What multi-wave observations of microwave negative bursts tell us about solar eruptions?

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Abstract. Plasma with temperatures close to the chromospheric one ejected in solar eruptions can occult compact sources in active regions as well as quiet solar areas. Absorption phenomena can be observed in microwaves as 'negative bursts' and in different spectral domains. We present three events with negative bursts. Two of the related filament eruptions were 'anomalous', with disintegration of an eruptive filament and dispersal of its remnants as a cloud over a large part of the solar surface. Such phenomena are observed as giant depressions in the HeII 304 Å line. We estimate parameters of absorbing material of an eruption from multi-frequency records of negative bursts. The model estimates of the ejected masses are ~10^{15} g, comparable to masses of typical filaments and CMEs. A possible scenario of an anomalous eruption is presented.

Introduction. Depressions of the total microwave flux discovered by Covington and Dodson (1953) and called 'negative bursts' were interpreted by absorption in ejected filament material. Later studies (e.g., Tanaka and Kakinuma, 1960) led to a general scenario of occultation of a compact source by an eruptive filament or surge (Sawyer, 1977). Thus, negative bursts can carry information about solar eruptions, but they rarely occur: their total number reported during 1990–2010 within observational daytimes in Nobeyama and Ussuriysk was 22. Multi-frequency data from NoRP, Ussuriysk (2.8 GHz), and Learmonth along with NoRH 17 GHz and EUV images allowed us to study several events with negative bursts. Their analyses by using a simple model of the radio absorption spectrum led to the following conclusions (Grechnev et al., 2008, 2011). Important can be **occultation of both compact sources and** large **quiet Sun's areas**. **Negative bursts are best observed** at **1–5 GHz**, where the corona is optically thin and ejecta has sufficient contrast against the quiet Sun, but **sometimes absorption appears at 17 GHz**. A post-burst decrease can be observed if a preceding flare is short with no bursts afterwards. When negative bursts occur, large **darkenings** can appear **at 304 Å** mismatching CME-related dimming in coronal bands. **Two occultation scenarios** were revealed. The **shape** and **structure** of an eruptive **filament typically persist**. **Occasional eruptions develop anomalously**: the **filament essentially changes**, while a part of its material disperses over a large area and lands far from the eruption site. Anomalous eruptions were not well known previously: observations in the Hα line are limited by the Doppler shift, which rapidly removes absorbing features from the filter passband, while observations at 304 Å were infrequent in the past.

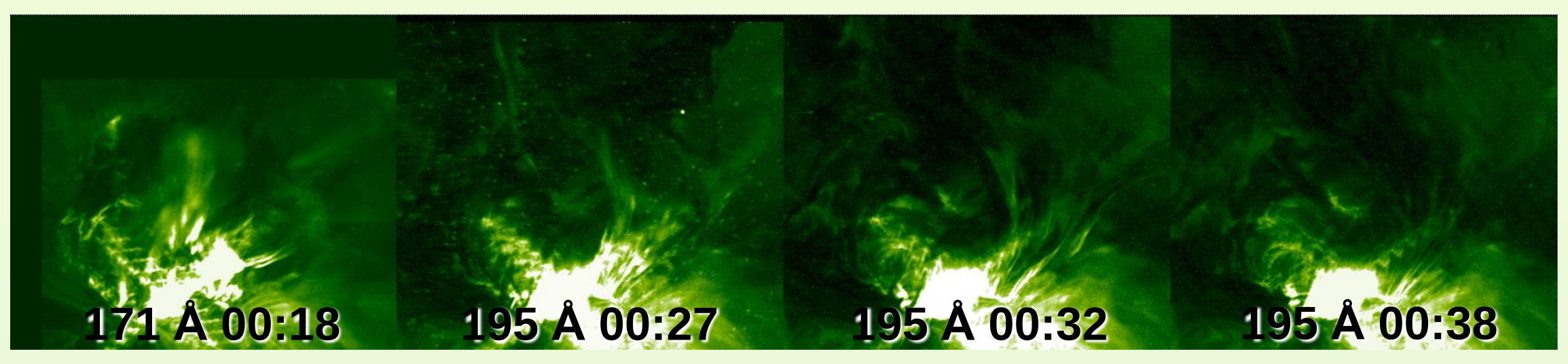

Fig. 1. Flare, bright jetlike eruption, and dark descending material of disintegrated filament (TRACE)

