Photometric mode identification of slowly rotating stars

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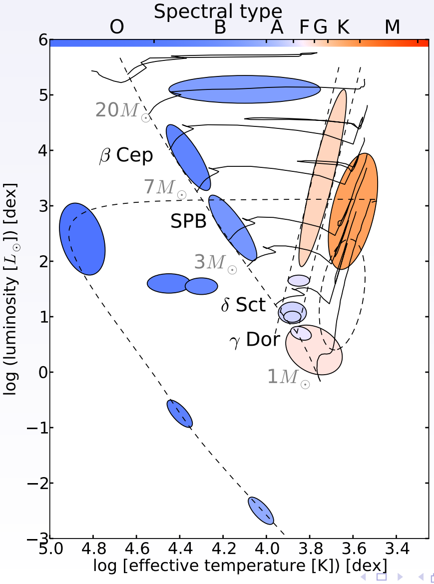
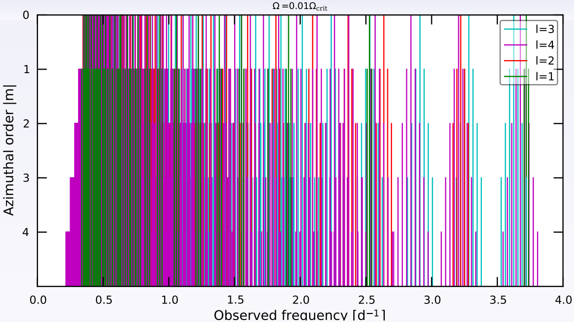
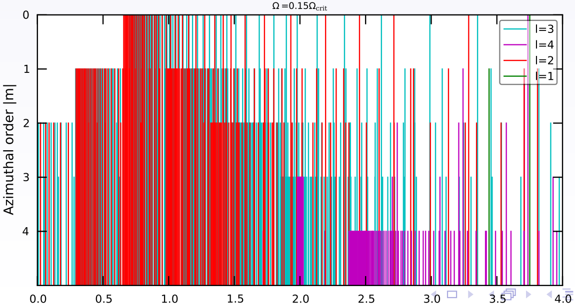
thanks to S. Bloemen, C. Aerts and
M.-A. Dupret (Ulg, Belgium)

Overview

Why mode identification?




Ω =0.01Ω$_{crit}$
Azimuthal order |m|
0
1
2
3
4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Observed frequency [d^{-1}]
l=3
l=4
l=2
l=1


Ω =0.15Ω$_{crit}$
Azimuthal order |m|
0
1
2
3
4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
l=3
l=4
l=2
l=1

Why photometric?

Why not spectroscopy?
Because photometry. . .

1. is less time consuming
2. requires smaller telescopes
3. is more easily obtained for samples
4. allows easier exploitation of existing surveys (e.g. OGLE, WISE, GAIA. . .)
5. is another independent method

But. . . in general poor quality

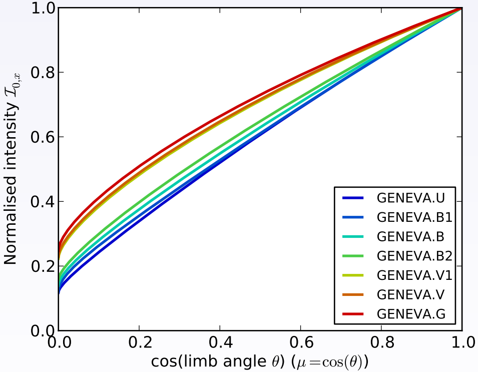
Why SPB stars?

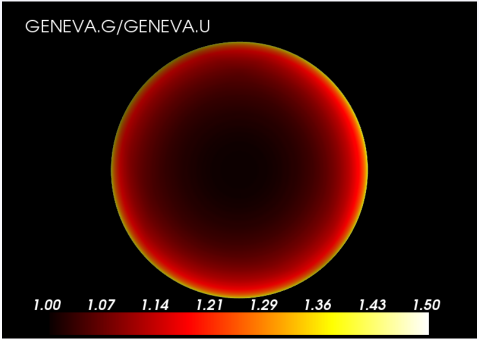
Because we can: De Cat et al., 2007

1. 28 stars observed with Mercator
2. Geneva filters
3. 1-5 frequencies for each target

