Neutron stars spectra
Probing the equation of state of dense matter

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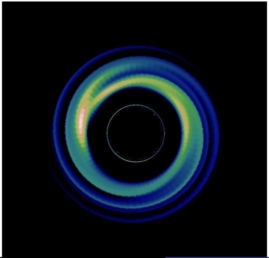
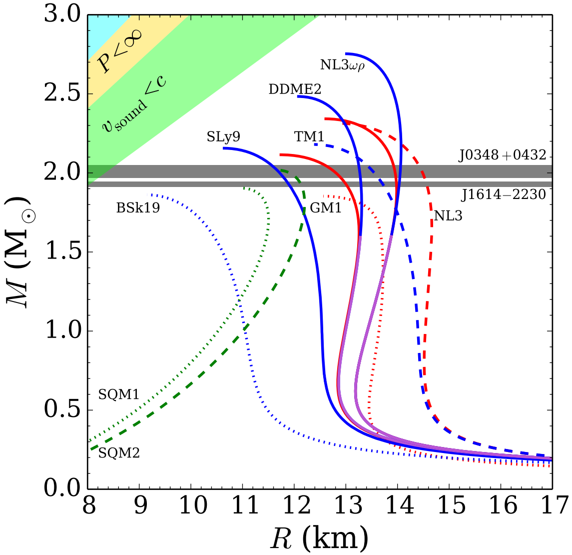


Credit : T. Piro

- Accretion $\rightarrow$ H, He atmosphere
- He runaway burning: burst
- Full star's surface shining Xrays
- Goal: model this; compare to obs

Interest of NS spectra

- Flux: $F_\infty = \sigma \left(\frac{R_\infty}{D}\right)^2 T_\infty^4$; Observed: F_∞, T_∞
- Light bending (Schwarzschild): $R_\infty = R_\star \left(1 - \frac{2M_\star}{R_\star}\right)^{-1/2}$
- Observed spectrum $\rightarrow$ constraint on $M_\star$, $R_\star$
- Interest: constrain EoS



Credit: M. Fortin

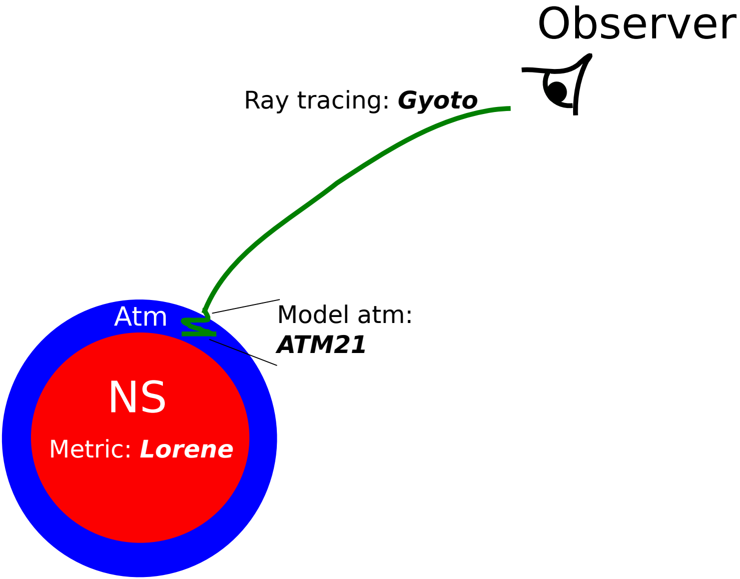
State of the art for fitting NS spectra

- Ray trace photons to distant observer
- **Emission**: pure **blackbody**
- **Spacetime**: Schwarzschild, Kerr, Hartle-Thorne (**analytic approx**)
- Star **rotation**: often neglected, or **small**

  (some recent analyses go further: Cadeau+, Baubock+)

Our goal

- More realistic emission $I_\nu(\tau, \cos i)$
- Accurate spacetime (numerical)
- Valid for any rotation



