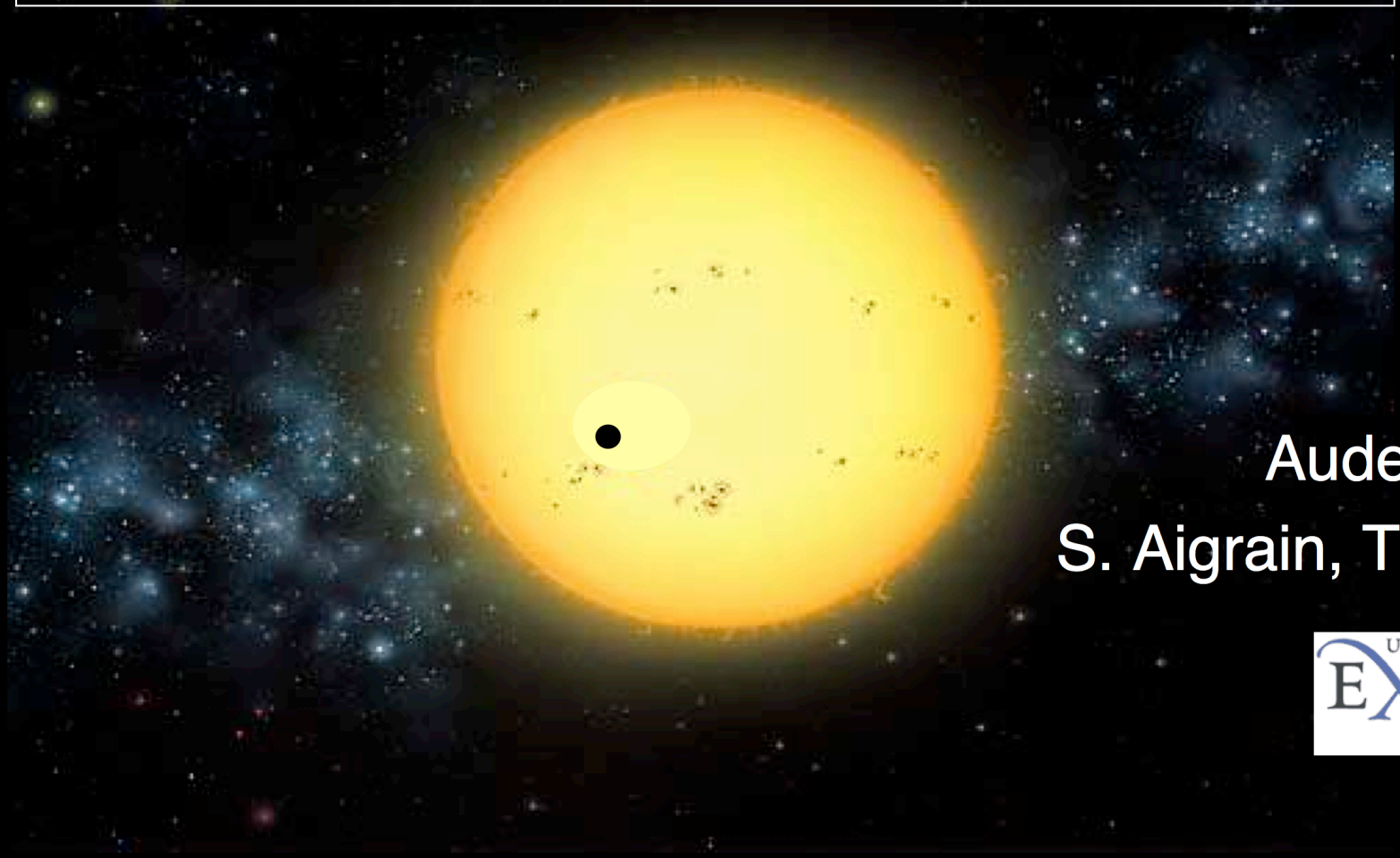
Precise planet parameters from transits

Reconstruction of the transit signal in the presence of stellar variability

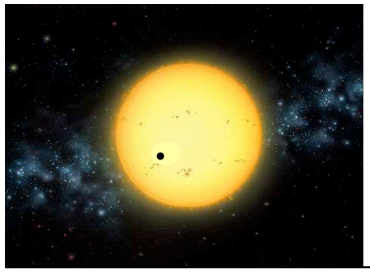


Aude Alapini

S. Aigrain, T. Naylor

UNIVERSITY OF EXETER U.K.

Modified version of picture on http://www.sr.bham.ac.uk/research/exoplanets/transits.html



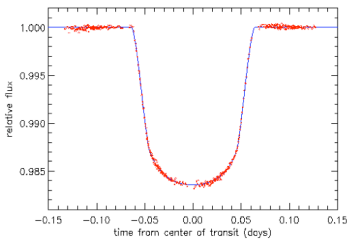
Planet parameters from transit + RV

Transit

Radial velocity

Spectroscopy

Brown et al. (2000)

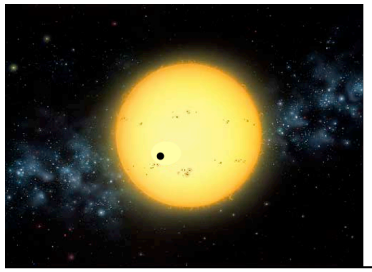


fit

$\Delta F/F$, P, i, R_*

$$R_p = R_* \sqrt{\frac{\Delta F}{F}}$$

$$M_p = M_*^{2/3} \frac{K}{\sin(i)} \left(\frac{P}{4\pi G} \right)^{1/3}$$



Planet parameters from transit + RV

Transit

Radial velocity

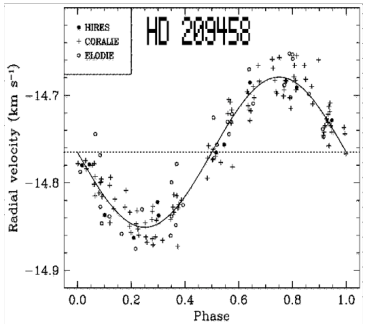
Spectroscopy

fit

$\Delta F/F$, P, i, R_*

K

http://www.astro.caltech.edu/~lah/ay20/tel/



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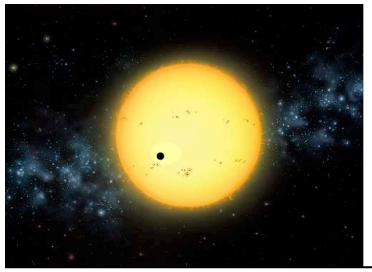
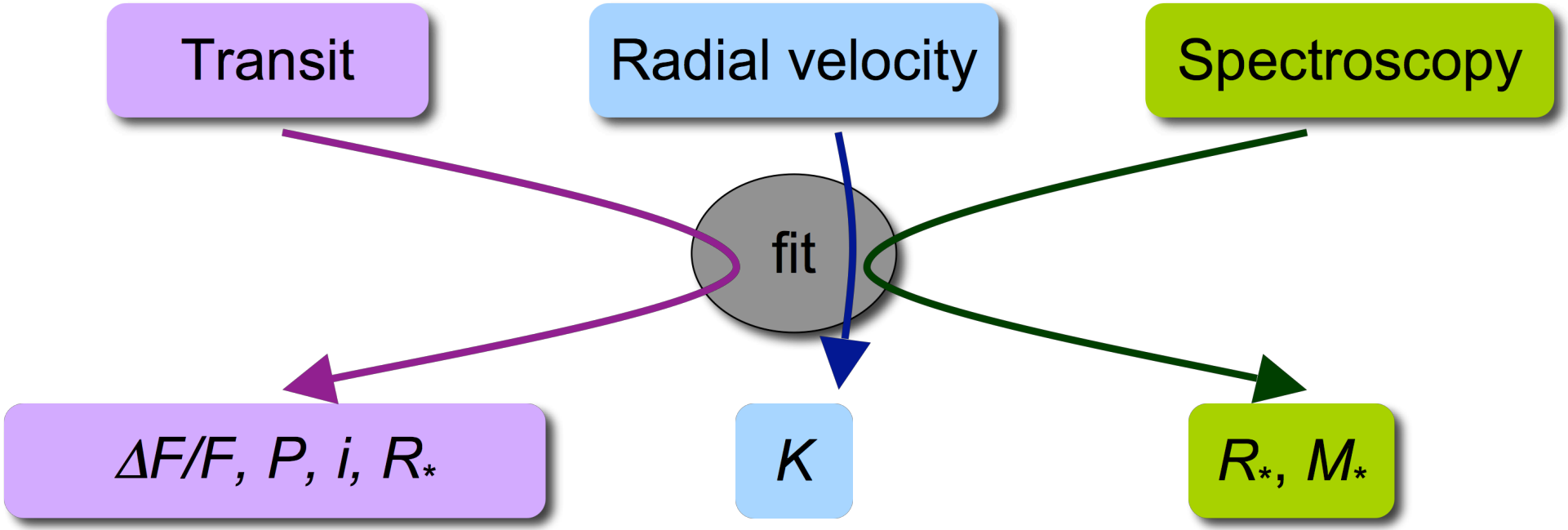


