

# The International Deep Planet Survey and Keck survey

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OBSERVING PLANETARY SYSTEMS II, Vitacura

2012 March 06

# Outline

Instruments and telescopes

Automatic pipeline

Databases

Detections

Statistics

# Outline

Instruments and telescopes

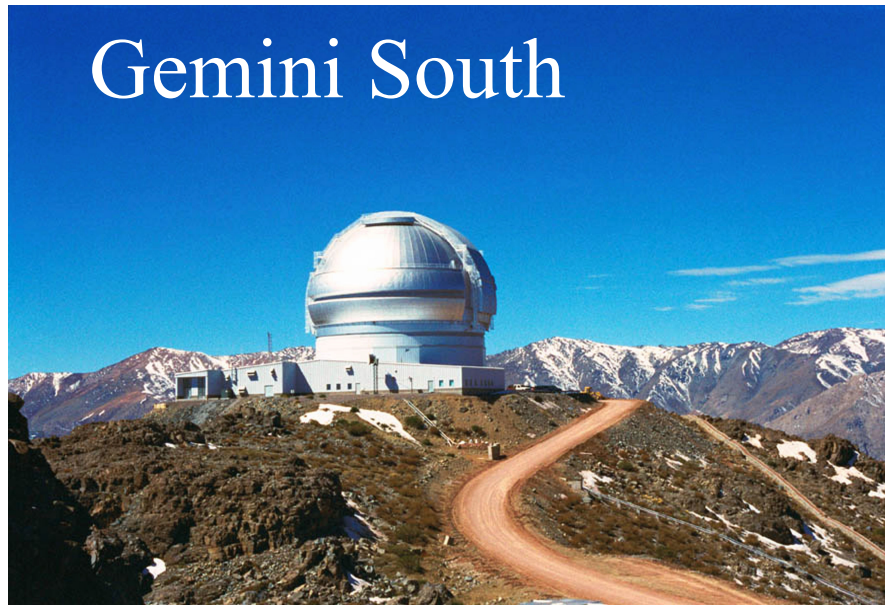
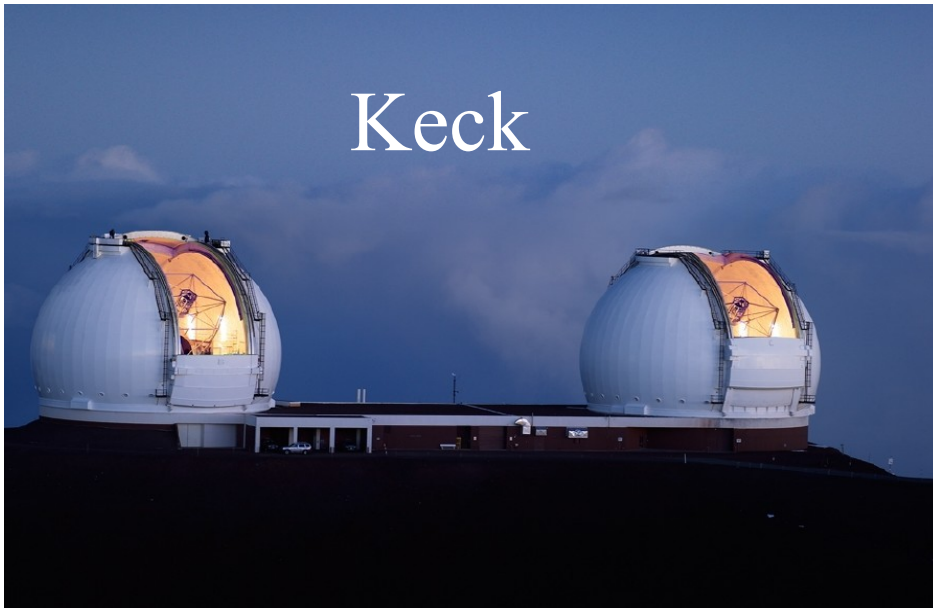
Automatic pipeline

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# Telescopes



# Instruments and history (1/2)

## NIRC2 KeckII

2000 to 2012 ~70 nights/half-nights

2000-2004 : fixed North, shallow contrast (no LOCI)

2004-2012 : pupil rotator off, deep contrast, w/wo coronagraph

Bands : CH4s, CH4l, H, K, L, M

Early and late type stars

## NIRI Gemini-North

2007 to 2012 (32h+30.5h+32h+24h+49h+18.5h)

Pupil rotator off, deep contrast, no coronagraph

Bands : CH4s and some H, K, and L

Early type stars (GDPS expansion)

# Instruments and history (2/2)

## NICI Gemini-South

2009 (25.3h)

Pupil rotator off, deep contrast, coronagraph

Bands : CH4s, CH4l, K

Late and early type stars

## NACO VLT

2007 - 2012

ADI, S13 camera,

Band : Ks

Mostly early type stars

## NIRI, NACO, NICMOS

Other team public data for follow-up

Total ~ 30 000 images... reduced ~5times each

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# LOCI : IDPS pipeline

- 1/ Sky, flat, distortions, background calibration (~automatic)
- 2/ ADI/SSDI/LOCI post-processing (automatic)
- 3/ Flag off-axis sources (by hand... automatic for sig>10)
- 4/ ADI/SSDI/LOCI procedure to retrieve astro/photo (automatic)
- 5/ Contrast curve (automatic)
- 6/ Fill out the databases (automatic)



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**Databases**

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# Databases

## Observations

Star, RA, DEC, nb im, coadd, itime, fov rot, tel, instru setup, filt, date

## Star properties

Star, RA, DEC, spec type, age, plx, prop motion, IR excess, B to L mag

## Planet candidates

Star&RA&DEC, sepa(""), sepa(AU), PA, contrast, abs mag, filt., tel., instru. setup, date, fov rotation, snr, mass, file pointer, bound/unbound/unknown

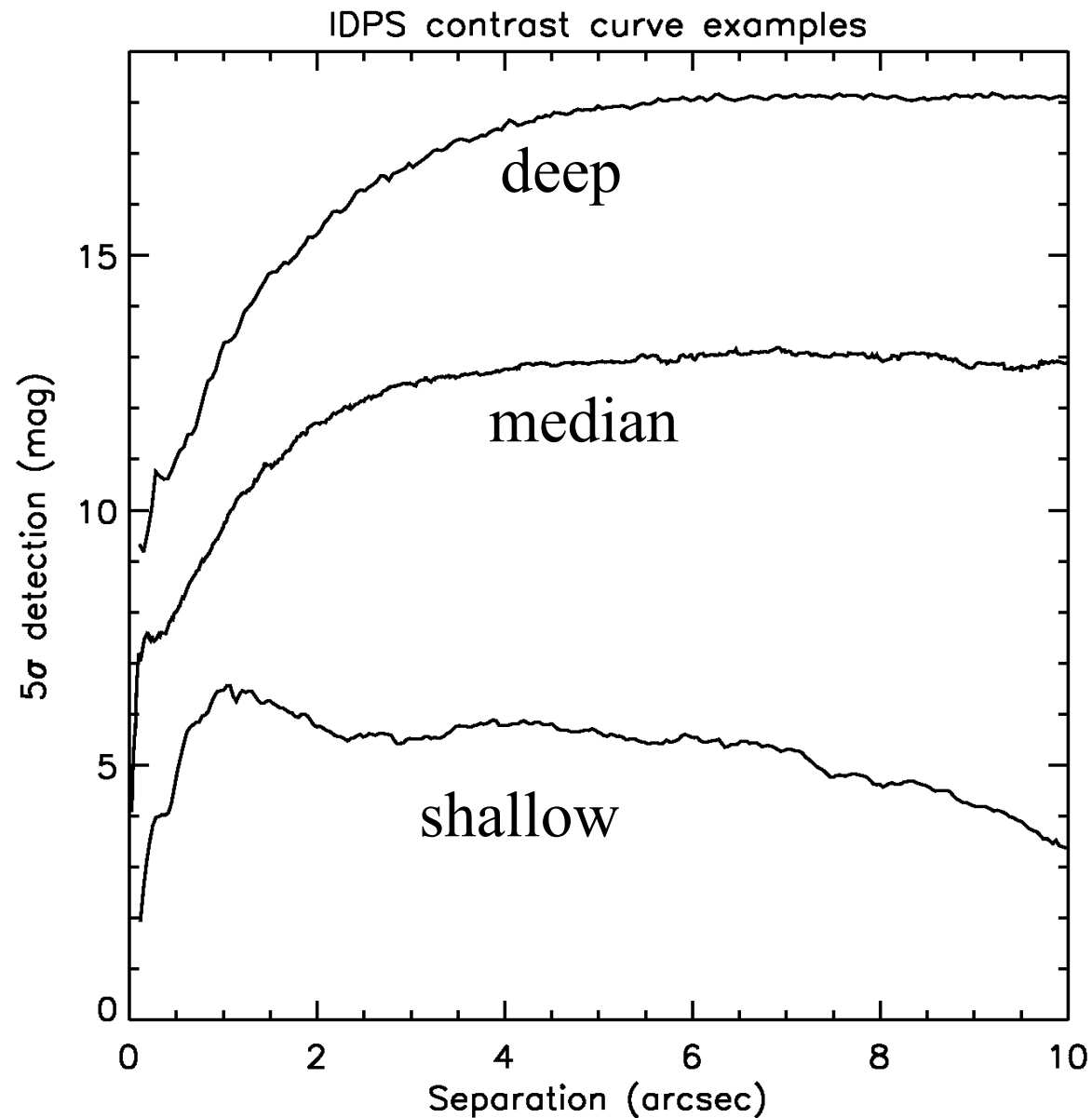
## Multiple stellar systems

Same as planet candidate database

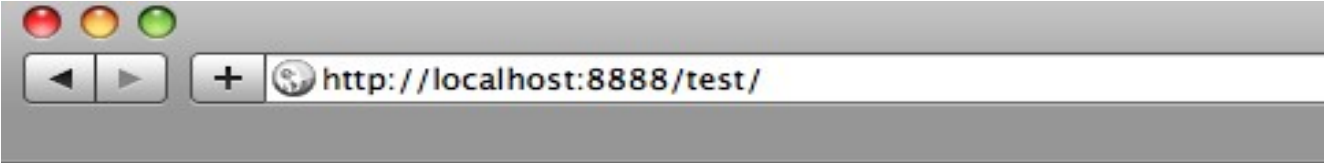
## Contrast curves

Star&RA&DEC, filt., tel., instru. setup, date, fov rotation, curve, file pointer

# $\sim 450$ contrast curves



# PHP/ MySQL



The screenshot shows a web browser window with the address bar displaying `http://localhost:8888/test/`. The page title is "International Deep Planet Survey". The form contains several input fields for astronomical coordinates and separation, a status dropdown menu, a sorting dropdown menu, and a list of checkboxes for telescope selection.

