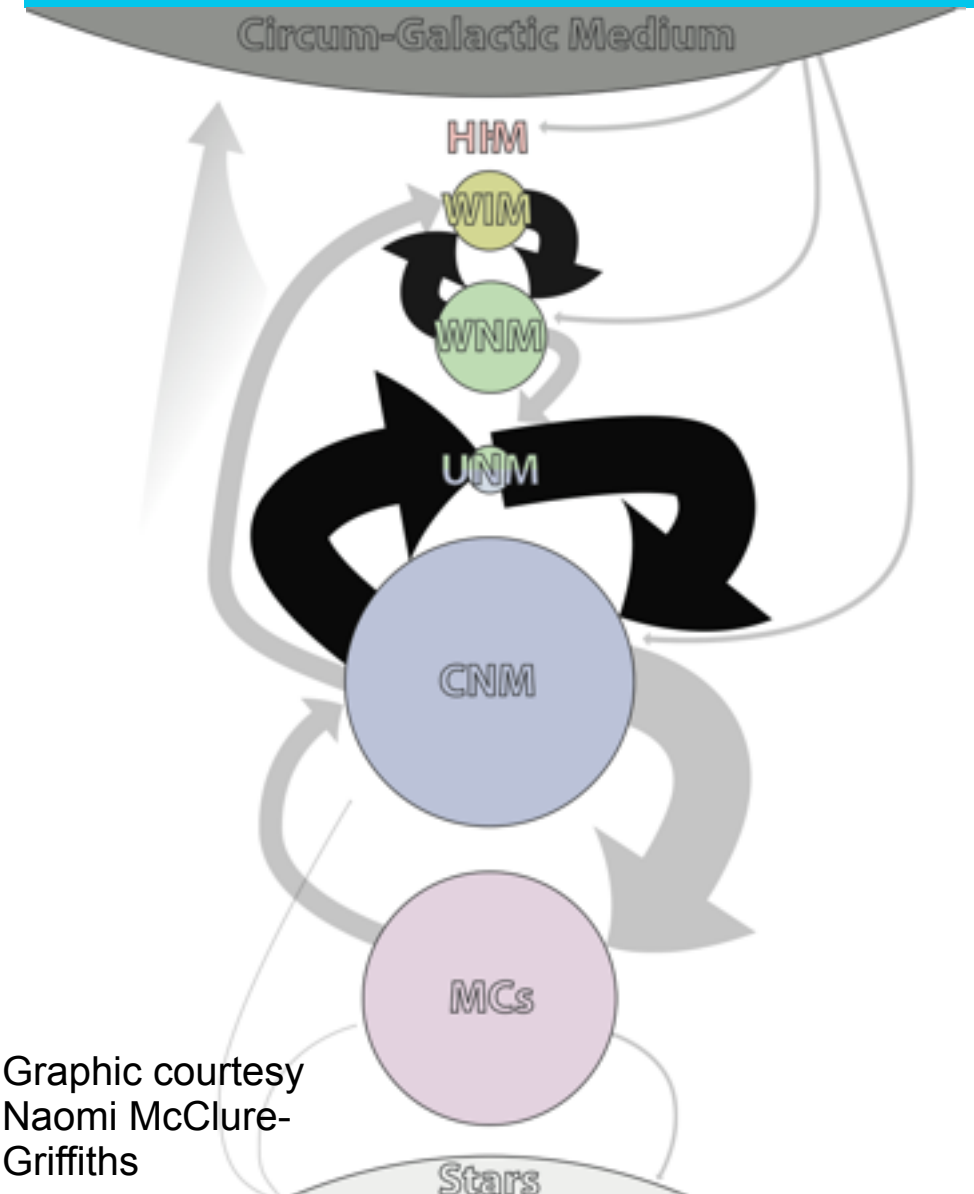
University of Hertfordshire

Milky Way SKA: the ISM, star formation and stellar evolution with the SKA

Mark Thompson, Grazia Umana, and the Our Galaxy SWG

Uncovering the ecology of baryons



Graphic courtesy Naomi McClure-Griffiths

How do galaxies work?

What is the flow of material from & to the Circum-Galactic Medium, the Interstellar Medium and stars?

What powers the ionisation of the Warm Ionised Medium?

How do molecular clouds form?

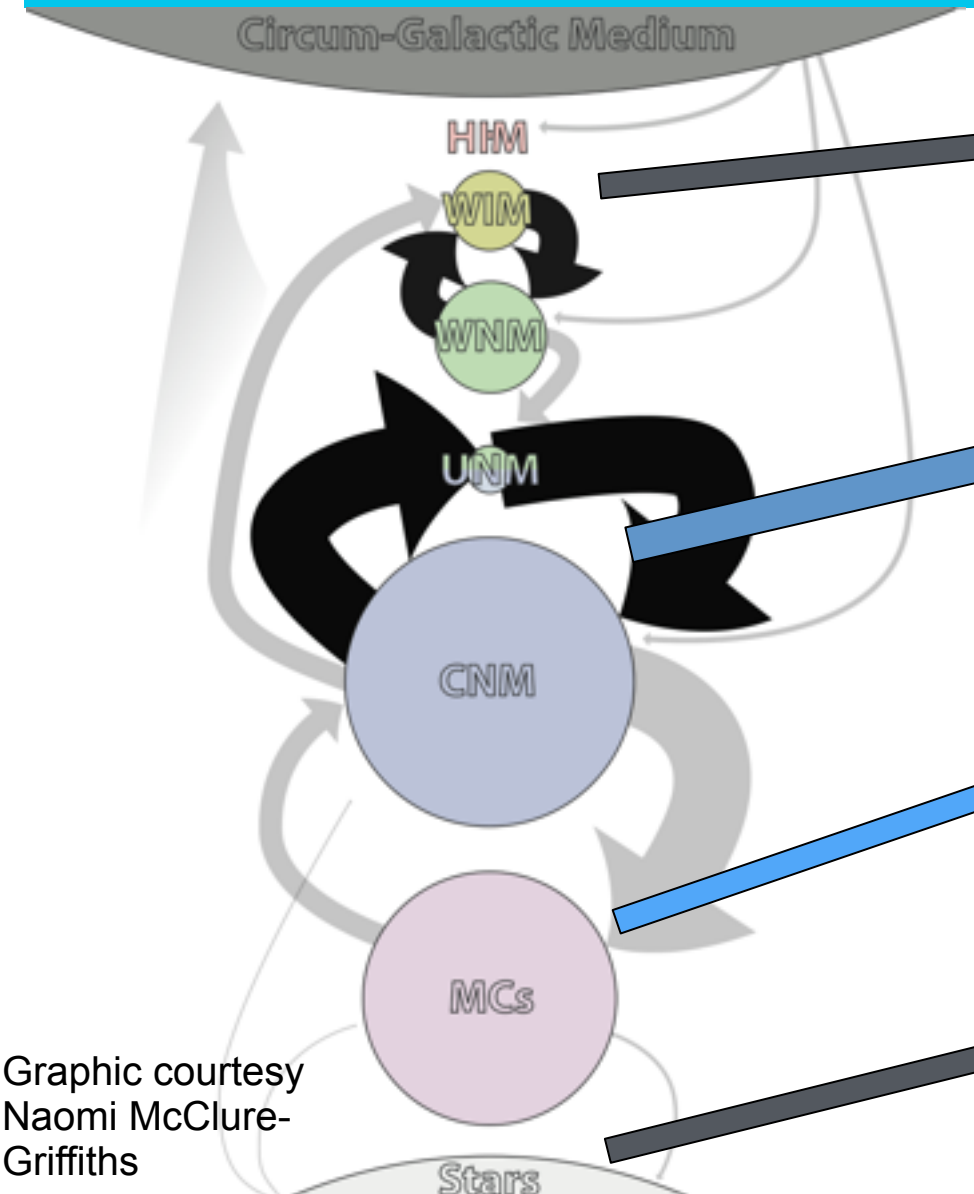
What is the relation between molecular clouds and star formation “laws”?

How do stars drive turbulence & energy into the ISM?

What can the structure of stellar clusters tell us about star formation?

What is the SNR/PNe formation rate in the Milky Way?

The SKA puts it all together



Thermal continuum from HII regions
Radio Recombination Lines

HI emission
HI absorption
HI tomography
Carbon Recombination Lines

H_2CO absorption
Thermal OH - CO dark gas

Thermal continuum from jets & winds
VLBI Tomography of young clusters
Stellar Radio HR diagram

