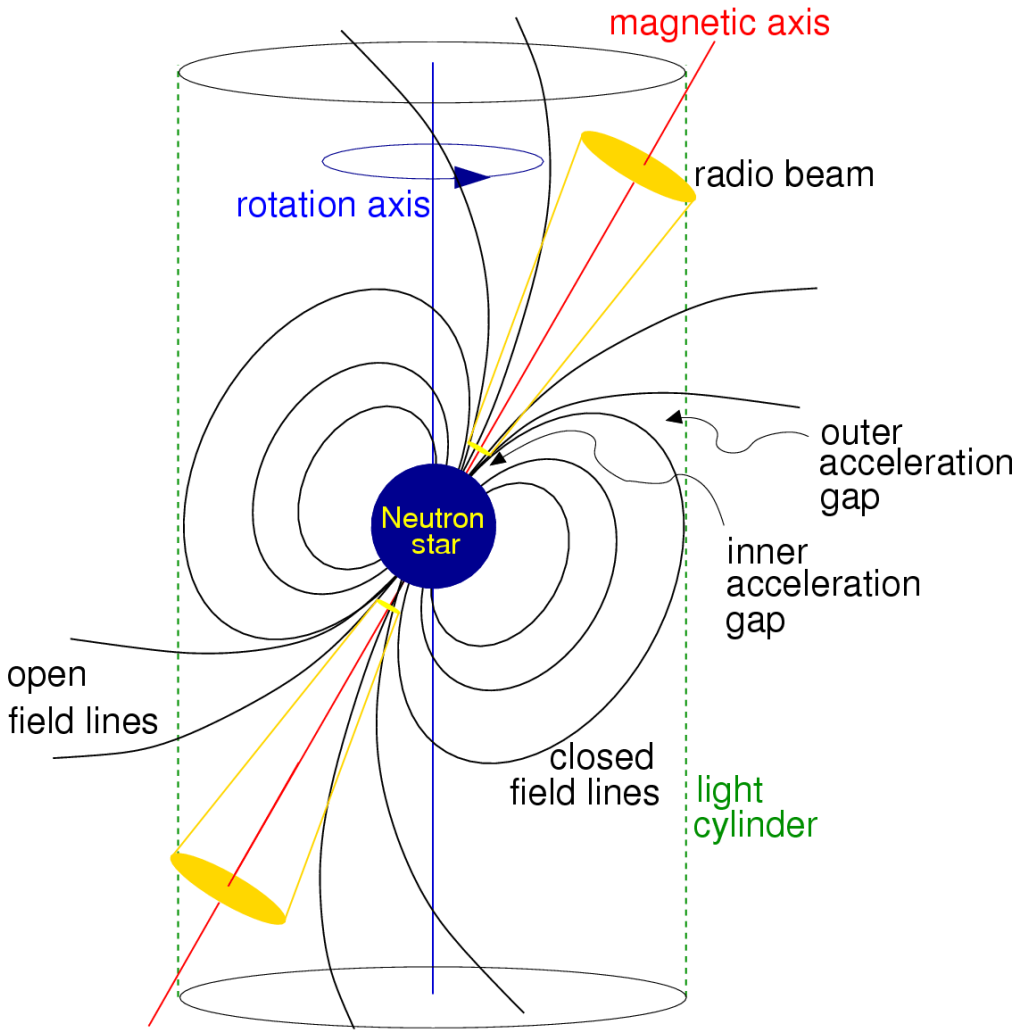
International Centre for Radio Astronomy Research

Resolving the emission region of pulsars with scintillometry

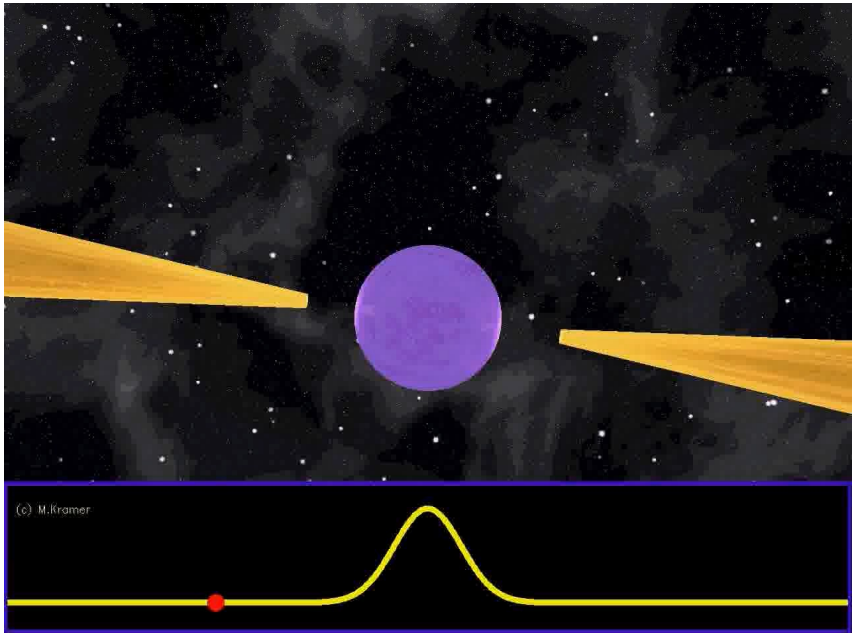
Franz Kirsten
J.-P. Macquart, U.-L. Pen, M. v. Kerkwijk

THE UNIVERSITY OF WESTERN AUSTRALIA

Pulsars

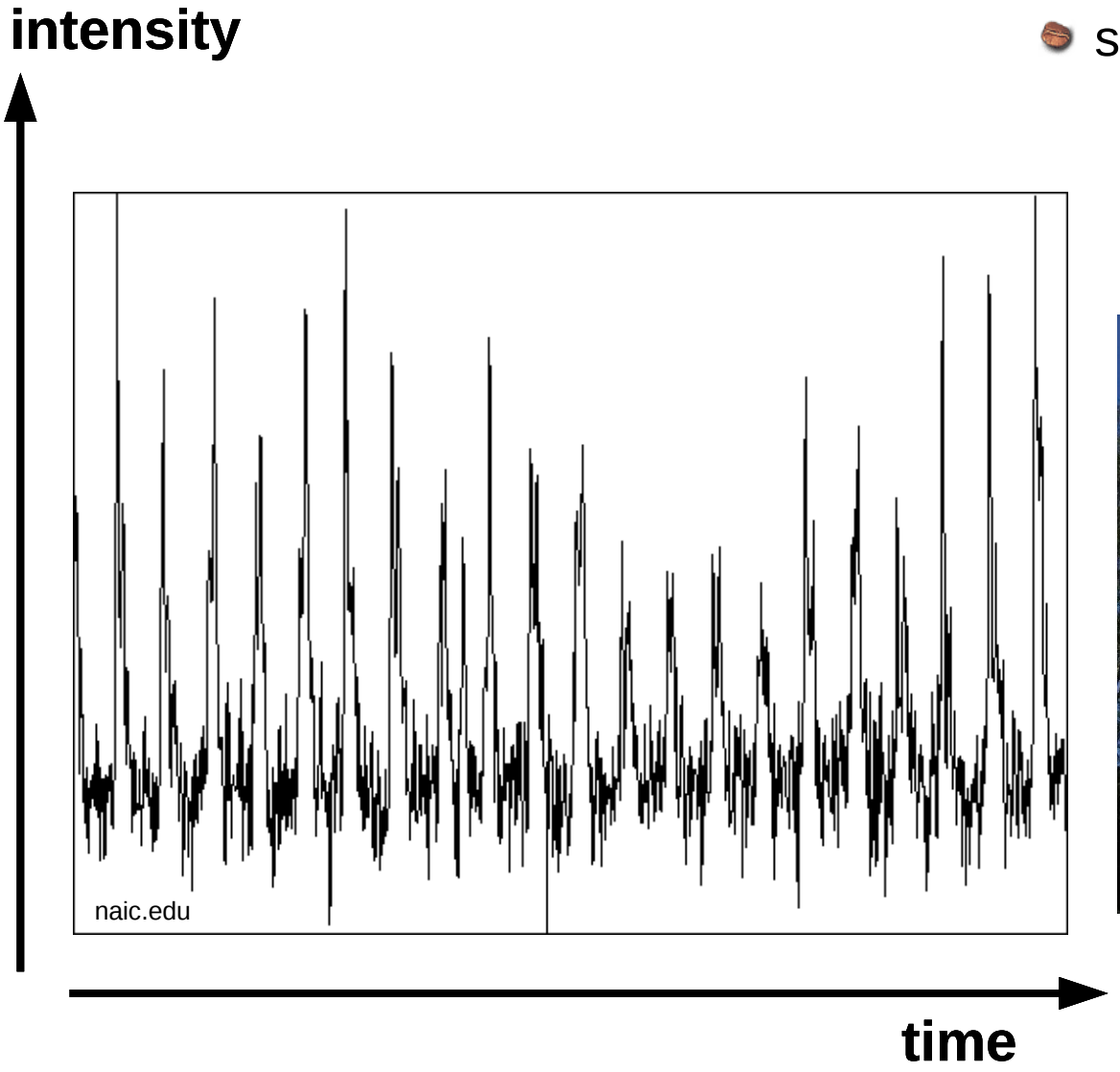


Lorimer & Kramer (2005)