**International Deep Planet Survey**

Minimum RA (h min sec)

Maximum RA (h min sec)

Minimum DEC (deg min sec)

Maximum DEC (deg min sec)

Minimum Separation (AU)

Maximum Separation (AU)

Status (B=Background, A=Associated or ?=Unconfirmed)

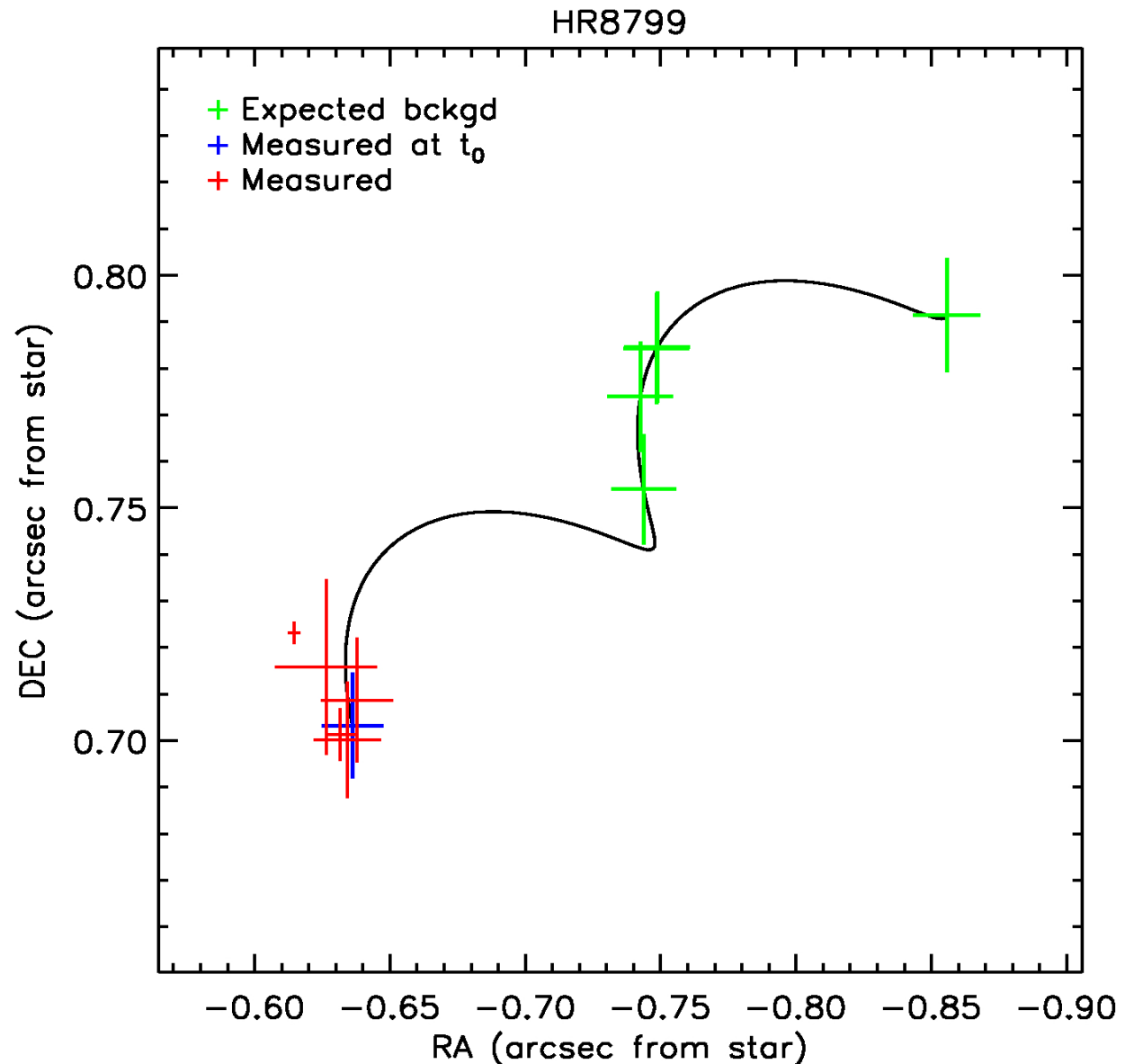
Ascending order by RA

☐ KeckII ☐ Gemini-North ☐ Gemini-South ☐ VLT ☐ HST

# Position vs prop mot + plx

For any  
candidate  
with  $>2$  epochs

Automatic  
procedure



# Outline

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Automatic pipeline

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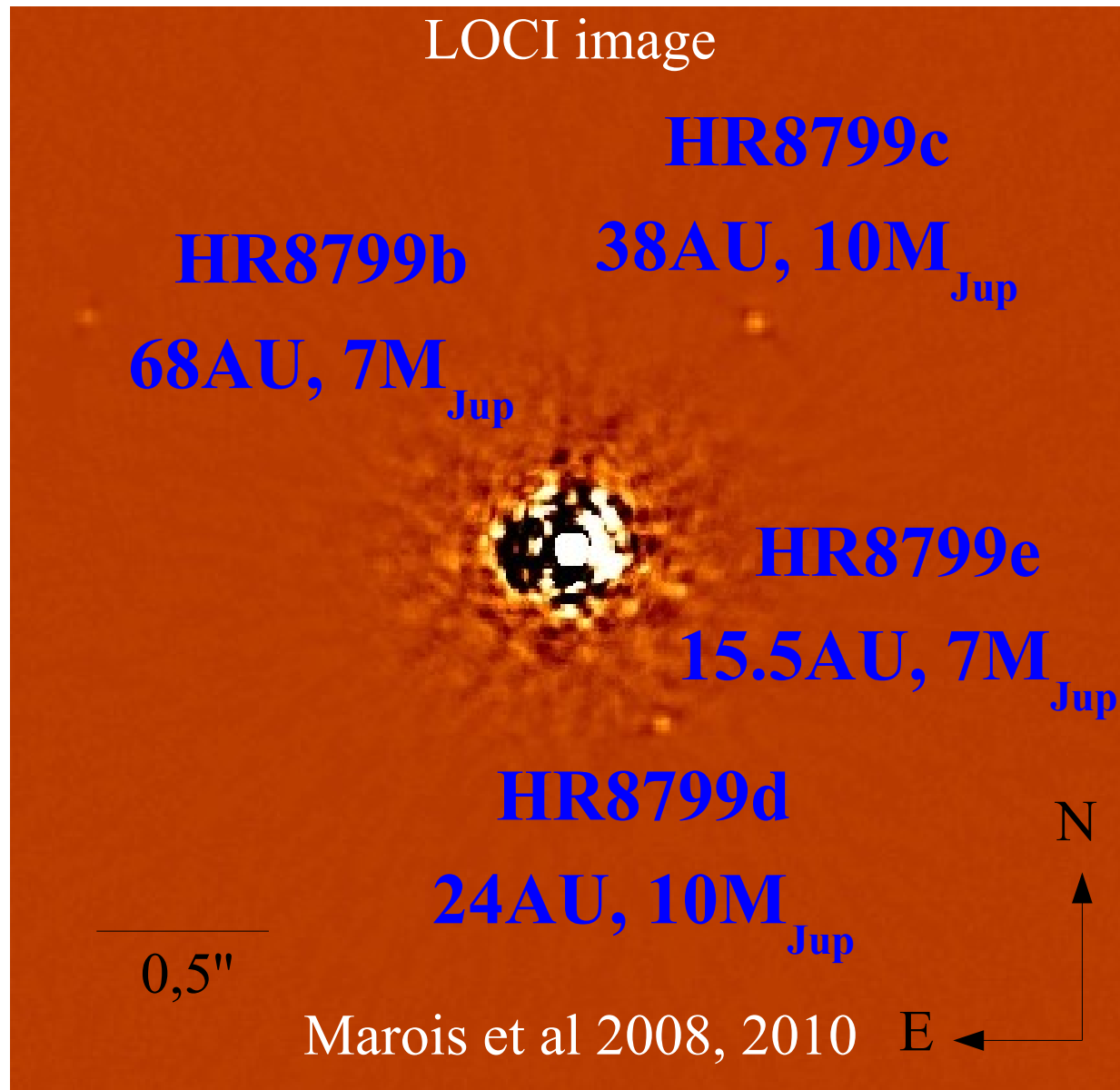
**Detections**

Statistics

# Detections during the IDPS

- $\sim 70$  binaries ( $< 200 \text{ AU}$ ) : 15 new systems
- 2 new triple stellar systems
- $\sim 200$  background sources
- 4 Jupiter-like planets : HR 8799