Graphic courtesy Naomi McClure-Griffiths

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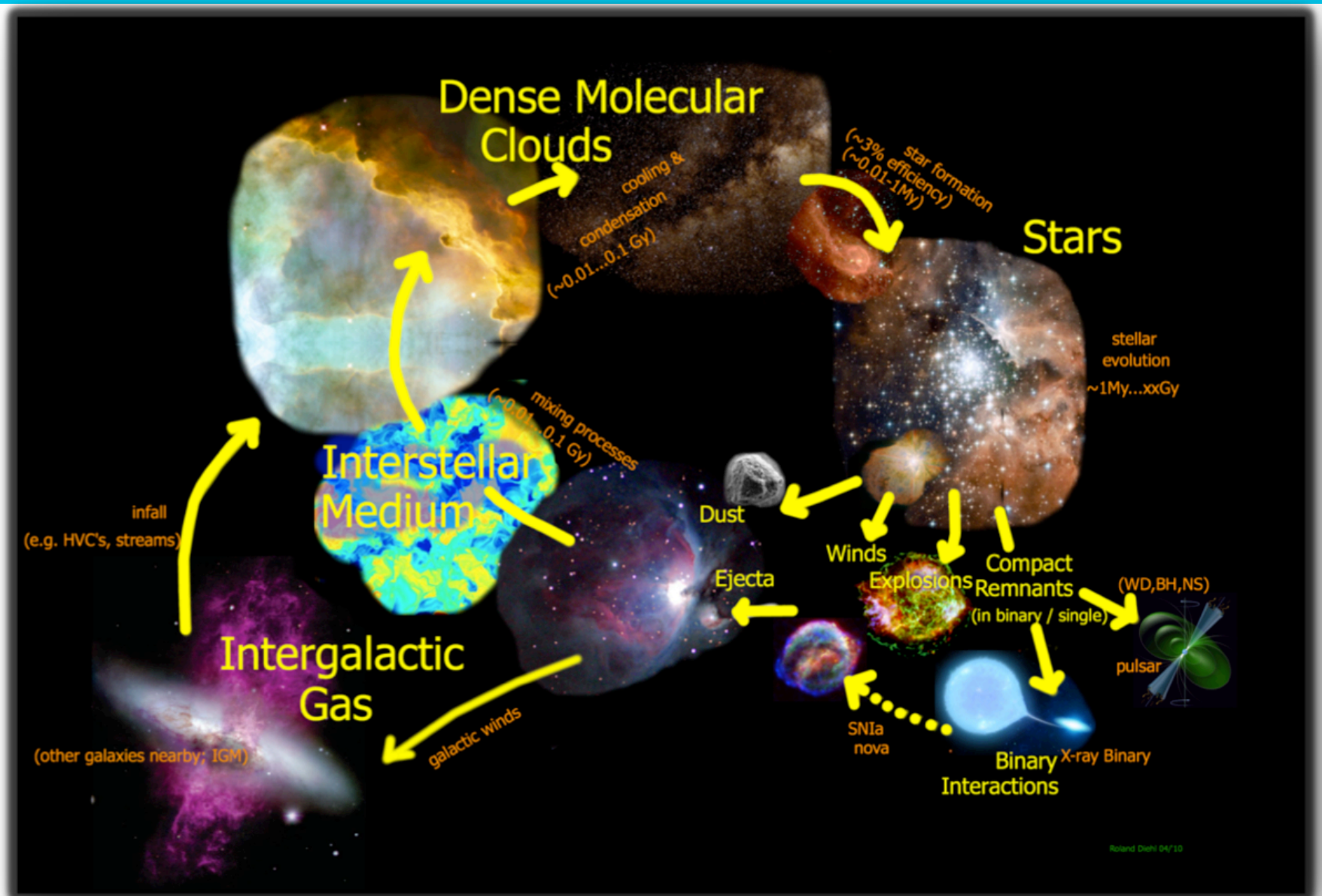
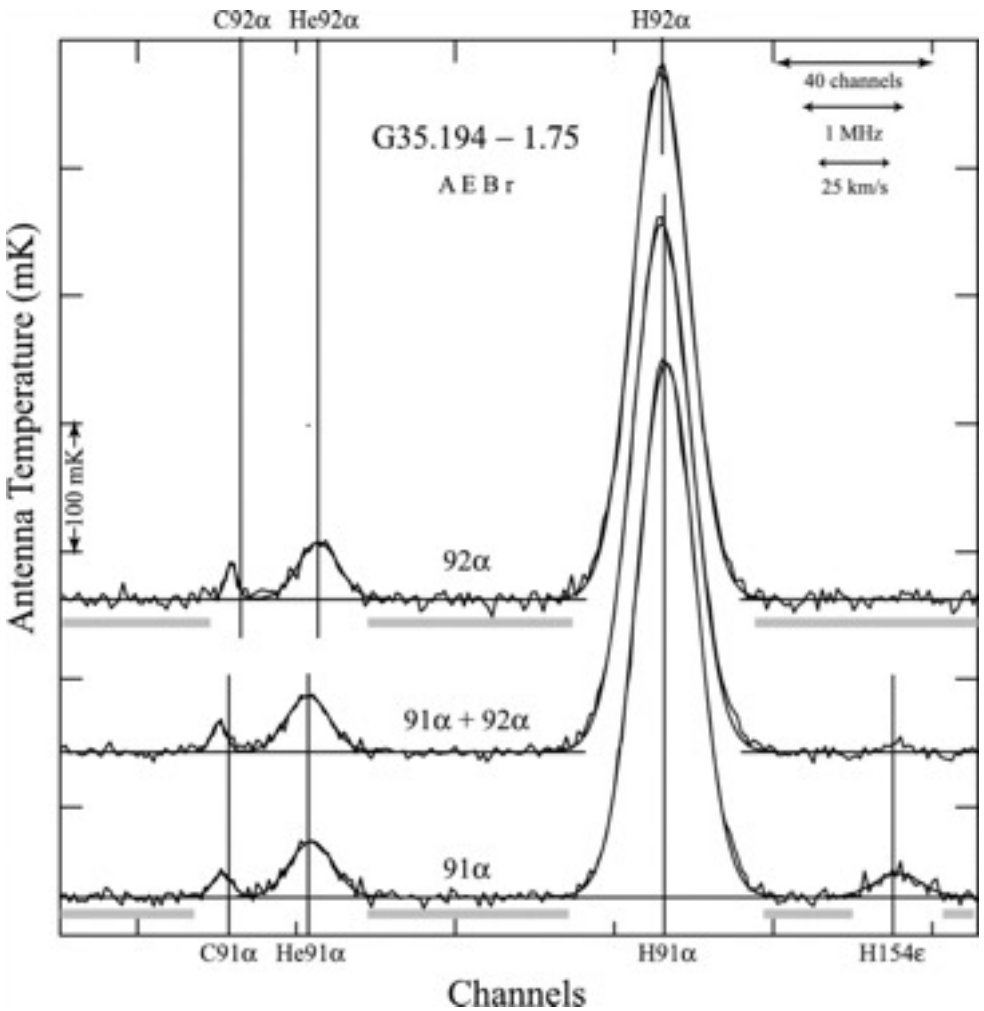


The ionised medium with RRLs



SKA will be a recombination line mapping machine:

Can simultaneously map 50 Hα (+ Heα + Cα RRLs) in Band 2 and 25 in Band 5

Continuum mode fine - but need better than 1 MHz sampling if zooms also used

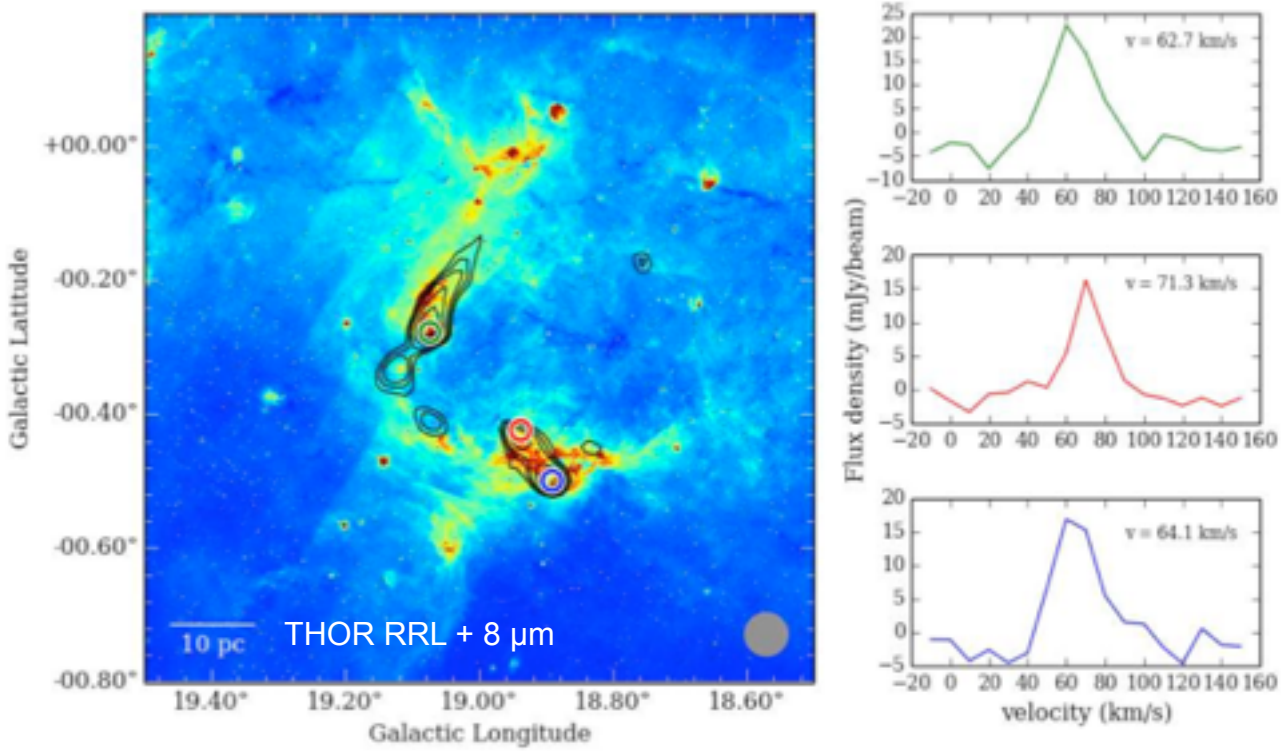
Band 2 **RRL** mapping speed of SKA1-mid comparable to VLA *continuum* mapping speed

SKA-Low unique probe of diffuse ISM via low frequency Carbon lines

Broad frequency coverage traces different electron densities

Multiple lines from multiple atoms allows metallicity, abundance, radiation field to be measured

A Band 2 RRL diffuse ISM survey



THOR detects RRLs toward bright continuum (> 70 mJy)

But in high densities & with pressure broadened lines

For diffuse unbroadened gas need to trace n_e~100 cm^{-3}

Needs ~1 hour/pointing for SKA1-mid w/ line stacking

Fully commensal with HI survey ~300 hours for entire Plane

Out of the box early science towards individual HIIs (~150 hours to map top 12 HIIs)

(THOR - The HI, OH, Recombination Line Survey of the Milky Way, Bihr et al 2015)

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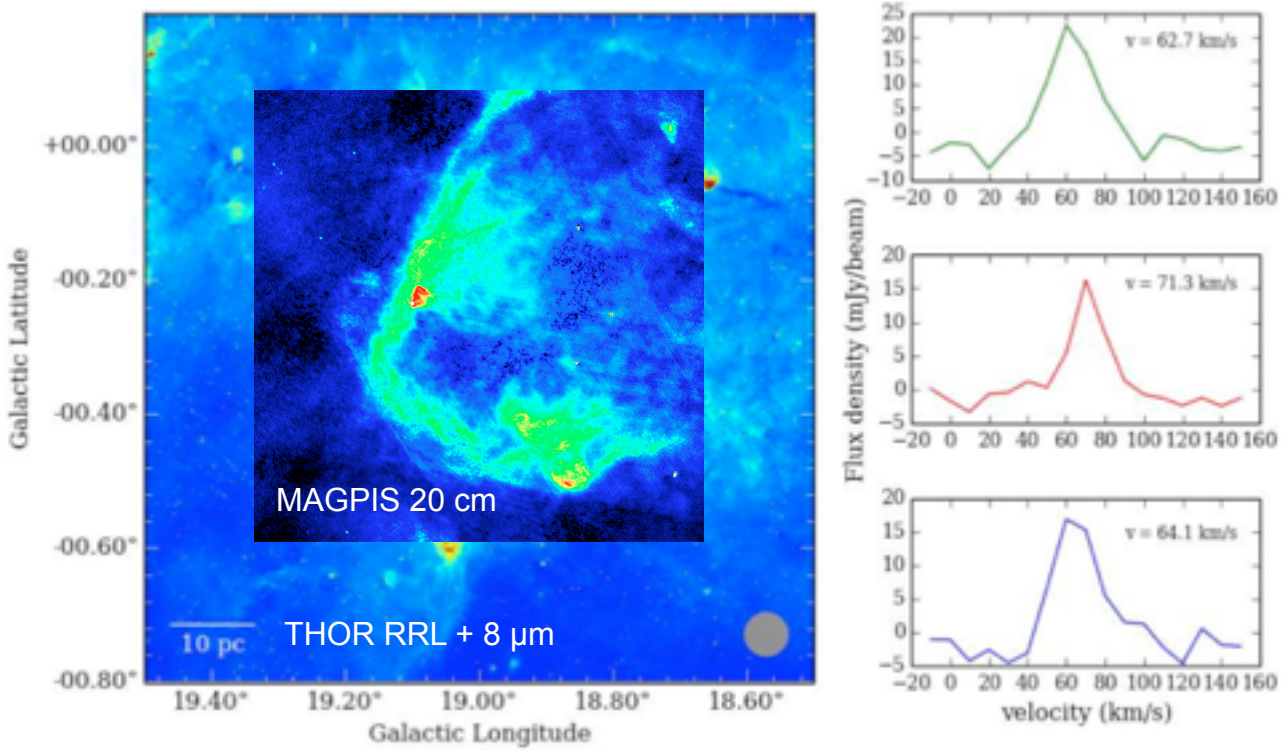