Planet parameters from transit + RV



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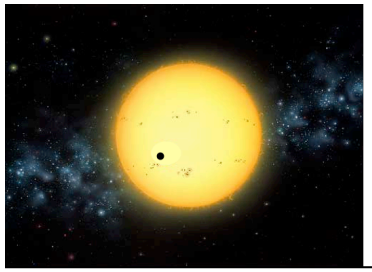
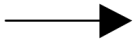
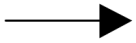


Determining planet composition

R_p, M_p

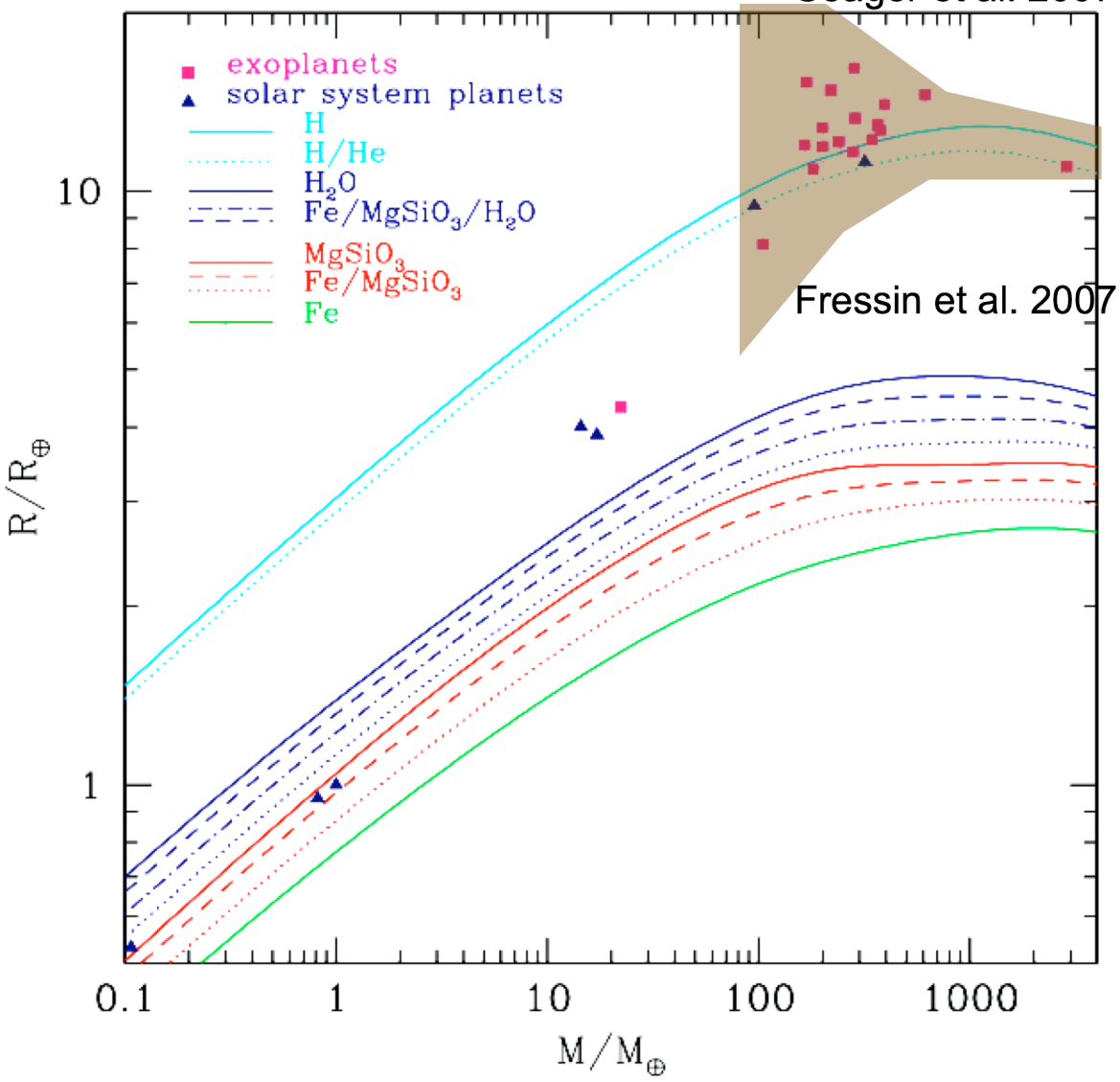


Planet structure models

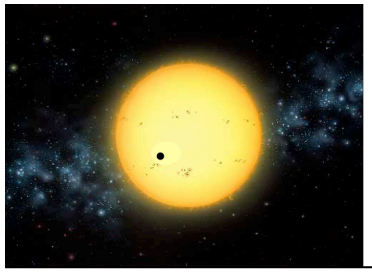


Seager et al. 2007

Fressin et al. 2007



Determining planet composition



R_p, M_p

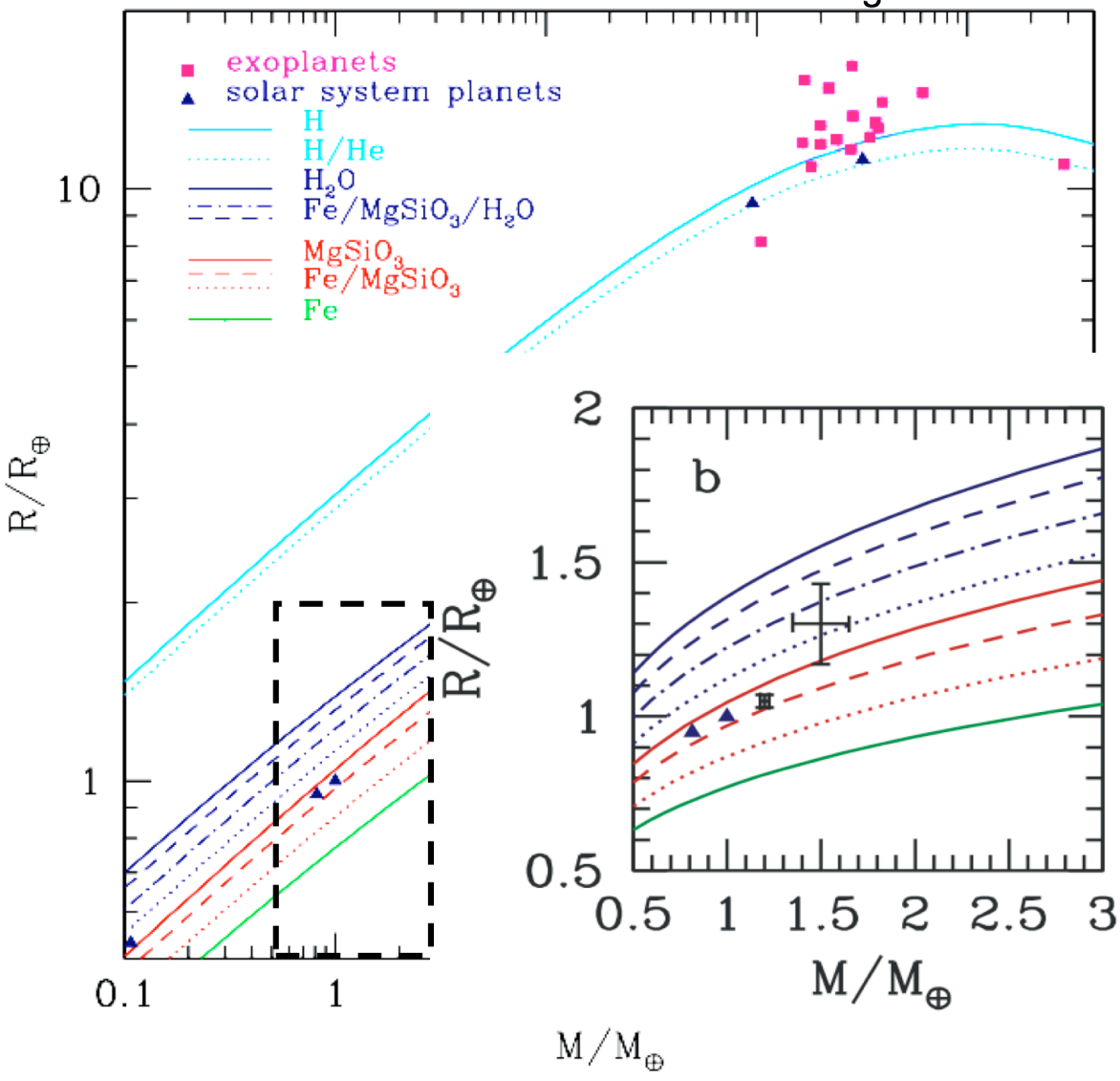
Planet structure models

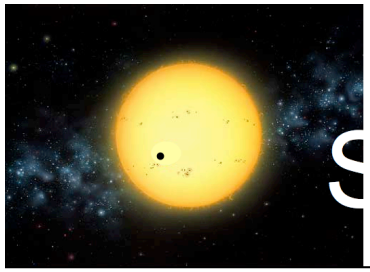
Planet types (gas, solids)