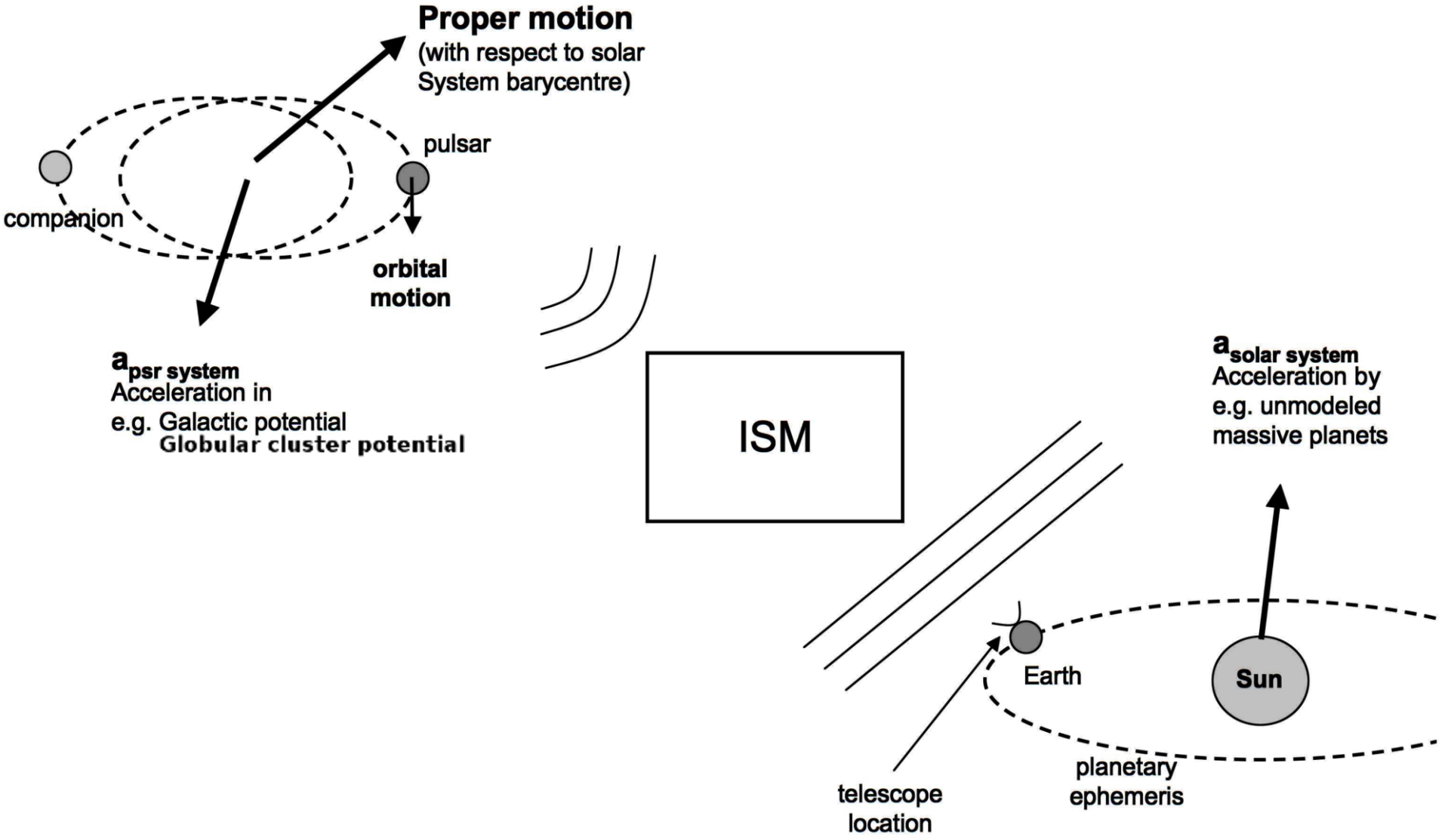
- final left over of a massive star that exploded in a supernova $(8 \lesssim \mathrm{M}_*/\mathrm{M}_\odot \lesssim 15)$
- $M_{\mathrm{NS}} \sim 1.4\,\mathrm{M}_\odot$
- $R_{\mathrm{NS}} \sim 10\,\mathrm{km}$
- $\rho_{\mathrm{NS}} \sim 2\rho_0$
  → extremely insteresting for condensed matter physics

Pulsars



- something ticking like a clock
  - $P \sim 0.001 - 10\,\mathrm{s}$
  - $\dot{P} \sim 10^{-20} - 10^{-13}\,\mathrm{s\,s^{-1}}$

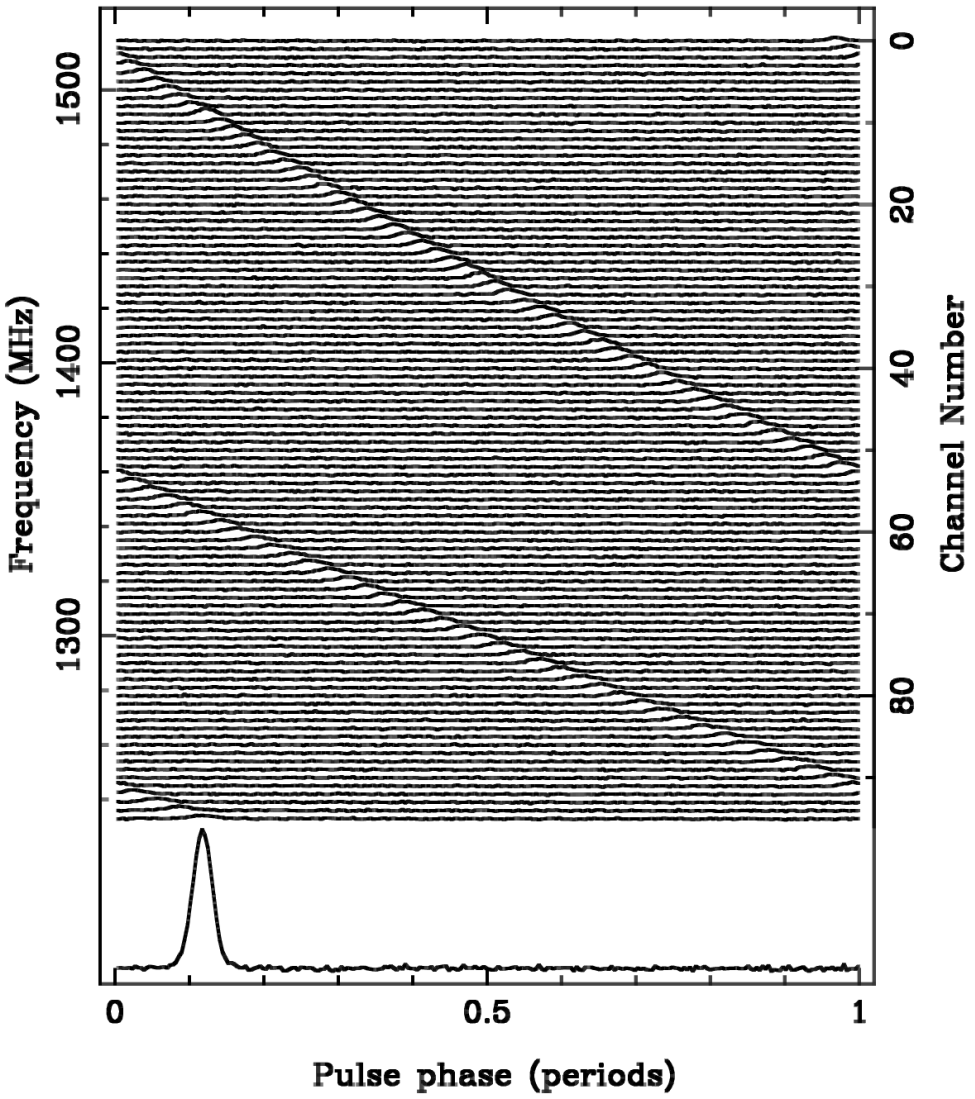
Pulsars



Adam Deller Phd Thesis, 2009

Pulsars

Lorimer & Kramer (2005)

