The first AU of protoplanetary disks as seen by PIONIER/VLTI

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(IPAG/ESO/MPIA/Caltech)

Why interferometry ?



 $\lambda/2B$ ~1.5-10 mas i.e., ~0.2-1 AU

 $V e^{i\phi} = FT\{ Object \} (B/\lambda)$

- visibility V : spatial extent
- closure phase $\Sigma \phi$: asymmetry



PIONIER

Context in 2009: imaging era at the mas scale (e.g. MIRC/CHARA: 6T in the NIR).

Building PIONIER:

- OK from ESO: End of 2009
- Integration: Jan.-Sep. 2010
- First Light: Oct. 2010
- PI : JB LeBouquin / JP Berger



Science goals : YSO + Debris disks

- sensitive
- accurate
- providing multi-baselines simultaneously

- Statistics of disk properties
- Study time-variable objects
- Image well-resolved disks



relative α (mas) interferometer resolution. The colors are scaled to the squared root of the intensity with a cut corresponding to the maximum Natta et al. (200 perced dynamic range (see text for details). The blue ellipse traces the location of the min secondary blobs, and the green dot-dashed ellipse corresponds to the location of the rim in the B10 models with its width given by the secondary blobs, and the he interferometric l



relative δ (mas) -10 relative a (mas)

asymmetry of the emission: a point-symmetric object as a zero ¹⁰⁹⁰⁴ asymptotic of the emission a point-symmetric object has a zero with the data favor closure phase. The main observables are therefore the squared (Thiébaut & Giov. ¹⁰⁸⁰⁷ Visibility amplitudes, V^2 , and the closure phases C_{P0} . The a scale of 0.2 main ¹⁰⁹¹⁴ and the image reconstruction is to numerically utrieve an inversely proportion ¹⁰⁹¹⁴ tipodyithan of the true brightness distribution of the source obtain two polych ¹⁰⁹¹⁶ transform of the image should in the measurements. However, ¹⁰⁹¹⁷ due to the source as there are unknowns end the nizely applied, we referred to the source obtain two polych ¹⁰⁹¹⁸ transform of the image should in the measurements. However, we applied, we referred to the source of the source of the nizely of the source of the nizely of the source of the source obtain two polych ¹⁰⁹¹⁹ transform of the source of the source of the measurements. However, we referred the source of the source problem is in posed as there are more unknowns, e.g., the *pixels* of the image, than measurements. Additional constraints are therefore required to supplement the available data and retrieve an unique and stable solution. Few algorithms exist to perform image reconstruction (Hofmann & Weigelt 1993; Ireland et al. 2006; Baron & Young¹⁰2008; Meimon et al. 2009). In this paper, we use the the Multi-Apertured alway on Reconstruction Algorithm

with the data. favo obtain two polych

3. Reconstruct

10⁶

We present in Fig. The interferometri and are defined as and V axis. The i around HR 5999, a

in the Fig. A Reands Kutankis (right) f The oneshical provide Hips Mar 296 With this bash a Fills?) Gaths an All thin the PREMalized ballds used a for the data back of the second state of the e H (1991 The Same a fus of tigne), a file Fisconvolution with a Gaussian between the minimum cut corresponding to the maximum expected

4. Discussion

In this section, we discuss the reconstructed images tral spot are also real. However, the clumpy structure of the ring