# HR 8799 : 4 planets





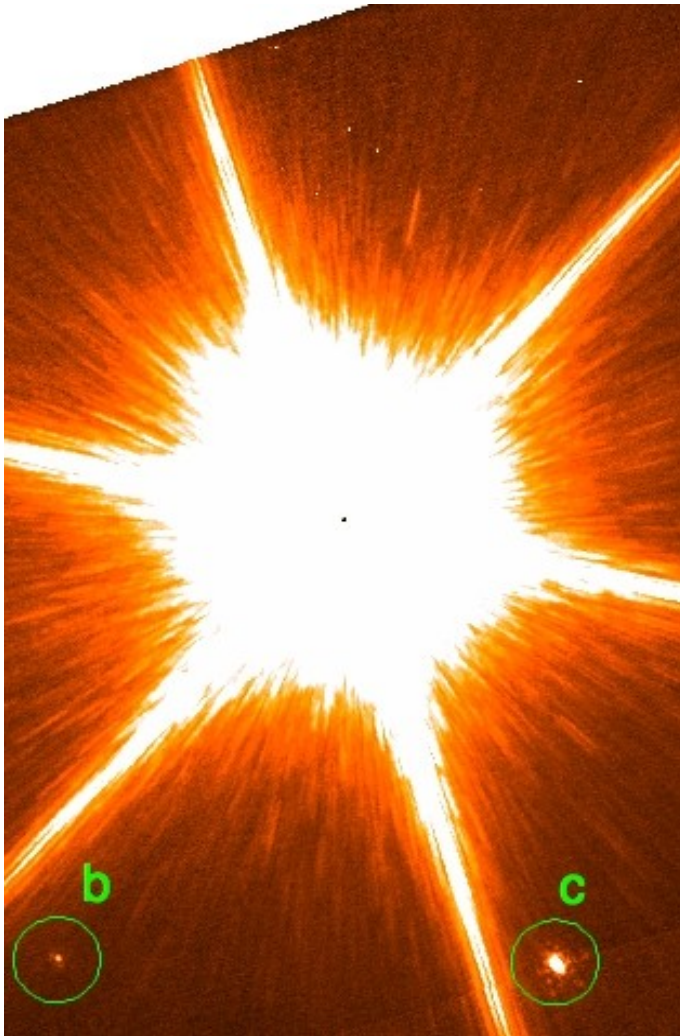
# Detections during the IDPS

- $\sim 70$  binaries ( $< 200 \text{ AU}$ ) : 15 new systems
- 2 new triple stellar systems
- $\sim 200$  background sources
- 4 Jupiter-like planets : HR 8799
- $\sim 100$  planet-candidates  $< 200 \text{ AU}$ 
  - most are expected to be background sources
  - a few are very exciting

