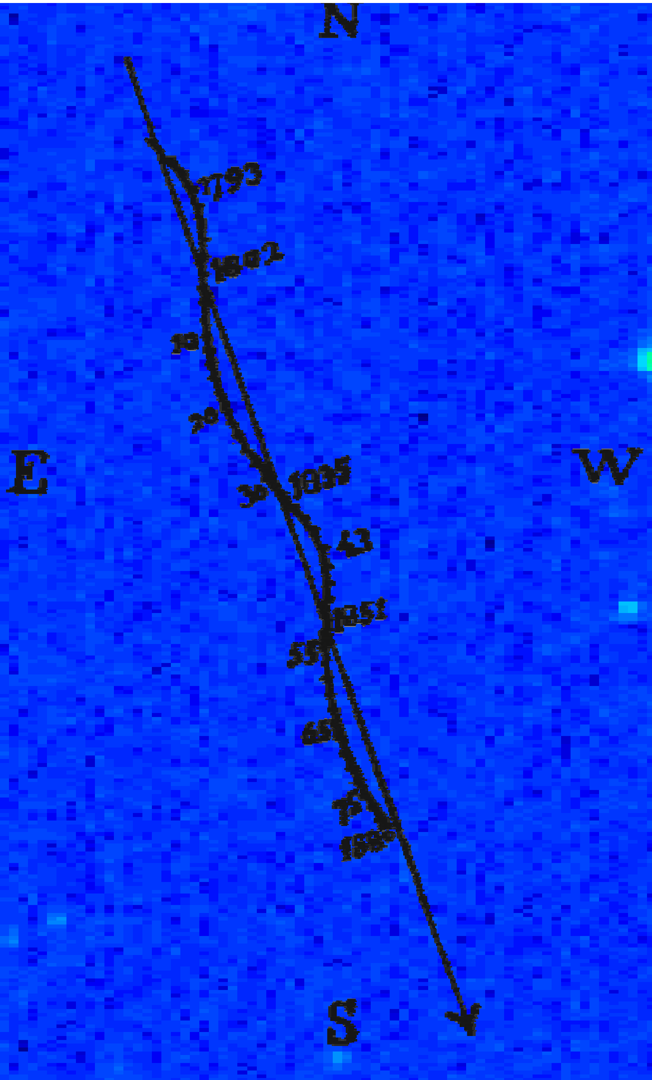
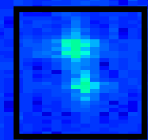


Double, multiple stars and exoplanets

Frédéric Arenou
Hans Bernstein
Jean-Louis Halbwachs
Bruno Lopez
Dimitri Pourbaix
Noël Robichon
Dimitris Sinachopoulos
Elena Schilbach
Staffan Söderhjelm
Alessandro Sozzetti
Alessandro Spagna
Paolo Tanga
Hans Zinnecker