The principle of photometric mode-identification

Limb darkening in different passbands act as spatial filters on the pulsations





Amplitude ratios are dependent on mode geometry

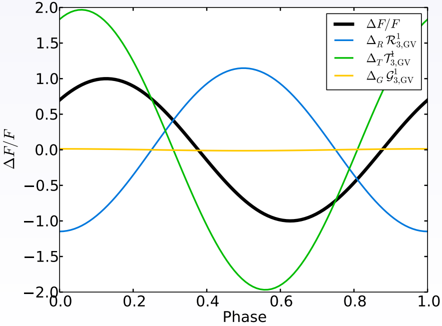
Without rotation

$$\frac{\Delta F_x}{F_x} = \mathrm{Re}\left[\left(\Delta_R \mathcal{R}^m_{l,x}(\theta,\phi) + \Delta_T \mathcal{T}^m_{l,x}(\theta,\phi) + \Delta_G \mathcal{G}^m_{l,x}(\theta,\phi)\right)\exp(i\sigma t)\right]$$

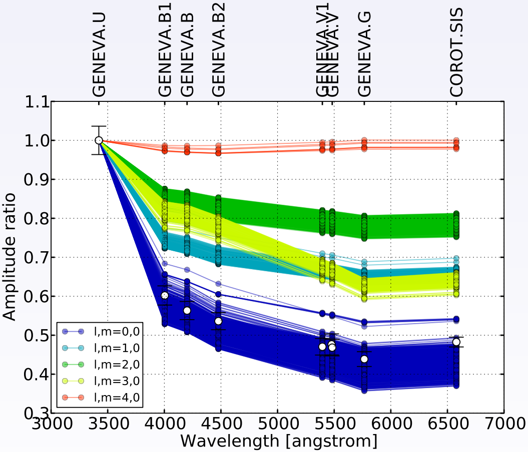
nonadiabatic coefficients, differential flux functions:

- $\mathcal{R}^m_{l,x}(\theta,\phi) = (2+\ell)(1-\ell)\frac{\mathcal{I}_{\ell,x}}{\mathcal{I}_{0,x}} Y^m_\ell(\theta,\phi)$
- $\mathcal{T}^m_{l,x}(\theta,\phi) = \frac{\partial \ln \mathcal{I}_{\ell,x}}{\partial \ln T_{\mathrm{eff}}} Y^m_\ell(\theta,\phi)$
- $\mathcal{G}^m_{l,x}(\theta,\phi) = \frac{\partial \ln \mathcal{I}_{\ell,x}}{\partial \ln g_{\mathrm{eff}}} Y^m_\ell(\theta,\phi)$

where $\mathcal{I}_{\ell,x} = \int_0^1 \mu P_\ell(\mu) I_x(\mu) d\mu$



Without rotation



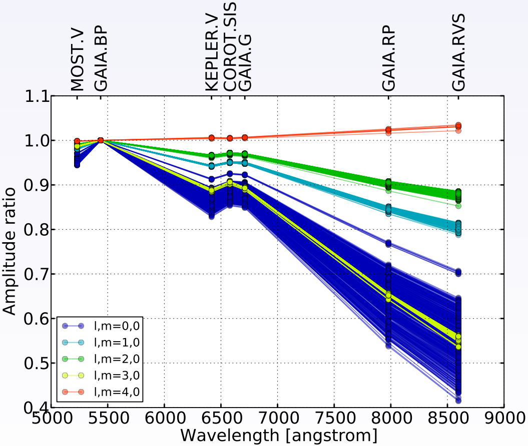
Photometric amplitude is dependent on passband and degree ℓ

(and mode eigenfunction)

$\Rightarrow$ allows identification of degree ℓ

Without rotation

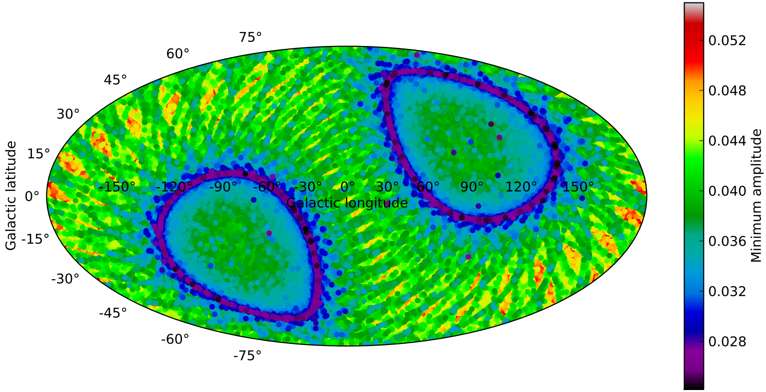
Traditionally always within one photometric system, but. . .