Statistics on types of planets

Planet formation models

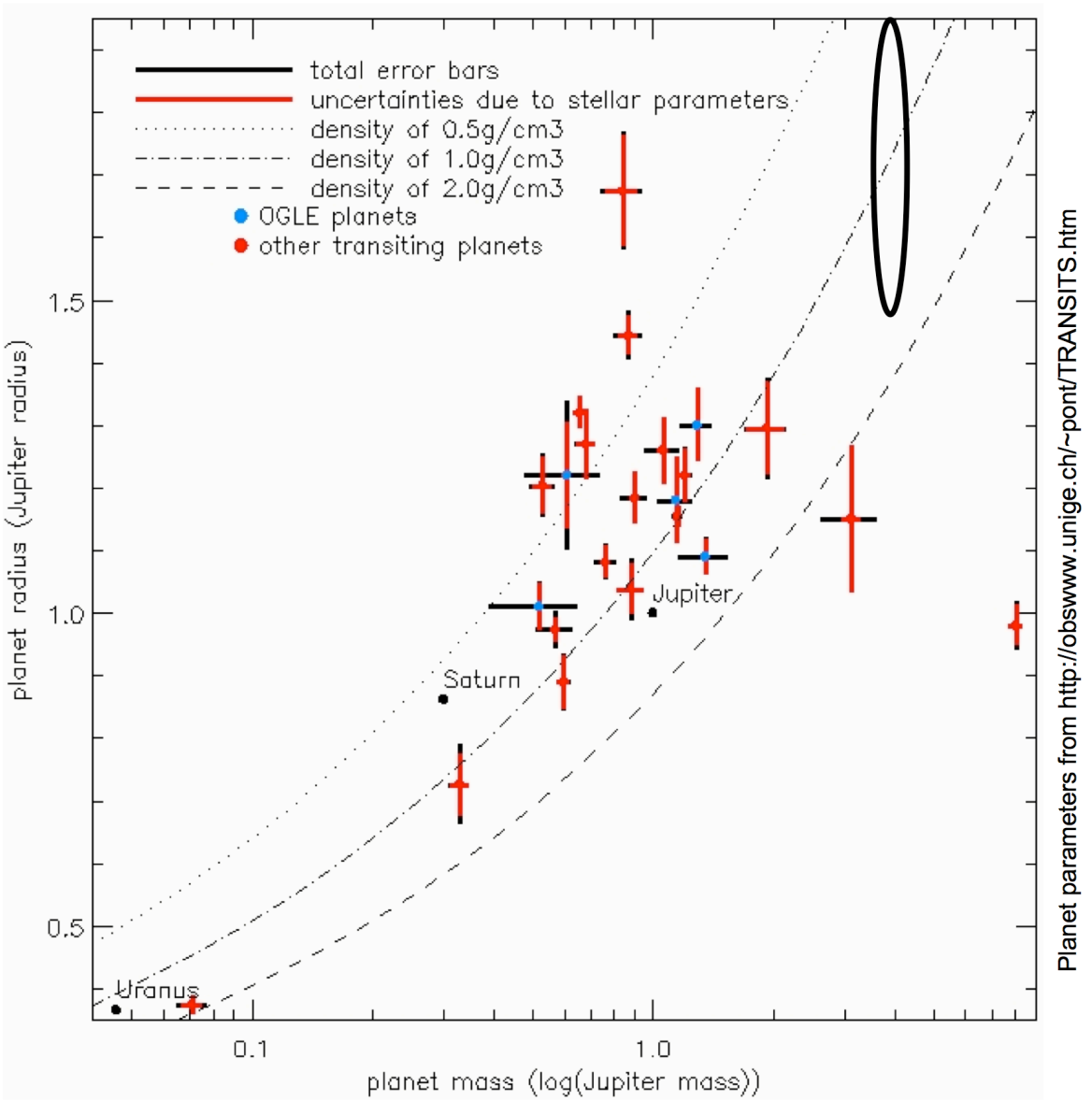
Seager et al. 2007

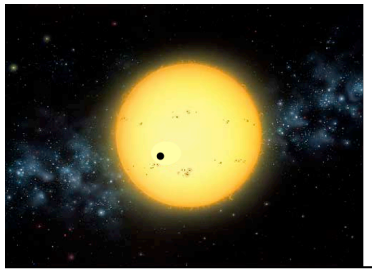




Sources of error on planet parameters

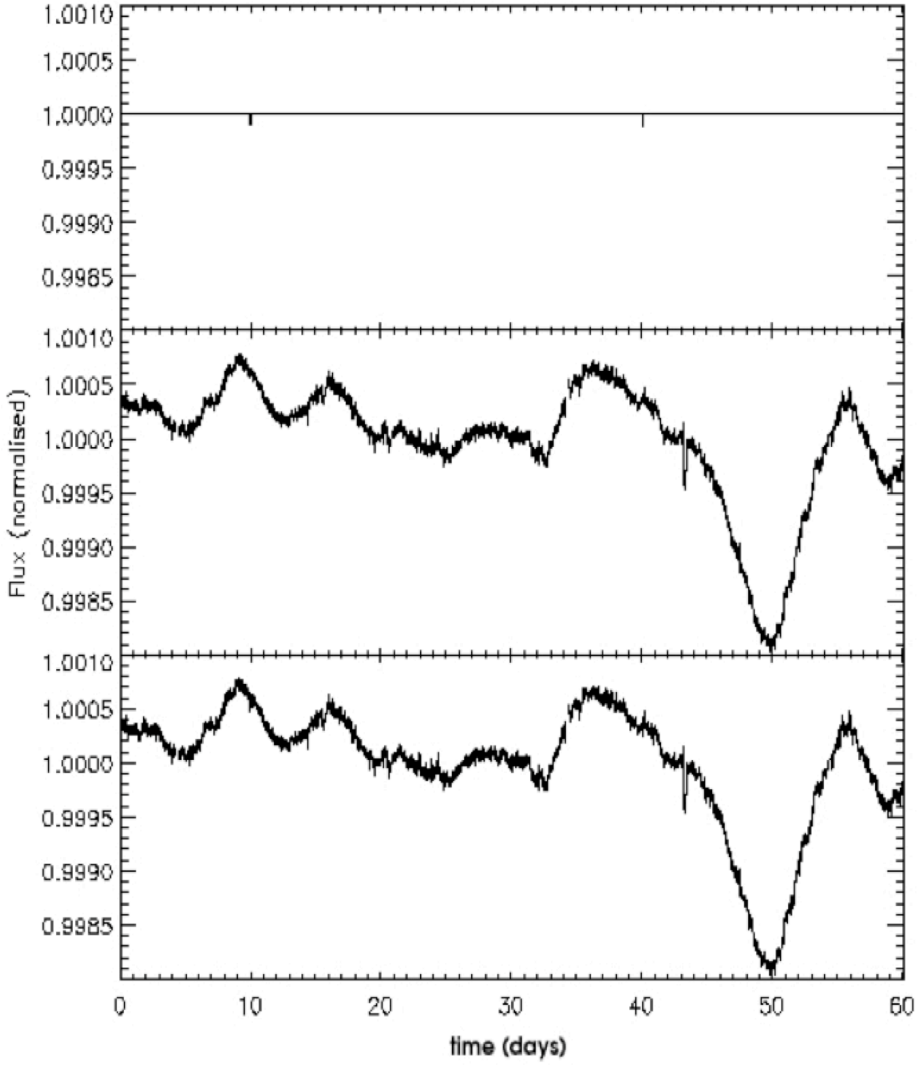
- Stellar parameters
  (see poster P01 by A. Alapini)
- Transit fit
  - Ground: atmosphere
  - Space: stellar variability
    (this talk)



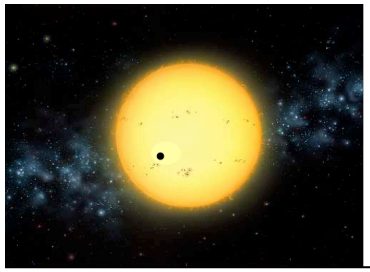


Why filter stellar variability?