> 10^7 orbits of astrometric binaries

> 10^5 orbits of resolved binaries

> 10^6 eclipsing binaries

~ 10^6 spectroscopic binaries

> 10,000 masses within 1% precision

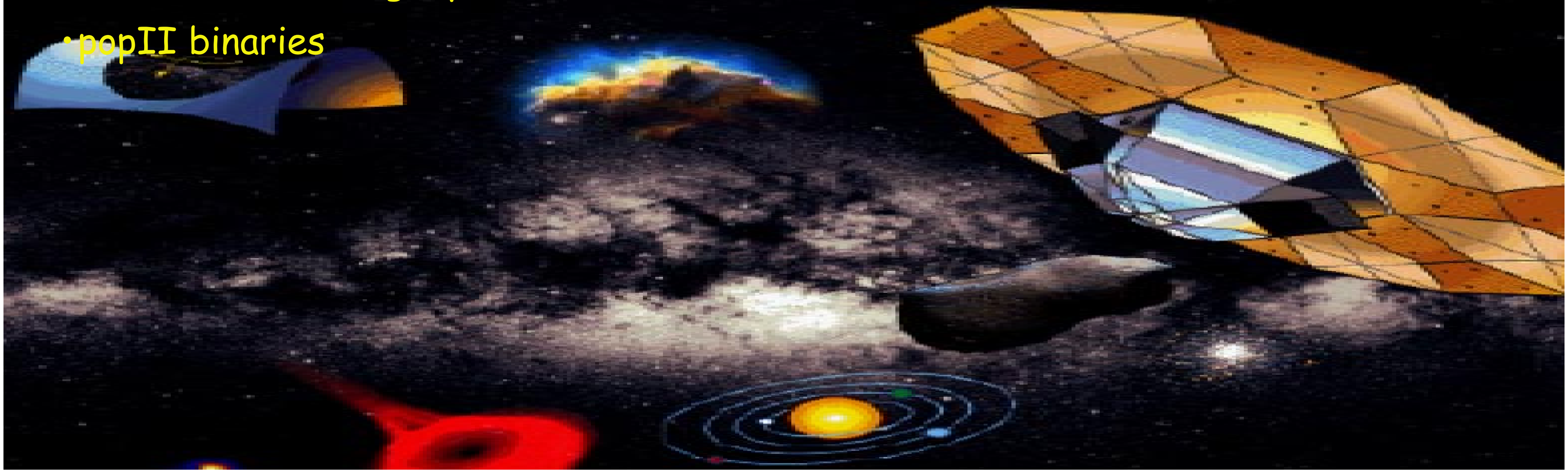
- Completude in the solar neighbourhood
- Multiplicity (rate, inclination, periods)
- Distribution of orbital parameters
- As a function of age, place of formation
- popII binaries

~ 5000 detected Jupiter by astrometry

~ 2000 good orbits (even multiple planets)

~ 10000 detectable Jupiters by transit

- Distribution of masses and orbital elements for planets and brown dwarfs
- Planetarity rate
- As a function of age, metallicity
- "cold" Jupiter for Earths in habitable zone



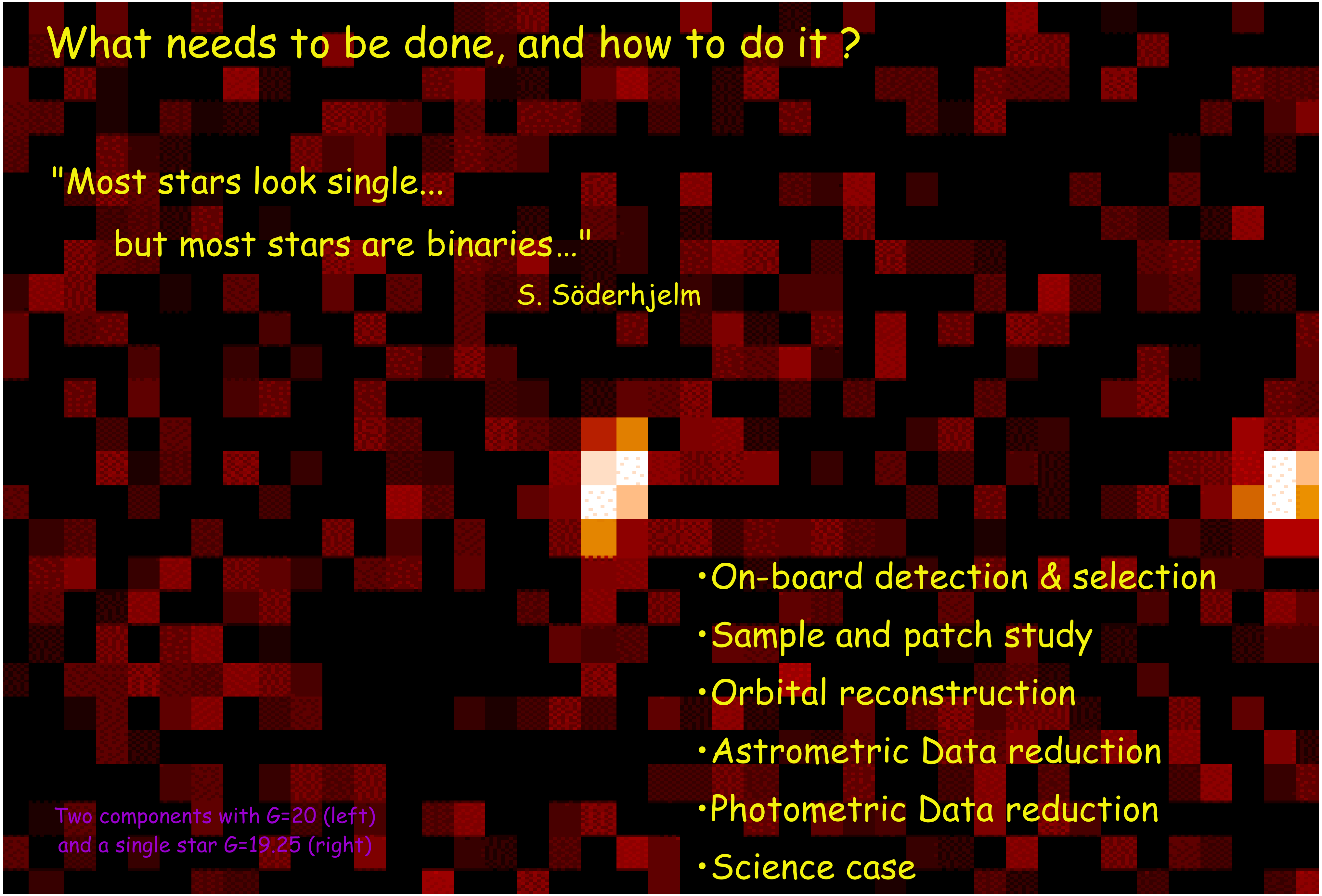
What needs to be done, and how to do it ?