Bad weather = no fup in 2011

# A new 2-planet system ?

If star at  $\sim 20\text{pc}$



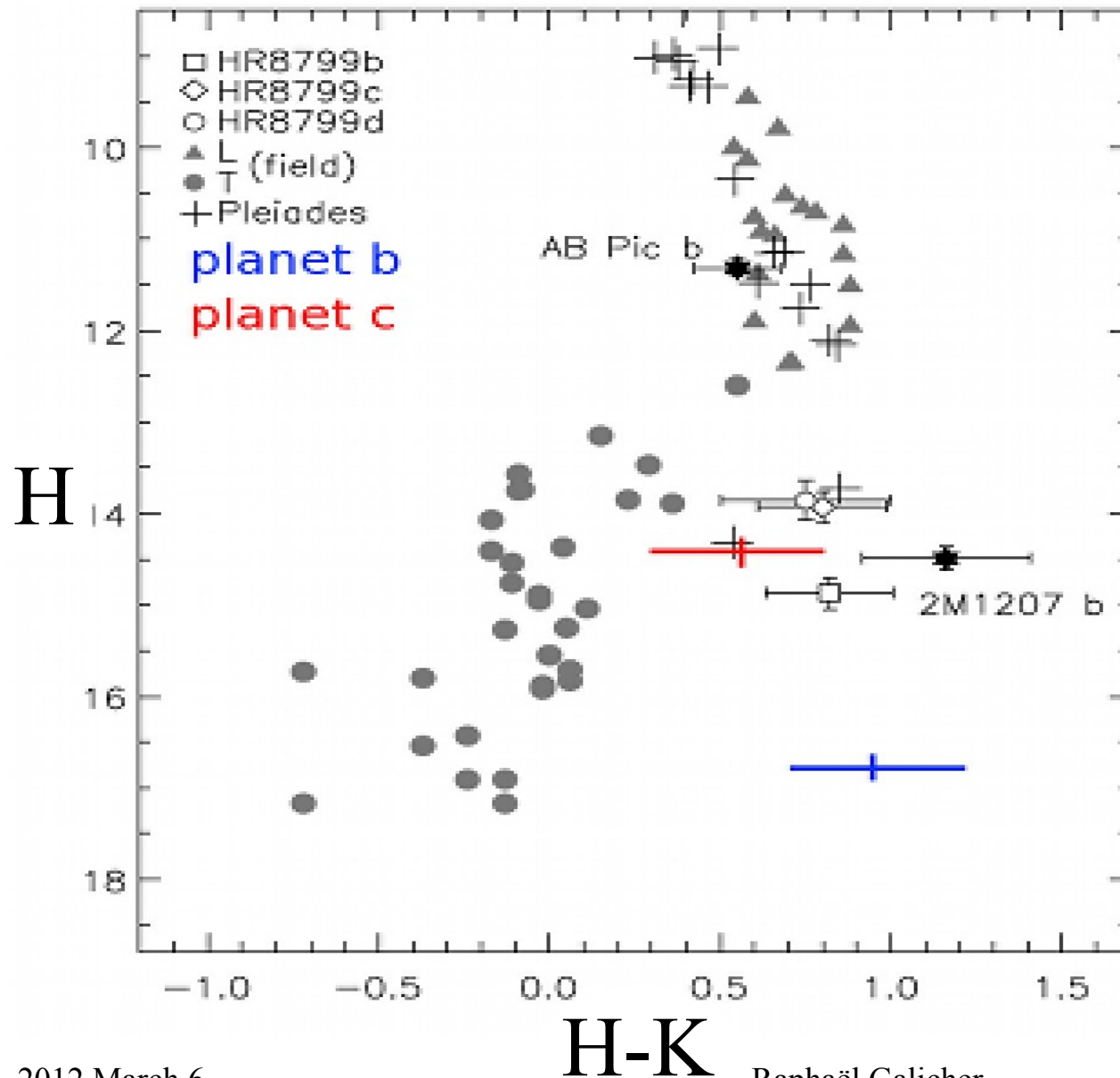
Planet b

$2-7M_{\text{Jup}}$  119AU

Planet c

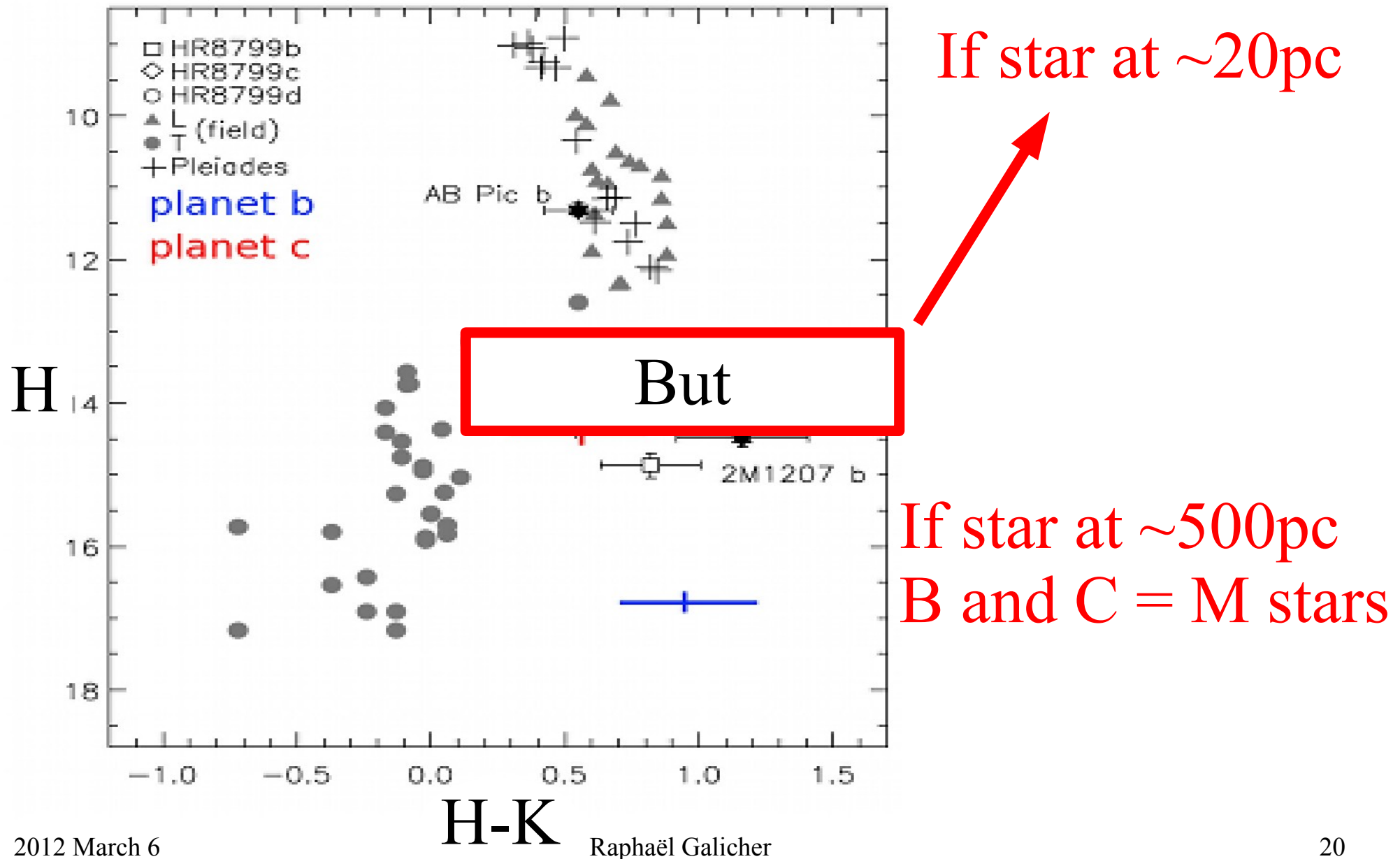
$3-11M_{\text{Jup}}$  112AU

# A new 2-planet system ?



If star at  $\sim 20$ pc

# A new 2-planet system ?



# Outline

Instruments and telescopes

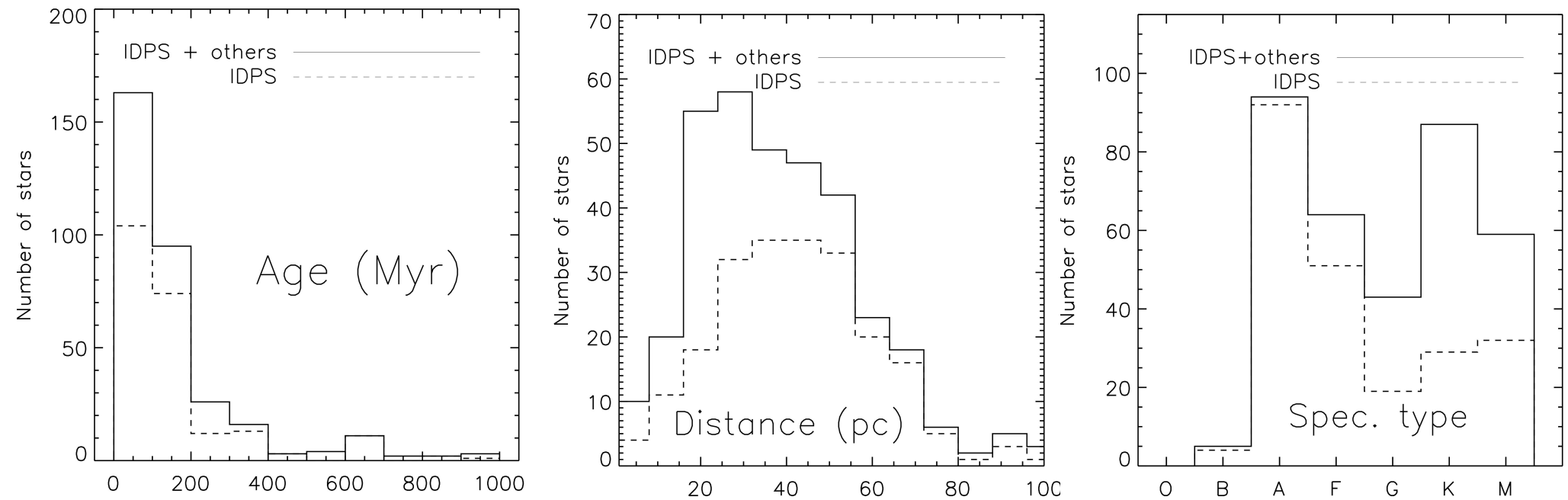
Automatic pipeline

Databases

Detections

**Statistics**

# Sample for statistics



IDPS : 227 stars

IDPS+GDPS (*Lafrenière et al 2007*)+DISYNAS (*Chauvin et al 2010*): **352 stars**

# Monte Carlo simulations

## 1/ Random planets

Mass and separation : flat distributions

Eccentricity : RV distribution

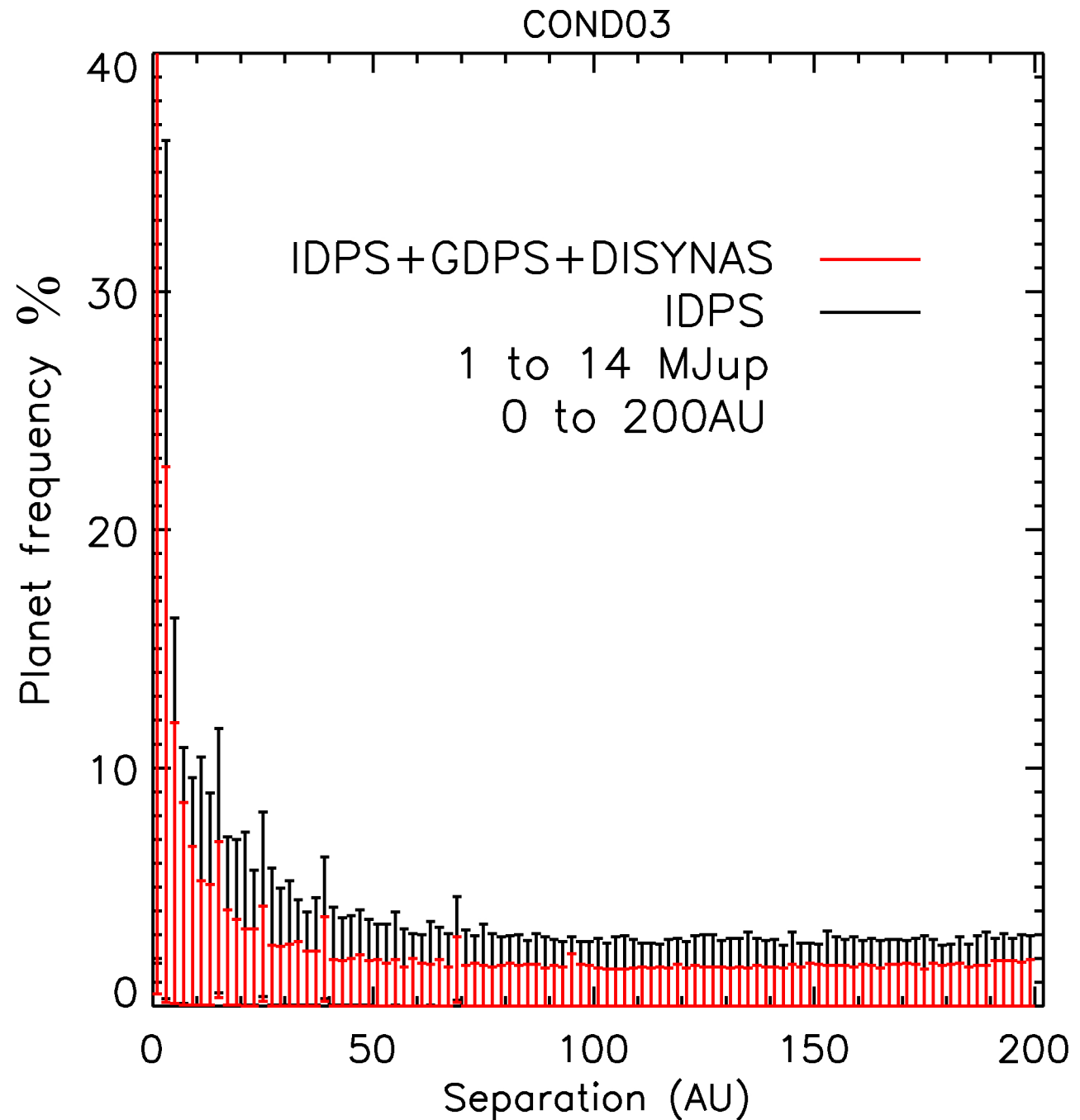
## 2/ COND03 atmosphere models → flux

## 3/ Detected or not for each observation

## 4/ Probability of detection for each star

## 5/ Planet frequency

95% certitude  
Bin :  
1-14MJup  
2AU





Probability that planet  
frequency is  $f$  vs  $f$

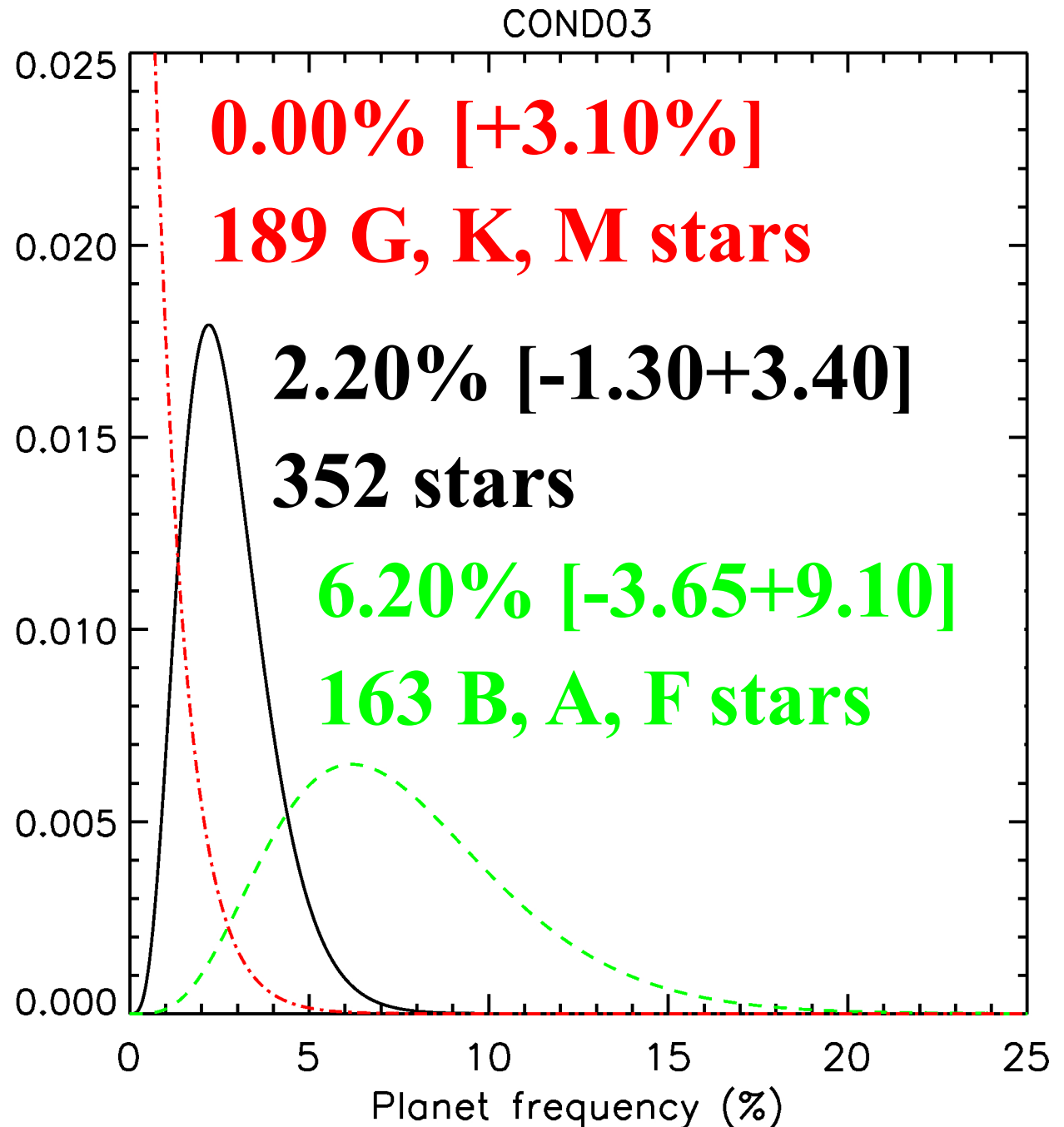
95% certitude

Bin :

1-14MJup

0-200AU

2012 March 6



# Conclusions

- **IDPS** : 12 years, 300 stars, 17 new multiple stars, 4 confirmed exoplanets,  $\sim 100$  candidates  $< 200\text{AU}$
- Automatic pipeline  $\rightarrow$  **GPI pipeline baseline**
- $f \sim 2\%$  stars have a 1-14  $M_{\text{jup}}$  between 0-200AU
  - $f < 3.1\%$  for G, K, M stars
  - $3.65\% < f < 9.10\%$  for B, A, F stars
  - $\rightarrow$  depends on spectral type (to be confirmed)