Observer
Ray tracing: ***Gyoto***
Atm
Model atm:
ATM21
NS
Metric: ***Lorene***

Lorene metric

- Input: $M_\star, \Omega_\star$, EoS
- Solves Einstein equation
- Output: $g_{\mu\nu}, \mathbf{u}_\star$

ATM21 atmosphere

- Input: atm composition, $T_{\rm eff}, g_{\rm surf}(g_{\mu\nu})$
- Solves hydrostatic and radiative equilibria,
  emissivity: blackbody+Compton; absorption: free-free
- Output: Emergent intensity, function of local angle

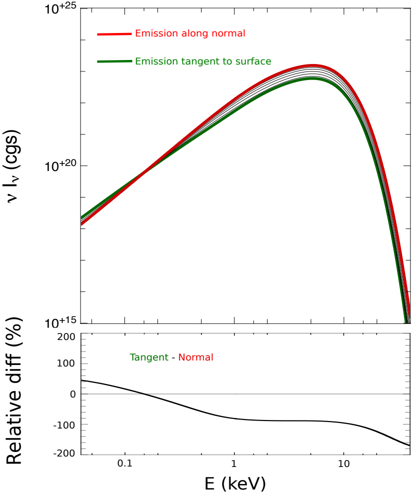
Gyoto raytracing

- Input: the 2 previous outputs
- Transports the radiation in the metric
- Output: observed spectrum

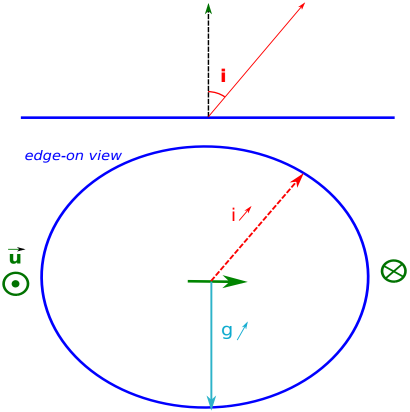
Setup chosen

- NS with EoS SLy4 (Douchin&Haensel01, Chabanat+98)
- $M_\star = 1.4\,M_\odot$, $\Omega_\star = 0; 716$ Hz
- Atm: H+He, solar abundance, $T_{\rm eff} = 10^7$ K