"Most stars look single...

but most stars are binaries..."

S. Söderhjelm

- On-board detection & selection
- Sample and patch study
- Orbital reconstruction
- Astrometric Data reduction
- Photometric Data reduction
- Science case



Two components with G=20 (left)
and a single star G=19.25 (right)

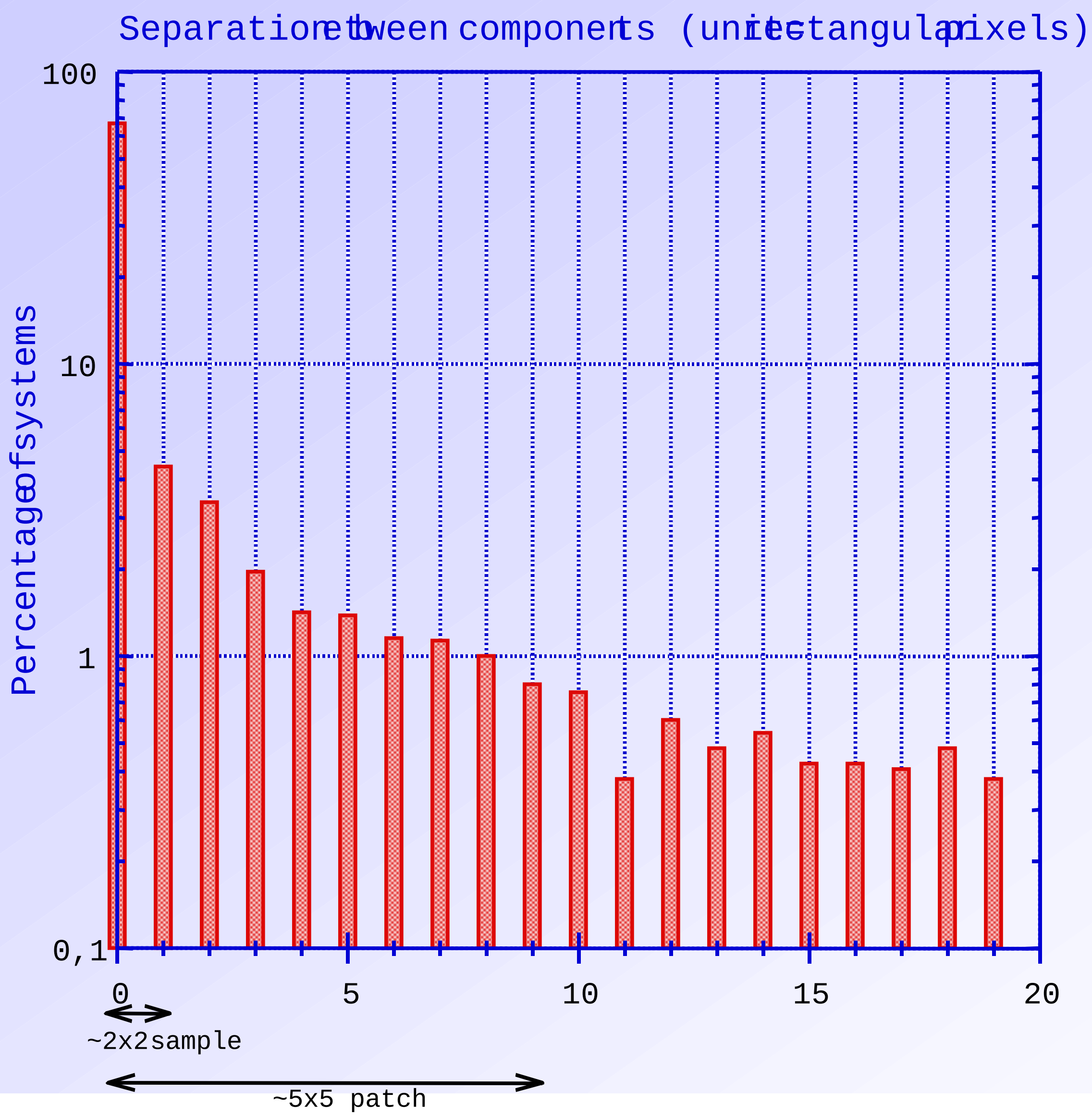
The current design is probably close to optimal...

