Second degree moments: a tool for fault plane detection

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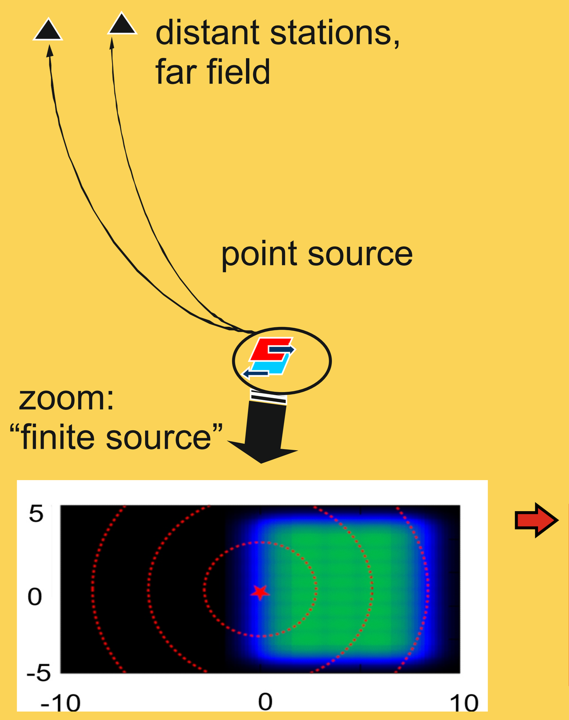
Introduction, motivation



"Finite source" parameters from point source approximation

- Detailed modeling of slip on the plane:
  - costly
  - often data not available (near the fault)
- 2nd degree moments are advantageous alternative

- geometry of the source
- duration of the source process
- spatial and temporal centroid
- rupture velocity vector

Theory

Representation theorem:

$$u_i(x,t) = \int_{-\infty}\int_V \partial\xi_k G^i_j(x,\xi,t-\tau) m_{jk}(\xi,\tau)\, dV d\tau$$

Zero degree moment tensor approximation $u_i(x,t) = G^i_{p,q}(\xi^0,x,t) * M_{pq}(t)$

FIRST and SECOND degree moments (Taylor expansion up to degree two)

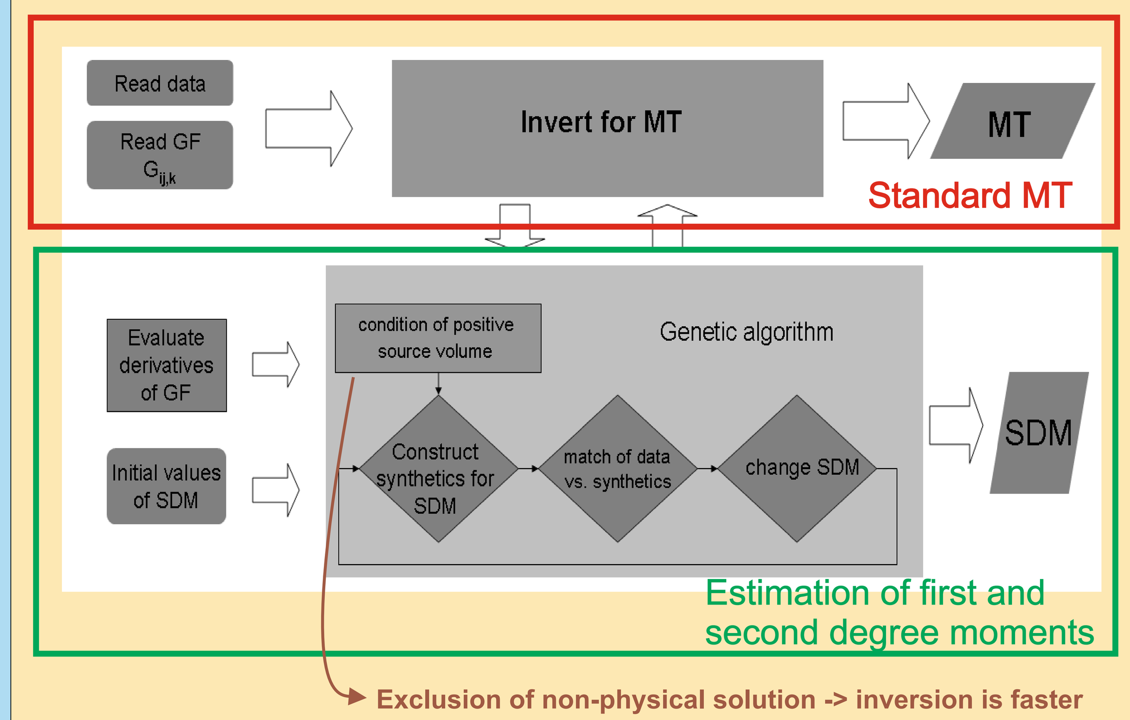
$$u_i(x,t) = G^i_{p,q}(\xi^0,x,t) * M_{pq}(t) + \dot{G}^i_{p,ql}(\xi^0,x,t) * M_{pq,l}(\xi^0,t) + \frac{1}{2}\ddot{G}^i_{p,qlm}(\xi^0,x,t) * M_{pq,lm}(\xi^0) + \ldots$$