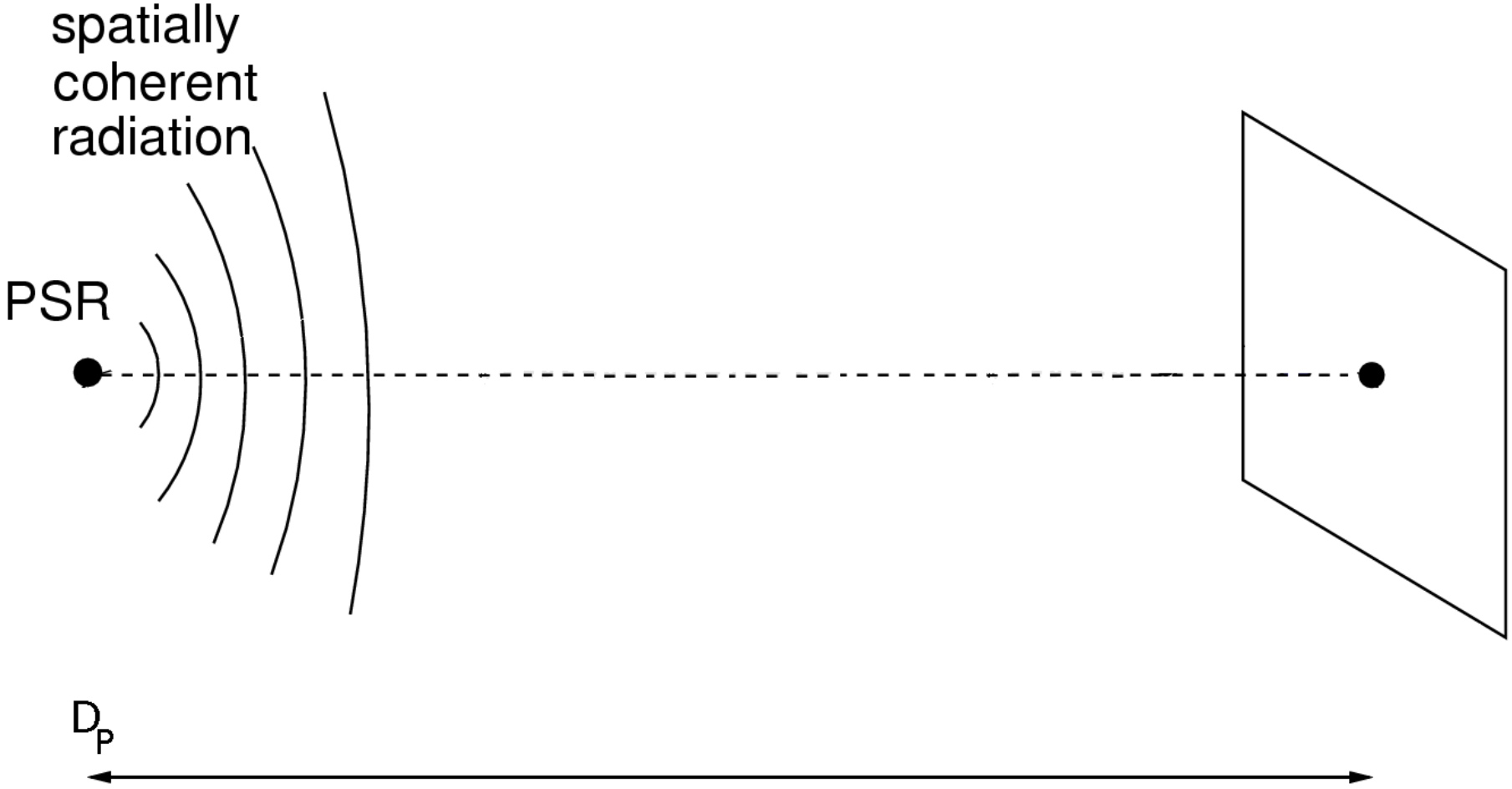


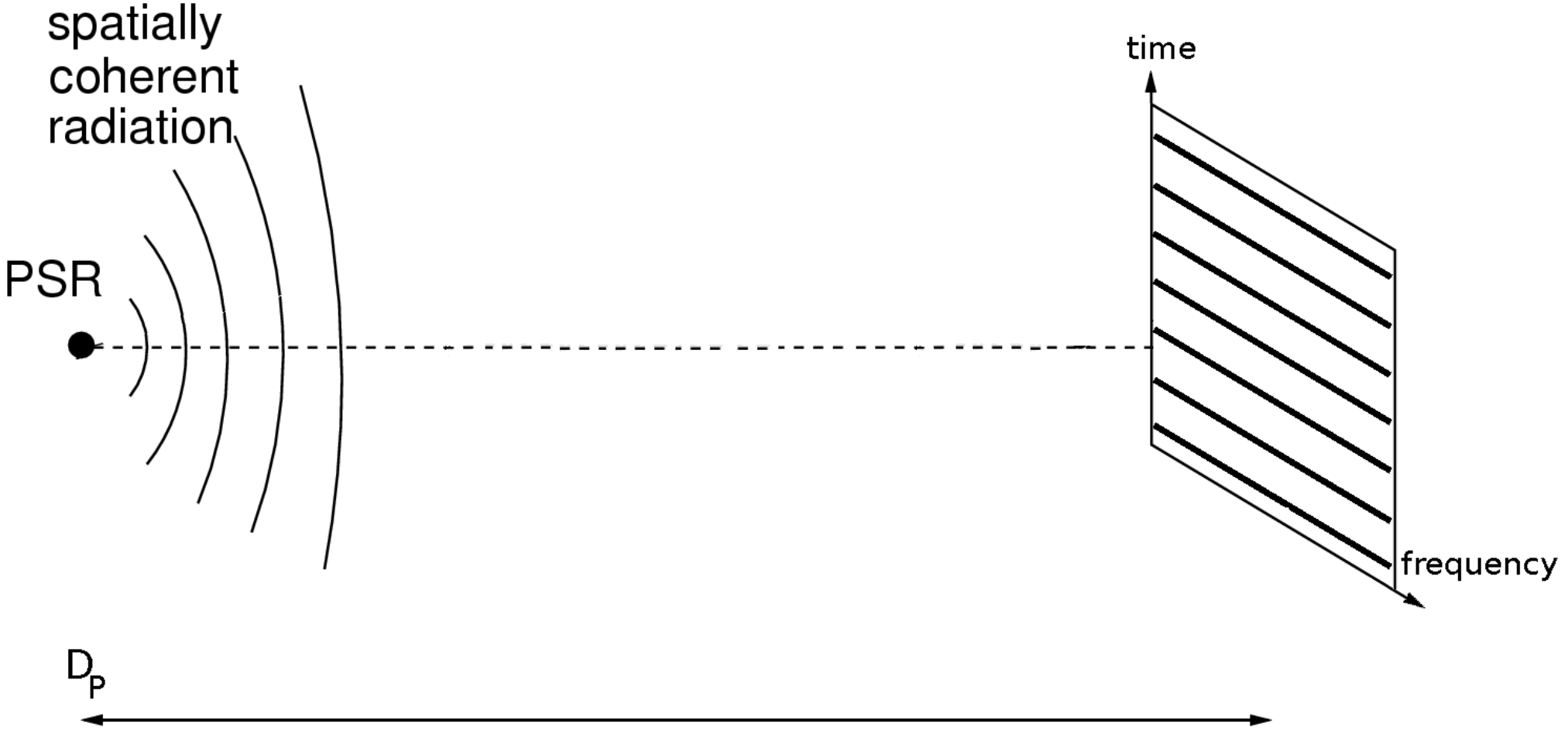
$$\Delta t \propto (\nu_1^{-2} - \nu_2^{-2}) \times \int_0^d n_e dl$$

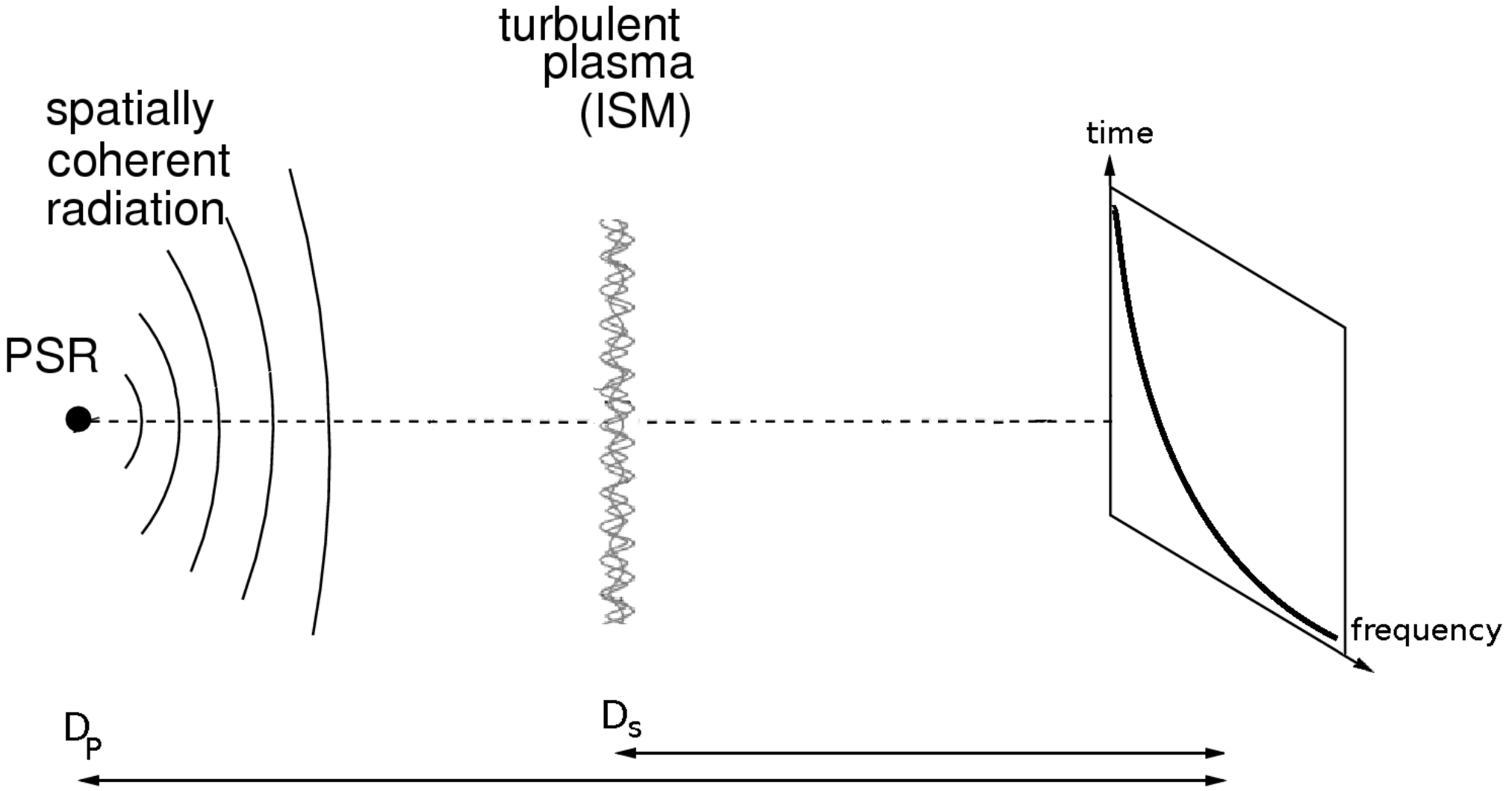
Pulsars astrometry with VLBI

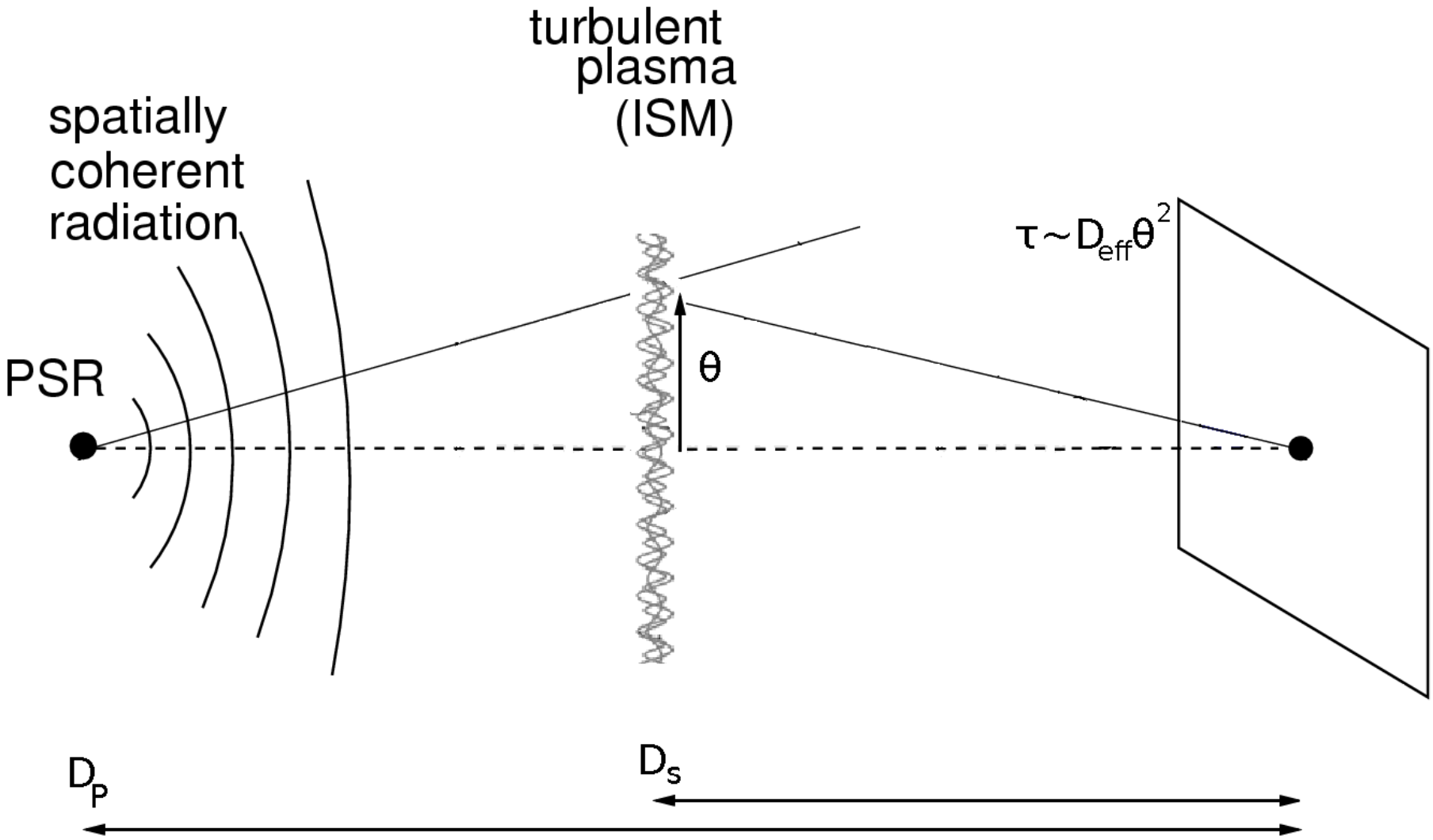
- Model independent determination of parallax and proper motion
- Confine Galacitic electron density models
- Lift degeneracies between pulsar timing model parameters
- Tie optical frame of reference to ICRF