... for single stars. But what about double and multiple systems ?

Q: what can/cannot be changed in the instrument ? (E. Schilbach)

Type	**Constraints**	**Interface**
Changing size of samples and patches	Telemetry Astrometric budget Imaging	5.2.5 5.2.1 5.3.3
Changing spin period (fainter companions, BD)	Payload design CCD	5.2.2 5.2.3
Increasing mission duration	Aging	5.2.3
Photometric system		5.3.1
Radial Velocity Spectrometer		5.4
Improving intrumental performances (sensitivity)		5.2.3

Distribution of binaries



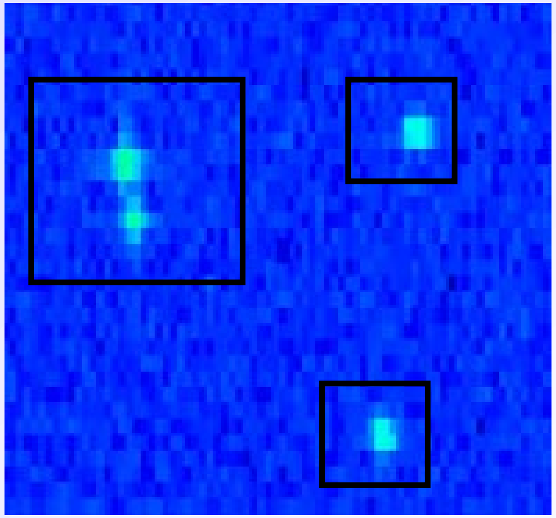
- Simulation of binaries
  - towards l=300, b=-2 with a galaxy model
  - Distribution in period gives the angular separation
- Most of them within one pixel
  - On-board detection for a few % only
- Impact on astrometry
  - < 5µas or 0.5 mas: single for Gaia
  - < 20 mas: unresolved photocentre (motion)
  - < 1" : resolved but overlapping
  - > 1": single for astrometry

On-board detection and selection

- Double & multiple objects should be detected as early as possible (on-board)
  - For the patch selection
  - Need of a subset of single stars for core processing
  - A detection algorithm optimised also for binaries

- How to detect
  - ASM3 (RON) + ASM1
  - Peak is significantly wider than the PSF of a single star
  - False duplicity detection for bright red single stars ?

- Selection algorithm
  - May have an impact on reduction (which component)
  - And on the scientific return



Sample and patch study

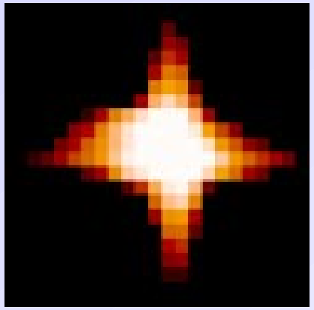
- Optimise sample size
  - Detection (e.g. which binning in ASM3)
  - No overlapping allowed for samples
  - Reconstruction
- Optimise patch size
  - Flux loss problem (components damaged)
  - Which telemetry budget on the average?
  - Adaptative for bright stars ?

