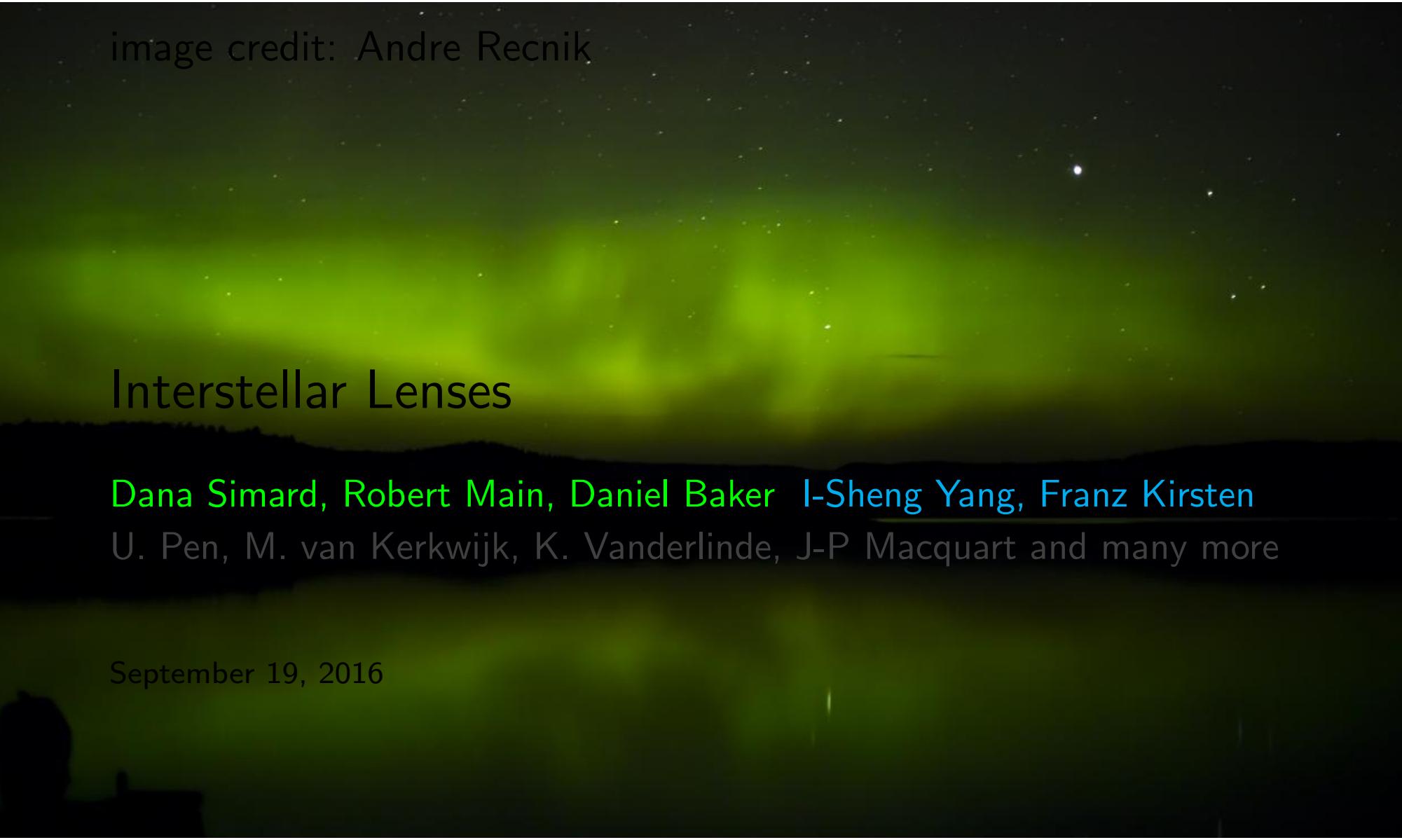


Interstellar Lenses

Dana Simard, Robert Main, Daniel Baker I-Sheng Yang, Franz Kirsten
U. Pen, M. van Kerkwijk, K. Vanderlinde, J-P Macquart and many more