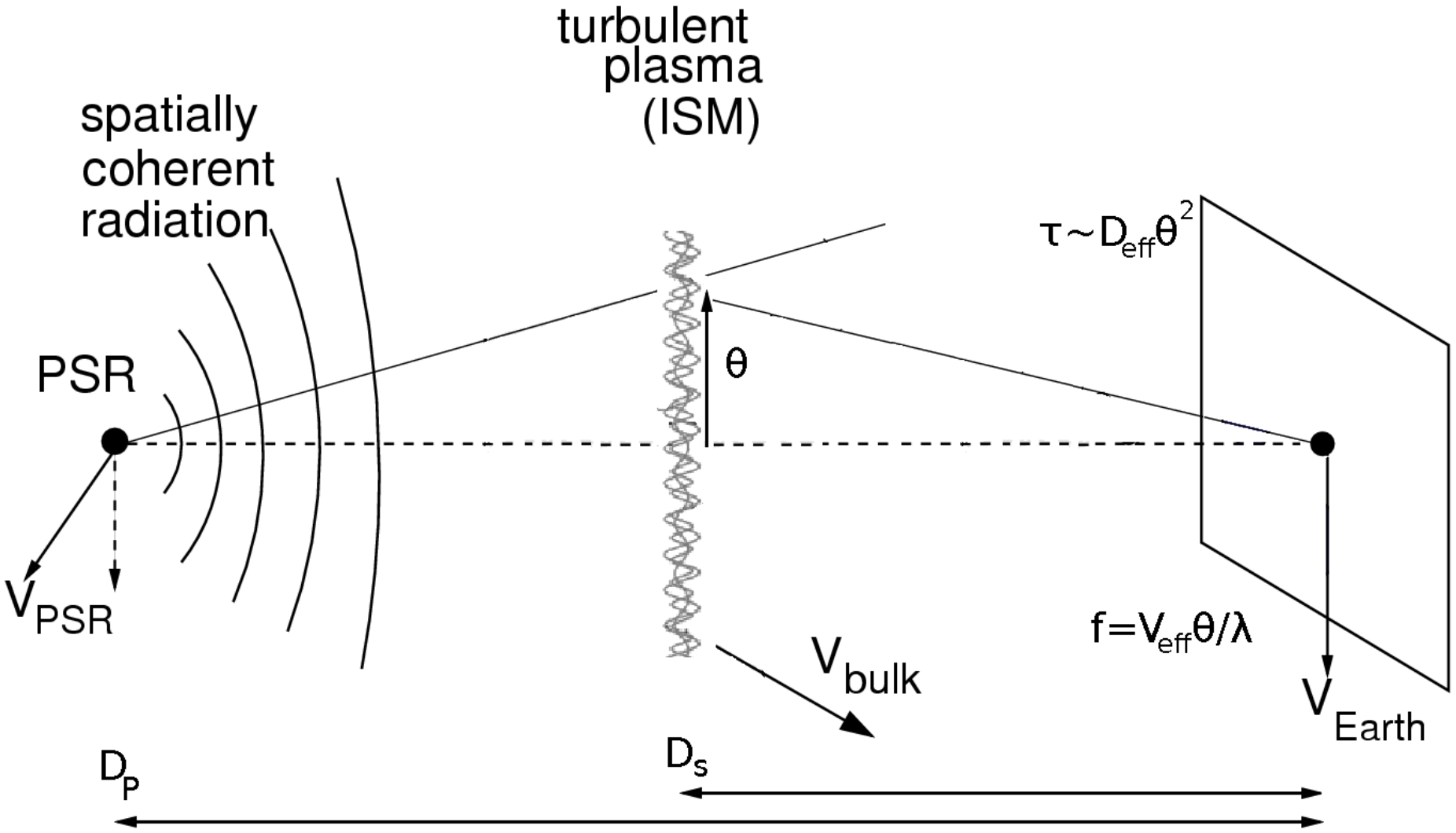
Pulsar scattering and scintillation

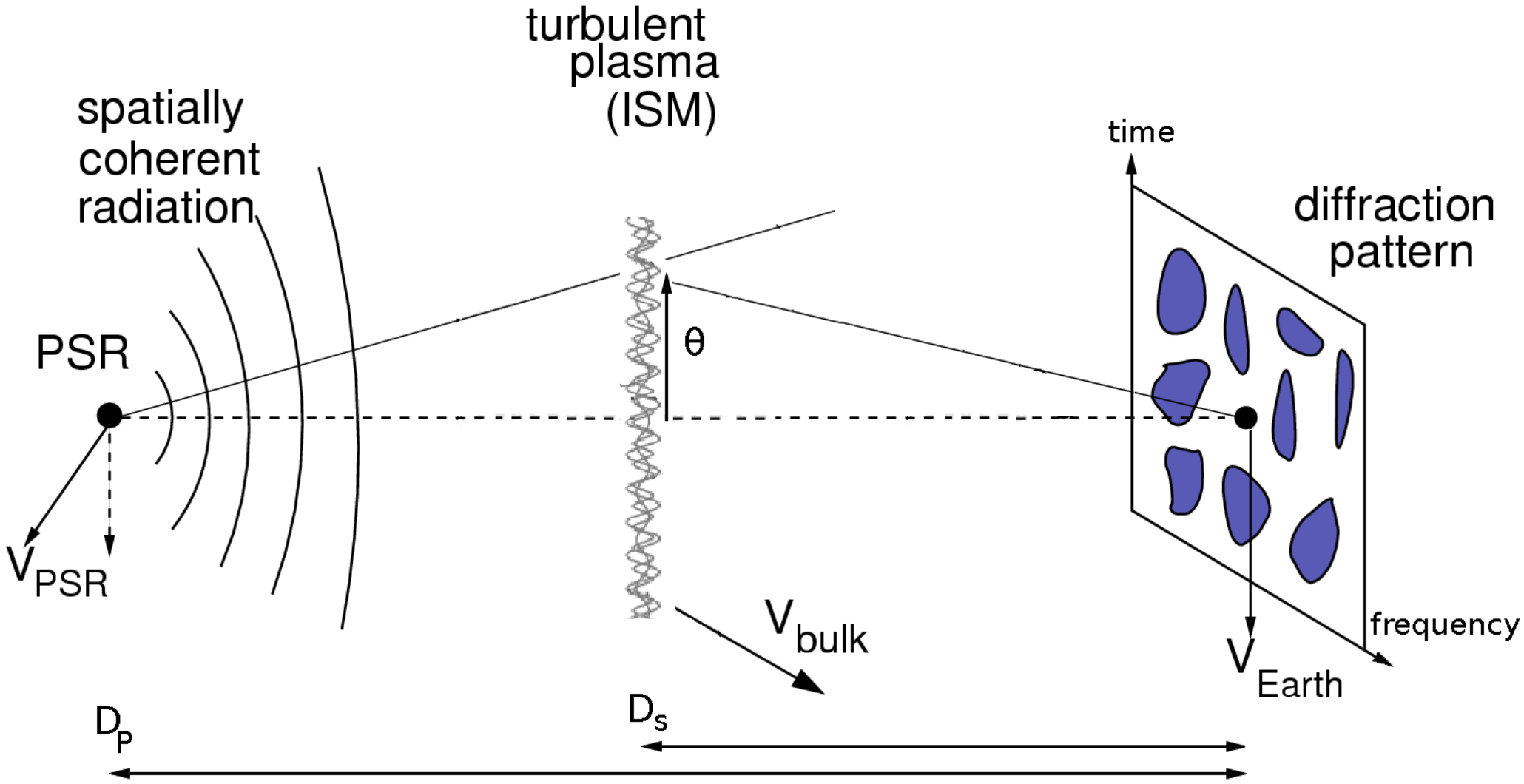



spatially
coherent
radiation
PSR
time
frequency
D_P

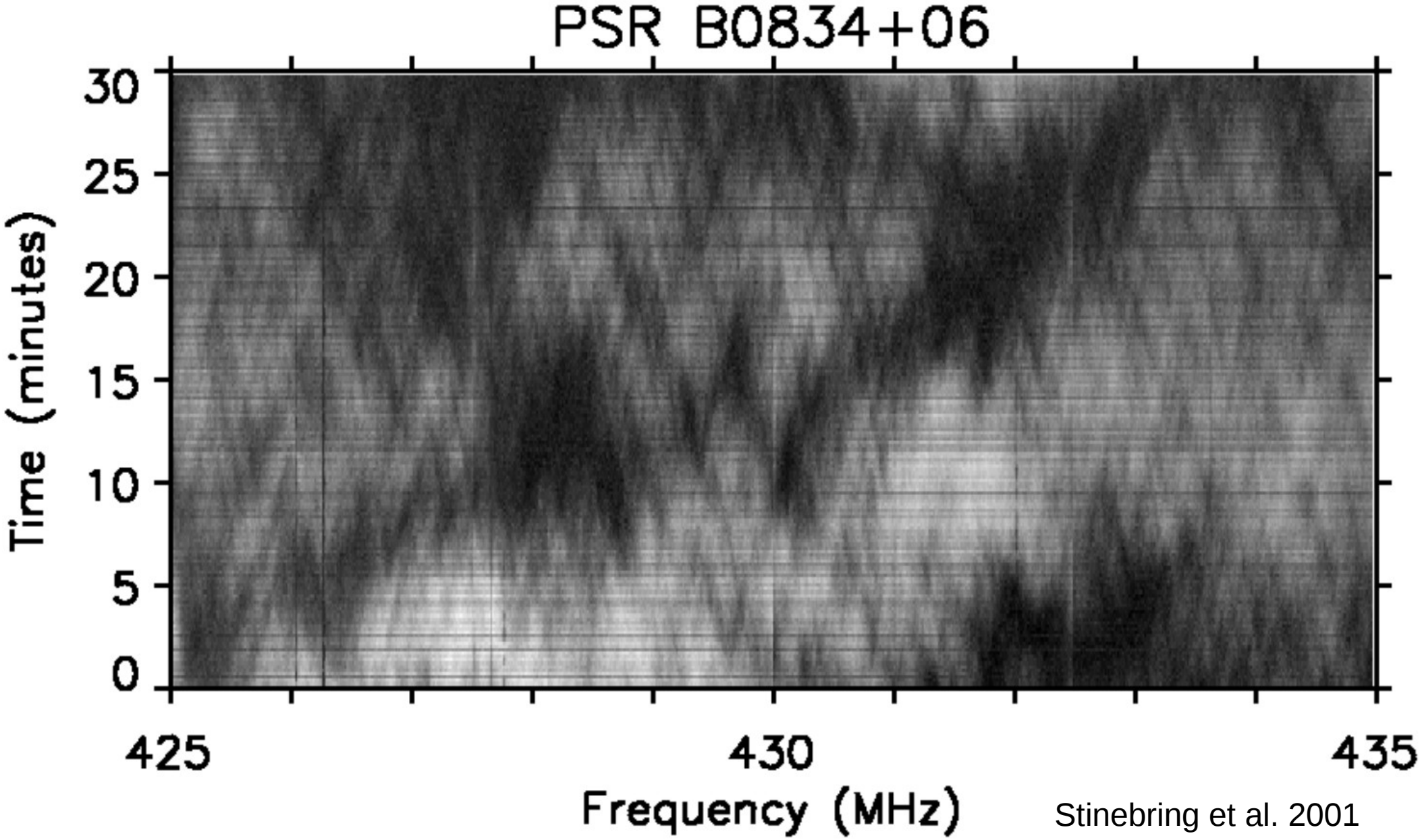

turbulent
plasma
(ISM)
spatially
coherent
radiation
PSR
time
frequency
D_P
D_s


turbulent
plasma
(ISM)
spatially
coherent
radiation
PSR
θ
τ~D_eff θ^2
D_P
D_s


turbulent
plasma
(ISM)
spatially
coherent
radiation
PSR
θ
τ~D_eff θ^2
V_PSR
V_bulk
f=V_eff θ/λ
V_Earth
D_P
D_s