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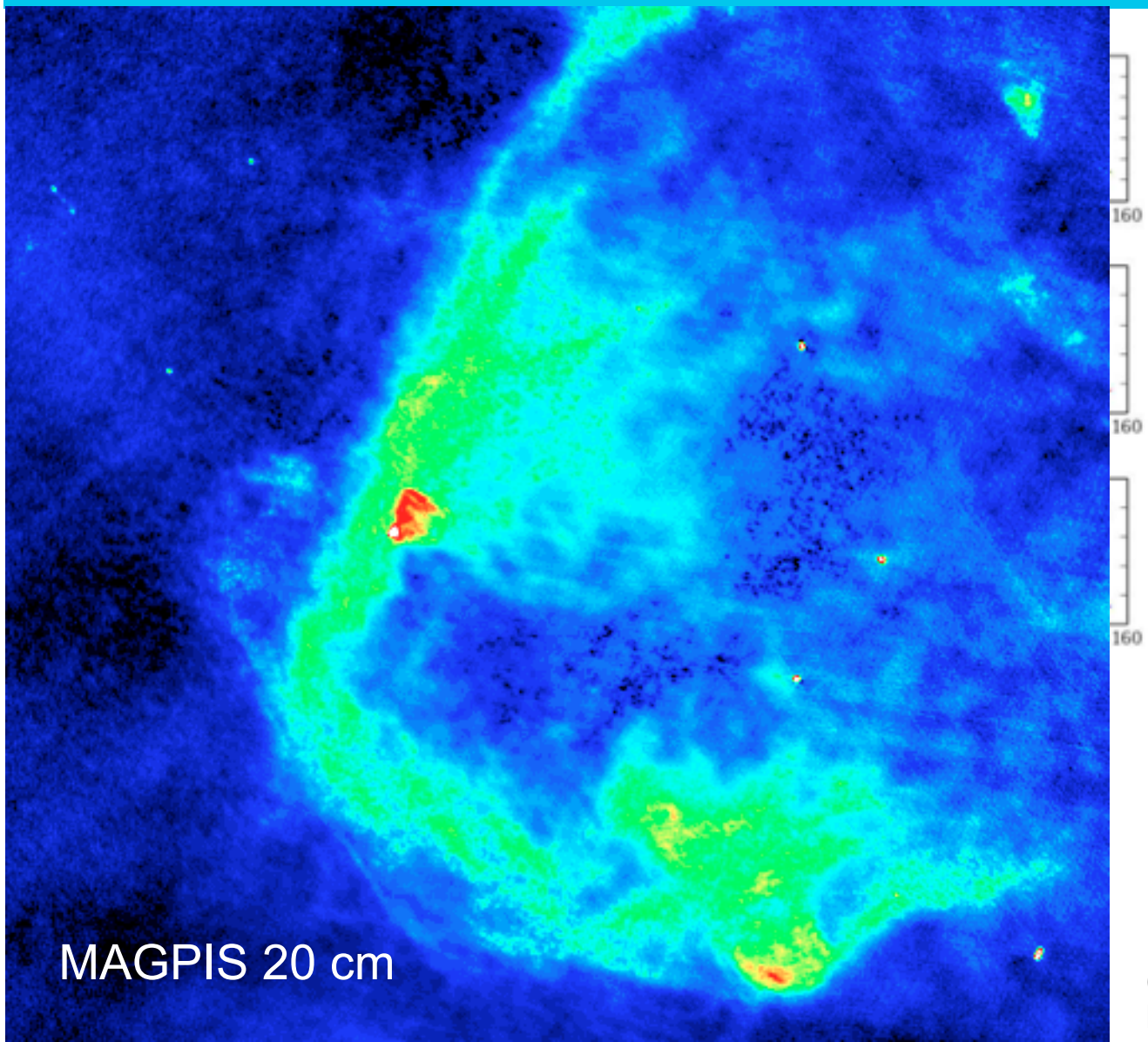

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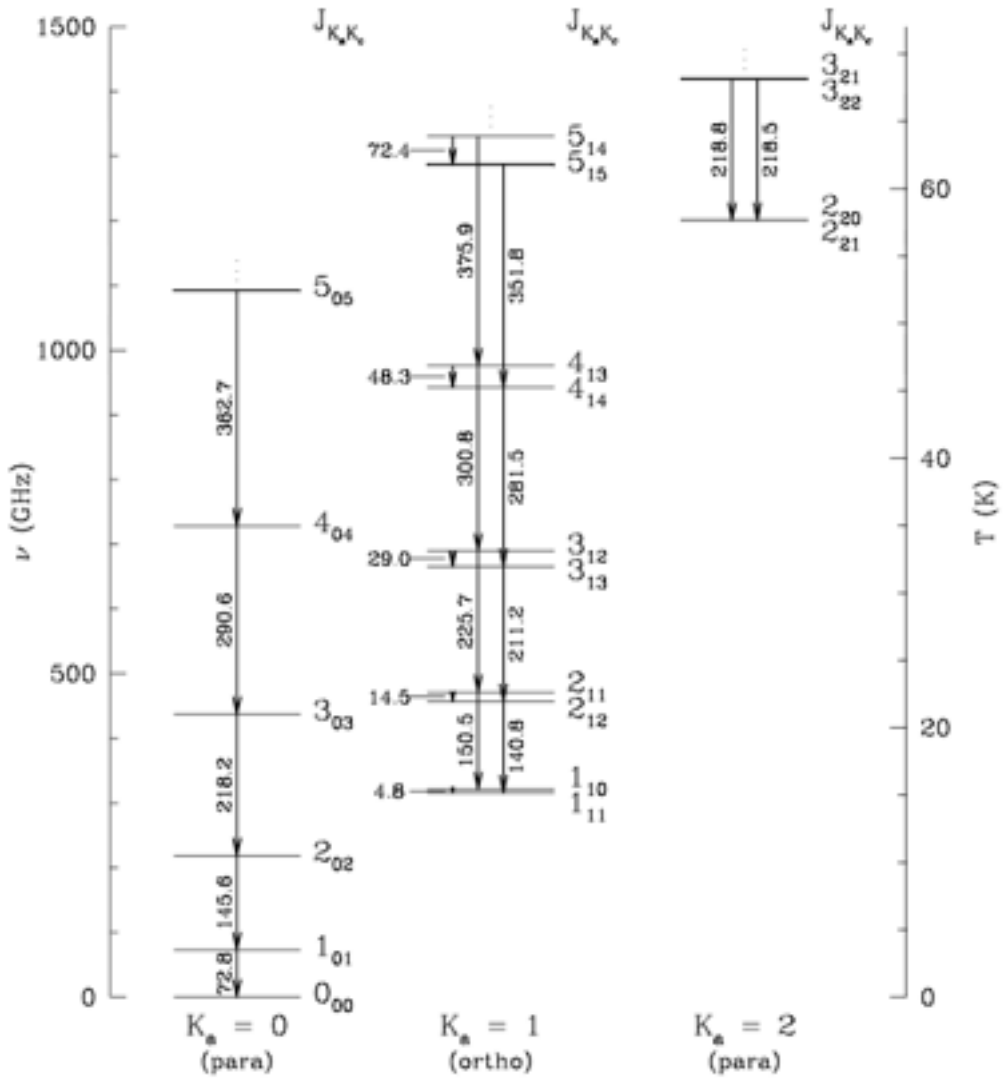
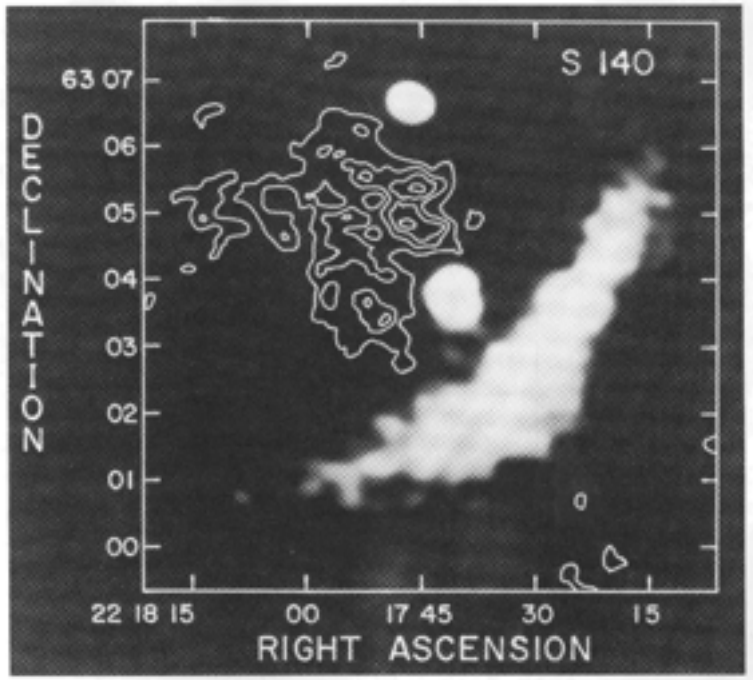
Molecular gas with H_2CO absorption





Evans et al 1987
First VLA detection

Collisional pumping drives population to lower energy states (anti-inversion)

