THE FINE STRUCTURE OF THE WEB OF INTERSTELLAR FILAMENTS IN THE GOULD BELT CLOUDS

ALEXANDER MEN’SHCHIKOV
Credits


- Thanks to all those involved in **Herschel**, who made it a great success.
Questions

- Are all interstellar clouds filamentary?
- Can filaments be considered as simple cylinders?
- Are dense large-scale filaments sub-structured?
- Do stars (prestellar cores) always form in filaments?
- What are the structural properties of filaments?
- Does appearance of filaments depend on distance?
- What can we learn from filamentary structures?
Multi-Scale, Multi-Wavelength Source Extraction Method


Decompose detection images in (many) spatial scales: \( I_{\lambda D} \rightarrow I_{\lambda Dj} \)

Clean single scales by removing noise and background: \( I_{\lambda Dj} \rightarrow I_{\lambda DjC} \)

Combine clean single-scale images over all wavelengths: \( I_{\lambda DjC} \rightarrow I_{DJC} \)

Detect & catalog sources in combined clean single-scale images: \( I_{DJC} \rightarrow C_D \)

Measure & catalog sources properties at all wavelengths: \( C_D, I_{\lambda O} \rightarrow C_{M,\lambda} \)

Visualize extracted sources: \( C_{M,\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i} \)

Successive unsharp masking:
\[
I_{\lambda j} = G_{j-1} * I_{\lambda} - G_{j} * I_{\lambda} \quad (j = 1, 2, \ldots, N_S);
\]
originals recoverable by \( I_{\lambda} = \text{sum} \{ I_{\lambda j} \} \)

For getsources applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Alexander Men’shchikov - ESA-ESTEC, November 2014 - Page 5
Multi-Scale, Multi-Wavelength Source Extraction Method


Decompose detection images in (many) spatial scales: \( I_{\lambda D} \rightarrow I_{\lambda D_j} \)

Clean single scales by removing noise and background: \( I_{\lambda D_j} \rightarrow I_{\lambda D_j C} \)

Combine clean single-scale images over all wavelengths: \( I_{\lambda D_j C} \rightarrow I_{D_j C} \)

Detect & catalog sources in combined clean single-scale images: \( I_{D_j C} \rightarrow C_D \)

Measure & catalog sources properties at all wavelengths: \( C_D, I_{\lambda O} \rightarrow C_{M\lambda} \)

Visualize extracted sources: \( C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i} \)

For *getsources* applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Alexander Men’shchikov - ESA-ESTEC, November 2014 - Page 6
Multi-Scale, Multi-Wavelength Source Extraction Method


- Decompose detection images in (many) spatial scales: \( I_{\lambda D} \to I_{\lambda Dj} \)
- Clean single scales by removing noise and background: \( I_{\lambda Dj} \to I_{\lambda DjC} \)
- Combine clean single-scale images over all wavelengths: \( I_{\lambda DjC} \to I_{DjC} \)
- Detect & catalog sources in combined clean single-scale images: \( I_{DjC} \to C_D \)
- Measure & catalog sources properties at all wavelengths: \( C_D, I_{\lambda O} \to C_{M\lambda} \)
- Visualize extracted sources: \( C_{M\lambda}, I_{\lambda O} \to I_{\lambda E}, I_{\lambda i} \)

For *getsources* applications, see talks by Ph. Andre and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Alexander Men’shchikov - ESA-ESTEC, November 2014 - Page 7
Multi-Scale, Multi-Wavelength Source Extraction Method


Decompose detection images in (many) spatial scales: \( I_{\lambda D} \rightarrow I_{\lambda Dj} \)

Clean single scales by removing noise and background: \( I_{\lambda Dj} \rightarrow I_{\lambda DjC} \)

Combine clean single-scale images over all wavelengths: \( I_{\lambda DjC} \rightarrow I_{DjC} \)

Detect & catalog sources in combined clean single-scale images: \( I_{DjC} \rightarrow C_D \)

Measure & catalog sources properties at all wavelengths: \( C_D, I_{\lambda O} \rightarrow C_{M \lambda} \)

Visualize extracted sources: \( C_{M \lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i} \)

For *getsources* applications, see talks by Ph. Andre and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Alexander Men’shchikov - ESA-ESTEC, November 2014 - Page 8
Multi-Scale, Multi-Wavelength Source Extraction Method


- Decompose detection images in (many) spatial scales: \( I_{\lambda D} \rightarrow I_{\lambda Dj} \)
- Clean single scales by removing noise and background: \( I_{\lambda Dj} \rightarrow I_{\lambda DjC} \)
- Combine clean single-scale images over all wavelengths: \( I_{\lambda DjC} \rightarrow I_{DjC} \)
- Detect & catalog sources in combined clean single-scale images: \( I_{DjC} \rightarrow C_D \)
- Measure & catalog sources properties at all wavelengths: \( C_D, I_{\lambda O} \rightarrow C_{M\lambda} \)
- Visualize extracted sources: \( C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda I} \)

For *getsources* applications, see talks by Ph. Andre and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Alexander Men’shchikov - ESA-ESTEC, November 2014 - Page 9
Multi-Scale, Multi-Wavelength Source Extraction Method