Broad space based filters ⇔ high amplitude precision

Without rotation

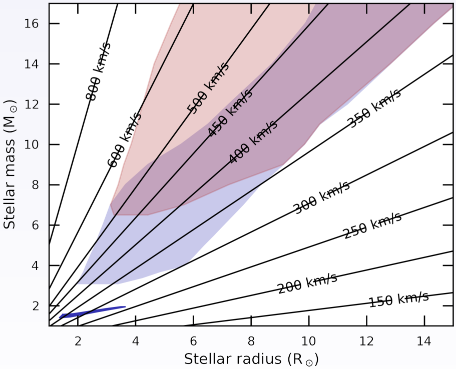
What can we do with GAIA?

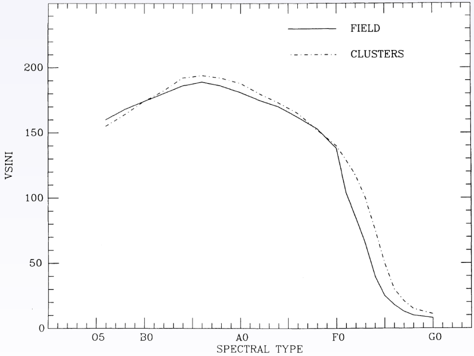


With (slow) rotation

Is the assumption of no rotation valid? No!

Is the traditional approximation valid?





(Stauffer, 1986)

With (slow) rotation

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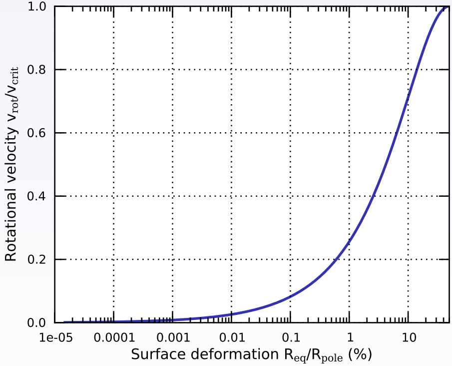

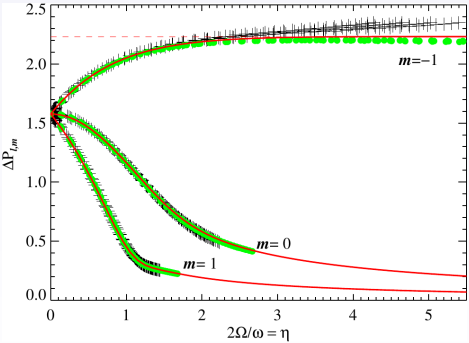

(Ballot, 2011)

With (slow) rotation

Approximate perturbations as linear combinations of spherical harmonics

$$\frac{\Delta F_x}{F_x} = \mathrm{Re}\left[\left(\Delta_R \tilde{\mathcal{R}}^m_{l,x}(\theta,\phi) + \Delta_T \tilde{\mathcal{T}}^m_{l,x}(\theta,\phi) + \Delta_G \tilde{\mathcal{G}}^m_{l,x}(\theta,\phi)\right)\exp(i\sigma t)\right]$$

- $\tilde{\mathcal{R}}^m_{l,x}(\theta,\phi) = \sum_j \mathbf{B}_j \mathcal{R}^m_{l_j,x}(\theta,\phi)$
- $\tilde{\mathcal{T}}^m_{l,x}(\theta,\phi) = \sum_j \mathbf{B}_j \mathcal{T}^m_{l_j,x}(\theta,\phi)$
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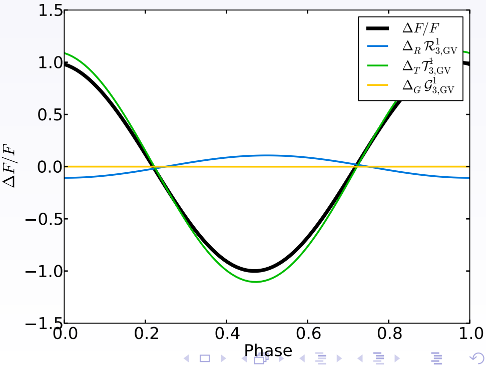
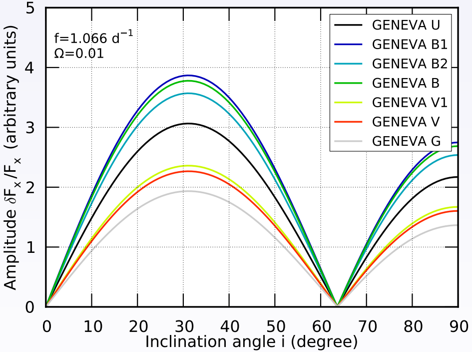
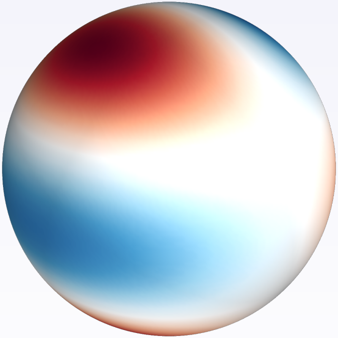