(S. Söderhjelm)

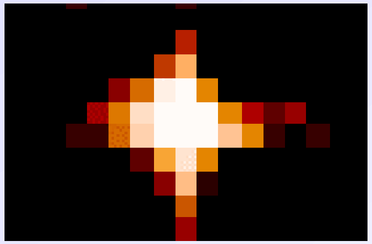
- Selection algorithm
  - How to manage when a large magnitude difference
- Tracking
  - Objects on sample boundaries
  - Which center of patch (observation strategy)
  - Multiple stars
- Hard for multiple objects
  - Stars or QSO

(D. Sinachopoulos)

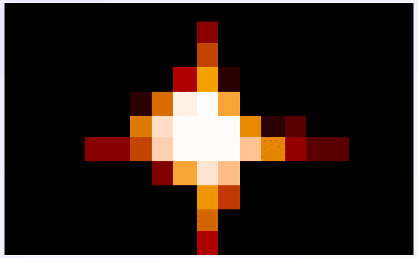
V=16 and V=17 separated by a few pixels, θ=10°, no background



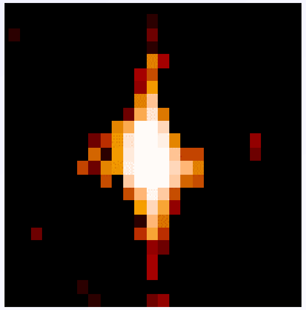
No noise, no binning



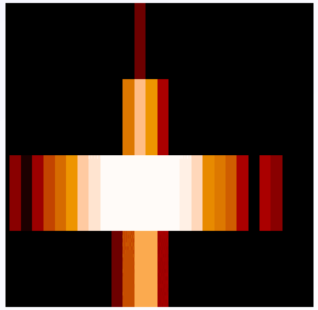
ASM1 2x2



ASM3 2x2 ($6e^-$)

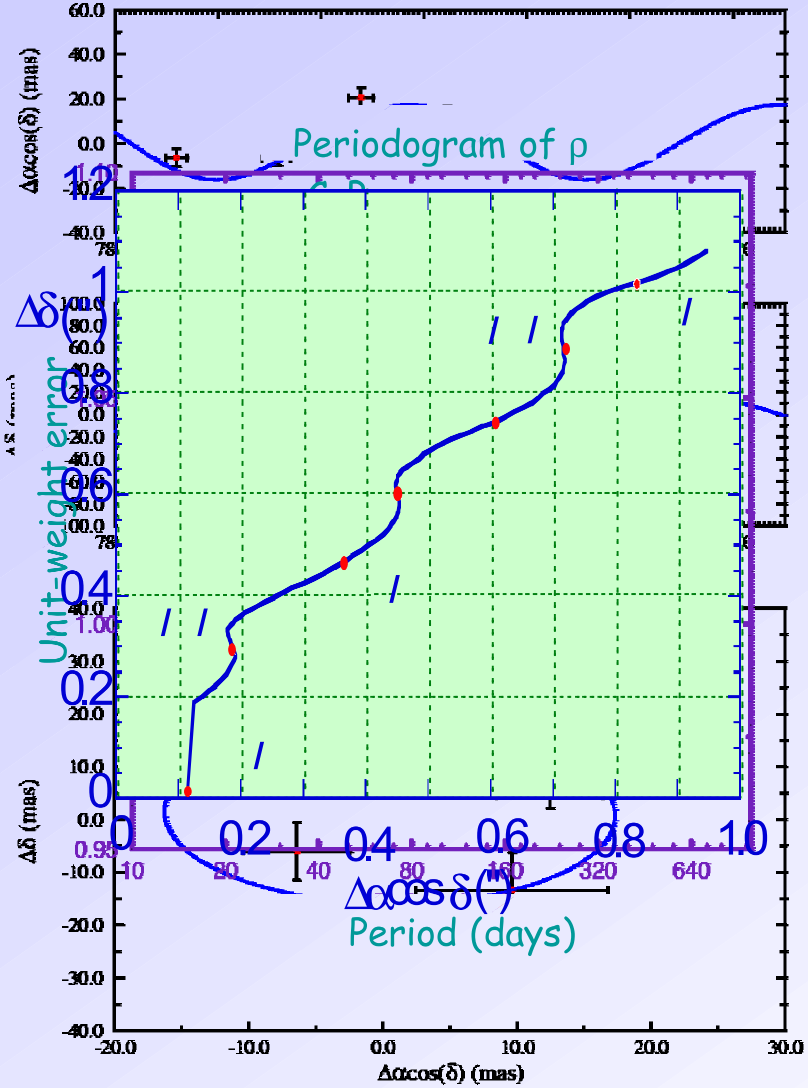


ASM3 2x1 ($7.6e^-$)



