Collisional Dust Avalanches

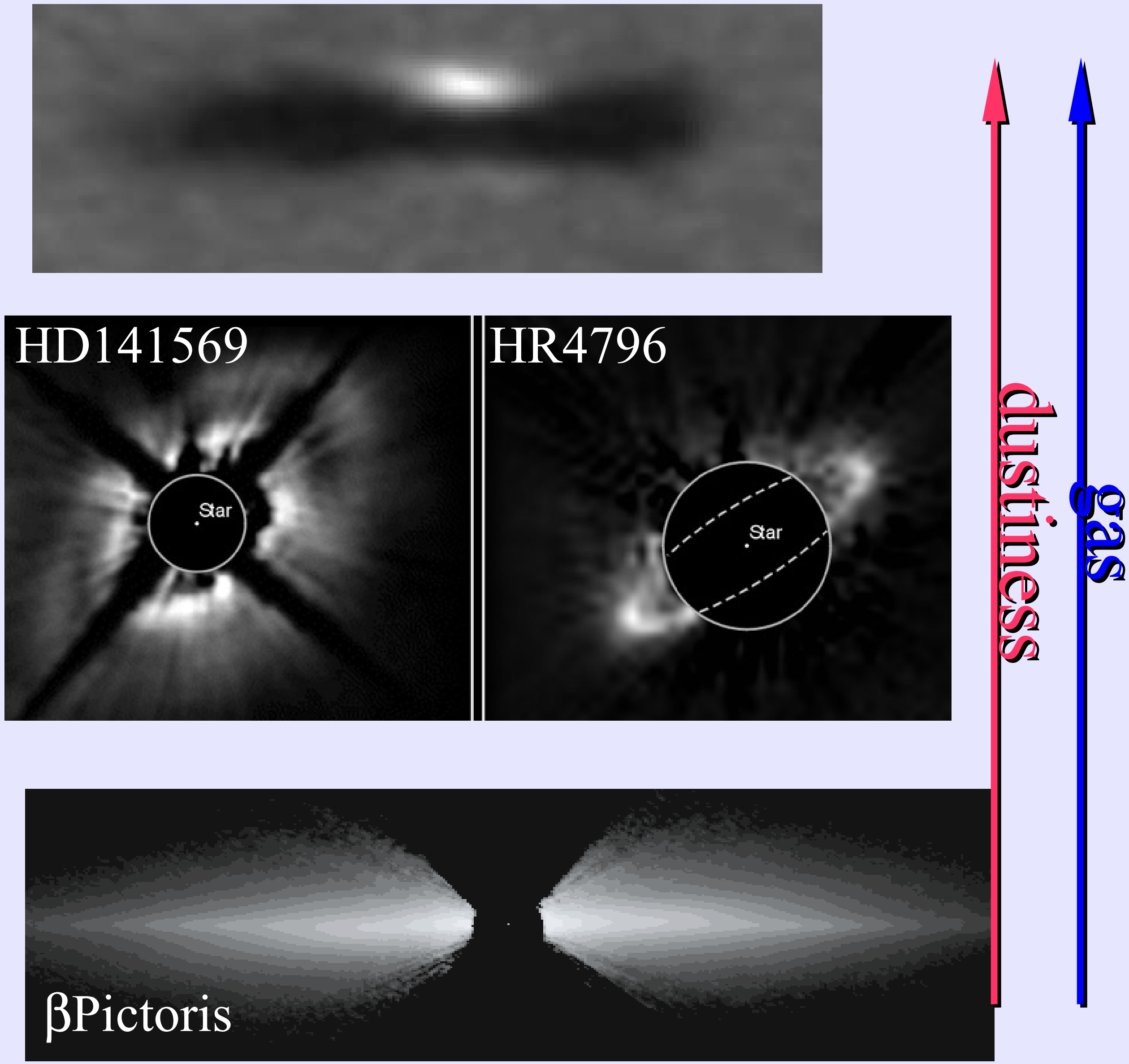
in debris disks

Anna Grigorieva

Stockholms Obsevatorium

Porto 2007

Circumstellar disks: stages of evolution



1 Myr

~5 Myr

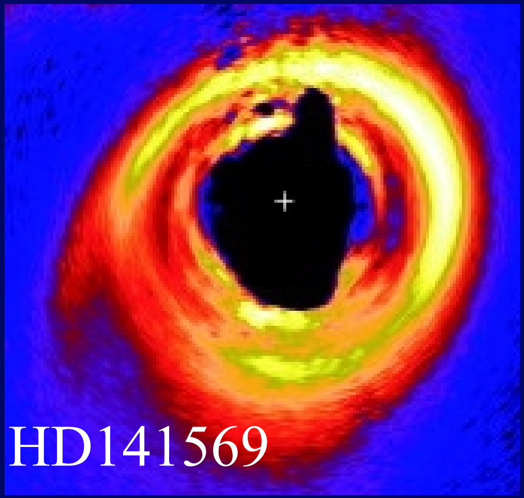
>10 Myr

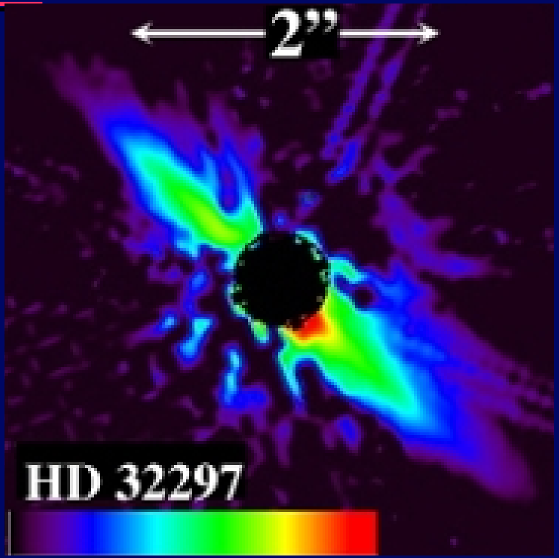
nearly gas free
$L_{IR}/L_* < 10^{-2}$

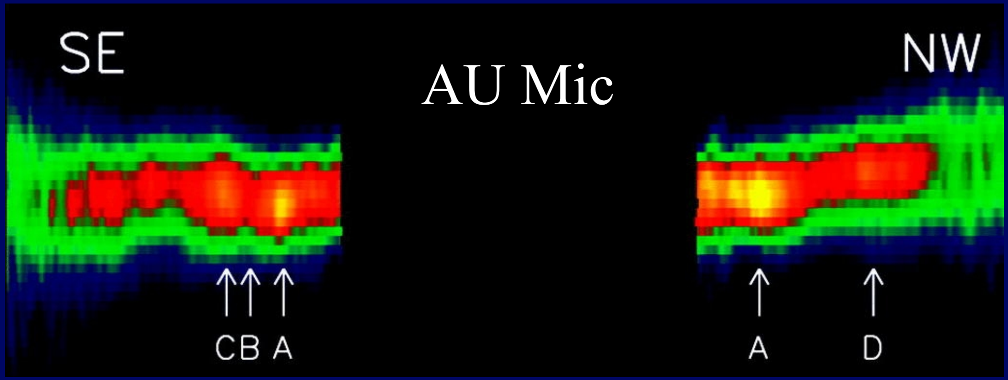
gas important dynamically
$L_{IR}/L_* \sim 10^{-2}$

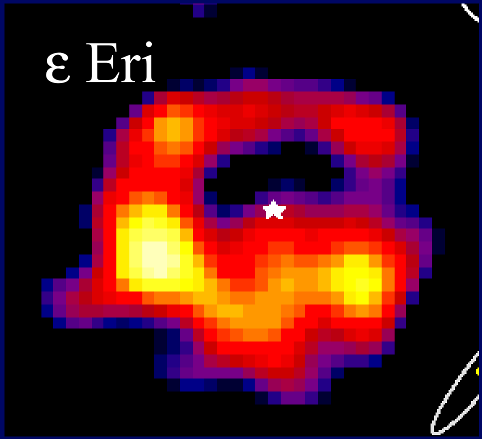
gas-rich
$L_{IR}/L_* > 10^{-2}$

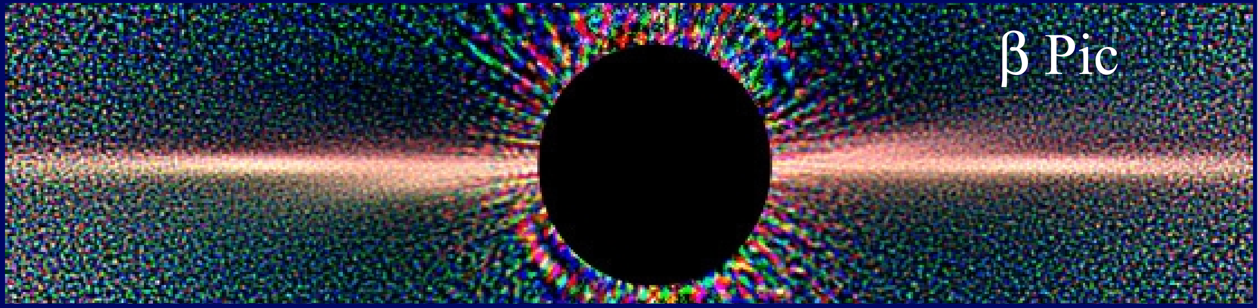
Circumstellar disks











Features & their Origins

FEATURES in disks: (9)

blobs, clumps
streaks, feathers
rings (axisymm)
rings (off-centered)
inner/outer edges
disk gaps
warps
spirals, quasi-spirals
tails, extensions

ORIGIN: (10)

instrumental artifacts, variable PSF, noise, deconvolution etc.
background/foreground obj.
planets (gravity)
stellar companions, flybys
dust migration in gas
dust blowout, avalanches
episodic release of dust
ISM (interstellar wind)
stellar UV, wind, magnetism
collective eff. (selfgravity)