Implications for mode visibility





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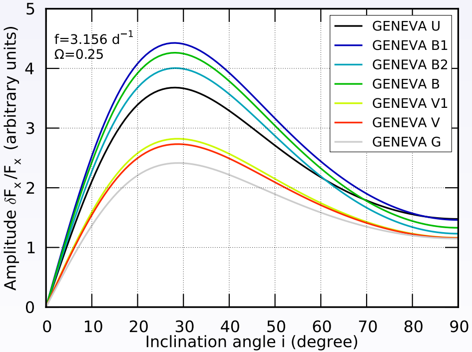
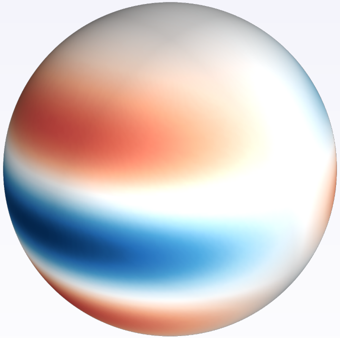
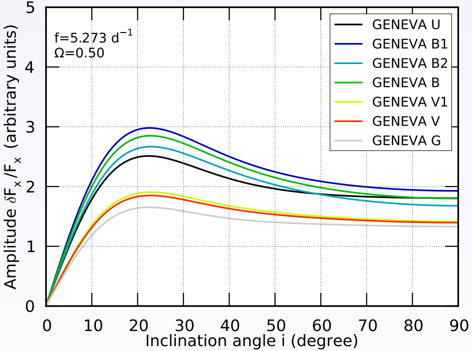
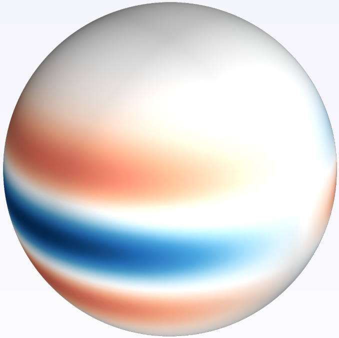




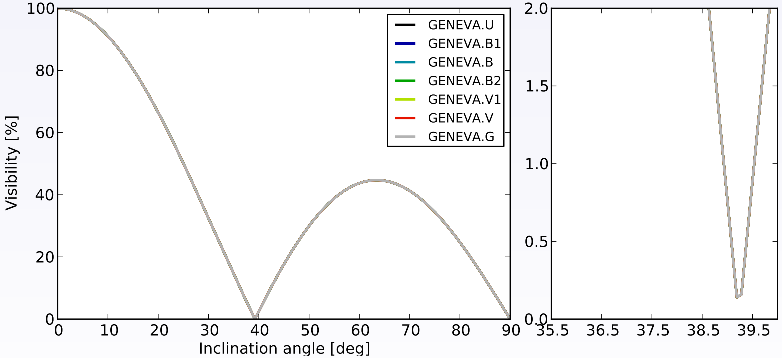
Implications for mode visibility





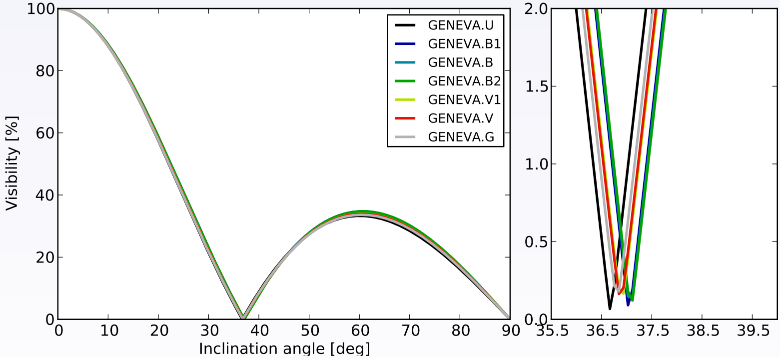
Inclination angle ($\ell = 3$)