Astro 1x8

Orbital reconstruction (I)



- Assume one year data reduction by someone working 24h/day
- 10 million orbits = 3s/orbit

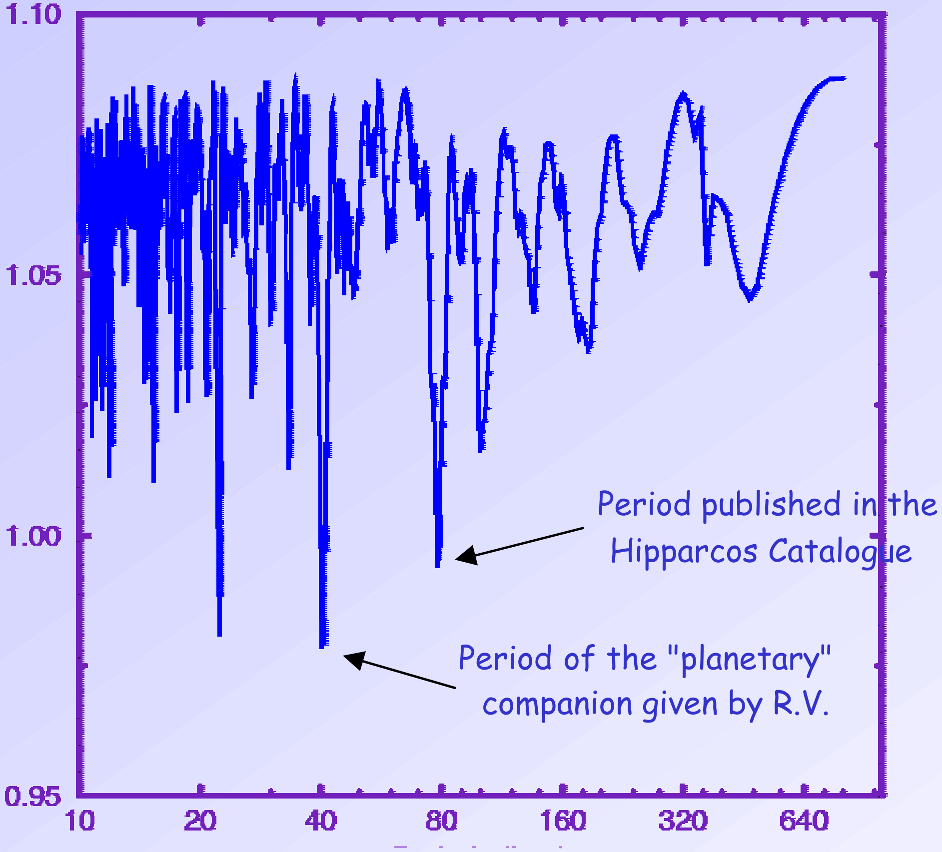
- Full automatisation

- Efficiency
  - Algorithm and computing power

- Robustness
  - Statistical and computational

Orbital reconstruction (II)