Standard MT; Temporal centroid; Spatial centroid

$$u_i(x,t) = M_{jk}[G^i_{j,k} - \dot{G}^i_{j,k}\Delta\tau + G^i_{j,kl}\Delta\xi_l + \frac{1}{2}\ddot{G}^i_{j,k}\Delta(\tau^2) - \dot{G}^i_{j,kl}\Delta(\tau\xi_l) + \frac{1}{2}G^i_{j,klm}\Delta(\xi_l\xi_m) + \ldots]$$

Source process duration; Rupture propagation; Source ellipsoid

Inversion scheme



2 step inversion:

1. standard MT inversion
2. estimation of first and second degree moments using genetic algorithm with additional condition of positive source volume

Detection of the fault plane

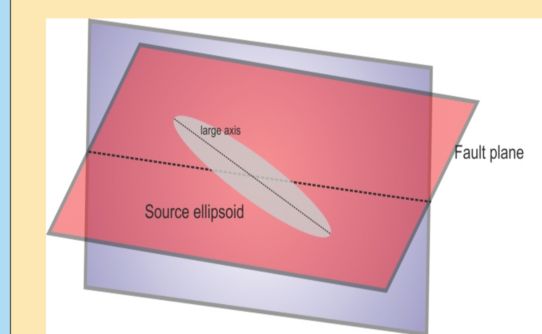
Moment tensor (DC part) ⟶ couple of planes (fault and auxiliary) ⟶ ambiguity

second degree moments ⟶ source ellipsoid (volume of the focus)

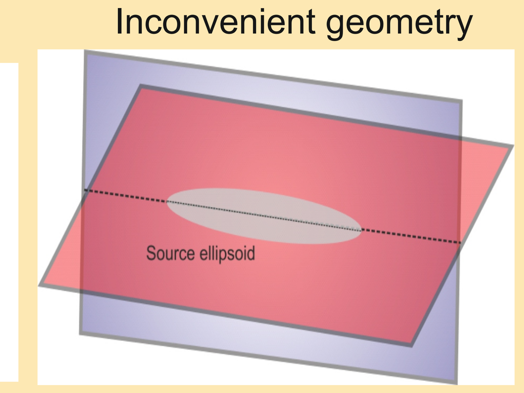
Removing ambiguity:

Plane containing the source ellipsoid (large axis) ⟶ fault plane

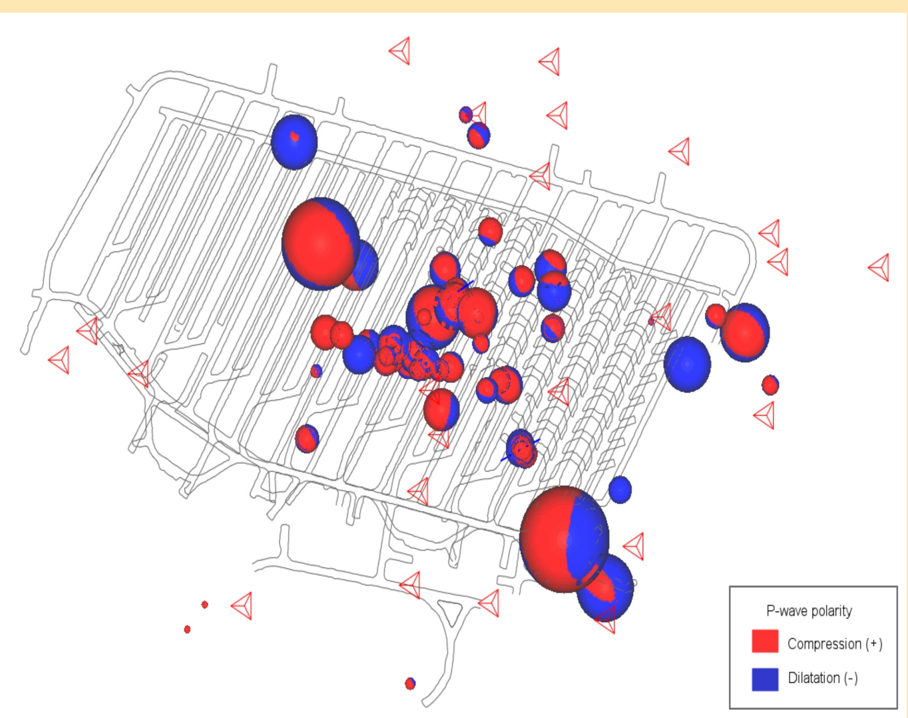
Convenient geometry



Inconvenient geometry



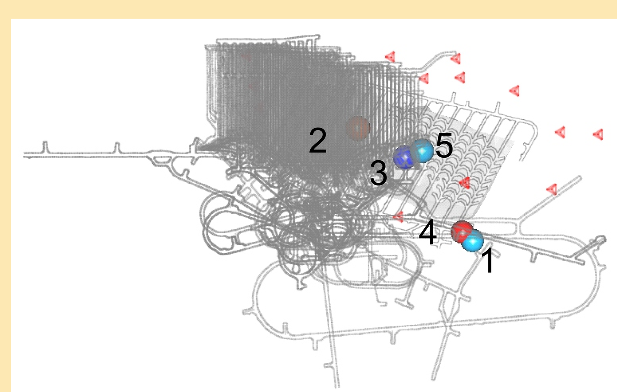
Ridgeway mine, Australia

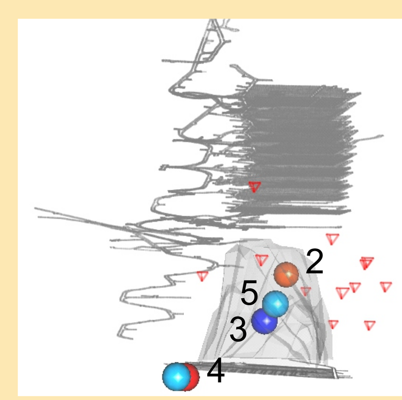


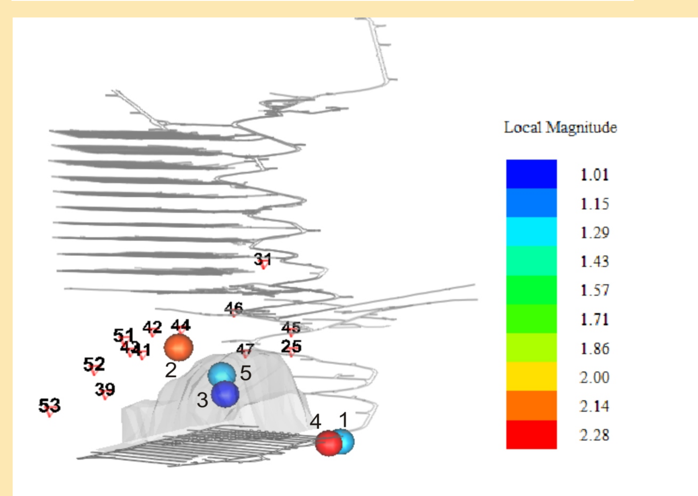
Seismicity in December 2009
(IMS South Africa, Stellenbosch)

Malovichko, D. [2010] Ridgeway. Routine estimation of the source mechanisms: December 2009.
ISSI Document Number: ISSREP_RWM_MECHANISMS200912.