- Stellar variability hinders transit detections
- Need to be filtered before running transit detection algorithms

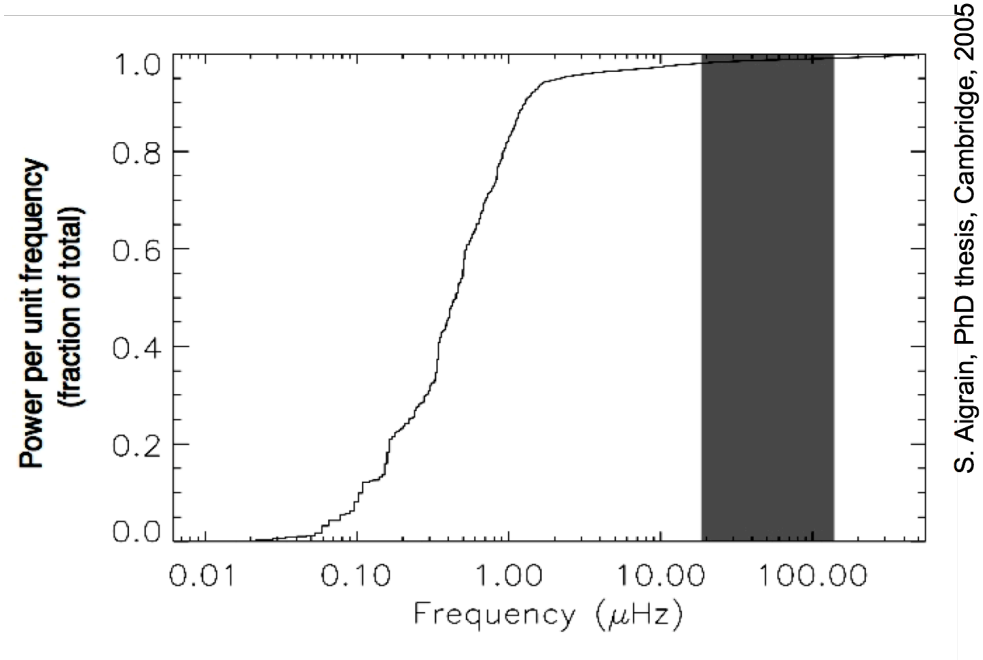


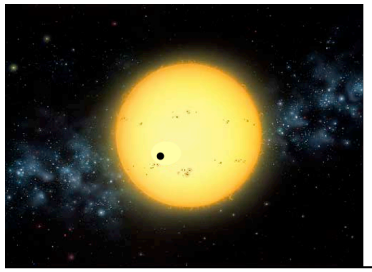
S. Aigrain, PhD thesis , Cambridge, 2005



Why filter stellar variability?

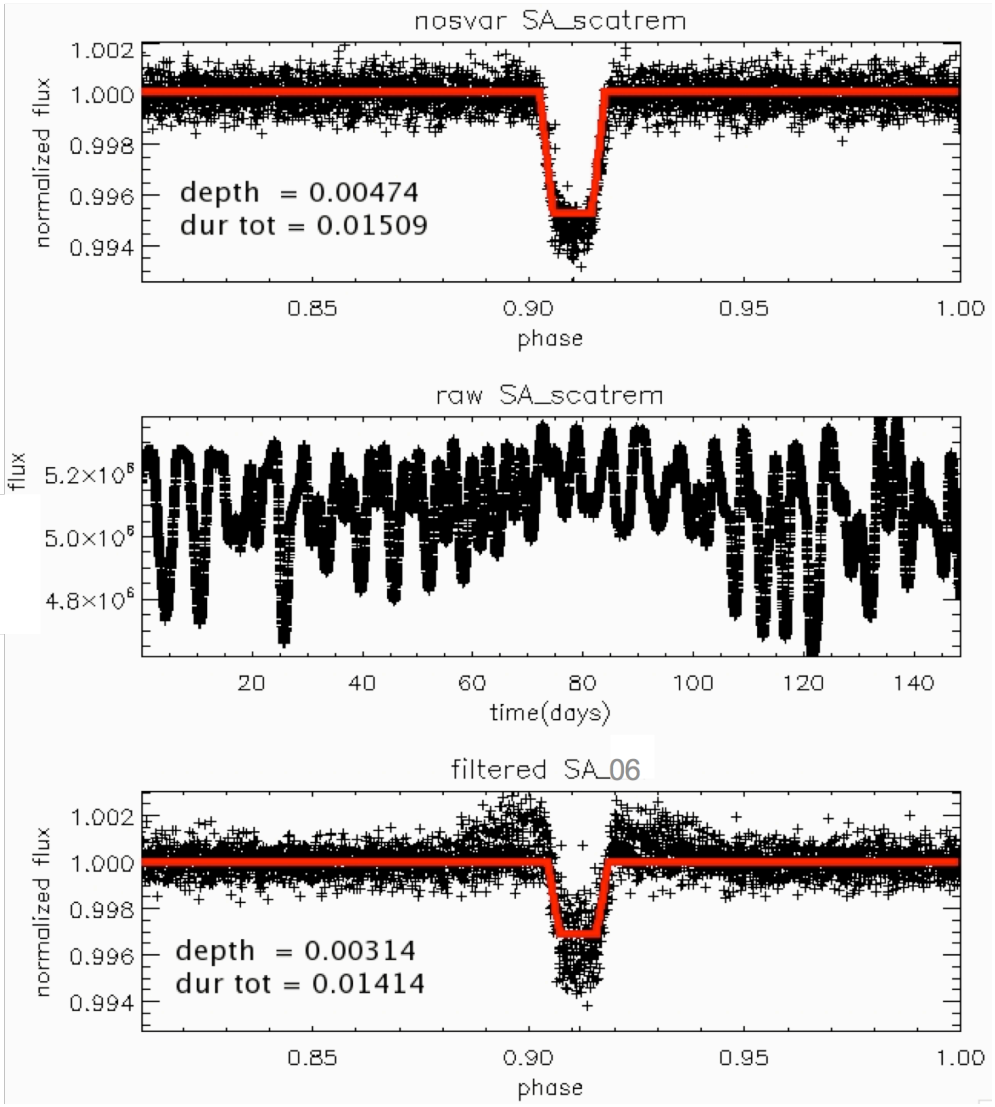
- Stellar variability hinders transit detections
- Need to be filtered before running transit detection algorithms
- Pre-detection filters are based on separating variations on different time scales
- Filters work well for transit detection (Moutou et al. 2005 - CoRoT blind test 1, Jenkins 2002)

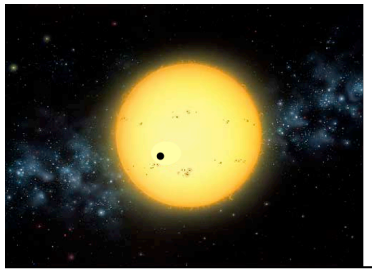




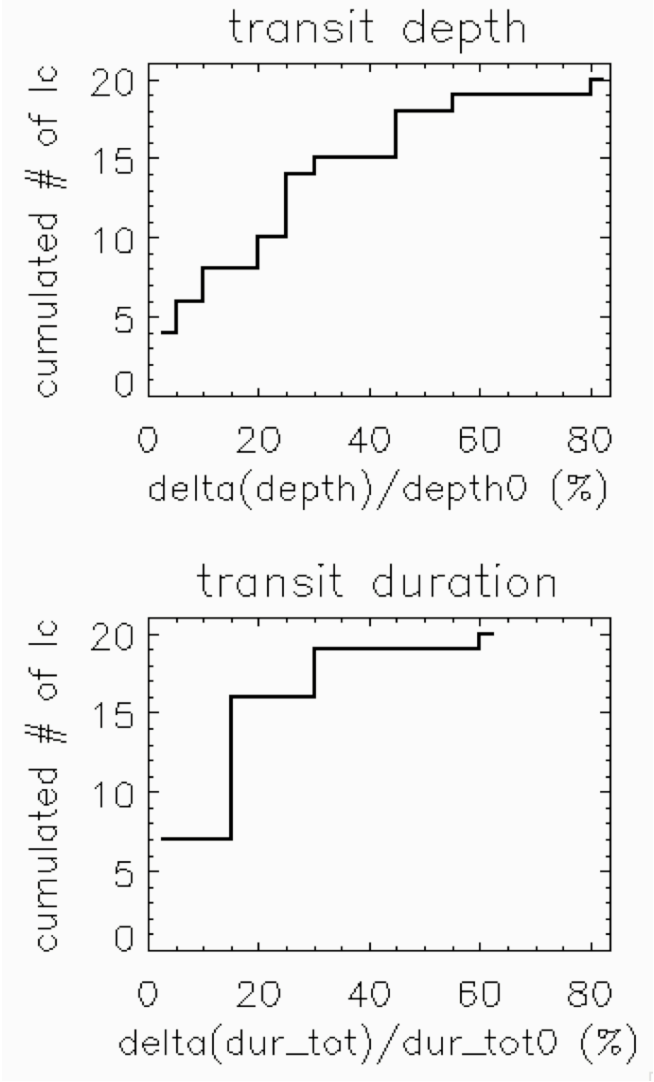
Side effects of pre-detection filters

Light curves from CoRoT blind test 2

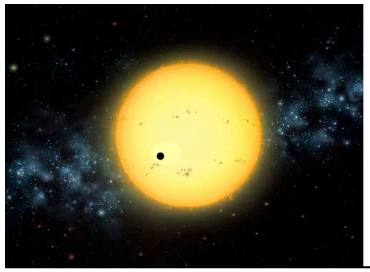




Side effects of pre-detection filters



- Current filters deform transit shape by shortening transit depth (~20%) and total duration (~15%)
- thus, derived R_p & M_p are miss-estimated
- We need a new filter that conserves the original shape of the transit
- Additional information post-detection: transit period