Shows up in absorption against CMB when $T_{ex} < T_{CMB}$

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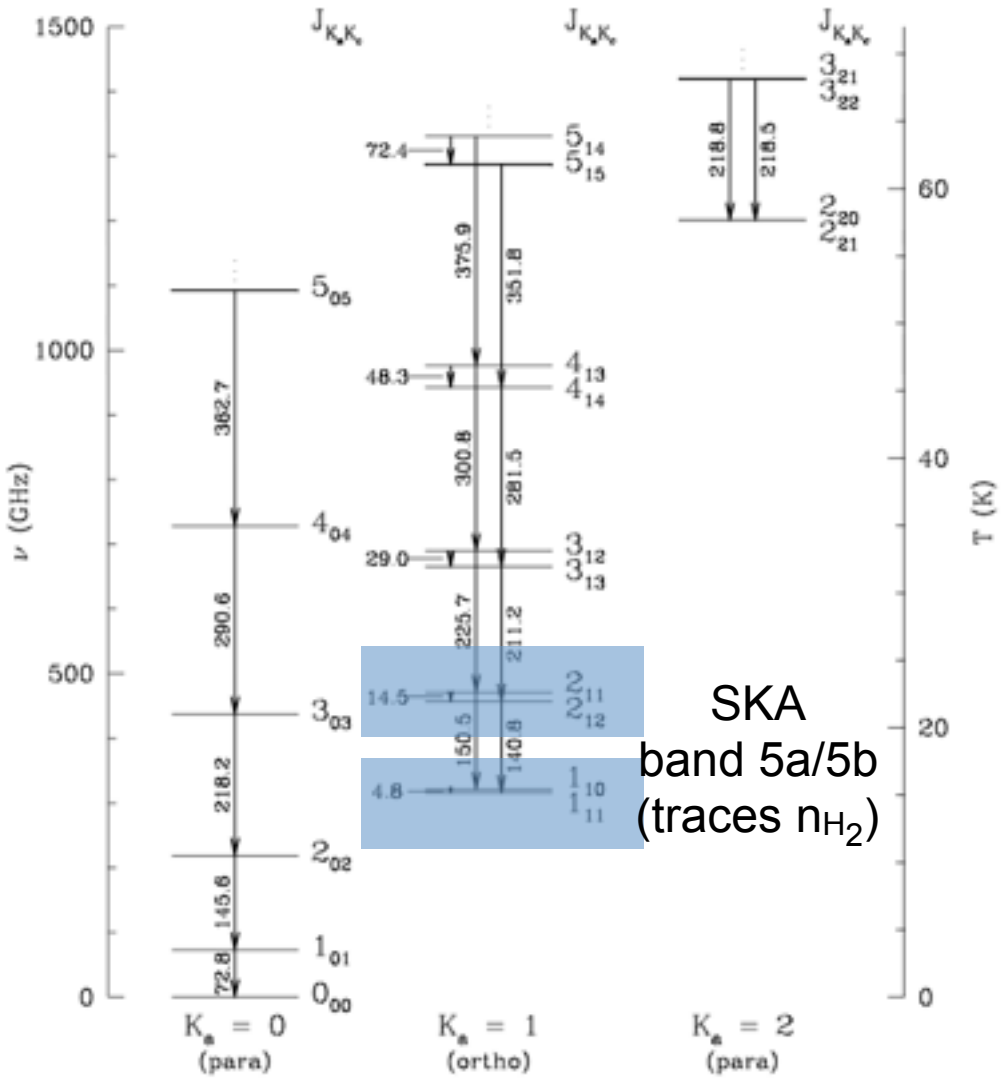
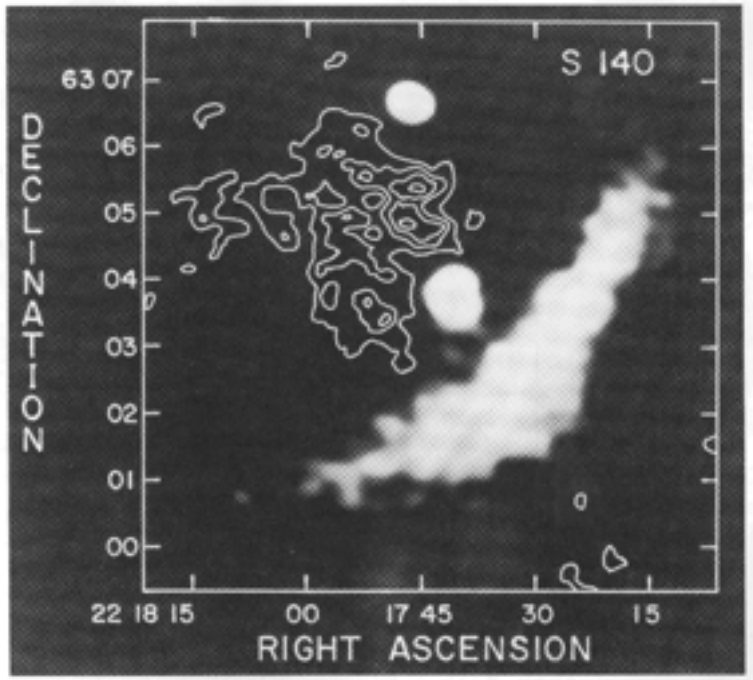


SKA band 5a/5b (traces n_{H_2})



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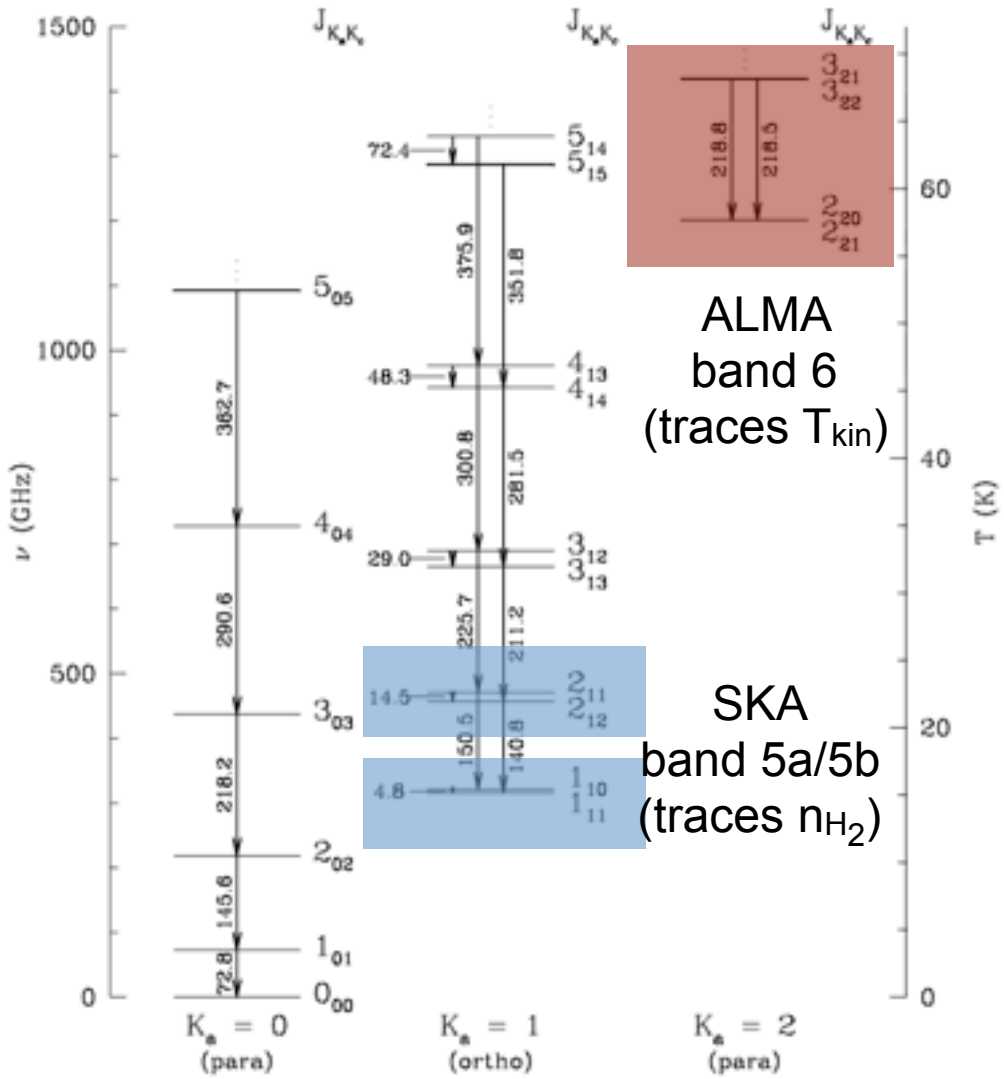

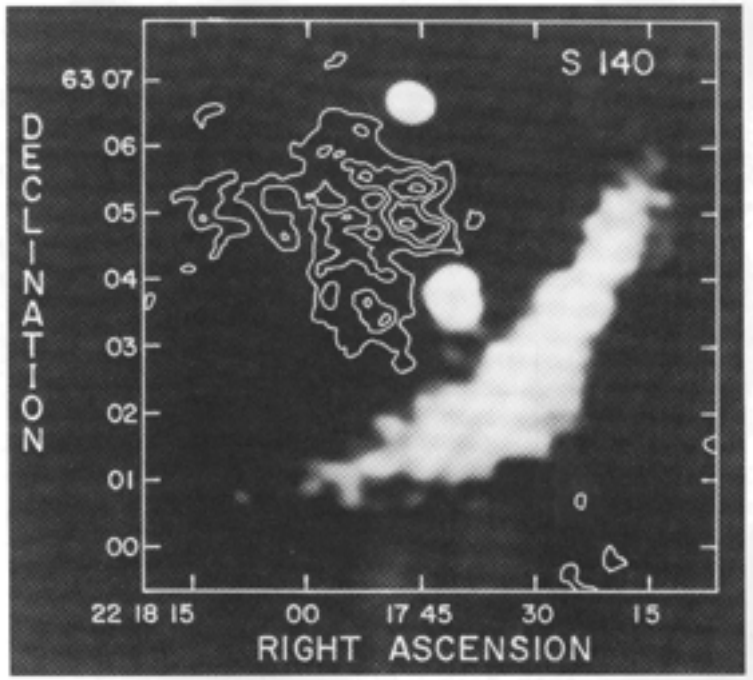

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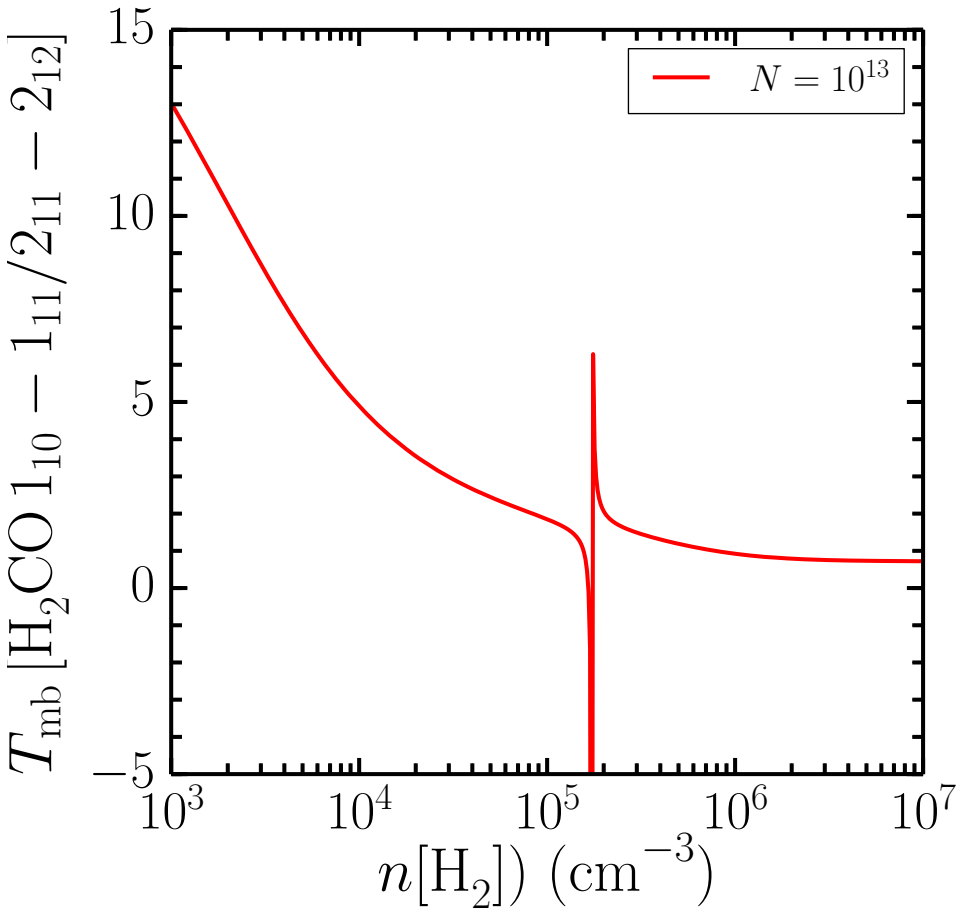
Advantages of anomalous absorption