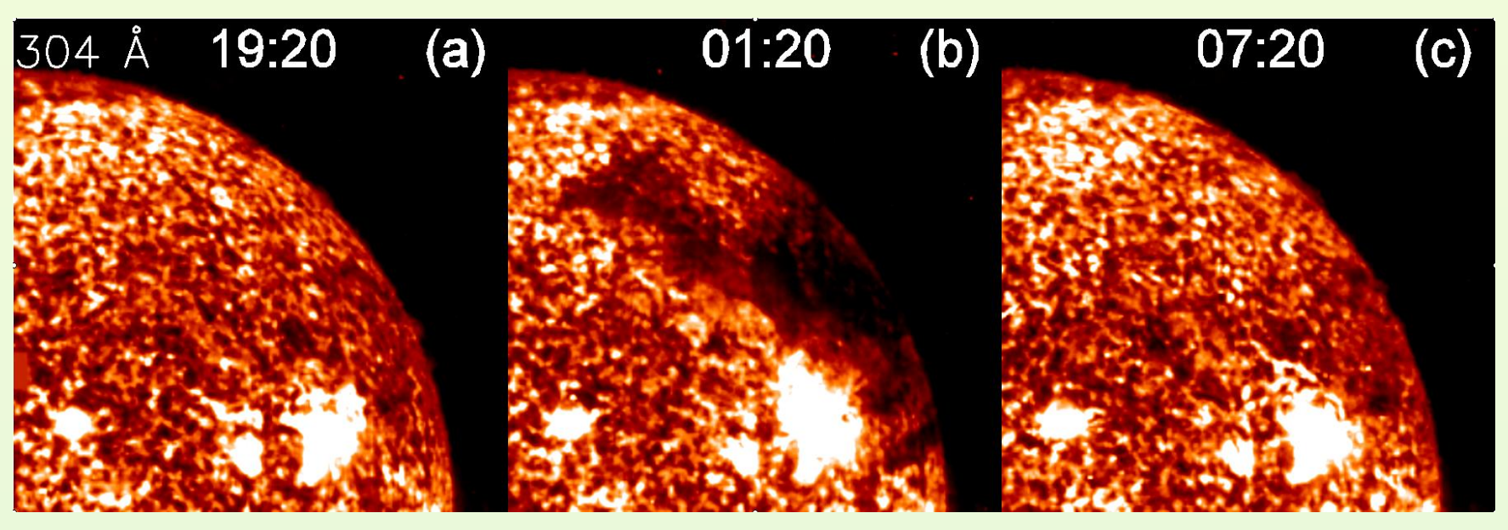

Fig. 2. EIT 304 Å images before (a), during (b) and after (c) the 2004-07-13 event

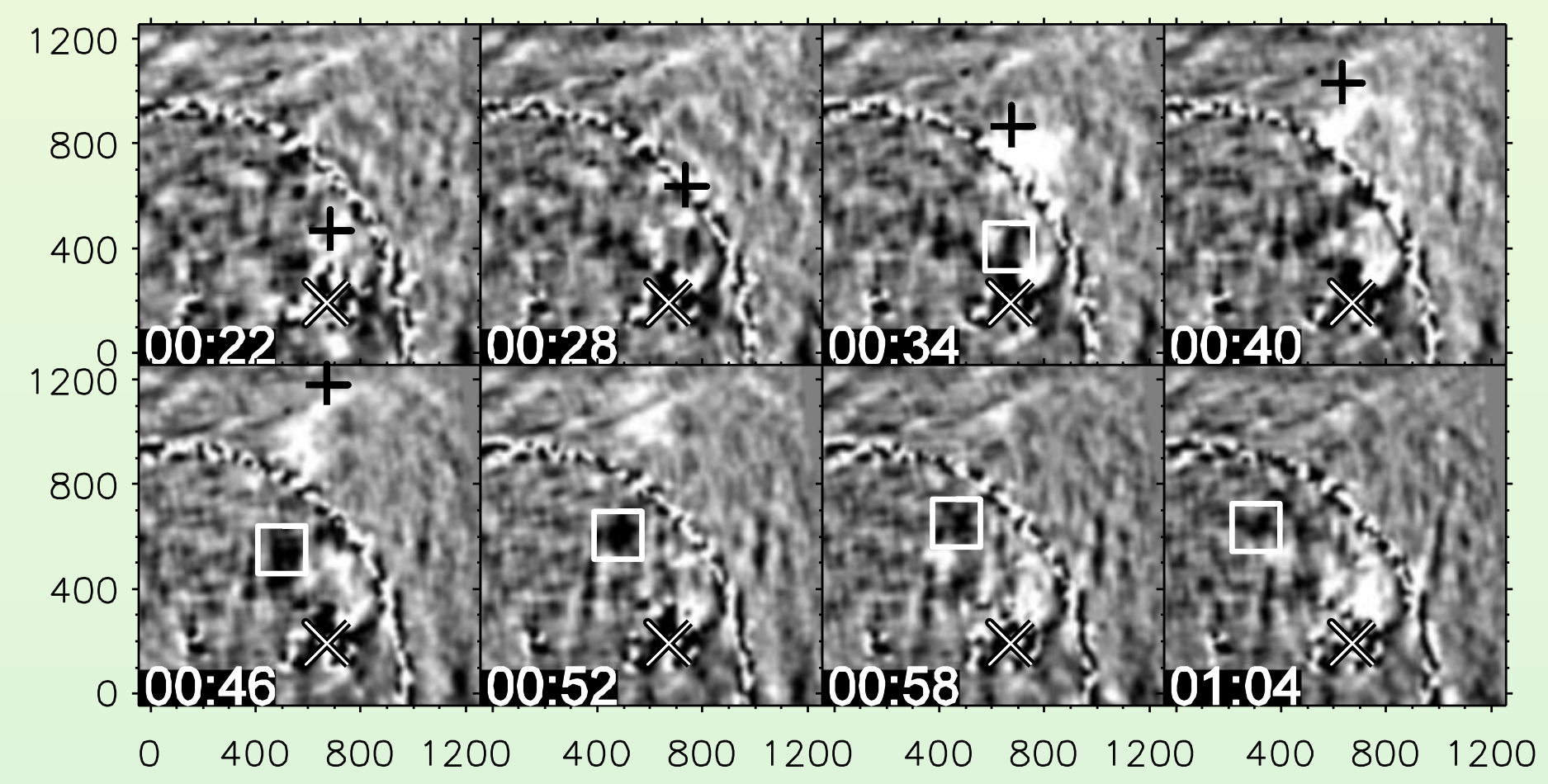

Fig. 3. Moving CME-related bright ejecta (+) and dark absorbing patch (☐) in NoRH 17 GHz difference images; (×) is the eruption center