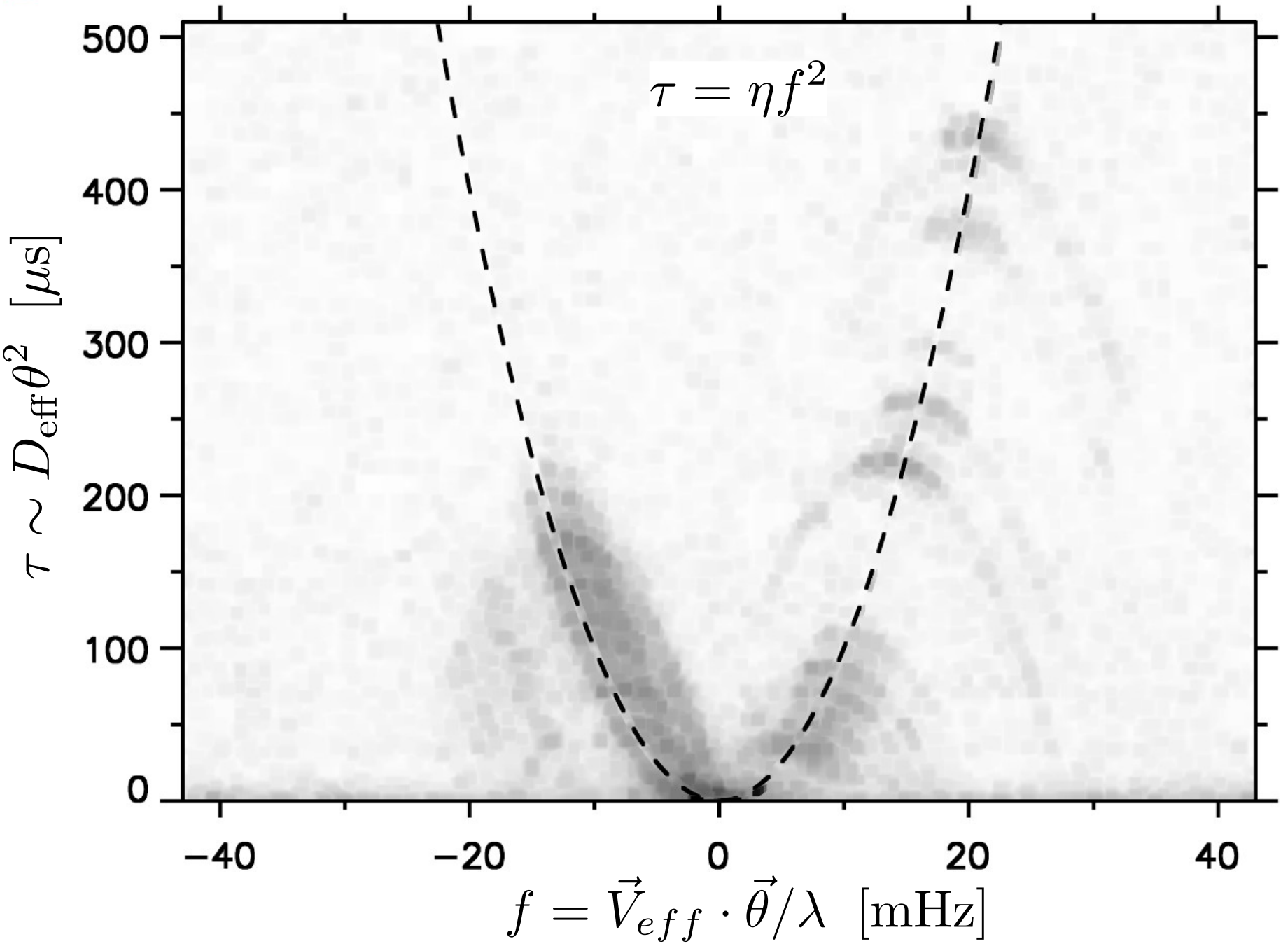

turbulent
plasma
(ISM)
spatially
coherent
radiation
time
diffraction
pattern
PSR
θ
V_{PSR}
V_{bulk}
frequency
V_{Earth}
D_P
D_s

Dynamic spectrum: I(t,v)