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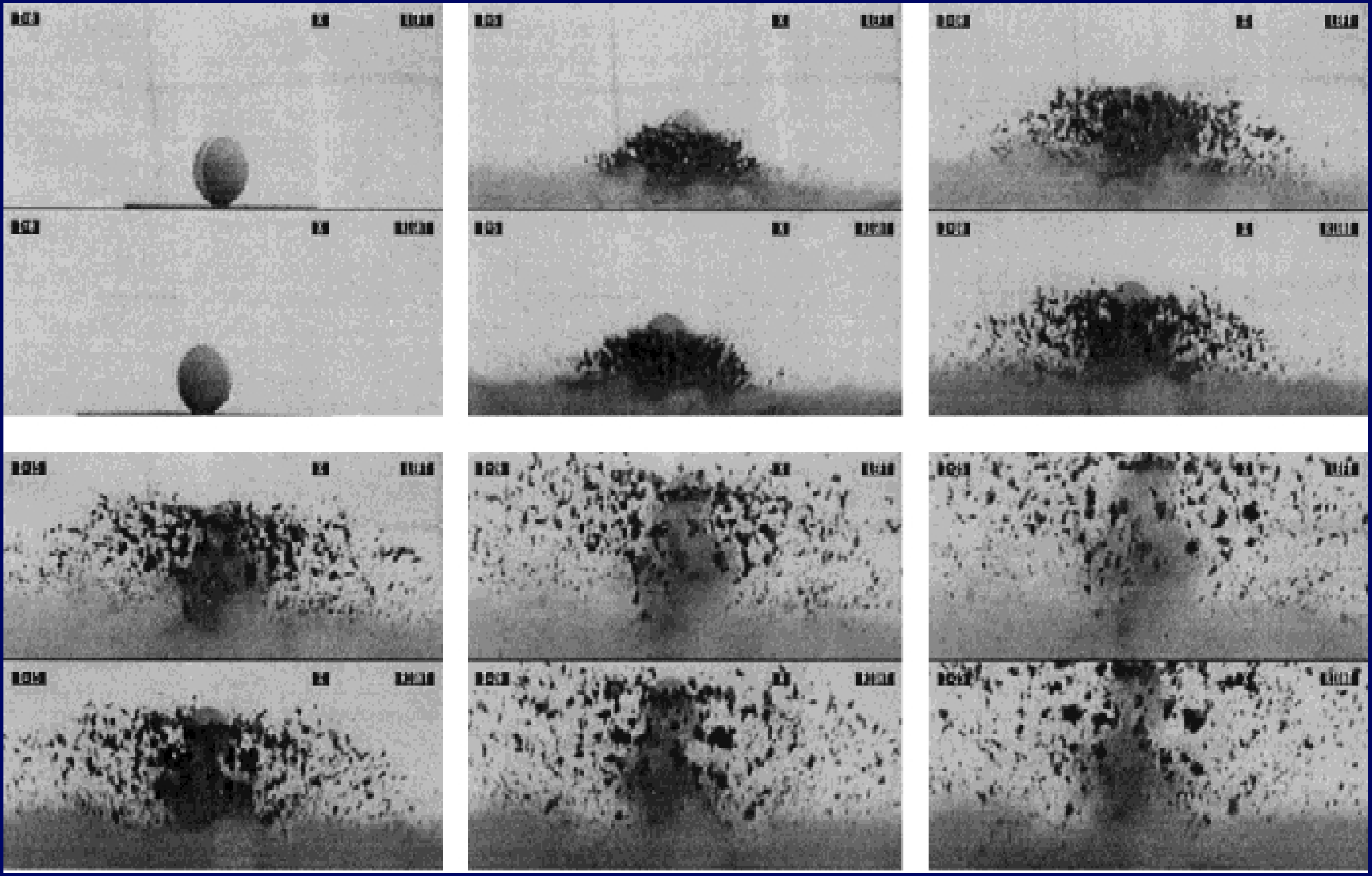
A catastrophic breakup



A catastrophic breakup

Wyatt & Dent (2002) :
clumps in Fomalhaut's debris disk

Telesco et al. (2005):
MIR brightness asymetries in ßPic
(order of magnitude estimate)

Kenyon & Bromley (2005):
