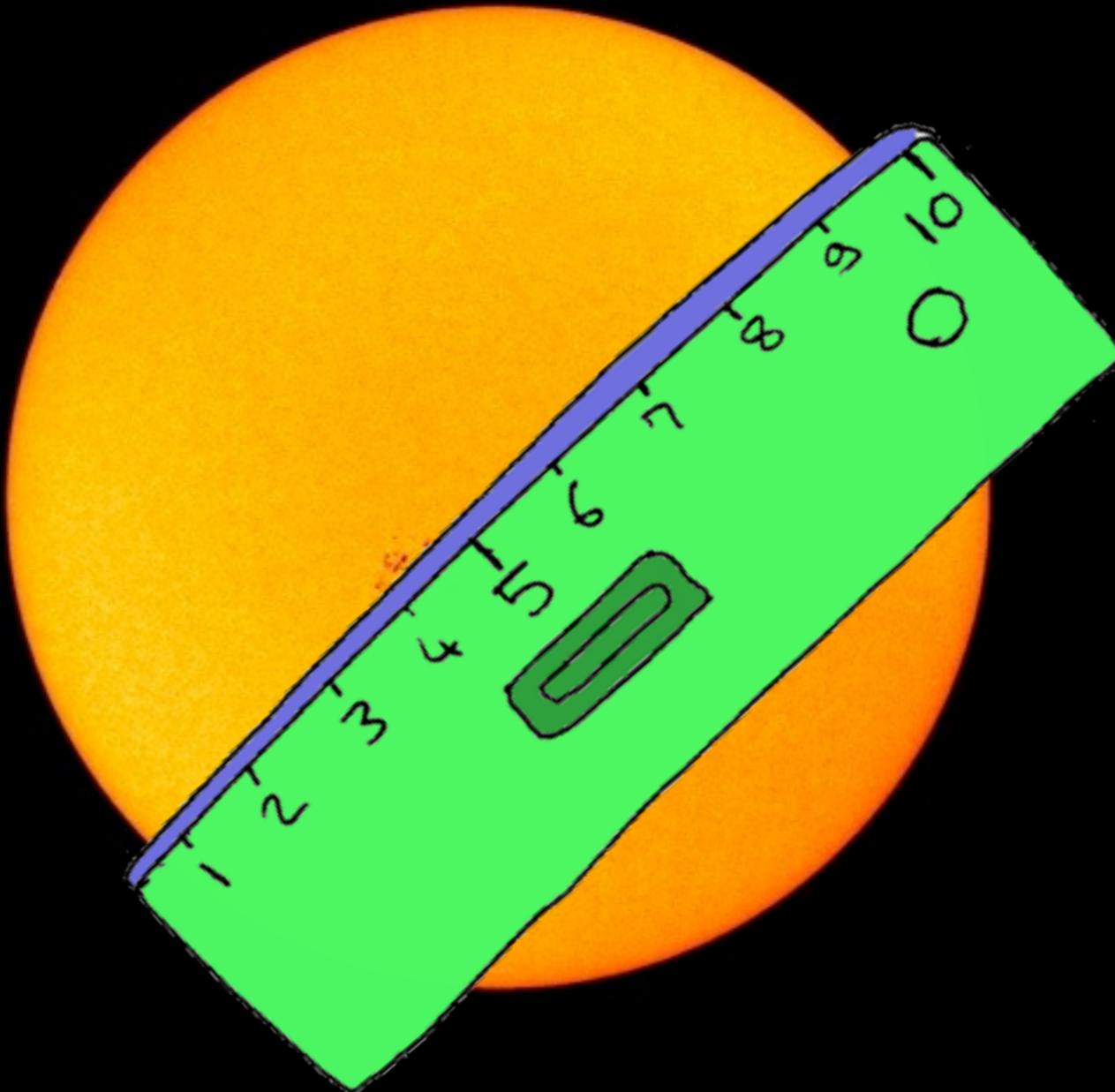


High-resolution solar diameter measurement techniques for PICARD



T. Dudok de Wit, A. Bustin, L. Bondonneau
LPC2E, CNRS et University of Orléans



Waiting for a student to help finish the work...



aveyron.com

Several objectives

- Measure the solar diameter, oblateness, etc.
- Detect changes in the solar limb shape
- Detect and extract solar features above the limb
(prominences, ...)
- ...

Outline: various strategies

■ Parametric approaches

- physical model for the limb shape
- Hough transform

■ Non-parametric approaches

- cake slice
- point of inflexion
- multiscale (aka wavelet)
- ...

Parametric approaches

Use limb profile model

- Several empirical models of the limb profile

[Rozelot et al., 2003, Neckel (2005), Haberreiter et al., 2008, ...]

$$I(x) = a_1 + a_3 \left(1 + \left(1 + e^{a_4(x-a_2)} \right)^{a_5} \right) \cdot \left(1 + \left(1 + e^{a_6(x-a_2)} \right)^{a_7} \right)$$

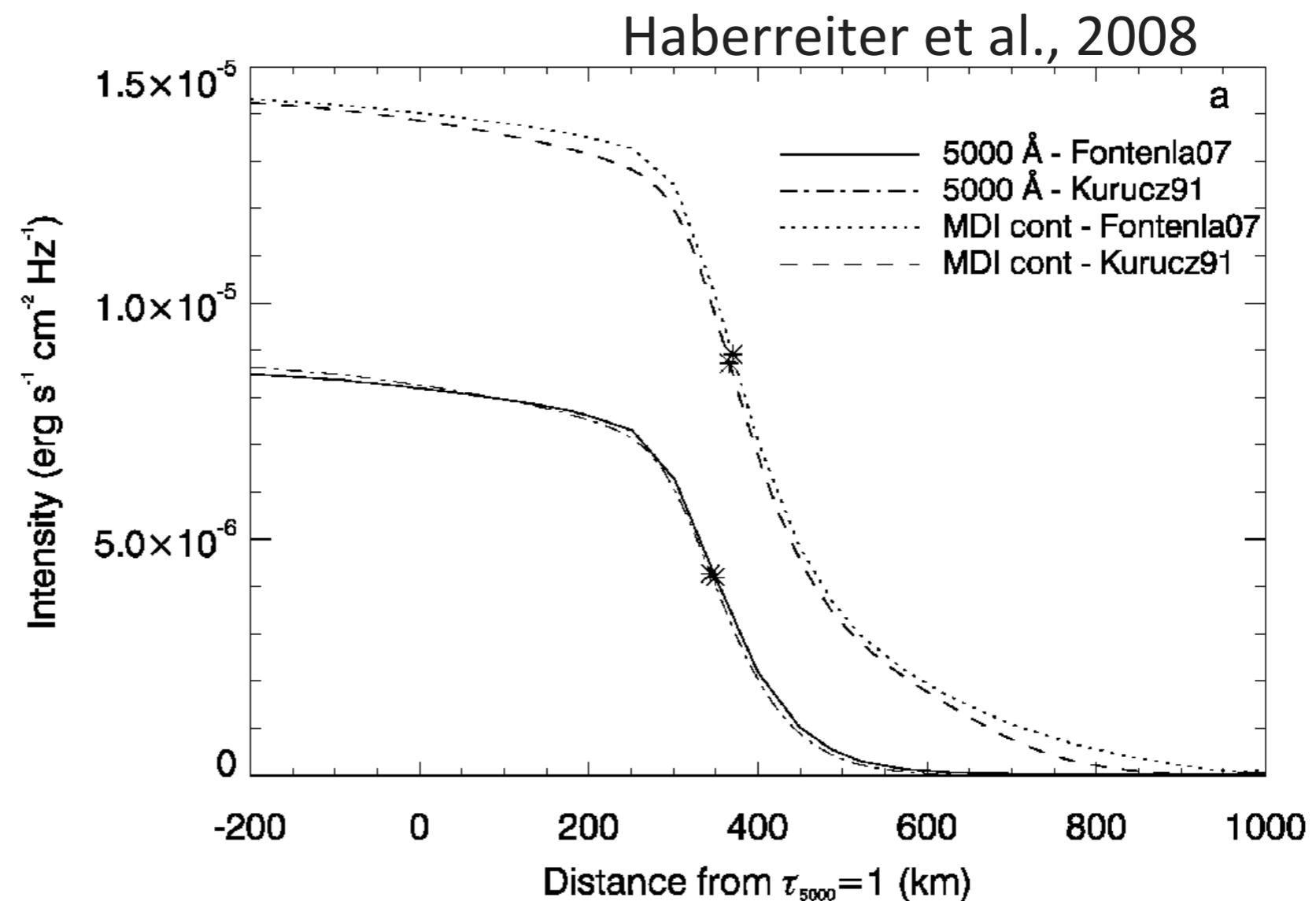
- Precision on limb position ~ 10 mas

What is the proper metric for locating
the edge of the limb ? $\tau_{5000} = 1$?

Use limb profile model

Advantage : physically sound

Disadvantage : results depend on model assumptions



Use limb profile model

- How applicable are these limb models ?

Empirical (data-driven)
approaches are often preferable

Hough transform

- Assume the parametric expression of the solar diameter to be known, e.g.