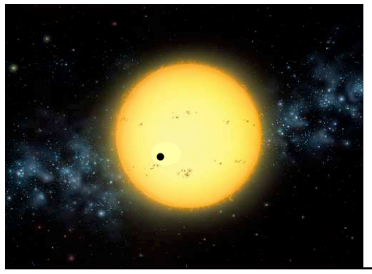
Post-detection stellar variability filter

- Similar problems exist from the ground, but with atmospheric red noise instead of stellar variability
- Kovacs et al 2005: iterative filter TFA
  - can be implemented prior to detection or after detection as a reconstruction tool
  - model light curve as

$$y = f + a + r$$

y = original light curve
f = systematics (red noise)
a = interesting signal (eg: transit)
r = residual (white noise)

  - filter is linear combination of template light curves (appropriate for systematics)
- We implement the same method (iterative filtering) with a different filter

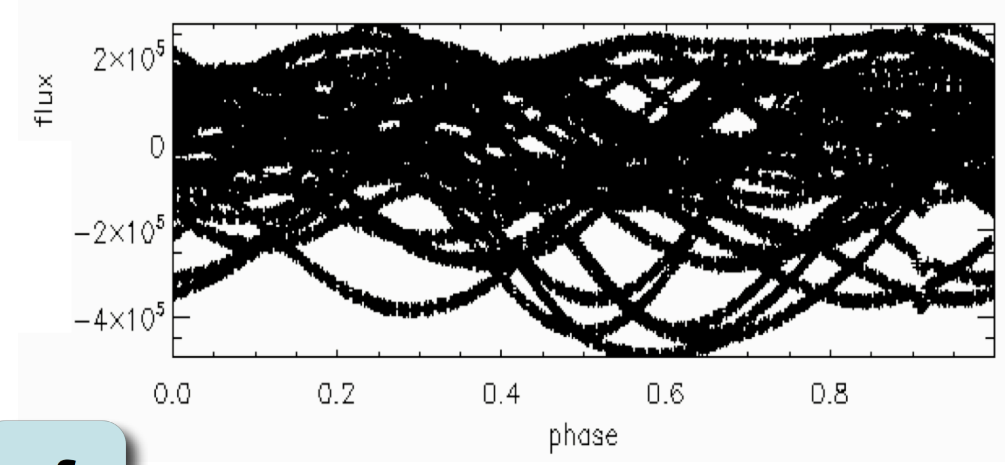


Implementation of the new filter

$$y = f + a + r$$

y = original light curve
f = stellar variability
a = transit signal
r = residual (white noise)

y

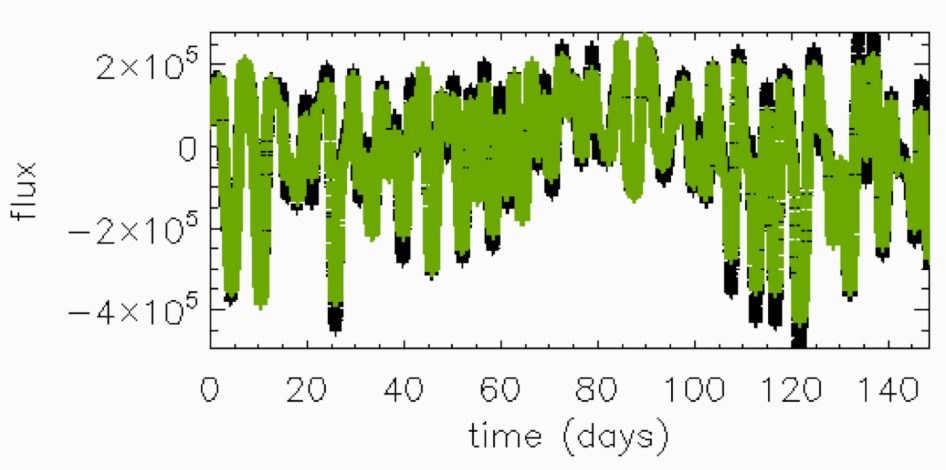


a

f

r

$$y = f + a + r$$



y

initialisation

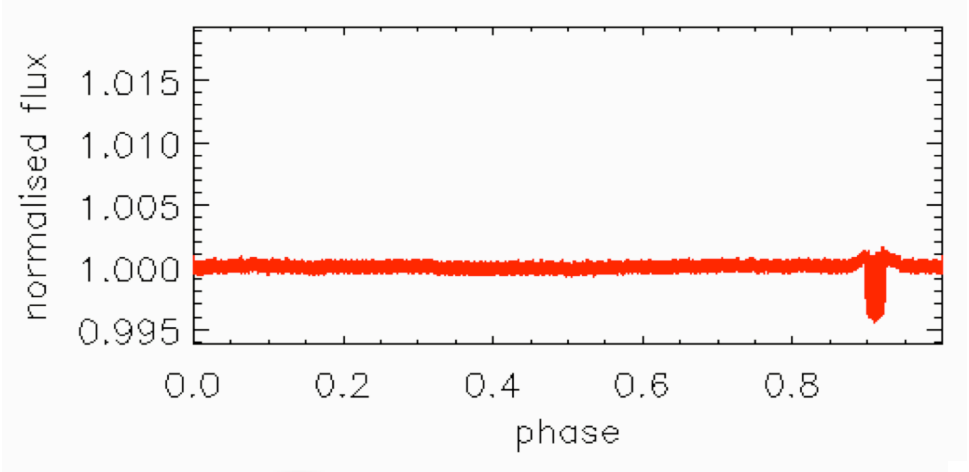
smoothing
(Aigrain & Irwin 2004)