detailed study on a possibility of detecting of a catastrophic 2body collisions in disks

Only debris produced **directly** by the shattering event are taken into account

A catastrophic breakup

Our goal:

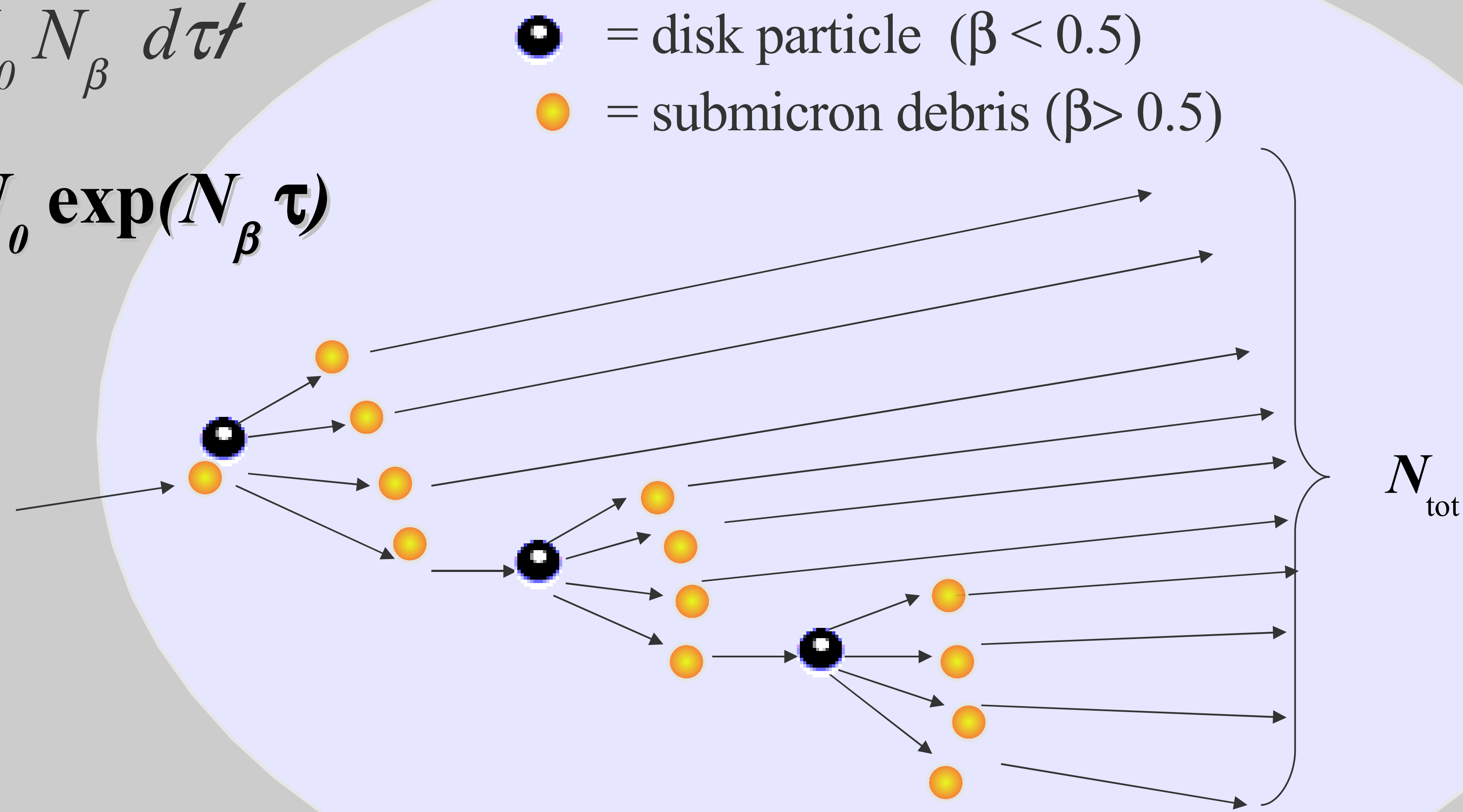
consequences of *an isolated shattering* event by considering the collisional evolution of the dust cloud AFTER its release.