1. Distance independent tracer
   The Milky Way, nearby galaxies, starbursts... (Mangum et al 2013)

2. Excellent and unique tracer of gas *density*
   Line ratio between 4.8 GHz & 14.4 GHz fixes gas density to ~0.2 dex with good dynamic range: 10^3 - 10^6 cm^{-3}
   (Ginsburg et al 2011)

3. Unaffected by line trapping, sub-thermal excitation or high optical depths
   - unlike CO, where $n(H_2)$ may not be constrained within 2 orders of magnitude

4. Removing the scatter in SF "laws"
   e.g. Krumholz 2014



Discontinuity shows where lines go into emission

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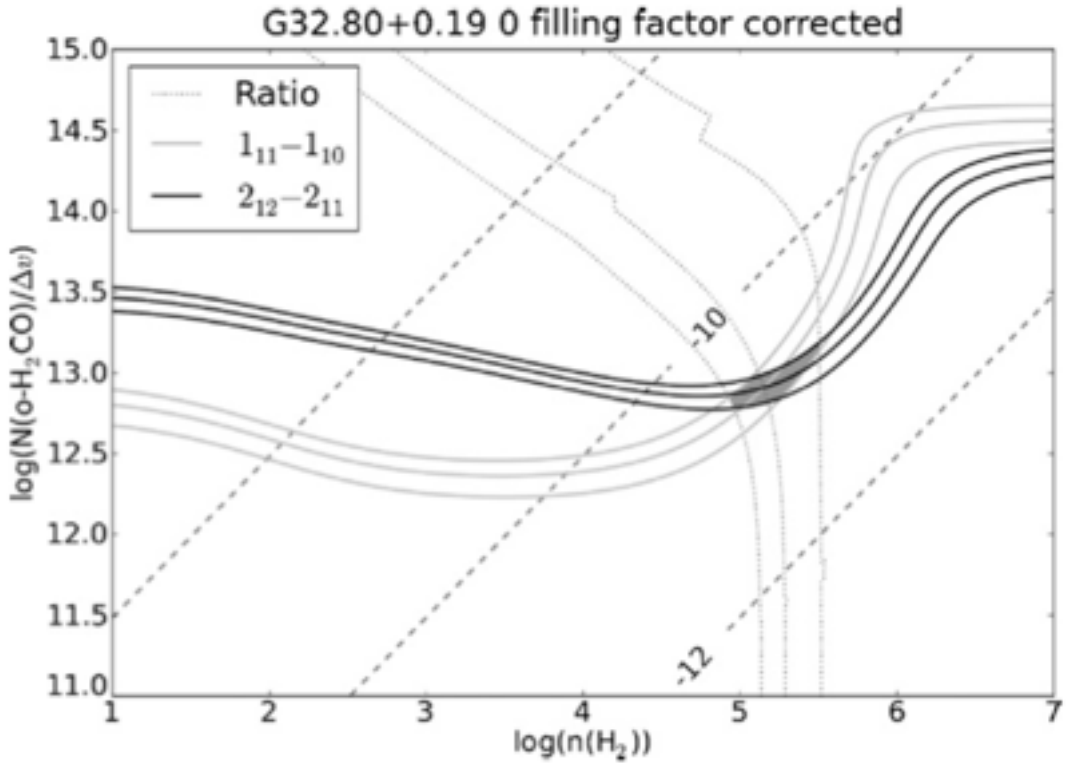

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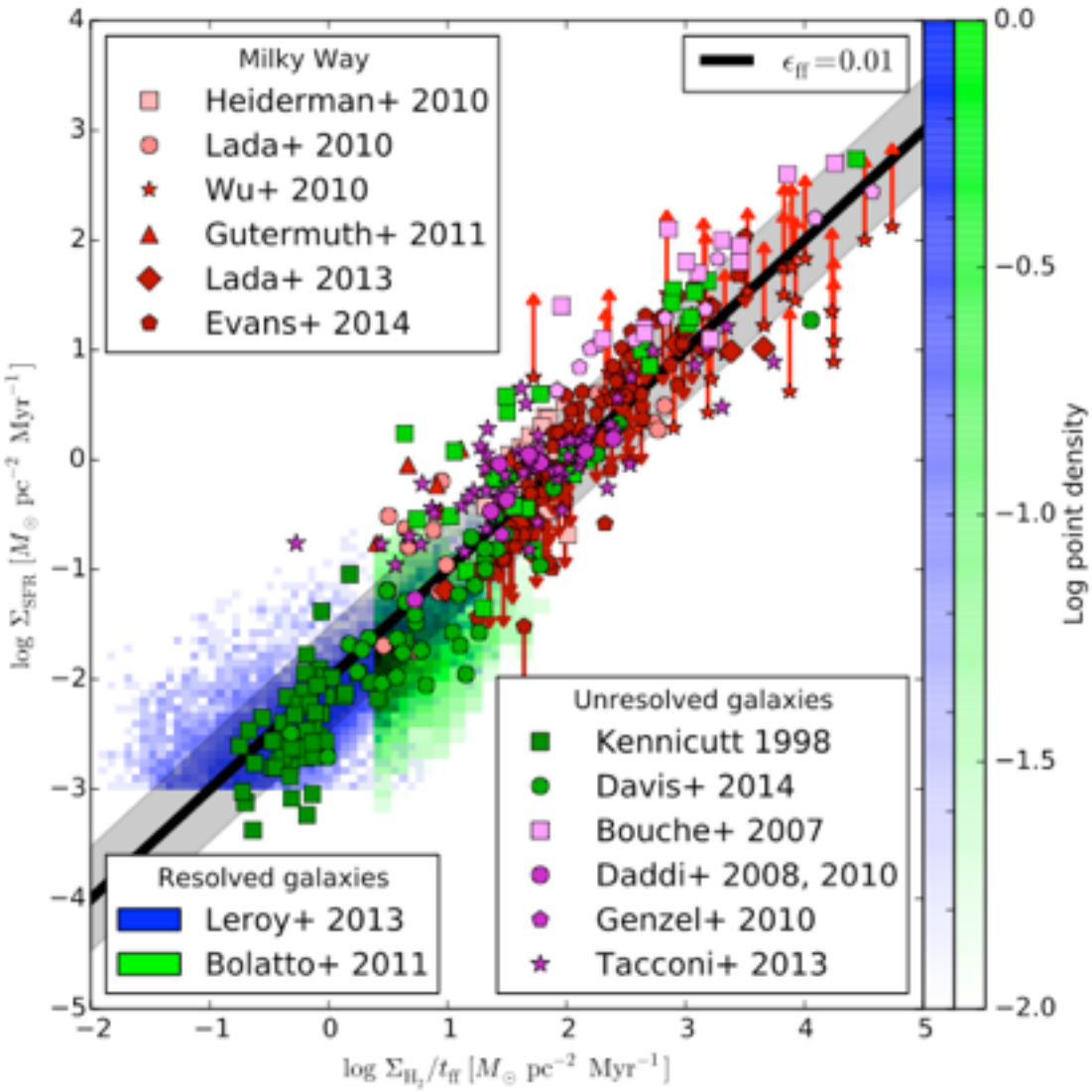


Galactic tomography of the ISM

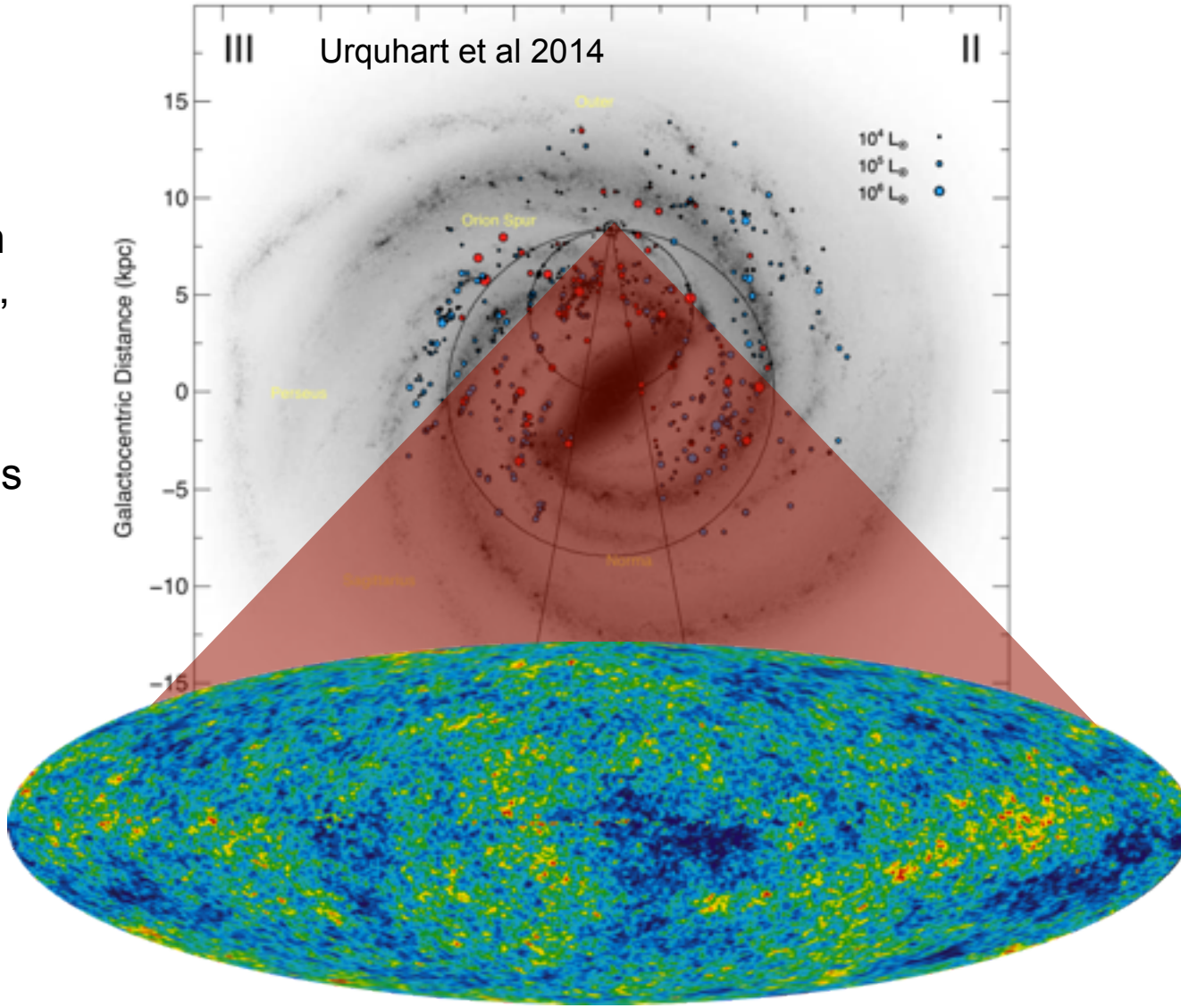
Anomalous absorption against CMB is not the only absorption that will be measured.