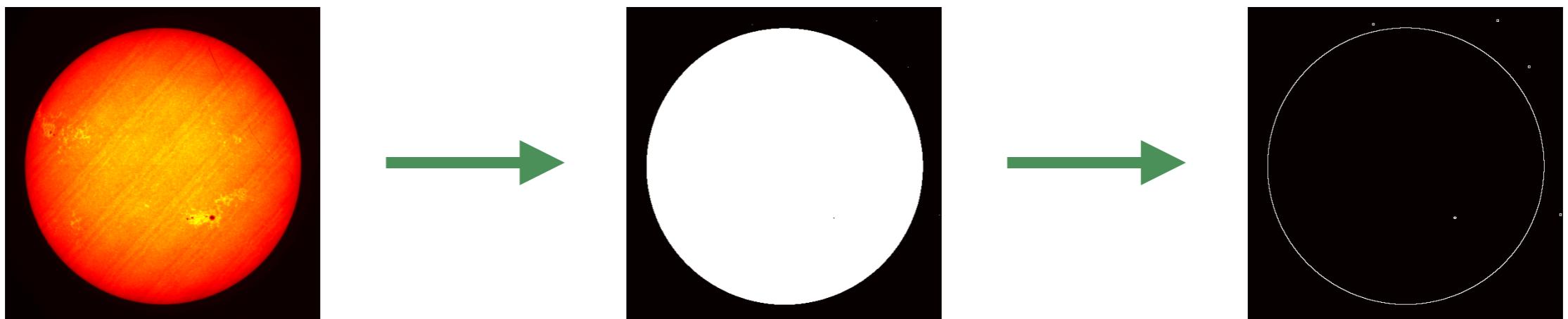
$$(x - x_0)^2 + (y - y_0)^2 = R^2$$

Hough transform

- Assume the parametric expression of the solar diameter to be known, e.g.

$$(x - x_0)^2 + (y - y_0)^2 = R^2$$

- Detect the position of the limb by some adequate technique, i.e. point of inflexion



Hough transform

- Now scan the binary image with parameterised curves

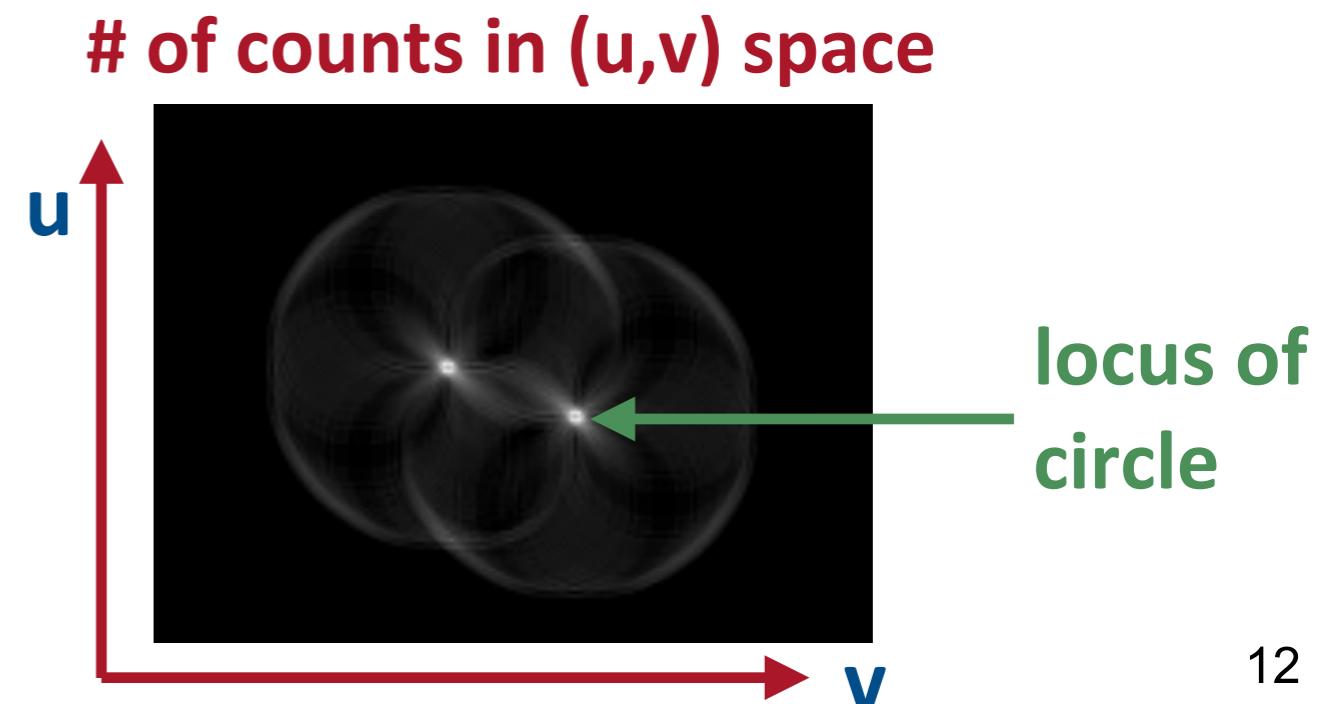
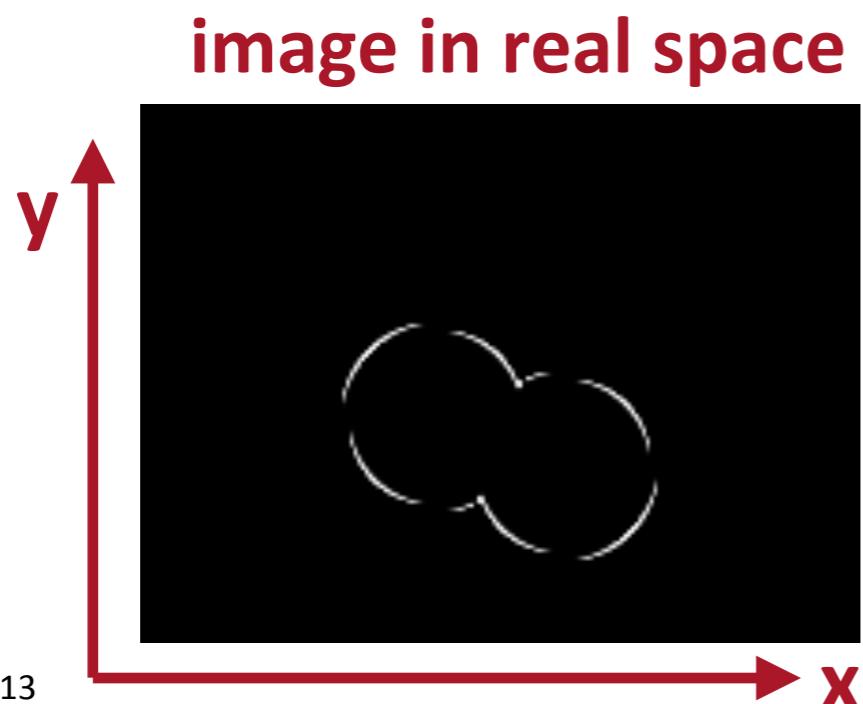
$$\begin{cases} x = \textcolor{red}{u} + R \cos \theta \\ y = \textcolor{red}{v} + R \sin \theta \end{cases}$$

Hough transform

- Now scan the binary image with parameterised curves

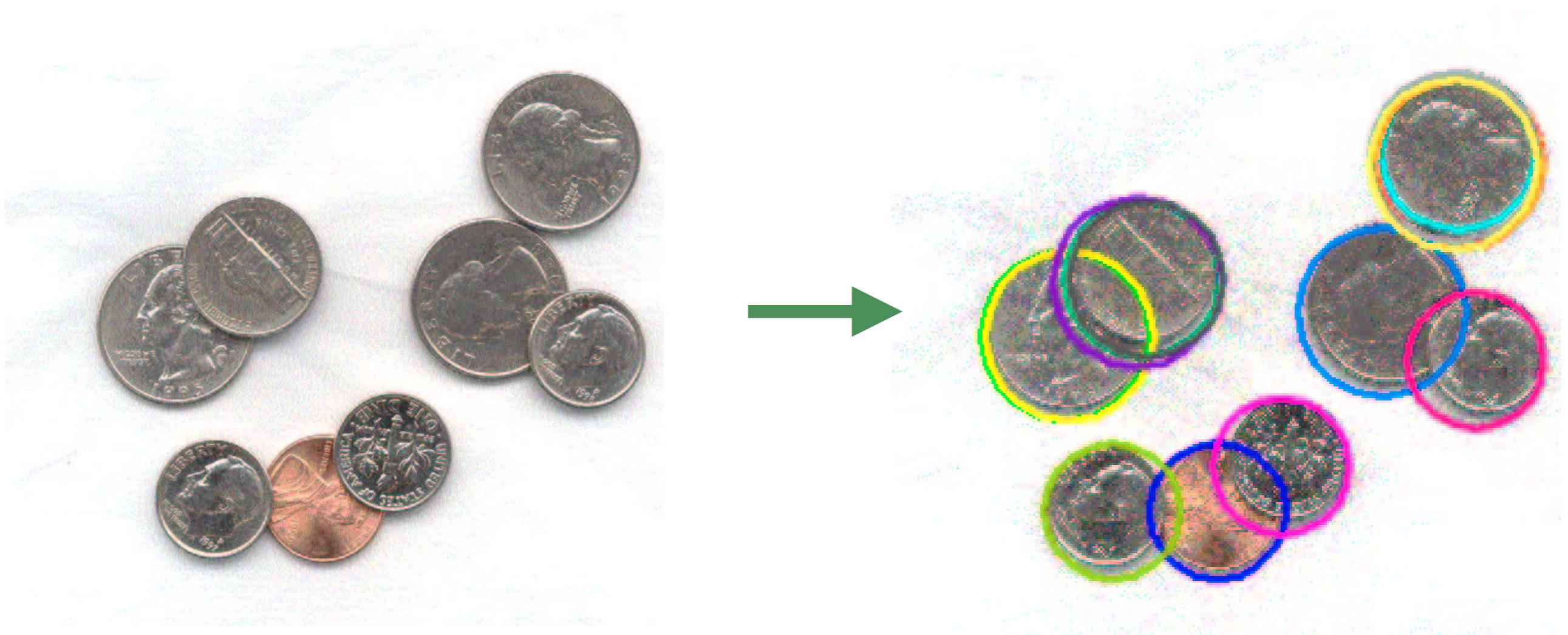
$$\begin{cases} x = u + R \cos \theta \\ y = v + R \sin \theta \end{cases} \quad \text{vary } u \text{ and } v$$