Collisional avalanche:

a chain reaction of outflowing debris striking disk particles & creating even more debris accelerated by the star's radiation pressure

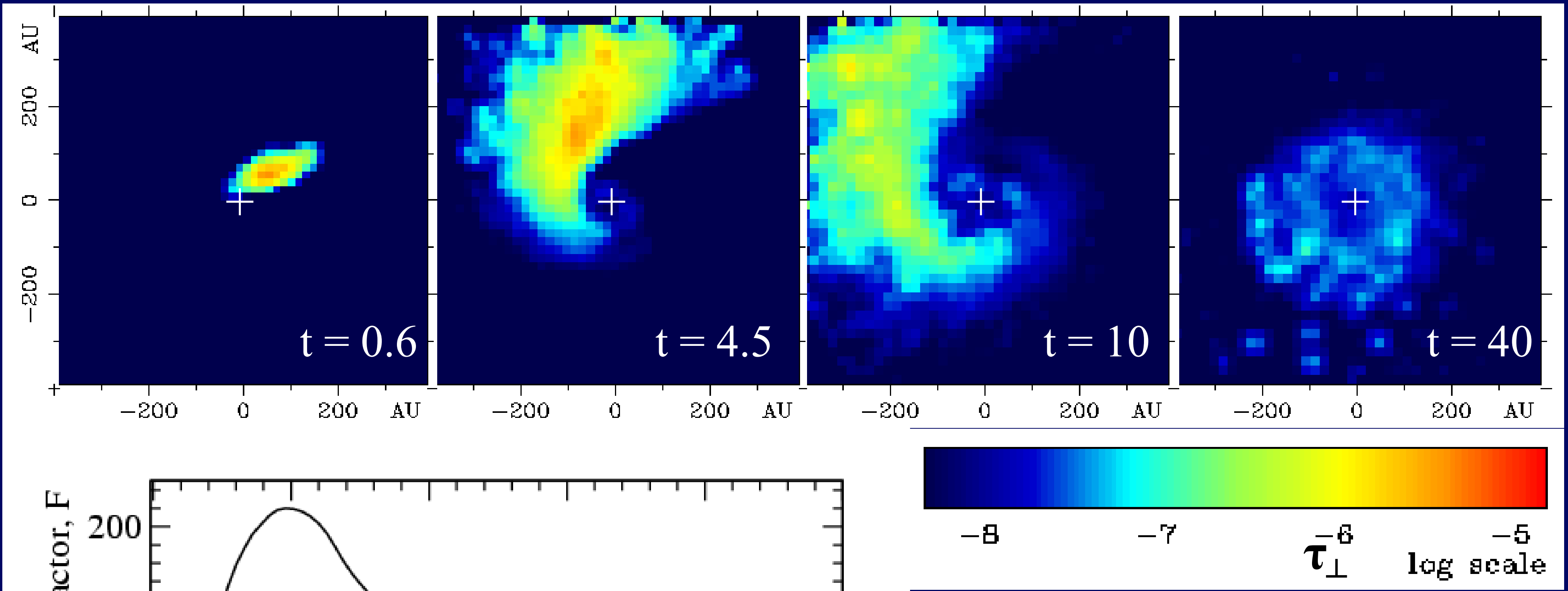
$$dN=N_0 N_\beta \ d\tau$$

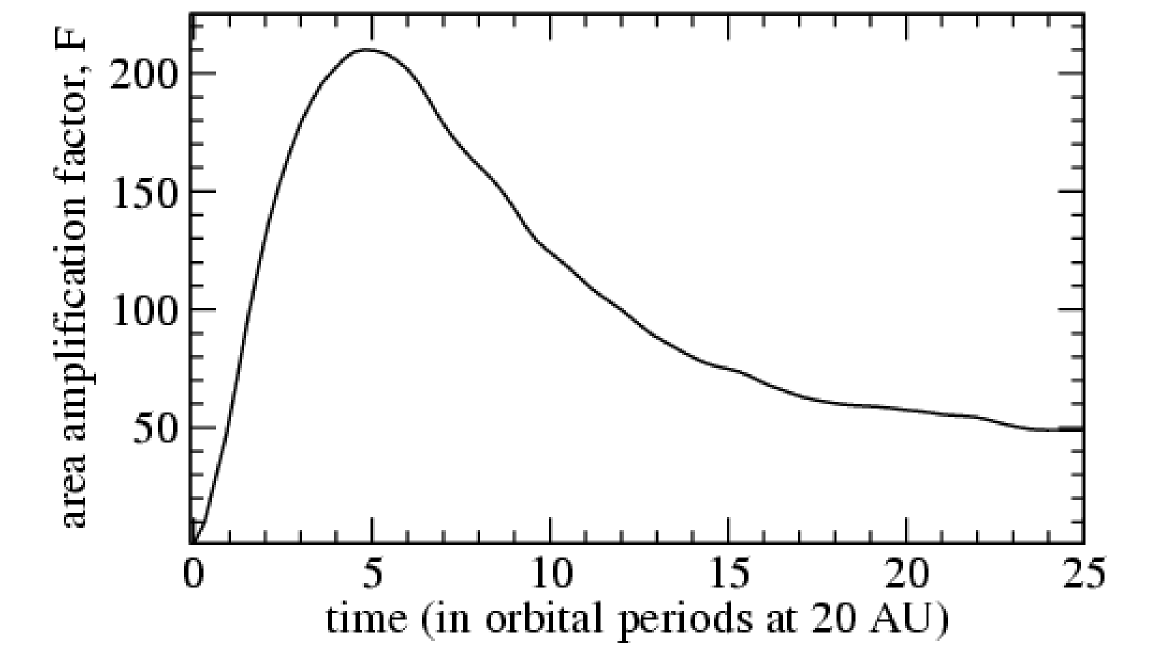
$$\boldsymbol{N_{tot}=N_0 \exp(N_\beta \tau)}$$



Results: β Pic-like disk

Time evolution of dust area of avalanche grains.





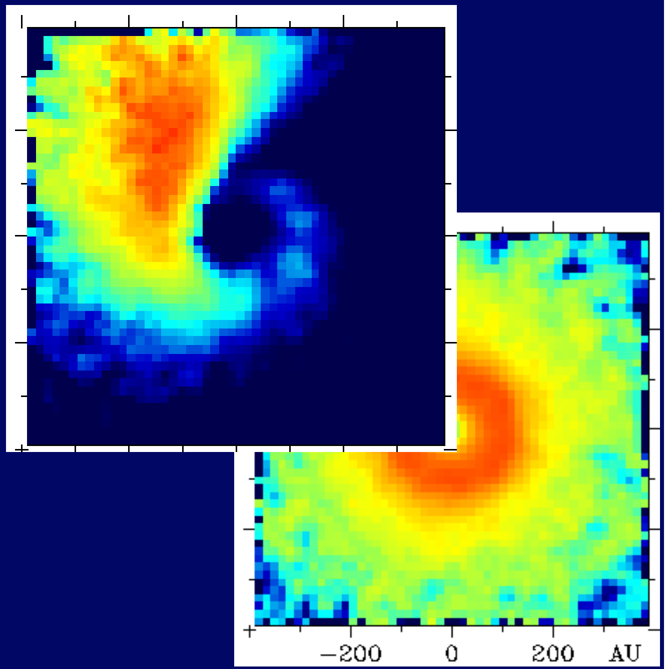
A_{cr} – total cross-sectional area of the avalanche grains