trai spot are also real. However, the clumpy structure of the ring is probably not representative of the reality, but only of the actual 4.2. Use of the spectral information (u, v) plane. More observations an different spatial frequencies will probably charge the different spatial frequencies along the efficience symplectic different tests made on the B10 the efficience with the observed distribution of the observed distribution of have enough data to pave the (u, v) plane and the wavelength peaks along an ellipse are real. This orientation and inclination dependency expected from circumstellar disks. Because of the are indeed very close to the orientation of the are indeed very close to the orientation of the orientation and inclination intrinsic chromaticity of the object, we prefer to reconstruct two et auherones, tiants are consistent with energious potimeters ratidif- separated images in the H and K bands, otherwise two separated ferent wavelenstorildes langt our 2007 er Toring cond state prashat visibilities, sampling different emitting regions, may correspond we think dian eptersentative of the areconstructed imagenisation to the same spatial frequency. We show in Fig. 5 the combinacentral spot is the show in Fig. 5 the combinaas appointutive that invagelto the flipphapeable that combeatropted is certain Applopen Een (2) nothe dating dynamic (rangepta 780) is though the main central spot are real. Their spatial distribution along an orbital statistication of the spatial distribution along an orbital spatial central spot are real. Their spatial distribution along an orbital spatial central spatial distribution along an orbital central spatial distribution along an orbital central spatial central spatial distribution along a central spatial central spatial distribution along an orbital central spatial central spatial central spatial distribution along an orbital central spatial central spatial distribution along and orbital central spatial central spatial distribution along and orbital central spatial central spatial distribution along an orbital central spatial central spatial distribution along and orbital central spatial central spatial distribution along and the central spatial central spatial distribution along and the central spatial central spatial central spatial distribution along and the central distribution along and the central spatial distribution along and the central distribution along

puted Minimum cut levels of 1780 aid 1840, respectively, are applied to all the K and H figures. stars

features. For each band, we used all the data points in the different spectral ghannels, assuming implicitly the object to be grey in **esth** separated to the model, this method pro-

To demonstrate that the bright inner disk is clearly seen Ringn tierces the entral spot includes nor energy that that from the star alone, reconstruction of a simpler model is performed. This model is the same as the B10 model but without the bright inner disk, *i.e.* a star surrounded by a Gaussian ring. The star fluxes in the H and K bands remain the same and the Gaussian ring accounts for 70% of the flux in the *H* band and 86% in the *K* band. Figure 4 clearly indicates that the star alone does not spread across more than over 4 pixels in the K band and 7 in the H band, which is less than in Fig. 3.

> This analysis performed on existing models allows us to state which features in the reconstructed images from Fig. 1 can be trusted. We argue that the main secondary blobs present around

corner. Same conventions as in Fig. 1.

The inner disk



Baseline (m)

Family portrait







Reconstructed images



Inner disk modeling

Parametric modeling: provides Rin, surface brightness, asymmetries





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Inner disk modeling

0

0.8

Parametric modeling: provides Rin, surface brightness, asymmetries





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Refine with ProDiMo e.g. sedimentation, physical conditions

"Tdust, Tgas from thermal balance, and full vertical hydrostatic"



Transition disks



| T Cha | (G8) | Gap < 12 AU | [Cieza+2011] |
|----------|--------|-------------|-----------------|
| SAO20646 | 2 (F4) | < 45 AU | [Andrews+2011] |
| HD142527 | (F6) | < 130 AU | [Verhoeff+2009] |
| | | | |



Complex disk structures [Fukagawa+2011,Muto+2012]

Companion candidates in the gap [Huelamo+2011,Biller+2012]

> Massive (resolved) outer disks [Andrews+2012]

> > Benisty et al. in prep

Close companions & asymmetries

Search for companions at separations 3-50 mas (~0.5-7 AU)

* SAO 206462 & T Cha: no companion (contrast>1.2%)

* HD142527: point source at ~1.5 mas (3% contrast)? Or inner disk rim ?

No detection of bright companions [Pott+2010]

Low asymmetry – no sharp rim

Explained with anisotropic scattering

HD142527

T Cha

* Candidate companion @ 6.7 AU ? [Huelamo+2011]

- * Single temperature black body ~ 1500 K
- * Tiny inner disk : 0.07–0.13 AU
- * M = 3 10^{-11} M $_{\odot}$ of carbon

* H=0.2 AU @ 1 AU sets outer disk radius

10

20

30

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40

 B_{max}/λ [10⁻⁶ rad⁻¹]

60

50

70

Olofsson et al. in prep

T Tauri stars

Planet forming region

Planet forming region

Reconstructed images

 $V e^{i\phi} = T.F.{Object} (B/\lambda)$

Image reconstruction algorithm (e.g. MIRA)

Baseline [Mλ]