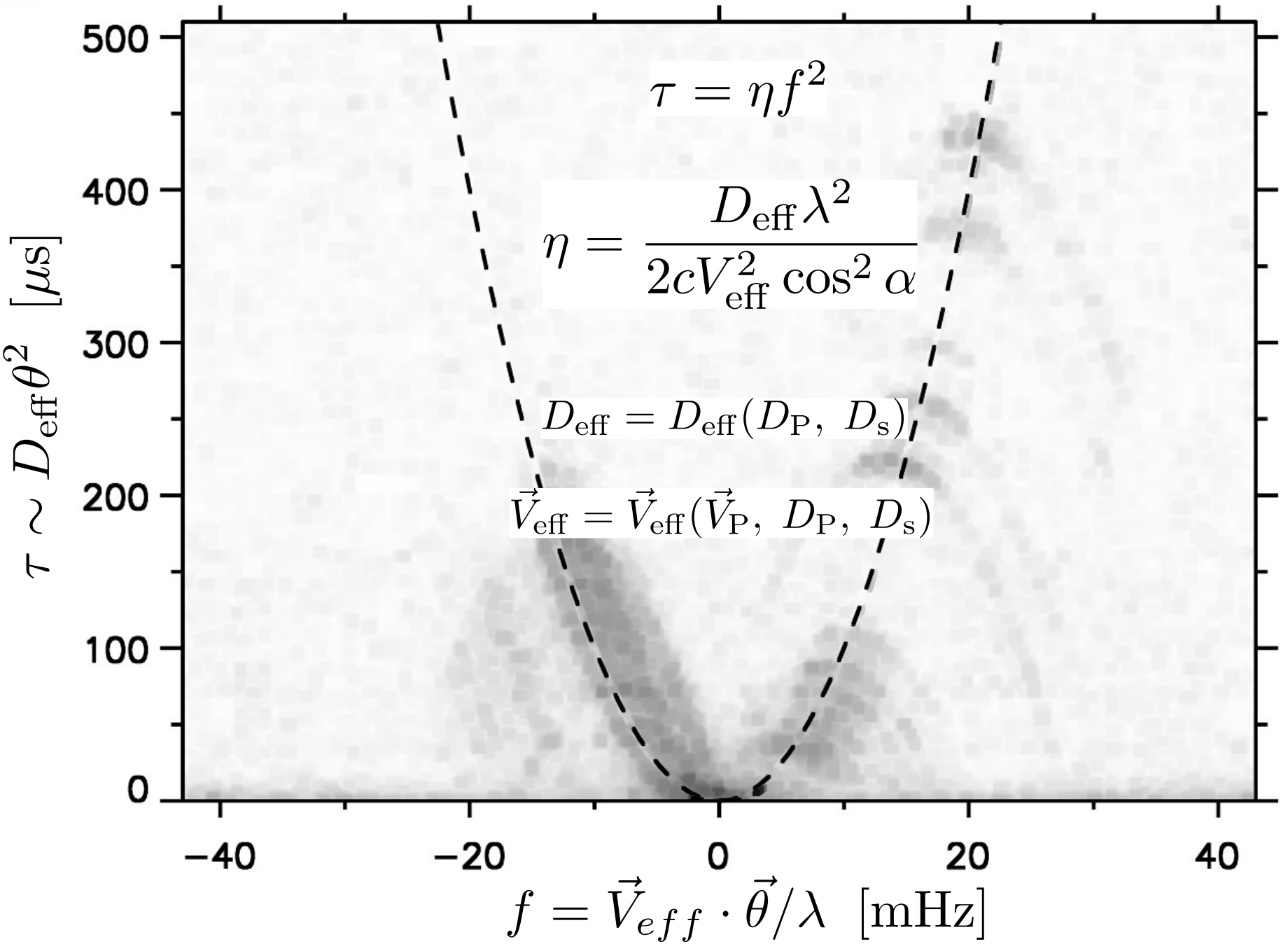
Stinebring et al. 2001

Secondary Spectrum: $|F(I(t,\nu))|^2$



Walker et al. 2004

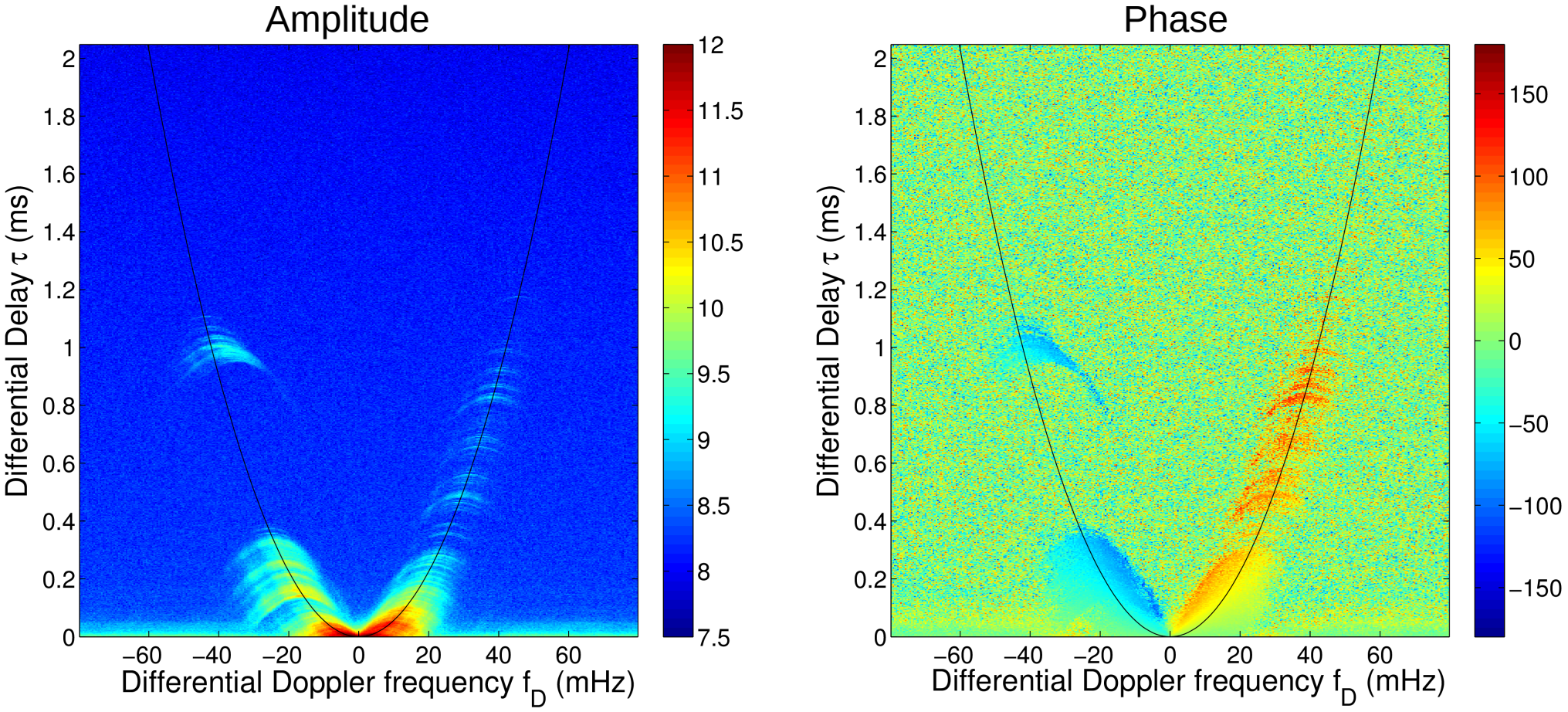
Secondary Spectrum: $|F(I(t,\nu))|^2$



Walker et al. 2004

Secondary Cross Spectrum

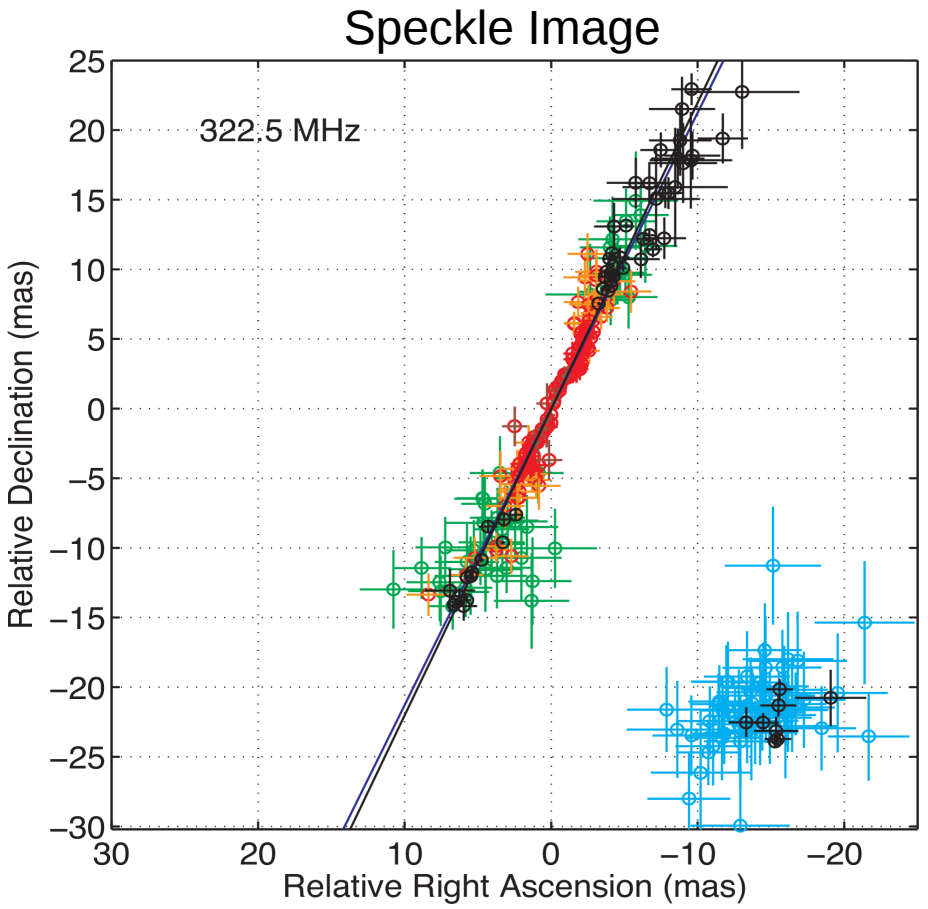
$$C(\tau,\ f,\ \vec{b}) = \tilde{V}(\tau,\ f,\ \vec{b})\ \tilde{V}(-\tau,\ -f,\ \vec{b})$$

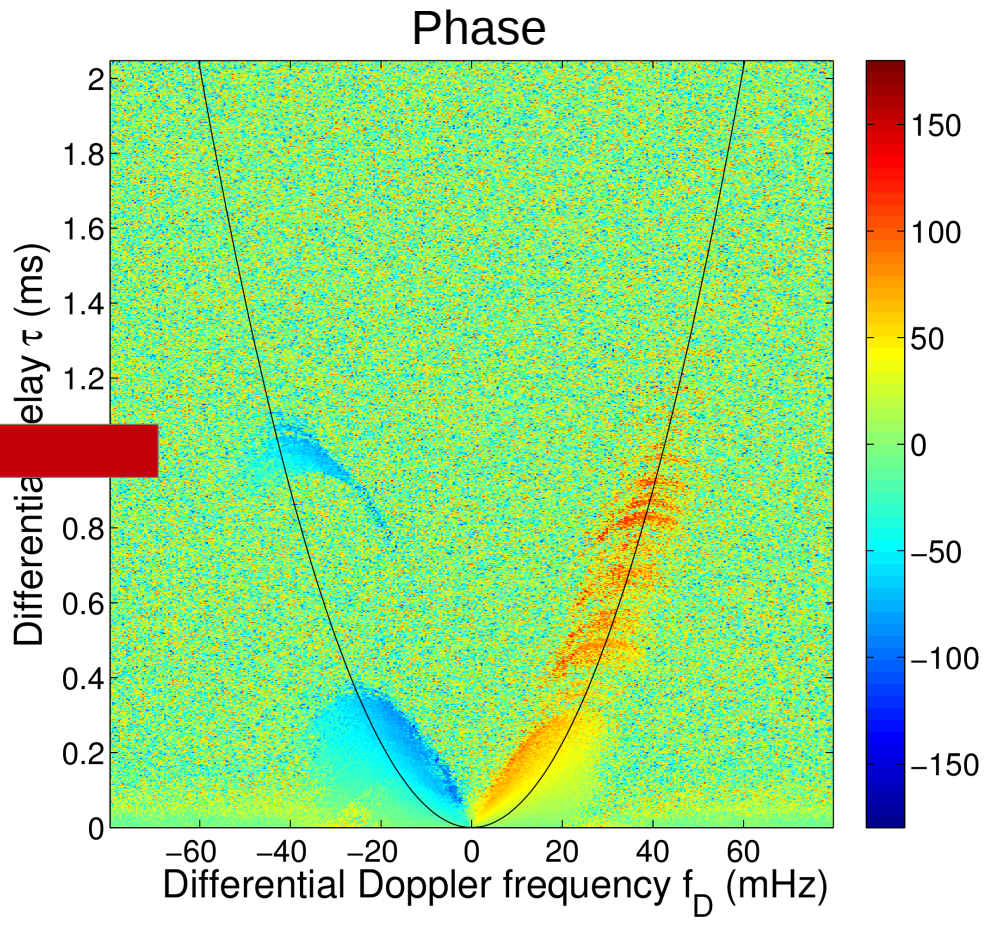


Brisken et al. 2010

Secondary Cross Spectrum

$$C(\tau,\ f,\ \vec{b}) = \tilde{V}(\tau,\ f,\ \vec{b})\ \tilde{V}(-\tau,\ -f,\ \vec{b})$$