- Count number of limb pixels intersecting these curves



Hough transform

Example with coins



Hough transform

Why the Hough transform is **not appropriate**

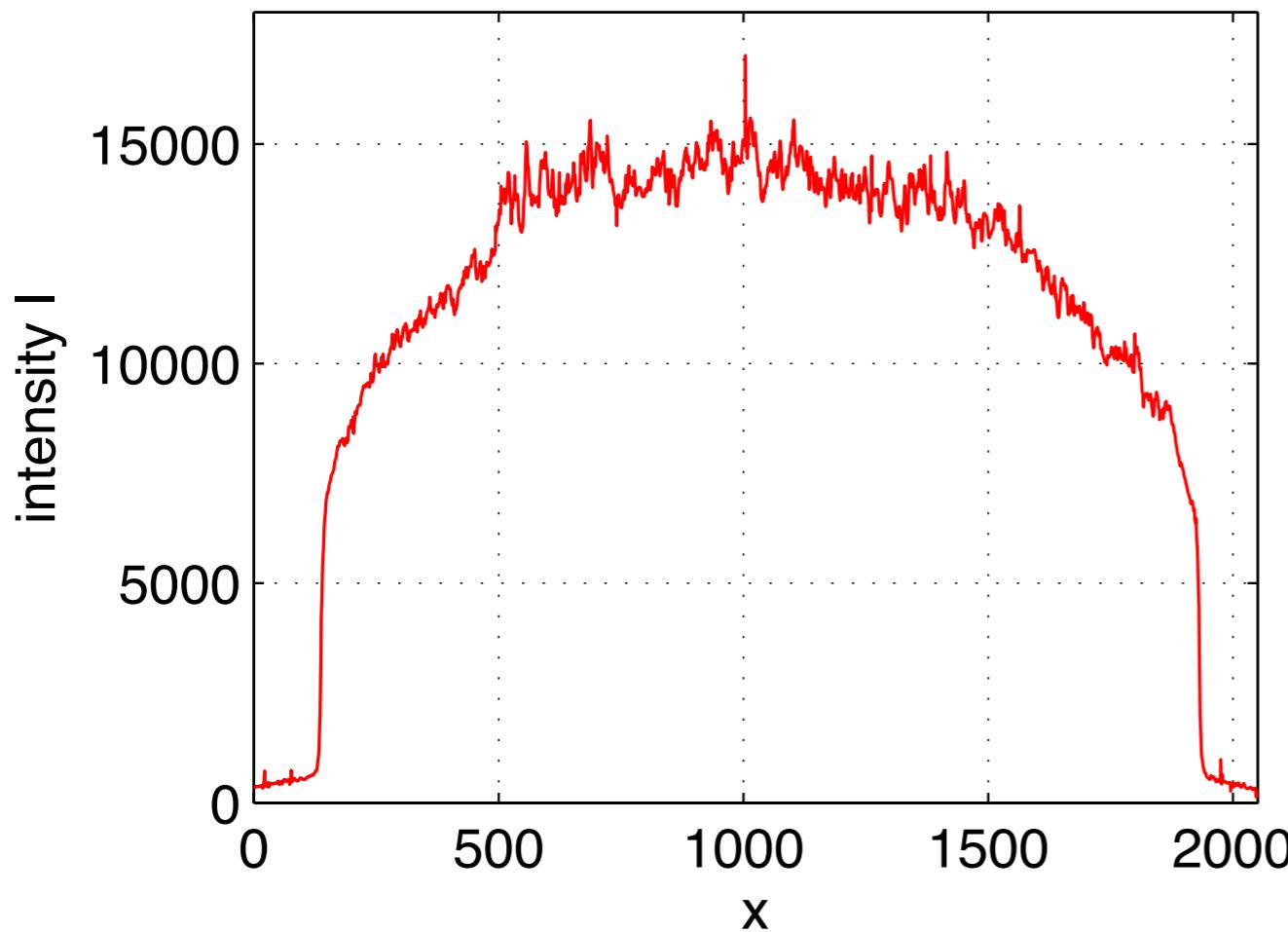
- Requires a robust criterion for detecting the limb
- Works well for circles, but intractable for more complex shapes (e.g. oblate Sun with bulges) :
N parameters = search in N-dimensional space

Non-parametric approaches

Cake slice

- Determine limb edge by intensity

Find (x,y) such that $I(x, y) = I_0$



Cake slice

Why the cake slice approach is **not appropriate**

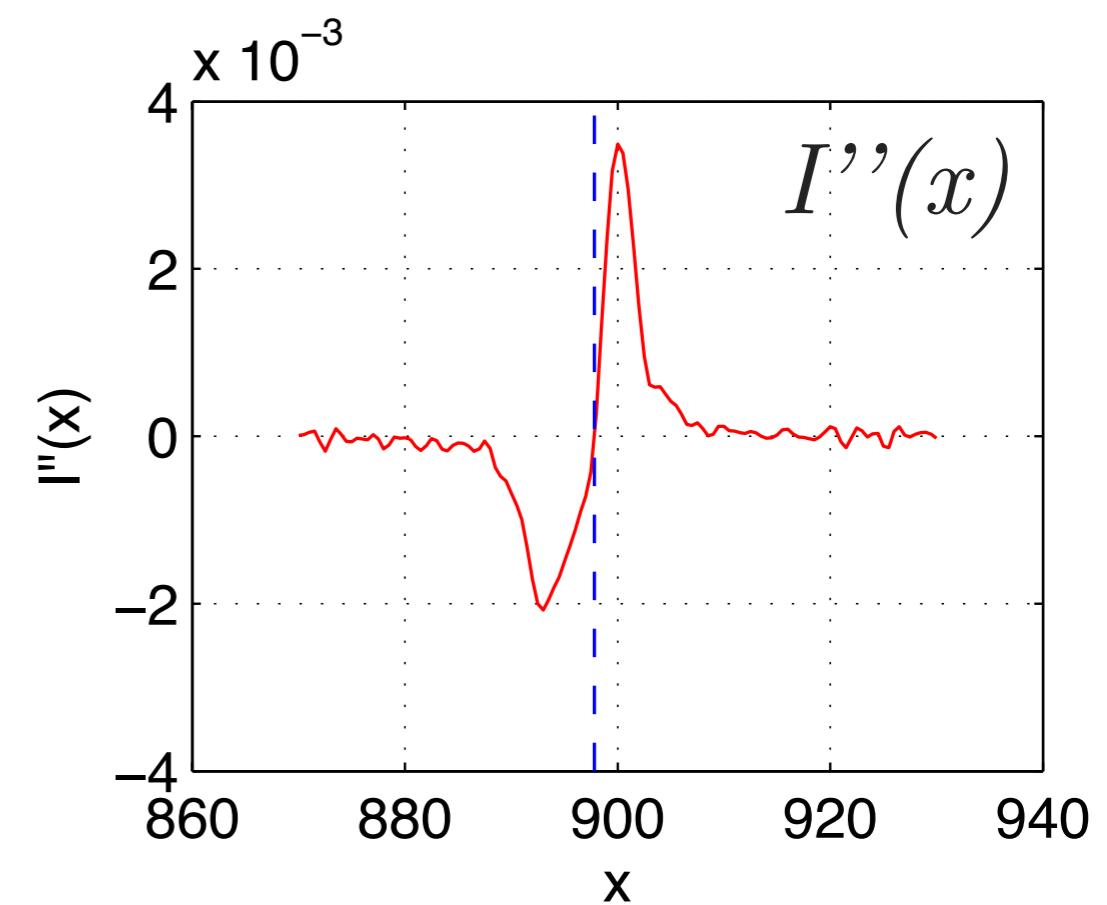
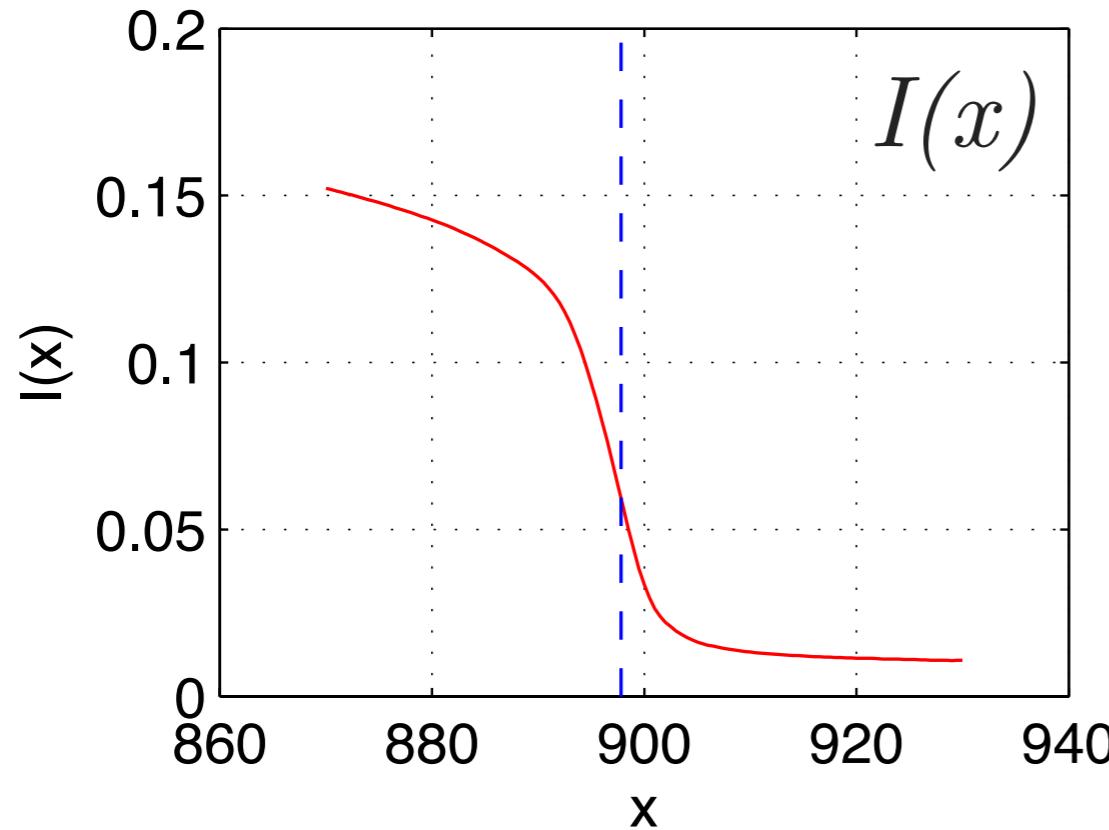
- Sensitive to image calibration (flat-field, ...)
- How to correct for variations that affect the intensity (solar-cycle, orbit, ...) ?
- No robust criterion for the limb edge

Inflexion point

- Limb edge is located at **inflexion point**

[Raponi et al., 2012, Djafer & Irbah, 2012, ...]