No rotation



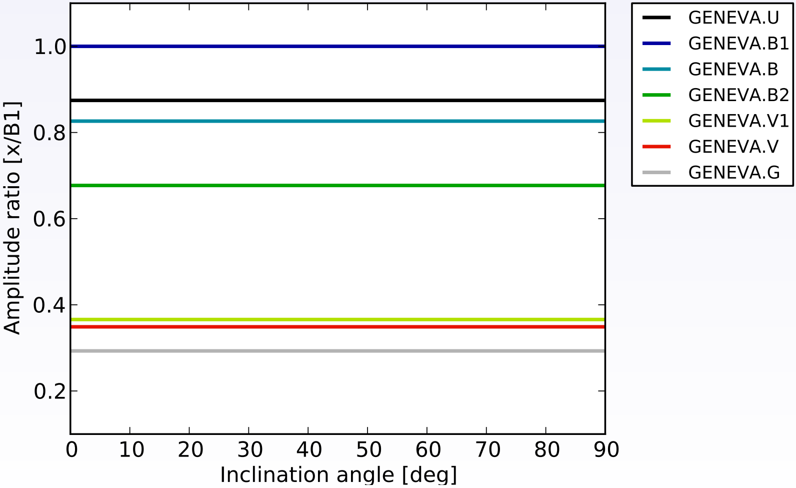
Inclination angle ($\ell = 3$)

Rotation



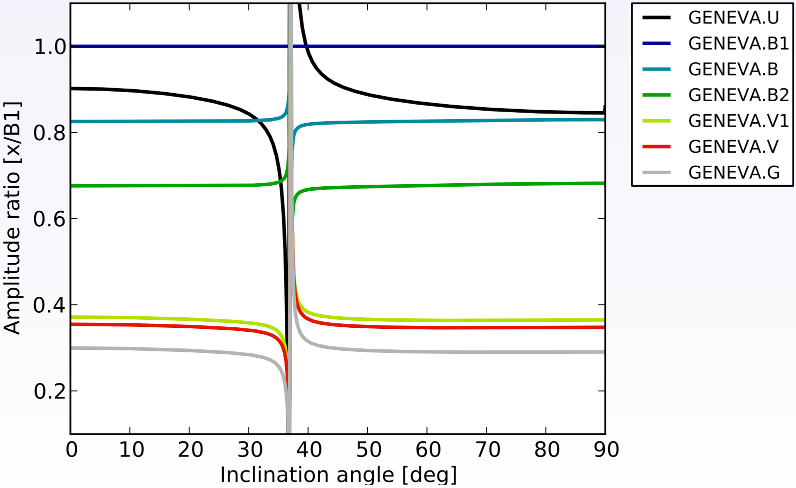
Inclination angle ($\ell = 3$)

No rotation



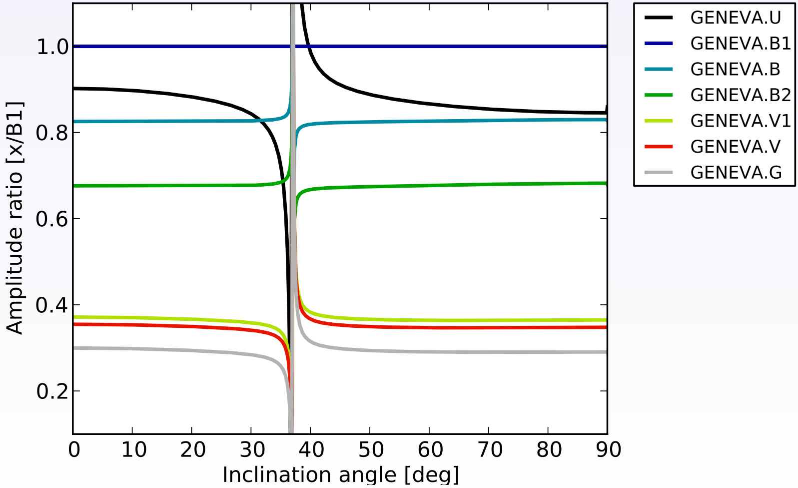
Inclination angle ($\ell = 3$)