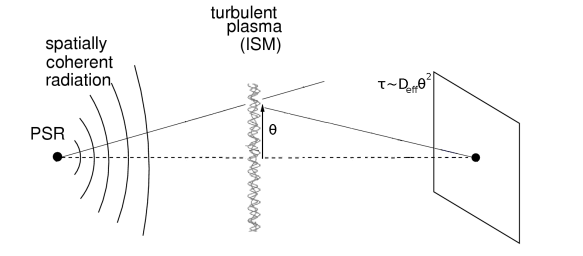


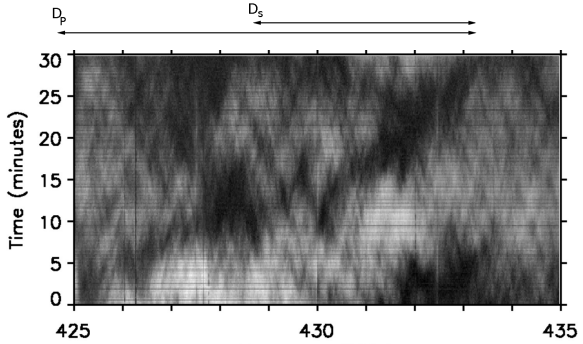


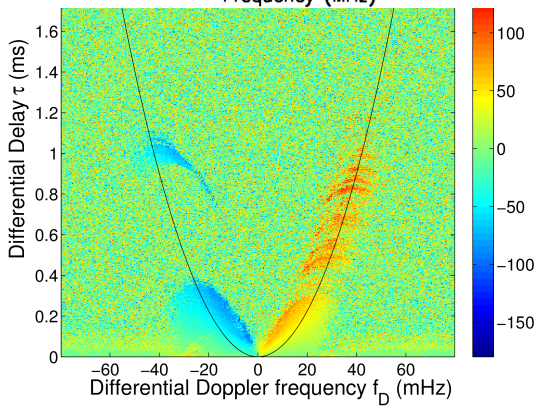
$$\tau = D_{\rm eff}\theta^2/2c$$

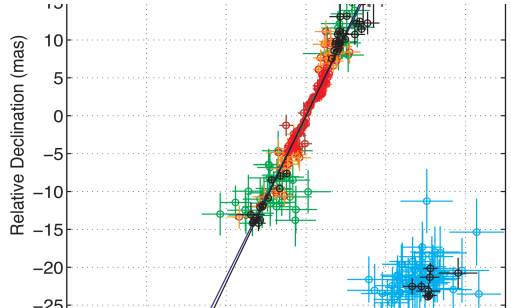
Brisken et al. 2010

In brief









Interference of Scattered waves

↓

Dynamic Spectrum

↓

Phase information in Secondary Cross Spectrum

↓

Speckle Image

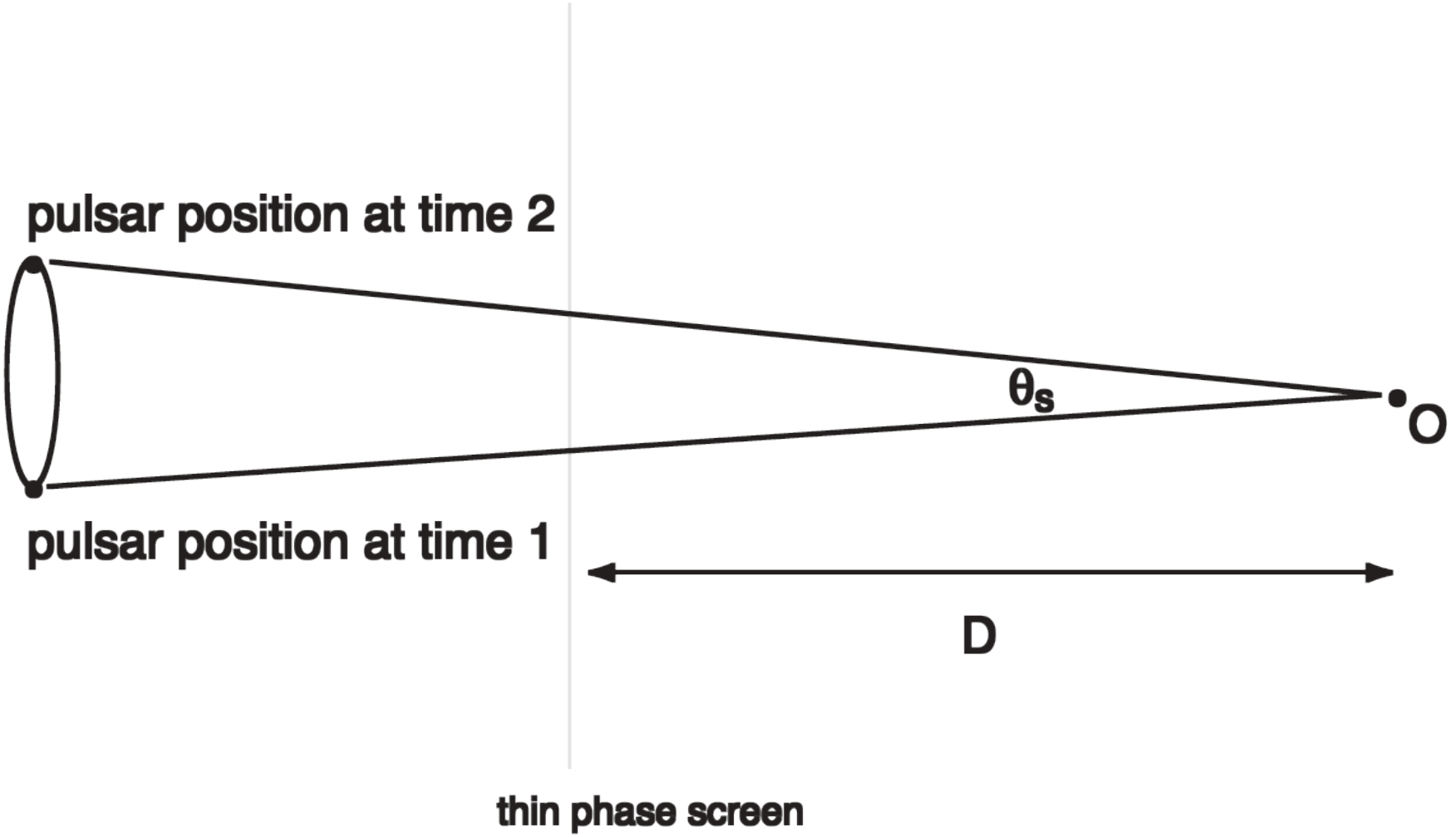
↓

Distance to Screen

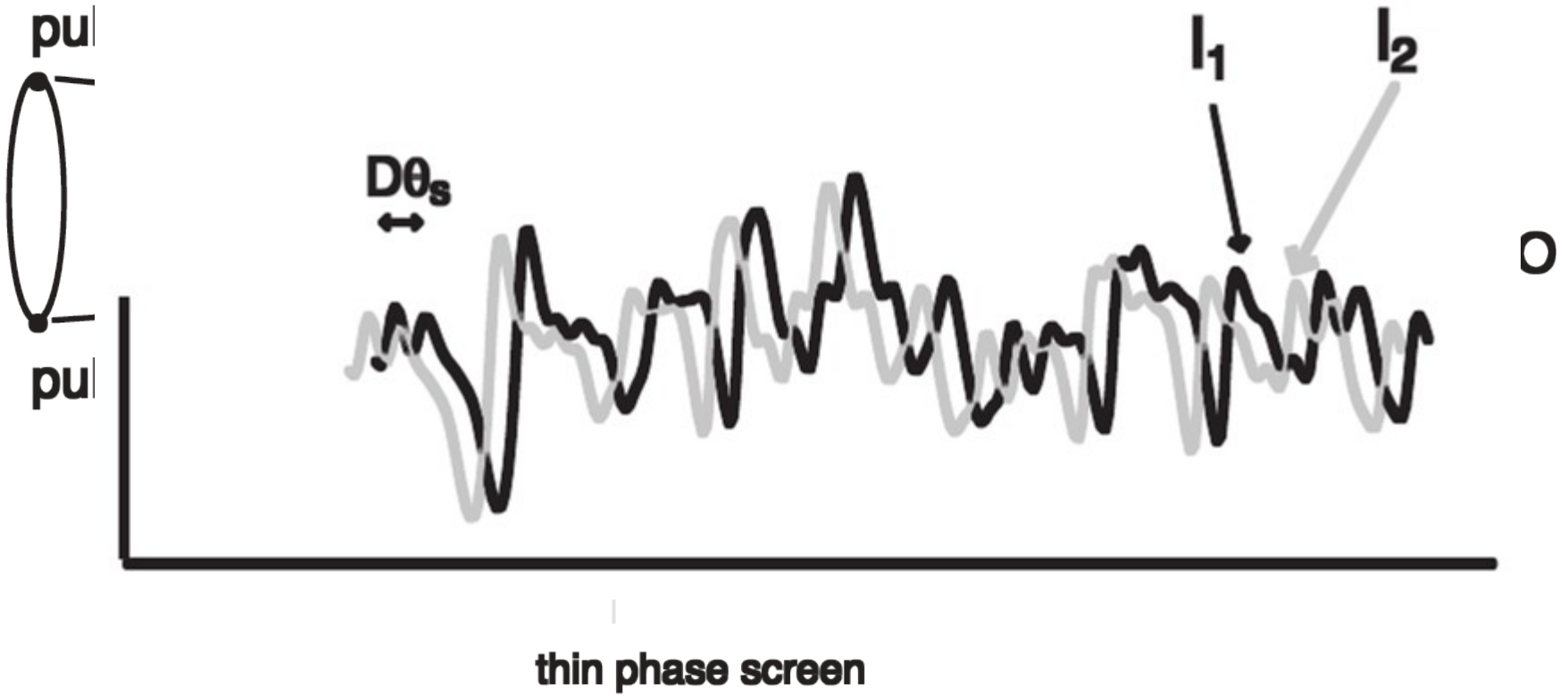
↓

Physical extension of speckle images

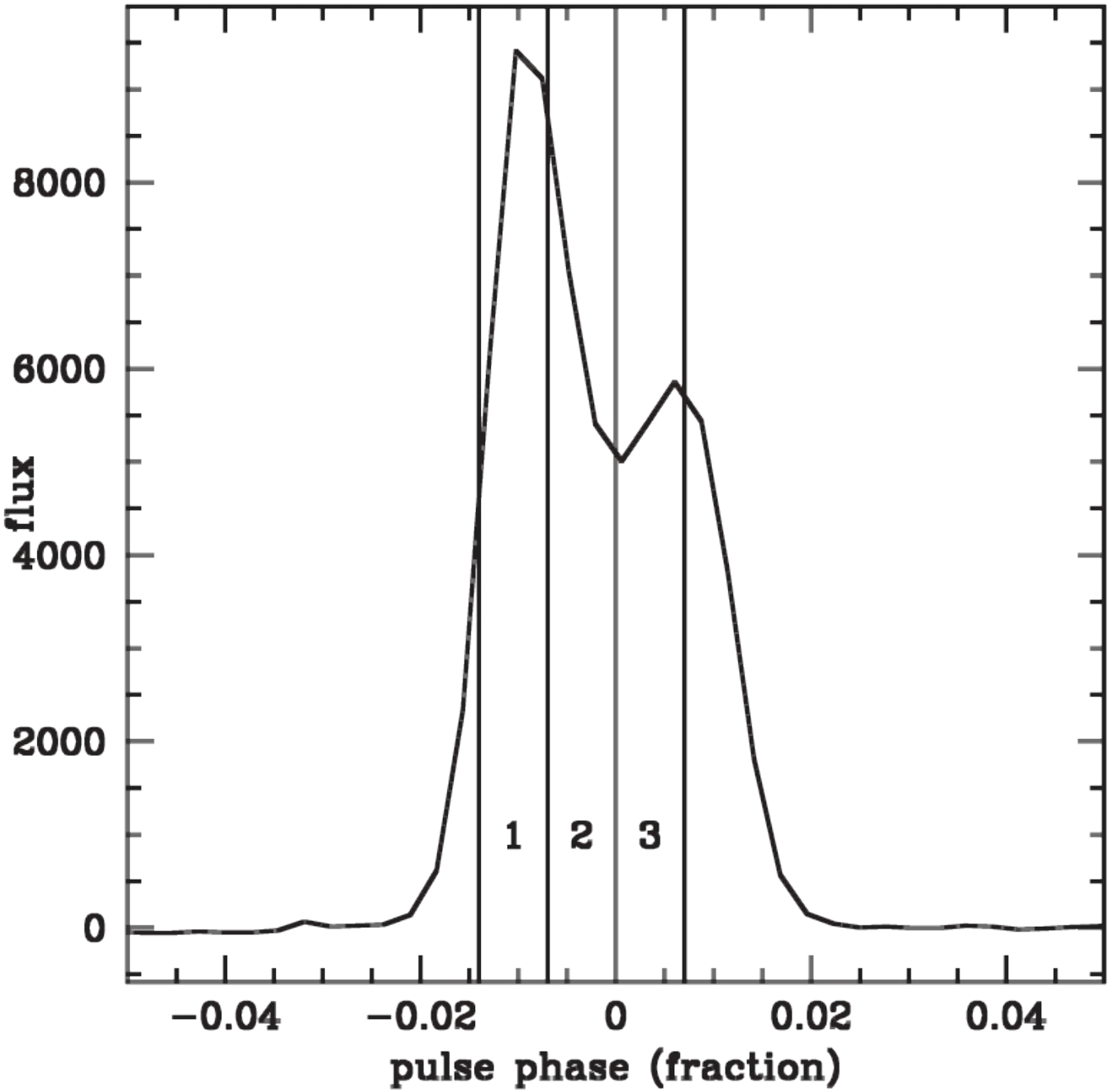
Applications – Pulsar positions



Applications – Pulsar positions

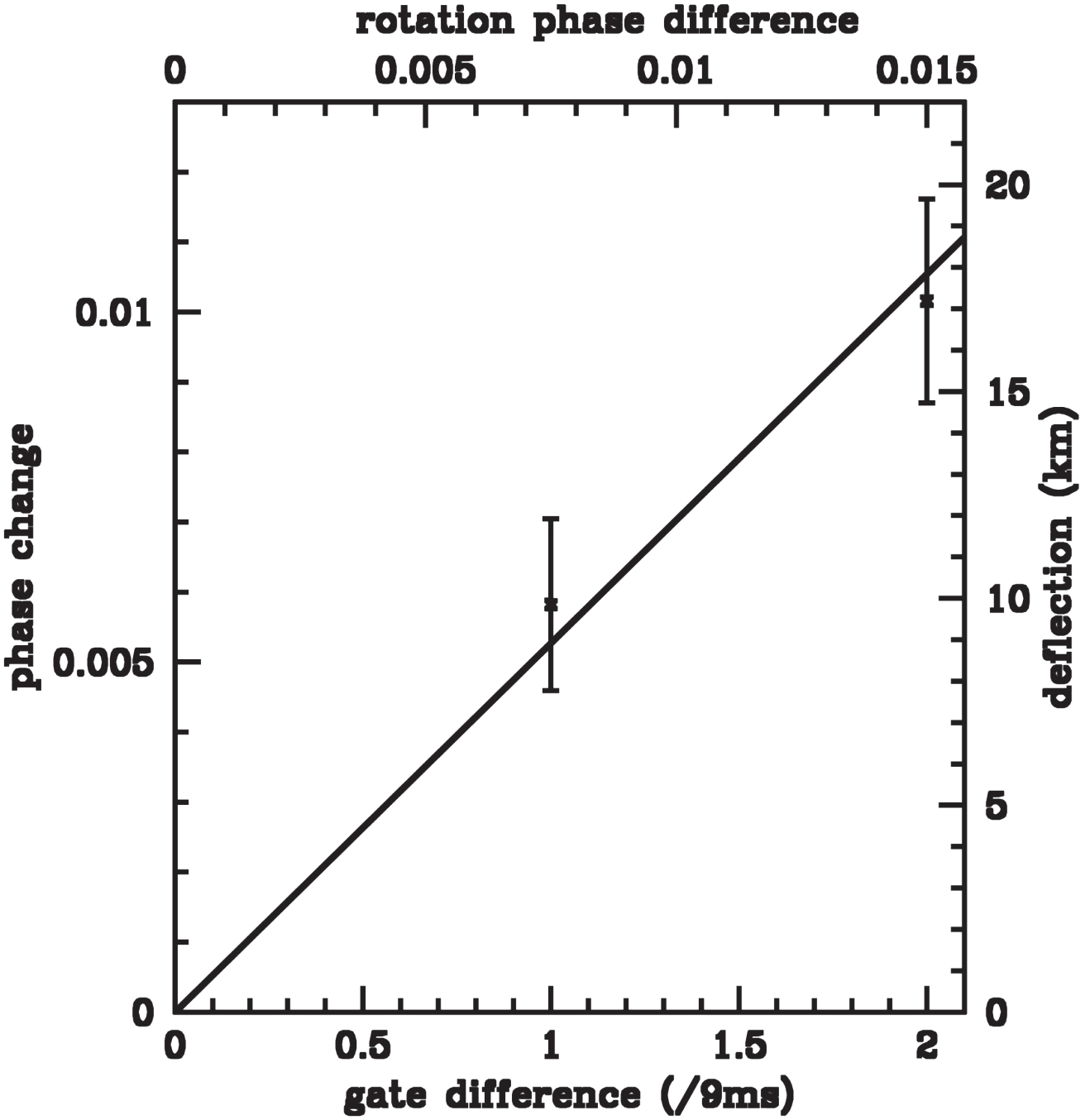