Find (x) such that $\frac{d^2I(x)}{dx^2} = 0$



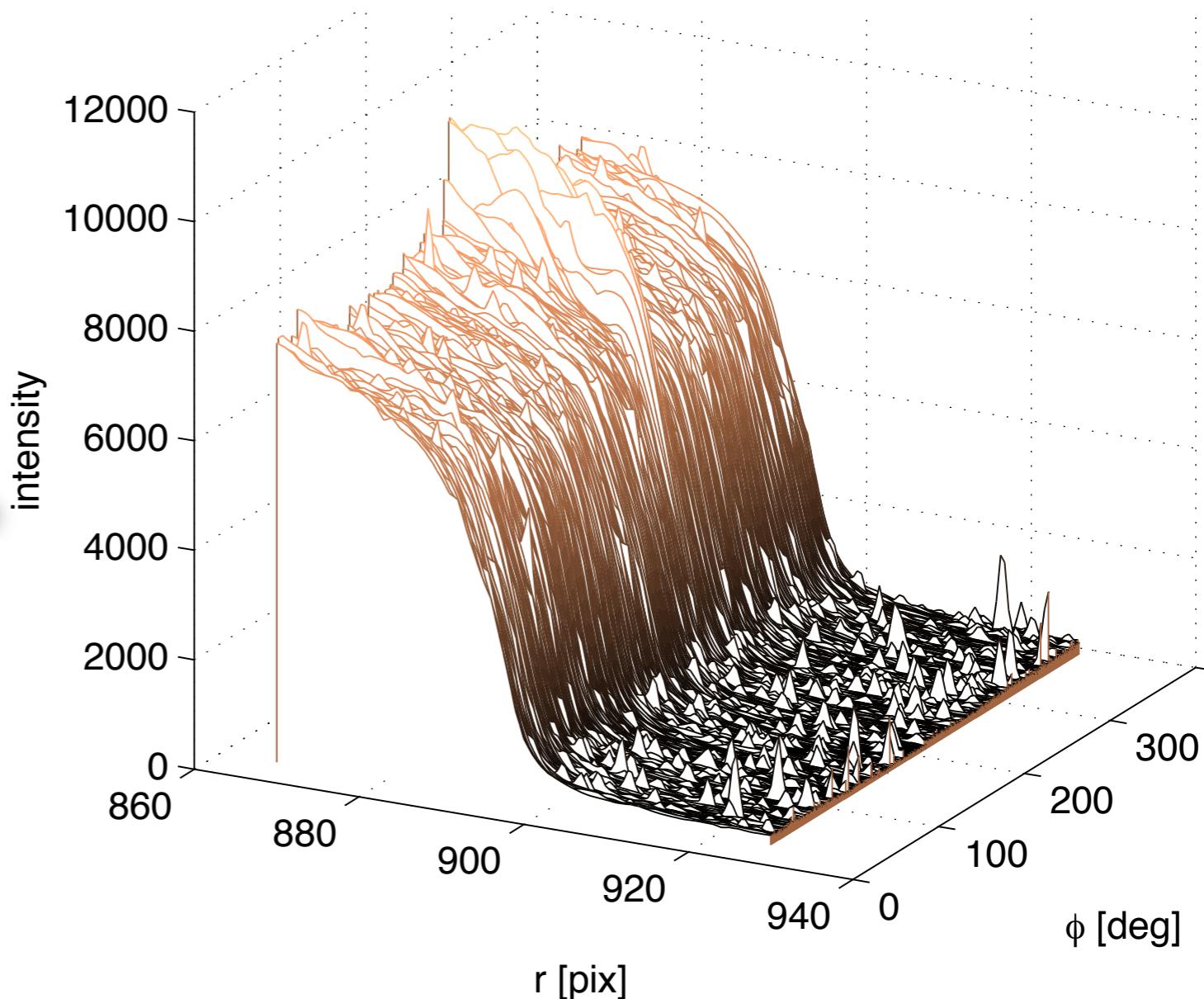
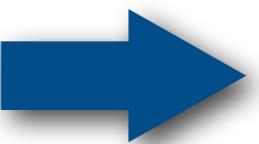
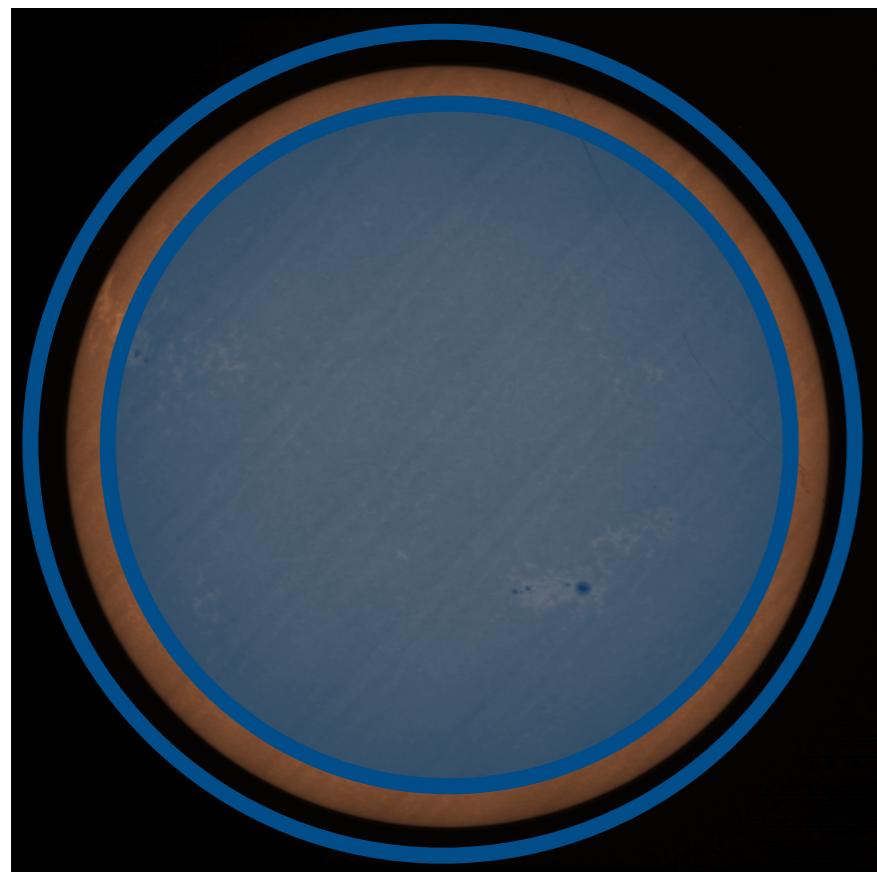
Inflexion point

Why the inflexion point is **not appropriate**, although physically sound

- Second order derivate is **very** sensitive to noise
- Limb edge determined by using local information only
(not using neighbourhood)

Use coherency

- The shape of the limb is very **coherent**
= local deviations from a standard shape are likely to be due to noise or to solar features

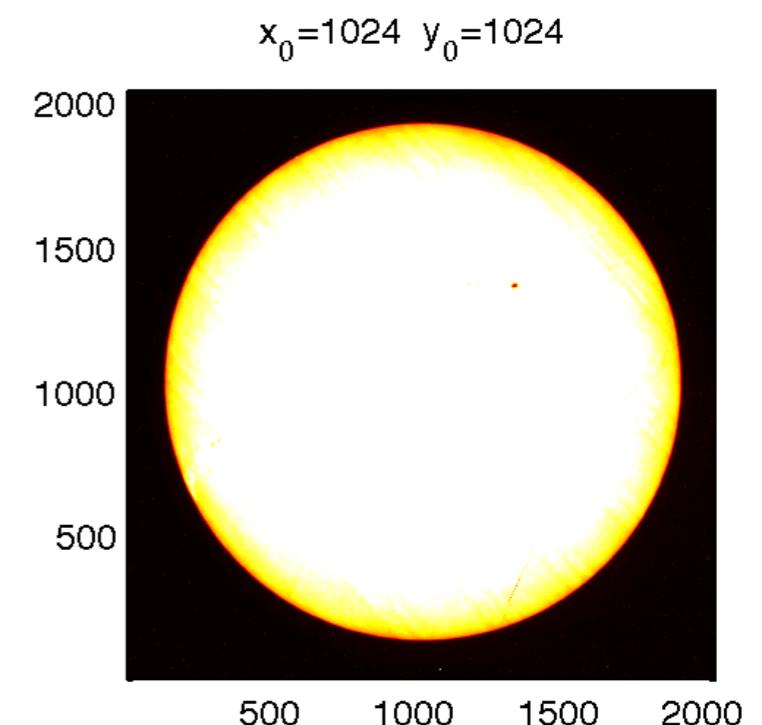
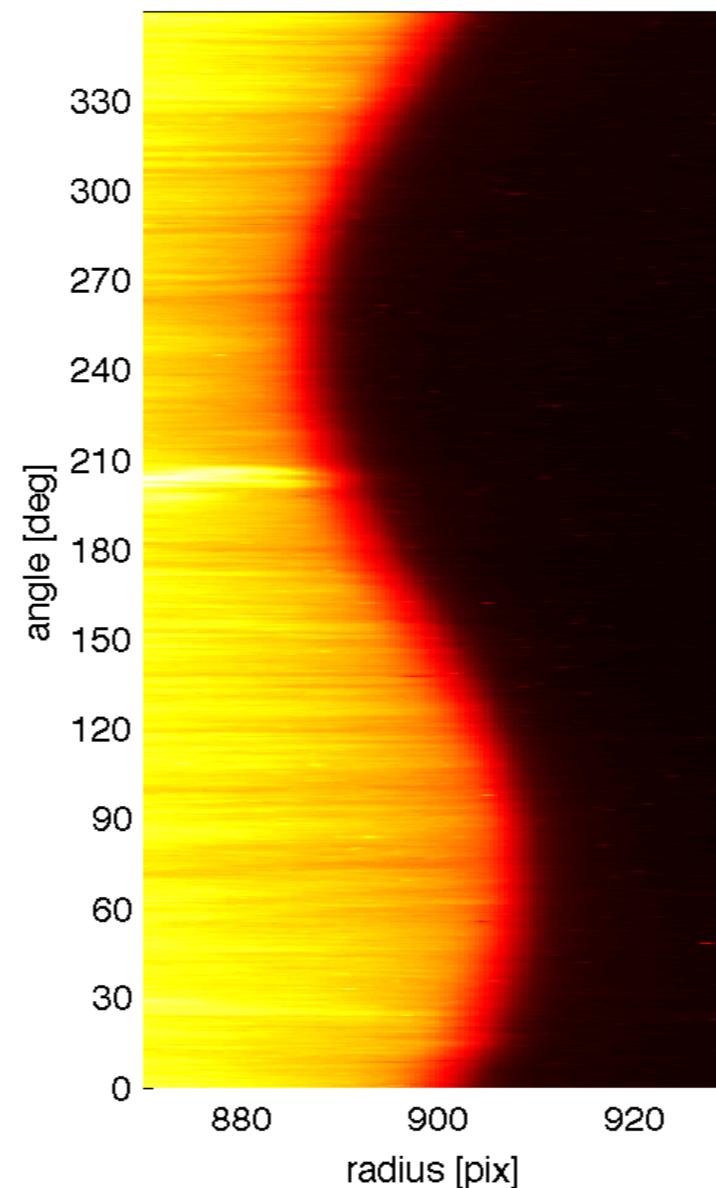