Location of selected events



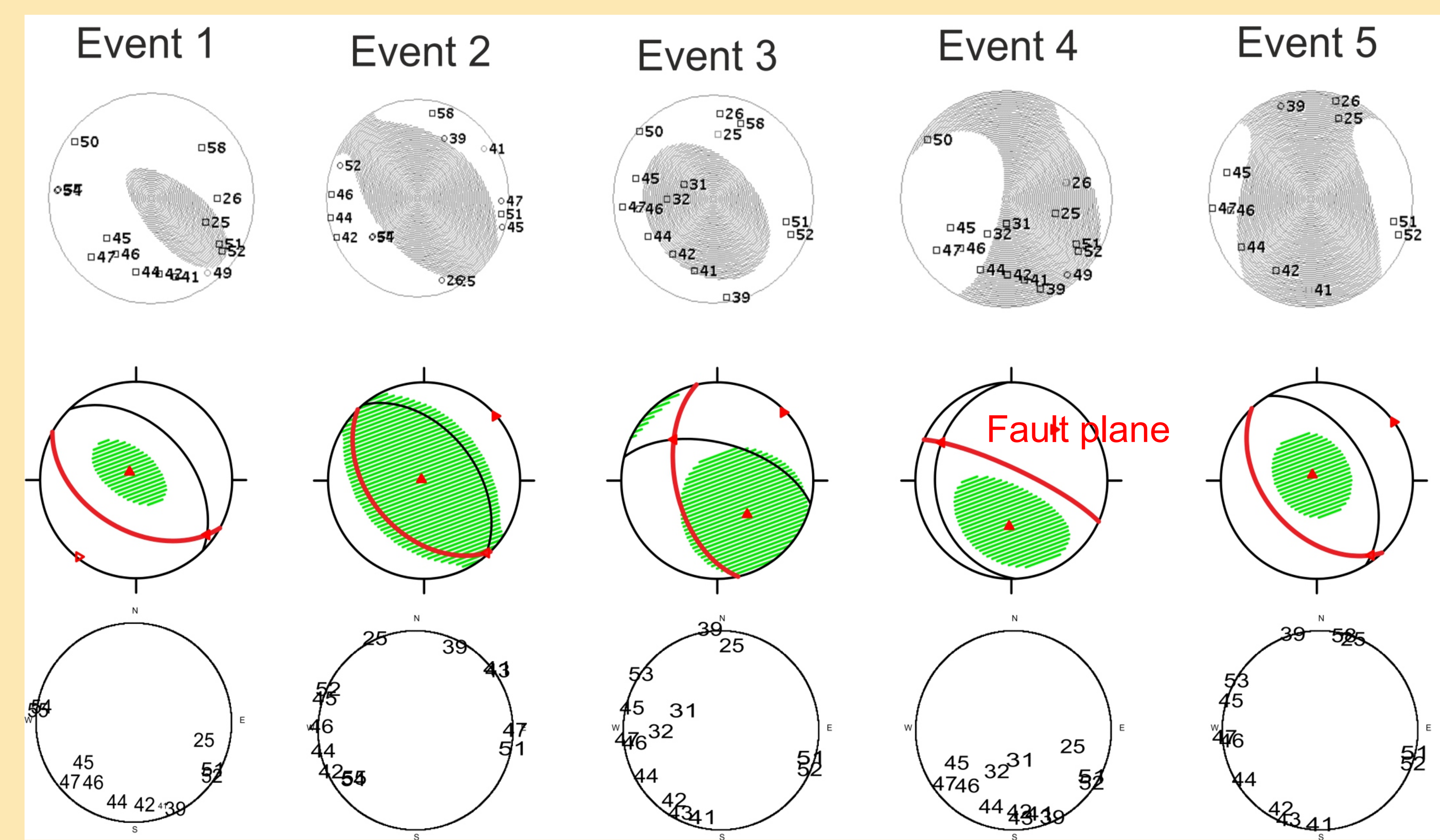




grey lines and areas - mine tunnels and mined out areas
colored sphere - selected events
triangles with numbers - stations used in the inversion