The first well-studied **anomalous eruption** occurred on **2004-07-13** (Grechnev et al., 2008). The ejecta disintegrated into two parts, one of which flew away as a decelerating CME, and another part dispersed over a huge solar surface. The latter part absorbed background solar emission in various spectral ranges (Fig. 1-3). A simple model was developed to estimate parameters of ejecta. Input parameters of the model are depression depths of the total flux at different frequencies and non-occulted fluxes of sources actually measured from NoRH images. Parameters of absorbing material estimated from the radio spectrum (Fig. 4,5) are typical of filaments.

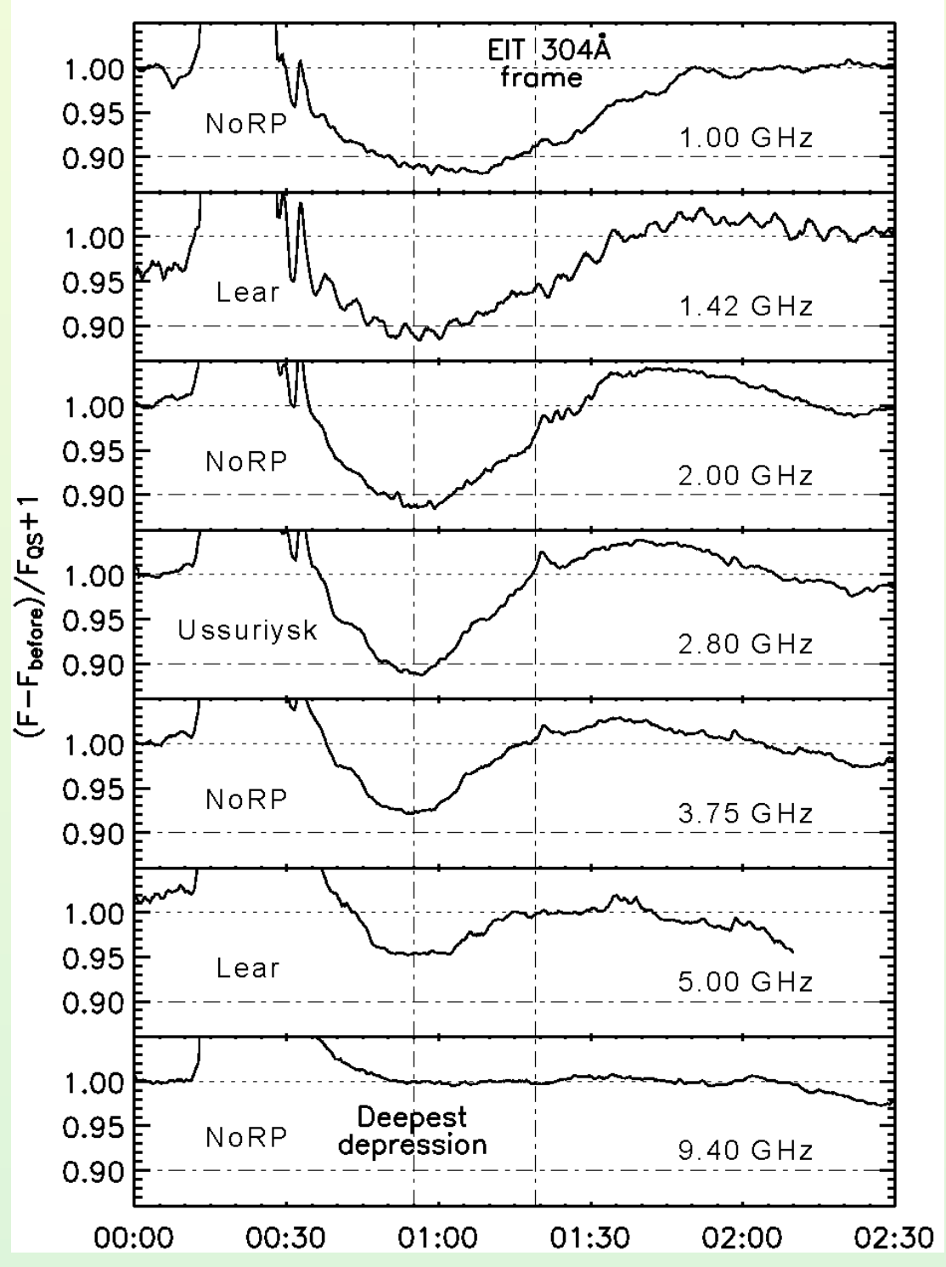

Fig. 4. Microwave total flux time profiles

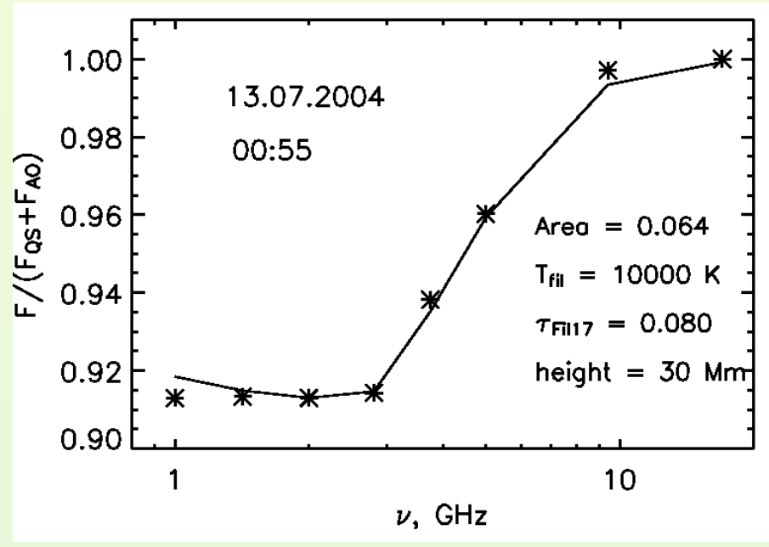

Fig. 5. The measured total flux depression depths (asterisks) and model calculation (line)

Geometrical depth
L = 70–100 Mm,
$m = (1.2\text{-}1.5)\times10^{15}$ g

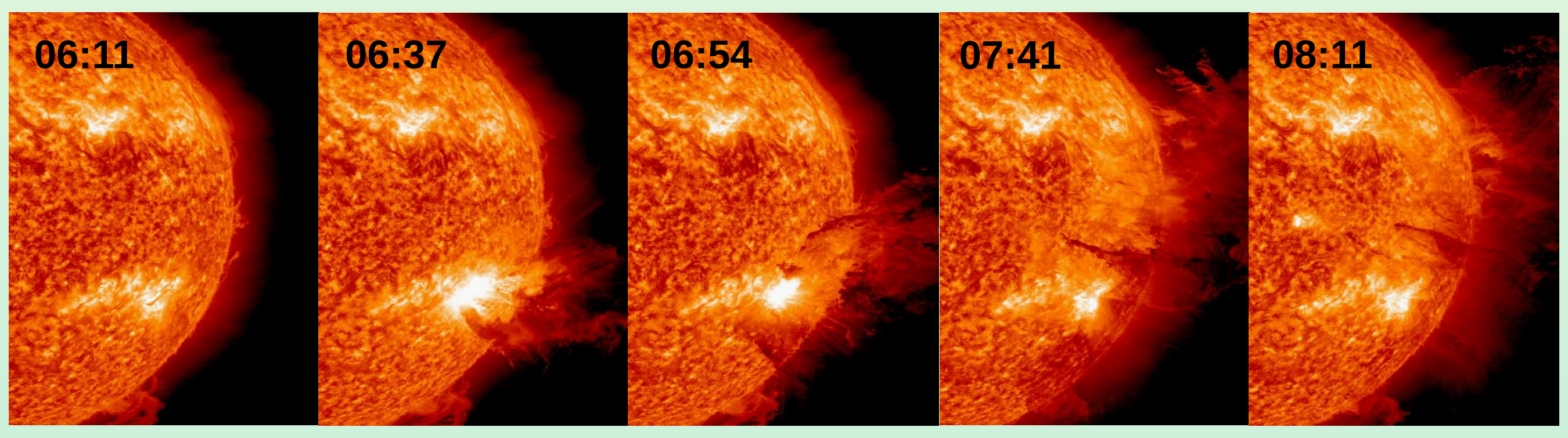

Fig. 6. Anomalous eruption on 2011-06-07 in SDO/AIA 304 Å images

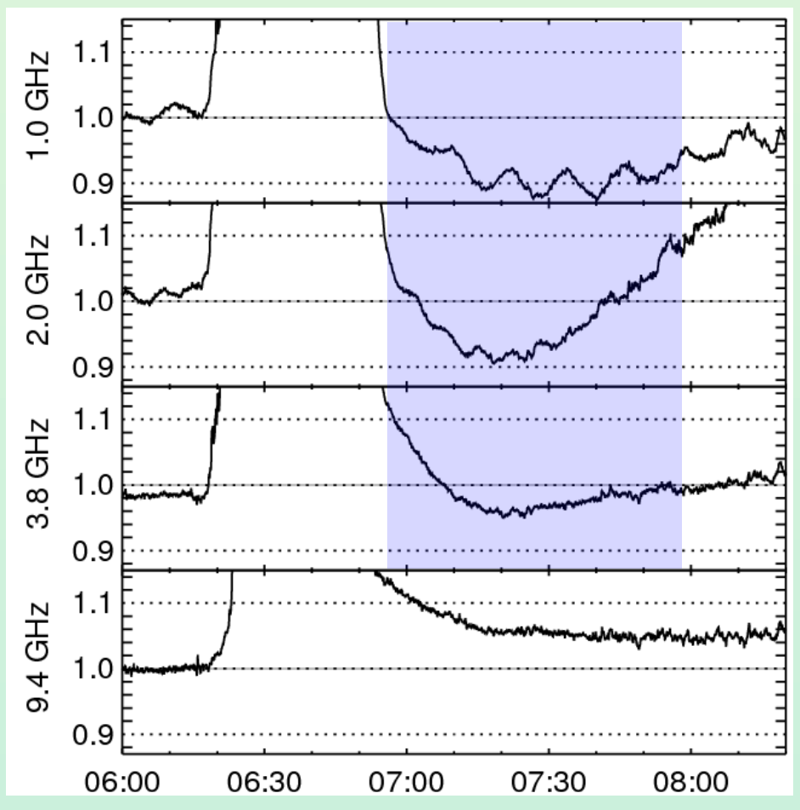

Fig. 8. Negative burst (NoRP)