Hipparcos periodogram of ρ CrB



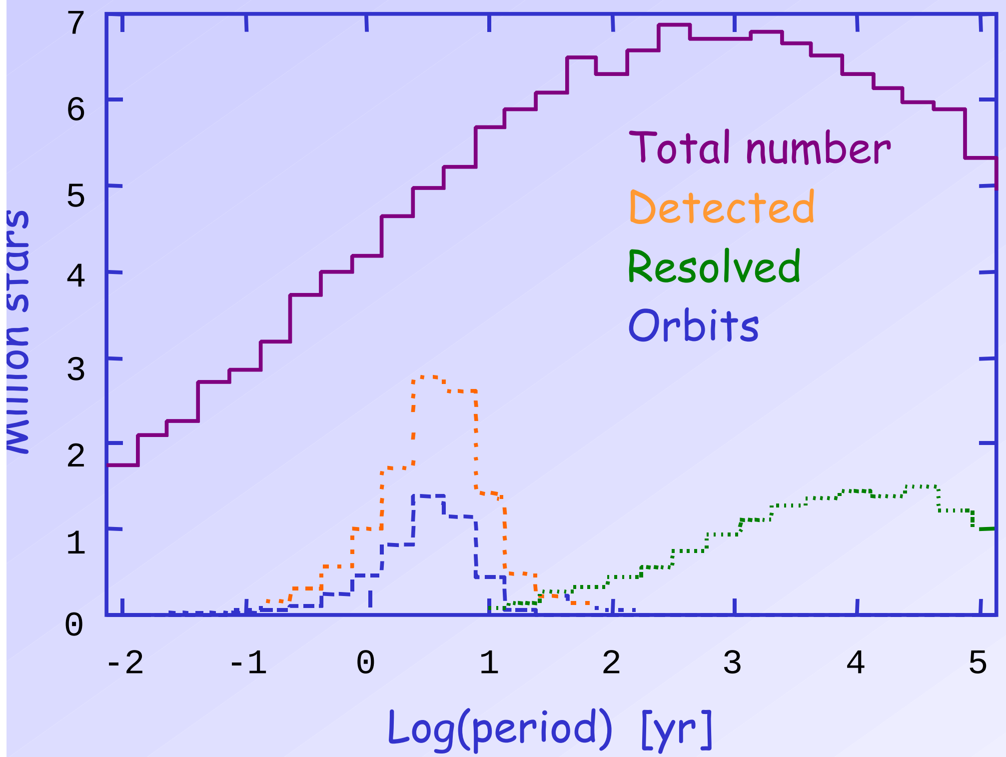
Period (days)

From Gatewood et al. (2001)

- One instrument only (e.g. planets by astrometry)
  - Detection of orbital motion
  - Period search (with aliasing problems)
  - Optimise Flux by transit / number of transits
  - Classical one-year orbit problem
- Radial velocity
  - Impact of resolution / pixel size
  - Reduction of SB2 (vs photocentre for astrometry)
- Combining orbits
  - Astrometry / spectroscopy / photometry
  - A lower detection threshold may be used
  - Incompatibilities between orbits (multiple stars)
- Orbit check
  - Significance
  - Weakness of available algorithms (precision and bias)

    (D. Pourbaix)
  - Short-period and long period regime
  - Exoplanets or double stars with flux ratio ~ mass ratio ?

Data reduction (astrometry)



Binaries, mag 15.0-17.5 © Söderhjelm+ESTEC

- Overlapping stars
  - Within or outside patch
  - 10% of objects with no sensible astrometric solution if duplicity not accounted for?
- Rejection for core processing
- Instrumental problems
  - CCD: Non-linearity of charge transfer
  - PSF: aberration, motion
- Optical doubles in dense areas
- All CCD patches should be used

- Meet the requirement on astrometric accuracy for bright (V<13) stars
  - Nearby stars hosting planets

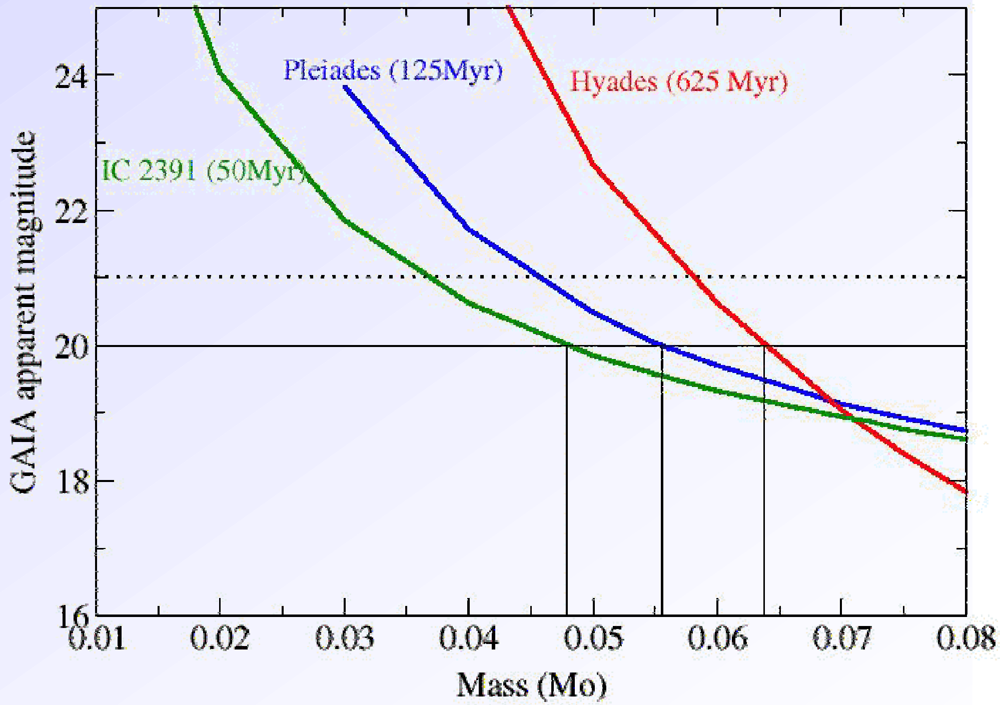
(A. Spagna)