Applications – Pulse emission region



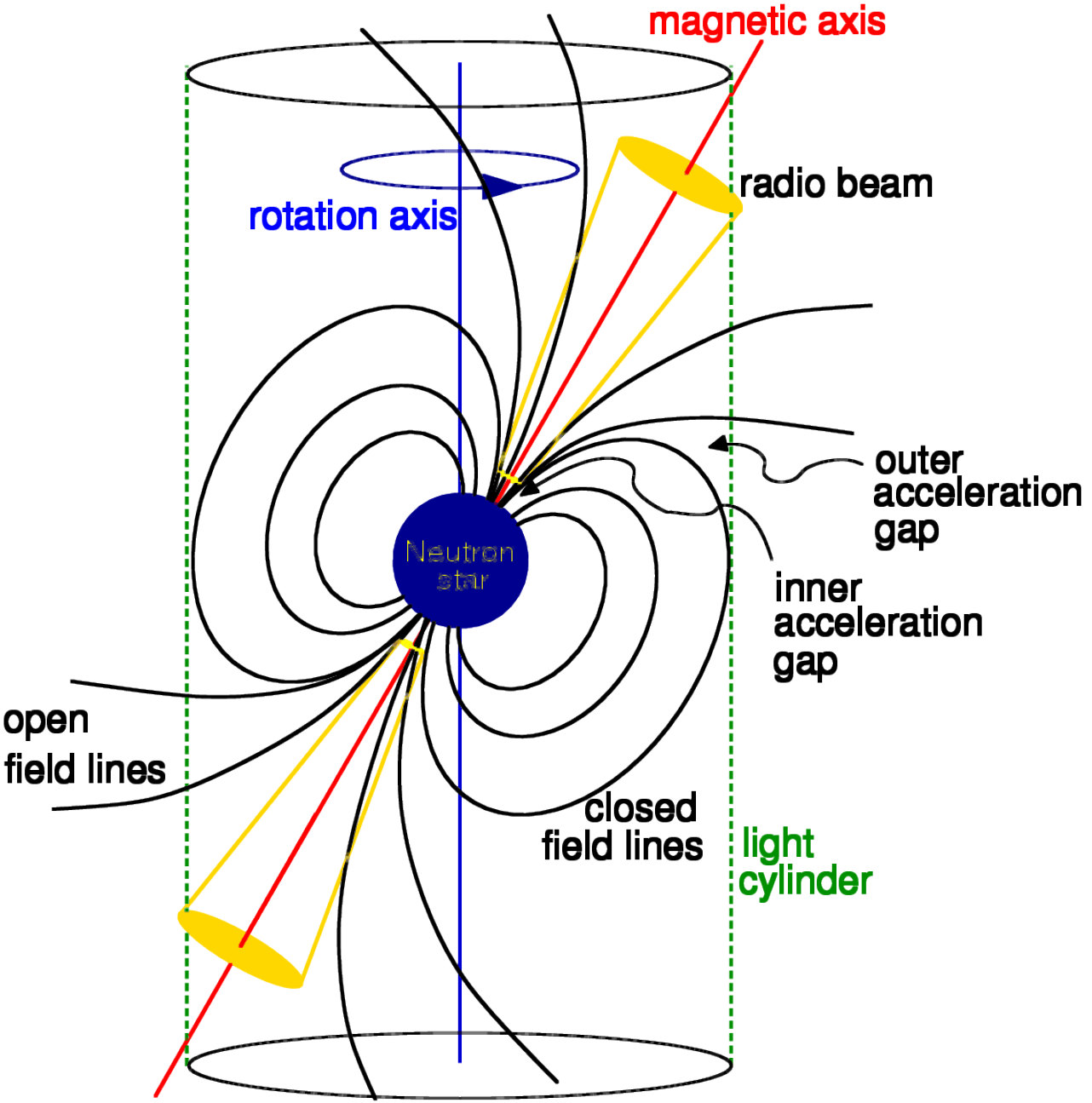
Pen et al. 2010

Applications – Pulse emission region



Pen et al. 2014

Applications – Pulse emission region



Current projects

http://chandra.harvard.edu

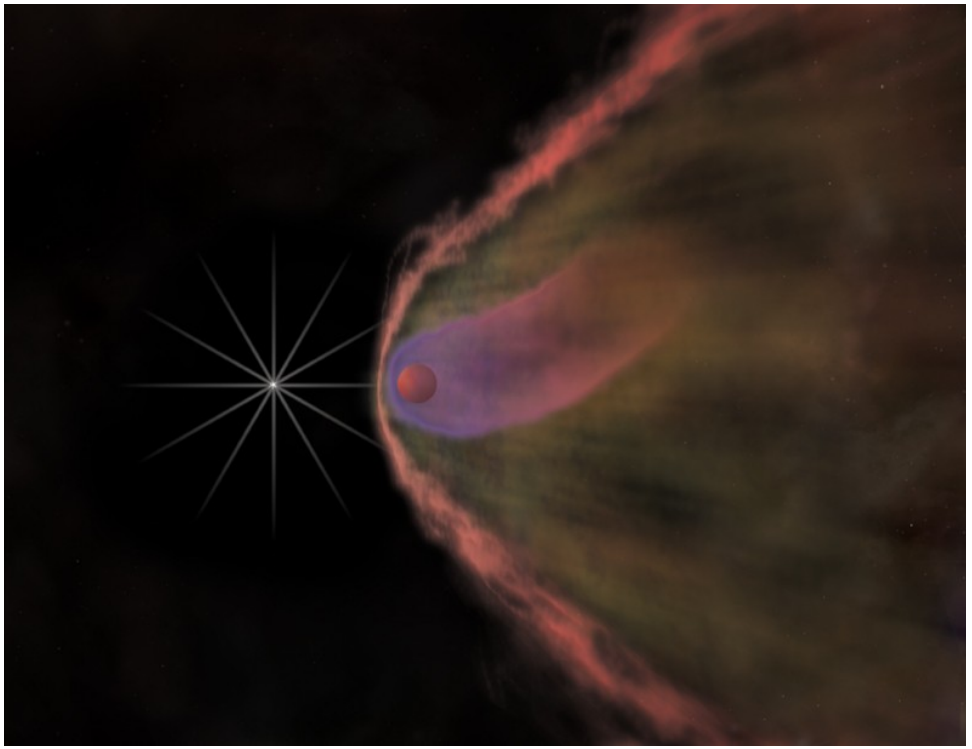
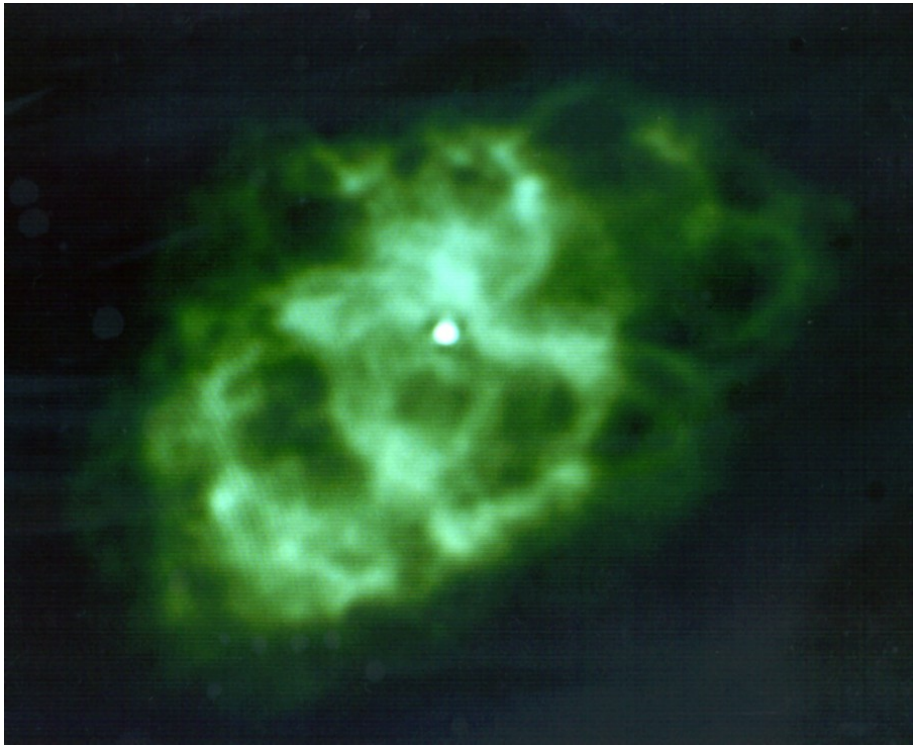


Image courtesy of NRAO/AUI



- B1957+20, aka 'Black Widow Pulsar
- Measure size of projected orbit and get inclination
- Measure mass of the pulsar (could be as high as 2.4 M_sol (van Kerkwijk 2011)

- B0531+21, aka 'The Crab'
- Measure deflection between components
- Measure deflection between normal and 'Giant' pulses
- Determine emission height

AOV Baselines