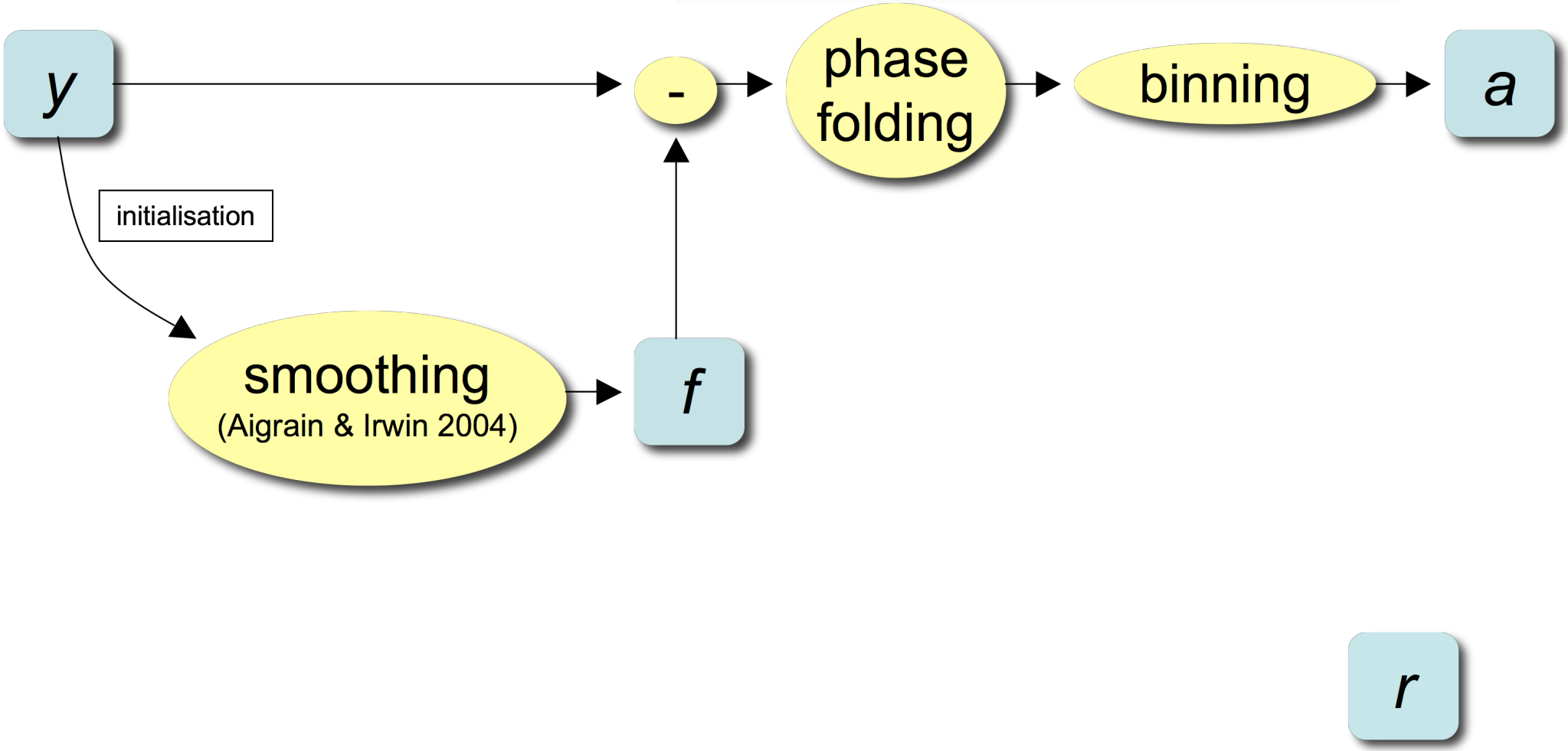
f

a

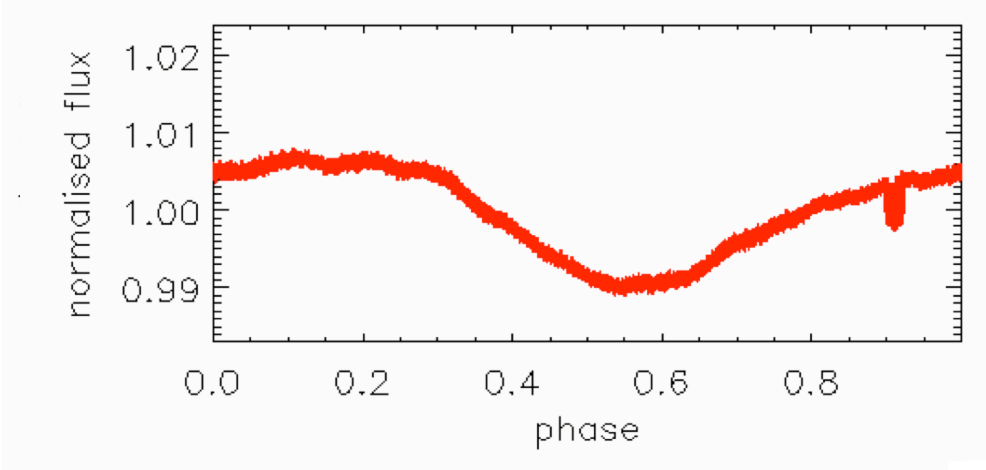
r

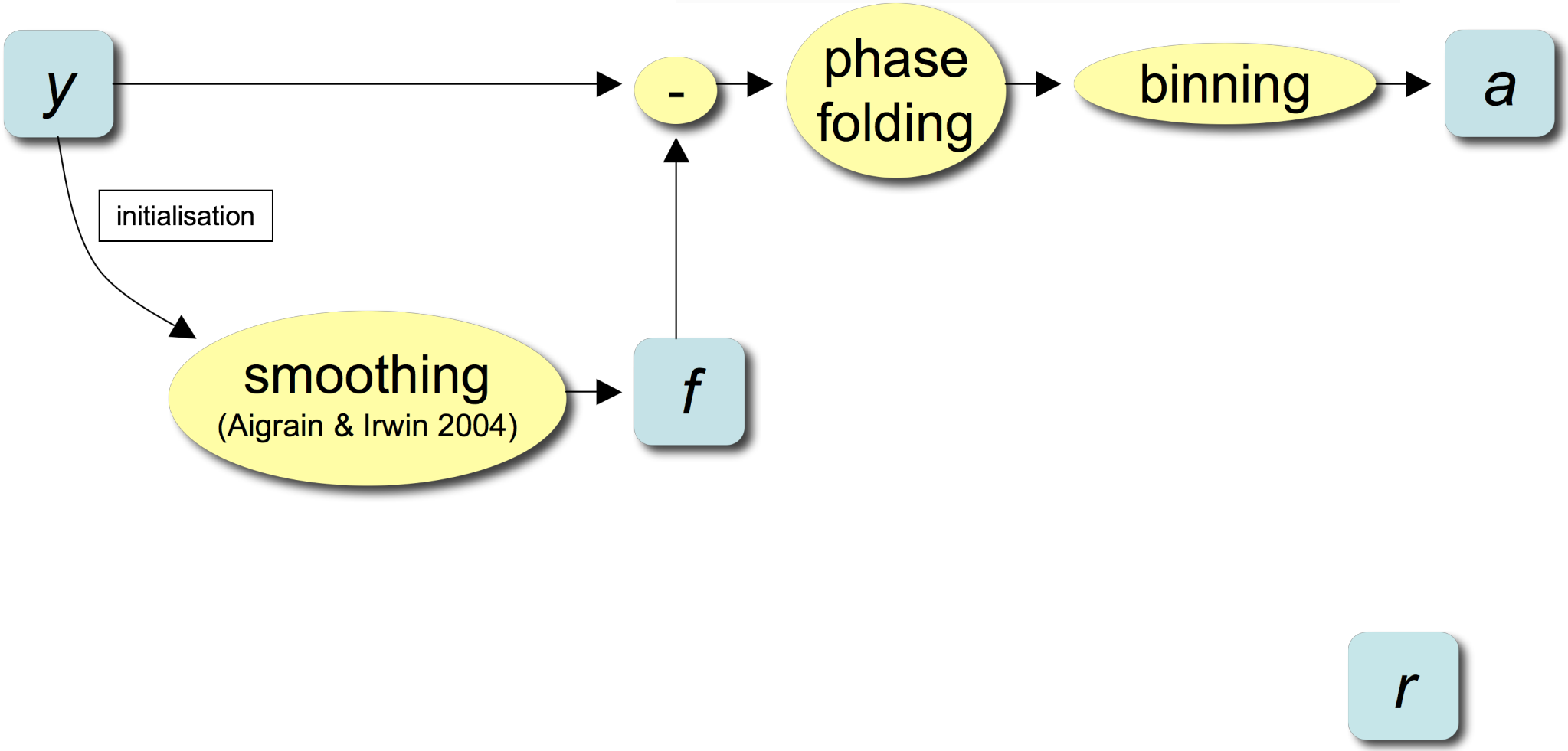
$$y = f + a + r$$


normalised flux
1.015
1.010
1.005
1.000
0.995
0.0
0.2
0.4
0.6
0.8
phase

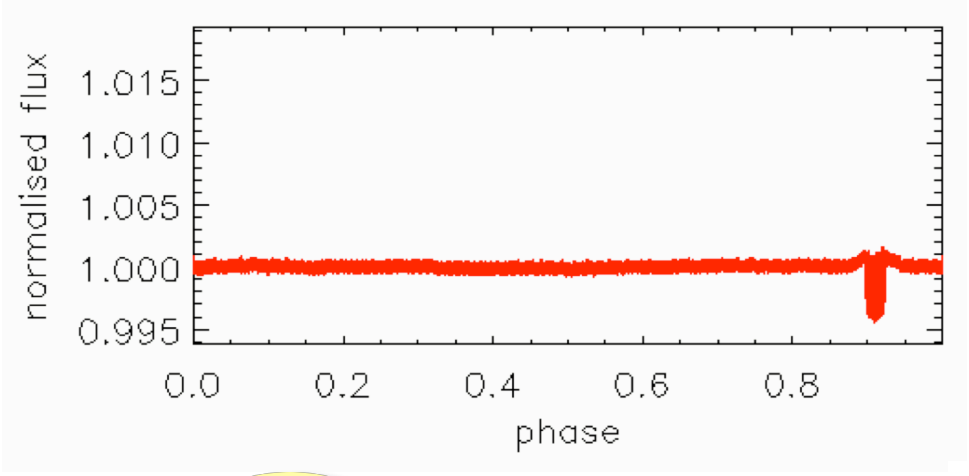

y
-
phase folding
binning
a
initialisation
smoothing
(Aigrain & Irwin 2004)
f
r

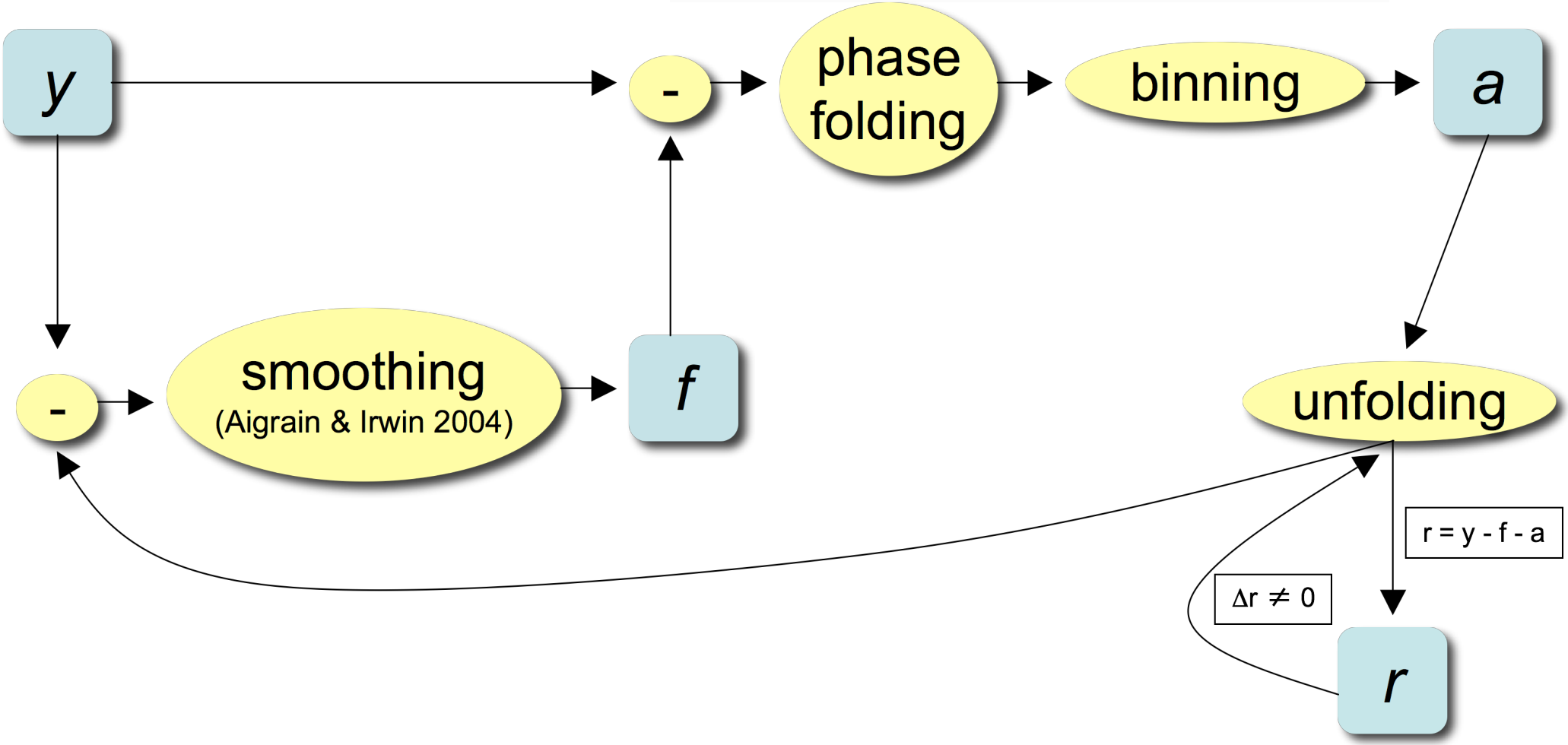
$$y = f + a + r$$


normalised flux
1.02
1.01