Local spectra



What impacts emitted intensity

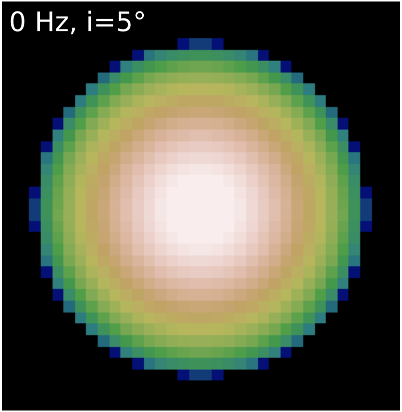


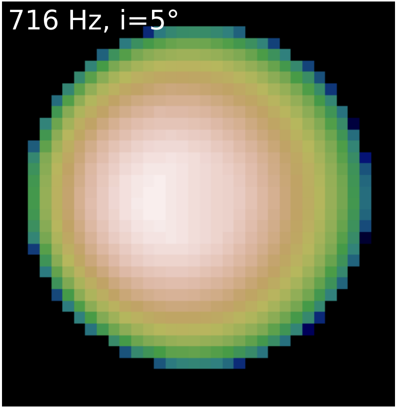
Angular: radial

Beaming: horizontal

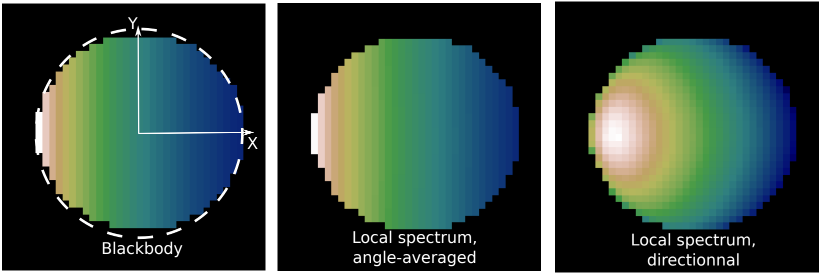
Gravity: vertical

Ray-traced images, face-on

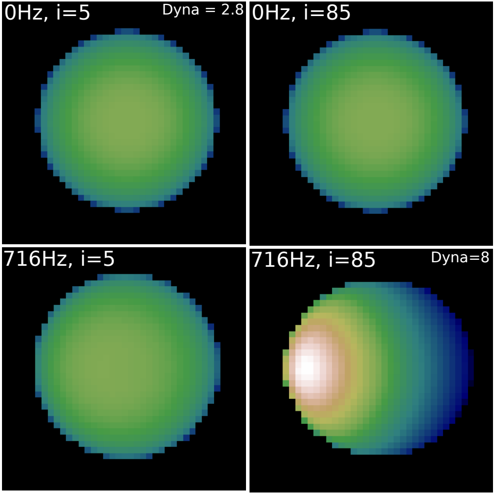




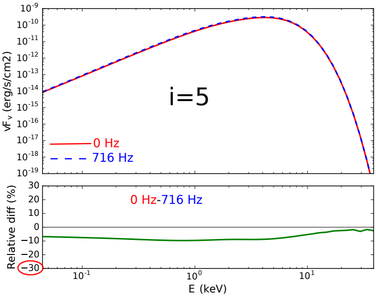
Ray-traced images, edge-on fast-rotating

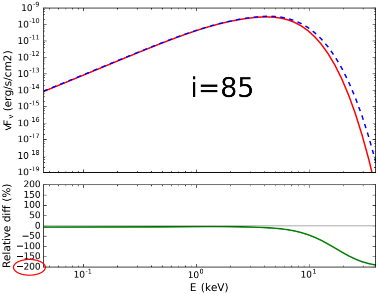


Ray-traced images, (Ω, i)

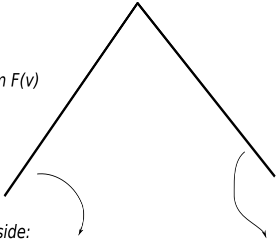


Directional: rotation impact





At high energy, Doppler + steep spectrum = strong beaming so rotating case very different wrt the non-rotating case.



Spectrum F(v)

Approaching side:

Kinematics: positive beaming

Doppler: $v_{em} < v_{obs}$

I_{em} pushed to low values

counterbalances beaming

Kinematics: positive beaming

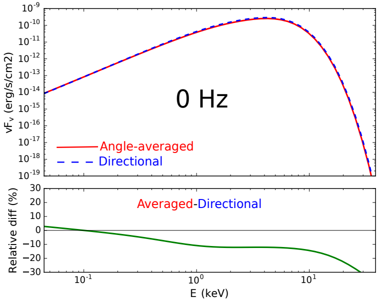
Doppler: $v_{em} < v_{obs}$

Iem pushed to higher values

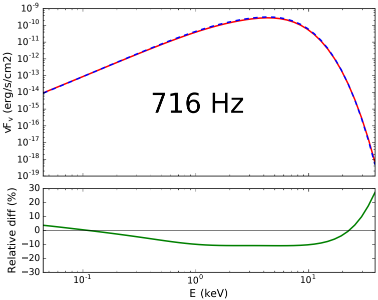
reinforces beaming

For rotating star, beaming varies like observed energy

i=85: emission angle impact



Directional: more weight to normal emission
Averaged-Directional ~ Tangent-Normal



High energy: Doppler + steep spectrum = strong beaming
Reinforces the tangent emission part: opposite behavior