# Future works

- IDPS : follow-up the candidates
- Test planet distributions vs mass and separation

$$dN = M^{\alpha} a^{\beta} dM da$$

1<sup>st</sup> tests → no agreement with Cumming et al 2008

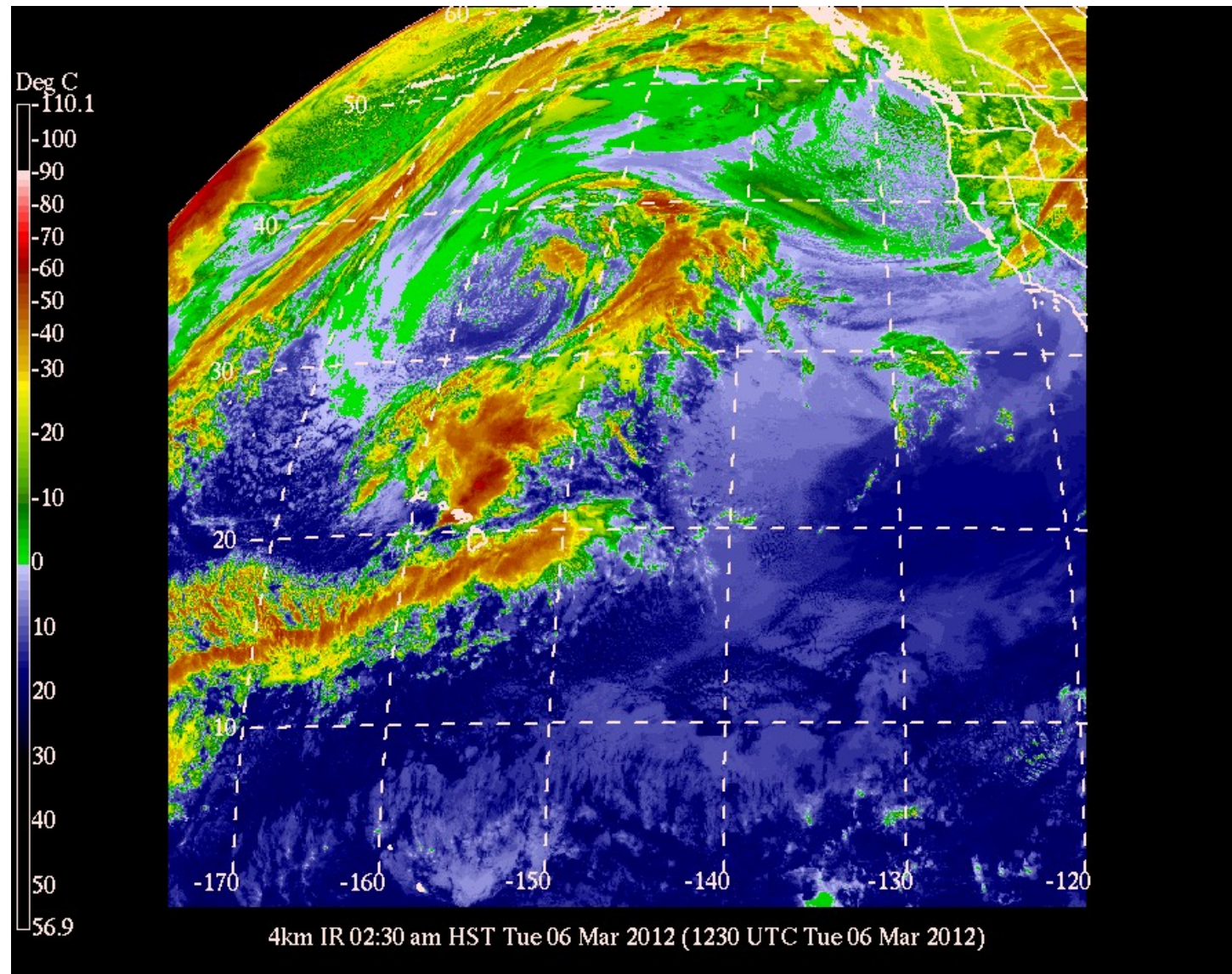
ok with micro-lensing conclusions (Cassan et al 2012)

- Release the IDPS website

Develop a common database for all the surveys

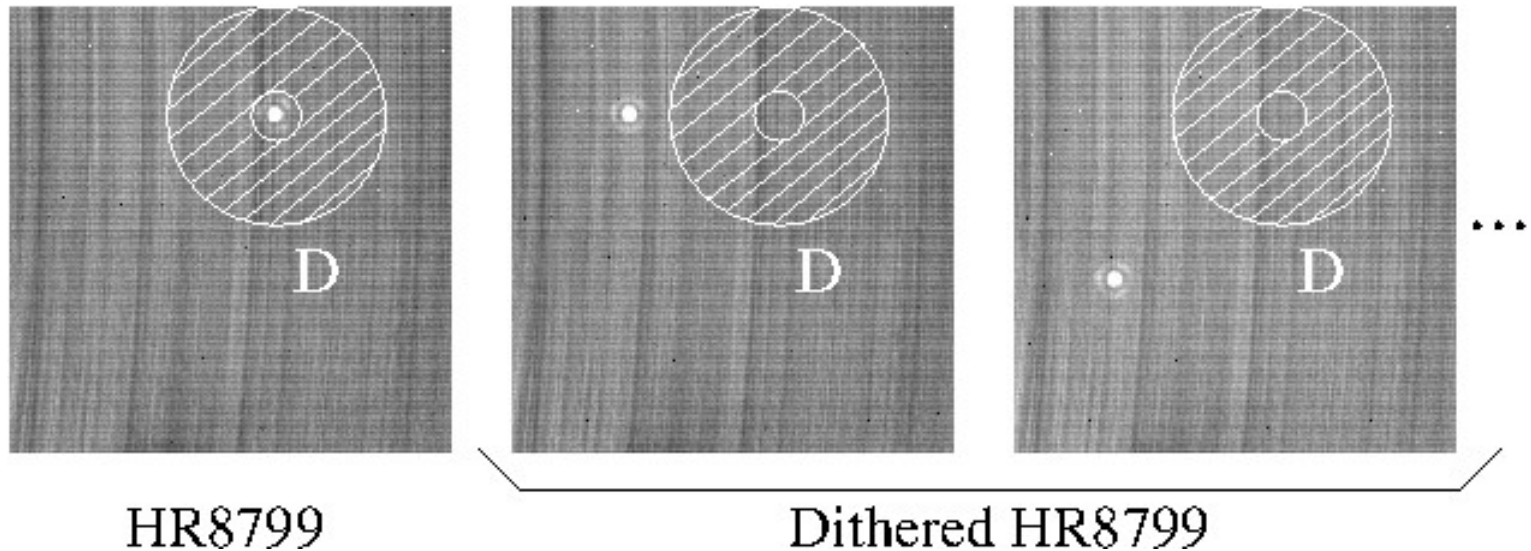
- SPHERE/GPI/HiCIAO/P1640 ...

# Thank you



# Background LOCI

M bands



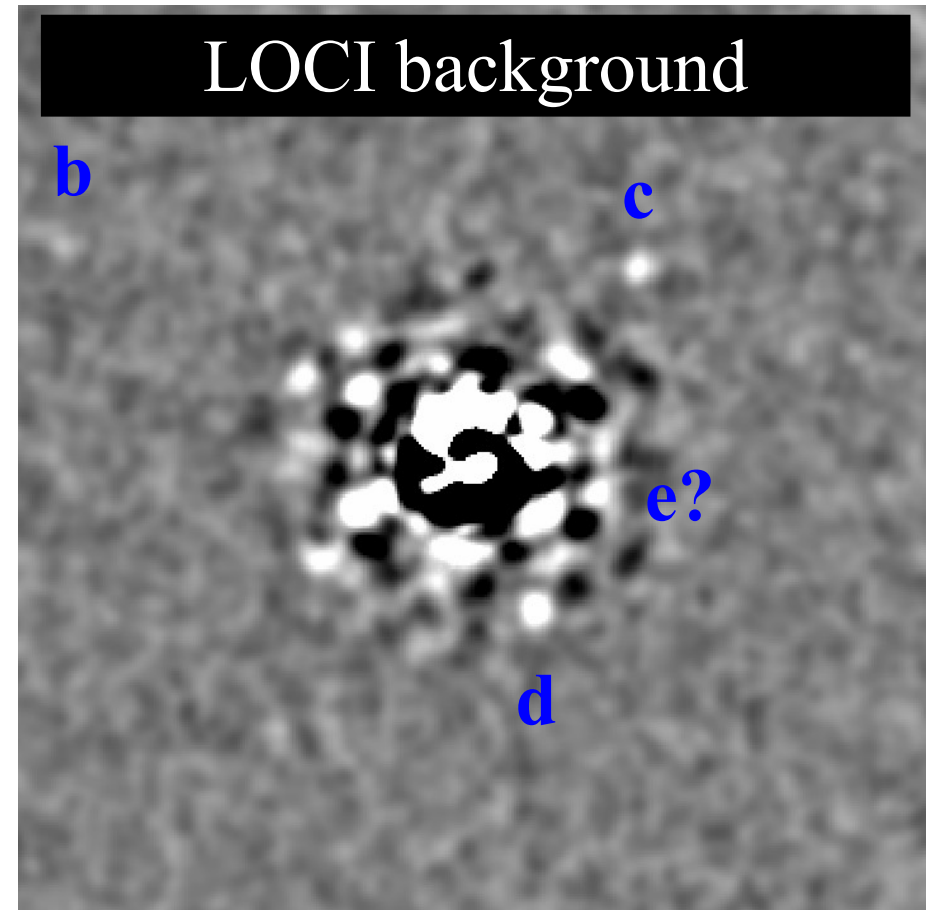
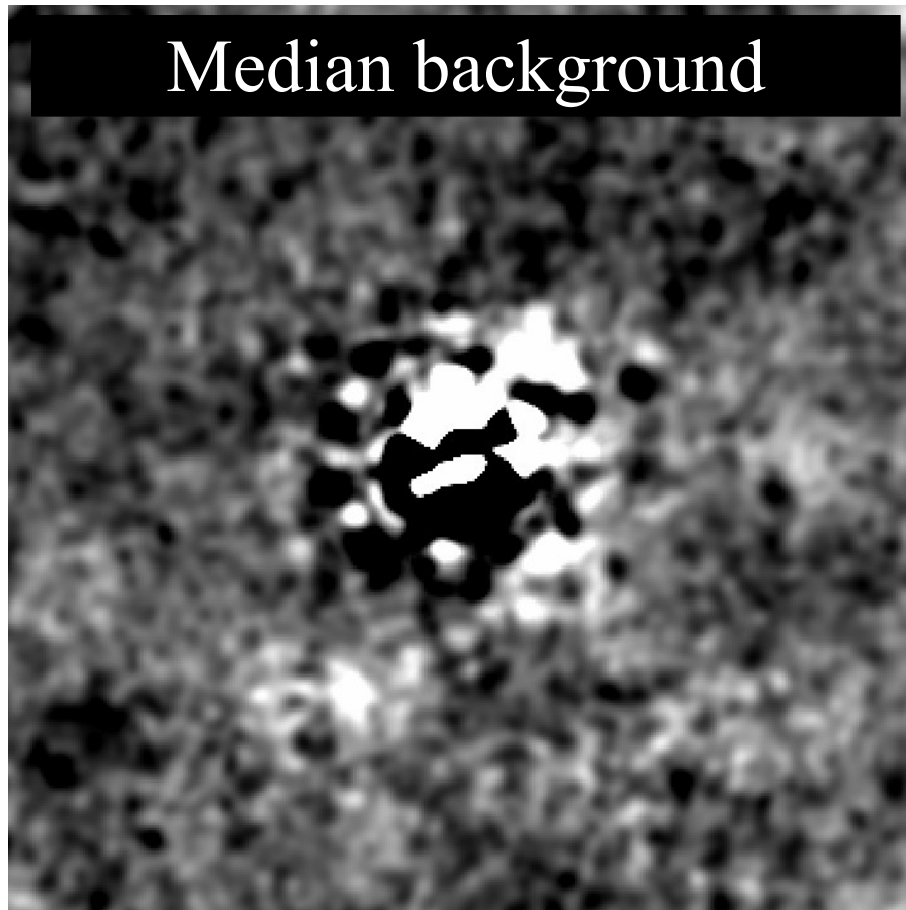
$$\chi_i^2 = \sum_{\text{pix}} |\text{Im}_i - \sum_j \beta_{i,j} \text{Im}_j|^2 D$$

