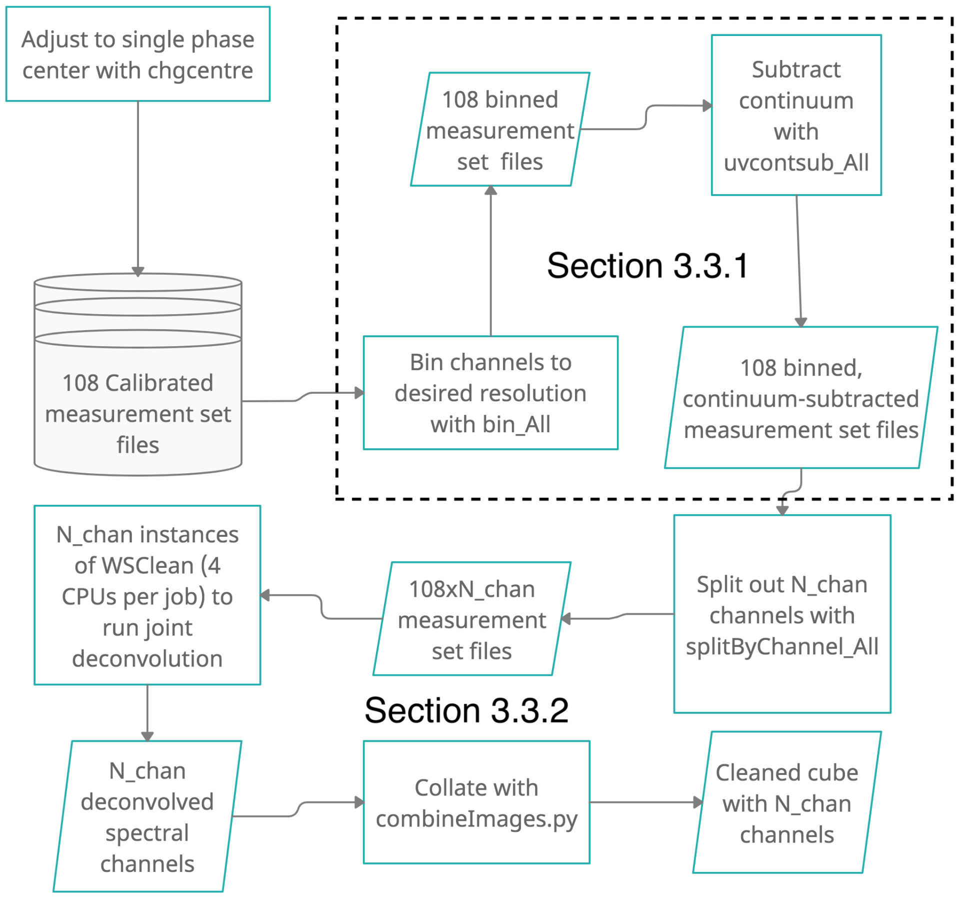
LMC Quality Gate Field



GASKAP WSClean Imaging Pipeline

- SLURM and PBS control scripts available to feed CASA and WSClean scripts
- Only pipeline that can run joint deconvolution in distributed manner
- Typical imaging job (single channel)
  - 5 CPUS (4 workers & 1 control)
  - 20000 iterations with ~10 major cycles
  - ~6-15 hours of processing





https://github.com/nipingel/GASKAP_Imaging

https://gitlab.com/aroffringa/wsclean