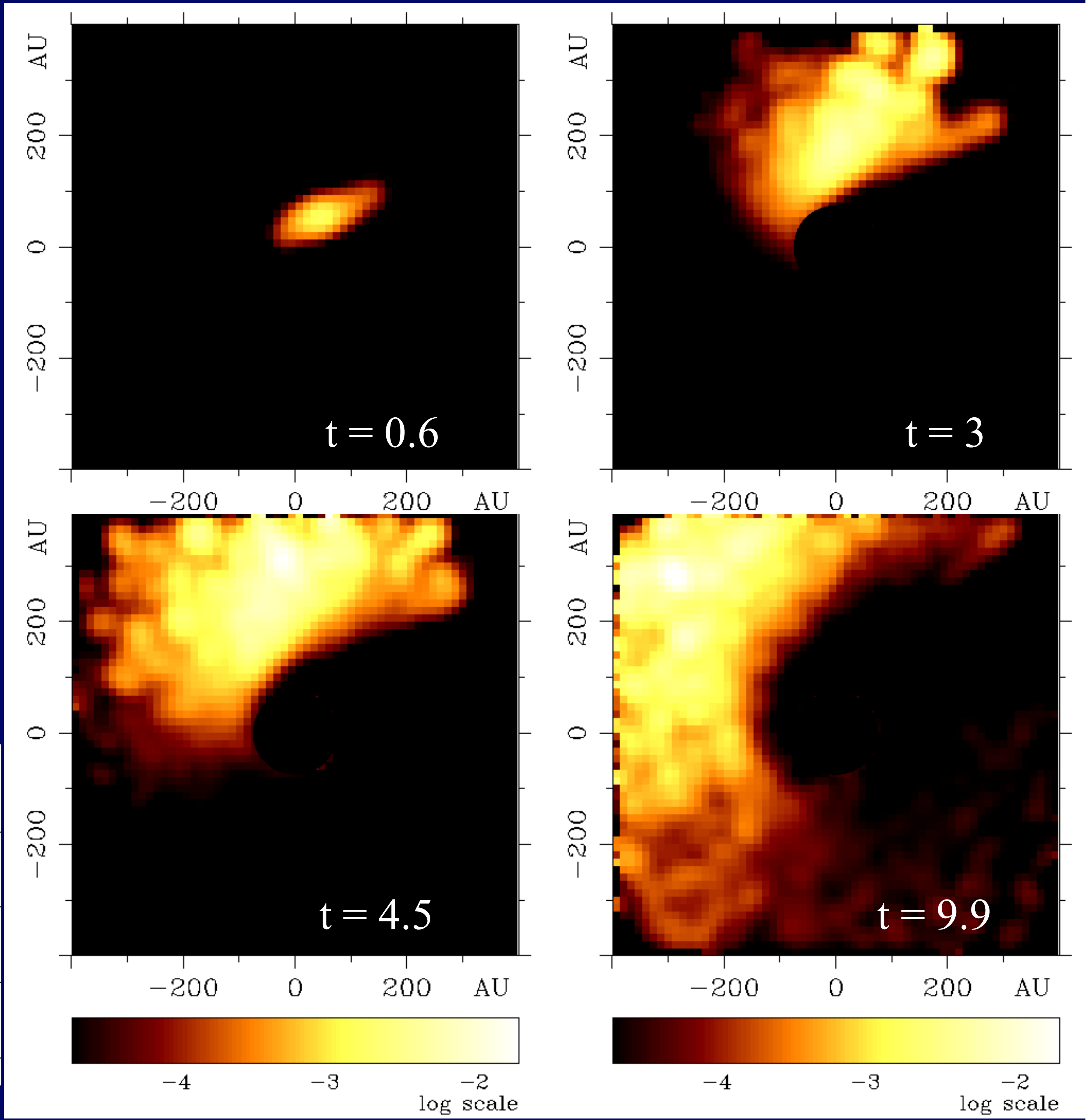
$$F = \frac{A_{cr}(t)}{A_{cr,0}(t=0)}$$

Avalanche vs. "Field"