1.00
0.99
0.0
0.2
0.4
0.6
0.8
phase

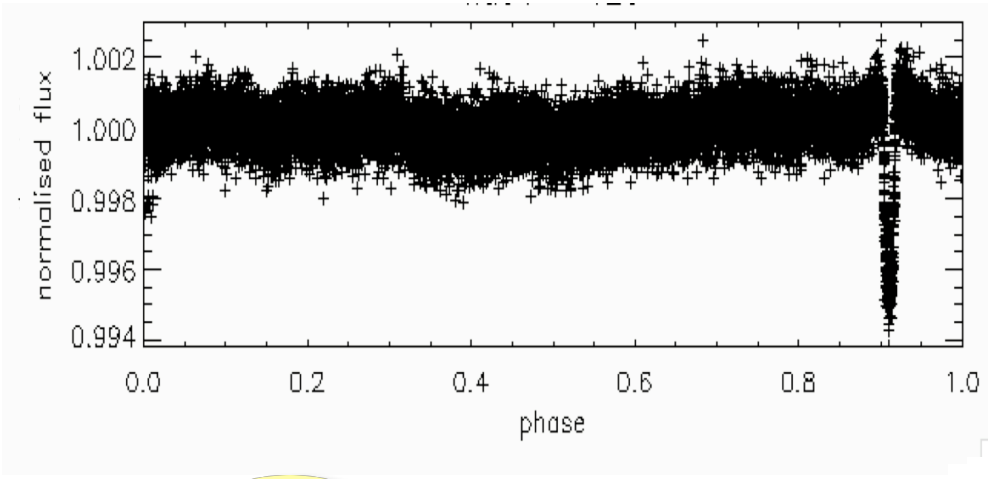

y
-
phase folding
binning
a
initialisation
smoothing
(Aigrain & Irwin 2004)
f
r

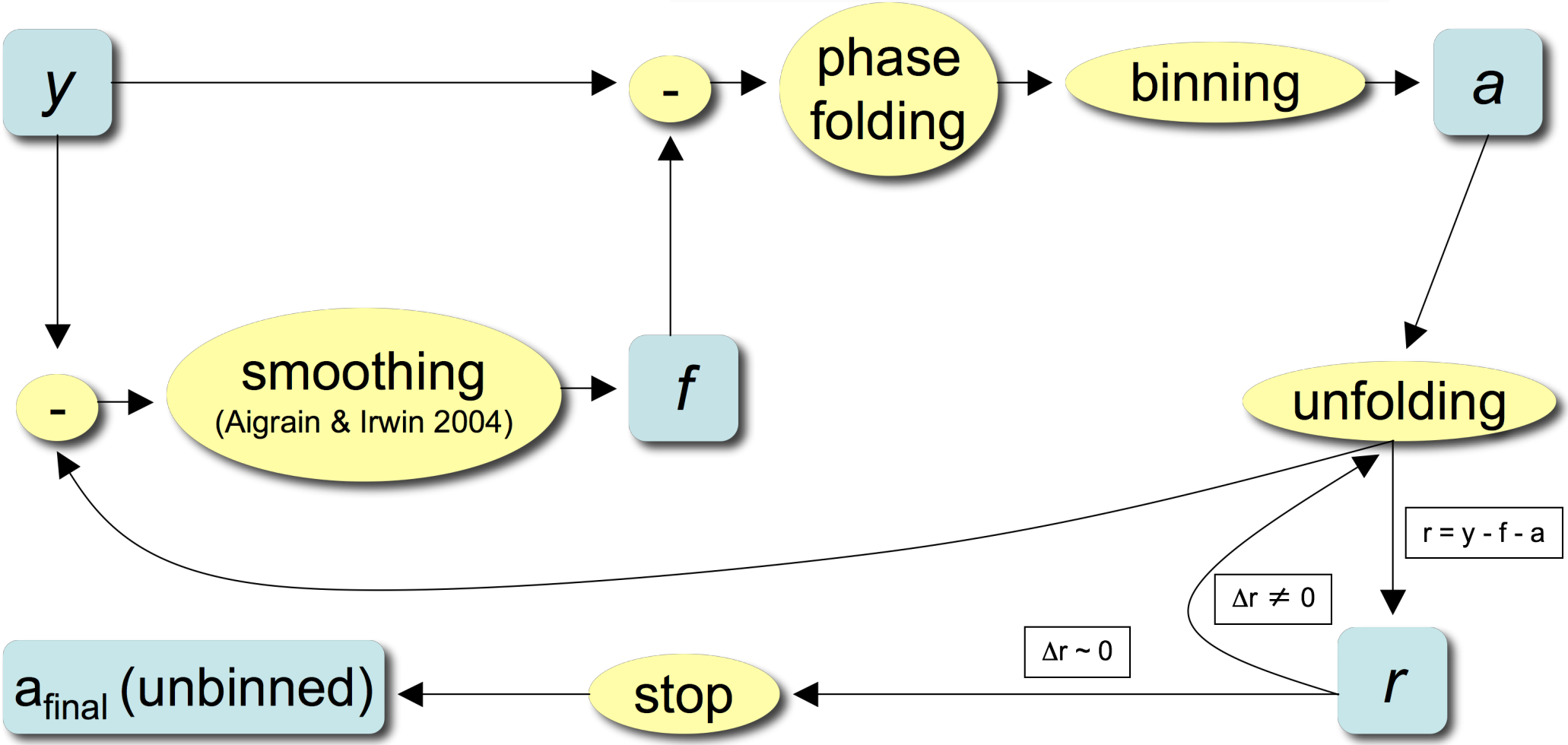
$$y = f + a + r$$

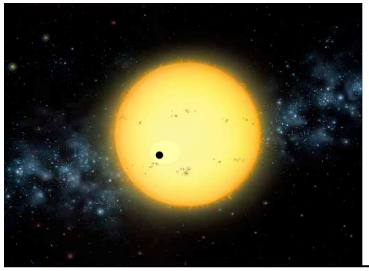

normalised flux
1.015
1.010
1.005
1.000
0.995
0.0
0.2
0.4
0.6
0.8
phase


y
-
phase folding
binning
a
-
smoothing
(Aigrain & Irwin 2004)
f
unfolding
r = y - f - a
Δr ≠ 0
r