j to have the star outside D

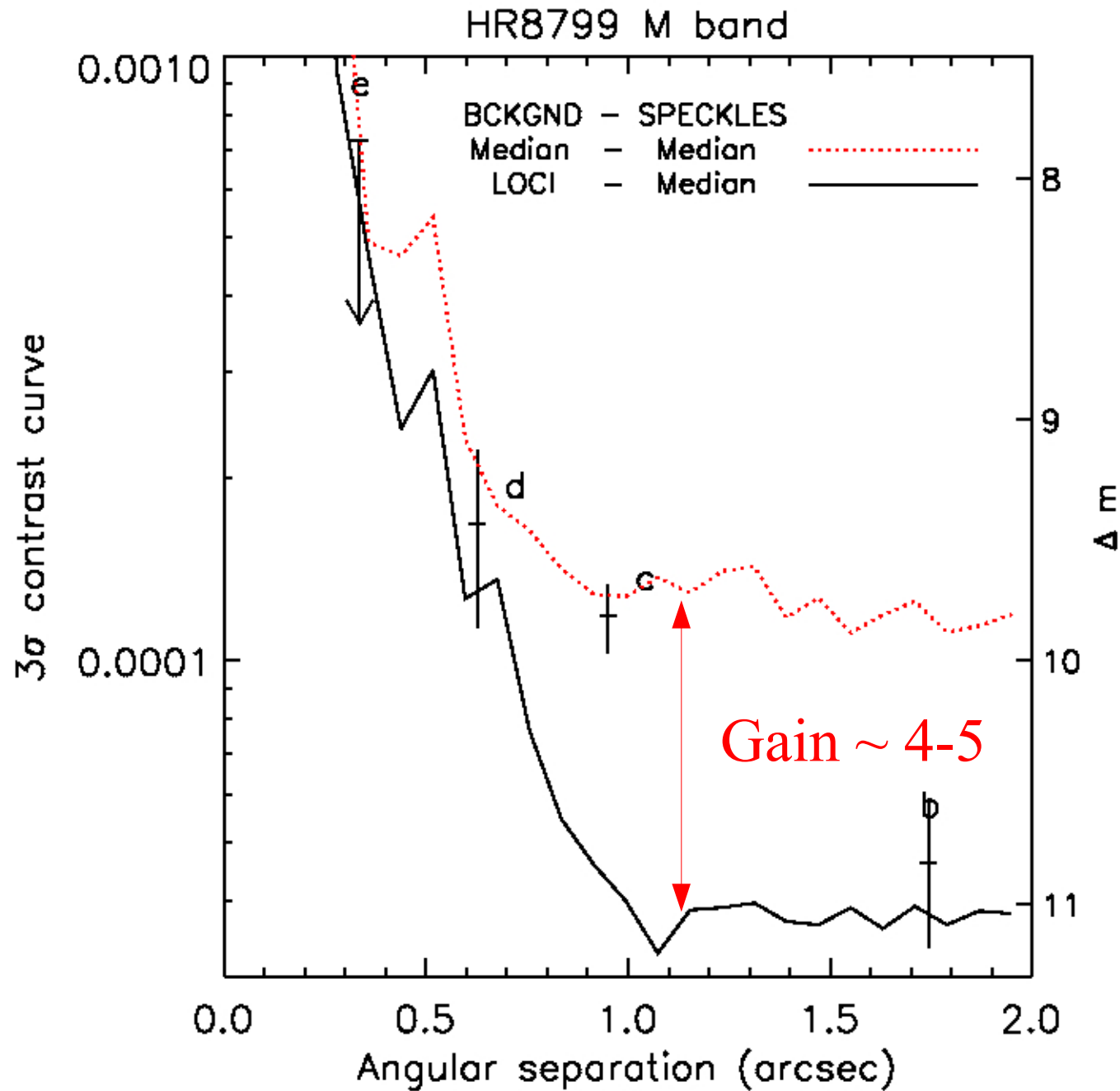
Planet impact <1%, and even <<1%



# HR 8799 at M-band



*Galicher et al 2011*

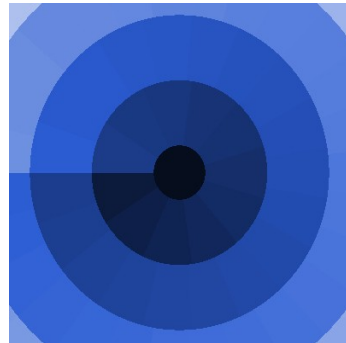
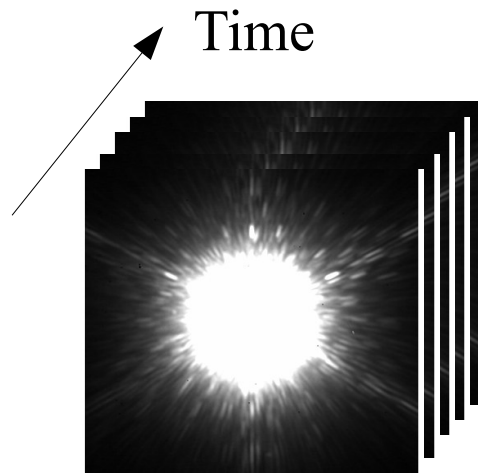


# HR 8799 at M-band

Telescope gain  
16-25 !

*Galicher et al 2011*

# LOCI : Locally Optimized Combination of Images

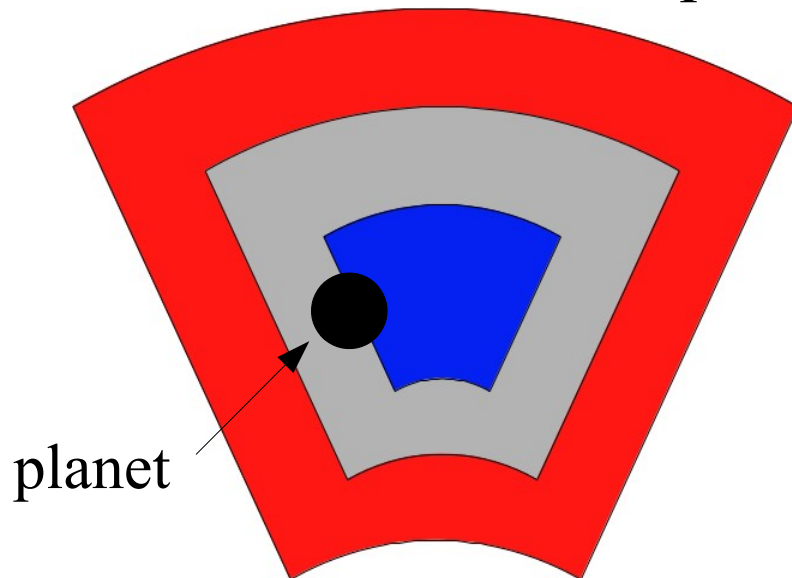


$$\chi_i^2 = \sum_{\text{pix}} |\text{Sec}_i - \sum_j \alpha_{i,j} \text{Sec}_j|^2$$

j for planet motion  $> g \lambda/d$

Minimization  $\rightarrow$  SVD  $\rightarrow \alpha_{i,j}$

Speckles are **temporally and spatially correlated**



- $\text{Sec}_i$  = sec of interest
- where  $\chi_i^2$  is minimized
- Not used

*Marois et al 2008, 2010*

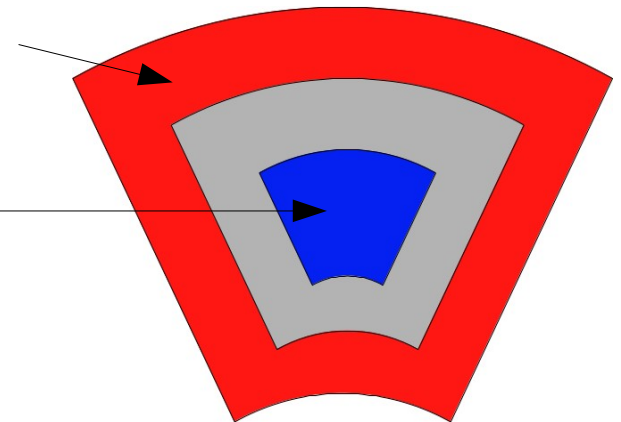


# LOCI parameters

$g$  = min planet motion between image and references

$r_{\text{opt},1}, r_{\text{opt},2}, \theta_{\text{opt},1}, \theta_{\text{opt},2}$  = optimizing region