- Decompose detection images in (many) spatial scales: \( I_{\lambda D} \rightarrow I_{\lambda Dj} \)
- Clean single scales by removing noise and background: \( I_{\lambda Dj} \rightarrow I_{\lambda DjC} \)
- Combine clean single-scale images over all wavelengths: \( I_{\lambda DjC} \rightarrow I_{DjC} \)
- Detect & catalog sources in combined clean single-scale images: \( I_{DjC} \rightarrow C_D \)
- Measure & catalog sources properties at all wavelengths: \( C_D, I_{\lambda O} \rightarrow C_{M \lambda} \)
- Visualize extracted sources:
  \[ C_{M \lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda I} \]

For \textit{getsources} applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

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Multi-Scale, Multi-Wavelength Source Extraction Method

getsources (Men'shchikov + 2012, A&A 542, A81)

Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda Dj}$

Clean single scales by removing noise and background: $I_{\lambda Dj} \rightarrow I_{\lambda D JC}$

Combine clean single-scale images over all wavelengths: $I_{\lambda D JC} \rightarrow I_{D JC}$

Detect & catalog sources in combined clean single-scale images: $I_{D JC} \rightarrow C_D$

Measure & catalog sources properties at all wavelengths: $C_D, I_{\lambda O} \rightarrow C_{M \lambda}$

Visualize extracted sources: $C_{M \lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i}$

For getsources applications, see talks by Ph. Andre and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Alexander Men’shchikov - ESA-ESTEC, November 2014 - Page 11
Multi-Scale, Multi-Wavelength Source Extraction Method

\textit{getsources (Men'shchikov + 2012, A&A 542, A81)}

1. Decompose detection images in (many) spatial scales: \( I_{\lambda D} \rightarrow I_{\lambda Dj} \)
2. Clean single scales by removing noise and background: \( I_{\lambda Dj} \rightarrow I_{\lambda DjC} \)
3. Combine clean single-scale images over all wavelengths: \( I_{\lambda DjC} \rightarrow I_{DjC} \)
4. Detect & catalog sources in combined clean single-scale images: \( I_{DjC} \rightarrow C_D \)
5. Measure & catalog sources properties at all wavelengths: \( C_D, I_{\lambda O} \rightarrow C_{M\lambda} \)
6. Visualize extracted sources: \( C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i} \)

Successive unsharp masking:
\( I_{\lambda j} = G_{\lambda j}^{-1} I_{\lambda} - G_{\lambda j}^{-1} I_{\lambda}^2 \) (\( j = 1, 2, \ldots, N_S \));
norials recoverable by \( I_{\lambda} = \text{sum} \{ I_{\lambda j} \} \)

Find cleaning thresholds (3-6) \( \sigma_{\lambda j} \) outside of sources and filaments and set all fainter pixels to zero.

For \textit{getsources} applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

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Multi-Scale, Multi-Wavelength Source Extraction Method

getsources (Men'shchikov + 2012, A&A 542, A81)

Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda Dj}$

Clean single scales by removing noise and background: $I_{\lambda Dj} \rightarrow I_{\lambda DJC}$

Combine clean single-scale images over all wavelengths: $I_{\lambda DJC} \rightarrow I_{DJC}$

Detect & catalog sources in combined clean single-scale images: $I_{DJC} \rightarrow C_D$

Measure & catalog sources properties at all wavelengths: $C_D, I_{\lambda O} \rightarrow C_{M \lambda}$

Visualize extracted sources: $C_{M \lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i}$

For getsources applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Multi-Scale, Multi-Wavelength Source Extraction Method

**getsources** (Men’shchikov + 2012, A&A 542, A81)

- Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda Dj}$
- Clean single scales by removing noise and background: $I_{\lambda Dj} \rightarrow I_{\lambda DjC}$
- Combine clean single-scale images over all wavelengths: $I_{\lambda DjC} \rightarrow I_{DjC}$
- Detect & catalog sources in combined clean single-scale images: $I_{DjC} \rightarrow C_D$
- Measure & catalog sources properties at all wavelengths: $C_D, I_{\lambda O} \rightarrow C_{M\lambda}$
- Visualize extracted sources: $C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i}$

For **getsources** applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Multi-Scale, Multi-Wavelength Source Extraction Method

\textit{getsources} (Mens’chikov + 2012, A&A 542, A81)

Decompose detection images in (many) spatial scales: \( I_{\lambda D} \rightarrow I_{\lambda DJ} \)

Clean single scales by removing noise and background: \( I_{\lambda DJ} \rightarrow I_{\lambda DJC} \)

Combine clean single-scale images over all wavelengths: \( I_{\lambda DJC} \rightarrow I_{DJC} \)

Detect & catalog sources in combined clean single-scale images: \( I_{DJC} \rightarrow C_D \)

Measure & catalog sources properties at all wavelengths: \( C_D, I_{\lambda O} \rightarrow C_{M\lambda} \)

Visualize extracted sources: \( C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda I} \)

For \textit{getsources} applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

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Multi-Scale, Multi-Wavelength Source Extraction Method


Decompose detection images in (many) spatial scales: \( I_{\lambda D} \to I_{\lambda Dj} \)

Clean single scales by removing noise and background: \( I_{\lambda Dj} \to I_{\lambda DjC} \)

Combine clean single-scale images over all wavelengths: \( I_{\lambda DjC} \to I_{\lambda DjC} \)

Detect & catalog sources in combined clean single-scale images: \( I_{\lambda DjC} \to C_{Dj} \)