A=cross-sectional surface density

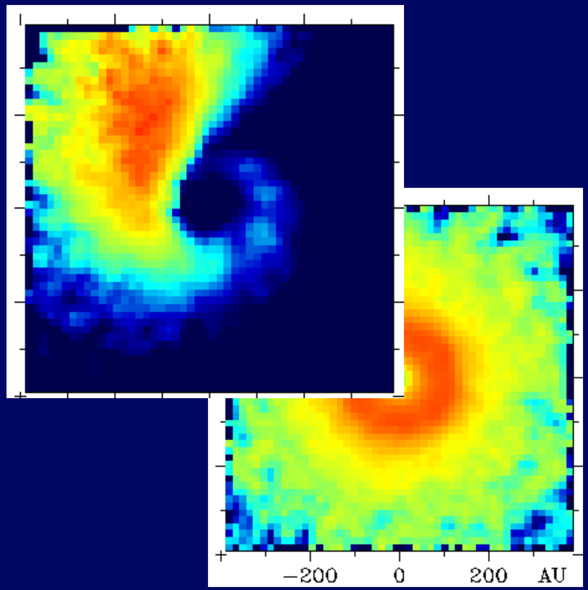
Map = A_av/A_field



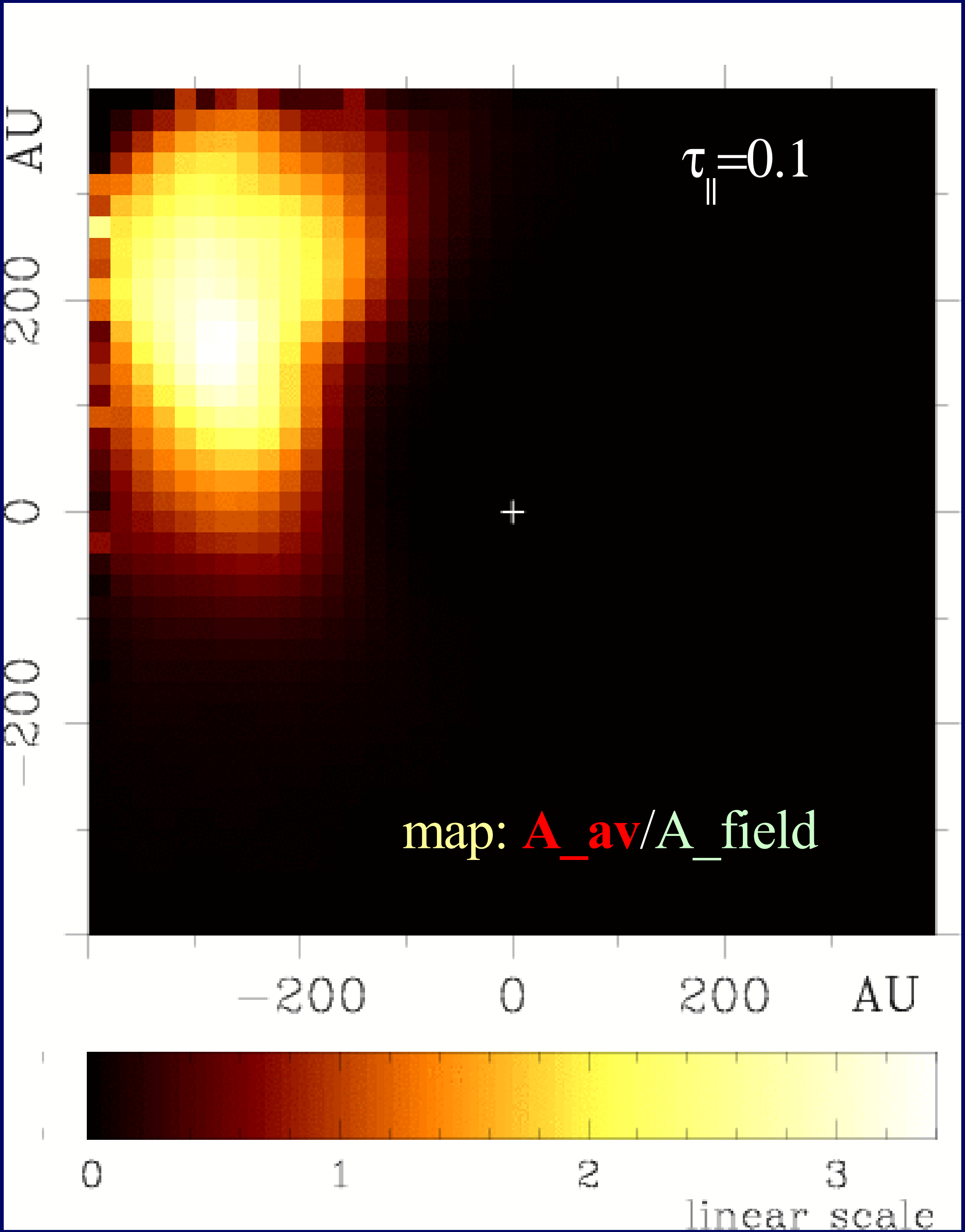


Asymmetry (face-on):

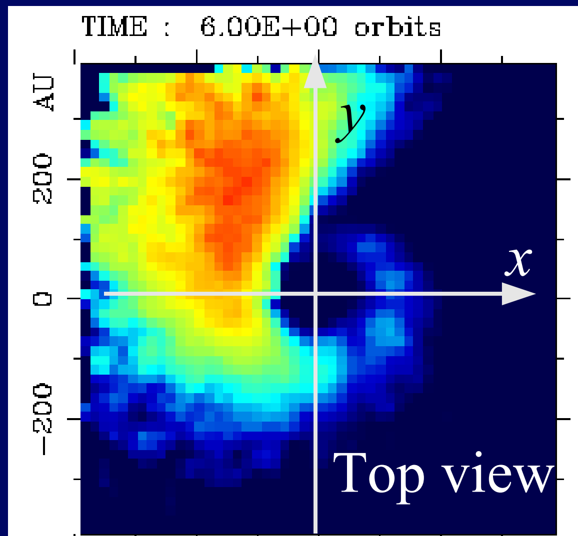
A=cross-sectional surface density



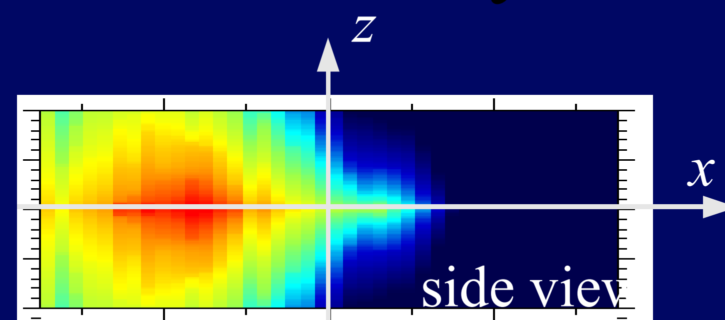
Notice that we use here a linear brightness scale, and the avalanche looks like a blob, not a spiral

