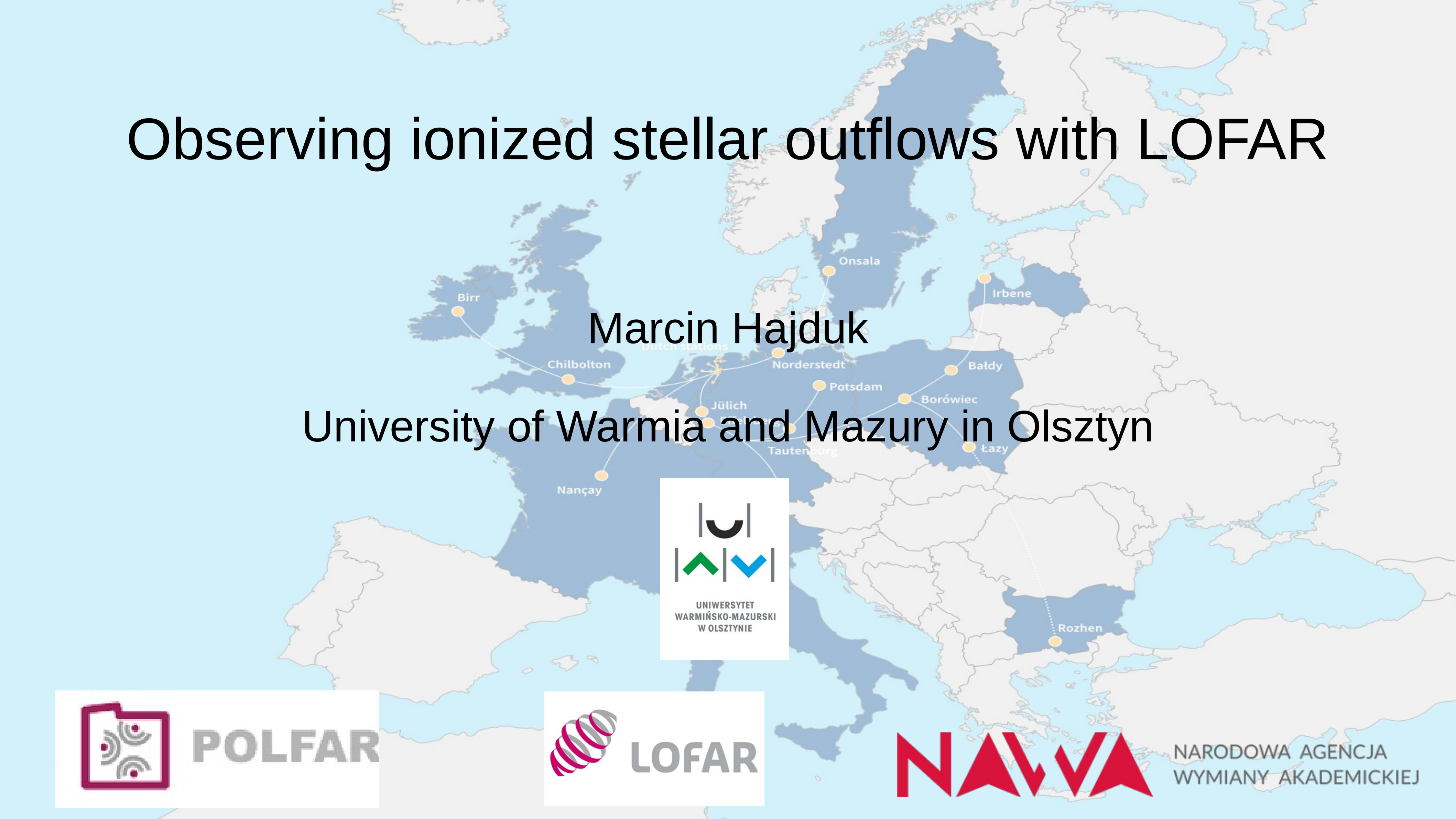
Observing ionized stellar outflows with LOFAR

Marcin Hajduk

University of Warmia and Mazury in Olsztyn



UNIWERSYTET WARMIŃSKO-MAZURSKI W OLSZTYNIE

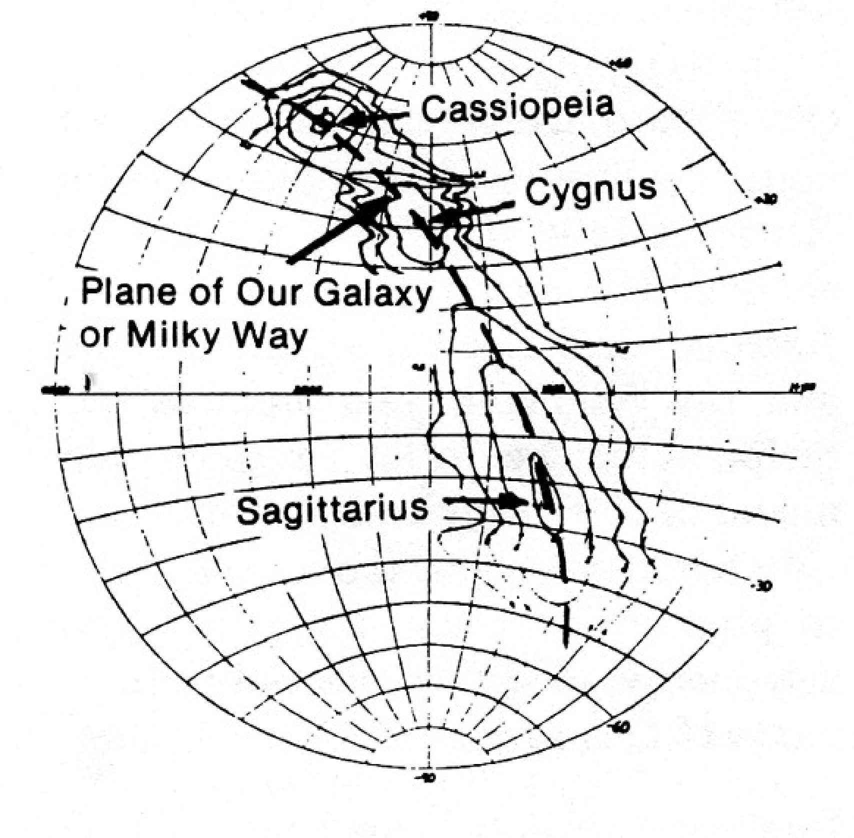
POLFAR

LOFAR

NAWA NARODOWA AGENCJA WYMIANY AKADEMICKIEJ

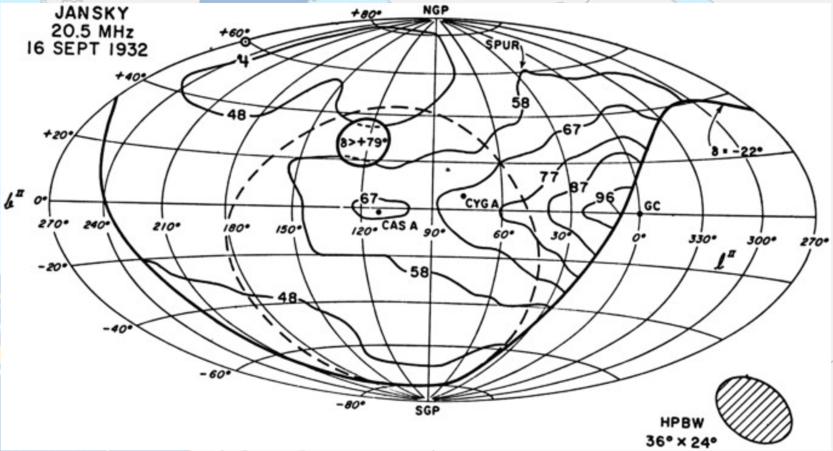
Stellar outflows observed in radio

Two-metre survey by Grote Rober



Rober G., *1944*, **ApJ**, *100*, 279

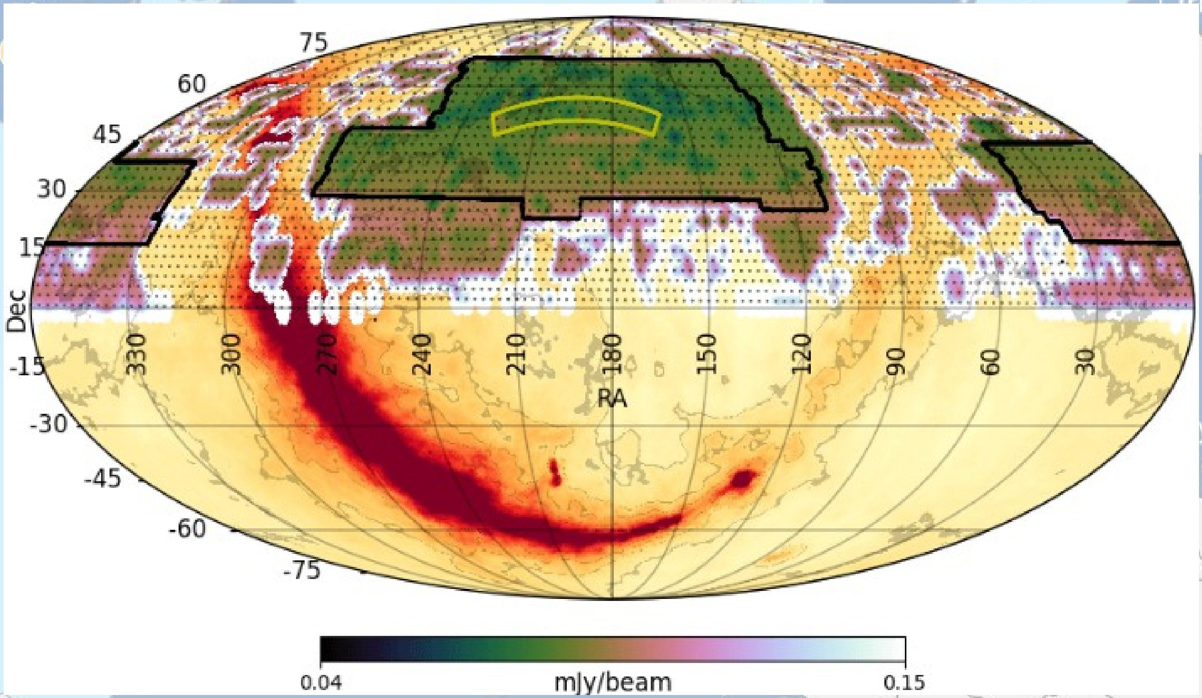
Stellar outflows observed in radio



20.5 MHz survey by Karl Jansky in 1932

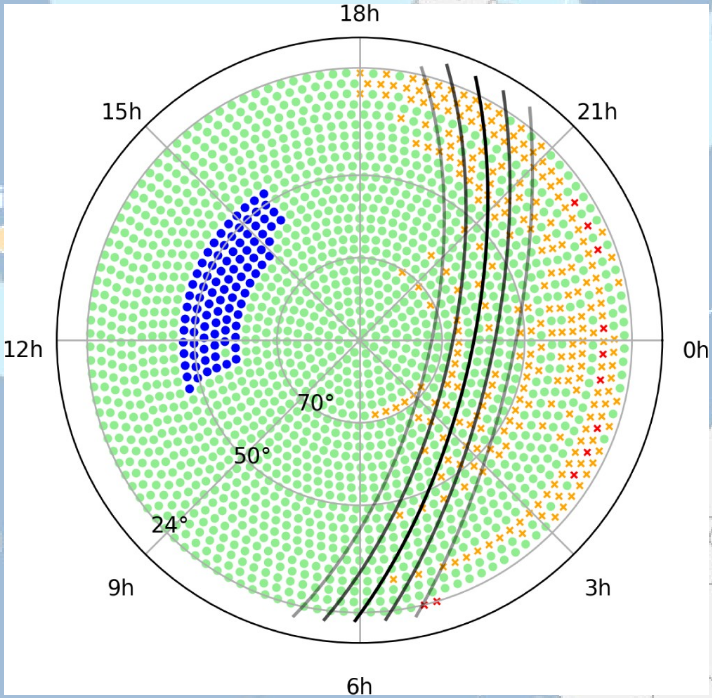
Sullivan, W., *1978*, **S&T**, *56*, 101

LoTSS 120-168 MHz



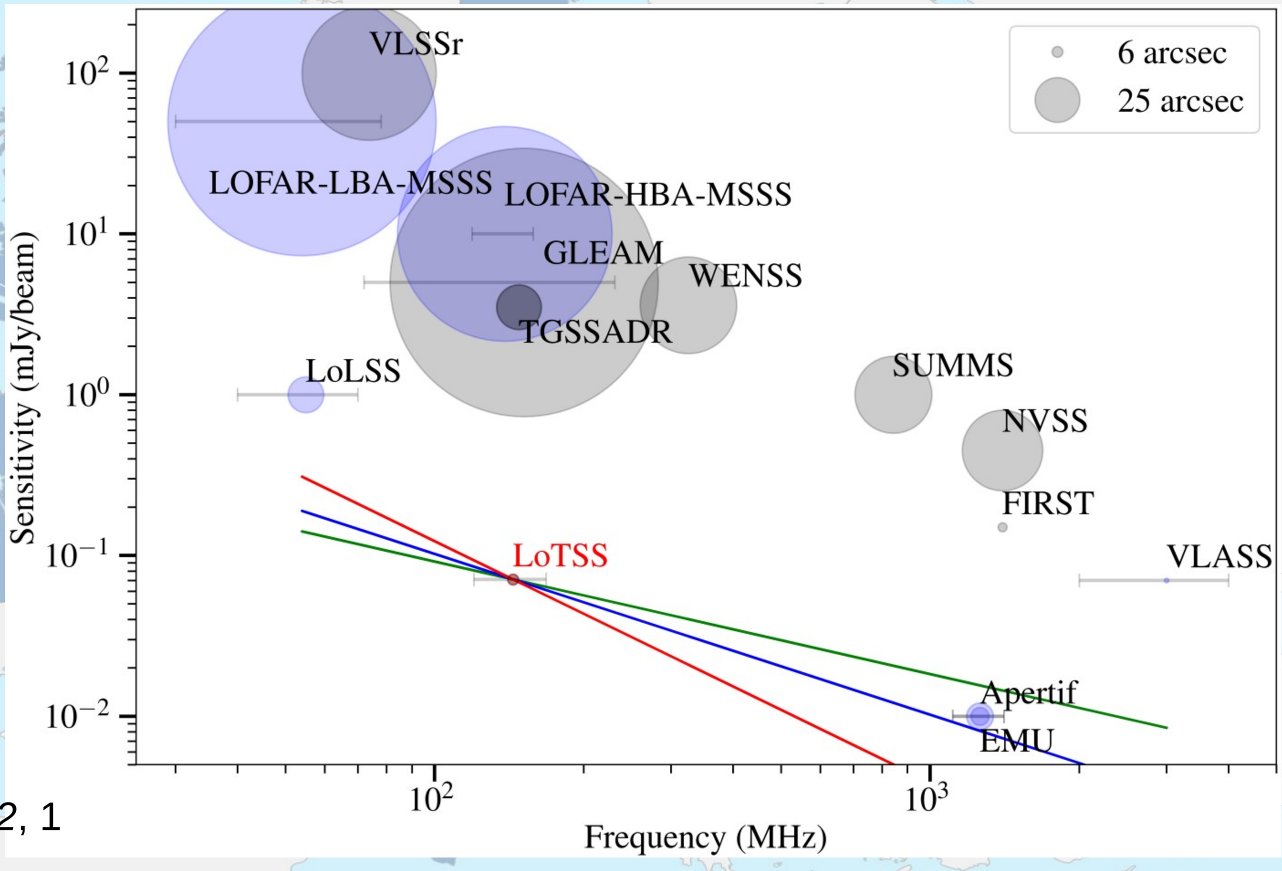
Shimwell, T., *2022*, **A&A**, *659A*, 1