Measure & catalog sources properties at all wavelengths: \( C_D, I_{\lambda O} \to C_{M\lambda} \)

Visualize extracted sources: \( C_{M\lambda}, I_{\lambda O} \to I_{\lambda E}, I_{\lambda i} \)

For getsources applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

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Multi-Scale, Multi-Wavelength Source Extraction Method


Decompose detection images in (many) spatial scales: $I_{\lambda,D} \rightarrow I_{\lambda,D_j}$

Clean single scales by removing noise and background: $I_{\lambda,D_j} \rightarrow I_{\lambda,D_jC}$

Combine clean single-scale images over all wavelengths: $I_{\lambda,D_jC} \rightarrow I_{D,jC}$

Detect & catalog sources in combined clean single-scale images: $I_{D,jC} \rightarrow C_D$

Measure & catalog sources properties at all wavelengths: $C_D, I_{\lambda,O} \rightarrow C_{M,\lambda}$

Visualize extracted sources: $C_{M,\lambda}, I_{\lambda,O} \rightarrow I_{\lambda,E}, I_{\lambda,i}$

146'' scale

For getsources applications, see talks by Ph. Andre and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Multi-Scale, Multi-Wavelength Source Extraction Method

**getsources** (Men’shchikov + 2012, A&A 542, A81)

- Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda D_j}$
- Clean single scales by removing noise and background: $I_{\lambda D_j} \rightarrow I_{\lambda D_jC}$
- Combine clean single-scale images over all wavelengths: $I_{\lambda D_jC} \rightarrow I_{D_jC}$
- Detect & catalog sources in combined clean single-scale images: $I_{D_jC} \rightarrow C_D$
- Measure & catalog sources properties at all wavelengths: $C_D, I_{\lambda O} \rightarrow C_{M\lambda}$
- Visualize extracted sources: $C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda I}$

For **getsources** applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07)

Multi-Scale, Multi-Wavelength Source Extraction Method

**getsources** (Men'shchikov + 2012, A&A 542, A81)

1. Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda DJ}$
2. Clean single scales by removing noise and background: $I_{\lambda DJ} \rightarrow I_{\lambda DJC}$
3. Combine clean single-scale images over all wavelengths: $I_{\lambda DJC} \rightarrow I_{DJC}$
4. Detect & catalog sources in combined clean single-scale images: $I_{DJC} \rightarrow C_D$
5. Measure & catalog sources properties at all wavelengths: $C_D, I_{\lambda O} \rightarrow C_{M\lambda}$
6. Visualize extracted sources: $C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i}$

Successive unsharp masking:

\[ I_{\lambda j} = \frac{G_{\lambda j} - I_{\lambda j}}{G_{\lambda j} + I_{\lambda j}} \quad (j = 1, 2, ..., N\lambda) \]

Originals recoverable by $I_{\lambda} = \text{sum} \{ I_{\lambda j} \}$

Find cleaning thresholds (3-6) $\sigma_{\lambda j}$ outside of sources and filaments and set all fainter pixels to zero.

Create wavelength-independent set of clean single-scale detection images.

For **getsources** applications, see talks by Ph. André and V. Konyves, and posters by K. Marsh (1.12) and A. Marston (2.07).

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Multi-Scale, Multi-Wavelength Source Extraction Method


Decompose detection images in (many) spatial scales:
\[ I_{\lambda D} \rightarrow I_{\lambda Dj} \]

Clean single scales by removing noise and background:
\[ I_{\lambda Dj} \rightarrow I_{\lambda DjC} \]

Combine clean single-scale images over all wavelengths:
\[ I_{\lambda DjC} \rightarrow I_{DjC} \]

Detect & catalog sources in combined clean single-scale images:
\[ I_{DjC} \rightarrow C_D \]

Measure & catalog sources properties at all wavelengths:
\[ C_D, I_{\lambda O} \rightarrow C_{M\lambda} \]

Visualize extracted sources:
\[ C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i} \]

Successive unsharp masking:
\[ I_{\lambda j} = G_{j, -1} * I_{\lambda} - G_{j} * I_{\lambda} \quad (j = 1, 2, ..., N_S) \]

Find cleaning thresholds (3-6) \( \sigma_I \)
outside of sources and filaments and set all fainter pixels to zero.

Create wavelength-independent set of clean single-scale detection images.

The method detects sources in filament-subtracted single-scale images and it measures sources in the observed (but also) filament-subtracted image.

For getsources applications, see talks by Ph. André and V. Kőnyves, and posters by K. Marsh (1.12) and A. Marston (2.07).