September 19, 2016

Facts

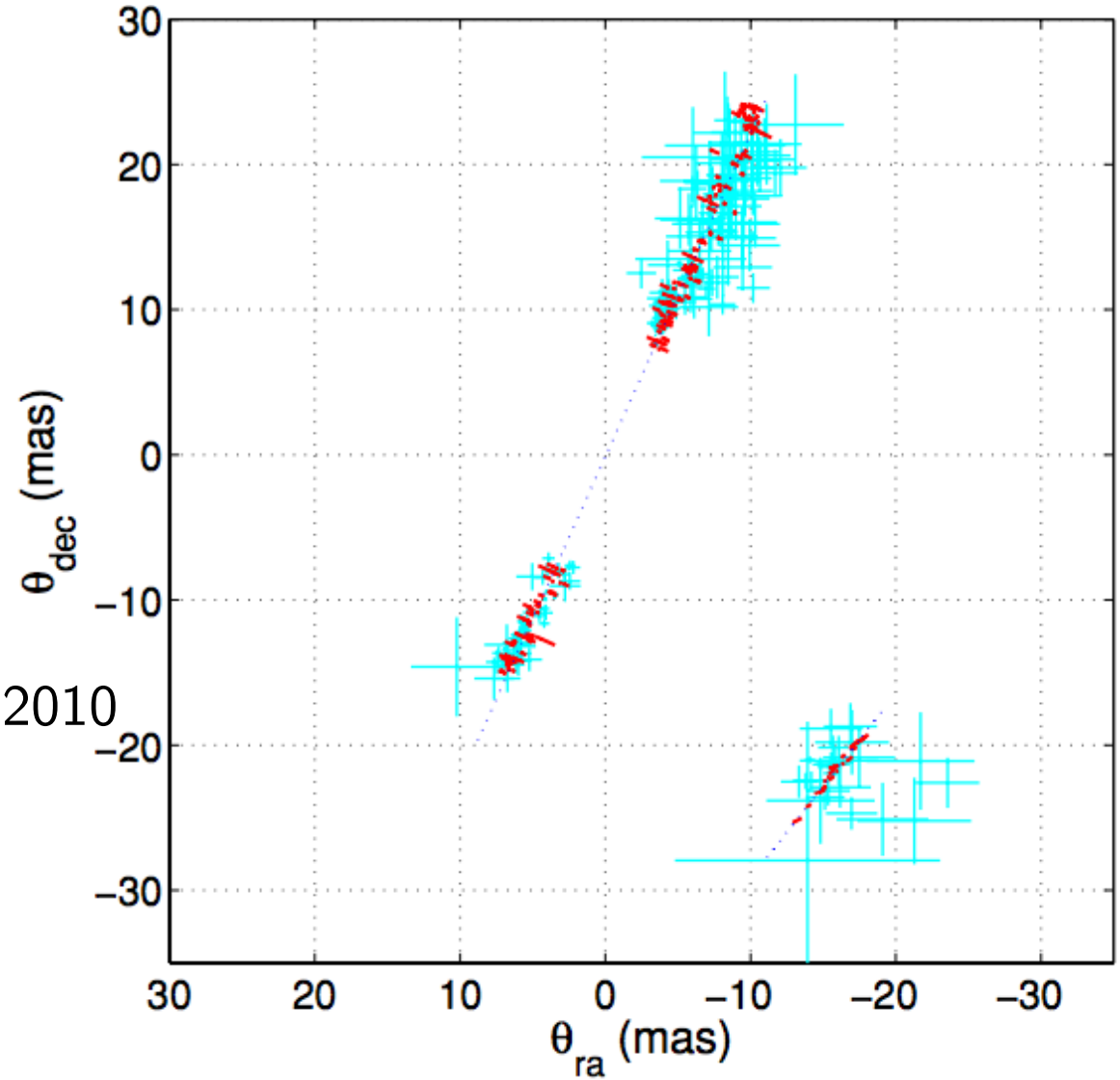
- multipath propagation leads to delays $\sim$ ms
- bending angles $\theta \sim$ mas
- for diffraction $\theta \sim \lambda/D \implies D \sim 1000$km
- for refraction $\theta \sim \Delta n \implies n_e \sim 100\text{cm}^{-3}$
- observed dominant isolated 1-D scattering screens (Stinebring et al 2000++: inverted parabolic arcs, Brisken et al: 2010 VLBI)

Diffraction

- first proposed half a century ago
- thought due to turbulence down to scales $D \sim 1000$km
- angles depend only on length scale, image intensity depends on density contrast
- intensity ok if space filling
- hard to reconcile with inverted parabolic arclets, VLBI