LoLLS 41-66 MHz



de Gasperin, F., et al., *2023*, **A&A**, *673A*, 165

LOFAR wide-area surveys



Shimwell, T., et al., *2019*, **A&A**, *622*, 1

Stellar sources in LOFAR

Kavanagh, R., et al., *2022*, **MNRAS**, 514, 675

Vedantham, H. K., et al., *2022*, **ApJ**, 926L, 30

Hajduk, M., et al., *2022*, **A&A**, 665A, 152

Pope, B. J. S., et al., *2021*, **ApJ**, 919L, 10

Vedantham, H. K.; et al., *2020*, **ApJ**, 903L, 33

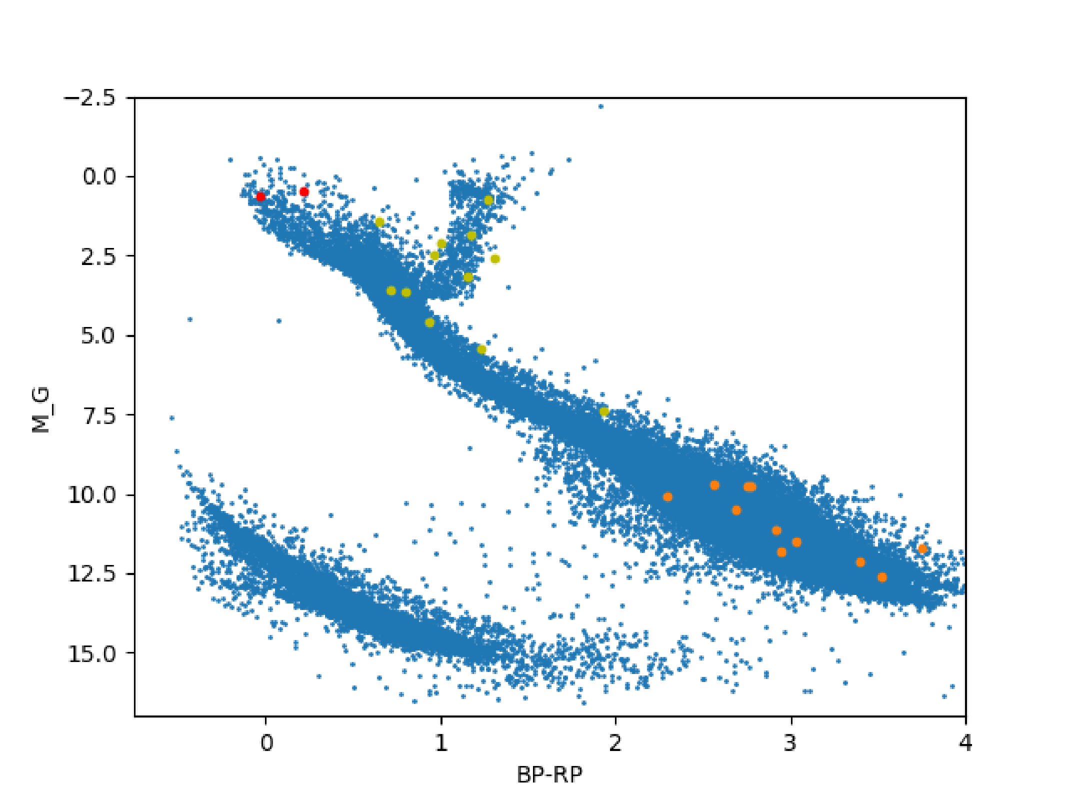
Callingham, J. R., et al.,*2021*, **Nature Aston.**, 5.1233

Vedantham, H. K., et al., *2020*. **Nature Astron.**, 4, 577

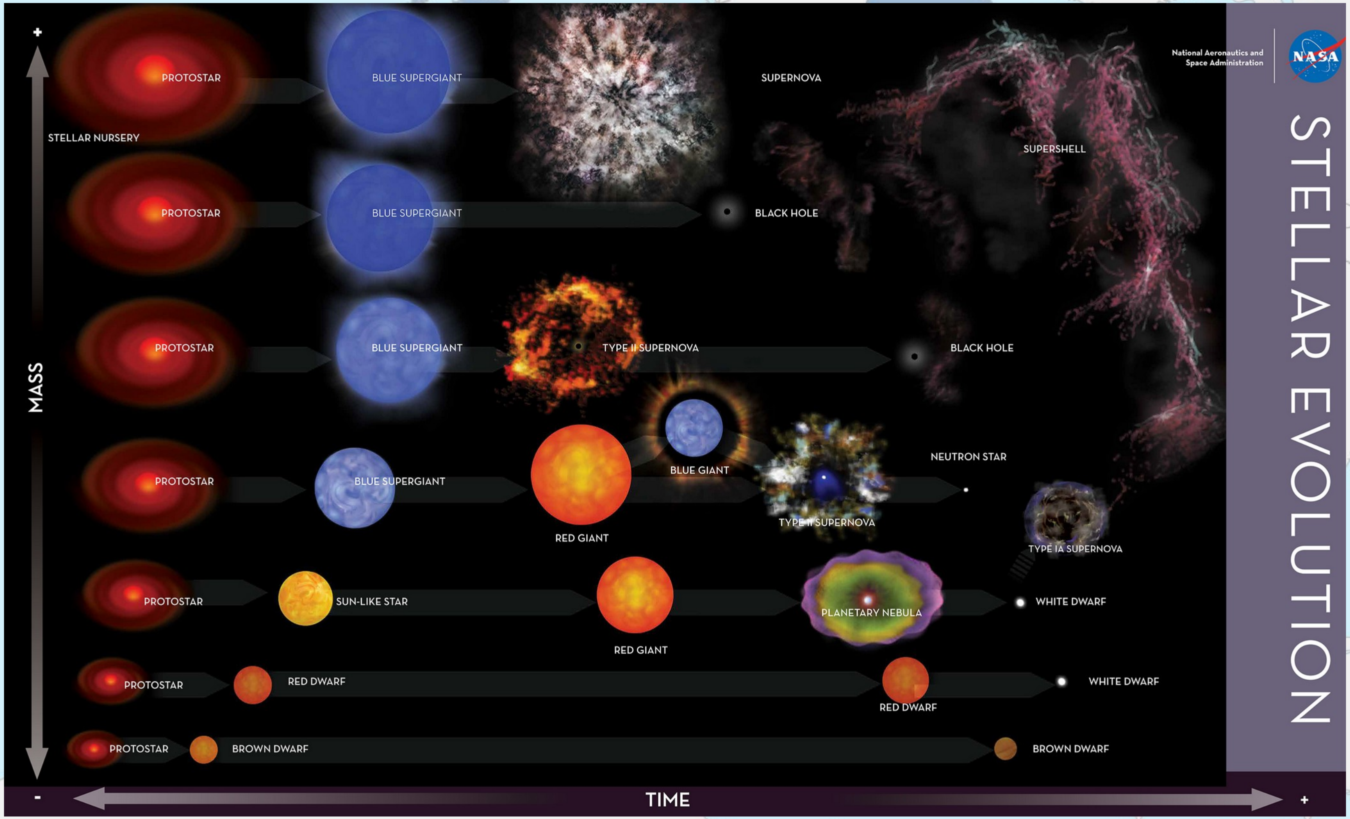
Vedantham, H. K., et al.,*2020*, **ApJ**, 903L, 33

Callingham, J., et al., *2021*, **A&A**, 648A, 13

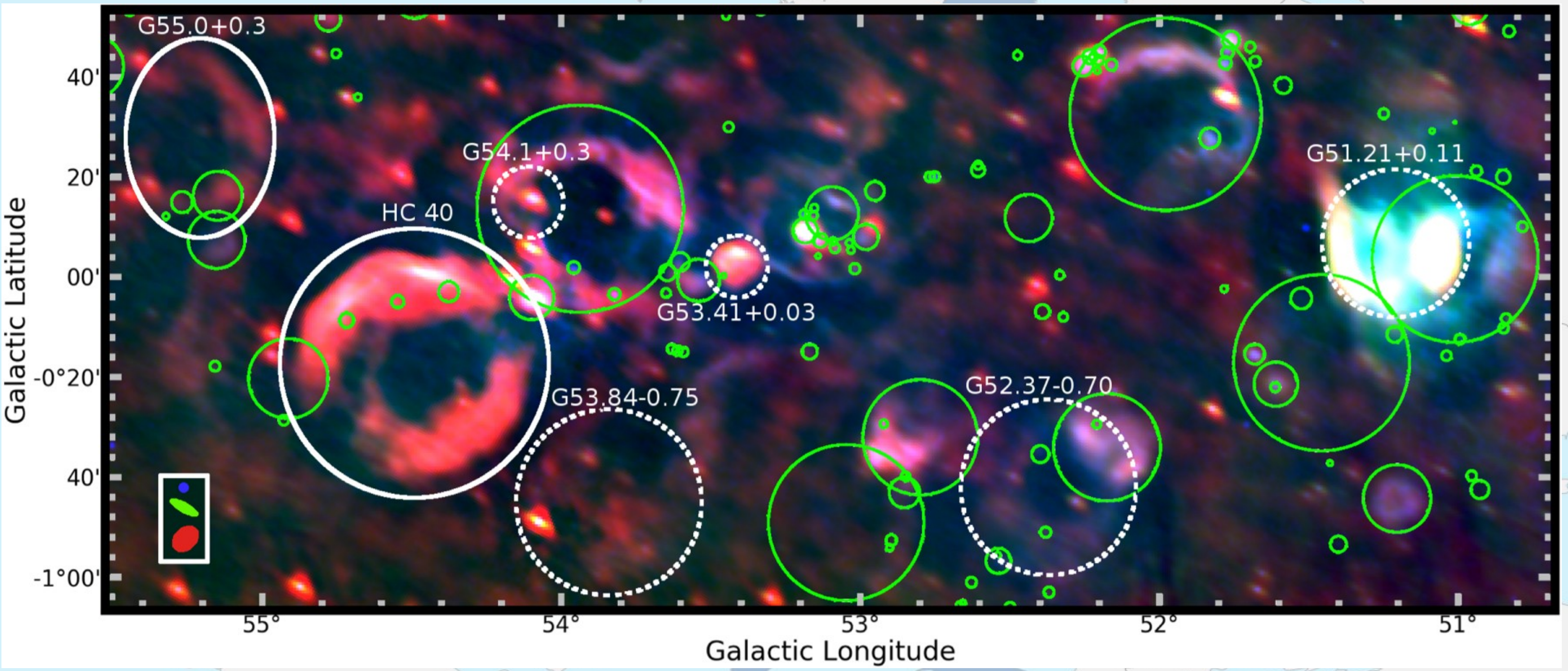
Toet, S. E. B., et al., *2021*, **A&A**, 654A, 21