Multi-Scale Filament Extraction Method

**getfilaments** (Men'shchikov 2013, A&A 560, A63)

- Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda Dj}$
- Clean single scales of sources, noise, and background: $I_{\lambda Dj} \rightarrow I_{\lambda DjC}$
- Measure & catalog properties of filaments at all waves: $C_D, I_{\lambda O} \rightarrow C_{M\lambda}$
- Visualize extracted filaments: $C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i}$

Successive unsharp masking:

$$I_{\lambda j} = G_{j-1} * I_{\lambda} - G_{1} * I_{\lambda} \ (j = 1, 2, \ldots, N)$$

Originals recoverable by $I_{\lambda} = \text{sum} \{ I_{\lambda j} \}$

For **getfilaments** applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

Alexander Men'shchikov - ESA-ESTEC, November 2014 - Page 21
Multi-Scale Filament Extraction Method

getfilaments (Men'shchikov 2013, A&A 560, A63)

Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda Dj}$

Clean single scales of sources, noise, and background: $I_{\lambda Dj} \rightarrow I_{\lambda DjC}$

Measure & catalog properties of filaments at all waves: $C_D, I_{\lambda D} \rightarrow C_{M \lambda}$

Visualize extracted filaments: $C_{M \lambda}, I_{\lambda D} \rightarrow I_{\lambda E}, I_{\lambda i}$

For getfilaments applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

Alexander Men’shchikov - ESA ESTEC, November 2014 - Page 22
Multi-Scale Filament Extraction Method

**getfilaments** (Men’shchikov 2018, A&A 560, A63)

Decompose detection images in (many) spatial scales: \( I_{\lambda D} \rightarrow I_{\lambda Dj} \)

Clean single scales of sources, noise, and background: \( I_{\lambda Dj} \rightarrow I_{\lambda DjC} \)

Measure & catalog properties of filaments at all waves: \( C_D, I_{\lambda O} \rightarrow C_{M\lambda} \)

Visualize extracted filaments: \( C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i} \)

For **getfilaments** applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

Multi-Scale Filament Extraction Method

getfilaments (Men'shchikov 2013, A&A 560, A63)

1. Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda Dj}$

2. Clean single scales of sources, noise, and background: $I_{\lambda Dj} \rightarrow I_{\lambda DjC}$

3. Measure & catalog properties of filaments at all waves: $C_D, I_{\lambda O} \rightarrow C_{M\lambda}$

4. Visualize extracted filaments: $C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i}$

Successive unsharp masking:
$I_{\lambda j} = G_{j-1} * I_{\lambda} - G_{j} * I_{\lambda} \ (j = 1, 2, ..., N_s)$
originals recoverable by $I_{\lambda} = \text{sum} \{ I_{\lambda j} \}$

Find 10 $\lambda_j$ cleaning thresholds and remove clusters of pixels that are insignificantly elongated – those whose area $A < \sim 20 \times \pi \times \text{(scale size)}^2$.

For getfilaments applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

Alexander Men'shchikov - ESA-ESTEC, November 2014 - Page 24
Multi-Scale Filament Extraction Method

getfilaments (Men'shchikov 2013, A&A 560, A63)

- Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda D j}$
- Clean single scales of sources, noise, and background: $I_{\lambda D j} \rightarrow I_{\lambda D jC}$
- Measure & catalog properties of filaments at all waves: $C_D , I_{\lambda O} \rightarrow C_{M \lambda}$
- Visualize extracted filaments: $C_{M \lambda} , I_{\lambda O} \rightarrow I_{\lambda E} , I_{\lambda i}$

For getfilaments applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

Multi-Scale Filament Extraction Method

*getfilaments* (Men'shchikov 2013, A&A 560, A63)

- Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda D j}$
- Clean single scales of sources, noise, and background: $I_{\lambda D j} \rightarrow I_{\lambda D/jC}$
- Measure & catalog properties of filaments at all waves: $C_D, I_{\lambda, o} \rightarrow C_{M, \lambda}$
- Visualize extracted filaments: $C_{M, \lambda}, I_{\lambda, o} \rightarrow I_{\lambda, E}, I_{\lambda, i}$

For *getfilaments* applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

Alexander Men'shchikov - ESA-ESTEC, November 2014 - Page 26
Multi-Scale Filament Extraction Method

**getfilaments** (Men'shchikov 2013, A&A 560, A63)

- Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda Dj}$
- Clean single scales of sources, noise, and background: $I_{\lambda Dj} \rightarrow I_{\lambda DjC}$
- Measure & catalog properties of filaments at all waves: $C_D, I_{\lambda O} \rightarrow C_{M \lambda}$
- Visualize extracted filaments: $C_{M \lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i}$

For **getfilaments** applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

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Multi-Scale Filament Extraction Method

\textit{getfilaments} (Men’shchikov 2013, A&A 560, A63)

- Decompose detection images in (many) spatial scales: $I_{\lambda \text{D}} \rightarrow I_{\lambda \text{Dj}}$
- Clean single scales of sources, noise, and background: $I_{\lambda \text{Dj}} \rightarrow I_{\lambda \text{DjC}}$
- Measure & catalog properties of filaments at all waves: $C_{\text{D}}, I_{\lambda \text{O}} \rightarrow C_{\text{M} \lambda}$
- Visualize extracted filaments: $C_{\text{M} \lambda}, I_{\lambda \text{O}} \rightarrow I_{\lambda \text{E}}, I_{\lambda i}$

For \textit{getfilaments} applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingram (1.17)

Alexander Men’shchikov - ESA-ESTEC, November 2014 - Page 28
Multi-Scale Filament Extraction Method

getfilaments (Men'shchikov 2013, A&A 560, A63)

1. Decompose detection images in (many) spatial scales: $I_{\lambda D} \rightarrow I_{\lambda Dj}$
2. Clean single scales of sources, noise, and background: $I_{\lambda Dj} \rightarrow I_{\lambda DjC}$
3. Measure & catalog properties of filaments at all waves: $C_D, I_{\lambda O} \rightarrow C_{M\lambda}$
4. Visualize extracted filaments: $C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i}$