Use coherency

STEP 1 convert limb into polar coordinates

- Requires good estimate of centre of the solar disc

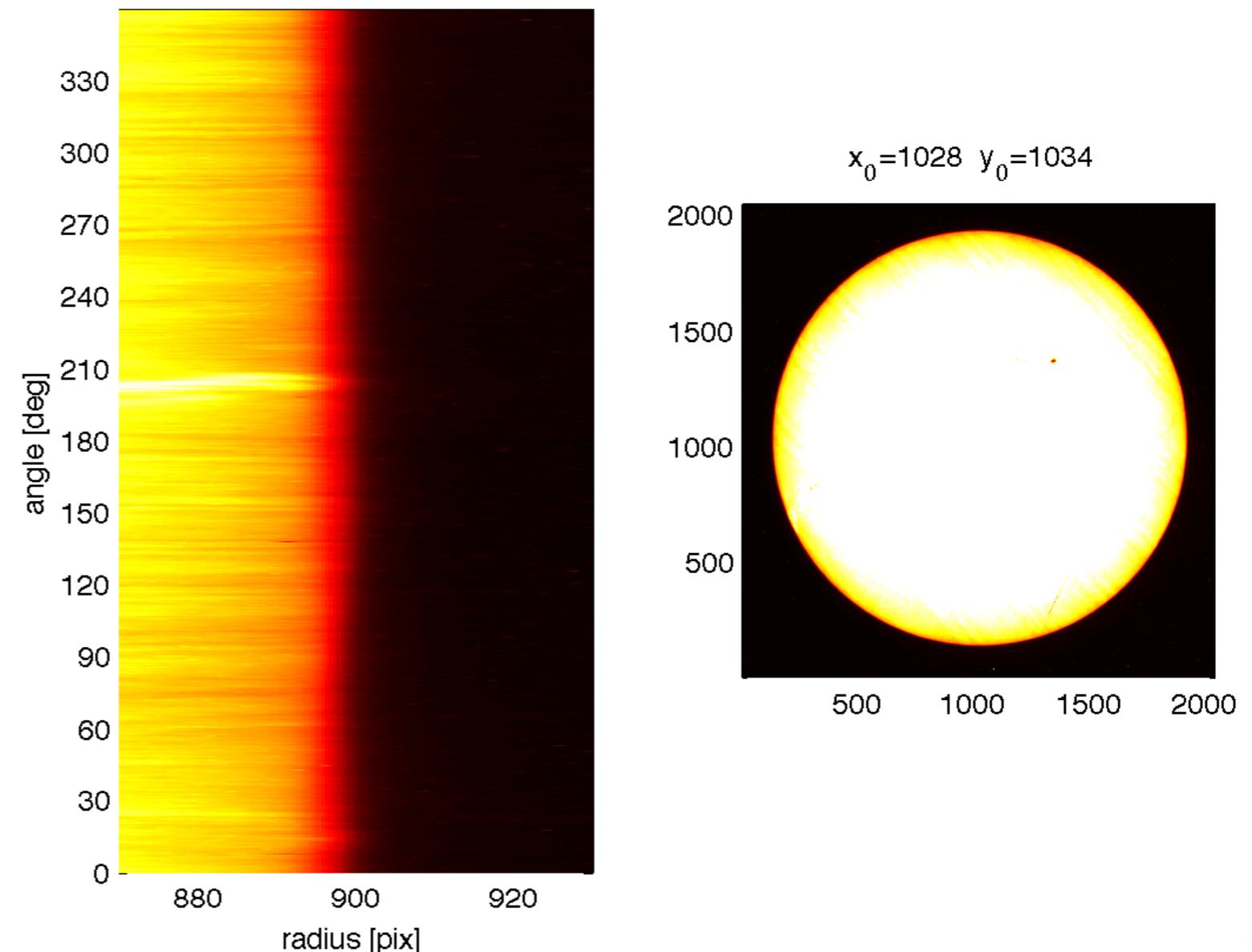
**Bad estimate of centre
= $\cos(\phi)$ modulation**



Use coherency

STEP 1 convert limb into polar coordinates

- Requires good estimate of centre of the solar disc



**Good estimate of centre
= no $\cos(\phi)$ modulation**

Use coherency

STEP 2 extract standard limb shape

- Assume the following limb shape model (locally for ϕ)

$$I(r, \phi) = f(r) \cdot g(\phi) + \epsilon(r, \phi)$$

Incoherent part

Use coherency

STEP 2 extract standard limb shape

- Assume the following separable limb shape model
(locally for a range of ϕ , typically 20°)

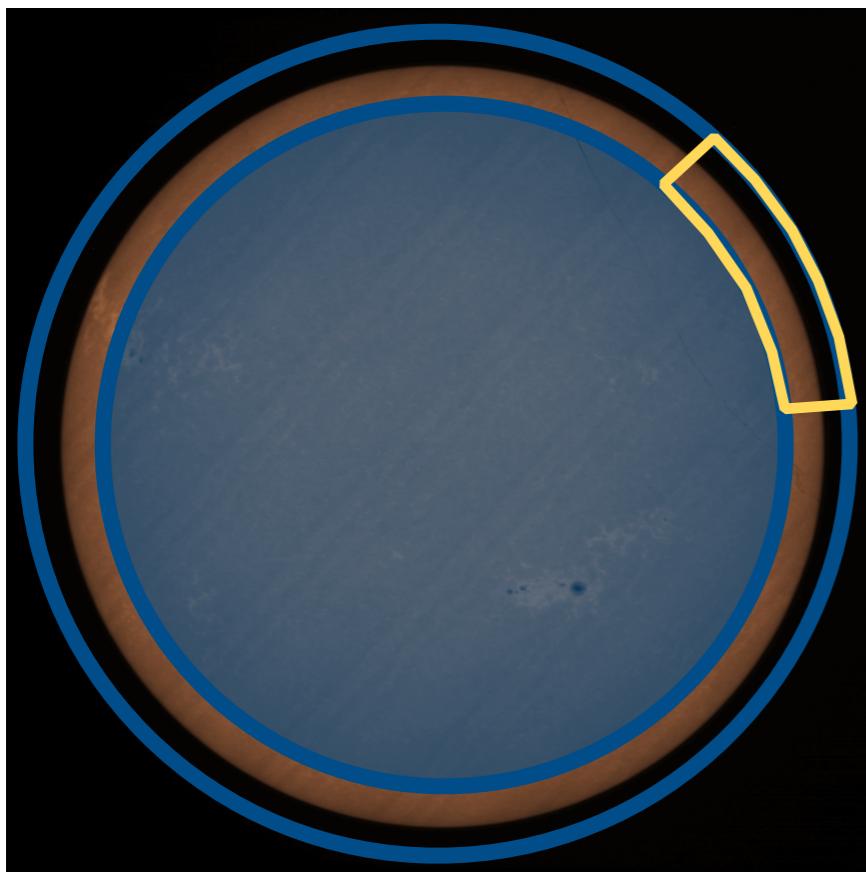
$$I(r, \phi) = f(r) \cdot g(\phi) + \epsilon(r, \phi)$$

Incoherent part

- Assume **incoherent** part consists of
 - large scale variations (in ϕ): solar diameter changes
 - small scale variations (in ϕ): instrumental noise, prominences, ...)

Use coherency

- We fit the model $I(r, \phi) = f(r) \cdot g(\phi) + \epsilon(r, \phi)$
 $\phi_1 \leq \phi < \phi_2$
- and keep $f(r)$ for further use