Will also be able to measure absorption against continuum sources (HII regions, PNe etc)

All of these HII regions will have velocities (simultaneous RRLs) & ~100's with accurate distances from SKA VLBI parallax (Green AASKA2015)

Network of illuminating sources - constrain absorption to particular distances

Tomography of the molecular ISM



Tomography of stellar clusters

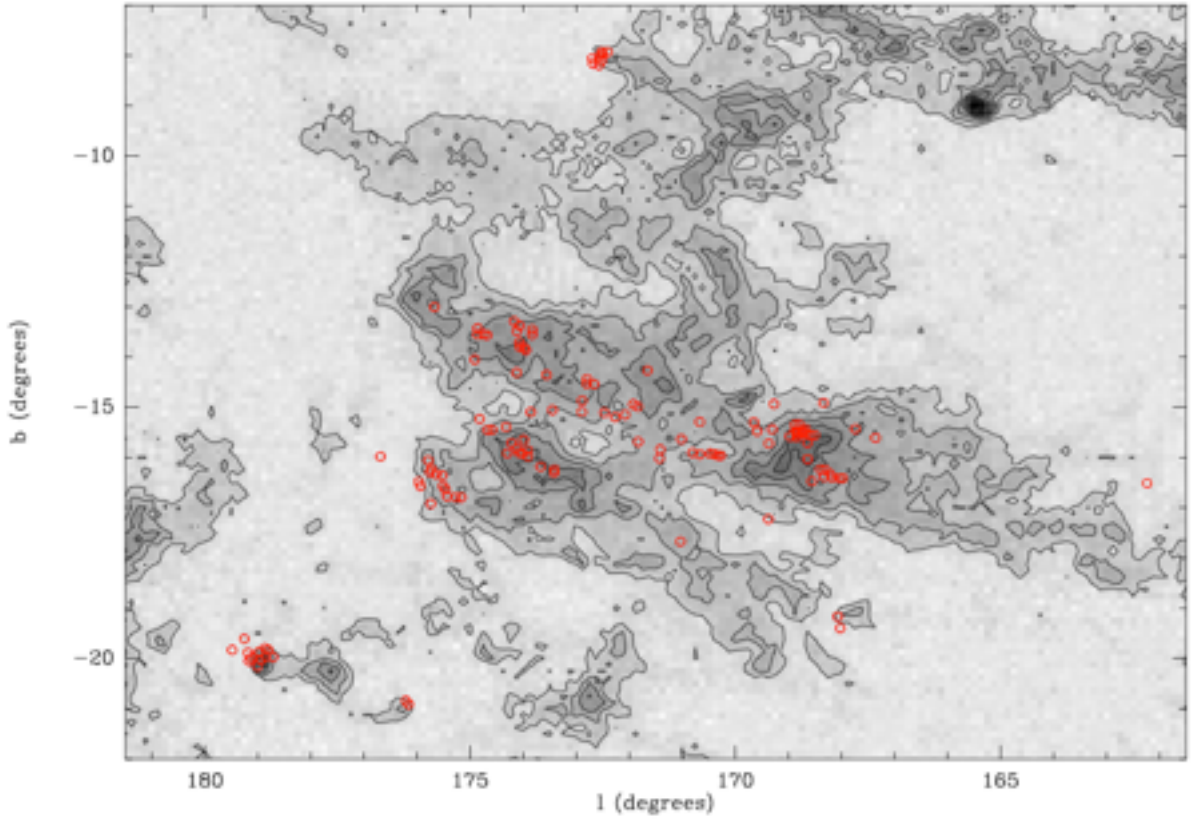
μJy sensitivity allows large numbers of YSOs to be detected via their thermal continuum (e.g. Dzib et al 2015)

SKA could realistically detect all nearby young stars in Band 5

SKA VLBI can measure parallaxes to 1% precision

Determine 3D structure of nearby stellar clusters (SKA1) & spiral arms (with full SKA)

Adding proper motions & kinematic information gives 6D picture of stellar structure and places strong constraints on cluster formation models



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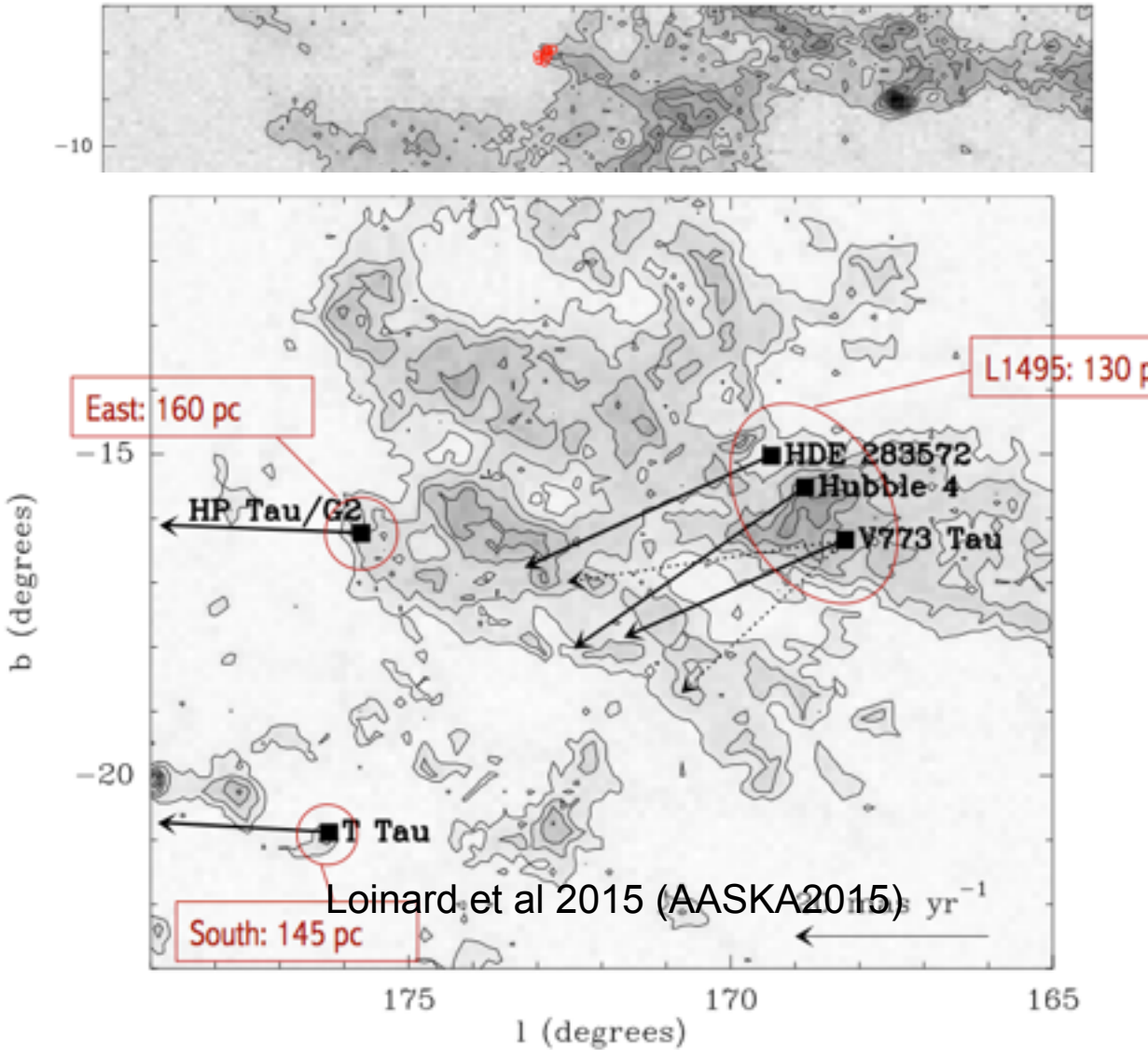
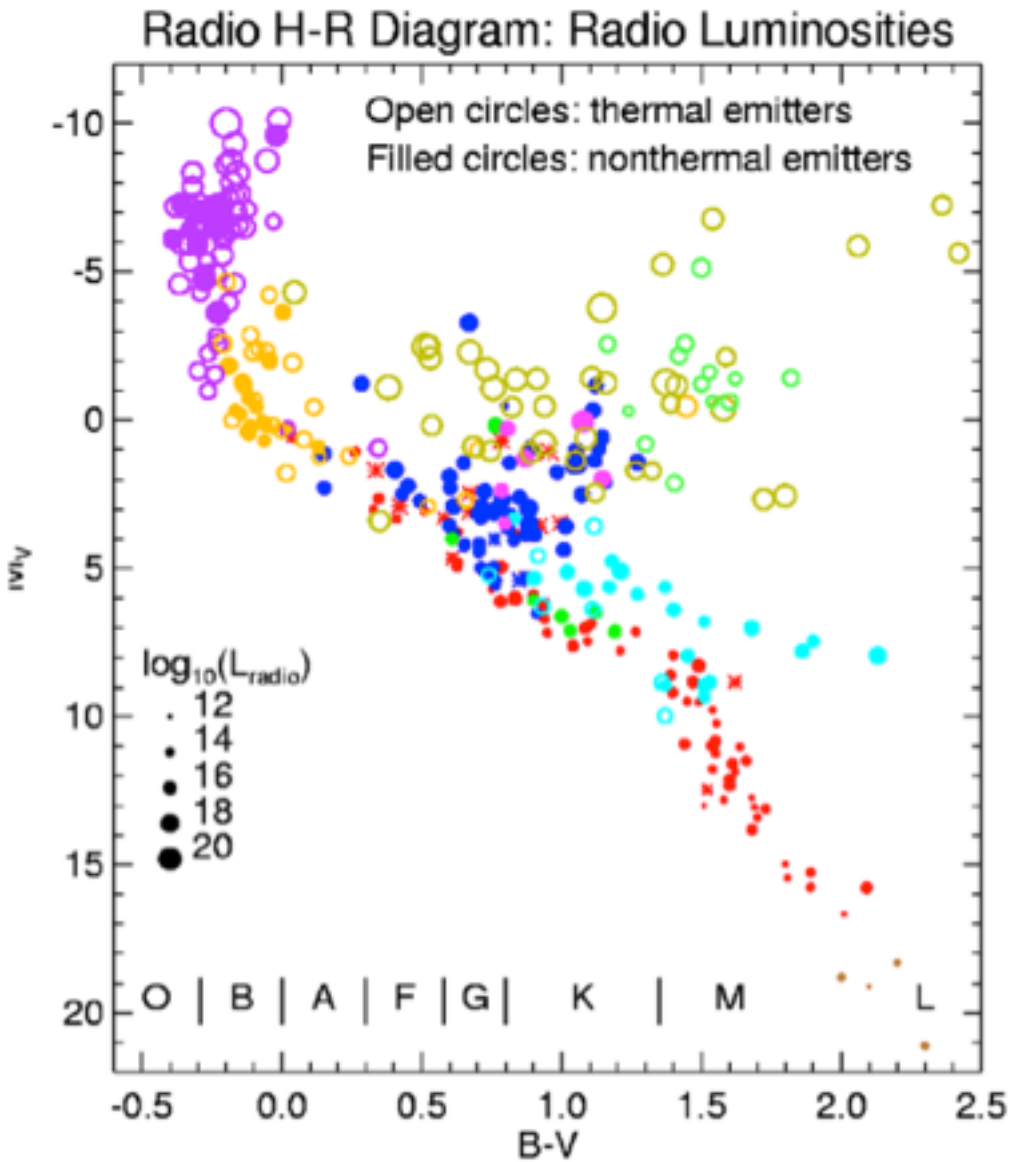