For getfilaments applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

Alexander Men'shchikov - ESA-ESTEC, November 2014 - Page 29
Multi-Scale Filament Extraction Method

getfilaments (Men'shchikov 2013, A&A 560, A63)

Decompose detection images in (many) spatial scales: \( I_{\lambda D} \rightarrow I_{\lambda Dj} \)

Clean single scales of sources, noise, and background: \( I_{\lambda Dj} \rightarrow I_{\lambda DjG} \)

Measure & catalog properties of filaments at all waves: \( C_D, I_{\lambda O} \rightarrow C_{M\lambda} \)

Visualize extracted filaments: \( C_{M\lambda}, I_{\lambda O} \rightarrow I_{\lambda E}, I_{\lambda i} \)

Successive unsharp masking:
\[ I_{\lambda j} = G_{j-1}^* I_{\lambda j} - G_{j}^* I_{\lambda j} \ (j = 1, 2, \ldots, N_J) \]
originals recoverable by \( I_{\lambda j} = \text{sum} \{ I_{\lambda j} \} \)

Find \( 10 \sigma_{I_j} \) cleaning thresholds and remove clusters of pixels that are insignificantly elongated – those whose area \( A < \sim 20 \times \pi \times (\text{scale size})^2 \).

Derive lengths, widths, curvatures, and profiles for skeletons in a range of spatial scales.

For getfilaments applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

Alexander Men'shchikov - ESA-ESTEC, November 2014 - Page 30
Multi-Scale Filament Extraction Method

*getfilaments* (Men'shchikov 2013, A&A 560, A63)

1. Decompose detection images in (many) spatial scales: \( I_{\lambda j} \rightarrow I_{\lambda j}^D \)
2. Clean single scales of sources, noise, and background: \( I_{\lambda j}^D \rightarrow I_{\lambda j}^D/C \)
3. Measure & catalog properties of filaments at all waves: \( C_D, I_{\lambda o} \rightarrow C_{M\lambda} \)
4. Visualize extracted filaments: \( C_{M\lambda}, I_{\lambda o} \rightarrow I_{\lambda e}, I_{\lambda i} \)

Successive unsharp masking:
\[ I_{\lambda j} = G_{j-1}^* I_{\lambda j} - G_j^* I_{\lambda j} \quad (j = 1, 2, ..., N_\lambda) \]
 originals recoverable by \( I_{\lambda} = \sum \{ I_{\lambda j} \} \)

Find \( 10 \sigma_{\lambda j} \) cleaning thresholds and remove clusters of pixels that are significantly elongated – those whose area \( A < 20 \times \pi \times (\text{scale size})^2 \).

Derive lengths, widths, curvatures, and profiles for skeletons in a range of spatial scales.

The method reconstructs *intrinsic* intensities of filaments: contributions of sources, noise, and background fluctuations are carefully removed from each spatial scale by the cleaning algorithm.

For *getfilaments* applications, see talk by V. Könyves and posters by K. Marsh (1.12) and A. Rivera-Ingraham (1.17)

Alexander Men'shchikov – ESA-ESTEC, November 2014 – Page 31
Filaments Extracted from MHD Simulations

Colliding flows of warm diffuse gas (Hennebelle + 2008)

Simulations from: http://starformat.obspm.fr/starformat/projects
Filaments Extracted from MHD Simulations
Colliding flows of warm diffuse gas (Hennebelle + 2008)

Simulations from: http://starformat.obspm.fr/starformat/projects

Column densities

simulation

scales < 20"
Filaments Extracted from MHD Simulations

Colliding flows of warm diffuse gas (Hennebelle + 2008)

Simulations from: http://starformat.obspm.fr/starformat/projects

Column densities

<Diagram>

Simulation

Skeletons
Filaments Extracted from MHD Simulations

Colliding flows of warm diffuse gas (Hennebelle + 2008)

Simulations from: http://starformat.obspm.fr/starformat/projects
Filaments in the *Horizon MareNostrum* Simulation

Formation of galaxies at high redshifts (Ocvirk + 2008, Devriendt + 2010)

Simulation from: [http://www.projet-horizon.fr](http://www.projet-horizon.fr)

Slice of gas densities

![Simulation](image1)

Simulation

![Filaments](image2)

Filaments
Filaments in the *Horizon MareNostrum* Simulation

Formation of galaxies at high redshifts (Ocvirk + 2008, Devriendt + 2010)

Simulation from: [http://www.projet-horizon.fr](http://www.projet-horizon.fr)

Slice of gas densities
Filaments in the *Horizon MareNostrum* Simulation

Formation of galaxies at high redshifts (Ocvirk + 2008, Devriendt + 2010)

Simulation from: [http://www.projet-horizon.fr](http://www.projet-horizon.fr)

Slice of gas densities
Filaments in the *Horizon MareNostrum* Simulation

Formation of galaxies at high redshifts (Ocvirk + 2008, Devriendt + 2010)

Simulation from: [http://www.projet-horizon.fr](http://www.projet-horizon.fr)

Slice of gas densities

$R < 2000$" $G < 160$" $B < 10$"

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Taurus  SPIRE 250 μm  5.8 × 2.6° = 13 × 6.5 pc  D = 140 pc