Ionized nebulae throughout stellar evolution

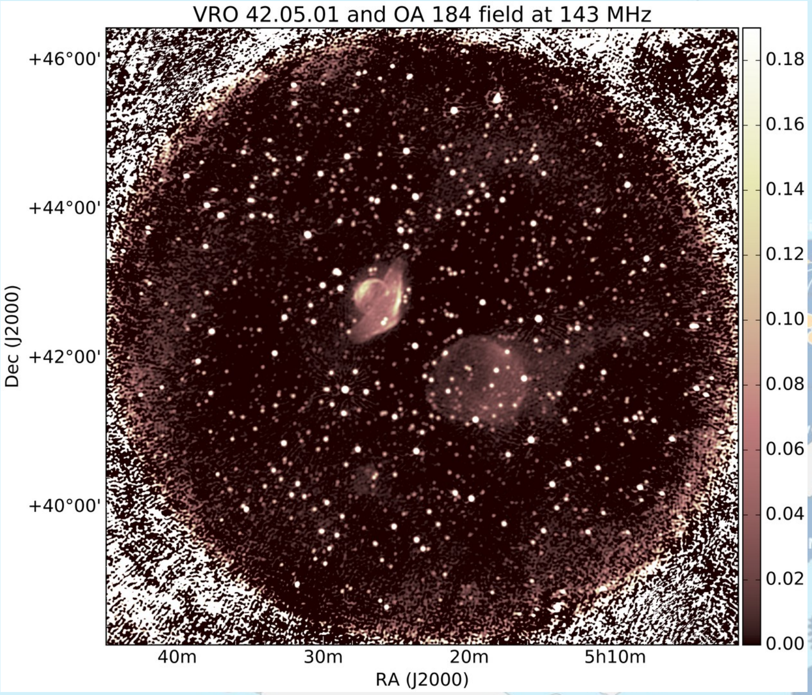


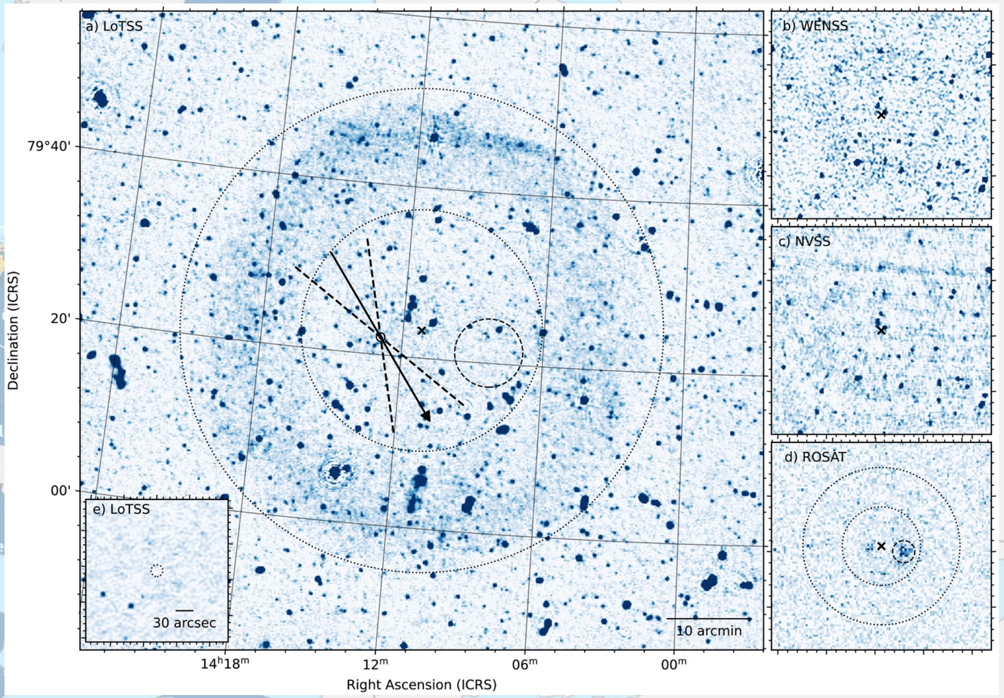
Supernova remnants



Driessen, L., et al., *2018,* **ApJ**, *860,* 133

Supernova remnants

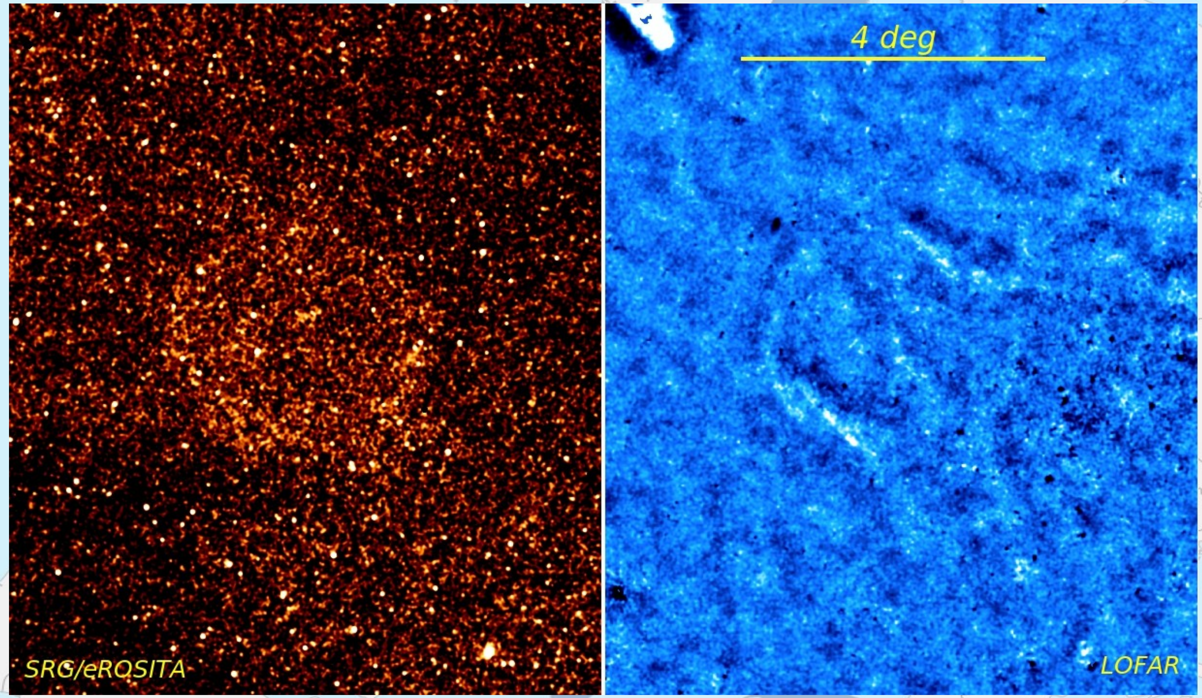




Arias, M., et al., *2019,* **A&A**, *622A,* 6

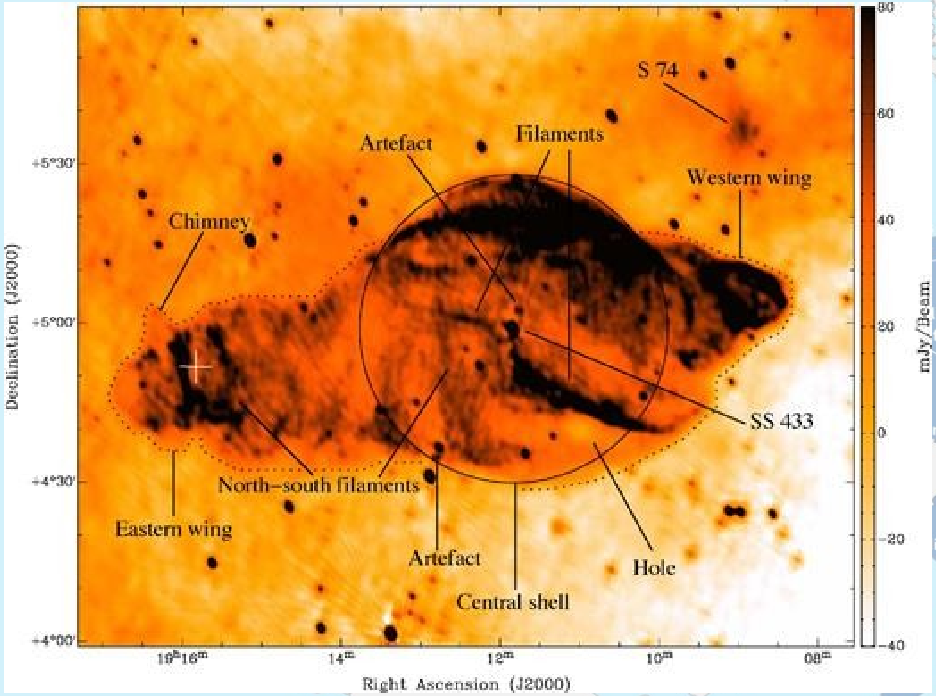
Arias, M., et al., *2022,* **A&A**, *667A,* 71

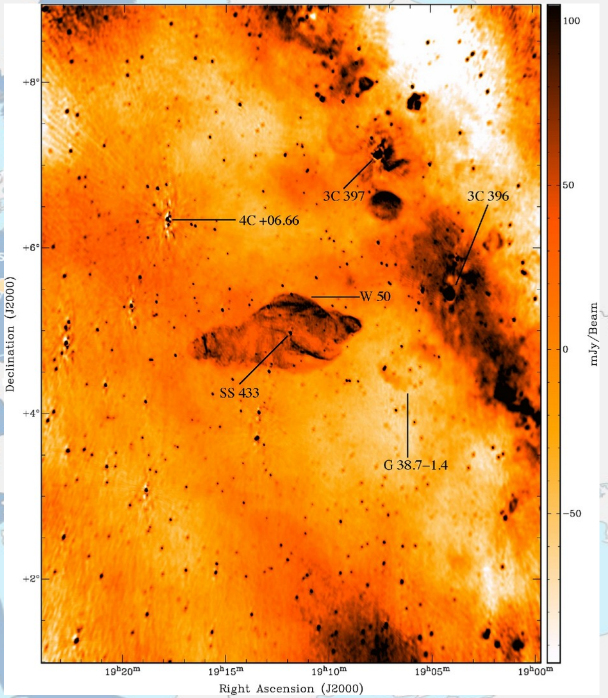
Supernova remnants



Churazov, E.M., et al., *2022,* **MNRAS***, 513L, 8*3

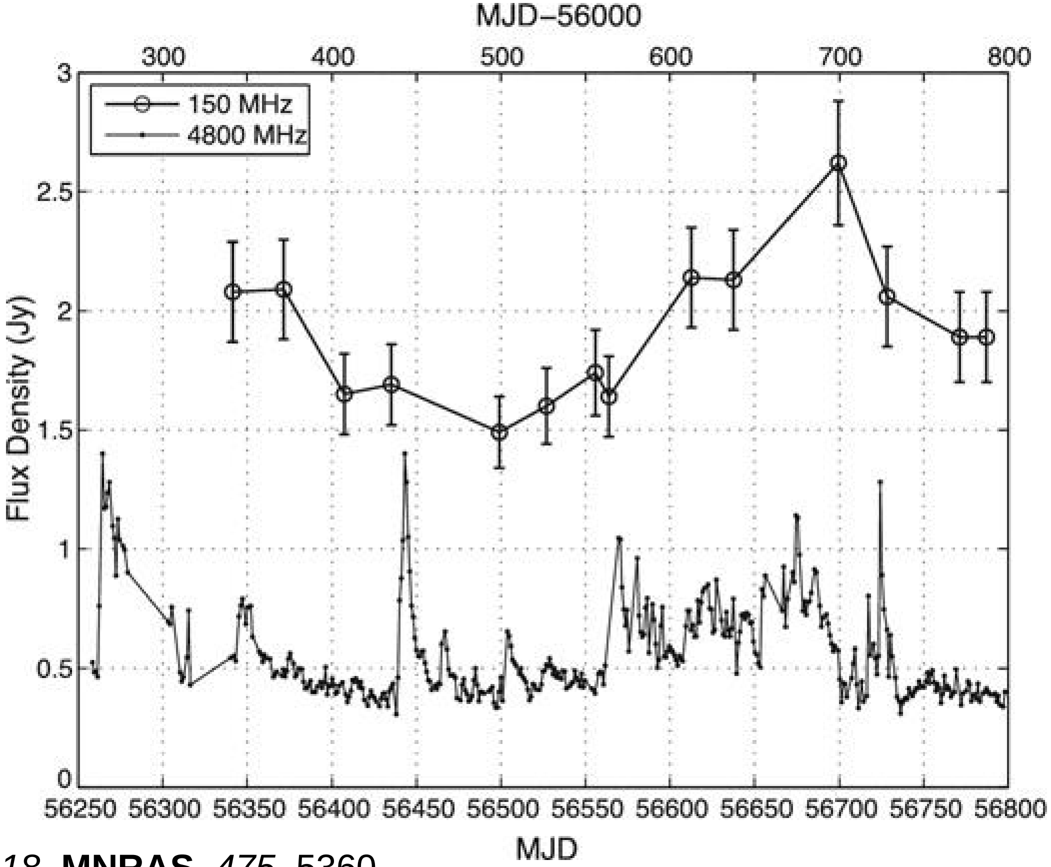
X-ray binary SS 433 and a supernova remnant W 50





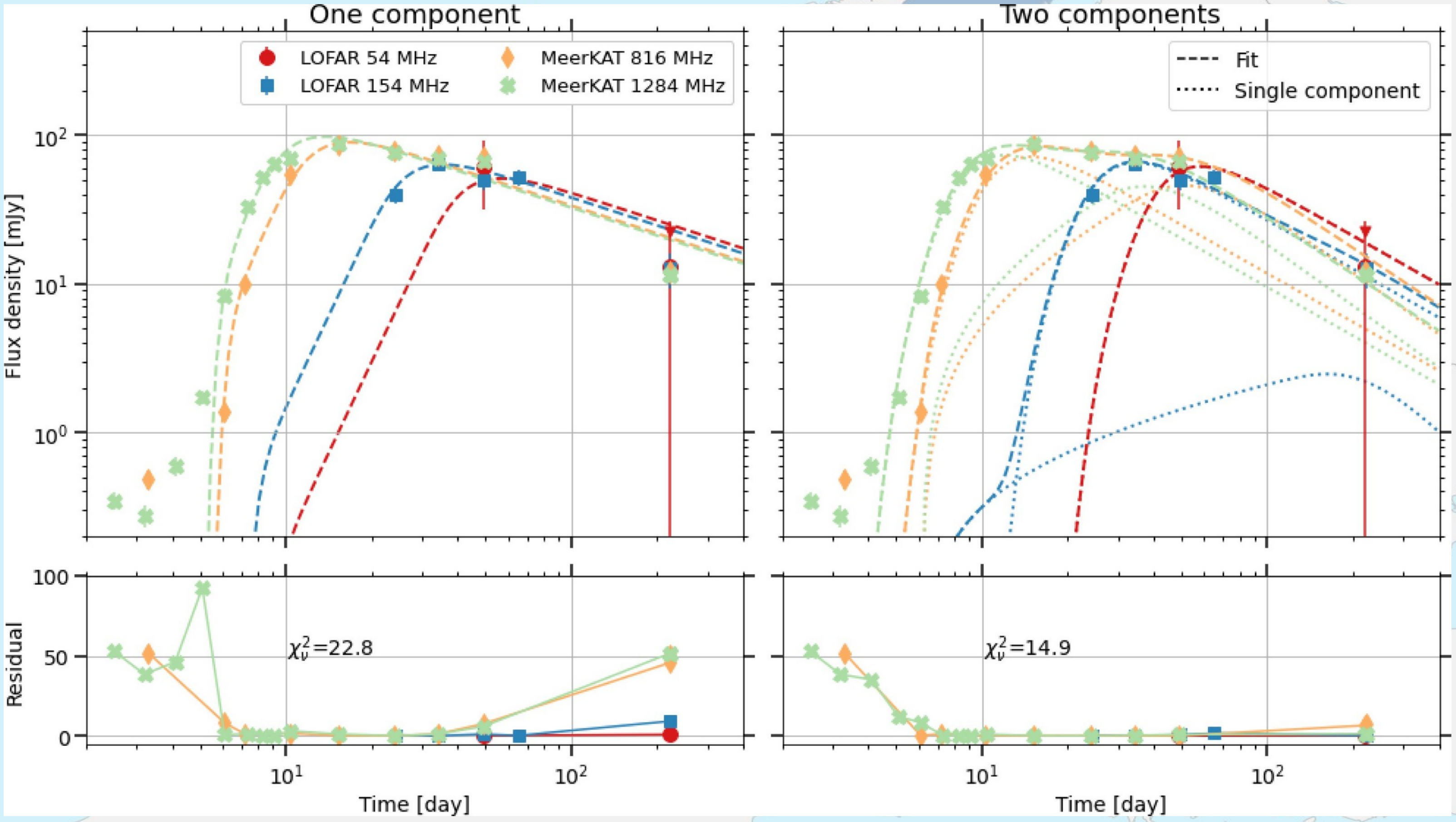
Broderick, J. W., et al., *2018*, **MNRAS**, *475*, 5360

X-ray binary SS 433 and a supernova remnant W 50



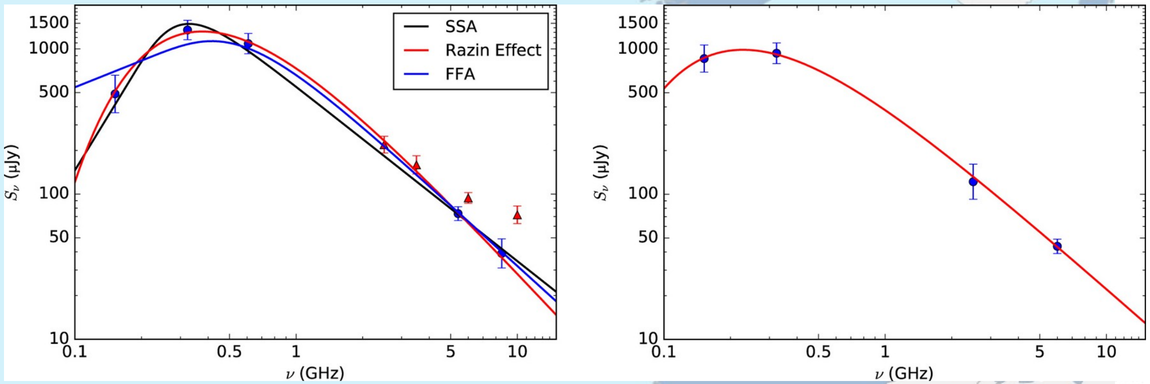
Broderick, J. W., et al., *2018*, **MNRAS**, *475*, 5360