$r_1, r_2, \theta_1, \theta_2$  = region of interest

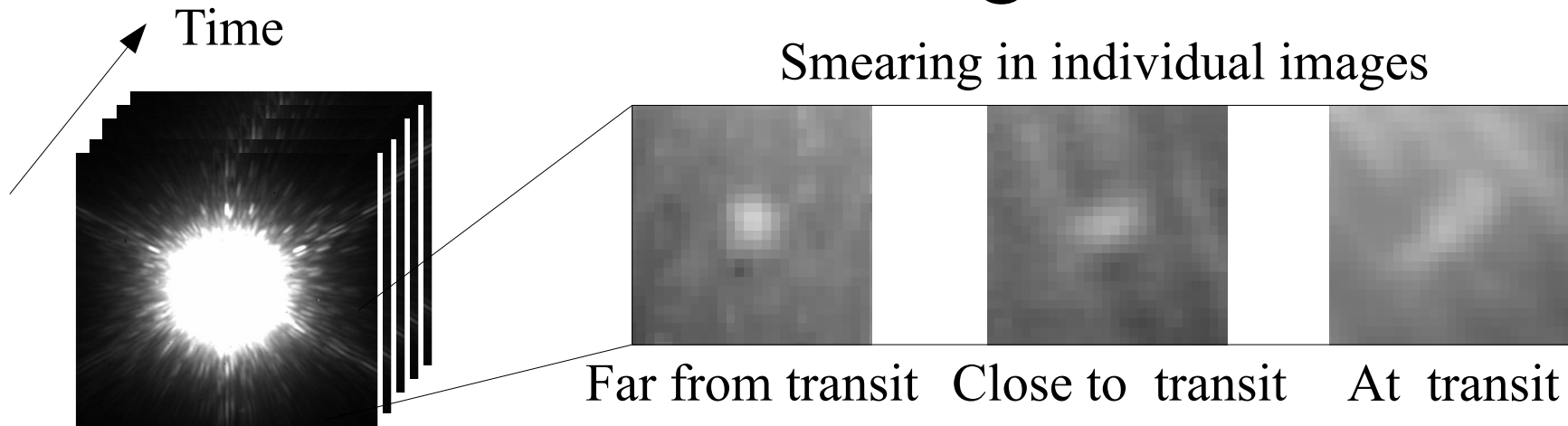


$N$  = max nb of references

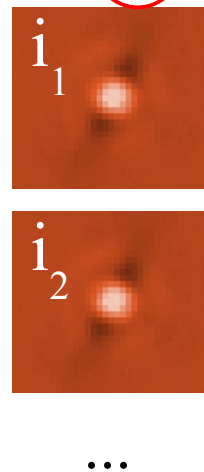
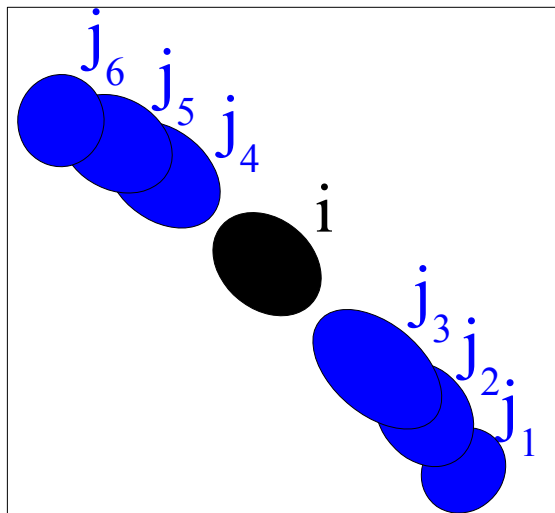
**SDI** = ADI+SDI at the same time with a LOCI algorithm (NICI data)

**Arch** = can use an archive of reference images (mainly for HST data)

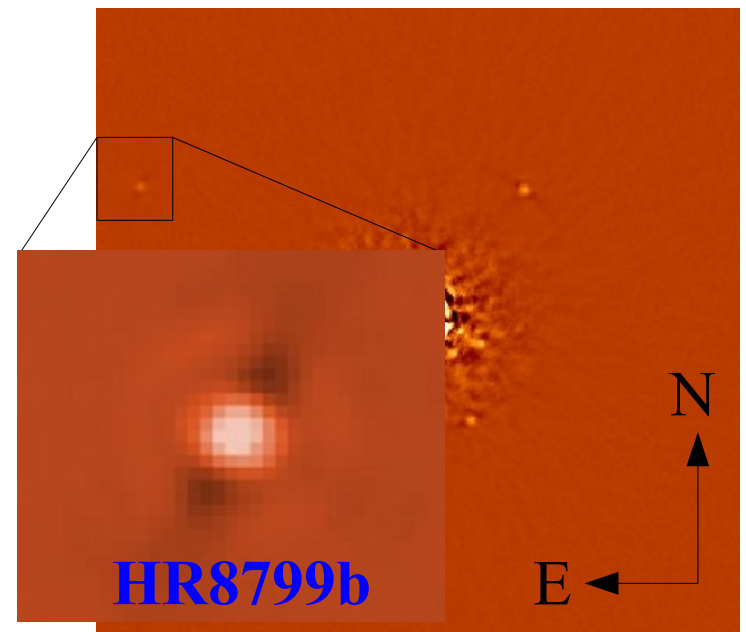
# LOCI : off-axis image formation



$$\text{Speckle Res}_i = \text{Sec}_i - \sum_j \text{LOCI coeff}_{i,j} \text{Sec}_j$$

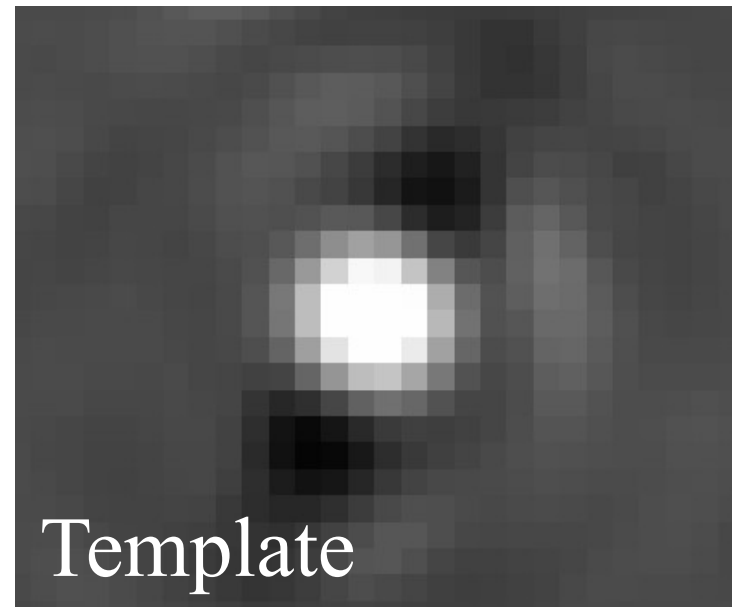
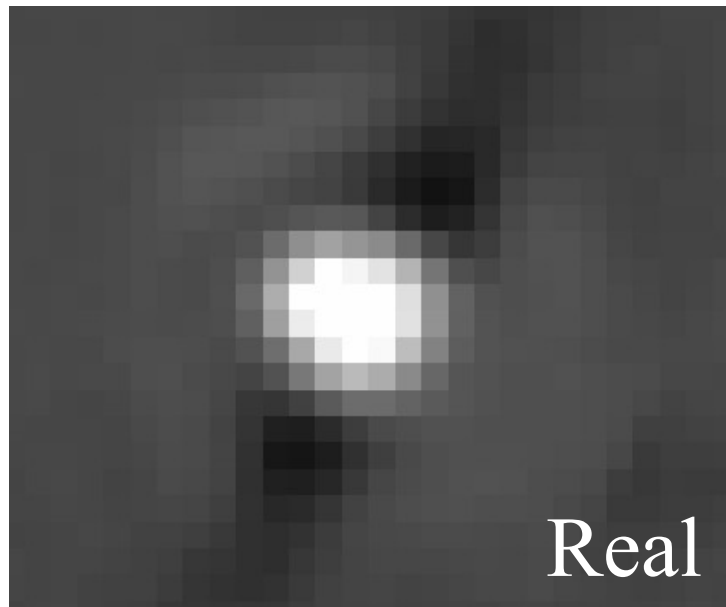