See also: P. Palmeirim (2013), J. Kirk (2103), K. Marsh (2014; also poster 1.12)
Taurus  SPIRE 250 μm  5.8 × 2.6° = 13 × 6.5 pc  D = 140 pc

See also: P. Palmeirim + (2013), J. Kirk + (2103), K. Marsh + (2014; also poster 1.12)
Taurus
SPIRE 250 μm 5.3° × 2.6° = 13 × 6.5 pc D = 140 pc

See also: P. Palmeirim + (2013), J. Kirk + (2013), K. Marsh + (2014; also poster 1.12)
See also: P. Palmeirim et al. (2013), J. Kirk et al. (2013), K. Marsh et al. (2014; also poster 1.12)
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Taurus  SPIRE 250 μm  \(5.3 \times 2.6^\circ = 13 \times 6.5 \text{ pc} D = 140 \text{ pc}\)

See also: P. Palmeirim + (2013), J. Kirk + (2013), K. Marsh + (2014; also poster 1.12)
Taurus SPIRE 250 μm  \(5.8 \times 2.6^\circ = 13 \times 6.5 \text{ pc} \) \(D = 140 \text{ pc}\)

See also: P. Palmeirim + (2013), J. Kirk + (2103), K. Marsh + (2014; also poster 1.12)
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See also: P. Palmeirim + (2013), J. Kirk + (2103), K. Marsh + (2014; also poster 1.12)
Taurus SPIRE 250 μm \(5.8 \times 2.6° = 13 \times 6.5\) pc \(D = 140\) pc

Starless (prestellar) and protostellar cores

Skeletons for scales up to 72" = 0.05 pc

See also: P. Palmeirim + (2013), J. Kirk + (2103), K. Marsh + (2014; also poster 1.12)
Taurus  SPIRE 250 μm  0.25 × 0.12° = 13 × 6.5 pc  D ≈ 3000 pc

See also: P. Palmeirim + (2013), J. Kirk + (2013), K. Marsh + (2014; also poster 1.12)
Taurus  SPIRE 250 μm  0.25×0.12° = 13×6.5 pc  D > 3000 pc

See also: P. Palmeirim + (2013), J. Kirk + (2013), K. Marsh + (2014; also poster 1.12)
Taurus  SPIRE 250 μm  0.25°×0.12° = 13×6.5 pc  D > 3000 pc

See also: P. Palmeirim + (2013), J. Kirk + (2103), K. Marsh + (2014; also poster 1.12)
Taurus

SPIRE 250 μm 0.25 × 0.12° = 13 × 6.5 pc

See also: P. Palmeirim et al. (2013), J. Kirk et al. (2013), K. Marsh et al. (2014; also poster 1.12)
Taurus  SPIRE 250 μm  0.25 × 0.12° = 13 × 6.5 pc  $D > 3000$ pc

$R < 2300”  G < 290”  B < 72” = 1.1$ pc

See also: P. Palmeirim + (2013), J. Kirk + (2103), K. Marsh + (2014; also poster 1.12)
Taurus

SPIRE 250 μm  \(5.8 \times 2.6° = 13 \times 6.5 \text{ pc} \)  \(D = 140 \text{ pc}\)

Unaffected by sources, noise and background fluctuations

Skeletons by getfilaments for scales up to 72″ = 0.05 pc
Taurus

SPIRE 250 μm  5.8 × 2.6° = 13 × 6.5 pc  D = 140 pc

Detects linear structures, essentially straight lines

Unaffected by stars and background

Image from the talk of J. Peek at Filaments 2014 (Charlottesville): filaments traced by RHT (Rolling Hough Transform, S. Clark + 2014)
Affected by sources, noise and background fluctuations

Skeletons obtained by P. Palmeirim + (2013) using DisPerSE (T. Sousbie + 2011)
Taurus  SPIRE 250 μm  5.8×2.6° = 13×6.5 pc  D = 140 pc

Intensities reconstructed up to 145" scale = 0.1 pc

Velocity-coherent fibers from A. Hacar et al. (2013)
See also: Figure 2 from Ph. André et al. (Protostars & Planets VI, 2014)
Taurus
SPIRE 250 μm  5.3 × 2.6° = 13 × 6.5 pc  D = 140 pc

Velocity-coherent fibers from A. Hacar + (2013)
Polaris

SPIRE 250 µm

4.2 × 4.2° = 11 × 11 pc  D = 150 pc

See also: Ph. André et al. (2010), A. Men'shchikov et al. (2010), M.-A. Miville-Dechênes et al. (2010), Ward-Thompson et al. (2010)
Polaris

SPIRE 250 μm

4.2 × 4.2° = 11 × 11 pc

D = 150 pc

Polaris

SPIRE 250 μm

$4.2 \times 4.2^\circ = 11 \times 11$ pc

$D = 150$ pc

See also: Ph. André et al. (2010), A. Men'shchikov et al. (2010), M.-A. Miville-Dechênes et al. (2010), Ward-Thompson et al. (2010)
Polaris