Data reduction (photometry)

- In relation with astrometry impact
  - Variable stars: VIM
  - Photocentric binaries in BBP
- Reconstruction by stacking patches
  - Faint companions detected with PSM (G=23.5 at 1")
  - Using all samples from all the CCDs
- Extraction of physical parameters in NBP
- Eclipsing binaries
  - simulation in all CCD fields
  - detection and astrophysical diagnostics
- Planetary transits
  - Detection and alert
  - False detections (grazing EB: need spectro precision)

(N. Robichon)

Brown dwarfs in nearby open clusters



Haywood, 2001

Science case

G=16 + 17 mag simulated over Orion (with WFPC2)

- General scientific return in 15 years from now
  - Exoplanets around evolved stars, white dwarfs

    (B. Lopez)
  - Delineating BD and exoplanets
  - Star-forming regions (selection function)
  - Orbital evolution, mass ratio, etc.
- Measurement capability of mass transfer
- Spectroscopic binaries
  - 2 km/s for cluster stars needed

    (J-L. Halbwachs)
- Detectability of brown dwarfs
  - Mass-luminosity of young BD ?
  - Contrast with stellar companion
- Combining Gaia with
  - Astrometric satellites (long-term motions)
  - Other ground-based data (light curves, radial velocity)
- Expected selection biases on binaries, on-board or after ?

What tools do we have/need ?

- The concept and Technology Study Report
- Galaxy models
- Simulation code in IDL (by A. Brown)
- Iraf+Web interface (C. Babusiaux+F.A.)
- But not complete…
  - No time evolution of objects (e.g. orbits)
  - Not the selection function+tracking
  - Not the patches obtained on the whole focal plane
- A better focal plane simulator will be operational within 6 months

- We need an, even imperfect, simulator of complex objects
  - Realistic duplicity model down to BD, planets
  - Orbital parameters
  - Frequency, multiplicity, as a function of primary
  - Magnitude, colour of secondaries
  - Temporal variations of both components (astrometry, spectroscopy, even photometry for eclipses or VIM)
  - It will be included in the focal plane simulator

- We need an, even crude, prototype of the reduction chain

- Methodology
  - fault-tolerant algorithms
  - parallel processing
  - double-bind procedures on simulated data

(A. Sozzetti)

Tasks, interface, schedule

Task		Names	Interface
Simulator of complex objects	X	S.Söderhjelm, D. Pourbaix, F. Arenou	5.7.2
On-board detection and selection			
+ Detection algorithm for multiple objects	X		5.2.4
+ Selection algorithm			5.2.4
Sample and patch study			
+ Optimise sample size	X		5.2.5
+ Optimise patch size	X		5.2.5
+ Observing strategy			
Orbital reconstruction			
+ One instrument only (detection, period)		D. Pourbaix	
+ Radial velocity (resolution, SB2)			5.4
+ Combining orbits, orbit check		D. Pourbaix	5.4
Data reduction (astrometry)			
+ Rejection for core processing			5.2.1
+ Prototype of the reduction	X		5.2.1
Data reduction (photometry)			
+ Reconstruction by stacking patches			5.3.3
+ Extraction of physical parameters in NBP			5.3.1
+ Eclipsing binaries/transits		N. Robichon	5.6.3, 5.3.1
Science case			
+ Measurement capability of mass transfer			5.6.3
+ Spectroscopic, eclipsing binaries			5.4, 5.3.1
+ Detectability of brown dwarfs			5.3.1
+ Selection biases on binaries			