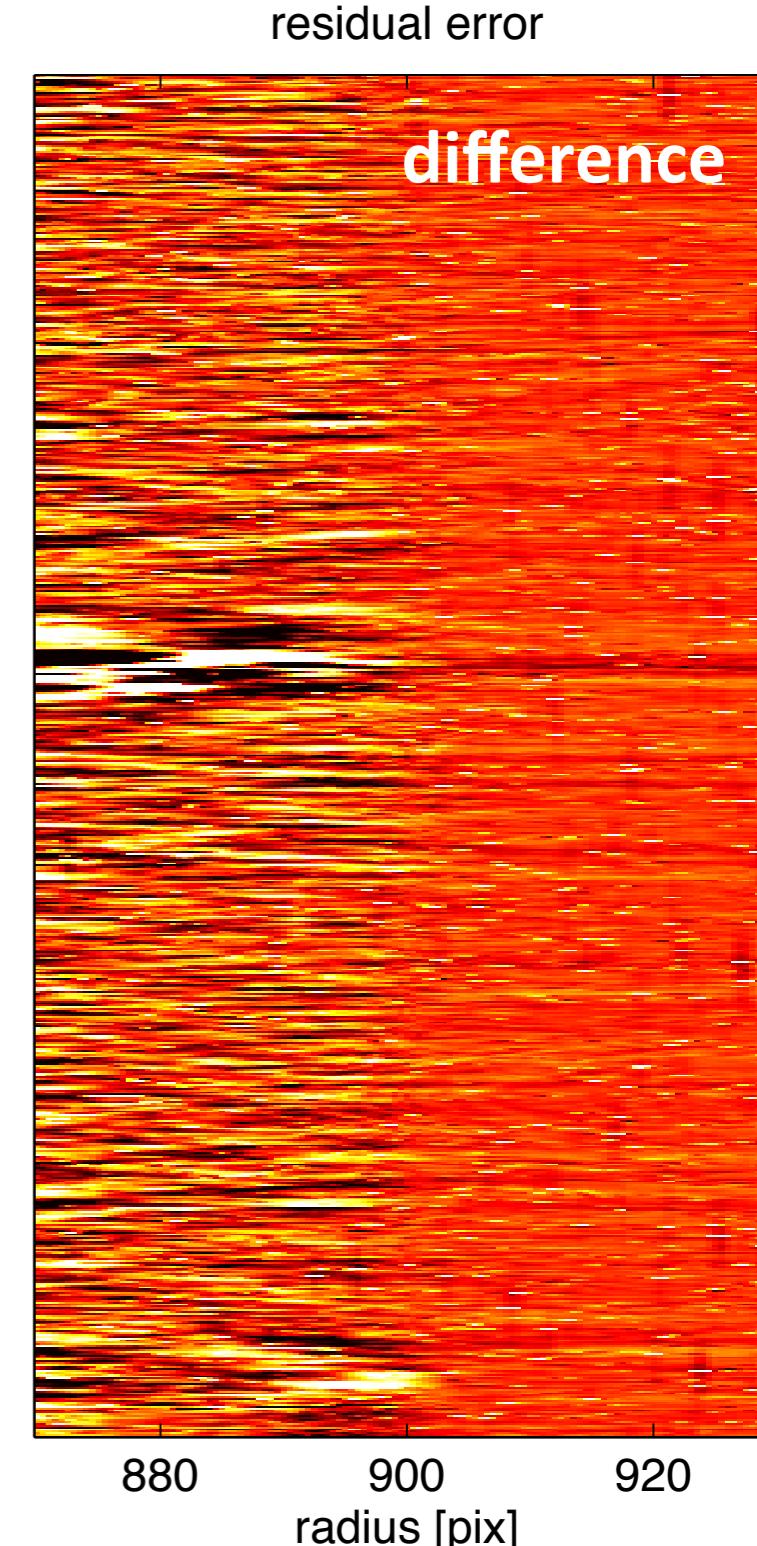
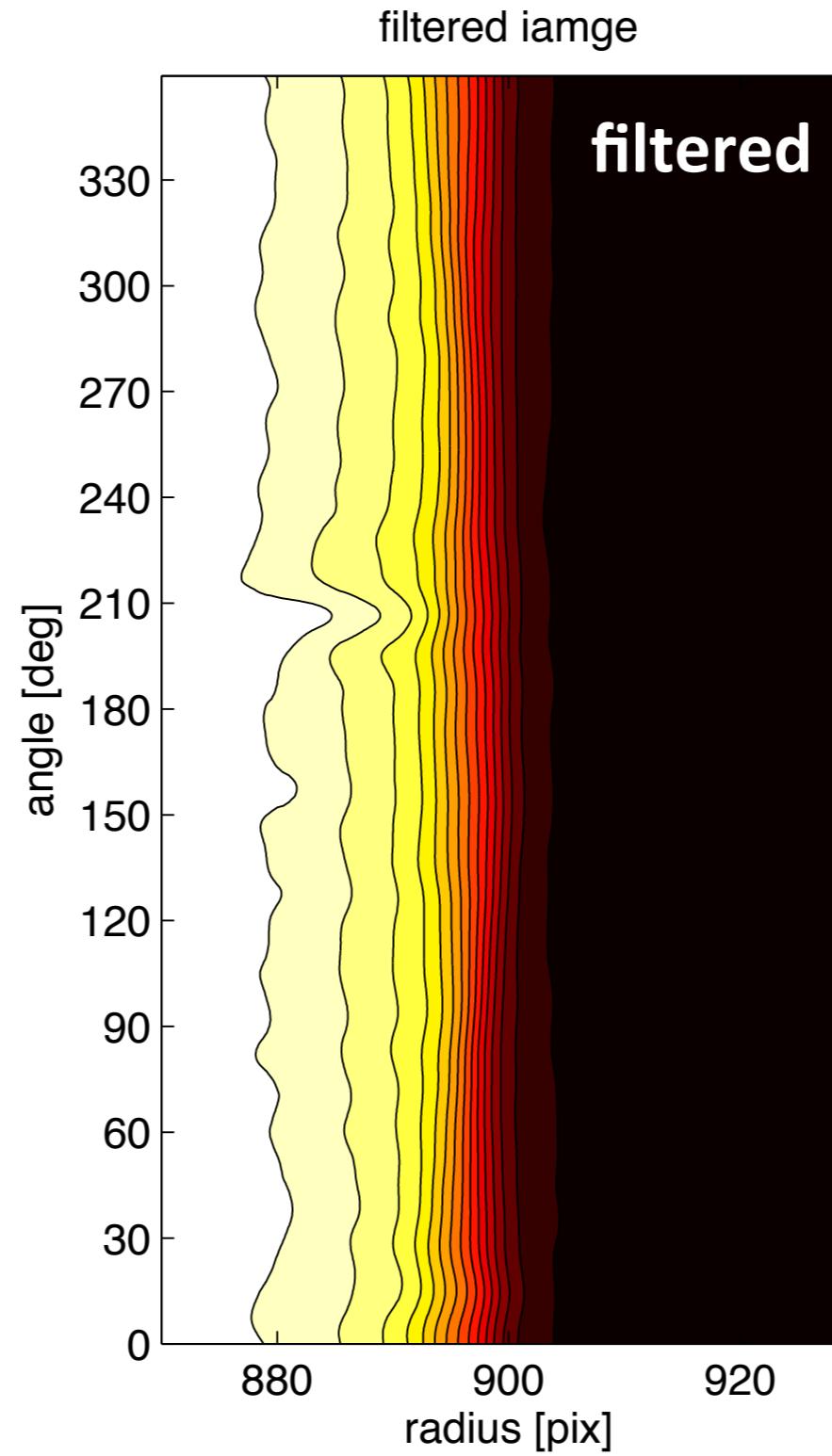
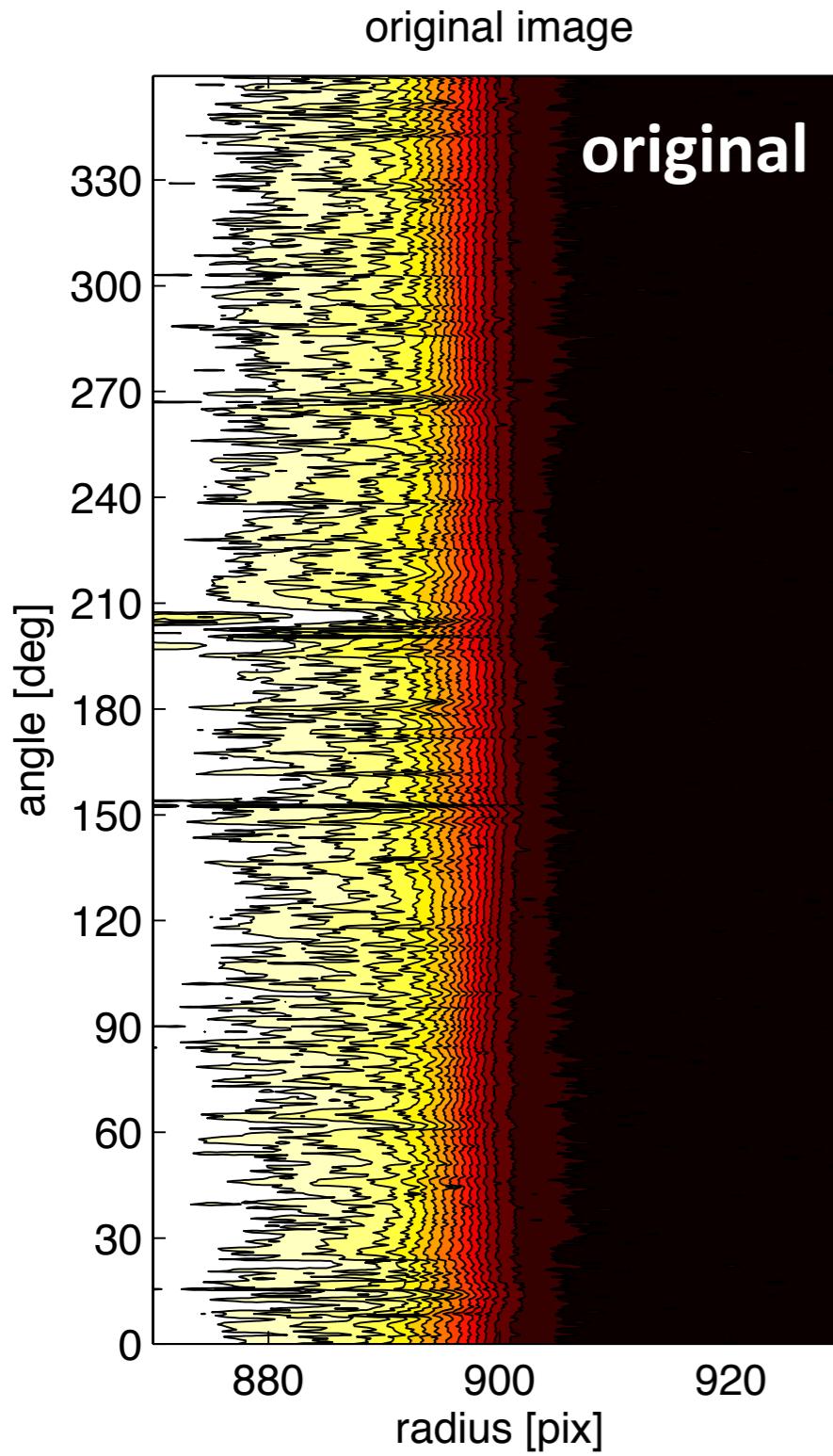


Advantage : no need to care about amplitude, contained in $g(\phi)$

In practice : $f(r)$ and $g(\phi)$ are estimated by Singular Value Decomposition (SVD)