SPIRE 250 μm

$4.2 \times 4.2^\circ = 11 \times 11 \text{ pc}$

$D = 150 \text{ pc}$

Polaris

SPIRE 250 μm

4.2° × 4.2° = 11 × 11 pc

D = 150 pc

Skeletons for scales up to 72" = 0.05 pc

Polaris
SPIRE 250 μm
0.21 × 0.21° = 11 × 11 pc
D > 3000 pc

See also: Ph. André + (2010), A. Men’shchikov + (2010),
Polaris

SPIRE 250 μm  0.21 × 0.21° = 11 × 11 pc  D ≈ 3000 pc

Polaris

SPIRE 250 μm  0.21 × 0.21° = 11 × 11 pc  D > 3000 pc

R < 2300”  G < 290”  B < 72” = 1.1 pc

See also: Ph. André + (2010), A. Men’shchikov + (2010),

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Aquila  SPIRE 250 μm  \(3.0 \times 2.1° = 14 \times 9.8\) pc  \(D = 260\) pc

See also: Ph. André (2010), A. Men'shchikov (2010), S. Bontemps (2010), V. Kónyves (2010; in prep.; also talk)
Aquila  SPIRE 250 μm  3.0×2.1° = 14×9.8 pc  D = 260 pc

See also: Ph. André (2010), A. Men’shchikov (2010), S. Bontemps (2010), V. Konyves (2010; in prep.; also talk)

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Aquila  SPIRE 250 μm  \(3.0 \times 2.1^\circ = 14 \times 9.8\) pc  \(D = 260\) pc

Starless (prestellar) and protostellar cores  \(R < 2300\)"  \(G < 290\)"  \(B < 72 = 0.09\) pc

See also: Ph. André (2010), A. Men'shchikov (2010), S. Bontemps (2010), V. Konyves (2010; in prep.; also talk)
Aquila

SPIRE 250 μm

3.0 × 2.1° = 14 × 9.8 pc

D = 260 pc

Starless (prestellar) and protostellar cores

Intensities reconstructed up to 72” scale = 0.09 pc

See also: Ph. André (2010), A. Men’shchikov (2010), S. Bontemps (2010), V. Kőnyves (2010; in prep.; also talk)
Aquila SPIRE 250 μm $3.0 \times 2.1^\circ = 14 \times 9.8$ pc $D = 260$ pc

Starless (prestellar) and protostellar cores - Skeletons for scales up to $72^\prime\prime = 0.09$ pc

See also: Ph. André ($2010$), A. Men'shchikov ($2010$), S. Bontemps ($2010$), V. Konyves ($2010$; in prep.; also talk)

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Aquila

SPIRE 250 μm

0.25 × 0.18° = 14 × 9.8 pc

D > 3000 pc
Aquila  SPIRE 250 μm  0.25×0.18° = 14×9.8 pc  D > 3000 pc
Aquila  SPIRE 250 μm  0.25 × 0.18° = 14 × 9.8 pc  D > 3000 pc

See also: Ph. André + (2010), A. Men'shchikov + (2010), S. Bontemps + (2010), V. Kőnyves + (2010; in prep.; also talk)

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Aquila  SPIRE 250 μm  0.25×0.18° = 14×9.8 pc  D > 3000 pc

R < 2300”  G < 290”  B < 72” = 1.1 pc

See also: Ph. André + (2010), A. Men’shchikov + (2010), S. Bontemps + (2010), V. Könyves + (2010; in prep.; also talk)

Orion B

SPIRE 250 μm
8.7 × 3.7° = 64 × 27 pc  D = 410 pc

See also: N. Schneider + (2018)
Orion B  SPIRE 250 µm  8.7 × 3.7° = 64 × 27 pc  D = 410 pc

See also: N. Schneider + (2018)
Orion B  SPIRE 250 μm  8.7×3.7° = 64×27 pc  D = 410 pc

See also: N. Schneider et al. (2018)
Orion B  SPIRE 250 µm  8.7×3.7° = 64×27 pc  D = 410 pc

See also: N. Schneider + (2018)
Orion B  SPIRE 250 µm  $8.7 \times 3.7^\circ = 64 \times 27$ pc  $D = 410$ pc

See also: N. Schneider + (2018)
Orion B  SPIRE 250 µm  8.7×3.7° = 64×27 pc  D = 410 pc

See also: N. Schneider + (2018)
Orion B
SPIRE 250 μm
$8.7 \times 3.7^\circ = 64 \times 27$ pc
$D = 410$ pc

See also: N. Schneider + (2018)
Orion B  SPIRE 250 µm  8.7×3.7° = 64×27 pc  D = 410 pc

See also: N. Schneider + (2018)
Orion B  SPIRE 250 μm  8.7×3.7° = 64×27 pc  D = 410 pc

R < 2300''  G < 290''  B < 72'' = 0.15 pc

See also: N. Schneider et al. (2018)
Orion B  SPIRE 250 µm  8.7×3.7° = 64×27 pc  D = 410 pc

Skeletons for scales up to 72” = 0.15 pc

See also: N. Schneider + (2018)
Orion B  SPHERE 250 µm  1.2×0.54° = 64×27 pc  D > 3000 pc

See also: N. Schneider + (2018)
Orion B  SPIRE 250 μm  \[1.2 \times 0.54° = 64 \times 27 \text{ pc}\] \[D \approx 3000 \text{ pc}\]

See also: N. Schneider + (2018)
Orion B  SPIRE 250 μm  1.2×0.54° = 64×27 pc  D > 3000 pc

See also: N. Schneider + (2013)
Orion B  SPIRE 250 µm  \(1.2 \times 0.54^\circ = 64 \times 27 \text{ pc}\)  \(D > 3000 \text{ pc}\)