Rotation



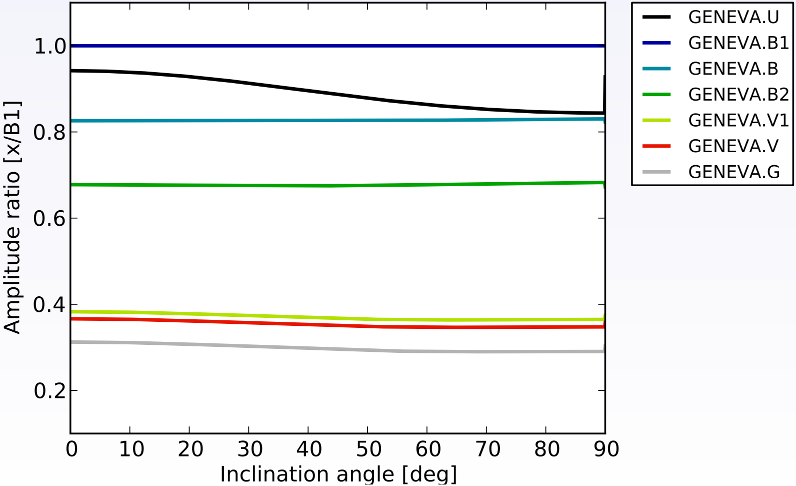
Azimuthal order ($\ell = 3$)

$m = 0$



Azimuthal order ($\ell = 3$)

$m = -2$



Photometric mode identification dependencies

Regarding input models:

- atmospheres (T_{eff}, $\log g$, Z, CT...)
- stellar structure (M, X, α, ...)
- rotation period
- nonadiabatic pulsation codes (opacities, eigenfunctions...)
- photometric calibration (zero points, response curves...)

Regarding observables:

- passband
- degree ℓ
- azimuthal order m
- inclination angle

Photometric mode identification dependencies

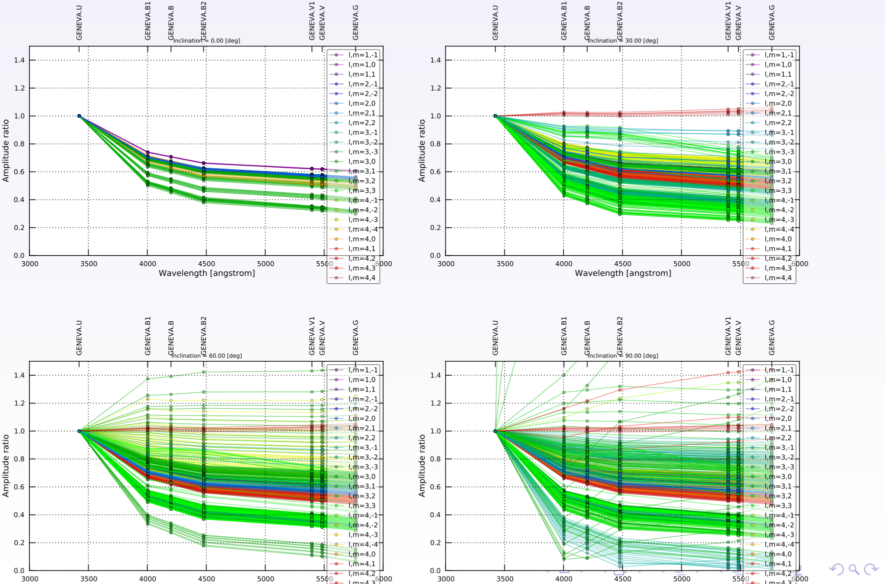
Regarding input models:

- atmospheres ($T_{\rm eff}, \log g, Z$, CT...)
- stellar structure (M, X, α, ...) FREE
- rotation period FREE
- nonadiabatic pulsation codes (opacities, eigenfunctions...)
- photometric calibration (zero points, response curves...)

Regarding observables:

- passband
- degree ℓ FREE
- azimuthal order m FREE
- inclination angle FREE

Mode identification diagrams



To be done. . .

Computations of
Evolutionary tracks + nonadiabatic oscillations