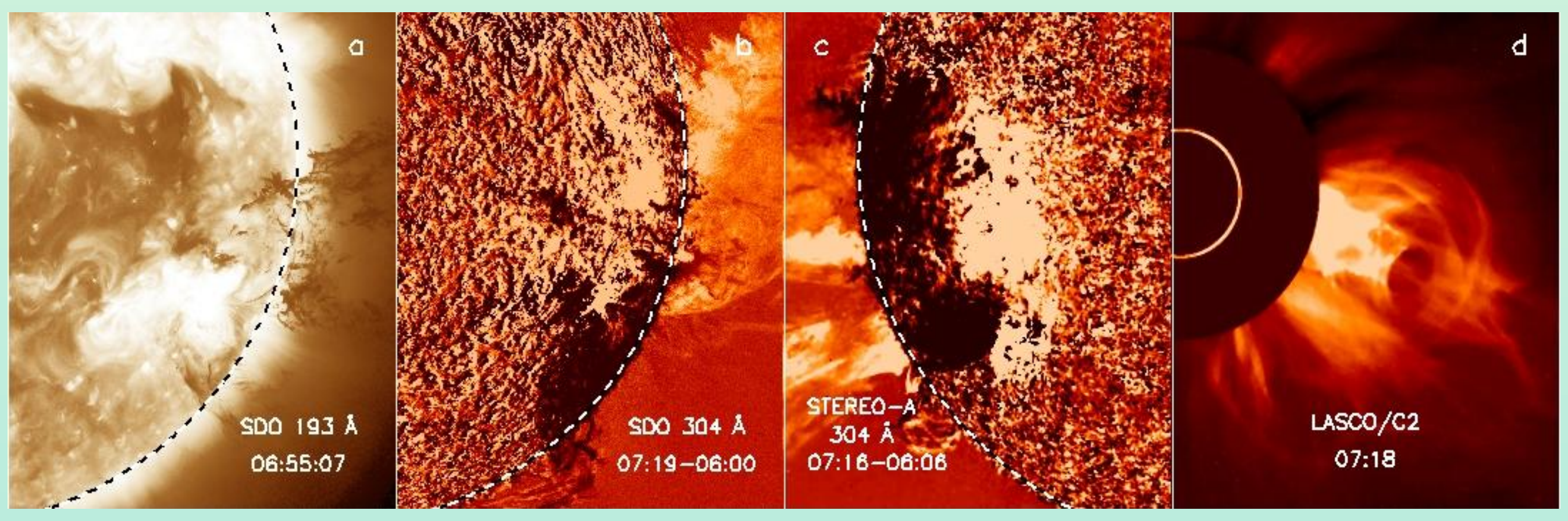

Fig. 7. SDO/AIA image at 193 Å (a), SDO & STEREO-A differences at 304 Å (b,c), and CME (d, SOHO/LASCO/C2)

The most demonstrative **2011-06-07** **anomalous eruption** ever observed confirms our conclusions (Grechnev et al. 2011). Absorbing fragments are well visible not only at 304 Å, but even at 193 Å (Fig. 6; 7a,b). The total area of the dispersed filament material was 6.6% from SDO/AIA data and 8% from STEREO-A/EUVI. The deepest local depression at 304 Å reached –90%. A brightening area (2.7% of the solar disk) indicates the presence of hotter material. Here the negative burst was due to occultation of both a compact source and a large quiet Sun's area. Parameters of the absorbing material estimated from the microwave spectrum: $\boldsymbol{T = 3\times10^4}$ **K,** $\boldsymbol{\tau_{17GHz} = 0.045, A_F/A_\odot = 15\%}$. With $L \approx 100$ Mm, $\boldsymbol{m \approx 6\times10^{15}}$ **g.**

An **isolated negative burst** (without preceding flare burst) on **2011-12-13** (fig. 9) was due to occultation of compact sources by a steadily expanding quiescent filament (Fig. 10,11). The fluxes from the compact sources in a 17 GHz NoRH image were ≈ 4 sfu, and estimated parameters of absorbing material $\boldsymbol{T = 10^4}$ **K,** $\boldsymbol{\tau_{17GHz} = 0.1, A_F/A_\odot = 1.2\%}$. The geometrical depth for an observer on Earth estimated from a STEREO-A/EUVI 304 Å image is $L \approx 90$ Mm, and the mass $\boldsymbol{m \approx 3\times10^{14}}$ **g.**