See also: N. Schneider + (2018)
Orion B  SPIRE 250 μm  1.2×0.54° = 64×27 pc  D > 3000 pc

See also: N. Schneider + (2018)
Orion B  SPIRE 250 μm  1.2×0.54° = 64×27 pc  D > 3000 pc

R < 2300″  G < 290″  B < 72″ = 1.1 pc

See also: N. Schneider et al. (2018)
IC5146  SPIRE 250 μm  2.5x1.4° = 21x12 pc  D = 460 pc

See also: D. Arzoumanian + (2011)
IC5146  SPIRE 250 µm  2.5×1.4° = 21×12 pc  D = 460 pc

See also: D. Arzoumanian + (2011)
IC5146 SPIRE 250 µm \[2.5 \times 1.4^\circ = 21 \times 12 \text{ pc}\] \[D = 460 \text{ pc}\]

See also: D. Arzoumanian \* (2011)
IC5146  SPIRE 250 μm  2.5×1.4° = 21×12 pc  D = 460 pc

See also: D. Arzoumanian et al. (2011)
IC5146  SPIRE 250 µm  2.5×1.4° = 21×12 pc  D = 460 pc

See also: D. Arzoumanian + (2011)
IC5146  SPIRE 250 µm  2.5×1.4° = 21×12 pc  D = 460 pc

See also: D. Arzoumanian + (2011)

HERSCHEL
Gould Belt Survey

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IC 5146  SPIRE 250 µm  2.5 × 1.4° = 21 × 12 pc  D = 460 pc

R < 2300”  G < 290”  B < 72” = 0.17 pc

See also: D. Arzoumanian (2011)
IC 5146 SPIRE 250 μm $2.6 \times 1.4^\circ = 21 \times 12$ pc $D = 460$ pc

$R < 2300''$ $G < 290''$ $B < 72'' = 0.17$ pc

See also: D. Arzoumanian + (2011)
IC 5146  SPIRE 250 μm  0.36 × 0.20° = 21 × 12 pc  D ≈ 3000 pc

See also: D. Arzoumanian et al. (2011)
IC5146  SPIRE 250 μm  0.36×0.20° = 21×12 pc  D ≈ 3000 pc

See also: D. Arzoumanian (2011)
IC 5146
SPIRE 250 μm
0.36° × 0.20° = 21 × 12 pc
D > 3000 pc

See also: D. Arzoumanian (2011)
IC 5146 SPHERE 250 μm

\[0.36 \times 0.20° = 21 \times 12 \text{ pc}\]

\[D \approx 3000 \text{ pc}\]

See also: D. Arzoumanian + (2011)
IC5146  SPIRE 250 µm  0.36×0.20° = 21×12 pc  D > 3000 pc

See also: D. Arzoumanian (2011)
IC5146  SPIRE 250 μm  \(0.36 \times 0.20° = 21 \times 12\) pc  \(D \approx 3000\) pc

See also: D. Arzoumanian (2011)
IC5146  SPIRE 250 μm  \(0.36 \times 0.20° = 21 \times 12 \text{ pc}\)  \(D \gtrsim 3000 \text{ pc}\)

See also: D. Arzoumanian + (2011)
W48
SPIRE 250 μm \(2.3 \times 2.3° = 124 \times 124\) pc \(D = 8000\) pc

R < 2300” G < 290” B < 72” = \(1.1\) pc

0.25 \(\times\) 0.25° = 14 \(\times\) 14 pc

size \sim\) Gould Belt clouds

See also: Q. Nguyen Luong + (2011), K. Rygl + (2014)

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W 48 SPIRE 250 μm 2.3×2.3° = 124×124 pc D = 8000 pc

R < 2300” G < 290” B < 72” = 1.1 pc

× 0.25° = 14 x 14 pc
~ Gould Belt clouds

Aquila at 3000 pc

See also: Q. Nguyen Luong + (2011), K. Rygl + (2014)
W48
SPIRE 250 μm  2.3×2.3° = 124×124 pc  D = 8000 pc

R < 2300”  G < 290”  B < 72” = 1.1 pc

0.25 × 0.25° = 14 × 14 pc
size ~ Gould Belt clouds

See also: Q. Nguyen Luong et al. (2011), K. Rygl et al. (2014)
W 48  SPIRE 250 μm  2.3×2.3° = 124×124 pc  D = 8000 pc

W 48 at 3000 pc

R < 2300” G < 290” B < 72” = 1.1 pc
× 0.25° = 14×14 pc

IC 5146 at 3000 pc

See also: Q. Nguyen Luong et al. (2011), K. Rygl et al. (2014)
Conclusions

- Gould Belt: fascinating web of omnipresent filamentary structures
- Filaments on all spatial scales; resolved fine structures abundant
- Sources, filaments, and backgrounds are blended components
- Methods to extract (separate) components: getsources, getfilaments
- Fine filaments are very complicated in shapes, heavily overlapping
- Large varieties of ordered patterns: plenty of valuable information
- Dense small-scale sub-structures: relationship with forming stars
- Distant clouds: fine structures (fibers, striations) become diluted
- Distant clouds: only few densest power-law filaments observable
- Distant clouds: all likely to have fine filaments, currently unresolved
- We need kinematical information, magnetic field measurements