Top left - plan view
Top right - section view looking east
Bottom left - section view looking north

Standard MT for selected events



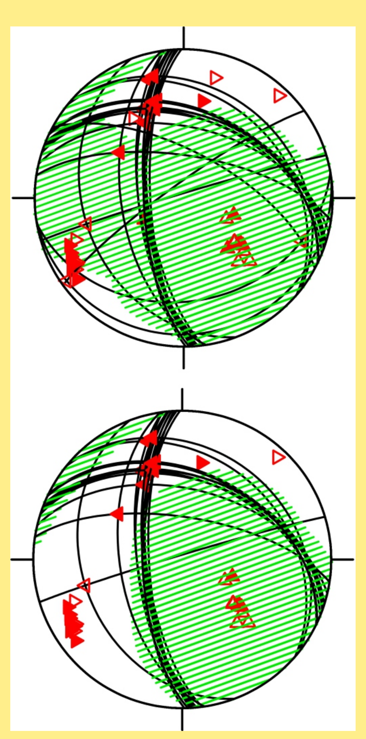
IMS solution from spectral amplitudes

Solutions from this study
red lines - fault planes

station coverage used in the inversion

Jack-knife test

Standard MT



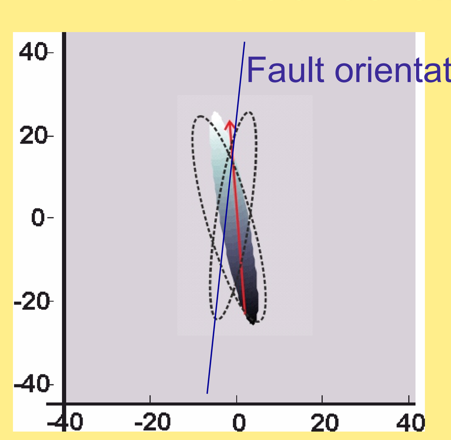
A: all jack-knife trials
B: all jack-knife trials except removing stations 25 and 39

First and second degree moments

- nearly the same values for all jack-knife trials
- source ellipsoid: the largest differences between jack-knife trials

Temporal centroid	0.01 sec
Source duration	0.1 sec
Rupture velocity	2.1 km/sec
Spatial centroid	1 m NS, 1 m EW, -10 m Z from the hypocenter

Source ellipsoid



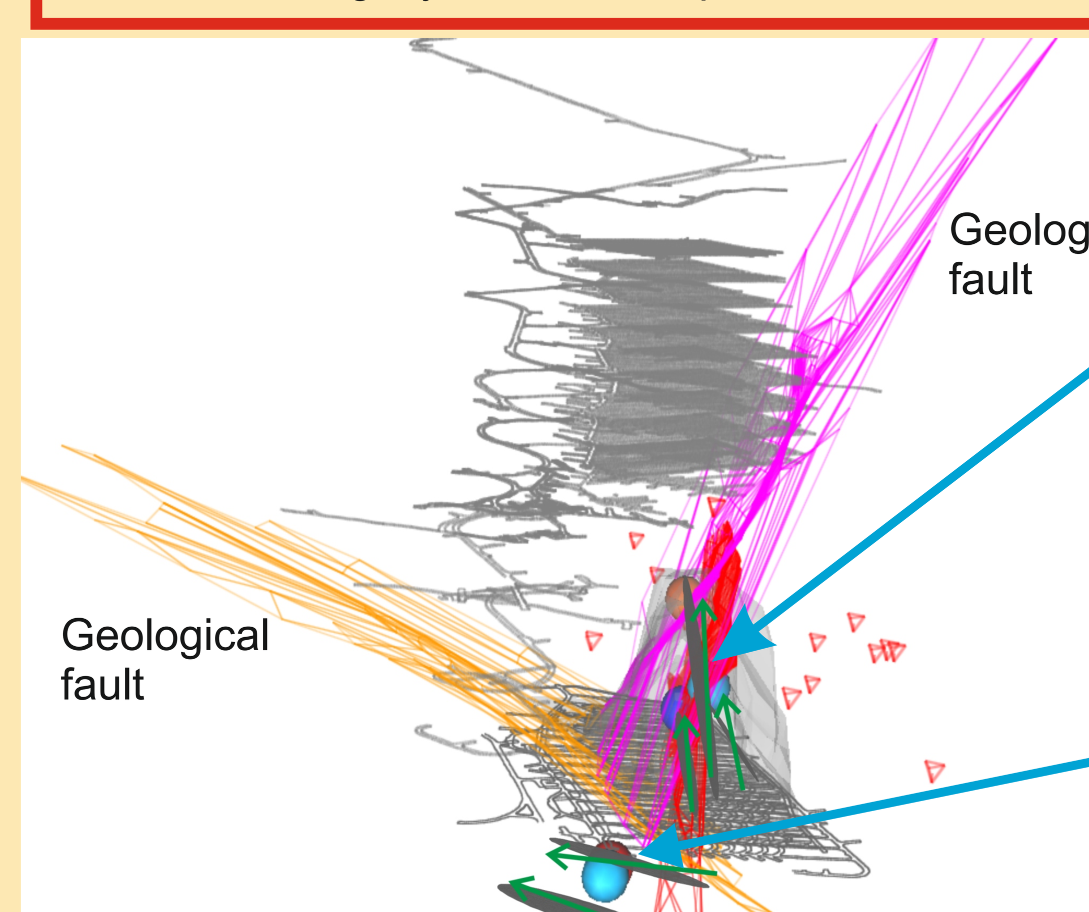
Gray ellipsoid: inversion from all stations