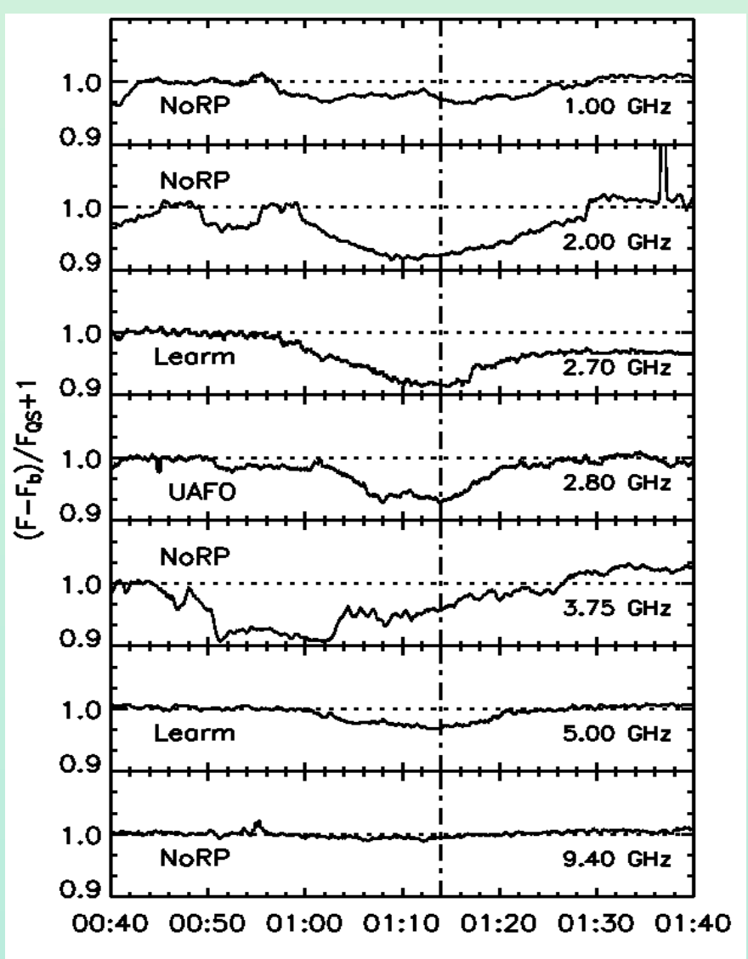

Fig. 9. Isolated negative burst recorded on 2011-12-13

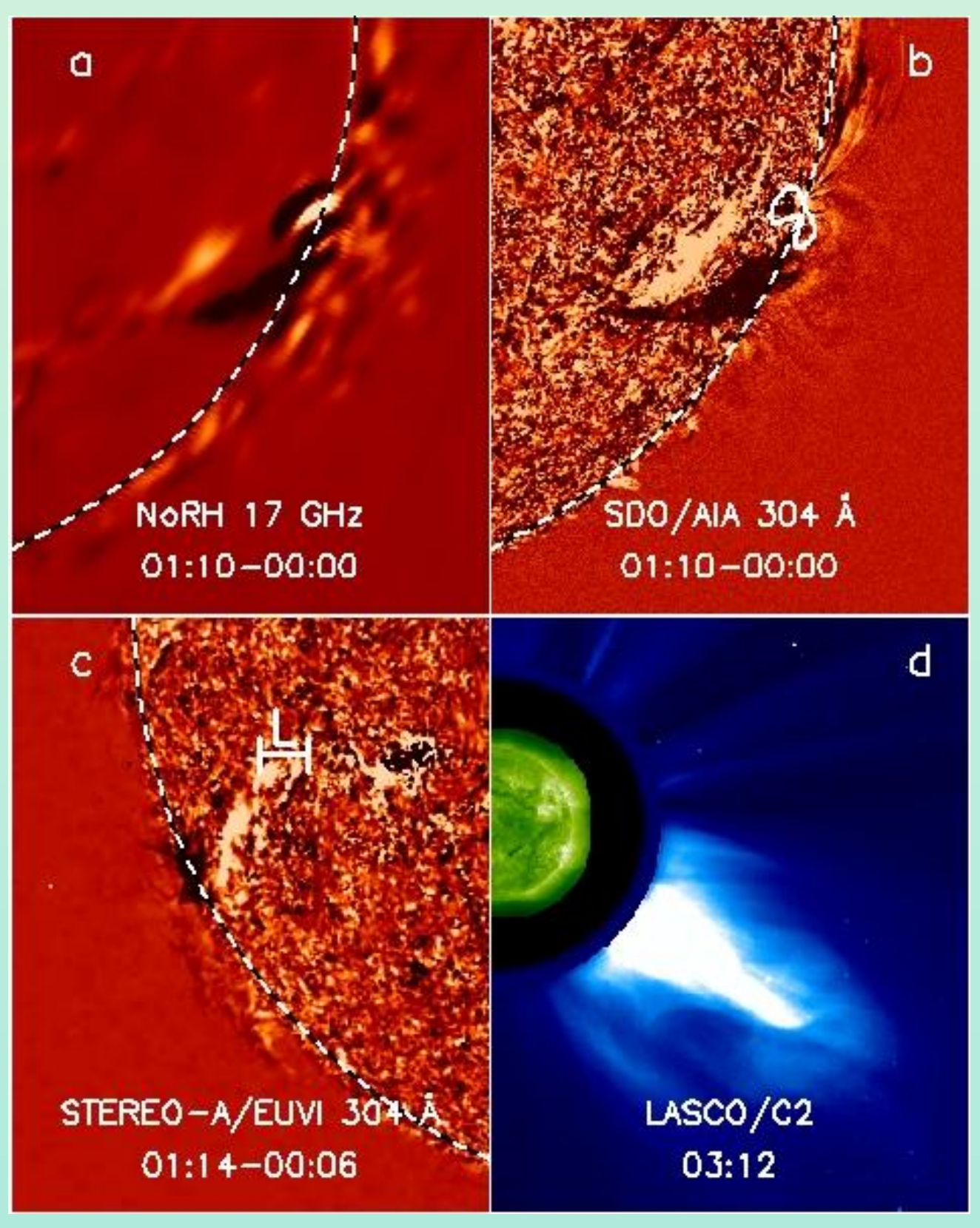

Fig. 11. Difference images of the 2011-12-13 eruption of a quiescent filament

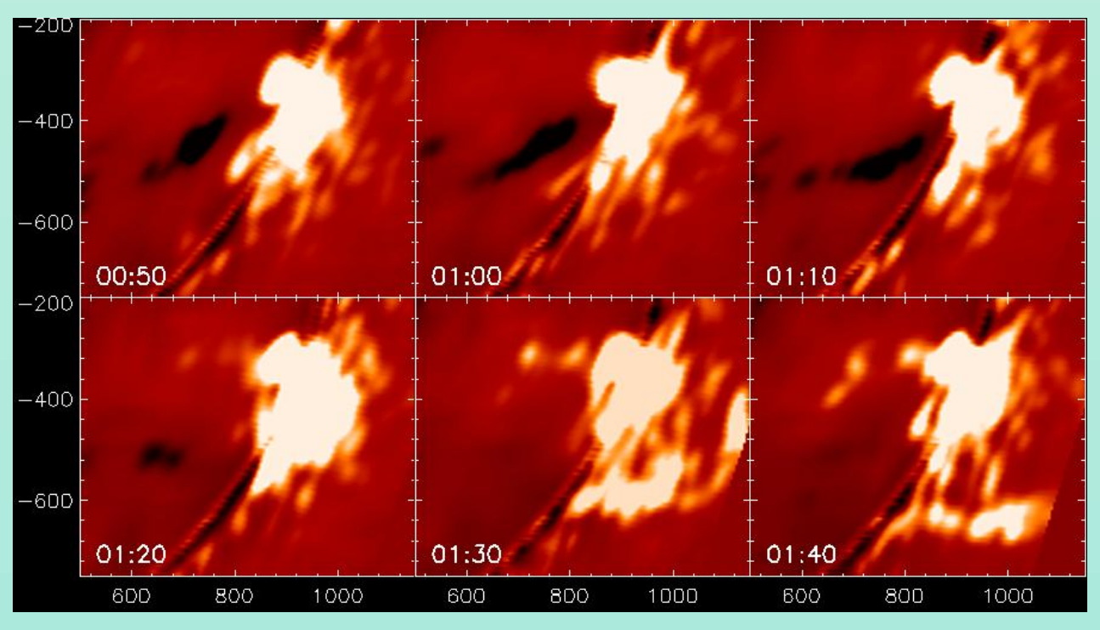

Fig. 10. NoRH images of the related filament eruption

A possible scenario of an anomalous eruption. Decay of the magnetic structure of an eruptive filament suggests reconnection between its internal magnetic fields and surrounding coronal magnetic fields. We consider a possible scenario of an anomalous eruption of an inverse filament in a quadrupole configuration. Fig. 12 shows an apex cross section of a 3D toroidal magnetic flux rope (cf. Fig. 7d) with ends rooted in the photosphere. The initial filament (t1) is in the equilibrium state. The pink dashed lines are initial separatrices. We follow the evolution of plasma (blue dots) within a ring flux rope's section. An upward rise of the flux rope leads to magnetic field stretching, and a vertical current sheet (orange) develops. Standard flare reconnection starts. With the flare onset (t2), separatrices *AA* and *BB* approach. In reconnection the flux rope acquires additional rings of the poloidal magnetic field, which creates a growing propelling force. Acceleration of the expanding flux rope increases. The flux rope exits into the outer domain (t3, Fig. 12c). By this moment separatrices *AA* and *BB* have already merged. A horizontal current sheet (orange) forms, and reconnection with the external magnetic field starts to 'undress' the flux rope thus making the blue ring portion of interest naked. The poloidal flux starts to decrease. Filament's plasma is dispersed over the solar surface (Fig. 12d–f). The 'undressing' of the blue ring portion goes on in reconnection with external magnetic fields (t4–t5). The newly formed magnetic tube straightens and becomes a static magnetic loop. The plasma upflow ceases (Fig. 12f). The sideward velocity of plasmas flowing from the top is almost equal to the upward velocity of the ejecta. The process results in dispersal over a large area of material, which was previously confined within the ring cross section.

Reconnection with external magnetic field in the course of 'undressing' of the flux rope tends to increase its velocity, while the decrease of the poloidal flux decreases the propelling force. The retarding influence of the toroidal flux and gravity persists. Most likely, the flux rope sharply accelerates and then gradually decelerates.