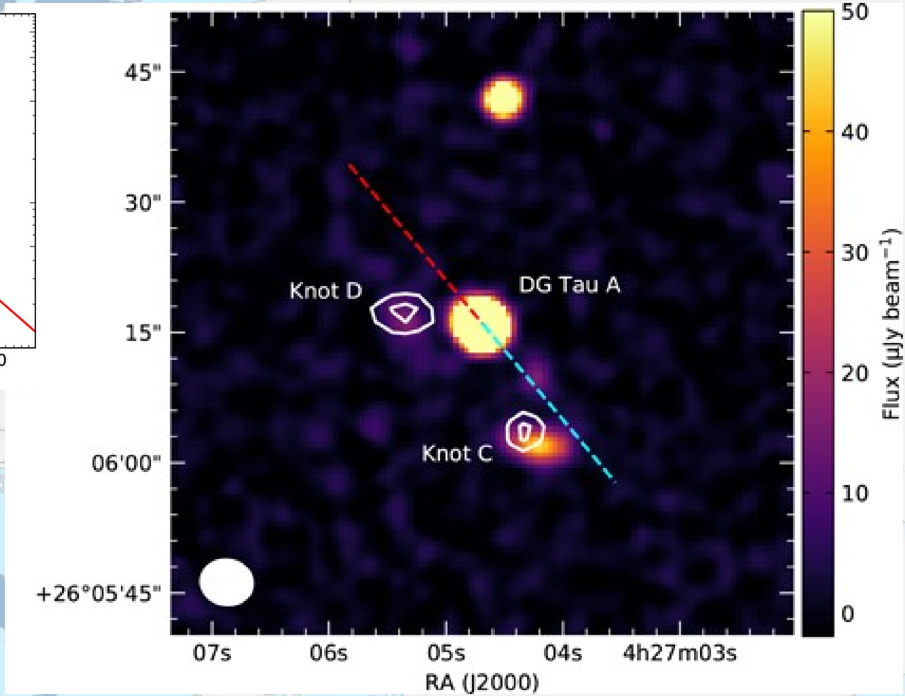
Recurrent nova RS Oph



de Ruiter, I., et al., *2023*, **MNRAS**, *523*, 132

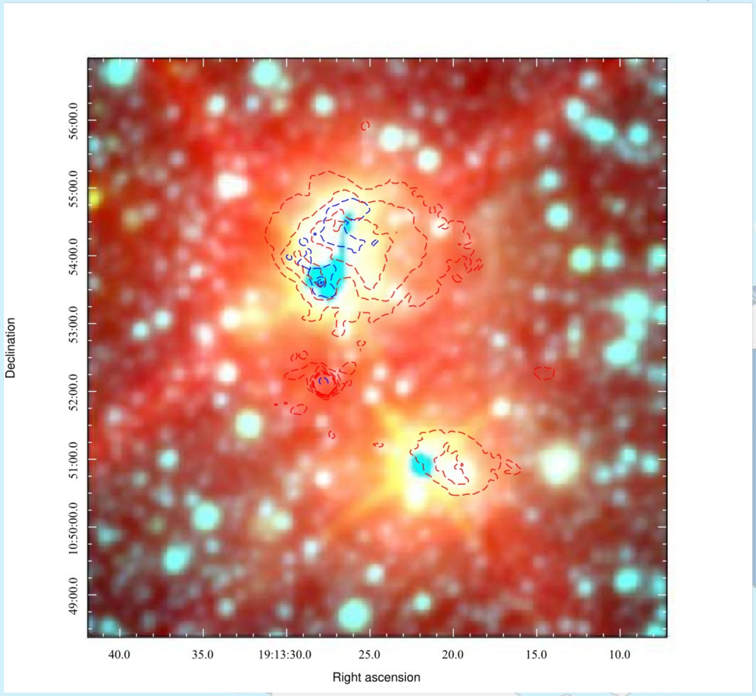
LOFAR observations of DG Tau

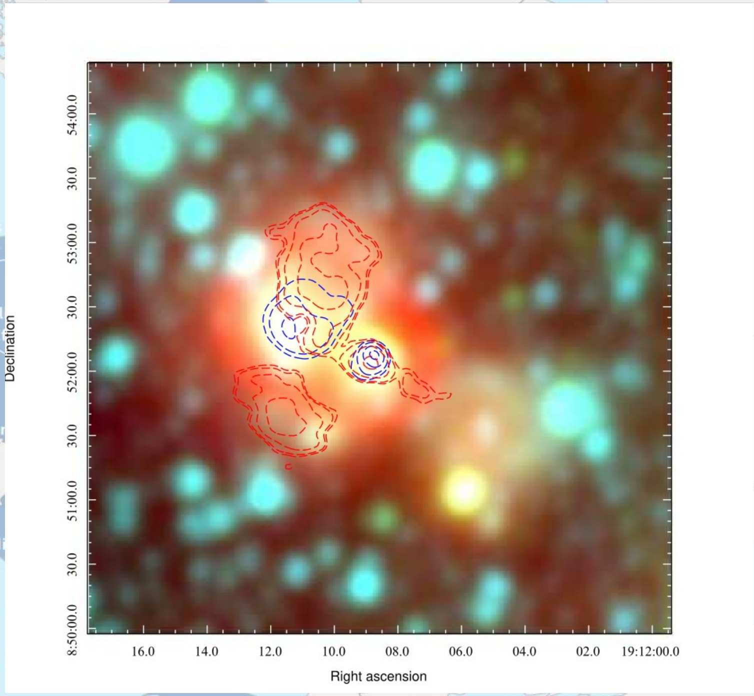




Feeney-Johansson, A., et al., *2019*, **ApJ**, *885L*, 7

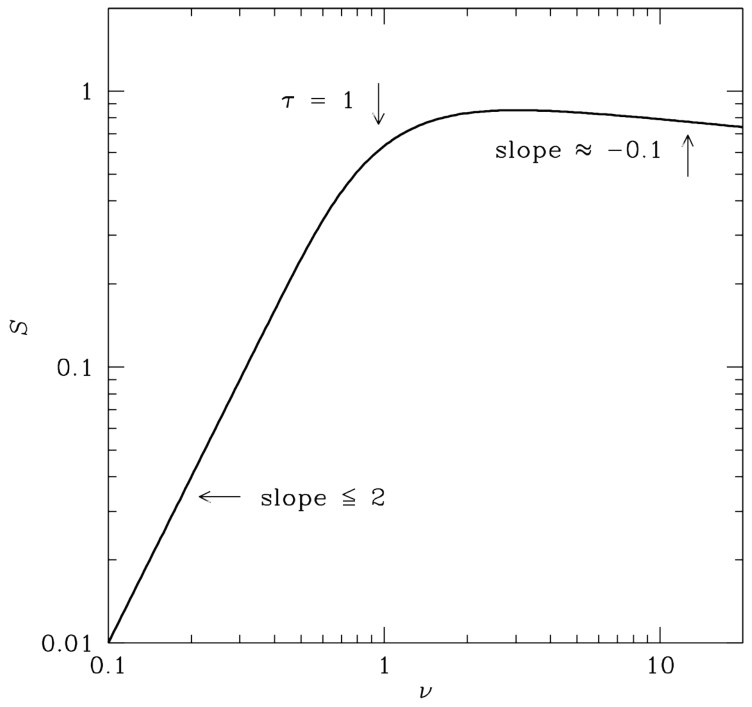
Young stellar objects



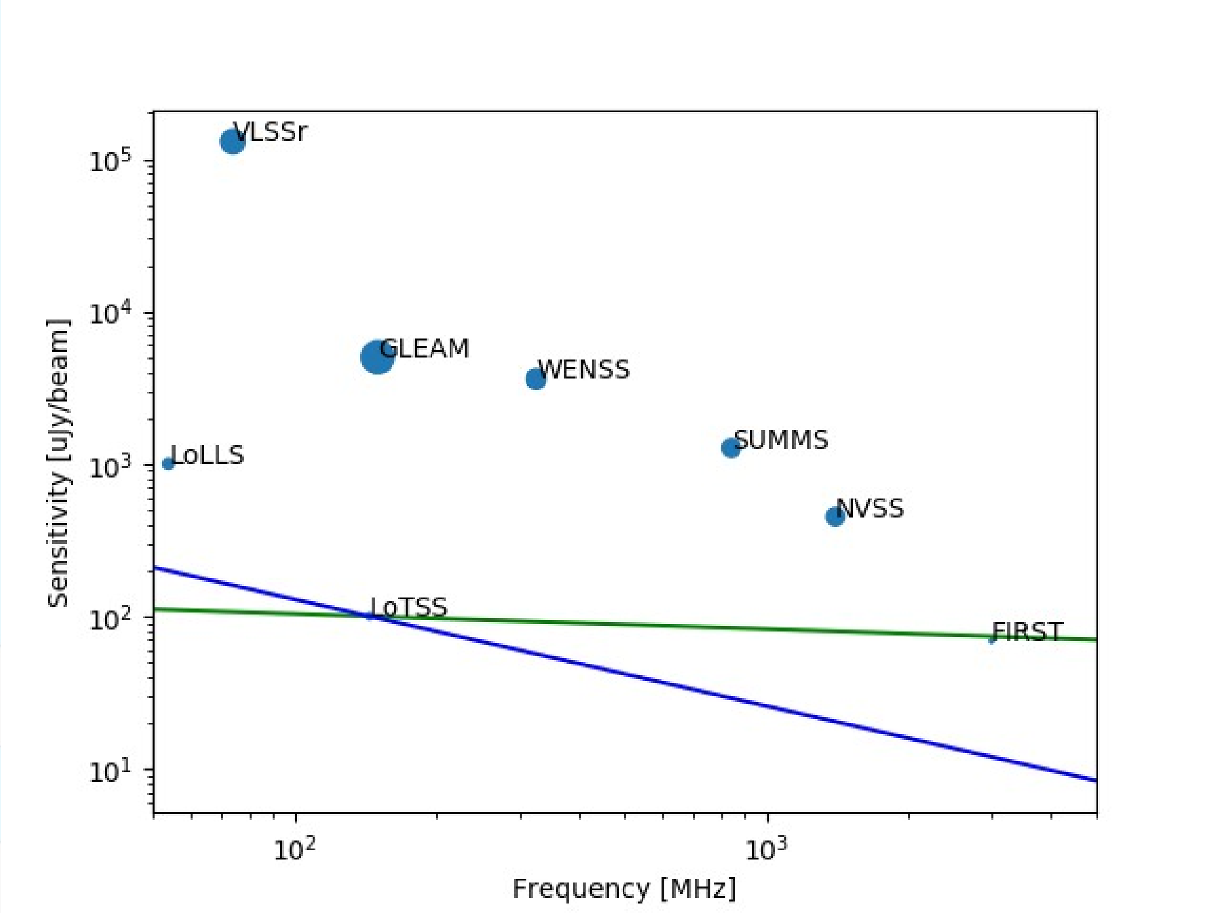


Olech et al., in prep.

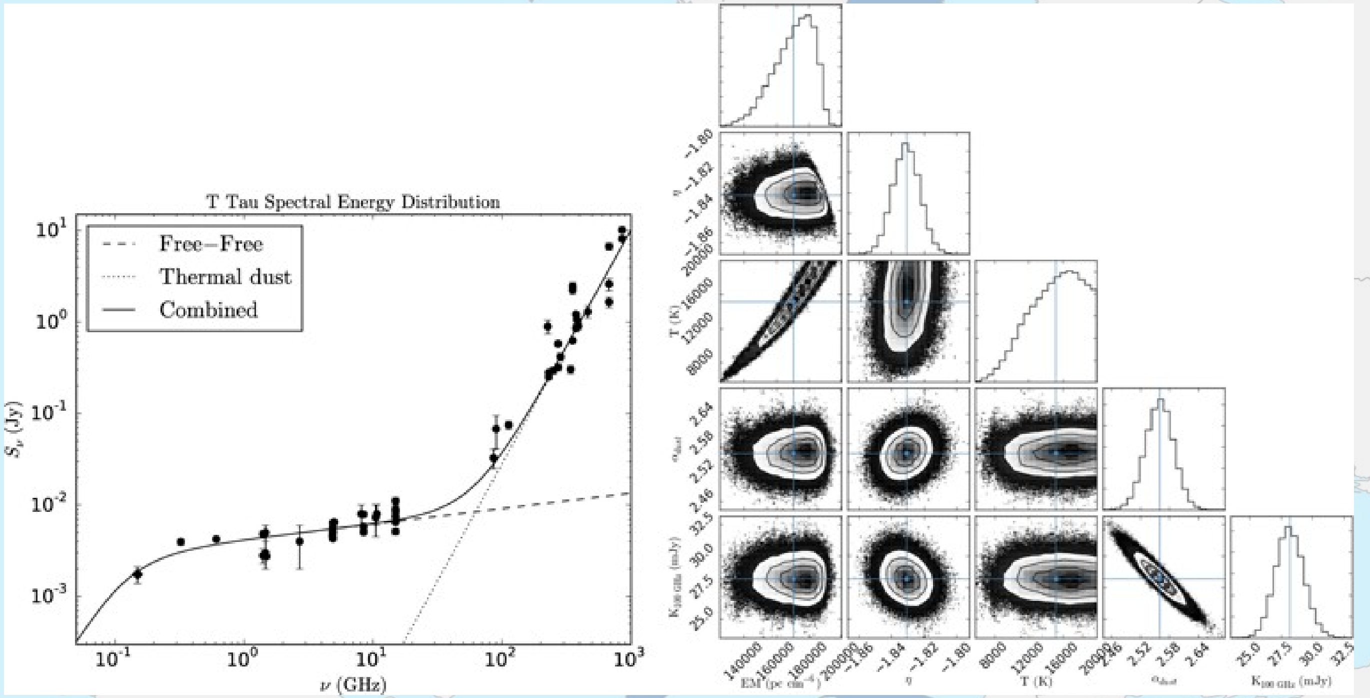
Thermal radio spectrum of an ionized shell