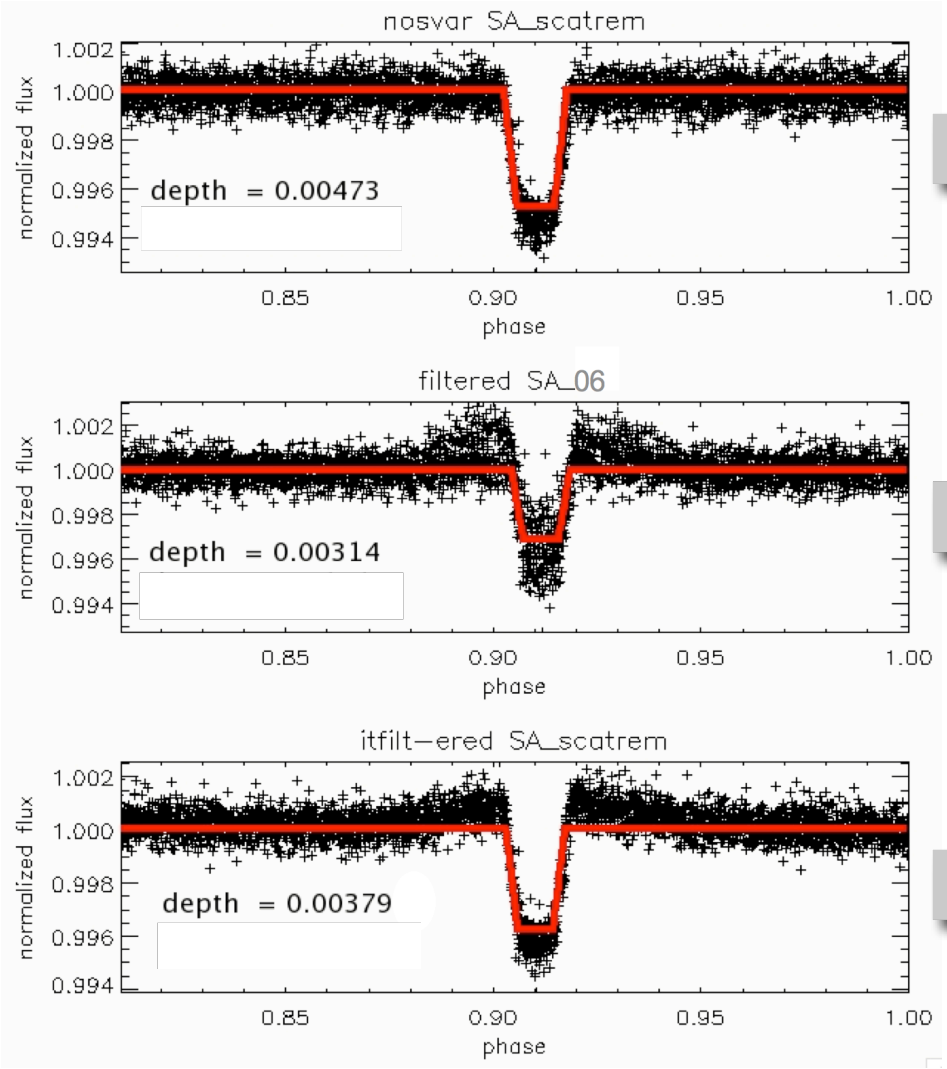
$$y = f + a + r$$


normalised flux
1.002
1.000
0.998
0.996
0.994
0.0
0.2
0.4
0.6
0.8
1.0
phase


y
-
phase folding
binning
a
-
smoothing
(Aigrain & Irwin 2004)
f
unfolding
r = y - f - a
Δr ≠ 0
Δr ~ 0
r
stop
a_final (unbinned)



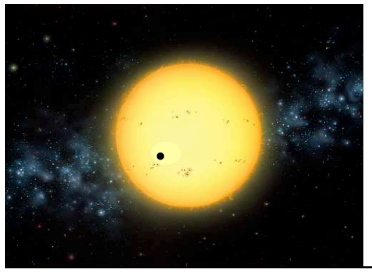
Comparison of performance



original

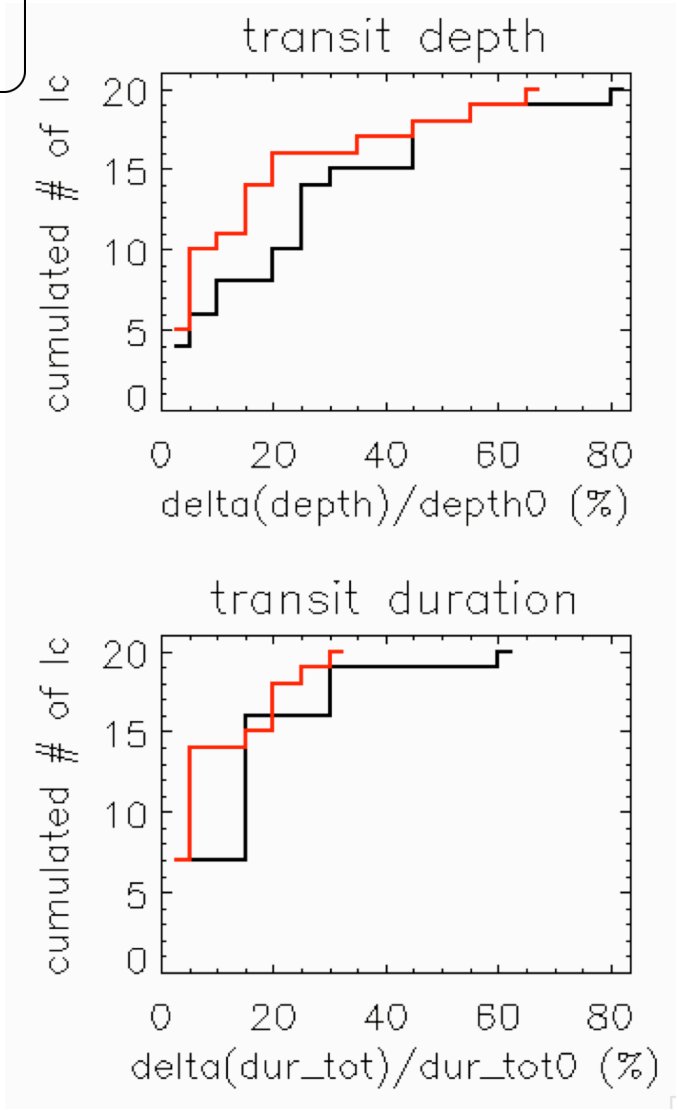
filtered with pre-detection filter

filtered with post-detection filter

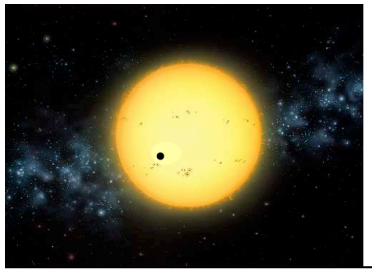


Comparison of performance

pre-detection filter
post-detection filter



improvement of ~15% on transit depth and ~10% on total transit duration



Summary & future work

- Deriving precise planet masses and radii is important to constrain planet evolution and formation models
- Stellar variability hinders transit detection
- Pre-detection filters have been developed
- Side effect: modify transit shape
- We have adapted Kovacs et al 2005 method to stellar variability filtering
- The new post-detection filter developed improves the estimation of the transit depth by 15% and the total transit duration by 10%
- Future work:
  - automated ‘stop’ procedure and best ‘smoothing duration’
  - apply to real data: CoRoT