Loinard et al 2015 (AASKA2015)

Radio stars



Currently ~420 radio detected stars (Guedel 2002)

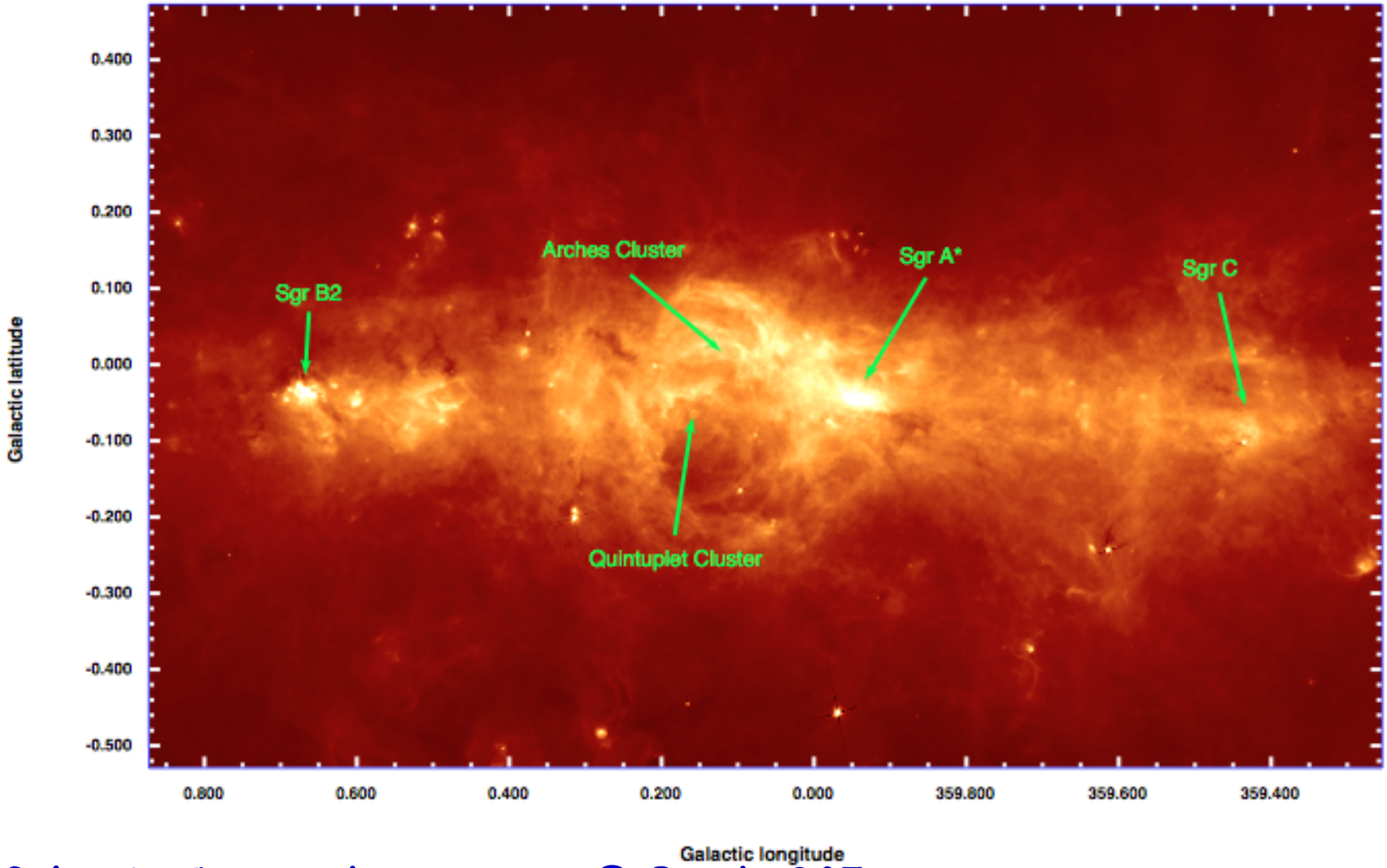
Radio probes astrophysical phenomena not detectable by other means:

B field & topology in flare stars, RS CVn
HII region in dust enshrouded sources
Wind-wind interactions
Stellar magnetospheres
Planetary nebulae shaping by jets?

Current major problems in radio stellar astrophysics are limited sensitivity & selection bias

SKA1 will revolutionise this field by introducing population studies

KSP The Galactic Center –synergy with Magnetism SWG



Galactic Centre deep survey @ Bands 2&5:

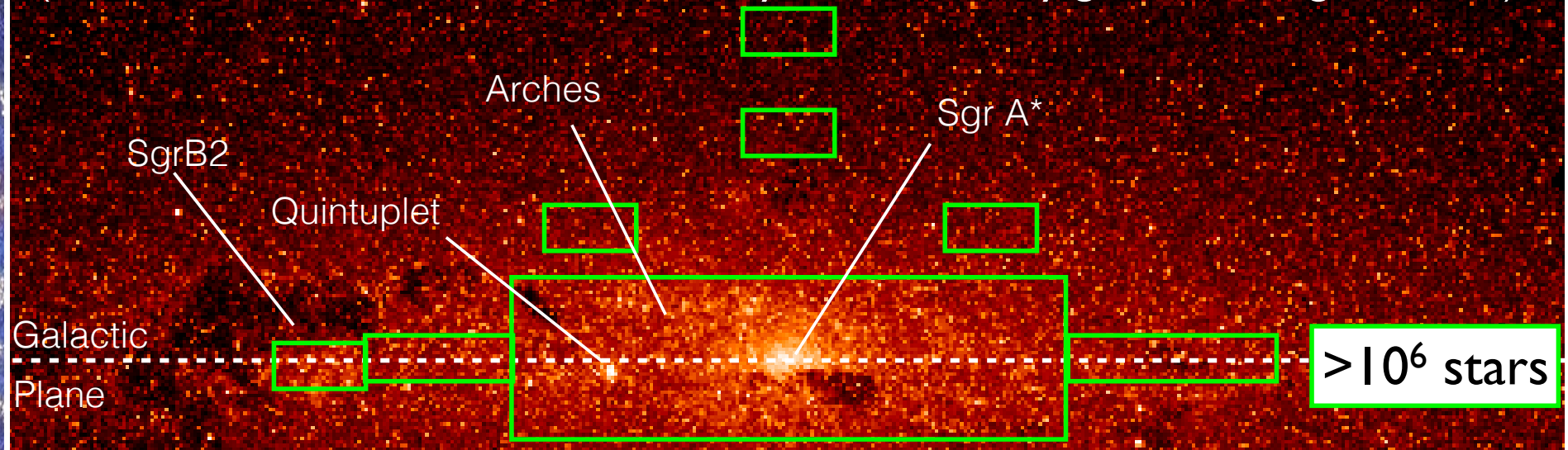
Thermal/non-thermal continuum from Galactic Centre clusters
Recombination lines for kinematics

Possible synergy with **CTA**?

Waiting for SKA….

Schodel and Alberdi

GALACTICNUCLEUS: High resolution (~0.2") multi band (1-2 μm) imaging study of Galactic Centre (GC); ongoing ESO VLT Large Programme (PI: Schödel, IAA-CSIC, Granada; survey area shown by green rectangles below).



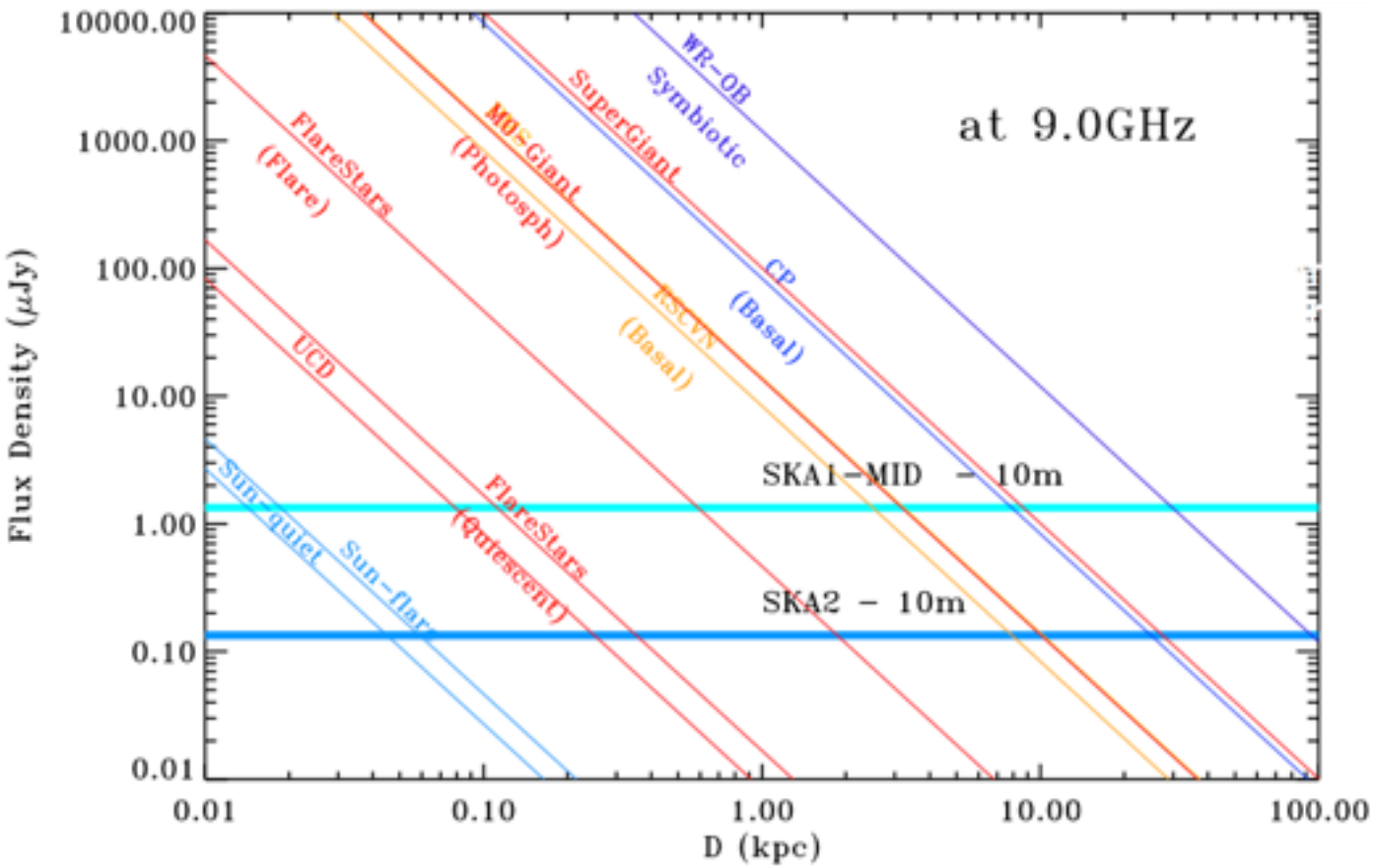
SKA: Massive young stars and YSOs (High-mass end of IMF; Multiplicity; Star formation in Sgr B2; Stellar winds and post-main sequence evolution; Accreting objects; Astrometry - GAIA blind toward GC)