LOFAR Sensitivity for thermal emission

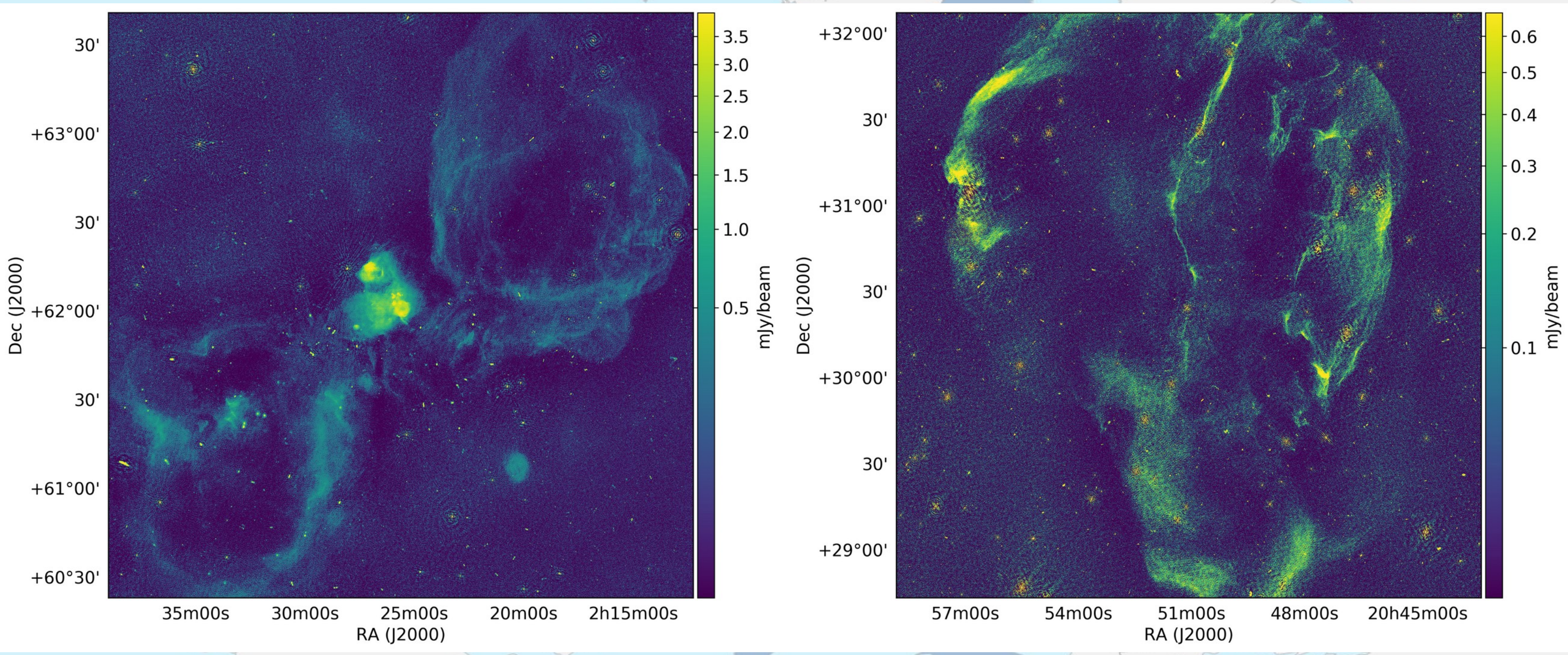


Turnover in T Tau



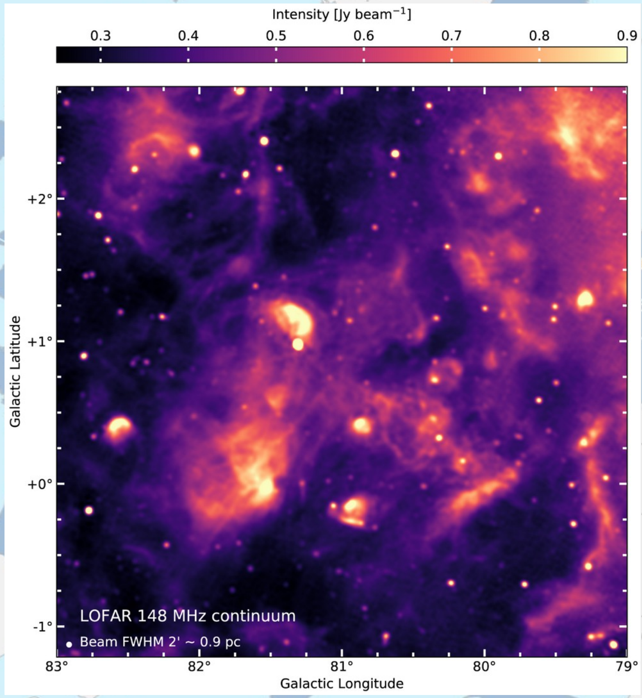
Coughlan C. P., et al., 2017, ApJ, 834, 206

W3/W4/HB3 star forming region (left) and the Cygnus loop supernova remnant



Shimwell, T., et al., *2022*, **A&A**, *659A*, 1

Cygnus X



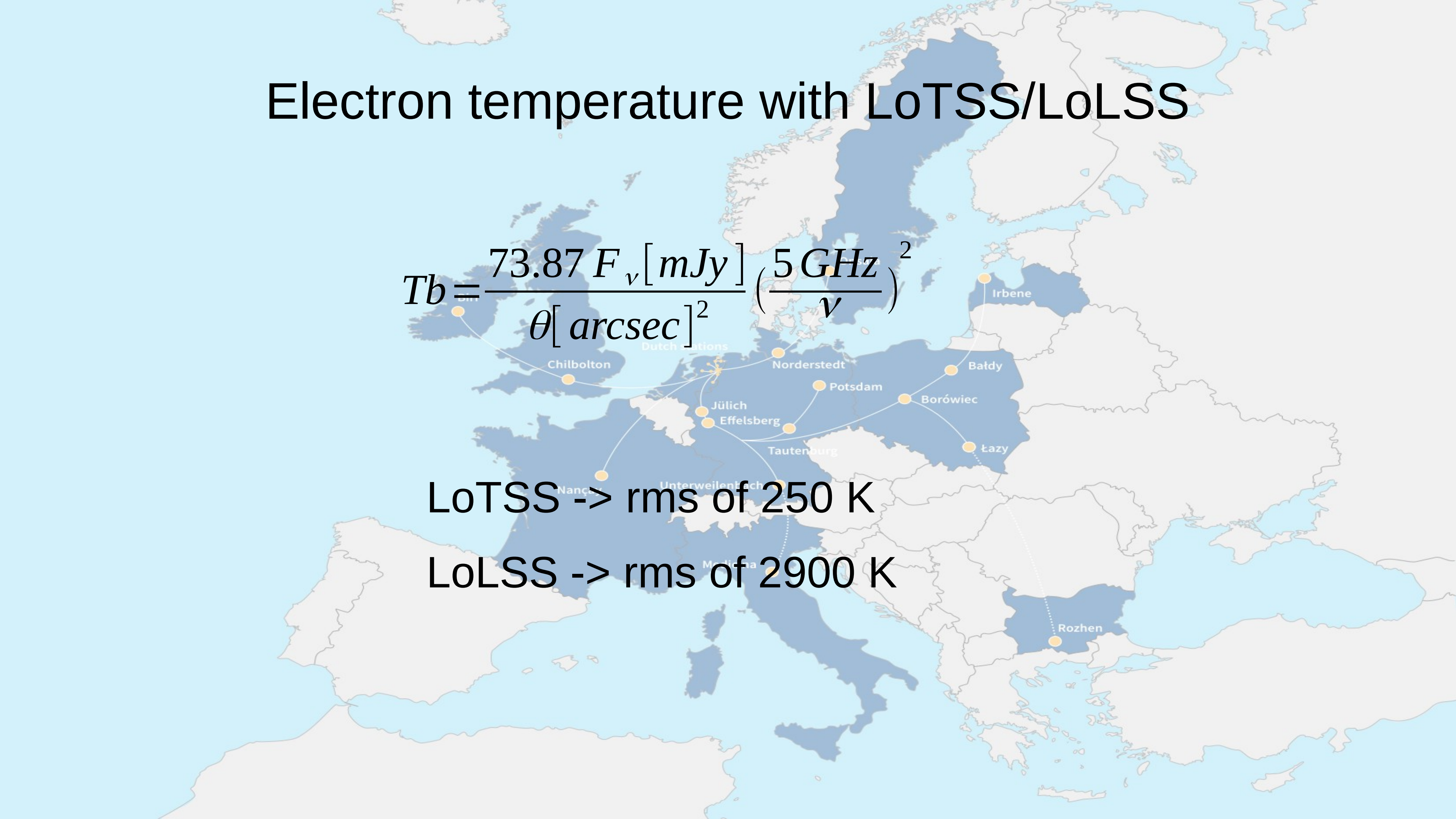
Emig, K. L., et al., *2022*, **A&A**, *664A*, 88

Electron temperature with LoTSS/LoLSS

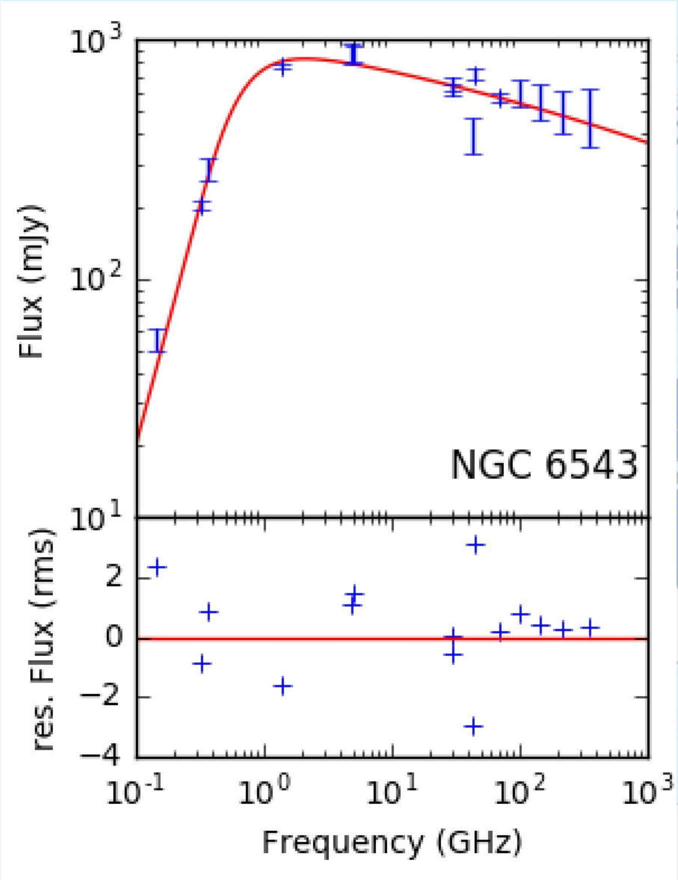
$$Tb = \frac{73.87\, F_{\nu}[mJy]}{\theta[arcsec]^2}\left(\frac{5\,GHz}{\nu}\right)^2$$

LoTSS -> rms of 250 K

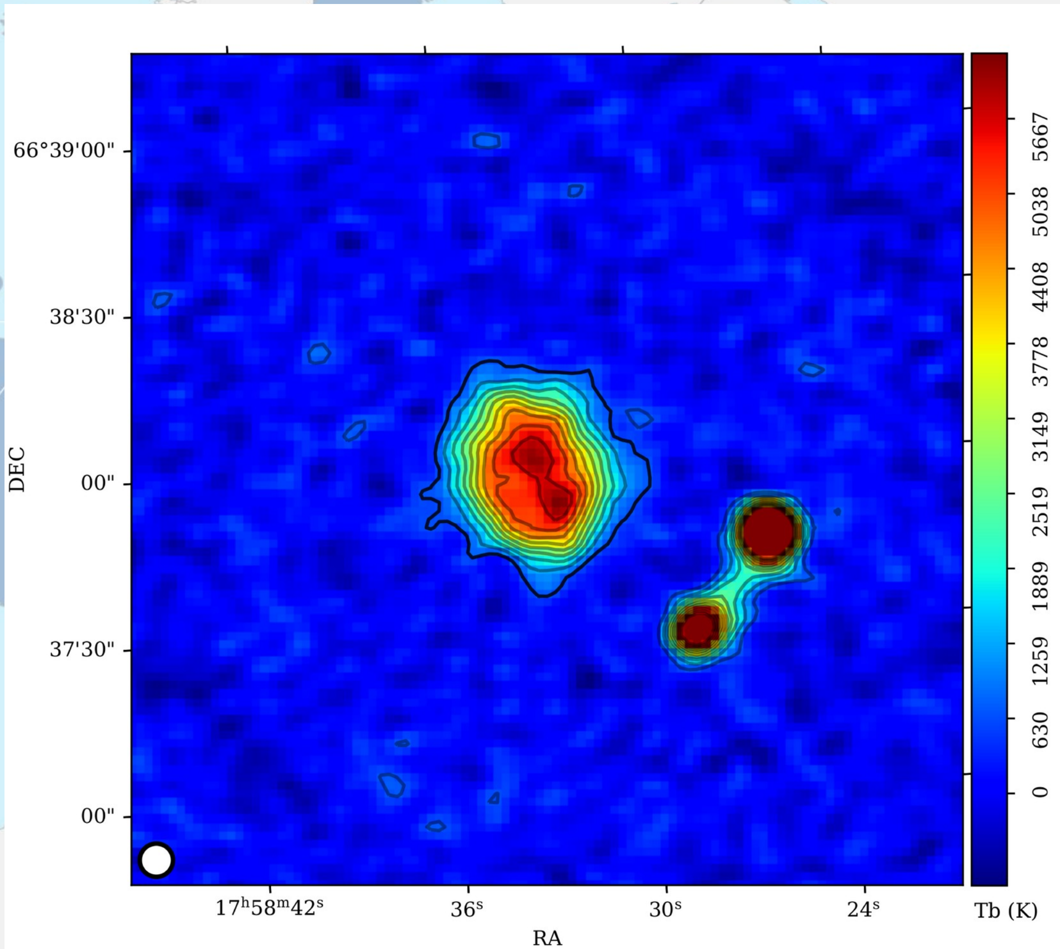
LoLSS -> rms of 2900 K



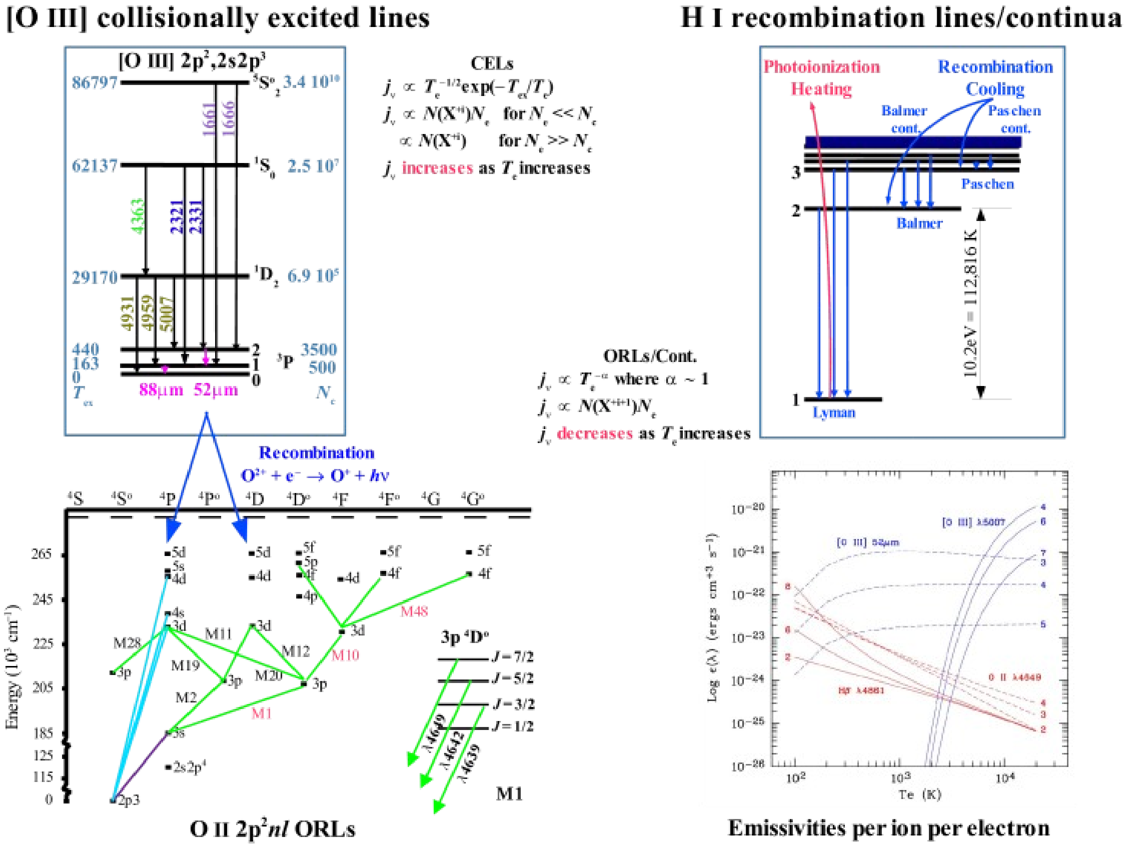
Cat’s Eye planetary nebula (NGC 6543)