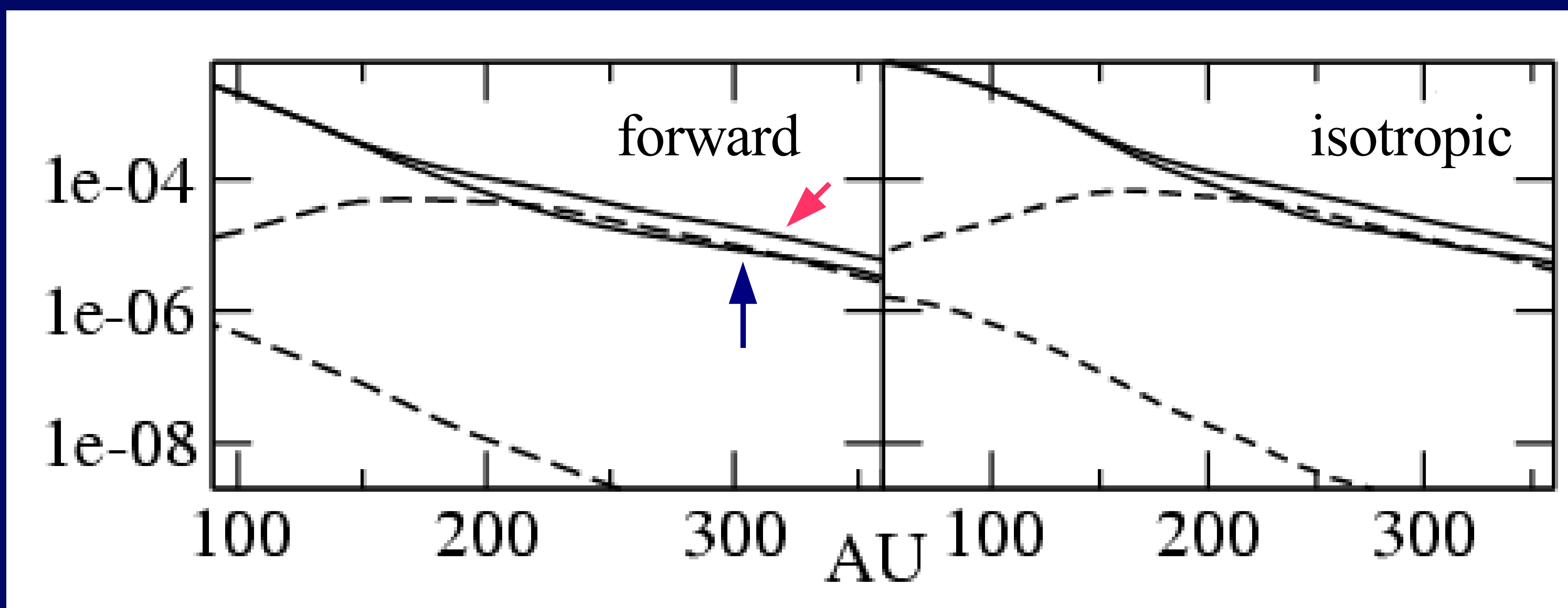


Asymmetry (edge-on orientation)

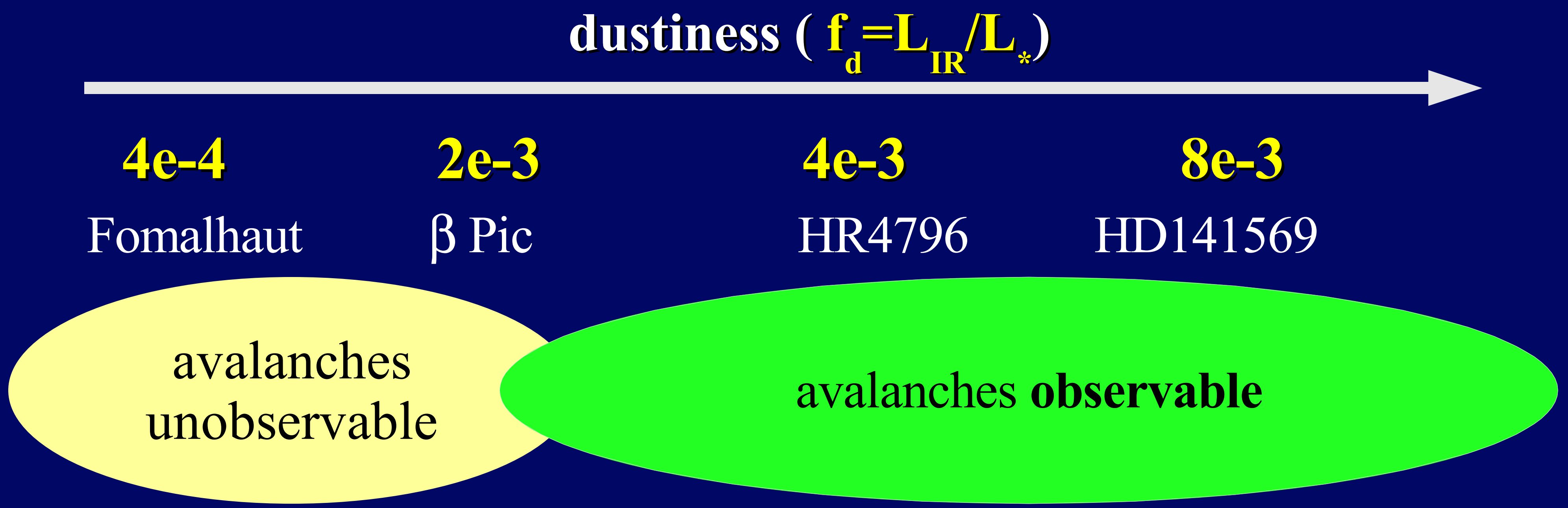


Two-sided asymmetry





projected distance from the star


dustiness ($f_d = L_{IR}/L_*$)
4e-4
2e-3
4e-3
8e-3
Fomalhaut
β Pic
HR4796
HD141569
avalanches unobservable
avalanches **observable**

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4e-4	2e-3	4e-3	8e-3
Fomalhaut	β Pic	HR4796	HD141569

avalanches unobservable

avalanches **observable**

avalanches **dangerous** for disk survival

Gas needed to damp avalanches !!!

Conclusions

- **First quantitative study of the avalanche mechanism,**
(*Grigorieva, Artymowicz & Thébault, A&A, 2006, subm.*)
- **A powerful mechanism**: **amplification factor >100**,
  triggers significant asymmetries.
  The avalanches are most powerful if :
  - they originate in the innermost part of the disk
  - gas-free system with a relatively dense dust population;
  - if the dusty grains experience higher radiation pressure or more easily disrupted in collisions.
- **Observability** strongly dependent on disk dustiness.
  Moderate collisional dust clouds suffice for observability in disks with disk much dustier than b Pic. Otherwise larger impacts needed (but improbable!)
- **Can be observed as spirals or "blobs".**