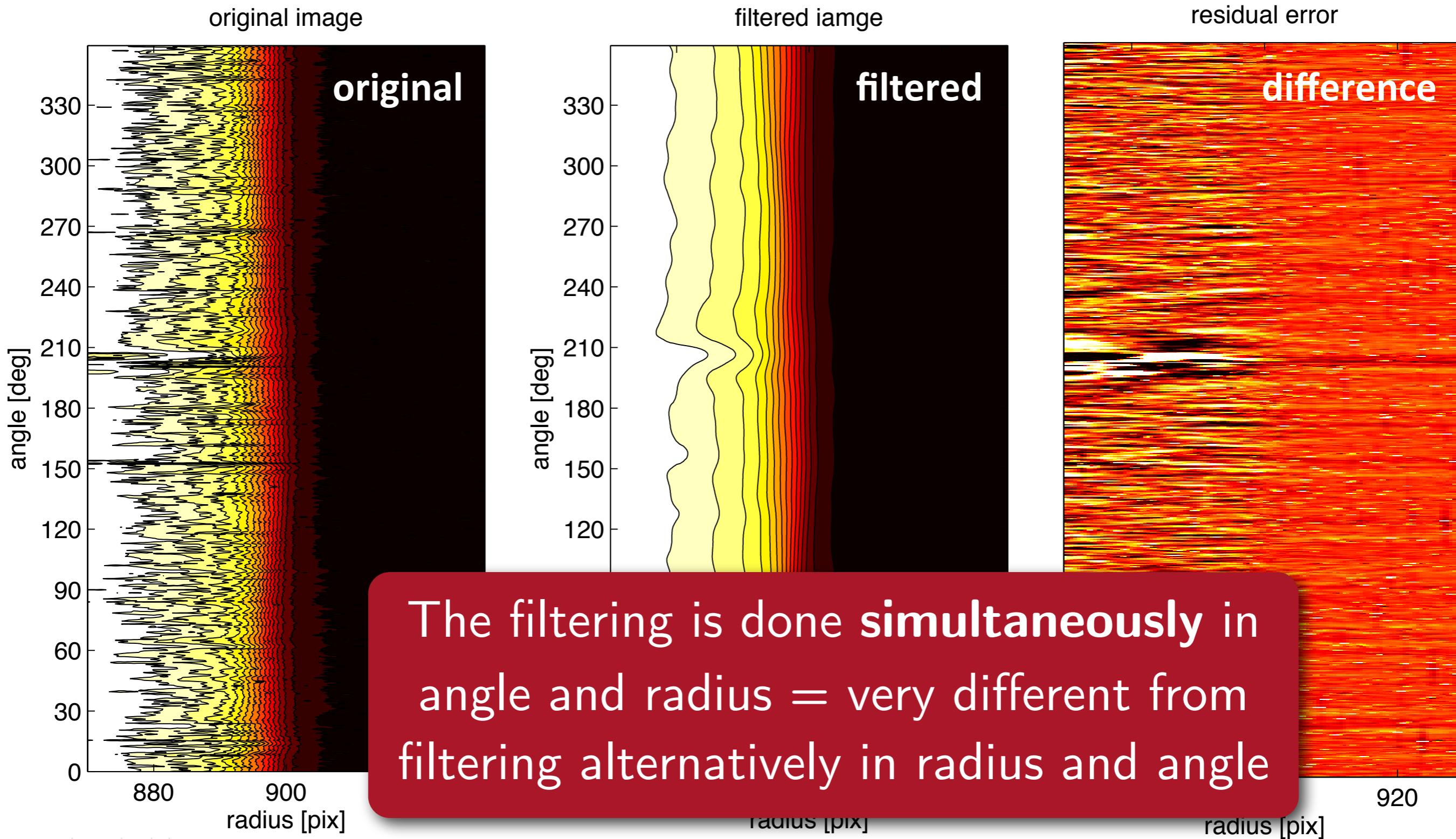
Use coherency

Example with angular resolution of 30 °



Use coherency

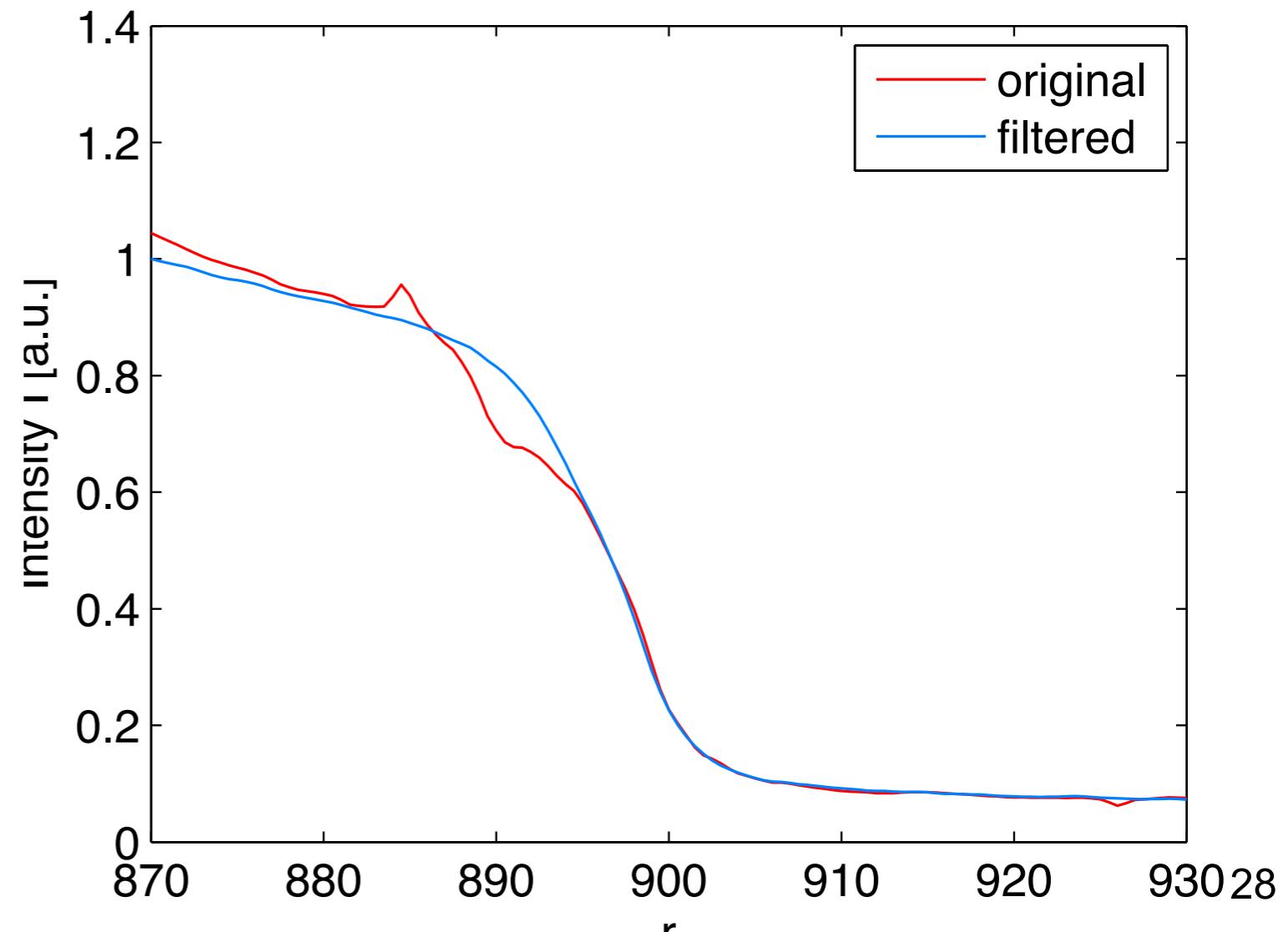
Example with angular resolution of 30 °



Use coherency

STEP 3 locate limb edge by using inflexion point

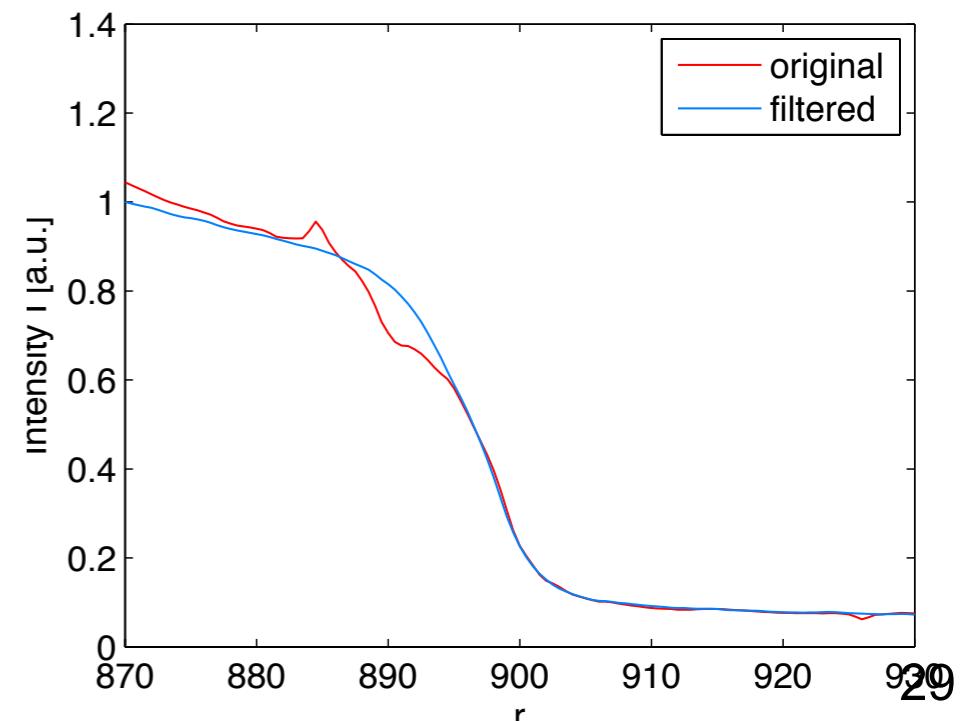
- Do NOT use 2nd order derivative (even if limb profile is now much more regular)