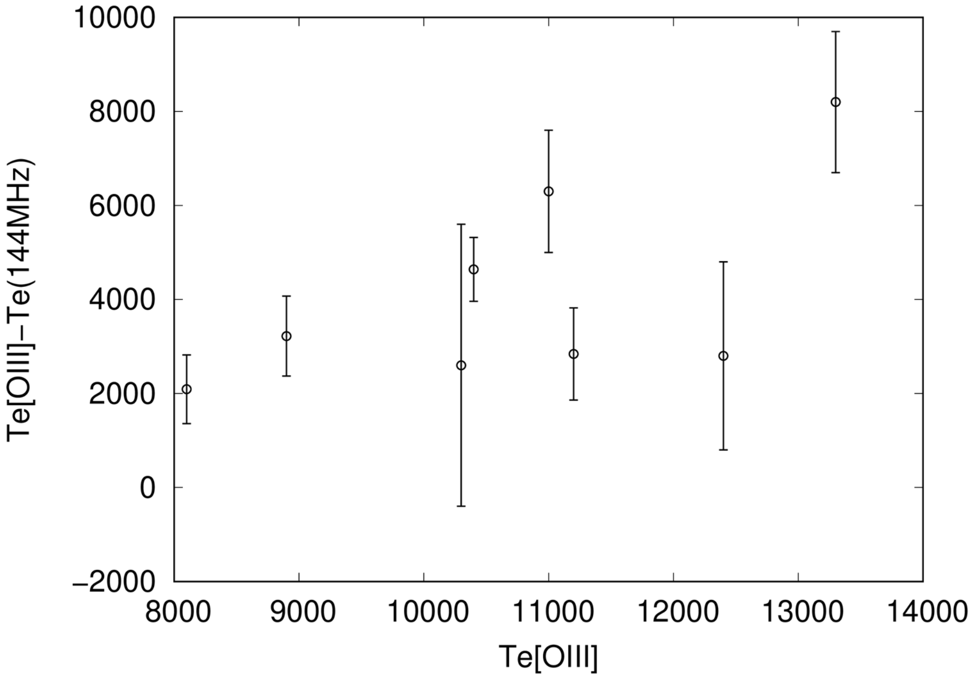
Hajduk, M., et al., *2021*, **ApJ**, *919*, 121



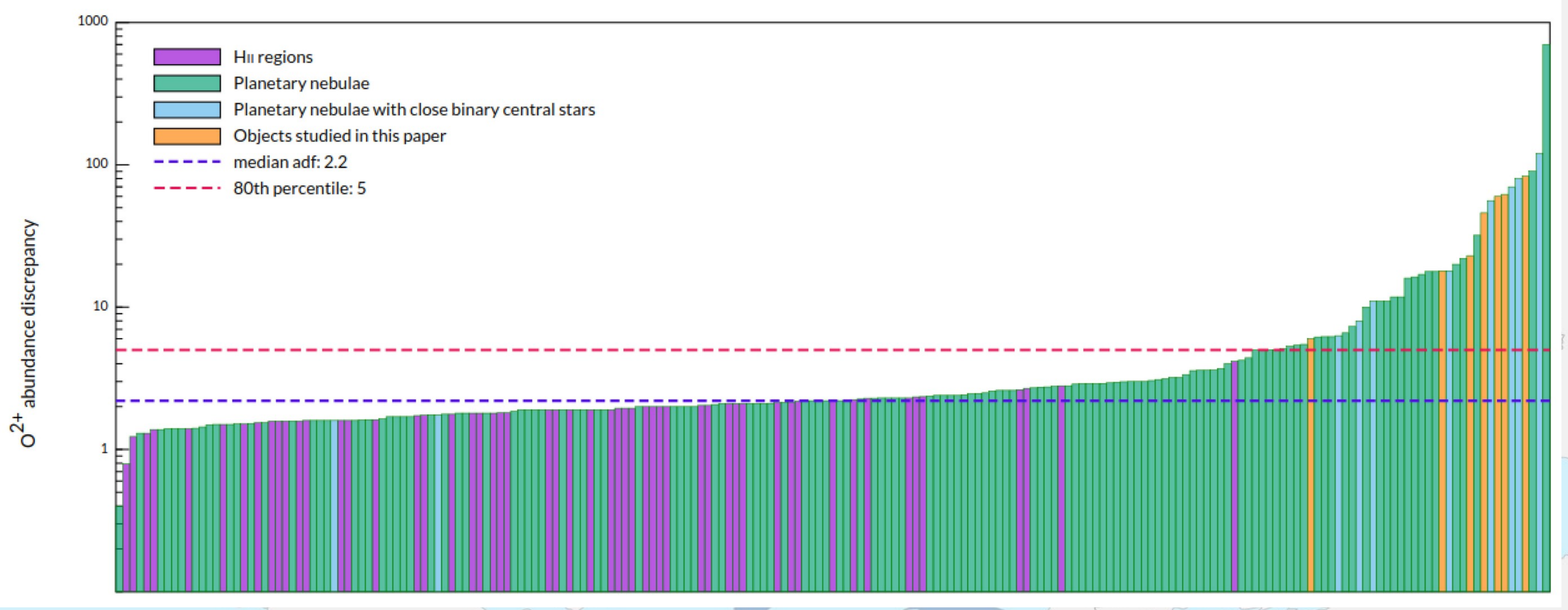
Eletron temperature determination from atomic lines



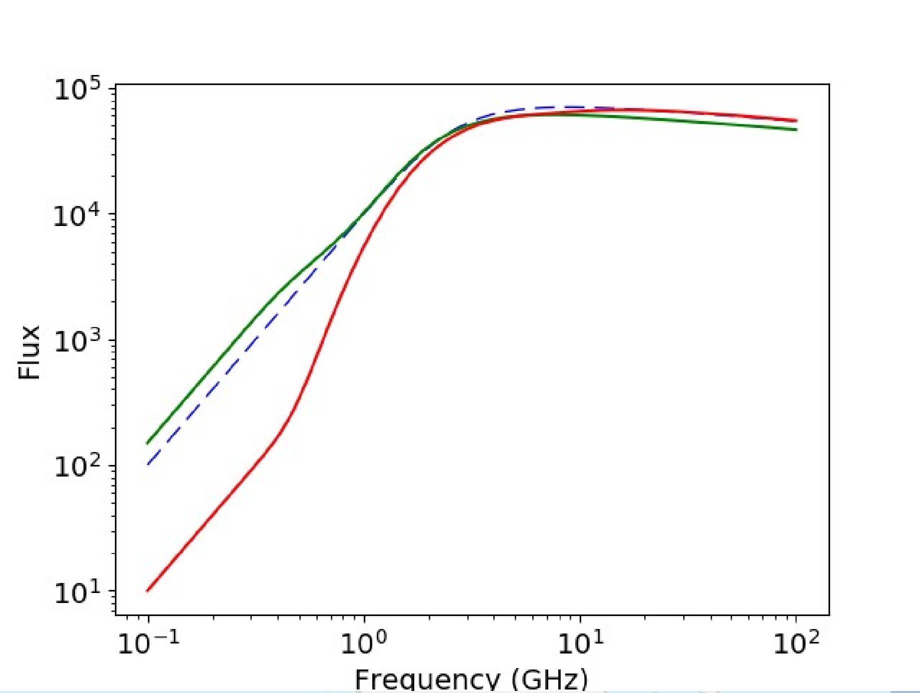
Temperature difference in T_e(144MHz) and T_e([OIII])