Rotation  
→  
+ median



# LOCI : photometry/astrometry

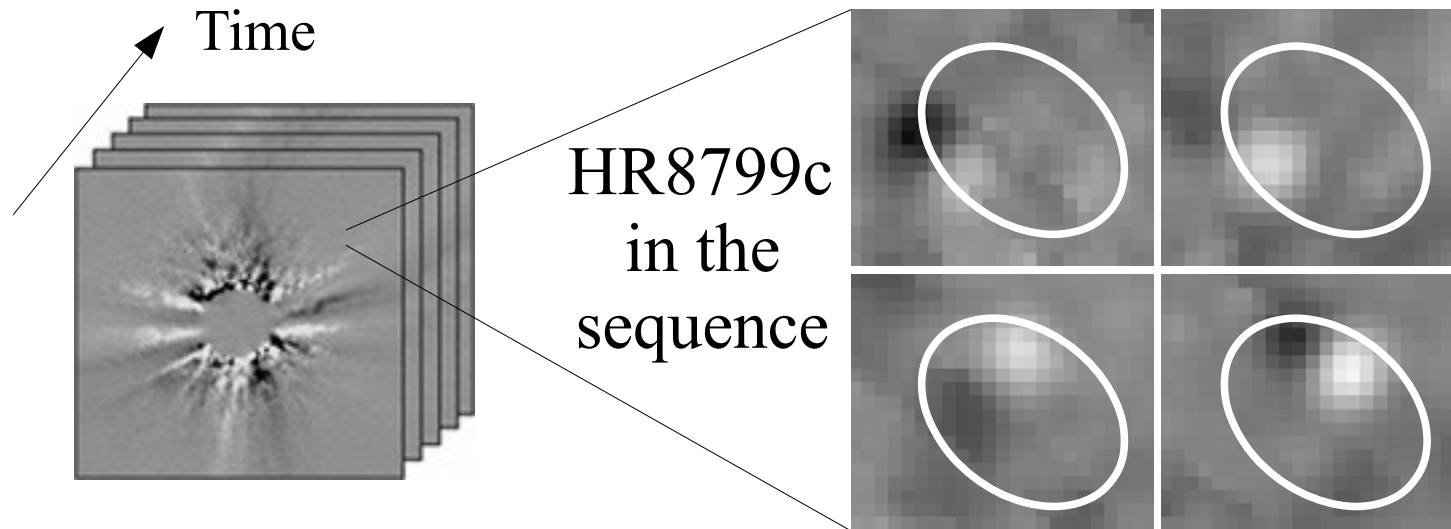
- 1/ Off-axis source cube (positions and smearing)
- 2/ LOCI using the already calculated  $\alpha_{i,j} \rightarrow$  template
- 3/ Fit the template to the real image



Astrometric errors include errors on the PSF  
Photometric errors + star flux variations in unsat data

# LOCI : global shift

- 1/ degrades the contrast
- 2/ biases astrometry/photometry



Global shift  $\Delta x = 2\text{pix}$   $\Delta y = -4\text{pix}$

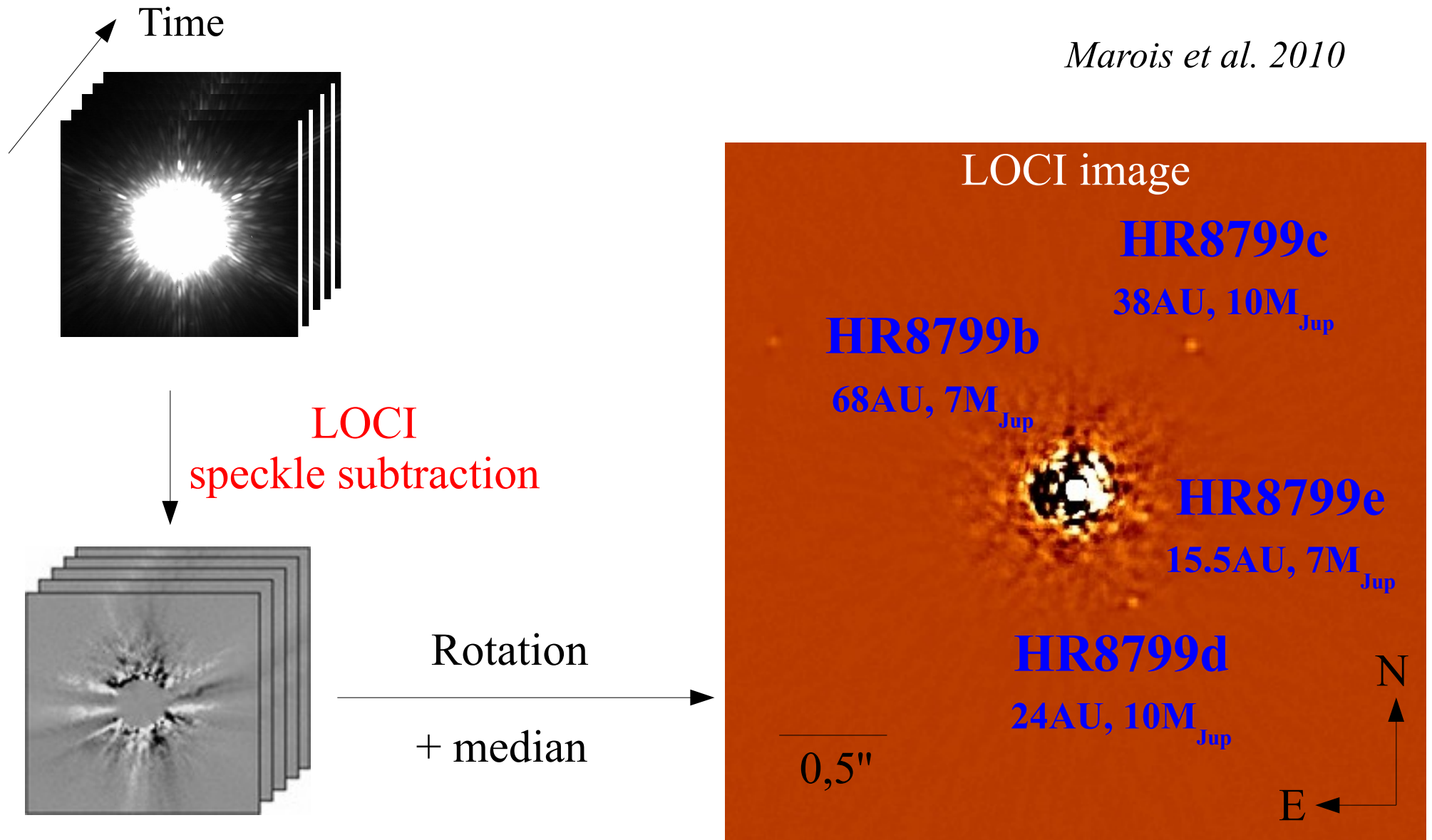
Maximizing off-axis source flux :

1/  $\Delta x$  et  $\Delta y$  du cube

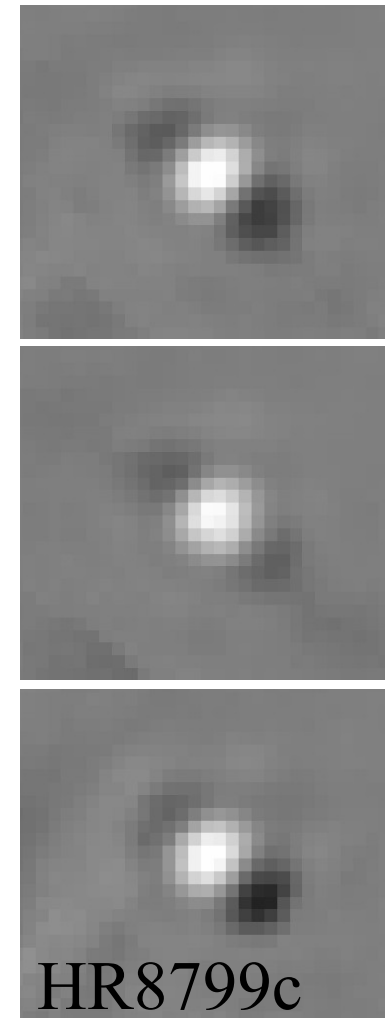
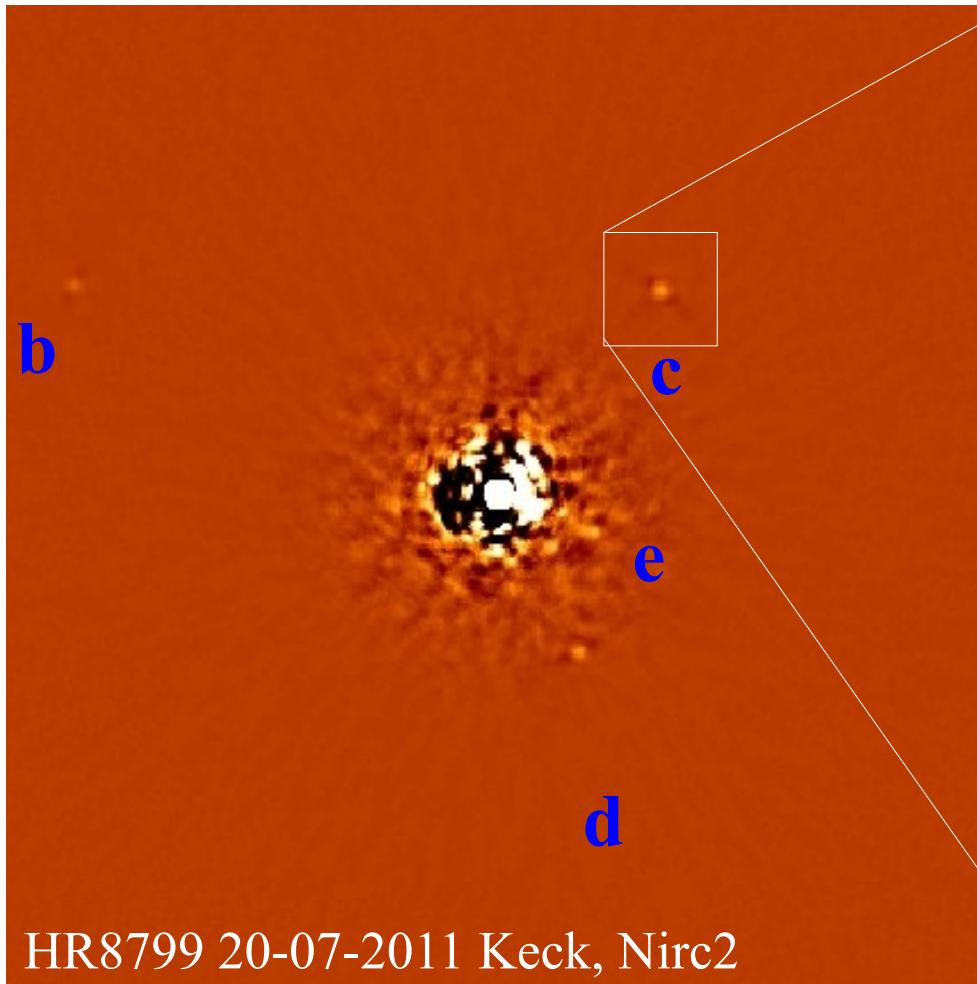
2/ offsets on telescope latitude and header sidereal time

# LOCI/SOSIE

*Marois et al. 2010*



# LOCI : off-axis image biases !



Same  
sequence  
but  
different LOCI  
parameters

**LOCI => biased photometry and astrometry !**

Planet frequency  
(%)

95% certitude

Bin :  
0-200AU