Pilot study of Arches/Quintuplet cluster underway with JVLA (Schödel, Alberdi)

Image: IRAC/Spitzer, 3.6 μm

250 pc/1.7 deg

Radio stars

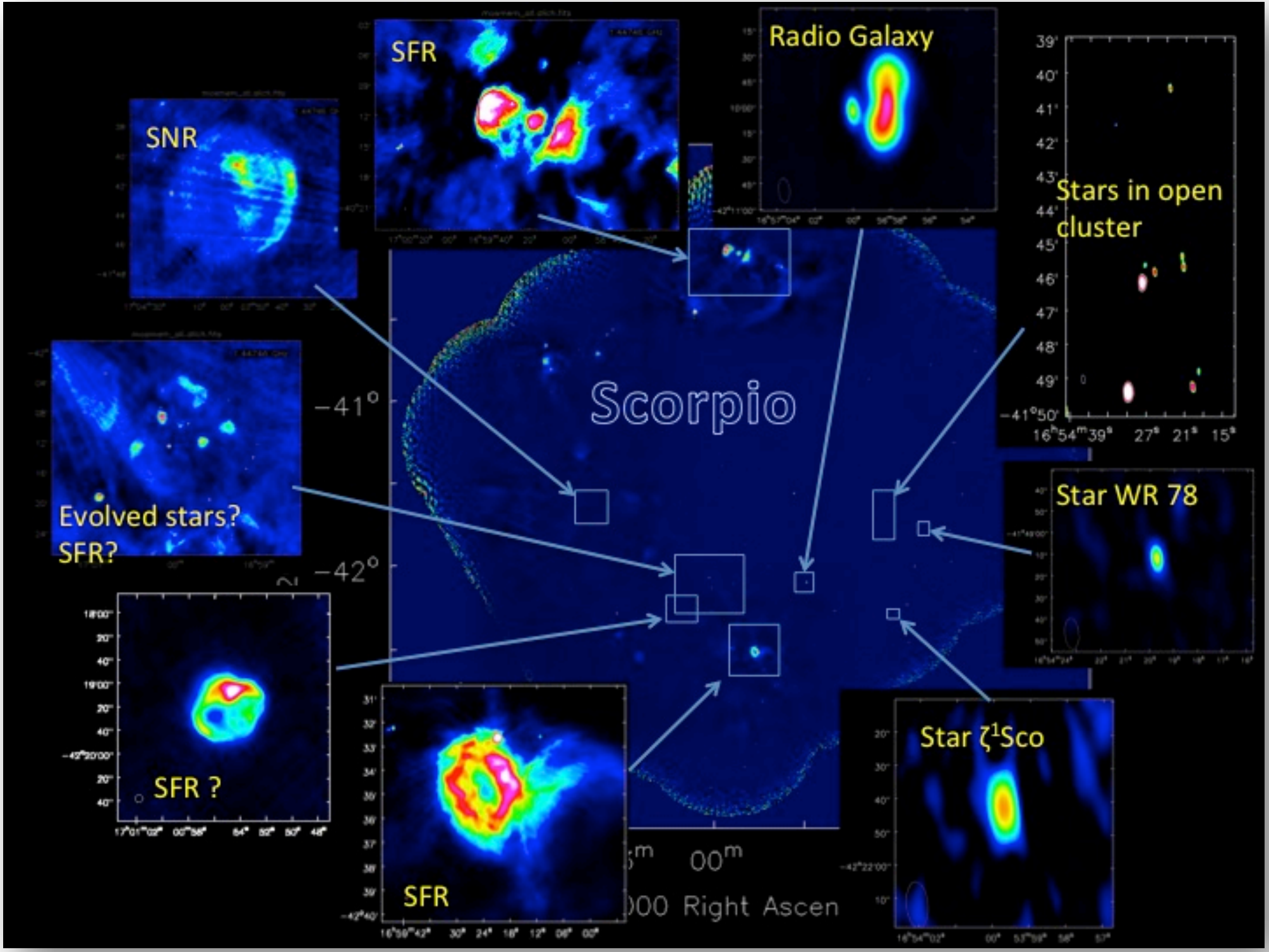


10 minute observations with SKA1 & full SKA

SKA1 - all WR & OB plus CP, PMS, RSCNS & SG to the Galactic Centre

Full SKA - solar analogues to 50 pc & all above classes in the MW & in nearby galaxies

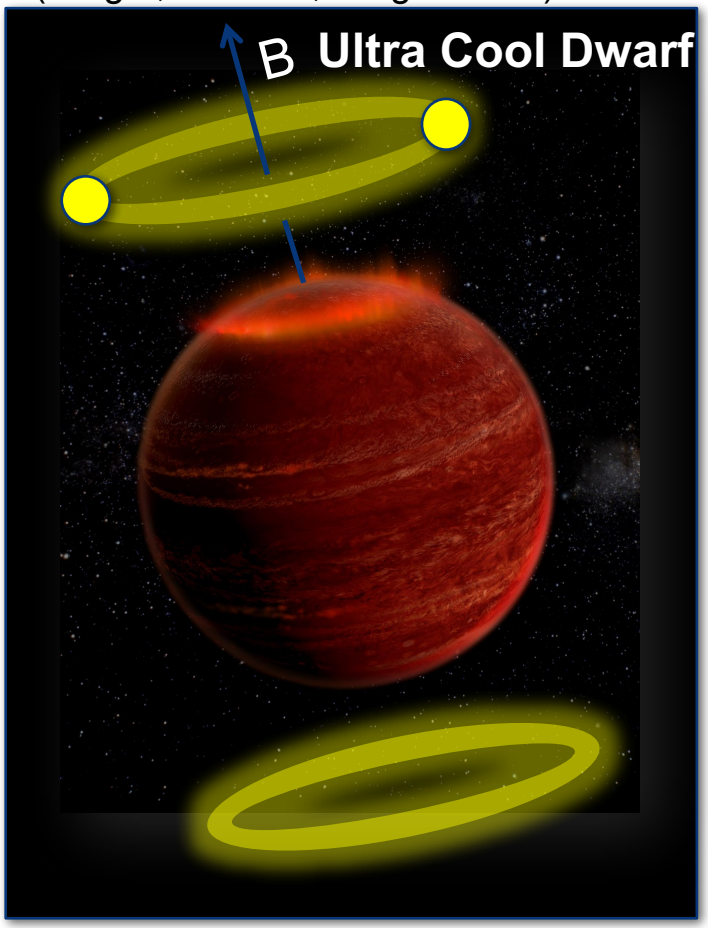
A real revolution in stellar astrophysics



Umana et al 2015

Ultracool dwarfs

2M 0746+20, LSR 1835+32
2MASS J00361617+1821104
DENIS 1048
(Berger, Hallinan, Burgasser...)



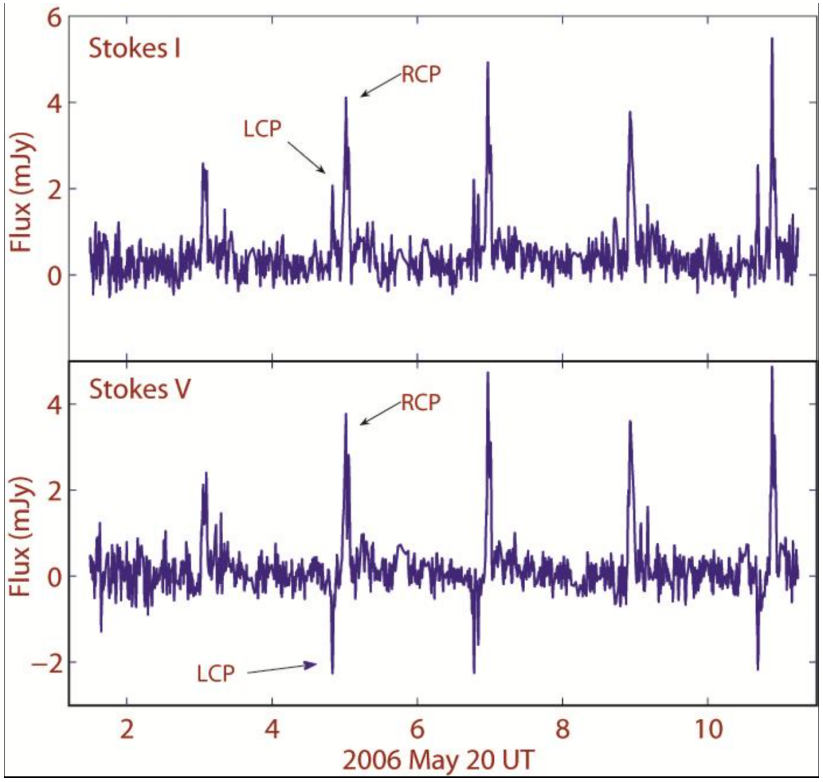
TVLM 513-46
M9V

M_{star}=0.07 $M_{\odot}$

Auroral Radio emission
Radio Pulse not always observed
-but –when observed- at the same orbital phase

Intermittent Maser: triggered by???

Due to Star-Planet Interaction?



Hallinan et al. 2007, 2008

A wedding cake of KSP ideas

1. Targeted observations of nearby stars (SKA1-Low)

2. Targeted SKA1-Mid Band 5+VLBI studies of nearby stellar clusters

4. SKA1-Mid Deep Band 5 deep spectroscopic survey of Galactic Plane

5. SKA1-Mid Shallow continuum survey of Galactic Plane

6. SKA1-Mid Band 2 RRL survey - Galactic Plane/“All Sky” generic survey

http://astronomers.skatelescope.org/science-working-groups/milky-way/

Summary

SKA covers important Milky Way physics in breadth and depth

» The multiphase Milky Way - ionised, neutral, molecular

» Mass flow into and out of the Milky Way

» Formation of molecular clouds

» Tomography, Tomography, Tomography
(neutral, molecular, stars)

» The full radio HR diagram & stellar evolution

Commensality is the key to achieving maximum science output

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