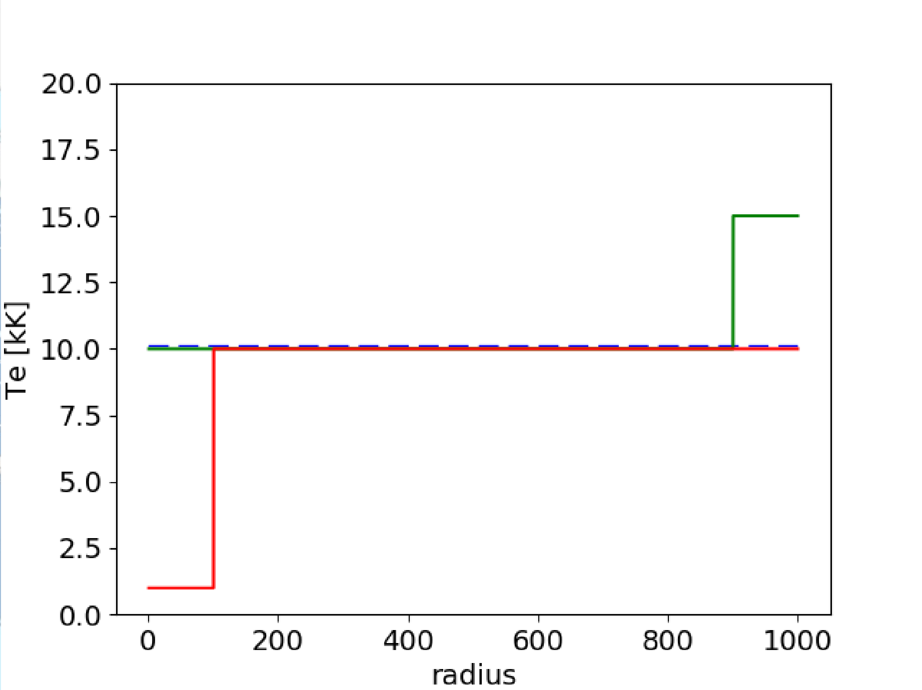


Abundance discrepancies in PNe and HII regions

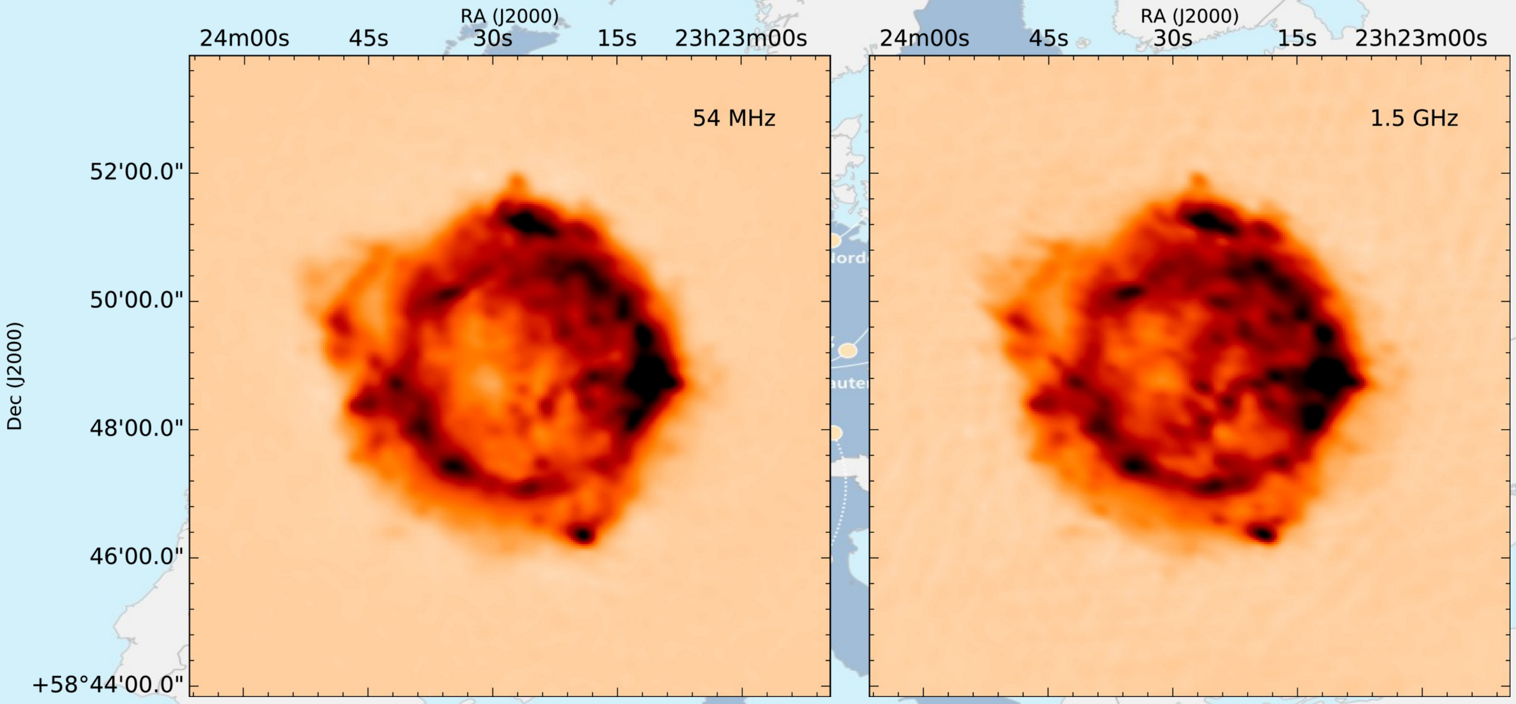


Temperature gradients



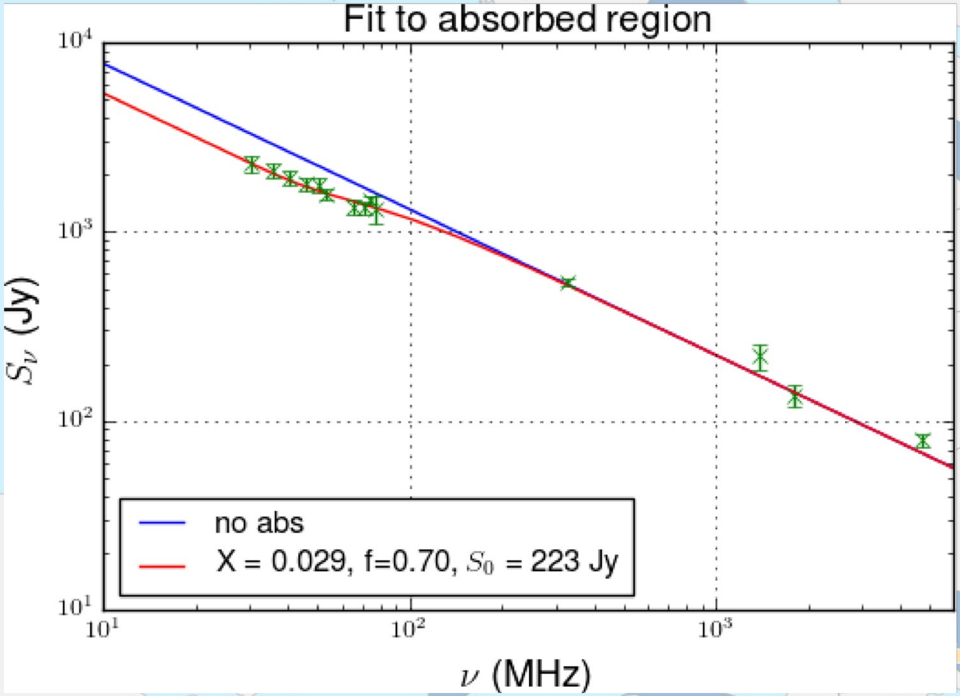


Free-free absorption in Cas A



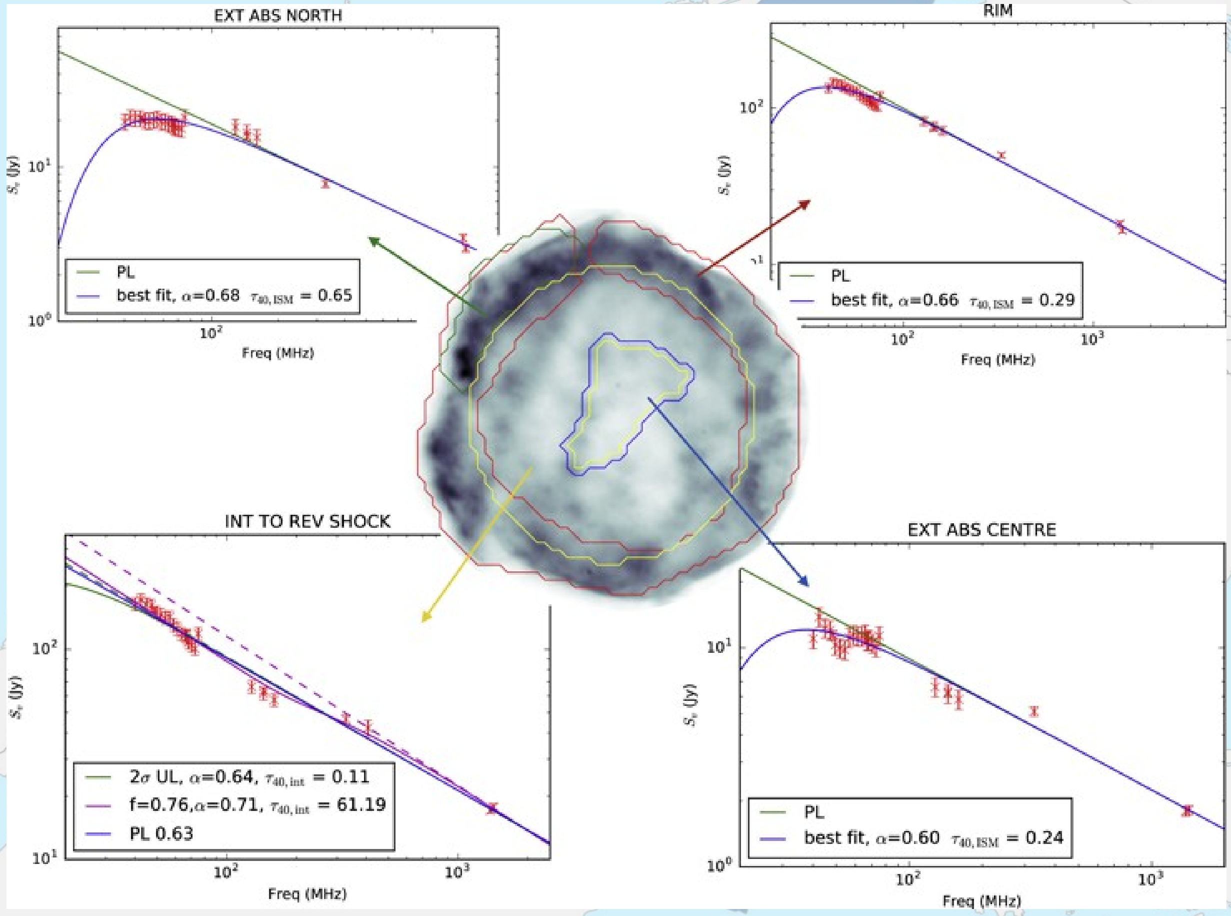
Arias, M., et al., *2018*, **A&A**, *612A*, 110

Free-free absorption in Cas A



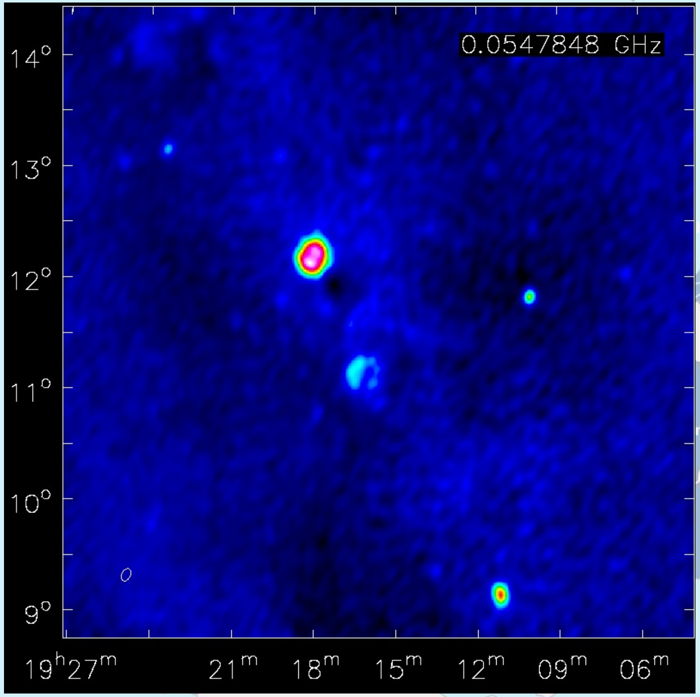
Arias, M., et al., *2018*, **A&A**, *612A*, 110

Tycho's Supernova Remnant



Arias, M., et al., *2019,* **AJ**, *158,* 253

LBA and HBA observations of HII regions



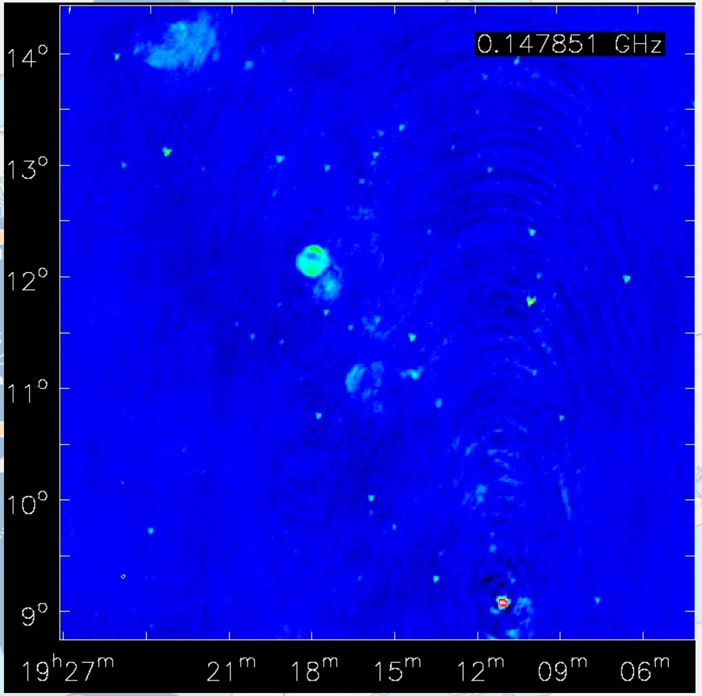
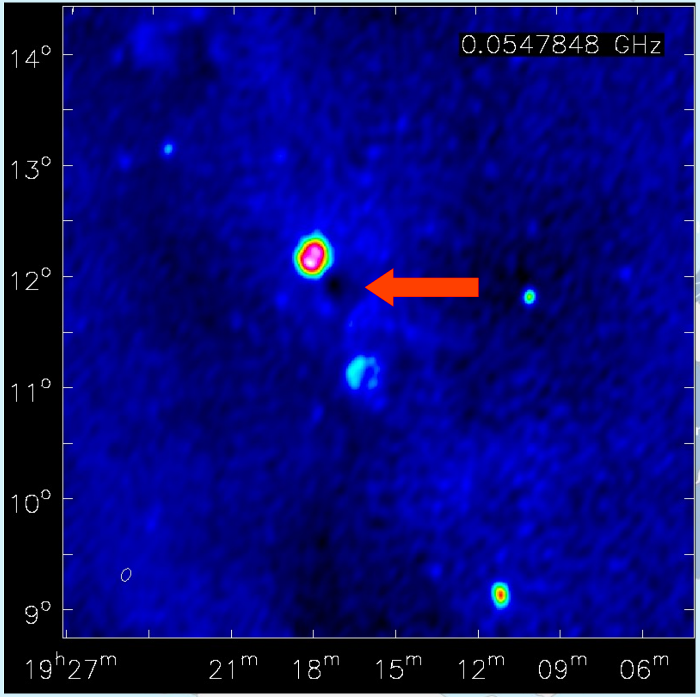


Image curtuesy of Irene Polderman

LBA and HBA observations of HII regions



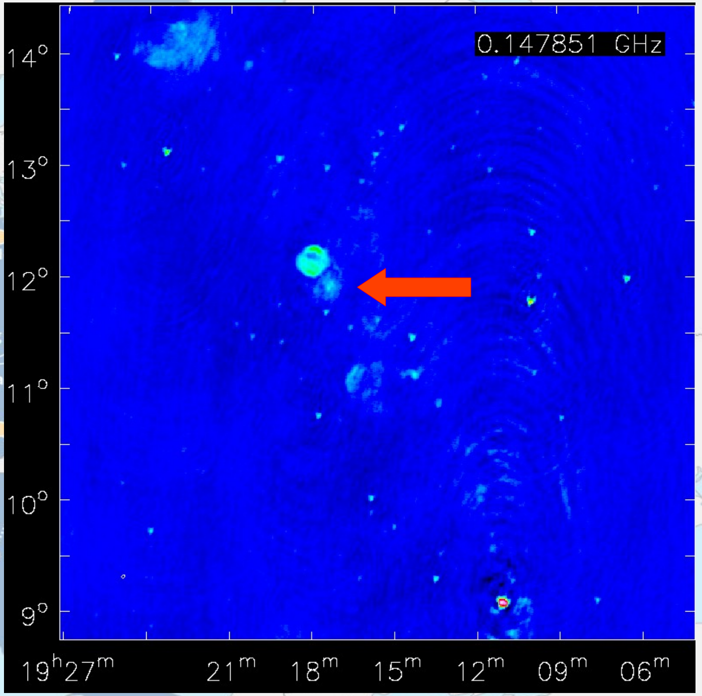
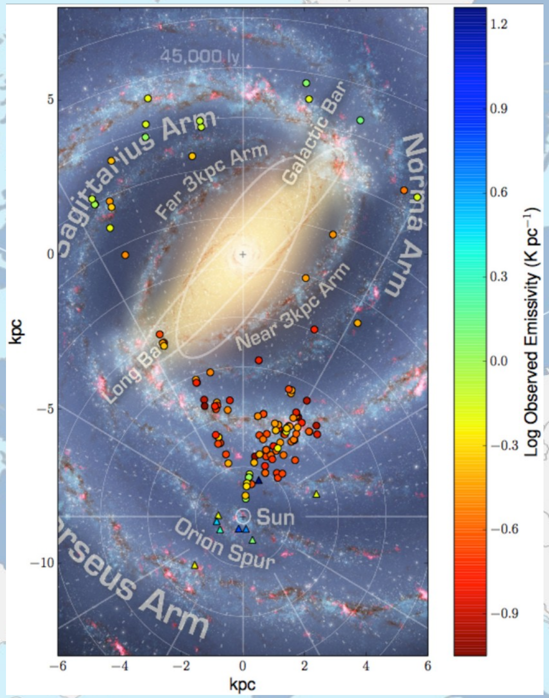