Sheets

$D_S = 640$pc
$D_L = 400$pc
Brisken et al 2010



Refraction

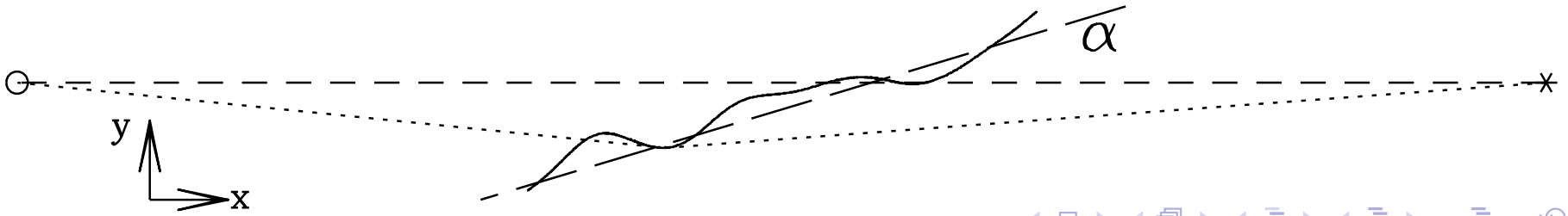
- modest number of real, refractive images interfere to create interference pattern
- observational effects similar to diffraction
- to form real image for two light rays separated by $D \sim 10^{10}$m requires $\sim \lambda$ path length difference.
- $\lambda = \int_z \Delta n \implies \Delta n \sim \lambda/z$
- for isotropic lens $z \sim D$ we get
- $\Delta n = -\lambda^2 r_e n_e / 2\pi \sim 10^{-11} \frac{n_e}{0.03\mathrm{cm}^{-3}} (\frac{\lambda}{\mathrm{m}})^2$
- at face value requires $n_e \gg 1$ (free electrons, $T >$10,000K)!

Challenges to refactive picture

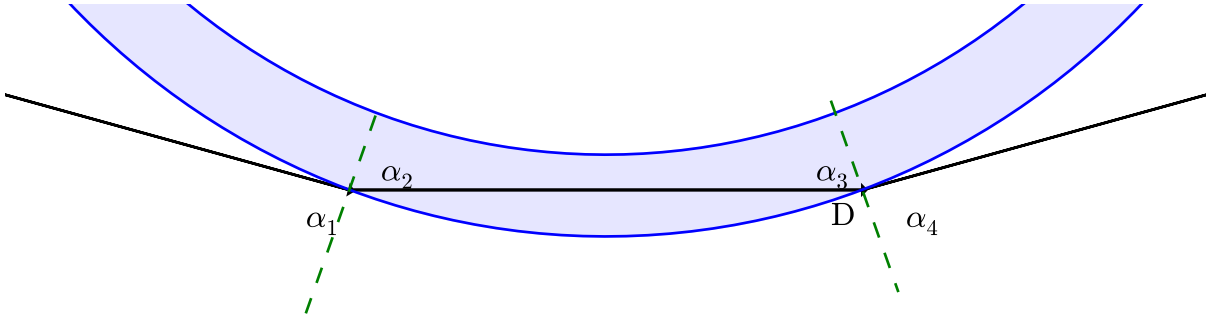
- unreasonable plasma densities for pressure equilibrium $P = nkT$
- proposed solutions: 1. explosive. strange quarklets (Pérez-García et al 2013), baryonic dark matter (Walker 2001++)
- 2. static. isotropic: cosmic strings (Thompson),
- anisotropic: folded sheets (Goldreich-Shridhar 2006, ULP-Levin 2014)
- Note: random filaments not dominated by extreme alignments, sheets always dominated by extreme.

Speculation

- reconnection sheets
- grazing incidence
- ULP + King 2012
- ULP + Levin 2014
- Liu + ULP 2015
- 1-D structure
- localized scattering



Folds



Refraction of light rays near point D. The black lines are the light paths. The shaded region indicates the lensing sheet caustic. The angles obey Snell's Law $\frac{\sin(\alpha_1)}{\sin(\alpha_2)} = \frac{\sin(\alpha_4)}{\sin(\alpha_3)} = \frac{n_{\rm sheet}}{n_{\rm ISM}}$.

Magnetized plasmas

- local fields relax to straight lines: anlogy to ferromagnet (Gruzinov 2009, braithwaite 2015)
- domain boundaries form with current sheets
- likely long lived (Sweet-Parker 1956)
- corrugated by 'ducted waves'
- not to be confused by 'tearing modes' etc.

Predictions

- doppler velocity dependence of RM (LOFAR?)
- (non-) evolution of inverted arclets, VLBI image positions
- (evolution of) space-VLBI visibilities
- multi-plane geometries (Liu+Pen 2015)

Looking Forward

- new paradigm emerging for ISM structure
- pulsar VLBI monitoring
- connection to Extreme Scattering Events (ESE).
- galactic center scattering
- magnetosphere mapping
- see talks by Dana, Rob, Daniel, Franz, etc