Scintillation from VERY Small-Scale HI

Carl Gwinn (UCSB), John Reynolds (CSIRO), Warwick Wilson (CSIRO)

See also: www.physics.ucsb.edu/~cgwinn/
Demos: Randy Russak

Outline

VERY Simple models
Optics Effects: Laser Demos
Observations and Analysis
Conclusions
Perhaps Neutral Gas is Unrelated to Small Ionized Structures: $l \approx 0.01$ AU
But Maybe Neutral Gas Has Very Small-Scale Velocity or Density Gradients, Too:

\[ \frac{\Delta V}{\Delta x} \approx 1 \text{ km s}^{-1}/0.1 \text{ AU} \]

(Thermal Speed)/(Scattering Angle×D)?
Or Maybe Tiny Ionized and Atomic Structures Have Similar Scales: $l \approx$ Fresnel Zone $\approx 0.01$ AU?
Scintillation: Light Traveling Along Different Paths Interferes, and the Speckle Pattern Sweeps Past Earth
Light Close Enough* in Frequency Will Create Identical Speckle Patterns

* Within 1 Scintillation Bandwidth
When Half the Scatterer is Occluded, the Speckle Pattern Changes
If the Occluder Blocks Only 1 Frequency, the Speckle Pattern Changes ONLY at That Frequency
If the Scatterer is Immersed in Material with an Index of Refraction, Speckles Change
If the Material Refracts at 1 Frequency, Speckles Change Only at that Frequency
Simulation:

• Continuum Scintillates
• Absorption Scintillates

Independently
PSR J1456-6843: HI Emission Off-Pulse and Absorption On-Pulse  
(see Koribalski et al. 1995)  
No Variation in Absorption Line Over ≈2.5 Yr  
(see Johnston et al. 2003)
Continuum flux density varies: consistent with scintillation

At $f_{\text{obs}}=1420$ MHz:
- Expected scintillation timescale $\Delta t_{\text{ISS}} \approx 1$ hr
- Expected scintillation bandwidth $\Delta \nu_{\text{ISS}} \approx 150$ MHz

Observations: 3 Nights at Parkes
Intensity in One Channel far from the HI Line Correlates Well with Scintillation Over a Wider Continuum Band
Intensity Variation at the Absorption Line Doesn’t Correlate as Well with Continuum Scintillation
The Mean Square Residual from Proportionality Quantifies the Correlation
Mean Square Residual Agrees with Expectation for Noise (Deshpande 2000) …and is less than expected for Neutral Material varying 100% in column density across the scattering disk
Conclusions

• *Really* small-scale HI structures could create:
  – Differences in scintillation **on** and **off** the HI line

• We *don’t* see differences, other than those expected from noise

• Our observations say: HI absorption can’t vary by 100% across the scattering disk, for PSR J1456-6843
1.2x10^{21} \text{ cm}^{-2} \text{ HI Atoms will introduce a phase change of 1 radian (at } f_0=1.42 \text{ GHz, } T_s=100 \text{ K, } T_{\text{kin}}=100 \text{ K)}

8.1x10^{10} \text{ cm}^{-2} \text{ electrons will introduce a phase change of 1 radian (at } f_0=1.42 \text{ GHz)}

\textbf{PSR J1456-6843}

3x10^{19} \text{ cm}^{-2} \text{ electrons}

1x10^{20} \text{ cm}^{-2} \text{ HI Atoms}
In the ISM:

Ionized Gas Structures Can Be Very Small

Are Atomic Clouds Small Too?
Perhaps Atomic Gas is Unrelated to Small Ionized Structures, But Maybe Atomic Gas Has Small-Scale Velocity or Density Gradients, Too:

$$\Delta V/\Delta x \approx (\text{Sound Speed})/(20 \text{ AU})$$

Or Maybe Ionized and Atomic Structures Have Similar Scales.
Intensity variations at Maximum Absorption Don’t Correlate as Well
But if absorbing material were scintillating, we would see zero correlation.
Yup, Much Smaller
Intensity Variation at the Absorption Line Doesn’t Correlate as Well

We can quantify the difference with mean square residual.
Intensity Variation at the Absorption Line Doesn’t Correlate as Well
The RMS Residual Agrees with Expectation for Noise
See Deshpande 2000

Mean square instead of square, show height as found from simulation, compare with depth of abs feature in previous