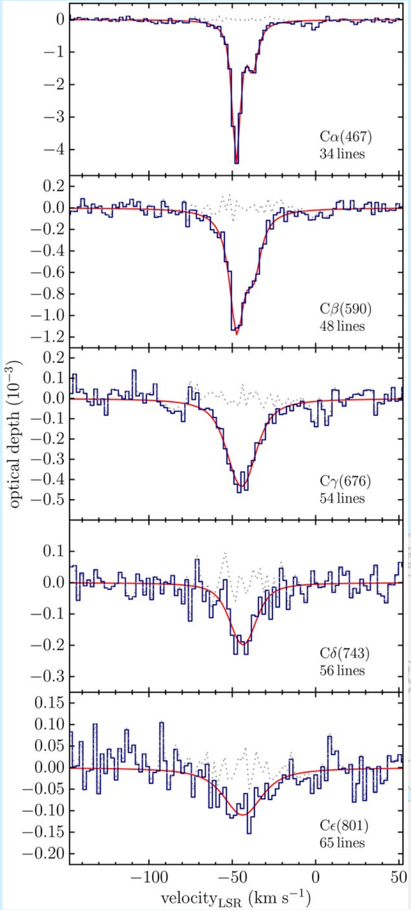
Image curtuesy of Irene Polderman

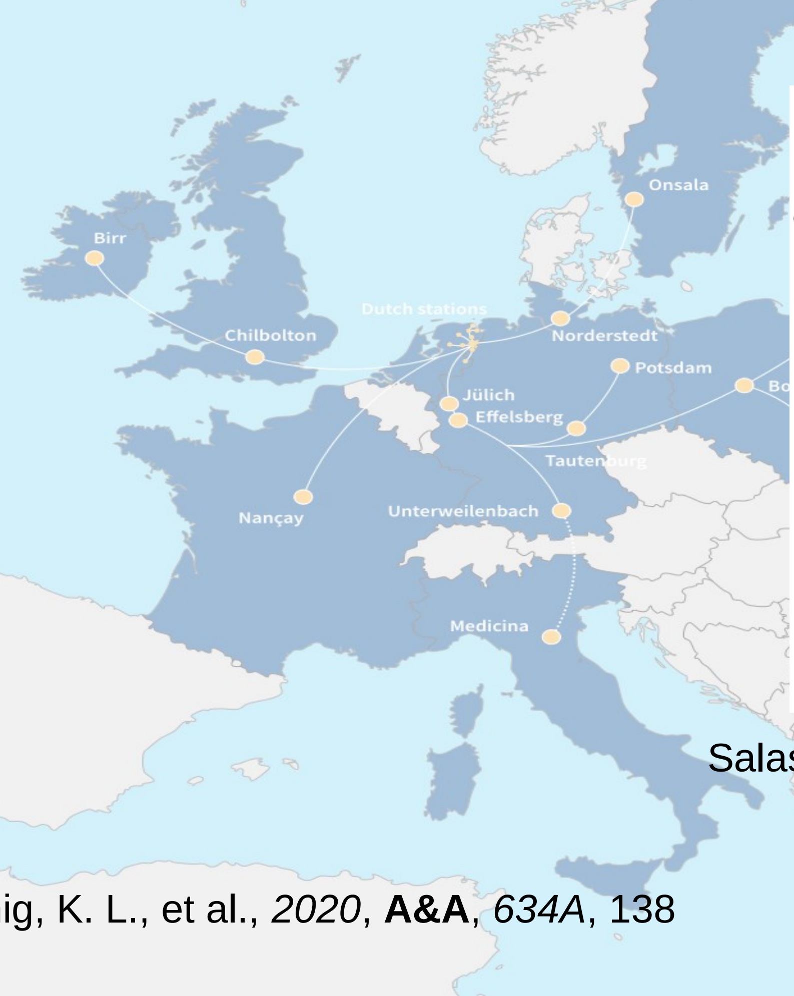
Studying Galaxy using HII regions

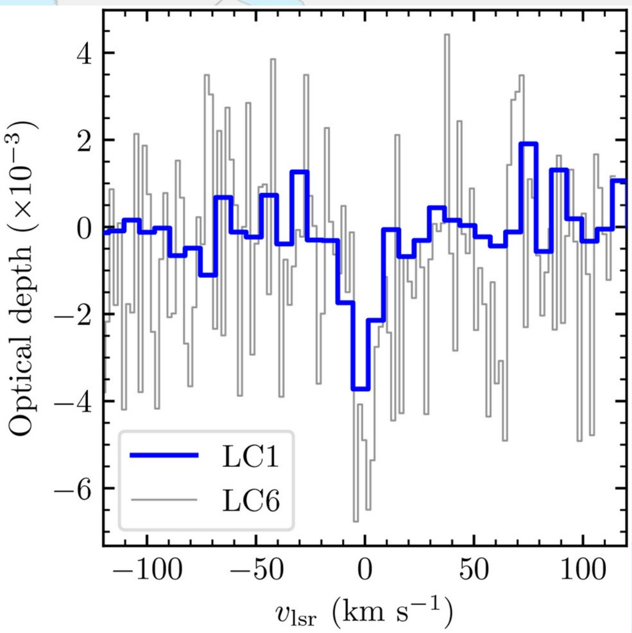


Poldrman, I., et al., *2019*, **A&A**, *621A*, 127

Radio recombination lines



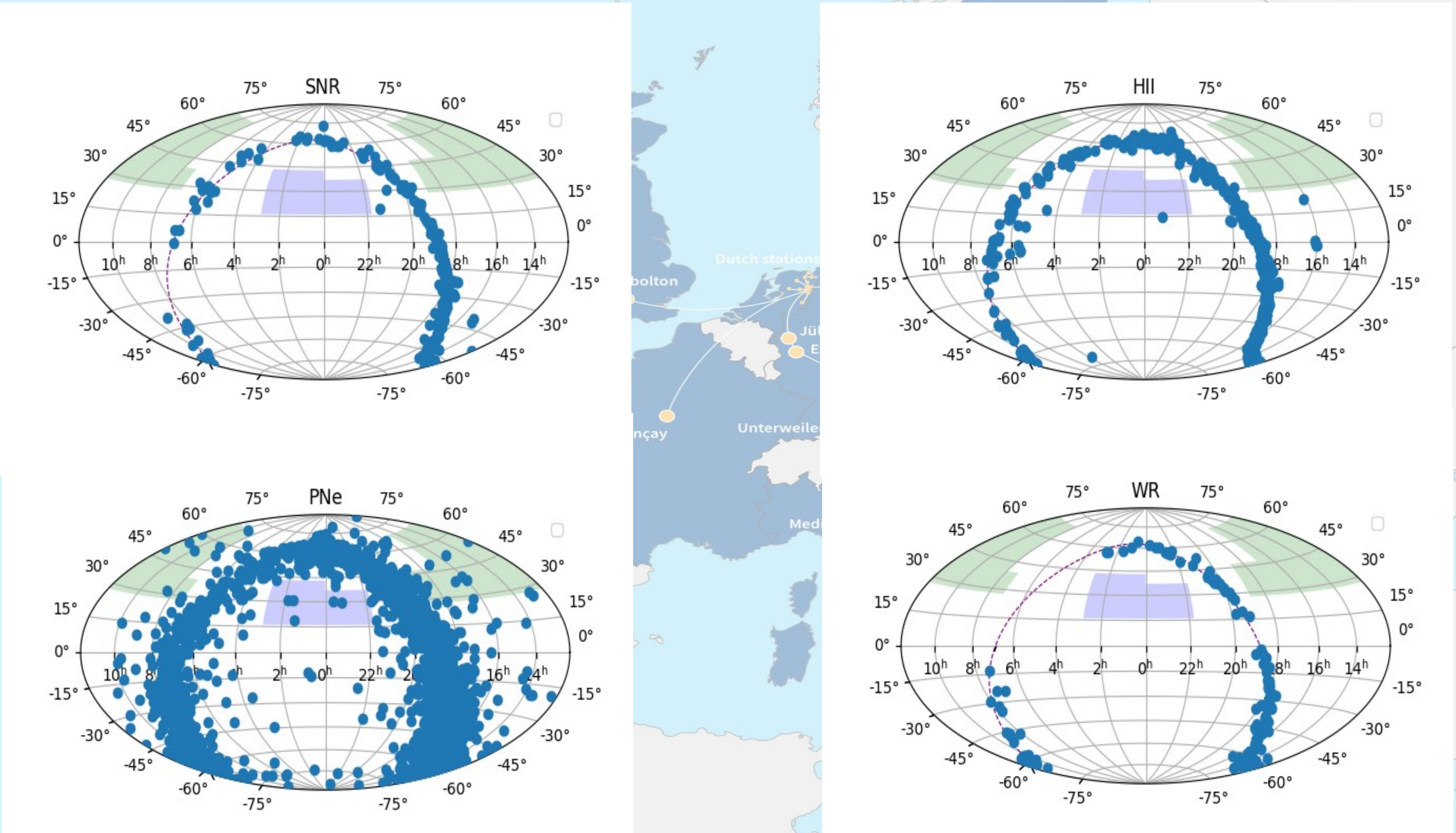




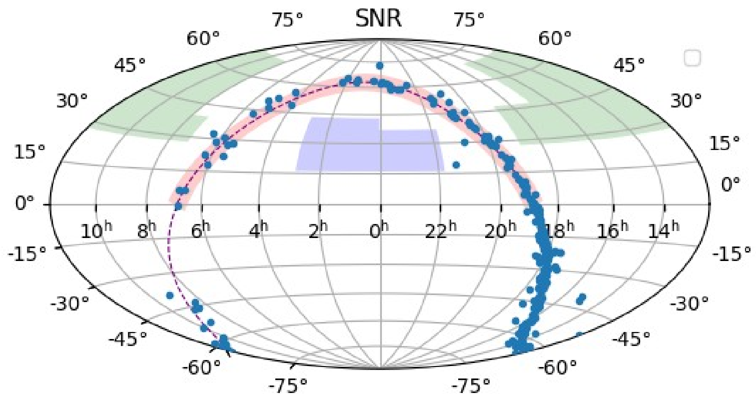
Salas, P., et al., *2019*, **A&A**, *626A*, 70

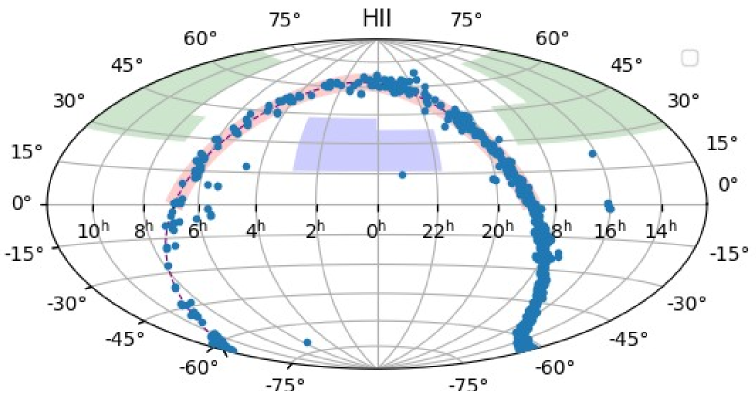
Emig, K. L., et al., *2020*, **A&A**, *634A*, 138

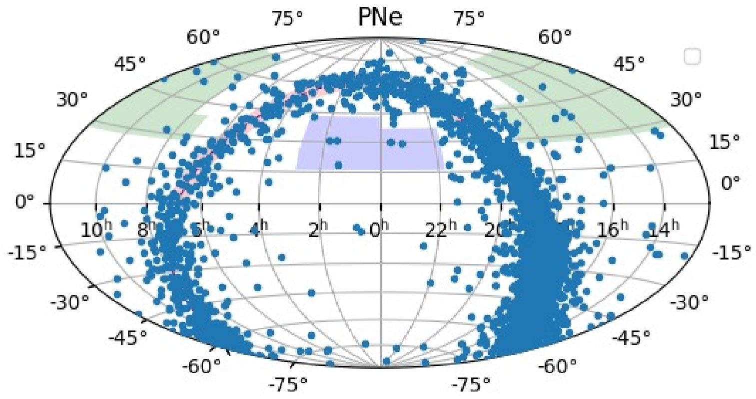
Sky distribution of Galactic nebulae

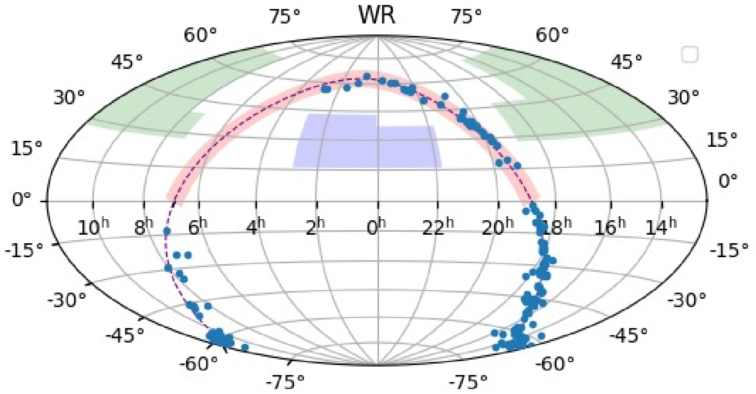


L2GPS – LOFAR 2.0 Galactic Plane Survey





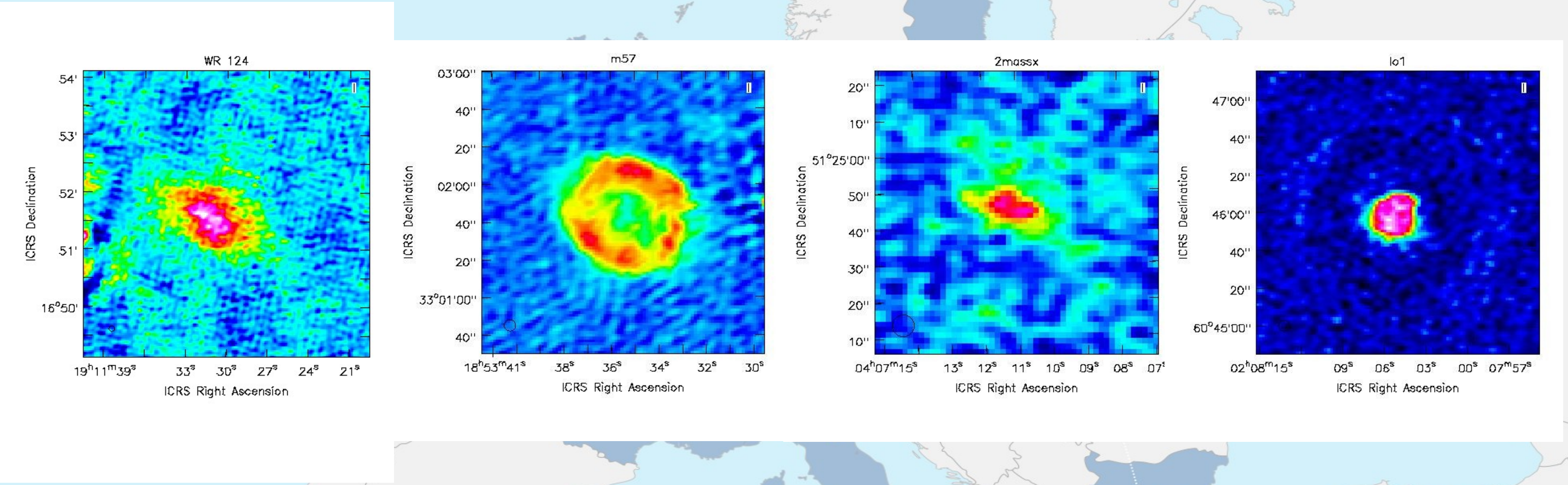




Galactic nebulae in LOFAR

- Ionized jets, shocked outflows in proto-stars
- Supernova remnants – identification, structure
- For opt. thick sources – mean and spatial variations of local electron temperature
- Interacting winds in WR binaries
- Novae, intermediate-luminosity optical transients,other cataclysmic variables
- Galactic structure using known HII regions and planetary nebulae
- Search for obscured HII regions and planetary nebulae

Galactic nebulae in LOFAR



For extragalactic objects see talks in the Nearby Galaxies session, e.g. by Etienne Bonnassieux, Lovorka Gajović, Deepika Venkattu