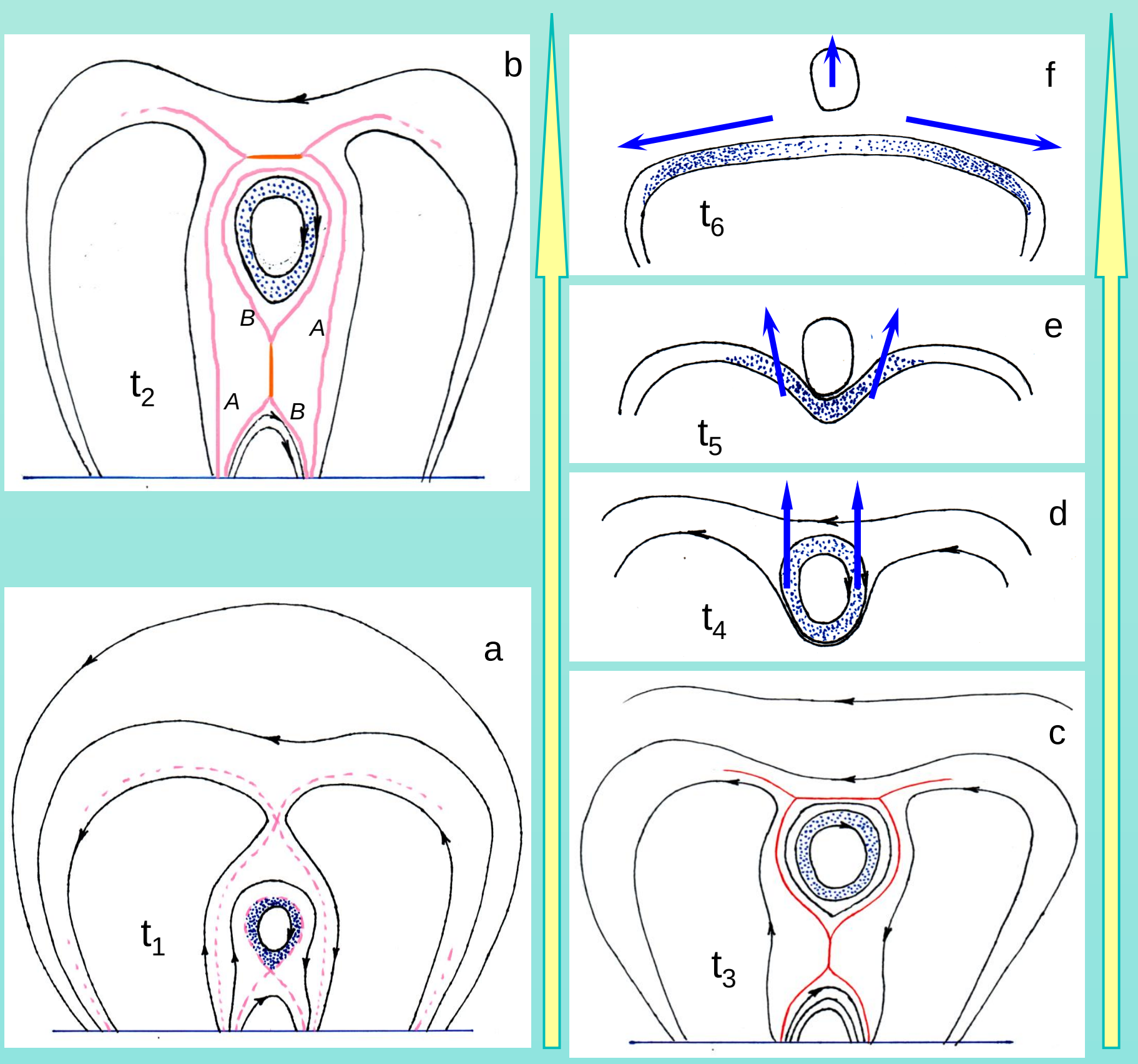

Fig. 12. A possible scenario of an anomalous eruption of an inverse filament in a quadrupole configuration.

Conclusions. Despite the rare occurrence of negative bursts, their studies based on NoRP and NoRH observations have provided **new results on solar eruptions**. They have revealed:

- different kinds of negative bursts such as well-known post-burst decrease and isolated negative bursts without preceding flare bursts;
- negative bursts caused by occultation not only of compact sources, but also large quiet-Sun areas;
- two scenarios of occultation by either steadily expanding filament or remnants of a filament dispersed in an anomalous eruption.
- **anomalous eruptions** and their expected properties **have been revealed** from scarce data of past years.

Anomalous scenario presumably occurs if an eruptive filament passes through vicinities of a coronal null point. This is favored by complex magnetic configurations and surrounding of the active region with others. The eruption might be accompanied by a powerful flare, surges, or sprays. Shock is expected to be manifest in a metric type II burst, 'EUV wave' and Moreton wave. Related CME can be coreless, fast, and decelerating. These expectations are confirmed by recent observations. **From** multi-frequency microwave total flux records of **negative bursts parameters of plasma** ejected on the solar disk **can be estimated**. **Ongoing observations with NoRP and NoRH** along with EUV data **can shed further light on** different scenarios and parameters of **solar eruptions**.

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