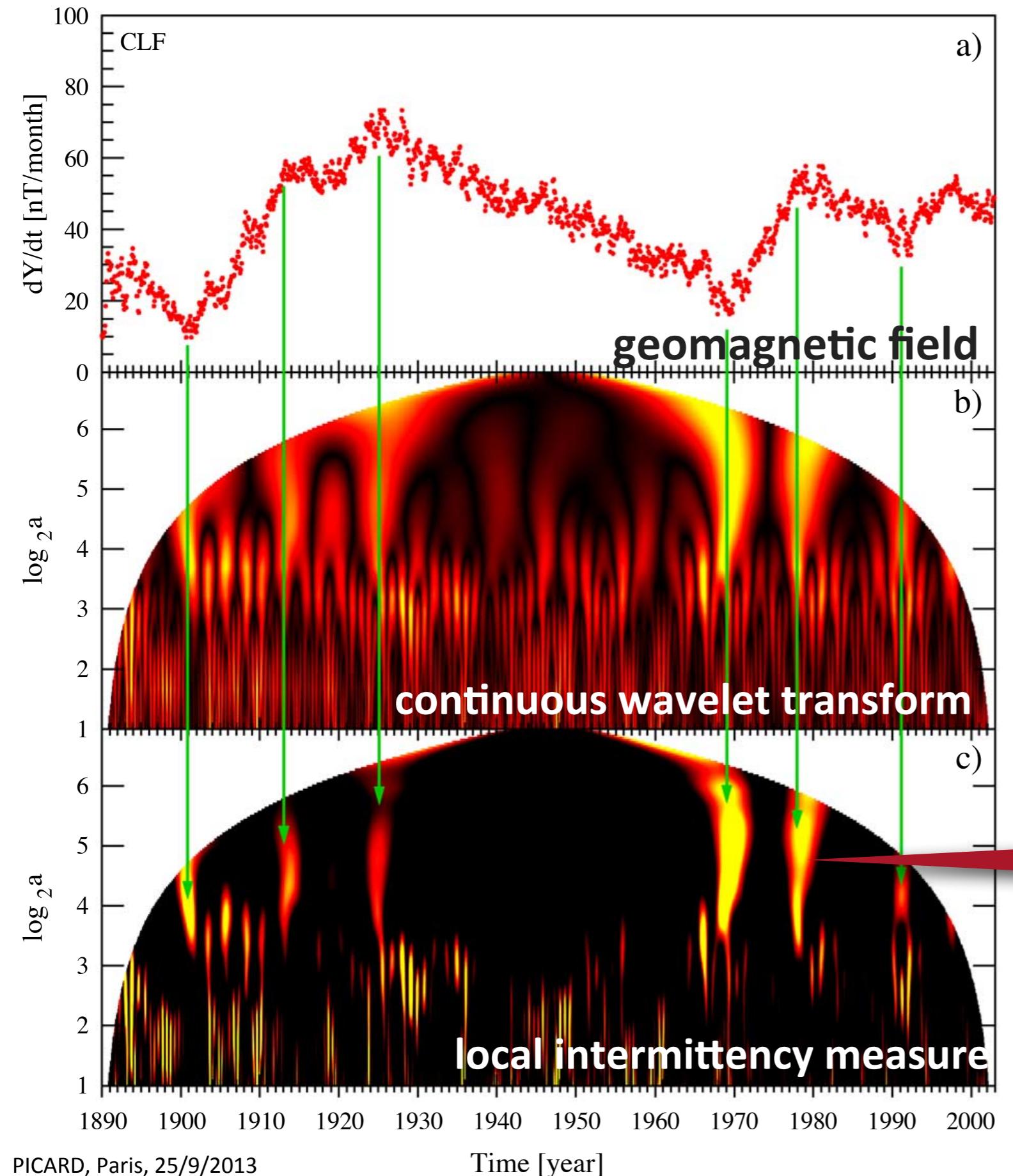
Use coherency

STEP 3 locate limb edge with inflexion point

- Do NOT use 2nd order derivative (even if limb profile is now much more regular)
- Use continuous wavelet transform instead: ideally suited for detecting discontinuities



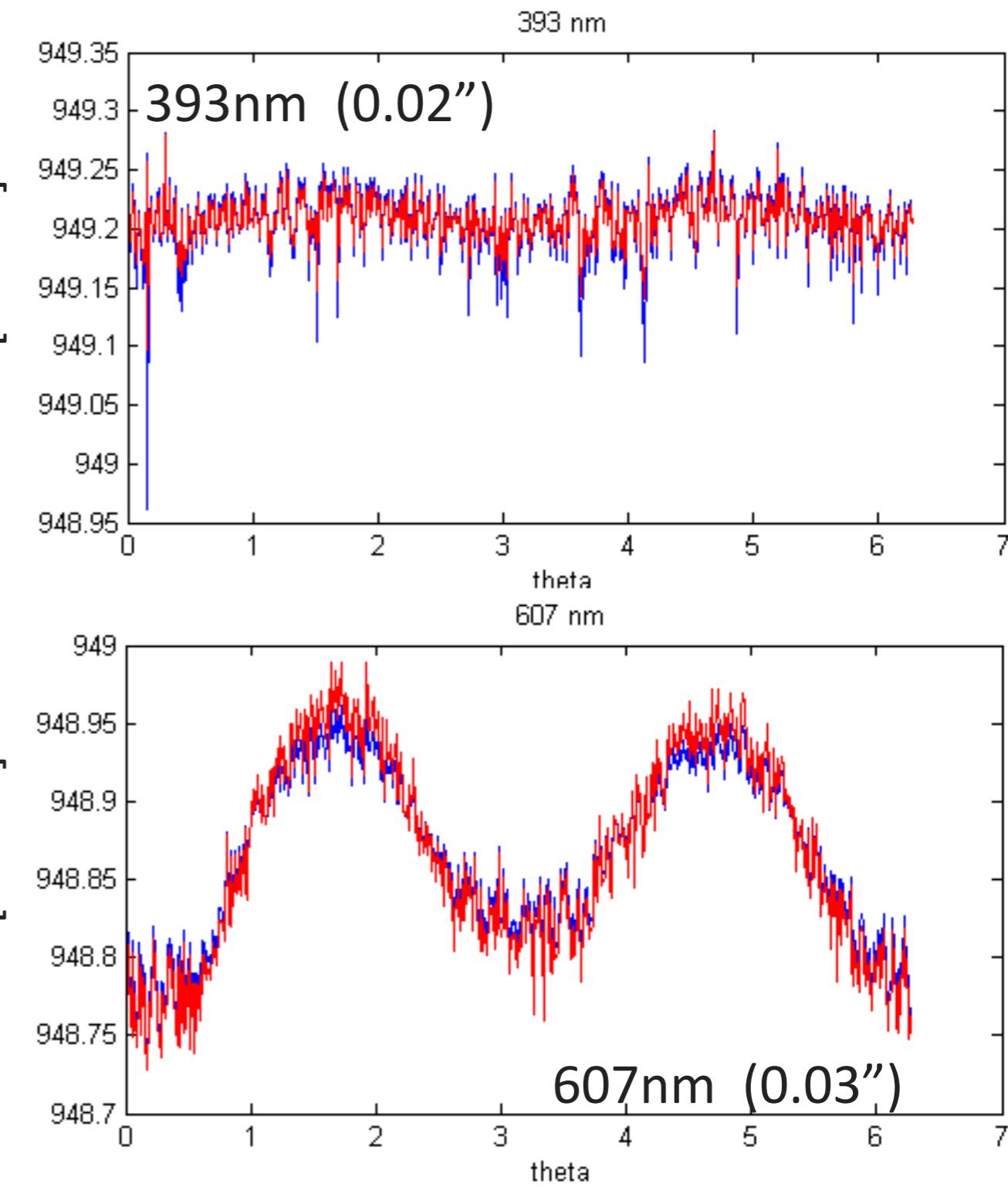
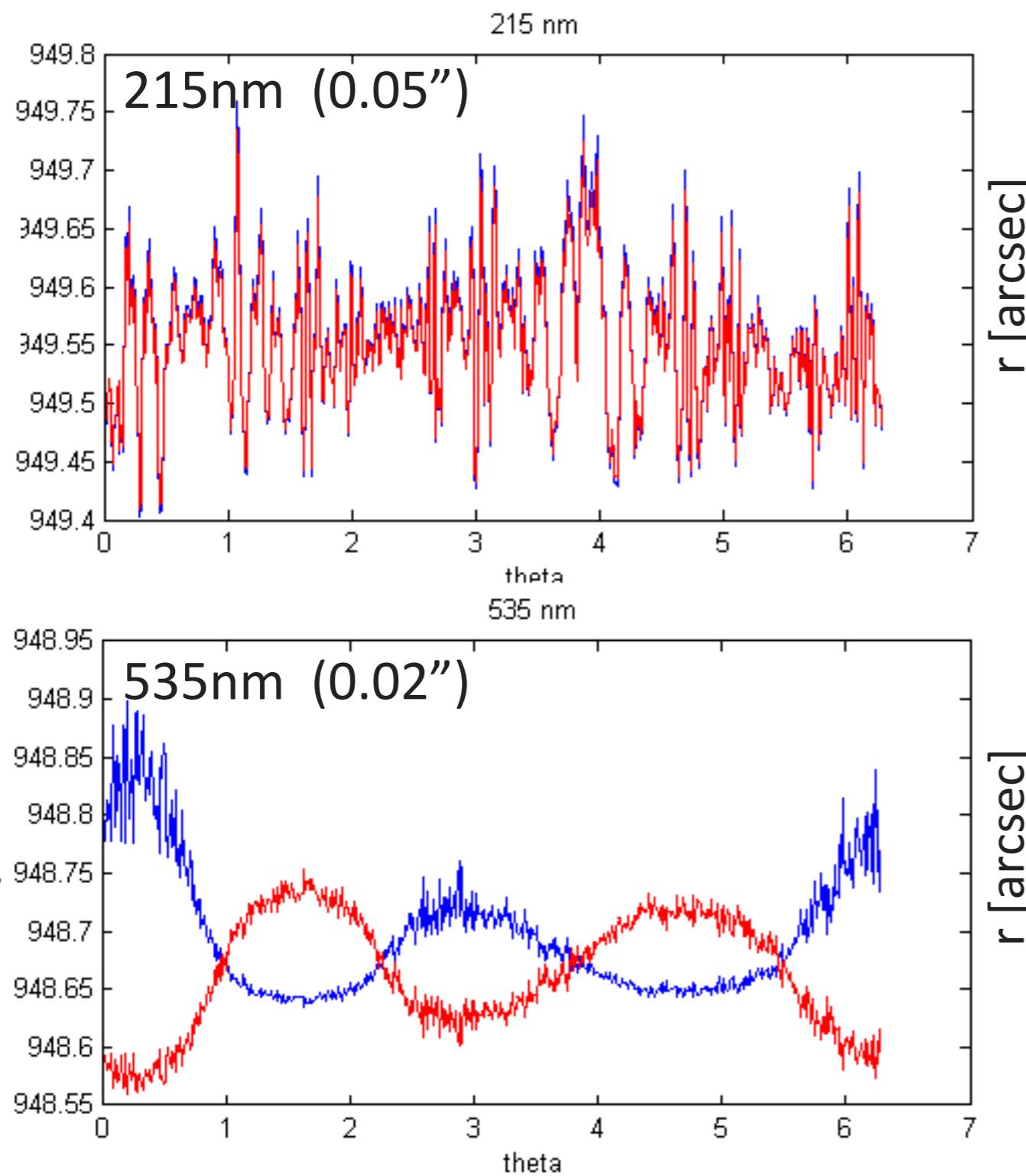
Use coherency



Example: detection of
geomagnetic jerks
[de Michelis et al., 2005]

Wavelet ridges are
ideally suited for
detecting inflexion
points

Results



Conclusions

- High-resolution technique exploits coherency of limb shape
 - filtering in r and ϕ
 - improved inflexion point location by using continuous wavelet transform
- But this is worthless as **careful validation is still needed** (bias, uncertainties, pixellisation, ...)
- By-product: extract solar features above the limb

Thank you !