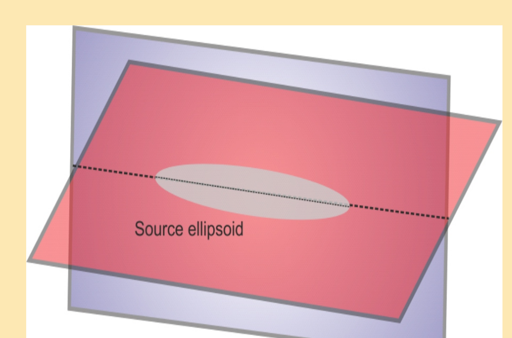
Dashed ellipsoids: jack-knife trials with extreme deviations

Source ellipsoids: correlation with geological faults

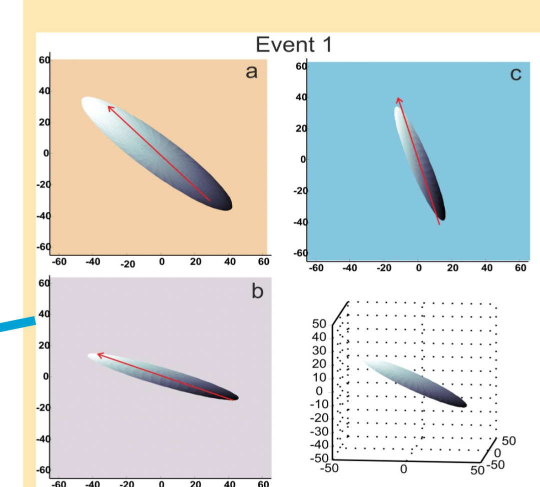
Estimation of the fault plane

- we have 2 planes from the MT solution
- from the orientation of the source ellipsoid we can remove ambiguity of the nodal planes

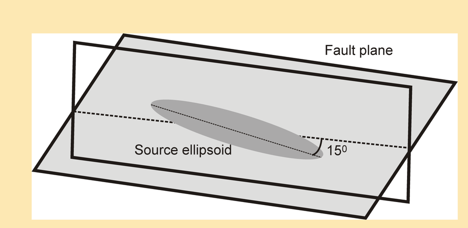




Inconvenient geometry for estimation of the fault plane: source ellipsoid and rupture velocity vector lie on the intersection of 2 nodal planes



Convenient geometry



Conclusions

- standard moment tensor: **dot**
  second degree moments: **beyond dot**
  - estimate of source shape, rupture propagation vector, ...
- second degree moments bring additional information to standard MT: *source ellipsoid, duration of the source process, average rupture velocity, ...*
- remove ambiguity of the two nodal planes